# SAR Incidence Angles for Mapping Areas Affected by Geological Hazards, Tropical Case Studies

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**Abstract:**

*Geologic hazards present danger to life and property particularly because population pressures lead to increasing number of people, living in disaster prone areas. SAR techniques can provide a means to monitor and map disaster prone areas. This paper reports on the uses of images from selected SAR incidence angles to map areas of geological hazards. The SAR images were used to map areas affected by volcanoes, land degradation and coastal erosion in different terrains in tropical areas. The interpretation is aimed at providing some guidelines for using the appropriate SAR incidence angles of current and future SAR satellites for mapping areas affected by geological hazards.*

## 1. Introduction

Using the most appropriate SAR incidence for geological hazard mapping is very important. This is based on the fact that the effects of terrain and surface roughness on RADARSAT backscatter vary with different viewing geometry. Geologists identify structures and landforms from changes in topography and textural patterns.The different ways the SAR views the terrain naturally affects the geological interpretation in terms of the delineation of features related geological hazards.

The use of airborne and spaceborne Synthetic Aperture Radar (SAR) images for structural, lithological and geomorphologic mapping in various terrains have been investigated by Lowman, 1994; Singhroy 1996b, Singhroy 1999, Singhroy and Saint-Jean, 1999 and others. Results have shown that the SAR viewing geometry is significant in the delineation of geological structures, surficial materials, lithological units and landforms. In addition, Raney and Ahern (1993) have shown that the effects of terrain slope on SAR backscatter are significant with different viewing geometry.

RADARSAT offers 35 different beam-mode combinations, with incidence angles ranging from 10 to 59 degrees, and spatial resolution varying from 8 to 100 m. ENVISAT (ESA, 2002), ALOS (NASDA, 2003) and RADARSAT 2 (CSA, 2003) also have multi incidence SAR capabilities, and as such choosing the most useful incidence angles for a geological interpretation is fundamental. This investigation provides examples using selected SAR incidence for geohazard mapping in tropical terrains.

Figure1 shows a model that can be used to guide the selection of RADARSAT beam and modes for geological mapping in various terrains (Singhroy and St Jean 1999). For the most part the RADARSAT images were interpreted for surficial geological mapping. Orthogonal viewing, which is determined by the local slope, is the most suitable for geological mapping. Using this model we have selected the appropriate RADARSAT incidence angles and provide geological interpretation of the selected images.

## 2. Mountainous Terrains: Nevado del Ruiz, Colombia

This case study shows that with RADARSAT incidence angles between 45 and 49 degrees, from

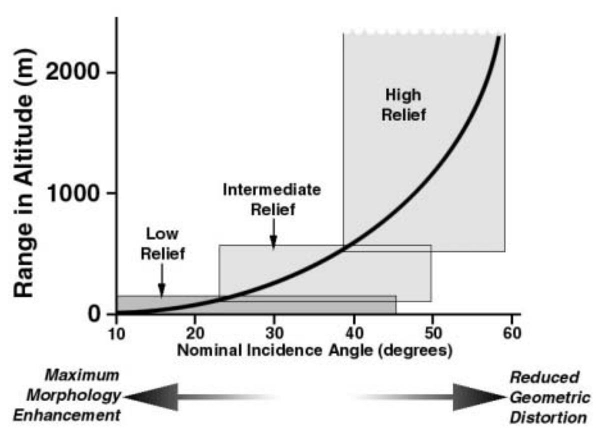


Figure 1: Guidelines for the selection of RADARSAT imagery

vertical, we identify distribution of lava flows, regional fault lines and lithological contacts, which assisted in geological mapping and hazard assessment of volcanic terrains in Colombia.

The rugged Andes dominates the geology of Colombia. They comprise the three subparallel - Western, Central and Eastern- southward-merging and north to north-north east trending cordilleras, separated by intermontane depressions. The Central Cordillera rises to 5800m, the Eastern Cordillera is 4600m, and the Western Cordillera generally lies below 4000m. All mapping programs using SAR images require the careful selection of the most useful incidence angles to facilitate geological and geomorphic interpretation.

