AIRS Calibration for Climate Trend Studies: Status and Future

AIRS Science Team Meeting

L. Larrabee Strow[1,2]

September 25, 2019

[1] UMBC Physics Dept.

[2] UMBC JCET

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_2, SST, etc allows stringent tests of stability

Climate Science Questions

All require min ~0.1K/decade stability

- Global Trending: T(z), H_2O (z), T_{surf}
- Water vapor feedback (Does relative humidity vary)
- Cloud feedback
- Trends in PBL cloud occurrence
- OLR anomalies separated by cause: T/H_2O/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 publicized 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

- 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

- Reproducibiity 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_2 and possibly N_2O and CH_4 can provide those standards
  - CO_2 is well mixed (on long time scales) and extremely well known
  - Establish AIRS stability by retrieving CO_2 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 Data Sets Used Here

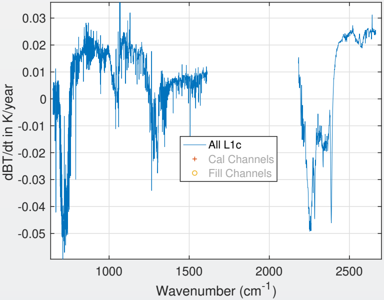
- Subsequent results use either:
  1. Clear ocean subsetting data; or
  2. A random, area-weighted subset of all scenes
- Clear scenes are zonally averaged into 40 latitude bins of 16 days length
  - The anomalies of these B(T) time series are created (remove seasonal, constant)
  - An optimal estimation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

OE Parameters

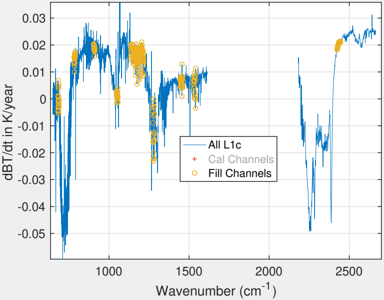
- First: use only channels where A/B constant through the mission
- But: include more channels than most retrievals, since we want to evaluate as many channels as possible
- Observation noise covariance (diagonal) computed from NEDN from all scenes, < 0.01K
- A-Priori trends are zero
- A-Priori covariance (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-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 All-Sky Global 16-Year B(T) Trends

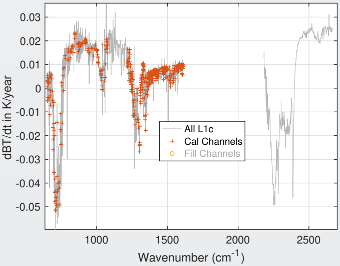
All channels (inc. fill)



Fill channels marked



Calibration channels

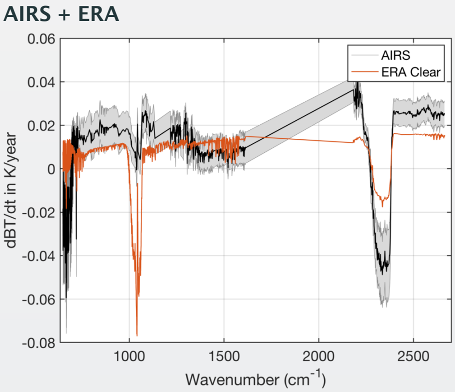


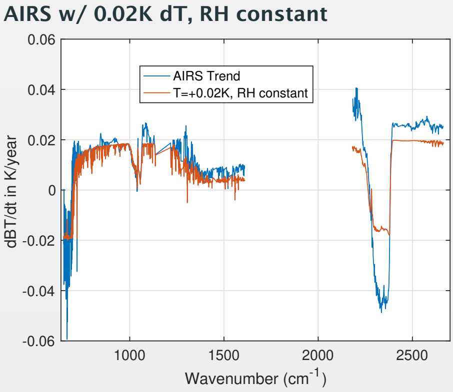
Channels used for calibration testing marked.

