RADARSAT AND DEM DATA FUSION FOR 3D VISUALISATION OVER THE REUNION ISLAND FOR GEOSCIENTIFIC APPLICATIONS

Thierry TOUTIN
Canada Centre for Remote Sensing
588, Booth Street, Ottawa, Ontario, K1A 0Y7, Canada
Tel: (613) 947-1293; Fax: (613) 947-1385
Email: thierry.toutin@ccrs.nrcan.gc.ca
Agnes REMOND
Bureau de Recherche Géologique et Minière
3, avenue C. Guillemin, BP 6009,
F-45060 Orléans cedex 2, France
Tel: (33) 2 38 64 38 53; Fax: (33) 2 38 64 33 61
Email: a.remond@brgm.fr
Erik HOEPPNER & Danielle HOJA
Technische Universitat Dresden
D-01062 Dresden, Germany
Tel: (351) 463-4809; Fax: (351) 463-7028
Christine KING
Bureau de Recherche Géologique et Minière
3, avenue C. Guillemin, BP 6009,
F-45060 Orléans cedex 2, France
Tel: (33) 2 38 64 33 92; Fax: (33) 2 38 64 33 61
Email: c.king@brgm.fr

1. Introduction

The spatial technology represent a major asset in the carried out programmes about prevention of natural hazards. Part of them are already considered as available in operational conditions, namely the optical satellite imagery (Scanvic et al, 1992), but also the use of digital elevation model (DEM). But it turns out that those data are sometimes difficult to be gathered in every point of the world depending on environmental conditions.

The launches of the European ERS-1 radar, the Japanese JERS-1 sensors, and more recently the Canadian RADARSAT provide Earth scientists with orbital synthetic aperture radar (SAR) data with global coverage. Because these active microwave imaging systems acquire data of fundamentally different natures in comparison with the passive remote sensing systems, they are expected to generate a complementarity wealth of information to geoscientists.

RADARSAT "views" the world at a wavelength (C-band, 5 cm) where the backscatter amplitude depends on surface interaction. In fact, surface roughness, vegetation cover and moisture content of the near-surface layers of the ground play an major role in modulating the signal. Furthermore, the RADARSAT many beam modes offer a variety of image-terrain configurations of a given location that are very different in terms of geometry and radiometry. Since SAR imagery mimics very well the land shapes and the topography due to its strong sensitivity to the relief, the foreshortening with steep look angles and the shadowing with shallow look angles generating different radiometric effects (backscatter) can be used to enhance the perception of relief features (Simonett and Davis, 1983).

On the other hand all the potentialities of SAR data are far to be exploited and validated. In those domain of geoscientific applications, these technical characteristics of RADARSAT are being proved highly attractive:

- possibilities to reach every point on the globe, namely areas where the setting up of permanent monitoring system is difficult, either due to the fact of cloudiness or due to the weak of logistic support on the field;
- agility in incidence, which allows to adapt the acquisition of data to the constraints of relief; and
- programming of acquisition in high or low resolution, a good tool to change scales over the priority basins of risk.

As part of the Applications Development and Research Opportunity (ADRO) program sponsored by the Canadian Space Agency (CSA), a research has been started on the potential of RADARSAT for the detection and monitoring of natural hazards. The main objectives of this research is to integrate RADARSAT images in projects of natural risks prevention to observe and understand phenomena of natural hazards. These projects are often limited by simple constraints: high relief contrast, accessibility of study site, limitation of optical images due to clouds, complex natural phenomena, etc. RADARSAT could then be integrated in a technical network concerning cartography and monitoring of risk areas to prevent the risk, to reduce impact an occurence and to better manage the environment.

Earth observations with any satellite must be able to localise sensitive region. Several approaches can be used:

- the detection of permanent factors at the origin of the processes (slope, unprotected soil, sensible surface); and
- the detection of characteristic changes on the surface, corresponding to the consequence of a hazard. In this last approach, time series are required.

