CERES Aqua Edition1B SSF Cloud Properties - Accuracy and Validation

This section discusses the spectral radiances and cloud products included in the **SSF** data set version **Aqua MODIS Edition1B**, hereafter, **Aqua 1B ok**. Additional information is in the Description/Abstract Guide. Cloud products in the SSF are the result of convolving the values for the clear-sky and cloudy data derived for each 1-km MODIS pixel sampled every fourth pixel and every other scan line (see Convolution Process) to give an effective resolution of 4 km to reduce processing time and data storage. Five primary radiances taken at 0.65 (visible, VIS), 2.13 (near infrared, NIR), 3.78 (solar infrared, SIR), 11.0 (infrared, IR), and 12.0 (split-window channel, SWC) µm, channels 1, 7, 20, 31, and 32, respectively, are used for each MODIS pixel. MODIS 1.38 and 8.55-µm channels are also used for cloud detection in this version.

Cloud Mask

Based on these radiances, each MODIS pixel is classified as clear, cloudy, bad data, or no retrieval. Each clear and cloudy pixel is categorized as weak or strong indicating the degree of confidence. Clear pixels can have an additional classifier: snow, aerosol, smoke, fire, glint, or shadow. Cloudy pixels can also have a glint sub-classification meaning that they were detected at angles favorable for the viewing of specular reflection from the surface. Atmospheric profiles of temperature, ozone, and humidity, model estimates of surface skin temperature, elevation, and one of the 19 surface types (CERES Surface Properties Home Page) are also associated with each MODIS pixel. Because of problems with Aqua MODIS channel 6 (1.64 µm), channel 7 (2.13 µm) is being used in its place. This substitution is especially critical for the ice/snow detection. Accordingly, clear-snow albedo models were developed for 2.13 µm to ensure reliable daytime snow detection. The behavior of the snow reflectance at 2.13 µm for Aqua MODIS cloud detection is modeled using the ratio of the Terra channel-7 and 6 reflectances (Fig. 1) along with the 1.6-µm models used for **Terra Edition2 (Terra 2)**.

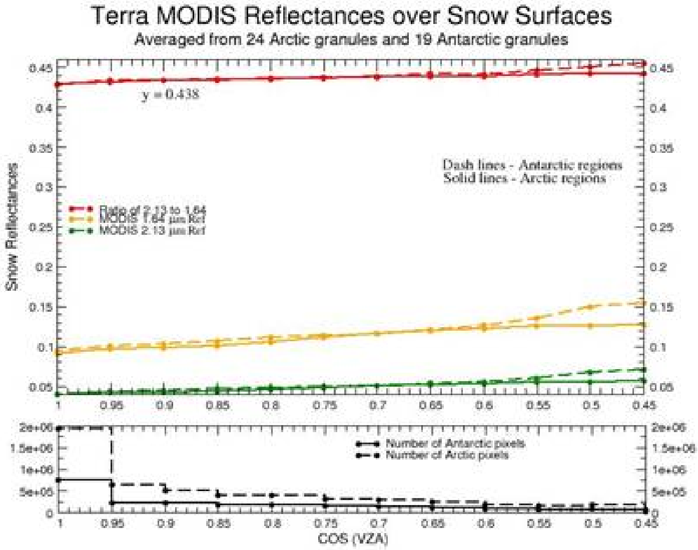

Fig. 1. Development of ratios to apply to Aqua 2.13-µm data to account for the lack of reliable 1.6-µm data.

The cloud masks rely on comparisons of the observed radiances to estimates of cloud-free radiances for a given pixel location and the relevant viewing and illumination conditions. These estimates are based on empirically derived maps of clear-sky overhead-sun spectral albedo, models of the solar-zenith angle (SZA) dependence of albedo, and surface emissivities that use the MOA input.

The Aqua 1B mask algorithm is the same as that for Terra 2 except several changes that were implemented to correct problems identified in the Terra 2 and Aqua Beta results. These changes, excepting the channel 7 substitution for channel 6 (see Fig. 2 of the Aqua Beta1 Cloud Properties Accuracy and Validation Section) are summarized in the following list.

1. A new thin cirrus test using additional channels, 1.38 and 8.55 µm, along with the MOA precipitable water and new 11-12-µm brightness temperature difference (BTD) means, was implemented over ocean, land, and desert surfaces. This new test is outlined in Fig. 2. It uses the mean values of BTD11-12, BTD8.5-11, and 1.38-µm reflectance derived from 70 Terra MODIS granules taken during 2002 and 2003. The example in Fig. 4 clearly shows improved thin cirrus detection along the edges of previously detected cirrus.

Land or Desert

If Ref1.38 > (R138_PW + 0.002) → R138_Flag = 1

If T11 – T12 > T11_T12_PW → T1112_Flag = 1

If T8.5 – T11 > T8.5_T11_PW + 1 → T8511_Flag = 1

If R138_Flag = 1 and T1112_Flag = 1 and T8511_Flag = 1 and T3.7-T11 – (Tcs3.7-Tcs11) > 1.0 → Thin Ci clouds

R138_PW:
land & desert: use 5th degree polynomial fit for PW and ignore vza dependent

T11-T12_PW:
land: use CERES predicted CST11-T12 – 0.5 to count for PW and VZA dependent
desert: use quadratic fit for PW dependent, ignore VZA dependent

T8.5_T11_PW:
land & desert: use 3rd and 4th degree polynomial fit for PW and ignore vza

Ocean

if Tcs11 – T11 > 2.5 and Ref138 > 0.008 and T11 – T12 > 0.7 T11-T12 – (Tcs11-Tcs12) > 0 → Thin Ci clouds

Fig. 2. New thin cirrus tests for **Aqua 1B**.

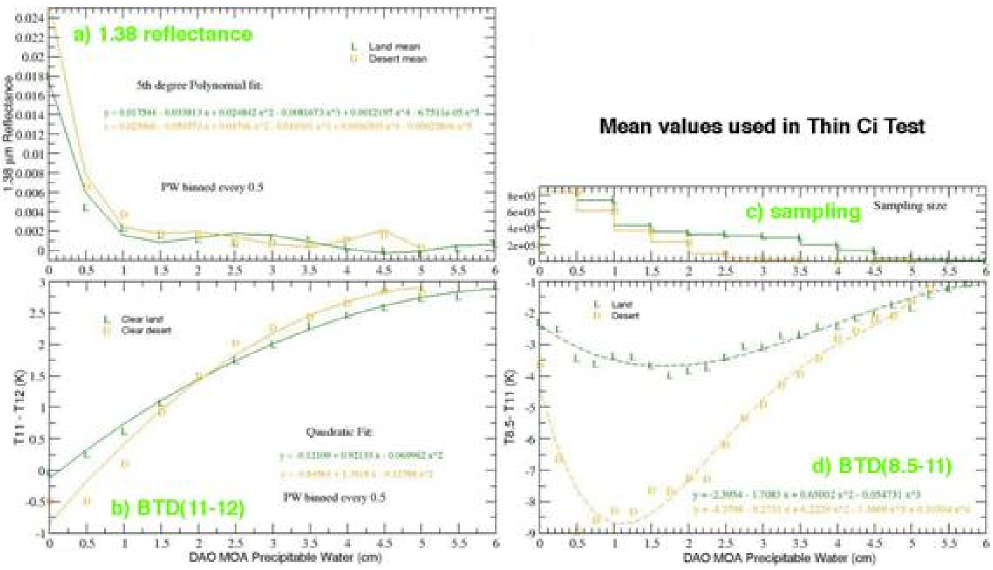

Fig. 3. Mean values for thresholding in new thin cirrus tests.

