Spectral and Geophysical Trends and Anomalies (2002-2024)

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Outline

Motivation:

- Determine climate level trends with CHIRP : 20 years AIRS/20 years CrIS
- Minimize uncertanties due to:
  - Absolute calibration
  - RTA bias errors
  - A-priori information

Approach: use AIRS L1C data from 2002/09 onwards

- Geophysical trends
  - Re-visit 20-year thermodynamic trend retrievals from radiance trends.
  - Uses retrieved trends to estimate climate feedbacks.
  - Compare to trends from monthly ERA5/AIRS L3/CLIMCAPS L3, MERRA2)
- Anomalies
  - Radiative closure : convert other radiance sets to spectral anomalies/trends for comparisons to AIRS spectral radiance observations.
  - Compare CERES,ERA5,AIRS L3 *broadband* anomalies vs AIRS L1C derived *broadband and spectral* flux anomalies

Desired Approach to handle clouds

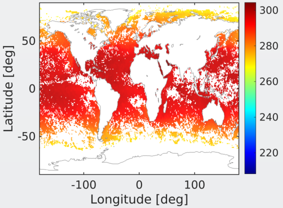
- CERES for example matches to MODIS to get information about clouds for its OLR product
- U.Wisc : Dave Tobin matched CrIS/VIIRS to make the IMG product
  - small files, colocated CrIS FOVs to VIIRS cloud mask info eg radiances, reflectances, and cloud mask
  - planned : cloud and aerosol products, including cloud top height, optical thickness, aerosol thickness, smoke, dust
- Full mission AIRS/MODIS product would be much preferred
- Will also allow studies of allsky trends and/or anomaly time series

Current Approach to handle clouds

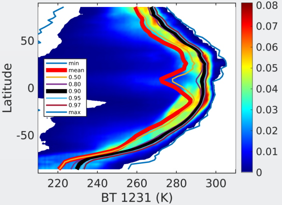
- We have a uniform clear flag, which works well over ocean but not land
- Use hottest 10% BT1231 observations for each 3 $\times$ 5 tile to make radiance anomalies/trends

Comparing the two methods (2012/08/27 - 2012/09/11)

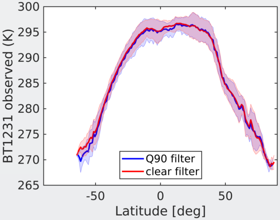
Uniform-clear



Quantiles



BT1231



OEM Retrievals

- Hotter quantiles (10%,5%,3%) have *very similar trends* (anomalies may differ)
- Use zero *a-priori* for temperature and surface temperature
- enforce constant Relative Humidity in lower atmosphere (instead of $\delta(WVtrend) = 0$ *a-priori*)
- fixed trace gas trends (CO2, N2O, CH4) to ESRL (Carbontracker)
- Retrieve T(z),WV(z),Tsurf trends

- Compare against these 20 year monthly clearsky datasets Sept 2002-August 2022
  - ERA5, MERRA2, GISS, AIRS3 L3, CLIMCAPS L3

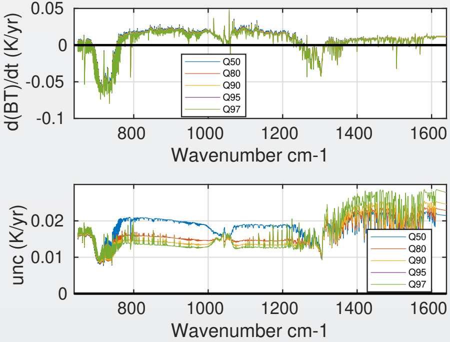
Advantages of our approach

- AIRS has 0.002 K/year stability (see "Establishment of AIRS climate-level radiometric stability using radiance anomaly retrievals of minor gases and sea surface temperature," Strow/Machado, https://doi.org/10.5194/amt-13-4619-2020)
- Only use 400 or so pristine LW channels, we do not use drifting SW channels even for warm observations

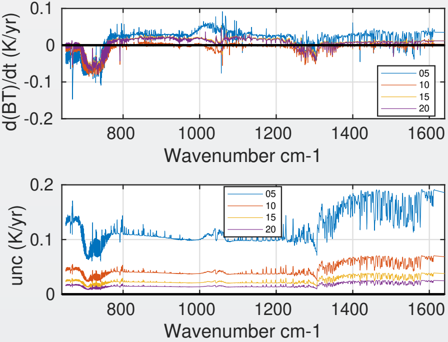
- One time per year or so
  - Making 16 day tiles (anomalies/trends) : about 2-3 days for all 4608 tiles
- Coming up with these results : multiple trials!
  - trend retrievals → 15 mins
- Effectively instantaneous compared to months if you re-process AIRS L2/L3, re-analysis etc
- once in Amazon Cloud, this will be accessible to anyone!

