PAPER ID - J.1

SLOPE CORRECTION OF SENTINEL-1 SAR DATA USING PHYSICAL MODEL OF TERRAIN-WAVE INTERACTION

Haris Suka Dyatmika and Katmoko Ari Sambodo, Indonesia
Remote Sensing Technology and Data Center, LAPAN
Jl. Lapan No 70, Pekayon, Pasar Rebo, Jakarta Timur 13710, Jakarta, INDONESIA

E - mail : haris.suka@lapan.go.id

Abstract

SAR (Synthetic Aperture Radar) is an active remote sensing technology using microwave, so that can operate all day and can penetrate even in cloudiness. However SAR data can be difficult to interpret especially because of slope effects. In the hilly area, the standard calibration i.e. radiometric calibration of SAR data is inadequate to get a data with good consistency. There are some additional errors due to differences in slope in non flat area. In the homogeneous land cover, the backscatter should be equal, but in non flat area it can be varies depending on slope relatively. Thus, it is advisable to apply some slope correction first before the utilization of the data. Applying a slope correction, the backscatter intensity corrected in order to equal the backscatter. This research applied a slope correction based on a simple physical of the terrain-wave interaction model into a Sentinel-1 data. The model describes terrain as uniform opaque volume of isotropic scatterers, which is independent of terrain type, frequency and polarization. The correction consider the effects of the slope variation that influence backscatter intensity for each pixel data. Two acquisitions of Sentinel-1 C-SAR (C-band Synthetic Aperture Radar) of south Sumatera data used in this research. One is Sentinel-1 C-SAR data with ascending pass, VV – polarization acquired on december 16th 2014 and the other is descending pass, VV & VH – polarizations acquired on december 24th 2014. Experiment results show in the homogeneous land cover with variated slope up to 47°, a decreasing amplitudo for slope effects ie. 1.5 dB was obtained. This improvement can also assest visualy by combining ascending and descending data then analyze the shifting intensity.

Key words: SAR, Sentinel-1, terrain correction, terrain-wave model

INTRODUCTION

SAR (Synthetic Aperture Radar) is an active remote sensing technology using microwave, so that can operate all day and can penetrate even in cloudiness. However SAR data can be difficult to interpret especially because of slope effects. Earth's surface topography (terrain) is one of the main factors that influence the interaction between microwave beam with observed object. The slope effects caused by rugged terrain have two components, called a geometric and a radiometric one (Tian, 2014). In this research, we are not reviewing about the geometric component, but focus on the radiometric one. Slope effects change the SAR backscatter intensity such as changing the number of scatterers per unit image area caused by the slopes. Related to the slope effects, radar incidence angle variation together with terrain slope steepness and slope aspect variation can have special effects on radar image data i.e foreshortening, layover and shadowing. Foreshortening is a slope effects when the radar beam reaches the base of a tall feature tilted towards the radar before it reaches the top. If the radar beam reaches the top of a tall feature before it reaches the base, layover occurs and the backscattering from the slope will mix with the signature from other targets. When a slope faces away from the radar and the slope is steeper than the incidence angle, shadowing occurs. There is no way to recover the signatures lost due to layover and shadowing with a single data (Sun et al, 2002). However with different directions data, that signatures lost can still corrected. Typically because of terrain slope steepness, slope aspect, land cover type, radar observation geometry, radar frequency band and polarization can be very complex slope effects.

Some SAR data utilization have to applying a slope correction in the processing step. For example in agricultural crop monitoring, time series data are required and better if images from different look directions combined. Combining ascending and descending images will be complementary information that will increase the accuracy of the utilization. Applying the slope correction to the ascending and descending images in the pixel value comparison plot can increasing correlation coefficient by almost exactly 100% (Georing et al, 1995). In biomass estimation, slope effects influences the radar backscatter modulation. More over, many forests are located on steep slopes (Hoekman et al., 2015). Small et al. (2010) recommended to consider a high level products that incorporate normalisations for terrain effects in Sentinel-1 standard processing chains.

