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A modelling study of an extraordinary night time ozone episode over Madrid domain

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Abstract

During the early morning hours on April 29, 2000, a time series of ozone observations from several stations showed that a unique and exceptional ozone episode occurred in Madrid city and surrounding areas, whereby monitoring stations reported ozone concentrations up to 1190 μg/m^3. In order to investigate this phenomenon, two different air quality modeling approaches are used here:

- The FLEXTRA trajectory model was initially used, suggesting that an intrusion of stratospheric air occurred over the Madrid area and brought stratospheric air down to 1000–2000 m AGL. The local circulation system, not resolved by the FLEXTRA trajectories, subsequently brought some of this stratospheric air to the surface. However, the maximum ozone concentration that could be explained by this process is much less than the observed one.
- The OPANA Air Quality Modeling System was also employed to study air quality over the Madrid community and city domains. Results suggested that the main wind direction returned to Madrid after 180° wind change direction 1 to 2 h before the "episode", bringing back ozone generated the day before (typical weekend day with high traffic density). On the other hand, convergence of winds along the South-West North-East axis over the Madrid community showed an important correspondence with the sequence of observations.

Preliminary conclusions show that the exceptional meteorological conditions on such a night could be reason for the occurrence of high values. Additional technical circumstances (such as technical incidences in some monitoring stations) also suggest that some instruments did not work properly under these high concentrations and, thus, real ozone concentrations may have been lower than those measured.

Keywords: Ozone episode; Atmospheric modeling

1. Introduction

Ozone is an important secondary pollutant in the atmosphere and also a major oxidant. Ozone episodes are defined as time periods during which concentration levels within the atmospheric boundary layer and near ground level exceed the air quality limit values that are set via legislation. High ozone concentrations are strongly related to meteorological conditions and usually occur during sunny days, when primary pollutants (NO_x and VOCs) interact photochemically, "supported" by strong solar radiation and high temperatures. During the morning hours ozone levels are usually low over large cities, the main reason being the increased

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near-ground emissions which serve as fast-acting ozone sinks. High NO_x emissions lead to a sharp rise of NO_2 concentrations over the centre of the city as a consequence of the oxidation of NO to NO_2 by O_3. Higher ozone levels are formed only after NO is depleted, e.g. during afternoon hours. Because of the transport and chemical transformation of the primary pollutants in central urban areas, high ozone levels are usually monitored in the suburbs where primary pollutant emissions are lower. For Madrid (Spain), the highly inhabited zone, where pollutant emissions have essentially an urban origin, stays frequently under the influence of high-pressure systems, which strongly influences the ventilation of the area and supports air pollution episodes of certain importance (Pujadas et al., 2000). This leads to ozone episodes which usually occur in the April–October period each year. Exceptional ozone episodes are considered as those occurring at "unexpected" times or seasons of the year with high values that cannot easily be attributed to anthropogenic activities. This is the case for the episode between 2h00 and 6h00 on the 29 April, 2000 over Madrid (Spain) city. Moreover, if the ozone levels reach values of 1000 $\mu g/m^3$ or more as was the case over Madrid, the explanation to be found should be somehow "exceptional", and either deal with the "massive" failure of the monitoring network, or be correlated to rare but possible meteorological conditions. Stratosphere–troposphere exchange can play an important role when explaining these unique episodes (Liu et al., 1987; Stohl and Trickl, 1999).

2. The Madrid air quality monitoring network

The Madrid metropolitan area is nearly in the centre of the Iberian Peninsula. It has an average altitude of 650/700 m ASL and is bordered on the North/North-West by the Central System range. These mountains, with maximum heights of 2500 m, are located 60 km away from the city. The surrounding zone presents a smooth slope following a South-West/North-East direction with an inclination of 2% within the city. The whole region is frequently under the synoptic influence of high-pressure systems, which causes poor ventilation and air pollution episodes in winter. The Madrid metropolitan area is one of the most densely populated regions in Spain, with around 5 million inhabitants, including the capital and the surrounding towns. Its industrial activity consists essentially of light industries, and only some medium-sized factories which are located in villages 35 km towards the east and 20 km to the south, and few small chemical industries in the north. The nearest heavy industrial activities are 200/250 km away in Puertollano (Ciudad Real) to the south and in Valladolid to the North-West of Madrid. As a consequence, the Madrid plume is typically urban, which means that it is fed mostly by traffic emissions and by domestic heating in winter.

Madrid city has a dense Air Pollution Monitoring Network with 24 automatic stations (Fig. 1). In each station the air is sampled at 2.5 m above the surface and the concentrations of SO_2, CO, NO_x, O_3, VOCs and particles are continuously monitored. The network was designed for air quality control purposes while also following management criteria, so it covers a rather limited area with an inhomogeneous distribution of the stations in the city. Moreover, the measurements are generally affected from nearby emissions because most stations are located at intersections and busy streets. In addition to this network, Madrid community has nine monitoring stations (Fig. 2). Both networks are operating on a continuous basis and provide information on air pollution concentrations to the local authorities.

3. The OPANA model

OPANA is composed of REMEST (non-hydrostatic mesoscale meteorological model, based on the MEMO model; University of Karlsruhe, Germany, 1994) and the SMVGEAR model (University of Los Angeles, USA, 1994: see also San José et al., 1999). There are five different important modules in OPANA: REMO, DEPO, REMEST, EMIMA and CHEMA. REMO, DEPO and REMEST are part of the MEMO adapted code. REMO is a module which provides automatic land use classification based on information provided by the LANDSAT-5 satellite images. This model uses the principal component and the cluster analysis for providing this information which is particularly useful for quantifying the biogenic emissions in EMIMA (San José et al., 1995). EMIMA is a module which provides the biogenic and antropogenic emissions for 250 m grid cells for Madrid mesoscale domain and with a temporal resolution of 1 h. REMEST is the transport model itself which calculates the wind components by solving the Navier–Stokes equations in the atmospheric fluid. REMEST is a transport module which includes a full non-hydrostatic mesoscale meteorological model which provides the three dimensional wind fields and the temperature and specific humidity scalar fields. The transport model provides prognostic and diagnostic information about the three dimensional distribution of the trace gases in an Eulerian context. The model solves the Navier–Stokes equations for the meteorological variables and the Eulerian transport equation for the quantities to be transported by the atmospheric flow (Moussiopoulos, 1984). The adopted temporal discretization uses of the second-order Adams–Bashforth scheme and for the vertical diffusion, the Crank–Nicholson method is applied. The advection term is solved using a modification of the TVD (total variation)