CLARREO: A key new system for detecting and assessing climate change:

*Relationship to AIRS, IASI, CrIS*

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AIRS Science Team Meeting
Marriott Greenbelt
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Climate Absolute Radiance and Refractivity Observatory (CLARREO): A Benchmark for Long-term Trends

NASA is pursuing CLARREO as a promising new start, based on the NRC “Decadal Survey” Report—Also strongly recommended by ASIC3, edited by George Ohring
**Climate Absolute Radiance and Refractivity Observatory (CLARREO):**
A Benchmark for Long-term Trends

<table>
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<th>Current Studies led by:</th>
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<td>NASA GISS (modeling)</td>
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<td>+ many other participants</td>
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CLARREO Community Workshop next week
21-23 October, L’Enfant Plaza Hotel, DC
A new type of mission focused on decadal time scales: measuring trends and testing model predictions

Integral part of major existing & planned research (EOS+) and operational systems for characterizing climate

From CLARREO Science Questions Document, 9 Oct '08
1. **Why we need CLARREO**
   
   Serious gap in capability of existing systems to unequivocally detect long term climate trends with high sensitivity

2. **Basic tenants and new paradigms for CLARREO**
   
   Starting with discussion of key new capability needed

3. **High-Level CLARREO requirements**
   
   Examples consistent with NRC benchmark climate mission
1. Why we need CLARREO

*Serious gap in capability of existing systems to unequivocally detect long term climate trends with high sensitivity*
Current System Limitations (1)

- **Broadband**: CERES, ERBE, ERB, Suomi
  - Only US spaceborne systems specifically designed for climate trending
  - Have revealed the basics of the radiation budget and put necessary constraints on climate models, **but**
    - **Very limited information content**
      (Total Solar, Total Solar & IR, Total Window)
  - Results in severely limited ability to detect decadal climate change
OLR can miss important changes

Yi Huang thesis (Ramaswamy, advisor), 2008

Differences in Window & Strat/upper Trop T compensate
Water vapor & mid Trop T

OLR agreement can be deceptive
Note **OLR Insensitivity** to the trends in Ts, Atmospheric T, WV, and Clouds.
Current System Limitations (2)

• **Filter Radiometer Sounders & Imagers:**
  HIRS, AVHRR…
  – Weather systems have served as valuable pathfinders for revealing climate processes and constraining climate models, **but**
    – Very limited accuracy, even IR
    – Spectral response uncertainty and inconsistency are major factors in IR
    – Results in severely limited ability to detect decadal climate change

• **Reflected solar radiance:**
  – **Accuracy generally limited to 2-3%**
Leaves too much doubt about observed trends

Channel 2 (14.7 micron) indicates a gradual cooling of the lower stratosphere.

Channel 4 (14.2 micron) reveals a significant change in brightness temperature between the HIRS/2 and HIRS/3 instruments. HIRS/3 started with NOAA-15 satellite.

Intersatellite bias for channel 4, 8 and 12 can be as large as 5 K. Differences in overpass time, instrument response, and orbital drift contribute to some of this bias.

Leaves too much doubt about observed trends

14.7 μm CO₂

14.2 μm CO₂

11.1 μm window

6.5 μm H₂O
Current System Limitations (3)

- **New High Resolution IR Sounders:**
  - AIRS, IASI, CrIS…
  - Tremendous advance in information content & accuracy
  - Huge advance for climate process studies, offering
    - High vertical resolution T and WV profiling
    - Trace gas distributions
    - Cloud and surface properties
  - Provide a solid foundation for CLARREO IR feasibility
  - **But, not optimized for unequivocal decadal trending**
    - Biased diurnal sampling
    - SI traceability post-launch limited to aircraft inter-comparisons
      (sounder-to-sounder comparisons useful, but do not have direct, timely connections to International Standards)
    - Inconsistent and incomplete spectral coverage among platforms
Example S-HIS Validation of AIRS

