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Geometric and Radiometric Calibration of RADARSAT Images

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ABSTRACT

Interpretation of SAR images in areas with significant relief requires rigorous calibration considering local illuminated area and incidence angle effects if one is to be able to perform meaningful multitemporal analysis using images acquired with different geometries and/or sensors. Given the large swaths made available by RADARSAT, even comparison of the near vs. far range sections of the same image requires such calibration.

We present here results from geometric and radiometric calibration of single beam mode RADARSAT SAR images, as applied to data provided under the *Application Development and Research Opportunity* (ADRO) programme. A high resolution elevation model is used first to terrain-geocode the data from ground range radar coordinates into the reference map coordinate system. Tiepoints are used to coregister both the slow and fast-time axes to a global Earth-centred rotating coordinate system.

Radiometric calibration is performed by compensating for effects of local illuminated area and incidence angle on the local backscatter. In particular, the effects of multiple DEM slopes ("facets") within a single radar geometry pixel (which can grow to over a kilometre in steep terrain!) are considered. The utility of the SAR data for thematic interpretation is presented, both before and after calibration.

Keywords: SAR Geocoding, RADARSAT, RSAT-1, DEM, SAR Image Simulation, Radiometric Calibration

1. INTRODUCTION

The highly variable SAR acquisition geometries made available by RADARSAT have intensified the need for terrain-correction of scenes with hilly or mountainous terrain.

Although the unchanging geometry of ERS-1 and ERS-2 allowed multi-temporal overlays in radar geometry, mixed mode RADARSAT image sets require terrain correction before any overlay is possible. That overlay is best performed in a map geometry. Geometric correction is necessary to bring the images from ground or slant range geometry into a map reference. However, radiometric correction is also necessary if mixed-mode thematic information extraction is not to be overwhelmed by terrain-induced distortions [8].

The work presented here was performed within an ADRO project to illustrate the benefits of geometric and radiometric terrain-correction for information retrieval.

An overview of the test site area is provided in Figure 1. One ascending and one descending single beam 100km swath ground range image were used for the study. Figures 2 and 3 show the two ground range (SGX) RADARSAT images. The city of Zürich is situated near the centre of both images, with Lake Zürich, Lake Zug, and Lake Lucerne prominently visible. Note the presence of extreme foreshortening, layover and shadow, particularly in the steep alpine terrain in the lower right corner of the images.

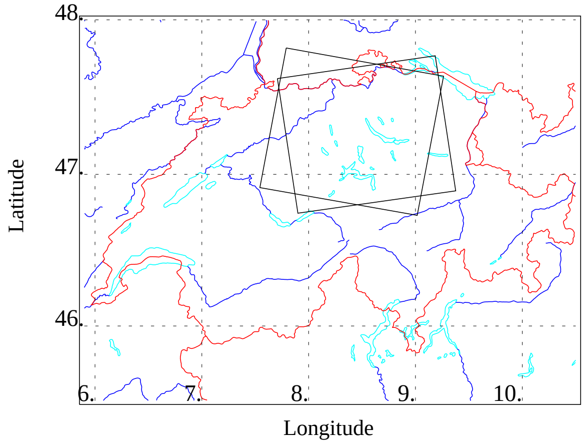

Figure 1: Overview of test area and SAR frames
Zürich, Switzerland

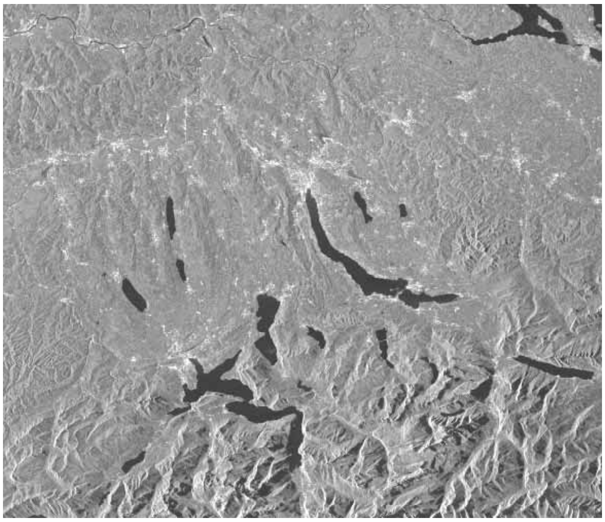

Figure 2: RADARSAT Standard Beam 7 ground range image
Zürich, Switzerland

August 30, 1996, Orbit 4290, Ascending, Right-looking, $\theta = 47°$, Resolution: 25×25m, Displayed pixel spacing: 192×192m, Image area 112×99km

