Analysis of the Effects of the Atmosphere on SAR Interferometry

M. ALBANI(*), G. SCHIAVON (*), D. SOLIMINI (*)

SUMMARY. - *A numerical simulation has been carried out to assess the errors possibly induced by changes of the tropospheric refractive structure in repeat-pass INSAR-derived elevation. Predictions have been checked through a case study for the Rome area.*

1. Introduction

SAR interferometry is based on the combination of two complex SAR images, acquired from different positions of the sensor, to obtain the height of the pixels from the relative phases of the corresponding backscattered field (1). The theoretical accuracy of the obtainable digital elevation model (DEM) is of the order of one meter, while changes in the altitude of the Earth surface with a theoretical resolution of the order of one millimeter can be detected with the differential technique.

2. Troposphere and SAR interferometry

The incident and backscattered waves propagate through the troposphere, hence the length of the electromagnetic path is proportional to the integral of the tropospheric refractivity along the total geometric path. This introduces a propagation delay with respect to vacuum, thus altering the interferometric phase Φ_i, which depends on the refractive index profiles corresponding to the acquisition times of the two images. While the effects of a constant variation of Φ_i for all pixels, in principle, can be eliminated, different variations for different pixels modify the interferometric phase pat-

---

(*) Università Tor Vergata, Dipartimento di Informatica, Sistemi e Produzione, Via di Tor Vergata 110, 00133 Roma, Italy, schiavon@disp.uniroma2.it, solimini@disp.uniroma2.it. Present address of M. Albani: ESA/ESTEC, Keplerlaan 1, AG-2200, Noordwijk, Netherlands.

tern and, in turn, the information on the relative altitudes between pixels, resulting in an increase of the elevation error of the generated DEM.

Since the length of the electromagnetic path is proportional to the integral of the real part of the refractive index, the propagation delay relative to each pixel can be considered as the sum of a scene mean delay due to the refractivity profile averaged over the image and a variable delay which depends on the spatial fluctuations of the refractivity profile on a scale larger than the pixel size (for ERS, greater than 20 or 40 meters depending on the interferometric processing) and smaller than the image dimension (of the order of 100 km). The two cases of homogeneous and inhomogeneous atmosphere have therefore been considered in the performed analysis.

3. Simulation setup

Simulations have been performed by using a suitably modified version of a computer code developed in 1991 at the Wave Propagation Laboratory (WPL) of the National Oceanic and Atmospheric Administration (NOAA) (2), which evaluates, by means of an adjourned version of the Millimeter-wave Propagation Model (MPM) developed by H. Liebe (3), the propagation delay from radiosounding data. Over 7000 radiosoundings have been used for the simulations. They have been acquired at the Italian meteorological stations of Pratica di Mare (Rome), Linate (Milan), and Campoformido (Udine) during summer season (June-September) in 1988 and 1990, and at the De Bilt (NL) site during the three year period 1994-1996. Summer months path delay statistics for the four considered sites (first four columns of Tab.1) and seasonal statistics for the De Bilt site (last four columns of Tab.1) have been generated. Moreover, statistics relative to path delays separated by a 24 hours interval have been considered, which are useful to characterize the "tandem" mission, where the ERS-1 and ERS-2 satellites, on the same orbit, pass one 24 hours later than the other. Histograms in Figs. 1 and 2, relative to the two different sets of results, summer and four season (De Bilt), respectively, show a nearly homogeneous behaviour over the four sites, and the progressive increase of the delays passing from colder to warmer months. It is interesting to note that the maximum standard deviation is obtained in autumn, while the most stable situation seems to be the winter one, characterized by the smallest values of both delays and their standard deviations (due to the least vapor content at the lowest temperatures).

Results of simulations have been applied to evaluate the possible effects of the troposphere on the interferometric phase, by assuming different refractive index profiles in correspondence to the two acquisitions. For a uniform variation, some effects are present only when the surface is not flat: in fact, the path length varies over reliefs, resulting in variations of the phase differences relative to pixels at different heights. The results show a maximum variation in the two-way delays of 9 cm (corresponding to about 3π in the interferometric phase at C-band), between pixels at zero level and pixels at 2000 m height. The simulation of the effects of refractive inhomogeneities, on its turn, has been performed in the hypotesis

