SYNERGIC USE OF EO, NWP AND GROUND BASED MEASUREMENTS FOR THE MITIGATION OF VAPOUR ARTEFACTS IN SAR INTERFEROMETRY

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Abstract*— Spaceborne Interferometric Synthetic Aperture Radar (InSAR) is a well established technique useful in many land applications, such as tectonic movements, landslide monitoring and digital elevation model extraction. One of its major limitation is the atmospheric effect, and in particular the high water vapour spatial and temporal variability which introduces an unknown delay in the signal propagation. This paper describes the general approach and some results achieved in the framework of an ESA funded project devoted to the mapping of the water vapour with the aim to mitigate its effect in InSAR applications. Ground based (microwave radiometers, radiosoundings, GPS) and spaceborne observations (AMSR-E, MERIS, MODIS) of columnar water vapour were compared with Numerical Weather Prediction model runs in Central Italy during a 15-day experiment. A dense network of GPS receivers was deployed close to Como, in Northern Italy, to complement the operational network in order to derive Zenith Total Delay as well as Slant Delay which can support InSAR processing. A comparison with Atmospheric Phase Screens (APS) derived from a sequence of Envisat multi pass interferometric acquisitions processed using the Permanent Scatters technique on the two test sites has been also performed. The acquired experimental data and their comparison give a valuable idea of what can be done to gather information on water vapour, which, besides InSAR applications, plays a fundamental role in weather prediction and radio propagation studies. The work has been carried out in the framework of an ESA funded project, named "Mitigation of Electromagnetic Transmission errors induced by Atmospheric Water Vapour Effects" (METAWAVE). This paper presents the general approach an the various methodologies exploited in the project, together with the overall intercomparison of the results. In deep details on the comparison with the InSAR APS maps derived by the PS technique, as well as on GPS receiver processing and water vapour tomography are reported in two companion papers.

INTRODUCTION

InSAR is based on the measurement of the difference in phase of the signal backscattered by each land surface element observed from different points and/or at different times [1]. The atmosphere, particularly due to the high water vapour spatial and temporal variability, introduces an unknown delay in the signal propagation. This effect might be also exploited, so as InSAR could become a tool for high-resolution water vapour retrieval. The ingestion of the latter into weather prediction models is very promising, since water vapour is one of the most significant constituents of the atmosphere, and its state change is responsible for cloud and precipitation and its interaction with radiation is a crucial factor in climate variation. Yet water vapour remains one of the most poorly characterized meteorological parameters. Improving knowledge of the water vapour field is needed for a variety of atmospheric applications and for studying the propagation of microwaves as well [2].

This paper is related to the ESA project METAWAVE (Mitigation of Electromagnetic Transmission errors induced by Atmospheric WAter Vapour Effects), where the above mentioned problematic is deeply investigated by a large team composed of SAR experts, meteorologists and atmospheric remote sensing experts. In the frame of such project the local circulation in the urban area of Rome has been studied using a high-resolution Mesoscale Model (MM5), a microwave radiometer, and Global Positioning System (GPS) estimates of integrated precipitable water vapour (IPWV). Few radioundings were also launched during a 15 day experiment and spaceborne estimates of IPWV also collected for comparison. In parallel, GPS receiver were deployed in Northern Italy, close to Como, to complement the operational network and to assess the potential to retrieve water vapour information with spatial sampling and resolution suitable to support InSAR processing. Besides standard techniques to estimate Zenith Total Delay, the estimation of the Slant Delay along the line-of-site of the SAR observation has been also attempted and described in a companion paper. The project is presently undergoing and the results of the multiplatform experiment are summarized in the paper, together with exploited methods and results in order to map the water vapour at a resolution suitable for mitigating its effect on InSAR.

THE ENVISAGED APPROACH

A. Numerical Weather Prediction models

The first sources of water vapour information potentially useful for InSAR data correction are the Numerical Weather Prediction (NWP) systems. The increased computational power of computer machines allows for a commensurate increase of the resolution of these models, which may become able to reproduce the physical phenomena involved in water vapour formation and evolution. The fully compressible non-hydrostatic models allows for reaching resolution in the order of 1 km or even better. In this project, it has been used the PSU/NCAR mesoscale model (known as MM5) that is a limited-area, nonhydrostatic, terrain-following sigma-coordinate model designed to simulate or predict mesoscale atmospheric circulation.