Aircraft is key approach for direct radiance validation of EOS & NPOESS

Fantastic Agreement, but 3-sigma uncertainty in validation is at least 0.5 K**

(70% chance error <0.16 K)

**Contributions from Sampling, Representativeness, Noise, Double differences, as well as S-HIS Accuracy
2. Basic tenants and new paradigms for CLARREO
1) **High information content**, rather than just monitoring total radiative energy budget (i.e. spectrally resolved radiances covering large parts of the spectrum as a product, rather than Total IR or Solar fluxes)

2) **Very high absolute accuracy**, with **measurement accuracy proven on orbit** (stability not sufficient)
   a) minimizes climate change detection time and
   b) relieves the need for mission overlap
   (Must consider Total Accuracy = RSS of Spatial/Temporal biases and measurement accuracy)

3) **Commitment to ongoing Benchmark Missions** planned with 5-8 year lifetime every 8-10 years (Data for Model trend evaluation is needed for the foreseeable future, certainly the next century—therefore, affordability is a key ingredient)
CLARREO IR Accuracy

Radiance Accuracy: <0.1 K 2-sigma brightness $T$ for combined measurement and sampling uncertainty (each <0.1 K 3-sigma) for annual averages of large regions (to approach goal of resolving a climate change signal in the decadal time frame)

To avoid bias, use direct observable (Radiance) to assess climate, not FOV by FOV retrievals
Stratosphere (668 cm⁻¹) from 2007 near nadir AIRS
Upper Troposphere (720 cm$^{-1}$) from 2007 near nadir AIRS

Average Brightness Temperature for wavenumber=720.06

2007

$5^\circ \times 5^\circ$ bins
Window
(911 cm⁻¹)
from 2007
near nadir
AIRS

2007

5° x 5° bins
Key Advances needed from Dedicated Climate System (CLARREO)

- High information content, targeted for climate trend sensitivity (e.g. for emission spectra, include far IR; consider polarization for solar)
- Highest possible accuracy, proven with on-orbit SI traceability
- Unbiased diurnal sampling and complete global coverage using specialized orbits
- Consistent spectral coverage among platforms
- System designed for affordability, allowing continuation of benchmark for many decades
- Synergistic combination of measurements with SI-traceable data sets: e.g. Spectrally resolved IR radiance, GPS, & solar radiance
Example of IR & GPS synergy for CLARREO using CM2 20-yr IR Trend Contributors
Yi Huang thesis (Ramaswamy, advisor), 2008


Cancelation of Temperature and Water Vapor Effects can be easily separated using GPS with IR observations -valid for CO$_2$ also
3. High-Level CLARREO Requirements

Examples consistent with NRC benchmark climate mission
Flow-Down IR Requirements (1)

- **Spectral Coverage & Resolution:**
  3-50 μm or 200-3000 cm\(^{-1}\) with Δν=0.5 cm\(^{-1}\)
  (includes Far IR to capture most of the information content and emitted energy)
Flow-Down IR Requirements (2)

- **Spatial Footprint & Angular Sampling:** Order 100 km or less, nadir only (no strong sensitivity to footprint size, nadir only captures information content)

- **Temporal Resolution and Sampling:** < 15 sec resolution and < 15 sec intervals (adequate to reduce sampling errors and noise)

Not trying to replace or compete with sounders—that role for weather and climate is being done very well—Filling a need to further reduce overall biases to get decadal trends as soon as possible
CLARREO from AIRS, 2006, 13.5 km footprints

Annual Mean of 11 \( \mu \)m Brightness Temperature

Std. Dev. of 11\( \mu \)m Brightness Temperature

2° x 2° bins
CLARREO from AIRS, 2006, 13.5 & 100 km footprints

100 km

13.5 km

Std. Dev. of 11μm Brightness Temperature

2° x 2° bins
2006 Annual
911 cm\(^{-1}\), window
10\(^\circ\)x15\(^\circ\) bins
2006 Annual
911 cm\(^{-1}\), window
10°x15° bins