To allow the successful use and integration of the RADARSAT imagery with geoscientific data in these different approaches, the specific geometric and radiometric characteristics of the data have to be addressed adequately. This paper presents then a method and simple and operational tools serving to integrate and generate for geoscientific applications value-added products, such as the new-developed chromo-stereoscopic visualisation tool and the 3D images with RADARSAT data and DEM over a challenging study site: the Reunion Island in the Indian Ocean. Actual morphology can be studied and possible landslides hazards anticipated on this chromo-stereoscopic images. Moreover, with systematic data acquired at different period of the year, the evolution of this morphology is an asset to explain and model the erosion processes.

2. Description of the study site

In this context, the Island of la Reunion offers a threefold interest. First of all, it is particularly exposed to natural hazards of several types, especially volcanic risk, landslides and soil erosion. Secondly, a regular time series of observation on the island is very difficult to obtain in optical domain. RADARSAT is the first permanent operational SAR system covering this area. Only SAR data acquired by the American shuttle (SIR-C) were previously available on this Island. Finally, a permanent team of the Bureau de Recherche Géologique et Minière (BRGM), France is in charge of actions of cartography and monitoring of unstable terrain (Stieljes, 1986).

Reunion Island is located in the Indian Ocean. Due to its relief, its geology and its climatic context (tropical rains, cyclones...) this island suffers of very active erosion processes (collapses, landslides, mud flows, settling....). Into the bargain, the demographic pressure which modifies the agricultural land use of the soils and provokes deforestation (Desprats, 1992). Conjunction of this human pressure and the natural factors (precipitation and relief) increase the erosion processes. Thus, this region owns the sad world record of soil loss : 20 to 60 tons by hectare and by year (locally 100 tons). For example, during the "Hyacinthe" cyclone in 1980, precipitation of 7 meters of water have been registered in 12 days. The damages were considerable (flooding, destruction of dam of rivers, erosion of slopes, gullies, alluvial deposits....) and they affected either rural or urban housing of the agriculture and communication roads.

One of specific test sites concerning erosion processes is located in "Salazie" circle (North-East of the three large circles in the Island). Erosion and landslides often occurred in these circles and risks link to human activity are really important (more than 2 000 inhabitants, roads, agricultural plots). Since 1981, cartography of landslides at 1:25 000 scale have been realised by BRGM (Humbert et al, 1981). On several sites favourable to erosion, geological studies were organised. "Grand Ilet" region (Figure 1) is one of these sites where morphology is rapidly modified by large scale erosion.

Figure 1: "Grand Ilet" region in the Reunion Island showing morphology prone to large scale erosion.

3. Description of the data set

The remote sensing data consist of:

- two RADARSAT fine beam scenes (F1, F3) acquired October 6 and 13, 1996, respectively from descending orbits;
- a RADARSAT fine beam scenes (F4) acquired October 18, 1996 from an ascending orbit; and
- a SPOT panchromatic ortho-image acquired May 31st, 1996 with a 20-m pixel spacing.

The RADARSAT beam modes F1, F3, F4 have approximate viewing angles ranging from 37º, 41º, and 43º in the near range to 40º, 44º, and 46º in the far range, respectively. The data were processed at the Canadian Data Processing Facility (Denyer et al., 1993), and the resulting product is an image in ground range, with a pixel spacing of approximately 6.25 m in range by 6.25 m in azimuth, and oriented along the satellite track. For the data acquired from a descending orbit, the illumination direction is approximately from the west to the east (right to left in Figure 2).

The cartographic data include:
- topographic maps at a scale of 1:25,000; and
- a DEM with a grid spacing of 40 m, generated by the French company ISTAR in 1992 using a stereoscopic processing of two SPOT panchromatic images. The accuracy is evaluated to be 20 m in the lowlands and 80 m in the highlands. The elevation varies from 0 to 3070 m. The area covered is 88 km by 73 km.

4. Processing

Figure 2 is the raw RADARSAT F3 image with distortions typical of SAR images illustrating the need for geometric corrections before the generation of the chromo-stereoscopic image. 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 3 is the flow chart of the different processing steps to generate the final chromo-stereoscopic images. The RADARSAT-SAR processing includes the radiometric and geometric aspects:
- for the radiometry, the calibration using the calibration parameters extracted from the tape (Denyer et al., 1993), and the new adaptive speckle filtering developed at CCRS (Touzi, 1997). This speckle filtering can be incorporated in the resampling of the rectification process to avoid multiple resamplings; and
- for the geometry, the geometric modeling using ground control points acquired from the maps and the rectification using the CCRS developed method as explained previously.