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

Note sparsity of CO_2 channels in tropospheric sounding region

CO_2 and CH_4 Trends Removed, Fitted Chans Only

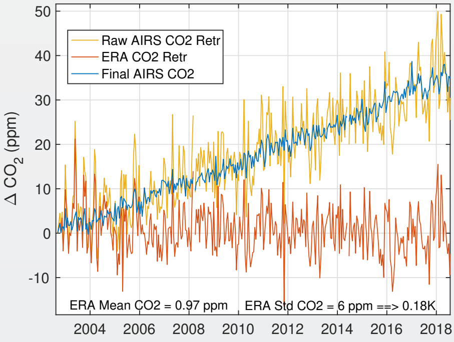




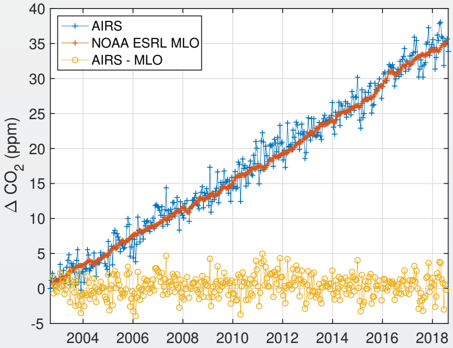
- Uncertainty (gray) is geophysical (Std over latitude).
- RHS: Trop T(z) + 0.02K, Strat T(z) - 0.02K
- H_2O trend is close to constant RH. (Varies with latitude).
- Could suggest RH is a bit lower over time??
- Shortwave appears to have a positive drift

Switch to Clear Ocean Time Series: CO_2 Anomaly Fit for 20° N. (MLO)

Fitting Trick

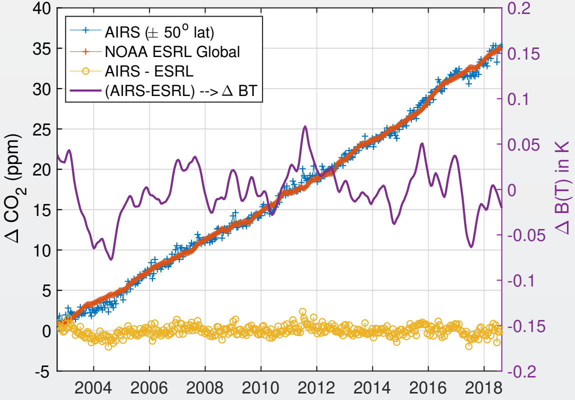


Fitted CO_2 Anomalies



- ERA simulations done per footprint
- Fit ERA simulation for CO_2
- Removes co-linearity? and lowers "noise"

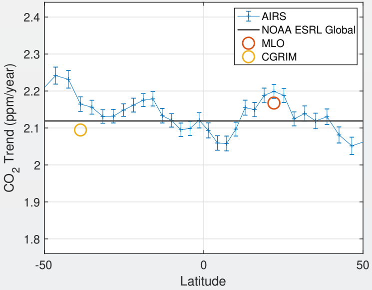
CO_2 Anomaly Converted to B(T) Trends



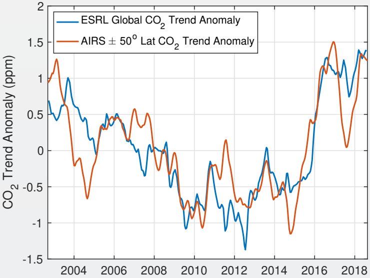
- Mean AIRS-ESRL CO_2 = 0.035 ± 0.032 pppm (1σ standard error)
- Mean AIRS-ESRL in BT Units = +0.0026K ± 0.0023K (1σ standard error)
- Sampling and ESRL errors hard to characterize
- Suggests our CO_2 and SST channels are reasonably well-behaved
- BUT: residuals of CO_2 sensitive channels do vary

