VALUE ADDED RADARSAT PRODUCTS FOR GEOSCIENTIFIC APPLICATIONS[1]

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ABSTRACT

Geoscientific applications benefit noticeably from RADARSAT flexibility in image acquisition with its variety of viewing modes. Value-added products are then key points for their successful and regular use to bridge the gap between the technology and the end user communities. Simple operational tools are presented for the generation of value-added products, which integrate RADARSAT and geoscientific data. Some of them can be viewed in 3D using the chromo-stereoscopic effect to benefit geoscientific investigations of the "Astroblème de Charlevoix" (Quebec). Depth perception is related either to the water depth or the terrain elevation.

RÉSUMÉ

La variété des modes de visée de RADARSAT permet une grande flexibilité dans l'acquisition d'images pour les applications géoscientifiques. Afin de combler une lacune entre les différentes communautés (technologie, utilisateurs), les produits à valeur ajoutée sont un atout important pour la bonne utilisation de ces données sur une base régulière. Des outils simples et opérationnels sont présentés pour la création de produits à valeur ajoutée avec des données géoscientifiques et de RADARSAT. Pour faciliter l'interprétation géoscientifique de l'«Astroblème de Charlevoix» (Québec), certains de ces produits sont visualisés en 3D grâce à l'effet de chromo-stéréoscopie. La perception du relief est due à la profondeur des eaux ou au relief du terrain.

1.0 INTRODUCTION

RADARSAT (Luscombe et al. 1993) is the first Synthetic Aperture Radar (SAR) satellite, which provides observations of the Earth's surface on an operational basis using a variety of viewing modes. Geoscientific applications stand to benefit noticeably from such flexibility in image acquisition. As an example, one can now achieve regular observations required for the monitoring of geological hazards or the observation of topographic elements under optimal illumination geometry. Consequently, an era of unprecedented application of SAR data to geosciences is under way. To spur the development of these applications, it is important to develop meaningful, value-added products, which bridge the gap between the technology and the end user communities.

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The ChromaDepth™ glasses can be used to perceive the 3D effect on the chromo-stereoscopic images. They are available in limited supply from the author at CCRS.

Previous research has demonstrated the synergism of multi-source data for different applications (Zobrist et al., 1979; Daily et al., 1979; Guindon et al., 1980, and others). The different beams (fine, standard, etc.), incidence angles (10º to 59º), and products (single or multi-looks, fine or coarse resolutions, etc.) of RADARSAT enable users to generate a variety of interesting value-added products when the SAR imagery are integrated with geoscientific data. Along with the flexibility of RADARSAT image products comes a range of geometric and radiometric characteristics which must be addressed adequately during the integration process to allow for the successful use of the imagery for geoscientific applications.

This Research Note presents simple and operational tools serving to integrate and generate value-added products, and shows preliminary examples of 2-D and 3-D products using RADARSAT and geoscientific data. Since the study site is located in the most seismically active area of Eastern North America, the region of Charlevoix, Quebec, a brief discussion is included on the utility of these value-added 3-D products for geomorphologic interpretations.

2.0 DATA ACQUISITION AND PROCESSING

2.1 Study Site

The area of interest is the Charlevoix region (Québec) located approximately 100 km NE of Québec City. The study site presents an unusual combination of geological characteristics, which are well suited to illustrate the benefits of value-added products in geosciences. The region is part of the "Jacques-Cartier" tectonic block (Du Berger et al., 1991) of the Canadian Shield where differential erosion over more than a billion years as well as glacial scouring have produced a well dissected landscape. The local physiography is, however, unique having been modified by the impact of a meteorite approximately 350 million years ago. The resulting structure is a semi-circular depression named the "Astroblème de Charlevoix" (Rondot, 1968) which is flanked to the southeast by the St. Lawrence River. Relief within the rim of the impact crater is subdued, and delineation of geologic contacts and structures based on imagery is more difficult. Within the impact structure, the highest relief is observed at the central peak named "Mont des Éboulements". Further detail on the geology of this area can be found in Rondot (1968) and Robertson (1968*)*. More recently, De Sève et al. (1994) investigated the usefulness of ERS-1 SAR data for the geomorphologic characterization of the crater and its surrounding area. Their work illustrates notably the use of integrating Landsat-TM and ERS-1 SAR data to overcome specific problems of radar imagery associated with foreshortening and shadowing.

