AIRS/CrIS Radiometric Stability Improvements Needed for the CHIRP Climate Data Record

AIRS Virtual Science Team Meeting

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Introduction (For all three talks)

- AIRS and CrIS exhibit excellent stability (stable blackbodies) that enable construction of long-term climate time-series and trends from 2002 through 2040s?
- Need continuity using different instruments (AIRS, CrIS, IASI)

Combined Hyperspectral Infrared Radiance Product (CHIRP)

- Provides common spectral instrument line shape (single RTA!)
- Inter-instrument radiometric offsets removed, for now use SNPP-CrIS as the standard

Further Requirement: Instrument stability

- We believe the AIRS blackbody is *extremely* stable based on recent work
- However, many AIRS channels exhibit non-physical changes that we can quantify
  - Jumps (mostly due to AIRS events)
  - Trends (root cause may be related slight changes in viewing angles)

Calibration Task(s) Needed for a Successful CHIRP

- Fix parent radiometric drifts when possible **(THIS TALK)**
- Otherwise, document in detail

Quantification of AIRS Trends

Our approach detailed in:

- Strow, L., & DeSouza-Machado, S. (2020). Establishment of AIRS climate-level radiometric stability using radiance anomaly retrievals of minor gases and sea surface temperatureAtmospheric Measurement Techniques, 13(9), 4619–4644, doi: 10.5194/amt-13-4619-2020.

Main Steps

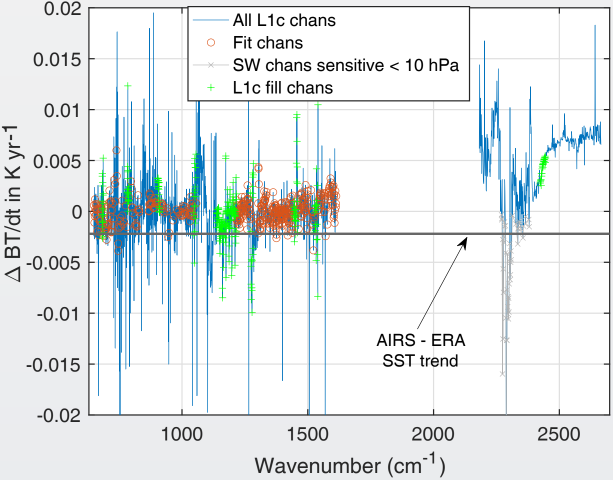
- Form radiance anomalies, 16-day averages of zonally gridded clear ocean scenes
- Use ERA to generate jacobians (kernels) of anomalies
- Retrieve all standard geophysical variables using "OE", but minor gases dominate!
- Use the excellent ESRL CO_2, N_2O, and CH_4 in-situ climate records as "standards"
- Also use ERA-SST (GHRSST) and OISST as "standard"
- Look for drifts, steps in either the retrieved variables, or in the fit residuals
- Most radiometric "errors" show up as geophysical variable errors
- Shortwave ignored since drifts are so large, unable to get convergence

Next Step

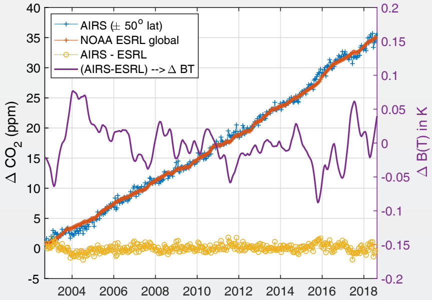
- These results should now be used to fix the AIRS L1c record
- Can that be done!
- Needed for our CHIRP products and for Level-2 CHIRP retrievals

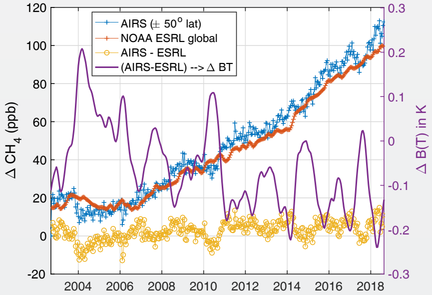
OE Anomaly Residual Trends (Descending Node ONLY)

