AIRS Plus CrIS/IASI Multi-Decadal Trends and Anomalies with Full Spatial Sampling and Rigorous Error Characterization

AIRS Science Team Meeting

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Motivation

- Produce Level 3 climate-level products with the most simple algorithm possible
- Minimize sensitivity to a-priori estimates, etc.
- Remove artificial sampling biases
- Perform as much analysis in radiance space for error traceability

We concentrate on Level 3 anomalies and trends, which are one main data types used for climate research.

This approach is very simple and quick, so that re-processing of the complete record can be done over and over, allowing rigorous testing of assumptions and algorithm approaches, and quick re-processing if the radiance calibration changes.

Overview: Two Products Proposed

(1) Multi-Instrument Hyperspectral Radiance Climate Time Series

- 1:30 Orbit: AIRS + CrIS, 9:30 Orbit: IASI
- Convert to common ILS to facilitate inter-instrument radiance calibration
- Emphasizes routine/fast processing of data for extensive testing
- Produce time/space grids of radiance time series and anomalies for climate analysis

(2) Level 3 Geophysical Products

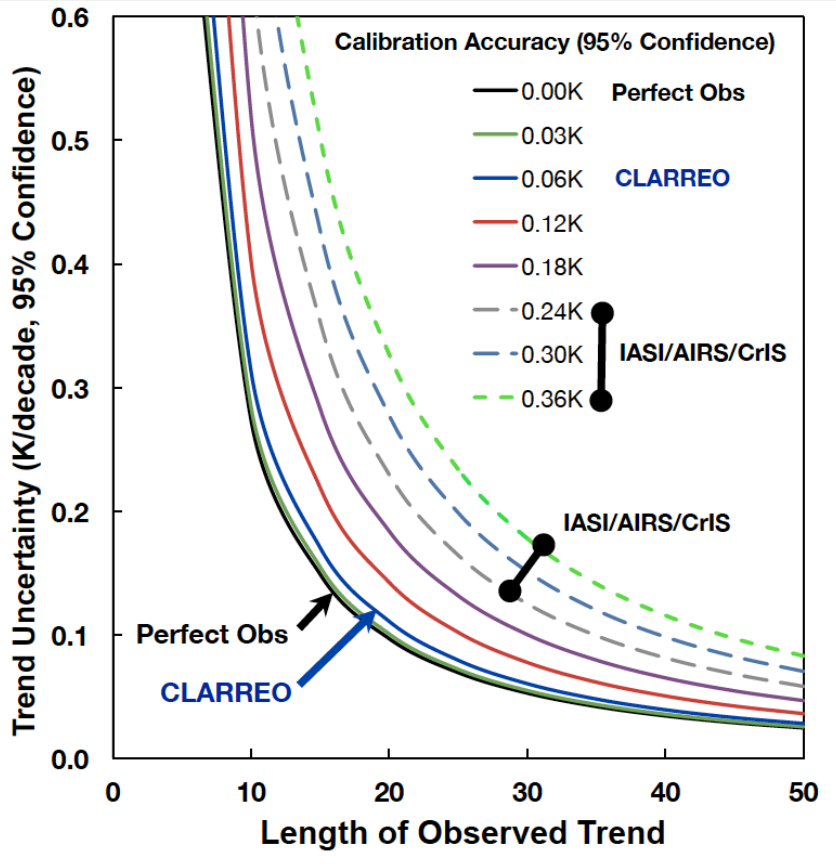
- Generate geophysical (T/Q, etc.) "Level 3" anomaly time series and trends from radiance trends and anomailes
- This approach reduces influence of the a-priori and allows better error estimation?
- May include well established microwave radiance products in retrievals

Validation/Comparisons

- Reanalysis: ERA+, MERRA-2
- Microwave
- Surface and SST climatologies
- GPS-RO (Leroy)

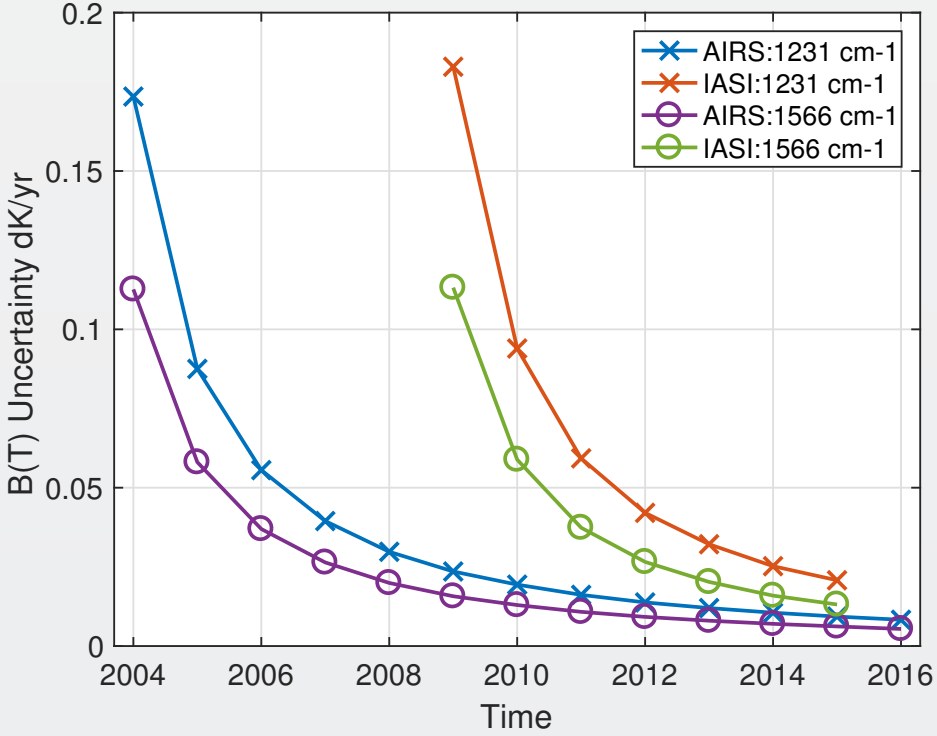
Time Series Length Nearing Climate Scales

