Development of New CERES/Terra Angular Distribution Models

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Outline

- TOA Flux Group Activities
- Terra SW ADM Development
- New Approach for SW ADMs in Cloudy Conditions
- SW ADMs Over Snow
- Clear and Overcast LW ADMs
- Regional Instantaneous TOA Flux Consistency Checks
TOA Flux Group Activities

May 2002 – September 2002
- ADM Publications:
i) Paper on TOA flux reference level in press (*J. Climate*)
ii) ADM paper (Part I) describing CERES/TRMM SW, LW & WN ADMs accepted (*J. Appl. Meteor.*).
iii) Parts II & III summarizing TRMM ADM validation results are in preparation.

September 2002 – June 2003
- Development and validation of Terra ADMs based on 2 years of CERES/Terra RAP measurements.
- So far, only 4 months…
Terra SW ADM Development

- Terra ADMs will be based on 2 years of CERES measurements.
- Increase angular resolution of ADMs (goal: $2^\circ$ or $5^\circ$).
- Increase the number of scene types.
- Snow and sea-ice.
- Use new MODIS products (e.g. aerosol properties)?
- Neural network scheme to improve TOA flux estimates for footprints with excessive “no retrievals”.
- Validation: Improve instantaneous TOA flux consistency tests (alongtrack).
- Comparisons with MISR?
Proposed Terra SW ADMs – Clear Scenes

Clear Ocean:
Similar approach as for CERES/TRMM but with 2° angular bin resolution. Wind speed dependent empirical ADMs + theoretical correction for aerosol optical depth variations.

Clear Land:
Stratify by IGBP type + vegetation index
  => Is there any change in anisotropy? Can we use MODIS aerosol product for smoke and dust ADMs?

Clear Desert:
Same strategy as CERES/TRMM but higher angular resolution (separate ADMs for dark and bright desert regions).

Clear Snow:
Stratify by permanent snow, fresh snow over land and sea ice. Use NDSI as additional classifier.
Terra SW ADMs – Cloudy Scenes

Clouds over Ocean:
“Continuous” ADMs using sigmoidal fit approach for 4 cloud phase categories.

Clouds over Land and Desert:
Similar approach as over ocean but with 2 phase categories.

Clouds over Snow:
Stratify by phase, cloud fraction and cloud optical depth.
Towards an Infinite Number of Scene Types for SW ADMs in Cloudy Conditions
Liquid Water Clouds $\theta_0 = 20^\circ - 30^\circ$ (Nov-Dec, 2000)

Cloud Fraction

$\langle \ln \tau \rangle$

$\ln[\int e^{\langle \ln \tau \rangle} \, d\tau]$

Normalized Ratio

Viewing Zenith Angle (°)
Liquid Water Clouds $\theta_0=40^\circ$-$50^\circ$ (Nov-Dec, 2000)

Cloud Fraction

$\ln \tau$

$\ln[\exp(\ln \tau)]$

Normalized Ratio

Viewing Zenith Angle (°)

Viewing Zenith Angle (°)
Uncertainties in Sigmoidal SW Radiance Fits
(Liquid Water Clouds; $\theta_0=34^\circ-36^\circ$; $\Theta=50^\circ-52^\circ$; $\phi=6^\circ-8^\circ$; TRMM+Terra RAPS+Alongtrack)

**SW Radiance vs $\ln[f_x e^{\langle\ln \tau\rangle}]$**
- Bin Averages
- Instantaneous
- Sigmoidal Fit to Averages

**Sigmoidal Fit SW Radiance Error**
- Fit - Actual Radiance (W m$^{-2}$ sr$^{-1}$)
- $\log[f_x e^{\langle\ln \tau\rangle}]$

**Statistics**
- Avg Rad = 70.5 W m$^{-2}$ sr$^{-1}$
- Bias = 0.038 W m$^{-2}$ sr$^{-1}$ (0.05%)
- Stdev = 5.26 W m$^{-2}$ sr$^{-1}$ (7.5%)
SW Radiance vs $\ln[f \ e^{\langle \ln \tau \rangle}]$

($\theta_0=48^\circ-50^\circ$; $\theta=0^\circ-2^\circ$; $\phi=0^\circ-2^\circ$)

**Liquid Water Clouds**

- Avg Rad = 42.3 W m$^{-2}$ sr$^{-1}$
- Bias = 0.003 W m$^{-2}$ sr$^{-1}$ (0.0%)
- Stdev = 3.76 W m$^{-2}$ sr$^{-1}$ (8.9%)

