# AIRS 13-Year Trends from Radiance Derivatives Compared to AIRS L3 and ERA Interim Reanalysis

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# Overview

## AIRS + CrIS Lifetimes Entering Climate Regime

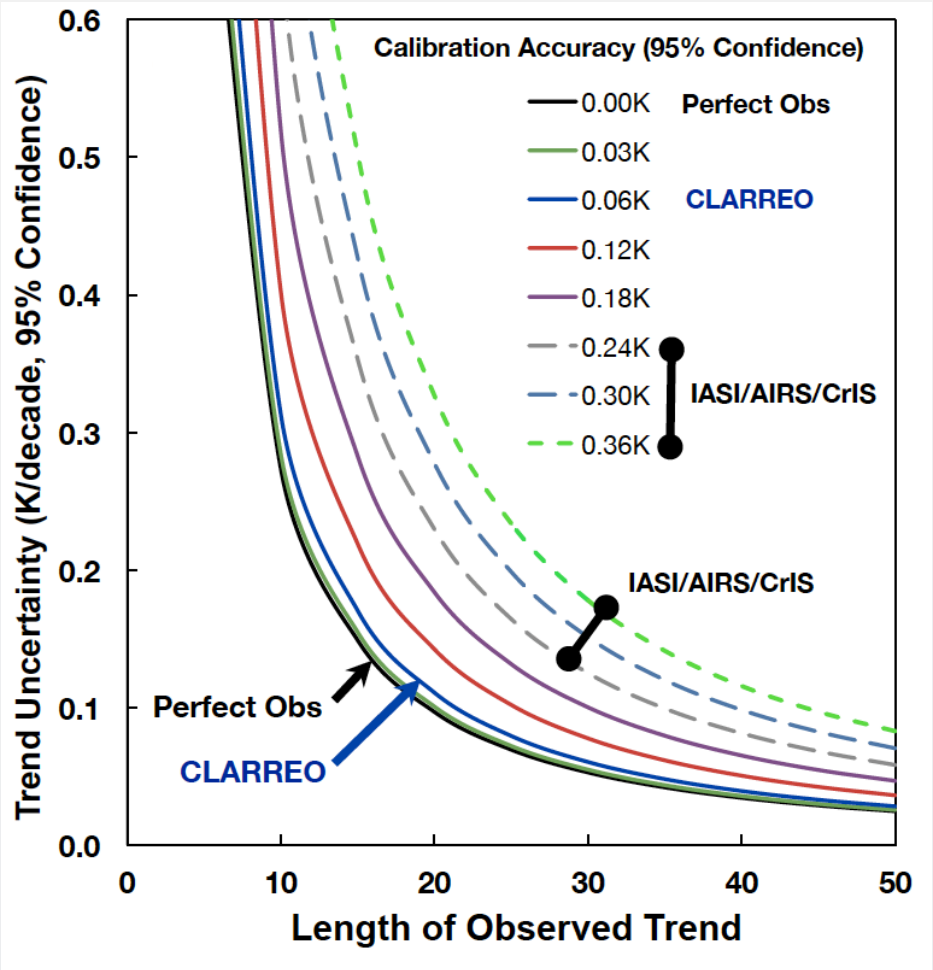
- AIRS products developed for NWP
- Is our existing approach going to meet climate requirements?
- How will we connect AIRS + CrIS + IASI, etc.?

## 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.

# Climate Variabililty and Measurement Accuracy

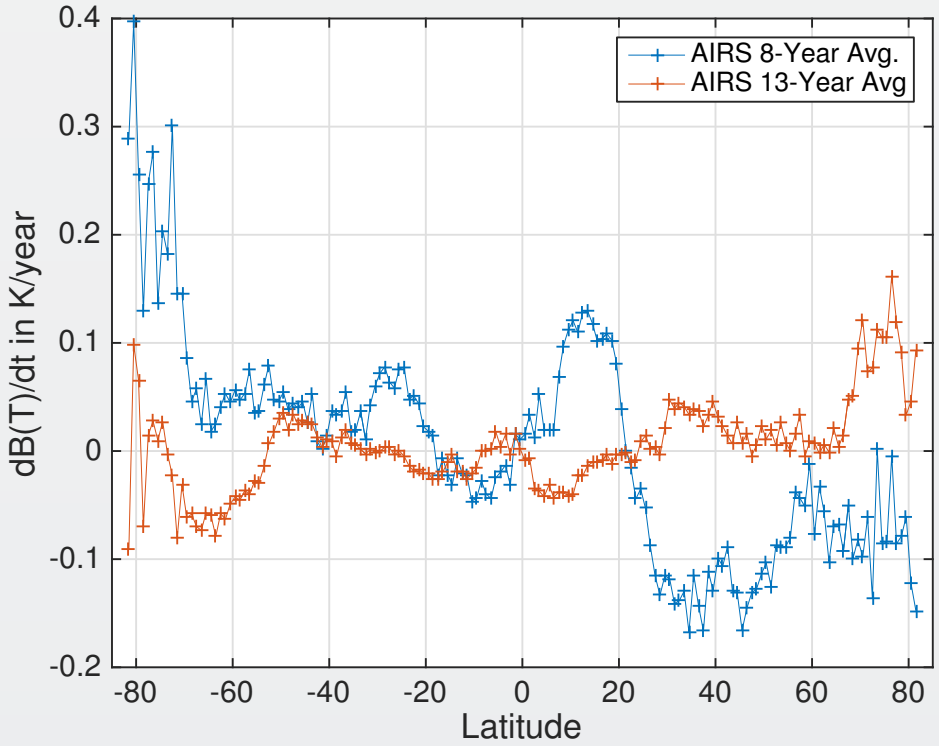



## AIRS+CrIS: 13+ Years

- Study by Leroy (left) shows transition after ~ 12 years
- Uncertainty more sensitive to measurement accuracy (not inter-annual variability)
- Are the instrument labels correct??
- AIRS stability 2X (or more) lower than 0.01K/year
- Last STM: AIRS + CrIS SNO difference stats imply "stiching" to well below 0.01K
- Last STM: Convert AIRS to CrIS ILS for radiance time series

# 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).

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*.
- Using a L1-type Tikhonov empirical smoother with some help from an estimated 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

# Examine Zonal Trends

- Zonal trends commonly used in climate/feedback studies
- Zonal averages let's us keep all data in memory
- No reason we cannot transition to gridded trends in the future

