IMPROVING DEMS USING SAR INTERFEROMETRY

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ABSTRACT

Interferometric synthetic aperture radar (InSAR) processing relies on phase unwrapping to convert interferometric phase to topographic height. Phase unwrapping is a difficult non-linear process that is still the subject of on-going research. Rather than processing the complete phase image to extract a digital elevation model (DEM), we use existing coarse DEMs as an integral part of the InSAR algorithm. Firstly, we estimate the baseline parameters accurately without phase unwrapping. This facilitates the removal of the coarse DEM topographic phase from the interferogram without phase unwrapping the entire interferogram. The residual interferogram after the removal of the topographic phase is generally more amenable to simple filtering and is also easier to phase unwrap. After phase unwrapping, the coarse DEM model can again be used (if needed) to constrain the baseline parameter estimates and an output InSAR DEM is produced. We apply our algorithm to both ERS Tandem Mission data and RADARSAT-1 interferometric SAR data to investigate the feasibility of using coarse DEMs in the InSAR processing algorithm. Substantial improvement is shown in the InSAR DEM quality compared to the input coarse DEMs with respect to a high quality DEM used for ground truth.

Keywords: InSAR,baseline estimation,phase unwrapping, DEM accuracy

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 interferogram 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 post-processed 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:

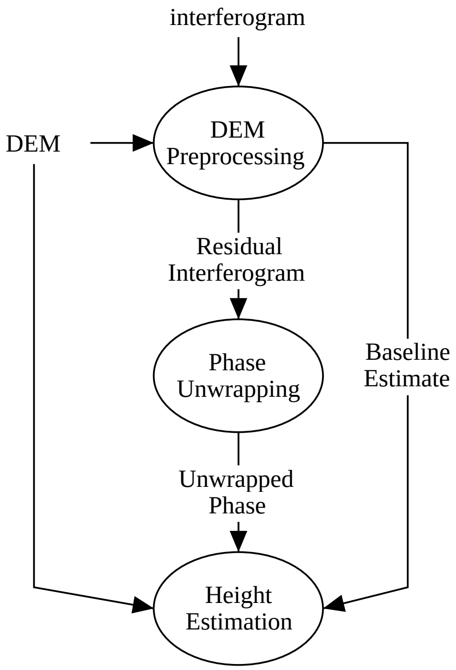


Figure 1: Algorithm for updating DEMs.

1. *"Flattening" with the input existing DEM [1].*

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.*

The residual phase of the interferogram after the removal of the topographic phase represents information and some noise in the interferogram that is not represented by the input coarse DEM. Generally, phase unwrapping must be performed to convert the residual phase to topographic height. Note that by "flattening" using a coarse model of the topography, one shrinks the bandwidth of the residual interferogram, allowing simple 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 and a RADARSAT-1 interferogram using our automated technique. The Chilcotin area of British Columbia was chosen as a test site because the topography was very challenging with large height variations and some layover. In addition, the Chilcotin test site has small amounts of vegetation and tends to be dry; two conditions necessary for good likelihood of two-pass satellite InSAR coherence.

DEMs of 3 different qualities are available (see Table 1) for the test-site. 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 or bi-linear error trends.

The ERS Tandem mission data are an ERS-1 SAR image (orbit 21730) and a co-located ERS-2 SAR image (orbit 2057), collected on September 10, 1995 and September 11, 1995 respectively at a local time of approximately 10 AM PST. The ERS parameters are given in Table 2. The SAR data was collected on track 199 at frame 2565 for both satellites. From the ERS InSAR baseline listing [2], the normal baseline is estimated to be -42 meters, well within the desirable range for SAR interferometry. See Figure 2 for the InSAR data from the ERS Tandem Mission data.

The RADARSAT processing example was taken from data collected in "FINE 3" beam mode, with the parameters given in Table 3. The two passes were collected on April

DEM	Sample Spacing	Vertical Accuracy (meters)	Horizontal Accuracy (meters)
TRIM [4]	≈ 100 meters in flat terrain,≈ 75 meters in rough terrain	5 (LE 90%)	12 (CE 90%)
DTED[5]	3 arc-seconds gridded (≈ 90 m)	30 (LE 90%)	50 (CE 90%)
GTOPO30[6]	30 arc-seconds gridded (≈ 1 km)	86[7] (RMSE)	N/A

Table 1: Summary of DEM characteristics.

