Road Extraction from Stereo RADARSAT Data[☻]

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Abstract

Two stereo pairs generated with fine mode images (F1-F5) and standard mode images (S1-S7) are used to evaluate the potential of RADARSAT-SAR for extracting planimetric features on a PC-based stereo workstation. First, monoscopic and stereoscopic plotting are evaluated. It is prerequisite to acquire GCPs in stereoscopy since monoscopic collection mode degrades the relative and absolute orientations of the stereo model with a ratio of two to four depending of the stereo geometry. It is more important for smaller intersection angle stereo pairs with shallow viewing angle, such as F1-F5. The stereo extracted roads are then compared with the roads of the digital topographic maps. Statistical results over a large sample (more than 900 km) show accuracy of about one and two to three radar resolution cells (about 8 m for fine mode and 25 m for standard mode) with 68% and 90% confidence levels, respectively. These road positioning accuracy results are quite encouraging since they correspond to the 1 : 50,000 map standards. To further increase this accuracy fine modes images with an oversampled pixel spacing should be preferred, such as the "Path Image Plus" format. A comparison with the ortho-rectification process shows that the stereoscopic method to extract planimetric features is four times more accurate since the positioning of features is independent of elevation errors from the stereo compilation or an a-priori existing DEM.

Introduction

In the 1960's, stereoscopic methods [La Prade, 1963] were first applied to radar images to derive ground elevation leading to the development of radargrammetry. Unfortunately, research uncovered contradictions and a dichotomy between error propagation theory and practical results, particularly over high relief areas [Leberl *et al.*, 1988]. These contradictions combined with the lack of stereo radar pairs led to the relative decline of radargrammetry.

The launch in 1995 of Canada's first earth observation satellite, RADARSAT (see Figure 1) with the various operating modes of the Synthetic Aperture Radar (SAR) and its specific geometric characteristic [Parashar *et al.*, 1995] has turned the tide. It is the first commercial radar system from which true stereoscopic images can be generated at different resolutions and from its wide range of incidence angles (from 10º to 60º). It thus enables us to take advantage of the three-dimensional (3D) representation of the terrain from stereo images with various geometry and radiometry (see Figure 2).

