

# **AIRS Calibration for Climate Trend Studies: Status and Future**

AIRS Science Team Meeting

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# Calibration Requirements for Climate Science

- AIRS 17+ year record long enough to address key climate questions
- Stability of radiometric calibration is key
- AIRS sensitivity to CO<sub>2</sub>, SST, etc allows stringent tests of stability

## Climate Science Questions

*All require min ~0.1K/decade  
stability*

- Global Trending: T(z), H<sub>2</sub>O (z), T<sub>surf</sub>
- Water vapor feedback (Does relative humidity vary)
- Cloud feedback
- Trends in PBL cloud occurrence
- OLR anomalies separated by cause: T/H<sub>2</sub>O/cloud/surface, etc.

## Hyperspectral IR Advantages

- AIRS senses both climate forcings, and responses
- Clean separation of tropospheric vs stratospheric temperature trends (unlike microwave)
- Multiple long-term overlapping missions (AIRS, CrIS, IASI)
- AIRS, CrIS, IASI already agree to ~0.1-0.3K and can be merged to 0.03K or better.

Significant AIRS calibration drifts have **already** resulted publication of in-accurate data that were publized by NASA/GSFC and the media (Washington Post, Scientific American). *This talk suggests how to make AIRS an accurate instrument for climate science.*

# Weather versus Climate Research

## Weather Applications

- AIRS original focus was for NWP
- Both 1Dvar retrievals and data assimilation *require* bias removal
  - NWP: biases due to the instrument, RTA, model
  - Retrievals: biases due to the instrument and RTA
  - Bias removal is generally in the ~0.1-0.3K range
- Radiometric accuracy is important
  - But, below the nominal ~0.3K range we cannot differentiate instrument vs RTA errors.
  - Spectroscopy errors are at the 1-2% level, or 0.1-0.3K

## Climate Applications

- Anomalies are the main language of climate observations
- Although energy budget and fluxes are important, AIRS is not a major contributor
- For AIRS, radiometric stability is most fundamental calibration requirement

Hyperspectral IR instrument stability appears to be 1-2 orders of magnitude better than absolute accuracy. This is where we can shine, especially with a 17+ year record.

# Climate Product Characteristics

## Uncertainty Estimates

- If we provide something unique, validation will be difficult
- Internal product uncertainty estimates will be far more important than for weather applications
- Establishing uncertainties for products is a NASA ROSES requirement!

## Reproducibility

- Reproducibility of results is becoming increasingly important
- Difficult to achieve with our Level 2 approach
- For climate simpler algorithms with reproducible results would enhance our impact on the broader community

There is a long history of controversies in climate measurements (esp. microwave temperature trends). AIRS derived results will be heavily scrutinized, we need to be prepared for that to retain trust.

# AIRS Stability Calibration: An Approach

- External standards needed to establish stability
- CO<sub>2</sub> and possibly N<sub>2</sub>O and CH<sub>4</sub> can provide those standards
  - CO<sub>2</sub> is well mixed (on long time scales) and extremely well known
  - Establish AIRS stability by retrieving CO<sub>2</sub> anomalies (vs time)
- SST is the other well established climate record
  - Similarly, use retrieved SST anomalies to test AIRS stability
- Land surface temperatures are another possibility, although less reliable than SST but of great interest and heavily studied.

Essentially you need to perform climate-level retrievals to test the capabilities of your instrument.

A *key* requirement is the need to reprocess the *full record* many times. NOT possible with Level 2 approach! Need **fast** alternatives that may also address issues of reproducibility.

# Characteristics of AIRs Long-Term Radiance Trends

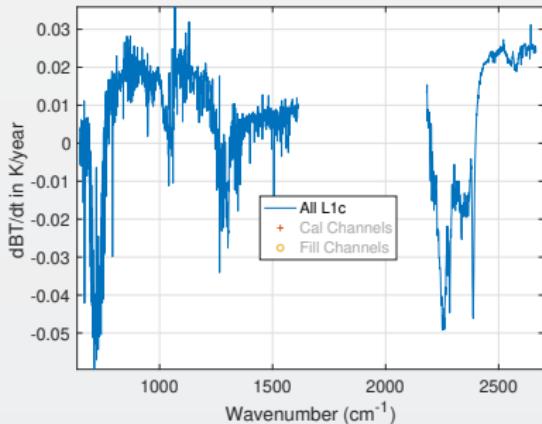
- Subsequent results use either:
  1. Clear ocean subsetting data; or
  2. A random, area-weighted subset of all scenes
- Clear scenes are zonally averaged into 40 latitude bins of 16 days length
  - The anomalies of these  $B(T)$  time series are created (remove seasonal, constant)
  - An optimal estimation retrieval for  $T(z)$ ,  $H_2O(z)$ , SST,  $CO_2$ ,  $CH_4$ ,  $N_2O$ , and CFCs is performed

## OE Parameters

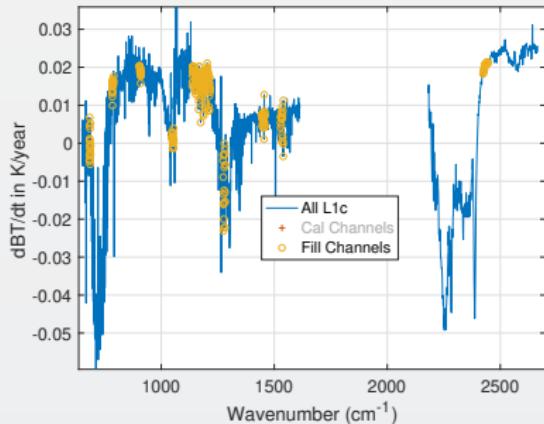
- First: only channel where  $A/B$  constant through the mission
- But: include more channels than most retrievals, since we want to evaluate as many channels as possible
- Observation noise covariance (diagonal) computed from  $Nesr$  from all scenes,  $< 0.01K$
- A-Priori trends are zero
- A-Priori covariance (empirically spread across diagonal) are equal to estimated change in gas for 1-year, so 2 ppm for  $CO_2$ . Using 5 ppm covariance made little difference.
- Since we start with  $a\text{-priori} = 0$ ,  $CO_2$  changes so large needed finite-difference Jacobians
- Jacobians generated with kCARTA (LBL) from ERA profiles. (Not difficult to switch to retrievals to get 16-day mean state one day.)

