MODELLING THE METEOROLOGY AND TRAFFIC POLLUTANT DISPERSION IN HIGHLY COMPLEX TERRAIN: THE ALPNAP ALPINE SPACE PROJECT.

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INTRODUCTION

The study of the atmospheric pollution due to the traffic in a mountain valley involves a lot of physical processes and possible problems, related to the peculiarity of both meteorological and dispersive characteristics in such complex topography. Both mean flow and turbulence, having as a forcing the large scale motion, are heavily modified by the complex orography, and secondary circulations, like mount-valley breeze, superposes on it generating daily cycles of complex circulation and dispersion regimes. These particular conditions are of great importance in determining the effectiveness of the dispersion of road traffic pollutant, and cannot be treated with simplified models or parameterisations. Thus it is necessary to apply or develop properly sophisticated models that are able to reproduce this level of complexity. In ALPNAP Project, for a detailed reproduction of the atmospheric circulation in West Frejus transect area, a downscaling from the regional to the local scale is performed. The pollutant dispersion, related to the emissions from the major traffic routes in Susa (Italy) and Maurienne (France) valleys, is then simulated in subdomains where the highest grid resolution of the meteorological fields is provided, from 1 km down to 100 m. Three periods, characterized by critical conditions of the dispersive scenarios, are chosen in the reference year 2004. The prognostic modelling system RMS (RAMS-MIRS-SPRAY) is used for the simulation of atmospheric circulation and pollutant dispersion down to 1 km resolution. To obtain the meteo fields at 100 m resolution, a mass-consistent diagnostic model, MINERVE is used in cascade after RAMS and in input to SPRAY. Here, a discussion of the methodology and the main results of the first part of the work are presented. The output data, consisting of the main meteorological fields, the ground level pollutant concentration of NOx and PM10 and the plume dynamics, will be transferred to the ALPNAP partners to support the part of the project related to the noise study and the impact assessment.

THE ALPNAP PROJECT

ALPNAP is an international project in the framework of the Alpine Space programme INTERREG IIIB of the European Union. A detailed description of the project can be found on the ALPNAP website http://www.alpnap.org. In the following we report an extract from the Introduction of the ALPNAP Intermediate Report (2006), available on the website.

ALPNAP is dealing with problems of air pollution and noise along major Alpine transit roads. The final goal of ALPNAP is to describe the peculiarities of the dispersion of air pollutants and the propagation of noise in Alpine valleys and to provide science-based methods and tools for monitoring and predicting of environmental impact due to trans-Alpine traffic. ALPNAP intends to formulate recommendations how these methods and tools would best be applied for minimisation of the adverse effects of transport in the Alps. ALPNAP investigation is focused on two major Alpine transit corridors, the Fréjus corridor linking Lyon in France with Torino in Italy and the Brenner corridor linking München in Germany with Verona in Italy. In both corridors traffic is found on road, motorway and highway, and rail as well. Special investigations are focussed on sub-target areas, where the impact of air and noise pollution on the population and environment is more consistent.

THE MODELLING SYSTEMS

The RMS modelling system is based on the off-line interface between the meteorological model RAMS (Pielke et al., 1992, Cotton et al., 2001) and the Lagrangian stochastic particle model SPRAY (Tinarelli et al., 1994a and 1994b, Tinarelli et al., 2000), through the parameterisation code MIRS (Trini Castelli and Anfossi, 1997; Trini Castelli, 2000).
RAMS is a widely adopted prognostic non-hydrostatic model, designed to simulate a large range of atmospheric flows from local and regional to the synoptic scale. The model includes a large number of options for the description of physical processes in atmosphere, like two-way interactive grid nesting, terrain-following coordinates, stretched vertical coordinates, nudging system, different options of numerical schemes, several top and lateral boundary conditions and a conjunct of physical parameterisations. RAMS includes also a model for soil and vegetation temperature and moisture. MIRS ingests the meteorological fields produced by RAMS or, alternatively, other kind of data fields, deriving by observations or diagnostic models. Topography, wind speed, potential temperature is the minimum information requested, then turbulent kinetic energy, diffusion coefficients and surface fluxes are treated when available. MIRS calculates the surface layer and boundary layer parameters and the Lagrangian turbulence variables. Several alternative options are available for the parameterisations of the atmospheric boundary layer and turbulence processes. The fields of data are then processed to prepare a meteorological file to be used as input information for SPRAY. SPRAY is a three dimensional particle Lagrangian model that operates the transport and diffusion of chemically neutral airborne species in complex real conditions (complex orography, landuse heterogeneity, low wind regime), characterized by non-homogeneity in space and time of meteo-diffusive variables (wind vertical shears, breezes caused by non-uniform terrain). SPRAY reconstructs the concentration fields determined by point, line, area and volume sources. The behaviour of the airborne pollutant is simulated through 'virtual particles' whose mean motion is defined by the local wind and the dispersion is determined by velocities obtained as solution of Langevin differential equations, able to reproduce the statistical characteristics of the turbulent flow. In cascade after RAMS-MIRS, MINERVE mass-consistent model can be used to increase the resolution up to an order of 100 m. MINERVE is a diagnostic 3D model that interpolates the input 3D wind field on a new domain through an objective analysis based on the mass conservation equation. In this way, it is possible to better account for the effect of the local scale forcing over the synoptic and mesoscale fields.

