2.8 NEW GEOSTATIONARY-ENHANCED CERES MONTHLY MEAN RADIATIVE FLUXES AND CLOUD PROPERTIES

David F. Young, Bruce A. Wielicki, Takmeng Wong
NASA Langley Research Center, Hampton, VA

Martial A. Haeffelin
Laboratoire de Meteorologie Dynamique, LMD-Ecole Polytechnique, F-91128 Palaiseau Codex, France

David R. Doelling
AS&M, Inc., Hampton, VA

Jeff S. Boghosian
SAIC, Hampton, VA

1. INTRODUCTION

The Clouds and the Earth's Radiant Energy System (CERES) Experiment is the latest and most accurate satellite-based instrument designed to measure the Earth's global energy budget (Wielicki et al., 1996). With improvements in instrument calibration accuracy and stability, coupled with the development of new angular directional models, temporal sampling is the largest remaining error source for CERES regional monthly mean fluxes. CERES addresses the time sampling issue in two ways. First, CERES was designed to sample the diurnal cycle using a 3-satellite constellation with instruments aboard the sun-synchronous Terra and Aqua satellites and the temporally precessing Tropical Rainfall Measuring Mission (TRMM) spacecraft. Second, improved modeling of unsampled time periods is provided by the incorporation of 3-hourly radiance and cloud property data from narrowband instruments aboard geostationary (GEO) satellites. The failure of the CERES TRMM instrument in April 2000, and launch delays for Terra and Aqua have resulted in single-satellite coverage for most of the mission to date. The use of geostationary data has become crucial for the accurate modeling of diurnal variations of clouds and radiation during these time periods when the full complement of CERES instruments is not available.

This paper reviews the techniques used to calculate monthly mean fluxes for CERES and the first results of this new interpolation process. Comparisons between monthly mean fluxes calculated with and without geostationary imager data provide a look at the improvement derived from this technique. Finally, a summary is provided of the methods used to validate these data.

2. CERES MONTHLY PRODUCTS

The CERES Project operationally produces several complementary monthly mean products. The first publicly available CERES product was the ERBE-like product which is designed to provide a climate data record consistent with the Earth Radiation Budget Experiment (ERBE). The second generation CERES monthly mean products, called the Monthly TOA/Surface Averages (SRBAVG), have been processed using algorithms that remove angular and sampling biases found in the ERBE-like data and provide extensive additional cloud and radiation information.

Table 1. Comparison of ERBElike and SRBAVG products

ERBE-like	**SRBAVG**
ERBE scene ID algorithm	Scene ID from imager data
Fluxes derived using ERBE ADMs	Fluxes derived using new CERES ADMs
ERBE interpolation algorithm	GEO-enhanced interpolation
2.5¡ equal-angle grid	1.0¡ equal-angle grid
TOA fluxes only	TOA and Surface fluxes
Limited cloud information	Detailed cloud properties

The SRBAVG data product contains monthly and monthly-hourly regional, zonal, and global averages of the top of the atmosphere (TOA) and surface longwave (LW), shortwave (SW) and Window (WN) fluxes and the observed cloud conditions. The regional means for each 1¡ equal-angle grid box are calculated by first interpolating each parameter between the times of the CERES observations in order to produce a complete 1-hourly time series for the month. After interpolation, the time series is used to produce mean parameters on two time scales. Monthly means are calculated using the combination of observed and interpolated parameters from all days containing at least one CERES observation. Monthly-hourly means are produced from the time series by dividing the data into 24 local hour bins to define a monthly mean diurnal cycle. There is one SRBAVG product for each month of data from each CERES instrument. There is also a separate SRBAVG for each possible combination of data from multiple CERES instruments.

The major differences between the SRBAVG and ERBE-like products are summarized in Table 1.

3. METHODOLOGY

Two methods of interpolation are used to produce two separate sets of monthly means that are archived

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**Corresponding author address*: David Young, MS 420, NASA Langley Research Center, Hampton, VA 23681. email: d.f.young@larc.nasa.gov.