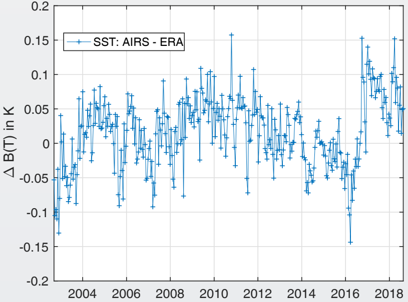
- The OE anomaly residuals should have zero trend if successful
- We ignored shortwave, but here show the Obs-Fit where Fit uses the longwave, midwave fit parameters



Retrieved Anomalies







- CO_2 channels stable, minor offset in Nov. 2003
- CH_4 channels show 2003, 2010 offsets (2003 maybe temporary)
- (AIRS - ERA) SST show offset in 2016 due to AIRS event (cooler restart)
- N_2O (not shown) has two offsets, removal removes any trend!
- Next: Turn these geophysical offsets into AIRS channel corrections

AIRS Stability Summary

From AMT paper

CO_2	-0.023 ± 0.009 K/decade
N_2O	-0.141 ± 0.012 K/decade (-0.022 ± 0.009 if fix jumps)
CH_4	-0.107 ± 0.024 K/decade (jumps in 2003, 2010)
SST ERA (GHRSST)	0.022 ± 0.024 K/decade
SST OISST	0.034 ± 0.021 K/decade (shifted in Sept. 2016, as shown)

N_2O drift at nominal climate change level

- These results suggest a very stable AIRS blackbody.
- Detailed examination of residual suggests A/B detector drifts (known to AIRS Cal Team)
- Shortwave drifting (descending node)
- Excellent starting point: but we have the information to provide improvements that should make AIRS a "climate standard".
- Selling AIRS (CHIRP) to the climate community will take work

Next Task: Remove temporal offsets and trends in the AIRS L1c record, using as much physics as possible.

Sample Study: AIRS DCC Trends

- DCC: deep convective clouds
- Aumann noticed drifts in DCCs in the shortwave relatively early in the mission
- Pagano has modeled them assuming the AIRS FOV has changed (broadened) over time

This Work

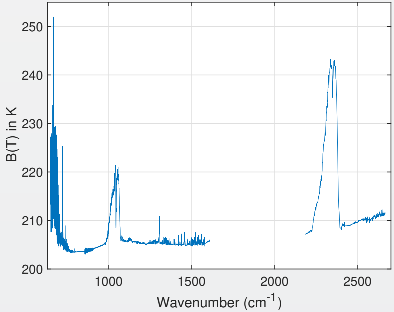
- Quick look to see if DCC trends can explain shortwave trends in the (relatively warm) anomaly spectra
- Cold shortwave channels very sensitive to changes in AIRS space view (SV) counts
- Work by Overroye has shown some time-dependent variabiliy in how AIRS views the SV.

AIRS Radiometric Drifts via DCC's

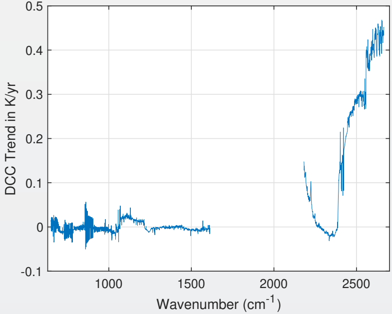
- Previous work using comparisons of clear-ocean scene trends show that the AIRS shortwave band is drifting hot, ~6 mK/year over 16 years.
- We could *not* fit the clear-ocean scene anomalies if the shortwave was included. If excluded resulting SST trends were in agreement with OISST, etc. to 2 mK/year.
- Since AIRS L2 uses shortwave for surface T, we content this leads to inaccurate surface T trends using AIRS (reported in the Wash. Post!).
- Large BT trend observed in DCC's (0.45 K/year) suggests a cold scene (space view) problem.
- Can DCC results be (a) understood, (b) appear "reasonable" with quantifiable uncertaintes, and the hard one (c) be transferred to warmer scenes to remove the AIRS shortwave drifts.