# AIRS Global 16-Year B(T) Trends (no OE fitting yet)

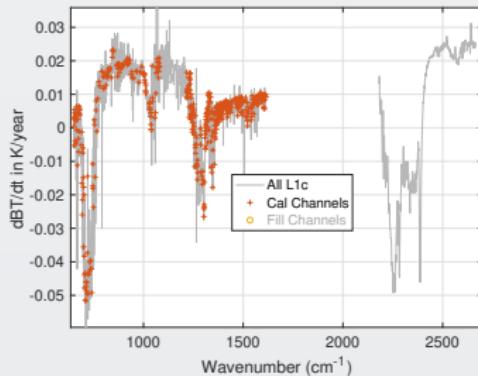
All channels (inc. fill)



Fill channels marked



Calibration channels



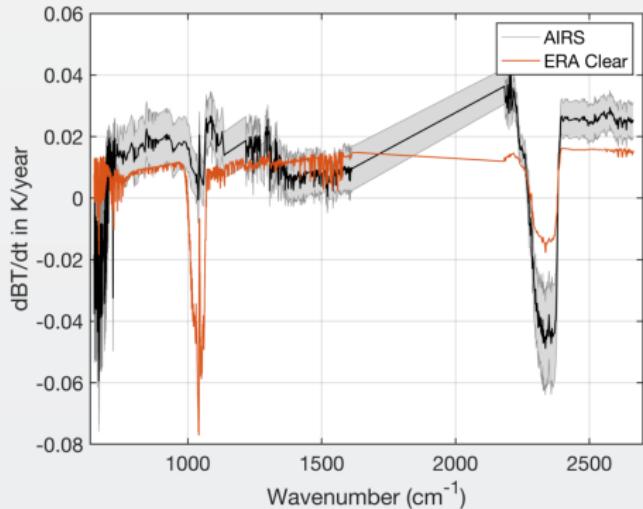
Channels used for calibration testing marked.

These channels have no A/B state changes, good S/N, small drift

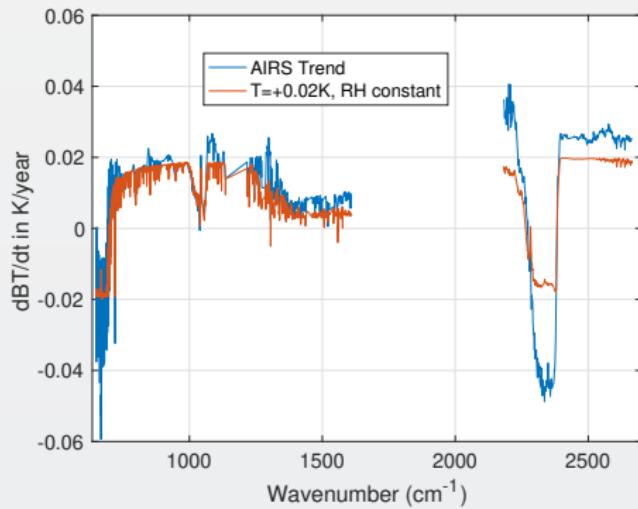
Note sparsity of CO<sub>2</sub> channels in tropospheric sounding region

# $\text{CO}_2$ and $\text{CH}_4$ Trends Removed, Fitted Chans Only

AIRS + ERA



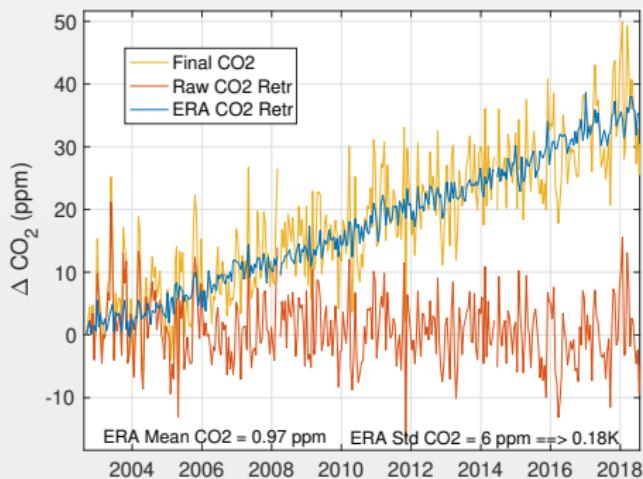
AIRS w/ 0.02K dT, RH constant



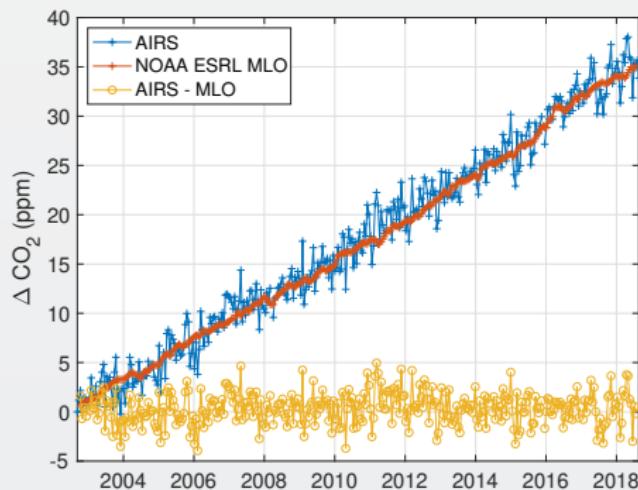
- Uncertainty (gray) is geophysical (Std over latitude).
- RHS: Trop  $T(z) + 0.02\text{K}$ , Strat  $T(z) - 0.02\text{K}$
- $\text{H}_2\text{O}$  trend is close to constant RH. (Varies with latitude).
- Could suggest RH is a bit lower over time??
- Shortwave appears to have a positive drift