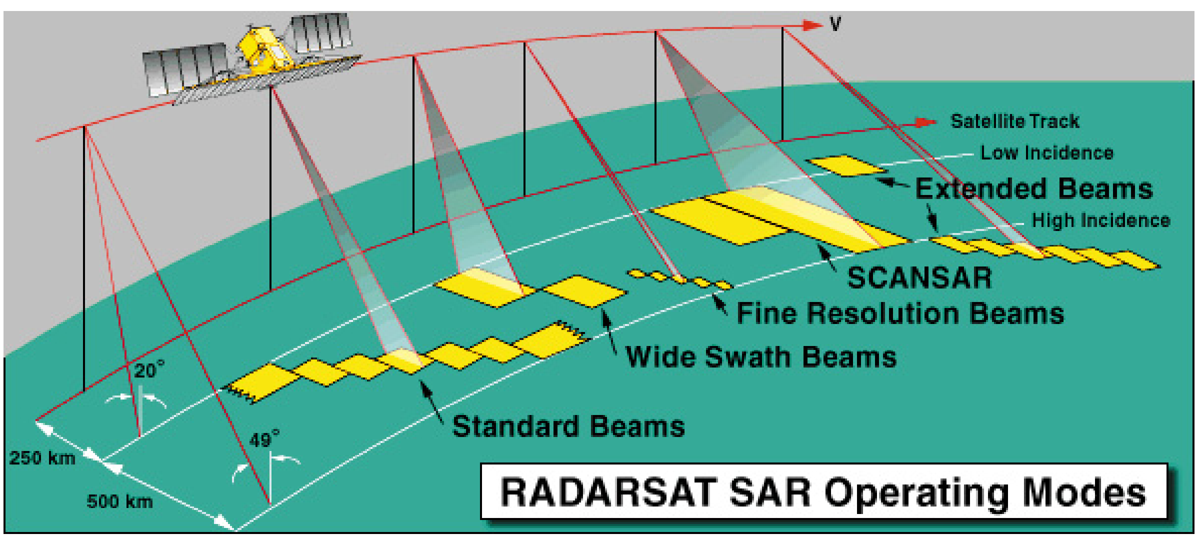

Figure 1. Operating modes of RADARSAT-SAR

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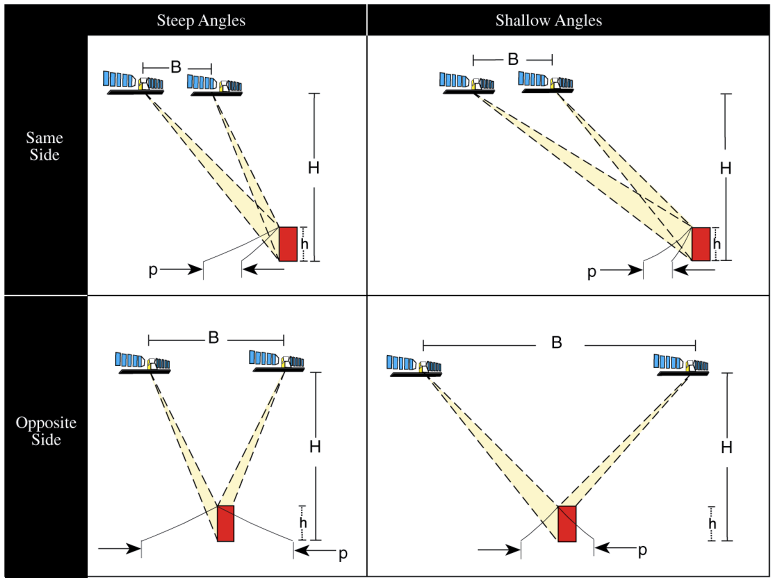

Figure 2. Various configurations of RADARSAT-SAR stereo pairs

Radargrammetry has once more become a hot R&D topic. Unfortunately, it is only used for digital model elevation (DEM) extraction in the international research communities. By analogy with photogrammetric stereo-methods, it also can be used to extract planimetric features on a digital stereo workstation without *a-priori* existing elevation information. Subtle features not discernible in a single SAR image are often recognized in stereo images. The stereoscopic viewing enhances our ability to interpret two-dimensional (2D) images. The naturalness of 3D representation has major advantages towards perceiving and extracting physical information when compared to flat 2D imagery. It supplies important information about the relationship between the land shape and structure, slope and waterways, surface and vegetation growth.

Few qualitative and quantitative results have been published on cartographic feature extraction from RADARSAT images. Sempere [1998] made a quantitative evaluation of the planimetric potential of ortho-rectified RADARSAT images in a French operational context for topographic mapping and digital data base updating. However, it requires precise DEM for the ortho-rectification. Stereoscopy is thus an important issue in countries where precise DEM and maps are not available. Furthermore, the SAR stereoscopic method has been proven to be more accurate for planimetric feature extraction, because the feature positioning is not affected by any elevation error in the existing DEM (no rectification) or in the stereo compilation (the operator plots at the vertical of the point) [Toutin, 1997]. With ortho-image generation, the DEM error propagates through the differential rectification process and planimetric feature extraction with a ratio of one to five depending on the SAR viewing angle.

As a result, researchers at CCRS have undertaken an exhaustive study under the Applications Development and Research Opportunity (ADRO) program sponsored by the Canadian Space Agency (CSA) to evaluate the parameters, which enable a general understanding of radar stereoscopic capabilities for mapping applications. First results have been presented for the geometric evaluation [Toutin, 1998] and for DEM generation [Toutin, 1999]. The objectives of this paper is to present the first results of the RADARSAT potential for planimetric feature extraction using the stereoscopic method.

Study Site and Data Set

The topographic data are the Sherbrooke Data Set in the province of Quebec (Canada) for the topographic applications of remote sensing [Lassere et Lemieux, 1990]. The study area is made up of two one-half 1 : 50,000 map sheetsproduced by Geomatics Canada and represents land coverage of approximately 40 km by 26 km (see Figure 3). 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 cartographic data used in this experiment are:

- 235 reference points which have been obtained from photogrammetric triangulation using an STK-1 stereocomparator for the photo-measurements. The root mean square error of the cartographic coordinates are better than three metres. These points are mainly intersections of expressways, highways, roads, streets or railroads; and
- the vector data of the digital topographic map. All the elements are positional data, as observed on the surface of the Earth in X, Y and Z coordinates and without movement of the element due to cartographic generalization. They have been stereo-compiled (B8-S, 2nd order) in 1986-87 from aerial photographies taken in 1985. The field completion was done in 1985-86. The positioning accuracy of the data is in the order of five meters.