SIMULATIONS AND DISCUSSION OF RESULTS

In the collaboration between ISAC-Torino, ARPA Piemonte and CETE de Lyon (Centre d'Études Techniques de l'Equipement de Lyon) partners, we proceeded in identifying some episodes, in the base year 2004, typical of Winter and Summer seasons, characterised by critical meteo-diffusive situations at the local and regional scale. For this reason, we considered the observed concentrations of the main pollutants in 2004, that is the annual trends of hourly averaged NO_2 and daily averaged PM10, in all the available measuring stations in Frejus transect. It was thus possible to single out some critical episodes, characterized by high pollutant concentrations during a well marked period, taking care of including the most interesting periods identified for both French and Italian sub-domains. The selected periods were a Summer episode (3-13 July) and two Winter episodes (10-20 December and 8-18 February). In the numerical simulations, four nested 3D grids were used in RAMS-MIRS: the largest one (1088 x 1088 km^2) had a horizontal resolution of 64 km, the second one (592 x 464 km^2) with 16 km grid-mesh, while grids 3 (196 x 132 km^2) and 4 (101 x 81 km^2) had respectively 4 km and 1 km grid meshes. In the vertical, 27 levels on a stretched grid were used, the first level being at 24 m height and the top of the domain at 17 km. The smallest domain, where SPRAY was run, was covering the most part of both Susa and Maurienne valleys (Figure 1).

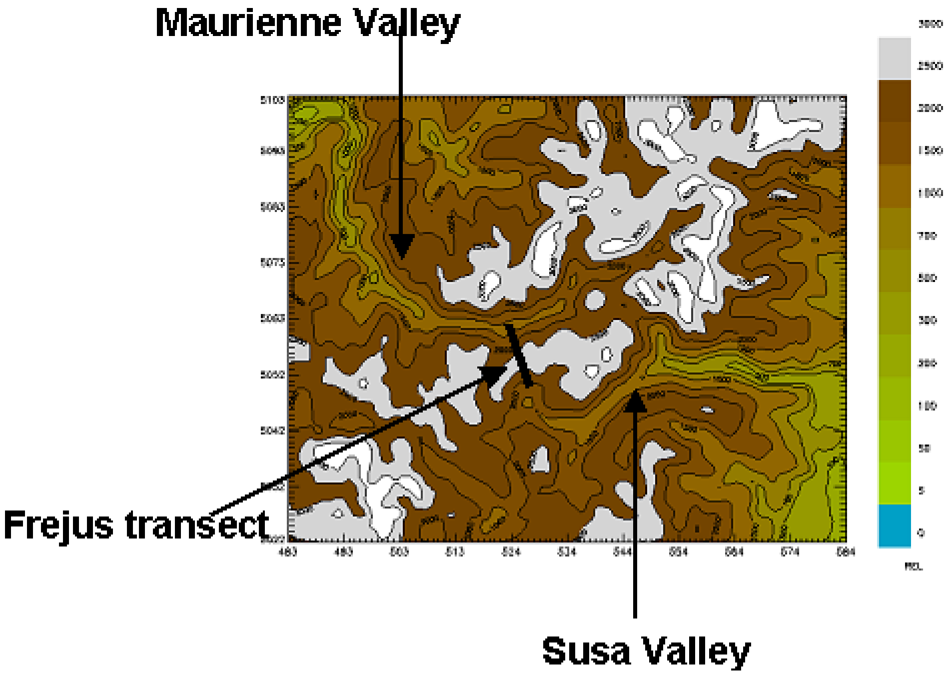

Fig. 1; RMS simulation domain, 1 km horizontal resolution.

