

Construction of input meteorological data files for EPA Victoria's regulatory air pollution model (AERMOD)

Draft guideline



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Introduction

The Environment Protection Authority (EPA) of Victoria has adopted the US EPA regulatory air dispersion model AERMOD as the replacement for AUSPLUME for regulatory air impact assessments in Victoria.

Meteorology is one of the crucial inputs to air dispersion models. Preparation of this key input (data) needs to be done following recognised and accepted procedures.

AERMOD requires the input of two meteorological files; a 'surface' (.SFC) data file and a 'profile' (.PFL) data file. In the USA, these files are typically provided by the AERMET meteorological pre-processor, however, the use of AERMET is not suitable for standard use outside the USA in its current form due to the very 'USA-specific' nature of the basic input requirements.

This guideline describes the methods to be used in the construction of the AERMOD meteorological input data files (metfiles) when using AERMOD for air impact assessments in Victoria.

Note that:

- Air impact assessments using AERMOD in Victoria need to be based on 5 years of meteorological data. This can be achieved with a single model run with a 'surface' and 'profile' file containing all 5 years of data, but more likely with model runs based on yearly input meteorological files.
- The 'profile' data file allows for the input of meteorological data at multiple levels in the vertical (e.g. from a wind tower with appropriate instrumentation at various vertical levels), however, such data are rarely, if ever, available in Victoria (or indeed throughout Australia). As such, this guideline and the associated 'profile' data files, focus on situations when suitable data are only available at a single vertical level (typically at the standard 10m height above ground level).
- EPA, Victoria have created a series of 'regulatory' AERMOD meteorological data input files for various locations/regions throughout Victoria. These meteorological input data are available from EPA, Victoria in the form of 5 x yearly files for each location/region.
- This guideline not only contains the methodology adopted by EPA, Victoria in the construction of the 'regulatory' input files, but importantly provides the basis for the construction of additional files, particularly given that EPA; Victoria may not automatically update these files in the future.

The construction of the metfiles involves the following steps:

1. Compilation of all required representative meteorological data for the application site.
2. Determination of surface characteristics for the application site.
3. Estimation of scalar parameters.
4. Estimation of hourly mixing heights (boundary layer heights - convective and stable)
5. Formatting all data/information into AERMOD compatible file formats.

Content of AERMOD input meteorological data files

Hourly values (preferably hourly averages) of the following meteorological parameters are in the input files:

1. Surface data file (.SFC)

- a) Scalar wind speed (m/s) at wind reference height (e.g. 10m).
- b) Wind direction (degrees measured clockwise from true north) at wind reference height.
- c) Ambient temperature (°K) at screen level height (e.g. 2m).
- d) Surface characteristics of the application site
 - i) albedo
 - ii) Bowen Ratio
 - iii) surface roughness (m)

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e) Scalar parameters

- I friction velocity (m/s)
- II convective velocity scale (m/s)
- III monin-Obukhov length (m)
- IV sensible heat flux (W/m^2)

f) Mixing heights (m)

- I convective boundary layer height (CBL)
- II stable boundary layer height (SBL)
- g) Vertical gradient of potential temperature ($^{\circ}K/m$)

h) Precipitation code

- i) Precipitation rate (mm/hr)
- j) Surface pressure (hPa)
- k) Relative humidity (%)
- l) Total cloud amounts in 10ths

Note that:

- Parameters (a) to (g) are mandatory and the remaining parameters are required to predict deposition.
- Parameters (a), (b), (c), (h),(i),(j),(k) and (l) are based on direct measurements, albeit that data from prognostic models may be acceptable in some situations (see Section 1 below on page 3).
- The remaining mandatory parameters are derived parameters determined using other relevant information and/or US EPA recommended algorithms in AERMET or AERMOD (see Sections 2 and 3 below on pages 5 and 8).
- Data coverage of a yearly file should be 90% or better.
- Yearly files for recent 5 years should be used for air impact assessments related to new work approvals as well as for risk assessments.
- The file may contain missing days and the days need not be sequential, however, there cannot be any missing hours in a day.
- The directly measured parameters (a), (b) and (c) must be site-specific (must within 5 KM radius of the application site) and the rest of measured parameters should be site-representative.

2. Profile data file (.PFL)

- a) Measurement height for each level (m)
- b) Wind directions at the current level (degrees measured clockwise from true north)
- c) Wind speed at the current level (m/s)
- d) Temperature at the current level ($^{\circ}C$)
- e) Sigma-theta (standard deviation of horizontal wind direction fluctuation) at the current level (degrees)
- f) Sigma-W (standard deviation of vertical wind direction fluctuation) at the current level (m/s)

Note that:

- Parameters (a) to (d) are mandatory and based on direct measurements, albeit that data from prognostic models may be acceptable in some situations (see Section 1 below).
- Parameters (e) and (f) should be based on direct measurements, but are optional with AERMOD adopting default values or algorithms in their absence.