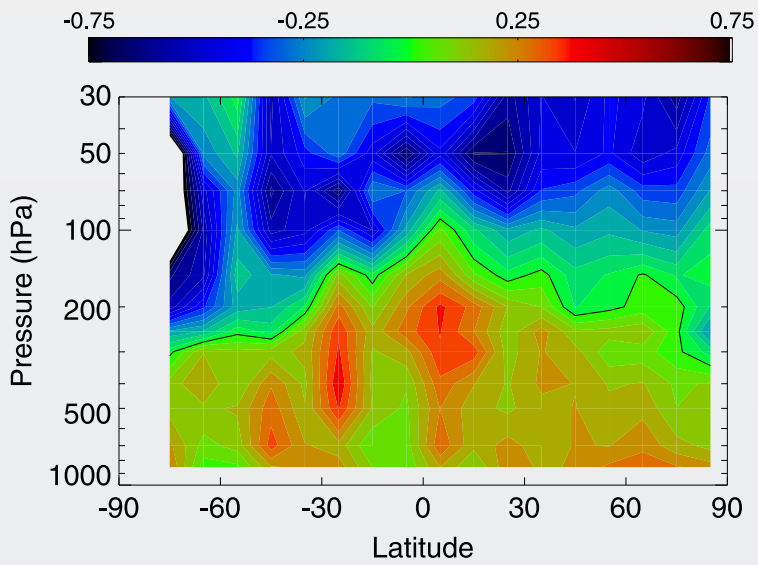
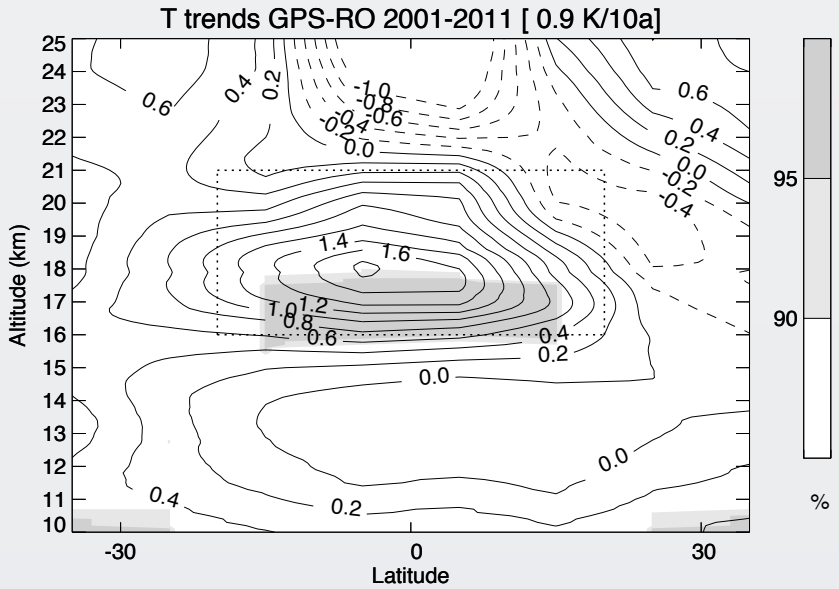
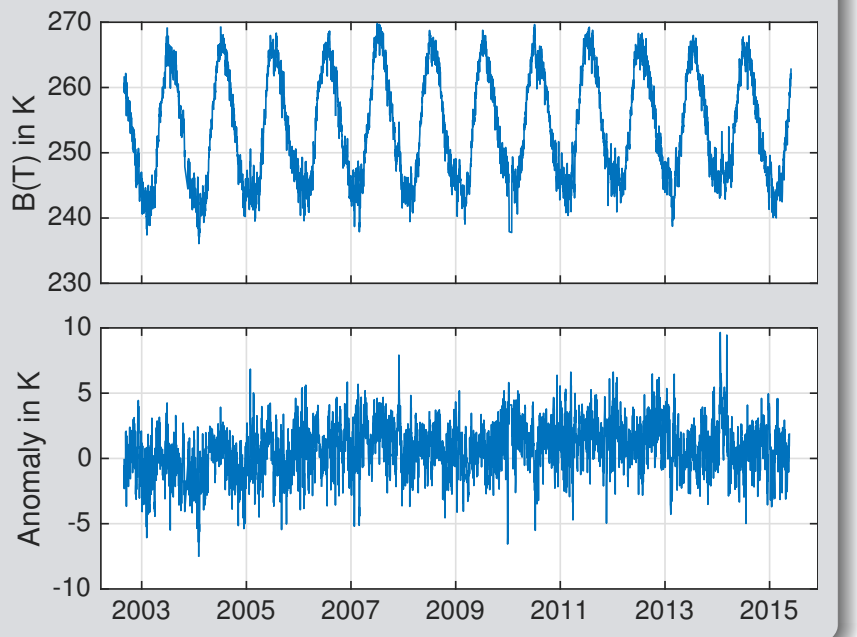



**Figure 1.** Temperature trend 1960–2012 versus latitude and pressure. The value for each latitude and pressure is the medians of the trends at individual stations in that (10°) latitude bin. Units are °C per decade.

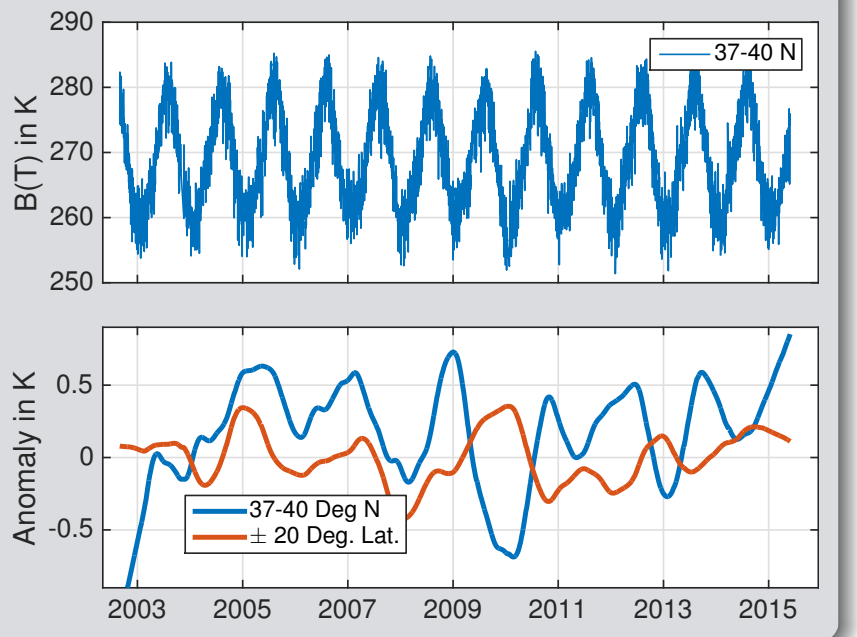


# Radiance Time Series and Anomalies

## Artic 1231 $cm^{-1}$ Time Series



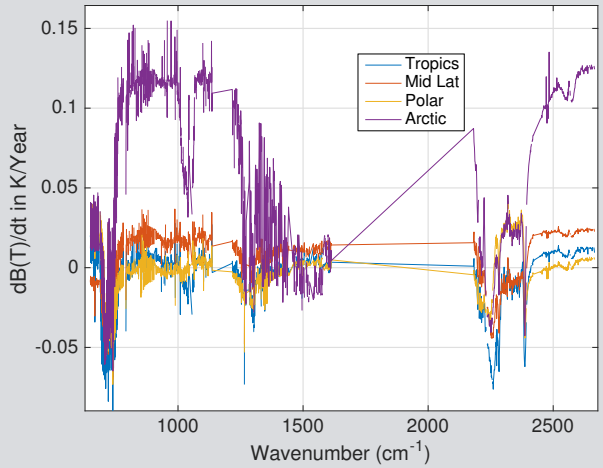

## Mid-lat 1231 $cm^{-1}$ Time Series



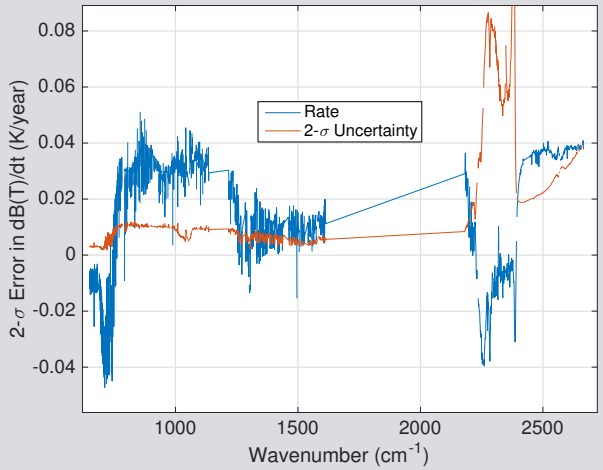

- Data Set: 2378 channels by 40 zonal bins
- Fit to a constant, a time derivative, and annual sinusoids and harmonics.
- Generate jacobians
- Retrieve geophysical rates and anomalies from radiance rates and anomalies.

# Rate Retrieval Inputs

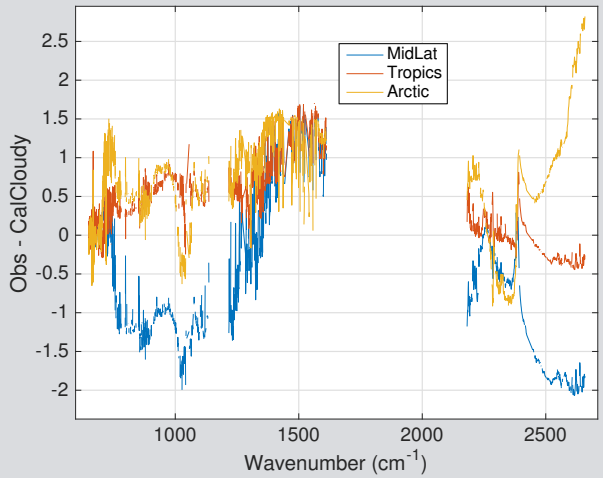
## Sample Spectral Rates




## 45 North Rate with Uncertainty




## Cloudy Simulation Errors




## Cloudy RTA

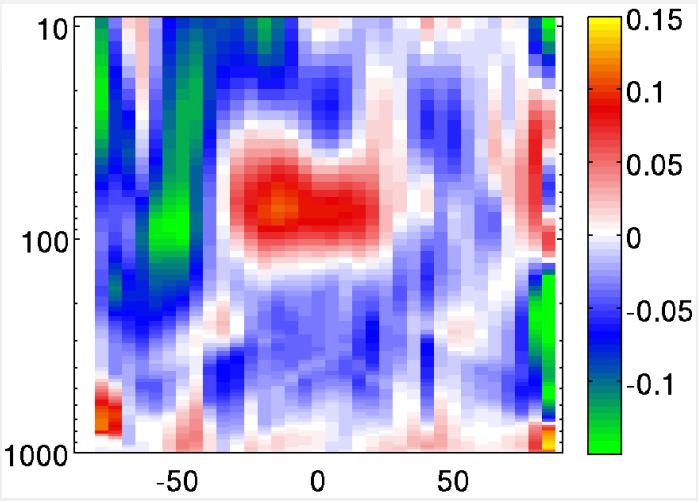
- Approach very tough: all sky
- RTA using ERA clouds statistically good to 0.5-1.0K
- *Easy* to reduce sensitivity to clouds (bin data by cloudiness and use less cloudy as a-priori for more cloudy bins).

