TRANSPORT OF VOLCANIC AEROSOL IN THE TROPOSPHERE: THE CASE STUDY OF THE 2002 ETNA PLUME

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ABSTRACT

We present some preliminary results from an integrated observations and modelling approach to the study of the time and space evolution of the atmospheric composition. In this case, we focus on the increased load of aerosol due to the emission of the Etna volcano which occurred in October and November 2002. Extensive lidar measurements performed during a specific campaign, AVHRR satellite images and numerical simulations performed using the BOlogna Local Area Model (BOLAM) allow to follow the evolution of the aerosol load over southern Italy and to detect some relevant characteristics of the phenomenon.

1. INTRODUCTION

Understanding and forecasting transport events at different space and time scales, from the global to local ones, is a topical point for climate and environmental studies. Observations and modelling must be integrated in order to gain better knowledge and improve planning and mitigation actions.

As an example, lidar observations allow to evaluate the occurrence of specific intense cases of transport of aerosol, and transport modelling can integrate the empirical knowledge helping in the identification of sources. At the same time, the comparison with data leads to verify model skills.

However, in a more integrated scheme, the observations can be assimilated into the model extending methods already developed for 'meteorological' variables. This leads to a feedback that is expected to improve forecasting for one side, and to provide more consistent datasets for the other side (analysed datasets, again according to the meteorological language).

The more relevant goal of this approach is that the integrated use of observation and modelling will build tools suitable to understand phenomena that drive the evolution of the composition of the atmosphere, checking the present knowledge and stimulating novel research.

At the initial stage of the development of such integrated approach, we have used lidar observations of aerosol and numerical modelling of weather conditions to understand some features of dust transport emitted during a volcanic eruption from Etna.

Lidar technique and, in particular, Raman-elastic backscatter lidar, is a powerful tool for aerosol studies, because of the high temporal and vertical resolution and because of its capability to give information about optical and microphysical properties of aerosol. Long-term lidar observations allow characterisation of typical aerosol content, while special measurement campaigns are devoted to investigate occurrences of particular events such as Saharan dust intrusions, forest fires and volcanic eruptions [1], [2], and [3].

As far as aerosol transported over relatively short distances is concerned, far from the atmospheric boundary layer, trajectories of passive particles are a suitable tool to investigate the observed phenomena. Particle trajectories can be either computed in parallel with Eulerian atmospheric models (run-time method) or post-processed from the model outputs (post-mortem-method) ([4]). The latter allows calculations of forward as well as backward trajectories. Here, the run-time method is adopted since there is an interest to analyse forward in time particle dispersion from a point-source. This constitutes a first step for more in depth and detailed studies on transport and diffusion.

In this paper we present a preliminary example of application of this approach. In Sect. 2 the model is described. In Sect. 3 the aerosol observations are reported. In Sect. 4 some results of the numerical simulations are discussed and compared with the data. Finally, in Sect. 5 conclusions are drawn.

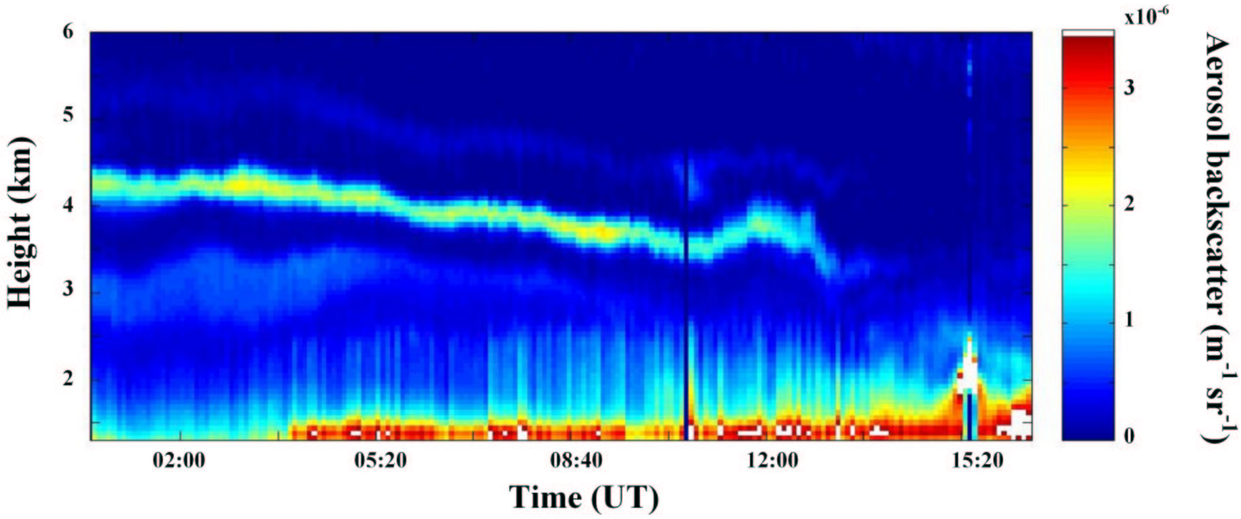

Figure 1. Temporal evolution of the aerosol backscatter coefficient at 532 nm, measured at IMAA on 2 November, 2002. Each profile has a vertical resolution of 60 m and corresponds to 5 minutes of temporal integration.

