MODELLING AIR QUALITY IN DEEP VALLEYS USING AN OPERATIONAL DISPERSION MODEL

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ABSTRACT

The prediction of pollutant concentrations in very complex orography still remains a difficult task as its accuracy is highly depend on a good prediction of a complex flow field. The overall boundary layer structure over complex terrain displays many modifications as compared with the flat terrain case. In complex terrain, thermal local circulation may occur and this further complicate pollution distribution predictions. The aim of this paper is to investigate the applicability of the quasi-Gaussian, UK-Atmospheric Dispersion Model, ADMS-Urban to the prediction of pollutant concentrations in a deep Alpine valley. We compared model results with concentration data from a three week field campaign. To assess model performance we used both statistical criteria available from the literature and model sensitivity to different input data.

INTRODUCTION

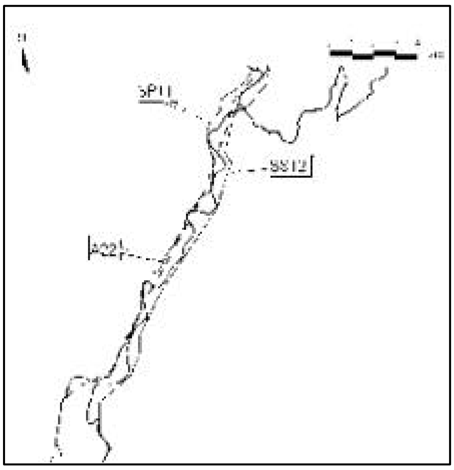
During last years, public opinion towards air quality issues is increased in relation to the increased concern about the effects of pollution anthropogenic sources on human health. Traffic sources in most cities are one of those issues that have received much attention. Recently, the interest has focused, besides urban areas, on those regions characterized by large freeways: the Alpine valleys are an example of those regions. In these areas, wind flow is strongly influenced by mountainous terrain. Thermal circulation may be dominant and the presence of strong inversion layers may lead to poor dispersion in those areas. Pollutant transport is influenced by down-slopes flows which typically occur during the night (catabatic wind) and up-slope flow (anabatic wind) which occur during the day.

In this work we focus on one of the Alpine regions affected by major air pollution issues. The Italian Alps, crossed by intricate road links with the rest of Europe, show complex terrain features (deep valleys, rugged orography) that are critical to dispersion modelling (*Nanni, A. et al.,* 1996). Most operational dispersion models used for the prediction of pollution concentration in very complex situations have not undergone a complete validation. Those predictions may be affected by large errors. The study presented here is part of the European project ALPNAP whose aim is the integration and the harmonisation of main methodologies available for the prediction of pollutant concentration with emphasis on Alpine regions. We focused on an Alpine target area such as the Adige Valley for which concentration measurement were available from a three week field campaign (from 21 February 2006 to 14 March 2006). The aim of this work is to test the applicability of the quasi-Gaussian, UK-Atmospheric Dispersion Model, ADMS-Urban (*ADMS-Urban 2.2*, 2005) for the prediction of pollutant concentrations in this very deep valley. ADMS-Urban has been widely used to model flow and pollutant concentrations over hills with small slope. However, the model has not been extensively applied to very complex terrain where slopes were very large as they are in Alpine regions. The slopes in our case are between 30% and 70%. It is imperative that dispersion models are properly evaluated with observational data before their predictions can be used with confidence. Model results often influence decision making that have large public-health and economic consequences (*Chang, J.C. and S.R. Hanna,* 2004).

METHODOLOGY

The methodology adopted in this study are summarized in the following steps: 1) reconstruction of emission data; 2) model simulations and 3) model assessment. The study area is the Adige Valley which is a deep narrow valley with a main axis in the North-East South-West direction. The valley is crossed by three major roads: the SP11, the SP12 roads and the highway A22 (Fig. 1a). It is characterized by a very complex terrain with high mountains reaching over 2000 m. To simulate this area we restricted ourselves to an area of 16 km x 16 km. We used meteorological data recorded by the fixed Monitoring Meteorological Station of ARPA Veneto, near the little town Dolcè, situated on the South-West of the valley. Available routine measurements include wind speed and direction, temperature, humidity and solar radiation at 2 m or 10 m from ground level. In the framework of the ALPNAP project four mobile air quality monitoring stations were placed on the slope of the valley: three located near three small village, Colle Dosson, Peri and Fosse (which did not work properly), and one not far the highway A22 (Fig. 1b). During a three week field campaign (from 21 February 2006 to 14 March 2006) both meteorological parameters and concentrations of pollutants, in particular NO_x and SO_2, were hourly recorded.

