CHARACTERIZING AND MONITORING ROCKSLIDES FROM SAR TECHNIQUES

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ABSTRACT

Worldwide, thousands of landslides occur annually moving millions of tons of material. Based on estimates from the International Federation of Red Cross and Red Crescent Societies there are on average 1,550 landslide-related deaths per year. Developing new remote sensing techniques to identify, characterise and monitor motion of landslides will assist in the current national landslide inventory and hazard mapping in mountainous areas. Recent research has shown that interferometric SAR techniques can be used to monitor landslide motion under limited conditions. In this study we used interferometrically derived images, to monitor post slide motion and a RADARSAT fine mode image to characterise the debris size and distribution of a 30x $10^6 m^3$ rock avalanche, in the Canadian Rockies. These techniques will assist in the understanding of landslide processes, post failure mechanism and mobility.

INTRODUCTION

Traditionally, the field of civil engineering has been involved in the assessment of landslide hazards. Slope stability analysis has been used to assess landslide hazards, and more recently remote sensing techniques are being used in stability assessment (Murphy and Inkpen, 1996; Singhroy et al., 1998; Singhroy and Mattar, 2000; Bulmer et al., 1999). Two distinct approaches can be used to determine the characteristics of landslides from remotely sensed data. The first approach determines the number, distribution, type and character of landslides using high-resolution stereo and fused images. The second approach complements the first one, by measuring dimensions (length, width, thickness and local slope, motion, and debris distribution) along and across the landslides using stereo SAR, InSAR and topographic profiles (e.g. laser altimeter profiles). Where possible these dimensional data are compared to field information and previous studies.

Several case studies have reported the use of differential interferometry to monitor landslide motion (Fruneau et al., 1996; Vietmeier et al., 1999; Rott et al., 1999). Provided coherence is maintained over longer periods, as is possible e.g. in non-vegetated areas, surface displacement of a few cm per year can be observed. Rott (1999), reported on successfully mapping landslide motion above the treeline from interferograms covering time spans of up to three years. Depending of course on the rates of movement expected, in data pairs with short perpendicular baselines and short time intervals between acquisitions the effect of topography on the differential interferogram is minimized, and coherence is more likely to be maintained in non-vegetated areas, therefore allowing for more reliable measurements of surface displacement.

Contrary to motion on the detachment zone, roughness and distribution of landslide debris and their post slide stability has not been studied in detail using remote sensing. This is due in part to the lack of topographic data for blocky landslides and therefore the link between debris roughness and radar backscatter (σ_0) has remained elusive. Roughness is defined as the topographic expression of surfaces at horizontal scales of centimetres to a few hundred meters. Landslide surface structures and roughness provide information on flow emplacement parameters (such as emplacement rate, velocity, and rheology). Laser altimeters are used to calculate surface roughness. Digital image analyses of large-scale photographs were used to examine grain size distribution of rock avalanche debris (Couture et al., 1998). In-situ methods used to examine the statistical roughness of geologic surfaces can improve the interpretation of remotely sensed data at all wavelengths.

STUDY AREA

Our study focused on the Frank Slide, a 30x $10^6 m^3$ rockslide-avalanche of Paleozoic limestone which occurred in April 1903 from the east face of Turtle mountain in the Crowsnest Pass region of southern Alberta, Canada (Figure 1). Seventy fatalities were recorded.

Several investigations have focused on characterizing grain size and distribution of this rock avalanche, in order to understand post failure mechanism and mobility (Couture et al. 1998; Cruden and Hungr, 1986). "Factors contributing to the slide have been identified as the geological structure of the mountain, subsidence from coal mining at the toe of the mountain, blast induced seismicity, above-average precipitation in years prior to the slide, and freeze-thaw cycles" (Alberta Environment, 2000). In 2001, 6000 tons of rock fell from the north slope of the Frank slide which led to our SAR investigation. This paper discusses the results of characterizing landslide deposits from the SAR image and the use InSAR techniques to monitor post slide motion of a large rock avalanche in the Canadian Rockies.

