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Earthquake rapid mapping using ascending and descending Sentinel-1 TOPSAR interferograms

Oscar Mora*, Patrick Ordoqui, Rubén Iglesias, Pablo Blanco

TRE ALTAMIRA, SLU, Còrsega 381-387, 08037 Barcelona, Spain

Abstract

The availability of new Sentinel-1A/B (S1A/B) satellites provides geohazards community with a large amount of Synthetic Aperture Radar (SAR) acquisitions over critical areas around the world. The current S1A mission has a minimum re-visit time of 12 days, but with the recent launch of S1B, this temporal gap will be reduced to only 6 days. This high acquisition frequency, jointly with the large coverage and high quality of S1 data, allows the rapid generation of interferograms[1,2] for sudden events, such as earthquakes. This rapid response is crucial for the damage evaluation and fault model refinement.

This paper presents results obtained for the latest earthquakes occurred in Japan in April 2016. Two S1A interferograms in ascending and descending orbits have been generated, and after phase unwrapping[3,4] processing the Line Of Sight (LOS) motion maps are obtained. This LOS[1,2] component corresponds to the range distance between the satellite and ground, and it does not provide real horizontal and vertical information of the displacement. The usage of two different view directions, in ascending and descending orbits, allows the decomposition of LOS motion into horizontal (West-East) and vertical (Up-Down) directions. These new motion maps are essential to better understand the dynamics of the earthquake and to perform further analysis and modelling by seismic experts.

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Keywords: DInSAR; Earthquakes; Interferometry; Sentinel-1

* Corresponding author. Tel.: +34-931-835-750; fax: +34-931-835-759.
E-mail address: oscar.mora@tre-altamira.com

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1. Sentinel-1 acquisition geometry

Sentinel-1 satellites, operating at a center frequency of 5.405 GHz (C-band), follow polar orbits with ascending and descending flight directions with respect to North (right looking geometry). Due to this fact, the same area is viewed from two different geometries (and on different dates). When the satellite travels in the descending part of its orbit, meaning that it is travelling from North to South, it views a target area looking westward while during the ascending part of its orbit, that is, when it moves from South back to the North, it views the same target area looking eastward. See Fig. 1 for an illustrative example of the two different acquisition geometries offered by a spaceborne SAR sensor given the same ground surface. This figure represents two satellites passes in ascending and descending geometry on two different dates looking at the same ground area. From a geometric point of view ascending refers to the view from the western side and descending from the eastern side.

Spaceborne SAR sensors have oblique acquisition geometry. They look at the ground with a particular incidence angle θ (expressed as the angle between the incidence and vertical) which defines the Line Of Sight (LOS)[1,2] of the acquisition. The track heading δ is defined as the angle between the orbit and the North-South direction. The motion measured by the InSAR data is the projection of the true motion into the LOS. The measurement in the satellite LOS of a true given motion depends on the incidence angle used – more vertical incidence angles are more sensitive to vertical motions.

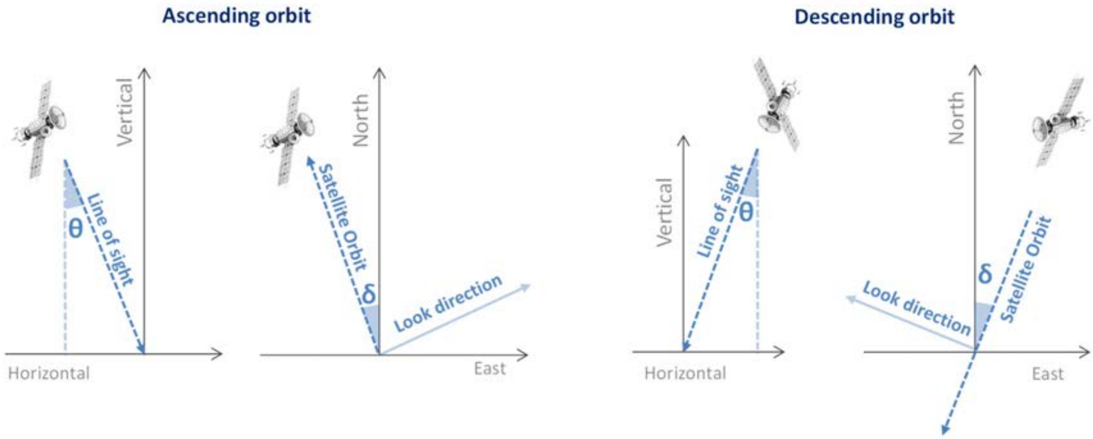

Fig. 1. Line Of Sight (LOS) acquisition geometry of Sentinel-1.