Night Spectral Trends : Quantile vs TimeSpan Variations (Global Average)

Q50/80/90/95/97



05/10/15/20 years

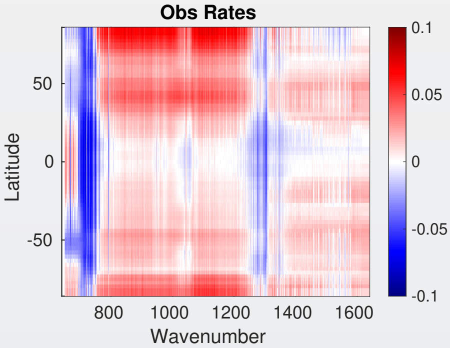


- Trends very similar, anomalies show diffs
- Q50 (average) has most uncertainty

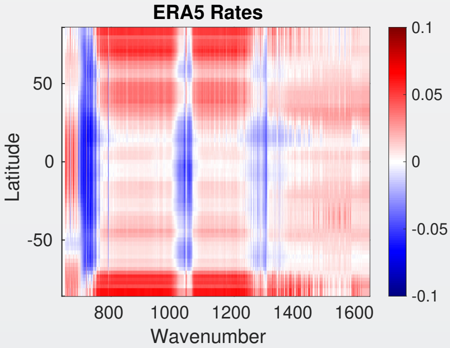
- uncertainty decreases with timespan (see eg S. Leroy)
- ENSO cycles start affecting eg window channel trends

Comparing AIRS L1C vs ERA5 clear sky simulations

AIRS L1C : trends from hottest 10% observations

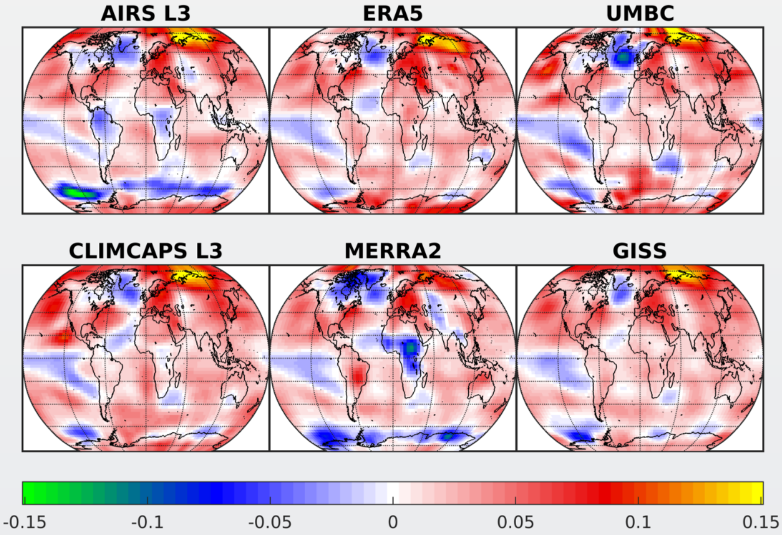


ERA5 : monthly fields → SARTA simulations → trends



- 15 um trends look somewhat similar, though diffs in ERA5 in strat channels (we used constant CO_2 VMR(z))
- O3 look rather different ....
- S. Polar ERA5 has more warming (far less*in-situ* sites)
- Some differences in WV at 1500 cm^{-1} in N. Polar (and S. Polar)
- ERA-I known to have O3 issues, may be better in ERA5 (Variability of temperature and ozone in the upper troposphere and lower stratosphere from multi-satellite observations and reanalysis data, Ming Shangguan, Wuke Wang, and Shuanggen Jin, ACP **19, 6659–6679, 2019)**

Surface temperature trends (K/year)



