National Environment Protection (Ambient Air Quality) Measure

Technical Paper No. 6

Meteorological Measurements

Prepared by the
Peer Review Committee

May 2001

PREAMBLE

The National Environment Protection Measure (NEPM) for Ambient Air Quality was made in June 1998 with the desired environmental outcome of "ambient air quality that allows for the adequate protection of human health and well-being" across Australia. The NEPM sets national standards against which ambient air quality can be assessed. The NEPM includes a monitoring protocol to determine whether these standards are being met. Each jurisdiction is required to submit to the National Environment Protection Council (NEPC) a monitoring plan consistent with the protocol.

The Peer Review Committee (PRC) was established to assist NEPC in its task of assessing and reporting on the implementation and effectiveness of the NEPM by participating jurisdictions. The PRC includes government experts from all participating jurisdictions, in addition to representatives from industry and community groups. A significant activity of the PRC is the provision of advice to NEPC on the adequacy of jurisdictional monitoring arrangements, to ensure as far as possible that a nationally consistent data set is obtained.

To assure the consistency and transparency of its advisory function, the PRC has developed a set of guidance papers that clarify a number of technical issues in interpretation of the NEPM protocol. These Technical Papers provide the basis for PRC assessment of jurisdictional plans, aimed at assuring the quality and national consistency of NEPM monitoring.

The PRC Technical Papers are advisory for jurisdictions, and they will evolve with time as the science of air quality monitoring and assessment develops and as practical experience with monitoring increases.

M J Manton
Chair
Peer Review Committee

1. PURPOSE

The purpose of this paper is to provide guidance on the collection and use of meteorological data for the Ambient Air Quality - National Environment Protection Measure (AAQ NEPM).

2. INTRODUCTION

The NEPM for Ambient Air Quality does not explicitly require meteorological measurements to be undertaken. Nevertheless the Peer Review Committee (PRC) recommends that meteorological monitoring is included in the AAQ NEPM monitoring plans for each jurisdiction for the following reasons:

- meteorological monitoring adds significant value to air quality data, allowing qualitative and quantitative assessment of pollution episodes and, in particular, assists in the identification and explanation of trends and any exceedences of the AAQ NEPM Standards;
- meteorological data are a necessary consideration in extrapolating the results of air quality monitoring to other regions;
- meteorological data provide essential inputs to air quality models simulating the dispersion, transport and transformation of pollutants;
- meteorological data are required to assess the exposed population represented by a performance monitoring station; and
- at performance monitoring stations, meteorological monitoring can be achieved for a relatively small cost increment given that a data logger, telemetry, and other necessary facilities are already in place.

Quality assured meteorological data are needed for source impact and air quality assessments and in policy formulation for air quality management. Meteorological parameters used in air quality applications include primary variables which are measured directly, such as wind direction, wind speed, temperature, humidity, radiation, pressure, and rainfall, and derived variables which are estimated from other measured variables, such as stability and sigma theta. Mixing depth is often estimated, but sometimes is measured directly.

In this paper, guidance is provided on the measurement and computations of primary variables, and on the methods for determining the derived variables. The recommendations in this technical paper reflect current best practice but their application should not exclude alternative methods of appropriate technical quality.

3. STANDARDS AND GUIDELINES FOR SELECTING, INSTALLING AND OPERATING METEOROLOGICAL EQUIPMENT

The Australian Standard, AS 2923 – 1987 "Ambient Air – Guide for Measurement of Horizontal Wind for Air Quality Applications," sets out a guide for measurement of horizontal wind speed and direction. The USEPA document "On-site Meteorological Program Guidance for Regulatory Modelling Applications," EPA–450/4-87-013, and its revisions (USEPA, 1987) provide more comprehensive guidance on all meteorological measurements. The quality assurance aspects of on-site meteorological measurements are discussed more completely in another USEPA publication, "Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV, Meteorological Measurements."

The Australian Standard, AS 2923, should be used as the primary reference in relation to wind measurements. Within the framework of AS 2923, the PRC considers that:

- for air quality applications, "sensitive accurate sensors" as defined in AS 2923 are preferable;
- wind monitoring for purposes of the AAQ NEPM is considered to warrant "class 2" calibration and maintenance, as detailed in section 7 of AS 2923;

- anemometers sited near obstructions such as a performance monitoring station should comply with the relevant provisions of both AS 2923 and USEPA (1987), the latter being clearer and more stringent; and
- with respect to data processing, USEPA (1987) contains a few recommendations which either exceed, or differ from, the requirements of AS 2923 and are, in the PRC's view, desirable. These are listed in Attachment 1. The PRC recommends that wind speed, wind direction and sigma theta data are collected and processed according to the most stringent requirements of the two standards.

In relation to the other meteorological parameters the PRC has agreed that monitoring of these should be in accordance with USEPA documents, which provide comprehensive guidance. Recommended response characteristics for all meteorological sensors are given in the USEPA (1987).

Specialised assistance should be sought for operation of remote sensing equipment such as a SODAR or RASS-radar. The USEPA provides guidance for the operation of these instruments in its report "600R94038D Quality Assurance Handbook for Air Pollution Measurement Systems Volume IV: Meteorological Measurements (March 1995 revision)."

If the recommendations of the listed documents are not achievable, non-compliance should be documented as part of metadata. In particular, instruments have their own requirements with respect to exposure, and compromises in meeting these requirements may lead to the data being considered sub-standard.

