MODELLING OF SUMMER PHOTOCHEMISTRY AND WINTER AEROSOL IN GRENOBLE URBAN AREA IN THE FRENCH ALPS

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INTRODUCTION

In mountainous area, town air quality is strongly determined by a combination of urban meteorology and processes due to orography. Complex atmosphere dynamics develop with slope and valley winds generated by solar heating while inversion may trap stable layers near ground for days. Grenoble (400 000 inhabitants) which is located at the crossing of three valleys may be considered as typical of city in the Alps. The air quality agency (ASCOPARG) supports extended and good quality measurements and needs models to be developed for the purpose of forecasts and design of atmosphere protection plan (PPA). A specific chain of models has been developed in order to deal with the topography while keeping computing time low enough to run simulation along months and allow real time calculation for decision makers. Seasonal dependence is of course strong. In summer, photochemistry induces significant ozone production whereas in winter particles and primary pollutants concentrate in lower layers. Because of orography the interaction between local meteorology and synoptic winds may change from day to day leading to either trapped or free boundary layer regimes with consequences in air quality.

Grenoble site exhibits significant differences from nearby Chamonix and Maurienne valleys were similar models were already developed in the frame of the POVA program (*Brulfert et al,* 2005) because of the more complex orography of a junction of three valleys and significant emissions from 400 000 inhabitants. In both cases, biogenic emissions are significant due to forest areas covering slopes at rather short distance from city center.

MODEL

The PREVALP model may be viewed as an extension of the PREVAIR model (*Vautard, R. et al.* 2001, 2005) towards mountainous area. Non hydrostatic models allow to deal with vertical motions enhanced by orography and thermal convection. A full set of photochemical reactions is considered. Three domains are nested in order to correctly describe interactions between synoptic and local scales. At 18km and 6km grid size, MM5 (*Grell, G.A. et al.,* 1995) is run for dynamics and CHIMERE for chemistry. METPHOMOD (*Perego, S.,* 1993) is used at finer 2km grid size for both chemistry and dynamics as already done by *Couach O.et al.* (2003, 2004) on the very same site of Grenoble. Appropriate nesting was prescribed for computational domains with procedures to embed the 72 species of the RACM chemical scheme of the METPHOMOD code into the 44 species scheme of CHIMERE. Emissions at 6 and 2km are provided by CITEPA from a 1km grid inventory. The 50 km grid EMEP data are used for coarser 18 and 6 km grid. Emissions are desegregated with time according to season, day and hour of the day. Biogenic emissions are fully considered as most of mountains around Grenoble are covered with forest. Concentrations of the numerous species involved in the chemical scheme are computed at every time step and location making possible to analyse not only ozone and nitroxydes but also, for instance, benzene which is considered here below. Benzene was added to the RACM mechanism with explicit splitting into toluene and benzene and the introduction of appropriate reaction rates with radical HO. In METPHOMOD, benzene is determined as a part of aromatics with factor determined from tuning on measurements, hence appropriate only for the period under consideration Particle matter (PM10) which is mainly from local origin, is computed as gaseous passive scalar and introduced through an emission inventory derived from NO_x emission taking account of above average district heating in Grenoble area. No particle sedimentation was considered because of scale and duration of interest.

The relevance of the PREVALP numerical model was tested against: a full set of wind profiler and ground data from field measurements of the 1999 GRENOPHOT campaign (*Couach, O. et al.,* 2003), and ground stations operated by ASCOPARG (*Chaxel, E.*, 2006) (*Chaxel, E. and J.P. Chollet,* 2007). In these summer conditions, valley wind direction reverses twice a day, ground temperature evolution and daily ozone cycle are well described. As is usual, significant discrepancies are observed for humidity because of ground heterogeneity and for primary pollutants because of possible inadequacy of the time-disaggregation function on the day of interest.