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Construction procedures

1. Data requirements & sources

Wherever possible, a site-specific meteorological data file constructed with at least 12 months of local or on-site meteorological data is to be used for AERMOD modelling.

Measured meteorological data such as Wind Speed, Direction and Temperature using AS2923, *Ambient Air Guide for Measurement of Horizontal Wind for Air Quality Applications*, by a NATA accredited laboratory is preferred, however, in the absence of such data, local meteorological measurements by the National Weather Service Australian Bureau of Meteorology (BOM) may be used. Preference is given to BOM weather stations having 1 minute or 10 minute average wind and temperature data.

Quality mandatory data can be obtained from Automatic Weather Stations (AWSs) operated by state environment authorities or similar organisations. Some industries often operate similar type of AWSs.

Supplementary data needed to determine other parameters and mixing heights should be obtained from a site-representative weather station maintained by BOM.

Meteorological files constructed using meteorological data generated by prognostic models such as TAPM or MM5 may also be acceptable in situations where there are no measured mandatory data within a **5 km** radius of the application site.

Sources of mandatory measured meteorological data include;

1.1 Data measured meeting AS2923

Measured meteorological data using AS2923.

Mandatory data required;

- a) hourly averaged **scalar** wind speed
- b) hourly averaged vector wind direction
- c) hourly averaged screen level temperature

Optional data

- d) Hourly Averaged (60 minute) Sigma-theta

1.2 Data measured by BOM

Local meteorological measurements by BOM can be used in the absence of the data described in Section 1.1. Short term average wind data (1 minute or 10 minute averages) are preferred. The procedures outlined in Appendix A should be used to calculate hourly average wind data from short term average wind data.

Mandatory data required;

- a) **Scalar** wind speed (hourly average based on 1 or 10 minute average)
- b) Vector wind direction (hourly average based on 1 or 10 minute average)
- c) Screen level temperature (last 10 minute average or instantaneous)

Supplementary data needed to determine secondary parameters and convective mixing height;

- d) Surface pressure
- e) Dew point temperature or relative humidity
- f) Hourly or 3 hourly total cloud cover
- g) Rainfall rate
- h) Twice daily vertical temperature and moisture profiles

When there is no representative cloud cover data, net radiation predicted for the site by running TAPM (See Section 1.3) or MM5 should be used. Measured net radiation (if available for the application site) is preferred over cloud observations.

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Notes for BOM measured data:

- Wind measurements and processing may not meet AS2923 at BOM's weather stations
- Wind speed, usually recorded in km/hr or Knots, needs to be converted to m/s.

1.3 TAPM generated data

For locations where there are no measured data available, the mandatory data and supplementary data that are required may be generated by a prognostic meteorological model.

The prognostic model specified is the Meteorological module of TAPM (Version 4 or later, available from CSIRO).

TAPM Setup;

The following model set-up is the minimum specification that must be used to generate required data.

- a) Outer Grid Resolution of 10 km with nesting grids 3 km, 1 km and 0.3 km (note that nesting to an inner grid of resolution of 1 km is regarded as appropriate for flat country regions).
- b) 41 by 41 horizontal grid points, centred at the location of the required data point.
- c) 25 vertical levels.
- d) 9-Second terrain height database.
- e) TAPM default databases for land use and sea surface temperature (provided with TAPM software).
Note that the default vegetation and soil type data may be modified if more representative site-specific data for the locality are available.
- f) Synoptic analysis data for the recommended year (can be purchased from CSIRO).

TAPM Output:

The following TAPM-generated parameters (data) extracted at the point of interest for the innermost grid (1 km or 0.3 km) are to be used to construct meteorological input files for AERMOD:

- a) 10m wind speed (WSPD)
- b) 10m wind direction (WDIR)
- c) Screen level Temperature (TEMPSCR)
- d) Screen level Relative Humidity (RHUM)
- e) Net Radiation (NETR)
- f) Daytime Mixing height (ZMIX) - only to be used when there are no upper air station/s in the region of interest

Note that:

- The option available in TAPM to generate complete AERMOD type meteorological files is not acceptable since the algorithms in TAPM may not be up-to-date or in line with US EPA recommended procedures.
- Sigma-theta and Sigma-w values at the 10m level in the constructed 'profile' file should be set at 99.0 (i.e. the missing data indicator).
- In some situations the TAPM-generated profile of wind and temperature may also be used to provide multiple levels in the constructed 'profile' file (again with sigma-theta and sigma-w values at each level set at 99.0). However, it is important to note that situations where the profiles indicate significant wind direction shear with height may reflect the need to choose an alternative model that is capable of utilising 3-dimensional meteorology fields (see Section 11 in guideline document 'Guidance for using the Regulatory Air Pollution Model AERMOD in Victoria').