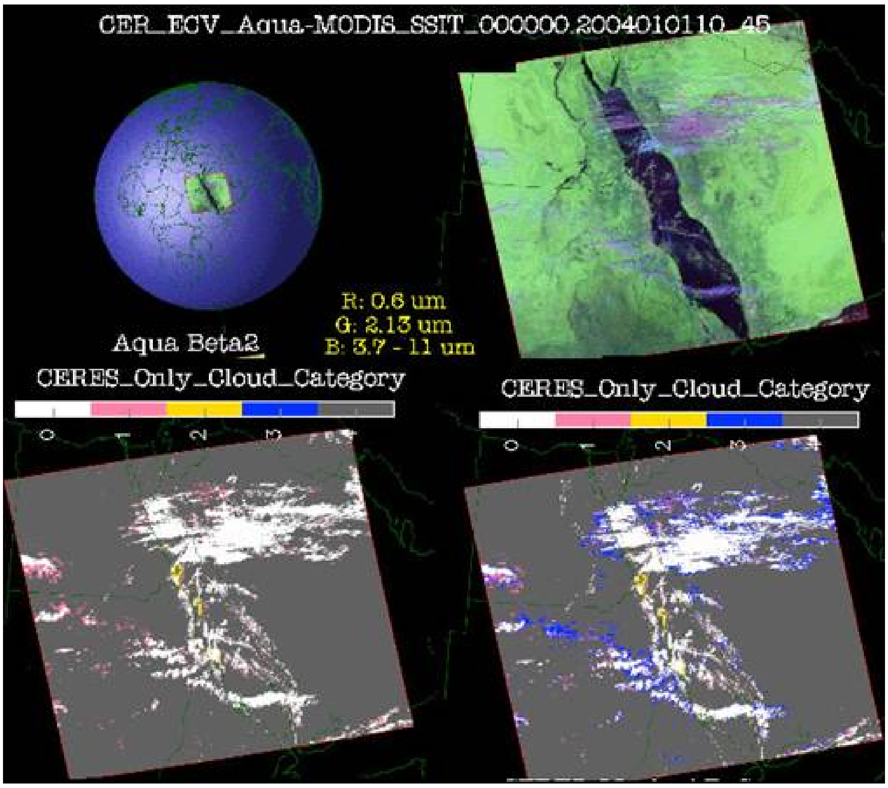

Fig. 4. Example of improved thin cirrus detection in Aqua Edition 1B over Red Sea area, 1 January 2004. Results of Terra 2 algorithm in lower left panel. Cloud cover added with new Aqua 1B cirrus tests in blue in the lower right panel. White, pink, and yellow denote strong, weak, and glint cloud detections, respectively.

2. Revised polar background and masks.

   a. Over polar regions, the Ice Map conditions were changed resulting in improved phase determinations. In Terra 2, the cloud retrieval technique could not obtain a valid cloud retrieval so that the polar mask was negated for those pixels and they were reclassified as clear. The result is much fewer pixels with no retrievals and an increase in daytime cloud amount over the poles. The example in Fig. 5 shows a significant increase in both water and ice cloud coverage.

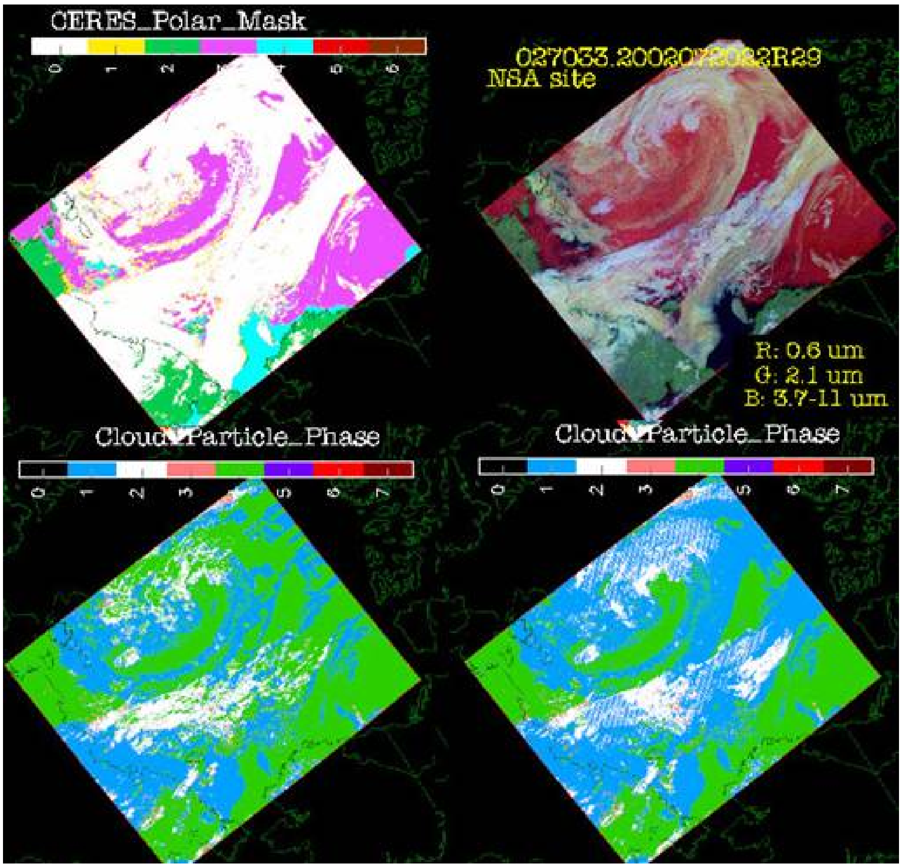

Fig. 5. Daytime cloud phase determination from Terra 2 (lower left) and Aqua 1B (lower right) masks for Aqua data over the Arctic Ocean north of the Bering Strait, 20 July 2002. Blue, green, white, and beige denote water cloud, clear, ice cloud, and

TBD, respectively. CERES polar mask (upper left) shows clear snow/ice (magenta), land (green), and ocean (blue), and strong (white) and weak (yellow) clouds.

b. Improved twilight cloud and snow detection for a smoother transition between the areas where the polar and non-polar algorithms are applied. Improved polar night and daytime cloud detection.

