ON THE USE OF COSMO-SKYMED SAR DATA AND NUMERICAL WEATHER MODELS FOR INTERFEROMETRIC DEM GENERATION

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ABSTRACT
The present study is aimed at investigating the potentialities of the COSMO/SkyMed (CSK) constellation for ground elevation measurement with particular attention devoted to the impact of the improved spatial resolution wrt the previous SAR sensors. Assuming no movement and successful orbital error removal, the main problem in height computation through InSAR techniques derives from the interferometric phase artifacts related to the interaction between microwave and the lower layers of the atmosphere (APS, Atmospheric Phase Screen). Different strategies can be adopted to filter out this signal, ranging from the exploitation of the well-known spatial and temporal statistics of the APS to the estimation of independent APS measurements through Numerical Weather Prediction (NWP) models. Their feasibility and the achievable accuracies are discussed here.

Index Terms— SAR Interferometry, COSMO/SkyMed, Numerical Weather Model, GPS ZTD

1. INTRODUCTION
DEM products for Earth observation space-borne applications are being to play a role of increasing importance due to the new generation of high resolution sensors (both optical and SAR). These new sensors demand elevation data for processing and, on the other hand, they provide new possibilities for DEM generation. Till now, for what concerns interferometric DEM, the Shuttle Radar Topography Mission (SRTM) has been the reference product for scientific applications all over the world. SRTM mission [1] had the challenging goal to meet the requirements for a homogeneous and reliable DEM fulfilling the DTED-2 specifications. However, new generation of high resolution sensors (including SAR) pose new requirements for elevation data in terms of vertical precision and spatial resolution. DEM are usually used as ancillary input in different processing steps as, for instance, geocoding and Differential SAR Interferometry. In this context, the recent SAR missions of DLR (TerraSAR-X and TanDEM-X) and ASI (COSMO-SkyMed) can play a promising role thanks to their high resolution both in space and time. In particular, the present work investigates the potentialities of the COSMO/SkyMed (CSK) constellation for ground elevation measurement with particular attention devoted to the impact of the improved spatial resolution wrt the previous SAR sensors.

Assuming no movement and successful orbital error removal, the main problem in height computation derives from the atmospheric contribution. Different strategies can be adopted to filter out this signal:

- By processing stack of images and through advanced multi-temporal interferometric analysis, it is possible to infer with sub-metric precision the height of targets which behave coherently in time (persistent scatterers). These techniques allow to filter out the atmospheric signal thanks to its decorrelation in time and correlation in space. The main drawback is related to the availability of coherent scatterers on the scene. High resolution sensors (as CSK) allow to increase the density of the measurable targets.

- By using tandem-like high resolution interferometric pairs and a reference low resolution DEM, it is possible to filter the differential phase field in order to remove the atmospheric artifacts. The filtered InSAR phase may hence improve the accuracy of the original DEM.

- Through Numerical Weather Modeling (NWM), it is possible to estimate the InSAR phase related to the interaction between microwave and atmosphere. One of the problems of this approach is related to the spatial resolution of these models that doesn’t match that of SAR data in particular when dealing with X-band high resolution data (as CSK).

We present results obtained by processing both Spotlight and Stripmap acquisitions through standard SAR
Interferometry as well as multi-pass interferometry [2] with the aim of measuring ground elevation. We also investigate the use of numerical weather modeling to provide an estimation of the atmospheric contribution to the SAR signal which has to be filtered out to generate DEM.

## 2. CSK DATASET

Italian Space Agency (ASI) mission is made of 4 satellites able to acquire SAR images in several imaging modes. CSK SAR sensor works in X-band providing spatial resolution one order of magnitude better than the previous available satellite SAR data, as well as short revisit time (up to 8 hours for the full constellation). The recent scientific works have shown the advantages of using CSK in the monitoring of terrain deformations caused by landslides, earthquakes, etc [3,4]. On the other hand, thanks to the high spatial resolution, CSK appears to be very promising in monitoring man-made structures, such as buildings, bridges, railways and highways, thus enabling new potential applications as urban monitoring as well as precise DEM [5]. We used two CSK datasets made of 55 Stripmap images (res. = 3x3 m²) and 33 images Enhanced Spotlight (res. = 1x1 m²) acquired over Parkfield (California, USA) with very close incidence angles, thus allowing cross-comparison of the results. Both dataset were used to experiment the reliability of multi temporal analysis processing for height computation. For the weather modeling we used a tandem-like pair acquired in Stripmap mode with a normal baseline of about 3m optimal for differential interferometry.

