Scientific Research

Simple Relationship Analysis between L-Band Backscattering Intensity and the Stand Characteristics of Sugi (*Cryptomeria japonica*) and Hinoki (*Chamaecyparis obtusa*) Trees

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Abstract

In this study, we have performed an analysis between the L-band backscattering intensity derived from the slope corrected ALOS PALSAR remote sensing data and the *in-situ* stand biophysical parameter of Sugi (*Cryptomeria japonica*) and Hinoki (*Chamaecyparis obtusa*) trees at the forests of Chiba Prefecture, Japan. Diameter at breast height (DBH), tree height, and stem volume were statistically compared with the slope corrected sigma naught backscattering in an empirical approach. It was found that the relationship between the backscattering and the stand characteristics was strongly dependent on species showing different trends between the Sugi and Hinoki trees. The Hinoki trees showed an increasing backscattering with increasing parameters (higher DBH, higher Tree height and higher stem volume), as it was mentioned on various researches, while the Sugi tree showed and decreasing backscattering with increasing parameters. We have also found for the Sugi trees that the backscattering is affected strongly by the number of stems. We have assumed that this is because of the characteristics of the Sugi trees which have high moisture content in the heartwood of the stem, compared with other tree species in Japan. The results pave the way to the possibility for estimating biophysical parameters within the forests of Japan by considering such trends and at highly rugged areas by using slope corrected imagery of the SAR data.

Keywords

SAR, ALOS/PALSAR, Forest, Backscattering, Stem Volume, Biophysical Parameter

1. Introduction

Synthetic Aperture Radar (SAR) application in land remote sensing is becoming one of the top methods chosen among the researchers for solving issues that were facing difficulties when only optical data were selected. The field varies from land cover change, detection analysis, to disasters such as land degradation, earthquakes, and to the application in forest management. Developing algorithms for extracting information's from the Earth's surface (e.g. biophysical parameters) is especially of high interests because of the potential of the remote sensing technique where we can interpret areas which are remote and difficult to access, and furthermore, for the use as performing continuous monitoring of our forests resources.

The use of SAR for a biomass/biophysical parameter application is likely to be processed with the relationship between the radar backscattering and the parameters of the forests. This works out because of the characteristics of the radar information; radar waves are longer than the optical waves. As a result, the scattering of the radar contributes from not only the surface of the top layer (e.g. canopy) but also from the medium of the objects (e.g. branches, stems) for the L-band radar [1]-[7]. Various studies have investigated the correlations between biomass/biophysical parameters with SAR backscattering information to understand the trend and reliability of the usage of SAR for the extraction of the forests information so that it could be further applied for the use in forest management [3] [8]-[12]. However, most of the studies focus on forests that are located in regions that are on relatively flat areas, which is understandable due to the difficulties of the SAR distortions caused by the hilly terrains [13] [14] making the interpretation of ground lying objects falling into an erroneous assumption. Some studies have shown the challenges in analyzing the trend at mountainous regions [15], but they still show the difficultness in applying studies on such areas. The majority of these studies conclude that their understanding of the relation to backscatter and forests biomass/biophysical parameter shows that the backscattering tends to increase with relating biomass and biophysical parameters such as stem volume or tree height and comparing with the co-polarized signal such as the HH polarization. The cross-polarized HV backscattering shows more sensitivity to the growing parameters [1] [2] [4] [16]-[22]. Although, not all of the studies show clear increasing relationships of the parameters with the increasing backscattering, such as the works done by Kobayashi *et al.* [9] and Wijaya [12] when studying the relation of the backscattering with the changes of the stand characteristics within the forests of Indonesia. They have described that the backscattering increases with increasing biophysical parameter, but it also starts to decreases at a certain point of the growing parameter. Clear description of this phenomenon wasn't stated, however, Kobayashi *et al.* [9] stated that the backscattering may be affected by the leaves of the tree due to its size and the moisture content.

Studies applied in the forests of Japan are rare, Motohka *et al.* [23] investigated the relationship between the backscattering information of HH and HV polarized gamma naught values and biomass of Japanese natural forests for the retrieval of forests above ground biomass (AGB), showing a positive logarithmic relationship and showing also the usefulness with the performance of slope correction. However, not a significant relation can be seen through the study. We believe that the forest inventory data in their study were used from different experimental sites with various forest types and species, which makes difficult to determine the true backscattering relations, as Santoro *et al.* [24] explained that accuracy of forest biometric parameter estimations are site dependent.

Leblon *et al.* [25] described that the influences to the backscattering at forested areas are affected by vegetation types, species and structures [2] [26]-[28], vegetation biomass [4] [29]-[31], topography and surface roughness [32] and canopy height [2] [4], flooding and the presence/absence of the standing water, and near surface moisture or fuel moisture [10] [25] [33]-[36]. If backscattering information changes from such various aspects, there needs to be a strong care when we make relationship analysis between the biomass and biophysical parameters because the difference in region and environment will affect the changes in the response from the forests.

A number of studies have been implemented throughout various regions in the world, but not many studies have been applied at the forests of Japan for understanding the trends between the structure of the Japanese forests and SAR information. Even the work that has been implemented by Motohka *et al.* [23] is limited to the natural forests, while it considers the AGB but not the actual biophysical parameters that influence to the resulting AGB. Most of the studies do not look through the characteristics of the backscattering with the relation on different tree types at different growing stages, and according to the former studies we believe that there might be some differences in the characteristics of the stands in the Japanese forests which could influence to the resulting backscatter, and those needs to be considered for when making relationship between the backscattering and the stand characteristics for a better understanding and development of accurate biomass/biophysical parameter extraction method.

Therefore, our objective is to analyze the relationship between backscattering information with the biophysical parameters (diameter at breast height (DBH), tree height, stem volume) from different tree types (Sugi (Japanese cedar: *Cryptomeria japonica*) and Hinoki (Japanese cypress: *Chamaecyparis obtusa*) at different polarizations in the forests of Japan.

2. Study Area

Our study area is focused on the Prefectural owned forests of Chiba Prefecture, Japan. Chiba Prefecture is located on the east coast of Japan along the Pacific Ocean, just east of Tokyo metropolitan area where the peninsula sticks out, approximately between 139.75˚E and 140.88˚E, 34.89˚N and 36.10˚N, where a total land area of 5156 km^2 (**Figure 1**). Official figure shows that 1606 km^2 (about 1/3) of Chiba Prefectures lands are covered by forests. The terrain of Chiba is rather flat compared to the other places of Japan. The Boso hills, a chain of hills ranging from 200 m to 300 m in altitude, and the highest peak can be seen at Mt. Atago, which ranges up to only 408 m.

