

SAR IMAGE TECHNIQUES FOR MAPPING AREAS OF LANDSLIDES.

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ABSTRACT

This paper shows that InSAR perspective view and airborne InSAR images are very useful for geomorphic characterization of landslide features in high relief terrains. Landslides cause approximately 1000 deaths a year, worldwide, with property damage of about US \$4 billion. Developing new remote sensing techniques to identify and characterise landslides and debris flows will assist in the current national landslide inventory and hazard mapping in mountainous areas. Geomorphic characterization using large scale air photos are essential for large scale landslide hazard zonation maps. This is effectively done from the interpretation of large scale stereo air photographs and field mapping. In this study, we report on the use high-resolution airborne InSAR and perspective visualization techniques to map detailed landslide features in high relief terrains. We also show that high resolution fine mode (8m) RADARSAT image (40-50 degrees), although not as useful as the airborne InSAR images, can be used to identify some landslide features, thereby assisting in hazard mapping. The SAR image techniques provided information on detail slope profiles of the large rockslides occurring on steep slopes and along faults. From the images, faults, rock slumps, block slides, slide scars and debris slopes and ridges were identified. This study points the way of the potential of using high resolution optical and SAR stereo images to identify landslide features in areas where air photos are not readily available.

1 INTRODUCTION

Landslides are abrupt shortlived geomorphic events that constitute the rapid downward motion of soil and rock materials occurring in sloping terrains. The triggering mechanism may include excessive precipitation, earthquakes, or deforestation which upset the natural stability of the slope, resulting in falling, sliding or flowing of landmass under gravity. They cause approximately 1000 deaths a year, worldwide, with property damage of about US \$4 billion, and pose serious threats to settlements, and structures that support transportation, natural resources management and tourism. In many cases, expanded development and unwise man's activity, such as modified slopes and deforestation, can sometimes increased the incidence of landslide disasters. Recent development in large metropolitan areas intrudes upon unstable terrain. This has thrown many urban communities into disarray, providing grim examples of the extreme disruption caused by ground failures.

The movement occurs when the shear stress exceeds the shear strength of the material. Therefore, the analysis of the increase of the shear stress and/or decrease of the shear strength of the material provides the understanding of landslides. Shear stress are usually caused by the removal of lateral and underlying support, increases in loading and lateral pressures, vibrations, and regional tilting and geomorphic conditions Decreases in material strength are caused by changes to the internal properties of the material such intergranular forces and fracturing.

Aerial photography has been used extensively to characterize landslides and to produce landslide inventory maps, particularly because of their stereo viewing capability and high spatial resolution. Airphotos were used to identify steep slopes underlain by weak soils, slopes undercut by rivers and waves, tension cracks, steep hummocky topography, failed surface scarps, anomalous bulges and lumps, terraced slopes, discontinuous bedding planes, drainage-vegetation patterns and elongated ponds on hillslopes (Mollard & Janes, 1983; Mollard, 1977; Alfoldi, 1973; Cruden and Lu, 1992; Savigny, 1993; Nilsen and Brabb, 1977).

The spatial resolution of satellite data TM and SPOT are generally too coarse for landslide characterization unless the image data is resampled and merged with other higher resolution airborne images. Currently, high resolution IKONOS images are being evaluated. This synergistic use of satellite images for landslide hazard assessment is demonstrated by Singhroy et al 1988, Singhroy 1995, Leroi et al.,1992; McKean et.al 1991; Rengers et al.,1992; Koopmans and Forero, 1993. In this study, we report on the use high-resolution airborne and spaceborne synthetic aperture (SAR) images, to map landslide and debris flow areas in high relief areas. Examples are selected in the Canadian Cordillera, and in the upper Yunnan Province, China. Developing new remote sensing techniques to identify and characterise landslides and debris flows will assist in the current national landslide inventory and hazard mapping in mountainous areas.

2 THE FRASER VALLEY

The Fraser valley in the Canadian Cordillera, is one of the most strategically important transportation corridors in Canada. Almost all the transportation lifelines that link the resource rich prairie provinces with metropolitan Vancouver utilize this corridor. Recently, these landslides have caused serious damage to the major transportation links. In the spring of 1997, landslides have caused the derailment of the CN railway resulting in two deaths and 20 million dollars of damage. In 1965, a large rock avalanche (48×10^6) known as the Hope slide, occurred 160 km east of Vancouver (Figure 1). The slide probably triggered by two small earthquakes (M) 3.2 and 3.1, buried three vehicles and claimed four lives. Thirty-five large landslides ranging in size from at least 1 million to more than 500 million cubic metres have been identified in the Fraser Valley. The causes of landslides in the area include the weakening of failure planes in carbonate rocks, solution erosion, seismic shaking, the presence of clay infilling along discontinuities, steep slopes, excessive precipitation and deforestation. Savigny (1993) identified three types of slides in the Fraser Valley. These include (1) slump and earth flow of surficial materials, mainly glacial drift; (2) rock slide with slide scars and multiple scarps and (3) rock slumps with several arcuate scarps. These slides mainly occur along the contact between plutons and metamorphic pendents and are associated with regional north trending thrust and strike slip faults. This case study uses interferometric SAR, and high-resolution (8m) RADARSAT images to map the geomorphic features of the landslide areas.

