Accounting for Topographic Slope Effects on Radar Backscatter in Siberian Forests

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***Abstract* - The effects of slopes on radar backscatter are well known to impact the classification of land cover in mountainous terrain. Remote sites in the mountainous regions of south-central Siberia are the focus of a forest disturbance study using radar backscatter. The slope effect and methods to account for and reduce these effects were studied. Techniques employed included correction of illuminated area variations due to incidence angle, ratioing of radar images having different frequencies and polarizations, and principal components analysis of ratios. The results are presented and recommendations are made for use of these techniques in mountainous terrain.**

I. Introduction

While research has proven SAR to be a unique source of information, there are still limitations in using SAR for monitoring terrestrial, vegetated surfaces. In areas with topographic relief, radiometric variations are introduced to the imagery caused by the imaging characteristics of SAR. These variations are related to several factors — changes in incidence angle, shadowing, image foreshortening, and image layover. Land cover classification and the derivation of ecological characteristics of the vegetation based on radar imagery is a complex process, even if the terrain is relatively flat [1]. However, if there is a strong topographic gradient, some type of radiometric correction must be performed before the scene can be classified and/or vegetation characteristics can be extracted. Biomass estimation based on certain radar ratios has also been successful on flat terrain [2], however, it is not known whether ratioing can also be used as a way of diminishing the radiometric distortions caused by the topography. Wever and Bodechtel [3] proposed using LHV and XVV ratios and difference images for radiometric rectification without the use of a DEM (digital elevation model).

The purpose of this paper is to evaluate different approaches for correcting radiometric variations introduced by topography in SAR imagery. Multi-frequency and multi-polarization SIR-C data obtained during the April 10, 1994 SRL-1 (Space Radar Laboratory — 1) mission were used.

II. Study site

The Western Sayani mountains are located in Eastern Siberia, 350 km South of the city of Krasnoyarsk and 125 km East from the Yenisey river at 53º 4.2' N latitude and 93º 14.3' E longitude. The area is sparsely populated and the most significant anthropogenic influence on the landscape is the logging of coniferous trees.

The 25 by 50 km study area is characterized by a steep elevation gradient, ranging from 280 to 2100 m. Along this vertical gradient vegetation zones vary from forest-steppe at < 300 m elevation through aspen, birch pine, and spruce-fir forests to alpine tundra elevations >1800 m. Aspect may also be an important factor in forest type distribution. However, preliminary analysis including visual inspection and computation of texture measures of 1m resolution IKONOS data suggests that on the selected sites there are no forest type or density variations that could be attributed to aspect.

III. Data Analysis

A. Microwave Data

The images used in this study (L and C-band SAR data, HH, HV, and VV polarizations) were recorded on April 10, 1994 during the SRL-1 mission and pre-processed by JPL (Jet Propulsion Laboratory). The pixel spacing was 13.33 m in the range direction and 5.8 m in the azimuth direction. The data were multilooked to 26.6 m in the range direction and to 34.55 m in the azimuth direction in order to reduce speckle. Then they were converted from slant to ground range using orbit information extracted from the image header and filtered using 5 by 5 averaging to reduce image speckle. Fig. 1 shows the SIR-C l LHH image.

The radar images were then geocoded using a Level 1 DTED (Digital Terrain Elevation Data) or Digital Elevation Model (DEM). The horizontal resolution DEM is about 50 x 100 which was resampled to 50 x 50 m.

The radar images cannot be directly registered to the DEM because of the presence of distortions on the radar image caused by the terrain. Therefore, a simulated radar image was generated from the DEM to enable correction of terrain distortions such as foreshortening. The radar images were co-registered with the simulated radar image by selecting 21 control points on both the radar images and the simulated image. The original radar images were resampled and the geometric terrain distortions caused by the topography of the site (such as foreshortening) were corrected for.

