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MODELLING URBAN AREA IN ALPINE COMPLEX TERRAIN IN WINTER TIME

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1. INTRODUCTION

Urban areas which are situated at the intersection of Alpine valleys are submitted to complex atmospheric flow patterns with significant impact on air quality. Local dynamics develop systems of slope and valley winds which interact ones with the others. Pollutants evolve according to chemical reactions homogeneously as gases and heterogeneously with particulate matters .There is a growing concern about PM10 and PM2.5 which are considered as harmful for health. They mostly come from combustion processes, directly or through chemical transformation : street and road traffic, industry and also domestic heating which is a significant contributor in winter at mid latitude.

Atmosphere dynamics combine with chemistry in determining the evolution of these pollutants since they are transported from emission through winds which are highly changing along the day and with the location inside the area or interest. Dilution of chemical species is due to turbulence of the atmospheric flow. Consequently, it varies with time and in space.

In winter, pollution is characterized by significant concentrations of PM10 and other gases such as benzene. Although emissions are the primary reason, atmosphere dynamics significantly determine air quality. Cold ground favours stable flow which induces low mixing by damping kinetic turbulent energy and reducing vertical length scales. Nevertheless, even in winter, sun radiation can induce some convective activity strong enough to develop significant mixing height during daylight hours while at night soil cooling makes flow getting more and more stable. In a real terrain, these processes are unevenly distributed in space which results in complex wind patterns developing local shears and stagnation zones

Urban areas in the Alps are most often situated at the junction between two valleys which makes atmosphere dynamics more intricate than the usual configuration of a single valley with its associated slope- and valley- winds (Brulfert et al. 2005). Alpine valleys are relatively deep and narrow which emphasizes orography contribution to the way local atmosphere develops specific features significantly different from what is observed at larger scale.

Ground cover in mountainous region is also distinctive with wide forest and rural zones. Housing and industries are mainly located along the bottom of the valleys.

Grenoble, a 400 000 inhabitants town in the French Alps, is selected as being typical of such an area. Summer conditions with ozone peak values were extensively considered in previous studies (Couach et al. 2003, Couach et al. 2004, Chaxel 2006). Several systems of numerical models were successfully used to efficiently describe summer weather with predominantly convective activity. Winter episodes were also considered by Chaxel (2006) and Chemel et al. (2007).

Because of the interest in health impact, there is a need of refining model grid size. Street models (e.g. Soulhac et al. 2001) are currently used in assessing exposition. Most often, they are driven by data from a so called representative measurement station. Too many stations should be used when orography is complex and urban canopy very inhomogeneous. Hence, one has to rely on results from numerical models rather than on site data. Therefore it make senses to attempt downscaling meso scale models to few hundreds meters, at least in the urban area.

Numerical simulations are appropriate tools to take account of the interactions of length scales (from tens meters to synoptic scales) and time scales (few minutes to one or several days). These simulations are also used to provide databases to be used by forecasters. They also support scenarios to assess the impact of urban development, traffic regulation, constructions (e.g. tunnel). They can also be used to appraise local influence from global climate change.

Focus is put here on transport and mixing properties. Chemistry is not taken into account. The paper is organized as follows. After the introduction, the site of Grenoble and the episode under scrutiny are described. The conditions of use of the Meso-NH simulation code are detailed. Then Evolution in time and space is analysed for 2 grid resolutions. Conclusions introduce further prospects.

2. THE SITE AND THE EPISODE

Specificities of towns at the intersection of alpine valleys are not only the topography but also the ground cover with inhabited zones and roads along the valleys and forests relatively close to city

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centres. The orography acts upon the flow field through its different length scales (width, height) and the orientation of mountain ridges and valleys with respect to synoptic wind. Sun radiation is also significant by generating thermal circulations, even in winter. Local systems can develop at least for some time along the day with evolutions of winds, temperature, and humidity significantly different from what can be observed in surrounding plains.

There is no hope of defining any representative location for measurement because of the variability of local atmosphere from a place to the other. Observed data have to be considered in the very site where they are gotten. Similarly, the dependence with time is quite strong because of sun radiation, directly through heat flux at ground and indirectly because of changes in winds and temperature at larger scales which results from differential sun heating. Observations are nevertheless necessary in order to assess the accuracy of the models by comparing them with calculated values computed at corresponding computation node.