CLARREO Schematic: Our Uncertainty?



AIRS, CrIS, IASI are *all* very stable

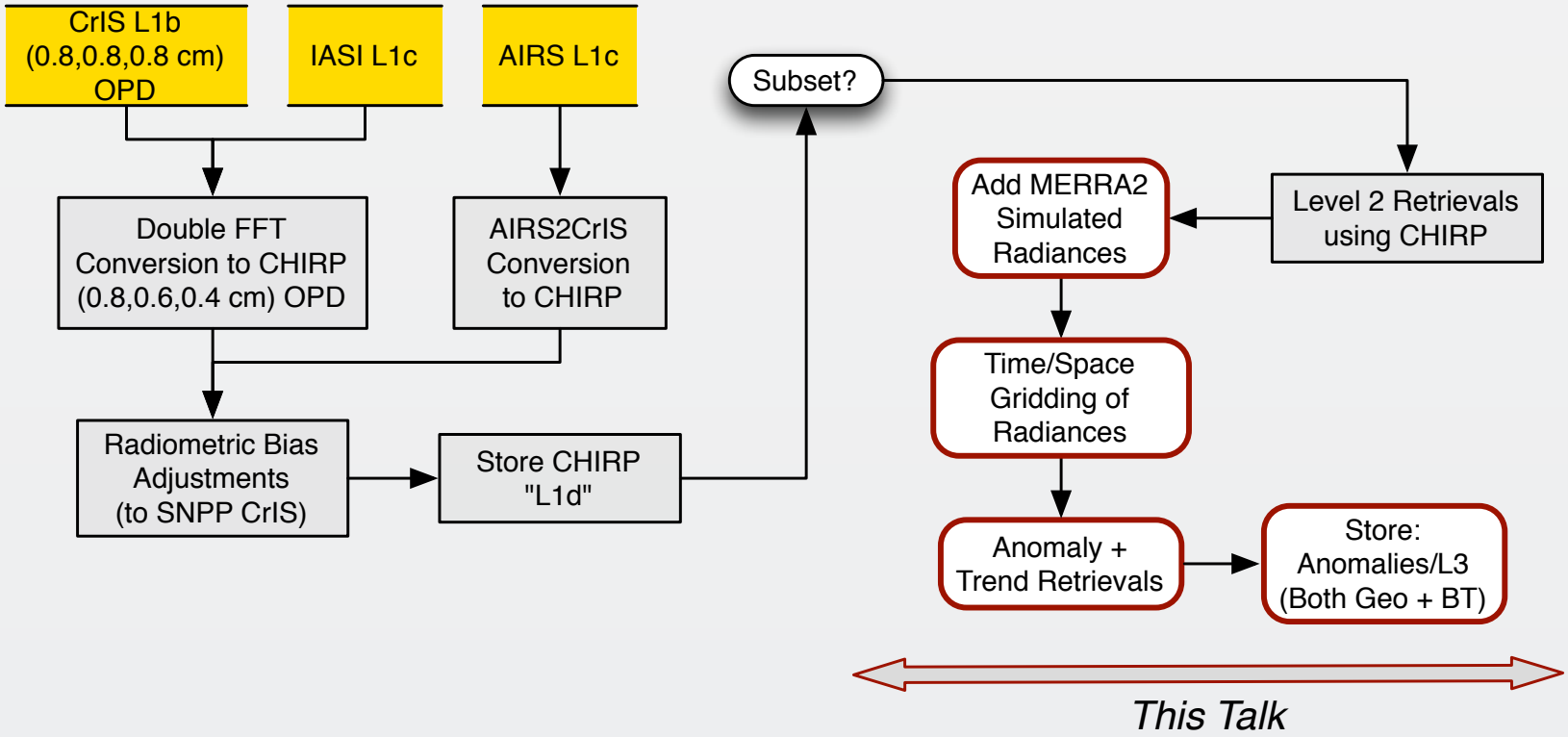
AIRS 14-Year global trends



These are 2-σ B(T) statistical uncertainties due to inter-annual variability.

Some channels, some latitudes not gaussian (strat sudden warmings, QBO, etc.)

