# GCOM-C Biomass product
# GCOM-C Vegetation Roughness Index product
# Algorithm Theoretical Basis Document

Version 2.0

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# 1. Algorithm Outline

This document is the Algorithm Theoretical Basis Document (ATBD) for GCOM-C/SGLI Above Ground Biomass (AGB) product and Vegetation Roughness Index (VRI) product. It's explained by this single document about two products because the two product generation process stage is just different in last product generation processing, and the most part of the process to source data is common.

## 1.1 Above Ground Biomass (AGB)

AGB is estimated using two sets of the red and near-infrared channel data observed from nadir and slant viewing direction by SGLI sensor.

The empirical estimation equation using the parameters which are obtained by a change of category area ratio, that are canopy in a sunny place, shadowed canopy, forest floor in a sunny place, shadowed forest floor, trunk in a sunny place and shadowed trunk, in the sensor IFOV. These ratios define BRF and changed by sun-target-sensor geometry on SGLI observation condition.

## 1.2 Vegetation Roughness Index (VRI)

VRI is the index that expresses the degree of the unevenness changes in spatial distribution of canopy density of vegetation. When VRI has large value, the target vegetated area has large magnitude of unevenness. VRI also calculated from two sets of the red and near-infrared channel data observed from nadir and slant viewing direction by SGLI sensor.

In the AGB and VRI product generation process, the nadir and slant view of the pixels in the corresponding ground position is used in simultaneously. Since SGLI can observe nadir and slant direction in along track, cloud / aerosol screening will be applied to the region of spatially continuous state in atmospheric condition. However, since the use of data from different observation path when using MODIS like sensor to verify the performance of the algorithm, the number of pixels after the screening is extremely low in spatially continuous region, the number of available pixels is also very less to. Currently, the performance test results have some limitations.

## 2. Theoretical Description

### 2.1 Above Ground Biomass: AGBIO and VRI

#### 2.1.1 Basic concept

Figure 1 shows schematic diagram of the transition of the reflectance in the case of observing the same vegetation region from nadir and slant direction by the red and near-infrared channel. Change in the category area ratio of the field of view due to the canopy structure, causes a change indicated here. However transition direction in the two-dimensional space is different by canopy structure.

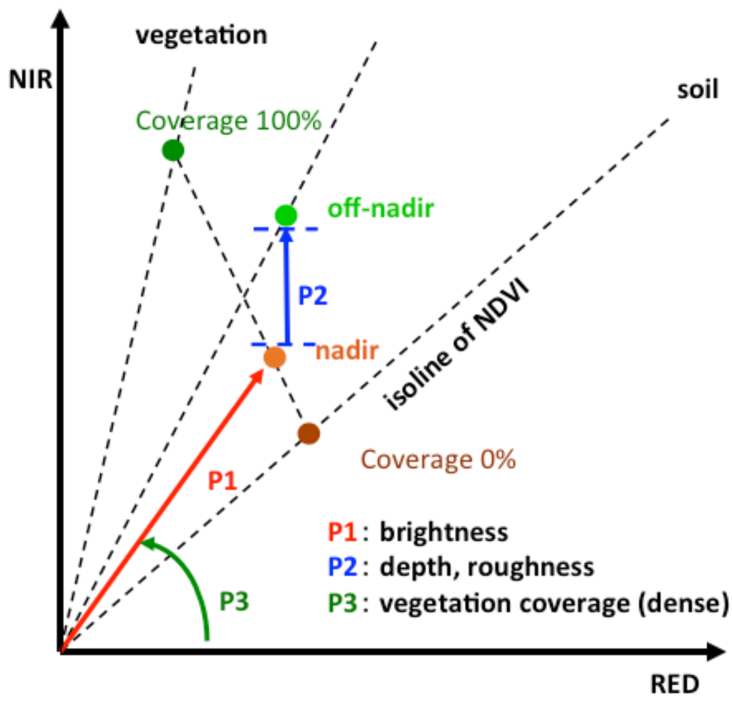



Figure 1. Transition of the red-NIR reflectance on nadir and off- nadir observation.

