WORLD METEOROLOGICAL ORGANIZATION

INSTRUMENTS AND OBSERVING METHODS

REPORT No. 1

AUTOMATED METEOROLOGICAL SYSTEMS

PAPERS PRESENTED
AT THE TECHNICAL CONFERENCE
ON EVOLUTION AND STANDARDIZATION OF
OBSERVING TECHNIQUES IN LIGHT
OF AUTOMATION
WORLD METEOROLOGICAL ORGANIZATION

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Norrköping (Sweden) 1 - 5 September 1980

SECRETARIAT OF THE WORLD METEOROLOGICAL ORGANIZATION - GENEVA, SWITZERLAND - 1980 -
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Introduction

The thirty-first session of the WMO Executive Committee (1979) approved a proposal of the President of the Commission for Instruments and Methods of Observation to organize a Technical Conference on the Evolution and Standardization of Observational Techniques in the Light of Automation. The technical conference will be held in Norrköping (Sweden) from 1 to 5 September 1980 at the kind invitation of the Swedish authorities.

The technical conference topics cover recent advances in the automation of meteorological observations and how best to deal with integrating and standardizing these developments with the existing meteorological observing networks. Emphasis is given on sensor and system developments, on applications and on results.

This publication, which reproduces most of the papers to be presented at the technical conference, is being issued in advance in order that the papers may be available to participants for study prior to the technical conference. At the same time the publication will place these papers on permanent record and make them available to a much larger audience than the participants at the technical conference.

Credit for preparation for the technical conference is due to the international programme committee under the chairmanship of Mr. M. Aronsson, the local organizing committee, and to the invited speakers and session chairmen, and to all the individual scientists who have contributed their papers in advance.
PROGRAMME SUMMARY

Monday, 1 September 1980

08.30-09.30  Registration (also on Sunday, 31 August, 12.00-18.00)
09.30       Opening of the Conference

Address by the Permanent Representative of Sweden.
Address by a representative of the Secretary-General of WMO.
Introductory remarks by the Chairman of the International Programme Committee.

10.40  Session I  Sensors used in surface-based automated weather
         observing systems (conventional sensors and
         remote sensing equipment)

Chairman - S. Huovila

Tuesday, 2 September 1980

09.00      Session I  Continued
10.30      Session II  Description of automatic surface observation
                      systems

Chairman - H. P. Treussart

Wednesday, 3 September 1980

09.00      Session III  Automation of upper-air measurement

Chairman - A. Hooper

13.15      Session IV  Automatic observation systems used at aerodromes

Chairman - D. T. Acheson

Thursday, 4 September 1980

09.00      Session IV  Continued
10.30      Session V  Role of satellites in the automation of measurement

Chairman - H. Yates

13.15      Session VI  Results from using existing automatic systems

Chairman - D. Simidchiev
### Friday, 5 September 1980

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Introduction

The present situation in the field of sensors for automated meteorological systems is still far from satisfactory. Some meteorological parameters such as temperature, pressure or direction and speed of wind can be measured by a wide variety of commercially available sensors. One may expect that the best of those sensors will work correctly for several years at a remote automatic station without substantial service and maintenance costs. Some other parameters are either more difficult to measure and evaluate automatically or the sensors suffer from degradation and need care and attention more frequently.

The recent evolution of remote sensing technics also promises well for the automation of weather observing systems. Today it is possible in principle to evaluate automatically complicated weather parameters such as present and past weather. Actually, the human observer has throughout the ages estimated those particular parameters by using his eyes or ears as passive remote sensors and his brains as a microprocessor.

A suitable combination of conventional and remote sensors would indeed today reveal the type and intensity of most weather phenomena quite correctly. But limiting factors such as climatic hazards, power shortage, expensive service and, above all, high investment and development costs have strongly retarded the introduction of advanced sensors. As a somewhat ironical result the best furnished automatic weather observing systems with remote sensors are usually to be found in the neighbourhood of the best service facilities, i.e. at leading airports and research centers while remote automatic stations mostly rely on proven conventional sensors and technics.

The role of meteorologists is of paramount importance when selecting and evaluating sensors for automated systems. This role is still more important during the installation and service trips to remote stations. Experience has shown that the field engineers of the system manufacturers are usually very competent in electronics but their meteorological knowledge may be insufficient for locating or calibrating the sensors correctly according to WMO rules.

Comments on conventional sensors

By conventional meteorological sensors one may mean those commercially-available and reasonably priced sensors which have been generally adopted by instrument experts as a part of "proven techniques". This adoption does not necessarily mean that such sensors are unconditionally warranted as suitable for use under varying climatological and other environmental conditions.
Even the most reliable conventional sensors may suffer from certain limitations due to the thermal, dynamical, electrical etc. properties of the sensor or its surroundings. A properly-made temperature measurement presumes not only a good temperature sensor but also thorough consideration of solar radiation, ventilation etc. Investigations of such peripheral factors may turn out to be much more valuable than traditional figures of the lag time, resolution or linearity of the temperature sensor. Reference is made to the paper of McKay and McTaggart-Cowan (5) on radiation shields for automatic stations.

Another good example of problems among conventional sensors is to be found in anemometry. Old data of wind speed and its extreme values are rather ambiguous almost everywhere due to the unknown dynamical constants of anemometers in the past. Papers of Mazzarella (1) and of Lamboley and Viton (3) are recommended for further studies. An unambiguous wind observation network apparently needs not only identical sensors but also identical recording and evaluating systems at every station. In addition, much experience and good judgement are needed when selecting consistent wind measuring sites.

One more example of the problems facing us again and again is that of humidity sensors. If these sensors are judged on the basis of reliability, easy maintenance and wide operation range, one must confess that the best humidity sensors date from the last century. Numerous electric hygrometers have been developed after the Second World War and some properties such as smaller lag time or better linearity are very welcome in many applications. However, the degradation of electric hygrometers due to natural or industrial air pollution, and other negative features have retarded their use as AWS sensors especially at remote automatic stations. This rather confusing situation would be a good reason for CIMO to outline a plan for a long-term comparison of humidity sensors under varying conditions of temperature, humidity and air pollution.

Remote sensing in automated systems today and in the future

The definition of remote sensing may be somewhat indistinct in meteorology. Actually, measurements of radiation and sunshine as well as most man-made visual or audible observations of weather phenomena may well be included within the frame of passive remote sensing. In order to avoid confusion the following discussion is limited to active remote sensing which in practice presupposes a transmitter-receiver combination at the measuring site.

Active remote sensing in meteorology was mainly started in order to fulfill the needs and prospects of aeronautical meteorology. The instruments were normally installed at main airports or research centers where adequate sources of service personnel and electric power did not limit the maintenance periods or power requirements of the equipment. As a result of this process most of the traditional remote sensing devices such as weather radars, ceilometers or visibility meters are problematic to use at distant automatic stations.

There are also many new meteorological remote sensing devices, some of them at an experimental and some others already at a commercial level of development. Methods for remote sensing of cloudiness were described in references (2) and (4) while a number of acoustic Doppler systems, sonic anemometers etc. were tested during the WMO/CIMO intercomparison of low level sounding techniques in Boulder, Colorado in August-September 1979. Although some of these new devices are very promising their utilization at remote automatic stations would entail reconsideration of the interpretation methods.

In order to increase the applicability of remote sensing devices outside the areas of top-ranking technology we should necessarily need a modified design philosophy. Simple modular construction, low power consumption, light weight and a wide range of environmental tolerances may be mentioned among the expected design features for active remote sensing devices.
New prospects and challenges

Experience has shown that the development of meteorological instruments and their sensors usually proceeds slower than one might anticipate. The causes of these difficulties are rather simple and evident. The fraction of purely meteorological devices in the total industrial volume is very negligible and we cannot expect leading companies to invest large sums on meteorological devices. Rapid development of a meteorological instrument or sensor usually derives from an immediate application of an invention made elsewhere for other purposes.

There are, however, some challenges which would return feasible applications against moderate research investment. One promising starting point would be to combine in an objective way the information simultaneously obtained from several simple sensors at distant low power automatic stations.

Only very few countries can afford a large number of fully automatic observing stations equipped with many active remote sensing devices. On the other hand, a combination of inexpensive passive sensors would produce data to be further compared with typical threshold and class values in the computer memory. Let us assume that our station contains simple yes/no sensors for precipitation, sunshine and lightning as well as intensity sensors for precipitation, solar radiation and infrared radiation. Such synoptically important parameters as type and amount of clouds or present and past weather could now be derived rather reliably as a result of a chain of decisions made by the computer at the receiving station.

Summary

The purpose of this paper is to describe some features of the present conventional and remote sensors intended for automated weather observing systems. This description is intentionally done in very round and realistic terms in order to avoid details or plain references to best or worst available sensors.

A suggestion is made for a comparison of humidity sensors under the supervision of WMO/CIMO. This proposal is mainly due to the prevailing uncertainty and the rapid degradation of some hygrometers under certain climatic or environmental conditions which may lead to short service intervals or useless data at remote automatic stations.

The vast majority of sensors in automated systems may be called conventional. Active remote sensors are most frequently used at main airports and research centers where continuous service and unlimited power are available. A modified design philosophy is necessary for increasing the share of remote sensors at far-off or badly-accessible automated stations.

Slow progress in the development of meteorological sensors is mainly due to the very limited research funds of instrument manufacturers. One method of overcoming this difficulty and producing more weather information at reasonable cost would be to use a combination of simple on/off or intensity sensors at automatic stations, and to let a central computer classify and process the collected data for synoptic or warning purposes.
References


SENSORS USED, OR PLANNED TO BE USED, AT AUTOMATIC WEATHER-STATIONS IN SWEDEN

by Sverker Magnusson

SMHI (The Swedish Meteorological and Hydrological Institute)

Introduction

During the last 10 years a rapid development of datalogging-, transmission- and acquisition-systems has taken place. Unfortunately, during the same period of time, the evolution of meteorological sensors, has been far less impressive. A great number of, more or less clever, constructions have been made but few have survived the step from the laboratory to the hard reality at an automatic station.

A sensor at such a station must be extremely reliable and only require a minimum of maintenance. It must for example be able to operate within its specifications of accuracy, in temperatures from -40°C to +40°C. When mounted on a lighthouse it must stand splashes of salt water. Automatic stations in Sweden are used mainly as synoptic stations and stations for energy prospecting. Sensors used, or planned to be used, at such stations are listed in fig. 1. Some of them are described more detailed below.

Wind direction and wind speed

At the synoptic stations an SMHI made integrated sensor with cup anemometer and wind vane is used. The cup anemometer has a threshold of 0.3 m/s and a distance constant of 5 m. The overspeeding appears to be low. We are just now testing this instrument in order to get a quantitative understanding of the overspeeding effect. This sensor participated in a WMO-comparison of routine anemometers in Paris 1976-77. The dynamic performance was found to be far beyond the average. At the stations for windenergy prospecting separate sensors for wind direction and -speed are used. The cups are the same. The angle sensing in the direction sensor is performed by a very reliable resolver. An identical resolver works as pulse generator in the speed sensor. One advantage is that we can use identical sensors for speed and direction measurements except for the cups and the vane. Resolvers are used also in some of the integrated sensors.

Wind vector

A pneumatic air speed sensor, with pressure transducers, manufactured by Rosemount has during the last winter been tested at a station with heavy ice formation problems. No cup anemometers have been able to operate satisfactorily at this station, which is located at a height of 1100 m. No evaluation of the test has been made yet but the sensor seems to have worked without ice problems.

Temperature

In general, resistance thermometers (Pt-100) are used. We find them to be very stable and hardly ever need recalibrations.

When measuring the air temperature they have of course to be mounted in some sort of radiation shield. At the synoptic stations we still use ordi-
nary wooden Stevenson screens. We do so, mainly by tradition and for con-

nuity reasons, in spite of the fact that it is well known that temperature 

measurements in such a screen can, at some conditions, be a couple of de-

grees too high. In all other applications we use aspirated shields (Gill or 

Teledyne) which give much more accurate measurements.

**Humidity**

We still use hair hygrometers, not because we think they are good but, 

because we still have not found an other sensor stable, reliable and cheap 

enough to replace the hair hygrometer.

We use Lambrecht sensors with resistance output.

**Pressure**

Since over 13 years an SMHI construction has been used for air pressure 

measurements. It consists of an aneroid pile the axial deformation of which 

is sensed by a differential transformer. In order to get a homogeneous 

temperature in the aneroid pile the whole instrument is mounted inside a 

Dewarflask. An inhomogeneous temperature could cause a bending of the pile. 

The instrument is sufficiently stable and the accuracy is better then 250 Pa.

At two airfields, with automatic weather data acquisition systems, pressure 
sensor from Setra, modified by ASEA, has been installed.

The aneroid box in this sensor is a quartz capsule with platinum electrodes 
on the inside surface. These electrodes form a capacitor. A certain air 

pressure corresponds to a certain distance between the electrodes measured 

by the capacitance. The experiences of this sensor are good so far, with 

a good stability and an accuracy better than ±30 Pa.

**Visibility**

A fog detector from AGA, WM-500, with analog output has been tested at SMHI 

for measuring the visibility. The sensor is in use at several lighthouses 
as fog detector with good results.

The operation is based on the backscatter principle and a comparison bet-

ween the reflected part of an emitted IR-light and a pilot light. The pilot 

light is arranged so that it also passes through the receiving lens of the 
sensor. The pilot light is set with the aid of an electronic servo to the 

same intensity as the reflected light. This arrangement results in an auto-

matic compensation for contaminated lenses.

The range is 0-15000 m and the light source is an 0.9 μm LED.

**Cloud base**

The ASEA laser cloud ceilometer QL 1211 has not yet been installed at any 

automatic weather station but has been used since several years on air-

fields in Sweden. It has proved to be a very reliable sensor. The light 

emitting component is a gallium arsenide (GaAs) diode laser. The range is 

10-1500 m.

**Precipitation**

Since several years we have used different types of automatic precipitation 
sensors and the type that probably will be used at automatic stations in 
the future is the tipping bucket sensor RG 200 from Gertsch.
By a thermostat the collecting surface is held at a temperature not below +3°C which means that the sensor can measure snow and hail. We have compared it to manual precipitation sensors for long periods of time.

It is obvious that, when measuring snow the Gertsch sensor gives markedly lower values than the manual sensor. On the other hand, when measuring rain, somewhat higher values are obtained.

**Duration of sunshine**

Different types of electronic sunshine detectors have been tested at SMHI during the last 8 years. The one probably will choose is the sensor SOLAR III from Haenni. This sensor and two others have been compared for one year with an Eppley NIP pyrheliometer, the output of which has been discriminated at 200 W/m². The results are not evaluated yet.

**Global radiation**

Kipp & Sonen and Eppley PSP pyranometers are used. Those are well known instruments and need no special presentation.

**Direct solar radiation**

This parameter is measured with an Eppley normal incidence pyrheliometer (NIP) mounted in an electronically guided solar tracker from Autonik. The NIP has an opening angle of 5° and is temperature compensated. The radiation is sensed by a thermopile.

**Net radiation**

SMHI has used several different types of net radiation sensors. Today we use mainly sensors from Siemens-Ersking. A big problem is the difficulty to calibrate net radiation sensors. Comparisons between sensors from different manufacturers using the original calibration constant often differ 10% or more. We have no good system for calibration.

**Wave height**

Two types of sensors are in operational use at 4 stations measuring wave height. Those measurements are made for energy prospecting of wave power. One type of sensor from Simrad consists of an inverted echo sounder mounted on the bottom of the sea. By making repeated measurements of the distance to the surface, parameters as wave height and frequency are calculated by the automatic station's microcomputer.

The other sensor is a waverider buoy with accelerometer. The acceleration is transformed into a frequency modulated signal which is fed into a radio transmitter, which is operating in a 27 MHz band. The receiver of the signal is connected to the automatic station and the same program as above makes the calculations.
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<td>Wind vane and Cup anemometer</td>
<td>SMHI</td>
<td>3.6 V/600 Ω or 2 kHz Option: Heater 24 VAC, 3A</td>
<td>10 mV/°</td>
<td>0-360°</td>
<td>Potentiometer</td>
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<td>Wind speed</td>
<td></td>
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<td></td>
<td>120 m/pulse or 0.625 m/pulse</td>
<td>0-50 ms⁻¹</td>
<td>Microswitch</td>
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<td>Wind vector</td>
<td>Pneumatic airspeed sensor with pressure transducers model 853 All5</td>
<td>Rosemount</td>
<td>220 V 50 Hz</td>
<td>x) -5 - +5 VDC, y) -5 - +5 VDC</td>
<td>0-30 ms⁻¹ or 0-70 ms⁻¹</td>
<td>Resolver</td>
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<td>Pt 100</td>
<td>Rosemount</td>
<td>2.5 mA</td>
<td>1 m V/°C</td>
<td>±50°C</td>
<td>In Stevenson Screen or aspirated radiation Shield type, Gill or Teledyne</td>
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<td>Humidity</td>
<td>Hair hygrometer 809L 100</td>
<td>Lambrecht</td>
<td>1 V/130 Ω</td>
<td>10 m V/% RH</td>
<td>0-100% RH</td>
<td>Potentiometer</td>
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<tr>
<td>Pressure</td>
<td>Aneroid</td>
<td>SMHI</td>
<td>6 V ±0.05% or 20 mA</td>
<td>0.4 m V/Pa, 3 kΩ, Min. load 10k</td>
<td>94-106 k Pa</td>
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A DIGITAL ANEMOMETER SYSTEM FOR METEOROLOGICAL WIND MEASUREMENTS

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The automation of observations in the Canadian Meteorological Service created a requirement for a new anemometer system. Our climatological anemometer (Type 45B) had sliding contacts which are difficult to interface to electronic data systems (particularly low power systems). It also requires a large number of conductors for good direction resolution. Our synoptic anemometer (Type U2A) uses a direct current generator for speed and a synchro for direction. Sophisticated interfaces and substantial power are required to interface with synchros. Generators with the required linearly are becoming quite expensive. Any anemometer to be considered as a replacement must maintain the robust characteristics of present units. In addition factors such as low power consumption, ease of remoting, protection from electromagnetic interference, and cost, must be considered important.

A literature search was made to determine if there were commercially available replacements for our systems. We were not able to find a satisfactory replacement for either system, however our search did indicate some desirable techniques.

1. Cup wheels and vanes provide the most practical sensing technique for the Canadian Environment.
2. Optoelectronic components provide excellent bounce-free switches for electronic components. Gray type encoders combined with photomasking techniques can provide accurate reproducible direction units with no critical adjustments.

Commercial units which had these desirable properties were all plagued by the following problems.

1. Optoelectronic components were continuously powered, therefore the anemometer required considerable power.
2. Optoelectronic components were not protected from external interference (particularly lightning).

Since A.E.S. Instrument Branch had experience in pulse powered optoelectronic sensing and lightning protection, we decided to develop our own anemometer systems (Van Cauwenberghe et al 1980).
It was determined that two anemometers would be developed. The first would be a climatological anemometer to replace the Type 45B. This should operate with the MATER (Magnetic Tape Event Recorder) but must also be able to interface with the present electromagnetic event recorder (Anemograph) at existing stations. The synoptic anemometer would replace the U2A system but would provide a digital output rather than the analog display used in the current system (an analog recording remains a requirement). Our design goal was to have some commonality between the two systems to reduce costs and ease maintenance. One area of commonality chosen was to use the existing U2A cups, vane, and housing. This was done because it has given satisfactory service, is not overly expensive, and more importantly would eliminate sensing as a factor in evaluating the new transducer. (Note: there will be slight differences in the sensing characteristics because the original transducers required some torque to operate them. The errors are not expected to be significantly different than the normal errors between "identical" anemometers).

The Climatological Anemometer (Type 77C)

This is a straightforward application of the techniques described by Van Cauwenbergh et al. A pulse from each turn of the cupwheel is fed into an electronic counter. After a fixed number of turns (373 for 1 kilometer) an output pulse activates the direction head which uses the most significant 3 bits of the encoder. Combinational logic is used to convert the gray code to 8 directions, and then to recombine it into the four cardinal directions in the same format as the Type 45B anemometer. A simple interface at the anemograph allows these low current lines to activate the anemograph relay coils. Figure 1 and 2 show simplified schematics of the 45B and 77C Anemometer.

The Synoptic Anemometer (Type 78D)

This is a much more complex application because it must provide higher resolution and also give readings in "real time". The output of the anemometer must provide not only average wind speed and direction but also information on the variability. In particular peak wind speed is an important parameter for "real time" wind information.

Many methods could be used to obtain a similar (but digital) output as our present anemometer. However, we wanted a technique which would overcome one of the serious shortcomings of our present system, that is the need for high quality dedicated wires for remoting the anemometer readings to a display device.

The technology now exists to process the wind speed and direction information at the anemometer head and send this information via a serial digital message. Our prototype unit uses an Intel 8748 single chip microcomputer to process the data and send a serial ASCII message to the remote readout device.
In order to minimize transmission time (and at the same time conserve power) we chose to have the anemometer process the wind for a 5 second period, then transmit the results. This means that "the outside world" will not see wind resolution of less than 5 seconds. Papers by J. Wieringa (1979) and E.L. Deacon (1975) show that this does not represent a great sacrifice in terms of information provided. However we gain a great deal in terms of simplicity of programming, reduction in power requirements and the fact that we can use identical wind speed sensor electronics for both the synoptic and climatological units.

In order to provide wind averages both within the anemometer head, and the longer averages which may be calculated at the display site, we have chosen to break the wind down into orthogonal vector components. These components are retained throughout the averaging process. This not only gives a more realistic wind average, it also eliminates the 360°-0° crossover problem.

The operation of the type 78D anemometer is illustrated by the simplified flow chart (Figure 3) for the microcomputer. Wind run is detected once per cupwheel revolution (2.68 meters of wind). Each time the cupwheel revolves a direction sample is taken, broken into orthogonal components (North and East) and the result added into the appropriate register. Figure 4 shows how a series of unit length vectors are added to produce an average wind. At the end of the 5 second period the registers are converted to ASCII numbers for transmission and then reset for the next period. While the message is being transmitted the microcomputer continues to monitor and process wind information.

![Flow Chart for 78D Anemometer](image)

![Anemometer Head Wind Averaging](image)

Scaling is done within the anemometer so that all calculations can be done with 16 bit binary numbers (including representation of negative numbers). Since the most likely use of the output is for aviation purposes, the output values are binary multiples of knots. The sine and cosine values are combined with the scaling factors in a lookup table in the microcomputer program memory. We also output the number of anemometer turns in order that total wind run can be recorded at the remote site. Also, since wind run tends to be slightly larger than average wind we plan to use it to compute peak speed thus slightly compensating for the loss in peak speed predicted by Deacon.

Current State of the Anemometer Development

The design of the climatological anemometer is essentially complete. We currently have six preproduction models on field test. We have also 5 feasibility models which have operated for about 18 months. Extensive laboratory simulated environmental tests have been carried out. These included cycling through the temperature range of -70 to +70°C,
and coating the optical components with layers of water, frost, dust and mud. Operation continued well past what we felt were extreme conditions. We also made optical tests to determine sensitivity to manufacturing tolerances. Although all tests were successful we plan to include an extra margin of safety on our production units. Finally we have carried out a number of electromagnetic interference tests. So far we have successfully passed all of them.

At the time of writing we have one prototype of the synoptic anemometer. We have been running it for about 3 months to compare its output with our U2A anemometer. We have a feasibility model for the readout device that receives the anemometer message and does further averaging and formatting. A large amount of work still remains in environmental testing of the synoptic anemometer, however, the success of our tests with the climatological unit in this regard makes us confident of a successful conclusion.

Our future plans call for replacing the Intel 8748 microcomputer with an equivalent CMOS (complementary metal oxide semiconductor) microcomputer. This will considerably reduce the power consumption and should improve its resistance to electromagnetic interference and voltage fluctuations.

The readout device allows individual users to tailor the readout to their needs. The heart of it is a processor which receives the ASCII message from the anemometer and carries out further processing. Our current model provides 2 minute mean wind with gust, 10 minute mean, 5 second analog output (using a reliable inexpensive recorder) and provides "special wind report" information for an automatic weather station. Other outputs could be provided for specialized users.

Acknowledgements

I would like to acknowledge Roger Van Cauwenberghe who designed the optoelectronic components for the anemometer and Tom Hacking who patiently put them together, tested them under horrible conditions and mothered the prototype units through commercial manufacture. I would also like to acknowledge Earle Robinson who wrote the program for the type 78D microcomputer.

References

Introduction

Over the years, suitable cupwheels and vanes have been developed which convert wind speed and direction into shaft speed and direction, but suitable transducers to convert these shaft outputs into usable electronic outputs have not been developed.

The desirable characteristics are that it be accurate (+1°), have low rotational drag, operate over a wide range of temperature and voltage, operate on less than 2 milliwatts, be compatible with modern data acquisition technology, be inexpensive, require no adjustments, have small diameter, and tolerate mechanical shock, corrosion and fouling.

A new optical shaft encoding scheme based on the Gray code which meets the above requirements is described in this paper.

Direction

The direction sensor is shown in Figure 1. The encoding optics is built into the upper part of the housing.

The Gray Code Shutter

Although most commercial optical shaft encoders use glass or film shutters, it was deemed that a chemically milled metal shutter would be cheaper and have a better optical transmission ratio. However, this method of manufacture results in a flimsy shutter, which requires webbing to provide structural strength. A comparison of Fig. 2 and Fig. 3 shows that the webbing consumes considerable radial space.
A Manipulation of the Gray Code

There are several transformations which can be made in order to reduce the complexity and the required radius of the encoding wheel while making it sturdier.

The track shown in Fig. 4(a) is called the reference track and is any track in the Gray code. If one wishes to have the next lower order track but does not have space for it, it can be derived from the reference track. In Fig. 4(a), the detectors A and B are displaced $\pm \frac{1}{4}$ bit from the reference position. If the outputs of A and B are exclusively ORed to give C, the result is the same as that of a single detector of the track shown in Fig. 4(b). This can be extended to the next lower order track but at the cost of 4 detectors and so on. The detectors too, can be placed in several alternate positions along the track giving increased flexibility in design.

Because of symmetry in the Gray code, the highest order track is in effect displaced $90^\circ$ from the next track. This leads to the result that the second track can be derived from the first track by a second detector placed $90^\circ$ from the first detector. This track could then also generate the third track by the method of exclusive ORing.

The resulting shutter for six bits of resolution appears in Fig. 5. For extra mechanical strength, the track order has been turned inside out. Note that the shutter center is D shaped. The flat that aligns the shutter on the shaft is milled in the same operation as the flat that aligns the vane, resulting in automatic alignment of vane to housing. The aperture plate is illustrated in Fig. 6. Each small aperture defines the light as shown in Fig. 7f. The three larger holes are mounting holes.

Figure 4 Equivalent output from two different tracks

Figure 5: The shutter. Note that there are only three tracks.

Figure 6: The aperture plate. Note that there are eight apertures for six outputs since two pairs are exclusively ORed to give one output per pair.
A design objective was to have the complete assembly process without adjustments. Tolerances should be such that alignment would be automatic. The optics was therefore designed so that components which have wider tolerances in location, such as light emitting diodes and phototransistors would be less critical and that the precision would arise from components which naturally have close tolerance control such as apertures and shutters.

Numerous optical arrangements were considered as illustrated in Fig. 7. All use non-focused optics.

Fig. 7. Optical arrangements: A-aperture plate, S-shutter, D-detector, E-emitter

Space does not permit an explanation of all the arrangements. The problem was further complicated because of adjacent emitter/detector pairs and the possibility of cross-talk. Also it was not considered desirable to have to coat all of the inside with optical paint. For these reasons, arrangements d) and f) fare better because the detectors view only the small portion of the aperture plate which they are close to.

Optical performance is degraded badly when a continuous water droplet is formed from the emitter to detector. Thus the emitter was spaced away from the aperture plate as in d) and f) so that a droplet could not bridge the gap. In both d) and f) satisfactory performance is obtained when the area between the apertures, shutter and detector are completely bridged by water.

Ice crystals formed on the surface had little effect unless the ice was very opaque. Under these conditions f) operated better than d) and the actual transmission compared well with calculations, assuming that light was scattered isotropically from the apertures. The configuration in d) meant that light was scattered twice and the attenuation was correspondingly high.

Configuration f) was eventually chosen as being the simplest and capable of withstanding extreme conditions including operating immersed in water, covered in dust, mud and ice as well as being insensitive to normal variation in light efficiency and photo-transistor sensitivity.

The size and shape of the aperture hole are determined by several factors. The width of the slot determines the rate of change of illumination with angle of rotation, while the area determines the amount of safety factor for decreasing illumination.

The optical configuration was designed to work over a 500:1 light ratio. On the low end, failure occurs due to insufficient photo-transistor sensitivity, high attenuation by foreign material, or poor light emitting diode efficiency.
On the high end, failure occurs due to multiple reflections and scattering. This is minimized by choice of optical coating and by radial tolerances of the aperture and shutter discs. Position tolerance of the emitters and detectors are not critical, nor are the axial tolerances of the complete assembly. A view of the assembled optics and circuit boards is shown in Fig. 8 and Fig. 9.

**Fig. 8.** Cutaway view of the optics.

**Fig. 9.** Elevation view of the complete assembly

**Power Consumption**

Since the largest consumer of power is the current through the light emitting diodes, this current is pulsed when a direction measurement is required. The optimum pulse length and current value must be determined experimentally. Bear in mind also that immunity from the effects of dark current and production tolerances are important in the selection of final circuitry and hence speed and efficiency are compromised somewhat.

The operating point chosen, shown in Fig. 10, is 500 milliamperes for 75 microseconds resulting in 37.5 microcoulombs of charge passing through the light emitting diode for each sample of wind direction.

**SPEED**

Monitoring the speed of the cupwheels (Fig. 11) is very straightforward. The shaft, which is rotated by the cupwheels, turns the shutter shown in Fig. 12. The path of the light is blocked and clear for each alternate half cycle of the shaft.

The 1/2 cylinder arrangement was chosen over a disc to ease assembly and disassembly problems.

**Fig. 10.** Charge requirement for different optical attenuation and pulse lengths.
Sampling rate and power consumption

In order to represent the number of turns of the cupwheel it is necessary to sample for the presence of the shutter at a speed of at least twice the rotation rate.

Since the optical attenuation will not be as high as for the direction head with its small aperture, a different set of charge requirement curves were constructed.

Sufficient power to punch through ice crystals, dust etc. is developed at the operating point shown in Fig. 13. A current of 67 milliamperes for a duration of 15 microseconds results in a 1 microcoulomb charge requirement per sample of wind speed. If 60 samples per second are required for an anticipated maximum rate of 30 revolutions per second, the average current drain is only 60 microamperes.

In practice the pulse technique reduces the current consumption by a factor of four hundred for speed and is even greater for direction.

Fig. 11: The cupwheel

Fig. 12: The optical arrangement for speed.

Fig. 13: Charge requirements for different optical attenuations and pulse lengths.
CONCLUSIONS

The design is that of a six bit shaft encoder but it has been implemented also as a three bit shaft encoder (McKay 1980) by leaving out some emitters and detectors.

Using the techniques described it is possible to design a five bit shaft encoder using only two tracks and seven emitter-detector pairs.

If more resolution is desired this concept could easily be pushed to seven bits using the techniques and optics described. By changing to the configuration shown in Fig. 7(d) it would be possible to go to nine or ten bits of resolution with some decrease in specification for fouling and icing. Resolution beyond this would require much larger diameters or other refinements.

All of our initial goals were met or exceeded in the design of this device. Tests in the environmental lab and in our test site have been successful as have tests of a number of prototypes in different areas of Canada in all seasons. Tolerance and assembly procedures compatible with normal manufacturing practise have been demonstrated.

ACKNOWLEDGMENTS

The authors would like to thank the people in the Instruments Shop for their design and construction of test jigs and fixtures, especially Dan Broomer and George Giles, and to Yasmin Jamani for her work in many painstaking accuracy and environmental tests.

BIBLIOGRAPHY

MEASUREMENTS OF HORIZONTAL WINDS BY DOPPLER SODAR AND TOWER SENSORS

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INTRODUCTION

During the past decade acoustic Doppler measurements have developed into a useful method for studies of air motions in the planetary boundary layer (Beran and Willmarth, 1971; Ottersten et al. 1973; Mahoney et al. 1973; Owens, 1977; Brown and Hall, 1978). The WMO International Intercomparison of Low-level Sounding Techniques partly aimed at studying the accuracy of different acoustic sounding techniques, e.g., monostatic and bistatic antenna configurations and different methods of extracting the Doppler shift.

Our Doppler sodar system used in the experiment was a preliminary version, with two tilted antennas in an orthogonal configuration. Fig 1 shows a block diagram of the system (Salomonsson and Hurtig, 1979).

Fig 1. Block diagram of the acoustic Doppler sounder.
The horizontal wind components were obtained as averages of 20 minutes, or means from about 240 individual values. The average wind components were then combined to produce the horizontal wind vector by using the assumption of a zero mean vertical wind component during the averaging period. The wind vectors were compared with corresponding wind measurements obtained from sonic anemometers mounted at 8 levels on the 300 m tower at Boulder Atmospheric Observatory (BAO-site).

The Doppler information obtained by two antennas as well as the variability of the temperature fluctuations received at one of the antennas were digitalized and recorded on magnetic tape and presented in real-time on a colour display.

MEASURING RESULTS

The present analysis is restricted to results obtained at the altitudes of 100 and 150 m. Fig. 2 shows a scatter diagram of the north to south and east to west wind components (denoted by V and U, respectively).

Due to the design of the antenna shields, which were not built for this purpose, it was not possible to tilt the antenna beams more than 22° from the vertical. More reliable results would have been obtained if a tilt angle of 45° had been used. Especially during periods with pronounced convective plumes the determination of the horizontal winds were probably seriously contaminated by the vertical wind components. However, in thermally stable air the averaging period of 20 minutes should be adequate provided there is negligible influence from the topography (Kaimal and Haugen, 1977; Salomonsson and Holmgren, 1980).

Fig. 3 shows a scatter diagram representing the time interval 14.20h-14.40h (local time) of all days during the experiment period. At this time of the day the convection was generally strong with well-developed Cb-clouds. The diagram shows a wide scattering indeed, probably caused by the convective instability. Calculations of bulk Richardson numbers for the air layer between 10 and 150 m confirmed that strong instability generally existed during this time interval.

One further point should be added as regards Fig. 3. The rather low pulse power (100 W) and the rather high transmitter frequency (2.4 kHz) tended to reduce the signal-to-noise ratio, especially during periods with strong convection. The low signal-to-noise ratio probably caused some doubtful values (Beran and Clifford, 1972; Brown and Clifford, 1976).

Fig. 4 shows a scatter diagram for the period 20.20h-20.40h. The average Ri-numbers for this period show a marked stable stratifica-

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Fig 2. Scatter diagram of wind components measured at 100 and 150 m by the tower sensors and the Doppler sodar. The V and U components correspond to N-S and E-W components, respectively.
tion. The agreement between Doppler and tower measurements is better than in Fig 3. When the air becomes thermally stratified - the potential temperature increases with height, the signal-to-noise ratio increases and the influence of the mean vertical wind upon the measurements decreases.

CONCLUSIONS

This short analysis shows that horizontal winds may be obtained using two monostatic antennas. Our system can be much improved. A higher pulse power and a lower frequency would give a better signal-to-noise ratio. A third antenna for measuring the vertical winds would certainly give more accurate values of the horizontal winds especially in situations with convection.

REFERENCES


1. Introduction

There has long been a need for a continuously indicating raingauge with an output suitable for use with automatic weather station systems. What is needed is a gauge which will provide information upon the questions:

a. Is it raining - YES/NO?

b. What are the "instantaneous" rate of rainfall and the maximum and minimum values of this quantity since the last interrogation?

c. How much rain has fallen since some defined zero of time?

The United Kingdom Meteorological Office has developed a prototype raingauge based upon the idea of continuously weighing a tipping bucket mechanism and of sensing the change in weight in terms of the frequency of vibration of a taut wire. The idea of weighing the amount of rain which is falling or has fallen is not new (1) (2) but the advent of the low capability microprocessor has made it possible to couple to the raingauge an "intelligent" interface which can provide a continuous output of rainfall rate and cumulative rainfall totals.

2. The Weighing Tipping Bucket

2.1 Theory

The frequency of vibration, \( f \), of a stretched wire of length \( l \) and mass per unit length \( \mu \) under tension \( S \) is given by the well-known relationship

\[
\frac{1}{f} = \frac{1}{2l} \sqrt{\frac{S}{\mu}}
\]

Consider a simple system in which one end of the wire is fixed and the load on the free end of the wire is \((M+m)g\) where \(M\) is the fixed mass of the tipping bucket mechanism and \(m\) is the changing mass of the rain being collected. Then we may write

\[
S = (M+m)g
\]

where \(g\) is the acceleration due to gravity and

\[
(M+m)^2 = 2lf \sqrt{\frac{A}{g}}
\]
Now for practical purposes $M$ is very much larger than $m$ so that we have

$$\frac{1 + \frac{m}{2M}}{2l} \approx \frac{2l}{g} \sqrt{\frac{M}{g}}$$

So the rate of rainfall, $\frac{dm}{dt}$ is given by

$$\frac{dm}{dt} = \frac{4l}{g} \sqrt{\frac{M}{g}} \frac{df}{dt}$$

In the real situation we must allow for effects in the lever mechanism of the wire and we may therefore write

$$\frac{dm}{dt} = K \frac{df}{dt}$$

where $K$ is a constant to be determined empirically by calibration.

2.2 The Equipment

The original weighing tipping bucket was an unpublished idea by Whittaker (3) which has been much developed and modified by us to improve its performance and to make it more robust. The present configuration is shown in Fig. 1. The bucket, which tips once for every 0.2 mm of rain collected, is mounted on a platform which is suspended parallel to a fixed plate by a phosphor-bronze flexure pivot. The weight of the platform and the bucket is supported by a length of 0.2 mm diameter piano wire anchored at one end and which passes between the poles of a fixed magnet.

By passing a current through the wire, it is caused to deflect and the motion of the conductor through the magnetic field generates a small emf. This voltage is amplified and fed back to the wire supply which in turn amplifies the wire displacement so that the wire is forced into oscillation at its fundamental frequency. As the tension in the wire increases, the fundamental frequency of the wire changes and the feed-back circuit automatically causes the system vibration frequency to change in the same manner. The frequency is detected and counted continuously by a binary counter, which is of the non-resetting type to eliminate quantisation errors.
Microprocessor electronics has now reached the stage where quite complex processing of a relatively simple measurement can be achieved as an integral part of the sensor function. The output of the interface can then be presented as the ultimate functional output of the sensor. In the case of the weighing tipping bucket, the drive and interface electronics are shown in block diagram form in Fig 2. We have used an Intersil IM 6100, 12-bit CMOS processor to interrogate the output of the frequency counter at intervals of two seconds determined by the self-contained crystal clock. In addition, we maintain a record of whether or not the bucket has tipped in the two seconds since the last interrogation. The entire gauge mechanism and the drive electronics for the vibrating wire are mounted on the cast base-plate of a standard tipping bucket gauge and are covered by the normal moulded fibreglass collector. The new gauge is therefore externally identical to the current gauge and will not present any new problems of exposure. Although for this prototype version the microprocessor interface is separate from the gauge there is, in principle, no reason why this component should not also be housed within the gauge cover.

2.3 The Software

The simple programme concepts of the device are represented in the flow diagram shown in Fig 3. The binary counter increments continuously as the frequency changes and the values are taken into store once every two seconds. These values are differenced twice and the second differences are then added together to improve the signal to noise ratio. Running differences for any chosen period are formed from these cumulative data and these differences are proportional to the average value of $\frac{df}{dt}$ over the chosen period. The period $\Delta t$ for the average can be selected as a compromise between the competing demands of high resolution and high accuracy; any value may easily be incorporated into the software. The ultimate choice of averaging period for operational use will probably need to be made in the light of operational experience.

When the tipping bucket tips, the frequency of the wire suffers a step change and this causes false data to appear in the list of first differences. To avoid the problem which this causes in the computation the software checks whether a bucket tip has occurred between the present reading and the previous reading. If so, two status flags are set and the current and succeeding second differences are set to zero. The status flags are cleared if no tip has occurred. The zero value for the second difference is the most probable value and, even if incorrect, does not cause a major error in integration periods as short as one minute. For shorter integration periods this procedure could generate an unwelcome inaccuracy unless the sampling rate is also reduced. However, it is in principle possible to set the second difference to a most probable value based upon the recent past values which would reduce the potential error significantly. So far we have not attempted this increase in the sophistication of the system.

The result of the computation of $\frac{df}{dt}$ is at present output through a digital-to-analogue converter on to a pen chart recorder. Once the performance characteristics of the sensor have been studied it will be possible to process this signal further by the incorporation of the empirical calibration constant, $K$, to provide the actual rate of rainfall over the integration period and, by integration of $K \frac{df}{dt}$ the total amount of rain which has fallen since some chosen zero of time.
2.4 Results

Fig 4 shows some early results of the output from a period of intermittent rain. The signal is proportional to $\frac{df}{dt}$ and is averaged over five minutes. The onset and cessation of $\frac{df}{dt}$ rain is easily identified. The zero marks indicate that the bucket tipped.

2.5 Future Developments

This sensor, still in an early stage of development, promises to provide in a single unit a raingauge which will provide answers to all the questions which the users of rainfall data for a given site require.

A future development which we envisage is to use the accumulated bucket tip information, compared to the integrated output of $\frac{df}{dt}$ to keep a check on the drift in the calibration of $\frac{df}{dt}$ the device. Differences in these values will at least indicate the need for a recalibration but may be usable for the direct, on line and continuous re-calibration of the sensor.

We expect that a sensor as flexible and potentially useful as this one will soon find a permanent place in the body of standard meteorological instruments. In more general terms it represents one of the first of a new generation of sensors which have their own, dedicated microprocessor-based intelligent interface and which will prove orders of magnitude more powerful than their predecessors.

REFERENCES

AN AUTOMATED MAXIMUM-MINIMUM THERMOMETER FOR CLIMATOLOGICAL USE

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Canada has a vast climate network made up of approximately 2500 stations. Of these almost 2100 record maximum and minimum temperatures.

Over the past several years good quality liquid-in-glass thermometers have become much more expensive, the labour intensive job of calibrating them is more expensive, as is the Stevenson screen to house them. Breakage of liquid-in-glass thermometers is also high, particularly maximum thermometers which are reset by centripetal force.

In the meantime, the cost of analog to digital electronic components has decreased and their temperature range has increased to the point where electronic thermometers are becoming an economically viable alternative. Figures 1 and 2 reproduced from McKay and McTaggart-Cowan (1977) show that inexpensive shields for electrical thermometers compare favourably with standard Stevenson screens.

Figure 1 - Parallel Plate Shield

Figure 2 - Stevenson Screen
With this in mind we made up a wish list (Fig. 3) and showed it to several manufacturers. The discussions which followed indicated that the electronic max-min thermometer was feasible at a price of about $300. For approximately $400 the unit would include memory to save several days information, a calculation of daily mean temperature and a real time clock to automatically transfer previous days mean, maximum, and minimum values, and reset the current days values at midnight local time.

Since we have been finding it increasingly difficult to find climate observers who were willing to take seven-day-a-week observations, the extra cost of providing memory was readily accepted.

A request for quote (RFQ) was prepared in which the basic requirement was for a battery operated electronic maximum-minimum thermometer which could store four days data and have an accuracy of ±0.5°C from -50°C to +50°C. Much of the design of the unit was considered straightforward but there were several areas where we felt that we were not dealing with existing technology, and these were emphasized in the RFQ. Some of these areas were:

1) Ability to operate for at least a month at -40°C on a set of batteries, and to provide a warning of low battery condition.

2) Ability to measure temperature to within ±0.5°C with a low power sensor over the environmental temperature range.

3) The ability to verify temperature readings before they are considered for maximum or minimum values.

4) Ability to access the required information and verify if necessary with a minimum amount of steps.

5) Some means of checking the validity of the internal memory.

**Desirable requirements for the solid state temperature device**

- Be capable of operating in an unheated environment with temperatures ranging from -50°C to +50°C.
- Operate off a small battery pack for a reasonable length of time (at least 1 month).
- Be inexpensive (probe, electronics, display and shield should be less than $300).
- Deliver a digital display of a sign plus 3 digits.
- Deliver a maximum and a minimum temperature capable of being selected for readout and capable of being reset to the present temperature.
- Be capable of being removed (distance) to either a recorder or a second display (2 wire remote is preferred).
- Be capable of delivering the present temperature both on-site and remote.
- Option to be able to store 3 or 4 days of max min temperatures on-site and then read them out at the end of that period - this necessitates an automatic reset as well.
- Display does not have to be mechanically connected to the sensor and shield, and in fact should be capable of being mounted by itself.
- Desirable to have the output to the display in a serial train.
- Required to have an accuracy not including shielding errors of ±0.5°C and a desirable accuracy of ±0.1°C over a period of at least 2 years.
- Be rugged enough to be shipped anywhere without losing calibration.
- Sensor, shield, electronics and display should be metal.
- Display must be able to be read at all times - day and night.

**Figure 3 - Wish List**
From the submitted bids, Sonotek Ltd. of Mississauga, Ontario, was selected to design the unit and provide 15 prototype units for evaluation. The design of the operating scenario involved considerable interaction between Sonotek and ourselves. In operation the unit would make a temperature reading every 6 minutes (10 per hour). Each reading would be tested for maximum or minimum and would be added into the daily mean. At local midnight the daily mean would be calculated based on all valid readings and it, along with the maximum and minimum temperature readings would be entered into "yesterdays" data registers. Similarly previous days readings would be shifted one day further into the history file. Then the new days maximum and minimum would be preset to the present temperature.

Two techniques were used to verify the temperature data at each reading. Firstly, no temperature reading is permitted for at least six minutes after an observer activates the readout. This is particularly important for very cold conditions when the observer's presence could influence the temperature by radiation from the observers warm body. Secondly, the more important verification is that, at each reading period we must get three consecutive samples (approx. 1 second apart) to agree within 0.1°C. A maximum of nine attempts may be made before a sensor failure error is declared and the attempt is aborted.

Data readout is accomplished with four seven-segment heated filament displays. The filament is preferred over light emitting diodes because the higher luminence allows it to be read even in bright sunlight. The display itself is powered for only about 2 seconds to conserve power, however, the readout technique is designed to allow a reading to be repeated with a minimum amount of operations.

The readout is done with a single two-way toggle switch. Activating the switch in one direction steps from the displayed days data to the previous day, while toggling the switch in the opposite direction steps through the three temperature values (present/mean, maximum, minimum) and an index number referring to the day in question (i.e. day 0 is today, day 1 is yesterday, day 2 is two days ago, etc.).

The storage used in this design allows for nine days of storage in addition to the current days values.

The temperature sensor chosen was an Analog Devices Model AD 590 temperature to current transducer. It is an integrated circuit which utilizes the temperature variation of contact potential across the base-emitter junction of a transistor as a sensor. Several other transistors in the integrated circuit are used to linearize the change in voltage with temperature and to convert the voltage change to a current change. The end result is a two terminal device which generates a current directly proportional to the temperature.

This sensor was chosen as a compromise. It provides a linear output which is sufficiently large so that it doesn't require much amplification before the analog to digital conversion. The disadvantage is that it is somewhat more difficult to calibrate and its long term stability is not as well known as for platinum resistance thermometers.

The electronic design is considerably more complicated than one might expect for a microprocessor based system. The reason for this is power conservation. At the time the design was finalized no suitable low power microprocessor was available. In order to keep the power drain of a conventional microprocessor at a minimum, it is only powered up long enough to carry out a basic task, then is turned off. Lower power CMOS (complimentary metal oxide semiconductor) circuitry is used for data storage, for controlling when the microprocessor is to be powered up, and to control the display. The 6 minute timer also uses CMOS circuitry. Figures 4, 5, 6 and 7 show several views of the thermometer and its components.
Operation of the Max-Min Thermometer

In normal operation the microprocessor is not connected to power. Two conditions will cause the processor to be activated. Its first task is to determine the conditions which caused it to be powered up and then to execute a particular set of instructions related to the condition.

One condition is that the internal timer has reached 6 minutes. With this condition the processor commands power to the sensor, and commands the A/D (analog to digital) converter to read the temperature. If three successive readings (out of a possible total of nine) agree within one count (0.1°C) the temperature is valid. The valid temperature is added to the daily mean to date, the valid reading count is incremented and the temperature is tested against the stored maximum and minimum values. The value is transferred to the present temperature register (and its backup) and then the processor shuts itself off.

The other condition is that one of the manually operated switches has been activated. The processor determines which switch position was activated and carries out the appropriate instructions. On the first activation of the Day/Temperature toggle switch the processor loads lamp check data into the display. The next activation of the Day toggle will load the first of two possible error messages. If no errors have happened the processor begins to access the data stack and loads the day index number (day 0 - today). Each subsequent activation of the Day toggle causes the data pointer to move down the data stack to the next days information. Data on the data stack is stored in the form mean/present, maximum, minimum. Activation of the Temperature toggle will step the display through each value (one value per activation) for the current day and back to the day number. The day number, which occupies the first position in the display rotation is stored outside the data stack. Another days data can only be accessed by activating the Day toggle.

For each display the processor loads the appropriate number into the display electronics, then powers down before the display lights are activated. A hardware control removes power from the display lights after about 2 seconds.

The remaining manual control is the function button. Activation of this switch changes program control of the Day/Temperature toggle to a "real time clock" update control. Hours and tenths of hours are respectively incremented by toggling the Day position or the Temperature position. Reactivating the function switch returns normal program control. The last position on the data stack (after day 9 data) is the value of the 24 hour real time clock. This allows the observer to verify the internal time against local time.

The unit can be left with the data pointer or program control in any position. The occurrence of the next six minute time pulse will restore the data pointer to the top of the data stack and ensure program control in the Day/Temperature format.

Error Displays

As mentioned earlier a valid temperature reading requires three successive samples to be within 0.1°C. Since the samples occur at approximately 1 second intervals and the sensor has a lag coefficient of about 90 seconds, invalid readings should not occur in normal operation. If an invalid reading does occur the sensor error flag is set and this results in the display unit showing the error message 66.6 following the lamp check. The error flag will remain set until the internal clock goes through midnight and the error message has subsequently been displayed once.

All data on the data stack is stored in two locations. When the Day/Temperature switch is first toggled the processor compares the values at each location. If any differences occur the display will show the error message 77.7 on the display following the lamp check. In addition, the display will momentarily flash an E proceeding the display of the particular data value which didn't agree. No attempt is made by the unit to determine whether the primary or the backup data value is in error.
If, during operation, the voltage of the battery falls below a preset value (about 9.5 volts) an L will be displayed beside the day index number to warn the observer of the low battery condition. At this point there will still be plenty of power to read the unit, however, the accuracy of the A/D converter will begin to deteriorate if the batteries are not changed.

Conclusion

At the time this paper is being written we are just beginning our field tests of the instruments. Our laboratory testing has been very promising. A minor modification in the program to make the unit measure and display temperature every 8 seconds, made adjusting the calibration of the sensor easier than anticipated. Errors of less than 0.1°C resulted from having only the sensor immersed in the temperature bath. This makes calibration potentially as easy as if a platinum resistance sensor had been used.

We are well aware of the problem of battery replacement. This can become a substantial cost, however, we have several years experience in using rechargeable batteries in the field (including use of solar power rechargers). If our field tests using primary cells are successful, we will have a rechargeable battery pack designed for the unit.

One of the items on our wish list was to provide a remote readout. Although this has been superficially demonstrated, our present feeling is that this unit should be treated as a stand-alone, and that a different operating procedure be chosen for remote reading thermometers.

References

SOME METROLOGICAL ASPECTS OF THE CLOUDINESS MEASUREMENTS AUTOMATION

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Abstract*

There is no accepted method for automatic measurement of a cloud field, particularly for determining cloudiness. Presently, only visual methods are relied upon, and the results obtained are very limited in value since they have low accuracy.

In this paper, some metrological aspects of determining cloudiness are discussed. The described method is based on the scanning of a cloud field using a laser-set. The technical parameters of such a laser-set are set forth.

The number and distribution of sounding points is determined by the required accuracy. A model based on previously mentioned methods is proposed.

The authors suggest that after applying certain modifications and improvements, which are described, the method can be applied for use in automatic weather stations.

* Abstract only available
SOME ASPECTS OF AUTOMATING VISIBILITY OBSERVATIONS

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1. Introduction

Visibility is one of the most difficult meteorological parameters to measure at automated stations. There are as many definitions of visibility as there are users of the information. Member states of the World Meteorological Organization specify visibility parameters to meet their own operational requirements. Thirty years ago Middleton recognized the impossibility of instrumental visibility measurements satisfactory to all. In the final chapter of his classic monograph "Vision Through the Atmosphere"(1), he recommends: "make good instrumental measurements of the extinction coefficient and then calculate something which will be of interest to the user of the datum." In 1957, the WMO recommended the adoption of meteorological optical range (MOR), a parameter intended to standardize the measurement of the optical state of the atmosphere. MOR is the distance through the atmosphere for which the transmission is 0.05. The spectral response of the measurement system should match that of the human retina. The 0.05 value is tentative, subject to recommendations of a working group of the WMO Commission for Instruments and Methods of Observations. If a value can be selected to agree with typical luminance contrast thresholds at high ambient light levels, then sensor MOR measurements will be in good agreement with daytime visibility observations.

The MOR parameter is suited to automation because the definition neglects factors affecting the human observation such as the effect of ambient illumination on both the luminance contrast threshold and the apparent contrast of the marker and its background. In practice, the atmospheric transmittance is measured over a fixed baseline of a few tens of meters, and the result extrapolated assuming a uniform atmosphere. This approach is more practical than varying the baseline until 0.05 transmittance is achieved. The question addressed here is how well does the MOR definition and its practical application represent human visibility observations, and what is the cause of discrepancies.

