A training package on: How to use RADARSAT Data in Stereo[1]

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Abstract

The following paper reports on some of the findings made using RADARSAT data in stereo. Characteristics of RADARSAT imagery were observed by comparisons with aerial photography, Landsat and SPOT imagery, and ERS-1, JERS-1 and airborne SAR imagery and by studying the effects of sensor, satellite and Earth parameters on stereo image pairs. This analysis of RADARSAT imagery was undertaken as part of the construction of "RADARSAT in Stereo: a Training Tool Kit".

1 Introduction

RADARSAT has the ability to provide stereo coverage of a geographical area. As RADARSAT can acquire data from a combination of beam modes, positions and two Earth relative look directions, users are allowed a wide variety of possible stereo image pairs. This wide choice can make the selection of the best stereo pair for a given study site and application difficult.

Viewing RADARSAT images in stereo is more complex than viewing aerial photographs or VIR satellite image pairs. In order to better understand the factors that impact the stereo-viewability of RADARSAT data, this paper will:

- examine the basics of depth perception and stereo,
- provide a brief description of RADARSAT data in stereo,
- address parameters related to the sensor and satellite, and the Earth which effect stereo viewing, and
- provide the results of experiments with simple image processing techniques to enhance the viewability of RADARSAT stereo pairs.

These considerations provide information which will enable users to generate the best stereo pair according to the data set, study site and thematic application they are working with.

2 Basics of depth perception and stereo

Depth perception is a combination of four physiological and six psychological cues (Okoshi, 1976). The four psychological cues are: accommodation, convergence, binocular disparity and motion parallax. The six physiological cues are: retinal image size, linear perspective, areal perspective, overlapping, shade and shadows, and texture gradient. A detailed explanation of these cues is available in Toutin and Vester (1997), or in the training tool kit (Vester and Toutin, 1997).

Binocular disparity predominates over other cues when viewing optical/VIR imagery in stereo. It is also important when viewing RADARSAT and other SAR imagery in stereo. However, other cues, particularly shade and shadow, have a strong impact on any SAR imagery. Therefore, the information that RADARSAT and other SAR images display is different than that provided in optical/VIR (Landsat, SPOT) imagery. It may take our brains time to assimilate this new information. However, practice makes

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"perfect". With experience, RADARSAT image pairs can be viewed in stereo as easily as aerial photographs or VIR satellite image pairs.

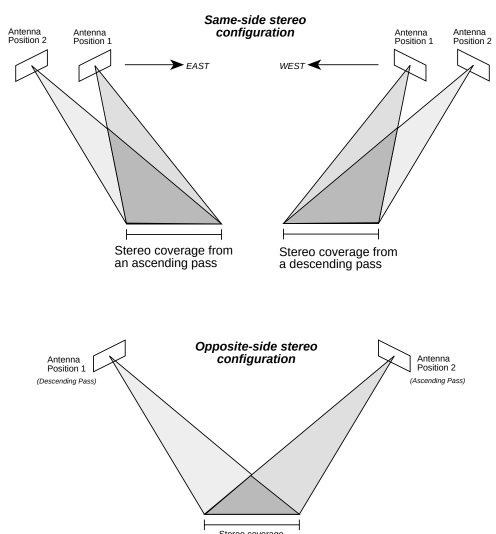
3 Brief description of RADARSAT in Stereo

The stereo parallax necessary for a stereo image pair is created when an object is viewed from two different positions. The range of beam positions of the SAR sensor, and RADARSAT's ability to collect data on an ascending or descending pass allow the satellite to collect data over the same geographical area from a number of possible positions (Luscombe et al., 1993).

Each RADARSAT beam position is defined by a near and far edge incidence angle. The incidence angle is the angle between the line of sight from the SAR to an element of an imaged scene and the vertical direction defined by the Earth's idealized geoidal surface. These angles increase from the first (steepest) to the last (shallowest) position.

As the satellite descends from the North Pole to the Equator, the sensor faces west relative to the Earth's surface. On RADARSAT's ascending pass the sensor faces east. Beam positions on an descending pass increase sequentially to the west and on an ascending pass - sequentially towards the east.

