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THE IMPACT OF HIGH TIME RESOLUTION METEOROLOGY ON DISPERSION MODELS

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Abstract: Atmospheric dispersion models are commonly driven by meteorological data from Numerical Weather Prediction (NWP) models. The accuracy of dispersion model simulations is highly dependent on the accuracy of the input NWP data. With advancements in science and computing, meteorological fields from NWP models with higher spatial and temporal resolution are becoming available, but the use of these with dispersion models brings challenges due to large data volumes. We consider the benefit of using high temporal resolution input meteorological fields against the cost of increasing volumes of data.
Spectral analysis of NWP wind fields shows that higher frequency motions are better represented in higher time resolution NWP data. Atmospheric dispersion models parametrize the effects of motions not resolved by the input NWP data, so an increase in the NWP resolution will reduce the range of scales of motion the parametrization will be required to represent. We assess the benefits of using high resolution meteorological data by quantifying improvements in the accuracy of NWP wind fields when compared with meteorological observations in the boundary layer, and use the results to infer the parametrization values to use with higher resolution input NWP data. Using the UK Met Office's operational dispersion model, NAME (Numerical Atmospheric-dispersion Modelling Environment), we consider the impact of higher temporal resolution driving meteorology on the dispersion model predictions, as well as the feasibility of conducting such runs by comparing model run times.

Key words: *Temporal resolution, driving meteorology, dispersion models, unresolved motions*

INTRODUCTION

In recent years, NWP models have increased in spatial resolution but the temporal resolution of the input meteorological fields for the Met Office's atmospheric dispersion model NAME has not increased in line. The temporal resolution of the input fields is now relatively coarse in comparison to the spatial resolution, and improvements may well be gained by increasing the temporal resolution. For example, NAME typically uses meteorological data from the Met Office's Unified Model (UM), and in 2005 the global UM had a spatial resolution of 40 km and NAME input fields were three hourly. Today, NAME input fields from the global UM are still three hourly but the spatial resolution is now 10 km. Similarly, limited area NWP models have also increased in spatial resolution. For example, in 2007, hourly NAME input fields were used from a limited area model over Europe of 12 km resolution and the UK model of 4 km resolution. Today, the limited area model data we have available over the UK is at 1.5 km spatial resolution, but NAME continues to use hourly fields.

Driving NAME with higher resolution meteorological fields could lead to improvements in modelling, due to better representation of the advection, dispersion and deposition. Higher resolution meteorology would resolve more scales of the atmospheric motions, rather than parametrizing these in NAME, although we would need to consider the impacts on model run time, data storage and data transfer. At present, NAME driven by UM meteorology either uses global model output every 3 hours, or output from a limited area model over the UK (UKV) every hour. However, we could choose to use higher temporal resolution input fields for NAME, such as hourly data for global and UKV data every 15 minutes. With increases in spatial resolution (now at 10 km global and 1.5 km UKV), we consider whether the temporal resolution of the input meteorological fields is limiting the accuracy of NAME runs and if higher time resolution fields should be used.

Small scale atmospheric motions are unresolved by the NWP data but are important for dispersion predictions. The effects of these unresolved motions on the transport and dispersion of material need to be parametrized within the atmospheric dispersion model. The turbulence parametrization represents the effects of small-scale three-dimensional motions, while the unresolved mesoscale motions parametrization in NAME uses random walk techniques to represent the effects of quasi two-dimensional mesoscale motions which are larger than turbulence but not resolved in the NWP data. The scales of motion that this latter parametrization should represent is dependent on both the spatial and temporal resolution of the driving meteorology, so NAME requires parameter values appropriate for the NWP data resolution.

Spectral analysis of the wind fields identifies the additional atmospheric motions resolved by higher temporal resolution meteorological fields. This analysis also enables us to determine appropriate parameter values to use with the unresolved mesoscale motions parametrization in NAME when using this higher resolution data. We study trajectories to see how NAME output could differ based solely on the advection by the mean wind fields and consider run times of NAME when driven by meteorological data of different temporal resolutions.

SPECTRAL ANALYSIS OF WIND FIELDS

Spectral analysis allows us to quantify the extra flow information we could potentially gain from using higher time resolution meteorology. We follow the previous approach of Webster et al. (2016) and conduct spectral analysis on the instantaneous modelled and observed wind fields. By comparing the spectra of the modelled data with that of the observed data, we will be able to infer the appropriate parameter values to use in NAME for the unresolved mesoscale motions parametrization in order to correctly use this higher resolution NWP data. The raw spectral curve is noisy and hence a block averaging method is applied as in the previous study. The number of values to be averaged increases by approximately a factor of 1.1 from one block to the next.

