An Infrared Radiance Climate Record Combining AIRS and CrIS

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Overview

AIRS + CrIS Lifetimes Entering Climate Regime

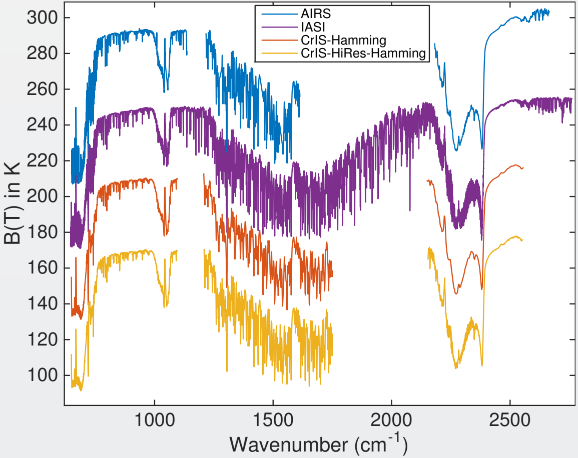
- AIRS products developed for NWP
- But, NWP and reanalyses, use radiance assimilation!
- Can existing approach transition to climate?

Climate Requirements

- Error characterization and traceability
- Data processing by others (reproducible)
- Transparent (simple?) processing algorithms
- Open source (NASA is requiring this now?)

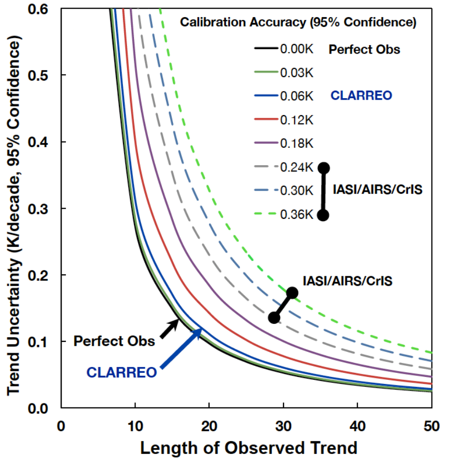
AIRS + CrIS brings a tremendous improvement to climate trending with high vertical sensitivity for temperature and humidity.

Hyperspectral Sounders: Sample Spectra



Different spectral resolutions and channel centers

Why a Different Retrieval Approach Now?

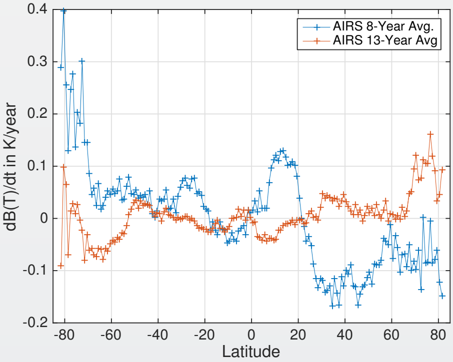


AIRS+CrIS: 13+ Years

- Study by Leroy (left) shows transition after ~ 12 years
- Uncertainty more sensitive to measurement accuracy (not inter-annual variability)
- Are the instrument labels correct??

Lower Zonal Variability with Time

A quick example of time-averaging.



1231 cm^{-1} Window Channel

- Linear trend: d(BT)/dt
- 8 year versus 13 year zonal trend
- Averaging over inter-annual variability mirrored in latitude dependence of change

Existing Retrieval Framework

1. Retrieval
   1) First guess: Neural Net (NN)
   2) L1b converted to cloud-cleared radiances (L2cc)
   3) Minimize L2cc - RTA(Level 2). No closure.
   4) 70-80% yield (enhanced by NN now)
   5) Note: NN trained on several months ECMWF with fixed CO_2.
2. Level 2 averaged to Level 3

OK for Climate Trending?

- Neural Net and cloud-clearing errors hard to characterize
- Influence of a-priori information unknown
- Partial scene-dependent sampling
- *No radiance closure!*
- L2 vertical kernel functions too narrow for AIRS (comes from NNet)

Alternative Retrieval Path for Climate *Trending*

Two Approaches

1. Derive trends and anomalies in radiance space, then retrieve geophysical variables
2. Examine trends in Probablity Distribution Functions (PDFs) of single channels to focus on extremes (if time).

T(z) and $H_2O(z)$ "Level 3" profile trends and anomalies are likely the most important variables AIRS + CrIS can contribute to climate. We are not suggesting this is a replacement for single-footprint Level 2 retrievals.