A same-side stereo configuration results when data of a particular area is collected from two ascending or two descending satellite passes. An opposite-side stereo configuration is the result of one image being acquired on a descending pass and the other on an ascending pass (Fullerton et al., 1986).



The left to right sequence of a stereo image pair depends on beam positions and whether or not data is collected from same or opposite sides. For example, the sequence of two images acquired with beam positions 1 and 5 (For example S1/S5), both on a descending pass, would be from 1 to 5. In order to image the same geographical area, the orbital path of the satellite at beam position 5 is east or right with respect to the orbital path of the satellite at beam position 1. If both images were collected on an ascending pass, the order of the image pair would be reversed.

When viewing an opposite-side stereo pair, the image acquired on a descending pass is viewed on the left hand side while the ascending pass image is viewed on the right hand side. This sequence may seem reversed to viewers accustomed to viewing aerial photographs. The explanation for this is the difference between the viewing geometry of optical/VIR and SAR sensors. On SAR images, relief displacement is towards the sensor, while on optical images relief displacement is away from the optical sensor. A SAR viewing angle (the complement of the depression angle), α, has approximately the same effect as an equivalent oblique optical viewing angle of $90° - \alpha$ (Toutin, 1996).

Vertical exaggeration is present in all stereo pairs and familiar to users of stereoscopes (Wolf, 1983). It is the difference between imaging (air) base to height and stereo viewing base to height ratios. In optical/VIR imagery the larger the base to height ratio the greater the vertical exaggeration. In radar imagery, vertical exaggeration increases with steepness of the incidence angle. Image interpreters take this effect into consideration when estimating heights of objects and rates of slopes.

The amount of vertical exaggeration evident in a RADARSAT stereo pair depends on the two positions of the satellite when the data was collected. An an opposite side stereo configuration will always result in more vertical exaggeration than a same-side stereo configuration. When the images are acquired on same-side orbital passes a S1/S7 image pair will show more vertical exaggeration than a S1/S2 pair.

4 Parameters related to sensor, satellite, and the Earth

To investigate the effects of sensor, platform and the Earth on RADARSAT stereo pairs, image pairs acquired by aerial photography, airborne SAR, SPOT and ERS-1 satellites were compared with RADARSAT imagery. This allowed us to understand how data collected by airborne versus spaceborne platforms differed. It allowed us to visually compare the output of optical and VIR sensors versus radar sensors in terms of radiometric information provided. Comparing different sets of RADARSAT data allowed us to understand how terrain type, geographical location, beam mode, beam position and look direction affect RADARSAT image pairs. These different stereo pairs are displayed at the GER97 Poster session and are available with the RADARSAT in Stereo: a Training Tool Kit.

4.1 Airborne versus Spaceborne platforms

Several observations can be drawn from the comparison of RADARSAT data with data sets obtained via aerial photography or airborne SARs.

The most obvious point of comparison between a RADARSAT stereo image pair and aerial photographs is that they provide a different scale of information. With images covering approximately 100 square kilometres (Standard mode) RADARSAT provides a much bigger picture of a geographical area than aerial photography can. However, aerial photography provides much greater detail.

SAR imagery collected by airplane also covers a smaller geographical area than RADARSAT imagery. Depending on the SAR antenna configuration and data processing techniques, detail on airborne SAR images may or may not be greater than on RADARSAT images.

A RADARSAT image pair in a ground range representation will be much easier to view in stereo than airborne SAR imagery, acquired in nadir mode, in a ground range representation. This is due much greater height of the satellite which allows for more uniform intersection angles over the image area.

4.2 Optical and VIR sensors versus SAR sensors

Visually comparing SAR imagery with aerial photography or VIR satellite imagery shows many differences. For example, a single RADARSAT or ERS-1 image provides the viewer with an impression of the three dimensional nature of the ground being imaged which single aerial photographs, SPOT or Landsat images do not. Features on a SAR image may be a dark grey where they are bright on an optical/VIR satellite image or photograph. These differences are the result of imaging geometry and electromagnetic wave properties.

