COMBINATION OF X-BAND HIGH RESOLUTION SAR DATA FROM DIFFERENT SENSORS TO PRODUCE GROUND DEFORMATION MAPS

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ABSTRACT

The constitution of an archive of Synthetic Aperture Radar (SAR) data acquired over a site of interest is mandatory for PSI (Persistent Scatterer Interferometry) analysis. The application of PSI methodologies to detect ground motions requires the use of a large stack of data in order to identify the measurement points and properly separate the different phase components due to the ground motion, the topography and the atmospheric induced phase delays. When monitoring areas affected by strong gradients of deformation, the presence of unexpected gaps in the acquisitions plan can prevent from correctly measuring the motion; the maximum gradient of motion detected without ambiguity can be seriously degraded. This paper proposes an alternative, based on the combination of SAR acquisitions from different sensors. This is possible with sensors that operate similar carrier frequencies, modes of acquisition with similar resolution and with the selection of the appropriate orbital passes to obtain approximately the same observation geometry. Keeping the same geometry preserves the coherent target in the two data stacks and do not significantly affect the final density of the measurements. The approach developed has been optimized for the PSI study of a particular area of interest; the combination of two stacks of X-band SAR datasets acquired by the TerraSAR-X and COSMO-SkyMed (COnstellation of small Satellites for the Mediterranean basin Observation) satellites is proposed. The feasibility of the technique is showed with real data.

1. INTRODUCTION

The successful launches of TerraSAR-X (TSX) and of the satellites COSMO-SkyMed (CSK) allow making available high resolution SAR images with a reduced revisit time. The improvement, in terms of spatial resolution, of these new X-band sensors compared with the precedent C-band sensors on board ERS-1/2 or ENVISAT satellites is observed in an increase of Persistent Scatterers density [1]. As a result, more detailed deformation maps can be generated, showing a better delimitation of the areas affected by ground motion. Another improvement brought by X-band data is in the measurement precision; the shorter wavelength moreover increases the sensitivity to detect and monitor millimetric changes in the distance between the sensor and the ground targets. Finally the reduced revisit periods of those missions augment the monitoring capabilities of non-linear ground motion and which, in some way (jointly with the increase of spatial resolution), compensates the maximum gradient of deformation that could be detected with such a short wavelength.

However, those recent missions present some characteristics that must be accounted for when building an archive for PSI analyses. The considered X-band missions do not propose an extensive background acquisition program that allows the continuous monitoring of particular area of interest (e.g. main cities). Thus the acquisitions have to be programmed on request. Furthermore the satellites are intended for civil, military and scientific use. This sometimes leads in a situation of conflict with the scientific/military mode, causing the failure of one or even several consecutive acquisitions.

In any cases a minimum number of SAR imagery should be available before the first ground movements maps could be generated using PSI techniques. In normal conditions, considering the fast repeat cycles of the high resolution sensors this could take less than half a year (with approximately three images per month and considering the processing time).

This paper presents a solution to overcome the problem of the acquisition failure, based on the combination of stacks of SAR data acquired by two different sensors, in order to overcome the problem of the lack of data acquisition over an area of interest. In the study presented, the missing acquisitions are replaced with data gathered with the other X-band satellite, ensuring the continuity in the measurements. This is possible because the two considered sensors are wide-band systems, they operate with almost the same carrier frequency and their respective strip modes of acquisition have similar resolutions. With the selection of the appropriate orbital pass it is possible to have scenes acquired with approximately the same incidence angles; keeping the same geometry of observation is mandatory to preserve the coherent targets in the two stacks of data allowing the merging procedures.

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The feasibility of this type of techniques has been already presented in [2][3] as a demonstration of measurement continuity between ERS and ENVISAT data.
To design the optimum solution it is important to consider the characteristics of the area of interest (AOI). In our case, the site is located in a highly mountainous area (> 3000 m high) with arid terrain, affected by landslides. Only non-snow images are used in order to have high radar backscattering and high density of distributed scatterers like pixels. High revisit time was required to be able to detect motions of high magnitude.
The study was originally based on the use of TSX data. Many acquisition conflicts with the newly launched TanDEM-X mission [4] were however encountered, preventing from forming the required stack of images. The decision was thus taken to complete the stack considering the only current satellite operation with similar characteristics. The PSI processing was thus finally made using two data stacks of 4 TSX and 16 CSK datasets, respectively. The performance of this solution is tested and evaluated, the PSI processing if carried out with the SPN software, developed by Altamira Information [2].

