Advantages of Satellite Stereograms over Monoscopic Images from RADARSAT-1 for Geological Mapping and Exploration

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Abstract. *Mapping rock units and associated geological structures can be difficult to elucidate from single SAR images. Through stereoscopic examination of suitable SAR stereopairs, however, it is often concluded that recognition and interpretation geological features is greatly improved. To provide guidelines for selecting appropriate image pairs, several RADARSAT-1 images from tropical and arctic environments covering a wide range of incidence angles were examined. Best results for geological interpretation were obtained from same-side stereopairs. Where terrain relief is high, sufficient vertical exaggeration is attained with relatively small intersection angles (5-10°), whereas low relief environments require larger angles of stereo intersection (>15°). The proportion of overlap between specific beam modes is latitude dependent, thus a judicious selection of image pairs is required based on both terrain characteristics and specifications of RADARSAT-1 orbital tracks and imaging modes.*

Introduction

Since the first satellite images were acquired, images of Earth have been used for interpreting landforms. In general, interpretations derived from images viewed stereoscopically are often superior and made with greater confidence to those from a single image. It is therefore advantageous to make use of satellite stereo pairs wherever possible. Most Earth observing satellites acquire images from a fixed geometrical perspective, which precludes stereoviewing. Satellite imaging systems that are able to acquire images from at least two different viewing angles can be used for stereomapping and for generating digital elevation models (DEM) (*e.g.*, Toutin, 1999; Ostrowski and Cheng, 2000). The purpose of this paper is to explain the imaging parameters of RADARSAT-1 that describe the beam modes and influence the quality of stereoviewing for various image pair combinations.

RADARSAT-1 beam modes

RADARSAT-1 is a right-looking synthetic aperture radar (SAR) satellite operating at C-band (5.6 cm wavelength) and capable of producing images over a range of incidence angles (Raney *et al*., 1991). The imaging system is currently programmable for a total of 35 different beam modes and positions (*e.g*., Figure 1), thus SAR stereopairs are possible provided the common area imaged is acquired at different incidence angles. The two SAR images can be viewed together using traditional stereoscopic methods to provide a three-dimensional perspective of terrain landforms. This technique has long been used with aerial photographs for geological interpretation of landforms and is now routinely possible with RADARSAT-1 images over much wider areas.

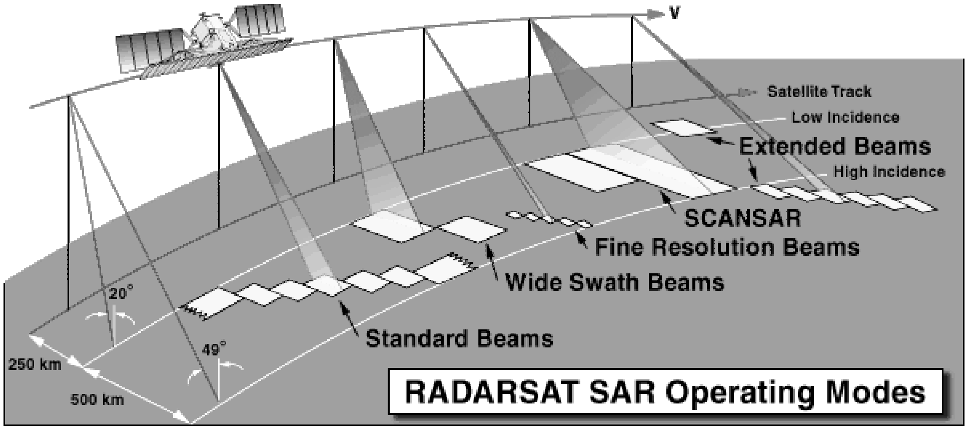


Figure 1. RADARSAT-1 beam modes.

RADARSAT-1 is the first commercial radar satellite to employ a programmable antenna which is able to collect images from a range of incidence angles, at different resolutions and ground swaths of different width. Some pertinent characteristics of these beam modes are summarized in Table 1.

