ON THE ROLE OF THE GRENOBLE VALLEY TOPOGRAPHY IN VERTICAL TRANSPORT OF MASS AND POLLUTANTS

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Abstract: The Grenoble urban area (France) is embedded within a highly complex alpine topography at the Y-shaped confluence of deep valleys. The uneven terrain of the Southern branch induces complex circulations, which may have significant impacts on both local (thermo) dynamics and air quality. Selected episodes in summer 2003 and winter 2005 are considered through numerical simulations in order to analyse the way the valley-wind system affects the dispersion of pollutants. Both the uneven terrain and the interaction of thermally-driven circulations in the Southern part of the valley are found to play a significant role in mass exchange with the free atmosphere. During the summer episode, the descending flow from the Southern part of the valley is found to strongly interfere with the up-valley wind. As a consequence, the air mass is pushed upwards, resulting in a net vertical transport of precursor gases to the free-atmosphere above. The winter episode is particularly stable and calm weather conditions lead to high concentrations of smog-forming pollutants and PM_{10} within the valley below a well-defined temperature inversion. In that case, the Southern branch of the valley either strengthens the slight down-valley wind or produces a recirculation zone within the valley.

Keywords: *complex topography, valley-wind system, vertical transport, air quality, numerical simulation*

1. INTRODUCTION

The Grenoble urban area (France) is embedded within a highly complex alpine topography, which is somewhat similar to that of the Chambéry urban area (France). Indeed, the whole core of the city is located at the Y-shaped confluence of deep and steep-side valleys, which cannot be considered as secondary tributary valleys. The flow dynamics within this Y-shaped valley is thus rather specific. On top of that the uneven terrain of the Southern branch induced complex circulations, which may have significant impacts on both local (thermo) dynamics and air quality. Hence, the objectives of our work are (*i*) to investigate the onset, development and seasonal variability of the flow in the Southern part of the valley and (*ii*) to quantify its impact on the structure of the atmosphere as well as on air quality within the valley.

A set of meteorological and air quality models using horizontal resolution down to 1–2 km, as well as existing data sets are used to detail the characteristics of that part of the valley for selected episodes in summer 2003 and winter 2005. Chemical transport models (CTMs), such as CHIMERE (Vautard et al., 2005) are used extensively to simulate photo oxidant pollution and its transport at regional scale. Nevertheless they are usually not able to reproduce sharp concentration gradients in complex-terrain areas. This is mainly due to a lack of horizontal resolution and / or appropriate modelling components. Hence, special attention needs to be paid to mountainous region. The methodology which is considered here has already been developed in the frame of the POVA project (e.g. Brulfert et al., 2005) and is extended here to the Grenoble urban area. Note that the POVA project dealt with typical narrow alpine valleys (Chamonix and Maurienne valleys, France), with small impacts of tributary valleys, high length-to-width ratio and rather low pollutant emissions.

2. MODELS

The integrated modelling system consists in the meteorological model MM5 (Grell et al., 1995) [or WRF (Skamarock et al., 2007)] and the CTM METPHOMOD (Perego , 1993). This system has been setup to include the interaction between different scales through nested domains with a horizontal resolution down to 1–2 km. Non hydrostatic codes are used to take full account of dynamics induced by orography and convection. Either MM5 or WRF is initialized and forced at the boundaries by 6-hourly gridded analyses from ECMWF at a 0.5° horizontal resolution. METPHOMOD is used to compute pollutant concentrations at the scale of the valley. The numerical code is formulated on a cartesian grid. Hence, the grid do not perfectly match the local orography that combines steep slopes with rather gentle slopes. The model includes 72 chemical species and the RACM chemical scheme is used. Boundary conditions for some of the species, among which ozone and some precursors, are provided from CHIMERE (Schmidt et al., 2001) calculations at regional scale.