24, 1997 (orbit 7675) and May 18, 1997 (orbit 8018) respectively at a local time of approximately 6 AM PST. The normal baseline was estimated from RADARSAT's orbit data to be approximately 375 meters which is well within the preferred range for RADARSAT fine beam data. See Figure 3 for the InSAR data from the RADARSAT-1 data.

Incidence Angle:	
near swath	20^o
far swath	26^o
Slant Range:	
near range	833 km
far range	873 km
Swath Width:	
ground range	100 km
slant range	40 km
Wavelength:	0.0566 m
altitude:	782 km

Table 2: Nominal ERS SAR parameters [3]

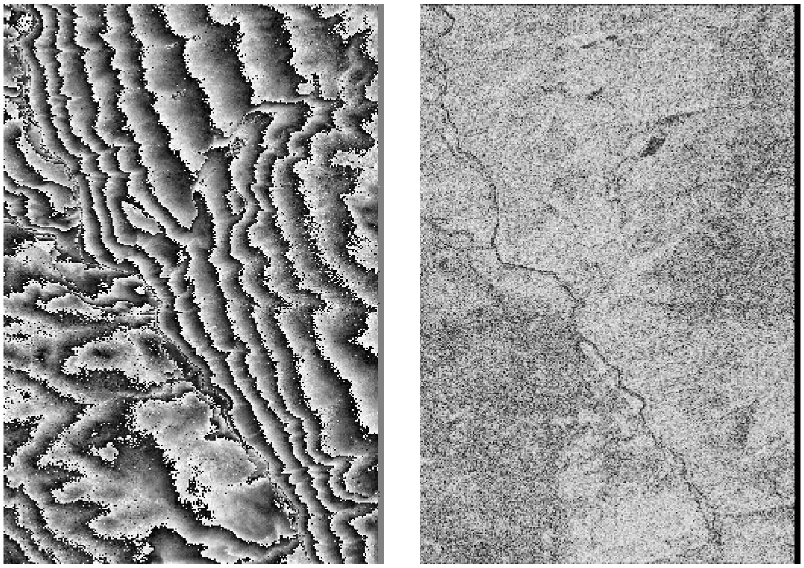
Incidence Angle:	
near swath	41.6^o
far swath	44.2^o
Slant Range:	
near range	1020 km
far range	1060 km
Swath Width:	
ground range	50 km
slant range	40 km
Wavelength:	0.056 m
altitude:	807 km

Table 3:Nominal RADARSAT Fine Beam 3 SAR parameters.

The baseline magnitude and baseline orientation were estimated using a linear model in azimuth for both the baseline orientation and baseline magnitude. The TRIM data set, the DTED-1 data set, and the GTOPO30 data were each used in turn as the reference DEM for the processing.

Each DEM was processed as follows:

1. The DEM was approximately resampled to slant range and azimuth (along-track) radar coordinates using the assumption of a broadside imaging geometry.
2. The offsets between the slant range DEM and the SAR imagery were manually estimated by coarsely matching the river and the bottom of the river valley in the resampled DEM.



a) Interferogram Phase b) Coherence Magnitude

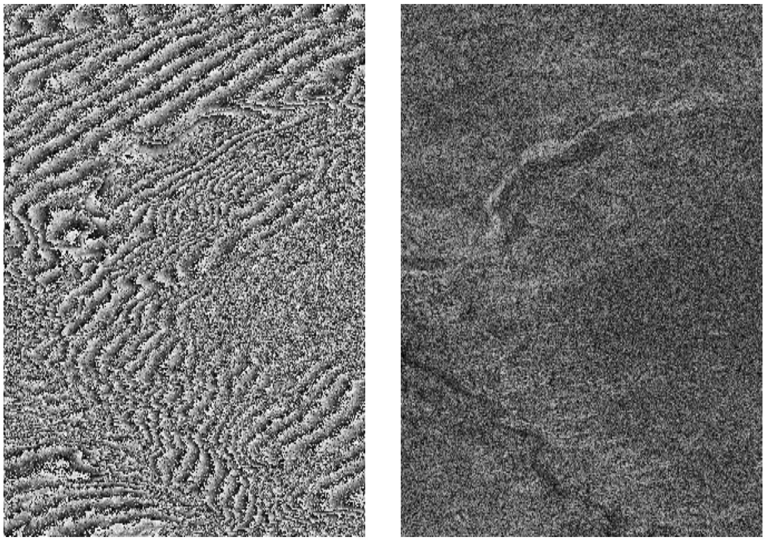
Figure 2: Summary of ERS Tandem Mission data.