4. COMPONENTS OF A METEOROLOGICAL MONITORING PROGRAM

4.1 Approach and objectives

The recommended approach is to install at least the minimum critical set of meteorological instruments at each performance monitoring station (subject to the issues discussed in section 4.2.1) but to also, if possible, install within each region a meteorological station with a comprehensive set of instruments. The latter may or may not be at the site of a performance monitoring station.

Furthermore, an analysis of the location of meteorological measurement sites within a region (including stations operated by the Bureau of Meteorology and other parties) may reveal the need for additional stations to provide an adequate network for modelling purposes. For example, relatively inexpensive stand-alone anemometers may provide invaluable data on the passage of sea breeze fronts, etc. This issue is region-specific and should be considered during the preparation of monitoring plans. Given the statutory responsibility of the Bureau of Meteorology for meteorological observations, liaison with the Bureau on the siting and operation of meteorological observations would be desirable.

4.2 Parameters measured at performance monitoring stations

The minimum set of parameters measured at a performance monitoring station should consist of wind speed and wind direction at 10 metres, and air temperature at 2 metres. Sigma theta (standard deviation of the horizontal wind direction) involves no additional measurement, and should be calculated according to the USEPA (1987). Barometric pressure could be added for instrument calibration purposes (adjusting diluent flow rates). Relative humidity can also be measured easily and is a worthwhile addition.

At least one performance monitoring station within a region should also include solar radiation, both for stability calculation and for photochemical smog modelling.

4.2.1 Wind measurements at performance monitoring stations

Before considering the full scope of a meteorological program, it is necessary to consider whether wind measurements at a performance monitoring station are acceptable in terms of compliance with standards or, at the very least, have an acceptable accuracy.

The standard exposure height of wind instruments over level, open terrain is 10 metres above the ground. Open terrain is defined as an area where the distance between the instrument and any obstruction is at least ten times the height of that obstruction. AS 2923 specifies that a 10-metre tower should (subject to provisions discussed below) be 10xH away from any obstacle (monitoring shed, tree, etc) where H is the obstacle height. For a typical air quality monitoring site with a 2.5 to 3 metre high shed, the tower should be 25 or more metres away from the shed to comply with this requirement. It is recognised that very few performance monitoring station sites in built-up areas would have the specified ideal exposure.

The Australian Standard, AS 2923 also includes, in section 8.1.3 and 8.1.4, a discussion of the effect of obstacles which applies to a monitoring shed and adjacent structures or trees. Three figures (3 to 5) show the approximate flow disturbance over structures of various shapes and the accompanying text states that these figures "may be used to estimate the distance above or away from an isolated obstruction at which representative measurements may be made." From inspection, it would appear that measurement at twice the height of an oblong shed should be adequate. Section 8.1.4 discusses the effect of multiple obstructions.

The USEPA (1987) specifies the "10xH distance from obstructions" rule as desirable. However it also provides guidance for siting wind sensors in the presence of buildings, as follows:

"If wind instruments must be mounted on a building (or other large structure) due to the lack of suitable open space, then the measurement should be made at sufficient height to avoid the aerodynamic wake area. This height can be determined by on-site measurements (e.g., smoke releases) or wind tunnel studies. As a rule of thumb, the total depth of the building wake is estimated to be approximately 2.5 times the height of the building."

Based on this rule of thumb, wind measurements taken at 10 metres on a tower which is mounted on top of, or immediately adjacent to, a 2.5 to 3 metre high shed would seem to be acceptable. This configuration also meets the requirements of AS 2923.

In light of the greatly enhanced value of integrated meteorological and air quality data, the PRC recommends that high priority is given to wind monitoring at performance monitoring stations whenever compliance with the provisions of both USEPA (1987) and AS 2923 can be achieved, as described above. Clearly this will not be possible for all performance monitoring stations (e.g., those surrounded by high rise buildings).

4.2.2 Temperature measurements at performance monitoring stations

The USEPA (1987) recommends that ambient air temperature is measured at two metres. This is similar to the World Meteorological Organization (WMO) standard for ambient temperature measurements. WMO specifies the general sensor exposure as "inside a suitable instrument shelter, at a height of 1.25 m to 2.0 m, over ground typical of surrounding terrain. The surface should be covered by short grass, or where grass does not grow, the natural earth surface.

Instruments should be protected from thermal radiation and adequately ventilated using aspirated shields.

Temperature sensors should be located at a distance of at least four times the height of any nearby obstruction.

Where measurements are made on towers, temperature sensors on towers should be mounted on booms at a distance of about one tower width away from the tower side.

4.3 Parameters measured at a comprehensive meteorological station

The following parameters should be measured, nominally at the heights shown:

Parameter	Measurement Height (m)
Wind speed	10
Wind direction	10
Air temperature	2
Temperature difference	between 10 and 2
Humidity or dew point	2
Solar radiation	as convenient
Net radiation	1 to 1.5
Rainfall	mounted near ground
Barometric pressure	2

Sigma theta and other derived variables can be computed from the above measurements.

There may need to be variations to the configuration of the meteorological station dependent on local factors, not the least being site security. For example, an acceptable alternative to having all of the parameters measured at one site would be to measure the wind and temperature difference at a clear site and to measure the other parameters at a nearby performance monitoring station.

Different measurement heights for wind and temperature difference may be appropriate for sites with large surface roughness or vegetation (USEPA, 1987).

