A further look at the tropical clear-sky OLR trend in the last two decades

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3. Princeton University, AOS program 4. GFDL/NOAA

5. Brookhaven National Lab 6. Pacific Northwest National Lab

CERES 2026 Spring STM
Hampton, VA
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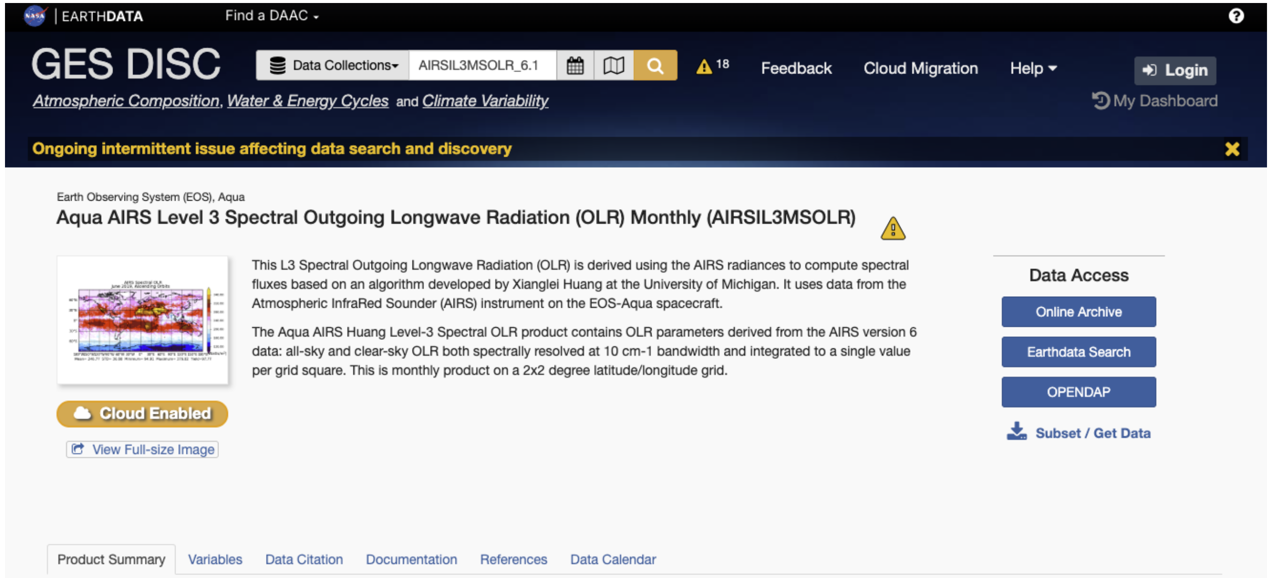
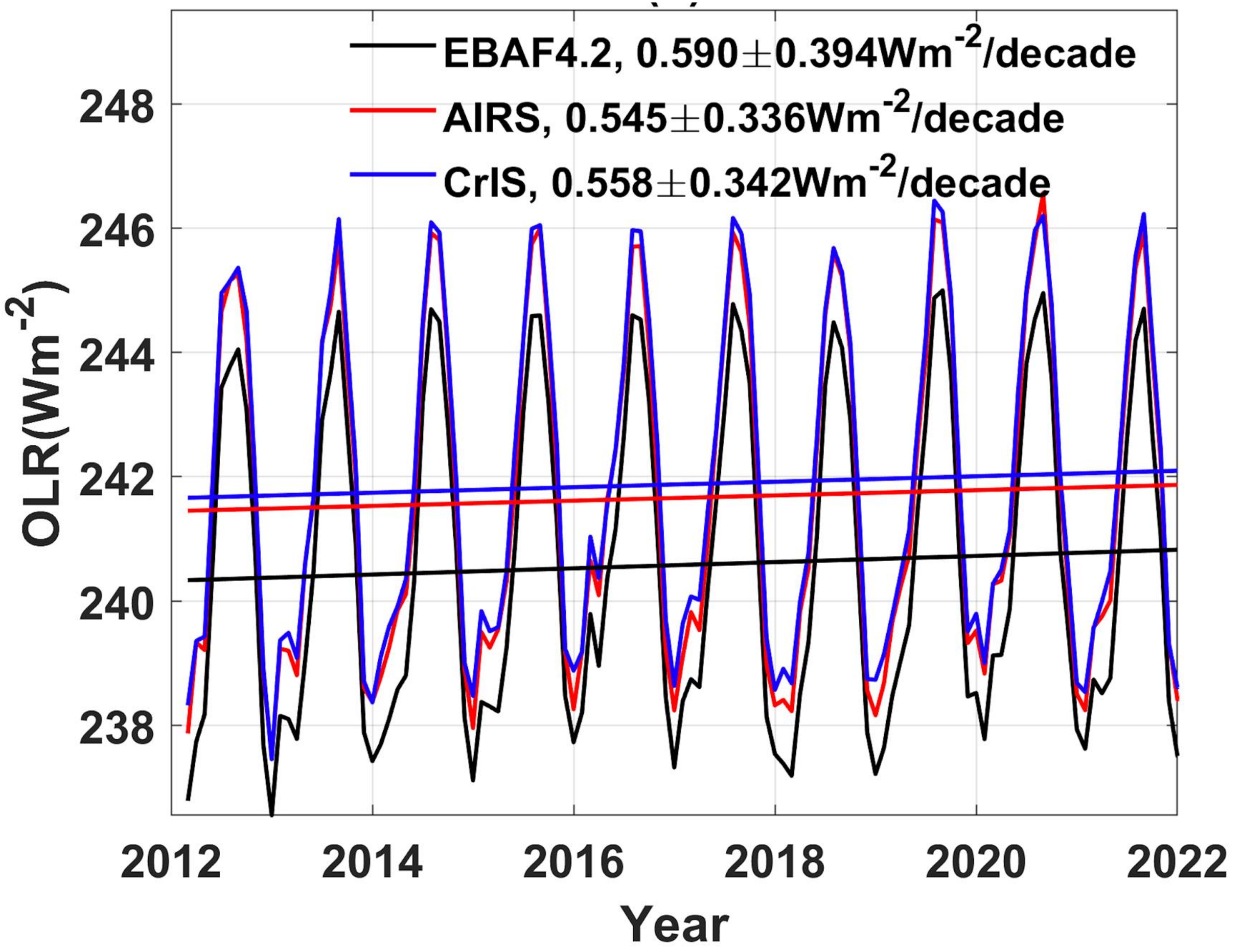
Observational availability

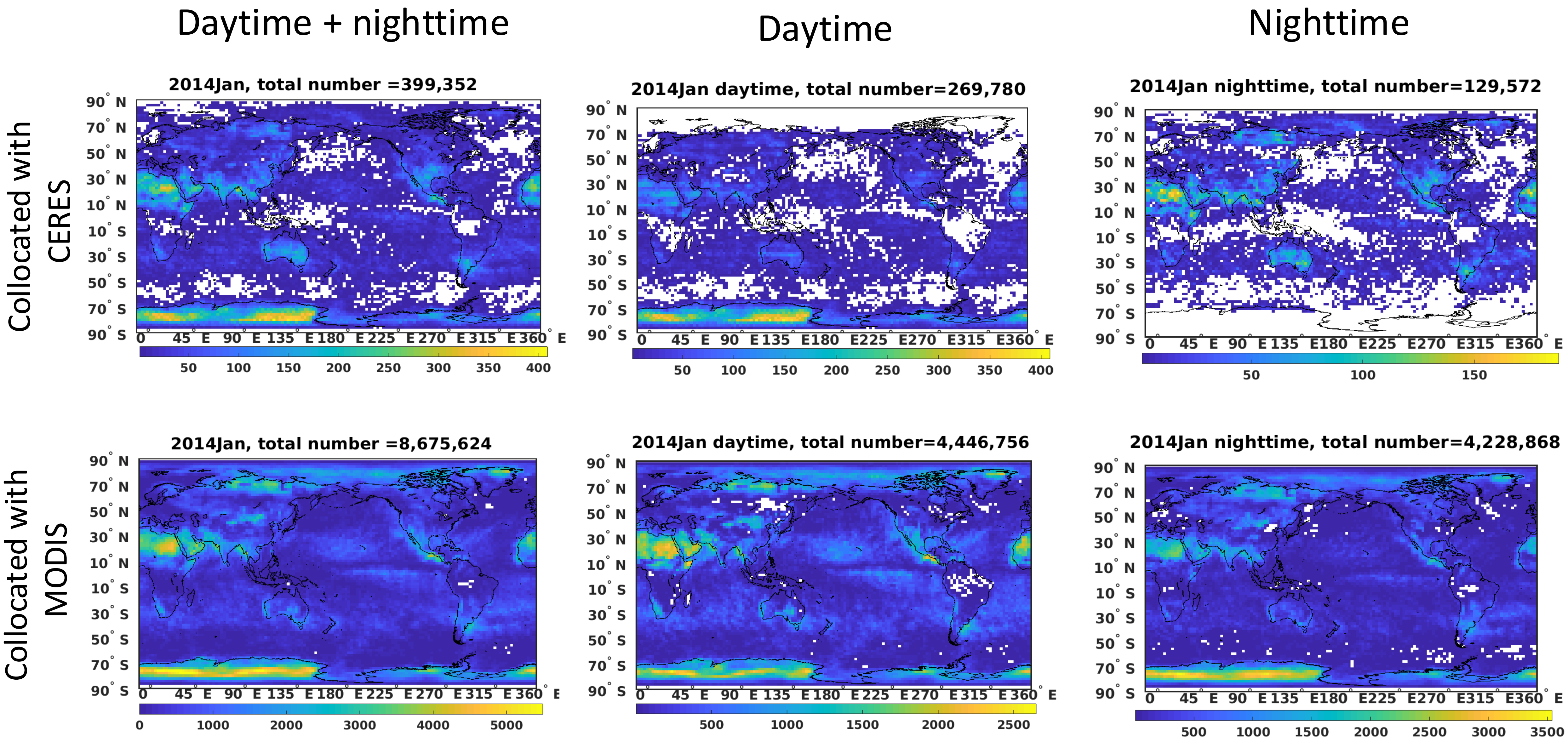
- CERES EBAF broadband OLR: most widely used "yardstick"for comparison.
- AIRS spectral OLR (Sep 2002 to present): an official AIRS L3 product made by our group
  - Spectral OLR with 10 cm^{-1} spectral bins over the entire longwave
  - Recently updated clear-sky spectral OLR with a factor of 10 in clear-sky sampling coverages
- Can also get it from CrIS



