Optimal Estimation Retrievals of Decadal Variability from AIRS Radiance Time Derivatives and Comparison to Re-Analysis Products

Sergio DeSouza-Machado, L. Larrabee Strow, Andrew Tangborn, and Chris Hepplewhite

Department of Physics, JCET, University of Maryland Baltimore County (UMBC)

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Acknowledgements:

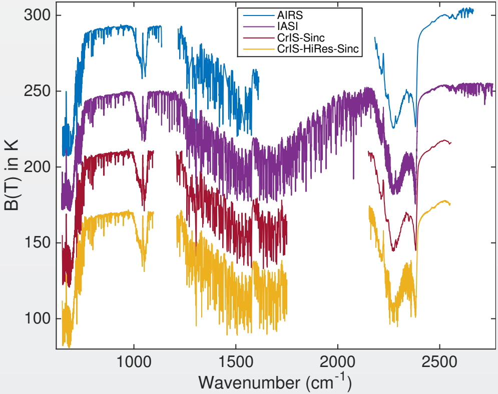
Overview

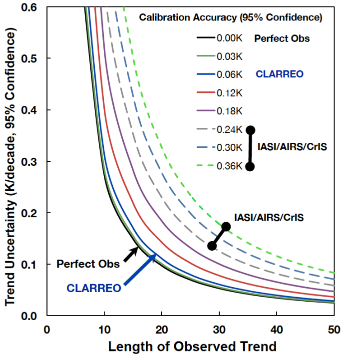
- Hyperspectral Infrared (IR)
  - 2000 to 8000+ spectral channels of earth's thermal emission, $\sim$ 12-20 km footprints
  - 45° swaths, high inclination sun-synchronous orbit, appox 16 day repeat period
  - Main purpose: Numerical Weather Prediction (NWP)
  - Spectra details allow discrimination of different processes
  - Started with NASA EOS-AIRS in 2002
  - Four hyperspectral sensors now operating (Aqua-AIRS, METOP IASI-1 and IASI-2, SNPP-CrIS) with substantial operating overlap, offer prospects for $>$ 25 year climate trending measurements.

We propose to demonstrate use of optimal estimation applied to temporal and spatial averaged radiance data, for determining trends of climate sensitive geophysical variables. This can be applied to multi-sensor records as long as a continuous observational record is available, and provides more straightforward error estimations when compared to level-2 derived climate trends.

Hyperspectral Polar Orbiting Sounders

Need $\sim$ 0.01K/year long-term stability





CLARREO approach: no overlap, high accuracy
This approach: sensor overlap, but still require stability

BUT: operational sensors also have slightly different spectral response (ILS)

Sensitivity to Geophysical Variables

- Temperature profile
- Water vapor profile
- Surface temperature and emissivity
- Cloud height (top), phase, particle size. (2+ degrees of freedom?)
- Minor gases: CO_2, N_2O, O_3, CH_4, CO, HNO_3, Freons, HDO, SO_2
- Particulates: Dust (including height), volcanic ash
- With additional data (reanalysis): long-wave cloud radiative forcing

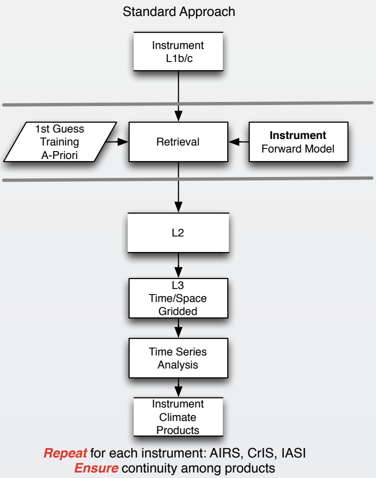
NOAA and EUMETSAT both committed to 25+ year time series:

Afternoon orbit: 2002 $\longrightarrow$ 2027+
Morning orbit: 2007 $\longrightarrow$???? ($>$ 25 years)

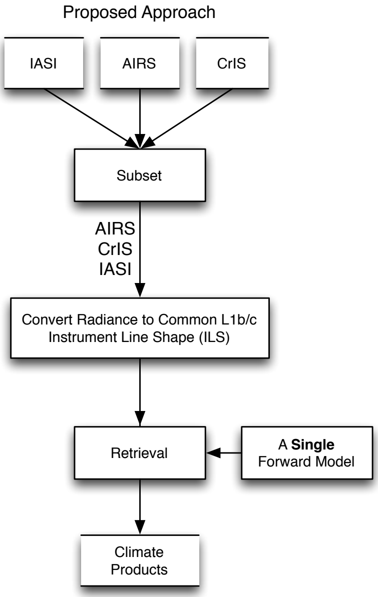
Basic approach

- Process data in radiance space as long as possible to ensure traceable accuracy.
- Ensure maximum sampling to minimize scene dependencies.
- In this study: use nadir subset FOVs , bin in 36 latitude zones averaged over 16 days.
- Determine sensor stability.
- Connect multiple sensors in the spectral radiance doman.
- OE utilizes some 1400 spectral channels, fits to a linear plus seasonal sinusoid, assumes zero a-priori.
- OE smoothing of profile usually done using a-priori co-variance, here done empirically using Tinkonov 1st derivative
- Instrument error (from last talk 0.005 K) and off-diagonal instrument error covariance less important.