The next step is the mosaicking of the descending F1 and F3 SAR ortho-images. The ascending F4 image cannot be used in the mosaic since large radiometric disparities should have generated artefacts in the viewing of the chromo-stereoscopic image. These disparities are due to the inversion of foreshortening and layover effects in the fore- and back-slopes of the mountains between the two opposite look directions.

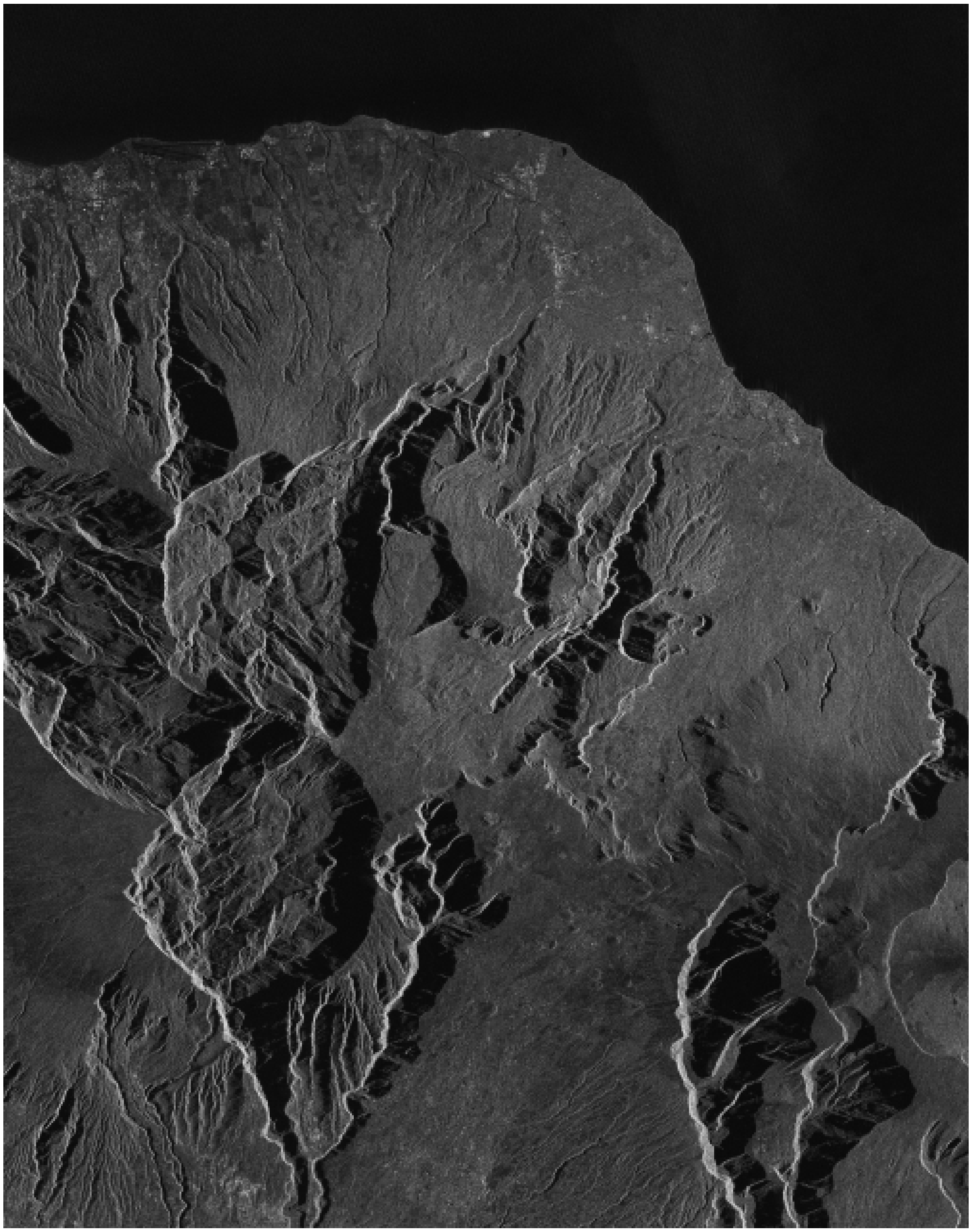

Figure 2: RADARSAT-SAR image (6178 pixels by 7846 lines) of the Reunion Island: descending orbit, fine beam (F3), ground range (6.25 m by 6.25 m), satellite track oriented. Illumination direction is approximately from right to left. © CSA/ASC 1996, Data received by CCRS, Data delivered by RADARSAT International Inc.

The last step is the integration of the ortho-RADARSAT mosaic with the DEM 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, 1997). The third dimension is colour coded into the image, then decoded with the refractive ChromaDepthTM 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 ChromaDepthTM glasses. Any quantitative or qualitative theme (DEM, bathymetry, gravimetry, road traffic, etc.) can be used to generate a chromo-stereoscopic image.

