SURFACE ROUGHNESS MODELING USING POLARIMETRIC SAR DATA TO DELINIATE GEOMORPHOLOGIC OF MINERALIZATION ZONES AT VOLCANIC TERRAIN

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Abstract — In this study, we used the fully Polarimetric Synthetic Aperture Radar (PolSAR) data to model the surface roughness at volcanic terrain. The PolSAR sensor enable to transmit and receive microwave radiation with four polarization modes: HH, HV, VH, and VV. The Horizontal and Vertical components indicate the direction of electromagnetic wave propagation, termed as H and V, respectively. The digital number of the four polarization types are converted into Normalized Radar Cross-Section (NRCS) and used as basis of surface roughness modeling. A simple fitting method was applied to the NRCS by incorporating the incidence angle to reduce the slope factors. The correctness of the surface roughness model was calculated from simple fitting to the field roughness measurement. Thirty four sample points of field roughness measurements were collected using a pin meter. The correlation between field measurement and the initial roughness model from PolSAR data was calculated to improve the correctness of the model. The iteration procedures were performed until the correlation coefficient about 0.9. Mt. Manglayang in West Java, Indonesia was selected as study area. Mt. Manglayang is a composite volcano (stratovolcano) with the summit elevation about 1818 m above mean sea level. Result of this study showed that the surface roughness could be modeled using PolSAR data. Then, the surface roughness parameter are used to predict the possibility of mineralization zones by taking into account the geomorphologic and structural features controlled the area.

1. INTRODUCTION

Indonesia is located between three tectonic plates, which is Eurasian plate, Indo-Australian plate and Pacific plate. These plates have a microscopic motion which caused formation of volcanoes. Indonesia has 129 volcanoes that potential to be mineral exploration area because there are a lot of valuable minerals formed in volcanic activity processes. Magmatic intrusion as part of volcanic activity causes magmatic water moves up to the volcanic surface. When magmatic water that contains sulfide ions, chloride ions, sodium ions, and potassium ions have interaction with meteoric water, cause sulfide ions and chloride ions that carry metal minerals become deposited. Meanwhile, heat emission of magma in the mineralization process causes erosion on the surface of volcano. Therefore, the mineralization zone can be identified by looking at the surface of a volcano that has a surface roughness value is smoother than the surrounding area.

Surface roughness has a strong controlling influence on radar scattering and other types of remote sensing observations (Campbell and Shepard, 1996). Volcanic surfaces roughness can be determined by utilizing remote sensing technology, such as Synthetic Aperture Radar (SAR). Radar energy is measured in wavelengths of centimeters that penetrate rain and clouds which is an advantage in tropical regions (Sabins, 1999). ALOS PALSAR is one of SAR satellite system that using microwave L band type with a wavelength is 23.6 cm, so it can be used to detect surface geology, including volcano surface roughness. ALOS PALSAR sensor has able to receive and transmit microwave radiation with four polarization modes (full polarimetric), such as HV, VH, VV, and HH. In this research ALOS PALSAR data was obtained to create a model of volcano surface roughness using full polarization SAR image data to delineate mineralization zones. Through this research we also want to identify the type of polarization combinations and initial roughness model formula in volcano surface roughness modeling.

2. RESEARCH AREA, INSTRUMENTATION, AND DATA

This research is located in Mt. Manglayang, West Java, Indonesia. Mt. Manglayang is a type of composite volcano with summit elevation about 1818 m above mean sea level. The data used in this study are grouped into primary data and secondary data. The primary data of this research is ALOS PALSAR images fully polarimetric data at level 1.5. The Polarimetric data are proved effective to characterize surface condition especially at volcanic terrain (Saepuloh et al., 2012). The secondary data is field roughness measurements data at 34 sample points. In order to define the surface roughness of volcanic terrain, a field measurement was done using pin meter. The pin meter that used on this research is consists of 60 metal pins with length 30 cm. To measure the surface roughness of volcanic terrain, the pin meter was set on the sample area. The top of pin meter will create the profile of the surface sample area. Field measurement data consists of 34 sample points that acquired from 2 different study areas. The root mean square (RMS) of surface height was calculated to qualitatively describe the surface roughness of each sample area. Furthermore, RMS height from each sample area was used to compare the accuracy of surface roughness value from SAR data model.

