CERES Overview: Clouds and the Earth’s Radiant Energy System

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Outline

• Climate change background
• CERES introduction
• Advances of CERES over ERBE
• Data product examples
• Web site links
• Selected journal references
• Future directions
Human Influence on Climate

Carbon Dioxide Trends: 100yr lifetime

Methane Trends

Sulfate Trends

Global Temperature Trends

From M. Prather University of California at Irvine
Global Temperature Predictions

Uncertainty in climate sensitivity

Uncertainty in future emissions

Bars show the range in 2100 produced by several models

IPCC, 2001
How does the Earth Respond?

Feedbacks examples:
- Water vapor (positive)
- Clouds (unknown)
- Snow/ice albedo (positive)
CERES Instrument

**TRMM:**
Jan-Aug 98
and Mar-Apr 2000
overlap with Terra

**Terra:**
Mar 00 - present
planned life: 2006

**Aqua:**
July 02 start
Now in checkout
Planned life to 2008

**NPOESS:**
TBD: gap or overlap?
2008 to 2011 launch
CERES Data Processing Flow

Algorithm Theoretical Basis Documents:
http://asd-www.larc.nasa.gov/ATBD/ATBD.html

Validation Plans:
Matching CERES Fovs with Imager Cloud Properties

- CERES footprint: 20 km
- Imager Pixel
- Top View
- Side View
- 4 Cloud Height Categories
  1. low clouds
  2. lower middle clouds
  3. upper middle clouds
  4. high clouds
- 300 hPa
- 500 hPa
- 700 hPa
- Surface
- Clear
Range of Cloud/Aerosol/Radiation Model Tests
ERBE Error Analysis: CERES goals

• **Instantaneous TOA Flux error dominated by:**
  – Angle Sampling Error: (new adms: factor 2-3 reduction)

• **Monthly mean regional TOA flux errors dominated by:** (CERES improvement)
  – Absolute calibration (factor of 2 improvement)
  – Angle Sampling Error (new adms: factor 2-5 reduction)
  – Time Sampling Error (add geo: factor of 2-3 reduction)

• **Interannual/Decadal errors dominated by:**
  – Calibration stability (< 1 Wm\(^{-2}\), goal 0.25 Wm\(^{-2}\))
Summary of CERES Advances

- **Calibration**
  Offsets, active cavity calib., spectral char.
- **Angle Sampling**
  Hemispheric scans, merge with imager matched surface and cloud properties new class of angular, directional models
- **Time Sampling**
  CERES calibration + 3-hourly geo samples new 3-hourly and daily mean fluxes
- **Clear-sky Fluxes**
  Imager cloud mask, 10-20km FOV
- **Surface/Atm Fluxes**
  Constrain to CERES TOA, Fu-Liou, ECMWF imager cloud, aerosol, surface properties
- **Cloud Properties**
  Same 5-channel algorithm on VIRS, MODIS night-time thin cirrus, check cal vs CERES
- **Tests of Models**
  Take beyond monthly mean TOA fluxes to a range of scales, variables, pdfs
- **ISCCP/SRB/ERBE**
  Overlap to improve tie to 80s/90s data.
- **CALIPSO/Cloudsat**
  Merge in 2004 with vertical aerosol/cloud

*Move toward unscrambling climate system energy components*
What makes CERES unique?

• Calibrate. Calibrate. Calibrate.
  - most accurate and stable of EOS radiometers.
  - climate is a 1% game: calibration before resolution.

• Sample. Sample. Sample.
  - Radiation is an 8-dimensional sampling problem:
    \(x, y, z, t, \theta, \phi, Q, F\)
  - 2 CERES scanners: one for \(x,y\). One for \(\theta, \phi\).
  - Imager for \(z, \theta, \phi\) (select ADMs. \(z\) later using lidar/radar).
  - TRMM precessing orbit: all \(\theta, \phi\)
  - Geostationary and Terra/Aqua orbits for \(t\)
  - Data products integrate up to 11 instruments on 7 spacecraft.
  - 500,000 lines of production code, another 500K offline.

• Validate. Validate. Validate.
  - Large ensembles of cases: ARM, BSRN, etc to reach 1%
  - Satellite checks using GERB (diurnal), Calipso/Cloudsat (\(z\))
  - Few field experiment cases not enough: A/C > Sfc > Sat
  - Created data quality summaries for quick assessment
  - Beta to Validated (Edition) to involve community early
CERES is Complex: Why does it work?

