AN EVALUATION OF ADEOS-II GLI LAND PRODUCTS FOR GLOBAL LAND SURFACE MONITORING

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ABSTRACT:

The Japan Aerospace Exploration Agency (JAXA, former NASDA) has successfully launched a new Advanced Earth Orbiting Satellite (ADEOS II) aboard an H-2A booster on December 14, 2002. Unfortunately, the operation of ADEOS-II satellite was stopped in the end of October. ADEOS II is designed to monitor global climactic change through researches of the Earth's environment. Four disciplinary components of the Earth system, namely atmosphere, ocean, cryosphere, and land, cover the monitoring activities with five sensors onboard the satellite including the Global Imager (GLI). All the five sensors were working normally, and had acquired the first light images as a part of the initial function verification test.

GLI allows us to observe vegetation status in the two different resolutions simultaneously (1km and 250m). There are four GLI Level-2 land products from these channels; those are PGCP (parameter@of geometric corrected image), L2A_LC (TOA reflectance), AC_LC (reflectance after atmospheric correction), and VGI (NDVI and EVI). The VGI products are expected to be a useful data set for global mapping of vegetation biophysical parameters such as LAI, fAPAR, NPP and so on. This paper shows ADEOS-II GLI land processing algorithm and evaluation of land products.

1 Introduction

Vegetation plays an important role of the carbon cycle on the earth. Carbon is the key element in all livings including human, and this element is stored in plants and trees. Carbon cycle is associated with global warming. Therefore, it is needed for vegetation monitoring to understand global warming.

The Global Imager (GLI) onboarded the ADEOS-II satellite was launched successfully on December 14, 2002. GLI is an optical sensor for the purpose of global and frequent observations of radiation reflected by land, ocean, ice/snow and atmosphere. The one of objectives of ADEOS-II mission is to research and estimate quantatively plant biomass and primary productivity. GLI was expected to give us the great contribution for understanding carbon cycle. Unfortunately, the operation of ADEOS-II satellite was stopped in the end of October, however, GLI has been able to obtain data during the important period in the northern hemisphere. Therefore, the collected GLI data have capability of potential for detecting of vegetation dynamics.

GLI has 23 channels in visible and near-infrared region (VNIR), five channels in short wavelength infrared region (SWIR), and seven channel in middle and thermal infrared (MTIR). Spatial resolution of the sensor is 1km at nadir excepts 6 channels in VNIR regions which have 250 m resolutions. Single mechanical scan covers 12 picture elements (12 km) along the forward direction and 1600 km along the cross-track. Total of 21 channels are dedicated for land observations in the two spatial resolutions; channels 1, 5, 8, 13, 15, 17, 19, 24, 26, 27, 30, 31, 34, 35, and 36 are for 1 km resolution, and channels 20, 21, 22, 23, 28, and 29 are for 250 m resolution. Thus, GLI allows us to observe vegetation status in the two different resolutions simultaneously.

2 Objective

GLI L1 and L2 products were released for public user on Dec.24 2003. GLI PI/CI researchers can obtain these products free of charge. Public users are also able to be provided with products with lower price. GLI higher level processed data are four kinds of products; those are PGCP(precise geometric correction parameter), L2A_LC (TOA reflectance), ACLC (reflectance after atmospheric correction), and VGI (NDVI and EVI). These products should be validated and should be more accurate products. The objective of this study is to show the algorithm of GLI land higher products and to evaluate these processed higher products.

3 GLI higher level processing

GLI higher level processing is mainly Precise Geometric Correction, Composite, Atmospheric Correction, and Vegetation Index. GLI 1km higher level standard products are provided by JAXA. 250m processing algorithm is under development, and these products will be research products. The official standard product of GLI 250m is Level 1. GLI 250m higher algorithm will be a little different from GLI 1km algorithm. The detail algorithm is described in the following sections. Table.1 shows the characteristics of GLI land channels, and Figure.1 is relative spectral response. GLI land channels are selected on the proper positions of various spectral reflectances over land.