Figure 1. Location of research area at Mt. Manglayang, West Java, Indonesia, showed by black rectangle.

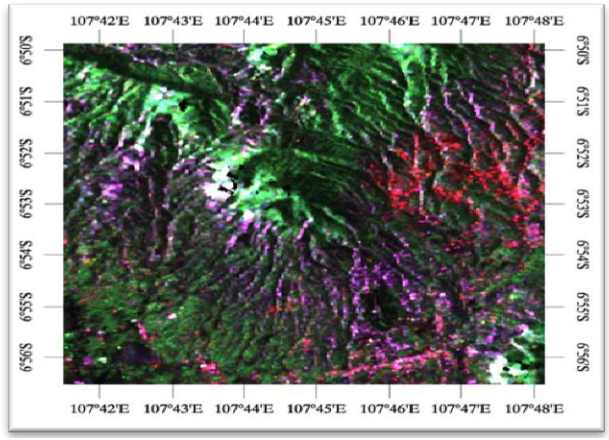

Figure 2. Research area showed by color composite of ALOS PALSAR for R, G, B = HH, HV, VV.

1. NCRS MODEL OF SURFACE ROUGHNESS

1.1 Conversion of Digital Numbers into NRCS

ALOS PALSAR image level 1.5 from four different types of polarization mode (HH, HV, VH, and VV) was extracted to obtain digital number of each polarization. Digital number of each polarization was converted into Normalized Radar Cross Section (NCRS). NCRS (σ^0) is a function of the surface roughness and electrical properties (Long D.G. et al, 1996). NCRS value is influenced by the backscattering intensity (β) that can be seen from digital number. NCRS was calculated from formula below (Shimada et al, 2007):

$$\sigma^0_{\eta\xi} = 10 \times log_{10}\left(\beta^2_{\eta\xi}\right) + cf \qquad (1)$$

Where β is the backscattering intensity, σ^0 is NCRS, and cf is conversion factor. Conversion factor of ALOS PALSAR is -83. The η and ξ are denote the polarization modes of σ^0 and β, which η indicates the transmit polarization and ξ indicates the receive polarization.

3.2 Initial Roughness Model

Initial roughness model is an expression that used to represent the estimate value of volcano surface roughness from ALOS PALSAR data. Initial roughness model was calculated by following relationship between NCRS value from HV polarization mode (σ^0_{HV}), incidence angles (ϕ), and wavelength scale (λ) (Campbell and Shepard, 1996):

$$h_0(\lambda) = \lambda \left[-\frac{1}{60}\ln\left(1 - \frac{\sigma^0_{HV}}{0.04\cos\phi}\right)\right]^{0.5} \qquad (2)$$

Where, the wavelength scale of L-band ALOS PALSAR is 23,6 cm. Furthermore, the correlation between initial roughness model and field measurement from PolSAR data was calculated to improve the correctness of the model. The comparison between initial roughness model and RMS height from field measurements has been illustrated by graph on Figure 3. Figure 3 shows that R^2 value between initial roughness model represented by equation (2) and RMS height of sample points is 0,0725. Value of R^2 represents the correlation coefficient between two data, whereas R^2 = 0,0725 indicates that the correlation is very small. Note that correlation coefficient ranges between -1 and 1, with -1 and 1 indicating the strong correlation between two data. Because of correlation coefficient value that have been explained above, the initial roughness model still need an improve to create a model of surface roughness which have a strong correlation with RMS sample. So, the initial model unable to describe the real condition of volcano surface roughness. At the further processing, formula (2) still used as a basis formula to create a volcano surface roughness models.

