The March 11, 2011, Tohoku-oki earthquake (Japan): surface displacement and source modelling

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SUMMARY

- The Tohoku-oki earthquake
- Tohoku-oki and Supersite Initiative: EO data available
- Surface movements mapped using InSAR
- Seismic source modelling
- Conclusions
The Tohoku-oki earthquake

- On March 11, 2011 (at 05:46:23 UTC) a disastrous earthquake (M 9.0) occurred near the NE coast of Honshu island (Japan)

- The seism originated near the subduction plate boundary between the Pacific and the North America plates. The epicenter is at about 130 km E of Sendai city, at a depth of about 32 km.

- A large foreshock of this earthquake took place at 11:45 local time on 9 March 2011, with a magnitude of 7.3, as determined by the Japan Meteorological Agency.

- Following the Tohoku-oki mainshock and on the same day, three aftershocks occurred with M ≥ 7.4, and many smaller aftershocks were recorded and located by the Japanese seismic network.
The Tohoku-oki earthquake

- Massive earthquakes with a Mw 9.0 have been known to occur in only a few areas of the world: Sumatra, Alaska, Chile, Kamchatka.
- The location, geometric parameters, and focal mechanism, all of these latter agree with the occurrence of the seism along the subduction plate boundary.
- The initial seismological analysis indicated that a surface of about 300 km x 150 km moved upwards of 30-40 m.
The Tohoku-oki earthquake

- The northern portion of the coast of Honshu has been hit by a large tsunami. In particular following the M 7.6 subduction earthquake in 1896 waves up to 38 m were measured. Later on the M 8.6 of March 2, 1933, generated waves of 29 m on the Sankiru coast.

http://iisee.kenken.go.jp/staff/fujii/OffTohokuPacific2011/tsunami.html
The Tohoku-oki earthquake

- The 2011 Tohoku-oki earthquake ruptured the plate interface along which the Pacific plate slides beneath northern Honshu at a rate of 78mm/year.

- Honshu island is in a very complex tectonic setting. In the subduction zones around Japan four plates interact with one another, North American (or Okhotsk), Pacific, Philippine and Eurasian plates.

- The movement of the Pacific plate with respect to the North America is about 83 mm/y in this area.

- The Japan Trench since 1973 has hosted nine events of M 7 or greater, the largest of which was a M 7.8 located about 260 km N of the March 11 epicenter. Later on in June 1978 a M 7.7 took place 35 km SW of March 11.
Tohoku-oki Supersite: EO data available

- The Tohoku-oki earthquake is one of the GEO Supersites ([http://supersites.earthobservations.org/sendai.php](http://supersites.earthobservations.org/sendai.php))

- The most important Space Agencies made available their data all over the epicentral region. JAXA (Japanese Space Agency), ESA (European Space Agency), DLR (German Space Agency), NASA (National AeroSpace Agency) and CNES (French Space Agency) provided a large number of SAR and Optical images.

- Each Agency applied a different policy for data delivery, from ESA and JAXA that freely opened the databases for Japan earthquake, up to CNES and DLR that made available data conditioned to a registration.
Tohoku-oki Supersite: EO data available

- The “Tohoku-oki INGV Team” coordinated the efforts and shared the satellite data to minimize the time for processing. More in detail, concerning SAR sensors, the following satellites/missions have been used:

- ENVISAT: three tracks along descending paths, 27 frames (IS6)

- ALOS PALSAR: two tracks, 16-18 frames FBS (Fine Beam Single) and FBD (Fine Beam Double) polarization.
Surface movements mapped using InSAR

• Three interferometric strips are composed of 13 (track 347, descending orbit), 8 (track 074) and 6 (track 189).
• The resulting interferogram covers most of Honshu island, the whole epicentral region and a large coastal area. The strips have been unwrapped to measure the Line Of Sight surface movement (right). The maximum displacement reaches about 2.5 m relative to a reference point located nearby the southern boundary.

![Map of Japan with earthquake epicenter and magenta lines showing movement](image)
Surface movements mapped using InSAR
• ALOS-PALSAR data processing was carried out using ROI_PAC 3.0.1 (*Repeat Orbit Interferometry PACkage*) from JPL (Jet Propulsion Laboratory, USA), with data from ascending tracks 401 (time span 28/10/2010-15/3/2011) and 402 (time span 29/9/2010-1/4/2011).
• ESA made available also data from the ERS2 satellite, previously moved on a new three days revisiting time orbit, providing precise orbit files based on Laser Range data with only two days delay.

