Validation of CERES Edition 4
Angular Distribution Models

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Ed4ADM delivered

- Ed4ADM was delivered in November 2013
- Data management team and data center have finished testing of the inversion code
- Production of Ed4SSF is scheduled to begin on May 2, 2014
- ADM methodology paper is almost done
- Validation of the CERES instantaneous fluxes
  - Direction integration
  - CERES-MODIS flux consistency test
  - CERES-MISR flux consistency test
  - CERES-C3M scene identification
Direct integration for SW flux

• Construct two sets of regional (10° X 10°) all-sky ADMs by season (e.g. DJF, MAM, JJA, and SON) from
  – CERES measured radiances
    \[
    I_0 \rightarrow F(\theta_0) = \frac{\pi I_o(\theta_0, \theta, \phi)}{R(\theta_0, \theta, \phi)}
    \]
  – ADM predicted radiances
    \[
    \hat{I} \rightarrow R(\theta_0, \theta, \phi) = \frac{\pi \hat{I}(\theta_0, \theta, \phi)}{\hat{F}(\theta_0)}
    \]

• Both sets of regional all-sky ADMs have the same sampling
• Apply regional ADMs to crosstrack data of the middle month of the season to determine the fluxes
• Compare fluxes derived from these two sets of ADMs
Direct integration SW flux error for 2002 Terra FM1 (flux from predicted radiance ADM – flux from observed radiance ADM)

Direct integration using Ed4ADM

Jan
DI flux difference for Jan. 2002:FM1 Ed4ADM

July
DI flux difference for July 2002:FM1 Ed4ADM

Direct integration using Ed2ADM

DI flux difference for Jan. 2002:FM1 Ed2ADM

DI flux difference for July 2002:FM1 Ed2ADM
SW flux error is less than 2 Wm$^{-2}$ for 95% of the $1^\circ \times 1^\circ$ region.

### 2002 FM1

<table>
<thead>
<tr>
<th>Abs. flux error (Wm$^{-2}$)</th>
<th>Ed4ADM (%)</th>
<th>Ed2ADM (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1</td>
<td>86.0</td>
<td>78.1</td>
</tr>
<tr>
<td>&lt;2</td>
<td>94.7</td>
<td>89.0</td>
</tr>
<tr>
<td>&lt;5</td>
<td>99.0</td>
<td>98.1</td>
</tr>
<tr>
<td>&lt;8</td>
<td>99.7</td>
<td>99.6</td>
</tr>
</tbody>
</table>

### 2004 FM4

<table>
<thead>
<tr>
<th>Abs. flux error (Wm$^{-2}$)</th>
<th>Ed4ADM (%)</th>
<th>Ed2ADM (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1</td>
<td>86.9</td>
<td>81.7</td>
</tr>
<tr>
<td>&lt;2</td>
<td>95.6</td>
<td>92.5</td>
</tr>
<tr>
<td>&lt;5</td>
<td>99.3</td>
<td>98.7</td>
</tr>
<tr>
<td>&lt;8</td>
<td>99.8</td>
<td>99.7</td>
</tr>
</tbody>
</table>
Zonal mean SW flux error for 2002 Terra FM1

**January 2002:**
- Bias: Ed4ADM = 0.06, Ed2ADM = -0.33
- RMS: Ed4ADM = 0.79, Ed2ADM = 0.96

**April 2002:**
- Bias: Ed4ADM = 0.08, Ed2ADM = -0.08
- RMS: Ed4ADM = 0.67, Ed2ADM = 0.84

**July 2002:**
- Bias: Ed4ADM = -0.20, Ed2ADM = -0.49
- RMS: Ed4ADM = 0.91, Ed2ADM = 1.06

**October 2002:**
- Bias: Ed4ADM = 0.02, Ed2ADM = -0.15
- RMS: Ed4ADM = 0.58, Ed2ADM = 0.75
Direct integration for LW flux