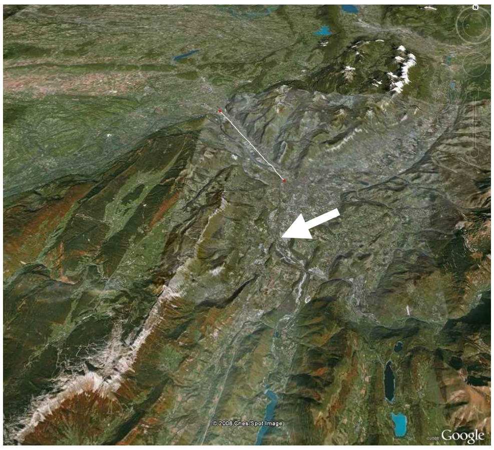

Fig.1: Grenoble (north at the top of the picture)

Grenoble (400 000 inhabitants) is typical of urban area at the intersection of valleys in the French Alps. The southern branch (the Drac valley) looks like an uneven and hilly slope contrary to the two other branches typical of U-shaped glacial valleys. Computational domains are centred on Grenoble (Latitude 45.14 ° Longitude 5,7°). The three valleys are such that :

valley	*orientation*	*length (km)*	*bottom width (km)*
Grésivaudan	North East	39	3 to 4
Drac valley	South	40	2 to 5
cluse de Voreppe	North West	15	2 to 3

Grenoble is situated at the flat bottom of the valley, at an altitude of 212 m. Surrounding mountains are from 1200 to 2000 m high. Distinctive characteristics of the site related to atmosphere dynamics were already discussed by Couach et al , 2003 and Chaxel 2006.

February 2005 episode was selected because of significant pollution with particulate matter PM10 , up to 90 micro-grams/m^3 (Chaxel 2006) .

3. THE SIMULATION MODEL

A non hydrostatic model with appropriate turbulent 3D formulation is run in order to cover a variety of flow regimes, from stable layers to fully thermal convective layers. The model is operated on nested grids to take account of the different scales of the terrain, from the Alpine massif to fine details in the valley.

The Meso-NH model (Bougeault et al., 2008) is used here, down to a 300 meters horizontal mesh size with 4 nested domains. It includes the SURFEX module for ground boundary conditions with a special handling of town canopy through the TEB model (Masson et al., 2002). The ECOCLIMAP climatologic global data base of ecosystems and land surface (Champeaux et al. 2005) is used for soil canopy modelling and topography. The space resolution of this database is 1 km.

In order to take full account of all the scales of the atmosphere, the model is run in 4 domains Di (i=1,4).as described below and in figure.2.

	mesh size (km)	number of nodes NX x NY	nesting	time step (sec)
domain D1	9 km	75 X 75	2 way	8
domain D2	3 km	75 X 75	2 way	4
domain D3	1 km	75 X 75	2 way	2
domain D4	333,3 m	90 X 90	1 way	1

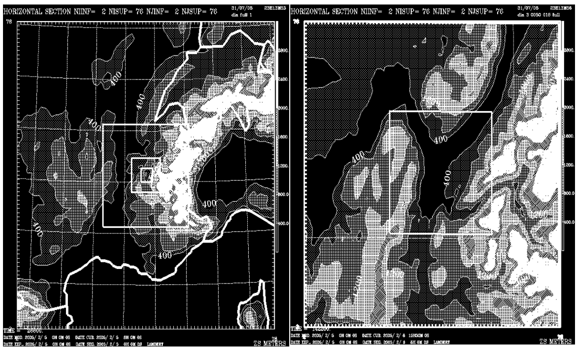

Fig.2: *left :* domains 2,3,4 *right :* domain 4
(white segments surround each domain)

Boundary conditions of the large domain D1 are forced by the ECMWF fields with updating every 6 hours. 60 levels are used along vertical direction with 15 m mesh size near ground. The vertical grid is the very same for the 4 grids Di.

For the inner domains turbulence is modelled with an equation for the evolution of the turbulent subgrid energy. Microphysics is minimal with no liquid water since considering sunny days corresponding to pollution peaks.