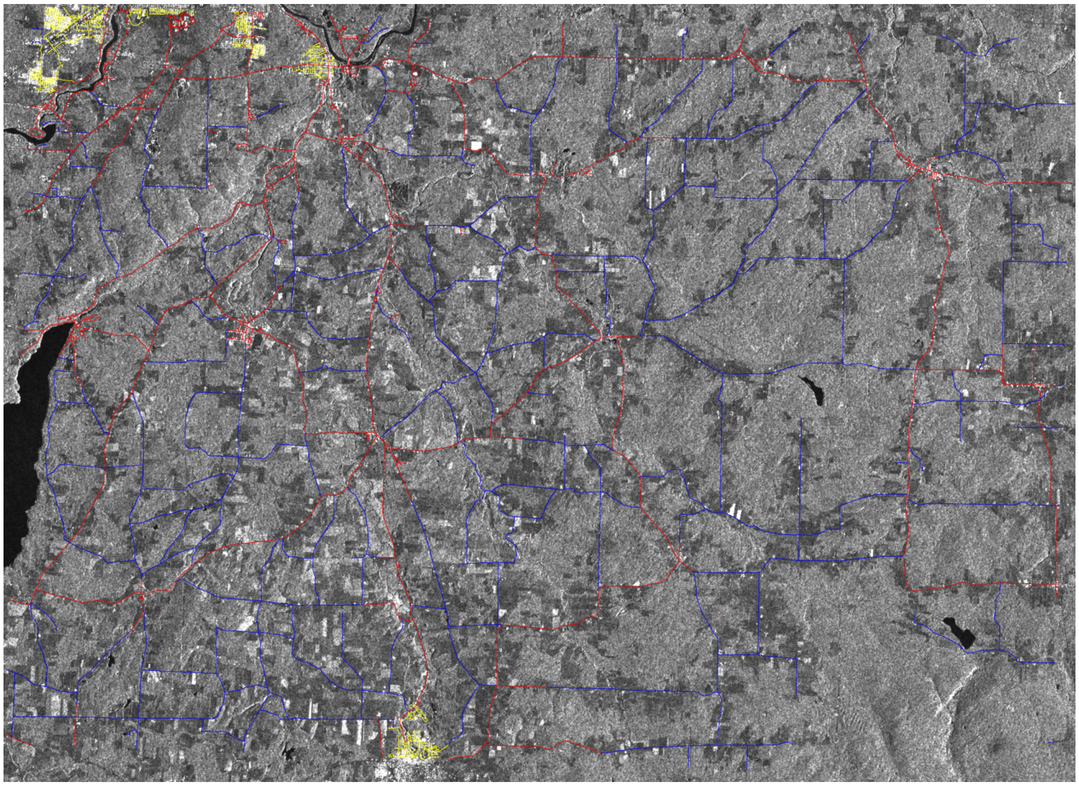

Figure 3. Ortho-rectified RADARSAT-SAR fine mode image with main (in red), secondary (in blue) roads and city streets (in yellow) overlaid. RADARSAT Image: Courtesy of CSA, 1996.

Figure 3 displays an ortho-rectified RADARSAT-SAR fine mode image with the main, secondary and city roads overlaid. The red lines represent the hard-surface all-weather roads (300 km of total length) with two lanes; the blue lines are the loose or stabilized surface all-weather roads (530 km of total length) with two lanes or less, and the yellow lines are the "unclassified city streets" (100 km of total length). The digital file of roads also includes hard-surface all-weather dual highways (6 km of total length).

The image data set used in this experiment includes only four RADARSAT images (C-band, HH-polarization) of the Sherbrooke region, Quebec, Canada of the twelve images acquired under the ADRO program sponsored by the CSA:

- Two fine mode scenes, single-look processing, F1 and F5 acquired from ascending orbit the 20/10/96 and 8/6/96 with a look angle of 37º-40º and 45º-48º, respectively; and
- Two standard mode scenes, four-look processing, S1 and S7 acquired from descending orbit the 24/10/96 and 11/10/97 with a look angle of 20º-27º and 45º-49º, respectively.