To present the results of the simulations of the atmospheric processes and meteorology, we show some comparisons between the model predictions and observations at surface stations.
We recall that a point-to-point agreement between observed and predicted data cannot be expected, for many reasons: (1) the model outputs are volume averages determined by the horizontal and vertical grid resolutions and refer to mean quantities, while the observations are instantaneous and single-point values; (2) in complex terrain the orography used in the simulations is generally smoother than the real orography, and this may cause that the measuring point and simulation grid cell have significantly different heights; (3) other limitations are related to the stochastic uncertainty and possible errors in the observed meteorological variables. The agreement between predicted and observed values can be considered good when the mean trend of measurements is reproduced by the simulated variables.

In Figures 2 and 3, an example of the wind speed evolution is presented at the Bardonecchia station for July and December periods simulated with RMS: the predicted data of the first model level (about 24 m high) at the four grid points around the station are plotted, in order to highlight the possible differences due to the different altitudes of the points.
The quality of the reproduction of the wind velocity field appears to be satisfactory and the main characteristics of the flow are well captured, in particular the occurrence of the fohen wind in December episode. In Figure 4 we compare wind speed obtained by RMS simulation (left) and MINERVE (right) in Bardonecchia for the February episode. We notice that, as expected, the scatter between the curves at the different points around the station reduces thanks to the higher resolution. The wind velocity and thermodynamics field at this resolution on 8 subdomains, including locations of interest, are supplied to ALPNAP partners who are responsible of the noise impact modelling and assessment, to support their study.

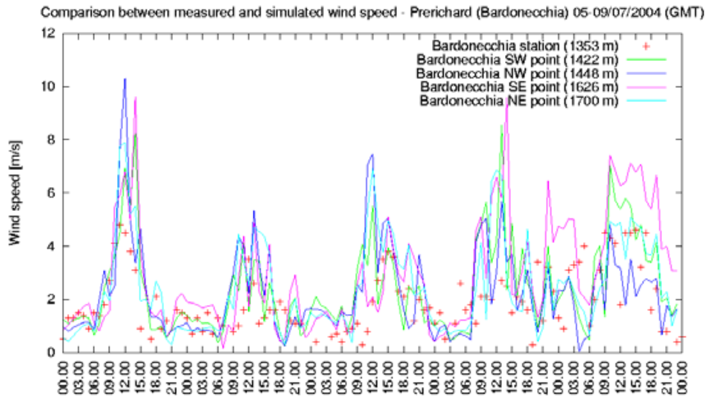

Fig. 2; RMS simulation, Bardonecchia station, 05-09 July 2004.

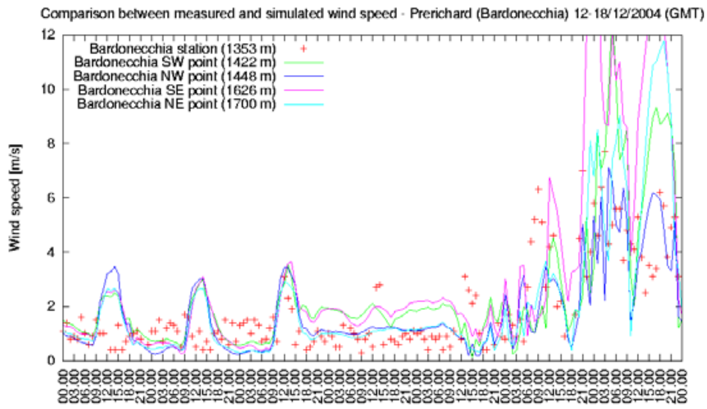

Fig. 3; RMS simulation, Bardonecchia station, 12-18 December 2004.