The vertical temperature difference is used in estimating surface layer stability parameters including the stability category, for stable atmospheric conditions. The USEPA (1987) specifies that for surface stability parameters the temperature difference should be measured between 2 and 10 metres. For Pasquill-Gifford stability categories derived via the Solar Radiation - Delta Temperature (SRDT) method, the lower temperature sensor should be in the range of 20zo to 100zo where zo is the roughness length (but not lower than 1 m) with the upper sensor about 5 times the height of the lower sensor.

For a site with a shed, it may still be possible to measure the above parameters but with a taller tower (e.g., 20 metres), so that temperature difference can be measured over a sizeable interval (e.g., 4 to 20 metres). There is a likelihood of the lower temperature measurement being affected by the shed. However, because the temperature difference data will mainly be used for stability calculation for night-time hours, the influence of a shed (i.e., radiation and turbulent heat transfer) will be relatively low. Note however that temperature difference measurements, if used for turbulent flux calculations, should be made within a horizontally uniform surface layer which, for near coastal sites, may be less than 20 metres deep.

Vertical profiles of wind speed and direction can be reliably monitored via SODAR or electromagnetic radar. Temperature profiles may also be monitored via a RASS system attached to an acoustic or electromagnetic radar. Operation of a SODAR or RASS Radar is a relatively expensive and specialised task which may consequently be limited to the period of major studies. Data from these instruments are of great value in assessing the performance of 3-D meteorological models (or providing data for model input). The PRC recommends that opportunities for siting such instruments in major airsheds, possibly in co-operation with the Bureau of Meteorology, should be explored.

5. ATMOSPHERIC STABILITY AND MIXING DEPTH

Many schemes for calculating atmospheric stability have been published. A summary of schemes in common use is given by USEPA (1987) and Lorimer (1996) "Plume Models: Techniques for Better Usage," Proc. 13th International Clean Air and Environment Conference, Adelaide, 1996.

The range of parameters in section 4 above will facilitate calculation of stability via schemes ranging from simplistic to rigorous. The recommended approach is briefly explained below. The fundamental stability parameter for the surface layer is the Monin-Obukhov length, L. To calculate L, measure or calculate the sensible (or virtual) heat flux, HS, and the friction velocity u*. These parameters, together with a measure or estimate of the inversion height, also allow calculation of the buoyancy velocity scale, w*, which is a determinant of dispersion in convective conditions.

HS and u* may be calculated as follows:

- during daylight hours, via a heat budget, preferably based on measured net radiation if reliable, which also preferably directly accounts for latent heat rather than employing a seasonal-average Bowen ratio (hence the need for rainfall and humidity data);
- during night-time hours, via temperature difference and wind speed, with a predetermined roughness length, allowing calculation of a Bulk Richardson Number and hence L.

The heat budget is robust during the day when sunlight is dominant, but is unstable at night when the net heat transfer may be very small. The temperature difference measurements are often quite large relative to measurement errors at night but are not so during daytime due to convective mixing.

The USEPA (1987, revised) has introduced the SRDT method which, whilst simplistic, employs a day/night split approach following the same rationale as above.

If mixing height is not measured continuously (it rarely is, at least not reliably) it needs to be calculated. Again there is a spectrum of methods for calculating the daytime mixing height and night-time nocturnal boundary layer height, with appropriate transitions. It is difficult to obtain reliable estimates without an initial temperature profile. A 0600 or 700 LST radiosonde release from a nearby airport is ideal. Given this, and the calculation of HS and u* described above, it is relatively easy to run a slab mixing model for daytime mixing which generally gives good results. Other simpler schemes are available.

The purpose here is not to propose a uniform approach but to confirm that the proposed range of parameters to be measured is adequate and necessary. The only parameter in the list which is possibly not commonly measured is temperature difference. Inclusion of this parameter is highly recommended by the PRC because it obviates the need to collect the cloud cover and ceiling height data required by Pasquill-Gifford and Turner stability calculation method (USEPA, 1987).

The foregoing is consistent with recommendations made by leading air pollution meteorologists over the past 15 or more years, e.g., Weil (1995) "Updating Applied Diffusion Models," J. Climate Appl. Meteor. Vol. 24, No. 11.

It should also be noted that, with the evolution of the operational numerical weather prediction system of the Bureau of Meteorology, routine estimates of mixed layer height and other surface parameters required for dispersion modelling are becoming available. The collection of data such as wind and temperature profiles for model initialisation and verification will still be necessary.

6. DATA PROCESSING

Meteorological data should be processed to generate hourly and additionally preferably shorter-term (5-, 10- or 15-minute) averages. Averages of scalar as well as vector wind should be generated. The wind is a vector quantity, but speed and direction can also be treated separately as scalar quantities. The scalar mean wind speed should be used in estimating dilution, while the vector (resultant) mean wind speed should be used in a variable trajectory model. In general, the scalar mean wind direction should be used in Gaussian models whereas the vector (resultant) mean wind direction is more appropriate for trajectory analysis.

Provision of meteorological data as hourly averages is consistent with the National Environment Protection (Ambient Air Quality) Measure Technical Paper No 5, "Data Collection and Handling." This technical paper specifies that as a minimum requirement, concentrations of gaseous pollutants should be provided as hourly averages. Furthermore, regulatory models generally require hourly averages of meteorological variables including wind speed, wind direction and atmospheric stability.

Hourly averages may be obtained by averaging samples over an entire hour or by averaging a group of shorter period averages. If the hourly value is to be based on shorter period averages, then the USEPA (1987) recommends that 15-minute intervals are used. The use of shorter period averages in calculating an hourly value has advantages in that it minimises the effects of meander under light wind conditions in the calculation of the standard deviation of wind direction.