3. The slant range DEM and SAR imagery were then finely registered by maximizing the coherence magnitude as a function of location and estimated baseline magnitude and orientation.
4. The baseline magnitude and orientation were then estimated using the initial registration parameters between the two SAR images as a starting point.
5. After the baseline parameters were estimated, the residual interferogram was computed.
6. The residual interferogram was unwrapped using a combination of weighted least-squares phase unwrapping [8] followed by a post-processing stage of either region growing phase unwrapping [9] (for the ERS Tandem Mission data) or minimizing phase discontinuities [10] (for the RADARSAT-1 data).
7. The baseline parameters were re-estimated with the total unwrapped phase and the InSAR terrain height estimates were calculated.

4. RESULTS

The results of the DEM updating algorithm applied to the ERS tandem mission dataset and the RADARSAT-1 dataset using TRIM, DTED-1 and GTOPO30 input DEMs are in Figure 4 through Figure 9 and shown numerically in Table 4.

The normal baseline for the ERS Tandem Mission dataset was estimated at approximately 45m for all input DEMs. A factor of about 4 improvement in standard deviation of height error is seen for the GTOPO30 dataset and a factor of about 1.25 improve-



a) Interferogram Phase b) Coherence Magnitude

Figure 3: Summary of RADARSAT-1 data.

ment is seen for the DTED-1 dataset. Note the similarity between the interferometric SAR derived DEMs and the reference TRIM dataset (Figure 4 a). 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.

The normal baseline of the RADARSAT-1 data was estimated at approximately 200m for all input DEMs. Approximately a factor of 5 improvement is seen for the GTOPO30 dataset while the DTED had a factor of 2.5 improvement in output height errors. There is a similar increase in detail between the InSAR DEMs and the input DEMs. The InSAR TRIM result represents the “noise floor” of the DEM reconstruction procedure in this case.

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 simultaneously estimating the baseline without phase unwrapping. Despite a small normal baseline, DEM improvement was demonstrated using ERS tandem mission data. Despite relatively low coherence magnitude, DEM improvement was also demonstrated for RADARSAT-1 data. In particular, significant improvement of the publicly available GTOPO30 DEM was demonstrated.

Dataset	DEM	σ in meters
ERS	InSAR TRIM	26.1
	DTED (Input)	34.3
	InSAR DTED	26.9
	GTOPO30 (Input)	115.8
	InSAR GTOPO30	29.3
RADARSAT-1	InSAR TRIM	12.2
	DTED (Input)	35.6
	InSAR DTED	14.3
	GTOPO30 (Input)	98.3
	InSAR GTOPO30	19.0

Table 4: Input DEM and InSAR output DEM error statistics (m) derived from comparison of uninterpolated InSAR heights with the reference TRIM dataset.

