CERES Terra Edition2A SSF Cloud Properties - Accuracy and Validation

This section discusses the spectral radiances and cloud products included in the **SSF** data set version Terra MODIS **Edition2A** and **Edition2B**. Terra Edition2A and Edition2B clouds are identical and may be referred to by either name or as Terra Edition2 Clouds. Terra MODIS validated Collection 4 radiance data were used for Edition2 analyses. Additional information is in the Description/Abstract Guide. The 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 reduce run times. This change has negligible effect on the mean SSF properties. Seven radiances taken at 0.65 (visible, VIS), 1.64 (near infrared, NIR), 3.75 (solar infrared, SIR), 6.7 (water vapor, WV), 8.5, (11.0 (infrared, IR), and 12.0 (split-window channel, SWC) µm, channels 1, 6, 20, 27, 29, 31, and 32, respectively, are ingested for each MODIS pixel for potential use in the cloud analyses.

On average, the CERES Edition2A cloud amounts are in good agreement with surface observer climatology and generally less than those from ISCCP climatology. The cloud heights are typically within 1-2 km of surface radar heights instantaneously and within 0.2 km of the physical top for thick clouds and 0.5 km of the physical center of thin clouds. On average the water droplet cloud effective droplet size, optical depth, and liquid water path are 14, 6, and 18% less than surface-based retrievals of the same properties. The following remarks summarize the findings as of December 2005.

Cloud Mask

Based on the values of 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 to indicate the degree of confidence in the selection. Clear pixels can also have an additional classifier: snow, aerosol, smoke, fire, glint, or shadow. The 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 (see MOA description), elevation, and one of the nineteen surface types (CERES Surface Properties Home Page) are also associated with each MODIS pixel. Trepte et al. (1999) discuss the general cloud-mask that is applied to VIRS and MODIS data in non-polar latitudes. The cloud masks used in polar regions, described in more detail by Trepte et al. (2001, 2002), have been updated for Edition2A. The changes to the polar masks are discussed further at the end of this section.

The cloud masks rely on comparisons of the observed radiances to estimates of the radiances for a cloud-free scene at a given pixel location and viewing and illumination conditions. These estimates are based on empirically derived maps of clear-sky overhead-sun spectral albedo (OSA), models of the solar-zenith angle (SZA) dependence of albedo (Sun-Mack et al. 1999; Chen et al. 2002a), and surface emissivities (Chen et al. 2001, 2002b) that use the MOA input. The MODIS Edition1A used the VIRS Edition2 clear-sky procedures and datasets except for the following changes. The clear-sky ocean reflectance model used for VIRS Edition2 was reduced in magnitude by 13% to account for the spectral differences between the VIRS and MODIS VIS channels (Chen et al. 2002a). Clear-sky snow reflectances are predicted using a model that is tuned to the MODIS observations (e.g., Trepte et al. 2001; Spangenberg et al. 2001). The twilight cloud masks are applied for SZA between 82.0° and 88.5°.

Several changes in the clear-sky reflectance predictions and the mask algorithms have been developed for MODIS Edition2A processing that either replace or are added onto those used for Edition1A. Clear-sky reflectance is computed using new a priori monthly maps of clear-sky OSA based on the Edition1A results (Sun-Mack et al. 2003). A time-dependent map of clear-sky 1.6-µm OSA generated and updated using observed clear pixels in the same manner traditionally used for 0.65-µm OSA. Over snow-ice non-elevated land surfaces, where an inversion cloud height was calculated from the lapse rate, the MOA skin temperature used in calculation was replaced by the daily averaged MOA air surface temperature. The largest change in clear-sky radiances was the replacement of the ECMWF skin temperatures and atmospheric profiles with their GMAO GEOS 4.0.3 counterparts. Both datasets provide atmospheric profiles on a 1° grid every 6 hours and skin temperatures, T_{skin}, every 3 hours. The GMAO dataset, however, only provides T_{skin} on a 1° grid compared to a 0.5° grid used by ECMWF. A new interpolation algorithm was developed to ensure that each cloud analysis tile used T_{skin} from the nearest box. The clear-sky temperature standard deviations used in the mask to set thresholds were increased by 30% only over land at night to reflect the greater uncertainty in the clear-sky conditions. Spectral surface emissivities are used to convert skin temperature to skin radiance at 3.7 µm for all surface types and at 11 and 12 µm for all land, snow-ice, and polar ocean surfaces for both day and night.

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 was the saturation of the thermal channels over land. The saturation temperatures for the Terra MODIS channels 20, 31, and 32 are 332, 324.9, and 319.4 K, respectively. Because of its relatively low maximum temperature and its reflected solar component, the 3.7-µm channel was often saturated during midday over deserts and scrubland. 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 particle size and optical depth.

The greatest changes to the CERES scene identification were made to the polar masks. During daytime, tests were included to reduce false cloud detection over super cold surfaces like those found on the high altitude Greenland and Antarctic ice sheets. New threshold test were added to detect thin cirrus clouds and additional tests using the visible and 1.6-µm channels were included to detect low clouds at large SZAs. A new skin temperature threshold test was also instituted to help detect clear land and snow/ice surfaces. The new twilight polar algorithm includes tests using the 0.65, 1.6, and 3.7-µm channels to detect clouds that were previously undetected. They dramatically reduced the discontinuities between day and night cloud fields. Separate tests were developed for the supercold ice caps (Fig. 1). An example of the new results is shown in Fig. 2.