3. Over land, low cloud detection and cloud detection over darker snow surfaces (e.g., forests) were improved. General impact is fewer low clouds than in Terra 2.
4. Over ocean, reduced impact of coastal discontinuities in clear-sky radiances and improved cloud detection in sun glint regions. Impact is more clouds in sun glint areas and fewer false clouds along the coasts.

Bad-data pixels are those having at least one radiance that was set to a default value or was outside of the allowed range. The greatest problem causing bad data is saturation of the thermal channels over land. The saturation temperatures for the Aqua MODIS channels 20, 31, and 32 are 330 K. Because of its reflected solar component, the 3.7-µm channel is occasionally saturated during daytime over deserts and in some extreme sunglint cases over ocean. No-retrieval pixels are those that are initially identified as cloudy, but their radiances cannot be interpreted with the theoretical models used to derive cloud microphysical properties. Further description and discussion of the cloud mask and data problems can be found in the Terra Edition1A and Terra Edition2 Cloud Properties Accuracy and Validation Sections, and in Trepte et al. (1999, 2001, 2002) and Spangenberg et al. (2004).

Cloud Property Retrievals

The following values are computed for each cloudy pixel: phase (ice or water), VIS optical depth τ, IR emissivity, liquid or ice water path *WP*, effective droplet radius r_e or effective ice crystal diameter D_e, cloud-top pressure, effective cloud height z_c and temperature T_c, and cloud-base and top pressures, p_b and p_t, respectively. Normally, the cloud phase, temperature, effective particle size and optical depth are computed using the VIS-IR-NIR-SWC Technique (VISST), which matches model estimates (Minnis et al., 1998) of radiances from clouds with the observations (Minnis et al., 1995). The VIS channel is primarily used to estimate τ; the IR channel is for T_c, and the SIR channel is used for the particle size (Minnis et al. 1995), and the SWC is used to help the phase selection. Cloud height and pressure are found by matching T_c to an altitude in MOA vertical profile of temperature for the pixel location and time. The VISST used for Aqua1B is the same as that for Terra 2, except for a small change in the phase determination that caused a 5% decrease of supercooled cloud cover. If the underlying surface is determined to be snow- or ice-covered either from the snow-ice maps or from identification of nearby pixels as clear snow, then the SIR-IR-NIR Technique (SINT) is applied. This technique, pioneered by Platnick et al. (2001) used 1.6-µm as the NIR channel for Terra 2 to compute optical depth. For the Aqua 1B, the 2.13-µm data replace the 1.6-µm data. Reflectance lookup tables were computed at 2.13 µm in the same manner used for the other channels.

Aqua MODIS Data

The cloud products rely on accurately calibrated imager radiances. Collection-4 Aqua MODIS validated radiance data were used for Edition1B analyses. The MODIS thermal infrared channels are calibrated with onboard blackbodies and the solar channels are calibrated approximately once per month using a solar-viewing diffuser. Space looks provide zero radiance levels for the calibrations (Butler and Barnes, 1998). The nominal MODIS calibrations were compared to other calibrated satellite data to determine stability and relative gains to detect any inconsistencies with other commonly used imagers. During the period from November 2002 through November 2004, following the approach of Minnis et al. (2002, b), the Aqua and Terra MODIS solar and infrared channels were compared to collocated and co-angled radiances from the eastern Geostationary Operational Environmental Satellite (GOES-12) between April 2003 and August 2004, the Meteosat-8 SEVIRI between April and August 2004, and the Visible Infrared Scanner (VIRS) on the Tropical Rainfall Measuring Mission (TRMM) satellite between November 2002 and November 2004. The Aqua and Terra MODIS data were also compared directly with each other between September 2002 and September 2004 to determine their relative calibrations. An initial analysis indicated that all of the Aqua MODIS channels are stable relative to VIRS and Terra MODIS and produce similar trends in the calibrations of the corresponding Meteosat-8 and GOES-12 channels. The Aqua 1.6-µm channel has previously been determined to noisy and unreliable with many missing pixels. Therefore, it was replaced with the 2.13-µm channel for processing of the Aqua data. Spectral differences were normalized for all of the imager comparisons.

Ch. 1, VIS (0.65 µm): The direct comparison of Terra and Aqua visible (VIS) channel reflectance consistently found that the Aqua reflectance was greater than its Terra counterparts. On average, the Aqua reflectance was 1.2% greater than that from Terra. No statistically significant trend was observed in the slope between the two sensors for the time period. The comparisons with VIRS data indicate that, on average, the Aqua measures radiances that are 4.6% greater than those from VIRS. The same comparisons using Terra data showed that Terra MODIS measured radiances averaging 2.6% larger than VIRS. Thus, from the VIRS comparisons, the Aqua VIS reflectance is 1.9% greater than that from Terra. Similar results were found when comparing to GOES-12 and Meteosat-8. Most of the VIRS excess reflection for dark scenes is due to strong Rayleigh scattering in the VIRS window relative to that for MODIS. The excess reflectance for MODIS relative to that for VIRS in brighter scenes appears to be a calibration difference. Therefore, the optical depths retrieved for thicker clouds should be somewhat larger from Terra MODIS than from VIRS for the same scenes and even larger for Aqua MODIS. Preliminary comparison of the CERES FM4 SW and Aqua MODIS VIS channel reflectance indicates that the Aqua VIS channel gain has degraded by less than 0.05%/year. This preliminary result is not statistically significant. Trend analysis continues. Only 0.1% of the difference between the Terra and Aqua VIS reflectances can be explained by differences in their filter functions. Thus, it is concluded that the Aqua VIS channel gain is between 1.1 and 1.8%, or roughly **1.5%**, greater than the corresponding value for Terra. Thus, cloud optical depths derived from Aqua data should be larger than those derived from Terra VIS data, all things being equal.

Ch. 2, NIR (2.13 µm): The Aqua NIR reflectances were compared indirectly with their Terra counterparts by computing averages for clear-sky conditions over ocean and land surfaces. The differences were negligible.