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2. Estimation of scalar parameters

All scalar parameters demanded by AERMOD depend on surface characteristics such as the Bowen Ratio, Surface Roughness and Albedo. These parameters must be determined referring to the latest available land use maps.

The US EPA AERMOD Implementation Guide and AERSURFACE User's Guide propose that with respect to surface roughness, a smaller upwind fetch (~ 1km) more appropriately represents the turbulent processes that may impact conditions at the meteorological station which is used to obtain mandatory data. As such, the surface roughness (z_0) should be determined based on land cover data within a 1 km radius from the meteorological site. If the value of z_0 varies significantly by direction, sector dependency should be used (sector width $\geq 30^\circ$).

The Albedo and Bowen Ratio should be determined based on land cover data within a 10 km by 10 km domain centered on the meteorological station. A simple un-weighted arithmetic mean should be used. There is no need to consider sector dependency.

Seasonal variations of above parameters, particularly for Bowen Ratio, should be incorporated.

Proposed values for those parameters are presented in the Appendix B (subjected to change in the future).

2.1 Surface sensible heat flux

The fluxes of heat and momentum drive the growth and structure of the planetary boundary layer (PBL). Good estimation of the surface sensible heat flux (H) which depends on the net radiation (Rnet) and surface characteristics such as the available surface moisture (described in the form of the Bowen ratio (Bo)).

Expression for surface heat flux

$$H = \frac{0.9 R_{net}}{\left(1 + \frac{1}{B_0}\right)}$$

If net radiation (R_{net}) is available then the sensible heat flux (H) should be computed using the above formula

If not, use cloud cover fraction (Source BoM) to calculate R_{net} using the formula below.

$$R_{net} = \frac{(1 - r(\Phi))R + c_1 T^6 - \sigma_{SB} T^4 + c_2 n}{1 + c_3}$$

Where

$$r(\Phi) = \alpha + (1 - \alpha)e^{a\Phi + b} \quad \text{When } \Phi < 30 \text{ else } r(\Phi) = \alpha$$

$$R = (a_1 \sin \Phi + a_2)(1 + b_1 n^{b_2}) \quad \text{- Total Solar Radiation (Global exposure-TSR)}$$

Where α is the Albedo

Φ is solar elevation angle (should be calculated in terms of longitude, latitude and the time of the day)

$$\varphi = \frac{(\varphi_{t+1} + \varphi_t)}{2} \quad \text{-Solar elevation angle}$$

$a_1 = 1150$	$W m^{-2}$	$a_2 = -30$	$W m^{-2}$
$b_1 = -0.75$		$b_2 = 3.4$	
$c_1 = 5.31 \times 10^{-13}$	$W m^{-2}$	$c_2 = 60$	$W m^{-2}$
		$c_3 = 0.12$	

$\sigma_{SB} = 5.67 \times 10^{-8} W m^2 K^{-4}$ is the Stefan boltzmann constant.

T -ambient temperature in Kelvin

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2.2 Friction velocity (Ustar) and Monin-Obukhov length (L)

Use the formula below to calculate both U* and L for daytime unstable conditions (Convective Boundary Layer-CBL)

$$u_* = \frac{ku}{\ln\left(\frac{Z_{ref}}{Z_0}\right) - \psi_m(Z_{ref}/L) + \psi_m(Z_0/L)}$$

$$L = - \frac{\rho C_p T u_*^3}{kgH}$$

Physical constants in the formula

- a) k-von Karman constant (0.4)
- b) ρ -density of air (kg/m³)
- c) Cp-specific heat capacity of air (J/Kg/K)
- d) g-acceleration of gravity (m/s²)

U -Wind Speed at reference height

Z_{Ref} -Wind Reference height (10m)

Z₀ -Surface Roughness Length (Sector and season dependent)

T -Temperature in Kelvin

The ψ terms are given by

$$\psi_m(z_{Ref}/L) = 2 \ln\left(\frac{1+\mu}{2}\right) + \ln\left(\frac{1+\mu^2}{2}\right) - 2 \tan^{-1}(\mu) + \pi/2$$

$$\psi_m(z_0/L) = 2 \ln\left(\frac{1+\mu_0}{2}\right) + \ln\left(\frac{1+\mu_0^2}{2}\right) - 2 \tan^{-1}(\mu_0) + \pi/2$$

And

$$\mu = (1-16z_{ref}/L)^{1/4}$$

$$\mu_0 = (1-16z_0/L)^{1/4}$$

This procedure requires an initial guess for U* which is found by initially setting the ψ terms to zero. The iteration continues until consecutive values of L differ by 1% or less.

