Consistency test of surface deformation determination using Sentinel-1A and Sentinel-1B images for the 2018 Oaxaca earthquake

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***Abstract*—By the launch of Sentinel-1B, a new satellite has become available for InSAR determination of surface deformation apart from Sentinel-1A. The two missions are essentially identical, which were planned to reduce the repeat time of imaging. Even so, it is important to analyze the consistency of the data each satellite can provide. In this study, the 2018 Oaxaca earthquake has been processed using images of these satellites independently, and based on that a comparison of their solution has been provided.**

I. Introduction

The basic concept of the dedicated joint Copernicus program of European Space Agency (ESA) and European Union (EU) is to provide continuous monitoring programmes over timescales of decades [1]. The Sentinel missions of the Copernicus program are primarily designed for routine observations of operational GMES (Global Monitoring and Environmental Security) services [2]. Among the 6 Sentinel mission, Sentinel-1 satellites are providing radar imaging for land and ocean services. Accordingly, Sentinel-1 images enable determination of surface deformation over large region even with some cm amplitude over short and long time scales as well.

Volcanic and seismic events are often accompanied by measurable surface deformations over large area within the time frame of some days. As it was already shown by [3], pre-, co- and post-seismic deformations can efficiently be determined depending only on the timing of the images with respect to the event. The timing of the images is,

Figure 1. Shake map (intensity) of the Oaxaca 2018 event [6]

however, haphazard, cannot be planned or controlled. Thus, the densification of similar images by the extension of the Sentinel-1 satellite mission with additional satellites is highly justified.

Meanwhile, the extension of mission with new satellites is valuable only if the different satellites provides equivalently useful result with similar accuracy at the same spatial resolution. As in 2018, Sentinel-1 mission contains two satellites: 1A and 1B [2], while two more satellites, 1C and 1D are already contracted for an unknown date of launch [4]. The repeat cycle of a Sentinel-1A satellite is 12 days, which has already been reduced to 6 days by the launch of Sentinel-1B satellite, which is an identical twin of Sentinel-1A with 6 days delay in its orbit. As demonstrated by [5], successful combination of Sentinel-1A and Sentinel-1B images can be achieved.

In this paper now we investigate whether the results achieved by of Sentinel-1A and Sentinel-1B images are consistent. It is tested by independent processing of the same event. Therefore, a suitable event was chosen for the analysis - an event generating notable magnitude of deformation over a very short time (i.e. some days). The short duration of the deformation is demanded to be able to find useful data by both satellites.

II. The Test Event

The test event is the deformation caused by the earthquake at 23:39:39 UTC of 16 February, 2018 in Oaxaca, Mexico (location: 16.386N, 97.979W) with a magnitude of 7.2 Mww, which has resulted in an intense shake over a huge region of South Mexico, c.f. Fig. 1 [6].

According to [6] the event is a shallow earthquake (depth of the hypocenter is 22.0 km), thus we may expect visible deformation over a finite region from Sentinel images. The focal mechanism shows a normal slip with a dip angle of the nodal planes of 12° (NP1) and 78° (NP2), c.f. the beach ball model of the event on Fig 2. The direction of the slip is completely downward (rake of NP1 is 91°, rake of NP2 is 90°), along the Middle America Trench, where the strike angle of NP1 is 297°, and of NP2 116° [6].

This event can be easily separated from others: there have been no relevant pre-shocks (the largest one has occurred 2 days before the main event with an M4.4 magnitude). The post shocks contain two notable events: there has been a quake approximately an hour after the main shock (at 00:36:52 UTC of 17 February with a magnitude of 5.8 Mww and depth of 3.5 km), and another one two days later (at 06:56:58 UTC of 19 February with a magnitude of 5.9 Mww). Even though the effect of these post-seismic events on surface displacement cannot be separated from the main event, they are negligible, as the seismic moment of the main event has is $7.996*10^{19}$ Nm, while for the post shocks is only $5.817*10^{17}$ Nm and $8.329*10^{17}$, respectively for 17 and 19 February events. It means that due to the post shocks the seismic moment (practically related to ground motions) became less than 2% of that of the main shock, so surface deformations are dominated by the main shock. The same can be understood when the released energy of the main shock and of the two largest post shocks are compared: the energy released by these events are $3.98*10^{15}$ J, $3.16*10^{13}$ J and $4.47*10^{13}$ J, respectively, so the energy released by the post-shocks is less than 2% of that of the main shock.