USEPA (1987) recommends that at least 360 samples are used to calculate a standard deviation and that at least 60 samples are used to calculate an average value, regardless of the averaging period. This recommendation is based on the evidence that 360 samples evenly spaced during the sampling interval will provide estimates of the standard deviation to within 5 or 10%. For an hourly standard deviation value, the data must therefore be sampled at least once every ten seconds. If data are first combined into 15-minute averages, then the data must be sampled once every 2.5 seconds to provide 360 samples during the 15-minute period, even if the four 15-minute values are later combined into an hourly value.

It is recognised that jurisdictions will differ in the way they store meteorological data. However, the PRC recommends that, as a minimum requirement, jurisdictions should be able to provide hourly meteorological data to correspond to hourly air quality data presented in AAQ NEPM data sets. For consistency with the AAQ NEPM and the Technical Paper No 5, the PRC recommends that the reported observation time for meteorological parameters refers to the time at the end of the averaging period.

7. DATA FROM THE BUREAU OF METEOROLOGY

There is a wealth of surface and upper air data available from the Bureau of Meteorology. Jurisdictions are encouraged to explore this source of data to supplement their own air quality and meteorological monitoring.

The Bureau of Meteorology operates a network of more than 460 Automatic Weather Stations (AWS) across Australia. A series of maps showing the location of Bureau's AWSs near capital cities is given in Attachment 2. The AWSs are designed to serve the purposes of providing real-time data for the Bureau's forecasting, warning and information services, as well as high quality data for the Bureau's climate database. The requirements to operate in extreme conditions and to provide high quality data mean the AWSs are constructed and operated to high standards.

Basic standards of instrument and observing practices are described in the "Guide to Meteorological Instruments and Methods of Observations," WMO No 8, sixth edition, 1996. Further information relating to siting of meteorological instruments can be found in the Observation Specification No 2013.1, "Guidelines for the Siting and Exposure of Meteorological Instruments and Observing Facilities," of the Australian Bureau of Meteorology. Functional specifications for a general purpose automatic weather station are given in the Instruments and Observing Methods Report No 65, WMO/TD – No 862, 1997, "Guidance on Automatic Weather Systems and their Implementation."

The WMO report (No 65) specifies the threshold (starting speed) for the sensors for wind speed and wind direction as 0.5 to 1 m/s. Typically for air pollution applications, more sensitive sensors are desirable; AS 2923 specifies a threshold less than 0.5 m/s, and USEPA (1987) similarly requires a threshold less than or equal to 0.5 m/s. These standards are more appropriate for air pollution applications. Sensitive sensors with lower thresholds and somewhat greater accuracy are more delicate than those used in conventional meteorological networks, and require more maintenance.

Bureau specifications for sensor interfaces for AWSs state that "the AWS must be capable of interfacing to any combination of the following sensors:

- Wind speed
- Wind direction
- Dry bulb temperature
- Wet bulb temperature
- Relative humidity
- Barometric pressure
- Rainfall

In addition to the above list of essential sensors, following is the list of optional parameters:

- Lightning
- Visibility
- Cloud height
- Sunshine duration
- Solar radiation
- Evaporation
- Wind run at 2 metres
- Soil temperature at 10, 20, 50 and 100 cm
- Grass temperature

The AWSs are versatile as they are used in various configurations at different locations and they are expected to be able to provide various message formats.

Typically, the Bureau AWSs are expected to generate five standard data formats. These are:
- One second (for maintenance and real-time readout)
- One minute (data logging and display)
- Ten minute (data logging)
- Thirty minute (forecasting)
- Three hourly (international exchange and archiving)

For meteorological purposes, in general, half hourly reports are based on samples collected over the 10 minutes preceding each half hour, rather than samples collected over the full half hour. However, the system has the capability and flexibility to provide any averaging required for air pollution applications. In some cases the Bureau captures and stores very detailed data, down to 1-minute averages.

AWS installations can be expected to be well sited from a meteorological viewpoint. If there is a need to site new performance monitoring stations in a region, there would be value in considering the suitability of sites close to an existing AWS. In addition, the inclusion of Bureau data is likely to provide a better representation of a region being modelled or assessed.

ATTACHMENT 1

SIGNIFICANT POINTS FROM USEPA "ON-SITE METEOROLOGICAL PROGRAM GUIDANCE FOR REGULATORY MODELLING APPLICATIONS" (1987 AND REVISIONS)

The section numbers refer to USEPA (1987).

A. Points which differ from the Australian Standard AS 2923

Wind data processing
Dilution in Gaussian models depends on scalar speed, not the magnitude of vector velocity, and should therefore be based on the scalar mean wind speed. Vector winds may be appropriate for "variable trajectory models".

Computation
Wind direction meander should not be included in 1-hour sigma theta. A 1-hour sigma theta, if required, should be calculated from the square root of the average of 15-minute variances.

(Subject to testing it may reasonably be assumed that 10-minute variances may be used in the same way.)