Ensuring Traceable Accuracy: A New Approach



Repeat the above process for each instrument, merge products that used different forward models, with different spectral resolutions.



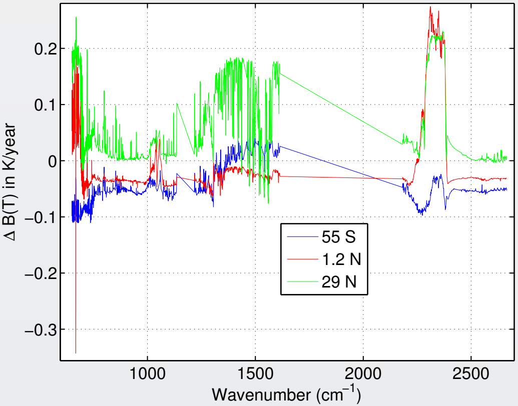
The standard approach L2 retrieval

- Very difficult to assign errors, especially for small trends
- Computationally expensive, cannot re-process at will.
- Significant component of a-priori (in AIRS neural net) that also uses cloud clearing - with additional uncertainty.
- Standard L2 typically exhibits sampling limitations.
- Re-analysis products very good for some variables, errors hard to tie down. Can have significant sampling biases, bias corrections tied to sondes, GPS, less to hyperspectral IR. Cloud forcing accuracy uncertain.
- In our approach: answer the technical questions in radiance space, then convert to a geophysical trend.

AIRS Stability: Using Clear Scene Subset

- Clear ocean scenes, binned by latitude daily for 10 years (hot PDFs).
- Create simulation set from ERA using forward model (SARTA)
- Determine 10-year linear BT rate (dBT/dt) from fit to 4-term sine series (seasonal and harmonics) + constant + linear rate.

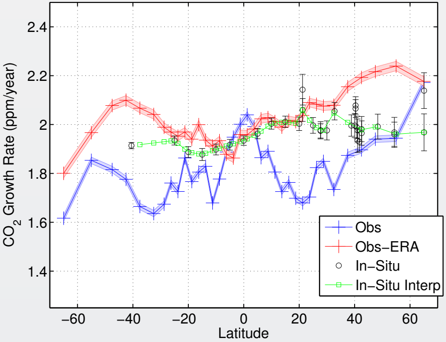
Sample Linear BT Rates and Fitting Errors



AIRS Stability

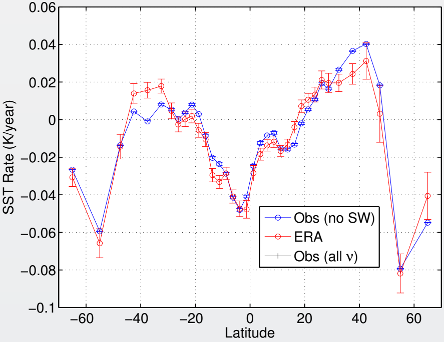
Compare OEM retrievals from clear subset to CO_2 and SST climatologies.

AIRS Retrieved CO_2 Growth Rate vs In-Situ: 2ppm ∼0.06K



AIRS - In Situ (± 40 deg.)
0.003 ± 0.004 K/year

AIRS Retrieved SST vs Tropical SST Climate Data Records

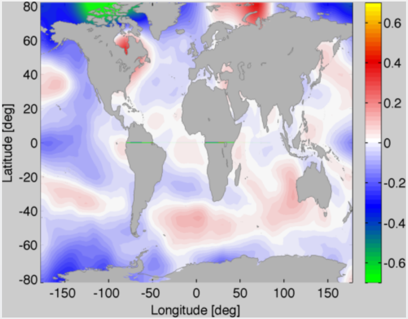


Tropical, no AIRS SW:
0.0015 ± 0.005 K/year

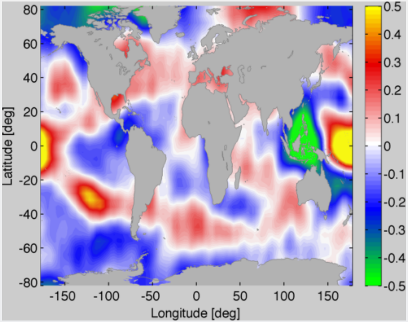
Two independent comparison in excellent agreement.