Single image and stereo-pair combinations of Extended Low, Standard, and Extended High beam images were examined for their information content. Tonal and textural features in the SAR images often reveal geological units and structures such as folds and faults. For images with the same look-direction, that is from ascending or descending orbital passes, the overall appearance of landforms is quite similar. Images acquired at small incidence angles display evident foreshortening effects of topography whereas those at large incidence angles minimize the geometric distortion of the terrain inherent to SAR. Image resolution exerts strong control on the textural detail, but under stereoscopic viewing, look-direction and incidence angle are important factors which affect the information content, as discussed below.

Look-direction

With the exception at high latitudes, the look-direction of RADARSAT-1 is fairly constant at approximately 78° azimuth for ascending passes and 282° azimuth for descending passes. The selection of ascending *vs*. descending images is best determined according to the morphology of the terrain, with the consequence of foreslopes (slopes facing *toward* the radar sensor) exhibiting foreshortening and backslopes (slopes facing *away* from the radar sensor) becoming elongated. Generally, more terrain morphology is visible on backslopes of the imagery. Occasionally where relief is very high, these areas may contain shadow zones. Two images taken from opposite look directions often contain complementary information. This effect is well illustrated in Figure 2. In these images from Sekalap Mountain in Malaysia, layered sedimentary rock units are consistently more discernible on the backslopes of the mountain, whereas in the foreslopes, lithological layering is not as apparent due to foreshortening effects and tonal saturation from high backscatter.

Table 1. Beam mode characteristics of RADARSAT-1.

Beam Mode	**Scene Dimensions**	**Nominal Resolution**	**Incidence Angle (near – far)**
Standard (S1 to S7)	100 × 100 km	25 m	19°(S1) – 49°(S7)
Wide (W1 to W3)	150 × 150 km	30 m	19°(W1) – 45°(W3)
Fine (F1N, F1, F1F to F5F)	50 × 50 km	9 m	36°(F1N) – 48°(F5F)
ScanSAR Wide-A	500 × 500 km	100 m	19°- 49°
ScanSAR Wide-B	440 × 440 km	100 m	19°- 46°
ScanSAR Narrow-A	300 × 300 km	50 m	19°- 39°
ScanSAR Narrow-B	300 × 300 km	50 m	30°- 46°
Extended Low (EL1)	170 × 170 km	35 m	10°- 22°
Extended High (EH1 to EH6)	75 × 75 km	30 m	49°(EH1) – 59°(EH6)

Incidence Angle

RADARSAT-1 incidence angles range from 10° to 59°, depending on the beam mode and beam position (see Table 1). For image interpretation from single SAR images, larger incidence angles are sometimes preferred because of reduced geometric distortion of the terrain relief. Singhroy and Saint-Jean (1999) describe guidelines for selecting the image mode with the appropriate incidence angle for monoscopic investigations. SAR stereopairs require a second image of the area acquired with a larger or smaller incidence angle.

