P1.15 SURFACE VALIDATION OF CLOUDS & THE EARTHS RADIANT ENERGY SYSTEM (CERES) SYNOPTIC (SYN) PRODUCT

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INTRODUCTION

Within the Clouds and the Earth's Radiant Energy System (CERES) science team (Wielicki et al. 1996), the Time Interpolation and Spatial Averaging (TISA) group is tasked with the final CERES data products that give global, gridded and temporally complete maps of Top of Atmosphere (TOA) and atmospheric fluxes. TOA fluxes come from either CERES observations, estimates of flux derived from geostationary (GEO) narrowband to broadband techniques, or interpolation of the above. In atmosphere and surface fluxes derive from a fast radiative transfer code originally developed by Qiang Fu and Kuo-Nan Liou (Fu and Liou, 1993) and subsequently highly modified by the CERES Surface and Atmospheric Radiations (SARB) group. Details on the code can be found in Kato et al. (2005) and Rose and Charlock (2006). Similar work is explained in Charlock et al 2006 detailing the process and validation of another CERS data product the Clouds and Radiative Swath (CRS). Execution of the code requires a host of inputs that define the atmospheric state. This brief monograph quickly outlines the SYN product; it's inputs and outputs and discusses the impact of using geostationary data to supplement Terra & Aqua CERES observations to fill in hours of the day when no CERES data are available. It shows comparisons of model results compared to TOA observations from both CERES and geostationary data and compares computed fluxes at the surface to observations.

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SYN DATA PRODUCT

The CERES Synoptic (SYN) product provides CERES TOA observed fluxes, associated cloud and aerosol properties and atmospheric column fluxes calculated from a radiation transfer model at 5 levels in the atmosphere at a one degree spatial and 3 hourly temporal resolution. CERES broadband observations which occur at approximately the same local time each day for each grid box, are supplemented by conversion of geostationary (GEO) satellite narrow band observations to broadband estimates. Cloud properties are derived from MODIS imagers on board the Terra and Aqua satellites when available or from GEO imager channels when available. Other hour boxes, not filled with either CERES observations or GEO estimates (both TOA fluxes and cloud properties) are filled via interpolation. Atmospheric state comes from the Goddard Modeling and Assimilation Office (GMA) GEOS-4 re-analysis product. Surface albedo is retrieved from clear sky toa albedo, when available. Surface properties are either derived during data processing or retrieved from predefined global maps. Aerosol optical depths come from standard MODIS MOD04 product or are given by the Model for Atmospheric Transport and Chemistry (MATCH) model Collins et al (2001). This model also specifies aerosol type, which is mapped to a predefined set of aerosol scattering characteristics. Though the radiation transfer code is run at a higher vertical resolution, radiative fluxes are archived at five levels, TOA, 70hPa, 200hPa, 500hPa, and the Surface.

TOA fluxes and radiation transfer model results are calculated for each grid box and hour of the day. Hourly results are average to 3 hours for archival and distribution through the CERES web page at:

http://ceres.larc.nasa.gov/ceres

and/or via the Langley Atmospheric Sciences Data Center (ASCD) at:

http://eosweb.larc.nasa.gov/

The three hourly data can easily be averaged to give true daily and monthly mean estimates of flux profiles through the atmospheric column. An example of the SYN output is shown in Figure 1. There the diurnally complete monthly mean model broadband shortwave (SW) flux for the month of July 2003 is shown.

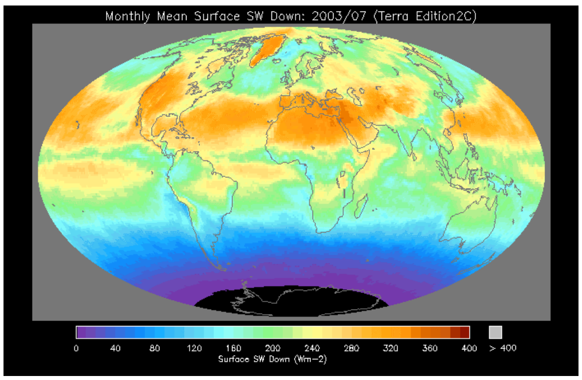

Figure 1. Global monthly mean broadband surface shortwave flux for July 2003 from CERES SYN data product.

