Satellite Hyperspectral Infrared Climate Time Series Combining AIRS and CrIS

Sun-Climate Symposium

Sergio DeSouza-Machado[1] and L. Larrabee Strow[1]

May 18, 2022

[1] UMBC Physics Dept.

Introduction

- Climate monitoring requires proven stability with high accuracy and/or sensor overlap
- Focus on simple retrieval approaches that are connected as closely as possible to the measured radiances and are amenable to frequent reprocessing
- We hope to show that hyperspectral IR radiance analysis provides important measurements of climate, with minimal a-priori information
- Fusion with different remote sensing data type can reveal null space error in both, allows corrections for both sensor types (GPSRO, MLS, Imagers, etc.)

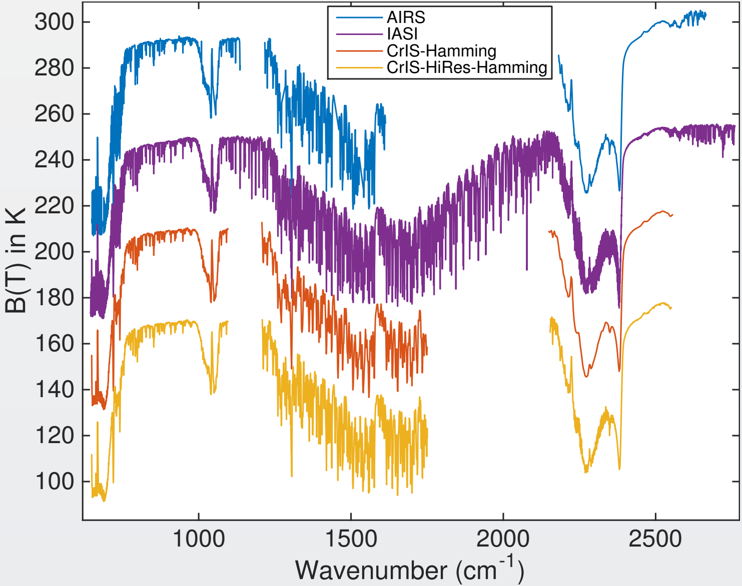
Satellite Measurements: ~12-km footprints, full coverage 2X/day

AIRS *1:30 orbit*	2002 - 202X??
0.5/1.0/2.0 cm-1 LW/MW/SW	
CrIS *1:30 orbit*	2012 - 204X?
1 SNPP-CrIS, 4 on JPSS	NSR 0.625/1.25/2.50 cm-1
	FSR 0.625 cm-1
IASI *9:30 orbit*	2007 - 204X?
3 on METOP-A series	
3 on METOP-SG series (2024)	
0.25/0.125 cm-1 LW/MW/SW	
(IASI-1 CDR available on request)	
CHIRP (AIRS+CrIS)	2002 - 204X
"Virtual" L1c for climate	0.625/1.25/1.25 cm-1

Each sensor produces ~2-3 million observations (spectra) daily.

CHIRP : AIRS and CrIS are very stable. Deconvolve AIRS radiances to 0.1 cm-1 grid (matrix inversions) then reconvolve to CHIRP IFS; CrIS radiances transformed to CHIRP ILS by IFFT/FFT. So can blend AIRS 2002/09 to 2015/08 to CrIS FSR 2015/09 - 204X/MM

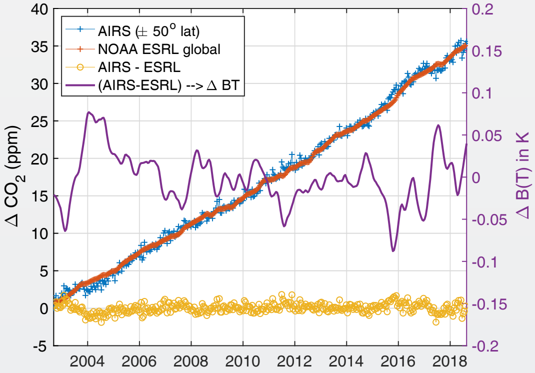
Example Spectra



Overall Approach

- Driven by Level 2 + Time $\neq$ Climate
- Full sampling not required for climate
- Manipulate data in radiance space "as long as possible" before retrievals
- Reduce sensitivity to calibration and RTA bias (radiance anomalies)
- Optimal estimation retrievals regularized more by smoothing than a-priori
- Develop analysis approaches that encourage more researchers to use radiances, rather than complicated Level 2 products for climate research, with quick turnaround.

