MITIGATION OF ATMOSPHERIC DELAY IN INSAR: THE ESA METAWAVE PROJECT

Daniele Perissin [(1)], *Fabio Rocca* [(2)], *Mauro Pierdicca* [(3)], *Emanuela Pichelli* [(4)], *Domenico Cimini* [(4)], *Giovanna Venuti* [(5)], *Bjorn Rommen* [(6)]

[(1)] ISEIS, Chinese University of Hong Kong, NT, Shatin, Hong Kong
[(2)] DEI, Politecnico di Milano, Milan, Italy
[(3)] DIEI, Università la Sapienza, Rome, Italy
[(4)] CETEMPS, University of L'Aquila, Italy
[(5)] DIIAR, Politecnico di Milano, Milan, Italy
[(6)] ESA, ESTEC Noordwijk, Netherlands

ABSTRACT

In this work we report the main conclusions of the European Space Agency (ESA) Metawave project *(Mitigation of Electromagnetic Transmission errors induced by Atmospheric Water Vapour Effects*) for what concerns the Synthetic Aperture Radar Interferometry (InSAR) viewpoint. The Atmospheric Phase Screen (APS) estimated with the Permanent Scatterers (PS) technique in the test sites of Roma and Como has been compared with MM5 simulations, Meris Water Vapor (WV) data and GPS Zenith Wet Delays (ZWD). The experiment shows that, even though MM5, Meris and GPS data detect the similar absolute amount of WV, their accuracy is not enough to compensate the InSAR sensitivity to the WV spatial variability. In particular, Numerical Weather Prediction models look promising for correcting long WV spatial wavelengths in presence of topography; GPS measurements reveal the best performances toward short WV spatial wavelengths, while Meris data in the analyzed area show generally poor reliability.

Index Terms— PSInSAR, atmospheric delay, GPS, MM5, Meris

1. INTRODUCTION

SAR interferometry is powerful technique to measure with millimetric precision displacements of radar targets that are coherently imaged by the radar at different times [1]. However, phase delays induced by the water vapor (WV) content in the atmosphere can prevent from reaching the theoretical accuracy [2]. Thus, atmospheric effects must be removed from interferograms in order to fully exploit the potentiality of InSAR [3]. At the moment, no instrument can estimate the atmospheric delay with spatial resolution comparable to that of spaceborne SAR. The atmospheric delay can be estimated only from long series of SAR images (as in the Permanent Scatterers (PS) technique [4]), by exploiting its statistical behavior in space and time. The Atmospheric Phase Screen (APS) estimated by the PS technique gather all phase delays that do not depend on the target elevation and on the adopted deformation model. Moreover, the APS is composed by different terms that depend on local atmospheric phenomena that can be linked to topography, land cover, air motion and turbulence [5].
Whenever PS's are present in the area of interest, unless affected by strong non-linear motions, the APS can be directly measured and compensated for. If the condition is not met, independent estimates are needed to achieve reliable deformation monitoring, not biased by the atmospheric delay [6].
This work carries the main results achieved by an Italian group of research centers (POLIMI-DEI, SAP-DIE, CETEMPS, UNIPG-DIEI, CINFAI-TO, POLIMI-DIIAR) within the European Space Agency (ESA) METAWAVE project (Mitigation of Electromagnetic Transmission errors induced by Atmospheric Water Vapour Effects).

2. MM5 SIMULATIONS VS INSAR

Data processed with the MM5 Numerical Weather Prediction Model [7] have been thoroughly analyzed in the Rome test site in correspondence of two SAR data frames, track 172, (ascending, evening) and track 351 (descending, morning). The most significant outcome of the analysis is shown in Figure 1, where the data refer to Track 172. In Figure 1, the linear dependence between the atmospheric delay and height is shown as estimated by MM5 (abscissa) and InSAR (ordinate). The quantity plotted in Figure 1 is thus an index of the stratification term of the atmospheric delay, and it is expressed as millimeters of IWV per meters of height. Each point in the plot refers to an acquisition, whose date is shown in the plot. Moreover, a color scale is used to show in which cases MM5 is able to successfully reduce the power of the atmospheric delay in InSAR data (orange) and in which cases the outcome is negative (blue).