Broadband OLR trend

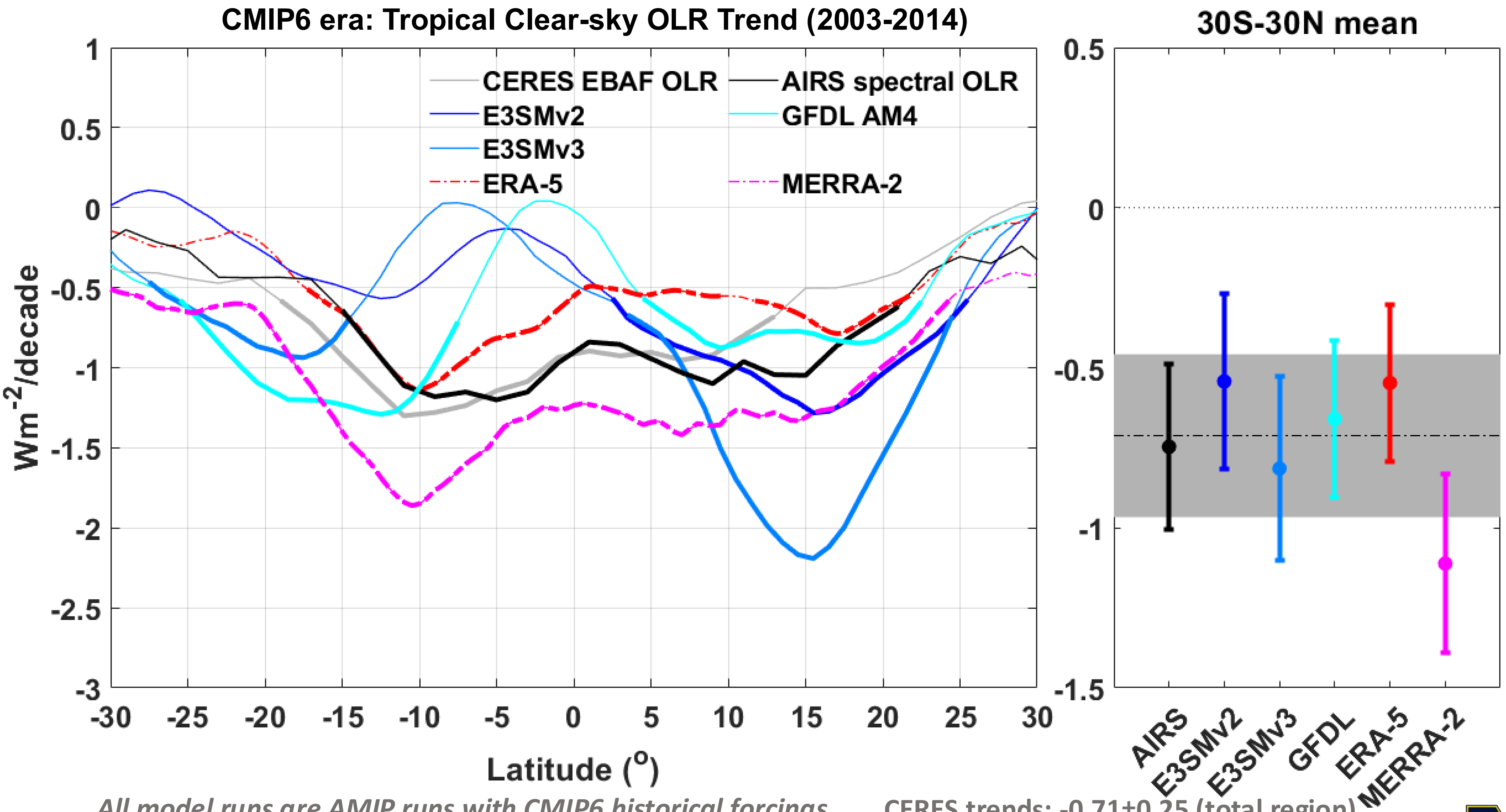


Number of clear-sky AIRS footprints as decided from different collocation strategy



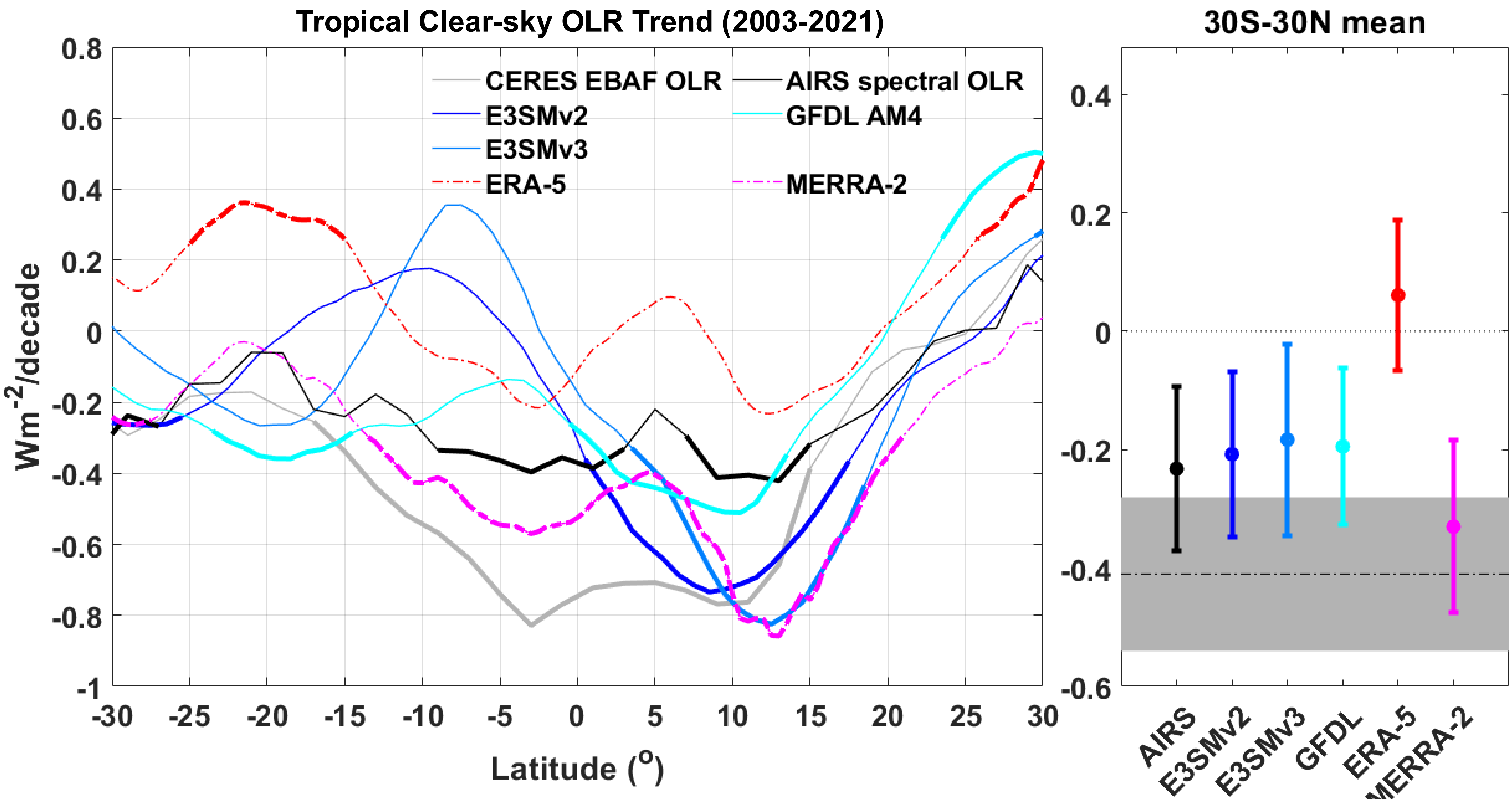
- *How good models can reproduce the observed clear-sky OLR trend in the tropics?*
- *How to understand the discrepancies in such comparisons?*
- *How to reconcile with theoretical estimations?*

- ❑ Observations: CERES EBAF 4.2 and AIRS Spectral OLR
- ❑ Reanalyses: ECMWF ERA5 and NASA MERRA-2
- ❑ Models: GFDL AM4, DoE E3SM v2 and v3
    - ❑ Forced by the observed SST
    - ❑ Two forcing period
        - ❑ 2003-2014 CMIP6 historical forcing
        - ❑ 2003-2021 CMIP7 historical forcing



All model runs are AMIP runs with CMIP6 historical forcings

CERES trends: -0.71±0.25 (total region)
-0.63±0.26 (cloud free)



All model runs are AMIP runs with recent CMIP7 historical forcings
Stopped at 2021 to avoid 2022 Hunga-Tonga eruption and the drift of Aqua

CERES trends: -0.41±0.13 (total region)
-0.35±0.14 (cloud free)

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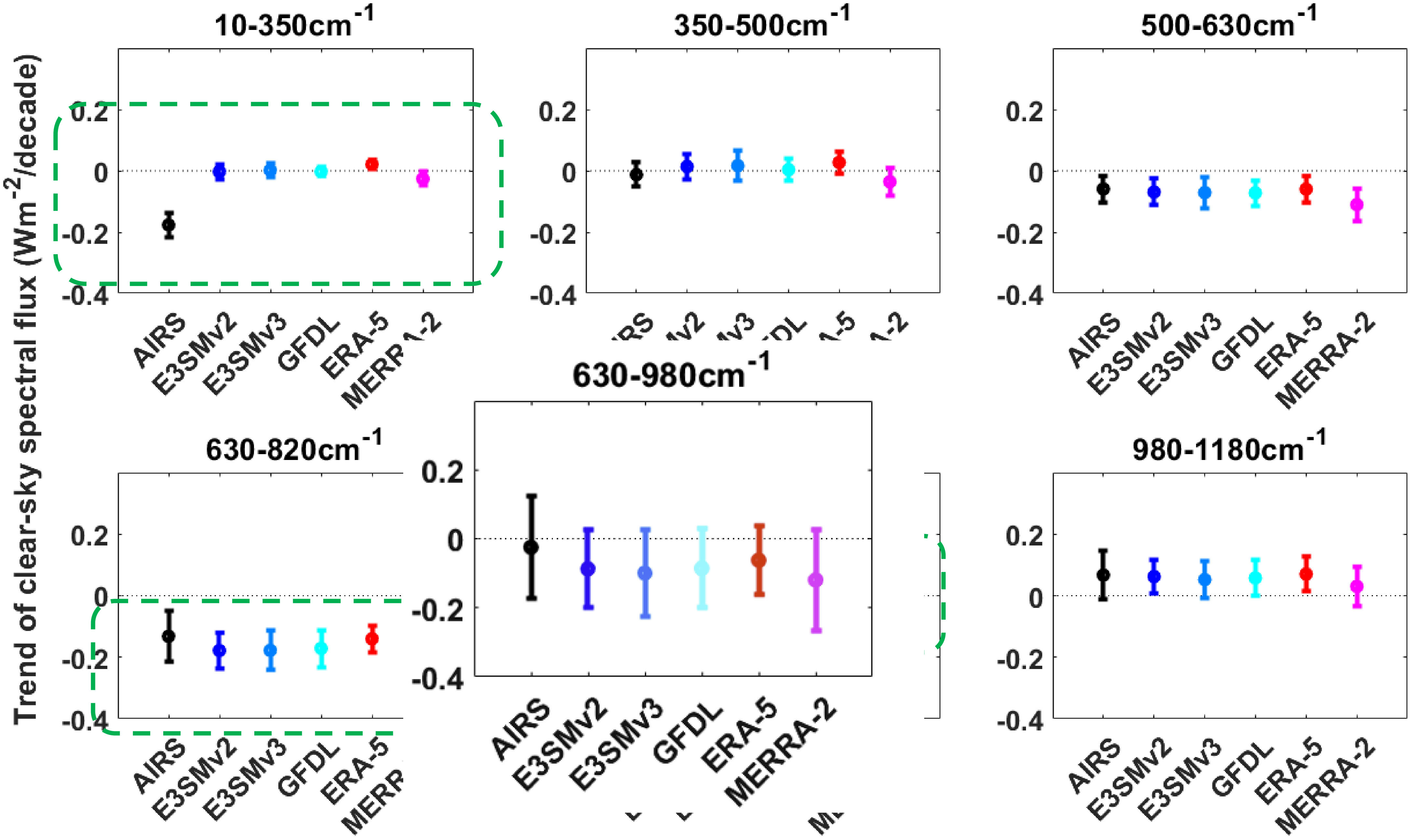
Tropical Clear-sky OLR Trend (2003-2021)



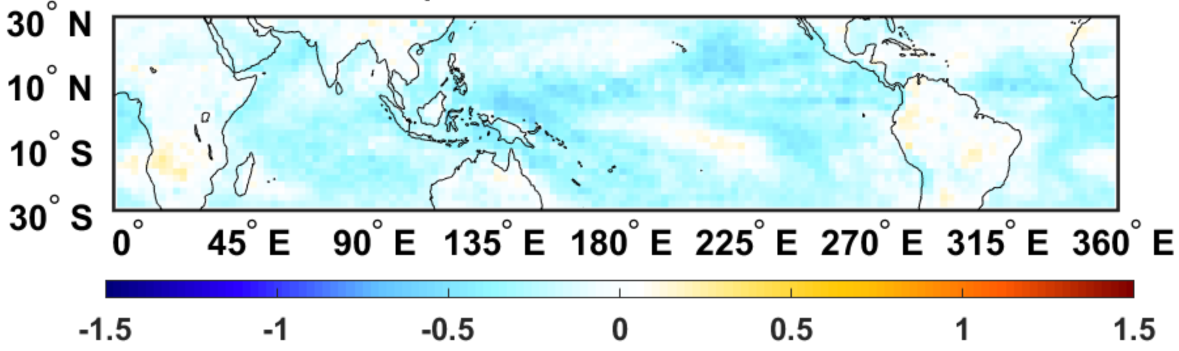
Clear-sky flux trend(2003-2021; 10-350 cm^{-1})