For a selection of Met Office meteorological observation sites, we compare the modelled wind spectra with the corresponding spectra obtained using wind observations. The spectra gives the variance at different frequencies of motion.

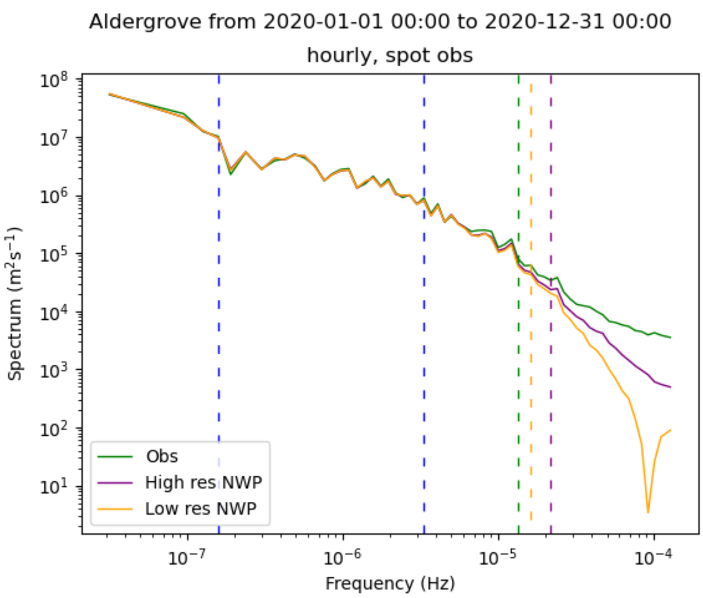

Figure 1. Observed and NWP (Global UM) spectra at Aldergrove. Blue dashed lines show the region used for scaling the UM data, green dashed line shows the frequency of diurnal motions, purple and orange dashed lines show the points at which the UM spectral curves diverge by at least 30 percent from the observation spectral curve.

Figure 1 shows a spectra plot for Aldergrove obtained using meteorological data for a period of 1 year of observations and Global UM output. The spectra are generated from hourly time series of observations and NWP data. The high resolution NWP time series is obtained by taking hourly data from the global UM, while the low resolution NWP time series is obtained by taking 3-hourly data from the global UM and linearly interpolating to give an hourly time series. This is consistent with NAME linearly interpolating between NWP output times for dispersion runs. Observations are taken every hour and are treated as instantaneous values (in reality, they are a one-minute average). The area under the spectral curve is the variance of the motions at the frequencies that the spectral curve represents. As expected, there is generally more variance of lower frequency motions than of higher frequency motions. In this plot, the lower frequency end represents motions on the scale of 1 year, and the higher frequency end is 2 hours. The highest frequency represented is dependent on the temporal resolution of the data ($1/2\Delta t$, in this case Δt is one hour) and the lowest frequency represented depends on the length of the time series.

There is a discrepancy at low frequencies between the observation spectra and the model data spectra due to biases in instrumentation and the model, and local site characteristics such as roughness, so as per Webster et al. (2016), we scale the model spectral curve to match that of the observations at the lower frequencies. After block averaging, we take the average difference between points at the low frequency end and use this to calculate a scaling factor. The region used for calculating the scaling factor is shown in Figure 1 as the region between the two blue dashed lines.

As would be expected, the model spectra begins to lose variance towards the higher frequencies compared to the observation spectra, but the higher time resolution model data spectra less so. In order to determine the parameter values in the unresolved mesoscale motions parametrization in NAME, the σ value (the square root of the missing variance) is determined from the area between the observation spectral curve and the model spectral curve from the frequency at which the two begin to diverge. In keeping with previous work, we take the divergence point to be the point at which the curves diverge by 30 percent (but it is also forced to be a higher frequency than time periods of a day to exclude diurnal variations). In Figure 1, the diurnal cut off is shown by the green dashed line, and the purple and orange dashed lines show the first frequency that the difference between model and observations spectra reaches 30 percent for high and low resolution model data respectively.

