IMPROVING DEMS USING SAR INTERFEROMETRY

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ABSTRACT

Interferometric synthetic aperture radar (InSAR) processing relies on phase unwrapping to convert phase to topographic height. Rather than processing the complete phase image to extract a digital elevation model (DEM), we take the approach of using existing coarse DEMs to estimate the baseline accurately and guide the phase unwrapping processing. We apply our algorithm to ERS Tandem Mission data to demonstrate a four-fold increase in DEM quality using an existing coarse DEM to aid in phase unwrapping and also to estimate the baseline.

1. INTRODUCTION

Topographic estimation using satellite SAR interferometry data is a difficult process primarily because of the phase unwrapping requirement but also because of the requirement for precise knowledge of the relative geometry (baseline) of the SAR images. Phase unwrapping refers to the non-linear process of estimating the required multiple of 2π to transform interferogram phase to a distance measurement. To accurately estimate topography using the unwrapped phase, the baseline must be known to within fractions of a centimeter.

We have considered the topographic estimation problem as one of updating existing, possibly very low quality DEMs. The first step of the algorithm is optimally “flattening” the intererogram phase contribution from the existing input DEM without unwrapping the phase. The flattening algorithm implicitly estimates the baseline. The accuracy of the baseline estimate depends on the quality of the input DEM. The residual interferogram formed by removing the input DEM’s contribution is then postprocessed to increase the resolution and accuracy of the input DEM subject to noise effects such as atmospheric artifacts.

In Section 2 we give a brief overview of the algorithm followed by a summary of the data we processed in Section 3. Processing results are reported in Section 4.

2. DEM IMPROVEMENT ALGORITHM

The algorithm for DEM improvement using InSAR techniques consists of 3 parts as shown in Figure 1:

1. *“Flattening” with the input existing DEM [1].*

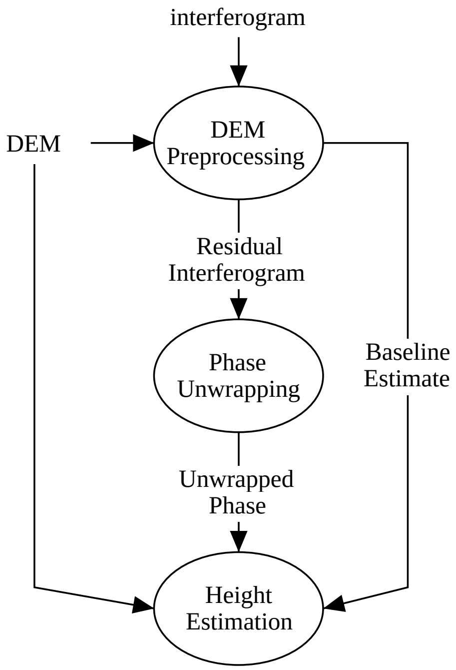

Figure 1: Algorithm for updating DEMs.

The interferogram is preprocessed using the DEM to obtain the baseline values and remove the topographic phase, yielding a residual interferogram representing the difference between the input topography and the measurement made by the interferometer. The accuracy of the baseline estimate can be checked by examining the spectra of the residual interferogram. Assuming the input DEM has no trend errors, the baseline estimate will be accurate if the residual spectra of the interferogram has a single significant peak at zero frequency. If the residual spectra has multiple significant peaks, the baseline must be re-estimated using the unwrapped phase.

2. *Phase unwrapping of residual phase signal.*

Phase unwrapping can be performed in many different ways. We use weighted least squares phase unwrapping applied to the down-sampled residual interferogram. By flattening using a coarse model of the topography, one shrinks the bandwidth of the residual interferogram, allowing filtering to reduce the noise in the interferogram phase.

3. *Height Estimation.*

Height estimation proceeds by reconstructing the interferogram phase using the DEM model and the unwrapped phase from the residual interferogram. If the baseline estimate is deemed to be valid, the topographic height estimates can be made directly. If not, a further round of optimization using the existing DEM must be performed to refine the baseline estimate.

3. DATA OVERVIEW

We processed an ERS Tandem Mission interferogram using our automated technique. The Chilcotin area of British Columbia was chosen because DEMs of 3 different qualities were available (see Table 1) and the topography was very challenging with large height variations and some layover. The TRIM DEM, which is the most accurate, will be used as a ground truth reference. A basic requirement of the flattening algorithm for producing accurate baseline estimates is that the input coarse DEM have no error trends [1]. We therefore pre-conditioned the DTED and GTOPO30 DEMs to have no linear error trends in range and azimuth.

The ERS tandem sub-scenes are centered at approximately 51^o $45'$ N and 122^o $14'$ W. The data covers a portion of the Fraser Canyon with peak to valley floor elevation change of about 1000m. This area provides good repeat-pass interferometric coherence because it is usually dry and has little vegetation. The reference elevation data for the processed slant range sub-scene are shown in Figure 3) e.

The reference SAR image, the flat earth corrected interferogram phase, and the coherence magnitude are shown in Figure 2. All images are oriented approximately with north at the top of the page. The ERS Tandem Mission data has high coherence with a mean coherence magnitude of approximately 0.7.

DEM	Data Posting	Vertical Accur.	Horiz. Accur.
TRIM [2]	≈ 75	5	12
DTED-1[3]	≈ 90	30	50
GTOPO30 [4]	≈ 1000	160	–

Table 1: DEM accuracy and data posting (m).

