CLARREO: Climate Absolute Radiance and Refractivity Observatory

Robert O. Knuteson,

Hank Revercomb,
Fred A Best

University of Wisconsin-Madison,
Space Science and Engineering Center

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Topics

1. **What is CLARREO?**
   National Research Council recommendation

2. **Why do we need CLARREO?**
   Serious gap in capability of existing systems

3. **Basic tenets and new paradigms for CLARREO**
   Measurement concept

4. **High-Level CLARREO requirements**
   Key technologies for on-orbit SI traceability.

1. What is CLARREO?

Long-term satellite climate monitoring with sufficient accuracy to detect decadal trends.

2007 NRC Decadal Survey (1st for Earth Science)

Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond

Committee on Earth Science and Applications from Space:
A Community Assessment and Strategy for the Future

Space Studies Board
Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

2007 NRC Decadal Survey Recommended Missions

the missions are given in Part II, and Part III provides the foundation for selection.

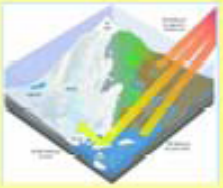
Decadal Survey Mission	Mission Description	Orbit	Instruments
Timeframe 2010 – 2013, Missions listed by cost			
CLARREO (NASA portion)	Solar and Earth radiation, spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer
SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	LEO, SSO	L-band InSAR Laser altimeter
Timeframe: 2013 – 2016, Missions listed by cost			
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	LEO, SSO	Multifrequency laser
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka-band wide swath radar C-band radar
GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	GEO	High and low spatial resolution hyperspectral imagers
ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	Backscatter lidar Multiangle polarimeter Doppler radar

Climate Absolute Radiance and Refractivity Observatory (CLARREO)

Launch: 2010-2013

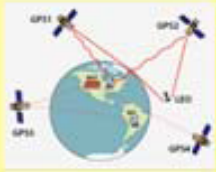
Mission Size: Small

Absolute spectrally resolved IR radiance

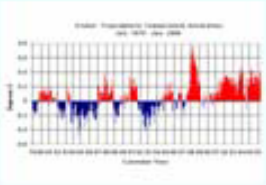


Incident solar and spectrally resolved reflected irradiance

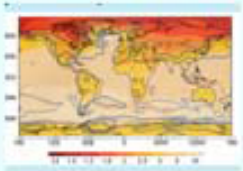
Absolute calibration for operational sounders



Pressure/ temp/ water vapor profiles



Benchmark climate record to improve climate predictions



Changes in sea level, storm patterns, and rainfall associated with temperature pattern changes

Ozone and surface radiation forecasts and public advisories

2. Why we need CLARREO?

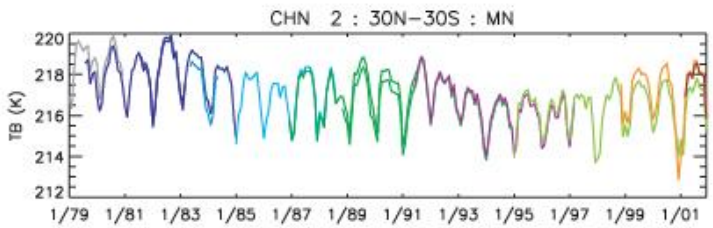
Serious gap in capability of existing systems to unequivocally detect long term climate trends with high sensitivity

Narrow Band IR Uncertainty

Jackson, Wylie, & Bates, 2003

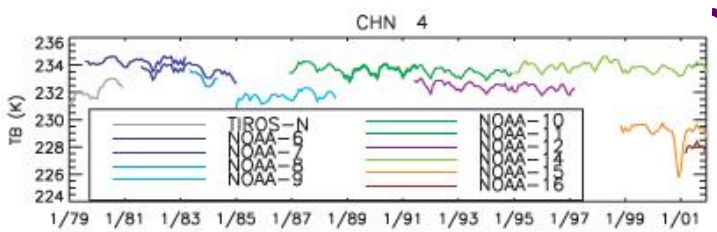
Observed Clear-sky bias

14.7 μm CO_2



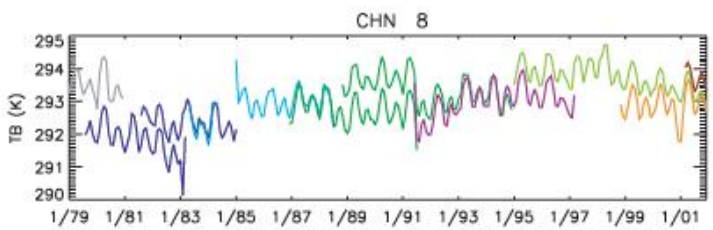
Channel 2 (14.7 micron) indicates a gradual cooling of the lower stratosphere.

14.2 μm CO_2

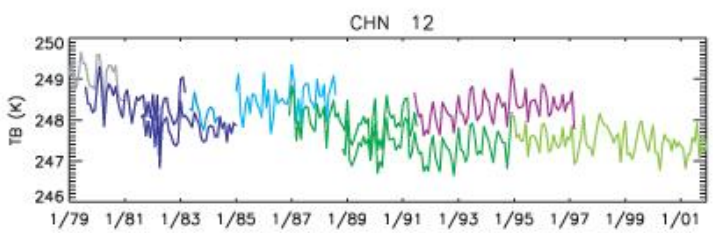


Channel 4 (14.2 micron) reveals a significant change in brightness temperature between the HIRS/2 and HIRS/3 instruments. HIRS/3 started with NOAA-15 satellite.