Climatic condition shows a warm oceanic climate, which is a condition that is high humidity, high precipitation on summer, and low humidity, low precipitation on the winter. However, compared to the southern and north eastern region of Chiba where the climate is warm throughout the year, the inland area shows more diversity such as a higher temperature drop in the winter. Annual precipitation shows highest at in the southern area with more than 2000 mm and next the northern area which is has about 1400 mm to 1600 mm. The difference in precipitation clearly shows the distribution of the forests being more dense at the south and sparse on the north.

3. Data Sets

3.1. Satellite Remote Sensing Imagery

For our analytical purpose, a microwave satellite data was considered in use. We have chosen to apply the Advanced Land Observing Satellite (ALOS) Phased Array L-band Synthetic Aperture Radar (PALSAR) provided by Japan Aerospace Exploration Agency (JAXA). Remote Sensing Technology Center of Japan (RESTEC) has started to provide the PALSAR Global Mosaic (PGM) product which covers global range in the ground range pixel spacing of 10 m or 25 m, along with the process of ortho-rectification and slope correction (selective) from the beginning of 2013. Since the topographic effects that causes distortions to the observed SAR data is critical, we have selected both 10 and 25 m pixel spacing data of the study area for the comparison with the slope corrected option. The observation date for the PALSAR image is July to September, 2009, where ranges in month occurs because the product is a mosaic image of the area with multiple scene tiles. The year 2009 data was used because both 10 m and 25 m data was available only for that year for the comparison, so that data was utilized for our analytical purpose. The PALSAR specification of the study area is at ascending Fine Beam Dual (FBD) polarization, characterized by 34.3 degree of off nadir angle.
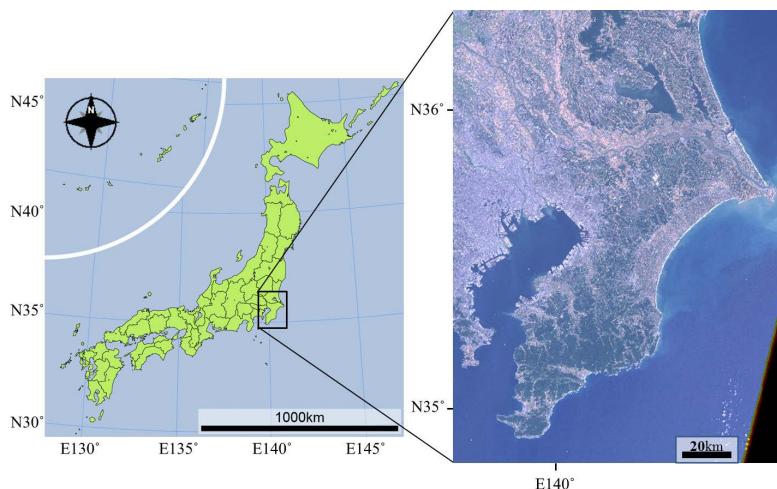

Figure 1. Our study area, Chiba Prefecture, Japan (Image source: left: modified from Google Earth; right: Landsat Oli).

3.2. Field Observation Data

We have collected a forest inventory data provided by the Prefectural Government of Chiba, which was obtained from the field observation implemented by the Chiba Prefectural Government, Agriculture, Forestry and Fisheries Department, Forest Division. Observations were made through 2011 and 2012 academic year at the prefectural owned forests located central to southern regions of the Prefecture. The data compiles with the information of tree type (Sugi or Hinoki), tree age, mean diameter at breast height (DBH), mean tree height, stem volume per unit area, stem density per unit area, mean basal area, and some other parameters which indicates the geological position of where the observations were made in terms of aspect and the position of whereabouts on the mountain (e.g. ridge). Information of the trees are collected within a plot area (0.01 ha) with the shape being similar to the satellite image pixel, which is normally square, and the coordinates of the plot is recorded only at the centre of the plots. Total observation plot size results up to 1939 plots; 838 for year 2011 (Central: 588 Southern: 250) and 1101 for 2012 (Central: 672 Southern: 429). Central and southern plot data on 2011 and the plot data at the central of 2012 will be used for the statistical analysis between satellite data and the field observation data.

3.3. Vegetation Continuous Fields (VCF)

Vegetation Continuous Fields (VCF) data developed by the university of Maryland [37] is utilized to quantitatively interpret the forest percent cover. By using this information, we can understand how the scattering behavior changes through the differences among the forested area differentiating it by each forest percentage cover. The data is available online from the Global Land Cover Facility Website. The original resolution for the product is 250 m, while we have resampled the data using bilinear method so we can match with the satellite image.

4. Analysis Method

4.1. Image Preprocessing for PALSAR

The PALSAR image used in this study was converted from the provided format which is in the Digital Number (DN) values, to the backscattering intensity information also known as backscattering coefficients or the Normalized Radar Cross Section expressed using Equation (1):

$$\sigma^0 = 10 \times \log_{10}\left(\mathrm{DN}^2\right) + \mathrm{CF} \tag{1}$$

where σ^0 is the backscattering intensity represented in decibel units (dB) and CF is the calibration factor for the data obtained, depending on the observation period and polarization [38]. The image is already in the process of ortho-rectification and slope correction, so we will work on the analysis directly using this data without any additional correction. The difference of the obtained image of the area for non-slope corrected and slope corrected is shown on **Figure 2** for the visual interpretation.
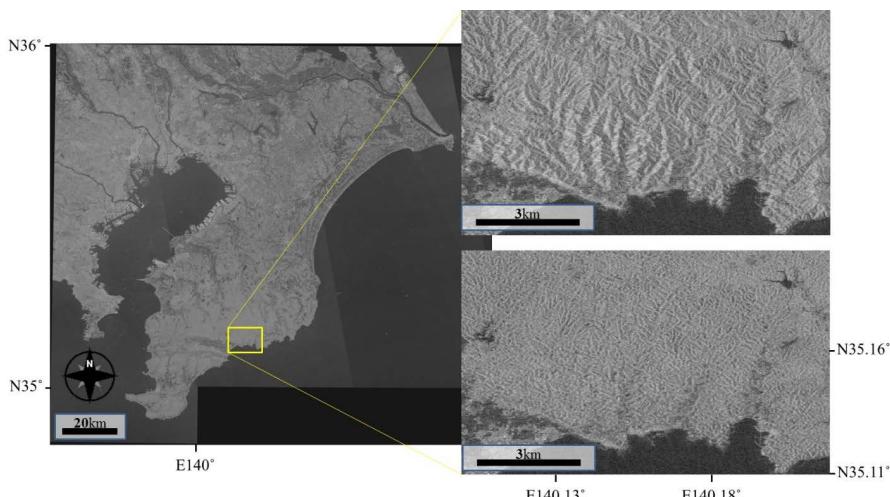

Figure 2. 25 m PALSAR Global Mosaic product (HV) of the study area, the left image shows the overall of the area and on the right shows the zoomed area with no slope correction (top) and slope corrected (bottom).