AIRS Stability Validation (Clear Ocean Scenes Time Series)



- CO_2 trend (using 400 "good" channels) suggests stability: -0.023 ± 0.009 K/decade. Picks up ENSO related variations in CO_2 growth at the 0.04K with good S/N
- CH_4 and N_2O trends exhibit small offsets (known events, fixable)
- (AIRS - GHRSST) SST trends:): -0.022 ± 0.012 K/decade
- This approach provides strong evidence of inherent radiometric stability at the climate level

Radiance Sampling

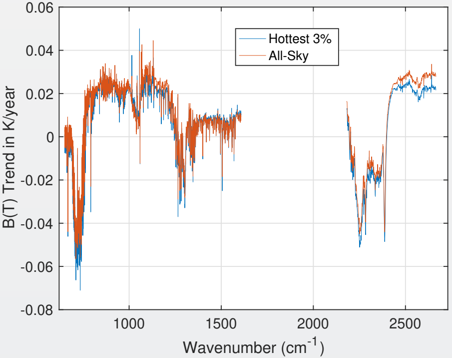
- Early testing shows identical surface T trends with 1%, 3%, 5%, and 10% hottest scenes per 16-day gridded lat/lon cell (3x5 lat/lon).
- Will this sampling provide accurate profile trends?
- Careful sampling of cloudier scenes does not preclude retrievals, just more care in cloud parameter a-priori values and parameterization
    - Hyperspectral IR retrievals really need footprint matched cloud parameters from MODIS (like CERES uses). Univ. Wisconsin has already generated this product for CrIS from VIIRS!
- Subsequent results used 3% surface T sampling (from 1231 cm^{-1} channel)

Trend retrievals in next few slides take ~1 hour max, so reprocessing is trivial.

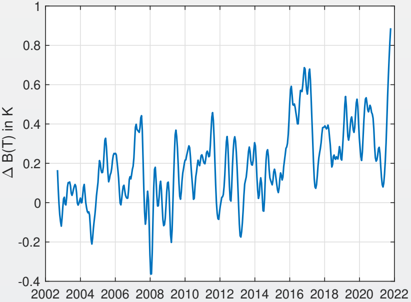
Resampling (say for fixed cloud forcing) takes ~2 days.

Global IR Radiance Trends and Surface-T Anomalies

Global Trends: Clear vs All-Sky

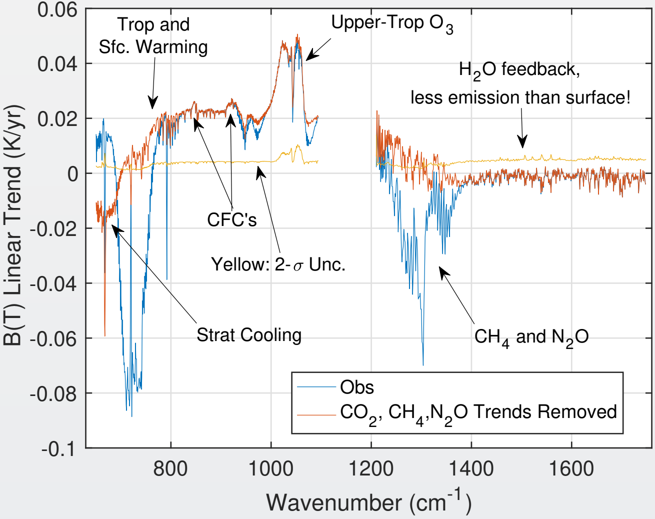


Tsurface Global Anomaly



- "Clear" 3% hot sampling trends almost same as all-sky
- Zonally averaged uncertainties (inter-annual variability) ~0.05K/Decade
- Good AIRS channels: stability ~0.02K/Decade
- Some water band drifts of up to ~0.04K/Decade (can be fixed)
- Shortwave known drifts (higher for cold scenes)