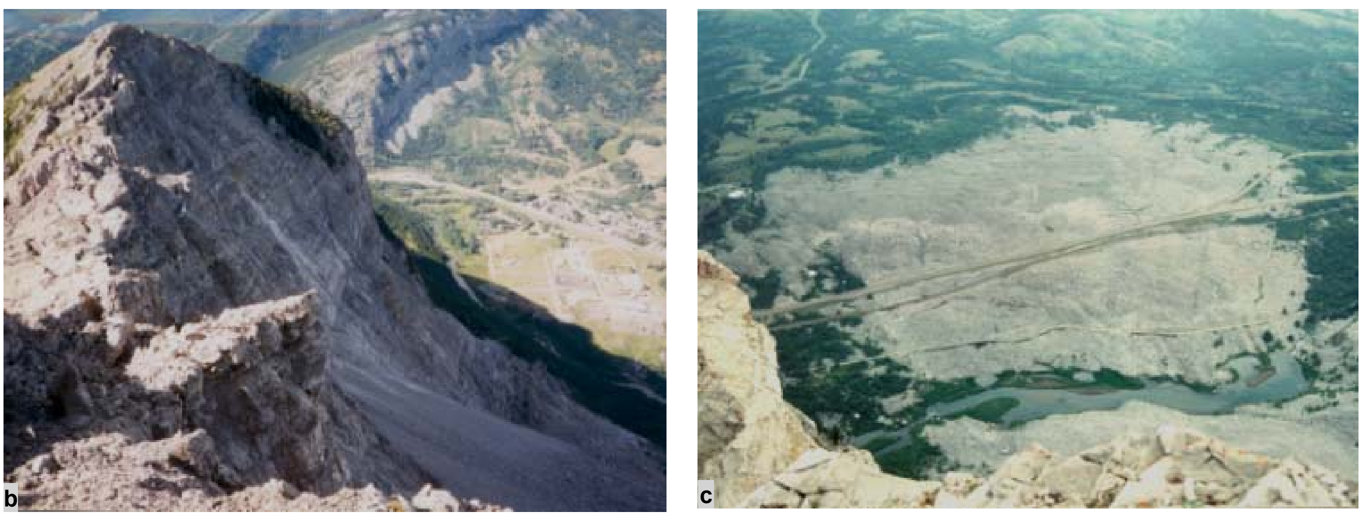

Fig. 1. The Frank Slide, Alberta. View from the Southeast (a), the detachment zone viewed along the ridge towards the north (b), and the accumulation area seen from the ridge looking eastward (c).

INSAR ANALYSIS

Data and Processing

ERS data were to be used for the InSAR analysis. In order to select a set of suitable scenes a thorough baseline analysis of all ERS-1 and ERS-2 ascending scenes acquired over the location (track 406, frame 989) during summer between 1992 and 2001 was performed. It was of interest to find as many data pairs as possible during that time period, yet keep the perpendicular baselines below 100 m, thus reducing contributions of topography on differential phase values. Ascending orbit was chosen so the look direction (right) would correspond with the aspect of the slope.

Seven scenes were finally selected for this initial reconnaissance study, which yielded five data pairs with perpendicular baselines below 100 m (Table 1). The scenes span the time period between 1993 and 1997.

The interferometric DEM used was generated from an ERS tandem pair of 25/26 September 1995 (B⊥ 191 m). Geocoding and elevation values were refined using ground control points taken from 1:50,000 scale topographic maps.

All data pairs with baselines below 100 m were processed to geocoded vertical elevation change maps using the software package EarthView-InSAR. Figure 2 provides an overview of the processing steps involved, as they are implemented in the software.

Table 1. Overview over perpendicular baselines in meters and timespans in days (B⊥ / days) between acquired scenes. Data pairs with perpendicular baselines below 100 m are highlighted.

Sensor	ERS-1	ERS-1	ERS-1	ERS-1	ERS-2	ERS-2	ERS-2
Years	1993	1995				1997	
Dates	24Jul93	17Jul95	21Aug95	25Sep95	26Sep95	22Jul97	26Aug97
24Jul93		573 / 723	700 / 758	**80 / 793**	138 / 794	611 / 1459	707 / 1494
17Jul95			127 / 35	245 / 70	436 / 71	**38 / 736**	134/771
21Aug95				369 / 35	560 / 36	**89 / 701**	**4.5 / 736**
25Sep95					DEM 191 / 1	282 / 666	372 / 701
26Sep95						473 / 665	563 / 700
22Jul97							**96/35**

