WORLD METEOROLOGICAL ORGANIZATION

INSTRUMENTS AND OBSERVING METHODS

REPORT No. 61

ROAD METEOROLOGICAL OBSERVATIONS

by
R.E.W. Pettifer, United Kingdom
and
J. Terpstra, The Netherlands

WMO/TD - No. 842

1997

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FOREWORD

The Commission of Instruments and Methods of Observations recognized at its eleventh session in 1994 that road meteorological observations could contribute to traffic safety and longterm cost savings. The Commission was of the opinion that valuable work could be done in standardizing instruments and methods of observations in this field and by providing guidance to Members to ensure cost-effective use of appropriate technologies. It was agreed to appoint within the *Working Group on Surface Measurements* two *Co-rapporteurs on Road Meteorological Observations*, namely Messrs J. Terpstra, Netherlands, and R.E.W. Pettifer, United Kingdom to provide an overview report in this field.

The report given in this publication is based on replies received to a questionnaire prepared by the Co-rapporteurs. It provides information in a field which bas been relatively new for CIMO and WMO and not many Meteorological Services were dealing with it so far. This may explain a disappointingly small number of responses received to the questionnaire.

I now would like to highlight some issues of concern reflected in the report:

- The use of meteorological observations to assist with the safe use of roads is increasing rapidly in many parts of the world.
- There seems to have been very little attention paid so far to the problems of ensuring that the meteorological data derived for this important application are of consistent and known quality.
- The report also shows, however, that much of this activity, although important and relevant to CIMO expertise, currently appears to lie outside the immediate sphere of CIMO and WMO action. It proposes that the way forward is for CIMO to cooperate with other interested bodies to raise awareness of and to encourage the introduction of, higher and more consistent standards of observational practice in this application area.

The information in this report will be useful to a wide variety of readers within and outside of the meteorological community.

I would like to thank the Co-rapporteurs for preparing this report and the Meteorological Services concerned for their support to this undertaking. I would also like to thank the Meteorological Services and other institutions that provided the information reflected in this publication.

(Jaan Kruus)
President of the Commission
for Instruments and Methods of Observation

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Abstract

This report is based upon the responses from WMO Members to questionnaires on road meteorological observations, upon literature searches and upon consultations with some of the leading practitioners in the field. It is intended as a statement of findings describing the state of current practice as reported to the authors and cannot be regarded as a completely comprehensive description of either all of the meteorological and related measurements made for road management purposes, or of the absolute state of the art. It reveals some problems with the meteorological measurements made for road and traffic management purposes, particularly with the methods of observation used, and highlights some of the consequential data quality issues which may exist. The work illustrates the multi-disciplinary nature of the activity and that it may be desireable in future for the CIMO community to co-operate more closely with the road and traffic management community than appears to be the case at present.

The principal findings of the study are that by far the majority of road meteorological measurements made at present are for the purposes of the prediction or warning of ice formation on the carriageway and that within this application area there is general agreement about the types of meteorological measurements required and about the instruments to be used to obtain them. There is, however, a very wide range of different observing practices in use, particularly in respect of the location and exposure of sensors. As a result, the meteorological quality of the data derived from these measurements is likely to be uncertain. It is especially important therefore that they are viewed with great caution if there is any temptation to use the data for purposes other than those for which they were specifically produced. This might be seen as unfortunate, because in some countries the size of the observing network producing these data rivals or even exceeds that used for conventional synoptic purposes by the relevant National Meteorological Service.

There is probably a case for a further study to inter-compare the different sensors and technologies used for the detection of road surface condition but this is not strictly a meteorological measurement and is thus essentially outside the scope of the work of CIMO. With the exception of these sensors, the instrumentation reported as being used in this application area is conventional and there appears to be no requirement for instrument inter-comparisons other than those which CIMO may decide upon for other reasons.

The apparent lack of any agreed definitions of meteorological variables required for road and traffic management purposes was noted. There seems to be no published work which examines this requirement and, at present, the users appear simply to apply to the problems of road management whatever data their instrumentation delivers. Since most of that instrumentation is taken directly from conventional meteorology, but in terms of exposure and in other ways is used differently, it is questionable whether the data are optimal for the intended application; they are unlikely to be of consistent, known quality even within some national networks and certainly not from network to network.

It is concluded that CIMO should extend its work in this field in co-operation and consultation with appropriate national or international organisations, with a view to developing a consensus upon such issues as the specifications of those meteorological variables which need to be measured for road meteorological purposes, and the optimal observational methods needed to obtain them.

1. Introduction

In recent years there has been substantial growth in the application of meteorological measurements to ensuring the safer, more cost effective, or more environmentally conscientious use of roads. Problems including the prediction of ice formation on road surfaces, strong winds on bridges, heavy rain creating aquaplaning conditions and the reduction of visibility by fog or precipitation have all been considered. This has resulted in a sharp growth in the use of meteorological observing systems, almost entirely automatic weather stations, to make and report real time surface meteorological observations. CIMO considered this development and decided to investigate the situation in order to better inform itself of the instrument and observational issues involved.