**Ice Clouds**

- Avg Rad = 126.0 W m$^{-2}$ sr$^{-1}$
- Bias = 0.026 W m$^{-2}$ sr$^{-1}$ (0.0%)
- Stdev = 4.91 W m$^{-2}$ sr$^{-1}$ (3.9%)
2D SHDOM Results Applied to Landsat Boundary Layer Clouds
(Nadir Viewing Zenith Angle)

\[ \theta_0 = 15^\circ \]
Rel. Err (1\(\sigma\)) = 9.2%

\[ \theta_0 = 35^\circ \]
Rel. Err (1\(\sigma\)) = 9.4%

\[ \theta_0 = 55^\circ \]
Rel. Err (1\(\sigma\)) = 9.8%

\[ \theta_0 = 75^\circ \]
Rel. Err (1\(\sigma\)) = 9.0%
CERES SW Radiances vs Viewing Zenith Angle
(Principal Plane; 4 Months Terra over Ocean)

Liquid Water Clouds ($\tau=5$)

- $\theta_0=40^\circ-42^\circ$
- $\theta_0=50^\circ-52^\circ$
- $\theta_0=60^\circ-62^\circ$

Ice Clouds ($\tau=5$)

- $\phi=178^\circ-180^\circ$
- $\phi=0^\circ-2^\circ$

SW Radiance (W m$^{-2}$ sr$^{-1}$)

Viewing Zenith Angle (°)
Errors in SW Radiance Sigmoidal Fits
(Liquid Water Clouds Over Ocean; $\theta_o=40^\circ-50^\circ$; $\theta=0^\circ-20^\circ$)
Errors in SW Radiance Sigmoidal Fits

(Liquid Water Clouds Over Ocean; $\theta_0=40^\circ$-50$^\circ$; $\theta > 45^\circ$; $\phi < 60^\circ$)
Errors in SW Radiance Sigmoidal Fits

(Liquid Water Clouds Over Ocean; $\theta_0=40^\circ-50^\circ$; $\theta > 45^\circ$; $\phi > 120^\circ$)
Relative Errors in Sigmoidal Radiance Fit

![Graph showing relative bias and RMS error as a function of solar zenith angle for different cloud types.](image)

- **Relative Bias (Liquid Water Clouds)**
- **Relative Bias (Ice Clouds)**
- **Relative RMSE (Liquid Water Clouds)**
- **Relative RMSE (Ice Clouds)**
Sigmoidal Fit in Sunglint Region
$(\theta_0=48^\circ-50^\circ; \quad \theta=48^\circ-50^\circ; \quad \phi=0^\circ-2^\circ)$

**All Cloudy Footprints**

**Only Footprints with $f > 50\%$**

![Graphs showing SW radiance vs. ln[f e^{ln(τ)}] for different conditions](image)
Sigmoidal Fit in Sunglint Region
($\theta_0=48^\circ-50^\circ; \ \theta=48^\circ-50^\circ; \ \phi=0^\circ-2^\circ$)

Only Footprints with $f \leq 50\%$
Broken Liquid Water Cloud Over Ocean
($\theta_0=48^\circ-50^\circ$; $f=40\%$; $\tau=1.4$)

Wind Speed (m s$^{-1}$)

- Black: 1
- Red: 3
- Green: 5
- Blue: 10

SW Radiance (W m$^{-2}$ sr$^{-1}$)

- $\phi=178^\circ-180^\circ$
- $\phi=0^\circ-2^\circ$

Viewing Zenith Angle (°)
SW Radiance Dependence on Glint Angle and Wind Speed
(Clear Ocean; $\theta_o=30^\circ-32^\circ$)
Albedo vs Solar Zenith Angle
(60°S-60°N; Ocean; TRMM RAP+Terra Nov-Dec 2000+Apr-May 2001)

Liquid Water Clouds

Thick Lines: TRMM ADMs
Thick Lines: Terra ADMs

Ice Clouds

- $\tau = 2.5 - 5.0$
- $\tau = 10.0 - 12.5$
- $\tau > 50$
Albedos Over Ocean Based on CERES TRMM ADMs & Terra ADMs
Solar Zenith = 20°-30°

![Graphs showing albedo differences between TRMM ADMs and Terra ADMs for liquid water and ice clouds.](image_url)
SW Flux Comparison: TRMM vs Terra ADMs (Nov-Dec, 2000)
SW ADMs over Snow
SW Radiance Anisotropy Over Snow

Stratify cloud-free scenes over snow by MODIS-derived Normalized Difference Snow Index (NDSI):

\[ NDSI = \frac{r(0.645) - r(1.64)}{r(0.645) + r(1.64)} \]

\( r(0.645) \) = MODIS reflectance from 0.645 \( \mu m \) channel.
\( r(1.64) \) = MODIS reflectance from 1.64 \( \mu m \) channel.
CERES SW Radiance vs $\theta$ and MODIS NDSI Snow Index
($\theta_o=70^\circ$-80°; Principal Plane; Nov-Dec, 2000+Apr-May, 2001)
December 2000; Permanent Snow

![Graph showing relative frequency of cloud fraction for Beta2 SSF and ValR1 SSF.](image)
Terra LW & WN ADMs – Clear Scenes

Clear Ocean:
- Scene types defined by fixed discrete intervals of: precipitable water, lapse rate and skin temperature.