2.2 Data Set

The remote sensing data consist of a RADARSAT standard beam (S2) scene acquired March 5, 1996 from a descending orbit. This beam mode has approximate viewing angles ranging from 24º in the near range to 31º in the far range. The data were processed at the Canadian Data Processing Facility (Denyer et al., 1993), and the resulting product is an image in slant range, with a pixel spacing of 8.1 m in range by 5.3

m in azimuth, and oriented along the satellite track. Since the data was acquired in a descending orbit, the illumination direction is approximately from the west to the east (Figure 1).

The cartographic data include:

- topographic maps at a scale of 1:50,000;
- a digital elevation model (DEM), with a grid spacing of 30 m, generated by the Canada Centre for Topographic Information (CCTI) from the 10 m contour lines of the 1:50 000 topographic maps. The accuracy is better than 10 m. The elevation varies from 0 to 1082 m. The area covered is 60 km by 70 km and centered on the "Astroblème de Charlevoix",
- the digital bathymetric data (DBM), with a grid spacing of 30 m, was generated in SPANS using a Krigging interpolation method applied to the digitized bathymetric map contours. The water depth varies approximately from-50 to 0 m.

2.3 Processing

Figure 1 is the raw RADARSAT image with distortions typical of slant range SAR images illustrating the need for geometric corrections. A geometric correction method developed at the Canada Centre for Remote Sensing (CCRS) (Toutin, 1995), commercially available and recently adapted to RADARSAT data, is used to geocode the RADARSAT imagery with the DEM. The method takes into account and corrects for all the distortions related to the full geometry of viewing (sensor, satellite, Earth including the terrain elevation), and the map projection. Further details on the correction method can be found in Toutin (1995). The final accuracy of the resulting ortho-images is dependent on the accuracy of the ground control points (GCPs) during the geometric modelling computation process, and of the DEM during the rectification process. Figure 2 gives the curves which represent the planimetric error on the ortho-image (5,10,...,40 m) as a function of the SAR image acquisition viewing angle and the DEM accuracy. These curves were mathematically computed using the elevation distortion parameters of the geometric correction model (Toutin, 1995). When two of these three parameters are known, the third one can be derived from this Figure. As an example, an 10-m elevation error in the DEM will propagate through the rectification process, and generate a planimetric error of about 20 m on the resulting ortho-image, if the SAR image was acquired with a viewing angle of approximately 27º at its centre. Inversely, if a 30-m accuracy for the ortho-image is required with a 20-m accurate DEM, the image should be acquired with a viewing angle more than 34°, such as F1 to F5, S4 to S7 and W3 RADARSAT-SAR images (Figure 2).

Figure 1: RADARSAT-SAR image (6590 pixels by 19172 lines) of the Charlevoix region: descending orbit, standard beam (S2), slant range (8.1 m by 5.3 m), satellite track oriented. Illumination direction is approximately from west to east. © CSA/ASC 1996

