Preprint/Prétirage

Synthetic Aperture Radar and Search and Rescue: Detection of Crashed Aircraft Using Imagery and Interferometric Methods

Tom I. Lukowski and

Francois J. Charbonneau*

Canada Centre for Remote Sensing

Natural Resources Canada

588 Booth St.

Ottawa, Canada

K1A 0Y7

Ph. (613) 995 0386 Fax: (613) 947 1383

e-mail: tom.lukowski@ccrs.nrcan.gc.ca

* Isosceles Information Solutions Inc.(Under Contract to CCRS)

Abstract

This paper summarizes some results of studies at the Canada Centre for Remote Sensing (CCRS) using Synthetic Aperture Radar (SAR) imagery from spaceborne systems for the detection of crashed aircraft. Studies have been carried out using detected products (intensity values only) and interferometric methods (using complex imagery). Due to the low resolution of single polarization single frequency spaceborne SAR imagery (approximately 8 metres ground range being the best currently available from operational remote sensing satellites), it is seen that such imagery cannot currently be used with much optimism although the techniques themselves show promise. Further study is needed to examine if the better resolutions that will be available from future systems such as RADARSAT-2 make possible the reliable detection of crashed aircraft. Other research, not described in this manuscript, is underway at CCRS through the support of the National Search and Rescue Secretariat examining the contributions to Search and Rescue that can be made using spaceborne polarimetric SAR systems including RADARSAT-2.

1. 0 Introduction

Most of the Canadian landmass is sparsely populated and there are significant northern areas that are in total darkness for prolonged periods each year. Airplane traffic has continued to increase and this will continue with further development in the North. Sadly, there are a number of crashes each year. The need to reach these crash sites (often of airplanes carrying less than half a dozen passengers) and to assist the victims is served by Search and Rescue (SAR) in Canada, which is the responsibility of the Department of National Defence and carried out through the Rescue Coordination Centres in Halifax, Trenton, and Victoria. [1]

A major improvement in Search and Rescue capabilities that has saved lives of crash victims was the COSPAS-SARSAT program made possible through the 1980 agreement between Canada, the United States, Russia and France to coordinate their efforts in the use of satellites in the detection of aircraft and ships in distress *(SAR, 2001).* This followed from investigations in a number of countries in the 1970's studying the use of satellites in the detection of emergency transmissions. Canadian research at the Department of National Defence had concluded as early as 1972 that the standard Emergency Locator Transmitter (ELT) carried by airplanes could be located within 30 kilometres of its position by means of such a polar orbiting satellite. This COSPAS-SARSAT has saved many lives beginning in September of 1992. Improvements in the systems over the years have increased the number of available satellites, hence decreased the length of time for system response to a distress call. They have also made it possible to find those in distress with a much better location accuracy. As of 1998, 90 percent of the calculated locations are in error by less than 20 km and for the newer radio beacons operating at 406.025 MHz, locations can be determined to within 5 km (90 percent of the time) (*Wallace et al., 1998)*.

ELT systems have been improving. However, the functioning of ELTs has been problematic, although recent years have seen improvements here as well. Statistics indicate that ELTs carried by general aviation aircraft currently function only about 25 percent of the time (*Dreibelbis et al., 1999*). In most cases, the ELT does not operate and other methods of finding the crash site are required. In the case of inclement weather, this could be performed by using synthetic aperture radar systems which can see through cloud (and at night as well). Aside from listening for ELT's, the current Canadian Search and Rescue procedure involves visual searches from spotter aircraft with personnel and aircraft not limited to the military but also made available through the Canadian

[1] Introduction to Search and Rescue in Canada is given in (*SAR, 2001*)

Civil Air Search and Rescue Association (CASARA). The methodology is described in the National Search and Rescue Manual (*National, 1998*).

The need to find such crash sites in particular in case of inclement weather and darkness provides the opportunity for assistance from scientists: The development of techniques which make use of microwave remote sensing systems can make it possible to provide assistance during such periods when both visual searches and optical imaging systems are not able to help.

However, even under good conditions, further information could be obtained through the use of airborne or spaceborne imaging systems. Unfortunately, microwave and optical imagery obtained from airplanes and satellites has yet to become an integral part of such searches even though the possibility of assisting in search and rescue has been examined previously. Indeed, such possible uses of satellite imagery were considered as early as the mid-1970's (e.g. *Sivertson, 1976*).

In recent years, there have been active initiatives in this area. In particular, the potential of SAR imagery has been explored by the Search and Rescue Mission at NASA Goddard Space Flight Center which launched a project in 1988 to investigate the feasibility of using space and airborne remote sensing technology to aid in beaconless searches (*Wallace et al., 1997*). This NASA GSFC SAR^2 Project, a technology development project, has carried out experiments beginning in 1989 using a variety of test targets and locales in the United States and SAR systems that have included the NASA/JPL AIRSAR, the Environmental Research Institute of Michigan (ERIM) SAR mounted on a U.S. Navy P-3, and SIR-C (*Wallace et al.,* 1997).[2]

A Canadian initiative at the Royal Military College examined the use of SAR and optical imaging from spaceborne platforms and other systems in Search and Rescue.[3]

---

[2] The work of the SAR^2 Project in the Search and Rescue Mission Office of NASA GSFC can be found on the website at http://poes2.gsfc.nasa.gov/sar/becnless.htm . A number of publications from this group and related work have appeared in Automatic Target Recognition VII, F.A. Sadjadi, Ed., SPIE Vol. 3069, 1997, Automatic Target Recognition VIII, F.A. Sadjadi, Ed., SPIE Vol. 3371, 1998, Orlando, Florida, and Automatic Target Recognition IX, F.A. Sadjadi, Ed., SPIE Vol. 3718, 1999, Orlando, Florida.

[3] The work of the project at RMC can be found in a number of publications including *Cunningham et al., 1994*; *Creber et al., 1997*; and *Singh et al., 1996*.

In our work, we are building on these previous efforts and on CCRS experience in Synthetic Aperture Radar (SAR), an activity which began in the 1970's and has included airborne and spaceborne systems.

Microwave imagery using SAR systems could be useful for the location of crashed airplanes since there could be significant microwave scattering by dihedrals formed by parts of the airplane structure. It has been noted that these dihedrals often survive the crash. If the orientation between the SAR system and the target makes it possible to image these dihedral structures, it can be straightforward to find the crashed aircraft (e.g. *Jackson et al., 1998*).

In this paper, we describe techniques using detected images and interferometric methods from spaceborne systems.