4.2. Statistical Analysis between Field Observation Data and Satellite Data

We have carried out a statistical analysis for formulating relationships among the field observation data of the forest stand characteristics and the remotely sensed microwave satellite data. The process will be taken by analyzing the relationships between SAR backscattering intensity (σ^0) and the stand characteristics (DBH, tree height, and stem volume) for both 10 m and 25 m pixel spacing PALSAR image to compare the differences of the results from higher and lower pixel spacing. The procedure for the relationship analysis was taken through multiple approaches:

a) Combine all the observation plots and make the analysis;
b) Divide the plots into per forest percentage cover;
c) Divide the plots to different stem volume range (lower range or higher range);
d) Divide the plots into separate species (Sugi and Hinoki).

We attempted to do this because the scattering mechanisms of the SAR backscatter in the vegetated areas are very complex; usually it is difficult to see any trends when we come across making relationships with the stands in various range of the structure when combined [35]. So we tried to break down the whole to a smaller category and see how the backscattering will respond to those structures. The confidence of the image pixel was considered using the mask data attached together with the PGM product. Plots that do not match the needs were omitted from the analysis by using the mask data.

5. Results

5.1. Statistical Analysis of Backscattering vs. Forest Stand Biophysical Parameter (Methods A, B, C,)

Statistical relationship between backscattering intensity (σ^0) and each forest stand characteristics (DBH, Tree height, stem volume) is investigated by using least-square method on the basis of the field observation plot. For reference, a regression line is drawn using second order polynomial. First, we have used all the plot information and made the relationship analysis (**Figure 3**).


(a)

(b)
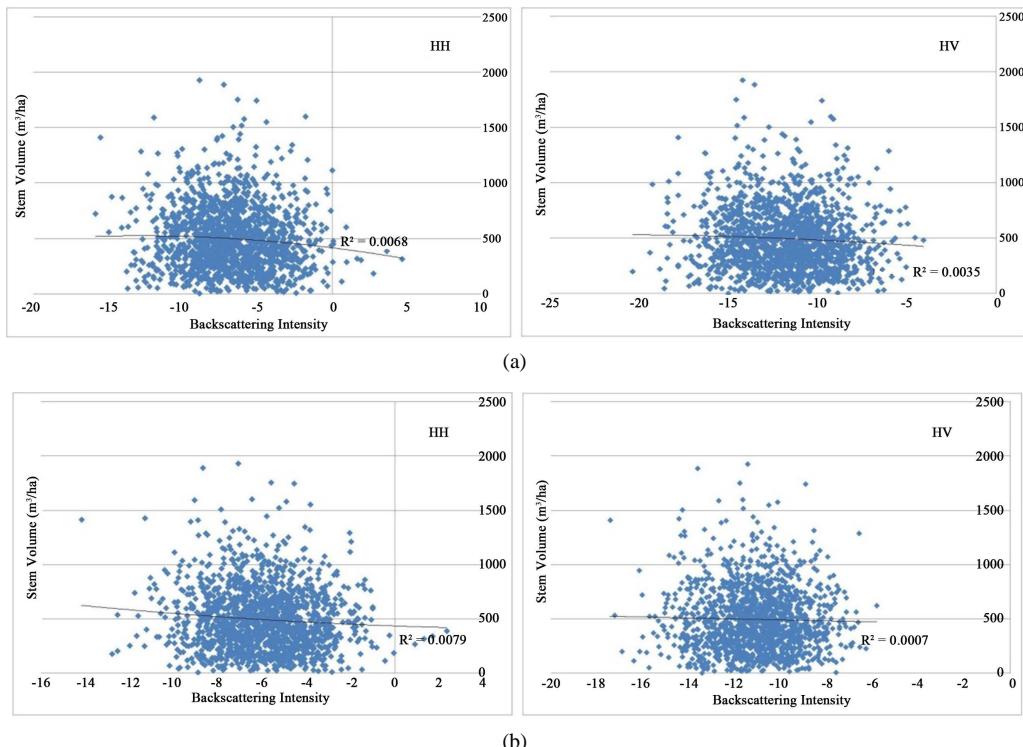
Figure 3. Relationship between backscattering and stem volume using all observation plots for the (a) 10 m and (b) 25 m pixel spacing data for both HH and HV polarizations.

It is obvious that we are seeing no relationship between the two. Usually, when empirical approach is taken, it doesn't show much relation because of the complexity in the scattering at the forested areas [39]. The trend shows the same for the other parameters also (DBH and tree height). Ulaby *et al.* [40] identified the scattering components that comes from the tree canopy, and showed that 11 different kinds of scattering was occurring; Fernandez-Ordonez *et al.* [41] showed 9 kinds of the scattering as a visual figure which consists of:

1) Diffuse scattering from the ground (no vegetation);

2 and 3) Direct scattering from various vegetation components;

4) Double-bounce vegetation–ground interaction;

5) Corner reflector between tree trunks and ground;

6) Direct backscatter from the forest canopy;

7) Volume scattering from within the forest canopy;

8) Diffuse scattering from the ground (with vegetation);

9) Shadowing by parts of the forest canopy of other parts of the canopy or the ground.

When we are making relationship with a forested area that is varied with different growth stages and at different density of the trees and different structure of the trees, it is very difficult to see a trend because of all of those different scatterings, which likely results as on **Figure 3**. Therefore we have taken the second and third approach for the analysis, which is to make the relationship analysis using the plot data filtering it by the forest cover percentage using the VCF data and at different volume range.

