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1 INTRODUCTION

The Clouds and the Earth's Radiant Energy System (CERES) project has recently released a multi-year global energy budget data set that represents a major advancement over currently available data. This 3-year Terra-based climate focused Clouds and the Earth's Radiant Energy System (CERES) Surface Radiation Budget Average (SRBAVG) data product contains 1° gridded radiative surface and top of atmosphere (TOA) fluxes, cloud and aerosol properties. A key feature of this product is the combination of CERES fluxes with imager-derived broadband fluxes from 5 geostationary (GEO) satellites at 3-hourly intervals to minimize diurnal sampling errors of the sun-synchronous orbit of Terra. The major breakthrough in this new release is the ability to eliminate GEO calibration changes in the merged CERES and GEO product.

CERES has two SRBAVG products depending on temporal interpolation between CERES measurements. The first method **SRBAVG-nonGEO (CERES only flux) product** interpolates the CERES observations using the assumption of constant meteorological conditions similar to the process used to average CERES ERBE-like data. The second interpolation method contained in the **SRBAVG-GEO (CERES & GEO flux) product** uses 3-hourly radiance and cloud property data from GEO imagers to more accurately model variability between CERES observations. This technique represents a major advancement in the reduction of temporal sampling errors (Young et al. 1998).

This paper is the companion paper to the Doelling et al. 2006, which describes the CERES SRBAVG products and the derivation of GEO fluxes from imager radiances in the SRBAVG-GEO product. This paper focuses on the validation of the GEO derived fluxes in the SRBAVG-GEO product, which were designed to ensure the GEO fluxes, are within climate quality standards. The GEO fluxes must maintain the CERES instrument calibration, with a calibration stability of better than 0.2% (Priestley et al. 2006) and be free of GEO sampling artifacts

The full suite of CERES GEO derived broadband flux validation activities will be presented in this paper. Much of this work is in the SRBAVG Edition 2D Data Quality Summary (DQS) (http://eosweb.larc.nasa.gov/PRODOCS/ceres/SRBAVG/Quality_Summaries/CER_SRBAVG_Terra_Edition2D.html), which inform users of the accuracy of the CERES SRBAVG data product as determined by the CERES Science Team. All the CERES products can be obtained at the Langley DAAC (http://eosweb.larc.nasa.gov/PRODOCS/ceres/table_ceres.php)

2 AQUA/TERRA COMPARISONS

The CERES instruments are onboard both the Terra Aqua satellites. Since Terra has an equatorial crossing time of 10:30 LT and Aqua of 13:00 LT, the interpolated fluxes of one satellite can be validated with the observed fluxes of the other on an instantaneous basis. Since the calibration differences between the Aqua and Terra CERES instruments are minimal (Priestley et al. 2006), the instantaneous difference is the error in the GEO flux derivation and GEO-CERES normalization in the SRBAVG-GEO (CERES & GEO flux) product from one satellite compared with an independent "truth" flux measurement. Similarly the analysis can be performed with the SRBAVG-nonGEO (CERES-only flux) product, which would measure the effects of temporal interpolation assuming constant meteorology. These temporal interpolation methods are outlined in Young et al. 1998 and are similar to the ERBE methods. In the LW linear interpolation is used to complete the hourly time series between measurements. For clear-sky LW land a half-sine fit between sunrise and sunset is used to account for daytime heating. In the SW, directional models or albedo versus solar zenith angle models based on linearly varying cloud conditions are used.

Fig.1 shows the rms error for the Terra interpolated and Aqua observed SW flux at 13:00LT for December 2002 for nonGEO and GEO products. Generally all regions had significant reduction in rms error. Instantaneous regional bias and RMS error statistics were computed for the flux differences of Terra temporally interpolated at Aqua observed times and visa

