Comparison of cirrus optical depths derived from GOES 8 and surface measurements

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[1] Ground-based passive radiometer measurements are used to validate satellite-derived cirrus optical depths over the Atmospheric Radiation Measurement Program Southern Great Plains site during March 2000. Optical depths derived from direct beam measurements by a multifilter rotating shadow band radiometer were well correlated with those determined from the Geostationary Operational Environmental Satellite, especially in relatively homogenous cloud fields. Compared to the multifilter rotating shadow band radiometer (MFRSR) results, on average, the satellite retrieval overestimated optical depth by ∼0.67 (29%), even though 75% of the GOES values were within ±1.0 of the MFRSR results. Some of the bias is attributable to cloud inhomogeneities, mismatches in observed clouds, errors in the surface albedo, and possible errors in the ice crystal scattering phase function. The results demonstrate the potential for using MFRSR data, available over many parts of the globe, for validating satellite cloud retrievals in many different surface and atmospheric conditions. *INDEX TERMS:* 0320 Atmospheric Composition and Structure: Cloud physics and chemistry; 0360 Atmospheric Composition and Structure: Transmission and scattering of radiation; 1640 Global Change: Remote sensing; 1694 Global Change: Instruments and techniques; *KEYWORDS:* cloud optical depth, GOES, MFRSR

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1. Introduction

[2] Accurate assessment of cirrus cloud optical properties is important for understanding the role of cirrus in the Earth radiation energy balance and in the hydrological cycle. Satellite remote sensing is crucial for better quantification of the global distribution of cirrus clouds and their microphysical properties, parameters essential for the development and evaluation of cirrus cloud parameterizations in climate models. Although satellite-derived cloud data are readily available for such purposes, the accuracy of many of those products is unknown. Thus it is essential to determine the accuracy of the statistical representation of satellite-derived cloud properties from a given algorithm by comparing them with well-validated surface retrievals of similar parameters at many different locations over a representative range of conditions. Completion of such efforts should provide a measure of the mean and instantaneous uncertainties in each of the satellite-based products.

[3] Many efforts have been made to validate cloud optical properties derived from satellites against surface retrievals [e.g., *Min and Harrison*, 1996; *Barker et al.*, 1998; *Trishchenko et al.*, 2001; *Dong et al.*, 2002]. Those efforts primarily focused on optically thick clouds. Some studies have focused more on optically thin clouds but were not particularly comprehensive because of limitations in both the surface and satellite retrieval capabilities [e.g., *Minnis et al.*, 1993] or in the number of samples [e.g., *Mace et al.*, 1998]. Accomplishing the goal of validating optically thin cirrus clouds over a statistically representative sample will require surface measurements over all major surface types and climate regimes. Although measurements by active sensors such as lidars or radars are extremely valuable for providing the surface-based validation data, the expense and logistics required to deploy and operate the necessary complement of instruments are prohibitive. Simpler instrumentation and techniques that can supplement the more complex active sensor retrievals are desirable components of a globally representative system of ground-based cloud monitoring for satellite validation efforts.

[4] *Min et al.* [2004] recently developed an approach for accurate retrieval of thin cloud optical depth from measure-

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ments taken by a multifilter rotating shadow band radiometer (MFRSR). Their method takes advantage of simultaneous spectral measurements of direct and diffuse transmittance of the MFRSR and temporal and spatial variations in the observed clouds and aerosols. More importantly, this instrument has been deployed at numerous sites globally. The objective of this paper is to demonstrate the feasibility of comparing cirrus optical depths derived from MFRSRs and satellites and to continue assessing the accuracy of the visible infrared solar-infrared split window technique (VISST) used to analyze Geostationary Operational Environmental Satellite (GOES) measurements [*Minnis et al.*, 2002].

2. Measurements and Retrievals

2.1. MFRSR

[5] The MFRSR is a seven-channel radiometer consisting of six passbands with 10-nm full width at half maximum centered near 415, 500, 610, 665, 862, and 940 nm and an unfiltered silicon pyranometer [*Harrison et al.*, 1994]. It measures the total horizontal, diffuse horizontal, and direct normal spectral irradiances through a single optical path using an automated shadow banding technique, which guarantees that the separated spectral irradiance components share the same passbands and calibration coefficients. Hence the Langley regression of the direct normal irradiance taken on clear stable days can be used to extrapolate the instrument's response to the top of the atmosphere (TOA), and this calibration can then be applied to both components of irradiance. Transmittances can be calculated subsequently under cloudy conditions as the ratio of the uncalibrated output to the extrapolated TOA value. The MFRSR has been continuously operated at the Atmospheric Radiation Measurement Program (ARM) Southern Great Plain (SGP) site for 10 years. Over 60 Langley events have been obtained each year. The solar constants at the passband obtained from Langley regressions are interpolated and extrapolated to any particular day by using a temporal and spectral analysis procedure [*Forgan*, 1988]. The accuracy of the solar constant at a nongaseous absorption passband, based on the Langley regression calibration, is better than 1% [*Michalsky et al.*, 2001]. Therefore the accuracy of transmittance under cloudy conditions is expected to be better than 1%.

