W O R L D   M E T E O R O L O G I C A L   O R G A N I Z A T I O N

INSTRUMENTS AND OBSERVING METHODS

REPORT No. 7

THE METEOROLOGICAL USE OF NAVAID SYSTEMS

- A BRIEF TECHNICAL ASSESSMENT

by

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The Meteorological Use of NAVAID Systems - A Brief Technical Assessment

1. Introduction

This brief report by the CIMO rapporteur on the meteorological use of NAVAID systems is a summary of his more detailed report, entitled "Meteorological Observations using NAVAID methods" which should be published by WMO in the future. This report should be used to augment the information contained in the document for CIMO-VIII on the same subject, agenda item 9.2.

2. The global distribution and quality of available NAVAID signals

(i) Omega and VLF

Omega is a long-range global navigation system transmitting radio signals at 10-14 kHz, for which the earth and the ionosphere act as a waveguide for their propagation. The large antenna structures of the eight transmitting stations, located around the globe, originate a pattern of waves that travel in all directions. When using the Omega system for navigation purposes, primary/secondary modal interference, multipath propagation of signals around the globe, and propagation anomalies caused by bombardment of the ionosphere by solar fluxes must be carefully taken into account. For windfinding, where the relative position changes of the sondes are determined, the same effects can still degrade the results.

The eight station Omega network has been established and seven stations are transmitting. The last station to be built, in Australia, should be operational by the end of 1981. Thus, the whole globe will be able to receive and use the Omega system for windfinding at least until 1995.

Other phase-stable VLF transmitters (e.g. the Soviet VLF navigation network) in the 15-25 kHz range have been successfully used for experimental windfinding. Now that the global Omega system is fully operational, the use of VLF stations, except for special projects, is not warranted because of the added complexity for the radiosonde.

(ii) Loran-C and Decca

These networks of navigational aids have only small-scale coverage. The Loran-C transmitters operate at 100 kHz. Significant portions of North-America, and parts of the North Atlantic Ocean, of Europe are covered. In such areas the system can be used to advantage. The Decca transmitters operate in the 84-128kHz band. Local coverage in diverse areas, but especially in Europe, combined with the rapid signal degradation beyond directly covered areas restricts the use of Decca signals for windfinding to small scale experimental soundings. Both systems should remain operational until at least 1995.

(iii) Terrestrially based precision radiolocation systems

There are several private small scale networks of this type which could only be used for research on local wind fields and for other small scale projects.

(iv) ARGOS-type location systems

The Service ARGOS Satellites measure the Doppler shifts of the data signals received from frequency-stable transmitters aboard platforms for which the position is to be determined. The coverage is world-wide, but the position determination requires two successive passes by a low polar orbiting satellite. Thus, it is only suited for tracking slow moving platforms for which the position information is not required more often than a few times a day. The service is expected to remain operational for another 5 to 10 years.

The TRANSIT navigation satellite system reverses the roles, as the satellites (five to cover the glove) transmit at a stabilized frequency, while the platform must be capable of analysing the Doppler shifts, which has kept the system unsuited to meteorological applications as yet.

(v) NAVSTAR type systems

The NAVSTAR global positioning system (GPS), under development, is a satellite system capable of providing continuous three-dimensional location and velocity measurements based on various ranging data. However, the high cost of GPS receivers and the use of the S-band keep this precision system out of the reach of operational meteorology.

(vi) Self-contained navigation systems

The inertial navigation system (INS) has become the workhorse of the navigation industry, while doppler radars and sonars are used for obtaining accurate ground velocity measurements. Both systems are useable world-wide, and have been used in connexion with meteorological observations taken by aircraft.

3. Telemetry for the relay of NAVAID signals

Radiosondes which use NAVAID windfinding sum the meteorological and the received NAVAID signals into the transmitter. Until now, the exclusive use of analogue transmission has made the careful design of the antenna structures a necessity.

Although, satellite communication links have been used successfully to relay radiosonde transmissions in the 400 MHz band to distant base stations, it is recommended that the raw sounding data be condensed by statistical smoothing prior to its retransmission in any operational system.

