

Climate Level Retrievals of Trends, Anomalies and PDFs from AIRS/IASI Radiance Time Derivatives

L. Larrabee Strow, Sergio De Souza-Machado, and Steven
Buczowski

UMBC
Department of Physics *and*
Joint Center for Earth Systems Technology

IASI 2016
Antibes Juan-les-Pins

Overview

Hyperspectral Sensors Becoming Climate Sensors

- AIRS (+CrIS): 13 → 35 years (JPSS 3+4 approved)
- IASI 9 → 30+?
- Years of overlap already to connect sensors
- Direct overlap not needed: For example can use IASI to transfer between AIRS and CrIS!

Climate Requirements/Users

- Can Level 2 provide accurate Level 3 climatologies?
- How provide error characterization and traceability?
- Data processing should be as simple as possible so reproducible by others (and is widely understood).
- Open source

Hyperspectral IR has outstanding radiometric accuracy, even better stability, and should greatly enhance climate trending of $T(z)$, $H_2O(z)$, surface T and emissivity, etc.

Scientific Questions

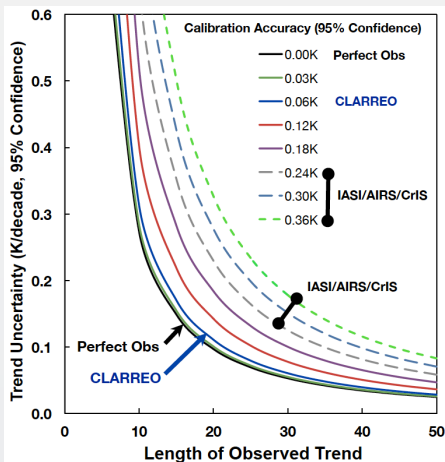
- $T(z)$, $H_2O(z)$, O_3 , and longwave cloud forcing trends
- H_2O feedback from warming
- Cloud feedback?
- Etc.

At present: compare trends to other popular approaches (microwave, sondes)

Soon: Begin answering the above questions, but how?

And: Ensure that the individual researcher can stay involved in climate research with hyperspectral data at the radiance level

Climate Variability and Measurement Accuracy



AIRS+CrIS: 13+ Years

- Work by S. Leroy shows transition after ~ 12 years
- After which instrument accuracy/stability is dominant error source
- Are the instrument labels correct??
- AIRS stability $\sim 0.003\text{K/year?}$
- **Hepplewhite Poster:** AIRS + CrIS SNO difference stats imply “stitching” to well below 0.01K
- **Hepplewhite Poster:** Convert AIRS to CrIS ILS for radiance time series

Existing Retrieval Frameworks

- ① Retrieval (**Weather oriented approach**)
 - 1) First guess: Neural Net (NN), climatology, microwave
 - 2) L1b converted to cloud-cleared radiances (L2cc), sometimes biased cold
 - 3) Minimize L2cc - RTA(Level 2). No closure.
 - 4) 70-80% yield
 - 5) Note: NN trained on several months ECMWF with fixed CO₂.
- ② Level 2 averaged to Level 3 (AIRS). IASI??

OK for Climate Trending?

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

An Alternative Retrieval Path for Climate *Trending*

Two Approaches

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

Level 3 anomalies (and rates) are generally what the community wants for understanding trends.

Radiance Based Trending

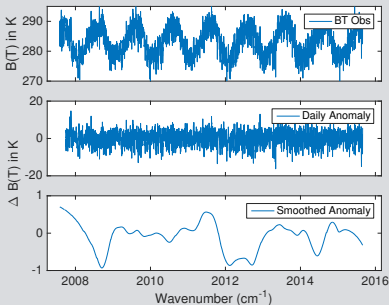
- Operate in radiance space as long as possible (error traceability)
- Lower data volumes (1-2%)
- Data averaging (gridded, zonal)
- Adopt OE retrieval framework with scattering RTA for conversion of radiance trends/anomalies to geophysical variables.
- A-priori state for trends is *zero*. (Jacobians evaluated at the mean state).
- Using a L1-type Tikhonov empirical smoother combined with an estimated (but loose enough) a-priori covariance.

13-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!).
Linear zonal rates just take a minute to run on 100 layers.

