An European heavy pollution episode simulated at the synoptic, regional and local scales

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Abstract

A mesoscale simulation system Meso-NH-C is presented allowing for on line coupling between dynamics and chemistry. Further advantages of this system lie in high vertical resolution, nesting/spawning capabilities and a full set of parametrization schemes. This system is applied to the 9 to 11 August, 1997 episode of a one-month pollution episode over Western Europe. For this episode, a two-scale analysis has been performed, at the European scale and at regional scale (Greater Paris area). The potentialities of such a modelling system have been emphasized, particularly as regards evaluation of the transboundary fluxes.

1 Introduction

Up to now, much attention has been devoted to urban air pollution. Nevertheless, heavy pollution episodes usually affect domains of regional to synoptic extents with local enhancements due to particular topographic and/or emission source factors. In the following, a particular three-day episode in August 1997 has been selected within a one-month heavy pollution period over Western Europe. This situation was chosen upon various reasons. First of all, its complexity. There, it shows a distinction to be made between clear polluted and cloudy areas and secondly upon the formation of two large transboundary pollution plumes, the major one over Germany, the Benelux, the North Sea and England. A last point of interest in this study lies in the use of Meso-NH-C, an on-line model with nesting capabilities, coupling dynamics and chemistry.
2 General overview

2.1 The mesoscale model Meso-NH-C

The Meso-NH Atmospheric simulation system (Lafore et al., 1998) is a joint research project between the Laboratoire d’Aerologie (LA/CNRS) and Météo-France (Centre national de Recherches Meteorologiques CNRM). Meso-NH is a non-hydrostatic numerical model which can simulate atmospheric motions from the alpha-to-gamma scales and even smaller (Orlanski, 1975). This model relies on a comprehensive physical package, a set of initialization facilities either idealized or interpolated from real meteorological analyses and/or forecasts. Some of the main characteristics of Meso-NH for our present purpose are as follows. One-and two-way grid nesting and/or spawning procedures are available. The convection parametrization scheme is based on Kain et al., 1990. An updated version of the land surface scheme ISBA (Interaction Soil-Biosphere-Atmosphere) is used (Noilhan et al., 1995). Furthermore, Meso-NH-C allows for the transport and turbulent diffusion of scalars coupled on-line with a gas-phase chemistry module. In the present study, this module has been obtained through reduction of the RACM scheme (Stockwell et al., 1997) down to 35 prognostic chemical species and 126 reactions. Before insertion within Meso-NH-C, this reduced mechanism has been favorably compared to RACM following the intercomparison procedure described by Kuhn et al., 1998. Furthermore, this reduced mechanism is consistent with the emission data base issued from the European GENEMIS programme over Western Europe. In GENEMIS, 33 emitted species are available at 30 km spatial resolution all over the domain at hourly time resolution and a thinner 10 km resolution over the middle north part of France where the spawning is made. Figure 1.a gives the \( NO_x \) emission map over Western Europe at 06 UTC for a typical summer reference day. The dry deposition scheme is based on a parametrization by Wesely, 1989 and Erisman et al., 1994 introduced within the previously quoted ISBA routine.

2.2 Simulation Characteristics

During the extended heavy pollution episode of August 1997, two simulations were performed, the first one starting on August 9, 1997 at 06 UTC and ending on August 11, 1997 at 21 UTC (simulation EURO?) while the second one (PARS?) took place between August 9, 1997 at 9 UTC and August 10, 1997 at 18 UTC. In these two simulations, there were 60 vertical levels from the surface to 13000 m, with a resolution of 40 m near the ground, regularly increasing to 800 m at the top of the model. In the EUROP simulation, mainly aimed at large scale pollution over Western Europe, the domain was 1900 by 1600 km with a 30 km resolution. The PARSP simulation resulted from a spawning procedure applied to the EUROP simulation over a 300 km by 270 km domain centered over Paris with a 5 km resolution.