Black denotes the direct results from models and obs

Red denotes results from kernel calculation

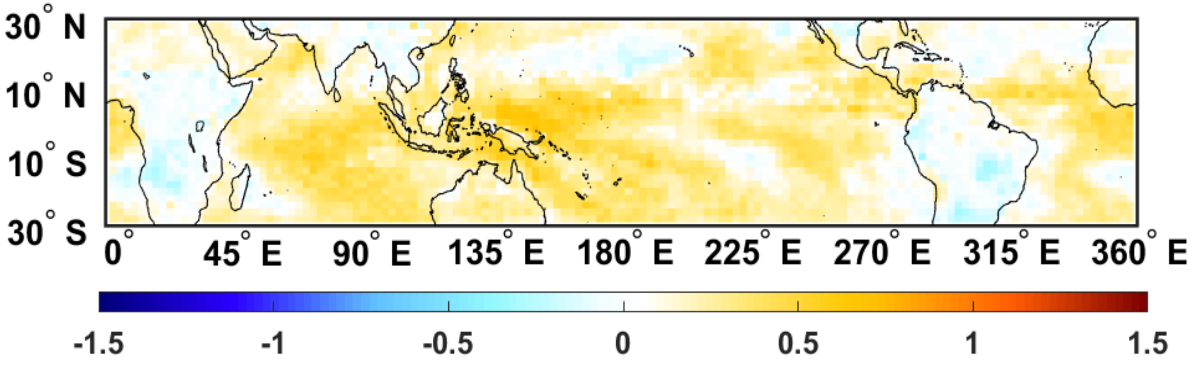
Note the land-sea contrasts

AIRS spectral OLR: $-0.17 Wm^{-2}$/decade

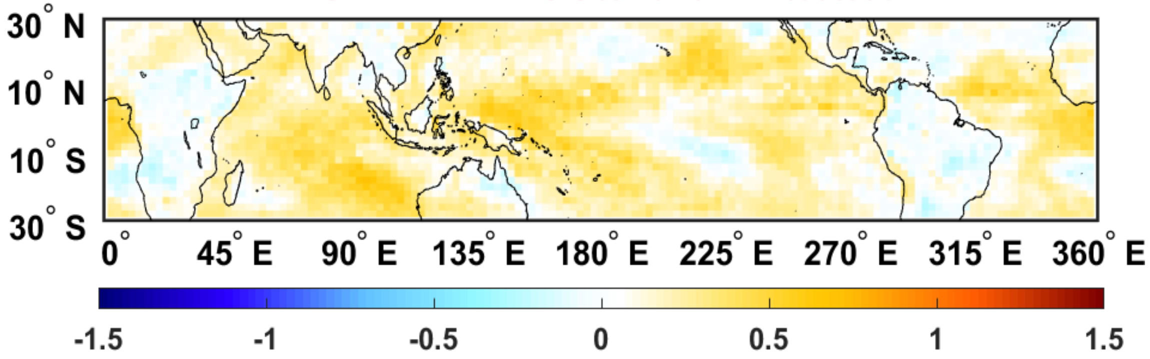


Trend difference from AIRS observation

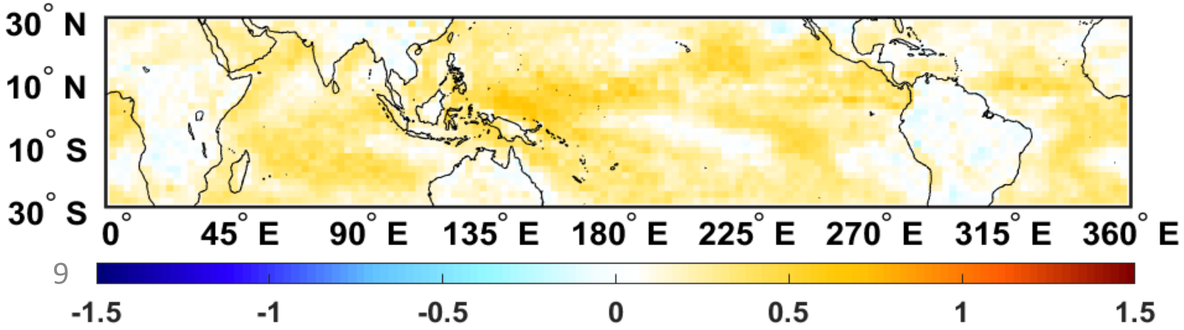
E3SM v3 - AIRS Obs.: $0.18 Wm^{-2}$/decade



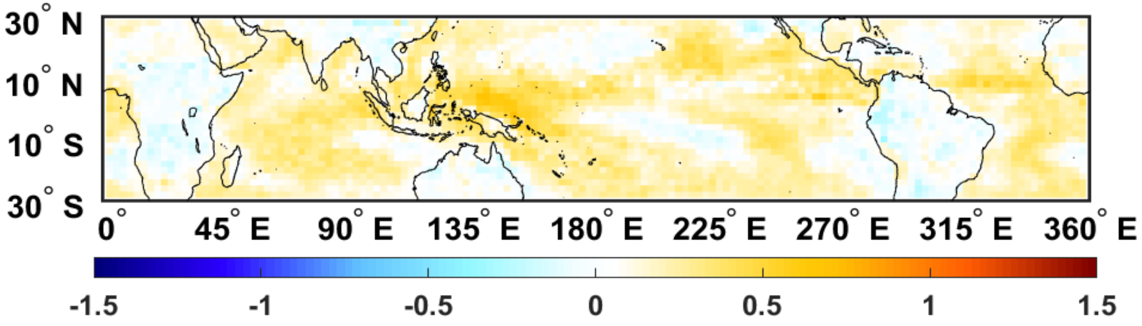
GFDL AM4 - AIRS Obs.: $0.18 Wm^{-2}$/decade



ERA-5 - AIRS Obs.: $0.20 Wm^{-2}$/decade



MERRA-2 - AIRS Obs.: $0.15 Wm^{-2}$/decade

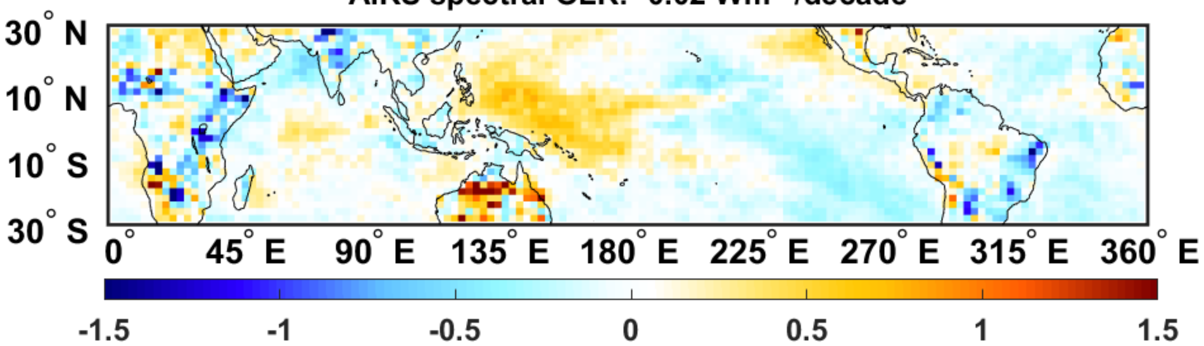


Clear-sky flux trend(2003-2021;630-980 cm^{-1})

Black denotes the direct results from models and obs

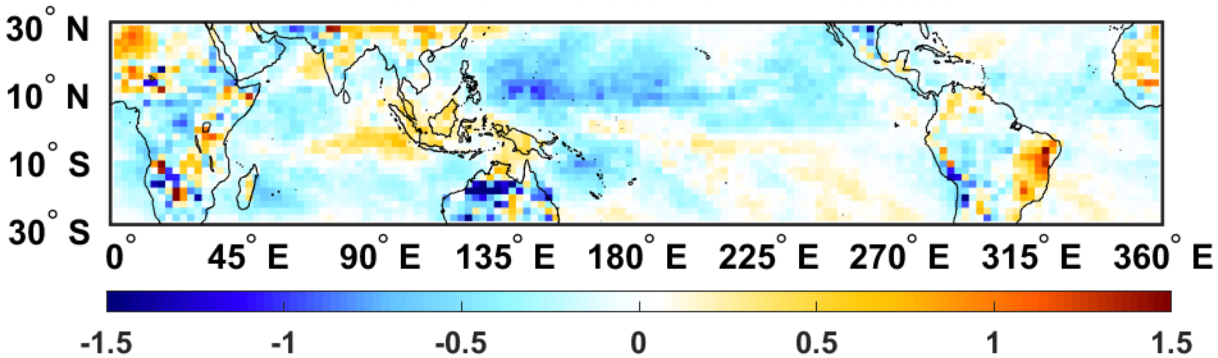
Red denotes results from kernel calculation

AIRS spectral OLR: -0.02 Wm^{-2}/decade

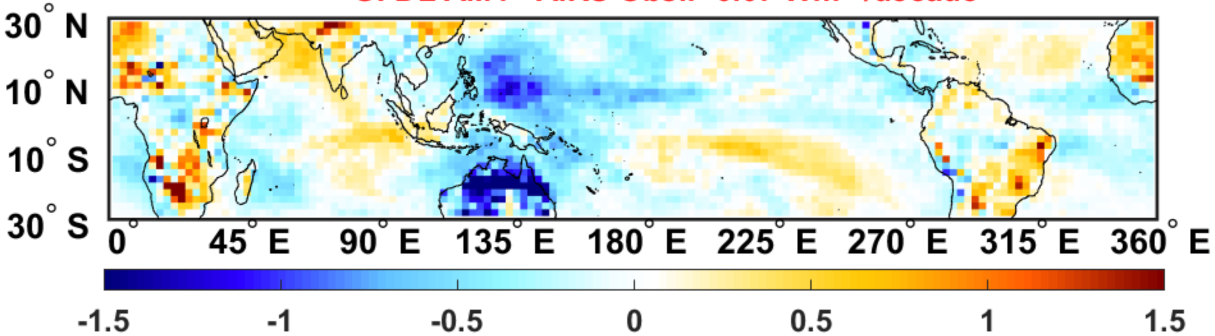


Trend difference from the AIRS observation

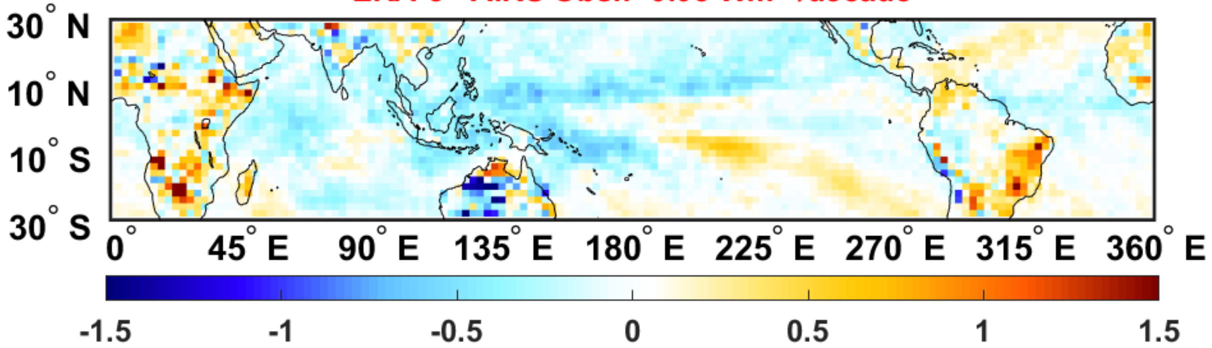
E3SM v3 - AIRS Obs.: -0.11 Wm^{-2}/decade



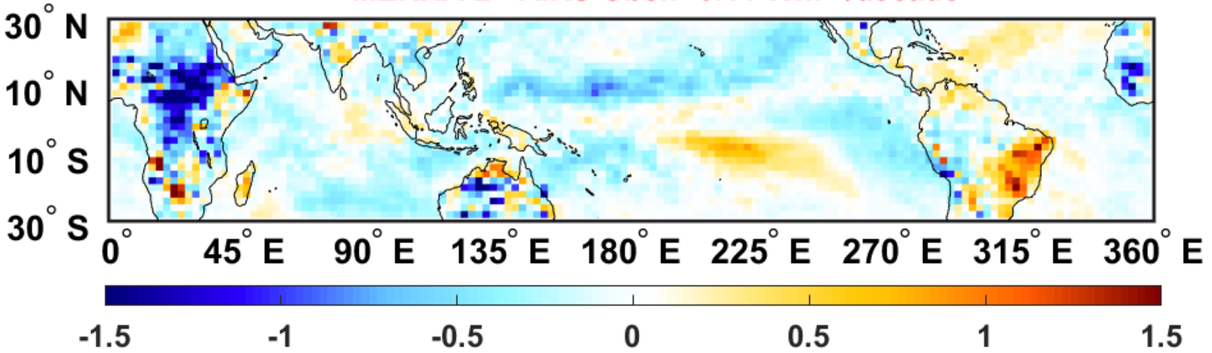
GFDL AM4 - AIRS Obs.: -0.07 Wm^{-2}/decade



