Uncertainty in cloud optical thickness estimation by GMS-5 S-VISSR algorithm and influence on the estimated radiative budget

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Abstract

APEX (Asian Atmospheric Particle Environment Change Experiment) project aimed at performing simultaneous analysis of cloud, aerosol and atmospheric radiation by various observation methods(satellite, airplane, ground base) in East China sea. Comparison of the optical thickness from GMS-5 S-VISSR with those retrieved from Terra-MODIS shows some remarkable differences. Causes of such errors were investigated. One of them was a scientific problem deriving from the difference in cloud droplet effective radius. However this can not explain by itself all the error encountered in the estimation of the cloud optical thickness. The other cause of error checked was the quantization noise. And, this happens to be an engineering problem. In the error evaluation of the algorithm used, we realized that the quantization noise induced much of the optical thickness difference. Using the radiative transfer code "RSTAR5b" we examined the influence of this error in the estimation of the radiative budget.

1.Introduction

GMS-5 is a geostationary satellite enabling observations every hour over the equative at a latitude of 140°E. By using these observation data, high temporal resolution is attained in the estimation of Earth's radiative budget. Based on the GMS-5 S-VISSR (Stretched- Visible and Infrared Spin-Scan Radiometer) visible channel data and assuming plane parallel cloud, the radiative transfer code "RSTAR4b" [Nakajima T. and M. Tanaka, 1986,1988] was used

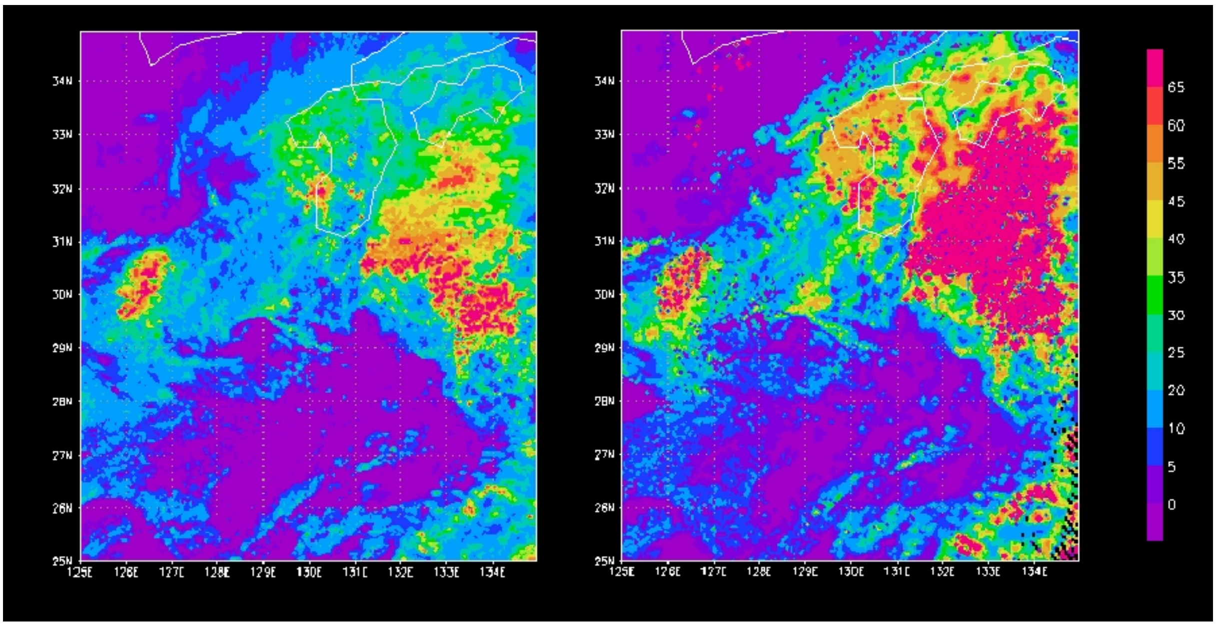


Fig. 1 : Cloud optical thickness estimation by GMS-5 S-VISSR (Left) and MODIS (Right) on April 9, 2001 in the study area (25°N—35°N and 125°E—135°E).

