A REVISED RADIOMETRIC NORMALISATION STANDARD FOR SAR

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ABSTRACT

Improved geometric accuracy in SAR sensors implies that more complex models of the Earth may be used not only to geometrically rectify imagery, but also to more robustly calibrate their radiometry. Current beta, sigma, and gamma nought SAR radiometry conventions all assume a simple “flat as Kansas” Earth ellipsoid model. We complement these simple models with improved radiometric calibration that accounts for local terrain variations. In the era of ERS-1 and RADARSAT-1, image geolocation accuracy was in the order of multiple samples, and tiepoint-free establishment of the relationship between radar and map geometries was not possible. Newer sensors such as ASAR, PALSAR, and TerraSAR-X all support accurate geolocation based on product annotations alone. We show that high geolocation accuracy, combined with availability of high-resolution accurate elevation models, enables a more robust radiometric calibration standard for modern SAR sensors that is based on gamma nought normalised using an Earth terrain-model.

Index Terms — Radar terrain factors, Radar cross section, Radar scattering, Radar imaging, Radar measurements

1 INTRODUCTION

The increased availability of highly accurate information describing the acquisition geometry of spaceborne SAR imagery since the launch of ENVISAT enables tie-point free orthorectification of imagery from (for example) the ASAR [7], PALSAR [6], and TerraSAR-X sensors [3]. Contemporary nearly ubiquitous highly accurate knowledge of the imaging geometry suggests that revisiting implicit assumptions made at the dawn of SAR imaging would be appropriate. Standard radiometric normalisation of the imagery provided by the sensors no longer needs to implicitly assume that only the broad ellipsoidal Earth geometry of the acquisition is well known. Instead, consideration of the radiometric influence of the actual lay of the terrain within the imaged area has become a realistic option.

2 METHODOLOGY

It is important to distinguish between geometric and radiometric terrain correction (GTC vs. RTC) of SAR imagery. The defining characteristic of Geocoded-Terrain-Corrected (GTC) imagery is that a DHM has been used to geometrically transform the SAR image into a 2D map geometry. The radiometric values within a GTC image are usually ellipsoid-model derived backscatter values $\sigma_0^E$ or $\gamma_0^E$.

N.B. Although the geometry is terrain corrected in a GTC product, the radiometry of the $\sigma^0$ or $\gamma^0$ backscatter contents remains ellipsoid-model-based, as in ESA ERS-1/2 GEC or ASAR IMG/APG ellipsoid-geocoded products. Only in Radiometrically-Terrain-Corrected (RTC) imagery [6] does the backscatter normalisation replace the GTC’s ellipsoid model with a digital height model. Image simulation algorithms, originally developed for mission planning [2] and geometry refinement [9] applications, can be refined to also “flatten” SAR image radiometry.

A simplified cross-section of the imaging geometry of a SAR sensor is shown in Figure 1. The satellite position $S$ is shown for a single target position $E$ on the Earth’s surface. The geocentre central angle between $S$ and $E$ is $\alpha$. A featureless ellipsoid is shown in blue representing a broad outline of the Earth’s surface. Terrain undulations that affect the geometry for every target imaged are shown in brown (not to scale). Note the difference between the ellipsoidal incidence angle $\theta_i$ and the terrain-induced local incidence angle $\theta_i$. Contrary to common misconception, robust radiometric normalisation is not achieved by simply locally substituting the latter for the former [10].

2.1 Ellipsoid-based Normalisation

The three well-known radar backscatter standard conventions $\beta^0$, $\sigma^0$, and $\gamma^0$ differ in their choice of definition of a standard reference area to be applied in the radar equation. The $\beta^0$ convention provides the natural radar observable [4], normalising simply by the areal sample interval in the slant range plane – the contents of images conforming to its convention are not subjected to modifications based on ellipsoid or terrain Earth models. Typical $\sigma^0$ and $\gamma^0$ conventions normalise by a standard area calculated using an ellipsoidal Earth model. For $\sigma^0$, the conventional “flat Earth” reference area $A_\sigma$ is defined to be in the plane defined by the local ellipsoidal Earth normal vector. For $\gamma^0$, the area $A_\gamma$ is the projection in the plane perpendicular to the slant range direction. Each reference area is illustrated in Figure 2.

We append to conventional ellipsoid-model-based $\sigma^0$ and $\gamma^0$ retrieval the subscript “E”:

$$\sigma^0_E = K_\sigma \cdot \frac{\beta^0}{A_\sigma}$$
$$\gamma^0_E = K_\gamma \cdot \frac{\beta^0}{A_\gamma}$$
where $K$ is a scalar constant. Given an ellipsoidal Earth assumption, substituting the values $\bar{A}_e = \delta_e \cdot \delta_o$ or $\bar{A}_e = \delta_e \cdot \delta_o$ as local reference areas, one derives a dependency on the ellipsoid incidence angle $e$, as documented for PALSAR [1] and ASAR [5]:

$$\sigma_\epsilon^0 = K_e \cdot \beta_\epsilon^0 \cdot \sin \theta_e \quad \gamma_\gamma^0 = K_\gamma \cdot \beta_\gamma^0 \cdot \tan \theta_\gamma$$

### 2.2 Terrain-based Normalisation

Although “terrain-geocoding” of SAR imagery has become increasingly commonplace since the launch of ERS-1, the word “terrain” there refers to compensation for the effects of terrain on the geometry of the resulting image, especially on elevation-induced shifts inherent in converting from slant range to a GTC image in a map projection geometry.