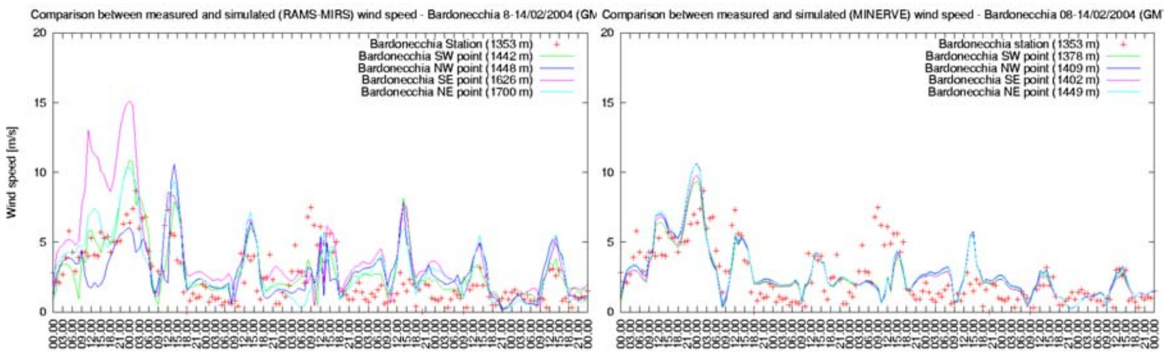

Fig. 4; RMS (left) and MINERVE (right) simulations, Bardonecchia station, 08-14 Feb. 2004.

To perform reliable simulation of the dispersion, a further processing of the emission data provided by CETE was performed so to include the presence of both viaducts and tunnels and treat their emissions properly. As viaducts need specific segments to identify their different slopes, the subdivision of the original emission arcs was modified so that viaducts were divided into subsequent sub-arcs and characterized by their specific height over the terrain. To account for the presence of tunnels, the tunnel emitted mass was split in two contributions and attributed to emission-segments adjacent to the tunnel entrances. The segment length was set 50, 100 or 200 m when the tunnel length was respectively less that 1 km, between 1 and 5 km and longer than 5 km.

SPRAY model was run both on the 1 km-mesh domain covering all the Frejus transect and on several subdomains, generally 15 x 15 km^2 with 100 m resolution. In Figure 5 we report an example of the final results for the mean and maximum concentration of NOx calculated over all the period in the February episodes. This kind of analysis allows identifying the most critical zones for the air pollution impact. The information is then transferred to the ALPNAP partners who are responsible of the impact assessment part of the project. The methodology proposed is thus proved to be efficient to simulate, then possibly forecast, the meteorology and dispersion in highly complex and inhomogeneous terrain.

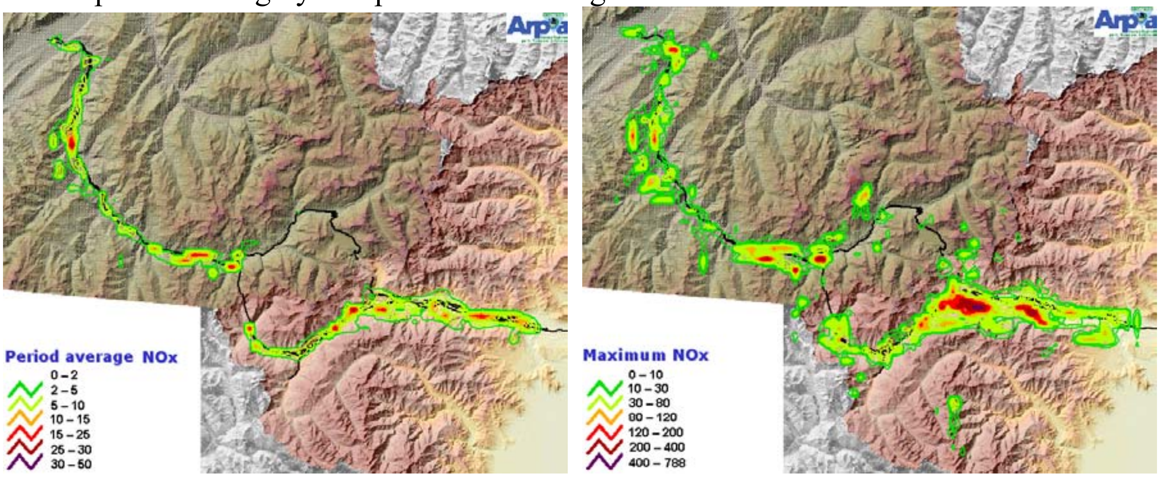

Fig. 5; SPRAY simulation on 1 km resolution domain: mean(left) and maximum(right) NOx concentration field calculated for all period 08-14 February 2004.

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