The SAR ground range resolution cell is 7.8 to 9.1 m in range by 8.4 m in azimuth for the fine mode and it is 20 to 26 m in range by 27 m in azimuth for the standard mode. The images are generated in the Path Image format: ground range presentation (ellipsoid projection without relief correction), aligned to the satellite's orbit path, with a 6.25-m and 12.5-m pixel spacing in range and azimuth for the fine and standard modes respectively, coded in 16 bits without radiometric processing. They are used to create two different stereo pairs in fine (F1-F5) and coarse (S1-S7) resolution with a small and large intersection angle, 8º and 25º respectively.

Experiment

The experiment is realized in two main processing steps: the stereo model set-up and the feature extraction. The stereo model set-up, based on a geometric modelling, is the mathematical reconstruction of the 3D-terrain model. The geometric modelling used in this experiment is a CCRS developed parametric model already tested on different data sets [Toutin, 1995]. The stereo model set-up is computed with an iterative least squares bundle adjustment (relative and absolute orientations together), that enables the parameters of the geometric model to be refined with ground control points (GCPs) and tie points collected in stereoscopy [Toutin, 1995, 1999]. Since most of radar commercial workstations, if not all, does not have full stereoscopic capabilities, the GCPs are also acquired in monoscopy to evaluate the impact of the GCP image positioning errors generated by the monoscopic collection method.

The planimetric feature extraction follows the stereo model set-up. It is done with the digital stereo workstation, the DVP (Digital Video Plotter), developed by Laval University, Quebec, Canada for air photos, in collaboration with CCRS for SPOT images and further adapted at CCRS for SAR images [Toutin, 1995, 1999]. Since the geometric modelling formulation (exterior orientation) and its inversion are straightforward one does not need to resample the images in a "common quasi-epipolar geometry", and the real time loop does not need a powerful real time processor, which has facilitated the implementation method on a low-cost PC.

The control of image positioning then follows the dynamic change to cancel the Y-parallax from the raw imagery, and retains real time performance in the stereo viewing and plotting. When the operator eliminates the X-parallax to fuse the two floating marks of the measured point, a 3-D stereo-intersection is performed. Cartographic co-ordinates (planimetry and height) in the user defined map projection system are determined in real time for the measured point using a least squares intersection process (four equations with three unknowns) based on the equations and parameters of the geometric modelling.

The roads (more than 900 km) are interactively stereo extracted by an operator and thus quantitatively compared with the digital topographic maps (accuracy of 5 m) in the ESRI ArcInfo geographic information system. The main advantages of the stereo viewing are that it improves the location of ground points and the extraction of information by integrating the simultaneous plotting, the general relief perception and the backscatter of both images, since it combines both geometric and radiometric aspects.

Results and Discussion

Stereo model set-up results

The first interesting result is related to the GCP collection method, which has an impact on the full processing. The number of GCPs of the 235 reference points acquired on each stereo pair and their accuracy vary according to the SAR image backscatter, which can affect the feature visibility and the shape and appearance of the targets. The GCP number is 180 and 135 for the fine and standard mode stereo pairs, respectively. The image co-ordinate accuracy is one to two pixels for each image in the monoscopic collection method and one pixel in the stereoscopic collection method. Since the general results on the geometric accuracy of RADARSAT data have been presented in details [Toutin, 1998], only the tests related to the GCP collection method are presented with all the collected reference points as GCPs. The results on these GCPs give a good indication of the potential accuracy because the number of GCPs used is larger than the theoretical minimum required in the stereo model set-up. Table 1 provides the root mean square residuals from the least squares adjustment of the stereo model set-up computed with the GCPs extracted with the monoscopic or stereoscopic collection method.

