NUMERICAL AIR QUALITY MODELLING ALONG THE BRENNER SOUTH ROUTE WITHIN THE ALPNAP PROJECT

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Abstract: The paper presents some preliminary results from numerical simulations of meteorological processes and air pollutant transport based on field measurements perfomed during winter 2006 at three target areas along the Adige Valley (Northern Italy) within the project ALPNAP, funded by the European Regional Development Fund under the initiative Interreg III B "Alpine Space"(cf. de Franceschi and Zardi, 2007). The model CALMET has been used for simulation of the meteorological fields over a domain of 40x95 km^2, including all the three target areas. As a second step, based on the output from CALMET, the simulation of pollutant dispersion processes has been carried out by means of the Eulerian-Lagrangian model CALPUFF, including a complete complex-terrain module. Data from intensive observations have been used for model calibration, with special emphasis on vertical temperature profiles and turbulence parameters. SODAR data have been used as upper air sounding for an initial-guess wind field. The results shown here consist of NO_x concentration fields within subdomains of about 15x10 km^2 at the three target areas of the field measurements. The model output allow to appreciate how local features affect the transport of pollutants emitted by the motorway. The comparison between model results and observed data shows, on average, a good agreement with only some underestimations of the concentration during traffic peaks very close to the source.

Keywords: *Numerical simulation, air pollution, mountainous area, ALPNAP*

1. INTRODUCTION

A huge quantity of meteorological and air quality data was gathered during a field campaign within the project ALPNAP performed during winter 2006 along the Adige Valley. Intensive surveys were performed at three Target Areas, shown in fig. 1 (see also de Franceschi and Zardi, 2007 for further details on the project). Since the project aims at setting up good practices in air quality survey and air quality assessment, a joint work on data analysis and numerical simulations was carried out, and in particular this work focuses on the second issue.

The model CALMET (Scire et al., 2000a) has been used for simulation of the meteorological fields over the domain. The computed quantities are the 3D fields of wind and temperature. Particular attention was paid on wind direction and temperature profiles estimated over complex topography. The simulation of the dispersion processes was carried out by means of the Eulerian-Lagrangian model CALPUFF (Scire et al., 2000b). At every simulation hourly emission factors were used, estimated with a properly adapted COPERT methodology in accordance with measured traffic flows.

2. METHODOLOGY

The CALMET simulations run from 1 January 2006 to 31 March 2006, covering the whole intensive observation periods in the three Target Areas. The CALMET model has been used for simulation of the meteorological fields over a domain of 40x95 km^2 (shaded area in Fig. 1), with an horizontal resolution of 250 m and 13 vertical levels not equally spaced (the same grid was used for air quality simulations). The computed variables are the 3D fields of wind and temperature, along with 2D stability parameters such as Monin-Obukhov length, friction velocity, vertical convective velocity scale and sensible heat flux. Data from all surface weather stations available from the field measurements and displaying good quality have been used as model input.

The model CALMET was also initialized using SODAR data as upper air sounding for an initial guess of the wind field, applying the default diagnostic adjustments for terrain and the objective analysis procedure using all available observations. For upper layer exceeding the range of the SODAR scan, suitable extrapolation was performed. To include information representative of synoptic weather conditions, data from the station of Monte Tomba (1766 m a.m.s.l.) were used. Pseudo-vertical temperature profiles registered along the valley side in the three Target Areas by means of small dataloggers were also used in order to derive the thermal structure.

It is noteworth to mention that some modification have been introduced in CALMET in order to account for the effect of shadowing on surface energy budget (see Antonacci and Tubino, 2005). A test simulation was performed, checking the difference between the modified and original CALMET model. Spatial variations in turbulent parameters determine variations of the computed turbulent diffusivity, which is the main parameter, together with mean wind speed transport, acting on pollutant transport processes.

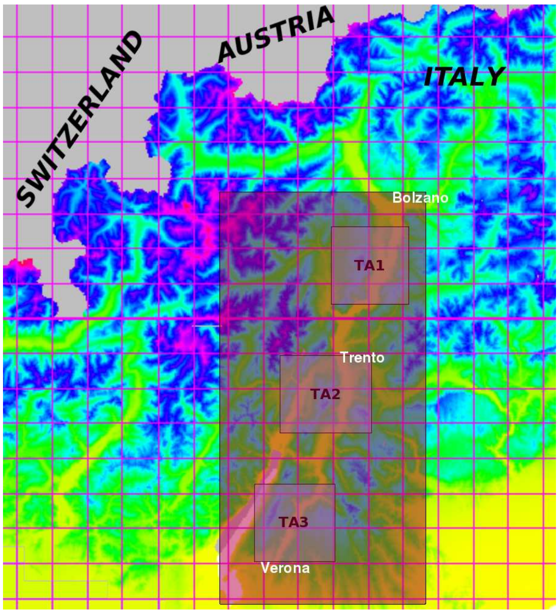

Figure 1: Simulation domain and identification of the three Target Areas in which intensive surveys were performed.