SUMMER EPISODE

Two summer episodes were considered. The 1999 GRENOPHOT and the august 2003 heat wave. Heat wave is of special interest as generating ozone peak values and also as getting higher probability of future occurrence in the prospect of climate change. Results are detailed in *Chaxel, E.* (2006) and *Chaxel, E. and J.P. Chollet* (2007). Peaks of ozone appear to be especially sensitive to a change in regime identified from the simulation as being either free or trapped convective boundary layer in the south part of the area. Depending on this regime, ozone observed in the plume may be attributed to local production with a factor of either 30 or 40 %. Biogenics VOC are observed to contribute to about 10% of ozone production because of forests covering slopes above the city. Results from the computation are compared to observations and scenarios are run to assess air quality in year 2010 according to various vehicle traffic extrapolations. For the purpose of contributing to data to be used in the PPA (air protection plan), the model was run from 1 to 15 august 2003 with 5 emission scenarios : either low or high local traffic combining with either regulated or non regulated emissions at regional and European scales. The emission inventories were adjusted appropriately in the different nested domains. Reductions strategies assigned to both Grenoble area and Europe result in a 54% reduction of the number of days with ground-level ozone exceeded objective (i.e. above 180 microg/m3) . Reduction of emissions in the only Grenoble area results only in a 8% improvement.

WINTER EPISODE

The episode from 1 to 15 of February 2005 is typical of stable atmosphere in winter with low pollutant dispersion. Thermal convection is not strong enough to get significant vertical mixing and break the inversion. Nevertheless the orography makes circulations possible along the valleys and at least to some extent along mountain slopes. Ground is assumed to be covered by snow above 1000m. As METPHOMOD is generally used to model summer weather, special attention was paid here to the estimation of thermal gradients and the comparison with the few available ground station data (*Chaxel, E.,* 2006). Temperature from simulation compares well with measurements at ground station up to a 2K error at maximal value for the second week, which can be attributed to ground getting dryer than expected from the model. Although winds are low (from 0 to 2 m/s), wind direction is well reckoned (figure 1) with reversal twice a day, except on 9 February because of a some cloudiness which was not considered by the model and prevented thermal convection from developing valley winds

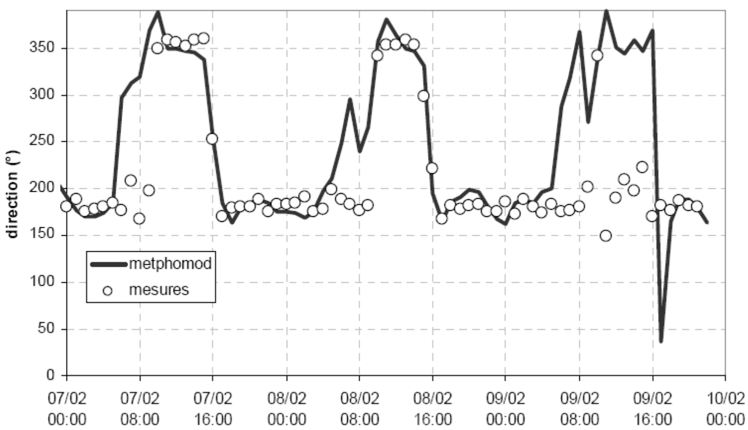

Fig.1 ; Wind direction versus time (UTC) at Pont-de-Claix, on 7 and 8 february 2005

Benzene concentrations are plotted in figure 2 and evolve according to the combination of changes in emission and in local dynamics . Two minimum values are observed, the first one from 4:00 to 5:00 because of low traffic emissions and the second one around 15:00 due to a growth of a convective layer which makes benzene to dilute. The maximum from 9:00 to 10:00 is due to traffic emissions whereas the maximum from 19:00 to 21:00 is induced by the stabilisation of the lower atmosphere layer. Maxima are not that much well represented, due to the short distance of the station from main roads while results from the model are averaged on the 2 km computational mesh.

