The Weighted Adaptive Variable-lEngth (WAVE) Technique for InSAR Analysis in Mid-to-Low Coherent Areas

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ABSTRACT

To satisfy the growing land demand for industrial and urban development, man-made lands, reclaimed from the sea, are used to build airports, harbors, and industrial areas. However, in such reclaimed areas, foundation deformation caused by unconsolidated soils are of public concern, and may induce severe damage to buildings and infrastructures. In such a context, Differential Synthetic Aperture Radar (SAR) Interferometry (DInSAR) technique [1] is able to retrieve ground displacements, with centimeter to millimeter accuracy, by exploiting the phase difference between two SAR images relevant to the same investigated area, acquired at different times and from different orbital positions. Advanced DInSAR approaches, such as the Small BAseline Subset (SBAS) technique [2], represent nowadays effective tools for remotely detecting and monitoring surface deformation phenomena, thanks to their capability to produce spatially dense velocity maps as well as long-term displacement time-series.

DEFORMATION TIME-SERIES ANALYSES OVER SHANGHAI COASTAL AREA

This study is focused on the retrieval of deformation signals over the ocean-reclaimed lands of Shanghai, China, and it is mostly devoted to the development of an ad-hoc procedure based on the exploitation of multiple-scale of resolution information. Over the last recent years, several investigations [3]-[4] have been carried out to study the deformation of the coastal area of Shanghai. In particular, the time evolution of ground deformation occurring over the coastal zone was derived from 2007 to 2017 [4] by jointly analysing sequences of X-band (COSMO-SkyMed) and C-band (Sentinel-1A and ENVISAT/ASAR) SAR images. To achieve this task, a novel approach to link the time-gapped COSMO-SkyMed and ENVISAT/ASAR data was applied and an SVD-based combination approach to link time-overlapped COSMO-SkyMed and Sentinel-1A SAR data was developed. However, the temporal decorrelation leads to a reduced number of detectable targets over the ocean-reclaimed platforms. To overcome this problem, in this work we propose to analyze a set of time-gapped CSK SAR images and to provide a hybrid analysis at full and multi-looked spatial resolution.