On 13 November 1985, a complex sequence of pyroclastic debris flowed from the Nevado del Ruiz Volcano in the Central Cordillera. The volcanic debris combined with snow and ice on its summit descended from 5100m, and flowed 104 km

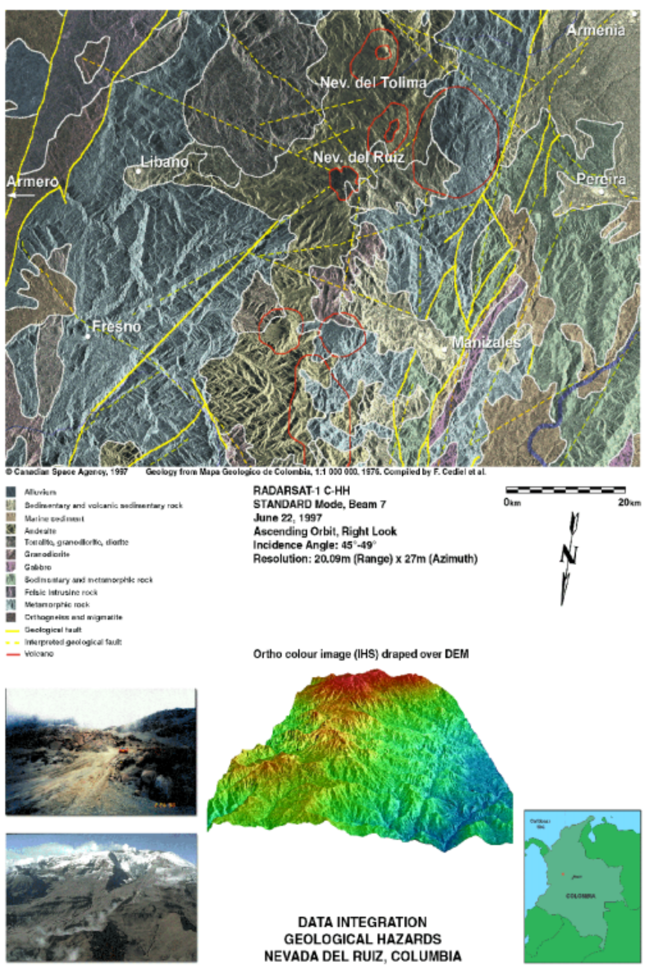


Figure 2: RADARSAT image of Nevado Del Ruiz, Colombia

downslope and burried the town of Almerio killing 23080 people, destroying 5092 homes and covered 210000 hectares of land with muddy debris (Pierson et al, 1990).

Detailed geological mapping has been carried out after the catastrophe using various techniques including Landsat 5 data processing techniques (Villegas 2000). Nevado del Ruiz is located on a complex intersection of four groups of faults, and as such the mapping of regional fault lines is fundamental to volcanic studies in the region

Stereo SAR images and the perspective views shown in Figure 2 were used to map the regional fault lines, as well as the distribution of lava flows in populated areas, such as the towns of Armero, Armenia and Pereira. The perspective view integrates the RADARSAT ortho-image with terrain elevation using techniques described by Lamongtagne et al 2000, and Toutin 99. It provides a visualization of the possible flow paths of new volcanic mudflows. The RADARSAT, standard beam mode 7 image ( $45^0$-$49^0$ ) was also used to assist in revising the interpretation of the lithologic boundaries of various rock units. The lithologic contacts were delineated from differences in SAR terrain roughness. For instance, the lava flows exhibit a characteristically smooth SAR texture as opposed to the rougher terrains of the intrusive rocks. The smooth lahars textures are characterized by mixtures of polygenic materials of varied sizes consisting of angular, subrounded to rounded clasts, with limited internal structures (Mojica et al, 1985, Pierson et al,1990, and Thouret, 1990).

## 3. Land Degradation on Moderate Relief, Colombia

The impact of global climate change is influencing terrestrial ecosystems. For instance, the humid tropics and semi-arid areas are not only very sensitive to global climate change but are areas of actual and potential food security problems related to degradation. In these areas, there is also a need to develop reliable synoptic techniques to rapidly detect and monitor land degradation in areas of deforestation.

Degradation is defined as the wearing down or reduction of the land surface by weathering and erosion. Accurate global estimates of are difficult to measure, and reliable measuring techniques still needed to be improved. On a global basis, the UN estimated that 1965 million ha of land are subjected