# CO<sub>2</sub> Anomaly Fit for MLO Latitude

## Fitting Trick

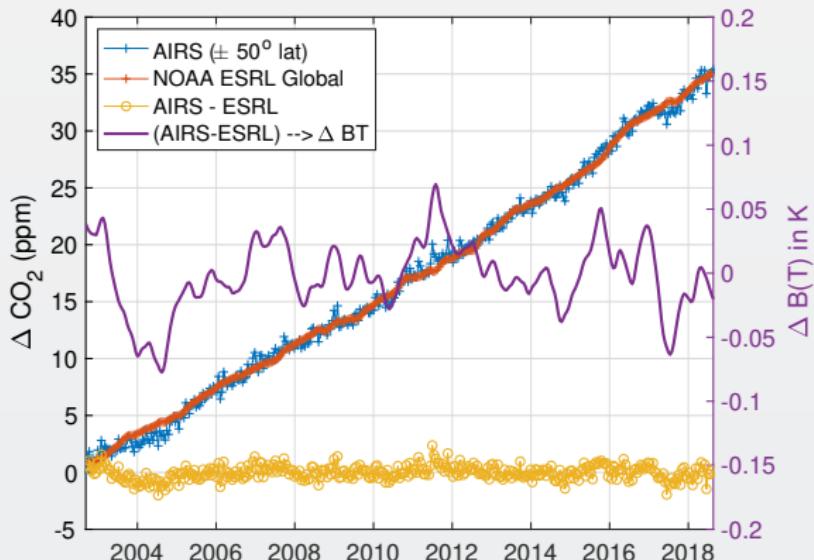


## Fitted CO<sub>2</sub> Anomalies



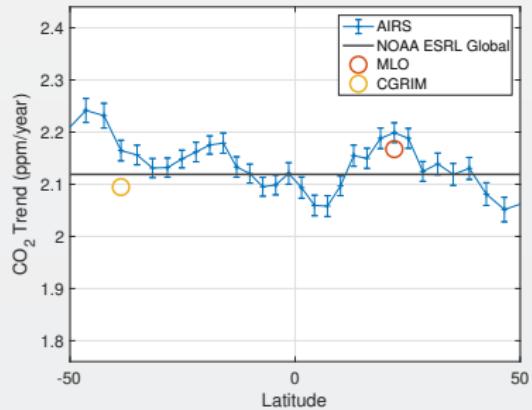
- ERA simulations done per footprint
- Fit ERA simulation for CO<sub>2</sub>
- Removes co-linearity? and lowers "noise"

# CO<sub>2</sub> Anomaly Converted to B(T) Trends

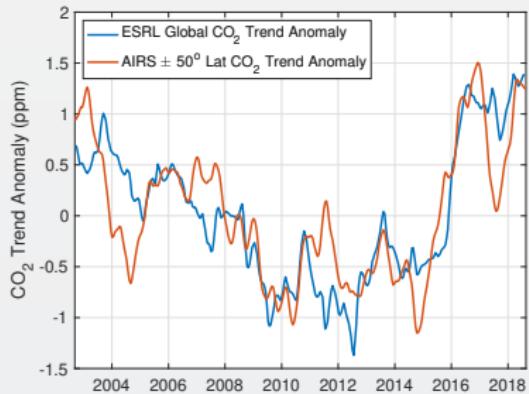


# Other CO<sub>2</sub> Diagnostics

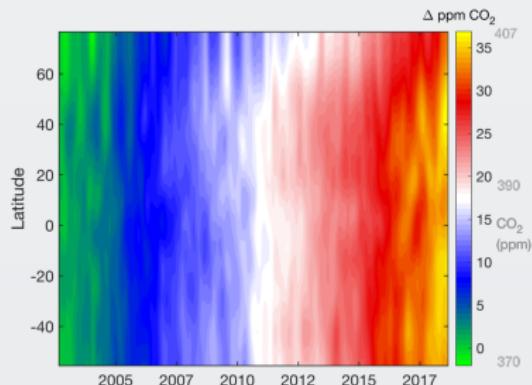
## Growth Rates



## Growth Rate Anomaly

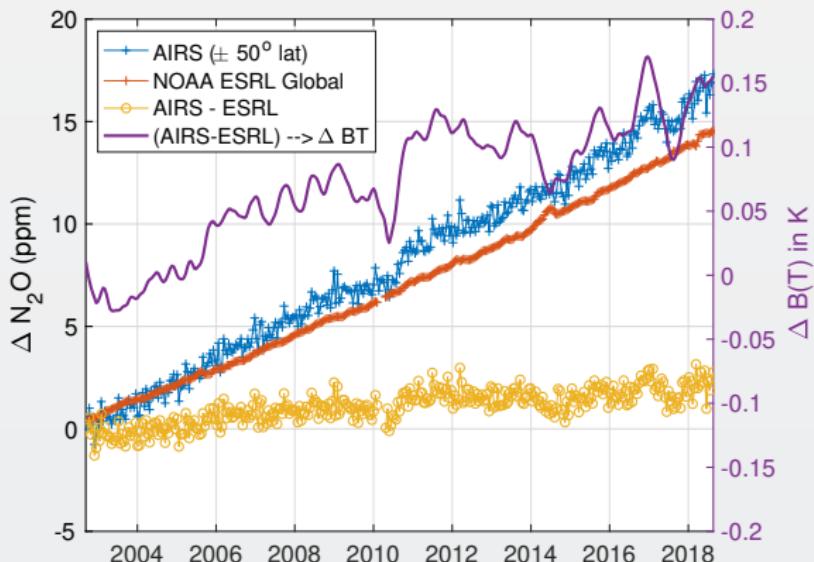


## Zonal Anomalies



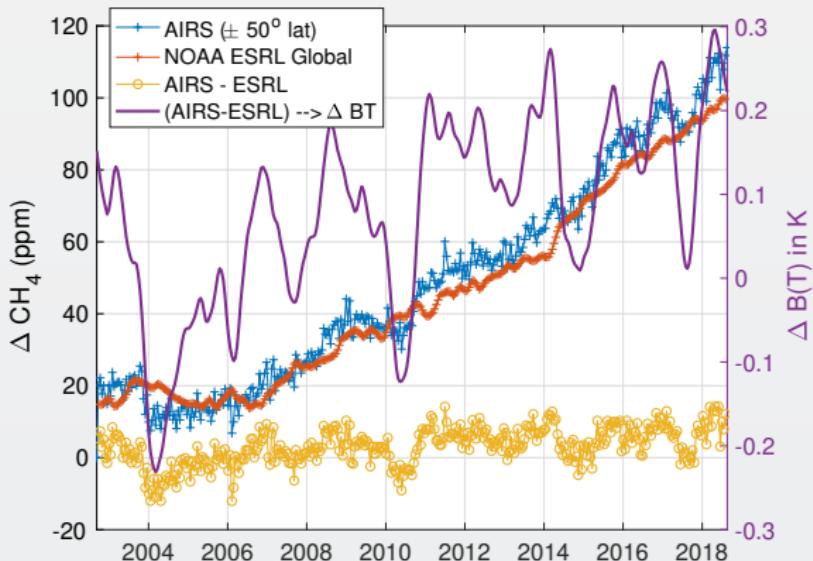
Growth rate anomaly accuracy very encouraging.