Use the formula below to calculate both U* and L for night-time stable conditions (Stable Boundary Layer-SBL);

$$U_* = C_D U_{Ref} / 2 \left\{ -1 + \left[\left(1 + (2u_0 / C_D^{1/2} u_{Ref})^2 \right)^{1/2} \right] \right\}$$

Where C_D is the neutral drag coefficient given by

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$$c_D = \frac{k}{\ln(Z_{Ref}/Z_0)}$$

$$u_0 = (5 Z_{Ref} f g (0.09 (1 - 0.5 n^2) / T)^{1/2}$$

Where n is the fractional cloud cover

Note:

For neutral conditions (L=0)

$$u_* = \frac{ku}{\ln\left(\frac{Z_{Ref}}{z_0}\right)}$$

For stable conditions (L>0) H should be recalculated

$$H = -\rho C_p u_* \theta_*$$

$$\text{Where } \theta_* = (0.09 (1 - 0.5 n^2))$$

3. Determination of boundary layer heights

Ideally, the mixing height should be obtained from on-site measurements by an acoustic sounder. Alternatively, it can be calculated as follows:

3.1 Height of the stable boundary layer (SBL)

The following simplified equation can be used to calculate mechanical mixing height (stable boundary layer(SBL)).

$$\text{MixH}_{\text{Mechanical (SBL)}} = 2300 U_*^{3/2}$$

3.2 Height of the convective boundary layer (CBL)

This can be calculated using twice-daily temperature soundings plus hourly wind speeds and ambient ground temperatures using the methodology described by Benkley and Schulman (Journal of Applied Meteorology, Volume 18, 1979, pp 772-780). This requires upper air observations containing temperature and moisture profiles (radiosonde) from a nearest upper air observing station.

In summary, the convective mixing height is approximated by extrapolating up a pseudo adiabat from hourly surface station temperatures to the intersection with the morning radiosonde profile.

The height of the convective boundary layer (convective mixing height) should be determined using a morning or daytime temperature sounding (vertical temperature and dewpoint profiles) in between sunrise and sunset. An evening or night-time sounding for the same day is used to adjust the daytime sounding to calculate the convective mixing height at different daylight hours (temperature difference at 700 hPa layer is used to correct for advection).

Note: If there is only one sounding for the day then you may skip the advection correction.

Note that:

- Upper air (radiosonde) stations are sparse but the available upper air stations typically represent a wider area (region).
- If there are no weather stations and/or upper air (radiosonde) station(s) in the region of interest, you may use TAPM-generated mixing height.

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3.3 Convective Velocity Scale (W^*)

$$W_* = \left(\frac{gH (CBL)}{\rho C_p T} \right)^{1/3}$$

Where H is the sensible heat flux (calculated)

PBL is the convective mixing height

T-temperature in Kelvin

Cp- specific heat capacity of air (J/Kg/K)

g-acceleration of gravity (m/s²)

4. Data format

AERMOD expects to read the meteorological data files; both surface and profile files in a fixed format.

Surface meteorological file should have one header line;

Latitude, Longitude, UA (Upper air station No.) identifier, SF (Surface Station No) identifier, OS(Onsite Station No-optional) identifier, Version

Format :2(2X,A8),8X, ' UA_ID :',A8, ' SF_ID :',A8, ' OS_ID :',A8,T85, 'VERSION:',A6

The lines after the initial header line should each contain a single hour of data.

4.1. Format and parameters in AERMOD surface (.sfc) data file

Format::3(I2,1X),I3,1X,I2,1X,F6.1,1X,3(F6.3,1X),2(F5.0,1X),F8.1,1X,F6.3,1X,2F(6.2,1X),F7.2,1X,F5.0,3(1X,F6.1)

Year, Month, Day, Julian Day, Hour then

1. Sensible heat flux
2. Surface friction velocity (Ustar)
3. Convective velocity scale (Wstar)
4. Vertical potential temperature gradient above PBL (VPTG)
5. Convective mixing height (PBL)
6. Mechanical mixing height (SBL)
7. Monin-Obukhovlength(MOL)
8. Surface roughness(ZO)
9. Bowen ratio (BRatio)
10. Albedo
11. Wind speed (WS)
12. Wind direction (WD)
13. Reference height for winds (WRef=10m)
14. Surface temperature (KTEMP)
15. Reference height for surface temperature (TRef=2m)
16. Precipitation code
17. Precipitation rate (RPPTN)
18. Relative humidity (RH)

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4.2 Format and Parameters in AERMOD Profile (.pfl) data file