B. Points which are more stringent than AS 2923

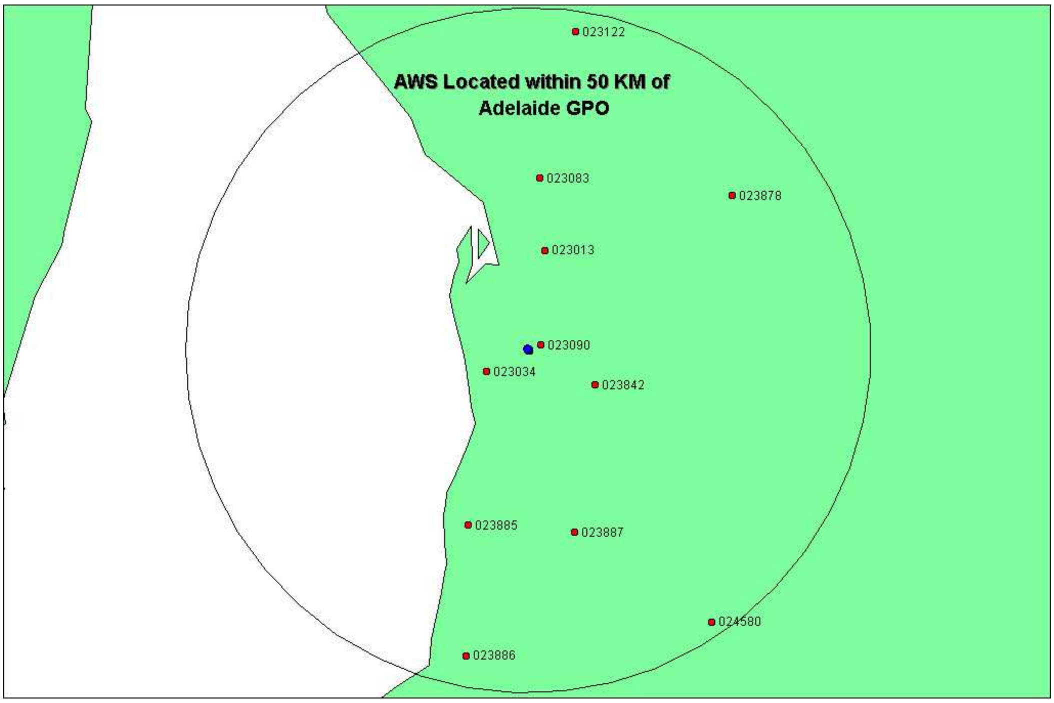
Computation
To calculate wind direction and/or sigma theta via a single-pass technique, the data collection system should sample at least once per second so that each successive direction sample is less than 180 degrees different from the previous sample.

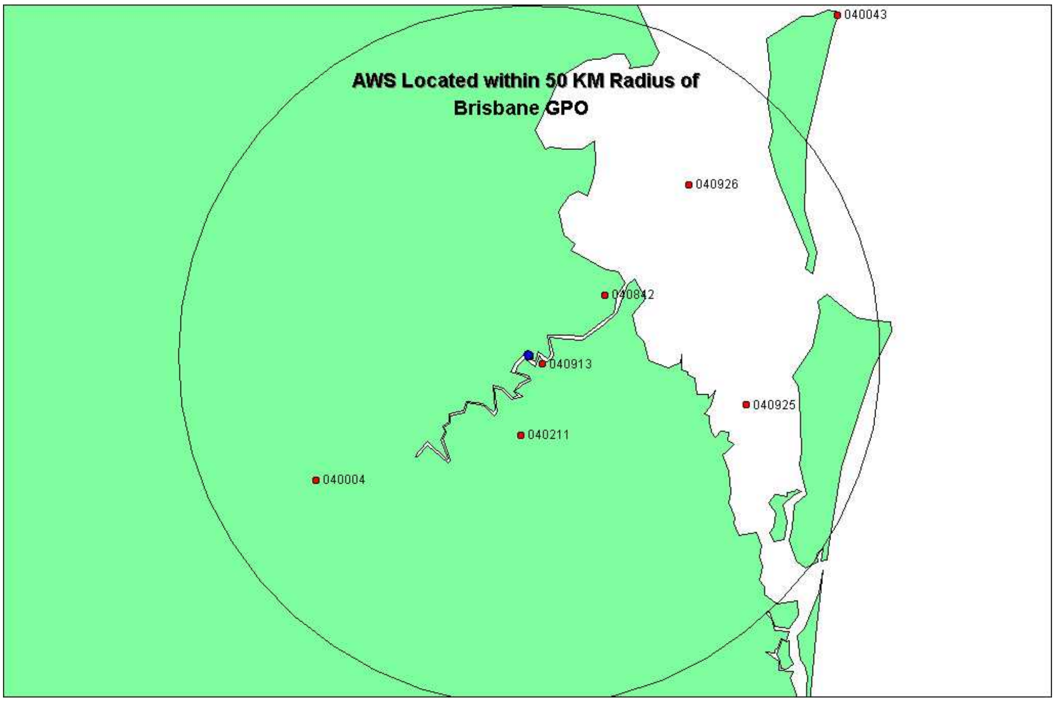
Sampling rate
Estimates of the mean wind speed or direction require at least 60 samples over the averaging period, while estimates of the standard deviation require at least 360 samples. (Note also the above requirement for single pass calculation of wind direction and/or sigma theta. The requirement of at least 360 samples for single pass sigma theta calculation is easily met by 1-second sampling over 10 minutes.)