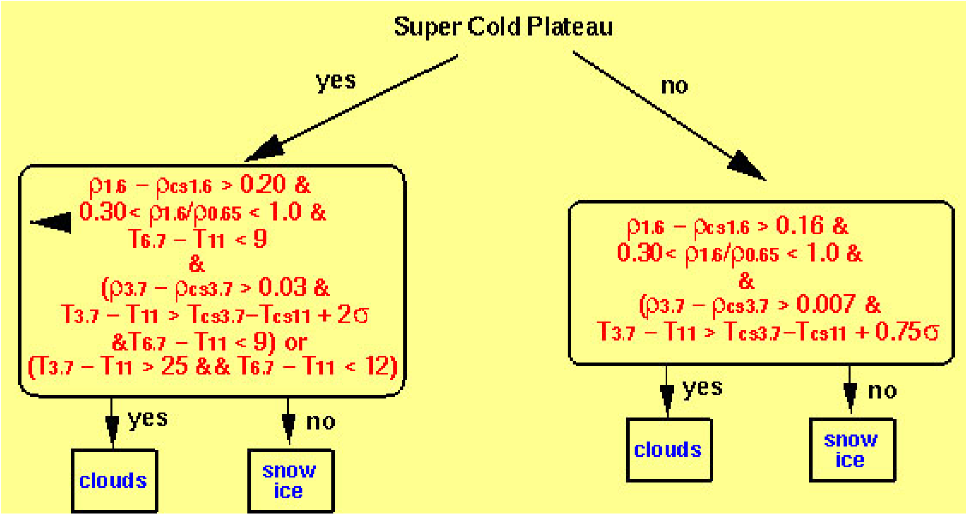

Fig. 1. CERES cloud mask for super cold plateau (Antarctica and Greenland) at twilight.

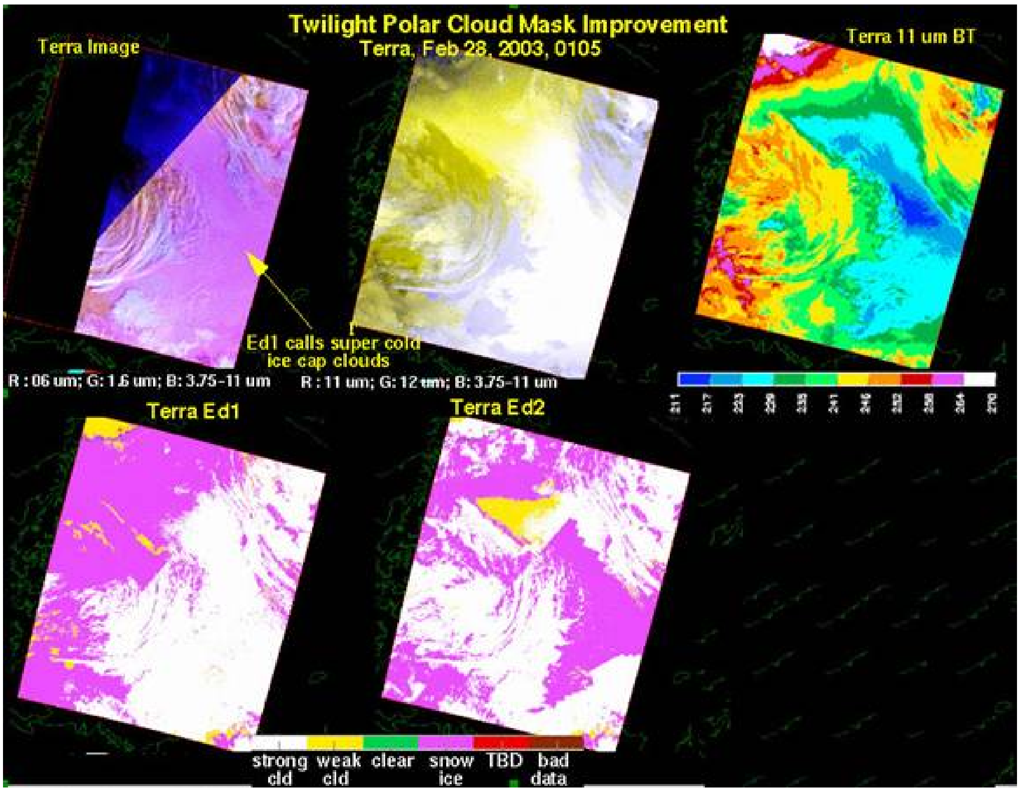

Fig. 2. Comparison of CERES old and new twilight polar cloud mask over Antarctica.

For data taken over Antarctica. The clouds in the darker section of the image are now picked up and the clear areas are detected where it is extremely cold.

The Edition2A nighttime polar mask uses refined thresholds to detect low clouds and inversion clouds and to discriminate between cloudy and clear snow/ice surfaces. The new channels, 6.7 and 8.5 Uµm, are used in brightness temperature differences with the 11-µm channel to aid cloud detection over the super cold plateaus and land surfaces. The polar tests were also extended to nonpolar areas where the snow/ice maps indicated snow. Decisions were made over coastal areas where the snow/ice maps are uncertain. In Edition1A, the Welch mask was used to overwrite TBD (to be determined) pixels whenever it had a definite scene classification. It was infrequently used as is no longer applied in Edition2A. The upshot of using all of the new changes is that considerably more cloud cover is detected over polar regions at night and in twilight conditions. TBD pixels were very common in Edition1A. They are extremely rare in Edition2A as seen in Fig. 3. The net result is an increase in polar clouds at night and better transition between day and night. Some discontinuities still remain, but they are much less prominent than in Edition1A.

