Monthly Mean Products
Level 3: Diurnal sampling by merging CERES and geostationary data

David F. Young

CERES Data Products Workshop
January 29 - 30, 2003
CERES Temporal Interpolation and Spatial Averaging (TISA)

Goals

• Produce climate quality monthly and daily means
  – Must maintain calibration

• Eliminate temporal sampling errors

• Retain consistency among TOA fluxes, cloud properties and surface fluxes

• Produce synoptic maps of TOA, surface, and atmospheric flux...
### CERES Instantaneous Gridded Data Products

<table>
<thead>
<tr>
<th>CERES Data Product</th>
<th>Subsystem Affiliation</th>
<th>TRMM Availability</th>
<th>Terra Availability</th>
<th>Aqua Availability</th>
<th>ERBElike Product</th>
<th>TOA and Surface Product</th>
<th>Atmosphere Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES9 (ERBElike Monthly Regional Averages)</td>
<td>3.0</td>
<td>Edition2</td>
<td>Edition2</td>
<td>Spr ’03 Edition1</td>
<td>X</td>
<td>X</td>
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<tr>
<td>SFC (Monthly Gridded TOA/Surface Fluxes and Clouds)</td>
<td>9.0</td>
<td>Edition2B</td>
<td>Beta1</td>
<td>2004 Beta1</td>
<td>X</td>
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<tr>
<td>FSW (Monthly Gridded Radiative Fluxes and Clouds)</td>
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<td>Spr ’03 Edition2C</td>
<td>Spr ’03 Beta3</td>
<td>2005 Beta1</td>
<td>X</td>
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<tr>
<td>SYN (Synoptic Radiative Fluxes and Clouds)</td>
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<td>2003 Beta1</td>
<td>2004 Beta1</td>
<td>2005 Beta1</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
# CERES Monthly Gridded Average Data Products

<table>
<thead>
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<td>Spr ’03 Edition1</td>
<td>X</td>
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<tr>
<td><strong>SRBAVG</strong> (Monthly TOA/Surface Averages)</td>
<td>10.0</td>
<td>Edition2B</td>
<td>Spr ’03 Beta1</td>
<td>2005 Beta1</td>
<td>X</td>
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<tr>
<td><strong>AVG</strong> (Monthly Regional Radiative Fluxes and Clouds)</td>
<td>8.0</td>
<td>2004 Beta1</td>
<td>2004 Beta1</td>
<td>2005 Beta1</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td><strong>ZAVG</strong> (Monthly Zonal and Global Radiative Fluxes and Clouds)</td>
<td>8.0</td>
<td>2004 Beta1</td>
<td>2004 Beta1</td>
<td>2005 Beta1</td>
<td>X</td>
<td></td>
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</tr>
</tbody>
</table>
Examples from SRBAVG March 1998

TOA LW Flux

TOA SW Flux
Examples from SRBAVG March 1998

TOA Clear-sky SW Flux

Surface Clear-sky SW Flux
The Steps Needed to Produce Monthly Means

- **Step 1**: Spatially average
  - Produce instantaneous averages on a fixed grid
  - Products: ES-9, SFC, FSW

- **Step 2**: Interpolate in time
  - Fill in times between measurements to remove sampling bias
  - Bring in ancillary data to improve accuracy
  - Products: GGE0, SYN

- **Step 3**: Temporally Average
  - Produce monthly means on a fixed grid
  - Products: ES-4, SRBAVG, AVG, ZAVG
Step 1: Gridding

- Simple averaging of CERES footprints on fixed grid

- SFC
  - Uses SSF as input
  - TOA and surface fluxes
  - Clouds in 4 layers
  - Serves as input to SRBAVG

- FSW
  - Uses CRS as input
  - TOA, surface, and atmospheric fluxes
  - Clouds in 4 layers
  - Serves as input to SYN/AVG/ZAVG
Example of Instantaneous Gridded Data

FSW CERES OLR (February 3rd 1998)

Mon Jan 27 15:10:30 2003

Mean = 259.81
Stddev = 44.30
Count = 21459
Step 2: Interpolation
Time Sampling Challenges