2. 0 Methods Using Single Images

The most straight-forward method of detection is carried out by examination of a number of bright targets in a single SAR image, looking for the one that is the crashed aircraft. The number and type of bright targets that are detected can be problematic, as all targets would have to be checked by the Search and Rescue observers looking for the accident location. Such a methodology, will only lead to the detection of a plane crash in exceptional cases: It is necessary that the region of interest be very well characterized in some form, so that a comparison is being made of the bright targets in the imagery with the absence of such a target in the known ground truth for the area.

Examples of imagery of a Fairchild-27 that crashed on Cornwallis Island, N.W.T. in June 1968 (*Thorsteinsson, 2000; Avery, 1998*) and is still mostly intact have been examined and compared to ground truth information obtained in 1998 and 1999 (Figure 1). The RADARSAT-1 imagery in Fine Beam F5 was processed to Single Look Complex (SLC) products. This imagery (at an incidence angle of approximately 46^{o}) shows this target at various times of the year (Figure 2). It is seen that the detectability of the target depends on the conditions of the background clutter, i.e. on the terrain itself as well as the effects of the weather and precipitation preceding and at the time of imaging. Significant temporal variation of the backscatter of the terrain can be expected for such regions significantly north of the tree line. The plane is clearly discriminated from the surrounding tundra for the two July images (Figure 2a and 2b), but, in the October case (Figure 2c) the target is "hidden" in the clutter.

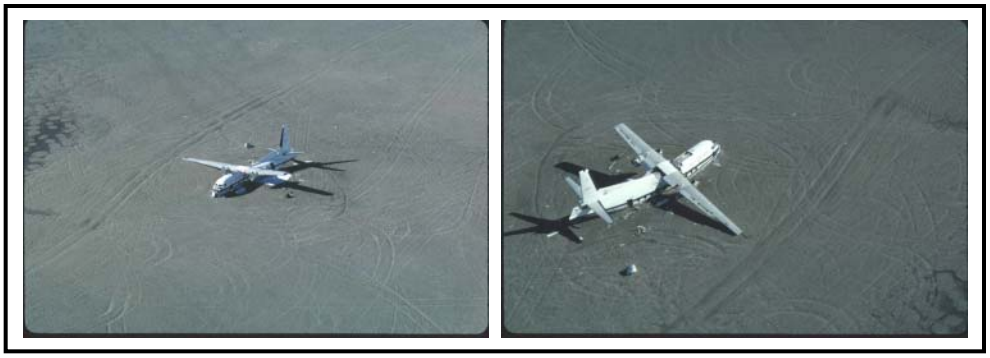
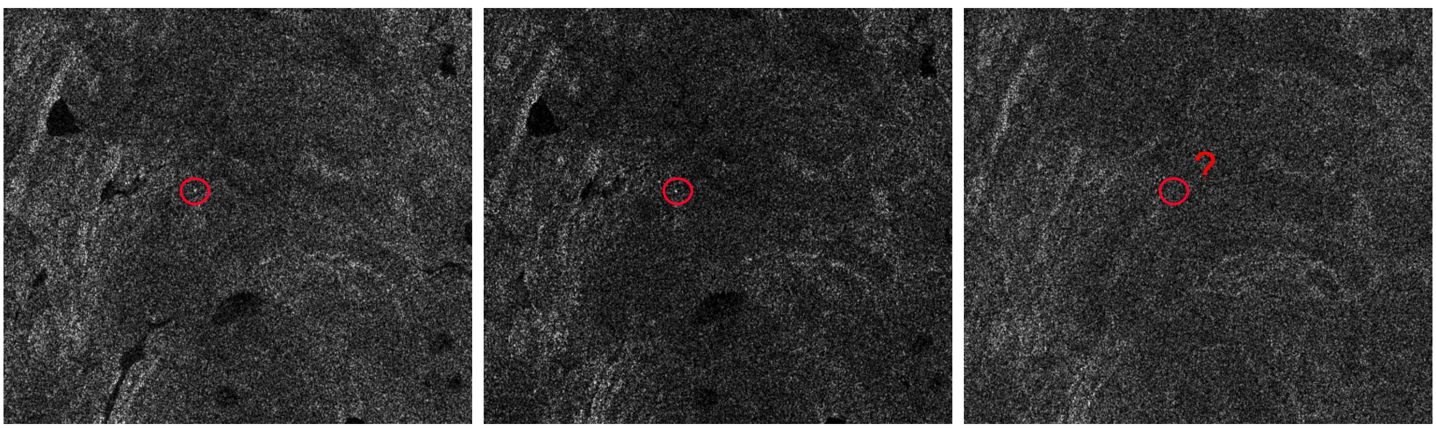


Figure 1. Crashed Fairchild-27, Cornwallis Island, The airplane heading is approximately 100° True. (Courtesy of P. Budkewitsch, CCRS).



a) b) c)

Figure 2. RADARSAT-1 Fine Beam (F5) single-look images of the Fairchild-27, Cornwallis Island, N.W.T. a) July 04, 1998, b) July 28, 1998 and c) October 8, 1998. These images are of approximately 23 km. by 25.5 km. Sample spacing is 4.6 m. (slant range) by 5.1 m. (azimuth).

We have tested several resolution enhancement techniques on these images (*Atlantis, 1999*). Such resolution enhancement has been applied in the processing of imagery of the Fairchild-27 and the results are shown in Figure 3: The ability to detect the aircraft is considerably improved.

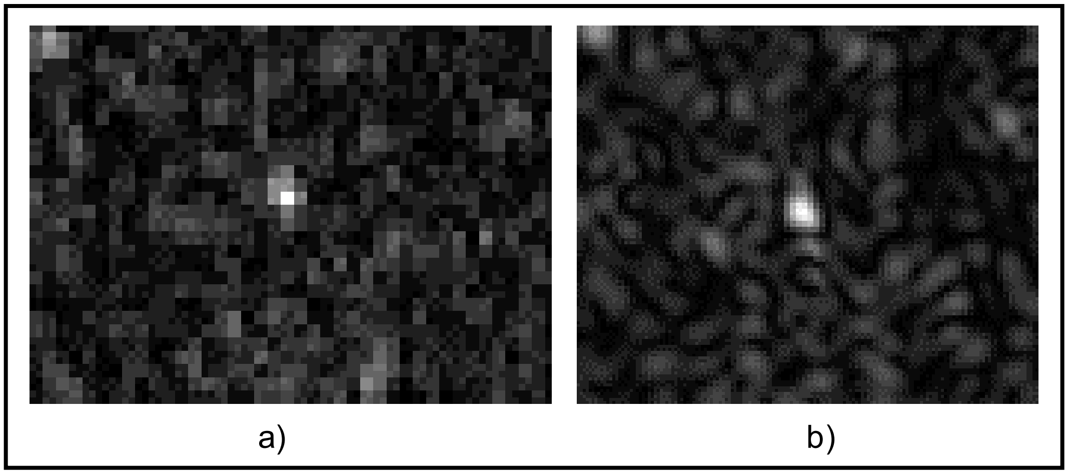


Figure 3. RADARSAT-1 F5 images, July 28 1998 of the Fairchild-27, Cornwallis Island, near Resolute, N.W.T. as in Figure 2. Images processed with a) APP default parameters; Sample spacing: Slant Range = 4.63m and Azimuth = 5.16m; b) APP Resolution enhancement module; Sample Spacing: Slant Range = 2.32m and Azimuth = 1.92m

