WIDE AREA PERSISTENT SCATTERER INTERFEROMETRY: ALGORITHMS AND EXAMPLES

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ABSTRACT

The persistent scatterer interferometry (PSI) is a well established monitoring technique for urban areas. It has been updated in order to process wide areas with the accepted characteristics in precision and resolution. Of course, the covered processing area now includes rural areas with a low persistent scatterer (PS) density. In order to bridge forested areas and water bodies, low quality and more distant PSs need to be included into the reference network. The development of the wide area product (WAP) succeeded to cope with the resulting difficulties resulting in spatial error propagation. In this paper, the developed WAP system is described and a processing example is presented.

1. INTRODUCTION

Sentinel-1 constitutes ESA's follow-up mission to the successful ERS and Envisat SAR satellites. In the course of these radar missions, SAR interferometry has been evolved into an operational monitoring technique for the generation of digital elevation models and for displacement of the Earth's surface. The state of the art processing for the observation of subtle deformation with Millimeter accuracy is the persistent scatterer interferometry (PSI) [1], [2]. By using large stacks of data and a time series analysis, this processing technique can separate the different interferometric phase contributions topography, atmosphere and motion of the scatterer.

For the upcoming Sentinel-1 mission, Terrain Observation by Progressive Scans (TOPS) is foreseen the standard acquisition mode to guarantee a continuous, repeated without gap and global mapping of the Earth's surface with conventional resolution. The idea at ESA is consequent to extend the interferometric processing also to such a large coverage. Subject is to map countries and continents based on the PSI technique. In spite, PSI is a well established and validated processing technique, this is a difficult task. Actually, this technique has been developed for urban areas with a typical persistent scatterer (PS) density of 100 PSs per square kilometer. This high scatterer density makes the atmosphere effect compensation straight forward. Now, non-urban areas need to be processed also. These are characterized by a rare occurrence of PSs and a spatially varying PS density as well as a low PS quality with respect to their phase stability. As a consequence of the increased distance between the usable scatterers, the correction for the troposphere propagation effect is not optimal any more. Besides, the number of outliers and estimation noise increases for the estimation on arcs too. As a result, spatial error propagation can become a significant problem.

This is the reason, a wide area product (WAP) for the PSI monitoring is developed at DLR. It is foreseen to be the standard level 1 product for the Sentinel-1 mission and is developed in the course of ESA's Terrafirma project. Practically, it is an update of DLR's operational PSI GENESIS system. Subject is an operator interaction free processing and quality assessment and an error propagation characteristic which meets the end users requirements. The key algorithms which need to be updated for the wide area processing are the PS detection and characterization, the reference network setup and its robust inversion as well as the troposphere effect mitigation. This paper presents the developed algorithms to avoid significant spatial error propagation and presents first WAP processing examples based on available ERS data from the Terrafirma project.

2. METHODS

DLR's operational persistent scatterer system PSI-GENESIS has been updated [3]. Fig. 1 visualizes the

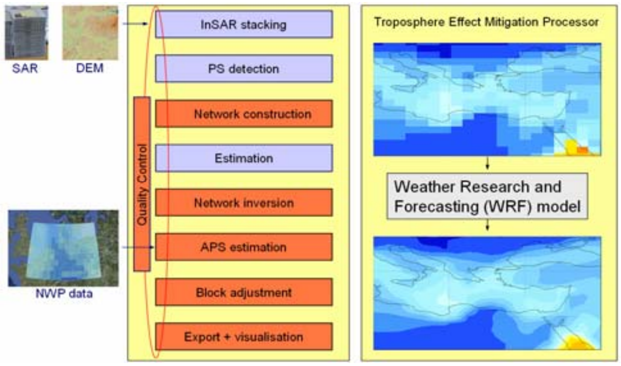

Figure 1: WAP PSI processing steps

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processing steps and highlights the algorithms which are adapted. Additional to the PSI processing updates, a Troposphere Effect Mitigation Processor (TEMP) has been developed. The following sections describe the Troposphere Effect Mitigation Processor and it's products and detail the algorithmic changes in the PSI processing chain.