2. Horizontal-Vertical motion decomposition

Under some assumptions, the acquisitions from different geometries and from different sensors can be combined over the same ground surface in order to measure the vertical and the horizontal component of the ground motion. The main requirement for this is that the ground surface must give a coherent and constant backscattering given the acquisition geometries and the sensor frequencies used. The main problem here is the identification of the natural elements over the ground surface acting as coherent points for different geometries and for different sensors.

As shown in Fig. 2 the measurements in the two LOS of both modes must be combined considering the acquisition geometries to retrieve the true motion vector. If the deformation is almost vertical, the results derived from both orbits should give a similar magnitude. Otherwise, it means that there is a contribution due to possible horizontal (East-West) displacements.

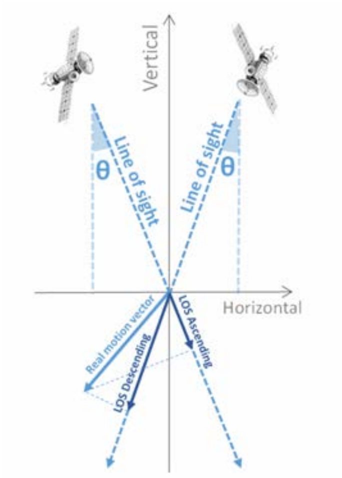

Fig. 2. Measurement of motion vector using ascending and descending orbits.

In order to measure the vertical and the horizontal component of the ground motion with InSAR technology, two independent acquisition modes need to be used, ascending and descending modes. Equation (1) illustrates the relationship between the acquisition geometry (incidence angle and satellite track heading angle) and the measurements (LOS ascending and descending) which must be inverted to retrieve the horizontal and the vertical components of the motion.

$$\begin{bmatrix} -\cos(inc_{AS}) & \sin(inc_{ASC})\cos(heading_{ASC}) \\ -\cos(inc_{DESC}) & \sin(inc_{DESC})\cos(heading_{DESC}) \end{bmatrix} \cdot \begin{bmatrix} MOV_{LOS\_ASC} \\ MOV_{LOS\_DESC} \end{bmatrix} = \begin{bmatrix} MOV_{VERT} \\ MOV_{HORI} \end{bmatrix} \quad (1)$$

3. Sentinel-1 earthquake results

S1A Interferometric Wide (IW) Swath TOPSAR[5] (Terrain Observation with Progressive Scans SAR) mode offers the possibility of acquiring images with a maximum temporal frequency of 12 days. This temporal gap will be reduced to only 6 days with the beginning of operations of S1B. This huge amount of images is extremely useful for the monitoring of geohazards, such as earthquakes. In this paper the rapid generation of ascending and descending TOPSAR interferograms[5] is presented for the last strong Japan earthquakes that occurred in April 2016[6].

Fig. 3 shows both interferograms generated using four Sentinel-1 images, on one hand the ascending pair corresponds to 8th and 20th April 2016, and on the other hand the descending pair composed by 3rd March and 20th April 2016 acquisitions. Each color fringe corresponds to approximately 2.8 cm of accumulated displacement. Note the strong motion gradient with very close fringes in several areas of the affected zone. It is also important to remark the different ground motion patterns in ascending and descending modes. This means that a noticeable horizontal motion component is present in the displacement pattern. In case of pure vertical motion, ascending and descending orbits would show similar phase fringes.

