Atmospheric heterogeneities in ERS tandem SAR interferometry

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Ramon Hanssen

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Preface

As the first publications on repeat pass SAR interferometry showed phenomenal results for terrain mapping and deformation analysis, the first signs of the disturbing influence of the atmosphere were somewhat discouraging. The question, however, was if the observed effects were just coincidental artifacts, or whether they are apparent in many or maybe all interferometric observations. A closely related question is to identify the driving atmospheric mechanisms for the observed effects. Clearly, the analysis of a single interferogram is not sufficient to comment on these issues. For this reason, the underlying report tries to evaluate a large set of interferometric data, and assess the influence of atmospheric processes in it.

The realization of this report was only possible due to the contribution of different groups and individuals. I would like to thank Steve Coulson, Nick Walker and Andrea Abellini at the European Space Agency for the provision of the data and their support for this study. At the German Aerospace Research Establishment (DLR), Richard Bamler, Michael Eineder, Nico Adam, and Birgit Schättler contributed significantly to the work, and I would like to thank them for their kind hospitality and the use of their interferometric processing software. Servus. Gerhard Gesell at DLR provided some beautiful NOAA AVHRR color composites, which proved to be valuable reference material. The meteorological interpretation of the data was performed at, and in close collaboration with the Royal Netherlands Meteorological Institute (KNMI). Henk Benschop and Arnout Feijt were of great help in the collection and processing of the many meteorological data sources. I especially would like to thank Frans Debie and Sylvia Barlag, who spent many days looking at the interferograms, trying to figure out what could have caused those strange phase effects. Their professional meteorological knowledge formed a major contribution to this report. Herman Wessels is acknowledged for his assistance on the weather radar data. The final parts of this work were performed at Stanford University, in the group of Howard Zebker. His hospitality and our stimulating discussions are greatly appreciated. Falk Amelung gave some great comments on the draft. Finally, I would like to thank Roland Klees at Delft University of Technology for his support and critical comments.

The majority of the meteorological data was kindly provided by the Royal Netherlands Meteorological Institute in De Bilt, the Netherlands. The radiosonde profiles of Ukkel and Emden were made available by the European Center for Medium-Range Weather Forecasts (ECMWF), Meteorological Archival and Retrieval System (MARS). These data were acquired by Koninklijk Meteorologisch Instituut (KMI), Ukkel, Belgium, and Deutscher Wetter Dienst (DWD), Offenbach, Germany.

The amount of data analyzed for this study is enormous. A printed version of this report, including all the studied images of the interferometric processing (interferograms, coherence images, amplitude images), the spaceborne weather images from NOAA-AVHRR and METEOSAT, the plots of the radiosonde observations, and the plots of the different synoptic observations, would largely exceed the limits of a compact format. I have chosen to limit the amount of graphs for that reason, although the current version still includes many figures. This implicates that not all information referred to in the text can be verified by the report only. I wish to stimulate the interested reader to contact me for further information at `hanssen@geo.tudelft.nl`.

This report shows that atmospheric signal cannot be ignored while using ERS tandem interferometry for topographic mapping. However, the availability of more tandem interferograms for a given site enables (1) selection of pairs with most favourable weather conditions, and (2) the application of stacking techniques to suppress atmospheric influence on the final DEM.

Finally, I wish to express my confidence that the ERS tandem SAR database has an enormous potential for the study of atmospheric dynamics, water vapor distribution, and signal propagation. Using even coarse reference elevation models, interferometric SAR images can be used to study properties of the Earth's atmosphere at an unsurpassed precision and resolution level. I hope that this study can be a contribution to new developments in this field.

Ramon Hanssen,
Stanford, February 1998

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Chapter 1

Introduction

1.1 Background

The ERS-1 and ERS-2 Tandem Mission, in which SAR pairs were acquired with an offset of one day, provided a unique dataset of SAR imagery which will be used in many years to come. The mission, in which ERS-2 followed 30 minutes behind ERS-1, in the same orbital plane, acquired about 110.000 SAR pairs over a period of nine months (August 1995 — April 1996) , covering nearly the total global land surface. Some 73% of the data has a perpendicular baseline between 50 and 300 m, 21% has a smaller baseline, and 6% a baseline between 300 and 600 m (Duchossois et al., 1996).