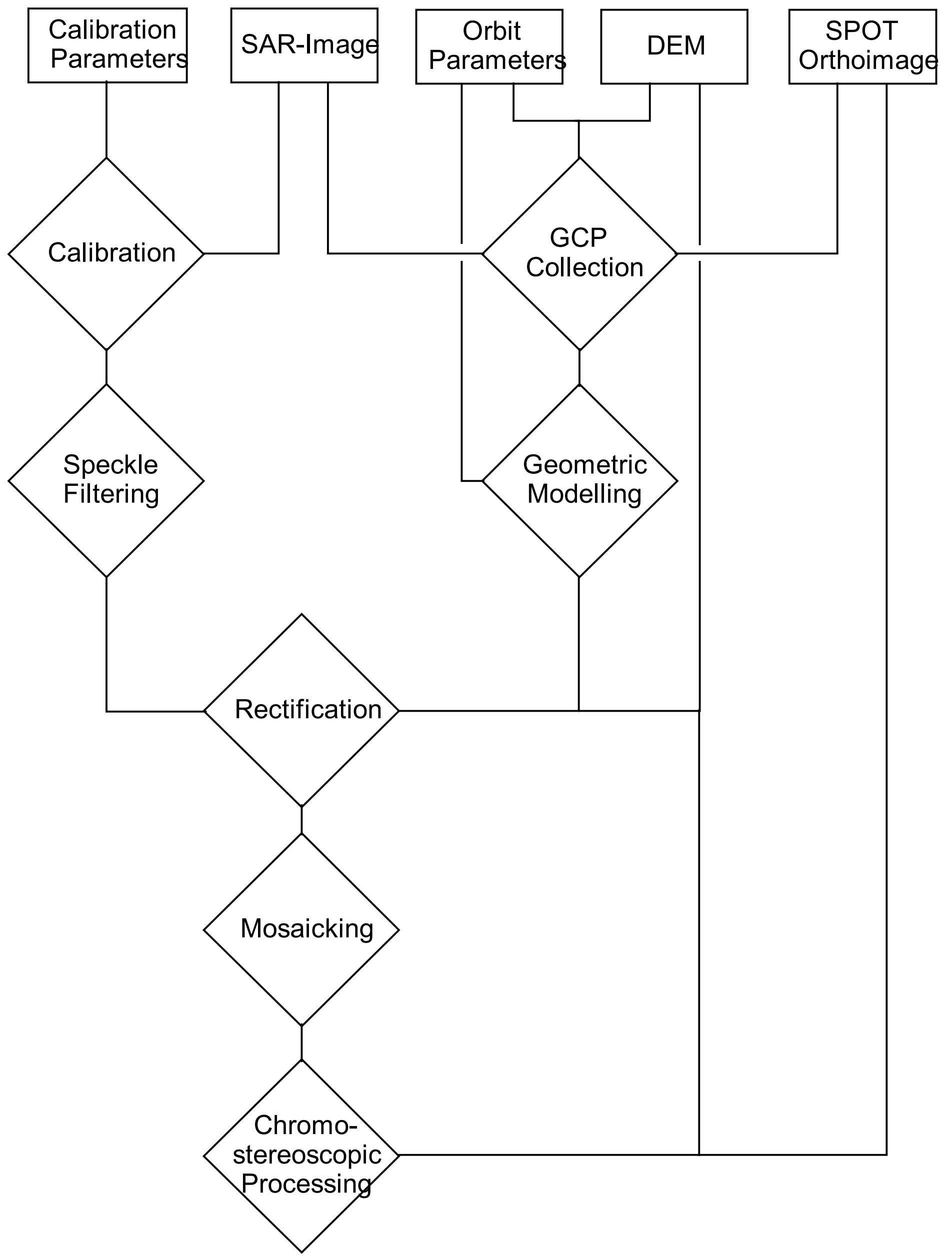

Figure 3: Processing steps for the chromostereoscopic image generation

The radiometric integration used is the intensity-hue-saturation (IHS) transformation with an image, the theme, and an other image assigned to I, H, and S respectively. If only one image is available a constant value (150) is assiged to the saturation. Further details on the chromo-stereoscopic method and the generation of 3-D images can be found in Toutin (1997).

