Combined use of Sentinel-1A and Sentinel-1B data for determination of post-seismic vertical surface deformation - a case study: Perugia, 2016

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***Abstract*— In this paper the feasibility of combined use of Sentinel-1 and Sentinel-1B images has been investigated by applying them for detecting vertical surface deformation due to a major earthquake event. The test event is the 24 August, 2016 event with Richter amplitude 6.2 in the vicinity of Perugia. The use of the two different satellites with identical technical parameters may be beneficial in the temporal resolution of the derived images. Even though in this study a successful application for the combination of the two independent images for InSAR processing has been demonstrated, it is just a case study, for a final proof more elaborated investigations should be performed.**

I. Introduction

In April 03, 2014 a new era has begun in space geodesy and remote sensing with the launch of the Sentinel-1A satellite [1] starting a dedicated joint Copernicus program of European Space Agency (ESA) and European Union (EU). The initial mission plans have contained three Sentinel series (1-3) with three satellite each (A, B, C), but afterwards a new satellite (Sentinel-1D) and three more series (4-6) has been added to the mission, which are scheduled to be launch after 2020 [2].

In this paper measurements of Sentinel-1A and Sentinel-1B have been used. The main technical parameters are listed in Table 1 based on [1].

Apogee:	693 km
Orbit regime:	SSO (Sun-synchronous Orbit)
Inclination	98.2°
Period:	98.6 minutes
Repeat interval:	12 days
Mission duration:	7 years planned, 12 years of consumables
Mission objectives:	atmosphere-, marine- and land-monitoring, climate change, emergency management and security.
Launch:	03-04-2014 (1A) and 25-04-2016 (1B) from Guyana Space Center.

Table 1. Sentinel-1A and B technical parameters [1]

Using the state-of-the-art vertical monitoring method, the Synthetic Aperture Radar Interferometry (InSAR) technology [3], a wide area of applications ranging from monitoring vertical displacement of discrete points, through monitoring movements of buildings, to observation of crustal movements on continental scale becomes feasible [4]. The SAR technology is an active remote sensing method [5], and as such, it is independent from the daytime cycle. The satellite radar interferometry is based on comparing one or more radar image. Using the phase values of the images, phase differences can be derived, which are then interfered at the steady (i.e. being in no motion) areas. Based on the interferences, an interferogram can be deduced to estimate the amount of vertical movement at the area of interest [6].

II. Case Study: Perugian Earthquake

The source of the Italian earthquakes is the subduction of the African plate under the Eurasian plate. These two plates are converging every year 2 cm to each other, causing smaller earthquakes almost constantly in the Italian peninsula. This motion has created the Alpine mountain range in the past, and will result in a total merge of the two continents in the future, diminishing the Mediterranean Sea eventually.

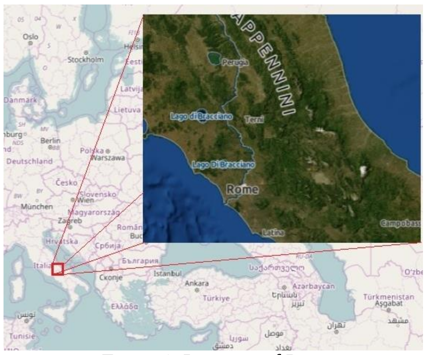

Figure 1. Location of Perugia

On 2016-08-24 an earthquake magnitude of 6.2 on Richter-scale shook the area of Perugia, 140 km North-East from Rome, c.f. Figure 1. Actually, several tremors been occurred within few hours as it is indicated by the purple circles on Figure 2, displaying seismic events according to the event catalog of the IRIS (Incorporated Research Institutions for Seismology) on that day [7]. Around Perugia as a consequence of these quakes some faults have appeared, manifesting that the area built on a very active part of Italy. [8]

Figure 2. The effects of the Perugian earthquake [7]

Sensing period:	2016/08/21-2016/08/27
Satellite Platform:	S1A_* or S1B_*
Product Type:	SLC
Polarization:	VV
Relative Orbit Number:	117