ADVANCED METHODS AND EXPERIMENTAL RESULTS

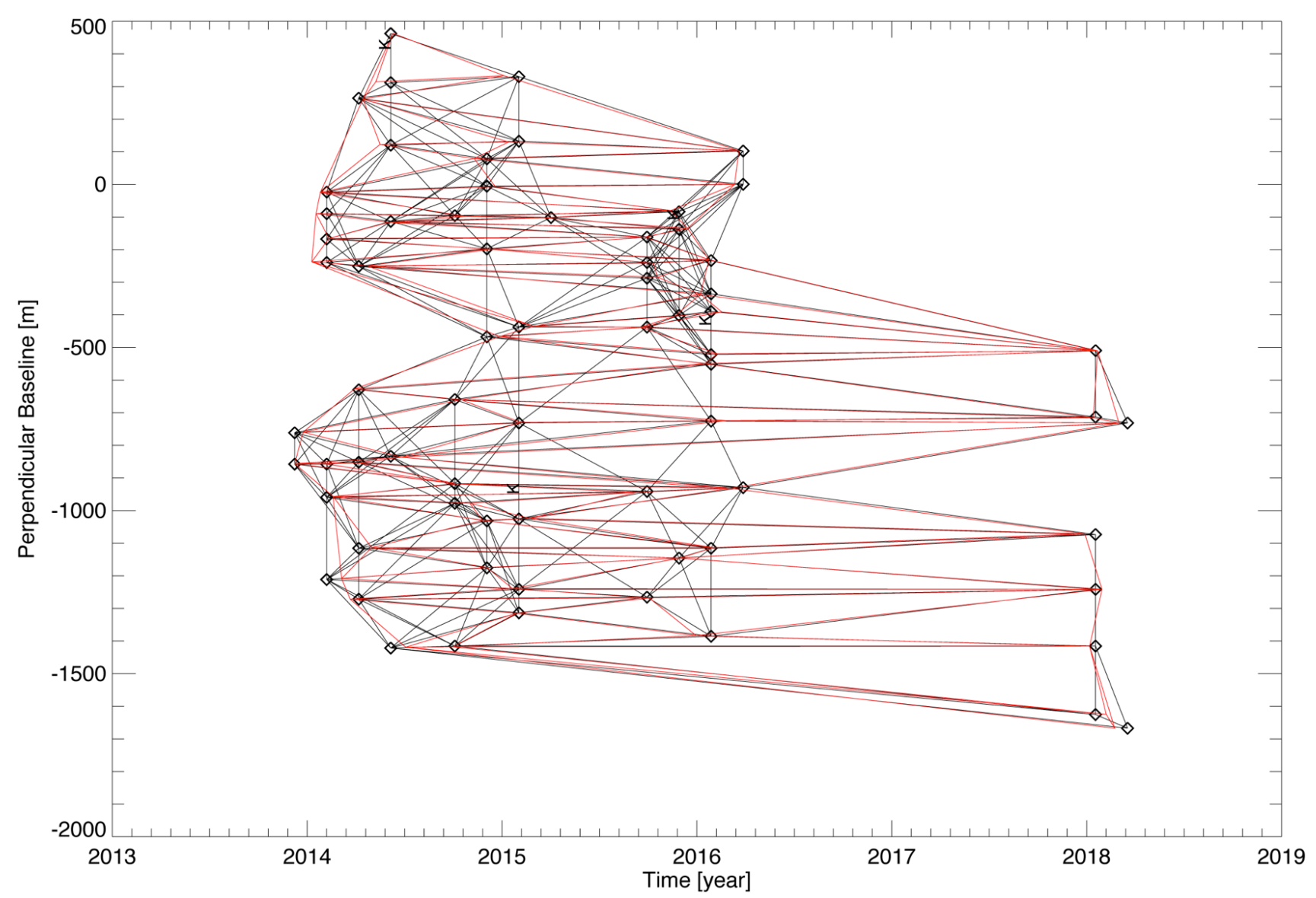

Fig. 1. SAR distribution of available CSK data.