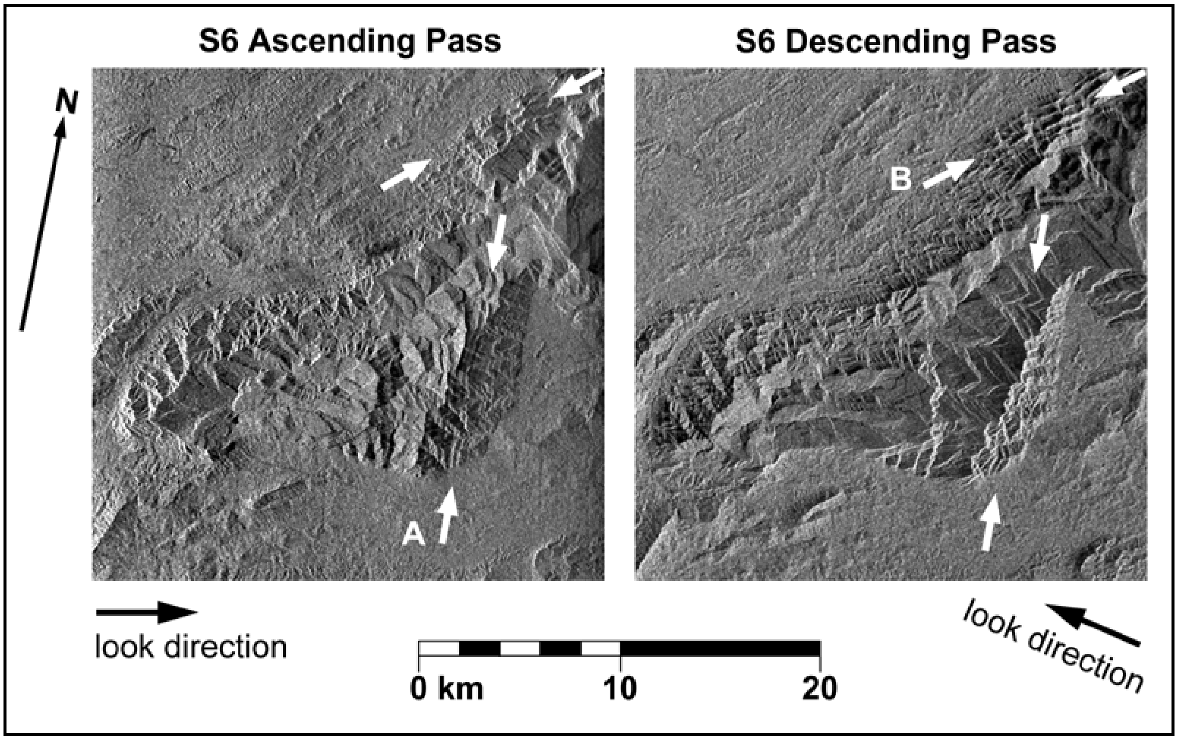


Figure 2. Sekalap Mountain (Sarawak, Malaysia) from ascending (left) and descending (right) orbit passes. The incidence angle in both Standard 6 images is approximately 45°, however radar look-directions are nearly opposite, as indicated by the black arrows below each image. The expression of thick, resistant sandstone alternating with recessively weathering shale beds (Belait Formation) appear different in each image. North-striking parallel layering is more apparent in "A", on the backslope in the left image than it is on the right image, where layering lies in the foreslope. Similarly, the trace of north-east striking lithologic layering is clearly defined at "B" in the right image (backslope area), but the same individual layers are more difficult to delineate in the left image (foreslope area).

SAR Stereopair Selection

Same-side stereo pairs consist of images with nearly the same look direction, that is, both images from ascending passes or both from descending passes. Opposite-side image pairs are composed of an ascending-pass and a descending-pass image. Opposite-side image pairs provide large vertical exaggerations, but are only suitable in areas of very low relief where image tone is similar from both look-directions (Leberl *et al.,* 1985; Leberl, 1998).

For most applications, same-side image pairs are recommended for all terrain types. A general guide has recently been developed by Cyr and Toutin (submitted) for selecting image pairs and is interactively accessible across the Internet.

SAR Data Processing

For visual stereoscopic interpretation, all SAR images in this study were filtered to diminish the effects of radar speckle and the data volume was reduced by 2 × 2 block averaging to yield a pixel spacing similar to the resolution of the beam mode. No other image manipulation or correction of the original ground range data to georeferenced or orthorectified products is required. Resampling or reprojection of data from original pixel row and column positions to new coordinate systems changes the relative position and distance between pixels. It is the relative parallax difference between the two images being compared that is necessary for stereoviewing, and thus the parallax should be preserved by leaving the data in their original ground range coordinates.

Image Pair Overlap and Vertical Exaggeration

The perception of vertical relief from viewing a stereopair is proportional to the angle of stereo intersection (Leberl *et al.*, 1985). This intersection angle is the difference between the incidence angle of each image in the stereo pair. In general, the greater the intersection angle, the greater the perceived vertical relief.

Table 2. Proportion of swath overlap between RADARSAT-1 Standard mode beam positions at the Equator (upper value, bold) and the nominal angle of stereo intersection (lower value, italics).

