The Santorini inflation episode: from start to finish

Ioannis Papoutsis[1,2], Xanthos Papanikolaou[2], Mike Floyd[3], Kang Hyeun Ji[3], Charalampos Kontoes[1], Demitris Paradissis[2], Demitris Anastasiou[2], and Athanasios Ganas[4]

[1] Institute for Astronomy, Astrophysics, Space Applications & Remote Sensing / National Observatory of Athens

[2] Dionysos Satellite Observatory / National Technical University of Athens

[3] Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology

[4] Institute of Geodynamics / National Observatory of Athens

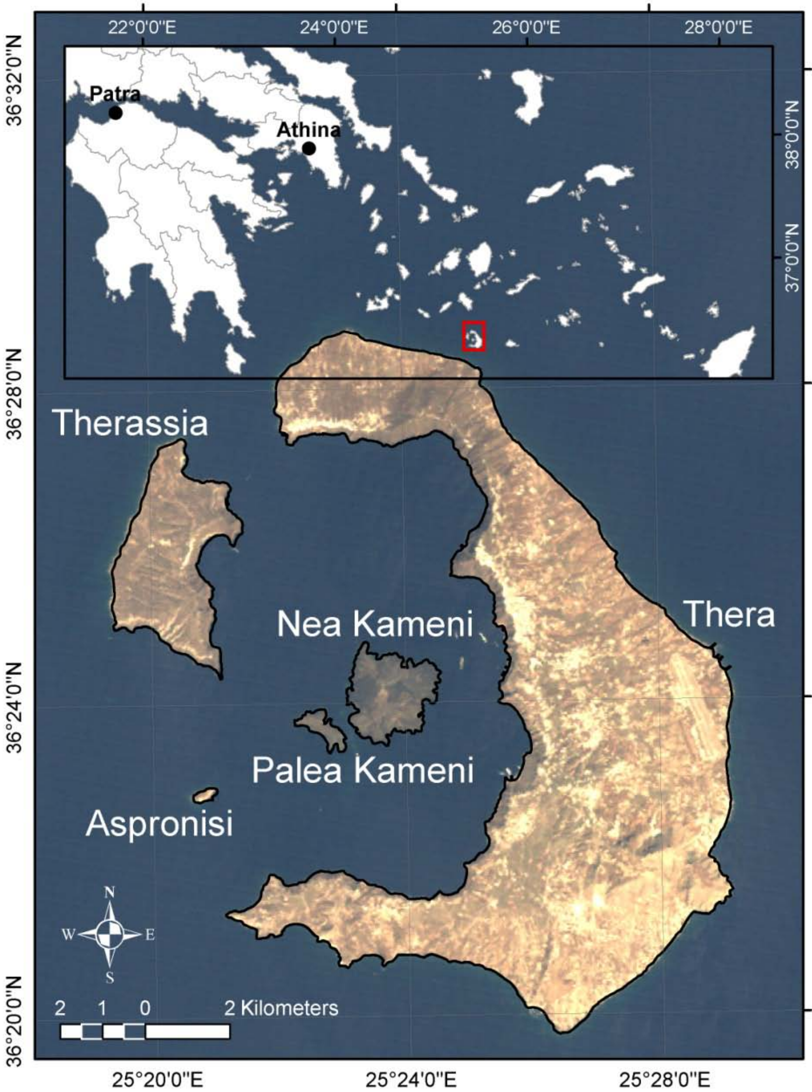
Background information on Santorini

- Santorini Volcanic Complex is the most active part of the South Aegean (Hellenic) Volcanic Arc.

- Several eruptions led to the present form of the Kameni islands (197 BC, 46 AD, 726, 1570, 1707, 1866, 1925, 1939, 1950)

- Most recent seismic sequence ended in 1950

- Since then, Santorini volcano has been in a ‘quite’ phase, with insignificant deformation (confirmed by GPS and InSAR)



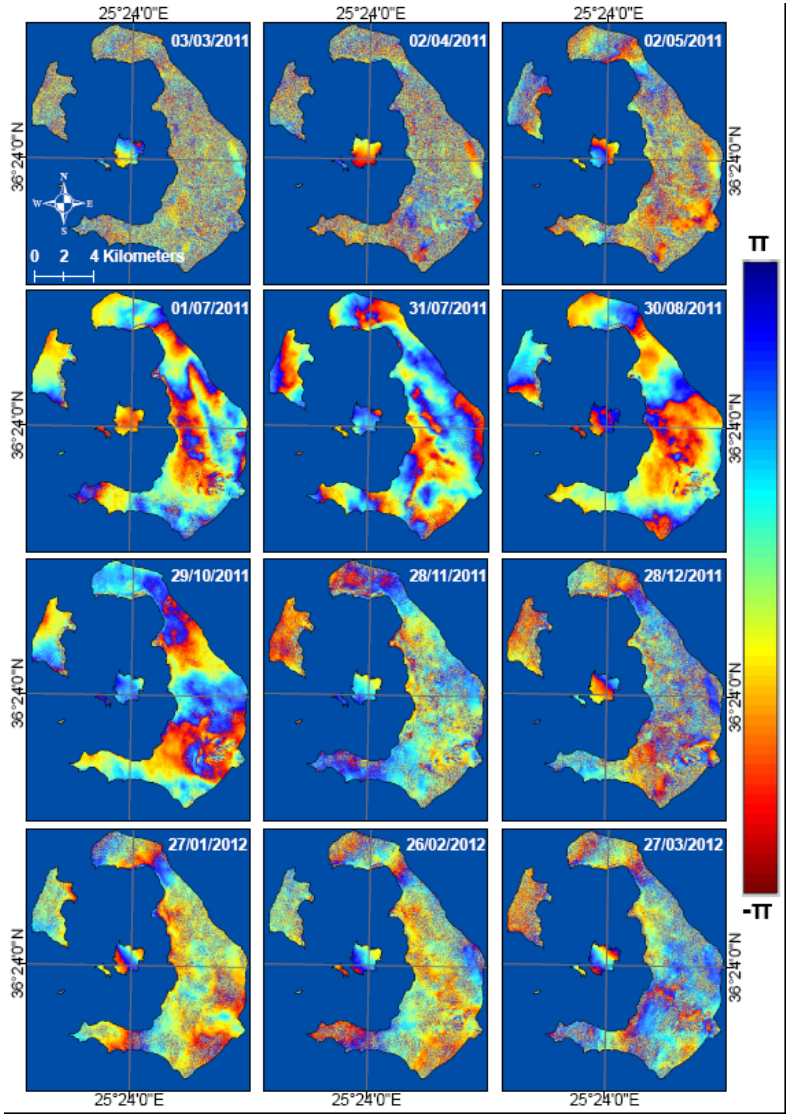
Recent publications on Santorini

- Newman et al., Geophysical Research Letters, March 2012
  - ➢ Conducted GPS campaigns to quantify unrest for the first time
  - ➢ Modeled volcanic source using a Mogi model
- Parks et al., Nature Geoscience, Sept. 2012
  - ➢ Used stacked Envisat and TerraSAR-X inteferograms
  - ➢ Concluded that shallow magma chamber is charged episodically by high-flux batches of magma in Santorini
- Papoutsis et al., Geophysical Research Letters, Jan. 2013
  - ➢ Applied PSI and SBAS on ENVISAT data
  - ➢ Analyzed data from 10 cGPS
  - ➢ Claimed that the unrest episode has ended
- Subsequent pubs (Parks et al./EPSL/July2013; Feuillet/GRL/July2013; Foumelis et al./GJI/April2013; Lagios et al./Tectonophysics/March2013; Tassi et al./Bul. Of Volcanology /March2013, Chouliaras et al./NHESS/April/2012)

Input data and methodology

Satellite interferometry – PSI & SBAS

- 13 ASAR ENVISAT, descending mode
- Last orbit before the end of the mission in April 2012
- Short spatial & temporal baselines
- Swath I6, leading to increased sensitivity to the E-W horizontal components
- S/W: Gamma, ROI_PAC, DORIS, StaMPS (Hooper et al., JGR, 2007)
- PSI challenging due to the limited number of scenes
- Oversampling by a factor of 2