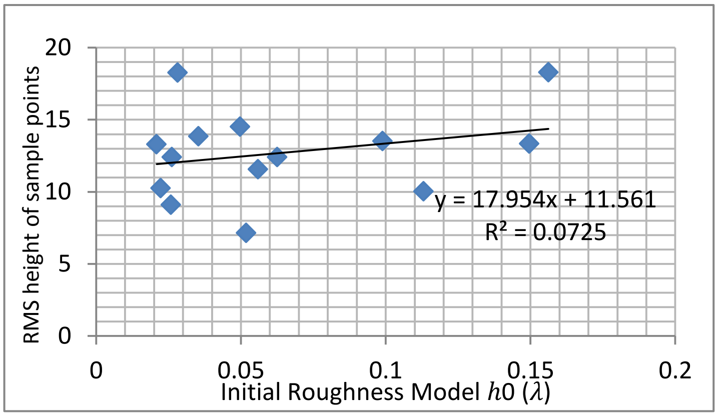

Figure 3. Comparison of $h_0(\lambda)$ from HV radar observation with RMS height of sample points from field measurement.

3.3 Initial Roughness Model Combination Polarization

Initial roughness model combination polarization was designed to obtain the model of surface roughness that more suitable to represent the surface roughness of volcanic terrain. In order to find the most suitable initial model combination, we should know the elements that give an effect to surface roughness modeling, such as backscattering coefficient and incidence angles.

Refers to initial roughness model calculation performed by equation (2), NCRS value that used into initial roughness model formula was from HV polarization mode (σ^0_{HV}). To determine the influence of other polarization modes (HH, VH, and VV), the initial roughness model has been calculated with the other polarization modes of NCRS value.

$$h_0(\lambda)_{\eta\xi} = \lambda\,[-\frac{1}{60}\ln\left(1-\frac{\sigma^0_{\eta\xi}}{0.04\cos\phi}\right)]^{0.5} \quad (3)$$

Formula (3) is used to calculate the initial roughness model as a function of NCRS from other polarization modes. For example, to determine the initial roughness model from HH polarization mode, we used NCRS value from HH polarization mode ($\sigma^0_{\eta\xi} = \sigma^0_{HH}$). The initial roughness model value from each polarization modes has been compared with field measurement data to know the correlation of each initial roughness model.

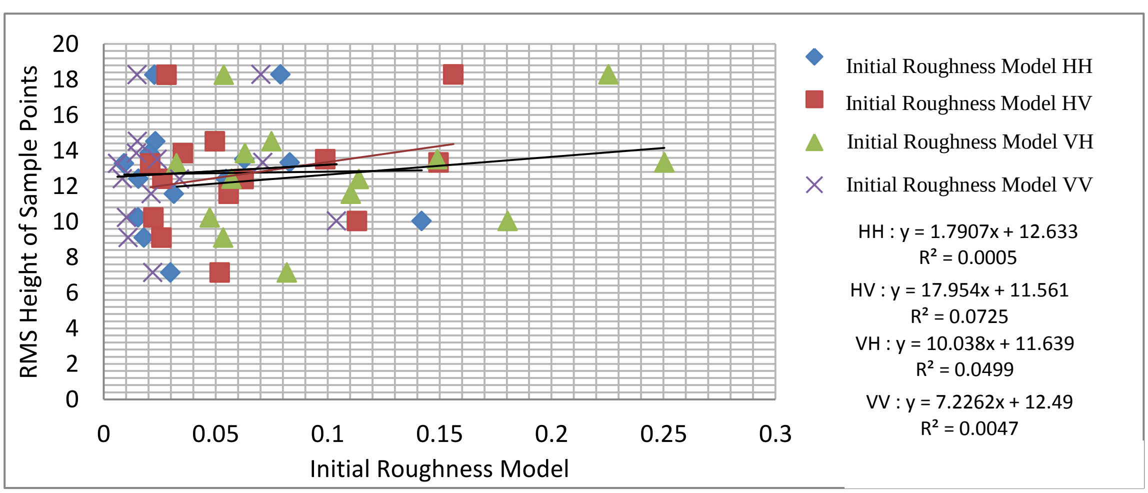

Figure 4. Comparison of initial roughness model from each polarization modes (HH, HV, VH, and VV) with RMS height of sample points.

