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PRELIMINARY POLLUTANT DISPERSION MODELLING WITH CALMET AND CALPUFF OVER COMPLEX TERRAIN IN THE BOLZANO BASIN (IT)

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Abstract: The assessment of the impact on air quality of a new waste incinerator for the city of Bolzano (Central Italian Alps) required to improve the forecast of dispersion processes within the Bolzano basin, especially in critical weather conditions (e.g. wintertime ground-based inversions under calm conditions). This led to test the CALMET and CALPUFF modelling chain performance in such a complex terrain. CALMET was used for the diagnostic reconstruction of meteorological fields, the input data being provided by a variety of in-situ measurements: surface temperature and wind (speed and direction) from eight different weather stations, wind profiles from a SODAR, and temperature profiles from a thermal profiler. Simulations performed with a prognostic approach (WRF model) showed that the strong complexity of the area affects the development of ground-based thermal inversions, as well as alternating up- and down-valley winds in the valleys merging into the basin. The simulation of such a complex pattern of meteorological fields is a challenging goal for the diagnostic pre-processor CALMET. Indeed in such a complex domain it is very difficult for CALMET to spatialize appropriately meteorological variables, such as surface temperature and wind speed and direction, strongly affecting the transport of pollutants. Therefore efforts were made to understand the causes of these deficiencies. In particular the operations of CALMET pre-processor were examined, and effects of different meteorological input passed to CALPUFF were analysed, to ascertain their impact on dispersion patterns.

Key words: *CALMET, CALPUFF, WRF, Alps, Bolzano basin, complex terrain.*

INTRODUCTION

Air quality scenarios provided by coupled meteorological and dispersion models can play a key role in supporting policies for monitoring pollutant dispersion and reducing health risks. However, air quality modelling in complex terrain still pose many challenges, due to the inherent difficulties in accurately reproducing both the atmospheric and the dispersion processes. Here we present some preliminary evidences from a project carried out in the Bolzano basin, in the Central Italian Alps. In July 2013, a new waste incinerator became operative 2 km Southwest of the city centre of Bolzano, the most populated town (about 106000 inhabitants) of South Tyrol. This new plant, with a maximum waste treatment capacity of 130000 t y^{-1} and a flow rate of 85000 Nm^3 h^{-1} released at 60 m a.g.l. at 413 K, required policy makers to improve the forecast of dispersion processes in the area (Ragazzi et al., 2013), with the aid of both atmospheric and dispersion modelling. A dedicated project was therefore set up to provide a technically-sound support for the design of a permanent air-quality station network, monitoring the effects of pollutants from the incinerator. Accordingly, a trustful modelling chain, able to provide emission-impact scenarios with yearly-based numerical simulations, was needed. To assess the appropriateness of the CALMET/CALPUFF modelling chain (Scire et al., 2000) for application over such a complex terrain, these modelling instruments were tested, by means of short-term (7 h) simulations in diagnostic mode, feeding them with all the available atmospheric measurements in the Bolzano basin. Testing and evaluation were performed under meteorological situations conducive to critical air pollution episodes, e.g. strong ground-based thermal inversion and calm conditions. Attention is focused on the reconstruction of meteorological fields, which are qualitatively compared with prognostic numerical simulations run with the Weather Research and Forecasting (WRF) model (Skamarock et al., 2008). As to the dispersion modelling, the release of a tracer from the chimney is simulated, in order to appreciate the potential effects on pollutant transport of different meteorological input into CALPUFF.

CASE STUDY

Bolzano basin

The city of Bolzano lies at 262 m a.s.l. on the floor of a wide basin at the junction of the Isarco Valley (East) and of the Sarentino Valley (North) with the Adige Valley (South and Northwest) (Fig. 1). The climate of Bolzano is continental, characterized by warm summers and cold winters. Wind regimes are dominated by terrain effects (Dosio et al. 2001), developing thermally-driven winds (de Franceschi et al. 2009), which however are mostly absent or very weak during wintertime (de Franceschi and Zardi 2009). This aspect, in connection with the frequent occurrence of ground-based inversions at the valley floor, determines frequent critical conditions for air quality. Figure 1 shows the study area in the Bolzano basin, its tributary valleys and all the available measurement stations.