From the correlation of the scatter plot in Figure 1 we can firstly assess that MM5 and InSAR are observing the same physical phenomenon. The dispersion of the cross-plot is 0.7 mm/km against an InSAR variability of 1.3 mm/km (IWV). Moreover, by observing that orange dots lie at the extremities of the scatter plot, we can easily understand that MM5 can mitigate InSAR WV delay only when the stratification term is predominant with respect to the turbulent term. This happens in this test site for about 30% of cases. In most of cases, MM5 cannot significantly reduce the InSAR atmospheric phase term. Moreover, in the descending test site the comparison is considerably worse.

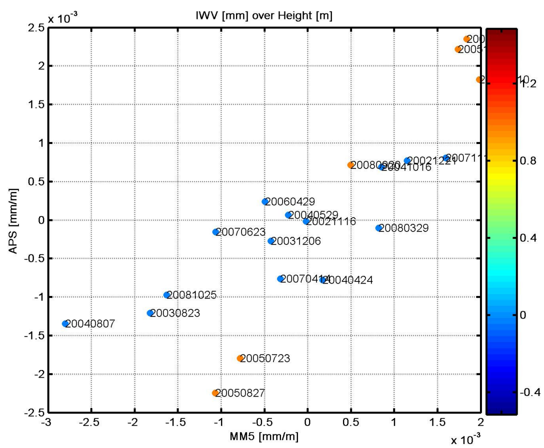

Figure 1. MM5 vs InSAR delay stratification terms in Rome, track 172, ascending. The scale is in mm of IWV per m of height. In orange cases in which MM5 can reduce the variance of the atmospheric signal.

3. MERIS VS INSAR

The spectrometer Meris onboard Envisat is able to provide IWV measurements at the same acquisition time of the ASAR instrument. Twenty-five images in correspondence of SAR acquisition dates over Rome, track 351, taken in the morning have been analyzed. From Figure 2 we can see that in at least 7 cases the cloud coverage prevented Meris from taking useful data. Moreover, no measurements can be expected for ascending orbits taken in the evening. We analyze anyway the available data.

By analyzing the spatial variograms, Meris shows a higher spectral content than MM5, and Meris and InSAR spectra match quite well, in particular after removing the "topographic bias".

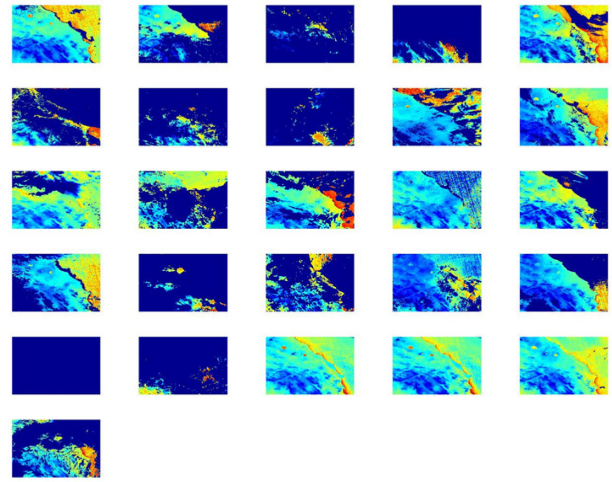

Figure 2. Meris examples of IWV estimation over Rome, Track 351, morning passes.

However, by looking at Figure 3 we see that the correlation between InSAR and Meris in the Rome test site is far below the expectations. Figure 3 shows in fact scatter plots in mm of IWV between InSAR and Meris for 15 dates, and in most of cases the correlation between the 2 quantities is less than 0.5. Only In 2 cases the correlation is good, and in those cases the dispersion of the scatter plot reaches minimum values, ~ 1mm of IWV.

Thus, notwithstanding the higher spectral content, Meris in the Rome area provided results not enough accurate to mitigate the InSAR atmospheric delay.

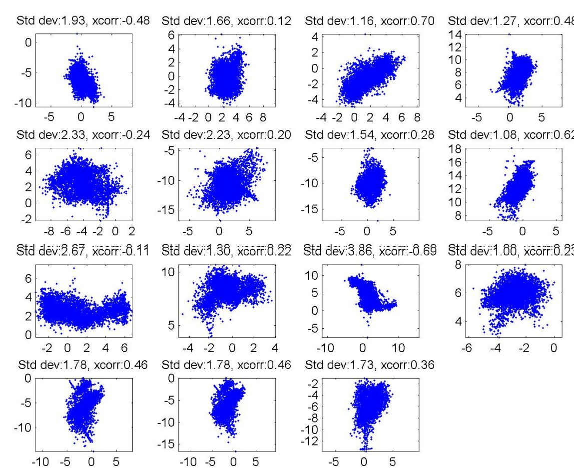

Figure 3. Scatter Plots between InSAR and Meris IWV for 15 dates. Standard deviations and cross-correlation coefficient are reported as well.

