3D temporal evolution of displacements recorded on Mt. Etna from the 2007 to 2010 through the SISTEM method

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A study of the ground deformation pattern of Mount Etna volcano, based on the results of the SISTEM (Simultaneous and Integrated Strain Tensor Estimation from geodetic and satellite deformation Measurements) integration method is reported.

In this work ground motion data provided by GPS surveys are integrated with the interferometric synthetic aperture radar (InSAR) Envisat data, collected from 2007 to 2010, to provide 3D displacements maps.

In particular, we performed a Persistent Scatterers analysis of the ENVISAT data, in order to reduce the noise which affected the interferometric phase, such as temporal and geometrical decorrelation problems, topographic effects and orbit errors, as well as atmospheric artifacts.
Mean ascending line-of-sight ground velocity (mm/yr) referring to the 2007 to 2010 time span.

These maps were obtained using the persistent scatterer software, known as StaMPS/MTI [Hooper 2008], using all of the available ENVISAT ascending data that were acquired for Mt. Etna from 2007 to 2010. The main discontinuities in the permanent scatterers velocity field detected by Bonforte et al. [2011] are shown as brown line.
Time series from permanent GPS network (2007-2010)
slope distance EMAL-EMEG (on the Mt. Etna Western flank)

June 2007 – May 2008
Pre-eruptive INFLATION

13 – May 2008
ERUPTION

May 2008 – Aug 2008
Post-intrusion DEFLATION

Aug 2008 May 2010
Post-intrusion inflation following the end of the 2008 intrusion

The inflation started before the end of the eruption

The mean LOS velocity maps were not adequate to depict this complex kinematic
Unwrapped phase time series

Ascending

Descending
Displacement vectors from the 3 GPS surveys carried out through the year before the eruption onset evidence a slow inflation of the volcano coupled with an eastward movements of the eastern flank.

This is confirmed by the ENVISAT data.
Displacement horizontal vectors and height variations from SISTEM integration. The arrows represent the horizontal displacement vectors, while the vertical displacement is presented by a color map.

The main discontinuities in the permanent scatterers velocity field detected by Bonforte et al. [2011] are shown as brown lines.

This image evidences clearly the inflation of the volcano coupled with an eastward movements of the eastern flank.
For investigating the short term deformations we consider:
- the deformation map from ascending ENVISAT pair 26 Mar. ‘08 – 04 Jun. ‘08 (B⊥ 279 m)
- the deformation map from descending ENVISAT pair 7 May ‘08 – 16 Jul. ‘08 (B⊥ 154 m)

The comparison between ascending and descending views highlights that the deformation pattern is no symmetric; eastward more fringes than westward.
**Thus the intrusion is not vertical.**

On both images is evident a rapid decay of the deformation gradient.
The deformation vectors measured the days or weeks across the eruption onset confirm the rapid decay of the deformation gradient. Around the summit craters, in the nearby of the eruptive fissures, are present the largest vectors (in the order of 80 cm 1 m). At 1500 m a.s.l. the vectors are ~ 1 cm.
The model from 2008 short term GPS vectors

Parameters of the deformation sources inferred by using a GA-based inversion. The dike is 3.7 m thick, 2.6 Km long and 0.5 km width.

Dislocation (Okada) source

<table>
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<th>Searched Parameters</th>
<th>Returned value</th>
<th>minimum</th>
<th>Maximum</th>
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Parameters of the deformation sources inferred by using a GA-based inversion. The search confirms that the dike is relatively shallow and that it is W-dipping. It passes beneath the summit craters area.
For investigating the long term deformations we consider:
- the displacement vectors obtained by comparing the June 2007 and June 2008 GPS surveys
- the deformation map from ascending ENVISAT pair 25 Jun. ‘07 – 04 Jun. ‘08 (B⊥ 32 m)

Both data set point out the decay of the gradient of the deformation at about 1500 m a.s.l. **Thus the intrusion is not deep.** The deformation is shaped by the NE Rift.
Results of the SISTEM

Values (cm)

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Errors (cm)

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The results agree with the structural framework of the intrusion. The northward evolution of the dyke is fine depicted. The deformation passes along the NE Rift. The Ripe della Naca fault plays a release role in the ground deformation pattern.
A detailed analysis of the geophysical processes acting at different spatial and temporal scales was performed by using the CGPS network (Aloisi et al. 2011). In particular, the variation of area calculated for two triangles:

(i) The first related to three summit GPS stations (EPDNEPLUECPN; black rhombi)
(ii) The second related to three intermediate altitude GPS stations (EMCN ESLN EMEG; white squares)

This two triangles showed a different behavior, allowing us to separate the analyzed period into three different phases:

The first phase (May 2008–August 2008), both the triangles showed a similar trend - DEFLATION
The second phase (August 2008–June 2009), showed a more complex deformation pattern.
The third phase (June 2009–May 2010), following the end of the 2008 eruption, both the triangles showed a similar trend. - INFLATION

The STAMPS ascending unwrapped phase is the only available data for this temporal interval.

It is evident an overall deflation following the beginning of the 2008 eruption.
Ground deformations after the 2008 intrusion – II° phase (August 2008–June 2009)

GPS Surveys

The GPS surveys show a slight deflation of upper part of the volcano, with a significant lowering of the uppermost NE-rift, and a strong sliding of the eastern flank.
Ground deformations after the 2008 intrusion – II° phase (August 2008–June 2009)

The second phase (August 2008–June 2009), showed a more complex deformation pattern with a lowering of the summit area and an uplift at lower heights.
Ground deformations after the 2008 intrusion – III° phase (June 2009–May 2010)

Post Eruptive period

The GPS surveys show an overall inflation of the volcano, with a sliding of the eastern flank characterized by a significant motion located between the Pernicana Fault and Santa Venerina Fault.
Ground deformations after the 2008 intrusion – III° fase (June 2009–May 2010)

SISTEM RESULTS

The third phase (June 2009–May 2010), following the end of the 2008 eruption, was characterized by an inflation over the entire scale of the volcano.
In this work, we propose an in-depth analysis of the SISTEM results using the ENVISAT STAMPS unwrapped displacements coupled with the GPS surveys collected at Mt. Etna from 2007 to 2010.

We perform the analysis of:

Pre-eruptive (June 2007-May 2008)
- characterized by one year of slow inflation and summit activity (frequent fire fountains).

Sin-eruptive (May 2008 -June 2009)
- The ground deformations recorded across the 2008-09 eruption onset; Dike intrusion
- The short term ground deformations after the 2008 intrusion (May 2008–August 2008); Deflation
- The long term ground deformations after the 2008 intrusion (August 2008–June 2009); characterized by a complex deformation pattern with a subsidence of the summit area and an uplift at lower heights

Post-eruptive (June 2009 – May 2010)
- Characterized by one year of slow inflation
Thanks