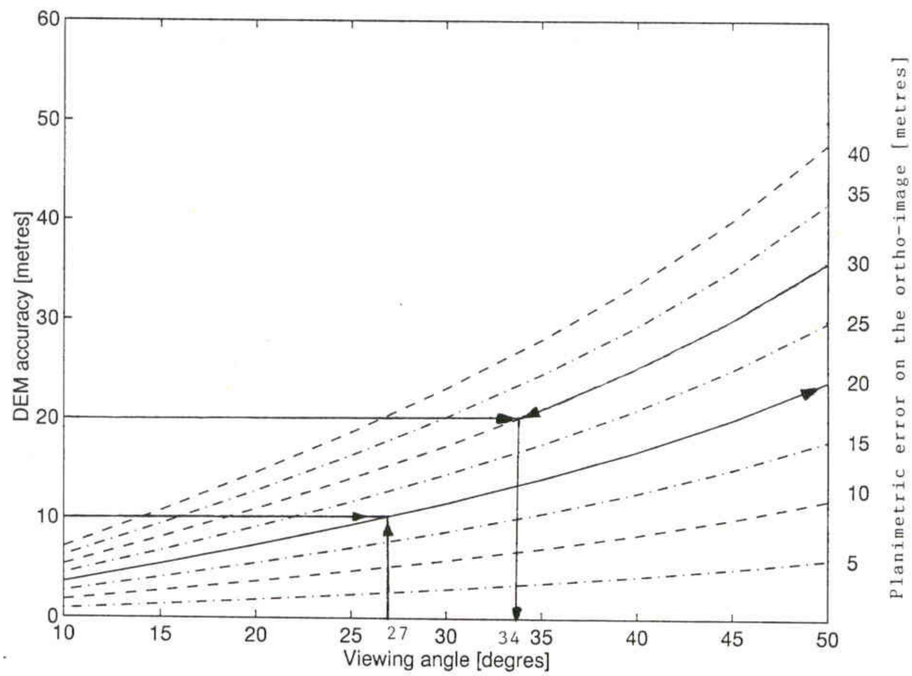

Figure 2: Relationship between the RADARSAT-SAR image acquisition viewing angle (degrees), the DEM accuracy (metres) and the planimetric error on the ortho-image (metres). The arrows and the solid curves represent numerical examples of the relationship between the three parameters.

In our study, the GCPs were digitized from the 1:50 000 maps and positioned mainly along water boundaries. Errors in the cartographic coordinates were of 30 m and 10 m for the planimetry and altimetry, respectively. The GCP positioning error on the image was in the order of 2-3 pixels (10-15 m). The root mean square residuals on the 28 GCPs collected, resulting from the geometric correction model computations, are in the order of 25 m in both directions (X and Y). Furthermore, since the DEM used in this study has an elevation error of 10 m, it generates with the S2 RADARSAT-SAR image (27° at its centre) a planimetric error of 20 m on the ortho-image, as explained earlier from the Figure 2. The ortho-image is then expected to have a final accuracy of 30 to 40 m. The Gamma adaptive filter (Lopes et al., 1993), was incorporated during the resampling process to reduce speckle. Filtering during the resampling step of the rectification avoids multiple resampling of the imagery, which degrades the radiometry and reduces the interpretability of the image. Finally, the DBM was combined with the DEM, and stored in a 16-bit signed file to take into account the negative values (-50 m to 0 m) of the water depth.

The last step is the integration of the ortho-RADARSAT imagery with the DEM and/or the DBM to generate chromo-stereoscopic images. Chromo-stereoscopy is a method which enables the display and perception of depth from multi-source data (remote sensing and geoscientific) (Toutin and Rivard, 1995). The third dimension is colour coded into the image, then decoded with the refractive ChromaDepth™ glasses (Steenblik, 1986). The resulting chromo-stereoscopic image is a 2D colour composite image, which can be viewed and interpreted monoscopically, but which "jumps" into 3-D when viewed with the ChromaDepth™ glasses. In the examples presented in this Research Note, the depth perception of the chromo-stereoscopic images is related to the water depth of the St. Lawrence River and/or to the elevation of the land mass. The radiometric integration used is the intensity-hue-saturation (IHS) transformation with the RADARSAT-SAR ortho-image, the DEM/DBM, and a constant value (150) assigned to I, H, and S respectively. Further details on the chromo-stereoscopic method and the generation of 3-D images can be found in Toutin (1997).