Radiance Based Trending

Assumes T(z),H_2O (z) anomalies versus time is the key trending product

- Operate in radiance space as long as possible (error traceability)
- Lower data volumes (1-2%)
- Data averaging (gridded, zonal)
- Adopt OE retrieval framework with scattering RTA: a-priori for trends is *zero*.
- OE a-priori covariance very loose, use L1-type Tikhonov empirical smoother.

12-year T(z), H_2O (z) anomalies (zonal) can be processed in 1-2 hours on 40 cpu cores! (Years to test AIRS V6 Level 3!).

Small data set for use by a larger community

Connecting AIRS + CrIS

Present Approach

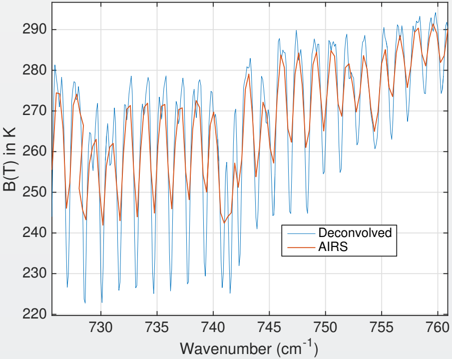
- Native radiances
- Different forward model (RTA)
- Different cloud-clearing (FOV geometry differences)
- Differing sensitivities
- How Connect?

Proposed Approach

- Convert AIRS radiances to CrIS instrument line shape (ILS)
- Adjust AIRS to CrIS radiometrically using SNOs (max $\sim$0.2K $\pm$ 0.01K adjustments)

Can be used in single-footprint methodology or using trending/PDF approaches discussed above.

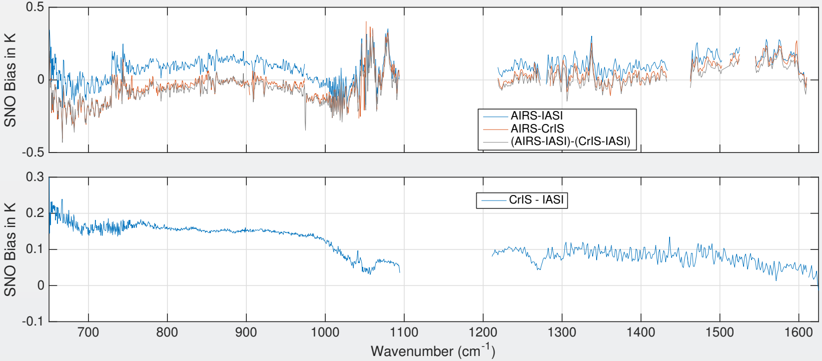
Conversion of AIRS to CrIS



AIRS ILS ⟶ CrIS ILS

- Deconvolve AIRS to 0.1 cm^{-1} grid.
- Classical approach only using AIRS measured ILS functions (no statistics or training)
- Re-convolve to CrIS ILS

Radiometric Agreement of AIRS and CrIS

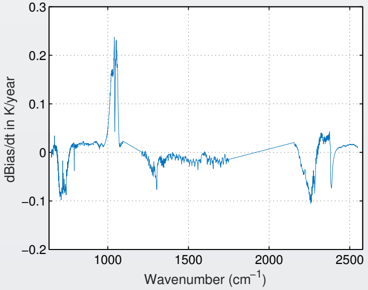


- AIRS, IASI both converted to CrIS ILS
- Uncertainty of SNO differences: $\sim \pm 0.01K$
- Recent work by CNES suggests SNO differences mostly IAS non-linearity
- High frequency hash in AIRS differences could be radiometry or AIRS SRFs

Stability of AIRS and CrIS

Two Independent Measurements of Stability

- Compare AIRS/CrIS to in-situ changes in CO_2 and tropical SST
- Done with retrievals of dBT/dt for clear-ocean scenes
- AIRS 12-year stability using CO_2: $+0.004 \pm 0.004K$
- CrIS 3-year stability using CO_2: $+0.005 \pm 0.001K$. (Versus ERA-Interim bias, so error smaller)



Left: CrIS - ERA dBT/dt over 1st three years of CrIS operation.

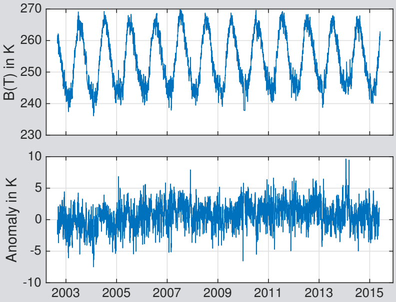
Sensor stability self-calibrating.

