SLOPE AND ASPECT DEPENDENCE OF RADARGRAMMETRIC DEM*

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ABSTRACT

DEMs are essential for many geoscientific applications such as drainage and watershed, surface slope calculation, and ortho-image generation. Consequently, it is important to know the accuracy of the DEM as a function of the terrain topography and its derivative topographic surfaces. This paper shows results of DEM generated from different RADARSAT stereo pairs (fine, standard, extended) using an automated image matching over a rolling topography study site. The DEMs are then evaluated with a precise topographic derived DEM as a function of the terrain slopes and aspects. The DEM accuracy is correlated with the terrain slopes, but differently depending on the RADARSAT stereo geometry, and it is not correlated with the slope aspects.

1.0 INTRODUCTION

Historically, the assessment of different radar stereo viewing strategies was impeded by a lack of suitable stereo data sets. Before RADARSAT, no satellite, and only a few airborne radar systems provided data over a broad range of viewing geometry for which various stereo configurations could be quantitatively analyzed. RADARSAT, which acquires imagery from a broad range of look directions, beam positions and modes at different resolutions meets this need (Parashar *et al.*, 1993).

Since RADARSAT launch numerous research studies have addressed the stereo capabilities, mainly for digital elevation model (DEM) generation. Most of the results were presented at the final RADARSAT Symposium held in Montreal, Canada in 1998 (CSA, 1998). The main issues involved in these research studies were the geometric characteristics of the stereo pair and their impact on the DEM accuracy. Some have also addressed the radiometric issues. Most of the time the DEM results are evaluated in term of absolute elevation by comparing point by point with ground truth. In the worst case the ground truth is a restricted number of well-defined check points, and in the best one a topographic derived DEM.

When using the first validation method with a relatively small amount of checked points the results are generally good. However, the results are biased since the checked points are most of the time well defined features in limited number and they are not a good statistically representative of the terrain. The second method gives a good overview but too general, because a single accuracy value does not well describe the full characteristics of the DEM and its different topography (flat, rolling, mountainous).

Since synthetic aperture radar (SAR) backscatter is very sensitive to local incidence angle, the elevation information can be extracted to generate a radargrammetric DEM from two overlapped SAR

* Presented at the Fourth International Airborne Remote Sensing Conference and Exhibition/ 21st Canadian Symposium on Remote Sensing, Ottawa, Ontario, Canada, 21-24 June 1999.

images using similar techniques as those employed with data in the visible spectrum. Consequently, it is expected that the radargrammetric DEMs will be anisotropic and much more dependent of slopes and aspects than the photogrammetric DEMs.

Previous studies have evaluated the accuracy of radargrammetric DEM with the focus on the stereo-image geometry (Sylvander *et al.*, 1997; Toutin, 1998). The basic aspects related to the terrain topography were also addressed (Toutin, 1999). Consequently, this paper instead of evaluating the radargrammetric DEM as a function of the stereo configurations expands the evaluation of radargrammetric DEMs as a function of the terrain slopes and aspects and its natural features. Twelve RADARSAT images in fine, standard and extended modes are used to generate eight stereo pairs over a rolling topography study site, Sherbrooke, Quebec, Canada. DEM are first generated using an image matching method and then compared to topographic derived DEM depending of the slopes and aspects.

2.0 STUDY SITE AND DATA SET

The topographic data are the Sherbrooke Data Set for the topographic applications of remote sensing (Lassere et Lemieux, 1990). The study area is made up of two half 1 : 50,000 map sheets of the province of Quebec (Canada), and represents land coverage of approximately 40 km by 26 km. It is a rolling topography with an altitude variation of about 450 metres with up-to-40º slopes in the alpine ski resorts. Stream bank slopes and glacial formations with drumlins and ridges indicate NE-SW ice advance, and NE-SW lineaments and folds are probably related to the structural trend of the region. The land cover is a mixture of coniferous and deciduous trees with large areas of agricultural land. Different types of water body are found: lakes, ponds, rivers and creeks.

The DEM was generated from the 10-m contour lines of the 1:50,000 maps with a 10-m grid. Hydrologic features were also used in its generation. The accuracy is in the order of five metres. The DEM is post-processed into the ESRI environment to generate derivative topographic surfaces: a digital slope model (DSM) and a digital aspect model (DAM).