DCC Observations

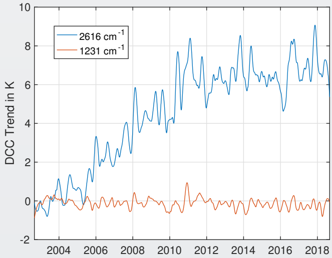
Mean DCC Spectrum



15-Year DCC Trend



Time Dependence of Trends



- DCC's defined here by BT(960 cm^{-1}) < 215K
- DCC's often used for calibration since extremely stable
- Trends are NOT seen in IASI shortwave
- A/B trends (longwave) and AIRS frequency shifts have similar time-dependencies!
- Shortwave sensitive to space view (SV) drifts.
- Suspect focal plane/optics shifts that change location of SV's

Using DCC Emission to Determine Calibration Drifts

- Simplified to ignore non-linearity and polarization
- Written differently than in ATBD, show Space View (SV) explicitely

$$R = \frac{EV - SV}{OBC - SV} R_{OBC}$$

- R is calibrated radiance
- EV/SV/OBC are the earth/space/blackbody counts
- R_{OBC} is the computed OBC (blackbody) radiance

Sensitivity of R to SV

$$\frac{\partial R}{\partial SV} = \frac{1}{OBC - SV}(R - R_{OBC})$$

Solve for SV using DCC Spectra

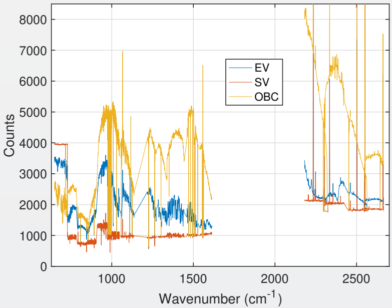
$$\delta SV = \frac{OBC - SV}{R_{DCC} - R_{OBC}} \delta R_{DCC}$$

Approach

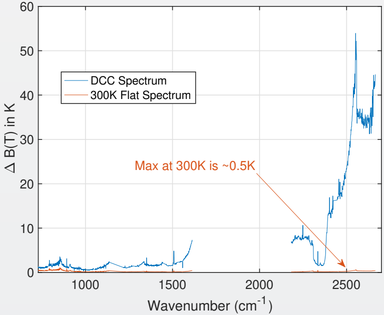
- Use DCC trends for δ R, solve for δ SV (≡ SV drift/year)
- Compute δ R trends for various scene types (R = DCC, clear, etc.)
- Convert to BT trends
- Ignore regions where emission exists above DCC's, ie stratospheric emission that could be varying in time
- Lien #1: used a single, randomly selected AIRS L1a scene to estimate (OBC - SV)
- Lien #2: DCC drift maximum near equator, drops 30% by ± 30° latitude (orbit phase or T. Pagano's FOV idea?)

