THE COSMO SKYMED CONSTELLATION TURN ON THE L'AQUILA EARTHQUAKE: DINSAR RESULTS OF THE MORFEO PROJECT

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ABSTRACT

On April 6th 2009 a M_w=6.3 earthquake struck the area around the city of L'Aquila in Italy. SAR systems have been proven to be valuable sensors for analyzing the effect of earthquakes and monitoring post-seismic displacements. Due to the low deformation rate, the study of post-seismic events requires the use of a multi-temporal InSAR approach. COSMO/SKYMED is a constellation of SAR sensors of 4 X-band sensors operative also for the civilian use. Thanks to the availability of a stack of ascending acquisitions, *ad hoc* programmed by ASI on the area stricken by the earthquake, it was possible to provide post-seismic deformation maps by using two different multi-temporal interferometric approaches: the SPINUA and SBAS techniques. The work is carried out in the framework of the MORFEO project dedicated to the monitoring of the landslides risk by means of Earth Observation data. The displacement maps related to the post-seismic activity are presented and commented. The results clearly show the potentiality of the COSMO/SKYMED constellation use for emergency monitoring.

***Index Terms*—** Multi-temporal SAR Interferometry, seismic deformation, COSMO/SKYMED.

1. INTRODUCTION

SAR systems have been proven to be valuable sensors for analyzing the effect of earthquakes. Many examples of the application of the Differential SAR Interferometry (DInSAR) technique, including multi-temporal stacking are given in the current literature to measure the co-seismic ground displacements: see for instance [1] [2] for co-seismic data analysis relative to the Landers (USA) and Bam (Iran) earthquakes and [3] for the monitoring of post-seismic effects of the Athens (Greece) earthquake.

COSMO/SKYMED (CSK) is worldwide a unique constellation of SAR sensors usable also for the civilian use. It is composed of four medium-size satellites, three of which already operational, each one equipped with a microwave high-resolution synthetic aperture radar (SAR) operating in X-band. The CSK mission is devoted to provide products/services for environmental monitoring and surveillance applications for the management of risks.

On April 6th 2009, at 01:32 GMT, a M_w=6.3 earthquake struck the city of L'Aquila and the surrounding region, killing more than 300 people. Several major aftershocks (M_w>5) and thousands of smaller events occurred in the next few months in an area extended NW-SE for about 35 km.

Starting from this date, following an official request of the Italian Department of Civil Protection, the CSK constellation was "turned on" with the highest priority (*very urgent operating mode*) to the monitoring of the L'Aquila area.

Co-seismic displacement maps were generated a few days after the earthquake by using CSK, ENVISAT, TerraSAR and Radarsat data: see [4] for the results of the analysis of mainly Envisat data, [5] for the modeling of co-seismic displacements and [6] for first results by using both C- and X-band SAR data.

Concerning the study of post seismic events, the low deformation rates involved in such a process require the use of multi-temporal InSAR approaches which in turn need the availability of tens of SAR acquisitions. CSK mission appeared well suited to support this kind of post-event emergency analysis thanks to the short X-band wavelength and to the short revisit time provided by the constellation configuration. From April to October 2009 the constellation was capable to acquire in HIMAGE mode 33 acquisitions with ascending passes (beam H4-09) and 44 acquisitions with descending passes (beams H4-05 & H4-09): on average about 1 acquisition each 3 days.

Within the MORFEO project (a project dedicated to the monitoring of the landslides risk by means of Earth

