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Evaluation of diabatic initialization improvements in the numerical weather prediction model Hirlam, focusing on the effect this may have on precipitation and dispersion forecasts

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ABSTRACT

Amongst the key issues concerning mesoscale modeling capability for air pollution and dispersion applications are precipitation and cloud cover forecasts. The long-standing problem of the spin-up of clouds and precipitation in numerical weather prediction models limits the accuracy of the prediction of short-range dispersion and deposition from local sources. Customary the spin-up problem is avoided by only using NWP forecasts with a lead time greater than the spin-up time of the model. Due to the increase of uncertainty with forecast range this reduces the quality of the associated forecasts of the atmospheric flow.

Improvements through diabatic initialization in the spin-up of large-scale precipitation in the Hirlam NWP model are discussed. In a synthetic example the effects of these improvements on a dispersion forecast are explored specifically for wet deposition. Using a case study of several weeks the optimal lead time for precipitation is discussed.

The analysis presented in this paper leads to the conclusion that, at least for situations where large-scale precipitation dominates, proper diabatic initialization of a weather model may limit spin-up so that its full forecast range can be used. The implication for dispersion modeling is that such an improved model is particularly useful for short-range forecasts and the calculation of local deposition. The sensitivity of the hydrological process to proper initialization implies that the spin-up problem may reoccur with changes in the model and increased model resolution. This is demonstrated using a recent version of Hirlam. Spin-up should therefore not only be an ongoing concern for atmospheric modelers, but a reason for close cooperation with dispersion modelers.

1. Introduction

The work reported in the article was prompted by contacts of the authors, as atmospheric modelers, with practitioners of dispersion modeling at the AQ7 conference (7th International Conference on Air Quality 24–27 March 2009 Istanbul). The dispersion modelers expressed a need to understand the characteristics of atmospheric models and their effect on dispersion forecasts. The focus of the article therefore is on the use of numerical weather prediction as input to dispersion models and on the effect in particular that spin-up of precipitation and clouds may have on the dispersion forecasts. The fact that model formulation has an impact on this and that in this respect a model change does not always imply an improvement is used to demonstrate the necessity of monitoring model performance as models change and for atmospheric and dispersion modelers to keep in close contact.

The strong relation between air quality and weather is evident from the large body of literature on air quality monitoring, modeling and regulation. It has long been established that pollution is not simply a local problem but transgresses regional and national boundaries because of the long-range transport of pollutants through the atmosphere. Precipitation may subsequently deposit this pollution at places remote from its industrial and traffic sources. Eliassen and Saltbones (1983) for instance found that for many European countries the deposition of sulfate from foreign sources outweighed that from indigenous sources. Emission controls at a supranational level to combat acid rain require a clear attribution of pollution to sources. Mueller (2005) in a study of sulfate trends in the eastern United States finds that it can be difficult to separate the influence of meteorology and changes in emission levels. Large local differences in deposition trends may result from the day-to-day and spatial variability of atmospheric flows and precipitation in

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combination with the high-frequency variability of emissions. This sensitivity to the exact weather conditions is even stronger in the case of accidental releases.

Air quality modeling and emergency modeling thus require meteorological input from high-resolution weather models. Theoretical consideration of scavenging, the process of removal of pollutants by cloud particles and precipitation, shows that the microphysical processes in a cloud, in particular the riming process, have a significant effect on the start and duration of rainfall and the uptake of pollutants and thus significantly affect the wet deposition of chemical species (Respondek et al., 1995; Spiridonov and Curic, 2005). Cloud chemical modeling therefore requires a consideration of the ice phase in clouds. Many dispersion models and weather models rely on a bulk removal rate, a direct relation between the modeled precipitation and wet deposition. Bulk removal schemes are not universal, but as they are averages over varying complex processes they depend on the situation and the application, e.g. plume type (Hales, 2002), convective versus large-scale precipitation and short-range versus long-range transport. The application of a single scheme for different meteorological conditions therefore introduces uncertainty in the outcome of dispersion models. However, sophistication in the modeling of scavenging will not greatly reduce the uncertainty in the outcome if weather models fail to accurately model the required hydrological parameters. In this respect the spin-up of the hydrological cycle in weather models is probably the biggest problem in their coupling with dispersion models. The spin-up of cloud formation and precipitation in numerical weather prediction models can be substantial. Betts et al. (1998) find a spin-up of 29% in precipitation during the first 12–24 h of forecasts with the ECMWF model, as an average over the spin-up of large-scale precipitation (39%) and convective precipitation (18%). Spin-up is a relaxation process that attempts to restore the dynamical equilibrium between the modeled flow, thermodynamics and hydrology, that has been disturbed by an inconsistent treatment of these processes in the model analysis, initialization and, in the case of limited area models, boundary specification. This inconsistency can be alleviated by diabatic initialization, diabatic forcing and the assimilation of liquid water. Huang and Lynch (1993) developed a diabatic initialization method based on digital filtering techniques for the Hirlam model. Hirlam is a high resolution limited area model, developed for operational use in the countries participating in the Hirlam consortium (Undén, 2002). Huang (1996) demonstrated that diabatic digital filtering initialization improves cloud evolution and reduces the spin-up time of the Hirlam model with intermittent data assimilation. Of course initialization in the strict sense that is implied here will not be sufficient to specify accurate starting conditions for hydrometeors and rain. For this the variational assimilation of remote sensing observations seems indispensable (Albers et al., 1996). As the versions of Hirlam used for this article do not yet incorporate these developments, they are not further discussed.