3.0 Intensity Change Detection

Speckle is an inherent part of SAR images. One unfortunate consequence is the difficulty of distinguishing point targets when they are not sufficiently stronger than the clutter to enable them to show up "above the clutter". Furthermore, what is needed is the determination of point targets which have appeared in images at locations where they were previously absent in order to detect changes between images obtained before and after a crash. Differences can appear in two different ways: They can be due to new targets in the post-crash imagery which did not appear prior to the crash, or as targets which have disappeared by the time of the post-crash imagery. This method has been used for detection of change in land cover and urban areas (e.g. *Cihlar et al, 1992; Weydahl, 1998*) and has been shown to work in some cases for other targets including intact and crashed aircraft (*Singh et al., 1996; Wallace, 1997; Mansfield et al., 1997*). Unfortunately, since these differences need to be performed on a pixel-by-pixel basis, there is a need for very accurate coregistration of images which can be difficult especially in areas of high relief and those with few easily identified tie points.

Differences of this type have been obtained by studying images obtained prior to and following a tragic crash in December 10, 1997 of an Embraer EMB-110P1 Bandeirante turboprop close to the airport at Little Grand Rapids, Manitoba (Figure 4) (*Transportation Safety Board of Canada, 1997*). In this case, the change detection was obtained by taking the difference of RADARSAT-1, Beam S4 SAR Georeferenced Extra Fine Resolution (SGX) images obtained on November 2, 1997 and December 20, 1997. Figure 5a shows the December post-crash scene. The Difference Image is formed by taking the ratio of images (in "power" units) (*PCI, 1998*). This function The resulting ratio image is thresholded to keep high positive changes and, thus, generate an output bitmap, as in Equation (1):

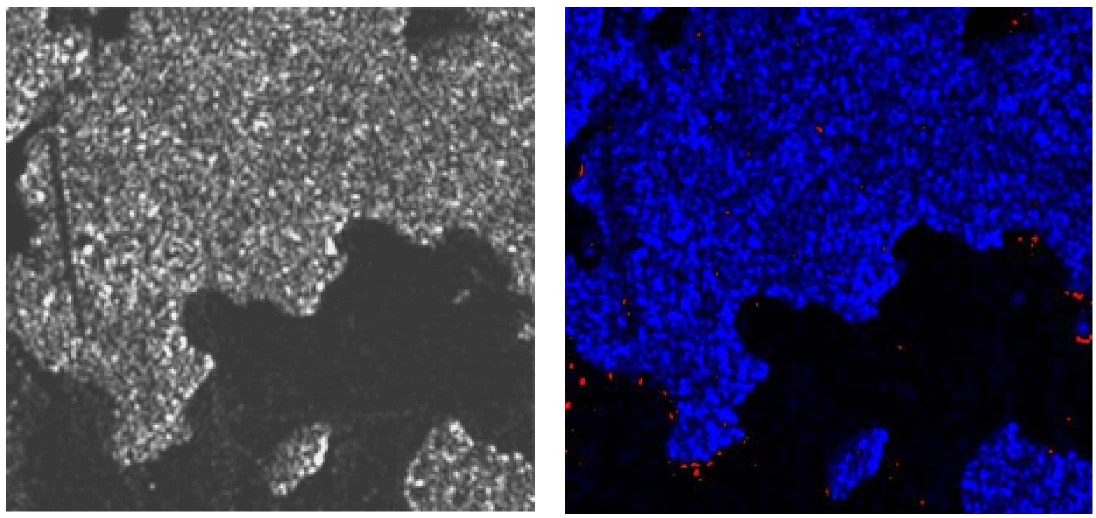
$$10\log 10\left(\frac{z_A^2}{z_B^2}\right) \geq \text{threshold [dB]} \qquad (1)$$

where z^2_A and z^2_B are the sample backscattering powers in the pre-crash (A) and post-crash (B) images.

Figure 4. Embraer EMB-110P1 Bandeirante turboprop which crashed on December 10 1997, close to the airport at Little Grand Rapids, Manitoba (Courtesy of Tony Gasbarro, Transportation Safety Board of Canada)

For a threshold at a power ratio value of 12 dB, the resulting possible crash sites are as shown in red in Figure 5b. Most of the false alarms are located on a lake area (which was not frozen in November). There are a few locations on land, but none are believed to correspond to the crash site. On reduction of the threshold value from 12 dB to 9 dB, a possible crash location near the area identified in the Transportation Safety Board Report (*Transportation Safety*

Board of Canada, 1997) is found to be represented by one sample, but the number of "false alarms" increases dramatically.



a) b)

Figure 5. Images of the Embraer EMB-110P1 Bandeirante at Little Grand Rapids, Manitoba, a) RADARSAT-1 S4 SGX, December 20 1997 b) Red: Bitmap output with threshold set at 12 dB, Blue: November image.

Alternate ways of looking at such changes is by the use of color with the images displayed on various channels with a color selection that clearly differentiates the points where change has occurred from those which have not. This has been done, for example, in a study examining the use of RADARSAT-1 data at the Royal Military College (*Singh et al., 1996*). In the Little Grand Rapids case, by displaying the pre-crash image in green, and that from after the crash in red, the crash site in the color composite, which was dark in the precrash image, should appear red. As we can see in Figure 6, there are a large number of red samples in the composite image, which can be explained as being due to speckle differences between the images and could be compounded by coregistration difficulties between them.