Twelve RADARSAT images (C-band, HH-polarization) of the Sherbrooke region, Quebec, Canada were acquired under the Applications Development and Research Opportunity (ADRO) program sponsored by the Canadian Space Agency (CSA). The image data set includes:

- Four fine mode scenes, 6.25-m range and azimuth spacing, ascending orbit (F1 and F5) and descending orbit (F2 and F4) ; and
- Six standard and two extended mode scenes, 12.5-m range and azimuth spacing, descending orbit (S1, S4, S7, H3 and H6) and ascending orbit (S2, S5 and S7).

Table 1 summarizes the general characteristics of the images. They are a good representative set of the most used RADARSAT images: ascending (asc.) and descending (desc.) orbits, various modes (fine, standard, extended), beams and viewing angles (20º to 60º). The images are in ground range presentation (ellipsoid projection without relief correction), orbit oriented, coded in 16 bits without any radiometric processing. Eight different stereo configurations have thus been used for the evaluation: fine or coarse resolution, small to large intersection angle (8º to 89º) with steep or shallow viewing angles. Only two F1-F5 and S2-S7 are generated from ascending orbits.

Table 1. General characteristics of the RADARSAT images data set over Sherbrooke, Canada.

Mode and Beam	Acquisition Date	Orbit	Viewing Angle (degrees)	Ground Coverage (km)	Ground Resolution (m)	Pixel Spacing (m)
Fin F1	20/10/96	Asc.	37° - 40°	50 x 50	9.1 x 8.4	6.25 x 6.25
Fin F2	21/10/96	Desc.	39° - 42°	50 x 50	8.7 x 8.4	6.25 x 6.25
Fin F4	04/10/96	Desc.	43° - 46°	50 x 50	8.1 x 8.4	6.25 x 6.25
Fin F5	08/06/96	Asc.	45° - 48°	50 x 50	7.8 x 8.4	6.25 x 6.25
Standard S1	24/10/96	Desc.	20° - 27°	100 x 100	26 x 27	12.5 x 12.5
Standard S2	03/11/96	Asc.	24° - 31°	100 x 100	22 x 27	12.5 x 12.5
Standard S4	14/10/96	Desc.	34° - 40°	100 x 100	25.7 x 27	12.5 x 12.5
Standard S5	24/05/97	Asc.	36° - 42°	100 x 100	24.2 x 27	12.5 x 12.5
Standard S7	10/05/97	Asc.	45° - 49°	100 x 100	20.1 x 27	12.5 x 12.5
Standard S7	22/10/96	Desc.	45° - 49°	100 x 100	20.1 x 27	12.5 x 12.5
Extended H3	04/04/97	Desc.	52° - 55°	75 x 75	19.1 x 27	12.5 x 12.5
Extended H6	12/01/97	Desc.	57° - 59°	75 x 75	18.0 x 27	12.5 x 12.5

3.0 EXPERIMENT

3.1 RADARGRAMMETRIC DEM GENERATION

The main processing steps for DEM generation are (i) the stereo model set-up and (ii) the data extraction by automated image matching and (iii) the 3D stereo intersection.

The stereo model set-up and the 3D stereo intersection use a parametric geometric model (Toutin, 1995) already tested on different stereo data sets: VIR images (Landsat, SPOT, IRS and MOS), as well as SAR satellite images (ERS, JERS-1, SIR-C and RADARSAT). The stereo model set-up is computed with an iterative least square bundle adjustment, that enables the parameters of the geometric model to be refined with ground control points (GCPs) and tie points acquired with stereo plotting capabilities (Toutin, 1995, 1998). The 3-D stereo intersection is performed using the previously computed geometric model to convert the pixel coordinates in both images determined in the image matching of the stereo pair to three-dimensional data. Cartographic coordinates (planimetry and height) in the user defined map projection system are determined for the measured point with a least-squares intersection process based on the geometric model equations and parameters.

Most automated matching relies on correlation using different primitives (points, gradient, areas, semantic lists) to produce a disparity map. An area correlation with the maximum of a coefficient, a hierarchical least-square area correlation or a multi-scale combined area/edge correlation have been proved to be successful for SAR images. The solution chosen and adapted in the PCI digital image analysis system is a multi-scale area correlation with the maximum of a correlation coefficient. The number of steps involved in the multi-scale matching varies from five to eight with a maximum resolution reduction of 16. The correlation window size varies from 8 “reduced” pixels at the coarsest resolution to 32 pixels at the full resolution. Elevation points were extracted every two pixels on the full study site (4 to 5 000 000 points) to be directly compared to the topographic DEM. This avoids errors in the interpolation.

