Available online at www.sciencedirect.com
ScienceDirect
Remote Sensing of Environment 106 (2007) 337–349
Remote Sensing of Environment
www.elsevier.com/locate/rse

Generation of geometrically and radiometrically terrain corrected SAR image products

Alexander Loew *, Wolfram Mauser

Department of Geography, University of Munich, Germany

Received 29 January 2006; received in revised form 29 August 2006; accepted 3 September 2006

Abstract

Terrain undulations affect the geometric and radiometric quality of synthetic aperture radar images. The correction of these effects becomes indispensable when quantitative image analysis is performed with respect to the derivation of geo- and biophysical parameters. The paper presents a rigorous approach for geometric and radiometric correction of SAR images. Using a digital elevation model, the imaging geometry is reconstructed and is used to perform geometric and radiometric correction of terrain induced distortions. The importance of a stringent radiometric correction based on the integration of the image brightness is emphasized. The approach guarantees that the energy contained in the image data is preserved throughout the geocoding process. The resulting backscattering images are fully terrain corrected and can be used for further quantitative investigations and may also improve qualitative studies as e.g. land cover classifications. The technique is applicable for different sensor types and image products, including already geocoded SAR images. The effect of different resolutions of digital elevation models used for the correction of the backscattering coefficient is investigated.

Keywords: Image enhancement; Image processing; Synthetic aperture radar; Terrain mapping; SAR geocoding; Radiometric normalization

1. Introduction

Topography has significant influence on the geometric and radiometric properties of synthetic aperture radar (SAR) images. Standard geocoded image products refer on an earth ellipsoid and don't consider local terrain undulations (Bamler & Schättler, 1993; ESA, 2003; Laur et al., 1998). Relative calibration accuracies on a flat earth are in the order of ±1.0 dB (Laur et al., 1993; Srivastava et al., 1999). In rugged terrain, the changing local imaging geometry may result in backscatter changes up to ±5 dB (Beaudoin et al., 1995) which is critical for quantitative image analysis and the derivation of bio- and geophysical parameters from SAR data as it may result in large uncertainties in the parameter retrievals.

Recent and forthcoming space borne SAR missions as RADARSAT, ENVISAT ASAR, TerraSAR or ALOS PALSAR allow for the acquisition of images in various geometries, which enables more frequent observations of an area of interest. The changing imaging geometry is related with different backscattering mechanisms and terrain induced distortions. The relief induced backscatter changes have to be treated as a systematic error and have to be compensated in a stringent way to generate relief independent SAR image products which only contain information about the surface characteristics. This is of special importance for the analysis of multitemporal image datasets in rugged terrain with changing imaging geometries as needed e.g. for time critical applications as flood forecasting or disaster management.

Numerous investigations are dealing with the terrain correction of SAR images, trying to compensate for the changing backscattering due to local topography. The approaches range from simple cosine correction methods (Bayer et al., 1991; Leclerc et al., 2001; Rees & Steel, 2001) to rigorous approaches (Small et al., 1998; Small et al., 1997; Loew & Mauser, 2003). The "facet method" proposed by Small et al. (1998) compensates the topographic effect by calculating for each image pixel a facet of a digital elevation model (DEM), which corresponds to the scattering area. A geometrical projection factor was proposed by Ulander (1996) instead, taking into account the slope and aspect of the DEM with respect to the viewing geometry, to compensate for the changing scattering area.

* Corresponding author. Department of Geography, Luisenstr. 37, D-80333 Munich, Germany.
E-mail address: a.loew@lmu.de (A. Loew).

0034-4257/$ - see front matter © 2006 Elsevier Inc. All rights reserved.
doi:10.1016/j.rse.2006.09.002

In the following, a rigorous approach for the geometric and radiometric terrain correction of SAR images is introduced. The algorithm is applicable to single-look-complex, as well as to geocoded image products as e.g. ScanSAR or precision image products. An accurate reconstruction of the SAR imaging geometry using orbit and topography information is required to achieve a good radiometric terrain correction. It is therefore presented first. Afterward a rigorous radiometric normalization method is developed, preserving the energy contained in the image data. The impact of the rigorous calibration on the image statistics is assessed for different imaging geometries and contrasted against standard image processing techniques and the effect of different resolutions of digital elevation models on the performance of the radiometric correction is investigated.