2. GEODETIC TRANSFORMATIONS

As the RADARSAT satellite's state vectors (within the CEOS header platform position data record) were provided in an iner-

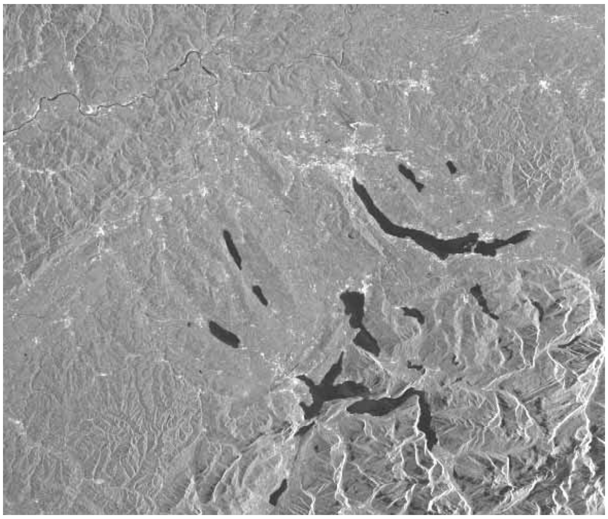

Figure 3: RADARSAT Standard Beam 4 ground range image - Zürich, Switzerland

August 31, 1996, Orbit 4297, Descending, Right-looking, $\theta = 36.5°$, Resolution: 25×25m, Displayed pixel spacing: 192×192m, Image area 112×103km

tial coordinate system (not Earth-Centred Rotating (ECR)), they were first converted into an ECR reference system. Intercomparison with Earth-referenced data (e.g. DEM height values) is best done in such a geometry.

The state vectors provided within the CEOS platform position data record were found to be quite inaccurate in comparison to the precise orbit (PRC) data products available for the ERS satellites. Substantial refinement of the orbit geometry (using tiepoints) was required.

Tiepoints were selected from 1:25'000 Swiss Topographic maps, and used to refine the orbit, as well as the azimuth (slow time) axis [6]. The images were then geometrically corrected (transformed into map geometry) using a backward geocoding technique [5]. This involves transforming each reference DEM point from map (Northing, Easting) to geographic (latitude, longitude) coordinates, to Cartesian coordinates, then through a seven parameter datum shift to the WGS84 global datum [2]. Once within this global reference system, DEM ground positions can be directly compared with the ECR orbit model. Inaccurate orbit ephemeris data hinder such direct comparison. For the RADARSAT data processed here, tiepoints were used to refine the connection between the reference map grid and the radar ground range geometry [9]. Both the orbit and azimuth (slow time) parameters were recomputed using the tiepoints.

Although the state vectors in the CEOS header were advertised (in the data quality summary record) to have nominal accuracies of 40 m (cross track) and 600 m (along track), the geometry refinement process shifted the orbit tracks by more than ten kilometers.

3. SAR IMAGE SIMULATION

SAR image simulation is useful for mission planning as an aid in estimating the amount of layover and/or shadow to be expected, for automatic tiepointing, but also for radiometric calibration.

One proceeds sequentially through the DEM area under study, forming facets from four adjacent pixels, and computing the local incidence angle at each point, as well as the local illuminated area. Both of these values are then transformed into the SAR ground range geometry. The local incidence angle value helps improve the local (radar geometry) estimate of mean local incidence angle. After confirming that the current map geometry pixel is not in radar shadow, one knows that it provides an illuminated area that contributes to the backscatter somewhere in the ground range geometry. The area estimate is added to that already contributed from other map-geometry pixels at that radar image coordinate. Note that this requires either an image blocking procedure [5] or a large memory size, as random access is required to the running sum of local illuminated area (in SAR geometry).

Depending upon the relation between the DEM and radar resolutions, the interpolation method used to resample from map to radar image geometry can become important. Bilinear interpolation uses the appropriate weighting to distribute the contribution of the local illuminated area into four adjacent radar geometry pixels.