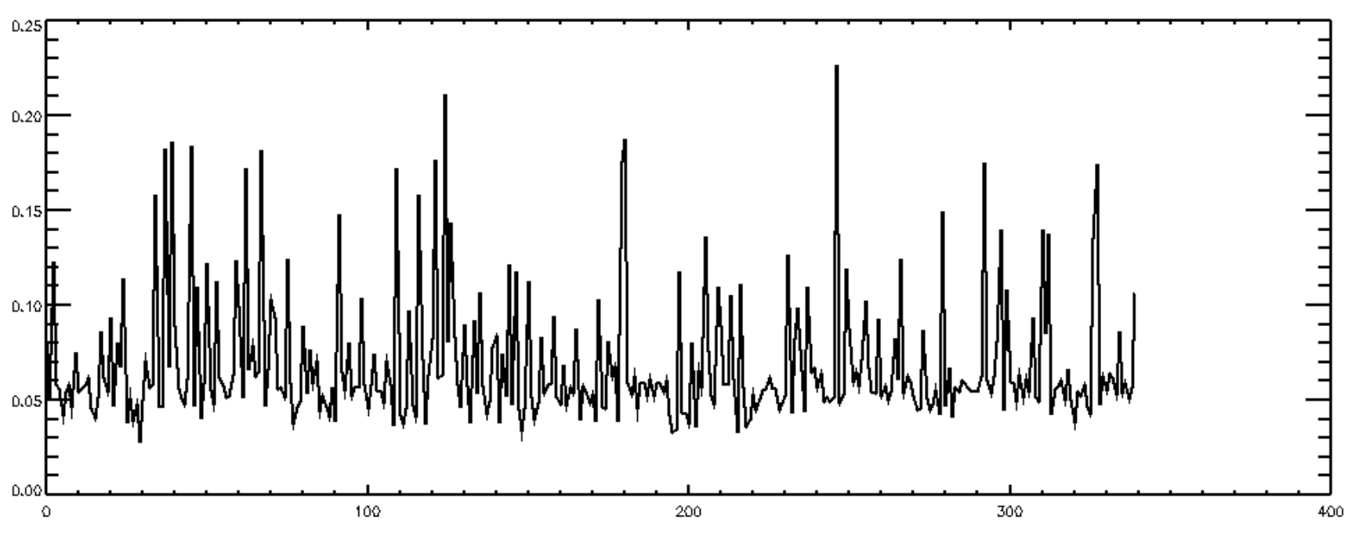

Fig. 3. Coherence improvement of the filtered interferograms.