[6] *Min and Harrison* [1996] developed a family of inversion methods to infer optical properties of warm clouds from diffuse measurements at the MFRSR 415-nm channel. *Min et al.* [2004] take advantage of simultaneous spectral measurements of direct and diffuse transmittance of a MFRSR and temporal variations to retrieve optical depths of optically thin clouds from direct beam radiances. To minimize the interference of gaseous absorption, the retrieval algorithm selects the 415- and 860-nm channels and separates aerosols from thin clouds based on their temporal and spectral characteristics. For optically thin clouds, particularly those with ice crystals, sensors with a finite field of view (FOV), such as MFRSRs, observe not only the attenuated direct solar beam but also radiation that has been forward scattered by cloud particles into the instrument's FOV. This induces a measurement error that is significant at low cloud optical depths. This issue was most recently addressed by *Joseph and Min* [2003]. A simple polynomial fitting technique, which effectively removes this error, was developed from simulated measurements of a MFRSR for a range of atmospheric conditions. The simulations were conducted using a modified discrete ordinates radiative transfer code that can accurately compute radiative intensity for strong forward scattering by thin cirrus and water clouds. An uncertainty analysis of the method shows that it produces retrievals that are better than 5% or 0.05 when cloud optical depth is <1, assuming the cloud is composed of the particle size and shape distributions used in the retrieval model [*Min et al.*, 2004].

2.2. VISST Retrievals From GOES

[7] Cirrus cloud optical properties were retrieved from GOES 8 half-hourly, 4-km radiance measurements [*Minnis et al.*, 2002] using the visible, infrared solar-infrared, split window technique (VISST algorithm). The VISST [*Minnis et al.*, 1995a] utilizes the split window (12.0 μm) and the infrared (10.8 μm) channels to determine cloud temperature and phase, the visible (0.65 μm) reflectance to retrieve cloud optical depth, and the solar-infrared (3.9 μm) radiance to derive cloud particle size. It uses the results from the visible infrared layered bispectral threshold method [*Minnis et al.*, 1995b] as an initial value and iterates to find best solution to match observed and modeled radiances in all four channels. The visible reflectance parameterization of *Minnis et al.* [1993] originally used in the VISST was replaced by a new version described by *Arduini et al.* [2002]. The GOES radiances were calibrated with collocated measurements from the Tropical Rainfall Measuring Mission Visible Infrared Scanner [*Minnis et al.*, 2002]. The VISST modeled radiances are based on various size distributions of water droplets and hexagonal ice crystal columns [*Minnis et al.*, 1998] to simulate liquid and ice clouds, respectively. The VISST retrieves cloud optical depth, phase, effective particle size, ice or liquid water path, effective radiating temperature, and effective cloud height. The last parameter is determined from the effective cloud temperature using a vertical profile of temperature for the particular location.

[8] Compared to detailed adding-doubling radiative transfer calculations, the new visible reflectance parameterization yields errors in TOA reflectance that are typically <1% for a Lambertian surface [*Arduini et al.*, 2002]. Because it explicitly accounts for both direct and diffuse radiation, the parameterization is designed to handle an anisotropically reflecting surface by the use of a bidirectional reflectance model. In general, the clear sky visible albedo is derived from the GOES data when the area is clear using the land bidirectional reflectance factors of *Suttles et al.* [1988]. The albedo is then adjusted to a solar zenith angle of 53° as in *Sun-Mack et al.* [1999], and the resulting value is treated as the diffuse albedo. The effect of the intervening atmosphere is removed by accounting for the ozone absorption and Rayleigh scattering to adjust the albedo from the TOA to the surface. Similarly, the albedo at a given solar zenith angle is adjusted to the surface and the direct beam reflectance is estimated by multiplying that albedo by the normalized bidirectional reflectance factor. This approach implicitly includes aerosols as part of the surface albedo. The resulting estimates of the diffuse surface albedo and the direct beam

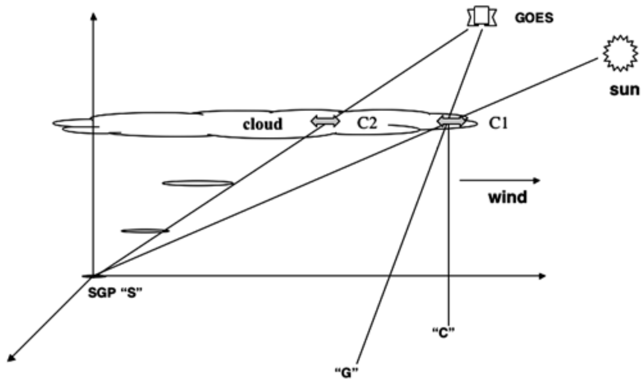

Figure 1. Observational geometries. SGP is Southern Great Plain.

reflectance are used in the model to account for the direct and diffuse components under the cloud. Any changes in aerosol loading or surface albedo between the time of the surface albedo estimate and the cloud retrieval can affect the retrieved optical depth. An underestimate of the reflectance from the cloud-free scene would cause an overestimate of the retrieved optical depth and vice versa.