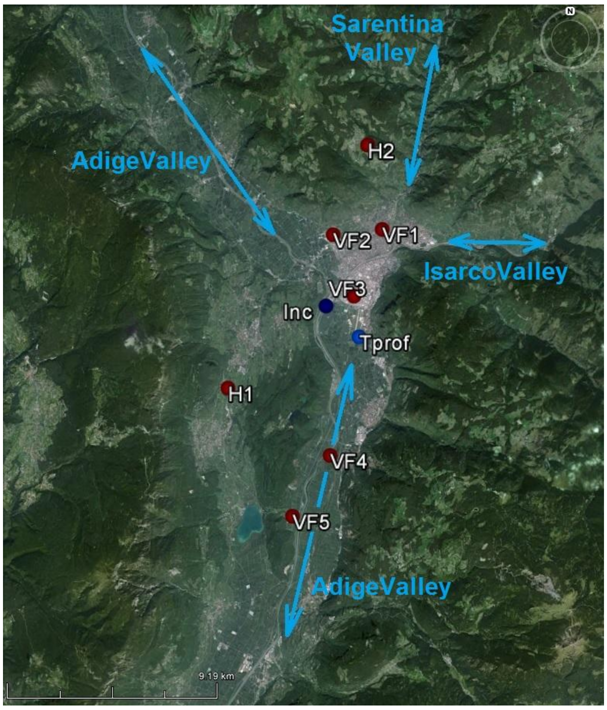

Figure 1. Bolzano basin with its tributary valleys. Locations of the available weather stations are also highlighted: "Inc" corresponds to the incinerator plant position; "Tprof" to the thermal profiler; "VF#" to the valley floor permanent stations and "H#" to the permanent stations on the sidewalls (background map from GoogleEarth).

Period of study: meteorological conditions

The 27th of January 2016 was chosen as the reference day for the simulations, covering a period of 7 hours, from 04 to 10 LST (UTC+1). Indeed, January 27th 2016 presented most of the typical wintertime meteorological conditions relevant for the stagnation of locally emitted atmospheric pollutants. Data from measurements showed a strong ground-based thermal inversion, developing up to 700 m above the valley floor, and relatively weak wind speeds at the valley floor. Fig. 2 shows measurements from a vertical temperature profiler ("Tprof" in Fig. 1), from a SODAR ("Inc" in Fig. 1) and from surface weather stations located both on the valley floor ("VF#" in Fig. 1) and at different heights along the sidewalls ("H1", 500 m a.m.s.l., and "H2", 1000 m a.m.s.l., in Fig. 1). In order to have a more detailed overview of the meteorological situation occurring on January 27th, high-resolution numerical simulations were run with a prognostic approach, with the WRF model. Simulations with the WRF model were performed with four nested domains, up to an horizontal resolution of 333 m over the Bolzano basin, where observational nudging was used. A 30-m resolved Digital Terrain Model and a 100-m land use map were used in order to properly describe the characteristics of the inner domain (panels 1 and 2, Fig. 3, show the inner domain topography). WRF simulations highlighted that the flow field in the Bolzano basin is very complex, due to alternating up- and down-valley winds flowing in the valleys which merge into the basin. In particular, a low-level nocturnal jet at the exit of the narrow canyon-like Isarco Valley adds complexity to the wind field and results to be relevant for the releases from the incinerator, as it flows exactly over the plant (Fig. 3 and 2). It is clear that the simulation of the interaction between these different local circulations, including their correct evolution in space and time, represents a very challenging task for a diagnostic model as CALMET, but their correct reconstruction is of fundamental importance for dispersion issues. In addition to this, WRF simulations show how meteorological near-ground variables, such as 2-m temperature and incoming radiation, are obviously strictly terrain-related, as shown in Fig. 3.