Average Brightness Temperature for wavenumber=911.24

100 km FOV

Mean

Standard Deviation

India

Climate Content Preserved
2006 Annual
911 cm⁻¹, window
10°x15° bins

Mean

Standard Deviation

Africa: West Central
2006 Annual
911 cm\(^{-1}\), window
10°x15° bins

Mean

Average Brightness Temperature for wavenumber=911.24

Standard Deviation

Africa: West Central

Climate Content Preserved
2006 Annual
911 cm⁻¹, window
10°x15° bins

Average Brightness Temperature for wavenumber=911.24

Mean

Standard Deviation

13.5 km FOV

Florida
2006 Annual
911 cm$^{-1}$, window
10°x15° bins

100 km FOV

Florida
Climate Content Preserved

Average Brightness Temperature for wavenumber=911.24

Mean

Standard Deviation

Preserved
Notable similarity for Clear & All Sky
Yi Huang thesis (Ramaswamy, advisor), 2008

All Sky

Clear

CLARREO does not need cloud clearing—already done well by high resolution sounders for understanding processes

Global Mean, Sept 2002 - Oct 2003
CM2 Annual Mean Spectral 25-yr Trend
Yi Huang thesis (Ramaswamy, advisor), 2008

Clear

a). clr-sky Global ocean annual mean radiance change

All Sky

b). all-sky Global ocean annual mean radiance change

Black dots indicate changes > 3 x standard deviation of unforced means
Flow-Down IR Requirements (3)

- **Orbits**: 3 90° inclination orbits spaced 60° apart (to minimize sampling biases that RSS with measurement uncertainty & achieve global coverage with nadir only views)
1987 Annual Mean of 11 μm Brightness Temperature

1987 Std. Dev. of 11μm Brightness Temperature
CLARREO from AIRS, 2006, 13.5 km footprints

Annual Mean of 11 \( \mu \)m Brightness Temperature

Std. Dev. of 11\( \mu \)m Brightness Temperature

2° x 2° bins
Flow-Down IR Requirements (4)

- **Validation, On-orbit:** Variable-temperature Standard Blackbody, with on-orbit absolute T calibration and reflectivity measurement (to maintain SI measurements on orbit)
A New Class of Advanced Accuracy Satellite Instrumentation for CLARREO

Viewing configuration providing immunity to polarization effects.

On-orbit Cavity Emissivity Module

On-orbit Absolute Radiance Standard (OARS) [widely variable T]

Beamsplitter polarization axis

Calibration Space View

Space View 2

Earth

OSRM
On-orbit Spectral Response Module

Calibration Blackbody [ambient or single T]

OCEM (2)

New Developments
On-orbit Absolute Radiance Standard (OARS)

- The OARS is a source that will be used to maintain SI traceability of the radiance spectra measured by separately calibrated dual interferometer sensors.
- Multiple phase change material signatures establish absolute temperature knowledge to 10 mK throughout the mission lifetime.
3 Melt Points Calibrate Wide Dynamic Range
(using GIFTS BB Configuration)

-40 °C  -20 °C  0 °C  20 °C  40 °C

-38.87 °C Mercury
0.00 °C Water
29.77 °C Gallium

Melt Signatures Provide Absolute Temperature Calibration Accuracies better than 10 mK for full atmospheric Temperature Range
Comparison to Traditional Approach

Temperature Probe
Heater
Melt Material
Temperature Controlled Bath

Blackbody
Cavity
Temperature Probe
Melt Materials (3 different)
Temperature Sensors (3)

Traditional Laboratory Calibration Scheme
New Blackbody Calibration Scheme
• A new spaceflight system optimized to benchmark the climate of the earth and establish longterm trends is urgently needed

• The CLARREO approach evokes new paradigms to define such a system

• Existing high spectral resolution IR instruments demonstrate the technical readiness to proceed with major components of CLARREO very expeditiously

• One key is an on-orbit calibration validation reference source, and an exciting new approach for on-orbit temperature calibration is now available for assuring the accuracy of that reference
CLARREO could have captured this benchmark record. Let’s make sure we start as soon as possible!