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Ground surface deformation of L’Aquila earthquake revealed by InSAR time series

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Introduction

- An Mw 6.3 earthquake occurred On 6 April 2009 close to the city of L'Aquila in the central Appennines at a depth of about 9 km. The main shock was followed by thousands of aftershocks, of which two large events were Mw 5.6 and Mw 5.4 on April 7 and 9, respectively. It caused heavy damage in the town of L'Aquila with inhabitants of 73,000 and in many neighboring villages, and resulted over 300 fatalities and thousands of injures and tens of thousands homeless.

- However, an earthquake case, from its seismogenic, to the rupture, and the effect after the quake, is a very complex geophysics process. For a long time, seismologists have been doing a lot of researches to explore the physical and tectonic mechanism of this process. In this paper, Based on previous work and by applying time series method to 9 repeat pass ASAR images, we represented the whole evolution processes of the displacement field of the L'Aquila earthquake. The results of this paper demonstrated the different deformation characteristics of the displacement field in the different phases caused by the earthquake during the imaging period. The deformation caused by different shocks, and the deformation in preseismic 、coseismic and postseismic of main shock were also analyzed. All of these results are consistent with the works derived by descending data(Luo Sanming et al., 2012), PS method(Luo Sanming et al., 2012) and SB method(Luo Sanming et al., 2011), respectively.

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Data description

- Data description

  In this paper, the available data contains 9 ascending ENVISAT ASAR images (ASA_IM_1) of track 401 spanning between October 2008 and September 2009(see Figure 1).Acquisition modes for ascending datasets are swath 2 (23 degrees), V/V polarization. Figure 1 shows the spatial and temporal repartitions of the data used for L′ Aquila earthquake. Table 1 is the details about 9 scenes. During the imaging period, about 500 foreshocks from October 2008 to April 6 2009 occurred and about 2000 aftershocks occurred between April 6 and April 30 2009(Di Luccio, F. et al. , 2009), respectively.

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- Tab.1 Processed Information from Ascending Orbit Data for L'Aquila Earthquake(Track: 401)
- No Orbit Date Sensor (m) (Hz) Days
- 1 34523 2008-10-06 Envisat 0 -560.63 0
- 2 35204 2008-11-10 Envisat 467 -551.44 35
- 3 36026 2009-01-19 Envisat 437 -555.95 105
- 4 36527 2009-02-23 Envisat -3 -550.54 140
- 5 37028 2009-03-30 Envisat 581 -553.11 175
- 6 37529 2009-05-04 Envisat -145 -557.86 210
- 7 38030 2009-06-08 Envisat -144 -564.12 245
- 8 38531 2009-07-13 Envisat 400 -549.31 280
- 9 39533 2009-09-21 Envisat 626 -548.84 350

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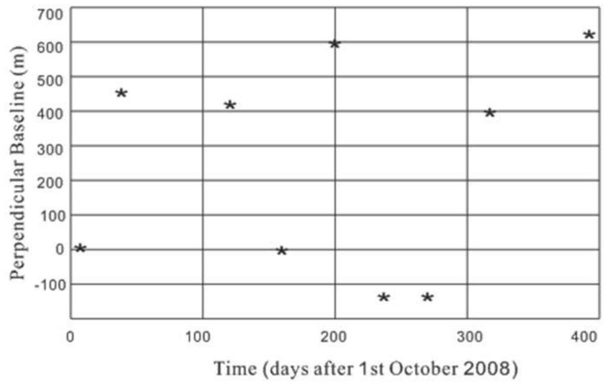

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- Phase unwrapping

  Phase unwrapping is the process of recovering unambiguous phase values from phase data that are measured modulo a phase cycle. On the whole pixel set, a three dimension spatiotemporal unwrapping was performed (C. W. Chen, 2001; Hooper A. et al., 2007) if the sampling rate is high enough over most of the data set that aliasing is avoided.