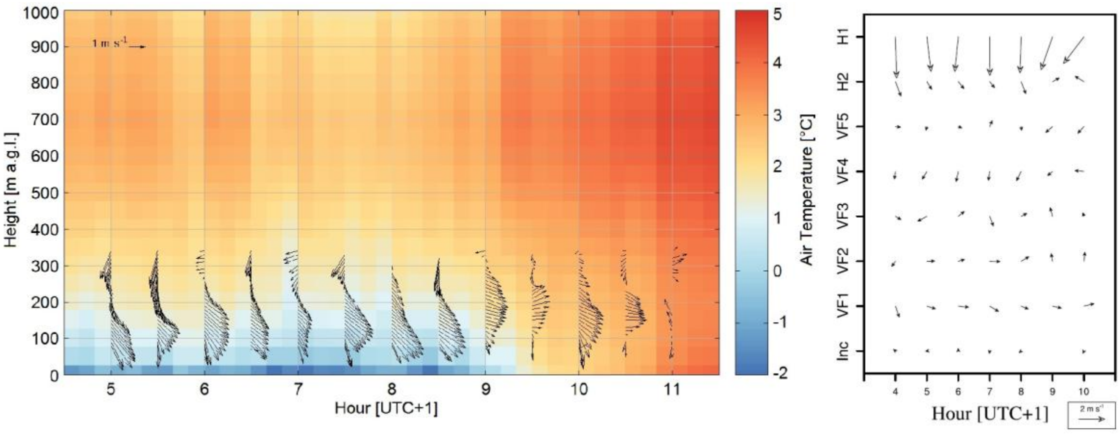

Figure 2. Observations of the vertical temperature and wind profiles (from “Tprof” and “Inc” in Fig. 1) up to 1000 and 340 m a.g.l. (left) and wind speed and direction measured at 10 m a.g.l. at various weather stations (right).

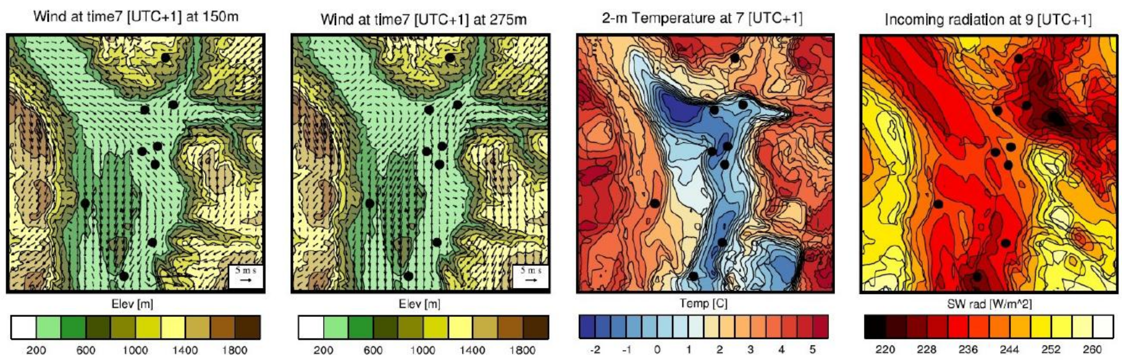

Figure 3. Topography of the inner domain of WRF simulations and simulated wind field at 150 and 275 m a.g.l. at 7 LST (panels 1 and 2); WRF 2-m temperature at 7 LST (panel 3) and WRF incoming radiation at 9 LST (panel 4) .