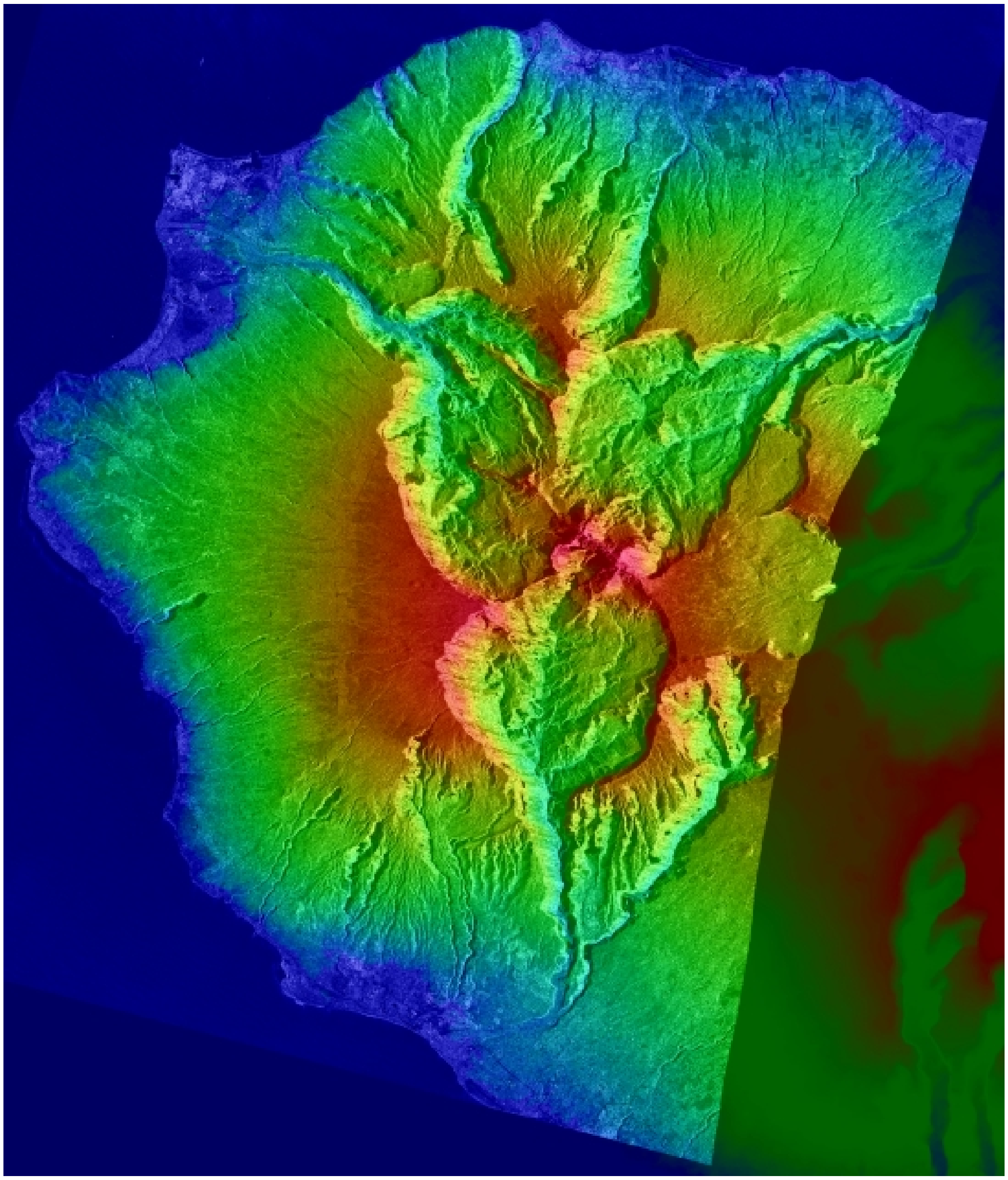

Figure 4: Chromo-stereoscopic image (3680 pixels by 4320 lines, 12.5-m pixel size) of the Reunion Island integrating the RADARSAT-SAR F1 ortho-image with the DEM © Canada Centre for Remote Sensing, 1998 © ISTAR, 1992