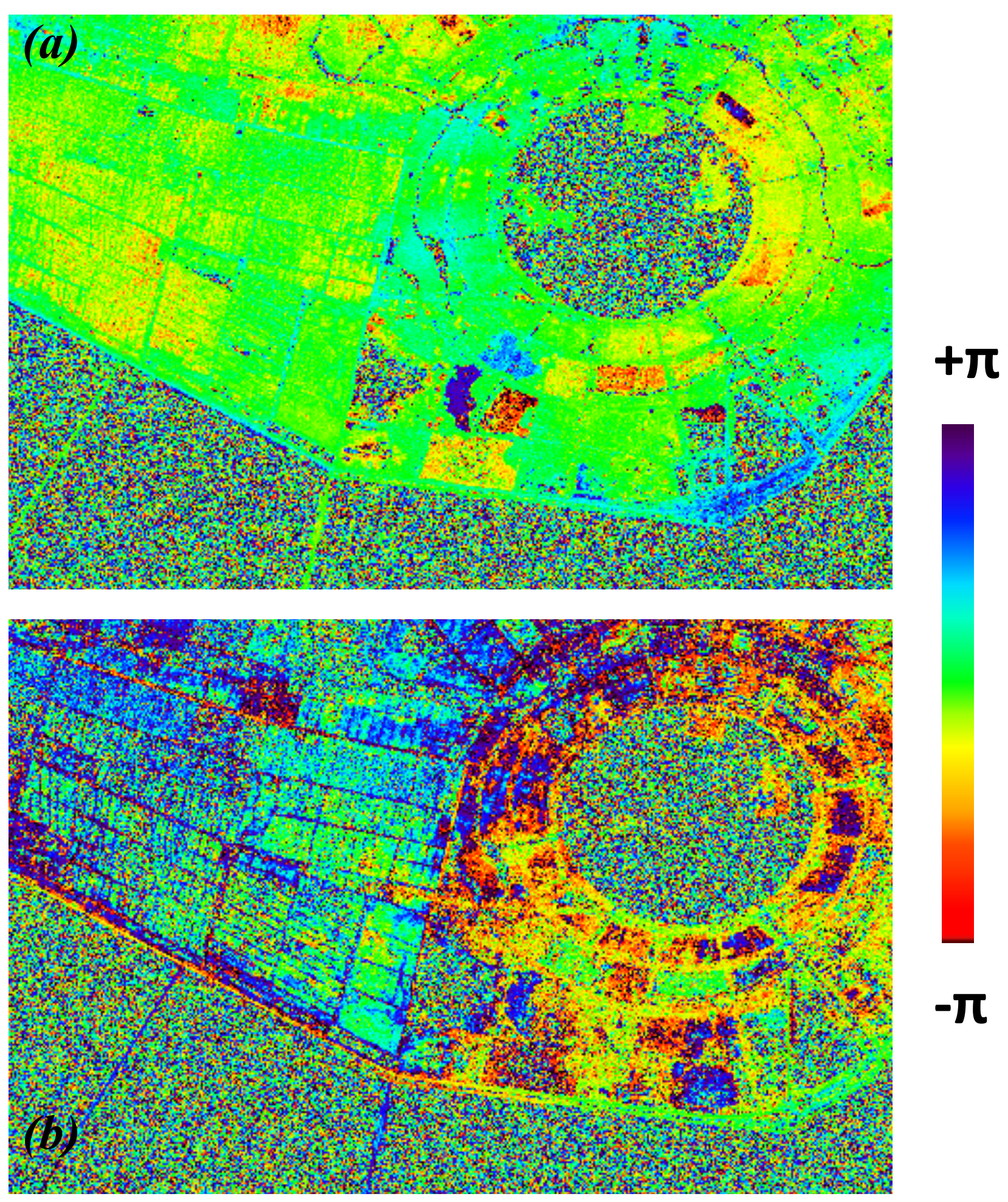

Fig. 2. Filtered interferograms (a) 07022016_15022016 – (b) 30012016_02032016.

The investigation relies on the use of a set of 69 CSK images acquired from 2014 to 2018. Unfortunately, there is a big time lapse of more than one year between the old (from February 2014 to March 2016) and the new CSK SAR dataset. Figure 1 shows the distribution of available SAR images and the selected set of Q=340 DInSAR interferograms used for the experiments. A multi-temporal noise filtering technique [5] was first applied to the generated interferograms. Figure 2 shows some filtered interferograms, and Figure 3 plots the spatial coherence improvement of each used interferogram. First, the conventional SBAS technique was applied. The map of the mean displacement velocity of the area is shown in Figure 4, where only the pixels with high temporal coherence values are depicted.

Subsequently, we focused on the group of highly coherent point-wise targets that preserve their coherence (also after one year) and we generated the CSK 2014-2018 surface displacement time-series relevant to those pixels, by applying a hybrid multi-resolution SBAS approach. Highly-coherent point-wise scatterers were identified by using the method presented in [6]. It is carried out by estimating the difference between the Q interferometric phases computed from the upper Φ_k^U and lower Φ_k^L range spectra of the corresponding SAR images, respectively. The equivalent coherence factor is then computed:

$$\Gamma_2(P) = \frac{\left|\sum_{k=0}^{Q-1} \exp\left\{j\left[\Phi_k^U(P) - \Phi_k^L(P)\right]\right\}\right|}{Q}. \quad (1)$$

Pixels with high values of this coherence are selected as detectable pixels, namely *D*. Note that the conventional two-step SBAS method [2] cannot be simply applied in this case because (due to the gap of one year) the distribution of well-unwrapped SAR pixels at the multi-look scale is not spatially dense, enough. For this reason, we applied a different strategy, based on performing the phase unwrapping operation directly at the full spatial scale, and using the region-growing multi-temporal PhU method [7].