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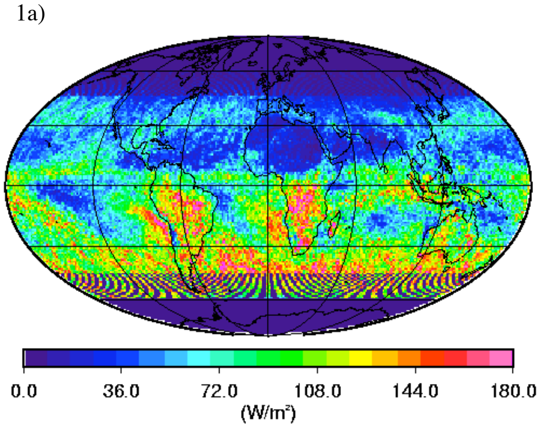
versa across the GEO domain of ±60° latitude, during July 2002 to February 2003. Table 1 shows the results for SW and LW daytime, and LW nighttime, for both SRBAVG-nonGEO and SRBAVG-GEO fluxes. There is generally a 50% reduction in the rms error between nonGEO and GEO SW and LW fluxes, whether temporally interpolating Aqua or Terra. The instantaneous GEO rms differences are 14.5% and 4.6% for SW and LW respectively. The GEO fluxes are able to capture the flux signal due to changing cloud conditions. However there is always the concern if there are systematic biases introduced with the addition of GEO fluxes in the data stream. The mean instantaneous bias differences are < 1% and no worse than the corresponding nonGEO fluxes. The one exception is LW night over land (not shown), where the bias is 1% and is due to a possible nighttime negative bias over deserts and land at night. The LW narrowband to broadband technique is being carefully examined, which will be manifested in the Edition 3 products.

1a)



1b)

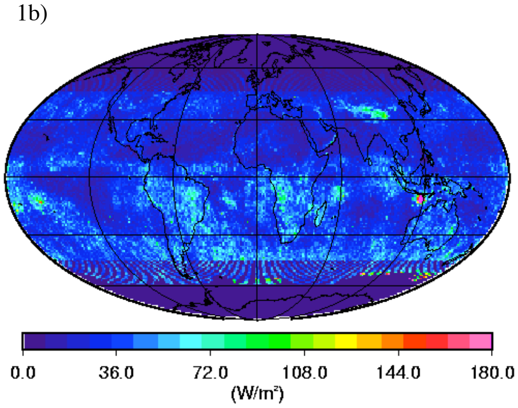


Fig 1. Terra interpolated fluxes – Aqua observed instantaneous TOA all-sky SW regional rms error for December 2002 for nonGEO a) and GEO b) fluxes. Disregard the patterns between 45°-60° latitude. The CERES nested grid is not properly displayed.

Table 1. Terra interpolated-Aqua observed (Terra) and Aqua interpolated-Terra observed (Aqua) instantaneous flux bias and rms errors during July 2002 to 2003. nonGEO and GEO flux statistics are given for ±60° latitude

(%)	nonGEO		GEO	
interpolated	Terra	Aqua	Terra	Aqua
SW bias	0.6	-1.0	0.4	1.0
SW rms	33.7	33.5	14.4	14.6
LW-day bias	-0.5	0.4	0.2	0.7
LW-day rms	8.0	8.2	4.6	4.6
LW-nite bias	0.3	0.0	-0.5	-0.3
LW-nite rms	7.5	8.3	4.3	4.7

The Aqua and Terra monthly means were tested for consistency between the nonGEO and GEO methods for the same domain and time period. One would expect a smaller difference in the GEO monthly mean derived from Aqua and Terra than with the nonGEO monthly mean. Table 2 shows the Terra-Aqua monthly mean bias and rms error for nonGEO and GEO products. The monthly mean regional rms error is 4.2% and 0.9% for GEO SW and LW respectively. This equates to a 60% and 30% reduction in rms error from nonGEO. There is no discernable difference in the bias between nonGEO and GEO SW or LW fluxes and they are within 1%.

Table 2. LW and SW Terra-Aqua global monthly mean bias and regional rms error for nonGEO and GEO for the same time period and domain as Table1.

(%)	nonGEO		GEO	
	bias	rms	bias	rms
SW	1.3	10.0	0.7	4.2
LW	0.0	1.4	0.2	0.9

3 GEO CALIBRATION SENSITIVITY STUDY

The purpose of the GEO calibration sensitivity study is to test the effectiveness of the GEO-CERES normalization. The GEO radiances are first uniformly calibrated with MODIS within an accuracy of 3-5% in the visible (VIS) and 1% in the IR. The GEO derived fluxes are very sensitive to GEO satellite calibration anomalies. These anomalies are removed with GEO-CERES normalization based on matched coincident measurements in order to maintain the CERES calibration in the GEO (CERES & GEO product) flux data stream. In this study the GEO radiances are artificially adjusted by ±5%, the limit of the calibration uncertainty with MODIS, directly impacting the flux estimates. Also, these radiances are then used to derive cloud properties, which effect the scene identification of the narrowband to broadband conversion and CERES angular directional models (ADM) to invert radiances fluxes.