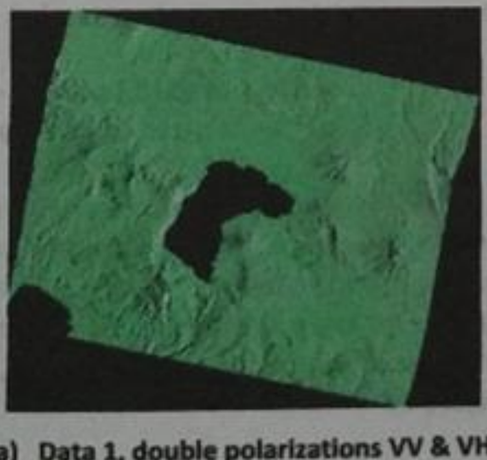
Many research related to the slope correction has been done with various approach by many author such as Ulander (1996), Lee et al. (2000), Sun et al. (2002), Small et al. (2010) and Hoekman et al. (2015). Ulander (1996) described an equation for radiometric slope correction using the information derived from a SAR interferograms. SAR interferogram have some. specific information such as phase which are common SAR data haven't. Another proposed method calculates the slopes effects from a comparation between the DEM-based Simulated SAR Image and the SAR slant range image. The slope correction effectively reduced the radiometric variation caused by the terrain height variation. This correction requires an accurate DEM of sufficiently high spatial resolution (Shimada, 2010). Hoekman et al. (2015) show some models related to the slope correction. One of the mentioned models is physical model of terrain-wave interaction. The model describes terrain as uniform opaque volume of isotropic scatterers, which is independent of terrain type, frequency and polarization.

The work reported here, we discuss the posibility applying slope correction Using Physical Model of Terrain-wave Interaction to Sentinel-1 SAR data. This model can be used for the correction considering the availability of the data i.e. intensity of Sentinel-1 SAR data. The work evaluated by qualitative and quantitative analyzing i.e. comparing between ascending and descending pass acquisition and analyzing the statistical of the data.

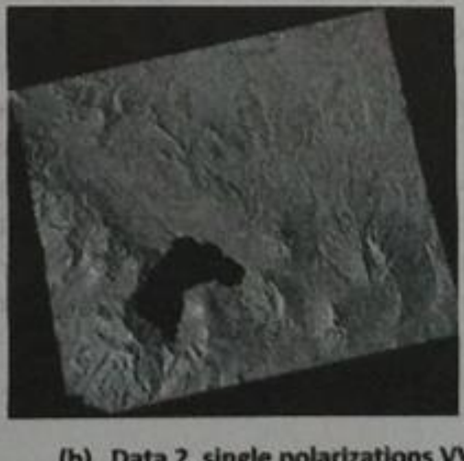
DATA AND METHOD

Data

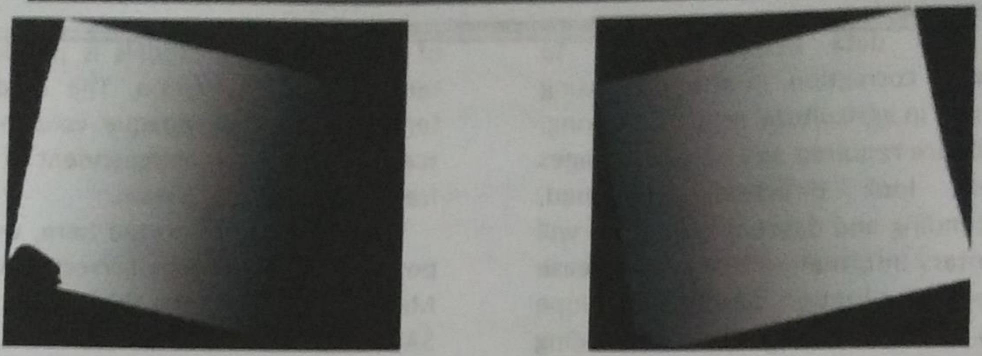
The main data used in this research is two acquisitions of Sentinel-1 C-SAR (C-band Synthetic Aperture Radar) Level-1 product Ground Range Detected (GRD) with pixel spacing range x azimuth 10 x 10 m near south Sumatera data. The data was equipped also with the incidence angle from ellipsoid interpolation. One is Sentinel-1 C-SAR data with ascending pass, VV – polarization acquired on december 16th 2014 and the other is descending pass, VV & VH – polarizations acquired on december 24th 2014. The data calibrated radiometically from intensity into γ^0 then applied a geometric correction i.e range-doppler terrain correction with Sentinel-1 toolbox. The additional data i.e. terrain slope steepness and slope aspect derived from the SRTM 90m DEM. Figure 1 show the data used in this research.