Particular attention was put on the estimate of meteorological fields in the layers closer to the ground, as the main issue of the ALPNAP project is the estimate of pollutant diffusion from linear sources at the valley floor, which can be confined to the lower layers especially in Winter due to stagnation and thermal inversion. In order to refine the representation of wind flow, especially near the valley floor and along the valley sidewalls, the "area of influence" of the meteorological stations used for generating the simulated wind field thorugh the interpolation algorithm, was taylored with an adjustable shape depending on local orography of the area (and not simply circular, as it is in the default version). The area of influence can now be considered as an ellipse with the major axis oriented according to main flow direction induced by the valley; moreover vertical thresholds can be used for the representativeness of the weather stations along the vertical direction.

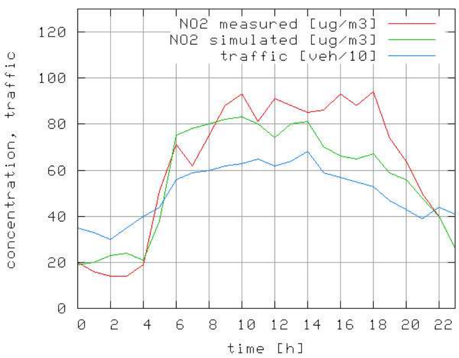

Figure 2: Measured vs. modelled NO_2 concentration in the Target Area “1” (18 January 2006).

Two steps have been performed for dispersion modelling. First of all a small scale approach has been used to calibrate the near-field diffusion induced from high traffic and speed, since it is known that this "mechanical mixing" factor is not negligible for highway emissions. Using traffic data provided by the Company operating the motorway (Autostrada del Brennero SpA), emission factors determined on the basis of the COPERT methodology from a suitable vehicle classification database, meteorological and air quality data form the intensive observation periods, the pollutant source have been calibrated, overcoming incomplete information on the vehicle fleet. An example of the results is shown in fig.2 where the simulated NO_2 concentration is compared to that measured by the air quality mobile station positioned close to the highway.

As a second step the 3D time-varying model CALPUFF has been used for the assessment of traffic emissions from the highway. The numerical code includes a module for the simulation of chemical processes: among these the pseudo-first-order chemical reaction mechanism has been chosen, being able to simulate the conversion of $SO_x$and NO_x, so that it was possible to predict concentrations of NO_2 from NO emitted by vehicle exhausts. This mechanism incorporates the most significant dependencies of spatially and temporally varying environmental conditions on the transformation rates. CALPUFF does not directly support linear sources handling for road modelling and does not consider traffic-induced turbulence explicitly. Therefore, the linear source is simulated as a series of "volume sources", and he initial vertical extent for adjacent volume sources was set at 3 m.

CALPUFF also allows the use of stability-dependent minimum turbulence velocities. This option should be selected whenever the velocities otherwise obtained (measured or predicted) are less than the tabulated minima; default values are based on the Briggs stability classes. When CALMET data are used as an input, the turbulence intensity is evaluated using the shear velocities, which are available also during calm periods. This procedure may be not robust if the wind data used by CALMET include true calms, because during such periods turbulent velocity fluctuations can by indeterminate. Particular attention was devoted to this problem because calm periods can be associated with very stable boundary layers, which are expected to occur very often in the region during Winter.

As wind calm periods produce in general the worst condition in terms of pollutants concentration, a tuning was done on the treatment of very low wind speed. CALPUFF uses the Eulerian-Lagrangian puff transport approach, also including a complete complex-terrain module. Within this framework, the usual assumption is that when the puff transport speed is less than a user-supplied threshold speed (typically 1 m s^{-1}), a calm period is identified. During calm period all puffs and slugs do not move in the horizontal plane; fresh puffs rise straight up from the source and are dispersed due to wind fluctuations. With this set-up CALPUFF is thus able to reproduce the dispersion processes which occur during calm period provided that several adjustments are made to the standard algorithms. For puffs that are released during a calm period the growth is based on time and not on travelled distance during the sampling step, regardless of the other dispersion option selected; in any case minimum values of the turbulence velocities are imposed, which is quite important in present case near the source where mechanical turbulence is not negligible.