Characteristics that are unique to radar imagery are foreshortening, pseudo-shadowing, layover, and shadowing (Elachi, 1987). *Foreshortening* is the effect where the slopes of hills and mountains facing the SAR antenna appear to be compressed. The image of these foreslopes appear brighter than other features on the same image. The greatest amount of foreshortening occurs when foreslopes are perpendicular to the incoming radar beam. Then, signals from the base, foreslope and top of the hill or mountain are received by the SAR antenna at the same time and will be superimposed on the image. Foreshortening can be minimized by using shallower incidence angles. However, shallower incidence angles result in more shadow on the image.

Pseudo shadow occurs when backslopes of hills and mountains are illuminated with as much energy as the foreslopes but, the return signal is spread out over a larger distance than the horizontal area occupied by the backslope (Leonardo, 1983). These dispersed return signals are not always detectable, but when they are the backslope will appear to be stretched out.

Layover is the visual effect where the image of an object appears to lean toward the direction of the SAR antenna. It is the result of the tops of objects or slopes being imaged before their bases. Layover effects are most severe on the near range side of images.

When the degree of backslopes is less than the incidence angle, true radar *shadows* mask down range features. In this case, slopes facing away from the radar antenna will return very weak signals if any. This results in dark or black areas on the image. Thus, in areas of high relief, as the incidence angle becomes shallower or increases, shadow length increases with range and more information will be lost. However, radar shadows provide the cue which allows viewer to receive an impression of three dimensionality with a single image.

SAR and optical/VIR images also differ dramatically because signals from the microwave and visible infrared parts of the electromagnetic spectrum react differently with respect to surface roughness and soil moisture content. Thus, a clear cut or a road may appear to be white on an optical/VIR image and dark on a SAR image. This is evident when RADARSAT and ERS-1 images were compared with aerial photographs, SPOT and Landsat images.

Comparing different SAR satellite imagery in terms of radiometry it was found that in general, land surface features can be seen more clearly on RADARSAT imagery than ERS-1 or JERS-1 imagery.

4.3 Sensor parameters and ground considerations
Some effects of ground considerations such as terrain type and geographical location and sensor parameters such as beam modes, beam positions, and look directions include:

- the amount of detail that can be seen in stereo,
- the amount of area that can be seen in stereo, and
- whether layover, foreshortening or shadowing become a barrier to effective stereo viewing.

To illustrate these factors RADARSAT stereo pairs were compared

4.3.1 Terrain type
The geometry inherent in a SAR remote sensing system such as RADARSAT was illustrated very well in a Fine Mode RADARSAT image pair of the mountainous Okanagan Valley region of British Columbia, Canada. Foreshortening, layover and shadow effects were clearly visible. Mountains were compressed on the west face and appeared to lean towards the sensor. Sides of mountains facing the sensor were bright and while backslopes were in shadow. Layover was visible along the ridges.

The effect of a rolling terrain was examined in an image pair of the Ottawa, Canada region which is characterized by the Gatineau Hills to the north, the Ottawa River Valley and flat lands to the south. Change in elevation between the river valley and the Gatineau Hills is approximately 300 m. Stereo viewing showed the relief of the Gatineau Hills and the rise from the Ottawa River clearly.

Fine mode RADARSAT imagery of the Tapagos Forest region of Brazil was chosen to examine stereo-viewability of flat terrain. This area is characterized by a change in elevation of less than 50 metres. A small change in relief between the coastal area and the inland plateau could easily be seen. Differences in height between the top of the tree canopy and fields cleared for agricultural crops could also be seen. As in any stereo image pair changing the order of the images should lead to a pseudoscopic stereomodel. However, with this stereo pair some people will still see a normal stereomodel. This is due to the fact that in image pairs of flat terrain, the psychological cue (shadow) is stronger than the physiological cue (binocular disparity).

4.3.2 Geographical latitude

At the equator successive orbital tracks are almost parallel. However, as RADARSAT approaches the poles orbital tracks converge. In northern latitudes this convergence angle between orbital tracks must be taken into account as images of the same geographical area will be skewed with respect to each other. An image pair of Bathurst Island, N.W.T., Canada - located at approximately 75° North - the convergence angle between the orbital tracks is quite large. As a result the right hand image had to be manually rotated with respect to the left hand image in order to view the images in stereo which resulted in a decrease in the amount of area that could be seen in stereo.

The area covered by the images over Ottawa, Canada is at approximately 45° North. In order to view these images with the stereoscope a very small manual rotation of the right hand side image is done with respect to the left hand image. The images of the Tapagos Forest in Brazil, 3° South of the Equator, not surprisingly, lined up perfectly.