RADARSAT-1 Standard beam positions	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
S1	..						
S2	**0.52** *4°*	..					
S3	**0.49** *11°*	**0.88** *6°*	..				
S4	**0.81** *13°*	**0.70** *9°*	**0.30** *3°*	..			
S5	**0.73** *16°*	**0.65** *12°*	**0.76** *5°*	**0.35** *3°*	..		
S6	**0.96** *21°*	**0.47** *17°*	**0.58** *10°*	**0.69** *8°*	**0.82** *5°*	..	
S7	**0.59** *24°*	**0.91** *19°*	**0.79** *13°*	**0.78** *10°*	**0.56** *8°*	**0.47** *3°*	..

The overlap between beam positions of two different incidence angles is partial and varies with latitudinal position because the ground tracks of different beam positions follow divergent paths. Near the Equator, for example, an S1/S6 image pair provides a 96% swath overlap, the maximum among all Standard beams. This large overlap diminishes to about 50% overlap toward latitudes 28°N and 25°S. For any region of interest on the globe (for all latitudes), Table 2 provides a complete list of the intersection angles between all Standard beam positions. As an example of the proportion of beam overlap, the values given in Table 2 are valid only for Equatorial latitudes.

Stereoviewing

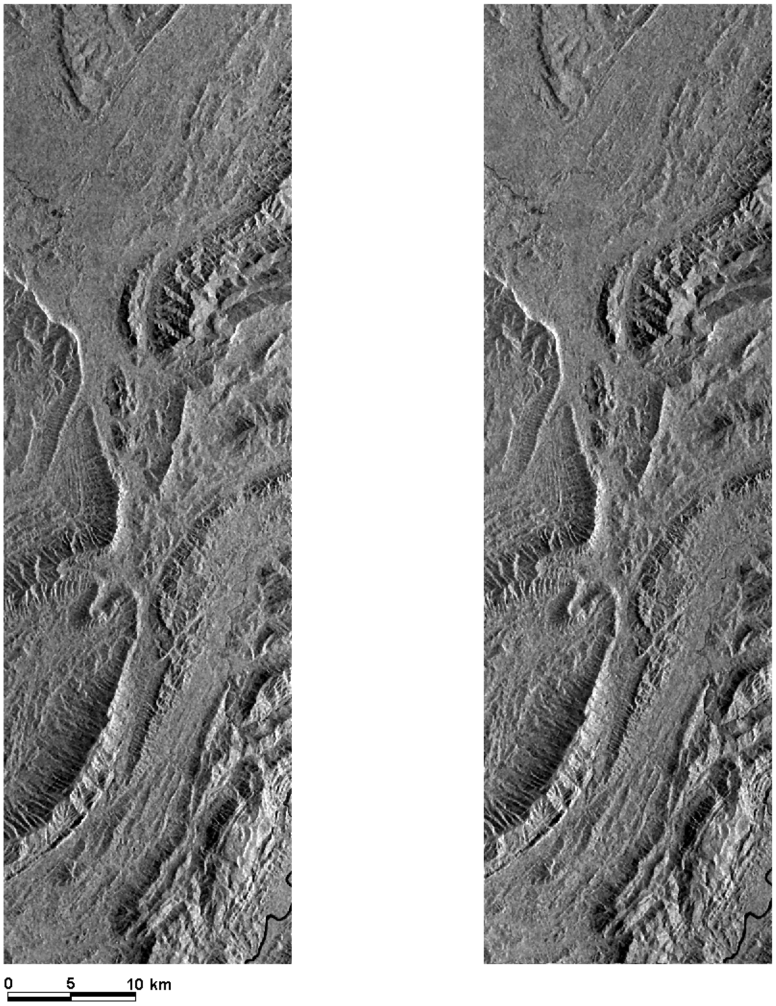
All RADARSAT-1 ground range SAR images were printed at the same-scale (approximately 1:180 000) on a Kodak 7700 continuous-tone dye-sublimation printer which produced high quality 11”× 11” prints suitable for conventional stereoscopic viewing. Prints used for this purpose should be of photograph-like quality. A WILD table model (ST4) stereoscope was used and good results are equally attainable with other stereoscopes, including pocket models.