In North America, the meteorological visibility parameter is prevailing visibility and it is reported in fractions of statute miles. These units will be retained in observations presented here. Prevailing visibility is defined as the maximum distance targets can be identified in azimuthal sectors comprising one-half or more of the horizon circle. It represents a median value when the visibility varies with direction. This paper examines the consequences of replacing this uniquely North American parameter with an automated MOR measurement. Prevailing visibility observations from a meteorological observing station at Toronto International Airport and MOR measurements from the station and from locations within the airport boundary are compared. Two topics are emphasized: the effects of spatial non-uniformity of visibility on the scale of an airport, and variations in the luminance contrast threshold of a typical group of meteorological observers.
2. The Experiment

Atmospheric measurements from a number of sensors and prevailing visibility observations by qualified meteorological observers have been recorded at an experimental site at Toronto International Airport since 1970. The most recent in a series of tests included two 180 meter baseline transmissometers sharing a common projector for determining the MOR at the observer's station, and four 80 meter baseline transmissometers used operationally by the Ministry of Transport for runway visual range observations. These are situated at a distance of 1 to 2 miles from the observer, one in each of the surrounding quadrants. A light sensor measures the total illumination falling on a horizontal surface.

All sensor outputs were integrated for one minute and recorded with the prevailing visibility and weather type every half hour if the observer's schedule permitted.

3.0 Analysis

There are inherent limitations to MOR measurements using a fixed baseline transmissometer. The exponential nature of the equation (see Section 4.5) converting transmittance to MOR, causes small errors in transmittance to convert to large error factors* in MOR at the limits of dynamic range. In practice transmissometers have a measurement range from 1/2 to 25 times the baseline. For the 180 meter baseline instrument, a 1% error in transmittance will result in an error factor of 1.1 at 3 miles. Errors in MOR above 3 miles increase very quickly. It is difficult to maintain 1% accuracy in transmittance without daily maintenance. The 100% transmittance calibration point is unstable because of changes in lamp intensity and alignment. Therefore it was necessary to normalize the 180 meter instrument to read 100% transmittance during periods of exceptional clarity. After normalization, the transmittances measured by the co-located instruments agreed to within 1%. For the 80 meter baseline instruments the upper limit is only 1 1/4 miles. Because these operational transmissometers were maintained on a daily basis, their outputs were not normalized. We limited our analysis to fog, snow and rain-fog conditions for which there was significantly numerous data in the dynamic range of the sensors.

Because the MOR calculation is based on Koschmieder's equation for determining visual range by contrast, we selected only prevailing visibility observations during the daytime and not observations of lights made at low ambient light situations. Daytime was defined as periods when the horizontal illumination exceeded 1000 lux. This level is equivalent to an overcast day.

4. Results

A least squares second order fit to a plot of MOR versus prevailing visibility in fog has a standard error of estimate factor of 1.4. This confirms the results of previous tests comparing scatter meters to prevailing visibility (2). We can then conclude that for a given weather type the accuracy of a prevailing visibility estimate from a scattering function measurement is equivalent to that of an extinction measurement.

* The term "error factor" is used throughout this paper to define a range of MOR on a logarithmic axis. For example an error factor of 1.4 at 2 miles MOR means the MOR has values from 2/1.4 to 2 x 1.4 miles. This convention is useful for expressing the standard deviation of parameters plotted on logarithmic axes.
4.1 Prevailing Visibility - MOR Differences

The standard error of estimate calculation weights all observations equally. It is more instructive to plot the standard deviation of MOR as a function of visibility by considering each reportable value independently.

Figures 1, 2 and 3 show this analysis for fog, snow and rain-fog respectively. The solid lines give the standard deviation of the MOR calculated from the output of the single transmissometer located near the observer for each reported prevailing visibility less than 4 miles. The most conspicuous feature of the fog and rain-fog graphs is the decrease in the standard deviation factor, from values in the order of 2.2, for visibilities less than 1/2 mile, to values of 1.35, at greater than 1 mile. The snow data were few below this range and this change is not evident.

We examined two occurrences of low visibility in fog when the observer and sensor differed by large amounts. In one case, the observer's reports were out of phase with all five transmissometers. Also the lowest observations were about 3/8 mile while the MORs were less than 1/8 mile. In the second example the observer's reports were in phase, but again higher by a factor of three than any of the transmissometers. The distribution of these instruments in the observer's field of view make the physical reality of these situations difficult to imagine. We ask why these differences should be more prevalent at visibilities less than 3/4 mile. One explanation is the lack of a sufficient number of visibility markers at distances less than a mile may cause a higher variance in the observation. Also the observers are busiest during periods of low visibility which may discourage precise interpolation where markers are sparse. It is also the range of visibility where temporal variability is greatest and we next examine this effect.

4.2 Temporal Stability

The one-minute sensor output integration period was designed to correspond as closely as possible, under normal practice, with the time of observation. Figure 4 shows a comparison of the MOR measurement in fog at the time of observation (solid line) with a one-minute integration recorded automatically five minutes later (long dashes). Below 1 mile, the five minute delayed count increased deviations significantly, while above 1 mile there was no significant change. This comparison indicates that a five minute delay in the observer's recording routine is most significant at low visibilities when it is most likely to occur due to higher priority activities.

To reduce the effect of asynchronous data, we selected a subset of fog data when the MOR did not vary by more than a factor of 1.20 during the five minute interval following the observation. Figure 4 also plots this comparison (short dashes). The most significant improvement occurred at 1 1/4 miles. There was insufficient data below this range for analysis. Above 1 1/4 miles there was little improvement indicating fewer rapid transitions at these visibilities.

4.3 Spatial "Averaging"

It was hoped that by spatially sampling the atmosphere at 1 to 2 miles from the observer, we could estimate the prevailing visibilities of this scale size more accurately than the single point measurement. Different approaches were used to determine an extinction coefficient representative of the optical path of the line of sight used for the observation. In all cases this value was then averaged with the extinction coefficient measured at the observing site since the visibility marker must be viewed through the local atmosphere also. Recognition of this fact significantly improved agreement between observer and sensor regardless of the spatial averaging technique used.
The simplest approach is to average the four extinction coefficients measured by the surrounding transmissometers and then to average this value and the one located with the observer. These results are given in Figures 1, 2 and 3 by the longer dashed lines. However, occasionally a local anomaly, such as a patch of fog at one of the four sites, significantly affected the average but did not obscure a sufficient arc of the horizon, as seen from the observing site, to change the prevailing visibility.

Therefore, a better procedure is to use the median of the four values. The maximum and minimum values were discarded and the remaining pair were averaged. This procedure assumes that if each of the four transmissometers represents the extinction at 1 to 2 miles in each of the four quadrants surrounding the observer, the median will approximate the maximum visibility prevailing over half of the horizon. These results are represented by the shorter dashed lines in Figures 1, 2 and 3.

As expected from the scale sizes, below 1 1/2 miles in fog there is no advantage in the multi-sensor estimate. From 1 1/4 to 4 miles only the median estimate shows an improvement. The rain-fog data below 3/4 mile is sparse and the improvement using the median and average may not be statistically significant. In the range 3/4 to 1 1/2 miles there is little difference in the methods and above 1 1/2 miles the single point measurement is superior to both multi-sensor estimates. The greatest improvement using a multi-sensor estimate occurs for snow. At 1 1/2 miles the median estimate reduces the standard deviation from 1.40 to 1.25.

Alternative spatial processing techniques were explored but the median technique gave the best agreement between observer and sensor. The minimum standard deviation factor was about 1.20.

4.4 Observer Variability

The observations for this experiment were made by 14 meteorological observers with varying degrees of experience. Middleton and Mungall (3) measured large variations in luminance contrast threshold of observers in field conditions very similar to those of the present experiment. With a telephotometer, they measured directly the luminance contrast of the immediate background and the visibility marker used by the observer to determine the prevailing visibility. The contrast thresholds calculated from 1000 observations were normally distributed about a mean of 0.030 with a standard deviation factor of two. The corresponding standard deviation factor in MOR is 1.25 and this value is labelled "MIDDLETON" on Figures 1, 2, 3 and 4.

Middleton stated that "this enormous spread of values is due to the difficulty of interpreting the official instructions, with its attendant absence of a stable criterion". Blackwell (4), in a controlled laboratory experiment involving 450,000 observations, found that for any given set of experimental conditions, the contrast threshold was normally distributed about the mean with a standard deviation factor of 1.5. This is equivalent to a factor of 1.16 in MOR and is labelled "BLACKWELL" in Figures 1, 2, 3 and 4.

We do not expect Middleton's or our standard deviations to necessarily attain the Blackwell limit because our experimental conditions have not been held constant. Since the Middleton limit was determined by a technique independent of the spatial uniformity around the observer, and since the lower limit of our deviations approximate this value, we conclude that the median technique for estimating prevailing visibility in inhomogeneous atmospheres was successful for visibilities in the range of 1 to 3 times the distance to the surrounding transmissometers.
4.5 Contrast Threshold Estimates

Transmittance measurements $T$, over a baseline $b$, and visibility observations $v$, can be used to calculate the luminance contrast threshold $\xi$, using Koschmieder's fundamental relationship: $\xi = \frac{TV}{b}$. However, the prevailing visibility definition is not well suited to contrast threshold calculations from a single transmittance measurement because of the non-uniformity of the atmosphere discussed above. We use the median MOR data because it is spatially more representative. The resultant "implied contrast threshold" should be distinguished from values measured in controlled laboratory experiments.

Figure 5 shows a family of lines of constant contrast threshold plotted on the scatter diagram of prevailing visibility versus median MOR in fog. The line through the origin represents a contrast threshold of 0.05 when the prevailing visibility equals the MOR. At each reportable visibility, the range of implied contrast thresholds is given by the location of the vertical column of data relative to the contrast threshold lines. The mean thresholds have a maximum value of 0.10 at about 1.5 miles decreasing to 0.05 at 3 miles. Above 5 miles the errors in the transmittance measurement significantly affect the results, evidenced by the non-linearity of the distribution. This pattern repeats for rain-fog and snow data. The maximum for snow is less at 0.085. The results are tabulated in Table 1. As described in Section 4.4, standard deviations in the contrast threshold less than Middleton's value of two, indicate data free from the effects of spatial non-uniformity. Therefore, these values accurately represent the mean contrast threshold of the several observers in our experiment at a particular visibility.

These values of contrast threshold were confirmed by analysis of a larger data base collected at the Toronto International Site from 1973 to 1975 (2). In this experiment, scatter function meter outputs were compared to prevailing visibility observations. The calibration of our reference Videograph backscatter meter is the same for both data bases. Now that this sensor has been calibrated in terms of MOR using the recent data, we can obtain an estimate of the contrast thresholds of a different set of observers from the earlier experiment. These results are also presented in Table 1. The agreement is noteworthy.

Table 1: Visual Contrast Thresholds in Fog

<table>
<thead>
<tr>
<th>Prev. Vis. (miles)</th>
<th>1979-80</th>
<th></th>
<th></th>
<th>1973-75</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of Obs.</td>
<td>Threshold</td>
<td>St. Dev.</td>
<td>No. of Obs.</td>
<td>Threshold</td>
<td>St. Dev.</td>
</tr>
<tr>
<td>1</td>
<td>14</td>
<td>0.076</td>
<td>2.59</td>
<td>58</td>
<td>0.128</td>
<td>1.34</td>
</tr>
<tr>
<td>1.25</td>
<td>39</td>
<td>0.010</td>
<td>1.57</td>
<td>58</td>
<td>0.097</td>
<td>1.90</td>
</tr>
<tr>
<td>1.5</td>
<td>30</td>
<td>0.010</td>
<td>1.46</td>
<td>90</td>
<td>0.103</td>
<td>1.90</td>
</tr>
<tr>
<td>2</td>
<td>21</td>
<td>0.076</td>
<td>1.50</td>
<td>126</td>
<td>0.086</td>
<td>1.83</td>
</tr>
<tr>
<td>2.5</td>
<td>36</td>
<td>0.069</td>
<td>1.74</td>
<td>157</td>
<td>0.061</td>
<td>2.03</td>
</tr>
<tr>
<td>3</td>
<td>22</td>
<td>0.041</td>
<td>1.93</td>
<td>253</td>
<td>0.060</td>
<td>2.18</td>
</tr>
</tbody>
</table>

These values are for the most part greater than the 0.05 value recommended in the present MOR definition. A review by the author (5) of other experiments indicated that most values fell in the range 0.02 to 0.05. One notable exception was the value 0.2 determined by Lefkowitz and Schlatter (6) for visibilities of about 1 mile. The implication is that automated observations using the 0.05 value in the present MOR definition would overestimate the prevailing visibility, as used in North America, by a factor of 1.3 in the 1 to 2 mile range.
FIGURE 5: CONTRAST THRESHOLDS IN FOG

CONTRAST THRESHOLDS

.2
.1
.05
.025
.0125

PREVAILING VISIBILITY IN MILES

MEDIAN MILE IN MILES

1/32
1/16
1/8
1/4
1/2
1
2
4
8
16
32
5. Conclusions

The past 30 years have seen little improvement in the automated measurement of the prevailing visibility parameter reported by North American observers despite an obvious improvement in the quality of instrumentation. Our experimental observations and the analysis demonstrate that, in fog and snow, the effect of atmospheric non-uniformity can be effectively eliminated by spatial sampling. When this is done, the standard deviation in MOR is reduced from a factor of 1.4 to 1.2 for prevailing visibilities of the same magnitude as the sampling distance.

This standard deviation factor of 1.2 lies between values determined from field measurements of Middleton and the controlled laboratory measurements of Blackwell. This variance is therefore due to both non-standard observing practices, as suggested by Middleton, and to the several factors effecting the visual acuity of observers as investigated by Blackwell.

The luminance contrast threshold, calculated for two sets of observers, is 0.1 at 1 to 2 miles, and about 0.05 at 3 miles.

Visibility studies are inherently statistical in nature and require large data bases in order to determine the relative contribution of the variety of factors effecting the observation. In particular, we have difficulties in obtaining sufficient low visibility data in snow and rain at Toronto International Airport. When more data is available we intend to examine the many factors effecting the contrast threshold in the field. These include the intensity and distribution of ambient illumination, variances amongst observers, and the number and distribution of the markers at the reportable distances.

References


SYSTÈMES D'OBSERVATION AUTOMATIQUE
DE SURFACE
H. TREUSSART
PRESIDENT DE LA COMMISSION DES INSTRUMENTS
ET MÉTHODES D'OBSERVATION

En 1975, à l'occasion de la conférence technique de l'OMM sur les systèmes météorologiques automatiques (TEAMS), dans un document intitulé "Les stations météorologiques - Possibilités actuelles et futures" (1), l'auteur concluait :

"L'observation météorologique n'est engagée, il y a une vingtaine d'années déjà, dans la voie de l'automatisation. Cette voie apparaît irréversible ; l'évolution des besoins, l'évolution des techniques, tout concourt à imposer un emploi de plus en plus grand de moyens hautement automatisés." 

Les cinq dernières années, malgré les contraintes économiques auxquelles ont été soumis la plupart des services météorologiques, ont confirmé cette irréversibilité. Le présent document a pour objectif de préciser les progrès accomplis au cours de cette période et de présenter quelques réflexions sur les axes le long desquels se développera le plus vraisemblablement l'automatisation au cours des prochaines années.

1) Conditions d'emploi des équipements automatiques

La pression des utilisateurs de données météorologiques n'a fait que s'accroître tout au long des cinq dernières années. D'une manière générale, tous les besoins en données nouvelles ou en données supplémentaires qui sont apparus pendant cette période ont été satisfaits par la mise en place d'équipements automatiques.

En fait, ces cinq dernières années ont été essentiellement marquées par la stagnation ou la réduction du nombre des stations conventionnelles (à observateurs) alors même que le nombre de points d'observation ne cessait de croître, les équipements automatiques satisfaisant tous les besoins nouveaux ou assurant le remplacement des observateurs humains d'un certain nombre de stations conventionnelles déjà en service.

Cette multiplication des moyens automatiques d'observation, quantitativement très satisfaisante, ne s'est malheureusement pas toujours produite d'une manière parfaitement harmonieuse par suite d'un certain manque de coordination entre les actions directement conduites par les météorologistes et celles menées par des utilisateurs de données, peu soucieux d'aligner les caractéristiques et performances des nouveaux équipements qu'ils mettaient en place, sur les règles de standardisation qui auraient permis à la fois une meilleure harmonisation des données recueillies et une sensible réduction des coûts des matériels.

Malgré la grande diversité des équipements ainsi produits, on peut cependant distinguer deux grandes classes d'équipements :
a) Les équipements fournisant des données en temps réel que l'on divisera en :
   - équipements à caractère synoptique, essentiellement destinés à pallier les insuffisances ou les faiblesses du réseau de la Veille Météorologique Mondiale (VMG).
   - équipements spécifiques destinés à fournir des données soit individualisées, soit limitées à un usage propre (stations météorologiques d'aérodrome, stations de protection de l'environnement, stations de protection des incendies de forêt, etc.).

b) Les stations fournisant des données en temps différé comprenant :
   - Des stations climatologiques complexes assurant l'enregistrement à long terme (de l'ordre du mois) d'un nombre élevé de paramètres ayant éventuellement subi un premier traitement (intégration, extraction de valeurs extrêmes, différenciation, etc).
   - Des équipements simples, aux possibilités d'enregistrement limitées à un nombre réduit de paramètres utilisés, le plus souvent soit pour satisfaire des besoins très spécifiques, ou pour pallier les difficultés de plus en plus grandes rencontrées pour recruter des observateurs bénévoles.

2) Equipements fonctionnant en temps réel

Trois tendances ont marqué le développement des nouveaux équipements :
   - Mise en place de stations organisées en réseaux ou mini-réseaux ;
   - Intégration aux stations de possibilités de traitement des données accrues ;
   - Mise au point d'équipements spécifiques de la PRMG.

2.1. Ensemble de stations

Déjà signalée il y a cinq ans (1), la tendance consistant à mettre en place des ensembles de stations soit inter-connectées, soit plus généralement connectées à un ensemble central qui en assure la gestion, s'est amplifiée. Cette tendance s'est affirmée soit dans l'exploitation de stations à vocation synoptique, soit encore, et d'une manière peut-être plus nette, dans des stations participant à des tâches de surveillance.

Si, à l'origine, ce type d'organisation a été essentiellement commandé par un désir de simplification des équipements assurant l'acquisition des données, depuis quelques années, ce désir de simplification n'est plus la motivation principale. La technologie, par ses progrès, a en effet permis de minimiser l'importance et le coût de certaines fonctions, et l'intérêt de limiter leur multiplication en les concentrant en un seul point est, au fil des années, apparu moins évident. Par contre, les impératifs d'exploitation se sont avérés, d'année en année, plus déterminants. En particulier, la nécessité de strictement coordonner la diffusion des messages produits par chaque station, afin de permettre une meilleure utilisation des fréquences radio utilisables, a imposé l'adoption de dispositifs centraux assurant le contrôle permanent des dispositifs de diffusion d'un nombre de stations pouvant être élevé.

On notera également une tendance de plus en plus affirmée à demander aux stations automatiques une densité d'informations supérieure à celle réclamée dans le passé. Si, en effet, au début de l'introduction des stations automatisées, la transmission d'observations tri-horaires a pu paraître satisfaisante, les exigences actuelles imposent le plus souvent des observations fréquentes pouvant, à la limite, conduire à un renouvellement suffisamment rapide des observations pour que...
le flux des informations ainsi produites puisse être assimilé à une description continue de la situation météorologique. Ceci est tout particulièrement vrai dans le cas des réseaux de surveillance (protection des incendies de forêt par exemple) pour lesquels la densité spatio-temporelle des observations réalisée pour des régions déterminées la fourniture permanente des paramètres météorologiques les plus significatifs pour le type de mission affecté au réseau considéré.

2.2. Intégration aux stations de possibilités de traitement des données accrues

Bien qu'ayant touché l'ensemble des équipements automatiques fournissant des données en temps réel, cette tendance a plus principalement marqué les stations à vocation synoptique. Celles-ci ont en effet, plus que toute autre, bénéficié des possibilités offertes par la généralisation des microprocesseurs. Ceux-ci, par leur souplesse de programmation et leur capacité de plus en plus importante de stockage des données, ont permis de réaliser des ensembles assurant sur les données brutes des capteurs un certain nombre de traitements (cumul, calcul de moyennes, extraction de valeurs extrêmes, etc) permettant une exploitation plus directe des données fournies par les équipements.

Dans les ensembles les plus élaborés, les microprocesseurs ont permis d'assurer la présentation, l'édition et la diffusion des données sous des formes diverses adaptées en fonction de l'utilisation qui doit en être faite. Cette possibilité, réservée il y a encore quelques années aux stations installées sur les grands aérodromes, a été récemment étendue à des stations dont le rôle essentiel est de fournir des données synoptiques en temps réel et des documents archivables destinés à satisfaire les besoins climatologiques.

2.3. Équipements spécifiques à la PEMG

En réclamant un accroissement de la densité des observations de surface, la PEMG a indirectement contribué à intensifier et accélérer l'effort de réalisation de nouveaux équipements automatiques d'observation. Cet effort a surtout visé à pallier l'insuffisance des observations sur les zones océaniques. À ce titre, les résultats obtenus au travers de la mise en place d'un ensemble de bouées dérivantes dans l'hémisphère sud sont exemplaires.

On rappelle qu'environ 300 équipements de conception particulièrement simple ont été mouillés dans le cadre d'une opération concertée à laquelle ont participé une dizaine de pays (2). Afin d'assurer le succès de cet important programme, il avait été convenu de limiter les informations fournies aux deux seuls paramètres : pression atmosphérique et température de l'eau de surface.

Les équipements, mis en place selon un programme précis en différents points de la ceinture océanique australe, ont été exploités en utilisant l'équipement ARGOS emporté par les satellites à défilement TIROS N et NOAA 1. Les données recueillies par ces satellites, acheminées vers le centre ARGOS du centre national d'études spatial français, ont permis de connaître 4 ou 5 fois par jour, pour chaque bouée utilisée, son identification, sa localisation, les valeurs de la pression atmosphérique et de la température de surface de la mer, des données de contrôle technique de la bouée.

L'ensemble de l'expérience a démontré le grand intérêt d'un tel réseau. D'un point de vue technique, elle a permis de vérifier :

- les possibilités effectives d'utilisation des satellites pour la localisation d'un ensemble de bouées dérivantes ;

- la relative facilité de mouillage de telles bouées qui, par suite de la limitation du nombre de capteurs, peuvent être maintenues à un poids raisonnable (de l'ordre
J. remarqua l'utilisation des bouées ARGOS, ce qui a permis de tracer avec une bonne précision les trajectoires de chaque bouée ;

- la fiabilité moyenne satisfaisante des mesures effectuées ;

- la durée moyenne de vie acceptable des bouées utilisées puisqu'un grand nombre d'entre elles ont fonctionné d'une manière satisfaisante pendant des périodes de l'ordre de 15 à 17 mois ;

- le bon rapport performance - prix des bouées utilisées.

C'est là un enseignement particulièrement appréciable qui plaide, comme en ont déjà exprimé le souhait les pays les plus directement intéressés par les données recueillies, pour une extension de l'exploitation de tels équiments au-delà du programme expérimental qui l'a généré.

3) Equipements fonctionnant en temps différé

Les cinq dernières années ont vu naître de très nombreux équipements à vocation climatologique. Leur développement a le plus généralement été commandé par des besoins spécifiques réclamant la connaissance de paramètres météorologiques particuliers fréquemment limités en nombre. Il en est résulté une production d'équipements très divers, chaque utilisateur ayant tendance à refuser l'effort de coordination et de normalisation qui aurait permis l'adoption, par la majorité des utilisateurs, d'ensembles à caractère pluridisciplinaire susceptibles de satisfaire le maximum des besoins exprimés.

C'est là un point qui n'est satisfaisant ni économiquement, ni techniquement, la multiplication de petites séries étant à la fois préjudiciable au coût et à la fiabilité des matériels. Malgré cette diversité, on trouve dans les équipements produits de grandes similitudes, chaque équipement comprenant essentiellement un ensemble d'acquisition des données plus ou moins complexe suivant le nombre de paramètres appréhendés et un dispositif d'enregistrement se réduisant le plus souvent à un système à mini-cassette assurant le stockage des données pendant une période plus ou moins longue (généralement un mois ou plus).

D'une manière générale, les traitements effectués sur les données sont nuls ou très réduits ; on préfère stocker les variables mesurées avec une densité temporelle suffisante pour assimiler l'enregistrement obtenu à une description continue du temps observé. Il en résulte la possibilité d'extraire à posteriori, par traitement au moyen d'un calculateur, l'ensemble des données élaborées souhaitées par l'utilisateur (moyennes, écarts, degrés/jours, fréquences, extrêmes, etc).

La réalisation d'un enregistrement essentiellement numérique assimilable à une représentation continue de la situation météorologique pose un problème de fréquence d'échantillonnage, celle-ci devant résulter d'une optimisation entre les caractéristiques de variabilité des phénomènes observés, les possibilités de stockage des enregistreurs et l'autonomie souhaitée pour l'équipement considéré. Il semble qu'une période d'échantillonnage de l'ordre de quelques minutes soit satisfaisante pour la majorité des paramètres et la majorité des besoins à couvrir. Aux latitudes tempérées, de nombreux utilisateurs ont adopté le dixième d'heure, cette valeur fournissant une base convenable pour le calcul de valeurs élaborées telles la vitesse moyenne du vent, l'intensité des précipitations, les températures extrêmes, les températures cumulées, etc. Il serait souhaitable que ce point particulièrement important fasse l'objet d'un examen au niveau international avec, pour objectif, l'adoption d'une norme commune à l'ensemble des météorologues.
Ces cinq dernières années ont également été marquées par l'apparition d'équipements faisant appel à des mémoires statiques pour assurer le stockage des données. Les essais effectués, même s'ils n'ont conduit jusqu'ici qu'à des résultats assez modestes préfigurent très certainement les stations qui seront disponibles dans quelques années. Les dispositifs à bande magnétique actuellement utilisés ne peuvent être considérés comme apportant la solution définitive au problème de l'enregistrement des données. Ils sont pour cela trop vulnérables aux conditions d'environnement qui peuvent être à l'origine soit d'incidents mécaniques de fonctionnement, soit, en particulier aux basses températures, à de mauvaises performances des bandes magnétiques. Leur remplacement par des équipements entièrement statiques peu sensibles à l'humidité et fonctionnant dans une large gamme de température est évidemment souhaité. Les équipements réalisés avec les mémoires actuellement disponibles ne peuvent cependant être considérés comme totalement satisfaisants, leur capacité de stockage trop limitée ne leur permettant ni une grande autonomie, ni l'enregistrement de nombreux paramètres. On peut toutefois penser que cette faiblesse sera corrigée à court ou à moyen terme par l'adoption des mémoires à bulles dont plusieurs industriels ont déjà annoncé la prochaine commercialisation.

Avant d'en terminer avec les stations climatologiques, il paraît souhaitable d'attirer l'attention sur les difficultés qui peuvent apparaître si l'installation d'un réseau de stations étant décidé on ne prévoit pas simultanément la mise en place des moyens de traitement nécessaires à l'exploitation des enregistrements fournis par ce réseau. C'est là une évidence, mais ces cinq dernières années ont montré que celle-ci a parfois été négligée. La tendance à sous estimer le travail d'exploitation des documents particulièrement denses fournis par les équipements automatiques est assez générale et, si l'on n'y prend garde, il peut en résulter un déséquilibre entre le flux des données brutes recueillies et les possibilités des équipements chargés d'en assurer le traitement.

4) Evolution des capteurs

Dans le domaine des capteurs, les progrès réalisés au cours des cinq dernières années ont été limités. Les problèmes identifiés à l'occasion de TECAMS restent (1), pour la plupart, à résoudre. Ils portent essentiellement sur :

- la protection des capteurs en environnement sévère ;
- la mesure de l'humidité ;
- la consommation électrique encore prohibitive de certains capteurs (capteurs de mesure de visibilité ou de la hauteur des nuages par exemple), qui limite leur emploi à des équipements installés en des lieux disposant d'une alimentation électrique convenable.

Ces problèmes, malgré leur importance, ne doivent pas être amplifiés. Il existe actuellement, pour la majorité des paramètres les plus fréquemment demandés, des capteurs donnant satisfaction dans les conditions d'emploi les plus habituelles des stations automatiques et la faiblesse des capteurs ne peut plus être raisonnablement invoquée pour différer l'emploi des équipements automatiques que pour les régions soumises aux conditions climatiques extrêmes (montagnes soumises à des phénomènes de givrage par exemple).

Les résultats positifs obtenus ces dernières années, même s'ils sont limités, ne doivent cependant pas être négligés. Ils ont été essentiellement obtenus dans les domaines de la mesure de la durée d'insolation pour laquelle sont apparus plusieurs types d'héliographes (3) fournissant des données accessibles aux équipements automatiques et dans le domaine de la mesure de la visibilité avec l'apparition de dispositifs consommant moins et fournissant une bonne précision de mesure dans une large gamme de visibilité. Il reste néanmoins, aussi bien pour la mesure de l'insu-
lation que pour celle de la visibilité, que les résultats obtenus ne sont appli-
cables qu'à des équipements automatiques non abandonnés qui, de ce fait, peuvent
être soumis à une surveillance relativement fréquente (une visite par semaine
au moins).

Enfin, on doit également signaler les travaux entrepris dans divers pays pour
la mise au point d'équipements assurant l'observation de l'activité orageuse
(4,5). Les premiers résultats obtenus permettent d'augurer qu'il sera bientôt
possible d'incorporer aux ensembles automatiques d'observation des capteurs four-
nissant une information sur l'activité orageuse à proximité d'une station mieux
localisée et plus fiable que celle obtenue jusqu'ici en utilisant des compteurs
de décharges électriques.

5) Evolution future de l'automatisation

L'irréversibilité de l'évolution vers une automation de plus en plus poussée
signalée en début de cet exposé doit se confirmer. Sous la pression d'utilisateurs
de données météorologiques de plus en plus nombreux, il est vraisemblable que les
équipements automatiques d'observation se multiplieront. On peut cependant penser
que cette croissance ne se fera pas d'une façon homogène. Assiègurement, il
est à craindre qu'elle se fasse moins vite pour les usages conventionnels, princi-
palement synoptiques, que pour les besoins nouveaux, en particulier de surveillance.
La raison principale à cela est liée au caractère plus complet des besoins jusqu'ici
exprimés par les synopticiens. Il s'affirme en effet de plus en plus que, les besoins
des nouveaux utilisateurs se limitant à des données relevant d'observations objec-
tives facilement automatisables. Par contre, l'observation synoptique, elle, reste
prisonnière de données acquises subjectivement (appréciation de la qualité des
nuages, la couverture nuageuse par exemple) difficilement appréhendables automati-
quement. Elle est également fortement handicapée par des techniques de diffusion
étalées il y a de nombreuses années alors même que l'automatisation n'existait
pas ou n'avait pas atteint le niveau qu'elle a atteint actuellement. En particulier,
le problème périodiquement évoqué de l'adaptation de nos codes météorologiques aux
moyens automatiques d'observation reste posé. L'adaptation des définitions de cer-
taines des sections de ces codes aux performances de nouveaux capteurs (on rappelle
une nouvelle fois le problème de l'activité orageuse) reste à faire et il est à
clairdre, si on en juge au travers des difficultés soulevées par l'introduction
d'un nouveau code, que cette adaptation ne se fasse que très lentement.

Plus satisfaisantes sont les perspectives offertes par l'éventuelle réalisation
d'un système d'observation intégré souhaitée par de nombreux météorologistes. En
combining véritablement les différents moyens d'observation existants, un tel
système devrait réduire l'importance des données actuellement acquises subjective-
ment par les stations synoptiques et ainsi contribuer à accélérer l'automatisation
de ces dernières.

Concernant la surveillance des zones océaniques, il est, dès maintenant, évident
que dans quelques années la majorité des observations proviendront de moyens
automatiques d'observation soit installés à bord des navires, soit intégrés à des
ensembles de bouées. L'expérience PEMG de l'hémisphère sud pose le problème du
choix du type de bouées à utiliser : bouées dérivantes ou bouées ancrées. En
l'état actuel des techniques, il semble difficile d'apporter une solution définitive
à ce problème. Le coût relativement faible des équipements utilisés pendant la
PEMG, joint aux durées de vie observées, plaide quelque peu en faveur des bouées
dérivantes. On notera néanmoins que ce résultat a été acquis en limitant très sensi-
blement le nombre des paramètres mesurés. Cette limitation a permis une simplicité
de réalisation qui ne peut malheureusement être étendue aux équipements devant
assurer des mesures qui, comme celles de la vitesse et de la direction du vent,
imposent des superstructures interdisant l'emploi de bouées légères. Il est donc
à craindre que les résultats fournis par la PEMG ne soient pas immédiatement extra-
polables à la réalisation de réseaux qui assureraient, selon le souhait de la majo-
rité des synopticiens, la mesure de ces paramètres importants.

Les bouées ancrées resteront, d'une manière générale, coûteuses. Il est vraisemblable que, pendant encore plusieurs années, elles seront principalement employées dans les zones côtières, là où les conditions d'ancrage permettent d'en limiter les dimensions et le prix à un niveau acceptable. Pour le grand large, le coût des équipements, les frais élevés d'exploitation liés à l'importance des moyens nécessaires pour assurer leur mise en place et les visites périodiques de maintenance, continueront à constituer un handicap qui ne sera surmonté que dans des cas particuliers limités. D'ailleurs la réduction du nombre ou la suppression des navires stationnaires pourrait être l'une de ces cas. On notera que les bouées ne pourront cependant, du moins à moyen terme, totalement remplacer cet important moyen d'observation musique n'assurant, pour le moment, que l'acquisition des données de surface. À long terme, par contre, il n'est pas déraisonnable de penser que des bouées de fort tonnage, véritables laboratoires automatiques flottants, pourront contribuer à la fois à l'observation de surface et à l'observation en altitude, cette dernière fonction étant réalisée en envoyant automatiquement, sur commande à distance, des fusées ou des ballons emportant des sondes dont les données seront directement transmises à des satellites. C'est évidemment là un objectif lointain, ambitieux réclamant des équipements complexes et ne pouvant être atteint qu'au prix d'un effort technique et financier particulièrement important.

C'est cependant pas une hypothèse de fiction et des projets, tel le projet français Leviathan, ont déjà atteint le stade des études de faisabilité. Il est cependant trop tôt pour pouvoir se prononcer sur l'avenir de tels projets.

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AUTOMATIC WEATHER STATIONS- ANATOMY OF A CONCEPT

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Introduction

Historical automatic weather station designs have provided a long list of both good and bad techniques which act as a development base for the next system development. Unfortunately, many of these precedents are time volatile and cannot be applied to the technology of the day.

One common strength of good designs is in the systematic architectural philosophies of the sensing, measurement, processing and communication portions of the automatic weather station. These may be mechanical, for early designs; electronic, for present designs, and/or software, for new designs. These philosophies very strongly impact on the procurement, installation, maintenance and adaptation of a particular system and may yield longer life and higher cost effectiveness.

Previous Design Philosophies

In the early 1960's, Canada developed a Meteorological Automatic Reporting Station (MARS-1) which provided unattended observations for distribution via the CNCP teletype network and a local display for direct use in attended applications.

This system, as shown in figure 1, used electromechanical technology in which servomotor bridge balance and contact positioning techniques were common. The control circuitry consisted of mercury wetted relays and stepping switch scanning relays which were controlled by discrete transistor amplifiers and switching logic.

A "bus" interconnecting technique was standardized to permit rapid "module" swapping for maintenance purposes. The message format was controlled by the order in which these modules were scanned and could be changed by reassigning cable interconnections. (figure-2) Individual modules were responsible for interfacing to the appropriate sensor and converting the measurement to engineering units or a suitable code. Processing was generally limited to transfer function conversion, linearizing and rounding off although mechanical integration techniques were used in the cloud height module.
The MARS-1 system worked well in the field and is still in use in approximately twelve sites. As time marched on, this system became more expensive to manufacture and logistically more unreasonable to install due to its size and weight.

In the late 1960's, a technological update took place to develop a smaller, more cost effective electronic equivalent of the MARS-1 which, surprisingly, was called MARS-2. This system generally used a similar architecture to the MARS-1 but was implemented with DTL integrated circuitry on standard 4 1/2" x 6 1/2" printed circuit boards as shown in Figure 3. Sensor interfacing was completely electronic and the scanning function was performed on a BCD, digit to digit basis. Fixed information was preset by a diode matrix, a forerunner of today's read-only-memory (ROM), and the message format was predetermined by a wirewrapped card cage. Figure 4 shows this interconnection technique.
The ability to reformat the message at the field station by reassigning cables was deleted from the MARS-2 design for several reasons, the primary one being the impact of message variances on the central code conversion computer. All MARS-2 messages are routed to this code conversion computer which has application software to support the synoptic code standards. This centrally recoded data is then routed into the CNCP communications computer and distributed to the users.

The central code conversion concept has several advantages over a normal collection network. The main advantage is to provide quality control of data and real time meteorological computation and data conversion for the entire network at one site. Also, changes to the synoptic code can be implemented for all stations with one change and a single station can be modified and supported without altering the standard codes. Unfortunately, there are also disadvantages to this central code conversion computer. Most changes require significant software modification and the queue resulting from numerous changes is rarely short. Programmer availability and computer capability limitations quickly become major stumbling blocks and the turn around time to support new requirements is usually long.

The MARS-2 stations were also very successful and there are approximately forty stations in the present network. One serious limitation to the MARS-2 architecture was the cost of change. As requirements for sensor modification and additional parameters arose, a flood of engineering change notices and wirewrap modifications also arose. The system was not designed for easy change, so when it occurred it was difficult and costly.

Also, the MARS-2 station was a room temperature, rack mounted and commercially powered system. As remote data requirements increased it became more and more difficult to adapt this system. Needs were developing for data collection in remote areas where low temperature, low power, small size and rugged construction were the prime concerns. Also, communications had to be either by radio, radio relay or satellite relay since commercial lines were not available.

These criteria lead to the development of a new limited automatic weather station by Bristol Aerospace Ltd. of Winnipeg, Canada, for some of these applications in the early 1970's. The architecture of this system used the same basic principles as the MARS-2 since it had a hardware digit scanner with similar sensor interfacing and limited processing techniques. The technology switched from DTL circuitry to CMOS devices which provided low power operation and more compact circuitry due to newer integration techniques and natural technological evolution. However, the packaging was realigned to functionally isolate individual parameters into easily handled modules with pseudo standard interconnections as shown in figure 5. Each module fully contained the necessary hardware to interface and process a specific sensor and a specific parameter and was connected to a dedicated connector via a module specific cable. This greatly simplified the sensor and/or parameter modification since the field requirement is to simply swap modules. Also, the field cabling went directly to the sensor interface module where electromagnetic interference (EMI) filtering took place in a separate compartment before the signals entered the main interface area, as illustrated in figure 6.

The first MAPS system was built in 1975 and was installed on an ice island in the Beaufort Sea in the Canadian arctic. This system, shown in figure 7, used a satellite data collection platform (DCP) for communication via the GOES satellite and took advantage of wind power for charging the batteries which are environmentally protected in the bottom of one of the tower footpads. The wind generator uses an inner Savonius rotor for initial starting torque and low wind speed power generation and an outer Darius airfoil blade for normal wind power translation.

There are approximately twelve active MAPS sites in the present network. Both MAPS and MARS-1 have been added to the central code conversion computer facility.
Figure 5 - MAPS Interconnection

Figure 6 - EMI Protection

Figure 7 - Beaufort Sea MAPS site
The Impact of Change

The trend in meteorological data collection in Canada is leaning toward more on site intelligence in the automatic weather station with an ability to quickly adapt to new requirements. Similarly, technological change is accelerating to such a pace that by the time a design is completed, tested and accepted it is surely obsolete. Not from the point of view of procurement but if designed again at that time it would certainly be modified.

The present microprocessor and microcomputer trends imply that sophisticated processing and communication verification techniques could be designed into field stations and specifically into sensor interfaces themselves. This would remove the need for central code conversion and would permit a significant realignment of processing concepts which were previously not possible. For example, a single large scale integrated (LSI) microcomputer circuit could be placed directly into a sensor package, such as an anemometer, and "front end" sampling, vector conversion and summation, ASCII translation and communication could be accomplished. Full remoting capability would be present with a field cabling overhead of only three wires. The processing requirements at the automatic weather station are now significantly reduced depending on the application. For example, another single chip microcomputer could perform ten minute running averages and extract gust information and specials as specified in appropriate WMO and MANOBS documents.

Another significant impact of this approach would be in the maintenance and training components of supporting organizations. Maintenance would be primarily involved in fault detection and module isolation with possible on site corrective action such as parameter bypass or deletion. It is highly unlikely that internal module tests and component changes would take place by this group due to the high technology in these inner devices. This role would need to be established with the manufacturer as a return and repair support function. Specialized equipment and personnel would be required for this ever changing role. Similarly, training would be primarily in the functional operation of specific system modules with emphasis on proof of performance testing as a "black box" in support of the module isolation technique for maintenance.

Today's Solution

"A new design philosophy should be able to satisfy today's needs with an ability to easily adapt to changing future needs and with minimal impact of new technology." General statements like these are all too common these days and they present a rather significant challenge to the designers of today's instrumentation. If technical standards can be developed which are not specific technology dependant, and intermodule protocols can be technically established, then it is within practical limits to attempt such a design.

We have pursued these standards and, although no unique solution exists, a practical system architecture has developed from these efforts. Figure 8 shows a block diagram of the proposed system.

Figure 8 - Practical Architecture for today's Field Station
This system permits true functional independence of individual sensor Peripheral Interface circuitry, processing algorithms, message formats and codes, reporting priorities and sensor remoting techniques. To use engineering terms, it is based on a multiprocessor, loosely coupled, non-shared resource architecture. This simply means that each module may have its own microprocessor with supporting hardware and that none of the hardware or software in one module is required for another module to properly function. The intermodule connections between the Shelf Controller and all Peripheral Interfaces use CMOS, parallel bus, low power, medium to high speed techniques which are software determined, thereby providing a large degree of technological independence in the specific design and retrofitting of individual modules. The detailed handshake sequences are defined in a protocol specification (PROTOCOL-2).

![Figure 9 - Typical Peripheral Interface Package](image)

![Figure 10 - Typical Field Station Shelf](image)

Similarly, the interconnections between the Communications Controller and the Shelf Controller use current loop, optically coupled, serial ASCII, software controlled techniques which permit easy remoting and technological independence. This is a sequential character protocol which uses industry standard, basic mode control procedures for string verification and delimiter recognition (PROTOCOL-1).

The Communications Controller provides all the necessary interfaces, controls and responses for a specific medium. For example, a VHF application would have a specific Communications Controller which would obtain data from the Shelf Controller in accordance with PROTOCOL-1 standards and would perform transmitter control and modulation functions for a specific commercial VHF transmitter. Similarly, a commercial DCP could be selected for satellite communications and a specific Communications Controller would provide the necessary data and handshake controls for this DCP. Each communication medium would require a specific generic Communications Controller design which would be functionally self contained and application unique. The most common Communications Controller will be a teletype collection line unit which will provide poll recognition and normal traffic channel verification responses. A local user will have a standard CRT terminal and a capability of monitoring the data from the automatic station, editing and/or adding data, performing system diagnostic checks for maintenance and monitoring normal line traffic in support of the collection network maintenance.
The Shelf Controller is a common module in every field station. This unit provides the standard data access capabilities for the Communications Controllers in accordance with PROTOCOL-1 standards. These include the ability to obtain formatted data, raw data, diagnostic data, station identification, date/time and station configuration, as well as the ability to transfer variables, such as setting the real time clock, and performing commands under remote control. The Shelf Controller also controls the scanning and data transfer handshake sequences from the Peripheral Interfaces in accordance with PROTOCOL-2. No data dependent decisions are made by the Shelf Controller. It simply acts as head librarian for all system information and routes these data in accordance to the standards it has established.

The Peripheral Interface has the responsibility to sample data from the sensor(s), linearize, average, interpret, convert and format these data into standard messages in accordance with user's requirements. Once these units are developed they may be simply plugged into the shelf in any location. The message construction is predetermined by the module design and the Shelf Controller will self configure the appropriate message. This capability provides central control of standard message formats while other locally used portions of the message can be locally controlled. Each Peripheral Interface may provide several types of information, namely: fixed formatted data, free formatted data, raw data, diagnostic data and a module type code. Fixed formatted data represents the standard operational synoptic information and has a predetermined reporting priority established at the time of Peripheral Interface specification. Free formatted data represents the supplementary information which would follow the fixed data in a normal message. These data are usually of interest locally and are therefore placed into the message in the order of local station configuration. Raw data represents "non-processed" sensor data. This group is used in complex peripherals for multiparameter calculations. For example, to obtain Mean Sea Level pressure it is necessary to know the station pressure and the average station temperature for the previous twelve hours. A pressure Peripheral Interface would not need its own temperature sensor with associated field cabling and radiation shield since temperature would be available on all stations. Data transfers would be monitored from the temperature Peripheral Interface and the raw data would be processed in the pressure Peripheral Interface to derive the necessary average value. Complex peripherals may also have a default position in the event that the required raw data is not ready or available.

Packaging

The packaging shown in Figure 5 solved many of the field problems associated with the installation, maintenance and logistics of field stations. It also created a serious new problem regarding cost. Individual packages were housed in custom, cast aluminum boxes which were then nickel plated for corrosion resistance and electrical integrity for EMI protection. The new system will use similar packaging blocks but at a significantly reduced cost. Figure 9 shows a typical module which can be built using standard sheet metal techniques. A printed circuit board mounted inside will house the necessary circuitry for interfacing, processing and handshaking with the PROTOCOL-2 bus via the rear, bifurcated, gold contact connector. The EMI Protection will be housed inside a simple compartment for cable transient protection. Figure 10 illustrates a shelf configuration with a few modules in place.

The present system design allows up to 32 modules to be plugged into the rear mother board. The shelf holds ten modules and there are ten modules in each of two expansion shelves. One slot is reserved for the Shelf Controller and three external addresses are reserved for external access, such as diagnostic data from power supplies, battery charges and transmitters.
Conclusions

Feasibility models have been built to demonstrate the capability of these concepts and test results look very promising. If the standards can be fully developed and rigidly maintained, without compromise, this architecture may provide the necessary technological independance and ease of procurement, installation, maintenance and field support which is so necessary to organizations which have the responsibility for long term operational networks.

References


ABSTRACT

During recent years increasing attention has been payed to climatological conditions in uninhabited areas such as deserts and high mountains. This has aroused a need for equipment measuring a number of parameters, processing measured data and transmitting it to a collecting point. All this has to be performed with a minimum of power consumption, a criterion which so far has made such measurements impossible.

Latest developments in the field of electronics, especially in CMOS technology, enable designs with large measurement capacity, a minimum of power consumption and high reliability.

Vaisala Oy has designed in co-operation with meteorological authorities a compact weather station for remote unmanned applications. This paper describes the MILOS AWS, the operational principles and application possibilities of the system as well as experience from installations in severe conditions.

1. Introduction

In 1968 a goal was set to establish the basis for achieving fiveday weather forecasts. This created a need to expand the existing networks of weather stations, the majority of which were manual. Parameters, such as temperature, humidity, wind direction and speed, air pressure and precipitation were to be measured at three hour intervals and transmitted to where forecasts were made.

A great number of such stations already existed but not enough. Vast areas were still uncovered. Such areas were, and partly still are, deserts, oceans, the uninhabited tundras etc. How would it be possible to cover such, often very hostile areas? The answer was the AWS, the Automatic Weather Station. A station able to automatically measure the parameters, process data, in some cases store it and transmit it in real time to collecting points. Actually this type of automatic equipment was nothing new. The first AWS had already been installed in the early sixties. They were, however, far from suitable for these remote applications.

So a new type of weather station had to be developed. A station that would operate where men could not. A station that could perform almost everything, that a man could and perform it with the same or even better accuracy and reliability. The solution was found in modern microprocessor technology.

In this presentation the microprocessor based MILOS will be described. The MILOS AWS developed by Vaisala Oy is specially designed to measure, process, store and transmit nine basic meteorological parameters in hostile environmental conditions.
2. Performance requirements

Functionally an AWS is a typical microprocessor application with either general or "tailor made" software. The system has to be able to perform the following tasks:

Sensor reading

The AWS should read and process different sensor inputs, such as analog current, voltage and resistive sensors, and serial as well as parallel digital inputs. The frequency with which sensors are read should be programmable.

Sensor control

Sensor power and status should be programmable.

Peripheral control

The use of different kinds of peripheral equipment should be possible, such as cassette units, display terminals, telex interfaces, wireless transceiver interfaces etc.

Maintaining real time

The central processing should maintain calendar time with 1 second resolution, maximum deviation should be only ±10 sec per month.

Remote control

The system should be able to receive control commands from a central station or local control terminal.

Forming meteorological reports

The AWS central processing should read the sensor values, store and processes it. From this data, standard meteorological messages are formed. The messages are in turn transmitted over telephone, telex or radio networks to data collecting units.

3. Hardware requirements

Compared to performance and software requirements the hardware requirements are outstandingly the hardest. The equipment should be able to operate in extremely hard environmental conditions. The ambient temperature range for example is -40 to +55°C and the power consumption should still be minimal.

Reliability

Automatic weather stations are often installed in places where maintenance is difficult if not impossible. Though the information relayed by the station may not be vital, it is still necessary to ensure uninterrupted data transmission. For these reasons high reliability as well as long service intervals are of utmost importance. The MTBF of an AWS should be better than 10,000 hours (over 1 year).

Flexibility

The system should be flexible and modular in order to suit the most varying applications. Special attention should be payed to expanding capability. It should be possible to connect new sensors and peripherals to the system in a later stage.
Rugged construction

During transportation, installation and sometimes also during operation the AWS are exposed to shocks and vibration and fast temperature fluctuations. The system should be reliable also under these conditions.

Low-power consumption

This is perhaps the most important criteria, but also the most difficult one to fulfill. The system should operate on +12 V DC. Under hard conditions energy costs are high. The power consumption should therefore be only a few watts. Only with CMOS technology is this possible.

4. Principle solution

Design principles

With microprocessors available today it is possible to design versatile equipment with computer features. To achieve maximum versatility the final application has, however, to be considered. The MILOS AWS central unit is therefore designed specially for this purpose.

Choice of logic

The choice of CMOS logic is due to its low-power consumption apparent. This specially as the idle state power consumption is minimal.

Choice of processor

When choosing processor many facts have to be considered. Such are circuit family and software special features, the character of interface, peripheral and memory circuits also have to be studied carefully. The most important software characteristic is obviously the instruction set and its versatility.

The Intersil IM100-LSI family offers a practical solution both from hardware and software point of view. The whole family is CMOS type and fulfills the requirements for an AWS central processing unit.

The family consists of all necessary Read Only and Random Access Memories as well as serial I/O circuits in addition to the processor itself.

The IM6100 recognizes the PDP 8/E computer assembler language instruction set. This ensures well documented firmware.

5. Milos AWS

The MILOS AWS is designed to measure a number of meteorological parameters. These are:

- Temperature
- Precipitation
- Wind speed
- Wind direction
- Solar radiation
- Rain duration
- Sun duration
- Atmospheric pressure
- Relative humidity
5.1. MILOS units

The Milos consists of the following functional and physical units:

1. Central processing unit
2. Interface unit
3. Cassette unit
4. Cassette drive
5. Motherboard
6. Rechargeable battery
7. Installation box

A complete MILOS automatic weather station also includes the following items:

8. Meteorological sensors
9. Mast
10. Bows and sensor supports
11. A set of cables
12. Power supply
13. Operators console or modem

As mentioned before MILOS is constructed around a specially designed microprocessor to fullfill the various functional requirements of a typical automatic weather station able to handle data from nine basic meteorological sensor. All measured and calculated values are recorded on a C-type data cassette. All values are also transmitted to the operators console. To allow outdoor installation Milos is housed in a "taylor made" compact glassfiber cabinet.

5.2. Operation

MILOS sends two different messages to the user: an IST instant message which contains instant sensor values and MES which also contains calculated data.

5.3. Sensors and interfaces

Temperature sensor interface

Temperature is measured with a platinium resistance PT100 element. A three-wire connection to the PT100 element is used to compensate for cable resistances. MILOS measures the temperature every 60 seconds.

Rain amount

The amount of rain is measured with a tipping bucket type raingauge. The raingauge has typically a mercury wetted or reed type contact that gives a pulse which corresponds to a certain amount of rain. MILOS simply counts the number of these pulsed during 24 hours.

Wind speed

Wind speed is measured with Vaisala WAA anemometer. This optoelectronic sensor has a frequency output which corresponds directly to wind speed. MILOS samples this frequency every 4th second. From this measured data, wind speed maximum and a ten minute average is calculated.
Wind direction

Wind direction is measured with Vaisala WAV windvane. The vane has a 6-bit Gray-code output. MILOS samples this input every 4'th second and calculates a ten minute average wind direction.

Solar radiation

Solar radiation is measured with a thermopile type radiation sensor. This sensor has an analog voltage output which is sampled by MILOS every 60 seconds. MILOS calculates the average radiation during the recording interval.

Precipitation detector (Rain duration)

This parameter is measured using Vaisala DPD precipitation detector. DPD is an on/off-type sensor. MILOS scans this input every 60 seconds and accumulates the number of on states during 24 hours.

Sun detector

The sun detector is an on/off-type sensor. It gives an output (closed contact) when sunshine warms up a bimetallic contact spring. MILOS scans this input every 60 seconds and accumulates the number of on states during 24 hours.

Atmospheric pressure

Atmospheric pressure is measured with an aneroid type pressure sensor. The sensor contains an amplifier which converts aneroid movement to an analog output. MILOS samples this every 60 seconds and calculates pressure minimum, maximum and average during the recording interval.

Humidity

Humidity is measured with a Vaisala HMP humidity sensor. This sensor has an analog output. MILOS scans this input every 60 seconds and calculates humidity maximum and minimum during the recording period.

5.4. Central processing unit

The central processing unit consists of the following functional blocks:

1. CMOS microprocessor
2. ROM-memory
3. RAM-memory
4. Serial output for the operator's console
5. Digital input/output ports
6. Analog interface
7. Real time clock
8. Watchdog timer
9. Intbus bus extension

CMOS microprocessor

The microprocessor consists of the IM6100 12-bit CMOS microprocessor. The 6100 recognizes the PDP 8/E instruction set.
ROM memory

MILOS programs are stored in three 1k x 12 bits metal mask Read Only Memories.

RAM memory

MILOS has six 256 x 4 bit CMOS Random Access Memories to store various data and program parameters.

