Comparative Study of Cloud Parameters Derived From Terra-MODIS and GMS-VISSR

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Abstract
Top cloud reflected solar radiance measurements directly recorded by satellites at various spectral bands and observation conditions are used to understand clouds' optical and physical characteristics. The magnitude of these radiance measurements modulates the energy balance of the Earth through absorption and scattering. The accuracy of the data obtained highly depends on the sensitivity of the recording sensors. The Visible and thermal infrared channels are mainly employed to extract, through various inversion techniques, cloud microphysical parameters such as the brightness temperature, optical depth, effective radius, top cloud temperature etc. This study examines reflectance and optical depth retrievals derived from cloud radiative measurement data collected by the SVISSR (Stretched Visible Infrared Spin-Scan Radiometer) and the MODIS (MODerate resolution Imaging Spectroradiometer) sensors onboard the geostationary satellite (GMS-5) and the polar-orbiting satellite (Terra) respectively. MODIS cloud optical depth as well as reflectance appears systematically higher than the SVISSR corresponding data. And, the largest differences are mostly seen in thick cloud areas. To understand these discrepancies, a cloud classification based on the split-window method, has been conducted and, the influence of various parameters on the measurements and retrievals among which, dimensional radiative effects (asymmetry of the clouds) and the sun-earth-satellite viewing geometry are examined.

Key Words: MODIS, SVISSR, cloud optical depth, reflectance

1. INTRODUCTION

Retrieval of cloud properties from passive remote sensing has extensively relied on satellite data. The cloud characteristics therefore retrieved from radiance measurements are mainly the clear or cloudy scenes distribution, the cloud fraction, reflectance and emissivity, liquid water content, phase (water or ice clouds), optical depth, effective radius, top cloud temperature etc. Various factors such as the solar altitude, the view angle geometry and the cloud inhomogeneity influence the accuracy of the cloud properties measurements. The degree to which satellite measurements are influenced by cloud inhomogeneities depends on the spatial resolution of the instrument, the sun-earth-satellite viewing geometry, and whether the observations are analyzed at the local pixel scale or over larger regions by averaging pixel-level values (Loeb and Coakley, 1998).

Various cloud detection methods have been adopted among which the maximum temperature (retaining of the highest temperature of a given area), the infrared variability, the two-wavelength infrared (split-window method), the two-wavelength visible-infrared (using reflected sunlight to detect clouds).

The GMS-5 satellite, launched in 1995 into a geostationary orbit above 0^o N, 140^oE, carries a Stretched Visible and Infrared Spin-Scan Radiometer (SVISSR) with four channels, one in the visible part of the spectrum (0.5 – 0.75 µm) and two in the infrared (10.5 - 11.5 µm and 11.5 –

12.5 µm) then one water vapor channel (6.5 – 7.0 µm). The ground resolution at the subsatellite point is 1.25 km in the visible channel and 5 Km in the infrared. It is not possible to derive cloud particle size with the SVISSR sensor due to the non-existence of the 3.9 µm channel (therefore, for optical parameters' retrievals, a fixed value of 10 µm was used as effective radius). The satellite however has a good time resolution with scanning intervals at least every hour. The SVISSR instrument noise is around 0.5 K (MSC, 1997).

MODIS (MODerate resolution Imaging Spectroradiometer) sensor onboard The Terra polar orbiting satellite is a 36-band spectrometer (ranging from 0.41 to 14.38 µm) providing a global data set every 1-2 days with a 16-day repeat cycle. The spatial resolution of MODIS (pixel size at nadir) is 250m for channels 1 and 2 (0.6 µm - 0.9 µm), 500m for channels 3 to 7 (0.4 µm - 2.1 µm) and 1000 m for channels 8 to 36 (0.4 µm - 14.4 µm), respectively. The sensitivity at the 11µm channel permits the detection of temperature differences as small as 0.01 K and the noise equivalent temperature difference is about 0.05 K. Because of this thermal detection capacity, adjacent pixels from MODIS data show higher variability than those from SVISSR data.