Table I: Parameters of the ascending pass COSMO/SKYMED dataset

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Month	April '09					May '09				June '09				July '09			
Day	04	12	13	20	29	06	14	30	31	07	15	16	23	02	09	17	18
Sensor	CSK-S1	CSK-S2	CSK-S3	CSK-S1	CSK-S3	CSK-S1	CSK-S2	CSK-S2	CSK-S3	CSK-S1	CSK-S2	CSK-S3	CSK-S1	CSK-S3	CSK-S1	CSK-S2	CSK-S3
B_t (days)	0	8	9	16	25	32	40	56	57	64	72	73	80	89	96	104	105
B_p (m)	686.0	254.6	220.4	-164.2	-333.8	-581.0	-255.4	119.6	-2.3	-75.2	418.5	349.3	263.0	-90.5	-113.8	-237.6	-53.0
f_{DC} (hz)	-322.3	-579.6	-1278.1	-517.9	-1216.2	-499.6	-545.1	-486.0	-1195.0	-408.4	-554.8	-1262.0	-470.2	-1233.3	-420.1	-497.5	-1218.4
IREA	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
POLIBA	✘	✔	✔	✔	✔	✘	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔

	18	18	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Month	July '09	August '09						September '09						October '09		
Day	25	02	03	10	18	19	26	03	04	11	19	20	27	05	06	13
Sensor	CSK-S1	CSK-S2	CSK-S3	CSK-S1	CSK-S2	CSK-S3	CSK-S1	CSK-S2	CSK-S3	CSK-S1	CSK-S2	CSK-S3	CSK-S1	CSK-S2	CSK-S3	CSK-S1
B_t (days)	112	120	121	128	136	137	144	152	153	160	168	169	176	184	185	192
B_p (m)	0.0	136.0	497.2	242.1	8.8	46.4	-122.4	-76.5	-12.5	15.6	296.3	441.0	623.0	528.4	434.9	175.4
f_{DC} (hz)	-440.5	-456.9	-1135.4	-553.0	-591.7	-1291.5	-518.3	-569.8	-1249.3	-427.8	-546.2	-1187.0	-397.9	-667.8	-1268.6	-457.9
IREA	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
POLIBA	✘	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✘	✘	✘	✘

Observation data) two partners, IREA-CNR and GAP (a spin-off company of *Politecnico di Bari*), are in charge of the interferometric processing of SAR data.
In this work we discuss the multi-temporal DInSAR results obtained by the two MORFEO SAR processing groups.

2. DATASET

Different datasets were acquired by the CSK constellation on the area stricken by the earthquake with different look angle, polarization and pass direction. The 33 SAR data used for the present study are in HIMAGE mode, relative to the beam H4-09 (Incidence Angle ~ 40.1°) and acquired looking at right. The wavelength is 3.12 cm (X band), the spatial resolution is around 2.5 m in both azimuth and ground range, while the polarization is HH. Table I provides details on the acquisition dates, the spatial and temporal baselines and the sensors which acquired the images (CSK-1, CSK-2, CSK-3). A plot of the distribution of temporal and spatial baselines is reported in Fig.1: it highlights the presence of main linear trend over the time of the spatial baselines. This trend, if not properly accounted for, may lead to a coupling of estimation of velocity and topography during the processing especially in presence of large displacements such as those associated to the displacements of the main shock in the co-seismic pair of April 4 and April 12, 2009.

3. RESULTS

The first results were achieved by GAP with SPINUA (*Stable Point INterferometry over Unurbanized Areas*) technique [7] over sites of particular interest. This PSI-like technique adopts some *ad hoc* solutions, as patch-wise processing, which enable to get fast results, on small areas by processing also scarcely populated stack of SAR images. Figure 2 shows the results around Paganica obtained by processing 26 out of 33 images of the ascending dataset as detailed in the last row in Table I. Here the presence of a clear post-seismic displacement pattern was detected along the Paganica fault along a NW-SE direction, approximately located by the blue line in Figure 2. These significant results were achieved thanks to the availability of a unique temporal acquisition rate which is currently possible only by using the CSK constellation.