3.0 VALUE ADDED PRODUCTS

The first product was derived from the ortho-image, geocoded to a map reference system, on which cartographic information has been added (Figure 3). It approximates an image-map and shows a sub-area of the raw image corresponding to the limited coverage of the DEM. The size of the ortho-image (60 km by 70 km) and the pixel spacing (30 m) were matched to that of the DEM for their integration and display as a colour composite image.

A quick comparison of the raw and ortho-images (Figures 1 and 3) shows the benefits of geocorrecting RADARSAT data using a DEM when conducting geoscientific investigations. With a correction for layover, steep cliffs, which mark the corridors of many regional structures, are properly located and are easily recognized. In general, all geographical and geological features are more accurately located and plotted on geocoded images (De Sève et al. 1996). Following the rectification, steep cliffs give rise to radiometric artifacts (Figure 3, letter a) which appear as bright striped areas ("expansion" of the foreshortening). The "Astroblème de Charlevoix" is difficult to recognize in the original image (Figure 1) because the semi circular shape is compressed in the range direction. The same can be said of the Mont des Éboulements, a near circular peak in the centre of the impact, which appears oblate in the raw image.

The other products are the chromo-stereoscopic images. Figure 4 (60 km by 70 km; 30-m pixel spacing) is the integration of the DBM with the RADARSAT-SAR ortho-image. Errors in coregistration are noticeable along the western shore of the St. Lawrence River and around Île aux Coudres. These are principally due to large errors in the position of the land-water boundary. Water depth for the St. Lawrence River has been coded to the full colour range (-50 m to blue, and 0 m to red). Using the full colour range, small depth variations of the water are better perceived with the ChromaDepth™ glasses. The trade-off is an erroneous effect whereby water is perceived to lie above land (black and white are lower than red in the colour depth range). This perception does not take place in Figure 5 because the water depth is coded only in the blue range. The choice of the colour range in Figure 5 is a compromise for a more realistic product rather than a scientific one.