4. Technology for the phase determination of NAVAID signals

(a) Hardware

A phase detector is the key component for determining the range-difference and radial-range using NAVAID systems such as Omega, Loran-C and Decca. There are several types and their characteristics vary a great deal in the presence and absence of noise. Analogue filtering can be used to limit the incoming bandwidth or to clip high amplitude signals or to blank noise peaks through use of the signals received directly at the base station. However, because such filter circuits tend to oscillate after a disturbance, a complementary approach is recommended, namely to use extensive digital filtering in connexion with the phase detection. Fourier transformation or cross-correlation techniques can be used to accomplish this.

Because of the complex interwoven nature of such processing, a microprocessor should be dedicated to automatic NAVAID signal acquisition and processing.

(b) Software (programming)

All the raw phase data must be smoothed using both non-linear (editing) and linear (filtering) processes. Because of the variety of NAVAID signal conditions, it is recommended that several smoothing modes be available.

Editing (elimination of wild points) can be accomplished either manually by the base station operator through the agency of an interactive video terminal connected to the computer system, or automatically in the computer by using piecewise low-order polynomials for statistical editing. In the latter case, the editing process will also filter the data sufficiently.

The filtering, if required, can be accomplished either by fast fourier transformation or spline techniques, after editing has removed the possibility of any undesirable oscillations.

5. Technology for wind computations

(i) The hardware

The most significant technological advances affecting the design of NAVAID ground-based equipment are the increased capability of small computers and the great reduction in the cost of memory. The new equipment can take advantage of solid state memory bank addressing techniques which make all programs and data files directly accessible. Peripheral equipment is required only to satisfy the input/output functions necessary for station operation.

Automatic aerological stations require a considerable amount of computation in order to generate the complete TEMP and PILOT messages, and this can be provided using an easily programmable minicomputer. As regards Omega-based systems, considerable computing power is also needed for the effective statistical editing of raw phase data.

The phase measurement information on the three or more selected stations is provided to the minicomputer for wind determination. The computer could also carry out other tasks, as required.

(ii) The software

In order to attain maximum accuracy and reliability, the NAVAID stations which are to be used should be selected on the basis of known propagation paths, and not exclusively on the basis of signal strength and phase stability. The use of the Differential Correction to remove propagation disturbances from directly received signals must be exercised with care because the signal received at the radiosonde location (beyond 100 km from the base station and above 10 km altitude) may not always be well correlated with that received at the base station.

The results of comprehensive studies on the software matters listed below are embodied in the suggestions for improvement found in paragraph 7.

- Use of the total differentials of the phase values
- Hyberbolic/elliptic windfinding solutions
- Use of the full covariance matrix of the phase residuals
- Internal consistency checks for the signals
- Estimation of windfinding accuracy
- Spline smoothing in the 3-dimensional space.

6. Expected accuracy of winds and locations using existing methods

(i) Omega

The fundamental characteristics of the VLF transmissions and of their long-range propagation must be taken fully into account if optimum performance is to be attained.

If the stations to be used are carefully selected, and if editing and sophisticated statistical computing techniques are employed, the Omega system is capable of providing wind accuracies of 1-2 m/sec for 2 minute averages in favourable day-time conditions and in favourable geographical locations. In the case of long propagation paths at night, typical error figures rise to 1-4 $m.s^{-1}$, depending on the geometry of the selected Omega station locations and the geographical location of the base station. At sunrise and sunset the height of the ionosphere changes abruptly causing anomalous phase jumps in the Omega signals. In such cases any Omega station, whose signals are so affected, must either be excluded or a differential correction must be applied, both of which result in somewhat larger error figures. However, some improvement can be gained by averaging the data over longer time intervals, provided that the resulting loss of vertical resolution can be accepted.

Preliminary studies based on the Omega data archives amassed during FGGE indicate that the global accuracy predictions made by M. Olson in 1968 are essentially correct (Reference 1) in areas having a good or satisfactory Omega coverage. However, the recently discovered problem with the multipath propagation of NAVAID signals from distant Omega transmitters must also be carefully taken into account, either by deleting such distant transmitters from the wind computations, if possible, or by use of a sophisticated correction procedure (Reference 9).

(ii) Loran-C

Loran-C offers the best windfinding accuracy of any general purpose NAVAID transmission system and allows the fine scale wind structure to be accurately determined. Typical accuracy is better than 0.5 m/sec for a one-minute average. This accuracy satisfies the synoptic sounding requirements and, indeed, has been found to meet the more stringent requirements of low level soundings for environmental pollution studies.