SNO inter-calibration nearly 0.01K.

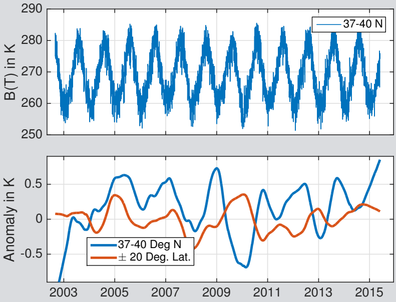
"Transfer" of calibration may be possible without direct overlap.

Radiance Time Series and Anomalies

Artic 1231 cm^{-1} Time Series

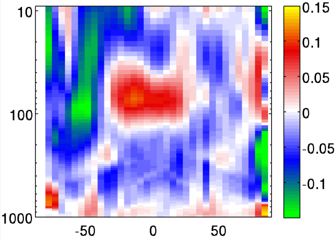


Mid-lat 1231 cm^{-1} Time Series

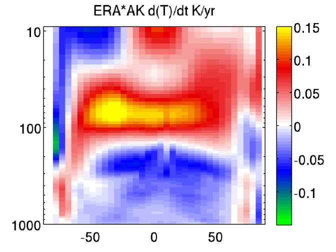


- Data Set: 2378 channels by 40 zonal bins
- Fit to a constant, a time derivative, and annual sinusoids and harmonics.
- Generate jacobians
- Retrieve geophysical rates and anomalies from radiance rates and anomalies.

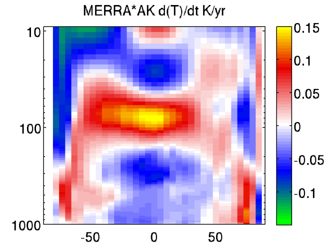
10-Year Temperature Trends: AIRS



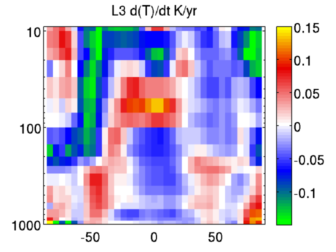
UMBC (K/year).



ERA × Averaging Kernel (K/year)

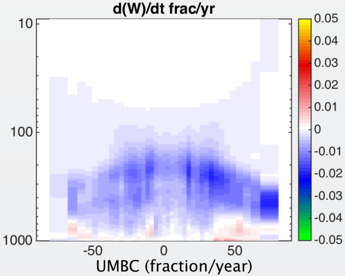


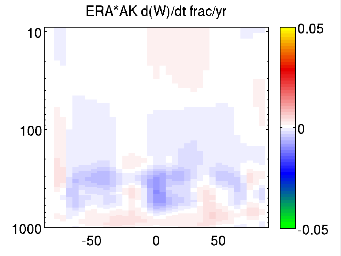
MERRA × Averaging Kernal (K/year)



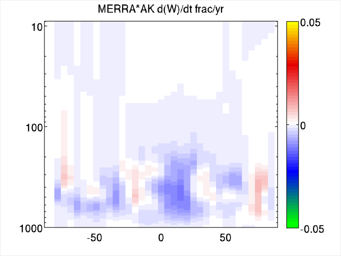
AIRS Level 3 (K/year)

10-Year Water Vapor Trends

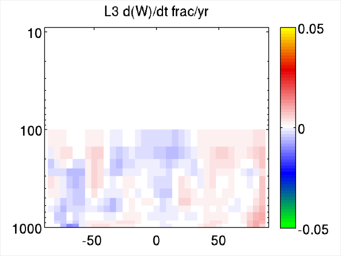




ERA × Averaging Kernel (fraction/year)



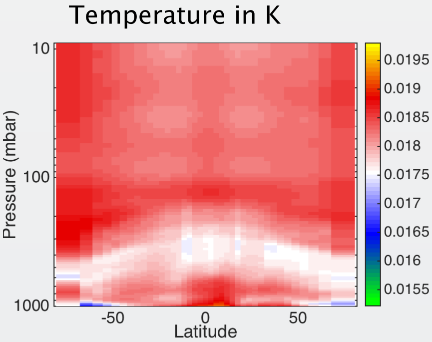
MERRA × Averaging Kernel (fraction/year)

