RADARSAT Repeat-Pass SAR Interferometry

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Abstract -- We demonstrate and assess the feasibility of repeat-pass synthetic aperture radar (SAR) interferometry (InSAR) with RADARSAT SAR data. The selection of InSAR image pairs with suitable interferometric baselines requires consideration of the acquisition with respect to RADARSAT's large orbit drift. We discuss some aspects of the interferometric processing of RADARSAT data.

1. INTRODUCTION

To date, SAR data from ERS-1 3-day repeat orbit phases and from the ERS-1/2 tandem mission have been used the most for various InSAR applications due to the availability of suitable interferometric baselines and short repeat orbit cycles.

However, it has been theoretically shown in [1] that especially RADARSAT's fine-resolution beam mode (F-beam) image pairs can tolerate baselines in the range of 6 km due to their high chirp bandwidth (i.e. 30 MHz) and large incidence angles (i.e. 45^o). In addition, beam modes having large incidence angles allow an unambiguous reconstruction of terrain with larger slopes than is possible with ERS.

On the other hand, RADARSAT was not originally designed for repeat-pass InSAR. Two key factors may decrease the probability of obtaining useful InSAR results: first, the RADARSAT orbit is not precisely known (i.e. there is neither laser tracking nor GPS data available for accurate orbit determination) and is not subject to tight orbit maintenance for provision of suitable InSAR baselines; and second, RADARSAT's 24-day repeat cycle is not very favourable for retaining useful scene coherence over vegetated areas.

In this paper, we demonstrate and assess the potential of repeat-pass SAR interferometry with RADARSAT SAR data. For this study, we processed and evaluated suitable InSAR image pairs from RADARSAT's fine-resolution (F-beam) and standard beam mode (S-beam), acquired over Bathurst Island (N 76^o W 98^o), Northwest Territories. In addition, from RADARSAT's 30 day long Antarctic Mapping Mission, carried out between September and early October 1997, interferometric data sets have been analysed to measure ice motion [2].

All data sets were obtained as RAW (signal) data product and were processed to single look complex (SLC) form on dtSAR, a workstation-based SAR processor in use at CCRS.

Table 1 RADARSAT data sets acquired over Bathurst Island

Acquisition Dates	Beam mode	f_{DCabs1} [Hz]	f_{DCabs2} [Hz]	$\lvert\Delta f_{DCabs}\rvert$ [Hz]	B_N [m]	$\Delta h_{2\pi}$ [m]
2-26 Mar. '96	F4	-3193	-3594	401	1415	15
4-28 Mar. '96	F5	2300	2409	109	1060	21
6-30 Mar. '96	F1	-2798	-3169	371	1126	17
2-26 Dec. '96	S7	-3303	-3225	78	72	315
2-26 Dec. '96	F1	-3166	-3173	7	109	176
3-27 Dec. '96	F4	3148	3043	105	119	182
10 Dec.96-3 Jan.97	F4	-2977	-2695	282	133	163

2. SELECTION OF RADARSAT InSAR PAIRS AND ORBIT CONSIDERATIONS

RADARSAT 's across-track orbit repeatability is specified to lie in the range ±5 km [3]. In theory, this would mean that only F-beam mode data sets with incidence angles $\theta \geq 40^o$ can be used for InSAR applications. However, considering RADARSAT's large orbit drift rate combined with its orbit boosts, occuring to date, roughly every 3 months, much shorter baselines can be obtained for acquisitions at time periods centred on the maximum orbit drift (when the drift rate is minimum), roughly half-way between orbit boosts. The anticipated equatorial satellite ground track drift projection, see Fig. 1, as provided by the Canadian Space

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Agency (CSA), may be used as a rough guideline for RADARSAT InSAR image pair selection in terms of determining the time frame for acquisitions of data sets with baselines both less than the critical baseline and suited for the required InSAR application (i.e. DEM generation or differential InSAR measurements). Note that the expected satellite ground track drift at the equator is not comparable with a interferometric baseline estimation over the area of interest due to non-parallel orbit tracks.