2.1 InSAR Techniques

C-HH airborne SAR were acquired by the Canada Centre for Remote Sensing over the landslide areas within in the Fraser valley. The airborne interferometric techniques were used to interpret of landslide features. The InSAR technique uses the single pass airborne interferometry, pioneered by Graham (1994). Details of airborne data acquisition and image processing techniques to produce the interferometric (InSAR) image shown in Figure 2 are described by Singhroy et al (1998). The combination of high resolution, wide swath, and direct registration of the scenes on the pixel level gives InSAR derived DEM an advantage as a tool for the derivation of terrain features. The InSAR image and superimposed DEM is shown in Figure 2. The DEM has a grid spacing of 10 m x 10 m and covers an area 7.9-km x12.2 km. Each colour cycle represents a 50-m change in elevation. The elevation varies from an average of 65 m in the valley to over 1300 m in the surrounding mountains. The black regions are areas where no data was available due to radar shadow, layover, or low return (as in the river itself). Most (but not necessarily all) of the shadow or layover regions could have been filled in had an opposite looking pass been available.

Slope geomorphology has been used traditionally to identify and recognize landslide features, (Gao & Lo, 1995, Mollard 1977, Piteau 1977, Evans and Savigny, 1994) along with geological, hydrological and soil-rock mechanics studies. The airborne InSAR image technique (Figure 2) provides an accurate representation of the slope geomorphology, thereby enabling the identification of landslide features in these difficult high relief terrains. Major geomorphic features such as (1) block slide, (2) debris slide, (3) slide scarp, (4) transverse ridges, and (5) faults associated with the landslides are well expressed and easily interpreted on the InSAR images (Figure 2). A more useful image for the geomorphic characterization of landslides is the perspective view produced from the InSAR image (Figure 3). This three dimensional view is so effective that the smaller geomorphic features, debris cones, minor fault scarp, breakaway scars are also easily identified.

2.2. RADARSAT Techniques

The fine mode RADARSAT (8m) images is the highest spatial resolution spaceborne SAR available to date, and is suitable to identify landslide features for a regional scale mapping. However, in most cases, 5m stereo images are recommended (Singhroy 1999). A number of RADARSAT images with different viewing geometry were evaluated to determine which beam mode is suitable for landslide characterisation in high relief terrains. The fine mode RADARSAT images also have the most suitable incidence geometry (40-60 degrees) because of less distortion (Singhroy and St.Jean, 1999). The RADARSAT SAR image processing follows the procedures described by Singhroy et al.(1994). Preprocessing reduces the radiometric and geometric distortions of the SAR image thereby facilitating subsequent data integration and image interpretation. Following preprocessing the image enhancement procedure include the use of a lee filter which reduce the radar speckle, and a simple contrast stretch which improves the visual interpretability of landslide features on the image. A comparison of the interpretation of landslide features identified on the InSAR and perspective images (Figure 2&3) with that of the fine mode RADARSAT image (Figure4), shows that the perspective view is the most useful.

A fine mode RADARSAT image (41-44 degrees) was also compared with field interpretation of debris flows and other landslide features along the upper reaches of the the Yangtze river. It is believed that the debris flow can affect sedimentation rates at the Three Gorges Reservoir. Recent results have shown that sedimentation is likely to compromise the operation of the dam. For this reason, it is necessary to map all the areas of debris flow, and monitor their flow rates. We compare the enhanced fine mode SAR image with known debris flow maps. Our interpretation of the Jin Shajiang area (Figure 5) shows that the RADARSAT image provide a useful means to map areas of debris flows, rock slides and regional fault systems that are associated with landslides.

3. CONCLUSIONS

This paper shows that

- InSAR perspective view and the InSAR images are the most useful for detailed geomorphic characterization and the identification of landslide features in high relief terrains.
- The fine mode (8m) RADARSAT image with incidence from 40-60 degrees are useful to identify more regional landslide features in mountainous areas.