To do this CIMO XI, by Resolution 3, appointed Mr. J. Terpstra of the Netherlands, and Dr.R.E.W. Pettifer of the UK as co-rapporteurs on Road Meteorological Observations, with the following Terms of Reference:

a. *To prepare a report on the state-of-the-art of:*
   1. *Meteorological instrumentation, required for road meteorological measurements;*
   2. *Sensors and systems to measure road surface conditions:*
b. *To prepare definitions of variables of interest;*
c. *To review relevant siting and exposure criteria:*
d. *To evaluate the need for an inter-comparison of particular sensors or measuring systems.*

They undertook their tasks by means of questionnaires, a literature search and personal consultation with experts working in the field. This report analyses the information provided to them through these processes and sets out their findings and recommendations.

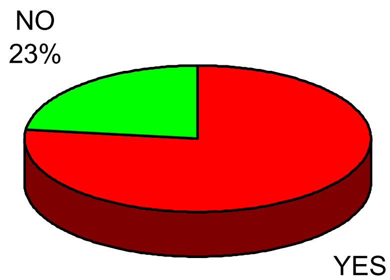
2 .The extent of road meteorological activity within CIMO

2.1 Level of Interest.

Initially simple questionnaires were sent out to all Permanent Representatives of WMO to solicit the level of interest in the subject. Seventy-four completed questionnaires were returned. These responses are analysed in Figs 1 (a) through (c).

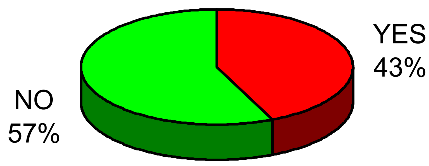
Fig 1 (a) shows that there was strong interest expressed in the subject of road meteorological observations among the Members who responded. Only seventeen Members (23% of the responses) indicated no interest whatever. Moreover, thirty-two (43%) of the respondents stated that they are now making or plan to make road meteorological measurements (Fig 1 (b)). In fact only two respondents indicated that such measurements are planned rather than presently made so there are apparently thirty Members who claim to be making these measurements. The distinction between experimental measurements and operational measurements was not drawn within the questionnaire, so there is the possibility that not all of these measurements are of an operational nature.

Fig 1 (a) Are you interested in road meteorological observations?



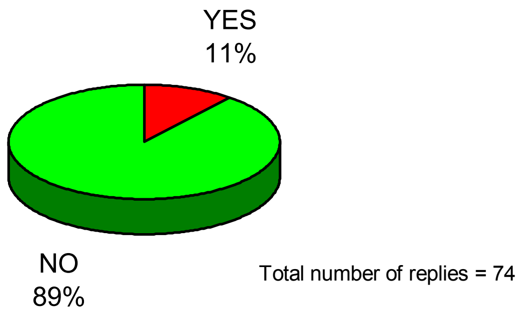
Total number of replies = 74

Fig 1(b) Are road meteorological observations made or planned in your country?



Total number of replies = 74

Fig 1 (c) Are publications/reports on road meteorological observations available in your country?



In view of the large number of Members reporting that they are making highway meteorological measurements it is perhaps somewhat surprising that, as Fig 1 (c) shows, only eight (11%) of respondents claimed that there are published reports or other material on the subject available in their countries. It may be concluded from this that the subject, whilst of importance and probably of growing importance, is as yet ill co-ordinated and ad hoc in nature. It seems likely that most of those involved, or who would like to become involved, are unaware of what is going on in areas other than their own.

3. Instruments and Measurement Practices.

3.1 The Detailed Questionnaire

To investigate further the instrumentation and observing practices among those members who indicated that road meteorological measurements are made in their countries, a total of 57 detailed questionnaires were sent out to the nominated contact points of those Members who had expressed interest in the subject. For reasons of space the text of this questionnaire is not included in this report but copies may be obtained by application to either of the authors. Disappointingly, by the time this report had to be drafted, only 10 replies had been received, one of which was a declaration of dis-interest and two were simply statements that every measurement is "desirable". These three have been excluded from the analysis given below, and references to "all respondents" should be taken to mean "all those who provided specific replies to the questions posed by the questionnaire". The analysis of the data from these questionnaires must therefore be treated with great caution. The sample is insufficient to permit the establishment of any firm consensus on the topics investigated and does not include information from some Members who are known by the authors to have road meteorological observations being made in their countries but who did not respond to the questionnaire.

3.2 General Points

In interpreting the responses, it must be remembered that although the Rapporteurs' brief covered all of "road meteorological observations", the great majority of the applications now at, or reaching, operational status are directed at the winter maintenance of roads. The questionnaire was therefore dominated by this sector of activity and although it contained sections for measurements not specifically related to winter maintenance, this section drew responses from only two nations, and even these were very brief comments. This is a pity, since it is known from the literature (Brisbane 1992, Douglas, 1978) that experimental work has been done in Australia and the UK on the relationship between visibility and traffic speed and on the possibility of using MOR to regulate traffic through advisory warnings, in some cases by the direct operation of variable traffic signs.

Similarly, no mention of the use of wind speed measurements to regulate traffic flow over exposed bridges or other potentially hazardous highways was made by any respondent to the questionnaire. But it is no more than the result of common observation to note that many such measurements are made and used and there are also references in the literature (Perry and Symons, 1991). The definition of, for example, "mean wind speed" or "gust" for these purposes, and the necessary observational methods, are areas where there seems to have been no systematic analysis within the meteorological literature and on which, so far as the information we obtained is representative, there seems to be no consensus among practitioners.