DIURNALLY COMPLETE TOA FLUX AND CLOUD PROPERTIES

Terra and Aqua orbit in sun-synchronous orbits. This implies they pass over each point on the Earth at approximately the same local time each day. Depending on latitude they may pass over only twice (as near the equator) or many more times as the orbit reaches higher and higher latitudes thus the satellite orbits preclude full diurnal sampling. To compensate for this problem CERES brings in data from five operational geostationary (GEO) satellites deriving cloud properties from imagers on board the GEO satellites and converting the narrowband observations from these imagers to estimates of broadband radiation. This is shown in the cartoon in Figure 2 for the time series of available TOA shortwave (SW) fluxes for a given grid box over the course of 24 hours. The blue columns indicate hours that Terra and Aqua satellites nominally view a grid box during the day (there would be similar overpasses 12 hours earlier at night).

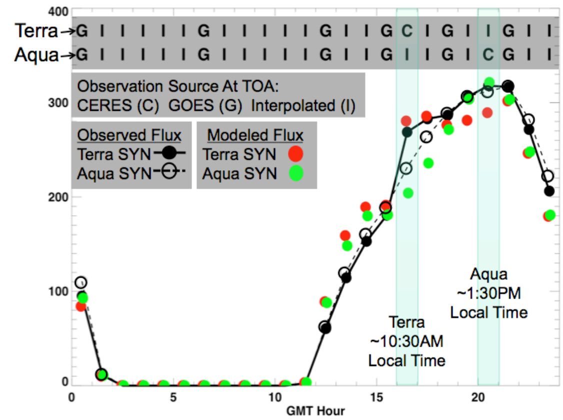

Figure 2. Time series of 24 hour boxes showing observed and modeled TOA SW flux and indices showing the source of the flux for each hour, either CERES observations (C), geostationary narrow to broadband estimations (G), or values interpolated from the first two (I).

These hours are indicated by “C’s” in the top two rows of the plot. Where GEO data are available and imager radiances are converted to broadband fluxes there is a “G” for each satellite data stream. Between these hours, where there is neither a CERES observation nor a GEO estimate, values are interpolated to fill in the remaining hour boxes and are indicated by the letter “I”. Cloud properties within each spatial grid and temporal hour box are required to run the radiation transfer model. At CERES overpass times, the MODIS imager on board either Terra or Aqua is used. At GEO times available imager radiances are used to determine cloud properties. When neither is available, cloud properties are interpolated through the intervening hours.

Consider the four values available at 16:00GMT in Figure 2. One can see that the model calculation of TOA flux from the Terra data stream at the Terra overpass (the red dot) better matches the CERES observed flux (black). Whereas the flux interpolated from the two GEO estimates (open circle) and the model flux calculated using interpolated clouds (green circle) seem far removed from the Terra CERES observation. The question arises what is the impact of using GEO fluxes and interpolated clouds on final results? Does the extra work, which is substantial, result in a better product. This is addressed in the next section.

EFFECT ON USING GEOSTATIONARY INPUTS ON TOA RMS

To test the impact of GEO fluxes and cloud properties on the SYN subsystem, a special end-to-end run of the code, excluding GEO cloud properties for the month of July 2004 was accomplished. To test fluxes at the TOA it is still necessary to derive an estimate of the TOA flux from the GEO narrowband radiances. For this run cloud properties from the MODIS imagers were interpolated across all intervening hours. We then compared 6-hour averages of morning and afternoon TOA and surface fluxes to see the effect of GEO clouds on SYN results. Shown below in Figure 3 are hourly results for 16 grid boxes that include surface observations at the ARM Southern Great Plains test–bed. Figure 3 shows visually (from the top two to the bottom two plots) the reduction in RMS at the TOA of both the LW and SW flux relative to the run where cloud properties were interpolated across the entire day.