Year, Month, Day ,Hour, Height, top, WDnn, WSnn, TTnn, SAnn, SWnn

FORMAT (4(I2,I1X), F6.1,I1X, I1,I1X, F5.0,I1X, F7.2,I1X, F7.1, 1X,F6.1, 1X,F7.2)
 where height = measurement height (m)

top = 1, if this is the last (highest) level for this hour, or 0 otherwise

1. WDnn = wind direction at the current level (degrees)
2. WSnn = wind speed at the current level (m/s)
3. TTnn = temperature at the current level (°C)
4. SAnn = Sigmatheta (degrees)
5. SWnn = SigmaW (m/s)

Figure 1 :Sample:AERMOD Surface data file (.SFC)

33.950N	83.317W	UA_ID:	99999	SF_ID:	00001	OS_ID:	0	VERSION:	06341															
8	1	1	1	-999.0	-9.000	-9.000	-9.000	-999.	-999.	-99999.0	0.334	1.50	1.00	0.00	0.	10.0	306.6	2.0	0	0.00	999.	1008.	7	
8	1	1	1	2	-999.0	-9.000	-9.000	-999.	-999.	-99999.0	0.334	1.50	1.00	0.00	0.	10.0	306.6	2.0	0	0.00	999.	1008.	7	
8	1	1	1	3	-9.0	0.115	-9.000	-9.000	-999.	90.	15.2	0.001	1.50	1.00	3.60	354.	10.0	305.6	2.0	0	0.00	999.	1008.	7
8	1	1	1	4	-999.0	-9.000	-9.000	-999.	-999.	-99999.0	0.334	1.50	1.00	0.00	0.	10.0	304.8	2.0	0	0.00	999.	1008.	5	
8	1	1	1	5	-9.4	0.103	-9.000	-9.000	-999.	76.	10.4	0.001	1.50	1.00	3.60	13.	10.0	304.4	2.0	0	0.00	999.	1008.	5
8	1	1	1	6	-1.3	0.033	-9.000	-9.000	-999.	16.	2.4	0.001	1.50	1.00	1.50	342.	10.0	303.6	2.0	0	0.00	999.	1008.	5
8	1	1	1	7	-0.5	0.022	-9.000	-9.000	-999.	7.	1.7	0.001	1.50	1.00	1.00	315.	10.0	302.4	2.0	0	0.00	999.	1009.	7
8	1	1	1	8	-0.5	0.022	-9.000	-9.000	-999.	7.	1.7	0.001	1.50	1.00	1.00	313.	10.0	300.6	2.0	0	0.00	999.	1009.	7
8	1	1	1	9	9.7	0.124	-9.000	-9.000	-999.	101.	-17.8	0.001	1.50	0.46	2.60	17.	10.0	302.5	2.0	0	0.00	999.	1009.	7
8	1	1	1	10	57.2	-9.000	-9.000	-999.	-999.	-99999.0	0.334	1.50	0.35	0.00	0.	10.0	305.5	2.0	0	0.00	999.	1010.	1	
8	1	1	1	11	117.9	0.229	-9.000	-9.000	-999.	251.	-9.1	0.001	1.50	0.25	4.60	4.	10.0	308.2	2.0	0	0.00	999.	1010.	1
8	1	1	1	12	154.0	0.278	-9.000	-9.000	-999.	337.	-12.5	0.001	1.50	0.23	5.70	326.	10.0	310.9	2.0	0	0.00	999.	1010.	1
8	1	1	1	13	168.1	0.321	-9.000	-9.000	-999.	417.	-17.6	0.001	1.50	0.22	6.70	323.	10.0	311.9	2.0	0	0.00	999.	1009.	1
8	1	1	1	14	160.5	0.253	-9.000	-9.000	-999.	295.	-9.1	0.001	1.50	0.23	5.10	339.	10.0	312.4	2.0	0	0.00	999.	1009.	1

Figure 2 :Sample:AERMOD Profile data file (.PFL)

