CLARREO A key new system for detecting and assessing climate change: *Relationship to AIRS, IASI, CrIS*

Hank Revercomb

Robert O. Knuteson, Dave C. Tobin, Robert Holz, Fred A Best, Joe K. Taylor, Steven Dutcher, Ray K. Garcia

University of Wisconsin-Madison,
Space Science and Engineering Center

AIRS Science Team Meeting
Marriott Greenbelt
14-17 October 2008

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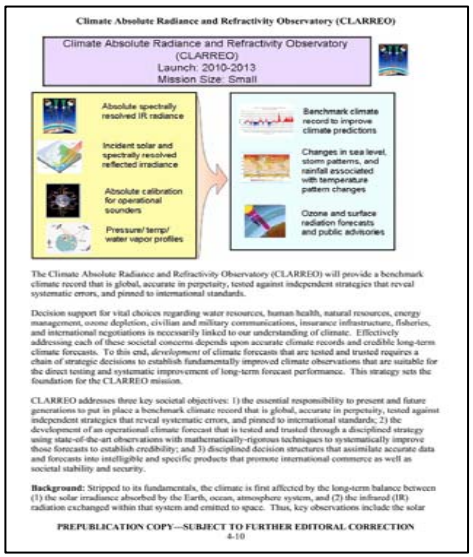
Climate Absolute Radiance and Refractivity Observatory (CLARREO):

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)

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

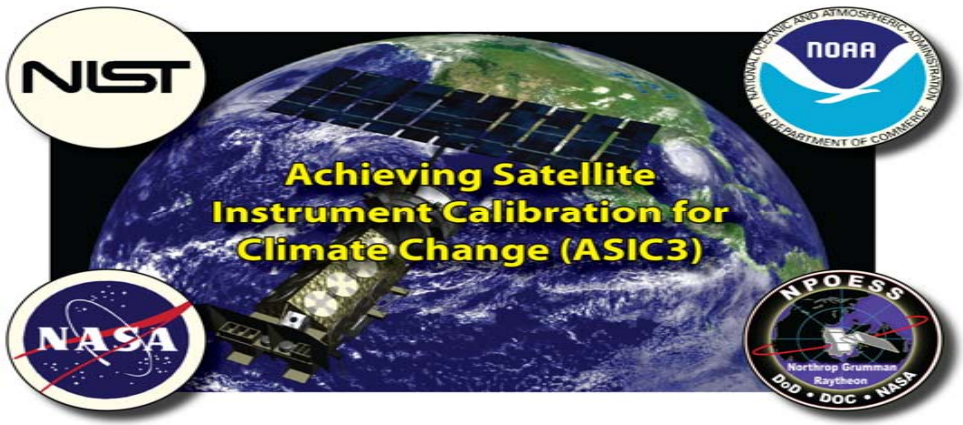
The Climate Absolute Radiance and Refractivity Observatory (CLARREO) will provide a benchmark climate record that is global, accurate in perpetuity, tested against independent strategies that reveal systematic errors, and pinned to international standards.

Decision support for vital choices regarding water resources, human health, natural resources, energy management, ozone depletion, civilian and military communications, insurance infrastructure, fisheries, and international negotiations is necessarily linked to our understanding of climate. Effectively addressing each of these societal concerns depends upon accurate climate records and credible long-term climate forecasts. To this end, development of climate forecasts that are tested and trusted requires a chain of strategic decisions to establish fundamentally improved climate observations that are suitable for the direct testing and systematic improvement of long-term forecast performance. This strategy sets the foundation for the CLARREO mission.

CLARREO addresses three key societal objectives: 1) the essential responsibility to present and future generations to put in place a benchmark climate record that is global, accurate in perpetuity, tested against independent strategies that reveal systematic errors, and pinned to international standards; 2) the development of an operational climate forecast that is tested and trusted through a disciplined strategy using state-of-the-art observations with mathematically-rigorous techniques to systematically improve those forecasts to establish credibility; and 3) disciplined decision structures that assimilate accurate data and forecasts into intelligible and specific products that promote international commerce as well as societal stability and security.

Background: Stripped to its fundamentals, the climate is first affected by the long-term balance between (1) the solar irradiance absorbed by the Earth, ocean, atmosphere system, and (2) the infrared (IR) radiation exchanged within that system and emitted to space. Thus, key observations include the solar

PREPUBLICATION COPY—SUBJECT TO FURTHER EDITORIAL CORRECTION
4-10



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Climate Absolute Radiance and Refractivity Observatory (CLARREO):

A Benchmark for Long-term Trends

Current Studies led by:

NASA LaRC, Lead Center	Harvard University
NASA GSFC	U Wisconsin-SSEC
JPL	U Colorado-LASP
NASA GISS (modeling)	
LBNL Berkeley (modeling)	+ many other
GFDL (modeling)	participants

CLARREO Community Workshop next week
21-23 October, L'Enfant Plaza Hotel, DC

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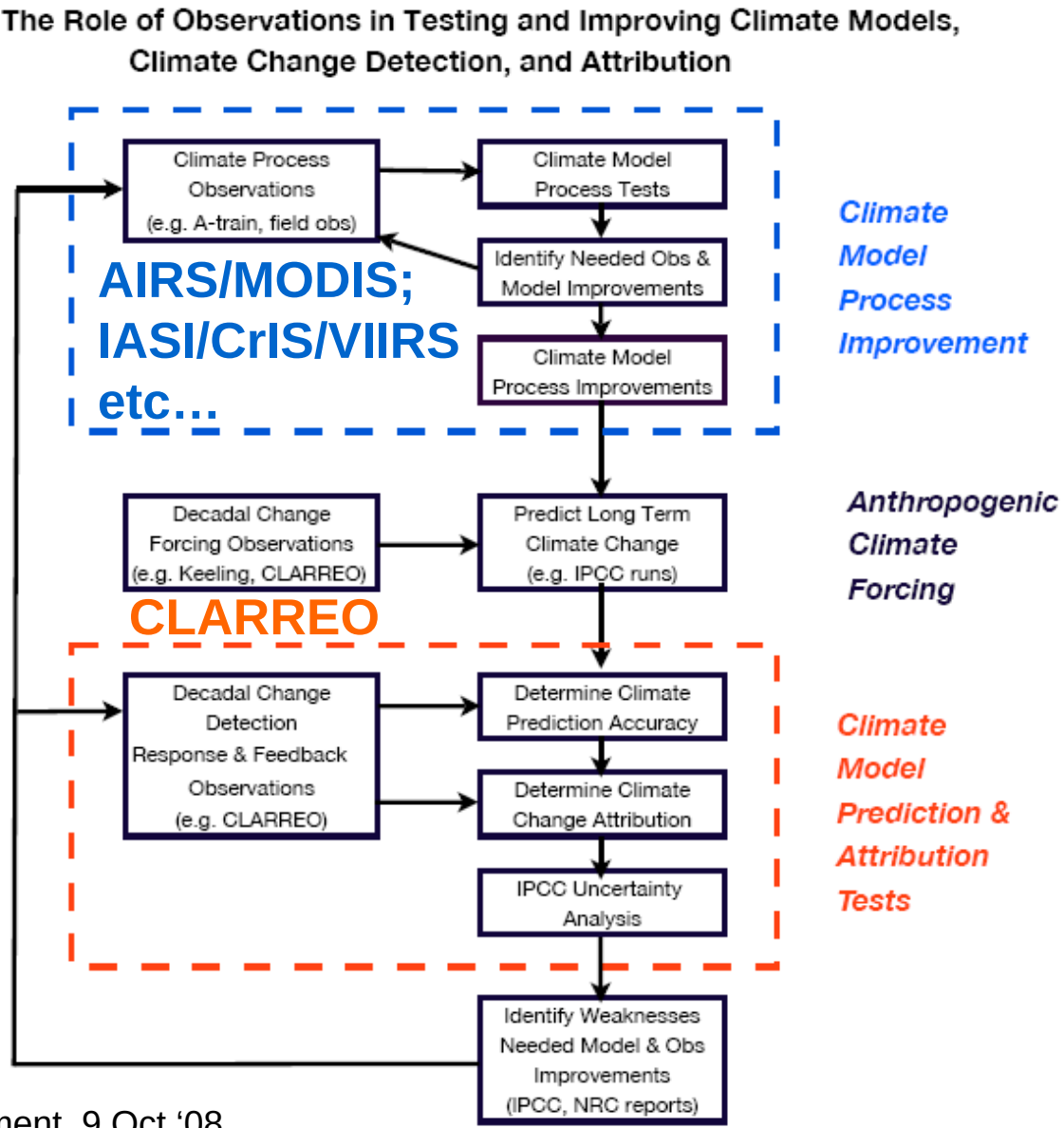
How CLARREO fits in

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

Topics

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

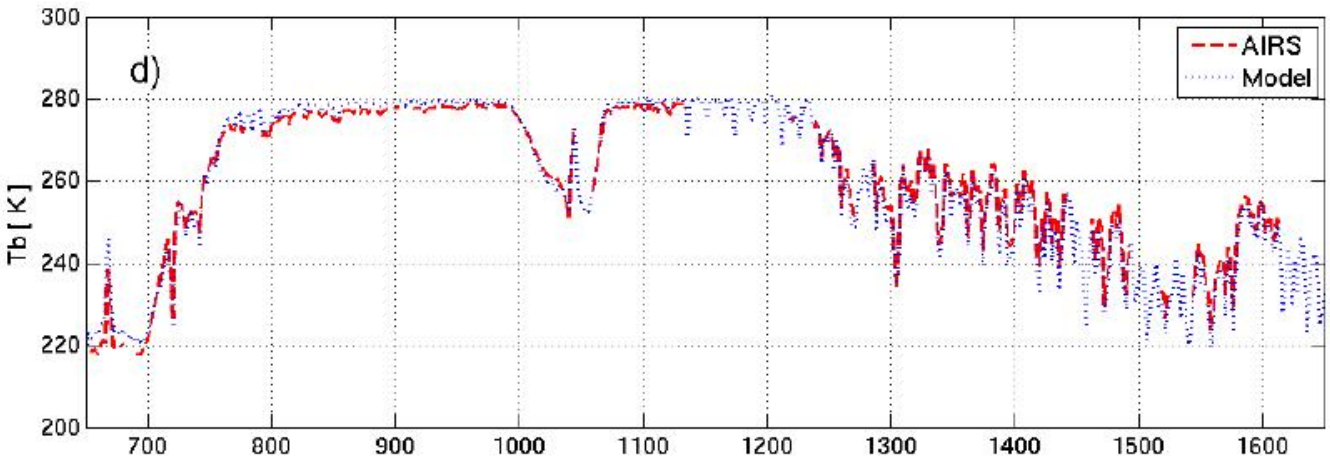
Serious gap in capability of existing systems to unequivocally detect long term climate trends with high sensitivity

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



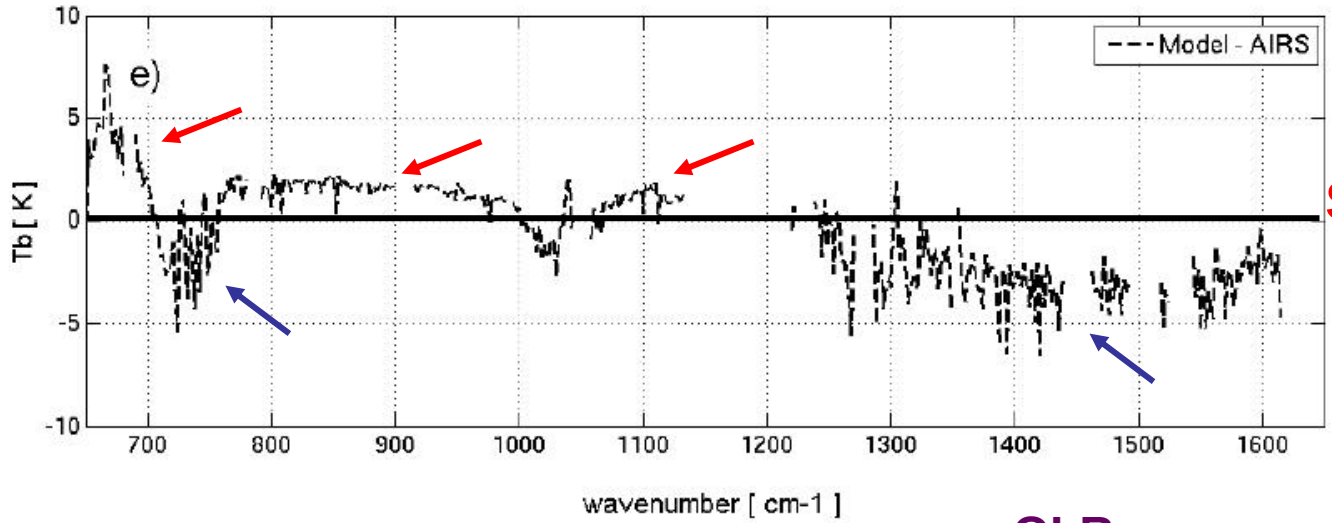
AIRS=Nadir ± 5º

Model= GFDL GCM

Sept 2002-Oct 2003

All Skies

Ocean only



Differences in

Window &

Strat/upper Trop T

compensate

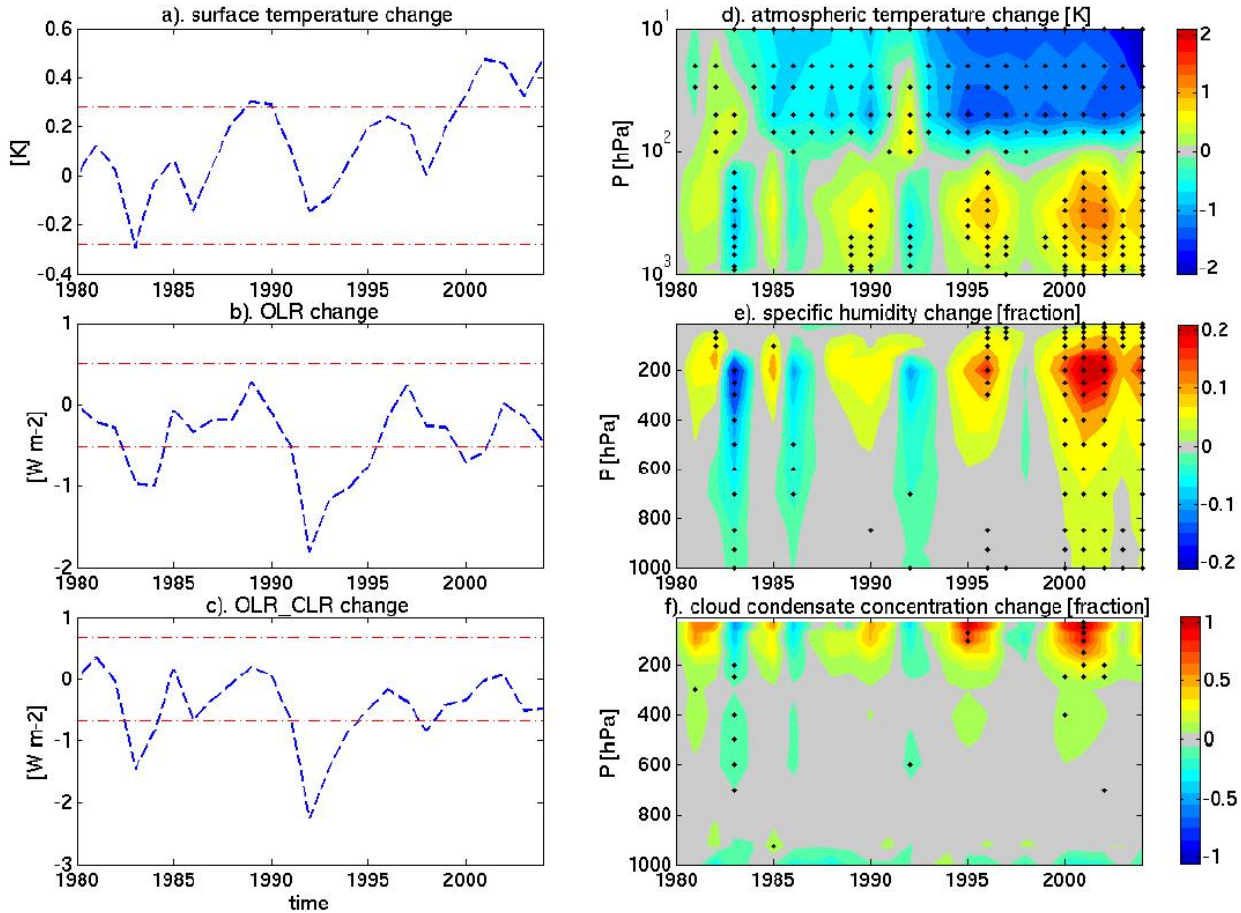
Water vapor &

mid Trop T

OLR agreement can be deceptive

CM2 25-yr Annual Mean Trends

Yi Huang thesis (Ramaswamy, advisor), 2008



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

Note <u>OLR Insensitivity</u> to the trends in Ts, Atmospheric T, WV, and Clouds

Current System Limitations (2)

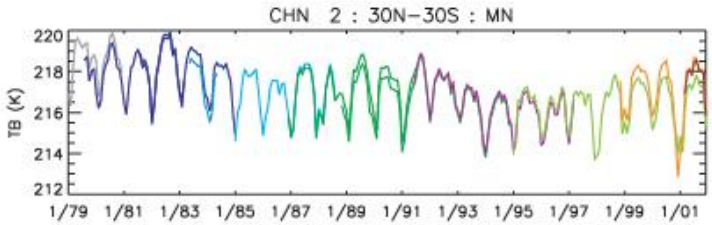
- **Filter Radiometer Sounders & Imagers:**
  HIRS, AVHRR…
  - Weather systems have served as valuable pathfinders for revealing climate processes and constraining climate models, **but**
  - Very limited accuracy, even IR
  - Spectral response uncertainty and inconsistency are major factors in IR
  - Results in severely limited ability to detect decadal climate change
- **Reflected solar radiance:**
  - Accuracy generally limited to 2-3%

HIRS Inter-satellite IR Biases

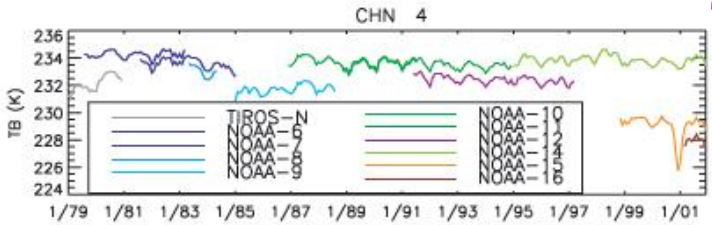
Jackson, Wylie, & Bates, 2003

Observed Clear-sky bias

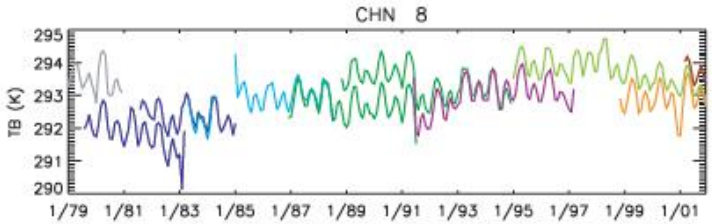
14.7 μm CO_2



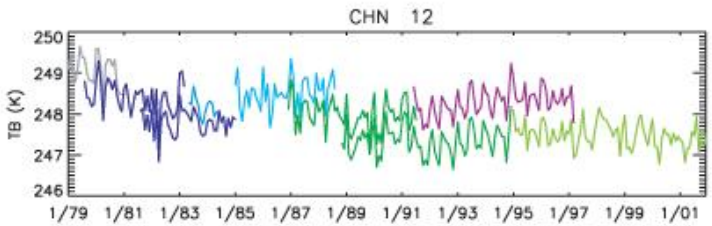
14.2 μm CO_2



11.1 μm window



6.5 μm H_2O



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

Current System Limitations (3)

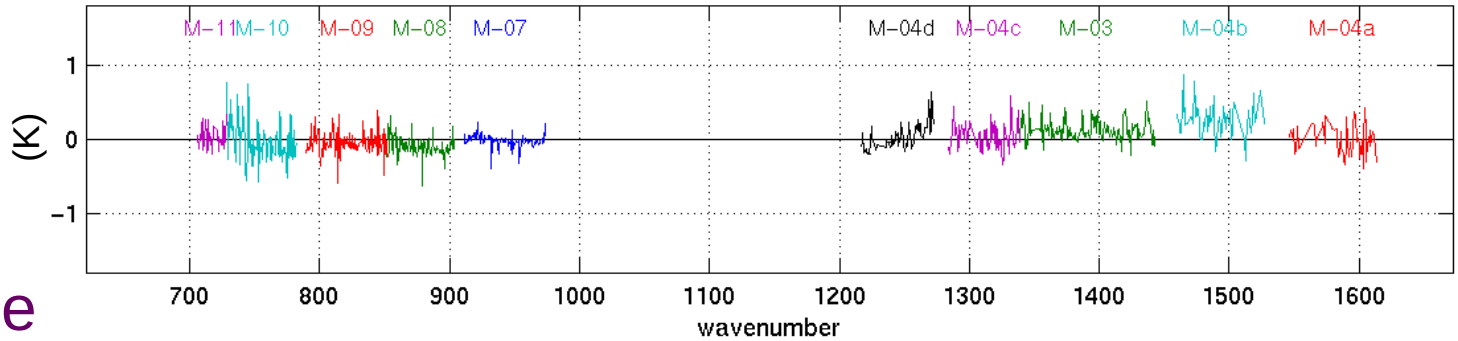
- **New High Resolution IR Sounders:**
  AIRS, IASI, CrIS…
  - Tremendous advance in information content & accuracy
  - Huge advance for climate process studies, offering
    - High vertical resolution T and WV profiling
    - Trace gas distributions
    - Cloud and surface properties
  - Provide a solid 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

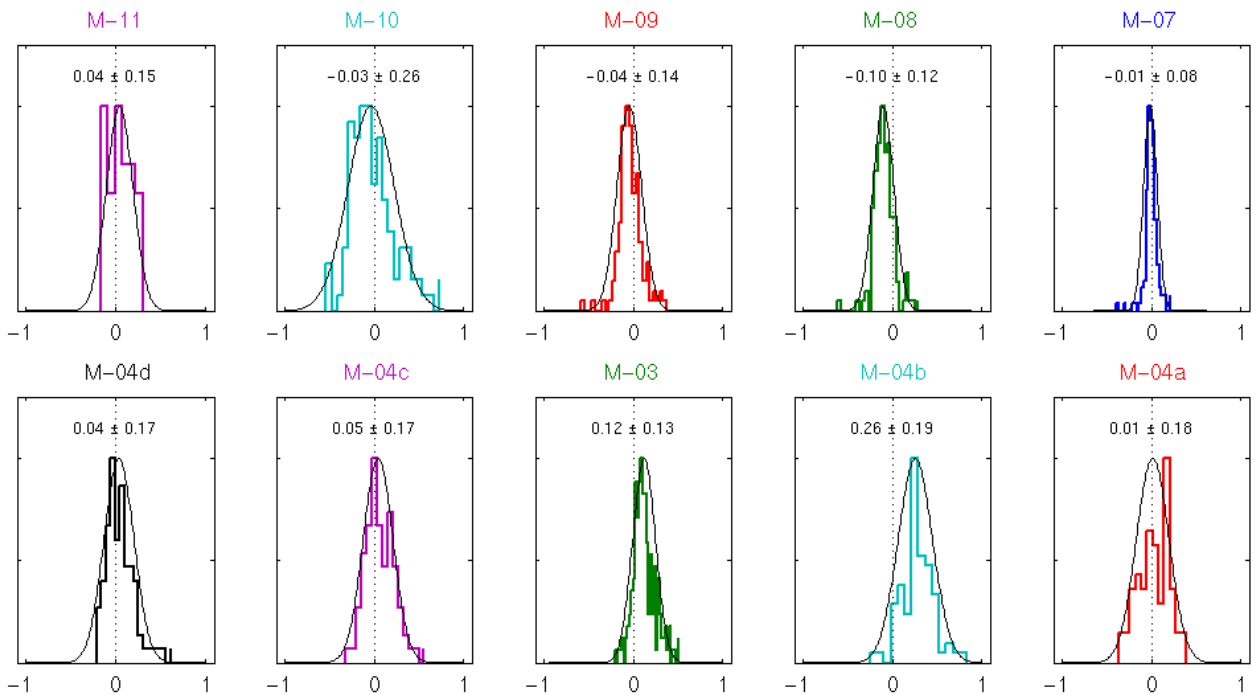
Example S-HIS Validation of AIRS

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)





21 November 2002

**Contributions from Sampling, Representativeness, Noise, Double differences, as well as S-HIS Accuracy

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2. Basic tenants and new paradigms for CLARREO

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)

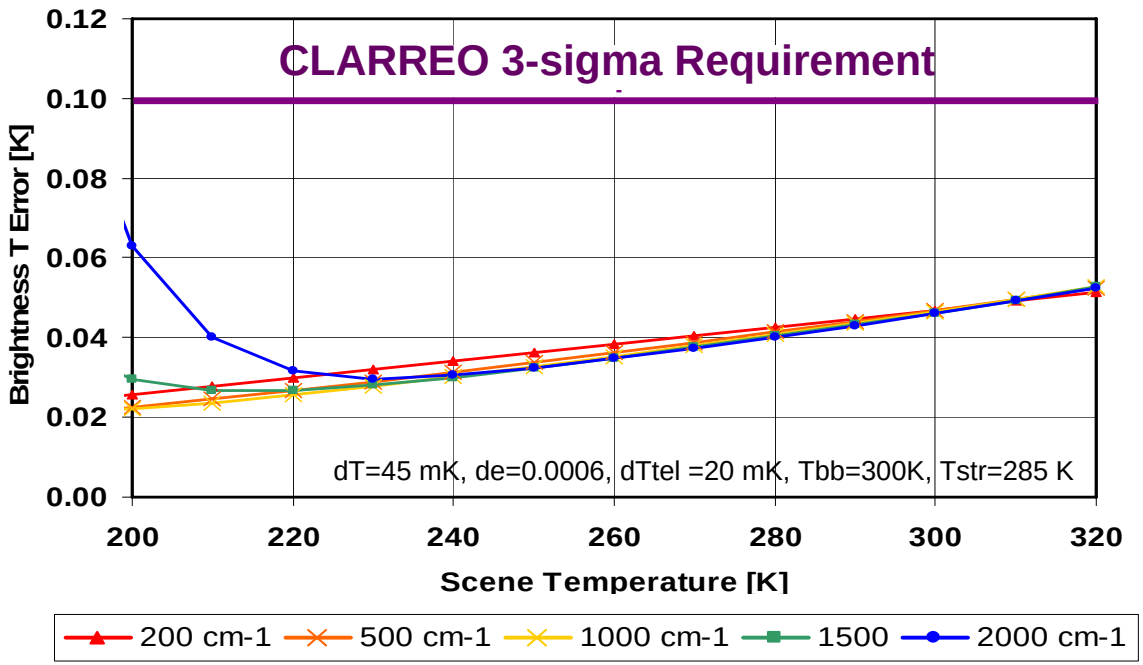
2) **Very high absolute accuracy, with measurement accuracy proven on orbit** (stability not sufficient)
   a) minimizes climate change detection time and
   b) relieves the need for mission overlap
(Must consider Total Accuracy = RSS of Spatial/ Temporal biases and measurement accuracy)

3) **Commitment to ongoing Benchmark Missions** 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)

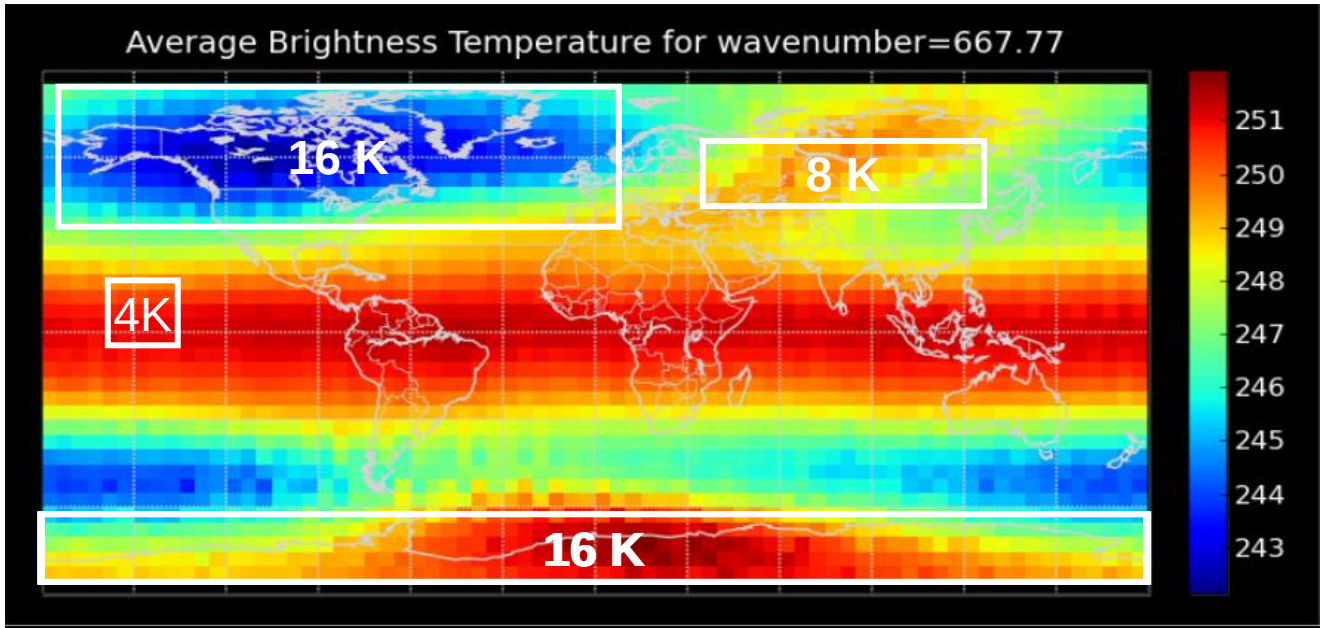
CLARREO IR Accuracy

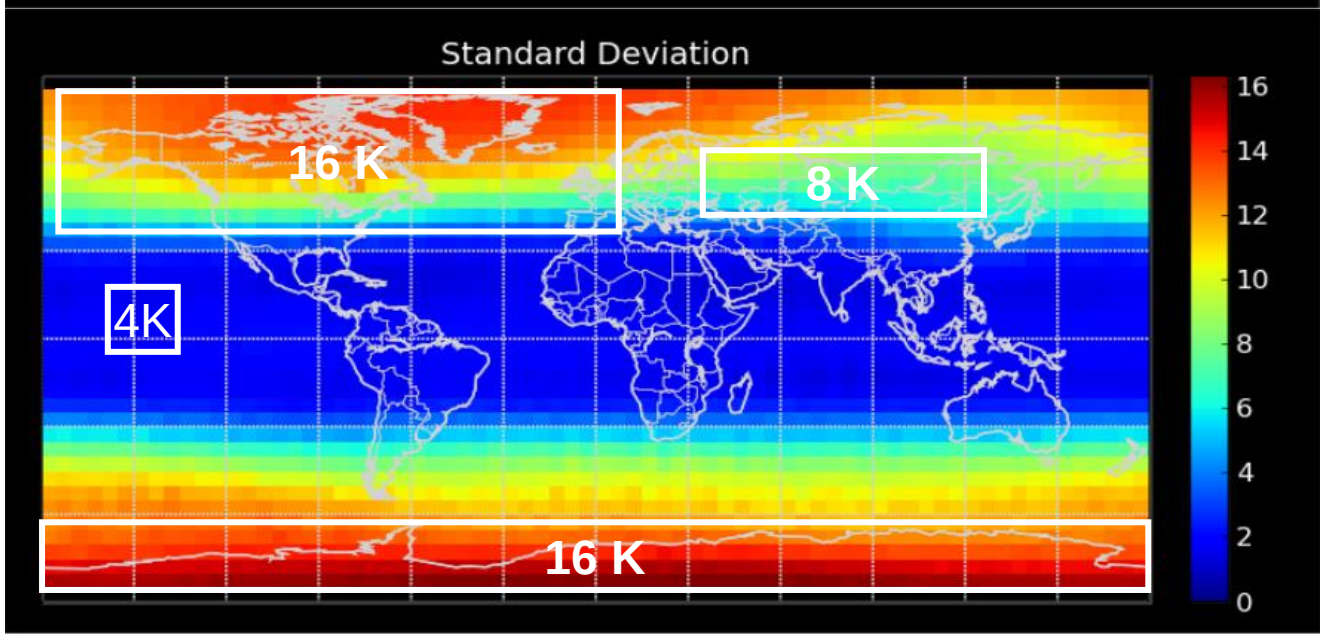
Radiance Accuracy: <0.1 K 2-sigma brightness T for combined measurement and sampling uncertainty (each <0.1 K 3-sigma) for annual averages of large regions (to approach goal of resolving a climate change signal in the decadal time frame)

To avoid bias, use direct **observable** (Radiance) to assess climate, not FOV by FOV retrievals



Strato-sphere (668 cm^{-1}) from 2007 near nadir AIRS



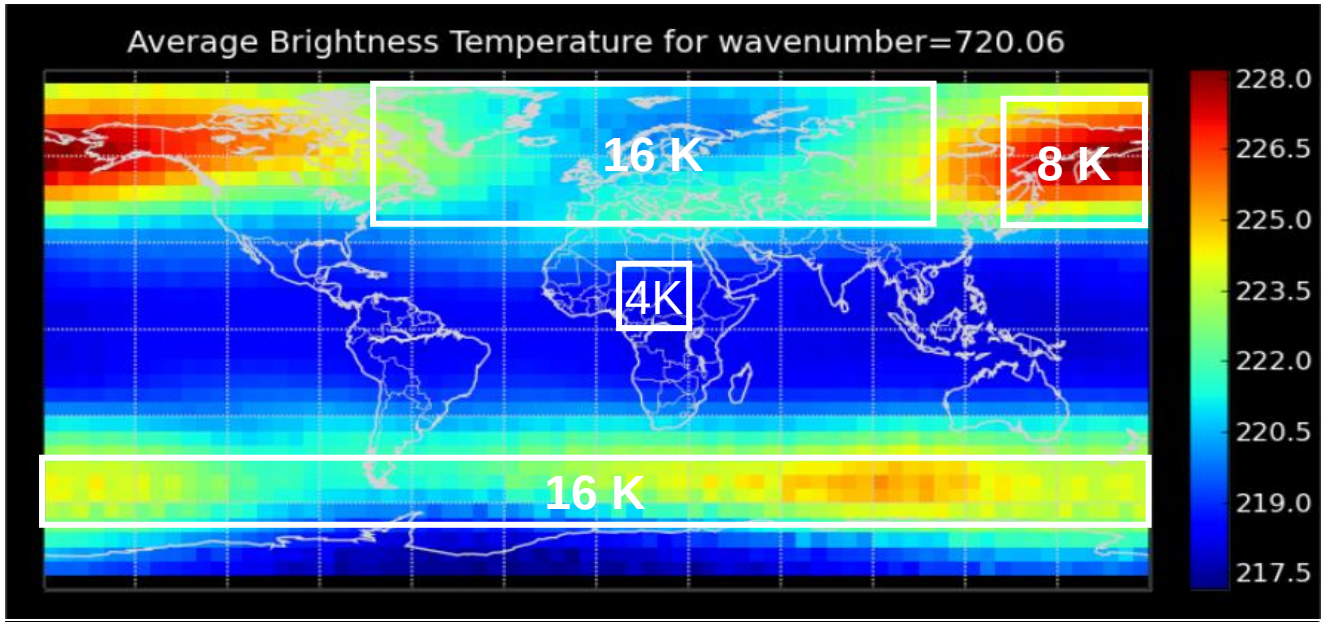


2007

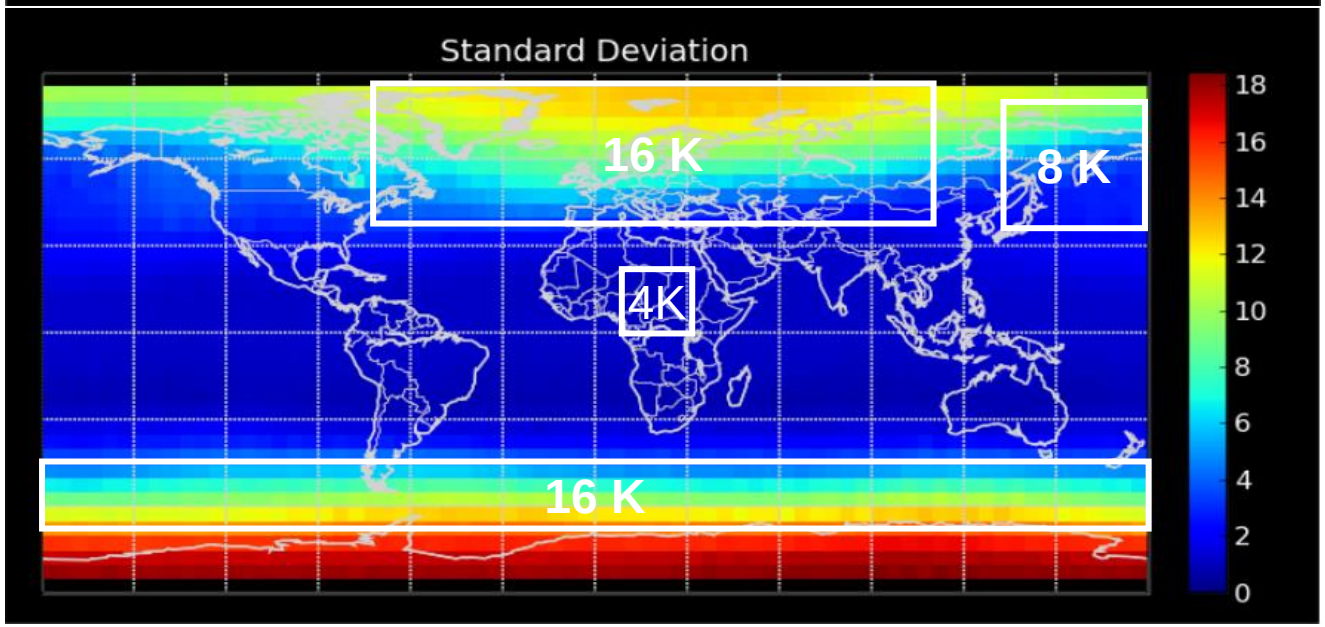
5° x 5° bins

Upper Tropo-sphere

(720 cm^{-1}) from 2007 near nadir AIRS

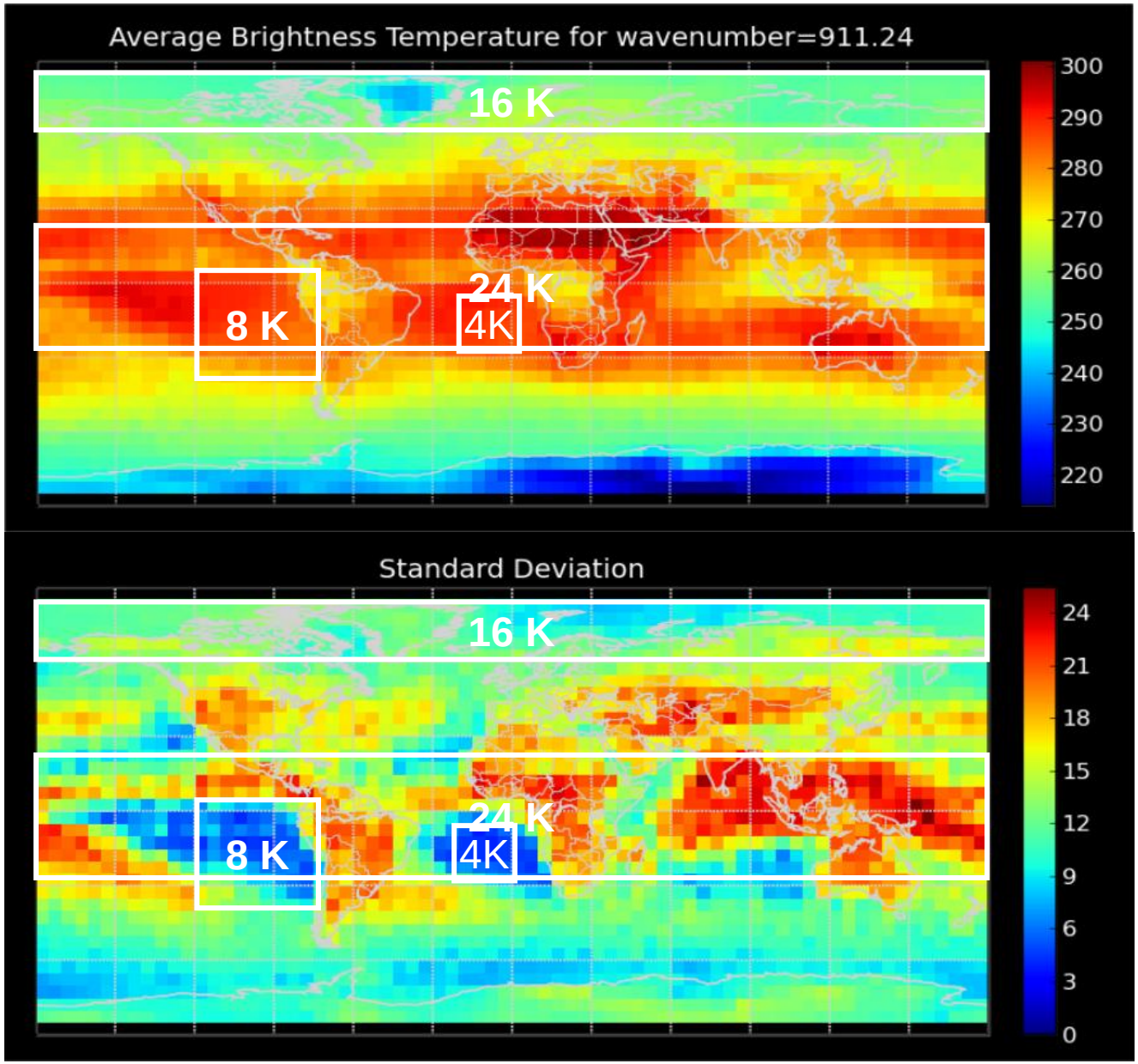


2007



5º x 5º bins

Window
(911 cm^{-1})
from 2007
near nadir
AIRS



2007

5° x 5° bins

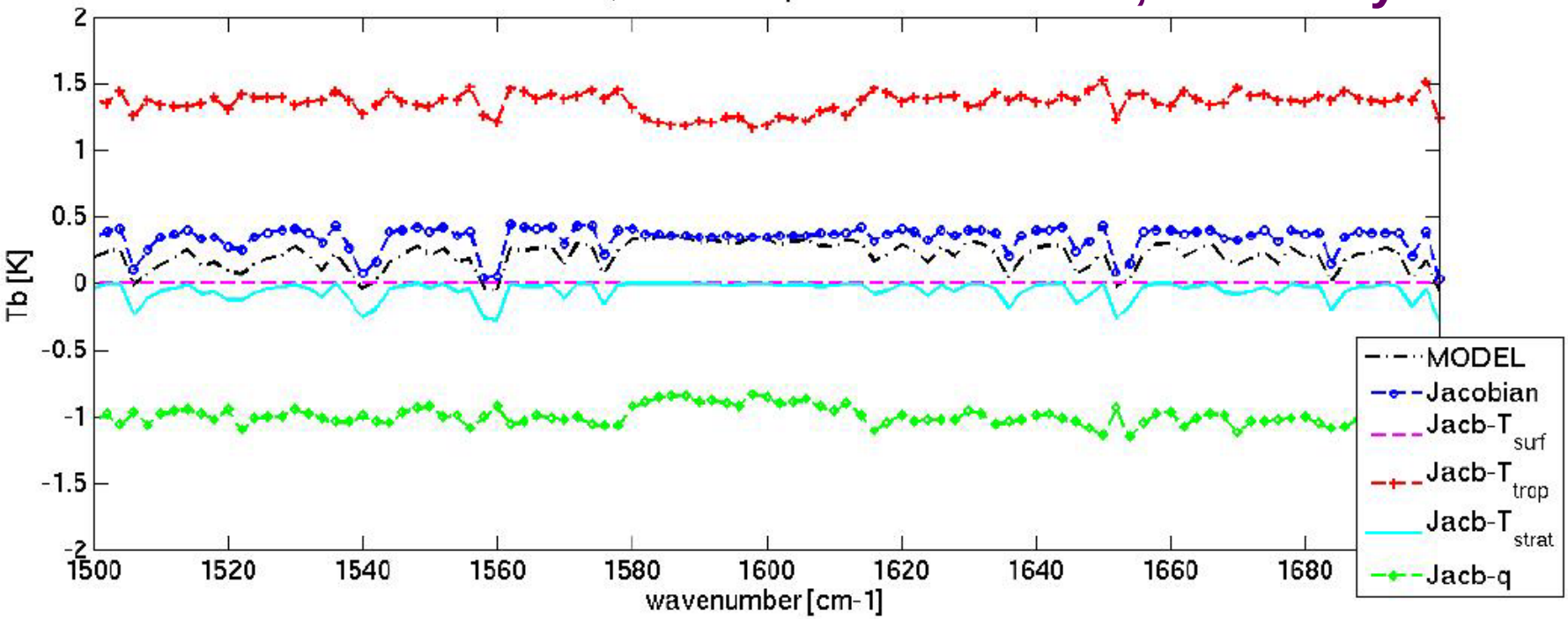
Key Advances needed from Dedicated Climate System (CLARREO)

- 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

2000-2004 mean minus 1980-1984 means, Clear Sky



Cancelation of Temperature and Water Vapor Effects can be easily separated using GPS with IR observations

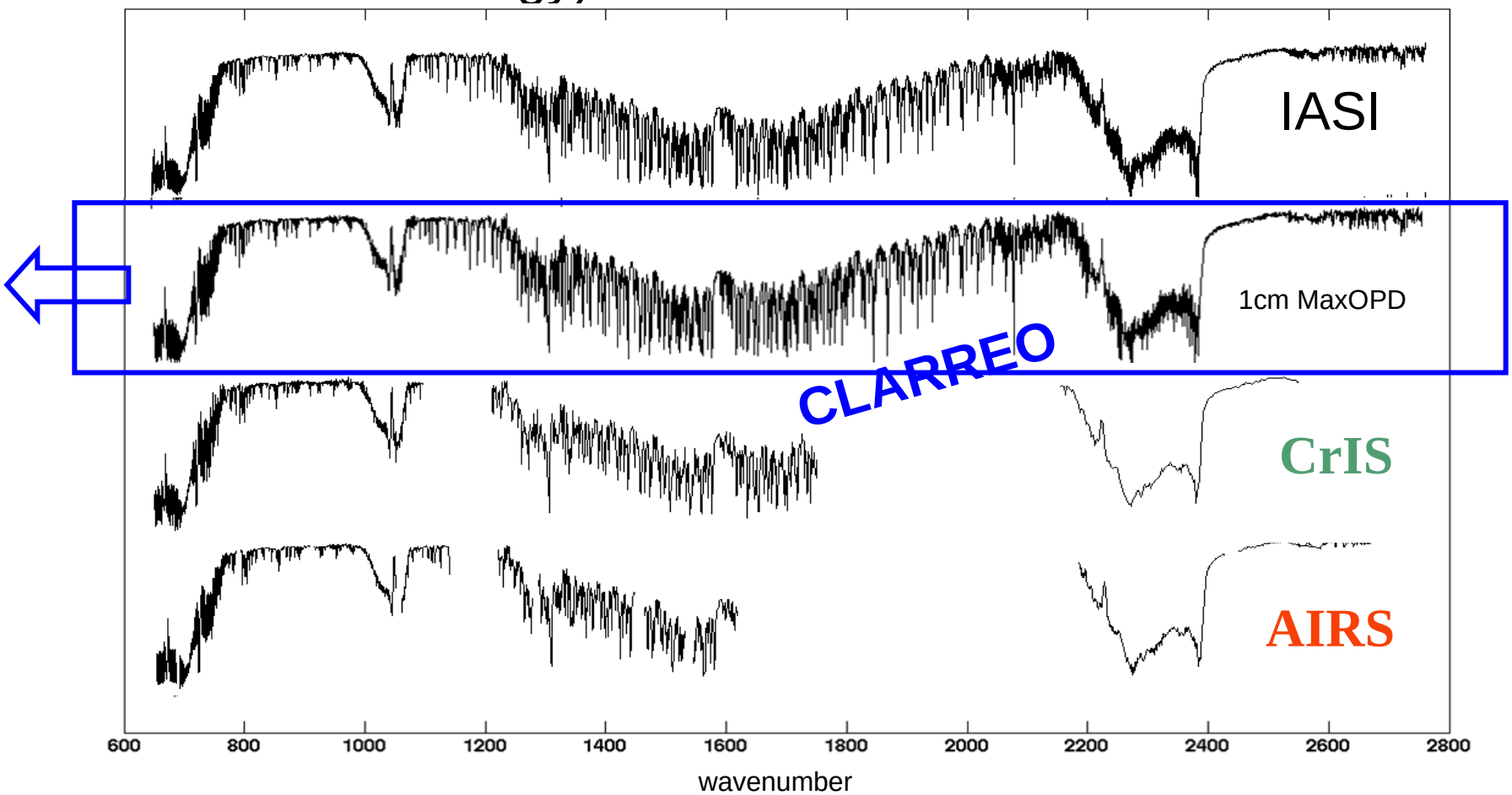
-valid for CO_2 also

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 $\Delta\nu$=0.5 cm^{-1}
  (includes Far IR to capture most of the information content and emitted energy)

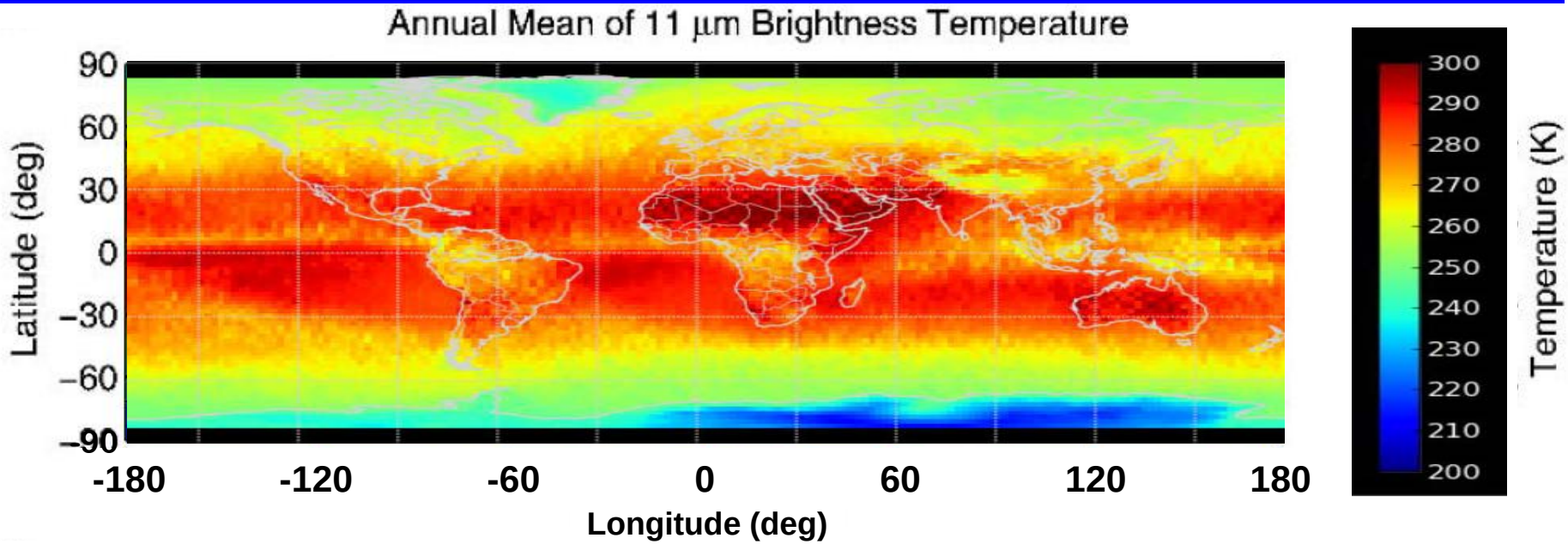


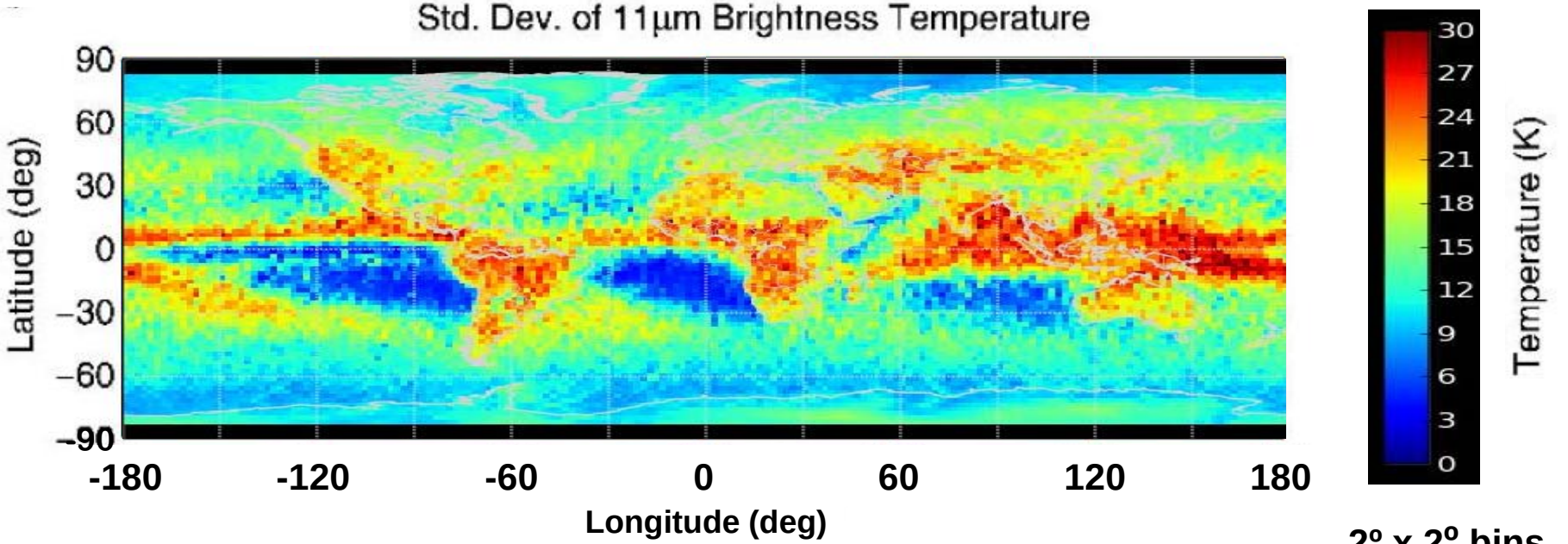
Flow-Down IR Requirements (2)

- **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

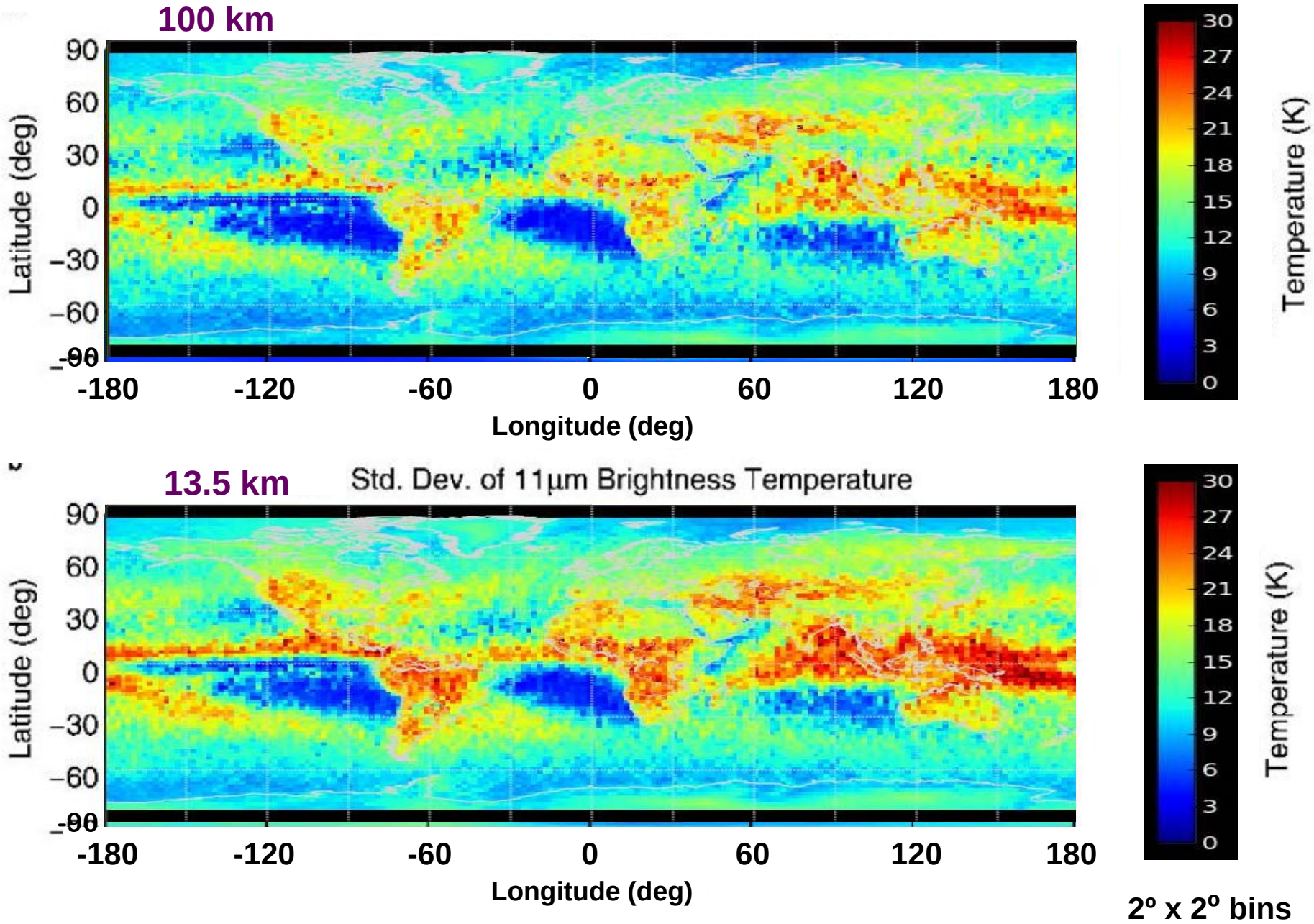
CLARREO from AIRS, 2006, 13.5 km footprints





2^o x 2^o bins

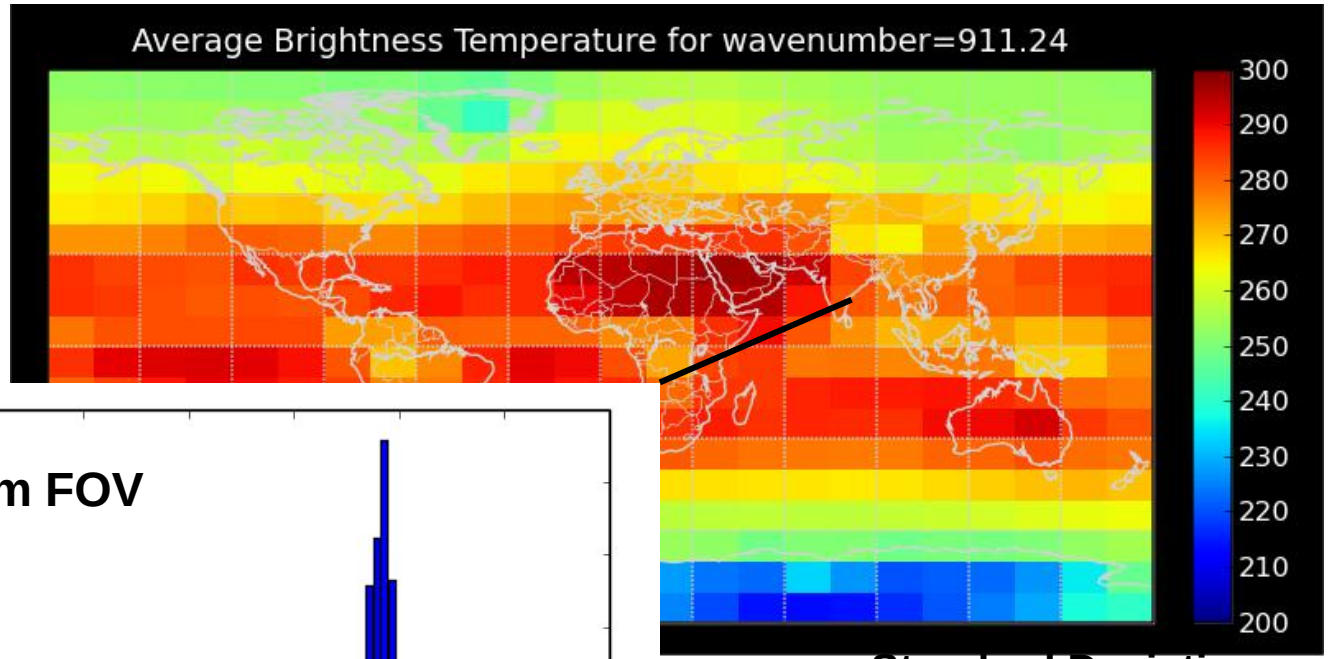
CLARREO from AIRS, 2006, 13.5 & 100 km footprints

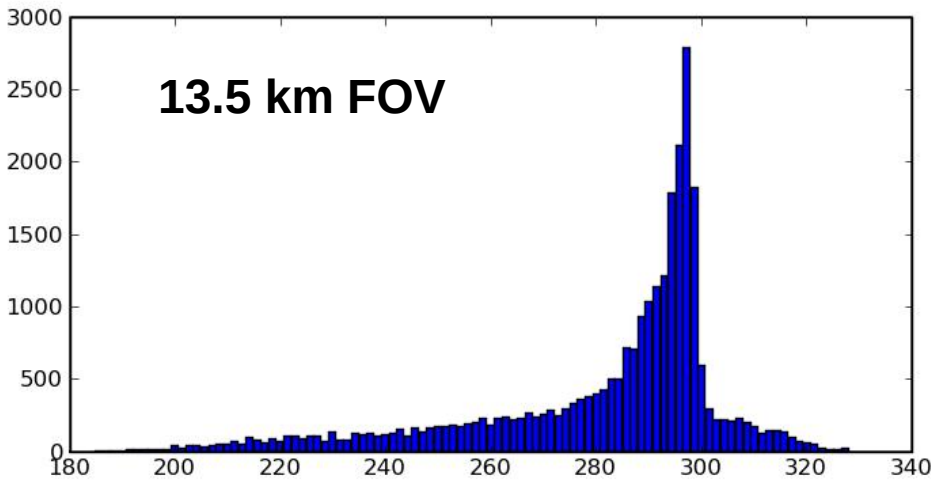


2° x 2° bins

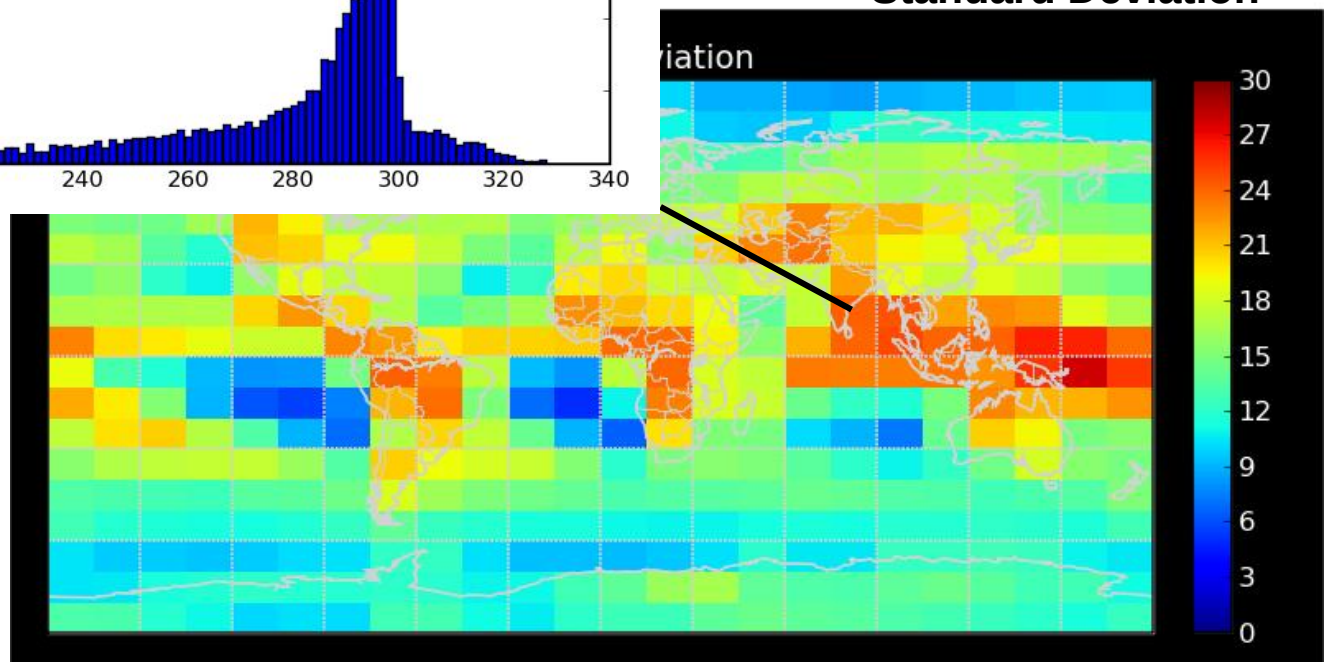
2006 Annual
911 cm^{-1}, window
10°x15° bins

Mean





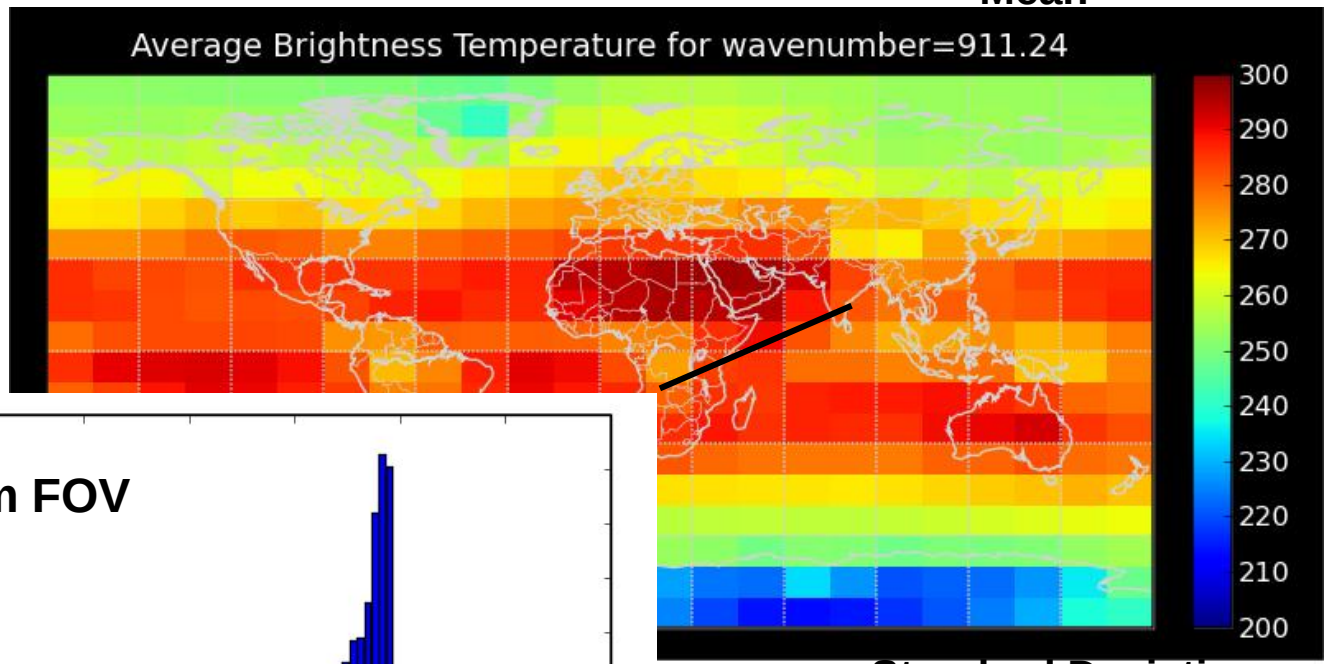
Standard Deviation

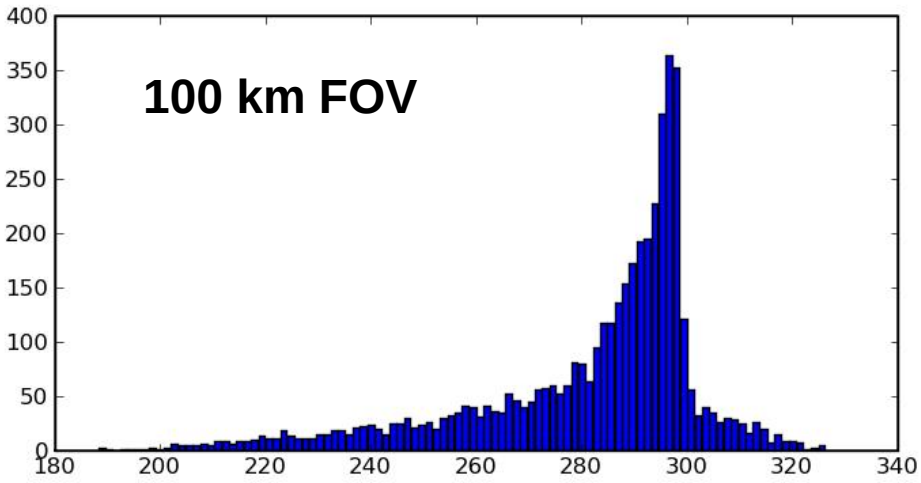


India

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

Mean





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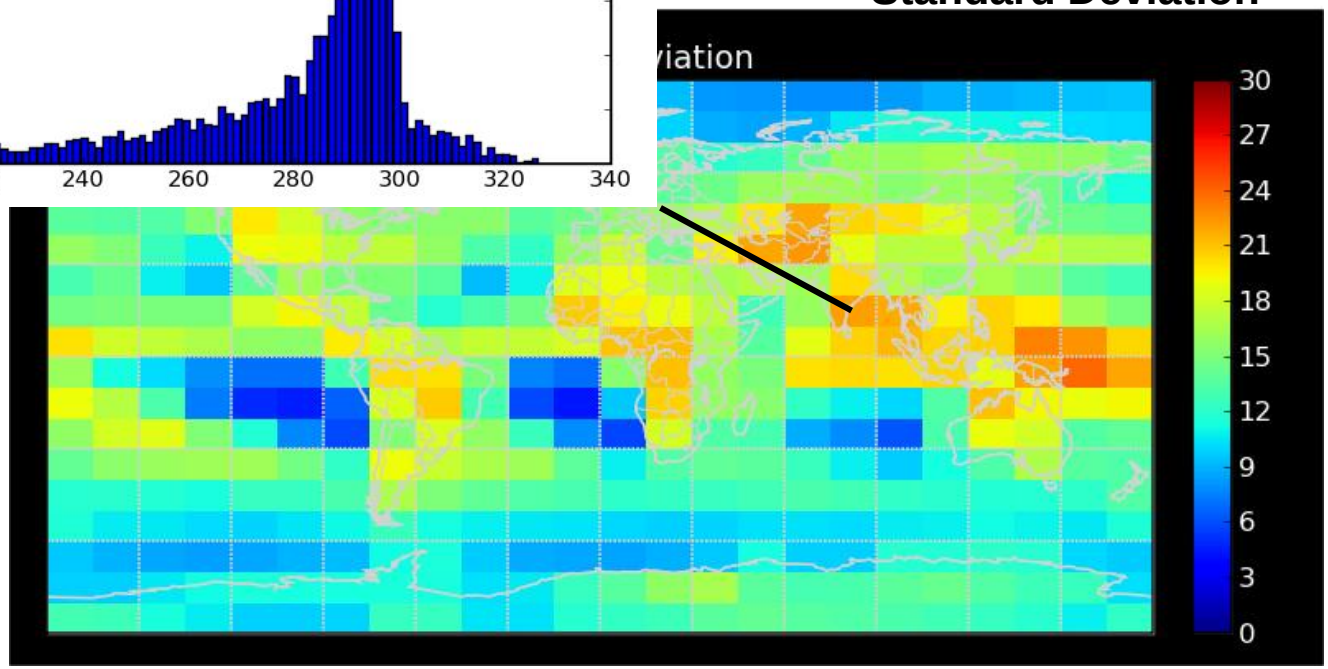
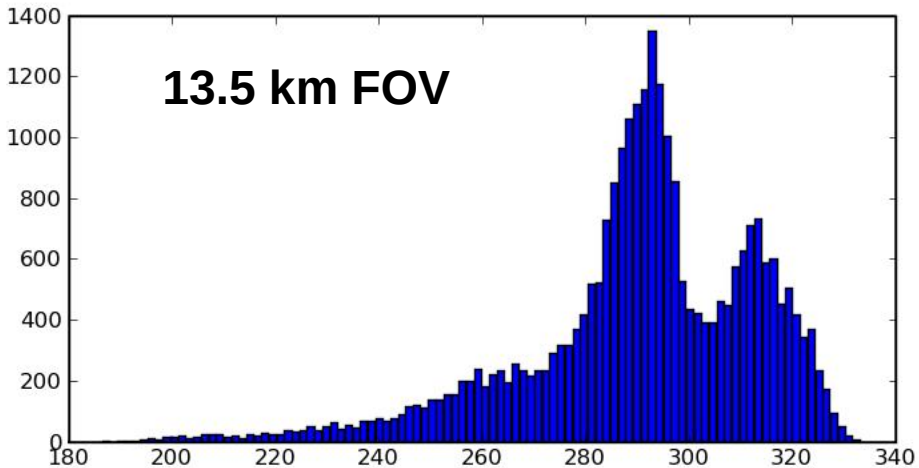


India

Climate Content Preserved

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



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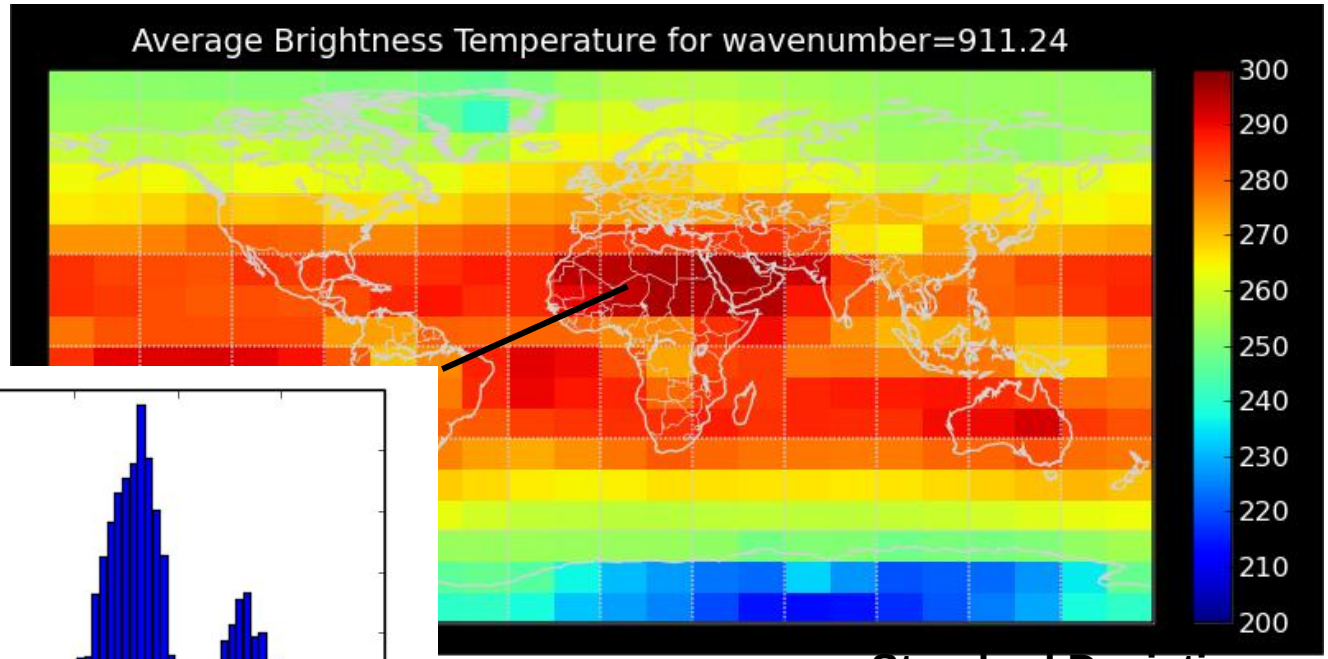

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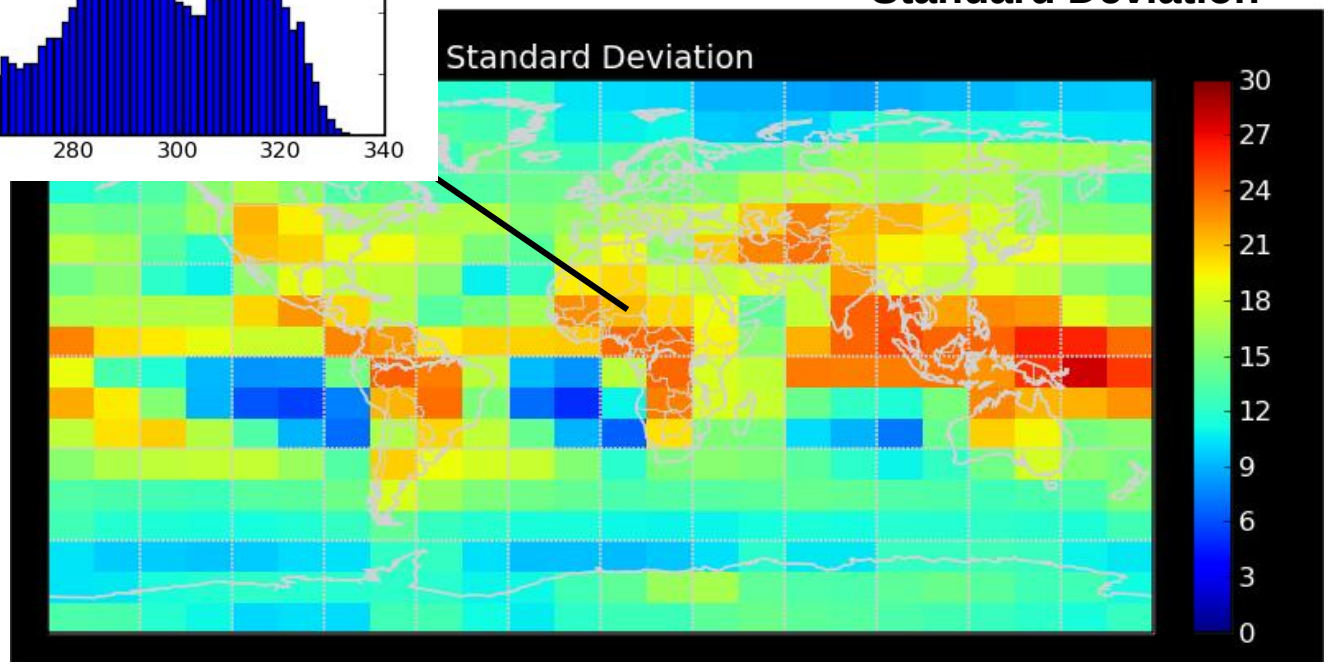
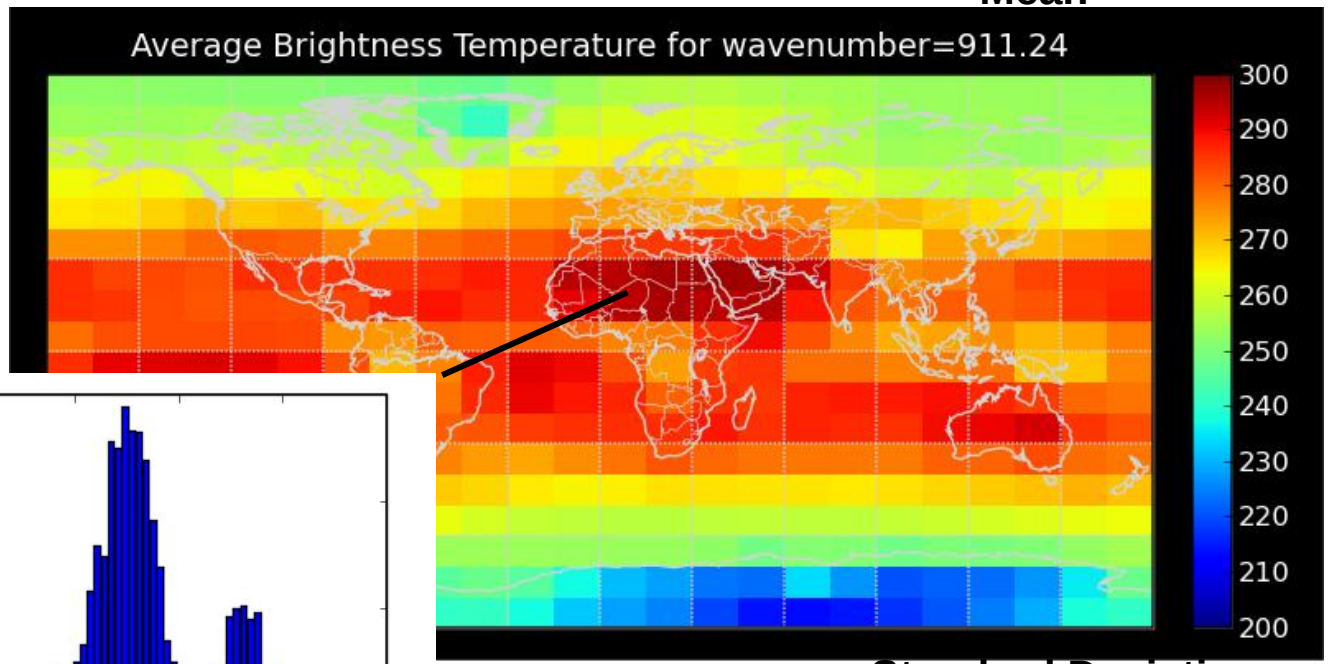
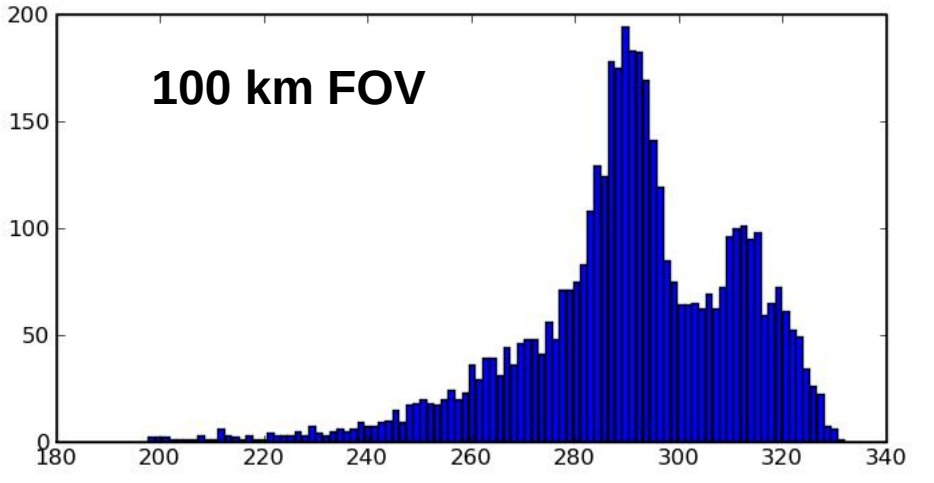


Africa: West Central

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

Mean





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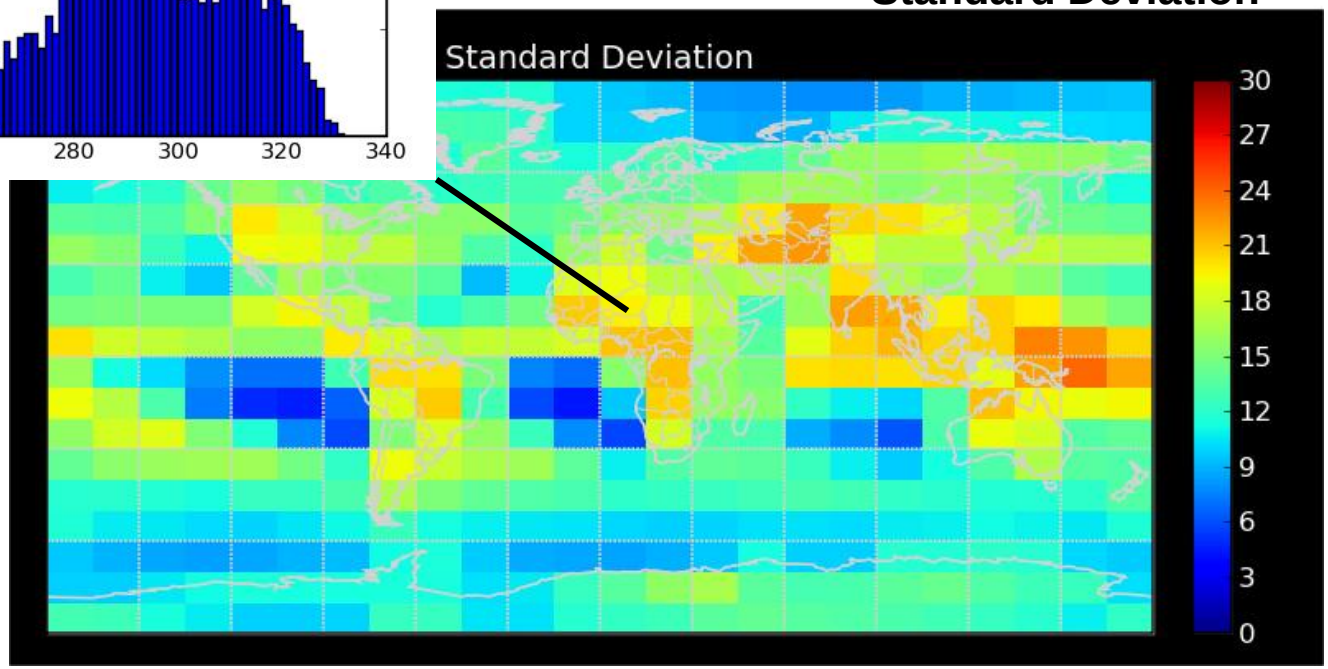
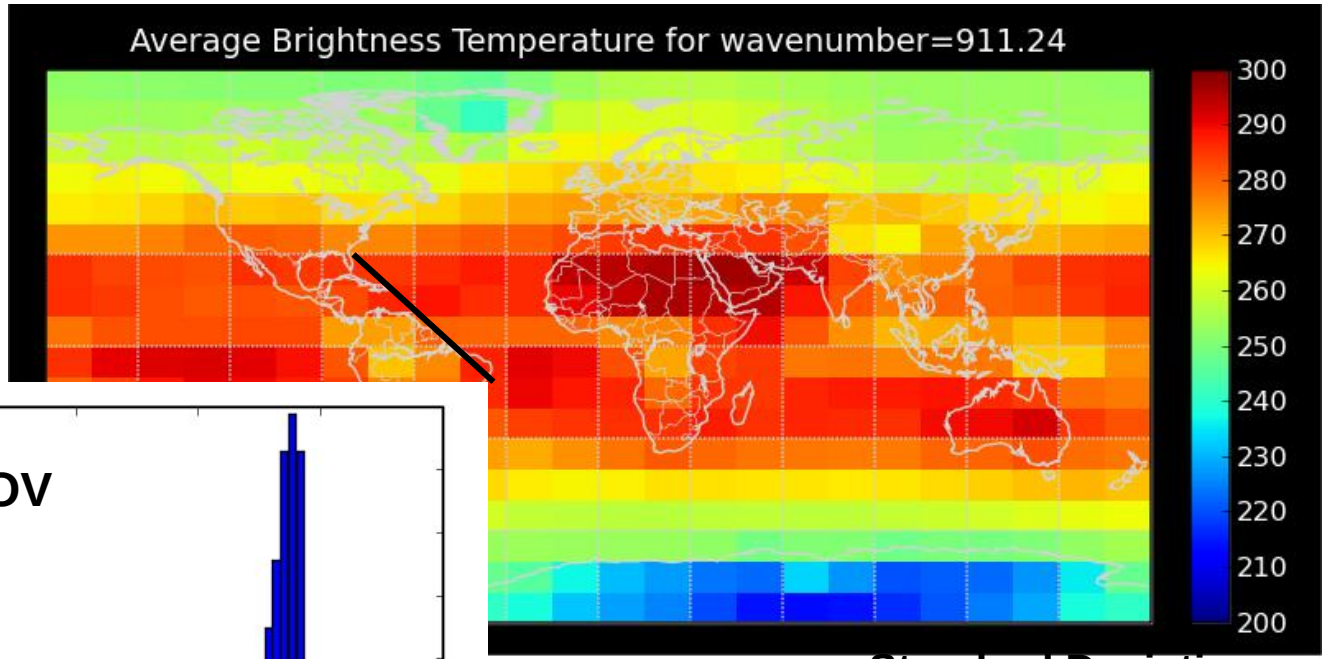


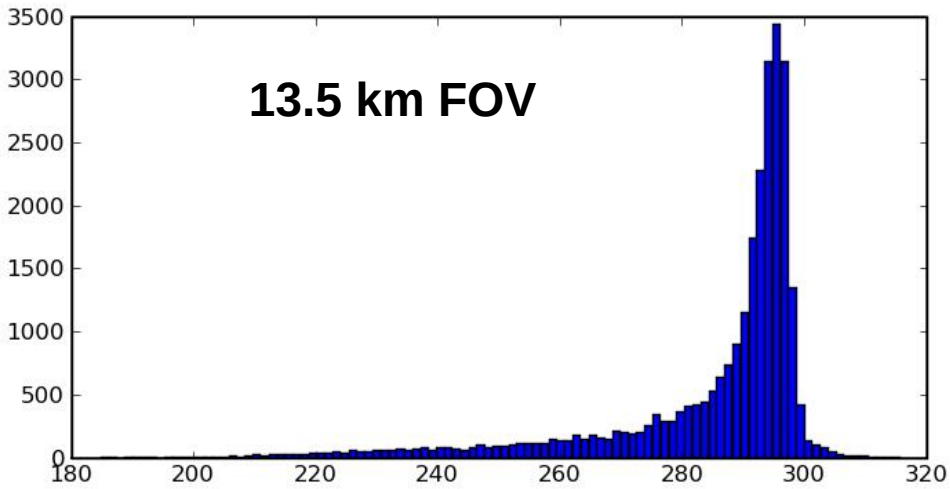
Africa: West Central

Climate Content Preserved

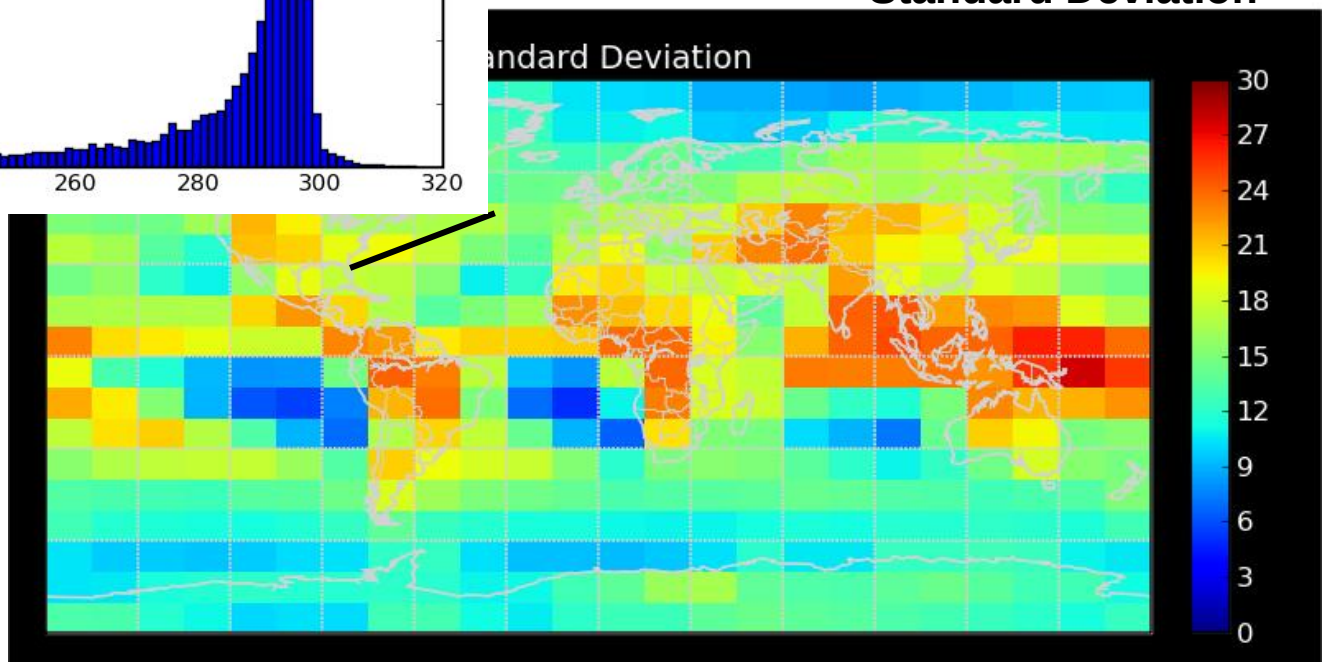
2006 Annual
911 cm^{-1}, window
10°x15° bins

Mean



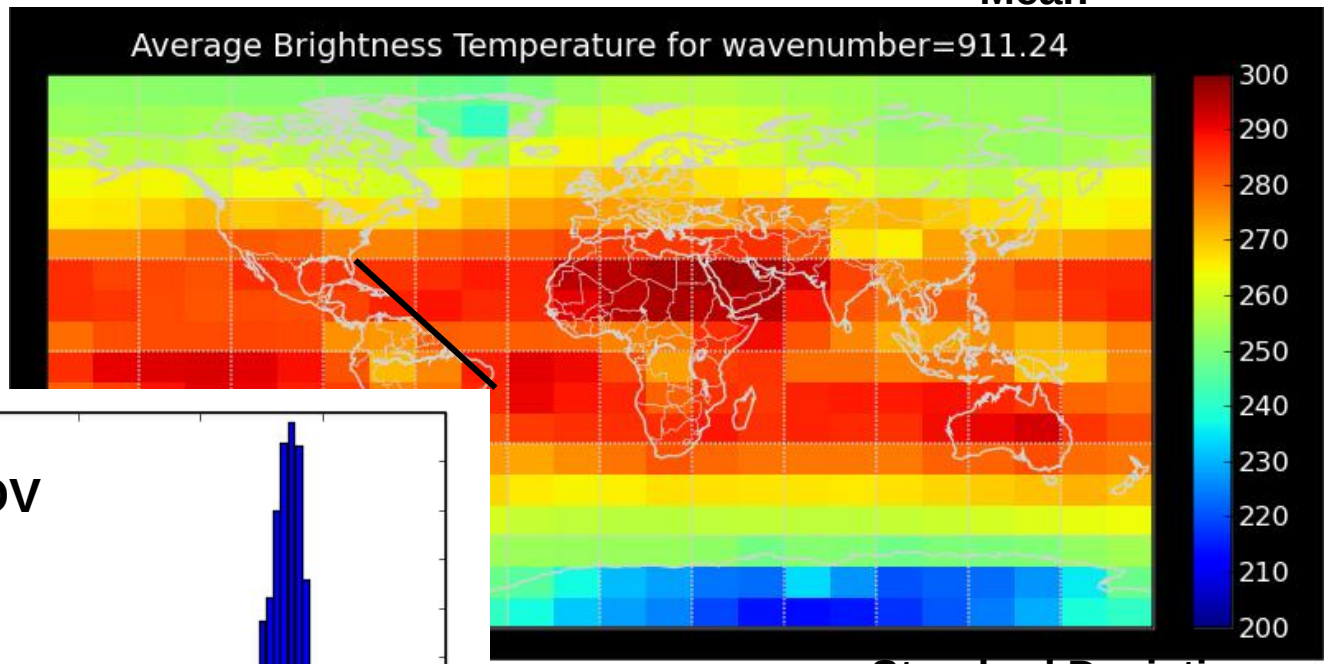


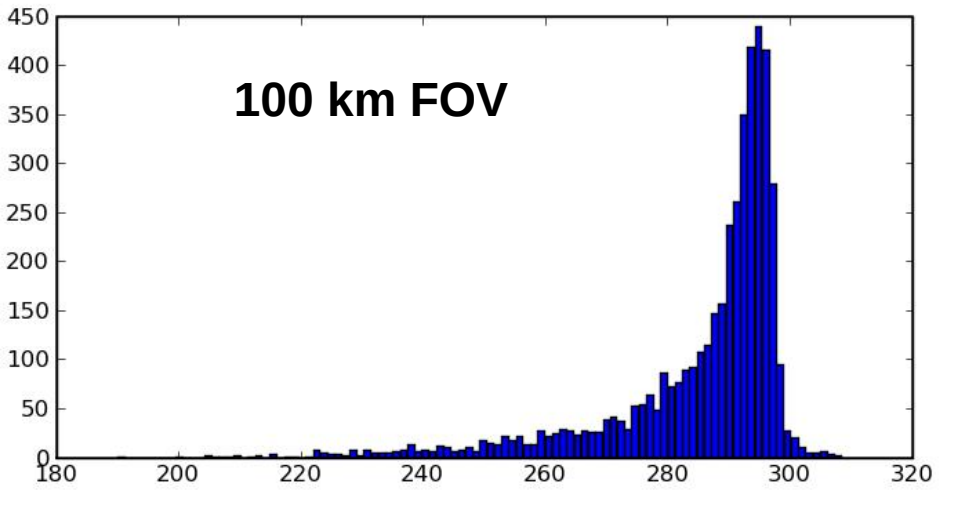
Standard Deviation

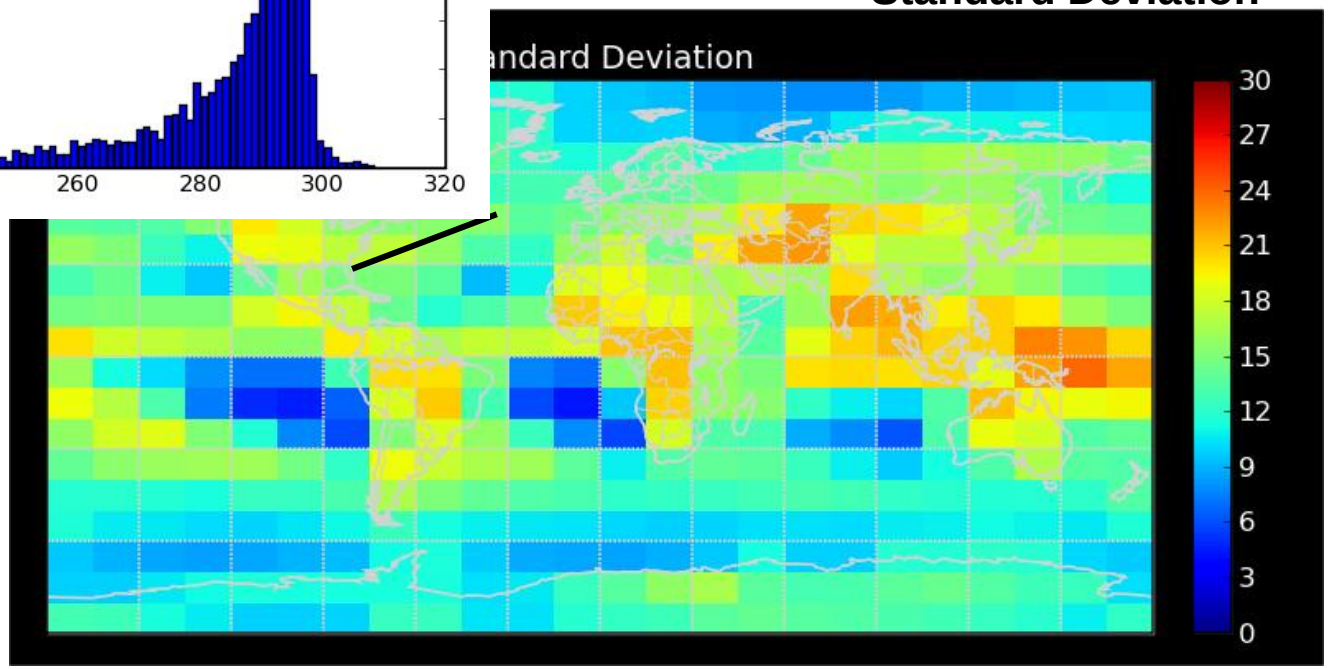


Florida

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







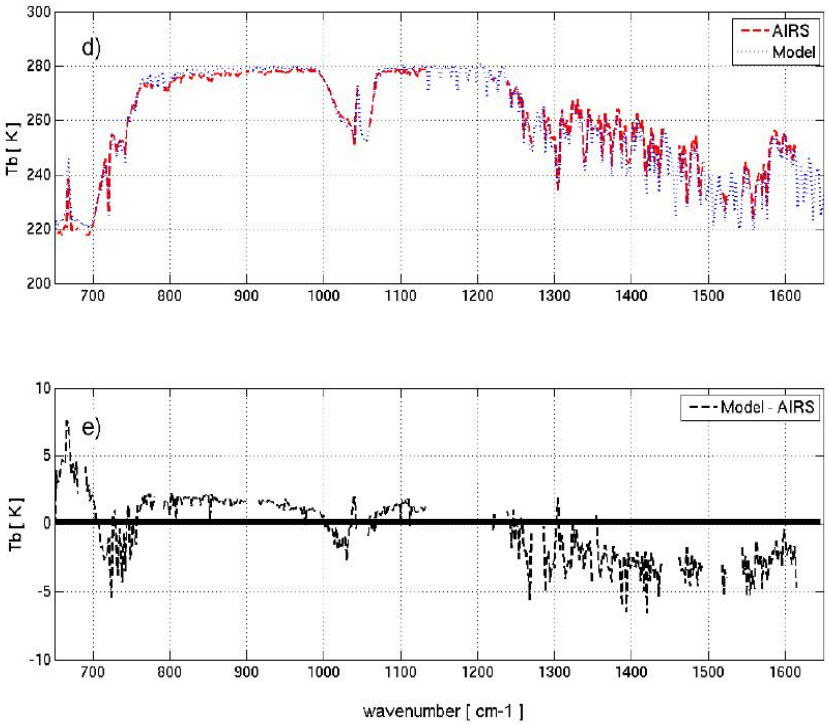
Florida

Climate Content Preserved

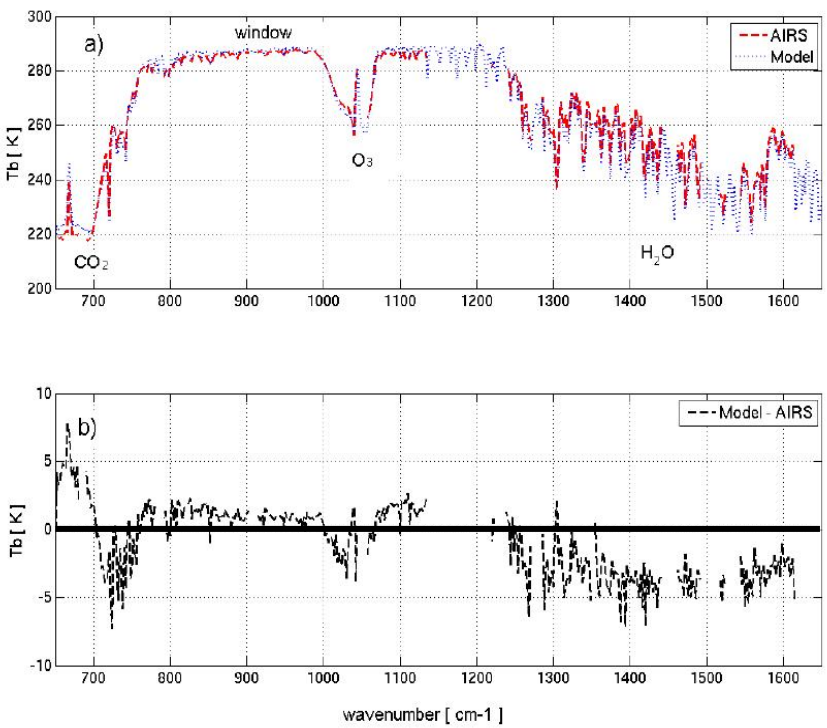
Notable similarity for Clear & All Sky

Yi Huang thesis (Ramaswamy, advisor), 2008

All Sky



Clear



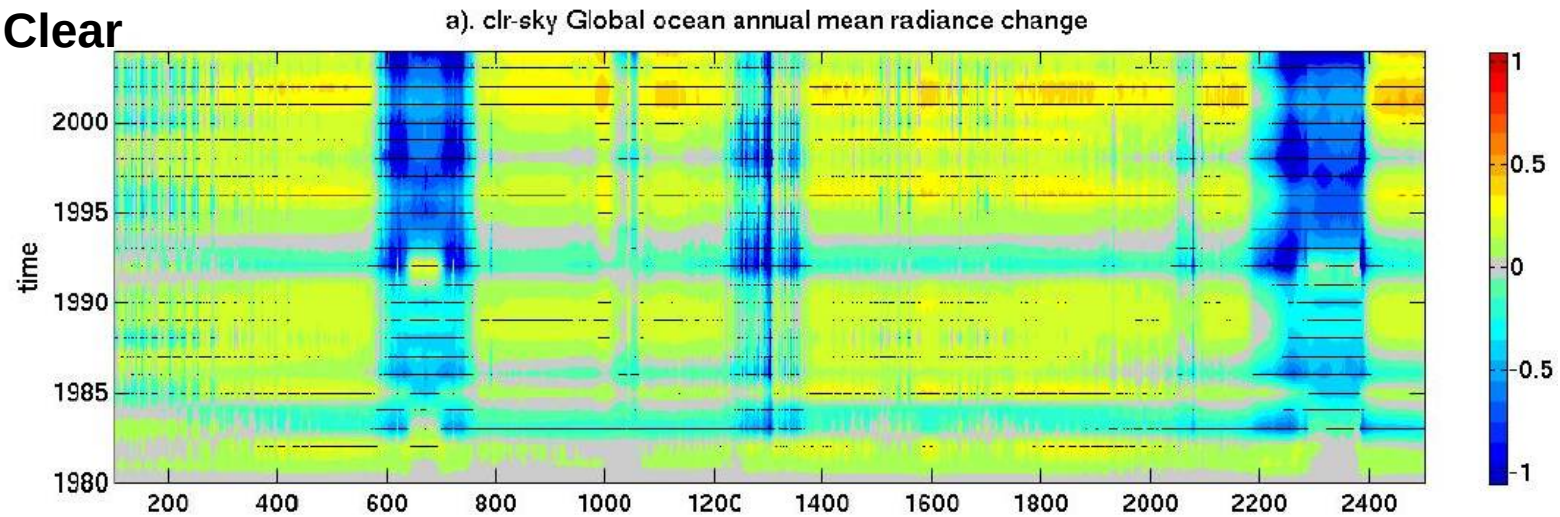
CLARREO does not need cloud clearing—already done well by high resolution sounders for understanding processes

Global Mean, Sept 2002 - Oct 2003

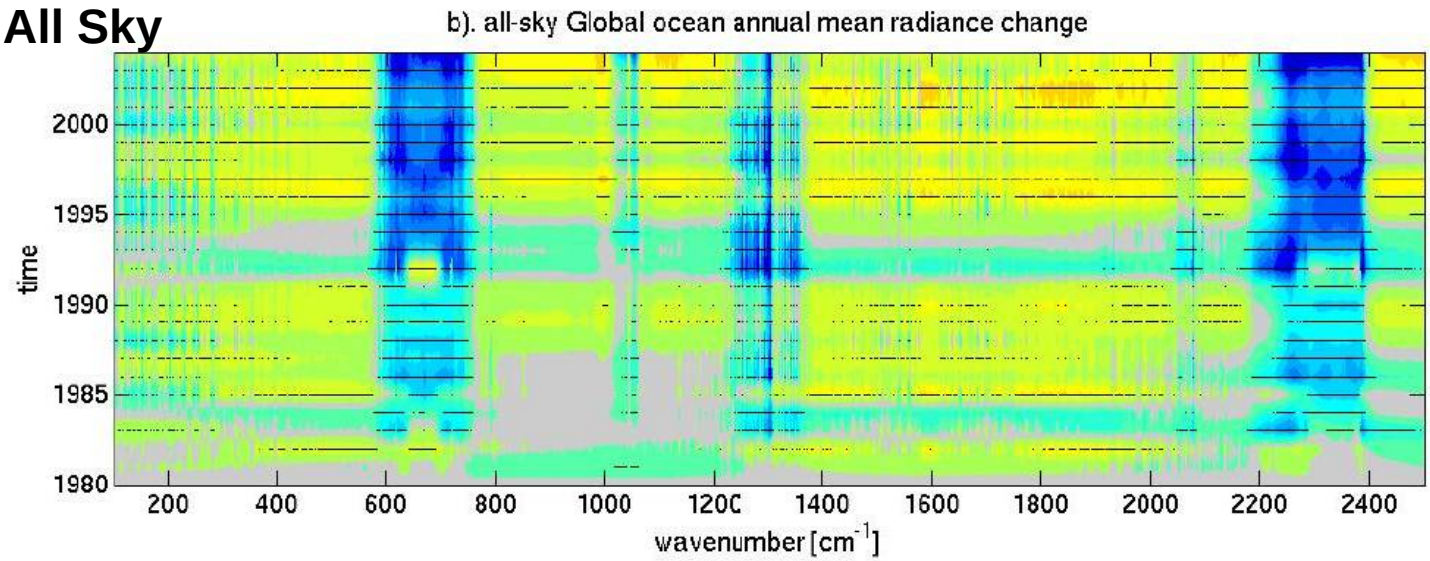
CM2 Annual Mean Spectral 25-yr Trend

Yi Huang thesis (Ramaswamy, advisor), 2008

Clear



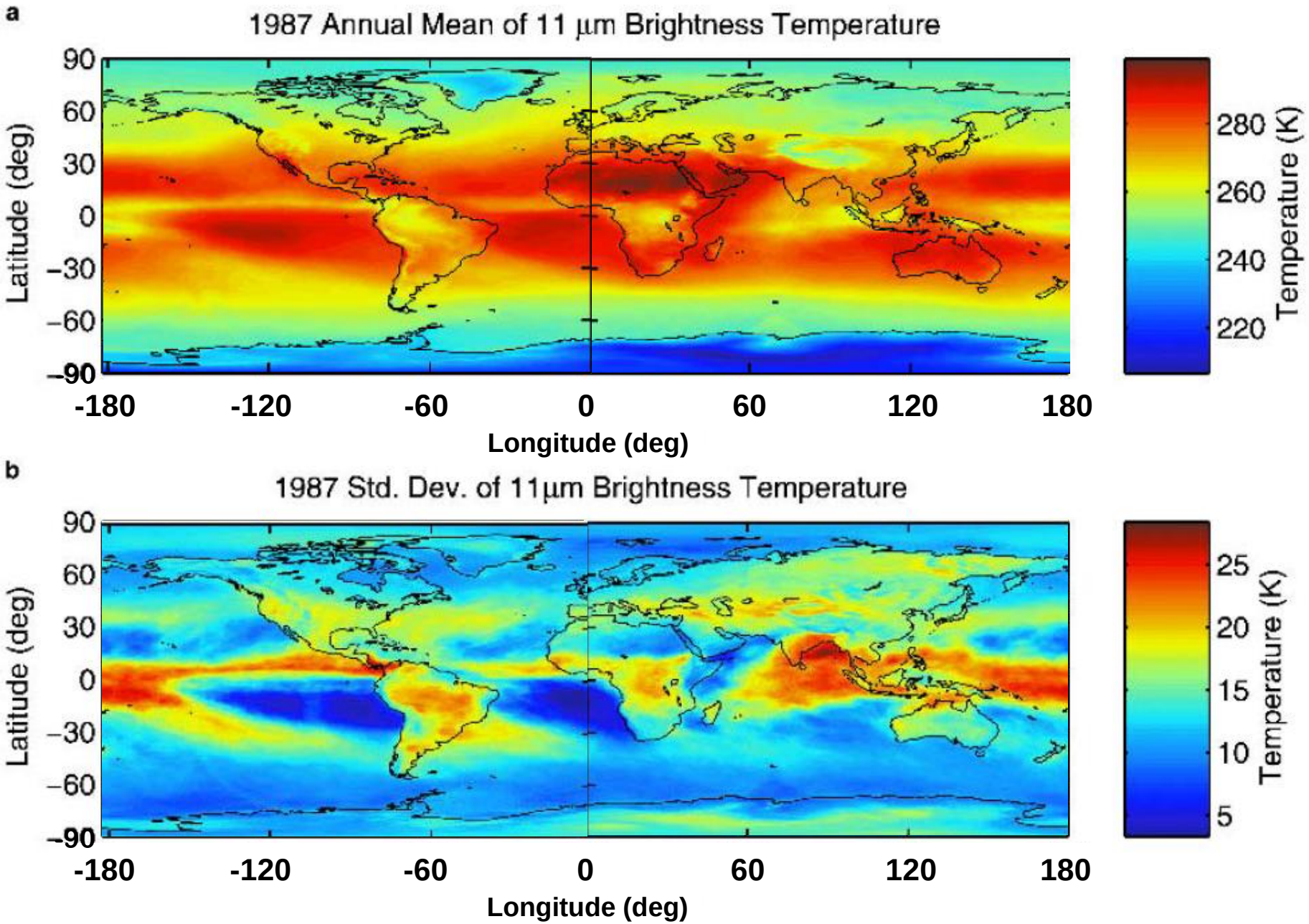
All Sky



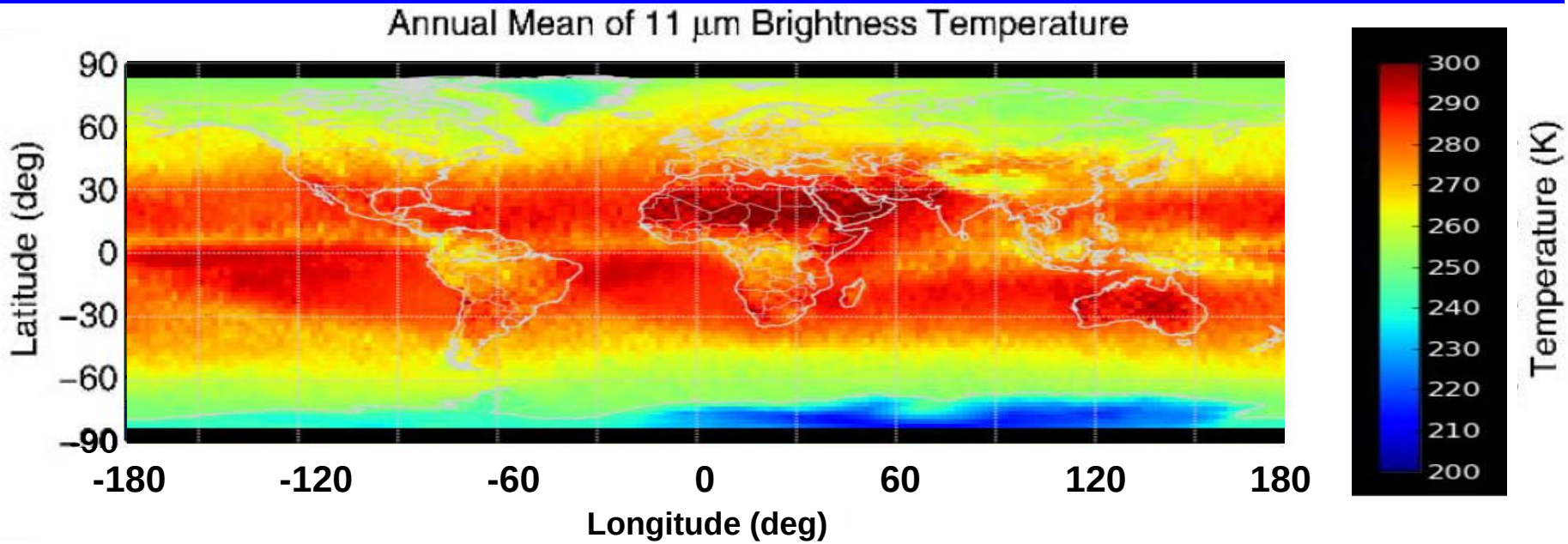
Black dots indicate changes > 3 x standard deviation of unforced means

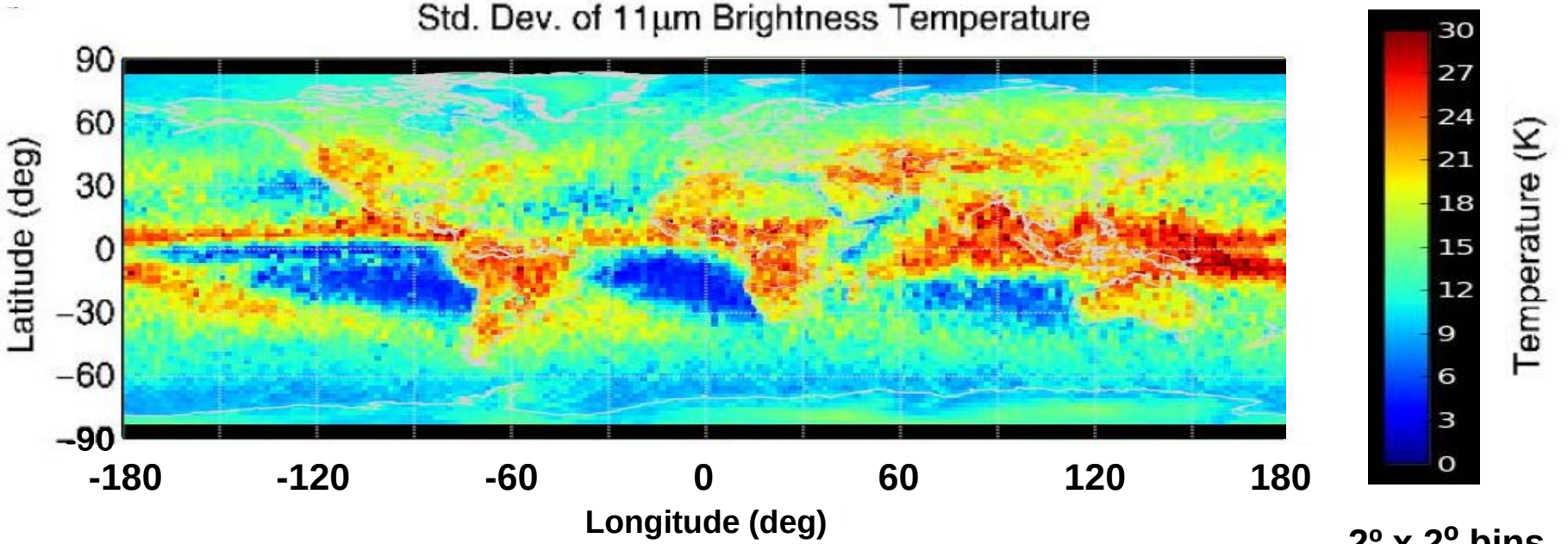
Flow-Down IR Requirements (3)

- **Orbits:** 3 90º inclination orbits spaced 60º apart (to minimize sampling biases that RSS with measurement uncertainty & achieve global coverage with nadir only views)


a
1987 Annual Mean of 11 μm Brightness Temperature
Latitude (deg)
90
60
30
0
−30
−60
−90
-180
-120
-60
0
60
120
180
Longitude (deg)
280
260
240
220
Temperature (K)
b
1987 Std. Dev. of 11μm Brightness Temperature
Latitude (deg)
90
60
30
0
−30
−60
−90
-180
-120
-60
0
60
120
180
Longitude (deg)
25
20
15
10
5
Temperature (K)

CLARREO from AIRS, 2006, 13.5 km footprints



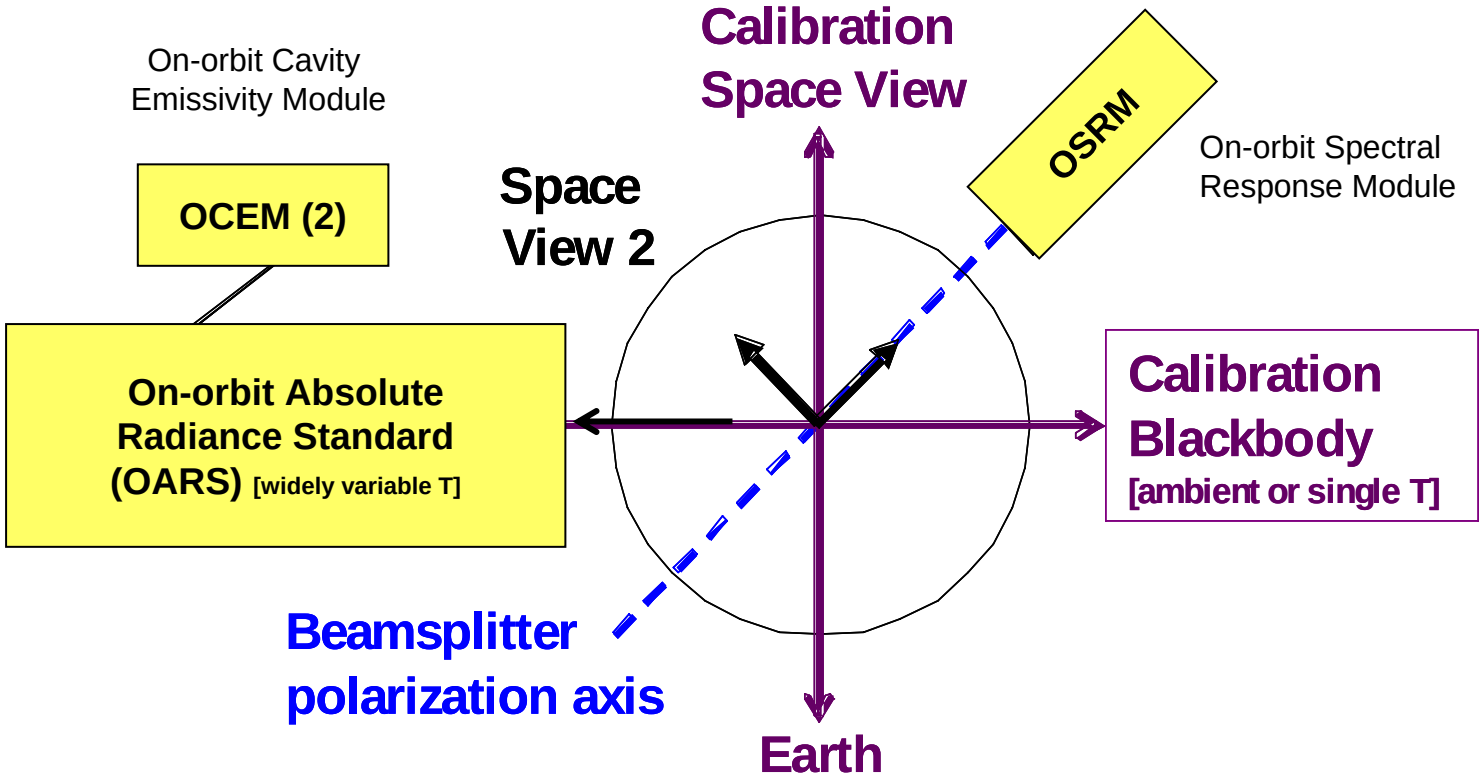


2^o x 2^o bins

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

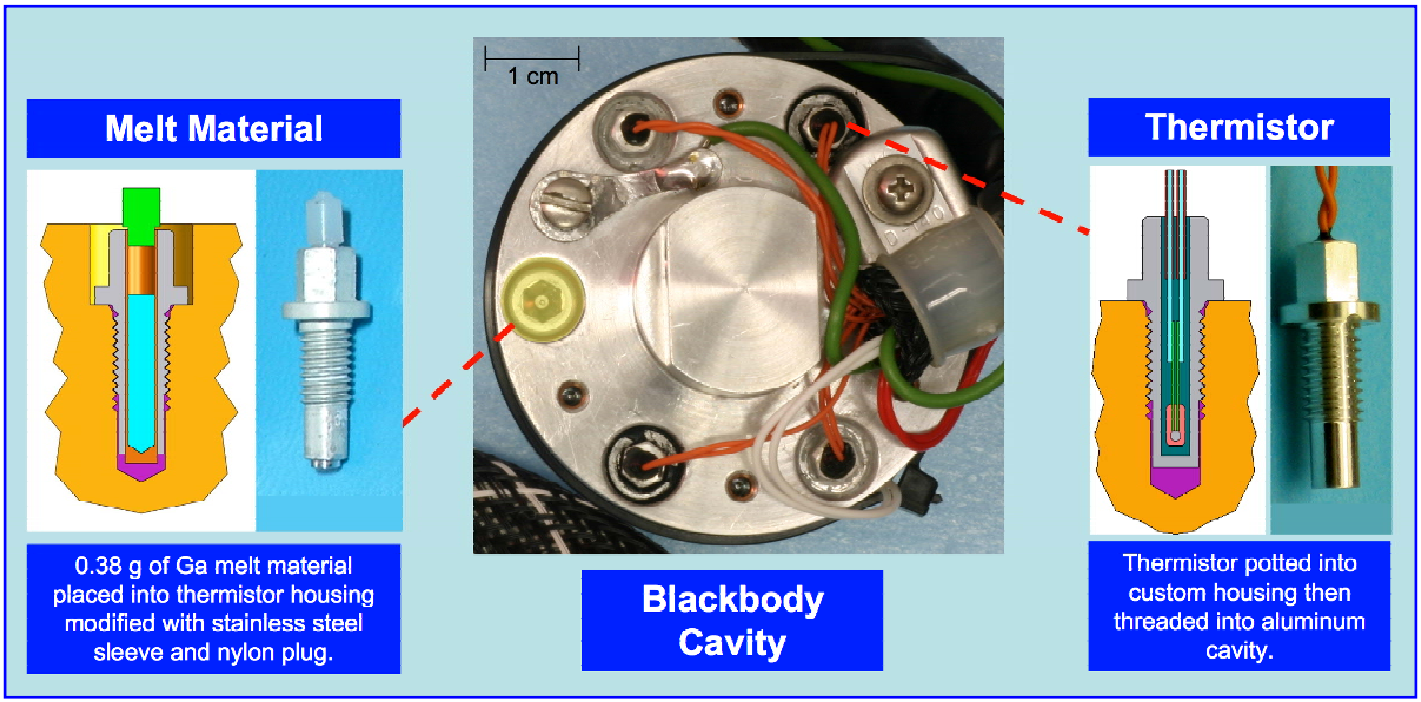


Viewing configuration providing immunity to polarization effects.

New Developments

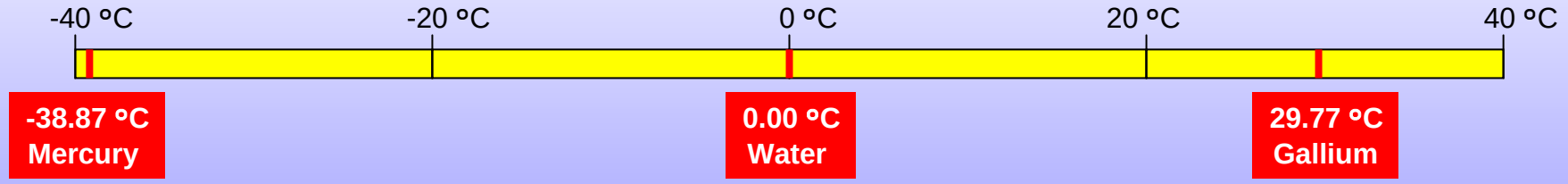
On-orbit Absolute Radiance Standard (OARS)

- **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**

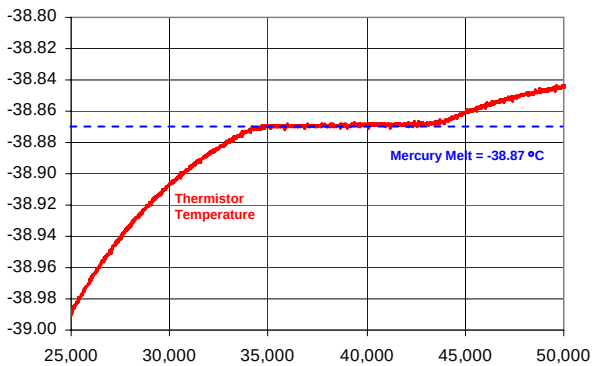


3 Melt Points Calibrate Wide Dynamic Range

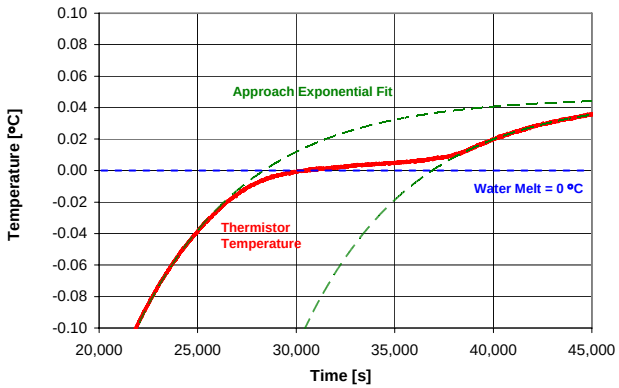
(using GIFTS BB Configuration)



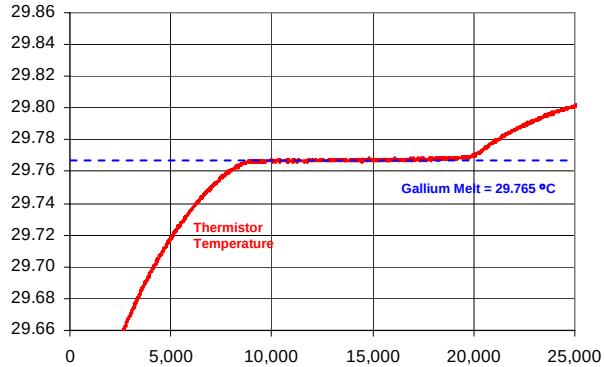
Mercury Melt (test data)



Water Melt (test data)

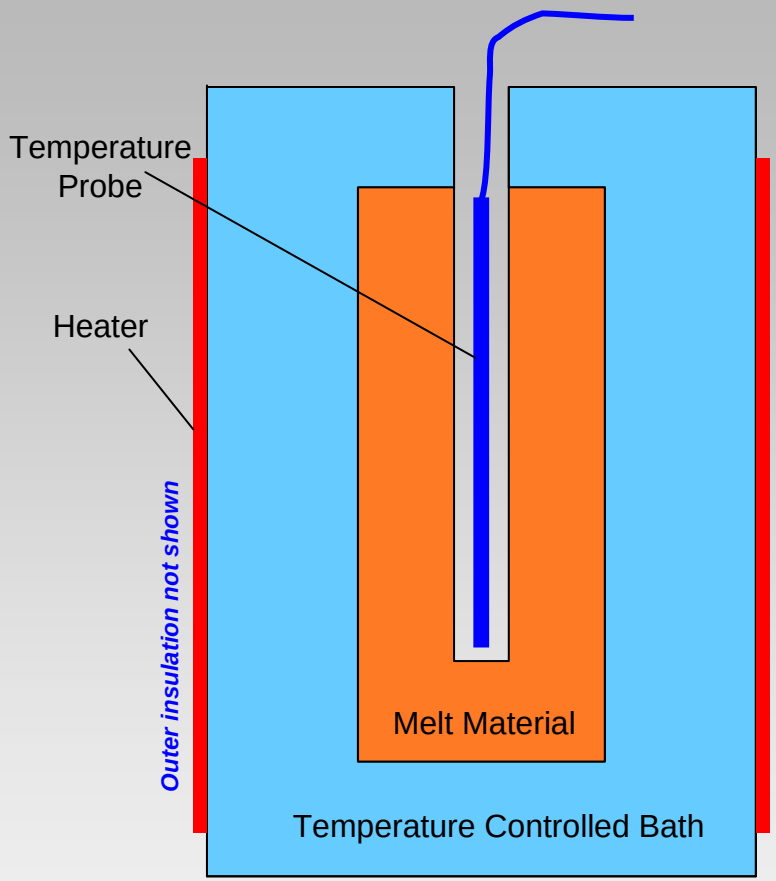


Gallium Melt (test data)

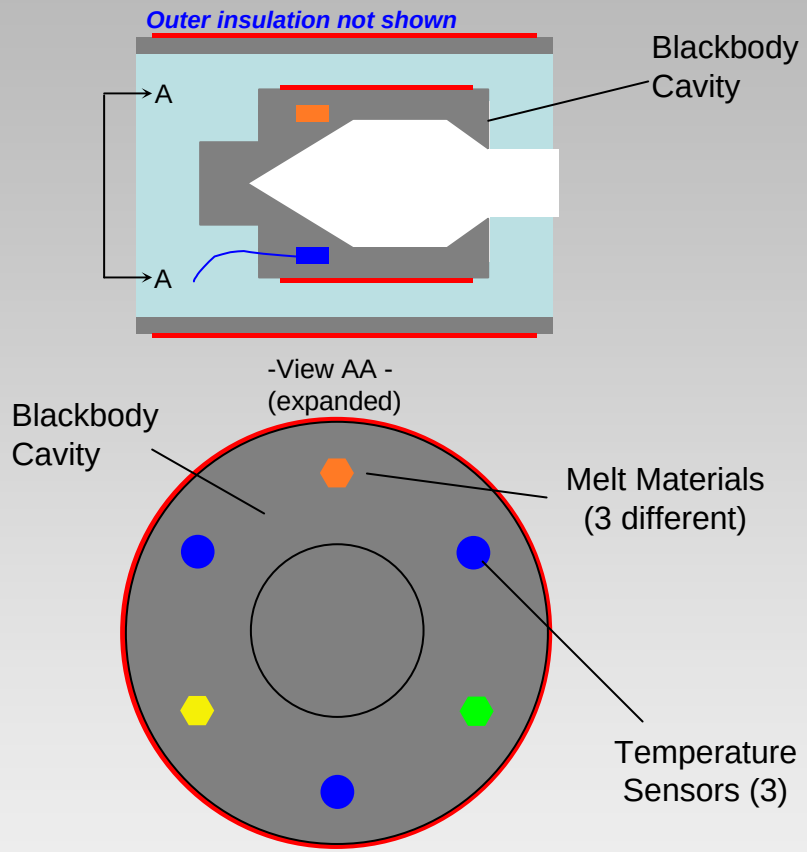


Melt Signatures Provide Absolute Temperature Calibration Accuracies better than 10 mK for full atmospheric Temperature Range

Comparison to Traditional Approach



Traditional Laboratory Calibration Scheme



New Blackbody Calibration Scheme

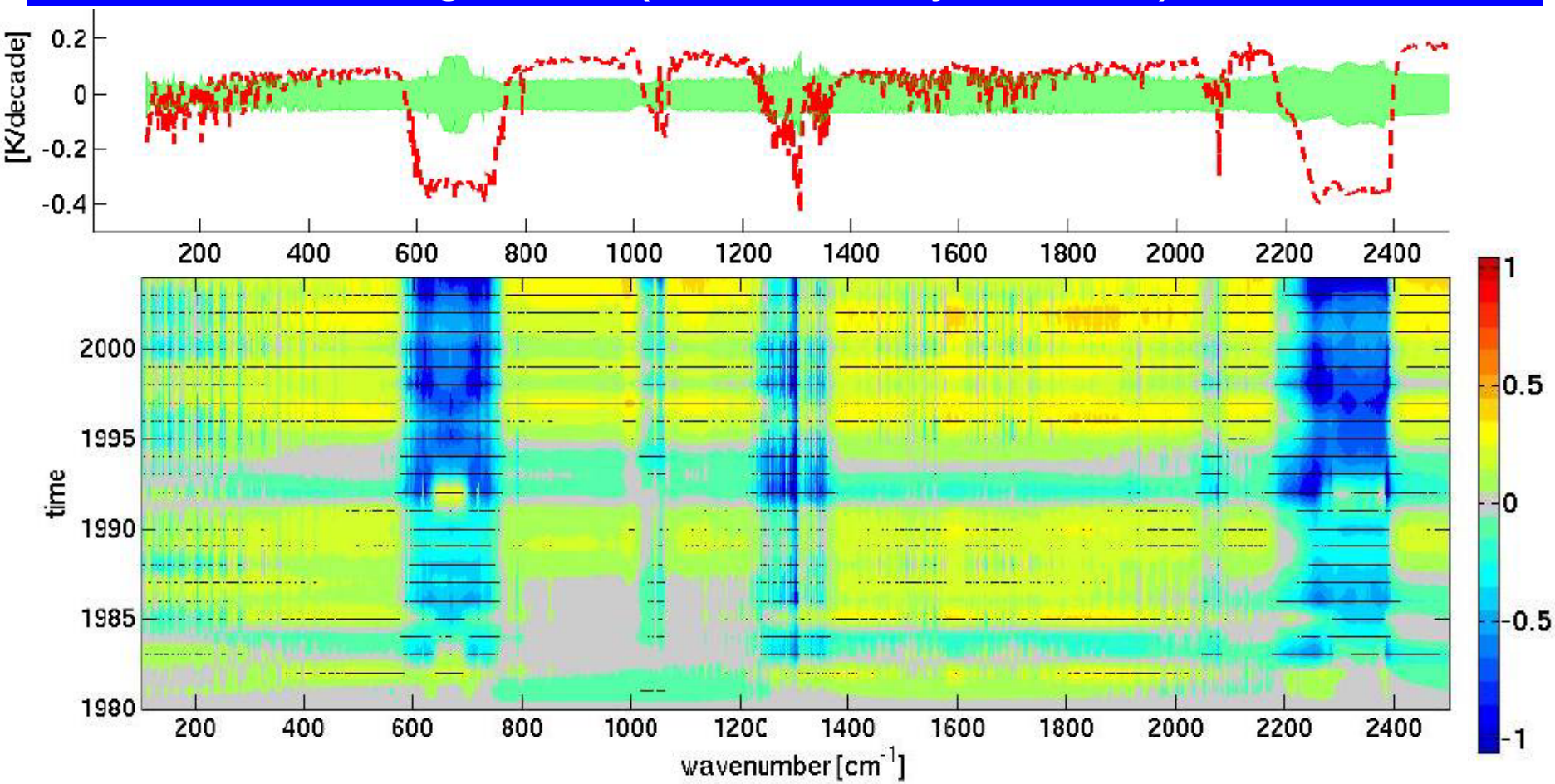
CLARREO Summary

- 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
- 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-type Benchmark Record

from CM2 Annual Mean Spectral 25-yr Trend

Yi Huang thesis (Ramaswamy, advisor), 2008



CLARREO could have captured this benchmark record.

Let's make sure we start as soon as possible!