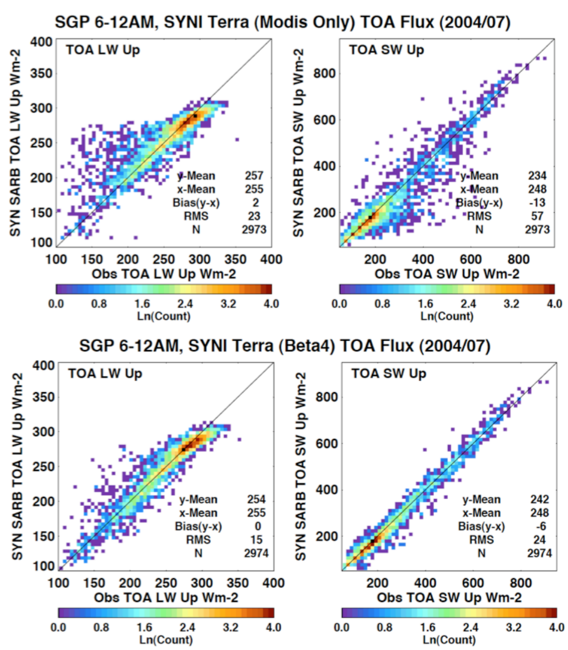

Figure 3. Modeled LW & SW flux up at TOA compared to observations, with and without GEO cloud properties.

Table 1 quantifies the RMS reduction for both morning and evening time periods for both the Aqua and Terra data streams for TOA observations and surface observations compared to model calculations. These results are for the CERES grid boxes containing 16 separate ARM surface observations sites. The columns on the right show the average change in Bias and RMS for these surface locations once GEO based cloud properties are used in the model calculations. In most cases bias is improved but in every case RMS is improved using the GEO based cloud properties. At times only slightly, for example for the LW flux down at the surface during the morning hours but other times RMS is significantly improved. For example TOA SW RMS is improved for the Terra morning calculations and the Aqua afternoon calculations by 34Wm^{-2} and 45Wm^{-2} respectively when GEO cloud properties are used.

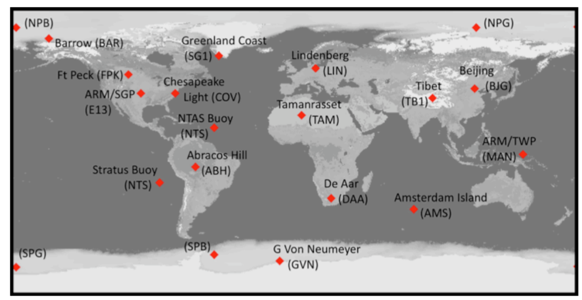

Figure 4. Location of grid boxes where calculated TOA and surface fluxes are compared to observations.

To assess the overall efficacy of SYN results we derive bias and RMS statistics for 20 grid boxes distributed over the globe as shown in Figure 4. These locations were chosen based on their (relatively) even distribution around the globe. Eleven of these locations contain long-term records of observed broadband flux down at the surface.

One broad measure of SYN results is to compare them to other similar global data sets. To that end Table 2 compares the bias and RMS statistics of monthly mean SW and LW downward surface flux to several other available data sets: GEWEX-SRB data are available from: http://gewex-srb.larc.nasa.gov/index.php.
ECMWF data were downloaded from the 40-year analysis ERA 40 from:
http://data-portal.ecmwf.int/data/d/era40_mnth/.
ISCCP-FD fluxes were obtained from the ISCCP web site at:
http://isccp.giss.nasa.gov/index.html

Terra	CERES Only		CERES & GOES			
6AM-12PM	Bias	RMS	Bias	RMS	Delta Bias	Delta RMS
TOA Up LW	2	23	0	15	+2	+8
TOA Up SW	-13	57	2	23	+11	+34
Surface Dn LW	-9	18	-8	16	+1	+2
Surface Dn SW	18	104	10	91	+8	+13
"+" indicates W/m^2 improvement in RMS or Bias						
Terra	CERES Only		CERES & GOES			
12-6PM	Bias	RMS	Bias	RMS	Delta Bias	Delta RMS
TOA Up LW	-11	26	-7	16	+4	+10
TOA Up SW	-16	57	-22	29	-6	+28
Surface Dn LW	-13	19	-11	17	+2	+2
Surface Dn SW	2	121	5	98	-3	+23
Terra equator crossing time is ~10:30AM, Aqua is ~ 1:30PM.						
Aqua	CERES Only		CERES & GOES			
12-6PM	Bias	RMS	Bias	RMS	Delta Bias	Delta RMS
TOA Up LW	-6	25	-2	15	+18	+10
TOA Up SW	-11	43	-17	29	-6	+14
Surface Dn LW	-10	17	-10	17	0	0
Surface Dn SW	-11	43	-17	29	-6	+14
"-" indicates W/m^2 degradation in RMS or Bias						
Aqua	CERES Only		CERES & GOES			
6AM-12PM	Bias	RMS	Bias	RMS	Delta Bias	Delta RMS
TOAUp LW	20	25	-2	15	+18	+10
TOA Up SW	-14	73	-4	28	+10	+45
Surface Dn LW	-9	17	-8	16	+1	+1
Surface Dn SW	22	123	10	93	+12	+30