• **TRMM**
  - Latitudinal coverage limited by 35° inclination
  - 46-day precession cycle causes large hemispheric asymmetries
  - VIRS 48° VZA limit

• **Terra / Aqua**
  - Sun-synchronous orbits limit diurnal sampling
SW Sampling From CERES TRMM
Equatorial Region  July 1998

TOTAL SKY SW Region Number: 34336 Data Date: 7/1998

Observation
--- non-CEO Method
--- GGEQ Method

Local Time (Day of Month)

Latitude: -5.500 Longitude: 315.500 Land %: 99.999 Ocean %: 0.000 GMA=Erlbe_likc: 71.577 GMA=Geo: 74.508

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SW Sampling From CERES TRMM
ARM SGP Site July 1998
CERES Interpolation Algorithms

- **ERBElike**
  - Assumes constant meteorology between observations
  - Uses no ancillary data
  - **LW**
    - Linear interpolation
    - Simple diurnal modeling over land regions
  - **SW**
    - Interpolation performed using directional models of albedo
    - Only 12 simple scene types

- **CERES nonGEO**
  - Same approach as ERBElike
  - Uses new CERES directional models (~200 scene types)
Using Geostationary Data for Temporal Interpolation of TOA Fluxes

• 3-hourly imager data from geostationary satellites is used to define diurnal variations between CERES observations

• Calibration is critical
  – GEO imagers calibration tied to VIRS

• Cloud retrieval is a subset of CERES VIRS algorithm

• Narrowband GEO data converted to flux using NB-BB relationship & CERES ADMs

• Final fluxes are normalized to CERES observations
Temporal Interpolation of TOA LW Flux
January 1998  E. Sahara 24.5N 20.5E

Graph showing the temporal interpolation of TOA LW Flux for January 1998 at E. Sahara (24.5N 20.5E) with observations, ERBE TSA, and CERES TSA curves.
Temporal Interpolation of SW Flux

Optical depth = 11
Variation with Cloud Fraction

Overcast Models
Variation with Optical Depth
GEO vs. nonGEO Monthly Mean Diurnal SW Flux
Equatorial Pacific Region   CERES DRM

Mean Difference = 1.8 W/m²

TOA SW Flux (W/m²)

0.00  50.00  100.00  150.00  200.00  250.00  300.00

0  6  12  18  24
Local Time

GEO
nonGEO
Temporal Interpolation RMS LW Flux Errors

Mean Instantaneous Interpolation Rms Errors Are Reduced By 50% For Both LW And SW TOA Flux Using Geostationary Data
Step 3: Averaging
## CERES Monthly Mean Products

<table>
<thead>
<tr>
<th>ERBE-like</th>
<th>SRBAVG</th>
</tr>
</thead>
</table>
| • Consistent with ERBE processing  
  • Useful for comparisons with ERBE climatology  
  • 2.5° grid  
  • TOA fluxes  
  • Limited cloud information | • Takes advantage of improved CERES fluxes  
  • Uses improved temporal interpolation to remove sampling effects  
  • 1.0° grid  
  • TOA and surface fluxes  
  • Detailed cloud properties  
  • Product contains GEO and nonGEO monthly means |
ERBE-like / nonGEO Comparisons

• nonGEO interpolation algorithm similar to ERBElke

• Major differences
  – 1° grid
  – CERES DRMs for SW
  – Input flux differences
    • CERES vs. ERBE ADM
    • Reference altitude: Surface vs. 30-km
    • VZ limit: 48° vs. 70°

• Comparisons use matched monthly means on 2.5° grid
  – SRBAVG nonGEO regridded to 2.5° grid
Monthly Mean CERES TRMM TOA Total-sky LW Flux

July 1998 ERBE-like

July 1998 SRBAVG nonGEO

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ERBElike vs nonGEO Total-Sky LW Flux
February 1998

ERBElike - SRBAVG
Mean = 0.0
\[ = 4.1 \]
ERBElike vs nonGEO Total-Sky SW Flux
February 1998

