MODELLING WET DEPOSITION WITH HIGH RESOLUTION PRECIPITATION DATA

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Abstract: Model parameterisations in atmospheric dispersion models are designed around the input meteorological data available at the time of their development. As this input data evolves over time, issues may arise as a result of discrepancies between the parameterisation and advances in the meteorological data. Precipitation data, in particular, is a key component of wet deposition schemes. Availability of high resolution input precipitation data has required some revisions to be made to the NAME wet deposition scheme. This paper describes some particular examples and raises awareness of this important issue.

Key words: *Wet deposition, aerosol scavenging, high resolution, convective precipitation, dynamic precipitation*

INTRODUCTION

Wet deposition is a key mechanism in the removal of aerosols from the atmosphere. It includes both below-cloud scavenging, in which material is swept out by falling precipitation elements, and in-cloud scavenging, where aerosols are incorporated into cloud droplets or ice crystals by either acting as cloud condensation nuclei (nucleation processes) or by interception or inertial impaction with the cloud droplets or ice crystals. Wet deposition is, in some situations, the dominant removal process for atmospheric aerosol and therefore an important component in atmospheric dispersion models. The efficiency by which material is scavenged depends both on properties of the aerosol (particle size, affinity to water) and the amount, type and intensity of the precipitation. Detailed wet scavenging calculations can be done in the context of aerosol and cloud microphysics schemes but are not usually possible in off-line atmospheric dispersion models. Traditional bulk parameterisations, representing the mean wet scavenging rate for the aerosol size range, are generally used instead. These bulk schemes assume that wet scavenging is equally efficient for aerosols of different sizes, although they have been shown to overestimate scavenging by a heavy or a long-duration medium rain in comparison to scavenging calculated explicitly (Feng, J, 2007).

NAME'S WET DEPOSITION SCHEME

The Lagrangian atmospheric dispersion model NAME (Numerical Atmospheric-dispersion Modelling Environment, Jones, A. R. et al., 2007) has had a wet deposition scheme to represent the removal of material from the atmosphere since early on in its development (Maryon, R. H. et al., 1999). It uses a traditional bulk parameterisation based on the depletion equation

$$\frac{dC}{dt} = -\Lambda C\,, \tag{1}$$

where C is the air concentration, t is time and Λ is a bulk scavenging coefficient. The mass m of pollutant is depleted according to

$$\Delta m = m\left[1-\exp\left(-\Lambda\Delta t\right)\right], \tag{2}$$

where Δm is the change in mass of pollutant over the model time step Δt. The scavenging coefficient Λ is given by

$$\Lambda = Ar^{B}\,, \tag{3}$$

where r is the (rain equivalent) precipitation rate, and A and B are scavenging parameters which vary for different types of precipitation and for different wet deposition processes (in-cloud / rainout and below-cloud / washout). The input precipitation and cloud data is usually provided by a numerical weather prediction (NWP) model, such as the Met Office's Unified Model. Precipitation rates from NWP models will, in general, underestimate the true precipitation rate within convective showers since they represent the mean rate over the NWP grid box. In reality, precipitation may only be occurring over a fraction of the area of the NWP grid box. To address this, NAME uses the convective cloud amount C_f to calculate an effective precipitation rate ($r_{eff} = r/C_f$) within the convective showers and depletes only a fraction C_f of the mass m according to equation (1),

$$\Delta m = C_f m\left[1 - \exp\left(-\Lambda \Delta t\right)\right], \tag{4}$$

where the scavenging coefficient Λ is calculated using the effective precipitation rate.

INPUT METEOROLOGICAL DATA USED IN NAME

NAME can use a range of input meteorological data but most commonly uses numerical weather prediction data from the Met Office's Unified model (MetUM) (Cullen, M. J. P, 1993; Walters, D. N. et al, 2011). Over the years, advances in science and computing have enabled NWP models to be run with greater complexity and at higher resolution. These developments have resulted in more accurate data for input to NAME but they also bring challenges in storing and processing the volumes of meteorological data involved. Different configurations of the Unified Model exist: a global model and a number of higher resolution limited area models. The global version of the Unified Model is currently run at a horizontal resolution of about 25 km in mid-latitudes with meteorological fields available every three hours. The limited area models output meteorological fields every hour and include a north Atlantic and European model with a horizontal resolution of about 12 km through to a UK model with a horizontal resolution at its core of 1.5 km (the UKV model). In particular, the UKV model does not run a convection parameterisation since the high spatial resolution enables convection to be resolved. Research and development plans for the Unified Model include intentions to increase both the temporal and spatial resolution of the data.

