INFLUENCE OF THE INTERACTIONS OF LOCAL DYNAMICAL PROCESSES WITH LARGE-SCALE FLOW ON AIR QUALITY IN THE GRENOBLE AREA

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Abstract: The vertical distribution of ozone over the Grenoble area is investigated for two summer smog episodes in 1999 and 2003. The effects of the interactions of local dynamical processes with large-scale circulations were estimated using numerical modelling. The results suggest that a terrain-induced shear layer above the boundary layer confines pollutants within the valley. Vertical exchanges through this shear layer have a considerable influence on the near-surface ozone concentration from day to day.

Keywords - *Complex terrain, Large scale – local scale interactions, Ozone residual layer, Summer smog*

1. INTRODUCTION

The city of Grenoble (France) embedded between the Rhône valley and the Alps frequently has ozone levels exceeding the French limit threshold of 90 ppbv during summertime. The Grenoble area is located in the Y-shape convergence of the Drac and Isère valleys (see Fig. 1). The fork in the upper part of the valley is open to broad plains whereas the lower part is connected to the foothill of the Alps. Pollutant concentrations at the ground surface are strongly influenced by the interactions of local dynamics with large-scale transport. A complex valley-wind system develops across the region with a well-established up-valley wind during daytime and down-valley wind during nighttime in the southern part.

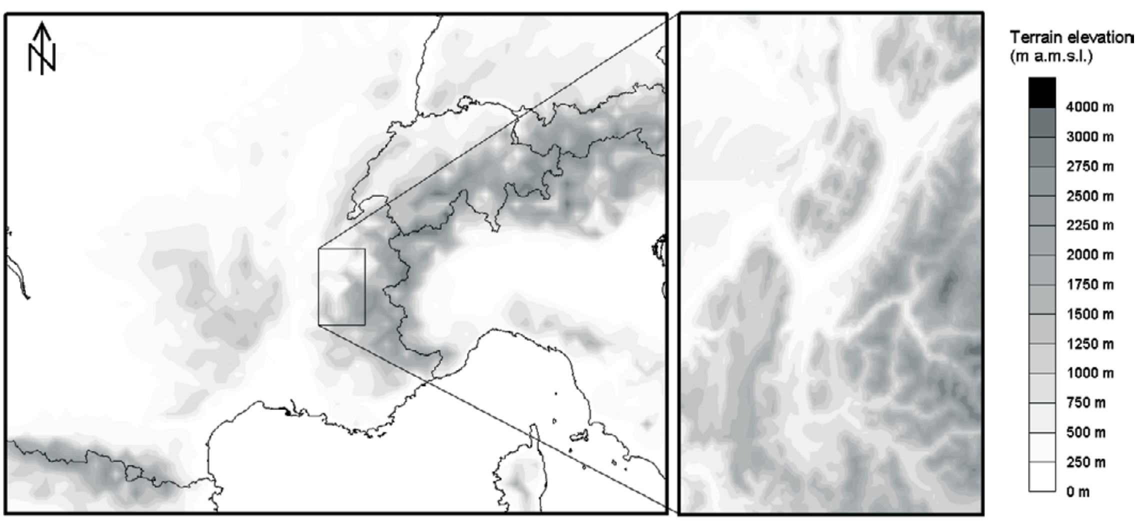

Figure 1. Overview of the Grenoble area in Lambert II Etendu coordinate system. Attached grey scale indicates altitude in meters above mean sea level (a.m.s.l.)

A multi-day ozone residual layer is often observed during summertime over the valley. The polluted air in this *reservoir* layer is mixed downward during daytime as the atmospheric boundary layer (ABL) grows up, increasing ozone concentration near the ground surface. The overall objective of this study is to investigate the processes leading to the formation, maintenance and destruction of this residual layer.

2. METHODOLOGY

2.1. Modelling tools

Numerical simulations have been performed with several nested domains to study atmospheric flow fields in the Grenoble area down to the submeso scale. The numerical simulations presented in this paper have been conducted with the Advanced Regional Prediction System (ARPS) version 5.1.5. Xue et al. (2000) give an extensive description of the code. Realistic topographic and soil-vegetation characteristics have been used to represent surface features. Boundary conditions of the coarser domain were driven by the European Centre for Medium-Range Weather Forecasts (ECMWF) gridded analyses available every 6 hours at 0Z, 6Z, 12Z and 18Z with a horizontal resolution of 0.5°and on 16 pressure levels from 1000 to 50 hPa. External boundary meteorological fields were applied to ARPS grids using one-way interactive nesting. A relaxation zone was employed to smooth gradients near the lateral boundaries. Three grid nesting levels (16, 4 and 1-km horizontal resolutions) were necessary to resolve atmospheric dynamics down to a 1-km horizontal resolution. The finer grid encompasses the domain in Fig. 1.

The chemistry transport models CHIMERE forced by the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5) version 3 at the regional scale (Vautard et al. 2003) and METeorological PHOtochemistry MODel (MetPhoMod) at the local scale are offline-coupled afterwards. This latter model has both a meteorological module to compute transport and a chemical module based on the Regional Atmospheric Chemical Mechanism (RACM) to process chemical reactions (Perego 1999).