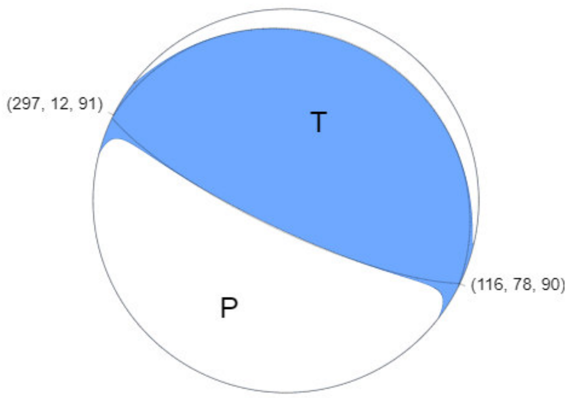

Figure 2. The beach ball model of the Oaxaca 2018 event [6]

Note finally, that this event has already been processed by [7] using only the Sentinel-1B satellite data. The deformation rings were observed to be essentially clear, confirming the choice of the event to be appropriate for overall analysis.

III. Data Processing

In order to analyze consistency of Sentinel-1A and Sentinel-1B, the same processing sequence has been performed for both satellite's images independently. First, images from the Copernicus Open Access Hub has been downloaded [8]. From the Hub images on 27 January and 20 February for Sentinel-1A, and on 5 February and 17 February for Sentinel-1B has been found accessible. Even though the time span is notably different, presumably differences in the deformation may be regarded mainly to the pre-seismic deformations, in which case the difference of starting at 27 January or at 5 February may be relevant, and partially may be regarded to the post-seismic differences, as the effect of the 19 February post-shock event is excluded from the Sentinel-1B, but included in the Sentinel-1A image.

A relevant difference of the acquired images is that in the case of Sentinal-1A images, these were taken along a descending orbit, while in the case of the Sentinel-1B images, it was an ascending orbit.

Using these images, processing was performed by using the Sentinel-1 Toolbox of the Sentinel Application Platform (SNAP), an open-source software provided by the ESA, jointly developed by Brockmann Consult, Array Systems Computing and C-S for processing images of orbiting Sentinel satellites [9]. The processing (including co-registration of the images, formation of the interferograms, deburst of the images, removal of the topographic phase, the Goldstein phase filtering, phase unwrapping, determination of the phase displacement, georeferencing and removal of the ellipsoidal correction) is done routinely, the sequence is detailed in [10].

The resulted phase maps are shown on Fig. 3 and Fig. 4. The structure of the deformation is visually similar, a difference in coverage of the test area can be observed due to the different areal coverage of taking the different images.

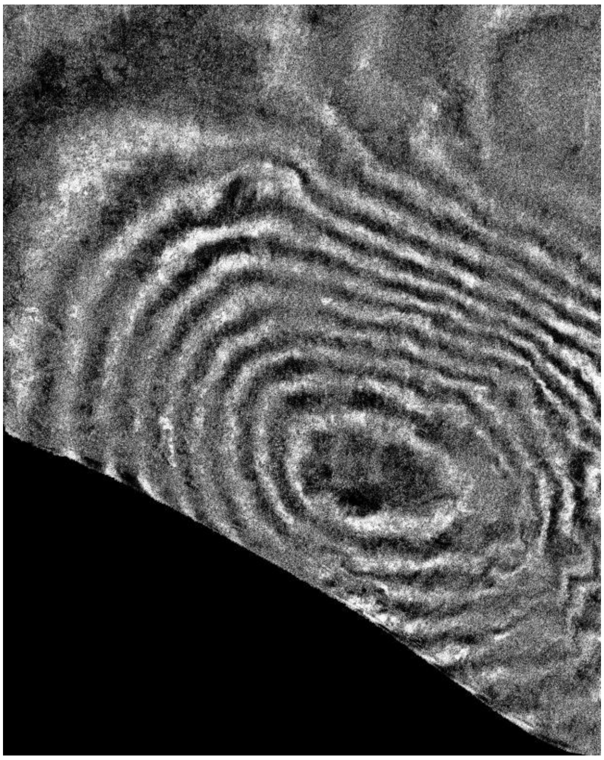

Figure 3. The phase map of the Oaxaca 2018 event based on observations of the Sentinel-1A satellite