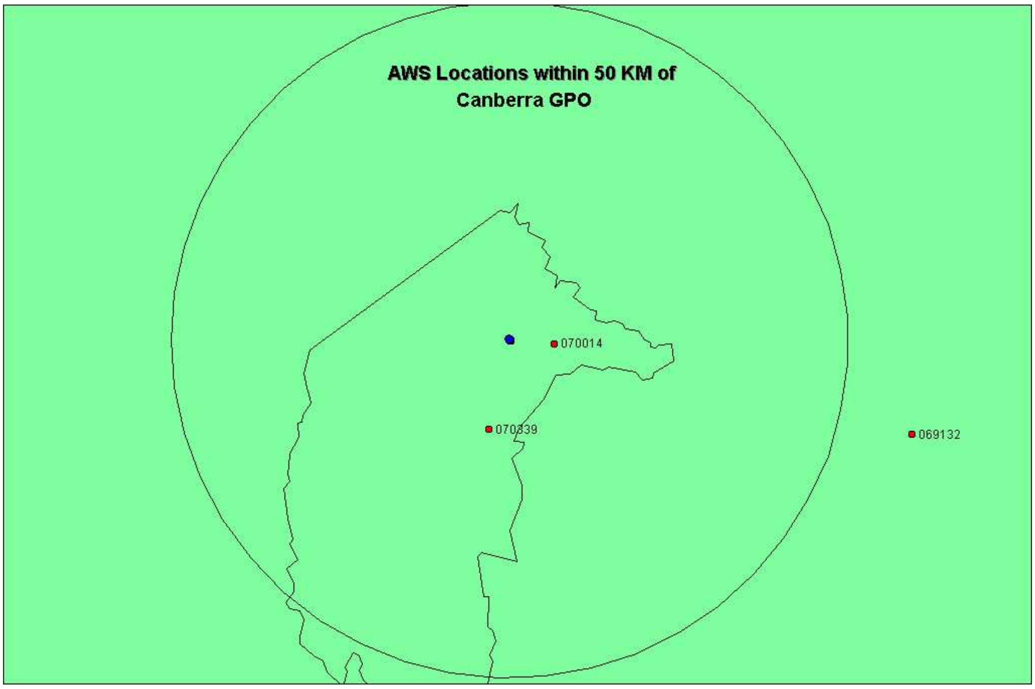
ATTACHMENT 2

Maps showing the locations of Bureau of Meteorology Automatic Weather Stations near capital cities follow for:

- Adelaide
- Brisbane
- Canberra
- Darwin
- Hobart
- Melbourne
- Perth
- Sydney



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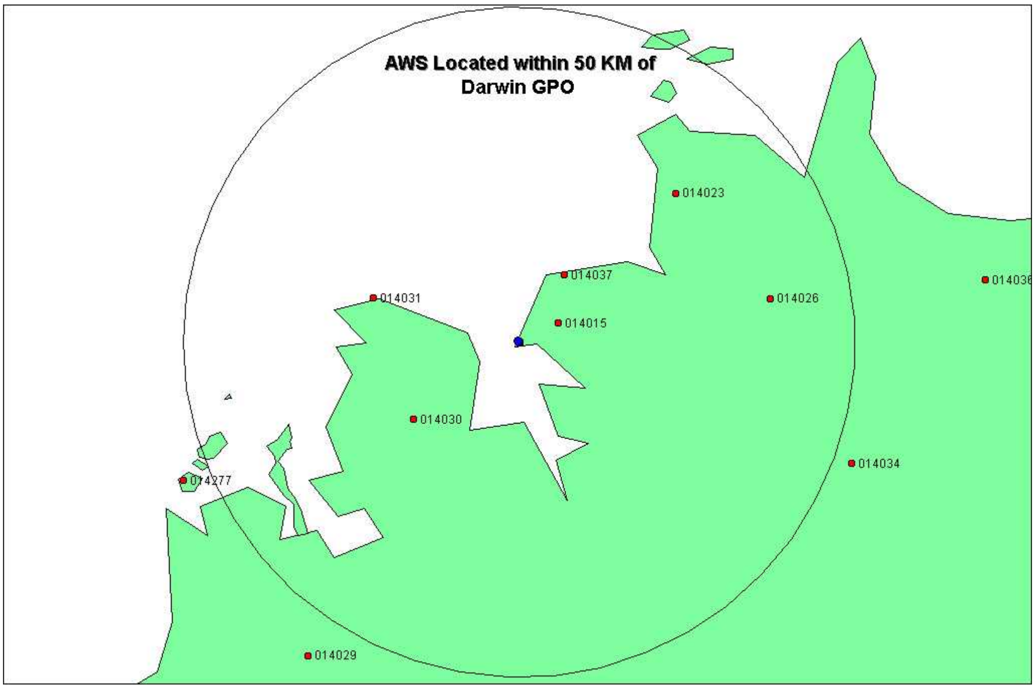
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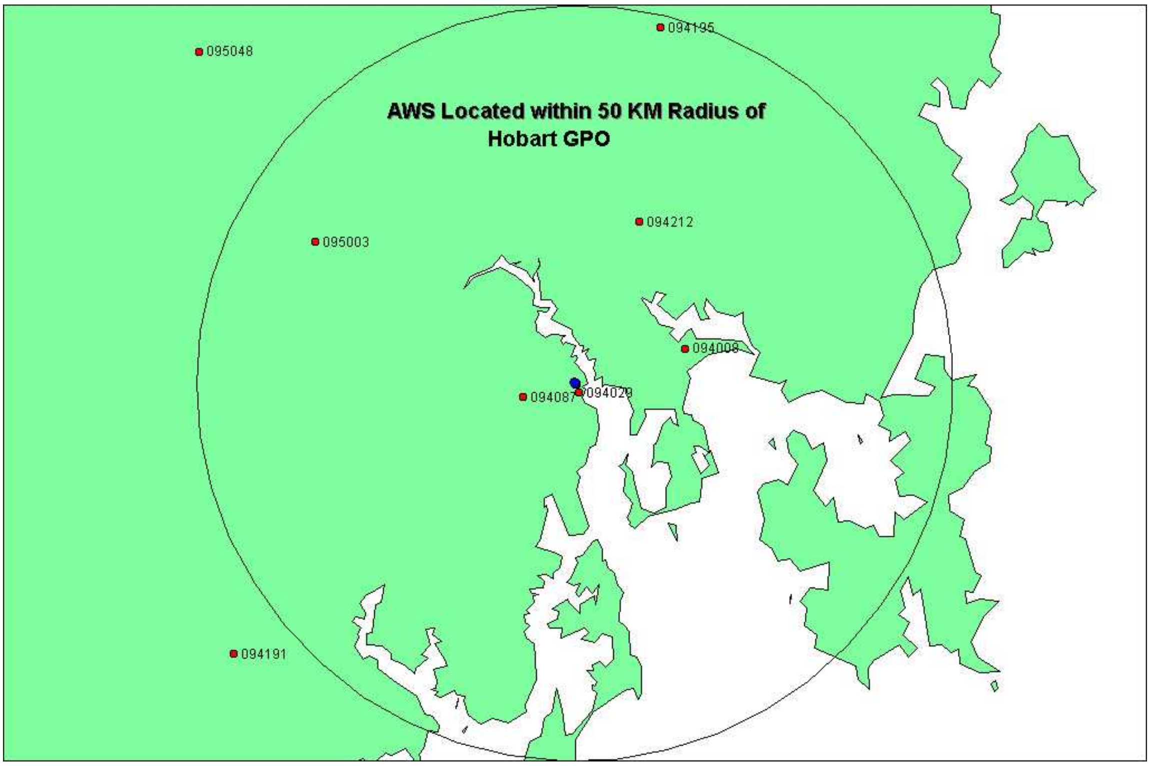