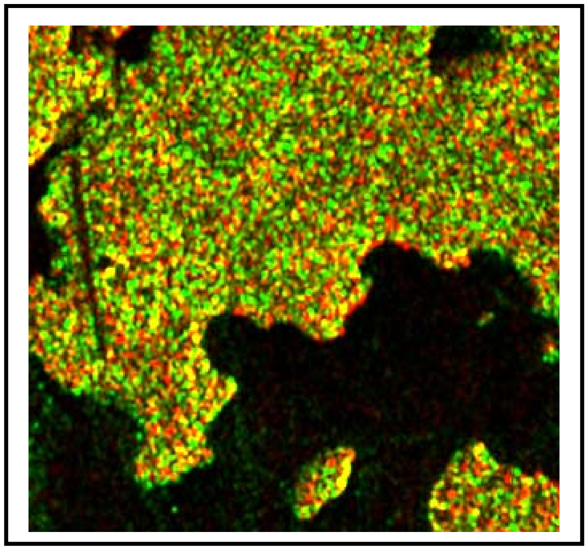


Figure 6. Color composite image formed with RADARSAT-1 S4 SGX December 20 1997 (red channel) and November 02 1997 (green channel) images over Little Grand Rapids.

There are other methods of detecting a target in clutter which were not explored in this study. These could be expected to require a larger number of image samples over the target of interest, which itself should be stronger than the surrounding clutter. One such method of incoherent change detection subtracts the modelled clutter in the expected region of a point target from the signal of the area and has been used in studies by the U.S. military (*James and Hendrickson, 1994*).

It is believed that some of the problems experienced here could be due to lack of precision in the resampling that forms part of the coregistration process. The consequent slight offset of samples between the two images makes a pixel-by-pixel subtraction difficult. It is expected that this could be ameliorated with more complex methods of resampling and coregistration. However, since the resolution is such that crashed aircraft do not occupy a large number of pixels in current satellite SAR images, and the image intensity of a crashed aircraft often does not significantly differ from the brightest speckle in the region, detection of a crashed aircraft using the difference technique is a very difficult problem which awaits improved resolution and finer sampling.

4.0 Interferometric Coherence and Change Detection

To exploit change detection without some of the inherent difficulties of detected SAR images, the effects of change on interferometric coherence have been examined in the same manner as has been previously carried out (e.g. *Rignot* *and van Zyl, 1993; Corr and Rodrigues, 1998, Geudtner et al., 1996*). This has the additional advantage of making it possible to detect changes even when the target is not a bright one. Processing to interferometric coherence and detection of the differences in coherence between pairs of images where one pair includes the crashed aircraft in both images and one pair in which at least one of the images does not include the crash can be used to determine the location of this target.

The interferometric coherence is a function of contributions due to the baseline, target temporal stability and system noise (*Zebker and Villasenor, 1992*). In the study of changes in man-made targets, it is desired to maximize the correlation of these targets while minimizing the correlation of the clutter. The orbit control and knowledge of the ERS-1 and -2 satellites are of significant assistance in this. The website of the European Space Agency (*earth.esa, 2001*) makes it possible to quickly determine if the perpendicular baselines is acceptable for the formation of interferometric pairs. Sufficiently small baselines act to minimize the decrease in coherence. (As interferometry was not a major requirement of the RADARSAT-1 programme, the ability to obtain acceptable baselines using this satellite has been found to be much more difficult.)

The interferometric coherence is given as:

$$\rho = \frac{\left| \sum_{i=1}^{N} z_{1i} z_{2i}^{*} \right|}{\sqrt{\sum_{i=1}^{N} \left| z_{1i} \right|^2} \sqrt{\sum_{i=1}^{N} \left| z_{2i} \right|^2}} \qquad (1)$$

where:

z_{1i} and z_{2i} are complex number amplitudes of samples i in sub-window images 1 and 2 of N samples (*Touzi et al., 1999; Mansfield et al., 1997*).

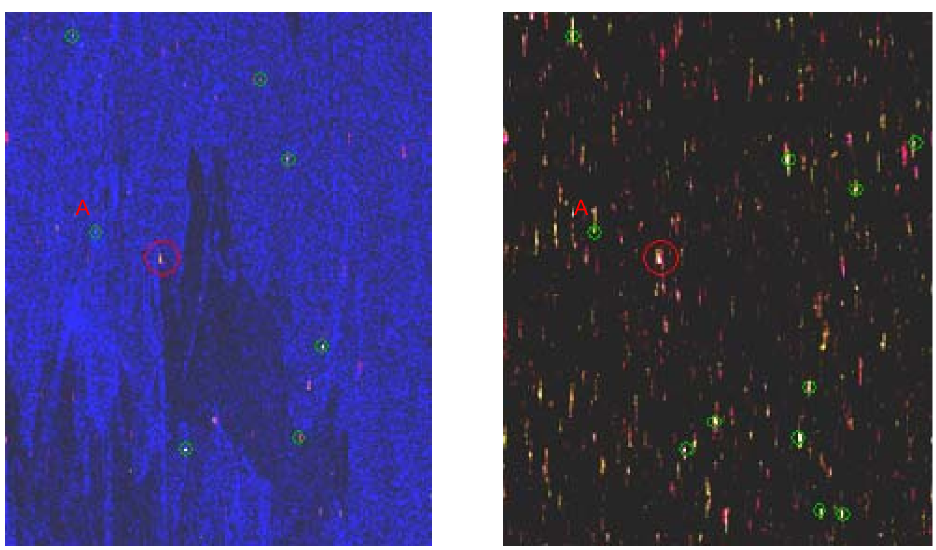
4.1 Analysis of Coherence: Little Grand Rapids

In this study, three ERS-2 images were used in the processing of the Embraer EMB-110 crash at Little Grand Rapids: One obtained prior to the crash (October 01 1997) and two obtained following it (January 14 1998 and March 25, 1998). Figure 7a shows the superposition of the coherence in a colour composite image. Here, the coherence between post-crash images (January-March Coherence: JMC) is on the red channel, with the coherence difference between JMC and JOC (January-October Coherence) on the green channel, and these are overlaid on the January image which is used as background (blue channel).

In this image, low coherence values have been removed by the use of a threshold function.

The color composite of Figure 7b represents the superposition of the post-crash coherence pair (JMC) with the two pre/post crash coherence pairs (JMC-JOC) and (JMC-MOC), where MOC is the March-October coherence. In this particular case, it is clearly seen that the largest and "whitest" point target is near the expected location of the crashed airplane. However, detailed examination of available information about the crash site location suggests that this may in fact not be the crashed aircraft, but rather, a false target.

