Ground Deformation Imagery of the May Sichuan Earthquake

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The magnitude $M_w = 7.8$ earthquake that struck China's Sichuan region on 12 May 2008 (Figure 1a) has been imaged by the Italian Space Agency's (ASI) Constellation of Small Satellites for the Mediterranean Basin Observation (COSMO)-SkyMed radar Earth observation satellites. Five images were availabletwo preseismic spotlight mode images and three strip-map mode images, two of which are preseismic and one of which is postseismic. We used two strip-map images (acquired 1 month prior to and 3 days after the earthquake) to generate the first ever X-band (i.e., microwave frequency domain, corresponding to about 3-centimeter wavelength) coseismic interferogram, which clearly shows part of the strong ground deformation caused by the fault dislocation. We also performed a change detection analysis of the same data that highlighted several changes in the radar response, presumably due to strong seismic damage, as far as 80 kilometers away from the epicenter.

The COSMO-SkyMed system is a constellation of four satellites (two are already in orbit, the first of which was launched in June 2007), developed to provide fast, meter-level-resolution, all-weather imagery for disaster management (http://www.asi.it/SiteEN/MotorSearchFullText .aspx?keyw=cosmo-skymed+sito). The system hosts a flexible, multimode X-band synthetic aperture radar (SAR), with right and left looking imaging capabilities, an incidence angle range of 20°–60°, and a minimum revisit time of 12 hours.

Sichuan Earthquake Coseismic Effects From COSMO-SkyMed

On 12 May, immediately after the main shock, the Italian Department of Civil Protection requested that ASI program the system to acquire new images over the Sichuan region, using strip-map (swath 40 kilometers wide, ground resolution 3 meters) and spotlight (swath 10 kilometers, resolution 1 meter) modes (http://www.asi.it/SiteEN/ MotorSearchFullText.aspx?keyw=cosmo -skymed+sito). Two spotlight images were acquired only a few hours after the earthquake, but there were no pre-event matching spotlight images. However, three strip-map images had already been acquired in the epicentral area, thus giving the possibility to compare pre-event and postevent data.

We applied differential SAR interferometry (DinSAR) [*Massonnet et al.*, 1993] to a strip-map image pair (specifically, 13 April and 15 May) to measure the coseismic ground deformation due to the fault slip. We calculated an interferogram with a reduced spatial resolution of 36×36 meters, to enhance the signal-to-noise ratio, and used the 90-meter Shuttle Radar Topography Mission digital elevation model [*Farr et al.*, 2007] to remove the topographic phase component. The interferogram shows eight fringes (i.e., phase cycles) trending approximately east-northeast/west-southwest, each representing a ground displacement of 1.5 centimeters, for a total ground displacement from south to north of approximately 12 centimeters (Figure 1b). The displacement is measured along the satellite line of sight (LOS) (i.e., from east-northeast to west-southwest, ~45° from the vertical). It indicates that the northern part of the image moved toward the satellite with respect to the southern part.

The limited coverage of the image does not allow inversion of the observed displacement to model the fault dislocation. We used the slip distribution obtained by the analysis of broadband seismic data (http://earthquake.usgs.gov/eqcenter/ eqinthenews/2008/us2008ryan/finite_fault .php) to calculate the expected coseismic displacement. We then projected the simulated deformation in the COSMO-SkyMed LOS, and calculated the synthetic differential interferogram shown in Figure 1b. Although the interferogram covers a small area within the displacement field, the synthetic and observed fringes are in good agreement.

