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Air pollution

USE OF THE ETA MODEL IN TRANSBOUNDARY POLLUTION PROBLEMS

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Abstract. During the cold season the Belgrade city heating facilities release to the atmosphere 1610 t of NO_2, 1281 t of SO_2 and 5939 t of CO. In order to use a meso-scale numerical model of the atmosphere to adequately predict the long range, transboundary transport of such a pollution it should have reliable data about the initial plume distribution, especially its vertical structure (the right position of the plume center of mass), the amount of the deposited (if any) material on the local scale during the release, etc. It is, therefore, of vital importance to have the correct measurements and/or prediction of the local atmospheric parameters such as the stability of the atmosphere, precipitation, turbulent regime, etc. In this paper we show an example of the Eta model results sensitivity to the initial plume structure during the release from a single point.

Keywords: air pollution, Eta model, Chernobyl.

AIMS AND BACKGROUND

Prediction of a long-range transport and transformation of pollutants requires using of numerical models of the atmosphere which are to drive chemistry models. A view is sometimes expressed that it is irrelevant which atmospheric model is the base for the chemistry model. In our early attempt to simulate the advection of a "passive" substance (Chernobyl case) we compared two modelling systems and noticed that there were significant differences in simulating the pollution arrival times for some of the European cities. This was due to a "slightly" different meteorology that the two atmospheric models provide. Namely, one of the atmospheric models predicted the low pressure center near the source of the pollution more realistically than the other. This low pressure center slowed down the general northward movement of the radioactive cloud so that the cities in Northern Europe were hit by the cloud somewhat later than in the case where the low pressure

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center was not simulated realistically. Another issue that we considered important in our simulations is the numerical treatment of the source of pollution in the model. We show that the model is very sensitive to the specification of the initial plume structure. Therefore, we suggest more complicated, but we believe more realistic treatment of the plume development during the initial stage of the release.

EXPERIMENTAL

Model and set-up. The atmospheric model used in this study is the so-called Eta model. The detailed description of the Eta model can be found in its documentation[1], which also contains other important references. It is a hydrostatic primitive equation model with a vertical coordinate permitting a step-like design of mountains. The horizontal momentum advection has a built-in nonlinear energy cascade control. Model has a comprehensive physical package consisting of: Mellor-Yamada level 2.5 and level 2 closures; ground surface processes including surface hydrology; large scale precipitation; cumulus convection; and radiation.

Concerning the application of the meso-scale numerical model of the atmosphere in air-quality studies one can perform the integration of the model, storing the historical data at relatively short regular intervals (say 1 h), and after completion of the run use stored data as input for a separate model of transport, transformation and deposition of various contaminants. Possible difficulties with this "split" approach are due to technical limitations – the time resolution of the stored data may be insufficient to represent accurately the effects of meteorological processes, such as the turbulent transport and precipitation, particularly convective one. Another approach, the one chosen by our group, is to incorporate the routines for the treatment of the transport, transformations and deposition of the contaminants directly into the atmospheric model, so that these processes evolve simultaneously with the meteorological fields. Following the latter approach a routine that treats transport, transformation and deposition of the contaminants was written. For this purpose the mass conservation equation is employed with prescribed constant for dry deposition velocity. The contaminant mass conservation equation has the following form:

$$\frac{\partial C}{\partial t} = -V \cdot \nabla C + \nabla \cdot K \nabla C + W_d + W_w - R_c + S$$

where C is the specific activity (Bq m^{-3}), V – the wind vector, K – the turbulent diffusion coefficient, W_w and W_d depict the loss of specific activity by wet and dry deposition, and S is the source term. The term R_c accounts for loss of material due to radioactive decay.

A common problem to all regional scale Eulerian models is the treatment of a point source. In our experiments we assumed that the model computational grid cell containing Chernobyl is in its entity the pollution source. This simple ap-