2.1. Troposphere Effect Mitigation Processor

Numerical Weather Prediction (NWP) can support the mitigation of atmospheric effects in the PSI processing [4], [5], [6]. For this reason, the Weather Research and Forecasting (WRF) model [7] is used to retrieve the normal temperature T, the partial water vapor pressure P_w and the total pressure P for the time of the radar acquisition. These parameters are converted into the scaled-up atmospheric refractivity N [8]. Actually, this parameter can be decomposed into the dry N_{dry} and into the wet air N_{wet} component. Both have different spatial characteristics which are visualized in Fig. 2. This is

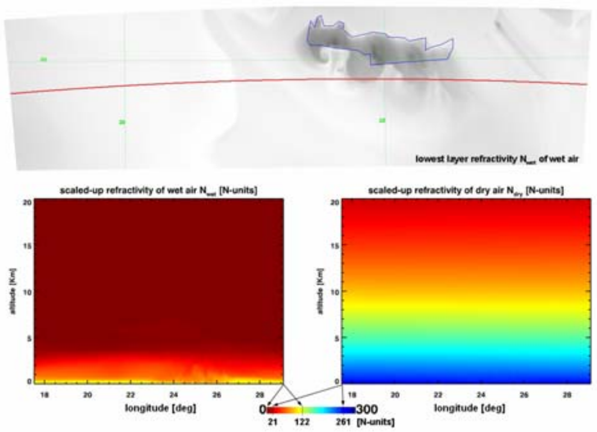

Figure 2: top: spatial characteristic of N_{wet} above the ground, lower left and right: spatial characteristic of N_{wet} and N_{dry} component along the red line (top figure)

the reason, the *Troposphere Effect Mitigation Processor* generates independent products for the dry and the wet effect. All products provide the integrated refractivity which finally corresponds to the range effect in mm in the line of sight (LOS).

The *Geocoded Projected Zenith Wet Effect Product* supports the master scene selection. This product (left column in Fig. 3) helps to predict the impact of the APS (right column in Fig. 3). In this example, the scene on the bottom is preferred which can be inferred from the smaller variation of the wet effect. It is computed from the WRF data only i.e. there is no need for a precise DEM. Practically, the integration is performed in zenith direction and scaled according the incidence angle to get the projection on the LOS.

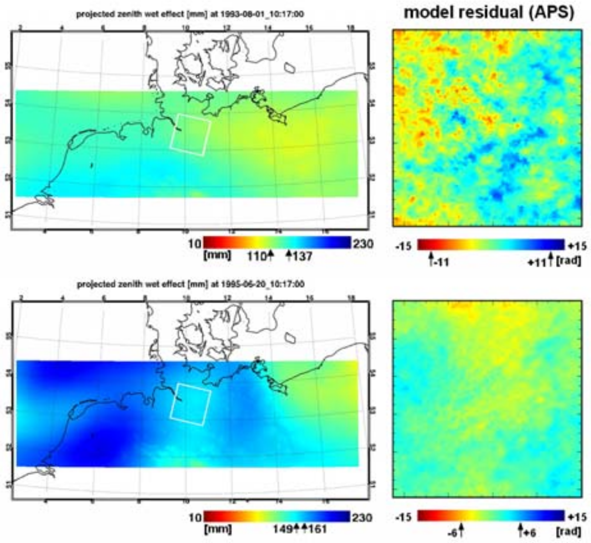

Figure 3: left column: Geocoded Projected Zenith Wet Effect Product, right column: respective APS

The *Precise Dry Range Effect Product* provides the LOS range effect in mm of the dry air in radar slant range coordinates. An example is shown in Fig. 4 (left). This product includes the precise topography from SRTM and performs integration along the topography dependent exact LOS over the dry scaled-up refractivity N_{dry}.

The *Precise Wet Range Effect Product* is shown in Fig. 4 (right). It is similar to the *Precise Dry Range Effect Product.* However, it integrates over the wet scaled-up refractivity N_{wet}. Therefore, it is spatially very turbulent.

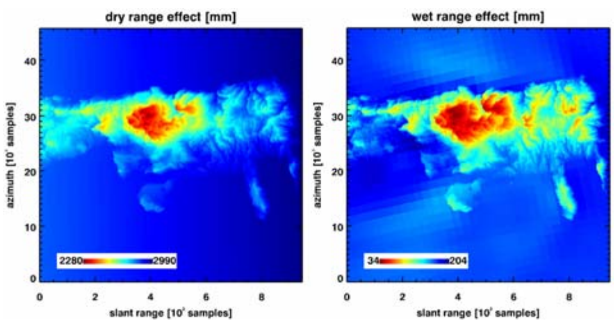

Figure 4: left: Precise Dry Range Effect Product, right: Precise Wet Range Effect Product