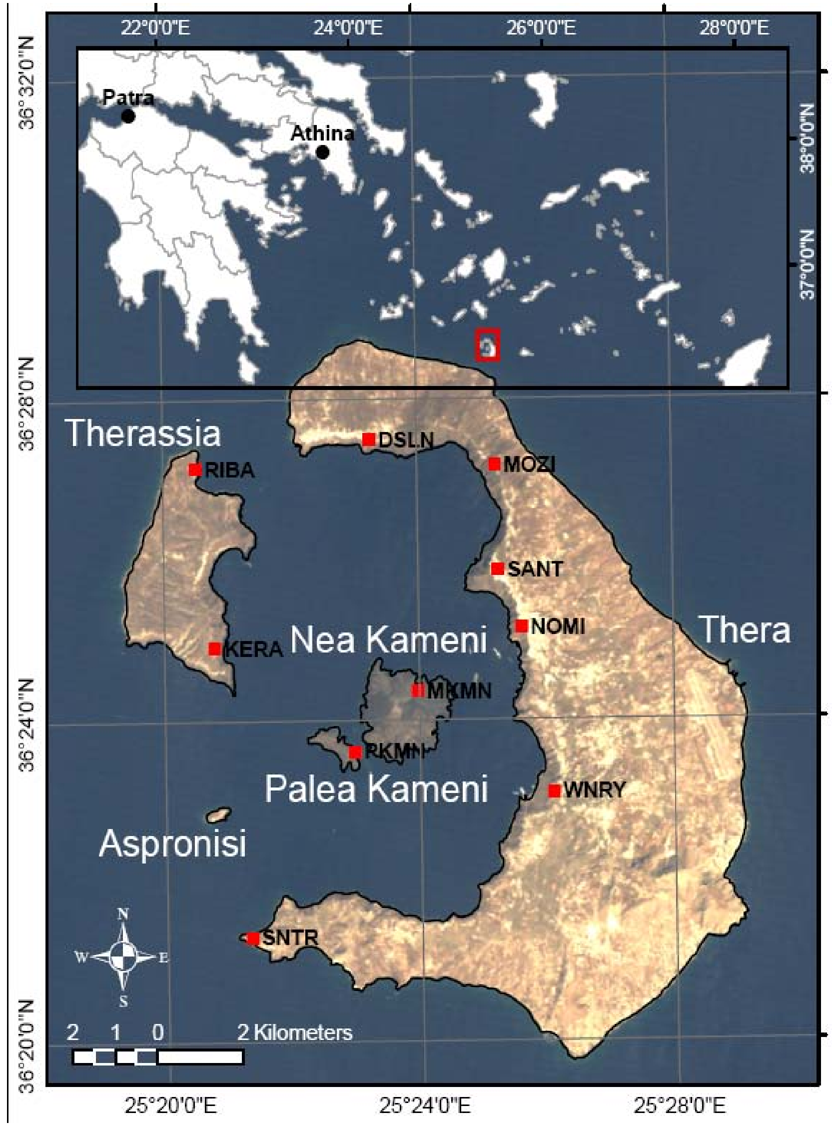


Input data and methodology

GPS

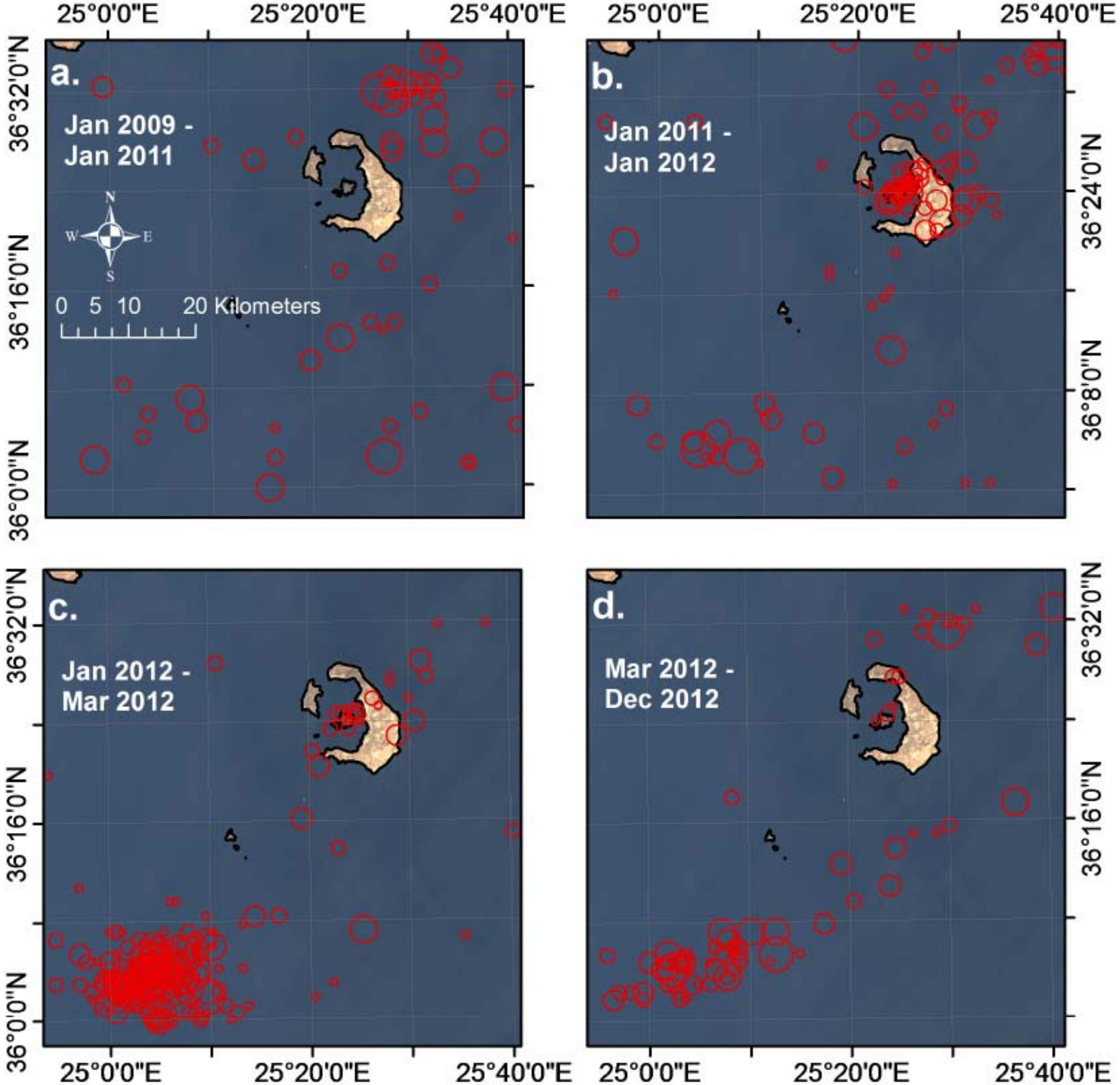
Receivers installed and maintained by:

- UNAVCO
- NTUA
- Georgia Tech/University of Patras
- COMET/University of Oxford
- NOANET/NKUA