DIAGNOSTIC NUMERICAL SIMULATIONS WITH CALMET/CALPUFF

Standard simulations with CALMET:

Simulations with the CALMET/CALPUFF model are run in diagnostic mode with a horizontal resolution of 200 m over a 20x20km^2 domain, and with 10 vertical levels from the ground up to 2400 m. The dispersion module is set up to simulate a tracer release from the incinerator chimney starting at 7 LST and lasting 40 minutes. Nevertheless, the focus of the present work is on the reconstruction of the meteorological fields provided by CALMET. The pre-processor is fed with different observations, both conventional and non-conventional. Indeed the following input data were provided to the model: wind speed and direction, temperature, relative humidity and atmospheric pressure from eight permanent stations, six distributed on the valley floor and two along the sidewalls (300 m and 700 m above the valley floor, respectively); vertical profiles of wind speed and direction from a SODAR, set up on the roof of the incinerator, reaching heights of 340 m; and a temperature vertical profile up to 1000 m measured in the centre of the Adige Valley. The temperature profile has a 10-min temporal resolution and is vertically 50 m spaced, while the wind profile has a 30-min temporal resolution and is vertically 20 m spaced. The vertical profiles of both temperature and wind, observed within the domain of interest, are uncommon data and should act as a relevant resource to guide the meteorological pre-processor to properly reconstruct meteorological fields, especially when run over complex terrain.

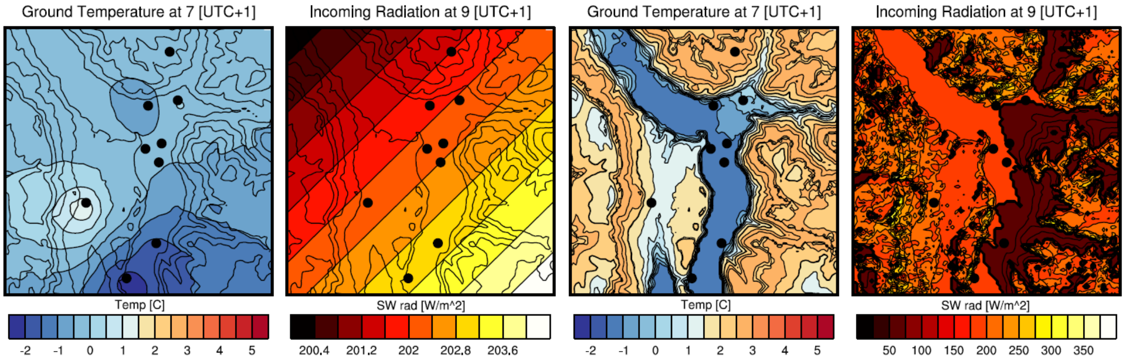

Figure 4. Near ground temperature and incoming radiation calculated by the CALMET model in its standard configuration (panels 1 and 2) and in its modified configuration (panels 3 and 4) where external temperature and irradiance fields are forced into the model.

Despite the quality and peculiarity of the input data, CALMET performance in reproducing reliable meteorological fields is unsatisfactory. Indeed, the model shows many difficulties in properly spatializing meteorological variables strongly affecting the transport and diffusion of pollutants. Figure 4, panels 1 and 2, show the inability of the CALMET model to take into account terrain effects on both near-ground temperature and incoming radiation: indeed, no thermal inversion is reproduced nor shadowing effects are accounted for.