# Treatment of Uncertainties in Rates

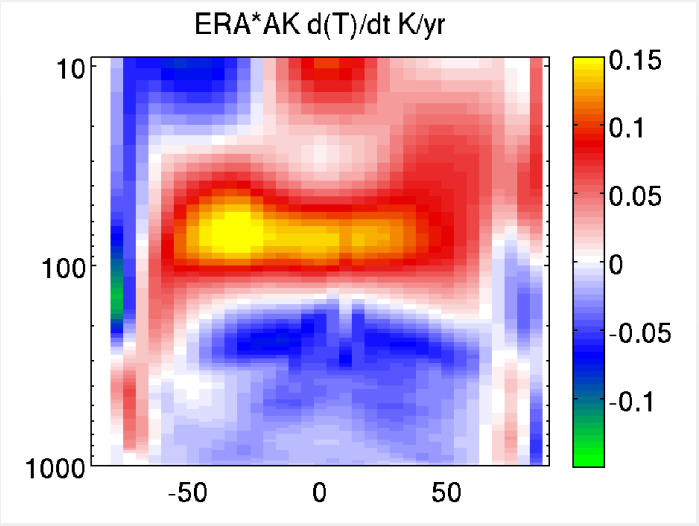
## Two approaches

1. Just comparing data sets: ignore uncertainty in spectral rates due to inter-annual variability. Uncertainty is just estimated instrument stability.
2. Scientifically valid rates: include uncertainty in spectral rates due to geophysical inter-annual variability.

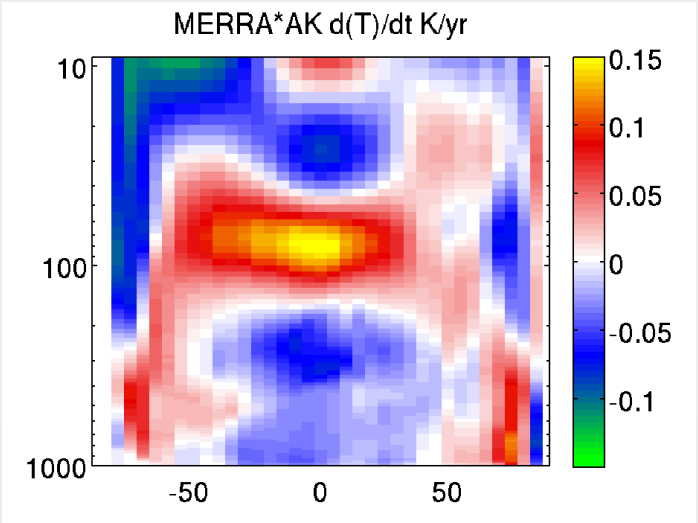
# *10-Year* Temperature Trends: AIRS OLD



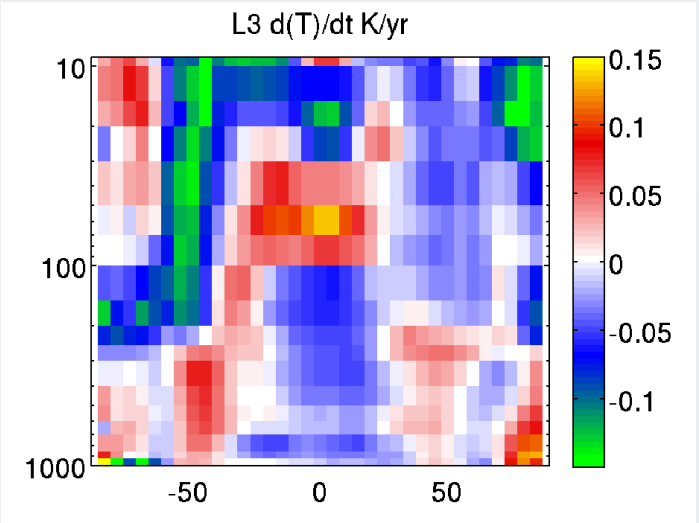

UMBC (K/year).




ERA × Averaging Kernel (K/year)

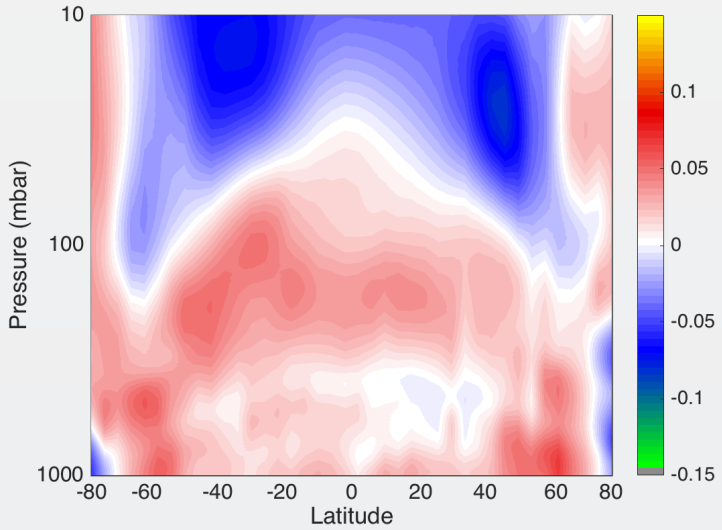



MERRA × Averaging Kernal (K/year)

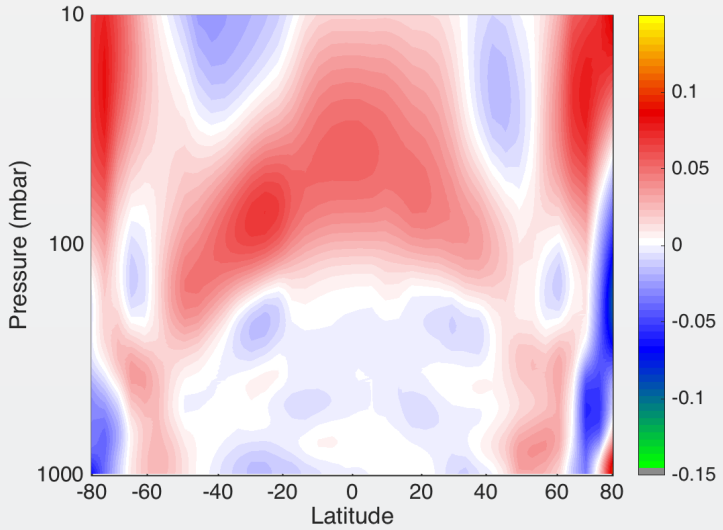



AIRS Level 3 (K/year)