CHIRB Processing Flow

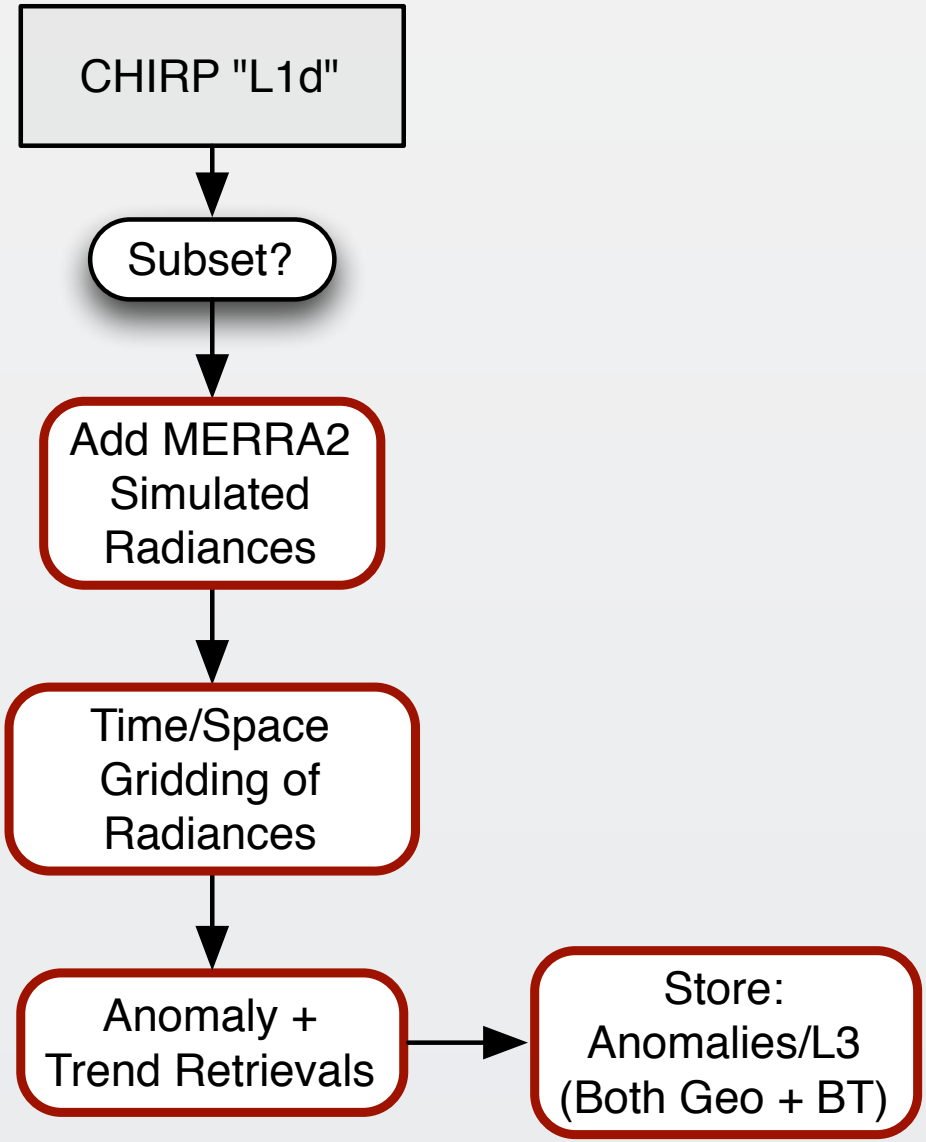


CHIRB: (Common or Climate) Hyperspectral InfraRed Basis

0.8 /0.6 /04

0.0625 / 0.0833 / 0.1250

Time/Space Gridded Radiance Data Flow



Anomaly and Trend Approach

Linear solution for trends with a-priori state = 0 given by,

$$\frac{dx}{dt} = \left(K^T S_\epsilon^{-1} K + R^{-1}\right)^{-1} \left(K^T S_\epsilon^{-1} \frac{dBT}{dt}\right)$$

- x is the atmospheric state
- K are the B(T) Jacobians
- S_ϵ is the observation error covariance matrix.
- R combines empirical regularization (Tikonov L1-type) and the *a-priori* covariance-based terms

S_ϵ covariances represent inter-annual variability and instrument stability. They introduce significant constraints compared to L3 time derivatives.

Jacobian state from standard all-sky retrievals or from re-analysis; high accuracy not needed.

MERRA2, ERA, etc (an aside)

- Barnet's CLIMCAPS will use MERRA-2 as a-priori
- My understanding is that MERRA-2 will be embedded in the CLIMAPS products

This Work

- We match every radiance measurement with ERA (and soon MERRA-2)
- We simulated radiances from MERRA-2 and use them to test our retrieval algorithms
- Our Jacobians are dependent on MERRA-2 profiles
- MERRA-2 also provides partial validation

Suggestion

- Create a separate Sounding Product that co-locates MERRA-2 with each observation
- Provides a common resource for our sounding algorithms and for future users
- Maybe we could get MERRA-2 integrated to the sensor observation time (w/in 1/2 hour instead of 3 hours)?