2. THE MODEL

The model used is the BOlogna Limited Area Model (BOLAM) (see [5]). Model dynamics are based on hydrostatic primitive equations, with wind components u and v, potential temperature, specific humidity, and surface pressure, as dependent variables. The vertical coordinate is terrain-following, with variables distributed on a non-uniformly spaced Lorenz grid. The horizontal discretisation uses geographical coordinates, with latitudinal rotation on an Arakawa C-grid. The model implements an original second-order, forward-backward, advection scheme (WAF, weighted averaged flux). The time scheme is split-explicit, forward-backward for gravity modes. The lateral boundary conditions are imposed using a relaxation scheme ([6], [7]). The water cycle for stratiform clouds is described by means of five prognostic variables (cloud ice, cloud water, rain, snow and graupel) with a simplified approach similar to ([8]). Deep convection is parameterised with a modified Kain-Fritsch ([9]) convective scheme. The surface and boundary layer scheme is based on the mixing-length theory, with exchange coefficients computed as a function of the Richardson number. Surface processes are described by water and energy balances in a three-layer ground model. Radiation is computed with the ECMWF scheme ([10], [11]), including the Rapid Radiative Transfer Model (RRTM).

Trajectories are calculated in parallel with the Eulerian model scheme, by integrating the u, v and $\dot{\sigma}$ fields. The former two are the eastward and northward wind components respectively, and the latter variable corresponds to the vertical velocity in the model coordinates ($\sigma = \frac{P}{P_s}$, where P is the pressure at the generic vertical level, and P_s is the surface pressure). The geopotential height, and surface pressure are then used to obtain the vertical coordinate (z expressed in m).

3. OBSERVATIONS

From the end of October until the end of December 2002, numerous strong events characterised the activity of the largest European volcano, the Mt. Etna, located in Sicily, Italy (37^o 44' N, 15^o E, 3350 m a.s.l.). In particular, on 1-2 November, 2002, AVHRR (Advanced Very High Resolution Radiometer) images show a direct transport of material emitted by Etna towards the peninsular Italy [3].The IMAA lidar station, operational in Potenza (40^o 36' N, 15^o 44' E, 820 m a.s.l.) since May 2000, performed an intensive measurement campaign in order to follow these eruptive events [12]. Fig. 1 shows the temporal evolution of the aerosol backscatter coefficient profile at 532 nm. Each reported profile has been obtained by integrating lidar signals over 5 minutes and with a vertical resolution of 60 m. A considerable aerosol load is evident at about 4 km a.s.l. around midnight of 2 November. An optical characterisation of this layer by means of the lidar ratio, i.e. the ratio between the aerosol extinction and backscatter, and of the backscatter Angstrom coefficient, had lead to assert that in this aerosol layer of volcanic origin there are not large ash particles, but young sub-micron sulfate particles and a low amount of soot [3].The aerosol layer decreases in altitude with the time until 1100 and it joins to underlying aerosol layer in the afternoon. The aerosol layer centre of mass, calculated starting from the aerosol backscatter profile at 532 nm, has a exponential decrease with the altitude and a mean falling speed of 0.017 ms^{-1}. The only sedimentation process cannot explain this fast falling speed for sulfate particle and its behaviour as function of the altitude [13]. Transport modelling could be a powerful tool for investigating the vertical motion of air masses as so for an explanation of the observed vertical behaviour of the volcanic aerosol layer.

4. RESULTS OF THE NUMERICAL SIMULATION

A numerical simulation is performed for a week-time interval from 27 October 0000 GMT up to 4 November 2002, 0000 GMT, which covers the time period for the observations in Potenza. BOLAM is run at 0.2^o,0.2^o resolution. Lateral boundary conditions are updated every six hours using the ECMWF analyses fields available at 0.5^o, 0.5^o resolution. This simulation reproduces the weather evolution during the observation period fairly well. As specified above, we choose to calculate passive particle trajectories during the meteorological run. Trajectories released in different points of the domain and starting at different times have been computed. Here we present some sample results simulating a continuous point source. A few trajectories are reported in Fig. 2. The initial point of the trajectories (the source) is located over the Etna Volcano, and released at heights between 3000 and 5600m. Outputs are reported at a 30-minute-time interval.

As a general comment, all the trajectories starting at 1 November between 1800 and 2 November 0000 GMT reach Potenza in about 12-18 hour-time interval. Fig. 2 shows some trajectories and their location with respect to Potenza. (Intermediate releases will span between the reported trajectories: the synoptic evolution during the period was fairly smooth.)