11.1 μm window



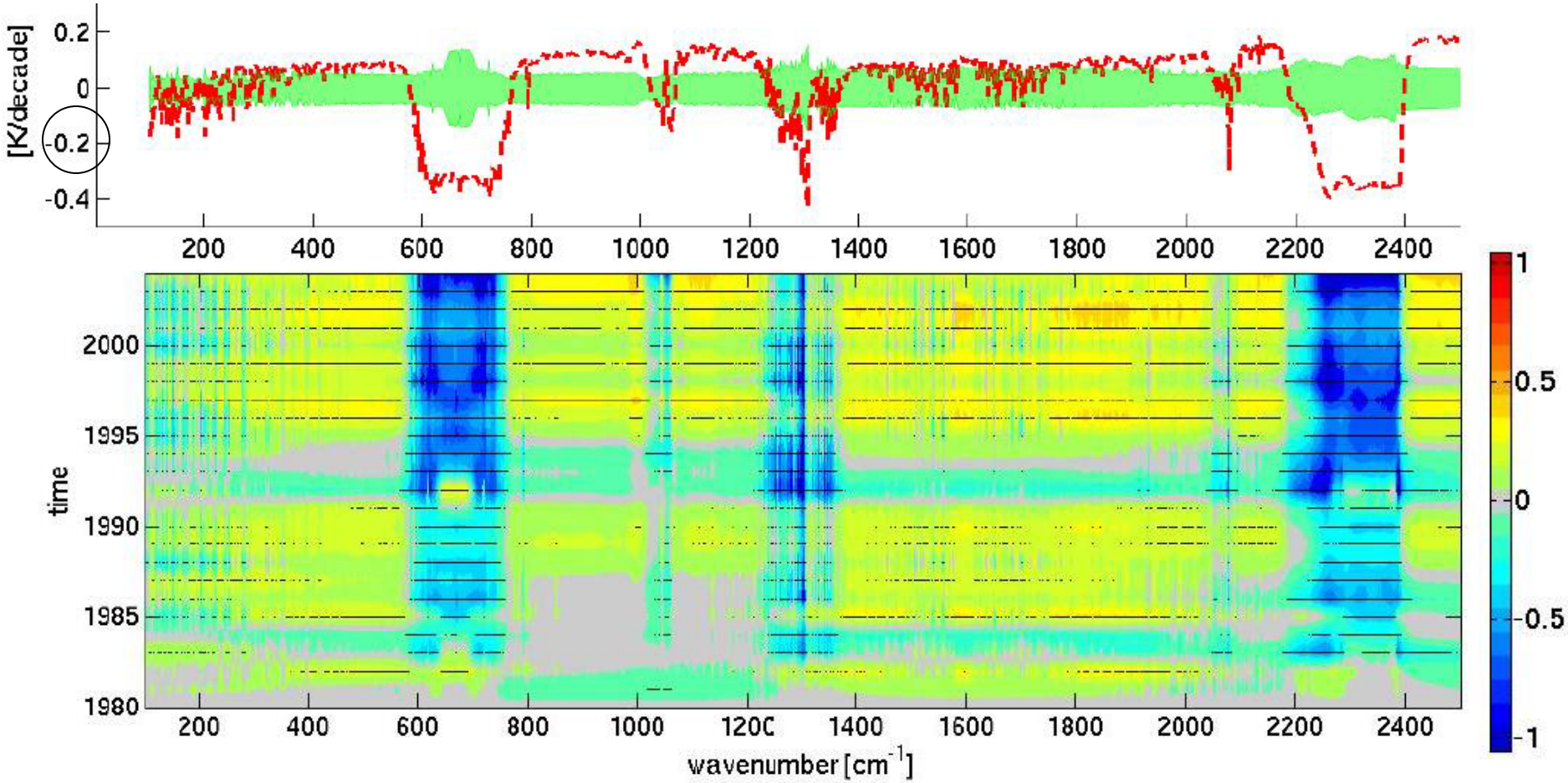
6.5 μm H_2O



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.

- **Lack of on-orbit standards leaves too much doubt about existing satellite data.**

CLARREO-type Benchmark Record
from CM2 Annual Mean Spectral 25-yr Trend
Yi Huang thesis (Ramaswamy, advisor), 2008



These radiance trends are detectable if measured accuracy are better than 0.1 K (95% confidence). OLR can miss important changes due to competing effects.

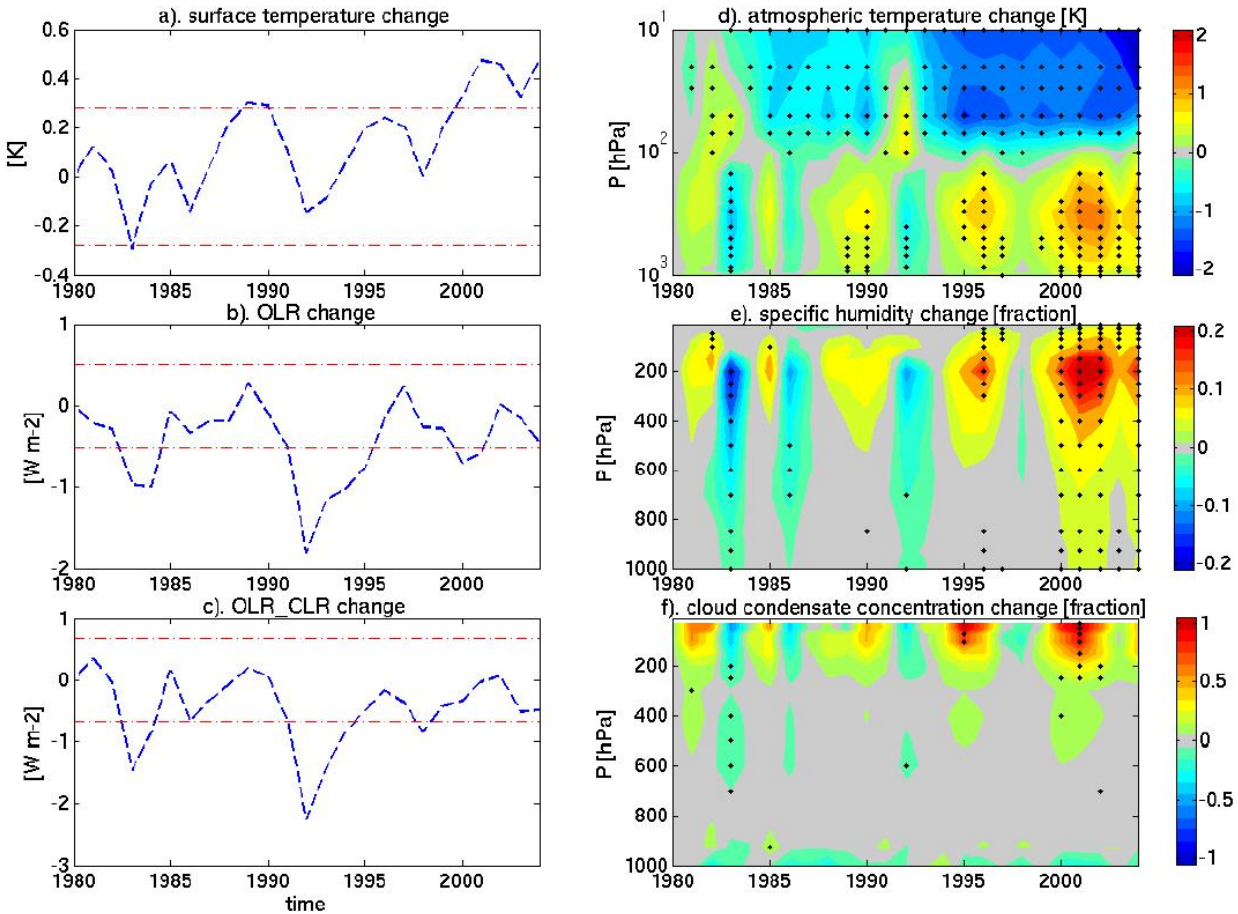
CM2 25-yr Annual Mean Trends

Yi Huang thesis (Ramaswamy, advisor), 2008

Ts

OLR

OLR Clear



T(p)

WV(p)

Cloud

Black dots indicate changes > 3 x standard deviation of unforced means

Note <u>OLR is NOT sensitive</u> to the trends in Ts, Atmospheric T, WV, and Clouds