# $\text{N}_2\text{O}$ Retrieved Anomalies



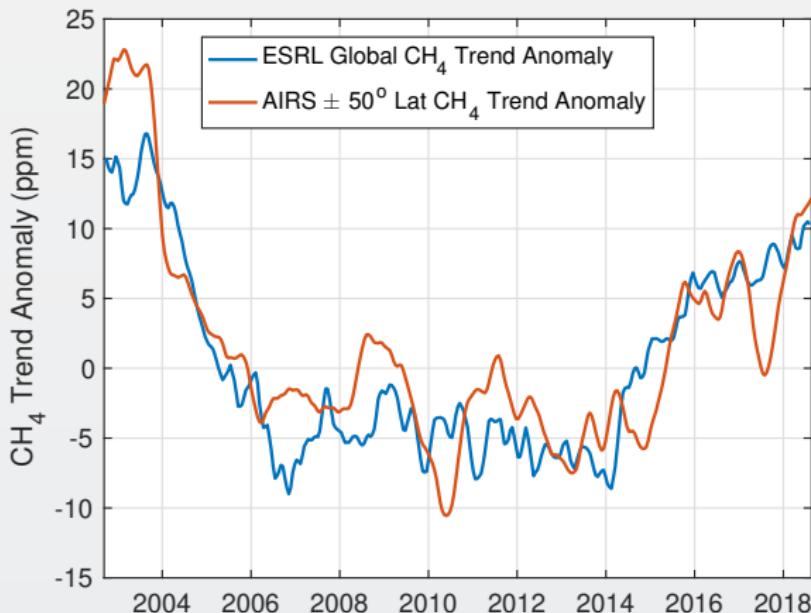
- This is what we are after
- Something a little before 2006?
- A jump due to the Jan. 2010 shutdown
- Stable otherwise
- Look at residuals of fits to understand guilty channels

# $\text{CH}_4$ Retrieved Anomalies



- Is  $\text{CH}_4$  well mixed enough for this analysis?
- Clearly an offset in Jan 2010 but it recovered (seen in spectral!)
- Clear Nov. 2003  $B(T)$  shift

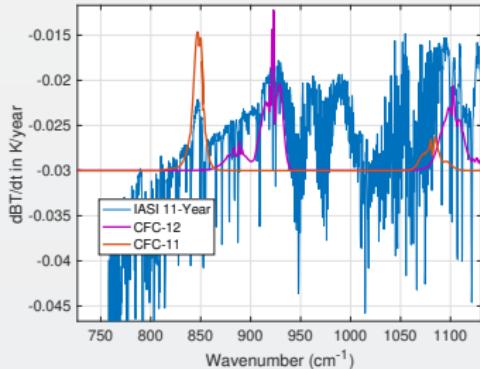
# $\text{CH}_4$ Growth Rate Anomalies



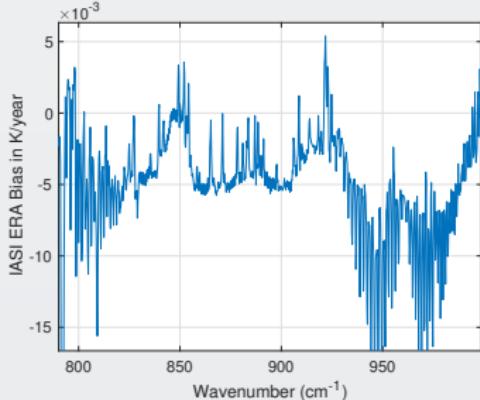
- Very nice agreement with NOAA ESRL in-situ
- Shows drop-off in global  $\text{CH}_4$  growth early in mission
- Then increasing growth starting in 2014

# Unlike Retrievals We'd Like to Examine Many Channels

## IASI: 11-Year Trend



## IASI Trend Zoom



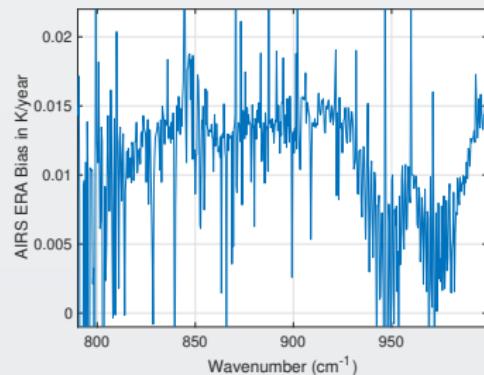
That means taking the CFC 11 and 12 into account.

Maybe 3 strong CFC 11 channels?

Maybe 3-5 strong CFC 12 channels?