4.3.3 Stereo configuration: Opposite-side versus same-side

In order to compare opposite and same-side stereo configuration, a data set composed of two Fine Mode images F2 and F4 collected on descending passes were combined with F1 and F5 images collected on ascending passes of the Sherbrooke, Quebec, Canada area. At this latitude, (approximately 45° North) the convergence angle between ascending and descending orbital passes is between 20° and 25°. To compensate for this, the opposite-side image pairings (F2/F1 and F4/F5) were rotated with respect to each other in order to obtain the stereomodel. Once the images had been oriented correctly the viewer, a smaller image area was viewable in stereo.

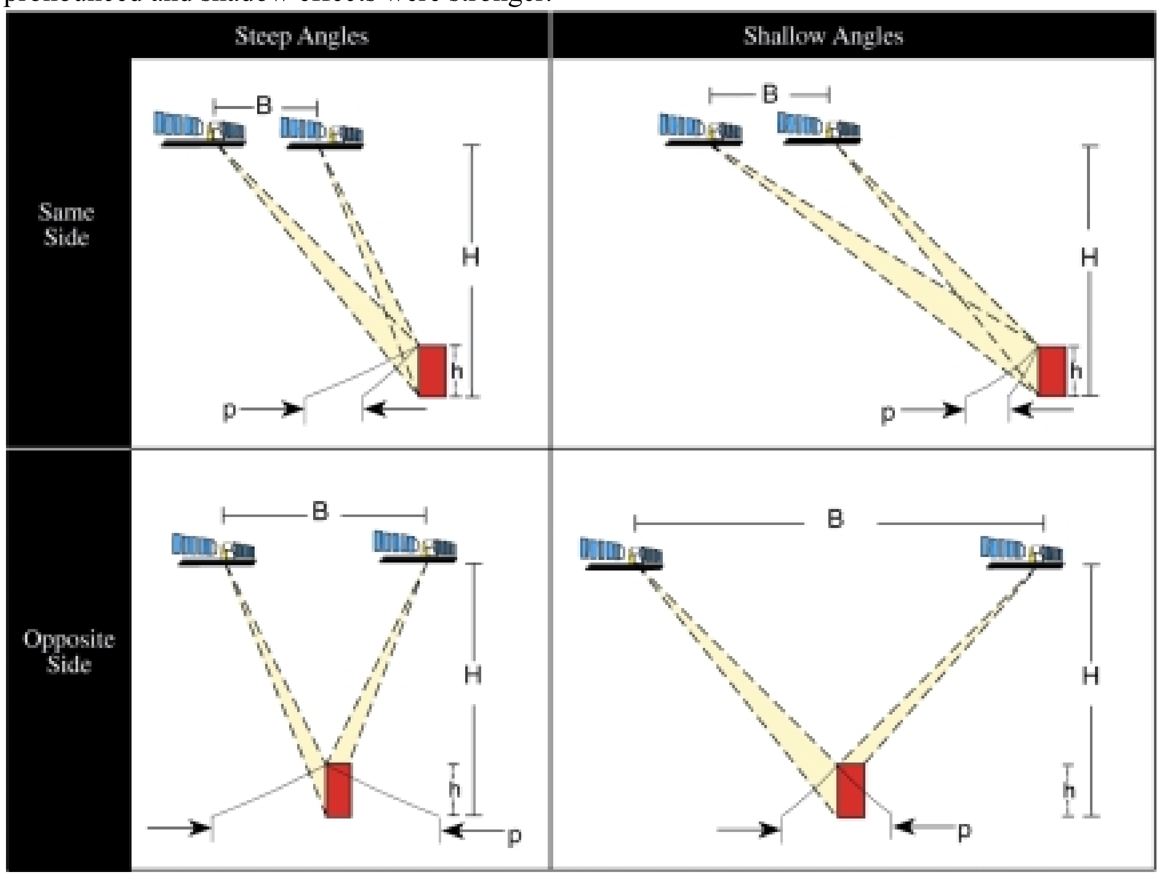
Vertical exaggeration was pronounced in both opposite-side image pairs due to large intersection angles. Thus, on these images, changes in elevation around Sherbrooke appeared to be much greater than the actual 250 m. The vertical exaggeration was more pronounced in the F2/F1 combination than the F4/F5 combination. The F1/F2 images display more foreshortening effects than the F4/F5 images. This is expected because the viewing angles of the former are steeper than the latter pair.