Serial output

MILOS has a modified RS232C serial output to communicate with the operator's console directly or via data modems. The serial output is also equipped with special status signals to interface with a simplex VHF radio link.

Digital input/output ports

Digital input circuitries contain certain level conditioners to get adequate logical levels to be connected to the microprocessor bus.

Analog interface

The analog interface consists of an analog multiplexer and an A/D-converter. The analog multiplexer handles 8 input channels, 4 of them are used to connect the analog sensors to the A/D-converter, one channel is used for internal housekeeping and three channels are used to compensate for the analog channel offset voltages.

Real time clock

The real time clock provides MILOS with the basis for maintaining calendar time in the system.

Watchdog timer

A special watchdog timer is included in the MILOS CPU. Its function is to issue a system reset if the CPU has for some reason lost control of the system.

Intbus extension

One extra location for an E2 PCB is equipped with CPU bus signals to allow special interfaces or programs to be added to the basic MILOS station.

6. Interface unit

The interface unit comprises the following functional blocks:

1. amplifiers for the four analog sensor signals
2. sensor power switches
3. power supplies for MILOS and for various sensors
4. reference voltage sources
5. error indicators

7. Cassette unit

MILOS contains an incremental cassette recorder to record all meteorological data on a C-type cassette. On a typical station a 300 foot standard tape can store 6 months of data (recording interval 3 hours). Data is recorded in BCD-format. In addition to meteorological data station number, date and calibration factors are also recorded.
8. Battery unit

The purpose of the MILOS internal battery is to allow standalone operation for two days with a typical sensor set. MILOS battery is a maintenance free, hermetic, gelled electrolyte, lead acid battery.

9. Motherboard

On the motherboard transient protections and station ID switches are mounted.

10. Mechanical construction

MILOS comprises 4 printed circuit boards: CPU, Interface board, cassette formatter and motherboard. Board dimensions are 100 x 160 mm and 233.4 x 160 mm according to E1 and E2 standards respectively.

The printed circuit boards with the battery and the cassette drive are housed in a watertight glassfiber box. The dimensions of MILOS are 370 x 270 x 340 mm and the total weight is 12 kg.

11. Calibration

All calibration and data scaling procedures are preformed with software. Data values are scaled using linear scaling. Scaling factors are user alterable.

12. Power supply

A complete MILOS AWS requires only a few watts of 12 DC. Due to this fact it is possible to use the system with independent power sources such as a wind generator or solar cells. A battery set can also be used. In this case, however, the transportation of recharged batteries to the installation site must be taken into consideration.

The wind generator provides an excellent solution. Many aspects, however, have to be taken into account. Such are calm spells and maximum wind force. The battery capacity has to be sufficient for many days of calm or wind below the threshold of the generator. At the same time the generator has to withstand extremely strong wind in some areas. In southern Finland a battery set of 90 Ah charged by a Savonius type wind generator giving 4 W at 5 m/s and backed up by a solar panel with 36 W peak power is enough to provide power for a MILOS installation. Such an installation has been operating since October -79 at the Vaisala test site 30 km from the factory. At the test site no mains power is available. Data transmission as well all other types of communication between MILOS and the Vaisala factory, where a printout unit is located, is arranged over a UFH (400 MHz frequency range) radio link.

The use of only solar panels together with a battery is possible in areas where snowfall does not occur. The solar panel often provides a more economical solution and certainly a reliable one due to the total lack of mechanical moving parts. If normal cells giving approximately 10 W at a radiation of 18 W/km² are used, a cell area of about 0.25 m² is required in Southern Africa or in Australia while it in Southern Finland it would be about 0.6m².

The MILOS has found many applications in various fields which are not always purely meteorological. On the Ahvenanmaa island in the archipelago between the South-West coast at Finland and Sweden, a MILOS equipped with a special program monitors wind energy. This is part of a project where the use of wind energy on a larger scale is being studied. The station has no data link. All data is recorded on the cassette which is changed at approximately 3 month intervals. The cassettes are covered and evaluated at Vaisala. The Ahvenanmaa station has been operating for a whole year uninterruptedly without any type of service.
In the Saimaa lake district a network of 5 stations was installed in early May 1980. The whole installation took 5 days. The network consists of 5 standard MILOS AWS, all connected to the national telephone network. The stations are regularly interrogated from a central. The meteorological data is transmitted to the Finnish Meteorological Institute but can also be directly relayed to vessels in the lake district. The latter serves mainly ships towing log rafts which are extremely vulnerable to sudden strong winds.

In September 1976 at the COST 72 A.W.S. conference in Reading, England a goal was set to develop an automatic weather station monitoring the so-called basic meteorological parameters. One of the most important criteria was low price. The MILOS is designed according to the technical requirements stated by the congress and provides a solution to meteorological, climatological and other related measurement problems.
Au cours des dernières années, l'évolution d'une part de la technologie et, d'autre part des problèmes opérationnels menés au Service Météorologique d'Exploitation a conduit le Centre Technique et du Matériel de la Météorologie Française à concevoir et réaliser de nouveaux équipements automatiques d'observation météorologique.

Les équipements décrits dans ce document sont destinés essentiellement à être utilisés pour la réalisation de réseaux automatiques d'observation météorologique, le choix entre les équipements étant fonction des problèmes spécifiques de chaque réseau (transmission, implantation, alimentation électrique, contraintes opérationnelles).

La première partie du document est consacrée à la description des stations d'acquisition, la deuxième partie concerne les stations de centralisation et dans la dernière partie est donné un exemple de constitution d'un réseau automatique.

I - STATIONS D'ACQUISITION

A - La Station DELTA

La station automatique DELTA est, dans sa version de base, un équipement d'acquisition, de traitement et de diffusion automatiques de paramètres météorologiques. Elle est destinée à constituer l'élément satellite du réseau d'observations automatiques, qui sera géré, par l'intermédiaire d'une procédure interconnexion-réponse, par un élément centralisateur. Le support de transmission utilisé entre le centralisateur et la station satellite DELTA est une liaison hertzienne UHF.

1 - Description de la station DELTA

1.1. Conditionnement

La station se présente sous la forme d'un coffret métallique portable comprenant deux compartiments.

1.1.1. Un compartiment étanche permettant d'occuper une surpression intense de sayon permettant d'éviter la rentrée d'air humide ou pollué. Ce compartiment comporte la totalité des sous-ensembles électroniques de la station.

1.1.2. Un compartiment étanche au ruissellement intégrant les fonctions :
- raccordement des canteurs, sous la forme de barrettes de raccordement à vis,
- protection contre la foudre, sous la forme de plaquettes facilement assemblables,
- initialisation du fonctionnement de la station, sous la forme d'interrupteurs permettant de sélectionner l'adresse de la station et les canteurs en service,
- la surveillance du fonctionnement sous la forme de voyants de test,
- la communication en rime vers le point central : sous la forme d'une prise de raccordement d'un micro et d'un basculeur interrompant le fonctionnement télémesure.

L'ensemble de ces fonctions est implanté sur une plaque de circuit imprimé en liai-
son avec l'électronique de la station par deux connecteurs étanches. Un couvercle facilement amovible permet d'accéder aux différentes fonctions sur le site.

1.1.3. Fonctionnement en température

L'ensemble de l'électronique de la station est conçu pour fonctionner entre - 20 et + 60°C.

2 - Organisation de la Station DELTA

La station DELTA est essentiellement modulaire et comprend, dans sa version de base les modules suivants :

- microprocesseur et mémoires associées,
- alimentation,
- acquisition (6 voies analogiques et 2 voies numériques),
- transmission.

En option, il est également possible d'ajouter :

- 1 module de connexion à une mini cassette,
- 1 modem pour liaison sur ligne téléphonique,
- 1 émetteur-récepteur pour liaison radio,
- 1 module d'acquisition complémentaire permettant de porter le nombre de capteurs connectés à 12.

3 - Mesures effectuées

Dans sa version de base, la station DELTA effectue les mesures de :

- température
- humidité
- durée d'insolation
- rayonnement
- vitesse et direction du vent
- quantité de précipitation

4 - Fonctions assurées par la station DELTA

La station DELTA assure les fonctions suivantes :

- Réception et identification des ordres émis depuis la station centrale.
- Acquisition séquentielle, numérisation et codage des grandeurs électriques délivrées par les capteurs.
- Transmission d'un message d'identification et d'information vers la station centrale.
- Détection d'alarme par comparaison à des seuils.

2 voies analogiques autonomes intègrent par le moyen d'un traitement numérique à logique câblée les fonctions :

- Détermination des valeurs extrêmes d'un paramètre depuis l'interrogation précédente (quelle que soit la période d'interrogation).
- Comparaison à des seuils pour la commande d'alarme.

Ces deux fonctions permettent, en ménageant la représentativité des informations acquises par la connaissance des extrêmes et en autorisant la fonction "surveillance de l'évolution" en temps réel, de réduire la période de scrutation des stations satel-
lites et ainsi d'augmenter leur autonomie.

5 - Alimentation en énergie

La station DELTA étant essentiellement conçue pour être utilisée sur des sites isolés, l'énergie électrique nécessaire est fournie par des batteries alimentées par panneaux solaires. Le dimensionnement des panneaux et batteries étant fonction des conditions d'ensoleillement sur le site d'installation.

6 - La station de télémesure numérique

Cette station est destinée à équiper le réseau des stations météorologiques effectuant l'observation de surface. Elle effectue la gestion des capteurs météorologiques installés à la station et les traitements de base nécessaires à l'obtention des valeurs des paramètres mesurés ; le nombre des capteurs dépendant de l'importance de la station météorologique et de la possibilité d'effectuer l'automatisation de la mesure des paramètres météorologiques.

La station de télémesure peut être installée dans le parc à instruments ou dans le local de la station météorologique. Elle est prévue pour fonctionner entre -27 et +45°C.

Les informations, mesurées toutes les six minutes, sont mises à la disposition de l'observateur sur une imprimante.

En option est prévu un enregistrement sur cassette magnétique pour une exploitation ultérieure à des fins climatologiques.

1 - Version de base

Dans cette version, les mesures météorologiques suivantes sont effectuées :

- vitesse et direction du vent,
- température sous abri et au sol,
- pression atmosphérique,
- humidité relative,
- température du point de rosée,
- durée d'insolation,
- hauteur de précipitation.

2 - Options

Suivant la nature de la station météorologique, un certain nombre d'options ont été développées :

- mesures de la hauteur des nuages et de la visibilité météorologique,
- mesures actinométriques,
- mesures des températures dans le sol (jusqu'à 8 points de mesure).

3 - Version mesures aéronautiques

Une version utilisable pour gérer les capteurs installés à proximité d'une piste d'aérodrome a également été développée.

Les possibilités de mesure sont alors les suivantes :

- vitesse et direction du vent,
- température,
- 3 points de mesure de la hauteur de la base des nuages,
- 3 points de mesure de la portée visuelle de mists.
4 - Alimentation en énergie

Ces stations étant destinées à être installées en des lieux habités, une alimentation à partir de la distribution 220 Volts/50 Hz est prévue. Seule la base de temps interne de la station est secourue par batterie rechargeable, l'autonomie étant de 3 heures, de façon à sauvegarder la fonction datage.

II - STATIONS DE CENTRALISATION

Deux types de stations peuvent être utilisés comme stations de centralisation pour la constitution d'un réseau de stations automatiques d'observation de surface, le choix entre les deux solutions étant essentiellement fonction de la nature des stations satellites d'acquisition (stations DELTA ou stations de télémétrie numérique).

A - Dans le cas d'un réseau constitué de stations DELTA, la station de centralisation est une station SIMOUN qui assure les fonctions suivantes :
- gestion de la date et de l'heure,
- interrogation générale ou selective, programmée ou manuelle des stations satellites, synchronisation des alarmes,
- réception et contrôle des messages qui émanent des stations satellites,
- traitement des informations validées,
- gestion des voies de sortie vers les Services d'exploitation.

La station SIMOUN permet :
- l'interrogation de 16 stations satellites par coupleur,
- la réception, contrôle et validation des messages émis par 16 stations satellites par coupleur,
- les traitements des informations reçues (conversion des grandeurs électriques en données météorologiques, codages des informations en SIMOUN, gestion d'enregistreurs magnétiques).

Les coupleurs disponibles sur la station SIMOUN permettent de gérer :
- des sorties sur téléimprimeurs 5 moments ou 8 moments,
- des sorties sur lignes téléphoniques 1200 bauds,
- des sorties sur moniteur de télévision au standard 625 lignes,
- des sorties sur enregistreur cassette aux normes EBCA 3A.

B - Dans le cas d'un réseau utilisant les stations de télémétrie numérique comme élément d'acquisition, tout équipement de traitement numérique du genre mini ordinateur ou microprocesseur peut être utilisé compte tenu du fait que les informations météorologiques sont traitées et élaborées par les stations de télémétrie, le rôle de la station de centralisation étant limité aux fonctions suivantes :
- gestion des stations de télémétrie,
- constitution des fichiers de données à diffuser,
- gestion des lignes de diffusion,
- gestion du conversationnel avec l'opérateur (pour correction éventuelle de données ou introduction de données complémentaires).
- La station SIMOUN est capable de gérer un maximum de 16 stations DELTA en liaison hertzienne directe et (ou) par l'intermédiaire d'autant de relais transparents qu'il est nécessaire.

- L'ensemble du réseau fonctionne sur une fréquence de trafic HF ou UHF.
THE AUTOMATION PROGRAM FOR SURFACE OBSERVING STATIONS IN CANADA

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Abstract

Canada has long had the problem of maintaining an adequate density of surface weather observations in an expansive country with relatively low population, and in varied climatological environments and operational circumstances. Existing designs of automatic stations in Canada have proven to be cost-effective replacements for some previously manned situations and for some remote operations, but they have not been sufficiently advanced to solve the more complex applications at manned station or aviation applications.

The development of a functional modularity concept for a new generation of automatic stations is discussed. This new approach to system design addresses the many problems of technology sensitivity, configuration requirements, changing program and data needs, training and maintenance requirements, and other operational problems, while still maintaining a continuing ability to incorporate new developments in sensor and automatic observing technology.

Introduction

The automation of synoptic scale surface observations in Canada began in the 1960's with the development of the MARS (Meteorological Automatic Reporting Station) series of land-based autostations. The first generation stations were designed for data sparse areas within the regions served by the Canadian landline communication network. Implementation of autostations was conservative at first, but as the operational value of autostation data become recognized, and as budgetary and other restrictions threatened the closure of parts of the manned observational programs, the implementation rate for automatic observing equipment was forced to accelerate considerably. The rapid advances in solid state technology in the 1960's and 1970's resulted in the development of a second generation of the MARS series autostation, and the need for meteorological data from regions beyond the landline network led to further contractual development of meteorological DCP's (Data Collection Platforms) using environmental power and satellite telemetry.
The present Canadian automatic station network consists primarily of 64 stations (installed or planned) mostly in the populated southern areas of Canada (Figure 1). The three main types include:

**MARS-I:** 13 first generation, electro mechanical stations feeding hourly messages in a special MARS code directly into the landline communication system from data-sparse sites.

**MARS-II:** 39 second generation solid state stations generating hourly messages in machine language, dependent on a central computer to encode into intelligible formats. The majority of installations are at land and marine lightstation sites where manned programs were cut back.

**MAPS**
Modular Acquisition and Programming System, a commercial DCP (Bristol Aerospace Ltd.) suitable for remote, communication-void regions, presently reporting through the American GOES telemetry system. The 12 installations serve regions previously served by manned radio stations or ships.

In the 20 years of Canadian experience with automation of surface observations, the cost effectiveness of the autostation over a manned station has been dramatically demonstrated at virtually every station where a manned program has been replaced. And with the gradual improvement of sensors and processing algorithms, the autostation has proven that it can equal or better the observing performance of a man for some parameters, particularly those requiring averaging or other statistical manipulation over a period of time. For much of Canada's arctic and remote wilderness areas, there is no alternative to the automatic station for the observing of meteorological parameters.
Yet with all the obvious advantages, the autostation network still falls short of many real needs of meteorology in Canada, and has posed operational limitations which must be overcome in future autostation implementations;

i) so far, no autostations have been used in aviation applications, primarily because of the inadequacy of current sensors and algorithms in measuring the parameters of most interest to aviation.

ii) all Canadian autostations are dependent in one way or another on a central computer to encode observations into National and International formats.

iii) the present three designs of autostations require three different systems of operational and maintenance support, with many associated hidden costs.

iv) in all cases so far, technology has advanced so much faster than the design and production of autostations that the autostations have been obsolete before installation, (with associated problems in procurement and maintenance due to unavailability of obsolete parts).

In recent years, the Atmospheric Environment Service has entered into the specification and development of a new generation of automatic observing stations, designed to surpass most of the limitations of autostation implementation and operations as experienced in Canada over the past 20 years, and designed to serve new and expanded roles in the AES observational network over this and the next decade. This new concept in technology-independent modular autostation system is designed to benefit rather than suffer from current and future advances in sensor and electronics technology, and to be flexible and versatile enough to be sited in a large variety of climates and operational configurations. This next generation autostation concept is designated READAC (Remote Environmental Automatic Data Acquisition Concept).

Canada's Autostation Requirements

Canada has long had the problem of trying to spread its limited observational resources over vast unserviced land areas, and operate over extremes of climatic conditions. Until recently, technology has been the main limitation to automated observations from data-sparse regions, but the current pressures to automate arise from the escalating costs and other problems associated with the manned observing network. One particularly significant factor in the AES observational program is that a proportion of meteorological observations are taken by other government agencies at stations offering direct services to aviation; cutbacks in these operations threaten the integrity of the observational program, and none of the existing autostation designs can meet the observational and communication requirements of aviation.

Consequently, the operational requirements for the next generation autostation must cover a broader spectrum of applications than previous designs. From an operational standpoint, the new system must:

a) meet not only the observational requirements of synoptic and international meteorology, but of aviation including the generation of aviation Special observations

b) operate in the full range of Canada's climates, including arctic, coastal and wilderness areas, and marine environments

c) provide on-site data processing and encoding into a standard Supplementary Aviation (SA) message format
d) serve in a broad range of configurations from remote applications with limited parameters and no power or communication services, through to full-program interactive man/machine mixes

e) interface with a variety of communication media (landline, satellite, radio telemetry systems) for network inputs, plus provide continuous data for local displays and information dissemination systems

f) be flexible enough to accept program reconfigurations, and to phase in new developments in sensors or system electronics individually as they become practical.

These, together with the requirements for system modularity to facilitate implementation and system sustenance operations, constitute the main design objectives for the READAC autostation system.

The READAC Modularity Concept

The technology of electronics and the technology of sensors and of automation are pushing conventional techniques aside. Sensors are ranging from the very simple to the very complex, and the processing is becoming more complex as the observations tend toward both the precision of the objective and the credibility and completeness of the subjective. This tendency means that the autostation can be no longer viewed as a data logger with a microprocessor, but as a multiprocessor system capable of being re-configured for different applications without any one time engineering. When a system is "put together" by a field technician he must be able to:

- marshal the pieces together easily, including pre-manufactured cabling
- set up the system without writing software or doing wiring
- test it with supplied test equipment
- be assured of a calibrated system
- have basic EMI (Electro Magnetic Interference) protection assured
- have full operation and maintenance documentation available.

In the READAC autostation, these are facilitated by a concept of functional modularity based on an earlier proposal by the AES for mesoscale autostations (Ref. 1, 2). Details of the READAC system anatomy are the subject of another paper (Ref. 3), but basically the system consists of an array of modules which perform individual system functions such as communications, power, sensor interfacing, etc.

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![Figure 2 - READAC System - Functional Modularity](image-url)
In the system diagram, Fig. 2, the modules on the right are the data acquisition modules (called Peripheral Interfaces or PI's). These modules are capable of connecting directly to the sensor via a pre-made cable without the need for junction boxes or terminal strips. The module is self contained and normally designed to handle only one sensor so that it can be called a "Wind PI" for example. It contains all the analog and digital circuitry necessary to convert the sensor signals to a complete observation including specials, diagnostic data, raw data and its own identification.

Each module interfaces to the Shelf Controller (SC) in exactly the same way. The Shelf Controller in the centre of Figure 2 is responsible for the scanning and organization of data to and from the PI's. The SC does not know which PI's are plugged into it or how many, it goes through specific routines (Ref. 4), and constantly checks for the correct operation of the PI formats etc. The SC forwards formatted messages to the communication modules; these messages can include an observation encoded into the aviation SA format, station diagnostic data, raw measurement data, or station configuration information. The SA encoded part of the message will be very similar to the current manually generated SA messages; the correct parameter sequence is contained within the corresponding PI's, and provision is made for limited changes in the future without reprogramming.

The modules on the left hand side can be of several types depending upon the mode of communication. They can range from very straightforward (a GOES radio set), to very complex (landline communication with voice synthesizer and interactive terminal).

**Mechanical Configuration**

The Shelf Controller and all PI's are individually packaged as shown in Figure 3a. This package provides mechanical protection for the electronics during transport and handling, isolation from Electro Magnetic Interference and lightning, and means of quick connection to sensors and system mainframe. All cable connections are made to the front plane, and all inputs and outputs pass through feed-thru capacitors and filters. Each module is clearly marked as to its function and type of sensor to which it interfaces.

![Figure 3a Module Package](image)

In a station, the module packages are arranged as shown in Figure 3b. The Shelf Controller and PI's slide into a mainframe rack, and make connection to a motherboard at the rear of the rack. When the rack is full of modules, the station becomes totally isolated from EMI, with all cable connections to the front plane; if the rack is not full, blank front panels can be installed to fill the vacant module spaces. Provision is made for stacking up to three racks (up to 30 modules) at a station, and for remoting PI's as required.

![Figure 3b READAC Mainframe](image)
Power Sources - The READAC system includes power sources for operation in remote areas and for standby power in other places. Figure 4a shows a typical application of a station in a remote area where power is provided by solar panels charging a battery in a silo. The READAC mainframe is mounted above ground in an insulated box and heated by a thermosiphon conducting ground heat into it.

In the man machine mix station, Figure 4b, the READAC unit can be located in the sensor area if it is some distance away, and heated with electrical power. Batteries would still provide a two day backup for the system and the lower power consumption sensors. If the sensor area is close to the building, the system may be located indoors.

Operations - Installing and Maintaining a System

When a site has been chosen and the sensor complement and communication decided upon, the parts of the system are fairly easy to order and marshal together as they are all identified by function, i.e. Wind PI, wind cable, wind sensor; Temperature PI, temperature cable, temperature sensor, etc.

Since the system is modular, all the manuals can also be modular, and collected into a book for a particular system complement. This applies to all system documentation such as maintenance manuals, manufacturing specifications, etc.

Installing the station is straightforward as all cables can be pre-wired. No terminal strips or other customized wiring is involved. Test boxes are provided to check out the shelf controller and the PI's. By using the test boxes, which are also modular, it is possible to zero in on where a defect occurs, i.e. at the sensor, the interconnecting cable or in the PI. Repair of the modules or cable is not necessary in the field; the field maintenance operation consists of replacing modules, cables or sensor.

The READAC has the capability of sending a diagnostic message consisting of general diagnostics and PI diagnostics. General diagnostics include parameters such as current drain, supply voltage, etc; the PI diagnostics are particular to the sensor involved and include such things as reference voltages and lamp condition. The general objective is to go to a maintenance-on-demand system (rather than routine maintenance) while still preserving credibility of the observation.

Figure 4a
A Remote Site Configuration

Figure 4b
A Flight Service Station Application
When it is necessary to add, delete or change a sensor at a READAC site it will not have to be reprogrammed or rewired. When a sensor is added, for example, the new PI for that sensor is plugged into any available slot and the cable which has been run out the new sensor is plugged into it. The major effort is in the installation of the sensor and cable rather than in re-engineering the system. A system can be upgraded or retrofitted with newly developed sensors and modules at any time simply by adding or interchanging the modules.

**READAC Implementation Plans**

Currently there are 285 manned stations in Canada producing regular Synoptic and/or aviation hourly observations; less than half of these stations are under the administrative control of the A.E.S. Continued government pressure to reduce costs in this manpower intensive network has resulted in a high priority for the autostation development program. A long term objective of the AES is that all surface real time observing stations in Canada be automated in varying degrees, to produce a hybrid network of automatic, part time automatic, and man/machine mix stations.

Unfortunately, this priority has not necessarily been supported by adequate funding and other resources. During the past two years, limited in-house development resources and contract funds have been devoted to developing the modularity concepts and specifications for the READAC system, and intermodule communication and control protocols. Only recently has the AES been able to negotiate and fund a major contract for the further development and engineering design of the autostation system; the first prototype stations will not be available for another year or more.

Initial stations built to this concept will be devoted to demonstrating capability in a variety of configurations. Some applications will be similar to those of present autostation designs, such as the limited program remote DCP application shown in Figure 4a. However, future implementations will be aimed heavily at aviation applications; new configurations will be tried such as the full-program, interactive man/machine mix (Figure 4b) such as might be encountered at Flight Service Stations in Canada, and a simpler aviation configuration with voice synthesized VHF output for unmanned airports and aviation navigation aid stations. To complement the aviation applications of the autostation system, heavy developmental emphasis will be placed on developing and/or evaluating new and better sensors for the measurement of parameters crucial to aviation operations.

In parallel with the station implementation program the AES also plans to decentralize its code conversion computers. Currently the encoding of autostation data into Synoptic reports for international distribution is done in a central computer located in Toronto. Future plans include the decentralization of autostation data processing and encoding to regional centres to allow for more effective handling and management of the autostation network and its information traffic. If prototype READAC stations are successful in their performance demonstrations, a subsequent implementation rate of 20 per year is planned.

**Conclusions**

Through its developmental work during the past two years on this autostation concept, and experimentation with feasibility hardware, the AES is now convinced that the READAC system is a viable approach to its autostation requirements, and is now committed to its development. Certainly the technology exists to achieve the technical design objectives, and the functional modularity allows sufficient flexibility for effective exploitation of future technologies instead of obsolescence before the system is even implemented.
The main problems encountered so far, apart from the lack of resources, have arisen not from the limitations of technology but from the conversion to a totally objective observational machine. Most of the subjective procedures and standards solidly established over the years of manned station operation must now be reviewed and revised to more objective forms, so that an automated system can make appropriate decisions. The effective integration of user requirements and technical design capabilities has been, and is a significant task in developing an autostation program.

Similarly, some of the traditional ideas and attitudes towards the automation of difficult parameters must be reviewed and objectively examined. Some of the non-acceptance of current autostation designs for aviation is undoubtedly based on a mistrust of totally automated sensors and systems, and on the inability of automated systems to take subjective and judgmental remote observations. Much of the gaps that exist between the perceived and traditional observational requirements and available sensor and autostation technology can best be bridged by active experience and objective collaboration and compromise by both the designer and data user groups.

References:


AUTOMATIC WEATHER STATIONS IN YUGOSLAVIA

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(Title only) *

* No abstract or paper provided
A NEW INTELLIGENT WIND DATA PROCESSING, DISTRIBUTION AND DISPLAY SYSTEM

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ABSTRACT

A wind system with computing capabilities is required in many wind measurement applications, e.g. at airports and synoptic weather stations. Such systems, however, tend to be bulky with separate computers and excessive cabling.

This paper describes a new wind measurement system based on a compact, intelligent display unit. System specifications, speed and direction averaging and other computing functions, display formats and system configuration are described. The sensor for speed and direction as well as optional modules for display, recording and printing are also briefly discussed.

1. Introduction

Many types of wind sensors, recorders and displays are available today. These wind measurement systems are adequate for measuring and displaying the instant speed and direction values, even integrated values in some cases.

The need for more information of wind exists. The parameters, most oftenly required, are speed and direction averages, maximum speed, variance, energy contents and wind vector components. Besides the normal synoptic usage these new parameters are now monitored by many users and can be applied to air traffic control at airports, ship weather information, energy management and pollution control, just to mention a few.

In this era of digital computers and with many sensors to choose of, nothing should be as easy as assembling of a wind system with the necessary computing capabilities. The basic components of such a system are:

1. The sensors
2. The computer or calculator
3. The output device, e.g. recorder, display or printer

Unfortunately, in practise one interposes a substantial set of problems. First, the sensor must be interfaced to the computer. This calls for a set of digital or analog interface cards, which can be costly. Second, the cabling between the sensors and the computer and the output device normally requires either special cores for analog signals, or many parallel leads for digital signals. In many applications, typically at airports and masts the distance between the sensors and the computer can be kilometers, and the cable can be more expensive than other parts of the system.
Figure 1. Remote Wind Measuring System

Front Panel Selection Of:

A 2 Minute Average (Mean) for Speed and Direction
B 10 Minute Average (Mean) for Speed and Direction
C Maximum Wind (Gust)

1. Average Wind Display Unit
2. Wind Display Unit
3. 3-Channel Analog Recorder
Figure 2. WA 21 Wind Measurement System
Third, you usually also need a power supply to feed the sensors, and your costs for cabling get even higher. Fourth, the computers are cheap enough, but they need programming, and that is neither easily available or cheap. Even the ready-made system suffer from programming costs, and separate general purpose computers. And the list goes on the interfacing of the output device can be tricky, the output format may not be suitable, and so on.

The WA 21 Wind Measurement System offers a new, cost effective solution to these problems. The system is based on a compact, intelligent display unit, communicating with the sensors over a two-wire connection, through which also the sensor power is fed.

2. WA 21 Wind Measurement System

The Block Diagram of the WA 21 System is shown in Figure 1. The system comprises the speed and direction sensors, the sensor control unit, the averaging display unit, the standard display unit and various optional items.

Wind sensor control unit

The system is based on the utilization of a two-wire connection between the measurement site and the display site operating to distances up to 4 kilometres. The wind sensor control unit samples the speed and direction sensors, converts the values into serial digital format and transmits the data to the serial line. Both the sensors and the control unit operate from DC power, supplied by the display unit through the same line. No power supply is thus needed at the sensor site, and the connection can be made via a standard telephone pair, normally already existing. The sensor control unit operates at -40°C to +55°C temperatures and is installed to the wind mast near the sensors.

Averaging display unit

The averaging display unit performs the functions of both the computer and the output (display device). The instantaneous data transmitted by the wind sensor control unit are received in real time by the display unit which performs averaging, minimum and maximum calculations and other required data processing and displays the instantaneous and computed values with a compact, solid state display panel. The display is designed for panel mounting, with standard 144 x 144 mm² face dimensions. The display is AC powered and also feeds the sensors via the 2-wire line. A three-channel analog output for analog recorders is included, as well as digital serial output for host computer or optional printer or cassette unit interface.

Standard display unit

The standard display unit is basically the same unit as the averaging display unit, but performs no data processing, and shows only instantaneous values. Figure 2. shows the block diagram of the wind control unit and the averaging display unit.

Optional units

Various optional items can be connected to the WA 21 system, including three-channel analog recorder for speed and direction averages and speed maximum. DC power supply (12/24 V) for the whole system, cassette recorder for digital storage of measured and computed data and hardcopy printer for digital printout. All units are compact and of modular design. At some locations sensor heating may be required.
3. Display operation and functions

Operation

- The averaging display unit calculates 2 and 10 minute mean speed and direction, updated every two minutes, and maximum and minimum wind speed over the selected period. Instantaneous speed and direction are directly obtained from the received wind samples. The unit also checks the speed against a fixed threshold and direction change against a sector, and performs data quality control.

Display functions

- The display section provides bright, clear display of both speed and direction parameters. The wind direction display consists of two rows of 36 light emitting diodes (LED's) arranged in a circularly formed scale. The inner circle of red LED's shows the instant, 2 minute or 10 minute average wind direction, as set by the selector switch situated on the unit front panel. The outer circle of yellow LED's shows the wind variance either over the past 5 seconds, 2 or 10 minutes as selected by the switch.

- The wind speed display consists of three seven-segment two or three digit displays. The display in the middle of the unit shows the instant (1, 2 or 4 second), or 2 or 10 minute average speed, as selected. The display can be either meters per second (three digits) or knots (2 digits). The smaller digital displays in the lower part of the unit show the minimum and maximum values over the selected period, and are blanked in the case of instant values.

- Two LED indicators are provided for status indicator, the LED’s will be on if the speed threshold or direction variance sector are exceeded.

- The analog outputs are independent from the display mode selection switch. The outputs are programmed to show maximum speed, and either 2 or 10 minute averages.

- The digital output transmits in serial form all the measured and computed values or a specified subset as required by the application.

As a summary, the following data can be displayed:

<table>
<thead>
<tr>
<th>INSTANT:</th>
<th>SPEED (1, 2 or 4 sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DIRECTION</td>
</tr>
<tr>
<td></td>
<td>DIRECTION VARIANCE (5 sec)</td>
</tr>
<tr>
<td>2 MINUTE:</td>
<td>2 MIN AVERAGE SPEED</td>
</tr>
<tr>
<td></td>
<td>2 MIN AVERAGE DIRECTION</td>
</tr>
<tr>
<td></td>
<td>2 MIN DIRECTION VARIANCE</td>
</tr>
<tr>
<td></td>
<td>2 MIN SPEED MIN, MAX</td>
</tr>
<tr>
<td>10 MINUTE:</td>
<td>10 MIN AVERAGE SPEED</td>
</tr>
<tr>
<td></td>
<td>10 MIN AVERAGE DIRECTION</td>
</tr>
<tr>
<td></td>
<td>10 MIN DIRECTION VARIANCE</td>
</tr>
<tr>
<td></td>
<td>10 MIN SPEED MIN, MAX</td>
</tr>
</tbody>
</table>
4. System configurations

Point to point link

Normally the sensor control unit and the averaging display are connected via a point-to-point link, maximum distance is 4 kilometres.

Loop configuration

Multiple displays can be connected to the same line enabling the information from the same set of sensors to be displayed in several locations. Only two wires are still needed, and the link operates to same distances. Averaging and standard displays can be freely mixed.

In some cases multiple sensor control units may be connected to the loop. A switch option must be used on the display unit for data source selection.

Multipoint configuration

Multipoint refers to a system where the sensor control units are cabled with individual pairs to one display unit. The configuration can be used with WA 21 system, only a switch option is required for data source selection.

5. Conclusions

The WA 21 system introduced in this paper combines the advantages of the modern electronics and experience from current wind system representing a unique, intelligent wind measurement system. The most stringent requirements at many installations, compatibility with a telephone pair and no AC power, are met. The system performs all the calculations and processing normally required at airport, synoptic stations, ship etc., display the data with a compact, clear display unit, and contains all the components for building up a complete wind monitoring station.
A CROP DISEASE ENVIRONMENT MONITOR

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Introduction

The incidence of many fungus diseases of important cash crops such as apples, potatoes and barley is known to be dependent upon the micro-climate of the crop canopy. Furthermore, these diseases can be fully controlled by a suitable, though expensive, fungicial spraying programme. The problem is to match the spraying programme to the expected onset of the disease. Hitherto, the only way in which meteorology has been able to assist with this problem has been to provide statements of measurements of the relevant meteorological variables (usually temperature levels and humidity levels) deemed to be applicable to large geographical areas. These values are then used in empirical forecast models to predict the risk of the diseases over these large areas.

The advent of microprocessor-controlled AWS systems has made it possible for a farmer to have his own disease prediction system for his own particular crops. He may even have different systems for different growing areas of his farm. Such disease and area-specific monitor systems can now be made quite cheaply and offer potentially great economic benefits from the optimization of the use of expensive chemical sprays. By reducing the number of occasions on which sprays are used to the minimum needed, they also serve to reduce the level of chemical contamination of the environment.

A microprocessor-controlled system for this function has been developed within the UK Meteorological Office and is called a Crop Disease Environment Monitor (CDEM). In this paper we describe the system and discuss some preliminary results of trials.

The Sensors

The measurements required for the diseases which we have tackled (apple scab, barley brown rust, potato blight, rhynchosporium and septoria) are dry-bulb temperature, relative humidity and the wetness of the crop leaves.

For dry-bulb temperatures we use a conventional electrical resistance thermometer and for relative humidity we have thus far used an identical thermometer exposed as a wet-bulb. This approach has several drawbacks over a more direct sensor for humidity such as the Vaisala Humicap or the PCRC-11. In particular the need to ensure that the wick is kept clean and moist and the considerable software overheads associated with computing relative humidity from dry and wet-bulb values. However, it has the considerable merits of cheapness and low power consumptions.

The two thermometers must be exposed in such a way that they sample the temperature and humidity which is relevant to the spread of disease in the crop and these may not be the same as the conventional synoptic meteorological values. The question of how best to expose these sensors is therefore one which the agricultural meteorologists are now studying but for
our initial trials we have exposed the thermometers in a small-sized conventional louvred wooden screen.

The problem of leaf wetness presented us with a new challenge. For many years there has been in service with the UK Meteorological Office a device which approximated a leaf wetness value by weighing the water absorbed by a small polystyrene ball. This device was known to be unsatisfactory and a new sensor was required. We approached the problem from the basic idea of two sets of interleaved electrodes on a surface which we have tried to make as leaf-like as is reasonable. We measure the electrical resistance of a circuit in which these electrodes form an element.

The sensor is made very thin so as to present similar areas on both top and bottom which may be expected to be at the same temperature. The responses to wind drying and to radiation effects may thus, crudely, be expected to approximate to those of real leaves. Several materials were tried for the electrodes including gold, rhodium and stainless-steel. Of these, only rhodium proved to be sufficiently corrosion-resistant to allow long-term deployment of the sensor without attention. Several different substrate materials were also tried including polyester film (melinex) and glass-fibre board. The most successful configuration was found to be a glass-fibre board 30 mm x 80 mm x 1.2 m with electrodes 320 μm in width separated by 320 μm. The electrodes were made by etching 35 μm thick copper and then plating with rhodium.

A typical sensor configuration is shown in Fig 1 and the response of the sensor to frost formation, evaporation and rain is shown in Fig 2. This response was obtained from a sensor continuously powered from a dc source. In the CDEM application the sensor is intermittently powered from a dc supply, the dc system is more prone to corrosion than the ac system but the basic principles of the sensor are very similar. The choice of level for a threshold of wetness in Fig 2 is a matter for the agronomists to determine. At present they work on a very low threshold but further experiments may enable them to optimize this level.

So far as we are aware, this and similar independent work recently reported (1), (4) are the first successful developments of leaf wetness sensors. There are a variety of commercial devices available, primarily intended for use in greenhouses but these have proved extremely unreliable when used operationally as leaf wetness monitors.

The Central Processor

The data acquisition and handling for CDEM is controlled by an Intersil IM6100 12-bit CMOS microprocessor. The block diagram of the logic of the system is shown in Fig 3. To enable the system to run for a complete season from a single set of 20 1.5 V dry-cell batteries the sensors are interrogated once every 20 minutes and are powered-up for only 20 seconds before each interrogation. The average current consumption of the device is 5-6 mA. The microprocessor is supported by 4K x 12-bit words of CMOS memory (3K words of EPROM and 1K words of RAM) and a real-time clock. The interface for the two electrical resistance thermometers consists of two Kelvin bridges whose amplified outputs are multiplexed to a CMOS analogue-to-
digital converter. The surface wetness sensor interface consists of a simple voltage comparator.

Operator controls have been kept to a minimum; two thumbwheel switches and a push-button which enable the operator to select from a range of display and system functions. Data are presented on a series of seven segment liquid crystal display units. Fig 4 shows the format and some sample contents of the display.

A serial input/output port provides an interface for a standard computer terminal. This can be used for system testing or to give an optional hard copy of the data on a teleprinter. The whole unit is contained in a weatherproof box suitable for use outside so that with sensibly short cable links the sensors can be deployed in or close to the crop to be monitored. The complete device is shown in Fig 5, mounted on a purpose-built stand. The stand is, of course, not essential and the box may be mounted on any suitable post or wall.

The Software

The software of the system is configured to perform the following functions:

a. Interrogate the sensors once every twenty minutes.
b. Calculate the average temperatures during periods of leaf wetness.
c. Obtain daily maximum and minimum temperatures.
d. Note periods of high relative humidity.
e. Calculate the risk of infection for the diseases Potato Blight, Rhynchosporium, Apple Scab, Septoria and Barley Brown Rust.

The basic structure and functions of the software needed to perform these tasks is straightforward and conventional and need not be described in great detail. Fig 6, however, shows the basic block diagram of the programme. The models used to compute the disease risk are empirical formulae which have been developed and discussed elsewhere (2), (3), (5).
Results

The prototype CDEM has been in operation since April 1980 and has already proved superior to the previous, rather general, techniques for forecasting these diseases. However at the time of going to press, detailed results of the first season’s performance have not yet been assessed.

The Future

The usefulness of this type of system depends mainly upon the efficacy of the mathematical models used to make the predictions which are the essential outcome of the operation of the device. Given that such models exist, the uses of these systems may be extended well beyond the bounds of agriculture and horticulture. Within the United Kingdom there is already interest in applying this type of system to the prediction of local road-ice conditions as well as widespread interest in the agricultural aspects.

Such systems as CDEM can be built now for not much more than half the cost of their sensors which are by far the largest cost involved. This fact may lead to strong pressure to adopt the use of cheap but inferior sensors as a means of keeping the total cost down. Such a move must be viewed with great circumspection because there is nothing easier than to make bad or inadequate meteorological measurements and, like all computers, CDEM is an unforgiving system - if you put rubbish into it you will get rubbish out.

However, given good sensors, properly exposed, the CDEM system or a variant of it could provide a new dimension to many important economic problems which depend upon the micro climate of small geographical areas.

Acknowledgements

We are grateful to members of the Operational Instrument Branch and the Agriculture and Hydrology Branch of the Meteorological Office for assistance with this work. In particular, Mr R. Francis and Mr S. Wass who developed much of the software and Mr F. Bond and Mr P. Westbury who developed the surface wetness sensor.
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<th>Volume/Issue</th>
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AUTOMATION OF UPPER AIR MEASUREMENTS

A.M. HOOPER

METEOROLOGICAL OFFICE UNITED KINGDOM

The expression "Upper Air Measurements" is wide-ranging. We can think of soundings made by sondes carried aloft, soundings made by sondes dropped from aircraft or floating balloons and soundings made from satellites. For data in the horizontal we have instruments carried by floating balloons and by aircraft. Some of us regard the upper air as all layers of the atmosphere not actually at the surface. Thus we may wish to include acoustics sondes, cloud base recorders and even thunderstorm location. Certainly automation has made an impact in all these and many other activities. My own involvement over the years has been in radiosonde matters and it is this particular upper air measurement that is considered here.

Automation of radiosonde measurements has proceeded to a varying extent and at a varying speed in different countries. As meteorologists we have to depend upon the general advance of mankind in technology. There are also other factors which influence our progress and these are often not within our control. The standing of meteorology in the community at large comes to mind. This can affect the availability of staff and funds. Sometimes we are limited to making small improvements to what we already have. At other times we may be able to replace an existing system completely. Another aspect is that the changes we make have to be achieved while maintaining continuity of observations for the users. Because of matters such as these advances occur at different times in different countries and it can be difficult to keep aware of other peoples' progress. For this reason I, myself, will illustrate the advance in automation of upper air measurements by looking at what has gone on in the United Kingdom.

In the thirty nine years since I was first shown a radiosonde ascent there have been many changes. At first we used a large team of people in a manual system. Now we have reached a point where the present system is operated by just one man. Table 1 shows the main steps in this progress.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>OBSERVER</th>
<th>PLOTTER</th>
<th>ANALYST</th>
<th>COMPUTER</th>
<th>WIND</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1940</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>1944</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>1945</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>1960</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>1964</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>1977</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2.2</td>
</tr>
</tbody>
</table>

In 1940 we needed six men to carry out a full upper air sounding of pressure, temperature, humidity, wind direction and speed. In those days the winds were determined
by radio-direction-finding. The sonde signals were observed from three stations each about thirty miles from the point of release. Thus both buildings and staff had to be provided at four places.

This situation was overcome four years later when primary radar became available at each central station. In this way the direction-finding stations were closed and the staff brought together at one point. The radars provided much more accurate winds and for this we accepted the penalty of carrying a special reflector with each radiosonde. The radars had separate controls for Slant Range, Elevation and Azimuth so that at first we still needed three wind observers. However, it was soon found that two observers were sufficient to operate the controls and to write down the readings.

Turning from the wind data to the sonde data, the next step was to record the sonde signals automatically. This saved another man. By that time our radars were old and costly to maintain. The opportunity was taken to replace them by radars with automatic-tracking and logging. Thus in the 24 years from 1940 we had reduced our sounding team from six men to three.

When programmable desk calculators became available their use at sonde stations was considered. This would have provided further automation and a reduction in the sounding team to two men. However, we were designing a completely new sonde by then and it was decided to go directly to a yet higher level of automation. This is represented by the last line of Table 1, which shows that we now use 1.2 men. The part man provides help with balloon filling and with balloon handling at launch. He is present on station for other reasons and it is thought better to use him in this way than to develop an automatic device for launching the balloon.

Thus over 37 years we have reduced the sounding team from six men to somewhat more than one. To an administrator this sounds a splendid improvement. However, as for so many advances in technology there are both benefits and disadvantages. It all depends upon one's point of view and responsibilities and we must look at the scientific aspects as well.

Before going on to do that I will add that the foregoing going remarks refer to the network of upper air stations within the UK itself. At some other stations we are using less automated systems as summarised in Table 2.

TABLE 2

<table>
<thead>
<tr>
<th>PTU</th>
<th>WIND</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>STAFF</td>
</tr>
<tr>
<td>Manual</td>
<td>Desk Calculator</td>
<td>Automatic</td>
</tr>
<tr>
<td>Automatic</td>
<td>Desk Calculator</td>
<td>Digital Computer</td>
</tr>
</tbody>
</table>

The first line is for Gibraltar where the 9aw sonde is used with human plotting and with a programmable desk calculator for data reduction and message selection. The wind data are obtained by radar. The second line of the Table relates to Ocean Weather Ships where we use the VIZ sonde in a LOCATE system.
People speak of "semi-automatic" and "automatic" systems. These labels are not well defined. It could be argued that it is only soundings made by satellite that are fully automatic. However the labels are convenient and we could use the expression "semi-automatic" for those systems in which data reduction is undertaken by a trained scientist aided by a programmable calculator of some kind. Systems in which the scientific tasks and observations are undertaken wholly by a digital computer can be deemed "automatic" even though an operator is needed to direct the process.

It may at first seem odd to be talking about staff savings at a technical conference. Designers of automatic systems are fascinated by the task of making machines undertake complex processes first done by human beings. They also like the challenge of doing the work more accurately and more quickly. However, this is not enough. Automation costs money and this has to be found in some way. In the United Kingdom it is usually the saving in staff costs that justify automation.

In developing an automatic system the benefits that we hoped to gain were:

a) a reduction in the number of staff
b) a reduction in the amount and level of training
c) the provision of more accurate and reliable results.

In addition it was hoped that the staff would gain satisfaction in the use of up-to-date technology and in the elimination of boring tasks.

We have certainly achieved our first aim in full. As for training, we have closed the school and staff no longer have to spend many weeks learning to select the right data and to compute with sufficient speed. Instead the staff now learn the quite different skill of ground-station operation on site. This is a manipulative skill in which the operator has to carry a model of the procedures in his mind. He has many settings to make and has to engage in a dialogue with the station computer by means of a teletype. Table 3 shows the tasks to be completed at various stages of the flight.

**TABLE 3**

<table>
<thead>
<tr>
<th>OPERATOR ACTIONS, UK RS3 SYSTEM</th>
<th>Pre-Flight</th>
<th>In Flight</th>
<th>Message</th>
<th>Post Flight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switches to be set or checked</td>
<td>92</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjustments to be made</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operations to be commanded</td>
<td>26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teletype query to Operator</td>
<td>64</td>
<td>3</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Number of different Operator Replies</td>
<td>31</td>
<td>6</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>Teletype Advisory Statements to Operator</td>
<td>48</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

The large amount of work before launch is to do with initialisation of the computer, calibration of two telemetry oscillators in the sonde, and with the base line check. The operator is able to proceed at his own pace and has time for brief references to a flow chart if necessary. Station calibration of the telemetry enables the cost of a central calibration plant to be saved.
In flight the work has to proceed at a speed set by the telemetry system of the sonde. There is no time to consult flow charts as to the course of action. Thus the queries to the operator have been made very few in number and seek instruction about the action to be taken by the digital computer when particular critical events occur. The many advisory statements are provided a) to re-assure the operator that all is going well and b) to advise him when any of the eight signals from the sonde (or the data from the radar) are missing or have failed quality control tests.

At this point I must say that we have not been entirely successful in maintaining job satisfaction. In the manual system the staff were able to look at their results as they plotted them on a sounding chart. The flights were different on each occasion and being meteorologists the operators could see and interpret fine-structure effects in terms of local weather. In addition, the operators were expert in high speed calculations and took a pride in their skills.

However, the automatic system does not provide results until the message is ready. Also, the fine structure results are logged only onto a magnetic tape which the staff cannot access. Thus the operators feel cut off from the meteorological content of their work. Moreover they no longer have special skills in which they can take pride. Once the new procedure has been mastered, the work is very much the same from day to day.

Happily it is likely that we shall be able to extend the computer software soon and make fine structure results available at stations. We hope also to provide the information to allow staff to make sounding calculations of their own. While these steps will increase their contact with meteorology it will remain true that automation has reduced the opportunity of staff to take pride in their skills. It has of course also reduced the opportunity for them to make mistakes and it is that aspect that bears upon the accuracy and reliability of the results.

In turning to this matter of performance it is necessary to note that in the UK we were obliged to introduce both a completely new sonde and an automatic ground station at the same time. It would have been better to have changed only the sonde to begin with. In this way the problems of making production sondes perform as well as the prototypes could more readily be identified and resolved. With this done the ground station would then be added and its particular problems dealt with. As it is, with the two changes being made together it has proved difficult to identify the course of some malfunctions.

A simple example of this is that the geopotentials at 100 mb are systematically low compared with the prototype sondes and with other sondes in Europe. This might arise from a manufacturing problem or from a mistake in the software. The latter has a very complex structure and it takes much time to trace it through when looking for errors. The work of eliminating them will be going on for some time to come. Until this period is complete the reliability falls short of that attained by our previous system over its 37 years in service.

Concerning accuracy however we are already enjoying results that are better in many respects and can hope for further improvement. Just what is the improvement so far? One measure of this is the variability of the reported geopotentials at 100 mb. The statistical extent that is that results for different soundings can vary due to the use of different radiosondes. Here is the distribution for 1979.

### TABLE 4

Estimated Variability of Sonde Geopotential at 100 mb in 1979

<table>
<thead>
<tr>
<th>Standard Deviations (metres)</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Sonde Groups</td>
<td>2</td>
<td>7</td>
<td>3</td>
<td>6</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
With the new system we have moved from about \( \pm 40 \) metres to about \( \pm 20 \) metres with the prospect of a smaller variability still as we overcome our residual problems. I should add that these results contain a contribution from the atmosphere itself so that the sondes considered as instruments in isolation have a rather smaller variability than the numbers shown. If we could remove the atmospheric effect then the smaller standard deviations would be reduced considerably but the largest standard deviations hardly at all.

Looking back over the development period of the RS3 system I would say that it has been a fascinating task with many problems overcome and some still remaining. Automation has enabled us to eliminate human uncertainty from the calculations with benefit to the results. The digital computer does not get tired and does not make arithmetic mistakes. Additionally we are able to use more complex corrections in the system and so to reduce the residual errors further. In doing this however we have lost two facilities that the human being is better at. Firstly he is able to make a better job of selecting the important features of the results. A better job, that is, of choosing the significant levels to be reported. Also the human being has a critical faculty which enables him often to realise that something is wrong even when the results are superficially plausible. It is two human abilities - to deal with patterns and to sense that something is wrong - that are so difficult to reproduce in computer software.

Many would say that if the human ability to discriminate is objective then its rules can be stated and a computer programme written to achieve the same results. This view does not face up to the restriction of computer speed and cost. When we look at radiosonde data recorded on a strip chart it is easy for us to see the main features of the ascent. In doing this we are comparing perhaps several hundred individual data values. The comparisons are not made with high precision but they are made in parallel. Since digital computers can only compare values with respect to zero one at a time they need great speed and large capacity to imitate us. To provide a result that is as satisfactory as the human brain does not seem to be within the capability of machines small enough and cheap enough for use at radiosonde stations.

In our UK system the present software is divided into various sections thus:

<table>
<thead>
<tr>
<th>Computer Allocations - UK RS3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Organisation</td>
<td>9 K</td>
</tr>
<tr>
<td>Storage of Raw Data and Archives</td>
<td>( \frac{32}{4} )K</td>
</tr>
<tr>
<td>Quality Control of Raw Data</td>
<td>2 K</td>
</tr>
<tr>
<td>Selection of Significant Levels (PTU and WIND)</td>
<td>4 K</td>
</tr>
<tr>
<td>Scientific Calculations (conversion to meteorological units)</td>
<td>7 K</td>
</tr>
<tr>
<td>Synoptic Message preparation</td>
<td>4 K</td>
</tr>
<tr>
<td>Tropopause Identification</td>
<td>( \frac{25}{4} )K</td>
</tr>
</tbody>
</table>

It can be seen that the scientific calculations occupy about twenty-two per cent of the capacity with selection of significant levels a further twelve per cent. Only six per cent of space is used for quality control of the raw data. The software extension to be made will allow improvements in Quality Control and Significant Levels work. It will also allow meteorological information of various kinds to be put out for the interest of the operators. However it does not seem possible to replace the job satisfaction that we have lost. We seem to have created something akin to an industrial assembly line. Perhaps we should be using staff with a reduced background of scientific training.
Overall it seems to me that the provision of programmable desk calculators for the reduction of sounding data is a very valuable step in automation. It improves accuracy and reliability, reduces drudgery, and retains human involvement in the results. The further step of eliminating the human being is a large one and of uncertain value. We obtain more accurate calculations but with a risk of less reliable results and we lose staff interest. Perhaps the second choice is best on balance. In choosing it, however, we have to realise that it is a choice with both advantages and disadvantages. Despite the disadvantages my own enthusiasm for automation makes me eager to learn how others have progressed in what is certainly a science and also to some extent an art.
IMPACT OF AUTOMATION ON UPPER AIR OBSERVATIONS

Pekka J. Kostamo
Vaisala Oy

ABSTRACT

This presentation reviews the effects of automation at the station and network levels. Automation causes significant changes in the operation practices of upper-air observatories, affecting organization as well as procedures. New opportunities are simultaneously offered for more extensive data collection and the enforcement of the methods of observation.