Such definitions might reasonably be supposed to be required and might also be supposed in the case of "visibility" to be related to the optical perception of drivers and background luminance, while for the wind case the dynamics and aerodynamics of vehicles should be important. Such regions of study may well be regarded as beyond the remit of CIMO, but there must be a case to be argued for CIMO to co-operate with other bodies, perhaps in an advisory role, to develop such definitions and standards as are needed, in a manner similar to that which is now well established in the aviation field.

It was notable that, with the single exception of one respondent from the tropics who suggested that the measurement and prediction of heavy rainfall would be of interest to manage traffic during flash flood conditions, no other application of meteorological observations on highways was mentioned in replies to the questionnaires. No comment was made for example of the need to measure precipitation for the purpose of determining surface water film or to measure road temperatures in summer for either traffic management or highway maintenance purposes both of which have been reported anecdotally as of interest to highway authorities in some countries. It cannot be concluded, however that such measurements are of no formal interest. It may be rather that the questionnaire, directed as it was at specialist "points of contact" nominated by Permanent Representatives, simply did not reach those with appropriate expertise in these matters.

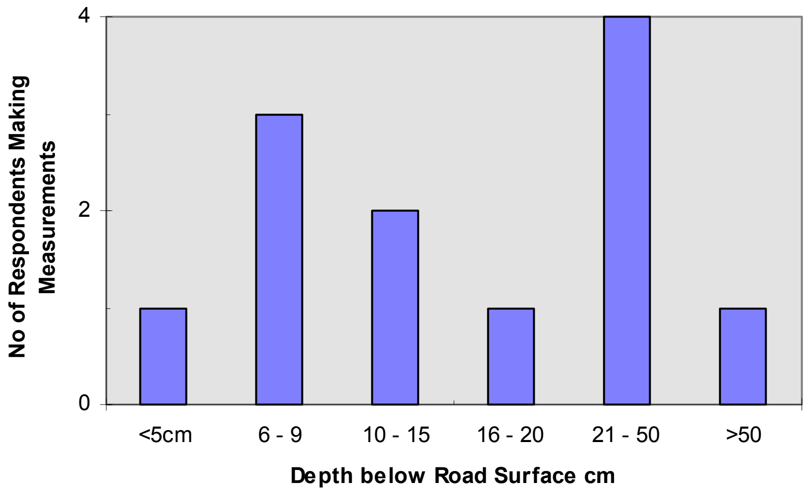
3.3 Temperature Measurements.

3.3.1 Sub-surface temperatures

For the case of ice prediction on roads, all respondents agreed that sub-surface temperatures are required. One emphasised that for the accurate numerical prediction of road surface temperature and condition, these measurements are essential. There was also agreement on the most appropriate instruments for these measurements; all respondents use either electrical resistance thermometers or thermistors. This may, however, have as much to do with what instrumental systems are available in the market place as with any specific consideration of optimum technology.

Despite the agreement on the need for and the method of obtaining these data, there was, as Fig 2 shows, almost complete disagreement about the number of levels at which measurements are required or the depths below the road surface at which these measurements should be made. Respondents were not asked why they selected the depths they use. The choices may relate to the particular application of these data, for example in one case they are used specifically to monitor the spring thaw for the purpose of deciding the maximum allowable vehicle load, and for this purpose much greater depths were reported than was the case for all other respondents. There is also the special case of bridges where the possible depth of sub-surface measurements is generally limited. Or it may be that the chosen depth(s) are defined by the type and characteristics of the surface temperature prediction model in use. However, in the absence of any agreed standards or guidelines, it is as likely that users simply leave the matter to those who make or install the instruments. But even different users of the same supplier's equipment reported that they made these measurements at different depths. It would appear that if there is any virtue in maintaining compatibility between data between different national networks, there is a need to consider this issue with a view to deriving some generally acceptable guidelines. That said, it is to be noted that in such specific application areas as we are dealing with here, there may be very little requirement for such compatibility and the choice of exposure for instruments may rightly owe most to the specific local conditions and demands of the application.

Fig 2: Depths of Sub-surface Temperature Measurements



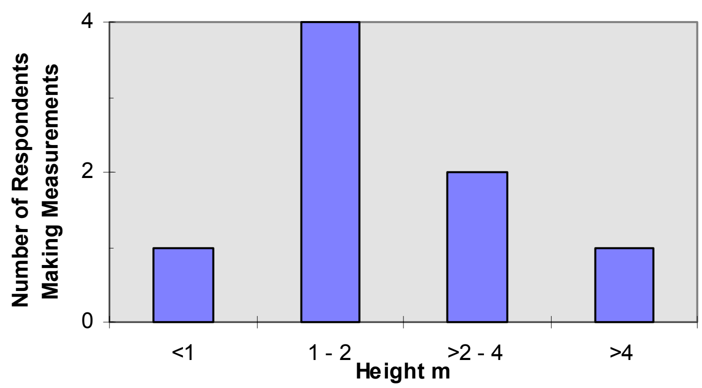
3.3.2 Road surface temperature.