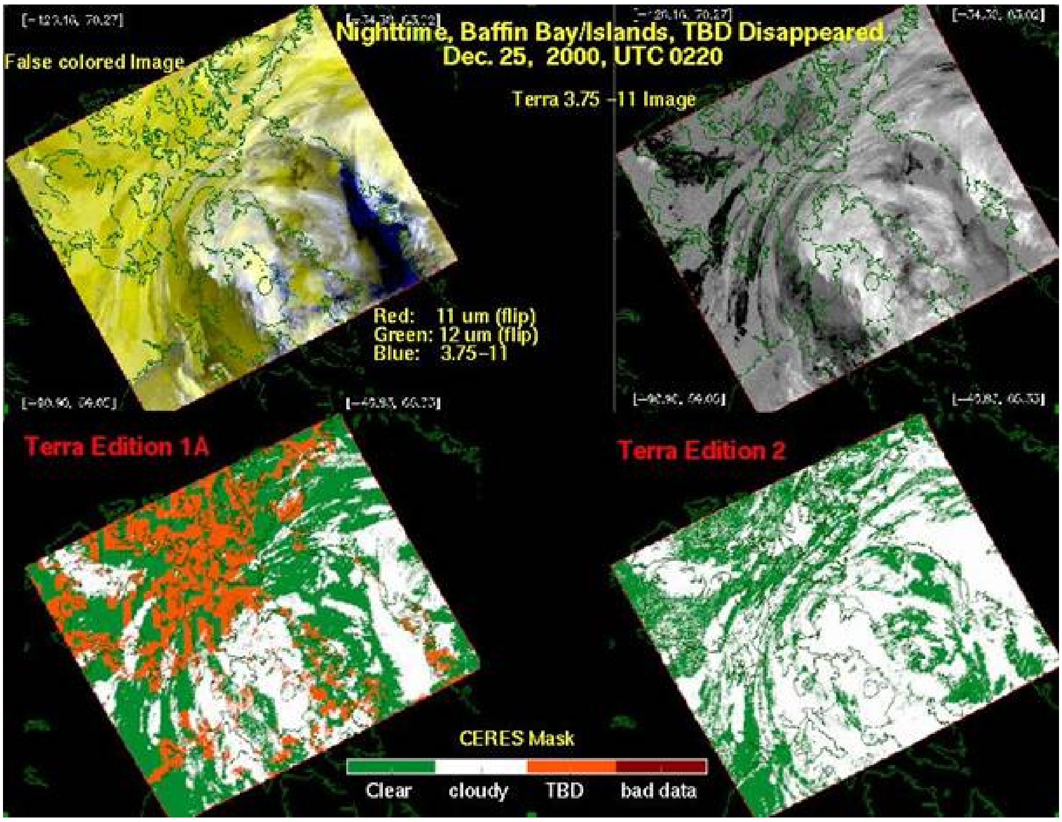

Fig. 3. CERES daytime polar mask and differences between predicted clear-sky and observed radiances for MODIS data over the Arctic Ocean, 1100 UTC, 26 April 2001.

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). 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 basic approach for deriving optical depth from the VIS reflectance for VIRS Edition2 and MODIS Editions 1A and 2A follows the methodology outlined by Minnis et al. (1993a) but includes a more accurate surface-cloud-atmosphere reflectance parameterization (Arduini et al. 2002). Water and ice solutions are computed for each pixel and the phase is selected based on the solutions and several other criteria. Each pixel is initially analyzed with the layer bispectral threshold method (LBTM, see Minnis et al. 1993b) and assigned an initial cloud height classification that is used in later steps to aid the phase identification. The LBTM is carries more weight in the MODIS phase algorithm than in the VIRS Edition2 methodology. The cloud reflectance and emittance models of Minnis et al. (1998) were updated for the VIRS spectral channels to use in the VIRS Edition2 processing. The SIR reflectance models were updated for the MODIS spectral bandpass and cloud reflectance models were also developed for the MODIS and VIRS NIR filter functions. The VIRS cloud emittance models are used for the MODIS Edition1A processing. Corrections for atmospheric absorption use radiative transfer calculation employing the correlated *k*-distribution method (Kratz, 1995) with the absorption coefficients reported by Minnis et al. (2002a, b).

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. In this approach pioneered by Platnick (2001), the NIR channel replaces the VIS channel for optical depth determination. Use of the VISST over snow typically overestimates the cloud optical depth (e.g., Dong et al. 2001).

The approach to retrieving cloud properties is the same as that used for Edition1A, except for cloud height. In previous editions, cloud-top height was generally overestimated for low clouds over land because of the inability of both balloon soundings and the MOA profiles to accurately define the temperature of the boundary-layer inversion. Edition2A institutes a new method for estimating cloud-top height from cloud temperature over land. This new lapse rate method is basically identical to that used by the methodology over ocean. Instead of using sea surface temperature to define the starting point for the lapse rate, the running 24-hour mean surface air temperature *T24* is used over land to minimize diurnal effects. Figure 4 compares the new modified lapse rate with the atmospheric temperature profile from ECMWF. The assumed lapse rate of Γ = -7.1 K/ km is initialized at the surface using *T24* and the temperature at each altitude *z* and pressure *p* is computed as

$$T(p) = T24 + \Gamma z(p) \quad (1)$$

at each level up to 700 hPa. Between 700 hPa and 500 hPa, $T(p)$ is computed by linearly interpolating between T(500 hPa) from MOA and T (700 hPa) from (1). For altitudes above 500 hPa, the original MOA sounding is used for the temperature profile.

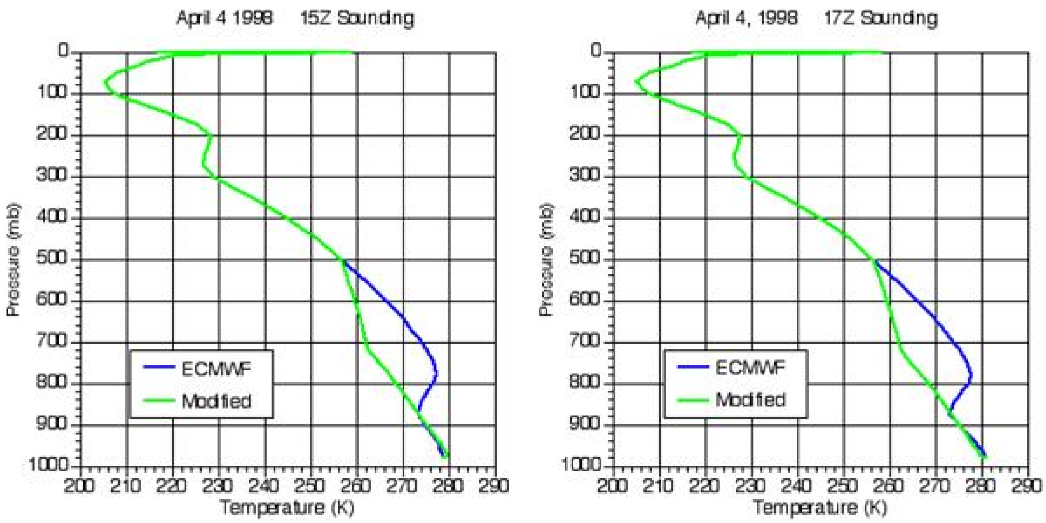

Fig. 4. Original and modified lapse rate for cloud height determination over land at ARM SGP site.