RADARSAT-SAR IMAGE-MAP
Astroblème de Charlevoix

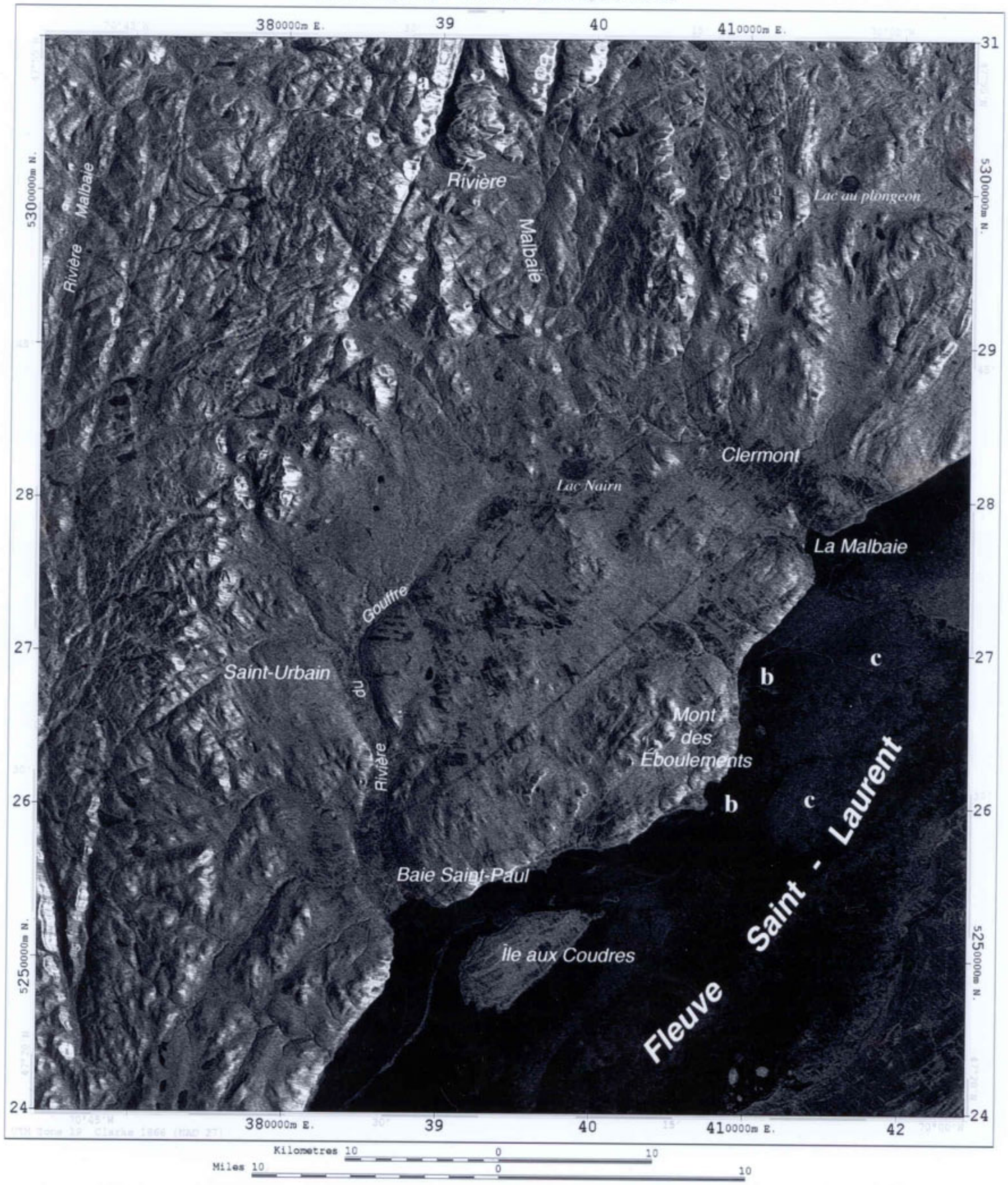

Figure 3: RADARSAT-SAR image-map of the "Astroblème de Charlevoix". Cartographic North is upward oriented.

As a tool for geoscientific investigations, the depth perception of the chromo-stereoscopic view of the DBM combined with the SAR offers no clues for mapping the southern continuation of lithologic layering (Figure 4) observed in the outer perimeter of the crater. There are, however, interesting correlation's between the DBM and the RADARSAT data which may be of interest to geoscientists studying coastal geology or the sedimentology of rivers. These correlations may illustrate the role of bottom depth on the stability and dynamics of river ice. Overall, the deepest parts of the river are along the western shore (Figure 4). In March, these deepest areas have provided low radar returns, probably due to the presence of smooth ice (Figure 3, letter b). Shallow areas along the shoreline do not display enhanced SAR returns but the shallower areas within the main channel were the site of stronger SAR returns likely due to rougher, broken river ice (Figure 3, letter c). As an example, the shallow location near the mouth of Rivière Malbaie is most likely the site of accumulation of sediments carried by this river. It appears that important transitions in depth within the main channel can result in a broken ice surface over shallow areas, which are discerned on the RADARSAT imagery. This interpretation should be the subject of further research.

Figure 5 is the chromo-stereoscopic image (60 km by 70 km; 30-m pixel spacing) integrating the combined DEM/DBM with the RADARSAT-SAR ortho-image. The color-coding is not optimized for investigation of the bathymetry but depth perception can be accentuated by increasing the distance between the viewer and the image. This is because, while the distance varies and the input ray angle remains fixed, the relative depth perception between the colours increases. Different oblique views of the image can provide different “artificial” perspective views, because the input ray angle varies. Consequently, by changing the azimuth and the elevation angle of the view, one can literally “fly” in the image in real time. These characteristics can be used to study the morphology of the terrain.