(a) Data 1, double polarizations VV & VH



(b) Data 2, single polarizations VV



(c) Incidence angle from ellipsoid Data 1, from 46.6° to 41.4°

(d) Incidence angle from ellipsoid Data 2, from 33.7° to 37.7°

(e) SRTM 90m DEM

(f) Slope steepness

(g) Slope aspect

Figure 1. Data used in this research. (a) Data 1, double polarizations VV & VH, with the color composite combinations (R= VH, G= VV, B=VH); (b) Data 2, single polarization VV; (c) Incidence angle from ellipsoid Data 1, from 41.4° to 46.6°; (d) Incidence angle from ellipsoid Data 2, from 33.7° to 37.7° ; (e) SRTM 90m DEM; (f) Slope steepness derived from the SRTM 90m DEM; (g) Slope aspect derived from the SRTM 90m DEM

Method

Modeling radar backscatter of object stands on slopes

Terrain-wave interaction be affected by wave geometry propagation and terrain geometry. The wave geometry propagation can be described by two angles i.e. the incidence angle (θ_i) and the look direction (φ_l). The Incidence angle (θ_i) is the angle between the backscatter direction and the normal to the surface of the ellipsoid at the cell location. The look direction (φ_l) is the angle between the target and the North at the sensor location. The terrain geometry can be described by two angles i.e. the slope steepness (α_s) and the slope aspect (φ_s) relative to the North. The wave geometry propagation can be derived from the metadata of SAR data. The terrain geometry can be derived from a DEM (Hoekman et al., 2015).

Slope correction using physical model of terrain-wave interaction

The slope aspect (φ_s) and the look direction (φ_l) can be combined as one parameter i.e. slope aspect relative to the look direction (φ_r) as follows:

$$\varphi_r = \varphi_l - \varphi_s \text{ ....(1)}$$

The slope steepness (α_s) and slope aspect relative to the look direction (φ_r) generate slope steepness angle in range direction (α_r) as follows:

$$\tan(\alpha_r) = \tan(\alpha_s)\cos(\varphi_r) \text{ or}$$
$$\alpha_r = \arctan(\tan(\alpha_s)\cos(\varphi_r)) \text{.........(2)}$$

The slope correction using physical model of terrain-wave interaction can be formulated by backscattering factors γ^0. The backscattering factors for the model simply follows the geometry of a resolution cell in range direction, sketched in Figure 2.