The methodology used here enhances the information "hidden" in the data. JMC represents the stability of a target and the differences (JMC-JOC) and (JMC-MOC) enhance the changes and remove the stable targets (e.g. buildings and rock faces) in pre/post crash pairs. The processing that is used for determination of the point targets is critically dependent on the thresholds chosen. It is believed that further study and a more adaptive (dynamic) methodology for the determination of threshold for point target determination using the coherence images will make it possible to decrease the number of false alarms. Some of these false alarms that will not be eliminated are those, which are due to true changes such as at point A (in Figure 7a and 7b) which was due to construction near the runway which added a building not appearing in the early imagery of this scene.



a) b)

Figure 7. a) January power image (blue) accompanied by JMC (red) and JMC-JOC (green); b) Color composite image of JMC (red) overlaid by JMC-JOC (green) and JMC-MOC (blue). A point near the expected crash site is

indicated within the circle. Descending Pass: Sample spacing: 7.91m. (slant range) by 3.95m. (azimuth).

It should be noted that three scenes are required for this processing. In the case of current spaceborne systems having orbit cycles of 35 days (ERS-1/2) and 24 days (RADARSAT-1); the time frames are too long for this application. This methodology is more suitable for future systems with much shorter repeat periods.

4.2 Analysis of Coherence: Cornwallis Island

Coherence analyses have been performed with the three RADARSAT-1 images (Figure 2) acquired of the Fairchild-27. Only post-crash images were possible in this case. Hence the methodology based on changes in coherence over the crash site is not useful. However, the seasonal temporal decorrelation of the scene could help. The snow cover and the variations in surface moisture are expected to decrease the coherence over the scene. Figure 8 (and its subimage in Fibure 9) is a colour composite composed of July 28, 1998 – October 8, 1998 coherence (red channel), July 4, 1998 – October 8, 1998 coherence (blue channel) and the July 28 1998 intensity image as background (green channel). In this scene, the coherence images have been thresholded to remove all values below a limit (in this present case, the threshold was $\rho = 0.4$) (*Atlantis, 1999*). Clusters of points were located for a cluster size restricted between three and five samples.

Close scrutiny of Figure 8 indicates that only one target was highlighted (the Fairchild-27). This is a consequence of the crashed aircraft having high backscatter and there being high coherence in both image pairs (i.e. white composite sample). The ground area being analyzed in these figures is approximately 33 km^2. The number of false alarms detected is less than .03 per square km.

If the plane was not "bright", hence, separable from its surroundings by the intensity contribution from the green channel, then, two further sites would be retained (appearing as pink samples in the composite image), corresponding to high coherence in both pairs, but not as strong an intensity. In this case we would have 2 false alarms in this area, hence .06 false alarms per square km.

If only one coherence pair was available, then yellow-orange or light blue composite samples on the same figure represent the resulting false alarms in the presence of bright target. Red or blue samples refer to coherent target with low backscattering behavior for a single interferometric pair.

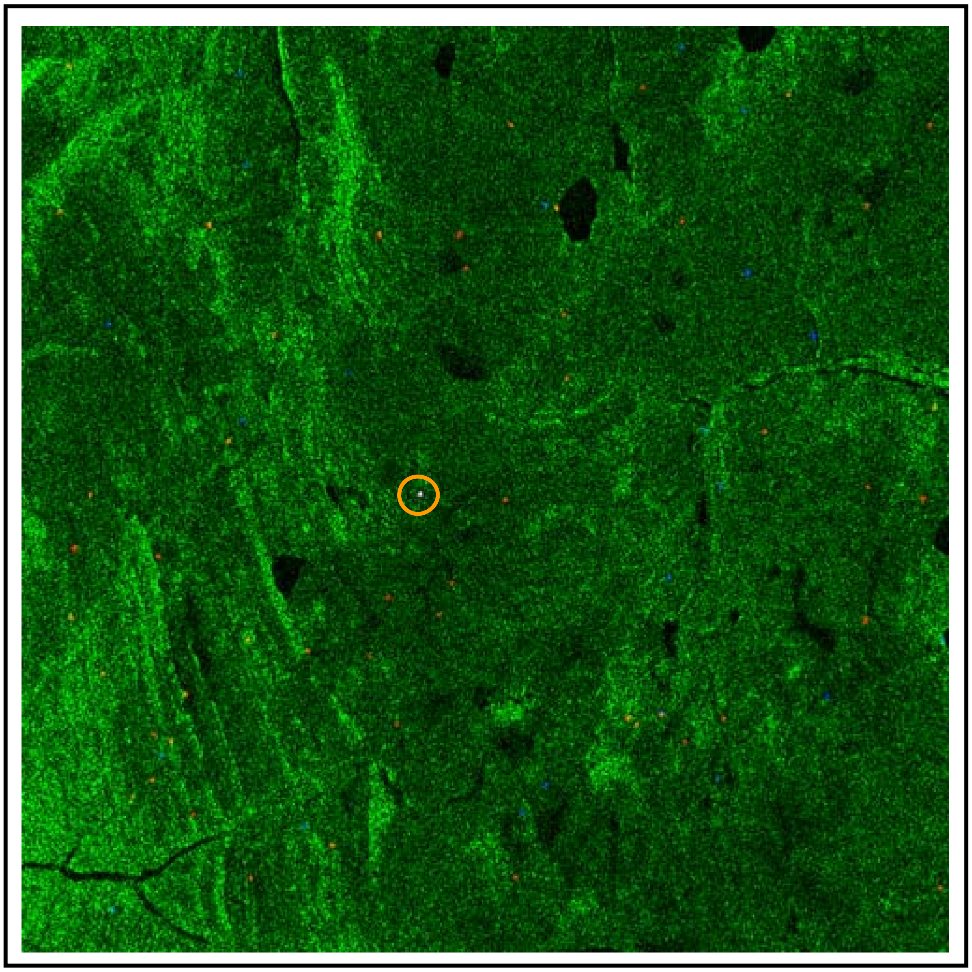


Figure 8. Colour composite of RADARSAT-1 F5 images over the Fairchild-27 on Cornwallis Island close to Resolute, N.W.T. Red channel: July 28, 1998 – October 8, 1998 coherence; Green channel: July 28, 1998 intensity; and Blue channel: July 04, 1998 – October 8, 1998 coherence. The orange circle indicates the airplane location.