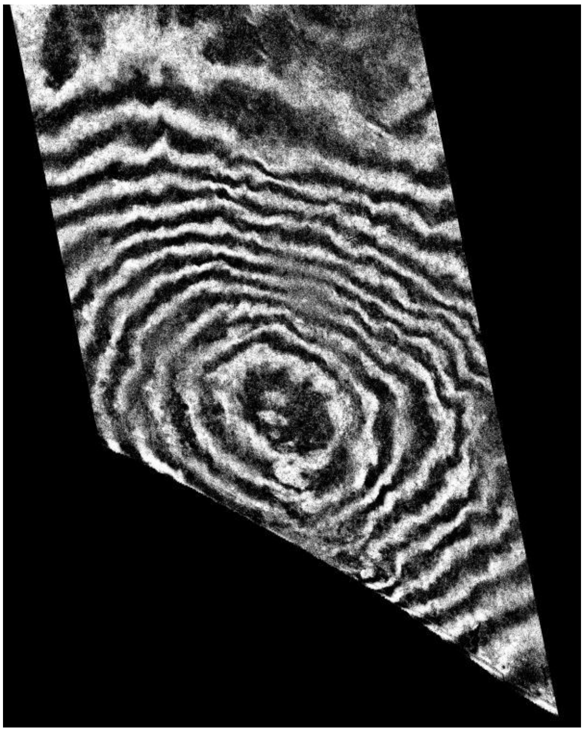

Figure 4. The phase map of the Oaxaca 2018 event based on observations of the Sentinel-1B satellite

IV. COMPARISON OF THE RESULTS

For numerical comparisons the phase maps shown on Fig. 3 and Fig. 4 should be georeferences. Fig 5., Fig 6 and Fig. 7 shows the georeferenced Sentinel-1A, Sentinel-1B and their difference phase maps, respectively.

According to this images it is obvious that there is a displacement of the center of the location of the maximal deformation. It may arise from the different circumstances of taking the images, i.e. taken along an ascending or a descending orbit.