Here, P1 is the norm of vector connecting the position of nadir observation reflectance and the origin. P2 is the norm of vector indicating the reflectance transitions along with sensor view angle change. P3 shows the angle between red axis and P2. Parameter P1 relates to total brightness including shadow effect in the field of view. P2 has close relation to reflectance change caused by canopy structure and P3 indicates apparent vegetation cover ratio, which has similar meaning of NDVI. Using these parameter, biomass can be estimated the following empirical equation.

$$AGB = C \cdot \left( \frac{P2}{P1} + 1 \right)^3 \cdot P3$$

C is determined for each canopy type based on the ground measurement, which is a proportionality constant that depends on the type of vegetation. However, obtained value of the same forest target P1, P2, P3 is varied with the solar zenith angle and relative azimuth angle at the time of satellite observations. Therefore, AGB estimation is performed with obtained parameters (P1, P2, P3) from simulated Bi-directional Reflectance Factor (BRF) on fixed Sun-Target-Sensor-Geometry (STSG).

2.1.2 Bi-Directional Reflectance Simulator

The simulator BiRS (Bi-Directional Reflectance Simulator) for estimating the reflectance to be used in this manner to calculate P1, P2, P3 was developed. BiRS uses Liner Mixture Model (LMM) as BRF model. That, the sensor observed BRF that is assumed could be expressed by the following equation.

$$BRF_\lambda(\theta_s, \varphi_s, \theta_o, \varphi_o) = \sum_{i=1}^{n} A_i(\theta_s, \varphi_s, \theta_o, \varphi_o) \cdot \rho_{\lambda,i}$$

$\theta_s$ : Solar Zenith Angle

$\varphi_s$ : Solar Azimuth Angle

$\theta_o$ : Sensor Zenith Angle

$\varphi_o$ : Sensor Azimuth Angle

$A$ : Category cover ratio

$\rho$ : Apparent category reflectance

$\lambda$ : Wave length

$i$ : Category number

In above equation, the parameter $A$ indicated category cover ratio in IFOV. In thi context, "category" is meant a ground configuration having different apparent spectral reflectance, such as illuminated canopy, shadowed canopy, illuminated stem or branch, shadowed stem or branch, illuminated soil, shadowed soil. Category area ratio varies with the viewing direction of the sensor, and its manner of change depends on the structure of the forest.

Category reflectance to be provided to the BiRS can be estimated using the LMM as shown from the BRF and the obtained category area ratio polygonal observed in field measurements shown in Figure 2.

Figure 3 shows schematic diagram of BiRS. While BiRS has been developed by Ono et al., in 2010, it has been modified to use canopy structure model in this project. Modified BiRS consists of following two parts: 1) Forest structure modeling part which calculates the category area ratio in IFOV by performing the ray tracing with a crown shape. 2) Reflectance simulator part calculates reflectance as the BRF from mixed category reflectance with Linear Mixture Model.