For the month of July 2002 the SW and LW fluxes were recomputed for VIS+5%, VIS-5%, IR+5%, and IR-5% cases. The global mean (VIS+5%)-(VIS-5%) and (IR+5%)-(IR-5%) LW and SW bias and rms error are shown in Table 3 for both clear-sky and all-sky conditions. This represents a change of 10% in GEO calibration. The largest GEO calibration uncertainty is in the visible and the all-sky SW bias is <0.1% and regional RMS <1%. This validates the effectiveness of the GEO-CERES normalization technique. Virtually no change is seen for all-sky LW and clear-sky SW. The clear-sky GEO SW replicates the nonGEO, since it is difficult to resolve GEO spectral differences over land and clear-sky albedos are predictable. However the amount of clear-sky could alter the global mean, but Table 3 shows that there is no such impact. However changes in cloud amount does effect the clear-sky LW, since a 5% increase in the IR increases the clear-sky amount. The IR clear-sky threshold is based on modeled (GEOS4) skin temperatures. The bias is 0.35%, however the uncertainty in the GEO IR calibration is 1% and the bias represents a 10% uncertainty. The GEO-CERES normalization removes the sensitivity to the GEO calibration

Table 3. The July 2002 global mean (VIS+5%)-(VIS-5%) and (IR+5%)-(IR-5%) LW and SW bias and rms error

(%)	(IR+5%)-(IR-5%)		(VIS+5%)-(VIS-5%)	
	bias	rms	bias	rms
SWall-sky	0.1	0.9	0.01	0.8
SWclear-sky	<0.01	0.2	<0.01	0.3
LWall-sky	<0.01	0.02	<0.01	<0.01
LWclear-sky	-0.35	0.7	0.03	0.2

4 SURFACE FLUX COMPARISON

Surface flux measurements remain one of the few high temporal site independent broadband flux datasets. CERES uses surface flux parameterizations to estimate surface fluxes (http://eosweb.larc.nasa.gov/PRODOCS/ceres/SSF/Quality_Summaries/ssf_surface_flux_terra_ed2B.html). Surface LW fluxes are essentially decoupled from the TOA, however the surface SW flux is highly dependent on the TOA flux. The monthly mean SW surface fluxes from the CAVE (http://www-cave.larc.nasa.gov/cave/) database, for 34 globally well distributed sites, were computed and compared with the Model B Langley Parameterized Shortwave Algorithm (LPSA) from the SRBAVG-GEO product during March 2000 to February 2003. Surface fluxes are not available with the SRBAVG-nonGEO product, however the CERES Single Satellite Footprint (SSF) product contains surface flux estimates based on CERES TOA fluxes from the LPSA method. Thus the GEO surface fluxes can be compared with SSF fluxes for consistency.

The SRBAVG-GEO monthly mean surface flux bias is 3.2% compared with mean instantaneous bias of 3.3% obtained from SSF. The corresponding rms error is 11.3% and 15% respectively. It must be remembered that the SSF surface flux is an instantaneous 10:30LT statistic, therefore one would expect a greater rms error in the SSF surface fluxes. There is always great difficulty when comparing with ground sites. Some ground sites are located on the coasts or mountainous terrain or at the edge of the 1° region that is used for comparison and would explain part of the large rms error. However the GEO and SSF biases are similar, indicating consistency of the TOA fluxes from CERES and GEO. The overall 34 station bias and is not representative of a global result since most sites are land based.