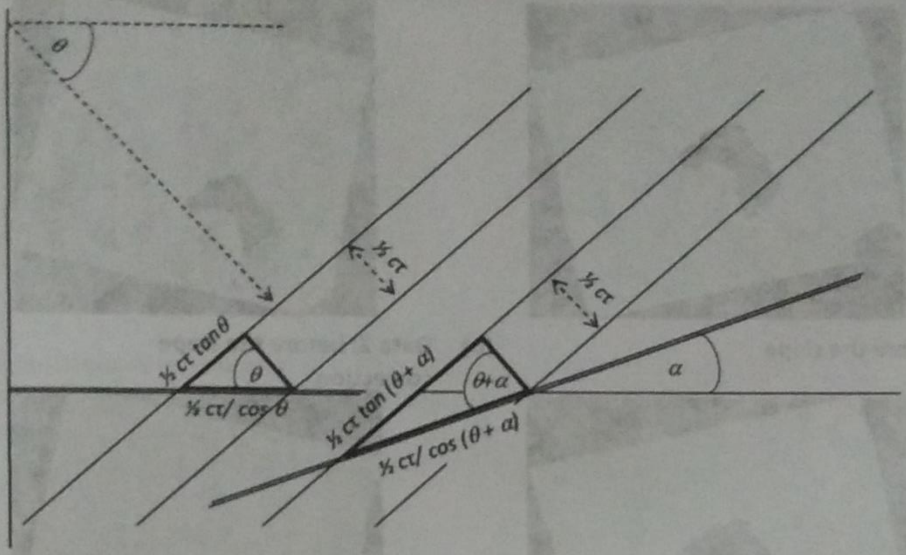


Figure 2. Geometry of resolution cell in range direction: flat terrain (left triangle) and facing slope (right triangle). The angle of slope steepness in range direction is α (or α_r); the incidence angle is 90°−θ; the range resolution is 1/ 2 cτ (half pulse length; where pulse length is the product of speed of light (c) and pulse duration (τ)) (Hoekman et al., 2015).

The correction will follows on the ratio between the observed volume on the tilted terrain (right triangle) and the observed volume on the flat terrain (left triangle). The volume equals the illuminated area (within the resolution cell) multiplied by the penetration depth in a direction normal to the surface of this volume. Hence, this penetration depth depends on the orientation of the surface of the volume element with respect to the backscatter direction. Note that this ratio equals the ratio of the surfaces (of these volumes) as projected in the backscatter direction.

Finally the ratio between backscatter on tilted terrain γ^0 and the backscatter on flat terrain $\gamma_f{}^0$ can be modelled using physical models of the terrain-wave interaction (Hoekman et al., 2015) is defined by the formula:

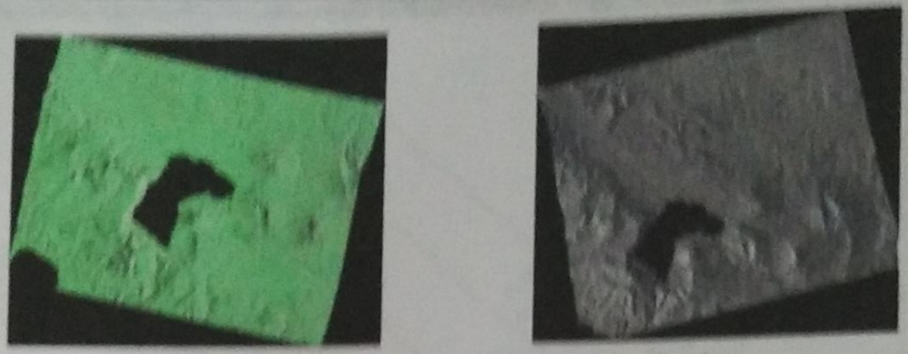
$$\gamma^0 = \gamma_f{}^0 \, \frac{\tan\,(90^0-\theta_i+\alpha_r)}{\tan\,(90^0-\theta_i)} \quad ....(3)$$

RESULTS AND DISCUSSION

Figure 3 show the slope correction of Sentinel-1 data results. Visualy, the image before the correction (3a & 3b) have a certain terrain rather than after correction (3c & 3d). Note that between the data pair was shown in same combination and stretching. On the tilted terrain, the image before the correction have a pattern i.e. a bright and a dark side. This pattern is affected by the slope effects which is the backscatter varies depending on slope relatively.

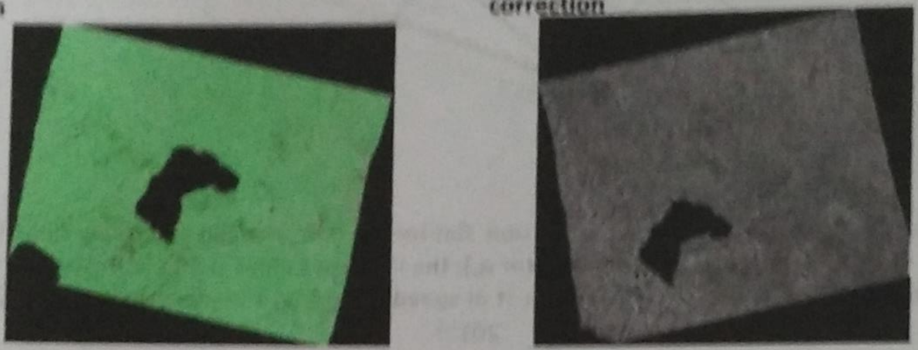
The data 1 and data 2 acquired in different pass. The descending pass (data 1) cross the equator from north to south and facing at the right. Hence, the image have a bright side on the right of the slope and a dark side on the left, inversely the ascending pass one. That happened because of the position of the radar relative to the observed object so the near range and far range of the image were inversely each other.

