The simulation of non-explosive volcanic emissions: the case of the SO_2 from the Etna craters

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1 Introduction

Recent improvements in mesoscale flow and dispersion models for complex terrain have allowed studying volcanic plume dispersion in the proximity of the source, where modifications of the synoptic field due to the local topography can be taken into account (e.g. Graziani et al., 1997, Pareschi et al., 1999). Here, the application to the Etna volcano is presented. In the case of Etna (3300m a.s.l), the summit cone emissions are usually transported by synoptic winds, with some exceptions that can be of great interest for risk calculation. In the following, flow models are described for the synoptic situation observed in the area during the summer campaign of 1994 (Ranci et al. 1998, Bogliolo et al. 1996). In Fig. 1, the topography of the region and the two innermost computational grids are shown together with the positions of the observational sites.

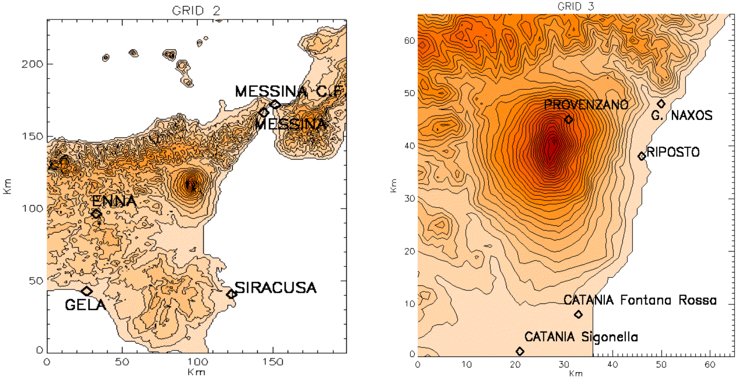

Figure 1 Mt.Etna (2nd and 3rd computational grids).

2 Flow model description

The regional atmospheric mesoscale flow model RAMS was used (Pielke et al., 1992), based on a finite difference approximation to the compressible, non-hydrostatic primitive 3-D fluid dynamic equations of continuity, motion, heat and moisture, written in a terrain-dependent co-ordinate system. An interactive nested grid scheme allows large domains to be modelled, while preserving a 1-Km grid size in the area of interest. In the innermost domain, diffusion was parameterised according the Deardoff scheme. Initial conditions of the mesoscale model are temperature, humidity and wind profiles as a function of height. RAMS employs a soil model (Tremback and Kessler, 1985) based on two diffusion equations, requiring the knowledge of initial temperature and moisture gradient in the soil, temperature and moisture at a deep level and soil type. Soil topography and land-use were specified with differentiation of soil characteristics at the mesh-size level.

3 Dispersion model description

The PDM Lagrangian particle model (Bianconi et al., 1999) simulated the dispersion of emitted gaseous material by means of a suitable number of fictitious, computational particles each carrying a fraction of the mass released. Each particle is moved, at each time-step, by pseudo-velocities, which take into account transport due to the mean wind velocity at each point in space derived from the flow models above mentioned, plus the dispersion due to the turbulent fluctuations of the wind components. The fluctuations are expressed in terms of turbulence parameters such as the friction velocity u*, the Monin-Obukhov length L, the convective velocity scale w*, and the height zi of PBL. The particles are reflected at the top of the domain and only partially at the ground because of the deposition velocity.

4 Observations at Mt. Etna

Mt. Etna is located in the eastern side of Sicily Island (Fig.1), with a base radius of about 15 km. The summit craters emit a non-constant flux of water vapour, SO2, CO2, aerosols and metals.

The simulation was performed on July 24-25, 1994 when a number of observations exist, including vertical profiles of wind and temperature, together with field measurements and remote sensing images of the plume. During the two days, characteristic synoptic winds were observed and compared with the results of ECMWF analysis at about 3,000 m a.s.l. At that height (corresponding to the volcano summit) the wind was blowing from North and veering to N-NW during the day and maintaining more or less this direction during the remaining period. Micro-meteorological measurements during the two-day period were gathered at a number of sites, both as ground measurements and as vertical profiles. In these days, together with wind observations, the plume from the volcano was observed by instrumentation at ground and by aerial visualisation. The SO2 concentration measurements at ground were performed by the COSPEC (Bruno et al., 1999) confirmed by the non-zero concentrations observed near Rifugio Sapienza (approximately 6 km south of the crater) across a transept from EW. The plume was recorded to extend between 80° to 140° from N at about 9:00 LST. Remote sensing images were taken with a MIVIS instrument from an aircraft flying at an elevation of about 5,000m a.s.l (several images). The aerial passages were from 7:19 to 7:41 LST during the 24th of July (diurnal passage) and from 4:22 to 5:18 LST on the following day (nocturnal passage).