2. PRINCIPLE FOR COMBINATION OF SENSORS: DISCUSSIONS AND DATA SELECTION

As in the case of ERS/ENVISAT [3] the combination of TSX and CSK data is not straightforward due to the fact that the satellites operate with different carrier frequencies and have different acquisition modes. Moreover in this case, the satellites have totally different orbital paths and fly at different heights [5][6].

Two options can be considered to combine the images of the two sensors. One option is to exploit the cross-interferometry and merge the data without considering their origin. The second option consists in merging the different sub-stacks of SAR data after the generation of the interferometric pairs. The two techniques require anyway that all datasets are projected in the same geometry; precise coregistration procedures should be applied in order to deal with large baselines and different image resolutions.

The selection of the more suitable solution depends on the characteristics of the area of interest. Moreover, it should be taken in consideration that in the present study the geometry of the observation was already set by the available stack of TSX data. The difficulty is thus in choosing the most suitable incidence angle for the CSK acquisitions, considering the characteristics of the two sensors and the topography of the site. Table 11 shows the main acquisition characteristics given by these two sensors; the most suitable incidence angle for the CSK acquisitions should be determined.

	CSK	TSX
Sampling Freq.	112.50 MHz	109.89 MHz
PRF	3061.22 Hz	3704.36 Hz
Carrier frequency (f_0)	9.60 GHz	9.65 GHz
Wavelength (λ)	0.03125 m	0.03109 m
Incidence angle	?	35.26º
Azimuth res.	2.3 m	1.9 m
Range res.	1.3 m	1.3 m
Orbital height (R_0)	619 Km	514 Km

Table 1: Main acquisition parameters considered to select the combination options [5][6]. The incidence angle of the CSK acquisitions must be selected.

2.1. Cross-interferometry option

The exploitation of the cross-interferograms has the advantage to give a real measure of the ground motion. However this approach has several limitations [3], as the reduced combination opportunities due to the common bandwidth, the variation of the SNR in function of the local slope along the swath, the complex adaptive filter needed to enhance the SNR over distributed targets and the severe affectation of the volumetric decorrelation.
Considering a zero baseline and a flat, the spectral overlap of CSK and TSX data is of about half of the range bandwidth (Figure 1).

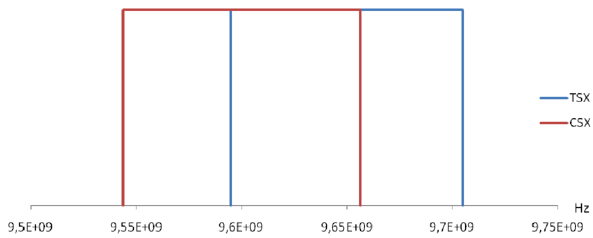

Figure 1: Range spectrums overlap between CSK and TSX SAR data in case of zero baseline and flat terrain.

Applying the expression of the range spectral shift [7] given by (1), a maximum overlap is achieved with a perpendicular baseline of -2200 Km if the topography of the site and the TSX acquisitions parameters are accounted for.

$$\Delta f = -\frac{f_{0_{TSX}} B_{perp}}{R_0 \tan(\theta - \alpha)} \quad (1)$$

In (1), θ is the incidence angle and α the local slope.
In practice, CSK images acquired with 25º of incidence meet this requirement. This difference of incidence of more than 10º with the TSX datasets prevent any cross-combination opportunity because of the change in backscattering intensities.
Another drawback is the variability of the SNR in function of the local incidence angle. This has more

impact in the present study which aims at maximizing the density of the distributed scatterers (DS) like pixels in the mountainous area.

2.2. Merging interferograms of different data-stacks

The merging of interferograms of different stacks is more straightforward in terms of processing and data combination. The SNR is kept along the swath; the methodology is thus more suitable for the exploitation of the DS like pixels.

The main limitation of this approach is nevertheless that it requires the definition of a ground motion continuity assumption that allows the combination of the retrieved time series of each sub-stack. This assumption must consider the time delays between each sub-stack and the nature of the ground motion, specially the time correlation.

In the present case, a dataset in each sub-stack was acquired with one-day separation (Figure 2) and the monitored motion was correlated with time. An offset value was then resolved between these two consecutive dates. In practice, the technical solution was based on the addition of a constraint into the equation systems that retrieves the time series of the ground motion, resolved by means of the application of the Singular Value Decomposition procedure (SVD) [8].

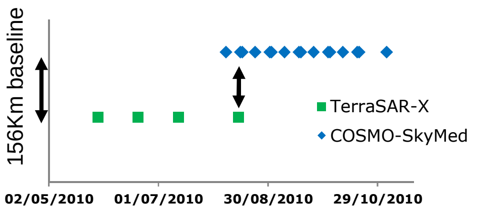

Figure 2: Temporal distribution of the 4 TSX and the 16 CSK used for this monitoring project. The black arrow indicates the calibration dates where the offsets between the two time series are retrieved.