Failed IRS, FAA, Denver baggage code similar size

- Difficulty of software is a power law: not linear in lines of code.
- CERES is ~ 500K lines of production code, and 500K lines of offline qc/validation. Failed FAA system was similar, but over $1B spent before failed.
- ERBE earlier experience with 1/4 the difficulty was key.
- Most of the team has been together for 10 to 20 years: turnover for software “contracts” can be 30%/yr
- Team dedicated to a mission, not a profession: a science advantage.
- Team focused first on interface definitions (data products) between major components and then let individual working group chairs control their part. Analogous to the way the web works.
- Science team, Algorithm team, Data Management team, Data Center team work together well: most at LaRC so that science and data are closely tied.
- Cost to develop CERES only 70% of computer industry cost for similar size developments.
Examples of Results
Unprecedented Accuracy of new EOS Radiation Data

Emitted Thermal Flux Measured By CERES
Terra  March 2000

ES-8
ERBE-Like

Watts per square meter
CERES Terra 14 day Running Average for TOA LW Flux
March 2000 to May 2001

T. Wong, NASA LaRC and Data Visualization Group, NASA GSFC
An overlapping Earth radiation climate record: 22 years from Nimbus 7 to Terra.

ES-8 ERBE-Like
Comparison of Observed Decadal Tropical Radiation Variation with Current Climate Models

Models less variable than the observations:  
- missing feedbacks?  
- missing forcings?  
- clouds physics?

LW:  
Emitted Thermal Fluxes

SW:  
Reflected Solar Fluxes

Net:  
Net Radiative Fluxes

ES-8 ERBE-Like  
Wielicki et al., Science 02
Jan/Feb 98 El Nino Thermal Flux Anomalies

NASA CERES Radiation Observations

NOAA GFDL Standard Climate Model

NOAA GFDL Experimental Prediction Model

Tak Wong

ES-8 ERBE-Like
1998 El Nino Tropical Mean (20S - 20N) Longwave Flux Anomalies
(Anomalies Referenced to 1985 through 1989 Baseline)

5 Climate Models and NCEP Re-analysis; All used observed SSTs; Climate Models: NCAR-CSM (Kiehl) UKMO (Allan, Slingo), GFDL and GFDL-EP (Soden, Gordon), CSU (Randall)
A New EOS Cloud Object Approach to Testing Climate and Cloud Resolving Models

Example: Tropical Deep Convective Cloud Systems Test

- NWP atmospheric state drives cloud models
  - Drive the ECMWF cloud model: 50 km global 3-D
  - Drive a Cloud Resolving Model: 1 km 2-D grid over 500 km domain.
- EOS cloud and radiation data for over 50 cloud systems verifies model performance: still a long way to go....

SSF TRMM Data

Kuanman Xu and Tak Wong
NASA EOS Data Directly Tests Policy Relevant Climate Sensitivity Hypotheses: The Iris

New EOS CERES fluxes accurate by cloud type allow direct testing of the Iris hypothesis: a simple climate model of strong negative cloud feedback:

Are the Iris assumed convective cloud radiative properties right?

The Iris assumed cloud radiative fluxes

CERES observed cloud radiative fluxes: differ by 80-100 W/m² from the Iris, and rejects the Iris Hypothesis.

B. Lin and L. Chambers
CERES Linkages

• Validation:
  – ARM (DOE), BSRN (International), Surfrad (NOAA), Aeronet (NASA)
  – Aircraft => ARM => Satellite as an overall strategy

• Climate Modeling Community:
  – Randall (CSU), Donner (GFDL), Miller (NCEP)
  – Kiehl (NCAR), Slingo/Allan (UKMO)
  – GCSS (Randall, Xu)

• Global Satellite Observations:
  – VIRS/MODIS imagers for cloud properties
  – ISCCP geostationary radiance data (3hrly time sampling)
  – GERB geostationary broadband validation
  – A-train Cloudsat/Calipso vertical aerosol cloud data
  – TRMM Precipitation for latent/radiative heat budget
K-12 Education Outreach: S’COOL
Student Cloud Observations Online

- Over 1300 schools
- Schools in 61 countries
- K – post-graduate, focus on grades 3-6
- Schools observe at satellite overpass time
- Over 17,000 ground observations for CERES validation

http://scool.larc.nasa.gov
L. Chambers
NASA’s Surface meteorology and Solar Energy (SSE) Project and Beyond

**Purpose:** Provide NASA ESE data for the feasibility analysis and preliminary design of renewable energy power systems from small to large (Solar, Wind, Buildings, etc.).

**Data Delivery Method:** Easily accessible data tables and maps generated real-time for user at

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

**Users:** Web site has 35,000 Hits/month, with 3,500 data downloads; the most accessed site at ASDC. Users include small to large companies, universities, government agencies, and banks.