Note that METPHOMOD was already used for the Grenoble valley during GRENOPHOT in summer 1999 (Couach et al., 2003). Thus, the model has undergone a validation step using data from the GRENOPHOT field campaign. Also, the model has been validated for the ESCOMPTE campaign in Marseille (Cros et al., 2004), for which both topography and see breeze effects played a significant role in dispersion of pollutants (see Chaxel, 2006, for a detailed validation).

3. SUMMER EPISODE

Numerical simulations were performed for the two-week period corresponding to the heat wave episode in August 2003. Under certain atmospheric conditions, the descending flow from the Southern part of the valley strongly interferes with the up-valley wind, which is well established within the valley (see fig. 1). The vertical structure of the atmosphere can be made of 2 to 3 distinct layers with significant shear between them. As a consequence of the interaction of the circulations due to topographic effects, the air mass is pushed upwards in the Southern part of the valley. The resulting net vertical transport is found to have a significant impact on the high concentration of precursor gases in the free-atmosphere above. Fig. 2 shows that ozone is injected from the mixed layer into the free atmosphere. As a consequence, a natural photo-chemical reactor builds up above the valley. It is very likely that this mechanism contributes to a large degree to the high concentrations of ozone in the area during summertime. During the August heatwave in 2003, a large part of the European lower troposphere was rich in ozone, so that regional transport was an important component of the pollution episode. Note that the mechanism described here is expected to play a role in transport of photo-oxidants as much important than hitherto considered.

4. WINTER EPISODE

Complex terrain enhances stratification effects in cold weather conditions. Strong temperature inversions inhibit vertical exchanges. Nonetheless a weak valley wind may develop due to ground surface heating at sunny hours and thus enable pollutants to be transported and mixed within a shallow mixed layer. Atmosphere stability makes numerical modelling a real challenge since vertical resolution near the ground surface should be increased whilst the dependency on initial and boundary conditions is more pronounced. Numerical simulations were performed for a two-week episode in February 2005 with gaseous chemistry. Particulate species were treated as passive scalars and included in the emission inventory. Hence, we can expect a realistic distribution in space and time. PM_{10} concentrations from measurements and results of METPHOMOD are found be in very good agreement (see Fig. 3). The concentration levels vary within a significant range from day to day although emissions, which are mainly due to trafic, vary on a 24-hour basis. The discrepancies on February 5 may be attributed to a holiday week-end with trafic jams along highways to ski resorts. The good agreement in amplitude in the morning shows that the thickness of the mixed layer is well reproduced in the model. Modelling fails when PM_{10} mainly comes from the domain boundary, as is the case on February 11.

5. CONCLUDING REMARKS

The modelling system, consisting in the meteorological model MM5 (or WRF) and the CTM METPHOMOD, was used to investigate pollution episodes in summer 2003 and winter 2005. The Grenoble urban area is situated at the confluence of three valleys which strongly differ one from the other in length and width and axis direction with respect to that of dominant synoptic winds. This makes the valley specific regarding the onset and development of the valley wind system. Depending on the direction of the wind in the Southern part of the valley, the ozone plume from the city may be either swept towards the South or blocked above the urban area. In winter, mixing remains very low due to the strong stability of the valley atmosphere. Nonetheless a weak valley wind may develop due to ground surface heating at sunny hours. This thus allows the dispersion of pollutants (as illustrated for PM_{10}).