Table 2. Search parameters

Satellite	Orbit	Date	Time
S1A	desc.	2016-08-27	17:05:42.593
S1B	desc.	2016-08-27	05:10:35.191
S1A	asc.	2016-08-26	05:19:22.305
S1B	asc.	2016-08-21	17:05:09.646
S1A	desc.	2016-08-21	05:11:16.928

Table 3. Search results

III. DATA PROCESSING

The first step before any actual processing is to acquire the data to work with. The source of data of this study is the Sentinel Scientific Data Hub site, operated by ESA (c.f. Figure 3). The processing software is also provided by ESA developed by Brockmann Consult, Array Systems Computing and C-S. This software is designed to process images captured by any Sentinel satellites. [9]

During the selection of the proper images the first step is to decide on the use of data type, SLC or GRD data. The SLC contains phase and amplitude values, while the GRD contains amplitude only. As for InSAR deformation monitoring phase information is also required, the SLC data were used.

Before the launch of Sentinel-1B it was essential to use images 12 days apart from each other, since this is the time period, when the satellite returns to the same position in every 175 full orbit [3], delivering appropriate pairs of images for processing. But since then, there are two Sentinel-1 satellites theoretically images from different satellites can be processed, because it would halve the time when satellites are in the same position, and could double the number of the suitable images.

After the image positions are selected, the polarization to be used should be decided. Usually the most reliable information on vertical deformation can be derived from the vertical-vertical (abbr. VV) polarization [10].

For this study two images were selected, a search for data has been performed for the 21 to 27 of August, 2016 period in the vicinity of the event, c.f. Table 2. There have been five images found (c.f. Table 3, Figure 4). Among them two images have been observed on ascending orbit (one 1A and one 1B), and the remaining three images on descending orbit (two 1A and one 1B).

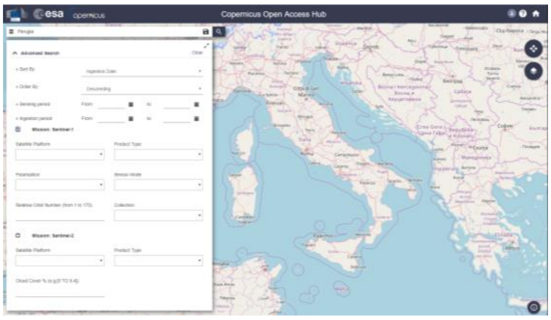

Figure 3. Scientific Data Hub

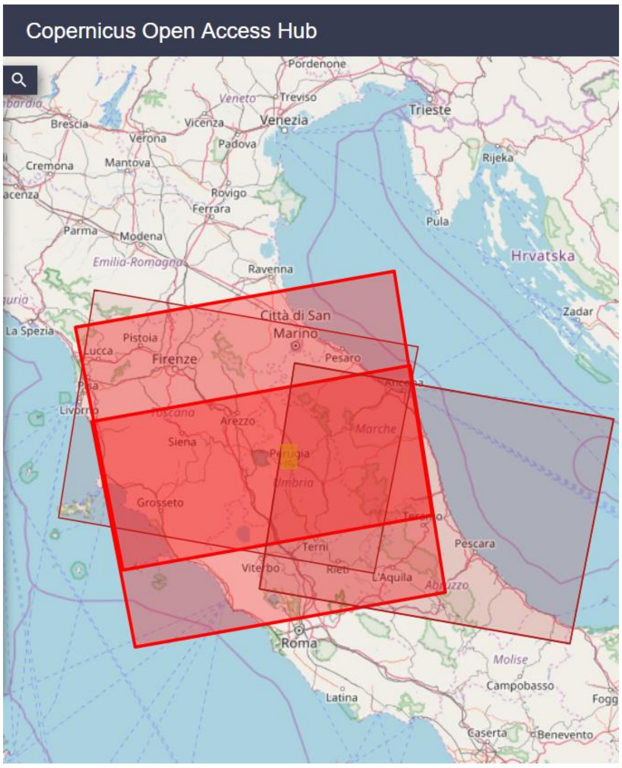

Figure 4. Search results and their positions

On figure 4 the two images, which were finally the source of the processing are highlighted. There were attempts processing the other three images. According to the tests it appeared that if the area of interest is close to the edge of the overlapping area, i.e. in the 10% border zone, then no vertical changes can be detected on the interferogram. Also, it turned out that images from descending and ascending orbits cannot be combined regardless the source of the image, i.e. identical or different satellites.