The first attempt at viewing these two image pairs was confusing. The opposite-side stereo configuration results in foreshortening and shadow effects to appear on opposite sides of land features. Depending on the individual viewer, foreshortening cues may overpower shadow cues and brighter aspects dominate darker ones, or vice versa. This means that, at first, it is not easy to see the depth of valleys or the heights of mountains in those local areas. However, with practice one can learn to be comfortable with these opposing effects and depth information will be taken from the dominant cue. In areas where changes in elevations are less pronounced stereo viewability is much easier.

The F1, F2, F4 and F5 used in the opposite-side configuration combinations were also be used to generate two same-side stereo image pairs. F5/F1 from an ascending pass and F2/F4 from a descending pass. These image pairs were easier to view in stereo than the opposite-side combinations. A larger image area is visible in stereo since the images did not have to be rotated with respect to each other. The most obvious difference between these two same-side image pairs and the opposite-side combinations is that a same-side stereo configuration does not produce the same amount of vertical exaggeration. Both image pairs display a much more realistic visualization of topography in the Sherbrooke area.

With images of flat terrain an opposite-side stereo configuration is as easy to view as a same-side stereo configuration (Toutin, 1995).

4.3.4 Stereo configuration: Same-side - Steep versus shallow incidence angles
S1/S4 and S4/S7 image combinations of the Sherbrooke, Quebec area were viewed to compare the effects of steep and shallow incidence angles. Both combinations were very easy to view in stereo. Due to the relative steepness of the viewing angles in the first pair, foreshortening and layover effects were more noticeable than shadow effects. As expected, since S7, the shallowest of the Standard Mode incidence angles, was used in the second image pair, foreshortening and layover effects were less pronounced and shadow effects were stronger.



4.3.5 Stereo Configuration: Same-side - Small intersection versus large intersection angles
In order to understand the effect of intersection angles on stereo-viewability S1/S2 and S1/S7 image pairs of the Ottawa, Canada region were studied. The intersection angles for the S1/S2 combination were 4°. For the S1/S7 combination, the near edge intersection angle was 22° and the far edge intersection angle was 25°.

The Gatineau Hills and the Ottawa River Valley were easy to see in relief on both image pairs. However, relief on both sides of the river was more pronounced than in the S1/S7 than the S1/S2 image pair. Of all the Ottawa image pairs discussed thus far, this pair shows the greatest stereo effect. The greater the intersection angle the greater the vertical exaggeration in a stereo pair.

4.3.6 Beam Mode: Standard versus Fine mode

Fine Mode and Standard Mode data sets acquired over the Sherbrooke, Quebec area were compared. Obviously, the Fine Mode data at a resolution of approximately 9 metres shows us more detail than Standard Mode imagery at a resolution of approximately 25 metres. The smaller resolution is advantageous if users are required to identify fine details for their particular application. However, Fine Mode data contains more speckle than Standard Mode data since it is subject to 1-Look rather than 4-Look signal processing.

Vertical exaggeration is more pronounced in Standard Mode than in Fine Mode stereo image pairs since the range of incidence angles is greater in the seven Standard Mode beam positions (20 - 49°) than the five Fine Mode positions (35 - 49°). Therefore, intersection angles can be larger in Standard Mode combinations. This was evident when comparing the Sherbrooke, Que. area same-side Fine and Standard Mode combinations.

The relative advantages and disadvantages of Fine and Standard mode mean that users compromise between a finer resolution, more speckle and less vertical exaggeration or larger resolution, less speckle and greater vertical exaggeration. The trade off should be a function of the application the imagery will be used for.

5 Simple image processing techniques to enhance stereo viewability

In this section, problems which affect stereo viewability, but can be corrected by simple image processing techniques, are discussed. Scale differences between image pairs, due to differing sizes of the data sets or to a slant range representation, were corrected. Rotations were be done in order to allow the viewer to see an image pair in stereo with greater ease. An antenna pattern correction was applied to an image where the antenna pattern interfered with the ability to see the image pair in stereo. Filtering techniques were used to reduce speckle. However, it should be remembered that image processing techniques involve resampling and/or radiometric transformation of the raw image. In order that too much information is not lost these techniques should be applied only when necessary.