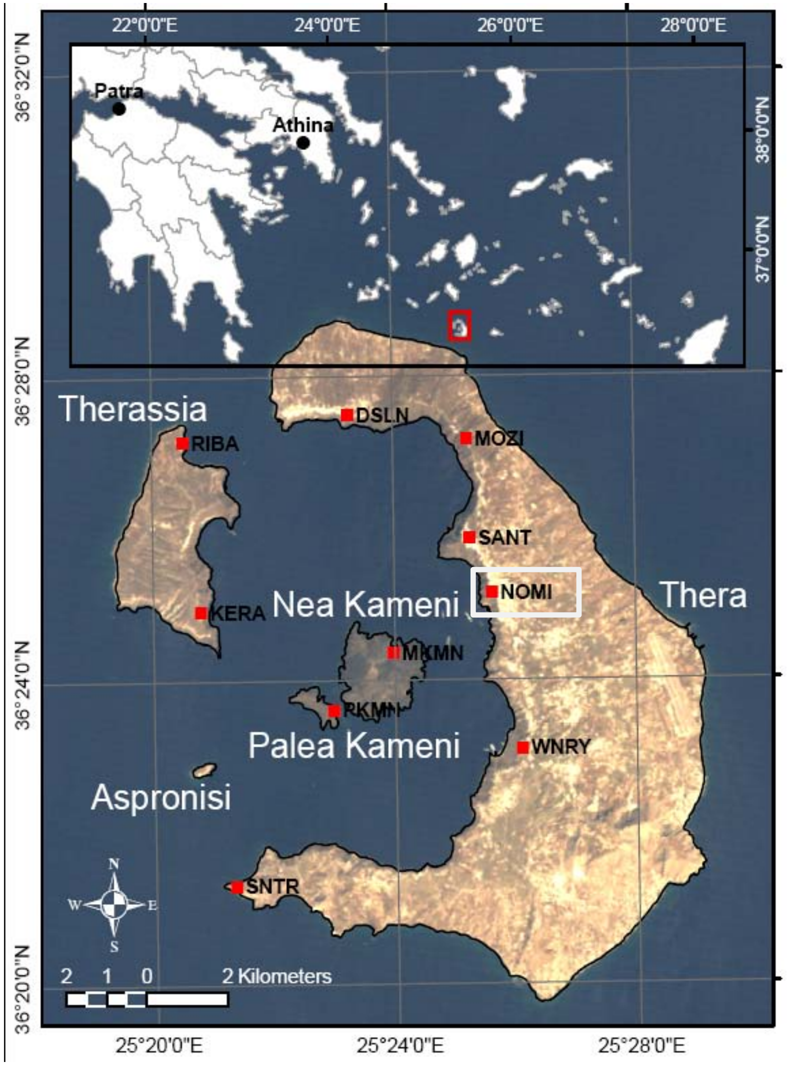
The 2011-2012 unrest

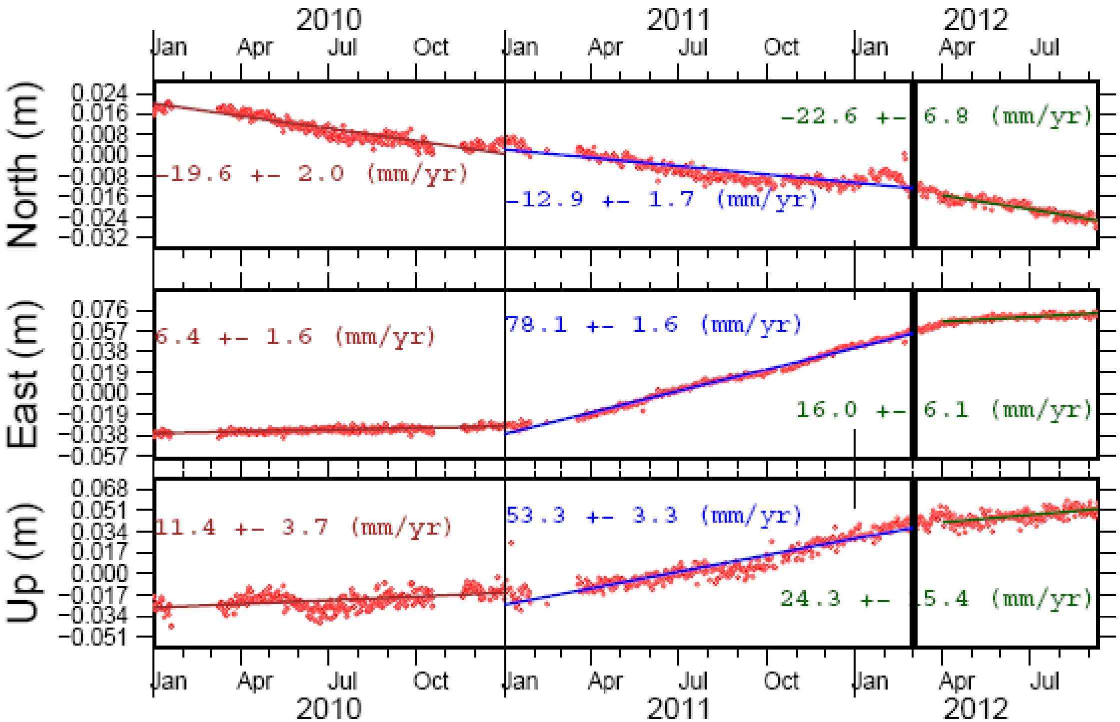
Seismicity



The 2011-2012 unrest

Deformation field - GPS

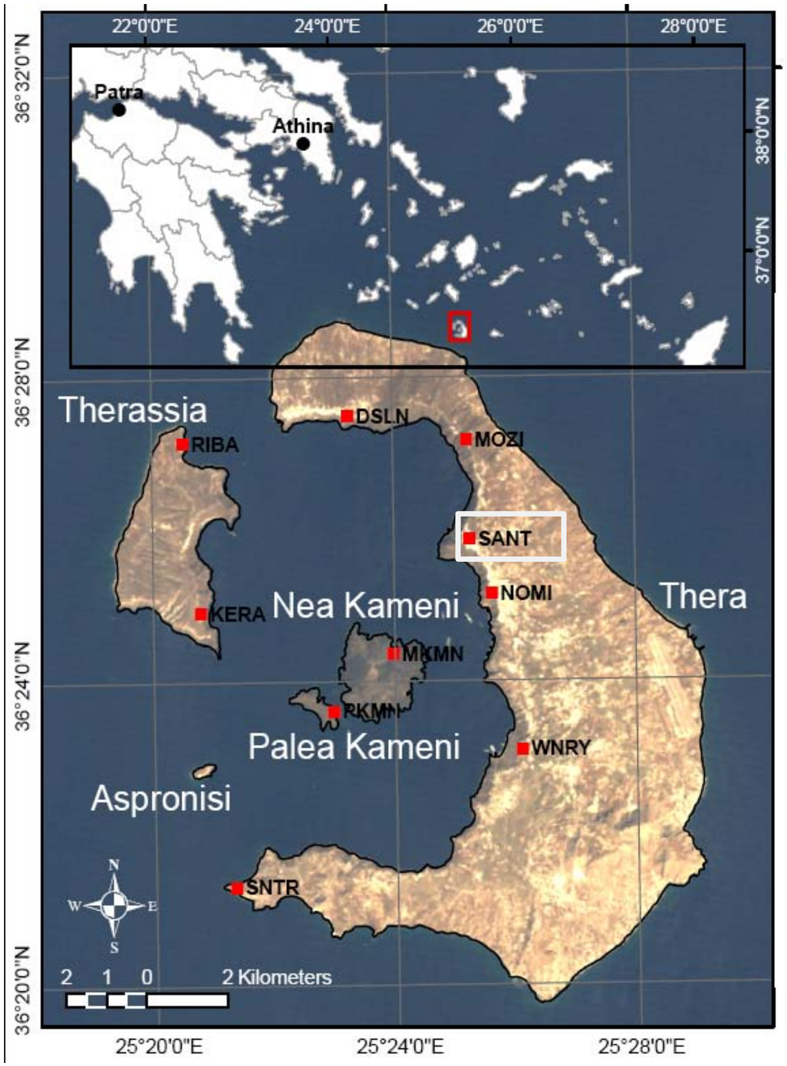




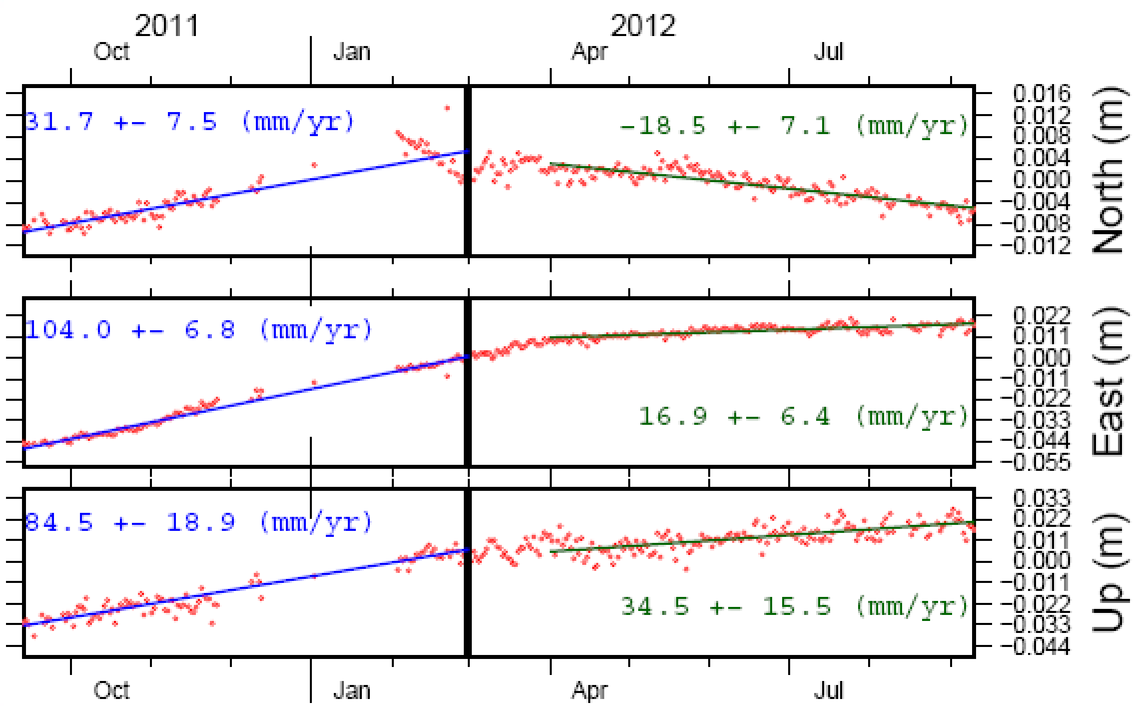
NOMI station

The 2011-2012 unrest

Deformation field - GPS



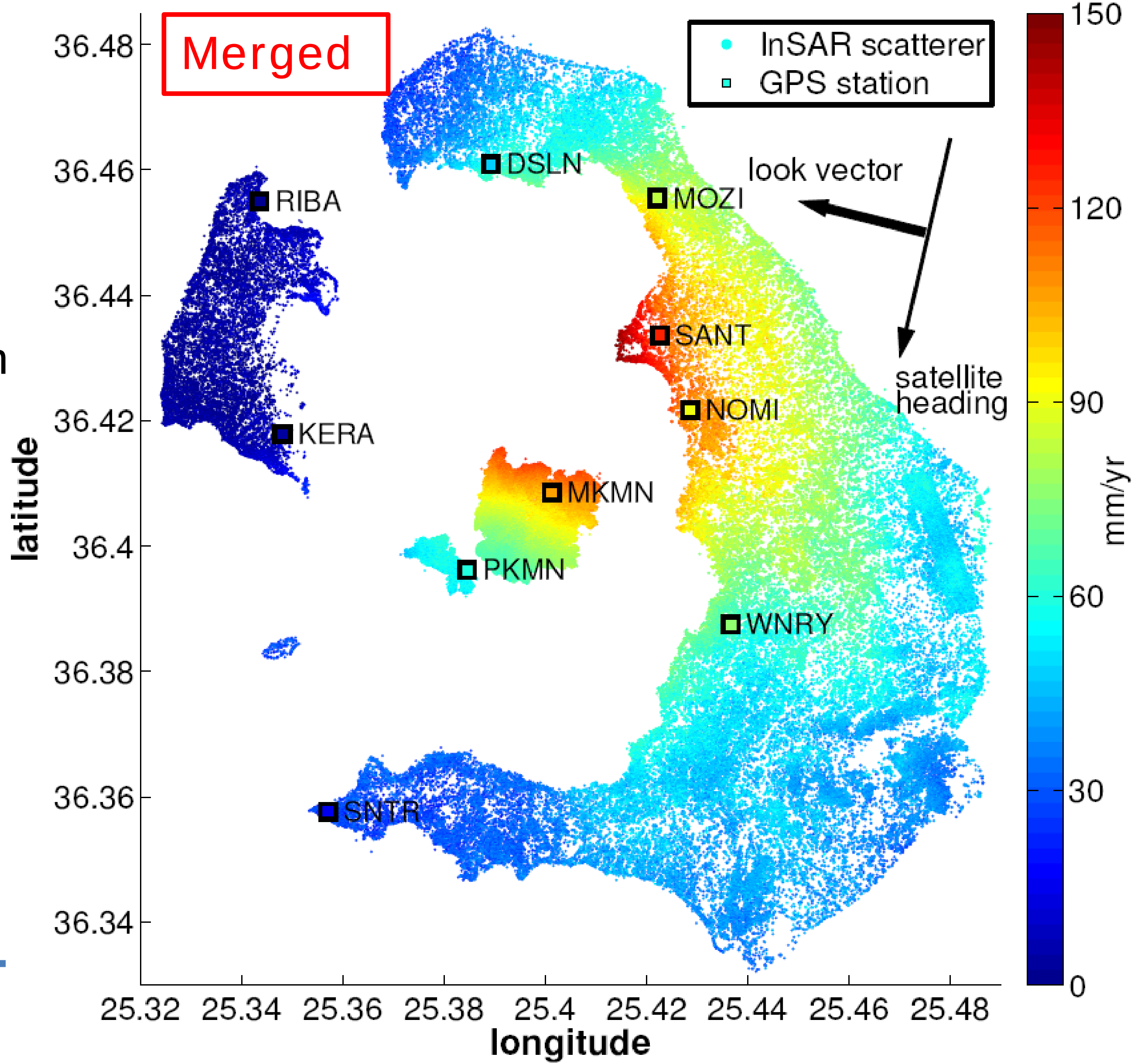