Ch 20, SIR (3.78 µm): The Aqua SIR channel is very similar to, but less opaque than its Terra counterpart. The Aqua Ch-20 solar constant is ~ 0.9% greater than that for Terra. From the direct comparisons, it was found that, on average, the Ch-20 brightness temperatures from Aqua, however, are **0.60 K less** than those from Terra. This result is consistent with Wan et al. (2002) who suggest that the absolute value of the Terra SIR radiances are biased high by 2 - 3%, equivalent to ~ 0.6 K at 283 K. Minnis et al. (2002b) found that the Terra MODIS channel 20 was 0.2 K colder than VIRS channel 3 at 300 K and 1.3 K warmer at 200 K during 2000. Such differences will introduce some discrepancies between the VIRS, Terra, and Aqua retrieved cloud properties. Theoretically, the three sensors should measure brightness temperatures to within 0.1 K of each other for clear and cloudy atmospheres. The latest comparisons between VIRS and Terra and Aqua MODIS data reveal that, in the mean, the VIRS SIR channel is 0.94-K and 0.75-K colder than Terra and Aqua, respectively, at night and 0.60 and 0.32-K colder during the daytime. Cloud droplet sizes derived from Aqua MODIS are 0.1 to 0.5 µm smaller than their VIRS counterparts and ~ 0.3-µm larger than those from Terra MODIS as a result of this calibration difference. The VIRS data agree better with in situ and surface-based validation data. It is concluded that the Aqua MODIS SIR calibration is the least biased of the three sensors.

Ch 31, IR (11.0 µm): Wan et al. (2002) found that the Terra MODIS infrared (IR) channel was accurate to ~ 0.4% or to ~ ± 0.2 K. Using data from 2000, Minnis et al. (2002b) found that MODIS is roughly 0.4 K colder than VIRS at 300 K and differs by 0.0 K at 200 K. Theoretically, it appears that MODIS should be 1.0 K colder than VIRS at all temperatures. The more recent analysis shows no trends in the average difference between MODIS and VIRS IR temperatures through January 2003. At night, the difference is 0.0 K, while during the day, VIRS is 0.3 K warmer than MODIS.

Ch 32, SWC (12.0 µm): Wan et al. (2002) found that the MODIS split window channel (SWC) was also accurate to ~ 0.4% or to ~ ± 0.2 K. MODIS is roughly 0.8 K and 0.7 K warmer than VIRS at 300 K and 200 K, respectively (Minnis et al. 2002b). Theoretically, it appears that MODIS should be nearly the same at 200 K and 0.5 K warmer at 300 K. No significant trend is apparent in the differences. At night, MODIS is 0.75 K warmer than VIRS. It is 0.85 K warmer during the daytime.

DATA PROBLEMS

Aqua Edition 1B uses Aqua MODIS Collection 4 radiances starting in July 2002.

Cloud Parameters

While direct comparisons of Aqua 1B cloud properties with ground truth data are underway, the validation of the Aqua results relies primarily on its consistency with the Terra MODIS results (e.g., Minnis et al., 2003), which have been compared more extensively with ground truth data. Preliminary assessment of the uncertainties in some of the cloud parameters has been completed for the Terra results from those comparisons. Many other datasets must be compared with the CERES MODIS cloud analyses before final error numbers are assigned. The cloud parameters have also been evaluated visually by comparing a large number of high-resolution images with pictures of derived cloud products over a selected number of regions to ensure that the results appear to be qualitatively consistent with the imagery. Some of the parameters have been compared with climatological values to obtain a rough quantitative evaluation. The results have also been averaged for various surface types and angular ranges to determine any systematic variability. The most quantitative evaluations use estimates of similar quantities derived from passive and active radiometric measurements at surface sites, in particular, the ARM Southern Great Plains (SGP) facility in central Oklahoma. The available ARM data have been compared with the VIRS Edition2, Terra 2, GOES-8 using the CERES VISST algorithm, and, on a limited basis, with Aqua 1B properties (see TRMM Edition2A and Terra Edition2A Cloud Properties Accuracy and Validation Sections) quantities and are being documented in several papers either submitted or currently in preparation (Mace et al., 2005). Some comparisons with Terra 2 datasets are discussed below. The results are similar to those found applying the CERES algorithm to GOES-8 data (Mace et al., 1998; Dong et al. 2002; Min et al., 2004).

Cloud amount: The primary changes to the cloud mask were over polar regions, for improving thin cirrus detection, and to reduce false low clouds over land. Although the Terra and Aqua orbits differ by 3 hours, it is expected that the mean cloud amounts should only differ by a few hundredths. Fig. 6 shows a comparison of the zonal means for two extreme months. During December 2002, the Aqua analysis shows a small increase at most latitudes, especially in the polar regions. In June 2003, the mean cloud amounts are very close, except for some dramatic changes over Antarctica. The Aqua cloud amounts are 0.2 to 0.5 less than the Terra 2 values during nighttime over the southern polar ice cap.

The same Aqua values are compared in Fig. 7 with the climatological means from surface observations (Hahn and Warren, 1999) and from the International Satellite Cloud Climatology Project (ISCCP; see Rossow and Schiffer, 1999). The Aqua results track the surface climatology very closely except at 25°N and 75°N during December. In general, the Aqua 1B means follow the same pattern as ISCCP also, but the values are typically smaller except over the Arctic during June. Overall, the differences between Aqua 1B and ISCCP are greatest over the polar regions during both months. The Aqua 1B means are in better agreement with surface data over Antarctica than either Terra 2 or ISCCP. It is difficult to conclude that the surface results represent the true large area means since the surface sites are so sparse in the Arctic and Antarctic. Thus, the actual uncertainties in cloud amounts over the polar regions remain large.

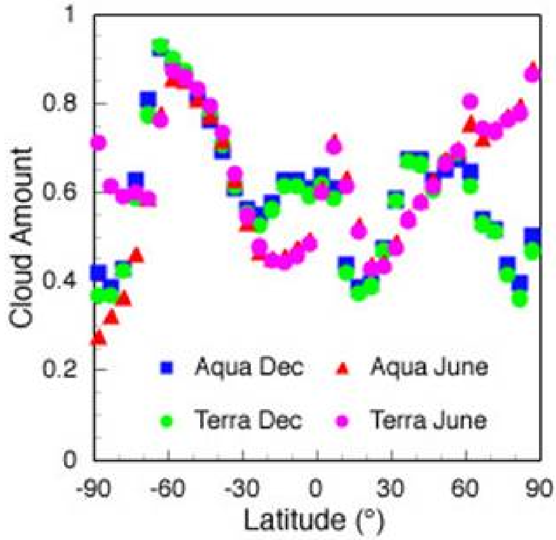

Fig. 6. Comparison of CERES mean cloud amounts for December 2002 and June 2003 derived using Terra 2 and Aqua 1B methods.