Other CO_2 Diagnostics

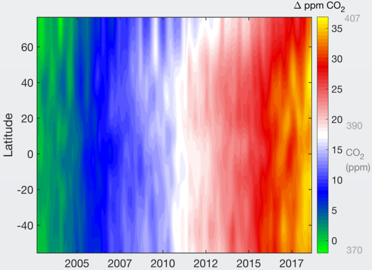
Growth Rates



Growth Rate Anomaly

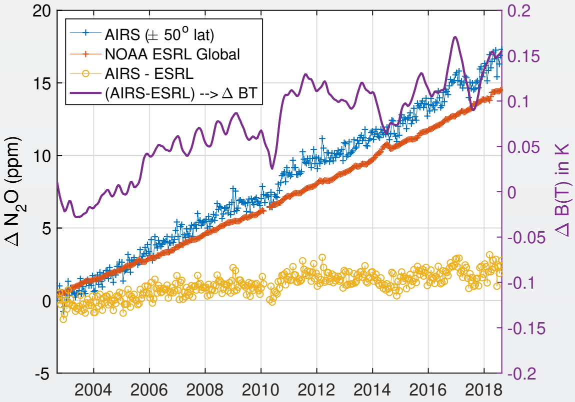


Zonal Anomalies



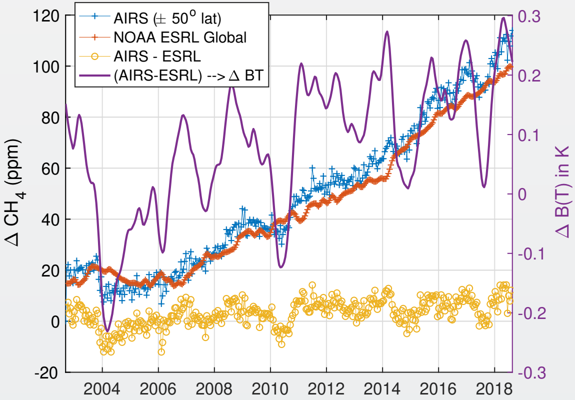
- Growth rate anomaly accuracy very encouraging.
- AIRS - Avg(MLO + CGRIM) growth rate difference: -0.0056K/year in BT units
- MLO, CGRIM growth rate uncertainty from ESRL ~0.0051K/year

N_2O Retrieved Anomalies



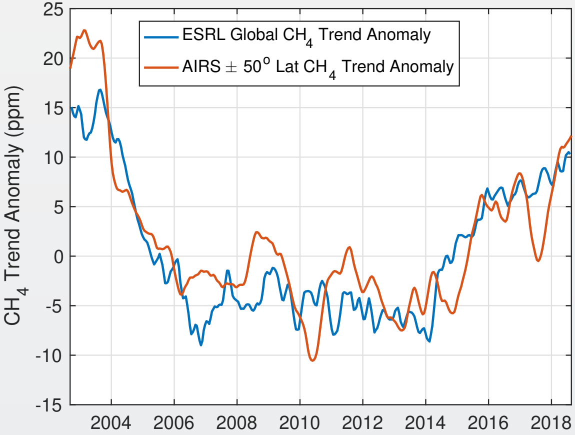
- This is what we are after
- Something a little before 2006?
- A jump due to the Jan. 2010 shutdown
- Stable otherwise
- Look at residuals of fits to understand guilty channels

CH_4 Retrieved Anomalies



- Is 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

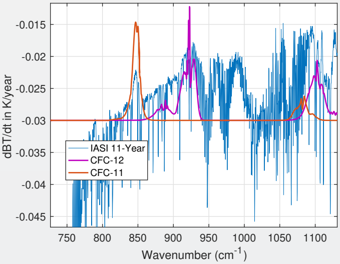
CH_4 Growth Rate Anomalies



- Very nice agreement with NOAA ESRL in-situ
- Shows drop-off in global 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



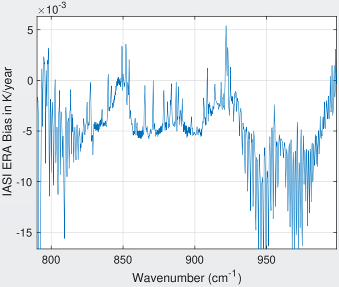
That means taking the CFC 11 and 12 into account.

Maybe 3 strong CFC 11 channels?

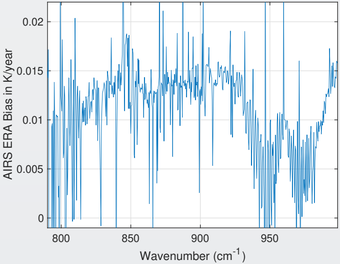
Maybe 3-5 strong CFC 12 channels?