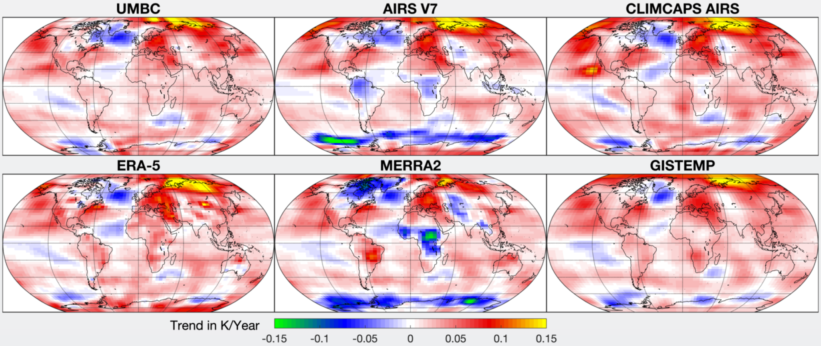
Follow-On Sensor: SNPP CrIS 8-Year Trends



Clear ocean scenes

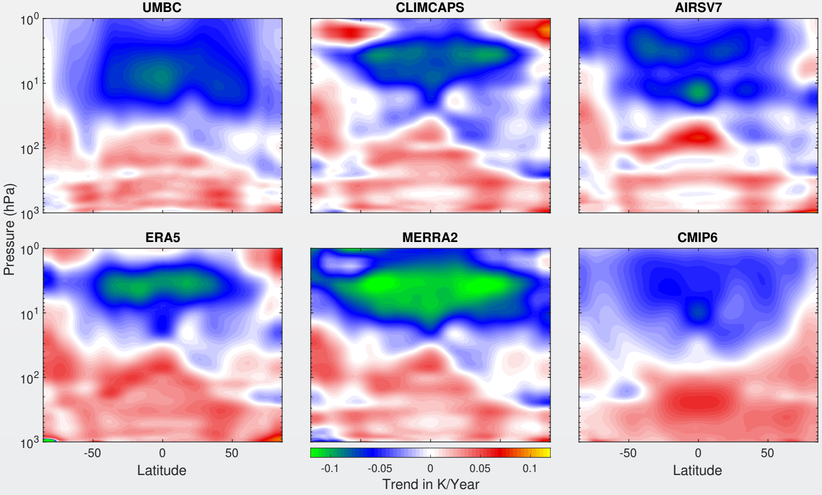
Less "hash" due to nature of FTS instrumentation

Surface Temperature Trend Comparisons



Data Source	Spatial Correlation (w/ UMBC)
CLIMCAPS AIRS	0.82
GISTEMP	0.74
AIRS V7	0.70
ERA-5	0.66
MERRA2	0.53

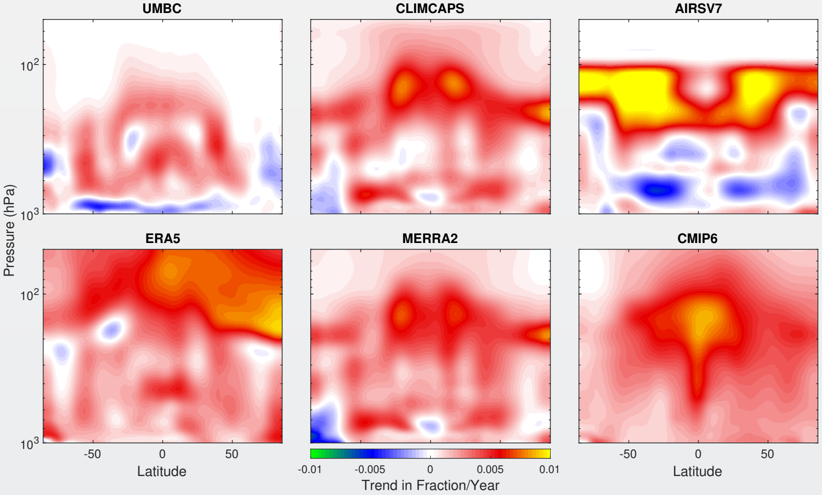
Zonal T(z) Trends (with CMIP6 to 2014)