3.2 DERIVATIVE TOPOGRAPHIC SURFACES

From the DEM the two derivative topographic surfaces, DSM and DAM are computed in the ESRI ARC/INFO environment. Conceptually, the slope function fits a plane to the elevation surface, and the aspect is the azimuth of the plane direction. Both are calculated from a 3 by 3 window. The slope function uses the average maximum technique and the aspect function identifies the down-slope direction of the maximum rate of change with the eight-pixel neighbours.

For the slopes, six classes are thus created: 0º, 1º to 5º, 6º to 10º, 11º to 15º, 16º to 20º, 21º to 40º, that represent approximately 23%, 63%, 10%, 2%, 1% and 1% of the entire study site, respectively. The 0º-class is particular since no aspect can be associated to this "slope". The slopes 21º to 40º are grouped together since they are represented in a limited amount in this rolling topography study site. Figure 1 displays the DSM over the Sherbrooke area (40 km by 26 km; 10-m pixel spacing): the 0º-slopes are represented in black and the largest one (21º to 40º) are in white. The Massawipi Lake can be recognized at the centre-left of the image. Since there is 99% of slopes less than 20º, other results over a study site in the Rocky Mountains in Canada are presented during the Symposium to evaluate more deeply the larger slopes.

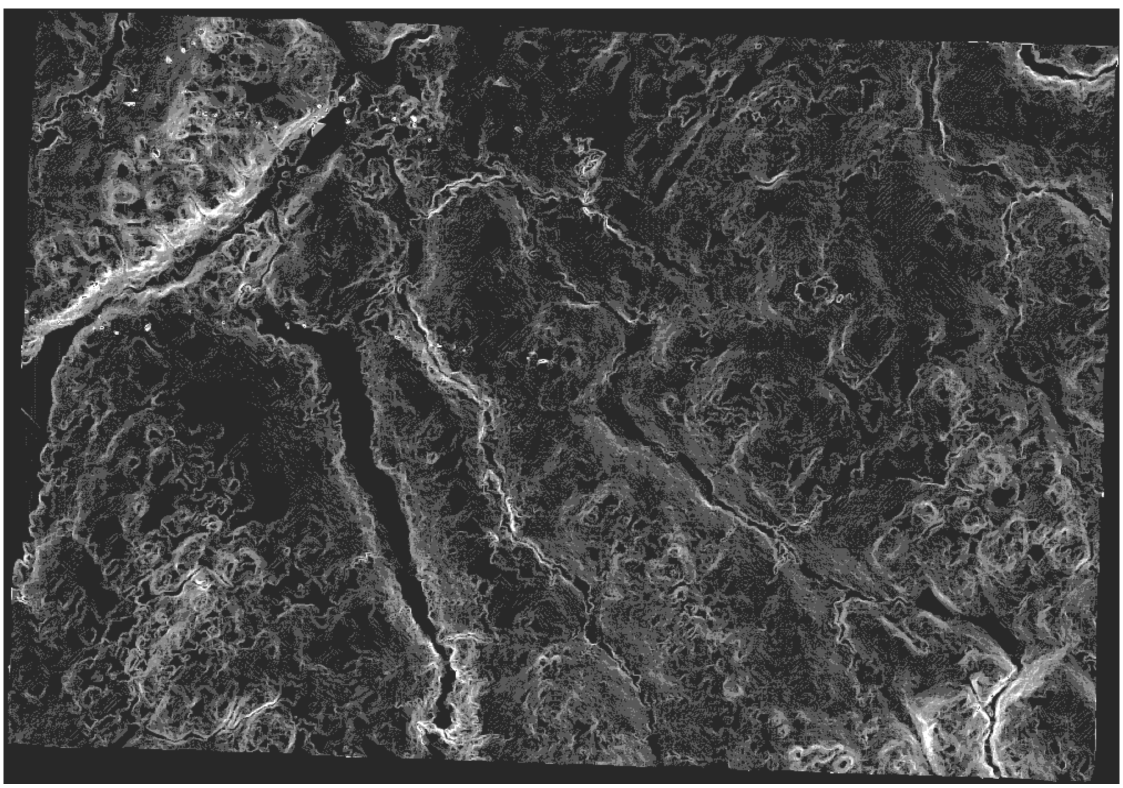

Figure 1. Digital slope model of the Sherbrooke area (40 km by 26 km). The 0°-slopes are in black, and the largest slopes (21° to 40°) in white.