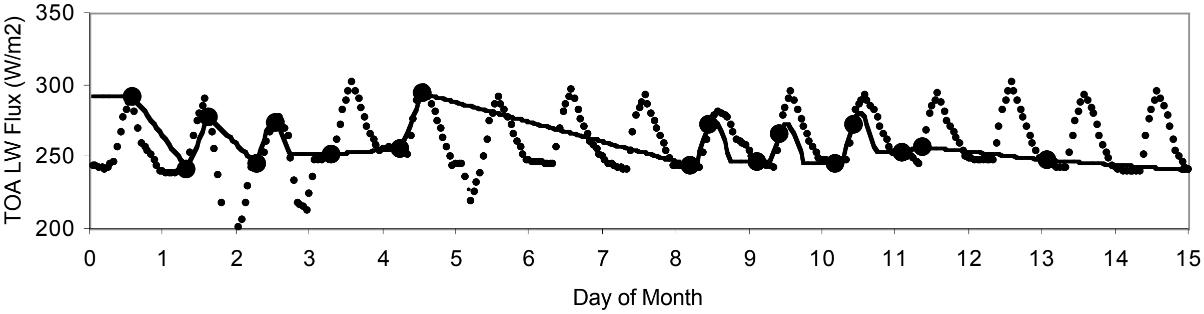

Figure 1. Example of GEO (small dots) and nonGEO (line) LW flux interpolation. The CERES observations are designated by the large solid circles. This example is from the first 15 days of January 1998 over the Eastern Sahara.

on the SRBAVG (Young et al., 1998). The first interpolation method (termed non-GEO) interpolates the CERES observations using the assumption of constant meteorological conditions similar to the process used to average CERES ERBE-like data. This technique provides the user with monthly fluxes that are more readily compared with the ERBE-like fluxes. These fluxes represent an improvement to ERBE-like fluxes due to improvements to input fluxes, scene identification, and new models of the solar zenith angle dependence of albedo as a function of the new CERES angular distribution model (ADM) scene types (Loeb et al., 2002). The second interpolation method (GEO) uses 3-hourly 0.65 and 11 µm radiance and cloud property data from geostationary imagers to more accurately model meteorological variability between CERES observations. The geostationary imager data from each satellite are calibrated against coincident TRMM VIRS imager measurements each month using the technique of Minnis et al. 2002. In order to ensure consistency with CERES cloud products, cloud properties are derived from the geostationary data using a subset of the CERES cloud property retrieval algorithms (Minnis et al., 1995). The narrowband radiances are converted to simulated broadband fluxes using scene dependent conversions based on matched VIRS and CERES data. Finally, the imager-derived flux time series is normalized to the CERES observations to eliminate possible biases due to the limited accuracy of simulating broadband fluxes from narrowband data.

A comparison of the GEO and nonGEO interpolation methods is illustrated in Fig. 1. On days with good sampling (for example, days 8–11), the nonGEO interpolation captures most of the diurnal variation in LW flux). However, the monthly mean diurnal cycle will be underestimated from days with no daytime sampling such as days 12-14. The GEO interpolation provides full diurnal sampling for each day. Note that the GEO time series is normalized to the CERES observations.

4. FIRST RESULTS

The first SRBAVG products released to the scientific community are derived from the TRMM time period, from January-August 1998 and March 2000. The temporal sampling by CERES on TRMM presents a unique challenge for temporal interpolation. TRMM is in a 35° inclination orbit that precesses through 24 hours of local time in 46 days. This orbit provides sampling at all local times during a single month only in latitudes near the equator. Regions between 25°-40°N and 25°-40°S are typically sampled disproportionally during either the daytime or nighttime. The temporal sampling patterns from February 1998 for regions at 35°N and 35°S are shown in Fig. 2. During this month, the sampling at 35°N is predominantly during daylight hours. The reverse is true for 35°S. If uncorrected, this sampling leads to overestimations of LW flux in the Northern Hemisphere and underestimates in the Southern Hemisphere, particularly for land and desert regions with large diurnal cycles.