In the present study, we would like to examine cloud mocrophysical parameters retrievals derived from cloud radiative measurements collected by the SVISSR and the MODIS sensors. Then investigations will be conducted on the effects that the random geometry of the clouds would have on the accuracy of the cloud reflected radiation. Beyond the comparison of satellite data, this study was motivated by the search of reasonable explanations and corrections of some important differences noticed in the optical and radiative properties retrievals and, measurements from SVISSR and MODIS sensors. The area of study chosen to conduct this work is mainly centered on the southern part of the Sea of Japan and limited by the following geographical coordinates 25N - 35N latitude and 125E - 135E longitude. The SVISSR and MODIS matching images on this area, have time differences of 3 to 28 minutes. A grid resolution of 0.05^{o} or 5 Km pixel's length is used for data processing.

2. METHODOLOGY AND OBSERVATIONS

Data from the MODIS sensor almost temporally coincident with the SVISSR images are analyzed. Visible and infrared channels are used to retrieve cloud microphysical properties such as the brightness temperature, optical depth, top cloud temperature, particle effective radius etc. Using the split-window technique (Brightness temperature difference at 11µm and 12 µm) on the SVISSR IR data, clouds were classified as cumulus, cumulo-nimbus and dense cirrus and, cirrus. This classification was attempted in order to understand the sensors' sensitivity to the morphological structure of the clouds encountered in the region. Large discrepancies in the microphysical properties (reflectance, optical depth mainly) of the clouds, generally in areas of thick clouds were observed. The MODIS data appear systematically higher than the SVISSR data in such areas. The best correlation between MODIS and SVISSR data is found with the relatively thin mid- and low-level clouds i.e. at cloud optical depth (COD)<20. Figure 1 is the illustration of the frequency distribution of the differences in cloud optical properties between MODIS and SVISSR. The split-window classification following these observations is made to identify the types of clouds associated with the strongest differences in cloud properties between both sensors. The last part of this study is devoted to investigations on possible causes of the discrepancies noticed. Among the reasons generally accounted for as influential in the accuracy of cloud microphysical properties: size, geometry and differentiation of cloud phases (water and ice clouds), differences in the resolution and spectral channels' separation, accuracy of the characterization of the cloud scenes, threshold for cloud detection, calibration errors of the sensors, misalignment of images (geolocation problem) and time differential in the scanning of the sensors, solar zenith and satellite view angles, scattering patterns and cloud geometries.

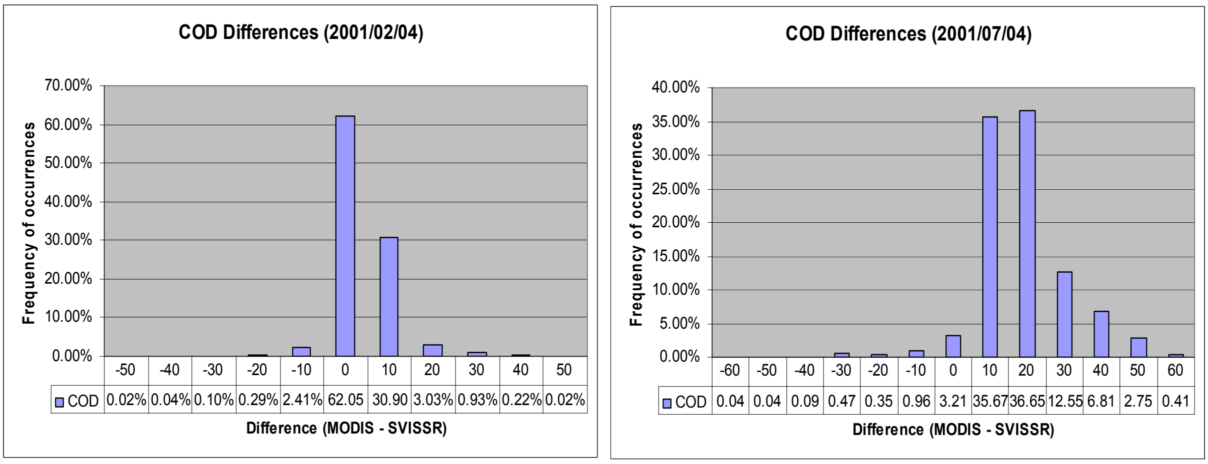

Fig. 1. Frequency histograms of the differences between the cloud optical properties obtained from SVISSR and MODIS