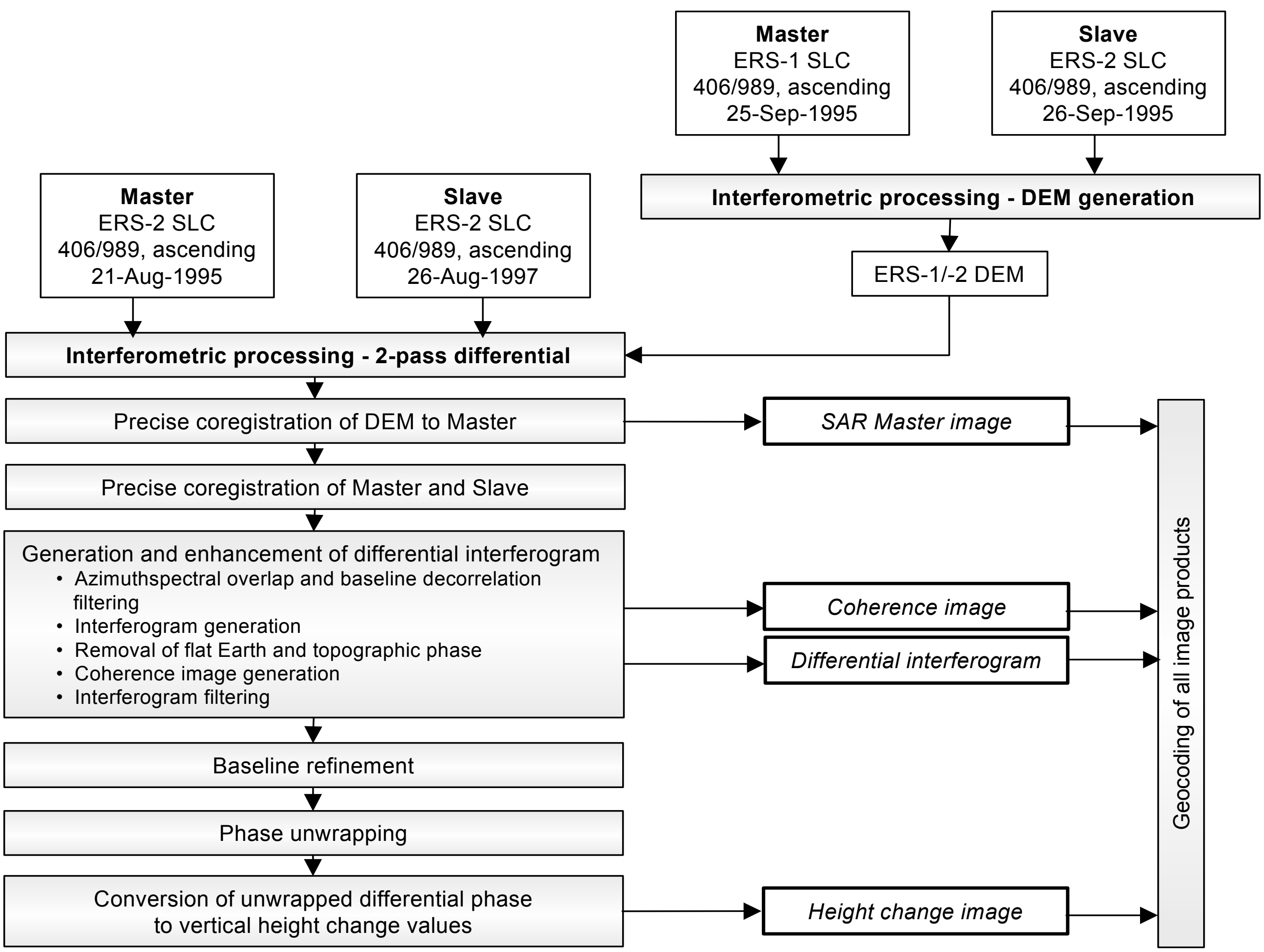

Fig. 2. Generalized processing steps involved in the generation of change maps from ERS interferometric data pairs. The Aug-95 / Aug-97 image pair is used as an example.

Optimization

For orbit determination during the processing, ERS precise orbit data provided by the Delft University of Technology were used (http://www.deos.tudelft.nl/ers/precorbs/). Within the differential interferometry processing sequence it was ensured that Master-to-Slave coregistration was precise to an RMS of better than 0.1 pixels in range and azimuth at the tiepoints. Employing a simulated SAR image generated from the external DEM, the DEM-to-Master coregistration was refined to below 3 pixels RMS, ensuring the best fit possible.