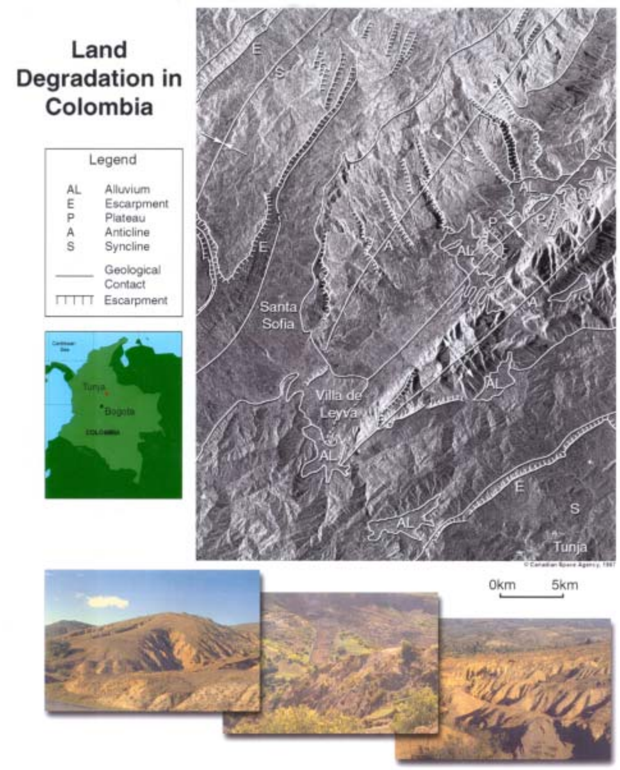


Figure 3: Land Degradation in Colombia

to degradation (UNEP/ISRIC, 1991). Oldemam (1990) estimates erosion by water affected 56%, erosion by wind affected 28%, and physical and chemical weathering affected 16% of the world land surfaces.

In the semi-arid and hilly Andean areas of Colombia deforestation and poor agricultural practices on weak soils have produced “badlands” which are difficult to revegetate. In this region, most of the hill slopes are long and smooth. Long, smooth and regular slopes normally generate significant surface overland high-energy flows, resulting in the erosion of materials from the hill slopes. The removal of the vegetation on these slopes results in decreased rainfall interception and infiltration, increased surface runoff, and accelerated erosion of the hill slopes.

Satellite SAR systems can provide a useful measuring and monitoring tool, but its accuracy has not been fully determined. This case study provides some early results in using high resolution RADARSAT images for mapping areas of land degradation. The selection of the most useful RADARSAT incidence is terrain specific (Figure1). Based on these considerations, we use a high resolution (8m), fine mode (F3) RADARSAT image with incidence angles between 41-44 degrees to identify the geomorphic features related to land degradation. The image was geometrically corrected using the local topographic maps at 1:100000.and enhancement was done using techniques described by Singhroy 1996. The SAR images were used to provide a preliminary inventory of the distribution and location of gullies along scarps. The identification of the distribution, density, and morphology of the gullies on a regional basis is the first step towards developing a systematic hazard assessment in the area. Based on the SAR terrain roughness, we identify the plateau, anticlines and synclines, and some geological contacts. These regional geomorphic units provide the basis for more site-specific field mapping, particularly in determining the local geological and geomorphic controls in gully formation. A fusion of the SAR image with other high-resolution optical images can provide more useful image map of the gully geomorphology, as well as the related land uses. Such fused images can assist in identifying the real causes of the land degradation before embarking on programs for their solution.

## 4. Coastal Erosion in Low Relief, Guyana

In low relief environments, small incidence angle (10 to 25 degrees from vertical) will produce the maximum relief enhancement but larger incidence angle (25 to 59 degrees) will also result in acceptable terrain rendition by increasing the terrain textural contrasts. For this reason we use a wide mode RADARSAT Beam 2 with incidence from 31 degrees to 39 degrees from vertical, to map agricultural land uses and estimate coastal changes along the flat coastal plain of Guyana. A more detail account of coastal zone mapping using SAR data fusion techniques is described by Singhroy 1996a & 1995.

This study shows that parts of the Guyana coastline have changed from a few meters to half of a kilometre over the past twenty years. This has serious implications for sea defence, coastal fisheries and commercial agriculture. All of the productive agricultural lands and 90 per cent of the population of Guyana live in the narrow and fertile coastal plain (425 x 20 km), which is partially below sea level. Elevation varies from 0.5m below to 2.4m above mean sea level. This coastal plain, which occupies only 7.5 per cent of the total land area, is the main agricultural region of the country. Sugar and rice are the principal agricultural exports. These crops require extensive drainage and irrigation to maintain their productivity