3. DATA ANALYSIS

As stated earlier, cloud optical properties data retrieved from MODIS appear systematically higher than those of SVISSR (See Figure 1). In order to understand these discrepancies, the first step of our work consisted in adopting a classification method permitting the differentiation of clouds based on their morphological structure. The method used in this study takes advantage of the existence of the 11µm and 12µm channels on the GMS-5/SVISSR. This method is based on split-window data (11µm-12µm) as suggested by Inoue et al. (1987). The cloud types identified are: Cirrus, dense cirrus, cumulo-nimbus and cumulus.

It was observed that the largest discrepancies in the cloud properties between both sensors mostly occur in the vertically well-developed cumulo-nimbus/dense cirrus type of clouds.
Most of the differences noticed in the optical properties between MODIS and SVISSR mainly occur in the vertically developing cloud structures represented by the cumulo-nimbus and dense cirrus clouds. The smallest differences are found in the cumulus type. It appears therefore that the morphology of the clouds may play an important role in the accurate determination of radiation measurements by both sensors. The second step of this work consisted in reviewing and evaluating the other possible causes of the optical properties differences. Particular emphasis will be placed among others on the relation between the cloud surfaces and the sun radiation geometry.

4. RESULTS AND DISCUSSION

For the visible channels, the radiance measurements made by the SVISSR are converted into reflectance products; the MODIS data available for this study are calibrated geolocated radiance products (at 0.86μm wavelength). These MODIS radiances can be translated into reflectance by using the following formula:

$$R(\mu, \mu_0, \phi) = \frac{\pi I(\pi, \mu_0, \phi)}{\mu_0 F}$$

With $I =$ radiance $\left(W\, m^{-2} sr^{-1} \mu\, m^{-1}\right)$
$F =$ Solar irradiance $\left(W\, m^{-2} \mu\, m^{-1}\right)$
$\mu =$ Cosine of the observer's zenith angle
$\mu_0 =$ Cosine of solar zenith angle
$\phi =$ Azimuth angle relative to the solar plane

In this section, observed reflectance data are discussed together with retrieved optical depths in order to evaluate factors likely to influence measurements and retrievals of satellite data. Among these factors:

1) Differences in resolution and spectral channels:
MODIS has a higher resolution (1 km at subsatellite) than SVISSR (1.25 km for visible and 5 km for IR). Lower accuracies expected for the SVISSR data could be most likely due the poorer spatial (5 km pixel against 25 pixel averages for the MODIS data) and lower digitization (8-bit against 10-bit for the MODIS). The higher resolution MODIS data should allow for better discrimination between clear and cloudy pixels than SVISSR but, as cloud thermal infrared brightness comparisons show relatively good matches, the resolution alone can not explain the differences in reflectance and optical depth noticed between both sets of data.

2) Improper thresholds for cloud detection and, accuracy in the characterization of the clear scenes (algorithm problem):
Equivalent assumptions were made in the algorithms used for the retrievals of both sets of data, this, minimizing possible retrieval errors. Furthermore, MODIS Cloud reflectance data appear too, generally higher than the SVISSR derived reflectance and show a trend consistent with that of COD retrievals from both satellite measurements.

3) Errors in calibrations:
Though, the calibration tables for IR channels 1 and 2 have errors of ±0.2 K due to quantization (Tanahashi et al. 2000), a consistent error trend is not visible in either IR data or reflectance data from both sensors.

4) Geolocation problem and Time differential in the scanning of both sensors:
A simple comparison of the SVISSR IR channel 1 images at 02 UTC and 03 UTC shows that in some areas, large temperature differences (therefore cloud movements) can occur in just an hour

time interval separating both measurements. This suggests that some of the wide temperature differences between MODIS and SVISSR IR data may be much more due to the time differential (3 to 28 minute-difference) than to possible geolocation problems. Figure 2 shows the images of the SVISSR (at 02 UTC and 03 UTC) and MODIS (around 45 mn after and 15 mn before the SVISSR 02 UTC and 03 UTC respectively) cloud movements and the corresponding IR temperature cross-section at 30N, on April 2, 2001.