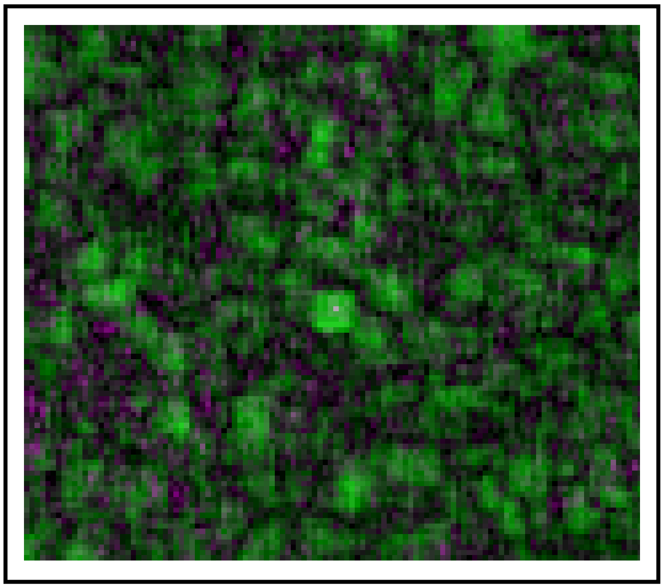


Figure 9. Zoom on the Fairchild-27 in Resolute in Figure 8. Color composite of RADARSAT F5 images: Red and Blue channels: July 04, 1999; Green channel: Coherence scene of July 04 1999 with July 28 1999.

Another examination of the use of coherence has been performed with the pair of images from July 4, 1998 and July 28, 1998. This processing shows that the pixel at the location of the Fairchild-27 is significantly decorrelated when compared to its surroundings (Figure 10a) The average coherence (ρ) over the crashed aircraft is lower than 0.3; in the higher coherence of the surrounding region, ρ varies from 0.4 to 0.8. It is not unexpected that high coherence would be obtained over the scene for small time separation between the two July images. What is not clear is the reason for the loss of coherence over the plane.

Because the terrain in the area of the crash is relatively uniform (as can be seen from photographic images), it is expected that the contribution to the phase change due to increasing slant range is well-behaved so that a one sample shift in the co-registration will not affect the coherence value as much in the surrounding terrain. However, if the target phase changes quickly, as occurs in the area of the point target, the coherence is expected to be radically reduced due to this coregistration error. Unexpected variations at point target locations may be the result of not clearly understood impacts on the phase distribution of interpolation in the resampling.

A linear translation of the July 28 image over the July 04 image, followed by a coherence evaluation was made. The translation was performed by taking the point target as a tie point for coregistration and the slave image was shifted by the column and row difference between the Master (July 04, 1998) and Slave (July 28, 1998) images. Figure 10b shows that the target coherence increased significantly compared to the initial processing and was accompanied by a noticeable reduction of the surrounding coherence. This suggests that the coherence could be improved through refinements in the coregistration techniques.

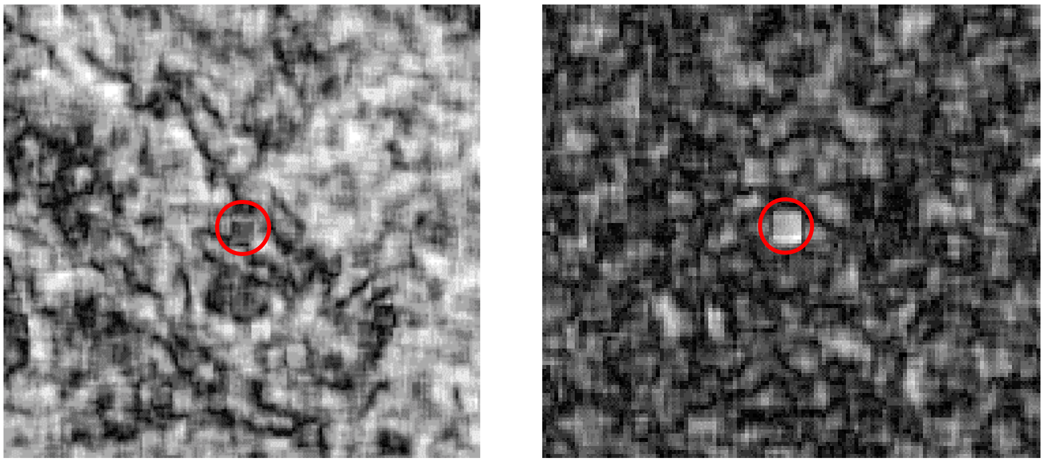

a) b)

Figure 10. Coherence generated with July 04, 1998 and July 28, 1998 interferometric pair (perpendicular baseline = 778 m). a) Spectrum correlation/coregistration. The target appears decorrelated compared to the surroundings. b) Linear translation coregistration. The target shows high coherence, and is accompanied by reduced coherence in the surroundings.

Another coherence analysis was performed between an image acquired on March 30, 1998 and these same three Resolute images. No coherence was found over the target for the 3 pairs (for baselines which varied from 381 m to 426 m) and the March 30 backscattering intensity over the plane was not higher than the surrounding clutter. Reasons for this lack of coherence are not clear.

Other examples of interferometric coherence have been obtained of a scene acquired in the region of Goose Bay, Labrador. In this case, only post-crash imagery is available: The airplane crashes of interest occurred between 1947 and 1998. For these cases, analysis has concentrated on determining the coherence.

4.3 Analysis of Coherence: Labrador

The choice of an appropriate threshold in two different coherence pairs is used to create a bitmap, which can be multiplied together and used with one of the SAR images to create an image of possible targets. Figure 11 shows the results for a B-36 that crashed in 1951. A coherence image was generated from a RADARSAT-1 interferometric pair using F3N images acquired on July 13, 1999 and August 6, 1999. The input images were processed from RAW product to SLC resolution enhanced product (*Atlantis, 1999*). The coherence over the scene was high, as expected, due to the short time interval between acquisitions. A threshold of 0.80 on the coherence scene combined with the constant threshold on the intensity August image (retained values higher than 150 on an 8 bit (0-255) range). In this case, the number of false alarms is 7 for a search area of 3.4 km^2 (i.e. 2 per km^2). In a realistic crash scenario, the number of false alarms would be decreased through the use of difference techniques, which, as shown in the imagery of Little Grand Rapids, can be used to eliminate targets which have not changed from the time prior to a crash to the time following a crash.