Over the TWP (Fig. 4), the water-droplet effective radii generally range between 9 and 16 µm with some larger values evident in overlapped cases. Some very small ice crystal diameters are also retrieved for other overlapped pixels. Values of *WP* exceed 3000 gm^{-2} in some areas with large cloud optical depths. The cloud water path is computed based on the retrieved particle size and optical depth (Minnis et al. 1998). Thus, if the cloud is identified as an ice cloud, then *WP* is computed assuming the entire column is filled with a cloud having the retrieved value of D_e and τ. For overlapped clouds or convective clouds, the column will often consist of a thick layer of liquid water topped by an ice cloud. Since the ice cloud particles are usually larger than their liquid counterparts, the WP computed for the entire cloud can be overestimated with this approach.

MODIS Data

The cloud products rely on accurately calibrated imager radiances. Terra MODIS validated radiance data were used for Edition1A 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). Wan et al. (2002) provide a preliminary calibration assessment of the MODIS thermal infrared channels for data taken during May and June 2000. 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 May 2000 through July 2001, the VIRS solar and infrared channels were compared to collocated and co-angled radiances from the eastern Geostationary Operational Environmental Satellite (GOES-8) and the Visible Infrared Scanner (VIRS) on the Tropical Rainfall Measuring Mission (TRMM) satellite. An initial analysis indicated that all of the MODIS channels are stable and very similar in response to the corresponding VIRS and GOES-8 channels, except for the VIRS. 1.6-µm channel, which appears to have a significant calibration bias. The GOES-8 was calibrated against the ATSR-2 on a monthly basis since 1995 to establish a trend line in the GOES gain. Thus, comparison of GOES and VIRS is equivalent to comparing ATSR-2 and VIRS over ocean for purposes of detecting long-term trends, because both VIRS and ATSR-2 use diffuser systems for calibrating their visible channels. Spectral differences were normalized for all of the imager comparisons. Except for the near-infrared gain changes, details of the calibration studies for each channel including comparisons with the MODIS channels are given by Minnis et al. (2002a, b). The following remarks summarize the basic findings.

Ch. 1, VIS (0.65 µm): The Terra MODIS visible (VIS) channel reflectance has been compared with the corresponding Version 5a VIRS channel for March 2000 through July 2004. No statistically significant trend was observed in the slope between the two sensors for that time period (Minnis et al., 2005). The MODIS reflectance exceeds the VIRS reflectance over bright scenes and vice versa for darker scenes (Minnis et al. 2002a). 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 MODIS than from VIRS for the same scenes. Comparison of the CERES SW and MODIS VIS channel reflectance indicates that the MODIS VIS channel gain has degraded by 0.2%/year. Comparison with the Aqua VIS channel shows a degradation of nearly 0.5%/year between July 2002 and July 2005. Cold cloud reflectance averages for Terra between 2000 and 2003 indicate that the gain has been increasing by 0.2%/year. The range of results indicate that the Terra MODIS response has been decreasing by 0.1 to 0.5%/year (Minnis et al., 2005). Trend analyses continues.

Ch. 2, NIR (1.64 µm): Comparisons of Terra MODIS and ATSR-2 NIR reflectances with VIRS are very consistent indicating that both the MODIS and ATSR-2 NIR reflectances exceed their VIRS counterparts by 15-17% as of late 2000. Comparisons of VIRS and MODIS retrievals show that the VIRS reflectances are unrealistic and that the MODIS calibration yields cloud particle sizes that are consistent with those derived with other channels. Comparisons with the CERES SW channel on Terra from 2000 through July 2005 indicate a 0.4%/year rise in the MODIS 1.6-µm gain, but no independent verification is available. Until indicated otherwise, it is assumed that the MODIS NIR calibration is correct and stable.

Ch 20, SIR (3.75 µm): The Terra SIR channel is very similar to, but narrower than the VIRS 3.7-µm channel. Wan et al. (2002) suggest that the absolute value of the SIR radiances are biased high by ~3%, equivalent to ~0.6 K at 283 K. Minnis et al. (2002b) found that the MODIS channel 20 was 0.2 K colder than VIRS channel 3 at 300 K and 1.3 K warmer at 200 K during March 2000. Such differences will introduce some discrepancies between the VIRS and MODIS retrieved cloud properties. Theoretically, the two sensors should measure brightness temperatures to within 0.1 K of each other for clear and cloudy atmospheres. Between February 2000 and July 2005, VIRS has been averaging almost 1.0 K colder than MODIS in the SIR temperatures during daytime and by 0.6 K at night. Comparisons with Aqua MODIS between July 2002 and July 2005 show that the Terra MODIS measures SIR temperatures almost 0.6 K greater than Aqua during the daytime and more than 1.5 K larger at night. The large errors at night are due to a loss of responsivity in the Terra MODIS Collection-4 3.8-µm radiances at higher temperatures than for either VIRS or Aqua MODIS. The Terra and Aqua nighttime radiances are linearly related with a slope near unity at temperatures > 240 K. At lower temperatures the relationship is nonlinear with the Terra values asymptoting to a value of ~ 217 K when the corresponding Aqua values are ~200 K. Cloud droplet sizes derived from Terra MODIS are 0.5 to 1 µm smaller than their VIRS and Aqua counterparts as a result of the daytime calibration difference. The latter data agree better with in situ and surface-based validation data. It is concluded that the Terra MODIS SIR calibration is biased. Trend analyses using VIRS, CERES LW, and Aqua data suggest no significant changes in the Terra MODIS gain with time.