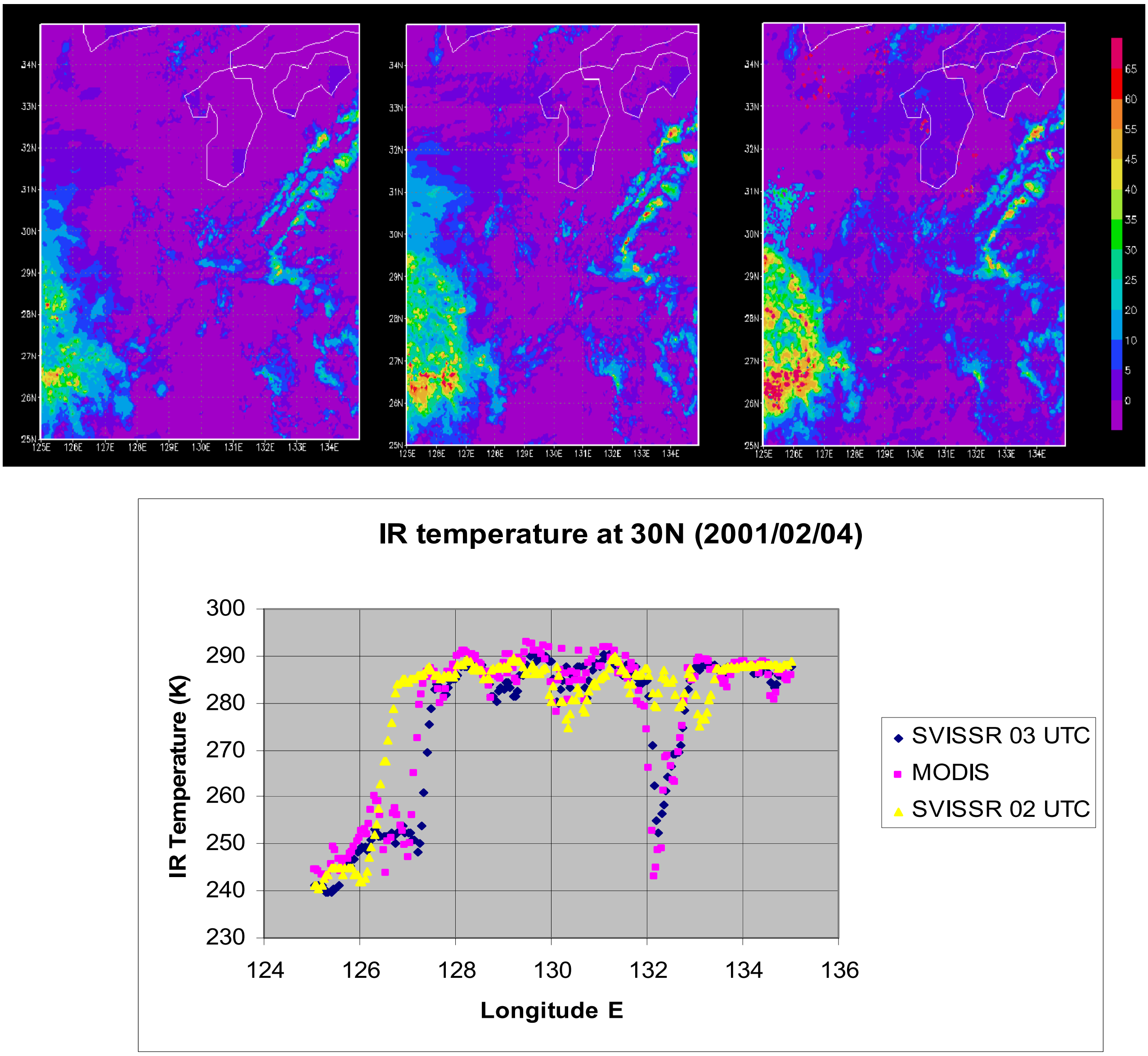

Fig. 2. Cloud movements as illustrated by the optical depth images (upper) and equivalent IR brightness temperature at 30° N latitude (lower diagram).

