Synergic Use of EO, NWP and Ground Based Data for the Characterisation of Water Vapour Field

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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 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. The acquired experimental data and their comparison give a first idea of what can be done to gather valuable information on water vapour, which play a fundamental role in weather prediction and radio propagation studies.**

I. 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 was 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 was 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 were also collected for comparison. The results of the multiplatform experiment are shortly summarized in the paper, together with a survey of methods and tools we have exploited in order to retrieve maps of the water vapour field and related characteristics at resolution suitable for mitigating its effect on InSAR.

II. The Envisaged Approach

A. Numerical Weather Prediction models

The primary providers 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.

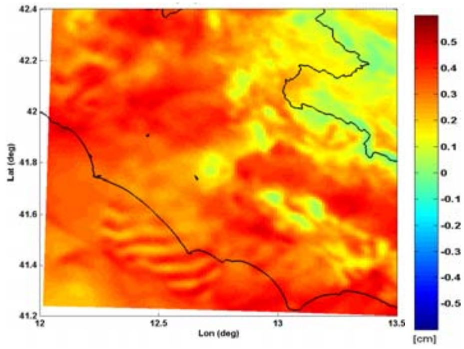

Fig. 1 Sample of MM5 integrated water vapour differences in the area of Rome (Italy) (February 3 and March 5, 1994 at 10:00 UTC) derived from ECMWF first guess. No assimilation of real observations was done.

Concerning NWP and InSAR, there are two open issues: the optimization of modelled high resolution water vapour to correct InSAR interferograms and, eventually, the assimilation of InSAR water vapour into the NWP 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.s 1 and 2 compare the difference of integrated water vapour at two different days (February 3 and March 5, 1994) predicted by MM5 (without any assimilation) and 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, as apparent for instance looking at the North East side of the image, covering the Apennine range.

A less successful comparison has been found when looking at the patterns associated to the atmospheric turbulent structures. A relevant conclusion of the study indicates as NWP may provide reliable and useful information on the stratified component of the path delay thought the atmosphere, which is dependent on the surface height and changes from time to time. It is more difficult to correctly reproduce the turbulent component at the scale required for InSAR data correction.

As far as the possibility to use InSAR Atmospheric Phase Screen (APS) into NWP models is concerned, a major difficulty is associated to the differential nature of the APS data (in time and space). APS's provide an insuperable high resolution mapping of the atmospheric path delay anomaly over points over the earth surface which remain steady in time, but they do not furnish absolute values. This property can be successfully exploited, and the high resolution APS information can be incorporated into the data used for initializing the NWP model. Without going into details, the project activity has demonstrated this is a promising way to use SAR data for atmospheric applications.

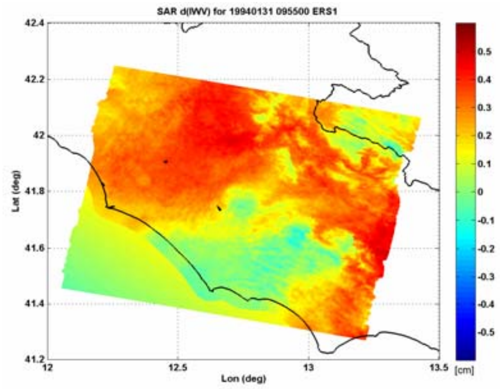

Fig. 2 APS from InSAR related to the acquisition of ERS-SAR on February 3, 1994 with respect to a master acquisition on March 5, 1994 at 9:55 UTC.

B. *Ground based networks*

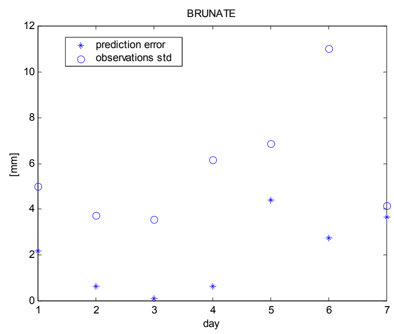

Fig. 3. Test of kriging performances comparing standard deviation of the error when estimating ZWD in a test station (Brunate) using data from the other stations in the network. The prediction error is significantly less of the prior variability of the path delay in the test station.