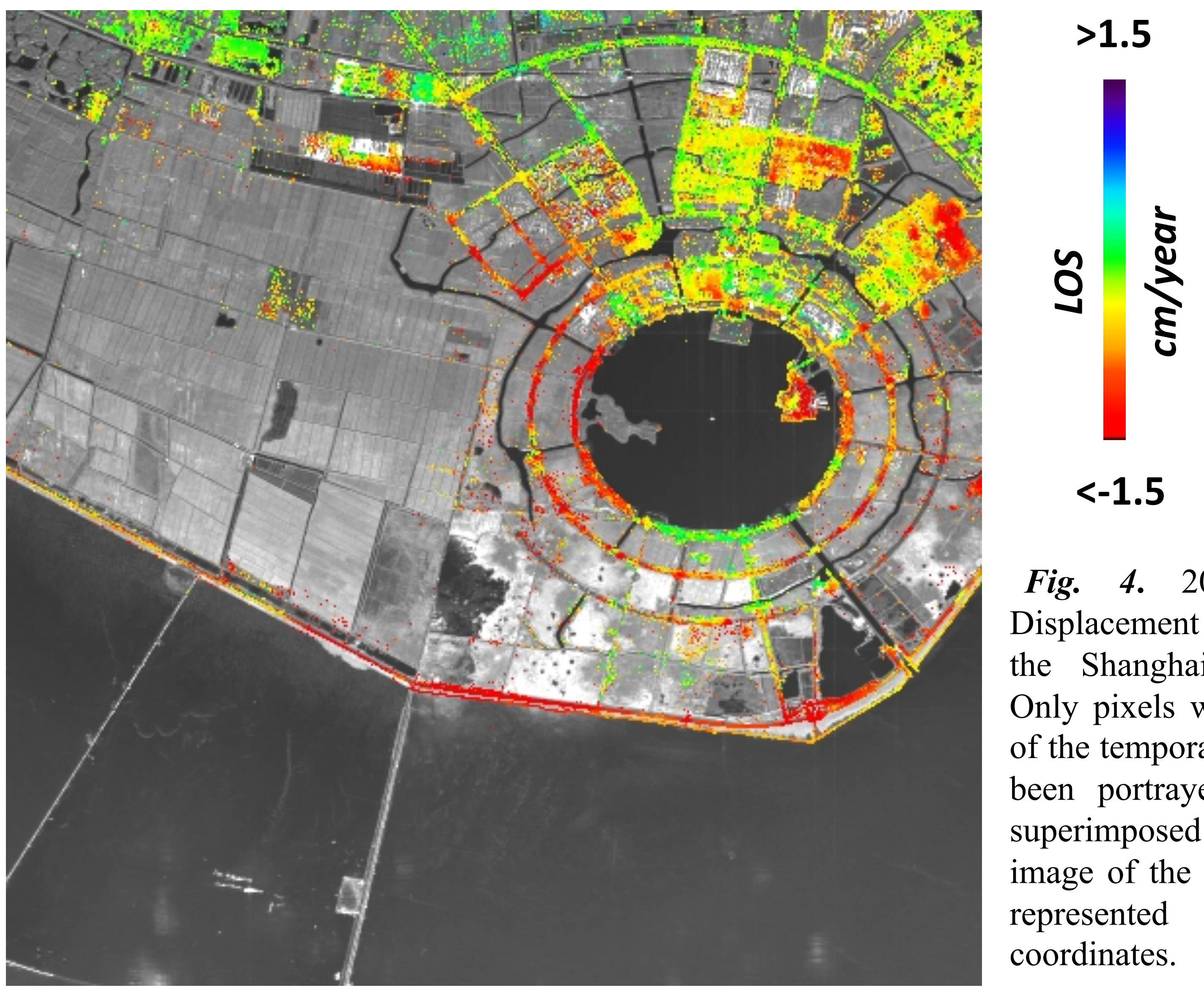

Fig. 4. 2014-2018 Mean Displacement Velocity Map of the Shanghai Coastal Area. Only pixels with a high value of the temporal coherence have been portrayed in color and superimposed to a multilook image of the area. The map is represented in RADAR coordinates.

The region-growing based PhU method consists in the preliminary estimation of the unwrapped phases relevant to a set of "Seed pixels" (at full spatial resolution scale). Seed pixels are a subset of the detectable pixels *D* in correspondence to which the phase stacks have been correctly unwrapped. Given the pixel *P*, with radar coordinates (x,r), the relevant sequence of unwrapped phases at *P* is obtained as follows:

$$\Psi_k(P) = \Psi_k^{(ML)}(P) + Wr\left[\Phi_k(P) - \Psi_k^{(ML)}(P)\right] \quad k = 1,\dots,Q \quad (2)$$

where $\Psi_k^{(ML)}$ and Φ_k are the unwrapped multi-looked and the wrapped single-look interferograms, respectively. Wr(.) is the wrapping operation. For each pixel *P,* the temporal coherence is then estimated [7], and the Seed Points are those with a temporal coherence greater than a threshold (i.e., 0.5). Applied multi-temporal region-growing PhU procedure [8] allows us to propagate the correct unwrapped solution to neighbouring pixels by checking reliability of all possible temporally coherent paths. After a LS inversion of the unwrapped stack, the displacement time-series are eventually obtained (see Figure 5).