SANT station



The 2011-2012 unrest

Deformation field – PSI & SBAS

- Merged rates from PSI and SBAS (Hooper, GRL, 2008)
- Identified more than 250000 coherent pixels
- Radially decaying deformation pattern
- 150 mm/yr maximum displacement rate



The 2011-2012 unrest

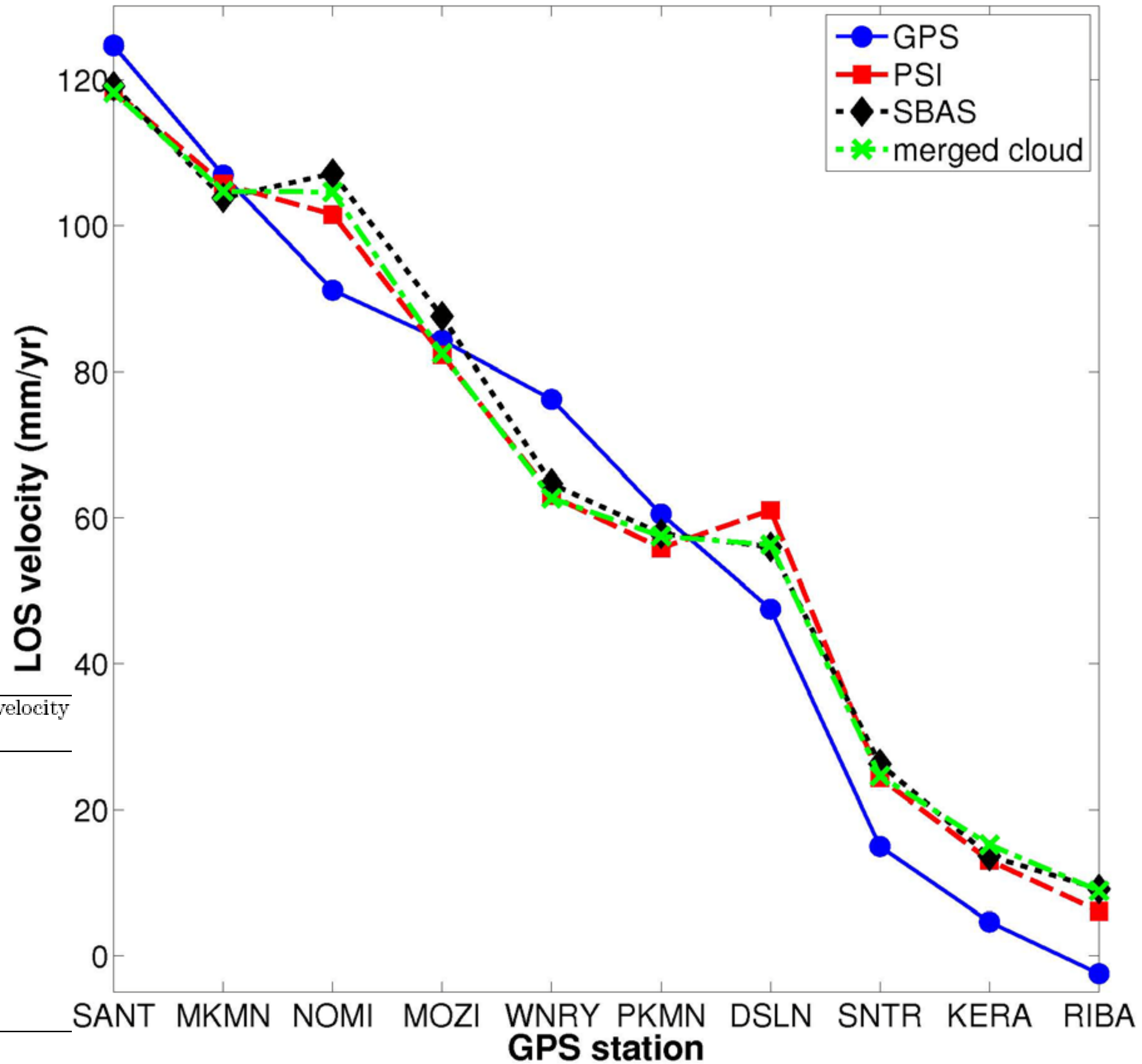
Deformation field – Interferometry & GPS