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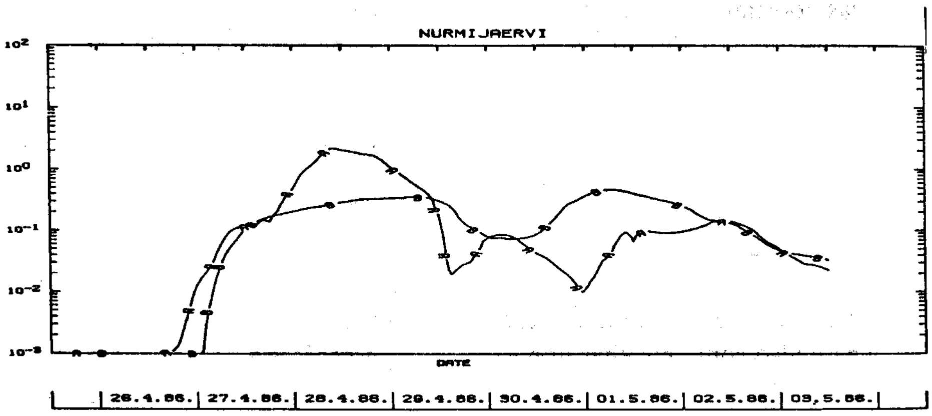
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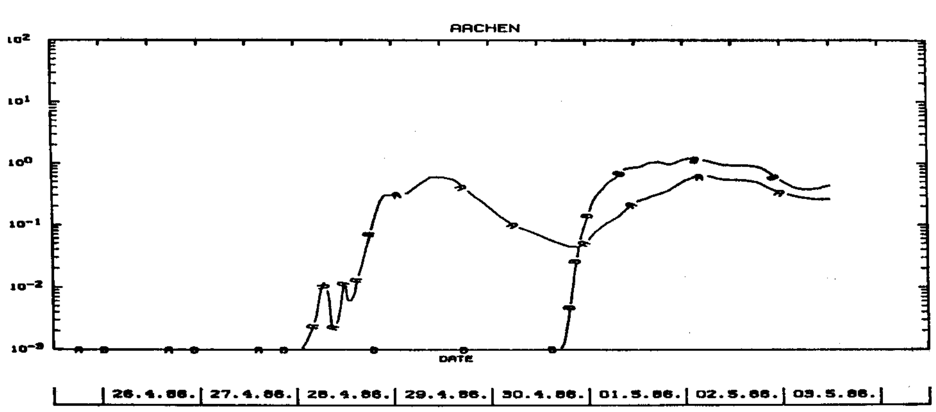
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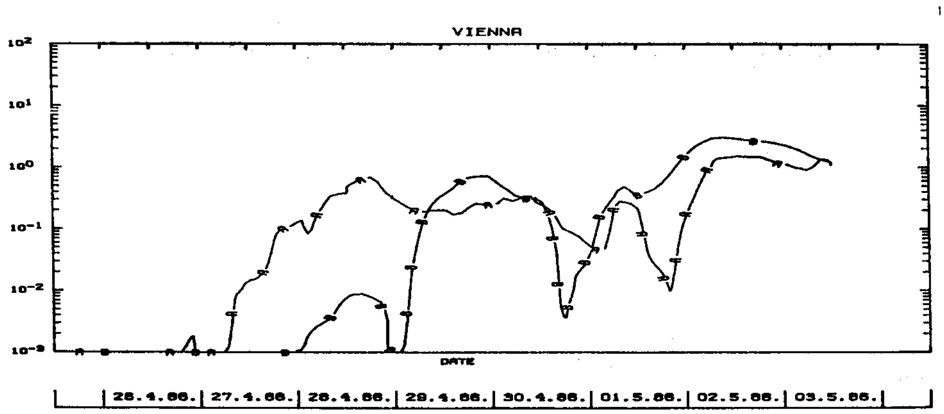
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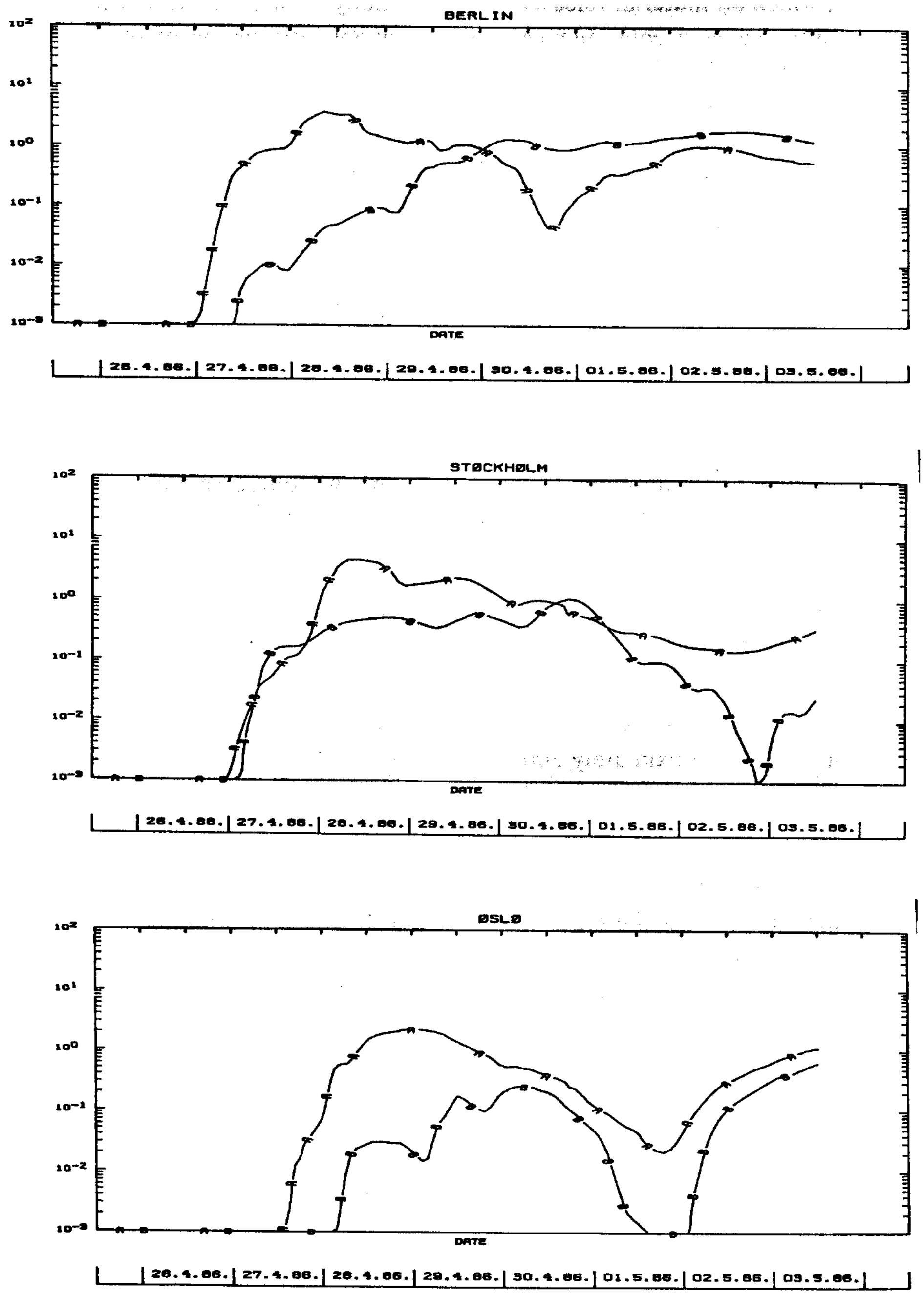