Visualy, the corrected image (3c & 3d) look quite flat indicate the succeeded of the terrain correction. But comparing both the corrected image, the data 2 was more flat than tha data 1. That could be because of the incidence angle of the data 1 is greater than the data 2. So the effects of the slope variation will give a bigger contribution that maybe difficult to correct.



(a) Data 1; before the slope correction

(b) Data 2; before the slope correction

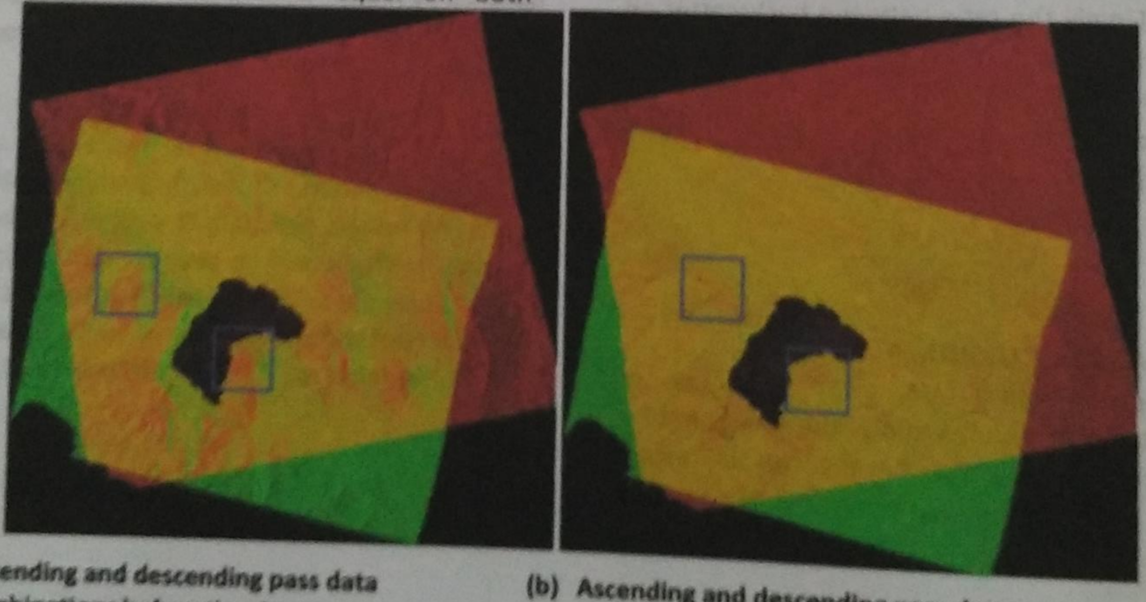


(c) Data 1; after the slope correction

(d) Data 2; after the slope correction

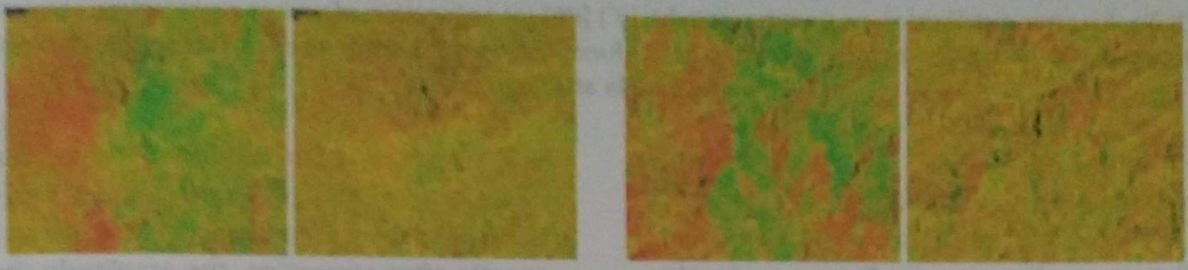
Figure 3. Data before and after the slope correction. (a) Data 1, double polarizations VV & VH, with the color composite combinations (R= VH, G= VV, B=VH) before the slope correction; (b) Data 2, single polarization VV before the slope correction; (c) Data 1, double polarizations VV & VH, with the color composite combinations (R= VH, G= VV, B=VH) after the slope correction; (d) Data 2, single polarization VV after the slope correction.