The baseline and interval characteristics ensure relatively good coherence values when an interferometric product is computed using the two SAR acquisitions, and provide good opportunities for deriving Digital Elevation Models (DEMs), or detecting deformations. Especially the possibility to make a nearly global DEM with one imaging system is unsurpassed at this time.

However, it has emerged that atmospheric variations, both in one scene and between the two SAR acquisitions, can lead to coherent phase artifacts in the interferograms, resulting in height offsets in the derived DEM.

The current study aims to provide a better insight in the driving mechanisms of the atmospheric influence on SAR interferometry, investigating the interferometric combination of 52 SAR images, each with its specific atmospheric characteristics.

1.2 Current state of affairs

Although the influence of the atmosphere on the propagation velocity of radio waves is already a long known fact, the first applications of repeat pass SAR interferometry did not reveal any signs of disturbance. This was mainly due to the fact that the images were acquired over areas were the phase effects were mainly caused by topography or deformation, which obscured the atmospheric signatures. Only after sound quantitative analyses with reference topography, or over areas without significant topography (Kooij et al., 1995), the residue phases were related with spatial variability in the atmosphere, influencing the propagation velocity of the radar signal, and hereby the observed interferometric phase.[1]

---

[1] A delay in the propagation velocity of the radar signal results in a phase shift in the interferogram. Since the effect of this phase shift on the derived DEM is dependent on the length of the perpendicular

Recent studies(Goldstein (1995); Massonnet and Feigl (1995); Tarayre and Massonnet (1996); Tarayre (1996); Hanssen and Feijt (1996); Hanssen and Usai (1997); Zebker et al. (1997); Dupont et al. (1997)) have shown that temporal and spatial variations of the refractive index of the propagation medium lead to phase variations in the derived interferograms.

Observations by Dupont et al. (1997) show phase variations with a low spatial frequency and an amplitude between 0.3 and 0.5 phase cycles in about 44 processed interferograms. In some interferograms, they observed localized phase variations with an amplitude of 1–3 phase cycles. Goldstein (1995) reports RMS phase variations of 0.1 phase cycles over the whole image, probably caused by turbulent mixing of water vapor and air, and maximum (peak-to-peak) variation of 1 phase cycle. Up to three phase cycles localized phase shift is observed by Tarayre and Massonnet (1996) corresponding with cumulus clouds, while Hanssen and Usai (1997) report wave effects with a wavelength of 1.5–2 km and an amplitude of 0.25 cycles, and localized phase shifts of up to 5 phase cycles. Zebker et al. (1997) analyzed L-band and C-band data from SIR-C, and found RMS values between 0.04 and 0.16 phase cycles for L-band, which would convert to 0.17 and 0.68 phase cycles RMS for C-band.

The refractive index $n(\vec{x}, t)$ is a function of time and space, and is being determined by mainly three components: pressure, temperature and water vapor. Therefore, in order to know $n(\vec{x}, t)$ we need to know the behavior of all three spatial components and exactly at the times of the SAR acquisitions. These requirements can not be met using current meteorological observations which lack in either temporal or in spatial resolution. However, even if image covering corrections for atmospheric delay seem unlikely at the time, it is necessary to achieve some better insights into the nature of the atmospheric mechanisms that cause the observed delays.

1.3 Goals of the study

This study analyzes the phase artifacts in a series of 26 interferograms and evaluates them using additional meteorological data. The main objectives are:

- to give a quantitative analysis of the observed atmospheric phase artifacts in terms of spatial scale and magnitude, and to make a classification of the effects,
- to compare these artifacts with appropriate meteorological information, and assess the atmospheric phenomena causing the artifacts,
- to investigate if, how, and which meteorological information can serve as a “warning flag” for the prediction of atmospherically induced artifacts in SAR interferograms,
- to give a first estimate of the number of artifact-free or artifact-low tandem pairs in the ESA Tandem archive (constrained by the chosen test areas), and
- to provide a brief summary of the contemporary theoretical understanding of phase artifacts induced by atmospheric heterogeneities.

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baseline between the satellites, it is not useful to express the atmospheric errors in terms of meters height error. Therefore this report will denote the phase shift φ in angular terms (radians or cycles), or as an effective one-way delay $\Delta\rho$ in meters, using $\Delta\rho = \frac{\lambda}{4\pi}\varphi$ where λ is the wavelength of the SAR (0.0566 m).