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. 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. Later analyses show no trends in the average difference between MODIS and VIRS IR temperatures through July 2005. At night, the difference is 0.0 K, while during the day, VIRS is 0.27 K warmer than MODIS. Terra and Aqua channel-31 temperatures show no differences during the daytime. At night, Terra measures temperatures 0.3 K greater than Aqua.

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. Initial comparisons showed that 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 0.84 K warmer than VIRS. It is 0.90 K warmer during the daytime. There are no differences between Terra and Aqua during the daytime, however, at night Terra is between 0.1 and 0.5 K warmer than Aqua. This difference follows an apparent trend with the difference decreasing by 0.09 K/yr. This difference is due to greater Terra temperatures at the low end of the scale, where the Terra values appear to diverge from their Aqua counterparts for temperature below 220 K, which are not seen in the daytime data. It has not yet been determined whether the nocturnal trend is real or not.

DATA PROBLEMS

Edition2A uses Terra MODIS Collection 4 radiances. MODIS data were not taken between June 16 and July 1, 2001 and during 3 days in March 2002.

Cloud Parameters

Preliminary assessment of the uncertainties in some of the cloud parameters has been completed. Many other datasets must be compared with the CERES MODIS cloud analyses before final error numbers are assigned. The cloud parameters have 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 results have been compared with the TRMM VIRS Edition2 and Terra MODIS Edition1A (see previous DQSs) quantities and are being documented in several papers either submitted or currently in preparation. Some preliminary comparisons with MODIS Edition2A datasets are discussed below. The results are similar to those found applying the CERES algorithm to GOES-8 data (Dong et al. 2002).

Cloud amount - The primary changes to the cloud mask were over polar regions, especially at night, the most difficult conditions for detecting clouds. One means for evaluating those changes is by comparing the measured downwelling longwave (LW) radiation at polar sites with similar values computed by CERES using the cloud data. The results in Fig. 5 for Barrow, AK are typical of those found over other polar sites. The CERES underestimate dropped from 60 using Edition1A to 25 W m^{-2} using the clouds from Edition2A indicating improved cloud detection.

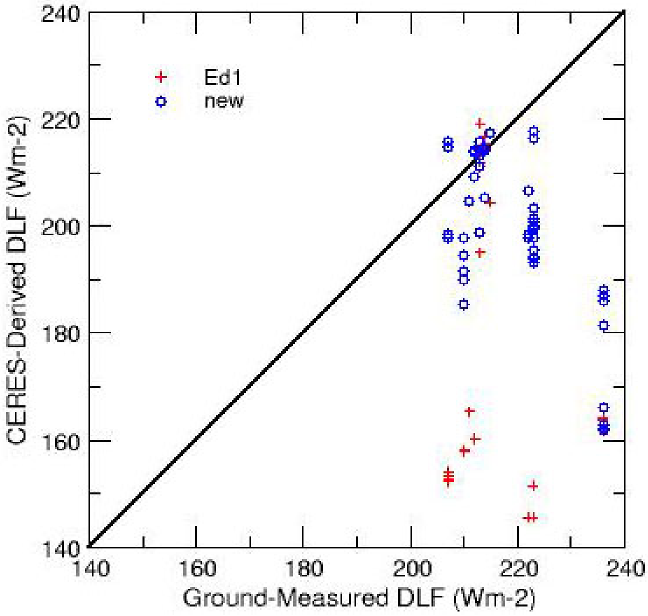

Fig. 5. Comparison of CERES-estimated and surface-measured downwelling LW flux at ARM site in Barrow, AK, November 2000 - March 2001.