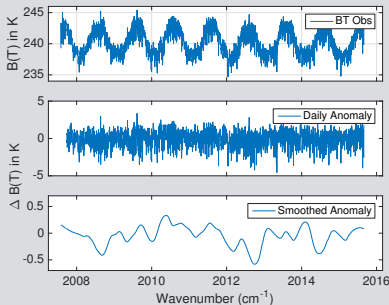
Small data set for use by a larger community

Radiance Time Series and Anomalies

Mid-Lat IASI 900 cm^{-1} Time Series

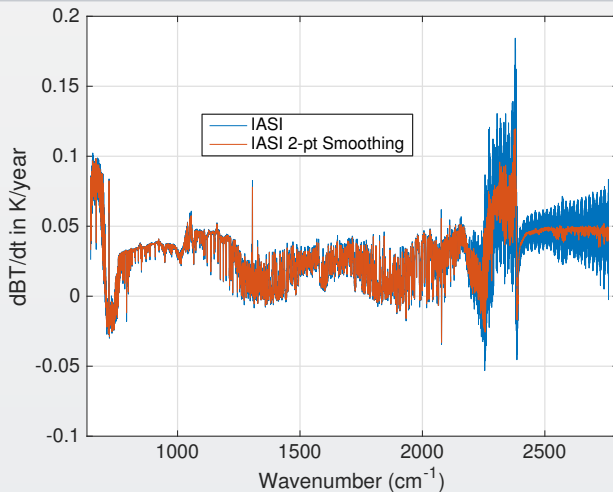


Mid-lat IASI 734 cm^{-1} Time Series



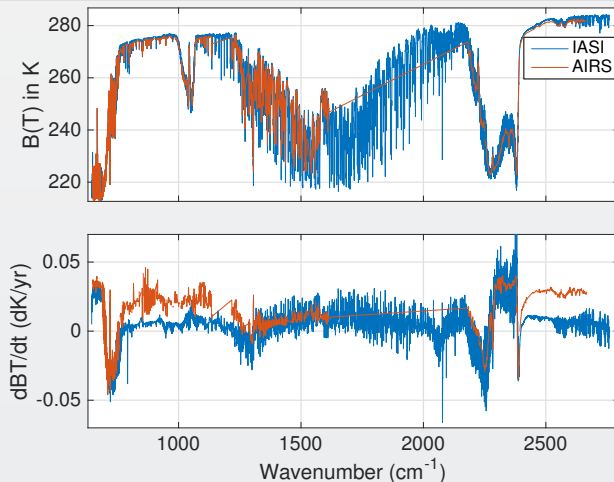
- Data Set: 8461 channels by 40 zonal bins
- Fit to a constant, a time derivative, and annual sinusoid plus first 3 harmonics.
- Generate jacobians (from ERA or mean BT retrievals)
- Retrieve geophysical rates and anomalies from radiance rates and anomalies.

Example: IASI dBT/dt for 8 Years for 55 Deg. North



Changes to IASI L1c algorithm changed ringing. From now on we will use averages of adjacent IASI channel for all retrievals.

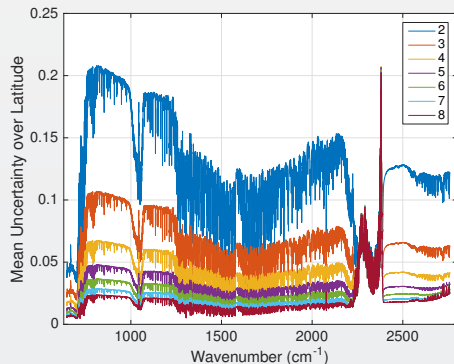
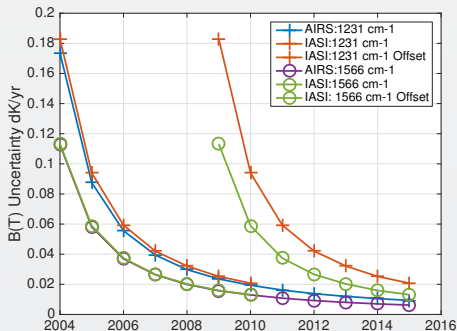
Compare IASI to AIRS 8-Year Trends: *GLOBAL*



Larger latitudinal variability, but only 8 years.