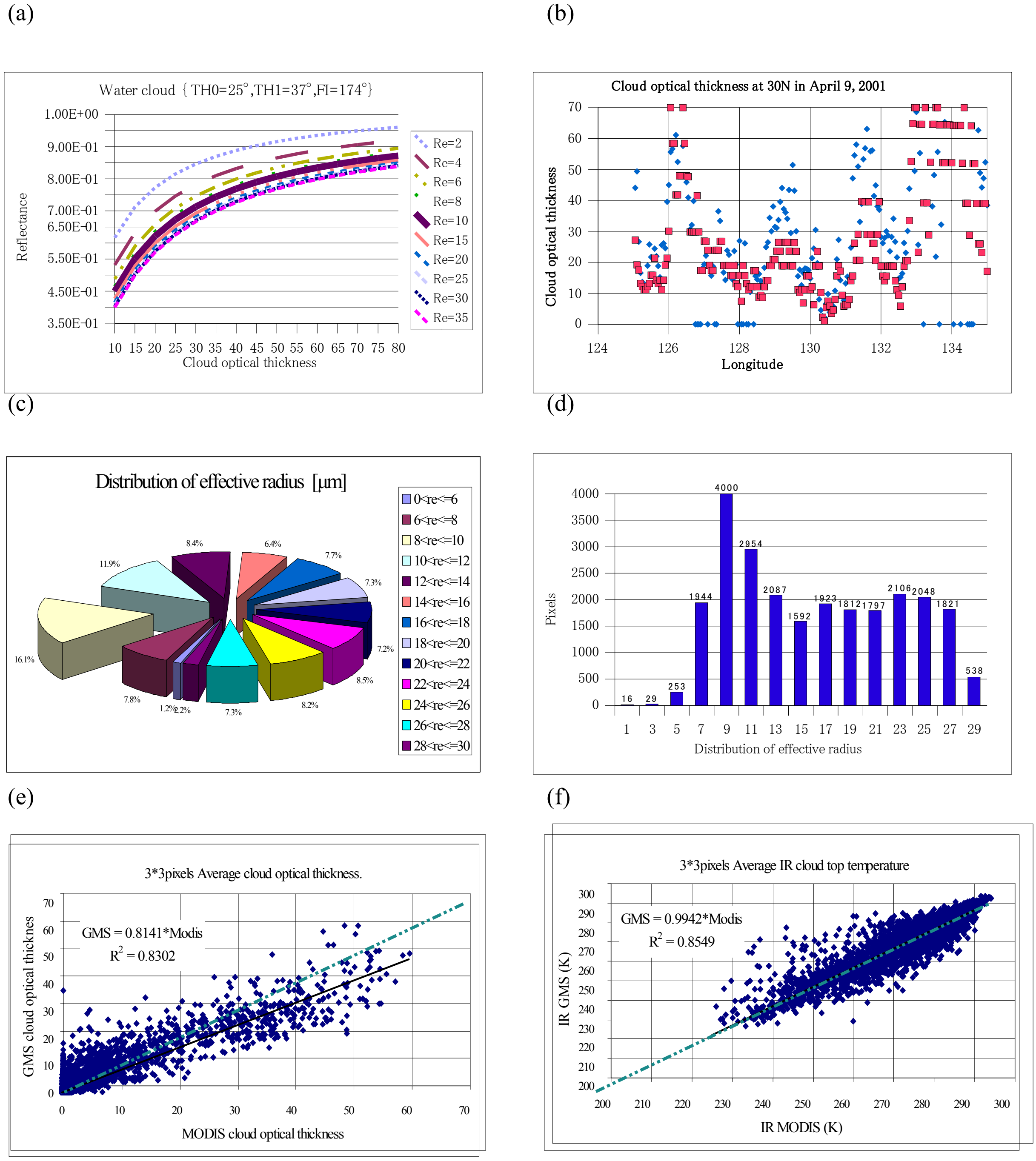


Fig. 2 : (a) Estimation curve of the cloud optical thickness with reflectance at GMS-5 S-VISSR ch1. The deep purple solid line shows the estimation from the algorithm used, with the water cloud droplet effective radius of 10μm. Assuming a solar zenith angle TH0=25 [degrees] , satellite zenith angle TH1=37 [degrees] and azimuthal angle FI=174 [degrees]. These angle values were determined from average data of April 9, 2001 (25°N-35°N and 125°E-135°E). (b) Cloud optical thickness at 30°N latitude of Fig. 1 (with intervals of 0.05°). Blue points (diamond) represent the cloud optical thickness from MODIS (0.05-degree data averaged from original 0.01-degree data), and red points (box) are those from GMS-5 S-VISSR. (c) Cloud droplet effective radius distribution (in %) from MODIS on April 9, 2001. The picked on the left of figure contains among other the10 [μm] effective radius. (d) Same as (c) but with total number of pixels per range. (e) Comparison of 3x3 pixels-average cloud optical thickness between MODIS and GMS-5 S-VISSR. (f) Comparison of corresponding to brightness temperature to Fig. 2e .

for retrieval of cloud optical thickness by the "solar reflection method" [T. Y. Nakajima, 2002] and the estimation of the radiative budget per hour. Analysis was conducted as in the APEX project where comparison of various observation data are made. Comparison of the retrieved optical thickness from GMS-5 S-VISSR with those from Terra-MODIS (Moderate Resolution Imaging Spectroradiometer) shows some remarkable differences. It seems that GMS-5 S-VISSR algorithm underestimates cloud optical thickness in certain conditions. Figure 1 is a comparison of the optical thickness data from MODIS and those from GMS-5 in the East Asia (25°N—35°N and 125°E—135°E) on April 9, 2001. Although distinction of cloud and the whole pattern look alike, the difference in absolute value can be noticed in the layers where optical thickness is high, while small optical thickness data show better correlation. MODIS data have a higher distribution of high optical thickness areas than GMS-5 S-VISSR data. The absolute value is fatally different.

2.Model analysis

There seems to be several reasons of difference of the cloud optical thickness between both satellite sensors. One of them was a scientific problem originating in the difference of an effective radius of cloud. Since GMS-5 S-VISSR does not have a water-absorbing channel (3.7micron), no effective radius can be retrieved from observation. For this reason, the cloud droplet effective radius has been assumed as 10µm (based on ISCCP : International Satellite Cloud