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REFERENCES

Alfoldi, T.T.,1993. Remote Sensing Analysis of the Chelsea Landslide, Technical Note 73-9, Canada Centre for Remote Sensing, EMR, Ottawa, 20 p.

Cruden, D.M. and Z.Y. L.,1992. The Rockslide and Debris Flow from Mount Cayley, B.C., Can. Geotechnical Journal, Vol. 29, pp. 614-626.

Evans, S. G. and Savigny, K.W. 1994. Landslide in the Vancouver – Fraser Valley- Whistler region; in *Geology and Geological Hazards of the Vancouver region, Southwestern British Columbia*, (ed). J.W.H.Monger; Geological Survey of Canada, Bull. 481, pp.251-286.

Gao, J., Lo, C.P., 1995 Micro-scale modeling of terrain susceptibility to landsliding from a DEM: A GIS approach. *Geocarto International*, Vol. 10, No. 4, 6p.

Graham, L.C., 1994. Synthetic Interferometer for Topographic Mapping, *Proc IEEE*, Vol 62, No. 6, pp 763-768.

Koopmans, B.N. and Forero, R., 1993. Airborne SAR and Landsat MSS as Complementary Information Source for Geological Hazard Mapping, *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 48, No. 6, pp. 28-37.

Leroi, C.E., O. Rouzeau, J.Y. Scanvic, C.C. Weber and Vargas, 1992. Remote Sensing and GIS Technology in Landslide Hazard Mapping in the Colombian Andes, *Episodes*, Vol. 15, No. 1, pp 32-36.

McKean, J., S. Burchel and Gaydos, 1991 Remote Sensing and Landslide Hazard Assessment, *Photogrammetric Engineering and Remote Sensing*, Vol. 57, No. 9, pp. 1185-1193.

Mollard, J.D. and Janes, J.R.1984, Airphoto Interpretation and the Canadian Landscape, *Canadian Government Publishing Centre*, 415 pp.

Mollard, J.D.,1977. Regional Landslide Types in Canada, in Engineering Geology, Vol. III, *Geological Society of America*, pp. 29-56.

Nilsen, T.H. and E.E. Brabb, 1977 Slope-stability Studies in the San Francisco Bay Region, California. In D.R. Coates (ed), *Landslides, Reviews in Engineering Geology*, Vol. III, Geological Society of America, Boulder, Colorado, pp. 235-243.

Piteau, D.R. 1977. Regional slope stability controls and Engineering geology of the Fraser Canyon, British Columbia. In D.R. Coates (ed), *Landslides Reviews in Engineering Geology, Vol.111. Geological Society of America*, pp 85-111.

Rengers, N., R. Soeters and C.J. van Westra., 1992. Remote Sensing and GIS Applied to Mountain Hazard Mapping, *Episodes*, Vol. 15, No. 1, pp. 36-45.

Savigny, W.K., 1993. Engineering Geology of Large Landslides in the Lower Fraser River Valley Transportation Corridor, Southwestern Canadian Cordillera, *GAC Special Volume*, Landslide Hazard in the Canadian Cordillera. 30p.

Singhroy, V. H.,1995 SAR Integrated Techniques for Geohazard Assessment. *Advances in Space Research*. Vol 15 #11 pp.67-78.

Singhroy, .V.,1996 Environmental and Geological site characterization in vegetated areas : Image enhancement guidelines .*Remote Sensing and GIS: Applications and Standards. ASTM Special Technical Publication #1279 . V. Singhroy, D. Nebert. and A. Johnson, Eds., American Society for Testing and Materials*. pp.5-17.

Singhroy, V., K.E. Mattar and A. L. Gray. 1998. Landslide characterization in Canada using interferometric SAR and combined SAR and TM images. *Advances in Space Research*. Vol.21.No.3.pp. 465-476.

Singhroy, V. and R. St. Jean. 1999. Effects of relief on the selection of RADARSAT incidence angle for geologic mapping. *Can. Journal of Remote Sensing*. Vol.25. #3, pp 211-218.

Singhroy, V. 1999 Landslide Hazard team Report: *CEOS Disaster Management Support Project*. Progress Report. NOAA, pp 93-91.