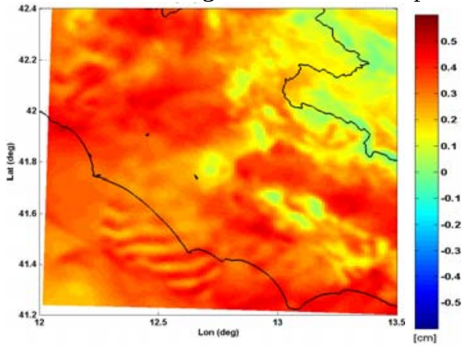

Fig. 1 Sample of MM5 integrated water vapour differences in the area of Rome (Italy) (February 3 and March 5, 1994 at 10:00 UTC) derived from ECMWF first guess. No assimilation of real observations was done.

There are two open issues: optimization of modelled high resolution water vapour to correct InSAR interferograms and, eventually, the assimilation of InSAR water vapour into the model. For what concerns the first problem, generally the water vapour produced by a high resolution NWP is a good approximation of the real distribution and can be used to correct the radar interferogram as was done in [3] using the UK Met Office Unified Model. A limiting factor for high resolution NWP is the poor resolution of the initial condition. In this respect, atmospheric Data Assimilation (DA) aims at incorporating observations into numerical weather prediction models with maximum accuracy and efficiency and fills in the data gaps using physical, dynamical, and/or statistical information. The envisaged approach foresees the assimilation of any observable (except InSAR APS maps) using the 3DVAR technique. We have followed the approach used in [4]. The observations to be considered for this scope may include ground based networks, such as GPS receiver slant-path delay or Zenith Total Delay (ZTD) estimates, or ground based microwave radiometers, as well as spaceborne remote sensors, such as microwave or infrared radiometers.

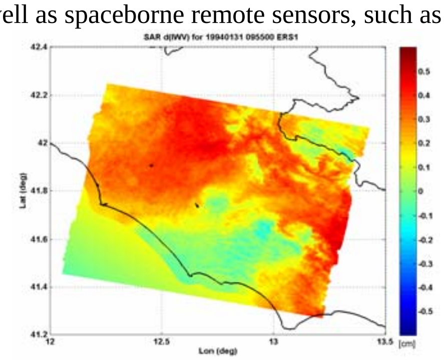

Fig. 2 APS from InSAR related to the acquisition of ERS-SAR on February 3, 1994 with respect to a master acquisition on March 5, 1994 at 9:55 UTC.

Fig.s 1 and 2 compare the difference in integrated water vapour at two different days (February 3 and March 5, 1994) predicted by MM5 (without any assimilation) with the APS map derived by InSAR acquisitions at the same days. The most evident "signal" in the map is correlated to the topography of the area and the comparison looks fairly good in this respect. The knowledge of this stratification can be very useful in InSAR processing, diminishing the number of interferograms to be stacked for a reliable mitigation of the atmospheric noise. A more deep analysis is required to single out the information content concerning the atmospheric turbulent structures of the specific meteorological conditions. This latter two aspects are deeply discussed in a companion paper.

B. Ground based networks

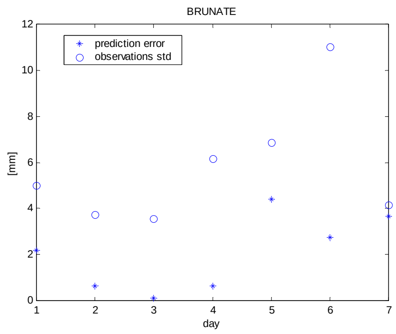

Fig. 3. Test of kriging performances comparing standard deviation of the error when estimating ZWD in a station assumed as test using data from the other stations in the network..

Another potential source of water vapour information is a network of GPS receivers, providing the ZTD from which the Zenith Wet Delay (ZWD), and thus the water vapour columnar content, can be derived by proper models. Those estimates, if available from a network with a sufficient spatial density can enable to infer the slant path delay along the SAR line of sight using geostatistical techniques, thus allowing to correct the InSAR interferograms in correspondence of specific targets to be monitored (e.g., landslides) as done in [6]. A sample of what can be expected from this approach is presented in Fig. 3, where the kriging interpolation from the network is compared with the real data collected by a GPS receiver used as test. If the slant path delays are derived in each GPS station one can also attempt to perform a tomographic processing to reconstruct a 3-dimensional water vapour field at high resolution. This latter aspect is investigate in another companion paper.

C. Earth Observation data

TABLE I
NOMINAL ACCURACY OF IPWV AND ZWD RETREIVAL FROM DIFFERENT REMOTE SENSING SENSORS.