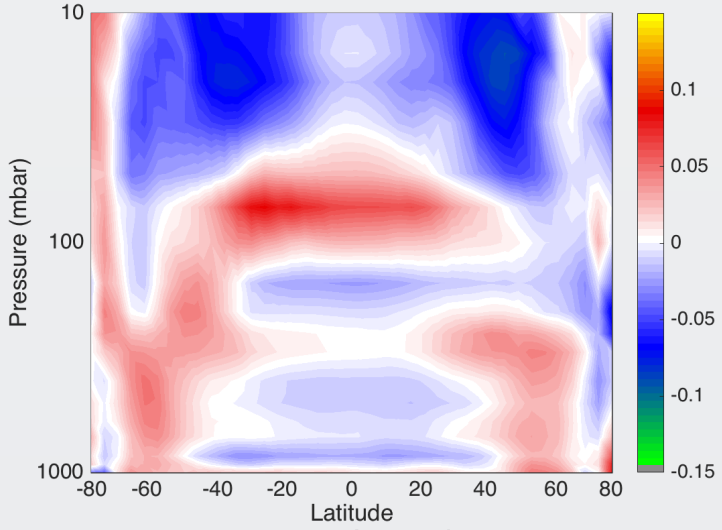
# 13-Year Temperature Trends: AIRS



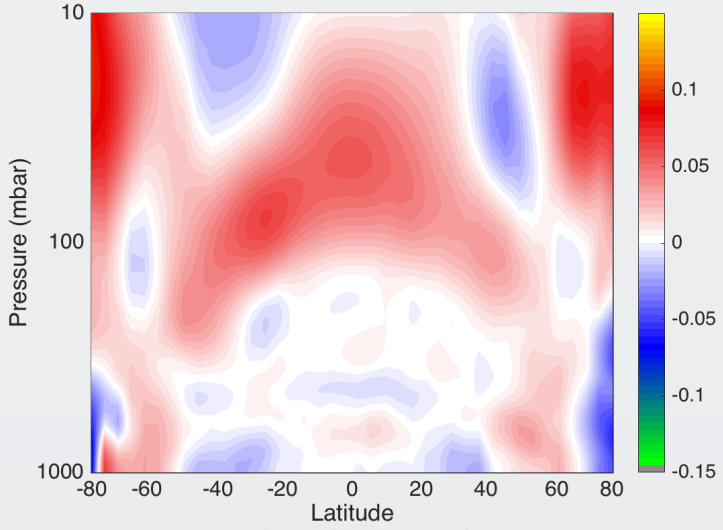

UMBC (K/year).




ERA × Averaging Kernel (K/year)

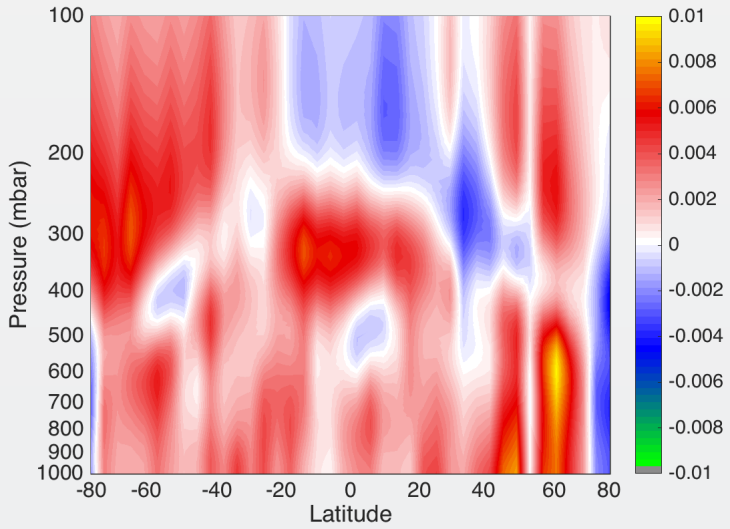



AIRS Level 3 (K/year)

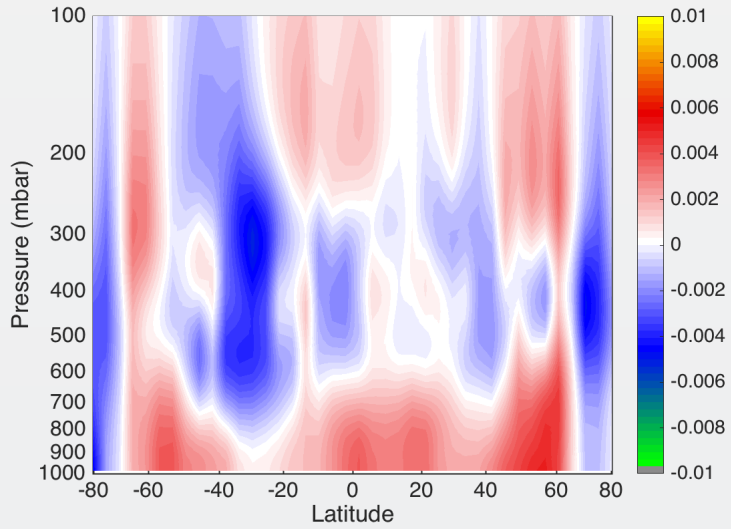



Simulated ERA (K/year)

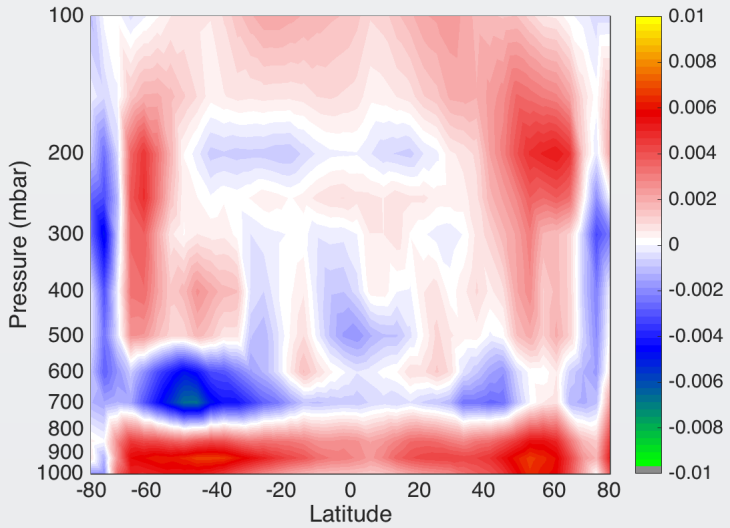
# 13-Year Water Vapor Trends



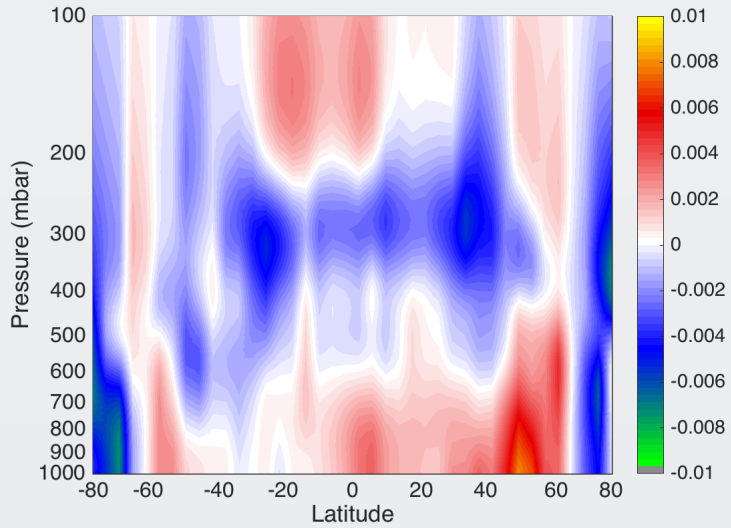

UMBC (fraction/year)




ERA × Averaging Kernel (fraction/year)

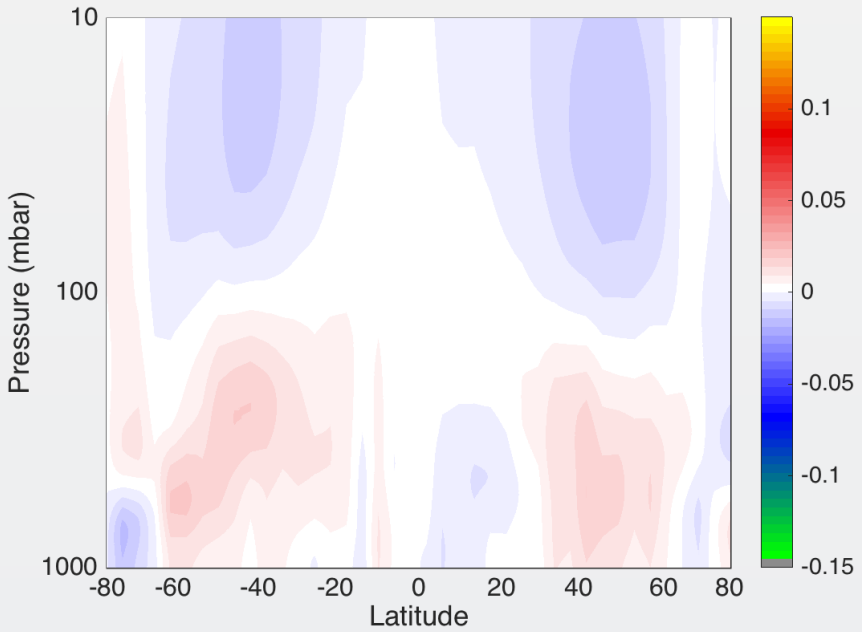



AIRS Level 3 (fraction/year)