ERA-5 - AIRS Obs.: -0.05 Wm^{-2}/decade

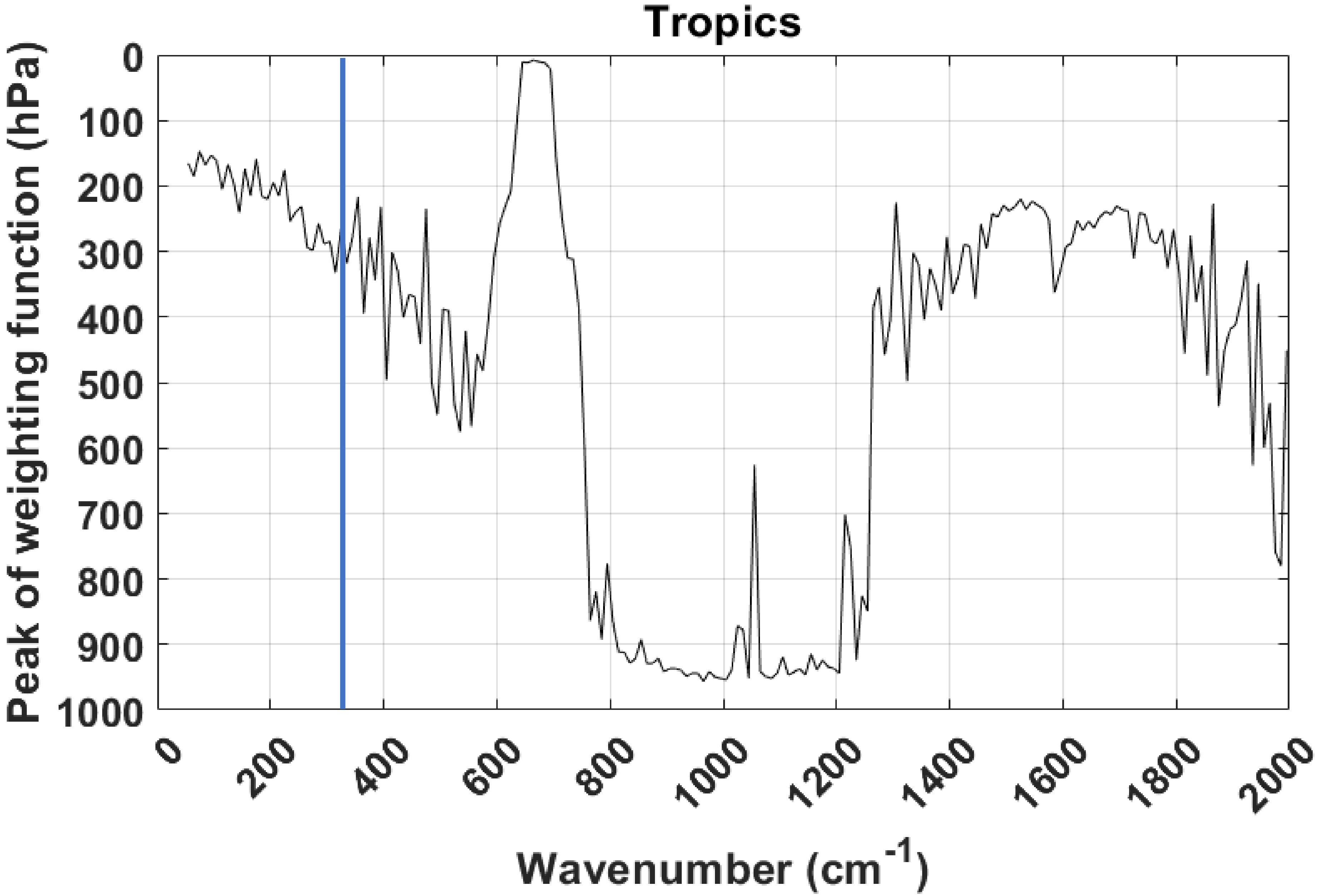


MERRA-2 - AIRS Obs.: -0.11 Wm^{-2}/decade



PBL bias in the western Pacific and the land surface bias contribute the most (SST prescribed)

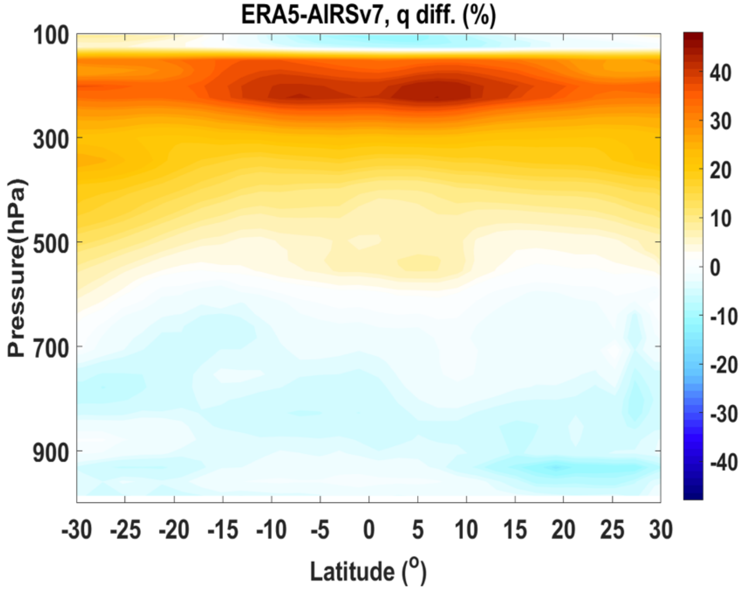
10-350 cm^{-1} is most sensitive to the "upper" part of the upper troposphere (100-300 hPa)



2003-2021 mean state q_{H2O}

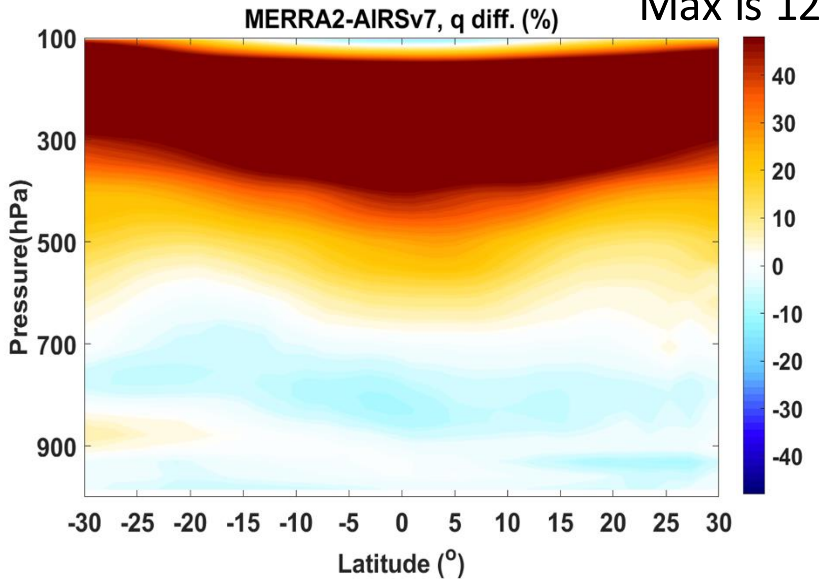
Mean state difference: models and reanalyses have *a much more humid UT* than the AIRS v7 retrievals

