PARAMETERISING LOW-FREQUENCY MEANDER IN ATMOSPHERIC DISPERSION MODELS

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INTRODUCTION

Large variations in wind direction have been observed in stable light wind conditions. In these conditions, vertical motions are suppressed by stability forces but two-dimensional eddies can have significant amplitudes. In atmospheric dispersion models it is particularly important to account for these atmospheric motions which have scales between the resolved motions of the input data (e.g. numerical weather prediction data) and the turbulence parameterisations for three-dimensional eddies. In stable light wind conditions, these meander scale eddies can dominate the dispersion of the plume and it has been suggested that estimates of mean concentrations can be at least factors of 4 – 6 too high if meander is not taken into account (Kristensen, L. et al., 1981). A number of authors have presented parameterisations of meander based mainly on observations in stable conditions (Hanna, S.R, 1981, Hanna, S.R, 1983, Pasquill, F, 1974 and Schacher, G.E. et al., 1982). In general, over an averaging time of one hour, the parameterisations suggest meander standard deviation (σ_v) values between 0.3 and 1.0 m s^{-1}.

NAME (Numerical Atmospheric dispersion Modelling Environment) is the UK Met Office's atmospheric dispersion model (Jones, A.R. et al., in press and Ryall, D.B. and R.H.Maryon, 1998) which is driven by input meteorological data from the Met Office's numerical weather prediction model (the Unified Model). NAME is a Lagrangian model in which large numbers of particles are released into the model atmosphere. For simplicity, low-frequency meander and turbulence are treated as additive and independent parts and each model particle is advected using the equation

$$\boldsymbol{x}_{t+\Delta t} = \boldsymbol{x}_t + \left[\overline{\boldsymbol{u}} + \boldsymbol{u}' + \boldsymbol{u}'_l\right]\Delta t, \qquad (1)$$

where $\boldsymbol{x}_t$ is the particle position at time t, $\overline{\boldsymbol{u}}$ is the resolved mean wind velocity from the NWP data, $\boldsymbol{u}'$ is the turbulent velocity component from the turbulence parameterisation, $\boldsymbol{u}'_l$ is the low-frequency meander velocity component from the meander parameterisation, and Δt is the time step. The vertical component of meander is set to zero since meander scale eddies are essentially two-dimensional as described above. Low-frequency (meander) horizontal wind fluctuations are modelled within NAME using random walk techniques analogous to those used to model random turbulent motions. At short range, the meander components are calculated from

$$\boldsymbol{u}'_{l,t+\Delta t} = \boldsymbol{u}'_{l,t}\left(1 - \frac{\Delta t}{\tau_{\boldsymbol{u},l}}\right) + \left(2\frac{\sigma^2_{\boldsymbol{u},l}\Delta t}{\tau_{\boldsymbol{u},l}}\right)\boldsymbol{r}_t, \qquad (2)$$

where $\sigma^2_{\boldsymbol{u},l}$ are the meander velocity variances, $\tau_{\boldsymbol{u},l}$ are the meander Lagrangian timescales and $\boldsymbol{r}_t$ are random Gaussian variables of zero mean and unit variance. At long range the simpler scheme

$$\boldsymbol{u}'_l = \sqrt{\frac{2K_{\boldsymbol{u},l}}{\Delta t}}\,\boldsymbol{r}_t \qquad (3)$$

is used where $K_{\boldsymbol{u},l} = \sigma^2_{\boldsymbol{u},l}\tau_{\boldsymbol{u},l}$.

SPECTRA

In constructing a meander parameterisation for NAME, it is necessary to understand the motions resolved by the NWP data. Spectra of the resolved motions were generated using a years worth of NWP data at fixed locations and compared against spectra generated from observational data at the same locations. Hourly mean and hourly spot (10 minute mean) observations of wind at a height of 10 m at three UK sites (Aviemore, Heathrow and Wattisham) were used for various years. In addition, 17.5 minute averages of 10 m wind data from the Meteorological Research Unit at Cardington were obtained. NWP data from both the mesoscale and global versions of the Unified Model were used to generate spectra. The mesoscale version of the Unified Model covers a local area containing the UK and north-west Europe and is of a higher spatially resolution (currently 12 km) than the global version (currently 60 km). The NAME archive of Unified Model data currently contains hourly fields for mesoscale data and three-hourly fields for global data. The NWP data is multi-linearly interpolated in three-dimensional space and time (if necessary) to give NWP data at a height of 10 m at the locations and time resolution of the observations.