Two images a Sentinel-1A image on 2016-08-21 and a Sentinel-1B image on 2016-08-27 has been used:

- S1A_IW_SLC__1SDV_20160827T170542_20160827T170609_012789_014270_B9C6
- S1B_IW_SLC__1SDV_20160821T170509_20160821T170538_001718_002770_6482

The main processing software was the Sentinel-1 Toolbox of the SNAP software, apart from the determination of the vertical deformation map from the interferogram, which can be performed in an independent step with the use of the Statistical-Cost, Network-Flow Algorithm for Phase Unwrapping (SNAPHU) program, every other step was performed by it.

The steps of the workflow can be seen below, c.f. Figure 5.

Figure 5. Processing workflow

During the first, *S1 TOPS Coregistration* step, the master and slave images has been chosen. Every image file (ref frame on Figure 6) contains three subsequent *Sub-swaths* (middle white frame on Figure 6), thus another selection has been made to choose that which part is the area should be processed. If necessary, the location can further be narrowed by using the tool *Bursts* (small white frames on Figure 6).

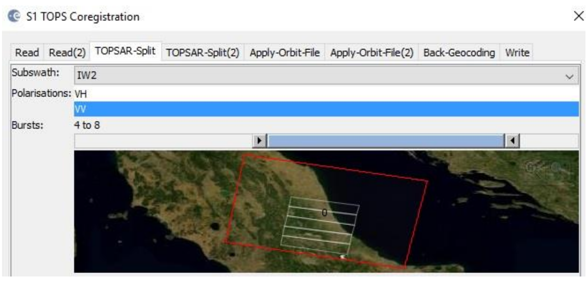

Figure 6. *S1 TOPS Coregistration* step with *Sub-swaths* and *Bursts*

The results are the intersecting parts of two datasets in the same position, as shown below c.f. Figure 7 and 8.

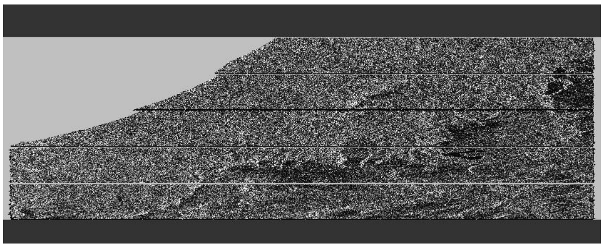

Figure 7. Bursts of master image

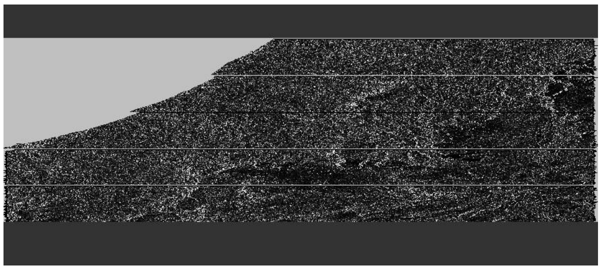

Figure 8. Bursts of slave image

In the next step, the *Interferogram formation*, the following corrections are applied [11]:

- $\Delta\phi_{flat}$: phase correction for the Earth curvature (often named as *flat Earth phase*),
- $\Delta\phi_{elevation}$: phase correction due to topography,
- $\Delta\phi_{displacement}$: surface deformation correction,
- $\Delta\phi_{atmosphere}$ phase correction accounting for atmospheric differences,
- $\Delta\phi_{noise}$: phase noise correction generated by temporal change of the scatterers, varying look angle, and volume scattering.