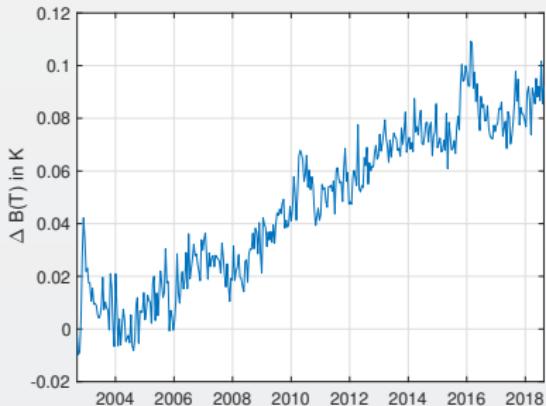
But, need to remove effects in wings

## AIRS Trend Zoom

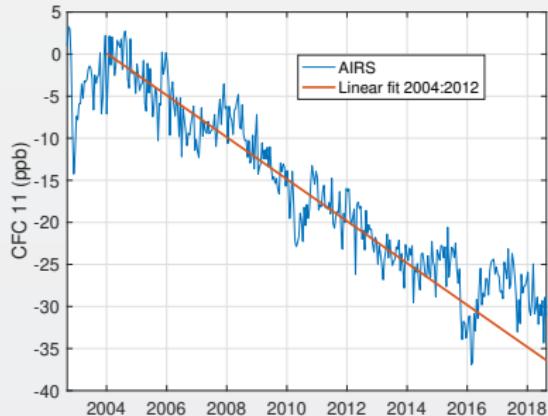


# Fit to AIRS CFC-11 for Removal in Fit Residuals

CFC-11 B(T) Trend

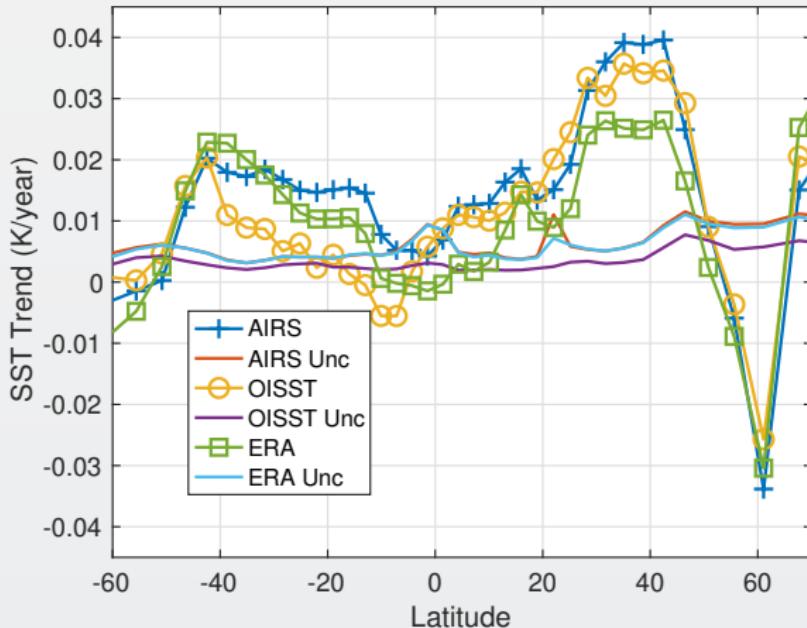


CFC ppb Trend



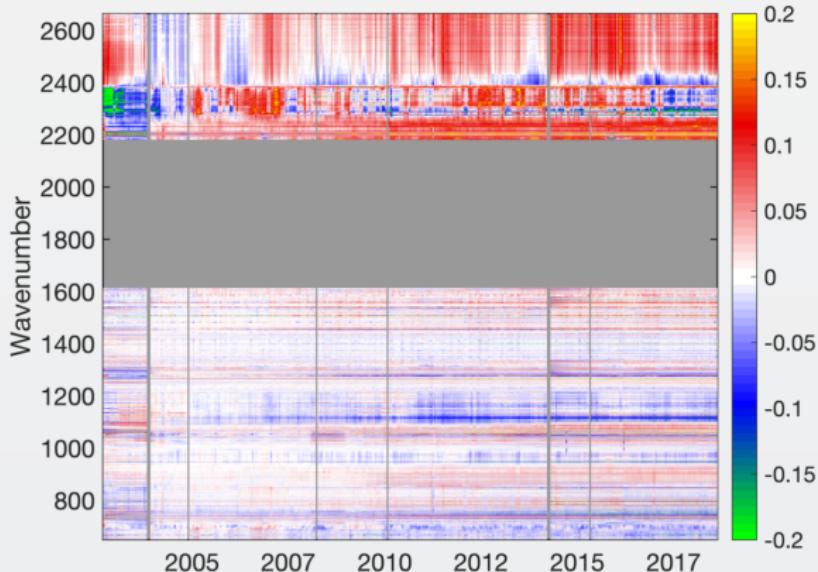
- Reasonably linear negative trend, as expected
- Values agree well with in-situ
- BUT, the trend appears to be decreasing!
- Also expected from in-situ: possible cause is Chinese production of CFC-11
- ENSO signals in time series: retrieval problem or something real?
- Clear problems due to Nov. 2003 AQUA shutdown

## SST Retrieved from Anomaly Fits



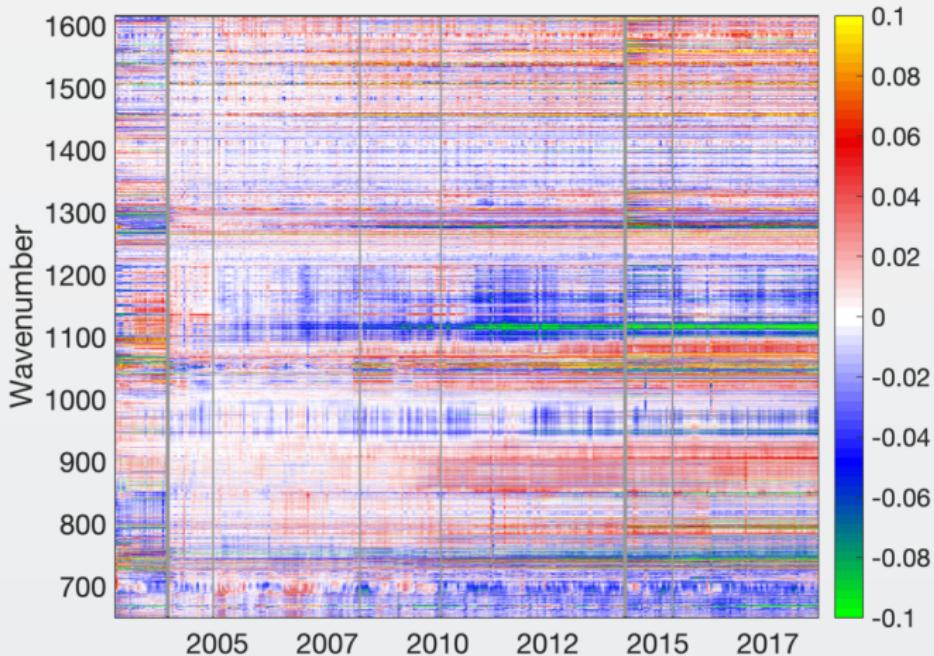
- OISST likely better?  $\text{AIRS-OISST} = +0.005 \pm 0.007 \text{ K/year}$  (tropics)
- ERA transitioned from RTG to OSTIA in Feb. 2009, we likely see that
- Differences very small and at limits of SST climatologies

# OE Fit Residuals: Main Diagnostic of Trends



- All residuals shown (including fill)
- Color scale is  $\Delta$  BT in K
- $\pm$  full scale equivalent to  $\pm 0.0125\text{K/year}$  drift
- Remember: we would like to get to the  $0.003\text{K/year}$  level or better
- Easy to see issues: Shortwave!!, Nov. 2003, some bad arrays, etc.