WET SCAVENGING ISSUES CONCERNED WITH INCREASING RESOLUTION OF PRECIPITATION DATA

In addition to problems concerning storing, transferring and running atmospheric dispersion models on large volumes of data from high resolution NWP models, we should also consider whether the parameterisations within dispersion models, which have often been tuned to (or, at the very least, designed based on) the input meteorological data, are still well suited when the resolution of the input data changes. The NAME wet deposition parameterisation has largely escaped modifications since its introduction more than 20 years ago when the input data was much coarser in resolution. Here we discuss two issues concerning the NAME wet deposition parameterisation which have arisen as a direct result of an increase in resolution of the input precipitation data.

'Dynamic' and 'convective' precipitation

The NAME wet deposition parameterisation was designed based on the assumption that the input precipitation data comprised of two elements: a resolved precipitation component, assumed to be large-scale (or dynamic) precipitation, and a parameterised component, assumed to be convective precipitation. This distinction enabled different scavenging coefficients to be used for scavenging by large-scale (resolved) precipitation and for scavenging by convective (parameterised) precipitation, acknowledging the different cloud and precipitation processes occurring in stratiform and convective clouds. Nowadays, however, the high resolution NWP models (such as the MetUM UKV model) are able to resolve convection and therefore do not include an explicit parameterised convection scheme. Hence these high resolution models have no parameterised component of precipitation with the resolved component representing the total (large-scale + convective) precipitation. Under the original NAME wet deposition scheme this results in the resolved component scavenging coefficient, intended for use with large-scale precipitation, being also used, perhaps unwittingly so, with convective precipitation. Furthermore, there is no obvious and simple way to reconstruct large-scale and convective components from the total precipitation output by high resolution NWP models. This makes it difficult to employ different scavenging coefficients for large-scale and convective precipitation within the wet deposition parameterisation. Indeed most models do not make a distinction (Apsley, D. D. et al, 2012; Simpson D. et al, 2012; Stohl, A. et al, 2010).

In addition, since the relative proportions of resolved and parameterised precipitation depend on the resolution of the NWP model, the predicted wet deposition also depends on the NWP model resolution since the scavenging coefficient is nonlinear in precipitation ($B < 1.0$ in equation (3)). Choosing equivalent A and B scavenging parameters (see equation (3)) to be used with resolved and parameterised precipitation, as suggested above, minimises this dependency on the NWP model resolution. (Note, however, that differences in the precipitation fields between NWP models mean that there is always going to be an unavoidable dependence on the NWP model.)

We choose to split the NWP model grid box into two parts: a fraction C_f within the region of convective precipitation and with total precipitation given by ($r_{dyn}+r_{con}/C_f$), where r_{dyn} denotes the resolved (historically, dynamic) precipitation and r_{con} denotes the parameterised (convective) precipitation, and the remaining fraction ($1-C_f$) outside of the region of convective precipitation with precipitation given by r_{dyn}. From this we calculate an overall total scavenging coefficient, Λ_{tot}, given by

$$\Lambda_{tot} = \left(1 - C_f\right) A r_{dyn}^B + C_f A \left(r_{dyn} + \frac{r_{con}}{C_f} \right)^B , \qquad (5)$$

where the A and B scavenging parameters are now set to be equivalent for large-scale and convective precipitation but which vary in-cloud and below-cloud and with rain or snow / ice. For purely convective or for purely dynamic situations, equation (5) gives the correct limits, $C_f A(r/C_f)^B$ and Ar^B, respectively. In addition, it also gives the correct limit for increasing NWP model resolution when $C_f \rightarrow 0$ and the resolved precipitation, r_{dyn}, becomes the total precipitation. Furthermore, equation (5) is preferable to summing wet deposition amounts by large-scale and convective precipitation (equations (2) and (4) obtained using separate scavenging coefficients for large-scale and convective precipitation) which depends on the model time step.

Validity time of input precipitation data

Historically, NAME's wet deposition parameterisation has used instantaneous precipitation rates as input meteorological data. This provides NAME with a snapshot of the precipitation fields at the time resolution of the input meteorological data (usually three-hourly or hourly), but does not give any detail of the precipitation field at times in between. This philosophy has served well for many years when the horizontal and time resolution of the input data resulted in subtle changes in precipitation from one meteorological field to the next.

In Figure 1 a thin frontal band of precipitation is moving south-eastwards across the UK. The global MetUM resolves this thin precipitation feature quite well but since the precipitation fields are only available every three hours, and the front is moving relatively quickly, the front appears to hop from one position to the next without advecting between locations. This is clearly unrealistic and results in an accumulated precipitation field with high precipitation at the frontal position at three hourly intervals and low (or zero) levels at the intervening locations (see left image in Figure 1). The resulting total wet deposition field from a continuous vertical line release is unsatisfactory and reflects the strange features of the accumulated precipitation field (see right image in Figure 1).