Figure 4 show the combinations of the ascending and descending images. Because of both data were acquired on the same month, so it could be assumed that the land use was same. But, the shifting intensity looks clearly on the image before the slope correction even more clearly than the original images. The yellow color mean that the backscatter is equal on both ascending and descending pass data. When the slope effects occurs, the intensity will shifting into the green if foreshortening and layover effects occur on the descending pass data or in oppositely way into the red. After the slope correction the image combinations is smoother and less shifting intensity were detected.



(a) Ascending and descending pass data combinations before the slope correction

(b) Ascending and descending pass data combinations after the slope correction

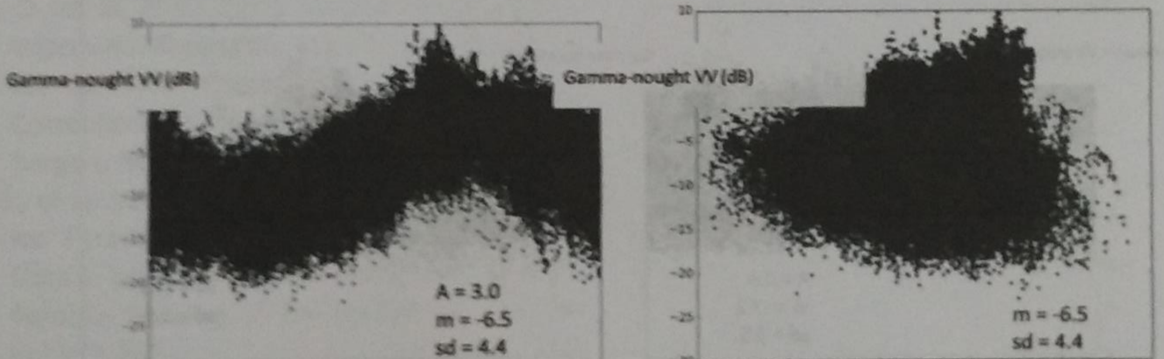


(c) Comparison on small sample area 1 **(d) Comparison on small sample area 2**

Figure 4. The combinations of the ascending and descending pass SAR data, VV – polarization (R= ascending pass, G= descending pass) (a) before the slope correction; (b) after the slope correction; (c) small sample area 1 in the homogeneous land cover, before correction (left) after correction (right); (d) small sample area 2 in the homogeneous land cover, before correction (left) after correction (right)

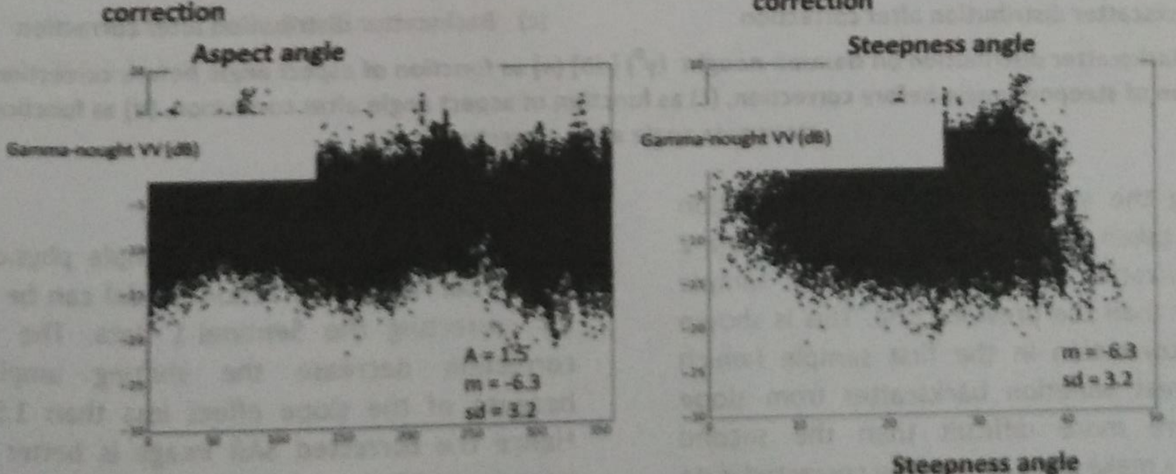
The data zoom in on the blue square mark i.e a small sample area in the homogeneous land cover for more details evaluation (Figure 4). The first sample (4c) is a hill with great steepness angle. The other sample (4d) is more flat than the previous.