Modifications to CALMET:
In order to overcome these deficiencies, modifications to the CALMET code (Bellasio et al. 2005) are made and temperature and incoming radiation fields are externally forced into the model: a terrain-related near-ground temperature field is calculated on the basis of hourly soundings while an hourly incoming radiation field is calculated by means of GRASS GIS analysis for the given day and DTM. Results of these interventions on the CALMET code are shown in panels 3 and 4 of Fig. 4, which highlight changes in 2-m temperature of 3 to 4°C and even more relevant changes in incoming radiation. Despite the significant modifications in both these meteorological variables, these changing have little impact on more dispersion-related CALMET fields, such as mixing height and wind speed and direction. In particular, temperature modification has no effect on derived parameters, confirming that the micrometeorological parameterization included into CALMET is almost non-sensitive to this variable. On the other hand, incoming radiation modification affects wind speed and direction but only near the ground, along shadowed sidewalls: this has an effect on related mixing heights which vary accordingly, as shown in Figure 5, panels 1 and 2. Both modifications have no effects on wind speed and direction at higher levels, where standard and modified CALMET results correspond one to each other and where the effective release of the tracer is expected (only one shown in panel 3, Fig. 5, at 7 LST). Comparing CALMET wind field, at 150 m a.g.l., with WRF simulation, it is clear that the CALMET model succeeds in reconstructing the main north-easterly wind flow coming from the upper part of the Adige valley and directly flowing over the incinerator plant. On the other hand, in upper layers, e.g. at 275 m a.g.l. (panel 4, Fig. 5), CALMET model shows its inability to identify the low-level nocturnal jet coming from the Isarco Valley, despite input data carry this information within the wind vertical profile. When dispersion simulations are run with the CALPUFF model, fed with the standard and improved meteorological

CALMET output, no differences can be appreciated in terms of plume dispersion trajectory (blue line in panel 3, Fig. 5) and of ground diffusion imprint.

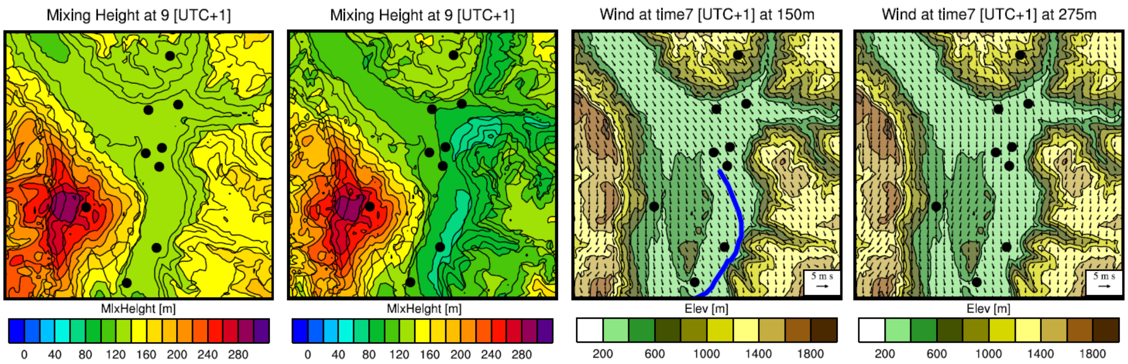

Figure 5. Mixing height obtained with the standard (panel 1) and modified (panel 2) CALMET simulations; wind speed and direction at release time, 7 LST, at 150 m (panel 3) and 275 m (panel 4), obtained with the CALMET standard simulation (which are coincident with the results of the modified CALMET simulation).

CONCLUSIONS

Numerical simulations run with the WRF model and a detailed analysis of observed meteorological data show that the Bolzano basin wind field is extremely complex. In such a complex environment, it is unlikely that the CALMET model, run in diagnostic mode, can capture the whole picture of the meteorological fields. In particular, deficiencies in the reconstruction of near-ground temperature and incoming radiation are identified and interventions are made on the CALMET code in order to solve these difficulties. Despite proper 2-m temperature and incoming radiation fields are forced into the model, these modifications have little impact on wind field and mixing height results. Indeed, CALMET results are definitely non-sensitive to the near-ground temperature field while only near-ground wind field and mixing heights are slightly affected by changes in the radiation field. These small changes have no effects on CALPUFF dispersion patterns, obtained with the standard and modified CALMET input, which basically correspond one to each other. The presence of a low-level jet flowing out of the Isarco Valley and crossing the Bolzano basin introduces big uncertainties in the direction of the tracer dispersion: indeed, small changes in the effective release height may lead, in reality, to very different trajectory scenarios, but no differences would be appreciated with the diagnostic CALMET/CALPUFF simulations.

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