ERBElike - SRBAVG
Mean = -1.6
\[ \square = 6.2 \]
<table>
<thead>
<tr>
<th></th>
<th>40°N - 40°S W/m²</th>
<th>ERBE-like (ES-4)</th>
<th>SRBAVG nonGGEO</th>
<th>ES4 - SRBAVG</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total-Sky LW Flux</strong></td>
<td>Mean</td>
<td>258.3</td>
<td>258.4</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Sigma</td>
<td>28.5</td>
<td>28.5</td>
<td>4.1</td>
</tr>
<tr>
<td><strong>Total-Sky SW Flux</strong></td>
<td>Mean</td>
<td>96.0</td>
<td>97.6</td>
<td>-1.6</td>
</tr>
<tr>
<td></td>
<td>Sigma</td>
<td>29.6</td>
<td>30.4</td>
<td>6.6</td>
</tr>
<tr>
<td><strong>Clear-Sky LW Flux</strong></td>
<td>Mean</td>
<td>287.3</td>
<td>287.4</td>
<td>-0.1</td>
</tr>
<tr>
<td></td>
<td>Sigma</td>
<td>12.9</td>
<td>14.0</td>
<td>3.0</td>
</tr>
<tr>
<td><strong>Clear-Sky SW Flux</strong></td>
<td>Mean</td>
<td>49.7</td>
<td>49.7</td>
<td>-0.1</td>
</tr>
<tr>
<td></td>
<td>Sigma</td>
<td>18.3</td>
<td>18.3</td>
<td>5.6</td>
</tr>
</tbody>
</table>
SRBAVG nonGEO vs. GEO Fluxes

- Comparison demonstrates changes due to inclusion of GEO data
  - GEO goal is reduction of temporal sampling errors
  - Major improvement expected in mean diurnal variation

- More direct comparison than ERBElike
  - Same input fluxes
  - Same 1° grid

- No GEO SW clear-sky fluxes
GEO Calibration and Cloud Retrievals

• GEO cloud properties retrieval goals:
  – Improvement of TOA flux interpolation (primary goal)
  – Improvement of diurnal modeling of cloud properties

• GEO calibration goals:
  – Consistency with VIRS calibration
  – Consistency with VIRS cloud retrievals
    • Most important parameter: cloud fraction
    • Optical Depth also used for DRM selection
    • Cloud temperature only used to sort by height

• Limitations
  – Only two channels (0.6 and 10.8 µm)
  – Single channel used at night
  – GEO spectral differences
GEO Calibration (Technique)

- VIRS/GEO calibration relationship calculated for:
  - Each Month
  - Each GEO satellite
  - Ocean / land / desert
  - 0.65 and 11 µm channels
- VIRS / GEO matched in space/time/viewing geometry
- Visible fit solves for slope and offset
- IR fit uses fixed intercept
- Time series of calibration used to check consistency
  - VIRS vs. nominal calibration compared at high and low radiance values (evaluates combined offset + gain)
  - Some variation expected due to sampling
  - Minnis et al. 2002 uses mean trend line
Instantaneous VIRS-GOES-9 Comparison
Ocean Daytime Cloud Percentage

VIRS: 71.1%  GOES-9: 71.7%
Mean Difference: 0.6%  RMS: 14.1%
## VIRS/GEO Cloud Property Comparison

<table>
<thead>
<tr>
<th></th>
<th>Cloud Fraction</th>
<th>Optical Depth</th>
<th>Cloud Temperature (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VIRS</td>
<td>GEO</td>
<td>VIRS</td>
</tr>
<tr>
<td><strong>Ocean Day</strong></td>
<td>0.60</td>
<td>0.63</td>
<td>6.7</td>
</tr>
<tr>
<td><strong>Ocean Night</strong></td>
<td>0.60</td>
<td>0.55</td>
<td>266.5</td>
</tr>
<tr>
<td><strong>Land Day</strong></td>
<td>0.54</td>
<td>0.67</td>
<td>10.1</td>
</tr>
<tr>
<td><strong>Land Night</strong></td>
<td>0.51</td>
<td>0.55</td>
<td>251.9</td>
</tr>
</tbody>
</table>
VIRS-GEO Cloud Fraction by Satellite Demonstrates Inter-satellite Consistency