A quantitative assessment are shown in Figure 5. The assessment is calculating the backscatter distribution on a small sample area in the homogeneous land cover (4c) against the aspect angle (5a & 5c) and steepness angle (5b & 5d). The small sample area is one of the hill in the SAR data. Hence it has a sinusoidal aspect angle (Figure 5a). Figure 5b indicated that the small sample area taken have a great steepness angle i.e. variated up to 47⁰. Amplitudo decrease about 1.5 dB and standar deviation decrease 1.2 in Figure 4 indicate that the correction did well.



(a) Backscatter distribution before correction

(b) Backscatter distribution before correction

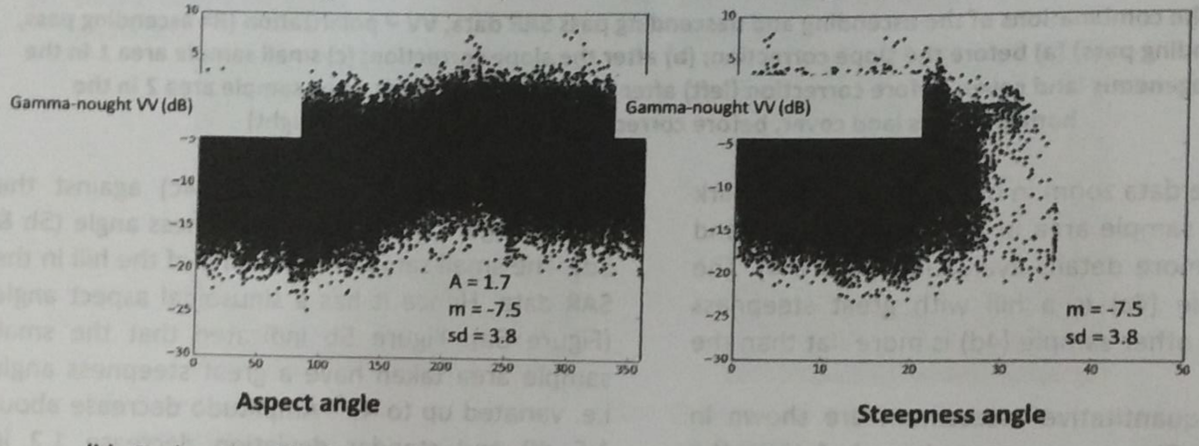


(d) Backscatter distribution after correction

(c) Backscatter distribution after correction

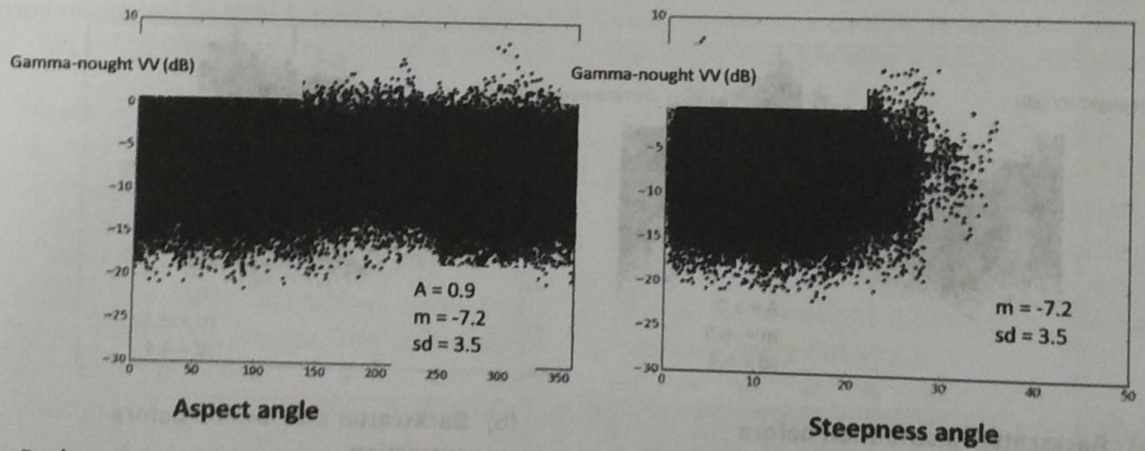
Figure 5. Backscatter distribution on Gamma-nought (γ^0) [dB] (a) as function of aspect angle before correction, (b) as function of steepnes angle before correction, (c) as function of aspect angle after correction, (d) as function of steepness angle after correction.

Another assessment on a small sample area in the homogeneous land cover (4d) are shown in Figure 6. In this assessment the area is more flat than the area in Figure 5. In this sample, the steepness angle variated up to 37^0. The decreasing amplitudo is less than the decreasing in the previous sample, the standar deviation also only decrease 0.3. However in both sample after correction, the amplitudo show that remaining slope effects are less than 1.5 dB.



(b) Backscatter distribution before correction

(a) Backscatter distribution before correction



(d) Backscatter distribution after correction

(c) Backscatter distribution after correction

Figure 6. Backscatter distribution on Gamma-nought (γ^0) [dB] (a) as function of aspect angle before correction, (b) as function of steepnes angle before correction, (c) as function of aspect angle after correction, (d) as function of steepness angle after correction.