Figure 1 shows the average of the *u* and *v* wind spectra generated from 2004 data at 10 m at Cardington and Heathrow. The spectra are block averaged and the area under the spectral curve gives the total variance. The increased resolution of the Cardington observations enables the spectra to be calculated at higher frequencies. The NWP spectral curves have been scaled to fit the observational spectra at low frequencies to eliminate any instrument calibration issues and model / true roughness length value differences.

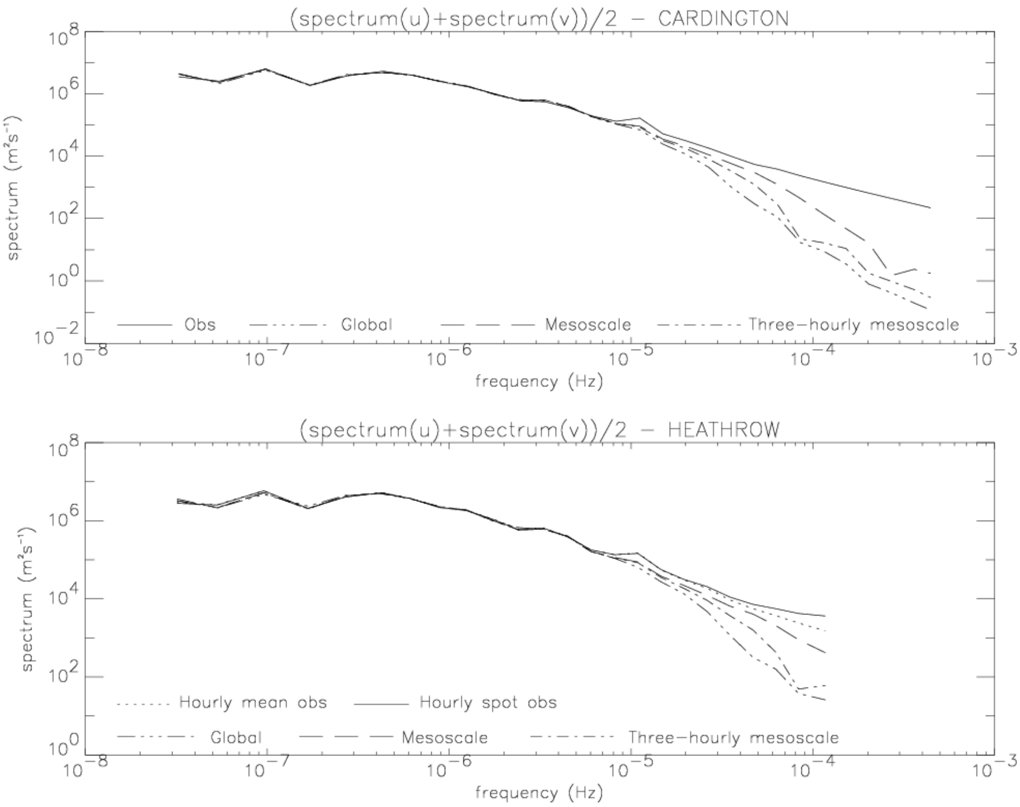

Fig. 24; NWP and observational spectra at Cardington and Heathrow, 2004.

There is good agreement between the hourly mean and hourly spot observations spectra except at high frequencies when the hourly spot observations have more energy. This suggests that the hourly spot observations contain more sub two-hourly fluctuations than the hourly mean observations. These high frequency fluctuations are aliased, due to the sampling rate, as lower frequency motions. As expected, the NWP spectra contain less energy at high frequencies than the spectra from observational data. We see that energy is lost in the NWP model at frequencies up to 24 hours and this missing energy needs to be accounted for by the meander parameterisation. The mesoscale spectra, calculated from the highest resolution input NWP data, has the least missing energy at high frequencies. The missing variance in the NWP spectra at high frequencies relative to the spectra of the observed hourly mean, hourly spot and 17.5 minute mean data was calculated. A summary of the σ values obtained from the missing variance calculations is given in Table 1. The hourly mean and hourly spot average values are obtained by calculating the average of the missing variance over the three locations, Aviemore, Heathrow and Wattisham. The 17.5 minute mean value is obtained from the missing variance in the NWP spectra for Cardington. During 2000, mesoscale NWP data for NAME was only stored as three hourly (rather than hourly) fields and hence there are no mesoscale values for 2000 given in Table 1.

