INTERNATIONAL VOLCANIC ASH TASK FORCE (IVATF)
SECOND MEETING
Montréal, 11 to 15 July 2011

Agenda Item 2: Report of the Science Sub-Group

2.2: Situational awareness improvements of impending volcanic eruptions

ERUPTION SCENARIO MODELLING AND FORECASTING: THE EXAMPLE OF MT. ETNA, ITALY

(Presented by the Rapporteur of the Science Sub-Group, in collaboration with the
Istituto Nazionale di Geofisica e Vulcanologia (INGV), Italy)

SUMMARY

The forecasting of aerial ash concentration and ground deposition is a key issue for the assessment of volcanic hazard and risk at Mt. Etna (Italy) due to its frequent explosive activity.

In the past few years, the Istituto Nazionale di Geofisica e Vulcanologia (INGV), in the framework of a project funded by the Italian Ministry of University and Research, has developed a multi-model and multi-scenario web-based forecasting system aimed at improving the situational awareness and preparedness of local and national civil protection authorities before and during the volcanic crisis. The system is based on the simultaneous use of five dispersal codes (based on different numerical approaches and physical formulations) and the simulation of three different eruption scenarios based on the recent eruptive record of the volcano.

Although the system is still in a testing phase, preliminary applications to recent events appear promising and able to provide useful information to the responsible authorities.

1. INTRODUCTION

1.1 Mt. Etna (Sicily, Italy) is a 3,300 m above sea level active volcano characterised by basaltic explosive and effusive activity. In recent years, the volcano has experienced intense paroxysmal explosive activity characterized by abundant release of ash in atmosphere. In particular, since the year
2000, Mt Etna has produced several long-lasting plumes that have seriously impacted the city of Catania (300,000 inhabitants located 30 km from the vent) and the surrounding towns and infrastructures such as local airports and highways (e.g. Andronico et al., 2005). Further, as reported in Guffanti et al. (2009), since 1979 eleven eruptions occurred at Mt. Etna that affected the closest airports (Fontanarossa and Sigonella). In 2000, an airplane reported ash encountering and experienced significant damage. The most recent eruptive activity started in the early morning of May 12, 2011, and was characterized by lava fountaining, and produced a 2-3 km high ash cloud that was directed toward SE by the main winds. Ash fallout was reported in the SE part of Sicily Island, and the Fontanarossa Airport was closed for one entire day due to ash presence.

1.2 In order to improve the situational awareness and preparedness of local and national civil protection authorities, before and during the volcanic crisis, the Istituto Nazionale di Geofisica e Vulcanologia (INGV) has developed a web-based platform where ash dispersal forecasts, based on a multi-model and multi-scenario approach, were illustrated and made available. Although the system is still under development and testing, it has already provided quite useful information during the most recent volcanic crises at Mt. Etna. In the following section, a brief illustration of the main aspects of the multi-model and multi-scenario approach being developed is provided.

2. DISCUSSION

2.1 The multi-model approach

2.1.1 Several numerical codes have been developed and used by the volcanological and atmospheric communities to describe the dispersal and deposition of volcanic ash under the action of prescribed meteorological conditions. Typically they are used to provide a fast description of the future dispersal pattern of the ash cloud in a deterministic way, and a single simulation forecast is often the only description produced of an on-going or future scenario event. However, this practice does not provide indications of the accuracy of model results or the uncertainty related to the forecasting of a future eruptive event.

2.1.2 In order to overcome the limitations implicit in choosing a specific numerical model and therefore to explicitly consider the modelling approximations, the INGV approach adopted different numerical codes to simulate each eruptive scenario considered (Bonadonna et al., 2011; Neri et al., 2009; Scollo et al., 2009). Each day, five different codes are executed to produce cumulative ash deposit maps and aerial ash concentration maps at specific altitudes above ground. The dispersal codes used are: TEPHRA (Bonadonna et al., 2005), HAZMAP (Macedonio et al., 2005), PUFF// (Scollo et al., 2011), FALL3D (Costa et al., 2006), and VOL-CALPUFF (Barsotti et al., 2008). The five models differ under several aspects that are briefly summarized in Table 1. It should be noted that, due to the specific characteristics of each model, just three of them (FALL3D, PUFF//, and VOL-CALPUFF) can be used to produced maps of ash concentration in the atmosphere.