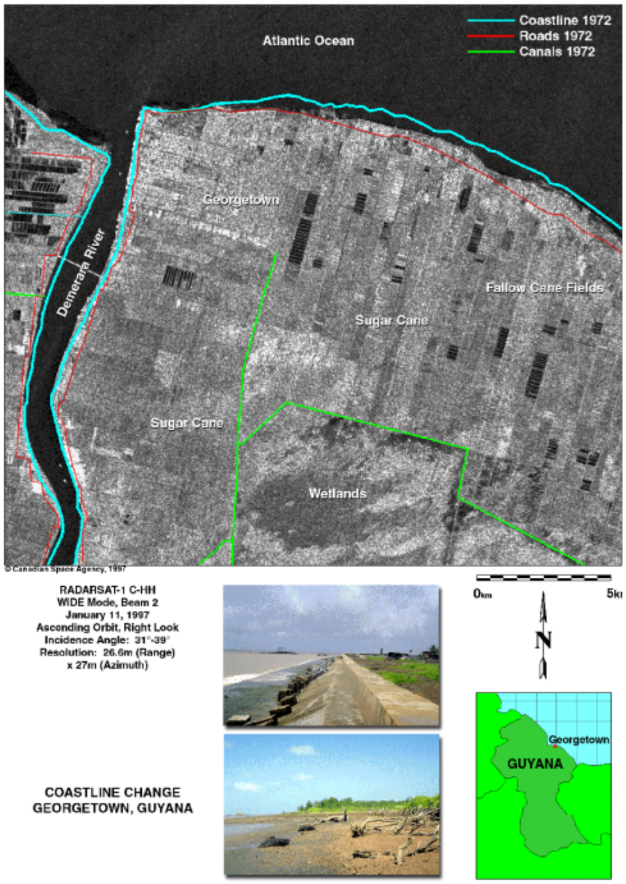


Figure 4: Coastal changes in Guyana from RADARSAT

Recently, the coastal dikes constructed for sea defence, and to improve irrigation of agricultural areas, have been eroded and broken by the increasing frequency and intensity of coastal storms, resulting in severe flooding. Large sections of the sea wall are collapsing and approximately two thirds of the coastline needs permanent structures or replacement. It is estimated that future large scale flooding could destroy almost $1 billion U.S. of economic activity in the coastal areas. The failure of the coastal defences is the result of a combination of factors. These include the depletion of the mangrove forest buffer caused by wood cutting for fuel and choking by sling mud; the increase in storm events; possible the rise of sea level, and the lack of maintenance of the engineering structures (dikes and earth dams). Although air photography and field mapping are now being used to assess changes that occurred along the coast, the SAR images can provide an ongoing method for monitoring coastal erosion. This case study reports on the use of RADARSAT images to monitor coastal changes to determine of the priority areas for the repair and maintenance of the sea defences.

The study area shown in Figure 4 shows the area of erosion in the vicinity of Georgetown (pop 500,000) the capital city. The geology, geomorphology, and agricultural land use of the study area are described in several publications (Bleackley 1957, Daniel 1986, Singhroy1995, Singhroy 1996a). The study area is below sea level, with gradual rise of one to four meters in areas covered by beach deposits. Approximately 30 km from the coastline, the land rises to 10 m, above sea level, in the white sand region. The surficial sediments include mud flats, fluvio-littoral sand ridges and aprons, alluvial silt and clay, and pegasse (organic) accumulations.

Coastal erosion and shoreline recession has been recorded over the past 200 years at rates varying between five and 20 metres a year at specific sites (Cambers et al. 1994). A comparison between the 1997 RADARSAT image and the 1972 topographic maps shows that parts of the coast have been subjected to severe erosion and accretion and some parts remain unchanged. Our estimate shows that the shoreline has retreated to a maximum of a half of a kilometre over the past 25 years. This is about 25 m a year of coastal retreat. These are priority areas where the dikes have been broken by coastal storm events.

Given the recent coastal flooding by salty seawater, there is an obvious need for reliable land use information, to update the current topographic/land use maps. The fact that only one usable, cloud free TM image exists in this area, to date, is an indication that SAR images are the only reliable EO data for tropical land use mapping. The RADARSAT (30m) images show the extent of urban areas, sugar plantations, and its management practice eg fallow fields and wetlands. Other land uses outside the study area, e.g. rice, sugar and coconuts plantations, pasture, mangrove and inland forest, forest cut over, wetlands, and flooded reservoir were also identified (Singhroy 1996a)

## 5. Recommendations

These recommended guidelines for the selection of SAR incidence angles for some geohazard studies are based on local topography. The three wide mode images of RADARSAT provide a large range of incidence angles and a larger area coverage. They are useful for surficial geological and land use mapping in both the low and moderate relief areas in support of geohazard mapping.

In mountainous terrains, incidence angles varying from 40-59 degrees are suitable for structural and geomorphic mapping. High-resolution fine mode images can assist in mapping areas of land degradation in moderate relief areas.

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