Figure 3 shows the improvement in modeling the LW diurnal cycle using the GEO method. The monthly mean noon/midnight flux difference was calculated for the GEO and nonGEO methods. Figure 3 is a plot of the increase in the diurnal range calculated using the GEO method. Differences as great as 60 W/m^2 occur over the Sahara and Gibson deserts.

Apart from the diurnal range, the monthly mean fluxes are also affected by sampling. The north/south temporal sampling differences illustrated in Fig. 2 can even cause errors in estimates of meridional flux gradients. Figure 4 shows the zonal mean GEO-nonGEO TOA LW flux difference for both clear-sky and total-sky conditions. The GEO method helps to reduce the positive flux bias in the Northern Hemisphere and the negative bias in the South.

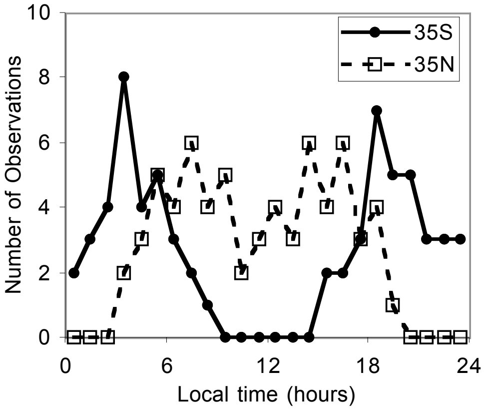

Figure 2. Temporal sampling by CERES for regions at 35°N and 35°S during February 1998.

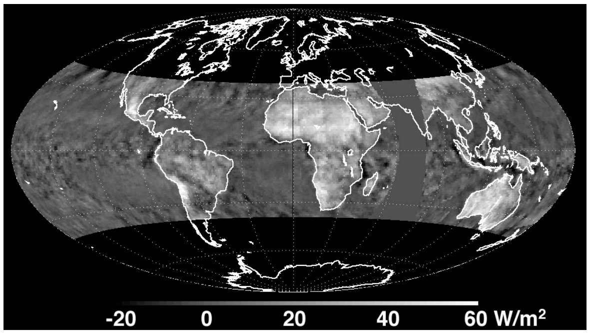

Figure 3. GEO - nonGEO difference in monthly mean noon/midnight LW flux variation.

5. VALIDATION & CONSISTENCY

Validation of the SRBAVG parameters involves three main areas. The first and most basic validation concerns checking the accuracy of both interpolated and monthly mean flux values using comparisons with other broadband data. The second main validation effort is focused on the radiance calibration and the cloud properties derived from the geostationary imager data. Finally, the models used in interpolating SW fluxes are tested using comparisons with direct integration of observed fluxes.

Preflight validation of the GEO flux interpolation techniques used comparisons of interpolated fluxes from ERBE observations from several satellites (Young et al., 1998). These simulations demonstrated that the GEO method reduced interpolation errors by 50% for both LW and SW TOA fluxes. Post-flight validation of the interpolated fluxes and the resulting monthly mean fluxes is difficult due to the lack of high temporal resolution broadband data sets. During the next 2 years, data from the Geostationary Earth Radiation Budget (GERB) experiment aboard the METEOSAT Second Generation satellite will be available to test the interpolations over a wide range of cloud and surface type regimes. The recent launch of CERES on Aqua will also enable CERES comparisons similar to the ERBE study.

One of the major advancements provided by the SRBAVG product is the inclusion of surface fluxes. These fluxes are derived from the CERES TOA fluxes using empirical TOA-to-surface relationships (Gupta et al., 2002). Surface fluxes can be used for validation since there are now several surface sites producing excellent quality time series of surface fluxes. An example of such a comparison is shown in Fig. 5. The time series of surface downwelling LW flux estimated by CERES and from surface instruments over the Atmospheric Radiation Measurement Program (ARM) Southern Great Plains (SGP) site is shown for the first 15 days of February 1998. The CERES data are fluxes valid at the local half-hour compared with 30-minute averages of the surface data centered on the local half-hour. The time series match well for most of the period with some notable exceptions. On Day 3, there is a large (approximately 90 W/m^2) discrepancy that is most likely caused by the presence of a nighttime low cloud that is not detected using the GEO data. The monthly mean bias for the entire month of February over this site is 1.8 W/m^2 with an hourly rms difference of 28.2 W/m^2. If the comparison is done using only the CERES observations and not the interpolated values, the mean and rms differences are reduced to –0.4 W/m^2 and 19.5 W/m^2, respectively. The slight increase in mean bias suggests that the interpolation should produce fairly accurate monthly means while instantaneous differences should increase in cases lacking sufficient cloud information.