2.2. Validation

The numerical tool, describing meteorology, pollutant emissions, transport, chemistry and deposition is a powerful tool to investigate processes and to allow effective control strategies. The model have undergone a validation step using reliable observational data collected during the first GRENOPHOT Intensive Observation Period (IOP) in 1999 (Couach et al. 2003), which ensures to some extent its accuracy. The IOP took place in the Grenoble valley from July 25 to July 27, 1999. The valley was equipped with a network of ground monitoring stations including measurements of pollutant concentrations such as ozone (O_3), nitric oxide (NO) and nitrogen dioxide (NO_2) and meteorological variables. Different ozone vertical profiles and ABL description using an ozone LIDAR-DIAL system, an instrumented aircraft and a UHF wind profiler were also available from the IOP.

The prevailing synoptic wind blew south-westward on July 25, changing to north-eastward on July 27. The whole 3-day period was used to validate the numerical tools in use. Wind direction and force from the wind profiler are compared to corresponding values computed in the model in Fig. 2 (a) to Fig. 2 (d). The daily periodicity of the valley wind is observed on both wind force and wind direction. Up to about 1700 m a.g.l., the wind reverses twice a day while wind at higher altitude remains unchanged. A pronounced shear layer with low wind speeds above the ABL up to 2500 m a.g.l. is observed until the synoptic wind shift on July 27 and is well reproduced by the model.

Fig. 2 (e) and Fig. 2 (f) show time-height cross sections of ozone concentration from the LIDAR observations and model results. The high ozone production associated with low wind speeds in the shear layer considerably influences the near-surface ozone concentration on the following day. This ozone trapping mechanism by the shear layer differs from the exchange process by vertical displacements of different inversion and reservoir layers characterized by different photochemical equilibrium conditions observed by Beyrich et al. (1996) in the Harz Mountains, Germany.

The model results match the observations satisfactorily. The simulation results are thus well suited to provide a coherent picture of the real flow evolution and to attempt a dynamical interpretation of some key flow features.

3. RESULTS AND ANALYSIS

The models have been set up to simulate atmospheric dynamics and chemistry during the heat wave in summer 2003 and have been validated using measurements at several ground stations.