Data Used for Preliminary Results

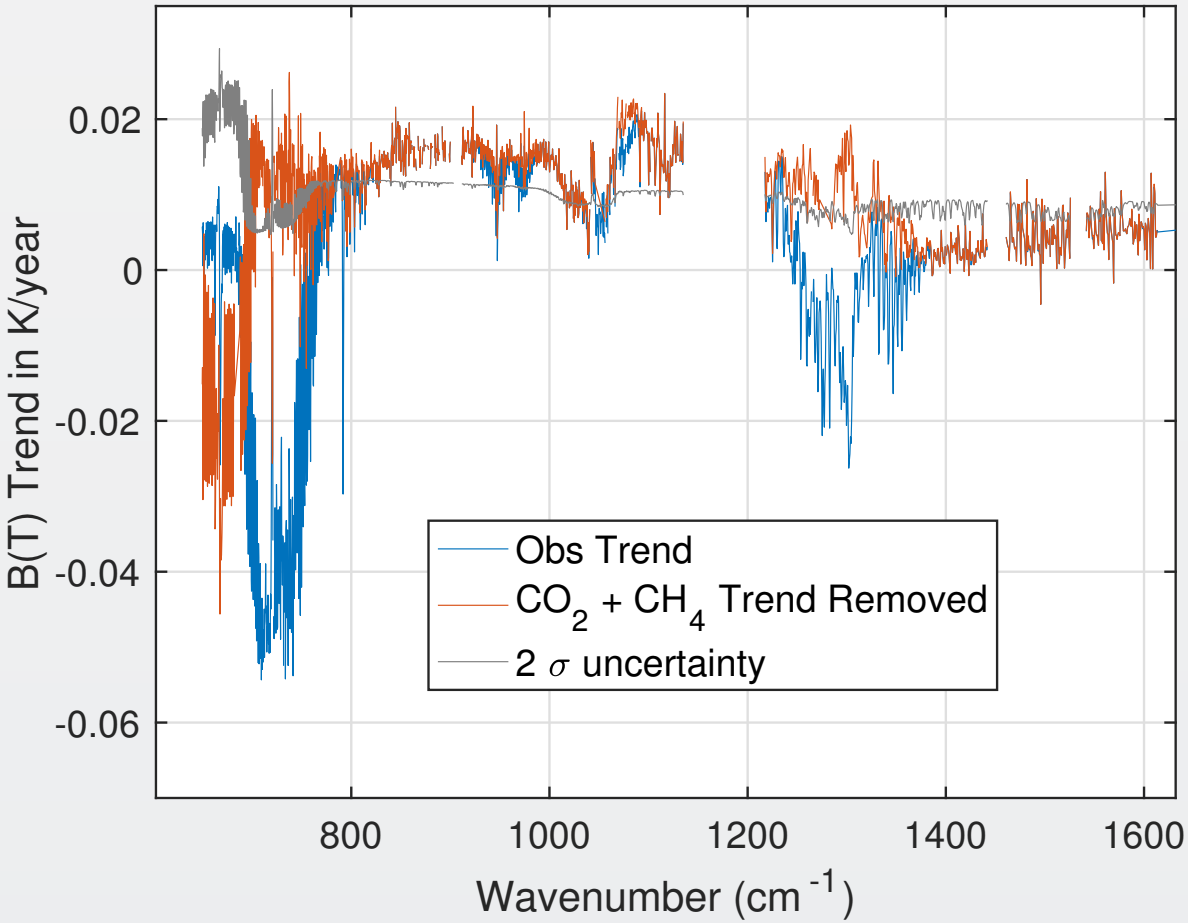
- Start with a ~1% random, area-weighted subset (for quick processing)
- Produce 40 area weighted zonal bins
- Save daily averages of these 40 zonal bins

Long-term: 16 day bins using 3x5 degree grids derived from all data (not from just 1% random subset)

Data set size for preliminary work:

- (5475 days) X (2645 L1c spectral channels) X (40 latitude bins)

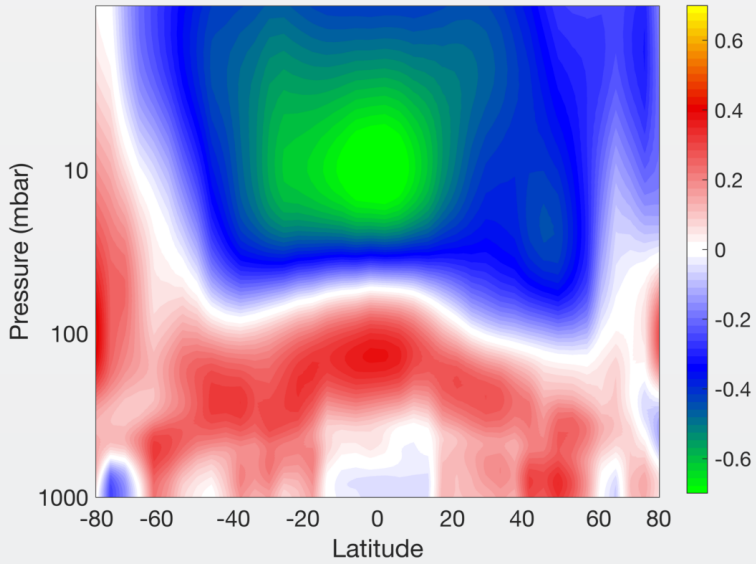
Global B(T) Trend (Area Weighted)