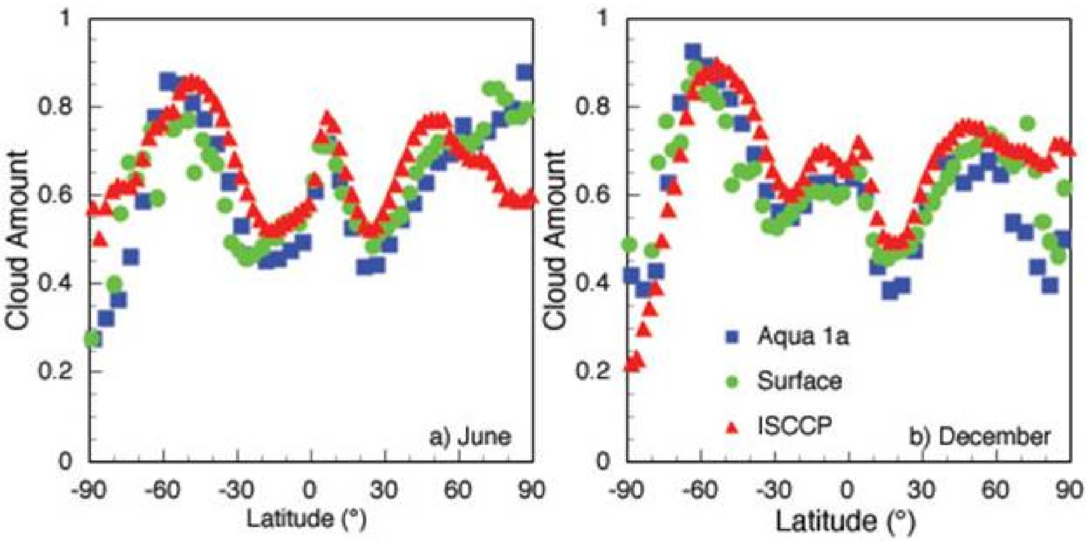

Fig. 7. Comparison of CERES monthly mean cloud amounts from Aqua 1B for June 2003 and December 2002 with climatological means from surface data (1971-96) and ISCCP (1984-98).

Table 1 compares mean cloud amounts for 2 months in the extreme seasons to ensure that one hemisphere was deep in polar night. When both global and non-polar areas are compared separately, the Terra 2 and Aqua 1B mean cloud amounts are within 0.3 to 0.6% of the surface data but are ~7% less than the ISCCP climatology.

Table 1. Monthly mean cloud amounts in percent from surface observations (Hahn and Warren, 1999), CERES, and ISCCP (Rossow and Schiffer, 1999).

Domain	Surface (1971-96)	Terra MODIS Ed 2 12/2002, 6/2003	Aqua MODIS Ed 1B 12/2002, 6/2003	ISCCP D2 (1984-98)
60°S - 60°N, December	60.9	60.3	61.2	68.2
90°S - 90°N, December	61.9	60.6	61.4	68.2
60°S - 60°N, June	58.6	58.6	58.9	66.6
90°S - 90°N, June	60.0	60.3	59.8	66.6

Cloud phase: Cloud phase statistics changed slightly between Terra 2 and Aqua 1B. Fig. 8 shows the distribution of ice cloud amount for March 2003. The patterns are very similar, except it appears that slightly more ice cloud cover is found by Aqua 1B. On average, Aqua 1B detects ~0.04 more ice cloud coverage during daytime than Terra 2 for the years of coincident data. There is virtually no difference at night. This difference is likely due mostly to the new thin cirrus cloud tests in the cloud mask and possibly, to some average diurnal changes in the 3 hours between the Terra and Aqua overpasses. The increase in ice cloud coverage, however, comes at the expense of water cloud coverage, which is reduced by ~3% during the daytime relative to Terra 2 values. Again, some of the change is expected, especially over large areas of stratocumulus clouds.

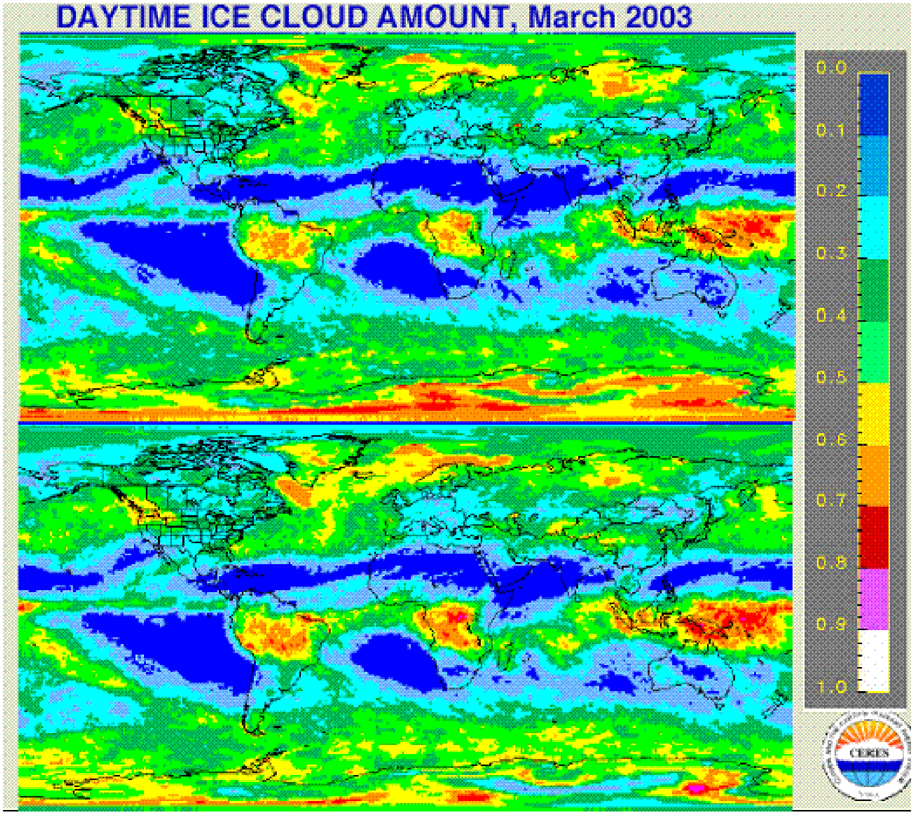

Fig. 8. Mean ice cloud fraction during March 2003 from Terra 2 (top) and Aqua 1B (bottom).

