GEOSTATIONARY IMAGER VISIBLE CHANNEL RECALIBRATION

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Abstract

A vicarious calibration methodology for geostationary satellites visible channel has been developed. The approach is based on comparison between satellite visible observations and radiative transfer calculations. It is important for reliable calibration to perform the comparison for proper observation condition. This study employs three types of reference areas as dark, medium, and bright reference including liquid cloud top. MODIS and ground-based observation are used as input data to simulation.

The calibration by this approach was examined for three-year visible data of the Geostationary Meteorological Satellite -5 (GMS-5). Results show that calculated calibration coefficients are more temporally stable than ISCCP ones. The calibration coefficients also show the improvement in products retrieved from calibrated visible data such as aerosol and cloud optical thickness. This approach is applicable to other satellites such as MTSAT-1R.

This study has been achieved under a cooperative research by Japan Meteorological Agency (JMA), the Center for Climate System Research, the University of Tokyo (CCSR), and Center for Environmental Remote Sensing, Chiba University (CEReS).

INTRODUCTION

Geostationary meteorological satellites have operated for more than 30 years, and the amount of archived data is expected to contribute climatological study. WMO have organized some projects related to climatological study relies on space-based observations such as International Satellite Cloud Climatology Project (ISCCP) and Global Precipitation Climatology Project (GPCP). In recent years, Sustained, Coordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE-CM) has been built to establish a network of facilities ensuring continuous and sustained provision of high-quality satellite products related to the Essential Climate Variables (ECV), on a global scale, responding to the requirements of the Global Climate Observing System (GCOS).

To utilize satellite observation data, the validation and recalibration of the data are important. For this purpose, Global Space-Based Inter-Calibration System (GSICS) was launched under WMO. GSICS orients near-real time and routine basis satellite data calibration system, and is organized by some meteorological agencies and research organizations. GSICS have established calibration algorithm for infrared channels. Visible channel is one of the next issues, since visible data is also valuable to retrieve climatological products such as aerosols, ground surface albedo, and downward solar flux.

There are various types of approaches for visible channel calibration of geostationary satellites, such as cross calibration or moon calibration. This study focuses on the vicarious calibration relies on radiative transfer calculation, which has advantage to be able to work out absolute physical values, radiance or reflectivity, corresponding to observations. This study proposes the methodology of the visible calibration first. Then, the calibration coefficients of the GMS-5 visible channel computed by this methodology are presented. Finally, aerosol, cloud and surface products are retrieved to evaluate the computed coefficients.

CALIBRATION METHOD

Overview

The approach in this study is vicarious calibration method. Its goal is to rebuild visible calibration table. The vicarious calibration approach relies on radiative transfer calculation. Satellite observations are compared with simulations which are referred as proper values to obtain new calibration table.

Imager output is generally linear with respect to observed radiance as shown in (1). L is observed radiance and X is the imager output. The "output" is, for instance, 10 bits digital number for MTSAT-1R or imager output voltage for GMS-5. The voltage is discussed in a following section.

$$L = aX + b \quad (1)$$

The observed radiances at each observed location are simulated under atmospheric and geometric conditions. The calibration coefficients a and b in (1) are computed by regression analysis for adequately many pairs of the X and simulated radiance. The calibration coefficients are not constant and change in time while the imager's operation period due to degradation or fluctuation of imager sensitivity. The vicarious calibration means to work out the appropriate coefficients based on radiative transfer calculation.

To reduce uncertainty of radiative transfer calculation, the calculation should be examined on spatially uniform and temporally stable area. Therefore, observed image is separated into small grids, and the simulation is examined only for suitable grids. Such grids are referred as "reference target" hereafter. The reference targets should be over wide range of brightness to obtain reliable regression line. This study adopts three types of reference targets, cloud-free ocean surface, cloud-free land surface, and spatially uniform liquid cloud top as dark, medium and bright reference target, respectively. The simulation requires some inputs depending on each type of the reference target.