2.3. Time and Space Averaging

[9] The data used here were taken at the ARM SGP site during March 2000 when the second ARM Enhanced Shortwave Experiment (ARESE II) field campaign was conducted. During the intensive observation period, all major instruments were well calibrated and operated continuously. On the basis of the reflectivity profiles from the ARM cloud radar, cirrus clouds were observed during 7 days. On 9 and 13 March, single-layer cirrus clouds lasted over 4 hours, providing a unique opportunity for surface satellite comparisons. During 1, 5, 6, 12, and 28 March, cirrus clouds were scattered or were separated by gaps, representing extremely challenging situations for satellite retrievals due to strongly inhomogeneous effects. Those data are also used in the statistical comparison.

[10] In general, various instruments have different sampling rates and observational geometries. Hence it is critical to understand the effects of spatial temporal variability of each parameter retrieved from multiple instrument measurements, particularly for comparison of satellite results (from reflectance) with surface retrievals (from transmittance). While GOES-VISST retrievals yield a spatial distribution of cirrus cloud optical properties at a given instant, the MFRSR measures the temporal variation of cloud optical properties along the Sun-sensor path. When a cloud is high and the solar and viewing zenith angles are large, the geolocation of the observed cloud differs from nominal geolocations of the MFRSR and the GOES pixels. To better match the satellite and surface-observed cloud fields, the geolocations of the cloud observed by the MFRSR, "C", is used to determine the corresponding location of the GOES pixel containing the cloud, "G", based on the solar position, the GOES viewing zenith angle, and the cloud height estimated from the cloud radar [*Clothiaux et al.*, 2000]. Figure 1 illustrates the observational geometries for both MFRSR and GOES and the corresponding geolocations. Horizontal transport of the cloud field is important to understand the spatial temporal effect. On the basis of the wind speed at cloud height from measurements of balloon soundings, the cloud optical depths derived from the MFRSR were averaged over 5 min (MFRSR_5) and 25 min (MFRSR_25) to match to the size of the GOES pixel and a ±0.15° area centered on the GOES pixel, respectively. To consider possible navigational errors, the GOES-VISST retrievals were spatially averaged around the "G" point within 0.03° (2 pixels) to achieve an instantaneous or pixel-scale result, "P", and within 0.15° (~60 pixels) to achieve a time-averaged or area-scale result, "A", respectively.

[11] Figure 2 shows the spatial domain and the horizontal distribution of retrieved cirrus optical depths from GOES 8 at 2215 UTC over the ARM SGP site on 9 March 2000 based on the nominal GOES geolocation algorithm, which assumes a view to the Earth's surface. "S", "C", and "G" represent the location of the ARM SGP site, the location of cloud observed by the MFRSR, and the corresponding location of GOES pixel, respectively. At that time the wind at the cloud layer height was southwesterly at 27 m/s (the arrow in Figure 2 indicates the direction of wind) as measured by an ARM balloon sounding. Optical depths derived from GOES-VISST are 1.0 and 1.9 at clouds "C2" and "C1" (Figure 1), corresponding to geolocations "S" and "G" points, respectively. Without such a dedicated matching procedure, there will be a factor of 2 difference in the comparison. The following comparison only uses data when 60% of pixels in the averaging domain are cirrus clouds to minimize the effects of partially filled pixels and cloud inhomogeneities.

3. Results

[12] Figure 3a illustrates a comparison of cloud heights inferred from GOES-VISST at the ARM SGP site (not at the "C" point) against the reflectivity profiles observed by the zenith-viewing ARM millimeter-wave cloud radar (MMCR) [*Clothiaux et al.*, 2000] on 9 March 2000. The effective cloud heights derived from GOES-VISST are close to the lower boundaries of the cirrus clouds. Figure 3b compares cloud optical depth derived from GOES-VISST with the MFRSR retrievals. While the optical depths of the background aerosols only change from 0.08 to 0.22, the cirrus cloud optical depths range from 0.1 to 3.4, illustrating considerable variation in the cloud fields. The difference between pixel level retrievals and area average results from GOES also demonstrates this large spatial variability. Temporal variation of cirrus optical depths is consistent between the surface results and GOES retrievals. There are some discrepancies between surface and GOES retrievals, particularly in pixel level results.

