# An Infrared Radiance Climate Record Combining EOS-AIRS, S-NPP/JPSS CrIS, and METOP IASI

L. Larrabee Strow, Sergio DeSouza-Machado, Howard Motteler, and Chris Hepplewhite

Department of Physics, JCET, University of Maryland Baltimore County (UMBC)

CALCON Meeting
August 2015
Logan, Utah

Work performed under NASA Grants NNX12AG66G and NNX14AK58G.

Thanks to H. Aumann and E. Manning (JPL) for preliminary AIRS L1c radiances

# Overview

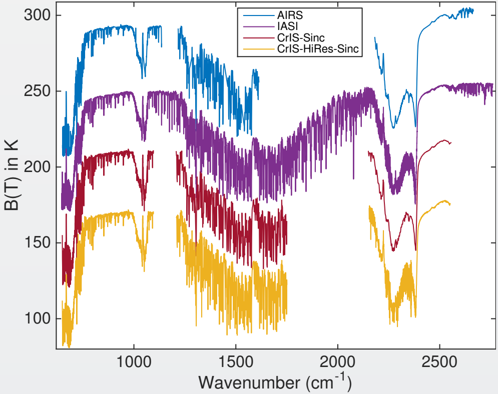
- Hyperspectral Infrared (IR)
  - 2000 to 8000+ spectral channels of earth's thermal emission, $\sim$ 12-20 km footprints
  - Main purpose: Numerical Weather Prediction (NWP)
  - Highly correlated with OLR, but spectra allow discrimination of processes
  - Started with NASA EOS-AIRS in 2002
  - Four hyperspectral sensors now operating (Aqua-AIRS, METOP IASI-1 and IASI-2, SNPP-CrIS) providing great opportunity for inter-calibration studies.

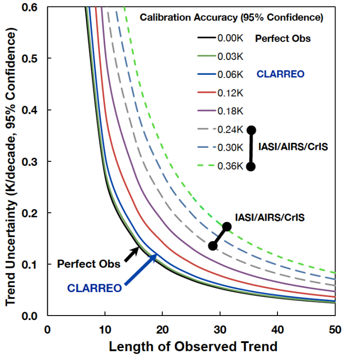
Approach taken for NWP applications may be problematic for climate-level records.

We propose a new approach to produce long term climate records with hyperspectral sounders with quantifiable error characteristics and uncertainties. Stand-in for long-wave part of CLARREO, now delayed until early 2020's.

# Hyperspectral Polar Orbiting Sounders

Need ~ 0.01K/year long-term stability




**CLARREO approach:** no overlap, high accuracy
**This approach:** sensor overlap, but still require stability

BUT: operational sensors also have slightly different spectral response (ILS)

# Sensitivity to Geophysical Variables

- Temperature profile
- Water vapor profile
- Surface temperature and emissivity
- Cloud height (top), phase, particle size. (2+ degrees of freedom?)
- Minor gases: $CO_2$, $N_2O$, $O_3$, $CH_4$, CO, $HNO_3$, Freons, HDO, $SO_2$
- Particulates: Dust (including height), volcanic ash
- With additional data (reanalysis): long-wave cloud radiative forcing

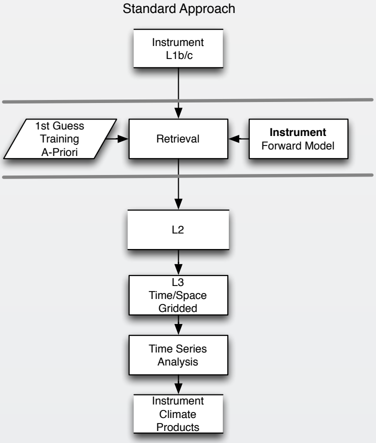
NOAA and EUMETSAT both committed to 25+ year time series:

Afternoon orbit: 2002 $\longrightarrow$ 2027+
Morning orbit: 2007 $\longrightarrow$ ???? ($>$ 25 years)