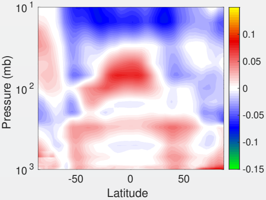
Cosine weighted global averaged surface temperature trends (K/yr)

SKT trend K/yr	ERA5	MERRA2	THIS WORK	AIRS	CLIMCAPS	GISS
ALL	0.022	0.011	0.020	0.015	0.024	0.021
TROPICS	0.015	0.010	0.013	0.011	0.016	0.015
MIDLATS	0.026	0.020	0.023	0.016	0.030	0.026
POLAR	0.038	-0.005	0.034	0.023	0.034	0.028
OCEAN	0.016	0.012	0.017	0.014	0.022	0.017
LAND	0.035	0.010	0.026	0.017	0.028	0.030

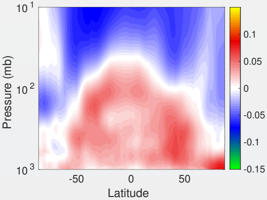
- Uncertainties are on the order of ± 0.015 K
- MERRA2 and AIRSL3 show cooling in Southern Ocean, over Amazon and C. Africa

Zonally averaged Temperature trends (K/yr)

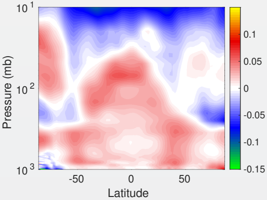
AIRS L3



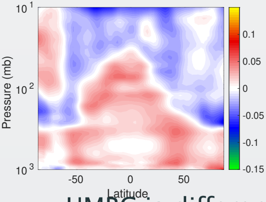
UMBC



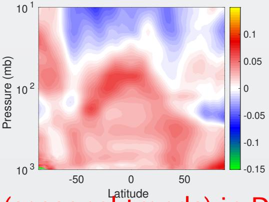
MERRA2



CLIMCAPS L3



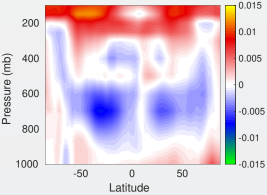
ERA5



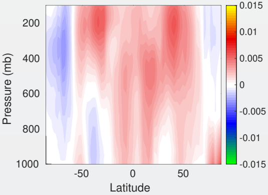
- UMBC is different over S. Polar region Slide 18 (seasonal trends) in DJF
- Observations (AIRS/CLIMCAPS/UMBC) have little to no warming over N. Polar 100 mb region

Zonally averaged WV trends (frac(WV)/yr = $\delta(WV)/ < WV >$/yr)

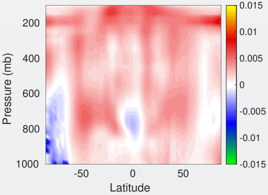
AIRS L3



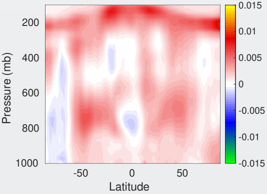
UMBC



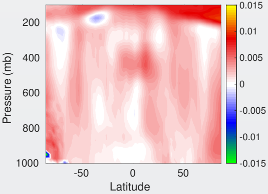
MERRA2



CLIMCAPS L3

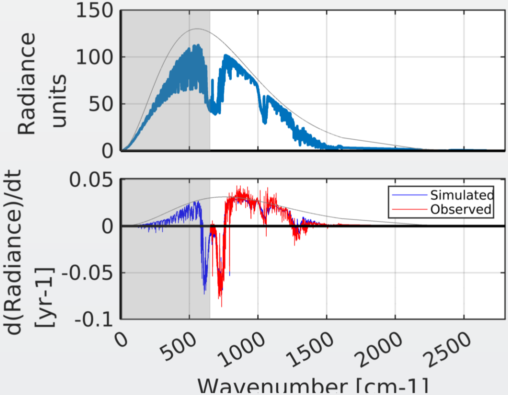


ERA5



- UTH dominated by *a-priori* : eg can put in MLS trends above 200 mb
- AIRS L3 quite different from rest
- UMBC has (more) drying over S. Polar than do eg AIRS L3 or CLIMCAPS
- ERA5 is the only one that shows moistening over S. Polar