Iizuka and Tateishi [42] showed the relation between the mean backscattering intensity as a function of forest cover percentage at the forests of Chiba Prefecture using 50 m PALSAR mosaic product, and mentioned about the decrease in the backscattering after when the forest cover percentage exceeds over 80% - 85% which might be occurring by the attenuation from the canopies. We have performed similar method to see the effect with this study and found that attenuation was occurring from the earliest, at 70% forest cover percentage for the coniferous trees (**Figure 4**). So to avoid the uncertainties in the scattering we have omitted such areas that could lead in errors to obtain correct interpretation of the backscattering information which should then directly respond from the stand characteristics.


(a)

(b)
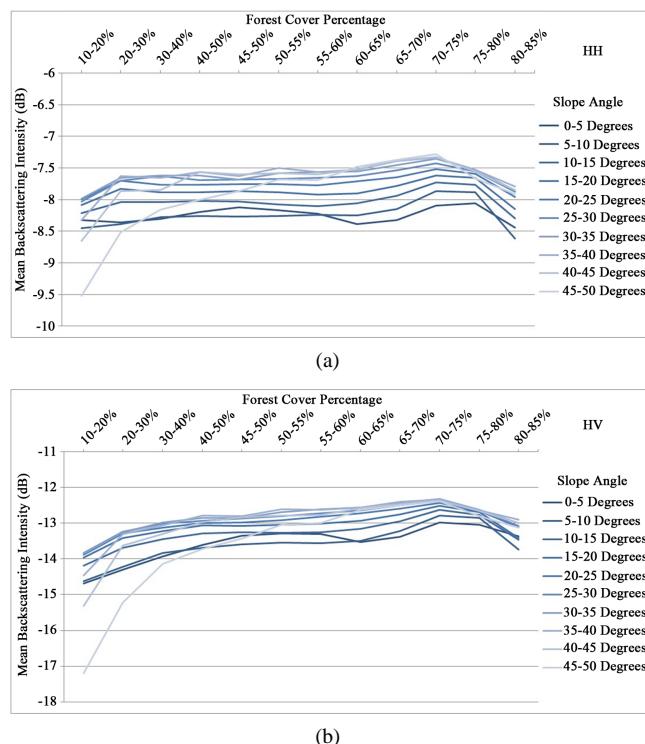
Figure 4. Mean backscattering response of 25 m PGM product from per slope angle as a function of forest cover percentage for (a) HH and (b) HV polarizations at forested areas (areas facing towards the sensor direction) from the forests of our study region.

Figures 5(A)-(C) show the relationship between the backscattering and the stand characteristics for DBH, tree height and stem volume respectively for the 10 m and 25 m pixel spacing data on both HH and HV polarizations, on the area where the forest cover percentage is below 65% coverage and at lower volume ranges (0 - 500 m³/ha).

For DBH, 25 m pixel spacing HH polarization showed the highest correlation ($R^2 = 0.109$) among the others, which is similar for Tree height (HH: $R^2 = 0.189$), but for Tree height, also the 10 m pixel spacing data showed some correlation too (HH: $R^2 = 0.1$) although it is a very low trend. Of them all, stem volume shows the highest correlation with the backscattering, and in this case the HH polarization showed better correlation than the HV (HH: $R^2 = 0.216$, HV: $R^2 = 0.107$) at 25 m pixel spacing data. In the overall trend, we can confirm that comparing with the 10 m and 25 m pixel spacing data, the 25 m data shows higher correlation for all the biophysical parameters. We believe this is occurring from the smoothing of the local backscattering area generated at the low pixel spacing images. The differences to the local scattering would average out when the pixel spacing becomes lower; as a result, errors reduce and better correlations would be seen. Some studies also confirm the increase of the accuracy and higher correlation when the pixel spacing reduces [43] [44].

5.2. Statistical Analysis of Backscattering vs. Forest Stand Biophysical Parameter (Method D)

Correlation between the backscatter and stand biophysical parameter showed better result in the 25 m pixel spacing PGM. So the third approach of the analysis will be based on the 25 m pixel spacing PGM (**Figures 6(A)-(C)**). The figures show the relation between the backscatter for the same as **Figures 5(A)-(C)**, but the plots were separated into differences of the species: Sugi (*Cryptomeria japonica*) and Hinoki (*Chamaecyparis obtusa*) trees. The relationship was analyzed for these species individually for each polarizations.

Compared to the analysis made using both species combined, we can see better correlation for both species and the characteristics of those are conspicuous. For the Hinoki trees, increase in backscatter shows clearly with the increase in biophysical parameters, showing highest correlation for the tree height for HH ($R^2 = 0.443$) and stem volume for HV ($R^2 = 0.282$) however, for stem volume HH shows higher correlation ($R^2 = 0.385$) than the HV. While for the Sugi trees, stand biophysical parameter decreases with increasing backscatter but at the highest backscattering point, the parameters increase. This phenomenon for the Sugi trees shows only at the lower volume case, and at the higher stem volume range (over 550 m³/ha), the relation of the biophysical parameter and the backscattering becomes obvious; backscattering decreases with increasing biophysical parameters (**Figure 7**). Unfortunately, the Hinoki trees mostly are in the range up to 500 m³/ha and could not find relevant number of samples over 550 m³/ha so we do not have the figure for the Hinoki trees to see the characteristics. At the higher volume range, the tree height at HV polarization showed the highest correlation with the backscattering ($R^2 = 0.214$), and at this stage of the stands, HV polarization started to show better correlation than the HH, however for stem volume, still HH showed higher correlation. If we look at the other parameters, for the HH polarization we can still see that correlation shows the highest for the stem volume ($R^2 = 0.113$), and for the HV, tree height and DBH showed some correlation (DBH: $R^2 = 0.177$, Height: $R^2 = 0.214$) but the stem volume showed low correlation ($R^2 = 0.095$) compared to the other parameter and by HH polarization. Unless the site is covered with the early stage Sugi plantation, majority of the areas of the Sugi forests would have a chance to be in the higher volume range, so the actual trend between the parameter and backscatter might be seen as like on **Figure 7**.