We propose to complement the conventional ellipsoid-based backscatter coefficient definitions with more rigorous terrain-based versions, whereby the actual local illuminated area is calculated for each slant range bin, enabling application of a locally appropriate terrain-based normalisation factor. We append to terrain-based sigma nought and gamma nought retrieval the subscript “T”:

$$\sigma_T^0 = K_T \cdot \beta_T^0 \cdot \bar{A}_T \quad \gamma_T^0 = K_T \cdot \beta_T^0 \cdot \bar{A}_T$$

### Table 1: SAR Image Radiometric Normalisation Conventions

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<tbody>
<tr>
<td>$\beta^0$</td>
<td>$\sigma_E^0$</td>
<td>$\gamma_E^0$</td>
<td>$\sigma_T^0$</td>
<td>$\gamma_T^0$</td>
</tr>
<tr>
<td>No Earth Model</td>
<td>Earth Ellipsoid Model</td>
<td>Earth Terrain Model</td>
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Five radiometric SAR image standards are summarised in Table 1. The first three are the common conventions [4], complemented here by two further terrain model-based options. In the following, we concentrate on the terrain corrected gamma radiometry (fifth option).

### 2.3 Radiometric Image Simulation

When images comprised of $\sigma_T^0$ or $\gamma_T^0$ values are terrain-geocoded, we refer to the resulting products as radiometrically terrain corrected (RTC) [8]. As might be expected, derivation of terrain-corrected gamma $\gamma_T^0$ is more complicated than the simple application of the tangent of the ellipsoidal incidence angle that is sufficient for retrieving an ellipsoid model-based $\gamma_E^0$ value. However, the extra effort can significantly improve the utility of the backscatter value.

A robust radiometric image simulation algorithm is used to estimate the relevant local area value at each radar geometry grid location. The algorithm dispenses with the fixation on incidence angles inherited from ellipsoid-based backscatter retrieval. In almost any realistic scenario where terrain influences radiometry, there is usually no single local incidence angle that can be used to estimate the local area [10]. Instead, taking care to ensure that digital elevation model facets out of view due to radar shadow are discounted, all remaining facets are integrated across the image to directly estimate the exposed area at each radar geometry grid location. Conforming to the definition of gamma, the area of each DEM facet projected into the plane perpendicular to the slant range look direction is evaluated and added to a “running total” kept for each range and azimuth grid location. After DEM traversal, the total area contribution at each grid location is available as a 2D raster, and can be output as the image simulation. However, the technique is best extended using an integrated approach, whereby variations in the local illuminated area as well as range spreading loss, and trends induced by elevation antenna gain pattern (AGP) draped on the scene’s specific topographic variations [8] are all considered in the radar image simulation result. Accounting for as many systematic influences in the simulation as possible improves the quality of the normalisation reference.
Figure 3: Ellipsoid vs. Terrain Model Area Normalisation: Zürich-Lucerne, Switzerland - Examples from ENVISAT ASAR (a-c), ALOS PALSAR (d-f), and TSX (g-i) – all images radiometrically scaled to 20dB dynamic range – N.B. no normalisation possible in radar shadow.

### 3 DISCUSSION & CONCLUSIONS

In Figure 3, ASAR, PALSAR, and TSX images are juxtaposed with their radiometric image simulations and normalisations. Standard ellipsoid-model $\gamma^0_e$ is shown in the left column, the terrain area $A_t$ image simulation in the centre, and terrain-model $\gamma^0_t$ in the right column. Compare the relative confusion of terrain-induced and thematic differences in the conventional ellipsoid-model gamma (left), with the terrain-corrected gamma values (right), where the influence of topography is considerably “flattened”. No normalisation is possible in areas of radar shadow (visible in
the PALSAR & especially TSX normalisations). Figure 4 shows RGB overlays of orthorectified $\gamma^0$ retrievals for the overlapping area of coverage for the ASAR, PALSAR, and TSX products illustrated in Figure 3. Ellipsoid-Earth model-based GTC $\gamma^0_E$ and terrain-model-based RTC $\gamma^0_T$ overlays are shown. Note how the forest boundary is visible in the RTC (but not the GTC), even in the hilly regions south of Lake Lucerne.

Thematic assessments of data collected from different tracks, even asc./desc., or multiple sources are improved; land cover interpretation and change detection from time series [11] are made less ambiguous when terrain-induced radiometric effects are first normalised to “flatten” scene-dependent differences. Although the effects are strongest in regions with strong topography, benefits are substantial also in non-mountainous regions. Insisting on radiometric terrain correction raises the standard from conventional geometric terrain correction, providing significant added value when image comparison from non-uniform geometries is required. The throughput of present & future SAR sensors that do or will support accurate geolocation, such as ASAR, PALSAR, TSX, RADARSAT-2 & Sentinel-1 would be further enhanced if images acquired within a short time frame in differing geometries are made radiometrically comparable with comprehensive terrain calibration. The influence of local terrain variations on SAR radiometry need not be accepted as a given. The hills can be radiometrically flattened.

4 ACKNOWLEDGMENTS

ESA is thanked for providing the ASAR and PALSAR data (AO3600 and ESRIN Contract No. 22501/09/I-EC). The TerraSAR-X data was provided within AO project CAL0163. All rectifications were performed using the swisstopo DHM25.

5 REFERENCES