At the network level an automated upper-air system presents new facilities of control and design. A system connected to the telecommunication network provides more data on the atmospheric parameters in alternative formats for different purposes. It can also provide technical control information permitting a more efficient organization of maintenance and calibration activity.

A further aspect of automation is, that it makes possible the establishment of new observation sites by reducing significantly the logistics costs. This is relevant particularly in remote locations and onboard ships.

INTRODUCTION

The new, computer based automation has widespread effect in all the industrial societies dependent on the collection and processing of information. The meteorologists will be strongly affected at all levels - being specifically an information collection, analysis and distribution community.

The meteorological organizations will obtain tangible benefits from the automation in the form of lower costs, better results and improved reliability.

This presentation discusses the various impacts of automation within a traditional key area, the aerological observation network.

AUTOMATION AFFECTS THE NETWORK

The aerological observation network is largely complete over the continents within the framework of synoptic scale forecasting work. It has been limited from developing further to cover the oceans or to serve the local forecasting by the relatively high costs.

The costs have slowly evolved in an unfavourable direction. Inflatory pressures have augmented regularly the cost of personnel, transportation and maintenance supplies. The de facto decrease in the cost of the major consumable item, the radiosondes, has not been able to compensate for all these increases.

The operating cost structure of a typical upper-air station is shown in Figure 1. The
Personnel costs are clearly dominant and growing more so. Figure 1 also shows the projected costs on a station using an automated observation system and a completely revised organization structure.

It is obvious that automation can improve the economic aspects of the upper-air network significantly, allowing even possibilities of opening new stations. The improved productivity justifies better compensation of the personnel. Simultaneously the basic cost structure will develop favourably into a direction where sensitivity to inflationary pressures decreases.

THE AUTOMATED UPPER-AIR STATION

Let us first briefly outline the highly automated upper-air station:

- Personnel is just one specialist and one or two operators with substantially lower training level than is required today. Alternatively a number of part-time observers may be used.
- Active working time is less than one manhour per ascent
- The system provides interactive, on-site operator training through a "beginner's protocol" in addition to the highly symbolic standard protocol
- Data acquisition, quality control and formatting requires no operator intervention
- Telecommunications procedures are fully automatic
- Technical performance monitoring is fully automatic with systematic reporting
Obviously this is more than has been achieved so far. There are, however, no technological obstacles preventing the development, and consequently such stations will be in operation in the near future.

THE OPERATING PERSONNEL

The radiosonde station staff is today highly specialized. Several weeks' full time instruction followed by a period of on-the-job training is common in the services.

The training covers a number of topics:
- operating procedures, related to the handling of the system in various operational situations
- data acquisition procedures, such as reading scales and making adjustments
- computational procedures for data translation
- data quality assurance methods and practice
- message coding and transmission
- ascent documentation to a standard format
- equipment routine maintenance and calibration checks
- reporting on equipment performance including also emergency procedures

In most cases several such specialists are required to carry out a single radiosonde observation.

There is obvious economic interest to attempt change by both reducing the training level and the number of operators. A lower training level would mean either a lower grade operator, or a large pool of trained personnel with a more flexible schedule of work. Fewer persons present at a sounding would directly reduce the costs.

In terms of working time this means a reduction from 3 to 6 active manhours per ascent by a skilled observer to less than one hour by a semi-skilled one.

Savings in the personnel represent the major economic potential due to the current cost structure.

THE ORGANIZATION

To realize the savings, the organizations must develop to accept the new technology.

From the current experience in the industry, the first impacts of automation will lead to a decrease of personnel at the lowest level - and to an increase in the clerical and lower management levels. This is not, however, a lasting effect. Automation is now improving rapidly the productivity at these higher levels as well, increasing the amount of work performed by the same staff and effort.

The current upper-air organization network has a well established organizational structure, often with substantial independence. Consequently there is considerable lag in the introduction of the automatic systems, and still more in the achievement of the economic benefits.
From the operational point of view, a merging of the upper-air station organization with another unit might make sense, provided that the units are co-located. This creates flexibility in the use of personnel for the various tasks.

The planning and procurement functions will change little. The training function will be largely eliminated.

Automation offers new opportunities to make upper-air observations. Two significant developments can be expected, both the direct result of the improved efficiency of personnel.

Shipborne observations can be carried out economically as the number of observers is low enough to be accommodated on the typical cargo ship, and the skill level requirement makes it feasible to train the professional seamen as observers.

The same justification will apply also for stations to be used for local forecasting purposes. An airport meteorological team can carry out soundings as needed in critical situations with a minimum of cost.

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**FIGURE 2**
ACTIVE WORKING TIME PATTERN ON A MANUALLY OPERATED UPPER-AIR STATION. THREE OPERATORS ARE NEEDED FOR ONE ASCENT.

---

**FIGURE 3**
TWO ALTERNATIVE ACTIVE WORKING TIME PATTERNS WITH AUTOMATIC EQUIPMENT.

"Two sites" may be applicable at airports with co-operating personnel launching the balloons and the meteorological observer monitoring the receiver.
THE DATA OUTPUT

Automation permits a new look at the products delivered by the upper-air stations. In general, both quantitative and qualitative improvements can be expected.

The machines do not get tired of handling numbers. Consequently more data can be obtained and recorded, to "more decimal places" than before. The limit on data quantity is set by the user, not any more by the collection system.

The changing cost structure may make it attractive to perform four complete RS/RW observations per day instead of the current two, thus improving also the time coverage.

The automatic system enforces the correct operating routine. The local traditions typical of each manually operated station will disappear. It is also possible to create more elaborate quality checks than can be reliably implemented in the manual methods.

In summary, there will be more data with better consistency and accuracy than before.

SYSTEM MAINTENANCE

On the upper-air stations of today, a substantial part of the maintenance is performed by the local personnel. Even in cases when a specialist has to be called, the operators are able to make a preliminary diagnosis or at least describe the symptoms.

The automatic systems are substantially more complex and require a different maintenance approach.

The first cornerstone of maintenance is the automatic internal check. A nucleus of the system is assumed to be operational, and used to verify the other system parts. The verification can be extended to both equipment and program contents. If the system nucleus is out of operation, the system will refuse to respond, which delimits the fault to this small section.

In addition to the basic operating check, the system may generate data during its normal operation, permitting a detailed monitoring of its status. Data quality procedures naturally provide this kind of information as a by-product.

The normal approach to maintenance in automated systems is to make modular replacements. Component level replacement can only be considered in specific cases, i.e. power supplies. The component level repair requires highly skilled personnel. Due to the low frequency of repair in a properly designed automatic system, it may not be economical to train an engineer at this level, but rather return the module to the manufacturer.

EQUIPMENT COSTS

The cost of equipment on an automatic upper-air station depends primarily on the basic principles of measurement. An automated radar is necessarily more expensive than a manually operated one. On the other hand, a highly automated NAVAID system, replacing moving mechanical parts with solid state electronics is lower in equipment cost than the manual radar.

The equipment costs vary with time, and depend strongly on the system structures. System parts of mechanical, electro-mechanical and custom design type will rise in cost rapidly due to their large work content. Those involving standard, large volume electronics parts in a standard configuration typically resist inflationary pressures.
This trend has been demonstrated during the past ten years, and there appears to be little reason to expect its reversal. In addition to the investment cost, the trend strongly affects the parts needed for maintenance.

The investment needed for automation is low in proportion to the benefits. Payback times of the order of two years can be expected in the industrialized parts of the world, with their current personnel cost levels.

IN SUMMARY

The advent of automation will strongly affect the current upper-air observation stations, and will make it possible to establish new ones onboard ships and on airports. Temporary personnel such as university students, housewives, etc. could be trained to operate such stations.

There will be important benefits on data quality and quantity, as well as the economy of operation. These benefits will be realized with lower personnel costs and less organizational overhead, as well as by means of lower costs of maintenance.

The cost distribution, now heavily dominated by inflation sensitive personnel costs, will show a larger segment of electronics dominated hardware costs that are more resistant in this respect.
A TRANSPORTABLE UPPER-AIR SYSTEM

Pekka J. Kostamo, Vaisala Oy

Abstract*

This paper introduces a transportable, highly automated upper-air observation system designed for research, weather modification and shipboard applications. The system configuration is described. The system is compact in size, but includes several data collection and post-ascent analysis options, and a BASIC language user programming capability. All programs are packed in modular solid state memories.

* Abstract only available
AUTOMATISATION DES MESURES EN ALTITUDE

G. OUAILID

DIRECTION DE LA MÉTÉOROLOGIE (FRANCE)

Dans une station de radiosondage classique on accomplit deux types de mesure :

- les mesures liées au secteur VENT effectuées au moyen d'un radar ou d'un radiothéodolite,
- les mesures liées à la Pression (P) Température (T) et Humidité relative (U) effectuées au moyen d'une radiosonde.

Lorsqu'on aborde l'étude de l'automatisation du traitement des données de mesures en altitude, on est conduit à scinder le problème en deux parties (PTU et Vent) dont les difficultés apparaissent inégales de part leurs contraintes spécifiques d'exploitation.

L'ensemble de traitement doit assurer :

- l'obtention automatique des caractéristiques de l'atmosphère traversée au cours de l'ascension de l'appareillage de mesure,
- le fonctionnement, suivant le type de mesures, du système globalement (PTU V) ou partiellement (PTU ou V),
- l'association, à certains niveaux, des résultats obtenus pour la rédaction de documents d'exploitation,
- la rédaction de messages sous forme TEMP ou PILOT directement exploitable par les transmissions.

Le système de radiosondage équipant les stations de la Direction de la Météorologie Française se compose :

- Pour le PTU, de la radiosonde FMY-1950 associée à un ensemble EIDER.
- Pour le VENT, - d'un radar à poursuite automatique RAFIX pour les stations métropolitaines,
  - d'un radar à poursuite manuelle ou d'un radiothéodolite pour les stations des Services OUTRE-MER.

- LA RADIOSONDE FRANCAISE FMY-1950

Cette radiosonde est équipée des capteurs suivants :

- une capsule en NISPAN C pour la pression ;
- une thermistance pour la température ;
- une peau de batteur d'or pour l'humidité.

Un convertisseur Résistance-Frquence permet de transformer la variation de résistance, en fonction de la température, en variation de fréquence.
Un codeur électromécanique transforme l'élongation des capteurs Pression et Humidité en nombre d'impulsions.

L'information T module en fréquence un émetteur 400 MHz avec un Δ F de ± 60 KHz. Chaque impulsion de Pression ou d'Humidité bloque la modulation de fréquence de l'émetteur. La recurrence des mesures de P ou de U est de 12 secondes. Une mesure de Pression dure au maximum 5 secondes. Une mesure de U dure 1 seconde. Pendant les temps restés libres sur un cycle de mesure (12 secondes), la sonde fournit une information Température.

Cette radiosonde présente quelques avantages du point de vue traitement automatique :

- L'absence de signaux de référence,
- Le codage qui fournit à la réception :
  4 chiffres pour la Température 3000 < T < 7500 Hz
  3 chiffres pour la Pression 110 < P < 700
  2 chiffres pour l'Humidité 12 < U < 99

- L'ENSEMBLE DE RECEPTION EIDER

Un récepteur 400 MHz associé à deux antennas commutables (une omnidirective et une directive) et son préamplificateur, capte les signaux émis par la radiosonde. Après détection, mise en forme et traitement, les informations sont :

- Affichées sur tubes électroluminescents,
- Dirigées vers un enregistreur graphique à 3 voies qui permet une visualisation des courbes de données primitives,
- Disponibles pour prise en compte par un équipement de saisies de données sous la forme :

  ttttt PPF ttttt TTTT ...... ttttt uu

- LE RADAR RAFIX :

Determine les coordonnées site, azimut et distance oblique de la cible emportée par le ballon. Les informations sont affichées sur tubes électroluminescents et disponibles pour une prise en compte par un équipement de saisies de données sous la forme :

  ttttt Az Az Az Az ss ss DDDD

- LE RADIOTHÉODOLITRE :

Fournit les informations site et azimut dans le cas d'un sondage avec PTU. Ces in-
formations sont associées à celles des repères pression d'un barocontacteur dans le cas d'un sondage vent seul.

Plusieurs ensembles de traitement se sont développés autour de la radiosonde française FM-1950 en adoptant des matériaux et des logiciels différents suivant l'évolution technologique tout en ayant des objectifs identiques.

Nous citerons dans l'ordre :

- Le système ETADAM
- Le système ETARDOM
- Le système CITAR

**LE SYSTÈME ETADAM**

Ce système est composé d'un ensemble EIDER, d'un radar RAFIX, d'un calculateur CP16, d'un téléimprimeur 6 moments et d'un téléimprimeur 5 moments. Il doit permettre d'effectuer par un seul opérateur un sondage PTU-VENT. L'automatisation devant être totale, elle inclut la rédaction des messages et des documents climatologiques (CRA et CRV).

L'ensemble se compose essentiellement de deux chaînes A et B de traitement d'informations, chacune de ces chaînes traitant les informations provenant de l'entrée qui lui est propre.

A certains niveaux du traitement, il peut y avoir communication entre ces deux chaînes pour l'élaboration des résultats finals communs. Ces deux chaînes doivent pouvoir fonctionner simultanément ou séparément.

Les informations proviennent d'une part de l'ensemble EIDER connecté à la chaîne de traitement A et d'autre part du radar RAFIX connecté à la chaîne de traitement B.

Chaque radiosonde est fournie avec son étalonnage. Le support de ces données est une bande perforée (code CCITT n° 5) sur laquelle se trouvent les coefficients représentatifs de la courbe.

Avant le lâcher du ballon, l'opérateur introduit la bande d'étalonnage dans le calculateur et effectue les contrôles de la sonde. Lorsque la sonde est acceptée par le calculateur, la phase d'initialisation, comprenant les données de surface, débute au moyen du clavier du téléimprimeur.

L'opérateur règle ses équipements de poursuite. Le ballon peut être lâché.

Dès le départ du ballon, l'opérateur n'a plus qu'à surveiller la qualité des signaux reçus et éventuellement effectuer des réglages de réception.

Les données primaires PTU et VENT sont acquises automatiquement par le calculateur qui effectue :

- le filtrage des informations,
- le calcul des différents paramètres,
- la recherche des niveaux imposés par l'exploitation :
  
  . niveaux caractéristiques,
  . niveaux standards,
  . altitudes principales.

Pendant l'ascension du ballon on obtient :

- Sur téléimprimeur 8 moments, les niveaux standards de pression dans la mesure ou tous les paramètres PTU et VENT de ces niveaux auront été calculés.
- Sur téléimprimeur 5 moments : édition et perforation du message VENT PRÉLIMINAIRE dès que le niveau 1500 mètres est atteint. Le message est ainsi disponible pour la transmission sur le réseau de télécommunication ;

- édition et perforation du message TEMP parties A et B dès que les données relatives aux niveaux 70 mb et 18500 m auront été calculées ;

- édition et perforation du message TEMP parties C et D dès que les traitements PTU et VENT ont permis de détecter une fin de sondage sur les deux chaînes.

Après la détection de fin de sondage on obtient sur l'imprimante 8 moments, l'édition du CRA et du CRV qui seront perforés sur bande pour un traitement climatologique ultérieur.

- repère C : niveau caractéristique
- repère O : isotherme 0°C
- repère D : isotherme -10°C
- repère T : tropopause
- repère S : niveaux standards
- repère G : altitudes principales
- repère X : vent maximum

La description ci-dessus concerne le cas d'un sondage PTUV. Le système ETADAM permet, en fonction d'une sélection effectuée par l'opérateur, plusieurs modes de fonctionnement :

- sondage PTUV
- sondage PTU
- sondage VENT
- sondage PTUV avec relâcher PTU ou relâcher VENT suivant le type d'incident en cours de sondage

LE SYSTÈME ETARON

Il se présente de la façon suivante :

Pour le PTU
- Un meuble EIDER.
- Un séquenceur qui réalise l'interface entre les sorties EIDER et l'entrée d'un perforateur code ASCII.
- Un perforateur qui sert de mémoire tampon en stockant les données primaires t, Dp, FT, Du.
- Un lecteur relié au calculateur.

Pour le VENT
- Un radar ou un radiothéodolite.
- Un lecteur relié au calculateur.

Pour l'ensemble PTUV
- Un calculateur HP 9825.
- Un téléimprimeur avec lecteur et perforateur de ruban 5 moments.

Le programme PTUV est introduit dans le calculateur au moyen d'une cassette magnétique. Avant le sondage et à l'aide de touches spécifiques, l'opérateur a la possibi-
lité en conversant avec le calculateur :
- d'entrer l'étalonnage d'une nouvelle sonde (capacité : 20 sondes mémorisées),
- de contrôler la validité de l'étalonnage après introduction des données de contrôle sol,
- d'obtenir la liste des sondes en mémoire,
- de supprimer certaines sondes en mémoire,
- d'obtenir l'étalonnage en clair avec correspondance,

\[
\begin{array}{c|c}
\text{Nombre Impulsions} & \text{P ou U} \\
\text{Fréquence} & \text{T}
\end{array}
\]
- de transférer les étalonnages d'une cassette sur une autre,
- de dupliquer les cassettes programme.

Avant et au départ du ballon les opérations de préparation du sondage sont identiques à celles effectuées dans le mode ETADA'1.

Pendant l'ascension du ballon, l'ensemble mobile EIDER - perforateur fournit une bande perforée des données primaires PCU. En ce qui concerne les données VENT, l'opérateur constitue une bande perforée des paramètres site, azimuth et éventuellement distance oblìque.

Le traitement du sondage peut alors débuter sur demande de l'opérateur qui reste maître du déroulement des séquences de programme. Un système d'interrogation-réponse permet le dialogue calculateur-radiosondeur. De ce fait, toutes anomalies telles que mauvaise réception, brouillage, mauvaise perforation des données primaires, etc... peuvent être corrigées.

A la fin du sondage, le programme permet d'obtenir :
- l'édition et la perforation des messages TEMP A, B, C et D (ces documents peuvent être obtenus en cours de sondage sur demande) ;
- la conservation des données du sondage par transfert sur cassette spécialisée (capacité 100 sondages). Cette cassette servira ultérieurement à l'élaboration du CLIMAT TEMP et sera expédiée au Service Central de Climatologie ;
- l'édition du compte-rendu Aerologique et Vent sur imprimante.

**LE SYSTÈME CITEA**

Développé initialement pour traiter le VENT avec entrée manuelle du VENT, des essais sont actuellement en cours pour intégrer le vent automatiquement à partir d'un radiothéodolite à sorties numériques.

L'ensemble CITEA comprend :
- un récepteur RRS 222
- un calculateur MT 9825
- un téleimprimeur

Le récepteur RRS 222, associé à une antenne omnidirectionnelle et son pré-ampli, capte les signaux émis par la radiosonde. Après détection, traitement et mise en forme, l'information est affichée sur diodes électroluminescentes et transmise au calculateur sous la forme :

\[
\text{ttttt} \quad \text{PPP} \quad \text{TTTT} \quad \text{UUU}
\]
tttt : représente le temps pris à la fin de la donnée Pression.

PPP : représente le nombre d'impulsions Pression.

TTT : représente la fréquence Température.

UU : représente le nombre d'impulsions Humidité.

Ces impulsions sont acquises directement par le calculateur qui effectue le traitement tout au long du sondage sans intervention de l'opérateur si ce n'est l'entrée des données VENT sur demande du programme. Les opérations d'initialisation du sondage sont semblables à celles du système ETARON.

En cours de sondage, au fur-et-à-mesure de l'acquisition des informations, le calculateur édite sur le téleximprimeur les valeurs correspondantes ZPTU pour contrôle.

Après l'acquisition des données relatives à la pression 100 mb (PTU + VENT) le calculateur édite et perfore sur bande 5 moments les parties A et B du message TEMP. Le sondage se poursuit jusqu'à un arrêt soit automatique par décroissance de pression ou arrêt émission soit par décision de l'opérateur. On obtient alors successivement :

- L'édition et perforation du TEMPS C et D
- L'édition du compte-rendu Aérologique
- L'édition du compte-rendu VENT

Depuis la mise en exploitation des différents systèmes, les résultats obtenus sont :

- 95 % de succès total avec ETARAM. C'est-à-dire que dans 95 % des cas où le sondage est traité, il n'y a pas d'intervention de l'opérateur. Le message et les documents climatologiques sont transmis sans nécessiter de correction.

- 100 % de succès avec le système ETARON.

Remarquons que la réussite de 100 % du système ETARON s'explique du fait de la possibilité donnée à l'opérateur de reprendre à tout instant le traitement du sondage et de le corriger.

Le traitement entièrement automatique du système ETARAM assure une sécurité dans la rigueur du traitement par contre l'intervention de l'opérateur soit de sa propre initiative soit par interrogation du calculateur, la manipulation de cassette, l'interprétation de certains résultats peuvent engendrer des problèmes au niveau de l'exploitation.
## ANNEXE

### COMPTÉ-RENDU AÉROLOGIQUE (ET VENT)

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### NIVEAUX CARACTÉRISTIQUES DE VENT

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**STATION: LE RIZET NR CRA:**

**HEURE (TU):**

**PROCÉDÉ:**
### ANNEXE

#### COMPTE-RENDU AÉROLOGIQUE (ET VENT)

**Station:** Le Raizet  
**Date:** 780730  
**Heure (TU):** 8  
**Ecart horaire:** 2  
**Procede:** 7

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#### Niveaux d'isothermes tropopause(s)

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In late August of 1980 the Atmospheric Environment Service of Canada will begin the installation of the Aerological Data Reduction System (ADRES). This system will automate the on-site computation of aerological data. Using a general purpose minicomputer connected to the GMD radiotheodolite, ADRES will replace the present manual computation. The main features of ADRES are the automatic acquisition of wind data, machine computation and message production, and a sophisticated command language. Since September of 1978 five prototype systems have been operating at different sites throughout Canada.

In an effort to automate wherever possible, we began to explore the introduction of computers into our upper air network in 1972. At that time a number of advantages were envisaged. Due to the isolated nature of our network much of the cost at our stations is related to life support and not operations. Thus even small staff reductions can considerably reduce costs. The morale of our staff could be improved by removing much of the drudgery involved in the present manual computation. The life of our GMD-1 and GMD-2 systems could be extended and maintenance costs reduced by replacing the least reliable component namely the GMD control recorder.

The principle advantage of automatic computations is the production of highly reliable information. Even with dedicated and well trained operators about twelve percent of all messages have at least one error. These errors can be partially attributed to the urgency of preparing the data for transmission as quickly as possible. A computer based
system will remove the pressure of time and will in fact allow the data to be available much closer to real time. Many of the quality controls used before the data is introduced into our weather models at the Canadian Meteorological Center or into our national archive by the Canadian Climate Center will now be performed automatically on site.

By automating the acquisition of the radiotheodolite synchro data the manual input by the observer into the computer terminal can be reduced by about 70%. The present GMD control recorder takes one sample of the synchro data each minute. With ADRES, sampling the data thirty times per second and using a least square fit to determine the minute value we are able to greatly reduce the errors generated by the radiosonde/tracking system.

A typical office layout (fig. 1) comprises the ADRES equipment rack and Decwriter terminal which form the computing nucleus of the system. The existing Leeds and Northrup meteorological data chart recorder is the source of the raob data. A paper tape reader/punch is used to input the pressure calibration chart for the radiosonde and to output the completed meteorological messages. The GMD radiotheodolite is located in a dome on the roof of the office.

The Digital Equipment PDP11/04 minicomputer (Figure 2) is the heart of ADRES. It has a full complement of 28 thousand sixteen bit words of MOS memory with battery backup. The programs are retained on standard eight inch floppy disks. One drive of the dual RX11 floppy disk system is used as the system software drive and the second is used as the archive drive. The Decwriter terminal acts as the input for the significant raob data as well as a hard copy 300 baud printer. These three modules are all common off-the-shelf components. By generalizing in this fashion, the system is more amenable to changes at a later date.

The meteorological data from an audio-modulated 1680 MHz sonde is output on the chart recorder. The observer selects the significant data and enters it into the computer via the terminal. Early in the project we decided not to automate this portion of work. The complexity was almost as great as the rest of the system and this would have increased
the cost by about thirty percent. Since the observer must be present a zero cost benefit would result from automating the raob portion of the flight. Furthermore by keeping the observer involved in the real acquisition of the data, it will not only tend to increase morale but help to keep the observer alert to the quality of the data.

The radiotheodolite outputs its directional data in the form of synchro information. The custom electronics, designated as the GMD control module (GCM), converts this data into a digital form for the computer. This module can also handle the ranging data from transponder radiosondes. The GMD control module contains all the metering functions and antenna control switches present on the GMD control recorder. This unit has as well a few computer control switches for the radiosonde flight. There are highly visible LED displays for the azimuth, elevation, range, GMT time and flight elapse time. The computer calculates the data for the first three displays from the digitized synchro information.

A remote control panel is located in the balloon release area. Most of it's displays and controls parallel the internal GMD control module. The elevation and azimuth displays are in an analogue form and allow the observer to quickly set the antenna on target after release. By removing the audio from the radiosonde RF signal until the moment of release, the GMD control module, once armed, will commence the flight automatically. Thus one operator using a train regulator, if necessary, can complete the release, slew the radiotheodolite on target and inform the computer when the wind data is valid.

The ADRES software is a heavily overlayed disk based RT-11 operating system. The software is grouped into twenty five overlays which are called from the disk as required and temporarily stored in one of two overlay areas in memory. Certain real time input/output handlers and the most frequently used commands are memory resident. The rather important power failure recovery routines are also memory resident. These power failure routines are very effective since no data is lost and the ADRES software will continue as soon as the power recovers.

The software used for flight operations (ADRES) consists of 309 modules. The modular approach speeds comprehension and simplifies software maintenance. A simulation version of the software (ADRESS) is also available which allows one to completely change and recompute a previously archived flight. This will be used by our quality assurance personnel before the data is entered into our national archives. For training purposes a special version of the software (ADREST) can simulate a flight including moving all displays in real time. A fourth version (RWT) computes the RMS error of the
radiotheodolite during a comparison with an optical theodolite. These four versions of
the software are available in both the French and English languages.

The command processor (Figure 3) through which the observer interacts with the
system is very versatile. The operator controls the entry of the data and the system does
not prompt him except in extreme cases. This approach has helped the system gain
acceptance by our experienced observers. We expect that this will also prevent the
observers from becoming bored or distracted thus leading to errors. The observer can
enter, delete, insert and modify data as he wishes. The computer will automatically
recompute the primary and secondary results each time. The validity of the wind data can
be changed as the observer sees fit in order to eliminate erratic data. This allows for
the removal of obviously erroneous data. The computer will then compute the results
through this missing wind stratum automatically.

To further reduce errors all correction tables (such as temperature and pressure)
are retained within the system on the systems disk. They become part of the data areas in
memory when the system is initialized. The system disk also retains any data which does
not change from flight to flight such as station name, latitude etc. The height data from
the previous flight is also saved.

The observer never has to compute any data before entry. Thus all slide rules,
tables, graphs, plotting machines and graphs are eliminated. Only the raw data is entered.
For example, at release the mercury barometer reading and attached thermometer are entered.
The computer automatically calculates the true station pressure taking into account the
station gravity and barometer scale corrections which are stored on the system disk.
Likewise the thermometer correction tables and the horizon obstruction table are retained.

The data areas contain all the information related to a flight. This includes the
initialization data, the input data and the calculated data. The observer may display
this data as he wishes but only the initialization and input data may be changed. If any
input data is altered then the system will automatically recompute all the calculated
data. The data areas are stored in memory during the flight and are transferred in their
entirety onto the archive disk when requested. Thus the flight data may be recovered at a
later date, allowing for correction and complete recomputation.

Though the meteorological algorithms comprise less than 10% of the 309 modules they
ensure that the engineering values are calculated consistently throughout the network.
Some of the engineering values are trend checked after they have been computed. All the
input data is limit check and/or trend checked where possible. There are also internal
software limits. As a temporal check the altitude data is compared with the previous
flight information. Where discrepancies are encountered the observer is alerted by
warning or error messages.

Most of the meteorological algorithms ran successfully in first software versions
of the prototypes, but we encountered errors when compared to the manual system as large
as five percent in relative humidity and 30 metres at 20 millibars. The former caused
serious problems in saturated conditions. The latter though very small was consistent.
Both of these faults were believed to be caused by the sensor conversion equations (1).
The improved VIZ (2) algorithms were introduced reducing the relative humidity errors to
1%. The height errors were improved slightly.

The availability of the hardware in the system has increased from 96.0% during the
test period in 1978 to 98.9% this winter. The software problems initially caused the
system to be down 4.5% of the time but this has been decreased to 1.8%. The downtime
reduction was made possible by the avoidance of one major software fault. The prototype
units will be retrofitted with new custom hardware this summer which will allow us to
introduce the latest software. The result was an overall system availability of 98.0% at
test sites. With the implementation of improved preventative maintenance schedules and
updated software even this value will be improved.

An intensive study (3) of the errors in the aerological messages indicated that
twelve percent of all messages have at least one error caused by the observer. The
communications network caused errors in twenty four percent of the messages. Both types of errors are proportional to the number of times the data is handled by the observers and communicators. Based on this assumption, ADRES will reduce the observer error to 0.5%. Since the aerological messages are prepared on paper tape for the communications network, the communications network errors will be reduced to 14%. The teletype networks themselves cause very few errors. Further gradual reduction in message errors is expected as local circuits are removed and the transfers between five and eight level coded data are made mechanically rather than by the communicators.

As mentioned before, the early availability of data would be one of the major benefits from the system. Our more skilled observers can have the first transmission (UM) which includes data to 100mb ready in 85 minutes after release. ADRES can have the same data ready in 55 minutes or about five minutes after the radiosonde reaches 100 millibars. This is a mixed blessing since the surface synoptic messages are being transmitted at that time and the teletype networks are fully occupied. Thus when all the stations are in operation we may have to transmit a reduced message (UX) before the synoptic hour and the complete message (UM) after the synoptic messages are transmitted.

With ADRES the archived data will be shipped to the Data Quality Control Section in the form of three diskettes per station per month. Presently they check the flights by analyzing a 100mb map of the archived data and rechecking any flight which deviates from the expected height by more than 50 metres. They also perform other checks and do random spot checks on complete flights. With ADRES, the same 100 millibar analysis check will be done but the detection of the errors and recomputation will be much more rapid. The difficulty will be the storage of these one hundred diskettes per month until all are received, checked, recomputed if necessary and transferred into the national archive. Taking into account the station archive backup disks, we expect in excess of two thousand diskettes will be required to operate the network.

There are other problems for which we have not completely satisfactory answers. In the winter the relative humidity often drops below ten percent in the most northern offices causing the system software to cease operation due to static discharge. Humidifiers are being used to alleviate this static. Releasing the balloons in bad weather by one person can be a hazard if problems arise. In the long term we will have to maintain the software mainly in order to allow for WMO or regional procedural changes. Though we will have a special development system one software specialist will have to remain conversant with the software.

The ADRES will give the Canadian upper air network a more reliable output. The observers can expect to have a versatile system at their disposal. The network management, though more complex, will yield a better overall product at a time closer to the actual observation.

A TOWER BASED WIND SHEAR WARNING SYSTEM FOR AIRFIELDS

J. Aspola, Vaisala Oy

ABSTRACT

A tower based data acquisition system gives real time data on the low altitude air conditions near the airport. The system especially monitors vertical wind shear and temperature inversions by means of the sensors installed at several levels of the tower, and alerts when set thresholds are exceeded.

The standard system provides sensors for measuring temperature at eight levels, wind speed and direction at four levels, and humidity also at four levels of the instrumentation tower.

The heart of the system is a microprocessor based processing unit, which takes care of measuring the sensor output signals, computing and storing the corresponding average, minimum, and maximum values, and finally providing the weather data to remote printer terminals and a cassette storage unit in one of the numerous operator selectable recording formats, including both numeric and graphic print-out formats. The system is flexible both in hardware and software allowing different amounts and types of sensors and recording terminals to be used.

As to installing the system, the basic approach is to use already existing radio and TV broadcasting towers, when they are at a suitable distance from the airport. The first system, designed in co-operation with the Finnish Meteorological Institute, was installed in the Kivenlahti broadcasting tower, 300 m high. The system supports two printer terminals, one of which is at the Helsinki-Vantaa international airport about 30 km away. After one and a half years of fully operational use the system is described as indispensable by the airport meteorological personnel.

1. Introduction

It is a well-known fact that modern big air- crafts with their heavy mass and wing load have poor slow speed characteristics, which makes them easily vulnerable by rapid air-density changes, especially during landing and take-off operations. This, together with the air-traffic ever increasing, makes it most important to rapidly detect abnormalities in low-altitude weather to forewarn the pilots.

In co-operation with the Finnish Meteorological Institute, Vaisala has developed a tower-instrumented data-acquisition system, Midas 200, to give real time information on low-altitude air conditions near the airport, and especially to alert when such phenomena as strong wind shear or temperature inversion are met.
The Midas 200 system continuously measures wind direction and speed, temperature, and humidity by means of the sensors installed at several levels of the instrumentation tower, and computes vertical wind shear magnitudes and temperature differences between the sensor levels. The scaled and computed data are sent to remote printer terminal(s) via public telephone lines automatically or on request.

The system may be used as an autonomous one giving data directly to users or as a subsystem of a larger data processing system. The relevant ICAO recommendations have been taken into account in the firmware design.

2. System Configuration

The main parts and features of the complete system MIDAS 200 are described below:

Sensors

In the standard system, sensors are provided for measuring temperature at eight levels, wind speed and direction at four levels, and humidity also at four levels of the instrumentation tower. All the sensor signal inputs are equipped with a transient protection circuitry to avoid surge voltages generated by lightning strikes.

The number of sensor levels in the system is accommodated to an instrumentation tower of 300 meters high, which is considered to be enough to provide sufficient information for the air traffic, specially during landing and take-off.

An example of the sensor configuration and installation is given in Appendix 1, Tables 1 and 2.

Data Processing Unit

The heart of the system is a microprocessor based processing unit, which measures the sensor output signals, computes and stores the corresponding average, minimum and maximum values, and finally provides the weather data to the printer terminals and the cassette unit in a format specified by the operator.

The processing system runs on 5 kilobyte program memory and 4 kilobyte buffer storage memory. It is able to support two independent data terminals and a cassette drive.

Data Output and Control Terminals

In the basic system, two 30 char./second printer terminals provide both for system control by the operator and for data output. The transmitting method between the processor and the terminals is bit-serial according to the EIA RS232C standard. If the terminals should be installed further than 300 meters away from the processing unit, a pair of data modems (300 bits/s) are needed for each terminal to transmit data reliably.

Furthermore, a C-type cassette drive serves as a mass storage memory.

Power Supply

The system is AC-powered, but the power supply has a battery back-up thus being capable to keep the whole system (including the optional data modems, excluding the printer terminals) fully operational about half an hour after an AC-power failure.
Installation Cabinet

Physically, the processing unit including the standard interfaces, the transient protections, the cassette drive, the data modems, and the power supply are all installed in a single free standing cabinet, provided with both front and rear access doors for maintenance.

A typical system configuration scheme is given in Appendix 2.

3. Measuring and Computing the Parameters

All the analog sensor signals (temperature and humidity) are measured at 30 second intervals and all the digital sensor signals (wind speed and direction) are measured at 2 second intervals.

At the end of each two minutes period the following values are computed and available as new data:

- Temperature, two minutes average values (°C) for each sensor level.
- Relative humidity, two minutes average values (%) for each sensor level.
- Wind speed, both two and ten minutes average, minimum, and maximum values (knots) for each sensor level.
- Wind direction, both two and ten minutes average, minimum, and maximum values (degrees) for each sensor level.
- Vertical wind shear values are determined by calculating the wind vector relative differences between each two successive wind sensor levels and furthermore between the upmost and lowmost levels. The shear values are computed on the basis of the two minutes average wind values (ICAO recommendation). Only shear vector magnitudes are available (knots/30 m).
- To detect temperature inversions the temperature differences between each two successive sensor levels and furthermore between the lowmost level and all the other levels are computed (these together make 13 comparisons).

The wind shear and temperature data are automatically given as an appropriate alarm message, if one or more of the shear values or temperature differences exceeds the alarm limits selected by the operator. All the other data are printed on request or at certain time intervals determined by the operator.

It is possible for the operator to exclude any sensor value from both the printout and the calculations. For instance, if the third wind sensor is excluded because of a sensor failure, the processor is clever enough to calculate the shear value between the second and fourth sensors. The same goes for temperature comparisons, too.
4. Data Output and Storage

The following types of data messages are available and sent to the printer terminals by simple commands:

1. Wind data, direction/speed average values from each level (degrees/knots).
2. Wind data, direction/speed maximum-minimum values from each level (degrees/knots).
3. Vertical wind shear vector magnitudes between the upmost and lowmost levels and between each two successive levels, five values together (knots/30 m).
4. Temperature data from each level (°C).
5. Humidity data from each level (% rel.).
7. Messages 1. and 2. together.
8. Messages 1., 2., and 3. all together.
9. Messages 1...5. all together.
10. Graphic profile of wind data: direction average and variation, speed average and variation (each level).
11. Similar to the message type 10., but only one selected level data.
12. Graphic profile of humidity data (each level).
13. Similar to the message type 12., but only one selected level data.
14. Graphic profile of temperature data (each level).
15. Similar to the message type 14., but only one selected level data.

Some printout examples are shown in Appendix 3.

All the message types above are available either on request or repeatedly at the time interval, which can be selected to be any number of two minutes increments from 1 to 255. In fact, there are two individual software counters for each terminal, which makes it possible to select two separate message types (for example a graphic one and a numeric one) to be printed out at separate intervals. All the messages are provided with current date and time, which can be set from the terminal.

If the wind shear or temperature difference values exceed the corresponding alarm limits set by the operator, the message type 3. or 4. (respectively) is automatically printed together with the alarm signal. Also an "alarm over" -message is sent as the air conditions go back to normal again. To prevent continuously repeated "alarm" and "over" messages a kind of software hysteresis is applied.
The system also has data banking capability, being able to store in its read/write memory up to 33 complete weather messages. This gives the operator the possibility to backtrack a weather case. The banking interval can be set alike the reporting interval, however, irrespectively to that. Recalling 11 days old data is possible, if the banking interval is set to its maximum (8.5 h).

Instantaneous sensor values, both scaled and unscaled, are also available, intended mainly for maintenance purposes. To ease the maintaining it has been made possible to set analog sensor scaling parameters from the terminal, without the need of hardware adjustment.

All the data are recorded on the cassette at selectable intervals. Cassette capacity permits recording of 50 days data when a half an hour recording interval is used. A separate cassette reader is needed to transfer data to other systems.

5. Conclusions

The impetus for the tower system came from the user side, which shows that such systems are needed. The biggest problem might be the demand of an instrumentation tower high enough and close enough to the airport to be of practical use. Nowadays such towers, however, are not so rare - the basic approach here is to use already existing radio and TV broadcasting towers. The first system was installed in the Kivenlahti broadcasting tower, 30 km away from the Helsinki-Vantaa international airport, and the airport meteorologists have been quite satisfied with the information received.

To get satisfactory information preconceives reference measurements at both sites, and still the meteorologist has to consider the validity of the data by taking the current weather situation into account.

The tower system offers an aeronautical meteorologist much better possibilities to prepare shear and inversion warnings than only using routine sounding. Preparing warnings for aviation is still not the only application for the system - it may also be used for example in collecting data for local forecasts and air pollution control.

The Midas 200 system was developed paying extra attention to the flexibility and versatility of the system software. Extra consideration was also given to make the system easily maintainable. The special software features, like graphic reporting as well as data banking capability have already proven their worth, but not the easy-to-maintain feature. The Kivenlahti system has already been running two years without a single hardware failure.
Specification of the sensors in the instrumentation tower

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sensor type</th>
<th>Qty</th>
<th>Signal type</th>
<th>Wires/sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Vaisala DTS 12, Pt 100</td>
<td>8</td>
<td>analog</td>
<td>3</td>
</tr>
<tr>
<td>Humidity</td>
<td>Vaisala HMP 14 U, Humicap</td>
<td>4</td>
<td>analog</td>
<td>4</td>
</tr>
<tr>
<td>Wind speed</td>
<td>Vaisala WAA 12, anemometer</td>
<td>4</td>
<td>digital</td>
<td>3</td>
</tr>
<tr>
<td>Wind dir.</td>
<td>Vaisala WAV 12, wind vane</td>
<td>4</td>
<td>digital</td>
<td>9</td>
</tr>
</tbody>
</table>

**TABLE 1:** Specification of the sensor types and quantities, and the corresponding signal types and signal wires required.

<table>
<thead>
<tr>
<th>Inst. level</th>
<th>Sensors</th>
<th>Signal wires required/level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T H WS WD</td>
<td>Analog (T, H)</td>
</tr>
<tr>
<td>300 m</td>
<td>X X X X</td>
<td>7</td>
</tr>
<tr>
<td>250 m</td>
<td>X</td>
<td>3</td>
</tr>
<tr>
<td>200 m</td>
<td>X X X X</td>
<td>7</td>
</tr>
<tr>
<td>150 m</td>
<td>X</td>
<td>3</td>
</tr>
<tr>
<td>100 m</td>
<td>X X X X</td>
<td>7</td>
</tr>
<tr>
<td>50 m</td>
<td>X</td>
<td>3</td>
</tr>
<tr>
<td>22 m</td>
<td>X X X X</td>
<td>7</td>
</tr>
<tr>
<td>10 m</td>
<td>X</td>
<td>7</td>
</tr>
</tbody>
</table>

**TABLE 2:** Sensor installation levels and signal wires required on each level (T = temperature, H = humidity, WS = wind speed, WD = wind direction).

**NOTE 1:** The analog sensor (T, H) and the digital sensor (WS, WD) shall not be connected into the same cable. Thus two separate cables are needed from the data processing unit to the installation levels 22 m, 100 m, 200 m, and 300 m.

**NOTE 2:** All the cables should be of shielded type. Cross-section of 0.75 mm² per wire is required.
INSTRUMENTATION TOWER

M FT FT
299 200
264 186
224 173
141 142
92 92
52 52
21 21
2 2

W TH TH TH TH
981 966 935 462
302 302
100

W: WIND DIRECTION WAV-12
SPEED WAA-12
T: TEMPERATURE Pt-100
H: HUMIDITY HMP-14U

W, T, H

PRINTER TERMINAL AT THE AIRPORT

PRINTERS
TERMINAL
SECONDARY PRINT TERMINAL

CASSETTE STORAGE SERIAL I/F SERIAL I/F
CENTRAL PROCESSING UNIT WITH 5 KB PROGRAM MEMORY AND 4 KB R/W MEMORY
DIGITAL I/F ANALOG I/F
TRANSIENT PROTECTION

DD 4119
Midas 200 system message examples

In printout, first number is message code followed by series of seven numbers indicating date and time.

1 2421655 219/22 231/24 236/26 242/27
3 2421655 01 02 01 02

Message type 8: 1) Wind direction and speed averages. 2) Wind direction and speed maximum - minimum values. 3) Wind shear magnitudes.

4 2411030 21,8 21,4 21,1 20,5 20,2 19,7 19,6 19,4
5 2411030 49 46 46 48

Message type 6: 4) Temperature values. 5) Humidity values.

23 00 03 06 09 12 15 18 21 24 27 30 33 36 00 10 20 30 40 50
PROGRESS AND PROBLEMS IN THE AUTOMATION OF OBSERVATIONS

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ABSTRACT

The National Weather Service, in concert with two other government agencies, is planning to procure totally automatic weather stations reporting almost all parameters currently observed and disseminated by humans. In replacing manual with automatic observations, no insurmountable technical problems exist. We have sensors in use or well into development to transduce pressure; wind speed; direction; temperature; humidity; cloud base height; and the presence of rain, hail, snow, fog, haze, freezing rain, and thunderstorms. We also have in the microcomputer, the means to process signals from these transducers inexpensively in real time to derive needed products and generate messages and displays in a variety of formats for both local and distant use. However, we do have a number of significant problems to solve. For example, it is tempting, but very inefficient and expensive, to require that automatic observations duplicate those of the human observer. Likewise, it is proving difficult to automate the data quality control functions provided by humans.

INTRODUCTION

In the most general sense, man has been observing the weather for longer than the span of recorded history. However, only for the past few centuries has he both possessed and used instruments to measure some atmospheric variables systematically and periodically. Furthermore, we still rely upon the unaided human to describe other variables as well as to read instruments and disseminate his observation.

This paper addresses the question of total automation—sensing, processing, and disseminating directly to the user complete synoptic and aviation observations without human intervention. Included are not only the historically objective measurements of pressure, temperature, humidity, wind speed and direction, and precipitation amount and the more modern but equally objective measurements of cloud base height and extinction coefficient; but also the subjective observations of obstruction to visibility, cloud amount, the presence of thunderstorms, freezing rain and others. We are not confined by either cost or technology to require a human to read dials or numeric displays and to format and transmit a message. Digital-to-voice devices allow the direct dissemination of observations by radio or telephone. The computer facilitates message composition and transmission to nearby displays and on the conventional meteorological data communication channels.

We have experimented with total automation (2,4,6)*. Other equipments, incorporating many features of total automation, are either under development or have found limited use in the observation network in the United States. We are planning total automation on a demonstration scale for the mid-80's.

* Indicates references
Before discussing details, some generalities deserve mention.

1. The mechanics of total automation has proved to be relatively easy and non-controversial when a variable has a history of being derived objectively, either by direct measurement alone or by direct measurement and subsequent "processing" with tables or special purpose slide rules or standardized procedures. Conversely, subjective observational procedures have been difficult to automate.

2. Eliminating the human does much more than tax the ingenuity of scientists and engineers tasked with sensor development. The observer injects a large measure of data quality control and usually can smoothly circumvent malfunctioning equipment.

3. At least in the United States, the market for meteorological equipment is too small to support an industry. Automation at any level depends upon fallout from other markets. We are masochistic, awaiting with pleasure coming developments of technology while still suffering the pains of having invested in past and now obsolescent technologies. To a certain extent, we can protect ourselves by a wise choice of technology, second-sourcing components, and by developing non-proprietary designs. We are not always successful in doing this.

4. It is convenient to regard a totally automatic weather station as consisting of sensors, a processor, and output devices. It is important to recognize that costs are not uniformly distributed among these three subsystems. For a minimal automated station, sensors cost about U.S. $100,000, processor hardware about U.S. $10,000, and output devices about another U.S. $10,000. Installation costs can easily run to U.S. $10,000. Initial microcomputer software development costs at least U.S. $100,000, but is amortized over the number of stations installed. But we must add to these figures any additional software development required for specific installations and the cost of both hardware and software maintenance over the life of the equipment.

**Problems and Progress**

**Sensors**

As noted above, pressure, temperature, humidity, wind speed and direction, and precipitation amount have a long history of objective measurement. For these variables, we have a reasonable selection of instruments and a reasonably well defined processing procedure to adapt for totally automatic weather stations. However, one may have difficulty compromising desired accuracy, cost, and reliability. We view our most pressing sensor needs as a ceilometer, and extinction coefficient sensor, and an instrument to determine the type of obscuration to visibility.

We have had fixed beam and rotating beam ceilometers for many years. They have proved expensive to maintain and difficult to reproduce at an acceptable cost. It does not require very profound analysis to show that the operating principle of the rotating or fixed beam ceilometer is fundamentally disadvantageous in contrast with the laser radar. Accordingly, all of our current interest is focussed upon monostatic laser ceilometers. Currently in the United States, three companies are active in designing and fabricating prototype laser ceilometers capable of measuring cloud base heights to 3000 meters or more at least once each minute.
We have years of largely satisfactory experience with the transmissometer as an extinction coefficient sensor providing input to runway visual range computations. Like the ceilometer, we find it difficult to reproduce at an acceptable cost. Furthermore, its operating principle favors accuracy at low visibilities at the expense of accuracy at high visibilities. Because of a critical transition from visual to instrument flight rules at 3 miles visibility and a requirement to report visibilities at and below 7 miles, we are actively investigating aerosol scatter sensors for total automation. Backscatter sensors exhibit strong dependencies upon both aerosol and hydrometeor type and extinction coefficient (3). Forward scatter (20 to 50 degrees) sensors exhibit a response almost uniquely dependent upon extinction coefficient (2, 5, 9).

Unlike cloud base height and extinction coefficient, no sensor for distinguishing among hydrometeors enjoys a history of use in an observational network. We are developing such a sensor. Its operation depends upon the interaction of hydrometeors with a collimated and coherent helium-neon laser beam. We have demonstrated the ability to distinguish between rain, snow, and fog (7, 8). With some modifications, rainfall and hail size distributions, rainfall rate, and possibly snowfall rate measurements and distinction among hail, rain, snow rain mixed with snow, fog, and rain mixed with fog will be attainable.

Processors

It is difficult for me to conceive of total automation without a computer. While the task can be done with a minicomputer, the development and availability of the microprocessor makes automation much easier. Total automation requires execution in real time. Some of the processing either required or desired is complex and time consuming. The microprocessor allows distributed processing at a very small increase in cost. Thus one can remove the constraint of time in part by dedicating a microprocessor to completing a complex task and then passing the results along to another processor.

However, any computer is merely an opportunity to shift most of the burden of design from hardware to software. It is not an opportunity to neglect, defer, or delegate design. Too many times I've heard "Let the software people take care of it.", "We'll write something quick and dirty to get the software going soon and do it right later.", "Don't worry, we'll document the software when it's done.", and "Test it? But it works!". I'm not saying these attitudes and problems are unique to software. But one should recognize that the processing needed for total automation can be orders of magnitude more complex than that feasible in hardware. Two very important software design problems, algorithms and data quality control, are discussed below.

For a variety of reasons, data processing algorithms in total automation tend to be a translation of procedures written for human observers into a computer language. When these procedures are unambiguous and objective and already involved the reading of an instrument by an observer, writing the algorithm is neither a difficult nor controversial job. However, when we rely upon the human to sense and to interpret subjectively, difficulties arise. There are at least three ways to solve the problem. First, one can expend resources to develop and evaluate algorithms whose output satisfactorily approximates that of the human. These solutions tend to be ad hoc, arbitrary, and characterized by empirical constants. Second, one can redefine the procedures to eliminate the difficulties. This usually results in a different observation. Third, one can simply decline to produce an element of an observation. This accommodates the case of having neither a sensor nor a means of combining sensor outputs to measure the atmospheric variable in question. Visibility is a good example. The human usually determines prevailing visibility, defined as "the greatest visibility equalled or exceeded throughout at least half the horizon circle which need not necessarily be continuous." We have adopted the first solution with input from three widely spaced extinction coefficient sensors. We have also adopted the second solution by using the output of a single sensor to compute "sensor equivalent visibility" with the equation for runway visibility. In the case of visibility, we cannot opt for the third solution.
The question of automating data quality control reduces to answering the following two questions. Is the hardware (sensors, telemetry, and processor) functioning properly? Are the output data of acceptable accuracy?

We have the tools to answer the first question directly. A remote data acquisition module (consisting of an analog multiplexer, analog-to-digital converter, and a device to serially transmit the converted data) allows rapid transmission of both meteorological data and sensor status information to the processor. Failure of the power mains at the sensor site, of DC power supplies in the sensors, of aspirators, etc. unequivocally indicate sensor failure. Injecting a signal of known magnitude into a multiplexer channel and comparing the value received with the expected value is a valuable check on the remote data acquisition equipment, the telemetry channel, and the processor itself. As a side benefit, acquiring and transmitting sensor status information opens many possibilities for the automated tracking of sensor subsystem reliability and the concurrent refinement of periodic maintenance schedules and more timely and efficient repair.

The question of output data accuracy is much more difficult to answer. In general, one should know the content of the sensor inputs to the processor—meteorological variability, sensor bias, and sensor zero mean error or noise—and how these inputs propagate through the processor. When all this information is available, it should be used directly to estimate the accuracy of the output data. However, it usually is not, and the input and/or output data itself must be used to estimate output data accuracy. To accomplish this, several techniques are available.

1. An oversampled time series of input data can be curve fitted and the residual variance used as an estimator of the accuracy of the mean or any other similar estimator obtained from the fitted curve. This technique can also be used to edit or reject spurious data points (1). While addressing the presence of meteorological variability and sensor noise, it does not address bias. It is superior to examining each datum as it is received and testing each for plausibility.

2. Systematic error or bias can be addressed by:
   a. Testing for physical or meteorological consistency among the output data or intermediate quantities derived during the processing. This should be done keeping the variability and noise estimates formed in (1) above in mind. As a simple example, dewpoint temperature should not significantly exceed ambient temperature.
   b. Using redundant sensors, but avoiding the incest associated with the use of duplicate but identical sensors.
   c. Implementing periodic field calibration of sensors.
   d. Investing the resources in sensor design and evaluation to obtain tested and proven reliability.
   e. Examining long term statistics and comparing them with similar information from adjacent and climatologically similar stations in the network.
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A FIELD-PROVEN METEOROLOGICAL OBSERVATION SYSTEM
FOR MEDIUM SIZE AIRPORTS

K. Luukkonen, Vaisala Oy

An economic requirement for uninterrupted and undelayed operation of scheduled air transportation even in rapidly changing weather conditions has increased the workload of weather observers at airports. This appears as demand for more frequent and accurate measuring of weather parameters, increasing work with data conversion and reduction calculations and data distribution leaving less time for data verification and general follow-up of weather conditions.

Recent development in sensors, data processing and display equipment has enabled design of systems allowing the observer to maintain reliable and fast supply of weather data in conditions referred above.

The meteorological observation system for medium size airports has been developed by Vaisala Oy in co-operation with aviation authorities. Several systems have been installed and taken into operational use in Finland during past two years.

A description of general system design approach, standard and optional sensor configuration, data processing with operational aspects and principles of data distribution are given in this paper.

1. Introduction

At the beginning of 1978 a decision was made at The Finnish Meteorological Institute to start furnishing of medium size airports in Finland with automatic observation systems. Operational experience of two years with large automatic observation system at Helsinki-Vantaa airport had proved the benefits of automation and formed a good basis for design requirements of new system for smaller airports. These one-runway airports are mostly used for domestic passenger traffic, up to 350 000 passengers and 30 000 operations per year. At these airports meteorological observations are made continuously, but during night-time with reduced personnel.