The graph on Figure 4 shows that the correlation between h_0 from each polarization modes and RMS height of sample points is still on low level correlation. The highest R^2 performed by $h_{0\ HV}$ with 0.0725. However, based on the graph can also be seen that each polarization modes give the different R^2 values, but the correlation value of all types polarization correlation is still below 0.1. Thus, the initial roughness model has not been able to describe the real condition of volcano surface roughness area.

Furthermore, a comparison between two initial roughness models had been calculates to identify the relationship between initial roughness models from a different polarization mode.

Table 1.Correlation coefficient values between two initial models from a different polarization

Polarization Mode-1	**Polarization Mode-2**	**Correlation Coefficient**
HV	VH	0.9785
VV	HH	0.9336
HV	HH	0.6844
VV	VH	0.7402
HV	VV	0.7277
VH	VV	0.6929

Table 1 shows that all of initial roughness models combination have a strong correlation between each others. So, it give us assumed that to improve the correlation of initial model could be done by combined the initial model from a different polarization modes. Furthermore, the initial model combination polarization performed to establish a better model which can represent the volcano surface roughness. Based on the following process, it was found that the best combination polarization with the highest correlation value was obtained by multiplication between the initial models. Correlation value of the combination polarization with the multiplication between initial roughness models can be seen in Table 2.

Table 2 shows that a pretty good combination polarization obtained by the multiplication between initimodel HV and VV with correlation value is 0.3237 and initial model combination of HH and VV with correlation value is 0.3175. However, that correlation value is still not able to represent the actual condition of the volcano surface roughness.

In order to create an initial model combination polarization which has a strong correlation with RMS height of sample point, we try to determine the influence of incidence angle.

Table 2. Samples of initial roughness model combination

Initial Model Combination	**Correlation Coefficient**
$h_{0\ HV}$ x $h_{0\ VV}$	0,3237
$h_{0\ HV}$ x $h_{0\ HH}$	0,0217
$h_{0\ HV}$ x $h_{0\ VH}$	0,0994
$h_{0\ HH}$ x $h_{0\ VV}$	0,3175

Table 3.Initial roughness model combination with the influence of incident angle

Initial Roughness Model Combination	**Correlation Coefficient**
$h_{0\ HV}$ x $h_{0\ VV}$ x $\sin\theta_i$	0,3814
$h_{0\ HV}$ x $h_{0\ VV}$: $\sin\theta_i$	0,1589
$h_{0\ HV}$ x $h_{0\ VV}$ x $\cos\theta_i$	0,307
$h_{0\ HV}$ x $h_{0\ VV}$: $\cos\theta_i$	0,3394
$h_{0\ HV}$ x $h_{0\ VV}$ x $\tan\theta_i$	0,3779
$h_{0\ HV}$ x $h_{0\ VV}$ x $\sec\theta_i$	0,3399
$h_{0\ VH}$ x $h_{0\ VV}$ x $\sin\theta_i$	0,4497
$h_{0\ VH}$ x $h_{0\ VV}$ x $h_{0\ HV}$ x $\sin\theta_i$	0,3019

Table 3 shows that incidence angle give an impact to increase the correlation of initial model combination. The highest correlation coefficient value is performed by multiplication between initial model VH, initial model VV and sin incidence angle. However, that correlation value 0.4497 is still unable to represent the actual condition of the volcano surface roughness.

From iteration procedures, it was found that the best combination polarization with the highest correlation coefficients value obtained by equation below:

$$h_{0(\sigma)} = 10\ (h_0(\lambda)_{VH} \times h_0(\lambda)_{VV})^2 \times sin\ \theta_i \qquad (4)$$

Where $h_{0(\sigma)}$ is initial roughness model combination polarization, $h_0(\lambda)_{VH}$ is initial roughness model from VH polarization mode and $h_0(\lambda)_{VV}$ is initial roughness model from VV polarization mode (calculated from equation 3). The correlation coefficient value performed by equation (6) is 0.7126 which has been able to represent the model of volcano surface roughness.

2. RESULT AND CONCLUSIONS

The chart from Figure 4 shows that correlation of $h_{0(\sigma)}$ with RMS height from field measurement is 0.7126. That correlation value has been able to represent the model of volcano surface roughness.