However, the clean ground wave signal will be contaminated by skywave reflections from the ionosphere when the distance from any transmitter is more than 1500 km. This effect results in inaccuracies as great as 2-4 $m.s^{-1}$ for one-minute average winds. Further, a degradation of accuracy may result from the interfering signals received in the broad frequency band of 85-115 kHz used by Loran-C.

(iii) METRAC

Simulation studies indicate that the METRAC system is extremely accurate. Under favourable conditions the accuracy may reach even a few centimeters per second for 10 second wind averages.

(iv) ARGOS

The position location error is of the order of 5 km and the velocity error about 1.5 m/sec for integration intervals of about 90 minutes at the altitudes of the constant level balloons. For slow-moving drifting buoys the position location is more accurate with an error figure of approximately 2 km.

7. Suggestions for improving existing methods

7.1 The hardware

(a) A future digitization of all telemetry (NAVAID and PTH signals) transmissions would result in a radiosonde with a lighter battery requirement, and the balloon size could be greatly reduced for tropospheric soundings. Further, the data would be more secure from noise degradation.

(b) The addition of monitoring peripherals (e.g. a video terminal, for displaying the raw NAVAID data) is highly recommended to allow for better editing and station selection.

(c) The computer system should have sufficient storage and computing capacity to allow repeated NAVAID recomputations.

(d) A future sounding system should make use of several tracking devices which would complement and stand behind each other in a hybrid system. A direction-finder would greatly enhance the accuracy obtained near the earth's surface where the Omega-based systems are less accurate due to the rather thick initial averaging layer. Of course, radars and radio-theodolites also have their problems near the surface.

7.2 The software

(a) Changes in balloon position are usually derived from the phase differentials of the NAVAID signal, which, in turn are obtained by multiplying the time intervals by the time derivatives of the phases, a process which results in an accumulated truncation error in the balloon position. It would be better to make use of the total differentials of the phases which can be computed without difficulty.

(b) The full covariance matrix of phase residuals should be used in the hyperbolic or elliptic windfinding solution, rather than the crude approximations which are usually employed.

(c) The propagation of the directly received Omega signals should be monitored by computing the ficticious motion of the sounding station. For moving base stations (ships or aircraft) the computation of the motion efficiently detects possible multipath propagation problems with signals from distant Omega transmitters, as well.

(d) A NAVAID sounding systems should be capable of reprocessing a sounding using modified control parameters including transmitter selection, the differential correction options and different smoothing modes so that a better overall result can be possible through a judicious combination of the individual calculations.

(e) A NAVAID sounding system should provide an estimate of its own accuracy both to the operator and to users of the data.

(f) A smoothed spline curve should be fitted through the consecutive balloon positions in the 3-dimensional space to enable the derivation of a suitably smooth wind profile. The degree of smoothing should be controlled by the estimated positioning error variances. Excellent algorithms are currently available for such smoothing.

(g) The elliptic windfinding solution is slightly more accurate than the standard hyperbolic one providing that the motion of the base-station is precisely known.

(h) Well-designed software modules are required to provide for the screening and possible interactive processing of the raw NAVAID data, by the operator via a video terminal.

(i) The NAVAID method usually relies upon an overdetermined equation system. Thus several means of checking the internal consistency of a measured phase value are available. The development of a fully automated sounding system based on built-in test software, enabling the system to verify its own status, and, to a certain extent, to perform self-adjustments is recommended. Reference is made in this connexion to the correction procedures mentioned in sub-division (i) of paragraph 6 of this report.

8. Qualification levels for observers using NAVAID-based windfinding systems

Current NAVAID-based windfinding systems must be operated by qualified radiosonde operators who are also specially trained on NAVAID signal propagation aspects. In future, when systems are introduced which include built-in tests and automatic correction procedures, the required qualification level of such observers will probably decrease. The maintenance of such systems is also expected to be simpler because of an improved modular construction.

9. The cost/performance aspects of windfinding systems

The use of NAVAID-based windfinding systems requires no expensive stabilized platforms for operation aboard mobile stations (e.g. cars, ships or aircraft).

The expanding capability and decreasing cost of computing hardware has made possible improved data quality and streamlined operational procedures at lower overall cost: for all upper-air sounding equipment. This is not true to the same extent with windfinding systems not based on NAVAIDS due to the need for moving mechanical parts (viz. radars, radiotheodolites), and to the retention of some older equipment.

While radiosondes for NAVAID systems are produced at prices almost competitive with conventional radiosondes, the small additional cost is incurred for each flight.

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