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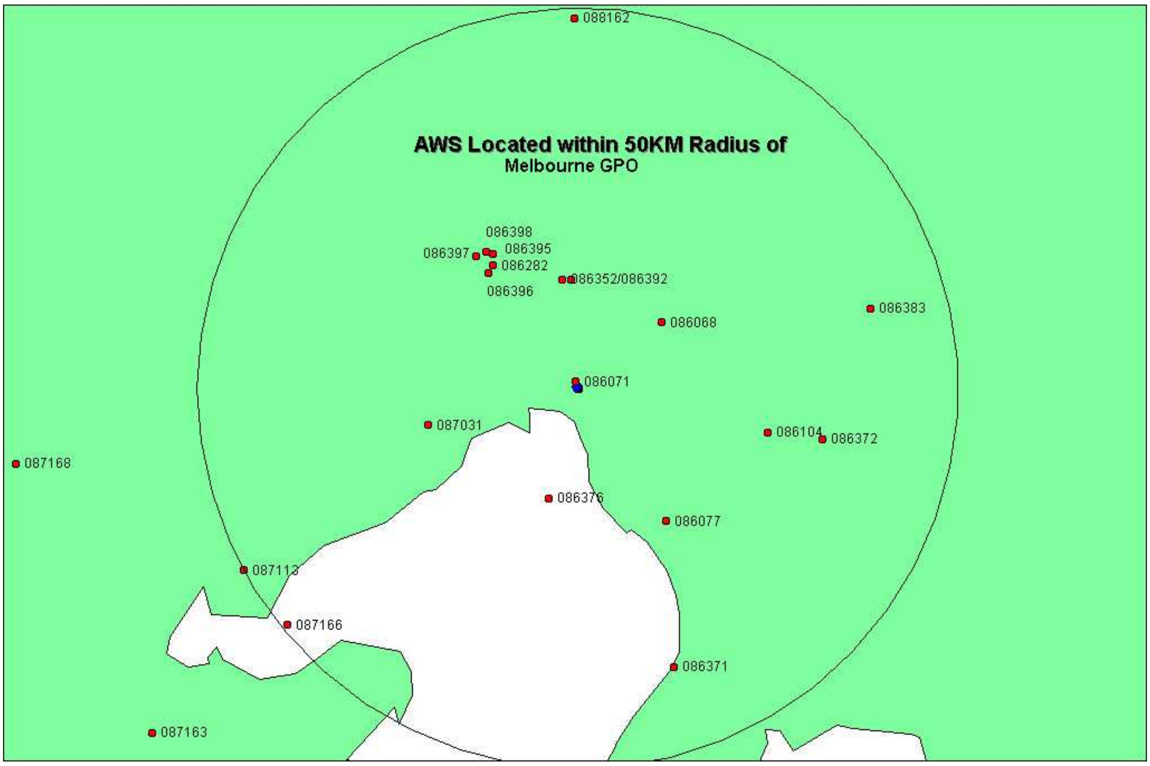
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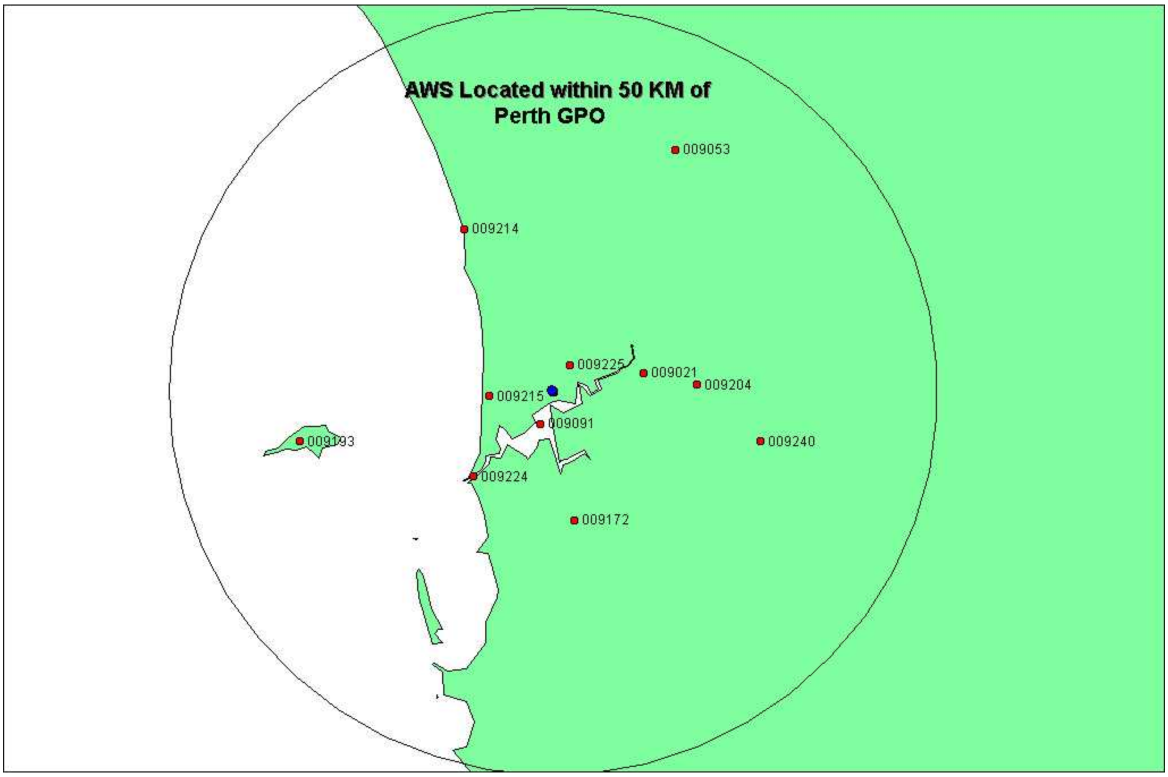
AWS Located within 50 KM of
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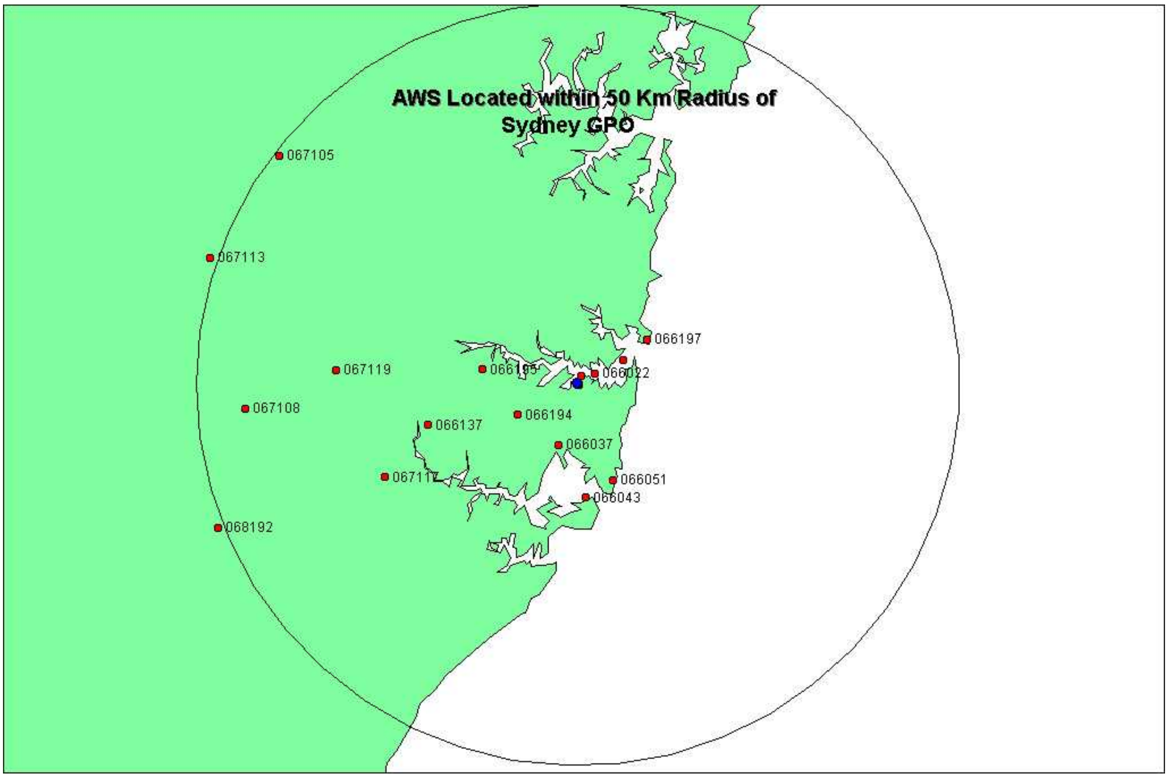
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