An analysis of the meteorological and air quality conditions during an extreme ozone episode over the northeastern USA

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Abstract: In this study, an extreme ozone episode that occurred during the period 12–15 July 1995 over the northeastern United States is investigated through model simulations. This paper is focused on the meteorological conditions prevailing during this ozone episode. The analysis is based on nested grid simulations performed with the meteorological model CSU-RAMS (Colorado State University - Regional Atmospheric Modelling System) and on the available surface and upper air observations. The definition of the model nests seemed very important in order to capture the prevailing atmospheric circulations which led to the build up of the air pollution episode.

Keywords: meteorological models, northeastern USA, numerical simulations, ozone episode.

Reference to this paper should be made as follows: Lagouvardos, K., Kallos, G., Kotroni, V. and Rao, S.T. (2000) 'An analysis of the meteorological and air quality conditions during an extreme ozone episode over the northeastern USA', *Int. J. Environment and Pollution*, Vol. 14, Nos. 1–6, pp. 581–587.

1 Introduction

The North American Research Strategy for Tropospheric Ozone-North-East (NARSTO-NE hereafter) field programme was conducted from 15 June to 9 September 1995 over the northeastern part of the USA (including New England and Mid-Atlantic States). The observational campaign provided an extensive surface meteorological network as well as dense upper air measurements. Routine air quality data were obtained by more than 200 monitoring sites, while nine new NARSTO-NE monitoring stations measured concentrations of chemical compounds as well as various meteorological parameters. A more detailed presentation of the observations can be found in Zhang *et al.* (1998).

For the purpose of this field programme, nested grid simulations with the Regional Atmospheric Modeling System (RAMS) were performed for the three summer months (June, July and August 1995). The purpose of this simulation was to provide threedimensional meteorological fields over the northeastern USA. These fields were used for seasonal ozone modelling with the UAM-V photochemical model. In addition, this large dataset permits the study of the meteorological conditions leading to the onset of air quality episodes over the northeastern USA.

During the field programme period, the national air quality standards for ozone were exceeded on 26 days in total, distributed into five major episodes. For this study, our interest is focused on the severe episode which occurred from 12–15 July 1995.

An important feature of RAMS is its capability of performing two-way interactive grid nesting which allows local fine mesh grids to resolve small atmospheric systems, while simultaneously modelling the large scale environment of the systems on a coarser grid. The most important features of RAMS were summarized by Pielke *et al.* (1992). Specific applications of this modelling system to air quality studies were reviewed by Lyons *et al.* (1993). Recent air quality studies based on the application of RAMS can be found in Fast *et al.* (1995), Poulos and Bossert (1995), Lyons *et al.* (1995), Lagouvardos *et al.* (1996) and Bossert (1997).

2 RAMS set up

For the performed simulations, three nested grids have been selected with the following configuration:

- The coarse grid with a mesh of 45 × 35 points and 108 km horizontal grid increment. The coordinates of the centre of the domain were at 38.6°N and 91.3°W.
- The second grid with a mesh of 89 × 77 points and 36 km horizontal grid increment. The coordinates of the centre of the domain were at 36.926°N and 85.037°W.
- The inner grid, which was the finest, with a mesh of 170 × 128 points and 12 km horizontal grid increment. The coordinates of the centre of the domain were at 38.393°N and 81.564°W.

A vertical nesting was also applied, allowing more vertical levels for the second and inner grids within the boundary-layer, thus permitting a very detailed description of this layer. The ECMWF 1° gridded analysis files (including geopotential height, horizontal wind components, temperature and relative humidity at 11 pressure levels — the 925 hPa level included) were used to initialize the model and nudge the boundaries at a nudging timescale of six hours. Surface observations provided by the NARSTO-NE meteorological stations were blended with the ECMWF gridded data. The ECMWF fields of the climatological sea surface temperature (1° resolution), as well as topography derived from a 30 arcsec terrain dataset, have been used for all grids. Moreover, vegetation type data with 10 arcmin horizontal resolution were used.