ERA-5 – AIRS v7

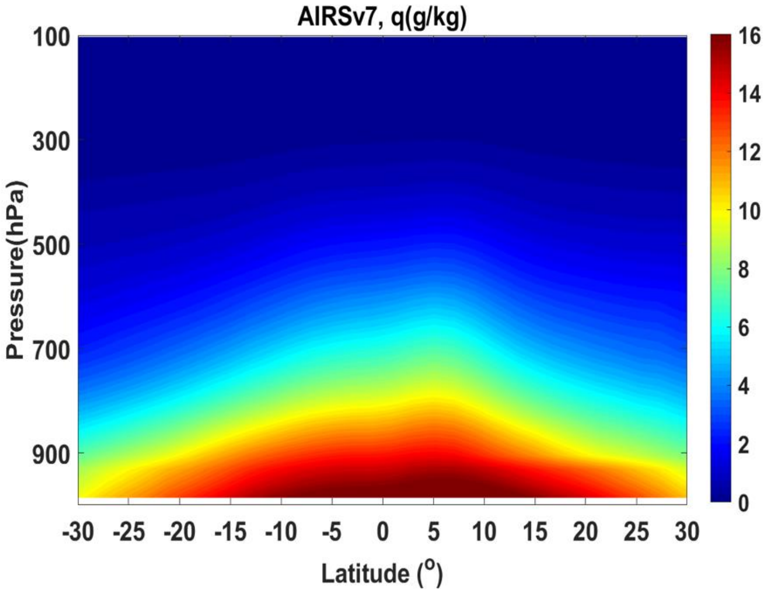


MERRA-2 – AIRS v7

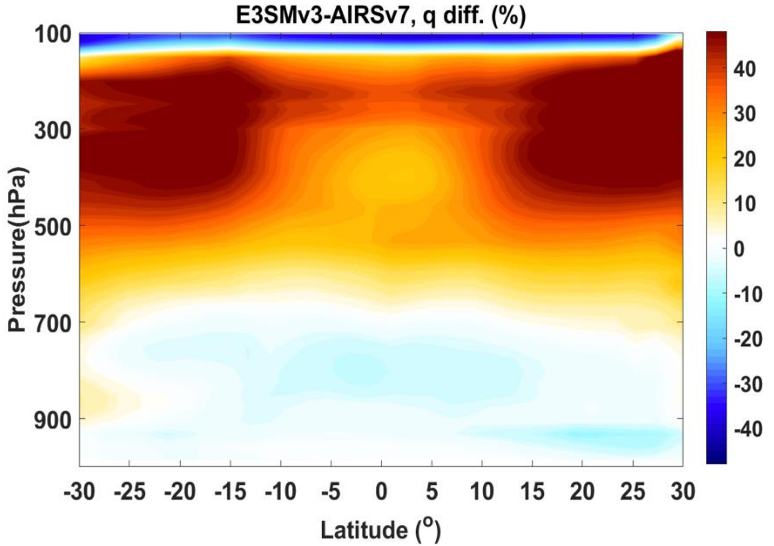
Max is 126%



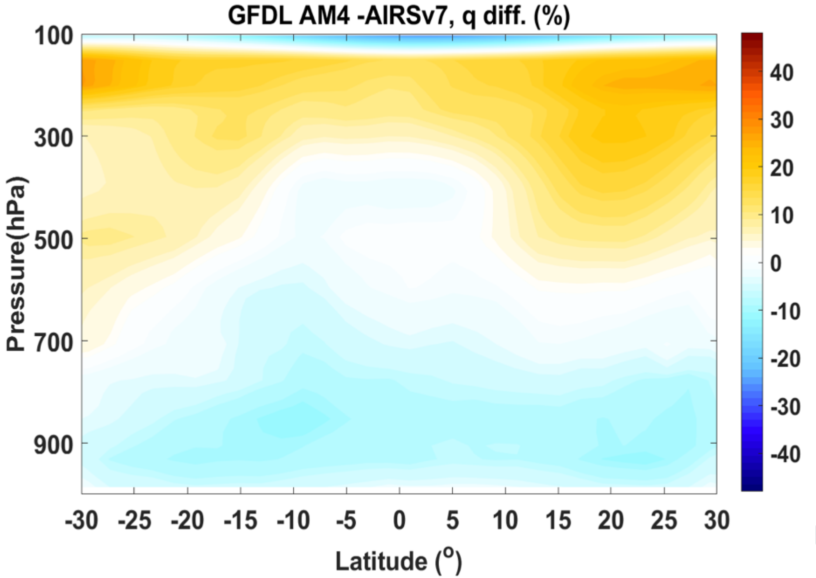
AIRS v7



E3SM v3 – AIRS v7



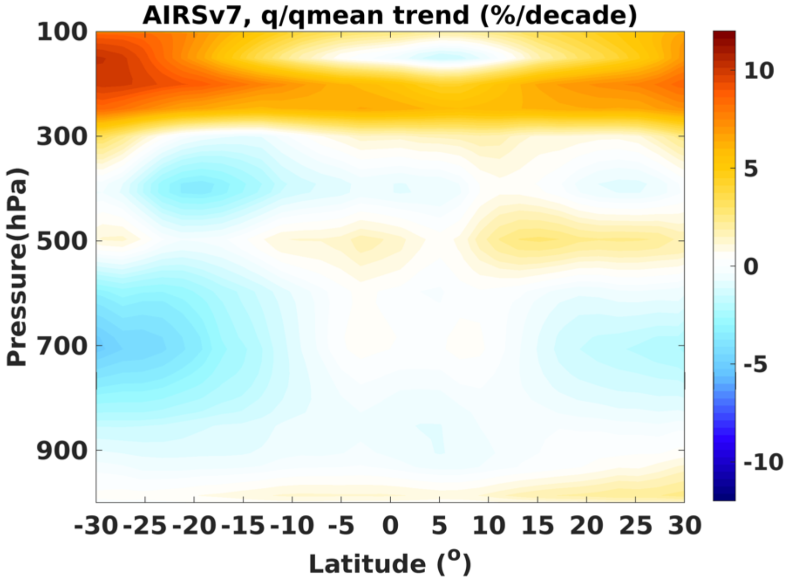
GFDL AM4 – AIRS v7



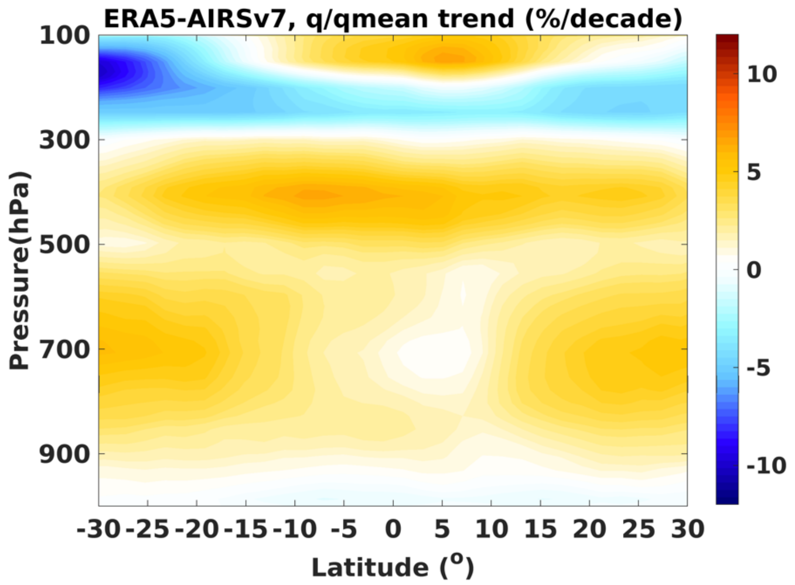
2003-2021 $q/\bar{q}$ trend difference in from AIRS v7

$$dF_{10-350cm^{-1}} \propto \frac{dq}{\bar{q}}$$

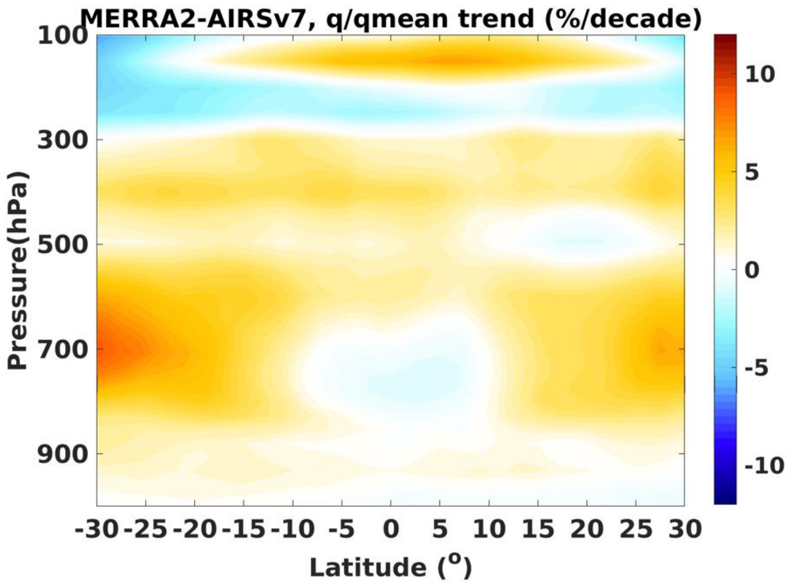
AIRS v7



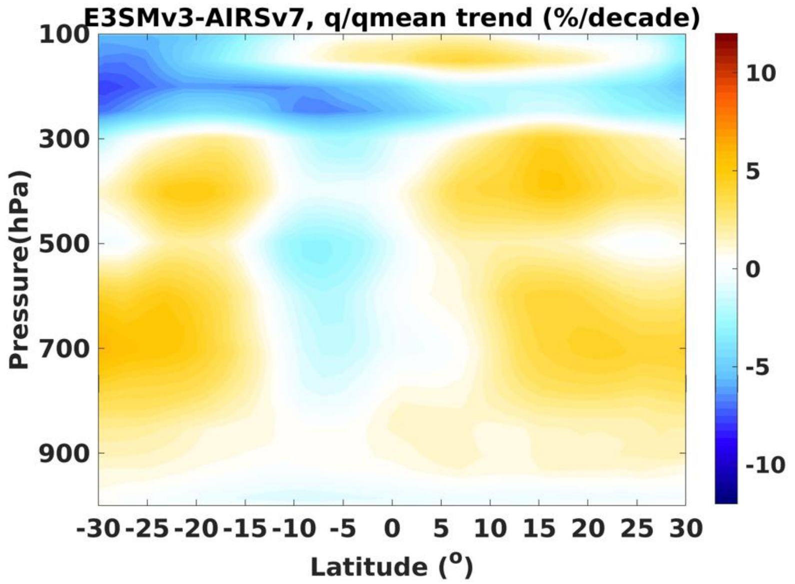
ERA-5 – AIRS v7



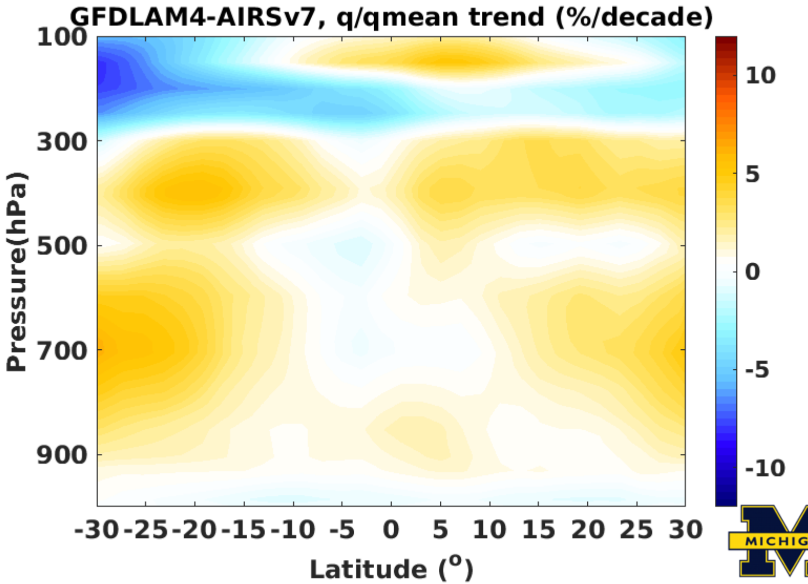
MERRA-2 – AIRS v7



E3SM v3 – AIRS v7



GFDL AM4 – AIRS v7



A "simple" paper and pencil calculation

AUGUST 2023 KOLL ET AL.

An Analytic Model for the Clear-Sky Lon

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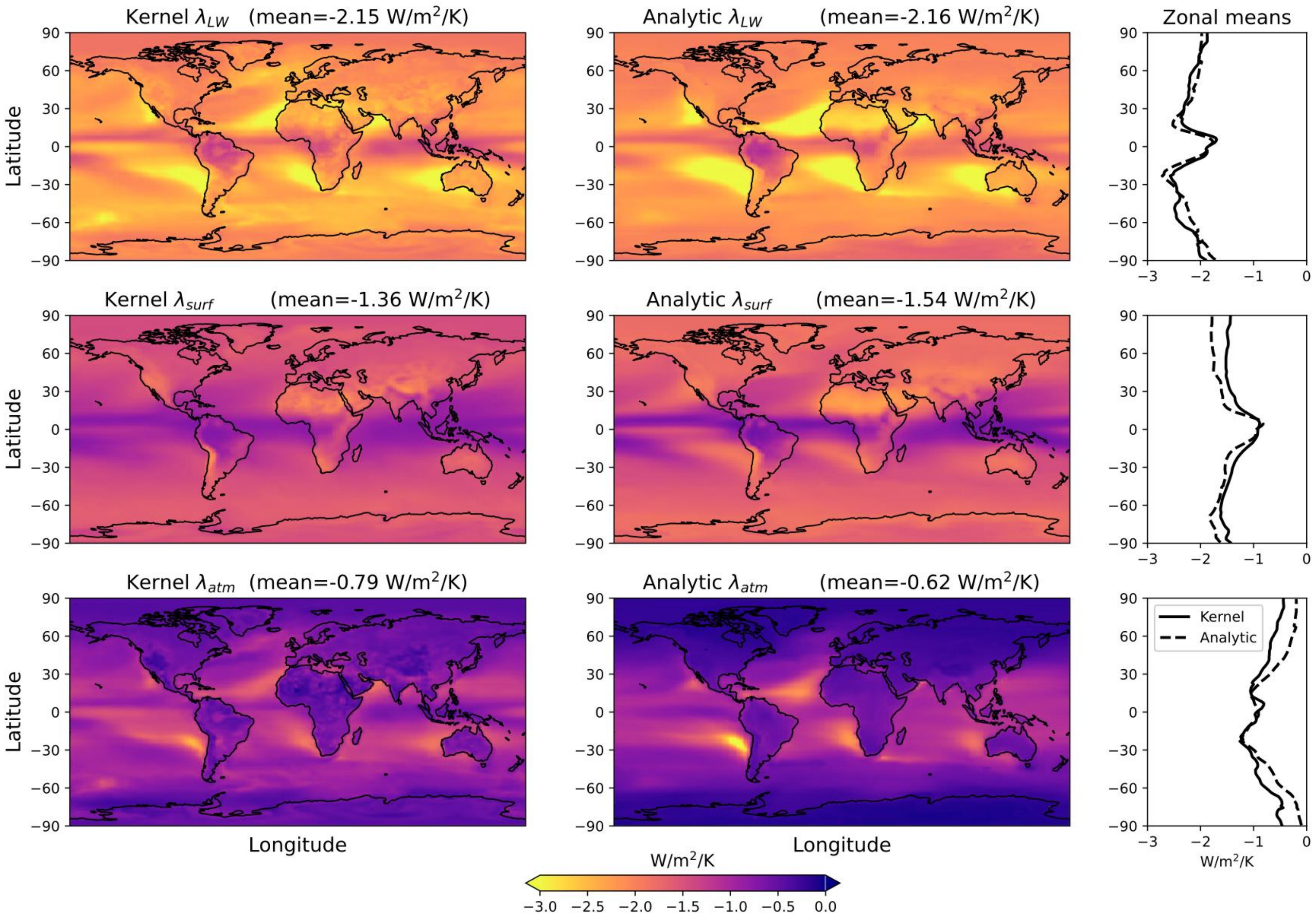
(Manuscript received 17 August 2022, in final form 17 April 2

ABSTRACT: Climate models and observations robustly agree that Earth's c
about -2 W m^{-2} K^{-1}, suggesting that this feedback can be estimated from
analytic model for Earth's clear-sky longwave feedback. Our approach uses a
feedback into four components: a surface Planck feedback and three atmospher
continuum. We obtain analytic expressions for each of these terms, and the mod
law and deviations therefrom. We validate the model by comparing it against
across a wide range of climates. Additionally, the model qualitatively matches
sive climate model. For present-day Earth, our analysis shows that the clear-s
surface in the global mean and in the dry subtropics; meanwhile, atmospheric
portant in the inner tropics. Together, these results show that a spectral view of
dates not only its global-mean magnitude, but also its spatial pattern and its
climates.