2.3 The meteorological synoptic situation

Figures 1.b, 1.c and 1.d give the IR satellite pictures over Western Europe for August 9, 10 and 11, 1997 at 13 UTC. On August 09, one observes in figure 1.b that Western Europe is under the influence of a large anticyclonic area, with a convective system located over central Spain. On August 10 (fig. 1.c), most of Europe remains under this influence with nevertheless an instability zone approaching the Atlantic coasts of France, with convective systems...
developing over the Atlantic and Spain. On August 11 at 13 UTC (fig. 1.d), a weakly active cloud band extends from England to South-West of France. A low geopotential centered off Barcelone generates a vortex cloud system covering southern France. A thin cirrus band is also seen from Savoie to central Italy. The Meso-NH simulation reproduces quite well these cloud systems of August 10 and 11, 1997. For example, figures 1.e and 1.f display temperatures of the cloud tops, thus allowing for a rather direct comparison with the IR satellite pictures (figures 1.c and 1.d) at 13 UTC (higher clouds (Ci or Cb) appear in white). The main cloud masses of figure 1.c appear in figure 1.e. One can notice the correct location of the convective systems over Spain, Brittony, over the sea off the south western tip of England, and of the small convective cells over Austria. The cirrus veil over England is also seen in figure 1.f, even though its southern extent is not as well simulated. On the contrary, the thin cloud band over Italy and the vortex is well simulated, a little further north for this latter than observed. From these comparisons, one can reasonably argue that the complex meteorological situation is rather well captured by the Meso-NH simulations.

3 Pollution at the west European scale

In the following, we proceed to a two-step analysis, respectively at the west European scale (coarse resolution), then at a regional scale over the Greater Paris area (fine resolution).

3.1 Situation of August 10, 1997

3.1.1 Meteorological analysis

On August 10, 1997, a persistent anticyclonic regime maintains over Western Europe an easterly flux (figures 2.a to 2.d). More specifically, in the low levels, there is an easterly wind (3 to 5 m s\(^{-1}\)) over the north of France, Germany, Benelux and the United Kingdom. Further south, winds are generally weak with a more complex organization. Nevertheless, one can depict a regime of autan wind over part of south France (figures 2.b, 2.c and 2.d) characterized by the flow east of the Pyrenees of an air mass from North-East Spain. One also observes (figures 2.a, 2.b, 2.c and 2.d) an anticyclonic rotation of the winds over the Atlantic and South-West France.

3.1.2 \(NO_x\) pollution

Figures 1.a displays the anthropogenic \(NO_x\) emission fluxes at 06 UTC, with strong heterogeneities in the distribution of the emission sources. Densely populated and heavily industrialized areas clearly appear in this figure, mainly north of Italy (Milan, the Po valley), Germany, Benelux, England. France and Spain are areas of general weaker emission fluxes. Only large cities such as Barcelone, Madrid, Rome, Marseille, Lyon and Paris clearly appear in figure 1.a. After a preliminary 24 hours simulation period (chemical spin-up), the \(NO_x\) distribution over Europe is given in figure 2.a, with an effect of boundary layer thickness locality leading to increase concentrations when vertical mixing is reduced. After a close inspection of this figure, two different regimes of \(NO_x\) concentration distributions can be seen, associated with the emission sources. First, a large scale (mesoscale) pollution regime affects most of Germany, Benelux and England. Over these regions
the emission sources cannot be longer identified, and show high concentrations over 25 ppb. Secondly, from a regional down to local pollution scale, some pollution plumes can be identifiable around the main towns. It is the case in figure 2.a for the plumes seen at night and during the first hours of the day in the south-west of Paris, over the Po valley, north of Marseille,... . For some coastal cities such as Barcelone or Rome, the pollution plume is extending over the sea. In figure 2.a, large NOx concentrations issued from Germany and the Benelux also can be seen over the North Sea towards England. At 12 UTC on August 10, 1997 (after 30 hours of simulation, in figure 2.b), there is a general decrease of NOx concentrations in the low levels of the atmosphere. This reduction, clearly apparent when comparing figures 2.a and 2.b can be explained by the thickening of the boundary layer over the continent due to diurnal surface heating and subsequent vertical mixing. Over the sea, this reduction effect is clearly less apparent, leading to higher NOx there (maxima off Barcelone, Rome for the mediterranean sea and over the North sea). As for the trans-boundary fluxes, of particular notice we can find:

- a 25 ppb NOx maximum advected from Benelux is seen over the eastern shores of England, even over the London area;
- high morning NOx concentrations over England (figure 2.a) have moved over Wales at 12 UTC (figure 2.b) and Ireland at 18 UTC (figure 2.c);
- the anticyclonic regime prevailing over the mediterranean sea creates an important NOx transport from the Milan area to the south-eastern French coasts (figure 2.b), then to Marseille (figure 2.c);
- the same case can be observed for the NOx maximum associated with Barcelone reaching as far as Toulouse following the autan wind regime;
- the high NOx concentrations over the Alsace region generates a pollution plume extending toward the Paris area (figures 2.b and 2.c).

At 21 UTC (figure 2.d), ground cooling leads to thinning of the boundary layer, thus determining higher NOx values near the sources. In this connection, a heavy polluted plume is seen emitted from Paris towards Rouen; the same for the polluted continuum between Milan and Marseille.

3.1.3 Vertical structure of the NOx pollution field between Germany, Benelux and England

To better document both horizontal advection and vertical evolution of the major NOx pollution field over the North Sea, between Germany and England, vertical cross-sections have been displayed in figures 3.a, 3.b, 3.c, along the line drawn in figure 2.b in Germany, the Netherlands, the North Sea, England and Wales. Figure 3.a gives the NOx field along this vertical cross-section for August 10, 1997 at 06 UTC. At this time, the boundary layer is thin (about 300 m) and NOx emitted at night are constrained near the surface. A pronounced TKE (turbulent kinetic energy) vertical gradient is observed at the top of the mixing boundary layer. In the stable atmosphere above, the NOx concentrations observed are partly due to vertical mixing in the thicker boundary layer the day before (no residual TKE). Nevertheless, higher up, two cores of TKE are observed at a height of about 1500 m
5 Conclusions

Simulations have been performed with the modelling air quality system Meso-NH-C based on coupling between dynamics and chemistry. The preliminary results bear upon the 9 to 11 August pollution episode of a prolonged situation in August 1997 over Western Europe. A two-scale analysis has been performed. First, this analysis has been made over Western Europe, with extended plumes between Germany and Wales and between north of the Po valley and south-east France. Secondly, particular emphasis has been put through a spawning procedure over the Greater Paris area and its evolving pollution plume. These preliminary results of Meso-NH-C have to be further extended to detailed analysis of other chemical species, to other documented episodes of the same period and to other periods. Furthermore, aerosol microphysics and chemistry have to be considered. Nevertheless, the results are quite promising with such a simulation system which proved to be apt to capture pollution episodes with their various synoptic to regional and local scales involved.

6 References


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over the North Sea and the Netherlands, associated with low clouds. Figure 3.b is relative to the \( NO_x \) vertical field at 12 UTC. Over the continent, the boundary layer has thickened, reaching up to about 2000 m. Enhanced vertical mixing results in \( NO_x \) concentration reduction at the surface (figure 3.b), stratification develops anew and the previous \( NO_x \) concentration evolution is repeated.