Not surprisingly, given the dominance of northern winter applications among those reported, these measurements were made by all respondents. Moreover, all respondents reported that they use in-situ devices (either resistance thermometers or thermistors), and one reported also using passive remote sensing methods for this measurement. There was disagreement about where in the carriageway these measurements should be made; a point which is discussed further in section 3.6. Some respondents stated that, in order to obtain accurate data, the techniques used to make these measurements must be *passive* i.e. must not involve the injection or extraction of energy from the surface e.g. by heating or cooling. There is some support for this idea in the literature (Lister, 1990) but very little specific research on the matter appears to have been reported in the public domain. There were no comments made about the significance of ensuring that the thermal and radiative properties of the sensors embedded in the road surface should match those of the road material, although some manufacturers have drawn attention to these as requirements. In much of the published literature dealing with the accuracy of road surface temperature prediction (see for example Thornes 1995) the root mean square errors of the differences between measurements and predictions is typically quoted to be around 1.5 deg C, and measurements of this uncertainty or better are being assumed. It is therefore surprising that there appears to be little attention paid to the radiative errors which might accrue from neglect of thermal or radiative mis-match between the sensors and their surroundings.

3.3.3 Air temperature measurements.

These were also seen as essential by all respondents but again there was disagreement about the requirements for exposure of the instruments. None of the users was following recommended CIMO practice for the exposure of thermometers to measure air temperature. In one case it was reported that the thermometers were exposed without even the benefit of a radiation screen, while in other cases it is known that "screens" of unconventional design and unverified performance are in widespread use in some geographical areas. The reported exposure heights for air temperature measurements are analysed in Fig 3 and varied between 2m and 10m. Although not part of the responses to the questionnaire, it is known that, especially in urban sites, the exposure will often not be over the recommended "short grass". Thus, for all that the measurements may serve the specific operational purpose for which they are made, these data should be viewed with considerable caution if there is any temptation to apply them to more general ends, such as, for example, climatological studies or the application to "synoptic" or general mesoscale forecasting problems.

Fig 3: Height of Air Temperature measurements



3.3.4 Other temperature measurements

There was only one explicitly stated requirement for any other temperature measurements for road meteorological purposes. This was to monitor the freezing temperature of salt solution on the road surface. Recent work (Turunen, 1997) has shown that this is by no means a trivial problem either of measurement or interpretation The technique indicated for making this measurement was a combination of in-situ conductivity measurements and remote microwave measurements. However, several of the proprietary road surface condition sensors now reported to be in use by respondents are able to provide information related to the freezing point of the material on the road surface, so it may be assumed that this measurement is de facto being made by some of those involved in road meteorological observations. One reply indicated that other temperature measurements are desirable, but gave no indication of what other measurements might be of use, nor of what the uses might be. In noting this result however, we should again bear in mind that we addressed our questions only to meteorologists and not to road engineers or traffic managers.

3.4 Moisture Measurements

3.4.1 Road surface condition

This was also seen as an essential measurement. All of those making these measurements were using in-situ techniques and two were also using remote sensing methods which, together with the one for air temperature and one for precipitation, were the only reports of such methods we received. The range of variables being measured was wide but seemed to be directly correlated with the particular manufacturer's instruments in use. There was comment from some respondents that the quality of the sensors in use for these measurements was only fair to poor and that they suffer from surface contamination. Some surface states, such as black ice, are detected by only one sensor among those available, but the lack of this measurement was not remarked upon as being a significant weakness in other cases. The ability to make measurements related to snow (Yes/No, Rate and depth) was reported in some replies as being available and by some as still required, although similar instrument suites were involved in all cases. It would be dangerous to conclude too much from our small sample but the indication appears to be that this may be an area of largely unfulfilled need in which such instrumentation as is available is not universally trusted.

Other specific comments related to the point nature of the measurements as a weakness, and to the absolute need for Thermal Mapping measurements (Shao et al, 1996) both to overcome this problem and to determine the optimal siting of road surface condition sensors. As with the case of road surface temperatures, there was disagreement about the optimum location for these sensors within the carriageway (see section 3.6 below).

3.4.2 Air humidity

The responses on this measurement paralleled those on air temperature. One respondent pointed out that these measurements are essential for the prediction of hoar frost, a condition of importance under some conditions. Measurements were mainly made with electrical hygrometers but in one case the use of hair hygrometers was reported. There was the same lack of unanimity about measurement heights as there was with air temperature measurements (Fig 3) and again, one respondent reported that they do not use a radiation screen for their measurements..

3.4.3 Precipitation.

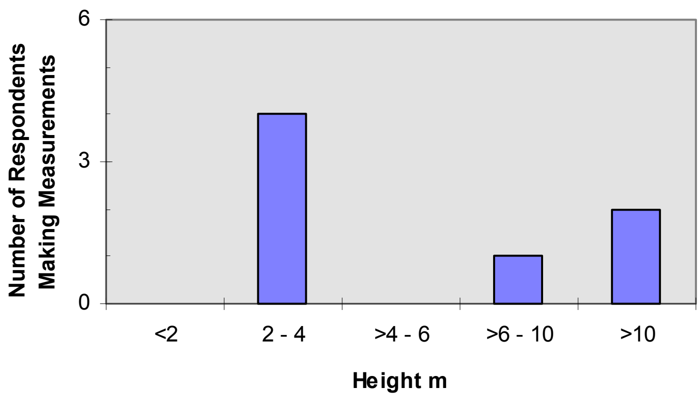
Another measurement seen as required by all seven respondents, it was noteworthy that in only one case was the use of conventional (heated tipping bucket) rain gauges or (unheated weighing) snow gauges reported. The presence of rainfall (rain Yes/No) was reported to be measured by all but two of the respondents but only four out of seven said that they measured precipitation amount and only three reported measuring rain rate. Five out of seven also said that they measure snow Y/N, four that they measure snow amount and only two that they measure snow fall rate, although in these two cases the questions about instrument type for these measurements were left unanswered. All respondents reported using in-situ measurement methods and in addition, one reported using "remote sensing". It has therefore to be assumed that almost all the precipitation measurements for this application are being made by the use of electrical, "surface wetness" detectors and that the type of precipitation is deduced from other complimentary measurements such as air temperature. Given that all the instruments of this type reported to be in use are claimed by the manufacturers to be capable of providing rate and amount measurements for both rain and snow, this lack of uniformity in the responses may indicate some lack of confidence in the users about these measurements and this might be an area for closer study than has been possible in this work.