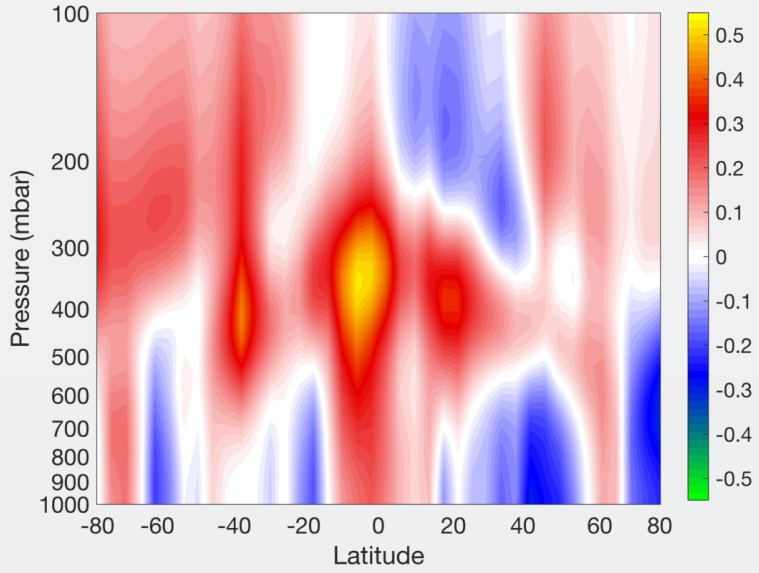
- CO_2 corrected trends show nominal 0.015K/year warming for the surface and throughout the troposphere
- CO_2 corrected stratospheric channels show cooling

Retrieved Zonal Trends ($T/H_2O/T_{surf}$)

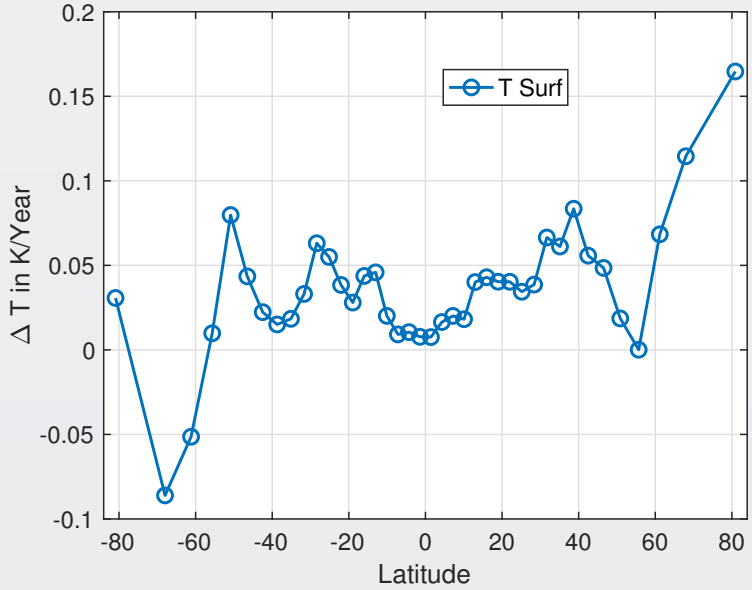
Temperature (K/Decade)



Water Vapor (%/Year)



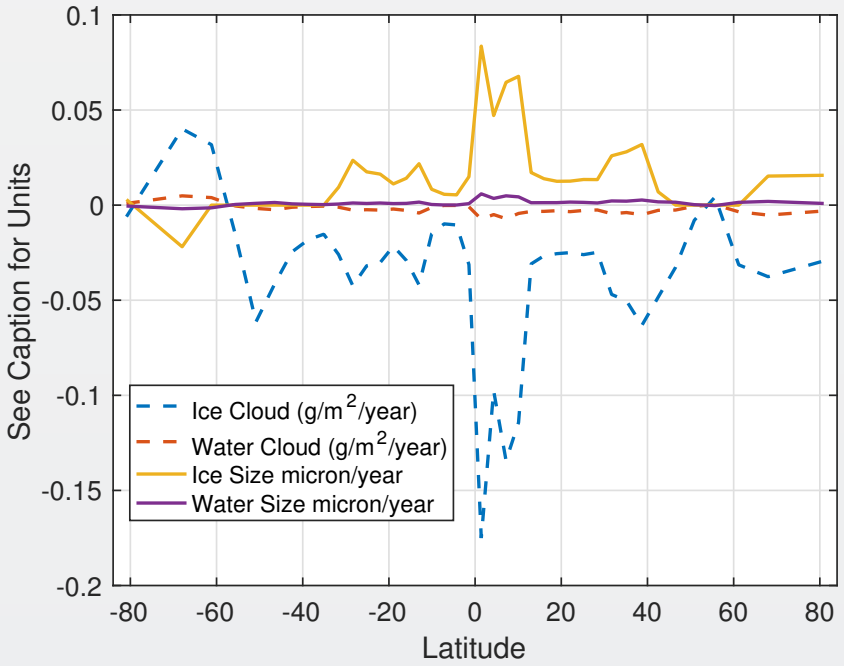
Surface Temperature (K/Decade)