2. SAR imaging model

Standard geocoded SAR image products as e.g. ERS PRI, RADARSAT PathImages or ENVISAT WideSwath images are ellipsoid geocoded image products taking into account the earth curvature, but not the local terrain height (Olmsted, 1993; Roth et al., 1993). These products are limited with respect to their geometric and radiometric accuracy due to significant distortions caused by rugged terrain. For the correction of this "topographic effect", precise terrain geocoded images are required (Meier et al., 1993a,b). This can be accomplished by using a digital elevation model (DEM) for the correction. The topographic effect has two components, namely a geometric and a radiometric one (Meier et al., 1993a,b; Schreier, 1993).

2.1. Imaging geometry

Assuming the imaging geometry given in Fig. 1, the image coordinates of a SAR system are given by the slant range distance R_s and the Zero-Doppler position. For a given sensor position S, in an earth centered fixed Cartesian coordinate system, the slant range distance to the target position P is calculated by

$$R_S = \sqrt{(\vec{S}-\vec{P})\cdot(\vec{S}-\vec{P})} \tag{1}$$

The Doppler frequency shift f_D is calculated using the sensors and targets position and velocity vectors v_p and v_s, given the carrier frequency f_0 of the sensor as

$$f_D = \frac{2f_0}{c}\cdot\frac{(\vec{v}_P-\vec{v}_S)\cdot\vec{R}_S}{|R_S|} \tag{2}$$

where c is the speed of light.

2.2. Geometric terrain effects

The side looking geometry of a SAR system causes significant distortions due to height differences in across track direction. They are well known as foreshortening, layover and shadow. The same ground range distance from the sensors nadir line can have completely different slant range distances and may therefore be positioned in different image columns (Meier et al., 1993a,b; Olmsted, 1993). Along track, the relative velocity between the sensor and the target changes with changing terrain height, which introduces an additional Doppler frequency shift which can amount up to a displacement of several image pixels in azimuth direction (Meier et al., 1993a,b).

The objective of the geocoding process is to reconstruct the correct imaging geometry to find for each image pixel, the corresponding position on the earth.

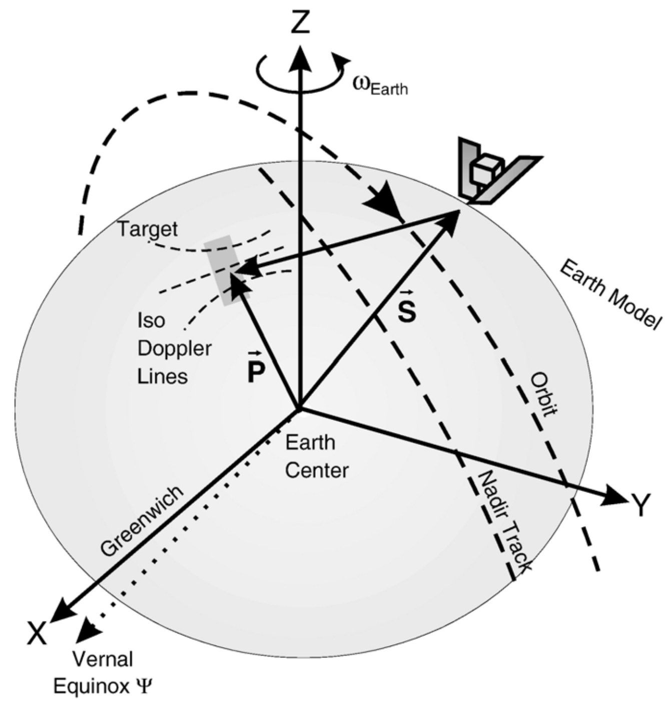

Fig. 1. SAR imaging geometry.

2.3. Radiometric terrain effects

For flat terrain, the radar brightness β^0, recorded at an image pixel is related to the backscattering coefficient σ^0 by

$$\sigma^0 = \beta^0\cdot\sin(\theta) \tag{3}$$

where θ is the incidence angle (Henderson & Lewis, 1998). The sine function approximates the scattering area A [m^2] as $A\sim 1/\sin(\theta)$ [m^{-2}] to account for the change of the scattering area from the near range to the far range region. Rugged terrain changes the recorded brightness values due to a) changes in the local scattering area and b) changing scattering mechanisms due to different incident angles. For slopes facing towards the incident wave front, a larger ground area contributes to the brightness value of a slant range resolution cell, than for slopes lying in the opposite direction. This results in significant brightness changes, dependant on the local imaging geometry. The slope and aspect of the scattering surface may produce significant changes of the scattering area within neighboring resolution cells (Bayer et al., 1991; Meier et al., 1993a,b; Small et al., 1998). The correction of this effect is therefore crucial to retrieve surface characteristics as