<u>RMS differences</u>

GPS-PSI: 8.72mm/yr

GPS-SBAS: 9.28 mm/yr

GPS-MERGED: 9.12 mm/yr



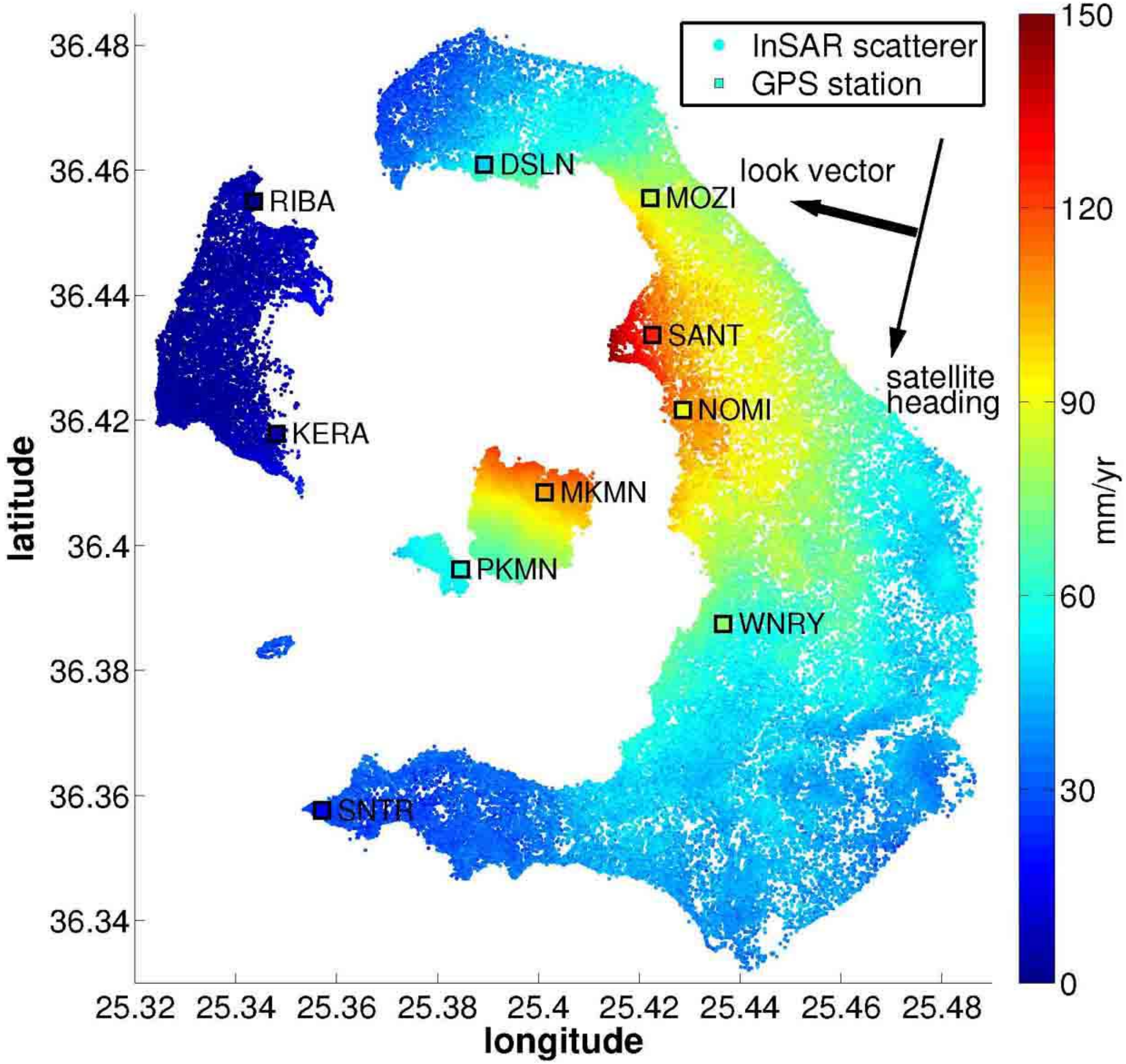
GPS site	GPS velocity (mm/yr)	PSI velocity (mm/yr)	SBAS velocity (mm/yr)	merged[a] velocity (mm/yr)
SANT	124.6	118.42	119.1	118.2
MKMN	106.9	105.68	103.8	104.7
NOMI	91.1	101.50	107.1	104.6
MOZI	84.3	82.28	87.5	82.5
WNRY	76.2	63.00	64.6	62.7
PKMN	60.5	55.80	57.8	57.5
DSLN	47.5	61.01	55.9	56.3
SNTR	15.0	24.3	26.2	24.6
KERA	4.6	13.0	13.6	15.2
RIBA	-2.5	6.1	9.1	8.9