  In InSAR time series, however, the phase is undersampled in time for every point in space, due to the variation in atmospheric delay, which can vary by greater than half a phase cycle in much less than the time between acquisitions for all existing SAR data sets. There is also a phase term due to error in orbital estimation that approximates a ramp in space. Though often small, this term can also be greater than half a phase cycle in magnitude.

- These terms are reduced to less than half a phase cycle over most of the image by estimating and subtracting the longer wavelength components of the phase change between each interferogram, which include most of the atmospheric and orbital error signal (R. F. Hanssen et al., 2001). For each pair of interferograms in time, the highest frequency component of spatially correlated phase is estimated. The complex phase difference between the interferogram pair is transformed to the frequency domain and iteratively low-pass filter, starting with a broad frequency response and decreasing the width until the filtered phase contains no residues. Unwrapping of the filtered phase is therefore unambiguous, and the estimation of the spatially-correlated look angle error was also used to help the unwrapping.

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- Results and Analysis
- Discussion and Conclusions
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Results and Analysis

- Figure 2 and Figure 3 are the interferograms time series of wrapping phase and unwrapping phase, respectively. Figure 4 is the displacement field revealed by pixels selected by StaMPS analysis method . Faults in Figure 4 were cited from Atzori et al. (2009). Reference pixels A, B, C and D for time sequence analysis in Figure 4 located in rupture area, and their time series curves are shown in Figure 5. The UU′ and VV′ indicate the positions of two profiles across the rupture area in Figure 5, and their profiles are shown in Figure 6(a) and (b), respectively. Figure 7 are the distribution of foreshocks in L′ Aquila area between October 2008 and April 2009 (following Di Luccio F. et al, 2009). Figure 8 is the statistics of the main shock and aftershocks higher than magnitude 1.5 (http://portale.ingv.it/primo-piano-1/news-archive/2009-news/april-6-earthquake/).

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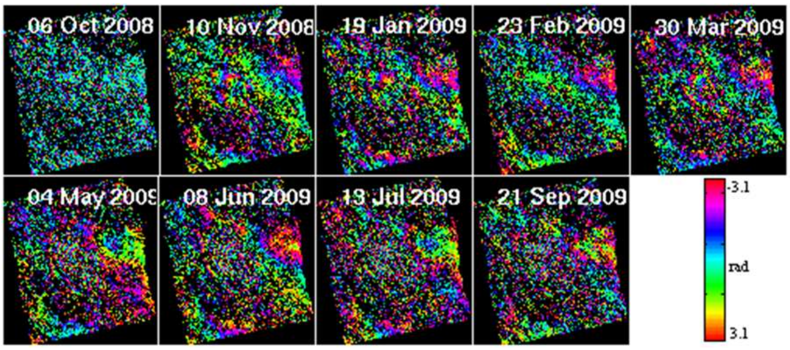

- Figure. 2 Wrapped interferograms in radar coordinates formed from ascending orbit data acquired over L'Aquila, with 4 looks taken in range and 20 in azimuth. The master acquisition date is 6 October 2008. Each color fringe represents 2.8 cm of displacement in the LOS, and the intensity reflects interferogram amplitude.

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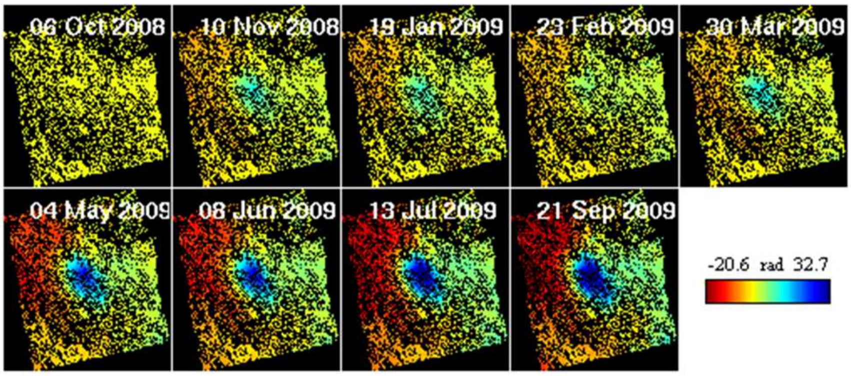

Figure.3 Pixels time series displacement field unwrapped phase formed from ascending orbit data over L'Aquila, dark blue section represents rupture zone.