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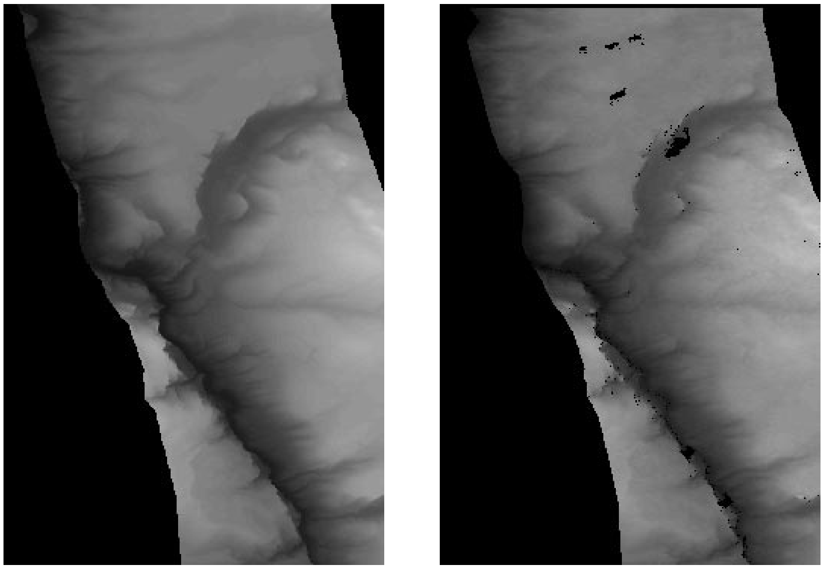
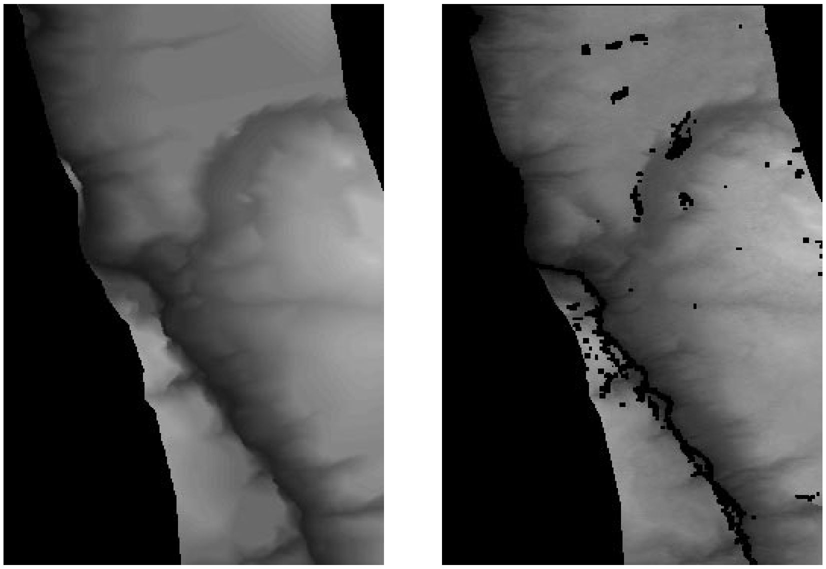


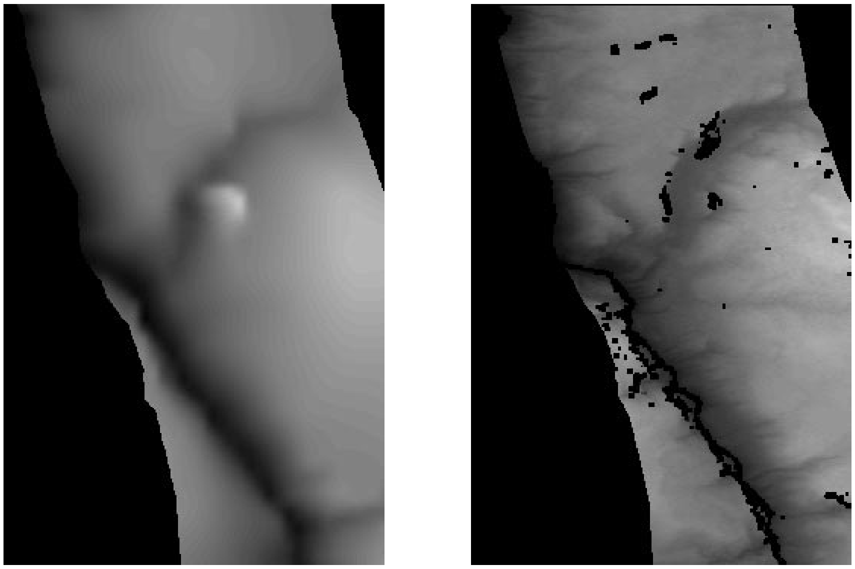
a) TRIM Input DEM b) InSAR TRIM Output DEM

Figure 4: DEM updating results for ERS Tandem mission data with TRIM data as input DEM.



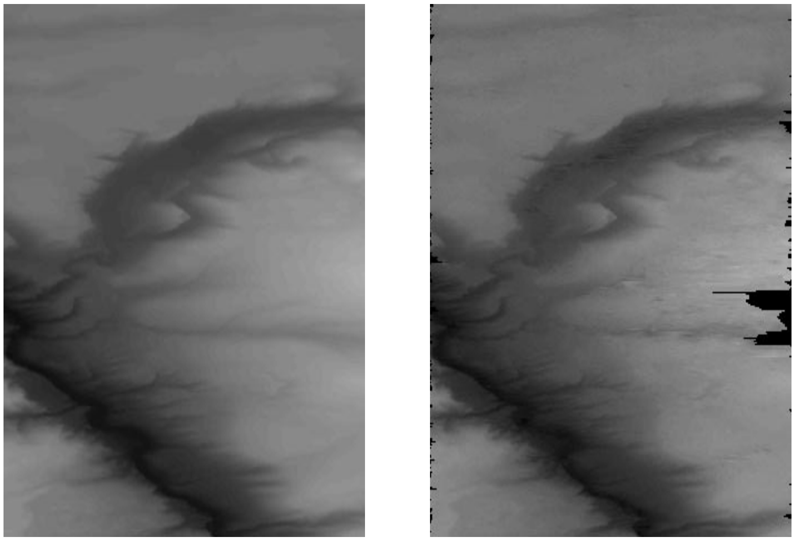
a) DTED Input DEM b) InSAR DTED Output DEM