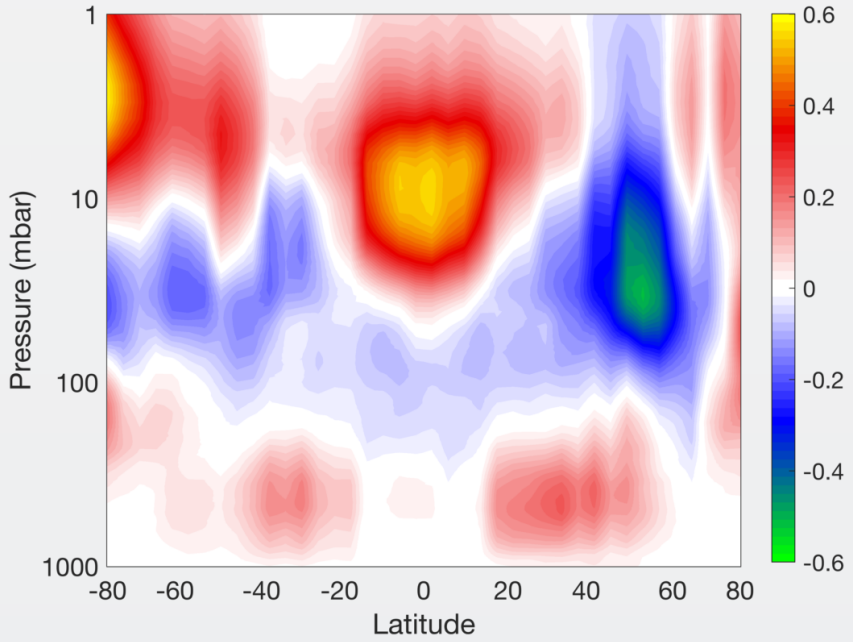
- Tropospheric warming, stratospheric cooling
- Very high arctic warming (as expected)
- Cloud problems ± 20 Deg lat in troposphere?
- Error estimates require off-diagonal measurement error covariance

Retrieved O_3, Clouds

Cloud Trends



Ozone Trends

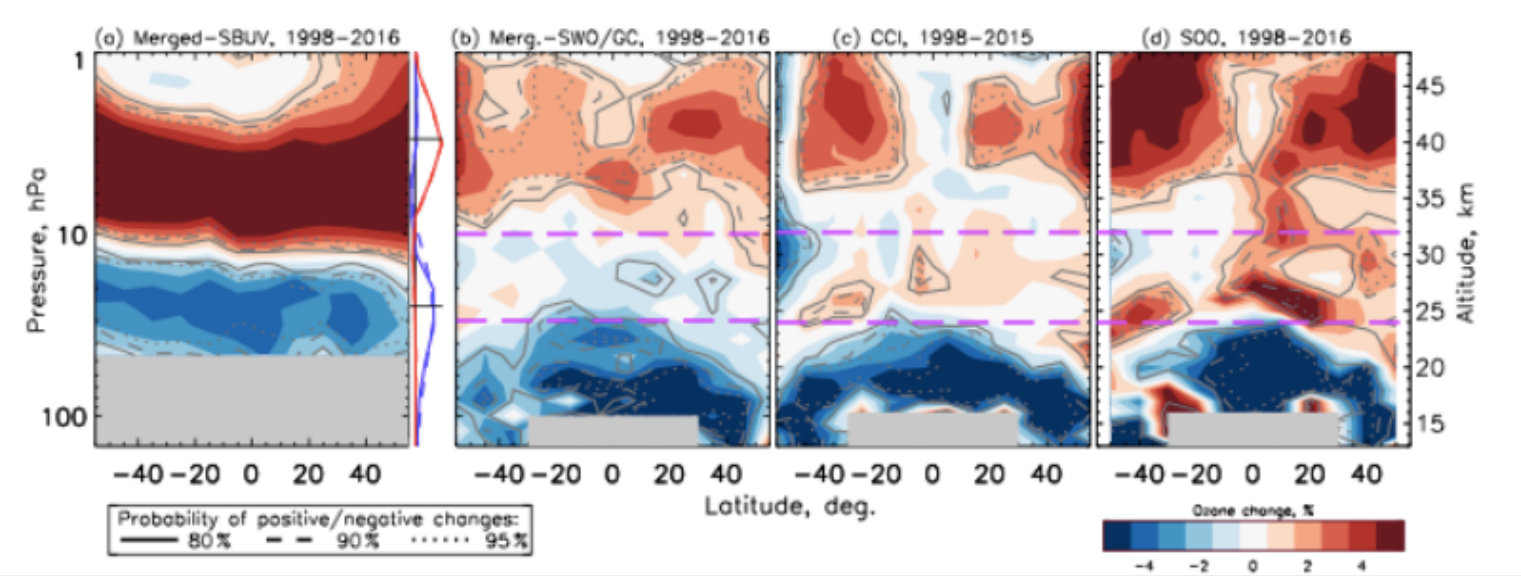


- Ice cloud trends some similarity to B. Kahn's 2018 paper!
- Except for decrease in ice water path near equator