Clear Land and Desert:
- Similar to ocean but separate ADMs for forests, savannas, croplands/grasslands, tundra, open shrubs and barren deserts.
- Is it necessary (and practical) to stratify ADMs by relative azimuth angle over rough terrain?

Clear Snow:
- Stratify by permanent snow, fresh snow over land and sea ice.
Terra LW & WN ADMs – Cloudy Scenes

**Clouds over Ocean:**
Scene types defined by fixed discrete intervals of: precipitable water, cloud cover, surface-cloud temperature difference and cloud emissivity.

**Clouds over Land and Desert:**
Same parameters as for ocean.

**Clouds over Snow:**
Fixed discrete intervals of cloud cover, surface-cloud temperature difference and cloud emissivity.
Clear LW ADMs \([w=0-1 \text{ cm}; T(\text{sfc}) - T(\text{sfc-300mb})=15-30 \text{ K}]\)
Clear LW ADMs \( [w=0-1 \text{ cm}; \text{T(sfc)} - \text{T(sfc-300mb)} < 15 \text{ K}] \)

- **Forests**
- **Savannas**
- **Croplands/Grasslands**
- **Open Shrublands**

Anisotropic Factor vs. Viewing Zenith Angle (°)
Overcast Ocean LW ADMs [w=3-5 cm]

Anisotropic Factor vs. Viewing Zenith Angle (°)

- ΔT = < 10
- ΔT = 10.0 - 30.0
- ΔT = 30.0 - 50.0
- ΔT = 50.0 - 70.0
- ΔT = 70.0 - 90.0
- ΔT = > 90

IR Emissivity:
- < 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- 0.8 - 1.0
- > 1.0

The graphs show the relationship between the anisotropic factor and the viewing zenith angle for different temperature ranges and IR emissivity levels.
Regional Instantaneous TOA Flux Consistency Tests
Objective: Compare ADM-derived TOA fluxes over 1° regions from different viewing geometries. Are TOA fluxes consistent?
Regional Instantaneous SW TOA Flux Consistency Test

**Approach:** For every 1° region:

1. Use nadir CERES footprints to train MODIS imager to produce broadband SW radiances over each CERES footprint within 1° region (linear fit).

![Sample 1° Region](image1)

![Relative RMS Errors in Nadir Narrow-to-Broadband Radiance Fits (Terra; October 23, 2001)](image2)
(2) Convert imager “broadband” radiance over every CERES alongtrack footprint to a flux by calling CERES ADM module.

=> Imager sees CERES alongtrack footprints from nadir direction only.

(3) For every 1° region, compare nadir imager TOA fluxes with alongtrack CERES TOA fluxes.

=> Since imager and CERES measurements are collocated, spatial matching errors are reduced with this technique.

=> Main Sources of Error:
   i) Radiance-to-flux conversion (ADM$s$)
   ii) Narrow-to-broadband conversion
1° Regional Instantaneous SW TOA Flux Consistency Test

Results: Based on 1 day of A-track and X-track CERES/Terra data.
Summary

- CERES/Terra ADMs:
  - Based on 2 years of measurements.
  - Increase angular bin resolution.
  - Increase number of scene types relative to TRMM.
  - New approach for “continuous” SW ADMs for clouds.
  - Empirical SW and LW ADMs over snow and sea ice.

- Early CERES SSF instantaneous regional TOA flux consistency checks show a factor of 1.8 improvement over ERBE-Like.
TOA Flux Working Group Agenda

1. Inversion of SW and LW Radiances into TOA Fluxes using Artificial Neural Network Simulation – Konstantin Loukachine
2. Plans for Terra ADM Development: ADM Parameter Studies – Nitchie Manalo-Smith
3. Some Preliminary Model Results of Longwave Anisotropy from CERES TRMM and Terra – A.V.Gambheer
5. Scheme for retrieval of ice clouds optical thickness and bulk phase functions using multi-angular data from POLDER.– Wenbo Sun
6. GERB inversions: Methods and Plan for Validation – Nicolas Clerbaux
7. Theoretical Simulations of ADMs based on Sigmoidal Fits – Lin Chambers