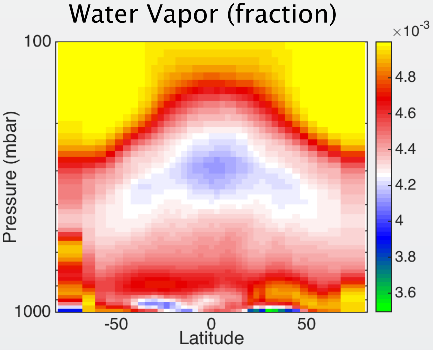


AIRS Level 3 (fraction/year)

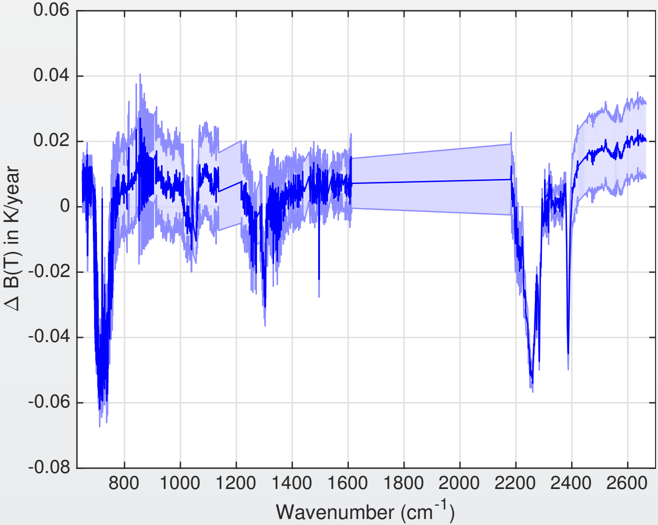
Uncertainty Estimates

VERY Preliminary: No account for serial correlation, etc.

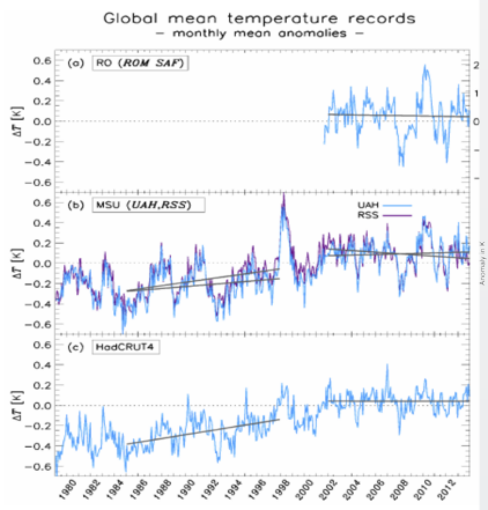




Global Mean Change in Observed B(T) for 12 Years



The "Hiatus"



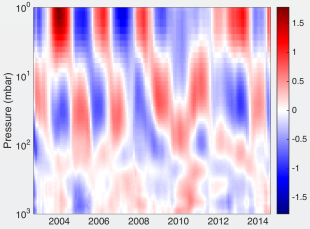
I used 200 to 950 mbar retrievals.

The "Hiatus": Need Vertical Resolution

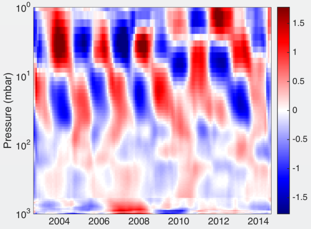
PRELIMINARY: Incomplete Error Analysis

- Karl: 2000–2014 gets 0.0116 ± 0.0067 K/year (1 sigma!). This is surface air.
- Christy: Almost zero during Hiatus. This is tropospheric average.
- Just for kicks, what do we get?
  - 950-200 mbar: -0.004 K/year ± 0.018/2 K/year?? (1 σ)
  - 950-700 mbar: +0.006 K/year ± 0.018/2 K/year?? (1 σ)
- The point is not the absolute numbers (although they are interesting) but that (a) we are in the ballpark with a very very simple and easy approach, and (b) we have vertical sensitivity
- So, maybe everybody is right! This is all on very thin ice.

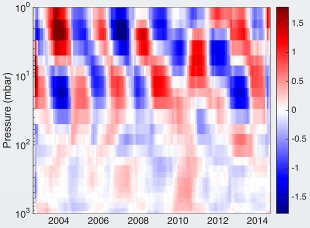
27N to 30N Zonal Temperature Anomalies



UMBC from radiance trends (K/year).