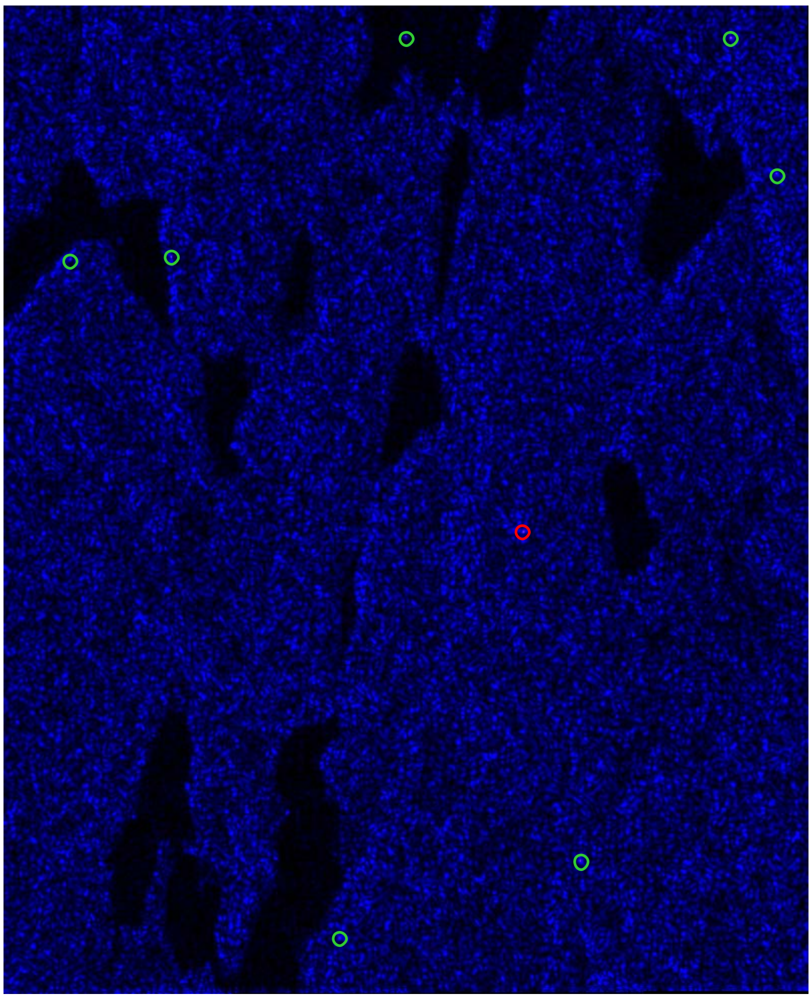


Figure 11. B-36 (red circle) found by coherence analysis of RADARSAT-1 F3N July 13, 1999 and August 06, 1999 resolution enhanced interferometric pair. Green circles (7) indicate other (false) targets detected over an area of 3.4 km^2.

Atlantis Scientific Inc. (*Atlantis, 1999*) does not recommend using resolution-enhanced products for interferometric analysis. Based on the work in this study, if there are enough possible well defined tie points in the scene (e.g. lakes and bright features as in Figure 8), resolution enhanced products can be used in "target coherence" analysis. In resolution enhanced products, local details are reduced, which implies difficulties in the "automatic" coregistration procedure which is based on spectrum analysis. Only entities like lakes and rivers kept their "appearance". Presence of such targets is essential for a good coregistration.

4.4 Analysis of Coherence: Near the Labrador-Quebec Border

Another study has consisted of images acquired prior to and following a crash in early July, 1999 of a Cessna-185 near the Quebec-Labrador border.

Three RADARSAT-1 F1 images acquired after the crash (October 7, 1999, October 31,1999 and January 11, 2000) were used. Bright targets were located in these images: Those which were found to recur between images were not located in the proximity of the coordinates of the crash. Those found in the proximity of these coordinates were seen to vary from image to image. In the coherence study, no conclusive results could be found because no distinguishable coherence was obtained in the coherence pairs of the local scene: Perpendicular baselines should have been acceptable for good coherence: October 7-January 11: 706 m. and October 31-January 11: 887m. and reasonable coherence (October 7-October 31: 1593m)

Coherence analyses have also been performed with ERS-2 data: One pre-crash scene acquired on May 17 1999 and 3 post-crash scenes (October 4, November 8 and December 13 1999). The perpendicular baselines for all possible pairs are short; the longest is 210 m for the May-December pair. With the November scene selected as the "master image" coherence over the crash site is not high in the post-crash pairs. The bitmap product of coherence scenes, thresholded at 0.4 for each post-crash interferometric pairs, does not help in the reduction of false alarms or in the detection of a target at the ground truth coordinates.

Initial conclusions on this unsuccessful study are that the resolution of the imagery provides an insufficient number of samples over the crashed aircraft.

5.0 Discussion

Coherence analysis over crash sites is very difficult to perform, in particular, for cases where the resolution is such that there are only a few samples in the final image due to backscatter from a crashed aircraft. In this work, we have explored the assumption that a stable target within variable surroundings should show a high coherence value and the surroundings a much lower one and found that this does not work efficiently. Most of the time airplanes are present as major contributors to such a small number of samples in a SAR image (even for RADARSAT-1 Fine Beam) due to the relatively low resolution (compared to other available SAR systems). Consequently, the contribution of "plane samples" is low in the coherence calculation which uses a larger number of samples . Thus, in many of the cases, the target is not able to sufficiently influence the value of coherence that is calculated. For cases, where the man-made target appears in a larger number of samples, as did occur for the location of the new building near the Little Grand Rapids runway, or is significantly brighter than the surroundings (e.g. Fairchild-27 at Resolute) coherence does make it possible to detect such a target. In fact, in the interferometric pairs analyzed, the coherence value was seen to be higher over buildings (as has been seen in other work). Thus, in higher resolution imagery, it is expected that this technique should be suitable,

From the literature, we do note as well, that there are cases where single point targets could be used (*Ferretti et al., 1999*), but this would require greater numbers of images and processing that is not currently included in the commercially available package.

Optimal coregistration of the slave image is not easy to perform and is clearly also the cause of some of the difficulties here. Even if the RMS error in the coregistration is lower than 0.2 samples, this does not imply that the particular point target in the master and slaves images are at the same position. In the case of Figure 10a, the coregistration RMS error was 0.05 samples, but, on close examination, it was found that the point target in the slave image was unexpectedly shifted by 1 line and 1 sample, hence, producing a low resulting coherence. The coregistration that was performed was carried out in the spectral domain, which is a good method for general interferometric analysis. However, in "target" analysis, it is believed that point target tie points should be used in the coregistration refinement process.

In forested areas, the coherence approach at C-Band and these resolutions has not been found, in general, to increase the "detectability" of the target. However, for permafrost areas, it does show success in the detection of the targets and the reduction of false alarms.

6.0 Conclusions

In this paper, we have examined a number of possible methods for assisting Search and Rescue in the finding of crashed aircraft in Canada using imagery from spaceborne SAR systems. Results indicate that there is a significant potential for using spaceborne SAR systems to assist in finding such crashes in the absence of operating beacons (Emergency Locator Transmitters), and in particular during times of darkness and inclement weather. Further success and application of these methodologies will be occurring in the future as the number of satellites, their resolutions and wavelengths of operation and the repeat coverage over an area (due to increased pointing capabilities of spaceborne SAR systems) are all improved.

These studies have provided a baseline in current capabilities using imagery and interferometry.