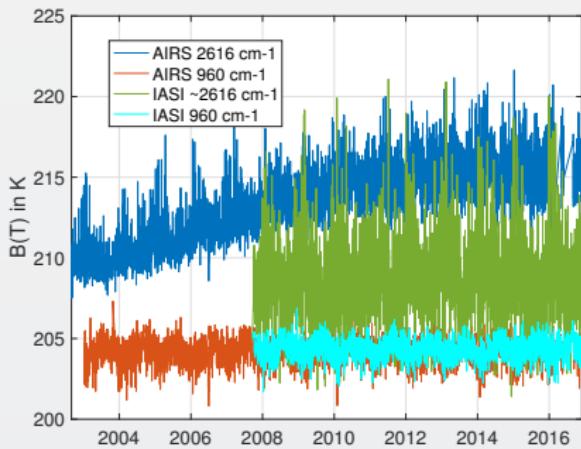
## Zoom of Residual w/o Shortwave



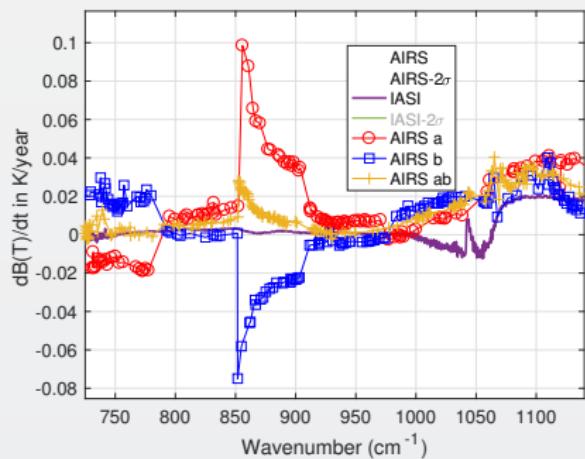
- Note: colorscale now  $\pm 0.1$  K
- But, only limited usefulness if fitted geophysical parameters are good!

# Deep Convective Cloud Time Series

AIRS vs IASI Time Series



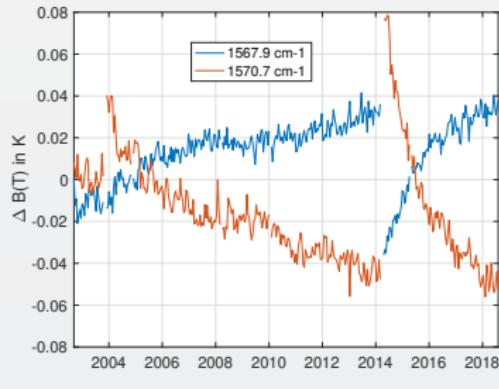
Trends (A/B detector issues)



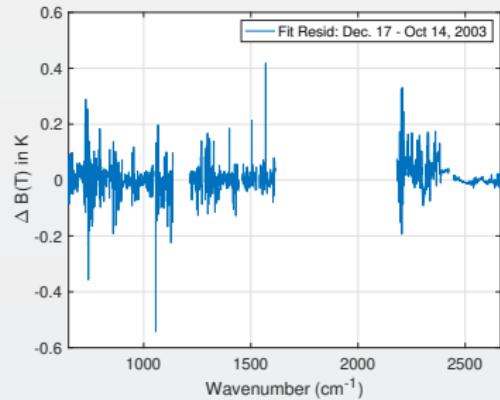
- Shortwave drift 2004-2012
- Consistent with Space Look getting colder
- Back of the envelope:
  - at 210K  $\text{dBT/dyr} = 0.47\text{K/ for } 2616 \text{ cm}^{-1}$
  - at 300K equivalent to  $0.0045\text{K/year!}$
  - at 255/265K (Arctic) equivalent to  $0.30/0.19 \text{ K/decade}$

# Sample Fit Residual Time Series

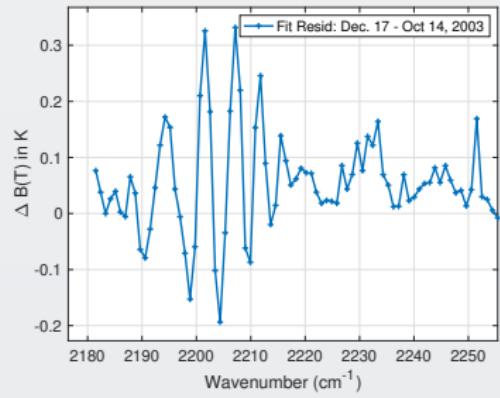
## Water Vapor Channels



## Effect of Nov. 2003 Shutdown



## Zoom of Nov. 2003 Shutdown (fringes)



- AIRS "events" easily seen
- Fix events, re-retrieve CO<sub>2</sub>, SST, etc. and test
- FUTURE: Use DCC spectra instead of clear for scene dependence

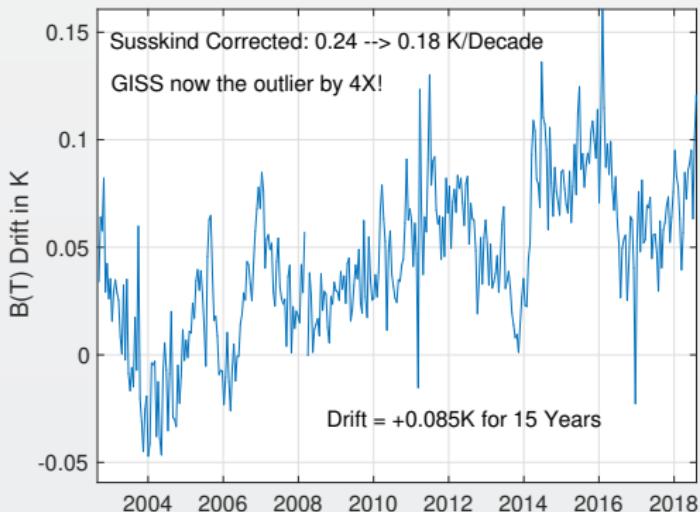
## Summary

- Validate OE retrieval products (done above)
- Adjust channel "event" offsets
- Re-do OE retrievals, re-validated.
- Add more channels as they are "fixed"
- etc.