Table 1. Table showing comparisons of morning and afternoon averages of hourly calculated and observed TOA and surface fluxes at 16 grid boxes near the ARM/SGP radiation test-bed in Kansas and Oklahoma. In every case RMS is decreased when using interpolated cloud properties from imagers on board the GEO satellites to fill in hours when no observation exists.

	SW Surface Down (Wm^{-2})				LW Surface Down (Wm^{-2})			
Model	Obs Mean	**Bias**	**RMS**	**N**	Obs Mean	**Bias**	**RMS**	**N**
GEWEX-SRB	188	-3	23	481	331	-1	11	480
ECMWF	191	-5	24	215	329	-0	14	213
ISCCP FD	188	-1	21	405	331	7	22	404
CERES Model-B	194	1	24	467	331	-1	11	480
SYN Aqua Tuned	189	4	11	269	334	-6	12	268
SYN Terra Tuned	188	5	13	480	331	-5	12	480

Table 2. Monthly mean bias and RMS of shortwave and longwave flux down at the surface (model minus observations at 11 surface sites around the globe.) SYN results (bottom two rows compare favorably with respect to RMS against other similar data sets, particularly for SW down values.

CERES Model-B are two *parameterized* models (also available on the SYN product) that take TOA fluxes to the surface as a function of atmospheric state. It should also be noted that the time series of monthly means used for these statistics do not match exactly for all six data set. It is hoped that since the observed mean fluxes for the data sets are similar that the data sets are representing similar atmospheric conditions over time. However this could lead to differences in the Bias and so the RMS is perhaps the more meaningful statistic for this comparison. For the SW flux at the surface then, the SYN RMS is significantly better than the other four data sets, essentially halving the RMS from near an average of ~22Wm^{-2} to an average for the SYN products near ~12Wm^{-2}. In the LW flux down at the surface the SYN product matches the average RMS of the GEWEX-SRB, ECMWF, and CERES Model-B results with the ISCCP-FD product, in this case being the outlier with an RMS significantly larger than the other data products.

The final two Tables (3 and 4) show comparisons of the Aqua and Terra SYN products compared at the TOA and surface to observations for the sites shown in Figure 4. In this case they show hourly, daily, and monthly mean bias (RMS) for each time period indicating the reduction in RMS as one averages over longer time periods. All numbers are Wm^{-2} except the last two rows in each table that show TOA albedo and surface transmission and so are unit-less quantities. The biases hear look very good. However it must be pointed out that the grid boxes chosen for this comparison, though not chosen to do so, do average out issues related to execution of the SYN product. In particular the LW surface bias shown in Tables 3 and 4 do not show a negative bias over land that exists due to a known cool near surface air bias over large areas of the Earth's surface in the GEOS-4 product. Likewise the TOA SW bias of -1Wm^{-2} does not reflect the fact that we know the SW TOA flux bias over ocean is generally quite large. For instance the TOA SW bias at the NTAS buoy site off the west coast of Peru, if isolated, shows a TOA SW bias near 10Wm^{-2}. Unfortunately there are very few ocean sites available so the SW ocean bias is masked by the larger number of land based sites.

Quantity N (Hours)	Obs Mean	Bias (Wm^{-2})			RMS (Wm^{-2})		
		Hourly	Daily	Monthly	Hourly	Daily	Monthly
SW TOA UP (564876)	102	-1	-1	-1	14	7	5
LW TOA Up (565521)	226	0	0	0	11	7	3
SW Surface Down (245999)	180	2	3	5	62	27	20
LW Surface Down (246528)	320	-1	-1	-1	23	16	10
TOA Albedo (303449)	40.2	-1.0	-1.2	-1.1	5.6	4.2	3.1
Surface Trans. (107846)	53.3	0.3	0.6	0.5	12.0	7.0	3.3

Table 3. Bias and RMS statistics for Aqua SYN time series shown at three temporal resolutions for 6 different variables at the grid boxes shown in Figure 4. There are 20 grid boxes used for TOA statistics and 11 for surface statistics.