2σ uncertainty $\sim 0.025\text{K}$ in window region for both

Variation in Trend Uncertainty over Time



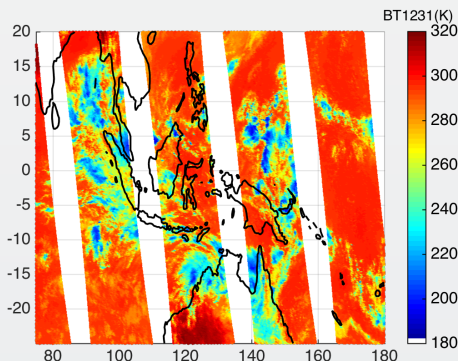
Trend uncertainty for AIRS going below 0.01K/year, reaching climate regime?

Careful work needed to determine instrument stability (using CO₂ and SST) and accuracy of inter-instrument calibration!

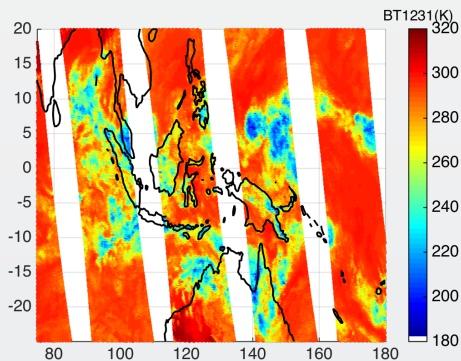
(Serial correlation not included, 650-750 cm⁻¹ will be 2-3x larger)

Retrievals: Switch to AIRS for Now

BT Obs

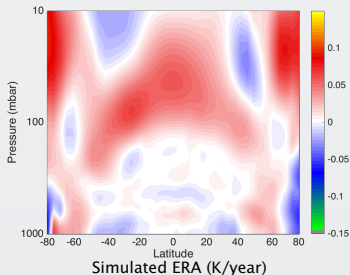
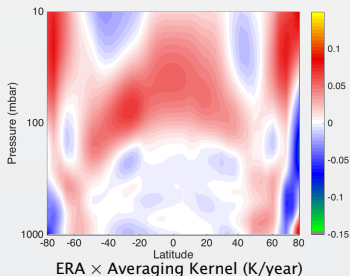


BT SARTA Calc

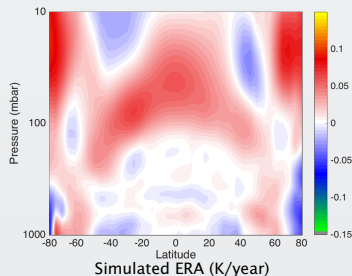
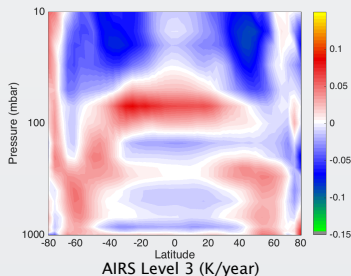
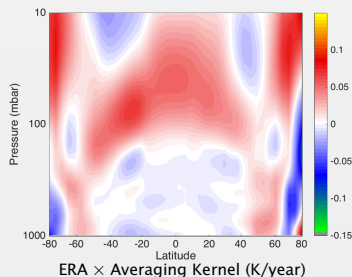
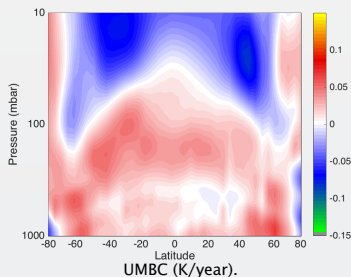


We match every scene to ERA, convert ERA clouds to 2-slabs (water, ice), and use with ERA $T(z)$, $H_2O(z)$, T_{surf} to generate our simulation set. We also use these 2-slab clouds in Jacobians to retrieve profile trends.