2.2. Reference Network Construction

All PS candidates are geocoded using a DEM and the arc length in the reference network is calculated from the geo-coordinates and the height of the PSs. Fig. 5 compares a simple reference network (left) which is suitable only in urban areas with the geocoded network (right). Now, the arc length and the expected height difference better correspond to the atmospheric effect which is compensated. Additionally, the network is

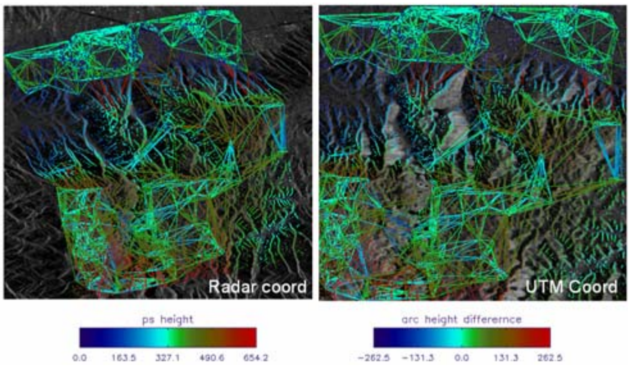

Figure 5: left: simple reference network in radar geometry, right: geocoded reference network

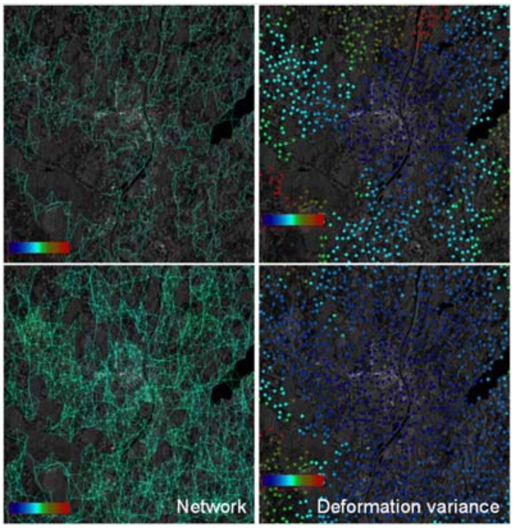

Figure 6: left column: network, right column: corresponding error propagation (estimation variance)

setup more redundant. A simple network (with e.g. three arcs per PS only) results in significant error propagation (which is difficult to detect), un-estimated areas and a high standard deviation which is demonstrated in Fig. 6 (top row). The bottom row provides an example for the reduced error propagation by the more redundant network. Here, the arcs better control each other allowing to detect outliers and to average estimation noise.

2.3. Network Inversion

The deformation on arcs is estimated by the LAMBDA estimator [9]. However, this estimate is affected by Gaussian noise or even can be an outlier exemplarily caused by a mis-detected or low quality PS. This is the reason, the reference network is now inverted in a two step procedure to estimate the velocity of the PSs. The L1-norm inversion is optimal with respect to outliers [10] which are removed from the network and the following L2-norm inversion is optimal for Gaussian noise [11] and guarantees minimal error propagation.

2.4. APS Estimation

Fig. 4 demonstrates (on the test site Crete) that the topography introduces a dominant systematic effect into the wet and dry range effect signal in each radar acquisition. Consequently, this vertical stratification effect can be predicted from the newly developed *Precise Range Effect Products* as demonstrated in Fig. 7. Practically, this systematic correction needs to be applied on the respective SAR scene and finally decreases the noise in the time series analyses.

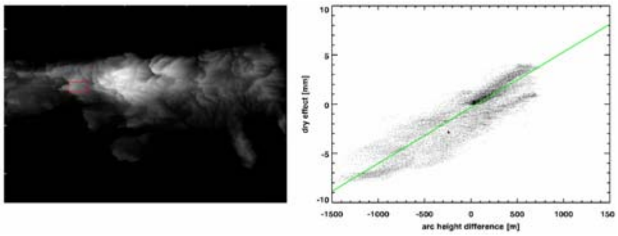

Figure 7: left: topography of the test site (island of Crete) used in Figure 4, right: estimated systematic correction for vertical stratification

2.5. Block Adjustment

The computational load and the memory consumption can be very high for a redundant reference network with about ten arcs per PS. In order to reduce the complexity, to increase the stability of the inversion, to speed up the processing and to keep errors local the scene is decomposed into overlapping blocks with a dimension between 8 km to 15 km. The common PSs in the overlapping area are used to mosaic the different blocks together as is visualized in Fig. 8. In order to get a consistent result, all blocks are merged by a least squares adjustment in a single processing step. An example for the characteristic and the shape the block adjustment network is provided in Fig. 9.

