Phase Unwrapping for Multiple Interferograms: An Airborne Experiment for TanDEM-X.

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Abstract

This paper describes a joint phase unwrapping approach for multiple interferograms acquired on different trajectories. The work done here was carried out for purposes of TanDEM-X [1] simulations, using the experimental airborne Radar System (E-SAR) of the German Aerospace center. The results are validated using ICE-SAT data takes.

1 Introduction

To simulate the feature of the upcoming TanDEM-X satellite constellation of generating interferometric data-takes covering the same region with a different effective baseline, an airborne experiment using the experimental airborne SAR sensor E-SAR was initiated. The main objective was to improve conventional phase unwrapping using multiple interferograms with different height of ambiguities as stated in [2] and [3]. Since TanDEM-X can be treated as a single pass constellation, the interferometric X-Band of the E-SAR has been used at different flight levels to simulate the different effective baselines without introducing temporal de-correlation.

2 Joint Phase unwrapping

Phase Estimates of interferometric SAR measurements are wrapped within $[-\pi, \pi)$. The aim of phase unwrapping is to reconstruct the unwrapped phase ϕ from the wrapped phase ψ which allows the reconstruction of the terrain elevation. It can be stated, that:

$$\phi = \psi + 2\pi n \tag{1}$$

where n denotes the number of unknown phase cycles in the signal. It is visible that the reconstruction of the unwrapped phase requires the estimation of the number of unknown phase cycles n.

2.1 Geometric considerations

In order to retrieve the topographic height from the unwrapped phase, the acquisition geometry has to be considered. The geometry can be expressed as the well known vertical wavenumber k_z,

$$k_z = \frac{R_1 \lambda \sin(\theta_1)}{4\pi B \sin(\theta_1 - \epsilon)} \tag{2}$$

listed as a first order approximation here. The Terrain elevation changes are direct proportional to the flattened phase ϕ

$$h = k_z \phi \tag{3}$$

and to the unknown phase cycles n via

$$h = k_z (\psi + 2\pi n) \tag{4}$$

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2.2 Data acquisition diversity

Equation 4 shows the ambiguous heights which can be retrieved when using one interferogram. These separation between two possible (ambiguous) heights follows as the height of ambiguity $h_{2\pi}$

$$h_{2\pi} = 2\pi k_z \tag{5}$$

. One should be able to resolve this ambiguity using multiple interferometric acquisitions with different vertical wave-numbers. Taking a look at equation 2 shows, that there are different possibilities to vary the vertical wavenumber:

- Baseline B: Varying the baseline B is possible in repeat pass interferometric configuration.
- Incidence Angle θ and Range R_1: Can be achieved using different altitudes in repeat and single pass configuration.
- Wavelength λ: Can be achieved in single pass configuration, using multi-frequency airborne sensors like the DLR's new airborne sensor, the F-SAR, or in repeat pass constellation.

Assuming m multiple interferograms with different heights of ambiguity, equation 4 expands to the following system of linear equations.

$$\begin{aligned} h &= k_z^1 \left(\psi^1 + 2\pi n^1\right) \\ &\dots \\ h &= k_z^m \left(\psi^m + 2\pi n^m\right) \end{aligned} \tag{6}$$

The unknown phase cycles $n^1 \ldots n^m$ can be retrieved by minimizing the difference between two of those equations.

$$min \left| k_z^i \left(\psi^i + 2\pi n^i\right) - k_z^j \left(\psi^j + 2\pi n^j\right) \right| \tag{7}$$

3 Implementation

To minimize equation 7 some data preparation steps and assumptions are necessary. The following sections describes them.

3.1 Projection

First of all, the different interferometric phases and vertical wavenumbers need to be projected to a common acquisition trajectory. This can be carried out using conventional co-registration methods for repeat pass interferometric configurations or by geographic projection for non parallel tracks.

3.2 Phase Calibration

Because of working with real heights the interferograms need to be calibrated e.g. using a corner reflector. The phase of a known height can be written as the difference between the height of the calibration target h_{cal} and the height assumed for flat earth phase removal h_{fe}.

$$\phi_{cal} = \frac{h_{cal} - h_{fe}}{k_z} \tag{8}$$

3.3 Minimization

To minimize equation 7 two considerations need to be done:

- Phase cycles can only take integer values.
- The phase cycles of two adjacent resolution cells can only differ by one.

It is also helpful, to start at a point with known phase cycles, and use them as start values for the minimization algorithm. The calibration point is applicable for this.