SV Trend Results

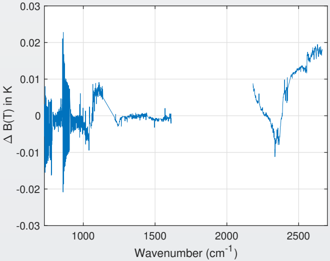
Sample Set of AIRS L1a Counts



δ BT for 1% SV drift for BT = DCC, 300K

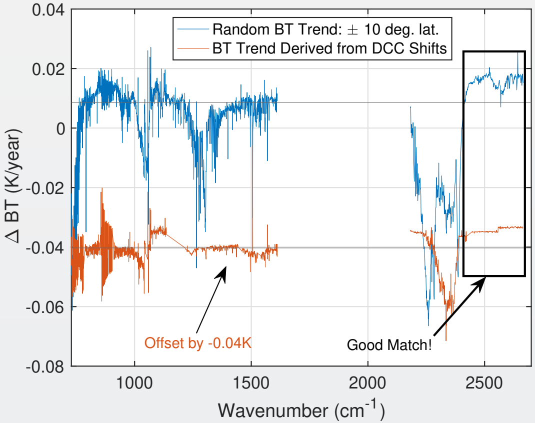


δ SV BT Trend for SV = 265K



- AIRS scene produces window BT ~275K
- Note high A/B variability in SV counts!
- Setting SV = 265K is just to illustrate magitude of SV drift
- SV drifts *small* but DCC's allow quantification
- Key conclusion: this approach predicts scene dependence

Do the DCC SV Drifts Predict All-Sky Trends?



- Blue is 17-year all-sky AIRS BT trend (black line denotes 1231 cm^{-1} channel)
  - CO_2, CH_4, N_2O, and O_3 exhibit greenhouse effect
  - H_2O also shows greenhouse effect
- Red are shifts predicted by SV drift. Nicely reproduces shortwave "false" extra warming
- Nominal agreement for detector side A/B ringing in window regions
- LIEN: SV trend likely orbit phase dependent, just like AIRS frequencies!

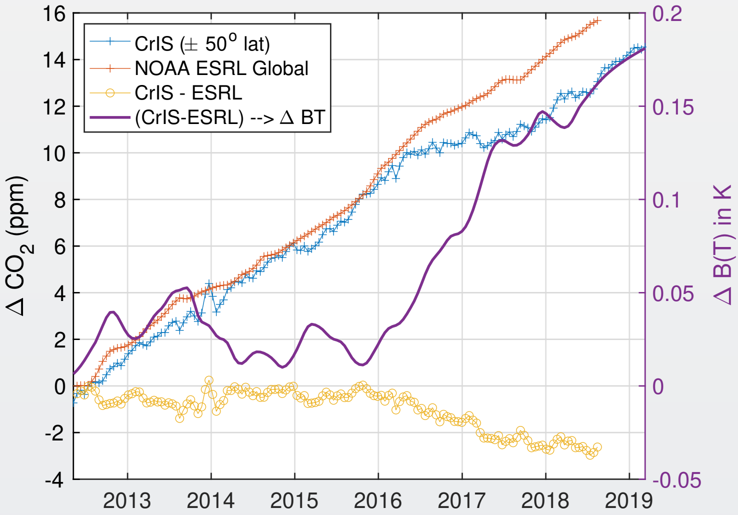
DCC Summary

- Results only apply to tropical descending node
- Recent work by UMBC suggests that ascending node shortwave drifts are small
- Past work by Aumman suggest that AIRS shortwave is stable at S. Pole (Dome Concordia) relative to IASI
- This all suggests a orbit phase component in SV counts, much more work needed to confirm!
- If drift is descending only, that still lowers Susskind et. al. surface temperataure results to in-between GISS and HADCRUT instead of being higher than all other climatologies

CrIS Stability

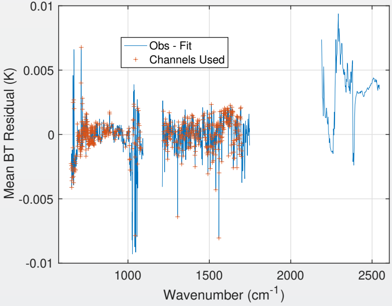
- We have done some *preliminary* work on SNPP CrIS stability
- Using same approach, OE retrievals from radiance anomalies
- CrIS has the "feature" that we can inter-compare among the 9 focal plane detectors!
- Results summarized below:
  - Preliminary!!
  - We see "events"
  - We see differential changes among detectors during these events (non-linearity)
- AGAIN we are just starting this work