The corrections are simply summed to a correction term, $\Delta\varphi$

$$\Delta\varphi = \Delta\varphi_{flat} + +\Delta\varphi_{displaceent} + \Delta\varphi_{atmosphere} + \Delta\varphi_{noise}$$

where:

$$\Delta\varphi_{flat} = -\frac{4\pi}{\lambda}\frac{B_n s}{R\tan\theta}$$

$$\Delta\varphi_{elevation} = -\frac{\Delta q}{\sin\theta}\cdot\frac{B_n}{R_0}\cdot\frac{4\pi}{\lambda}$$

$$\Delta\varphi_{displaceent} = +\frac{4\pi}{\lambda}d$$

In these equations B_n is the normal baseline, R_0 is the radar-target distance Δq is altitude difference, s is slant range displacement and θ is the radiation incidence angle with respect to the reference. (For the geometrical representation of some of these quantities, see Figure 9.)

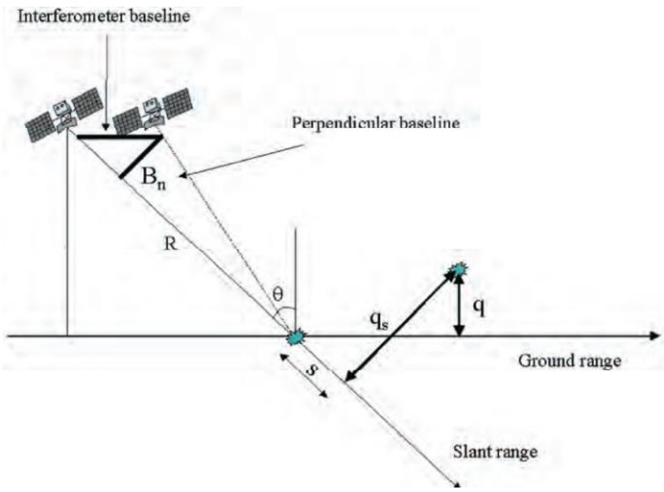

Figure 9. Sketch of the geometry of observing with a SAR satellite for the use of the InSAR technology. [12]

The *S1 Tops Deburst* function eliminates the horizontal lines on the images by merging the neighboring stripes.

To get an image where only the deformations remain, the topography effects must be subtracted by using the *Topographic Phase Removal* function (c.f. Figure 10.).

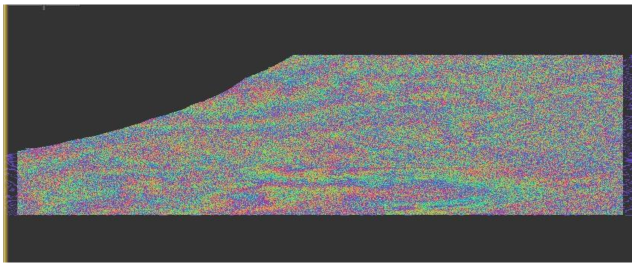

Figure 10. Phase image without topographic effects (red=0 blue=2π).

On the aforementioned figure (Figure 10.) the dotted nature is the consequence of the lack of coherence. Coherence loss can be occurred due to temporal and geometric decorrelations, volume scattering and processing errors. To reduce this noise, a filter should be applied. In the SNAP program this filter applies the Goldstein method, and the function utilized is the *Goldstein Phase Filtering.* The results of the filtering are shown on Figure 11.