In the dispersion simulations, meteorological fields provided by CALMET were used and compared for consistency check with the nearest measured data. Every simulation has been performed by using hourly variable emission factors, in accordance with traffic flows. The first day of simulation has been performed "from scratch", i.e. without setting specific initial conditions; the subsequent days have been initialized by means of the outputs produced by the previous run.

3. RESULTS

Results of the numerical simulations consist of 3D wind and temperature fields and NO_2 concentrations maps at ground level within the target areas. The temperature profile is successfully simulated also in mountainous domain, along with wind speed. The maps of estimated NO_2 concentration produced only by the highway estimated emissions were realized for the whole intensive observation period and an example is shown in figure 3. Being the highway a linear source at ground level, the impact area is of course confined quite close to the emission area and follows the shape of the motorway itself. This is the reason why high grid resolution has to be adopted for this kind of estimate. In general, the comparison between model results and observed data shows, on average, a good agreement, with only some minor underestimations of the concentration during traffic peaks very close to the source. This is a general issue concerning this kind of models and can be partially explained by the model spatial resolution vs. the single point measurements.

Some questions are nevertheless still open, regarding both diagnostic meteorological and dispersion simulation on complex orography.

As wind direction at lower levels is significantly influenced by the valley directions, results are not realistic and the CALMET simulations in this mode fail to reproduce the above vertical structure. To obtain sufficient information on the synoptic conditions while still resolving locally driven dynamics, a surface weather station located on a mountain peak was used as a "fictitious" upper air station, despite it is located within the domain but quite far away from the sub-target areas. CALMET simulations with this hypothesis are probably less accurate but successfully simulate the wind direction at lower levels when compared to the measured data.

Difficulties still occur mainly in comparing simulated and measured wind directions at lower levels, as the module of CALMET computing terrain driven winds adopts a local approach which sometimes tends to overestimate terrain effects. Anyway, while the relative errors for the horizontal component of velocity decrease when CALMET is operated without terrain adjustment, wind direction would result completely wrong. On the contrary there is no corresponding significant increase in the relative errors for the local wind speed. As far as temperature is concerned, lowest level estimate is quite accurate if the altitude correction foreseen in CALMET is adopted; otherwise, only horizontal interpolation between two stations at the same altitude, but divided by an orographic obstacle, can in some case produce non-realistic spatial variation in the temperature field.

For the simulation of pollutant dispersion the more relevant issue to be addressed involves at present the boundary conditions (regional scale transport), hence CALPUFF results cannot yet be fully compared with values measured in “background sites” at medium or high altitude (i.e. outside of the valley core).

As a final remark, results about the simulations on calm period show that the threshold used to identify calm period should be modified to reflect the characteristics of the used wind sensor and the acquired data.

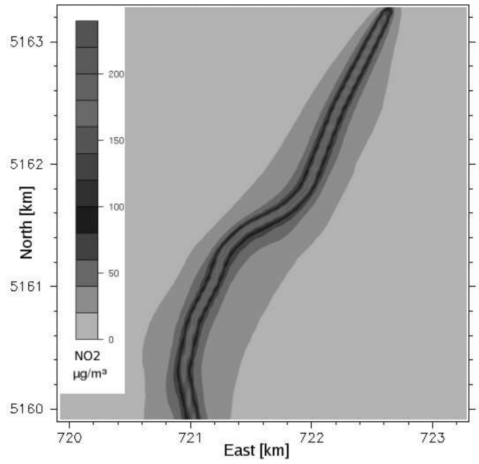

Figure 3: Example of NO_2 concentration map: contribution of the highway in the Target Area “1” (18 January 2006).

4. CONCLUSIONS

The results display good agreement between measured and predicted NO_2 concentration near the linear source, while concentrations are underestimated some kilometers away from it. As a general remark, it should be pointed out that other sources are also present (domestic heating, local traffic): these sources have been taken into account as an input background, nevertheless some underestimate of the model was expected. On the other hand the concentration predicted along the valley sides some hundreds of meters above the valley bottom are not far from measured values, and they are representative of the background concentration: this is quite true especially during winter time, when stable conditions cause pollution emitted at the valley floor to remain within the stable core.

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