Fig. 3 shows the height of the trajectories closest to the Potenza site. There is a slow decrease of the height of all the trajectories during 1 and 2 November, indicating the existence of a moderate subsidence over southern Italy. In particular around 12 GMT of 2 November the trajectory (c-labelled) located (at that time) over Potenza shows a strong descending motion. Note that the same observation holds also for the trajectory labelled as b in Fig. 2, at the same time, confirming that there is subsidence over a wide area at that moment. Furthermore, it is worth noting that few hours later the vertical velocity for most trajectories becomes positive.

The vertical motions are qualitatively consistent with the lidar observations (particles observed at about 4000-5500 m a.s.l.). Moreover, estimated values for the vertical velocity are of about 0.023 ms^{-1}, in agreement with the observed speed.

5. CONCLUSIONS

The integrated measurement and modelling approach to investigate the evolution of the atmospheric composition is presented in this preliminary study, focused on the investigation of transport of passive tracer from isolated sources.

The numerical results are fairly consistent with the measurements:

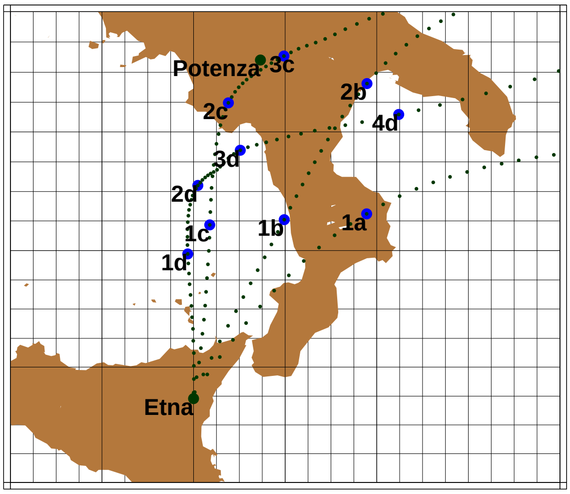

Figure 2. The plot refers to four trajectories released at the Mt. Etna location at a height of about 5600 m a.s.l. Trajectory a originates on the day 1 November at 0600 GMT, b at 1200 GMT, c at 1800 GMT, and d at 2 November 0000 GMT. Increasing numbering provides the particle position after every six hours.

- Most of the particles released between 1 November 1800 GMT and 2 November 0000 GMT reach Potenza in a 12-18 hour-time period and that is consistent with the lidar observations.
- The particle trajectories that are closer to the Potenza location reach vertical heights of about 5000 m, which agree with the lidar observations.
- Trajectories show a subsidence motion over a wide area above southern Italy. In particular, vertical velocities estimated above Potenza are about 0.023 ms^{-1}, reproducing the observed values.

Improvements of the approach will overcome the shortcomings of this preliminary study. For instance, the single (deterministic) trajectory method does not describe directly the observed spreading of the plume. To simulate dispersion, a more refined treatment of the stochastic properties of transport must be considered, related to indeterminacies of the initial condition and to the subgrid parameterisation of velocity. Furthermore, in the present model, transport is driven by the assimilated meteo data, and no assimilation of concentration data is performed. One of the critical aspects shall be the possibility to assimilate transport data, in order to obtain substantial improvements of the atmospheric evolution description.

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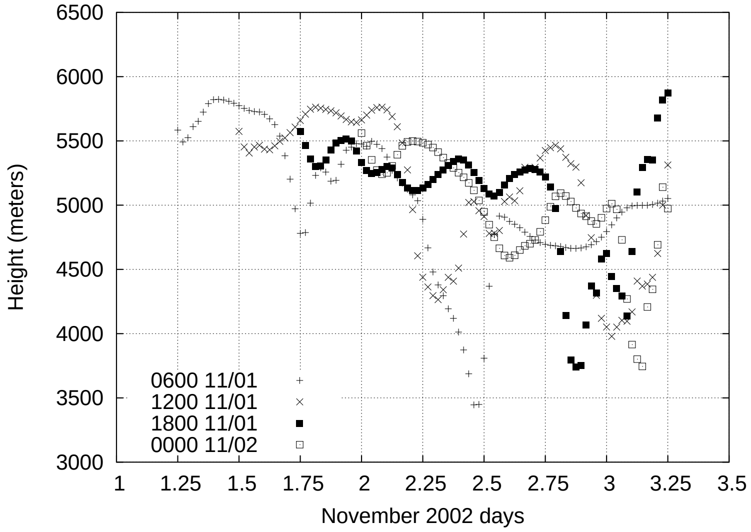

Figure 3. Time evolution from 1 November 0600 GMT for the vertical position of the four trajectories depicted in Fig. 2. Trajectory *c*, at 1 November 1800 GMT, is the closest trajectory to Potenza location.

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