Cloud height, pressure,temperature: These parameters are all related because the cloud temperature is used to ascertain cloud height and the height is used to select the pressure. Effective cloud height derived from MODIS should be an altitude somewhere between the top and base of the cloud. It corresponds to the mean radiating temperature of the cloud. For water clouds, the mean radiating temperature is usually within a few 100 m of the top. For cirrus clouds, it can be close to the cloud base or near cloud top depending on the density of the cloud. For an assessment of low cloud heights, see Terra Edition1A Cloud Properties Accuracy and Validation Section. The most recent comparisons using Terra 2 data indicate that in general for optically thick clouds, the effective cloud height averages 0.16 km less than the radar-determined cloud top with a standard deviation of 1.13 km. Initial comparison of optically thin cirrus clouds during daytime indicate that z_c is, on average 0.3 km below the radar cloud center with a standard deviation of 1.5 km. This result is consistent with that from Mace et al. (2005). At night, the effective height for optically thin clouds is 0.56 km below cloud top with a standard deviation of 1.7 km. Cloud height comparisons continue.

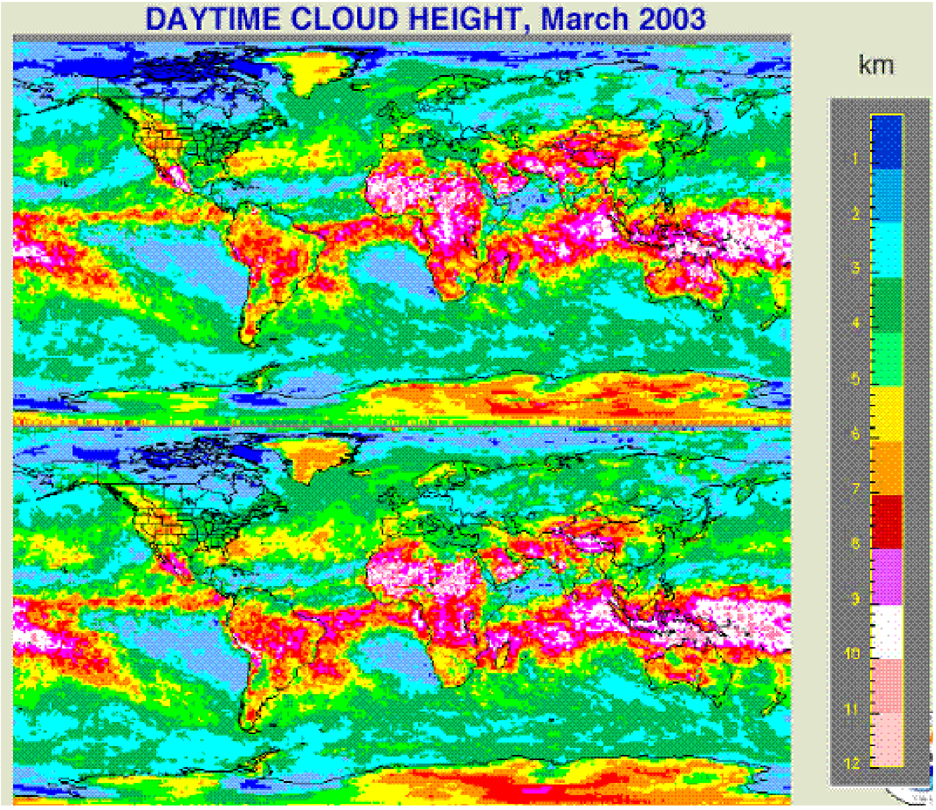

Fig. 9. Mean cloud heights during March 2003 from Terra 2 (top) and Aqua 1B (bottom).

[Fig. 9](#) shows the daytime cloud heights derived from Terra 2 and Aqua 1B for March 2003. The cloud heights over the polar regions appear to be a bit higher from Aqua 1B. On average, the ice cloud heights from Aqua 1B are 0.6 and 0.2 km higher than those from Terra 2. This is probably due to the use of the 2.13-µm channel in polar regions and the thin cirrus detection elsewhere. The Aqua 1B daytime water cloud height, on average, is roughly 0.3-km less than its Terra 2 counterpart. This difference is partially due to diurnal changes and to the classification of some supercooled clouds that would be Terra 2 water to ice in Aqua 1B. This 0.3-km discrepancy is also seen between the daytime and nighttime Aqua 1B results. This difference should not be construed as a diurnal change in low cloud heights.

Cloud optical depth, effective particle size: These parameters were evaluated for Terra 2 following the approach used by Dong et al. (2002) for comparing stratus cloud properties derived from GOES data using the CERES algorithm to retrieve the same quantities from surface-based instruments at the ARM site using the techniques of Dong et al. (1997). Only single-layered stratus cloud comparisons were reported. A similar comparison of Aqua 1B stratus clouds is underway. [Fig. 10](#) shows a comparison of liquid water path (LWP) from the ARM microwave radiometer and from Aqua 1B. The Aqua 1B values track the ARM results closely. On average, mainly as a result of the large outlier (sample 2), the Aqua 1B LWP is 10% larger than the ARM LWP. The mean difference is the smallest from the three imagers (VIRS, Terra, and Aqua). The stratus comparisons for Terra 2 are duplicated in [Table 2](#) for reference. Overall, the agreement between the two datasets for stratus clouds is excellent during the daytime. Because the nighttime microphysical properties are limited, the comparisons are not reported here. The optical depths derived from MODIS are restricted to roughly 10 or less at night because of the limitations of infrared retrievals. Thus, estimates of r_e, τ and LWP from MODIS at night should not be used except for optically thin clouds. Generally, the standard deviations during the daytime are within the CERES accuracy goals. The MODIS and surface daytime retrievals agree at roughly same level as a similar comparison of surface, aircraft, and GOES retrievals for stratus over the same site (Dong et al. 2002). The number of samples here is still too small for this one site. These results represent only one set of climatological conditions. Dong et al. (2001) compared the retrievals of cloud droplet size and optical depth derived using the SINT over the Arctic ice pack and found good agreement with the surface and in situ data taken in the same area. Comparisons at the SGP and other sites are ongoing (e.g., Spangenberg et al., 2002; Uttal et al., 2003) and will continue.