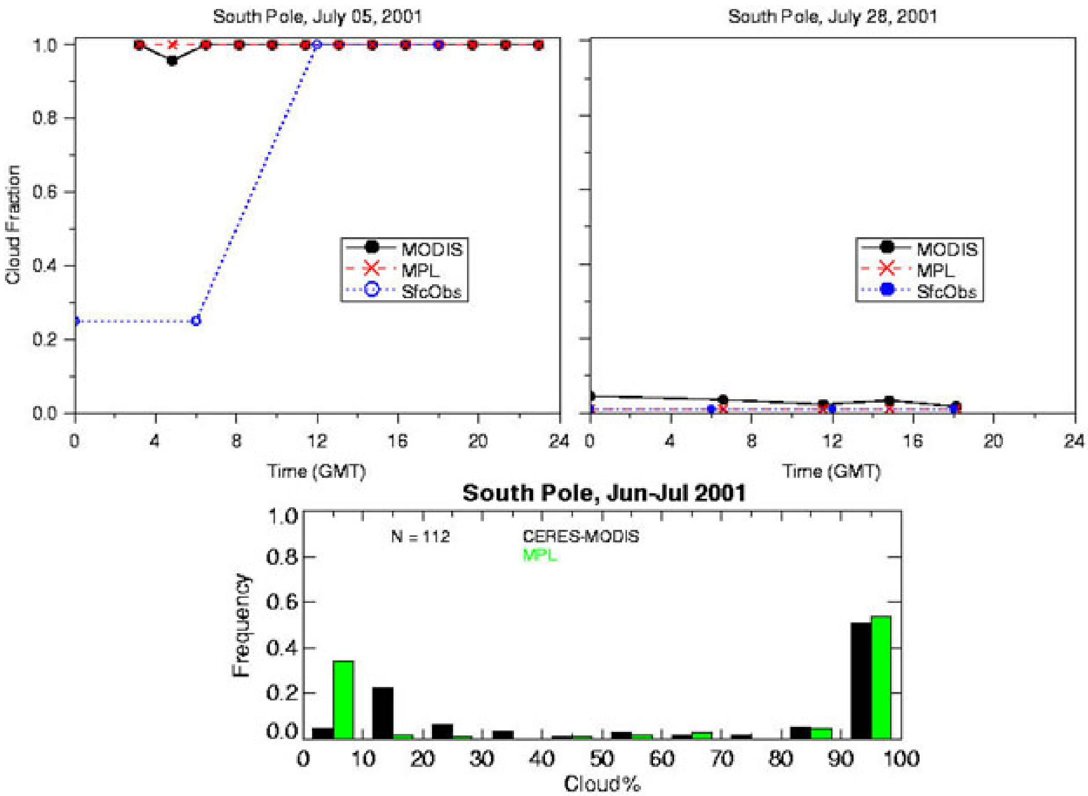

Fig. 6. Comparison of CERES Edition2A and surface-based cloud amounts at the South Pole for two individual days and for all days during June and July 2001.

The cloud amounts were also compared with cloud fractions estimated from surface observations and lidar at the ARM NSA site and at the South Pole. The results for polar night over the South Pole are summarized in Fig. 6. The MODIS cloud amounts are very similar to those from the Micropulse Lidar (MPL). The CERES mask tends to always detect a small cloud fraction in clear conditions causing a slight offset in the histograms at small cloud amounts.

The VIRS and Edition1A cloud amounts were compared with surface observer (Hahn and Warren, 1999) and ISCCP (Rossow and Schiffer, 1999) climatology on a global basis (see TRMM VIRS Edition2 and Terra MODIS Edition1A DQS). There was good agreement between the CERES results and the surface climatology except in polar areas. Table 1 compares mean cloud amounts for 2 months in the extreme seasons to ensure that one hemisphere was deep in polar night. When non-polar areas are compared, the Edition1A and Edition2A cloud amounts are within 0.2 to 1.9% of the surface data but are 5- 7% less than the ISCCP climatology. When polar regions are included, the MODIS 1A means differ by -7 to 1% from the surface amounts and by much more from the ISCCP values. For Edition2A, the CERES and surface global means differ by only 1.4 and 2.5% indicating much improved polar night cloud detection. The zonal means compare favorably as seen for Edition1A in non-polar areas and are in much better agreement over the poles with Edition 2A. The new polar masks represent a substantial improvement over Edition1A.

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 1A 12/2000, 6/2001	Terra MODIS Ed 2 12/2000, 6/2001	ISCCP D2 (1984-98)
60°S - 60°N, December	60.6	62.5	62.0	66.9
90°S - 90°N, December	63.2	56.3	65.1	69.6
60°S - 60°N, June	60.5	60.7	60.8	67.9
90°S - 90°N, June	63.1	63.9	65.9	66.7

Cloud phase - Cloud phase statistics changed negligibly between Editions 1A and 2A. Preliminary validation efforts are given in the Terra MODIS Edition1A DQS.

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. The new lapse rate method over land resulted in an average drop of 0.3 km in cloud effective heights over land areas. Comparisons with the radar observations over the ARM southern Great Plains (SGP) site are shown in Fig. 7 for optically thick stratus clouds observed during daytime using Edition1A (left panel) and Edition2A (right panel). With the older algorithm, z_c overestimated the cloud top by 0.6 km compared to only 0.1 km for the lapse rate method. The new technique also reduced the standard deviation of the difference. A similar improvement in the mean heights was realized at night also. The Edition2A cloud heights are generally the same as Edition1A over both land and water except for the 0.3-km decrease in heights over land.

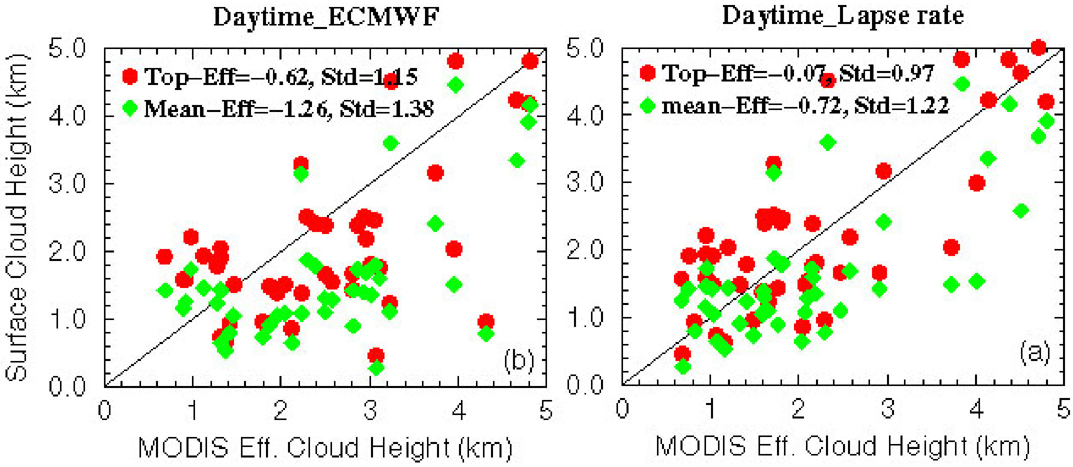

Fig. 7. Comparison of z_c and stratus cloud heights from radar data over ARM SGP for $\tau > 5$, 2000-2001.

For earlier validations, see the Terra MODIS Edition1A DQS. The most recent comparisons using Edition2A 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. At night, the effective cloud height for optically thin clouds is 0.56 km below cloud top with a standard deviation of 1.7 km. Cloud height comparisons are continuing.

Cloud optical depth, effective particle size - These parameters were also evaluated following the approach used by Dong et al. (2002) for comparing stratus cloud properties derived from GOES data with the CERES algorithm with retrievals of 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 are currently available. The stratus comparisons are summarized in Table 2. Overall, the agreement between the two datasets for stratus clouds is good during the daytime, except that the effective droplet radius from MODIS is underestimated by 14%. Combined with the small bias in optical depth, the r_e underestimate leads to an 18% understatement in LWP, on average. The bias in r_e is primarily due to the 3.75-µm calibration bias in Terra MODIS noted earlier. These results in Table 2 should be used as a guide to any desired adjustements in the results. In addition to the MODIS calibration, other sources of uncertainty include mismatches in surface and satellite fields-of-view and errors in the surface algorithms. 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.