Terrain pre-processing and initial field computations are done on a PC-Linux. Computation of time-evolving flow fields is done on the NECSX8 of IDRIS. Post process is done with a PC-Linux, mainly using *diaprog* utility. The code is run on 4 processors with cpu time to real time ratio about 2. Further optimization of the time step could reduce this CPU time while new machine at IDRIS is expected to allow efficient and more massive parallelism

Computation is run for 3 days, 5 to 7 February 2005 ; in order not to depend on spin up effects, the results are analysed for the 48 hours of 6 and 7 February

4. ANALYSIS OF RESULTS

4.1. Evolution with time in a given location

The evolution of velocities and temperature computed from the model is analysed with both time and space. First, the results are considered near ground level at Pont de Claix station (white symbol in figure 1) in peri urban area. The temperature at 2 meters evolves quasi periodically with maximum at 15:00 and minimum at 7:30 UTC .Little difference is observed when refining resolution from D3 to D4.

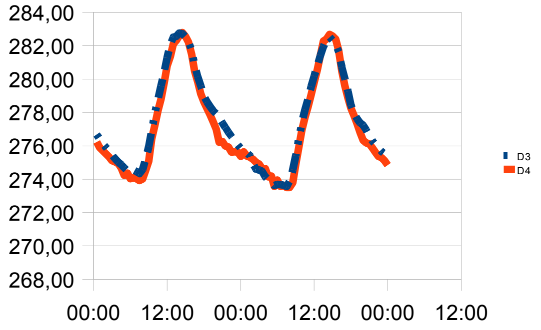

Fig. 3: evolution with time of temperature at 2 meters in Pont de Claix (blue dotted line : D3, red solid line: D4)

Horizontal wind at the first node above ground level shows drastic changes in direction (figure 4). Wind force is also given since in wintertime, winds are often low which can make their direction rather erratic. Except in the morning of the second day, directions calculated with the two resolutions (D3 and D4) are close one to the other -the direction axis is cyclic with 0°=360°. Measurements -only the second day- are not so in agreement, which would need to compare for a longer time and for other locations because of possible effects of neighbouring slopes for some wind directions. Wind force is observed to be generally stronger when calculated with the finer grid D4.

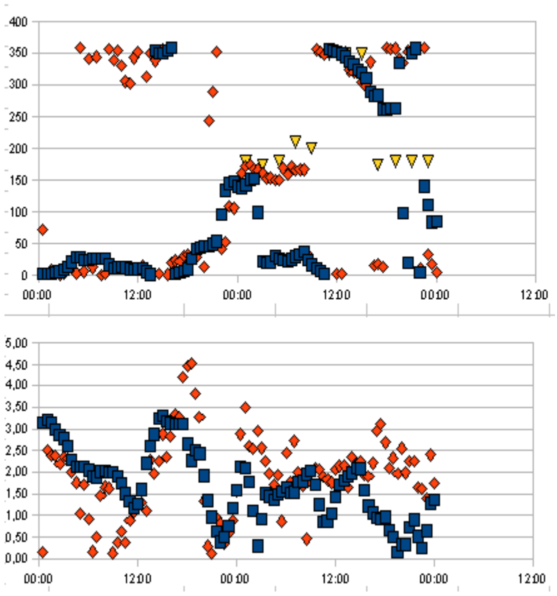

Fig.4 : wind near ground at Pont de Claix : *top :* wind direction, *bottom :* wind force ; blue squares : D3, red diamonds D4, yellow triangles : measurements

Even in winter, thermal exchanges between air and soil cover trigger vertical winds and mixing, since sunny days are considered here. Therefore, it is useful to plot not only temperature but also heat fluxes. In figure 5 evolution of heat fluxes with time for the 2 same days is plotted, with GFLUX the ground heat flux, H the sensible heat flux, LE the latent heat flux and RN the net radiation, These results are obtained with the D4 resolution. Negative heat flux contributes to warm up the atmosphere at night. This result holds only for this location. The analysis has to be repeated in other urban and rural places.