# Liens on Producing ESDR/CDRs

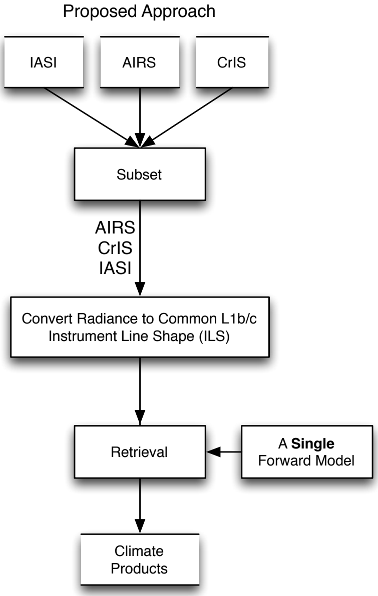
1. Afternoon orbit (U.S.)
   - Two different agencies (NASA is addressing this!)
   - AIRS very different from CrIS and IASI (see below)
   - Calibration experts for AIRS are "aging"
   - Retrieval approaches in flux, even after 12+ years
2. Morning orbit (EUMETSAT)
   - Starts almost five years later than A.M orbit record
   - Two more agencies: EUMETSAT and CNES
3. Common Liens
   - Data volume too large for individual researchers to use
   - **Retrieval products developed for NWP, not for climate monitoring.**
   - Example: The AIRS L2 retrievals do not provide radiance closure. Non-linear approaches (Neural Net, Cloud Clearing) difficult to characterize.

# Ensuring Traceable Accuracy: A New Approach



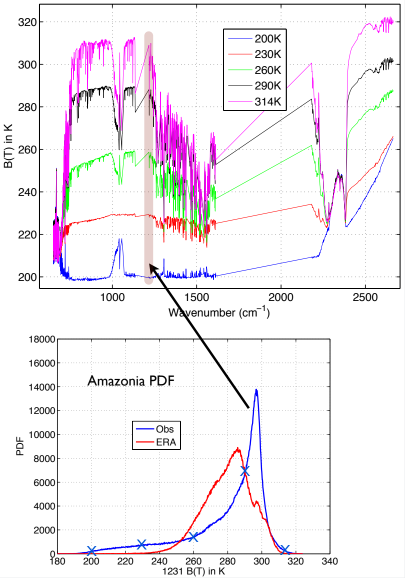

***Repeat*** for each instrument: AIRS, CrIS, IASI
***Ensure*** continuity among products

Repeat the above process for each instrument, merge products that used different forward models, with different spectral resolutions.



# PDF Measurement Approach

Do not average all-sky radiances.

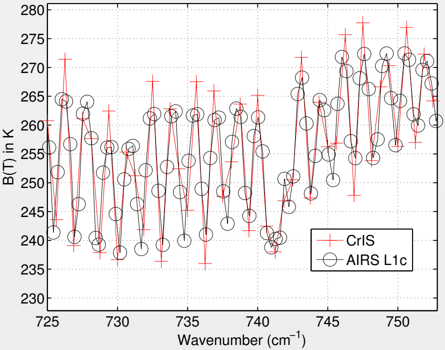



## Retain more information: PDF rates, not Radiance Rates

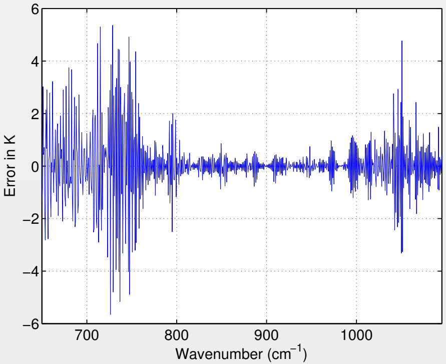
- Averaging clear with cloudy scenes destroys information
- Bin (create PDFs) versus variable related to cloudiness
- I used 1231 cm$^{-1}$ channel B(T): clearest window channel
- Data Set: 10 years of AIRS, only FOVs on each side of nadir
- Bins of B(T) 1231 cm$^{-1}$, from 190:1:320K
- Mean BT spectra in each bin are stable versus time
- All the information is in the PDFs in each bin