5) Size, geometry and cloud phase (water and ice clouds):

Due to the lack of channel 3.9 µm, cloud effective radius (r_{eff}) is not available from SVISSR; a constant cloud effective radius of 10 µm was used in the SVISSR retrieval of cloud microphysical data. The r_{eff} from MODIS retrievals vary widely from around 2 to 40 µm. This variation follows a unimodal distribution whose peak is generally around 10 µm. Regarding the cloud phases, it was noticed that the large cloud properties differences occur as much in the water as in the ice phase.

6) Influence of the solar zenith angle:

The solar zenith angles from the satellite images used are generally below 35^o. Analyses made so far, didn't allow us to give enough evidence of the existence of cloud properties' dependence on this parameter.

7) Dimensional radiative effects (cloud asymmetry) and relation with satellite viewing geometry:

The effects of finite cloud geometry have been analyzed with satellite observations mainly at infrared wavelengths. To understand the cloud asymmetry effect on the measurements of cloud properties, we'll use a technique of detection of these radiative effects over a chosen area, as proposed by Varnai and Marshak (2002). The method's basic idea is to estimate, for each basic pixel in the area, whether 3D effects are likely to have increased or decreased relatively to 1D theory, the pixel's brightness at the visible channel. The technique assumes that the question of whether 3D effects enhance or reduce the brightness of a pixel depends mainly on whether the pixel is on a slope tilted toward (illuminated slopes) or away from the sun (shadowy slopes). An area of (50 Km)^2 size is chosen with the goal that the area contains many pixels for statistical calculations but that they do not contain clouds from different cloud fields too often. Significant 3D effects can be revealed from the average brightness difference between the brightened (illuminated) pixels and darkened (shadowy) pixels. The implementation of the technique follows the steps below:

Step1: use the geolocation data to determine from which direction the sun illuminates the area of a pixel, and thus, which neighboring pixels are closest to the solar azimuth in front of it and behind it. Only cloudy pixels are examined. In our study area, the solar azimuth angle varies between 150 and 180^o, the sun incident direction adopted will be therefore from South to North.

Step2: determine whether the pixel is on an illuminated slope or shadowy slope. To detect this, the local gradient of brightness temperature (g) is calculated from the pixels in front and behind:

$$g = \left(T_{front} - T_{behind}\right)/d$$

Where d is the distance separating the pixels in front and behind (10 km)

-If $g > 0$, the pixel is on an illuminated slope

-If $g < 0$, the pixel is a shadowy slope

Step 3: After all cloudy pixels in a (50 km)^2 area are designated as either illuminated or shadowy the mean brightness (reflectance) of the illuminated (R_i) and shadowy (R_s) pixels is calculated. If the 2 mean values are close to each other, this indicates that 3D effects do not make much a difference in the (50 km)^2 area. If however, R_i is much larger than R_s, 3D effects (asymmetry) are expected to be strong.

Application of this technique to the data of this study shows that for the SVISSR Cloud optical depth and reflectance, the illuminated pixels are much more brighter than shadow pixels. This effect is less strong for MODIS data. This supposes that 3D effects due to the asymmetry of the cloud faces relative to the exposition to solar radiation influence both the cloud properties measurements and retrievals. High differences in cloud properties between both sensors are generally found when the SVISSR thermal gradient is negative i.e. the cloud face is on the shadow side relative to the solar radiation. This implies that the SVISSR data measurements and retrievals would be strongly affected and therefore lowered at the shadowy faces.

5. CONCLUSION AND FUTURE WORK

Comparison of MODIS and SVISSR derived cloud properties made in this study shows large discrepancies between the data retrievals and measurements from both sensors. Possible reasons of these discrepancies were discussed. It appears that time difference (in the scanning of both sensors) and the asymmetry effects of the clouds are the factors mostly accounted for as being at the origin of the differences noticed. Many more uncertainties related to the accuracy of the data acquired remain to be clarified. Future work would therefore consist of identifying these uncertainties (view angle differences and other aspects of the specific geometry of the clouds) and their quantification.

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