Climatology Project) [Rossow et al., 1989]. Figure 2a is the estimation curve of cloud optical thickness with observed reflectance. The solid line represents a curve for GMS-5 S-VISSR estimation. Various studies have shown the dependence of reflectance on the cloud droplet effective radius; reflectance is smaller when the effective radius becomes larger, and it increases when the effective radius become smaller. This shows that even for the same reflectance, the optical thickness may have a different. Figure 2b presents the optical thickness from MODIS and GMS-5 S-VISSR at 30°N latitude in Fig. 1. The difference between MODIS and GMS-5 S-VISSR appears remarkably well. Although a clear judgment is difficult around of 126°E and in the area from 133°E to 134°E (GMS-5 S-VISSR shows exceeding value), it appears generally that GMS-5 S-VISSR data are underestimated in comparison to the MODIS data around of 129°E and 131°E. Figure 2c is the effective radius distribution from MODIS data (25°N-35°N and 125°E-135°E) and Figure 2d is the number of pixels on April 9, 2001. Since the effective radius can not be retrieved from S-VISSR (for the reason given earlier), we analyzed only MODIS data. This analysis shows that the effective radius mainly varies from 7 to 28 [µm], with the peak is at 8<re<=10 [µm] (frequency of occurrence around 16.1%). The second highest frequency 11.9% corresponds to the range of 10<re<=12 [µm]. The remaining frequencies are mostly around 7~8%. Though the near 10µm range has the highest absolute value, and looking at the whole distribution, the contribution is relatively small. There are indeed variations in the cloud droplet effective radius and, the 10µm fixed effective radius used for the S-VISSR retrieval of optical thickness can give some errors. The fixed value, may result in an uncertainty in the estimation of the cloud optical thickness from the GMS-5 S-VISSR algorithm. Figure 2e shows 3x3pixels-average cloud optical thickness comparison of MODIS and GMS-5 S-VISSR. The regression line is inclined toward MODIS side, which means that GMS-5 S-VISSR values are lower than MODIS data. Considering that the different effective radius values noticed on Fig. 2c, the optical thickness differences may be related to the variation of the effective radius. Figure 2f is a comparison of IR data 3x3pixels-average between GMS-5 S-VISSR and MODIS: the regression line is well in agreement; this means that the same clouds are observed. Furthermore and although the difference of the reflectance of Ice cloud and Water cloud was also considered without the effect of the ice non-spherical shape, the influence was small enough.