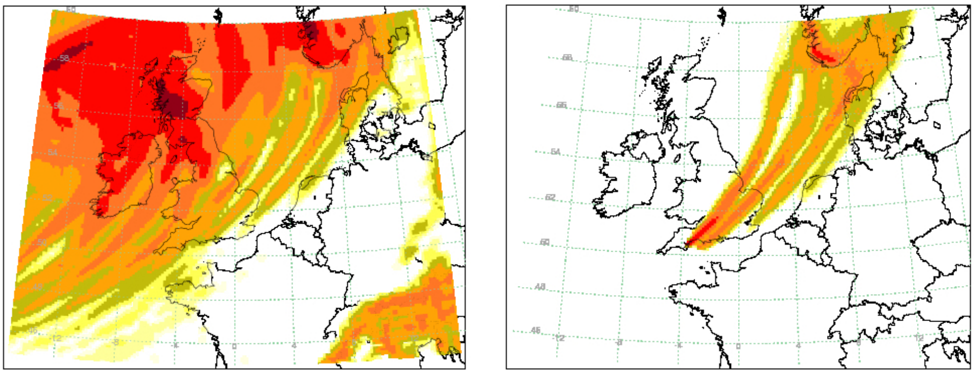

Figure 1. Example 24-hour accumulated precipitation (left) and corresponding NAME predicted wet deposition (right) obtained using 3-hourly instantaneous precipitation fields from the global version of the Unified Model.

The issues highlighted in Figure 1 are caused by a mismatch between the high spatial resolution but relatively low temporal resolution of the input precipitation data. If meteorological fields at additional data times are available, this issue could potentially be resolved by increasing the time resolution of the input data. However, this higher time resolution would increase further the volume of data needing to be stored, transferred and processed which may cause problems. An alternative solution is to consider the use of time-mean precipitation fields instead of instantaneous fields. Mean fields, averaged over the time period between input meteorological fields, are smoothed but give information on the precipitation detail throughout the time period. Figure 2 shows the same NAME simulation as Figure 1 but using mean precipitation fields instead of instantaneous precipitation fields. The precipitation and wet deposition fields are encouragingly similar but no longer display the unrealistic features observed with instantaneous precipitation fields.

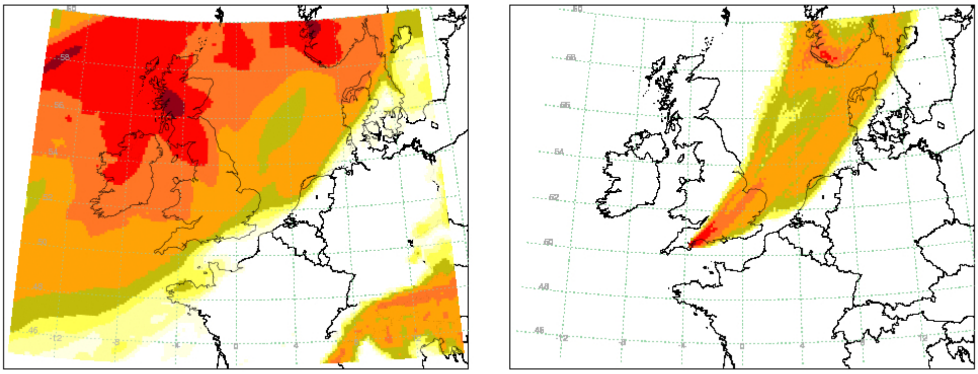

Figure 2. 24-hour accumulated precipitation (left) and corresponding NAME predicted wet deposition (right) for the same case as Figure 1 obtained using 3-hourly mean precipitation fields from the global version of the Unified Model.

CONCLUSIONS

Many years of scientific research into numerical weather prediction have been undertaken since the wet deposition scheme for NAME was first developed. This has resulted in substantial changes to the input meteorological data used with NAME with, in particular, significant increases in accuracy, resolution and data volume. In this paper we describe two examples where the NAME wet deposition scheme needed to evolve in line with input meteorological data changes. Both of these examples were due to the recent availability of high resolution NWP data at kilometre-scale. The first example showed how an assumption in the NAME wet deposition scheme concerning the input meteorological data was being violated by high resolution convection-resolving NWP models. It highlights the importance of having a good understanding of the underlying parameterisations and illustrates why regular reviewing of model components is good practice. The second example showed how spurious effects can arise when changes to the input meteorological data are made and indicated that mean precipitation fields are better suited for wet deposition schemes than instantaneous precipitation fields. This illustrates the importance of thorough model testing in revealing new issues.

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