2.1.3 Such a multi-model approach allows quantification of the model-dependent uncertainty characterizing the modelling capability. In fact, the five numerical codes, based on different modelling approach (e.g. Eulerian vs Lagrangian), different physical formulations of the process, as well as different numerical algorithms, provide independent representations of the phenomenon. Quantitative comparisons between different model results were performed estimating key variables of the volcanic plume, ash cloud, and ground deposit. Some of most important are the plume height, the main dispersal axis of the cloud, the ash cloud aerial extension and shape, as well as the tephra ground deposition at specific locations (Neri et al., 2009).
<table>
<thead>
<tr>
<th>CODE NAME</th>
<th>TYPE</th>
<th>SOURCE DESCRIPTION</th>
<th>OUTPUT</th>
<th>METEO DATA</th>
</tr>
</thead>
<tbody>
<tr>
<td>FALL3D</td>
<td>Advection-diffusion</td>
<td>User-defined (both predefined and computed)</td>
<td>Aerial concentration and ground deposit</td>
<td>Transient, 3D</td>
</tr>
<tr>
<td>(Costa et al. 2006)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HAZMAP</td>
<td>Advection-diffusion</td>
<td>User-defined (pre-defined)</td>
<td>Ground deposit</td>
<td>Transient and steady, 1D</td>
</tr>
<tr>
<td>(Macedonio et al. 2005)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PUFF//</td>
<td>Lagrangian</td>
<td>User-defined (pre-defined)</td>
<td>Aerial concentration and ground deposit</td>
<td>Transient, 3D</td>
</tr>
<tr>
<td>(Scollo et al. 2011)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TEPHRA</td>
<td>Advection-diffusion</td>
<td>User-defined (pre-defined)</td>
<td>Ground deposit</td>
<td>Steady, 1D</td>
</tr>
<tr>
<td>(Bonadonna et al. 2005)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VOL-CALPUFF</td>
<td>Hybrid (Eulerian-Lagrangian)</td>
<td>Computed</td>
<td>Aerial concentration and ground deposit</td>
<td>Transient, 3D</td>
</tr>
<tr>
<td>(Barsotti et al. 2008)</td>
<td></td>
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</tbody>
</table>

Table 1: The numerical codes used in the INGV system and their main characteristics.

2.2 The multi-scenario approach

2.2.1 During its eruptive history, Mt. Etna has shown a large variety of explosive styles, from long-lasting weak plumes to short-lived quite intense paroxysm (strong plumes). Due to the unpredictability of the next eruptive event and the uncertainties affecting the eruptive source, the INGV system adopted also a multi-scenario approach (Barsotti et al., 2008; Scollo et al., 2009). In particular, the five models described above were used to produce forecasting maps for three different kinds of plausible explosive scenarios. These consist of two prolonged low-intensity explosive events (weak plumes) and a more intense event lasting few minutes (strong plume). Table 2 reports the main parameters of the three scenarios defined.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Duration</th>
<th>Intensity (kg/s)</th>
<th>Grain-size</th>
<th>Reference eruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weak Plume (1)</td>
<td>continuous</td>
<td>5.0 \times 10^3</td>
<td>2\pm1.5 \Phi</td>
<td>2001</td>
</tr>
<tr>
<td>Weak Plume (2)</td>
<td>continuous</td>
<td>1.0 \times 10^5</td>
<td>0.5\pm1.5 \Phi</td>
<td>2002</td>
</tr>
<tr>
<td>Strong Plume</td>
<td>5 min.</td>
<td>1.0 \times 10^6</td>
<td>-0.5\pm1.5 \Phi</td>
<td>1990-1998</td>
</tr>
</tbody>
</table>

Table 2: Main parameters of the three eruption scenarios considered at Mt. Etna.

2.2.2 The two weak-plume scenarios roughly correspond to plume heights of 2-4 km above ground level (AGL) approximately matching the intensities observed during the sustained activity of 2001 and 2003. In comparison, the strong plume scenario was fixed to a single specific intensity corresponding to a plume height of about 8 km AGL (in a still atmosphere), due to the fewer examples of this kind of
activity historically reported. In the forecasting procedure, each scenario is assumed to start each three hours since 00UTC of each day, and the forecasting temporal window is 48 hours long. The weak plume scenarios are characterized by a 3-hour long continuous emission, whereas the stronger event is assumed to have an impulsive character with emission of 5 minutes.

