Study of the Precursor Aspects of Earthquakes Suing InSAR Case Study L'Aquila Earthquake

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Abstract— In this work, we are trying to assess the feasibility of the detection of small deformation of the crust, just few weeks before an earthquake using InSAR. The SAR data made available by the European Space Agency (ESA) after the L'Aquila earthquake (06 April 2009) Mw 6.3, was used for this purpose. Two tracks 079 (descending), 401 (ascending) of Envisat satellite were used. An anomaly in the topography was revealed in the interferograms generated for the period of one month before the earthquake. This anomaly quantified as half fringe = 1.4 cm in both ascending and descending couples. This anomaly was not present in the previous interferograms. The change in the instability of the ionosphere few days before the earthquake, leaded to a big difference in the value of the TEC between the acquisitions, and integrated a delay in the SAR signal.

1. INTRODUCTION

The interaction of powerful processes, which take place in the Earth crust, e.g., earthquakes (EQs), volcanoes, etc., with neutral and charged components of the atmosphere (ionosphere) is one of the most important problems of our environment. Evidences for ionospheric disturbances emerging days before the strong EQ shocks are widely considered in the literature. Data from a number of vertical sounding ionosondes have been analyzed for a thorough study of the F2 region ionosphere behavior. Ionospheric disturbances in F2 region have been shown to appear generally 1–7 days before the EQ event [2, 3, 5]. At heights of the maximum of the F2 region, the corresponding critical frequency (foF2) is strongly influenced by EQ preparation processes. Then the variations from its median values can exceed twice the standard deviation. Moreover, their localization is found to be centered at or near the epicenter of the forthcoming EQ (Liu et al., 2001, 2006). Analysis of GPS total electron content (TEC) data within the area affected by the EQ has revealed a systematic ionospheric variability several days before the seismic shock as shown for instance by (Liu et al., 2004, 2006) who observed a TEC variation up to 40TEC units.

Disturbances affecting the E and D ionospheric regions days before strong EQs have also been observed. First experimental evidences concerning the D region disturbances during the EQ preparation period are changes of the characteristics of VLF signals received by ground-based receivers from remote transmitters (Gokhberg et al., 1987, 1989). As for EQ-related disturbances in the E region there is a row of cases and statistical studies. The most frequent feature characterizing the E region is the appearance several days before of strong Es layers over the zone affected by the EQ (Ondoh and Hayakawa, 1999; Liperovsky et al., 2000; Pulinets et al., 2000; Chuo et al., 2002).

2. IONOSPHERIC EFFECT ON INTERFEROMETRIC SAR

The ionosphere is a region of the earth's extending from an altitude of about 50–1000 km where solar radiation ionizes atmospheric gases. For the purposes of SAR, it is sufficient to model the ionosphere as a thin layer, at an effective ionospheric height of 400 km. During its 2-way passage through the dispersive ionosphere, a SAR signal experiences a group delay and phase advance which are inversely proportional to frequency squared:

$$-\tau_{phase} = \tau_{group} = 2K_0 STEC/f^2 \tag{1}$$

where $K_0 = 40.28\,\mathrm{m}^2\mathrm{s}^{-2}$ and STEC is the Stant range TEC. TEC refers to the zenith value, the density of free electrons contained in a cylinder with unit area passing through the atmosphere in the direction of nadir. STEC is proportional to TEC through one over the cosine of the zenith angle. For interferometry, only the phase delay is of interest. The corresponding influence on a repeat-pass interferogram is obtained by replacing STEC in (Eq. (1)) with $\Delta STEC$, the difference in $\Delta STEC$ values between the master and the slave acquisitions, giving an Interferometric phase delay at the carrier frequency f_c of:

$$\phi_0^{iono} = -\frac{2K_0 \Delta STEC}{cf_c}(cycles) \tag{2}$$

The Interferometric phase at the carrier frequency is comprised of a topographic component due to the differential range between the master and the slave and an ionospheric component due to the differential phase advance.

$$\phi_0 = 2f_c\Delta R/c - 2K_0\Delta STEC/(cf_c) \tag{3}$$

These two components can be separated because of their different behavior (frequency) (B. Ramon et al., 2010).

