Towards an atmosphere free interferogram;
first comparison between ENVISAT's ASAR and MERIS water vapor observations

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***Abstract*—During ERS-1 and ERS-2 missions, the application of synthetic aperture radar interferometry (InSAR) become known as a very important method for topographic mapping and high accuracy surface displacement measurements. Further investigations, however, showed that expected accuracy couldn't be achieved. It appeared that radiowave propagation through the atmosphere causes significant distortion to the observed signal and obscures effects of topography and/ or deformations. Therefore, it became clear that in order to achieve very accurate measurements of surface displacements additional knowledge of state of atmosphere during InSAR measurements is necessary. In this paper the possibility of using Medium Resolution Imaging Spectrometer (MERIS) in combination with Advanced SAR (ASAR), both are on board of ENVISAT, for obtaining atmosphere free interferograms is discussed.**

Keywords-SAR interferometry; subsidence; atmosphere; ENVISAT; MERIS

I. INTRODUCTION

Water vapor and clouds have shown to be a major complication in using interferometric SAR (InSAR) for geodetic applications such as deformation studies and topography determination [1]. In the case of a strong atmospheric signal, measurements of the atmosphere by ground-based instruments, such as GPS and microwave radiometers, can be used to improve the interpretation of InSAR observations [2,3]. The drawback of this approach, however, is that it allows only to approximate the influence of the atmosphere on the measurements and not to compensate for it. To compensate for the influence of atmosphere it is necessary to have independent measurements of atmospheric water vapor with the same resolution, accuracy, and collocated in time and space with the SAR observations.

On board of the new European satellite, ENVISAT, are located a medium-resolution spectrometer, MERIS, and a synthetic aperture radar, ASAR. The MERIS is capable of medium-resolution, resolution of 300 m, water vapor observations. Thus, MERIS data could help in the validation and possible correction of interferometric SAR measurements. On the other hand, with known topography, and in the absence of deformation, the path delays of InSAR can be interpreted as a high accuracy, high-resolution relative atmospheric signal [4, 5]. The integrated water vapor obtained by MERIS would facilitate the assimilation of the long spatial wavelength absolute water vapor with the accurate relative delay measurements of the SAR.

Here, we are presenting a feasibility study of synergetic combination of spectrometer data with radar interferometry. MERIS will provide simultaneous observations of total water vapor content and cloud thickness, while ASAR provides relative delay differences, which makes the two techniques complementary. Based on this work a possibility of using MERIS data to compensate for atmospheric delay in InSAR measurements will also be discussed.

II. SAR INTERFEROMETRY

A. *Atmospheric signal*

Even though in the case of geodetic observations the atmosphere represents an unwanted component of a signal, given knowledge of the earth surface behavior, one can obtain very accurate information about the state of atmosphere at the time of a measurement. A well-known example of this approach is the use of GPS for the retrieval of water vapor profiles [6].

An SAR observation represents a high-resolution (~ 20m) image of the earth surface. A measured phase value for every resolution cell of this image can be decomposed to a phase component due to viewing geometry, a phase component due to propagation of the signal and due to scattering properties of the underlying surface [7]. In repeat-pass interferometry the observed phase is a phase difference between two SAR acquisitions. This phase difference, $\Delta\Psi$, can be written as [7]

$$\Delta\Psi=\Delta\Psi_{geo}+\Delta\Psi_{prop}+\Delta\Psi_{scatt} \tag{1}$$

where $\Delta\Psi_{geo}$ is determined by topography and satellite orbits and $\Delta\Psi_{scatt}$ is determined by scattering properties of the earth surface. The propagation phase difference in its turn is defined as

$$\begin{aligned}\Delta\Psi_{prop}&=\Delta\Psi_{iono}+\Delta\Psi_{tropo}=\\&=\Delta\Psi_{iono}+(\Delta\Psi_{hydr}+\Delta\Psi_{wet}+\Delta\Psi_{liquid})\end{aligned} \tag{2}$$

where $\Delta\Psi_{iono}$ is the ionospheric contribution to the phase delay, $\Delta\Psi_{hydr}$ is the hydrostatic part, $\Delta\Psi_{wet}$ is the wet phase delay and $\Delta\Psi_{liquid}$ is the phase delay caused by scattering on hydrometeors.