8	1	1	1	10.0	1	0.0	0.00	33.50	99.00	99.00															
8	1	1	2	10.0	1	0.0	0.00	33.50	99.00	99.00															
8	1	1	3	10.0	1	350.0	3.60	32.50	99.00	99.00															
8	1	1	4	10.0	1	0.0	0.00	31.60	99.00	99.00															
8	1	1	5	10.0	1	10.0	3.60	31.30	99.00	99.00															
8	1	1	6	10.0	1	340.0	1.50	30.50	99.00	99.00															
8	1	1	7	10.0	1	310.0	1.00	29.30	99.00	99.00															
8	1	1	8	10.0	1	310.0	1.00	27.50	99.00	99.00															
8	1	1	9	10.0	1	20.0	2.60	29.40	99.00	99.00															
8	1	1	10	10.0	1	0.0	0.00	32.40	99.00	99.00															
8	1	1	11	10.0	1	360.0	4.60	35.10	99.00	99.00															
8	1	1	12	10.0	1	330.0	5.70	37.70	99.00	99.00															
8	1	1	13	10.0	1	320.0	6.70	38.80	99.00	99.00															
8	1	1	14	10.0	1	340.0	5.10	39.30	99.00	99.00															
8	1	1	15	10.0	1	230.0	2.60	34.90	99.00	99.00															
8	1	1	16	10.0	1	190.0	5.70	26.60	99.00	99.00															
8	1	1	17	10.0	1	190.0	5.70	25.30	99.00	99.00															
8	1	1	18	10.0	1	200.0	6.20	24.10	99.00	99.00															
8	1	1	19	10.0	1	200.0	5.70	23.30	99.00	99.00															
8	1	1	20	10.0	1	210.0	5.10	23.10	99.00	99.00															
8	1	1	21	10.0	1	200.0	4.10	22.00	99.00	99.00															
8	1	1	22	10.0	1	200.0	4.60	20.30	99.00	99.00															
8	1	1	23	10.0	1	200.0	3.60	19.70	99.00	99.00															
8	1	1	24	10.0	1	200.0	3.10	19.30	99.00	99.00															

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Appendix A

Wind data processing

Scalar and vector averaging

Vector averaging technique was used to calculate hourly wind vector from ten-minute/one-minute wind vectors.

Vector averaging

In the Cartesian coordinate system the wind vector

$\vec{u}(u, \theta)$, can be expressed as two orthogonal components.

These are given by:

$$u_1 = u \cos \theta \dots\dots\dots(1)$$

$$u_2 = u \sin \theta \dots\dots\dots(2)$$

where θ is the direction from which the wind blows. u_1 and u_2 are the northerly and easterly components of the wind, and θ is zero for a northerly wind, increasing clockwise.

The component averages are given by:

$$\bar{u}_1 = \frac{1}{n} \sum_{i=1}^n u_{1i} \dots\dots\dots(3)$$

$$\bar{u}_2 = \frac{1}{n} \sum_{i=1}^n u_{2i} \dots\dots\dots(4)$$

where n = the number of observations over the averaging period. The magnitude of the average wind vector

$\vec{u}(\bar{u}, \bar{\theta})$ is then given by:

$$\bar{u} = |(\bar{u}_1^2 + \bar{u}_2^2)^{1/2}| \dots\dots\dots(5)$$

The direction was obtained from:

$$\bar{\theta}' = \arctan \left| \frac{\bar{u}_2}{\bar{u}_1} \right|, 0 \leq \bar{\theta}' \leq 90 \dots\dots\dots(6)$$

The average direction $\bar{\theta}, 0 \leq \bar{\theta} < 360$, is found from $\bar{\theta}'$ by considering the signs of \bar{u}_1 and \bar{u}_2 and is as given in Table 1.

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Table 1

Value of $\bar{\theta}$ for signs of \bar{u}_1 and \bar{u}_2

\bar{u}_1	\bar{u}_2	\bar{u}_2
+	+	$\bar{\theta}'$
-	+	$180^\circ - \bar{\theta}'$
-	-	$180^\circ + \bar{\theta}'$
+	-	$360^\circ - \bar{\theta}'$

Either sign was assigned to \bar{u}_1 and \bar{u}_2 when they are zero.

Scalar averaging

Scalar averaging is not a good approximation to vector averaging if the period of averaging is large so that distribution of direction is skewed. In general, this would be the case where the period of averaging is larger than 10 min or the range of direction values exceeds 45°. All applications of scalar averaging will result in the mean wind speed being over-estimated and skewed data will return a biased average wind direction.

The scalar-averaged wind speed is given by:

$$\bar{u} = \frac{1}{n} \sum_{i=1}^n u_i \dots\dots\dots(7)$$

Where n = the number of observations over the averaging period.

In the scalar averaging of wind direction ($\bar{\theta}_s$) the discontinuity at 360/0° must be considered. Difficulties do not arise for an observer reading a continuous recording of wind direction but automatic computation devices must be provided with an algorithm to compute averages correctly. This can be achieved by assigning a unit value of wind speed to each wind direction and treating the wind direction as a vector. Scalar-averaged wind direction was obtained as follows:

$$\overline{\sin \theta} = \frac{1}{n} \sum_{i=1}^n \sin \theta_i \dots\dots\dots(8)$$

$$\overline{\cos \theta} = \frac{1}{n} \sum_{i=1}^n \cos \theta_i \dots\dots\dots(9)$$

Where n = the number of observations over the averaging period.