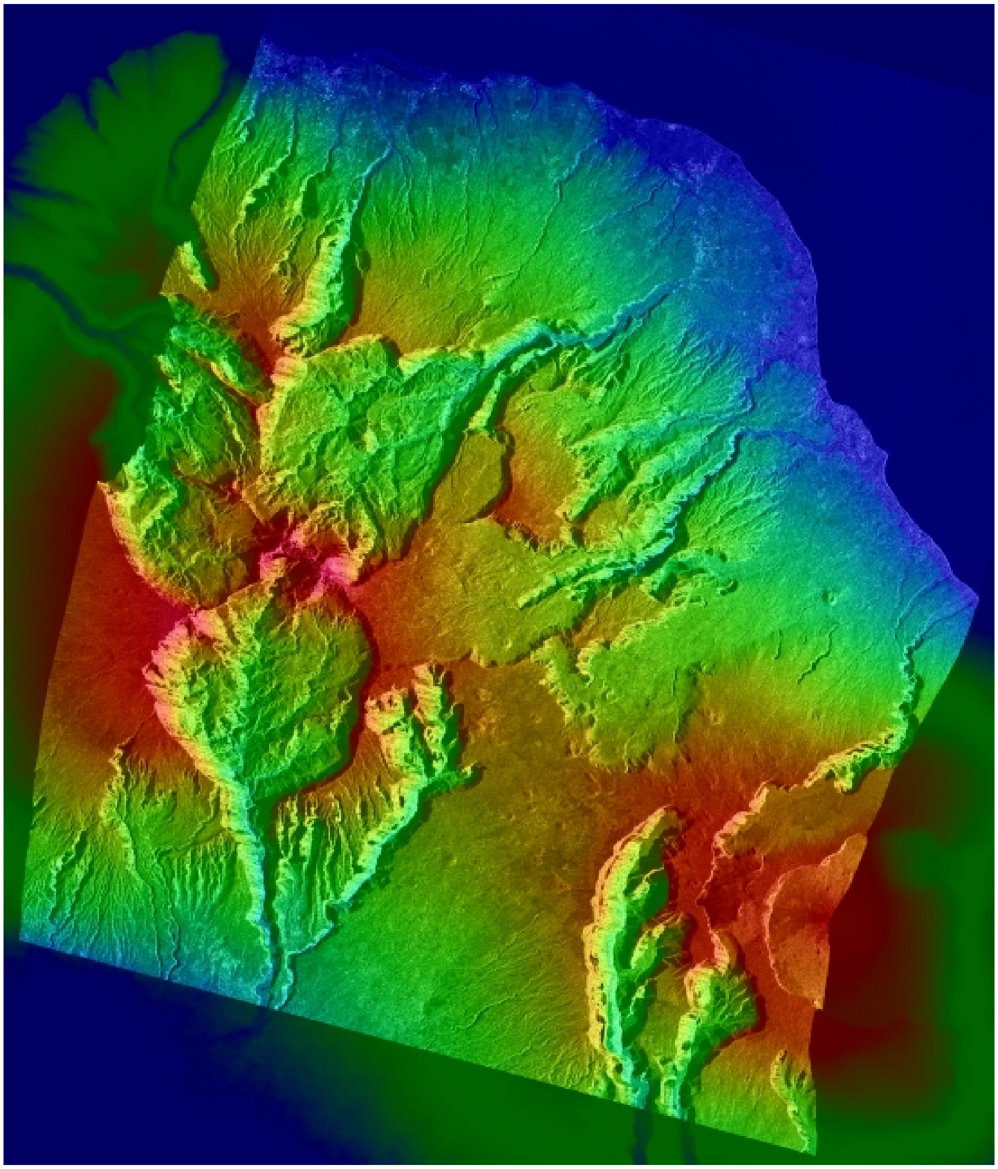

Figure 5: Chromo-stereoscopic image (3648 pixels by 4256 lines, 12.5-m pixel size) of the Reunion Island integrating the RADARSAT-SAR F3 ortho-image with the DEM © Canada Centre for Remote Sensing, 1998 © ISTAR, 1992

5. 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, and especially in this ADRO research for three kinds of analysis:

(1) the relationship between structural information provided by radar and geomorphological systems provided by DEM;

(2) the relationship between the state of surface provided by radar (roughness, gullies) and the potential of runoff of superficial water for assessing erosion effects;

(3) the detection of characteristic changes on the surface, corresponding to the consequence of a hazard, by using time series.

This paper has summarized the method with simple operational tools for the generation of chromo-stereoscopic images combining remote sensing and geoscientific data. RADARSAT and/or SPOT data with geoscientific data (cartographic, DEM). These tools include:

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

2/ an IHS radiometric transformation to generate the chromo-stereoscopic images.

The paper also presented the value-added products resulting from data integration for geoscientific applications: two chromo-stereoscopic images, which can be viewed in 3-D using the ChromaDepthTM glasses, in which the depth perception is related to the depth of the terrain elevation.

Acknowledgements

The RADARSAT images were given by CSA as part of an ADRO project n° 225 led by the BRGM. The DEM and the SPOT ortho-image were generated by the French company ISTAR..