But, need to remove effects in wings

IASI Trend Zoom

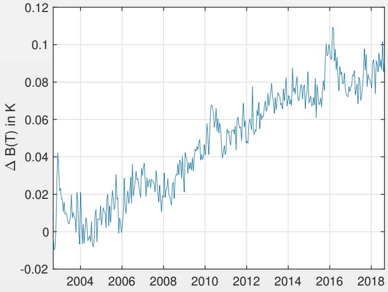


AIRS Trend Zoom

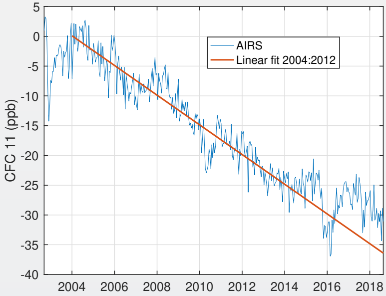


Fit to AIRS CFC-11 for Removal in Fit Residuals

CFC-11 B(T) Trend

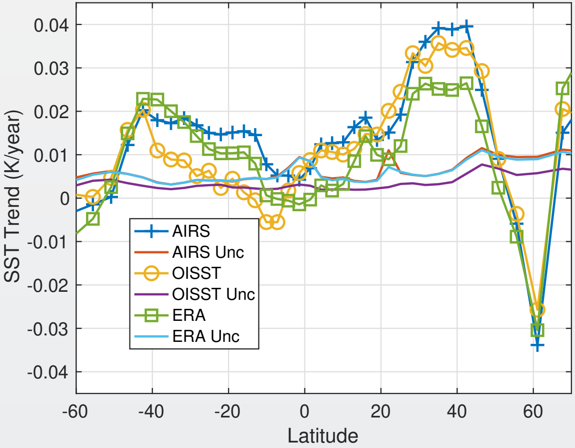


CFC ppb Trend



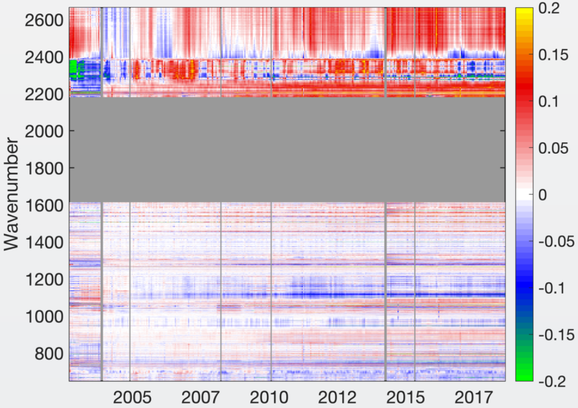
- Reasonably linear negative trend, as expected
- Values agree well with in-situ
- BUT, the trend appears to be decreasing!
- Also expected from in-situ: possible cause is Chinese production of CFC-11
- ENSO signals in time series: retrieval problem or something real?
- Clear problems due to Nov. 2003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

SST Retrieved from Anomaly Fits



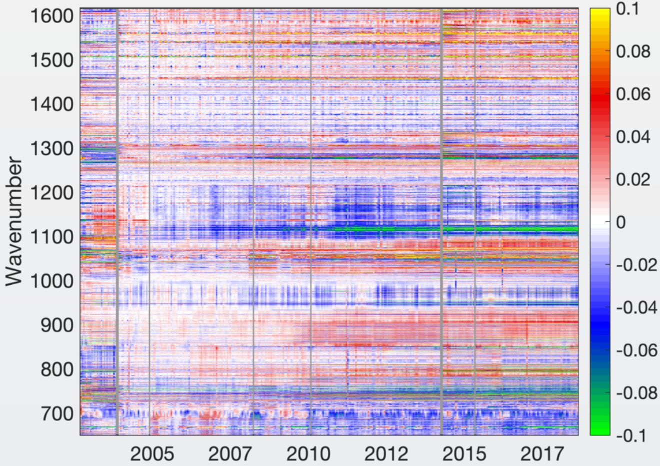
- OISST likely better? AIRS-OISST = +0.005 ± 0.007 K/year (tropics)
- ERA transitioned from RTG to OSTIA in Feb. 2009, we likely see that
- Differences very small and at limits of SST climatologies

OE Fit Residuals: Main Diagnostic of Trends



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

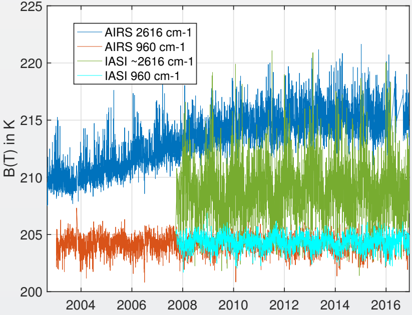
Zoom of Residual w/o Shortwave



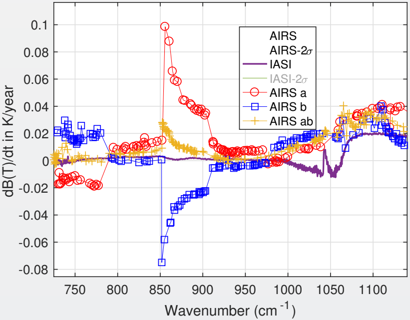
- Note: colorscale now ± 0.1 K
- But, only limited usefulness if fitted geophysical parameters are good!