3.Consideration of Quantization

We found a problem in work to examine the look-up table carefully. It has the possibility of losing important information by quantization of the sensor installed in satellite. Furthermore, test have been performed to check the consistency of the algorithm. Chart 1 is the flow chart of "Reversible conversion test". The problem is solved by assuming actual clouds and conducting comparison verifications with the output of the algorithm. This includes quantization. Figure 3a is the result of this "Reversible conversion test". Red points (diamond) represents the 35μm effective radius and, the blue points (box) is the 2μm effective radius. The influence of quantization is shown by the stair-like shapes on the figure and, the domain, which cannot be distinguished due to large errors occurrences is visible as well. Figure 3b is the quantized reflectance (blue box points) and the relative error % (red diamond points). Although the quantization made so that the changes shows a smooth trend, the red line on this Figure shows that, the error is big. Figure 3c is the absolute difference between the assumed true cloud optical thickness and the algorithm output cloud optical thickness. It appears that the error due to assumption of an effective radius is increased by the quantization noise in some cases. Based on Fig. 2d, it is thought that the weighting towards the red points (diamond) side, caused by the drift of the effective radius towards larger values than 10μm, and this actually appears in regression line of Fig. 2e. These two error-elements overlap and cause the error in the optical thickness estimation of clouds. This error nonlinearly exceeds 30% in Fig. 3d. Although the important factor of error of the effective radius is essentially a physical matter, quantization noise is not consistent with physics. If this type of error appears nonlinear and shows a non-essentially physical trend, they will become a serious obstacle for the estimation algorithm of physical quantities.

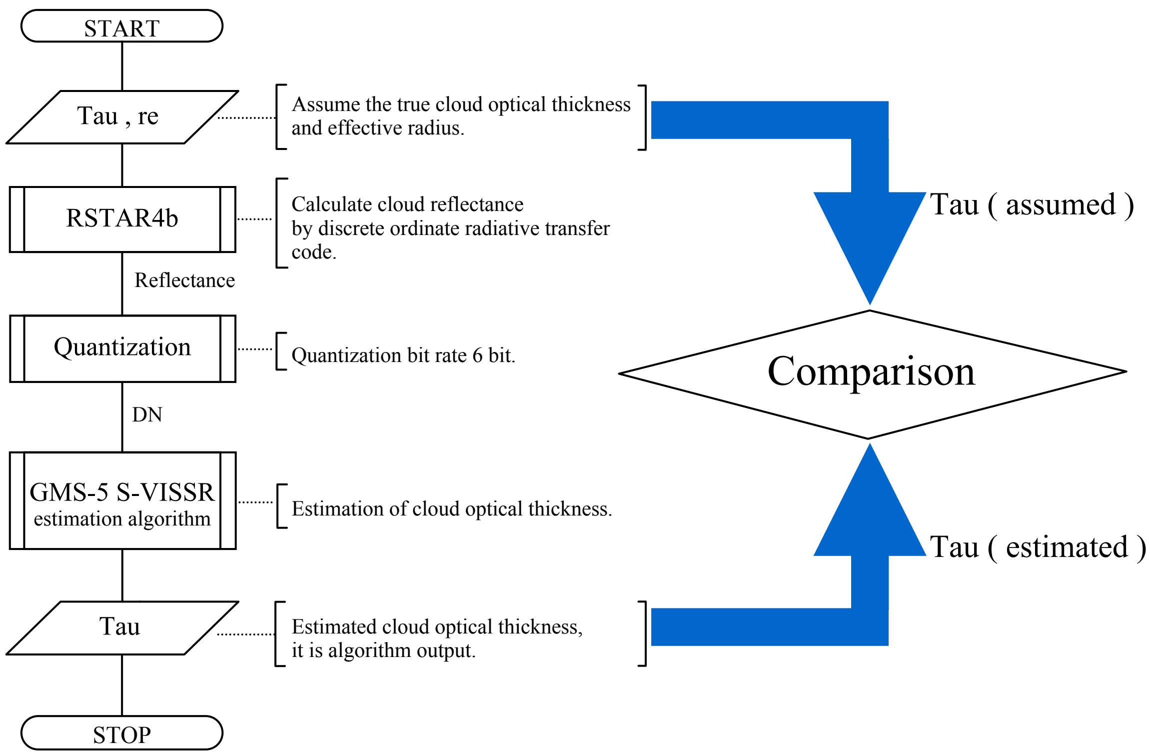
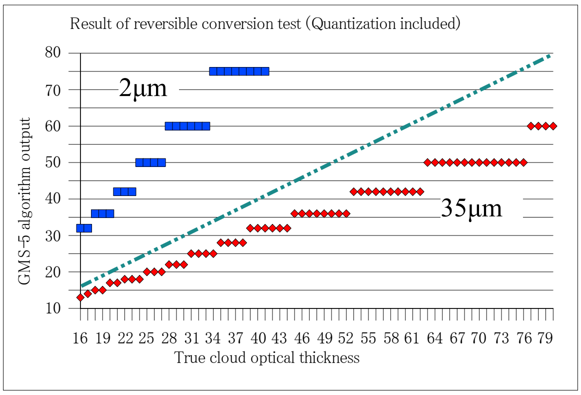
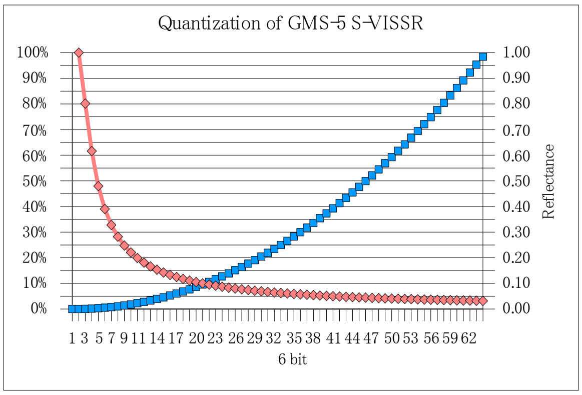