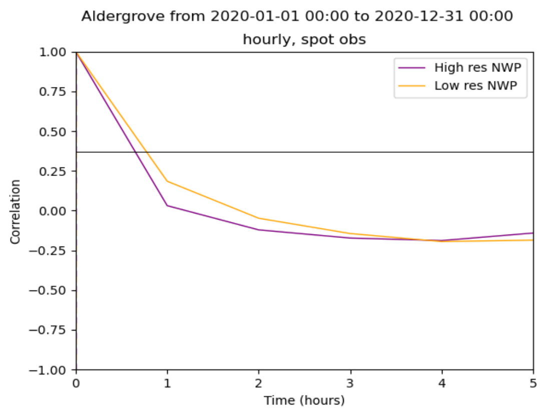

Figure 2. Normalised correlation function of the missing motions for Global UM data at Aldergrove. Black horizontal line shows e^{-1}.

The other parameter value needed for the unresolved mesoscale motions parametrization in NAME is τ, which represents the Lagrangian timescale of the unresolved mesoscale motions. To find this, we look at the correlation function for the missing motions with higher frequencies than the divergence point and normalise this so that the initial point is 1. The τ value is then calculated from the time that the normalised correlation function drops below e^{-1}. This gives the Eulerian timescale. In order to obtain the Lagrangian timescale, we follow the approach of Webster et al. (2016) and multiply the Eulerian timescale by 3. Figure 2 shows the correlation function for the same case as Figure 1. The first value of the correlation function (before it has been normalised) is another way of finding σ, and a way of checking the value obtained from the area between the spectral curves.

Parameter values

Table 1 shows an overview of the diffusivity values obtained from global UM data for different locations and time periods. The diffusivity (K) is given by $\sigma^2\tau$. We look at 17 cases over 7 sites, with time series between 8 and 12 months in length during 2018 – 2020. There is significant variation in the results, with a wide range of diffusivity values. However, the diffusivity values are smaller for the higher temporal resolution data, as expected. This is apparent both in the range as well as the mean and median, where the latter statistic is considered to reduce the impact of outlying cases.

Table 1. Diffusivity (K) values for hourly and 3-hourly global UM data.

	K (m^2s^{-1}) Hourly global UM	**K (m^2s^{-1}) 3-hourly global UM**
Median	3256	5105
Mean	3838	6054
Range	960 - 9198	3136 - 10488

NAME SIMULATIONS

NAME has been run using the higher temporal resolution UM meteorological data to begin to consider the impacts on the NAME runs and output.

Run times

The time taken for NAME to read in the NWP data increases proportionally with the amount of data being read in, so reading in hourly global data takes about 3 times longer than 3-hourly, and reading in 15 minute UKV data takes about 4 times longer than hourly. The impacts on the overall runtime of different types of runs will depend on how much the run type is dominated by the reading of the meteorology, so this 3 or 4 times increase will be an upper bound to the overall increase in runtime. This will clearly be ameliorated by parallelising the reading of the NWP data in NAME which is currently being developed.

Unresolved mesoscale motions parametrization

The effect of the unresolved mesoscale motions parametrization in NAME is considered by comparing the output of a dispersion model run with the parametrization switched off, with a run where the diffusivity (K) is set appropriately for the resolution of the driving meteorology, while the turbulence