Figure 5: DEM updating results for ERS Tandem mission data with DTED-1 data as coarse input DEM.



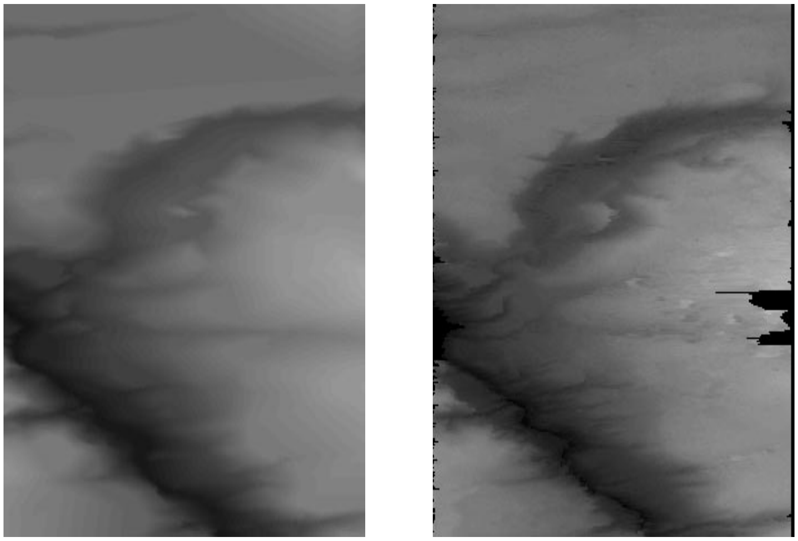
a) GTOPO30 Input DEM b) InSAR GTOPO30 Output DEM

Figure 6: DEM updating results for ERS Tandem mission data with GTOPO30 data as coarse input DEM.



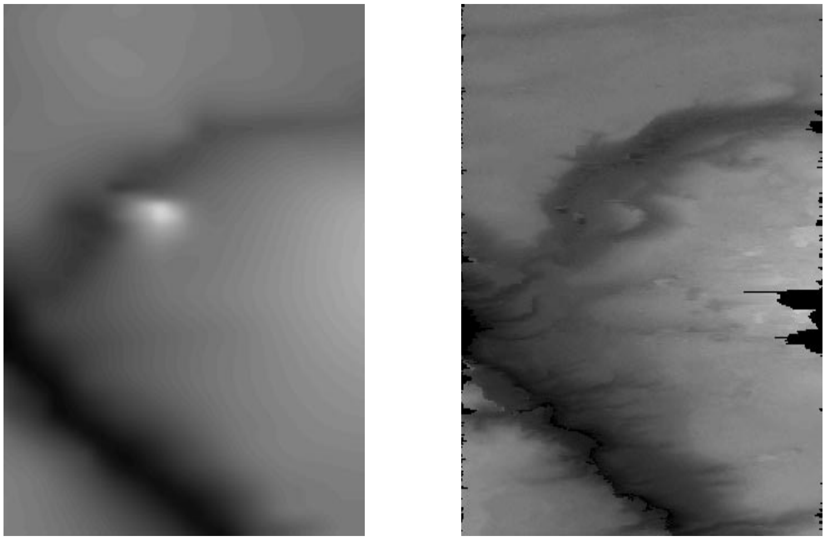
a) TRIM Input DEM b) InSAR TRIM Output DEM

Figure 7: DEM updating results for RADARSAT-1 data with TRIM data as input DEM.



a) DTED Input DEM b) InSAR DTED Output DEM

Figure 8: DEM updating results for RADARSAT-1 data with DTED-1 data as coarse input DEM.



a) GTOPO30 Input DEM b) InSAR GTOPO30 Output DEM

Figure 9: DEM updating results for RADARSAT-1 data with GTOPO30 data as coarse input DEM.