- LW flux is a weak function of solar zenith angle
- Use standard direct integration for LW flux
- Done separately for daytime and nighttime observations
- Weight the daytime and nighttime flux error by fraction of daylight at each latitude for each month to derive the 24h-averaged flux error
Direct integration LW flux error for 2002 Terra FM1
(ADM flux – DI flux)

Direction integration using Ed4ADM

Jan  DI flux difference for 24h Jan. 2002 FM1 Ed4ADM

July DI flux difference for 24h July 2002 FM1 Ed4ADM

Direction integration using Ed2ADM

Jan  DI flux difference for 24h Jan. 2002 FM1 Ed2ADM

July DI flux difference for 24h July 2002 FM1 Ed2ADM
LW flux error is less than $2 \text{ Wm}^{-2}$ for 99% of the $1^\circ \times 1^\circ$ region.

### 2002 FM1

<table>
<thead>
<tr>
<th>Abs. flux error (Wm$^{-2}$)</th>
<th>Ed4ADM (%)</th>
<th>Ed2ADM (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1</td>
<td>87.1</td>
<td>89.9</td>
</tr>
<tr>
<td>&lt;2</td>
<td>98.8</td>
<td>98.6</td>
</tr>
<tr>
<td>&lt;4</td>
<td>99.9</td>
<td>99.9</td>
</tr>
</tbody>
</table>

### 2004 FM4

<table>
<thead>
<tr>
<th>Abs. flux error (Wm$^{-2}$)</th>
<th>Ed4ADM (%)</th>
<th>Ed2ADM (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1</td>
<td>91.0</td>
<td>90.7</td>
</tr>
<tr>
<td>&lt;2</td>
<td>99.2</td>
<td>98.5</td>
</tr>
<tr>
<td>&lt;4</td>
<td>99.9</td>
<td>99.8</td>
</tr>
</tbody>
</table>
Zonal mean LW flux error for 2002 Terra FM1

Jan.

bias=0.37
rms=0.55
bias=0.15
rms=0.56

Apr.

bias=0.47
rms=0.54
bias=0.31
rms=0.56

July

bias=0.44
rms=0.57
bias=0.29
rms=0.59

Oct.

bias=0.40
rms=0.48
bias=0.21
rms=0.47
CERES-MODIS instantaneous TOA flux consistency test

\[ I_{sw}^{c} = d_0 + d_1 I_{0.65} + d_2 I_{0.86} + d_3 I_{1.63} \]

\[ I_{lw}^{c} = \alpha_0 + \alpha_1 I_{11} \]

\[ \sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left[ F(\theta_i^n) - F(\theta_i^o) \right]^2} \]

\[ \psi = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left[ \frac{F(\theta_i^n) - F(\theta_i^o)}{F(\theta_i^o)} \right]^2} \times 100\% \]
Bias and RMS error between CERES and MODIS fluxes

<table>
<thead>
<tr>
<th>Clear-sky</th>
<th>Ocean</th>
<th>Land</th>
<th>Snow/Ice</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bias (Wm(^{-2}))</td>
<td>RMS (Wm(^{-2}))</td>
<td>Bias (Wm(^{-2}))</td>
</tr>
<tr>
<td>SW</td>
<td>0.0</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td>LW day</td>
<td>-1.6</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td>LW night</td>
<td>-2.0</td>
<td>2.3</td>
<td>-1.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>All-sky</th>
<th>Ocean</th>
<th>Land</th>
<th>Snow/Ice</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bias (Wm(^{-2}))</td>
<td>RMS (Wm(^{-2}))</td>
<td>Bias (Wm(^{-2}))</td>
</tr>
<tr>
<td>SW</td>
<td>-0.7</td>
<td>15.1</td>
<td>2.6</td>
</tr>
<tr>
<td>LW day</td>
<td>-1.7</td>
<td>5.9</td>
<td>1.3</td>
</tr>
<tr>
<td>LW night</td>
<td>-1.2</td>
<td>3.3</td>
<td>-1.5</td>
</tr>
</tbody>
</table>
SW flux RMS error shows very little dependence on aerosol optical depth over ocean and land.