Chart.1 : The flow chart of the "Reversible conversion test".

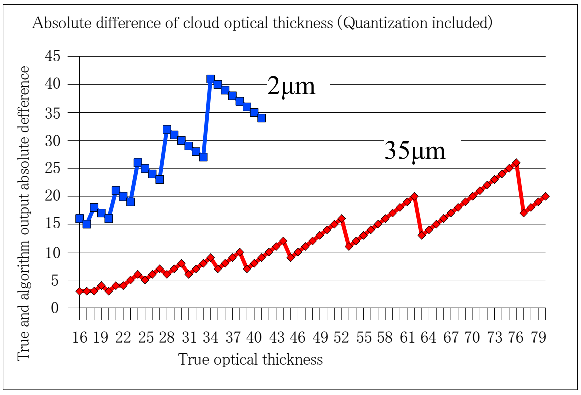


(a)



(b)

(c)



(d)

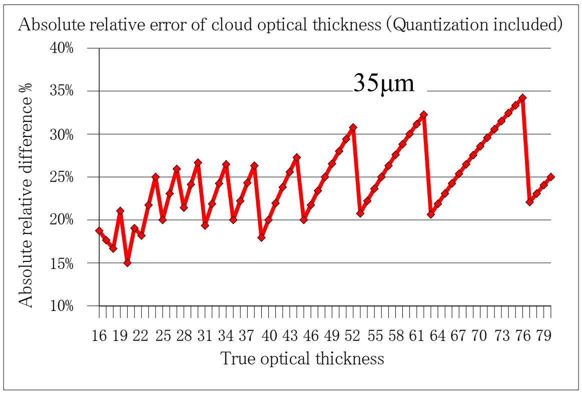


Fig. 3 : (a) Result of reversible conversion test on GMS-5 S-VISSR algorithm, including quantization noise. (b)Quantization of GMS-5 S-VISSR ch1: the Blue points (box) is the quantized reflectance, the red points (diamond) is the relative error of the reflectance. (c) Absolute difference of optical thickness between 10μm and 2μm than 35μm. (d) Absolute relative difference of cloud optical thickness at cloud droplet effective radius of 35μm including quantization noise on the worst case.