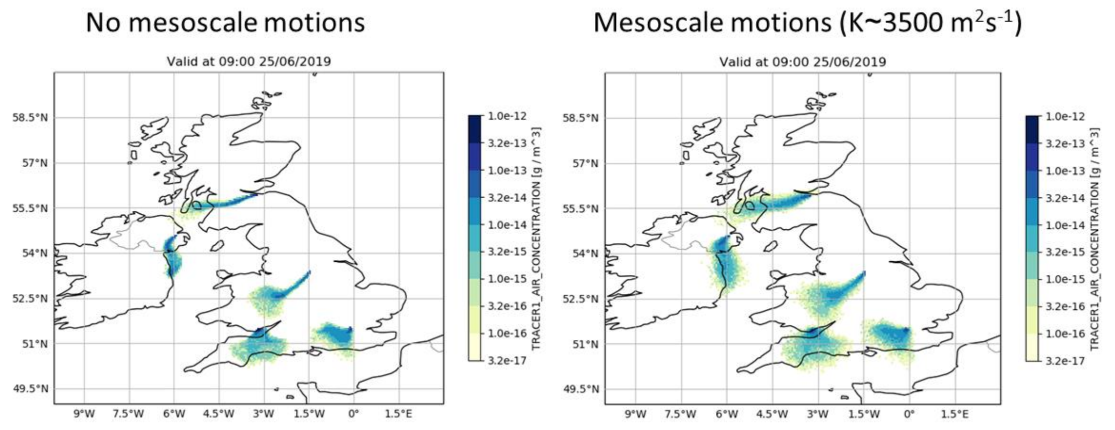

Figure 3. NAME predicted plumes driven by hourly global UM meteorology with the unresolved mesoscale motions parametrization using a diffusivity value, K, appropriate for the spatial and temporal resolution of the driving NWP data, compared with having the parametrization switched off.

parametrization is switched on in both runs. Figure 3 shows such runs when driven by hourly global UM data, with releases from 5 different locations in the UK. Without the parametrization, the modelled plume is unrealistically narrow. However, if the diffusivity in the model is set to be too large for the resolution of the driving meteorology, the plumes may appear too dispersed. The noticeable difference that this parametrization makes to the dispersion model output demonstrates the importance of correctly parametrizing these motions.

Mean particle trajectories

We consider some NAME single trajectories with both the turbulence and unresolved mesoscale motions parametrizations turned off, to see how using different resolution driving meteorology might impact the mean advection. Figure 4 shows single mean trajectories when driven by UKV 15 minute and hourly data. Although many cases are similar, these plots show that there are cases where the NAME particles follow significantly different mean trajectories solely due to using higher temporal resolution NWP data.

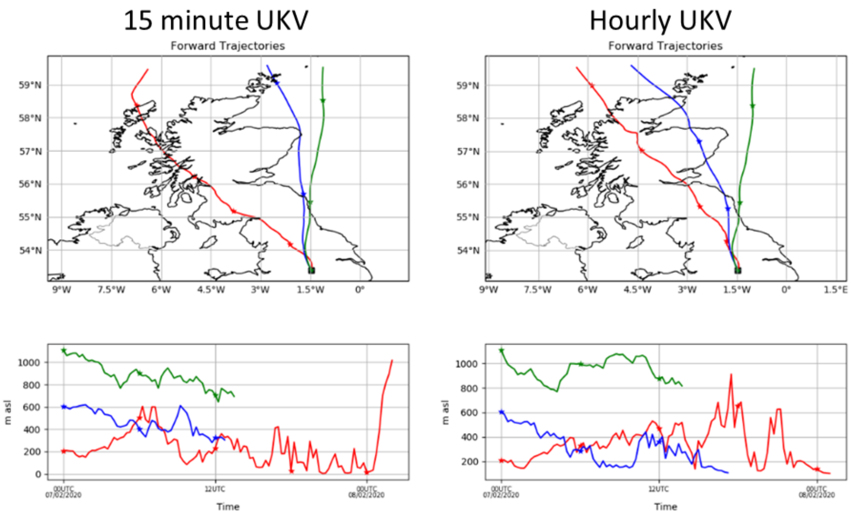

Figure 4. Particle trajectories originating at Sheffield at three different heights (100 m agl (red), 500 m agl (blue), 1000 m agl (green)) on February 7th 2020 00:00 UTC, using UKV mean wind fields only.

CONCLUSIONS

The increase in temporal resolution of the driving meteorology of the Lagrangian dispersion model NAME has been considered, by analysing the spectra of wind data and considering NAME runs. It was found from the spectral analysis that the higher temporal resolution meteorological data does contain more information regarding the variance of motions of smaller scales. Considering Global UM hourly and 3-hourly data, the diffusivity (K) to be used with the unresolved mesoscale motions parametrization is significantly smaller when driven by the higher temporal resolution meteorology (K~3500 m^2s^{-1} for hourly data, compared to K~5500 m^2s^{-1} for 3-hourly data), due to smaller scales of motion being resolved by the NWP data. NAME run times are longer, as expected, when reading in more meteorological data, but evidence suggests that there are cases where the higher temporal resolution does have a noticeable impact on the mean advection of a modelled plume.

As NAME is the Met Office's operational dispersion model, the effect of utilising higher temporal resolution driving meteorology needs to be considered in an operational setting. Investigating differences in computational cost and dispersion predictions should be considered for various types of operational runs in order to determine whether higher temporal resolution NWP data should be used operationally.

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