Another potential source of water vapour information is a network of GPS receivers, providing the Zenith Total Delay

(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 provide the slant path delay along the SAR line of sight using proper geostatistical techniques and mapping functions, 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. The experimental work has demonstrated as a GPS network can be useful and reliable to provide the stratified, height dependent, component of the path delay affecting the interferogram, similarly to the NWP models.

C. Earth Observation data

The project has also considered Earth Observation as a possible source of water vapour data, to be integrated with ground network measurements. 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 considered, 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).

TABLE I
NOMINAL ACCURACY OF IPWV AND ZWD RETRIEVAL 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

Retrieval of water vapour over land from spaceborne microwave radiometers suffers from the high emission of the land background, which limits the performance over land with respect to that above the sea surface. An attempt to improve the accuracy over land was an objective of the project, and in fact we obtained fairly good results using a Neural Network retrieval scheme. A sample of the result, comparing retrievals from AMSR-E and Integrated Precipitable Water Vapour (IPWV) from ECMWF is presented in Fig. 5.

Nevertheless, accuracy and especially ground resolution achievable by microwave radiometers alone cannot compete with the requirements of InSAR applications. A novel idea we have investigated in the project, consists in using high frequency radiometric channels, which can achieve better ground resolution, at the expense of a poor sensing of the lower part of the atmosphere. Such a millimetric radiometer, if embarked on the same satellite platform, could be useful to sense the vertical stratification of the atmosphere at the same time of the SAR overpass. A study for a suitable configuration of such radiometer as been carried out, whose details are beyond the scope of this paper.

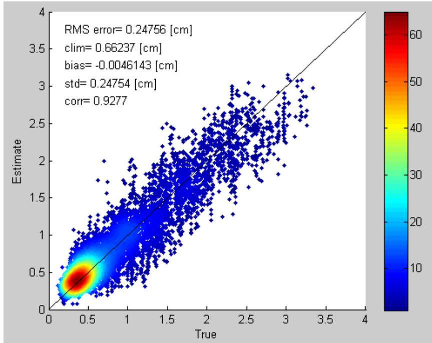

Fig. 5. Comparison of AMSR-E based retrievals of IPWV over the experimental site of Como and ECMWF data (considered as true data). The estimated accuracy is encouraging, but it is still under the requirements of InSAR applications, especially for what concerns spatial resolution.

D. Statistical data integration techniques

Beside data assimilation within NWP models, the integration of data from different sources, taking into account their different spatial and temporal scale and reliability, can be performed by geostatistical and downscaling techniques (see for instance [7]).

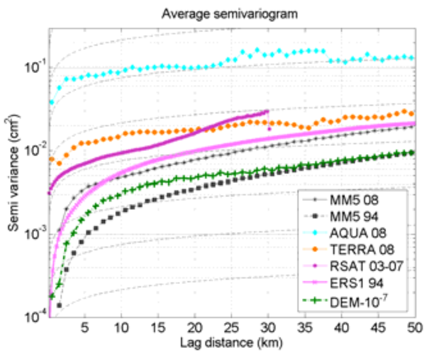

Fig. 6. Semivariograms of the IPWV field computed from different sources of data.

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 in the project, 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 (i.e., the stratification terms mentioned above). In the same figure, the spatial structure of the Digital Elevation Model (DEM) is shown as well for comparison.

III. CONCLUSIONS

The paper gives a short overview of what has been done for producing high resolution IPVW 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. 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 IPVW, 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 SAR data has demonstrated that a reliable information on the vertical stratification of the atmospheric path delay can be provided by NWP outputs and GPS networks. The same quantity could be directly measured by a millimetric radiometer. A reliable reconstruction of the high resolution horizontal pattern of the path delay affecting the SAR interferogram is still difficult to be achieved, at least operationally.

ACKNOWLEDGMENT

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