5 PRINCIPAL COMPONENT ANALYSIS

The purpose of this test is to detect GEO viewing geometry artifacts. A GEO satellite always samples a given region with the same viewing geometry, whereas the Terra sun-synchronous has random viewing geometry. If the GEO fluxes were not normalized with CERES properly, the GEO satellite boundaries will be easily identified. EOFs are computed from the monthly mean TOA LW and SW flux fields of 360 longitudes by 180 latitudes by 36 months. The GEO flux fields are first de-seasonalized to remove the seasonal component in the EOF. The first 20 EOFs are examined for GEO artifacts and compared with the nonGEO flux EOF for similarity. No discernable GEO viewing artifacts were noted. EOFs from the GEO-nonGEO de-seasonalized flux field exhibited no GEO patterns in either the LW or SW. However a 2-week nonGEO data drop out during June 2001 due to the MODIS imager electronics was clearly apparent (not shown).

6 GEO SAMPLING SENSITIVITY

The GEO-derived fluxes are based on 3-hourly GEO full disc images. Higher resolution GEO data is available but at considerable data volume. Significant temporal improvement needs to be established before the hourly GEO dataset can be justified. However increased sampling should also aid in the CERES-GEO normalization of fluxes. The CERES and GEO measurement matched times would be reduced from within 1.5 to 0.5 hours. For the month of December 2002 GEO regional monthly mean LW and SW fluxes were produced from 1 and 3-hourly GEO images. The global monthly mean SW and LW bias was < 0.1%. The associated rms error was 2.5% in the SW and 0.4% in the LW. Although there was improvement in the regional rms error it does not warrant using 1-hour GEO images. The 3-hourly GEO images sufficiently sample the diurnal variation.

7 GEO AND RADIATIVE TRANSFER FLUX COMPARISON

The CERES synoptic products include associated radiative transfer derived TOA fluxes (termed SARB) based on atmospheric profile and cloud retrievals along with the CERES observations (Rose et al 2006). The GEO and CERES instantaneous fluxes can be separately evaluated with SARB fluxes. The GEO fluxes are complemented by GEO cloud retrievals and the CERES fluxes with MODIS clouds. This validation would then test the consistency of the fluxes and cloud properties. Similar consistency between GEO and CERES flux and cloud properties would justify the merging of CERES and GEO fluxes in the SRBAVG-

GEO data stream. **Preliminary** results from July 2002 given in Table 4 reveal a SARB-GEO difference of 1.6% that is less than the SARB-CERES difference of 3.5%. Otherwise the SW and LW bias and rms error differences between CERES and GEO with SARB are similar, establishing GEO flux and cloud consistency with those of CERES.

Table 4. Preliminary July 2002 CERES and GEO instantaneous flux comparisons with SARB (radiative transfer derived)

(%)	CERES		GEO	
	bias	rms	bias	rms
SW	3.5	14.4	1.6	13.5
LW	-0.6	5.1	0.5	5.9

8 FUTURE GERB COMPARISONS

With the advent of plans for a Chinese geostationary broadband instrument and the Geostationary Earth Radiation Budget (GERB) instrument on the Meteosat-8 GEO satellite potentially will produce high temporal resolution broadband flux datasets for comparison. The GERB project has just released its first edition of fluxes. GERB will provide 15-minute full disc fluxes and will provide the best "truth" data for testing GEO derived fluxes from the same Meteosat-8 satellite.

9 CONCLUSIONS AND FUTURE WORK

All of the validation activities conclude that there are no systematic biases introduced in the GEO derived fluxes and are within climate quality standards. Also the GEO and CERES derived fluxes and cloud properties are consistent with one another. The GEO fluxes have reduced the monthly regional diurnal flux error by 50% over the nonGEO fluxes, which are based on constant meteorology. Summary statistics of all the validation activities is given in Table 5. In general all GEO fluxes have a bias of <1%, indicating the GEO fluxes do not have any significant systematic biases.

Table 5. A summary of GEO flux validation activities

	SW		LW	
(%)	Bias	RMS	Bias	RMS
Terra-Aqua day night (instantaneous)	0.7	15.0	0.5 -0.4	4.6 4.5
Terra-Aqua (monthly)	0.7	4.2	-0.2	0.9
Surface (monthly)	3.2	11.3	0.0	3.1
SARB (instantaneous)	1.6	13.5	0.5	5.9
GEO Calibration (monthly)	<0.1	<1.0	<0.1	<1.0
1 vs 3 hourly(monthly)	<0.1	2.5	<0.1	0.4
EOF	No GEO artifacts			

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