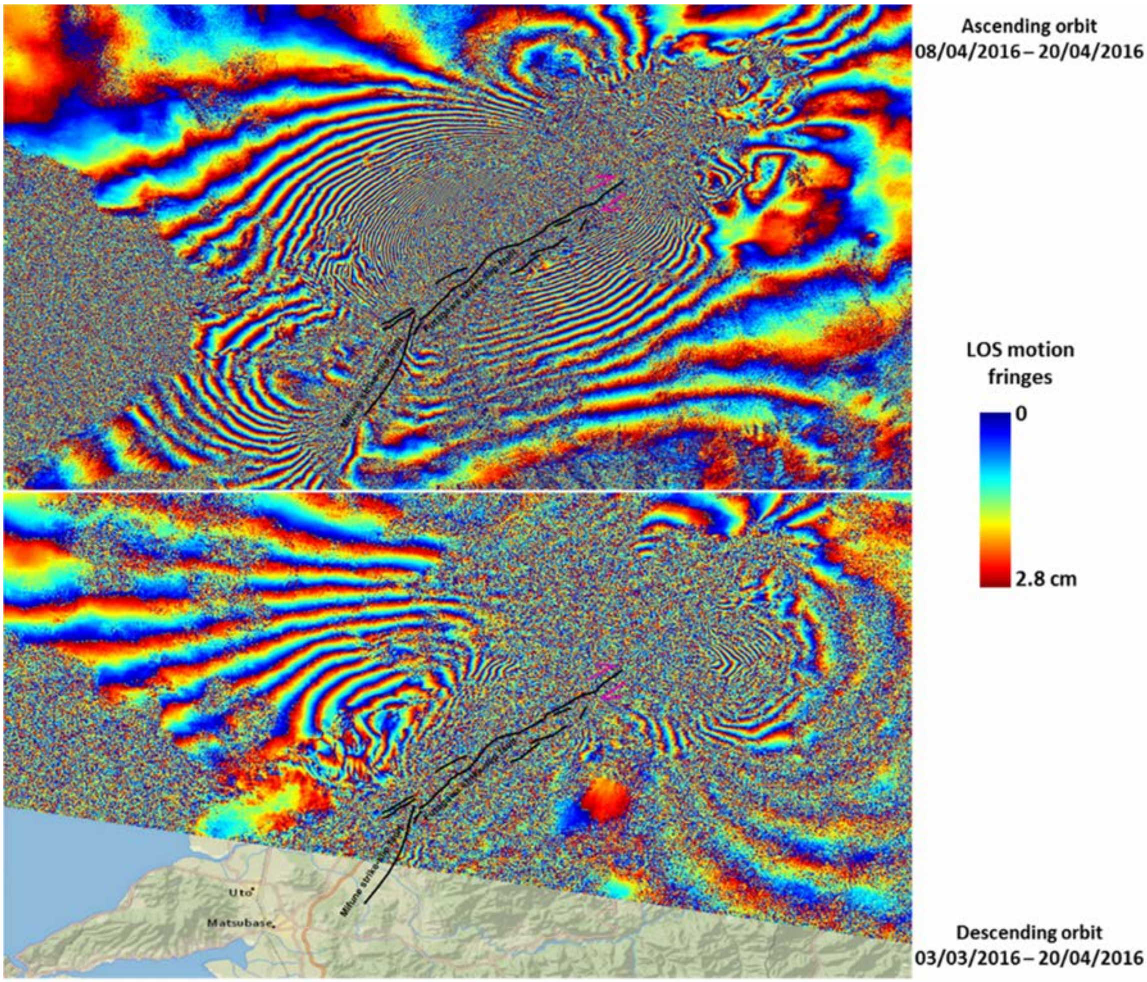

Fig. 3. Ascending and descending Sentinel-1 differential interferograms of Japan's earthquake[6].

In order to obtain the absolute value of displacement, interferograms must be unwrapped[3,4] and transformed from phase radians into motion. Fig. 4 presents the unwrapped version of interferograms in Fig. 3. In this case phase fringes have disappeared and absolute motion in Line Of Sight (LOS) is recovered. Nevertheless, LOS measurement is a projection of the real 3D motion, and therefore the decomposition computation of Equation (1) must be applied to obtain East-West and Up-Down components. Fig. 5 shows the final result of this decomposition, being clear that East-West component is stronger than Up-Down direction, as it was expected by visual inspection of wrapped interferograms. The mean incidence angles θ (see Fig. 2), in the area most affected by surface motion, for both ascending and descending orbits are approximately 35 degrees, but note that it can range from 29 to 46 degrees looking from near to far range, due to the large coverage of IW TOPSAR acquisition mode.