The aspects are separated into 24 15º-classes from 1º to 360º. Figure 2 displays for each class the percentage of aspect related to the entire study site.

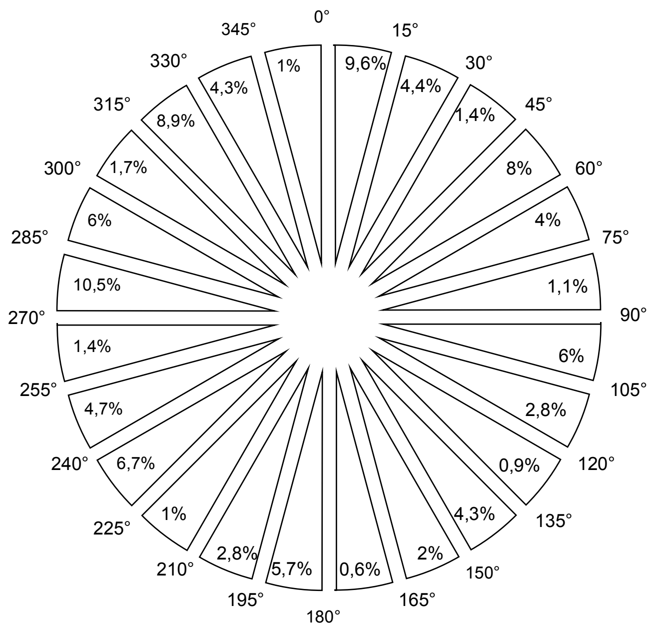

Figure 2. Distribution of the aspects into the 24-classes.

4.0 RESULTS AND DISCUSSION

For each slope and/or aspect class the radargrammetric DEM values are compared with the topographic DEM values and the standard deviations (STD) are computed. Figures 3 and 4 display the STD (in metres) for each class of slopes and aspects, respectively.

4.1 SLOPE RESULTS

From Figure 3 different remarks can be easily drawn:

- for most of stereo pairs the STD increases consistently when the slopes increases and they converge to almost the same values;
- this STD increase is stronger with the better stereo pair geometry such as with S1-S7 or S2-S7 due to the stronger increase of radiometric disparities between the images;
- for the weakest stereo pair geometry such as with F2-F4 or S7-H6 the STD variations are not significant for the different slopes;
- the opposite side F4-F5 stereo pair performs well only in the small slopes (0º, 1º to 5º, 6º to 10º) when the radiometric disparities between the images are small;
- for small slopes (0º, 1º to 5º, 6º to 10º) the better stereo pair geometry (intersection angle such as with S1-S7 or resolution such as with F1-F5) gives significant better results since the radiometric disparities between the images of stereo pairs are small; and
- for medium slopes (11º to 15º, 16º to 20º, 21º to 40º) the STD variations between the stereo pairs are smaller and less significant because the increase of radiometric disparities (weaker radiometry) offsets the stronger geometry.