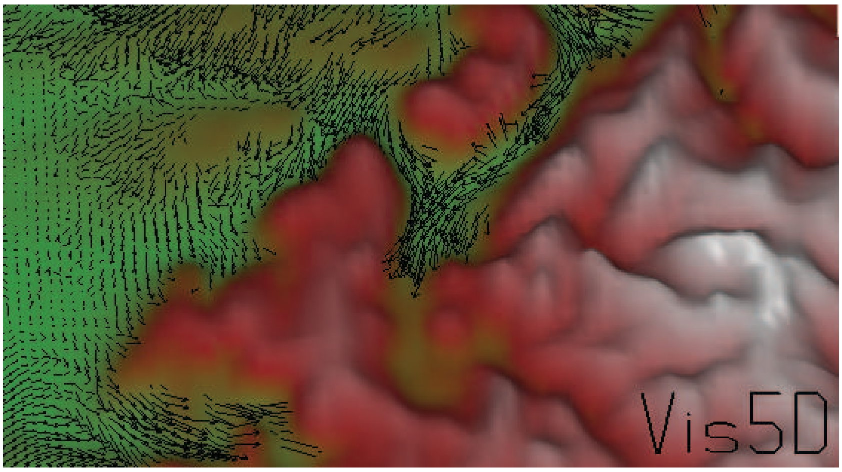

Figure 1: Horizontal wind field simulated by WRF on August 4 at 1500 UTC. At that time, the up-valley wind is well established within the valley.

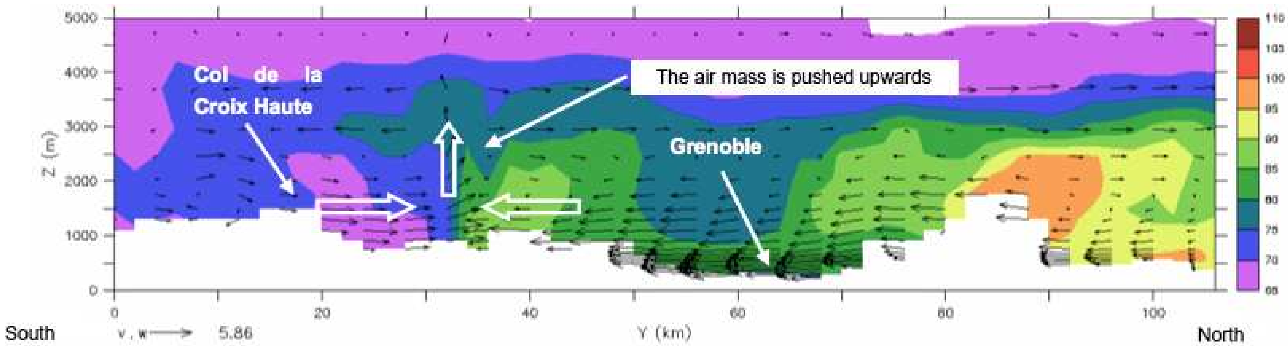

Figure 2: Ozone concentration (in ppbv) and velocity field simulated by METPHOMOD in a South-North along-valley section on August 4 at 1500 UTC.

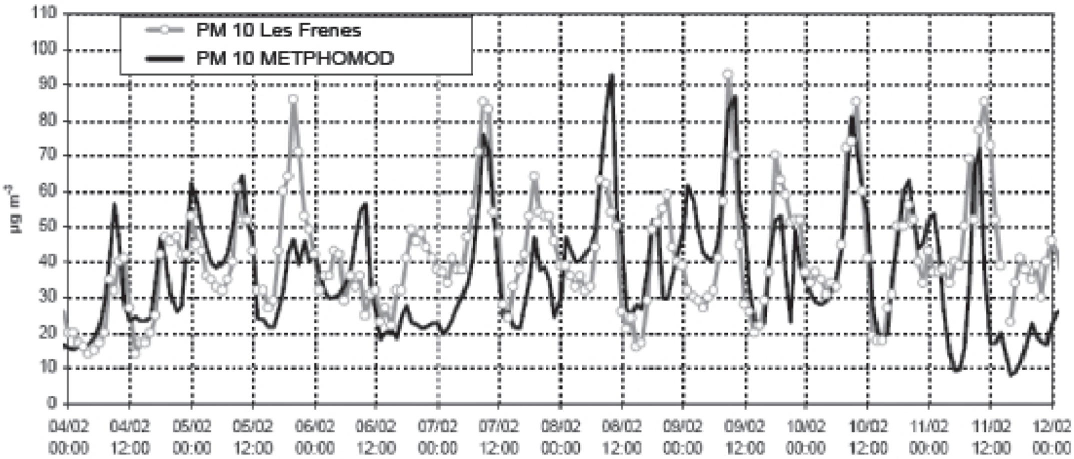

Figure 3: PM_{10} concentration at *Les Frenes* ground monitoring station from February 4 to 12, 2005: hourly-averaged measurements (grey line) and results from METPHOMOD (black line).