6. Discussion

6.1. Sugi Characteristics to Backscattering

Statistical relationship between the Sugi stand characteristics and the backscattering showed an astonishing result, showing that backscattering was decreasing with an increasing of the biophysical parameters. However, there were some questioning results for the Sugi trees at the lower volume range plots, where an increase in the parameter showed at the end of the increasing backscatter. We wanted to understand why this was happening, so closer analysis on those plots was carried out. From **Figure 6** we have focused on the stem volume information and extracted 4 points from the figure to see what was causing the difference in the backscattering from those points (**Figure 8**). The points were chosen because of similar stem volume per unit area but with a totally opposite backscattering value. **Table 1** shows the specifications of the Sugi tree characteristics at those plots, and
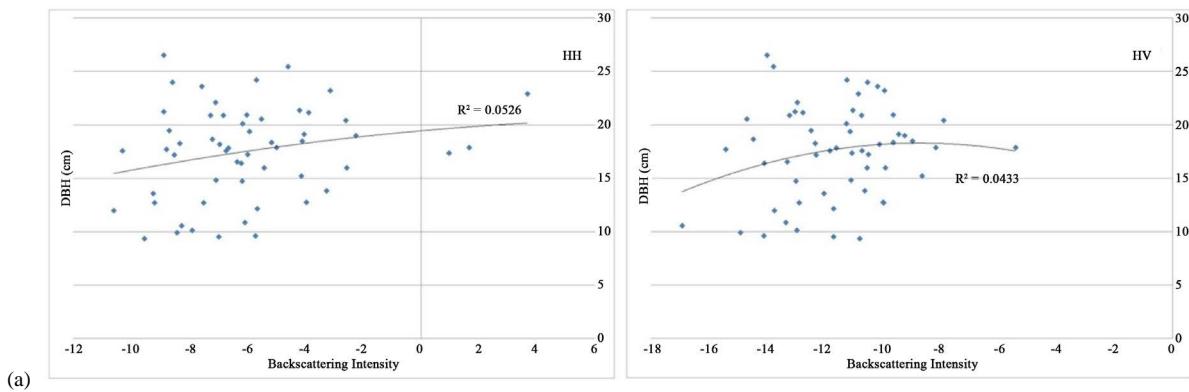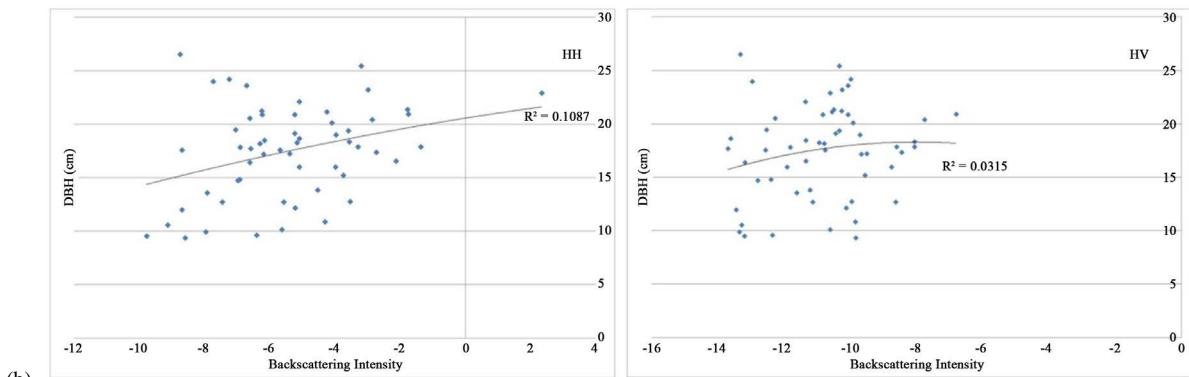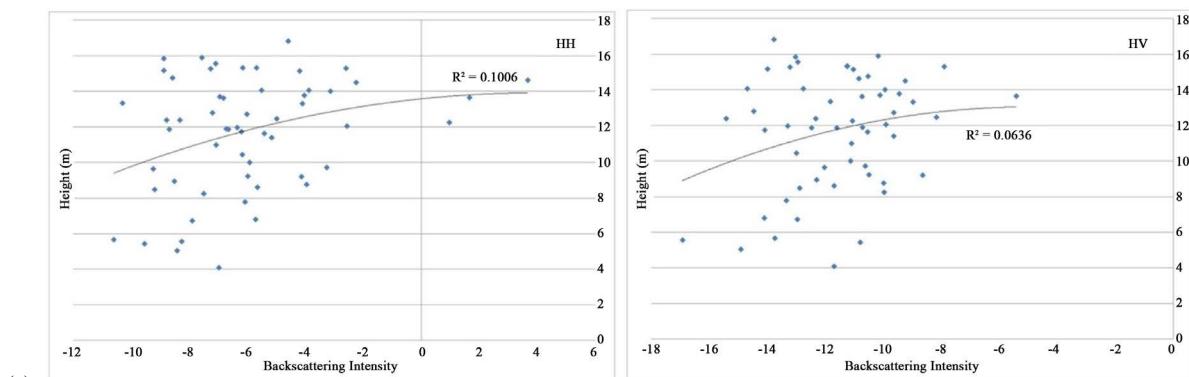
(A)
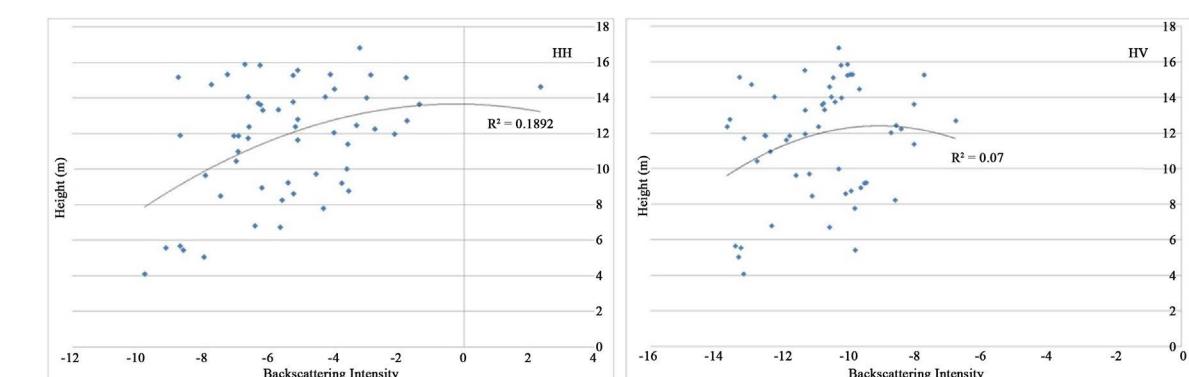
(B)
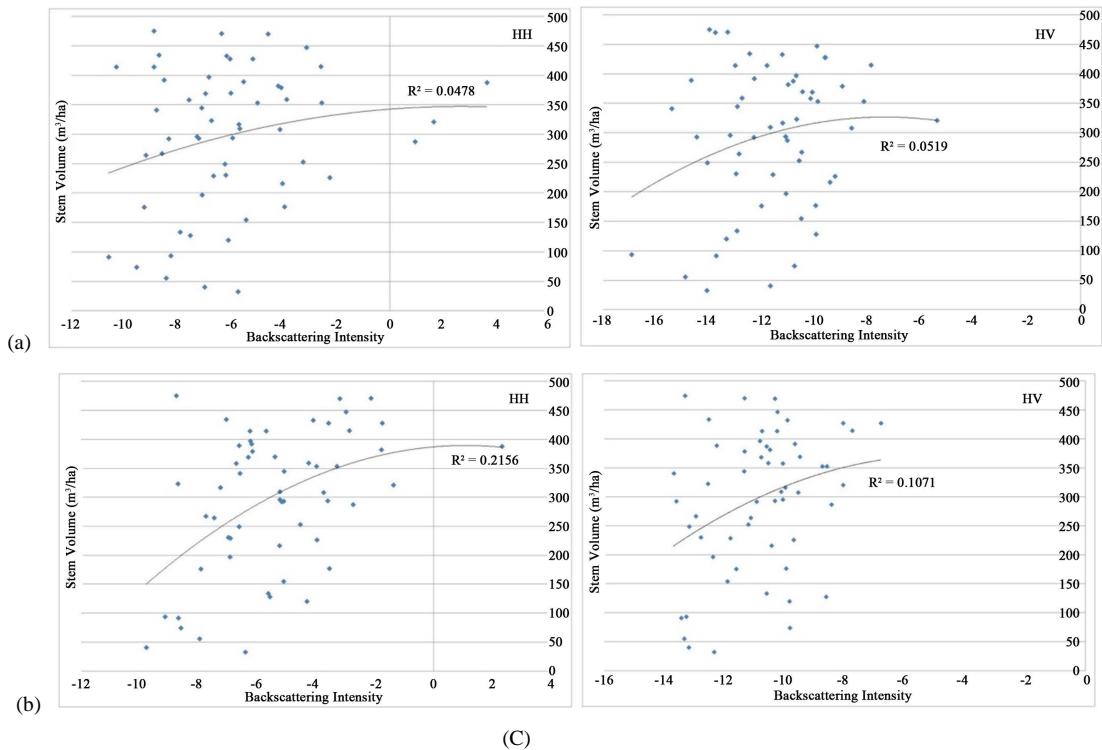
Figure 5. (A) Relationship between DBH (cm) and backscattering for (a) 10 m and (b) 25 m pixel spacing ((a) HH: R^2 = 0.053, HV: R^2 = 0.043; (b) HH: R^2 = 0.109, HV: R^2 = 0.032); (B) Relationship between Tree height (m) and backscattering for (a) 10 m and (b) 25 m pixel spacing ((a) HH: R^2 = 0.101, HV: R^2 = 0.064; (b) HH: R^2 = 0.189, HV: R^2 = 0.07); (C) Relationship between stem volume (m³/ha) and backscattering for (a) 10 m and (b) 25 m pixel spacing ((a) HH: R^2 = 0.048, HV: R^2 = 0.052; (b) HH: R^2 = 0.216, HV: R^2 = 0.107).