3.1 Precise Geometric Correction

Satellite data is often used for validation using ground based measurement. Therefore, it is needed to be precise position to pixel. The accuracy of geometric correction is dependent on the accuracy of the satellite position and attitude. The GLI precise geometric correction algorithm enables to determine the precise satellite position and attitude using ground control points (GCPs). This algorithm converts satellite position, velocity and attitude for one segment to navigation data. And then, precise satellite position and attitude are determined by utilizing GCPs. Conventionally, GCPs are obtained by human operator, but this algorithm is able to extract automatically by using each 1 path data. Sufficient numbers of GCPs are necessary for exterior orientation. Two image patches contain coastal lines. One is a template from the GSHHS fine coastal data. Another is a reference image made by the binarization of the original image. The template is selected as a GCP candidate from the GCP library which have to be prepared. In this work, the GCP collection is realized by the template matching. But it can get parameters to specify each scene. This algorithm is able to determine precise satellite position and attitude with methodology based on photogrammetry. The scene is rectified mapped image(Latitude/Longitude coordinates or Polar Stereo Projection). The rectification of original image is carried out using the results of the exterior orientation. GTOPO30 is the digital elevation data used for 250m geometric correction for terrain elevation. Output pixel value is radiance [W/m^2/str/μm] derived from L1B data. 1km precise geometric correction images are generated from L1B data. However, in 250m precise geometric correction, the algorithm will start from L1A on nadir data, which is similar to MODIS 250m processing described in Hashimoto(2002).

3.2 Composite

After precise geometric correction processing, output value is TOA radiance derived from L1B. When land users use optical moderate resolution satellite data, composite is conducted for clouds removal. And land users often use composited AVHRR-NDVI products, which generated with the maximum value composite (MVC) technique. MVC selects the maximum NDVI value on a per pixel basis over a set compositing period. However, this algorithm has problems associated with satellite sensor conditions. In practice, composite data are complicated owing to the intrinsic behavior of the sensor, surface bi-directional reflectance factors with STSG (Sun-Target-Sensor Geometry), and contamination of the various spectral response. Therefore, the constraint view angle maximum value composite (CVMVC) technique (Cihlar *et al.*,1994a) is applied to generate these composites in GLI higher level processing. This algorithm produces geometrically corrected 16-day surface composites, which may select the best value pixel over a composite period, based on cloudiness and atmospheric contamination. Cloud detection and screening algorithm products cloud flags on a pixel basis. This is similar to a threshold technique to prevent the selection of extreme off-nadir pixels. The CVMVC technique works very much the same way as the classical MVC. In 1st day composite, the pixels are selected by satellite zenith angle, and save as work file 1. In 2nd day composite, the pixels are selected by satellite zenith angle, and save as work file 2. In 3rd day composite, the pixels are selected by satellite zenith angle, and save as temporary file, and then maximum NDVI value is selected on each pixels in work file 1,2, and temporary file. Therefore, work file 1 is maximum NDVI pixels, and work file 2 is next large NDVI value pixels. After 4th day composite, it is same way as 3 day composite. Output value of this algorithm is TOA reflectance in VNIR and SWIR wavelength region (Ch.1-29),

$$\rho_{obs} = \frac{\pi L_{sat}}{F_0 \cos(\theta_s)}$$

where ρ_{obs} is GLI observed reflectance, F_0[W/m^2/μm] is irradiance based on Thuiller 2002, L_{sat}[W/m^2/str/μm] is GLI observed radiance, and θ_s[rad] is solar zenith angle. MTIR region (Ch.30-36) is GLI observed TOA radiance. The GLI project adopt solar irradiance from Thuillier2002 (Thuillier *et al.*,2003). GLI calibration team calculates GLI solar irradiances. These are the weight-integrated Thuillier2002 irradiances over GLI spectral responses. The GLI spectral responses are running averaged ± 2 samples (data interval is about 1nm) window to reduce a measurement noise, and both response and solar irradiance datasets are linearly interpolated to 0.1nm spectral resolution before the integration. Irradiance data sets are linearly interpolated to 0.1nm spectral resolution before the integration. Thuillier2002 is new spectral irradiance data set included SOLSPEC observed data, which is the UV and visible solar spectrum acquired by various spaceborne sensors flown during the ATLAS Space Shuttle missions (spectral resolution is 1nm-5nm, range 200nm-2500nm). In case of longer wavelength than 2500nm, MODTRAN4.0 IR solar irradiance is used. And the compositing algorithm will operate on projected gridded data defined by the GLI tile scheme (total of 56 tiles). In this study, 250m composite algorithm is same as 1km algorithm, CVMVC. But this paper shows the results of test running in central Japan in current status.