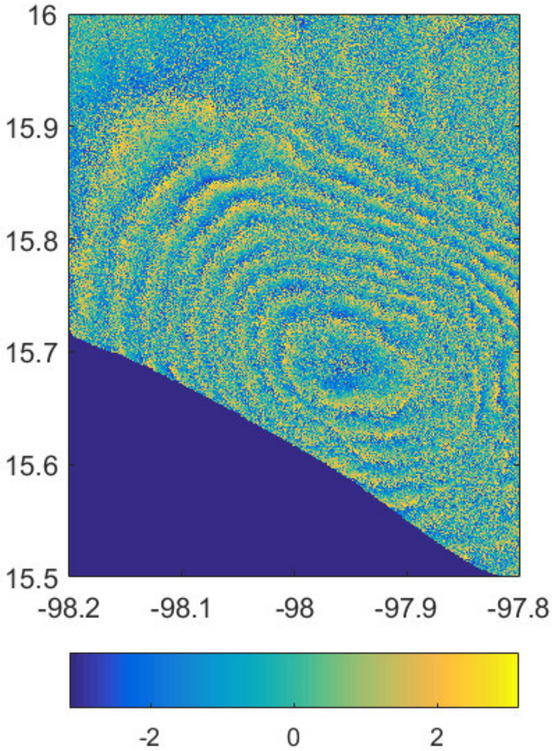

Figure 5. Georeferenced Sentinel-1A phase map

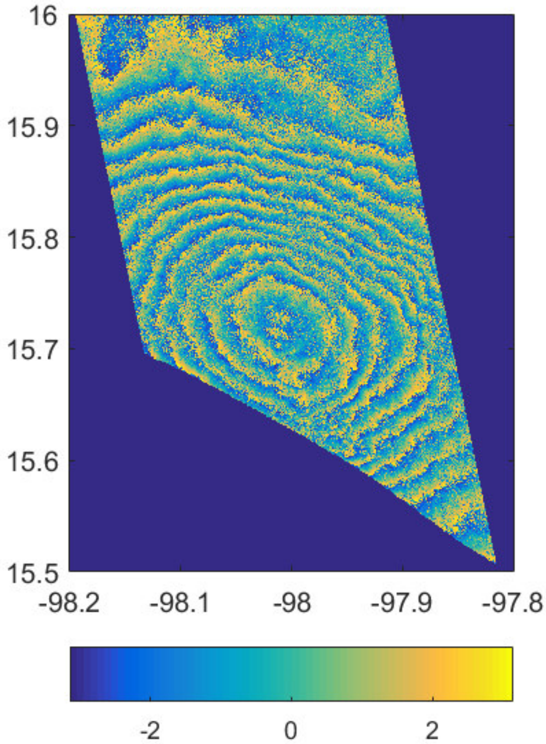

Figure 6. Georeferenced Sentinel-1B phase map

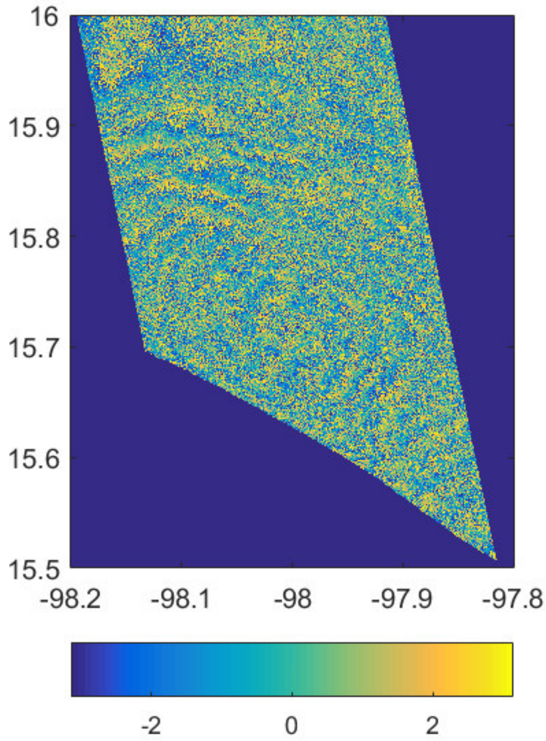

Figure 7. The difference phase map

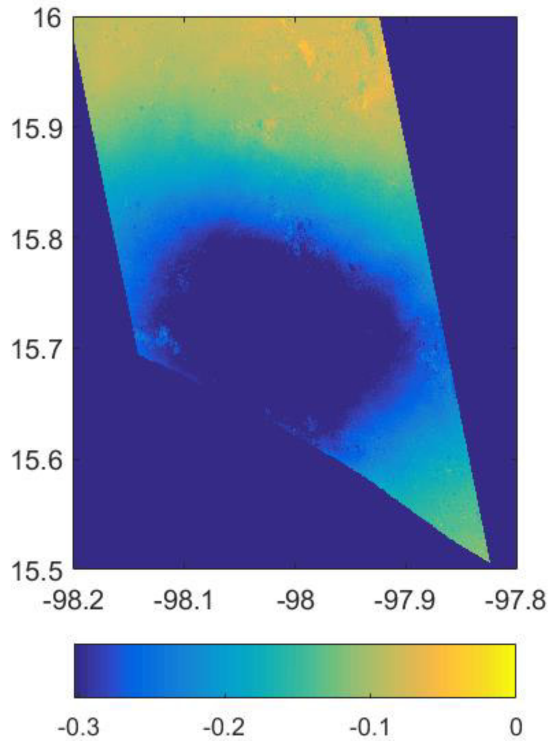

Figure 8. Deformation derived from Sentinel-1A images. Unit: [m]

The corresponding deformations have been determined by the Snaphu software [9]; these are displayed by Fig. 8 and Fig. 9, and their difference is on Fig 10.

According to the figures, no values below a threshold, in the present case below -30.34 cm, was observed, but all values stored to be the threshold value. Definitely, the deformation cannot be considered to be flat and fully horizontal over a huge region, therefore this is obviously a bug of the software.