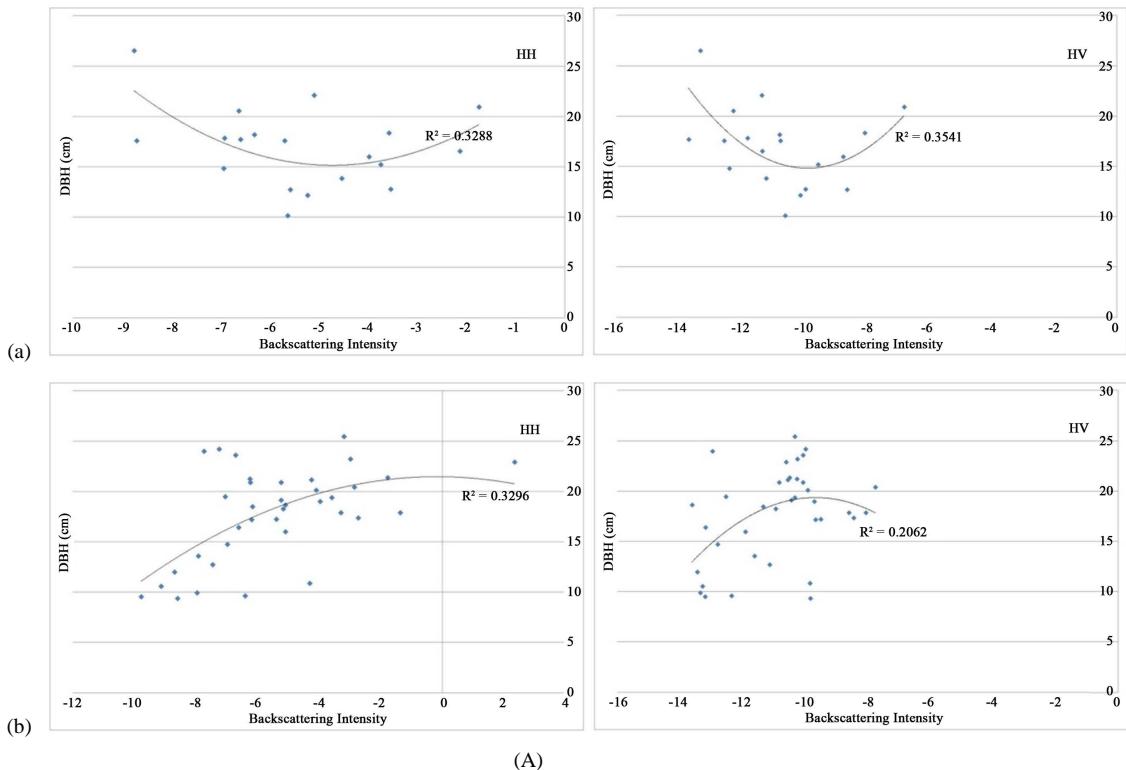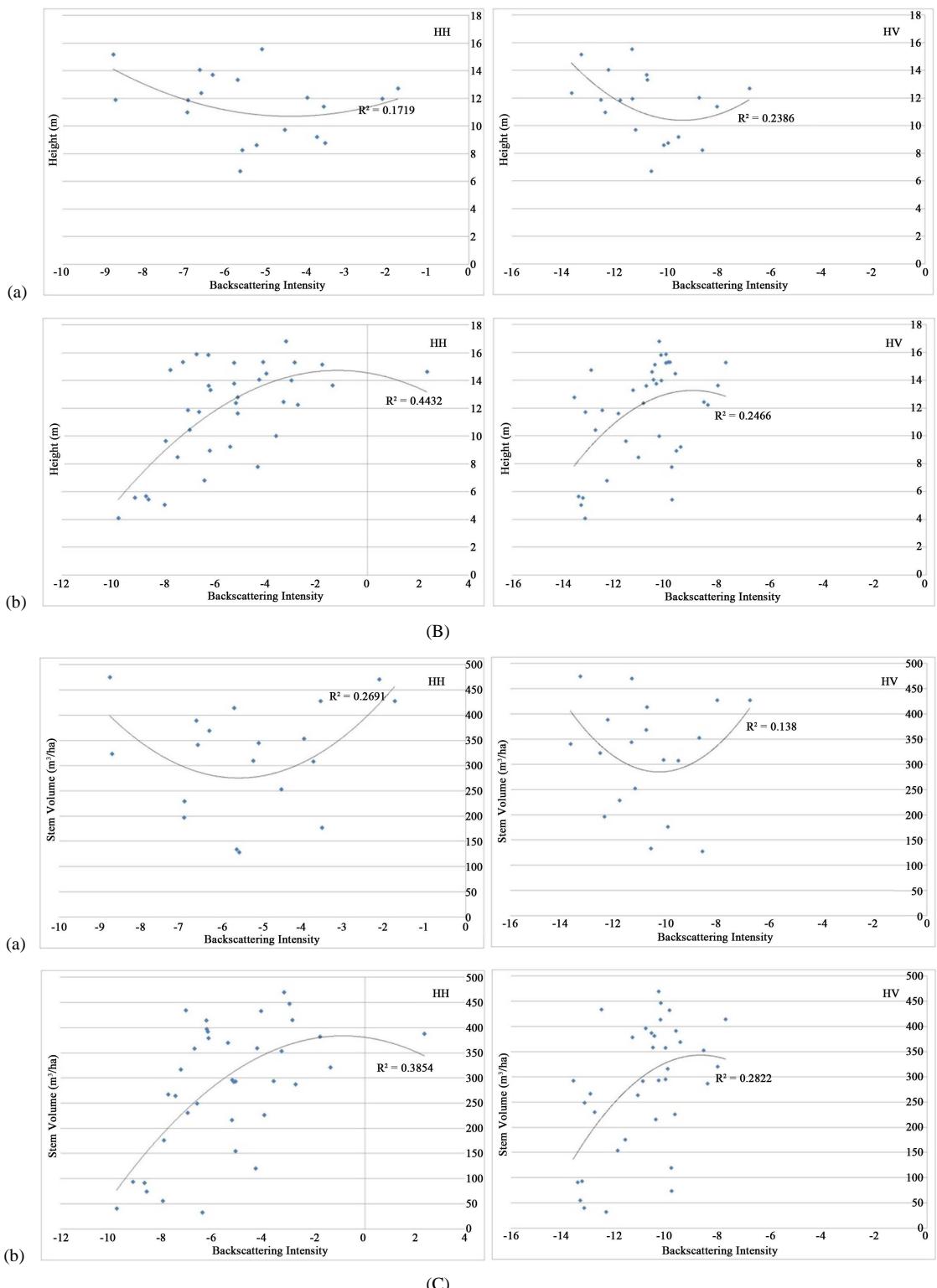
Figure 6. (A) Relationship between DBH (cm) and backscattering for (a) Sugi and (b) Hinoki tree at 25 m pixel spacing ((a) HH: $R^2 = 0.329$, HV: $R^2 = 0.354$; (b) HH: $R^2 = 0.33$, HV: $R^2 = 0.206$); (B) Relationship between Tree height (m) and backscattering for (a) Sugi and (b) Hinoki tree at 25 m pixel spacing ((a) HH: $R^2 = 0.172$, HV: $R^2 = 0.239$; (b) HH: $R^2 = 0.443$, HV: $R^2 = 0.247$); (C) Relationship between stem volume (m^3/ha) and backscattering for (a) Sugi and (b) Hinoki tree at 25 m pixel spacing ((a) HH: $R^2 = 0.269$, HV: $R^2 = 0.14$; (b) HH: $R^2 = 0.385$, HV: $R^2 = 0.282$).