3.3 Atmospheric Correction

Correction for rayleigh scattering and ozone absorption is applied in GLI land algorithm. Correction for aerosol over land is not conducted. Much of the computation during atmospheric correction requires intensive CPU time due to floating point processing. Therefore, this algorithm is adopted method using Look-Up Tables (LUTs). And this algorithm is applied after composite processing. GLI land atmospheric correction has some assumptions. Ozone layers are above molecular layer, and all molecules are above aerosols. Moreover, aerosol layer + ground surface is assumed as Lambertian, and all layers are horizontally homogeneous. Rayleigh scattering and ozone absorption are corrected with the assistance of ancillary data NOAA/TOVS data set and GTOPO30. GLI observed reflectance at Top-Of-Atmosphere is described as the following equation:

$$\rho_{obs}(\tau_{O_3}, \tau_R, \theta_s, \theta_\nu, \varphi_{s-\nu}) =$$

$$T_{O_3}(\tau_{O_3}, \theta_s, \theta_\nu)\times$$

$$(\rho_R(\tau_R, \theta_s, \theta_\nu, \varphi_{s-\nu}) + \frac{T_{R\downarrow}(\tau_R, \theta_s)\rho_s T_{R\uparrow}(\tau_r, \theta_\nu)}{1 - S_R(\tau_R)\rho_s})$$

where ρ_{obs} is GLI observed reflectance derived from composite algorithm, T_{O_3} is ozone transmittance, ρ_R is path radiance, $T_{R\downarrow}$ is downward transmittance, $T_{R\uparrow}$ is upward transmittance, S_R is Spherical Albedo, and ρ_s is Rayliegh/Ozone Corrected Reflectance, which is output of this algorithm. The path radiance, upward and downward transmittances and spherical albedo were tabulated as functions of optical thickness of rayleigh scattering (τ_R), view and illumination angles. Then, these four values will be retrieved based on the values of τ_R for each pixel at each land channel based on the pixel elevation, BPF, and STSG. τ_R relates to elevation through standard pressure and temperature (US62), which can be calculated with GTOPO30. And T_{O_3} can be derived from NOAA/TOVS data. This algorithm for 250m data will be also same as 1km algorithm. However, this algorithm is under development.

3.4 Vegetation Indices

The vegetation monitoring and the observation of vegetation distribution in large areas can be done with a vegetation indices (VI). They have been used for assessment of various plant biophysical parameters, such as leaf area index (LAI), percent green cover, green biomass, fractional absorbed photosynthetically active radiation (fAPAR), net primary production (NPP), and so on. Basically, they have capability of monitoring for seasonal change, phenological change, state, and condition of vegetation. The vegetation biophysical parameters should be provided with sufficient accuracy to be used as an input of general circulation models, where the satellite remote sensing also plays an important role. Therefore, VI should have continuity for long-term assessment and should be more accurate. Various VI products currently exist and more VI products are expected to be available simultaneously, the estimation of biophysical parameters through VI has to be compatible by various sensors to ensure continuity of global environmental simulation over generations. Normalised Difference Vegetation Index (NDVI) is most used for land from before. Therefore, NDVI should be land product for global land monitoring. The NDVI has been the most widely used index in global vegetation studies, including phenological studies of vegetation growing season and so on(e.g. Tucker and Seller, 1986). Many studies have shown a qualitative and quantitative analysis of NDVI in vegetation growth. The NDVI is described as the following equations;