Data were then delivered to IREA and processed via a *Small BAseline Subset* (SBAS) like technique: SBAS [8] is characterized by the capability of working at low spatial resolution to achieve a large spatial coverage. Starting from the low resolution product, a full resolution analysis were carried out in IREA by using a 4D (space-velocity) imaging based approach [9] which uses amplitude and phase of the received signal. The full resolution data highlighted, as for the SPINUA results, a very high spatial distribution of monitored points. Several post-seismic interferograms, generated during the SBAS processing, already indicated the presence of a larger (compared to the SPINUA high resolution results) post seismic deformation pattern, with a "drop shape" extending outside the Paganica town along

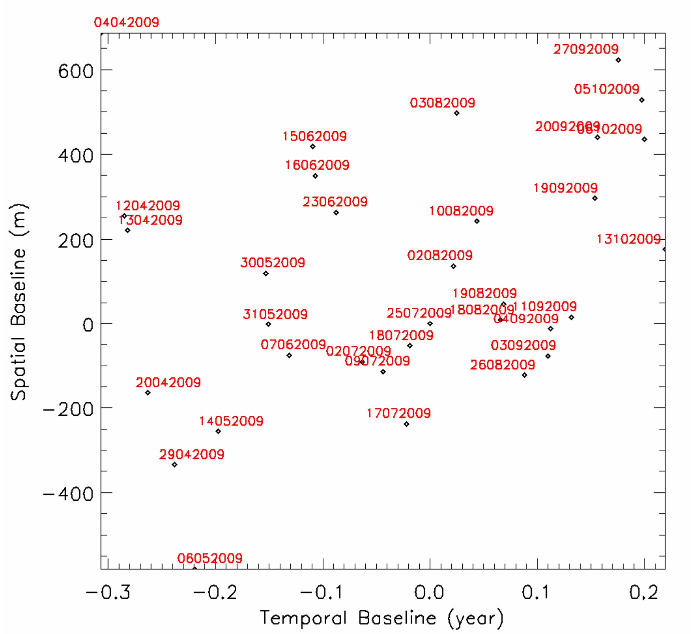

Figure 1. Spatial and temporal baseline distribution of the CSK dataset.

the fault. This pattern were confirmed by the mean deformation velocity map achieved by processing all the available data with the low resolution SBAS technique. The SBAS technique allowed to process the entire frame (about 40x40 Km). In Figure 3 we show the obtained results on an area of about 20x20 Km. The time series extracted from the pixels in the area over the fault interested by post-seismic displacements showed an exponential decay deformation in most of the cases limited to about four centimeters, which well agree with GPS measurements. In figure 4 we show the results at full resolution for the area of Bazzano (highlighted by the white box in Fig.3) obtained by the 4D technique in [9]: deformations have been tied on average in such a way that the results are comparable (in terms of color scale) with those in Fig.2. Together with the image in Fig.2 corresponding to the SPINUA results, this image shows the very high potentialities of the COSMO/SKYMED constellation to monitor man-made structures.

4. CONCLUSIONS

The paper presents post-seismic deformation maps related to the April 6th 2009 earthquake of L'Aquila obtained by processing a CSK dataset. Two different multi-temporal interferometric techniques were used: the SPINUA PSI-like InSAR analysis and a SBAS like technique. The work was carried out in the framework of MORFEO, a project founded by ASI and dedicated to the monitoring of the landslides risk by means of Earth Observation data. The discussed results clearly show the potentiality of the CSK constellation use for emergency monitoring. Analysis of the earthquake induced deformation, as well as monitoring of buildings, infrastructures, is clearly feasible by using such system with an unprecedented accuracy.

