Merged CERES/GEO Time Sampling
Part I: SRBAVG

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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
Start with Gridded CERES Observations
One hour of CERES TOA SW Fluxes
Organize Regional Data by Time
One day of CERES TOA SW Fluxes at 10:30 LT
Interpolate Fluxes and Clouds over Month
Regional Time Series of Flux from Terra over ARM SGP

TOA Albedo

TOA LW Flux (W/m²)

Day of Month

Day of Month
Create Temporally Interpolated and Averaged Data Products
TOA SW Flux Terra FM-1 July 2001
CERES Advanced TISA Processing

- SSF -> Grid -> SFC -> Interpolate and Average -> SRBAVG
- CRS
  - SARB
  - Grid -> FSW
  - Instantaneous Footprint
  - Interpolate + SARB
  - Global Synoptic
  - Average
  - Monthly Mean
  - AVG/ZAVG
CERES Monthly Mean Products

**SYN/AVG**
- Uses GEO-enhanced interpolation to produce global synoptic flux and cloud fields
- Separate monthly mean produced from hourly fields

**SRBAVG**
- 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
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
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 TRMM ADMs

- Final fluxes are normalized to CERES observations
  - Normalization applied to total-sky flux and SW clear-sky
Temporal Interpolation of TOA LW Flux

January 1998

E. Sahara 24.5N 20.5E

[Graph showing daily LW flux from January 1998 with observations and model predictions.]
Temporal Interpolation of TOA SW Flux
Step #1 NB Observations
Temporal Interpolation of TOA SW Flux
Step #2 Estimate BB Albedo

![Graph showing temporal interpolation of TOA SW flux with points for narrowband and broadband albedo vs local time.](image)
Temporal Interpolation of TOA SW Flux
Step #3 Use only days with CERES observations

![Graph showing the relationship between Local Time and Albedo with points indicating Broadband Albedo and CERES Observed Albedo.](image-url)
Temporal Interpolation of TOA SW Flux

Step #4: Interpolate to all daylight hours

Interpolated Broadband Albedo from GEO

CERES Observed Albedo

Albedo

Local Time

0.2
0.25
0.3
0.35
0.4

0 6 12 18 24

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Temporal Interpolation of TOA SW Flux
Step #5 Normalize time series to CERES

[Graph showing broadband albedo and its normalization to CERES.]
GEO vs. nonGEO Monthly Mean Diurnal SW Flux
Equatorial Pacific Region

Mean Difference = 1.8 W/m²
GGE0 Calibration Techniques

- Ray-matched MODIS vs GEO radiance data
  - Ties calibration to well-calibrated MODIS data
  - Limited geographic coverage

- Deep convective cloud albedo
  - Used to get trends (not absolute calibration)

- Noon matching of GEO data at central longitudes
  - Used to transfer calibration across all GEO satellites
Consistency of Calibration Methods

GOES-8 vs VIRS, 1998-2003

visible, 0.65µm

COLD CLOUD GAIN for GOES-8

DAY SINCE JAN 1, 1998

0 365 730 1095 1460 1825 2190

SLOPE FORCE

0.80 0.85 0.90 0.95 1.00 1.05 1.10

DAY SINCE LAUNCH (April 13, 1994)

1359 1724 2089 2454 2819 3184 3549

1998 1999 2000 2001 2002 2003 2004

gain

0.80 0.85 0.90 0.95 1.00 1.05 1.10

a0 0.8279
a1 7.419e-01
a2 9.543e-05
R² 0.9751
STDerr 0.0050
MEAN 0.983

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GGEO Cloud Property Retrievals

• Needed for SW interpolation & for monthly clouds
  – Necessary for ADM selection

• Uses IR/Vis retrievals (run as subset of CERES cloud algorithm)

• Uses CERES surface property maps and MOA soundings

• Properties
  – Cloud Amount
  – Cloud Temperature
  – Cloud Height (using standard 4 CERES layers)
  – Optical Depth/Emittance (Daytime Only)
Cal trend results

\[ y = 0.8335x + 0.2472 \]

\[ R^2 = 0.758 \]

Mean VIRS = 6.0
Mean GOES = 5.7

GEO Optical Depth

VIRS Optical Depth
GOES-8 Cloud Fraction: GGOE-VIRS

Day Ocean

<table>
<thead>
<tr>
<th>DIFF</th>
<th>AVE</th>
<th>SDV</th>
<th>MAX</th>
<th>MIN</th>
<th>RNG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-0.0079</td>
<td>0.0155</td>
<td>0.0439</td>
<td>-0.0321</td>
<td>0.0760</td>
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</table>