If the satellite sensor is composed of multiple detectors and each image pixels can be identified which detector observed the pixel, sensitivity difference between detectors need to be estimated after the calculation of the coefficients a and b and to be reflected to the new calibration table.

Simulation

Radiative transfer code

As a radiative transfer code, RSTAR developed by CCSR is employed (Nakajima and Tanaka, 1988). RSTAR requires atmospheric profile, total column ozone amount, surface reflectivity, optical parameters of scattering particles and viewing geometries. The input to the radiative transfer calculation should be independent to the satellite observation. In this study, therefore, atmospheric profile and ozone amount are based on Japanese 25-year reanalysis (JRA-25; Onogi et al, 2007) and Earthprobe/TOMS data, respectively. Scattering objects are aerosol (cloud-free sea and land reference target) and cloud (cloud reference target). The scattering particles' optical parameters are worked out from MODIS L1B data or ground observations depending on each reference target.

Simulation on cloud-free ocean reference target

On a cloud-free ocean reference target, sea surface reflectivity and aerosol optical parameters are necessary in addition to atmospheric profile and ozone total amount as input data into the radiative transfer calculation. RSTAR can retrieve sea surface reflectivity from sea surface wind speed. This study picks up sea surface wind speed from JRA-25. Aerosol optical thickness and Angstrome index are obtained from Terra/MODIS L1B data by using aerosol analysis package, REAP (Higurashi and Nakajima 1999). REAP computes the aerosol optical parameters from two channels of satellite data, visible and near infrared. The aerosol absorption/scattering parameters are non-absorption characteristics by Higrashi and Nakajima (2002).

NASA MODIS aerosol product (so called MOD04 and MYD04) can be another option for input data to the simulation instead of the REAP-retrieved-aerosol. However, a radiative transfer code to retrieve aerosol from MODIS L1B and a code to calculate simulated radiance should be consistent for accurate simulation. A radiative transfer algorithm included in REAP is same as RSTAR. Therefore, this approach inputs REAP-retrieved-aerosol to the radiative transfer code instead of NASA MODIS aerosol product.

Simulation on cloud-free land reference target

The key elements on a cloud-free land reference target are ground surface reflectivity and aerosol optical thickness. It involves uncertainty to retrieve aerosol optical thickness from satellite observation especially on land area. Though, the aerosol ground observation data is adopted instead of satellite product on cloud-free land reference target. Bureau of Meteorology (BoM) has ground observation sites on central part of the Australia continent, Alice Springs and Tennant Creek. The reference targets are picked up from 1 degree by 1 degree areas around these two sites.

To estimate ground surface reflectivity precisely, Bidirectional Reflectivity Distribution Function (BRDF) which shows a reflectivity corresponding to an incoming direction and an outgoing direction is necessary. The areas around the Alice Springs and Tennant Creek are not isotropic because of a little vegetation. This study utilizes the NASA MODIS BRDF product (Strahler et al. 1999) to take account of the anisotropy. The BRDF product provides parameters to characterize ground surface reflectivity depending on geometry information. The product supplies the parameters for the MODIS seven bands from visible to infrared channels and three broad bands. The parameters are not supported for GMS-5 Sensor Response Function (SRF), therefore, the ground surface reflectivity counting the GMS-5 SRF is approximated based on interpolation of the parameters for MODIS seven bands.

Simulation on liquid cloud reference target

Cloud parameters such as optical thickness and effective radius are dominant factor on liquid cloud reference target. Those parameters are obtained from Terra/MODIS L1B data by using cloud analysis package, CAPCOM (Nakajima and Nakajima, 1995). CAPCOM computes the cloud optical parameters from three channels of satellite data, visible, near infrared, and infrared. The radiative transfer algorithm included in CAPCOM is consistent with RSTAR. It endorses accurate simulation as mentioned about the ocean reference target. On this cloud reference target, the scattering object is not aerosol but liquid cloud particle.

It is worth while to consider ice cloud top as another brighter reference target, however, there is arbitrariness to decide parameters for radiative transfer calculation for ice cloud. In this study, only liquid cloud top is utilized as cloud reference target.