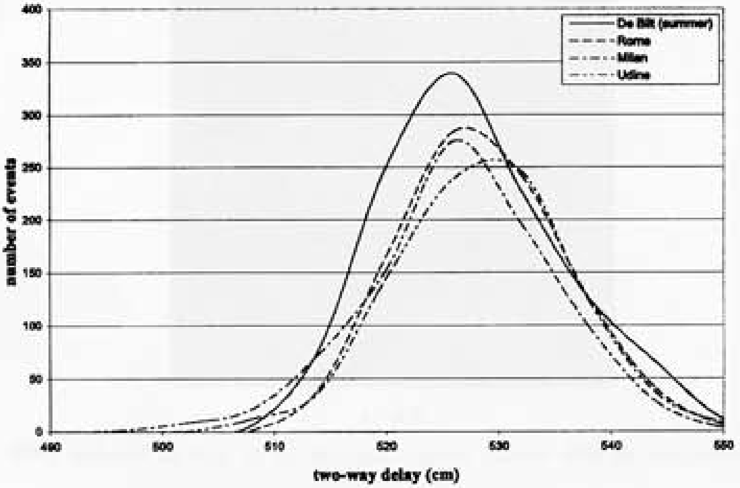

FIG. 1

Distribution of two-way delays: four sites summer.

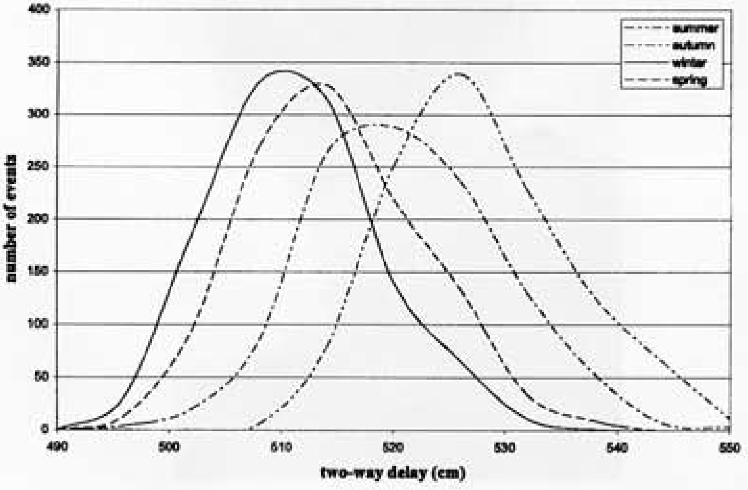

FIG. 2

Distribution of two-way delays: De Bilt seasonal.

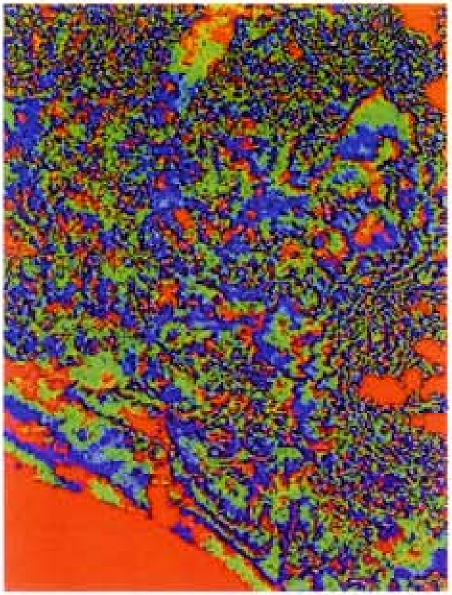

FIG. 3

Interferogram of ERS tandem images acquired on 11 and 12 October 1997.

FIG. 4

DEM derived from the interferogram of Fig. 3 (arrows point localized artifacts).

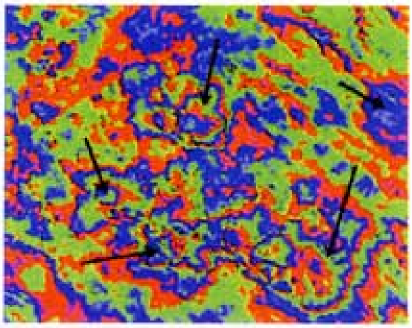

FIG. 5

15km×15km area selected from the interferogram of Fig. 3
(Arrows point localized artifacts)

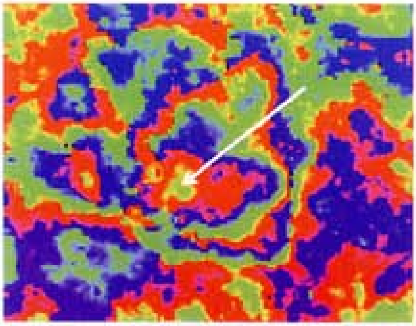

FIG. 6

Detail of a two-fringe artifact in the interferogram of Fig. 5

FIG. 7

DEM derived from the interferogram of Fig. 5.

that the temporal variations of the delays (relative to consecutive radiosoundings taken at six hour interval) on the same site, correspond to spatial variations within the scene. In this extreme situation, results show a maximum variation in the two-way delay of 34 cm, corresponding to a variation of about 11π in the interferometric C-band phase.