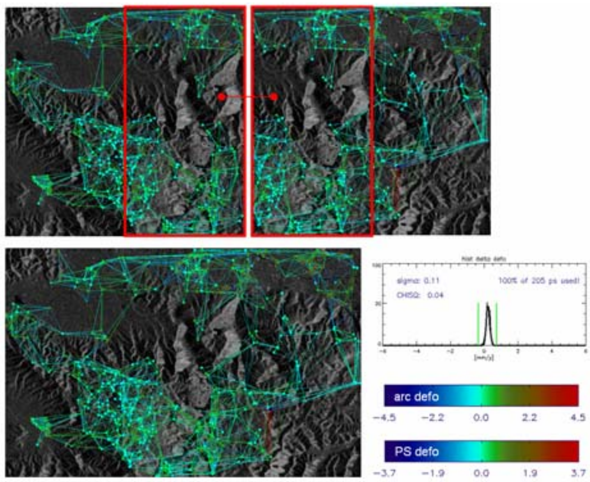

Figure 8: example for the block adjustment

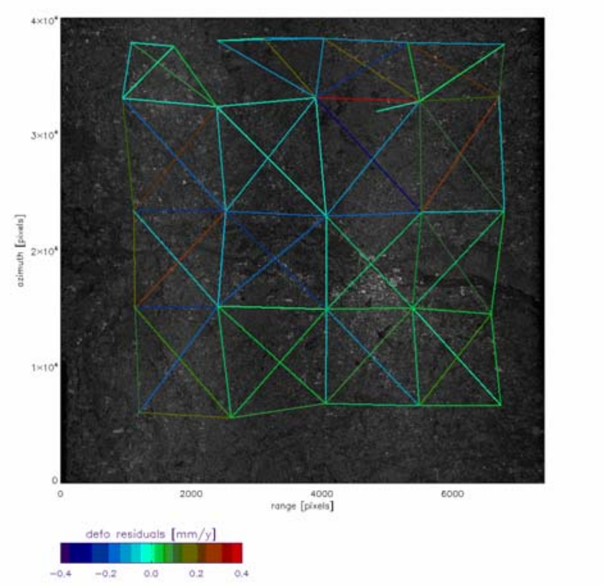

Figure 9: example for the characteristic and the shape of the block adjustment network

2.6. Merging of WAP Frames

The WAP is foreseen to provide coverage of a country or even a continent. Therefore, the block adjustment algorithm is applied on full frames as well using the overlap between the neighbored acquisitions. An example is shown in Fig. 10. The result is a homogeneous and consistent mosaic of 100 x 100 Km estimates which covers a wide area.

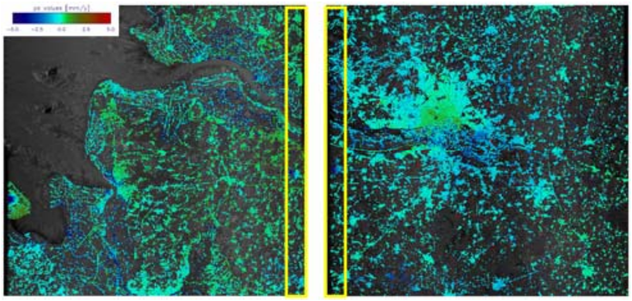

Figure 10: North Germany test case: Track 65 and Track 22 before frame merging

2.7. Quality Control

In order to allow an automated i.e. operator free processing and to prove the error free processing to the user, the Terrafirma quality control protocol has been implemented and extended [12]. Now, the important processing parameters and precision factors of each processing step are compiled and documented into a report which is part of the final WAP. I.e. it is delivered to the end user.

3. RESULTS

The WAP has been applied on the North Germany test case which consists of two ERS full frames. The resulting subsidence map covers an area of about 100 x 200 Km. It is visualized in Fig. 12 using Google Earth. Although, the coverage is significantly increased compared to a conventional PSI product, the full resolution (no spatial averaging of PSs) and the well established precision [13], [14] is maintained in the WAP. Fig. 11 demonstrates both facts zooming into the North Germany WAP and showing the oil underground storage induced subsidence in the city of Bremerhaven. The WAP is easy to interpret because the motion is restricted to a linear deformation model. Each point is characterized by latitude, longitude, the PS height with respect to the World Geodetic System 1984 (WGS 84), the average velocity and a quality indicator.