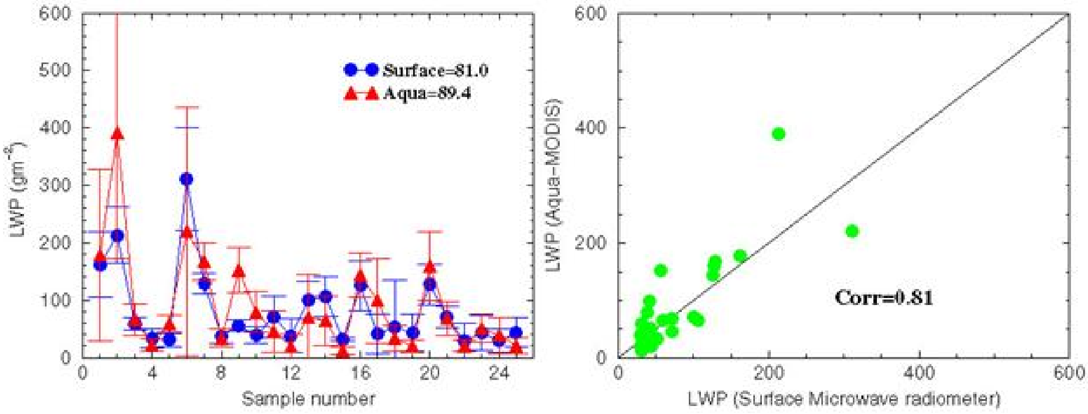

Fig. 10. Preliminary comparison of LWP from the ARM SGP site and Aqua 1B, 2002-20003.

The microphysical properties from Terra 2 and Aqua 1B are very similar as seen in Fig. 12 for the daytime water cloud optical depths and effective radii. The Aqua liquid water cloud optical depths are smaller than their Terra counterparts over many areas with some exceptions such as those over China and off the eastern USA coast. On average, τ(Aqua) is 27% less than τ(Terra). If nonpolar regions are considered separately, the difference is only 8% indicating the majority of largest differences occurred over polar regions where the SINT algorithm used the 1.6 and 2.13-µm channels to derive optical depth for Terra and Aqua, respectively. Thus, much of the difference is a result of the switch in the NIR channels. The Aqua ice cloud optical depths are 8% smaller, 6% smaller in nonpolar areas, than those from Terra, indicating that the channel switch had a smaller impact on the ice cloud optical depths. Because the Aqua VIS reflectance exceeds its Terra counterpart on average, it appears that the drop in τ in nonpolar areas is a physical change in the clouds between the overpasses.

The mean effective droplet radii from Aqua are generally greater than their Terra counterparts, but follow the same patterns. Over nonpolar areas r_e(Aqua) is 0.7-µm larger than r_e(Terra). Inclusion of polar regions yields a 0.3-µm difference. The ice cloud effective diameter from Aqua is 4% smaller than that from Terra.

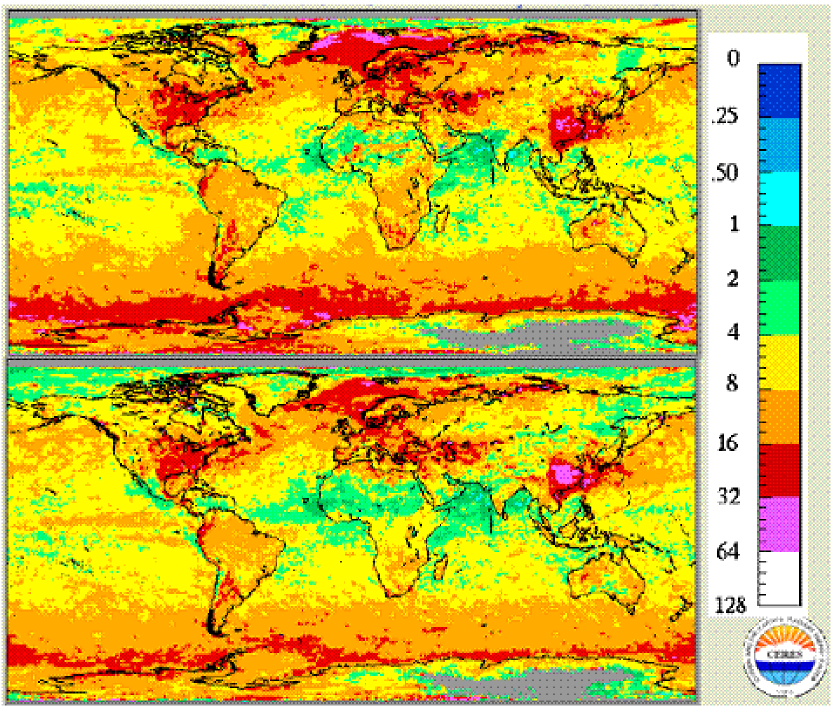

Fig. 11. Mean water cloud optical depths during March 2003 from Terra 2 (top) and Aqua 1B (bottom).

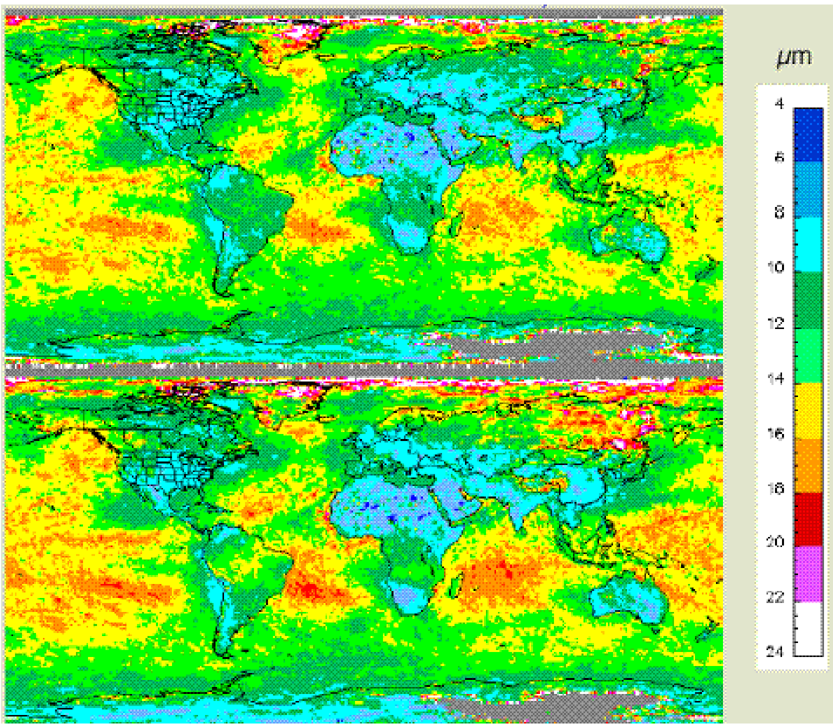

Fig. 12. Mean water cloud effective radius during March 2003 from Terra 2 (top) and Aqua 1B (bottom).