4.Influence on radiation budget

The cause of the differences became clear from the above-mentioned results. In this section, we investigate how much influence this error would have on the radiative budget. The radiative transfer code “RSTAR5b” was modified and used for calculation of radiative budget. Figure 4a is the estimated value of the downward shortwave flux at the surface, which includes each errors. When the cloud droplet effective radius is more than 10μm, radiative flux is overestimated, and vice versa. This is because, cloud optical thickness is overestimated when the effective radius is less than 10μm and underestimated when the radius is more than 10μm. The relative error on these conditions is set as on Fig. 4c. The proportion of the error increases with the cloud optical thickness, and this error may reach an inverse proportion for shortwave radiation at the surface. This error is nonlinear according to the quantization noise. The quantization noise making the error increase is well understandable. Fig. 4b is the estimated value of the upward shortwave flux at the TOA. If an effective radius of 35μm is assumed, the flux will be underestimated, and it is overestimated if a 2μm effective radius is assumed. Fig. 4d is the corresponding relative error. The error will decrease if the cloud optical thickness increases, this is because the error is relatively small compared to the increase of the reflectance of cloud. Fig. 4e is the albedo at the TOA, and Fig. 4f is the relative error. Since the downward shortwave flux at the TOA is fixed, this graph resembles the one of Fig.4d. And, the relative error of the energy absorbed by the Earth system is shown in Fig.5. The cloud optical thickness of 20 to 30 shows an error of 9% (overestimation).