2. General system design

Sensors and hardware modules

The hardware block diagram of the basic observation system, MIDAS 310, is shown in Figure 1.

The system can be divided in three main sections:

* sensors
* meteo instrumentation
* operator's equipment and data distribution system
Figure 1. MIDAS 310 block diagram
The sensors for wind speed and direction, air temperature and humidity and ground temperature are connected via airport cabling to the cable terminator. The transmitters of the RVR-system are connected to the RVR-computers. The signals from the pressure sensor, cable terminator and the RVR-computers are connected to the sensor interfaces in MIDAS 310 Central Unit.

The MIDAS 310 Central Unit consists of microcomputer modules developed by Vaisala for automatic weather stations. The main functional modules of the MIDAS 310 Central Unit are:

* DM 14 microcomputer
* sensor interfaces
* character generator
* power supply
* cabinet

The microcomputer contains a program for controlling all functions of the system. The character generator connects to the CCTV-network of the airport and provides the video signal for monitors which are normally installed in meteo and the control tower.

Separate displays for wind information (WAD 13) are normally located in meteo, the control tower and the rescue center. The operator console, normally printer terminal or CRT-terminal connects to the central unit.

Installation requirements

The sensor locations are selected individually according to the local circumstances. The operator terminal can be located in any place at airport. Video monitors can be located freely within airport area.

The system operates on 110/220 VAC. Central unit, sensors and sensor electronics have battery backup power for 24 hour operation.

3. System functions

Data acquisition

The system utilizes sensor data, internally generated data and manually entered data as follows:

* The basic sensors are measured automatically at selectable intervals
* Data from manual observations (e.g. clouds, visibility) are entered from the operator's terminal
* Automatic data quality control, conversion to meteorological units and storage to system memory
* Complete sensor control including error recognition, alarm printout, and sensor activation-deactivation commands

* Automatic sensor data can be edited from operator's terminal before dissemination

Computed parameters

The system performs the following computations:

* Mean wind speed (10 minute), updated every 2 minutes, and corresponding minimum and maximum speeds

* Mean wind direction (10 minute), updated every 2 minutes, and corresponding direction extremes

* QNH, QFE and QFF, computed from station level, air temperature and pressure

* Dew point, calculated from air temperature and humidity

* Transfer level (TRL), determined from QNH value

Significant change detection

The following features are realized in the system:

* The system automatically alerts the operator when significant change in weather parameters are detected

* Programmable alert limits and conditions for all significant sensors and computed values

Message generation and distribution

MIDAS 310 automatically generates standard METREP message at preset minute at 30 or 60 minute intervals:

* Messages are printed or displayed on operator terminal for acceptance

* Distribution to the CCTV network only by operator command after acceptance

* SPECIAL message can be initiated at any time

* Manually entered data automatically included to the messages

* Message format includes user fields for special messages and remarks

* All messages recorded on teleprinter (standard) and magnetic tape (option)
Operator commands

The operator has the following basic commands for controlling of the system operation:

* Set METREP generation time
* Enter data to message buffer
* Produce SPECIAL message
* Transmit message to the CCTV network
* Enter alert conditions and limits
* List system parameters
* Select automatic/manual sensor input

4. Optional features

Sensors:

Large number of additional analog or digital sensors can be connected to the basic system.

Remote sensor sites:

Large airports can utilize remote measuring sites equipped with Vaisala MILOS-type weather stations. MILOS is a very low power weather station having fixed set of 9 sensors. These kind of remote stations are connected to MIDAS 310 via telephone lines or radio links. The block diagrams of Figure 2, shows one possible solution for a multipoint observation system.

Figure 2. The meteorological observation and data distribution system with two remote measuring stations.
Telecommunication

MIDAS 310 provides hardware and software for operation in telecommunication network. The system can be interrogated remotely via telephone or telex lines.

5. Operational experience

Totally four MIDAS 310 type systems have been installed at four Finnish airports since January 1979. The systems have proved to be very reliable, have decreased the workload of the observers, have increased data distribution speed and have decreased error risk in observation work.

6. Conclusions

The system design of MIDAS 310 system has proved to fulfill the requirements set for the system. The main objectives of the automation have been achieved. The amount of meteorological data has increased without increasing of the number of personnel. The amount of manual work has decreased. The reliability of observations has increased, and errors in conversions and reduction calculations have disappeared.

The future trend in airport observations seems to be multipoint observation network at the airport area. MIDAS system has been designed for this concept and has also facilities for connection to integrated observation network.
INTTEGRATED AUTOMATIC SYSTEMS FOR ACQUISITION, PROCESSING, DISSEMINATION/DISPLAY 
AND DOCUMENTATION OF METEOROLOGICAL DATA AT CIVIL AERODROMES IN SWEDEN

Ari Gudmundsson
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1. Introduction

About ten years ago the first automatic systems for the assessment of runway visual range (RVR) were introduced at Swedish aerodromes. Small computers were used for the calculation and for the display of RVR-values on closed circuit television (CCTV) integrated with other information needed in ATS-units for take-off and landing operations. Information on runway condition and navigational aids as well as meteorological information were fed into the processor from a keyboard terminal in the meteorological station.

Changes in the ATS organization towards concentration of terminal control responsibility into a small number of control centres, located at the largest aerodromes, has made it necessary to supply these centers with real time information on landing and take-off conditions at all aerodromes for which they are responsible. To meet this requirement at Gothenburg/Landvetter and Stockholm/Arlanda new automatic systems were taken into operational use in 1977 and 1979, respectively. The systems are designed and put into operation by the Swedish company ASEA in cooperation with the Swedish Board of Civil Aviation and the Swedish Meteorological and Hydrological Institute (SMHI).

At smaller aerodromes the meteorological station is normally integrated with the aerodrome control (ADC) or the aerodrome flight information service (AFIS). To reduce the workload of these ATS units the use of a semiautomatic system for meteorological observations and reports have been tested at Jönköping aerodrome. The prototype system is designed by SMHI in cooperation with the Swedish Board of Civil Aviation.

2. GOTHENBURG/Landvetter MET/ATS INFORMATION SYSTEM

2.1 Principal functions

The principal functions of this system are to

. collect data from meteorological sensors

. communicate with data terminals and CCTV systems at the aerodromes concerned

. process data collected from sensors and data terminals for adequate display in ATS and MET units

. log data for system control, investigations and research purposes.
Processing of data for dissemination beyond the aerodrome in METAR and SYNOP code forms is not included in the system. These reports are prepared and transmitted manually by the observer using relevant outputs from the automatic system, such as average wind direction and speed, maximum wind speed, temperature, dew point temperature, QNH and QFF.

2.2 Principal system design

Figure 1 shows the following principal parts of the system:

- Central processing and communication units
- Sensors, data terminals, digital displays and CCTV monitors connected to these units.

Attachment 1 gives a detailed block diagram showing the different components of the Meteorological Transducer System (MTS), including the back-up system of analog recorders receiving signals from the sensors independent of the central processing units.

Figure 2 shows the locations of the meteorological sensors as follows:

- Two rotating cup anemometers near the touch down zones of the runway for measurement of wind speed and direction (S/D).
- Three ASEA QL 1250 systems for the assessment of runway visual range (RVR) and meteorological visibility for the touch down zones and the centre of the runway.
- A set of sensors for air temperature and relative humidity near the centre of the runway.
- A precision aneroid barometer placed in the computer room in the ATS building. As the computer room is airconditioned the aneroid is connected by a noncompressible plastic tube to a room not influenced by artificial pressure variations.
- Two ASEA QL 1211 ceilometers located at the ILS middle markers in the approach area. They may be connected to the processing units but the cloud signals are at present only displayed on analog recorders.
2.3 **Processing, display and logging of data**

As the processing within the RVR-system, including the meteorological visibility, will be described in another contribution to the conference, the following description will be limited to processing of wind, temperature, humidity and pressure information together with information received from data terminals.

a) Wind

Wind vector calculations are made every 2 seconds. Every 20 seconds (this is an adjustable system parameter) the following information is displayed and updated with respect to the reporting scale.
b) Temperature

Actual values as well as two earlier values (10, 20, 30, 40, 50 or 60 minutes ago) as chosen by an operator are displayed and updated every minute with respect to the reporting scale.

c) Humidity

Dew point temperature is calculated. The actual values of relative humidity and dew point temperature as well as earlier values are displayed and updated according to the same principles as for temperature.

d) Pressure

QFE, QNH and QFF values are calculated. Actual values as well as earlier values are displayed and updated according to the same principles as for temperature and humidity. Furthermore the QFE value three hours ago is updated in the same way.

e) CCTV displays

The wind, temperature, humidity, pressure, RVR and visibility values together with information fed into the system from data terminals are edited for display on CCTV monitors.

Figure 3 shows an example of a manually updated MET REPORT (left) and automatically updated information (right) primarily for use by MET personnel.

Figure 4 shows an example of automatically updated wind, RVR and pressure information (right) primarily for use by ATS personnel. MET REPORT is normally display to the left. Line 18 is used for aero-drome forecast (TAF) and line 20 for system information. The last four lines (21-24) are used for information on runway condition and navigational aids.

f) Data logging

The information displayed on the CCTV monitors is logged on a magnetic tape recorder as soon as a new MET REPORT or SPECIAL is issued for transmission on the Automatic Terminal Information Service (ATIS). The same recorder also logs for research purposes all information collected from the meteorological sensors.

For the system control a printer with a key-board is used. The printer is also used as a back-up for the magnetic tape recording of information displayed on CCTV monitors.
3. Prototype semi-automatic observation system at Jönköping aerodrome

3.1 Principal functions

The system is designed for use during short test periods in spring 1980.

Its principal functions are to

- collect data from sensors for wind, temperature, humidity and pressure
- process data collected from sensors or fed into the system from a keyboard in the aerodrome control tower. The aim of this function is the editing, display and recording of all information needed for take-off and landing operations as well as for dissemination beyond the aerodrome
- transmit reports in METAR and SYNOP code forms to the WMO regional telecommunication hub in Norrköping. During the test periods this function was limited to local printer and magnetic tape recording.

| 1 | Jönköping | 1 | 1979-04-02 | 11:32 |
| 2 | RWY 01 | MET REPORT 1120 | RWY MEAN10 MEAN02 VFR VFR MAX/MMN COMP |
| 3 | 350/25 VPS 350-09D MAX 38 NNM 10 | 101 080/18 060/20 340-09D 30/07 -15/R11 |
| 4 | VIS 1000 MET | 119 080/15 050/18 020-070 28/09 +15/L09 |
| 5 | MW 1600 M | |
| 6 | EKLYN | |
| 7 | 5/2 SSW FT RAG | |
| 8 | 7/3 NW 2000 FT | |
| 9 | T +5 | DP +7 |
| 10 | QNH 1008+6 | TL 40 | IT -4.8 | DP -6.6 | OFF 1010:1 |
| 11 | SEV TURB OGS IN APCH | I | MAX -4.8 | RH 85 | TEND -0.9 |
| 12 | | | | | | |
| 13 | | | | | | |
| 14 | | | | | | |
| 15 | | | | | | |
| 16 | METAR ESJ 021120 | |
| 17 | 050828/33 1000 R1600 858N59 5GB88 7GBQ20 M05/MB7 1008 VIS TO NW 5000N |
| 18 | SYNOP 02243 021100 | |
| 19 | 05714 10866 82455 59290 57609 85905 87920 00783 | |

Figure 5

3.2 Operational functions

The system configurations will be described in another contribution to the conference. The following descriptions and comments will therefore be limited to its operational functions.

Figure 5 shows an example of a display on the data terminal in the aerodrome control tower. Its principal disposition is as follows

- Upper right section contains automatically updated information from meteorological sensors
- Upper left section is disposed for the editing and display of MET REPORT and SPECIAL needed for take-off and landing operations
- Four lines (16-19) are used for the editing and display of METAR and SYNOP
Line 20 is reserved for system control information.

The lowest four lines are open for free editing and display of information by simple keyboard operations, the terminal may be ordered into different functional modes, such as

- MET REPORT (editing mode)
- METAR (editing mode)
- SYNOP (editing mode)
- SPECIAL (editing mode)
- FREE EDITING (Line 21-24)
- BLOCKING (of faulty sensor information)
- SEND (initiates recording and transmission of reports and puts the data terminal into display mode)

The editing of reports is made easier by use of special keyboard functions, such as CAVOK, and by automatic editing of information from sensors into the message. The preparation of a new report may be made through changes in the previous report.

3.3 Test result

The main purpose of the test was to evaluate the semi-automatic system as a method of operation.

The test seems to indicate that

- the operators consider the semi-automatic system as effective and easy to accept, at least after some minor improvements of the system
- the time savings are small but they are expected to result in less missing and delayed reports compared to the traditional method of operation, at least when the meteorological station is integrated with an ATS unit.
- the introduction of the system requires only few days of personnel training if the personnel is familiar with the traditional method of operation.

During the test periods the operators found the system reliable. The minor disturbances in some of the functions during the first period (one week) were eliminated before the succeeding period.
A micro computer controlled system for acquisition, processing, displaying, dissemination and documentation of meteorological information at airports is developed of the Swedish Meteorological and Hydrological Institute in cooperation with the Swedish Board of Civil Aviation.

This prototype system has been involved in a test activity at Jönköping Airport during the spring 1980. The main purpose of the test was to evaluate the test equipment from an operational point of view, when the equipment is integrated in the Air Traffic Service.

The system is mainly built up with standard components from an automatic weather station, completed with extended memories, CRT display, printer and special software, and during the test period the equipment has been connected to the existing wind measurement system at the airport and equipped with separate sensors for temperature, humidity and pressure. It is also possible to add sensors and software for cloud base height and RVR measurements to the system.

The system will be described from a technical point of view in this paper, the operational functions and results from the test period will be given in a separate paper.

2. System description

2.1 Sensors and sensor interfaces.

Wind: In the existing wind measurement system (equipped with two SMHI sensors for wind speed and direction, see [1]) the SAWO terminal is connected in parallel with the pointer instruments for wind speed and direction.

Air temperature: A ROEMOUNT platinum resistor thermometer (Pt-100) connected to a standard interface card with current generator and amplifier.

Humidity: LAMRECHT hair hygrometer type 809L 100.

Pressure: SETRA quartz capsule sensor integrated with interface amplifier.

Sensors like ceilometers and RVR equipment can be added to the system.
Figure 1

SAWO Block Diagram

![Block Diagram of SAWO System](image)

Figure 2

SAWO Program Description

![Program Flowchart](image)

Legend:
- **Data Acquisition and Calculating**
- **Presentation**
- **System Check**
- **Program Function**
- **Data Field**
- **Data Flow**
- **I/O Channel**
- **Sensor**
2.2 Terminal equipment

The terminal is an extended automatic weather station, type ASEA TAFS 8001, see \[2\]. This terminal is built in a modular system according to the "European Standard System" and it is easy to add modules to the system. See figure 1.

**Analog to digital converter/multiplexer:**
16 channel input ± 4095 mV
13 bit binary output

**Central processing unit:**
Micro processor INTEL 8080

**Memories:**
39 kbyte PROM
8 kbyte RAM

**Communication interface:**
300-9600 bps programmable, full modem control according to CCITT V24/EIA RS 232

2.3 Peripherals

**Display:** ALFASKOP 3550
4800 bps

**Printer:** Teletype 43
300 bps

**Tape recorder:** MEMODYNE 146
300 bps

**Telephone line:** 600 bps

The remote display and printer is connected to the SAWO terminal with base band modems.

3. Program description  

See figure 2.

The SAWO software is developed in high level language and the program consists of a number of parallel processes controlled by a small operating system.

3.1 Data acquisition and calculating

Program modules for following functions is used:

**Wind**
- Sampling interval: 2 s
- Wind vector calculations every 2 seconds
- Vector averaging every 20 seconds for:
  - Mean wind direction and speed during the last 10 min
  - Mean wind direction and speed during the last 2 min
  - Mean of runway components during the last 2 min
- Min and max wind speed during the last 10 min
- Extreme values of wind direction during the last 10 min

**Air temperature**
- Sampling interval: 6 s
- Arithmetic mean for 60 s
- Min and max temperature for 12 and 24 hours
Relative Humidity
- Sampling interval: 6 s
- Arithmetic mean for 60 s

Pressure
- Sampling interval: 6 s
- Arithmetic mean for 60 s
- Difference to value 3 hours ago
- Trend for the latest 3 hours expressed by its SYNOP code
- Determination of QFE, QNH and QFF

Dewpoint
- Calculated every 60 s

3.2 Presentation

The program function MEASUREMENT VALUES and TIME will renew the displayed information in the following way:
Every 20 seconds: WIND
Every 60 seconds: TIME
- TEMPERATURE
- HUMIDITY
- QFE
- QFF
- QNH
- 3 hour pressure difference
- Pressure tendency ("a" in SYNOP code)

Through the program function EDITING it is possible to execute following program functions:
- TIME; sets the real time clock and writes new time at the display
- FREE TEXT; makes it possible to write into the free text area at the display
- MET REP, SPECIAL, METAR and SYNOP;
  . the old telegram renewed with new coded information from the sensors is written in respective editing field
  . confirmation of the sensor data with possibility to change the data after exclusion of defective sensor
  . completion of the telegram with man-made observations
  . confirmation of all the telegram
  . sending; a new METREPORT/SPECIAL is written at the display and logged at the printer, new METAR and SYNOP is written in edited form with heading at the display and logged at printer and tape.
- EXCLUSION/RECOVERING;
  . possibility to exclude data from a sensor
  . invalidate the exclusion function
  . recovery of alarm from peripheral equipment
- ALARM; printout of alarm at the display, alarm is given of:
  . excluded sensor
  . malfunction of taperecorder and printer
  . full tape cassette

3.3 System check

The program function MONITORING includes
- system monitoring with
  . simple memory test every hour
  . continuous ADC test
  . counter for working hours from program restart
  . check of the A/D conversion time
- sensor monitoring including
  - limit check
  - exclusion
- monitoring of peripherals including
  - printer check
  - tape recorder check
  - full tape cassette

The SAWO system is also remote monitored via the switched telephone network by the automatic data acquisition central at SMHI, Norrköping. Every hour check parameters and sensor data is transmitted for monitoring and storage.

4. Test result

The test results from the operational point of view is given in a paper by Ari Gudmundsson at this conference [7]. From a technical point of view following summary can be made:

- the SAWO system has come up to expectations
- the program development was easy to do because that the program system was modular from the beginning
- it was easy to make modifications in the program system since the software was written in high level language (PL/M)
- if the system will be expanded with both additional sensors and additional communication routines, it is necessary to use a more powerful micro processor, e.g. INTEL 8086.

The SAWO software can easily be converted for this purpose.

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Introduction

Automated surface weather observations offer the advantage of objectivity, uniformity, timeliness and tirelessness. They create the opportunity to divert limited staffing to more creative and efficient assignments. Once initial investments have been made in the development of automated observing techniques and systems, costs decrease rapidly since personnel expenses can be reduced.

This paper reviews the role of the National Weather Service in modern automation of weather observations. Included are the developments of runway visual range and AUTOB, the latter being the first totally automated aviation weather observation system in the United States. Of particular emphasis in this paper is the evolution of a joint National Weather Service (NWS)/Federal Aviation Administration (FAA) program to automate cloud and visibility observations. An important output of this process is the growing awareness of the level of detail an automated weather observation should include.

Encouraged by the acceptance of first automation efforts, new overtures in this field are planned. These will be discussed along with status of operational systems and some automation limitations.

History

At about 1000 airports and other locations throughout the United States, large numbers of observers estimate and measure the weather 24 hours each day, 7 days a week. Most standard weather instruments are simple to read, and the information is readily transferred to the user. More difficult, however, is the requirement that the observers make largely subjective observations of visibility, cloud height, and sky cover. This personal impression must then be reduced to codes and symbols and transmitted to a remote user. Weather observations are standardized by a comprehensive set of rules at both the national and international level [12].

Automatic observations of simple meteorological parameters is not new. The first automation of observations was done by the Weather Bureau (now the National Weather Service) in 1946 when the NWS set up three automatic weather stations along the Florida Keys to detect approaching hurricanes. Stone [18] describes in detail the NWS effort to automate the objective portion of observations, including Automatic Meteorological Observing System (AMOS) and Remote Automatic Meteorological Observing System (RAMOS).
However, the movement toward fully objective automatic weather observations has only received increased emphasis in recent years. The World Meteorological Organization, for example has dedicated at least two international technical conferences exclusively to automation [20,21]. Efforts have been made to solve the problems of objective observations combining clouds and visibility, in particular the problems of approach light contact height and slant visual range [5,6]. Perhaps the most widely used automated techniques developed to date are those for runway visibility (RVV) and runway visual range (RVR) [7].

Visibility, as part of this aviation surface weather observation, is defined as prevailing visibility: "The greatest visibility equaled or exceeded throughout at least half the horizon circle, which need not necessarily be continuous" [12]. Aviation also required more specific information that identified location on a landing field and visual target. To satisfy these needs, automated techniques for determining RVV and RVR were developed. The two methods are derived from Allard's and Koschmieder's laws [11]. Although RVV and RVR can be sensory observations, they are usually based on measurements made by a transmissometer, an attenuation visibility sensor. For an RVV or RVR measurement the instrument is located at the designated point of observation, usually near the touchdown point of a specified airfield runway.

RVV is defined as the visibility along an identified runway and is less frequently used than RVR. The observational technique is simple. Transmissometer measurements are indicated on direct-indicating meters or recorders. The observer determines the appropriate set of tables to use (depending on day/night and the distance between the transmissometer projector and detector) and derives RVV in miles. Tables are based on the equivalent human sighting of dark objects against the horizon sky during daylight and the sighting of a 25-candella light at night. Automated methods such as RVN provided tailored data to resolve specific problems. But techniques for automating the basic aviation surface weather observation were still needed.

In 1970, it was decided that a method to generate cloud and visibility observations would have to precede the successful implementation of an automated weather observation system. As a result, in 1972 a joint FAA/NWS program was established. This program was called Aviation Automatic Weather Observing System (AV-AWOS). The development of AV-AWOS observing techniques was assigned to the Observation Techniques Development and Test Branch of the NWS Test and Evaluation Division (T&ED). In 1975 this branch was also given the charter to concurrently develop AUTOB (Automated Observation), an automated aviation weather observation intended for limited service locations with little or no aviation terminal activity. The fruits of these efforts have been documented in two reports: AUTOB in [13] and AV-AWOS in [14]. At the present time, the AUTOB observation is used operationally at seven locations. The success of AV-AWOS has led to the establishment of a joint FAA/NWS/Department of Defense effort discussed later.

Development of an Automated Surface Observation

The Observation Techniques Development and Test Branch had several prior experiences to draw upon. The Branch Chief had participated in the development of RVR and had operated the short range forecast mesonet at Atlantic City [8]. The branch had recently developed the concept of sensor equivalent visibility (SEV) [4], and had shown it was possible to calibrate a visibility sensor to human visibility. In addition, a study for T&ED by Stanford Research Institute showed that it should be possible to assign a sequence of cloud heights into meteorologically significant cloud layers using various mathematical techniques [2]. Both the visibility and sky condition techniques would require a network of sensors. The number and placement of such sensors could only be determined by field tests.

The development and testing of the automated observing techniques for AUTOB and AV-AWOS included three basic principles:

1. The visibility and cloud-observing techniques would be developed independently of each other.

2. The two elements would be combined for special cases, such as surface-based obscurations to vision.
3. The sensors would have to be off-the-shelf or readily available engineering models. This required the modification of some sensors and the use of less than ideal equipment. Although the automated methods are idealized, their use is restricted by hardware and sensor limitations. In addition, AUTOB was constrained to use only one cloud sensor, one visibility sensor and limited data processing.

In 1973, a Testbed for Automated Observation (TAO) was established at NWS's Sterling Research and Development Center (SR&DC) adjacent to Dulles International Airport (IAD) in northern Virginia. The testbed consisted of two equilateral concentric triangles, with the sensors situated at the vertices—a smaller triangle, with each leg of design length 4.8 km (3 miles), for visibility sensors and a larger triangle, with each leg of design length 11.3 km (7 miles), for cloud sensors. A more detailed description of the network is given in [10] and [14].

Describing the state of the sky is one of the more difficult tasks for weather observers. An observer must scan the entire sky from horizon to horizon, identify the cloud layers, estimate the height of each layer and then determine the percentage of sky coverage: the amount of the sky which is covered by clouds up to and including that layer. The observer must also determine the amount of sky hidden by surface-based obscurations, and in some cases, the vertical visibility into the obscuring phenomena.

This task must be done despite the limitations to vision such as precipitation, air, light, and darkness. Frequently, the observer's view of the horizon is limited by physical obstructions typified by airport terminal and office buildings.

Our procedures to automate cloud observations rely upon a network of Rotating Beam Ceilometers or other vertically pointed cloud height indicators (CHI) whose cloud information can be digitized into a computer or microprocessor programmed to mathematically separate the cloud heights into meteorologically significant cloud layers. This method assumes that the natural motion of the cloud elements over the sensor allows the substitution of time averaging for the space averaging of the human observer. The final output is a description of the cloud height and sky cover in a format similar to the human observation.

In our current system design, the algorithm samples one to three ceilometers once every 30 seconds for 30 minutes, receiving from each scan the height (in feet) of a cloud element for each ceilometer. (Each detection of a cloud height is called a hit). This height information is binned to the nearest 100 feet (200 feet above 5000 feet), clustered for each ceilometer independently (using hierarchical clustering [2]) to five layers, and these layers then further combined using limits derived from our meteorological experience. If a multi-sensor network is used, the layers derived from each ceilometer are grouped into one unit and combined using the same meteorological limits as for a single ceilometer. Cloud amount is determined for each layer using the summation total of hits up to and including that layer. Ratios of summation total to total possible hits of .06 to .55 for SCT; .55 to .87 for BKN; and .87 for OVC are used for cloud amount. If the visibility is less than 1 7/8 miles, the cloud layer amount is modified using the obscuration program. Remarks appropriate to Column 13 of Form PMH 10A are prepared and special observations are generated as necessary [12]. On any observation, up to three cloud layers are reported in the standard aviation format. The entire cycle is repeated each minute.

Visibility is the most difficult of the subjective observation parameters to automate since it is the attempt to logically define a human's personal visual impressions. However, by using the technique of "sensor equivalent visibility" (SEV), developed by George and Lefkowitz [4], we have been able, by processing measurements from a network of sensors, to produce a substitute for human visibility.

SEV is defined as any equivalent of human visibility derived from instrumental measurements. In practice, the sensor from which SEV is derived almost always requires uniform visibility for an accurate calibration. Once a sensor is calibrated under uniform visibility conditions, it can then be used to determine visibility under nonuniform conditions. SEV and prevailing visibility (PV) [12] have different principles of observation. SEV is
based on sensor measurement of a small volume sample with extrapolation to overall areal visibility. PV, as determined by a human, relies on sensory information obtained over a relatively extensive area. SEV, based on a point sensor, usually has strongest relationships with PV during homogeneous conditions. However, there is sufficiently strong correlation in periods of nonuniform conditions to warrant substituting instrumental visibility for human visibility.

The processing strategies for using the SEV's from individual or multiple sensors to approximate human visibility under nonuniform visibility conditions were the subject of Aviation Automated Observation System (AV-AWOS) experiments [14]. The underlying assumption was that while a vast network of (point) visibility sensors would be needed to perfectly replicate the PV described by the human observer, a smaller network could give an adequate description. From the results of the AV-AWOS experiment, we have specified a sample averaging time of 10 minutes from each sensor and, for the general site configuration, a three sensor network with PV defined as the central value of this three sensor visibility network.

The AV-AWOS experiments also showed that there was close agreement, in most cases, among the output visibilities from each of the three sensor sites. As a result, the panel on Automatic Meteorological Observing Systems (PAMOS) has recommended that for an automated system the definition of PV be changed to: "That horizontal visibility near the earth's surface representative of the visibility conditions in the vicinity of the point of observation or measurement" [3], and that the current definition of PV be the method or procedure used by human observers to produce visibility observations.

Analysis of Automated vs. Human Observations

The human is a versatile observing tool but is situation limited. This limitation is very apparent in the measurement of visibility. When the visibility is good, the observer reports (for example) "I can see all objects within 8+ miles of my point of observation." But when the visibility is poor, the observer can only say, "I can see all objects within 1/4 mile of my point of observation, but I have no idea of the situation 1/2 mile away." The human has similar limitations in cloud observations.

In the automation of clouds and visibility, we have attempted to maintain the versatility of the observer while developing an observation that is area specific. That is, we have attempted to develop an observation that is not only valid at the point of observation but also over some specified area. Thus, when our automated observation reports a visibility of 8+ miles, it is claiming that within a 2-mile radius of the point of observation, in that particular area, the visibility has a clarity of 8+ miles. Likewise when it reports a visibility of 1/4 mile, it is again saying that within a 2-mile radius of the point of observation, the clarity is only 1/4 mile. The automated cloud observations are also area specific within about a 5-mile radius. These are nominal values based upon our experience at IAD and later at Patrick Henry International Airport (PHF), Newport News, Virginia. Of course, these area specific statements can only be made after individual site surveys and field tests for the proper number and placement of sensors.

Our results show that while an automated system is not as versatile as the human observer, it can overcome many limitations by being area specific. Moreover, the information flowing to the user from an automated observation should prove more responsive to most user needs, especially for providing pilots with general in-flight information in the vicinity of an airport.

The automated system is more responsive to weather changes (if they occur within the range of the sensor). The AV-AWOS system takes an observation once per minute - 1440 observations per day. AUTOB updates once every 20 minutes. Often the human may take only one observation per hour. One index of the responsiveness of a system is the number of "special" observations. A "special" observation is an observation mandated to be taken by Reference [12] when specific weather criteria are met. In the AV-AWOS observations, these "special" observations are taken and reported when needed throughout the hour. At typical manned weather stations, 30 to 60% of all special observations are taken at the regularly scheduled hourly observation. Besides better distribution of "special" observations throughout the hour, the AV-AWOS system also showed a three to five-fold increase in the
Reference [12] is a guide to human observations. It has limitations when applied blindly to automatic observations. Reference [12] has always been modified or filtered by human selectivity and judgment. However, automation has now given us the ability to test the sensitivity of various weather parameters and the appropriateness of Reference [12] rules. As an example, Reference [12] requires that a variable ceiling be reported if the ceiling varies by one or more reportable values (100 ft) during the time the ceiling height is being determined. Our early work [1] showed the standard deviation of the cloud heights of a uniform cloud layer was greater than 100 ft. In another test, we computed the persistence of Column 13 Remarks required by [12]; that is, remarks deemed operationally important to the air traffic controller, pilot or meteorologist. Of eleven cloud or visibility remarks tested, 80% were reported on two or less consecutive 1-minute observations. Thus, we designed our output remarks to have the persistence and precision to be operationally significant. To do this in our algorithm development, the spirit of [12] was maintained but occasionally the requirements had to be relaxed to accommodate the greater sensitivity of an automatic measuring system.

Another strength of an automated observing system lies in the ability to place sensors in climatologically preferred locations. Many airports have preferred directions from which low clouds or visibility are advected. Early warning sensors can now be placed outside the airport to monitor the approach of these conditions.

There are, of course, limitations to an automated observing system. Most of these limitations stem from the measurement technique. In automation, it is assumed that the natural motion of the weather elements over or through some sensor path during a specified sampling period can be substituted for the space averaging of the human observer. The limitations to this observing method are described in [4] and [9].

One significant design limitation of the automated observation system was the requirement to maintain what the users are accustomed to receiving. There are over 1 million private pilots in the United States who receive weather briefings and understand the information currently given in the aviation weather observation. The automated observation had to meet this need. Did we succeed?

Objective comparisons of algorithm cloud height, amount, visibility vs. human reports are given in [13], [14] and [10]. Equally important is user assessment of automated systems. This assessment was made while the development model AV-AWOS underwent operational testing at PHF, during a four-month period in early 1978. In this development model, weather parameters observed, processed and transmitted by the AV-AWOS included cloud height and amount, visibility, precipitation (yes/no precipitation, thunderstorms, hail and freezing rain), sea level pressure, temperature, dewpoint, wind (speed, direction, gusts) altimeter setting, RVR and selected cloud and visibility remarks. The automated weather observation was transmitted via Service A (wire service), CRT displays, and by an automated voice response to a telephone dial-up and the VOR. Before this test, an assessment plan was prepared to test user reaction/acceptability of an automated observation. During the period of the test, nearly two-hundred questionnaires were returned by users of AV-AWOS data. Their responses showed that:

- 2% were bothered by an automated system (this was a measure of prejudice against the system).
- 82% felt AV-AWOS suitable with minor changes, while
- 41% felt the limitation in reporting the precipitation types was the system's least desirable feature. (AV-AWOS reported only "P" for precipitation occurrence; it could not distinguish between rain and snow).

With the general acceptance of AV-AWOS and the operational use of AUTOB, we feel the development stage of automation has firmly been established.
An Assessment of the Future

Based on the success of the developmental models of an automated observation system, the NWS, in conjunction with the FAA and the Department of Defense, is in the early stages of developing a Functional Requirement Document (FRD) for a Joint Automated Weather Observing System (JAWOS). In anticipation of this, during 1979, the T&ED of the NWS developed an assessment of the ability to automate each requirement levied by [12], both at present and during the next 3 to 5 years. This assessment [15] was based on knowledge of the state of current sensor availability and potential development and included areas where basic sensor development and research was believed to be necessary. There were several assumptions in this assessment:

- There is not at the present time, nor expected to be developed in the next 3 to 5 years, an instrument capable of quantitatively measuring the extent of partial obscuration, total obscuration or vertical visibility. Thus, inferring obscuration through indirect methods (visibility and precipitation), will remain the weakest element of the cloud observation.

- A Laser Weather Identifier (LWI) will be developed within the 3 to 5 years framework. This instrument deduces the type of hydrometeor passing through a collimated beam of laser light [17] and [19]. This instrument will be able to sense and report at least the following parameters: Rain, rainfall rate, snow, rain plus snow, rain plus fog and large hail.

- Other sensors (temperature, dewpoint, pressure, wind) are adequate but still need improvement.

- Certain elements (e.g., cloud type) are not likely to be automated.

- Assessment does not cover problems of maintenance at unattended stations.

A summary of the strengths and limitations of an Automated Weather Observing System by individual weather element is given in [16].

This study was based upon our evaluation of sensors available today and on the projection of sensor development during the next 3 to 5 years, and in the long term. Reference [15] and [16] are, of course, complimentary.

In conclusion, the development tests, especially AV–AWOS, and the operational use of AUTOB show that there is a great potential for automated weather observations. The charting of this development and use now lies in the capable hands of the JAWOS Committee.


ASSESSMENT OF RUNWAY VISUAL RANGE WITH THE AID OF TRANSMISSOMETERS USING VARIABLE BASELINE LENGTH (MULTIBASELINES).

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Introduction

Trials for the purpose of determining Runway Visual Range (RVR) with the aid of transmissometers using variable baseline length (multibaselines) have been carried out by the Swedish company ASEA since the early nineteen seventies. The intention was to test the possibility of applying the laser technique earlier used by the company for its ceilometer equipment, also for horizontal assessment of a meteorological quantity. It was also an idea, already at an early stage discussed with Swedish meteorologists, to determine RVR over a long distance beside the runway, a method which was looked upon as making possible a higher degree of representativity for the determination of this parameter. That idea could be realized, it was anticipated theoretically, by using a whole set of base lines for the measurement of the atmospheric transmission of light.

Studies in order to verify the theories were carried out during some years at both civil and military airports of Sweden. The results of the tests with experimental equipments were promising so the Board of Civil Aviation decided 1976 in co-operation with the experts of aviation meteorology of the Swedish Meteorological and Hydrological Institute (SMHI) to order a first system for operational purpose to the airport of Gothenburg/Landvetter which was then under construction. The system was to form part of the complete automatic observation system for the airport which was ordered simultaneously from the same company.

Description of the system and principles of operation

The system for RVR assessment that was installed in the autumn of 1978 at Landvetter airport got the designation QL 1250 and is called visibility meter as it has capacity to determine both RVR and meteorological visibility. It is made up by three laser transmissometers, two of them provided with background luminance meters, calculation and control units as well as displays and recorders. Data are presented with the aid of the MET/ATS system of the airport.

Each transmissometer has a tranceiver unit for the emission of light and for the reception of it from one of six reflectors. The optical unit of the tranceiver is movable horizontally and in that way its optical axis can be directed to a particular reflector by an optical direction selector. The reflectors are located at distances from 62,5 to 630 m and with small angles of 5 milliradians between the light beam lines from the tranceiver to resp reflectors (fig 1).
During periods of poor visibility the optical axis of the transmissometers is automatically directed from the most distant reflector (always used during good visibility) to the second most distant one etc, in that way scanning all reflectors necessary for the selection of a correct base line which can ensure that the signal is within the dynamic range of the signal detector. - It might be mentioned that a simplified system with only three reflectors can be used if the intensity of the edge line lights is less than 100 000 candelas.

If the system has to be used for Category III - operations, two additional reflectors are positioned at distances of 29 resp 42 m and if there is a wish to determine the meteorological visibility, this is possible with the use of another reflector as distant as 1300 m from the transceiver. - The transmissometers are positioned so as to be representative for the touchdown zones and the middle section of the runway of the airport, 03/21, at a distance of about 120 m from the runway centre line (normal positioning according to the recommendations of ICAO and WMO).

Calculation of RVR and meteorological visibility

The calculations of RVR and of meteorological visibility are based on the laws of Allard resp Koschmieder. That means that the RVR calculation takes into consideration data for the transmission of light measured by the transmissometer, light values of the high intensity lamps and for the background luminance. The edge line lights have a very high intensity with peak values varying between 150 000 and 250 000 candelas depending on voltage used and a value of 60 000 candelas is used when corrections for filter, ageing, contaminations etc have been introduced. RVR calculation can also be done for a reduction of the light intensity to 30%, 10% and 3% of the normal value if the ATS so wants.

- The centre line lights are comparatively weak (5-10 000 candelas) so therefore they are not used for the RVR-calculation (we don't have the normal configuration between the intensities of the two types of lights). For the measurement of the background luminance is used an instrument directed 5° above the horizon and with the luminance divided into 16 steps between 4 and 12 000 candela/m².
The calculation unit is a microcomputer with standard communication interface and a memory capacity of 16k 8 bit words (the capacity can be enlarged to 64k). The relation between transmission and background light, RWY light intensity and RVR data is stored as tables together with the programs. The calculation unit executes the calculations of the present RVR and transmits it further to the HET/ATS-system for presentation on the displays and monitors of the system. The configuration of the calculation unit, its connections with the instruments in the airfield and on the other side with the displays as well as recorders for transmission are shown in fig 2.

Comparative RVR-determinations, automatically and visually

In order to find out the connection between RVR-values determined automatically and visually, comparative studies were carried out during 1979 in both winterperiods, February-April and October-December. Altogether 338 observations were made during 24 study periods.

For most part of the time the visual observer was unfortunately placed in a slightly incorrect position not on the center line but about half the way to the edge line of the runway. However, it has been possible to compare results from the two methods also at these occasions taking into consideration the different intensity of the edge line lights obtained in that way. As it is easier to study and compare the results from series of observations with a correct position of the observer a compilation of these observations has been made and the result is given in fig 3. The diagram shows a rather good correlation between automatic and man made observations, particularly in the lower and more interesting range of RVR-values (fig 4).

As an example of the treatment of the individual series of observations can also be shown one of the longest and most interesting periods with 22 observations during two evening hours. There was a dense fog that evening and the comparison shows a very good correspondence between the two ways of RVR-assessment.
The evaluation of the study material was finished early this year and the results were looked upon as satisfactory. There was no intention to try to reach full correspondence between the values from the two different methods as they involve rather many diversities, like slightly different areas of observation, different persons for the visual observations etc. However, it was looked upon as valuable to find out if there is a reasonably good correlation between automatic and visual RVR-determinations. We also found such a degree of correlation and that was one the the parameters necessary for the approval of the automatic system to come into full operation which was issued last April. Some complementary studies are, however, also planned to be carried out during next winter season, among other things a comparison between automatically determined RVR-values and observations made by pilots just before departure in weathersituations of snow.
Fig. 4
A need for slant visual range (SVR) information has been stated by a number of ICAO Meetings during the past twenty years. At the Fifth Air Navigation Conference, (Montreal 1967), it was agreed that in the lower limits of Category I and in Categories II and III meteorological conditions there is a requirement to provide the pilot with slant visual range information prior to commencement of final approach thereby enabling him to assess whether he can expect to establish the necessary reference to a ground segment of visual aids, and whether this reference can be maintained for the completion of the approach and the touchdown on the runway. This requirement has been confirmed by the Ninth Air Navigation Conference (Montreal 1976).

It is of value for a pilot to know the visual conditions that he will encounter during the final part of the descent and during the flare manoeuvre. Probably the main advantage of a SVR system is its potential to improve the regularity of landings in all visibility conditions, without a reduction in the landing success rate. It would also provide more information on the current fog situation and conditions that occur in developing radiation fog. One example is shallow ground fog which is not detected by a conventional transmissometer until it has reached the light beam.

Studies and fog measurements made in several Member States have shown that, frequently, the density of deep fog increases with height, even though it may appear to be uniform along the ground. In those cases, SVR is likely to be less than RVR. It is not uncommon from a height of 30 metres in deep fog for SVR to be less than half RVR, when the MOR is between 300 and 600 metres. The most severe fog gradients seem to occur within this range of visibility.
A SVR definition, adequate enough for international recognition, has not yet been elaborated. The following definition has been suggested:

"Slant Visual Range is the distance to the farthest high intensity runway edge light or approach light, which a pilot will see from a height "H" above runway threshold elevation on the approach path. The pilot should see and continue to see a minimum ground segment equivalent to five light bars of the approach lights at 30 metres spacinga".

As it can be seen this definition involves both distance and height which, according to our opinion, is inexpedient, although we agree that in case the definition contains the word "distance" there must also be a height (or a point on the approach path) to which this distance refers. Furthermore we do not feel sure that it is advisable in the definition to include which lights should apply (it might for instance as well be the touchdown zone lights as the lights mentioned in the suggested definition).

The DRAFT ICAO Circular 113-AN/85 (Nov. 1979), CHAPTER 15 section 15.1.3 reads:

"The basic contents of slant visual range reports have not been decided, but they could indicate at what height the pilot should expect to make visual contact with the ground lighting system and to confirm that the visual segment will remain adequate to touchdown".

We are very much on a par with the contents of this section, and we are looking forward to being informed about the results of the next meeting of the ICAO Study Group on RVR and Runway-lighting as we think that this very group is a good forum for discussing a SVR definition.
PRINCIPLE.

The possibility of determining SVR is being investigated at Copenhagen airport. The system is shown diagrammatically in the figure above. It comprises a SVR instrument which has a light beam transmitter (2) and a backscattered light receiver (1) together with a background luminance monitor (4) which points in the same direction as the pilot looks when approaching the runway.

The system is located adjacent to the runway touchdown zone near the glide path origin and adjacent to a transmissometer (3).
PRINCIPLE (cont.).

The optical axes of the transmitter and receiver are parallel to the runway and elevated at the ILS glide path angle.

High intensity pulses of white light are emitted by the projector. A broad spectral light source is used because the reflectivity/extinction coefficient ratio is fairly constant for various sizes of scattering particles in the atmosphere in such light.

The light backscattered from sections of the projected beam at various distances arrives at the receiver at different times. A system of logic, started by a gate signal in the projector, controls electronic gates in the receiver and makes it possible to measure the backscatter from selected parts of the beam.

The output signals of the integrators are fed to a computer using a microprocessor. To this computer are also fed the luminance of the background and the intensities of the lighting system. By means of the computer the return signals are converted to represent the attenuation of light along the path of the projected beam.

COMPUTER.

The signals, backscattered from the different sections of the path, must be converted into extinction coefficient or transmittance. The relationship may be written: \( T = e^{-\delta d} \) (\( d = 200 \) m)

When calculating visibility where other than light sources are used as objects Koschmieder's law applies: \( \frac{VIS}{S} = \frac{d \cdot \Delta \phi}{L_a \cdot T} \) where, 

- \( I \) is transmission over \( d \), \( d \) is the distance over which \( T \) is based and \( \Delta \phi \) is the contrast threshold of the human eye (0.05).

When calculating the visual range for luminous objects Allard's law applies: \( E = \frac{T}{d_1^2} \cdot e^{-\delta d} \) where, 

- \( E \) is illumination (lux), \( I \) is luminance intensity of the light source (cd) in the direction of the observer, \( d \) is the distance from source to observer, \( \delta \) is extinction coefficient (1/m) and \( e \) is the base of Naperian logarithms.
COMPUTER (cont.).

The result of the calculation shall be the distance at which the pilot see the furthest lamp.

The illumination threshold $E_t$ of the pilot's eye depends on the background luminance, and for the present we use the values stated in the ICAO Circular 113-AN/85 as regards the relationship between illumination threshold and background luminance.

When illumination "E" of a lamp with the intensity "I" drops at a distance "d" to the illumination threshold "$E_t$" of the pilot's eye, then: $d = SVR$.

BLOCKDIAGRAM: SVR RECEIVER.

a) Circuitry for measurement.

The diagram below shows only one channel. The backscattered light is converted into electrical signals via the photodiode. The signals pass the impedance converter, where also the capacitance of the photodiode is compensated by the feedback capacitor Ck. The output-signals of the impedance converter are fed to the analogue switches I to VIII via the DC decoupling. The analogue switches are activated one after the other by the time control for each 1.33 microsec.
Signals reaching the photodiode at different times are separated in different channels. The switched signal is gained by the amplifier $v_x$. The gain varies from one channel to the other as illustrated in the diagram. By means of the different gains the signal reduction by the squared distance is compensated.

A number of pulses are integrated by the integrator. After the pulse burst the result of the integrator is passed into a sample and hold circuit within which the signal is hold until the next integration period is finished.

During the measuring period the analogue switch (parallel to the integrator capacitor $C_i$) is opened. After the signal is passed into the sample and hold circuit the analogue switch is conductive to reset the integrator until the next measurement.

The held signal (0 - 5 volt) is converted into a current 0 to 1 mA, and cable resistors are automatically eliminated.

**b) Circuitry for controllogic** - See diagram below.
The control logic is started by a light pulse reaching the photodiode via the light guide from the projector. The retriggerable mono FF1 is triggered and opens the reset of the integrator. At the same time the frequency generator is started. The clock pulses are fed to the shift register and to counter 1. This counter is waiting in the 0-position and loads a "High"-signal into the shift register. By the first clock pulse the "High"-signal is shifted to output 1, and counter 1 is now in position 1. The counter feeds only in position 0 a "High"-signal to the load input of the shift register. This "High"-signal is now shifted at each clock pulse of the frequency generator to the next output of the shift register. By this signal one after the other analogue switches are activated. When counter 1 reaches 0 again, the frequency generator is stopped, and a "High"-signal is fed to the load input of the shift register. The circuitry is now awaiting the next pulse (flash).

During the stand-by position of the retriggerable mono flip-flop 1 the shift register is kept in "clear"-mode, the integrators of the analogue circuitry are kept in "reset", and counter 2 is kept in "preset" - The number chosen by means of the pulse number switch is loaded into counter 2.

When a light pulse from the projector reaches the photodiode, the retriggerable mono FF1 is triggered and remains triggered for the whole pulse burst as the hold time of FF1 is longer than the time between two flashes.

With the flashes counter 2 counts down to 0. When counter 2 has reached 0, a low to high transition triggers the mono FF2. The output pulse of FF2 switches the sample and hold circuitries into "sample"-mode for a few ms.

When the projector stops flashing the retriggerable mono FF1 switches back. Now the shift register is kept in "clear", the integrators in "reset", and counter 2 in "preset"-mode. - The circuitry awaits the next pulse burst.
The projector is started by a counter preset pulse from the repetition timer. The counter is preset to the number which is set at the pulse number switch. If the pulse burst counter is not 0, the high voltage power supply is switched on via the on/off-control. Now the capacitor C is charged. When the voltage of the capacitor C has reached 5 kV, the comparator measures this via the voltage divider R1/R2 and a pulse is given to the ignition amplifier and to the pulse burst nr. counter. The spark gap SG is triggered by a high voltage pulse. The capacitor is now discharged via the spark gap. The spark gap emits a light pulse of a duration of 200 ns. Immediately after discharge the capacitor is charged again to 5 kV. The charging time is adjusted at the resistor R3 so that the flash frequency is 30 Hz.

The pulse burst number counter receives the pulses of the comparator and counts down from the preset pulse number to 0. When the counter has reached 0, the high voltage power supply is switched off, and the repetition timer is started. After the time set at the resistor R_T has been passed, the pulse burst number counter is preset again and a new pulse burst is started.

For triggering the receiver a light pulse of the spark gap is fed to the receiver via a light guide.
AN EXAMPLE OF OPTIMUM PROCESSING AND DISPLAYING OF DATA FROM SURFACE WIND SENSORS AT AIRPORTS.

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INTRODUCTION.

To automatize weather observation is not an aim in itself. The human observer is still indispensable and cannot be replaced by mere technics, and that will undoubtedly be a fact for many years to come. If you have in contemplation to automatize you must ask yourself such questions as:

a) is automation necessary in this particular case? and
b) do the circumstances clearly indicate that an automation will be beneficial in proportion to the existing state of things?

If the answer to both questions turns out to be negative, you must seriously consider once more if the planned project altogether should be commenced.

Many places on the globe are still so inclement and inaccessible that it would be unthinkable to station a human observer there, and in such a case it can be necessary, and beneficial too of course, to mount an automatic weather station. States may also have problems in stationing human observers for other reasons than the above mentioned - problems with regard to economy and lack of personnel are not rare, and automation is usually the only way out. In this case automation becomes a necessity and not obviously a beneficial solution.

If one or both of the above-mentioned questions can be answered in the affirmative, and if it is decided to start-up an automation project it is supremely important that meteorologists participate in the project from start to finish. The meteorologist must take a very active part all the way through, and it is thus not enough for the meteorologist just to define the task and then hand over the problem to the engineers.
The meteorological assistance is essential in for instance the choice of sensors (questions regarding accuracy, long-range stability, observance of international standards etc.) and in the choice of most suitable areas for exposure of the sensors. Still as far as hardware is concerned the meteorologist must also have a decisive influence on which output units should apply. Regarding the software of an automation project the meteorologist must contribute actively in defining the parameters in question (gust, dewpoint, relative humidity, qff, qnh, qfe, max surface wind, max and min temperatures etc. etc.) and in drawing up formulas to be used in connection with for instance conversions and table calculations.

As regards the aeronautical meteorological observation it is obvious that automation is distinctly more necessary. There are several reasons for that, but let us content ourselves to consider two of the most important ones. Firstly, the aeronautical observation service must be capable of supplying meteorological parameters (as for instance RVR and surface winds) which simply cannot be observed manually with the desired accuracy, and secondly, the service must live up to pretty tough demands concerning transmission speed and updating frequency.

The questions about necessity and advantage which were dealt with above are still relevant, and must therefore be asked also when speaking about automation in connection with aeronautical observation.

Observation services of most major airports have, in addition to the responsibility for aeronautical observation, also the responsibility concerning synoptic observation. This implies often, especially during bad weather conditions, that the observer on duty succumbs to heavy work load. The aeronautical part of the work done by the observer is at many airports probably considered being the most significant one as this part involves flight safety. However, it is very important that the aeronautical observation services bear in mind, that the synoptic part of the work also must be carried out in as responsible manner as possible.

In order to lighten the work load of the observer and to comply with the international demands for accuracy, automation is often the right solution. Processing of data from surface wind sensors is an area where automation certainly is advantageous, and in the following we shall examine more closely how this problem can be solved in a way that ensures an optimum utilization of the available data.
SURFACE WIND SYSTEM EKCH

SENSORS.

There are two sensor sites in our system, one close to THR 22L and the other close to THR 04L. Each site is equipped with a mast, on top of which (i.e. at a height of ten metres) a cupanemometer and a wind vane are separately mounted. Prior to mounting the sensors have been tested and calibrated in a wind tunnel.

Information about the rotation speed of the anemometers and the position of the wind vanes is derived by means of an optical system, which demands a power supply of 5 volt.

The lengths constants of the sensors are approximately 2 metres.

TRANSMISSION.

At the sensor sites the measured values are converted into digital signals, which are transmitted for a stretch of about 3000 metres to a computer. Telephone cables suffice for this purpose.

COMPUTER.

The computer has in it a central processing unit (CPU) for each site plus a back-up CPU which may be attached by means of a switch and thus replace one of the others. A built-in test unit allows you to check if your various electronic units perform satisfactorily.
In our system sampling time corresponds to 20 metres of wind.

The extreme values and mean values calculated by the computer are:

**Direction:**
- Instantaneous direction
- Mean of 2 minutes
- Mean of 10 minutes
- Instantaneous extreme clockwise
- Instantaneous extreme counterclockwise
- Extreme clockwise during the past 10 minutes
- Extreme counterclockwise during the past 10 minutes
- Variation (i.e. the difference between clockwise and counterclockwise)

**Velocity:**
- Instantaneous velocity
- Mean of 2 minutes
- Mean of 10 minutes
- Instantaneous extreme MNM
- Instantaneous extreme MAX
- Extreme MNM during the past 10 minutes (Abbreviated: MNM/10)
- Extreme MAX during the past 10 minutes (Abbreviated: MAX/10)
- MNM/10 proportional to mean of 2 minutes
- MAX/10 proportional to mean of 2 minutes
- MAX/10 proportional to mean of 10 minutes
- Extreme MAX for SYNOP (Code: 911xx).

**Crosswind:** Crosswind component for all runways.

**Wind shear:** It is possible in the computer to compare readings from the two sensor sites, and consequently it would be possible to calculate a horizontal wind shear component. This feature, however, needs to be investigated more closely before implementation.

**NB.** The expressions "Instantaneous direction" and "Instantaneous velocity" do in fact refer to a mean corresponding to 20 metres of wind; consequently "Instantaneous extreme" is a definable concept.
READOUTS.

The computer, located in the observer's office, controls readout units at different places all about the airport. The placing of the applied units and the nature of the readouts appear from the table below.