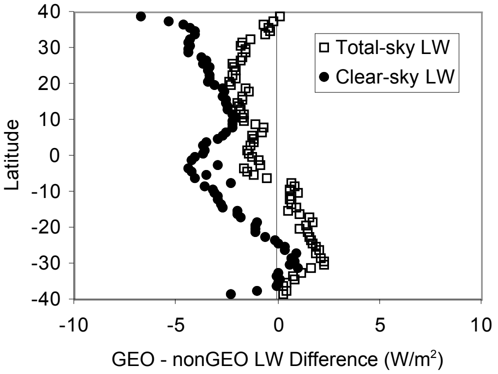

Figure 4. GEO – nonGEO zonal mean TOA LW flux difference for February 1998.

Further comparisons of surface flux will be performed using additional surface sites and all of the TRMM months. Monthly means will be compared with monthly estimates calculated by integrating the surface measurements. Comparisons with surface fluxes from the Surface Radiation Budget (SRB) project will also be used to expand comparisons globally.

The sensitivity of the monthly mean fluxes to calibration of the geostationary imager data has also been tested. Changes in the mean fluxes were calculated for four cases where the GEO imager radiances were changed by ±5%. This exceeds the expected accuracy of ~3% from VIRS matching. The results are summarized in Table 2. The flux normalization completely removes the calibration errors for the total-sky LW. The clear-sky LW changes only slightly (<0.2%) owing to changes in clear-sky determination in the GEO data. The biggest effect is in the SW flux where a 5% calibration error results in ~1% change in the monthly mean. However this effect is minimal compared with the advantages of defining the SW diurnal cycle provided by the GEO method.

Validation is also underway of the GEO calibration and cloud properties. Cloud temperature, fraction, and optical depth from each individual geostationary imager are compared with coincident estimates from VIRS. In general, the mean GEO imagers cloud fractions are within 5% of VIRS. GEO optical depths are consistently 8-10% less than VIRS due primarily to the larger pixel sizes and the inclusion of larger viewing zenith angles. Cloud temperatures are 2-3 K colder in the daytime due to the optical depth bias and 2-4 K warmer at night since no emissivity correction can be made using the single IR

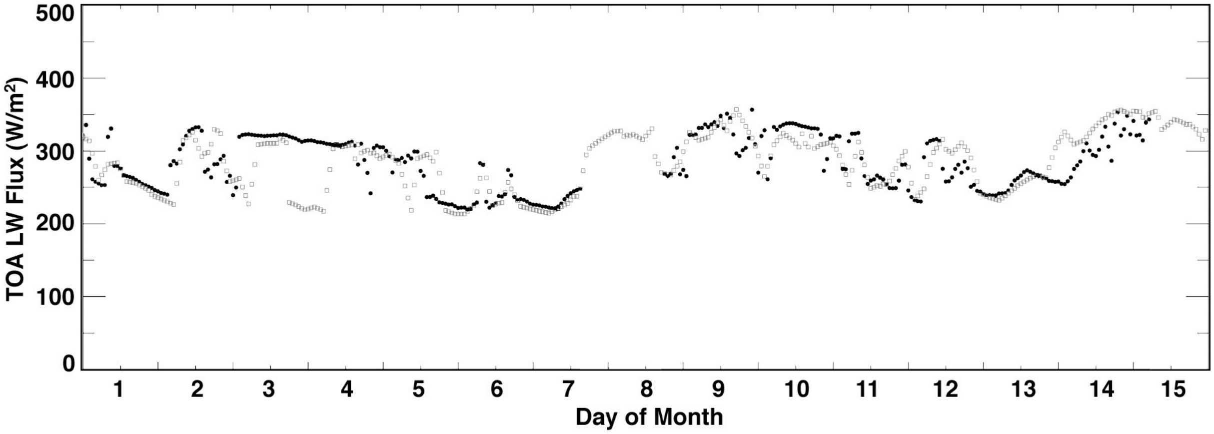

Figure 5. Time series of CERES (gray symbols) and surface-observed (black symbols) downwelling surface LW flux at the ARM SGP site from the first 15 days of February 1998.