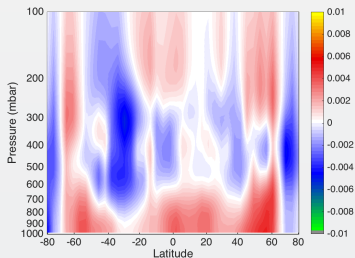
AIRS 13-Yr T(z) Trends: (Obs Uncertainty only 0.001K/Year Drift)



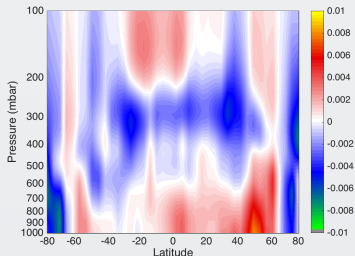
AIRS 13-Yr T(z) Trends: (Obs Uncertainty only 0.001K/Year Drift)



AIRS 13-Yr H₂O (z) Trends: (Obs Uncertainty only 0.001K/Year Drift)

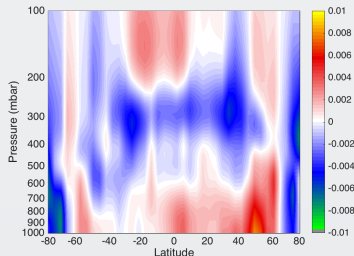
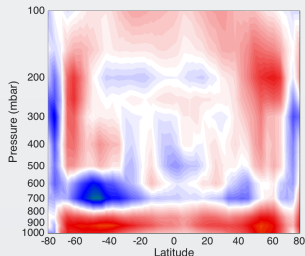
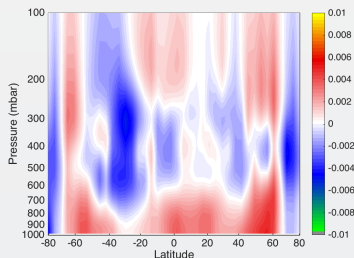
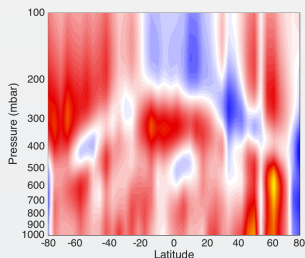


ERA × Averaging Kernel (fraction/year)

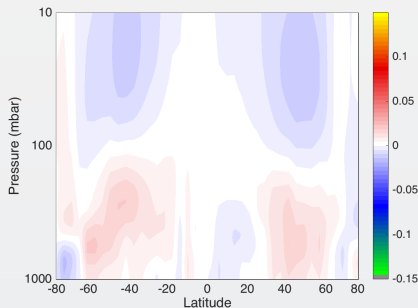


Simulated ERA (fraction/year)

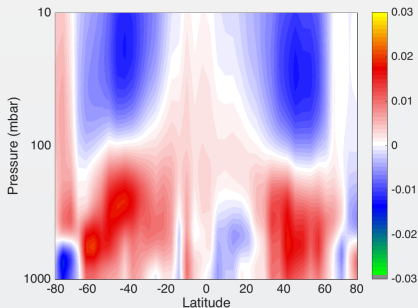
AIRS 13-Yr H₂O (z) Trends: (Obs Uncertainty only 0.001K/Year Drift)



AIRS 13-Yr Linear Temperature Trends w/ Obs Errors



UMBC (K/year).

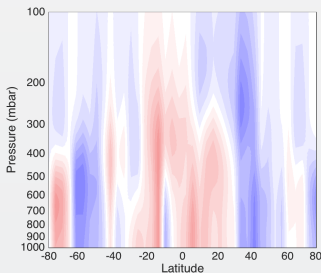


Scale Zoom of UMBC K/year

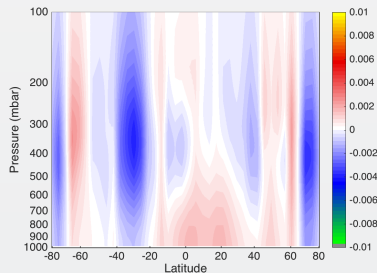
Tropospheric heating, stratospheric cooling. Tropical stratospheric heating quite small. Uncertainties $\sim 0.005\text{K/yr}$ BUT diagonal obs error matrix.

The AIRS Level 3, ERA temperature products are not amenable to this type of analysis.