# AIRS L1c: Mismatch due to ILS Differences

## Sampling of AIRS vs CrIS ILS

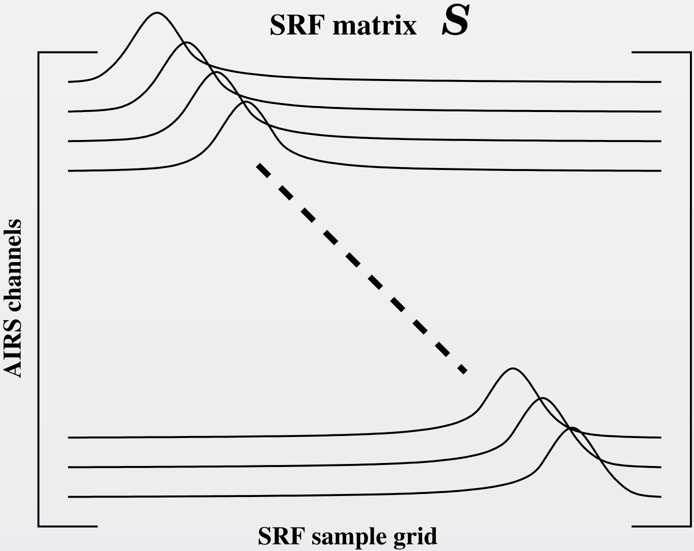



## B(T) error using just $\nu$ interpolation



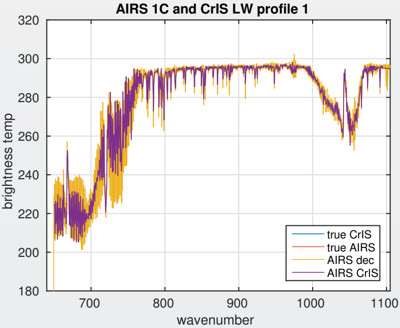
# AIRS to CrIS translation

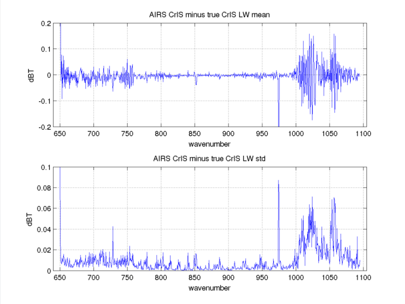
- let $c$ be a vector of AIRS channel radiances and $S$ a matrix whose rows are AIRS SRFs tabulated at a 0.1 $\text{cm}^{-1}$ grid
- then $d = S^{-1}c$ is the deconvolution of $c$ on that grid
- this can be reconvolved with a double Fourier transform to the CrIS user grid
- the useful channels are the intersection of the AIRS and CrIS bands
- the stability of $S^{-1}$ is significantly improved with the L1c in comparison with the L1b channel set, and further improved with a spacing constraint that drops a few of the closest L1c channels
- the condition of the $S_a$ matrix is then reasonably small and around 250 giving a useful inversion.


SRF matrix S
AIRS channels
SRF sample grid

# Motteler method: validation (LW)

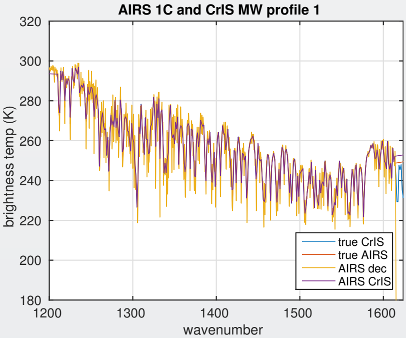
Translation of AIRS spectrum to CrIS spectral grid, involves deconvolution of AIRS using the measured SRFs to a fine grid then convolving to the measured CrIS ILS. Using kcarta with 49 sample atmospheric profiles to test:

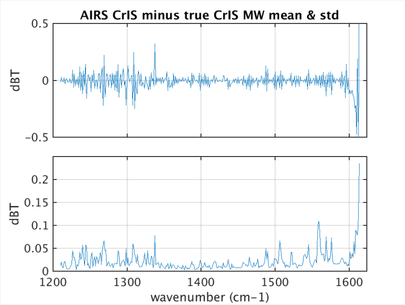


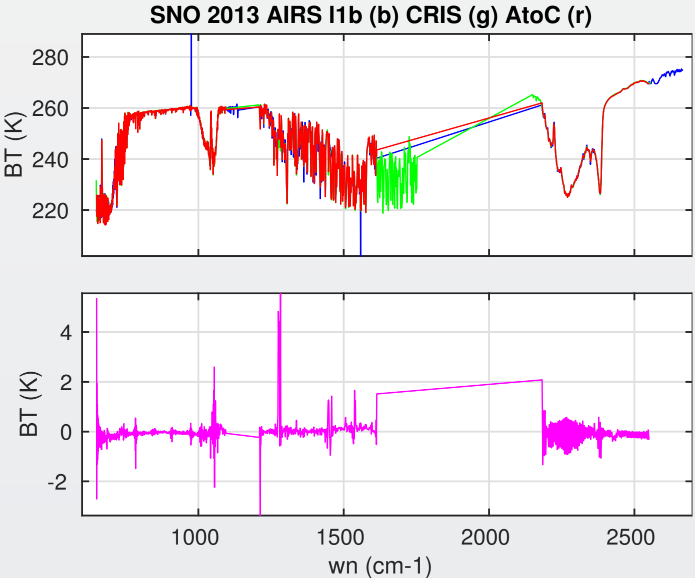
# Motteler method: validation (MW)

The method uses AIRS L1C (spectral gaps are filled and dead channels reconstructed) provides for well behaved matrix manipulation and restricts ringing effects to band edges.