10-Year Trends in AIRS All-Sky Radiances

SST Rates (ERA)



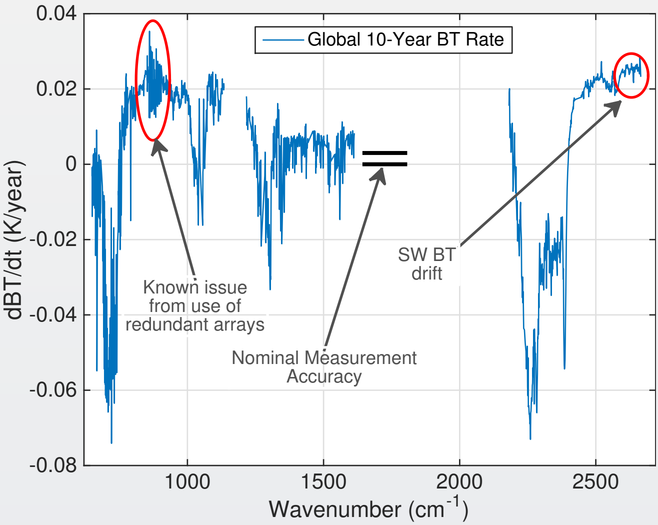
AIRS All Sky: 1231 cm^{-1}



- Units are K/year linear rate over 10 years
- Right: AIRS 1231 cm^{-1} window channel, Surface emission + cloud forcing
- 10 years too short: spatial variations dominated by ENSO/inter-annual variability
- But, global averages might be interesting.

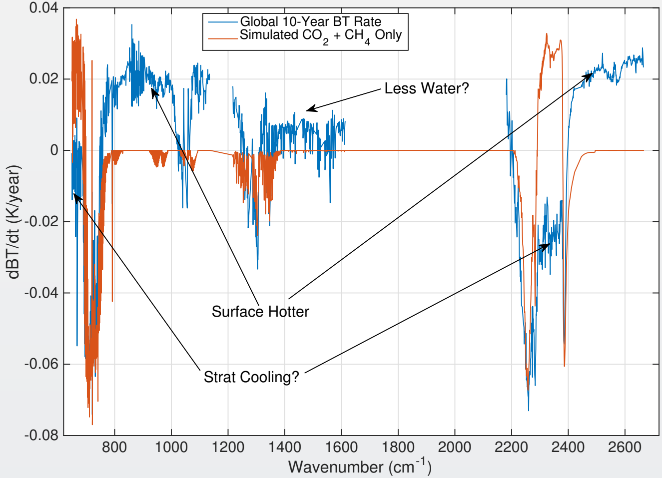
Globally Averaged AIRS 10-Year All-Sky BT Rates

Area Weighted



Global Averaged AIRS 10-Year All-Sky BT Rates

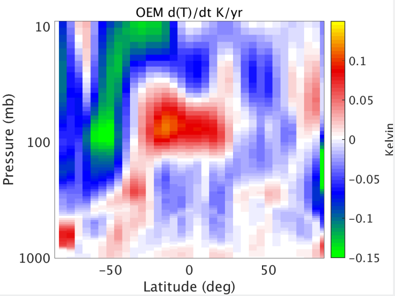
Comparison to All-Sky Simulations, but only changing $CO_2 + CH_4$.

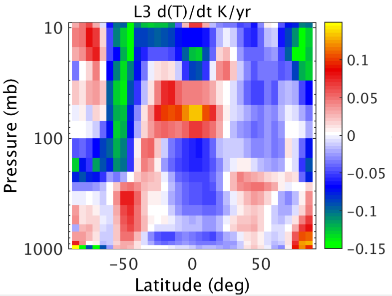


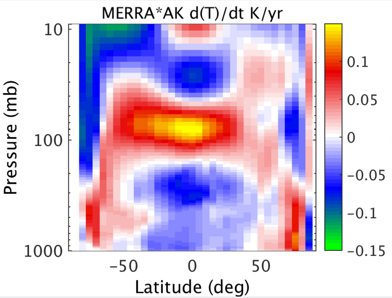
Little mid-trop ΔT, decrease in mid-trop H_2O $\sim$ 0.1%, surface T +0.02K. Main observation: Stratospheric cooling? Measurement error $\sim$ 0.003K?, geophysical variability higher.