4. RESULTS

The results of the DEM updating algorithm applied to the ERS tandem mission dataset using DTED-1 and GTOPO-30 input DEMs are depicted graphically in Figure 3 and numerically in Table 2. The normal baseline for the dataset was estimated at approximately 45m for all input DEMs. A factor of four improvement in standard deviation of height error is seen for the GTOPO30 dataset and a factor of 1.5 improvememt is seen for the DTED-1 dataset. Note the similarity between the two interferometric SAR derived DEMs and the reference TRIM dataset. There is also a substantial increase in the detail of the GTOPO30 based InSAR DEM compared with the input GTOPO30 DEM. The relatively high final error of the DEMs is due mostly to unfiltered phase noise combined with the relatively small normal baseline of the interferometric pair. There were no significant error trends in the output DEMs due to baseline parameter errors.

DEM	Input Mean	Input Std.	Output Mean	Output Std.
DTED-1	-0.64	38.59	-2.74	26.23
GTOPO30	-0.08	123.26	-1.99	27.32

Table 2: Input DEM and InSAR output DEM error statistics (m) derived from comparison with the TRIM dataset.

5. CONCLUSIONS

A modified interferometric SAR technique for updating DEMs has been presented. Our technique uses the input coarse DEM to ease the phase unwrapping problem while simulataneously estimating the baseline without phase unwrapping. Despite a small normal baseline, DEM improvement was demonstrated using ERS tandem mission data. In particular, significant improvement of the publicly available GTOPO30 input DEM was demonstrated. Work is on-going to process more difficult test cases.

ACKNOWLEDGEMENTS

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REFERENCES

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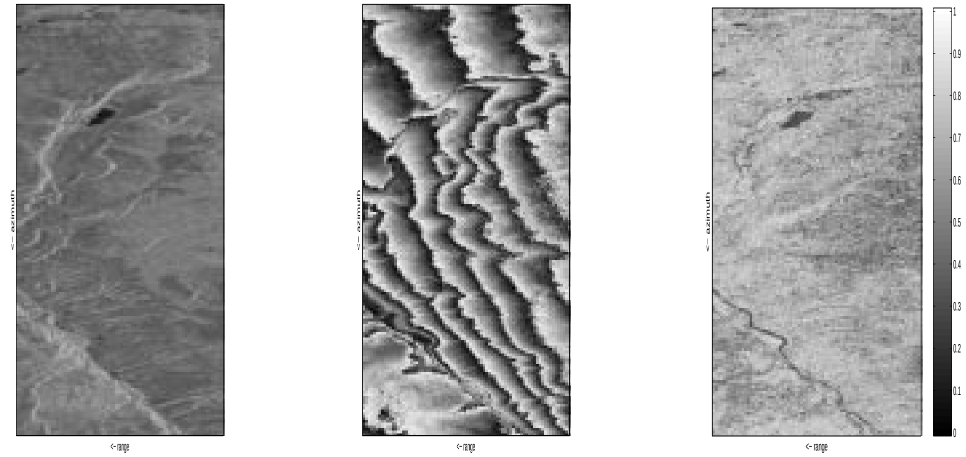
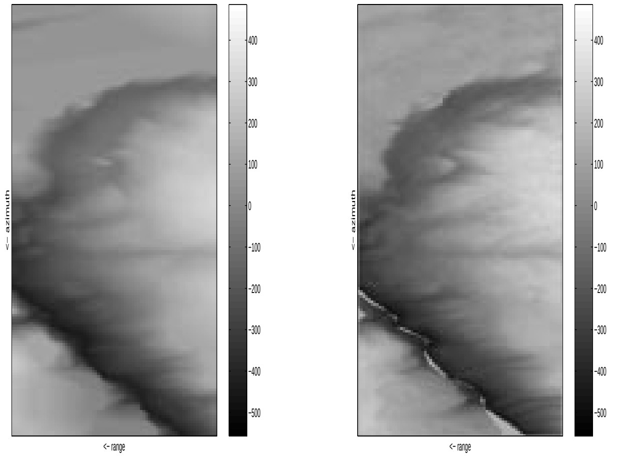
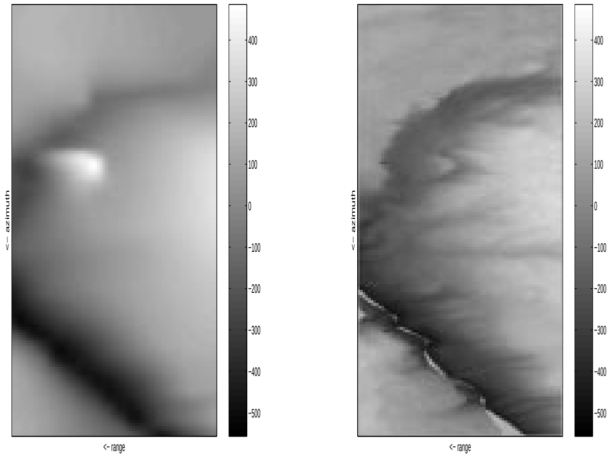


a) ERS Image Magnitude b) ERS Interferogram Phase c) ERS Coherence Magnitude

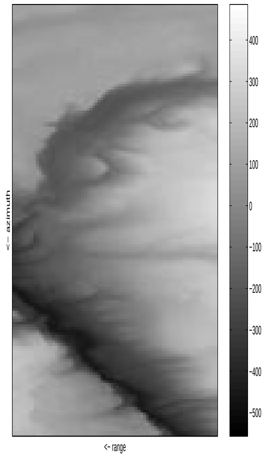
Figure 2: Summary of ERS Tandem Mission data.



a) DTED Input DEM b) DTED Output DEM



c) GTOPO30 Input DEM d) GTOPO30 Output DEM



e) TRIM reference DEM

Figure 3: Results of DEM updating algorithm illustrating how ERS interferograms can update coarse and medium-resolution DEMs.