OLR : broadband vs derived from AIRS



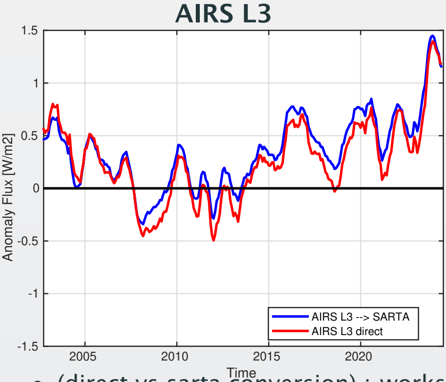
- Far-IR WV emission dominates atmospheric cooling, esp. in descending tropical regions
- AIRS observed mid-IR WV has sensitivity where (WV) OLR is large in far-IR
- Compute feedbacks from AIRS retrievals using computed OLR driven by mid-IR WV retrievals

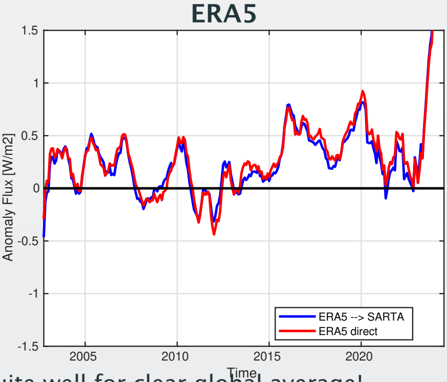
sarta (radiance W/m2/sr/cm-1) to ecrad (flux W/m2)

$F(W/m2) = 3.5788 \sum_{channels_i} r(\nu_i, satzen = 20^\circ - 30^\circ) + 88.73$

How good is $F = 3.5788 \sum_i r(\nu_i) + 88.73$?

monthly ERA5/AIRS L3 thermodynamic fields → sarta → OLR anomaly timeseries
monthly ERA5/AIRS L3 OLR fields → OLR anomaly timeseries



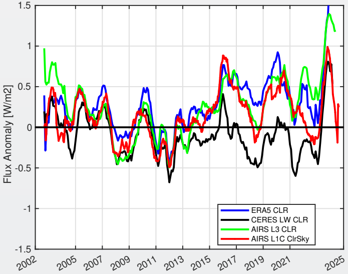


- (direct vs sarta conversion) : works quite well for clear global average!
- SARTA TwoSlab gives an offset, otherwise tracks cloudy OLR quite well
- Subdivide into RRTM bands = 630 700 820 980 1080 1180 1390 1480 1800

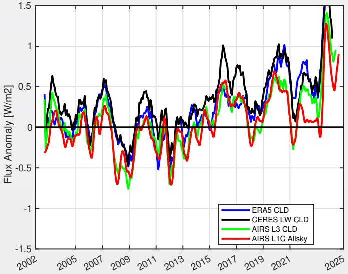
CERES, ERA5, AIRS L3, UMBC (where clear is Q90 and allsky is mean over all data)

Cosine weighted over our 64 latitude bins

CLEAR



ALLSKY

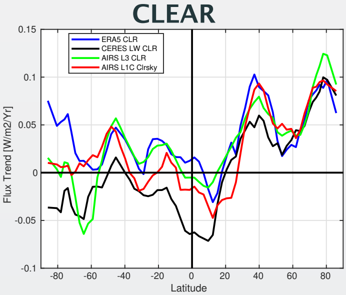


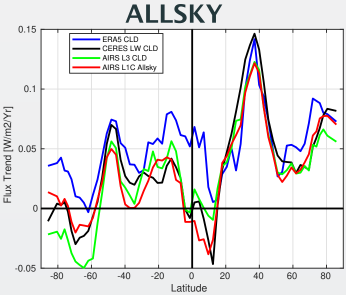
- CERES clearsky has two options
  - the clear filled region in a pixel
  - the empirically filled "Total" clear sky
- We used second option, not much change if we switch to first

Comparing Flux Trends (from anomalies)

CERES, ERA5, AIRS L3, UMBC (where clear is Q90 and allsky is mean over all data)