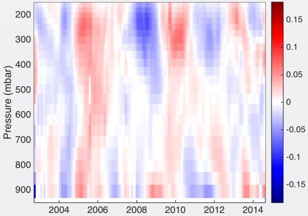


ERA × averaging kernel (K/year).

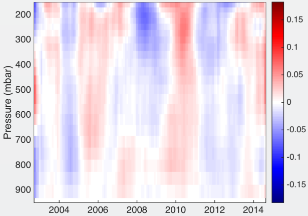


AIRS Level 3 (K/year).

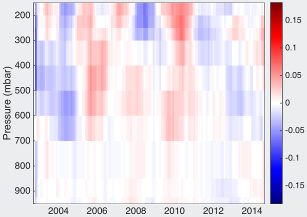
27N to 30N Water Vapor Anomalies



UMBC from radiance trends (fraction/year).



ERA × averaging kernel (fraction/year).



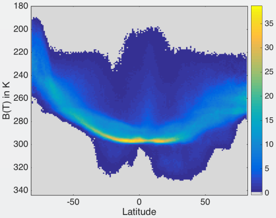
AIRS Level 3 (fraction/year).

Probability Distribution Functions (PDFs)

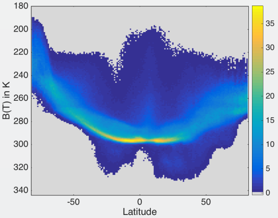
- Avoid data averaging to enhance trends
- More direct evaluation of changes in outgoing thermal radiation
- Helps identify when, where to do better single-footprint retrievals

Almost no manipulation of data, very convincing to the climate community.

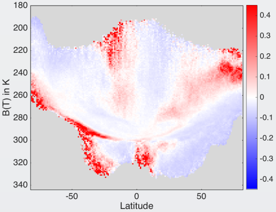
Radiance PDFs for the 1231 cm^{-1} Window Channel



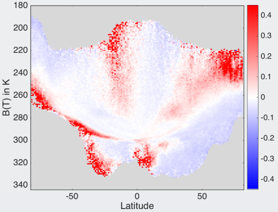
CrIS PDFs for 1231 cm^{-1} channel over 3 years.



AIRS Pdfs for 1231 cm^{-1} channel, same 3 years as CrIS.

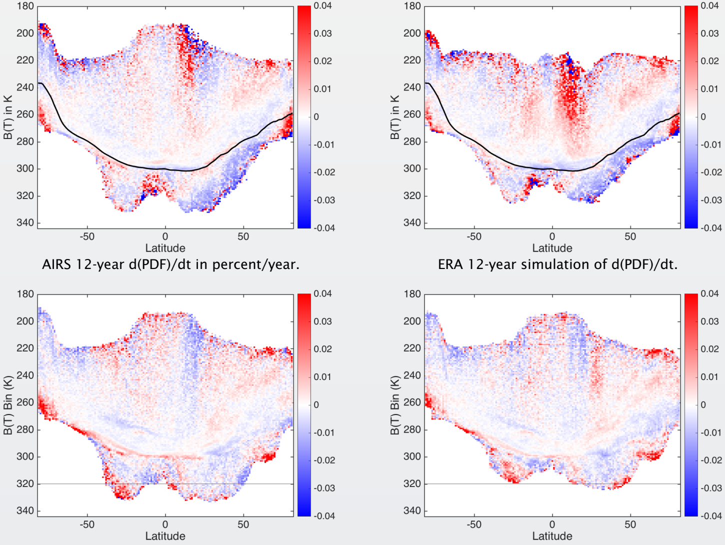


CrIS linear rate: Δ PDF/dt percent/year relative to each pixel.



Same as on left, but using AIRS.

Radiance PDFs for 1231 cm^{-1}: AIRS vs IASI



AIRS 12-year d(PDF)/dt in percent/year.

ERA 12-year simulation of d(PDF)/dt.

AIRS d(PDF)/dt, for IASI 8-year overlap

IASI 8-year d(PDF)/dtF

Final Thoughts

- Years between AIRS Product versions: 5+
- Overhead of producing all AIRS products is gigantic
- Time to produce L3 with new algorithm: 4-6 months?
- *Very* complex algorithm
- Algorithm code not generally available
- Data set is 100 TB+
- No one has suggested how to connect AIRS to CrIS via native retrievals. TBD.
- ***Algorithm does not estimate errors***