<table>
<thead>
<tr>
<th></th>
<th>GOES 8/9/10</th>
<th>METEOSAT 5/6/7</th>
<th>GMS 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean Day</td>
<td>-0.03</td>
<td>-0.01</td>
<td>-0.01</td>
</tr>
<tr>
<td>Ocean Night</td>
<td>0.05</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Land Day</td>
<td>-0.13</td>
<td>-0.13</td>
<td>-0.14</td>
</tr>
<tr>
<td>Land Night</td>
<td>-0.02</td>
<td>-0.04</td>
<td>-0.04</td>
</tr>
</tbody>
</table>
nonGEO vs. GEO Monthly Mean Total-sky LW Flux (February 1998)

GEO - nonGEO Mean = -0.2

GEO - nonGEO Flux (W/m²) = 3.4
## SRB AVG GEO - nonGEO Fluxes
February/May/June/July 1998

<table>
<thead>
<tr>
<th>40°N - 40°S W/m²</th>
<th>Feb</th>
<th>May</th>
<th>June</th>
<th>July</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total-Sky LW Flux</strong></td>
<td>Mean</td>
<td>-0.2</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Sigma</td>
<td>3.4</td>
<td>2.9</td>
<td>3.4</td>
</tr>
<tr>
<td><strong>Total-Sky SW Flux</strong></td>
<td>Mean</td>
<td>-1.2</td>
<td>-0.2</td>
<td>-0.7</td>
</tr>
<tr>
<td></td>
<td>Sigma</td>
<td>6.2</td>
<td>4.4</td>
<td>4.0</td>
</tr>
<tr>
<td><strong>Clear-Sky LW Flux</strong></td>
<td>Mean</td>
<td>-1.1</td>
<td>-1.0</td>
<td>-1.4</td>
</tr>
<tr>
<td></td>
<td>Sigma</td>
<td>3.6</td>
<td>1.6</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Monthly Mean GEO-nonGEO Total-sky SW Flux

February

May

-20 W/m²

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Zonal Mean GEO-nonGEO Total-Sky SW Flux Differences

![Graph showing differences in GEO-nonGEO Total-Sky SW Flux](image)
April Zonal Mean GEO-nonGEO LW Flux Differences

Ocean

Land

**GEO-nonGEO Total-sky LW Flux (W/m²)**

- **Latitude**
- **February Ocean**, **July Ocean**, **May Ocean**, **June Ocean**

**GEO-nonGEO Total-sky LW Flux (W/m²)**

- **Latitude**
- **February Land**, **July Land**, **May Land**, **June Land**

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Validation

- **GEO calibration**
  - Calibration sensitivity test
  - Cloud property comparisons with VIRS and ISCCP

- **Direct Integration**
  - Compare albedos from interpolation with observations composited from observations over a complete precession cycle

- **Surface Flux Comparisons**
  - Instantaneous comparisons
  - Monthly means
  - Comparisons with SRB
GEO Calibration Sensitivity Tests

• Goal: Test effect of imager calibration on monthly mean fluxes

• Test by varying imager gain by ±5%

• Calibration affects both radiances and cloud retrievals
  – Cloud properties affect selection of DRMs
  – Cloud mask affects selection of clear-sky radiances
### Calibration Sensitivity Summary

(Change in monthly mean flux due to a ±5% imager calibration error)

<table>
<thead>
<tr>
<th></th>
<th>Mean Flux</th>
<th>Mean &amp; rms Flux Difference (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>IR + 5%</td>
</tr>
<tr>
<td><strong>Total-sky LW</strong></td>
<td>257.6</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.08)</td>
</tr>
<tr>
<td><strong>Total-sky SW</strong></td>
<td>99.3</td>
<td>-0.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.35)</td>
</tr>
<tr>
<td><strong>Clear-sky LW</strong></td>
<td>284.7</td>
<td>-0.29</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.69)</td>
</tr>
</tbody>
</table>
Direct Integration Approach