## Improvements Possible

- More uniform sampling of clear
- Must add colder scenes (DCC's) to process since adjustments are likely scene temperature dependent
- OE can always be improved, start to look at  $T(z)$ ,  $H_2O(z)$ ,  $O_3(z)$  profile retrievals once have more uniform (gridded) sampling.

# SW Fit Residual Trends: Impact on Warming Estimates



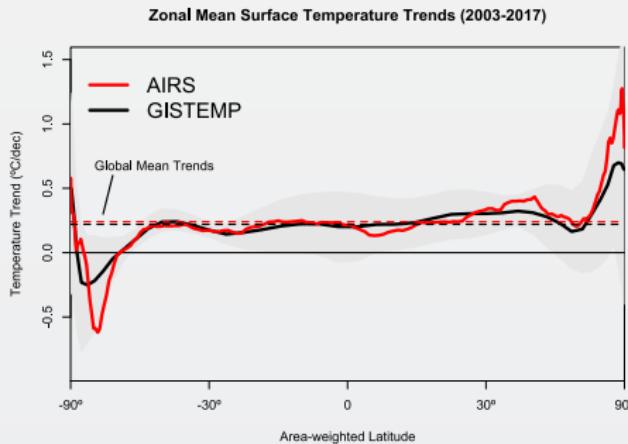
From Susskind et. al.

AIRS	$0.24 \pm 0.12$
AIRS Corrected	0.18
GISTEMP	$0.22 \pm 0.13$
HadCRUT4	$0.17 \pm 0.13$
C&W	$0.19 \pm 0.12$
ECMWF	$0.20 \pm 0.16$
UAH LT	0.18

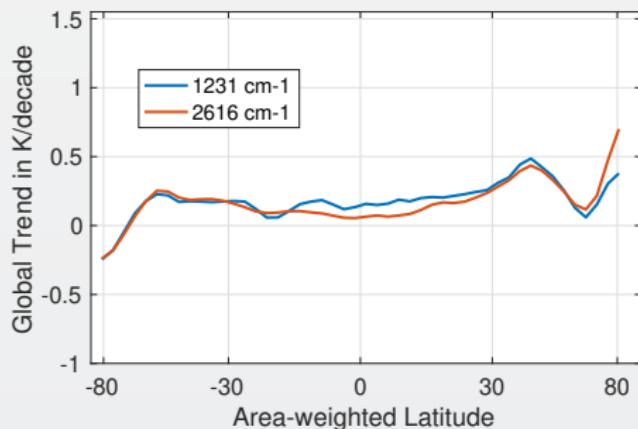
Shortwave drift correction reduces AIRS global temperature trend by 33% and bring AIRS into close agreement with HadCRUT4, C&W, and UAH LT, significantly worse agreement with GISTEMP.

# Latitude Dependence Surface Trends

## Susskind 2019: SW



## UMBC Trends: LW and SW



### Global Means

GISS	Susskind	UMBC-1231	UMBC-2616	HadCRUT4
0.22	0.24	0.18	0.17	0.17

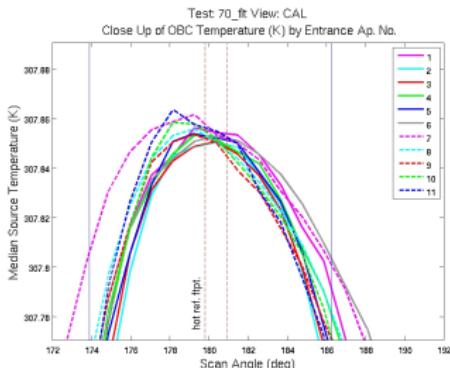
Note high/low Susskind values at poles not matched by UMBC

Artic: UMBC closer to GISTEMP, Susskind ~0.5K/decade higher than GISTEMP AIRS corrected 2616 trend from DCC Slide: 0.19/0.30K/decade at 265/255K! Why is UMBC-2616 not higher? But what about the S. Pole?? 2616 should be higher?

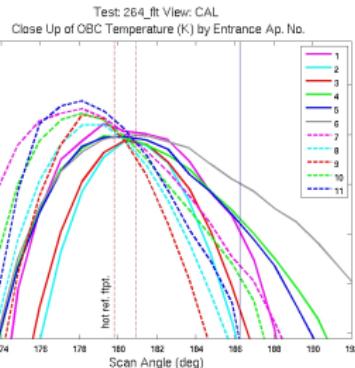
# Trends in AIRS Blackbody Scans (Courtesy Ken Overroye)

## Profiles with Expanded Temperature Scale

Test 70, July 2002



Test 264, April 2014



- Vertical blue lines define the limits of the normal calibration footprint
- Curvature within the limits probably indicate gradients within the OBC
- Some difference seen in the profiles, 2002 to 2014

- Strongly suggests B(T) trends maybe be associated with thermal drifts over time
- Same effects cause AIRS frequency shifts

# Quick Look at Fast $T_{\text{surface}}$ Algorithms

- Want to examine sensitivity to L1c adjustments **quickly**
- Examine channels separately

## Approach Presented (preliminary)

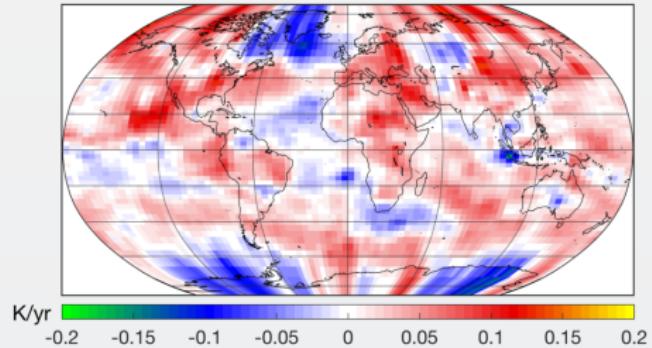
- Here we generated 1231 and 2616  $\text{cm}^{-1}$  time series from 1% of all data
- Gridded into lat/lon/16-day bins
- For each 16-day bin pick the hottest BT and keep it. So now about 0.02% of all data
- Form the BT anomalies for each bin and retrieve linear slope (trend)
- Compare to ERA, OISST, etc.