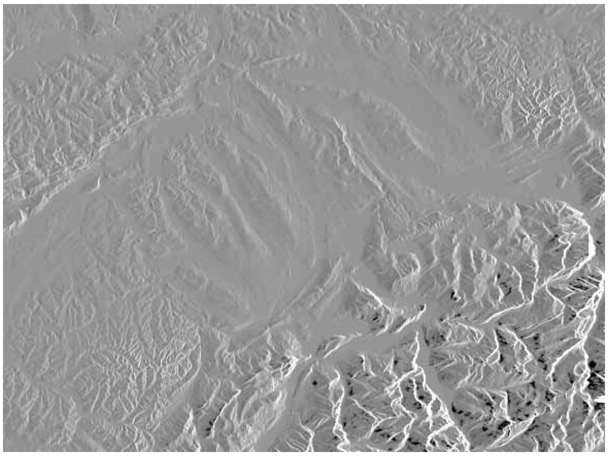

Figure 4: Simulation of RADARSAT Standard Beam 4 ground range image - calculated using DHM25, courtesy Swiss Federal Office of Topography

Zürich, Switzerland

August 31, 1996, Orbit 4297, Descending, Right-looking, $\theta = 36.5°$, Displayed pixel spacing: 192×192m

4. RADIOMETRIC CORRECTION

The amplitude values retrieved from the SAR are related to the local area illuminated by the beam [1]. Area estimates from terrain facets calculated using the reference DHM were summed sequentially, and output in the SAR ground range geometry. Given the local area estimates, the backscattering coefficient may then be calculated as

$$\sigma^0(\theta) = \frac{\bar{I}}{K} \cdot \frac{A_0}{A_{local}}, \qquad (1)$$

where σ^0 is the backscattering coefficient, $\bar{I}$ the pixel intensity, K a calibration constant, θ the local incidence angle, A_{local} the local ground scattering area, and A_0 the reference ground scattering area.

The local area estimates provided by the SAR image simulation are used to normalize each ground-range pixel with respect to a reference area.

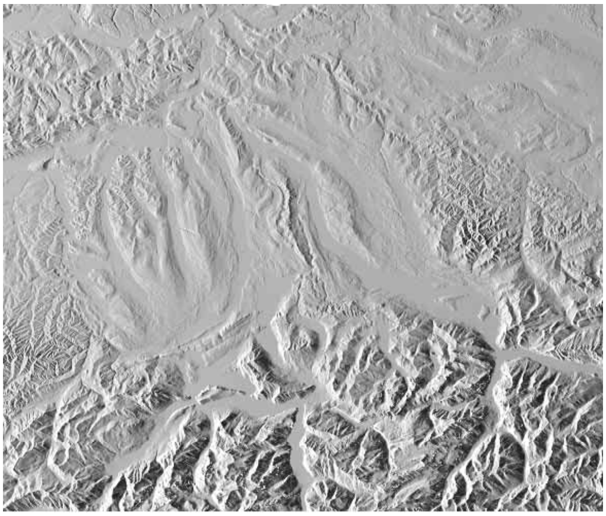

Figure 5: Local incidence angles for RADARSAT Standard Beam 7 ground range image - calculated using DHM25, courtesy Swiss Federal Office of Topography
Zürich, Switzerland

August 30, 1996, Orbit 4290, Ascending, Right-looking, $\theta = 47°$, Displayed pixel spacing: 192×192m, Image area 112×99km

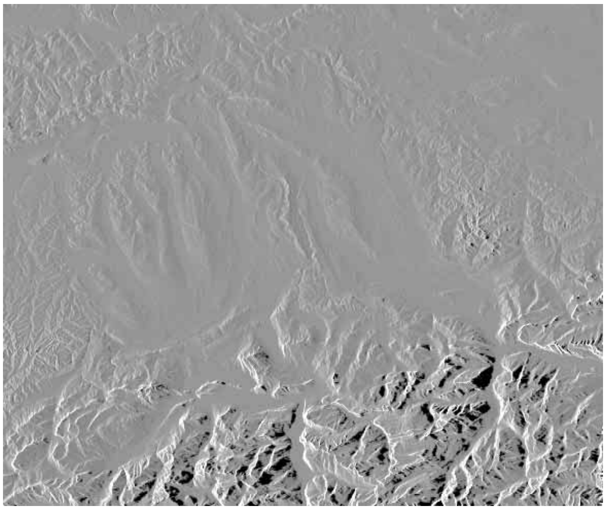

Figure 6: Simulation of RADARSAT Standard Beam 7 ground range image - calculated using DHM25, courtesy Swiss Federal Office of Topography
Zürich, Switzerland