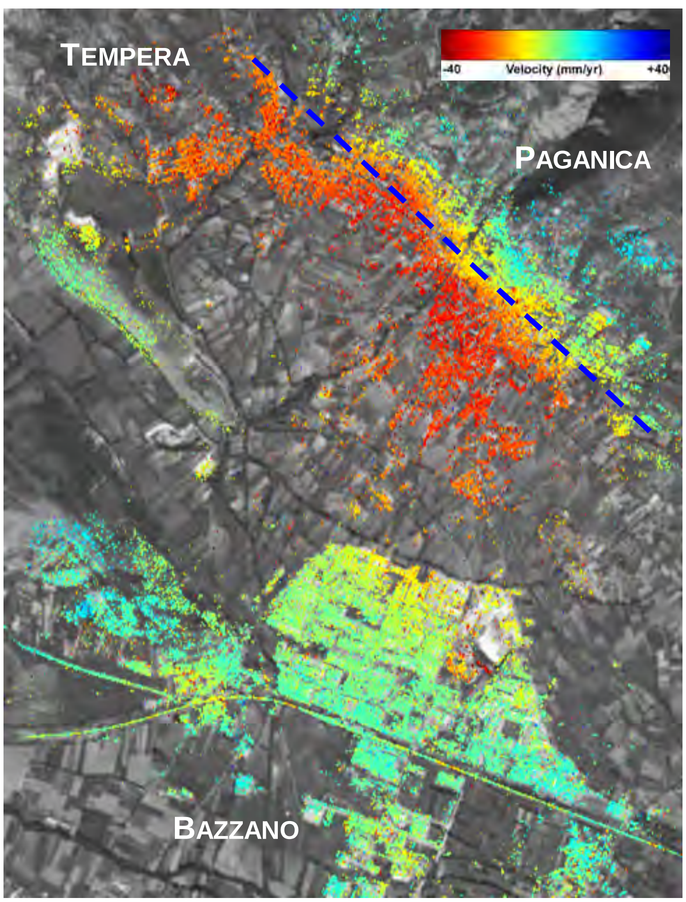

Figure 2. Mean deformation velocity map achieved by the SPINUA technique over the area mainly stricken by the main shock. The outcrop of the Paganica fault is roughly located by the blue line

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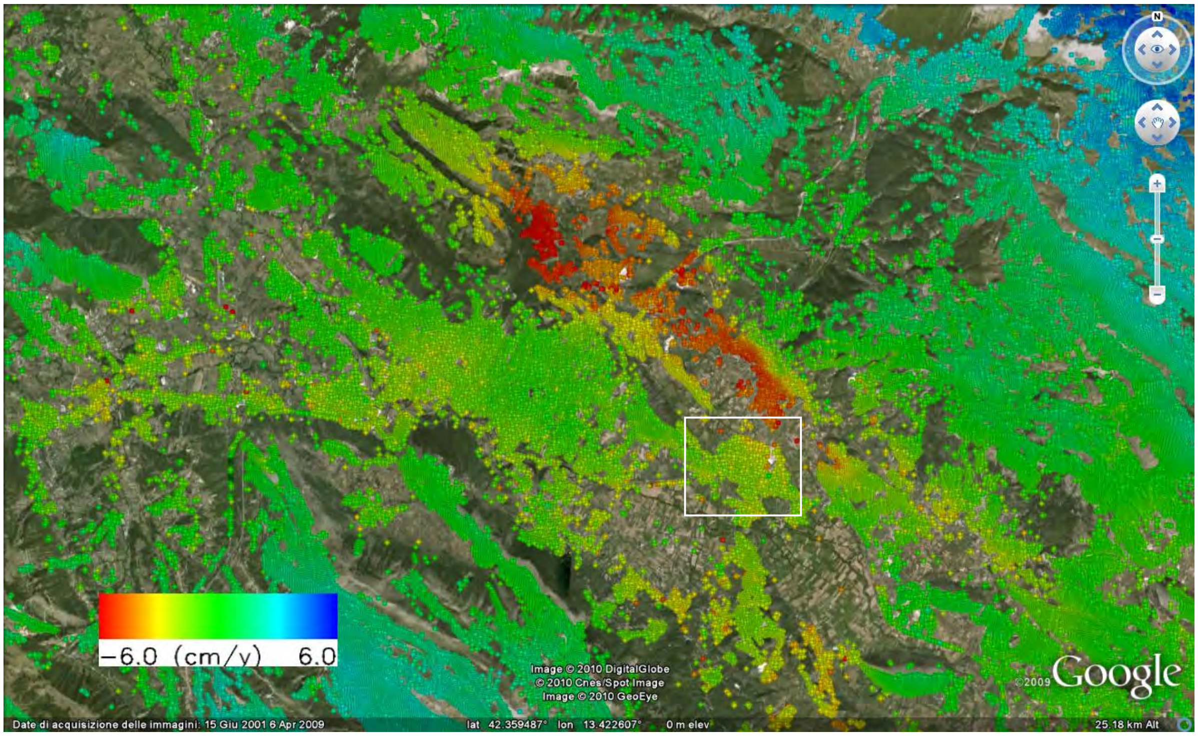