a)



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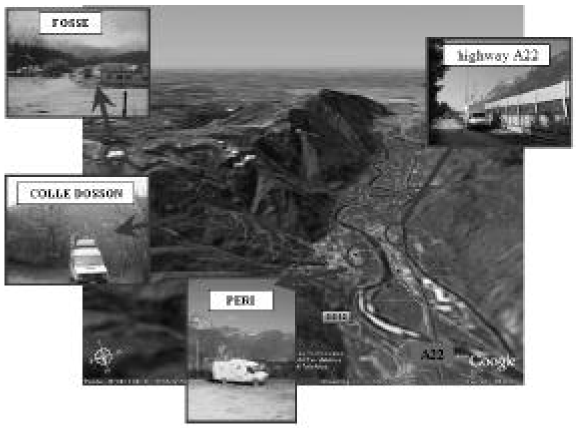


Fig. 1; a) The area of study: the Adige Valley. In this valley there are three major roads: the SP11, the SP12 roads and the highway A22; b) The location of mobile air quality stations.

First step: Reconstruction of emission data

An emission inventory for this valley suitable for dispersion modelling was not available prior this study. The constitution of a suitable emission database formed an important preliminary phase of this study. The main elements of this database were: emissions from traffic, industrial sources and domestic sources. Traffic data, collected by the Province of Verona, were divided in two classes according to vehicle length: light vehicles (those with length between 0 and 7.5 m) and heavy vehicles (those with length larger than 7.5 m); for both the selected classes we calculated the average vehicle speed and the daily traffic flow. Only two industrial point sources were incorporated in this study. The emissions data were provided by ARPAV Verona Emissions Inventory; for both industrial sources we specified the height and the stack diameter, gas temperature, exit velocity and emission rate. Domestic source emissions produced by the combustion of domestic heating were harmonised using raw data from the Provincial Emission Inventory.

Pollutant concentrations monitored by the measurement station Colle Dosson localised in the deeper point of the valley were considered as background concentrations. A diurnal variation of the traffic flows, together with a distinction of week days, were used to calculate emissions from major road traffic. To estimate emissions from those raw data we used the EMissions

Inventory Toolkit (EMIT) (*EMIT 2.2,* 2006) that allowed us to determine the total emissions of each pollutant.

Second step: Model simulation

The information collected in the previous stage was used to run ADMS-Urban to evaluate air quality in the valley. ADMS-Urban is integrated with a complex terrain module for the treatment of pollutant dispersion in complex terrain. This module refers to the FLOWSTAR model (*FLOWSTAR 7.1*, 2004) which allows us to calculate air flow and turbulence on complex terrain. The Digital Terrain Model (DTM) of the valley (Fig. 2) has been elaborated from the data of the Veneto Regional Technical Paper. The ground level data were irregularly collected and they were interpolated to obtain a regular grid in which the points were placed every 30 m. The resulting DTM was used as input data for concentration modelling.

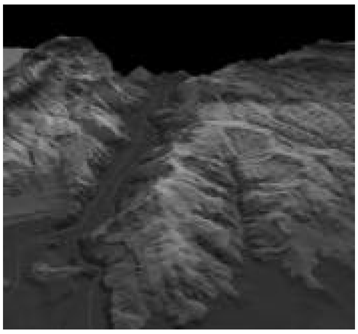


Fig. 2; The Digital Terrain Model.

Third step: Model assessment

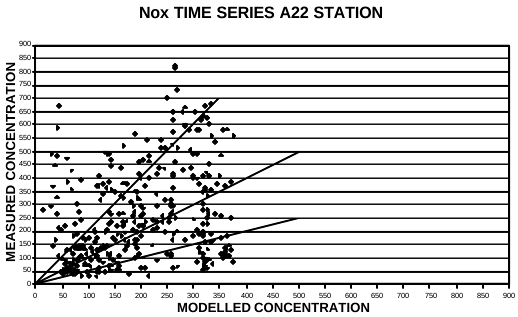
In this step we tested model performance and model sensitivity to input data. In particular we investigated the sensitivity to Digital Terrain Model input data. We used a short term simulation suitable for hourly comparison between field data and modelled. We focused only on NO_x and SO_2 as they were the most complete time series in all monitoring stations.