Future interferometric COSMO-SkyMed acquisitions (Figure 1a) will allow for covering a continuous strip of land perpendicular to the fault strike. Further data also will be provided in the near future by other SAR satellites (the European Space Agency's European Remote Sensing Satellite (ERS) and Environmental Satellite (Envisat) and the Canadian Space Agency's Radarsat at C-band; and NASA's Advanced Land Observation Satellite (ALOS) at L-band). We expect that the integration of these data sets-obtained at different times and with different SAR wavelengths, incidence angles, and resolution-will help define a more accurate inverse model of the fault dislocation. For instance, using scalar displacements observed under four or more different incidence angles may allow resolution of the three-dimensional ground movement, reducing the ambigui-



Fig. 1. (a) Epicentral area of the 12 May 2008 earthquake. The red star is the epicenter, and the black line is the approximate seismogenic fault trace. Blue squares show the acquired COSMO-SkyMed frames. (b) Synthetic interferometric fringes obtained from modeling the seismic data with the overlapping COSMO-SkyMed differential interferogram. (c) Change image (result from preearthquake and postearthquake image difference) of an industrial area in Chengdu city. Red indicates presumed damage. (d) The detail (white box in Figure 1c) shows a presumably collapsed bridge.

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ties in the model solutions [*Wright et al.*, 2004].

The pairing of pre-event and postevent strip-map images allowed for the fast generation of a reconnaissance map showing presumed strong damage to man-made structures. Such maps, albeit preliminary, are highly valuable in the aftermath of large disasters, helping to effectively direct the rescue missions. A change image approach (pre-event and postevent image backscattering variation) has been applied [*Stramondo et al.*, 2006] to the radar intensity, and some strong changes in the city of Chengdu, located approximately 80 kilometers from the earthquake epicenter, have been pointed out.

Figures 1c and 1d show some details of the presumably damaged structures at a pixel scale of 6×6 meters. The differences between the pre-event and postevent images are striking and affect mainly bridges along motorways and large buildings. Furthermore, when additional high-resolution SAR and optical data sets are made available, more sophisticated feature extraction techniques [*Stramondo et al.*, 2006] can be used to improve the accuracy of damage assessment.

Even in its present partial configuration, COSMO-SkyMed has successfully demonstrated the ability to acquire, within a very short time period, high-quality images of

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Honors

Robert Detrick has been appointed director of the Division of Earth Sciences of the U.S. National Science Foundation's (NSF) Directorate for Geosciences. Detrick, currently a senior scientist and vice presidisaster areas, which are useful for crisis management and scientific research.

Damage Detection in Urban Areas From COSMO-SkyMed

The first COSMO-SkyMed satellite became fully operational in June 2008, and by 2009 the system will progressively reach its complete monitoring capacity with all four satellites. For the most effective use of COSMO imagery in disaster applications using the assessment of changes between pre-event and postevent conditions, a background data acquisition policy will need to be devised to acquire and archive, on a routine basis, imagery with the same geometry and resolution over selected disaster-prone areas worldwide.

ASI is presently funding several large research projects to exploit the potential of COSMO-SkyMed imagery for the study of natural phenomena including earthquakes, volcanoes, landslides, floods, and oil spills. The goal is to transfer the scientific knowledge developed through "off-line" modeling of these phenomena into operational systems able to generate quasireal-time information useful for scenario assessments. The high flexibility of the COSMO-SkyMed SAR sensor was originally designed mainly for disaster reconnaissance and assessment, and the Sichuan earthquake was its first test.

dent for Marine Facilities and Operations at Woods Hole Oceanographic Institution, will begin his NSF position on 3 November 2008. Detrick is a geophysicist and seismologist whose research has focused primarily on the structure and evolution of oceanic crust; the size, depth, and physical properties of ridge crest magma chambers; and the effect of hot spots on the thermal evolution of the lithosphere. Detrick is an AGU Fellow and former president of AGU's Tectonophysics section.

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In Memoriam

Lloyd O. Bacon, 92, 15 April 2008, Geomagnetism and Paleomagnetism, 1946 Fedor Ostapoff, 83, 2 June 2008,

Ocean Sciences, 1958 **George Platzman**, 88, 2 August 2008, Fellow, Atmospheric Sciences, 1950

Karen L. Von Damm, 53, 15 August 2008, Fellow, Marine Geochemistry, 1980