$\lambda_{LW,tropics} \approx -1.7$ W m^{-2} K^{-1}:

1944 JOURNAL OF THE ATMOSPHERIC SCIENCES VOLUME 80



CO_2 radiative forcing with stratospheric adjustment

GEOPHYSICAL RESEARCH LETTERS, VOL. 25, NO.14, PAGES 2715-2718, JULY 15, 1998

New estimates of radiative forcing due to well mixed greenhouse gases

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Eleanor J. Highwood and Keith P. Shine
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Frode Stordal
Norwegian Institute for Air Research (NILU), Norway

Abstract. We have performed new calculations of the radiative forcing due to changes in the concentrations of the most important well mixed greenhouse gases (WMGG) since pre-industrial time. Three radiative transfer models are used. The radiative forcing due to CO_2, including shortwave absorption, is 15% lower than the previous IPCC estimate. The radiative forcing due to all the WMGG is calculated to 2.25 Wm^{-2}, which

Previous estimates of radiative forcing [*IPCC*, 1995] have not necessarily been based on consistent model conditions.

This work presents new calculations of radiative forcing due to the most important WMGG, using a consistent set of models and assumptions. Three radiative transfer schemes are used, a line-by-line (LBL) model, a narrow-band model (NBM) and a broad band model

$$\frac{d\Delta F}{dt} = \alpha \frac{1}{\bar{C}} \frac{dC}{dt}$$

Table 3. Simplified expressions used in *IPCC* [1990] (Table 2.2)

Trace gas	Simplied expression Radiative forcing, ΔF, Wm^{-2}	Constants α IPCC	Best estimate this work[a]
CO_2	$\Delta F = \alpha \ln(C/C_0)$	6.3	5.35
CH_4	$\Delta F = \alpha (\sqrt{M} - \sqrt{M_0})$- (f(M,N$_0$)-f(M$_0$,N$_0$))	0.036	0.036
N_2O	$\Delta F = \alpha (\sqrt{N} - \sqrt{N_0})$- (f(M$_0$,N)-f(M$_0$,N$_0$))	0.14	0.12
CFC-11[b]	$\Delta F = \alpha (X - X_0)$	0.22	0.25
CFC-12	$\Delta F = \alpha (X - X_0)$	0.28	0.33

$f(M,N)=0.47 \ln[1+2.01\times10^{-5}(MN)^{0.75}+5.31\times10^{-15}M(MN)^{1.52}]$
C is CO_2 in ppmv
M is CH_4 in ppbv
N is N_2O in ppbv
X is CFC in ppbv

- 2003-2021 (375-416 ppmv CO_2)

$$\frac{dT_s}{dt} \approx 0.18 \pm 0.02 \frac{K}{decade}$$

$$\frac{dCO_2}{dt} \approx 22.8 \frac{ppmv}{decade}$$

$$\frac{dOLR_{clr}}{dt} = -\lambda_{clr,tropics} \frac{dT_s}{dt} - \frac{5.35}{395.5} \frac{dCO_2}{dt} = 0.0\ Wm^{-2}/decade$$

- 2003-2014 (375-398 ppmv CO_2)

$$\frac{dT_s}{dt} \approx 0.027 \pm 0.035 \frac{K}{decade}$$

$$\frac{dOLR_{clr}}{dt} = -\lambda_{clr,tropics} \frac{dT_s}{dt} - \frac{5.35}{386.5} \frac{dCO_2}{dt} = -0.24\ Wm^{-2}/decade$$

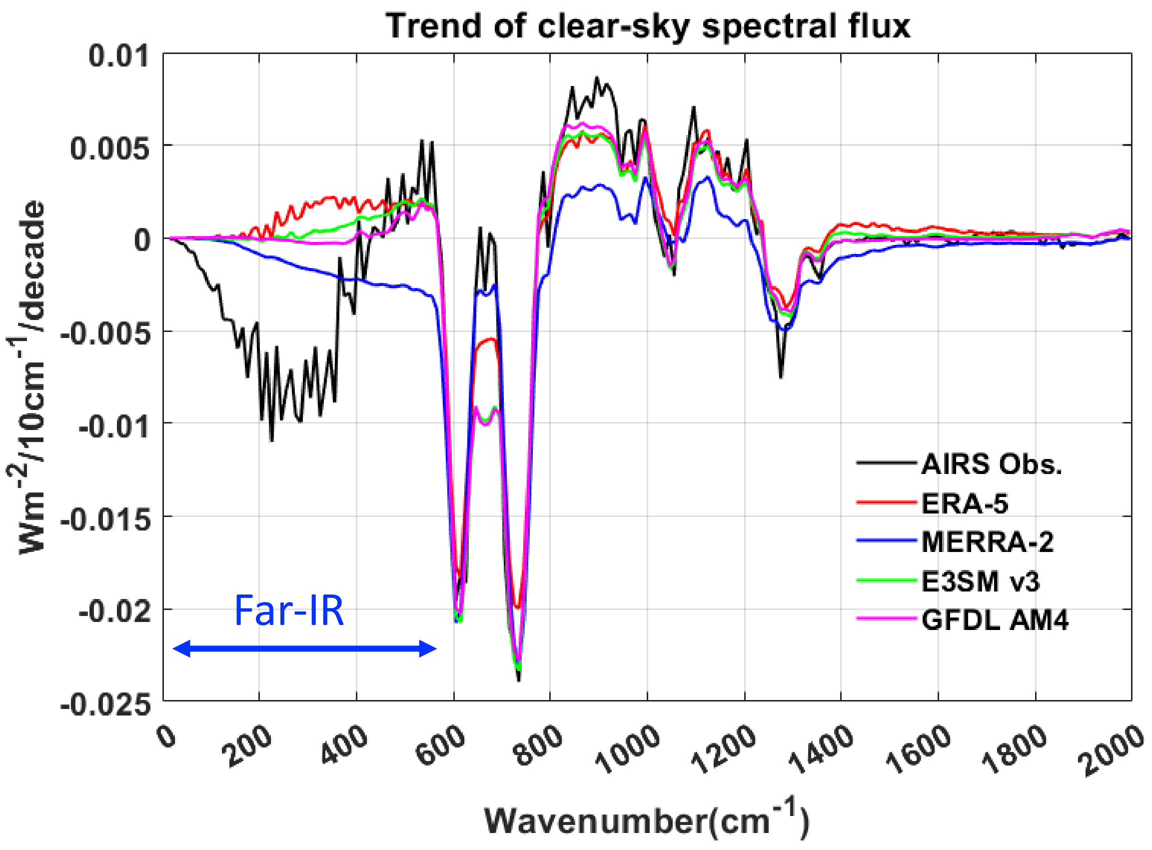
"One number calculation" is not enough to match the results; the spatial pattern of Ts needs to be considered.

Conclusions and discussions

- Last two decades have seen a positive trend in tropical surface temperature, but the clear-sky OLR trend is negative and statistically significant
  - Note this is not the case outside the tropics: positive Ts and clear-sky OLR
- Two models and ERA5 seem to agree with the broadband trend from the AIRS and overlap with the CERES trend uncertainty range
- But this agreement is due to a compensation between the far-IR H_2O band and the CO2 + window bands
- The $q/\bar{q}$ trend in the 100-300hPa is most responsible for the far-IR band difference
  - Models and reanalyses have not moistened as fast as the AIRS v7 retrievals implied, even though their mean states are much wetter than the AIRS v7 retrievals
    - Note AIRS v7 is a retrieval, which could have been biased too.
- Need to reconcile the model/obs with theoretical understandings

Conclusions and discussions (II)

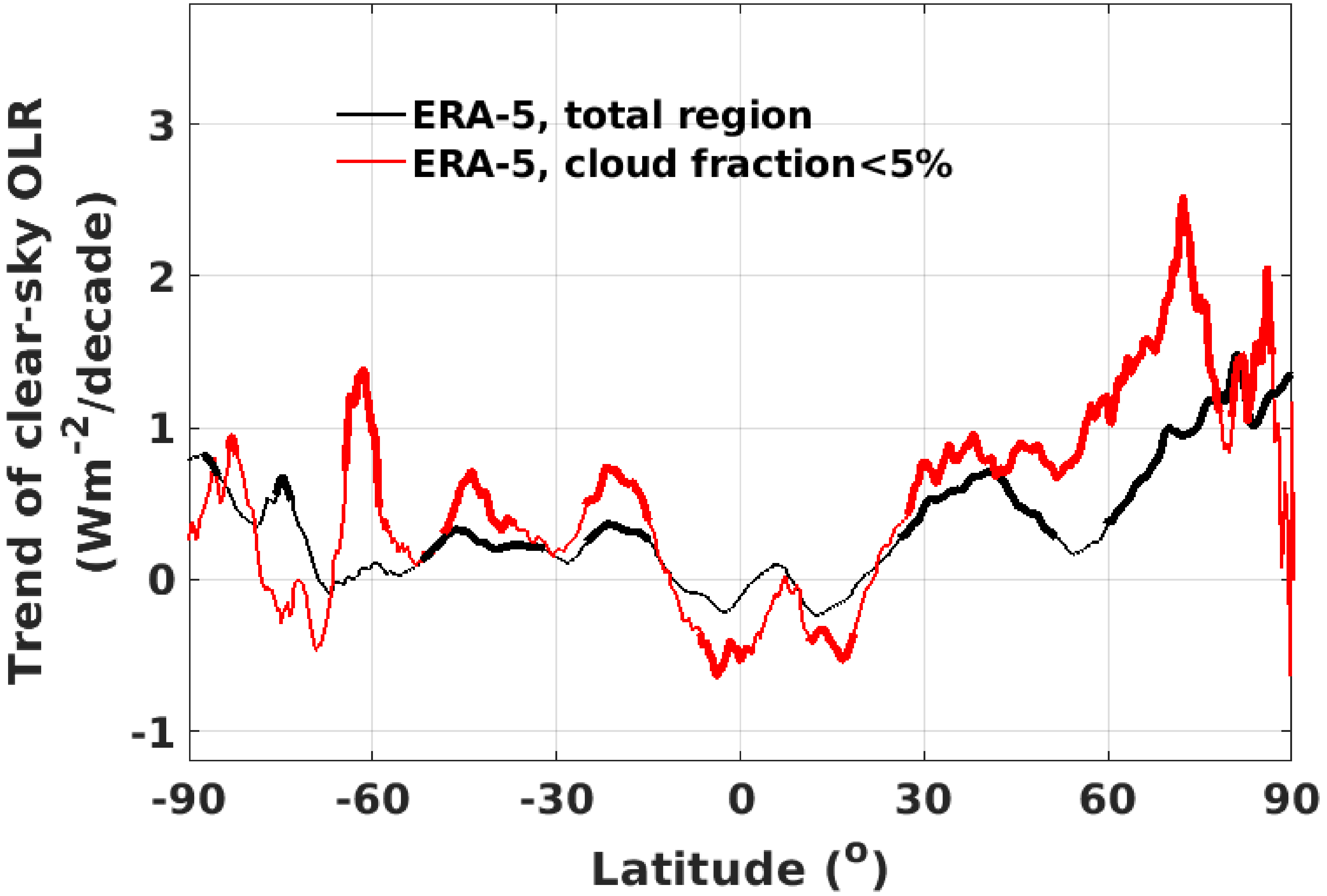
- Far-IR flux in AIRS spectral OLR is indeed an estimation using mid-IR observations
- NASA's PREFIRE mission (2024-present) will be the first mission to provide multi-year far-IR direct observations



Thank You!