[13] The effect of cloud imhomogeneity on surface satellite comparisons can be seen from the contour of GOES-VISST retrievals, shown in Figure 2, and in the inferred optical depths of pixels around the "G" point, shown in Figure 4. At 2215 UTC a clear sky gap passed over the "G" point (shaded area in Figure 4) followed by a thick cirrus cloud. The averaged optical depth of the cirrus cloud pixels was 1.92, almost twice the maximum optical depth derived from the MFRSR during the period (±15 min). On the basis of the advection speed of the cirrus layer the clear sky gap seen by the MMCR was about a few tenths of a kilometer.

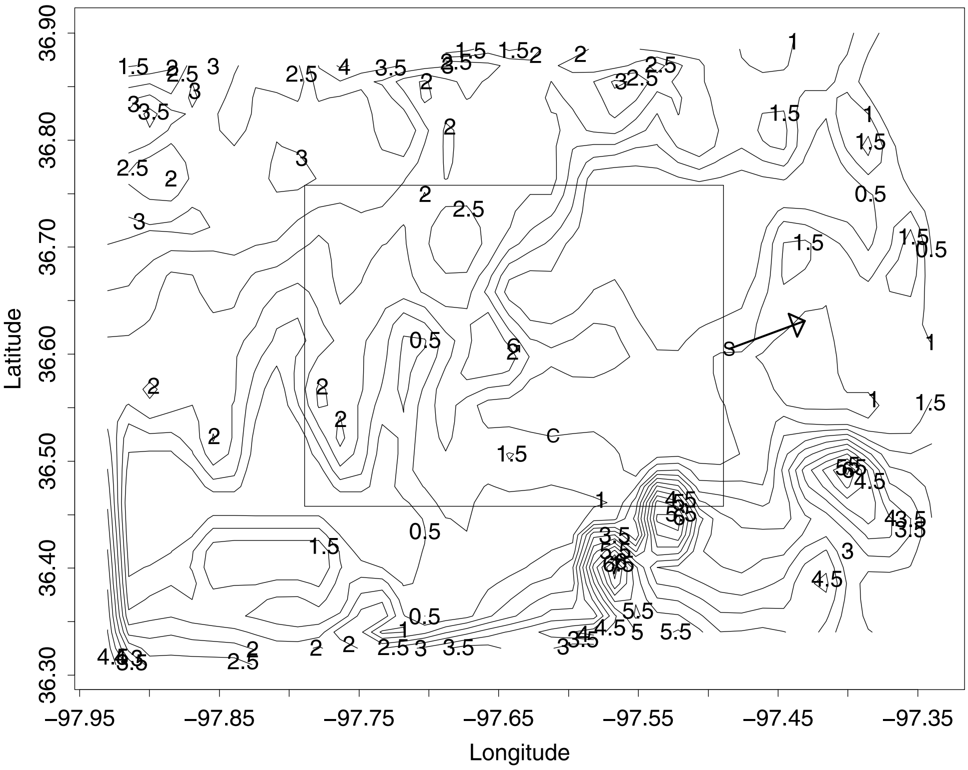

Figure 2. Contour of inferred cirrus optical depth from GOES 8 at 2215 UTC on 9 March 2000 over the ARM SGP site. Box in the center of the figure represents ±0.15° area centered on the GOES pixel.