Fig. 1. Curves denoted by A are valid for the experiment with the initial center of the plume's mass 500 m higher than for the experiment B. Abscisa – time; ordinate – concentration of Cs^{137} (Bq/m^3)

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proach in which all material released from Chernobyl is distributed to four neighboring points has as a consequence an instantaneous dispersion of the released material to the scale of the grid size of the model, which could be regarded as unrealistic. More sophisticated way to treat the point source in a meso-scale model could be to apply the Gaussian dispersion model to calculate the plume development during the initial stage of the release, and then to feed only those computational points of the meso-model which are most affected by the plume according to the results of the Gaussian model. At that point calculation of the diffusion will be handled by the mass conservation relation of the meso-model.

Three forecasting episodes were used to follow the spread of radioactive cloud: (a) 25-28 April 1986; (b) 28 April-1 May 1986; and (c) 1-4 May 1986. Input fields were: geopotential, temperature, horizontal wind components and specific humidity. The model domain covers all of the Europe. The time step was 7.5 min. There were 16 levels in vertical direction.

By keeping the assumptions, parameterizations and source estimation as simple as possible we made a run which is close to the uncertainties we would experience in real emergency situation. Preparation time for input data and computational time is kept on minimum so that we would be able to run an ensemble of such experiments in real situation varying the parameters that we could not know in the early stage of a possible accident (e.g. source properties like intensity of emission and plume rise). To test the model sensitivity to the initial structure of the plume we run two experiments, which differ in the height of the centre of mass of the initial plume for approximately 500 m.

RESULTS AND DISCUSSION

There are two major differences between the results of the two experiments. The first is that for some of the cities we observe differences in pollution concentrations which are within the order of magnitude, keeping the general shape of the time series curve the same. The second is that the arrival times between the experiments differ, particularly in the case of Aachen where we see that the initially higher cloud arrived almost 48 h earlier (Fig. 1). This implies that it would be essential to know the initial plume structure in detail as well as to predict the meteorology the best way we can. For that reason we suggest the use of a Gaussian dispersion model for the initial stage of the possible release. Such a model together with the precise measurements in the vicinity of the potential source of emission could provide information about the initial behaviour of the plume. Once we know where the plume is moving on the short-range and how much of the material is deposited (if any) on the local scale, we are able to feed the large-scale model in a proper way.

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CONCLUSIONS

In this paper we conclude that with relatively few changes in the model code and modest increase in computational time the operational Eta model is able to produce reasonably good predictions of transboundary transport during ecological emergencies even in the case of crude plume initialization. We, therefore, advocate the development of a system consisting of a couple of automatic meteorological stations which would provide the meteo-data for the Gaussian dispersion model operating on the local scale in the vicinity of the potential pollution source. Gaussian dispersion model on the other hand would help to specify the initial data for the long range transport model which may be based on the Eta model.

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