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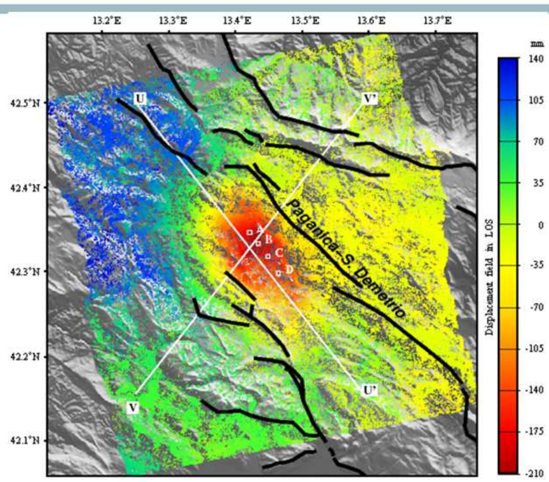

- Figure.4 Pixels displacement field(LOS) over L'Aquila zone from 6 Oct 2008 to 21 Sep 2009

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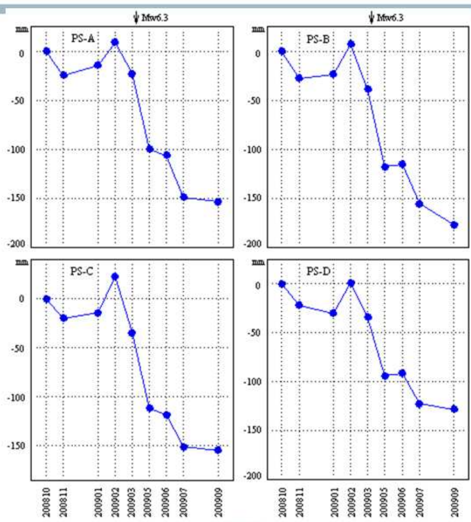

Figure 5 Reference Pixels time series displacement(LOS)

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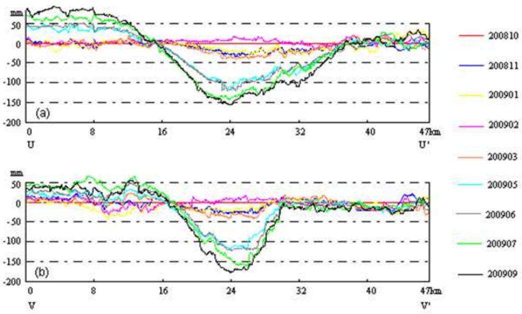


Figure 6 Displacement field profiles across the rupture area. Figure (a) shows the profile along the UU′ and (b) along the VV′ in Figure 3, respectively.

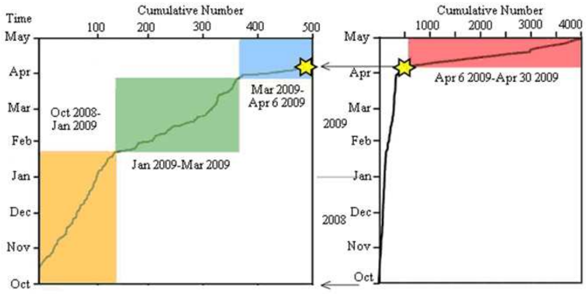
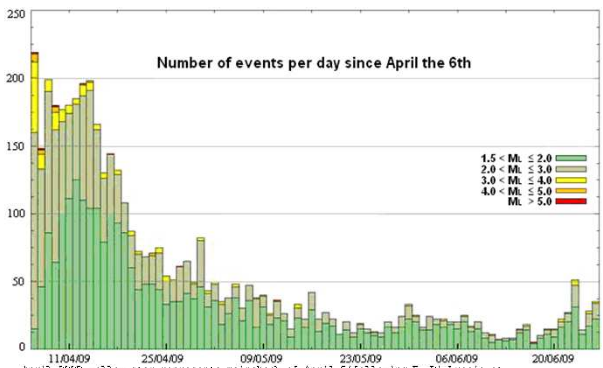


Figure 7 Time versus cumulative number of earthquakes for the period October 2008-April 2009, yellow star represents mainshock of April 6(following F. Di Luccio et al.).