Figure 3. Mean deformation velocity map at low resolution achieved by the SBAS technique

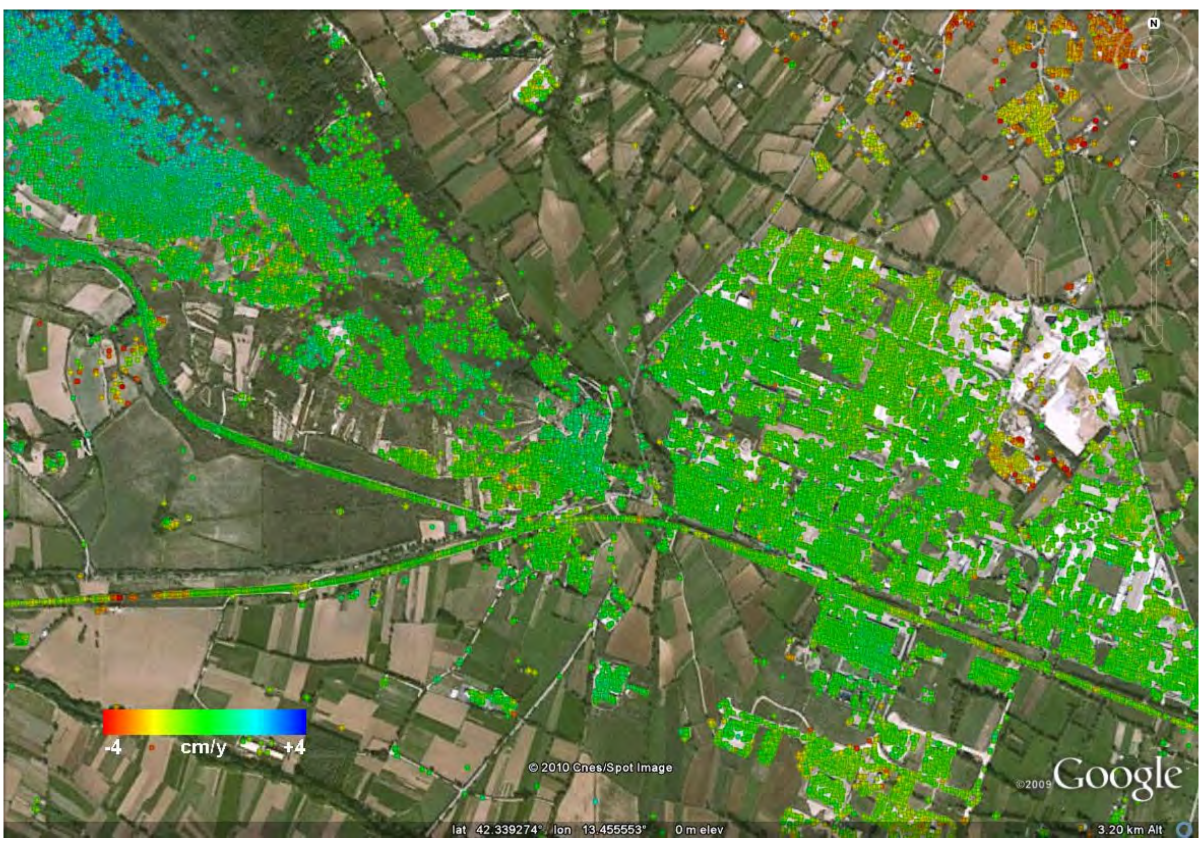

Figure 4. Mean deformation velocity map at high resolution achieved by the 4D imaging technique in [9]