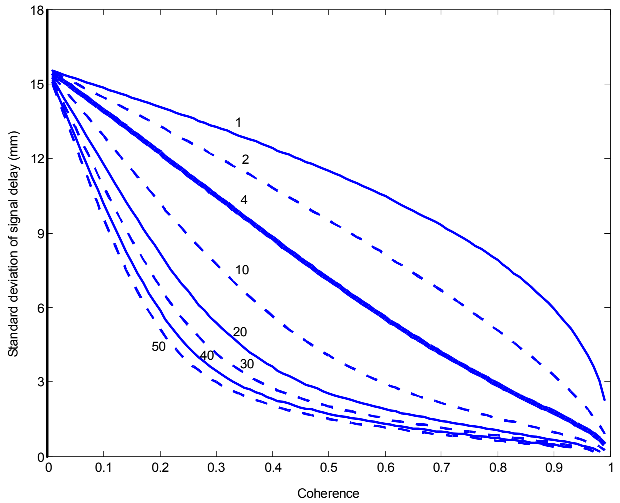

Figure 1. Standard deviation of the interferometric delay as a function of coherence for different number of looks.

The sensitivity of InSAR observation for atmospheric signal is confined to a spatial range from roughly 50m to 100 km, determined by spatial resolution and standard image size. Therefore, for our consideration we can neglect a contribution of the ionosphere to the delay signal, for the reason that ionospheric signal has a rather long wavelength variability and have a limited contribution to the interferometric phase variability, especially in non-polar regions.

The hydrostatic delay can be written as

$$\Delta\delta_{hydr}=10^{-6}k_1 R_d P_s/(g_m \cos\theta) \quad (3)$$

where $k_1=77.6\ K$ hPa^{-1} [8], R_d is the specific gas constant for the dry air, g_m is the approximate local gravity at the centroid of the atmospheric column [9] and P_s is the surface pressure. Since the pressure changes are usually limited the hydrostatic component will result in long wave delay variation and can be reduced by spatial detrending of the interferometric delay.

A much shorter wavelength variability is expected for the wet delay $\Delta\delta_{wet}$

$$\Delta\delta_{wet}=\frac{10^{-6}}{\cos\theta}\int\left(k_2\frac{e}{T}+k_3\frac{e}{T^2}\right)dh \quad (4)$$

where k_2=71.6 K hPa^{-1} and k_3=3.75x10^5 K^2 hPa^{-1} [8], T is the temperature in Kelvin, and e is the partial pressure of water vapor in hPa.

A delay due to scattering on liquid particles is usually much smaller that the wet delay [10]. However, for strong rain intensities it can be as large as several centimeters. In these cases a weather radar data should be used to estimate an effect of rain on interferometric delay.

From the discussion above we can conclude that interferometric delay variability will mainly be caused by changes in water vapor concentration and therefore additional measurements of water vapor are necessary to eliminate the atmospheric delay.

B. *Signal distortions*

The analysis presented in the section above was performed for an ideal case when phase differences due to changes in the scattering properties of the earth surface can be neglected. Moreover, it was assumed that there is no topographic signal or that topography was effectively removed by using a precise digital elevation model (DEM), and in the absense of surface deformations.

In most cases of InSAR measurements, however, the electromagnetic property of the earth surface will change from one SAR acquisition to another. Therefore, the observed interferometric signal will lose its coherence [11]. To improve a measured phase behavior an interferogram is averaged over several resolution cells (looks). A result of such multi-looking is given in Figure 1. In most cases we reduce InSAR resolution to 160 x 160m.

Errors in DEMs would result in an additional phase component, which however can be estimated if more than one interferogram of the same area is available.

III. Medium Resolution Imaging Spectrometer (MERIS)

As we have discussed, a spatial variability in atmospheric delay may cause significant errors in SAR interferograms, those errors are mainly induced by the water vapor distribution. A correction of this error signal based on additional complementary measurements is restricted to temporal coincidence, high resolution, accuracy, and total atmospheric column WV content measurements. Such measurements have not been available before the launch of ENVISAT with ASAR and MERIS on-board.

Satellite microwave radiometers are able to retrieve columnar total water vapor content with a resolution of about 50x60 km, independent of cloud cover, with an accuracy (mean error in water vapor column content) of 7%. Unfortunately, this only works over water surfaces. Over land surfaces, infrared sounders can be used for this goal, under cloud-free conditions, with an accuracy of 20%, and with coarse resolutions.