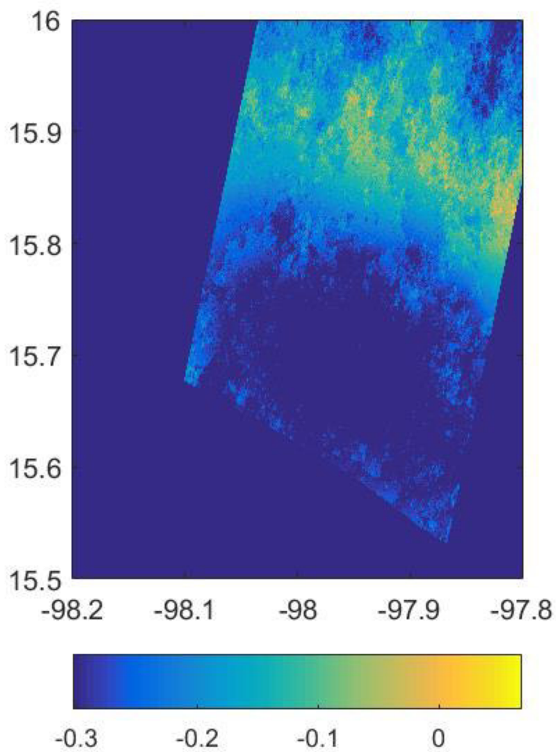

Figure 9. Deformation derived from Sentinel-1B images. Unit: [m]

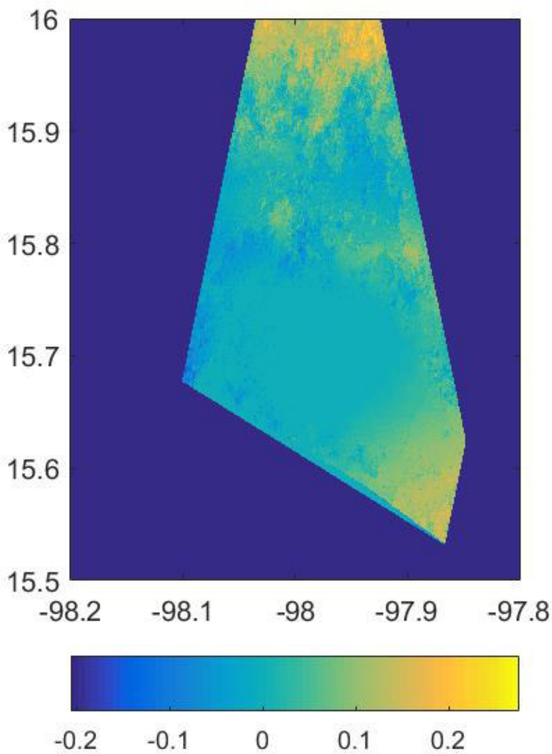

Figure 10. Deformation differences. Unit: [m]

Still the results are interesting. Apart from the threshold truncation problem, there are relevant features can be detected. First of all, the shape of the deformation seems to depend on direction of the beamline of acquiring the image as the tilting of the displaced area is in accordance with that of the imaging beamline, c.f. Fig. 8 and Fig. 9.

Also, it is obvious that close to the edge of an image that acquired data is less reliable, it results in a relevant difference at the Northern edge of the ascending and descending images. It may be a consequence of the different direction of the beamline, as it may reflect that in one case the beamline could reach the ground from one direction, while it is shadowed from the other.

V. Conclusions

A statistical comparison of each cases are also derived. The deformation was observed to occur in the [-30.34 cm, +0.01 cm] and in the [-30.34 cm, +0.07 cm] intervals for the Sentinel-1A and Sentinel-1B cases, respectively. The maximal sinking is a bug; in reality the deformation for sure extend this value. The range, however, is similar for both cases, as the bug influenced region has a similar area.

Fig. 10 shows the difference deformation map. It is dominated by the Northern edge difference. Including this area as well, the residual RMS was found to be 5.05 cm, showing that the two solutions are similar to each other in the cm level. It may not be considered to be an adequate validation as a notable area of the test is infected by software bug, still it is a notation that the satellites can contribute identical results to surface deformation analysis in the cm level.