2. Spin-up characteristics of Hirlam

Spin-up is caused by an inconsistent treatment of the modeled flow, thermodynamics and hydrology in the analysis, initialization and boundary specification of a model. Therefore spin-up effects have both temporal and spatial aspects. To focus on the temporal aspects of spin-up it is useful to employ model diagnostics averaged over the model domain. In Fig. 1 the domain averaged total precipitation rate is given as a function of time. In this figure all forecasts starting from consecutive analyses in the period of the 5th through the 13th of August 2004 are superimposed. These results derive from a reforecast with Hirlam 6.3.7. Here 6.3.7 is the sequential version number of the model, indicating that this is the 6th major release, 3rd update, 7th bug revision. We will refer to these model versions in full to retain the chronology of their development. Model version 6.3.7 includes diabatic initialization developed by Huang and Lynch (1993). The superposition of consecutive runs shows a spin-up effect for each run as a deviation of the average temporal evolution of the total precipitation rate. It also shows a variation in the precipitation rate from run to run in the order of 10%.

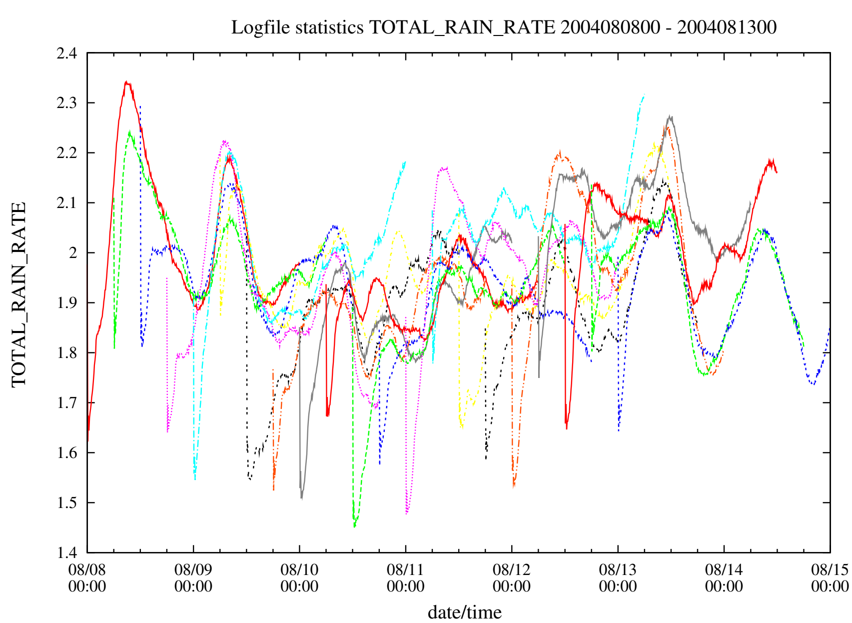

Fig. 1. Total precipitation rate as a function of forecast length in hours, for successive runs. Different colors show the different runs. Vertical scale runs from 1.4 to 2.4 mm 24 h^{-1}. The total precipitation rates shown are instantaneous values, in the sense that they are averaged over the model timestep. The model timestep used is 360 s. The horizontal axis shows the date and time. Successive runs start every 6 h, the first one shown in the plot starts at 0 UTC on August the 8th 2004 (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).