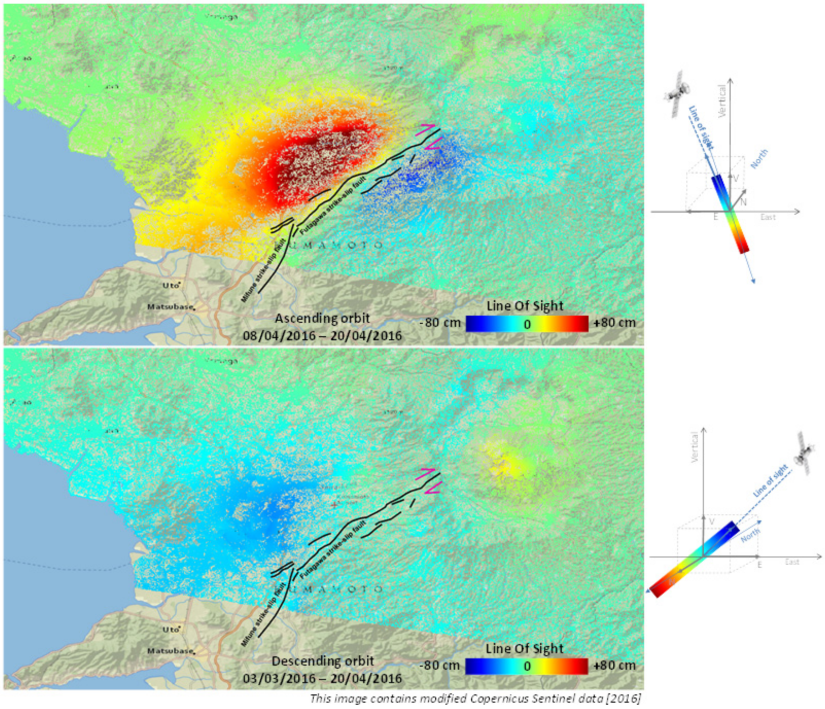

Fig. 4. Ascending and descending LOS motion maps of Japan's earthquake[6].

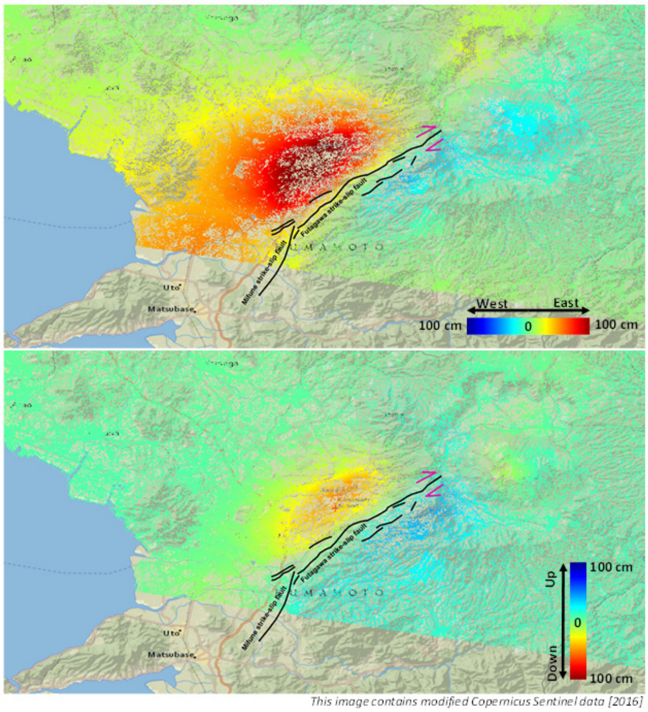

Fig. 5. East-West and Down-Up motion maps of Japan's earthquake[6], using ascending and descending orbits.

4. Conclusions

Massive acquisitions of Sentinel-1 data allow geohazards community to monitor earthquakes with a rapid response using ascending and descending orbits. The combination of these orbits, jointly with a phase unwrapping processing, results in horizontal (West-East) and vertical (Up-Down) ground motion maps. The presented example of April 2016 Japan earthquake demonstrates the capability of Sentinel-1 data to generate these products in a very short temporal period, providing valuable information to seismic experts and civil protection authorities.

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