Fig. 11 and Fig 12. Present two different cross-sections of the deformation map. These cross-sections indicate the nonsense characteristics of the maximal deformation as both data suggest a flat and horizontal bottom of the deformed area, while no indication of such flatness in the phase maps, c.f. Fig. 3 to Fig. 6 can be observed. The cross-sections, on the other hand shows that the slope of the deformed area is similar from the two independent sources, which is a notable indication that the satellites observes some real change with a similar accuracy. This similarity is distorted by approaching to the Northern edge of the test area, as it has already been mentioned before.

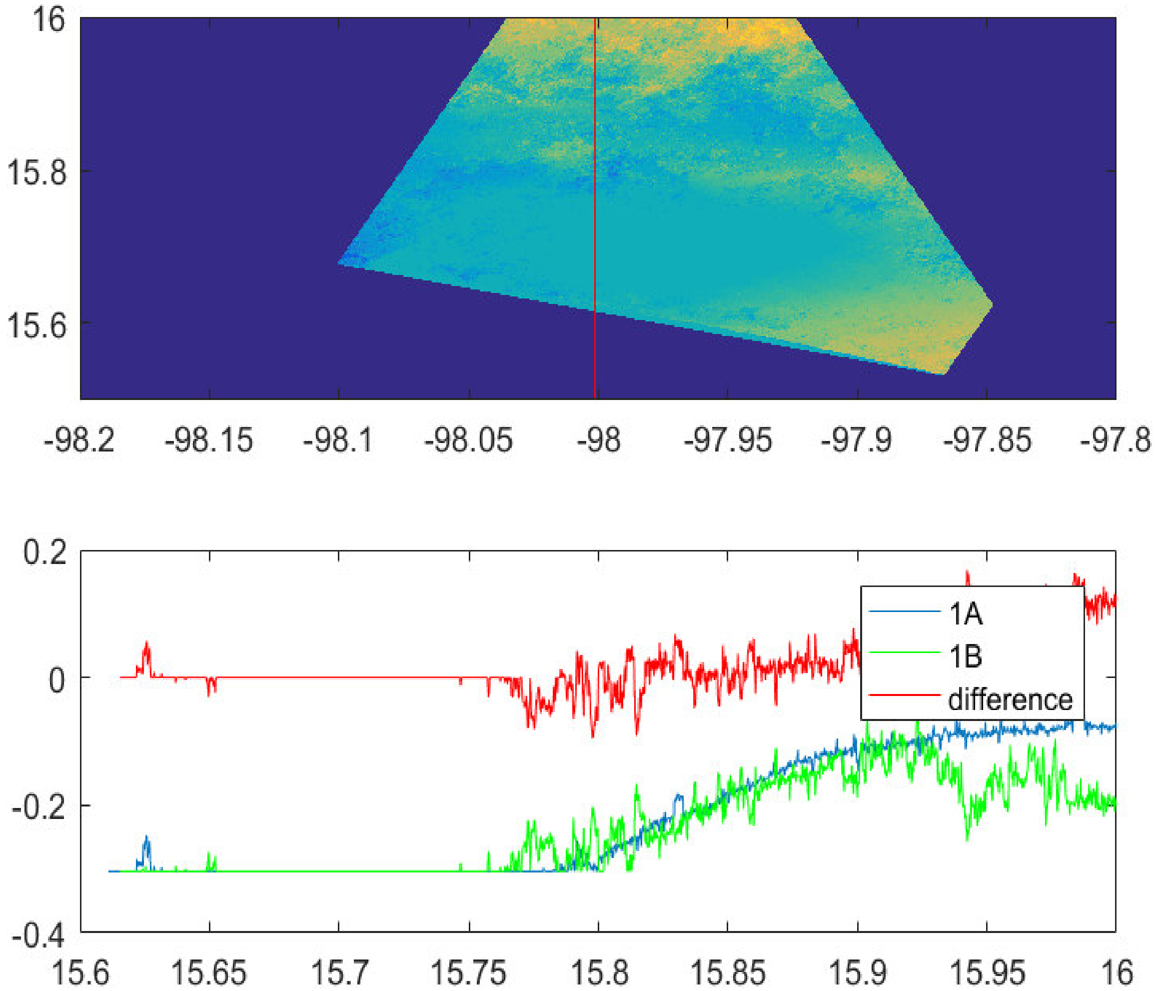

Figure 11. Cross section at E98-00-04 longitude.