AIRS 13-Yr Linear H₂O Trends w/ Obs Errors

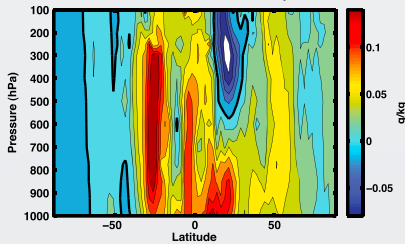


UMBC (fraction/year).

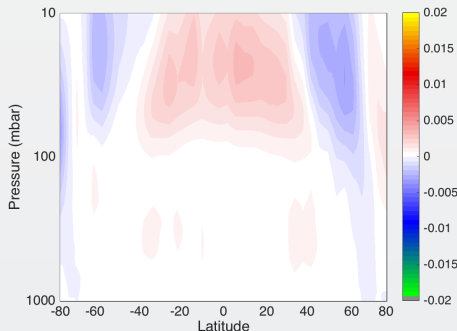


ERA \times AK

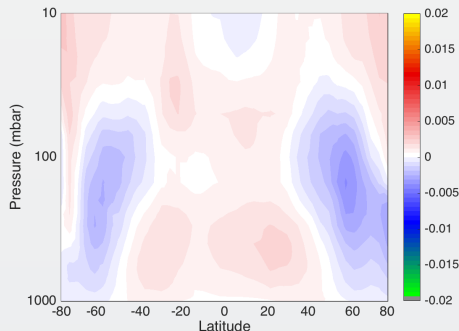
a) Difference in q between the warmest and coldest of the last 88 months of the 20th century in CCSM



13-Year Ozone Trends?



UMBC (fraction/year).

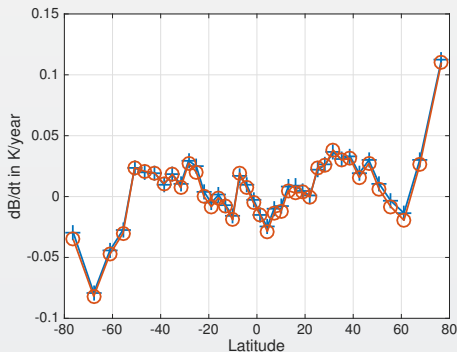


AIRS Level 3

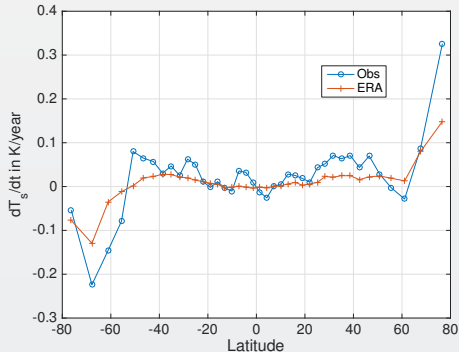
Roughly same rates as Sciamachy for 2000-2010, including latitude dependence in stratosphere.

Are the ERA O₃ profiles good enough for our Jacobian evaluations?

Window Channel Rates and Surface T Retrievals



Window Channel BT Rates

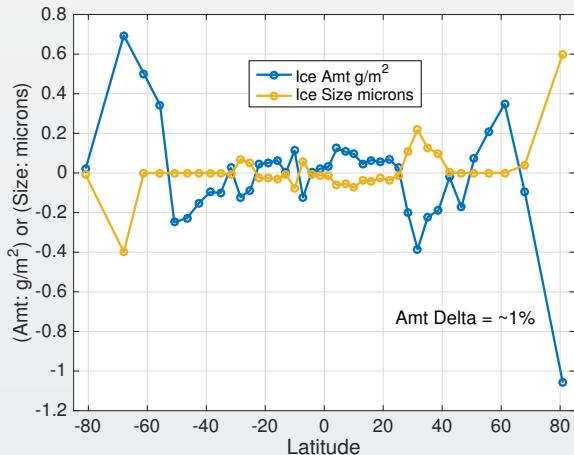


Retrieved Surface T Rates

Our mid-latitude surface temperature rates are quite high?

The fix: Separate retrievals in a subset of clear, less clear, full clouds. First results recently done and are encouraging.