Table 1 Statistics of performed simulations

	Rome	Udine	Milan	De Bilt			
				summer	autumn	winter	spring
Number of profiles	909	846	857	1103	1090	1083	1103
Mean delay (cm)	531.7	531.7	529.7	530.5	524.0	514.3	517.8
Variance (cm2)	55.2	58.2	67.4	63.0	71.7	53.9	60.4
Standard deviation (cm)	7.43	7.63	8.21	7.94	8.47	7.34	7.77
Maximum delay (cm)	567.7	555.5	552.0	555.2	554.1	543.5	543.3
Minimum delay (cm)	513.0	508.4	501.8	510.1	498.6	497.5	497.8

4. Comparison with experimental results

An analysis of atmospheric artifacts has been carried out at ESA/ESRIN premises in Frascati (Italy), by processing a set of ERS images of the area of Rome. METEOSAT images, acquired about six minutes after the satellites pass, have been used to support the interpretation of results. Among the pairs of SAR images, considerable artifacts of likely atmospheric origin have been detected in the tandem images acquired on 11 and 12 October 1997. The considered area, 34 km × 60 km, is centered on Rome and presents a maximum height of about 1000 m in correspondence of the Monte Cavo mountain. The METEOSAT image acquired on October 11, nearly at the same time of the ERS-1 pass shows a few scattered clouds, while that of October 12, corresponding to the ERS-2 pass, shows a heavy and irregular cloud cover. The interferogram (Fig. 3) and the derived DEM (Fig. 4), as previously stated, show visible artifacts. An area of 15 km × 15 km adjacent to the Grande Raccordo Anulare between the Rome-Naples and the Rome-L'Aquila highway crossings has been selected to analyze these effects in detail. Artifacts consisting in an interferometric phase modification up to two and even three fringes (highlighted by arrows) can be detected by visual inspection (Fig. 5). One of the artifacts, corresponding to a height variation of about 85 m, is represented in detail in Fig. 6. The DEM obtained from the interferogram of Fig. 5 is shown in Fig. 7, where the height of the darker areas is between 100 and 140 m lower than that of the lighter areas. Since the considered area is relatively flat, such height variation can not be considered real and are probably due to bubbles of water vapor, as is indeed suggested by the METEOSAT image.

5. Conclusions

The experience acquired till now in the processing of interferometric images seems to point out that propagation effects in the troposphere can set an upper limit to the accuracy of DEMs which can be generated in some climatic zones by repeat-pass interferometry. It would be advisable to devise suitable correction techniques which, based on meteorological information, could possibly reduce interferometric phase variations due to the refractive variability of the troposphere.

Acknowledgments

This work has been partially supported by ASI (Agenzia Spaziale Italiana). Radiosonde data have been provided by the Meteorological Service of the Italian Air Force and by the Dutch National Meteorological Institute (KNMI). The authors thank the European Space Agency for the availability of SAR data and facilities at ESA/ESRIN in Frascati (Rome, Italy).

REFERENCES

(1) H. TARAYRE, *Extraction de Modèles Numériques de Terrain par Interferometrie Radar Satellitaire: Algorithmie et Artefacts Atmosphériques,* Phd. Thesis, Institut Polytechnique National de Toulouse, 1996.

(2) E.R. WESTWATER, J.A. SCHROEDER, *User Guide to WPL Microwave Radiative Transfer Software*, NOAA Technical Memorandum ERL WPL-213, 1991.

(3) H.J. LIEBE, G.A. HUFFORD, M.G. COTTON, *Propagation modelling of moist air and suspended water/ice particles at frequencies below 1000 GHz*, Proc. AGARD 52nd Apecialists' Meeting of the Electromagnetic Wave Propagation Panel, Palma de Mallorca, Spain, 17-21 May 1993, pp. 3-1/3-10.