3 The ozone episode of 12–15 July 1995

This section is devoted to the discussion of the meteorological conditions leading to the onset of a severe ozone episode over the northeastern USA. The NARSTO-NE field measurements taken during 12–15 July 1995 indicated that ground-level ozone concentrations exceeded the national air quality standards. On 14 July 1995 ozone exceedances occurred at 37 sites along the northeast urban corridor (Zhang *et al.*, 1998). Peak ozone concentrations of 170 ppb and 175 ppb were measured on 14 July at sites in New Jersey and Connecticut.

Figure 1 shows the mean sea-level pressure valid at 12:00 UTC on 13 July 1995. A high pressure system covers the eastern United States with a surface pressure of 1020 hPa over the eastern coasts while a weak southwesterly flow is established over the northeastern United States. Twenty four hours later, the high pressure and the weak pressure gradients persist over the area of interest, while a cold front located parallel to the United States–Canada border is approaching from the north (not shown).

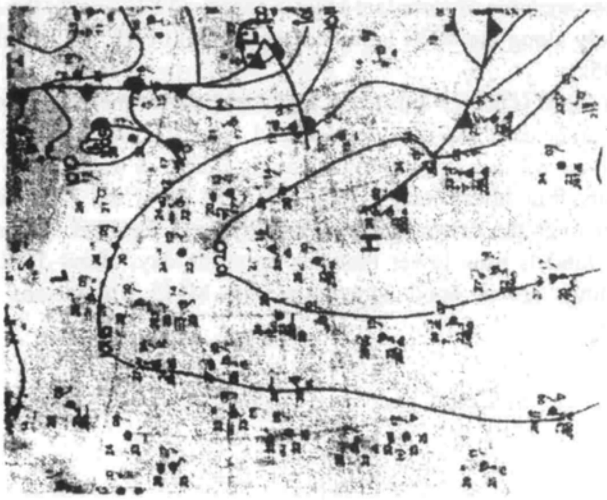

Figure 1 Mean sea-level pressure analysis valid at 12:00 UTC on 13 July 1995. Isobars are plotted every 5 hPa (from the European Meteorological Bulletin).

Figure 2 ECMWF analysis file: temperature (plotted every 2°C) and wind at 850 hPa level, valid at 18:00 UTC on 13 July (left) and 14 July 1995 (right) inside the second grid of RAMS. A full barb corresponds to 4 ms^{-1} and a half barb to 2 ms^{-1}. The 20°C isoline is in bold. Wind barbs are plotted every second grid point.

A series of 850 hPa wind and temperature charts at 18:00 UTC on 13 and 14 July 1995 from RAMS output data on the second grid of simulation is shown in Figure 2. Light winds prevail over the eastern United States from 13 to 14 July, while an important warming of the lower tropospheric levels is evident. Note the progression of the 20°C isoline within 24 hours: at 18:00 UTC on 14 July, the northeastern United States experienced temperatures greater than 20°C, with a maximum of 26°C over the Great Lakes at the 850 hPa level. Note that within 48 hours the temperature over the northeastern United States increased approximately 8° at this level.

The evolution of the planetary boundary-layer during this episode can be investigated now by inspecting latitudinal cross-sections inside the inner grid of RAMS. Figure 3 presents vertical cross-sections of turbulent kinetic energy (TKE) inside the inner grid of RAMS, approximately along the 40°N latitude line, at 18:00 UTC on 13 July and 18:00 UTC on 14 July 1995.

During the day (18:00 UTC, 13 July), the TKE field shows the abrupt growth of the turbulent boundary-layer over the land, as deduced from the vertical extension of the 0.1 $m^2 s^{-2}$ TKE isoline, while a very shallow mixing height is depicted over the ocean (100–200 m). Twenty-four hours later (18:00 UTC, 14 July) the TKE field shows a shallow mixed layer over the ocean, growing rapidly over the land. The depth of the mixing height over land is now lower than the previous day, about 1500 m over the ground. These findings are in good agreement with MM5 simulations reported by Berman *et al.* (1997).