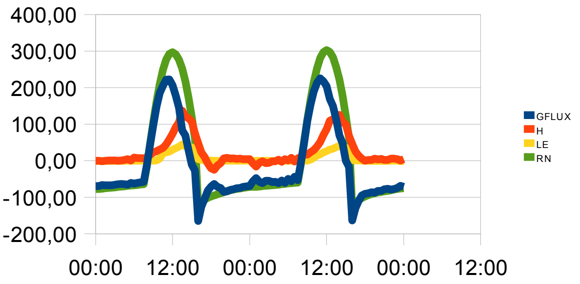

Fig.5 : evolution with time of heat flux (W/m^2) : blue : GFLUX, red : H, yellow : LE, green RN

4.2. Evolution with space and time

The temperature at 2 meters a.g.l. computed with the finer grid D4 on 7 February 2005 at 18:00 and 24:00 is given in figure 6. Urban heat island effect is detected with about 4 to 5K as the difference between temperature city centre and rural area in the low part of the valley. This effect is still noticeable at 00:00 on 8 February, at least not too close to slopes.

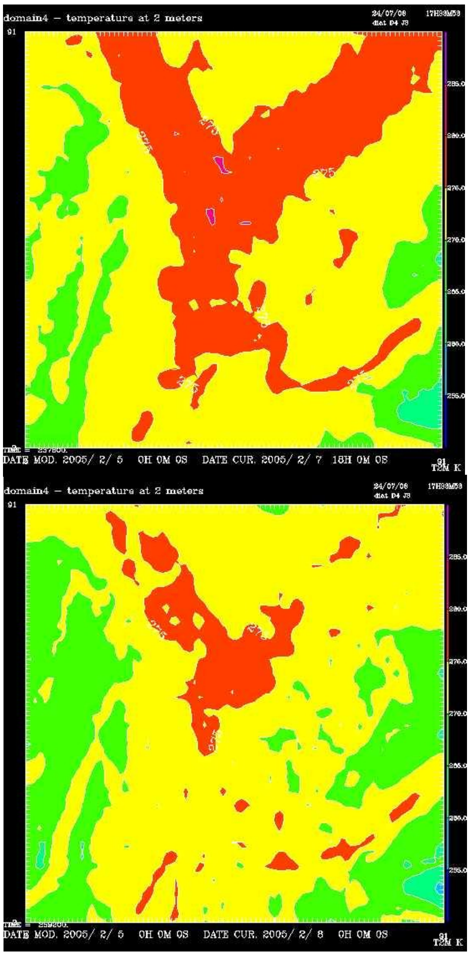

Fig. 6 : temperature at 2 m a.g.l. on 7 february ; *top :* 18:00, *below* : 24:00

The vertical structure of the atmosphere is of primary interest to explain transport and mixing of air masses. A vertical cross section is considered in each of the three valleys : [S] to South (Drac Valley), [NW] to North West (cluse de Voreppe), [NE] to North East (Grésivaudan). Pictures are given at 18:00 on 7 February in figure 7 from results computed in domain D4. The evolution should be considered with both space and time (see Appendix for videos). On [S] section, three layers may be identified : wind blows from north near ground, from south in an intermediate layer and from north but at low force at high altitude. Temperature decreases near ground all along the section. [NW] section goes from Belledonne foothills to cluse de Voreppe outlet. Oscillations on the left side may be due to computation artefacts which would need to tune domain nesting at a boundary located in a zone of steep slope. As for [S] section, wind direction determines three layers. Temperature near ground decreases from both the foothill slopes and the valley end. On [NE] section, Vercors cliffs are on the left side, Wind blows from the Gresivaudan valley through a 600m high layer above ground while the wind direction is the opposite above the altitude of mountain ridge. Low layer cooling proceeds from NE to NW. Horizontal flow fields should also be considered in order to prevent from misinterpreting components of the only vertical cross section .