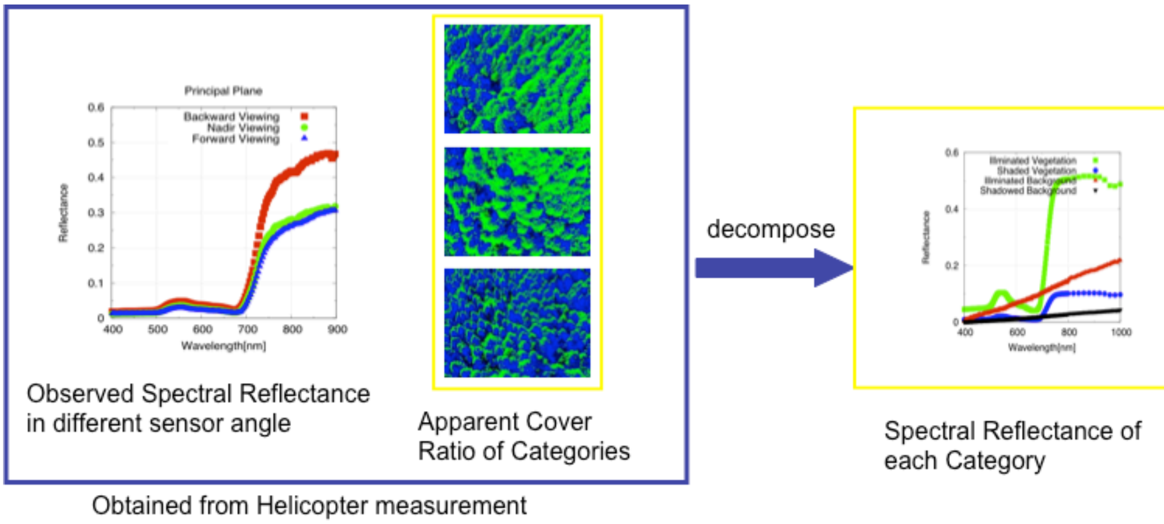



Figure 2. Obtain apparent category reflectance from in-situ observation.

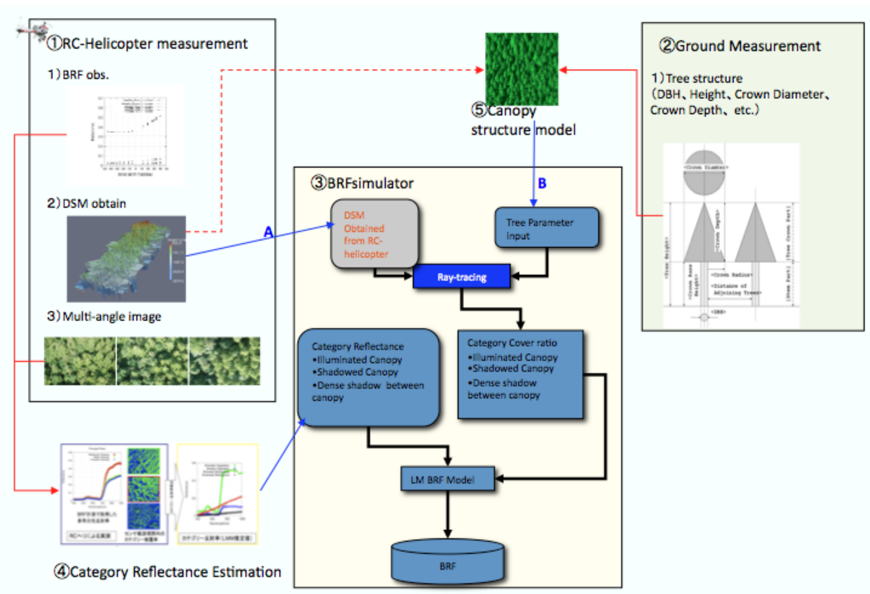



Figure 3. Schematic diagram of BiRS.

Forest structure model create virtual forest characterized by following parameters of mean individual tree distance, trees position, average height, average crown diameter, average crown depth, average diameter at breast height, that are to form a normal distribution. Against the virtual forest that has been generated here, the ratio of category area on any of STSGs which are obtained by ray tracing and calculating BRF by giving a set of category reflectance.