The MERIS data can be used to determine total water vapor content, as demonstrated in [13-16]. Using two channels for water vapor measurement (800 nm and 900nm), MERIS will produce the columnar amount of water vapor over water, land, and clouds, with an accuracy of 1.6 kg/m2 over land and 2.6 kg/m2 over water. Note that total water vapor column observations will only be obtained in cloud-free conditions. MERIS spatial resolutions of 300x300 m, will be averaged to 1.2x1.2 km to allow for noise reduction [14-15]. An accuracy of 1.6 kg/m2 maps to an integrated precipitable water vapor accuracy of 1.6 mm, which corresponds to a delay accuracy of 1.04 cm. Therefore by using MERIS together with ASAR we can dramatically improve InSAR geodetic measurements and create a virtually atmosphere free interferogram.

IV. DISCUSSION AND CONCLUSIONS

In Figure 2 a simulation of a synergy between MERIS and ASAR is shown. This simulation was obtained from ERS-1,2 tandem pair. It is expected that by using MERIS data to suppress atmospheric signal we will introduce additional white noise to our data but we will remove the stochastic atmospheric signal. Moreover, it is assumed that water vapor variability is not related to cloud cover.

InSAR measurements are mainly affected by variation in water vapor concentrations; this variability of atmospheric signal causes dramatic reduction in the quality of surface deformation measurements. But since the launch of ENVISAT with MERIS and ASAR aboard we have got an opportunity to reduce the effect of atmosphere on interferograms, at least for clouds free areas. This paper has discussed the feasibility of such a synergy. More detailed study using MERIS and ASAR data would be carried out as soon as measurements would become available.

InSAR observations give us possibility to obtain high-resolution total water vapor maps. These maps, however, are only relative since an interferogram is calculated from two SAR acquisitions. Nonetheless, if a large number of interferograms is available for the same area an absolute water vapor map can be estimated [12]. Moreover, if one of the interferograms is cloud free than MERIS data can be used to estimate an atmospheric free master SAR image and therefore facilitate construction of absolute water vapor maps.

ACKNOWLEDGMENT

The presented research is a part of the ESA AO 636 project.

REFERENCES

[1] R. Goldstein, "Atmospheric limitations to repeat-track radar interferometry," Geophysical Research Letters, vol. 22, No 18, pp. 2517-2520, 1995.

[2] D. N. Moisseev, R. F. Hanssen, and F. J. van Leijen, "Water vapor observations with SAR, microwave radiometer and GPS: comparison of scaling characteristics," *in Proc. ERAD*, Copernicus GmbH, pp. 190-194, 2002.

[3] A. van der Hoeven, R. F Hanssen, and B. Ambrosius, "Tropospheric delay estimation and analysis using GPS and SAR interferometry," Physics and Chemistry of the Earth, vol 27, pp. 385-390, 2002.

[4] R. F. Hanssen, A. J. Feijt, and R. Klees, "Comparison of precipitable water vapor observations by spaceborne radar interferometry and Meteosat 6.7- mum radiometry," Journal of Atmospheric and Oceanic Technology, vol 18, No 5, pp. 756-764, 2001.

[5] R. F Hanssen, T. M. Weckwerth, H. A. Zebker, and R. Klees, "High-resolution water vapor mapping from interferometric radar measurements," Science, vol 283, pp. 1295-1297, 1999.

[6] M. Bevis, S. Businger, T. A Herring, C. Rocken, R. A Anthes, and R. H Ware, "GPS meteorology: Remote sensing of atmospheric water vapor using the Global Positioning System," Journal of Geophysical Research, vol. 97, No 15, pp. 787-15,801, 1992.

[7] R. Hanssen, Radar Interferometry. Data interpretation and error analysis. Dordrecht, Kluwer Academic Publishers, 2001.

[8] E. K. Smith, Jr. and S. Weintraub, "Theconstants in the equation for atmospheric refractive index at radio frequencies," Proc. Of the IRE, vol. 41, pp. 1035-1037, Aug. 1953.

[9] J. Saastamoinen, "Introduction to Practical Computation of Astronomical Refraction," Bulletin Geodesique, vol . 106, pp. 383-397, 1972

[10] D. Moisseev and R. Hanssen, "Influence of hydrometeors on InSAR observations, " in Proc. IGARSS, IEEE, Toulouse, France, 2003

[11] H. A. Zebker and J. Villasenor, "Decorrelation in interferometric radar echoes," IEEE Trans. Geosci. Remote Sens., vol. 30, No 5, pp. 950-959, 1992.

[12] R. Hanssen, D. Moisseev , and S. Businger, "Resolving the acquisition ambiguity for atmospheric monitoring in multi-pass radar interferometry" in Proc. IGARSS, IEEE, Toulouse, France, 2003

[13] B.-C. Gao and A.F.H. Goetz, "Column atmospheric water vapor and vegetation liquid water retrieval from airborne imaging spectrometer data," Journal of Geophysical Research., vol 95, pp 3549-3564, 1990.