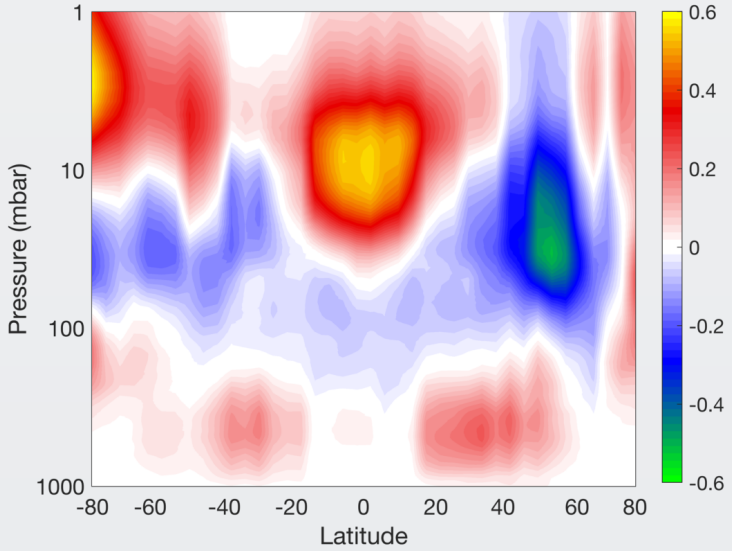
- Tropospheric O_3 increases similar to the recent literature
- Stratospheric variability also in agreement, hot topic right now

Stratopsheric Ozone Trend Inter-Comparisons

Ball et. al., ACP (2018)



AIRS Ozone Trends

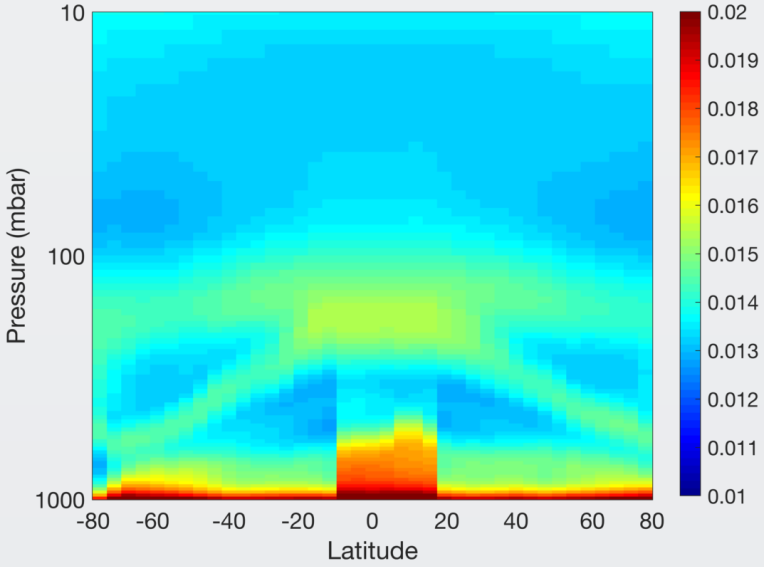


- We see a nominal 10-100 hPa reduction in O_3 (Chinese CFC issue?)
- And, somewhat similar increase in O_3 in the upper strat
- Encouraging results for first look

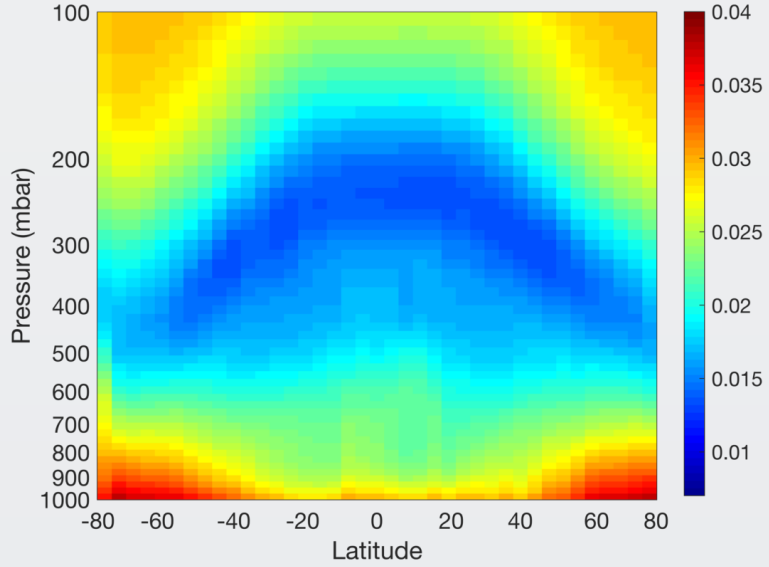
Trend Uncertainties: Only Diagonal Meas. Error Covariance