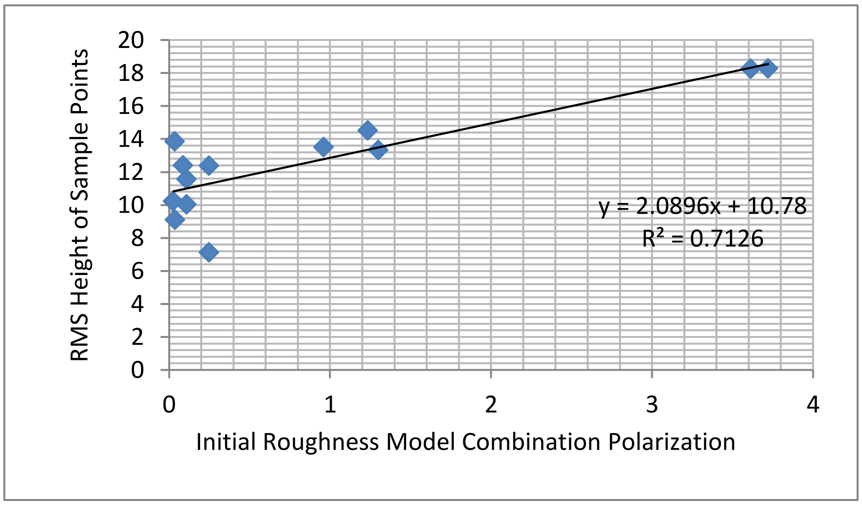

Figure 5.Comparison of initial roughness model combination polarization with RMS height of sample points.

Based on data processing was found that the model of volcano surface roughness which has been able to describe the real condition of the volcano surface roughness obtained by a combination of the initial model VH and VV. Refers to initial roughness model combination polarization formula (6), there are the square of multiplying formula between initial model VH and VV. Based on that we can assume that initial model VH and VV give a strong effect on surface roughness modeling from PolSAR data. However, correlation value 0.7126 show that initial model from combination polarization still contain the error value which is caused due to several aspects, such as the high vegetation at the research area. While, the electromagnetic waves used by ALOS PALSAR is the L band with a wavelength of 23.6 cm is only able to penetrate the leaf cover but unable to penetrate the tree trunk.

Based on this research can be concluded that surface roughness modeling from ALOS PALSAR data was influenced by backscattering coefficient and incidence angle. The influence of incidence has been used to reduce the slape factors of SAR satellite. To obtain the model of volcano surface roughness that able to describe the actual conditions of volcano surface, required the combination polarization of initial roughness model. The best combination polarization for surface roughness modeling was obtained by combination of initial roughness model VH and VV.