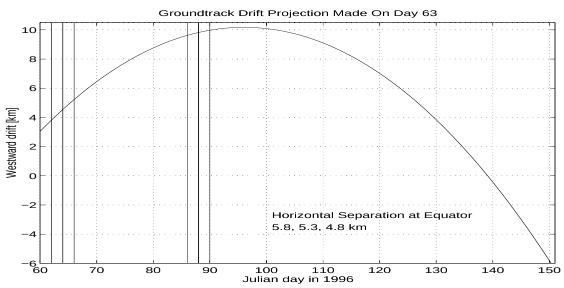

Fig. 1 Ground track drift for March 1996. The vertical lines mark the acquisition dates of our data sets.

3. InSAR PROCESSING

Accurate interferometric processing of RADARSAT image pairs requires consideration of the data spectra in azimuth and range which may differ from the known ERS SAR data.

Azimuth

Unlike ERS, RADARSAT is not operated in a yaw-steering mode which compensates Earth rotation with changes in the satellite's yaw angle. Thus, RADARSAT can have large squint angles. The resulting Doppler centroid frequencies f_{DCabs}, therefore, may not lie within the pulse repetition frequency (*PRF*) baseband, as we measured in our data sets, see Table 1. A key requirement for achieving signal correlation in azimuth is that the difference between f_{DCabs} of the two images, $|\Delta f_{DCabs}|$, should not exceed the processed azimuth bandwidth *PBW* (in our processing: $PBW=900\ Hz$). In other words, only image pairs with $|\Delta f_{DCabs}| < PBW$ are suitable for InSAR. Note that phase preserving image co-registration and oversampling in azimuth, both of which must account for the azimuth passband, may require evaluation of $f_{DC\ abs\ 2}$ within the PRF baseband. Analyses of our data sets have further shown that, for image pairs with $\Delta f_{Dcabs} > 200\ Hz$, performing an azimuth bandpass filtering [4] first to compensate for spectral misalignment decorrelation, improves the results of image co-registration.

Range

We observed in our scene pairs a frequency band shift f_r in the range data spectra, see Fig. 2. This frequency shift arises from RADARSAT's large squint angles due to the dependence of the azimuth chirp frequency modulation rate (FM rate) on range and time (i.e. Stolt interpolation) [5] and may be calculated as follows:

$$f_r = \frac{f_{radar}}{2}\left(\frac{\lambda f_{D_{abs}}}{2 v_s}\right)^2 \qquad (1)$$

where λ is the wavelength, f_{radar} is the carrier frequency, and v_s is the sensor velocity with v_s = 7.55 km/s.

For InSAR, we are more interested in the relative band shift Δf_r between the two range spectra. According to (1) and using the maximum allowable $|\Delta f_{DCabs}|=900Hz$, the resulting relative band shift is $\Delta f_r=0.2\ MHz$, which is negligible with respect to the spectral alignment. However, accurate estimation of the dimension of the range spectral bandpass filter [6] may require consideration of the frequency band shift in range.

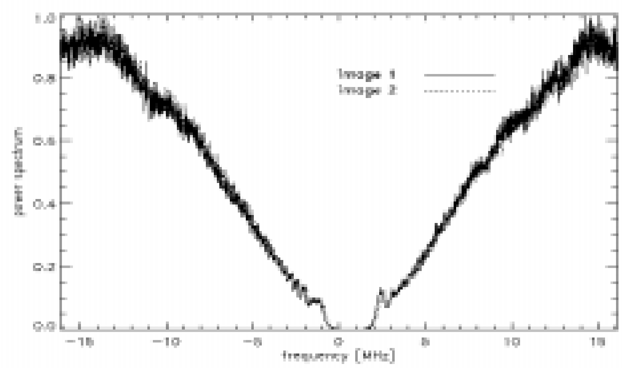

Fig. 2 Range data spectra of the 2/26 March pair. The band shifts are 0.37 MHz and 0.47 MHz, respectively.