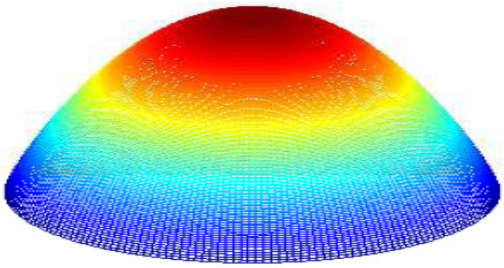

Figure 4. Mean square interpolation errors for an APS known along a circle of diameter D (thus corresponding to a circular distribution of stable scatterers). The surface tops to q. The APS is then interpolated in another point within the circle

4. INSAR VS GPS

Finally we consider the results of the comparisons between InSAR and GPS wet delays. The data are based on, on average, 5 stations per 5 days in the Como test-site. Ascending and descending passes are available. The main results are reported in Table 1. For each date, standard deviations (in mm of delay) and correlation coefficients are shown. As visible from Table 1, GPS data have the best performances among the analyzed instruments for compensating the InSAR wet delay. The ascending case shows the best correlation, on average in 50% of cases the output is positive.

5. INSAR ALONE

Before concluding we want to recall the precision that can be reached by processing series of InSAR data with the Permanent Scatterers technique.

Let us consider to have a distribution of stable PSs along a circle with diameter D (in meters). Then, we wish to estimate the APS at the location of another PS (slowly moving in an unknown way) located inside the circle. The mean square interpolation error reduction factor q is plotted in Figure 4. The maximum value (at the center) is approximately:

$$q = 0.36\frac{D}{10000}$$

We consider an empirical APS spatial autocorrelation given by the following exponential function (as eg for the ERS Three days experiment in Rome [8])

$$r_\varphi(x) = \sigma_\varphi^2 \exp(-x/D); \sigma_\varphi^2 = 1; D = 10km$$

One radian phase shift corresponds to a one way travel path dispersion of 4.6mm. In a diameter of 1km we would have an error 4.6mm*sqrt(0.036)=4.6*0.19=0.9mm, that is about 1mm path delay. This assessment matches pretty well the numbers reported in Table I. When GPS and InSAR reach the maximum correlation, the dispersion approaches 1mm.

6. FINAL CONCLUSIONS

Given the experiments carried out in Rome (MM5 simulation, Meris maps) and in Como (GPS time series) and the respective comparisons with the Atmospheric Phase Screen estimated by means of the PSInSAR technique, we can draw the conclusions of the Metawave project from the InSAR side.

- Simulations conducted with the MM5 model have shown a strong "random" component, depending more on secondary inputs as the simulation starting time than on assimilation of external data as GPS ZWD. On

Ascending				Descending			
GPS std	InSAR std	diff std	corr coeff	GPS std	InSAR std	diff std	corr coeff
3.69	3.37	3.43	0.53	3.43	1.72	2.85	0.56
2.34	4.27	4.27	0.28	2.73	5.26	3.52	0.79
3.61	5.00	1.98	0.95	0.63	3.35	3.03	0.59
2.94	3.36	1.06	0.95	5.36	6.07	2.79	0.89
2.18	1.15	1.27	0.89	1.67	1.83	2.05	0.32

Table I. Statistics of the comparison between InSAR and GPS WV estimates

the other side, MM5 model provides a more stable and reliable estimation of the stratification term, as given also by simpler models as Sastamoinen.

- Meris has higher spectral content, closer to the APS estimated by InSAR, as demonstrated also in deserted areas [9], but in the Rome test site it showed a quite low correlation with the InSAR delay, in particular for what concerns the stratification component.
- GPS data among all others show the higher correlation with the InSAR delay. The success is close to 50% on the analyzed 5 stations.
- In general, the connection between the InSAR world and the rest of the analyzed instruments lies in the estimation of the stationary term canceled out by the InSAR differential nature. A wrong estimation of the stationary atmospheric term can prevent from successfully employ external WV estimates.
- For mitigating atmospheric delay in SAR interferograms, the most accurate technique with the highest spatial resolution is the Permanent Scatterers one. In areas characterized by a lack of PSs, where even partially coherent targets fail, GPS stations can provide the better strategy for atmospheric delay estimation continuity

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