UMBC dT(z,lat)/dt results agree quite well with ERA5, MERRA2, AIRS v7, CLIMCAPS
IR has null space near the tropopause. But our trends change sign there as well

UMBC uncertainties ~0.01K/year (inter-annual variability)

Water Vapor Trends (with CMIP6 to 2014)

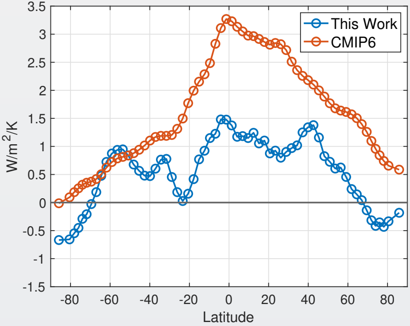


- UMBC a-priori of zero influencing upper-trop WV
- Quick test using MLS trends as a-priori for UMBC upper-trop
- Higher sampling (warmest 10% or even allsky) may change UT/LS

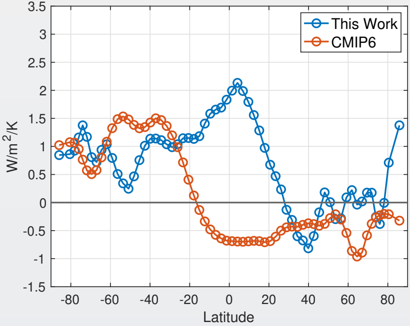
Climate Feedback Estimation from Trend Retrievals

- CMIP period ends 2014 compared to our 2002-2021 time period
- OLR differences directly from trends, no use of inter-annual variability for kernels
- UMBC results similar to ERA-5 (not shown).
- Cannot use MERRA2 surface T due to poor trends.

λ WV



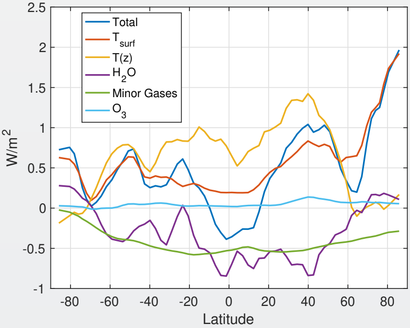
λ Lapse Rate



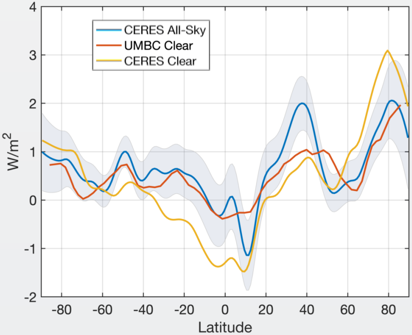
Note Positive lapse rate feedback in tropics for 2002-2022.

OLR Clear Sky Trends from AIRS (UMBC version)

Components from AIRS Trends



Total Δ OLR (clear) over 19 Years



- Hyperspectral dBT/dt retrieval → composition decomposition ≃→ broadband CERES trends
- Clouds not changing too much; but we expect some small changes to our decomposition, final trends
- UMBC clear closest to CERES All-Sky (but not perfect)

Summary and Future

- Hyperspectral IR observations are a unique dataset to monitor and understand climate change, for weather prediction and reanalysis, and to evaluate climate models
- Hyperspectral IR radiances provide insights into the physics of the climate system that are not possible using broadband observations
- Clear sky (hottest 3%) sample shows dST/dt, dT(z)/dt trends very comparable to ERA5
- Planning on increasing sampling to do retrievals higher in the atmosphere (these hottest trends will be used a *a-priori*
- We are starting to successfully merge hyperspectral IR radiances from different instruments which is critical for climate monitoring (GPSRO, MLS, MODIS/VIIRS)
- Will improve merged products using more sophisticated approaches and including additional observations
- CHIRP already on Amazon Web Services cloud (AWS)