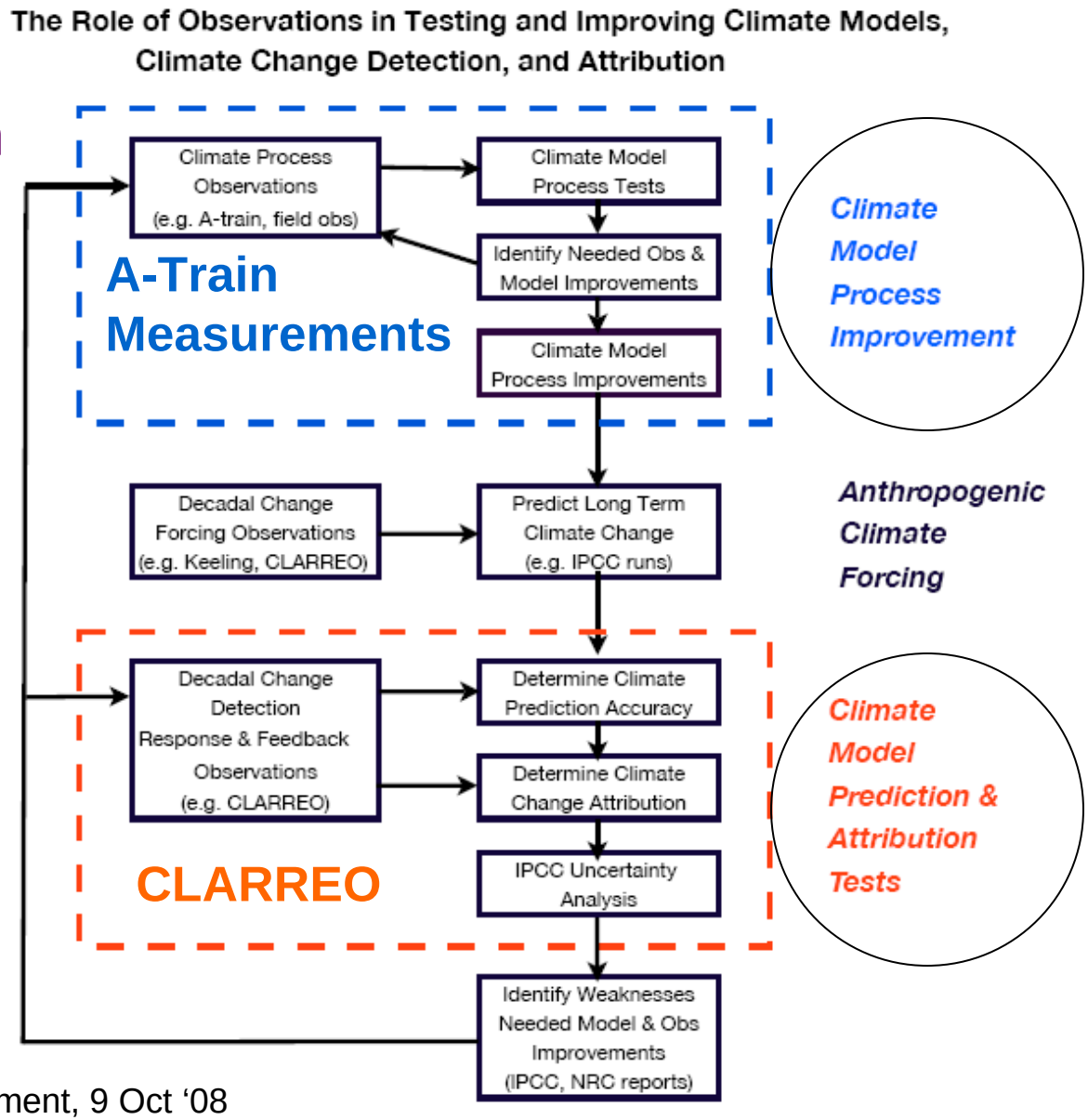
3. Basic tenets and new paradigms for CLARREO

Measure spectrally resolved LW & SW directional radiance instead of total and SW flux.

How CLARREO fits in

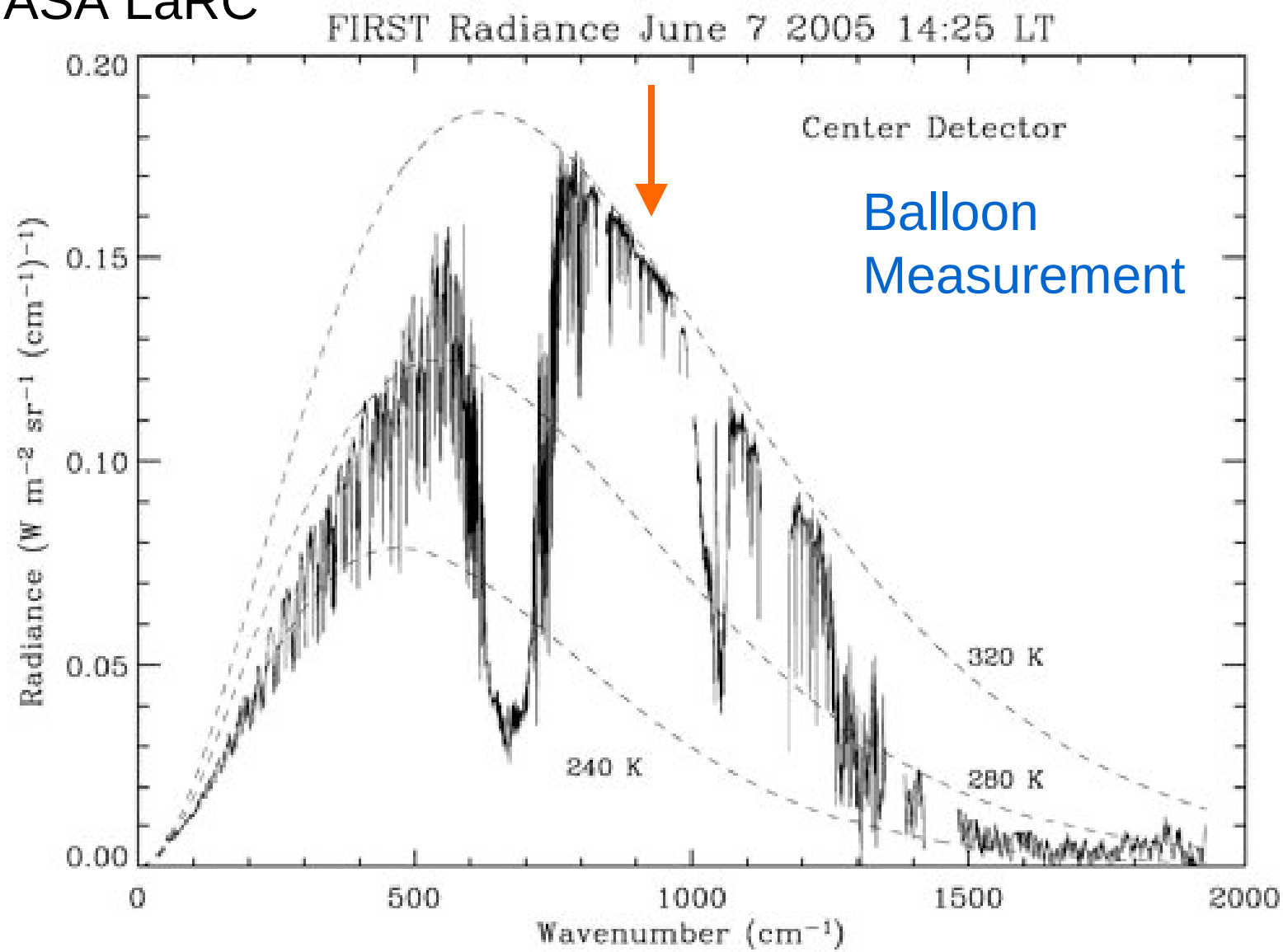
A new type of mission focused on decadal time scales: measuring trends and testing model predictions

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



From CLARREO Science Questions Document, 9 Oct '08

NASA LaRC



- Very similar to ARM ER-AERI from above

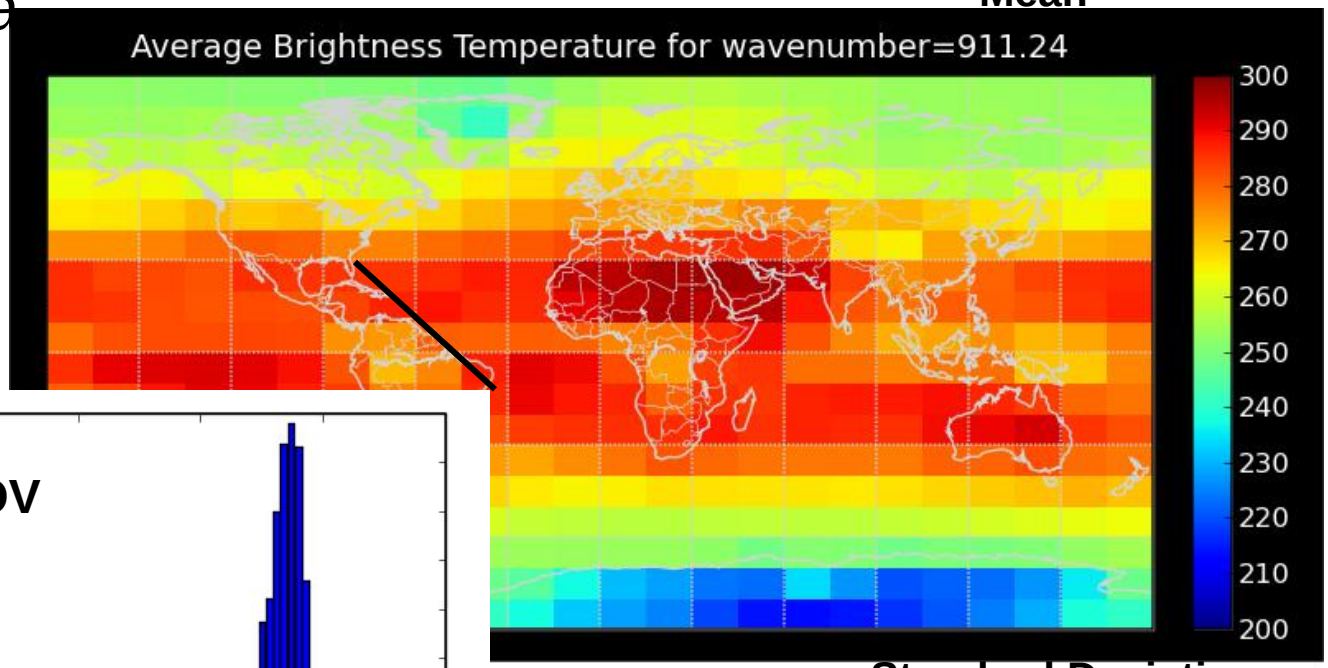
Example: Florida

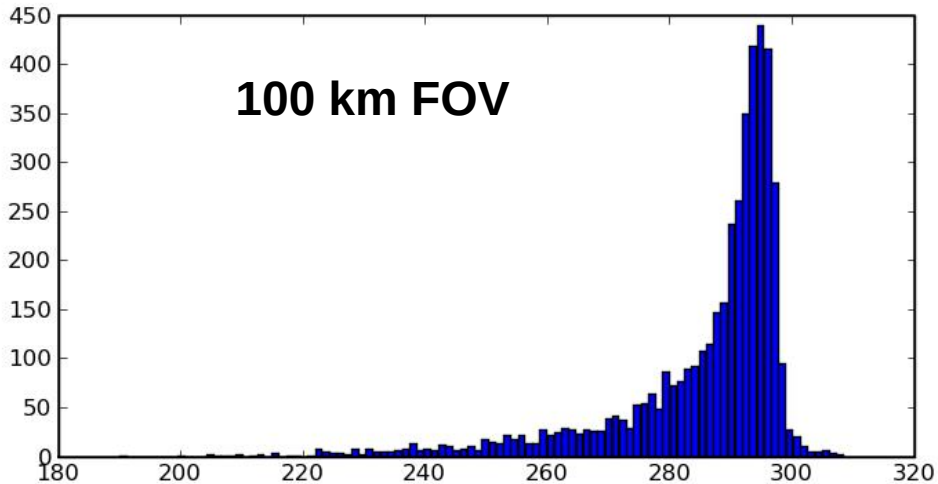
2006 Annual

911 cm^{-1}, window

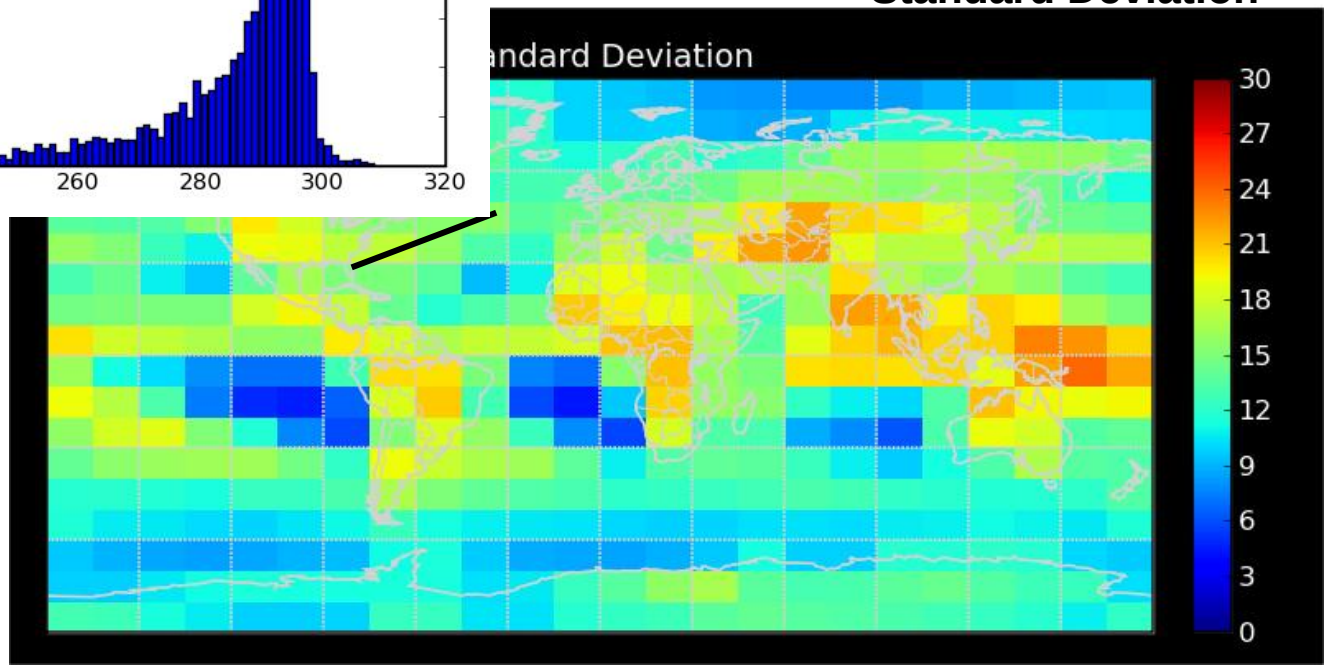
10ºx15º bins

Mean





Standard Deviation



Florida

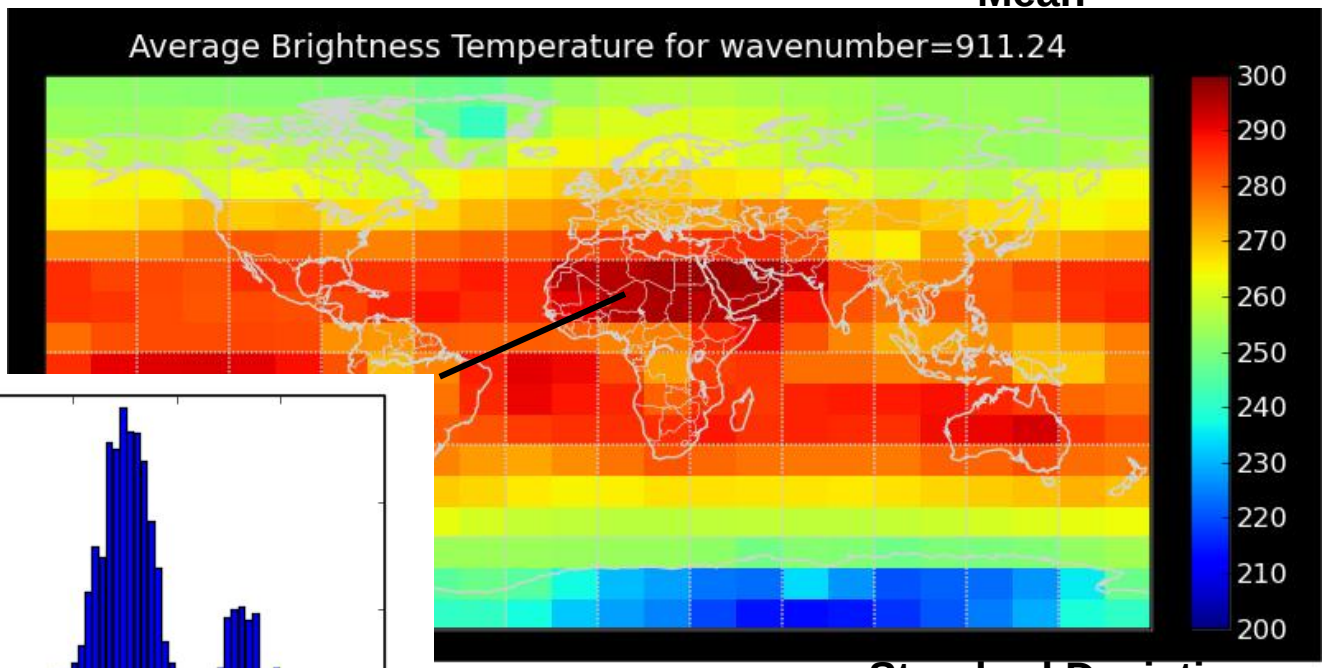
Example: Sahel

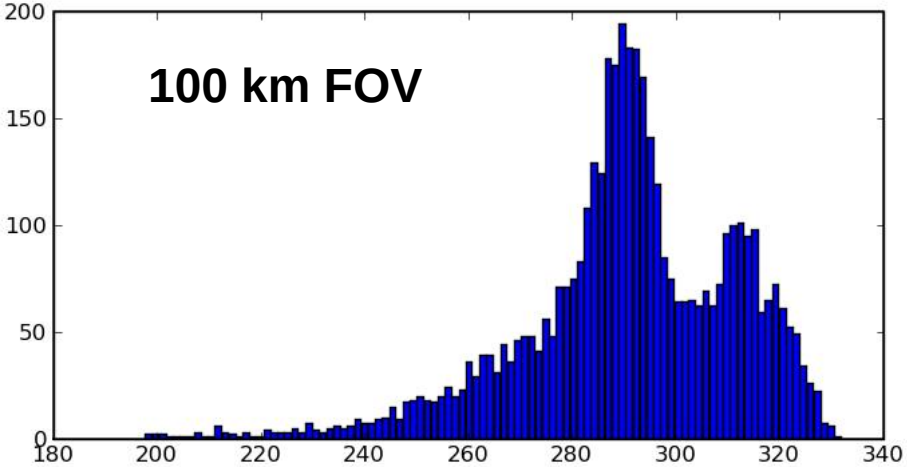
2006 Annual

911 cm^{-1}, window

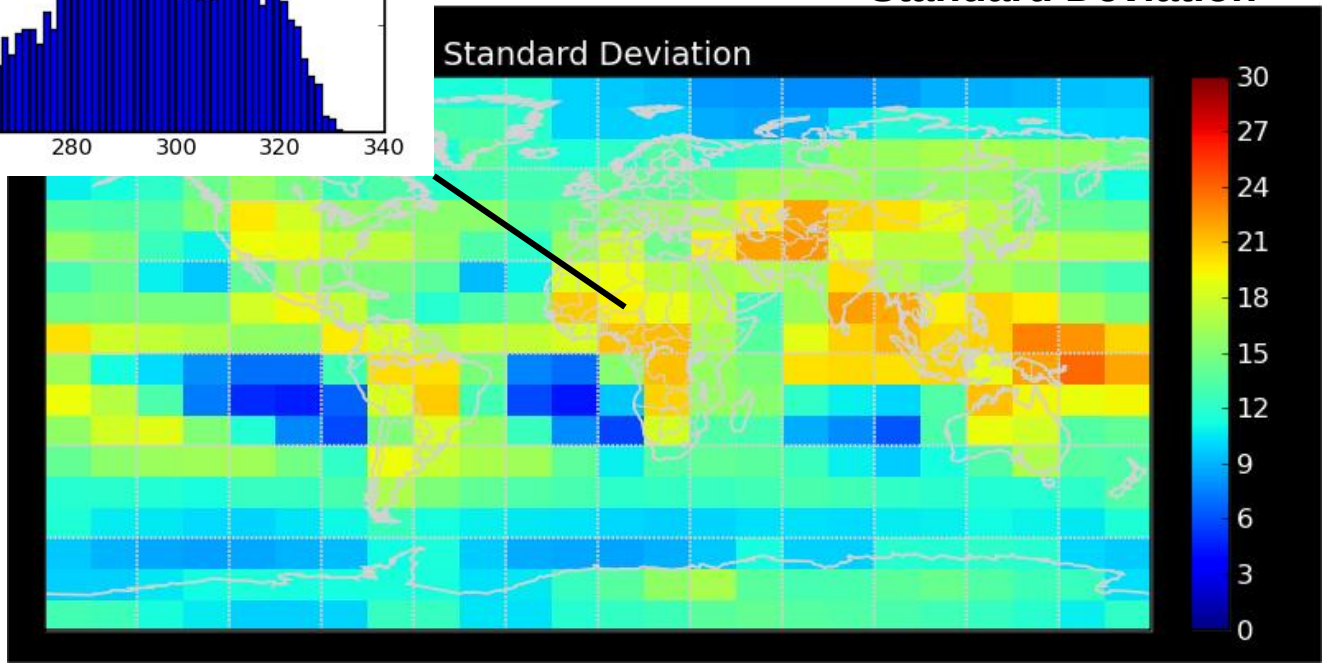
10°x15° bins

Mean





Standard Deviation

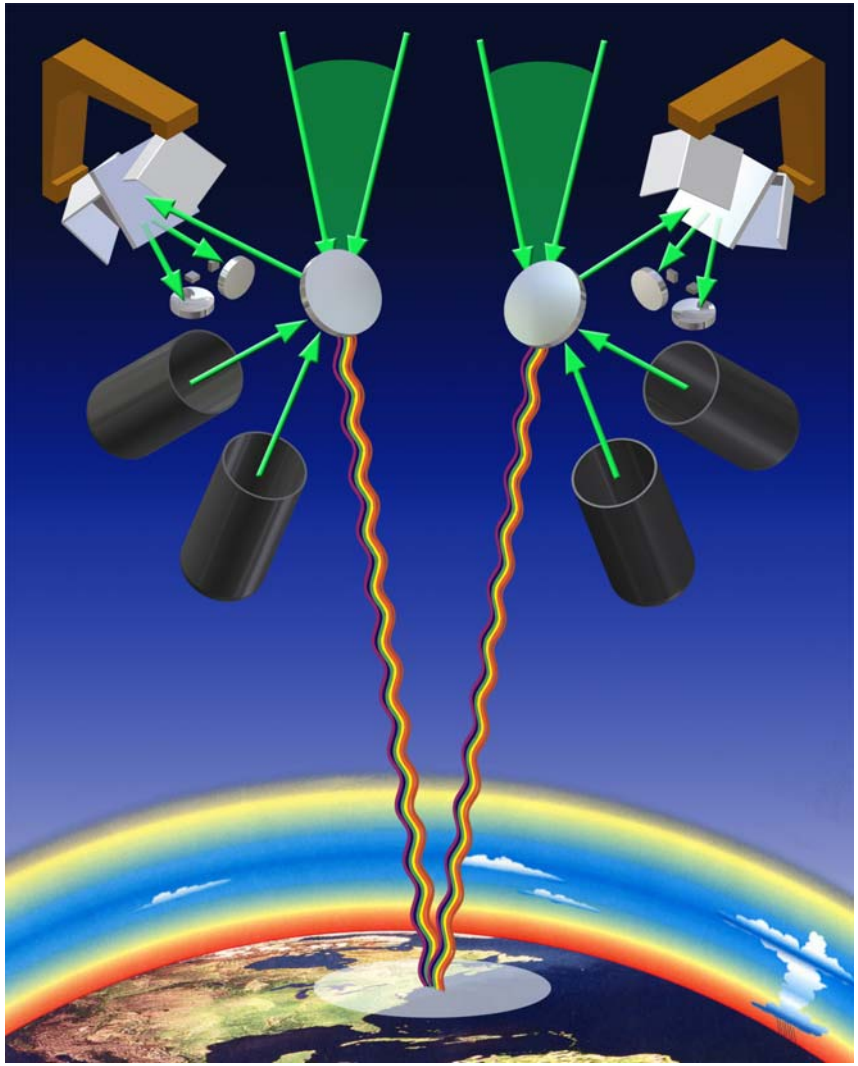


Africa: West Central

4. High-Level CLARREO Requirements

Examples consistent with candidate NRC benchmark climate mission

The CLARREO Satellite



Unbiased Sampling: Three true 90° polar orbits with orbital planes spaced by 60° 750 km altitude

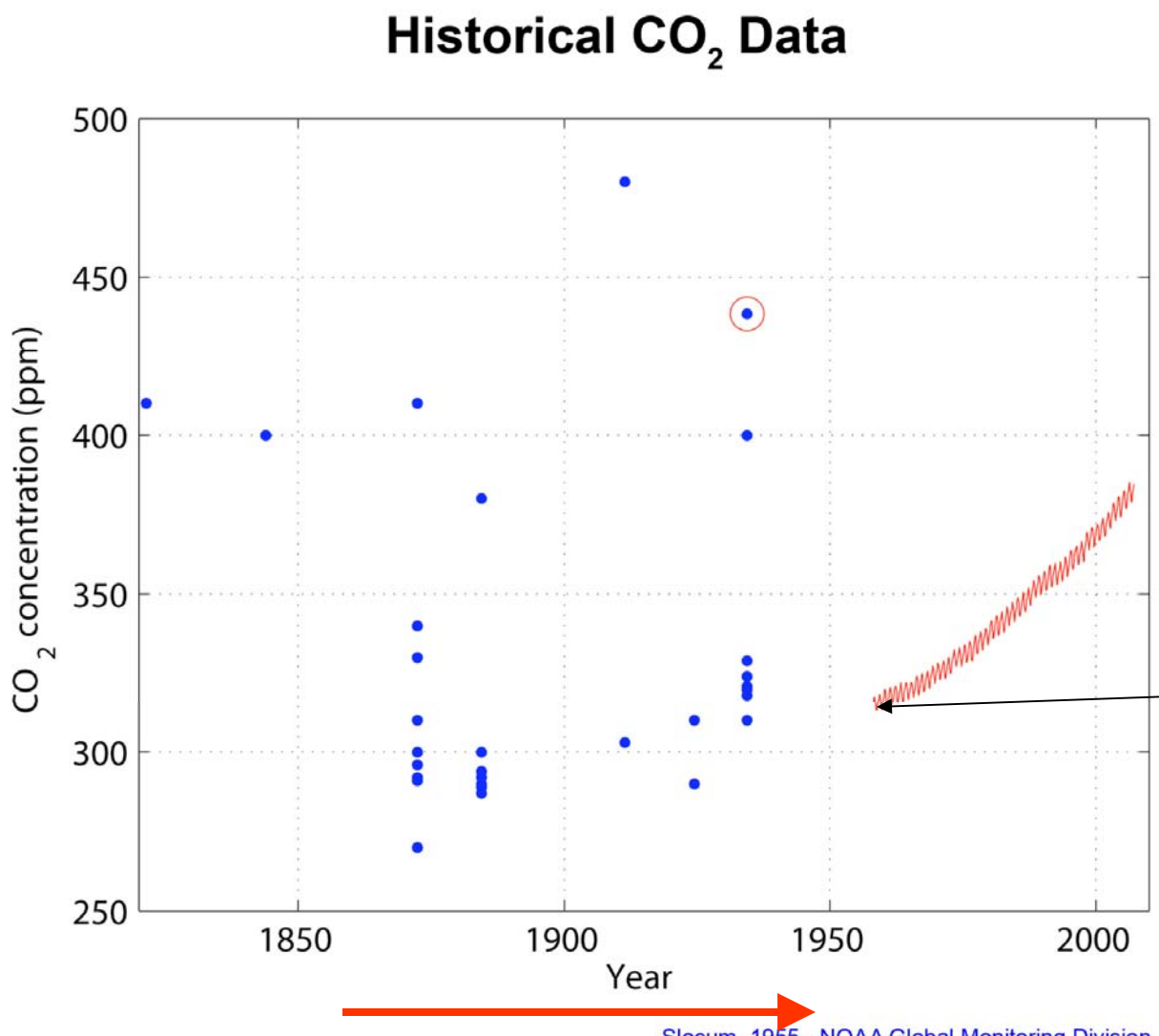
CLARREO: New Paradigms for Benchmark Climate Measurements

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**
e.g. 5-8 year lifetime every 8-10 years (TBD by studies)
(Data for Model trend evaluation is needed for the foreseeable future—
therefore, affordability is a key ingredient)

“Keeling” CO_2 Record: Mauna Loa, Hawaii



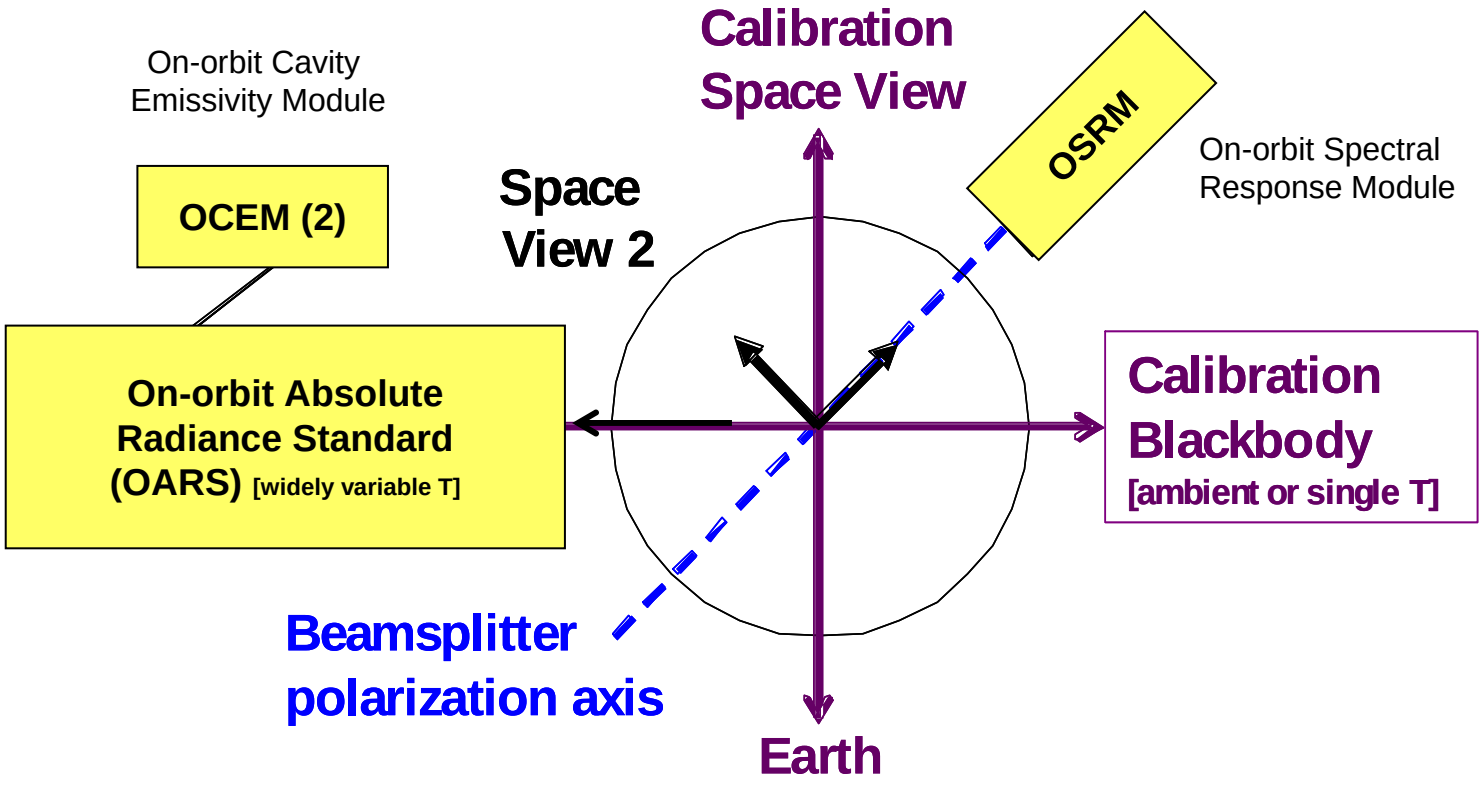
Accurate Monitoring Only Since

1958 IGY

(50 years!!!)

Time

A New Class of Advanced Accuracy Satellite Instrumentation for CLARREO



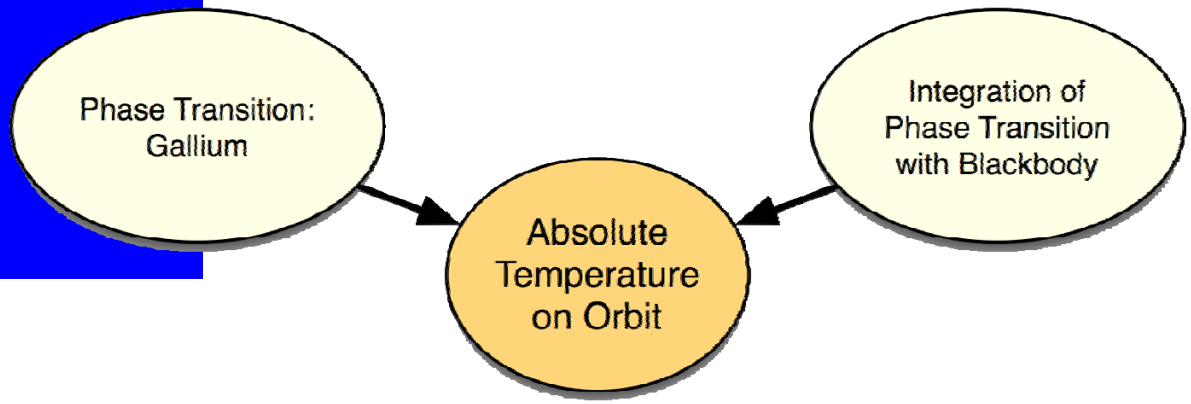
Viewing configuration providing immunity to polarization effects.

NASA Instrument Incubator Program (IIP)

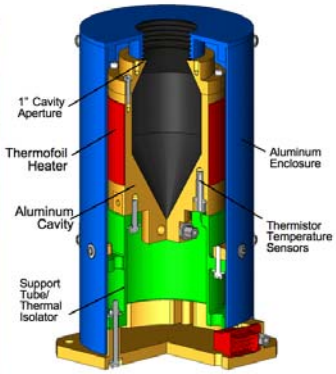
New Developments

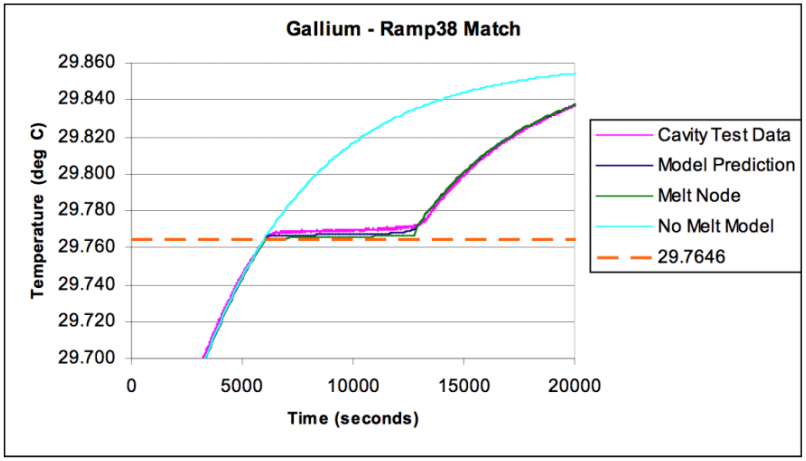
SI Temperature On-Orbit: Integration of Phase Transition Cell with Blackbody

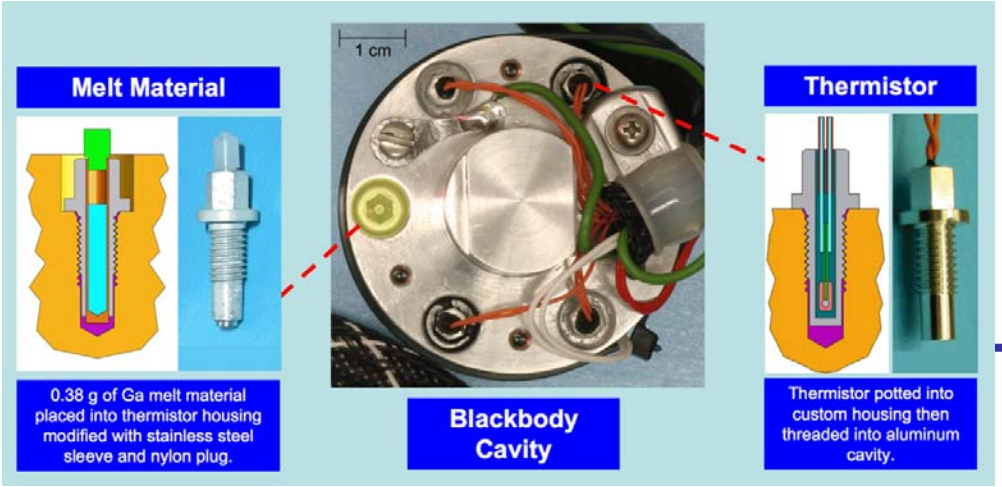
Uni. of Wisconsin-Madison

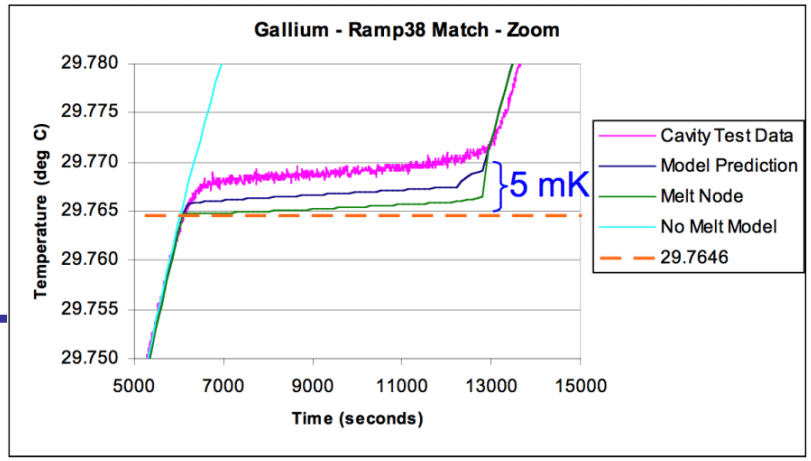


Key Parameter	Specification	As Delivered
Measurement Range	233 to 313 K	233 to 313 K
Temperature Uncertainty	< 0.1 K (3 σ)	< 0.056 K
Blackbody Emissivity	> 0.996	> 0.999
Emissivity Uncertainty	< 0.002 (3 σ)	< 0.00072
Entrance Aperture	1.0 inch	1.0 inch
Mass (2 BBs + controller)	< 2.4 kg	2.1 kg
Power (average/max)	< 2.2/5.2 W	2.2/5.2 W





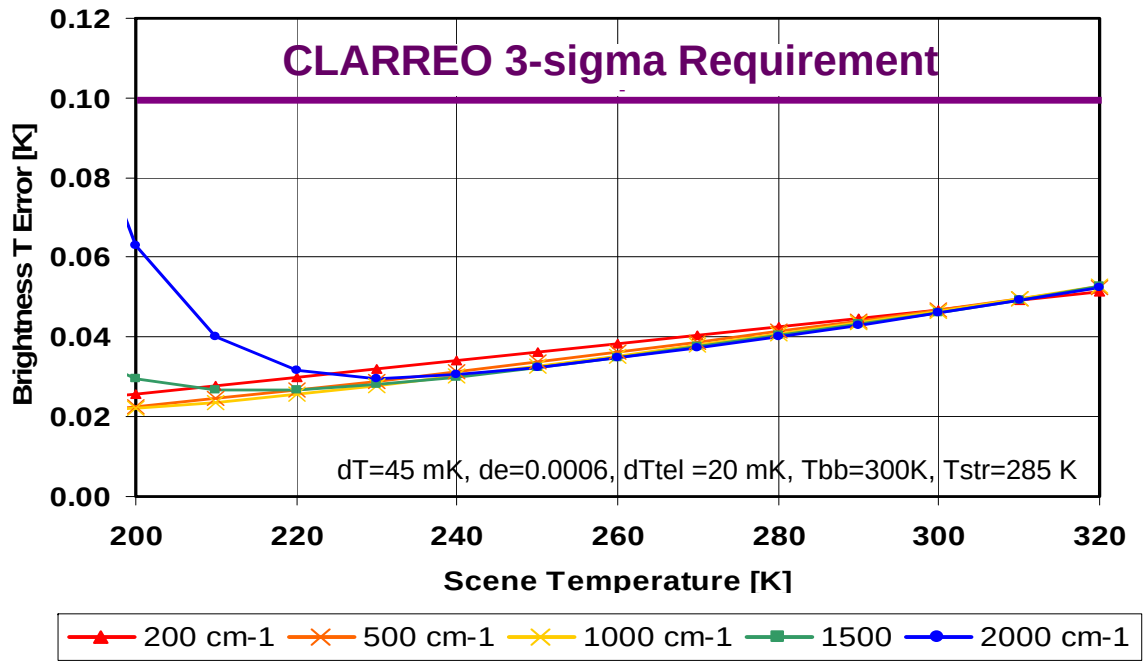




CLARREO IR Accuracy

<u>Radiance Accuracy</u>: <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 T, WV retrievals



Summary

- 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
- Unbiased sampling strategy is a key part of CLARREO overall accuracy
- Key to the IR is an on-orbit calibration reference source using phase change materials.

http://nasascience.nasa.gov/missions/clarreo