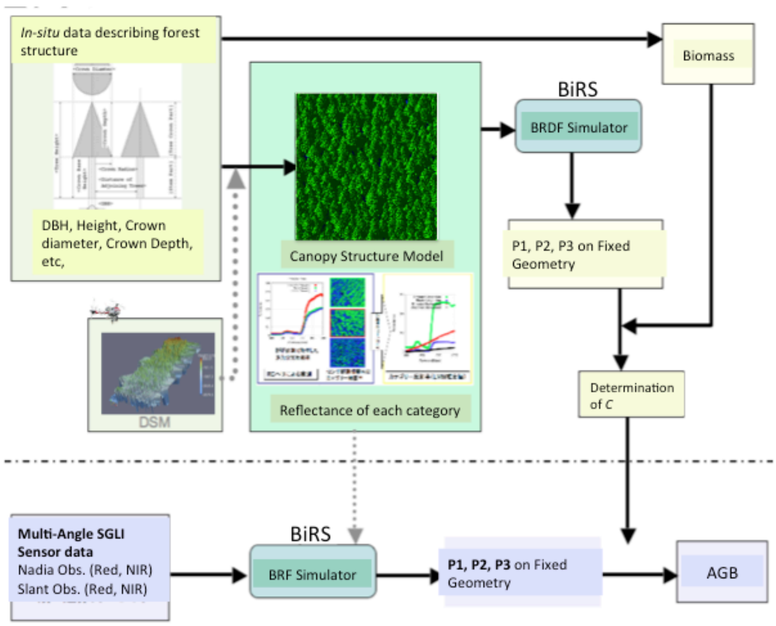



Figure 4. Schematic diagram for AGB estimation.

2.1.2 Canopy structure model

In AGB estimation schemes, BiRS to use the canopy model in order to convert the SGLI observed value to a fixed geometry. The canopy model used following parameter , tree the height,  crown diameter , crown depth and the tree standing position in order to form a virtual forest. Canopy consists of individual branches surrounding the trunk, crown shape is formed by giving an overall shape as their aggregates. Figure 5 shows an overview of this Canopy model to be used in the BiRS. The other parameters mentioned above, the number of branches of the branch layer, a tree canopy structure is determined by specifying the distribution of the angle to the horizontal plane of the branch layer. For each branch it is possible to specify the details of leaf, and also each branch layer is determined position in the vertical direction of each branch by normal randomize, single tree as shown in Figure 5 of shape is completed. Finally it is possible to configure the virtual forest arbitrary shape as shown in Figure 6 by giving the parameters such as the position of the trees.

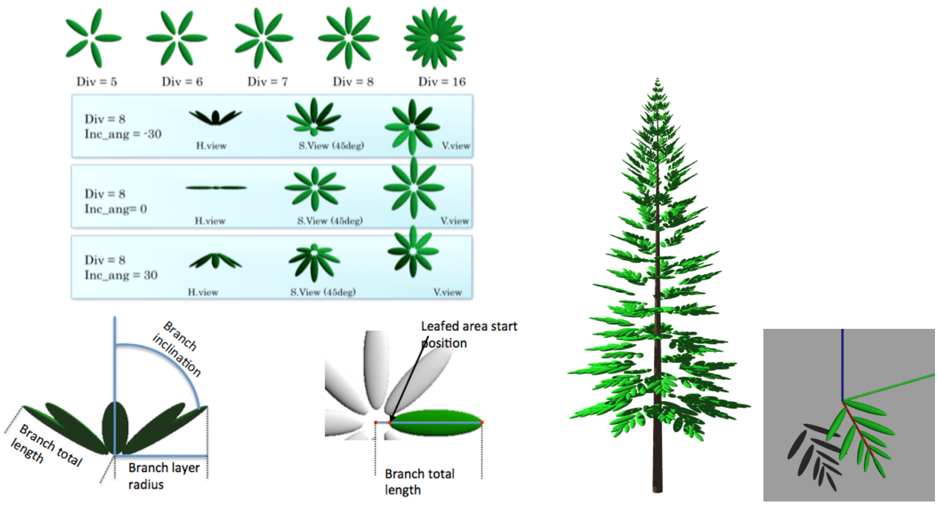



Figure 5. Canopy model used for modified BiRS.