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$$

where ρ_{NIR} is reflectance in near infrared region, and ρ_{RED} is reflectance in visible red region (ρ_{obs} or ρ_s). This index can reduce noise and uncertainty associated with instrument characteristics, topographical effect, and so on. On the other hand, this index also has disadvantages. This index saturates at the high biomass area, and has sensitivity to canopy backgrounds over open canopy conditions (Huete *et al.*, 1997). GLI land team adopt more another new index, a new 'Enhanced Vegetation Index' (EVI) for increased sensitivity over a wider range of vegetation conditions, removal of soil background influences, and removal of residual atmospheric contamination effects present in the NDVI. The soil background adjustment is based on the soil adjusted vegetation index (SAVI) (Huete 1988). An atmospheric resistant term is derived from the atmospherically resistant vegetation index (ARVI) (Kaufman and Tanré,1992). The EVI equation shows as the following;

$$EVI = G \times \frac{\rho_{NIR} - \rho_{RED}}{L + \rho_{NIR} + C1 \times \rho_{RED} - C2 \times \rho_{BLUE}}$$

where L is the canopy background and snow correction caused by differential NIR and red radiant transfer (transmittance) through a canopy; and C1 and C2 are the coefficients of the aerosol 'resistance' term, which uses the blue channel (ρ_{BLUE};ρ_{obs} or ρ_s) to correct for aerosol effects in the red channel. Huete *et al.*(1997) shows that the currently used coefficients, G = 2.5; L = 1; C1 = 6; and C2 = 7.5, are fairly robust. Especially, aerosol variations are considerably reduced via the self-correcting combination of the red and blue channels as less prone to instrument noise compared with the AVHRR. GLI 1km bands are much narrower than the GLI 250m bands, and provide increased chlorophyll sensitivity (band 13) and avoids water vapor absorption (band 19). The blue band provides aerosol resistance in the EVI.

4 Discussion and conclusion

Requirement of geometric correction algorithm for land products is less than 1 pixel. The accuracy of precise geometric correction for both of GLI 1km and 250m is less than 1 pixel. Band-to-band registration errors are less than 0.5 pixel. GPSR has sometimes stopped in ADEOS-II operational period. However, the error is around 70-80m, which is enough small for 1 pixel size. Therefore, geometric accuracy is almost satisfied with the requirements. GLI geometric calibration team will continue to check error pattern. Especially, GLI 250m data and tilt data should be evaluated. The saturation level for land is almost satisfied with maximum radiance of specification. In case of GLI 1km land channel, Ch. 5,8,13,15,19 may be saturated in high bright cloud and ice cloud. In land area, the saturation is not confirmed. In case of GLI 250m channel, Ch.22 is sometimes saturated on the part of desert bright area as estimated by the pre-launch analysis. And Ch.23 is rarely saturated like 1km land channels without the extreme bright cloud. The DN of VNIR2 (land channel Ch.13,19,22,23) turns down partly in the range exceeding the saturation level (over saturation). They will not be critical problems in unsaturated areas. Detector sensitivity normalization error, mirror reflectance normalization error, and electric system noise of MTIR are sometimes appeared. The L1B DN of Ch.30 (3.7 μ m) frequently becomes zero in low-temperature (<240K) areas, however this will be occurred at the top of high-altitude clouds and in polar regions in the nighttime. Left image of Figure.2 shows the example of precise geometric corrected GLI 1km L1B image around Black Sea, and right image shows 250m. Both of these images are captured on June 3, 2003. GLI 1km/250m data is able to monitor global area and local area at same time.

Figure.3 shows the example of GLI 1km and 250m NDVI. Right image is atmospherically corrected 16-day composite NDVI by using the above data. Unfortunately, in this paper, 250m atmospherically corrected data is not shown in this paper, because algorithm is under development. However, it is not so difficult to complete this code, because it simply needs to change LUTs for rayleigh scattering and ozone absorption. Scatterplot of relationship between satellite zenith angle and atmospherically corrected Ch.5/Ch.8/Ch.19 reflectance using proposed algorithm in this paper is shown in Figure.4, because NDVI and EVI use these channels. Ch.5 (blue channel) reflectance is largely corrected, and Ch.8 (red channel) is slightly corrected. On the other hand, Ch.19 (NIR channel) is almost same as atmospherically uncorrected reflectance. Therefore, this is expected and appropriate result. However, especially, Ch.5 reflectance indicates the dependance on satellite angle. In blue channel, it is able to consider that there is not so much BRDF effect on the ground surface. As mention the above, GLI 1km/250m atmospheric correction algorithm can remove only the rayleigh scattering and ozone absorption. The algorithm proposed in this paper cannot remove the aerosol over land, therefore, the aerosol effect might be one of the reason for this characteristics. GLI 1km global 16-day composite NDVI/EVI image, which is conducted atmospheric correction, is shown in Figure.5. There are some pixels affected by satellite zenith angle. Especially, these are distributed around central Africa, south America, and so on.