\[ \sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} [F(\theta^i) - F(\theta^o)]^2} \]

mean CERES flux and standard deviation \( (F^o \text{ and } F^n) \) over clear ocean

Total sample number: 208297
CERES-MODIS flux consistency over clear ocean: dependence on MODIS fine mode fraction is smaller than using Ed2ADM
For a CERES footprint, MISR provides spectral radiance measurements from nine camera angels.
For $M$ CERES footprints, we calculate the mean standard deviation:

$$\bar{\sigma} = \sqrt{\frac{\sum_{i=1}^{M} s_i^2}{M}}$$

and the overall relative consistency:

$$CV_T = \left( \frac{\sqrt{\frac{1}{M} \sum_{i=1}^{M} s_i^2}}{\frac{1}{M} \sum_{i=1}^{M} F_{sw}^i} \right) \times 100\%$$

$$CERES \ ADM$$

$$F_{sw}^j, I_{sw}^j, I_{csw}^j$$

$$I_{sw}^j = c_0 + c_1 I_{0.45}^j + c_2 I_{0.67}^j + c_3 I_{0.87}^j$$

$$CV_{NB} = \left( \frac{1}{m} \sum_{i=1}^{m} \left( F_{sw}^j - F_{csw}^j \right)^2 \right) \times 100\%$$

$$CV_{ADM} = \sqrt{CV_T^2 - CV_{NB}^2}$$
Flux consistency for single-layer clouds over ocean

<table>
<thead>
<tr>
<th></th>
<th>partly cloudy</th>
<th>mostly cloudy</th>
<th>overcast</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF</td>
<td>0.1~40%</td>
<td>40~99%</td>
<td>&gt;99%</td>
</tr>
<tr>
<td>Occurrence frequency</td>
<td>&lt;0.1%</td>
<td>0.1-1%</td>
<td>1-5% 5-10% 10-20% &gt;20%</td>
</tr>
</tbody>
</table>

PCL: CF = 0.1-40%
High: EP < 440 hPa
Thin: $\tau < 3.35$

MCL: CF = 40-99%
Mid: EP = 440-680 hPa
Mod: $\tau = 3.35 - 22.63$

OVC: CF = 99-100%
Low: EP > 680 hPa
Thick: $\tau > 22.63$
• Surface is used as the reference level to collocate MISR Level 1B radiances with the CERES data:

\[ CV_T^2 = CV_{ADM}^2 + CV_{NB}^2 + CV_{PX}^2 \]

• MISR Level 2 data are projected on to the reflecting layer reference altitude:

\[ CV_{2T}^2 = CV_{ADM}^2 + CV_{NB}^2 \]

• Parallax effect can be quantified as:

\[ CV_{PX} = \sqrt{CV_T^2 - CV_{2T}^2} \]
Flux consistency for single-layer clouds over ocean

Occurrence frequency

- <0.1%
- 0.1-1%
- 1-5%
- 5-10%
- 10-20%
- >20%
Flux consistency for multi-layer clouds over ocean

- **partly cloudy**
  - ADM+plx
  - ADM

- **mostly cloudy**
  - high
  - mid
  - low

- **overcast**
  - high
  - mid
  - low

Occurrence frequency
- <0.1%
- 0.1-1%
- 1-5%
- 5-10%
- 10-20%
- >20%
Uncertainty from Parallax is about 2% over ocean, 0.8% over land, and negligible over snow/ice under all-sky conditions.
MISR flux consistency shows little dependence on aerosol optical depth and fine-mode fraction over ocean.
MISR flux consistency shows very little dependence on aerosol optical depth over land.