Total region: 0.06 Wm^{-2}/decade

3-hourly cloud fraction<5% region: 0.003 Wm^{-2}/decade



Band-by-band breakdown (RRTMG_LW bands)

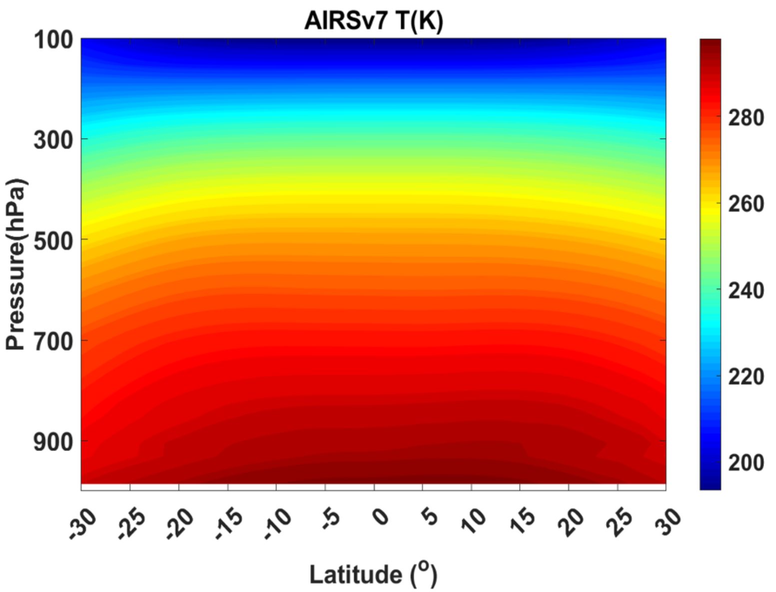
Band (cm^{-1})	Trend ($W\ m^{-2}$/ decade)							Major Absorbers
	AIRS observation	Calculation from AIRS v7	Calculation from ERA-5	Calculation from MERRA-2	Calculation from E3SM v3 With co2 forcing	Calculation from E3SM v2 With co2 forcing	Calculation from GFDL AM4	
10-500	-0.18±0.05	-0.03	0.05	-0.06	0.02(0.01)	0.01(0.01)	0.00	H_2O
500-630	-0.06±0.03	-0.08	-0.06	-0.11	-0.07(-0.09)	-0.07(-0.09)	-0.07	H_2O, CO_2
630-820	-0.13±0.04	-0.17	-0.14	-0.15	-0.18(-0.15)	-0.18(-0.16)	-0.17	CO_2, H_2O
820-980	0.11±0.05	0.10	0.08	0.03	0.08(0.03)	0.09(0.03)	0.09	H_2O (continuum)
980-1080	0.02±0.05	0.02	0.03	0.01	0.02(-0.00)	0.02(0.00)	0.02	O_3, H_2O (continuum)
1080-1180	0.05±0.03	0.05	0.04	0.02	0.04(0.03)	0.04(0.03)	0.04	H_2O (continuum)
1180-1390	-0.02±0.02	-0.02	-0.01	-0.05	-0.02(-0.01)	-0.01(-0.03)	-0.02	H_2O, N_2O, CH_4
>1390	-0.00±0.02	-0.00	0.02	-0.02	0.01(0.00)	0.01(0.00)	0.00	H_2O
Broadband OLR	-0.23±0.22	-0.15	0.01 (0.06)	-0.33(-0.33)	-0.11(-0.18)	-0.09(-0.21)	-0.12 (-0.20)	

CERES ERAF 4.2 cloud free: -0.35±0.31 $W\ m^{-2}$/ decade
total region: -0.41±0.27 $W\ m^{-2}$/ decade

Spectral radiative kernel results (model/reanalysis own results)

2003-2021 mean

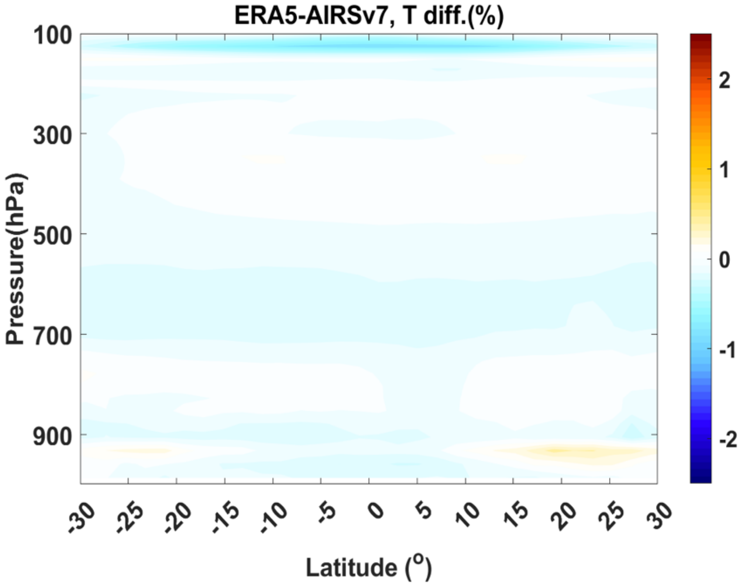
AIRS v7



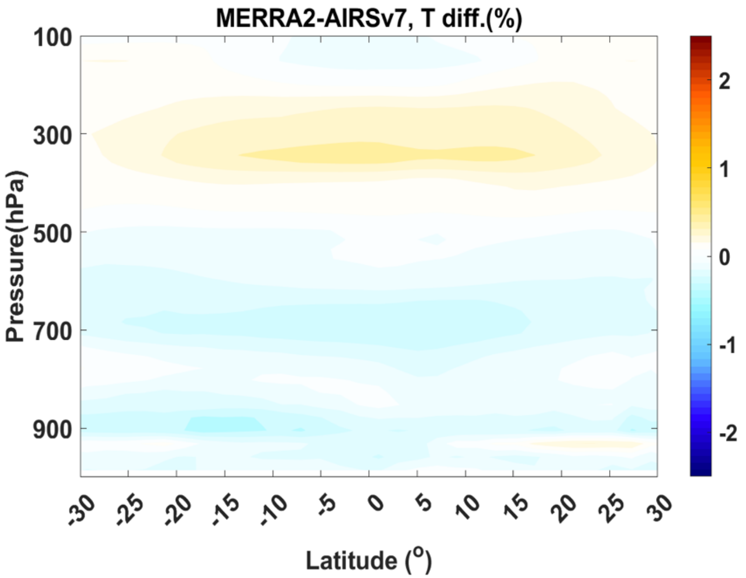
2003-2021 mean state T

2003-2021 mean relative difference (%)