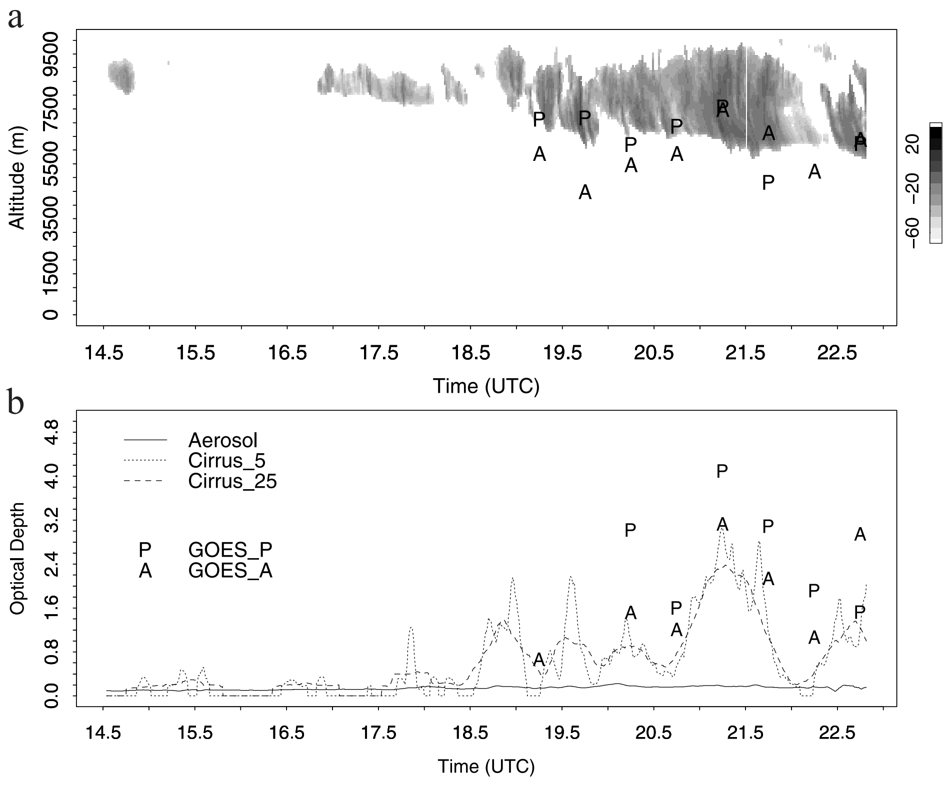

Figure 3. (a) Millimeter-wave cloud radar reflectivity profiles and cloud heights inferred from GOES and (b) cloud optical depths inferred from a MFRSR and GOES 8 on 9 March 2000 at the ARM SGP site. GOES_P is GOES result in pixel level, GOES_A is GOES result in area scale, cirrus_5 is surface MFRSR retrieval with 5-minute average, and cirrus_25 is 25-minute average.

Longitude

Latitude	-97.69^0	-97.66^0	-97.63^0	-97.60^0	-97.57^0
36.66^0	2.22	2.22	0.00	0.00	0.84
36.60^0	1.55	2.73	1.11	1.40	1.13
36.55^0	1.85	0.71	0.57	0.52	0.49

Figure 4. Inferred cirrus optical depths for pixels around the "G" point (shaded area) from GOES 8 at 2215 UTC.

Given the orientation of the optical depth distribution and the wind direction it is possible that the MFRSR and the radar missed all of the optically thick clouds that were observed by GOES. On the other hand, gaps in an optically thin cloud deck could result in the classification of a pixel as clear by GOES-VISST, so that some of the thinnest clouds would be missed in the averaging. The pixels classified as cloudy were on the edge of the thicker cirrus clouds. It is possible that the GOES imager was viewing the side of the cloud and receiving more radiation than it would have if it viewed only the top of the cloud, because GOES viewed the illuminated side of the cloud. It is clear that comparing the surface and satellite retrievals in these inhomogeneous cloud conditions greatly exacerbates the interpretation of the results and requires extremely careful positioning of the matched data.

[14] The largest difference between the surface retrievals and GOES pixel level results occurred at 2015 UTC, where the surface retrievals varied from 0.6 to 1.4 within 15 min of GOES measurement, and the GOES pixel level retrieval was 3.0. As shown in Figure 5, the horizontal distribution of cirrus optical depths retrieved from GOES was relatively homogeneous around the geolocation of "G". Thus the spatial temporal effect and inhomogeneous cloud may not be the reason for the satellite overestimation at this point. Additional study is warranted to investigate the causes of such discrepancy.

[15] Figure 6 shows a relatively homogeneous cloud case on 13 March 2000, as indicated by the mostly small differences between the VISST_A and VISST_P optical depths. The larger differences appear to be associated with the internal structure of the cirrus clouds, as discussed previously. Under these relatively homogeneous conditions, the GOES-VISST retrievals agree very well with the MFRSR results. Additionally, the cloud heights derived from GOES-VISST agree well with the MMCR measurements for these relatively thick cirrus cloud cases. The greatest difference of cloud heights occurs at 1645 UTC when the cloud is very inhomogeneous and at 2245 UTC when the solar zenith angle is very large.

[16] Figure 7 shows scatterplots of optical depths retrieved from the surface MFRSR data and from GOES-VISST for all of the cirrus cases during March 2000 (Pixel_ALL and Area_ALL). The least squares fits indicate a positive bias of GOES-VISST retrievals relative to the MFRSR results. Data from two relatively homogeneous cirrus days (Pixel_TWO and Area_TWO) were also analyzed separately to determine the differences between the homogeneous clouds and all clouds. All of the statistics are listed in Table 1. The slopes under all four conditions are near unity, and the correlation coefficients are significantly high, indicating that GOES retrievals track well with surface observations. Under homogeneous cloud conditions the correlation coefficients are greater and the standard deviations are less than under all cloud conditions. Generally, the area level comparison is much better than the pixel level comparison. These statistics demonstrate that the GOES-VISST retrieval algorithm does a good job and illustrate impacts of cloud inhomogeneity on satellite retrievals and on surface satellite comparison. The intercept in the fits is misleading because many of the VISST values for small optical depths are very close to the surface-derived values. More than 75% of the points are close to the line of agreement for the Pixel_ALL plot. The remaining outlying points that drive the intercept values and the bias could be due to mismatched fields of view and would warrant further examination.