GGOE-VIRS Cloud Fraction

SLPx = -0.0000
R² = 0.0740

March 2000 to March 2003
July 2001 GGE0 & ISCCP Zonal Averages

Cloud Fraction

- MEAN (coincident)
- GGE0 60.08
- ISCCP 60.04

Cloud Fraction %

Latitude

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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 (TRMM)
(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>Total-sky LW</td>
<td>257.6</td>
<td>0.01 (0.08)</td>
</tr>
<tr>
<td>Total-sky SW</td>
<td>99.3</td>
<td>-0.04 (1.35)</td>
</tr>
<tr>
<td>Clear-sky LW</td>
<td>284.7</td>
<td>-0.29 (0.69)</td>
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</tbody>
</table>
Narrowband-to-Broadband Conversion

- Removing spectral differences key to accurately incorporating GEO data

- TRMM processing used global NB-BB fits
  - Separate relationships for land, ocean, and desert regions
  - LW relationship includes RH dependence
  - SW relationship includes SZA dependence

LW (rms ~3-5%)  SW (rms ~10-15%)
Improved Narrowband-to-Broadband Conversion

• Goal: Develop SW narrowband to broadband relationships to account for
  – Viewing geometry
  – Scene type (geo-type, cloud optical depth and phase)
  – Individual satellite spectral response functions

• Implement as visible to broadband radiance based conversion
  – Apply conversion before applying broadband ADM
  – Use gain and offset approach rather than a ratio
    • Not strictly tied to cloud property results to take into account misidentified scenes and differences between geostationary satellite derived cloud properties
Data

• TRMM CERES SSF broadband cross-track footprints provide coincident, collocated and co-angled visible (VIS 0.65µm) and broadband (BB 0.3-5µm) radiances at 10 km resolution.
  – The precessionary TRMM orbit provides good angular sampling in cross-track mode.
  – VIRS sampling limited to 47° view angle.

• CERES and VIRS visible (VIS) radiances are binned as follows:
  – Are nearly the same as the CERES bidirectional model bins
VIRS and CERES Reflectance for Selected Angular Bins

CLEAR OCEAN GLINT BIN
VZA=35° AZA=20° SZA=35°

OVERCAST OCEAN BIN
VZA=25° AZA=60° SZA=45° 18<τ<40 liquid
VIRS and CERES Reflectance for Selected Angular Bins

TRMM GRASS BIN
VZA=45° AZA=5° SZA=55°

TERRA GRASS BIN
VZA=55° AZA=40° SZA=25°

Color coded by 0.86 µm reflectance
Clear ocean, SZA=35°
Fill Unsampled bins

• Estimate the slope and offset for bins that are unsampled by generating footprint level reflectances using filled VIRS bins and theory

• Use DISORT to compute VIRS and BB reflectances for the given bins
  – Only 3 geo-types used, ocean, prairie and desert

• Use the following equation
  – where (j) is the unsampled bin and (i) is the sampled bin

\[
\rho_{j,k} = \frac{\sum_{i}^{N_{\text{VIRS bins}}} \sum_{k}^{N_{\text{bin footprints}}} \rho_{\text{VIRS},i,k}}{\rho_{\text{mod},i}^{\text{mod},j}}
\]
Ocean VIS reflectance, sza=35°

DISORT

VIRS

DISORT+VIRS
Ocean VIS/BB ratio, sza=35°

DISORT

SZA=35
RAT=0.838

DISORT+VIRS

SZA=35
RAT=0.974

VIRS

SZA=35

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VIS/BB albedo ratios

- GRASS
- FOREST
- ICE CLOUD (tau=27)
- WATER CLOUD (tau=27)
- OCEAN

VIS/BB ratio vs. solar zenith angle (deg)
VIRS/GEO model

- To account for surface and satellite spectral differences
- Use DISORT to compute GGEQO visible bin reflectances
  - VIRS, MODIS, Meteosat-7, Meteosat-5, GMS-5, GOES-10, GOES-8
  - Only 3 geo-types used, ocean, prairie and desert
- For each angular bin, geo-type and phase compute a least squares regression between VIRS and the given GGEQO reflectances as a function of optical depth
GGEO spectral response functions

Normalized Spectral Response

0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1

µm

0.0 0.2 0.4 0.6 0.8 1.0

0.65 RESPONSE FUNCTIONS

virs.1
terra.1
met7.1
met5.1
gms5.1
gos10.1
gos8.1
Comparison of Coincident CERES and GEO-derived Broadband Fluxes

CERES - GEO mean and (rms) SW flux Difference (W/m²)