Baseline estimation and correction of the systematic imaging geometry phase contribution

The time-variant interferometric baseline has been calculated based on an algorithm for estimation of the zero-Doppler satellite positions corresponding to the same point on the ground by using the reference state vector and the polynomial coefficients given in the image annotation data [7]. Then, based on the reconstructed imaging geometry, the interferogram has been corrected for the expected phase contribution of a topographically flat, ellipsoidal Earth (i.e. the "flat earth" phase). The results have shown, as illustrated in Fig. 3 for the image pair acquired on 4/28 March 1996, that RADARSAT orbit information is sufficiently accurate to be used for a geometric correction of the systematic imaging geometry phase term. The use of definitive orbit data, which includes state vectors at an interval of 8 min (i.e. 15 state vectors cover one orbit cycle) has, so far, not improved the baseline estimation or "flat earth " phase correction.

4. CONCLUSIONS

In this paper, we have discussed the feasibility of repeat-pass SAR interferometry with RADARSAT. The selection of data sets with suitable baselines requires consideration of the satellite drift. Estimation of corresponding acquisition times may be based on evaluation of the projected equatorial satellite groundtrack drift. The InSAR processing must account for large Doppler centroid frequencies exceeding the PRF baseband. The orbit data have sufficient accuracy which allows a geometric correction of the systematic imaging geometry phase term. However, a detailed evaluation of the orbit accuracy, including the incorporation of tiepoint data sets for refining the reconstruction of the imaging geometry is required to estimate the potential of using RADARSAT InSAR image pairs for DEM generation and/or differential measurements. So far, the preferred application for RADARSAT repeat-pass InSAR is the generation of scene coherence maps, which may be used for geomorphological mapping and for surface change monitoring (e.g. desertification) and are less dependent on accurate orbit data or on ground control points.

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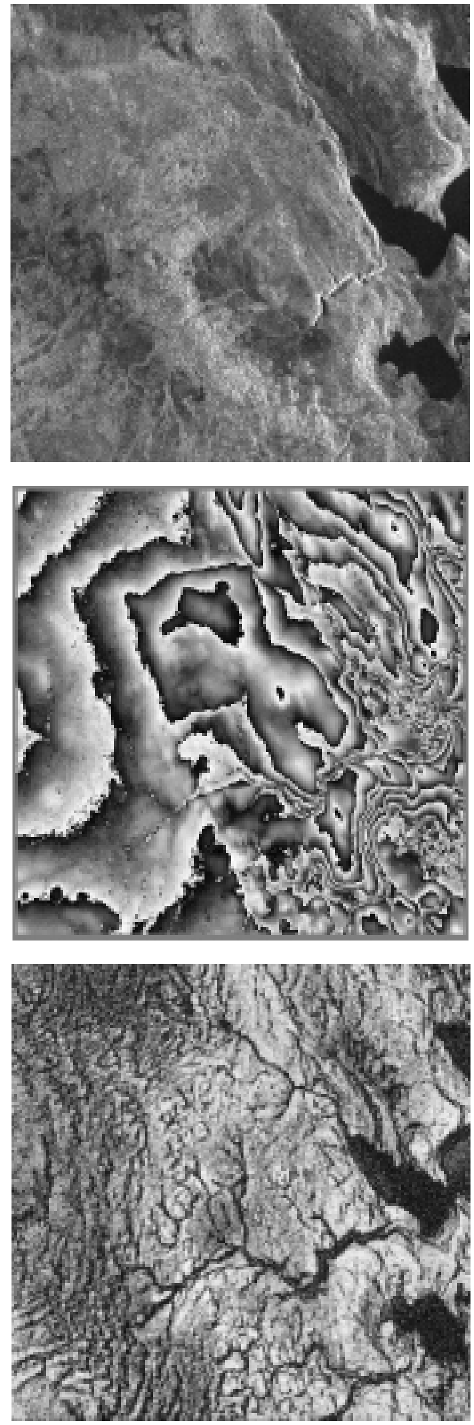

Fig. 3 a) Interferogram-magnitude, b) "Flat earth" corrected phase, and c) Scene coherence. One phase cycle represents a relative change in elevation equal to 21 m.

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