channel from the GEO imagers. Cloud properties are also being compared with the recently released 1998 International Satellite Cloud Climatology Project data. These comparisons will be completed before the final release of the SRBAVG data.

Finally, SW interpolation is being tested by comparing monthly mean diurnal cycles from the GEO method with diurnal variations derived by direct integration of the observations over one or more complete 46-day precession cycle. It should be possible to demonstrate that the GEO method can produce the same diurnal variability using time scales of less than 46 days (such as the length of a calendar month.)

6. CONCLUDING REMARKS

The new geostationary-enhanced monthly mean CERES data products represent a major improvement over previous Earth radiation budget data sets. The first Beta quality SRBAVG products became publicly available in May 2002. Although Beta products are not deemed ready for use in scientific publications, these products still provide the user with an example of the types of products soon to be available. The first validated SRBAVG products are scheduled to be archived in September 2002. The data can be obtained from the NASA LaRC Atmospheric Sciences Data Center (http://eosweb.larc.nasa.gov).

Table 2. Sensitivity of monthly mean fluxes to GEO imager calibration

	Mean Flux	Mean & (rms) Flux Difference (W/m^2)			
		IR+5%	IR-5%	Vis+5%	Vis-5%
Total-Sky LW	257.8	0.01 (0.08)	-0.01 (0.08)	0.00 (0.00)	0.00 (0.00)
Total-Sky SW	99.3	-0.04 (1.35)	0.54 (3.10)	0.94 (1.31)	-0.94 (1.31)
Clear-Sky LW	284.7	-0.29 (0.69)	0.30 (0.92)	0.01 (0.27)	-0.02 (0.26)

REFERENCES

Gupta, S. K. D. P. Kratz, P. W. Stackhouse, Jr. and A. C. Wilber, 2001: The Langley Parameterized Shortwave Algorithm (LPSA) for Surface Radiation Budget Studies, NASA TP 2002-211272, 31 pp.

Loeb, N. G. et al. 2002: Angular distribution models for top-of-atmosphere radiative flux estimation from the Clouds and the Earth's Radiant Energy System instrument on the Tropical Rainfall Measuring Mission satellite. Part I: Methodology. Submitted *J. Appl. Meteorol.*

Minnis, P. et al., 1995: Cloud Optical Property Retrieval (Subsystem 4.3). In *Clouds and the Earth's Radiant Energy System (CERES) Algorithm Theoretical Basis Document, Volume III: Cloud Analyses and Radiance Inversions (Subsystem 4)*, *NASA RP 1376 Vol. 3*, edited by CERES Science Team, pp. 135-176.

Minnis, P., L. Nguyen, D. R. Doelling, D. F. Young, W. F. Miller, and D. P. Kratz, 2002: Rapid calibration of operational and research meteorological satellite imagers. Part I and II. *J. Atmos. Oceanic Technol.*, in press.

Wielicki, B. A., B. R. Barkstrom, E. F. Harrison, R. B. Lee III, G. L. Smith, and J. E. Cooper, 1996: Clouds and the Earth's Radiant Energy System (CERES): An Earth Observing System Experiment. *Bull. Amer. Meteor. Soc.*, **77**, 853-868.

Young, D. F., P. Minnis, D. R. Doelling, G. G. Gibson, and T. Wong, 1998: Temporal Interpolation Methods for the Clouds and Earth's Radiant Energy System (CERES) Experiment. *J. Appl. Meteorol.,* **37**, 572-590.