(A)

(B)

(C)
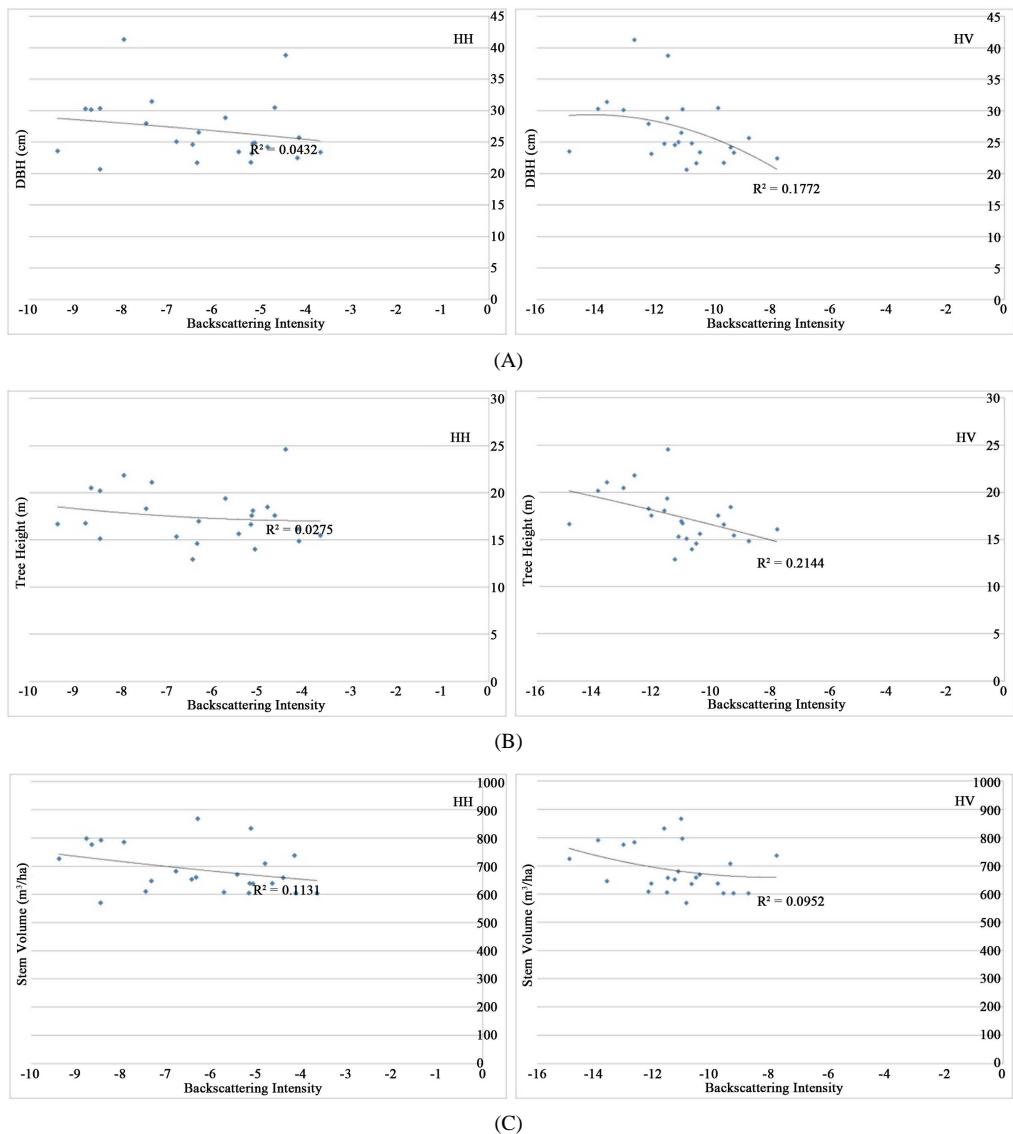
Figure 7. Relationship between (A) DBH (B) tree height and (C) stem volume against backscattering for both HH and HV polarization of Sugi tree at 25 m pixel spacing at higher volume range (over 550 m^3/ha). Coefficient of determination are (A) HH: $R^2 = 0.043$, HV: $R^2 = 0.177$; (B) HH: $R^2 = 0.028$, HV: $R^2 = 0.214$; (C) HH: $R^2 = 0.113$, HV: $R^2 = 0.095$.
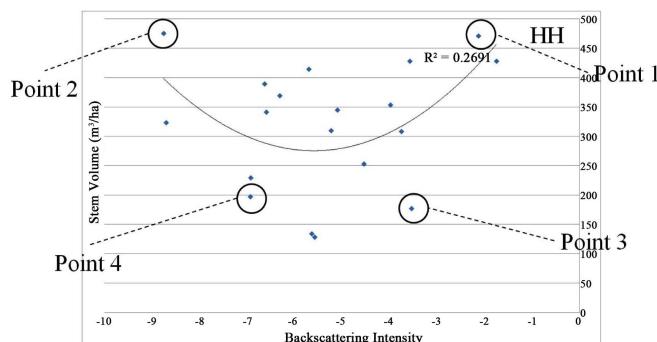
Figure 8. Extracted points where the stem volume per unit area lies on the similar value but with opposite backscatter.

(A)

(B)

Figure 9. Relationship between stem density (N/ha) and backscattering for (A) Sugi and (B) Hinoki trees for both HH and HV polarization at 25 m pixel spacing ((A) HH: $R^2 = 0.17$, HV: $R^2 = 0.241$; (B) HH: $R^2 = 0.185$, HV: $R^2 = 0.024$).

6.3. Complexity of Backscattering at Forested Areas

As mentioned in the former section, backscattering is occurring from various mechanisms within the forested area. For example, Ulaby *et al*. [40] identified 11 different components that are affecting the total backscatter and this backscatter would differ due to the different environment in terms of species, structures, soil moisture and so forth. Moreover, it would also depend on the density of the forests, where there are attenuations, saturations, and maybe other more that we still don't understand about. In the case of this study in Chiba, Japan, most of the forested areas are generated over the hilly rugged terrains, even though various radiometric corrections are developed for the normalization [1] [14] [51] [52], there are still lot of issues we need to overcome, such as the radiometric accuracy of those correction methods. We here note that in our work, the PALSAR PGM product was utilized for the analysis and the data is processed with ortho-rectification and slope correction method developed by Shimada [51]. The PGM product is described that the geometric accuracy is 13 m RMSE and the radiometric accuracy of the product is 0.76 dB.

In our study, the relationship between the biophysical parameters and backscattering was performed in very limited conditions, such as areas that are less than 65 % forest cover considering the attenuation from the dense forests. It is said that P-band SAR can sense more to the parameters than the L-band because it has longer wavelength. We guess this is true if we look at the studies that use P-band radar for the relationship analysis, indicating higher saturation points than the L-band data [7] [19] [53]. But for our case, we can say that it could be used at more dense forests to extract more precise information of the forests structure, and not only the saturation point for detecting higher AGBs. We need to note that backscattering does not measure direct AGB, but it gets affected to the structure of the forests relating to its growth that forms to the resulting AGB, so it is better to understand the scattering mechanism from the forest stand characteristics to make better prediction and extraction of the forest biophysical parameter or the AGB for the forests of each region in interest.

7. Concluding Remarks

In this study, we have performed a statistical analysis in relation of the backscattering intensity from the L-band PALSAR and the *in-situ* stand characteristics of Sugi (*Cryptomeria japonica*) and Hinoki (*Chamaecyparis obtusa*) trees. The relation showed an acceptable result for the Hinoki trees, where backscatter increased with increasing biophysical parameters (DBH, tree height, stem volume). However, for the Sugi trees, the trend showed completely opposite where the backscattering decreased with increasing biophysical parameters. It was surprising that totally opposite trends showed for the same coniferous trees. This difference is assumed that it is coming from the characteristics of the Sugi tree, where it contains of high moisture content resulting with high dielectric constant to affect the backscattering with the increasing stem density, and attenuations caused from increasing DBH and tree height. However, there are still needs of validation for this hypothesis and we need to verify on more relationship analysis for different species other than the Sugi and Hinoki trees because it might have different trends in the scattering we would like to consider this as our future works.

Acknowledgements

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