5 Flow model results

The results of flow model application indicate that, during night, drainage flows are created at the top, mainly at the lee-side of the mountain. The synoptic flow gets round the obstacle represented by the volcano; the two streams re-join on its eastern side, close to the shore. This result is typical for the night regime and may be considered constant until sunrise. After that, heating over the land begins to generate slope breezes on every side of the volcano that are reinforced by the sea breeze on the eastern side of the mountain. In the morning, the sea breeze penetrates inland already one hour after sunrise and enters inland for a few kilometres, corresponding to the ground elevation of about 1 km. There it is reinforced by the valley flow directed to the top of the volcano. During the day, the breezes increase and surround almost completely the cone, converging on its western slopes (Fig. 2a).

The results of the flow model were compared with the ground meteorological observations gathered at the Sigonella and Fontana Rossa, two sites in the Catania plains. In both cases the model reproduces well the sea-breeze cycle with a variation in wind direction of approximately 180° from the night to the day and with a corresponding diurnal reinforcement of wind intensity. The cycle starts around 10:00 LST and ends in the evening at about 20:00 LST.

Comparison of calculated profiles of meteorological variables with vertical observed profiles is performed at Provenzano (Fig. 3) indicating that the general features of the wind and potential temperature are well reproduced by the model.

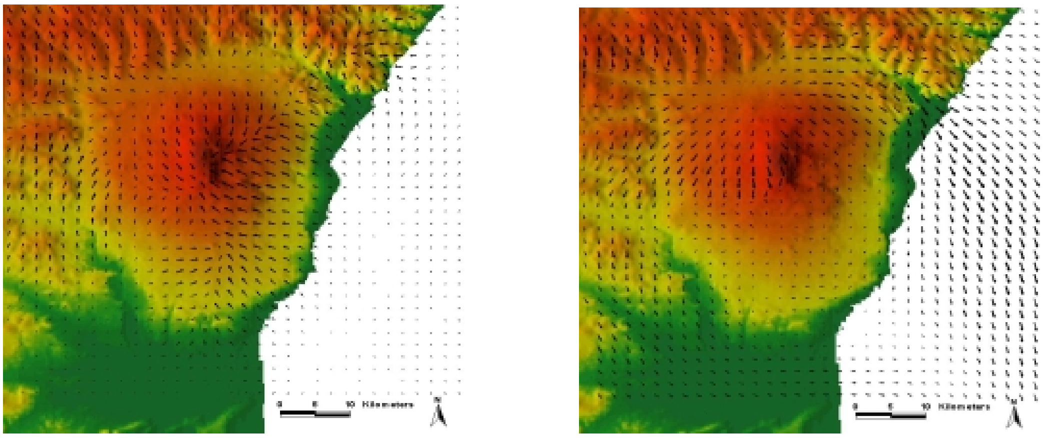

Figure 2 a) Simulation at 10:00 LST, July 24, 72 a.s.l., b) Simulation at 5:00 LST, July 25, 72 a.s.l.

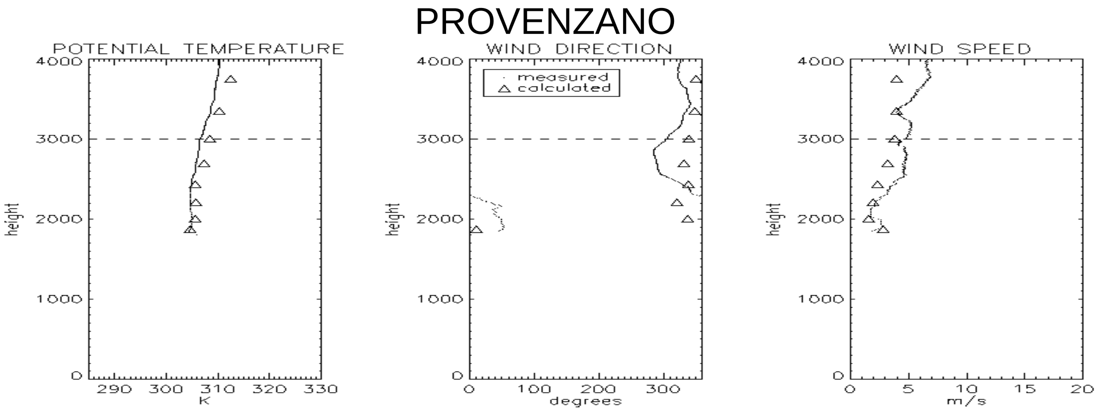

Figure 3 24/07/94 08:00 LST.