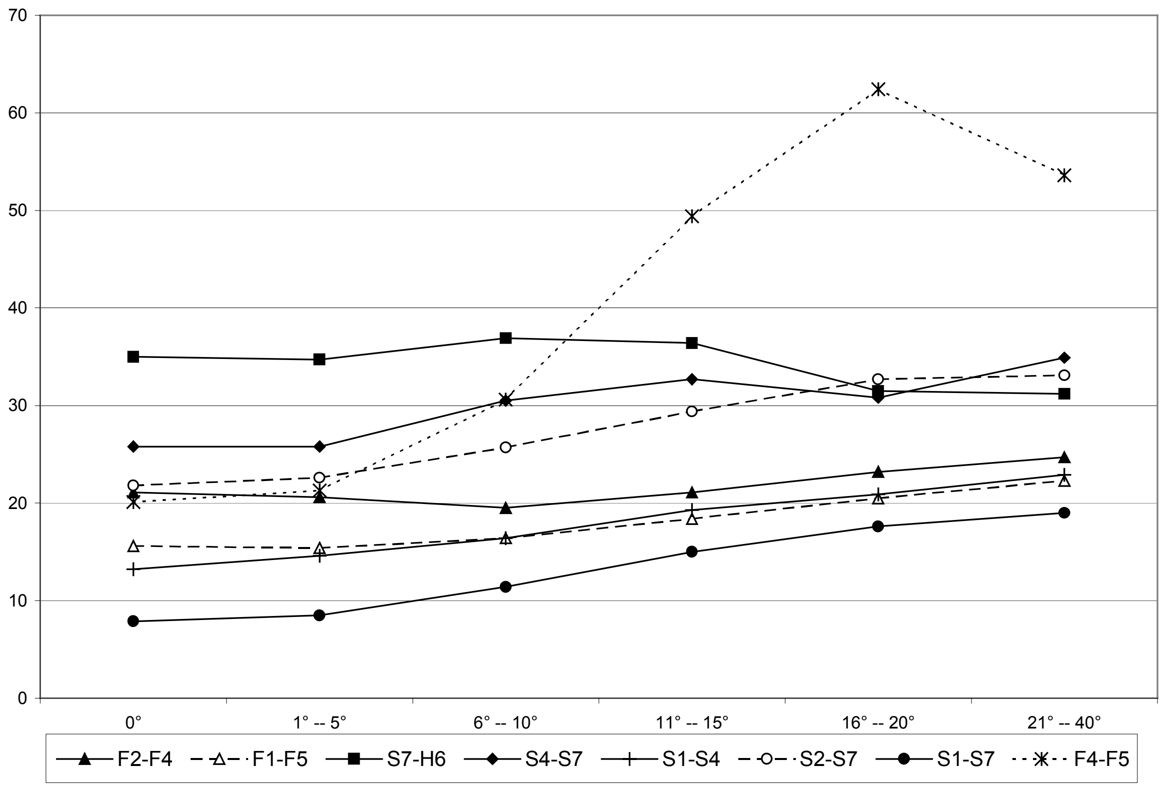

Figure 3. Standard deviation (in metres) of the DEM computed on each class of the terrain slopes for different RADARSAT stereo pairs.

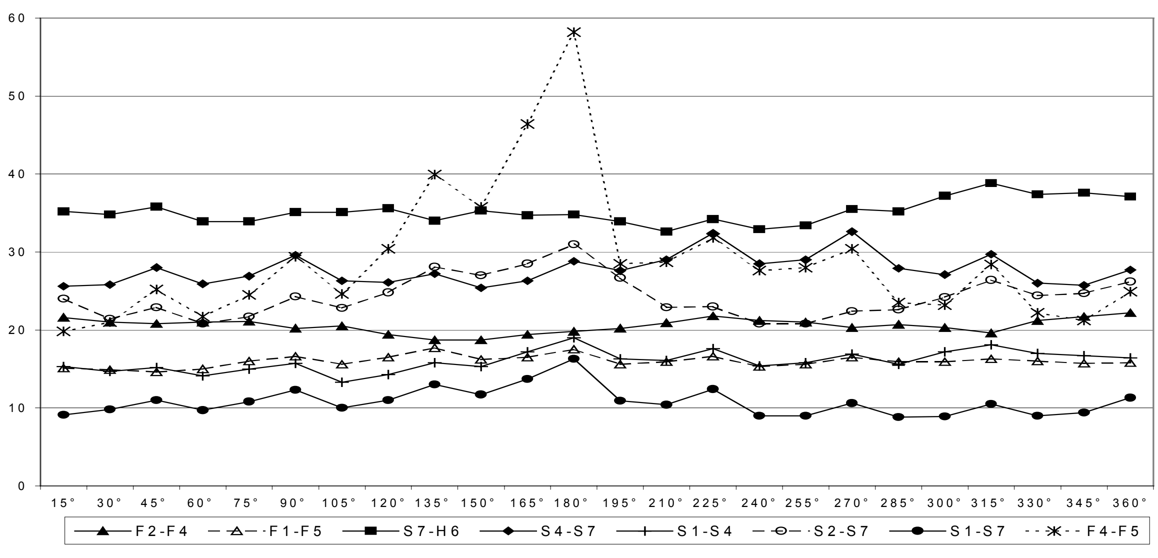

Figure 4. Standard deviation (in metres) of the DEM computed on each 15°-class of the slope aspect for different RADARSAT stereo pairs.

