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Interactive Comment

Interactive comment on "Advanced interpretation of land subsidence by validating multi-interferometric SAR data: the case study of the Anthemountas basin (northern Greece)" *by* F. Raspini et al.

F. Raspini et al.

federico.raspini@unifi.it

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We would like to thank the anonymous reviewer for his valuable comments and suggestions. Our reply to his general comments is:

1)As mentioned by both referees the results referring to the activity of the NW-SE striking fault (Thermi fault in the manuscript), bordering the northern part of the Anthemountas plain, are not well founded. Both referees report that there is not a clear correspondence between the ground deformations and the fault. As mentioned in the manuscript “Density and distribution of PS targets offer a synoptic view of the linear deformation patter along the NE side of the Anthemountas basin, indicating that a possible tectonic component might be included at this deformation“. So, we also have our doubts about the potential activity of this fault. As a result, following the instructions of the referees we decided to remove all references to the activity of the Thermi fault and we are planning to collect more data and evidences to support this interpretation and in order to better found this result in a future publication.

2)The main steps of the PS technique can be listed as follow:

-Interferogram creation: interferograms are formed with respect to the selected master image.

-DEM and differential interferograms creation: thanks to the Tandem pairs (i.e. ERS-1/2 data with a temporal baseline of 1 day), a conventional InSAR DEM can be reconstructed and subtraction of topographic information from each interferogram can be performed. As an alternative, pre-existing DEM (e.g. such as the Shuttle Radar Topography Mission, SRTM or the ASTER Global DEM) can be used as reference. DEM and precise orbital data are used to create differential interferograms.

-Estimation of PS motion, elevation error, and atmospheric contribution: once the topographic phase and orbit errors are removed from interferograms, the remaining signal is composed of two contributions: the deformation signal and the atmosphere-related signal. Atmospheric artifacts have been compensated by using image stacking. Spurious atmospheric effects are estimated and filtered out through a statistical analysis of the signals and applying specific algorithms: atmospheric artifacts are strongly correlated in space within each SAR scene, but are uncorrelated in time. Conversely, target motion usually shows strong correlation in time and can exhibit different degrees of spatial correlation. In other words, to assess the atmospheric delay, the deformation signal is assumed to have a common trend to all interferograms, while the atmospheric signal is mostly uncorrelated among each individual SAR image.

Besides the intrinsic 1D measurement capacity of InSAR approaches, other limitations of these techniques are related to the range of velocity actually detectable, to the kinematic behavior of the investigated phenomenon and to the linear model used during the PSI processing. In most PSI applications, without any a priori knowledge about deformation, a simplified model (which assumes a linear, constant-rate phase variation with time) is usually assumed to retrieve ground motion. Assumption of linear model of deformation for SAR interferometry processing is adequate for steady state displacement with respect to image sampling (e.g., subsidence). In most of the cases, geological processes, such as landslides, cannot be described with a linear trend. By using a linear predefined displacement model, the extraction of phase variations related to displacement for each scatterer can be inaccurate: during phase unwrapping the non-linear component of deformation becomes indistinguishable and is included into other phase terms, leading to the underestimation of the actual deformation patterns. This limitation is particularly relevant for low PS density and/or low temporal sampling with respect to deformation and/or geological processes with strong deformation magnitudes. Moreover, during phase unwrapping, ambiguity related to the discrete interval sampling (phase is measured modulo 2π) of wrapped phase can remain unsolved. Without any further information on behavior of ground deformation the maximum displacement between two successive acquisitions (the temporal sampling of ERS1/2 scenes is 35 days) and two close PS of the same dataset, is limited to a quarter of the wavelength ($\lambda/4$ i.e., 1,4cm for C-band sensors).

We will include a short paragraph of these features in the revised version of the manuscript, without going into detail, because a dissertation on this topic doesn't fit with the paper purpose, as it deals with post-processing analysis.