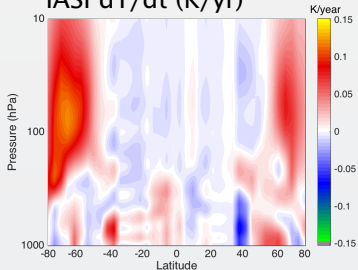
Cloud Trends: Very Preliminary



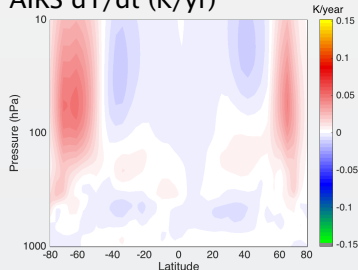
Is amount/size correlation reasonable? Water cloud changes extremely small.

IASI 8-Year T Rates: CO₂ + CH₄ fixed at in-situ values

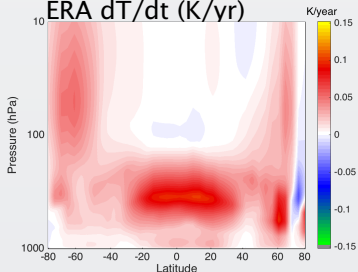
IASI dT/dt (K/yr)



AIRS dT/dt (K/yr)



ERA dT/dt (K/yr)

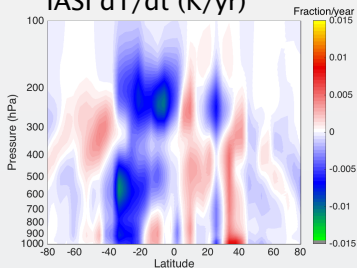


IASI Very Sub-Optimal

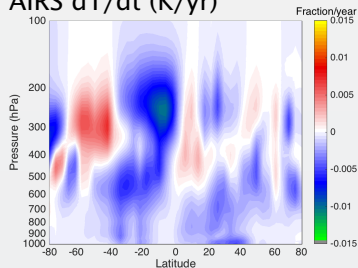
- Roughly every 8th channel used
- A-Priori covariance and L1 smoothing not tuned
- We forgot and added in shortwave (unlike AIRS!)
- O-F residuals large for some latitudes

IASI 8-Year H₂O Rates:

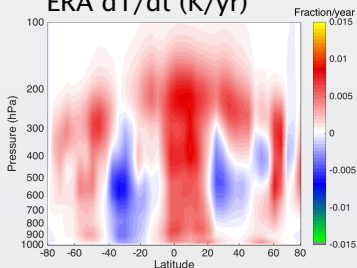
IASI dT/dt (K/yr)



AIRS dT/dt (K/yr)



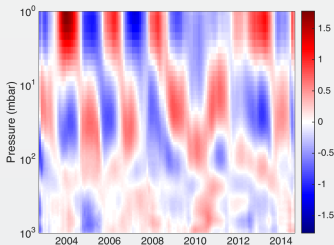
ERA dT/dt (K/yr)



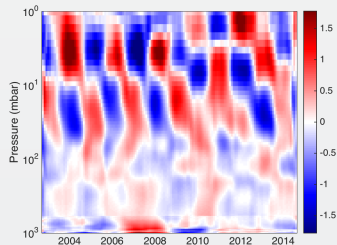
- AIRS and IASI more similar than either with ERA
- Same fits as for T(z), so same liens
- Short time periods more sensitive to inter-annual
- AIRS and IASI O₃ almost identical

27N to 30N Zonal Temperature Anomalies

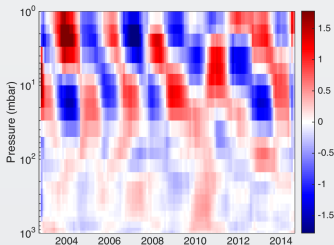
UMBC (K)



ERA \times averaging kernel (K)

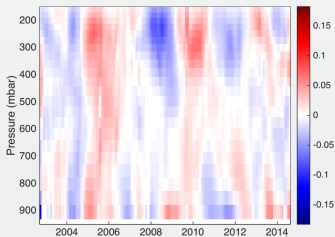


AIRS Level 3 (K)