• The optimal ERS2 orbital control allowed getting very short baseline values as well. All data were along ascending track.

• The choice of the ERS2 processed interferograms, has been done based also on the occurrence of some strong aftershocks (April 7\textsuperscript{th}, M7.4 and May 5\textsuperscript{th}, M6.3) after the mainshock of March 11\textsuperscript{st}.
Seismic source modelling

- GPS and InSAR results have been combined in order to estimate the 3D displacements.

- We integrated the GPS displacement vectors provided by Piatanesi et al., obtained by comparing the position estimates averaged 15 minutes before and after the main shock, and the ENVISAT InSAR displacement map relevant to the Track 347 (descending orbit) obtained considering the passes of 19/2/2011 and 21/3/2011.
We applied the SISTEM approach (Guglielmino et al., 2011) in order to estimate the gradient displacements tensor.

SISTEM takes into account both the in situ geodetic measurements and the DInSAR LOS displacement maps.
Seismic source modelling (preliminary results)

- Forward modeling with a spherical layered self-gravitating coseismic model
- Rheological layering is obtained by means of a PREM discretization
- Source geometry is fixed, seismic moment release is obtained with a linear damped least-squares inversion
- Source parameters:
  \[ M_0 = 1.65 \times 10^{23} \]
  \[ M_w = 9.35 \]
- The largest misfit is obtained on the vertical component (see next slide)
Residuals (observed – modeled)
Conclusions

- The Tohoku-oki “Supersite” earthquake has been studied using an unprecedented number of EO data, mainly from SAR sensors

- The surface displacement field covered most of Honshu island with a maximum LOS deformation up to 2.5 m

- The integration of GPS and InSAR has allowed to measure the East, North, Up displacement components

- The seismic source modelling revealed that most of the misfit is over the Up component. The slip distribution reveals a maximum along the north sector of the subduction zone

- Further studies are addressed to integrate other data sources (tsunami waveforms)
Special Stream
EO and in situ data analysis for New Zealand and Japan Earthquakes

Following the earthquakes that affected New Zealand and Honshu Island (Japan) in the last months, the Earth Science and Earth Observation Communities have been deeply involved in the analysis of the enormous amount of EO and in situ data available, and very interesting results have been proposed in many venues. Satellite information, seismic, GPS and buoy measurements have been used to measure surface movements, characterize changes, assess damages, model the seismic source and discuss/amend existing theories.

In order to help researchers to deliver the outcomes of their work in a quick and timely manner, the IEEE Geoscience and Remote Sensing Letters (IEEE GRSL) is glad to open a "Special Stream" dedicated to the New Zealand (NZ) and Japan earthquakes.

A "Special Stream", as opposed to a Special Issue where all the papers referring to a topic are published at once, is an ongoing stream of papers published on-line as soon as they are accepted, and appearing in multiple printed issues according to their acceptance dates with a common link across the issues.

The Table of Contents of each issue of IEEE GRSL will identify the papers on the selected topic by suitably grouping and highlighting them. The first issue containing a paper in the Special Stream will also include a one-page introduction to the theme, and the last issue will feature an Editorial, summarizing the published results and discussing open paths for future researches.

Papers are solicited on the following non-exhaustive list of topics for the NZ and Japan earthquakes:
- surface displacement field investigation and measurements using EO data processing techniques (e.g., SAR interferometry);
- damage assessment using EO data, possibly in combination with in situ data;
- seismic source modeling results using EO and in situ data;
- monitoring and modeling tsunamis, landslides, liquefaction and other hazards using EO and in situ data;

Submissions to the Special Stream are now open and will stay open until September 30th, 2011. The first IEEE GRSL issue featuring this Special Stream will be the January 2012 issue.

Prospective authors should submit their manuscripts electronically using the following web page:
http://mc.manuscriptcentral.com/grsl
Instructions for creating new user accounts, if necessary, are available on the login screen. Please indicate in your submission that the paper is intended for the NZ and Japan Special Stream by selecting "NZ and Japan Special Stream" from the menu for manuscript type. Submissions must be no longer than 5 pages in IEEE double column format and will be evaluated through the standard IEEE GRSL peer review procedure.

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Thank you!