<table>
<thead>
<tr>
<th>COMPUTER</th>
<th>MET OBS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analogue recorders.</td>
<td>For the use of documentation.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Digital displays.</th>
<th>For the use of:</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Reports for take-off and landing</td>
<td></td>
</tr>
<tr>
<td>b) Met report (transmitted to ATC via TV)</td>
<td></td>
</tr>
<tr>
<td>c) Metar</td>
<td></td>
</tr>
<tr>
<td>d) Synop.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MET OFFICE</th>
<th>Analogue recorders.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Located in the forecaster's office.</td>
<td></td>
</tr>
</tbody>
</table>

| Analogue meters. | Located in the briefing office. |

<table>
<thead>
<tr>
<th>ATC OFFICES</th>
<th>Digital displays.</th>
</tr>
</thead>
<tbody>
<tr>
<td>For the use of:</td>
<td></td>
</tr>
<tr>
<td>Reports for take-off and landing.</td>
<td></td>
</tr>
</tbody>
</table>

It has been discussed whether a push-button, by means of which instantaneous values (direction) could be displayed, should be installed in the controller's desk.

NB. Analogue recorders and analogue meters read out instantaneous values.
SOFTWARE PROBLEMS.

As basic material for the programming we used ICAO's ANNEX 3, which is identical to the TECHNICAL REGULATIONS of WMO (at any rate as far as observing and reporting of surface wind is concerned). We realized soon that in using this very material we got into trouble. In some cases the material is ambiguous, and furthermore some of the parameters are not defined well enough.

To illustrate this let us ask some relevant questions:

1. Must the velocity of the wind always decrease to the mean value when a gust ceases?
2. Which axis of time should apply when determining the duration of a gust?
3. Should a MAX of 10 knots be reported? (Para. 4.5.6 says no, while para. 4.5.8 indicates the opposite).
4. What is the definition of MNM?
5. Should MNM be reported only when MAX fulfil the conditions? (Example: MAX is 8 kt greater and MNM is 15 kt smaller than the mean - should such conditions be reported?)
6. How should variable wind be defined? (Para. 4.5.6 says: When the velocity is more than 5 knots directional variations of 60 degrees or more should be reported - later on in the same paragraph: When the velocity is 5 knots or less directional variations should be reported whenever possible). What is "whenever possible"? You can easily detect a variation of for instance 20 degrees, and a variation of 200 degrees is also detectable - Should such variations be reported?

We have, of course, come to a decision as to those kind of problems, but as ANNEX 3 is somewhat uninterpretable we cannot be sure that our national decisions are fully consistent with international regulations, and that is the reason why we mention such problems in this context. We would therefore ask WMO/ICAO to consider a revision of the above mentioned basic material so that it becomes applicable also for the solution of problems that arise in connection with automation.
SURFACE WIND SYSTEM EKCH: PRINCIPLE DIAGRAM.
Abstract

The control of satellites and the processing of their remotely sensed data have always been predominantly automated out of necessity. Recently, however, it has been demonstrated that quantitative products, such as sea surface temperature and atmospheric temperature profiles, can be significantly improved both in accuracy and coverage through the introduction of human judgment at key points in the processing. This procedure, called interactive processing, is currently either under development or being implemented for most operational products in the United States.

Introduction

Satellites, their observing instruments, and their data processing systems have been largely automated from very early in their development. The very nature of their operation and the character of their data not only encourage but virtually require control in the absence of an operator and automatic data processing. Many satellites used for meteorology and earth observations are not within view of a ground control station for long periods of time and all functions and commands must be stored in an on-board computer providing automated control for these "dark" periods of the orbit. The quantity of data associated with most satellite products is so large that processing it would be impractical to the point of being essentially impossible without automated procedures on computers. For example, the images of the earth from the U.S. Geostationary Observational Environmental Satellite (GOES) contain $10^8$ bits of digital information in the visible region images and $10^9$ bits in the infrared images. Each of two satellites produces a visible and infrared image every half hour (except that visible images are not retained for much of the dark side of the earth) and numerous sectors, or enlarged portions of special interest, are produced from the full-earth images. Without automatic data processing techniques very little of this would be possible. With automated techniques a large number of customers is served essentially in real time and with specially processing techniques, such as image enhancement, in most cases.

Remotely Sensed Data

Satellites collect earth environmental data in two ways: (1) receiving data from in-situ sensors on ocean buoys, balloons, etc. and transmitting it to a central processing station, and (2) making physical observations with remote sensing instruments on-board the satellite. Where the satellite acts only as a data relay, the data is in conventional form and there is no unique characteristic imparted by the satellite. In the case of remote-sensing data, however, the information collected directly by the satellite is not usually in the parameter being sought. For example, the infrared radiation emitted by the surface waters of the sea is measured by a radiometer, converted to an apparent brightness temperature, and corrected for the effect of the intervening atmosphere to yield a measure of the temperature of the surface of the sea. The velocity and direction of small, distinctively shaped clouds is measured to infer the wind, assuming that the cloud is traveling at the same velocity as the air surrounding it. The temperature
of the atmosphere is inferred from infrared and microwave radiances emitted by carbon dioxide and oxygen in the atmosphere. In the derivation of all of these quantitative products, a complex mathematical process is usually involved adding to the data processing problems created by the large quantities of data.

A characteristic of satellite data is its global coverage and the normally uninterrupted flow. These combine to produce data sources available for environmentalists far transcending those that have been available from conventional sources. For example, the number of soundings produced by the worldwide net of upper air radiosonde stations for one synoptic (12 hour) period is shown in Figure 1. A comparable set, produced in a 24-hour period by one of the two polar-orbiting satellites operated by the U.S. National Environmental Satellite Service (NESS), is shown in Figure 2. The radiosonde net provides adequate coverage of the major populated land masses but virtually nothing over the oceanic areas, particularly in the Southern
As a case study, it is interesting to review the processing of radiances into temperatures for the atmosphere. Layer mean temperatures are produced for 15 layers between 1000 and 1 mb at each point on the earth where an S appears in Figure 2. The details of the instruments used to make these observations are available elsewhere [Reference 1] and will not be repeated here. As a starting point in the process we will take the radiances produced by the three remote sensing instruments which comprise the TIROS Operational Vertical Sounder (TOVS) system aboard the TIROS-N polar-orbiting satellite. These instruments, the High-Resolution Sounder (HIRS/2), the Microwave Sounding Unit (MSU), and the Stratospheric Sounding Unit (SSU), make observations in 27 separate spectral channels, each of which has a
unique distribution with altitude of the energy received from the gases, CO₂ and O₂ of the atmosphere. These 27 channels are automatically processed into the final product, temperature as a function of altitude for the atmosphere, in a fully automated process displayed diagrammatically in Figure 3. Starting at the top the data flows in from the TIROS-N satellite to the Command and Data Acquisition (CDA) Station at Gilmore Creek, Alaska or Wallops Island, Virginia, is relayed to the Satellite Operations Control Center (SOCC) in Washington, D.C. via microwave link, is preprocessed by a Systems Engineering Laboratories (SEL) computer for calibration, earth location and registration and stored on a Tera Bit Memory (TBM) high density tape. At this point the data is in Level 1B form and is retained as an archive. Processing into temperatures begins thence below the dotted line on Figure 3 in an IBM 360/195 computer. The details of the step-by-step process are contained in Reference 2 and will not be repeated here. It is important to note the feedback loops contained within the process. In particular, the TIROS Atmospheric Radiation Module (TARM) clear radiances module is used to calculate from the observed radiances the corrections necessary for the intervening cloud, aerosol, and foreign gas intrusion. This is the most important single step in the process since clouds are the most serious problem encountered in the entire operation. In the process of automatically recognizing specific quantitative features such as cloud amount in the field of view, cloud altitude, cloud emissivity, and/or the presence of more than one layer of clouds, there are numerous tests and checks for which boundary values must be established. In two years of operation with this system, which produces an average of 7,000 individual soundings per day, it has been found that these boundary values need adjustment from time to time to allow them to pass naturally variant data and to stop wild values. We have recently concluded that a fully automated system will never be able to compete with the judgment of a trained, skilled operator. As a result, development activities within NESS today are aimed
primarily at what we call interactive systems.

In the area of remote sounding, described above as the TOVS processing system, intervention by a human operator is being introduced in several locations. The most important of these is the superposition of the output product, temperatures at a level, on analyses displayed on a computer video screen. The operator can judge the value of individual points, delete those which he considers to be invalid, and can direct the system to recalculate on the basis of more propitious conditions. For example, our best soundings are produced in the area most free of clouds. The fully automatic system operates on a pre-set grid. If the operator sees a sounding in a densely cloudy area that looks questionable and there is a moderately clear area nearby, he can call for a recalculation in the clear area. The operator is also capable of screening the raw radiances in gridded form or the output of the clear radiances module and can make adjustments at these points based upon other data such as National Weather Service (NWS) analysis, high resolution satellite images of the area being viewed, ground radar images, or any other ancillary data set available to help him in assessing the specific situation. The impact of this is that future systems using large quantities of remotely sensed data will move out of the totally automated realm into the interactive realm. This will have three major advantages over the present, totally automatic process: (1) It allows relaxing the boundary values in the automatic process thus reducing the chance that a large variation that is real will be discarded; (2) It provides skilled operator judgment to edit out wild values passed by relaxing the boundary terms and to inject skill that we have been unable to incorporate into computer programs (the human brain appears still to have more impressive capabilities than any existing computer); and (3) It provides for the introduction of data from ancillary sources which can aid the operator in making his judgment.

Some additional examples of combining automated processing on computers with interactive inputs by a skilled operator are: (1) Sea surface temperature fields where the operator can examine the horizontal gradient fields as well as data from other sources such as cloud cover, water vapor fields, and sea state (wind stress) in assessing areas requiring special attention. (2) Precipitation estimation—particularly heavy precipitation capable of producing flash floods—where the operator examines the time history of convective formation, identifies areas according to their importance, selects the initial processing procedures, and starts the automated process. (3) Areal snow-cover measurement where the operator uses images in several different wavelength regions and at different times to separate and identify clouds, solid snow and melting snow.

This trend has also encouraged a move away from the large central computer concept to the smaller, dedicated computer systems. Helped along by the almost explosive development of moderately-priced, versatile peripheral computers, the development path is toward separate systems, fed in some cases by a central data base, dedicated to a particular product.

References
THE RETRIEVAL OF OBSERVATIONS FROM MERCHANT SHIPS

R. G. Flavell and R. E. W. Pettifer

Meteorological Office, United Kingdom

1. Introduction

To weather forecasters situated on the western side of continental Europe, observations from the North Atlantic area are of prime importance. The normal progression of depressions and fronts is from west to east and, because suitably-placed islands are few and widely spaced, great reliance has to be placed on a regular supply of data from ships at sea.

In recent years there has been a steady decline in the number of merchant vessels at sea and, furthermore, of those which remain, very few carry more than one Radio Officer. As a consequence of this the prompt receipt of merchant ship observations, particularly the vital ones done at 00, 06 and 12 hrs GMT, has also declined.

On British Merchant Vessels, the observations are the responsibility of the Deck Officers and the ships' log books analyzed at Bracknell show that the observations are regularly made and recorded. The problem lies purely in the area of communications. It was to address this problem that the MOSS (Meteorological Observing System for Ships) project was undertaken within the UK Meteorological Office.

2. The objects of the MOSS project

The project has as its principle aim to increase the number of weather observations from at least sixty ships in the N Atlantic area, particularly during the hours of darkness, and to get them to a collecting centre in time to be of value to the forecaster. The target set for the MOSS project has been a delay of not more than two hours, with an emphasis on the observation for 00 UT.

It has been recognized that there are two ways of achieving this:

a. By installing on the ship a fully-automatic system which uses modern techniques to sample sensors electrically at set times, compiles a message in standard SHIP code using a microprocessor, and then transmits it to the collecting centre, all without intervention by any of the ship's personnel.

b. By using a dedicated semi-automatic transmission system handling manually-prepared observations.

In both cases there is a basic need to provide some form of automatic communication facility and the activity on the MOSS project has concentrated upon trying out a series of different possible communication techniques.
3. The Communication Trials

Three basic systems have been tried and a fourth considered in some detail. Two of the systems made use of the normal Ship H.F. radio transmitter while the other two were methods which made use of satellite systems. Of these, one, which used the geostationary GOES E/ METEOSAT system was highly successful; the other, which would have used the TIROS-N/NOAA A polar-orbiting satellites, was shown to be non-viable and was not actually tried out.

3.1 The HF W-T Trial

This was the first of our two attempts to use the normal ship's radio transmitter to carry meteorological messages at times when it would normally be unmanned and therefore shut down. The radio transmitter on the container ship CF Discoverer (London-Quebec) was modified so that it could be left in a standby mode and activated by a time pulse from a data processor or code generator device. The equipment is shown in block diagram from in Fig 1. Six special IGOSS frequencies were allocated for this work and it was a task for the ship's radio officer before going off watch to select the frequency which he judged to be the most appropriate for the forthcoming night-time period.

On shore, a bank of six radio receivers was used, each tuned to one of the possible frequencies. The receivers were continuously searched by a signal recognition device which looked for a series of 'A's which were transmitted prior to each meteorological message and which were used to permit the receiver equipment to lock-on to the appropriate frequency. Forward error correction equipment was included in both the transmitting and receiving systems. The shore station equipment is shown in Fig 2.

In spite of many attempts to make this system work, it was never satisfactory. The HF marine bands are crowded and noisy and very prone to multipath forms of signal distortion. These effects can be significantly mitigated by the manipulation of radio controls by skilful operators but proved too difficult a problem for this relatively simple automatic equipment. Furthermore, when good messages were transmitted it became clear that the time required to identify the transmission channel in use, to lock the receiver equipment to it and to synchronise the two forward error correction units was too long (several minutes) to allow more than a very few ships to be successfully handled this way. It was clear that this solution would certainly not be able to deal with meteorological messages from sixty ships and the trial was therefore abandoned.
3.2 The HF RTT Trial

The advantages of this system over the WT system were that for any ship already fitted with radio teleprinter facilities there would need to be only a small, cheap interface modification made to the standard ship-borne equipment and, furthermore, no special shore facilities would be required because messages would be passed through existing shore stations, manned throughout the 24 hours by PTT staff. The disadvantages of the HF-WT system associated with the choice of frequency and the problems of distortion and crowded HF bands remained. A further difficulty was that very few UK ships plying the N Atlantic are actually equipped with RTT facilities and to provide them solely for meteorological message purposes would be too costly.

Two further difficulties arose. One was that as a result of the lack of radio officers on night watch on UK ships there has been a fall in general traffic levels which has resulted in the likelihood that the appropriate shore stations will not be manned at night either, thus removing one of the advantages of the method. Secondly, this type of semi-automatic system met with considerable opposition from organized labour, particularly among those who man receiving stations. Of a total of 1000 observations made during the trial period, fewer than 60 attempts were made to pass the message and of these only a handful were completely successful.

We concluded that the scheme was not viable and discontinued the trials.

3.3 The Geostationary Satellite Systems

3.3.1 Marisat. The use of Marisat for the purposes of the MOSS project was considered but was not pursued because there are very few ships in the UK N Atlantic merchant fleet which are suitably equipped; the costs of equipping a ship just for meteorological purposes would be prohibitive and the unit cost per message for handling is too high to be economic for the number of messages involved.

In addition to all this, the routing of all messages through the USA was expected to generate unacceptable delays in the receipt of synoptic observations. Marisat, in its present form therefore appears unattractive to us for the task of retrieving ship observations from the N Atlantic. On the other hand, if the cost per message reduces as the system becomes more widely used and if a receiving station were to be set-up in NW Europe then the system might become more attractive.

3.2 METEOSAT/GOES

An opportunity arose during the MOSS project to co-operate with ESA and the British Antarctic Survey in a trial of a Meteosat communications system on the BAS ship RMS Bransfield. ESA fitted the ship with a Meteosat DCP for a voyage to Antarctica with a view to establishing the southernmost limits of the Meteosat Data Link coverage. By negotiation with ESA and BAS, the Meteorological Office added to the system a keyboard and a store and forward unit known as a "Comstore." The ship-board system is shown diagrammatically in Fig 3. The aerial system employed for this trial was a stabilized, hemispherical pattern device.
Each six-hourly meteorological observation was entered by the deck officer through the keyboard to the Comstore where it was held until called forward and transmitted to Meteosat at the assigned time by the DCP. The Comstore allowed the data to be keyed-in at the operator's rate but clocked out at a fixed rate required by the satellite system. The DCP was arranged to transmit every three hours, alternate messages being test texts. The six-hourly observations were sent to Bracknell in parallel by normal HF methods and the text of these messages and those received via Meteosat were compared.

The trial began on 27 October 1978 and by mid-March it was sufficiently successful that ESOC began to pass the routine ship observations directly onto the GTS.

For the purposes of analysis the voyage was divided into a series of legs as follows:

1. Southampton–Port Stanley (27.10.78-7.12.78)
3. Weddell Sea/Halley Bay (30.12.78-3.2.79)
4. Palmer Peninsula (4.2.79-24.3.79)
5. Geophysics Cruise and South Georgia (25.3.79-5.4.79)
6. South Georgia–Southampton (1.5.79-28.5.79)

The summary of the results obtained on these legs is shown in Table 1. The "No Message" column includes all causes for the lack of a message including occasions when none was sent, a period on leg No 2 when the DCP failed, occasions when the vessel was in port and the aerial take-off was obstructed by adjacent buildings etc and any time when the ESOC facility was out of service for any reason.
### TABLE 1
THE RECOVERY OF OBSERVATIONS FROM THE RMS BRANSFIELD VIA METEOSAT

<table>
<thead>
<tr>
<th>Leg of voyage</th>
<th>Message Error Rate</th>
<th>No Message</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>00.0%</td>
<td>00.1-00.9%</td>
</tr>
<tr>
<td>1</td>
<td>51</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>(73.0%)</td>
<td>(5.7%)</td>
</tr>
<tr>
<td>2</td>
<td>37</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>(21.1%)</td>
<td>(1.7%)</td>
</tr>
<tr>
<td>3</td>
<td>179</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>(62.2%)</td>
<td>(4.5%)</td>
</tr>
<tr>
<td>4</td>
<td>92</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>(23.4%)</td>
<td>(3.3%)</td>
</tr>
<tr>
<td>5</td>
<td>192</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>(82.4%)</td>
<td>(3.4%)</td>
</tr>
<tr>
<td>6</td>
<td>190</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>(87.6%)</td>
<td>(0%)</td>
</tr>
</tbody>
</table>

Notes:  
* DCP failure for one week - loss of about 60 messages.  
* Vessel on extreme edge of Meteosat area on this leg.

It is not possible in this short paper to analyse this data in detail but some important points emerged and are worth special comment. On the fourth leg of the voyage there were twenty-eight cases where one thousand consecutive characters were received without error when the elevation of Meteosat was 1.9° or less with respect to Bransfield. Successful messages were received from satellite elevations as low as -0.5° and in most cases in which messages failed at low elevations, the failure could be readily associated with topographical or other obstructions in the line of sight from ship to satellite.

As a result of this extremely encouraging trial, we have now installed a still simpler Meteosat/GOES system on the N Atlantic container ship CP Discoverer. This system consists of a keyboard device which incorporates the functions of the Comstore (the ESL-Racal Store and Forward terminal) a DCP and a simple unstabilized aerial. The ship's deck officer keys his observation into the terminal and has a very simple edit facility which enables him to correct any errors he may have made. He presses a single key to enter the data into the DCP which then broadcasts at the assigned time to the satellite. By using an international frequency either Meteosat or GOES E may be utilized and since both satellites cover the entire N Atlantic at about 55°N we have a very secure system with built-in redundancy. The system has proved very successful so far although the trial is temporarily halted because of a fault on the DCP.

As a final phase of this work a complete production system of store and forward terminal, DCP and aerial has been designed and built by McMichael Ltd in UK. This system has been tried out as a land link and has proved highly successful and is particularly easy to operate. There is no doubt that it could serve many meteorological data transmission purposes both on land and at sea.
RESULTS FROM USING AUTOMATIC METEOROLOGICAL SYSTEMS

K.N. Manuilov
USSR State Committee for Hydrometeorology and Control of the Natural Environment

For a long time the automation is one of the main trends of the measuring meteorological system development. In a number of countries, e.g. France, the USSR, the USA, etc., the development and operation of automatic weather stations were realized in the thirties-forties. In the fifties-sixties the systems, consisting of a number of automatic meteorological stations and a centre of meteorological data acquisition and processing, are appeared. The rapid development of electronics and calculating equipment during the last decade promoted the process of rapid improvement of the systems and stations. Now many countries have great experience of using automatic stations and systems of various purposes. At this session we shall hear a number of papers dedicated to the results from automated system operation in the USA, Sweden, Bangladesh.

The automated meteorological systems used in various countries can be divided by their purposes into two main groups: the systems which work out restricted information, used for direct employment in industry, agriculture, building, transport, etc. and the systems providing synoptics and climatologists with meteorological information.

The automated systems of the first group carry out different tasks: realise the control and signalization about coming of dangerous weather phenomena, i.e. storms, showers, floods, tsunami, etc., provide the aircraft take-off and landing on the aerodromes with meteorological information, control hydrological regime of water storage basins, rivers and so on. The systems of this group are practised on the largest scale because of their evident economical efficiency.

The automated systems of the second group are used for meteorological networks expansion, in particular for getting additional data from inaccessible and sparsely populated regions as well as an aid to observers at a traditional meteorological network or their partial replacement.

The automatic station system operated in Byelorussia and AKMS system used in the GDR are the typical examples of automated systems functioning at a traditional meteorological network. These systems measuring, collecting and processing meteorological data on 12-14 meteorological elements and moreover providing the signalization on coming and ending a storm situation are operated for more than 10 years. The experience of their operation is of interest.
The wide development of automated systems designed for using at a traditional meteorological network is restricted, as the economical efficiency of their use is not always indisputable.

To assess the efficiency of such systems and an observer operating under the conditions of a usual meteorological network I wish to show the comparison of their possibilities.

<table>
<thead>
<tr>
<th>Observer</th>
<th>Automatic station (system)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. An observer has a possibility to make measurements of meteorological elements and carry out observations of weather phenomena in a full conformity with existing manuals and meteorological codes.</td>
<td>An automatic station (system) can make measurements only of a restricted number of meteorological elements. The measurements of the rest of meteorological elements and observations of weather phenomena, indicated in manuals and codes, cannot be automated due to the absence of sensors and methods.</td>
</tr>
<tr>
<td>2. An observer can make accurate measurements using simple and unexpensive instruments (for example, mercury thermometers and barometers). The cost of operation and repairing of the instruments used is not great.</td>
<td>It is necessary to use complex and expensive equipment requiring high expenditure on its operation and recovery to provide accurate measurements.</td>
</tr>
<tr>
<td>3. As an observer has a logical thinking, it is not peculiar to him to make gross blunders.</td>
<td>An automatic station (system) can make blunders during a measurement, although up-to-date apparatus allow to carry out measurement quality control, based for example on compatibility of different data measured.</td>
</tr>
<tr>
<td>4. An observer cannot make a continuous observation for meteorological elements and realise timely signalization about the beginning, end and changing of storm gradations.</td>
<td>An automatic station can fix exactly enough the moments of the beginning, end and variation of storm gradations and signalize about storm timely.</td>
</tr>
<tr>
<td>5. An observer cannot realize the processing of data measured, for example, to provide the time filtering of high-frequency components of meteorological element spectrum with the view of increasing the data accuracy.</td>
<td>An automatic station is able to process data operatively, making their filtration, for example.</td>
</tr>
<tr>
<td>6. A careless observer can falsify measurement data and produce not quite objective meteorological information.</td>
<td>The full objectivity of measurements is inherent in an automatic station.</td>
</tr>
</tbody>
</table>
It follows from this comparison that with a view of existing requirements to a scope and types of meteorological data collected at a network, specific possibilities of an observer give him some advantages over an automatic station. The limited possibilities of an automatic station in providing a full scope of measurements and observations, necessary for synoptics require to have the observation staff at a network.

Automated network systems allow to increase measurement accuracy and objectivity, provide synchronization and reduce the time of collecting, transmitting and processing meteorological data, make continuous observations of weather events, timely signalize on storms, etc. These advantages make quite desirable the use of automated systems at a station network.

At present it is ascertained that there is a possibility to turn to operation in an automatic regime without an observer on a part of selected meteorological stations at night-time and on days-off. On such a station the staff can be reduced up to one-two persons.

A more cardinal change to automatic measurements is likely to be expected in future. It will be promoted by:

- raising a technical level of automatic station, wide use of microprocessors, development of new sensors and methods of measurement;
- working out of methodologies and algorithms of recovery of meteorological elements, which are not measured automatically, by the analysis of the measurements of other meteorological elements and the measurements made by means of other systems (radars, satellites, etc.).

At present a partial automation of a main meteorological network to assist an observer seems more rational. This allows to extend the functions of an observer. A remote or semiautomatic measuring system with depiction of the results on a display, providing signalization when achieving threshold values of a meteorological element and registration on carriers, convenient for putting information into a communication channel can be related to the "aids-to-observers" equipment. The facilities for operative calculation, measurement quality control, etc. are related to this equipment too. The "aids-to-observers" equipment must be cheaper than automatic measuring stations and its operation entails less expenses.

With the purpose of cutting down the expenses on the manufacturing of network meteorological equipment and providing its flexibility an aggregate complex of meteorological equipment is developing in the Soviet Union. This complex comprises a set of standard modules (sensors, converters, commutative, timing, coding, functional devices, various registers, etc.), by means of which it is possible to create different systems and instruments. The aggregate complex allows, if necessary, to change flexibly the equipment used at a network, converting a remote or semiautomatic measuring system into a completely automatic one by adding standard elements and so on.

Summarizing the above-stated I can draw the following conclusion:

1. The development of automated meteorological systems, which produce data for direct use in various branches of the economy, is restricted in general by the requirements in these data. There is a number of outstanding technical problems, in particular connected with the shortcomings of sensors.
2. The development of automated systems, which produce information for synoptical purposes, is restricted in general by the impossibility to measure and observe all the meteorological elements and parameters in accordance with existing manuals and meteorological codes.

3. It is expedient to use automated systems at some part of selected meteorological network stations with turning to automatic operation without observers at night-time and in days-off.

4. It is reasonable to equip the rest of network stations by "aids-to-observers" facilities.
Throughout the United States Federal Government, there is increasing pressure to limit or reduce total employment and expenditures. The U. S. National Weather Service (NWS) in the 1980's must respond to this pressure, and at the same time, try to meet the demands of an increasingly knowledgeable public for greater forecast accuracy and improved weather services.

Key factors in our ability to do this are:

- replacement of the National Meteorological Center computers and continuing improvement of guidance products;
- improvements in internal communications (AFOS) and dissemination;
- improvements in satellite, radar (RADAR, Doppler), and surface observations; and
- revisions to the forecast organization.

This paper deals with one of these factors -- the automation of surface observations.

Today, about 1,200 employees of the NWS are involved, at least part time, in providing surface weather observations at over 260 locations throughout the United States. The method of weather observing has remained much the same since the days of Thomas Jefferson. Today's systems are still overwhelmingly manual. With the help of sensors of varying sophistication, the observer personally views the present status of each weather element, converts to the proper units, records the data, and manually enters it into one or more communication systems (e.g., teletype). This sequence is repeated at least hourly at most locations, with additional "special" observations taken whenever significant meteorological changes occur. Typically, this function requires roughly 25% of an observer's time. Time required can double during bad or changing weather -- just when the time is most needed for issuing warnings, operating local-warning radars, updating continuous Weather Radio broadcasts, and other critical public service activities. With recent technological advances, it's now possible to fully automate the surface observation, and provide additional time for increasingly more important public service functions. Not only does this improve productivity at the individual weather station level, it makes possible much greater efficiencies by enabling a larger, systematic restructuring of the NWS workforce. The net result will be improved service to the public through automation of surface observations.
In recognition of the importance of this program, the Federal Coordinator for Meteorological Services and Supporting Research has conducted an inter-departmental cross-cut study on agency requirements for automated surface observing systems. The study concluded that the Departments of Commerce, Defense, and Transportation (DOC, DOD, and DOT) have common requirements and programs that should be merged into a joint development and procurement effort. It was also concluded that surface automating was a cost effective solution to the workload and increasing maintenance problems being experienced by the three agencies.

BACKGROUND

NWS Field Structure

The NWS, in order to develop weather forecasts and warnings, requires information on meteorological parameters observed from the earth's surface; i.e., surface observations. These parameters include air temperature and dew point, pressure, wind speed and direction, precipitation type and amount, visibility and sky condition. While surface observations are taken by many Federal and non-Federal organizations, only DOC, DOD, and DOT have significant activities which directly support weather forecasts and warnings and aviation operations. Together they maintain over 1,000 observational sites for these purposes, and provide the observations to each other, the aviation community, and a host of other users.

Presently the NWS maintains a network of manned facilities across the nation that provides both the necessary weather observations and the subsequent array of weather services, i.e., the weather forecasts, dissemination of warnings and advisories to the public and local governments, and a wide array of other essential services. The location of these facilities is dictated principally by the need to obtain representative weather observations for large areas, essential for weather analysis and weather and to obtain point observations in support of aviation operations.

Manual surface observations are almost completely a part-time function. The few sites where the only function is observing have been or will be put on contract to private industry. Typically, the function requires roughly 25% of the time of the person on duty, or (since a staff of at least five people are required on duty to provide round-the-clock coverage) about 1.25 staff years per 24-hour observation site. The manned system, while consuming very few dedicated personnel positions, does consume a significant amount of staff time each year that could be used more effectively at sites that have other, non-observational responsibilities. Once the observation can be done by automation, the service functions can be separated from the observing sites. It thus becomes possible to define Weather Station locations and staffing requirements on the basis of public service. Automation of surface observation will lead to major service improvements, including a truly continuous weather watch, and also permit service expansion with minimum additional personnel costs. New technology, currently under development by the three agencies, promises a capability of full automation of surface observations by the mid-1980s.

Current Sensors and Systems

Electronic sensors of varying designs and sensitivities are available at many locations to measure and display wind speed and direction, temperature and dewpoint, precipitation accumulation, and pressure. Major observing locations have sensors to measure cloud base height.
(ceilometers), but many stations still rely on crude and often unreliable methods to estimate extent of cloud cover. Cloud cover, prevailing visibility and present weather (i.e., precipitation type, thunderstorms, and obstructions to visibility) must be subjectively determined by the observer.

NWS currently has in the field over 100 automatic observing systems which report a partial set of the parameters needed for a complete surface observation. The basic Automatic Meteorological Observing System (AMOS) is a solid state system capable of measuring and reporting temperature and dewpoint, wind, speed and direction, pressure and precipitation. At some locations, which are staffed only part time, these systems are used to provide 24-hour observations. At others, they provide observations from locations where it is not feasible or economical to provide staff -- thus the name RAMOS, or Remote AMOS. A Manual Entry Device (MED), when added to an AMOS or RAMOS, allows an observer to enter the non-automated parameters. At a few locations, sensors for sky cover and visibility, together with some additional data processing, have been added to the AMOS to form the Automatic Observing System (AUTOB). It is the forerunner of the stand-alone, automatic observing system of the future, while the AMOS/MED combination is the predecessor of semi-automation.

**Technology Assessment**

The next generation automatic meteorological observing system is a logical extension of the existing AMOS systems which have been in use for a number of years. The use of microprocessor technology, however, allows the new automated systems to be more sophisticated than previous systems, more flexible, and more reliable at the same time.

The feasibility of such an automated system has been clearly demonstrated by the Federal Aviation Administration's (FAA) AViation Automated Weather Observing System (AV-AWOS). This system, developed jointly by the FAA and the NWS, is an experimental, mini-computer based system utilizing AMOS type sensors, arrays of ceilometers and visibility sensors, and some innovative processing techniques. It was installed at Patrick Henry Field, Virginia and operated side-by-side with FAA and NWS weather observers from January to May, 1978. This operational test demonstrated that the technology exists to automatically provide virtually the entire aviation weather observation in enough detail to satisfy both aviation interests and National Weather Service forecasters.

Sensor hardware development has also been proceeding rapidly. Private industry is already producing a multitude of sensors for most of the "easy" parameters, and little development is needed to meet the (generally more rigorous) NWS requirements for accuracy and reliability. Principle exceptions to this are the "key sensors" for the traditionally visual elements: sky condition, visibility, weather and obstructions to vision. In this area, sensors are either not yet available or not adequate for full automation. However, developments are promising:

**Sky Condition.** Laser ceilometers are preferable to the existing Rotating Beam Ceilometer in terms of performance, ease of installation, and reliability. Recent developmental models are presently undergoing joint testing by the FAA and the NWS.

**Visibility.** Newly developed forward scatter and backscatter sensors are under test, and show great improvements over the existing transmissometer, which is no longer available. The DOD (Air Weather Service) has been deeply involved with visibility sensor development for that last few years.
Weather and Obstructions to Vision. Private industry has been developing some specialty sensors (e.g., thunderstorm, fog, freezing rain and precipitation detection) with limited capabilities, but most development work on weather discrimination has been done within NOAA's Environmental Research Laboratory and NWS's Equipment Development Lab. The NWS's experimental Laser Weather Indicator (LWI) has been tested successfully for some "present weather" elements, and additional development is underway to expand its capabilities to accurately discriminate a broader complement of weather parameters.

Although sensor development by the three agencies is progressing, it takes a significant time to yield the fully-tested, production hardware needed for field deployment. In the meantime, the flexibility of the automated system will allow the use of existing sensors supplemented with manual input (the semi-automated systems). New technology sensors can be incorporated as they are developed, and systems upgraded to full-automation. In addition, each individual system can be tailored to its specific site requirements. The fully automated systems will provide observation programs similar to those at today's WSO's, WSMO's, and some of the larger contract observing stations. The observations will be complete with visual elements, including "present weather" and remarks. Figure 1 illustrates the distinction between the initial semi-automated system and the fully automated system.

THE NWS PROGRAM

Full automation of surface observations has the potential to not only make more efficient use of personnel resources, but also to effect savings in personnel without seriously affecting weather services. The technology is nearly available. The keys to developing its potential are to develop operational procedures which capitalize on the new technology, and gain user acceptance of the new mode of operation. The implementation of fully automated surface observations at a few stations around the nation could provide these keys by demonstrating the performance of the system under various modes of station operations, various climates, and various present weather conditions.

While the sensors needed to support full automation are just around the corner, the capability for semi-automation is available today, and is a natural prelude to full automation. Substantial benefits in productivity and improved service can be realized by early deployment of these semi-automated systems.

NWS envisions a three-stage, phased implementation of full automation.

The First Stage (beginning in 1981)

The first stage of the planned NWS program for Surface Automation has two major elements.

(1) To continue and accelerate the development and engineering of the fully automated system. Significant effort has already been invested in system, sensor and algorithm development and field verification. Major efforts are still required to bring along a number of sensors, finalize algorithms, and merge them into an effective, reliable and maintainable system. Although the technology exists today for the semi-automated system, additional funding is required for:

- Prototype contracts -- to acquire and field test competitive designs before full-scale production, and
## Sensors Required for Automated Systems

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Present Weather</th>
<th>Approx System Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$125 - 150K</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$275 - 400K</td>
</tr>
</tbody>
</table>

- **N** - New sensors required for automation
- **E** - Uses existing sensors (where available)
- **-** - Not required for semi-automation
- Systems engineering -- to merge individual sensors and algorithms with processor and software to form a fully integrated surface observing system.

Full automation requires additional efforts to complete development and testing of state-of-the-art sensors of "present weather" phenomena, plus a continuing investment in algorithm and sensor refinements. Since the sophistication required of "full automation" increases with the utilization of these systems, refinements in accuracy and discrimination must keep pace with deployment.

(2) To implement 9 fully automated systems (using a mix of production and prototype components), dispersed throughout the country. These systems will be used for developmental refinements and for operational experience, specifically for:

- advanced algorithm development and refinement in translating sensor outputs into meteorological parameters
- field verification of new sensors (hardware and algorithms)
- optimizing multiple sensor arrays to handle non-homogeneous site conditions -- where local weather conditions often result in differing sky cover and visibility around the site, such as coastal and marsh areas and mountainous locations.
- procedure development and familiarization for meteorologists, aviators, and other users, and in various climatic regimes (e.g., coastal, plains, mountainous, arid, Alaska)
- future workforce management, with use in various office settings, e.g., offices with large service and observing programs and other workload, contrasted with smaller offices, for optimizing use of the automatic equipment.

This activity would guide the integration of fully automated system into the overall service operation, and initiate critical training and procedure development in anticipation of implementing a fully automated, operational system at a large number of stations.

The Second Stage (beginning in 1982)

To implement automated observations of most of the required surface variables at about 100 selected stations where the existing heavy load of observing and dissemination functions limit the effectiveness of the staffs in providing services, especially during times of bad weather when the need is greatest. Our records show that the typical station experiences a heavy observer workload about twice a week for a span of several hours, covering 5 percent of total station operating time. Naturally, these periods coincide with the heaviest demand for local forecasting, public service briefings, and dissemination over NOAA Weather Radio, etc. "Semi-Automation" substantially increases the time available for these public service functions (from 30 to 50+ minutes per hour) during critical periods allowing the National Weather Service to give highest priority to warning and dissemination functions. The initial system would use demonstrated technology to observe the parameters listed in Figure 1. The station staffs would continue to make observations of the remaining variables, notably those that require distinguishing the types and rate of precipitation and enter them manually into the system.
These semi-automated systems would have a flexible, modular design that explicitly anticipates expansion to automated observation of all required surface variables after additional sensors and algorithms suitable for operational use have been demonstrated.

**Implementation Strategy**

The deployment of the approximately 100 semi-automated systems is based on a priority schedule keyed to selected stations with the greatest workload and staffing shortages. The highest priority grouping are those observing stations that also have local warning radar and NOAA Weather Radio and other service functions. The next highest priority group generally is similar, but with network radar in lieu of the local warning radar (the network radar sites presently have a dedicated radar observing staff). The third priority grouping are those selected sites with growing service program responsibilities; e.g., agricultural weather programs, flash flood prone, etc., and the Forecast Offices with observing programs.

The proposed program would be accomplished jointly with DOD and DOT (Federal Aviation Administration). Their requirements for surface observations and automation are sufficiently similar that a single modular system will suffice. The development of system functional requirements, development and acquisition strategy, procurement and operational testing will be accomplished by a Joint Systems Program Office. NOAA 1981 funds would be used to complete development and engineering and initiate procurement of the automated system. DOD and DOT (FAA) would join NOAA in purchasing additional systems in 1982 and beyond. To date, considerable progress has been accomplished by the three cooperating agencies in specifying the functional requirements of the systems.

**The Third Stage** (beginning around FY84):

- implements surface automation throughout the NWS network;
- deploys additional systems and upgrades the "semi's" (deployed in the second stage) to achieve a mix of semi- and fully-automated stations, depending on operational requirements; and
- provides a degree of flexibility permitting field structure realignment and consolidation.

Figure 2 illustrates the phased implementation schedule for all three stages of the program.
AUTOMATION OF SURFACE OBSERVATIONS

<table>
<thead>
<tr>
<th>Year</th>
<th>79</th>
<th>80</th>
<th>81</th>
<th>82</th>
<th>83</th>
<th>84</th>
<th>85</th>
<th>86</th>
</tr>
</thead>
</table>

**STAGE 1**
- Development & Engineering
- Demonstration System & 9 Stations
- System Design & Planning
- Continuing Sensor Developments
- Procure
- Deploy

**STAGE 2**
- Semi-Automation & 100 Stations
- Procure
- Deploy

**STAGE 3**
- Full Automation of NWS Network
- Validate Requirements
- Spec
- Procure
- Deploy
THE AUTOMATIC SURFACE OBSERVATION SYSTEM IN SWEDEN - EXPERIENCE AND FUTURE OUTLOOKS
by Ture Hovberg
SMHI (The Swedish Meteorological and Hydrological Institute)

1. Introduction

The Swedish Meteorological and Hydrological Institute has today 12 years experience in automatic data acquisition for meteorological use. The structure of and the experiences gained from this first computercontrolled system for acquisition via the public switched telephone network, has been described in [1] and [2].

A new data acquisition central for automatic stations was installed in 1975. It was prepared for communication with the new type of automatic stations, which are equipped with microcomputers. The data acquisition central and the automatic stations have been produced by ASEA, Västerås, Sweden. The automatic stations, equipped with microcomputers, have great flexibility and are not only used for meteorological measurement, but also in hydrology, oceanography and for special studies of alternative sources of energy.

Of special importance, are the possibilities of using the microcomputers for data-reduction at the measuring sites. With this technique, costly leased telephone lines are avoided between the measuring sites and the central computer. Instead, one can obtain much cheaper collection of reduced or stored information via the public switched telephone network, for example, once an hour, or at any other desired interval. The relatively high transmission rate, 600 baud, has resulted in short transmission times and low costs, 0.18 Swedish Crowns (US$ 0.043) per telegram.

Besides data acquisition via the public telephone network, test activity also is performed by ARGOS communication technique.

2. The data acquisition system

2.1 General description. The system consists of a central station (CS) for data acquisition and a number of field stations (FS). CS is situated at SMHI in Norrköping and most of the existing and the planned station sites are situated along the Swedish coast, normally at caisson lighthouses, see picture 1.

The transmission channels are established via the switched public telephone network with radio link extensions from lighthousemounted stations.

CS initiates data acquisition from FS at preprogrammed intervals, and the connection is established by assistance of an ACE (Automatic Calling Equipment) controlled by the computer. The collected information is checked formatted and distributed to local and remote operators via CRT displays.
SMHI AUTOMATIC DATA ACQUISITION SYSTEM

SENSORS FIELD STATIONS (FS)

RADIO SUB MODEM TELEPHONE MODEM CENTRAL TELETYPewriter CRT

STATION (TTY) DISPLAYS

COMPUTERS TRANSMISSION STORAGE

PICTURE 2
and teletypewriters, and the system is connected to the ATESTO system via the communication computer SAAB-D5. ATESTO is a short form for Automatic Telegraph Equipment for Stockholm Telegraph Office. This system has handled the whole national and international meteorological telegram traffic in Sweden since March 1974. For further information, see [3].

Synoptic coding, quality check and data storage is performed by the D5 computer. In 24 hour intervals the stored data will be transmitted from the disc memory of the D5 computer to the tape memory of the SAAB-UNIVAC 1100 (SU 1100) computer. See picture 2.

2.2 Sensors and sensor interface

Operative and planned sensors are described in another paper given at this conference by Sverker Magnusson, SMHI [4].

Among the sensors I would like to mention a few from a technical point of view.

- the SMHI-type wind sensor, which presented good dynamic characteristics at a WMO intercomparison of wind sensors, performed by the French Met. Office [5].
- cloud base height is measured by a ceilometer type QL 1211 manufactured by ASEA, Sweden. The ceilometer is measuring with laser technique.
- visibility is measured by an AGA/SATT visibility meter VM500 which operates in the infrared spectrum on the back-scatter principle.
- waves are measured by an inverted echo sounder produced by SIMRAD A/S, Norway. The echo sounder, which is placed at 25 m depth and at a distance of 100-200 m from the lighthouse tower, is operating at 710 kHz. If there is a long distance between the wave measurement site and the field station, the DATAWELL waverider buoy is used. The communication between the buoy and the FS is performed by 27 MHz radio link.

The sensors are terminated to overvoltage protection modules. When necessary, the analogue signals are standardized to ± 4V in special interfaces.

2.3 Field stations (FS)

The FS is built up in either a modular system (TAFS 8001) or an integrated one (TAFS 8002) both according to the "European Standard System". The modules are mounted in 19" frames with power supply for 220 VAC or 24VDC. The frames can be mounted in racks or placed on a table.

The modules are interconnected by a data highway. All communication between different modules is controlled by a control unit which includes an INTEL 8080 micro processor. The data highway contains lines for data, addresses and "handshaking" signals.

The control unit can for example be programmed for the following functions:

- scanning of sensors
- communication with remote sensors
- calculations of mean values
- linearising of measured values
- optional advanced data reduction
- telegram formatting
- communication with central station (CS)

For the communication with CS a start/stop character communication according to ISO 1177 is used. The used code is CCITT No 5. The same type of
interface and code can be used for connection of remote sensors.

A typical field station consists of the following units:

- power supply AC/DC or DC/DC
- control module (including real time clock 1, 10 and 100 ms)
- memory PROM/RAM (can be expanded in steps of 2k byte to 64k byte)
- communication interface
- MUX/ADC (can be expanded in steps of 16 channels)
- signal conditioner for each sensor

In the integrated system, TAFS 8002, the processor, memories, MUX/ADC and communication interfaces are built up at one double size module according to the "European Standard System".

2.4 Central Station (CS)

The central station consists of two identical computer systems, CS1 and CS2.

During the extension phase of the automatic stations network the online system CS1 will collect the information from the stations, and the back-up system CS2 will stand by. "Fail over" switching can be performed manually or automatically. The back-up system CS2 can be used for test purposes or for special studies of a certain station at more frequent interrogations. Only the on-line system will transmit data to the communication computer SAAB-D5. After the extension phase CS1 and CS2 can be run with shared station load. At "fail over" signal from CS1, CS2 will take over all stations and conversely.

Configuration of CS1 (and CS2):

- computer ALPHA LS1 2/20, with 24 k 16 bit memory and power failure re-start
- communication interface for peripherals
- calendar clock with stall alarm
- 2 automatic calling equipments (ACE)
- DIDARX receiver (for old stations)
- 2 modems

3. Field stations, micro processor software

3.1 General: The field station is a microcomputer equipped, autonomously working equipment for collection of analog and digital signals. If required the values of these signals can, after processing/conversion to suitable engineering quantities, be sent to the main computer or other recording equipment via a communication line.

All collection, as well as processing or conversion of the incoming signals, is under control of the micro-computer and consequently, the software of the field station. This also applies to routine communications.

The program is stored in a number of PROMs (Programmable Read Only Memory) while variables, in the form of measured and calculated values are stored in a RAM-memory (Random Access Memory).

The software contains a real-time monitor which controls the start of the remaining sections. The monitor determines amongst other things, the moment of each collection sequence. In order of function, the monitor requires a

x) Digital Data Acquisition, see [1]
system clock and this is placed on the equipment's system-module, where it is possible, from the processor's crystalcontrolled clock-frequency, to obtain time pulses with steps of 1, 10 och 100 ms.

Software also contains routines for format-conversion, as well as mathematical, buffer-handling and communication routines, drivers for the management of different I/O-modules and routines for software check of the hardware.

A number of tables in the main program of the field station are controlling acquisition, data processing and telegram description. In one table the input unit and corresponding measurement range is specified for each parameter. In another table the names of a set of programme modules for corresponding acquisition and processing is listed. Those modules is then in proper order linked into the main program from a program library.

The program modules are principally written in high level language (PL/M) and designed in a uniform manner to simplify documentation, declarations and program code.

3.3 Program modules: Software modules is developed for following parameters:

- wind - rolling vectorial mean value
  - rolling speed mean value
  - rolling direction mean value
  - extremes of direction and speed
  - variance of direction
  - energy
- temperature - water/air
  - extremes 12h and 24h
  - profiles
- humidity
- dew point
- air pressure - reduction
  - trend
- precipitation
- water current (like wind)
- water conductivity
- sea waves - significant wave height
  - average wave period
  - wave energy by FFT (Fast Fourier Transform), see $\text{\textsuperscript{6}\text{\textsuperscript{7}}}$
- water level - rolling mean value
- semi-automatic telegram editing - SYNOP
  - METAR
  - MET REPORT
- sensor check

The program extent for an automatic station equipped with sensors for wind, temperature, humidity and precipitation is 7 kbyte PROM and 2 kbyte RAM.
When producing new program modules, great importance is placed upon the fact that the programs can generally be used for different categories of use, e.g. that a program for vectorial integration can be used for current meters and wind gauges. For program development SMHI has provided a programming system of type Intel MDS. This is a necessary aid in order to obtain maximum utility of the automatic station's system for different applications.

4. Present situation

The automatic stations in operation today (marked with black dots in picture 1), and also those planned but not yet installed (marked with circles), are distributed over varying fields of application and measuring surroundings in the following way:

<table>
<thead>
<tr>
<th>Type</th>
<th>Mountains</th>
<th>Inland</th>
<th>Innertown</th>
<th>Coasts</th>
<th>Off shore</th>
</tr>
</thead>
<tbody>
<tr>
<td>M/O/wae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>M/wae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>M/O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 (8)</td>
</tr>
<tr>
<td>M</td>
<td>(3)</td>
<td>(3)</td>
<td>(3)</td>
<td>1</td>
<td>1 (2)</td>
</tr>
<tr>
<td>C</td>
<td>2 (1)</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>awqm</td>
<td>1</td>
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<td></td>
<td></td>
<td></td>
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<td>wie</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>swl</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sawo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(3)</td>
</tr>
<tr>
<td>soe</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

M = meteorological measurements, at least 5 sensors in accordance with sensor specification list in [5]

O = oceanographical measurements, sensors for measurements of current, salinity and temperature, at one or more levels

C = climatic measurements, stations with few parameters, for measurement of air temperature, humidity and precipitation and in a few cases also water level

swl = sea water level, stations with few parameters

awqm = automatic water-quality monitor, system for measurement of turbidity pH, oxygen and redox [7]

wae = wave energy measurement, power spectrum and also significant wave heights and time period [6]

wie = wind energy measurements, sensors for wind direction, wind speed and temperature at 3-7 levels [8]

sawo = semi-automatic weather observation station for airports, prototype system [9,10]

soe = solar energy measurements, sensors for air temperature, humidity, wind direction & speed, global radiation, direct solar radiation and infrared radiation
Parallel to plans of expansion of the automatic station network in the coastal areas, work has begun to establish automatic stations in high mountain areas. Those stations are included in a project for obtaining optimal water energy production. Due to its position, one of them also is interesting as a warning station for improving mountain safety. A special problem in certain parts of the Swedish mountain areas is severe ice-covering which occurs at heights of about 1000 m and above. As a result of ice-covering, wind measuring with rotating anemometer is pointless, as despite heating, the anemometer quickly freezes. Because of this, experiments are in progress using an heated statical sensor (ROSEMOUNT). The sensor operates according to the principle of pressure difference measurement around a circular pole. It has successfully been tested at automatic station situated 1100 m above sea level during the last winter.

As another project in progress within this field of automatic data acquisition one can add the automation of data collection from manually operated, synoptical observing stations. The need for this has arisen due to rationalisation of certain civil airports which have also previously operated as collection centres for synoptic data acquisition. This service is to cease and collection will be carried out with automatic stations, completed with terminal equipment, where the observer feeds the observation data. The information can then be collected via the automatic acquisition system.

5. Future outlooks

5.1 ADAS (Automatic Data Acquisition System):
In 1982 the existing automatic stations will be integrated in a new automatic data acquisition system, ADAS. The central computer equipment of this system, ADAC, will have functions for communication with the automatic stations (new name ADAT, Automatic Data Acquisition Terminal), via the switched telephone network and the new switched "Public data network". ADAS will be connected to the new computerized system for quality control and storage of national surface data, that will be put into service in 1982.

5.2 PROMIS-90 (PRogram for an Operational Meteorological Information System):
In the discussion of the future weather service in Sweden, the PROMIS-90 report has an essential function. This report outlines a regional weather service with great support from technical facilities like computers, satellite and radar observations, automated surface observations etc. ADAS will be an important part of this system, the outlined number of ADAT:s is 300.
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SAWO - a microcomputer controlled system for semi-automatic weather observations of airports. *)

"DATA ACQUISITION, PROCESSING AND LOCAL ARCHIVING TECHNIQUES FOR METEOROLOGICAL MEASUREMENTS"

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In considering the content of this Session one is struck by the breadth and range of the activities which could be considered to be included, and concerned that this Session should not duplicate the work covered by the earlier Papers. "Data acquisition, processing and local archiving techniques" can be thought to include the methods used in automatic weather stations in processing the raw data obtained from sensors; methods of communication and telemetry; methods of disseminating data through a network; quality control; local or central "massaging" of data with various algorithms; local recording of data on various media; archiving of data in local or central data banks etcetera. The emphasis in this Session should not be on the technology which is used, since this is changing and evolving rapidly, but on a more general discussion which may consider, and perhaps identify, which areas of automation lend themselves to some form of internationally common standards, and to contrast these with other areas where the rate of change of hardware and software is so great that standardisation is not possible, or indeed desirable. Also, there is no need to limit our discussion to automated surface observing equipment, since these general points are just as important in treating other measurement systems, such as radiosonde systems, automatic weather radar systems, automated Sferic detection systems and so on.

So in order to set the scene for detailed papers to come I can identify a number of the questions we should be seeking to answer, and make some general remarks on each of these in the context of work in the field of system development which is currently being pursued in the United Kingdom.

1. **Data Acquisition**

Raw data, in the form of a direct output from a sensor, can be in analogue or digital form. In considering what to do with it, we have to ask ourselves the following questions:-

- What is the time constant of the sensor?
- In what frequency range are we interested?
- Do we wish to pre-process the data with filters?
- How frequently should the data be sampled?
- Do we wish to apply a digital filter after sampling?
- Do we wish to apply more complex processing algorithms to the data in, or close to, the sensor?

These questions can be illustrated simply by considering an automatic weather station measuring wind alone. In the case of wind measurements, the application (or user) will define whether we are interested in the high frequency events such as gusts or turbulence, or only in long-term averages such as the run-of-wind over ten minutes. We then must ensure that the sensor has adequate characteristics, and that the sampling rate is sufficiently fast to meet the requirement. If the data is to be averaged (ie filtered) at the sensor by analogue or digital (microprocessor) methods problems of signal aliasing, attenuation and phase shifting have also to be considered. In a typical anemometer installation today this type of processing is not done at the sensor, and the raw sensor output is fed back to a central processing unit, but this may well change in the future; and one can envisage that pre-processed data will emerge directly from a sensor housing in which some of this initial work has already taken place.
2. Local Processing

In most current automated systems the raw (or pre-processed) data from a number of sensors is acquired in the field via a multiplexer unit and fed into a "black box" in which either the data is organised for immediate further onward transmission or in which local processing occurs prior to further outputs. Here, the main question to be asked is:

How much processing should we do locally in the field?

With subsidiary questions such as:

- Is ample power available?
- Is a local "human" operator available for interactive processing?
- What degree of reliability/maintainability do we seek?
- Should we use standardised algorithms?
- How much "quality control" is required?
- What forms of data output are required?
- What format standards are required in this output?