Table 14. σ values (in m s^{-1}) obtained from calculating the missing variance in the NWP spectra

Year	Observations	σ (m s^{-1})			
		Mesoscale		Global	
		Average	Range	Average	Range
1998	Hourly mean	0.86	0.65 – 0.98	1.05	0.79 – 1.22
	Hourly spot	1.00	0.87 – 1.10	1.17	0.98 – 1.30
	17.5 min mean	0.97	-	1.10	-
2000	Hourly mean	-	-	0.92	0.83 – 0.96
	Hourly spot	-	-	1.04	0.94 – 1.10
	17.5 min mean	-	-	0.93	-
2001	Hourly mean	0.68	0.61 – 0.77	0.90	0.85 – 0.93
	Hourly spot	0.84	0.72 – 0.92	1.02	1.01 – 1.04
	17.5 min mean	0.83	-	0.93	-
2004	Hourly mean	0.76	0.71 – 0.84	0.95	0.88 – 1.00
	Hourly spot	0.89	0.82 – 0.98	1.06	1.02 – 1.09
	17.5 min mean	0.89	-	1.07	-

There is some variation with year and location, the year to year variability possibly having some contribution from changes in the Unified Model over this period. However, the variation is not large. The missing variance (σ^2) calculations using hourly spot observations suggest a meander $\sigma_{\mathbf{u},l}$ value of about 1.0 m s^{-1}. On average, the missing variance calculations using hourly spot observations suggests a σ value which is 0.13 m s^{-1} larger than that given by the missing variance calculations using hourly mean observations. This is consistent with Hanna's value of σ_v = 0.5 m s^{-1} (Hanna, S.R, 1990) for sub-hourly fluctuations ($(\sigma_{hourly} + 0.13)^2 = \sigma^2_{spot} = \sigma^2_{hourly} + (0.5)^2$).

The difference between the observations spectra and the NWP spectra multiplied by frequency was plotted and showed a consistent maximum between year and location at a frequency of approximately 1.1×10^{-5} Hz. This suggests that most energy is lost in the NWP data at this frequency. A meander timescale value, $\tau_{\mathbf{u},l}$, of roughly 4 hours is calculated using $\tau_{\mathbf{u},l} = 1/(2\pi f)$, where f is the frequency at which most energy is missing. This together with the missing energy calculations gives the values $\sigma_{\mathbf{u},l} = 1.0$ m s^{-1} and $\tau_{\mathbf{u},l} = 4$ hours as the suggested meander parameterisation for NAME.

IMPACT OF NWP DATA RESOLUTION

The impact of time resolution of the NWP data on the amount of missing energy was investigated by comparing spectra generated from linearly interpolated hourly and three-hourly mesoscale fields. In addition to the spectra generated from mesoscale and global NWP data and the hourly mean, hourly spot and 17.5 minute mean observations, Figure 1 also shows spectra generated from three-hourly mesoscale data. There is more missing variance in the three-hourly mesoscale spectra than the hourly mesoscale spectra. The three-hourly mesoscale spectra and the global spectra (also calculated from three-hourly fields) are similar which suggests that the time resolution is more important here than the spatial resolution.

Table 2 summarises the σ values obtained from the missing variance calculations in the three-hourly mesoscale spectra relative to the observed spectra. The average and range values are calculated in the same way used in Table 1. Comparing Tables 1 and 2, we see that three-hourly (as opposed to hourly) mesoscale data increases the σ value by, on average, 0.1 m s^{-1}.

Table 2. σ values (in m s^{-1}) obtained from calculating the missing variance in the three-hourly mesoscale NWP spectra

Year	Observations	σ (m s^{-1})	
		Three-hourly mesoscale	
		Average	Range
1998	Hourly mean	0.96	0.73 – 1.07
	Hourly spot	1.09	0.94 – 1.16
	17.5 min mean	1.06	-
2000	Hourly mean	0.83	0.77 – 0.91
	Hourly spot	0.96	0.89 – 1.04
	17.5 min mean	0.91	-
2001	Hourly mean	0.80	0.77 – 0.84
	Hourly spot	0.94	0.90 -0.97
	17.5 min mean	0.92	-
2004	Hourly mean	0.87	0.85 – 0.89
	Hourly spot	0.98	0.96 – 1.02
	17.5 min mean	0.98	-

Using the formula $\sigma = \beta T_A^n$, in which the value of σ depends on the averaging time T_A, together with the hourly spot values in Tables 1 and 2, yields the values β = 0.84 – 1.00 and n = 0.08 – 0.10 for mesoscale data. We see that there is a dependence on time resolution but the dependence is rather weak compared to the expected exponent $n = 1/3$ corresponding to a -5/3 power law inverse energy cascade. At the same temporal resolution (three hours), the difference between global and mesoscale data shows there is a dependence on spatial resolution too, but again this is weaker than the expected 1/3 power law. Perhaps the mesoscale model does not have time to fully develop its small scales during transit across the domain, or the time resolution of our data is such as to damp such scales.

The sensitivity of NAME to the meander parameterisation has been tested using a number of case studies. These sensitivity tests confirm the importance of the meander parameterisation in light wind conditions.

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