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$$\bar{\theta}_s' = \arctan \left| \frac{\overline{\sin \theta}}{\overline{\cos \theta}} \right|, 0 \leq \bar{\theta}_s' \leq 90 \dots\dots\dots(10)$$

The direction $\bar{\theta}_s, 0 \leq \bar{\theta}_s < 360$, is found from $\bar{\theta}_s'$ by considering the signs of $\sin \theta$ and $\cos \theta$ and is as given in Table 2.

Table 2

Value of $\bar{\theta}_s$ for signs of $\overline{\cos \theta}$ and $\overline{\sin \theta}$

$\overline{\cos \theta}$	$\overline{\sin \theta}$	$\bar{\theta}_s$
+	+	$\bar{\theta}_s'$
-	+	$180^\circ - \bar{\theta}_s'$
-	-	$180^\circ + \bar{\theta}_s'$
+	-	$360^\circ - \bar{\theta}_s'$

Either sign was assigned to $\overline{\cos \theta}$ and $\overline{\sin \theta}$ when they are zero.

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Appendix B

Proposed surface characteristics to be used to develop meteorological data file for AERMOD

Surface roughness Z_0

Land Use	Seasonal Surface Roughness			
	Summer	Autumn	Winter	Spring
Open Water	0.001	0.001	0.001	0.001
Low intensity Residential	0.40	0.40	0.30	0.40
High intensity Residential	1.00	1.00	1.00	1.00
Sites at Airports	0.07	0.07	0.07	0.07
Industrial/Commercial Not at airports	0.70	0.70	0.70	0.70
Quarries/Strip Mines/ Gravel	0.30	0.30	0.30	0.30
Deciduous Forest	1.30	1.30	0.60	1.00
Mixed Forest	1.30	1.30	0.90	1.10
Shrub land (Arid Region)	0.15	0.15	0.15	0.15
Shrub land (Non-Arid Region)	0.30	0.30	0.30	0.30
Grassland	0.10	0.10	0.010	0.05

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Albedo

Land Use	Seasonal Albedo			
	Summer	Autumn	Winter	Spring
Open Water	0.10	0.10	0.10	0.10
Low intensity Residential	0.16	0.16	0.18	0.16
High intensity Residential	0.18	0.18	0.18	0.18
Sites at Airports	0.18	0.18	0.18	0.18
Industrial/Commercial Not at airports	0.18	0.18	0.18	0.18
Quarries/Strip Mines/ Gravel	0.20	0.20	0.20	0.20
Deciduous Forest	0.16	0.16	0.17	0.16
Mixed Forest	0.14	0.14	0.14	0.14
Shrub land (Arid Region)	0.25	0.25	0.25	0.25
Shrub land (Non-Arid Region)	0.18	0.18	0.18	0.18
Grassland	0.18	0.18	0.20	0.18