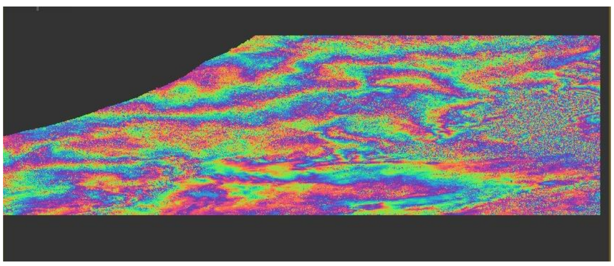

Figure 11. Phases after the Goldstein filter has been applied (red=0 blue=2π)

The improvements are conspicuous between the two processing states (Figure 10 vs. Figure 11.) The results are ambiguous since the values in every pixel are between 0 and 2π. In order to interpret the results for engineering purposes, the displacement values in meter dimension are preferred. In order to achieve this, a so-called *Phase Unwrapping* step should be applied. This is the step, which can be done in a separate software (SNAPHU) dedicated to this task. Phase unwrapping solves this ambiguity problem by integrating phase difference between pixels next to each other. (c.f. Figure 12.) [1]

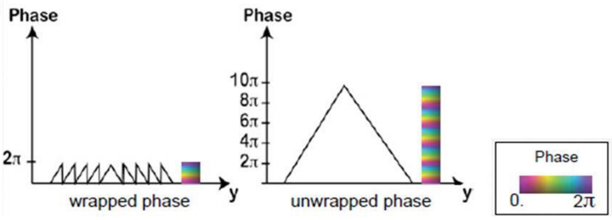

Figure 12. Phases before and after unwrapping. [1]

Subsequently, the *Phase to Displacement* function can be used for obtaining vertical displacement values as distances.

The two final steps, the *Update Geo Reference* and the *Ellipsoid Correction* is needed in order to transform the results into geographically correct coordinate system. (c.f. Figure 13.)

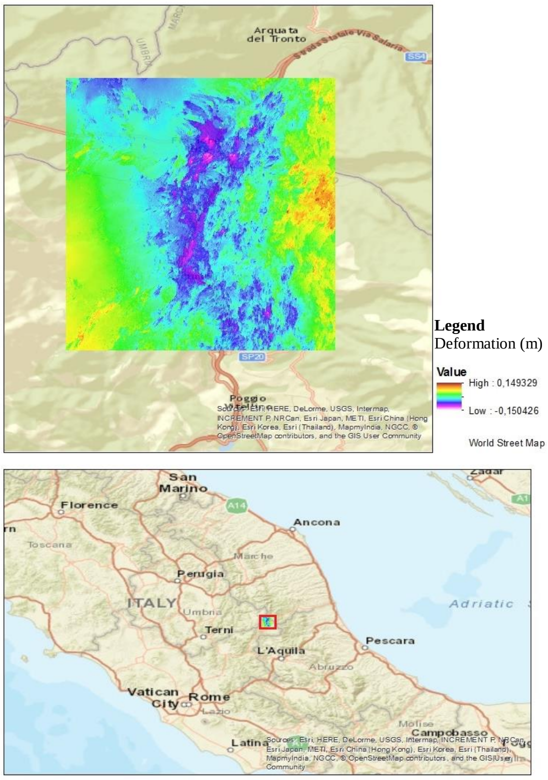

Figure 13. The displacement results in geographically correct position

IV. Results

In the study an attempt has been done to combined use of Sentinel-1A and Sentinel-1B images. For the purpose a major earthquake has been analyzed as a case study. According to the investigations it was found that

(1) If the area of interest is close to the edge of the overlapping area, i.e. in the 10% border zone, then no vertical changes can be detected on the interferogram.

(2) Images from descending and ascending orbits cannot be combined regardless the source of the image, i.e. identical or different satellites.

(3) Images of different satellites, 1A and 1B (with both being on ascending orbit) could efficiently be used for vertical deformation analysis.

The successful processing of 1A and 1B satellites ascending images has led to comparable results with other studies. According to our investigation, on the 24th of August, 2016, the area of Perugia due to the earthquake has been sunk about 14-15 cm. In a similar study published on Geo-Sentinel website [13], a subsidence of 20 cm has been determined. The difference arises from the different data they used, the different processing software, which involves several differences of processing, such as phase filtering method, or correction models.

The vertical changes follow the tectonic lines, in the lower areas subsidence, in the higher areas uplift can be detected, so the motions are consistent to the topography.

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