As an example of a complex automated system in which all these questions had to be answered, one can consider the United Kingdom Mark 3 Radiosonde System. In this system the radiosonde transmits digital measurements of pressure, temperature and humidity sequentially to the ground receiving station. At the ground station the frequency of each measurement is measured and is fed automatically to a central processor (in fact a Ferranti Argus 700E mini-computer). The computer program evaluates the data in real time sorting out the various variables, applying quality control and evaluating a list of all the significant measurements. At the same time wind finding radar data is also fed into the mini-computer for evaluation, so that for each "turning point" measurements of temperature, humidity and wind can be stored, together with the pressure and radar height at which they occurred. This list of measurements gives a picture of the detailed fine structure of the atmosphere as it varies with height, but the computer program also evaluates the standard WMO coded message from the more detailed list, as soon as the necessary data is available. This coded message is automatically punched out on paper tape at the request of an operator, who acts as a final human "quality control." The operator verifies that the message is "reasonable" before the tape is fed down the standard telex channel to the central computer at Bracknell. The list of fine detail measurements, together with a copy of the standard WMO measurements, is transferred to a magnetic tape cartridge at the end of the flight, forming a small local archive on magnetic tape.

In a system such as this, a large number of different algorithms are used to define the quality control routines; to evaluate with appropriate smoothing the physical quantities from the digital measurements; to define the position of turning points and significant levels, such as the tropopause; and to translate the resulting list of measured quantities into the formal format of the WMO-code. Some of these processes could be standardised on an international basis, but as far as I know this has not been attempted yet. It is only through the efforts of the Working Groups of CIMO that this type of problem can be addressed.

In other sorts of system the local processing of the input data may not need to be complex, or a decision may be taken to transfer the processing required to a remote, central station. In many simple automatic weather stations the field "processor" merely calls for
the data either on a fixed clock program or when interrogated, and transmits the raw
data to a central computing station where the main data processing occurs. This is of
great advantage on remote sites where batteries have to supply the power, there is no
local operator and reliability is of prime importance. There are however disadvantages on
sites where the data is required locally as well as in the central station. Here the
evolution of the microcomputer with the possibility of high reliability and low power con-
sumption allows one to consider inserting processing power at the field station so that
local displays of processed data can be available, and processed (or partly processed)
data transmitted on to the central station.

As an example of this latter type of automatic weather station, the proposed UK network of
Synoptic Automatic Weather Stations (SAWS) currently being purchased, has a data processor
capable of scanning and accepting the inputs from a number of sensors and sensor interfaces,
processing the data (including quality control, calculation of averages and maximum and
minimum values), the assembly and output of messages in standard WMO format, and trans-
mitting the data on command over dedicated lines to a Collecting Centre. It also has a
local display of processed data which is available on demand. As in the Mk 3 Radiosonde
System, a number of different algorithms have to be specified to define the methods of cal-
culating the means, maxima and minima of the meteorological variables, and the quality con-
trol that is applied. An example of some of the algorithms specified in the SAWS system
is at Annex A.

3. Local archiving

I take the term "local archiving" to mean the local recording of data on various types of
media. There is of course a close tie between emergent technology and the quantity of
data which can be archived, so this will have to be borne in mind. The simplest form of
local record is an autographic trace, but if we assume that this data will have to be
transferred at some later date into numeric form, then it must be acknowledged that "trace"
data is inaccessible, and reading it by hand is labour intensive and slow. Thus the
requirement now is to put local archive data onto a computer-compatible medium, such as
magnetic tape cassettes, or onto solid state memory stores, such as bubble memories. The
questions we should ask for a given application include:

- What data do we need to archive locally?
- How much data do we wish to store over what period?
- How do we store it?
- How do we transfer this local archive to a central archive (if at all)?

At first sight the answer to the first question is simple. If the automatic equipment is
simply a recording device, for example storing away sampled data from an anemometer, the
question reverts to the earlier set of queries concerning data acquisition from a sensor.
However in more complex equipment in which there is a field processor, the question is
relevant. In the Mk 3 Radiosonde System the main local archive is kept on a magnetic tape
card, and consists of all the fine structure measurements evaluated during the sonde
flight plus the special data evaluated at significant levels for the WMO coded message.
This data is collected for a period of up to two weeks, and is then copied prior to sending
the cartridge to the main computer centre at Bracknell where the data is transferred to a
data bank. The local archive cartridges are used also in the local production of the
monthly "CLIMAT TEMP" statistical summaries using the local mini-computer to re-read and
process the data. The fine structure data stored in the central computer data bank is
kept for some years, and is available to researchers when required. Other local records
are also kept, for example there is a chart recorder output for operator information, and
the raw sonde data is logged on an "emergency magnetic tape cartridge" so that it can be re-played if required. This type of local data storage is essentially transient, since these records are only kept for a limited period.

The type of storage used will depend on the amount of data we need to store, and the current state of technology when the question is asked! A few years ago paper tape was used to form local archives of data. Now we look at cassettes, cartridges, and floppy discs. In the near future commercially available solid-state semi-conductor stores, and "bubble memories" will be available. In all cases attention has to be given to the reliability of the device, its capacity to store and read out error-free information, and the risks of losing the data due to loss in transit, or finger-trouble during translation. The cost of collecting the data may have been high, so it is worth paying especial care to its safe custody once in store. A problem which we have encountered in using magnetic tape cartridges concerns the capacity for a cartridge written on a tape drive in the field to be read again, error free, on the tape drive at the central station. Standardisation, good maintenance, and some flexibility in adjustment is essential if an operational network using transcribed cassettes or cartridges is to be trouble-free.

4. Telemetry/Communications

The technology of transferring data from one location to another is also changing at an ever increasing pace. From the use of postal services and simple telephone lines we have moved to digital data links over the telephone services, HF and VHF radio links, and the use of satellites, both polar orbiting and geostationary, in order to get data rapidly to a point where it can be processed and passed into the WMO Global Telecommunications System. The questions to be asked are:-

What type of data are we transmitting?

Is the communications technology proposed cost-effective?

Does it meet the requirement in terms of amount of data transmitted and speed of transfer?

Should the date be moved rapidly to a control centre, or is a network or circuit approach more appropriate?

For example in the UK Synoptic Automatic Weather Station (SAWS) network mentioned earlier it was decided that the appropriate system for the UK requirement would be a number of Collecting Centres each polling up to 16 SAWS. At the Collecting Centres the AWS data, which is already in WMO-code format, is verified by a human operator on a VDU type display prior to onward transmission to the Bracknell Regional Telecommunications Hub (RTH) where it can be put into the general communications system.

5. Conclusions

Some of the more general questions which must be asked when setting up a meteorological data acquisition and processing system have been reviewed. There are of course many other technical problems which must be faced, but if the system is to be well based and of maximum utility to the meteorological user then I am sure that these questions will be of value in the effort to introduce some kind of philosophy into the observing network.

The great problem at present is to plan ahead for systems which will have the flexibility to make a proper use of the new technology which will appear inexorably during the coming decade. For example, it is clear that new concepts in terms of monitoring complex remote
equipment are now practicable by using interactive communications links, and employing hardware redundancy under software control. This can be achieved by having a number of independent identical units within the hardware which can be tested remotely. Any failures can be overcome by reconfiguring the system software to avoid the faulty units, and the system continues with a slightly degraded performance until repair is possible. Similarly it is possible to control digital filters, and run sensor calibration routines under remote control, thus maintaining system flexibility and system accuracy. It will be necessary to compare these practicable but complex automatic systems with the more familiar, simple, manual systems which have been with us for many years, and to judge their cost effectiveness and utility. Decisions are not going to be simple, but in a world where we are increasingly asked to reduce both the financial and human resources employed, they are decisions which will have to be made.

ANNEX A

CALCULATION OF MEAN, MAXIMUM AND MINIMUM VALUES OF METEOROLOGICAL VARIABLES, INCLUDING QUALITY CONTROL

1. QUALITY CONTROL - WIND SPEED AND DIRECTION
   a. Wind Speed
      i. Sample every 200 ms.
      ii. Compare the value with the previous sample and accept the value if the difference between the two samples is less than 10 kn.
   b. Wind Direction
      i. Sample every 200 ms.
      ii. Compare the value with the previous sample and accept the value if the difference between the two samples is less than 30°.

2. MEAN AND MAXIMUM VALUES OF WIND SPEED AND DIRECTION

Using the above sampling frequency and quality control the requirements will be met as follows:

   a. Wind Speed
      i. Computations of average speeds will use one accepted sample per second. The one-second samples will be linearly averaged to provide values over one-minute and ten-minute intervals. These will be updated at one-minute and five-minute intervals respectively. Note that an incomplete ten-minute mean is not to be put out from the systems.
      ii. To minimise the use of core store the following procedures would be acceptable.
The latest accepted 200 ms sample is held in store and the current value transferred to another store on the second. Five one-second values are linearly averaged to produce a 5-second mean. Four five-second values are used to produce a 20-second mean. Three twenty-second values are used to produce a 1-minute mean. Five one-minute values are used to produce a 5-minute mean. Two five-minute values are used to produce a 10-minute mean.

b. Wind Direction

i. Five second, one minute and 10 minute averages will be derived as for wind speed, to be updated at 5-second, 1-minute and 5-minute intervals respectively.

c. Maximum Wind Speed

i. Two consecutive accepted 200 ms samples will be averaged if each exceed the previous maximum speed value by more than 0.2 knots. This average will be stored as the maximum speed. The maximum speed will be selected for hourly periods. If this average is greater than the previous maximum speed value, the maximum speed will be updated. The latest 5-second mean direction at the time the maximum speed is selected will be taken as the wind direction at the time the maximum speed is selected. The time of the maximum speed (to the nearest minute) will be that of the whole minute at the time the maximum speed is selected.

3. QUALITY CONTROL - TEMPERATURE

Quality control is required primarily to remove any 'spikes' influencing individual samples. The algorithm to be used is:

a. sample regularly every 5 secs.

b. compare the value with the previous sample and accept the value if the difference between the two samples is less than 0.3°C.

4. MEAN VALUES - TEMPERATURE

Average arithmetically the accepted samples, over 1 minute.

5. QUALITY CONTROL - PRESSURE

Quality control for pressure will be as for temperature except that the "acceptable difference" will be less than 0.3 mb.

6. MEAN VALUES - PRESSURE

Average arithmetically the accepted values over 1 minute.
AUTOMATION OF A METEOROLOGICAL DATA ACQUISITION AND PROCESSING SYSTEM FOR SURFACE, SATELLITE, AND RADAR DATA

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1. INTRODUCTION

PROPS (Prototype Regional Observing and Forecasting Services) is a recently established NOAA program with the objective of developing and demonstrating effective methods to improve local weather services. A major requirement is to provide nowcasting and short term forecasting (0-12 hours) capabilities based on mesoscale data bases. In order to satisfy this requirement, we have established an experimental real-time computer-controlled system, an Exploratory Development Facility (EDF), for the acquisition, processing, dissemination, and display of five classes of data sources. These data sources are 1) meteorological satellites; 2) conventional and Doppler weather radars; 3) a surface network of twenty stations equipped with conventional meteorological sensors; 4) synoptic scale meteorological data bases available from the National Meteorological Center and the National Weather Service's NAMOS network; and 5) surface-based remote sensors.

Computing hardware for the EDF consists of two Digital Equipment Company VAX 11/780 computers (one presently installed, the second planned for mid-1981) and an ancillary system of a variety of microprocessors and minicomputers to affect the data acquisition, data base management, and data processing functions. Much of the data dissemination and display functions will be via intelligent, inter-active color-TV display terminals permitting the merger of satellite and radar images with graphics of analyzed meteorological fields.

We provide system test output to the Denver National Weather Service Forecast Office as well as to our own facility. Thus, the task of evaluating the effectiveness of any particular technique for observing, analyzing, forecasting, disseminating or displaying weather events is a joint effort shared by meteorological research and operational personnel of NOAA. In order to facilitate this task, the computer system is operated continuously in a nowcasting and forecasting mode so that evaluation of various techniques is automatically accomplished in an operational environment.

A broad perspective overview of PROPS will not be presented here. The best source for that at the moment is a document known as the PROPS Implementation Plan which is available from the PROPS Program Office. Copies of this document may be obtained by contacting Dr. Donald W. Beran, Director, PROPS Program Office, NOAA/ERL, Boulder, CO 80303 (telephone 303-499-1000, x 6765). Two recent papers by Beran and Little [2,3] also provide useful background material on the purposes, goals, and concepts of the PROPS program.

2. PROPS MISSION

The primary mission of PROPS is to improve local weather services. In the course of designing a program and an organization to accomplish this mission, many people of varied backgrounds contributed to the identification of areas needing improvement, recommended methods of approach, and attempted to judge likelihood of success of various approaches. The PROPS program as it currently exists is a direct outcome of that design activity.
Design team members were drawn from National Aeronautics and Space Administration (NASA); Air Weather Service (AWS); Air Force Geophysics Laboratories (AFGL); Federal Aviation Administration (FAA); various elements of Environmental Research Laboratories (ERL), National Weather Service (NWS), and National Environmental Satellite Service (NESS); private meteorologists; and university professors from the disciplines of meteorology, economics, sociology, and market survey techniques. A varying number of these people met in Boulder one to two weeks every month from March through July 1979.

A basic conclusion of this team was that a vastly improved service could be achieved simply by improving dissemination techniques. However, all team members also emphasized the need to observe, analyze, and forecast mesoscale weather events as an obviously important factor for significant local weather service improvement. Mesoscale weather events are not now universally or uniformly observed; improvements in forecasting or dissemination of mesoscale weather events therefore depend on improved local observational and analysis systems.

The simplicity of this concept in fact leads to an extremely complex program. There are a number of techniques for observing local weather events; each technique suffers from its own particular limitations and must be considered as one of a total array of techniques; evaluation of effectiveness of complementary techniques requires a facility with sufficient computer power to handle tremendously large data sets in the short time scales associated with mesoscale circulations; effective "technology-transfer" of techniques from the research community to operational practice requires constant attention to the proper human/hardware/software mix needed to distinguish between "information content" and "streams of data." Consideration and analysis of all details making up these complexities is a continually-evolving, system development process. In parallel with this system development effort, we are in the process of implementing the EDF which is designed to accommodate our present understanding of these complexities and to be flexible enough to be expanded or modified if and when necessary. The primary purpose of this EDF is to provide the resources required to permit members of the PROFS staff to select, test, and evaluate the array of techniques which will eventually make up a local weather service. The description of the EDF that follows treats the elements of observations, analysis, forecasting, and dissemination in turn.

3. PROFS EXPLORATORY DEVELOPMENT FACILITY

As presently conceived, there are five major observational sources for inclusion within the EDF: 1) satellite-based visible and infrared images of the earth's surface and cloud cover as well as infrared and microwave radiometer radiance measurements which can be mathematically inverted to provide temperature profile information; 2) conventional weather radar measurements of precipitation areas coupled with Doppler radar measurements of winds and circulation patterns associated with convective storms; 3) surface networks of conventional meteorological sensors measuring wind, temperature, dew point, pressure, rainfall rate, visibility, and solar radiation; 4) surface and upper-air observations and analyses on a synoptic scale available from the Automation of Field Observations and Service (AFOS) network of NWS; 5) surface-based remote sensors to provide upper air data on a space and time scale required for sophisticated mesoscale numerical models. Let us examine some of the characteristics, advantages, and disadvantages of each of these data sources for mesoscale applications.

3.1 Satellite Data

Satellite data will be obtained by PROFS via a high-speed communications link to Colorado State University (CSU) at Fort Collins, Colorado. A satellite data receiving and processing system exists at CSU that is capable of receiving images and generating digital data products from two geosynchronous satellites which routinely provide visible and IR images every thirty minutes during daylight hours, and IR images only during nighttime hours. Resolution of the images at the nadir (directly below the satellite) is roughly
0.8 km for the visible data and 8.0 km for the IR. The images must be navigated with reference to fixed, known geographical reference point(s) in order to take advantage of this resolution. This operator/machine interactive process takes 3 to 5 minutes. Typical digital data products derived from these images include cloud-top heights, cloud motions or cloud-derived winds, and horizontal distribution of rainfall areas and amounts. The geostationary satellite systems are also capable of a 3-minute observational duty cycle. This rapid duty cycle will be exercised for selected periods in time, but initial experience will be based on the 30-minute cycle.

Data from polar-orbiting satellites will be made available to CSU and to PROFS from the University of Wisconsin/NESS/Space Science and Engineering Center at Madison, Wisconsin. The most important additional data type possible from this link is the temperature profile data derived from the radiance measurements made on the orbiting satellites, a data type not presently available operationally from the geostationary satellites. Excellent horizontal resolution (from ~0.5 to 10 km) is possible for these data, but they are available only twice per 24 hour-day. By roughly 1982 or 1983, temperature profiles will become available on geosynchronous satellites on a routine basis. Thus, the primary data set from satellites for the next two or three years will be images and products derived from these images.

3.2 Weather Radar Data

The NWS operates two conventional weather radars within the PROFS "region" — one at Limon, Colorado, the other at Cheyenne, Wyoming. Current planning is to pre-process the digital data streams at each of these sites to provide reflectivity, convective storm moment and three-dimensional echo distribution to the EDF and to CSU. Once implemented the pre-processing systems will provide products similar to those described recently by Saffle [12].

The need for Doppler radar data was stressed by the PROFS design team members. At present, the earliest possible date for this to occur is September 1981 when the National Center for Atmospheric Research (NCAR) may be able to operate a 10-cm Doppler radar in the PROFS region for an extended period of time. Until then it appears likely that the only radar data that will be consistently available to the EDF will be those from Limon and Cheyenne. This is unfortunately somewhat limiting, not only because of the lack of Doppler data, but also because the size of the "core region" for PROFS approaches the range limits of present NWS radars.

3.3 Surface Network Data

The nucleus of this data source is a twenty-station network of conventional meteorological sensors located within a 50-mile radius of Boulder. Sampling and averaging of these data is accomplished by computer control. The basic data base unit is a 5-minute average along with maximum and minimum values for each 5-minute period of wind speed and direction, temperature, dew point, rainfall rate, pressure, visibility, and solar radiation. In addition to this basic network, data from two rain gauge networks will be sampled: 1) a Colorado-wide network maintained by the NWS, the Automatic Hydrological Observation System (AHOS/S), with communication via satellite; 2) a Boulder Valley network of up to twenty rain gauges operated by Denver's Urban Drainage and Flood Control District (UDFCD) with communication via VHF radio. Two other networks, a 5-station wind and temperature network operated within metropolitan Denver by the Public Health Service, and a 5-station wind network operated in Boulder by the Wave Propagation Laboratory (WPL) will also be incorporated within the EDF data base to provide details of the city heat-island of Denver and of downslope wind events.

The major advantages of surface networks are low maintenance costs and well-established, time-proven reliable technology. The major disadvantages are the lack of measurement in the vertical and a non-uniform, inadequate horizontal resolution. It is likely that the
network of rain gauges will "miss" more convective rain storms than they "see." This has the potential of being a very serious limitation for the task of tying together satellite, radar, and surface data in the manner required for quantitative precipitation estimates.

Some alleviation of the disadvantages will be achieved by mid-1981 when a network of some 100 observers using touch-tone phone entry to the EDF data base will be implemented. This will be conceptually identical to the observational system already proven in the CRAB nowcasting experiment (Scofield and Weiss, [14]).

3.4 Synoptic Scale Data

The EDF will include an APOS terminal in an expanded WSO configuration. This connection with the national meteorological data base is essential for the proper nesting of the EDF mesoscale data base within the larger scale. For example, merging of Limited Fine-Mesh model (LFM) products from the National Meteorological Center (NMC) with local satellite and radar products is expected to be a very frequent and useful activity.

Because of present uncertainties in the APOS-activation schedule on a national basis as well as potential data transmission delays of gridded LFM products, we have also planned a direct tie-in to NMC products via a data link that presently serves National Center for Atmospheric Research (NCAR) and the Bureau of Reclamation. The synoptic scale national data base will be available to PROFS by late 1980 either through NMC, APOS, or both.

3.5 Surface-Based Remote Sensors

A widely-recognized requirement for initializing mesoscale dynamic forecast models is upper-air data on a commensurate scale. Except for intensive research experiments of finite duration, rawinsonde networks do not appear to be economically viable. Remote sensors designed to provide continuous profiles of wind, temperature, and moisture are presently under development by WPL. Three to five of these profiler devices will be installed in the PROFS region at separation distances of 100 to 200 km by 1982/1983. They will provide continuous ten to fifteen minute averages of upper air data to PROFS.

4. NOWCASTING, FORECASTING, AND DISSEMINATION

At the present time a significant fraction of the PROFS staff is dedicated to establishing a functioning EDF with the capabilities outlined in the previous schedule. It is expected that our first products will consist of nowcasts based on analysis and displays of weather information drawn from the basic data base. Updating of the nowcasts will be possible on five to fifteen minute duty cycles. Forecasting models will be limited initially to advective, pattern recognition, and statistical techniques and will be targeted for the half to three hour time period. Examples of such models are a snow depth forecast model for the Colorado Rockies (Rhea, [11]), single-station model statistics (Miller, [10]), precipitation area and amount forecasts derived from satellite images (Scofield and Oliver, [13]), cell-tracking and precipitation forecasts for convective storms derived from radar data (Elvander, [8]; Crane, [7]; Bellon and Austin, [1]). Activity is underway to implement these and similar models within the EDF for testing, comparison, and evaluation of their reliability and effectiveness in an operational setting.

The operational dissemination point for EDF products is the Denver Weather Service Forecast Office (WSFO). The WSFO is being equipped with a color graphics work station which will have full interactive capability. Nowcast products are available on hardcopy from the surface network; initial satellite images are available now on a "dumb" terminal; fully interactive graphics and image capability will be available by mid-1981.

Forecasts based on a combination of satellite, radar, and surface network data will be disseminated by mid-1981, using the models listed above as well as others. The basic
thrust will be to provide a test platform within the EDF and the Denver WSR-57 to judge the operational effectiveness of various techniques. Real-time data acquisition, rapid analysis schemes, frequent nowcast and forecast updates are all critical elements of this effort. Extensive development work is required to achieve this capability and we are drawing heavily on experience and work of other groups and organizations to guide and influence our efforts: McIDAS effort at the University of Wisconsin (Smith, [15]); AOIPS effort at NASA/Goddard, Greenbelt, MD (Bracken, et al., [4]); flash flood programs of the NWS Hydrologic Research Laboratory (Greene, et al., [9]); the satellite/radar based precipitation forecasting program in England (Browning, et al., [5]) and Canada (Bellon and Austin, [1]).

By 1982 we expect the PROFS EDF to be capable of disseminating computer-based products directly to selected test populations of the general public using voice response systems such as presently being tested by the FAA (Chokhani, [6]), menu-selective TV displays, and animated displays on cable TV.

The nowcasting, forecasting, and dissemination activities are areas within which our successes and accomplishments will be measured by the meteorological community as well as by the general public and special users of mesoscale weather information. Future reports from PROFS staff members will be devoted to these aspects of the program.

5. ACKNOWLEDGMENTS

We are grateful for many discussions with all members of the PROFS design team and the PROFS staff, for the opportunity to share in the PROFS program and to summarize some aspects of the program in this paper. Drs. Donald Beran and Peter Mandics deserve special thanks for reviewing this paper as well as for their continuing guidance and consultation. Ms. Mildred Birchfield deserves special thanks for typing the manuscript.

6. REFERENCES


INTRODUCTION

Automated meteorological networks are now installed for many purposes, not only for replacing existing observation systems as synoptic or climatologic stations, but also for new dedicated investigations as for instance traffic assistance, airport control, nuclear power plant and high power lines meteorological control, dedicated hydrological systems for flash flooding and water basin studies, air and water pollution, urban climatology, local weather forecast, etc. With this evolution, new problems arise which are mainly due to the specific spatial and temporal characteristics of the meteorological events to be observed. As most of these applications are related to local or meso-meteorological conditions, dense networks and high sampling rates are, in principle, required. Moreover, additional meteorological information, obtainable by specific sensors, are now asked for.

The aim of this study was to investigate the different problems lay down by the execution of meteorological measurements in urban environment attempting to examine the various techniques which are in use or which can be used, to determine the incidence of instrument exposure on the precision of the measurements and to investigate the spatial and temporal representativity of the observations. The study is based on the experience acquired by the installation and operation of 5 automatic meteorological networks in the major cities of Belgium and on replies to a questionnaire which was send, via WMO, to all CIMO members.

1. URBAN METEOROLOGICAL OBSERVATIONS

Since the WMO symposium on Urban Climates (8) a large number of cities has already been subjected to extensive meteorological studies, many have dwelt especially with the spatial variation of the urban heat island with primary emphasis on near surface temperature measurements. Only a limited number of papers attempted to describe spatial and temporal changes in wind and temperature profiles, radiation and precipitations. Even less has been done to determine changes in the turbulent structure of the urban boundary layer and energy balance. These limitations in our knowledge of the Urban Climate are to some extent related to the particular problems lay down by the execution of meteorological measurements in urban environment, among others, by the high degree of turbulence, the presence of obstacles and the fact that the urban climate is a mixture of different microclimates. Considering the purposes of urban studies, measurements can roughly be divided into three general categories with special requirements for each:

a. Climatological observations with special emphasis on urban-rural differences and long term trends. It is suggested that each National Weather Service should at least have one station whose site remains unchanged for years in each climatological region of the country for homogeneity of observations and detection of temporal changes. Climatological observations do not in general include analysis of statistical properties of fluctuations of wind speed and direction. However as the demand for such information increases, new methods of record reduction and data processing will be highly necessary.
b. Operational activities as air pollution control and local weather forecast. There is still a handicap brought on by the lack of facilities to achieve rapid reduction and analysis of the basic data. Time lost until analysis is available might be appreciable in a field operation far removed from computer facilities, precluding immediate actions, if required, to counter existing conditions.

c. Research studies. There is little uniformity because the instruments are highly specialised and because each group has usually developed its own favourite techniques and instrumental equipment. Depending on the purpose of the observations, an appropriate configuration of an automated station or network is envisaged. As there seems to be no obvious reason for an unique automated system for all purposes, in the next paragraphs, common types of measurements, which are desirable for understanding the urban mechanism, are discussed separately. Only parameters are considered for which sufficient information exists.

1.a. GROUND-BASED AUTOMATIC METEOROLOGICAL OBSERVATIONS

TEMPERATURE

The urban island is one of the most documented climatological effects of atmosphere modification attributable to urbanisation. In almost all cities the heat island is detected with the aid of mobile surveys. The technique consists in mounting one or more temperature sensors in an artificially aspirated radiation shield in front of an automobile at a height of two meters above the ground.

The method consists in traversing the city at a speed of about 40 km/hour following predetermined itineraries, several reference stops are foreseen in order to compare data with previous or later traverses. In many cases different cars simultaneously traverse the city in order to get a maximum of data in a minimum of time. In general resistance or thermistor continuous measuring systems are used and an accuracy of 0.2-0.5°C with 0.1°C resolution and a 2-3 seconds time constant are considered as satisfactory.

Although the traversing procedure is superior to the use of fixed stations in that it allows improved spatial sampling, due to operational constraints, temporal sampling is limited. As a consequence the procedure is suitable to highlight special land use effects but do not help in the search for governing mechanisms. From a more practical point of view mobile temperature surveys are generally considered as valuable and inexpensive tools for preliminary investigations aimed at future installations of fixed meteorological networks not only for temperature measurements but also for parameters which variation influences or is influenced by the heat island configuration such as radiation and wind.

Temperature observations at fixed stations allow better studies of the important temporal aspects of the heat island than mobile surveys as far as a sufficiently dense network of stations is available covering the whole city with its distinct land-use areas. An indication of required horizontal density is given by the replies to the questionnaire. For the U.S. a spacing of 5 km is probably adequate. For Japan and also France (DETTWILLER (1)) this density depends on the scale and topography of the urban area but it should be high in urban and low in sub-urban; Japan requires one station at intervals of 10 km or less. India prefers observations at much closer distances (1 km) inside the city and wider (3-4 km) as one goes away from the center. For Australia three or four stations are sufficient for most purposes for urban areas up to 100 km² provided limited field traverses with mobile equipment are made to delineate isotherms patterns over the whole area. Israel and Canada recommend preliminary surveys to determine the standard error and to calculate an adequate sample size. There is no clear solution with regards to the height of the observation. All temperature measurements with the traversing method take place in the meso-scale street level environment, but the coupling between this environment and the urban meso-scale boundary layer is not yet understood. From a practical point of view, the definition of an "urban surface" is most desirable. However, this involve detailed research into radiation and energy balances. In the Belgian network two temperature measurements are made, one at 2 meter and one at the top of a 30 meter height tower. However, almost all countries mention that special attention has to be paid to the different land-use in the city and that at least two or more measuring points, representative for each specific
region, should be installed.

For specific purposes it will be necessary to lay down new rules, so that site selection procedures could include the investigation of the representativity of the measuring point with respect to the character of the surface material and amount and degree of aggregation in cities. However, a representative exposure of the desired environment is probably a very difficult parameter to establish and the most likely source of errors or unknown.

**WIND**

It is well known that cities reduce high windspeeds and can generate their own circulation system at windspeeds less than 3 to 4 m/sec. As a consequence wind data obtained at a close, but rural, site, e.g. an airport, are not representative and in-city measurements are desirable.

Following the questionnaire a network with a grid spacing of about 10 km is considered as satisfactory. However, the density may vary widely with the purpose of the study, with magnitude of local-meteorological variations, local topography, heat island configuration, presence of large water surfaces and the number of different land-use areas. As for temperature an appropriate classification of different areas is most desirable. In the United Kingdom, for example, environments are categorised for design purposes as "suburban" (mean heights of obstacles : 10m) or "city center" (mean height of obstacles : 25m). To obtain values representative of the whole urban area, wind observations should be made in both types of environments and also for comparison purposes at an unobstructed site close to but outside the city area. To provide an observation which is representative of an urban area rather than merely of the observation point itself, the sensors should be placed significantly higher than the general level of roof tops. A height of 15 to 20 meter above the roof level is a generally accepted minimum. The allocation of heights above the general level of the rooftops in urban areas is sometimes difficult; ideally the sensors should be mounted above a building of height similar to that of its immediate neighbours and should be unobstructed by higher buildings located within 300-400 meter. As an example, in the Belgian urban networks all windsensors are installed at the top of a 30 meter height tower. However, in order to make sound deductions from recorded urban wind data, it is essential to know the effective height of the instrument and to have some estimate of the surface roughness of the surrounding area in all directions. The absence of this information is a major limitation on the usefulness of urban wind data.

Due to the high degree of turbulence in cities, wind sensors, usually calibrated in wind tunnels, show systematic errors which are considerably higher than the 1% accuracy commonly demanded. These errors arise from sensor sensitivity to relative wind direction, sensor dynamic response characteristics and data averaging procedures. MAC CRABADY (4) stated that for light winds and in rough terrain such as in cities, the difference between the readings for different types of fast response sensors easily amount to 30-40% and for larger or slower sensors the difference would diverge even more rapidly, even so large that their magnitude cannot be accurately estimated. These errors may effect the design and interpretation of wind measurements in urban area. Additional theoretical work, wind tunnel studies and field comparisons between commercial and very fast response sensors is desirable. The response characteristics of the different parts of the measuring system should be sufficiently small so that statistics can include the contribution of all short-period motions affecting sensibly the phenomena under study. Following MAC CORMICK (3) the response of sensors and recording equipment is probably sufficient fast if a faithful reproduction is obtained of those fluctuations whose period is equal or less than one half ratio of the height of observation to the wind speed. Since most of the urban modification to the synoptic circulations occurs during periods of calm or very light wind, starting thresholds of 0.5 m/s and even 0.2m/sec are now asked by many users.

In general continuous recording is asked for. This method allows calculation of mean wind speed and direction over appropriate time intervals (in general half hourly or hourly means) and analysis of wind fluctuations. It is to be noted that more users ask for such analysis not only for special purposes such as energy measurements but
also for pure climatological purposes. The inability to use all of the information available from a continuous recording is considered as a serious limitation of wind measurements. Therefore several users ask for convenient methods for record or data reduction preferably by means of a device which is an integral part of the wind sensing and recording instrumentation.

RADIATION

Since the WMO symposium on Urban Climatology (Brussels, 1968) several research studies have shown that due to different atmospheric properties and surface characteristics the component short and long wave radiation fluxes and their related surface radiative fluxes experience changes. Nevertheless OKE (6) stated that much remains to be explored. Urban radiation measurements are desirable and the following measurements should be useful: continuous measurements of the global and diffuse radiation; sporadic measurements, although more difficult, of the direct solar beam, eventually with the aid of appropriate filters and net radiation balance measurements if possible (very difficult to find an appropriate site). The density of a network is related to the horizontal variation of the parameters which, in the case of radiation measurements, is still not very well known. Furthermore in order to avoid redundancy of observations the variations must be larger than the instrumental accuracy which is for global radiation measurements about ± 2% for diffuse and direct radiation and for balance measurements about ± 10%.

PRECIPITATION

Important rainfall increases are observed in many urban areas of varying size, type and climate. This increase is also observed at considerable distances in the downwind rural area. As a consequence precipitation measurements in the city as well as up to 40-45 km downwind are useful. However, the question remains open wether it is necessary to install large and expensive networks or wether it is sufficient to install a limited number of stations taking into account results of research programs such as Metromex. Following the questionnaire urban networks with a 5 km grid spacing are considered as a minimum; different countries even prefer much denser observations of the order of 2 km grid spacing if the necessary funds would be available. Segments of urban areas subject to flash flooding, as mentioned by Australia, can require much closer networks e.g. a 500 meter grid. France (DETTLWILLER (1)) prefers, taking into account the natural variability of rainfall rate both in space and time, a limited but well selected network equipped with high quality instruments. The density of the grid in a city often precludes the application of the WMO Guide to Hydrological Practices. Guidance on instruments exposure and site selection is the result of experience or opportunity. As an example, the U.S.A. resorts to roof tops in the densest population areas but try to find surface sites usually even though these would be more sheltered than desirable. Wind and his associated turbulence created by buildings or other obstructions are the two most important factors that would tend to change the collection efficiency of rain gauges in urban environment.

1.b. LOW ALTITUDE MEASUREMENTS

Demands for data in the urban boundary layer have increased dramatically in recent years and the acquisition of vertical profiles of different parameters and reliable air trajectory information becomes a problem of concern to meteorologists. Different experimental approaches are used which roughly can be divided into high tower measurements and low level aerological measurements. However, no single system meets all requirements and each has shortcomings even for making the measurements for which it is best suited. High tower measurements are the only means of making accurate and especially continuous measurements but their altitude coverage is limited to heights far below upper limits of the urban phenomena. Also the number of towers available in cities is very low. Low level aerological measurements allow improved spatial sampling but their temporal sampling is limited due to operational constraints. New techniques, in casu remote sensing, seems to offer new possibilities. The problem then consists in whether such low altitude measurements can be made automatically or semi-automatically (necessitating human intervention) followed by introducing the measured data into the data stream of an automatic network. There seems to be no major problems for meteorological towers. According to replies to the questionnaire
high tower measurements are preferred for routine data collection and detailed studies. The sensors should at least have the same instrumental characteristics as surface instruments and for temperature the accuracy should even be better (0.1°C). The U.S.S.R. mentions that at least four different observation levels are to be envisaged. A very critical problem is the correct exposure of the sensors because sensors are usually mounted on existing towers, pylons or even stacks which are often not very suited for meteorological measurements. Very interesting guidelines for the distance and direction in which sensors should be located to achieve a specified accuracy are given by GILL (2). These guidelines rely on typical meteorological towers but can be generalised to different shaped towers.

Vertical sounding systems which are now in use are: pilot balloon systems for wind measurements and free flying or captive radiosondes for temperature and, for some purposes, also pressure and humidity measurements eventually combined with a wind tracking systems. Inexpensive tethered systems are introduced which have the same possibilities as radiosondes and, in addition, are equipped for in situ windspeed and direction measurements. Several systems now exist which are equipped with a completely automatic data acquisition and processing systems. As a consequence the incorporation of such measurements can be made with a minimum of human intervention. With regards to the horizontal station density, some countries consider a network with a spacing of 3 to 15 km as necessary; for other countries one or two stations are a reasonable starting point for small and medium size cities and two or more for metropolitan areas. Regarding the temporal density, most countries consider 2 to 4 observations a day as highly desirable. It is suggested that as a preliminary experiment hourly observations may be made at all locations and the number may be reduced to a bare minimum after evolving some empirical relationship for the diurnal variation. For some countries only occasionally but very intensive (hourly) measurements are foreseen according to the weather situation (e.g. air pollution control).

Because of their unique possibility of sensing the urban boundary layer with only ground based equipment, remote sensing presents many advantages over low level in situ sounding systems and are generally considered as very attractive tools. Systems based on the interaction of acoustic waves with the atmosphere are most advanced. The monostatic acoustic radar or acdar is the best known and already more than 200 systems are in operation all over the world. This instrument seems to be very interesting for investigations of the structure of the urban boundary layer and heights of inversion although it does not allow absolute measurements of meteorological parameters. Problems associated with the interpretation of the recorded pattern and proper shielding against background noise still wait for solutions (VAN GYSEGEM (7)). Wind measurements systems are also field tested but more research is necessary to render these techniques suitable for urban operation, to extend the range of measurements to heights of 1000-1500 meter, to make all weather systems and to process the large amount of data. Over the last years important progress is made in the digitalisation of acdar recordings. Several methods are proposed for condensing the considerable amount of data into integrated data and classification of typical patterns into a limited number of data to be transmitted. Some countries have the intention to incorporate such measurements in an automatic meteorological network. Wind acoustic system or DOPPLER system have already digital outputs and can easily be incorporated into automatic networks.

2. GENERAL REMARKS

In order to investigate the spatial and temporal characteristics of the urban climate appropriate and relatively dense networks of meteorological observations are desirable, indicating the use of automated meteorological systems. The density which is desirable or practical depends on different factors, the importance of which varies from city to city, the horizontal and vertical variation of a meteorological parameter considered and the purpose of the observations. Special attention should be paid to:
- the sensor response in the highly turbulent urban atmosphere involving field comparison between commercial and very fast response sensors conducting to sensor standardisation in accordance with the space and time scale of urban phenomena;
- the incidence of instrument exposure on the precision of the measurements leading to site selection criteria of the microposition of the observing system;
the representativity of the observations in space and time. An important point is a definition of the different land-use regions in a city (domestic, industrial, commercial, residential, etc.). This specific land-use regions with areal continuity among materials, e.g. buildings and street pattern should be quantified if possible by physical parameters like thermal conductivity, roughness length, heat capacity, etc.

The interpretation of urban meteorological phenomena not only require ground based measurements at some "urban surface" but also the inclusion of low level data. Recent developments seems to open new possibilities for the introduction of these data into automated systems. In addition specific measurements of physical variables responsible for urban climates and additional specific meteorological measurements such as heat, moisture and momentum exchanges could be incorporated in routine automatic measurements. There are still important problems waiting for experimental approaches such as radiation, water and energy balances and climatological effects such as atmospheric humidity.

Faced with the enormous complexity of the city/atmosphere interface, the attitude of many meteorologists has been to avoid measurements and to favour the construction of numerical or other models. This trend could lead to an odd situation where research activity is divorced from physical reality. Therefore complex networks such as the Metromex approach (Metromex, 1974) are necessary but not in all cities.

This contribution is to be considered as an approach, in the general scope of CIMO, of a particular application of automated networks. As the number of "dedicated" automated meso-meteorological networks is fast growing and future users are not always very familiar with the complexity of the experimental approaches, guidelines or general information could be given by for instance CIMO.

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WEATHER PROFILING BY GROUND BASED LIDAR

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Introduction

In remote sensing methods for the measurement of atmospheric parameters the interaction of waves (acoustic or electromagnetic) with the molecules and particles of the atmosphere is used. The remote sensing methods have several advantages over conventional methods especially in automatic operation. Mapping over large volume can be performed by scanning the field of view, true vertical profiles can be obtained continuously with high temporal resolution without moving a sensor and the influence on the atmosphere by the sensor is practically eliminated. Automatic unmanned operation implies low operation costs which compensates for higher investment costs.

In this paper we will describe the use of LIDAR, (Light Detection And Ranging), which is the optical counterpart to radar, for atmospheric probing. Lidar techniques became feasible when the laser was invented in 1960 and since then the evolution of lidar methods has been rapid. The interaction of optical radiation with atmospheric molecules and aerosol particles is strong and therefore lidar has potentially a wide field of applications and is suitable for quantitative measurements. Another less favourable consequence is that the lidar range is limited by optical attenuation in fog and clouds. So far the lidar has not become an operational meteorological tool except for rather simple cloud base meters, but it has been widely used for research. In this paper we will briefly discuss a number of lidar methods and finally in more detail describe two methods for humidity measurement which we are investigating.

An extensive review of lidar methods is available in a book edited by Hinkley (2). Ottersten and Högärd (4) have written a review describing Sodar and Lidar measurements. Both reviews contain extensive lists of references.

The Lidar principle

A pulsed laser is normally used as radiation source in a lidar. Short pulses of radiation are emitted in a narrow beam into the atmosphere and are scattered by the molecules and particles. Radiation scattered backwards is collected in the lidar receiver telescope, focused on a detector and converted to an electric signal which is displayed. The time delay from pulse emission to detection of the return from a certain scattering volume element is proportional to the range to the volume and thus the receiver signal versus time displays the density of scattering particles as a function of range. The receiver signal versus range is expressed by the Lidar equation.

\[ P(r) = C_1 \eta(r)\beta(\lambda) \exp(-\alpha_\lambda r) \int_0^r \left( \sigma(x) + \sigma(\lambda) \right) dx \]  

(1)
where \( r \) is the range (m) to the scattering volume element and \( P(r) \) is the received power (watts), and \( C_1 \) is a system constant which is proportional to the emitted pulse energy and to the receiver field of view and laser beam in the near zone. For large \( r \)-values \( \eta(r) \) is normally 1. The term \( r^{-2} \) accounts for the normal illumination law or the decreasing angular area of the receiver with increasing range. \( \beta(r) \) is the backscattering coefficient or backscattering cross section per unit volume. The exponential term accounts for the two way optical attenuation due to the gas absorption coefficient \( \sigma \lambda \) and the gas concentration \( c(x) \) and to the scattering coefficient \( \sigma \).

The spatial resolution is determined by the laser pulse length \( t_p \) and the light speed \( c \).

\[
\Delta r = t_p \frac{c}{2}
\]  

(2)

The accuracy of lidar measurements is to a great extent determined by the signal/noise ratio of the detected signal. In the near UV and visible region the noise is mainly caused by sky radiation during daylight conditions. To reduce the noise level, the receiver field of view is made as narrow as possible and a narrow bandwidth optical filter is used in front of the detector. The ability of the laser to generate narrow beams with high spectral purity has made these noise reduction techniques feasible. In the IR-region the sky radiation has low intensity and allows day and night measurements with equal performance. A method to improve the signal/noise ratio, which is especially useful in the IR-region is heterodyne detection. This implies mixing the detected radiation with a local oscillator beam and requires a laser with good coherence and stability. The heterodyne technique has also the important advantage that the frequency shift of the detected radiation can be measured. When the scattering particles have a velocity component along the lidar beam, the detected radiation has a "Doppler shift", which is proportional to the velocity component. This can be used for wind measurement. Design data for lidar systems vary depending on the applications. As examples we refer to the systems described later in this paper. High power laser beams in the visible and near IR-regions can be dangerous to the eye even at several km range and safety precautions are necessary. IR-lasers above 1.4 \( \mu \)m are far less dangerous and the eye safety problem can normally be ignored.

The scattering coefficient \( \beta \) is proportional to the number density of scattering particles and to the scattering cross section of the particles. Elastic scattering results in scattered radiation at the laser wavelength and is obtained from molecules as Rayleigh scattering or from aerosol particles as Mie scattering. The Rayleigh scattering cross section varies with wavelength \( \lambda \) as \( \lambda^{-4} \). Mie scattering has a complicated dependence on wavelength and size distribution and refractive index of the particles. Elastic scattering appears without any interaction with internal molecular energy states and therefore contains no information on the type of molecule involved.

Raman scattering, which is a non-elastic scattering process, produces radiation with a spectrum that is shifted from the laser wavelength due to interaction with vibrational and rotational states of the scattering molecules. The Raman spectrum is therefore characteristic for the type of molecule. The form of the spectrum also contains information on the temperature. The Raman cross sections are very small and therefore powerful lidar systems are required.

The extinction coefficient \( \sigma \) due to scattering at the wavelength of maximum eye sensitivity, 0.55 \( \mu \)m, is related to the meteorological visibility \( V_M \) as

\[
\sigma = 3.9/V_M
\]

(3)

where \( V_M \) is defined as the range of 2 \% contrast transmission.

In the DIAL-method a tunable laser is used to measure gas concentrations. Elastic scattering from aerosols is detected with the laser tuned on and off an absorption line of the gas. By comparing the received signals at the two wavelengths the gas concentration versus range is inferred.
A short presentation of some useful lidar methods for different meteorological variables follows:

**Temperature profiles**

Raman scattering from $N_2$ and $O_2$ can be used. An accuracy of ±0.5 K at 2000 m altitude has been estimated from measurements at night. Daylight operation requires a laser in the UV-range below 300 nm, where ozone attenuates the sky radiation.

Doppler methods to measure the Brownian motion of air molecules and DIAL-methods that utilize the temperature dependence of absorption line strengths are promising, but require further development. Ranges of several km have been estimated.

**Humidity profiles**

Raman scattering has been used up to altitudes above 2 km and an accuracy around 10% has been obtained at night. Daylight operation in UV is possible. DIAL-measurements with a Dye-laser to an altitude above 3 km have been reported with estimated errors around 10% at night.

**Wind profiles**

Heterodyne Doppler detection of aerosol scattering with CO$_2$-lasers has been demonstrated for wind profiling to above 2 km. An accuracy better than 1 m/s can be obtained. Focused continuous wave lasers, which give poor range resolution at long ranges, have been used, but pulsed systems with far better resolution has now been developed. A Doppler CO$_2$-lidar is developed for the space shuttle project as described by Huffaker (3). With correlation techniques the flow of aerosol density structures with the wind can be measured using an incoherent pulsed lidar with beam scanning.

Other important lidar applications are mapping of aerosol layers, cloud height and cloud structures studies and visibility measurement. An important application, which needs further study is slant visibility measurement at airports.

**Raman lidar for water vapor profiling**

In order to study the feasibility of the Raman lidar technique for humidity profiling, we participated in a field experiment organized by the Swedish Meteorological and Hydrological Institute in May 1980 at Klockrike. The lidar profiles were compared with profiles of water vapor mixing ratio obtained from balloon soundings performed by the Military Weather Service. Estimated mixing ratio accuracy from the Vaisala radiosondes is 10%.

The lidar, which is described in a thesis by Fredriksson (1), is truck mounted. A YAG-laser emits 10 pulses/s with a pulse length of 10 ns. We used the third harmonic at 355 nm with a pulse energy of 30 mJ. The beam was directed vertically along the optical axes of the receiver telescope, which has 30 cm diameter and 1 mrad field of view. Two interference filters, with center wavelengths corresponding to the $N_2$ Raman (386 nm) and to the H$_2$O Raman (408 nm), mounted on a wheel in front of the photomultiplier detector, were alternated. The filter bandwidths are 9 nm and the transmission factor 0.4. An extra attenuation with a factor 10 was added to the $N_2$-filter to avoid saturation by the strong $N_2$-return.

The signals were digitized to 8 bits with 100 MHz sample rate and the signals due to $N_2$ and H$_2$O were stored in separate memories. A minicomputer controlled the measurement process, so that during a complete sequence, lasting 10 minutes, 3400 H$_2$O-returns and 1700 $N_2$-returns were added. Without processing, the range resolution was 1.5 m. To reduce the noise level, the sum signals were multiplied by a Gaussian weighting function to produce a running mean value. The half value width was 7.5 m for ranges up to 360 m and 30 m for longer ranges with lower signal to noise ratio. Data from the night between the 9th and 10th of May are presented below. In figure 1 the H$_2$O and $N_2$-signals summed over a 10 minute's period at 2 a.m are shown versus altitude. The signals increase at low altitudes due to increasing overlap $\eta(r)$ and then decrease due to $r^{-2}$. The signal at a given altitude is proportional to the concentration of $N_2$ and H$_2$O respectively.
Fig. 1. Raman signals versus altitude at 2 a.m.

With the minicomputer the ratio of the H$_2$O-signal to the N$_2$-signal was calculated. This ratio, which is proportional to the H$_2$O mixing ratio, has been multiplied by a calibration constant equaling the lidar ratio to the radiosonde mixing ratio at 200 m. Lidar mixing ratios calibrated in this way are plotted together with radiosonde ratios as profiles in figure 2. The local time is written above each profile. Above about 1800 m at night the H$_2$O-sIGNALS have decreased due to r$^{-2}$ and H$_2$O-concentration to reach approximately the noise level. In the evening at 9 p.m and in the morning at 5 a.m the sky radiation increases the noise and decreases the range to below 800 m. For altitudes below 30 m the lidar signals are low due to beam mismatch and no correct ratio is obtained.

Fig. 2. Lidar profiles and radiosonde profiles of water vapor mixing ratio for the night between May 9 and May 10.

Lidar profiles were measured at two occasions 1 a.m and 3 a.m without radiosondes. The correspondence for the other occasions is satisfactory. As the balloon sondes drift with the wind while the lidar is constantly pointing upwards, some differences should be expected. Improvements on this lidar technique can be made. With narrower filter and higher...
laser power the range can be increased. With the 4th harmonic YAG at 266 nm, where ozon attenuates the sky light, daylight operation should be possible.

**CO₂-lidar for water vapor profiling**

As previously mentioned the CO₂-lidar around 10 μm is interesting for meteorological applications and differs from the Raman UV and visible lidar with respect to eye safety and background independent operation. Another advantage is the possibility of wind measurement. Disadvantages include limited range capability due to low atmospheric scatter at 10 μm, unless heterodyne detections is used. This technique requires, however, further experimental verifications and can probably not be operational for water vapor profiling within the next few years.

On considering the sensitivity limits for water vapor profiling with CO₂-lidar we return to the lidar equation (1). The received power P(r) depends strongly on the aerosol scattering (by β and σ) but also on the water vapor absorption (α), which in turn depends on the choice of laser lines. We have calculated the lidar signal versus height P(h) using a laser energy E₀ = 1 J and an effective receiver area 10⁻¹ m². To characterize in this manner two extreme atmospheric conditions, we have chosen one hazy and one very clear situation with a ground level water vapor concentration of 10⁻² and 10⁻³ atm respectively. Very few measurements of β at 10 μm have been reported. Schwiesow et al (5), however, have investigated the variation of β (10 μm) with height. From their work we assume typical exponential height profiles for β and σ.

The expression for the minimum detectable water vapor concentration is:

\[ C_{min} = \left( \frac{S}{N} \cdot \Delta \alpha \cdot \Delta H \right)^{-1} \tag{4} \]

where \( \frac{S}{N} \) is the voltage signal-to-noise ratio, \( \Delta \alpha \) the difference in absorption between the weak and strong absorption lines and \( \Delta H \) the range resolution. Following the analysis by Østergård (6) we use the expression for the signal-to-noise ratio for a differential absorption lidar considering effects of speckle noise. Using P(h) and reasonable assumptions on the sensitivity of the receiver we can evaluate \( \frac{S}{N} \) and use equation 4 to calculate the minimum measurable water vapor concentration as a function of height with 100 m range resolution. For simplicity we use \( C_{min} \) as a value for the uncertainty in the measurement.

The result of the calculations are shown in fig. 3. Obviously the heterodyne detection scheme is superior in sensitivity and range. One notices from (5) that the signal-to-noise ratio is virtually independent of laser pulse energy as long as the received power is larger than the local oscillator shot noise. This means that in the heterodyne case much lower pulse energy than the assumed 1 J can be used to have good performance out to several kilometers. Improvement in direct detection capabilities is straight forward with scaling up laser energy or receiver area but the heterodyne lidar needs more experimental investigation.

![Fig. 3. Calculated uncertainty limits for water vapor profiles measured with a CO2-lidar at 10 μm. The two profiles assumed represent two situations with very low and high humidity respectively.](image-url)
At NDRI we use a CO$_2$-lidar based on a pulsed grating tuned TEA-laser, a Newtonian telescope Zn Se focusing lenses and an HgCdTe IR-detector. The signal is amplified, digitized, integrated and the average of a preset number of pulses is stored on tape for later analysis in a desk top computer.

The goal for the measurements is to investigate the possibility of using a single ended system for measuring atmospheric extinction at 10 $\mu$m, especially for slant paths. Backscatter and extinction coefficients are evaluated from the atmospheric return. By using the DIAL method the extinction due to water vapor can be estimated as well as the water vapor concentration itself.

Examples of results are given in fig. 4 and 6. In fig. 4 the column content of water vapor averaged over a 2 km path is shown together with water vapor concentration obtained from a hygrothermograph at the lidar site. Here the laser echoes were obtained from a topographic target and the water vapor content could be measured by tuning the laser at two different wavelengths and comparing the signals obtained. The points in the figure are grouped according to separate occasions. The time delay between measurements within the group is on the order of minutes and each point is the result of averaging 25 pulses on each wavelength. Although it is hard to assign the variations specifically to the lidar or the atmosphere, these measurements still serve as an indicator of the reliability of the system.

![Fig. 4. Water vapor concentration deduced from hygrograph readings at the lidar site compared with horizontal average concentration obtained from laser echoes from a target 2 km away.](image)

In fig. 5 we show the atmospheric backscatter at a strong and a weak H$_2$O-absorption line respectively. The signals are averaged over 25 pulses to avoid too long delay between the strong and weak absorption because of the low repetition rate (1 Hz) of the laser. At present the maximum range of the system is limited to 1 - 2 km depending on the atmospheric scattering. By normalizing and dividing the two curves in fig. 5 we obtain the range resolved water vapor profile in fig. 6. The curve is obtained by consecutively averaging the concentration over a 150 m long sample cell. The noise obviously begins to dominate beyond 500 m as indicated by the error bars, which are evaluated due to the signal noise only and do not take into account the error due to the time delay between the measurements. Filtering the curves in fig. 5 with a properly chosen weighting function will probably decrease the error in the concentration profile.