6 Dispersion model results

The dispersion model uses the wind and turbulence data from RAMS and an emission starting early in the morning (7:00 LST). The qualitative comparison with MIVIS data is rather good (Fig.4a), indicating similar directions of the cloud. The cloud elevation corresponds closely to the cone elevation, indicating that the bulk of it is transported by the synoptic wind. The calculated horizontal dispersion of 1 km after 6 km displacement from the source is confirmed by the COSPEC observations (Fig.4b).

The nocturnal dispersion of the emitted gases looks however rather different. Near Mt. Etna summit, the particle trajectories are close to the ground because of the drainage flow of cold air, well reproduced by the model (Figs. 5a-b). These results agree again very well, at least qualitatively, with those from the MIVIS (Fig.6) that indicate a nocturnal direction towards South-East (Valle del Bove).

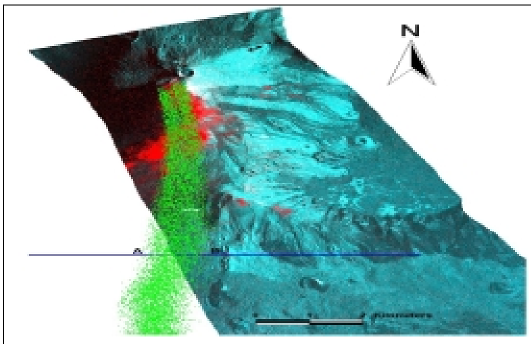

Figure 4a Comparison between simulation and MIVIS data (the red area represents the SO2 plume content).

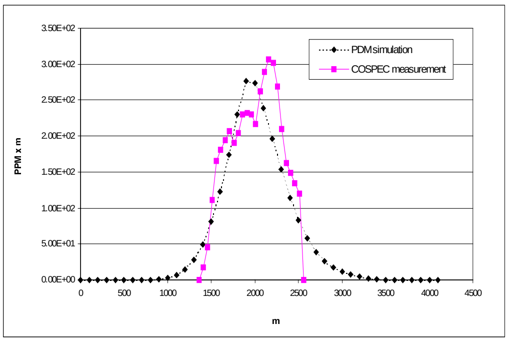

Figure 4b Comparison between simulated and COSPEC integrated along z concentrations (after Caltabiano et al., 1994).

7 Conclusions

The results indicate that the effects of the synoptic circulation are predominant during the diurnal period. During the night, in the first hundred meters the plume follows the terrain according to the local nocturnal downslope breeze, reinforced by the N-NW synoptic wind over the volcano summit. The fact that the volcano is continuously emitting complicates the evaluation of the concentration, part of which remains in the area due to mesoscale re-circulation effects. The qualitatively agreement obtained between model results and remote sensing observations will be further carried on to arrive to the quantitative agreement. This could in turn lead to a general re-normalisation technique by model results, with MIVIS data capable to represent the 3-D cloud distribution for the determination of the SO2 emission from volcanic sources. This will allow in future to use the foreseeable available remote sensing images in the MIVIS spectrum, probably continuously produced in satellite survey, to complete them with 3D flow and dispersion model results. These results were already used to better evaluate the SO2 flux based on COSPEC measurements. Caltabiano et al. (1994), previously determined by the use of the synoptic winds. Starting from the same integrated concentration given by the COSPEC data, and using the wind calculated by RAMS, one obtains a more reasonable total SO2 flux of 700 ton/day instead of the previously estimated 1800 ton/day.

Acknowledgements

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References

Bianconi R., S. Mosca, G. Graziani, 1999*: PDM: a Lagrangian Particle Model for atmospheric dispersion*. EUR Report 17721EN-1999.