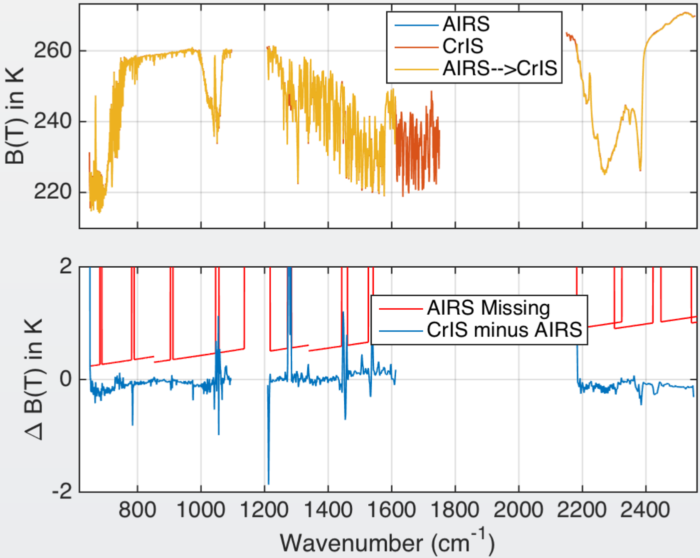


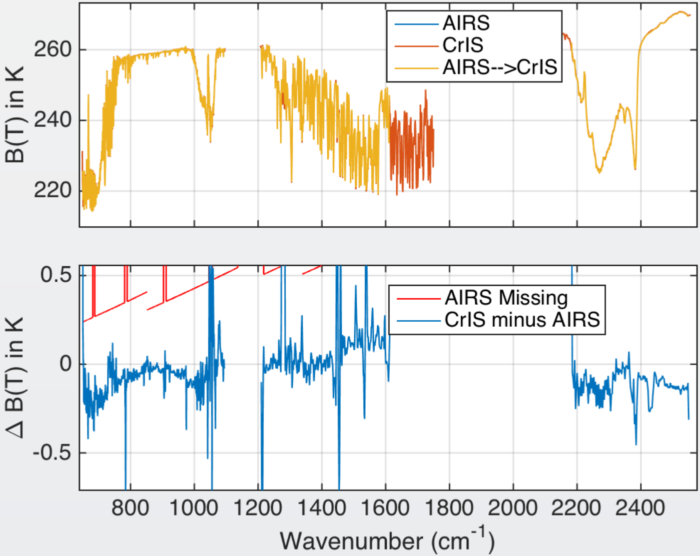
# Full Spectrum Actual AIRS CRIS SNOs for 2013