4. Discussion and Conclusion

[17] GOES-VISST retrievals of cirrus cloud optical depth and cloud height were matched and compared with surface measurements at the ARM SGP site during March 2000. Statistical analyses and time series plots illustrate that the

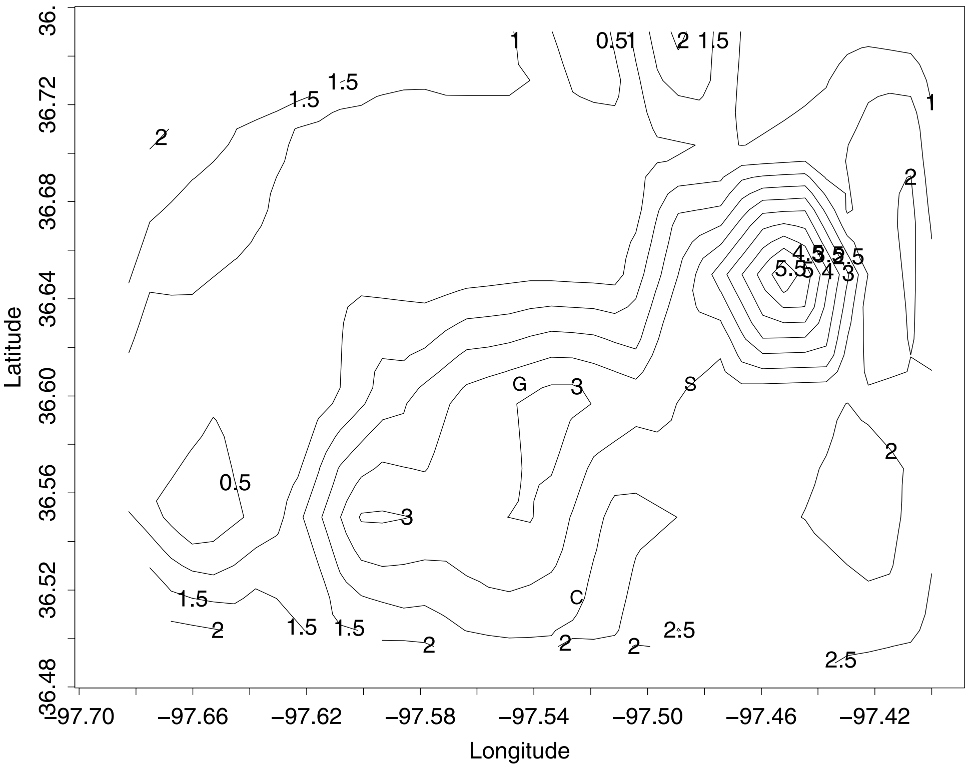

Figure 5. Contour of inferred cirrus optical depth from GOES 8 at 2015 UTC over the ARM SGP site.

GOES-VISST retrievals track well with surface observations of cloud height and cloud optical depth. However, the cirrus cloud optical depth derived from GOES-VISST, on average, exceeds its counterpart determined from surface MFRSR data. To better understand those statistics, it is essential to analyze various uncertainties and sensitivities to provide a measure of the absolute errors and to search for methods to minimize them.