In a recent paper, Symons and Perry (1997) have drawn attention to the value of Weather Radar measurements of precipitation as an aid to the nowcasting of road hazards. However, none of the respondents to our questionnaire made any reference to such measurements, despite the fact that they are widely available, at least in Europe and N. America.

3.4.4 Wind speed

This measurement was seen as required by six out of the seven replies and as desirable by the seventh. All the reported measurements were being made using rotating cup or propeller anemometers; no other technology was reported to be in use. Half of the respondents reported that they use sensor heating and half that they do not. As with temperature and humidity, there was disagreement about the optimum measurement height for this variable, with four nations measuring in the range 2m - 4m, one in the range 6m-10m and two at heights above 10m (Fig 4).

Fig 4: Height of Wind Measurements



There would seem to be some need for guidance as to the "correct" height for these measurements but there is the clear message that measurements such as these, made for specific applications on the mesoscale, cannot be relied upon to be made in a manner consistent with normal CIMO recommendations. There is also the possibility that attempts to meet the "normal" CIMO exposure guidelines for measurements such as this may result in users making measurements which are not optimised for the application for which they are made. The questionnaire did not address details of the measurement such as the sampling and integration time for high frequency variables like wind speed and it may be that similar arguments apply also to these aspects of the measurement process. This would seem to be an area within which further study could usefully be undertaken.

3.4.5 Wind direction

Almost the same points can be made here as are made in 3.4.4. in relation to wind speed. It is noteworthy, perhaps, that all respondents saw this variable as either "required" or "desirable".

3.5 Other measurements

3.5.1 Visibility

Seen as "desirable" by six out of seven respondents, only one reported actually making such measurements. The measurement technique reported was in-situ, short base-line, forward scattering, although the wavelength in use was not reported. It is known from the literature (Brisbane, 1992, Perry and Symons 1991, Douglas, 1978) that visibility measurements are being, or have been made experimentally on roads in several countries, some of which were not among the respondents to our questionnaire and the others of which did not report actual measurements. This serves to illustrate that in directing our enquiries only to PRs and the expert points of contact they suggested, we may not have reached all of the relevant sources of information on the application of meteorological measurements to road operations. No comment was made by any respondent about the validity of MOR measurements as an aid to driver behaviour or road safety although the authors found one specific reference to this approach in the literature (Brisbane, 1992). It may be that this work should be seen as still at an early stage and that such issues have yet to be widely confronted.

3.5.2 Cloud cover.

Seen as "required" by one respondent for the specific purpose of monitoring daytime snow and ice melt and it's subsequent re-freezing at night, circumstances which lead to extremely hazardous road conditions, and as "desirable" by two others, no one reported making these measurements directly. It was claimed in two cases that the information can be deduced from other measurements, including radiation and precipitation data, and by another to be available from adjacent METAR reports. The importance of the data for road surface temperature prediction was stressed in one response, but present operational practice would appear to indicate that the added value that would be provided by separate measurements directly related to this variable (e.g. by the use of lidar cloud base measurements) does not at present justify the cost of making them.

3.5.3 Radiation

Only one reply reported actual measurements of sunshine, global and net radiation for road meteorological applications. The purpose of the measurements was given as the deduction of information on cloud cover, and for computations of heat fluxes. No details were given of the methods or instruments in use.

3.6 Instrument Exposure

It has been pointed out by one of us (Pettifer, 1989) that while it is easy to obtain data from *in-situ* atmospheric monitoring, it is difficult to get good data reliably. One of the principle reasons for this lies in the problems of instrument exposure. As is indicated above, there was widespread divergence of practice over the exposure of instruments for road meteorological applications, both in respect of the choice of sites for suites of instruments and the exposure of individual sensors at the chosen sites. The choice of sites at which to locate road weather stations seems often to be dictated by the availability of services such as power supplies and communications. The cost of installing such services to remote sites will often exceed by orders of magnitude the cost of the instrumentation, so it is unsurprising that siting compromises based largely on these considerations were reported by most respondents. The use of solar power and of radio-based communications (such as cellular telephone systems) are ways in which the need for these compromises could be reduced and might with advantage be encouraged, but the present extent of their use was not a subject of our questionnaire and was not commented upon by any respondent.

That exposure of instruments is an issue not to be ignored in this case, whatever the compromises which are defined by *force majeure,* is illustrated by the potential effects due to the shading of roads on the road surface state which has been modelled by Shao, Lister and Fairmanner (1994). Their preliminary results show that the siting of instruments with respect to such factors as the presence of tall buildings, trees or similar influences, is of critical importance to the value of the data to the application for which it is acquired. It appears to be the case, however, that few, if any, experimental studies of these matters have been reported in the available literature.