Target selection

Simulation should be examined on specific areas which meet some conditions such as spatial uniformity to mitigate uncertainty of radiative transfer calculation. To find suitable areas, the GMS-5 image is separated into 0.1 degrees by 0.1 degrees grids, and grids satisfying all the following four checks are adopted as targets.

- Spatial uniformity check
  To select a spatially smooth grid, the uniformity of GMS-5 visible data in the grid is checked. For this check, if a histogram width of observed GMS-5 visible digital counts in a grid is wider than a threshold, the grid is rejected.

- Observation time check
  There is observation time difference between the MODIS L1B data to compute the input into radiative transfer calculation and the GMS-5 visible image for each grid. If the observation time difference for a grid is larger than a threshold, the grid is rejected.

- Geometry angle check
  To avoid simulation on grids with much large satellite and solar zenith angle, if the satellite and solar zenith angle on a grid is larger than a threshold, the grid is rejected. A grid corresponding to sun glint area is also rejected.

- Target-specified check
  In addition to the aforementioned three checks, a grid needs to pass reference target type specified checks as follows.

(Cloud-free ocean reference targets)
- If any pixels in a grid are not clear pixels, the grid is rejected.
- To examine simulation only on ocean area, if a grid is on land or coastal area, the grid is rejected.

(Cloud-free land reference targets)
- If any pixels in a grid are not clear pixels, the grid is rejected.
- The interpolated ground surface reflectivity as mentioned in a previous section is reliable only for areas with less vegetation. The vegetation can be checked by a simple numerical indicator, Normalized Difference Vegetation Index (NDVI), which can assess whether the target being observed contains live green vegetation or not. If the NDVI on a grid is larger than a threshold, the grid is regarded as a vegetated area and is rejected. This check uses NASA MODIS NDVI product.

(Uniform liquid cloud reference targets)
- If ratio of cloudy pixels in a grid is smaller than a threshold, the grid is rejected.
- To adopt only liquid cloud as a target, if a cloud top temperature in a grid is lower than 273K, the grid is rejected.

Pixels in a grid do not have exactly same observation value even if the grid passed the above checks. Though, a mode value of the observations in a grid is picked up as a representative observation value of the grid and compared with simulated radiance.

Post simulation analysis

Conversion to voltage

GMS-5 imager, Visible and Infrared Spin Scan Radiometer (VISSR), visible channel observation radiance is encoded into 6 bits information. It has 64 level radiometric resolutions. The 6 bits digital number (DN) has quadratic-curve-like relationship to the VISSR output voltage. The VISSR doesn't guarantee the linearity between the observed radiance and the digital numbers. The DN-Radiance table, i.e. calibration table, is not linear but the Voltage-Radiance table is linear. Therefore, the observed data are converted to the VISSR output voltage and compared with simulated radiance.

Stripe noise removal

The VISSR visible channel is composed by four primary and four redundant detectors. The four of eight are operational and the other four are standby status. Each detector's sensitivity is not exactly same. The sensitivity difference causes stripe noise on observed image. To take into account the sensitivity difference, a detector is designated as a standard detector and conversion coefficients between the VISSR output voltage by the standard detector and other detectors' voltages are calculated. The simulation and the reference target selection are examined for observations by the standard detector. After the calibration coefficients for the standard detector are obtained, the calibration coefficients for the other three detectors are calculated according to the conversion coefficients.

Evaluation of simulation accuracy

To estimate accuracy of this approach, the simulated radiance on the three types of reference targets are compared with not GMS-5 observed radiance but Terra/MODIS radiance. MODIS carries onboard calibrators for visible bands, which is well-calibrated and reliable. The input factors to radiative transfer code are same as the simulation for GMS-5, such as JRA-25 and aerosol and cloud optical parameters retrieved from MODIS L1B.

Fig.1 shows the match-up between the simulated radiance and the MODIS observed radiance. The error between both radiances is less than 1%. It means that the methodology is sufficiently reliable.