- Comparison performed on 10° x 10° grid
- May/June/July SRBAVG vs 2 TRMM precession cycles
- Direct Integration
  - Use CERES SSF footprint data from 2 46-day precession cycles
  - Save mean albedo vs sza (5° bins)
  - Integrate using correct solar weighting
- SRBAVG data
  - Combine 1° grid data on 10° grid from 3 months
GEO - Direct Integration Albedo
GEO - Direct Integration Albedo (ERBE DRM)
## Summary of Direct Integration Results

<table>
<thead>
<tr>
<th></th>
<th>40N - 40S</th>
<th>30N - 30S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>nonGEO (CERES DRM)</td>
<td>GEO (CERES DRM)</td>
</tr>
<tr>
<td>Mean Albedo Difference</td>
<td>0.001 (0.6%)</td>
<td>0.002 (0.7%)</td>
</tr>
<tr>
<td>RMS Difference</td>
<td>0.010 (4.1%)</td>
<td>0.011 (4.3%)</td>
</tr>
</tbody>
</table>

For 30N - 30S:
|                | nonGEO (CERES DRM) | GEO (CERES DRM) | GEO (ERBE DRM) |
| Mean Albedo Difference | 0.001 (0.6%) | 0.002 (0.6%) | -0.001 (-0.4%) |
| RMS Difference   | 0.006 (2.6%) | 0.006 (2.7%) | 0.011 (4.8%) |
CERES Surface-Only Fluxes

• Downwelling clear-sky and all-sky SW and LW surface fluxes derived from relationships with TOA fluxes and atmospheric data.

• Each component computed from two models

<table>
<thead>
<tr>
<th></th>
<th>Model A</th>
<th>Model B</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW</td>
<td>Clear</td>
<td>Li et al.</td>
</tr>
<tr>
<td></td>
<td>All-sky</td>
<td></td>
</tr>
<tr>
<td>LW</td>
<td>Clear</td>
<td>Inamdar and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ramanathan</td>
</tr>
<tr>
<td></td>
<td>All-sky</td>
<td></td>
</tr>
</tbody>
</table>

• Validation data sources:
  ARM Central facility and extended facilities
  BSRN and CMDL sites
July 1998 Monthly Mean Surface Downwelling Clear-sky Flux

LW Model A

LW Model B

LW Model A - Model B

Mean -0.5 (-0.1%)  Sigma 5.8 (1.6%)

SW Model A

SW Model B

SW Model A - Model B

Mean -2.5 (-1.0%)  Sigma 11.8 (4.5%)
Comparison with Surface-Based Measurements

ARM SGP CF  February 1998

Downwelling LW Flux  Region Number: 19163  Data Date: 02/1998

<table>
<thead>
<tr>
<th></th>
<th>Flux Bias</th>
<th>Flux RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instantaneous</td>
<td>-0.05</td>
<td>19</td>
</tr>
<tr>
<td>Interpolated</td>
<td>-2.9</td>
<td>25</td>
</tr>
</tbody>
</table>
Monthly mean Total-sky Surface Flux
SRBAVG vs. BSRN

SW Downwelling

SRBAVG-BSRN
Mean = 3.4 (1.7%)
Sigma = 8.9 (4.7%)

LW Downwelling

SRBAVG-BSRN
Mean = 1.8 (0.5%)
Sigma = 10.3 (2.8%)
TISA Validation Summary

• ERBElike, GEO and nonGEO monthly means typically agree on average < 1%
  – Difference consistent with sampling
• Direct integration results demonstrate no bias in SW modeling
• Calibration sensitivity
  – < 1% for 5% SW imager errors
  – ~0% for IR imager errors
• Surface flux comparisons
  – Errors similar to instantaneous comparisons
  – Monthly mean agree well with surface data
  – Additional months to be added soon
Status & Future Work

- TRMM SRBAVG available this month
- Terra Beta SRBAVG available soon
- TRMM Beta SYN by Spring
- Algorithmic improvements
  - Improved GEO cal
  - Improved NB/BB
  - Add daily means
- Validation
  - Full comparison with surface/SRB
  - GERB comparisons
End