August 30, 1996, Orbit 4290, Ascending, Right-looking, $\theta = 47°$, Displayed pixel spacing: 192×192m

Radiometric correction often also requires consideration of the antenna pattern variation over the swath. For certain SAR geometries (e.g. SIR-C, wide swath ScanSAR) the local terrain height should also be considered during this correction. However, for single-beam RADARSAT scenes, the high altitude of the satellite together with the relatively small range of incidence angles and the "flatness" of the antenna pattern within a single beam swath reduces the magnitude of such radiometric errors to one or two dB [3][7]. They are therefore neglected here.

In addition to the local illuminated area, truly robust radiometric calibration of the radar backscatter should incorporate correction for local incidence angle and antenna pattern distribution effects [4].

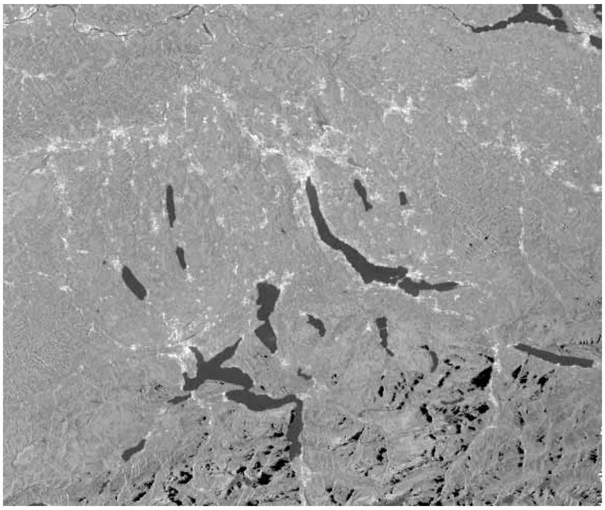

Figure 7: Radiometrically corrected RADARSAT Standard Beam 7 ground range image - Zürich, Switzerland

August 30, 1996, Orbit 4290, Ascending, Right-looking, $\theta = 47°$, Resolution: 25×25m, Displayed pixel spacing: 192×192m, Image area 112×99km

5. RESULTS / DISCUSSION

Two datasets provided through the ADRO programme were used to illustrate the method. Our test area (see Figure 1) is situated in the area surrounding Zürich, Switzerland. We have an original 25 metre grid size *DHM25* height model from the Swiss Federal Office of Topography at our disposal for use in terrain-correction of SAR data. The model was provided in Swiss map geometry with an original raster of 25m in Northing and Easting.

Images were geometrically and radiometrically calibrated using the methods described above.

For the ascending scene, the mean local incidence angle image (in SAR ground range geometry) calculated as a by-product of the image simulation is shown in Figure 5.

The original ascending ground range SAR image is shown in Figure 2, which may be compared to the concomitant image simulation in Figure 6. Figures 3 and 4 allow the same comparison for the descending scene. Note the strong layover and radar shadow effects in the lower right corner. Comparisons between the image simulations and their corresponding true RADARSAT images show that the strong returns from layover are modelled well. Shadowed areas are also reproduced realistically.

After radiometric correction through normalization for the local pixel area, the calibrated image (see Figure 7) appears much "flatter", with most topography-induced distortions (with the exception of radar shadow) substantially reduced. In the case of radar shadow, there is no signal to normalize, and no improvement is to be had. However even extreme layover can be handled using the multifaceted image simulation, as an accurate normalization factor may be calculated from the reference DEM.

Terrain geocoded versions of many of these images were also calculated. The local incidence angle map (in map geometry) is shown in Figure 8. The geocoded version of the real RADARSAT image may be seen in Figure 9.