We are at present looking for improvement of the system to extend the maximum range and increase signal to noise ratio. In a later step we hope to introduce heterodyne detection to essentially improve the system performance in accordance with the results obtained in fig. 3.
Fig. 5. Examples of backscatter signals for R(18) and R(20) lines in the 10 μm band of CO₂. R(20) is more absorbed by H₂O in the atmosphere. The curves are based on 25 laser pulses each.

Fig. 6. Range-resolved water vapor profile as a function of range. The profile is calculated by dividing the two curves of fig. 5. The large variations in the latter part are probably due to the noise in the signals and could be reduced by proper digital filtering of the backscatter signals.

References


DATA ACQUISITION, PROCESSING AND ARCHIVING
TECHNIQUE IN BANGLADESH

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Abstract

Acquisition of Meteorological Data both for immediate use in forecasting and future long-term use in climatologic and research purposes are carried out in Bangladesh Meteorological Service through the telecommunication system such as ordinary telegram landline teleprinter, SSB for within the country and RTT for data outside the country. The processing of these synoptic data for immediate use such as decoding, plotting, quality control and analysis is done manually through eye-hand and brain method. The data of sunshine, hourly rainfall, hourly run of wind required by the Climatologists and not normally contained in synoptic messages along with self-recording observations of pressure, temperature and humidity are collected by the Climatological Centre in graphical form, as they are in source station through ordinary post. Extraction of these data is made manually. Checking for quality control of all the above mentioned data is carried out manually with the help of scales, calculator etc. where necessary.

Processing such as calculating the average, preparation of normals, finding the extremes, preservation of data i.e. development of archive are being done, since very recently, by electronic computer method. Effort has, therefore, been made in this paper to describe mainly the technique used in archiving the meteorological, hydrological and Climatological data in the service of Bangladesh.
MATER FOR AUTOMATED CLIMATE DATA - ENCODING

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The Magnetic Tape Event Recorder (MATER) is a low power, low cost data acquisition system designed to automate the recording and the abstraction of data at climatological stations. (1)

A. Principle of Operation

When an event occurs, its channel number is coded on the tape, and the tape is advanced one increment (0.1mm). A one minute crystal clock is assigned to one of the channels to keep track of the time of occurrence of the events.

The coding used enables digits 0 to 8 to be encoded on a two track Philips style Compact Cassette. The digits are coded by combinations of positive or negative pulses on the two tracks as shown in figure 1.

![Figure 1 Recording Format](image)

B. Recorder Specification

By using input memories and scan techniques, up to 2 events per second from any or all channels may be recorded. The tape capacity is approximately 850,000 events on a C-60 Compact Cassette. The recorder consumes less than 1 Ampere-Hour of power in one month from a 12V supply. The outdoor unit can operate in the ambient temperature range of +50°C.

C. Sensor Compatibility

The MATER interfaces directly with many existing climatological sensors that have contact closure outputs, such as tipping bucket rain gauges and anemometers. As a general philosophy, other sensors are converted into the event mode by micropower electronics built into the sensor. This enables long line interfacing, easy system configuring and simple system trouble shooting.

Thermopile Radiation sensors are interfaced through an electronic integrator package that is bolted to the side of the MATER box. This integrator package, while being able to interface most analogue sensors, does drastically increase power consumption to about 10AH/month per integrator. (2,3)
### Sensor Output Parameters

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Parameter</th>
<th>Range</th>
<th>(Resolution)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tipping Bucket</strong></td>
<td>Liquid</td>
<td>unlimited</td>
<td>.2mm</td>
</tr>
<tr>
<td></td>
<td>Precipitation</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Type 45B and 77C</strong></td>
<td>Wind</td>
<td>0 to 100 mph</td>
<td>1 mile</td>
</tr>
<tr>
<td></td>
<td>Speed</td>
<td>0 to 160 km/hr.</td>
<td>1 km</td>
</tr>
<tr>
<td></td>
<td>Direction</td>
<td>8 point</td>
<td>45° at time of speed contact</td>
</tr>
<tr>
<td><strong>Component Propeller</strong></td>
<td>Vector Wind</td>
<td>0 to 160 km/hr</td>
<td>1 km or 100 meters</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>-60 to +50°C</td>
<td>0.3°C/hr above -60°C</td>
</tr>
<tr>
<td><strong>MITS</strong></td>
<td>Humidity</td>
<td>0 to 100%</td>
<td>1%/hr</td>
</tr>
<tr>
<td><strong>MIRHS</strong></td>
<td>Radiation</td>
<td>0 to 15 mv</td>
<td>0 to 1500 counts/hr.</td>
</tr>
<tr>
<td></td>
<td>Net Radiation</td>
<td>-10 to +10 mv</td>
<td>0 to 1500 counts/hr.</td>
</tr>
</tbody>
</table>

### Event Amount

- **Liquid Precipitation:** unlimited .2mm
- **Wind Speed:** 0 to 100 mph, 0 to 160 km/hr.
- **Wind Direction:** 8 point, 45° at time of speed contact
- **Vector Wind:** 0 to 160 km/hr, 1 km or 100 meters
- **Temperature:** -60 to +50°C, 0.3°C/hr above -60°C
- **Humidity:** 0 to 100%, 1%/hr
- **Radiation:** 0 to 15 mv, 0 to 1500 counts/hr.
- **Net Radiation:** -10 to +10 mv, 0 to 1500 counts/hr.

1. **Tipping Bucket Rain Gauge:**

   The sensor output is activated by a magnet mounted on the bucket. When the bucket dumps (0.2mm of rain) the magnet passes a mercury wetted reed switch which gives the contact closure that the MATER records.

2. **Type 45B Anemometer:**

   The wind vane moves a 45° brush plate across a 4 segment (90°) commutator plate. Each (N,E,S,W) is assigned a MATER channel. The cup's rotation is scaled by gears to activate a switch for each mile of wind.

   When the mile switch closes, the position of the vane is recorded on the MATER.

   In order to avoid redundancies at higher wind speeds, (ex. NE meaning 1N followed by 1E or 1 from NE), the MATER codes each distance closure as a pair:
3. **Type 77C:**

This sensor uses the same cup and vane as the 45B, but features optical direction and distance detectors. The distance signal is scaled to 1 km. By activating the L.E.D.'s with short pulses at about 65 Hz, the average power consumption is reduced to less than 100 micro-amps from 12V supply. (4)

The coding on the MATER is the same as the type 45B anemometer.

4. **Component Propeller:**

Two orthogonal propellers are sensed with optics and scaled to 1, 10, 100 or 1,000 meter outputs. Power consumption is also reduced to less than 100 µA at 12V by duty cycling the L.E.D.s, as in the model 77C anemometer.

5. **Micropower Integrating Temperature Sensor (MITS):**

In order to minimize power and tape consumption, the following technique is used. Every 4 min. an update command is sent to the sensor from the MATER. An analogue to digital converter takes a reading (2200 counts for full scale of +50°C, 0 counts for -60°C) and is then powered down. This count is run through a 100 counter whose output feeds the MATER. As the 100 counter is always powered up, it retains the remainder for the next update cycle.

The normal data resolution is 1°C per 20 minute period or 1/3°C per hour.

The accuracy of the complete sensor and electronics is ±0.2°C from -30°C to +30°C and ±0.5°C from -50°C to +50°C.

A parallel plate radiation shield is used.

6. **Micropower Relative Humidity Sensor (MIRHS):**

The sensor itself is a Lambrecht Model 800N30 human hair hygrometer with a non-linear output.

The linearizing technique achieves electronics performance well within 1% throughout the ambient temperature range of ±50°C.

![MIRHS SIGNAL FLOW]

Upon receipt of an update pulse a 3 step conversion commences.
1. The A/D reads the sensor.
2. The A/D output is fed through a ROM whose output goes through a D/A to apply a correction to the sensor drive. The second corrected reading is taken.
3. The second reading is scaled and shifted out to the MATER. The normal data resolution is 1% per hour. (full scale 100%)

7. Sunshine Sensor:

The sensor consists of a vertical array of solar cells mounted around the outside of a cylinder. Sunshine is detected as a sufficient difference between those in the shade and those in the sun. The optical performance is enhanced by diffusers in front of the cells and a combination of shade rings and reflectors to allow a uniform response for all solar elevations to 80°, with the sensor mounted level for all latitudes in Canada.

Since the multiplexer is driven by a crystal clock, the time spent above the reference threshold is accumulated in the scaler whose output is a contact closure for each 0.1 hr. of accumulated sunshine.(5)

8. Radiation Integrators:

The millivolt signal is amplified through an instrumentation amplifier, before being fed into the A/D. The A/D is updated every 2 seconds, and its output is scaled and fed as an event to MATER. This simulation of an integrator was chosen because its stability depends primarily upon a crystal clock and a reference diode.

Full scale counts of 1500/hour provide high resolution but do use up tape quickly. A station with 5 radiometers and a temperature sensor will fill a tape in 2 weeks in midsummer, which was the desired time in terms of sensor cleaning requirements.

D. System Configurations:

At present the most popular system configurations are for climat applications and radiation.

Climat MATER is available as an indoor model that can be used with existing ink event recorders as well as a solar powered tower mounted application. The standard Climat MATER recorder precipitation, wind, temperature and sunshine.

Radiation MATER is available as an indoor system which can accept up to 6 thermopile sensors and a temperature sensor.

Due to the ease of configuration, to date about one quarter of the MATERs used have been for research and special project purposes. A new application only requires a new label for the terminal strip, and an entry on the decoding computer station file.(6)
E. Field Decoding:

A fully portable, battery operated MATER decoder is available for decoding in the field(6). The following programs are available:

Program 0: (PGM 0 TEST TAPE) Prints the digits as they were recorded on the MATER tape.

Program 1: (PGM 1 CL HR) Hourly values of climat. data and daily minimum and maximum values of temperature, sunshine, precipitation, wind speed and wind direction are printed.

Program 2: (PGM 2 CL HR) Daily minimum and maximum values for all climat sensors are printed, as well as system parameters that are relevant for a quick system performance evaluation while re-winding the tape on site.

Program 3: (PGM 3 RD HR) Hourly values of radiation data and daily minimum and maximum values of temperature, sunshine, RF-1, RF-2, RF-3, RF-4, and RF-7 are printed.

Program 4: (PGM 4 RD QC) Daily minimum and maximum values for all radiation sensors are printed, as well as system parameters that are relevant for a quick system performance evaluation while re-winding the tape on site.

Sample printouts are shown below (reduction is about 1.6 to 1).
The portable decoder hardware and the interactive graphics computer decoder for MATER are covered in the accompanying paper(6).

Bibliography:
MATER' FOR AUTOMATED AES DATA - DECODING

A.D. Stewart
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Introduction

The MATER as a complete data acquisition system is shown in the MATER system overview in Fig. 1.

MATER recording stations (Encoders) presently in existence are generic in nature being of two distinct types; radiation MATER or climate MATER. As a result the MATER Decoders have their software similarly divided to decode either radiation cassettes or climate cassettes. A typical radiation cassette is shown in Fig. 2.

Figure 1 - MATER System Overview

Figure 2 - MATER Radiation Cassette
Sonotek Inc. has constructed, to AES specification, a portable, rugged, lightweight, battery powered unit which provides, within 15 minutes, a processed hourly printout of observations. This decoder has the tremendous advantage of allowing the operator to verify (in the field) that his station is giving him the results he desires (see Fig. 3). The decoder is being supplied at a cost of $8,000. This decoder is under the control of two microprocessors whose architecture and software data flow diagrams are illustrated in Fig. 4. Sample output printouts are provided in J. Cook's paper (ref. 6).

Some technical problems still persisting with the portable decoder are as follows:
- only two cassettes per battery charge
- some components overheating
- SC/MP microprocessor too slow for application and difficult to find knowledgeable programmer to maintain the data processing software.

Graphics Decoder

This decoder is the AES' operational decoder and is shown in Fig. 5. The hardware and software architecture are shown in Fig. 6.

Sonotek Inc. can provide the system at a cost of $50,000 to $100,000. Technical problems at the time of this paper include:
- Slowness (3 hrs per cassette) due to the basic language interpreter rather than a compiler generating directly executable object code (standard computer technique). Selective use of assembly language subroutines is solving the problem (20 mins per cassette).
- Restricted CRT resolution of 455V x 560H pixels allows only every third minute of solar radiation to be plotted when viewing a full day zoom of one channel, this resolution is sufficient for the application but makes precise cursor positioning difficult.

**Graphics Decoding Concept**

Recognizing that the standardization of observational techniques is continuously undergoing evolution or change, we have attempted to move the data processing into the large, high speed, easily programmed, ABS archive computers. This decoder thus concentrates on providing data in the lowest common denominator "raw sensor events (ASCII)" transcribed onto the highest common denominator of output medium 1600 BPI, "IBM compatible 9 track tape". The output tape format consists of an index file followed by two files for each MATER cassette decoded.

The 1st file contains four records with each record containing 1000 bytes. The four records are as follows:

- Header with cassette on time, off time, station number and comments (1000 bytes).
- Current station file with all related parameters as they existed just before the cassette was removed (1000 bytes).
- Old station file with all related parameters as they existed just after the cassette was installed (1000 bytes).
- Quality control record having abort notice and number of times data has been edited (1000 bytes).

Thus, the graphics decoder is intended to be the single entry point not only for the cassette but also all meteorological, geographical and station configuration parameters or changes which are associated with the data. Two examples of this station file as the graphics operator sees it are shown in Tables 1 and 2. The second file contains up to 860 records of raw data and each record is 1000 bytes.

![Table 1, Radiation Station File](image1)

![Table 2, Climate Station File](image2)
The finished product with its two files illustrate the decoder's basic function which is to transcribe both the parameters and the data to IBM compatible 9 track tape. The largest 27 cm diameter output tape will hold 26 full MATER cassettes due to a 50% tape utilization (1 1/2 cm gap, 1 1/2 cm data records).

**Analogue Recovery**

MATER radiation sensor events are summed to provide integer minute counts. The minute counts as shown for RFI in Fig. 7 are then put through a moving, gaussian shaped digital filter whose equation is:

$$M_{\text{plotted}} = (M_{-3} + 3M_{-2} + 5M_{-1} + 5M + 5M_{+1} + 3M_{+2} + M_{+3})/23$$

(see Fig. 8). The results of using the digital filter on the minute counts is shown in Fig. 9 and may be compared to the strip chart analogue record shown in Fig. 10.

**Climate Viewing**

Mr. Gord Howell of the Alberta Research Council is providing the climate application programming and, at this time, full graphics editing capability is not complete. The seven day climate viewing graph is shown in Fig. 11. In Fig. 12 AES shows how a typical wind rose may easily be generated from a MATER cassette.
Radiation Editing Requirements

The types of errors and corrections desired by the AES data management division are illustrated in Figs. 13 and 14.

Figure 11 - 7 Day Climate

Figure 12 - Wind Rose

Figure 13 - Winter Radiation Editing Specifications
Figure 14 - Summer Radiation Editing Specifications

As a point of interest, unofficial tests between the MATER and existing Honeywell radiation systems show agreement to within 1% when measuring a daily total of 17.5 MJm\(^{-2}\) from FRI (ref. 1).

Drum Roll

Four weeks of seven days by seven channels may be displayed for any radiation cassette decoded (cassettes are normally changed every two weeks). Pushing the special roll up or roll down keys allows one to view the entire cassette data a week at a time as shown in Fig. 16. If a day does not look right the operator may zoom in on a particular day for a closer look. The day is selected by the cursor which moves in jumps of 1/4 day horizontal or 1/3 day vertical like a bouncing ball. The upper right hand corner of Figs. 15 and 16 illustrate the selections as follows; H1 is first half of day, W is whole day, H2 is second half of day, R is raw counts, F is filtered counts.

Figure 15 - Before Time Amend  
Figure 16 - After Time Amend
**Time Amendments**

Time may need amending because the cassette installer made an error in writing down the MATER on time or perhaps tape dropout caused a section of the tape to be undecodable. Time may be amended by estimating the error from the displayed graphs or from the "databreak" time sync (every 1024 minutes) put on the cassette by the MATER recorder. Examples of time amending are shown in Figs. 15 and 16.

**Amplitude Amendments**

Amplitude amendments can be made in one of three ways -

**SEMI-AUTOMATIC:** They can be made directly by having the operator amend the integer minute sum for the channel in the disc data array file (data is filed by day and channel in minute sums). The error is pointed out by limit tests, one of which is indicated in Fig. 19, the B10 indicates that there were only 10 temperature bursts from the sensor for that hour (there should be one every four minutes).

**AUTOMATIC:** A look ahead/look back algorithm corrects the minute sums by averaging over the gap pointed out by the B10 flags.

**SPLINING:** The operator manually inserts data points using the cursor positioning controls. The computer uses a 'cubic spline' function having 'natural end' conditions (ref. 7 has an easy to use Fortran subroutine).
Clear Air Curve

Using physical, environmental, sensor and recorder parameters as found in the station file data base shown in Table 1, together with an algorithm developed by Thorne Won (ref. 2), we compute hourly estimated global radiation in MJ/m², which is converted to equivalent RF1 sensor counts per hour, using a formula given in ref. 3.

This curve then is used as the basis for comparison and is time shifted to local or 'wrist watch' time and automatically displayed with RF1. Wrist watch time is used to reduce the cassette on time error originating when people install cassettes in their MATER recorders.

Decoder Availability

The MATER is protected by Canadian Patents and Developments Limited. It is being licensed for production by:

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Acknowledgements

J. Cook
T. Won
Sonotek Inc.
J. Megyes
G. Howell
D. Struthers

MATER Concept
Clear Air Model and $ Funding
Systems Design of Portable & Graphics Decoders
Application Programmer Radiation Graphics
Application Programmer Climate Graphics
Assembler Speed Up

References


ON THE COMPARISON OF SENSORS AND AUTOMATIC OBSERVATION SYSTEMS

D. A. Simidchiev
(Institute of Hydrology and Meteorology, Sofia)

Introduction

The objectives of the automatic meteorological data acquisition could be summarized as follows 1/:

1) The automatic data acquisition compared to the manual one should provide an equal in quality but a cheaper way of acquiring of meteorological information for operational and scientific purposes.

2) If not cheaper, it should provide a way of data acquisition, difficult or even impossible to attain manually (in terms of quality, speed or obtaining information from uninhabited areas, or such of difficult access.

It seems that the second objective has dominated the development of automation in its early stages. In fact, the first steps in the automation of the meteorological observations have been made by a few developed countries during the time span between 1940 to 1945 in an endeavour to obtain meteorological information on a continuous basis from the remote and unpopulated Arctic, Franz Josef Land, the Pamir mountains /5,6/ and the hurricane plagued ocean areas off-shore Florida /6/.

Although not strikingly successful these first attempts in the automation of meteorological observations proved useful. They have been followed by conceptually more mature projects, bringing into existence in the late fifties and early sixties, of a number of Automatic Meteorological Stations (AMS) of the "hard-wired" type. Many of these AMS have been equipped with traditional sensors, some of them mechanical.

Since that time the activities on a global scale, in the field of the automation of meteorological observations have been on the escalation. It was through the effort of WMO however, that a decisive boost has been given to the process. WMO sponsored technical conferences on automation and meteorological instruments and methods of observation, made available to the nations of the world the collective knowledge and experience in that field /6/.

Ever since in a small number of highly developed countries, the automation of the meteorological data acquisition, propelled by the unrivalled dynamism of the development of the automation engineering technology, has reached remarkable results. There are already in existence a considerable number of types an models of AWS. A number of operation and design concepts have been developed. However, the routine use of AWS is lagging behind this progress in many parts of the world. The practical results of the automation of the meteorological observations in action have been subjected to evaluation in the highly developed countries /1/. The long term advantage of the complete automation of the meteorological data acquisition over manual methods has been proved to be valid for these countries beyond doubt. Still could this conclusion be taken for granted for other countries too? How can the potential user of automation, the one with no production record in that field, decide on his own trends of development?

The problem of automation in meteorology is not merely a technical one. However, its technical basis makes necessary to approach the question first of all from a technical point of view.
The AWS sensors' comparison

The sensor is that part of the automatic measuring system which couples the measured parameter to the system. Usually a physical property of the sensor is affected by the measured variable and a signal is obtained as a sensor's output. The signal may be a mechanical change of dimension of the sensor, or change of its electrical resistance, capacitance or some other property. The signal is further processed by the AWS stages in a way appropriate for the automatic measurement.

Already there is a vast number of different sensors, which could be used in the measurement of the different meteorological parameters. Only for the measurement of the air humidity more than 25 sensors are known. The use of the different sensors in various AWS designs is based on the designer's own criteria for suitability. A comparison between presently used sensors with automatic equipment, based on presently available publications reveals that not all these designers' criteria are purely metrologically based /4/.

How could one compare the various sensors for measurement of a meteorological variable?

Obviously a common denominator should be found. It should be general and in the same time specific enough to be suitable for a comparison of the sensors, as regards their use with automatic equipment.

All sensors' features may be considered as falling into two major groups:

1) Sensors' functional features
2) Sensors' automatic equipment coupling features

Not all of the sensors' features are equally important for the purpose of a competitive comparison. The following four functional sensor features are valid, according to the author's views, for use in such a comparison:

a) Accuracy
   The accuracy of a sensor is considered as a compatibility of its response with the scale of its standard instrument of calibration /4/.

b) Stability of calibration characteristics
   This is a feature of the sensor related to the reproducibility of its response throughout its operational life. It is almost evident, that only high calibration stability sensors are suitable for application in automation.

c) Specificity of response
   A sensor should respond to the changes of the measured variable only, and be insensitive to other variables.

d) Durability
   A sensor's operational life span should be guaranteed by its capability of withstanding all operational weather extremes without deterioration of its sensing abilities.

As regards the group of the sensor's automatic system coupling features, the following sensor characteristics could be considered:

A) Parameter-to-sensor algorithm
   A simple linear relationship between the measured parameter and the signal at the sensor's output is an advantage of a straight technical meaning.

B) Sensor exchangeability
   Sensors used with automatic equipment should possibly be exchangeable without a necessity of adjustments or alterations in the sensor/equipment interface.

C) Sensor maintenance requirements
   A sensor used in conjunction with automatic equipment should be as maintenance free as possible (especially by unattended AWS).

D) Sensor power requirements
   The sensor operational power requirements should be fractional from the total AWS power needed.

There is one sensor feature which does not belong to either of the
group listed above. This is the cost of the sensor. The sensor's cost however, should be taken into consideration too. Very much so the cost of the sensor's adapter. Some meteorological parameters' measurement (cloud ceiling for example) requires sensor's adapters of a complicated electronic design. The cost of such sub-assemblies is not at all small compared with that of the basic equipment.

It should be noted before attempting to list the sensors compared, that during the 40 odd years of development of the automatic data acquisition systems in the field of meteorology, very few new sensors have been developed /8/. The survey of the reference materials available makes possible the listing of the sensors used with automatic equipment having a climatological, surface synoptic, aviation or special purpose application. The sensors listed are indexed by a "priority index of use" based on their relative frequency of usage in the various AWS designs /5,6,7,8/.

<table>
<thead>
<tr>
<th>Measured parameter</th>
<th>Sensor type</th>
<th>Priority index of use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Platinum resistance therm.</td>
<td>(1)</td>
</tr>
<tr>
<td></td>
<td>Thermistor (expon. response)</td>
<td>(3)</td>
</tr>
<tr>
<td></td>
<td>Thermistor (linear resp.)</td>
<td>(2)</td>
</tr>
<tr>
<td></td>
<td>Bi-metallic thermometer</td>
<td>(4)</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>-</td>
</tr>
<tr>
<td>Humidity of the air</td>
<td>Hair hygrometer</td>
<td>(3)</td>
</tr>
<tr>
<td></td>
<td>&quot;Pernix&quot; hygrometer</td>
<td>(4)</td>
</tr>
<tr>
<td></td>
<td>LiCl dew-cell</td>
<td>(1)</td>
</tr>
<tr>
<td></td>
<td>Optical dew-point meter</td>
<td>(6)</td>
</tr>
<tr>
<td></td>
<td>Psychrometer</td>
<td>(2)</td>
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<tr>
<td></td>
<td>Humicap type</td>
<td>(5)</td>
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<tr>
<td>Pressure</td>
<td>Mercury barometer</td>
<td>(2)</td>
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<tr>
<td></td>
<td>Aneroid capsule</td>
<td>(1)</td>
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<tr>
<td></td>
<td>Semi-conductor press. capsule</td>
<td>-</td>
</tr>
<tr>
<td>Wind speed</td>
<td>Cup-wheel</td>
<td>(1)</td>
</tr>
<tr>
<td></td>
<td>Propeller</td>
<td>(2)</td>
</tr>
<tr>
<td></td>
<td>Ion displacement anemometer</td>
<td>-</td>
</tr>
<tr>
<td>Wind direction</td>
<td>Wind vane</td>
<td>(1)</td>
</tr>
<tr>
<td>Precipitation</td>
<td>Tipping bucket</td>
<td>(1)</td>
</tr>
<tr>
<td></td>
<td>Weighing balance</td>
<td>(3)</td>
</tr>
<tr>
<td></td>
<td>Valve volumetric bucket</td>
<td>(2)</td>
</tr>
<tr>
<td>Cloud ceiling</td>
<td>Rotating beam ceilograph</td>
<td>(1)</td>
</tr>
<tr>
<td></td>
<td>Lidar</td>
<td>(2)</td>
</tr>
<tr>
<td>Visibility</td>
<td>Transmissometer</td>
<td>(1)</td>
</tr>
<tr>
<td></td>
<td>Back-scatter visib. meter</td>
<td>(2)</td>
</tr>
<tr>
<td>Sunshine duration</td>
<td>Photocell</td>
<td>(1)</td>
</tr>
<tr>
<td></td>
<td>Bi-metallic sensor</td>
<td>(3)</td>
</tr>
<tr>
<td></td>
<td>Thermistor</td>
<td>(2)</td>
</tr>
<tr>
<td>Solar radiation</td>
<td>Thermopile</td>
<td>(1)</td>
</tr>
<tr>
<td>Luminance detector</td>
<td>Photocell</td>
<td>(1)</td>
</tr>
</tbody>
</table>
The sensors listed above are ranked according to their use in automatic devices, as reflected in the reference. It is the AWS designer's approach to the sensor question, which is pictured above. Some of the sensors' ranking is in conspicuous discord with the desirable features as laid down at the beginning of the paragraph. Most conspicuous is the "wide spread" use of the LiCl dew-cell despite of its fast calibration deterioration even in a relatively unpolluted environment, far from modest power requirements and side effects on the humidity measurements by ventilation and ambient temperature (especially extreme negative ones). Another example is the hair hygrometer which comes before the better "Pernix" sensor.

Evidently it is the industrial availability of the sensor which plays a role in its choice for the job. Another reason for the discord mentioned is the limited validity of this comparison due to the relatively small sample of sensors discussed. A third reason is based on the fact, that compared sensors are used in stations of different application and "age group": mechanical sensors of simple analog data loggers from the early stages of automation are compared with the sensors of modern, real-time, microprocessor-based AWS. This is how the bi-metallic sensor appeared in the list of the sensors compared, inspite of its inferior qualities.

Some of the newly developed sensors are omitted from the list because of insufficient operational record. In the same time a number of conventional sensors with known sensing merits, but a rather short history in automation and inconclusive results as AWS sensors have found place in the comparison as the only representatives of its kind. This is the case with the transmissometer and the back-scatter visibility meter. Evidently the use of the one or the other in AWS is based on the designer's consideration other than simply metrological ones.

The ranking of the rotating beam ceilometer (RBC) first, before the Lidar, whose accuracy, at least, is expected to be superior /7/ to that of the RBC, may be a result of a designer's preference based on the cost of the device.

The kind of the signal output of the sensor is a ground for a preferred application in AWS. Digital output sensors are simpler to use in certain AWS types.

The Automatic Weather Stations' Comparison

The main advantages of automation in meteorology are quality and speed of data acquisition. The main advantages of the manual system are the presence of human judgement in the process and a certain degree of operational flexibility /1/.

The ideal automatic system would be the one surpassing the manual one in all respects, while easily attainable and operated at a lower cost.

The basic unit of the automatic system is the Automatic Weather Station. A wide variety of AWS, differing in their specific meteorological application, complexity an capabilities are in existence nowadays. In order to carry out a comparison between all these it would be necessary:

a) To make a suitable categorization of the AWS, based on the least number of possible categories covering the total population of AWS, and offering criteria for their placement in the different categories.

b) To list a set of valid AWS characteristics to be used for the purpose of the comparison.

It seems that there is no better categorization of the AWS, than the existing one based on the meteorological use of their data output:
A) Regime data AWS
B) Real-time data AWS

Category (A) covers all AWS measuring hydrometeorological parameters necessary for the regime studies of the environment. Presence or absence of telecommunication link in these AWS is not considered as a typical feature of the category.

Category (B) covers all AWS used for operational purposes (synoptic, aviation, adverse weather warning, etc.) whose data output is used on a real-time basis and is transmitted to the user via wired or wireless telecommunication link.

Each AWS should be compared with the rest of its own category. This is necessary because of the different weight of certain AWS features given in the comparison, depending on the category.

The set of primary AWS characteristics are more general, the subsets of secondary characteristics are more specific.

The cost of the AWS is a primary characteristic of a composite nature. The following secondary characteristics may come into consideration:
- Capital investment, comprising the total price of the equipment and accessories, eventual transportation included.
- The cost of automation project studies (or system design cost) comprising the expenditures connected with the study of the automation application to a concrete data acquisition project, taking into account the local conditions (technical, economical, man-power factors), as well as outside consultancy.
- The AWS installation cost.
- The AWS operation cost. Expenditures covering the salaries of operating personnel (of attended stations), communication facilities rents, expendables, etc.
- The AWS maintenance and repair cost. Expenditures connected with the establishment of workshop and support of maintenance crews, spares.

The data acquisition capacity of the AWS is another primary characteristic suitable for the comparison. It includes features like:
- The number of the AWS channels
- The sampling rate of the station

The technical/operation level of the AWS is a third primary characteristic accounting for the station's sophistication. A number of AWS secondary features are reflecting the operational flexibility of the equipment:
- Hard-wired/programmable design
- Expandable construction, enabling through the addition of modules to enhance the AWS' measuring or data processing capabilities.
- Manual input capabilities (of special importance to aviation stations) making possible the input of "visual" or other selected parameters by a man-operator.
- On-site/off-site data processing
- Memory and memory-size expansion
- Communication capabilities, wired, wireless links, programmed and/or interrogated.

The reliability is the fourth comparison characteristic of primary importance. If available the AWS reliability figures could be directly compared. Secondary features:
- Environmental protection
- Use of high reliability components
- Availability of a failure warning system

The maintainability of the AWS in the sense of easy, simplified maintenance and repair of the equipment is the fifth primary characteristic.

Secondary features:
- Maintenance-free sensors
- Modular design (enabling repair by a lower standard of qualification personnel).
- Fault finding programme (by computer controlled AWS)
Simplified logistics

The five primary AWS comparison characteristics have been selected as the most relevant ones. Four of them are independent of each other, but all of them could be translated into monetary terms - they are cost dependent.

In fact if money are not of importance any desired level of perfection in the automation of meteorological data acquisition could be reached and the question of a comparison renders itself useless.

This however is not the case.

From all five primary characteristics the cost takes into account the "local conditions" of the establishment of the automatic system. The presence of the factor "local conditions" limits the validity of a general study of the benefits from the automation. Such studies should be carried out for the specific country of application of the automation, taking into account the economic, technical and man-power factors.

In the outline on the comparison of AWS only the narrow "national" aspects of the question were considered. An approach based on the need of automation of the meteorological observations on a global scale, stemming from the necessity of data acquisition of a higher level of perfection, to be used with modern numerical weather prediction methods, seems equally relevant.

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ON THE COMPARISON BETWEEN THE AUTOMATIC WEATHER STATIONS AFMS AND M-106M

S. KLEMM

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INTRODUCTION

In accordance with the agreement on scientific-technological cooperation between the Meteorological Service of the German Democratic Republic and the State Committee for Hydrometeorology and Control of the Environment (GOSKONGIDROMET) of the USSR an exchange of the automatic weather stations AFMS and M-106M took place for field comparison purposes in 1975.

The AFMS of the Meteorological Service of the GDR has been in the network in routine use for rt- and nrt-purposes for several years and the M-106M of the GOSKONGIDROMET of the USSR has been in routine use in the network of the BSSR for some years as well.

In the network of the MS of the GDR there are installed 40 AFMS mainly at category-III stations with only one observer [1]. This observer adds to the automatically obtained data (air temperature, dew-point temperature, psychrometric difference, soil temperatures, pressure, maximum and mean wind speed, mean wind direction, amount and duration of precipitation, global radiation, number of lightnings) during day-time some visual observations as for instance total amount of clouds, genus of clouds and state of the ground. About the same number of M-106M with similar parameters are installed in the network of the BSSR [2].

The AFMS was installed by specialists of the Meteorological Service of the GDR in Stolbzy in the BSSR and the M-106M was installed by specialists of the USSR at the airport-station Berlin-Schönefeld in the GDR.

The international comparison between these two automatic weather stations was carried out both in the USSR and in the GDR from 1976 till 1977.

The results of this first international comparison of automatic weather stations were discussed at the 4. International Symposium "On the Efficiency of Automatic Weather Stations" in Potsdam, 1978 [3,4].

In Stolbzy data of the AFMS were compared directly with data of the M-106M in a field comparison. Data obtained by the automatic weather station M-106M in Berlin-Schönefeld were compared with data obtained by conventional measurements taken by observers of the station. Thus, the M-106M was compared in the same way as it is done with the AFMS two times a day in the network of our Service. In this way the M-106M was compared indirectly with the AFMS.
COMPARISON RESULTS IN STOLBZY

During the comparison period in Stolbzy the ANS was in operation in 98.7% and the M-106M in 99.7% of the period. There were no serious maintenance problems with the ANS and the M-106M. These results show a high reliability of the two automatic weather stations.

The comparisons in Stolbzy were carried out for the following parameters three times a day and with the following permissible differences between ANS and M-106M:

- air temperature ± 1°C
- dew-point temperature ± 1°C
  - within the range -3°C - 45°C ± 1°C
  - beyond this range ± 2°C
- maximum wind speed ± 3 m/s
- mean wind speed ± 2 m/s
- mean wind direction ± 45°
- atmospheric pressure ± 1 mb

These permissible differences were exceeded in Stolbzy by

- air temperature in 1.0 %
- dew-point temperature in 5.7 %
- maximum wind speed in 1.7 %
- mean wind speed in 1.2 %
- mean wind direction in 3.2 % and
- atmospheric pressure in 5.1 %

of the comparison measurements during the comparison period.

The statistical distribution of the values of air temperature shows that 83.5% of all temperature differences are within the range of 0 - 0.5°C, 10% within 0.5 - 1.0°C and 1% beyond the tolerance of 1°C; a high correspondence between the temperature measurements of the two stations in different Screms.

The dew-point temperature comparison results with 59.4% within 0 - 1°C, 40.2% within 1 - 2°C and 0.4% higher than 2°C gave some conclusions for the special problem of dew-point temperature sensors. Therefore in the last few years great and successful efforts have been made to improve the accuracy of dew-point temperature measurements by means of IA-Cl sensors both in the USSR and in the GDR.

The differences of the wind parameters maximum and mean wind speed are beyond the permissible differences of ± 3 m/s resp. ± 2 m/s only in 1.7% resp. 1.2% of all cases. The values of the mean wind direction show 3.8% beyond the permissible tolerances. The reason for this relatively high percentage is the fact that the sensitivity of the wind vane of the ANS is reduced intentionally.

The values for atmospheric pressure show differences of up to 1 mb in 76.8%, between 1 and 2 mb 18% and higher than 2 mb 5.1%. The reason for these results was an imperfection at the ANS-sensor which has been eliminated in the meantime as a further result of this comparison.
For other parameters as for ground temperature, number of lightnings and global radiation no regular comparisons were carried out. Therefore there are not given any statistical distributions. Whereas the M-106M was already equipped with a sensor for heights of clouds at that time the AFHS was not.

**COMPARISON RESULTS IN BERLIN-SCHÖNEFELD**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Between</th>
<th>M-106M - conv.</th>
<th>AFMS - conv.</th>
</tr>
</thead>
<tbody>
<tr>
<td>air temperature</td>
<td>± 0.3° C</td>
<td>84.8 %</td>
<td>93.3 %</td>
</tr>
<tr>
<td></td>
<td>± 0.6° C</td>
<td>95.6 %</td>
<td>99.3 %</td>
</tr>
<tr>
<td></td>
<td>± 0.9° C</td>
<td>100 %</td>
<td>100 %</td>
</tr>
<tr>
<td>dew-point temperature</td>
<td>± 0.3° C</td>
<td>71.1 %</td>
<td>84.4 %</td>
</tr>
<tr>
<td>(with improved AFMS</td>
<td>± 0.9° C</td>
<td>88.6 %</td>
<td>93.5 %</td>
</tr>
<tr>
<td>sensor)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pressure</td>
<td>± 0.3 mb</td>
<td>78.7 %</td>
<td>82.9 %</td>
</tr>
<tr>
<td></td>
<td>± 0.5 mb</td>
<td>92.3 %</td>
<td>93.0 %</td>
</tr>
<tr>
<td></td>
<td>± 1.0 mb</td>
<td>99.8 %</td>
<td>99.3 %</td>
</tr>
<tr>
<td>precipitation</td>
<td>± 1.0 mm</td>
<td>88.3 %</td>
<td>94.4 %</td>
</tr>
<tr>
<td></td>
<td>± 2.0 mm</td>
<td>97.5 %</td>
<td>98.1 %</td>
</tr>
</tbody>
</table>

Table 1. Distribution of the comparison values M-106M - conv. and AFMS - conv.

Similar good results show the field comparisons in Berlin-Schönefeld in the GDR. In table 1 you find the statistical distribution in percentage of the comparisons between the conventional measurements and M-106M values on the one hand and AFMS values on the other hand for the compared parameters.

<table>
<thead>
<tr>
<th>temperature</th>
<th>dew-point temp.</th>
<th>wind speed</th>
<th>pressure</th>
<th>precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>M-106M</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1976</td>
<td>- 0.32</td>
<td>0.40</td>
<td>- 0.07</td>
<td>0.53</td>
</tr>
<tr>
<td>conv.</td>
<td>- 0.11</td>
<td>0.43</td>
<td>- 0.11</td>
<td>0.94</td>
</tr>
<tr>
<td>AFMS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1976</td>
<td>0.04</td>
<td>0.20</td>
<td>0.05</td>
<td>0.33</td>
</tr>
<tr>
<td>conv.</td>
<td>0.03</td>
<td>0.22</td>
<td>0.04</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Table 2. Yearly mean values of the comparisons M-106M - conv. and AFMS - conv.

The first two lines in table 2 give the results for the comparison between M-106M and conventional measurements and the next two lines between AFMS and conventional measurements at the station Wittenberg.

**CONCLUSIONS**

The results obtained from more than 2000 comparison measurements for each parameter underline the high correspondence and the relatively high accuracy of the measurements of air temperature, dew-point temperature, pressure, wind speed, wind direction and precipitation of the two automatic
Besides the above-mentioned results of the comparison specialists of both countries for automatic meteorological data acquisition, for maintenance problems and for raw-data using became acquainted with new sensors and with another automatic weather station in a practical way. Some conclusions could be drawn for further developments or improvements of AFMS-sensors as for dew-point temperature and pressure and for automatic weather stations.

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Heinrich Borchardt
Deutscher Wetterdienst, Instrumentenamt Hamburg

For some years laser ceilometers are in use in meteorological services. Its technical conception is a mixture of laser range finders, LIDAR, and conventional ceilometers. They are easy to handle and probably will replace the conventional ceilometers some day.

Bearing in mind the accuracy of laser range finders in determining the true distance to targets on the ground or in the air, one would expect the same precision in measuring the height of cloud bases.

Certainly the displayed height of meteorological targets in the atmosphere, from which the laser ceilometer is recording echoes, will be correct within the accuracy of the system itself. The question arises whether the recorded signals can be interpreted only as cloud in general or, what we really want to measure, the height of the cloud bases.

Unfortunately, the different users are not in accordance with the definition of cloud base. Speaking of cloud base, the cloud physicist operates with the size of droplets or the water content per volume air. The meteorologist defines the cloud base as the level where condensation occurs. For the airline pilot, who approaches the runway, priority is given to slant range visibility and for him at least this problem is not only an academic discussion, but may have very serious consequences when he relies on detailed cloud base informations which do not meet his idea of this zone.

This problem has been discussed as long as ceilometers are in use in meteorological routine work, but it has become more important in connection with the new regulations for aircraft landing operations. Even when there is agreement about the meaning of cloud base, a lot of difficulties are left in the interpretation of measurements with laser ceilometers and they are present just in bad weather when we urgently need a clear information about the conditions aloft for approaching aircrafts.

An experienced observer, relying upon the analog record of the ceilometer might be able to find the appropriate value for the cloud height. On the other hand, when the ceilometer is part of an automatic weather station transmitting digitized values to distant locations, the operator, in many cases, will have difficulties to interpret the data.

The laser ceilometers react on backscatter of short light pulses impinging aerosol or hydrometeors in the atmosphere. Backscatter is a function of the particle size, of the amount of particles and the refractive index according to the physical treatment of Mie. A quantity often used is the volume backscattering coefficient \( \beta_{180} \).

It is defined as a fictitious area per unit volume, that scatters the incident radiation isotropically and yields the same return at the receiver, as is in fact, received from the unit volume of the atmosphere at that range. This quantity can be related to meteorological parameters as visibility, water content, rate of rainfall etc. The value of \( \beta_{180} \) for water clouds, haze or fog ranges from \( 10^{-4} \) to \( 10^{-3} \, \text{m}^{-1} \), corresponding to a visibility of 10000 to 20 m.

The state of the art of laser engineering permits to realize laser ceilometers with which one can get signals even in case of very small backscattering coefficients over all distances of interest. With LIDAR-instruments, having light pulse outputs of about 100 MW, minute concentrations of aerosol in the atmosphere can be detected.

The situation is quite different of laser ceilometers used in routine work on aerodromes. Because of human eye safety the output has to be limited to about 20 W. With light pulses like this the backscatter signal of normal clouds is so small, that one has to make use of technical tricks to trace the wanted signals at all.
In practice hundreds of backscatter pulses will be integrated to separate the wanted signal from the receiver noise. When this integration procedure reaches a certain level, a final signal is generated, that marks the presence of backscattering elements in that height interval scanned in the moment. The scanning gate is then shifted to the next higher position and the interrogation process starts again. The same process is repeated as long as the scanning gate reaches the final position, that is the maximum height of the instrument, and then another measuring cycle is started. The sensitivity of the laser ceilometers depends, besides other technical parameters, on the threshold level for the measuring signal and the amount of pulses, due to each integration process. By controlling the number of single pulses to be added up in each range gate, one can compensate for the normal attenuation.

This procedure which is used in all laser ceilometers with only slight deviations, inheres two problems, which are more or less responsible for the difficulties in comparing and interpreting the measuring results. Since there is no defined cloud base, the manufacture or the user of the ceilometer makes his own cloud base by simple manipulations of the sensitivity controls of his instrument. The result is an undefined overall sensitivity of all laser ceilometers. In order to overcome this dilemma the engineers need a clear standard to which they can refer any time by constructing and calibrating the ceilometers. After that, the user has to be told what he is allowed to conclude from the measurements of his instrument.

The second point responsible for some uncertainty in the interpretation of records from laser ceilometers is a technical one, and is due to the measuring method utilizing the pulse integration procedure. The output of a laser ceilometer is a Yes-No-report. It only tells us, whether there was a target in a certain height, which has scattered enough light to fill a certain box in a certain time or not. We have neither an information of the quality of the single backscatter pulse nor of the number of pulses necessary to trigger the height marking signal. With other words: Backscatter signals from the atmosphere, passing over some fixed electronic threshold, cannot be analyzed in detail. Cloud droplets, raindrops or ice crystals present in a volume with some concentration, and therefore having quite different backscatter coefficients, will be marked as the same meteorological target. The following examples gained with two different laser ceilometers were taken from a series of observations over a period of about 5 months in Hamburg, initiated in order to compare the two ceilometers on their technical reliability. The laser ceilometers were set up side by side and their height measurements were recorded in analog and digital form. Looking at the records one has to know, that Impulphysik only marks the lowest heights of the targets with an accuracy of 50 feet, whilst ASEa shows some penetration of the transmitted light pulse into the meteorological target, too. The accuracy of these height measurements are about 30 feet.

Figure 1 shows a record where there is rather good agreement in the display of both instruments. The height of clouds can be determined without any difficulty in the time between 13 and 17 hours. In contrast, the records during the time between 10 and 13 hours gives an idea about what happens when precipitation occurs. The distinction between precipitation and clouds is not possible, moreover, the technical accuracy of 30 or 50 feet in height measurement is without any use in this situation.

Figure 2 shows the digital read out of both ceilometers on the same day from 13.05 to 13.17 hours with backscatter from clouds only. The outputs do not run synchronous because of some seconds difference in the measuring interval. The agreement between the height measurements is remarkable good. One can notice, that the change of the measured cloudheight from one point to the next one within 15 seconds is very often larger than the difference between measuring heights of both ceilometers. This fact proofs the uneveness of the base of clouds. It raises the question, whether we have to bring in a time factor, when we are looking for a definition of the cloud base in respect of cloud height measurements.
The next example (Figure 5) of laser ceilometer record reveals some more interpretation problems. There is a cloud layer having its base in about 1000 feet height and for some time light or heavy snowfall on the ground, which is marked best by the rapid and deep droops in the record line of the visibility measurement. At times when no snow is falling, there is a rather good agreement between the both cloud height measurements, but during the time of snowfall a single record can be as misleading as in the last example. The marks in the height level around 300 feet on the Impulsphysik record do not represent the real cloud base. Bearing in mind the specific characteristics of this ceilometer to display the lowest height of a back-scattering volume, one has to understand these signals as the lowest level of a big air volume filled up with snowflakes and cloud elements without any transition. On the other hand, with two exceptions, there is no corresponding return signal on the record of the ASEA ceilometer. The gaps in signal bands of the cloud layer, caused by the strong attenuation of the transmitted and back-scattered light during heavy snowfall, again fit together properly.

It makes certainly no sense to speak of cloud base height measurements in fog. Nevertheless, when laser ceilometers are working in such weather conditions the records look as shown in figure 6.
Height measuring data like these, as an output of an automatic weather station every 15 seconds, can probably irritate weather observers. Before the data are presented to users, which depend on digital informations from laser ceilometers only, they should be upgraded by a statistical treatment. In this case such a treatment would result in a reliable mean of the cloud height. Nevertheless it is very doubtful, whether it will bring much help to understand the real conditions in the atmosphere when the cloud cover is broken, when there is more than one cloud layer or when there are clouds and precipitation and altogether is completely mixed up.

Figure 3 presents the digital read out of both laser-ceilometers for a period of 9 minutes on the same day when rain was falling. The only conclusion to be drawn from height measurements like this is, that precipitation occurred, an information which one can get by other means with much better efficiency.

Figure 4 gives an example of confusing cloud height measurements. The observer reports light rain all the time and the amount of rainfall per hour changes from 0.4 to 2.7 mm. From 7 to 11 hours the laser ceilometer of Impulphysik displays heights of the cloud between 2500 and 3000 feet in accordance with the visual observations from the ground. The same does the instrument of ASEA, but 600 feet below this record there is another broad band, most probably marking the falling rain. The records look quite different after 11 hours. Now both displays show the same band and height measurements agree almost completely, but it is not possible to decide if it is the cloudbase or precipitation. At least during the first part of this record the digital read out of the height measurements with the ASEA instrument gives total misleading information about the height of the cloud. Most probably the reason for such remarkable differences in height measurements is a small difference in the overall sensitivity of both ceilometers. In this case the backscattered light from the cloud layer is sufficient to exceed the threshold level of both instruments to create a measuring signal. The volume backscattering coefficient of light rain, normally is somewhat less than that of clouds, and a function of dropsize distribution and state of phase. It changes the value on the way from the cloud to the ground and therefore may reach values in certain heights, sufficient to be detectable by a specially calibrated laser ceilometer with a certain threshold level. Because the measuring system gives a Yes-No-information only,
There is dense signal trace on the ASEA record in the first part. The upper limit of this trace reaches the height of 300 feet. It was proofed at some other similar occasions by comparison with ground inversions that this upper limit of the record represents the top of the fog layer. The broken line of backscatter signals on the record of the other ceilometer gives no interpretable information for the same time. With the improvement of the visibility and the dissolution of the fog the height display shows a fully converted picture. The stratus cloud layer, in a height of 150 and 300 feet as reported by the weather observer, is clearly detected by the laser ceilometer of Impulsphysik, but there is no return signal with the ASEA instrument for most of the time.

It is to be emphasised that those very serious differences observed during the test period in Hamburg and shown in this report with some examples out of a lot, are not due to technical failures of the instruments or unqualified manipulations. At least a great deal of these effects result from different technical handling of received signals and slight differences in the sensitivity of the instruments. As long as the meteorologists do not tell the engineers what they really want to be measured, the manufacturers cannot be blamed for unsatisfying cloud height measurements. Because of the complexity of light scattering by hydrometeors and the difficulties in cloud and precipitation physics we cannot expect absolutely correct measurements by means of laser ceilometers, but the results of the measurements of identical conditions in the atmosphere in same moment should be comparable at least.
DATA ACQUISITION, PROCESSING AND ARCHIVING Technique IN BANGLADESH

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Introduction

The Bangladesh Meteorological Department operates a total of 37 meteorological stations throughout the country. These stations undertake various types of meteorological observations both surface and upper-air for use in short and long-range forecasting. Surface weather observation for elements like temperatures, wind velocity, atmospheric pressures, humidity, rainfall, etc. which are made at intervals of 3 hours daily while eight upper-air stations consisting of pilot balloon and 3 of which consisting radiosonde also undertake observations of various weather elements at different levels 4 times and once daily respectively. In addition, radar and satellite data are likewise being made twice daily on two radar stations, one in Cox's Bazar and the other in Dacca. Satellite pictures received from the satellite receiving station in Dacca, these materials are most importantly used for tracking of cyclones and other severe weather phenomena affecting Bangladesh.

For forecasting purposes, real-time weather observations which include all types of data are received minutes after they are made from field observations through the network of teleprinters, Single-Side Band Radios and through the usual telegraphic service. These data are then plotted in the weather charts at the National Forecasting Centre, whereafter analysis, interpretations are made and hence, the weather forecasts for aviation, shipping and for public consumption.

Non-real-time data are transmitted to the climatological Division from field observatories for computer processing, quality-control and statistical analyses, the purpose of which is to provide various users with quality data for researches and other information needed for the development of the countries resources. Other non-real time data include agrometeorological data from few agrometeorological observatories operated by Bangladesh Agriculture Development Corporation (BADC) as well as hydrometeorological data from about 300 rainfall stations maintained by the Bangladesh Water Development Board (BWDB).

Data Acquisition

Real-time weather observations are acquired in coded forms as per World Meteorological Organization standards. While they are used immediately at the National Forecasting Centre for forecasting, they are retransmitted world wide through satellite communication facilities to New Delhi Broadcast Centre for international dissemination in the same manner through which the Bangladesh Meteorological Department forecast centre receives international data for its own use.
On the other hand, non-real-time data considered as climatological records are likewise transmitted world-wide through similar facilities cited above but on the monthly basis. These are solely used for long range forecasting purposes. Such data from the local observatories are entered into standard forms compatible for computer processing. A number of such types of data forms have been provided for various types of data at the Climate Division.

**Computer Data Processing**

The present volume of climatological data accumulated since the birth of the Bangladesh Meteorological Department which available records exists even before Pakistan times, poses a complicated problems to the Department. And with its steadily increasing volume, it is assessed that manual processing would not serve usefully to provide up-to-date climatological information to various users. Rather, these could only be achieved through the use of an electronic computer.

Through the WMO/UNDP's assistance, an IBM system 34 with capacity of 48K bytes memore, 13.2 megabytes disk divers and its associated data entry stations had been made available for climatological use in the Bangladesh Meteorological Department. Though the system is still currently in installation process, much preparatory data processing workd had already been made according to the normal technical plan of data computerization process.

As envisaged, climatological computerization activities invalue data preparation, data entry and finally, computerization process as depicted in the following diagram:

![Diagram of data processing](image-url)
Data preparation, which is not taking place, consists of the transcription of various climatological parameters available in the archive into respective computer compatible forms designed for its purpose. The objective is to facilitate the next step of processing which is the entry of data into computer media, such as diskettes and/or main disk through the data entry stations of the system. This phase of the job is envisaged to be started soon after computer installation.

Print outs of data entered into disks and/or diskettes will be examined for validity after sorting them to preparatorily get rid of manual errors. Later, proper and systematic quality-control of data will be applied. Processed data will be permanently started in disk and/or diskettes for further analytical functions. Publication of climate records is similarly envisaged from processed data thereafter.

Computerization phase, however, involves tremendous jobs in computer programming not only in quality-control process but also in data file creation forms. This phase requires expert computer programmers to achieve the tasks. Thus, provision for fellowship training abroad on the part of the job have made through WMO/UNEP in addition to local and in country trainings which have already been started.

Another constraint to achieve the plan of computerization is the proficiency of data entry operators. The volume of data which will be processed in the computer depends upon their operation and that the volume of data to be entered into computer media depends upon the availability of transcribed data. It therefore, appears that both three phases of data computerization process shall work cohesially and consistently to achieve the whole objective.

**Dissemination, Archiving and Retrieval**

Processed data in standard forms whether real-or non-real-time are disseminated for world-wide information. Records are kept in the climatological archive which include analysed weather for research. Later original new records are then replaced by computer processed ones to minimize the bulk of forms being stored. All printed records are normally put into micro-films for convenience in their retrieval. This is done upon completion of the computerization process. Data files in computer disks and/or diskettes are also deposited in the climatological archive for safe keeping. Data on disk/diskette work files are retrieved through standard small programs which command the computer to print desired copies in a very efficient and expeditious manner. This system is envisaged to be applied in handling and keeping climatological records in the Bangladesh Meteorological Department.