5.1 Re-scaling to correct differences in data set size

Stereo-viewability can be improved by using a simple scaling process to make the image sizes equal. As a general rule, scale differences greater than 10 percent in RADARSAT imagery will result in too much Y parallax and the inability to view the image pair in stereo.

5.2 Slant range to ground range correction

A slant range to ground range correction can be useful in order to view a RADARSAT image pair in stereo. This was made evident when we compared two image pairs of Indonesia, both in an opposite-side stereo configuration, one in slant range presentation, the other in ground range presentation. The full area of stereo coverage could be viewed only in the ground range presentation.

A slant range presentation causes distortions in scale between the two images. An opposite-side stereo configuration results in resolution differences as the most compressed near edges will be on the outer edge of the stereo pair while the least compressed far edge is at the center of the stereomodel. This means the same land features are resolved differently. This was particularly evident when shorelines and other shapes were examined. Great variation in existed between the two images. As a result of the slant range presentation and the opposite-side stereo configuration only small local areas of this image pair were able to be viewed in stereo at a time.

5.3 Rotation

Rotation of one image with respect to the other can be useful when the images are acquired over far northern or southern latitudes (greater than 60 degrees) or, when an opposite-side stereo configuration is used to make up the stereo pair.

Bathurst Island is at latitude 75° North. In order to rotate the right hand image, common control points along the coastline were collected. The right hand image was then registered to the left using a first order polynomial transformation and a bilinear resampling kernel. This results in a right hand image which can be horizontally lined up with the left hand image. Manual rotation is no longer necessary.

Another example of imagery which could be digitally rotated in order to improve stereo-viewability by eliminating the need for manual rotation is imagery which has been acquired on an ascending and a descending pass. This causes the resulting two images to be rotated with respect to each other.

5.4 Antenna pattern Correction

An antenna pattern correction can be applied to radar imagery where necessary. This results in a clearer image and therefore greater stereo-viewability when viewed with another image.

5.5 Filtering

Where it is necessary to increase image scale for interpretive purposes, the application of a FGAMMA (Lopes, 1990) or other filter can be used to decrease the impact of speckle thereby increasing stereo-viewability.

As mentioned RADARSAT data acquired in Fine Mode is more prone to speckle than Standard mode data. Filtering can be used to reduce speckle which is more visible as image scale is increased. At larger image scales speckle interferes with stereo-viewability. To understand whether applying a filter would be useful in order to increase stereo-viewability an area of approximately 10 x 10 km of the Fine Mode Okanagan, B.C. data was printed with and without a filter. The unfiltered version contains a large amount of speckle which interfered with stereo viewing. A FGAMMA filter was used to reduce the amount of speckle. This resulted in a cleaner image which is easier to view in stereo. However, there was a loss of some detail. Roads, and boundaries between water bodies and land were not as clearly delineated in the filtered image as in the unfiltered image. Elevation information was also lost.

6 Conclusion

When viewing stereo image pairs it should be remembered that it will be easier to perceive depth in some image pairs than in others. Viewing a stereo pair of aerial photos or SPOT satellite images will seem easy and "natural" because these are optical systems. Our eyes, and consequently our brain, perceives objects as optical systems do. Initially, RADARSAT and other SAR image pairs may be more difficult to view in stereo. Psychological cues, such as shade and shadow are different on optical and SAR images. SAR images also contain foreshortening and layover effects.

The previous paragraphs have described the effects of terrain type, geographical latitude, beam position and beam mode on RADARSAT image pairs. Opposite-side and same-side stereo configurations were also described. Simple image processing techniques used to improve the stereo-viewability of a stereo pair were outlined.

The RADARSAT in Stereo: a Training Tool Kit was compiled from many sources. It includes details on the considerations discussed in this paper, and background information necessary to understand the links between 3D viewing methods, stereo, radar remote sensing and using RADARSAT imagery in stereo. More information on the training tool kit and its availability can be obtained from CCRS.

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