In future, GLI land higher level algorithm should include correction for aerosol over land. And then, GLI 250m land higher algorithm is also needed to complete to develop as soon as posiible. As described in the above, 250m channel is expected to be affected by water vapour, because these channels are broader band than 1km channels. 250m algorithm may have to be different from 1km algorithm. Moreover, those products should be evaluated by ground based data and other sensors' data.

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Table.1: GLI Land channels

ch	Wave length [nm]	Dynamic range [W/m2/str/μm]	SNR (input L)	ch	Wave length [nm]	Dynamic range [W/m2/str/μm]	SNR (input L)	ch	Wave length [nm]	Dynamic range [W/m2/str/μm]	SNR (input L)
VNIR (1km) (#p: *piecewise linear band*)				15	710.1	233 (369)	300 (10)	**250 m bands**			
1	380.7	683	467 (59)	16	749	11 (17)	991 (7)	20	462.4	691	241 (36)
2	399.6	162	1286 (70)	17	762	246 (473)	293 (6)	21	542.1	585	141 (25)
3	412.3	130	1402 (65)	18	866.1	8 (13)	1309 (5)	22	661.3	115 (156)	255 (14)
4p	442.5	110 /680	893 (54)	19	865.7	211 (339)	386 (5)	23	824.1	210 (287)	218 (21)
5p	459.3	124 /769	880 (54)	**SWIR (1 km)**				28	1644.9	76	298 (5)
6	489.5	64	1212 (43)	24	1048.6	227	381 (8)	29	2193.8	32	160 (1.3)
7p	519.2	92 /569	627 (31)	25	1136.6	184	412 (8)	**MTIR (Kelvin, NEΔT at 300K)**			
8p	544	96 /596	611 (28)	26	1241	208	303 (5.4)	30	3721.1	345 K	0.07 K
9	564.8	39	1301 (23)	27	1380.6	153	192 (1.5)	31	6737.5	307 K	0.03 @285K
10	624.7	28***1** (39***2**)	1370 (17)	•Dynamic range and SNR are cited from "Tanaka, K., GLI Mission Data Evaluation Test results, NASDA ADEOS-II Project, ADEOS-II/GLI Workshop, November 14-16, 2001, Tokyo, Japan".				32	7332.6	322 K	0.03 K
11	666.7	22 (31)	1342 (13)	•Center wavelength is derived from GLI spectral response.				33	7511.4	324 K	0.02 K
12	679.9	23 (33)	1293 (12)	•S/N tests are in ambient (VN+SW) and high temp (MT) condition.				34	8626.3	350 K	0.05 K
13	678.6	342 (522)	235 (12)	•*1 Maximum radiance for **linear response (VN2)**				35	10768	354 K	0.05 K
14	710.5	16 (24)	1404 (10)	•*2 Predicted maximum radiance for **DN=4095 (12bit) or saturation.**				36	12001.3	358 K	0.06 K
									NASDA GLI CAL Group, May 1, 2002		
											:1km Land Channel
											:250m Land Channel