3)In the framework of the ESA GMES Terrafirma project, the German Space Agency (DLR) processed several satellite image frames using a special semi-automated processor and then mosaic adjacent data-stacks with uniform quality to produce a PSI ground motion map of Greece. This deformation map covers 65 000 km2 – approximately half of the country's territory. This map was created using 10 individual ERS-1/2 stacks, each stack being a time series of 58 to 76 SAR images acquired from 1992 to 2002 for a total of 671 images. WAP identified over a million persistent scatterers over half of Greece's territory. In the author's opinion this huge amount of information can be exploited in a dual mode:

- making available these data among different levels of government (central government or local authorities) to provide useful information for the creation of a synoptic view of the instability phenomena (potential and / or in progress) throughout the country. Treasuring the experience of the Italian PST (Extraordinary Plan of Environmental Remote Sensing; http://www.pcn.minambiente.it/Gn/progetto_pst.php?lan=en), we can state that the creation and availability to the public administrations of remotely sensed spatial information on land motion increase their awareness of geological risks;

- scanning wide areas to identify "hotspots", which correspond to those sites characterized by high hydro-geological hazard. These sites are assessed as the most critical in terms of hydro-geological hazard, both for the type of identified instability events and/or the extent of the detected phenomena and/or the measured deformation velocities and/or the presence of elements at risk. Moreover, by identifying specific areas of deformation within wider regions of interest, different level of priorities can be established when planning field surveys and in situ validation campaigns, in order to optimize field work and to save economic resources. Greek WAP, for instance, shows strong subsidence in the Thessaly plain as well as ground motion associated with an earthquake in the area close to the city of Athens. High subsidence was detected in Athens, Larissa, west of Thessaloniki and around the Gulf of Corinth. Among these places, we selected the Anthemountas basin because deformation affects important infrastructures and because subsidence extends on an area wider than expected.

In the author's opinion, the referee is partially right stating that this case study is a merely a standard application of the PSI algorithm. Despite the limited extension of the study area, the referee should consider that it is only a small fragment of the PSI dataset actually available. In the revised version of the paper a paragraph clarifying this topic will be added.

Considering the main technical corrections our reply is:

Line 206: Multi-temporal InSAR technique encompasses a family of different approaches based on processing of several (at least 15, or more), co-registered, multi-temporal space-borne SAR imagery of the same target area. In general, the larger the number of images, more precise and robust the results. Two classes of multi-interferometric processing techniques techniquesâĂŤfirstly, the Permanent Scatterer, PS (e.g., Ferretti et al., 2000; Hooper et al., 2004; van der Kooij et al., 2006) and secondly the Small BAseline Subset (SBAS) techniques, are used for processing long series of SAR imagery. Within the first family, PSInSAR (Ferretti et al. 2000, 2001) was the first technique specifically implemented for the processing of multi-temporal radar imagery. Signal analysis of a network of coherent radar targets (persistent point targets), exhibiting high phase stability over the entire observation time period, allows to estimate occurred displacement, acquisitions by acquisition, by distinguishing the different contributions related to ground motions from those due to atmosphere, topography and noise. More recently, the ability of PSInSAR has been extended to natural terrain thank to the implementation of the SqueeSAR technique (Ferretti et al. 2011). Small-BAseline Subset (SBAS) technique is an alternative method, developed at IREA-CNR (Institute for Electromagnetic Sensing of the Environment National Research Council of Italy). The method was originally developed and presented by Berardino et al., (2002) for low-resolution DIFSAR (Differential SAR) data analysis and further implemented by Lanari et al., (2004) for full resolution data. This approach relies on the use of a large number of SAR acquisitions distributed in small baseline subsets. Small baseline methods are based on combining a set of unwrapped interferograms. Interferograms are computed in order to minimize perpendicular, temporal and Doppler baseline and to reduce phenomena of spatial phase decorrelation between different SAR acquisitions. The technique allows to link independent SAR acquisition datasets, separated by large baselines using a combination of differential interferograms produced by data pairs characterized by a restricted to small orbital separation, finally leading to the generation of deformation velocity maps and displacement time series. Another application of Small Baseline approach is presented by Schmidt and Bürgmann, 2003 and by Mora et al., 2003. Mixed approaches have been also proposed (e.g., Hooper et al., 2008): these methods combine both approaches, resulting in a better spatial sampling (deformation signal at more points has been retrieved) and in a higher signal-to-noise ratio. Practically, this hybrid methods identify and exploit the phase of mixed scatterers, selected from Small Baseline interferograms, with the phase of selected pixels from PS interferograms. The revised version of the manuscript will include a brief description of the different approaches.