Table 1. Root mean square residuals (RMSR) from stereo model set-up on the mono and stereo extracted GCPs

Stereo-pair	*GCP collection method*					
	monoscopic			*stereoscopic*		
RMSR (metres)	R_X	R_Y	R_Z	R_X	R_Y	R_Z
F1-F5 (180 GCPs)	34	7	32	9	5	7
S1-S7 (135 GCPs)	38	17	31	18	11	11

Collecting the GCPs in monoscopy for both stereo pairs generates errors in the stereo model set-up two to four times larger than collecting them in stereoscopy for S1-S7 and F1-F5, respectively. The main reason is purely geometric since the GCPs are relatively well-defined targets in the SAR images (road and railway intersections). When they are independently collected with a 1-2 pixel accuracy, it generates artificial parallaxes (in column and line) between the two images, which propagate through the exterior orientation of the stereo model, mainly in the X and Z directions. Due to same-side stereo geometry, the error increases with smallest intersection angle and shallowest viewing angle, such as with F1-F5. Conversely, true stereoscopic collection enables a better relative correspondence of the same GCP between the two images and better orientations of the stereo model.

Consequently, the stereoscopic collection of GCPs with SAR stereo pair is a prerequisite before any feature extraction to avoid large error propagation in the stereo model and the extracted features. These results are consistent with the theoretical analysis of error propagation, which demonstrates that the accuracy in range and elevation increases with the intersection angle [La Prade, 1963]. This error analysis is only true when the geometric aspects are more important in the errors than the radiometric aspects, such as with the GCPs definition and collection [Toutin, 1998].

Road extraction results

As mentioned previously the roads were separated into four categories according to 1 : 50 000 map Canadian standards: highways, main roads (two and more hard-surface all-weather lanes), secondary roads (two and more loose or stabilized lanes), and unclassified "city streets". The entire data set (more than 900 km of roads) is used in the statistical accuracy evaluation. Only the stereo pairs computed with the GCP stereo collection method are used to extract the roads. From the comparison of the topographic roads and the extracted roads, the omission error and the circular errors, CE68 and CE90 with 68% and 90% confidence levels, respectively are computed for each stereo-pair. Table 2 represents a summary of these results (omission, CE68 and CE90) for the stereo pairs F1-F5 and S1-S7.

Table 2. Omission, CE68, CE90 of the road extraction for the stereo pairs F1-F5 and S1-S7

Stereo-pair	*Road category*	*Omission*	*CE68*	*CE90*
F1-F5	Highways	0 %	6 m	12 m
	Main	7.5 %	10 m	20 m
	Secondary	31 %	11 m	24 m
	City	7 %	9 m	17 m
S1-S7	Highways	25 %	18 m	37 m
	Main	47 %	18 m	40 m
	Secondary	55 %	22 m	48 m
	City	73 %	10 m	18 m

Obviously, the omission errors are larger for the standard mode stereo pair for each category of roads due to the coarsest resolution cell (20 to 26 m in range by 27 m in azimuth, average 23 by 26 m). The errors are related to the physical characteristics, the definition and the visibility of each feature in the SAR images, but also are dependent of their surroundings. As examples, the highways are easier to perceive in the fine mode stereo pair since they are long strait lines over more than three to four image pixels, and the houses in the city act as dihedral corner reflectors with also a strong backscatter from sloped roofs. It better defines the roads due to more contrast.

The other results are related to the positioning accuracy of the extracted features. The errors are more and less the same whatever the category of the road, except the city streets with S1-S7: around one resolution cell for the CE68 and two to three for the CE90. However, the standard mode stereo pair gives slightly better results relatively to the image resolution because the standard mode images are oversampled (12.5-m pixel spacing versus 20 to 26-m resolution cell) while the fine mode images are undersampled (6.25 m pixel spacing versus 8 m resolution cell). This confirms the first results of this ADRO research on the geometric accuracy of RADARSAT images [Toutin, 1998].

The main differences in the results between the categories of roads, but also between the stereo pairs can be accounted for:

- the different physical characteristics of roads related to the SAR and surface interaction; and
- the contrast within their surroundings (forest, bare soil, agricultural fields, houses, etc.),which determines the road limits.

The same explanations given previously for the omission errors (highways, houses) applied for the statistical results. It is particularly obvious that the "double-bounce" due to the houses and the strong backscatter of the sloped roofs have helped the extraction of the city streets in the standard mode stereo pair since the accuracy is almost one-third of the resolution cell.