The existence of known hazardous areas and the selection of “climatologically representative” sites were two other considerations reported as determinants for the choice of measurement locations. The second of these is well supported in the literature (Bogren and Gustavsson, 1986) and the essential need for Thermal Mapping data (see Section 3.7 below) to facilitate this procedure and to allow the accurate interpolation of both actual measurements and forecasts of conditions was stressed by one respondent. This technique appears to be the only one presently available to provide some quantitative and “scientific” guidance on the optimum location of road weather stations (Shao et. al. 1997).

The exposure of individual instruments at road weather sites is shown by the results of this survey to vary widely from country to country. Some practitioners appear to have attempted to follow standard CIMO guidelines where possible (by exposing wind sensors at 10m for example) but it is clear that, to the extent that they are the result of anything other than force majeure, there are many different views as to the optimum heights, and conditions of exposure for common instruments such as thermometers, hygrometers, wind sensors and precipitation detectors. The most extreme case reported to us was the lack of radiation screens for air temperature and humidity measurements. It may of course be that the differences (if any) in the data quality which result from these different measurement practices are insignificant for the purposes of road and traffic management, in which case there is simply nothing to be gained from seeking to standardise them further. However, there is no evidence reported here, nor was any experimental measurement evidence found in the literature examined for this report, which bears on this point one way or the other. It is, however, clear that these data are unlikely to be fully consistent with the data obtained from normal WWW stations or from local area networks of "synoptic" stations. Unlike the case of observations made for aviation, there has been no attempt to harmonize the measurement methods and practices with those of "synoptic" meteorology, and the use of road meteorological measurements to extend or to supplement normal "synoptic" or climatological data sets should be undertaken with great caution. In extreme cases, the data may simply be inadequate for such purposes.

The location within the carriageway for road surface temperature and condition sensors seems to be the subject of wide disagreement. They were variously reported as being sited between wheel tracks in both "fast" and "slow" traffic lanes, in the wheel tracks, between the wheel tracks and the shoulder of the road, and in the centre of the fast lane. In several cases, either no information was given or the advice of "highway experts" was cited without indicating any specific siting rules or practices. Shao et. al. (ibid.) have remarked that road surface temperature differences arise across a carriageway but it would appear that there is very little if any well founded knowledge derived from systematic research upon which to base these decisions. This is an area in which there is scope for further study and inter-comparison. It is, however, arguable that such work is peripheral to the basic objectives of CIMO and that it would be more appropriately undertaken by those whose task is the study of roads and traffic rather than measurements of the atmosphere.

3.7 Thermal Mapping

There was no specific part of the detailed questionnaire devoted to Thermal Mapping (Shao, Lister and Pearson, 1996) but the topic was raised by two of the respondents who emphasised the need for this technique both for the choice of location for road weather stations and for the interpolation of road surface temperature and condition measurements and forecasts of these variables. By the nature of the most widely used in-situ measurement methods, it is the case that measurements are made at discrete points in the road surface and such point measurements can be seriously misleading under some circumstances. Thermal Mapping provides a method of reliably interpolating road surface temperatures, and in some cases condition, between such discrete measurement points. It also allows the reliable characterisation of road networks into reasonably homogeneous "climatic domains" within which representative measurement sites can be located. Such a procedure contributes substantially to the optimisation of an observing network and to the full utilization of the data obtained from such a network.

4. Definitions of variables of interest.

4.1 General

From the comments made by respondents to the detailed questionnaire and from a perusal of the literature available to us we have found no existing proposals for definitions of meteorological variables of specific interest to road meteorological observations which have arisen from the meteorological community. Thermal Mapping is the only exception to this and that may be regarded as only a meteorologically related, rather than a strictly meteorological, measurement. This does not indicate that such definitions are not required. In a private communication arising from the enquiries made for this report attention was drawn to work by Raatz and Jacobs (1996), in which the Deutscher Wetterdienst have indicated that they have adopted a standard exposure height of 4m for temperature and humidity based upon the need to keep contamination from road dirt and spray to a minimum and on "experience" showing that measurements at 4m do not differ significantly from those made at 2m height. They did not, however, cite any evidence to support their choice of -30 cm for the depth of sub-surface temperature measurements and the middle of the fast lane for the location of road surface condition measurements.

As has been pointed out above, no public consideration seems yet to have been given to such questions as what sampling frequency and filtering period should be applied to wind speed and direction measurements for this application, to the optimum sampling and averaging algorithms for the various temperatures of interest, to a consistent set of exposure criteria such as the appropriate depths for sub-surface temperature measurements and so forth. What is less clear is whether such issues matter greatly for measurements which are made for specific mesoscale applications and which are not intended for widespread dissemination beyond their immediate user community.

For the case of visibility, although there is a substantial literature dealing with the effects of fog on roads and dating back to early measurements reported by Douglas (1978), much of which is cited by Perry and Symons (1991), it appears that in terms of the definition of measured variables, it has all been based upon the normal meteorological concept of MOR, a strategy which the aviation case illustrates may not be optimum for highway applications.