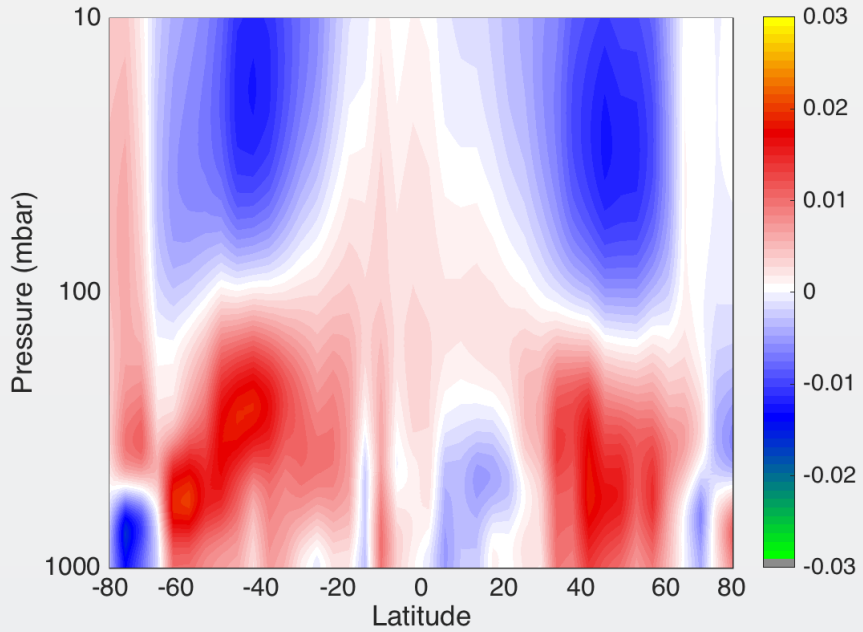



Simulated ERA (fraction/year)

# Scientifically Valid 13-Year Linear Temperature Trends




UMBC (K/year).

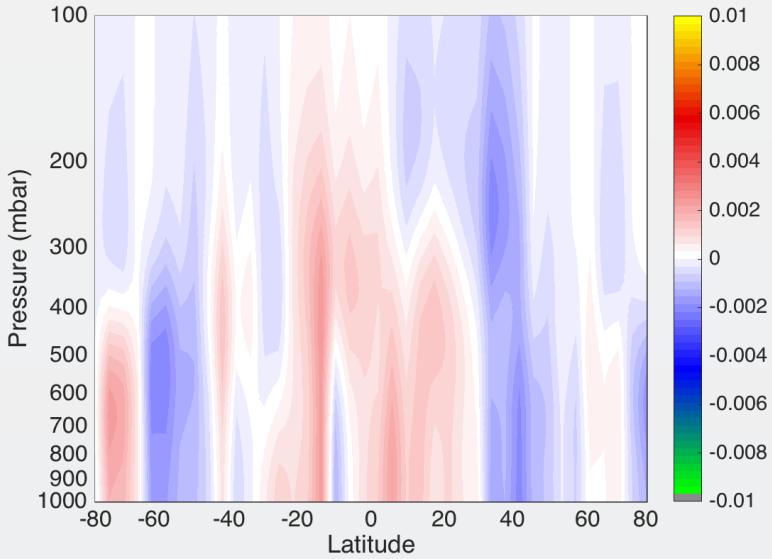



Scale Zoom of UMBC K/year

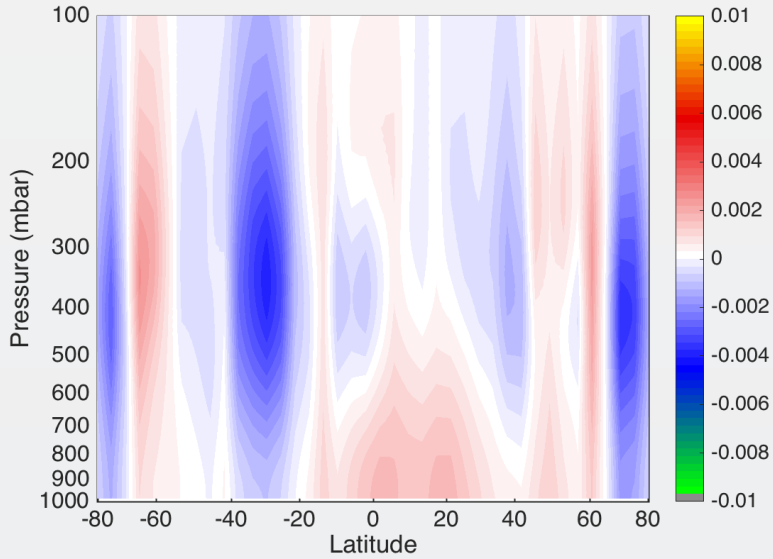
Tropospheric heating, stratospheric cooling. Tropical stratospheric heating quite small.

The AIRS Level 3 temperature product is not amenable to this type of analysis, so the previous results are the best I can do.

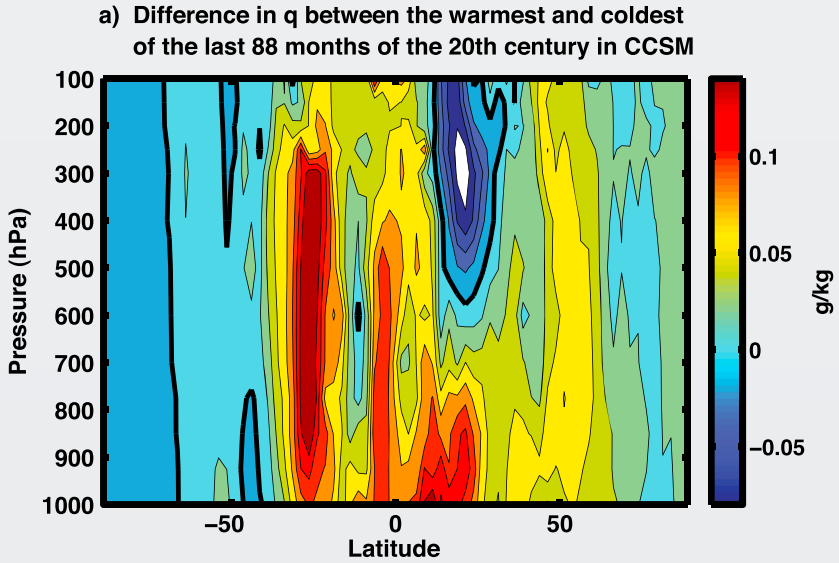
# Scientifically Valid 13-Year Linear Trends in Water?



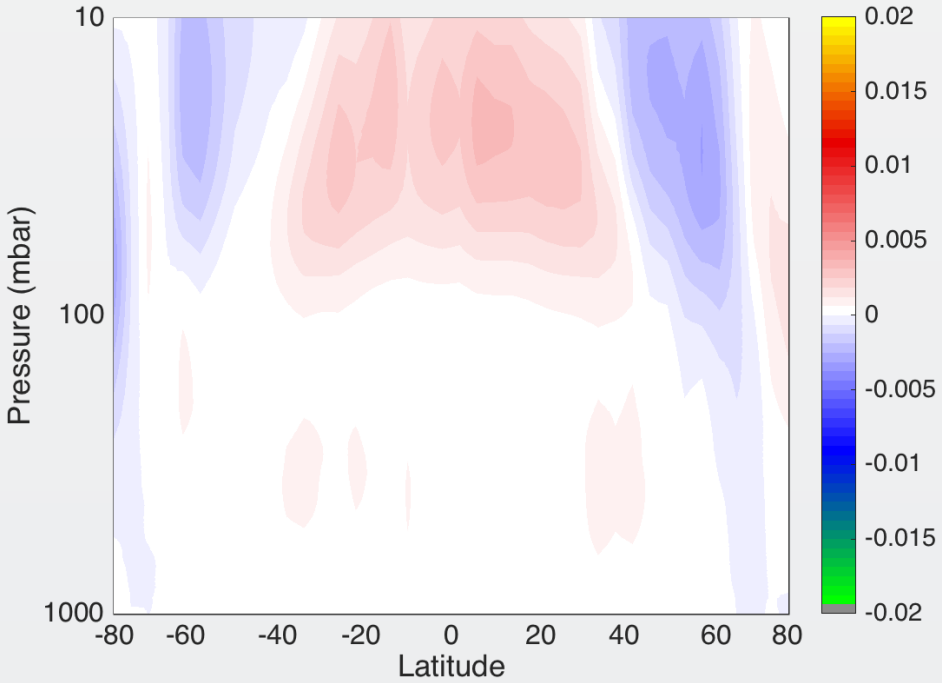

UMBC (fraction/year).