April 2009, yellow star represents mainshock of April 6(following F. Di Luccio et al.).

Figure 8 Aftershocks charts of L'Aquila earthquake from 6 April 2009 to 26 June.

- The results measured between March and May 2009 in Figure 3 and Figure 5 also show that the displacement field changed rapidly during the shocking and subsequence. The variation of deformation in LOS at rupture zone achieved 100 mm, the majority of which was formed in this phase. Meanwhile, the main shock was followed by thousands of aftershocks, the 7 of which with magnitudes greater than Mw 5.0 (Chiarabba, C. et al. ,2009)(Figure 8). The increasing changes of the displacement field can be the results of the combined effect of the main shock and thousands of aftershocks, included the 7 large aftershocks.

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- Figure 4 shows that the surface faulting within a zone of about 22 km x14 km, with an orientation of 135°, occurred along the NW-striking and SW-dipping Paganica-S. Demetrio normal fault. This is agreement with field investigations carried out by EMERGEO Working Group(EMERGEO Working Group,2010), and also well fitting with the conclusions using DInSAR and GPS data(Atzori et al., 2009; Anzidei et al., 2009; Chiarabba et al., 2009).

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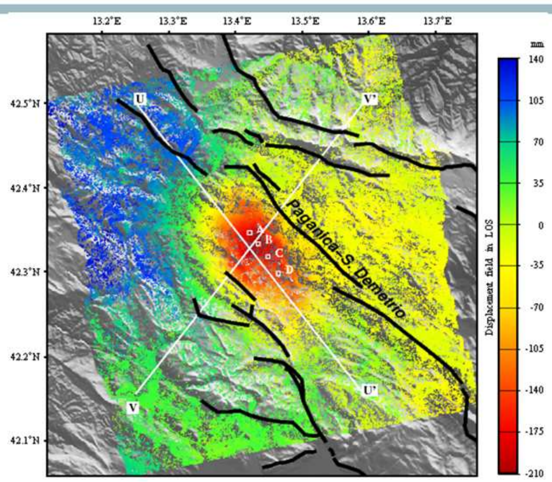

- Figure.4 Pixels displacement field(LOS) over L'Aquila zone from 6 Oct 2008 to 21 Sep 2009

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Discussion and Conclusions

- (i) In the half year before the earthquake, the surface of the epicenter has already begun to change slowly, after the earthquake, subsidence in the fracture zone increased with the large magnitude. The cracking propagated along the epicenter in the southeast direction. A large subsidence bowl was formed in the epicenter.
- (ii) In 2003 Hunstad I. et al. processed the GPS data and triangulation network observation data since 1860, and their results show the significant strain accumulated over the past 130 years may not have been released in the past earthquakes in the Apennines (Hunstad I. et al., 2007). Although the L'Aquila earthquake that occurred on 6 April 2009 is the strongest event since the M7.0 Fucino earthquake in the central of Italy in 1915(E. Falcucci et al., 2009), the results in this paper suggest that this area might be susceptible to a stronger earthquake in the future since the L'Aquila shock was not strong enough to release the long-term strain accumulated in the area.

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- (iii) Synthetic aperture radar interferometry can obtain the change information and evolution processes of surface “field” without any artificial targets. This promises the continuity of data chain, and the continuous information can be obtained even in the rupture zone. This is impossible using conventional geodetical methods. Thus, the work in this paper has provided a comprehensive case for understanding new methods for earthquake forecasting with time sequence DInSAR.

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- End of report

- Thank you for your attention!
- If you have quastion,please send to e_mail:mxg612@126.com