There are now in existence some very large national networks of road meteorological observing stations (one respondent listed over 200 stations and Thornes (1995) lists inter alia a total of 3121 road meteorological stations in 15 countries with the largest networks, each of 550 stations, in the UK and Sweden) and it may be inevitable that the data from these networks becomes more widely available than is predicated by their original purposes. They are certainly likely to find their way into at least national data bases of some kind and their value would be significantly enhanced if they are known to have been made to a consistent and agreed set of measurement standards and following a defined set of practices. Whether this goal is achievable is less than clear but it may well be that CIMO should take a lead to establish some form of mechanism to consider these issues, which involves both the meteorological and the road management communities.

4.2 Thermal Mapping

This process has been defined in the literature (Shao, Lister and Pearson, 1996) as:
"A process for quantifying the variation of night-time road surface temperature in a geographical region and presenting the data as a series of colour-coded maps."

an alternative, though similar, definition has been proposed by Thornes (in Perry and Symons, 1991, pg. 43) as:

"The measurement of the spatial variation of road surface temperature along a road using an infra-red thermometer or camera."

These definitions are essentially descriptive rather than prescriptive but are nevertheless probably all that is really required for the present purposes. The first is to be preferred to the second on the grounds that no reference to specific measurement technology is included.

4.3 Specifications and Definitions from other sources.

4.3.1 The DRIVE Project

Under the Commission of the European Communities R&D programme, Telematics System in the Area of Transport (DRIVE II) Project V2045 Road Safety Enhancement System (ROSES), a series of work packages was undertaken relating to the impact of meteorological effects on road safety. Some of the reports from this work contain proposals for variables of importance to this field and outline specifications for such variables. To the extent that they are proposals arising from the R&D and do not appear to have been further discussed or examined in the open literature, they represent, perhaps, starting points rather than end points of the process of establishing accepted international definitions and specifications. They do however seem to constitute perhaps the only significant statement of this type of data freely available which is based upon systematic research processes. As such, the relevant summary tables are reproduced as Appendices A, B and C of this report. This work was done under the auspices of the Netherlands Road Vehicle Research Institute with input from KNMI, and could usefully form a foundation from which to develop fully agreed definitions and specifications, if, indeed, such universal agreement is ultimately believed to be necessary.

4.3.2 Other literature

In the time and with the resources available to undertake this report, it has not been possible comprehensively to survey both the meteorological and the highway research literature for references to this topic. The following remarks are therefore to be regarded as a summary of work published mainly in the meteorological journals which has come to our attention. In recent years there has been a steady flow of published papers in the subject area of road meteorology but by far the majority of this work is devoted to the forecasting of road surface temperatures and conditions. The development of suitable prediction models, their accuracy, timeliness and the effectiveness of reactive systems based upon their outputs have all been extensively considered. But very little appears to have been published on the instrumentation and methods of measurement associated with the acquisition of the basic data needed to produce and verify these forecasts. There seems to be an implicit assumption, particularly when assessing the accuracy of forecasts, that the data are all of the same quality and are good representations of "truth", irrespective of the instruments or methods of observation used to obtain them. The dangers inherent in this have been illustrated in just one paper presented some years ago at a London meeting of the Royal Meteorological Society (Lister, 1990) and the lack of study in this area is a significant deficiency of the present body of published knowledge in this field.

A substantial programme of intercomparison of the performance of road surface condition sensors from several manufacturers and of the performance of infra-red remote sensing devices for measuring road surface temperature and condition has been undertaken in Austria. The results have appeared as an internal government report and in summary in the Proceedings of the Third International Symposium on Snow Removal and Ice Control Technology (Scharsching 1992). These data are in now some six years old but seem to be the only data published in the open literature concerning the comparative performance of road surface condition sensors. The authors did not find any published reports on such matters as the optimum siting and exposure of meteorological sensors for this application, the efficacy of present measurement techniques or any other aspect of road meteorological measurements. This is represents a lamentable void in the body of open scientific knowledge of a topic of great importance to the safety of life and the economics of road transport.

5. Recommendations.

As the result of our work, we make the following recommendations for the further prosecution of this area of activity.

1. That steps should be taken to encourage the pursuit of consensus among interested Members of CIMO in relation to the need for and form of guidance in respect of the specifications for the measurement of meteorological variables for road meteorological purposes, including inter alia:
   siting,
   exposure,
   data sampling and processing
   for the most commonly used measurements, and should attempt to stimulate R&D programmes in the road meteorological measurement field by proposing an inter-comparison of road surface condition sensors under closely monitored meteorological conditions.

2. That, in view of the multi-disciplinary nature of the subject, CIMO should seek to forge co-operative links to appropriate national or international highway organisations, such as The Standing International Road Weather Conference (SIRWEC), so as to serve, primarily in an advisory capacity, with regard to the meteorological measurement requirements of the road traffic sector in a manner similar to the present relationship with aviation.
3. That CIMO should, in order to begin the process of meeting recommendations 1 and 2 above, seek to arrange jointly with a suitable parallel international body in the road traffic field, an international workshop directed at defining the present state of the art and charting the way forward.
4. That CIMO should appoint a Rapporteur (or Rapporteurs) in this subject for the next inter-sessional period, with terms of reference directed at meeting the above objectives.