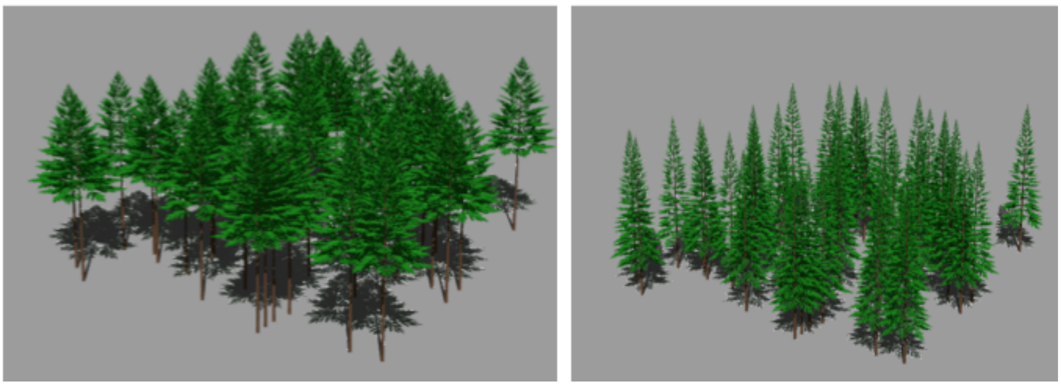
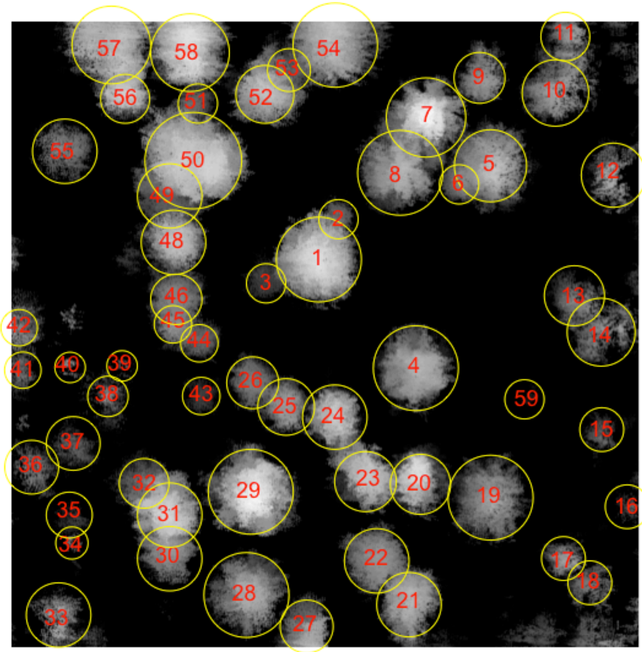


Figure 6. Examples of virtual forest formed by using the canopy model

2.1.3 Performance of modified BiRS

In order to test the performance of modified BiRS using canopy structure model, utilizing in-situ measured tree parameter and MODIS observing STSG to the simulator. Figure 7 shows tree parameter obtained from point cloud obtained by radio controlled helicopter (UAV) equipped LIDAR system. Tree position, crown diameter, tree height of each tree was used to form the virtual forest for simulates particular reflectance on MODIS observing geometry. Figure 8 shows a virtual forest that was constructed using the in-situ measured parameters.