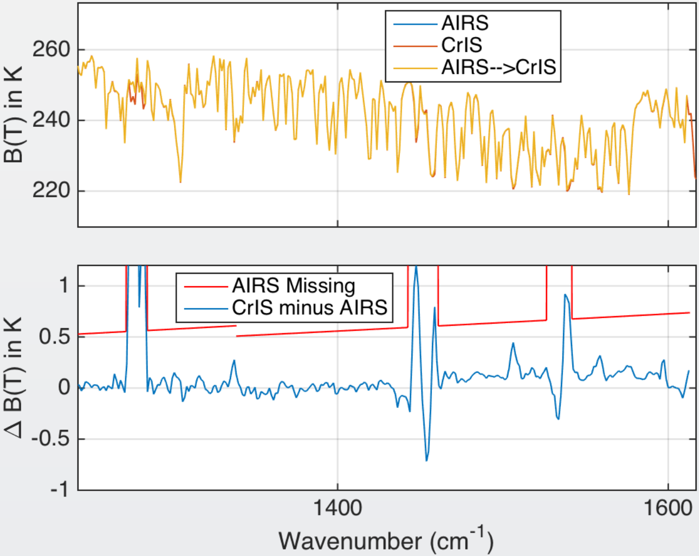
# L1c for AIRS Conversion to CrIS



# L1c for AIRS Conversion to CrIS

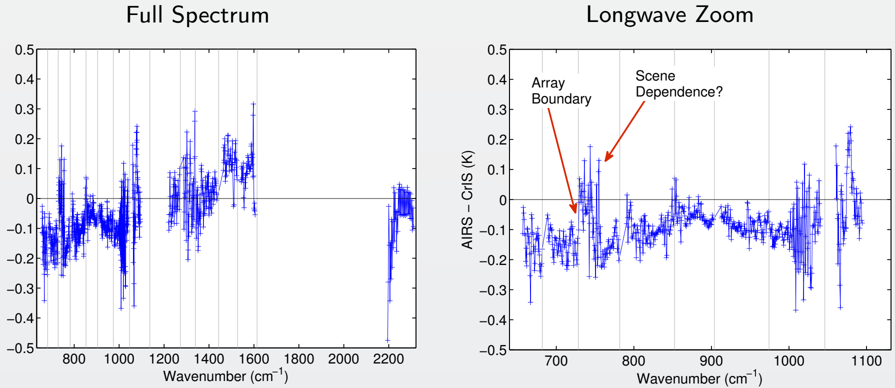


# L1c for AIRS Conversion to CrIS



# Full Spectrum Differences: AIRS/CrIS SNOs

AIRS deconvolution –> reconvolution, *not* statistical, uses measured ILS functions

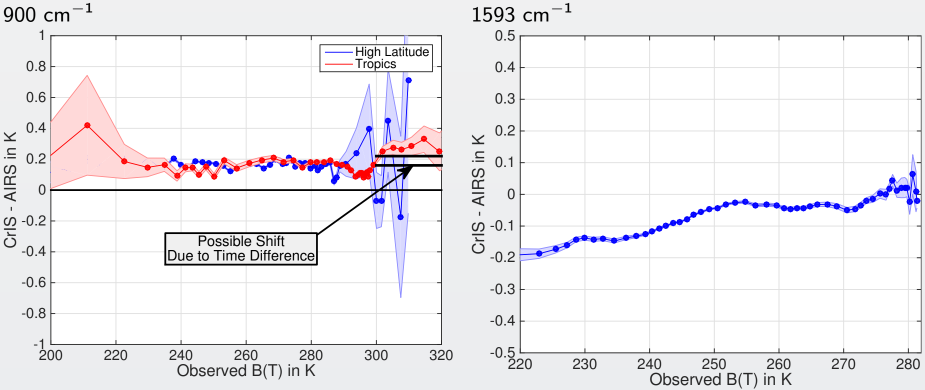



0.2K "ringing" has many sources, all being worked.

ILS differences largely gone, remaining are radiometric issues.
Standard error of these results *very* low, well within 0.01K uncertainty.

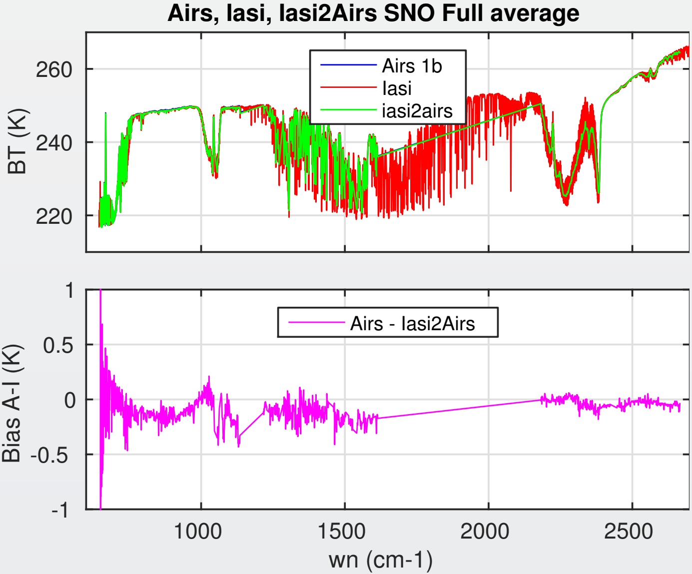
# CrIS - AIRS SNOs versus Scene Temperature

Detector non-linearity can cause scene dependent differences among sensors. Here we show longwave (for year 2013) CrIS minus AIRS SNO differences for window and deep water line channels. The AIRS 1593 cm$^{-1}$ channel ILS has been converted to the CrIS ILS.