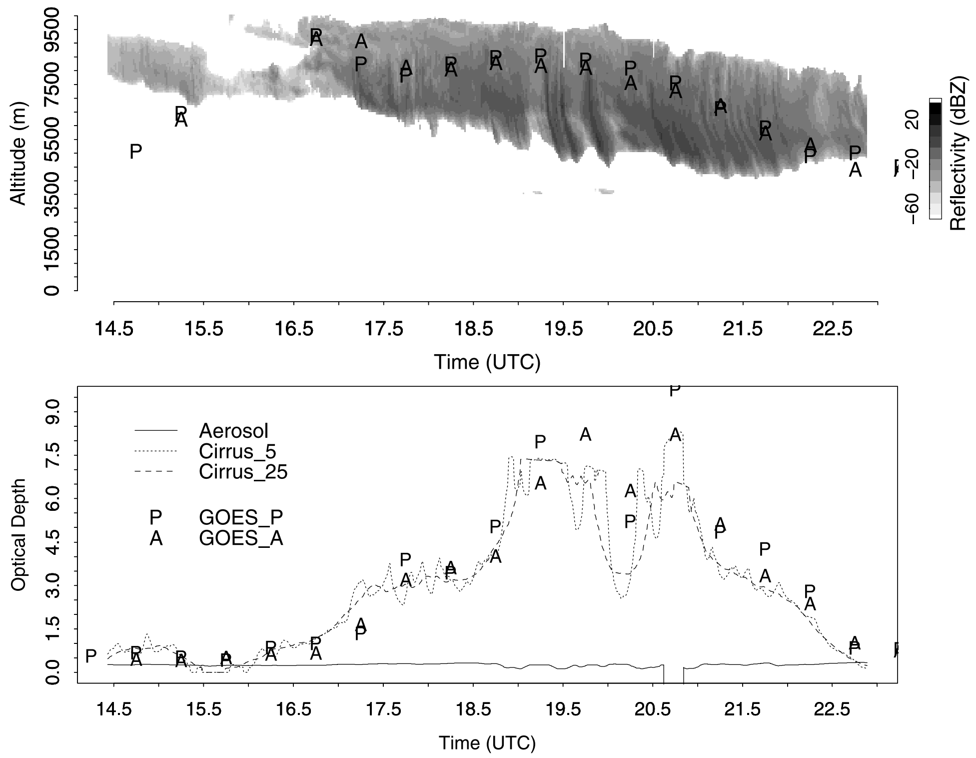

Figure 6. Same as Figure 3 but on 13 March 2000.

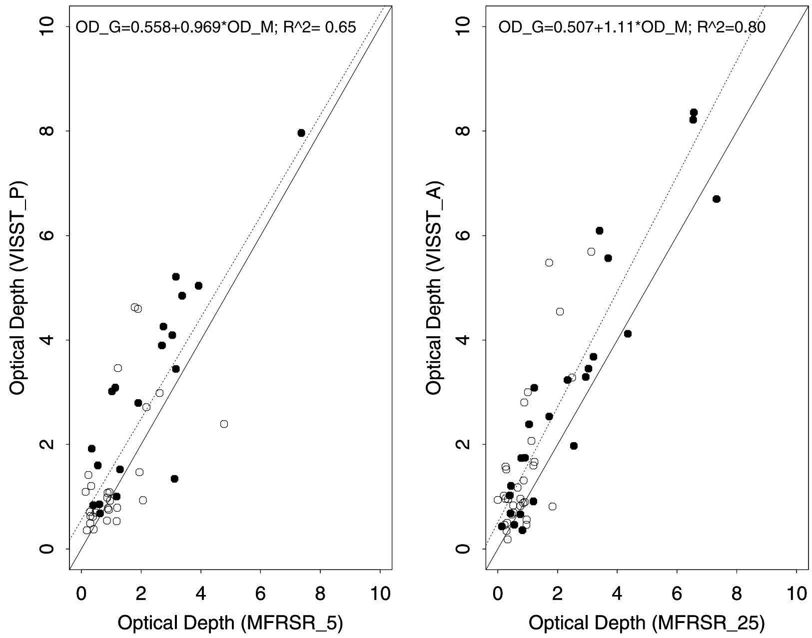

Figure 7. Scatterplots of optical depth derived from MFRSR and GOES for all cirrus clouds during March 2000 over the ARM SGP site. Solid circles are from 2 days with relatively homogeneous clouds. Open circles are for all other days. OD_G is optical depth retrieved from GOES, OD_M is optical depth retrieved from MFRSR, and R^2 is correlation coefficient (R).

[18] In the real world, cirrus clouds are composed of particles with complex shapes and sizes that can be oriented in particular directions. These features of real clouds will induce significant uncertainties in the radiative properties, such as the phase functions, that are used in the retrievals. One of the error sources for surface retrievals is the uncertainty of the cloud scattering phase function, particularly the forward scattering peak for scattering angles <10°, since the polynomial fitting correction for forward scattering strongly depends on the phase function used in the simulation [*Min et al.*, 2004]. The stronger forward scattering phase function of large ice particles will result in a greater cirrus optical depth. On the basis of a sensitivity analysis using several phase functions, the uncertainty associated with the real phase function will introduce a 5% error in the retrievals. Another error source stems from the polynomial fitting of the forward scattering correction, resulting in a 5% uncertainty or 0.05 when optical depth is <1. Overall, the uncertainty will be <10% (6% in a closure test of *Min et al.* [2004]).

[19] Since the VISST optical depths of cirrus clouds are derived from observed visible reflectance, uncertainties may arise from various aspects of atmospheric and surface radiative properties used in the radiative transfer calculations. The uncertainty of cirrus cloud phase function, particularly in large scattering angles, can introduce significant error in the satellite retrievals because the retrieval models assume a particular shape and orientation of the crystals for a given particle size [e.g., *Chepfer et al.*, 2002]. When both the surface and satellite methods use similar shapes and sizes in the retrievals and the results are in good agreement, it is likely that the assumption of particle shape was correct. If the shapes and sizes differ, then disagreement between the two methods is expected. Thus some of the differences in Figure 3 could be due to the use of particle shapes in the retrievals that were not predominant in the observed clouds.