## Liens and Future Changes

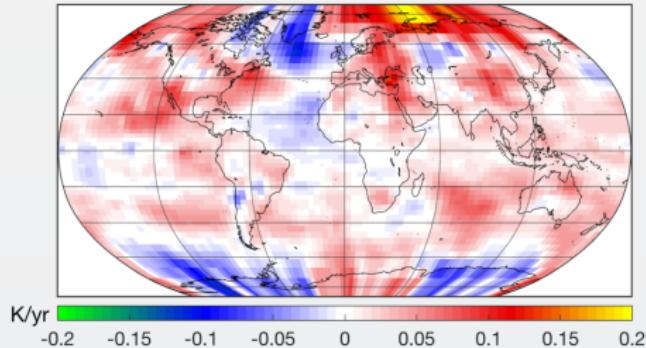
- 1231  $\text{cm}^{-1}$  needs  $d\text{BT}/dT_{\text{surf}}$  adjustment (used mean values from ERA)
- Additional adjustment needed if  $\text{H}_2\text{O}$  varies significantly (not done)
- Picking hottest only is quite a small subset.
- In future use all data, not 1% random subset (done) and use more than just hottest scenes
- Pick up enough full-spectrum data to fit for  $\text{H}_2\text{O}$  trends for 1231  $\text{cm}^{-1}$  adjustments

# Surface T Trends Using $1231\text{ cm}^{-1}$ Channel

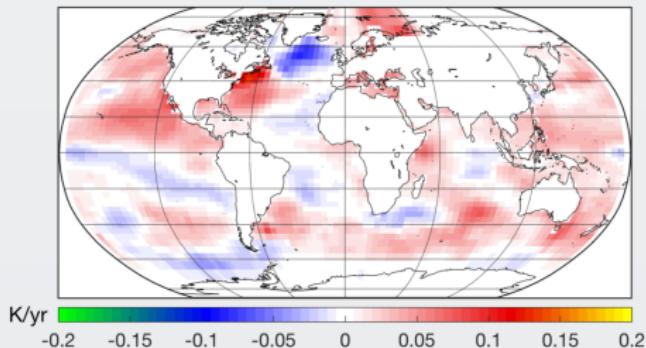
AIRS  $1231\text{ cm}^{-1}$



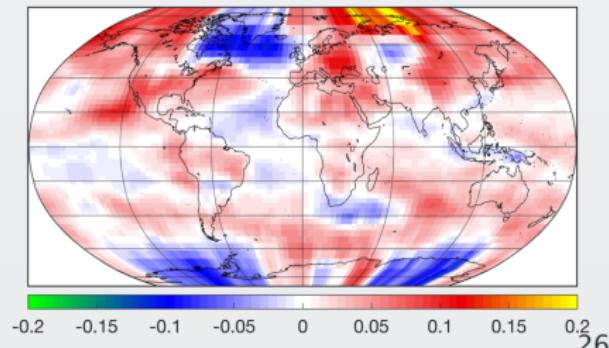
ERA



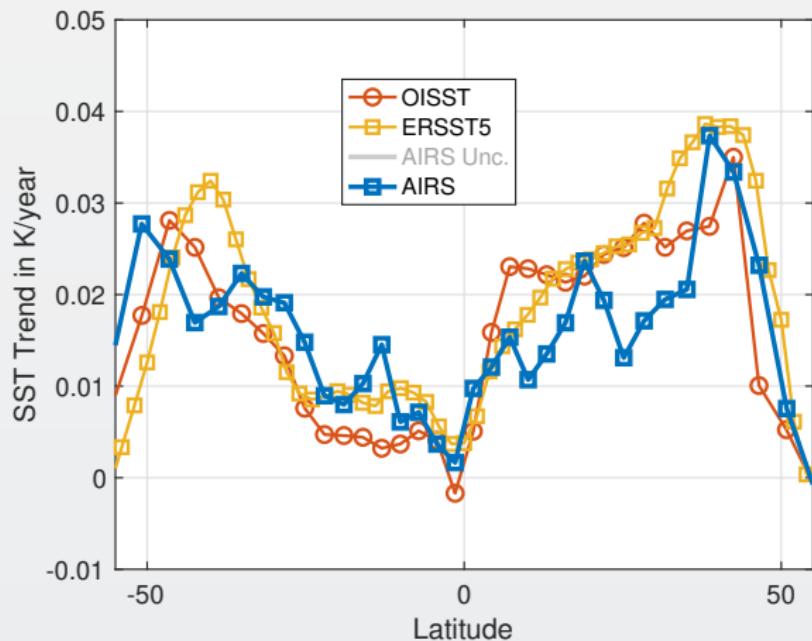
OISST



AIRS  $2616\text{ cm}^{-1}$



## SST Trends of Previous Mapped Data ( $1231\text{ cm}^{-1}$ only)



- ERSST5 is considered one of the best climate surface T products
- ERA is NOT a measurement, but sure is good!
- Will expand to HADCRUT, GISTEMP, etc. in the future

# Conclusions

- We have a tremendous instrument, with a very stable blackbody reference
- But, small thermal shifts in the grating system produce BT trends that can vary with channel
- Cold (space look) measurements appear to be the culprit?
- The approach to fixing these problems seems doable, but will require a significant effort
- Most climate questions can be answered if the radiometric trends are fixed
- Better absolute radiometry will not impact most science we need to do, it's already quite good!
- This work needs to be done now before Level 2 is used too much for climate research!