The selection of the optimum CSK acquisition parameters must ensure the preservation of the same radar backscattering and geometric distortions in both datasets. In consequence, the number of common DS like pixels to both geometries should be maximized.

CSK acquisitions were thus ordered with an incidence angle of 40º, which results in a perpendicular baseline of about 156Km. Note that this value prevents the use of cross-interferometry as the spectrums are completely disjoints, as shown by Figure 3.

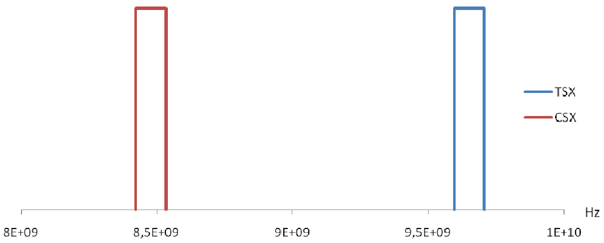

Figure 3: Range spectrum of the TSX and the CSK acquisitions with a perpendicular baseline of 156Km.

3. PSI PROCESSING APPROACH

The developed solution considered the exploitation of interferograms of different data-stacks within the same PSI processing in order to maximize the final number of measurement points. The Figure 4 diagram details the main processing steps related with the key points of the solution:

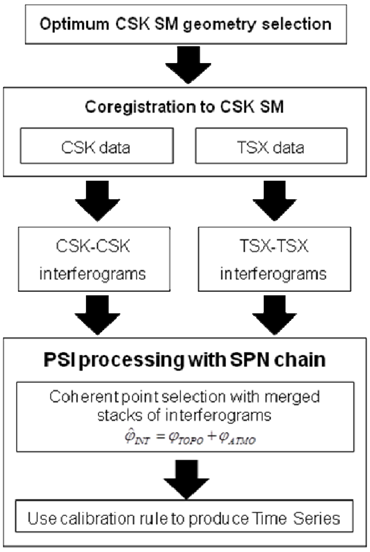

Figure 4: Main PSI processing steps used in the developed approach.

A CSK image was set as master image geometry, this choice being based on the fact that the CSK stack was larger than the TSX one (4 TSX and 16 CSK).

All images of each sub-stack were coregistered to this common geometry. CSK data required a previous resampling step to adjust the pixel spacing of both data-stacks. Precise coregistration routines are required in order to deal with large image distortions induced by the large orbital baselines and the important topography of the area of interest.

Once coregistered, the CSK-CSK and the TSX-TSX interferograms were generated. The next step is the PSI processing performed with the SPN processing chain [2]. The key point within the PSI processing is the identification of the common DS like pixels to both geometries. This identification is based on a phase model coherence which considers a topographic model and the atmospheric phase screen (2).

$$\rho = \frac{\left|\sum_{N_{INT}} e^{j\varphi_{INT}-\hat{\varphi}_{INT}}\right|}{N_{INT}} \quad with \quad \hat{\varphi}_{INT} = \varphi_{TOPO} + \varphi_{ATMO} \qquad (2)$$

The last critical step is the retrieve of the time series of ground motion. The time series were obtained by solving equation systems by means of SVD. As explained in the section 2.2, the calibration rule is based on setting an extra equation that solves the offsets between both sub-stacks. In our case the offset was estimated with two consecutive acquisitions.

4. RESULTS

TSX images were successfully coregistered to the CSK master geometry. The achieved coregistration quality was satisfactory for the AOI which is located in downslope areas. However, in layover and foreshortening areas, the important geometric distortions between both geometries could not be properly compensated in the coregistration process. Figure 5 illustrates the coregistration quality with an RGB composite amplitude image. It can be seen that in downslope areas the alignment of the two amplitudes is the same and also the radiometric level is very similar. In the slopes facing the satellite the coregistration didn't give a good alignment resulting in important difference in the RGB image.

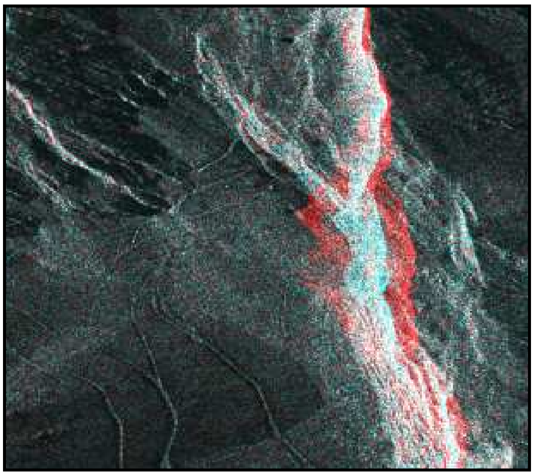

Figure 5: RGB image to show coregistration quality. Green and blue channels represent the CSK master amplitude, Red channel contains one TSX image in CSK geometry.