<table>
<thead>
<tr>
<th>July 2001</th>
<th>Mean SW</th>
<th>GEO Data</th>
<th>MODIS Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean</td>
<td>210.8</td>
<td>2.7 (28.5)</td>
<td>-1.2 (18.2)</td>
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<tr>
<td>Land</td>
<td>302.0</td>
<td>-12.0 (34.3)</td>
<td>-9.6 (24.1)</td>
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<tr>
<td>Desert</td>
<td>310.3</td>
<td>1.6 (27.4)</td>
<td>2.9 (20.4)</td>
</tr>
</tbody>
</table>
Adding GEO Data Decreases Temporal Sampling Errors
TOA LW Flux Change  Terra FM-1 July 2001

Decrease: Yellow-red
Increase: Blue
Adding GEO Data Decreases Temporal Sampling Errors
2:30 - 9:30 LT LW FLUX Terra FM-1 July 2001

PM Higher: Yellow-red
AM Higher: Blue
Adding GEO Data Decreases Temporal Sampling Errors
TOA SW Flux Change  Terra FM-1 July 2001

Decrease: Yellow-red
Increase: Blue

Data:
(1)Mean
(2)Std Dev: Watts per square meter, (3)Num. Obs.: Unitless
Adding GEO Data Decreases Temporal Sampling Errors
2:30 - 9:30 LT SW FLUX Terra FM-1 July 2001

PM Brighter: Yellow-red
AM Brighter: Blue
ERBElike - SRBAVG Annual Net TOA Flux

Net Flux Difference (W/m²)

Latitude

nonGEO

GEO
ERBElike - SRBAVG Annual SW TOA Flux

Latitude vs. SW Flux Difference (W/m²) for nonGEO and GEO.
ERBElke - SRBAVG Annual LW TOA Flux

LW Flux Difference (W/m²) vs. Latitude

-3.0  -2.0  -1.0  0.0  1.0  2.0  3.0

-90 -60 -30  0  30  60  90

nonGEO
GEO
Global TOA Net Flux Comparison
Beta 2 SRBAVG January-December 2001

Net Flux (W/m$^2$)

-10
-5
0
5
10
15
20
Jan Feb Mar Apr May Jun Jul Aug Sept Oct Nov Dec

4.6 W/m$^2$
5.0 W/m$^2$
6.5 W/m$^2$

ERBE-like
SRBAVG-GEO
SRBAVG-nonGEO
Global TOA LW Flux Comparison
Beta 2 SRBAVG  January-December 2001

ERBE-like  238.7 W/m²
SRBAVG-GEO  237.5 W/m²
SRBAVG-nonGEO  238.2 W/m²
Global TOA SW Flux Comparison
Beta 2 SRBAVG January-December 2001

ERBE-like 98.0 W/m²
SRBAVG-GEO 98.6 W/m²
SRBAVG-nonGEO 98.1 W/m²
### Global Mean TOA All-sky Fluxes

<table>
<thead>
<tr>
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<th>July 2001</th>
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<td>Beta</td>
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<tr>
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<td>GEO</td>
<td>GEO</td>
<td>GEO</td>
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<tr>
<td>LW</td>
<td>243.1</td>
<td>242.4</td>
<td>241.8</td>
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<td>SW</td>
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<tr>
<td>Net</td>
<td>-4.8</td>
<td>-2.8</td>
<td>-3.3</td>
<td>-2.4</td>
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<table>
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<tr>
<td>LW</td>
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<td>234.8</td>
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<td>101.8</td>
<td>107.8</td>
<td>102.5</td>
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<tr>
<td>Net</td>
<td>13.5</td>
<td>15.3</td>
<td>9.9</td>
<td>15.8</td>
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Validation

• Surface flux comparisons
  – Monthly mean downwelling fluxes at BSRN sites
  – Instantaneous comparisons at ARM SGP

• Direct Integration
  – Similar to ADM test
  – Only possible for TRMM, but errors masked by compensation

• TRMM/Terra and Terra/Aqua comparisons
  – TRMM/Terra from March 2000 only
  – Terra Aqua in initial phase (Beta Aqua just becoming available)

• Waiting breathlessly for GERB
Summary

• Major improvements have been made in NB-BB conversion
• Large regional temporal sampling errors corrected using GEO data, but…..
• Global imbalance remains unchanged
• What next?
  – Product scheduled for release in July 2004
  – Testing of GGOE data will continue
    • CERES-to-CERES comparison
    • Tests for normalization flatness
  – Surface flux comparisons for Terra
  – Flux imbalance
    • Twilight
    • Directional models