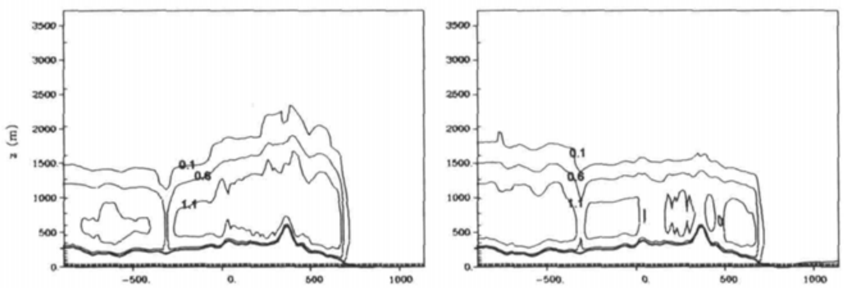

Figure 3 Vertical cross-section of TKE (at 0.5 $m^2 s^{-2}$ intervals, first contour line is 0.1 $m^2 s^{-2}$) inside the inner grid of RAMS, approximately parallel to the 40°N latitude line, valid at 18:00 UTC, 13 July (left) and 14 July 1995 (right).

The wind field and temperature at the lowest model level at 18:00 UTC, 14 July 1995 in the inner grid of RAMS is shown in Figure 4. The surface winds have a more organized western orientation over the area of interest, ahead of a cold front approaching from the north. However, the wind flow over land is still weak, but over the ocean surface winds exceed 8 ms^{-1} offshore of Connecticut. This field is in good agreement with the observations as well as with numerical simulations performed for the same day by Zhang *et al.* (1998). The near surface temperature now shows very high values, exceeding 36°C over some parts of the northeastern states (shaded areas in Figure 4).

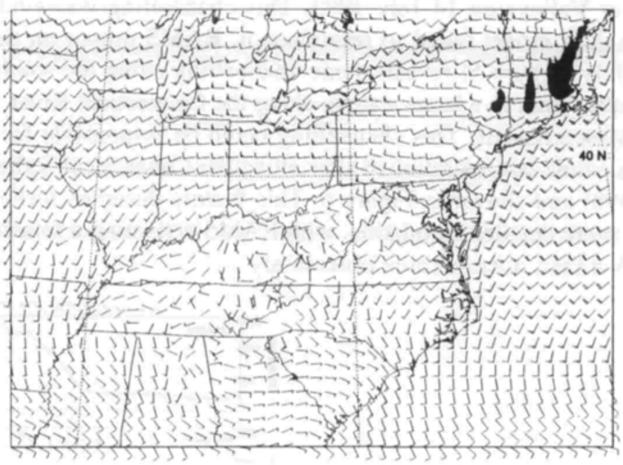

Figure 4 Wind field inside the inner grid of RAMS at z = 16 m, valid at 18:00 UTC, 14 July 1995. One full barb equals 4 m s^{-1} and one half barb equals 2 m s^{-1}. Wind barbs are plotted every fourth grid point. Temperature values greater than 36°C over the eastern part of the domain are shaded.

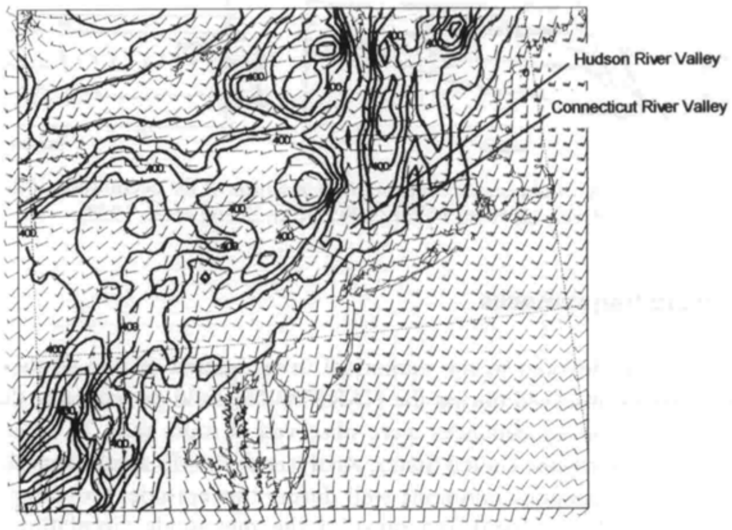

Figure 5 Zoom over the northeastern portion inside the inner grid of RAMS, valid at 00:00 UTC, 14 July 1995. One full barb equals 4 m s^{-1} and one half barb equals 2 m s^{-1}. Wind barbs are plotted at every grid point. Topography is contoured at 100 m intervals.