Azimuth spectral overlap filtering was performed during the processing given that e.g. the azimuth spectral overlap for the data pair Aug-95 / Aug-97 was at 85%. Since numerous steep slopes are present in the area surrounding the Frank Slide, a phase slope image was generated and integrated into the coherence estimation and the interferogram enhancement steps. Thus, coherence estimates on steep slopes are improved and large biases reduced. Phase information in the differential interferogram is better preserved with the phase slope image subtracted from the interferogram prior to filtering (Atlantis Scientific, 2002).

For all data pairs processed, coherence values were generally high on the slide itself, even for temporal baselines of more than 700 days. Values e.g. for the Aug-95 / Aug-97 pair (736 days) are in the range of 0.73 to 0.91. This can be attributed primarily to the lack of vegetation on the slide and indicates a general stability of the individual scatterers on the slope. Figure 3 shows the coherence image for the Aug-95 / Aug-97 data pair.

Residual topographic phase was removed from the differential interferogam through baseline refinement by iteratively adjusting the slave state vector. Especially for InSAR pairs with longer baselines this led to an improved differential interferogram. The phase was unwrapped using an iterative disk masking algorithm. The unwrapped phase was then translated to vertical height change values and subsequently geocoded. The resulting differential interferogram and vertical displacement map are shown in figure 4.

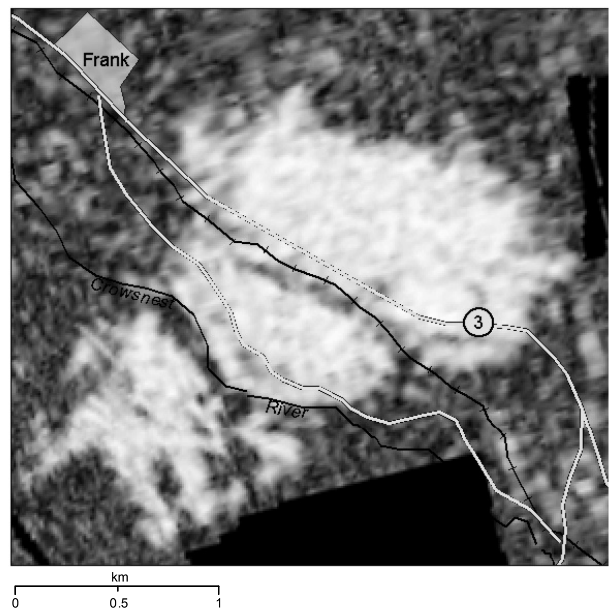

Fig. 3. Coherence image, window size 81 pixels, for data pair Aug-95 / Aug-97.

DEBRIS DISTRIBUTION INVESTIGATION

For the slide debris distribution study, a RADARSAT Fine Mode, Beam 4, (incidence angle 43°-46°) ascending, acquired on 1-September-2001, was used. It was verified, that there had been no precipitation on the acquisition date as well as several days before in order to eliminate ground moisture induced effects on the radar backscatter. The data were processed to a 16-bit path oriented, ground-range single look product with 6.25 m pixel spacing (SGF). The image data were not filtered or rectified in order to avoid any disturbance of pixel neighborhood relationships introduced through the re-sampling procedures involved.

Several methods are available for evaluating SAR texture parameters and for subsequent classification; well-established are texture measures retrieved from co-occurrence matrices and the analysis of local histograms (Keil et al., 1997; Lohmann, 1994). In this study the latter method was used.

From field and aerial photographs of the accumulation zone, three areas of predominantly coarse, medium textured, and fine debris were selected for local histogram analysis. After linearly scaling the RADARSAT data to 8 bit, the pixel values for three windows of approximately 1400 pixels each, falling within the selected areas, were extracted from the SAR image. Histograms were generated for each sample, depicting gray value frequencies. Various statistical parameters can be used to describe the local histograms' distribution (Figure 4).