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. The cirrus comparisons are underway and will be reported when available. Prior to CERES, the method for retrieving cirrus particle size, optical depth, and, hence, ice water path has been validated to some extent by comparisons with in situ and surface active remote sensors (Mace et al. 1998, Young et al. 1998). Duda et al. (2002) compared retrievals from MODIS with in situ data taken over Scotland and found excellent agreement between the in situ particle sizes and D_e for one case. Initial comparisons of cirrus cloud properties with radar (Mace et al. 2005) and radiometer (Min et al., 2004) retrievals indicate that the cirrus cloud optical depths are overestimated by ~0.5, the effective particle sizes are within 1 -2 µm on average, and the ice water paths are within a few gm^{-2}. Thus, it is concluded that the cirrus cloud optical depths are reasonable. However, a more quantitative evaluation is underway using the SGP radar data and additional in situ data taken during recent field programs.

Table 2: Uncertainties in cloud parameters based on comparisons at the ARM SGP site.

		Mean difference (CERES- ARM)	Standard deviation	Mean (Stddev) 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	-1.5 km	1.2 km	-	34
	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	-1.2	7.7	-6 (36)	36
	Stratus effective radius	-1.3 µm	2.8 µm	-14 (30)	36
	Liquid water path	-29 gm^{-2}	85 gm^{-2}	-18 (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 Edition2 and

Terra MODIS Edition1A Data Quality Summaries. No differences are expected for Terra MODIS Edition2A.

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).

Consistency with VIRS and Aqua

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 Edition2 zonal mean results for December 2000 and June 2001 have been compared to those from MODIS Edition1A products for the same time period to provide a measure of the consistency in the results for the two instruments. The consistency is the same for Edition 2B as that found for Edition1A except that the MODIS water cloud heights over land are reduced on average by 0.3 km as a result of the new lapse rate method for determining height from cloud temperature. Many comparisons have also been performed between the Aqua Edition1B and Terra Edition2B. The reader is referred to the Terra MODIS Edition1A and Aqua MODIS Edition1B Data Quality Summaries (Cloud Properties - Accuracy and Validation Section), Minnis et al. (2002c, 2002d, 2003, 2004), and Sun-Mack et al. (2006) for details.

Sub-polar Daytime Cloud Amounts

(Applies only to Terra Edition2 and not any Aqua versions)

After processing of Terra Edition2 began, a coding error was discovered that has a *severe negative impact* on the quality of some cloud products, primarily amount, in some ocean areas within the latitude bands, 50°N-60°N and 50°S-60°S during their respective summer and autumn periods. The 50°-60° latitude band is the polar transition zone. This error affects ocean and coastal regions only. Pure land regions are unaffected. The error is operative over the Northern Hemisphere roughly between April and October. Conversely, the Southern Hemisphere transition region is affected between October and April. The problem is not significant in most areas, but in the noted regions, the Terra Edition2A data should be used with caution. In the current formulation, the ocean clear-sky albedo is only updated in polar regions. In non-polar areas, the clear-sky ocean visible reflectance is specified using the standard ice-free ocean albedo model. A clear-sky albedo map is used in the polar regions. If no ice is present in the snow-ice map, the standard ice-free ocean albedo model is used to specify the clear-sky reflectance and the standard non-polar cloud mask is used. If the mask classifies a scene as clear ocean in the transition zone, the clear-sky map would not be updated to reflect that condition since the ocean map is only updated in polar regions. When the ice-snow map indicates ice or snow in a given 10' box, then the mean snow-ice albedo is used to specify clear-sky reflectance. If the polar mask detects clear snow and ice, the clear-sky map is updated to use the detected value as the new clear-sky albedo. This new updating scheme is used to ensure that the changes in the albedo of the melting ice pack during summer are incorporated into the clear-sky background reflectance because the ice visible albedo can vary by almost a factor of two during the summer even if it never melts completely. The effect of the updating can be seen in Fig. 8 off the coast of Baffin Island and over the Laptev Sea off the coast of Siberia. The area covered by ice shrinks in both of these regions between July 4, 2001 and July 31, 2001. Similarly, most of the albedos of the Arctic Ocean ice pack decreased from 0.7 - 0.9 to 0.6 - 0.8 during the same interval.

The problem arises in the transition zones. Whenever the snow-ice map indicates ice in the ocean for these zones, the polar mask will be used and the clear-sky albedo will be updated if the clear ocean is detected. If clear ice/snow is present then the region will be given the bright albedo, or if clear ocean is detected, it will update the map using the lower observed value. In this zone, however, the map was never updated when the snow-ice map indicated no snow or ice. Therefore, whenever the snow-ice map no longer indicated the presence of ice, the algorithm did not update the albedo. The result is that in some areas within the transition zone, the bright updated albedo remained in the clear-sky map even after the snow melted. Instead of using the ice-free ocean albedo normally applied in non-polar regions, the algorithm used the clear-sky albedo map and the standard mask was used. This effect is evident in Fig. 8 in the Hudson Bay and the Sea of Okhotsk between the Kamchatka Peninsula and mainland Asia.