Zhang *et al.* (1998) reported a channelling of the flow along the Hudson and Connecticut River Valleys on 14 July 1995. This channelling was evident on surface observations but their model failed to reproduce it. RAMS output on the inner grid at 00:00 UTC, 14 July (Figure 5) reveals some channelling along the southern part of the Hudson River Valley and, to a lesser extent, along the Connecticut River Valley through Connecticut to Massachusetts. This channelling could be responsible for the successive delay in the peak ozone concentration at sites along the Connecticut Valley, discussed in Zhang *et al.* (1998) and shown in Figure 6. This feature deserves further investigation and, therefore, a more detailed simulation, with RAMS activating a fourth grid with very fine resolution (3–4 km), over this area is necessary.

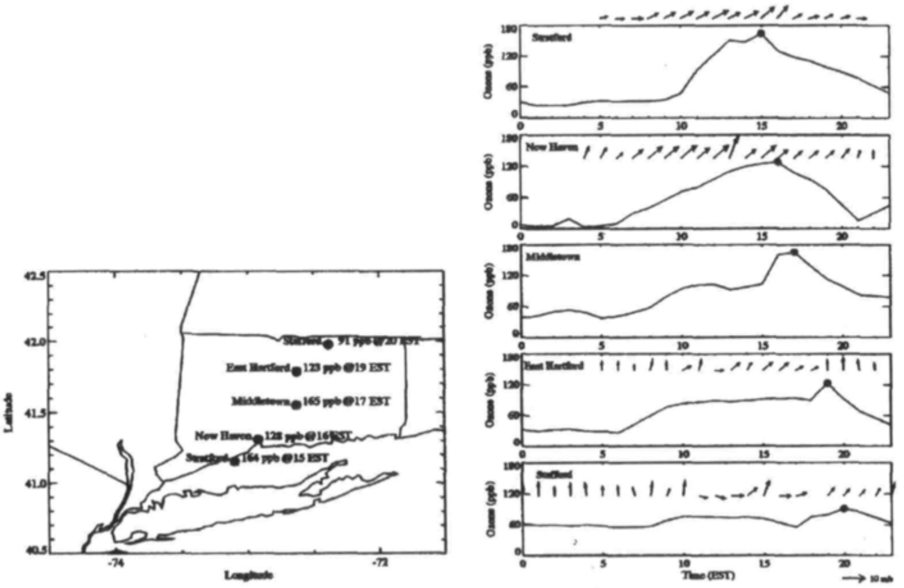

Figure 6 The peak 1 hour ozone concentration and time of the occurrence of the peak at sites along Connecticut River valley on 14 July 1995 (from Zhang *et al.*, 1998).

4 Concluding remarks

This study was devoted to the numerical investigation of one of the most prominent ozone episodes observed during the NARSTO-NE field programme, that of 12–15 July 1995, when ozone exceedances were observed at more than 37 sites along the urban corridor of the northeast United States. Analysis of RAMS results revealed that the model reproduced the synoptic conditions well during this episode, providing also an accurate description of the regional and most of the mesoscale circulations. RAMS results revealed that this episode was accompanied with a pronounced warm air advection. It should be noted that on 14 July 1995, very high temperatures (>36°C) and very light winds prevailed over the northeastern US. However, some meso-β scale phenomena (e.g. sea-breezes) could not be resolved adequately by the horizontal grid increment used on the inner grid of RAMS (12 km). This is mainly related to the inaccurate representation of the sharp gradients characterizing the sea-breeze front passages.

The RAMS inner grid showed also a channelling of the wind flow along the Hudson and Connecticut River Valleys, a channelling which could be responsible for the successive delay in the peak ozone concentration at sites along the Connecticut River Valley, shown in Figure 4 and also discussed in Zhang *et al.* (1998). For that reason, a more detailed simulation over this area is required. A fourth grid with very fine resolution (4 km) will be necessary to capture the meso-β features.

5 Acknowledgement

This research was supported by the Electrical Power Research Institute (EPRI) under Contracts #W03189-12 and #W04447-01.

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