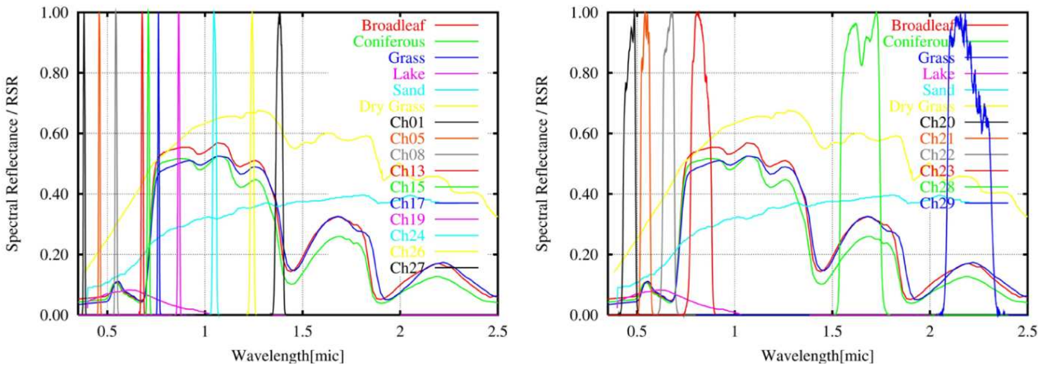

Figure.1:Relative Spectral Response of GLI land channels(Left:1km Right:250m)

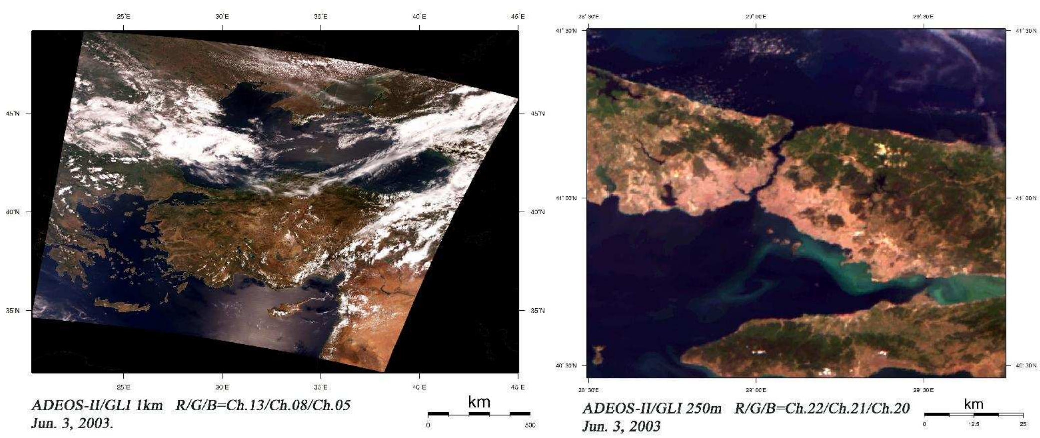

Figure.2: Example of GLI 1km and 250m Visible images

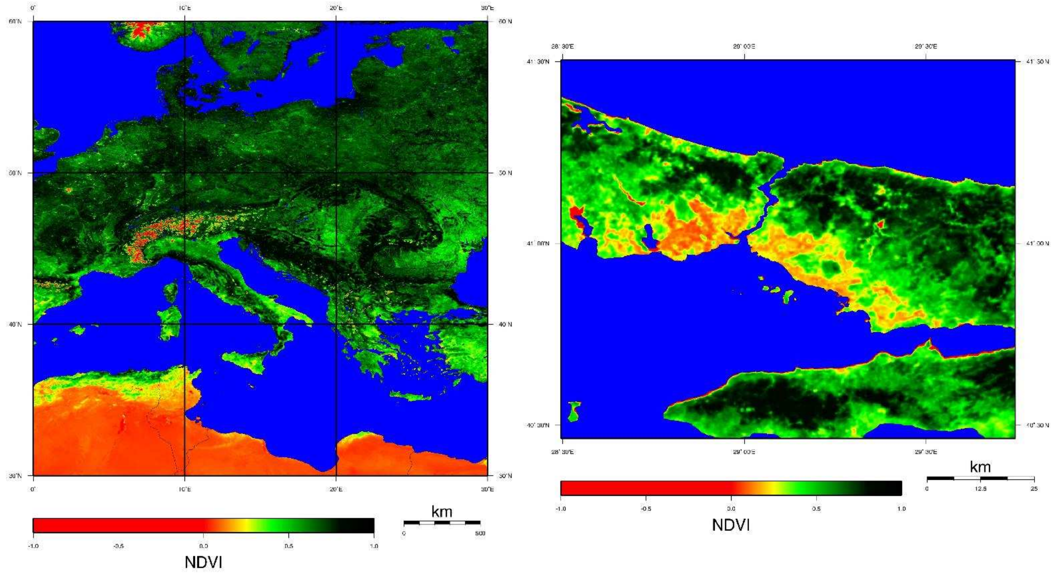

Figure.3: GLI 1km 16-day NDVI composite (Right, Atmospherically Corrected), and GLI 250m NDVI (Left, Atmospherically Uncorrected)