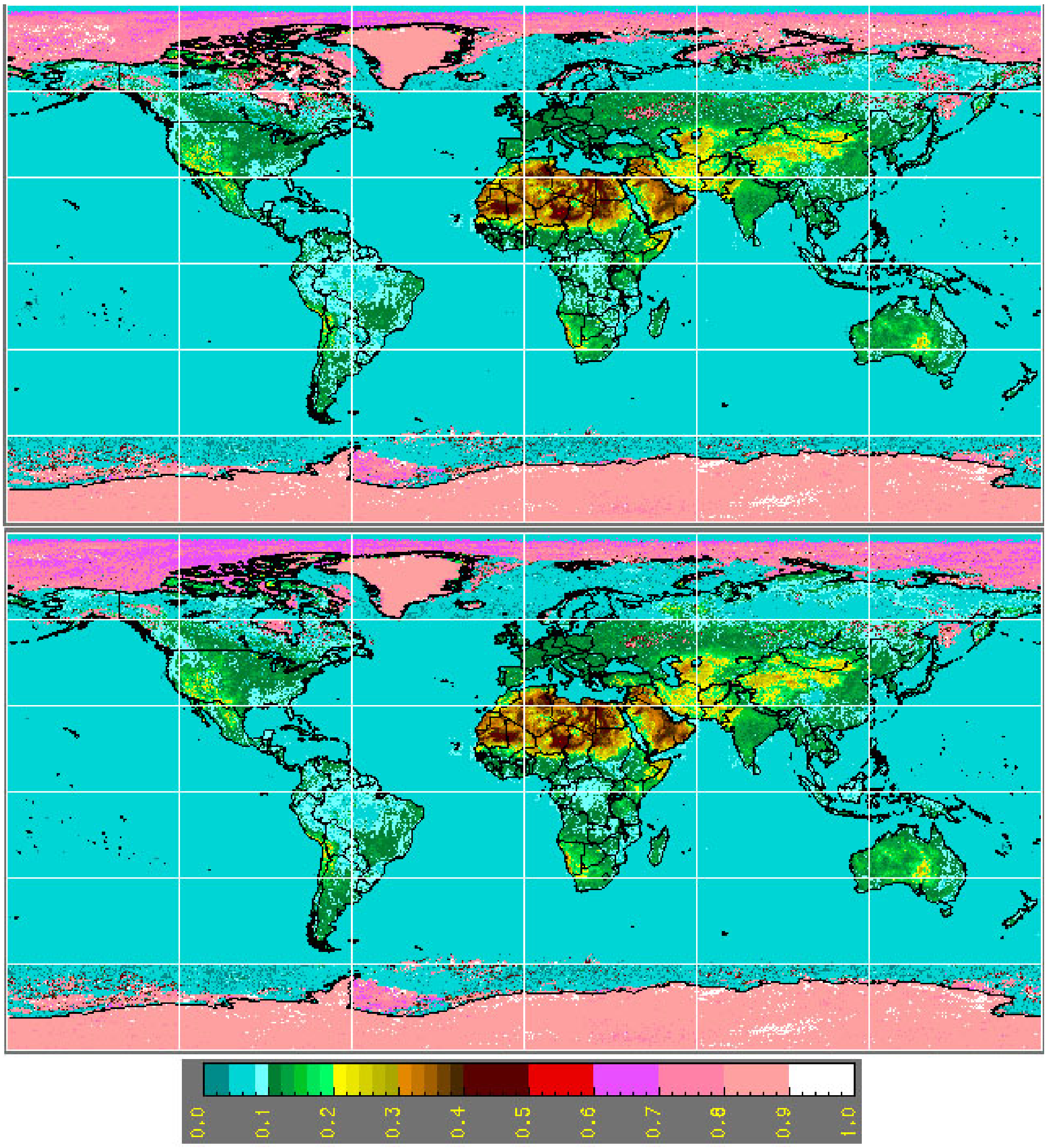

Fig. 8. Updated clear-sky albedo maps for July 4, 2001 (top panel) and July 31, 2001 (lower panel).
The clear-sky albedo is not updated over the Hudson Bay or Sea of Okhotsk south of 60°N to account for melting of the ice.

The effect of this error is to overestimate cloud cover in any area affected by this problem. Subsequent effects will be the selection of the wrong anisotropic directional model for interpreting the CERES SW and LW radiances and cause flux errors. The potential errors are confined to any ocean or coastal region within the transition zone that is subject to freezing and ice formation.

To examine the effects of this error, the algorithm was corrected and run offline for 4 summer days in each hemisphere. The results are summarized in Table 3 for the two regions most affected by this problem. The Sea of Okhotsk is the worst with cloud cover overestimates exceeding 40% on 2 days. The number of no retrieval cloud pixels is also very large because the clear-sky background albedo is not consistent with the scene. Over the Hudson Bay, the errors are significant but not as large as over the Sea of Okhotsk. Overall, for the remainder of the Northern Hemisphere transition zone, the cloud fraction differences are all less than 1% between the Edition2 and corrected version that was run offline. The small difference in these other areas is primarily due to some slight differences in the operational clear ocean albedo and the one used in the offline startup albedo map. In the Southern Hemisphere transition zone, the "bright spots" are much smaller and concentrated near longitudes 10°E, 150°E, and 100°W. The cloud amount overestimates in those bright spot areas are between 2.5 and 3.5%. The no-retrieval percentages are around 1.5% for Edition2 and 0.5% after the algorithm was corrected. The small differences in the other parts of the zone are primarily due to the operational and offline ocean albedo maps. The problem is not significant in most areas but in the noted regions, the Terra Edition2 data should be used with caution.

Table 3. Differences in regional cloud amounts for 4 days in July 2001 using current Edition2 and corrected version and number of no retrieval cloud pixels for each case.

Location	Day	Correct - Ed2 water	Correct - Ed2 ice	No Retrievals (%)	
				Ed2	Correct
Sea of Okhotsk	4	33%	0.6%	5.0	0.5

	11	28%	14%	20.0	1.4
	21	40%	1.6%	13.5	3.0
	31	41%	0.1%	4.3	1.8
Hudson Bay	4	6.3%	0.1%	2.7	2.3
	11	2.6%	0.7%	2.4	1.7
	21	5.0%	3.6%	2.8	1.7
	31	0.9%	0.5%	1.5	1.3

Return to Quality Summary for: SSF Terra Edition2A