Figure 5 provides better visualization of the topographic depression and the outer deformation zone of the Astroblème de Charlevoix. The present erosional outline of the crater is not circular and some irregularities along its perimeter appear to correlate with lithologic contacts or layering internal to lithologic units, a result of fabric in the target rocks subsequently enhanced by erosion. In the crater, the impact breccias mapped in the Mont des Eboulements (Rondot, 1968), are characterized by a smoother SAR terrain texture and green-yellow hues. Color-coding of the DEM clearly enhances the relief of the ”Central Peak” area (orange-yellow hues) and reveals a concentric ring of smaller hills between the two “Inner flats”(green hues). One of these flats forms a semi-circular ring surrounding the “Central Peak”, and its extension in the river appears to be visible in the bathymetric data (area marked “deep” in Figure 4). A second, larger circular depression can be seen from Baie St. Paul to La Malbaie. Chromo-stereoscopic products are preferred for morphologic studies because variations in cover types, which are a distracting element in the image, are subdued. As an example, agricultural areas outlined in Figure 5 appear subdued when compared to Figure 4.

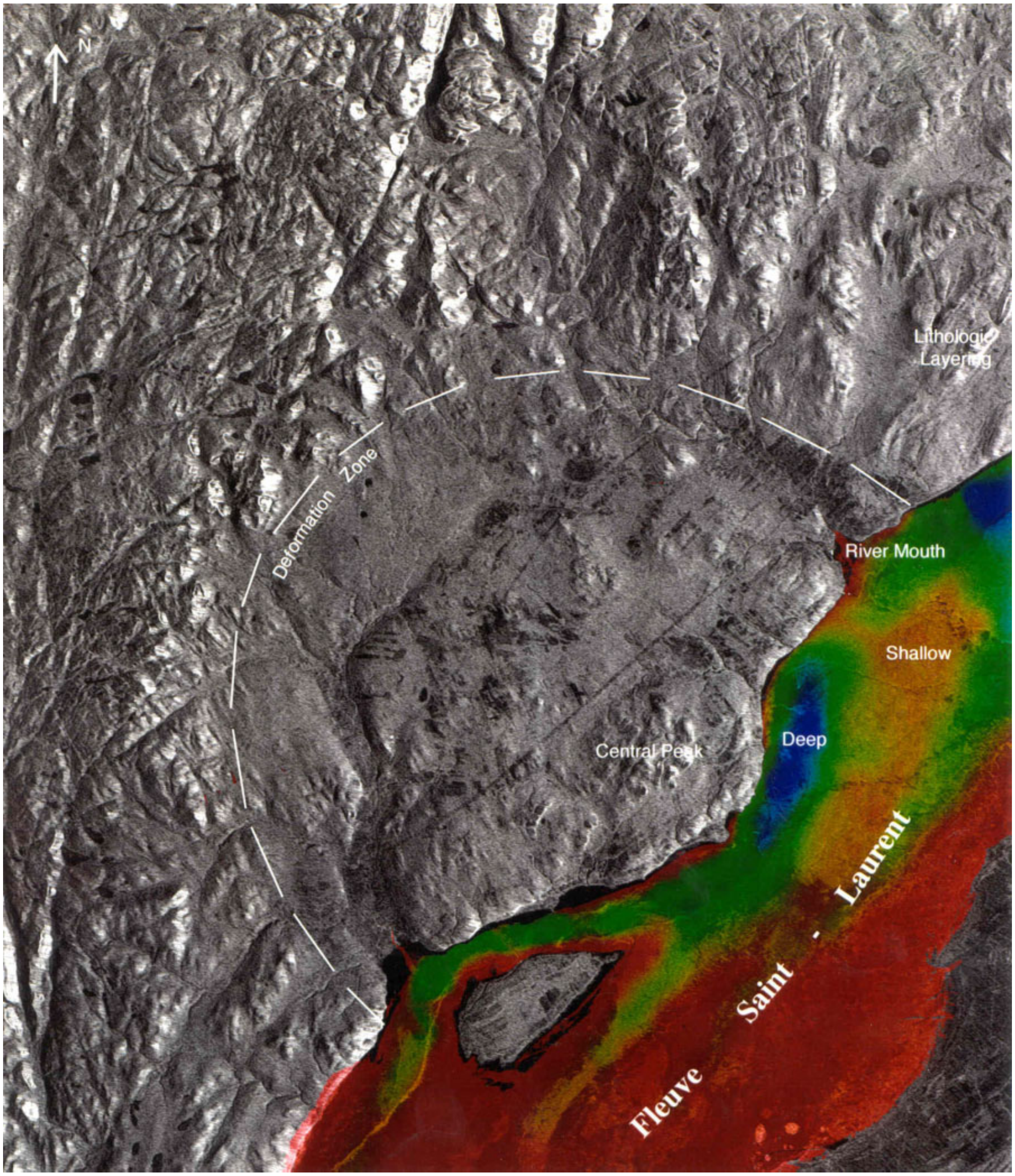

Figure 4: Chromo-stereoscopic image (60 km by 70 km; 30-m pixel size) integrating the RADARSAT-SAR ortho-image with the DBM. The full colour range (-50 m in blue and 0 m in red) has been used to code the DBM for a better perception of the water depth in 3-D with the ChromaDepth^{TM} glasses, but some areas are perceived to lie above land.