[a] merged PSI and SBAS cloud

The 2011-2012 unrest

Mogi model - InSAR

InSAR analysis

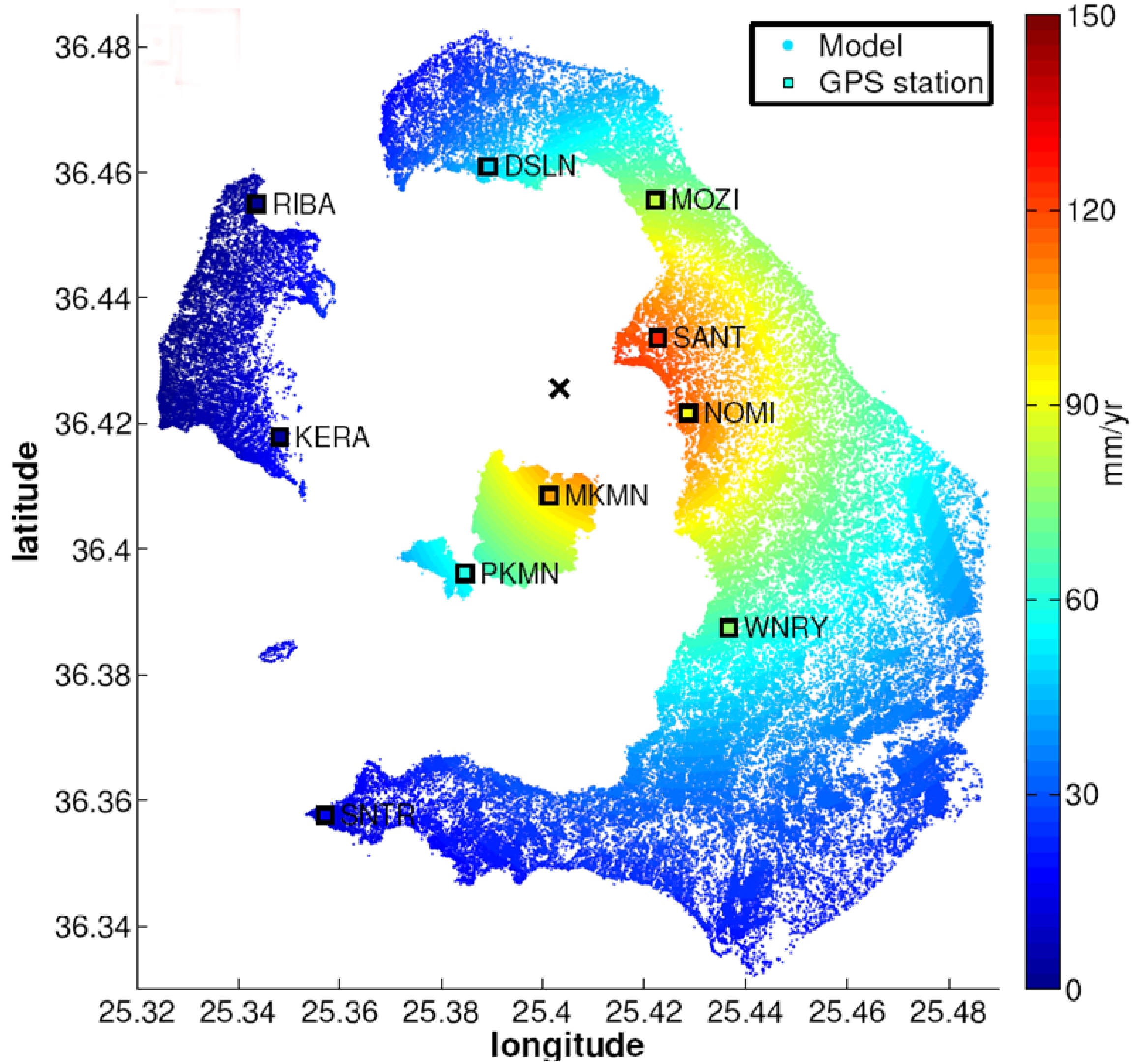


The 2011-2012 unrest

Mogi model - InSAR

x marks the location of the Mogi source inferred from InSAR

Mogi model

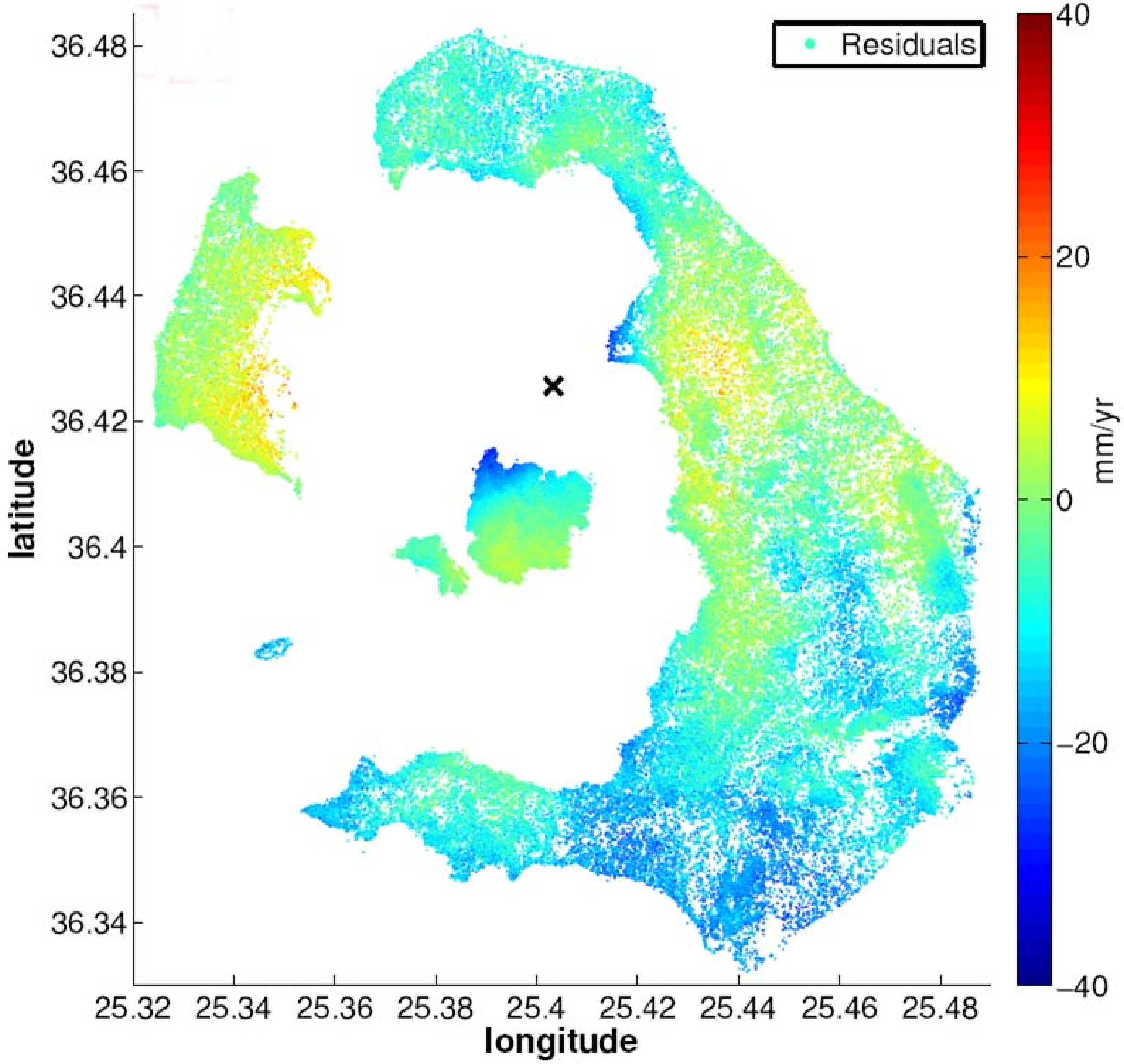


The 2011-2012 unrest

Mogi model - InSAR

x marks the location of the Mogi source inferred from InSAR

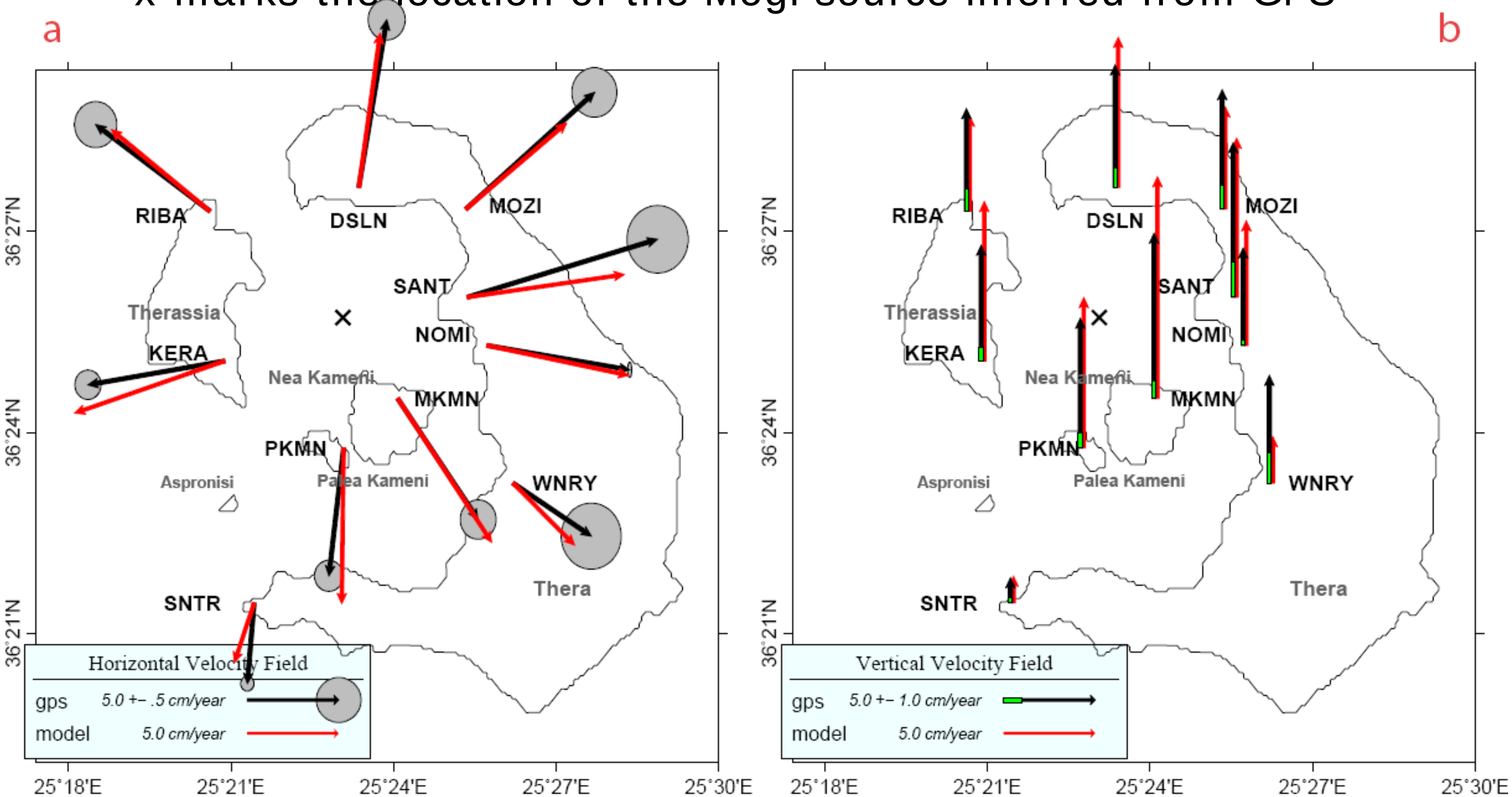
Residuals (model-InSAR)