3. DATA ANALYSIS

We used five Envisat images covering the period before the L'Aquila Earthquake (06 April 2009). Three ascending (Track 401) and two descending (Track 079).

Table 1: Envisat data used in this study.

Date	Track	orbit
19/01/2009	401	asc
23/02/009	401	asc
30/03/2009	401	asc
01/02/2009	079	desc
08/03/2009	079	desc

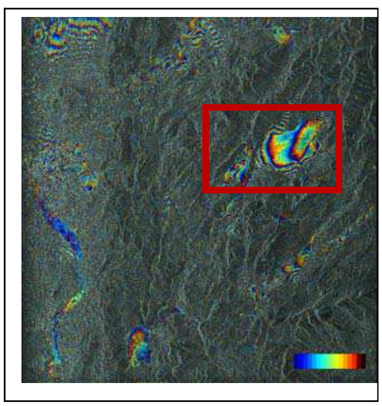

Figure 1: Couple 20090119–20090223.

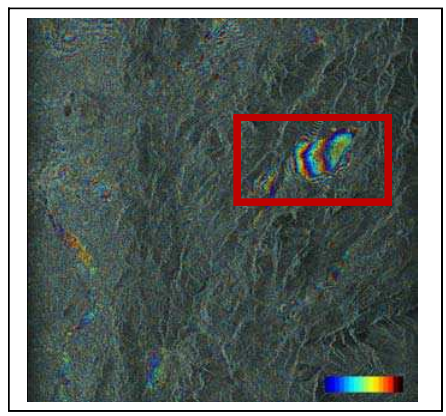

Figure 2: 20090223–20090330.

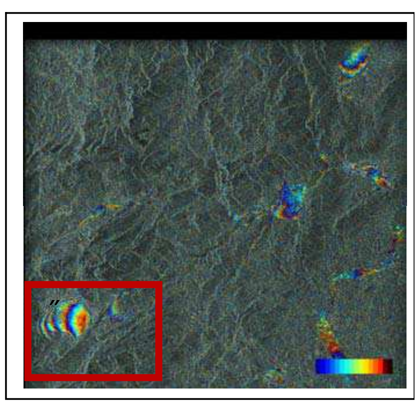

Figure 3: 20090201–20090308.

The area delimited by red rectangles, represent the city of L'Aquila (Italy) where the Earthquake of magnitude 6.3, occurred on 06 April 2009. In the interferograms 20090223–20090330 and 20090201–20090308 we can see that there is an extra 1/4 fringe added to the topographic phase comparing to the Interferogram of the couple 20090119–20090223. The first guess would be a bad corregistration of the images. But since all the interferograms was coregisterred the same way and with the same parameters. This leads to an external source of bias.

[1] used data from Rome and Sofia Ionospheric stations, to study the period of earthquake activity for earthquakes of magnitude (M) between 5 and 6 in central Italy. They found that several ionospheric disturbances occurred in the intermediate E–F region before the earthquake shock.

Another study, [4] of earthquakes of magnitude between 5.5 and 6. Observed in Italy for the period 1979–2009 including 06 April 2009 L'Aquila earthquake. They also used the ionospheric station situated in Rome. The precursor identification for L'Aquila earthquake, used the observed $\Delta h'Es$, δf_0Es, and δf_0F2. The study of these parameters helped to understand the empirical dependencies for the seismo-ionospheric disturbances relating the earthquake magnitude and the epicenter distance.

Another study [7], was dedicated to the use of Demeter satellite that gives the VLF measurements data and GPS observations that used to compute the TEC. In normal cases, the TEC values are correlated to the geomagnetic variations and the ACE data, because all of them are triggered by solar events. However, they find that before the L'Aquila earthquake occurrence the TEC increased but the other parameters didn't show similar variations. So, it is supposed that the electron number enhancement must have another source than the sun and might be a regional phenomenon related to earthquake.

The use of TEC maps in [7], revealed that there was an increase in the values of the TEC starting from 30 March which corresponds to the date of acquisition of the third image in Table 1 (track 401). This image is heavily affected by ionospheric effect due to the variation of TEC in that day, thing that affected all the interferograms generated using this image.

4. CONCLUSION

The analysis of the interferograms related to the period preceding L'Aquila earthquake, within few days. Revealed the precursor feasibility of SAR interferometry for the study of earthquakes.

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