Introduction to CLARREO

(recent material from CLARREO Project Lead Dave Young and from UW/Harvard Instrument Incubator Project)

IR Intercal with CLARREO

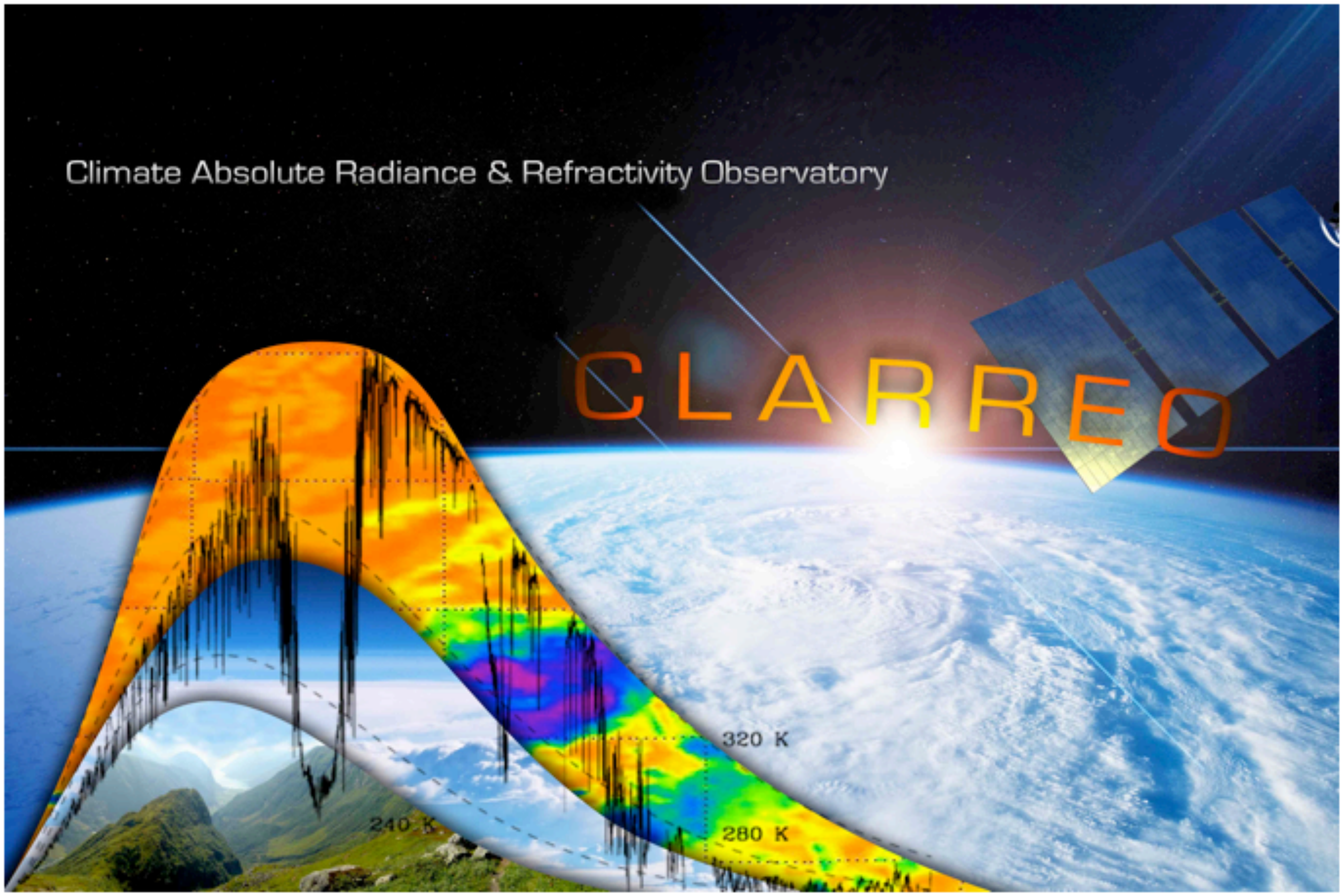
(material from October 2008 CLARREO workshop)

presented by
Dave Tobin
University of Wisconsin-Madison

GSICS Meeting, 29 Jan 2009 (JST)

Langley Research Center

Initiating a New Highly Accurate Climate Record with CLARREO



David Young
CLARREO Mission Study Lead

16th Conference on Satellite Meteorology and Oceanography

January 13, 2009

What is CLARREO?

- **Climate Absolute Radiance and Refractivity Observatory**
- **One of the highest priority missions described in the NRC Earth Science Decadal Survey**
  - **Recommended in first group of 4 missions ("Tier 1")**
- **A climate-focused mission**
  - **Foundation is on-orbit S.I. traceability of calibration**
  - **Long-term trend detection**
  - **Improvement and testing of climate predictions**
  - **Calibration of operational and research sensors**
- **Joint NASA / NOAA mission**
  - **NOAA portion of CLARREO is the continuation of solar irradiance and earth radiation budget observations (TSIS and CERES)**

Baseline Mission from the Decadal Survey

- **Three satellites in 90° orbits to provide accurate temporal sampling**
- **Instruments**
  - **Redundant hyperspectral IR spectrometers** on each satellite
    - 200 - 2000 cm-1 with 1 cm-1 resolution
    - Nadir viewing with ~100 km FOV
    - Accuracy goal: 0.1 K (3 σ)
  - **Hyperspectral solar spectrometers** on third satellite
    - 300 - 2000 nm with 15 nm resolution
    - Accuracy goal: 3 parts per 1000
  - **GPS radio occultation receivers** on each satellite

- ***This is the starting baseline, but we are now working to provide a much more rigorous determination of CLARREO requirements***

A new class of Advanced Accuracy Satellite Instrumentation (AASI) for the CLARREO Mission

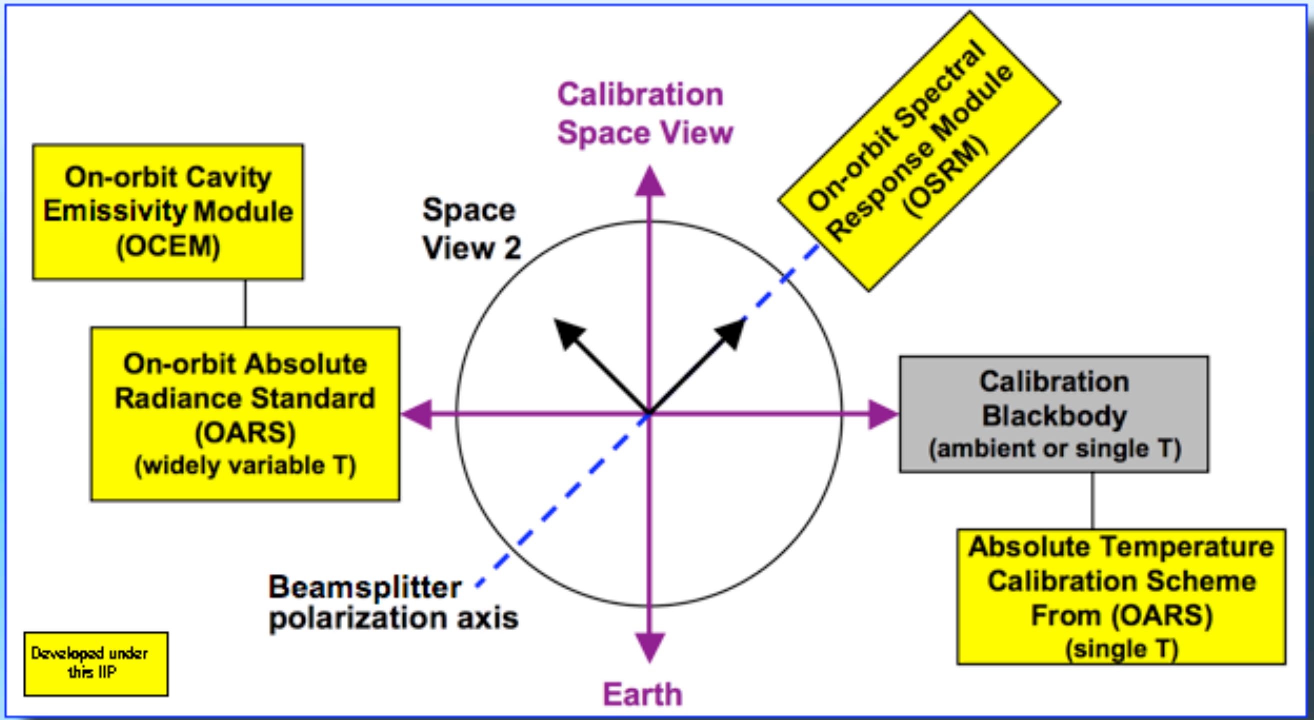
[NASA IIP-07-0006]

6 Month Interim Review

University of Wisconsin and Harvard University

20 January 2009

CLARREO Viewing Configuration



Viewing configuration providing immunity to polarization effects.

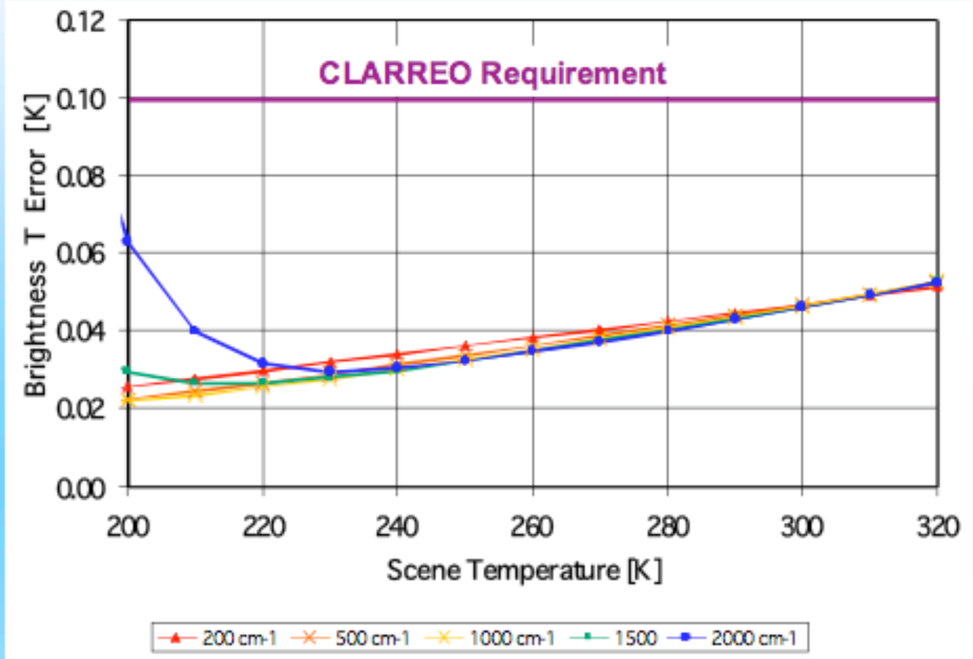
CLARREO FTS Scene Mirror Provides Earth and Space Views as well as Views to Targets Involving Technologies Developed Under this IIP, That Give Unprecedented Absolute Calibration Accuracy on-orbit.

CLARREO Radiometric Performance

Calibration Model Parameters and assumed uncertainties

T_{bb}	300 K
δT_{bb}	0.045 K
E_{bb}	0.999
δE_{bb}	0.0006
T_{str}	285 K
δT_{str}	5 K
$\delta T_{telescope}$	0.2 K

**Blackbody performance Demonstrated with UW-developed GIFTS Blackbody.*



Estimated 3-sigma calibrated brightness temperature uncertainty shown as a function of scene brightness temperature, based on use of the AASI.

The uncertainty of the blackbody radiating temperature (45 mK, 3-sigma) dominates, except for large wavenumbers at cold temperatures where the assumed telescope temperature change of 20 mK between earth and calibration views becomes important. We assumed an emissivity of 0.999 with 0.0006 uncertainty and a blackbody temperature of 300 K, while the instrument is at 285 K.

Project status

(ala DCT)

- NASA LaRC led mission
- Partners: Harvard, UW, LASP, Univ. of Colorado, UC Berkley, GISS, GFDL
- Center Participants: GSFC, JPL
- Current Pre-Phase-A efforts aimed at defining specific science questions and linking them to Level 1 mission and sensor requirements
- Relevant NASA Instrument Incubator Program efforts at UW/Harvard (Revercomb), LaRC (Mlynczak) and LASP (Kopp, Pilewskie)
- Working towards Mission Confirmation Review in late 2009/early 2010; launch in 2015-2017
- Next CLARREO team meeting the week of April 13th in Hampton, VA.

Inter-calibration of Operational IR Sounders using CLARREO

Dave Tobin, Bob Holz

Fred Nagle, Bob Knuteson, Fred Best, Hank Revercomb

Space Science and Engineering Center,

University of Wisconsin-Madison

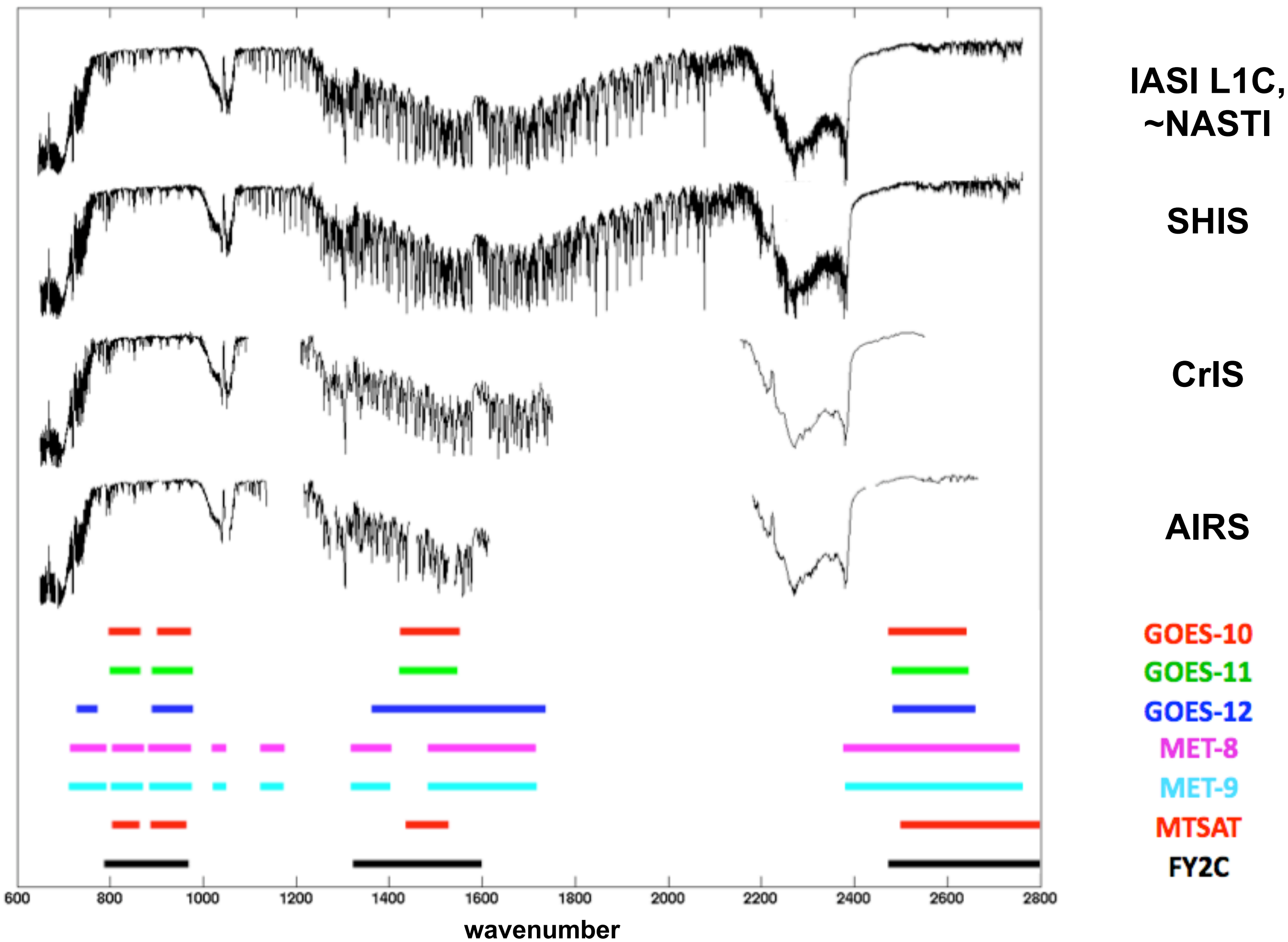
2008 CLARREO Workshop

L'Enfant Plaza Hotel, Washington, D.C.

October 21-23, 2008

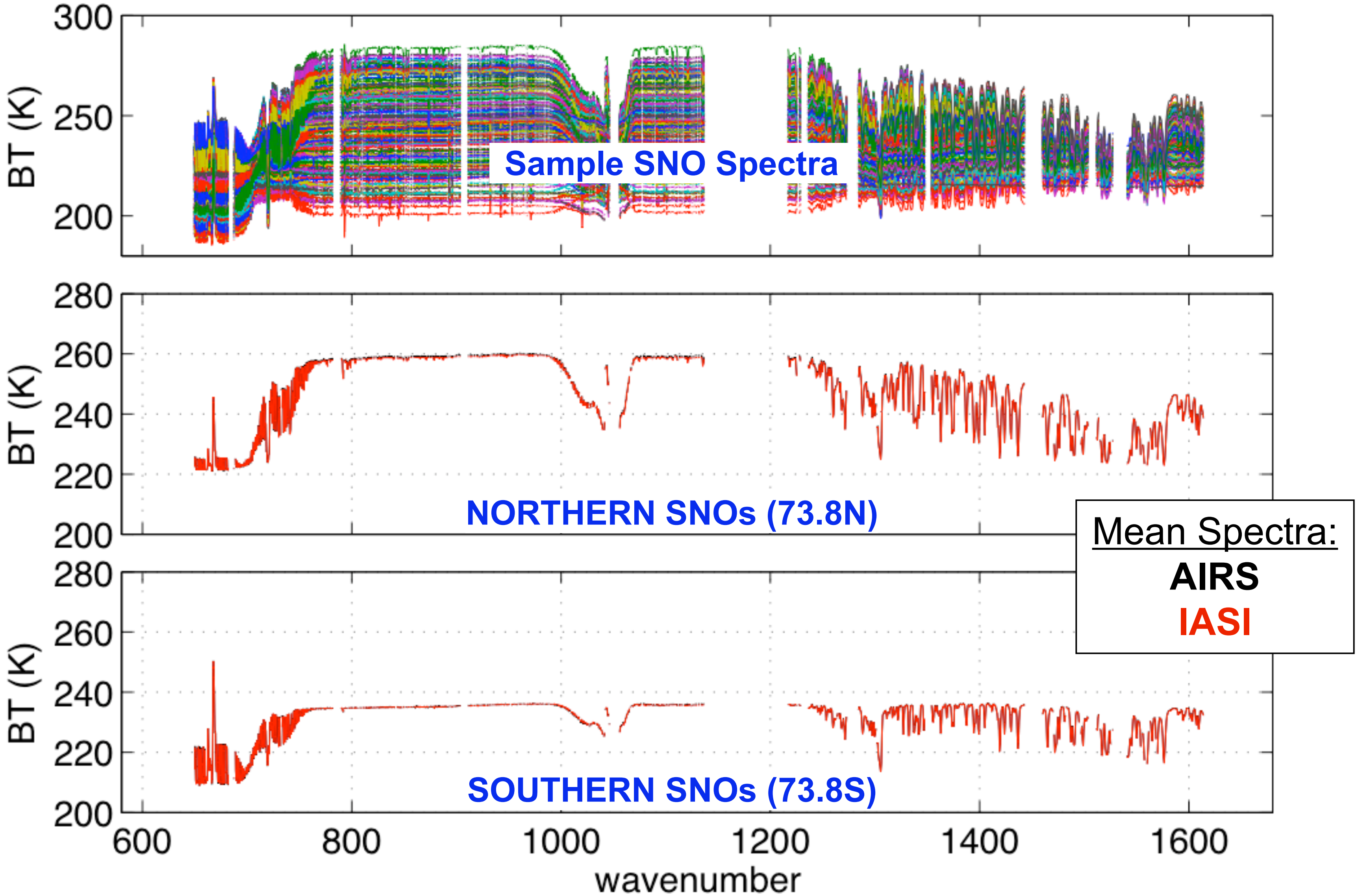
Many recent examples demonstrating the value of high spectral resolution IR for Intercal

E.g. AIRS and IASI for Geo Intercal:



Direct comparisons of IASI and AIRS

created from an ensemble of SNOs collected from May 2007 to January 2008



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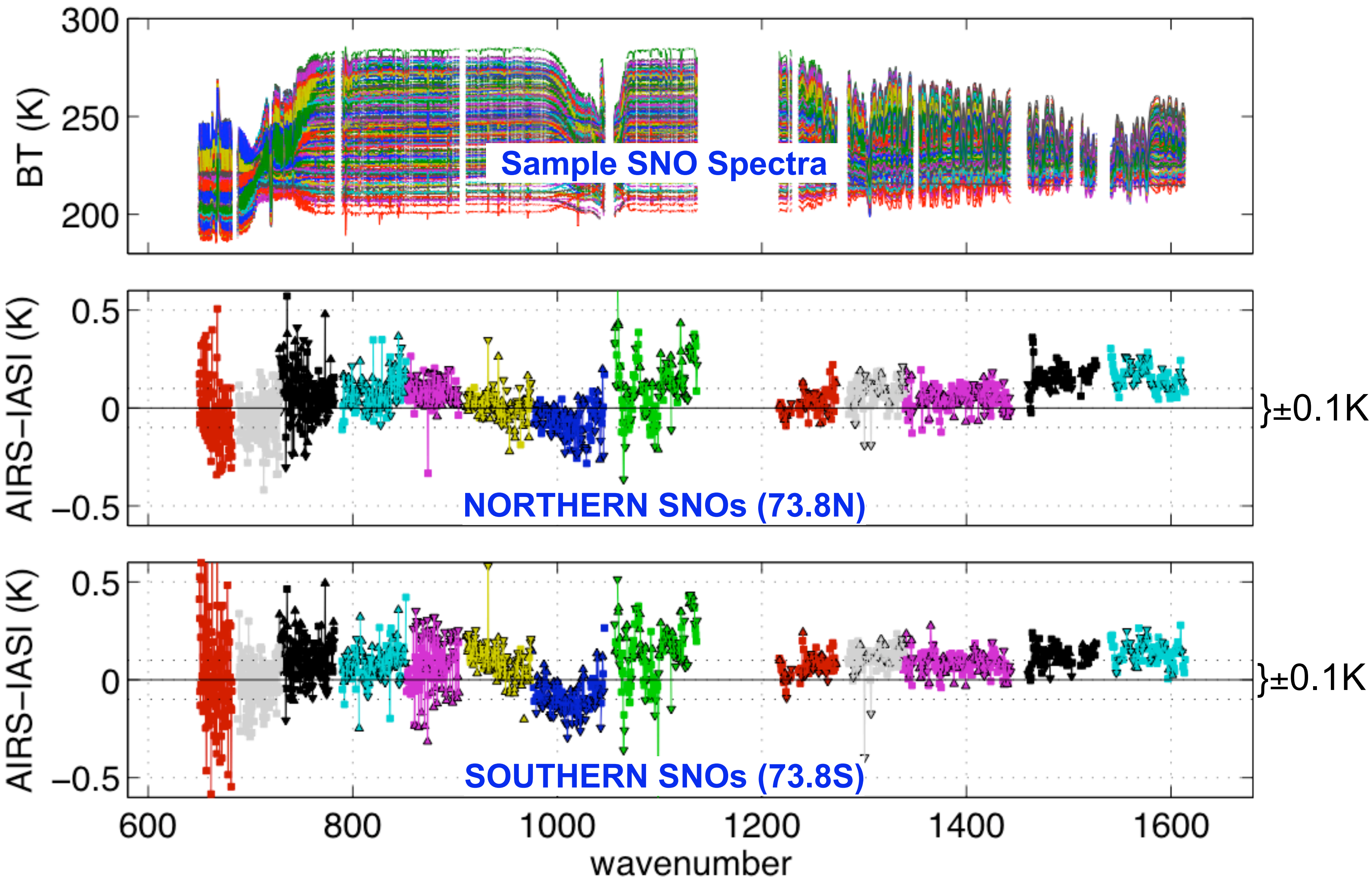


Question:

Given a candidate CLARREO mission optimized for producing the climate benchmark products (a mission, for example, consistent with the NRC DS consisting of three 90 degree polar orbits, 100 km footprints, 0.1K radiometric accuracy, 1K NEDT, broad and continuous spectral coverage at high spectral resolution), how well can we meet the CLARREO objective to serve as an inter-calibration reference for the operational IR sounders ?

(The goal is to be capable of performing the inter-calibration with uncertainty comparable to the CLARREO radiometric accuracy.)

Study Approach:

A simulation study using real MODIS data.

Same basic approach as presented at the first CLARREO workshop, the CLARREO science team meeting, and recent AGU and SPIE meetings.

Find Simultaneous Nadir Overpasses (SNOs) of CLARREO and EOS Aqua for 2006, and for each SNO use MODIS radiances to estimate the spatial and temporal sampling differences between CLARREO and CrIS/AIRS or IASI.

Opposed to actual inter-comparison studies involving two sensors, this approach removes the unknown sensor biases and allows spatial and temporal inter-calibration differences to be examined.

Outline

CLARREO/Sounder SNO characteristics

Estimating space/time sampling differences

100 km diameter footprint results

- Monthly uncertainties
- MODIS Bands 31, 27, 36
- Impact of non-uniform spatial response
- Annual “nonlinearity” curve

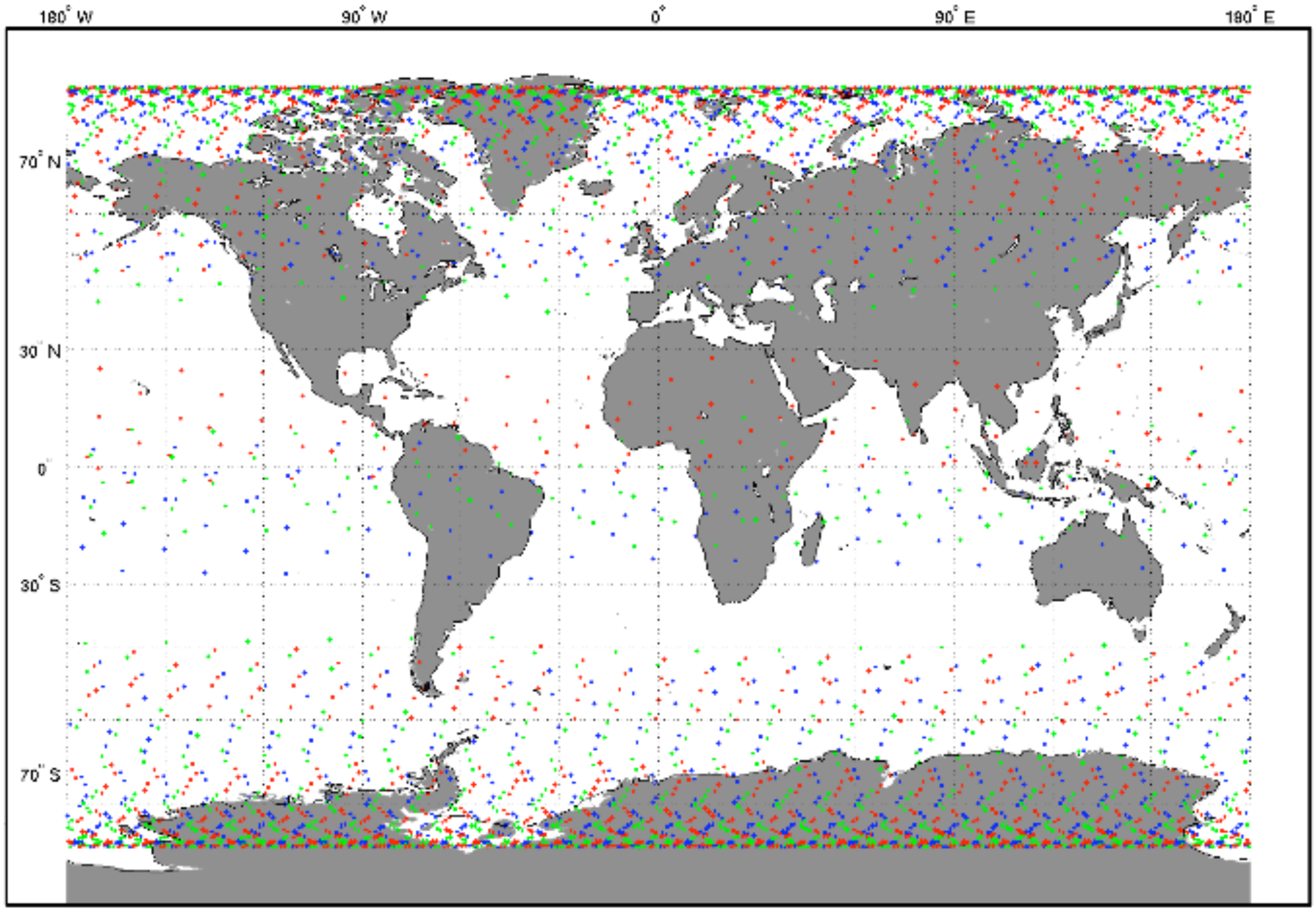
Dependence on footprint size

Spectral considerations

Summary

CLARREO/Aqua SNOs in 2006

Three 90-degree CLARREO orbits with right ascension separated by 120 degrees are “launched” on January 1st, and the SNOs for CLARREO and EOS Aqua are identified for the year of 2006.

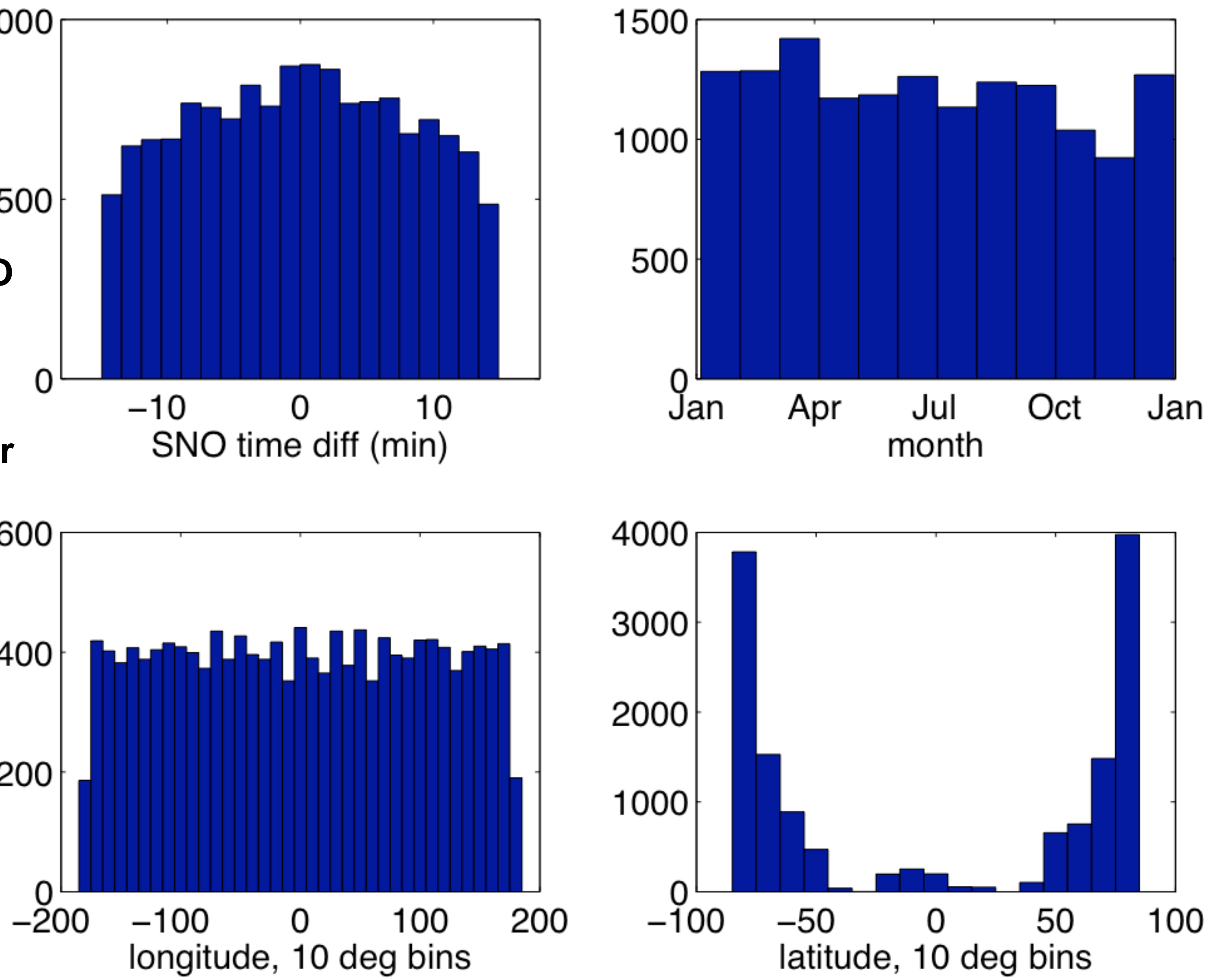


CLARREO/Aqua SNO stats

with 100 km CLARREO footprints every 14s

SNO Δt ≤ 15 min
sounder ≤ 10° off-nadir

14432 pts total
~1200 pts per month



Estimating brightness temperature differences due to spatial and temporal sampling differences

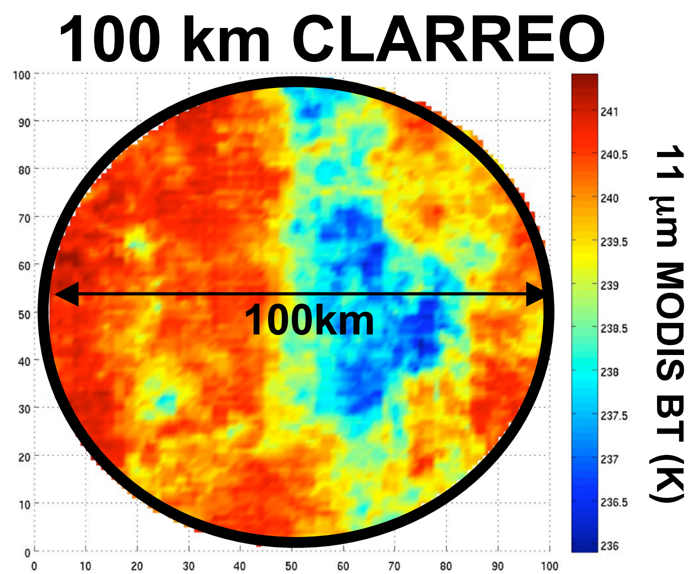
<u>**Spatial:**</u> **Compute mean of 1km MODIS observations within the CLARREO footprints and also within the CrIS/AIRS or IASI footprints. (Also record the standard deviation of the MODIS observations within the CLARREO footprints.)**

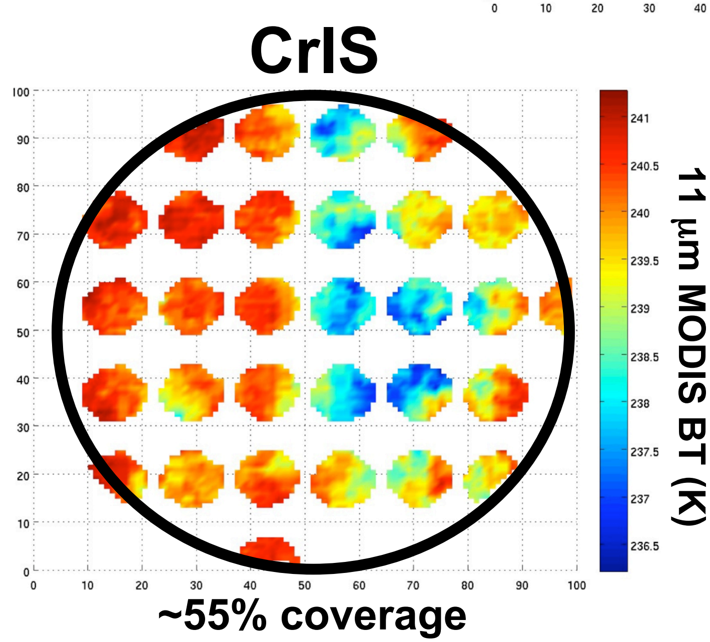
<u>**Temporal:**</u> **simple Lagrangian approach; compute the mean of MODIS observations within a displaced CLARREO footprint using known CLARREO/Aqua time difference and 13 m/s wind.**

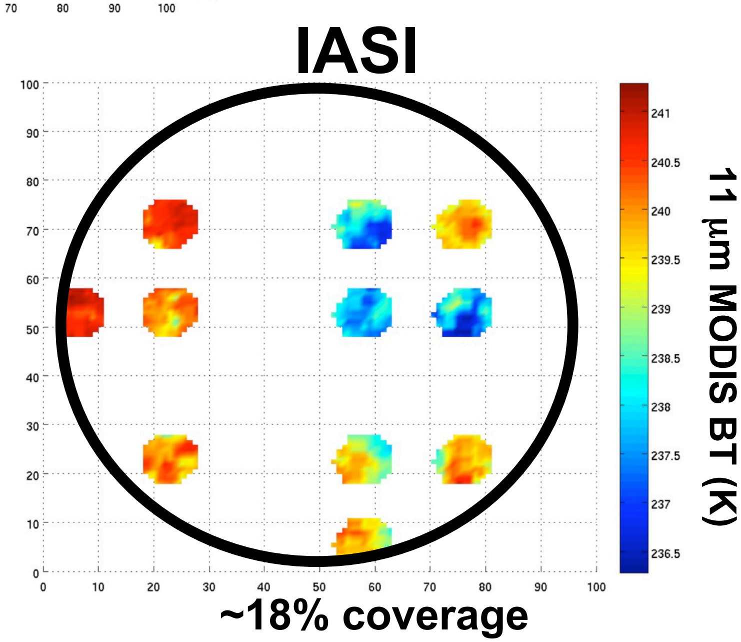
Spatial Sampling Differences

“spatial difference” (K) =
mean w/in CLARREO FOV
minus mean w/in CrIS/IASI FOVs

“BT STDEV” (K) =
Standard deviation w/in
CLARREO FOV

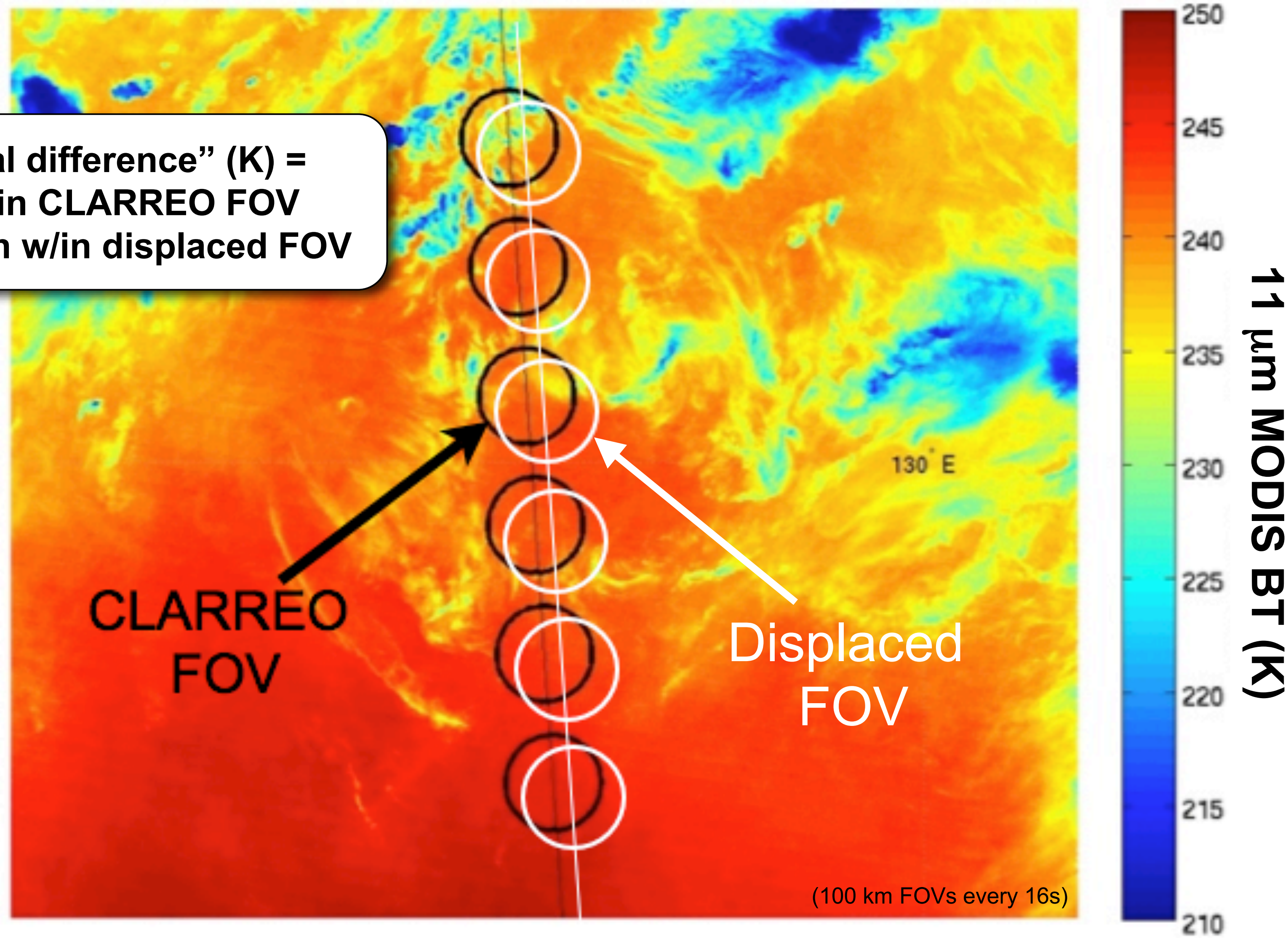






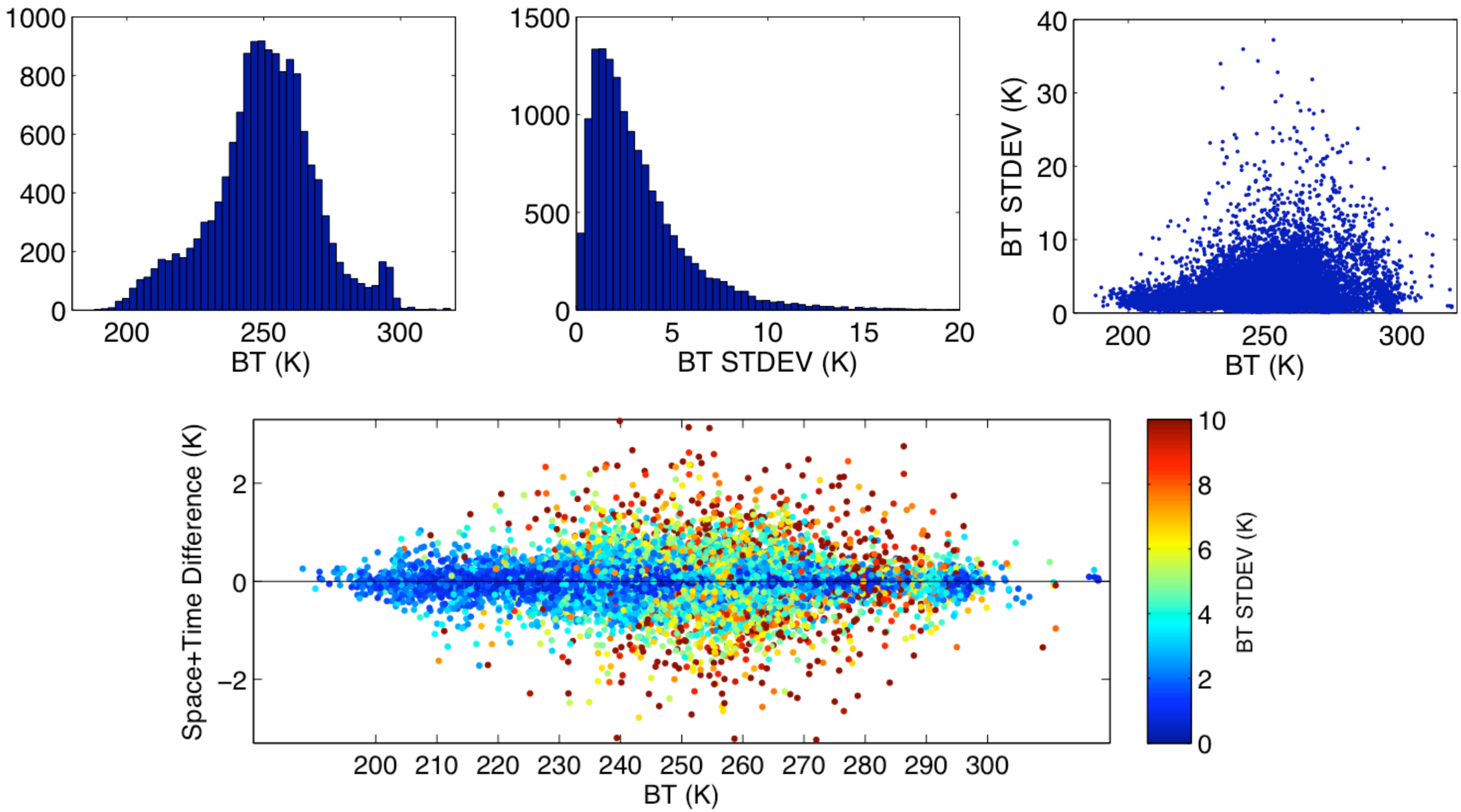
Time Sampling Differences

"temporal difference" (K) = mean w/in CLARREO FOV minus mean w/in displaced FOV



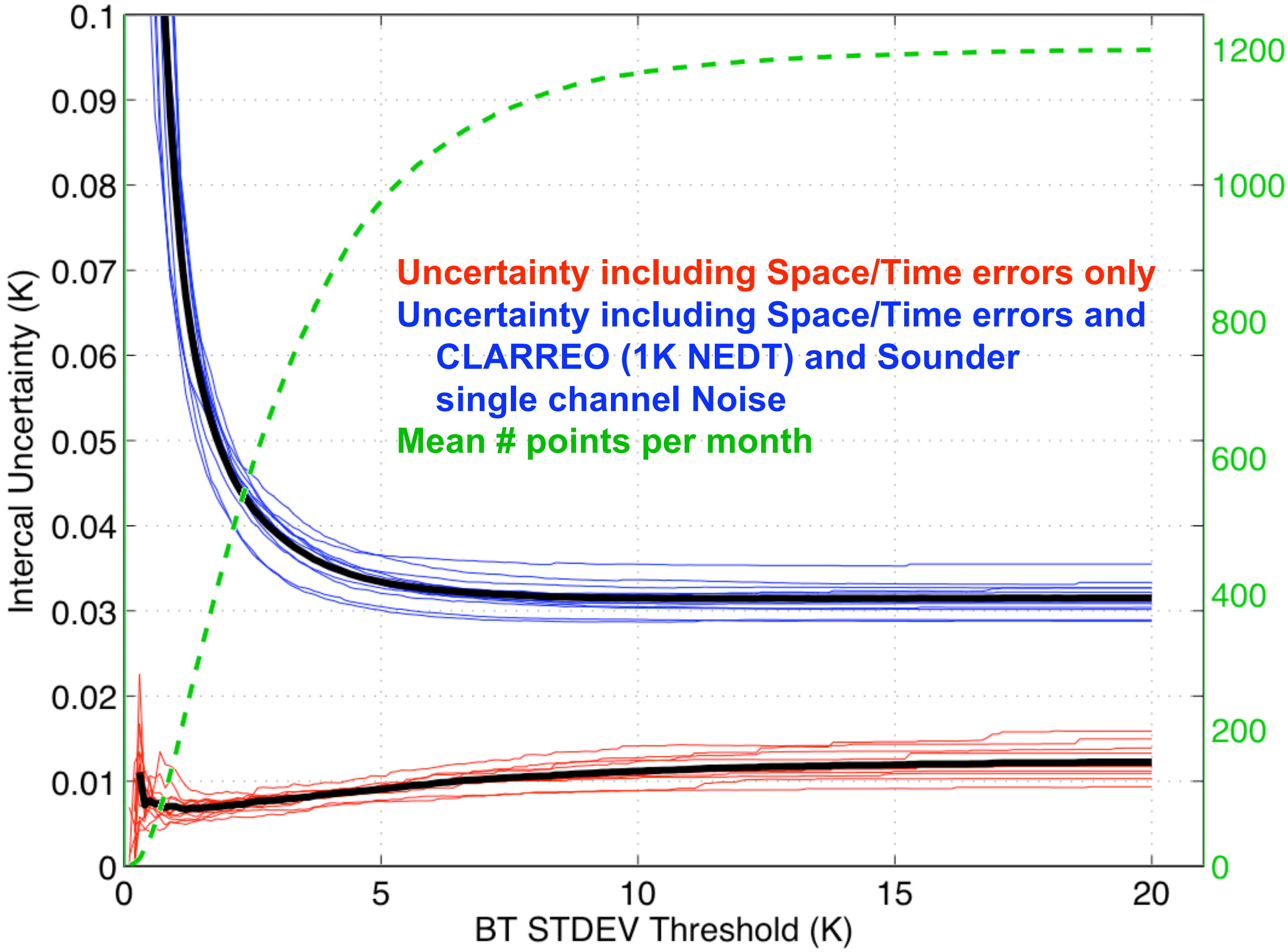
2006 SNO BT stats

MODIS Band 31@11μm; 100km CLARREO FOVs every 14s; CrIS/AIRS



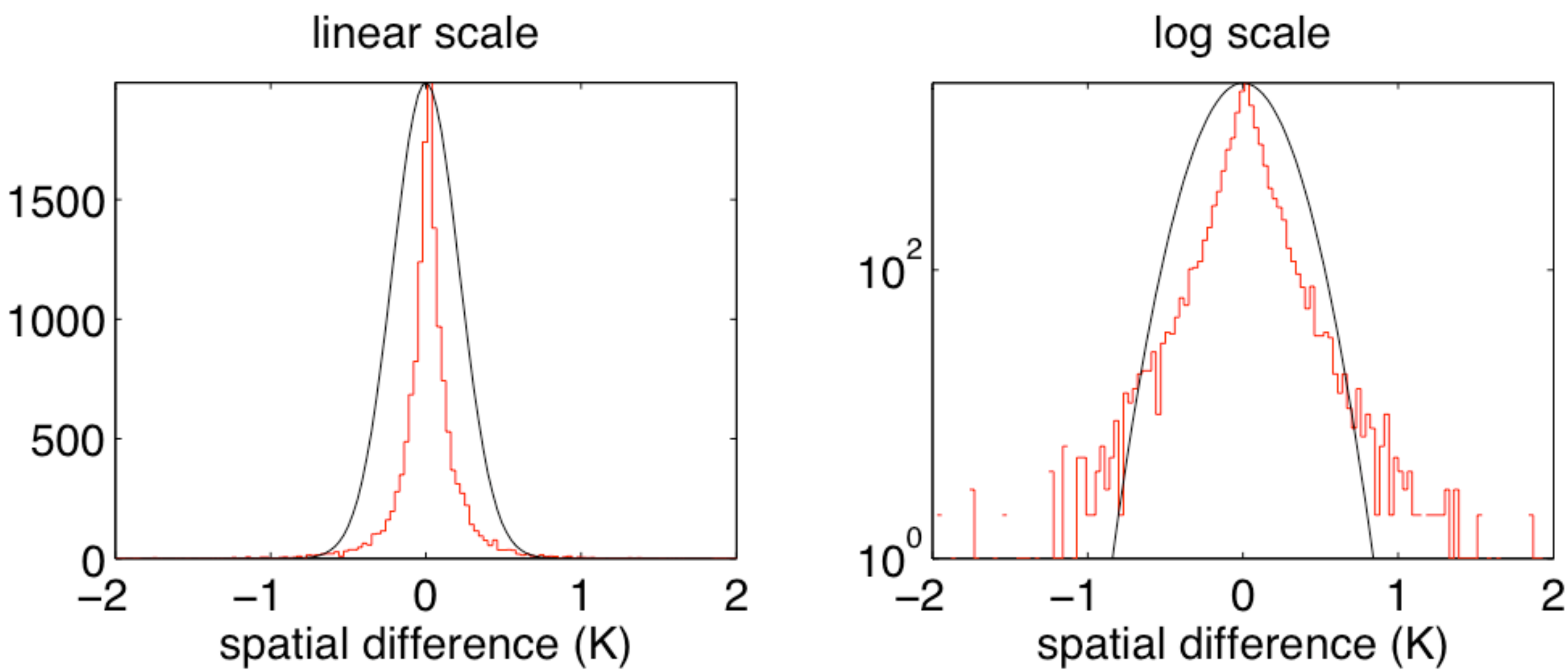
Uncertainty in Monthly Means

MODIS Band 31@11μm; 100km CLARREO FOVs every 14s; CrIS/AIRS



Spatial Sampling Differences

MODIS Band 31@11μm; 100km CLARREO FOVs every 14s; CrIS/AIRS

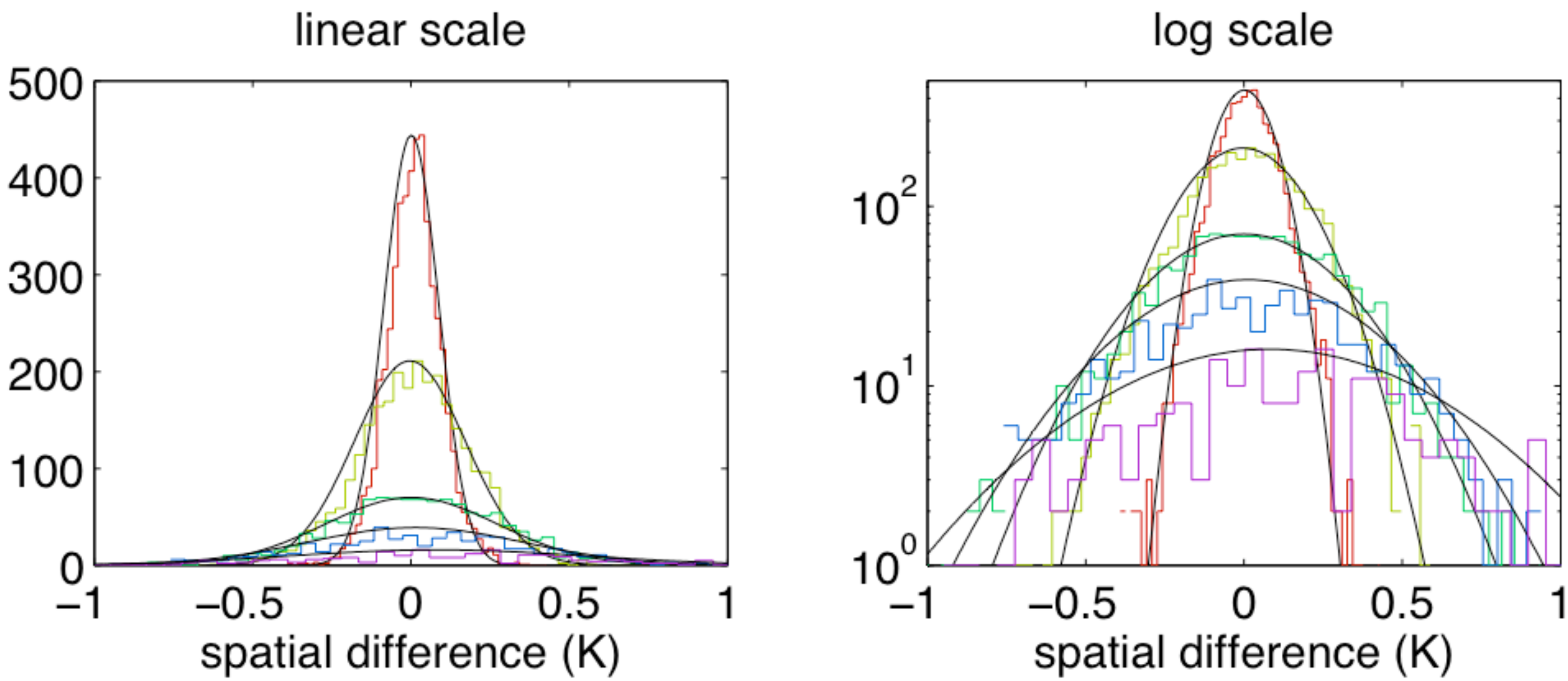


Red = the data (stdev = 0.216 K)
Black = Gaussian with stdev = 0.216K

Gaussian ?

Spatial Sampling Differences

MODIS Band 31@11μm; 100km CLARREO FOVs every 14s; CrIS/AIRS

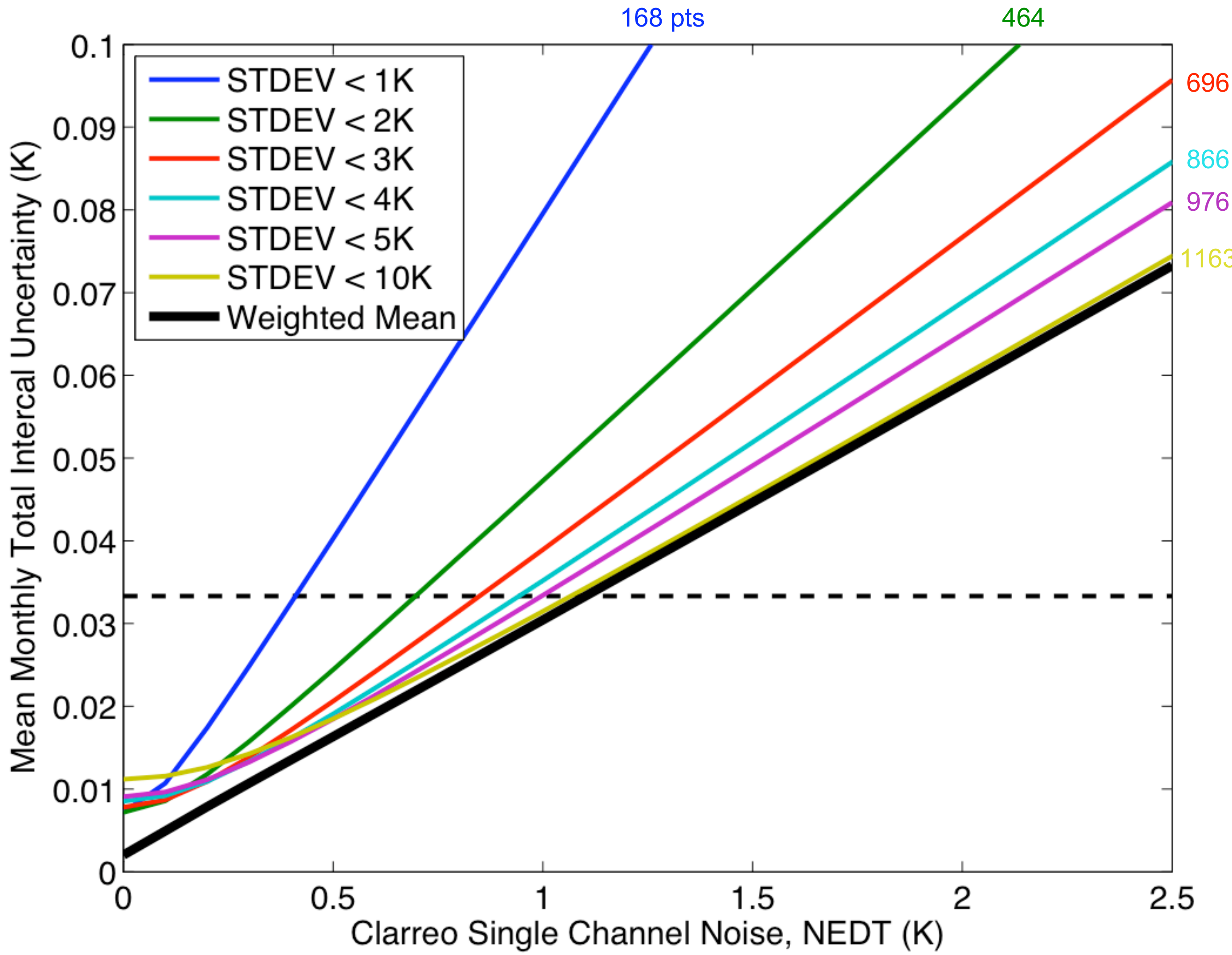


1 ≤ STDEV ≤ 2 (5074 pts, stdev=0.08)
3 ≤ STDEV ≤ 4 (2783 pts, stdev=0.18)
5 ≤ STDEV ≤ 6 (1179 pts, stdev=0.27)
7 ≤ STDEV ≤ 8 (563 pts, stdev=0.34)
9 ≤ STDEV ≤ 10 (211 pts, stdev=0.47)

Yes, Gaussian.

Uncertainty in Monthly Means:
Threshold method and Weighted means

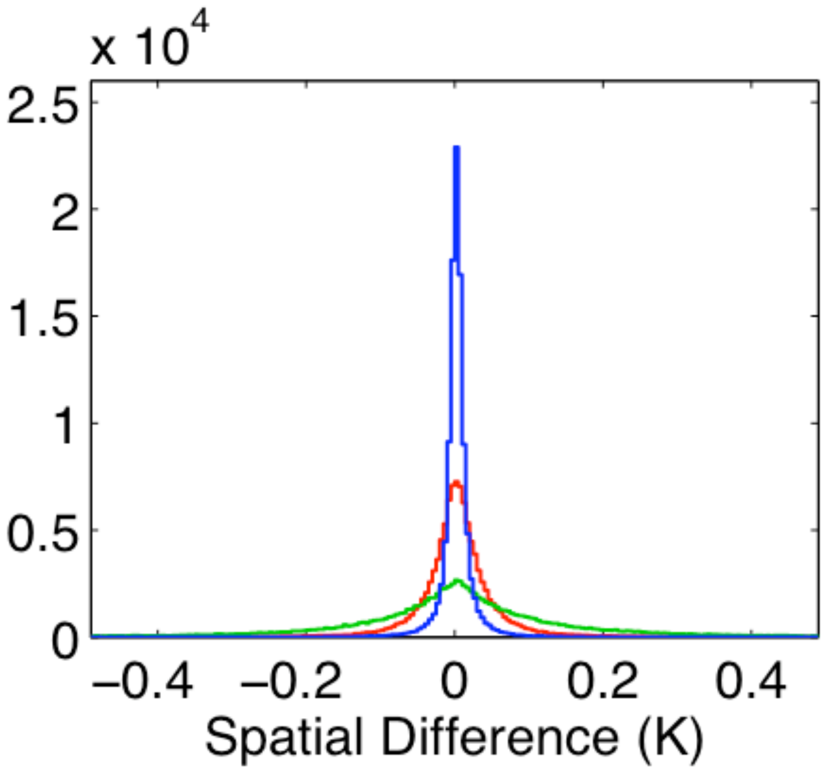
MODIS Band 31@11μm; 100km CLARREO FOVs every 14s; CrIS/AIRS

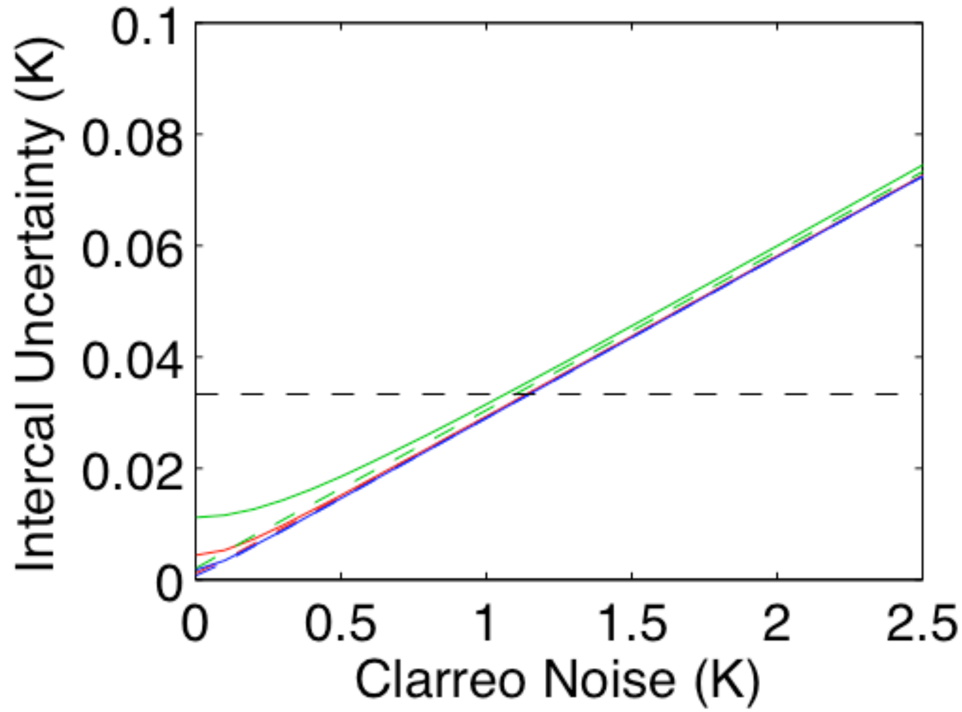


Uncertainty in Monthly Means

MODIS Bands 27@6.7μm , 31@11μm, and 36@14μm;

100km CLARREO FOVs every 14s; CrIS/AIRS





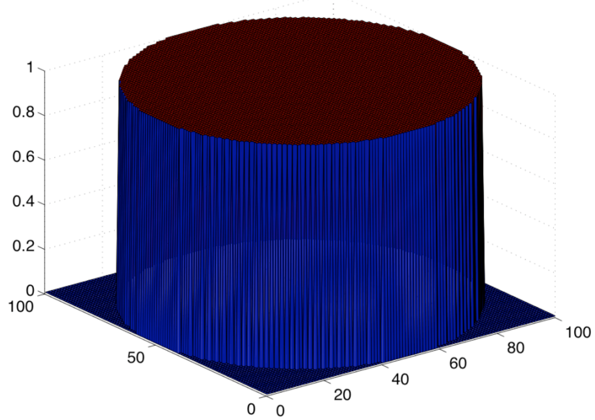
MODIS Band 27, STDEV = 0.070 K
MODIS Band 31, STDEV = 0.214 K
MODIS Band 36, STDEV = 0.034 K

Solid = threshold method, BTSTD ≤ 10K
Dashed = uncertainty in weighted mean

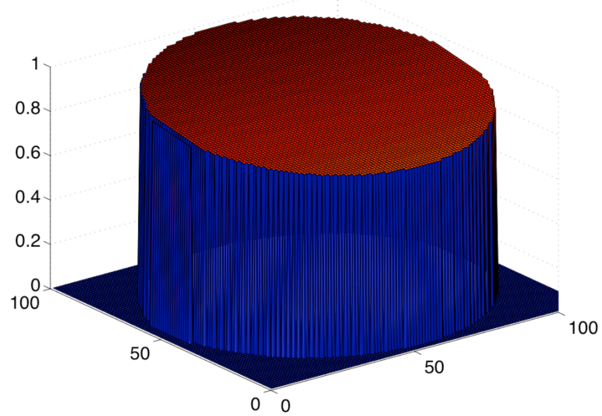
Mean of all months

Non-uniform Spatial Response

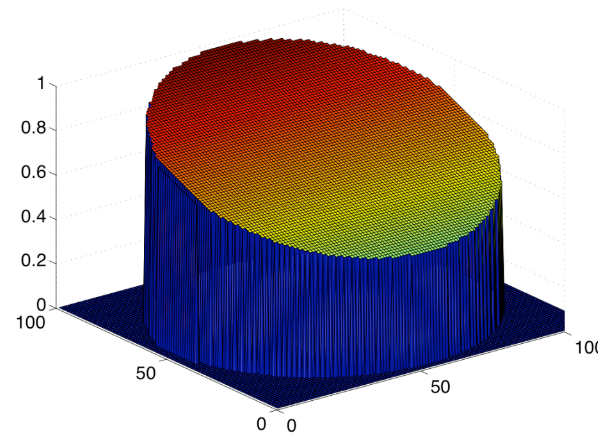
Uniform



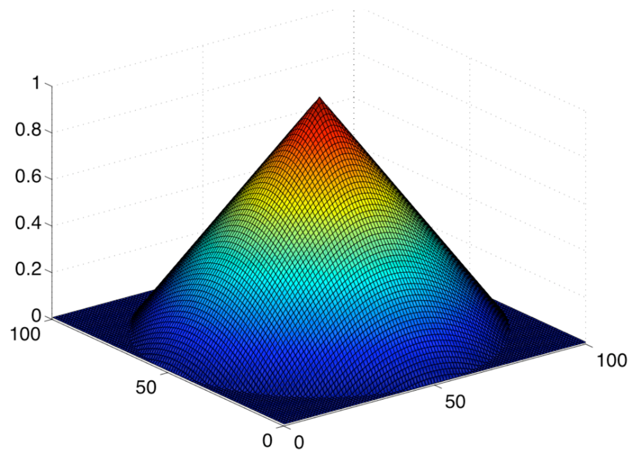
Linear, ±10%



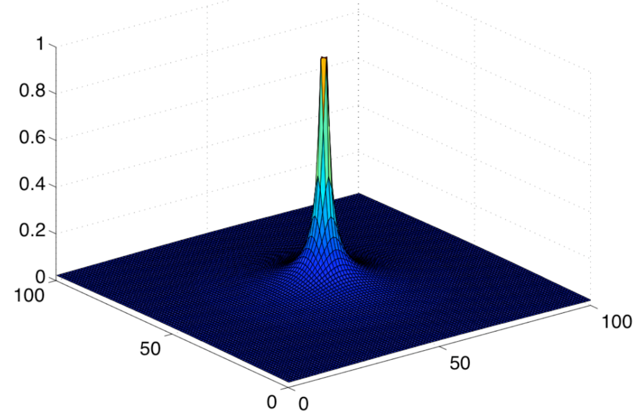
Linear, ±25%



Cone



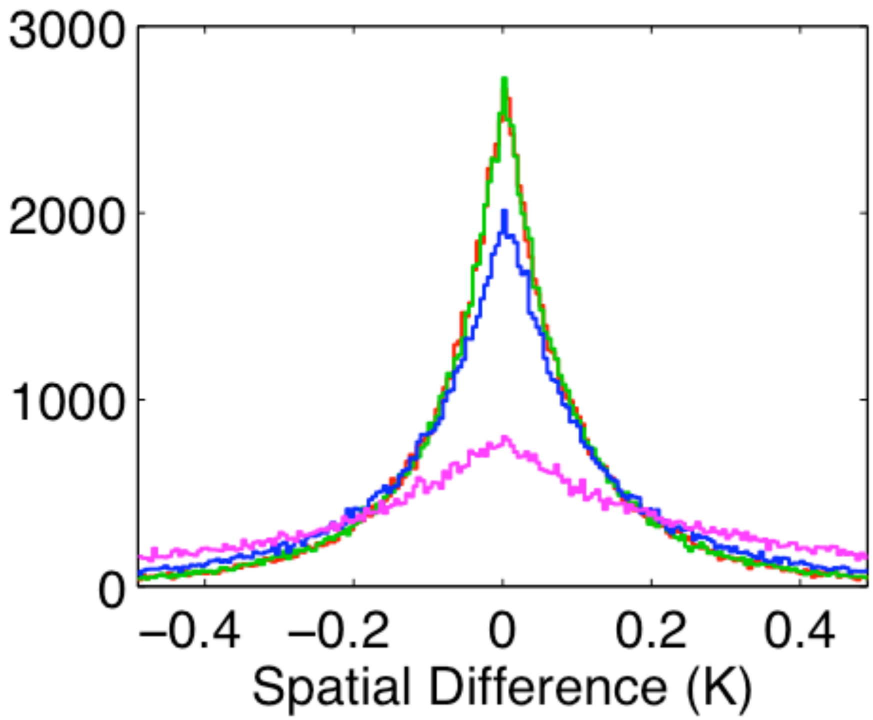
~1/r² (~4km FWHM)

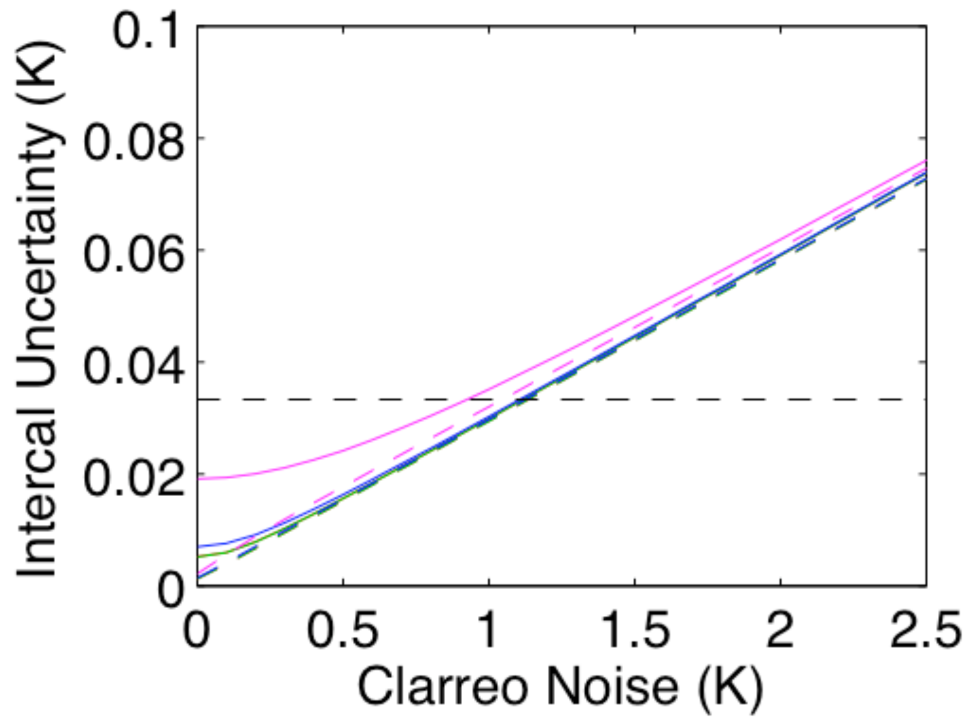


Uncertainty in Monthly Means

Uniform, Linear 20%, Linear 50%, ~1/r^2

MODIS Band 31@11μm; 100km CLARREO FOVs every 14s; CrIS/AIRS

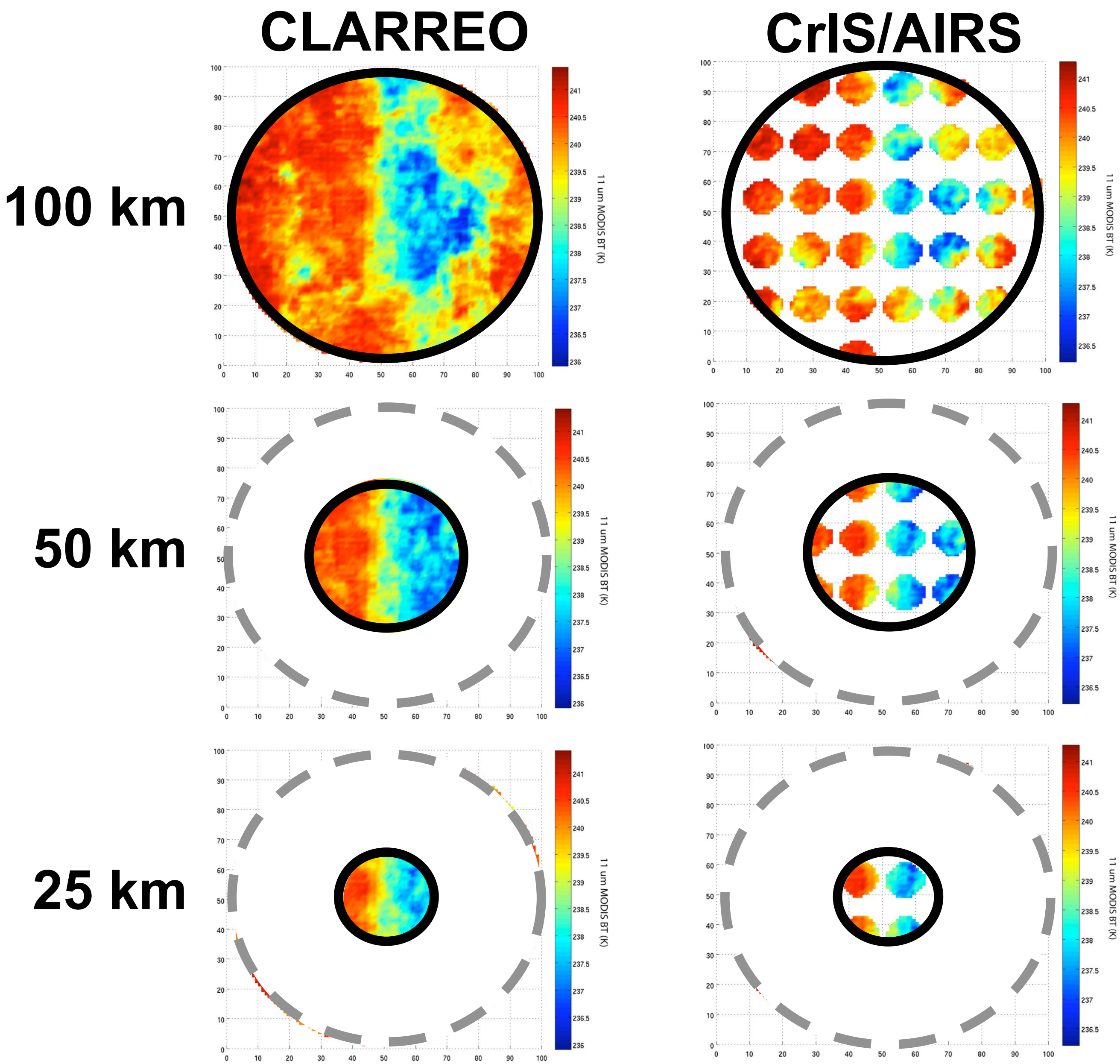




Tophat, STDEV = 0.214 K
20% linear: STDEV = 0.220 K
50% linear: STDEV = 0.290 K
~1/r^2: STDEV = 0.803 K

Solid = threshold method, BTSTD ≤ 10K
Dashed = uncertainty in weighted mean

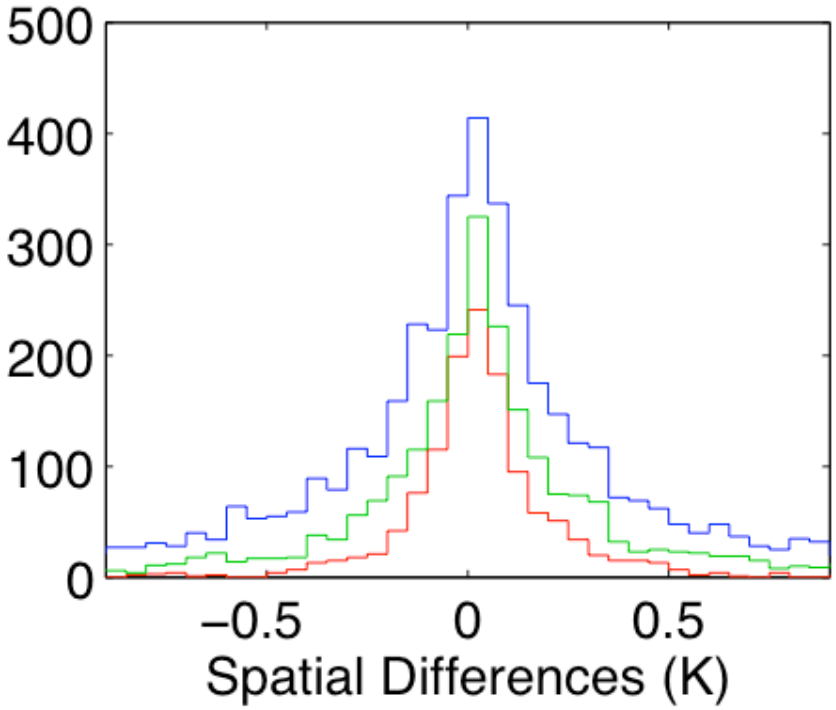
Footprint Size

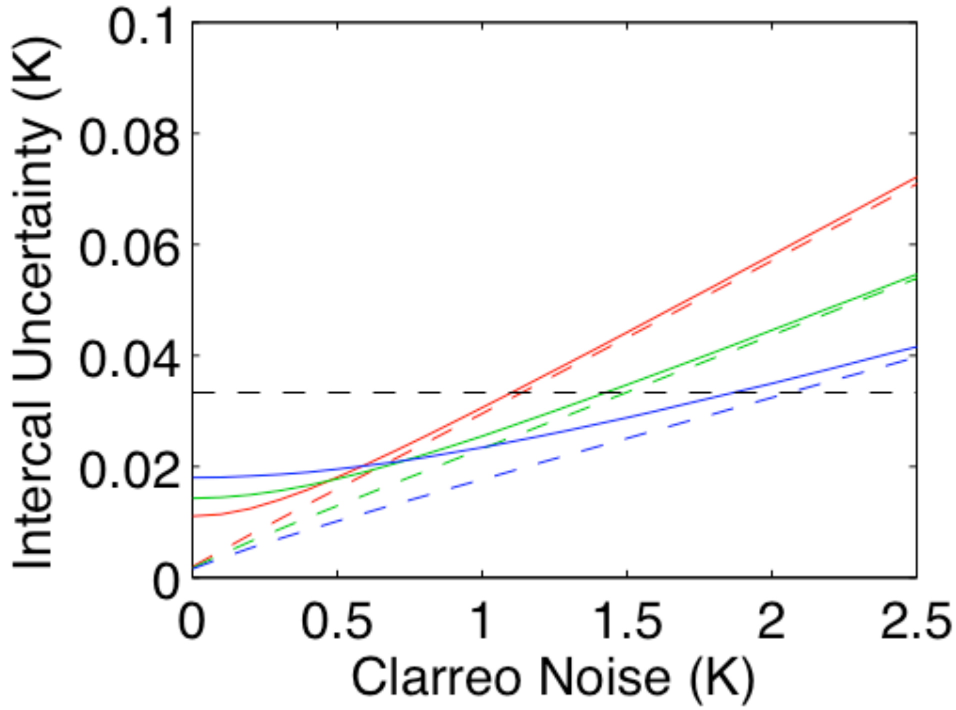


Uncertainty in Monthly Means

100 km, 50 km, and 25 km diameter footprints

MODIS Band 31@11μm; CrIS/AIRS





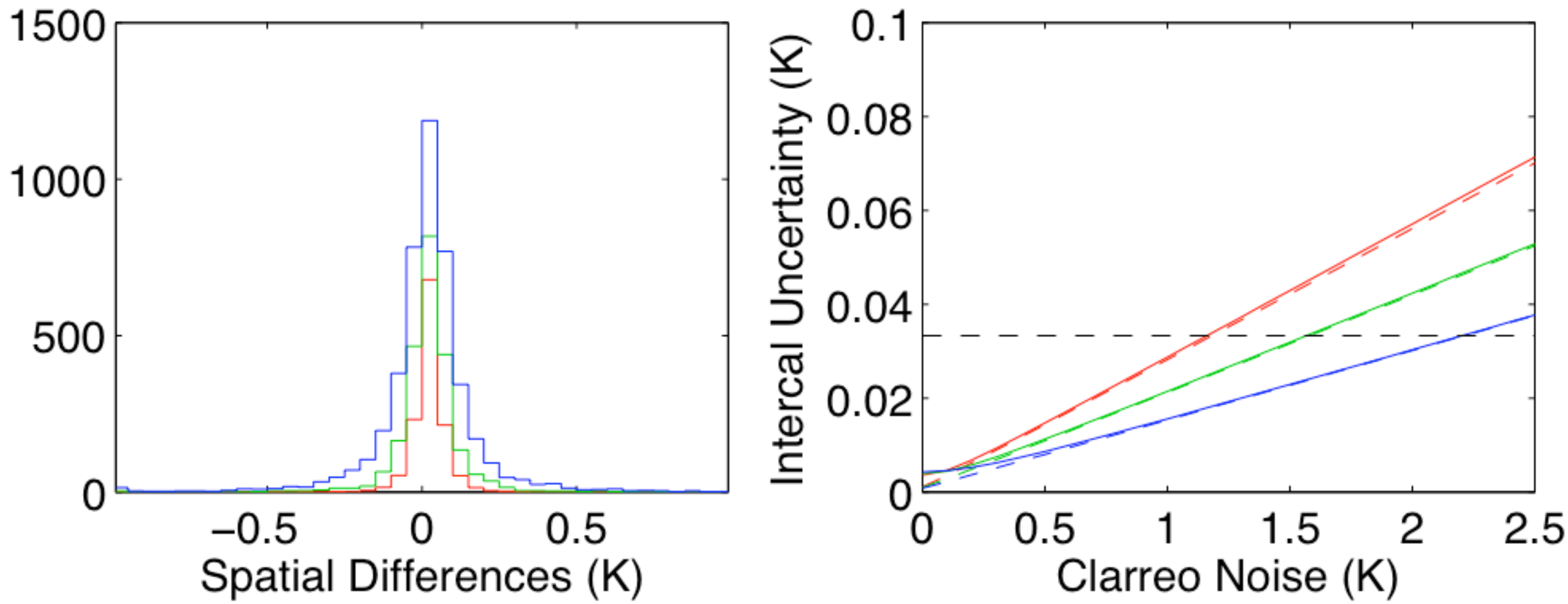
100km (14s), 1276 pts, STDEV = 0.214 K
50 km (8s), 2286 pts, STDEV = 0.460 K
25 km (4s), 4474 pts, STDEV = 0.918 K

Solid = threshold method, BTSTD ≤ 10K
Dashed = uncertainty in weighted mean

Uncertainty in Monthly Means

100 km, 50 km, and 25 km diameter footprints

MODIS Band 27@6.7μm; CrIS/AIRS



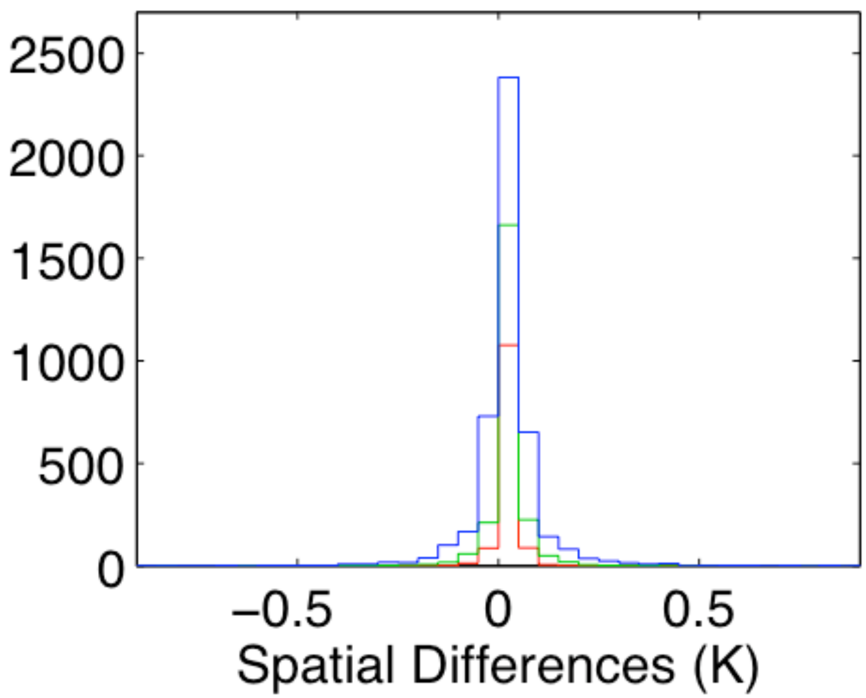
100km (14s), 1276 pts, STDEV = 0.061 K
50 km (8s), 2286 pts, STDEV = 0.119 K
25 km (4s), 4474 pts, STDEV = 0.204 K

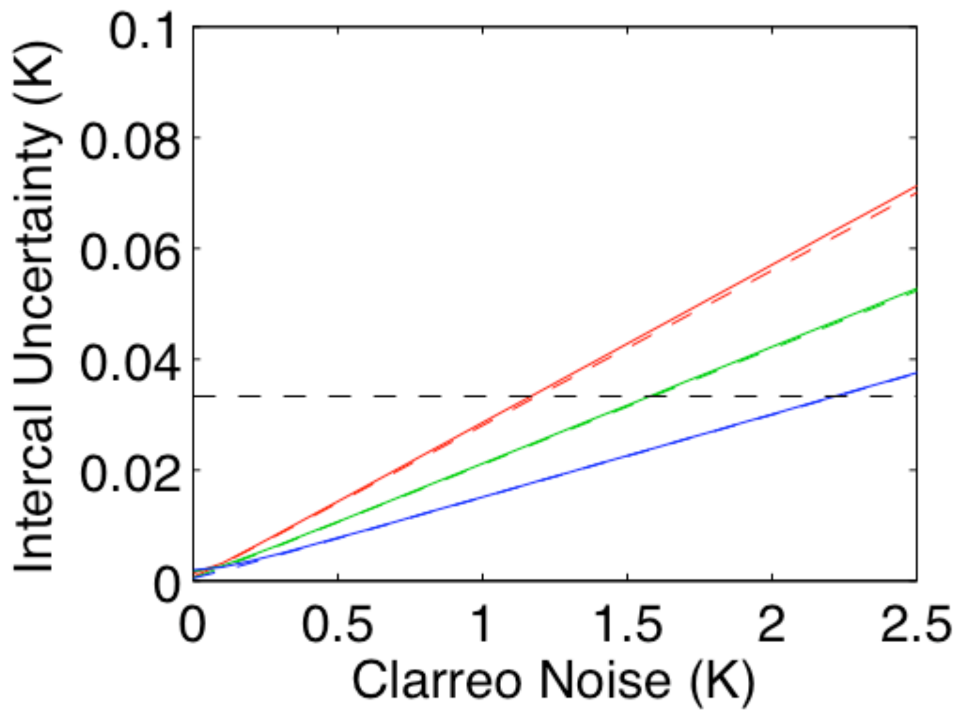
Solid = threshold method, BTSTD ≤ 10K
Dashed = uncertainty in weighted mean

Uncertainty in Monthly Means

100 km, 50 km, and 25 km diameter footprints

MODIS Band 36@14µm; CrIS/AIRS



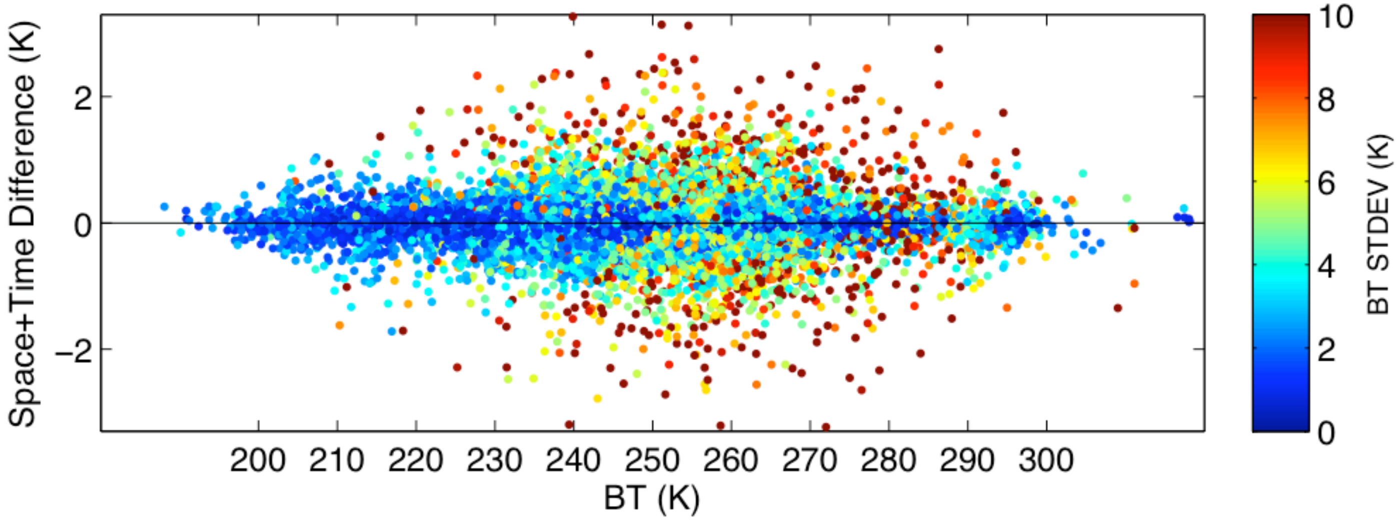


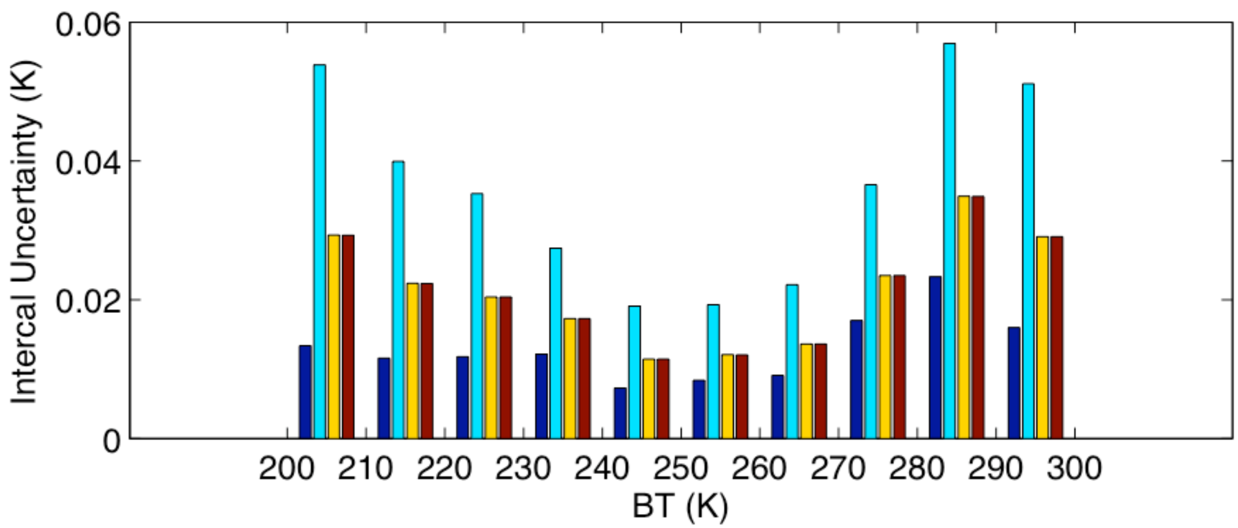
100km (14s), 1276 pts, STDEV = 0.029 K
50 km (8s), 2286 pts, STDEV = 0.062 K
25 km (4s), 4474 pts, STDEV = 0.104 K

Solid = threshold method, BTSTD ≤ 10K
Dashed = uncertainty in weighted mean

"Nonlinearity Curve" from Annual data

MODIS Band 31@11μm; 100km CLARREO FOVs every 14s; CrIS/AIRS





<u>**10K bin Uncertainties**</u>

Blue = space/time only

Cyan = plus CLARREO (1K NEDT) and Sounder Noise

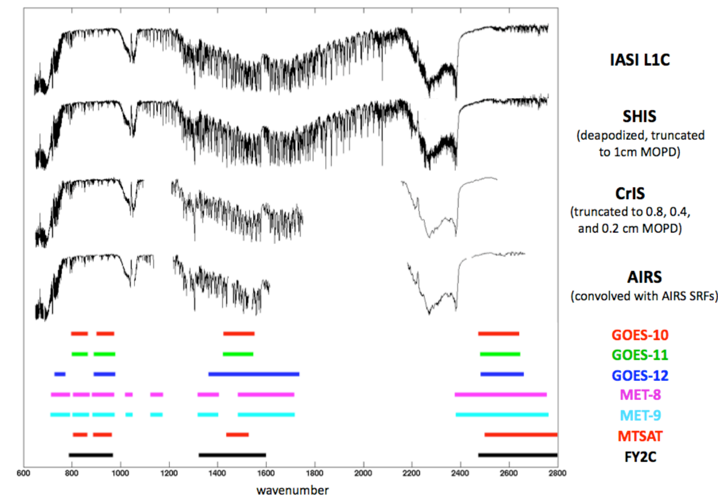
Yellow = plus CLARREO (0.5K NEDT) and Sounder Noise

Red = CLARREO (1K NEDT) and Sounder Noise, averaging 4 adjacent spectral channels

Spectral Considerations for Intercal

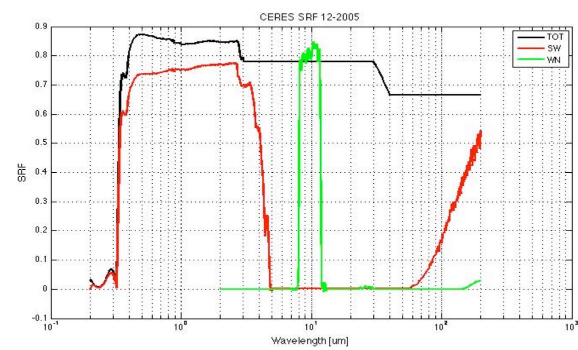
Broad coverage (how broad ?)

- IR operational sounders: ~3 to ~15 μm
- What does intercal for CERES imply ?



Continuous and Nyquist sampled spectra

- To allow resampling to other arbitrary grids and integration over broadband SRFs
- Gaps require corrections



High spectral resolution (how high ?)

- 1 cm opd is adequate

Non-uniform scene effects on the ILS

- Limit angles through interferometer and/or use on-axis detectors to make negligible

Summary, Conclusions

For the nominal CLARREO DS mission and reasonable SNO thresholds, the monthly intercal uncertainty budget is dominated by the assumed CLARREO radiometric noise level.

With CLARREO radiometric noise of 1K NEDT, the 1-sigma uncertainty in monthly single-channel intercal is less than 0.03K.
For annual ensembles, a wide range of intercal BTs and low uncertainties in 10K bins are obtained.
Lower uncertainties are obtained with smaller (and more numerous) footprints and/or lower radiometric noise. The use of a PCNF can also be considered.

Non-uniform spatial response has very small impact on these results.

Need to consider spectral properties for intercal objectives.

The analysis system/process is in place to assess other candidate missions.