Total sample number: 1.2m

Sahara: total sample #: 0.5m

Amazon: total sample #: 28k
Daytime clear-sky LW flux uncertainty from scene identification

<table>
<thead>
<tr>
<th>Daytime Sfc. Type</th>
<th>$\Delta f$ (CERES-C3M) (%)</th>
<th>$\Delta LW$ (CERES-C3M) (Wm$^{-2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ocean</td>
<td>-12.9</td>
<td>0.7</td>
</tr>
<tr>
<td>land</td>
<td>-13.9</td>
<td>1.8</td>
</tr>
<tr>
<td>snow/ice</td>
<td>-10.8</td>
<td>0.3</td>
</tr>
</tbody>
</table>

C3M clear footprints from MODIS Jan. 2010

Frequency

- CCCM Cloud Cover (%)
- Cloud Optical Depth
- Effective Cloud Top Temperature (K)
Daytime LW flux uncertainty from scene identification

CERES overestimates clear-sky daytime LW flux by 1.2 Wm$^{-2}$

CERES overestimates all-sky daytime LW flux by 1.1 Wm$^{-2}$
Nighttime clear-sky LW flux uncertainty from scene identification

<table>
<thead>
<tr>
<th>Nighttime Sfc. Type</th>
<th>Δf (CERES-C3M) (%)</th>
<th>ΔLW (CERES-C3M) (Wm-2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ocean</td>
<td>-20.1</td>
<td>1.9</td>
</tr>
<tr>
<td>land</td>
<td>-20.1</td>
<td>2.0</td>
</tr>
<tr>
<td>snow/ice</td>
<td>-24.7</td>
<td>0.7</td>
</tr>
</tbody>
</table>
Nighttime LW flux uncertainty from scene identification

CERES overestimates clear-sky nighttime LW flux by 2.1 Wm$^{-2}$

CERES overestimates all-sky nighttime LW flux by 0.8 Wm$^{-2}$
Comparison between Aqua and SNPP: Daytime cloud properties

Aqua

SNPP

Diff.

Daytime Cloud fraction properties

20120201:Aqua Cloud fraction mean f=65.2%

20120201:NPP Cloud fraction mean f=64.3%

Day 20120201:NPP−Aqua Cloud fraction mean Δf=−1.0%

Daytime Optical depth properties

20120201:Aqua Cloud τ mean τ=6.5

20120201:NPP Cloud τ mean τ=6.8

Day 20120201:NPP−Aqua Cloud optical depth mean Δτ=0.3
Comparison between Aqua and SNPP: Daytime SW and LW flux
SNPP SW flux is higher than Aqua SW flux by 6.7 Wm$^{-2}$, and daytime SNPP LW flux is lower than Aqua LW flux by 1.6 Wm$^{-2}$.
Comparison between Aqua and SNPP: Nighttime cloud properties

Aqua

SNPP

Diff.

4/22/2014

CERES STM
Nighttime SNPP LW flux is lower than Aqua LW flux by $0.2 \text{ Wm}^{-2}$.
More talks on ADM

• Lusheng Liang: Edition 4 clear-sky shortwave angular distribution models over ocean

• Zach Eitzen: Uncertainty of LW fluxes due to scene identification

• Joe Corbett: Expanding the SSFM dataset for CERES ADM validation
Summary

• CERES TOA SW flux uncertainties
  – global mean uncertainty is less than 0.2 Wm\(^{-2}\)
  – instantaneous uncertainty is 15~18 Wm\(^{-2}\)

• CERES TOA LW flux uncertainties
  – global mean uncertainty is less than 0.4 Wm\(^{-2}\)
  – instantaneous uncertainty is 3~6 Wm\(^{-2}\)

• Clear-sky SW flux consistency tests show little dependence on aerosol optical depth over ocean and land

• LW flux uncertainty from scene identification is about 1 Wm\(^{-2}\)

• Global mean SW flux from SNPP is higher than that from Aqua by 2~3\%, consistent with the SW radiance difference between SNPP and Aqua.

• LW fluxes from SNPP and Aqua are within 0.1\%.