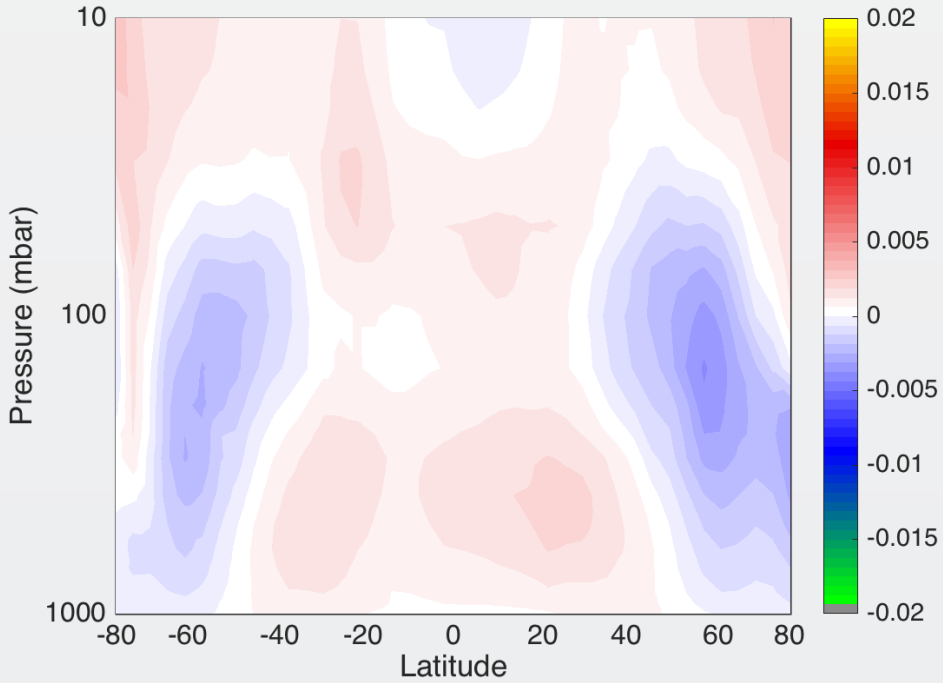

ERA × AK



# Scientifically Valid 13-Year Ozone Trends?



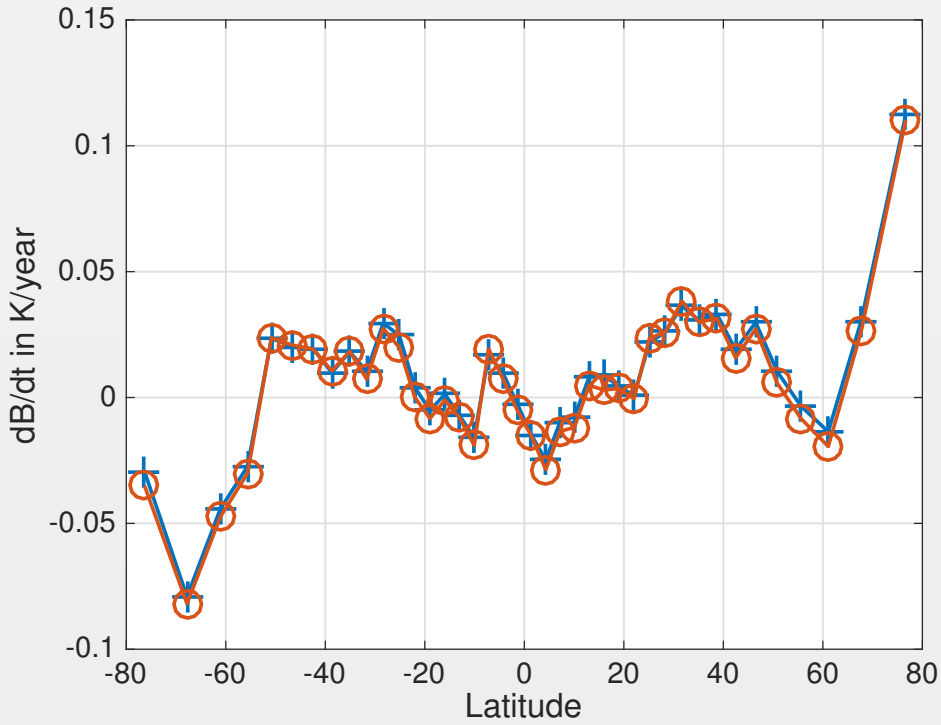

UMBC (fraction/year).