SENSOR	Literature (nominal)		*ΔIPWV [mm]*		*ΔZWD [mm]*	
	Rms error Over ocean	Rms error Over land	Over ocean	Over land	Over ocean	Over land
MERIS	20 % Over glint: 10%	10 %	1-8 Over glint 0.5–4	0.5–4	6-48. Over glint 3-24	3-24
MODIS	20 % Over glint 10%	10 %	1-8 Over glint 0.5–4	0.5–4	6-48. Over glint 3-24	3-24
SSM/I	7%	0.4 - 0.5 g/cm^2	0.35–2.8	4-5	2.1-16.8 mm	24-30
AMSR-E	0.2 g/cm^2	0.6 g/cm^2	2	6	12	36

The project has also considered Earth Observation as a possible source to be integrated with ground network data. Optical infrared and microwave radiometers have been assessed. The expected accuracy, according to the literature, is summarised in Table I. The ground geometrical resolution is another factor, to be compared with the resolution of the InSAR interferogram, which is in the order of tens of meters. The optical sensors have a resolution in the order of some hundreds of meters, whereas the microwave radiometer resolution is several kilometres, but they are able to operate both day and night and also in cloudy conditions (with some degradation of the accuracy).

Retrieval of water vapour over land from spaceborne microwave radiometers suffers additionally from the high emissivity of the land background with respect to the sea surface. An improvement was an objective of the project and some comparison between retrievals from AMSR-E and ECMWF IPWV are presented in Fig. 5 which are based on a Neural Network retrieval approach. Although the results are not bad when compared to what found in the literature, they still have a poor resolution with respect to the interferograms one should correct. Besides presently operating spaceborne radiometers, one can try to design a system devoted specifically to InSAR correction. Considering the inherent limit of the microwave radiometry in terms of spatial resolution, such a system could be useful to evaluate the horizontal stratification of the atmosphere within a SAR frame if high frequency channels are used in order to achieve a resolution at least in the order of a few kilometres. A study to figure out the best channels to fulfil this objective has been done, showing that an estimation of the atmospheric path delay as function of the surface height (i.e., the stratification we are speaking about) can be made within the SAR frame with good accuracy.

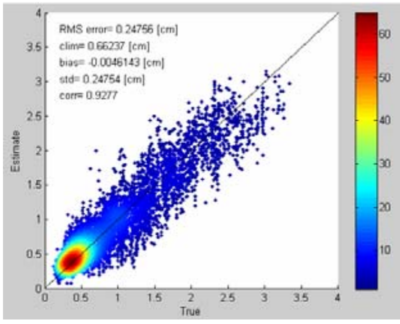

Fig. 5. Comparison of AMSR-E based retrievals of IPWV over the experimental site of Como and ECMWF data (considered as true data). The estimated accuracy is encouraging, but more reliable testS will be based on the comparison with ground based experimental data.

D. Statistical data integration techniques

Beside data assimilation within NWP models, the integration of data from different sources, taking into account their different spatial-temporal scale and reliability, can be performed by geostatistical and downscaling techniques (see for instance [7]). Without going into details, both techniques require the knowledge of the spatial characteristics of the field to be estimated at the best possible resolution. This information can be represented in terms of bidimensional spectral density or semivariogram. As a by-product of the activity performed up to know, the plenty of data we have collected have enabled the study of the spatial structure of the water vapour. Fig. 6 compares the semivariograms derived from different data sets with different spatial resolutions after removing the average dependence on the topography. In the same figure the spatial structure of the Digital Elevation Model (DEM) is shown as well for comparison.

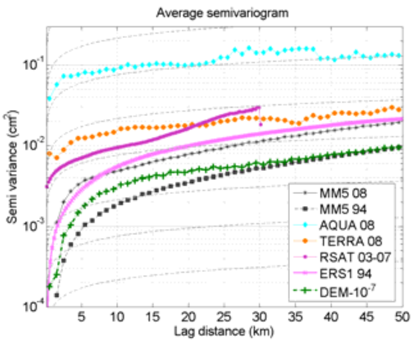

Fig. 6. Semivariograms of the IPWV field computed from different sources of data.

CONCLUSIONS

The paper gives an overview of what has been done for producing high resolution IPW maps in order to mitigate the tropospheric artefacts in SAR interferometry. A data set has been collected in Central Italy during a 15 day experiment and close to Come. Maps of IPW provided by a NWP systems and different observations (both from ground and from satellite) have been compared and integrated by geostatistical and downscaling techniques. The paper shows as high resolution maps of IPW, with sampling in the order of few hundreds of meters, can be produced with significant consistency between them. Their absolute accuracy is difficult to claim since at present the collection of ground truth on a spatial domain is a difficult task. The comparison of these maps with APS maps from InSAR are object of another paper, as well as the detailed description of the tomographic technique implemented using ZTD and STD from a GPS receiver network.

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