We used a set of quantitative statistical performance measures as recommended by *Hanna, S. R. et al.* (1991, 1993). Those measures have been widely used in many studies (*Ichikawa, Y. and K. Sada,* 2002, *Nappo, C.J. and K.S.M. Essa, 2*001, *Mosca, S. et al.,* 1998). They include the fractional bias (FB), the geometric mean bias (MG), the normalized mean square error (NMSE), the geometric variance (VG), the correlation coefficient (R) and the fraction of predictions within a factor of two observations (FAC2). In general, for dispersion modelling where concentrations can vary by several order of magnitude, MG and VG are preferred over FB and NMSE, even if they may be influenced by very low values. The FAC2 is probably the most robust performance measure, because it is not overly influenced by either low or high outliers. Considering all meteorological conditions in complex situations, the uncertainties on emissions, the limited availability of data in some sites, an agreement between 10% and 20% between model results and measurement will be considered a good agreement for this specific study.

RESULTS

Fig. 3 shows the comparison between measured NO_x concentration and modelled data and their comparison with FAC2. The figure shows a good agreement between measured data and model results for the three monitoring stations. We observed that a larger part of the data is within the FAC2. In particular for Colle Dosson station, the model shows an overestimation of about 3%. These values corresponded to meteorological conditions with low wind speed which are typically critical for Gaussian-type models such as ADMS-Urban. For Peri station we observed that about 20% of the values are under-predicted. This is probably because in the deeper zone of the valley and closer the sources, the effects of the thermal stratification are predominant and the model does not reproduce those conditions very well. For SO_2 (not reported here) we have noticed some differences between the results of Colle Dosson station and the other two stations. In fact, the comparison between measured and modelled data for Colle Dosson station shows a good agreement, emphasizing the model ability to well simulate pollutant dispersion. For the others two stations we suspect that some errors exist in the measurements.

a)



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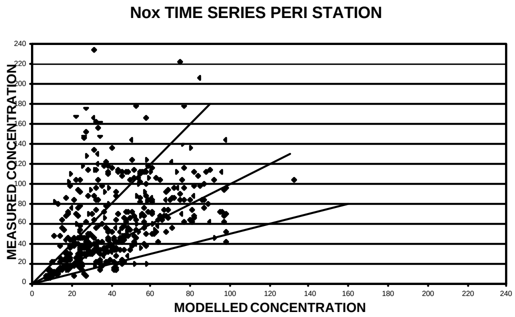

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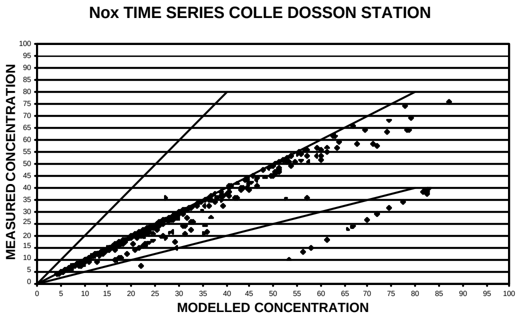

Fig. 3; Results of comparison between measured and modelled concentrations with FAC2 for a) A22 station; b) Peri station; c) Colle Dosson station.

Results of statistical performance are summarized in Tables 1 and 2. Overall, they are fulfilled. However, we observed that for Colle Dosson the model slightly under-predicts, while slightly over-predicts in the other cases as it is shown by MG, NMSE and VG values. Overall the best agreement between model and measurement results are obtained for Colle Dosson.

Table 1. Results of statistical performance for NO_x.

NOx				
Station	FB	MG	NMSE	VG
Colle Dosson	-0.15	0.87	0.15	1.10
Peri	0.37	1.32	0.67	1.55
A22	0.26	1.17	0.66	2.03

Table 2. Results of statistical performance for SO_2.

SO_2				
Station	FB	MG	NMSE	VG
Colle Dosson	-0.002	0.99	0.001	1.00
Peri	0.50	1.58	0.88	1.68
A22	1.00	2.82	2.97	4.63

CONCLUSIONS

The aim of this study was to assess the suitability of the ADMS-Urban dispersion model for air quality management applications in very complex topography. This study is also a first attempt to better understand to which extreme complex topography the model can be used. For this reason the results should be considered as preliminary. ADMS-Urban well reproduces concentration far away from the main sources where the slopes are lower than other areas. The good agreement between experimental data and model results is also confirmed by the direct comparison of the data time series. However, when slopes are around 70% (the bottom of the valley) the model underestimates concentrations. During calm conditions, the model tends to overestimate concentrations. We can conclude that the model can be used for the prediction of pollutant concentrations in extreme cases with a certain degree of reliability. However, further studies are still required to assess model performance in different meteorological conditions.

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