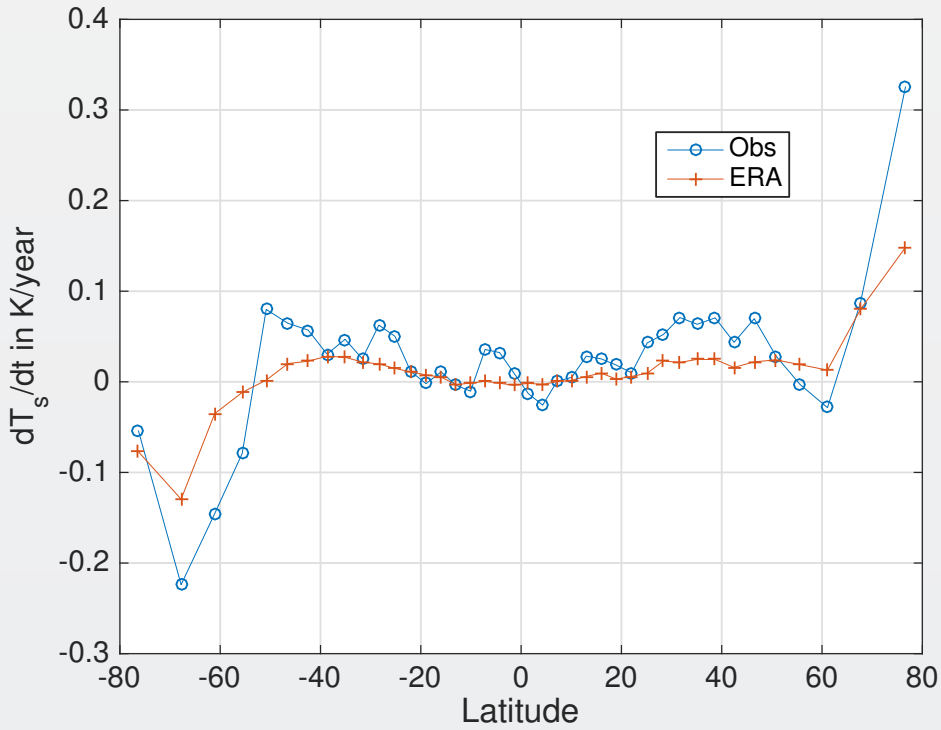

AIRS Level 3

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

# Window Channel Rates and Surface T Retrievals




Window Channel BT Rates

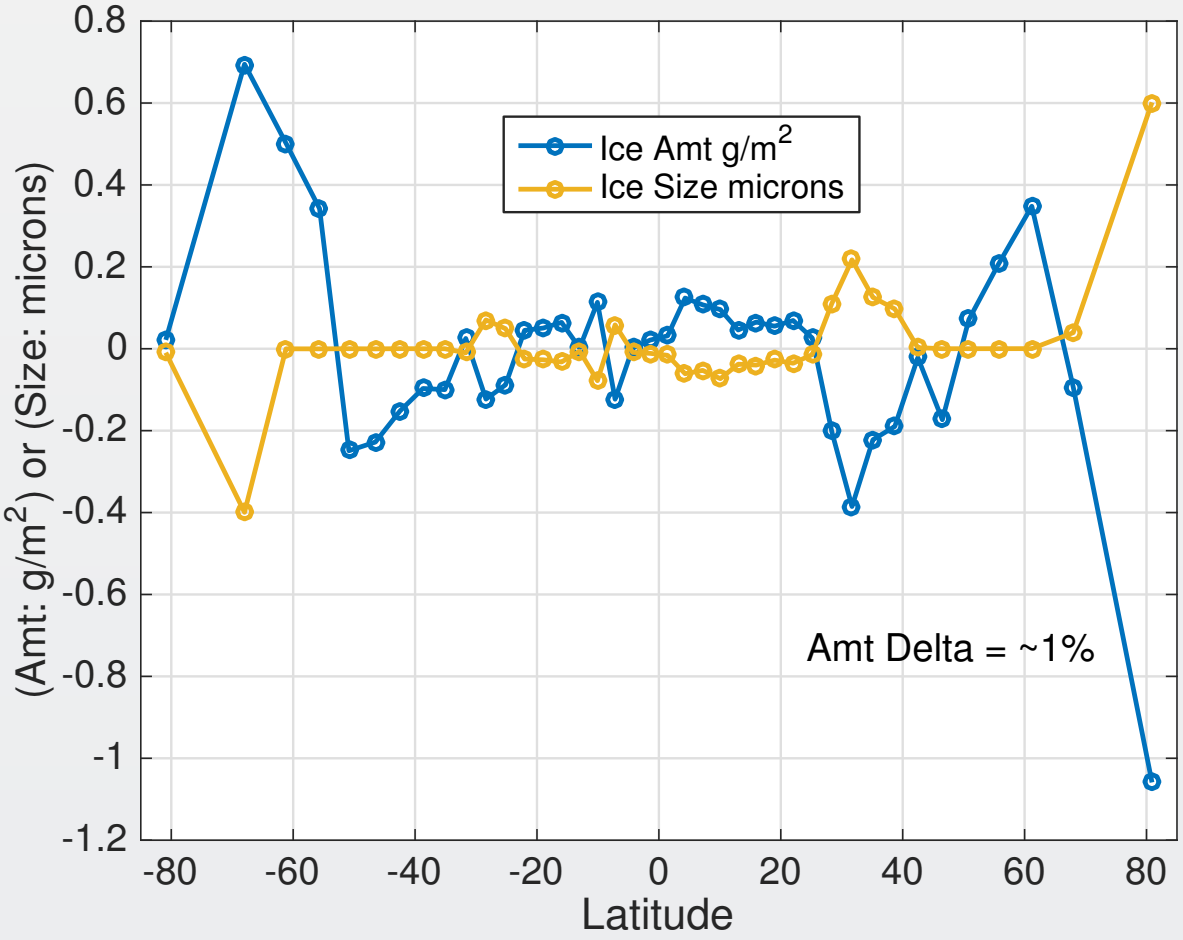



Retrieved Surface T Rates

Our mid-latitude surface temperature rates are quite high?

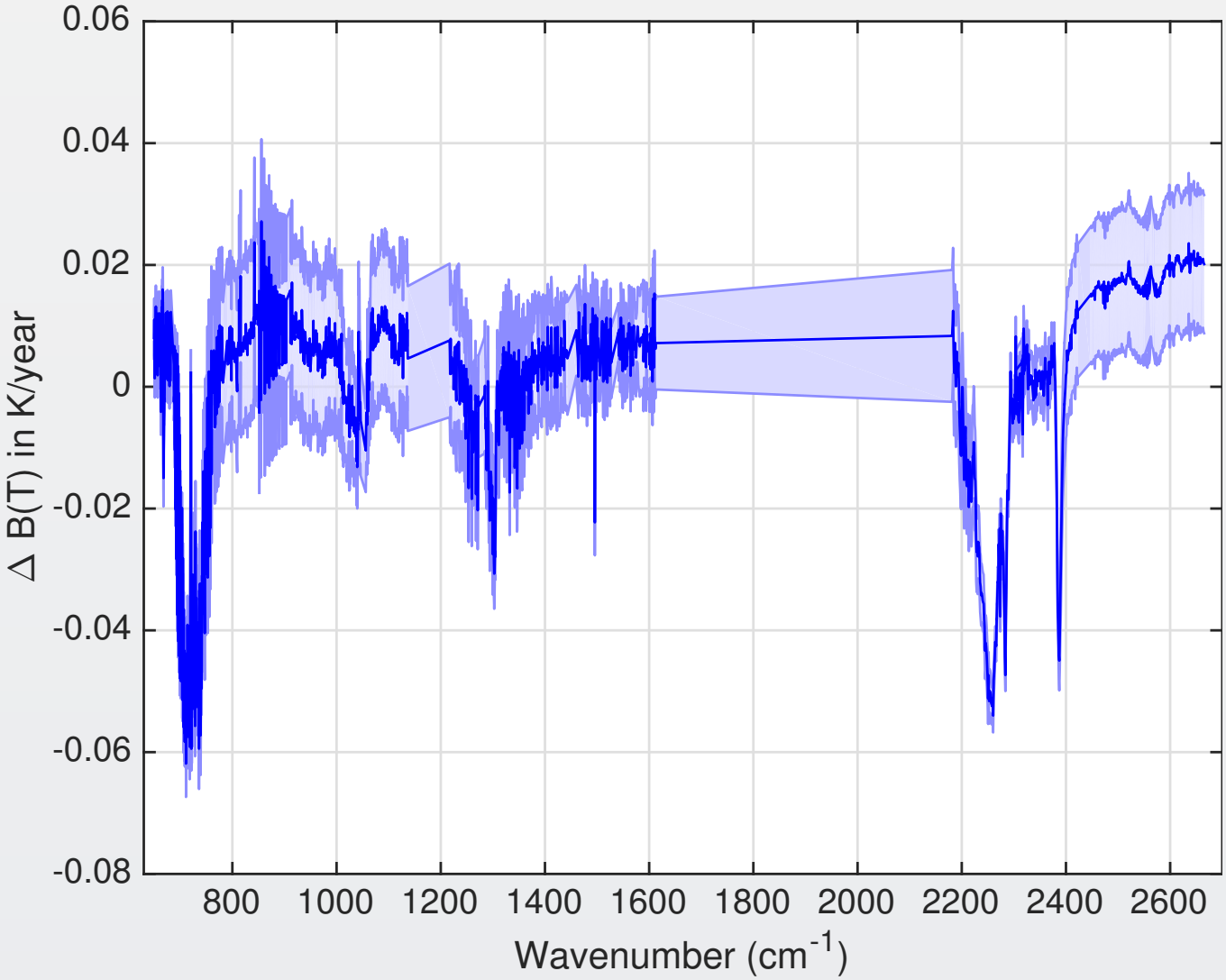
The fix: Separate retrievals in a subset of clear, less clear, full clouds. First results recently done and are encouraging.