Cosine weighted over our 64 latitude bins



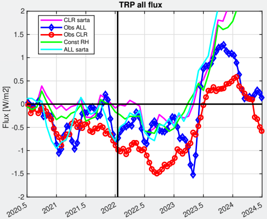


- CERES clearsky has two options
  - the clear filled region in a pixel
  - the empirically filled “Total” clear sky
- We used second option, not much change if we switch to first

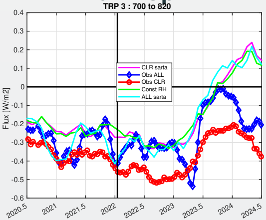
Zooming in on tropics 2020-2025, certain bands

Green curve : d(RH) = 0

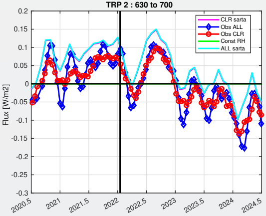
ALL



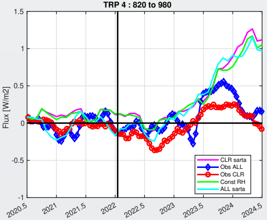
Mid Trop T



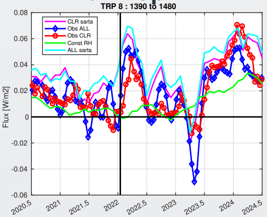
Strat T



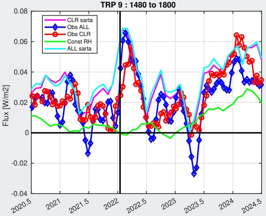
Window



Mid Trop WV

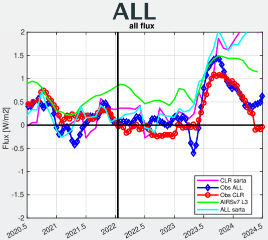


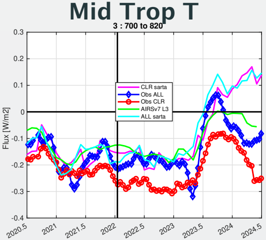
Strat WV

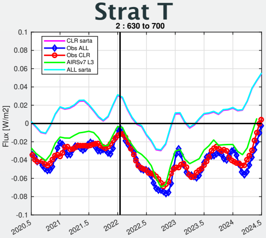


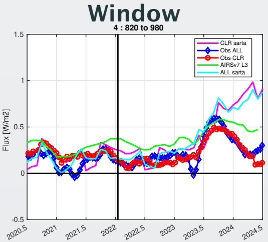
Global Averages 2020-2025, certain bands

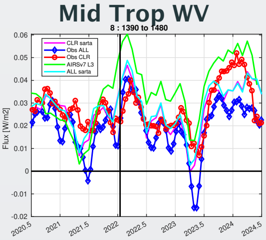
Green curve : AIRS L3 → SARTA

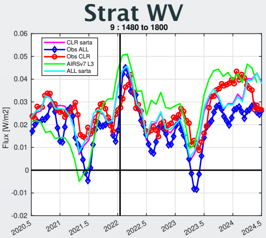




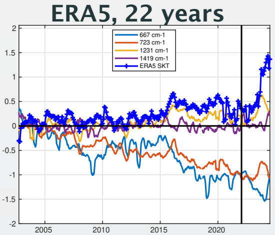


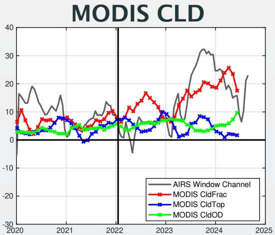


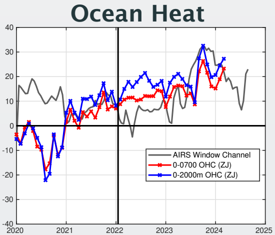


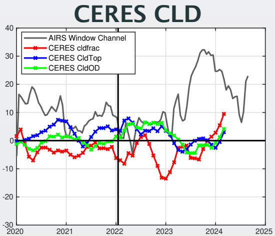


Various anomalies vs AIRS L1C window channels









Climate Clear Sky Longwave Feedbacks

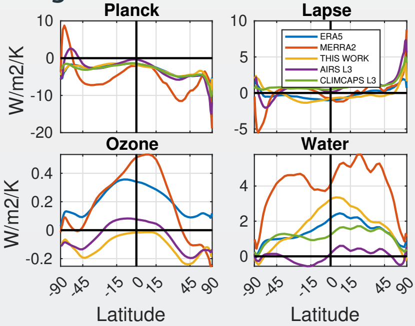
- use average monthly ERA5 profile per tile to compute base clear sky OLR using *ecRad*
- perturb the profile according to trend, recompute clear sky OLR
- compute feedbacks using One sided OLR change equations from Nadir Jevanjee *et. al.* “Simpsons law and spectral cancellation ” GRL 2021
- have previously compared to CERES OLR trends; our results look like their allsky trends

