Remote sensing for ground deformation analysis during the eruptive event of July 2001 at Mt. Etna

Alessandro Bonforte (1), Carlo Colesanti (2), Alessandro Ferretti (3), Francesco Guglielmino (1), Mimmo Palano (4), Claudio Prati (2), Giuseppe Puglisi (1) and Fabio Rocca (2)

(1) Istituto Nazionale di Geofisica e Vulcanologia, Piazza Roma, 2, 95123 Catania, Italy
(2) POLIMI-DEI, Piazza Leonardo da Vinci, 32, 20133 Milano, Italy
(3) Tele-Rilevamento Europa S.r.l., via Vittoria Colonna, 7, 20149 Milano, Italy
(4) Università degli Studi di Catania, Corso Italia, 55, 95129 Catania, Italy

The July - August 2001 Mt Etna eruption has been studied using the DinSAR technique and monitored through both continuous GPS measurements on a network of permanent and static stations, as well as daily static and kinematic GPS measurements, made by INGV-CT, on geodetic networks. This eruption, one of the most important lateral eruptive events in the last 30 years, was characterized by an unusual eruptive style, with lava flow emissions at different altitudes along a complex fracture system. A seismic swarm started on July 12th 2001, with most of events located beneath the upper southern flank of the volcano. The number of the daily events gradually decreased until July 18th. The eruption began with the opening of the eruptive vents occurred between 2700, 2500 and 2100 m of altitude, from July 17th to 19th. Lava flows came out from these vents and covered the upper and middle southern flanks of the volcano. A little flow came out also on the north-eastern flank, from an eruptive fracture opened later in the Valle del Leone area.

We started our analysis considering the ground deformation measured by the GPS network during the one-year period preceding the eruption, by comparing the GPS survey carried out on the whole network, just before the emplacement of the dyke, to that carried out in July 2000. The data showed a general radial spreading of the volcano, with an uplift centred on its upper north-western flank. Such a deformation was inverted using a pressure source model, located beneath the upper western flank. To refine the modelled deformations on the eastern and southern flanks, two sub-horizontal dislocation planes beneath the southern and eastern flanks, already modelled by previous GPS data (Bonforte and Puglisi, 2003), were added to the inversions.

The first six months of the same interval were also investigated by DInSAR data, by coupling the August and December 2000 ERS-2 ascending passes. The interferogram shows an uplift (1 fringe) of the summit area and an apparent subsidence (2 fringes) on the lowest flanks (at the scale of the entire volcano). Because the subsidence was not visible on the GPS data previously analysed, we suspected that this might be the effect of the troposphere, as already occurred in interferograms studied in previous works. We tried to model the tropospheric effect related to the topography; this correction removed the two fringes on the external part of the volcano, leaving the uplift of the summit part. The synthetic interferogram resulting by the combination of the sources modelled from GPS data is quite similar to the filtered DInSAR interferogram.

The second half of the year preceding the eruption was investigated by GPS data. In that case the network was smaller than that considered previously; in fact, the GPS survey carried out on January 2001 was aimed at measuring ground deformation eventually produced by a seismic swarm occurred that month and it covered only the lower southern-eastern part of the volcano. The comparison between this survey and that carried out before the July 2001 eruption shows a marked uplift of the uppermost station (at about 1000 m of altitude), suggesting that the uplift of the upper part detected by DInSAR was continuing down slope. Furthermore, GPS data show also subsidence on a narrow NNW-SSE trending area, coinciding with the “Timpe” fault system. This feature is probably a local effect of the faults, so that the model proposed for this period considers two NNW-

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SSE dislocation planes whose movement, together with the eastern sub-horizontal plane before considered, can justify the observed deformation pattern.

At the beginning of 2001, ERS-2 gyroscopes had serious mechanical problems and they could not be used to get the necessary platform attitude information. As a consequence, the Doppler Centroid of ERS-2 images varied randomly from one observation to the next thus making the generation of SAR interferograms impossible. A back-up attitude control system was activated and tuned by the ESA-ESRIN staff, and in June 2001, the interferometric capability of ERS-2 was partially recovered. In fact, the POLIMI team, in cooperation with T.R.E. (POLIMI commercial spin-off), was able to obtain clear surface deformation maps related to the June 5th, July 11th and August 15th 2001 passages.

The interferogram resulting by combining the June 5th and July 11th ascending passes shows only a wide uplift (2 fringes), affecting the entire volcano, as already deteceted by GPS data. Fortunately, the July 11th 2001 ERS-2 ascending pass occurred just before the beginning of the seismic crisis accompanying the dyke intrusion. A preliminary analysis of the interferogram resulting by coupling this passage with the next one occurred on August 15th, shows an extremely interesting pattern that appears associated to the ground deformation produced during the eruptive events. The volcano is split into two different areas showing opposite deformation on the two sides of the dyke. In particular, the eastern area located in the Valle del Bove shows a strong subsidence, while the western area shows an opposite behaviour with an evident uplift.

Throughout the pre-eruptive and eruptive periods, several GPS surveys were carried out on Etna. These GPS data allowed the near real time monitoring of the eruption and, by accurate post processing and data inversions, to obtain an accurate eruptive model.

During the days of the dyke intrusion, GPS measurements were carried out in kinematic mode on the southern half of the N-S profile. On July 17th, these measurements detected strong displacements on the upper southern part of the volcano, due to the dyke intrusion that, indeed, reached the surface between July 17th and July 19th. Particular attention was paid to the analysis of the kinematic GPS data collected almost daily since July 18th along the E-W profile. Displacements observed between 25th and 27th July highlighted a deformation episode occurring in the area of the 1989 fracture system (Bonforte et al., in print). Data inversion located two deformation sources: a narrowing of the eruptive dyke and a dextral dislocation NNW-SSE trending fault, on the upper south-eastern flank of the volcano, which movement is in agreement with the sliding movement of the eastern flank of the volcano.

The GPS survey carried out on whole network in September 2002, confirmed the strong deformation of the edifice, showing displacements vectors of several tens of centimetres on the upper part, characterised also by significant subsidence. The intensity of deformations progressively decreases from higher to lower altitudes, becoming negligible along the coastline. The model obtained by inverting these data defines a complex framework of ground deformation sources, that were active in summer 2001, which includes the dyke, the NNW-SSE fault and the sub-horizontal planes. The ground deformation pattern calculated from this model, produces GPS displacement vectors in good agreement with the observed ones, as well as the synthetic interferogram in agreement with that obtained from the July-August pair.

After the earthquake occurred in October on the lower south-eastern flank of the volcano, another GPS survey was carried out on the same area surveyed in January. The resulting displacements from September to October 2001 show a significant deformation of the lowest flank that gradually decreases towards the upper part. The model obtained form the inversion of these data confirms the same structural framework of this sector of the volcano already assessed for the January – July 2002 period; it is characterized by two vertical planes (Timpe faults) an the eastern sub-horizontal plane.

In summary, we can affirm that the deformation of the volcano from 2000 to 2001 was mainly produced by a deep pressure source and to the shallow eruptive dyke, whose effects were superimposed to the sliding of the eastern sector.

References

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