B. Selecting Forested Slope Sites

Minimizing surface roughness and dielectric properties of the surface can be achieved by selecting sites that have homogeneous stand density and structure, and similar growth forms. The sites selected also had to have different terrain characteristics, so that a range of slope and aspect values would be included.

Landsat 7 ETM+ (Enhanced Thematic Mapper) scenes of July 6, 1999 were acquired. The data were co-registered with the radar data set and the DEM. IKONOS image acquisition was ordered through NASA Stennis Science Data Purchase program in July 2001. Six scenes of IKONOS data were acquired from August 17 to 20, 2001, and received in October, 2001. The resolution of the Landsat 7 multispectral data set is 30 m (15 m for the panchromatic band) while the resolution of the Ikonos multispectral data is 4 m (1 m for the panchromatic band).

Using Landsat 7, IKONOS images, and our knowledge gained from field observation in August 2000, 26 conifer forest areas were chosen that had similar stand density. By choosing homogenous stands, the backscatter variations due to the surface roughness and dielectric components were minimized. Using the slope and aspect information derived from the DEM, it was insured that the site selected also had a wide range of slope and aspect values. Since the DEM contained periodic grid-like artifacts, these grid-like features were removed from each training site to ensure that artifacts did not affect the results of the analysis.

C. The incidence angle based model

Local slope and local aspect images were generated from the DEM using the slope and aspect calculating modules in PCIworks [4]. Slope values always range from 0 to 90 degrees. The surface aspect (or orientation) angle is the angle between north (the top of the image) and the projection of the normal vector of the slope plane onto the horizontal plane.

The local incidence angle was calculated by:

$$\cos(i) = \sin(\beta)*\sin(\gamma)*\cos(\alpha-\alpha_s)+\cos(\beta)*\cos(\gamma) \quad (1)$$

where i = local incidence angle

β = local slope

γ = incidence angle of platform at the center of image

α_s = aspect angle of local slope

α = the azimuth angle of the illumination direction of the platform

The slope, aspect, incidence angle and backscatter information from all 26 coniferous sites were extracted and combined. The local aspect (r=0.40) were more correlated with LHH backscatter than local slope (correlation coefficient, r, =0.12). Fig. 2 shows the strong correlation (r =-0.67) present between local incidence angle and LHH backscatter.

The model, described by Kellndorfer *et al.* [5] is shown in the following equation:

$$I_{corr} = DN*(\sin(i_{dem})/(\sin(I_{ref})) \quad (2)$$

where: I_{corr} = Intensity corrected for local incidence angle

DN = digital number of pixel in intensity format

i_{dem} = local incidence angle at each pixel = $[\cos(i)]^{-1}$ (from Equation 1)

I_{ref} = the incidence angle of the platform at the center of the image

This model corrects for the geometric component of radiometric distortion. It does not attempt to model either scattering phenomena due to the roughness and dielectric properties of the surface or their interactions with surface geometry. This procedure was completed for all six original radar images. All corrected image channels were found to correlated with local incidence angle. Minimum correlation was for LHV (-0.62). Maximum correlation was for CHH (-0.67).

B. Ratioing

From the six original, geometrically corrected radar images (LHH, LHV, LVV, CHH, CHV and CVV) 15 unique ratios were generated. Absolute values of correlation coefficients of ratio values with incidence angle ranged from 0.02 for LHH/CVV to 0.12 for CHH/CVV.

C. Principal Component Analysis

Principal component analysis was also performed using all fifteen ratio images. The first four components accounted for over 97% of the variation. Absolute values for correlation values for the relationships of the first four principal components and local incidence angle ranged from 0.0 to 0.20

IV. Results and Discussion

Figure 3a is a scatter plot of local incidence angle and the LHH incidence angle corrected backscatter. Although the correlation of the relationship diminished from r =-0.679 to -0.19, it is still stronger than the correlation between local incidence angle and any ratio. For example, LHH/LHV (r= 0.06) ratio brightness is shown on Fig. 3. The relationship between local incidence angle and the 1st principal component shown on figure 3c (r=-0.18). Based on the results, the ratio correction method was the most successful at eliminating the dependence of image brightness on local incidence angle. Overall, there was a weak correlation between band ratios and local incidence angle, meaning that the ratios of any of the six channels reduced the effect of terrain.