[14] J. Fischer and R. Bennartz, ATBD 2.4 Retrieval of Total Water Vapour Content from MERIS measurements, ESA Technical Report PO-TN-MEL-GS-0005, 1997.

[15] R. Bennartz and J. Fischer, "Retrieval of column water vapour over land from backscattered solar radiation using the Medium Resolution Imaging Spectrometer," Remote Sens. Enviroment, vol 78, pp 274-283, 2001.

[16] P. Albert, R. Bennartz, and J. Fischer, "Remote sensing of atmospheric water vapour from backscattered sunlight in cloudy atmospheres," Journal of Atmospheric and Oceanic Technology, vol 18, No 6, pp. 865-874, 2001.

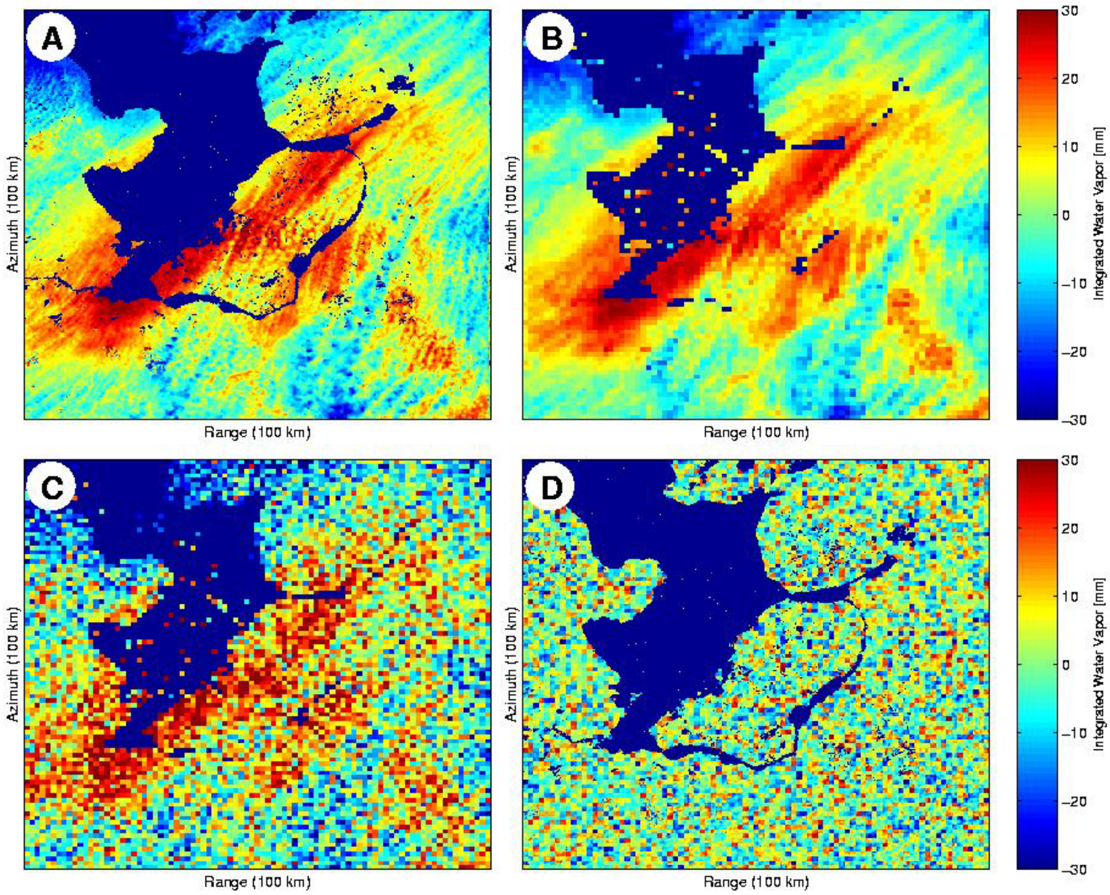

Figure 2. Atmospheric delay due to water vapor in a 100x100 km ERS-1/2 tandem interferogram over the Netherlands. B) Simulated noise-free MERIS WV product, assuming cloud free condidions. C) Simulated MERIS WV product including uncorrelated noise of 1.6 kg/m2. D) Corrected SAR interferogram, after subtraction of MERIS WV information.