4 Experimental Results

The presented unwrapping algorithm needs two interferograms with two different heights of ambiguity. These were acquired using a constant baseline at two different flight levels. The Parameters of the experiment are listed in Table 1.

	Flight 1	Flight 2
Center Frequency	$9600MHz$	$9600MHz$
Altitude above Ground	$3000m$	$4000m$
Baseline Length	$1.6m$	$1.6m$
Baseline Tilt	13.3	13.3
Average Height of Ambiguity	$25m$	$37m$

Table 1: Experimental Overview

Both interferograms were created using a conventional processing chain, including motion compensation with respect to their real altitude above ground. After processing, the interferogram and the vertical wavenumber were projected to a common trajectory. Figure 1 shows the two different interferograms projected to the same trajectory.

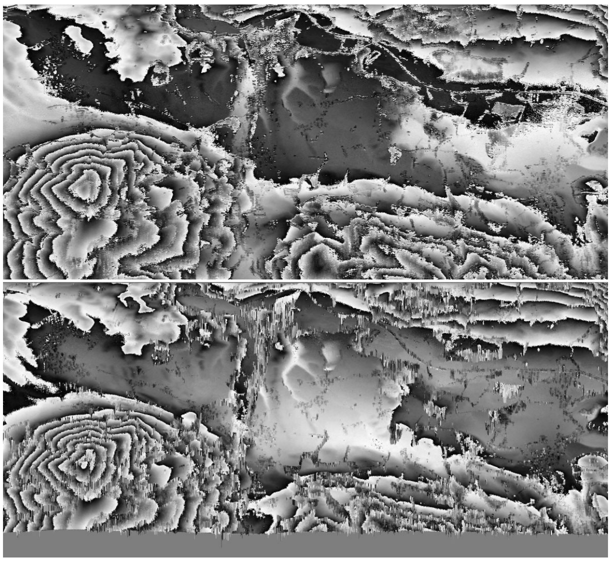

Figure 1: Interferograms with different height of ambiguity projected to the common geometry

After projection, the phases are calibrated using a corner reflector. The corner reflector was also used to determine the start value of unknown phase cycles for the minimization process. The minimization started from the corner reflectors coordinates, and followed a cyclic path to the borders if the image.

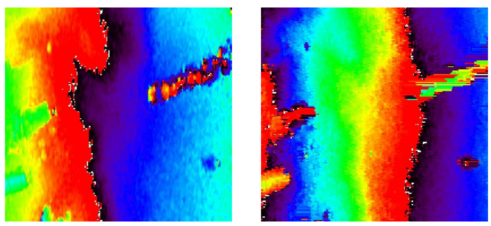

Figure 2: A subset of the wrapped phases in Figure 1, scaled between $-\pi$ (black) and π (red)

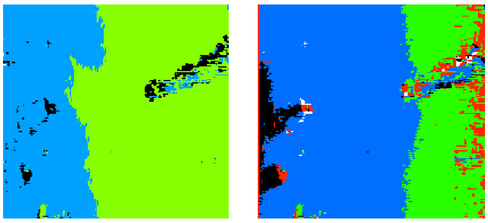

Figure 3: The estimated unknown phase cycles to unwrap the phase in Figure 4. Green corresponds to 2 phase cycles, blue to 1 and black to 0 phase cycles.

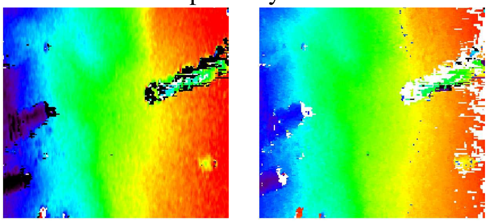

Figure 4: Unwrapped phases using the information from Figure 4 and Figure 3

References

[1] *TanDEM-X DLR Web Page [online]*, http://www.dlr.de/hr/tdmx 2007

[2] Wei Xu, Chien Chang, Leong Keong Kwoh, Hock Lim, Wang Cheng Alice Heng: *Phase-unwrapping of SAR Interferogram with Multi-frequency or Multi-baseline*, Proceedings of IGARSS 1994, Volume 2, Page(s) 730-732

[3] Michael Eineder and Nico Adam *A Maximum-Likelihood Estimator to Simultaneously Unwrap, Geocode, and Fuse SAR Interferograms From Different Viewing Geometries Into One Digital Elevation Model*, IEEE Transactions on Geoscience and Remote Sensing, Vol. 43, No. 1, pp. 24-32, January 2005