2.2.3 The key idea of the forecasting system is therefore to provide a range of ash dispersal forecasts, each one associated with a different hypothetical scenario pre-defined on the basis of the past and recent activity of the volcano. In this way, it is possible, to some extent, to account for the intrinsic unpredictability of the volcano’s behaviour.

2.3 Forecasting maps and the web-site

2.3.1 Volcanic ash can have an impact on a quite wide range of spatial scales. Given the relatively small-scale activity expected at Mt. Etna, the INGV forecasting system adopted a regional domain of 170x170 km² which includes the Eastern part of Sicily and the Calabria tip (see Figure 1 below). In this limited area, three main airports are included: Fontanarossa International airport (located 30 km from the vent), Sigonella airport (35 km away from the vent) and Reggio Calabria airport (65 km away from the vent).

2.3.2 Over this domain, both cumulative ground deposition and aerial ash concentrations are mapped. The cumulative deposition is computed as the total ash loading accumulated on the ground three hours after the beginning of the eruption. The 2D maps report six contour lines corresponding to values of 1 up to 5x10³ g/m².

2.3.3 A more complex representation is required to map the 3D ash concentration in the atmosphere. In this case, 2D aerial ash concentration maps are reported at three specific altitudes. The altitudes correspond to three flight levels of relevance for flight operations (e.g. take off and landing). Each code produces ash concentration maps at FL060, FL120 and FL180 every three hours, plotting concentration contours corresponding to 2x10⁻⁴, 2x10⁻³ and 4x10⁻³ g/m³. In addition to these maps, the codes compute also the ash columnar content over the entire vertical extension of the ash cloud. For this variable the plotted thresholds are 10⁻², 10⁻¹ and 1 g/m². This last cumulative information provides at a glance the significant ash concentration values by spatial sector of interest, independently from the altitude of the ash.

2.3.4 A web-site (http://dbstr.ct.ingv.it/upnv/) administered by INGV-Osservatorio Etneo, Unità di Progetto Nubi Vulcaniche, each day uploads and manages all the produced 48-hours forecasting maps valid for the current day. The authorized user can have access to the outputs of each model in addition to a synthesis map which contains the outcomes coming from all the adopted models and shows the areas of complete or partial agreement between models for each plotted variables and for each simulated scenario. As an example, Figure 1 below shows a snapshot of the web-site page illustrating the cumulative columnar content as produced on May 12, 2011. The activity occurred on that day showed a 2-3 km high column (above the vent) and lasted more than one hour starting on 0400 UTC. Figure 1 shows the simulated scenario closest to the real event; i.e. the weak plume I scenario started at 0300 UTC and lasted until 0600 UTC on 12 May 2011.
Figure 1: Example of ash dispersal forecasts as provided by the INGV system. Plots refer to the columnar content as computed by three models (FALL3D, PUFF, and VOL-CALPUFF) and their combination (bottom-right plot). The maps correspond to the forecasts produced during the recent activity occurred at Mt. Etna on 12 May 2011 at 0400 UTC.

Model forecasts were remarkably consistent with the observations carried out by the Osservatorio Etneo that actually recorded significant fallout in the SE direction.
3. **SUMMARY**

3.1 The INGV system developed for Mt. Etna is a first step towards producing a robust forecasting tool able to help civil protection and air traffic authorities in the management of volcanic risk associated with ash dispersal and deposition at that volcano.

3.2 The system aims to account for the main sources of uncertainty by adopting a multi-model and multi-scenario approach. This goal is achieved by adopting five different numerical codes of ash dispersal and deposition and by simulating three different plausible eruptive scenarios based on the volcano eruptive record. Although the system does not express the forecast results in probabilistic terms or explicitly quantify the uncertainty affecting the results, it has been proved to effectively communicate the different sources of uncertainties that affect the system.

3.3 First applicative tests of the system carried out during recent eruptive events at Mt. Etna were promising and able to illustrate the potentialities and limits of the approach.

3.4 Research work is in progress to better quantify the accuracy of the different models as well as to express the uncertainty affecting the forecasts in a quantitative way. A further long-term step forward should consist of linking selected and representative monitoring data to the eruptive scenario forecasts.

4. **ACTION BY THE IVATF**

4.1 The IVATF is invited to note the contents of this information paper.
APPENDIX

REFERENCES


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