It is interesting to compare this stereoscopic method based on photogrammetric principles with the traditional monoscopic method based on the ortho-rectification process. Fist, stereoscopy does not need any *a-priori* terrain elevation information since the terrain relief is "included" or perceived in the stereo model. Consequently, the positioning accuracy of planimetric feature is completely independent of any potential elevation error in the DEM and in the stereo compilation. On the other hand, any error from an existing or stereo-extracted DEM propagates through the ortho-rectification and extraction processes. Consequently, the DEM used to ortho-rectify F1 or S1 images should have 6-m accuracy to achieve the same accuracy than obtained for roads extracted in stereoscopy, 9 m or 18 m respectively. Conversely, a 25-m accurate DEM generated from a RADARSAT stereo pair will create an error of 35 m on the F1 ortho-image and any subsequent extracted feature, but an error larger than 60 m on the S1 ortho-image. That is a four-fold degradation relative to the results achieved directly with stereo restitution from the raw SAR stereo-images. It is in accordance with previous quantitative and comparative results of lake extraction from single and stereo ERS-1 SAR images [Toutin, 1997].

The other main advantages of the stereoscopy, when compared to single image processing are that they improve the location of targets or ground features and their extraction by integrating the simultaneous compilation and superimposition, the general relief perception and the backscatter of both images. It then combines both geometric and radiometric aspects of the images and the stereo pair. It shows that using three-dimensional representations facilitates the interpretation of cartographic information relatively to flat 2-D representations.

Conclusion

Two RADARSAT stereo pairs with fine (F1-F5) and standard (S1-S7) mode images have been evaluated for planimetric feature extraction in regard to cartographic applications. The 1 : 50 000 digital topographic map (accuracy of 5 m) of the Sherbrooke region, Canada has been used to validate the roads interactively extracted on a PC-based stereo workstation, the DVP, adapted at CCRS for processing SAR stereo images.

The roads were set into four categories according to 1: 50 000 Canadian map standards: highways, hard-surface all-weather roads with two lanes, loose or stabilized surface all-weather roads with two lanes or less and unclassified city streets. The total length of roads for each category (6 km, 300 km, 530 km and 100 km, respectively) were stereo-compiled and used for the planimetric positioning accuracy evaluation.

First, tests were done to evaluate the impact on GCP collection method and accuracy. Due to the 1-2 pixel plotting error on each image, artificial parallaxes in the stereo model are generated with the monoscopic collection method and degrade the relative and absolute orientations of the stereo pair with a ratio of two to four depending of the stereo geometry. It is more important for smaller intersection angle stereo pairs with shallow viewing angle, such as F1-F5. Since stereoscopy increases the location and collection accuracy of GCPs and then of the stereo model set-up, it is a prerequisite to use stereoscopic collection method before any feature extraction (planimetric and/or elevation). The roads are then stereo compiled only from stereo pairs computed with the stereoscopic GCPs.

The omission errors depend mainly on the definition and the visibility of each road category by itself and with its surrounding element (forest, bare soil, agricultural fields, houses, etc.). It varies from 0% for the highways extracted from F1-F5 stereo pair to 73% for the city streets extracted from S1-S7 stereo pair.

The extraction from both stereo pairs (F1-F5 and S1-S7) gave accuracy with 68% and 90% confidence of about one resolution cell and two to three resolution cells, respectively. The physical characteristics of each road category (width, contrast with surroundings, etc.) and their backscatter related to SAR and surface interaction account for the difference in accuracy. However, the results are better with the standard mode stereo pair because the images are oversampled. Consequently, fine mode stereo pairs with oversampled pixel spacing should be preferred to increase the 10-m positioning accuracy obtained so far. The Path Image Plus format generated from the fine mode RADARSAT data with 3.125-m pixel spacing could thus be a better image data for stereo mapping. Nevertheless, these road accuracy results obtained from the stereo compilation are quite encouraging since they correspond to the positional accuracy standard of 1 : 50 000 maps. Some completeness has also to be realized due to the omission errors.

Qualitative and quantitative comparisons have shown the superiority of the stereoscopic method when compared to the ortho-rectification method in order to precisely extract planimetric features, such as roads. In fact, to achieve the same accuracy with F1 or S1 ortho-images the DEM used in the ortho-rectification process should have 6-m accuracy. Conversely, 25-m accurate DEM generated from F1-F5 stereo pair will generate a positioning error of 35 m in the F1 ortho-image and in any subsequent extracted feature, but more than 60 m in the S1 ortho-image. This corresponds to a four-fold degradation relative to the results achieved directly with stereo restitution from the raw SAR images.

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