RESULTS

Fig.2 shows an example of the match-up between the simulation and GMS-5 observation. Three clusters of plots in the fig.2 correspond to three types of the reference targets, ocean, land and liquid cloud. The plots are on a line, which bears out that VISSR visible channel have a linear characteristic between radiances and the observed values. A regression coefficients and the DN-Voltage table give a new calibration table.

ISCCP presents calibration coefficients defined by (2),

$$L = S \cdot L_n + I \tag{2}$$

Where L and L_n are the corrected and the nominal scaled radiances, S and I are slope and intercept, respectively. Fig.3 shows a history of the calibration coefficients in the notation of (2), the slope and the intercept. Terra/MODIS started its operation since the end of Feb. 2000. The calibration coefficients are obtained after Mar. 2000. Coefficients by the ISCCP are also shown in Fig.3. The calibration coefficients by this study are more temporally stable than the ones by ISCCP.

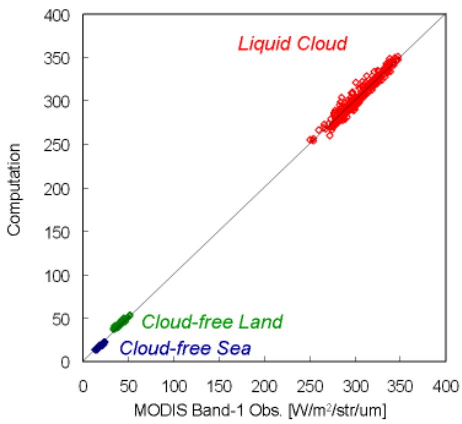

Figure 1: **Match-up between simulated radiance and Terra/MODIS observed radiance. A slope of the regression line is 1.00 and bias is almost zero. The radiative transfer code can simulate MODIS observed radiance with error less than 1%.**

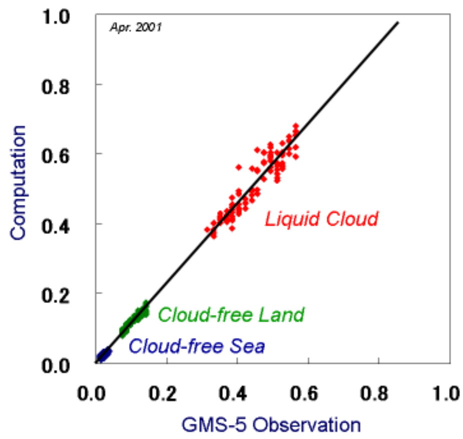

Figure 2: **Match-up between simulated radiance and GMS-5 observation. To simplify explanation, horizontal axis is GMS-5 observed reflectivity converted from sensor output voltage. The data period is one month, April 2001.**

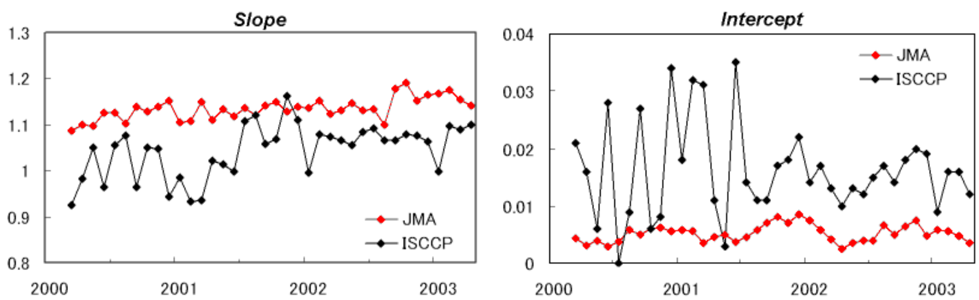

Figure 3: **A history of the calibration coefficients (Left) the slope and (Right) the intercept in the notation of (2). Black solid line is the new calibration coefficients and red solid line is the coefficients by ISCCP.**

VALIDATION

One of simple approaches to check validity of newly generated calibration table is to compare the calibrated radiance with the observed radiance by other reliable sensors. The sensor SRFs are, however, different from each other. The calibrated radiance can not be compared with the other sensor's radiance directly. Therefore, this study utilizes physical quantity products to check the calibration outcome. When the retrieved product has good accuracy, it means that the calibration table is also reliable. This section introduces two examples, aerosol and cloud optical thickness.