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Appendix A

Road Condition and weather parameters

	Parameter	Application	Dimension
1.	Road Condition		
	1. 1.: Water layer thickness	aquaplaning	mm
	1. 2.: Wet/dry/icy	all	type
	1. 3.: Type of ice	ice	type
	1. 4.: Local wind direction	cross-wind	o
	1. 5.: Local gust speed	cross-wind	m/s
	1. 6.: Visibility distance	visibility	m
	1. 7.: Viscous aquaplaning	aquaplaning	type
	1. 8.: Snow-thickness	snow	type
2.	Meteo Condition		
	2. 1.: Temperature medium height	all, dew-pnt	^oC
	2. 2.: Temperature road surface	ice, snow	^oC
	2. 3.: Temperature soil	all	^oC
	2. 4.: Temperature 10 m	fog	^oC
	2. 5.: Relative humidity	all, dew-pnt	%
	2. 6.: Air pressure	all	hPa
	2. 7.: Global radiation	fog, ice	W/m^2
	2. 8.: Longwave radiation	fog, ice	W/m^2
	2. 9.: Amount of precipitation	aquaplaning	mm
	2.10.: Main intensity	aquaplaning	mm/hr
	2.11.: Global wind speed	cr.-wind, all	m/s
	2.12.: Global wind direction	cr.-wind, all	o
	2.13.: Electric conductivity	humid., salt	S
	2.14.: Cloud cover	fog, ice	oktas
	2.15.: Ground wetness	fog	type
	2.16.: Electric capacitance	dry/bl.ice	F

Appendix B

Aspects of a road database

		AQ	IC	CW	VB [1]	comments
1	Number of lanes	*	*	*	*	
2	Lane width		*	*		
3	Transverse gradient	*				
4	Transverse cross-section	*				
5	Afflux length	*				
6	Texture depth	*	*			
7	Friction vs. Water depth	*				
8	Surface type	*	*			
9	Water source index				*	Vicinity water
10	Topography index				*	Hill/valley
11	Occurence of bridges		*	*		
12	Curves/bends	*	*	*	*	Risk.
13	Environment index				*	Rural/city
14	Site index		*	*	*	Open/sheltered
15	Aquaplaning map	*				
16	Thermal map		*		*	
17	Curve radius		*	*	*	
18	Visual connection lanes	*	*	*	*	
19	Local configuration	*	*	*	*	Risk.
20	Wind tunnel results			*		
21	Nominal deviation			*		
22	Maintenance experience		*			
23	Presence of lighting				*	
24	Orientation of the road		*	*	*	
25	Altitude	*	*	*	*	

[1] Indication whether the specific parameter is applied for aquaplaning (AQ), icy conditions (IC), crosswind (CW) and/or visibility (VB).

Appendix C

Technical specifications weather and road data

	Parameter	Resolution	Upd.(s)[1]	Accuracy	Range	Dimension	M[2]
1	Water layer thickness	0.1	12	0.1	<3	mm	*
2	Wet/dry/icy	1	60	1	1,3	--	
3	Type of ice	1	60	1	1,2	--	
4	Local gust speed	1.0	0.5	1.0	<50	m/s	
5	Local wind direction	5	0.5	5	0,360	o	
6	Visibility distance	10%	12	20%	0,300	m	
7	Viscous aquaplaning	1	60	1	1,2	--	
8	Snow/ice-thickness	0.5	60	0.5	<5	cm (?)	
9	Temp.medium height	0.1	12	0.3	-10,+20	^{o}C	*
		1.0	60	1.0	-30,+50	^{o}C	
10	Temp. road surface	0.1	12	0.3	-10,+20	^{o}C	*
		1.0	60	1.0	-30,+80	^{o}C	
11	Temp. soil	0.1	12	0.3	-10,+20	^{o}C	*
		1.0	60	1.0	-30,+80	^{o}C	
12	Temp. 10 m	0.1	12	0.3	-10,+20	^{o}C	*
		1.0	60	1.0	-30,+50	^{o}C	
13	Relative humidity	2.0	12	2.0	70,100	%	*
		2.0	30	5.0	0,110	%	
14	Air pressure	0.2	12	1.0	930,1060	hPa	*
15	Global radiation	5.0	12	5.0	0,500	W/m^2	*
16	Longwave radiation	5.0	12	5.0	0,100	W/m^2	*
17	Amount of precip.	1.0	300	1.0	0,15	mm	*
18	Rain intensity	1.0	300	10	0,150	mm/hr	
19	Global wind speed	0.5	3	0.5	0,15	m/s	*
		1.0	3	1.0	15,50	m/s	*
20	Global wind direction	5.0	3	5.0	0,360	o	*
21	Ground wetness	y/n	600	95%	- reliability	-	
22	Electric conductivity	0.5	60	0.5	0,1000	µS	
23	Cloud cover	1.0	600	1.0	0,8	Oktas	*
24	Transv. Gradient	.001	--	.001	.001	m/m	*
25	Afflux length	1.0	--	1	1,70	m	*
26	Texture depth	.1	--	.1	0,5	mm	*
27	Water source index	1	--	1	1,4	--	*
28	Topographic index	1	--	1	1,4	--	*

29	Site index	1	--	1	1,4	--	*
30	Environment index	1	--	1	1,4	--	*
31	traffic flow	200	600	200	<2000	veh./hr	
32	traffic speed	1	600	2	<50	m/s	
33	standard dev. speed	1	600	1	<25	m/s	
34	ratio heavy vehicles	.1	600	.1	0,1	--	

[1] update rate (sec.)

[2] M, data important for meteo