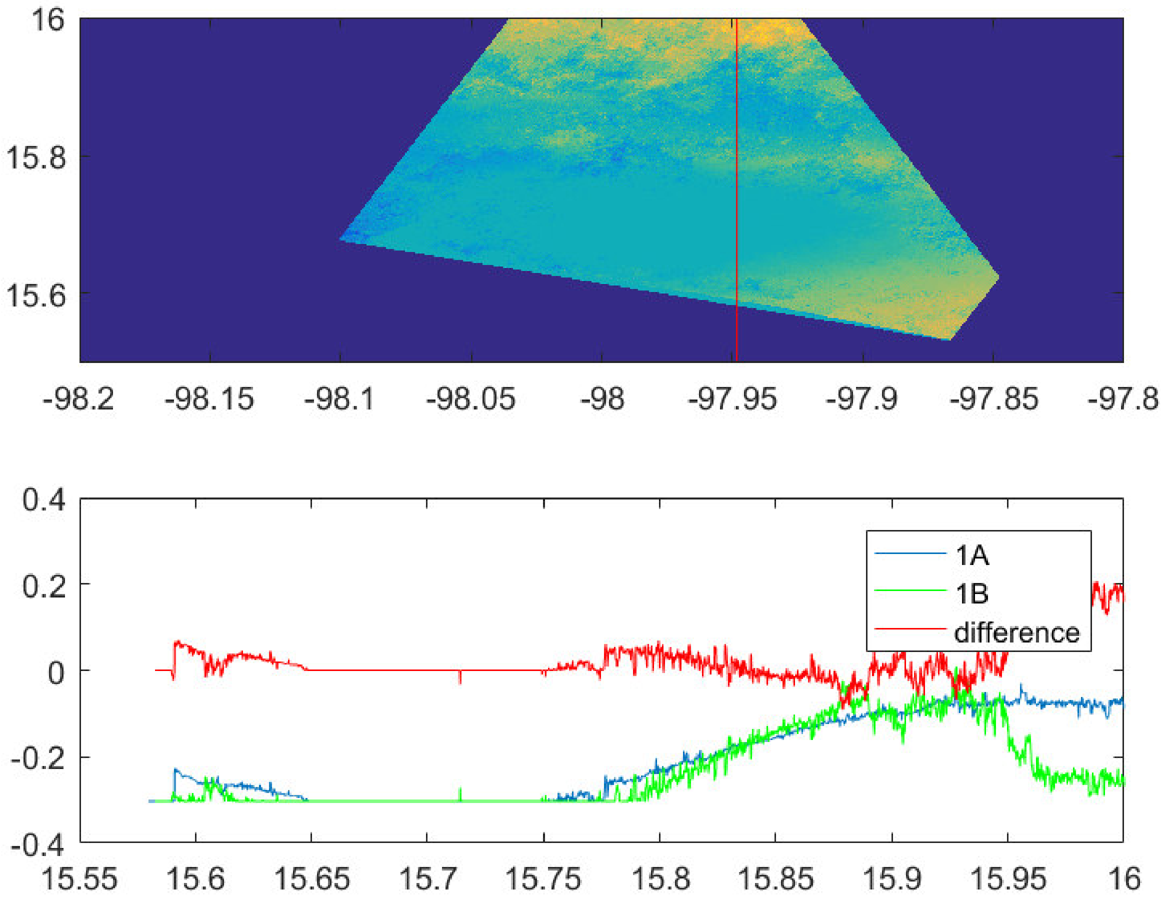

Figure 12. Cross section at E97-56-54 longitude.

The strength of the present analysis that it has dealt with images taken by two different satellites, along two differently oriented orbits, still the similarity at cm level could be detected. Definitely, further analyses may take place making also use of combinations of identical satellite-borne images along two different orientations, and also different satellite-borne images taken from identical orientations.

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