[20] Unlike the surface retrievals from direct beam measurements the GOES-VISST retrievals are sensitive to the surface albedo. For thin clouds, in particular, both direct and diffuse solar radiation can reach the surface and are reflected by the surface anisotropically. The uncertainty in the bidirectional reflectance model, as a result of variations in soil moisture and vegetation, is one of the major contributors to errors in satellite retrievals for optically thin cloud cases. However, it is possible and necessary to characterize such errors in satellite retrievals from a large ensemble of comparisons over a range of solar zenith angles and for different surface conditions.

[21] As pointed out by a surface closure study [*Min et al.*, 2004], the uncertainty of aerosol loading under thin cirrus clouds has a significant impact on diffuse radiation calculations. Both the single-scattering albedo and aerosol optical depths vary from time to time for the cases studied here. Therefore some of the differences between GOES-VISST

Table 1. Statistics of Regressions Between GOES-VISST Retrievals and Surface MFRSR Results[a]

	Number of Samples	Intercept	Slope	Correlation Coefficient (R^2)	Bias	Standard Deviation
Pixel_ALL	47	0.56	0.97	0.65	0.51	1.06
Area_ALL	55	0.51	1.11	0.80	0.67	0.88
Pixel_TWO	19	0.86	0.99	0.77	0.83	0.86
Area_TWO	24	0.47	1.07	0.87	0.65	0.77

[a]Pixel_ALL and Area_ALL are pixel level and area level comparisons, respectively, for all of the cirrus cases during March 2000. Pixel_TWO and Area_TWO are data from two relatively homogeneous cirrus days.

and surface results may be due to the errors in background albedo used in the VISST. The VISST applies a simple Rayleigh-scattering formula to convert clear sky reflectance to the background reflectance. When aerosols vary, this correction may increase the error in the retrieved surface albedo. The VISST retrievals rely on the assumption that the clear sky reflectance at a particular hour remains constant throughout the month. The value used for the month is based on a minimum albedo test. Thus if the clear sky albedo, and hence reflectance, varies significantly from the minimum, then the optical depth will be overestimated for thin clouds. A preliminary analysis of this possibility revealed that during 5 March 2000 the VISST retrieval used the prescribed reflectances, which varied from 0.119 to 0.208 for the cirrus retrievals, which were too low. Average reflectances for nearby clear pixels ranged from 0.128 to 0.215 during the day. Thus the VISST optical depths were probably overestimated. Additional evaluation and improvement of the clear sky input is necessary to fully understand the impact on these cases.

[22] The effects of the three-dimensional structure of the cloud field and the spatial temporal variability on surface satellite comparison are clearly evident, even though the cases were carefully selected, and the viewing geometries of GOES and MFRSR were matched closely. For instance, in the case of Figure 4 the VISST-derived optical depth south of the MFRSR view would be closer to the MFRSR result than the average of the surrounding pixels. A shift of 1 pixel in the matching results would greatly alter the comparison. Thus some large differences between the two methods can occur when the field is very inhomogeneous. In addition, the inhomogeneities affect the satellite retrievals because they rely on plane-parallel radiative transfer to model the observations. Under homogeneous cloud conditions the correlation coefficients are greater and the standard deviations are less than under all cloud conditions, and the area-averaged comparison is much better than the pixel level comparison. To further assess the spatial temporal effects and three-dimensional cloud effect requires much additional validation using various cirrus cloud conditions, such as broken, scattered, or horizontally and vertically inhomogeneous clouds.

[23] Retrieving microphysical and optical properties of cirrus clouds from a satellite platform is an extremely challenging task because of its optically thin and inhomogeneous nature. It is critical to compare satellite retrievals against the well-validated surface retrievals to assess the accuracy and precision of satellite products. The analyses of the GOES-VISST retrievals relative to the surface results represent another step in the long-term task of validating satellite retrievals at various spatial and temporal scales. The results demonstrate the potential for using surface retrievals from MFRSRs, which are widely deployed over the globe, to validate satellite retrievals in many more conditions than would be possible using only available radar and lidar sites. To further understand and quantify the errors arising from the various physical constraints on the retrieval systems, future comparisons of satellite retrievals with surface measurements will be performed over a variety of background surfaces (forests, agriculture crops, bare soil, and grasslands) and climate and emission regimes (tropical, arctic, midlatitude, rural, urban, island, and coast). In-depth analyses of the cloud three-dimensional effects and spatial inhomogeneities will also be pursued to better understand how much they affect the retrievals.

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