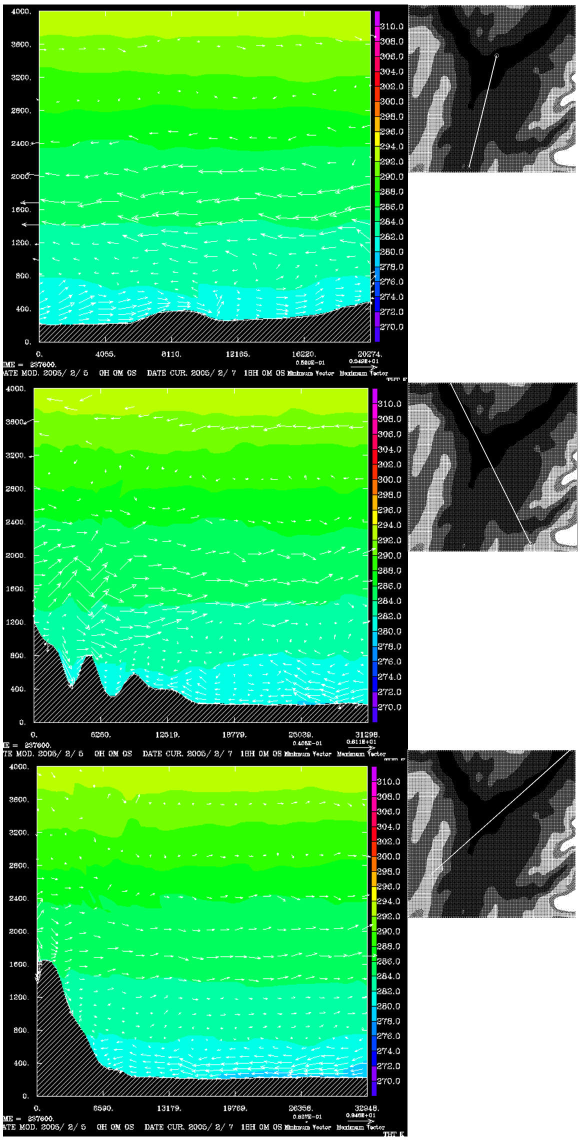

Fig 7 : vertical cross section of potential temperature and velocity vectors at 18:00 on 7 February 2005 from from *top to bottom :* [S], [NW], [NE]

5. CONCLUSIONS AND PROSPECTS

Numerical simulation of the Grenoble area has been extended with finer space resolution and focus on winter episode. The Meso-NH model has been used with horizontal grids from 9 to 1/3 kilometres. The organization of air mass and wind systems is complex both *(i)* horizontally because of the orography with the system of 3 valleys at large scales and smaller scale topographic features, *(ii)* vertically with layers moving at different velocities and continuously evolving with time. When comparing resolutions of domains D3 and D4, some of these patterns are resolved only with the finer grid (D4). The effect of orography is quite dominant for the temperature distribution as compared to urban island effect. Nevertheless, in the afternoon and at the beginning of the night, temperature remains relatively high in the urban area. So far, there were few comparisons with measurements because of a lack of available data, and the sensitivity to their location.

Idealized valleys have also to be considered as in Largeron et al. (2008) to get better understanding of detailed mechanisms such as waves which can develop in stable layers. The variety of slope orientations in the real terrain such as Grenoble site can make most of the difference with such an ideal case.

In order to fully benefit from the finer resolution, soil cover database has to be handled at grid size finer than 1km in order to better assess variability of heat fluxes from urban to rural cover and even inside the urban area. Difficulty arises from the change of ground cover with season, especially snow which may cover the mountains above an altitude which should be prescribed to the model at the beginning of the episode rather than being predicted.

More data have to be collected on Grenoble area even if unfortunately available only at ground level. Any 3D probing of the atmosphere would help to check results from simulation against the real vertical organisation of the atmosphere (as in 1999 summer GRENOPHOT, Couach et al., 2003). Modelling similar but different site would be helpful especially if data are available. The results which are presented here are related to a 3 day episode of February 2005, with not so stable conditions at least at scales local to the valley. Other cases have to be treated in order to cover a variety of winter weather types such as cases of long lasting low inversions inside the valley.

As air quality is a major concern in the urban area, pollutant advection and mixing will be considered using the Meso-NH chemistry solver for gas and aerosols. Particulate matter, at least the locally emitted contribution, can be, at first modelled with a passive scalar as in Chaxel, 2006. Lagrangian tracers would be also helpful, especially for assessing residence time in an attempt of documenting pollutant stagnation where and when velocity is observed to vanish or recirculate.

APPENDIX

Time evolution of fields computed from the simulations are available as videos at : www.legi.hmg.inpg.fr/~chollet/winter_vids

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