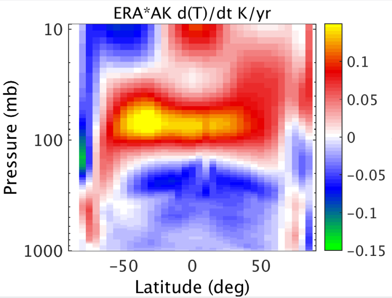
UMBC Temperature vs ERA-Interim, MERRA, AIRS L3

Retrievals from 10-Year zonal mean linear radiance rates (colorbar = Kelvin)



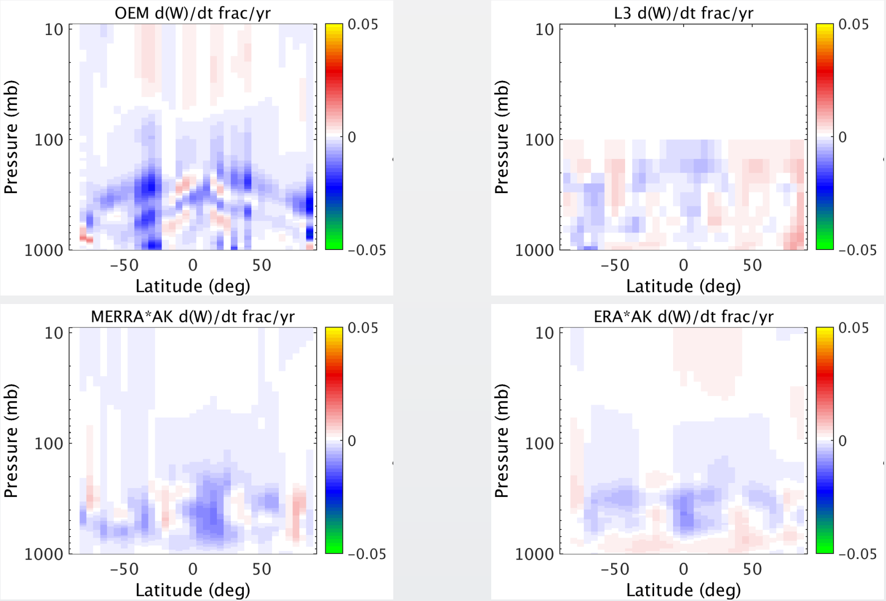






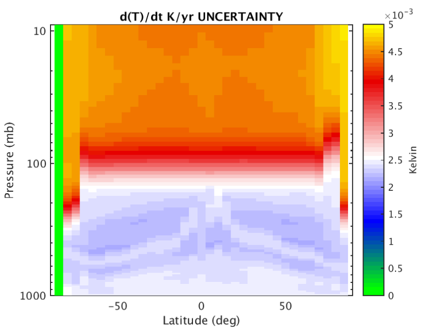
UMBC Water Vapor vs ERA-Interim, MERRA, AIRS L3

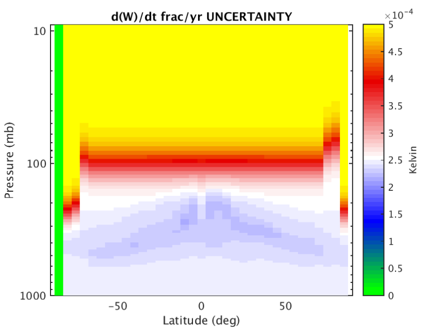
Retrievals from 10-Year zonal mean linear radiance rates (colorbar = fraction)



Uncertainty estimates of the UMBC linear trend

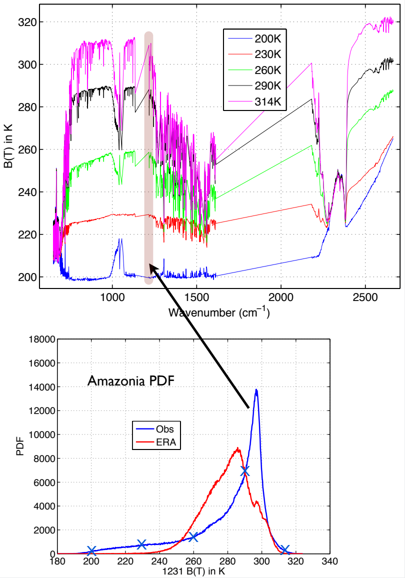
The uncertainty reflects the loss of sensitivity with altitude, and the error covariance matrices chosen, and at lower altitudes is dominated by inter-annual variability.





PDF Measurement Approach

Do not average all-sky radiances.



Retain more information: PDF rates, not Radiance Rates

- Averaging clear with cloudy scenes destroys information
- Bin (create PDFs) versus variable related to cloudiness
- I used 1231 cm^{-1} channel B(T): clearest window channel
- Data Set: 10 years of AIRS, only FOVs on each side of nadir
- Bins of B(T) 1231 cm^{-1}, from 190:1:320K
- Mean BT spectra in each bin are stable versus time
- All the information is in the PDFs in each bin

Conclusions

- Operational sensors have the stability needed for climate
- In-orbit overlap should allow stitching records with uncertainty equivalent to 0.1K/decade. Some risk.
- Demonstrated re-analysis level results with all-sky retrievals derived from radiance trends
- PDF approach may lower sensitivity to instrument accuracy for some variables
- This approach allows a much more rigorous error analysis needed for community acceptance of satellite derived climate change.