Deep Convective Cloud Time Series

AIRS vs IASI Time Series



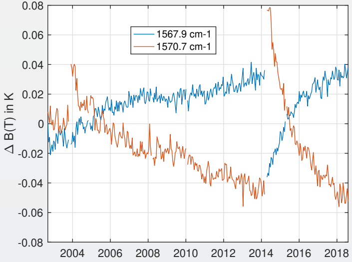
Trends (A/B detector issues)



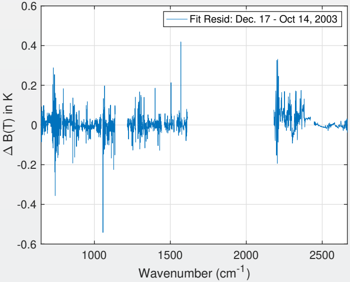
- Shortwave drift 2004-2012
- Consistent with Space Look getting colder
- Back of the envelope:
    - at 210K d(BT)/d(yr) = 0.47K/yr for 2616 cm^{-1}
    - at 300K equivalent to 0.0045K/year!
    - at 255/265K (Arctic) equivalent to 0.30/0.19 K/decade

Sample Fit Residual Time Series

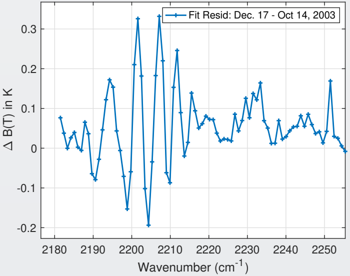
Water Vapor Channels



Effect of Nov. 2003 Shutdown



Zoom of Nov. 2003 Shutdown (fringes)



- AIRS "events" easily seen
- Fix events, re-retrieve CO_2, SST, etc. and test
- FUTURE: Use DCC spectra instead of clear for scene dependence

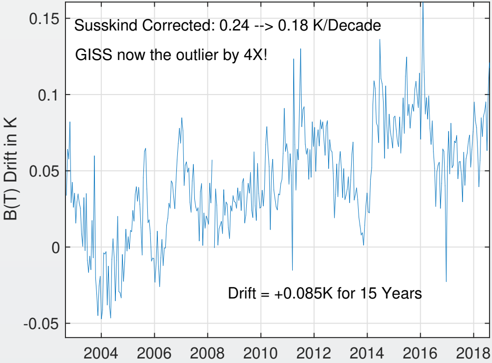
Summary

- 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



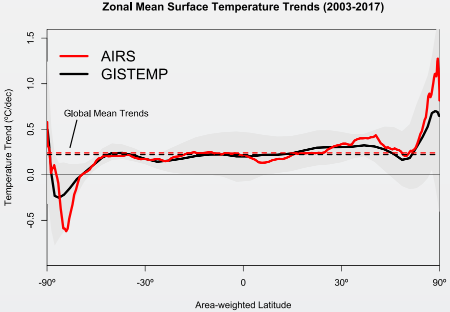
From Susskind et. al.

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

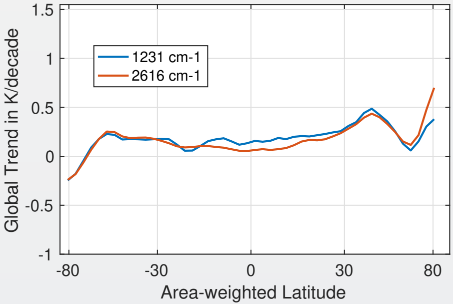
Shortwave drift correction reduces AIRS global temperature trend by 33% and bring AIRS into close agreement with HadCRUT4, C&W, and UAH LT, significantly worse agreement with GISTEMP.

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

Arctic: 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?

We Need to Get This Right!

Washington Post Quotes on Susskind Paper

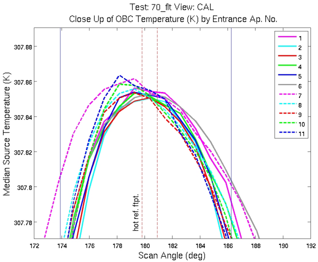
“We may actually have been underestimating how much warmer [the Arctic’s] been getting,” said Gavin Schmidt, who directs NASA’s Goddard Institute for Space Studies, which keeps the temperature data, and who was a co-author of the new study released in Environmental Research Letters.