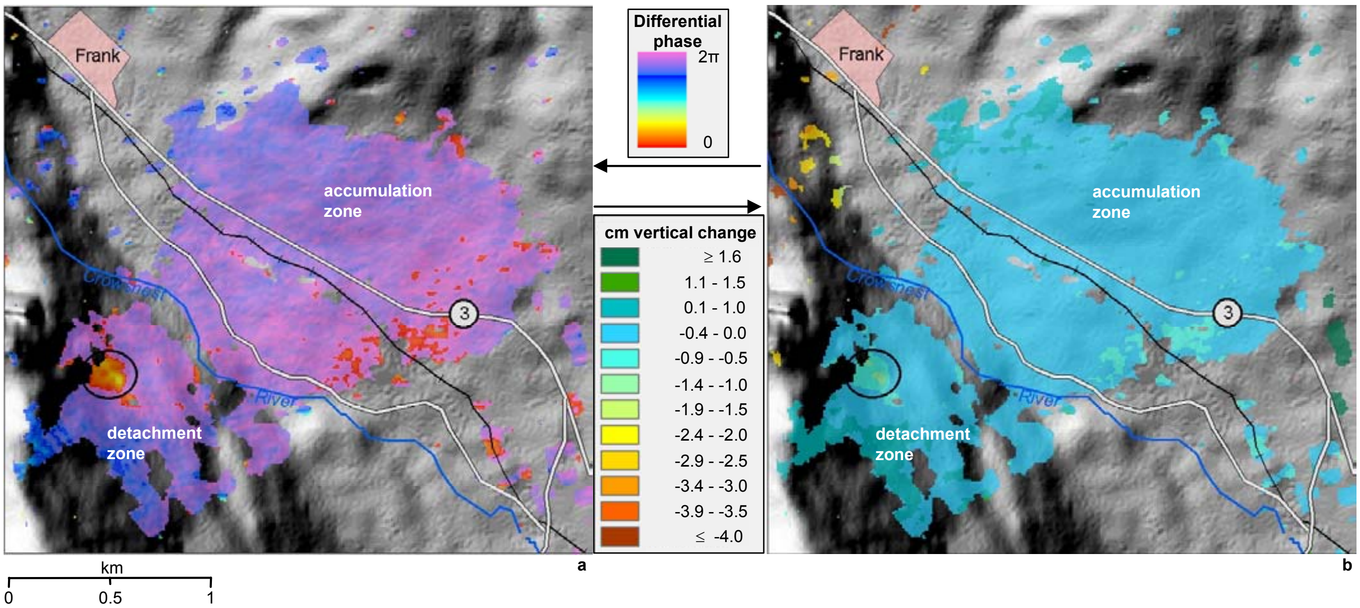

Fig. 4. Differential interferogram (a) and vertical elevation change (b) for ERS-1 / ERS-2 data pair Aug-95 / Aug-97. Values are only displayed where scene coherence exceeds 0.5. A remaining fringe (circled) with a corresponding maximum elevation change of -1.3 cm can be seen at the northern end of the detachment zone.