References

Denyer, N., R.K. Raney and N. Shepperd, 1993. The RADARSAT SAR Data Processing Facility, Canadian Journal of Remote Sensing, Vol. 19, No. 4, pp. 311-316.

Desprats J.F., King C., Stieljes L., 1992. Etude par télédétection de l'évolution de l'occupation du sol sur l'île de la Réunion entre 1981 et 1989 ; Rapport BRGM R 34944 SGN 92.

Humbert M., Pasquet R., Stieltjes L., 1981. Les risques géologiques dans les cirques de Salazie et de Cilaos. Rapport BRGM 81 SGN 543 REU

Scanvic J.Y., Rouzeau O., Leroi E., 1992. La télédétection spatiale stéréoscopique. Un outil de géomorphologie qualitative et quantitative : exemple d'utilisation en région andine pour la cartographie des zones de susceptibilité aux mouvements de terrain. Bull SFPT n°125, 26-40

Simonett, D. S. and R. E. Davis, 1983. Image Analysis - Active Microwave, Manual of Remote Sensing (2nd Ed.) American Society of Photogrammetry and Remote sensing, pp. 1125-1181.

Steenblik, R.A., 1986. Stereoscopic Process and Apparatus Using Different Deviations of Different Colours, U.S. Patent No. 4-597-634.

Stieltjes L., 1986. Atlas hydrogéologique de La Réunion. BRGM

Stieltjes L., 1986. Coulées historiques du Piton de la Fournaise (île de la Réunion, Océan Indien) ; carte géologique au 1/ 25 000.

Toutin, Th., 1995. Multi-source data fusion with an integrated and unified geometric modelling, EARSeL Journal "Advances in Remote Sensing ", Vol. 4, No. 2, pp. 118-129.

Toutin, Th., 1997. Qualitative Aspectsof Chromo-Stereoscopy for Depth Perception, Photogrammetric Engineering and Remote Sensing, Vol. 63, No. 2, pp. 93-103.

Touzi, R., 1997. Personal communication and filtering software, CCRS.