| ID | x | y | th | cd |
|---|---|---|---|---|
| 1 | 329 | 246 | 166.69 | 81.63 |
| 2 | 382 | 265 | 48.17 | 30.27 |
| 3 | 259 | 266 | 44.15 | 30.15 |
| 4 | 228 | 354 | 131.81 | 75.50 |
| 5 | 491 | 147 | 144.91 | 73.54 |
| 6 | 457 | 166 | 89.35 | 27.77 |
| 7 | 423 | 97 | 193.24 | 82.95 |
| 8 | 390 | 150 | 134.10 | 71.70 |
| 9 | 479 | 63 | 108.02 | 43.00 |
| 10 | 557 | 67 | 118.40 | 61.10 |
| 11 | 567 | 13 | 112.11 | 35.73 |
| 12 | 613 | 164 | 133.09 | 51.62 |
| 13 | 581 | 291 | 97.18 | 43.01 |
| 14 | 609 | 318 | 109.71 | 65.10 |
| 15 | 601 | 421 | 71.83 | 34.41 |
| 16 | 632 | 496 | 73.50 | 37.00 |
| 17 | 564 | 551 | 111.89 | 35.00 |
| 18 | 591 | 576 | 84.84 | 52.50 |
| 19 | 487 | 488 | 123.12 | 75.43 |
| 20 | 417 | 469 | 164.70 | 58.00 |
| 21 | 406 | 589 | 130.92 | 62.43 |
| 22 | 372 | 550 | 105.98 | 60.42 |
| 23 | 362 | 465 | 145.99 | 57.58 |
| 24 | 328 | 403 | 147.75 | 53.25 |
| 25 | 280 | 393 | 110.30 | 49.65 |
| 26 | 245 | 368 | 84.64 | 45.04 |
| 27 | 301 | 620 | 127.97 | 56.00 |
| 28 | 240 | 585 | 125.14 | 82.04 |
| 29 | 245 | 483 | 189.11 | 86.05 |
| 30 | 162 | 544 | 113.76 | 50.99 |
| 31 | 160 | 502 | 159.44 | 65.00 |
| 32 | 135 | 477 | 83.50 | 48.80 |
| 33 | 46 | 609 | 120.97 | 60.28 |
| 34 | 59 | 531 | 96.62 | 19.70 |
| 35 | 61 | 510 | 42.43 | 37.64 |
| 36 | 24 | 458 | 90.40 | 55.15 |
| 37 | 63 | 434 | 67.15 | 43.86 |
| 38 | 98 | 383 | 110.36 | 45.45 |
| 39 | 114 | 352 | 72.19 | 17.49 |
| 40 | 56 | 351 | 101.12 | 20.02 |
| 41 | 3 | 358 | 77.54 | 30.00 |
| 42 | 4 | 132 | 107.65 | 40.01 |
| 43 | 193 | 381 | 42.24 | 26.17 |
| 44 | 193 | 325 | 71.91 | 26.08 |
| 45 | 171 | 310 | 101.44 | 33.24 |
| 46 | 168 | 283 | 91.49 | 51.62 |
| 47 | 121 | 242 | 67.07 | 21.00 |
| 48 | 145 | 200 | 144.59 | 60.00 |
| 49 | 161 | 172 | 69.51 | 76.97 |
| 50 | 188 | 139 | 154.85 | 101.18 |
| 51 | 187 | 85 | 72.93 | 32.28 |
| 52 | 261 | 75 | 141.78 | 69.12 |
| 53 | 291 | 48 | 66.34 | 37.05 |
| 54 | 325 | 21 | 138.36 | 84.84 |
| 55 | 54 | 130 | 92.16 | 51.88 |
| 56 | 114 | 76 | 154.09 | 49.82 |
| 57 | 97 | 20 | 143.41 | 75.85 |
| 58 | 178 | 26 | 169.55 | 73.56 |
| 59 | 528 | 382 | 26.46 | 13.33 |