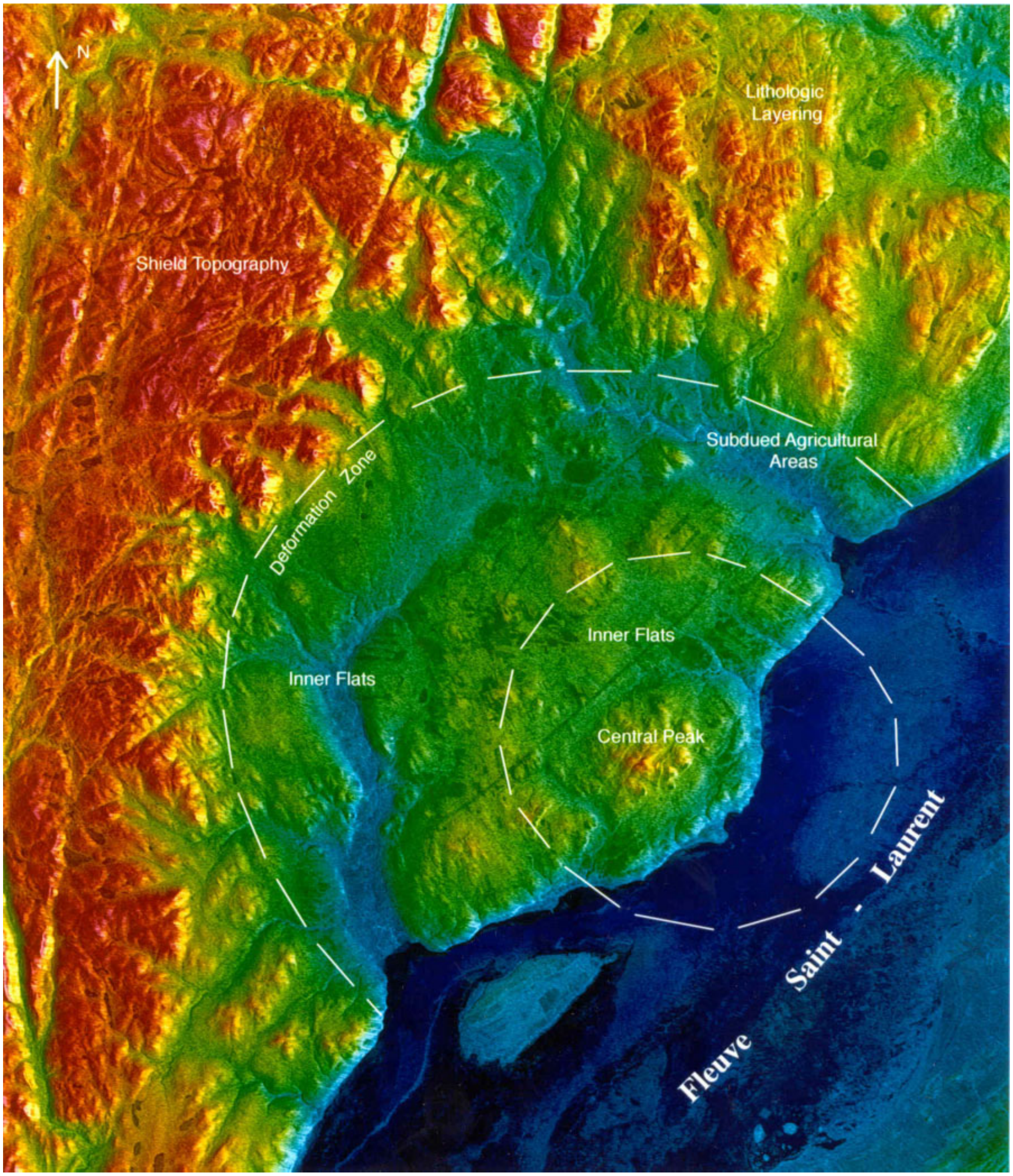

Figure 5: Chromo-stereoscopic image (60 km by 70 km; 30-m pixel size) integrating the RADARSAT-SAR ortho-image with the combined DBM/DEM. The colour range varies from -50 m in blue to 1082 m in red. Note the presence of two topographic circles within the crater. The first is formed by smaller hills between the two Inner flats. The second is larger and outlines the impact from Baie St. Paul to La Malbaie.

4.0 CONCLUSIONS

Integration of multi-source and multi-date data and generation of value-added products are key points for the successful and regular use of these data for geoscientific applications.

This paper has summarized simple operational tools (Toutin, 1995; Toutin and Rivard, 1995; Toutin, 1997) for the integration of RADARSAT data with geoscientific data (cartographic, DEM, bathymetric). These tools include:

1/ a CCRS developed geometric process to correct all the distortions of the slant range SAR image. An adaptive speckle filter has also been incorporated in the resampling during the rectification step to avoid multiple resampling; and

2/ an IHS radiometric transformation using the RADARSAT-SAR ortho-image, the DEM and/or DBM, and a constant value (150) in I, H, and S respectively.

The paper also presented the following value-added products resulting from data integration for geoscientific applications:

1/ the RADARSAT-SAR ortho-image with cartographic information to create an image-map; and

2/ two chromo-stereoscopic images, which can be viewed in 3-D using the ChromaDepth™ glasses, in which the depth perception is related to the Saint-Lawrence water depth and/or the terrain elevation.

Chromo-stereoscopic images were shown to benefit geoscientific investigations, in this case facilitating the detection of landforms diagnostic of impact structures, and the delineation of lithologic layering in bedrock units surrounding the impact structure. These images facilitated the detection of the impact breccia and concentric topographic rings within the crater which appear to extend under the St. Lawrence River. An ADRO proposal (Desjardins et al., 1996), part of the Long Term Space Plan of the Canadian Space Agency, will likely provide new answers on these issues. Fine tuning of chromo-stereoscopic products for the investigation of small bathymetric variations has enhanced an existing correlation between water depth and the amplitude of the SAR backscatter. Our preliminary interpretation is that the surface expression of shallow waters is registered as a stronger SAR return due to the presence of a broken and irregular ice surface. The chromo-stereoscopic method may therefore be a useful tool for fluvial geomorphology. Further work is necessary to confirm this hypothesis.

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