CrIS CO_2 Anomaly Retrieval

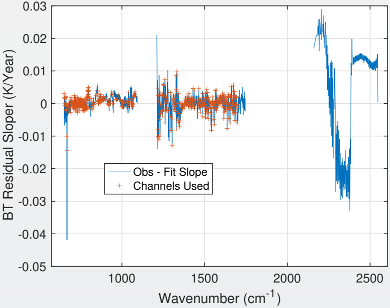


CrIS OE Fit Residuals (Obs - Fit BT Anomaly)

Mean Residual (over time)



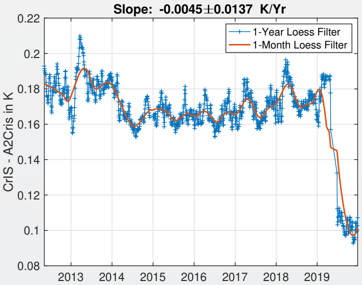
Residual Time Trends



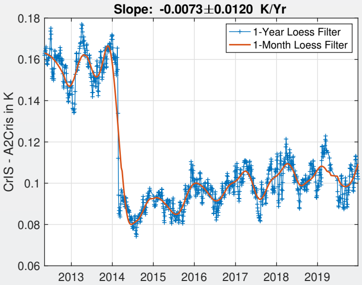
- Short wave "drifting" up??
- But AIRS was like this, another space view scene issue?
- Problems fitting extreme longwave CO_2, non-linearity issue?

698.75 cm^{-1} CrIS-AIRS SNOs: Tropics by FOV

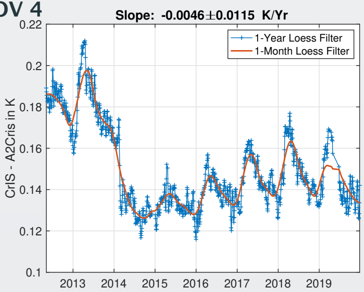
FOV 5



FOV 9



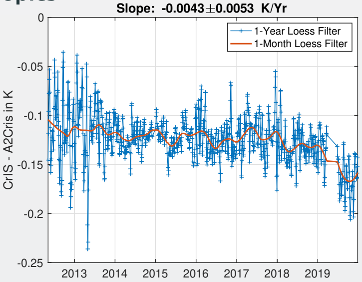
FOV 4



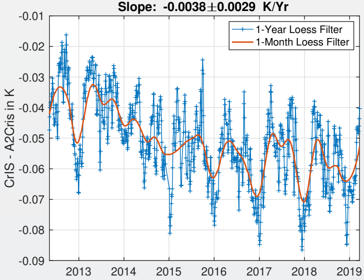
- Associated with non-linearity?
- Why ~Feb. 20, 2014?
- Feb. 20, 2014 start of MX8.1
- UMBC uses fixed ILS and a2's but not other vars
- August restart changed!

1493.7 cm^{-1} CrIS-AIRS SNOs (Suggests change in non-linearity)

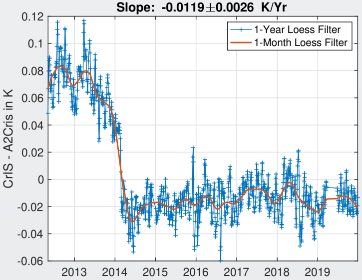
Tropics



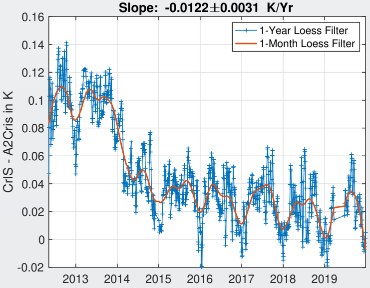
Polar



Tropics FOV 7



Polar FOV 7



Conclusions

- We have very stable instruments in orbit, but there are known stability liens.
- AIRS/CrIS/IASI promise proposed IR CLARREO level science (maybe even better if sensor overlap continues).
- We can rigorously detect instrument shifts/drifts using radiance anomaly time series
- Fixing these drifts should be a high priority, since they directly impact the uncertainty in AIRS/CrIS derived trends
- This is a non-trivial task!