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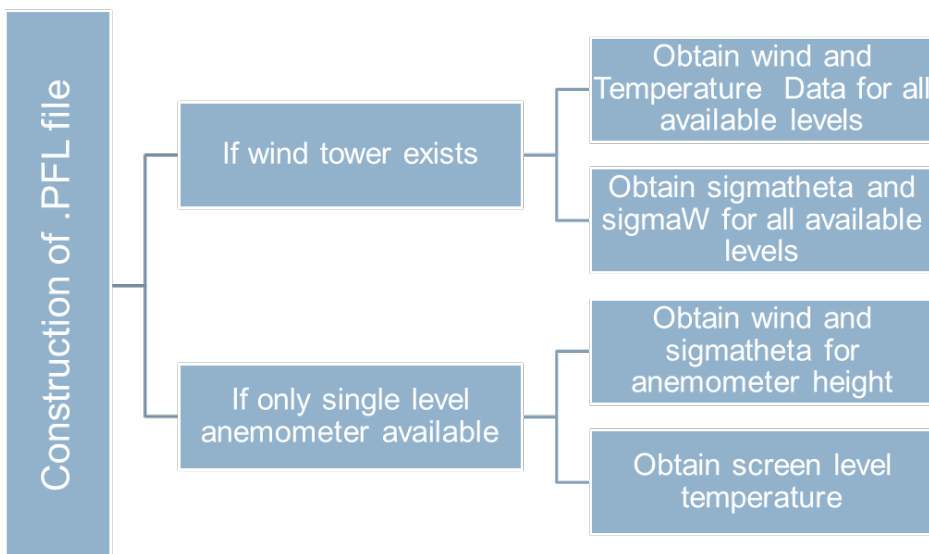
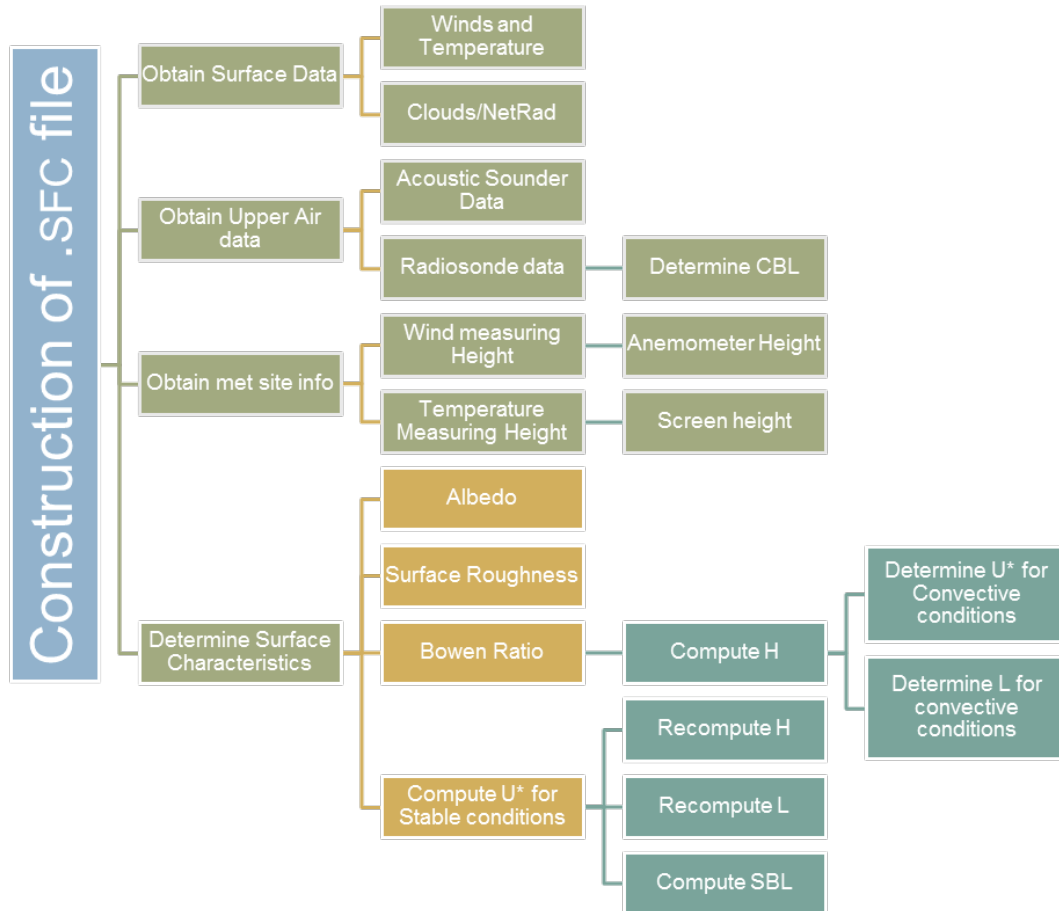
Bowen Ratio

Land Use	Seasonal Bowen Ratio											
	Average				Wet				Dry			
	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring
Open Water	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100	0.100
Low intensity Residential	0.800	1.000	1.000	0.800	0.600	0.600	0.600	0.600	2.000	2.500	2.500	2.000
High intensity Residential	1.500	1.500	1.500	1.500	1.000	1.000	1.000	1.000	3.000	3.000	3.000	3.000
Sites at Airports	1.500	1.500	1.500	1.500	1.000	1.000	1.000	1.000	3.000	3.000	3.000	3.000
Industrial/ Commercial	1.500	1.500	1.500	1.500	1.000	1.000	1.000	1.000	3.000	3.000	3.000	3.000
Quarries/Strip Mines/Gravel	1.500	1.500	1.500	1.500	1.000	1.000	1.000	1.000	3.000	3.000	3.000	3.000
Deciduous Forest	0.300	1.000	1.000	0.700	0.200	0.400	0.400	0.300	0.600	2.000	2.000	1.500
Mixed Forest	0.300	0.900	0.900	0.700	0.200	0.350	0.350	0.300	0.600	1.750	1.750	1.500
Shrub land (Arid Region)	4.000	6.000	6.000	3.000	1.500	2.000	2.000	1.000	6.000	10.000	10.000	5.000
Shrub land (Non-Arid Region)	1.000	1.500	1.500	1.000	0.800	1.000	1.000	0.800	2.500	3.000	3.000	2.500
Grassland	0.800	1.000	1.000	0.400	0.400	0.500	0.500	0.300	2.000	2.000	2.000	1.000

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Appendix C

Flow Charts - Construction Procedure



Construction of input meteorological data files for EPA Victoria's regulatory air pollution model (AERMOD)

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