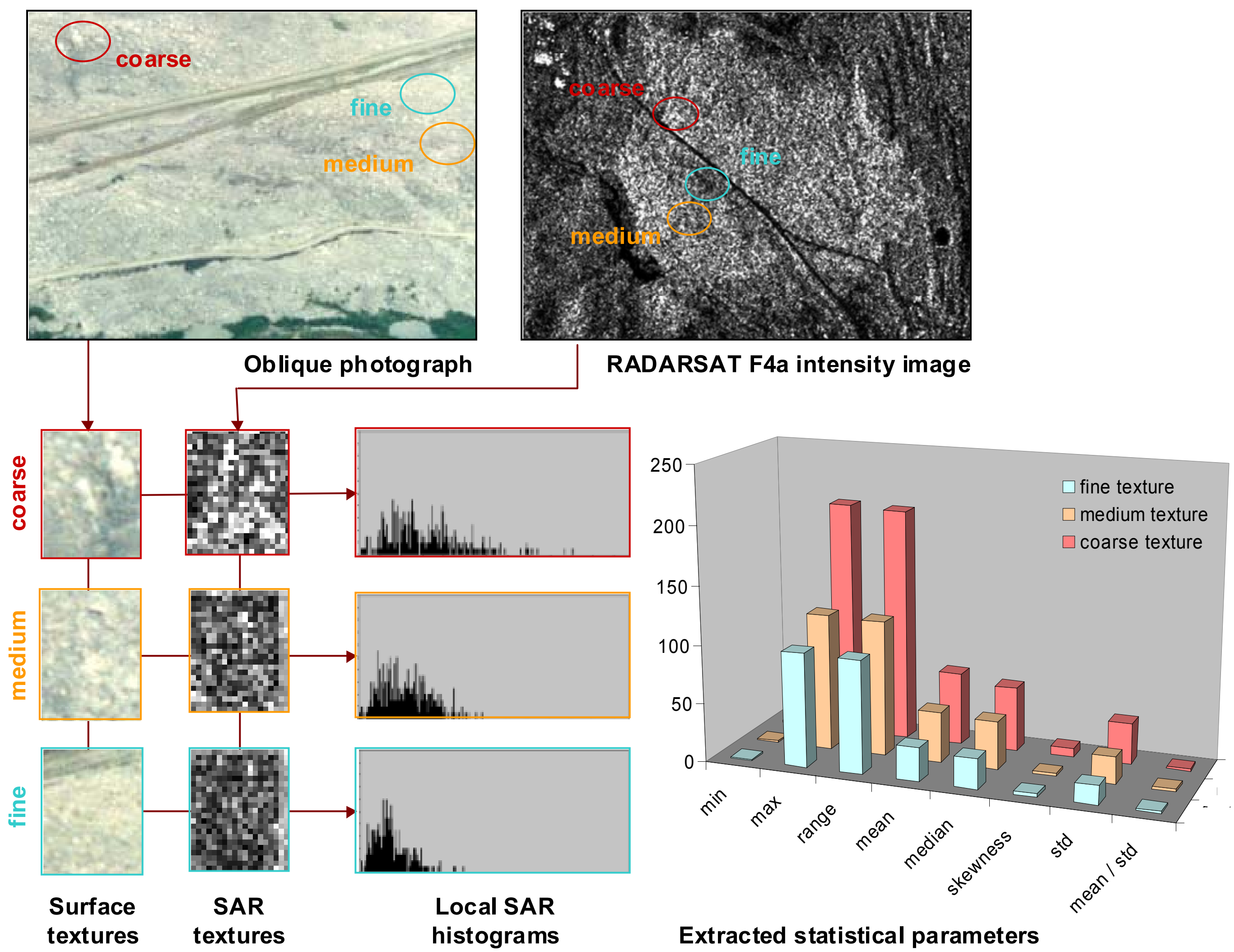

Fig. 5. Location of selected sample sites on oblique photograph and RADARSAT F4a intensity image, extracted samples, local histograms, and statistical parameters describing their distribution.

RESULTS

InSAR

The InSAR investigation revealed the presence of a near circular fringe in the refined differential interferogram (Figure 4). Corresponding maximum displacement values are at -1.3 cm, and indicate possible gradual motion of the rock face, prior to the 2001 rock fall. Due to the small perpendicular baseline of only 4.5 m for this InSAR pair (Aug-95 / Aug-97), topographic contribution to the differential phase was minimal and has been removed during the processing. Some factors potentially also influencing the differential phase, such as atmospheric and system noise (Sandwell and Sichoix, 2000), have not been accounted for yet. However, the fact that the area of the detected surface displacement (circled on Figure 4a and b) corresponds to the location of the 2001 rock fall, suggests that the instability is real, and that InSAR techniques, if carefully applied, can locate areas of instability prior to an actual landslide.

Debris Distribution Investigation

The results from our debris distribution investigation at the Frank slide have shown that a SAR textural map of a large rock avalanche can be a useful first step in the understanding of post failure mechanism and mobility.

- There is a close relationship between the SAR textural measurements from local histograms and the debris size distribution and ridge morphology.
- There is a random distribution of coarse debris throughout the deposit, except in areas where boulder ridges were identified. This would confirm that the dispersive forces during shearing and motion induced vibration would create such roughness distribution (Cruden and Hungr, 1986).
- Lateral ridges and distal rims characterized by coarse debris at the surface and a clean sharply defined edge of boulders were identified in the field (Cruden and Hungr, 1986) and on the SAR debris distribution map.
- Close up field photos show vertical size sorting and a strong inverse grading described by Cruden and Hungr (1986). They show the general abundance of coarse debris at the surface followed by the medium and fine. This confirms the motion induced vibration mechanism.
- The fine materials in the splash zone at the side margins were not identified mainly because these areas are now covered by vegetation.

CONCLUSION

Our case study has shown that SAR textural and interferometric techniques can assist in the understanding of landslide processes, post failure mechanism and mobility. We demonstrate that InSAR images (Aug-95 / Aug-97), show evidence of motion, prior to the 2001 rock fall on the north slope. The InSAR pairs with small baselines provide more accurate results. This suggests that InSAR techniques can be used to supplement field monitoring techniques on active landslides. The close relationship between the SAR textural measurements and the debris size distribution and ridge morphology, suggest that high resolution SAR images are useful tools to characterize landslide debris.

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