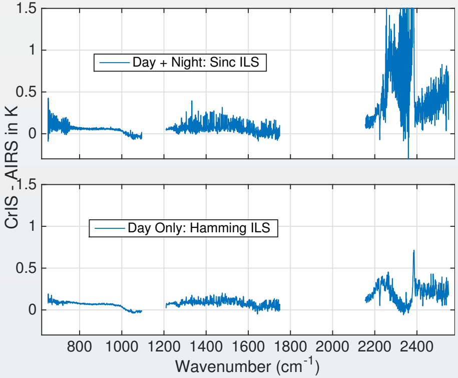



All CrIS FOVs are included here, non-linearity likely causing slope at 1593 cm$^{-1}$. Clearly, AIRS/IASI/CrIS already agree ~0.2K with no adjustments! SNO should allow adjustments (when needed) with high precision.

# Full Spectrum Actual AIRS IASI SNOs for 2013



# CrIS/IASI SNO's, Dec. 5-6, 2014:



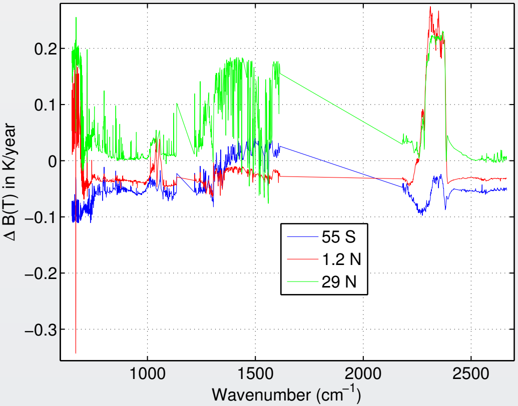

- Ringing in longwave: several contributions (IASI->CrIS, CrIS ringing, IASI?)
- Non-linearity in either instrument could effect low-BT mid-wave water lines. (CrIS FOV7)
- Low shortwave BT's enhances errors in differences. Higher daytime temperatures (due to non-LTE) reduces difference in day only.

Proposed climate record will use lower panel ILS (possibly reduced even more)

# AIRS Stability: Using Clear Scene Subset

- Clear ocean scenes, binned by latitude daily for 10 years (hot PDFs).
- Create simulation set from ERA using forward model (SARTA)
- Determine 10-year linear BT rate ($dBT/dt$) from fit to 4-term sine series (seasonal and harmonics) + constant + linear rate.

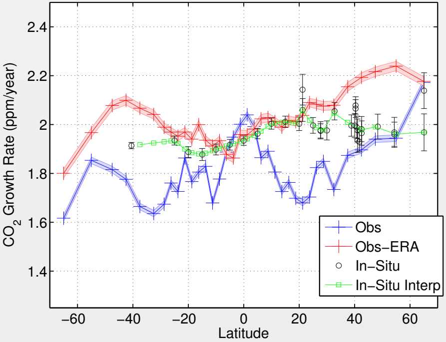
Sample Linear BT Rates and Fitting Errors



# AIRS Stability

Compare OEM retrievals from clear subset to $CO_2$ and SST climatologies.

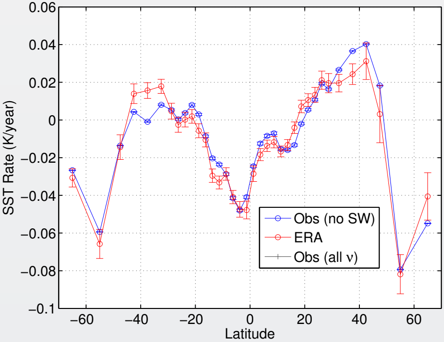
AIRS Retrieved $CO_2$ Growth Rate vs In-Situ: 2ppm ∼0.06K




AIRS - In Situ (± 40 deg.)

0.003 ± 0.004 K/year

AIRS Retrieved SST vs Tropical SST Climate Data Records




Tropical, no AIRS SW:

0.0015 ± 0.005 K/year

Two independent comparison in excellent agreement.

# Conclusions

- Operational sensors have the stability needed for climate
- In-orbit overlap should allow stitching records with uncertainty equivalent to 0.1K/decade. Some risk.
- Demonstrated re-analysis level results with all-sky retrievals derived from radiance trends
- PDF approach may lower sensitivity to instrument accuracy for some variables
- This approach allows a much more rigorous error analysis needed for community acceptance of satellite derived climate change.