Aerosol optical thickness

JMA has observed aerosol optical thickness (AOT) at three ground observation sites around Japan. AOT can be retrieved from GMS-5 data over clear ocean based on Okawara et al. (2003). Clear ocean appears dark area on satellite image. The aerosol product can play a role to check the calibration table for dark object.

Fig.4(Left) shows the retrieved AOT compared with the ground observation. Two AOT products are on the fig.4(Left), the one is based on the new calibration table and the other is based on the original calibration table. Both products are compared with ground observations. The product by the original table tends to underestimate, meanwhile, the product by the new table is good approximation for the ground truth. In this example, the RMSE of the AOT improves from 0.17 to 0.07.

Degradation of sensor sensitivity makes observed image darker than proper brightness, and it causes underestimated AOT. Fig.4(Left) means this vicarious calibration process successes to correct sensor drift for dark object observation, i.e. clear ocean area. It is confirmed that the entire AOT over the calibrated period, March 2000 to April 2003, are improved.

Cloud optical thickness

Thick and bright cloud with large cloud optical thickness (COT) over ocean area can be utilized to check the calibration table for bright object. The COT retrieved from GMS-5 by using the cloud analysis tool, CAPCOM, is compared with the one retrieved form MODIS L1B as a reliable reference.

Fig.4 (Right) shows the COT observed by GMS-5 and MODIS. Two kinds of the GMS-5 COT which are based on the original and the new calibration table are presented on fig.4 (Right). In this example, the RMSE improves from 10.5 to 4.8. It means the new calibration table successes to correct underestimated COT arisen from sensor drift, and the vicarious calibration process works fine for bright object, i.e. thick liquid cloud.

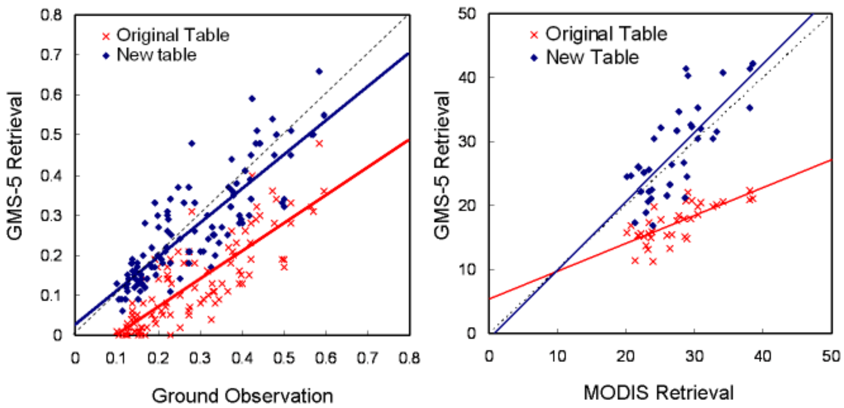

Figure 4: **(Left) Match-up between AOT ground observations and retrieval from GMS-5 data. For red x-marks, GMS-5 retrieval is based on the original calibration table, and for blue circles, it is based on the new calibration table. Red and blue solid line shows the regression lines for red and blue plots, respectively. The blue regression line is closer to the diagonal line than red line, which means improvement of this product. The sample period is one month, April 2001. (Right) COT retrieval from MODIS L1B and from GMS-5 data. The meaning of red and blue plots is same as left figure.**

APPLICATION

Reliable calibration table is necessary especially for climatological applications. This study introduces an example of applications to show impact of the calibration.

JMA decided to cooperate with SCOPE-CM, WMO project for climatological study, and to create surface albedo product under cooperation with EUMETSAT. Surface albedo is on the list of Global Climate Observing System (GCOS) Essential Climate Variables (ECV). Since the surface albedo product is retrieved by visible channel image, it becomes a good demonstration to check impact of the calibration table.