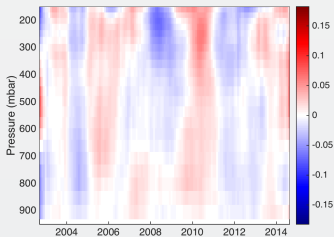


27N to 30N Water Vapor Anomalies

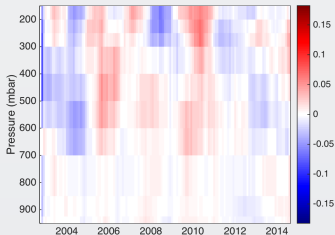
UMBC (frac/yr)



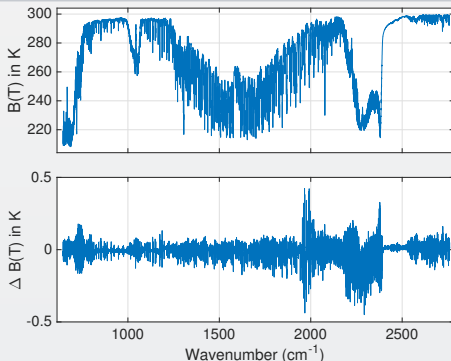
ERA \times avg kernel (frac/yr)



AIRS Level 3 (frac/year)



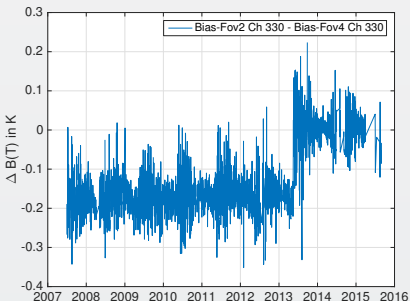
Liens on IASI Radiances



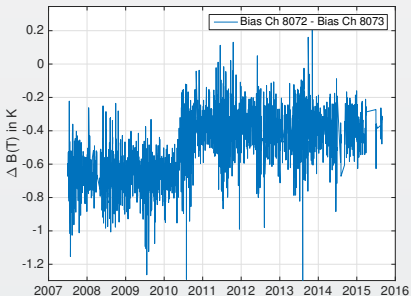
- Mean difference between FOV2 and FOV4
- ~ 6 ppm $\Delta\nu$ in longwave
- FOV-dependent ν scales in band overlap regions cause distortion
- Only in IASI-1! Gone in IASI-2.
- Mostly easy to correct, or leave as is if keep uniform mix of all FOVs.
- Assume LW ν differences due to detector x,y location errors?

Radiance Offsets

Chan 330, Bias (FOV2-FOV4)



Bias Chan 8072 - Chan 8073 for FOV-1

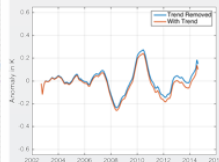
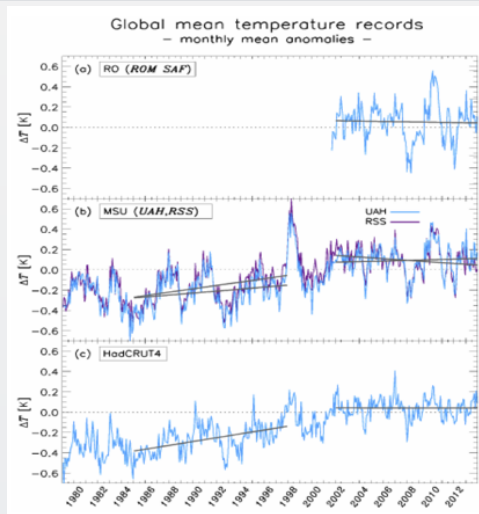


Offsets appear at different dates.

Conclusions

- AIRS, and soon IASI, lifetimes are reaching climate timescales
- A new radiance-based approach for hyperspectra IR climate products appears promising
- Low storage
- Mission reprocessing can be done in an hour
- Approach simple compared to L2 with less A-priori “bleed-through”. Our L3 trends constrained by retrieval, unlike L3 derived from L2 products.
- Provides error estimates (more work needed on this)
- We plan to connect AIRS + CrIS, both to IASI in radiance space (using CrIS ILS). (See Heppleworth poster)

The "Hiatus" (using anomaly retrievals shown later)



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 $\pm 0.018/2$ K/year?? (1 σ)
 - 950-700 mbar: $+0.006$ K/year $\pm 0.018/2$ 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?