## 3. MULTI-TEMPORAL INTERFEROMETRIC ANALYSIS

The SPINUA (Stable Point INterferometry over Unurbanised Areas) [6] is a Persistent Scatterer (PS) interferometric algorithm for multi-temporal Differential SAR Interferometric analysis. The processing chain is the result of a joint effort of the Remote Sensing Group of the Department of Physics at Politecnico di Bari and the ISSIA-CNR institute of Bari. SPINUA has been developed with the aim of detection and monitoring of coherent PS targets in non- or scarcely-urbanized areas. The processing chain has been further updated in order to deal properly with X-band data from both CSK and TerraSAR-X.

Multi-temporal interferometric analysis allows to compute [6]: i) the deformation signal occurred within the time interval covered by the available acquisitions; ii) the differential atmospheric signal between the images used to generate the interferograms; iii) the height of the coherent scatterers with a sub-metric precision.

In the present work we processed the CSK datasets with the aim of experimenting the potentialities of high resolution CSK data for height retrieval. In particular, we were interested in verifying the impact of high resolution to the density of measurable pixels (PS) which is important for continuous height surface generation (DEM). Here we report the results obtained by processing through SPINUA algorithm the enhanced spotlight dataset. Fig. 1-A shows the height corrections computed wrt an SRTM DEM at 1 arcsec (resolution cell of 30x30 m², [1]) used as reference DEM in the InSAR processing. Although the site is not urbanized, the result shows very high PS density (70’000 PS/km²). Areas without PS are mainly vegetated or located over slopes affected by layover and shadow. The resolution of the product is that of the input SAR data (1x1 m²). The correction provided by the multi-temporal analysis is within [-20m, 20m]. The approach is thus able to increase the resolution of the reference DEM as well as the height precision. Finally, comparable result was obtained by processing the Stripmap dataset (lower resolution but wider coverage). Fig. 1-B and Fig. 1-C show respectively the histogram of the height differences (STD = 0.65m) and the scatter plot between the height measurements derived by the two datasets (correlation coefficient = 0.99), thus confirming the potential of PSI to provide height measurements with sub-metric precision.

## 4. NUMERICAL WEATHER MODELING

Here we present preliminary investigations concerning the estimation of the atmospheric contribution to InSAR phase...
through numerical weather modeling. We first select a tandem-like couple of Stripmap acquisitions which has a normal baseline of about 3 meters, an ideal setting for differential interferometry (very low sensitivity to elevation).

Through standard interferometric processing we generated the differential phase by using as reference DEM an SRTM DEM at 1 arcsec \([1]\). Since 1 day separates the two acquisitions, no movement is expected and hence the differential phase is related mainly to the difference between atmospheric conditions at the times of the two acquisitions.

We generated a synthetic interferometric phase field by using a NWM to compute the atmospheric path delay introduced by both wet and dry the components of the troposphere \([2]\). We used RAMS (Regional Atmospheric Modeling System) \([7]\), a multipurpose, numerical prediction model designed to simulate atmospheric circulations spanning in scale from the hemisphere down to large eddy simulations (LES) of the planetary boundary layer. In particular RAMS was “cold-started” by configuring 3 nested grids (see Fig. 2), 50 vertical levels and a maximum resolution of 500m. Initial and boundary conditions were provided by the North-American Mesoscale Model (NAM) with 12 km spatial resolution, twice better than the resolution of global scale ECMWF model, commonly used in analogous studies. Fig. 3-A and B show the wrapped differential phase fields derived respectively by processing CSK Stripmap data (A) and by modeling the atmosphere contributions (B) (tandem-like acquisition dates: 3-4 November 2009, 02:11 UTC ; \(h_b=3m\)); (C) DTM of the area of interest; (D) path delay related to the hydrostatic component of the troposphere for the master image.

The experiment was repeated by considering 5 tandem-like CSK Spotlight pairs with different values of height sensitivities (see Table 1). In this case we used high precision height measurements coming from PSI analysis as reference values to check the accuracy of the height inference obtained from the interferograms in Table 1, after the removal of APS fields estimated from RAMS outcomes.