Fig.5 shows the surface albedo products based on EUMETSAT algorithm (Govaerts, 2004). The one product is based on the original calibration table, and the other is based on the new calibration table. The product by the original table tends to underestimate, and the difference of albedo value is around 0.01.

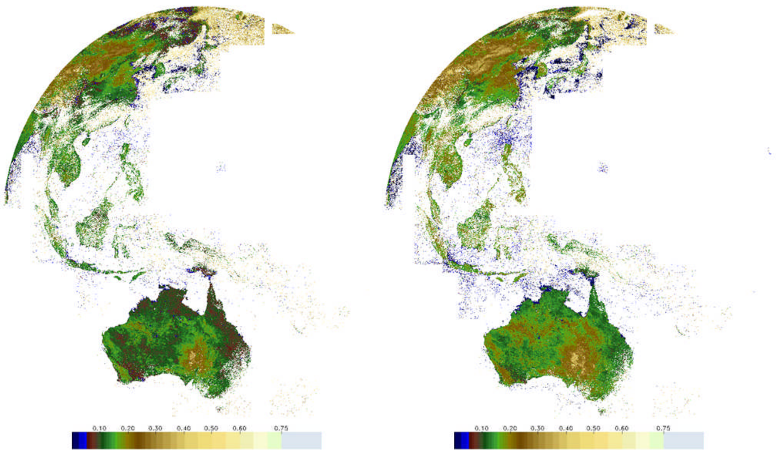

Figure 5: **(Left) An example of the surface albedo product by GMS-5 image based on EUMETSAT algorithm. The data period is 1 to 10 May 2001. The visible calibration table is original one. The average of global albedo value is about 0.189. (Right) The surface albedo product based on the new calibration table. The average is about 0.199.**

CONCLUSION

This study presents a visible vicarious calibration method referring three types of reference targets, cloud-free ocean, cloud-free land, and uniform liquid cloud as dark, medium, and bright reference targets, respectively. Regression analysis for comparison between simulations and observations brings new calibration tables which are more temporally stable than ISCCP ones. The reliability of the obtained new calibration table is confirmed through the validation for the physical quantity products such as aerosol and cloud optical thickness.

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APPENDIX

The approach in this study is applicable to the MTSAT-1R and other geostationary satellites. To adopt this method to MTSAT-1R, slight modification is required, since there are two differences between MTSAT-1R HRIT disseminated image and GMS-5 image.

- Observed digital numbers by MTSAT-1R have linear relationship with radiance, unlike GMS-5. Thus, for MTSAT-1R, it is no need to convert DN to the imager output voltage.

- The MTSAT-1R image doesn't have any information to identify individual detector for each pixel. On the imager specification, the stripe noise on the image is removed in advance of its dissemination. Therefore, the calibration procedure can be simpler than the GMS-5.

Fig.6 shows an example of the match-up between simulated and MTSAT-1R observed radiance. The scatter plots looks approximately linear. It demonstrates this approach is applicable for MTSAT-1R.

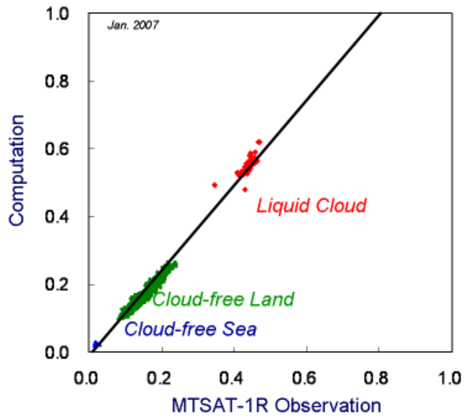

Figure 6: **Comparison of simulated and MTSAT-1R observed radiance. Red, green and blue plots correspond to liquid cloud, cloud-free land, and cloud-free ocean target, respectively. The data period is one month, January 2007. These plots are on a line, which brings calibration coefficients.**

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