To evaluate the number of DS like pixels which are coherent to both geometries the phase model coherence defined in (2) was evaluated with and without the TSX interferograms. The number of points retrieved with a coherence higher than 0.75 is reduced by a 10% when combining the TSX and CSK interferograms within the same estimation procedure. It is important to point out that this lost can be due to the change of wavelength (50MHz) and to the change of acquisition view (5º of difference).

The SPN PSI processing has been successfully applied using TSX-TSX and CSK-CSK interterferograms. The results show a very high density of reliable measurement points over the area of interest, of about 900 points/km^2. The results allow detecting some landslides with accumulated displacements up to 6 cm in 6 months. As it can be observed in Figure 6, thanks to the spatial density the landslides location and extension can be clearly identified with the produced ground motion maps.

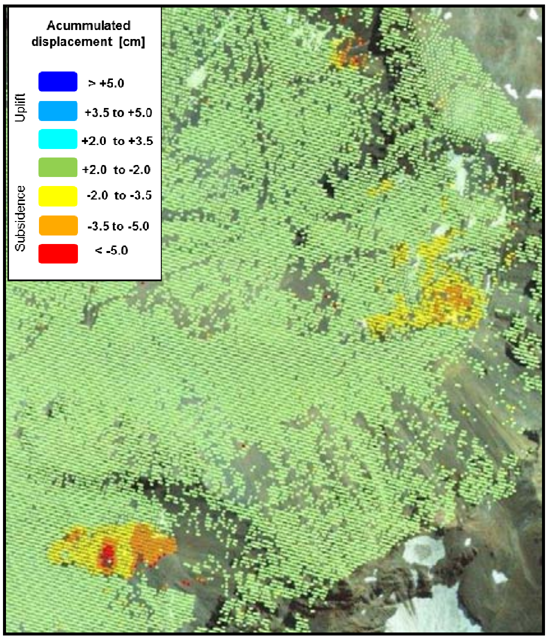

Figure 6: geocoded PSI total accumulated motion for the total time period.

Figure 7 and Figure 8 illustrate the correctness of the application of the calibration rule for the estimation of the time series. As it can be checked the two time series present consistent movement between TSX and CSK data. This proper combination of sensors allowed the continuity of the ground motion measurements.

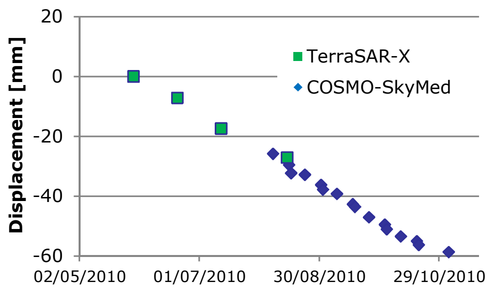

Figure 7: Time Series of a measurement point in an area affected by landslide.

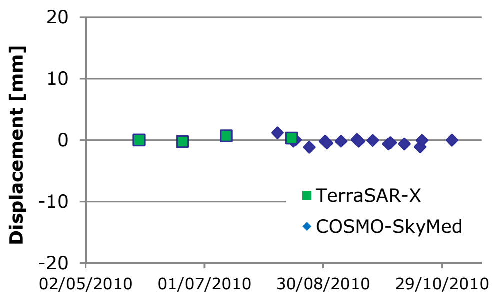

Figure 8: Time Series of a measurement point in a stable area.

5. CONCLUSIONS

Merging sub-stacks of different sensors of the same frequency band but with slightly different characteristics can allow continuous monitoring of ground motions. A key point to maximize the final density of the measurement points is the selection of the acquisition geometry. Both sub-stacks should be acquired with similar incidence angles in order to have similar radiometric levels and image distortions due to the local topography.

Most probably this data selection would prevent the use of the cross-interferograms because of the spectral shift would not be properly compensated by the baseline separations. However, it has been demonstrated that the combination of interferograms of different sub-stacks within the same PSI processing is suitable to retrieve the majority distributed-scatterers like pixels.

There are three key points that must be considered applying this PSI processing approach:

- Precise coregistration is required to deal with large image distortions induced by the very large baselines.
- The identification of the coherent scatterers common to both geometries should be optimized.
- The methodology requires the definition of a calibration rule to combine the time series obtained by the two sub-stacks.

6. REFERENCES

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