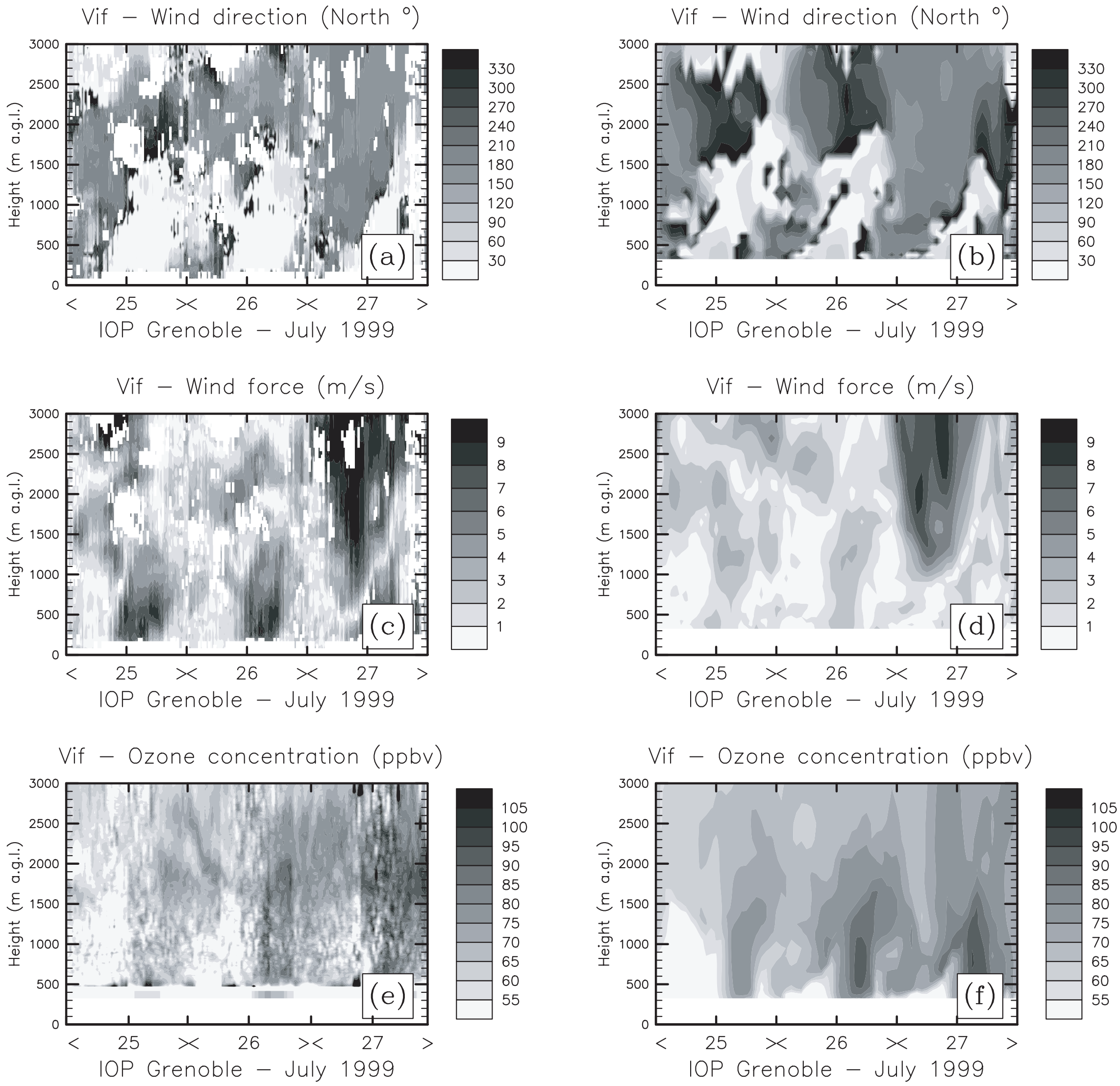

Figure 2. Time-height cross sections of horizontal wind direction and force from the UHF wind profiler **(a)** and **(c)** and model results **(b)** and **(d)** and ozone concentration from the LIDAR-DIAL system **(e)** and model results **(f)** from July 25 to July 27, 1999 at *Vif* in the Grenoble valley

Different processes are relevant for the vertical ozone distribution over the Grenoble area. Due to mixing, dispersion, and chemical reactions, air masses lose their original properties during the transport. Large-scale transport is a *preconditioning* process for high-ozone episodes (Couach et al. 2004). The diurnal cycle of ozone is also driven by vertical mixing processes in the ABL. The spatial and temporal variation of horizontal winds in the daytime ABL controls peak pollutant concentrations. During periods of high ozone loading, documentation of mechanisms affecting horizontal circulations is crucial. The schematic illustration of the prevailing flows in Fig. 3 (a) shows the complexity of the wind system.

The maintenance of vertical shear in the ozone residual layer is a key process during high ozone events in the Grenoble valley. The growth of the morning convective layer allows the chemical composition of the residual layer from the previous day to mix to the surface at the same time that photochemical production of ozone is beginning in the first daylight hours. This mixing should lead to an increase in ozone concentration at the surface and to a decrease in the residual layer. However the high ozone production associated with low wind speeds in the shear layer located between 1500 and 2500 m a.g.l., highlighted in Fig. 3 (b), prevents ozone depletion and contributes to long-lasting pollution.

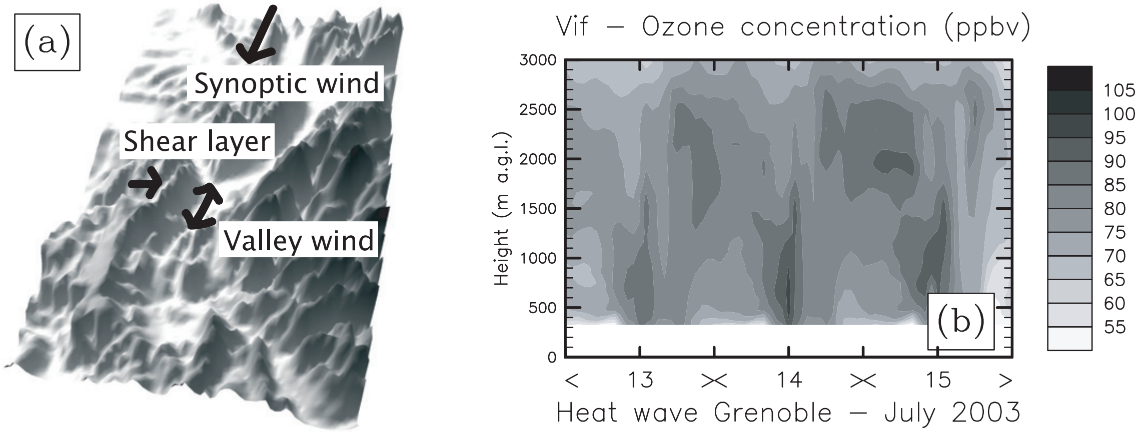

Figure 3. (a) Schematic illustration of the prevailing flows in the Grenoble area **(b)** Time-height cross section of simulated ozone concentration from July 13 to July 15, 2003 at *Vif* in the Grenoble valley

4. CONCLUSIONS

Photochemical pollution events are explained according to the interactions of local dynamics with large-scale transport. A terrain-induced shear layer produces long-lasting pollution episodes by trapping ozone-rich air masses within the valley during daytime and forms a reservoir layer staying overnight. These vertical exchanges have a drastic impact on the local air quality in the Grenoble area. Local emission reduction measures should have an enhanced effect on ozone concentration in the residual layer and should be more effective from day to day.

Acknowledgement: *The research has been supported by the GIERSA group of air quality networks.*

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