- Trend retrieval *measurement errors* are (a) inter-annual variability (b) instrument drift, and (c) sampling noise
- Off-diagonal elements of (a) are LARGE and have not been used/characterized, thus error estimates are incorrect. Trial covariance matrices have large condition numbers.
- However, uncertainties using diagonal only errors do show reasonable patterns
- Striping in tropical troposphere likely related to clouds

Temperature Uncertainties

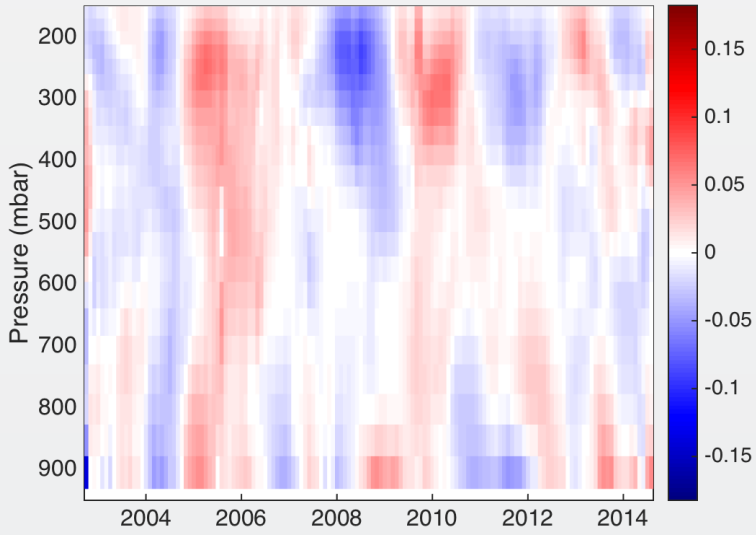


Water Uncertanties

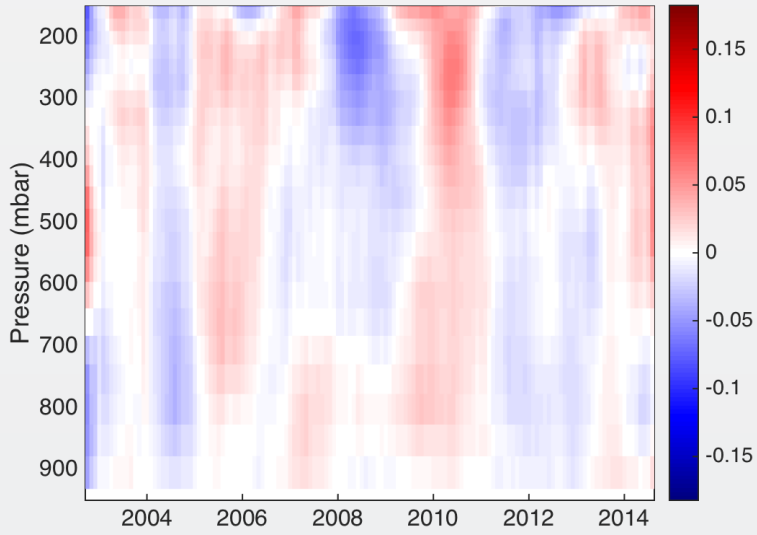


Anomaly Example: Water Vapor (27N to 30N Latitude Zonal)

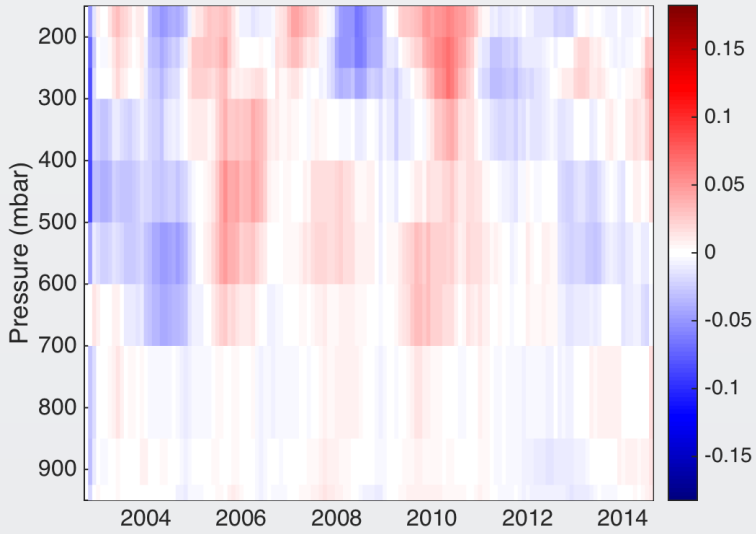
This work



ERA × Avg Kernel



AIRS Level 3



- Input: radiance anomalies, a-priori of zero
- These are old, working on updates
- New work using Jacobians that vary with time, here just using a single Jacobian for all times

Conclusions and Future Work

- Develop gridded radiance product using CHIRP data
- Refine and validate trend and anomaly geophysical products derived from these radiance grids (zonal for now)
  - Introduce off-diagonal measurement error covariances
  - Test TwoSlab cloud approach in more detail
  - Include microwave in trend/anomaly retrievals?
  - Validate, esp. using GPS-RO
  - Retrieve CO_2 and other minor gases (trends and anomalies)