When using high resolution Fine mode data, smaller scale images can be created. In our opinion, however, RADARSAT-1 Fine mode images printed at scales larger than approximately 1:75 000 are of diminished quality because individual pixels become increasingly apparent. Such images are perceived to be more “grainy” and consequently more difficult to visualise clearly. One approach to printing at the largest scale with the highest quality is to match (1:1) the number of pixels of the data to the resolution and dimensions of the print media.

Example Sites

Small subscenes of RADARSAT-1 images from tropical and polar environments are presented as examples for assessing the satellite image pairs for stereoscopic examinations. Figure 3 illustrates a rainforest site located in Sarawak, Malaysia. This area is located east of Bintulu (3°N /114°E) on the island of Borneo. The region is heavily forested and the geology is characterized by folded and faulted sandstones and shales of Late Cretaceous to Tertiary age. Topographic variation of the terrain is accentuated in the SAR images and can be related to the differential erosion of the underlying bedrock. Low lying topography in the northern part of Figure 3 contrasts with the rugged, mountainous terrain in the southern part, which marks the head waters of the Rajang River basin. Locally, this drainage divide parallels the Bukit-Mersing Line which separates deep water flysch deposits of the Rajang Group in the south from deltaic and shallow marine rocks of the Miri Zone in the north (Hutchison, 1989).

Geological maps are available at 1:250 000 scale, yet the complexity of deformation and potential economic importance of the region merits further investigation. More detailed



Standard 5 (descending) **Standard 6 (descending)**

Figure 3. Left image: S5 subscene (28-May-96). Right image: S6 subscene (04-June-96). RADARSAT-1 same-side (descending orbital pass) stereo pair from a mountainous region covered by dense tropical forest in Sarawak, Malaysia. The C-band radar backscatter originates from the forest canopy and, in some sense, the canopy can act as a surrogate for ground surface below in revealing the topographic variations. Look direction is toward the left (west).

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mapping is difficult to exercise in this kind of terrain given the risks, accessibility, cost and climate. Preliminary studies with airborne SAR (D'Iorio *et al.,* 1995) show that updating the geological information is greatly assisted by the interpretation of SAR images. Many fold and fault structures shown on the 1:500 000 scale compilation map of Yin (1992) are recognized in the RADARSAT-1 data. Numerous other structures and smaller faults have also been identified in the region with the aid of SAR stereopairs (D'Iorio *et al.,* 1997).

In the mountainous area in the south, over 1000m of vertical relief is present and landforms controlled by fold structures are easily recognized in the S5/S6 stereopair of Figure 3, although the angle of stereo intersection is merely 5°. In the northern part where relief is low, however, no new structures or relationships are revealed beyond what can be recognized from monoscopic inspection of either S5 or S6 image. Stereopairs from S1/EH6 and EL1/EH6 (not shown here) provide 35° and 42° angles of intersection respectively (Table 2). These stereopairs yield the greatest vertical exaggeration and subtle fold structures, otherwise ambiguous to interpret from single RADARSAT-1 images, are more easily identified.