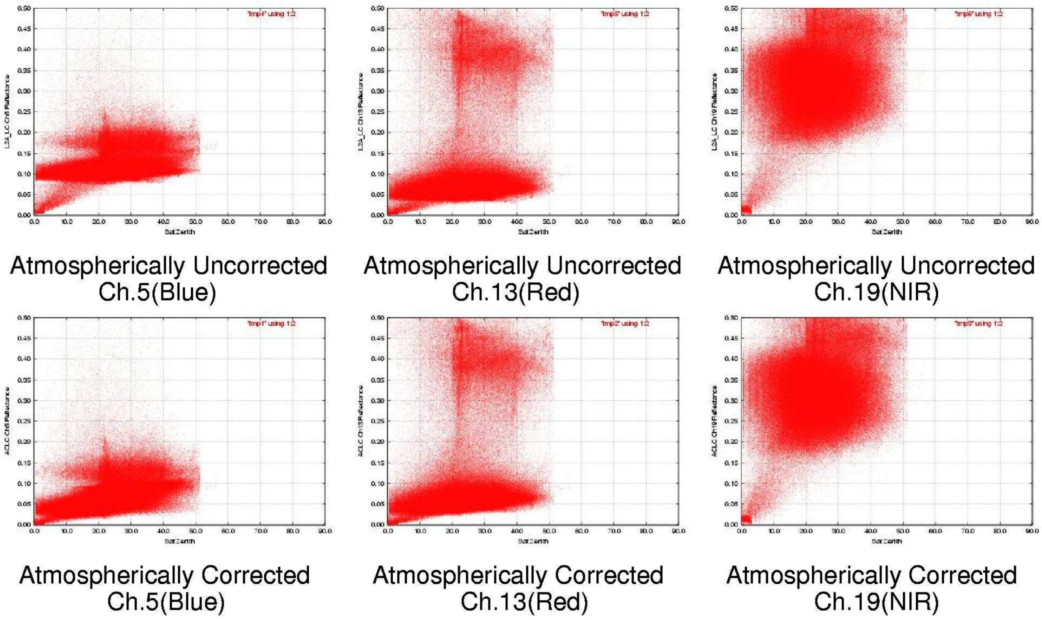

Figure.4: Satellite Zenith Angle vs. Atmosperically Uncorrected/Corrected Reflectance on GLI 1km 16-day VGI(NDVI,EVI) composite

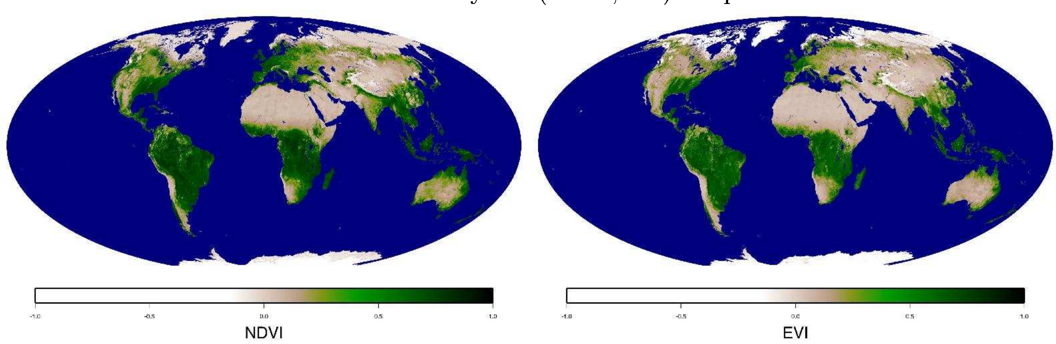

Figure.5: GLI 1km 16-day Atmospherically Corrected NDVI/EVI composite (Apr. 7, 2003.-Apr. 22,2003.)