Figure 1 Rockslide (Hope, British-Columbia, Canada)

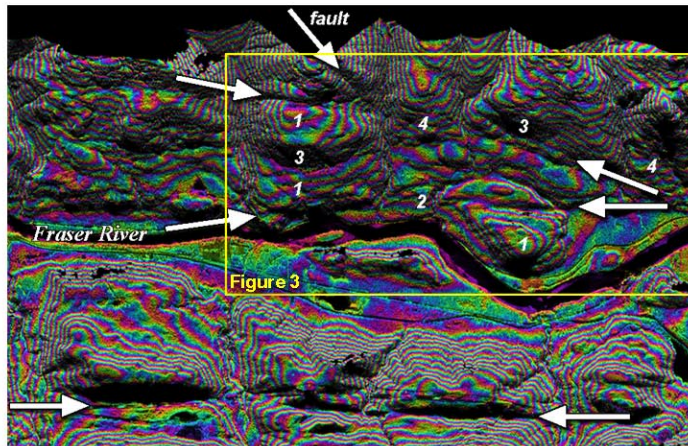


Figure 2 InSAR DEM of Fraser Valley (red to red is 50m change in elevation)

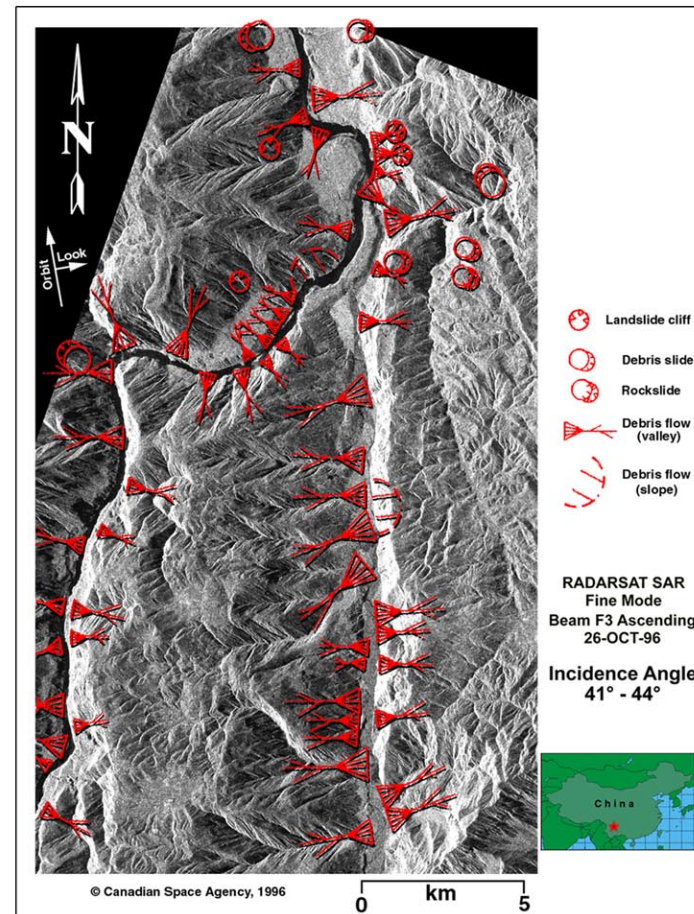


Figure 5 Landslide areas in Jin Shajiang Region, China

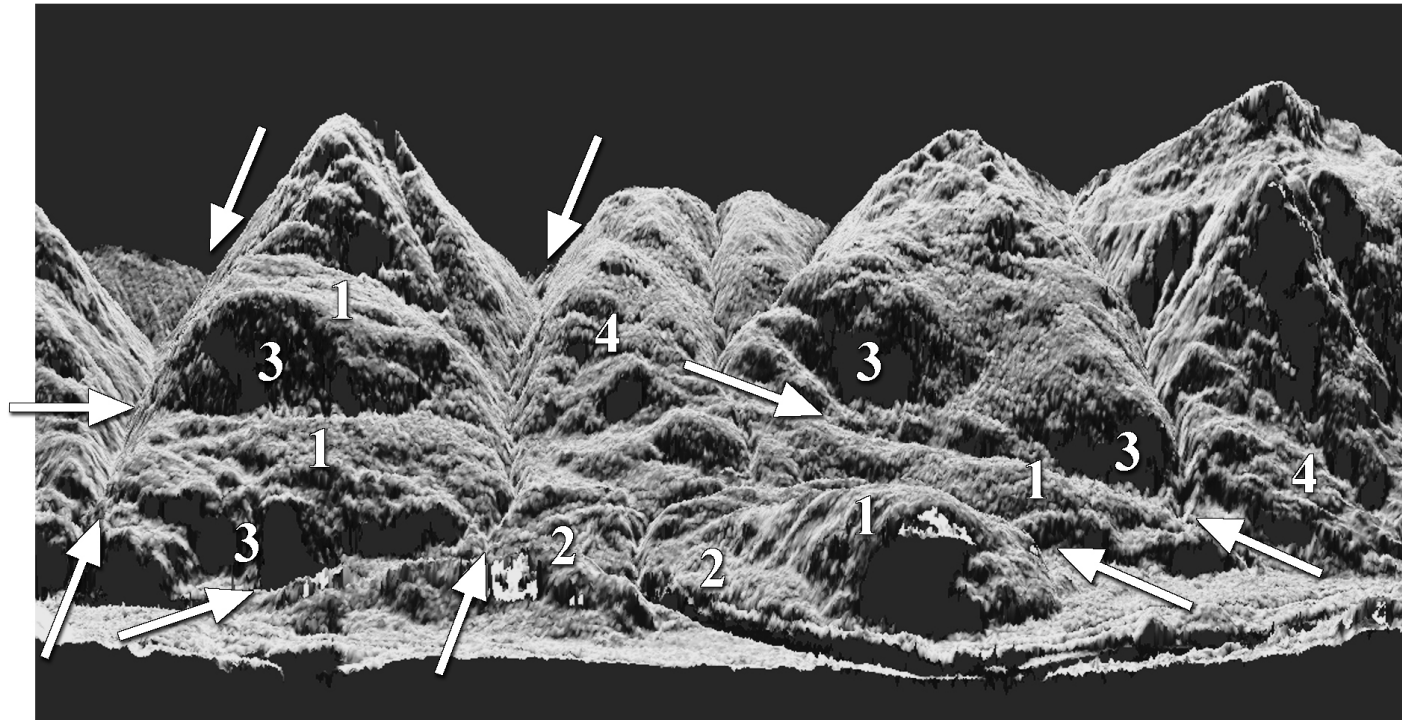
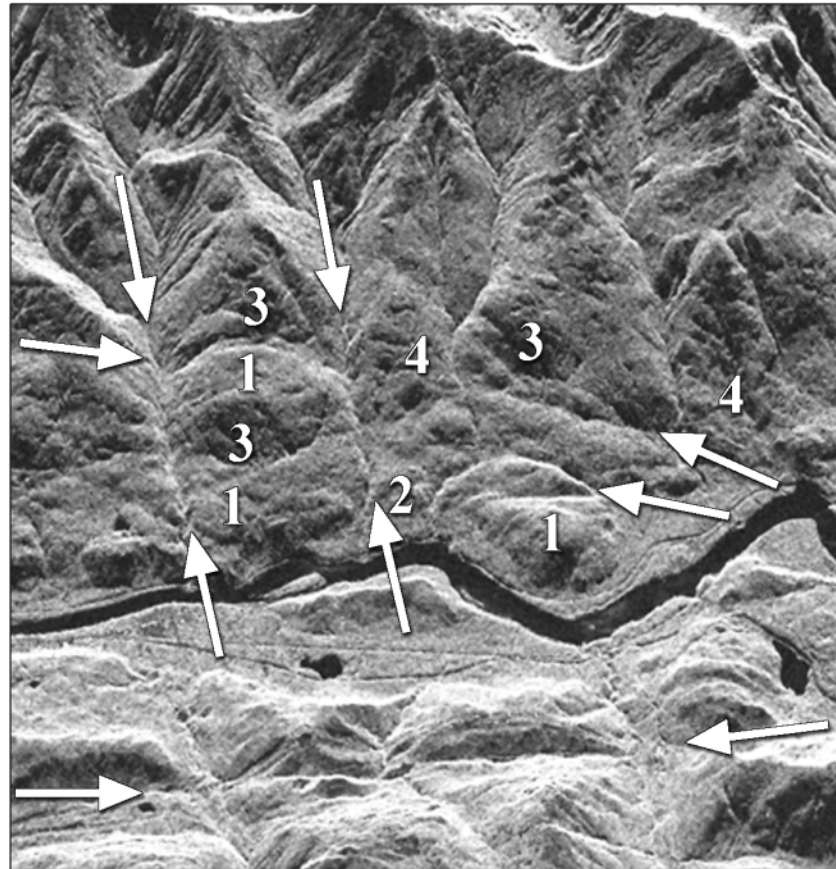


Figure 3 Perspective view of landslide area in Fraser Valley derived from InSAR DEM (East looking)

- (1) Block Slide
- (2) Debris Slide
- (3) Slide Scarp
- (4) Transverse Ridge
- Fault



- (1) Block Slide
- (2) Debris Slide
- (3) Slide Scarp
- (4) Transverse Ridge
- Fault

Figure 4 Landslide area, Fraser Valley
RADARSAT-1 Fine Mode (F2 Ascending)
Incidence Angle : 39° - 42°
Resolution : 8.7m (rg) x 8.4m (az)