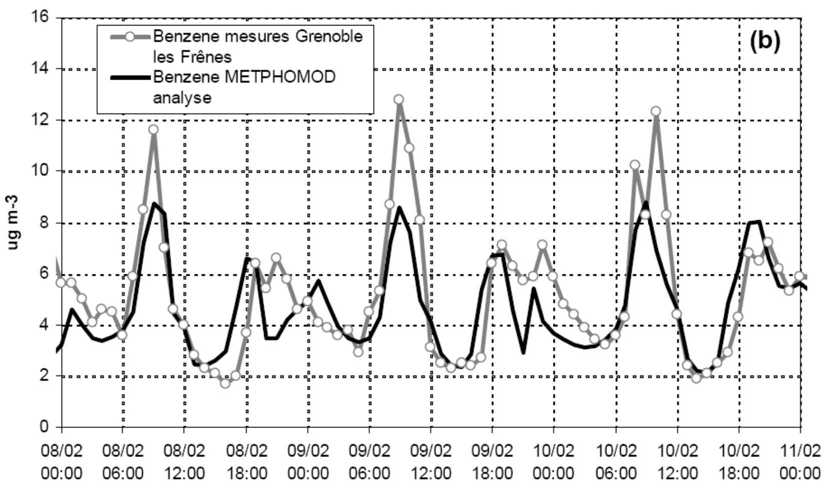

Fig. 2 : Benzene concentration at Les Frenes from 8 to 11 february 2005
(grey line : measurements, black line : model)

As shown in figure 3 for a week from 4 to 11 February, PM10 particles evolve like benzene although heating system contribute significantly to their emission. Road traffic leads to maximum in the morning while the second maximum is associated to stable layers while traffic emission remains strong. Analysing discrepancies helps to understand model relevance: on 5 February, the traffic was underestimated by the model which could not take account of the fact that it was holiday ; the weather cloudiness was not considered in the model for 5 to 6 February ; changes at synoptic scale were not well transferred through the boundary by the nesting on 11 February. This episode was long enough to exhibit two different regimes : a trapped layer, under an inversion at large scale, and a free layer with low level inversion which cannot maintain along day because of convective mixing with valley winds developing but at much lower intensity than in summer (2 m/s versus 7 m/s).

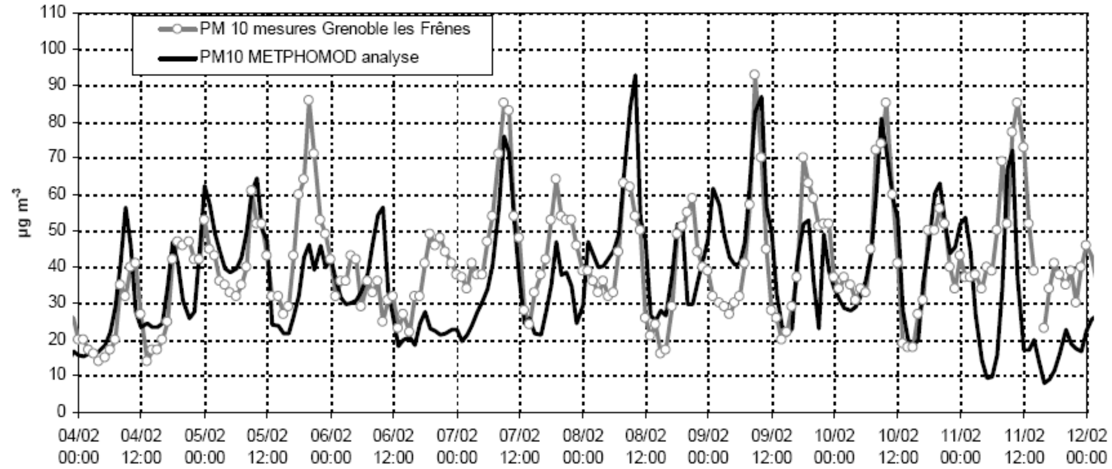

Fig3: PM10 concentration at Les Frenes, from 4 to 11 february 2005
(grey line : measurements, blak line : model)

Taking advantage of benzene measurements through passive tube campaign at regional scales, sensitivity to emissions and dry deposition is assessed.. Correlation in figure 4 between results from the model and measurements is rather good for NO2 (R^2=0.82), and low (R^2=0.37) for benzene. This suggests that improvements are needed in modelling benzene. Emission inventory has to be improved. Deposition has also to be better assessed as suggested by the comparison of figure 4 between ISERE which includes Grenoble area and together with SAVOIE is characterized by significant rural and forest area contrary to RHONE which is mostly dense-urban and industrial.