Notably, AIRS sometimes shows more warming than the NASA data set, and especially does so in the Arctic, a region where measurements are scarce and warming is fastest. Shockingly, it even finds that over the Barents and Kara seas in the Arctic, the warming trend is at a rate of 2.5 degrees Celsius — or 4.5 degrees Fahrenheit — per decade.

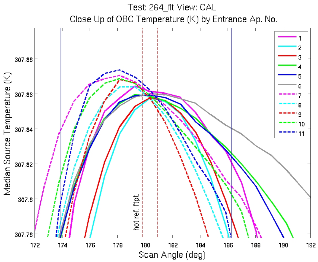
Trends in AIRS Blackbody Scans (Courtesy Ken Overroye)

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 $T_{surface}$ Algorithms

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

Approach Presented (preliminary)

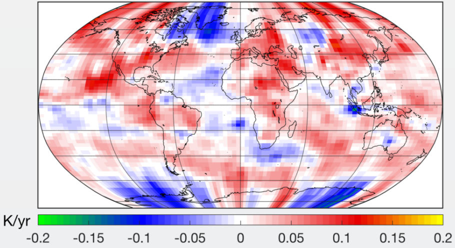
- Here we generated 1231 and 2616 cm^{-1} time series from 1% of all data
- Gridded into lat/lon/16-day bins
- For each 16-day bin pick the hottest BT and keep it. So now about 0.02% of all data
- Form the BT anomalies for each bin and retrieve linear slope (trend)
- Compare to ERA, OISST, etc.

Liens and Future Changes

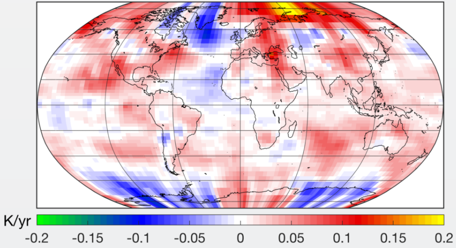
- 1231 cm^{-1} needs dBT/dT_{surf} adjustment (used mean values from ERA)
- Additional adjustment needed if H_2O varies significantly (not done)
- Picking hottest only is quite a small subset.
- In future use all data, not 1% random subset (done) and use more than just hottest scenes
- Pick up enough full-spectrum data to fit for H_2O trends for 1231 cm^{-1} adjustments

Surface T Trends Using 1231 cm^{-1} Channel

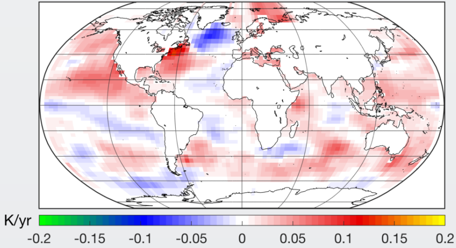
AIRS 1231 cm^{-1}



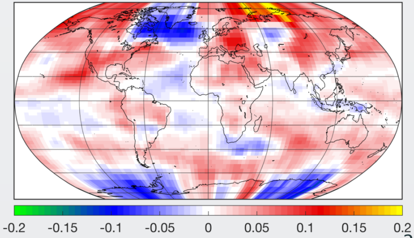
ERA



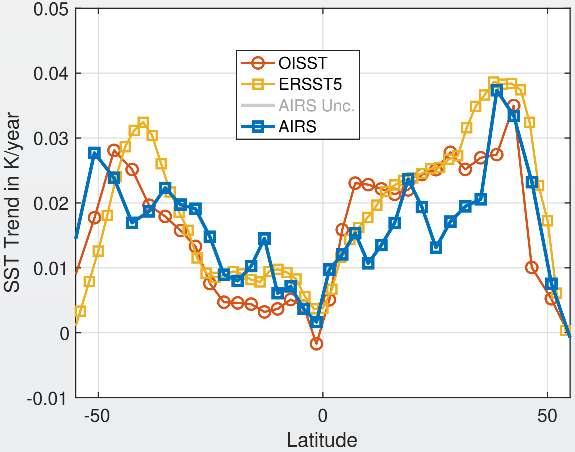
OISST



AIRS 2616 cm^{-1}



SST Trends of Previous Mapped Data (1231 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
- Important 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 works needs to be done now before Level 2 is used too much for climate research!