The integrated modelling system presented here is used for operational purpose. Improvements are expected from any refinement in the description of the emission inventory and the urban canopy, especially with respect to the estimation of humidity fluxes. The Meso-NH model (Lafore et al., 1998) is currently under preliminary use with the purpose of providing a detailed diagnostic of the distribution in time and space of vertical fluxes with a special focus on the Southern part of the valley. Wintertime with stable conditions needs also special attention. Indeed, katabatic flows may develop along significant distance in the Southern part of the valley (see Chemel et al., 2007). Occurrence of internal gravity waves and possible breaking of the waves could be considered as a source of mixing.

Acknowledgements: *The local air quality agencies ASCOPARG and GIERSA are acknowledged for their cooperation and for making pollution data and emission inventories available. We would like to thank R. Vautard from IPSL and O. Couach from EPFL for their help in setting up CHIMERE and METPHOMOD, respectively.*

REFERENCES

Brulfert, G., C. Chemel , E. Chaxel , J.-P. Chollet, 2005: Modelling photochemistry in Alpine valleys. *Atmos. Chem. Phys.*, **5**, 2341–2355.

Chaxel, E., 2006: *Photochimie et aérosol en région Alpine : mélange et transport*. Thesis manuscript, Université Joseph Fourier - Grenoble I, Grenoble, France [Available on http://tel.archives-ouvertes.fr].

Chemel, C., C. Staquet, M. Tavernier, 2007: Internal gravity wave breaking as a source of mixing in a stably-stratified valley atmosphere? *29th ICAM Proceedings*, 4 pp.

Couach, O., I. Balin, R. Jiménez, P. Ristori, S. Perego, F. Kirchner, V. Simeonov, B. Calpini, H. Van den Bergh, 2003: Investigation of the ozone and planetary boundary layer dynamics on the topographically-complex area of Grenoble by measurements and modeling. *Atmos. Chem. Phys.*, **3**, 549–562.

Cros, B., P. Durand, H. Cachier, P. Drobinski, E. Fréjafon, C. Kottmeier, P. E. Perros, V.-H. Peuch, J.-L. Ponche, D. Robin, F. Saïd, G. Toupance, H. Wortham, 2004: The ESCOMPTE program: an overview. *Atm. Res.*, **69**, 241–279.

Grell, G. A., J. Dudhia, D. R. Stauffer, 1995: *A description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5)*. NCAR Technical Note NCAR/TN-398+STR, NCAR, Boulder, CO, USA, 117 pp.

Lafore, J.-P., J. Stein, N. Asencio, P. Bougeault, V. Ducrocq, J. Duron, C. Fischer, P. Héreil, P. Mascart, V. Masson, J.-P. Pinty, J.-L. Redelsperger, E. Richard, J. Vilà-Guerau de Arellano, 1998: The (Meso-NH) Atmospheric Simulation System. Part I: adiabatic formulation and control simulations. *Ann. Geophy.*, **16**, 90–109.

Perego, S., 1993: Metphomod – a numerical mesoscale model for simulation of regional photosmog in complex terrain: model description and application during Pollumet 1993 (Switzerland). *Met. Atm. Phys.*, **70**, 43–69.

Schmidt, H., C. Derognat, R. Vautard, M. Beekmann, 2001: A comparison of simulated and observed ozone mixing ratios for the summer of 1998 in western Europe. *Atm. Environ.*, **35**, 6277–6297.

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang, J. G. Powers, 2007: *A description of the Advanced Research WRF Version 2*. NCAR Technical Note NCAR/TN-468+STR, NCAR, Boulder, CO, USA, 100 pp.

Vautard, R., C. Honoré, M. Beekmann, L. Rouil, 2005: Simulation of ozone during the August 2003 heat wave and emission control scenarios. *Atm. Environ.*, **39**, 2957–2967.