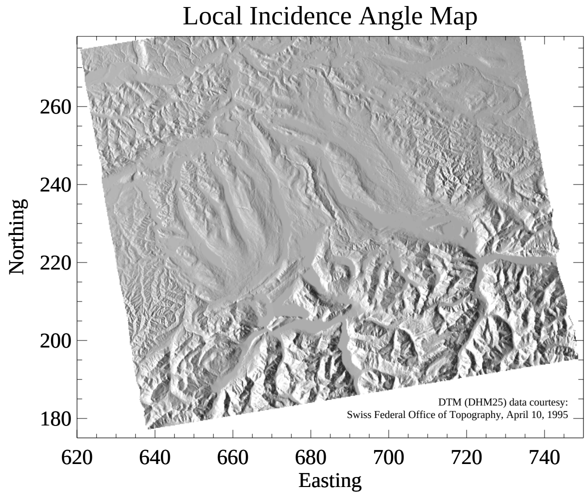

Figure 8: RADARSAT Standard Beam 7 - Incidence Angle Map - calculated using DHM25 - Zürich, Switzerland

August 30, 1996, Orbit 4290, Ascending, Right-looking, $\theta = 47°$, Displayed pixel spacing: 200×200m

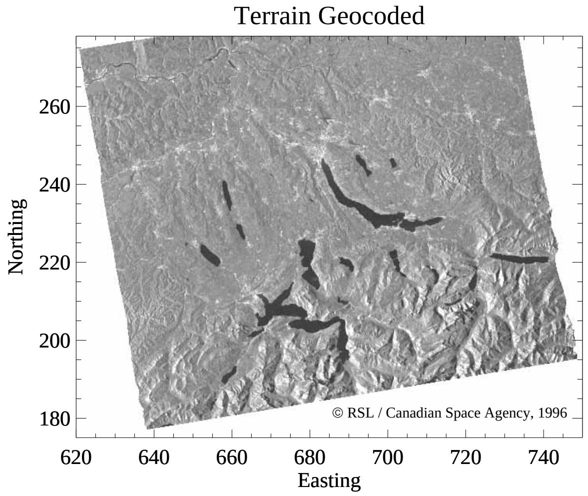

Figure 9: RADARSAT Standard Beam 7 terrain-geocoded image - Zürich, Switzerland

August 30, 1996, Orbit 4290, Ascending, Right-looking, $\theta = 47°$, Resolution: 25×25m, Displayed pixel spacing: 200×200m

After radiometric correction, thematic information that relate to radar backscatter differences (low backscatter from water bodies, strong double-bounce returns from urban areas) becomes clearer without the distraction of topography-induced distortions.

The radiometrically corrected ground-range image (Figure 7) was also terrain-geocoded. The result is displayed in Figure 10. Intercomparison between mixed mode data (differing incidence angles, ascending/descending, etc.) is made much easier without the distraction of topography-induced distortions.

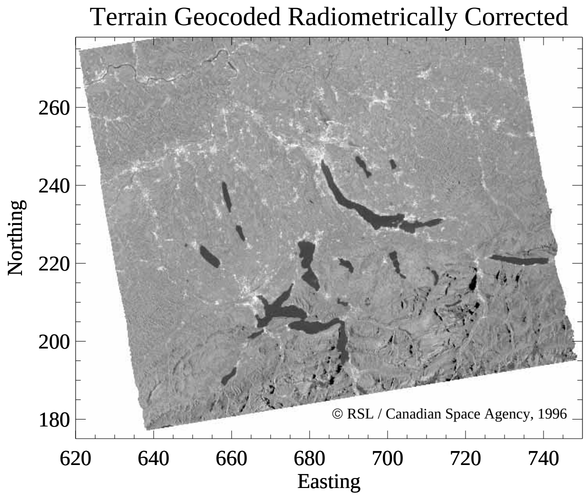

Figure 10: RADARSAT Standard Beam 7 terrain-geocoded radiometrically corrected image - Zürich, Switzerland

August 30, 1996, Orbit 4290, Ascending, Right-looking, $\theta = 47°$, Resolution: 25×25m, Displayed pixel spacing: 200×200m

6. CONCLUSIONS

The inaccuracy of the orbit data provided for the RADARSAT satellite inhibits more efficient geocoding and image simulation. Substantial refinement of the SAR geometry is required using tiepoints.

SAR image simulation is a useful tool both for mission planning (more important than ever with RADARSAT's wide palette of available modes), as well as for radiometric calibration.

Radiometric normalization for the local illuminated pixel area removes distractions from topography-induced distortions. Even layover areas can be satisfactorily normalized - unfortunately, with no improvement to their poor local resolution in map geometry. However, no radiometric improvement is to be found in radar shadow areas, as there is no signal to normalize in such cases.

7. ACKNOWLEDGMENTS

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Paolo Pasquali deserves thanks for many stimulating discussions.

8. REFERENCES

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