Unit : cm

Figure 7. Tree parameter obtained by UAV equipped LIDAR system

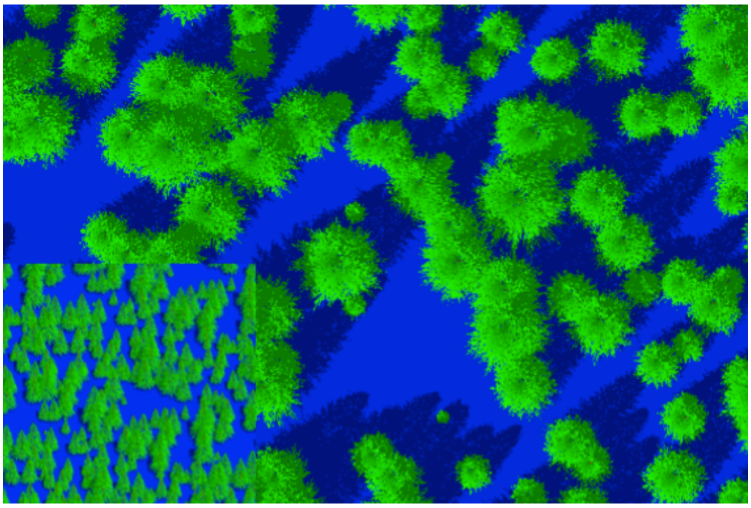


Figure 8. Virtual forest constructed using the in-situ parameters

This modeled forest was used to simulate the reflectance of MODIS. The result of the simulation is shown in Figure 9. A portion surrounded by a pink square is the result of the term that has conducted a field observation. Change in reflectance of the apparent reflectance by STSG can be seen that are well reproduced.

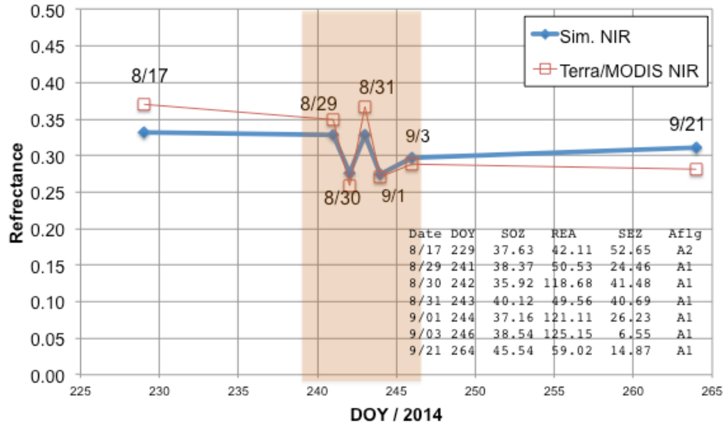



Figure 9. Simulation result of modified BiRS for MODIS observed reflectance.

2.1.4 Performance of AGB estimation methodology using in-situ data

As an example, time series biomass estimation results for larch forest are shown in figure 10. These biomass values are estimated by using Digital Surface Model (DSM) of the canopy, and BRF that were acquired from UAV observation. Four blue dots indicate the time series values, within 6 years, on Yatsugatake larch forest test site located Yamanashi prefecture. Red dot indicates the results for another larch forest test site located near mt. Fuji. Based on this result, it can be said that even in different forest, if tree type is the same, proposed method is valid to estimate Above Ground Biomass.