A significant amount of other work including the use of polarimetric Synthetic Aperture Radar systems for assisting Search and Rescue in finding crashed airplanes has not been described here. Such studies supported by the New Initiatives Fund of the National Search and Rescue Secretariat are ongoing at CCRS.

7.0 Acknowledgments

We would like to thank Paul Budkewitsch (CCRS), Tony Gasbarro (Transportation Safety Board of Canada) and Clinton Mowbray (444 CS Squadron, 5 Wing Goose Bay) for assistance, in particular, with ground truth images and coordinates of crashed aircraft described in this document. We thank Mr. J. Campbell for his assistance in giving the approximate location of the crash site at Little Grand Rapids. and to Universal Helicopters, Goose Bay for their assistance (under contract) in the ground truthing at Goose Bay, Labrador. We are indebted to the many others who have taken the time to discuss with us and have provided information on the locations and ground truth information for other crashed aircraft in various regions of Canada and the methodologies of Search and Rescue. We thank Laurence Gray, Paris Vachon, and Bob Neville of CCRS and Karim Mattar of DREO for useful discussions and/or useful comments on the manuscript.

8.0 References

Atlantis Scientific Inc. 1999a. *EarthView Advanced Precision Processor (APP for SAR), Version 1.5 User's Guide*, 150 p.

Atlantis Scientific Inc. 1999b. *EV-InSAR Version 1.2 User's Guide*, 318 p.

Avery,N. 1998. *Whiskey Whiskey Papa*, Norman Avery (Publisher), Ottawa, Canada.

Buckley, J. and P. Somers. 1996. "Evaluation and Validation of RADARSAT Imagery for National Defence Air and Land Operations, Centre for Space Research, RMC, Technical Report CSR96-01," 12p.

Cihlar, J., T.J. Pultz, and A.L. Gray. 1992. "Change Detection with synthetic aperture radar," *International Journal of Remote Sensing*, 13(3): 401-414.

Corr, D.C. and A. Rodrigues. 1998. "Coherent change detection of vehicle movements," *Proceedings of International Geoscience and Remote Sensing Symposium*, Seattle, Washington: 2451-2453.

Creber, K.A.M. A.R. Green, E.A. Ough, and V. Singh. 1997. "A Comparison Study of Data from RADARSAT, Landsat, A Multispectral Camera, A Field Portable Spectrometer and A High Resolution UV-Vis-NIR Spectrometer," *Proceedings of the International Symposium on Geomatics in the Era of RADARSAT*, 5p.

Cunningham, C.J., W. Millett, and P.W. Somers. 1994. "Multispectral Satellite Imagery for Search and Rescue," *Proceedings of the 8th CASI Conference on Astronautics*: 97-99.

Dreibelbis, R., D.W. Affens, H. Rais, and A.W. Mansfield .1999. "The Montana Project, " *Proceedings of SPIE Conference on Automatic Target Recognition IX*, *SPIE,* 3718: 221-229.

ESA, 2001: http://earth.esa.int/l2/4/eeo4.444

Ferretti, A., C. Prati, and F.Rocca. 1999. "Permanent Scatterers in SAR Interferometry*," Proceedings of International Geoscience and Remote Sensing Symposium*, Hamburg, Germany, 3 p.

Geudtner, D., R. Winter, and P.W. Vachon. 1996. "Flood Monitoring Using ERS-1 SAR Interferometry Coherence Maps," *Proceedings of International Geoscience and Remote Sensing Symposium*, Lincoln, Nebraska, 966 -968.

Jackson, C.R., H. Rais, and A.W. Mansfield. 1998. "Polarimetric target detection techniques and results from the Goddard Space Flight Center Search and Rescue Synthetic Aperture Radar (SAR^2) program*," Proceedings of Automatic Target Recognition VIII, SPIE*, 3371: 185-193.

James, R.R. and C.R. Hendrickson. 1994. "Efficacy of frequency on detecting targets in foliage using incoherent change detection," *SPIE*, 2230: 220-229.

Mansfield, A.W., P.L. Poehler and H. Rais. 1997. "SAR coherent change detection (CCD) for search and rescue", *Proceedings of Automatic Target Recognition VII, SPIE,* 3069: 224-233.

National Search and Rescue Manual (B-GA-209-001/FP-001, DFO 5449) Issued on Authority of the Chief of the Defence Staff and the Minister of Fisheries and Oceans, 1998.

PCI Geomatics. 1998. PCI-EASI Pace Version 6.3, PCI Geomatics, Richmond Hill, Canada

Rignot, E.J.M. and J.J. van Zyl. 1993. "Change detection techniques for ERS-1 SAR data," *IEEE Transactions on Geoscience and Remote Sensing*, 31(4): 896-906.

SAR 2001:
http://www.dnd.ca/menu/SAR/eng/index.htm

Singh, V., J.R. Buckley, and P. Somers. 1996*. Evaluation and Validation of RADARSAT Imagery for National Defence Air and Land Operations, Centre for Space Research, RMC, Technical Report CSR96-01*, 12p.

Sivertson, W.E. , Jr., 1976. *A Global Search and Rescue Concept Using Synthetic Aperture Radar and Passive User Targets NASA Technical Report NASA -TN- D-8172*, NASA Langley Research Center, Hampton, Va., U.S.A., 29 p.

Thorsteinsson, Ray. 2000. Private Communication, April 2000.

Touzi, R., A. Lopes, J. Bruniquel and P.W. Vachon. 1999. "Coherence Estimation for SAR Imagery", *IEEE Transactions on Geoscience and Remote Sensing*, 37(1): 135-149.

Transportation Safety Board of Canada. 2000. *Aviation Occurrence Report: Collision with Terrain Sowind Air Limited Embraer EMB-110P1 BandeiranteC-GVRO, Little Grand Rapids, Manitoba, December 9, 1997, Report Number A97C0236*

Wallace, R.G. D.W. Affens, and H. Rais. 1997. "Beaconless Search and Rescue Overview - History, Development, and Achievements," *Proceedings of Automatic Target Recognition VII, SPIE*, 3069 ; 162-166.

Wallace, R.G., D.W. Affens, and S.W. McCandless, Jr. 1998. "Search and Rescue from Space," *Proceedings of Automatic Target Recognition VIII, SPIE*, 3371: 174-184.

Weydahl, D.J. 1998. *Analysis of satellite SAR Images for change detection over land areas*, Dr. Scient. Thesis, University of Oslo, Norway, 234 p.

Zebker, H.A. and J. Villasenor. 1992. "Decorrelation in Interferometric Radar Echoes", *IEEE Transactions on Geoscience and Remote Sensing*, 30(5):950-959.