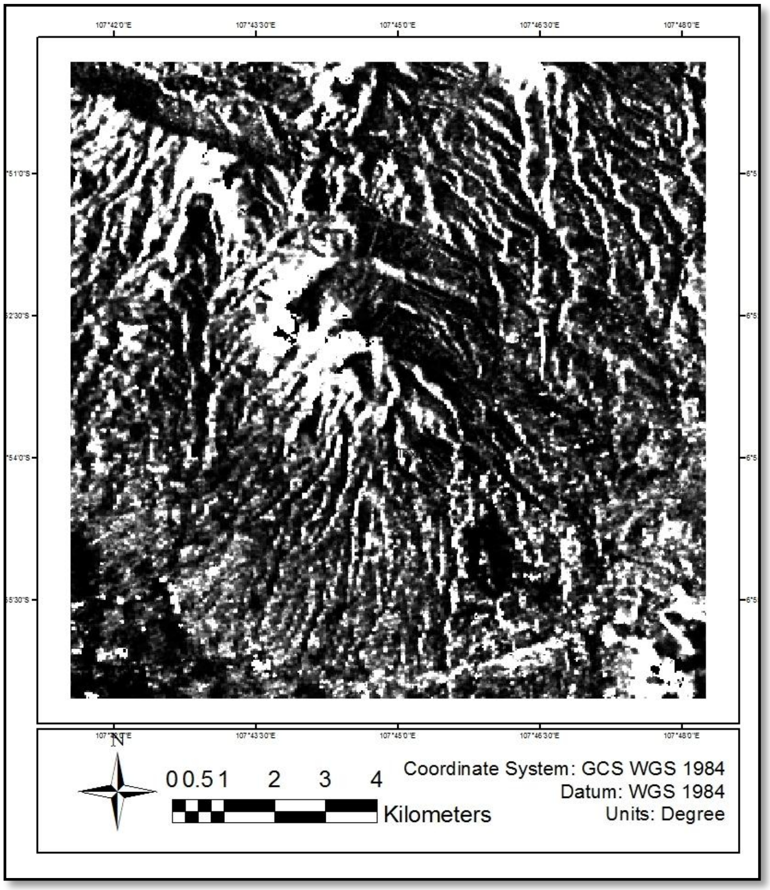

Figure 6. Final roughness model from ALOS PALSAR Polarimetric image

3. REFERENCES

Nashabibi, A., Ulaby, F. T., and Sarabandy, K. (2006). Measurement and modeling of the millimeter-wave backscatter response of soil surface. IEEE Transactions on Geoscience and Remote Sensing Vol.34 No.2, pp. 561-572.

A. Mushkin, and Gillespie, A. R. (2005). Estimating sub-pixel surface roughness using remotely rensed. Remote Sensing of Environment 99, pp. 75-83.

Bronto, Sutikno. (2006). Fasies gunung api dan aplikasinya. Jurnal Geologi Indonesia, Vol. 1 No. 2, pp. 59-71.

Bryant, M., Thoma, D. P., Collins, C. D. S., Skirvin, S., Rahman, M., Slocum, K., Starks, P., Bosch, D., and Dugo, M.P.G. (2007). Measuring surface roughness height to parameterize radar backscatter models for retrieval of surface soil moisture. IEEE Geoscience and Remote Sensing Letters Vol.4, pp. 137-141.

Campbell, B. A., and Shepard, M. K. (1996). Lava flow surface roughness and depolarized radar scattering. Journal of Geophysical Research Vol.101, No. E8, pp. 18,941-18,951.

Mazzarini, Fransesco, Favalli, M., Isola, I., Neri, M., and Pareschi, M.T. (2008). Surface roughness of pyroclastic deposits at Mt. Etna by 3D laser scanning. Annals of Geophysics, Vol. 51, No. 5/6, pp. 813-822.

Kim, S.B., Moghaddam, M., Tsang, L., Burgin, M., Xu, X., and Njoku, N.G. (2014). Models of L-band radar backscattering coefficients over global terrain for soil moisture retrieval. IEEE Transactions on Geoscience and Remote Sensing, Vol.52. No.2, pp. 1381-1396.

Long, G. D., Collyer, R., and Arnold, D. V. (1996). Dependence of normalized radar cross section of water waves on bragg wavelength-wind speed sensitivity. IEEE Transactions on Geoscience and Remote Sensing Vol.34 No.3, pp. 656-666.

Kervyn, M., Kervyn, F., Goossens, R., Rowland, S. K., Ernst, G. G. J. (2007). Mapping volcanic terrain using high-resolution and 3D satellite remote sensing. Geological Society, pp. 5-30.

Oh, Yisok., Hong, Suk-Young., Kim, Yunjin., Hong, Jin-Young., and Kim, Yi-Hyun. (2009). Polarimetric backscattering coefficients of flooded rice fields at L- and C-bands: measurements, modeling, and data analysis. IEEE Transactions on Geoscience and Remote Sensing, Vol.47, No.8, pp. 2714-2721.

R. Bryant, M. S. (2007). Measuring surface roughness height to parameterize radar backscatter models for retrieval of surface soil moisture. IEEE Geoscience and Remote Sensing Letters, Vol. 4, No. 1, pp. 137-138.

Sabins, F. F. (1999). Remote sensing for mineral exploration. Ore Geology Reviews 14, pp. 157–183

Saepuloh A., Koike K., Omura M. (2012), Applying bayesian decision classification to Pi-SAR polarimetric data for detailed extraction of the geomorphologic and structural features of an active volcano. IEEE Geoscience and Remote Sensing Letters (GRSL), Vol. 99, No. 4, pp. 554-558.