**Future:** Teaming with NOAA, DOE/NREL, and Electric Power Research Institute to expand into forecasted data sets

P. Stackhouse
CERES by the Numbers

Publications (CERES team):

<table>
<thead>
<tr>
<th>Year</th>
<th>Journal</th>
<th>Conference</th>
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<tr>
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<tr>
<td>1999</td>
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Data Products Delivered:

- 8,000 Gbytes of data to date
- 4,000 Gbytes/yr currently
- 50 unique users per quarter
- 1/3 international (15 countries)

ES-8/4/9 ERBE-Like most popular early, then SSF dominates (TRMM).

*Shipped 3.3 times the volume of all L2 and L3 validated products*

Data Products Processed at Full Production:

- **Input Data:**
  - up to 11 instruments on 7 spacecraft:
    - 1,000 Gbytes/month, in 20,000 files
- **Output Data Products:**
  - 600 Gbytes/month, in 3,000 files
  - 75% in SSF and CRS Level 2 pixel products

*Products range from 262GB/month (CRS L2) to 30MB/month (ES4 L3)*
CERES Reference List

• CERES General Background
  – CERES Brochure (on the CERES home page)

• CERES Data Products and Algorithms
  – CERES Data Products Catalog: summary of data products
  – CERES Data Collection Guides: one per data product; defines formats/variables.
  – CERES Data Quality Summaries: one per data product; summarizes current estimates of the accuracy of variables in each validated archived CERES product.
  – The above can be found at: http://asd-www.larc.nasa.gov/ceres/docs.html

• Tropical decadal variability
  – Chen et al., Science, Vol 295, Feb 1, 2002 p838-841. (hadley/walker hypothesis)
  – Wang et al., GRL, 29, No. 10, 2002. (SAGE II cirrus height changes)
CERES Reference List, con’t

• **1998 El Nino Radiative Anomalies**
  - Cloud Forcing Ratio Anomaly/SAGE II cloud height anomalies: Cess et al., GRL, 28, 4547-4550, Dec 15, 2001

• **Iris tropical cloud negative feedback hypothesis**
  - The Iris Hypothesis: Lindzen et al., BAMS, 82, 417-432, 2001.
  - Cloud radiative properties: Lin et al., J Climate, 15, 3-7, 2002.
  - Improved cloud radiative properties using new CERES merged cloud/radiation data products (TRMM SSF): Chambers et al., J Climate, in press (for a pdf copy, contact l.h.chambers@larc.nasa.gov)
Where do I go for CERES data and documentation?

- CERES Data Orders at http://eosweb.larc.nasa.gov/project/ceres/table_ceres.html
“A-Train” Formation for Aerosol and Cloud Vertical Profiles
Atmospheric State => Aerosol/Cloud => Radiative Heating

A-Train Launch: 2004
D. Winker and P. McCormick, P.I.’s

A-Train Launch: 2004
D. Winker and P. McCormick, P.I.’s
Calipso, Cloudsat and Aqua in Formation: Testing Global Cloud Models

CALIPSO Lidar and Cloudsat Radar: aerosol and cloud vertical profiles

Aqua

Cloud/Aerosol Physical Property Vertical Profiles

Predict Solar and Thermal Infrared Fluxes

Aqua

Surface, Atmosphere, Top of Atmosphere Flow of Radiative Energy (Solar, Thermal)

Aqua

Heat or Cool Surface & Atmosphere

Aqua

State of The Surface and Atmosphere

AIRS/AMSU/MHB Temperature, Humidity, Winds

CERES energy fluxes, MODIS cloud optics
Currently EOS to NPOESS transition has a 50% risk of a critical radiation data gap.

NASA is trying to resolve this with NPP mission planed for launch in 2006 if funding allows.

NPOESS only plans to replace after failures....

Symptomatic of a climate observing system spread across agencies with different missions & priorities: climate is not #1 at any of them.

CERES continues as ERB on NPOESS in 2011

What about end of Aqua in 2008 to 2011? NPP?

What is an acceptable gap risk? 5%/decade? 10%/decade?

A climate observing system should have hot spares designed to assure overlap: not there yet.
CERES Data Processing Flow

CERES Data

6 Months

CERES Calibration/Location

Cloud Imager Data

18 Mo.

Cloud Identification; TOA/Surface Fluxes

24 Mo.

Surface and Atmospheric Fluxes

36 Mo.

Time/Space Averaging

42 Mo.

CERES Time Averaged Cloud/Radiation TOA, SFC, Atmos

6 Months

ERBE Inversion

Angular Distribution Models

36 Mo.

CERES Surface Products

Diurnal Models

36 Mo.

ERBE Averaging

ERBE-Like Products

6 Months

Algorithm Theoretical Basis Documents:
http://asd-www.larc.nasa.gov/ATBD/ATBD.html

Validation Plans: