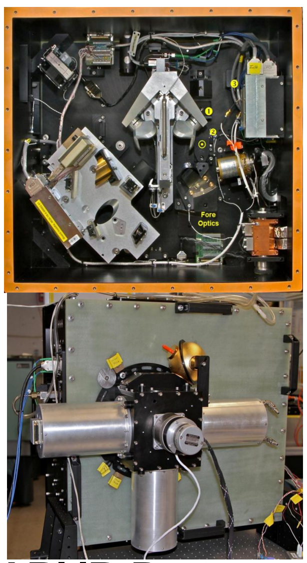
CLARREO IR Intercalibration

Dave Tobin

University of Wisconsin-Madison

Space Science and Engineering Center



ARI IR Prototype

GSICS Annual Meeting

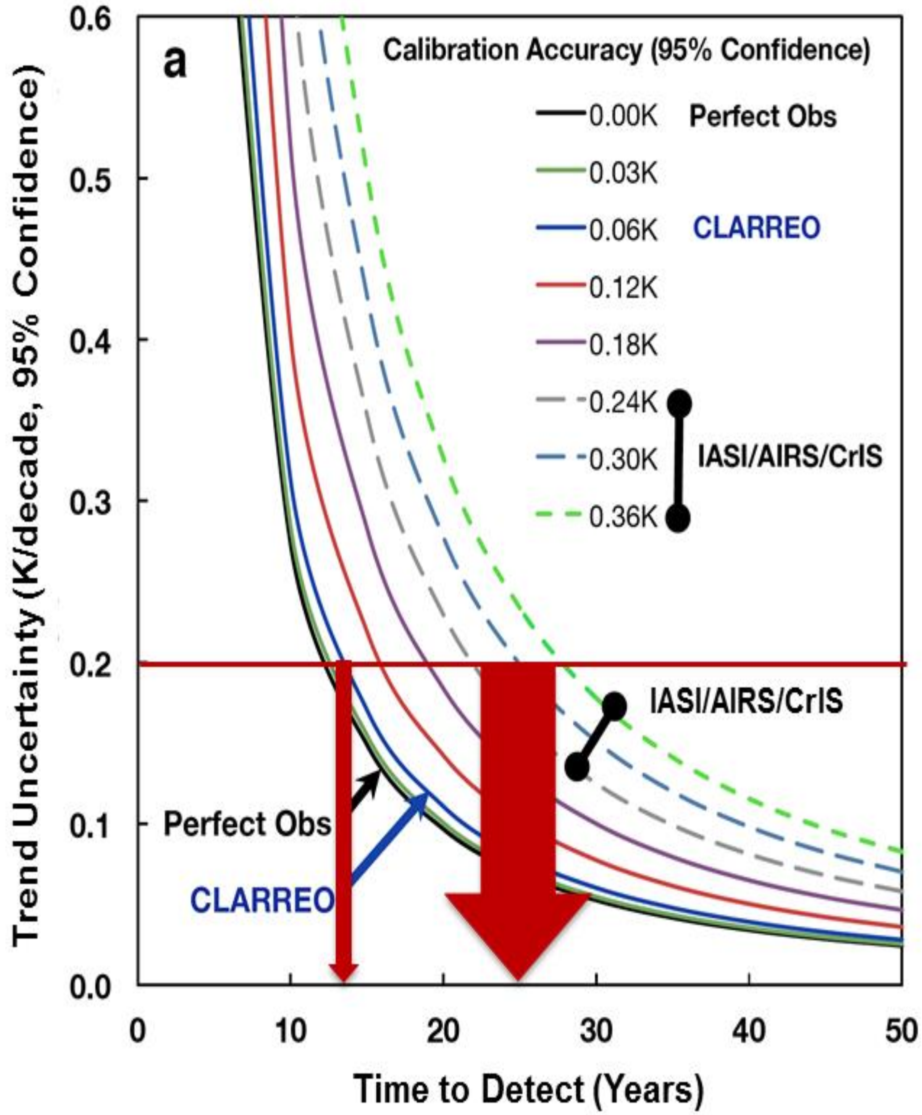
UW-Madison, 20-24 March 2017

1. Science and Applications Target (Objective)

- **…establishing a global benchmark of the current climate from space** using highly accurate measurements of spectrally resolved Earth emitted radiance.
- **Key to this objective is employing the principles of metrology in a new way by requiring the SI Measurement Standard to be used on-orbit**, not just reproduced with transfer standards in preflight thermal/vacuum testing, and by following rigorous traceability of uncertainty for flow-down to the intercalibration of other spaceborne measurements and to climate products (Revercomb et al., SPIE, 2016).
- **…large reduction in the time to detect climate trends** would clearly be an important contribution to Earth System Science theme IV, and would have large societal/ economic benefits.

1. Science and Applications Target (Objective)

- **Trend (marked in red) is that chosen in Cook, et al., 2016 to establish a best estimate of the economic value from a system flown in 2020 of $9 trillion US.**
- More than a decade improvement over current sounders, and proven on-orbit.
- Even more over CERES



Radiance Intercalibration Traceability for improving the Accuracy of Operational IR Sounding Instruments

JGR-Atmospheres paper

Characterization of the Climate Absolute Radiance and Refractivity Observatory (CLARREO) ability to serve as an infrared satellite intercalibration reference

International Space Station

Tobin, D., R. Holz, F. Nagle, and H. Revercomb

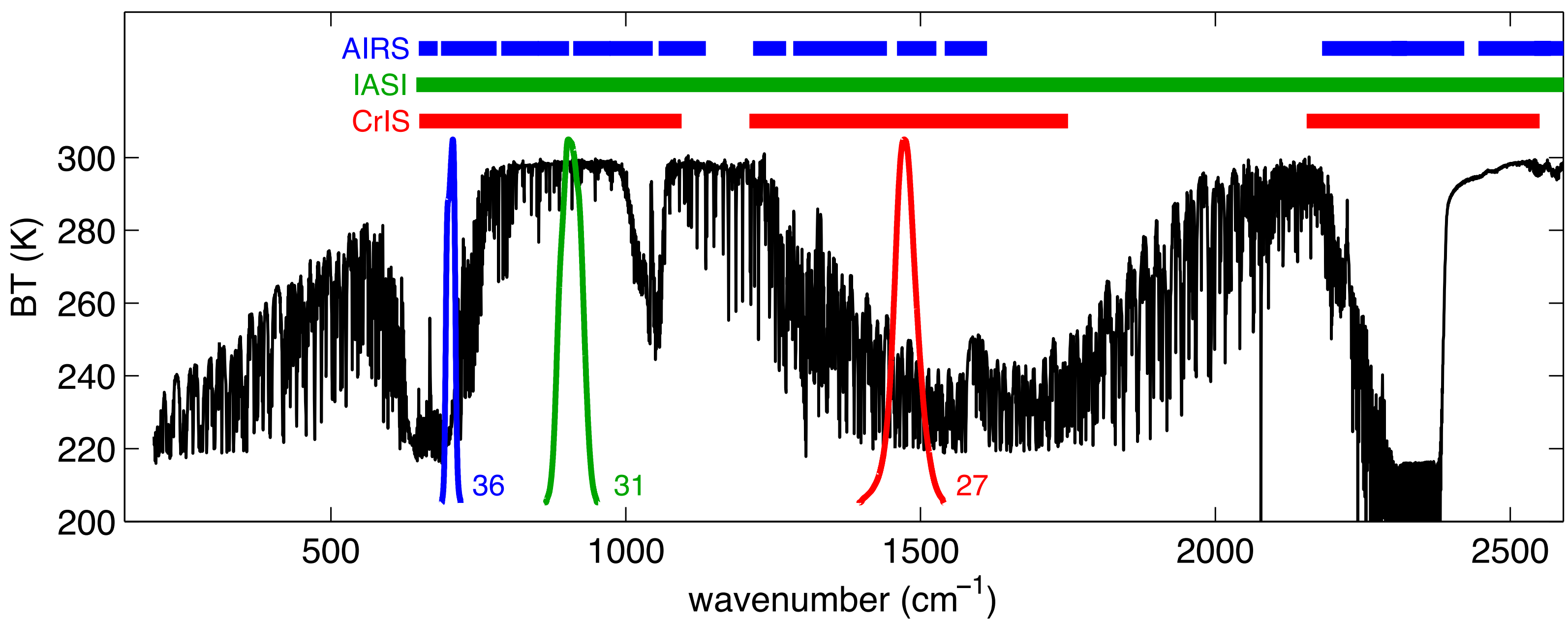
J. Geophys. Res. Atmos., 121, doi:10.1002/2016JD024770 (2016).

Investigation performed with support from the NASA LaRC CLARREO Project

Method for minimizing the effects of space/time sampling differences and defining associated uncertainty

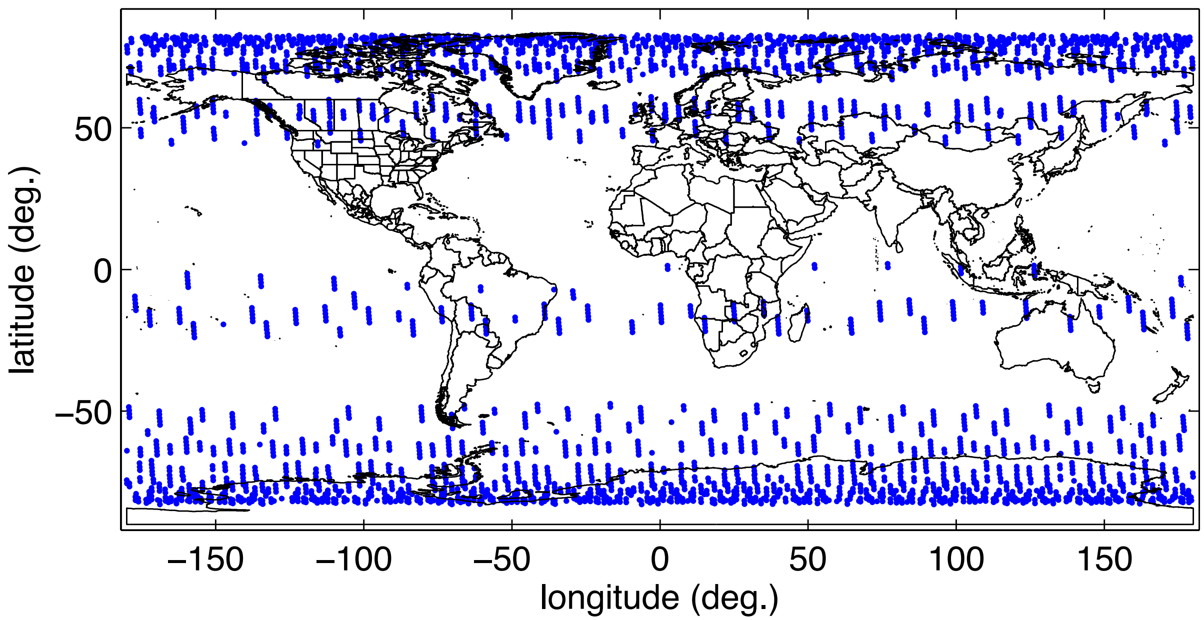
Characterization of the CLARREO IR Spectrometer ability to serve as a satellite intercalibration reference

- Providing a highly accurate intercalibration reference (for both infrared and reflected solar sensors) is a primary objective of the mission
- The Absolute Radiance Interferometer (ARI) Prototype has demonstrated better than 0.1 K 3-sigma accuracy, at least 3-5 times better than current sounders



Paper simulates intercalibration sampling errors using MODIS images from bands 36 (14.2 micron CO_2), 31 (11 micron window), 27 (6.7 micron water vapor)

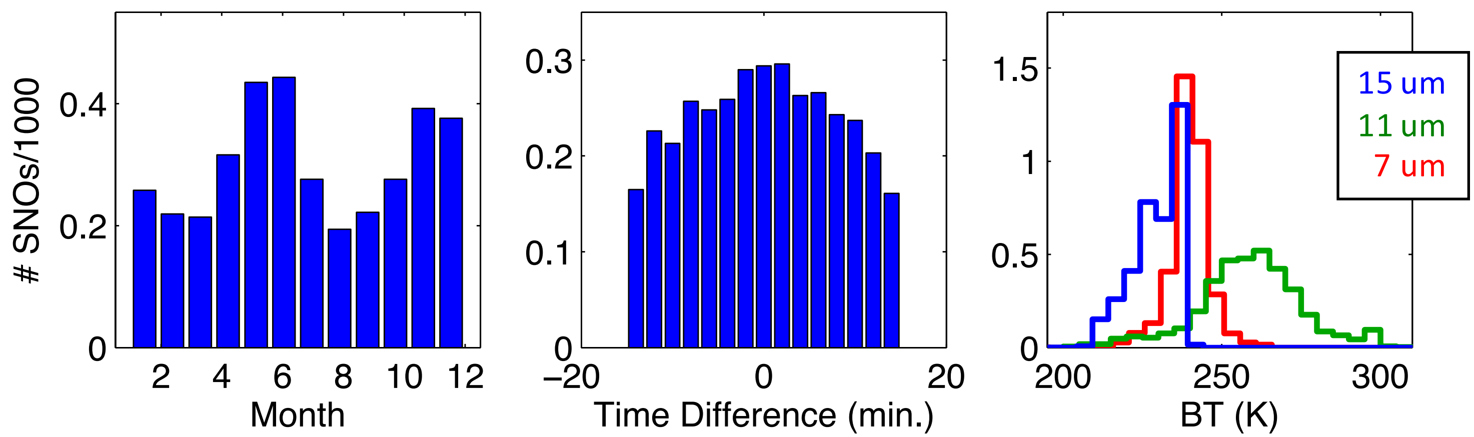
Characteristics of CLARREO to Sounder Simultaneous Nadir Overpasses (SNOs)



Samples for 1 year

Sounder in
Sun-Synch Orbit

1 CLARREO in
true polar orbit



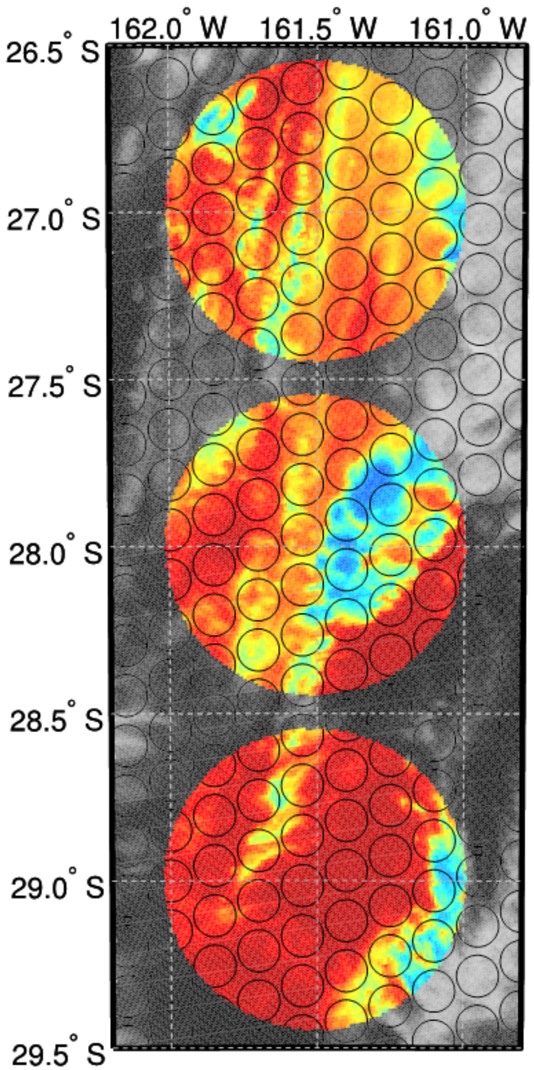
- **Provides intersections with good seasonal, time-of-day, and signal level coverage**

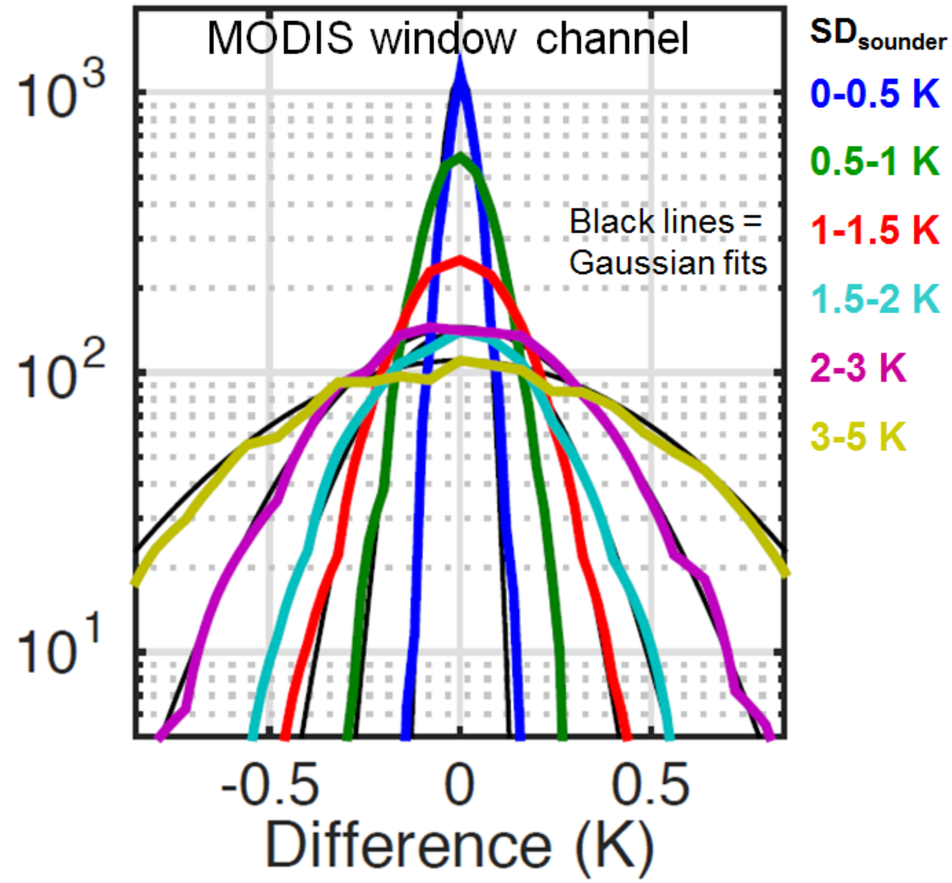
Simulation study used MODIS temporal & spatial variability to evaluate sampling colocation errors

MODIS window channel image
(gray scale)

CLARREO 100 km FOV
(colored circle)

CrIS (or AIRS) 14 km FOVs
(small circles)

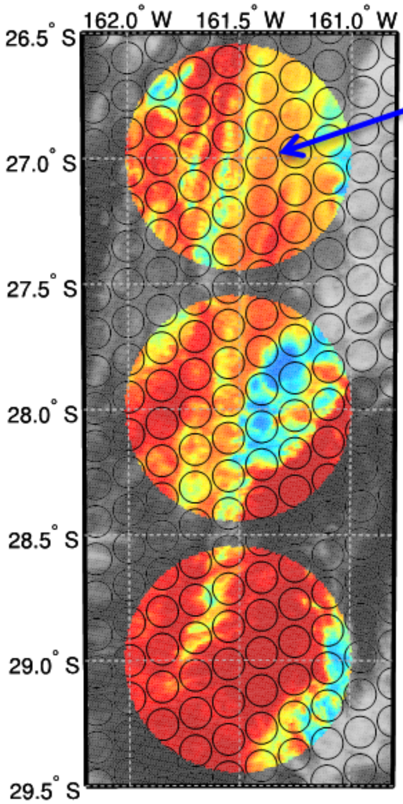




CrIS–CLARREO T_b Distribution for SNOs
separated by standard deviation of sounder sub-samples

Shows that the limited space/time coverage of each SNO leads to sampling difference residuals with Gaussian PDFs characterized by the Standard Deviation of sounder samples

Mathematics of sampling colocation errors



M = # sounder footprints overlapping the CLARREO footprint
N = # sounder footprints that would fill the CLARREO footprint
[by area, i.e. N=(diam CLARREO/diamSounder)^2]
$\sigma_{i\ sounder}$ = Standard Deviation of sounder footprints for ith SNO

(Sounder – CLARREO) sampling error for SNO$_i$

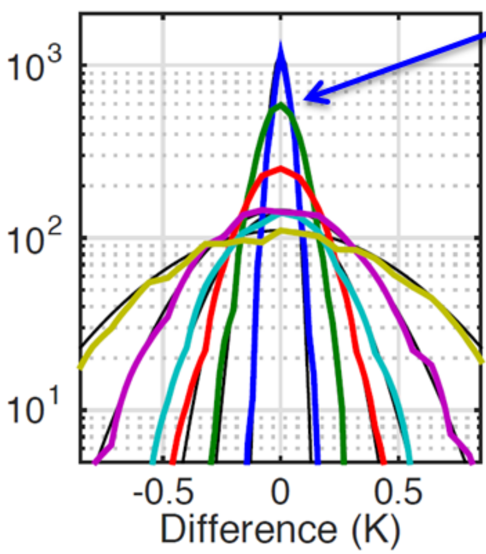
$$\sigma_{SNOi} = (M/N) \bullet zero + ((N\text{-}M)/N) \bullet [\sigma_{i\ sounder} / (N\text{-}M)^{1/2}]$$

Overlap area fraction

Non-Overlap fraction

Error of mean for non-overlapping samples

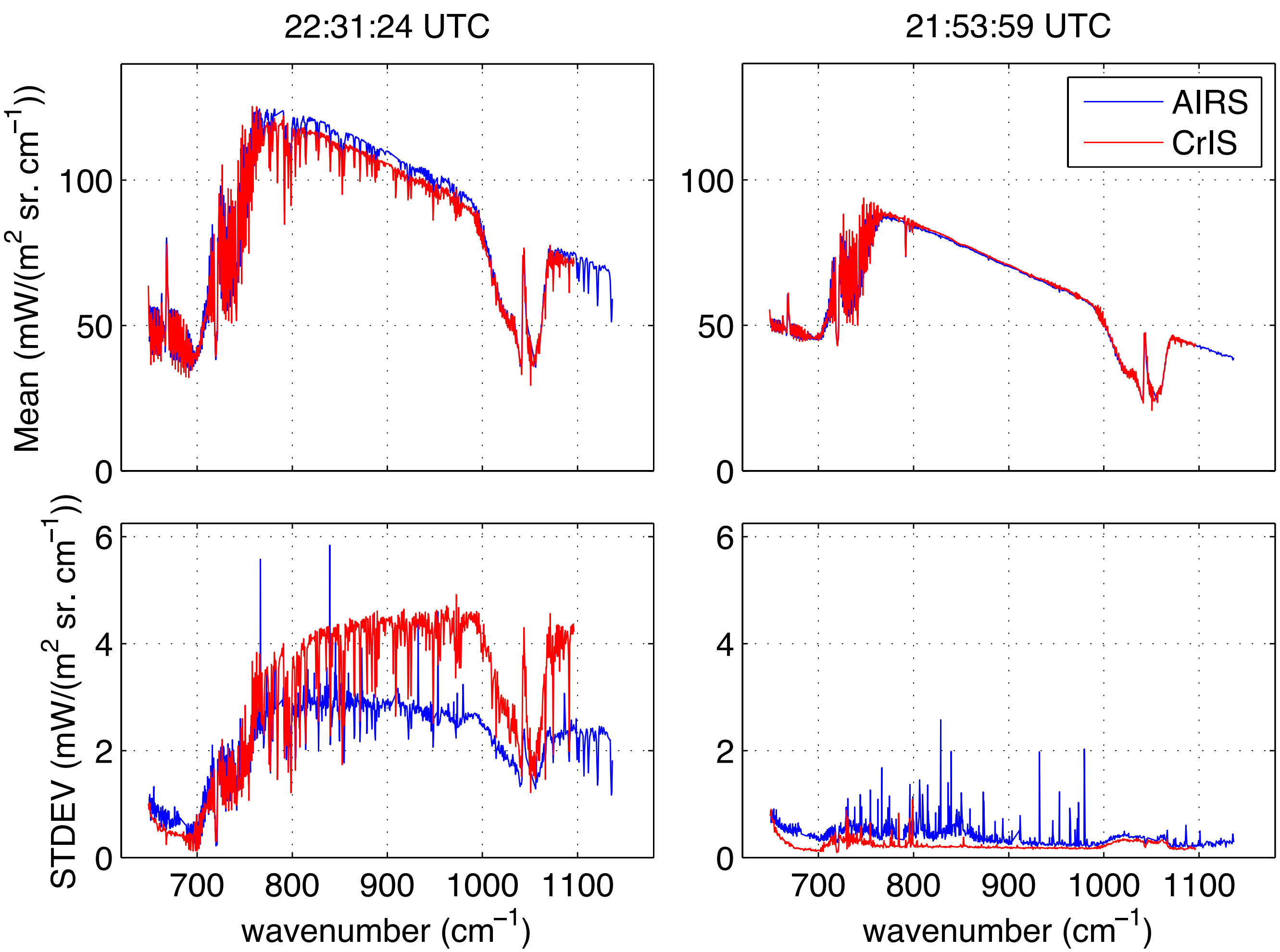
$$\boxed{\sigma_{SNOi} = (1 - M / N)^{1/2}\, \sigma_{i\ sounder} / N^{1/2}}$$



This spatial sampling error formalism can be used [combined with noise and temporal sampling errors] to optimally weight mean SNO differences [weights w_i = 1/(total error variance for SNO$_i$)] and yield a <u>rigorous uncertainty estimate</u> [$=1/\Sigma w_i^{1/2}$]

This approach results in a rigorous mean difference and uncertainty, with no clear sky selection or other SNO filtering!

Examples with real data: AIRS/CrIS SNOs

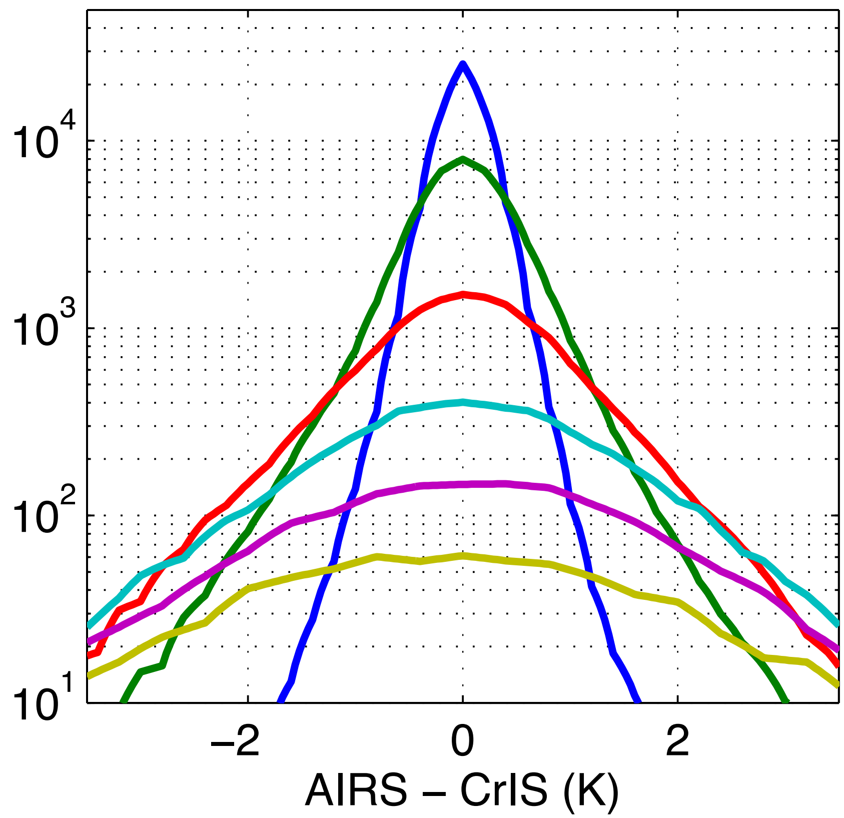


50 km radius "big circle" SNOs

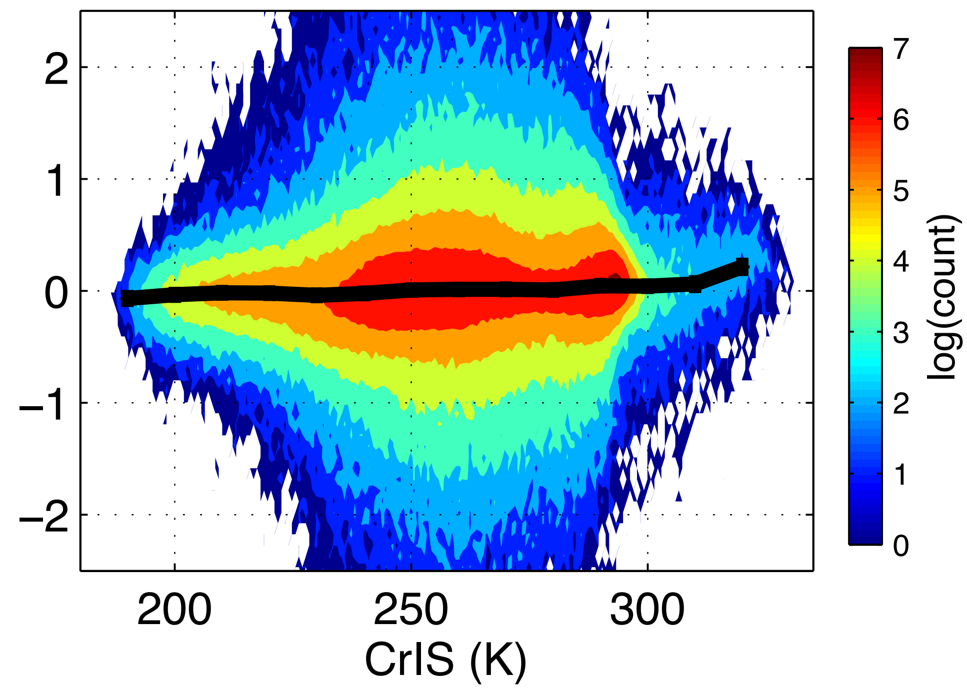
Observed spatial variability is a very good indicator of the quality of the SNO

Examples with real data: AIRS/CrIS SNOs @ 900 cm^{-1}

SNO differences (AIRS-CrIS) for 6 spatial variability bins

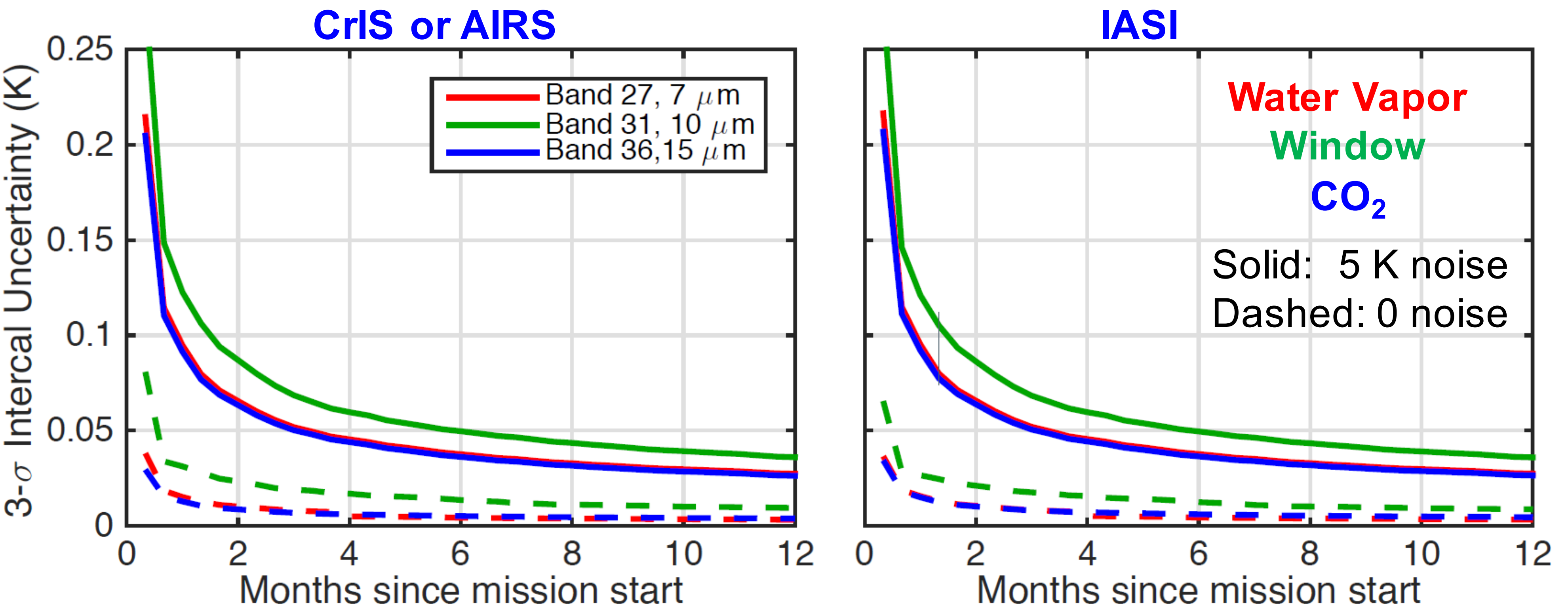


AIRS-CrIS (K) differences as a function of scene temperature



Observed behavior is remarkably similar to model results

Intercalibration Uncertainty (IU)
as a function of time since mission start

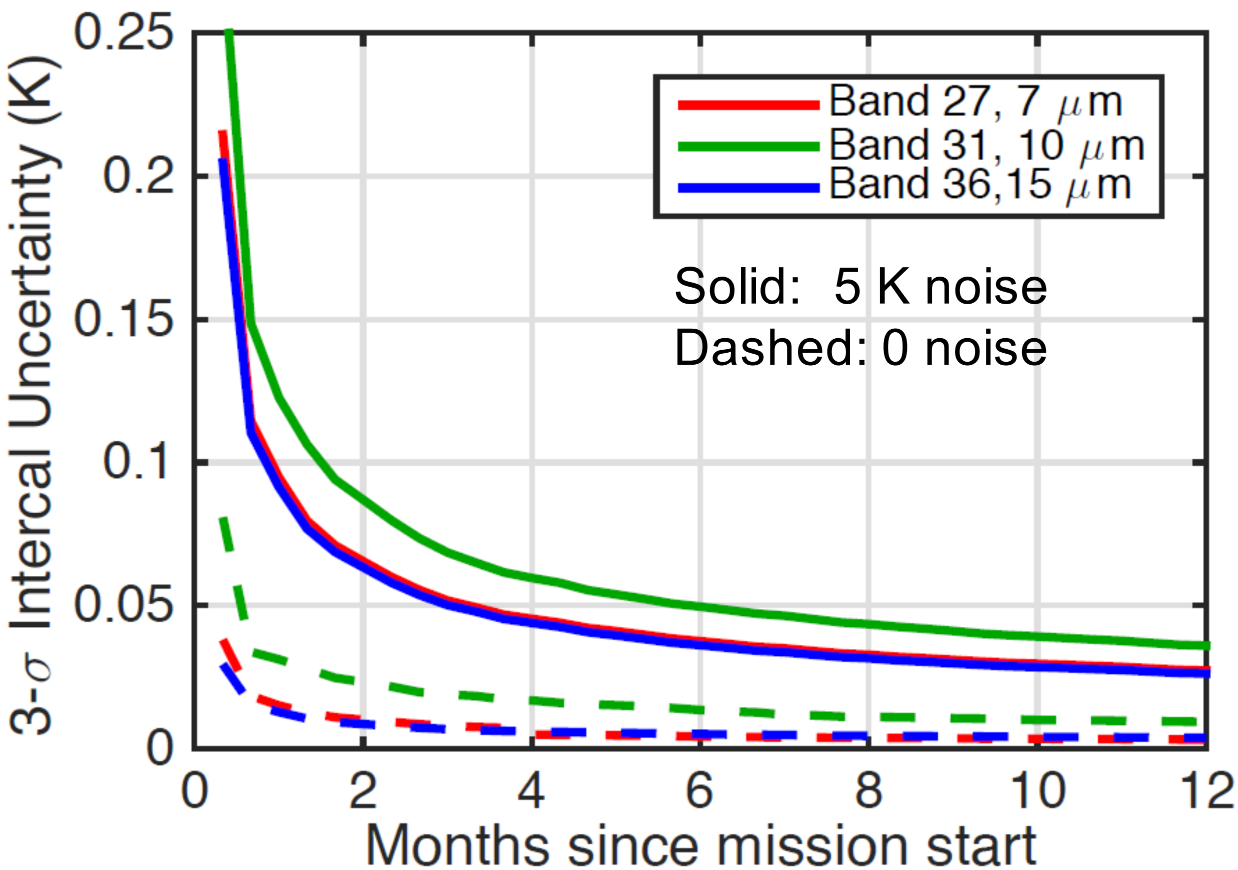


Simulations include CLARREO in 90 degree polar orbit, CLARREO FOV diameter of 50 km, and 20 seconds between adjacent CLARREO FOVs.

<u>Intercalibration Uncertainty is less than 0.05 K 3-sigma in 6 months,</u>
even assuming a reasonably large CLARREO noise and
for a window channel where spatial non-uniformity is largest

Intercalibration uncertainty of CLARREO with CERES as a function of CLARREO mission length

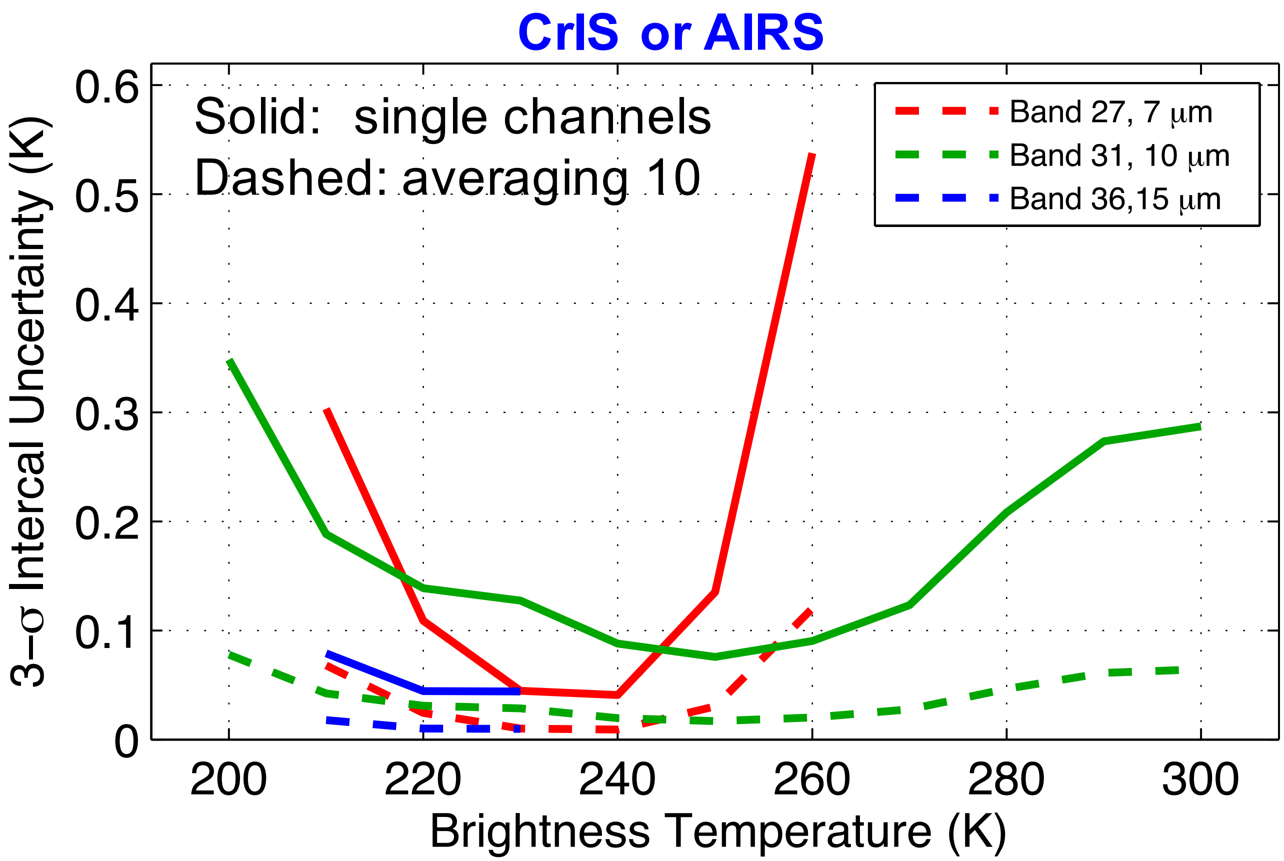
The figure shows the 3-sigma Intercalibration Uncertainty of CLARREO with observations from a sun synchronous sensor as a function of mission length, for representative spectral wavelengths. The 10 micron results are representative of intercalibration of CLARREO with the CERES Longwave Window channel, and the CERES Infrared (Total minus shortwave) are represented by a combination of the three wavelengths. Solid curves assume 5 K CLARREO and dashed curves illustrate the results with zero noise.



within several months of mission start, very good intercalibration can be achieved to assess the absolute calibration of CERES also

Essentially the same as IASI

Intercalibration Uncertainty for 10K scene temperature bins
(e.g. nonlinearity assessment)



CLARREO/AIRS/CrIS Intercalibration uncertainty as a function of scene brightness using one year of SNOs. Simulations include CLARREO in 90 degree polar orbit, CLARREO FOV diameter of 50 km, and 20 seconds between adjacent CLARREO FOVs.

Results demonstrate the practicality of identifying mechanisms for intercalibration biases from which corrections can be based.

Conclusions from the paper

- **Biases between CLARREO and sounder observations can be determined with low rigorously defined uncertainty and with high time frequency during a CLARREO mission**
- A CLARREO footprint of 50 to 100 km in diameter is optimal for intercalibration
- Intercalibration uncertainty will be less then 0.1 K for channels at infrared window wavelengths using 2 months of SNOs (and even lower uncertainty with more time averaging)
- For more absorbing channels with less scene variability the uncertainties are less than 50 mK in 2 months
- **With CLARREO providing very high accuracy, proven on-orbit, intercalibration can be used to transfer the higher accuracy to other concurrent sensors with rigorous traceability**.