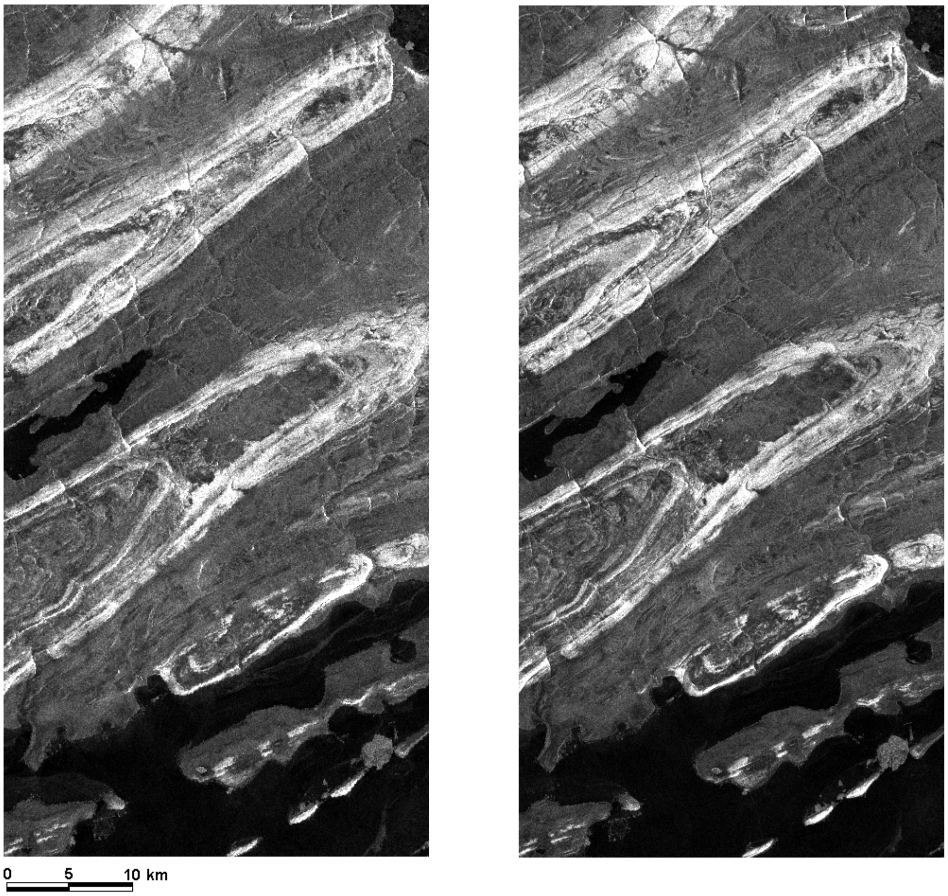
The second site described (Figure 4) is from Bathurst Island (75°N/100°W) and located in a polar environment with little or no vegetation cover. Strong backscatter differences are a function of contrasting smooth and rough ground surfaces. Frost action breaks-up bedrock to form a block or gravel field (felsenmeer) whose particle size is often controlled by the lithology. Terrain topography is moderately low, with local vertical relief less than 300m.

By inspection of the images in Figure 4, the synclinal fold structures of the deformed sequence of Phanerozoic clastic and carbonate rocks are easily recognised. In contrast to the open synclines outlined by units with high backscatter, the intervening anticlinal structures are less clearly traceable because of the low backscatter characteristics in these areas. In this low relief setting, only a subtle topographic expression of the bedrock anticlines is present. In stereoviewing mode, however, the S2/S7 stereopair has a 19° intersection angle and affords sufficient vertical exaggeration such that the expression of anticlinal traces can be perceived and mapped with greater clarity.

Conclusions

The main use of SAR satellite stereopairs is for DEM generation, however geological interpretations from stereoviewing of wide areas (*ca*. 100 km) is possible from two overlapping images of different incidence angles. Our investigation of several RADARSAT-1 Standard, Fine and Extended beam modes reveal that with a minimum of image manipulation and processing, excellent stereo pairs can be created and viewed with traditional optical stereoscopes. Careful selection of beam modes and positions must be made to maximize overlap of image pairs. Resolution differences among beam modes pose no restriction as long as images are printed at the same scale.

Best stereoviewing results were obtained from image pairs with the same look-direction because of their similar tonal characteristics. Small intersection angles (*e.g.* 5-10°) between images are sufficient for high relief areas, whereas higher vertical exaggerations are required for low relief topography, achieved by selecting image pairs with larger intersection angles (*e.g.* >15°).



Standard 2 (descending) **Standard 7 (descending)**

Figure 4. Left image: S2 subscene (26-Mar-96). Right image: S7 subscene (21-Mar-96). RADARSAT-1 same-side stereopair of Bathurst Island in the Canadian Arctic Archipelago. High backscatter (Hecla Bay Formation) quartzites outline doubly-plunging synclines of the Parry Islands Fold Belt. This lithologic unit lies in strong contrast against siltstones and shales which have low backscatter. Look direction is toward the left (west), but difficult to deduce in this low relief terrain.

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