The 2011-2012 unrest

Mogi model - GPS

x marks the location of the Mogi source inferred from GPS



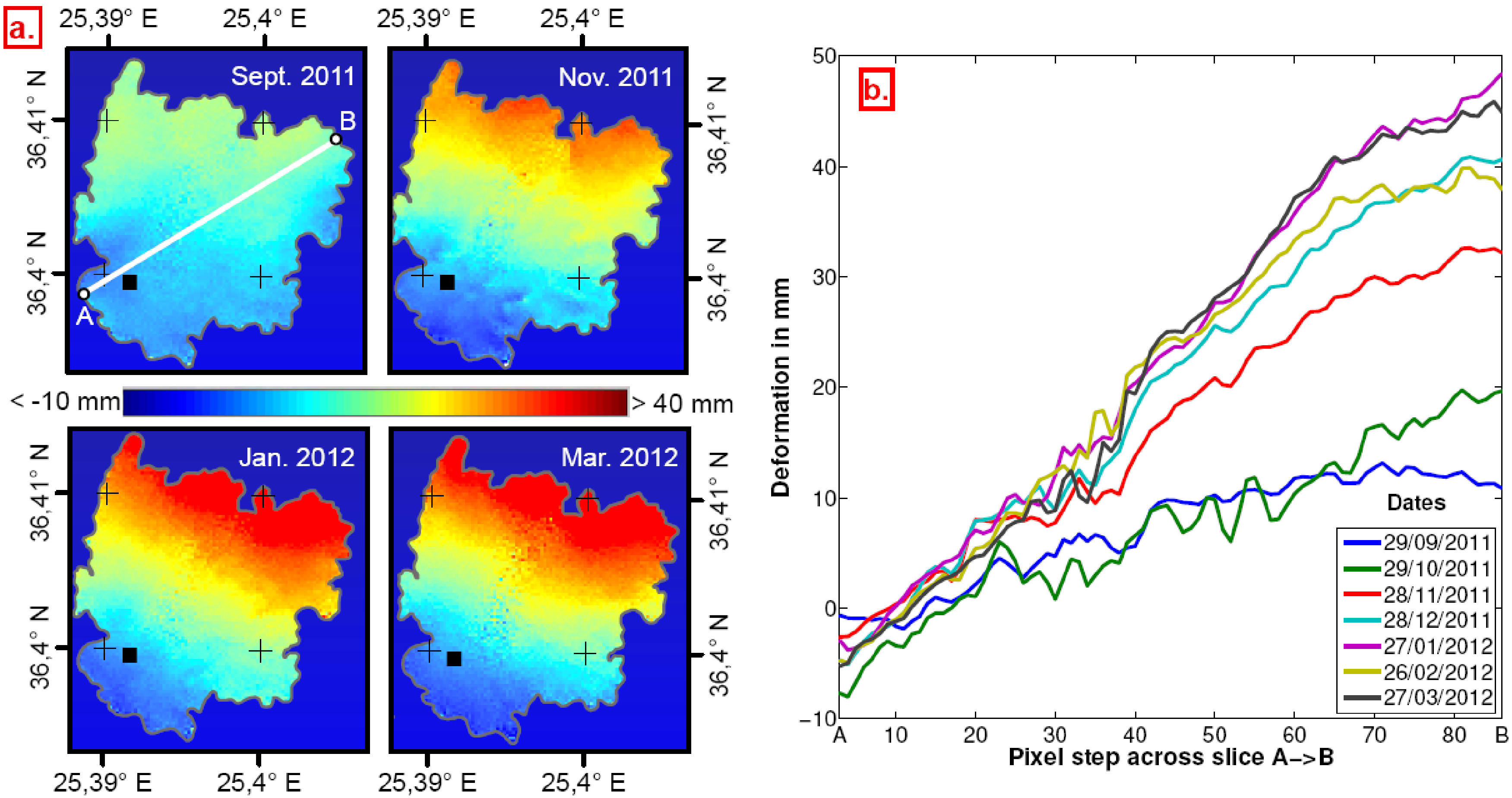
Mogi model best fit parameters for the GPS and InSAR data

Data set	Longitude	Latitude	Depth/km	$\Delta V/10^6 m^3/yr$	X^2/dof[a]
3-component GPS	25.3844	36.4286	$3.48^{+0.19}_{-0.17}$	$12.4^{+0.9}_{-0.8}$	9.1
InSAR	25.4033	36.4256	$6.28^{+0.02}_{-0.02}$	$24.2^{+0.1}_{-0.1}$	3.52

[a]Degrees of freedom.

The end of the episode

InSAR

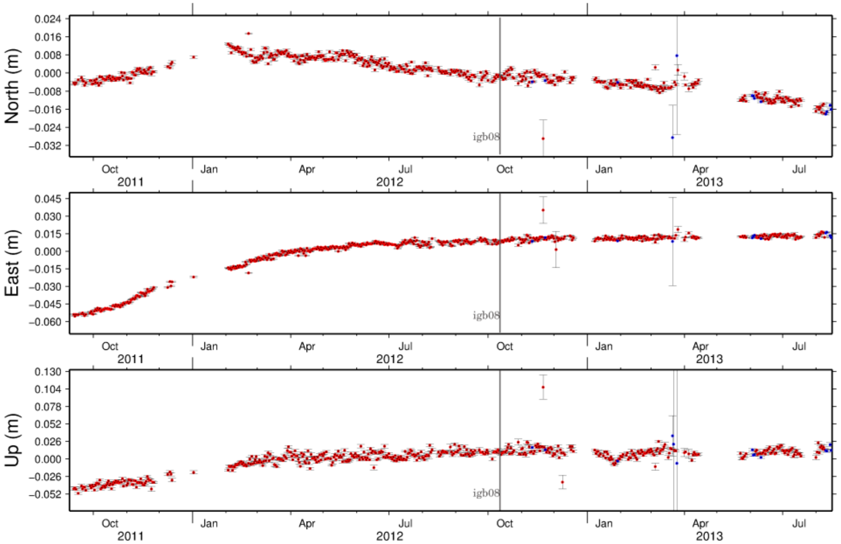


(a.) Unwrapped differential interferograms zoomed in on the Nea Kameni region with reference to 03/2011. While the magnitude of uplift clearly increases for the first three interferograms, in 03/2012 the deformation is similar to the one observed in January 2012. (b.) Cumulative deformation in millimeter across slice AB for selected Envisat acquisition dates.