As detailed in \([9]\), RAMS performances tends to vary considerably from one interferogram to another thus further confirming that the role of weather models may change oppositely from a delay mitigator to an error contributor.

5. NWM OUTCOMES COMPARISON WITH GPS DATA

GPS daily RINEX data recorded by 67 UNAVCO stations installed on the AOI were processed at ASI/CGS and analyzed by e-GEOS using the NASA/JPL GIPSY-OASIS II \([10]\) for data reduction, in order to infer the atmospheric Zenith Total Delay (ZTD) and validate the outcomes of the NWM. ASI/CGS ZTD estimates have been extensively validated against independent techniques as radiosonde data \([12]\).

The Precise Point Positioning approach \([11]\) was applied fixing JPL fiducial-free satellite orbits, clocks and earth orientation parameters, IGS absolute phase center variations and estimating, with a cut-off angle of 7deg, site coordinates, station clock, phase ambiguities, ZTD and tropospheric gradients. ZTD and tropospheric gradients are modeled as random walk processes and estimated with a sampling rate of 5 minutes.
Negligible biases have been found between differential ZTD data coming from GPS measurements and inferred from RAMS outcomes, with a centimetric RMSE (Fig. 4): 

\[ \sigma = \left( \frac{1}{N} \sum_{i=1}^{N} (ZTD_{\text{GPS}} - ZTD_{\text{RAMS}})^2 \right)^{1/2} \]

Differences are not correlated with the topography thus suggesting that the main cause of the mismatches relies on the tropospheric turbulence. Since ZTD data provided by GPS have millimetric accuracy, the analysis further confirms that the accuracy achievable with NWP models is one order of magnitude worse.

5. CONCLUSIONS

This work is aimed at experimenting the potentials of CSK in measuring ground elevation as well as to assess the feasibility of using numerical weather models to mitigate the atmospheric artifacts affecting the interferometric phase.

We first processed through SPINUA PSI algorithm a stack of tens CSK spotlight data acquired over Parkfield (California, USA), measuring with sub-meter accuracy the ground elevation of available coherent targets. Then we used this set of measurements as reference values to check the accuracy of the height inference obtained by processing 5 tandem-like CSK Spotlight pairs with different values of height sensitivities. In order to suppress the atmospheric artifacts affecting the interferometric phase we experimented the use of the atmospheric fields derived by running RAMS numerical weather model, which is suitable for small scale features representation. Results indicate that the mitigation of atmospheric artifacts through NWP models is still unfeasible especially for X-band SAR interferometry. SAR processing indeed requires millimetric accuracy for the atmospheric propagation delay while the outcomes of numerical models are in the order of centimeters, as confirmed by the cross-comparison of the corresponding ZTD estimations with GPS measurements. Possible improvements can derive by the assimilation of surface observations and soundings in the RAMS weather modeling.

6. ACKNOWLEDGEMENTS

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7. REFERENCES


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Table 1: List of CSK Spotlight tandem-like pairs

<table>
<thead>
<tr>
<th>Master Pair ID</th>
<th>Pair 1</th>
<th>Pair 2</th>
<th>Pair 3</th>
<th>Pair 4</th>
<th>Pair 5</th>
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<tr>
<td>Sensor 2</td>
<td>2010/04/24</td>
<td>2010/07/31</td>
<td>2010/04/28</td>
<td>2010/04/09</td>
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<td>CSK-S2</td>
<td>CSK-S2</td>
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<tr>
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<td>CSK-S3</td>
<td>CSK-S3</td>
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<tr>
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<td>317.9 m</td>
<td>361.2 m</td>
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<td>18.3 m</td>
<td>21.8 m</td>
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<td>33.5 m</td>
<td>66.2 m</td>
<td>133.9 m</td>
<td>178.2 m</td>
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<tr>
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<td>113.5 m</td>
<td>147.2 m</td>
<td>317.9 m</td>
<td>361.2 m</td>
</tr>
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<td>57.5 m</td>
<td>44.3 m</td>
<td>20.3 m</td>
<td>18.0 m</td>
</tr>
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</table>

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Figure 4. Histogram of differences between differential ZTD data obtained from GPS measurements and inferred from RAMS outcomes for the following pairs: (A) 11-12/11/2009 (m=0.4cm); (B) 09-10/07/2010 (m=0.6cm); (C) 10-11/08/2010 (m=1.7cm).