V. Conclusions

Based on this analysis it can be concluded that: all 15 band ratios are weakly correlated with local incidence angle. The ratios of two co-polarized or two cross-polarized channels tend to be less correlated with local incidence angle. The ratios of a cross-polarized channel and a co-polarized channel are more correlated with local incidence angle. This effect seems independent of wavelength

It is also important to consider that even if one ratio, or one combination of wavelength and polarization, was found to be a superior way to correct the presence of terrain features in radar images, it would still remain to be seen whether or not this ratio is also useful for other applications, such as biomass or snow pack thickness estimation or even for land cover classification. For example, the ratio of LHV/CHV has been used in an earlier studies to improve biomass estimation (e.g.,[1]).

Most ecological studies reporting the use of SAR data have been conducted in areas with relatively flat terrain so that difficulties of the radiometric bias introduced by the presence of terrain could be avoided. The development of successful radiometric correction methods will make similar studies on mountainous terrain possible and it will contribute to better understanding of the planet s ecosystems

ACKNOWLEDGMENT

This research was partially supported by NASA HQ Office of Earth Science NASA Grant NAG-5-3548 and RTOP 662-92.

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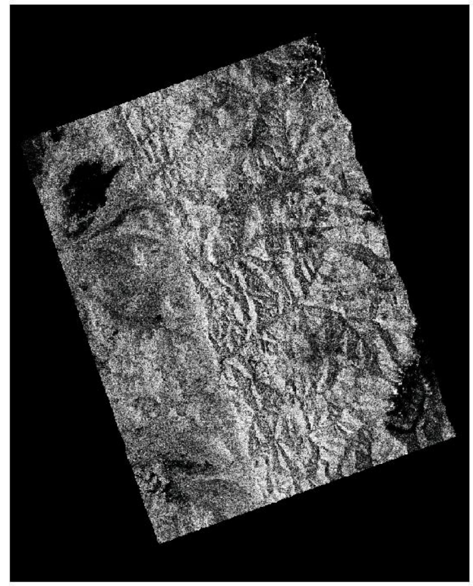

Fig. 1. The original SIR-C LHH image of a portion of the Sayani Mountains in central Siberia. Note the strong topographic effect from east-west oriented mountains. North is at left side of image.

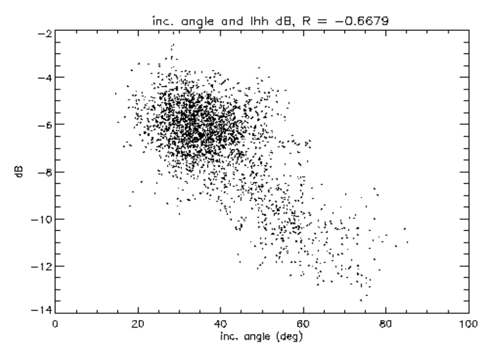

Fig. 2. Incidence angle and LHH backscatter.

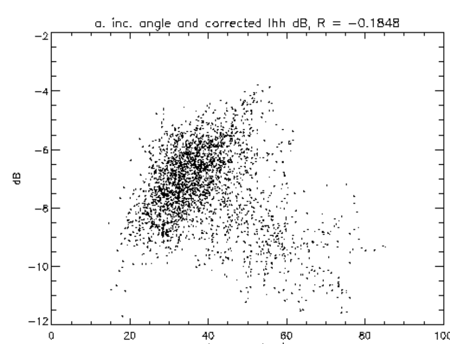

Figure 3. Relationship of a) incidence angle corrected LHH backscatter, b) LHV/CHV ratio, c) 1st principal component and local incidence angle.