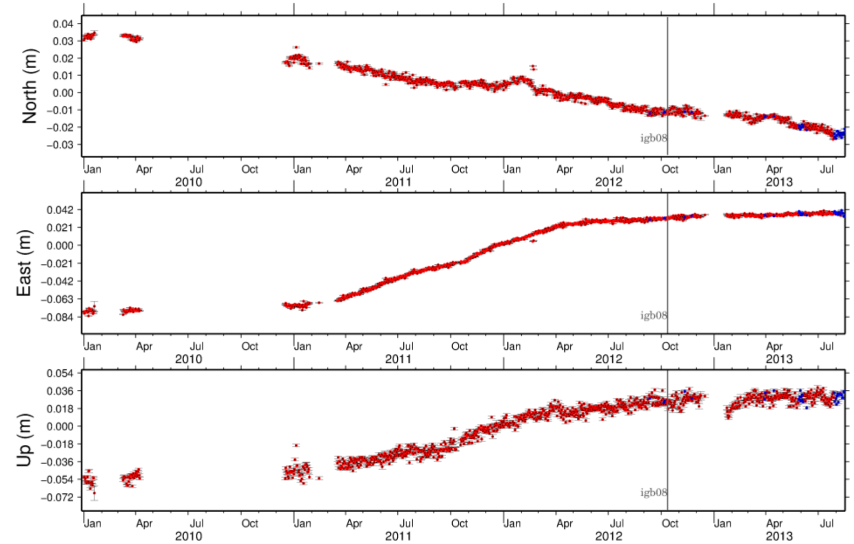
The end of the episode

GPS – Raw data

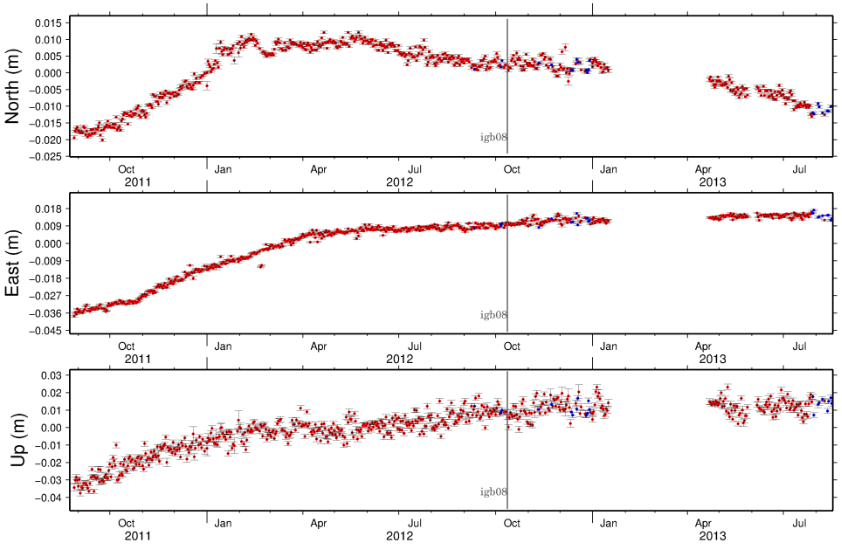
cGPS station sant



cGPS station nomi

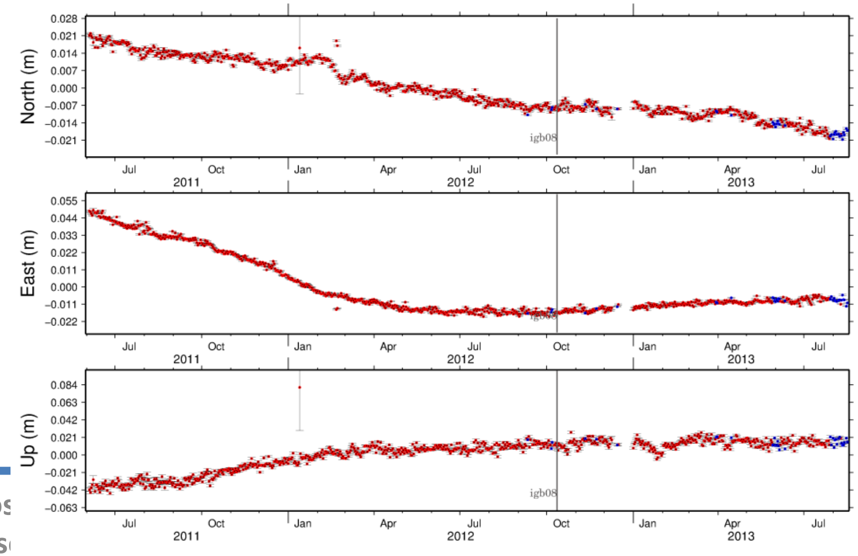


cGPS station mozi



GMT 2013 Aug 29 13:16:16 compiled by dso[AT]ntua

cGPS station kera



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Conclusions

• Mogi source model seems to be suitable (in agreement with Newman et al., Parks et al.)

• Unless a very deep hydrothermal fluid reservoir exists beneath the caldera, this episode was likely to be one of magmatic inflation of the shallow chamber

• Inflation has diminished since the end of February 2012

- ➢ New phase of relative stability
- ➢ Reduced probability for an imminent volcanic eruption

Keep on monitoring Santorini
GPS & InSAR

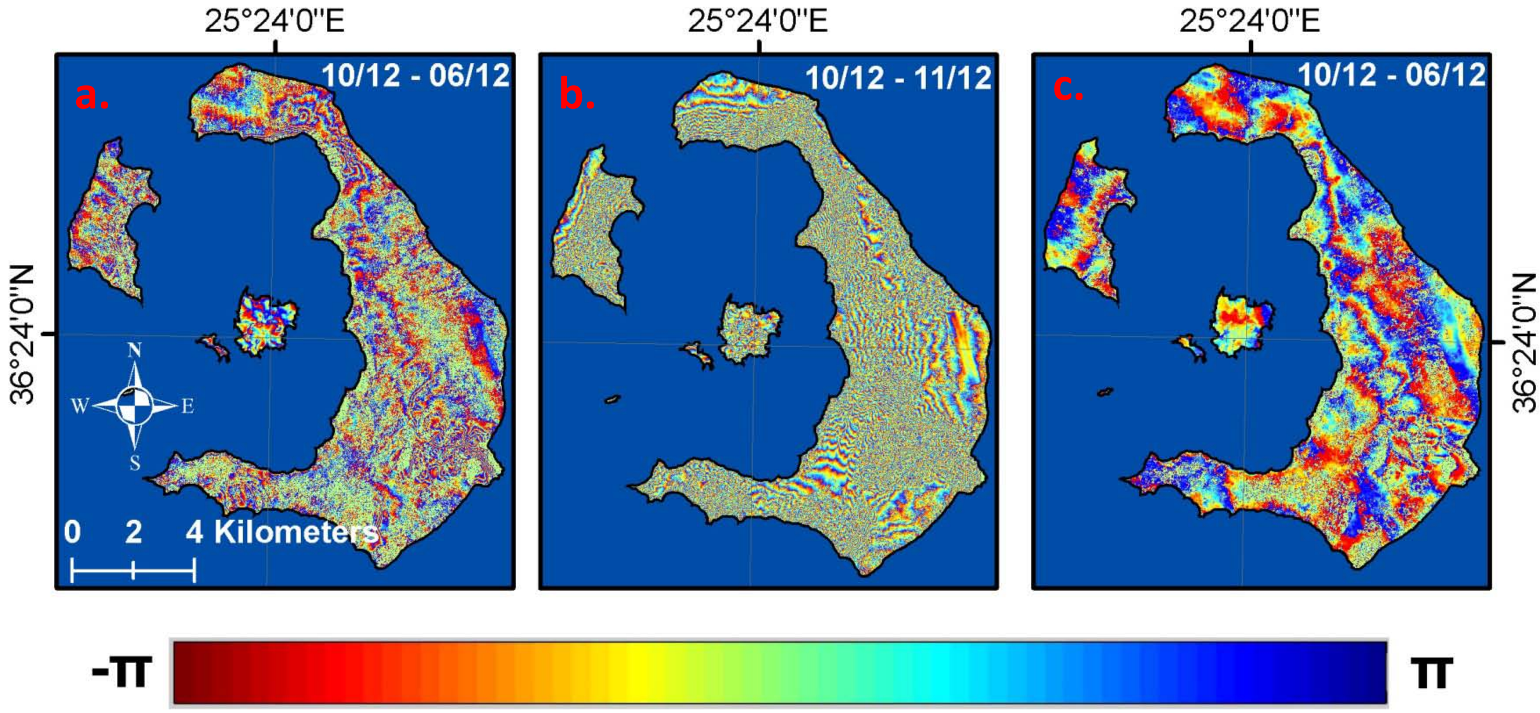
- Daily GPS solutions for Santorini
  - http://dionysos.survey.ntua.gr/src/cgps_processing_main.htm

Ongoing work with COSMO-SkyMed SAR data (3-pass interferometry)

a. Short perpendicular, long temporal baseline interferogram => deformation

b. Long perpendicular, short temporal baseline interferogram => DEM

c. Differential interferogram for 3-pass interferometry



Keep on monitoring Santorini

BEYOND center of excellence

- BEYOND project aims at establishing a Centre of Excellence for Earth Observation based monitoring of Natural Disasters in south-east Europe
  - ➢ http://www.beyond-eocenter.eu/
  - ➢ June 2013 – 2016, €2.3M EU contribution
  - ➢ Beneficiary is the National Observatory of Athens
- In the framework of BEYOND we will:
  - ➢ Set up innovative integrated observational solutions that allow to a multitude of monitoring networks (space borne and ground-based) to operate in a complementary, unified and coordinated manner
  - ➢ Create archives and databases of long series of observations and derived higher level products.
  - ➢ Collaborate with key players in Europe for geophysical research
  - ➢ Recruit experienced researchers and upscale s/w and h/w capacities