SUMARRY

We have introduced and assessed the new fusion data product from CERES the synoptic (SYN). The SYN supplies global maps of observed flux at the Top of the Atmosphere (TOA) and modeled flux for 5 levels in the atmosphere at the surface. The SYN is spatially and temporally complete at 1-degree equal angle and 3 hourly time intervals. A significant enhancement of results is achieved by utilizing cloud properties based on geostationary radiances within hour boxes when CERES (MODIS) based cloud properties are unavailable. By comparing morning and afternoon averages of flux with and without the inclusion of GEO cloud properties we find a significant reduction in surface and TOA RMS when GEO cloud properties are included. Comparisons with other available, similar, data sets is encouraging with the SYN showing significantly less RMS in model minus observed surface SW fluxes and comparable RMS' for LW surface fluxes.

ACKNOWLEDGMENTS

CERES data is made available from NASA Langley's Atmospheric Sciences Data Center:

http://eosweb.larc.nasa.gov/

All surface observed fluxes can be accessed from the CERES ARM Validation Experiment (CAVE) web site at:

http://www-cave.larc.nasa.gov/

Quantity (N Hours)	Obs Mean	Bias (Wm^{-2})			RMS (Wm^{-2})		
		Hourly	Daily	Monthly	Hourly	Daily	Monthly
SW TOA UP (873198)	103	-1	-1	-1	13	7	4
LW TOA Up (874105)	226	-1	-1	-1	11	7	4
SW Surface Down (403186)	183	2	2	4	65	28	19
LW Surface Down (407521)	318	-1	-1	-1	23	17	10
TOA Albedo (466750)	40.4	-0.9	-1.1	-1.1	5.6	4.4	3.3
Surface Trans. (177562)	53.5	0.3	0.6	0.5	12.3	7.2	3.6

Table 4. Bias and RMS statistics for Terra SYN time series shown at three temporal resolutions for 6 different variables at the grid boxes shown in Figure 4. There are 20 grid boxes used for TOA statistics and 11 for surface statistics.

ACKNOWLEDGMENT OF ORIGINAL SURFACE FLUX DATA PROVIDERS.

SURFRAD data are made available through NOAA Air Resources Laboratory/Surface Radiation Research Branch.

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NTAS & Stratus Buoy data was made available from the Upper Ocean Processes group at Woods Hole Oceanographic Institute.

BSRN data is made available from the Baseline Surface Radiation Network team at http://www.bsrn.awi.de.

REFERENCES

Charlock T. P., and F. G. Rose, D. A. Rutan, Z. Jin, and S. Kato, 2006: The Global Surface and Atmospheric Radiation Budget: An Assessment of Accuracy With 5 Years of Calculations and Observations, Proceedings 12th Conf. on Atmos. Radiation, Madison, WI, July 10-14.

Collins, W.D., P.J. Rasch, B.E. Eaton, B.V. Khattatov, J.-F. Lamarque, and C.S. Zender, 2001: Simulating aerosols using a chemical transport model with assimilation of satellite aerosol retrievals. Methodology for INDOEX. J. Geophs. Rev. 106, 7313-7336.

Kato, S., F.G., Rose, and T.P., Charlock, 2005: Computation of Domain-Averaged Irradiance Using Satellite-Derived Cloud Properties, J. of Atmos. Ocean. Tech., 22b, pp 146-164.

Minnis, P.; and co-authors: Cloud Optical Property Retrieval (Subsystem 4.3). "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, December, 1995, pp. 135-176.

Rose F. G., T. P. Charlock, B. Wielicki, D. Doelling, and S. Zentz, 2006: CERES Synoptic Gridded Diurnally Resolved Radiative Transfer, Proceedings 12th Conf. on Atmos. Radiation, Madison, WI, July 10-14.

Rutan, D. A., F.G. Rose, N. Smith, and T. P. Charlock, 2001: Validation data set for CERES Surface and Atmospheric Radiation Budget (SARB), WCRP GEWEX Newsletter, 11, No. 1, 11-12.

Fu, Q., and K.N. Liou, 1993: Parameterization of the radiative properties of cirrus clouds. J. Atmos. Sci., 50, 2008-2025

Wielicki, B.A., B.R. Barkstrom, E.F. Harrison, R.B. Lee, 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.Ω