These new results strongly confirm the preliminary studies showing that the type of relief is one of the principal parameters that has a significant impact on the DEM accuracy. However, they also show the STD increases differently depending of the stereo pair: weak or strong geometry, small or large radiometric disparities. For "small slopes" study site, which generates low radiometric disparities between the images, stereo pairs with a strong geometry (even an opposite side) should be preferred to insure the best DEM. As soon as the slopes increase the choice of the stereo pair is "less important". Inversely, stereo pairs with a weaker geometry should be used to the detriment of the loss of precision when an equal STD is needed for the DEM over the full study site, whatever the slopes. However, 99% of the slopes (20º) of this study site are smaller or equal than the smallest incidence angle of the SAR data set (20º for S1). Consequently, this study site does not generate too large geometric and radiometric relief distortions in the different images. These conclusions can be used only for this type of rolling topography, which still represents a large part of the Earth. Extrapolating to rougher terrain should not be done without care. Results for largest slopes (more than 20º) are given over the Rocky Mountains study site, Canada during the Symposium to validate these general conclusions in mountainous areas.

4.2 ASPECT RESULTS

Surprisingly, the aspects do not significantly affect the STD for any stereo pair, except for the opposite-side stereo pair F4-F5. No valid reason can explain to date the large variations around 180º for the stereo pair F4-F5. Furthermore, there is no specific trend in these curves. Although the SAR image grey level is a strong indicator of the range component of the terrain slope (Guindon, 1990), there is no difference for the STD in the illumination directions. The illumination directions are approximately 105º for the foreslope and 285º for the backslope with the descending stereo pairs (black solid symbols) and 195º for the foreslope and 15º for the backslope with the ascending stereo pairs (white symbols). One of the main reasons is that 96% of the slopes less or equal to 10º do not generate large radiometric differences between the different orientations of the slopes, such as a flat earth. It is confirmed by drawing the same "aspect curves" than in Figure 4, but only for the smallest slopes (classes of 1º to 5º and 6º to 10º). Results for largest slopes (more than 20º) are given over the Rocky Mountains study site, Canada during the Symposium to validate the range component effect in mountainous areas.

5.0 CONCLUSION

Radargrammetric DEMs were evaluated as function of derivative topographic surfaces to understand the impact of the terrain slopes and aspects on the DEM accuracy. Twelve RADARSAT images (fine, standard and extended modes) were used to generate eight stereo pairs over a rolling topography study site, with up-to-40º slopes. From the topographic derived DEM, DSM and DAM are created with 10-m pixel spacing. Six classes of slopes (generally 5º-range) and 24 15º-classses of aspects were generated. For each class the radargrammetric DEMS are compared with the topographic DEM to compute the standard deviation of the elevation difference.

The results show the DEM accuracy is correlated with the terrain slopes, but differently depending of the RADARSAT stereo geometry. There is less difference in the STD between the stereo-pair results in medium topography than in flat topography. Furthermore, the degradation of the STD is larger with the stronger stereo pair geometry, such as S1-S7 or F1-F5, and more homogeneity is obtained with weaker stereo pair geometry, such as S7-H6 or F2-F4. When a DEM with a homogeneous accuracy over the various topography of a large area is requested such stereo pairs could be preferred to the detriment of precision.

Surprisingly, there was no specific trend in the aspect results for any stereo pair, except for the opposite side F4-F5. To date no valid reason explains the STD degradation around 180º for this opposite side stereo pair. Even in the SAR illumination direction for the foreslope or backslope, there was no significant amelioration or degradation, respectively. More results over a rough topography study site in the Rocky Mountains, Canada are presented during the Symposium to better address the evaluation for the slopes larger than 15º, since only 98% of the total slopes of the rolling topography study site in Sherbrooke was less than 15º.

6.0 ACKNOWLEDGEMENTS

This research is part of an Applications Development and Research Opportunity project at the Canada Centre for Remote Sensing. The Canadian Space Agency has sponsored the RADARSAT data. The author would like to thank M. René Chénier of Consultants TGIS inc. for the image processing.

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