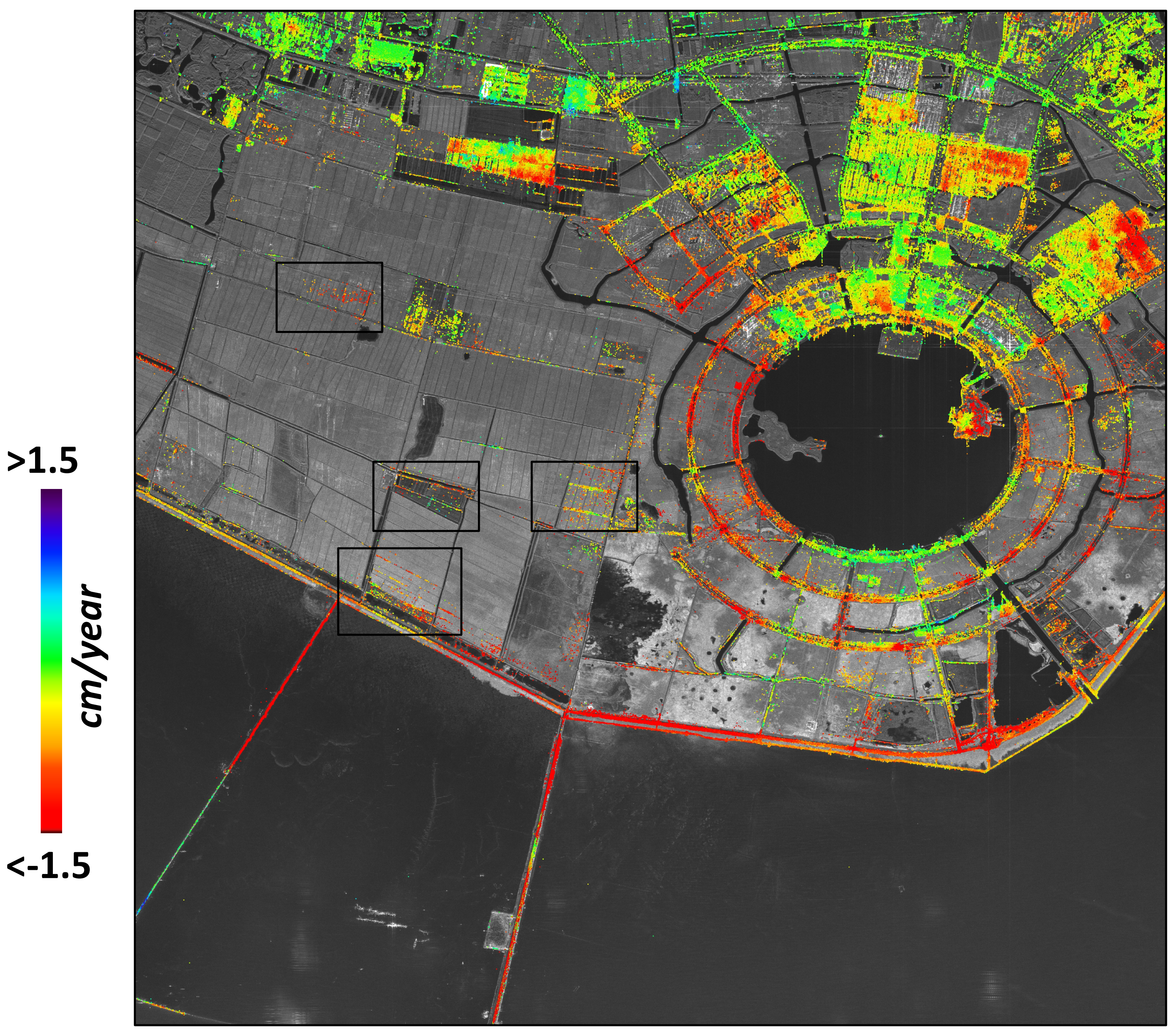

Fig.5*. CSK 2014-2018 Mean deformation velocity map at the finest pixel spacing (3 mx 3 m).* In this map, the black boxes identify the areas characterized by *significant improvement in terms of of spatial coverage of detected targets. More specifically, an improvement of about 150% has been achieved.*

Acknowledgements

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