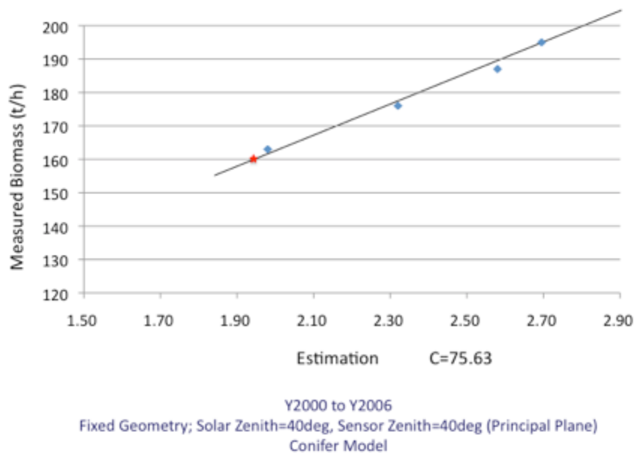



Figure 10. AGB estimation result using in-situ data

2.1.5 Processing flow

Figure 11 shows the processing flow of AGBIO product. AGBIO uses 1km atmospheric corrected products of following channels, VN8(nadir observed red), VN11(nadir observed NIR), P1(slant observed red), P2(slant observed NIR), as the source data. Since algorithm performance test should be used MODIS sensor data before GCOM-C1 launch, green dotted line surrounded part is added to system. This part is for selection valid nadir/slant sensor view conditions. For the SGLI sensor data, after checking aerosol/cloud flag, channel reflectance product data will directly input to reflectance conversion process. The process for reflectance conversion, consist of tree parts, 1) referencing land cover data that has information of vegetation type for particular location, select the lookup table for the corresponding vegetation type. 2) Obtaining Sensor geometry from ancillary data of SGLI and calculate STSG using the DSM/Slope data of target area. 3) Searching lookup table to obtain a set of reflectance of each channel.

After reflectance conversion process, VRI is calculated using unit C value (=1). Finally, AGB is calculated with applying corresponded C value of the vegetation type.

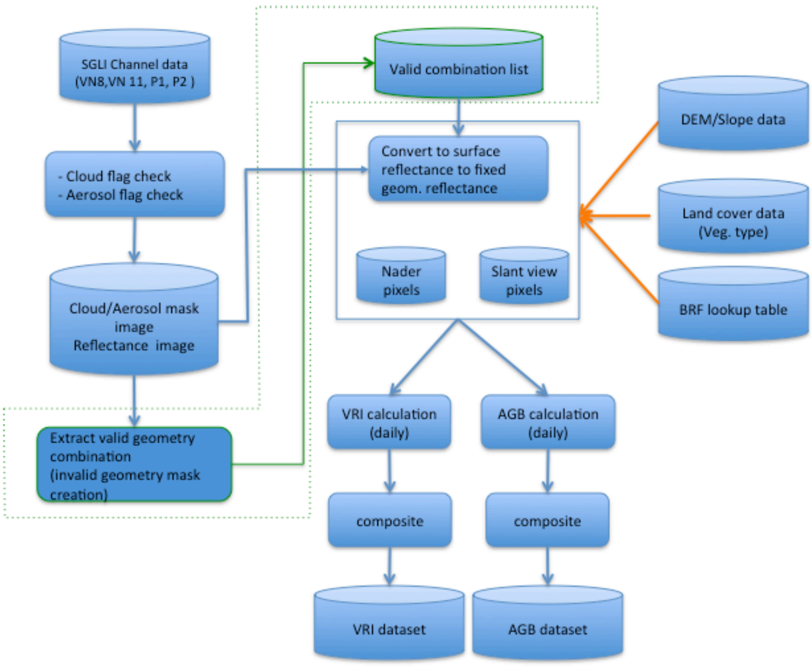



Figure 11. Processing flow of AGBIO product

Since AGBIO algorithm uses the active vegetation canopy reflectance, it cannot estimate the winter season's data. Because of this reason, NDVI mask process will be performed before estimation. Figure 12 indicates the QA flag of AGBIO product. When NDVI low flag is set, AGBIO and VRI algorithm will not be performed and set the 0 value to the flag for algorithm performed (LSB of QA flag).

AGBIO QA description

| Bit No. | Parameter name | Bit Combination | Description |
|---|---|---|---|
| 0 | AGBIO/VRI algorithm performed | 0 | Not Processed |
| | | 1 | Processed |
| 1 | Land Mask | 0 | Not Lnad (include inland water) |
| | | 1 | Land |
| 2 | Forest Mask | 0 | Not Forest |
| | | 1 | Forest |
| 3 | Cloud Flag | 0 | Both Band Clear |
| | | 1 | Cloudy at least 1 band |
| 4 | Aerosol Flag | 0 | Both Band low |
| | | 1 | High at least 1 band |
| 5 | Nadir NDVI sate | 0 | High |
| | | 1 | Low (< 0) |
| 6 | reserved(DEM state) | 0 | simple slope |
| | | 1 | complex terrain |
| 7 | reserved | | always 0 |

Figure12. QA flag definition for AGBIO