Explicit validation of cirrus clouds is relatively difficult because of the extreme variability in the cirrus cloud optic properties. The surface-based cirrus retrieval method is limited to optically thin clouds and loses reliability for clouds with $\tau > 3$. The cirrus comparisons must be performed with extreme caution because of the variability of cirrus and because of the effect of clouds underneath the cirrus. Previous comparisons between surface and in situ data are discussed in previous DQS's. More recently, VISST cirrus cloud properties were compared with radar (Mace et al., 2005) and radiometer (Min et al., 2004) retrievals, which indicate that the cirrus cloud optical depths are overestimated by ~0.5 or less, the effective particle sizes are within 1-2 µm, and the ice water paths are within a few gm^{-2} on average. Thus, it is concluded that the cirrus cloud optical depths are reasonable. The differences between the Terra and Aqua retrievals noted above will simply shift the relationships between Terra and ARM when considering Aqua. Cirrus validations are continuing and will be reported as they become available.

Table 2: Uncertainties in Terra 2 cloud parameters from comparisons at ARM SGP site.

	Mean difference (CERES- ARM)	Standard deviation	Standard dev of difference (%)	N
DAY				
Thin cloud temperature vs mean	7.0 K	6.4 K	-	34
Thick cloud temperature vs mean	-5.0 K	10.5 K	-	53
Thin cloud height vs. mean	-0.3 km	1.5 km	-	34
Thin cloud height vs. top	-1.7 km	1.2 km	-	45
Thick cloud height vs. mean	1.5 km	1.5 km	-	53
Thick cloud height vs. top	0.2 km	1.2 km	-	53
Stratus optical depth	-0.8	7.7	36	36
Stratus effective radius	-1.2 µm	2.8 µm	30	36
Liquid water path	-29 gm^{-2}	85 gm^{-2}	52	36
NIGHT				
Thin cloud temperature vs mean	-0.8 K	11.4 K	-	52
Thick cloud temperature vs top	0.4 K	9.9 K	-	53
Thin cloud height vs. mean	0.5 km	1.8 km		52
Thin cloud height vs. top	-0.6 km	1.7 km	-	52
Thick cloud height vs. mean	1.4 km	2.0 km	-	53
Thick cloud height vs. top	-0.1 km	1.7 km	-	53

Angular Dependencies

The angular variations for VZA, SZA, and relative azimuth angle are summarized by Heck et al. (2002) and in the TRMM VIRS Edition2A and Terra MODIS Edition1A Cloud Properties Accuracy and Validation Sections. No differences are expected for Aqua 1B.

Overall, the angle dependencies show that the derived cloud properties are reasonable at a level of 25% or better. More likely, the values are consistent at a higher level of accuracy because of the natural variability that occurs in clouds but is reflected in the angular dependencies (i.e., the SZA-diurnal variation, the RAZ-location variation). The VZA dependencies in cloud optical depth and cloud particle size are probably mostly due to the increase in cloud fraction with VZA. More optically thin or broken clouds are detected at higher VZAs resulting in a decrease of the mean τ, which in turn would cause an apparent increase in the effective particle size. The ice crystal phase functions for CERES yield results that appear to be as representative as the water cloud phase functions because the variations of D_e with any particular angle are no worse than the variations in r_e. This result is consistent with the findings of Chepfer et al. (2002). Ayers et al. (2005) performed a comparison of cloud properties derived from GOES-10 and 12 over the same areas at different scattering angles to assess the angular errors due to 3-D effects and uncertainties in the scattering phase functions. Figure 13 shows an example of the preliminary results for the hour with the most extreme differences in scattering angles. The water cloud optical depths from GOES-12 are, on average, 11% greater than their GOES-10 counterparts. Part of the difference is expected because of differences in 3-D effects (shadowing) because the GOES-12 view is almost direct backscatter compared to a side view from GOES-10. The ice cloud optical depth bias is also 11% in the same direction, but larger scatter is seen. Overall the RMS biases for all hours of the day are 10 and 15% for water cloud τ and r_e, respectively, and 19 and 12% for ice cloud τ and D_e, respectively. These results confirm the general conclusions that the retrieval for a given angle is generally less than 25%, on average.

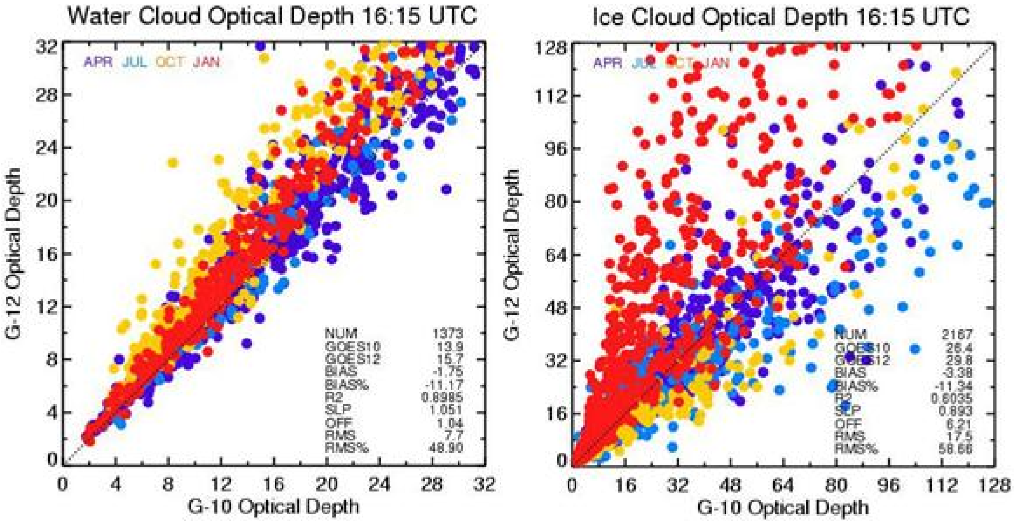

Fig. 13. Comparisons of water (left) and ice (right) cloud optical depths for overcast 0.5° regions over the United States during 2004. Scattering angles for GOES-12 (G-12) range from 165-175° and for GOES-10 (G-10) vary from 60-105°.

Consistency with VIRS and Terra MODIS

One of the goals of the CERES program is to provide a continuous series of cloud and radiation measurements that are consistent from one satellite to another. The VIRS Edition 2 zonal mean results for December 2000 and June 2001 have been compared to those from Terra 2 products for the same time period to provide a measure of the consistency in the results for the two instruments (Minnis et al., 2002c). The consistency should be similar for Aqua 1B as that found for Terra 2 except that the MODIS water cloud heights are reduced on average by 0.3 km as a result of the new lapse rate method for determining height form cloud temperature. The reader is referred to the Terra Edition1A and Terra Edition2A Cloud Properties Accuracy and Validation Sections and Minnis et al. (2002c) for details. The results presented above indicate excellent consistency, overall, between Terra 2 and Aqua 1B.

Return to Quality Summary for: SSF Aqua Edition1B.