$$\overline{\delta SKT} = \frac{\sum_{i=1}^{4608} \delta SKT_i cos(\theta_i^{lat})}{\sum_{i=1}^{4608} cos(\theta_i^{lat})} \quad (1)$$

from which the non-local averaged feedback $\overline{\lambda}$ is

$$\overline{\lambda_{nonlocal}} = \frac{1}{\overline{\delta SKT}} \frac{\sum_{i=1}^{4608} \delta OLR_i cos(\theta_i^{lat})}{\sum_{i=1}^{4608} cos(\theta_i^{lat})} \quad (2)$$

Longwave Feedbacks



Non local Values W/m2/K

	Planck	Lapse	Ozone	WV	Total
THIS WORK	-3.50	0.40	-0.12	1.22	-2.10
ERA5	-3.49	0.20	0.17	1.18	-1.94
MERRA2	-3.98	-0.19	0.12	3.40	-0.54
AIRS L3	-3.48	1.38	-0.07	-0.02	-2.59
CLIMCAPS L3	-3.55	1.27	-0.00	0.96	-1.21

Uncertainties on order of ± 0.30 W/m2/K per component
Spectral cancellation means summed values uncertainty about ± 0.10 W/m2/K

20 year Trends and Clear Sky Feedbacks : COMPARISONS

	ERA5	MERRA2	THIS WORK	AIRS	CLIMCAPS	CESM2.3.X
SKT trend K/yr	0.022	0.011	0.020	0.015	0.024	0.024
Feedbacks W/m2/K	-1.94	-0.54	-2.10	-2.59	-1.21	-2.18

"Direct observation of Earth's spectral long-wave feedback parameter", Nature Geoscience 2023 (15 years of IASI, simulations) Roemer *et. al.*

Article

https://doi.org/10.1038/s41561-023-01175-6

Extended Data Table 3 | Simulated clear-sky spectral long-wave feedback parameter λ_ν integrated over different spectral bands

spectral band	spectral range cm^{-1}	seasonal variability $W\,m^{-2}\,K^{-1}$	interannual variability $W\,m^{-2}\,K^{-1}$	surface feedback $W\,m^{-2}\,K^{-1}$
FIR H_2O	100–570	−0.14	−0.32	−0.07
CO_2	570–770	−0.11	−0.32	−0.07
window	770–990, 1080–1250	−1.21	−1.11	−1.09
O_3	990–1080	−0.16	−0.17	−0.16
MIR H_2O	1250–2000	−0.11	−0.15	−0.06
combined H_2O	100–570, 1250–2000	−0.25	−0.47	−0.13
total	100–2760	−1.78	−2.12	−1.49

The λ_ν are derived from seasonal and interannual variability calculated from simulations based on the MPI-ESM1-2-HR model. The surface feedback is an estimate based on those simulations, calculated using Eq. (14) (Methods). All errors are < 0.004 $W\,m^{-2}\,K^{-1}$.

Conclusions

- Assessed Q90 clear selection against uniform clear
  - Would like to have AIRS/MODIS matchups
- Showed 20 year thermodynamic trends, compared to AIRS L3, CLIMCAPS L3, ERA5, MERRA2, GISS
  - T(z),SKT trends inter-compare quite well (our work shows less warming in polar upper atmosphere)
  - AIRS L3 shows largest differences in mid trop WV trends
- Generated 22 year OLR anomaly trends, compared to CERES, ERA5, AIRS L3
  - Simple model turns AIRS radiances into OLR fluxes (see D. Tobin's talk)
  - Our clear sky compares better against CERES Allsky (?!?)
- Computed OLR 20 year clear sky feedbacks, compare quite well to other work