Bogliolo, M.P., M.F. Buongiorno, S. Salvi, S. Teggi, S. Pugnaghi, M.J. Abrams, D.C. Pieri, V.J. Realmuto, and T. Caltabiano, 1996*: Ground measurements of physical parameters at Vulcano island and Mount Etna in support of the MIVIS remote sensing campaign «Sicilia-94»*. Pub. 577, Ist. Naz. Di Geofis., Rome.

Bruno N., T. Caltabiano, R. Romano, 1999*: SO2 emissions at Mt. Etna with particular reference to the period 1993-1995*. Bull. Volcanol., 60, 405-411.

Caltabiano, T., R. Romano, and G. Budetta, 1994*: SO2 flux measurements at Mount Etna (Sicily)*. Journal of Geophysical Research, 99, no. 12, 809-819.

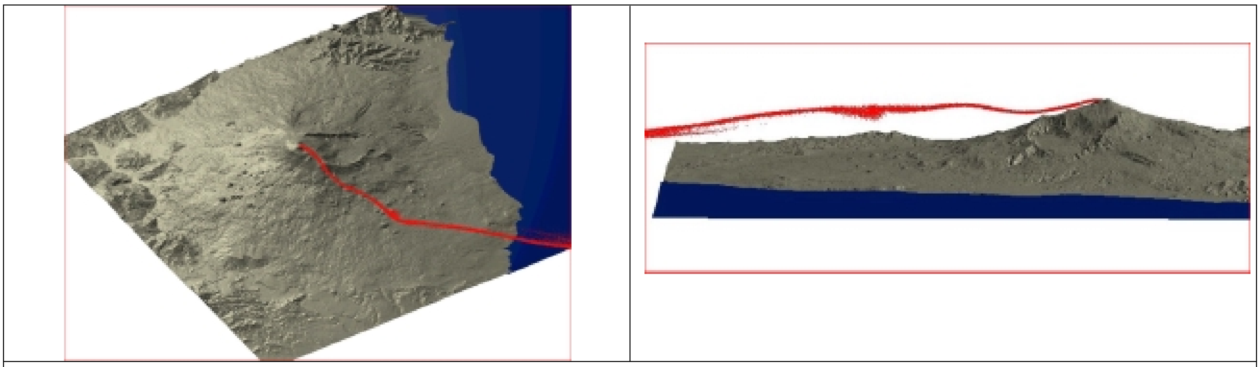
Graziani G, Martilli A., Pareschi M.T., Valenza M*., Atmospheric dispersion of natural gases at Vulcano island*, Journal of Volcanology and Geothermal Research, 75, 283-308, 1997.

Pareschi M.T., M. Ranci, M.Valenza e G. Graziani, 1999: *The assessment of volcanic gas hazard by means of numerical models: an example from Vulcano Island (Sicily)*. Geophys. Res. Letters, Vol. 26, n. 10, 1405-1408.

Pielke R.A., W.R. Cotton, R.L. Walko, C.J. Trenback, W.A. Lyons, L.D. Grasso, M.E. Nicholls, M.D. Moran, D.A. Wesley, T.J. Lee e J.H. Copeland, 1992: *A comprehensive meteorological modeling system - RAMS. Meteorology and atmospheric physics*, 49, 69-91.

Ranci M., G. Graziani e M.T. Pareschi, 1998. *A comprehensive database on synoptic and local circulation over Sicily for mesoscale applications*. Il Nuovo Cimento, 21C (5), 463-483.

Tremback, C.J. e R. Kessler, 1985: *A surface temperature and moisture parametrization for use in mesoscale numerical model*. 7th conference on numerical weather prediction, 17-20 June1985, Montreal, Canada.



Figsure 5a-b 3D views of the simulated plume, 5:00 LST, 25 July

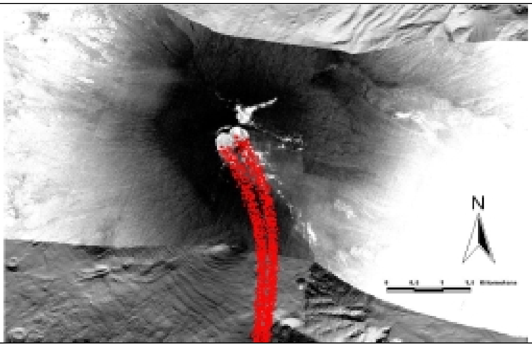


Figure 6 **Simulated plume (red) compared with the MIVIS data (lighter grey levels correspond to the warm plume). On the background the digital elevation model.**