Comparing the sample results after correction which are taken in a same SAR data i.e in data 2 VV – polarization, the result in the last sample still better than the previous one. This is shown that the correction in the first sample (which have a great variation backscatter from slope effects) are more difficult than the second sample. It's make a sense why the corrected data 2 was more flat than the data 1.

CONCLUSION

Slope correction based on a simple physical of the terrain-wave interaction model can be used for correcting the Sentinel-1 data. The slope correction decrease the shifting amplitudo because of the slope effect less than 1.5 dB. Hence the corrected SAR image is better than uncorrected SAR image. However, the correction on the high steepness angle are more dificult to correct than normal steepness angle. The slope correction still leaves a bit of terrain effects especially on the high steepness angle and also on the great incidence angle.

REFERENCES

Tian, B., et al. 2014. Mapping mountain meadow with high resolution and polarimetric SAR data. Institute of Physics (IOP) Conference Series: Earth and Environmental Science.

Hoekman, D., et al. 2015. Multi-model radiometric slope correction of SAR images of complex terrain using a two-stage semi-empirical approach. Remote Sensing of Environment, Vol. 156, pp. 1-10.

Lee, J. S., et al. 2000. Polarimetric SAR Data Compensation for Terrain Azimuth Slope Variation. IEEE Transactions on Geoscience and Remote Sensing, 2153-2163.

Shimada, M., et al. 2010. Ortho-Rectification and Slope Correction of SAR Data Using DEM and Its Accuracy Evaluation. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, Vol. 3, No. 4.

Small, D., et al. 2010. Terrain-Corrected Gamma: Improved Thematic Land-Cover Retrieval For Sar With Robust Radiometric Terrain Correction. ESA Living Planet Symposium, Bergen, Norway

Sun, G., et al. 2002. Radiometric Slope Correction for Forest Biomass Estimation from SAR Data in Western Sayani Mountains, Siberia. Remote Sensing of Environtment, Vol.79, pp. 279-287.

Ulander, L., et al. 1996. Radiometric Slope Correction of Synthetic Aperture Radar Images. IEEE Transactions on Geoscience and Remote Sensing, 34(5), 1115–1122.