Line 262: new version of the paragraph: “All available images of the data stack are focused and co-registered on the reference sampling grid of a single master acquisition. The master image is selected such as the dispersion of values of the geometrical baseline, temporal baseline and Doppler baseline are as low as possible.The master image is selected to maximize the coherence of the computed interferograms. It has been proved (Kampes, 2006) that the stack coherence is larger when the master is selected centrally in time. On the other hand coherence decreases when the master doesn’t lie centrally with regard the geometrical and Doppler baseline.”

Line 299-301: new version of the paragraph: “Graph in Figure 5 compares the LOS deformation rates to the elevation above sea level of individual scatterers. The most common deformation values (between +1.5mm/yr and -1.5mm/yr) are observed over a wide range of elevations through the investigated area, i.e., velocity and elevation are not correlated. However, the negative (subsidence) values all occur at low elevations (usually less than 50-100 m a.s.l.). This is also consistent with the hypothesis that subsidence largely affects the plain sectors of the Anthemountas River, as a consequence of intense overexploitation of the aquifers located in the low-lying alluvial basins.” Line 317-321: signs have been changed in the revised version of the paper. Line 360-362:

new version of the paragraph: “The two sets of scattered points have been used to extend the information (i.e., to interpolate) to areas with lower PS density, assigning values to unmeasured location through the IDW (Inverse Distance Weighted) method. To create an interpolated surface, IDW method uses a weighted average of the available neighborhood PS. The weight of input points decreases as the distance between the known point and the interpolation point increases.” Line 512-513: The numbers have been deleted because incorrect. New version of the paragraph: “...Furthermore, given their intrinsic characteristics (wavelength and revisiting time), this generation of radar sensors allows monitoring faster movements. The enhanced characteristics of the new generation of SAR sensors have improved the capability of PSI....”.

The rest of the technical corrections were accepted. We have done all necessary corrections to the manuscript.

References

Ferretti, A., Prati, C., Rocca, F., (2000). Nonlinear subsidence rate estimation using Permanent Scatterers in differential SAR interferometry. IEEE Transactions on Geoscience and Remote Sensing. 38 (5), 2202– 2212.

Ferretti, A., Prati, C., Rocca, F., (2001). Permanent Scatterers in SAR interferometry. IEEE Transactions on Geoscience and Remote Sensing. 39 (1), 8 –20.

Ferretti, A., Fumagalli, A., Novali F., Prati C., Rocca F., Rucci A. (2011). A new algorithm for processing interferometric data-stacks: SqueeSAR™. IEEE Transactions on Geoscience and Remote Sensing. (99), 1-11.

Berardino, P., Fornaro, G., Lanari, R., Sansosti, E. (2002). A new Algorithm for Surface Deformation Monitoring based on Small Baseline Differential SAR Interferograms. IEEE Transaction on Geoscience and Remote Sensing. 40(11), 2375–2383.

Hooper, A., Zebker, H.A., Segall, P., Kampes, B. (2004). A new method for measuring deformation on volcanoes and other natural terrains using InSAR persistent scatterers.

Geophysical Research Letters. 31.

Hooper, A. (2008). A multi-temporal InSAR method incorporating both persistent scatterer and small baseline approaches. Geophysical Research Letters, 35

Kampes, B. M. (2006). Radar Interferometry Persistent Scatterer Technique. Dordrecht, The Netherlands: Springer.

Lanari, R., Mora, O., Manunta, M., Mallorqui‘, J. J., Berardino, P., Sansosti, E. (2004). A Small Baseline Approach for Investigating Deformation on Full resolution Differential SAR Interferograms. IEEE Transaction on Geoscience and Remote Sensing.

Mora, O., MallorquÄś′, J. J., Broquetas, A. (2003). Linear and nonlinear terrain deformation maps from a reduced set of interferometric SAR images. IEEE Transactions on Geoscience and Remote Sensing. 41, 2243– 2253.

Schmidt, D., R. Bürgmann (2003). Time-dependent land uplift and subsidence in the Santa Clara valley, California, from a large interferometric synthetic aperture radar data set. Journal of Geophysical Research 108: 2416–2428.

Van Der Kooij, M., Hughes, W., Sato, S., Poncos, V. (2005). Coherent Target Monitoring at High Spatial Density, Examples of Validation Results. Fringe, ESA, Frascati, Italy.

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