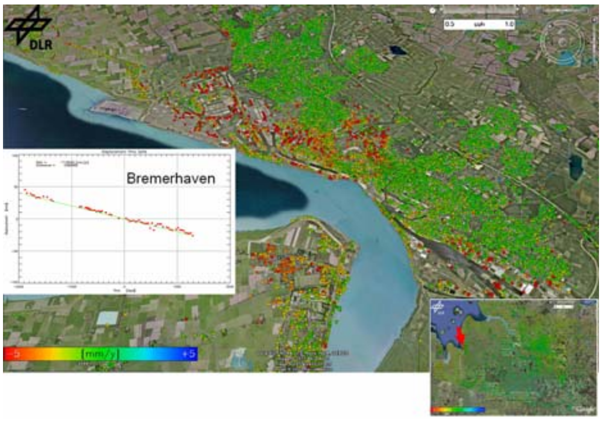

Figure 11: detail of the North Germany WAP showing the city of Bremerhaven

4. SUMMARY

DLR's operational PSI GENESIS system has been updated for a wide area processing including rural areas. Moreover, the North Germany test case is demonstrated. Challenges are the requirements of an operational processing and avoiding error propagation. Robust algorithms are therefore developed. Finally, the developed WAP provides on the one hand the well established high resolution and precision Earth deformation maps and on the other hand a wide coverage which is foreseen to be in the scale of countries and even on continents.

5. ACKNOWLEDGEMENTS

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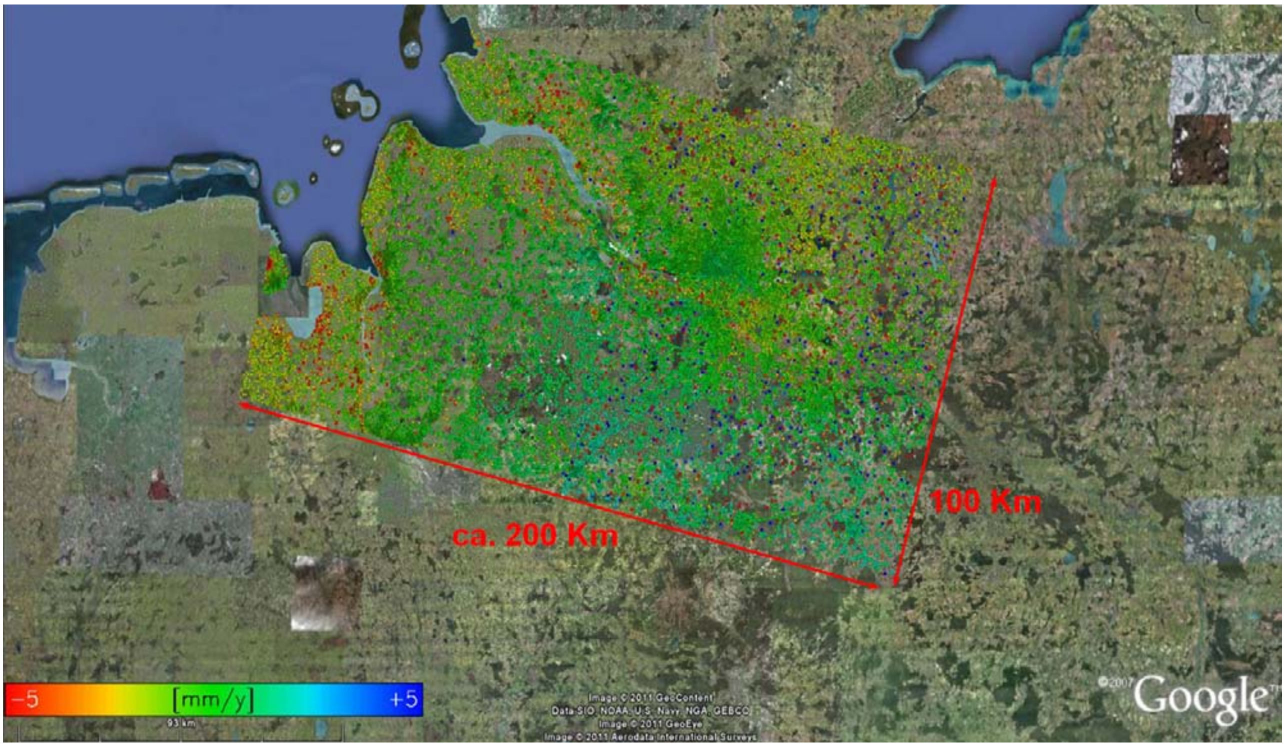

Figure 12: Wide Area Processing test case North Germany

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