# Cloud Trends: Very Preliminary

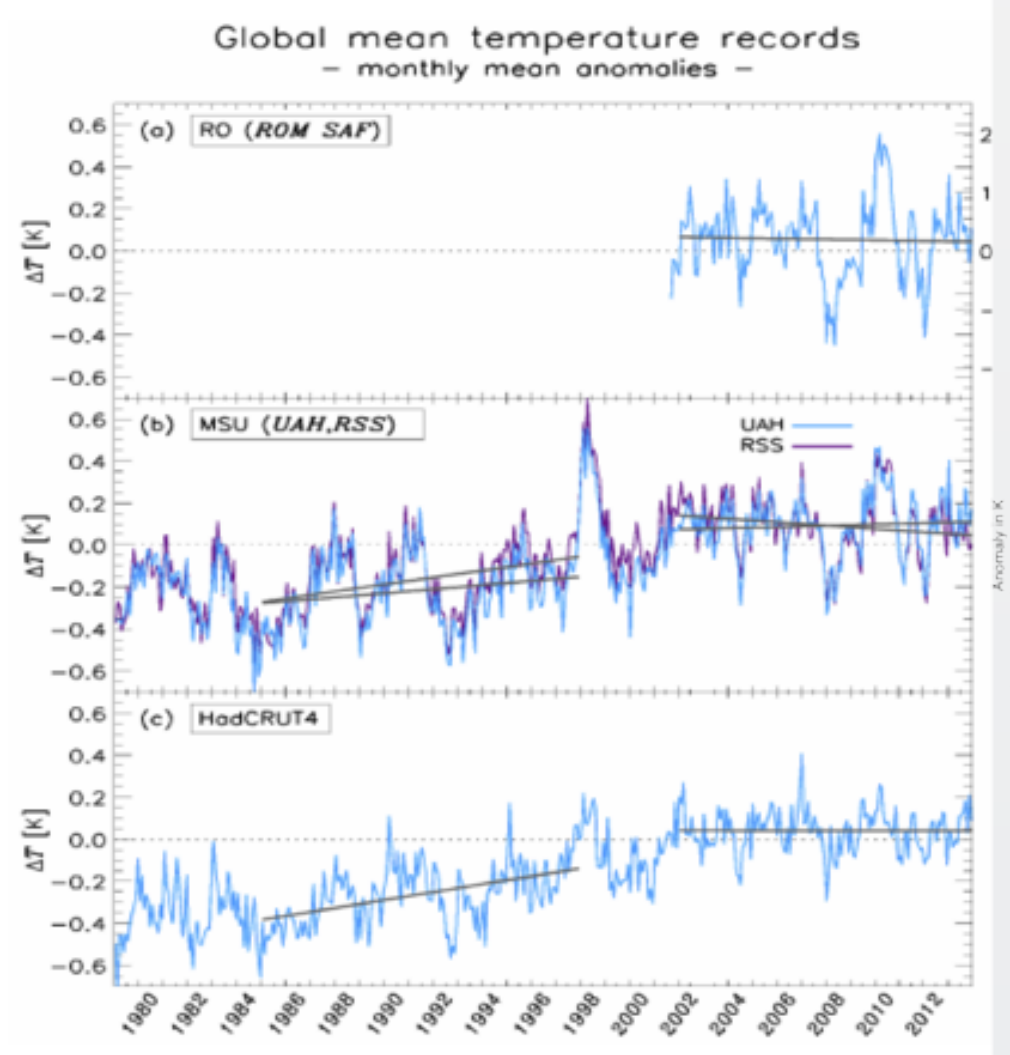



Is amount/size correlation reasonable? Water cloud changes extremely small.

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



# The "Hiatus" (using anomaly retrievals shown later)





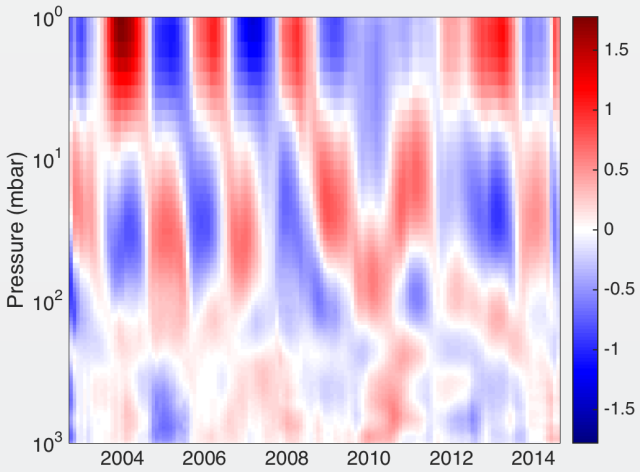
**I used 200 to 950 mbar retrievals.**

# The "Hiatus": Need Vertical Resolution

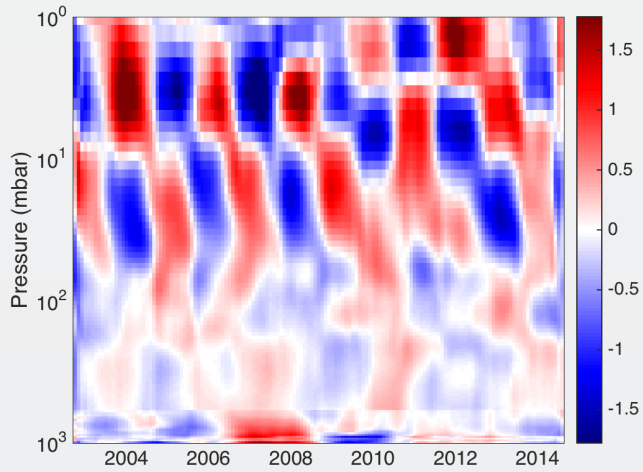
## PRELIMINARY: Incomplete Error Analysis

- Karl: 2000–2014 gets 0.0116 $\pm$ 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 $\sigma$)
  - 950-700 mbar: +0.006 K/year $\pm$ 0.018/2 K/year?? (1 $\sigma$)
- 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?

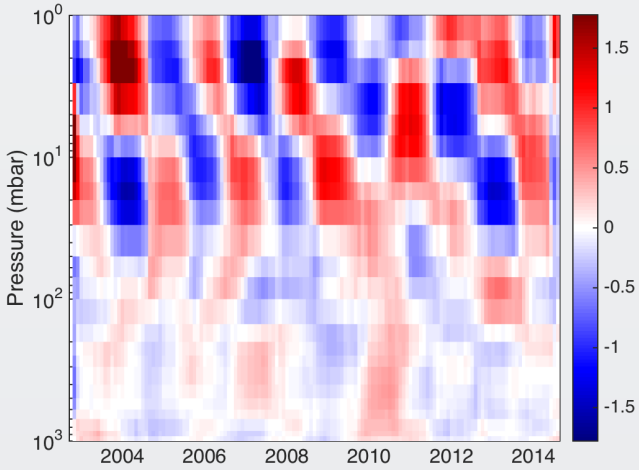
# 27N to 30N Zonal Temperature Anomalies




UMBC from radiance trends (K/year).

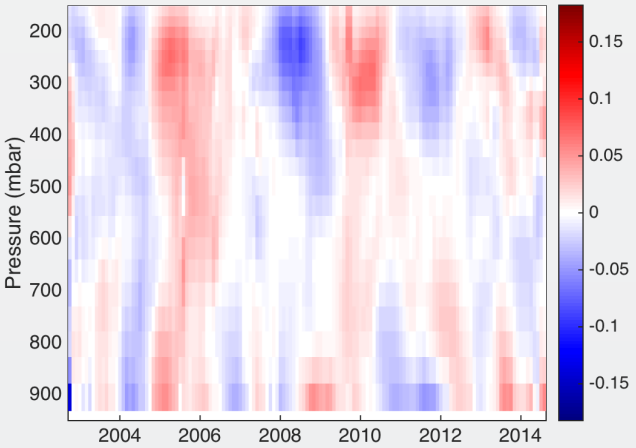



ERA $\times$ averaging kernel (K/year).

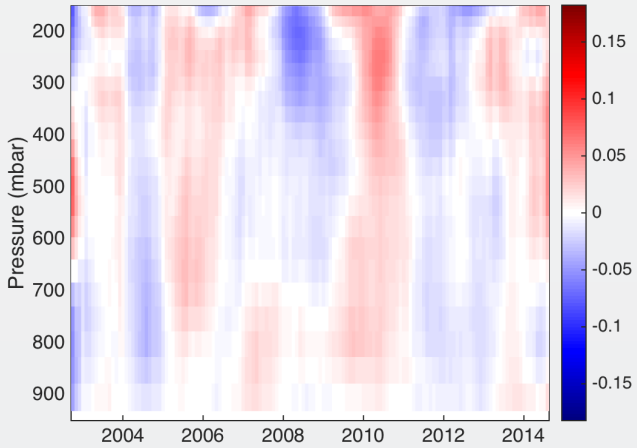



AIRS Level 3 (K/year).

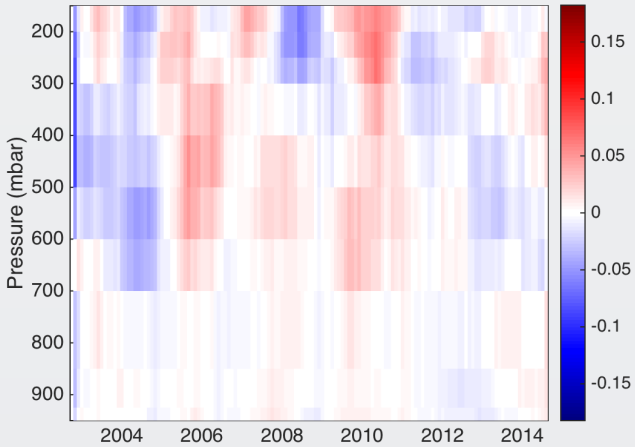
# 27N to 30N Water Vapor Anomalies




UMBC from radiance trends (fraction/year).




ERA × averaging kernel (fraction/year).




AIRS Level 3 (fraction/year).

# Final Thoughts

I believe we need to re-think how to do climate with AIRS (+CrIS), especially trending.

- 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***
- Trending with AIRS Level 3 might? be problematic.