4 Pollution in the greater Paris area

These are fine resolution (5 km) simulations performed over the Paris area through a spawning procedure applied to the coarse resolution simulations previously performed over Western Europe. In this section, particular emphasis is put on the evolution of the pollution plume emitted over Paris during August 9 and 10, 1997. On August 9, the wind regime is from the North-East over most of the domain. At low levels, the wind speed is weak (about 2 m s\(^{-1}\)), which is favorable for the formation highly polluted plumes of small extent (figures 4 a to f). At 15 UTC, after 6 hours of simulation, a \( NO_x \) plume is clearly seen in figure 4.a, with concentrations over 20 ppb in the south-west of Paris, towards the town of Orleans. The background \( NO_x \) concentration is established at low levels (lower than 0.5 ppb), presumably partly due to incomplete chemical spin-up out of the major polluted zones. Nevertheless, apart from the Paris plume itself, one can observe other smaller plumes due to smaller towns such as Orleans, Melun, Chantilly, Rouen and Le Havre. The surface ozone field (figure 4.c) exhibits a weak minimum of 40 ppb at Paris associated with the high \( NO_x \) concentrations in figure 4.a. located at the West of the main plume (at Trappes), within an area of moderate \( NO_x \) values (3 ppb), one can observe an ozone maximum of about 60 ppb. When considering another pollutant (formaldehyde in figure 4.e), another maximum (at 3 ppb) is found south-west of Paris. Formaldehyde is not only a primary species, but is also formed through reactions between \( NO \) and peroxy radicals. Its associated plume thus largely coincides with an ozone production area (rich in \( NO \)), which can explain its wider horizontal extent than the \( NO_x \) plume. On August 10, 1997, wind blows from east to south-east over the north-western part of the domain, while wind speed has increased to 5 to 6 m s\(^{-1}\). One observes in figures 4.b a \( NO_x \)-plume directed from Paris to Rouen along the Seine valley. The maximum of 25 ppb is located west of Paris. High \( NO_x \) values (over 8 ppb) are advected at distances over 100 km from Paris. On August 10, the \( NO_x \) background levels is largely superior to its values the day before, with values of about 2 ppb at the surface. The result on ozone concentrations is the reverse of the day before (figure 4.d), with a pronounced ozone minimum of 20 ppb at the location of the \( NO_x \) maximum and low values all over the \( NO_x \) plume. This anti-correlation between \( NO_x \) and \( O_3 \) emphasizes the \( O_3 \) chemical destruction regime. Elsewhere, the ozone concentrations keep average values of 40 ppb, the same as the day before. Figure 4.f displays a \( CO \) plume with a maximum of 250 ppb at Paris. \( CO \) presents a more non-homogeneous distribution than \( NO_x \). High \( CO \) values, over 100 ppb are advected over Le Havre, as far as 180 km from Paris. Elsewhere, \( CO \) concentrations are below 70 ppb.
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NO\textsubscript{x} emission rates (in ppb m/s)

Figure 1: (a) \(NO_x\) emission rates in \textit{ppb m s}^{-1}. NOAA IR satellite image over Western Europe for August 9, 1997 at 13 UTC (b), August 10, 1997 at 13 UTC (c) and August 11, 1997 at 13 UTC (d). Temperature at the top of clouds simulated by Meso-NH in simulation EUROP for August 10, 1997 at 13 UTC (e) and August 11, 1997 at 13 UTC (f). The grey scale values of temperatures are given in degrees Celcius (the darkest, the highest concentrations).
Figure 2: \(NO_x\) Surface fields in simulation EUROP on August 10, 1997 at 06 UTC (a), at 12 UTC (b), at 18 UTC (c) and at 21 UTC (d). The grey scale values of surface fields are in ppp (1 ppp = 10^9 ppb; the darkest, the highest concentrations). The Meso-NH surface wind vectors are surimposed on the concentration fields (scales at the bottom of each figure). Mark for the vertical section (dashed in (b)).
Figure 3: Vertical cross section in simulation EURO? for NO\textsubscript{x} on August 10, 1997 at 06 UTC (a), at 12 UTC (b) and at 21 UTC (c). The grey scale values are reported at the right in ppp (1 ppp = 10\textsuperscript{9} ppb; the darkest, the highest concentrations). Vertical isolines of Turbulent Kinetic Energy (TKE) are surimposed on the concentration fields.
Figure 4: Surface fields in simulation PARSP for (a) $NO_x$ on August 09, 1997 at 15 UTC, (b) $NO_x$ on August 10, 1997 at 18 UTC, (c) $O_3$ on August 09, 1997 at 15 UTC, (d) $O_3$ on August 10, 1997 at 18 UTC, (e) $HCHO$ on August 09, 1997 at 15 UTC and (f) $CO$ on August 10, 1997 at 18 UTC. The grey scale values of surface fields are in ppp on the right (1 ppp = $10^9$ ppb; the darkest, the highest concentrations). The Meso-NH surface wind vectors are surimposed on the concentration fields (scales at the bottom of each figure).