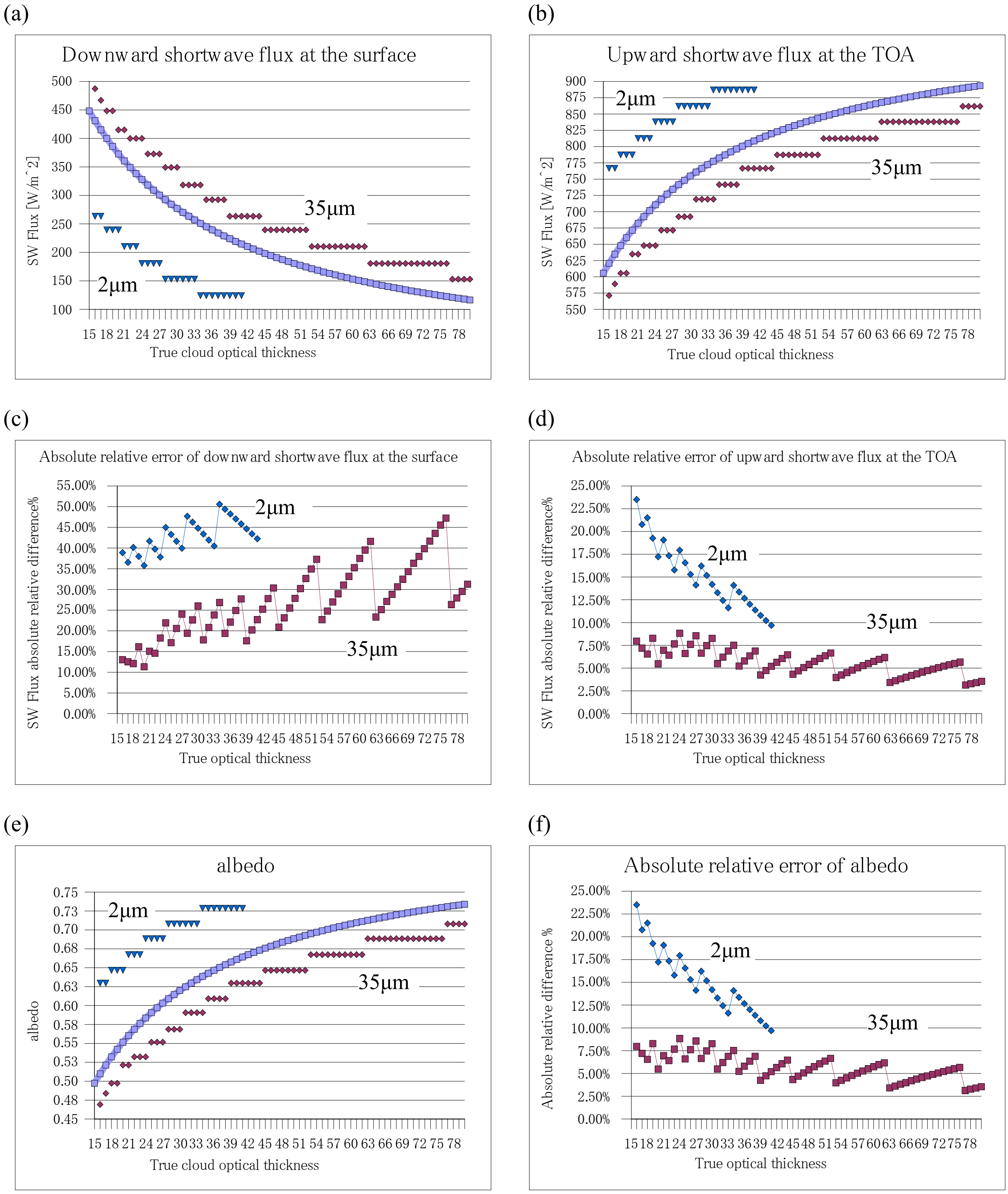


Fig. 4 : Error influence on the radiative budget. X axis is the assumed true optical thickness, Y axis corresponds to the radiative flux and albedo. The purple line is the estimation of the radiative budget by true cloud optical thickness. The red line includes errors by the 35μm effective radius, the blue line by the 2μm effective radius. These values were calculated by the radiative transfer code RSTAR5b, modified for short wave flux calculation. Calculation conditions are solar zenith angle = 25 degrees, an atmospheric model using US standard, surface albedo = 0.1 (assumed Lambert surface), and all clouds are assumed water cloud and

plane parallel. (a) The downward shortwave flux at the surface. (b) The upward shortwave flux at the TOA. (c) The downward shortwave flux absolute relative difference (%) at the surface. (d) The upward shortwave flux absolute relative difference (%) at the TOA. (e) The albedo from downward and upward shortwave flux at the TOA. (f) The albedo absolute relative difference (%) at the TOA.

5.Conclusion

When estimation and comparison of the cloud optical thickness are performed, the remarkable differences are noticed. The causes were investigated; one is an error by assumption of a fixed effective radius, the other is quantization noise. There is a possibility that a large difference is caused by them. These errors are nonlinear and exceed 30% according to the conditions of estimation of cloud optical thickness. The influence of these errors on the radiation budget was estimated. The both errors have some influence on the estimation of the radiation budget of the Earth.

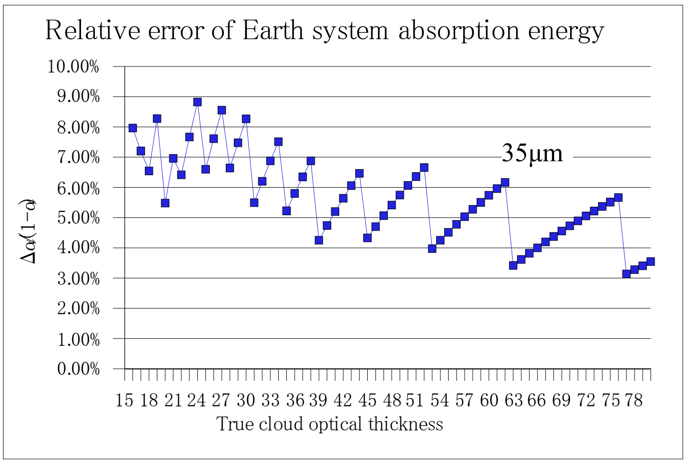


Fig. 5 : Earth system absorption energy relative error, including GMS-5 S-VISSR error due to differences in cloud droplet effective radius and quantization noise.

References

Nakajima, T. and M. Tanaka, 1986: Matrix formulations for the transfer of solar radiation in a plane-parallel scattering atmosphere, J. Quant. Spectrosc. Radiat. Transfer, 35.

Nakajima, T. and M. Tanaka, 1988: Algorithms for radiative intensity calculations in moderately thick atmospheres using a truncation approximation, J. Quant. Spectrosc. Radiat. Transfer, 40.

T. Y. Nakajima, 2002: Development of a comprehensive analysis system for satellite measurement of the cloud microphysical properties. EORC Bulletin Technical Report No.10.

Rossow, W.B., L. C. Garder, and A. A. Lacis, 1989: Global, seasonal cloud variations from satellite radiance measurements. Part I: sensitivity of analysis. J. Climate, 2.