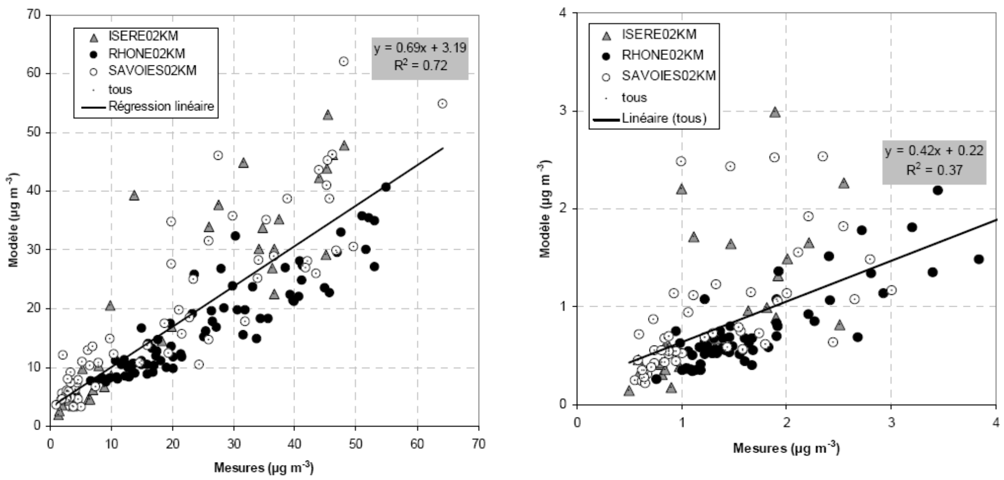

Fig. 4 : model versus measurement concentrations from passive tube campaign from 1 to 15 February 2005 left : NO2, right : Benzene ; Grenoble is in the ISERE domain (triangle) , SAVOIE (squares), RHONE (black dots)

CONCLUSIONS

Orography of mountainous regions strongly determines meteorology in urban area. In summer, thermal convection induces slope and valley winds and lifts mixing layer up . Ozone

produced in the city, from 30 to 40 % of total ozone, can goes to higher altitude or be swept in a plume . In winter, models also work in spite of difficulties due to enhanced dependency on initial and boundary conditions, impaired mixing, local and temporary changes from stable to mixed layer. PREVALP model has demonstrated its ability to deal with various situations both in summer and winter. Evolution depends on the combination between local flow, mainly from convection even in winter, and synoptic circulation. For instance a close analysis of the south part of the area shows two different regimes labelled either as trapped or free layer respectively, with obvious consequences on the evolution of pollutants.
There is a growing interest in computing pollution levels at the street level. Atmosphere dynamics is too complex to make simple dispersion model operate on their own, even in winter. At least for mountainous regions like Grenoble area, this study emphasizes the need of a good mesoscale model down to grid as fine as 1 to 2 km in order to drive computations of dispersion inside the streets, since orography makes local meteorology strongly change from a place to the other and with time of day.

Finer resolution down to 200 to 400 meters should help to secure well resolved solutions at 1 km scale in order to take a better account of heterogeneity of urban canopy especially in winter when low winds creates slow but efficient pollutant transport. The analysis has of course to deal with skill scores based on statistics but the challenge for the model is first to capture regime transitions with as exact as possible location and time of occurrence, for instance in valley wind reversal and inversion breaking.

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