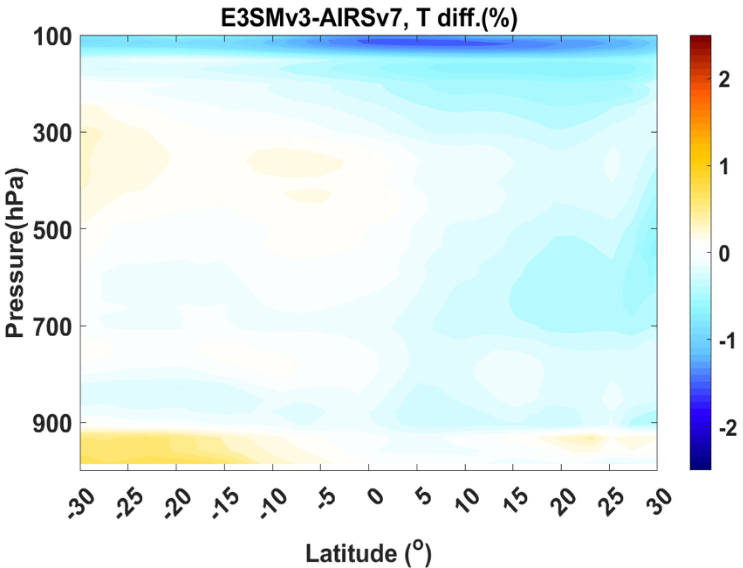
ERA-5 – AIRS v7



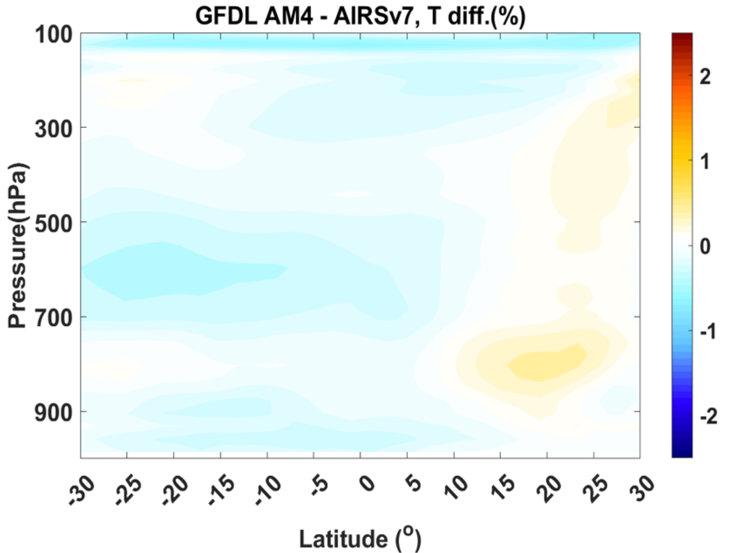
MERRA-2 – AIRS v7



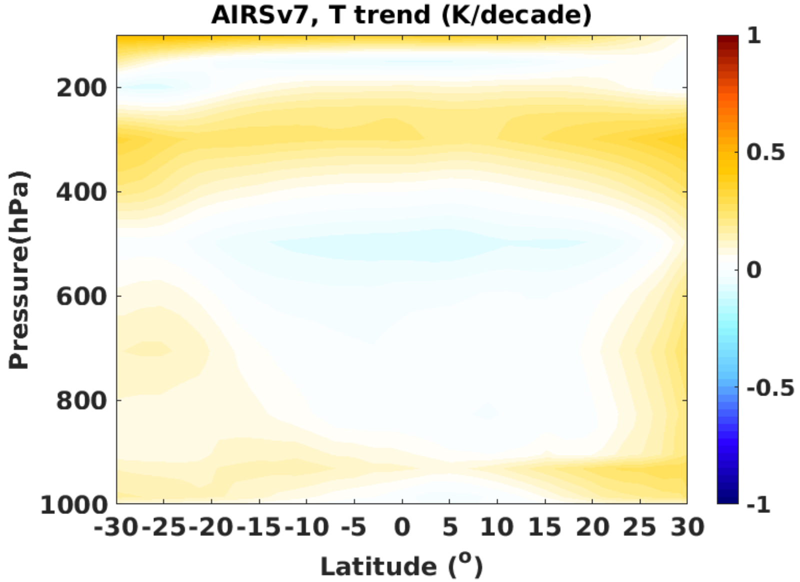
E3SM v3 – AIRS v7



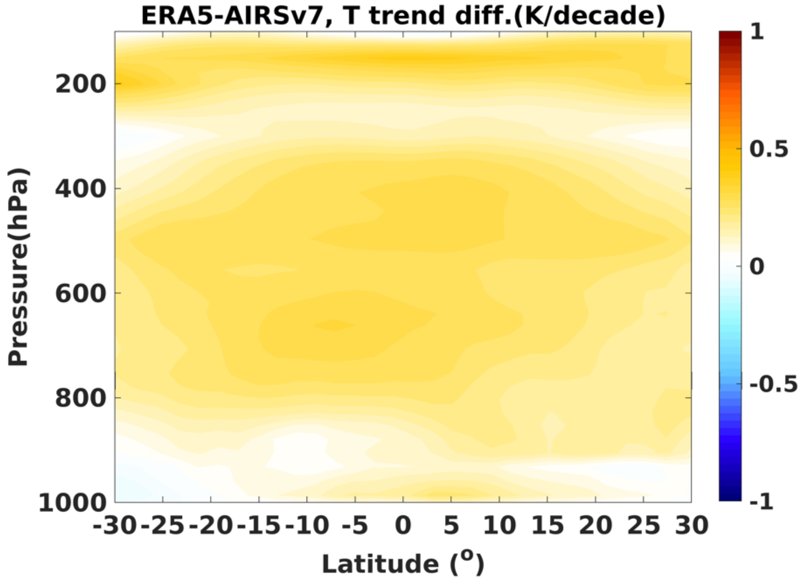
GFDL AM4 – AIRS v7



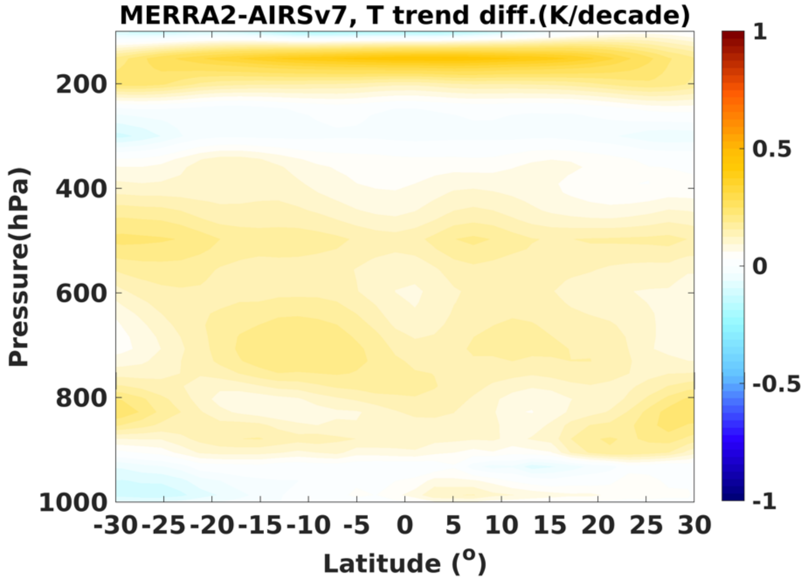
AIRS v7



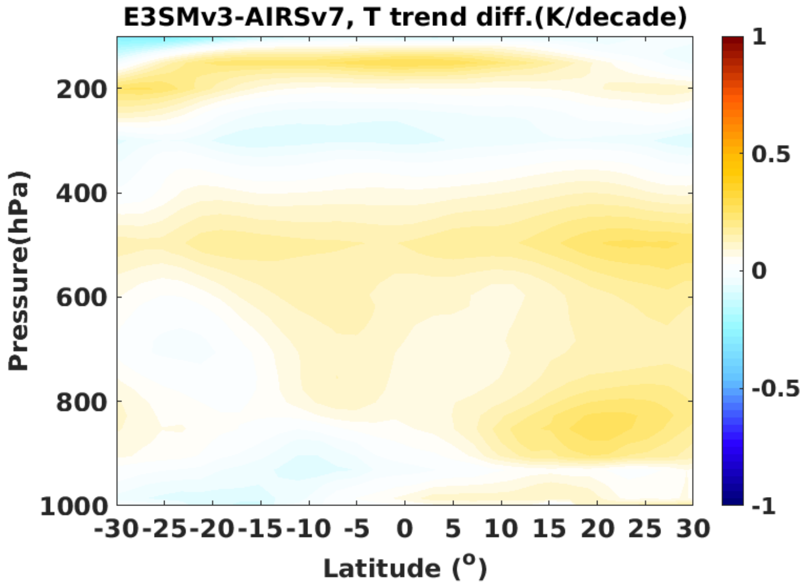
ERA-5 – AIRS v7



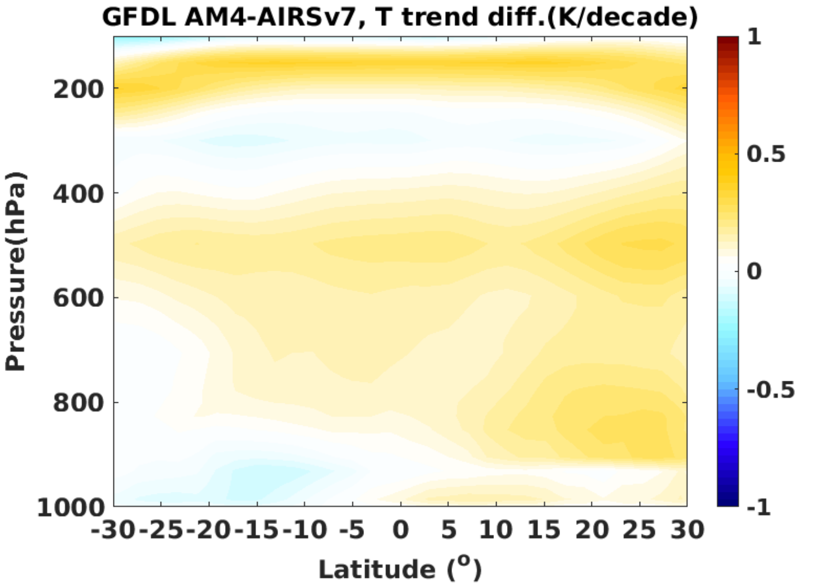
MERRA-2 – AIRS v7



E3SM v3 – AIRS v7



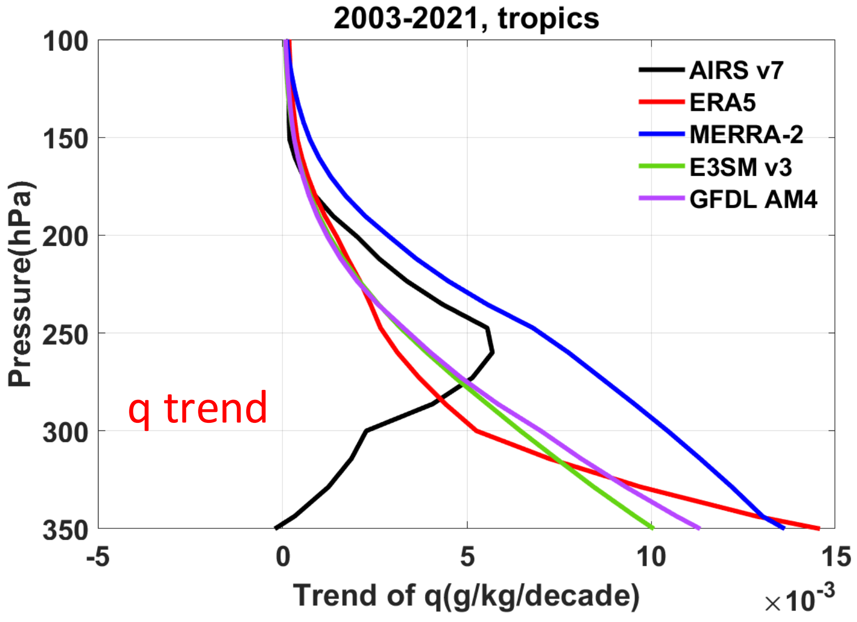
GFDL AM4 – AIRS v7

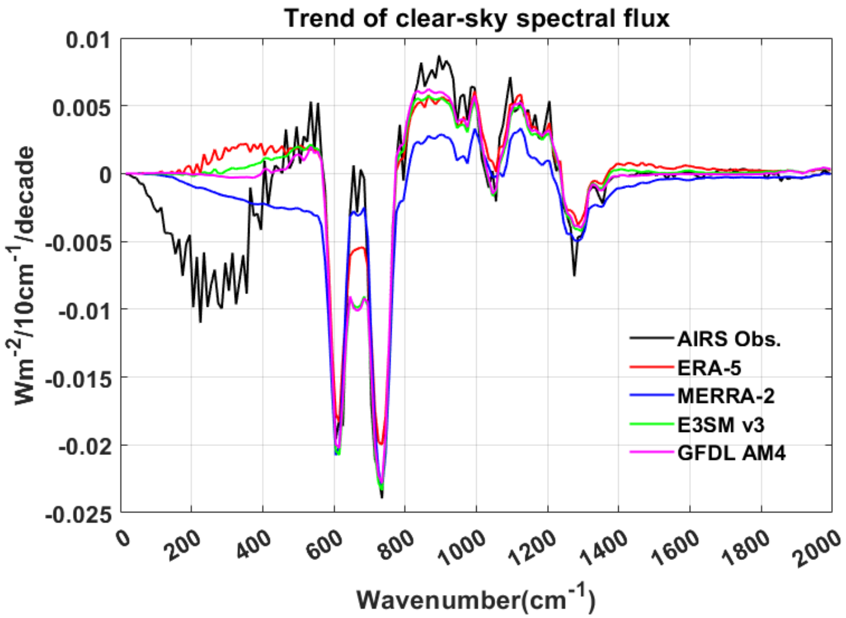


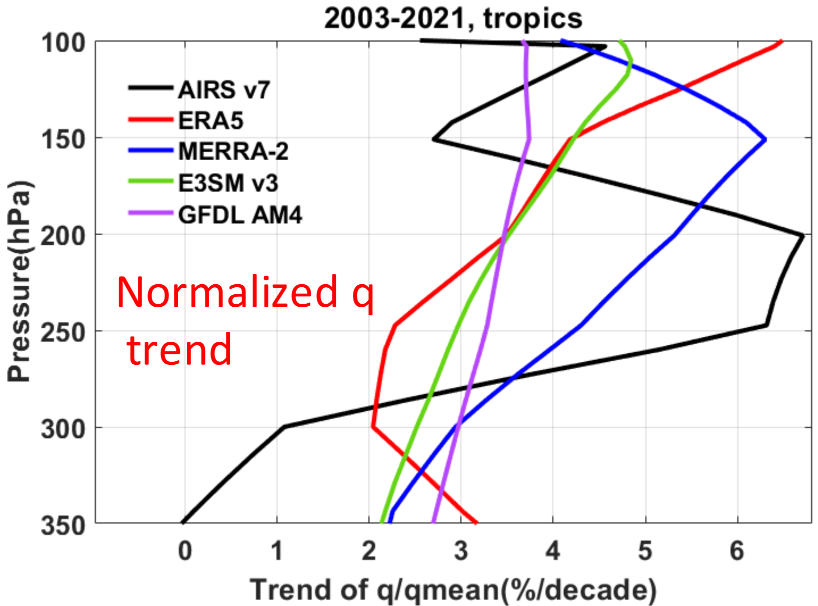
Trend difference from AIRS v7
2003-2021

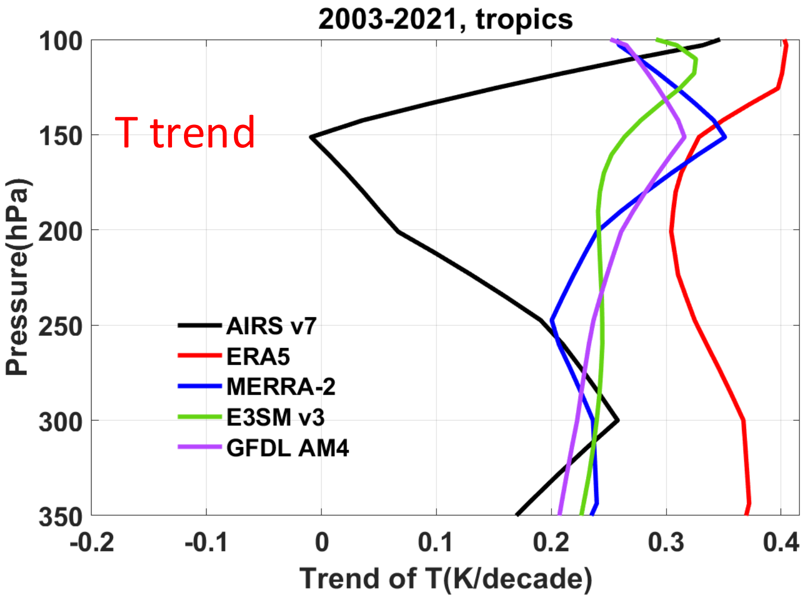
T & q trend vs. flux trend

2003-2021



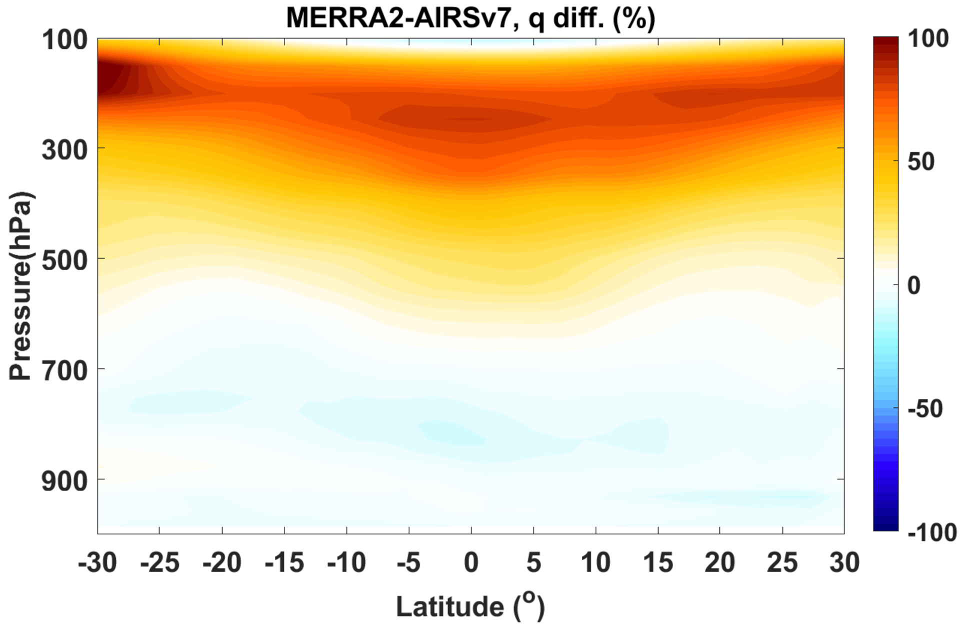




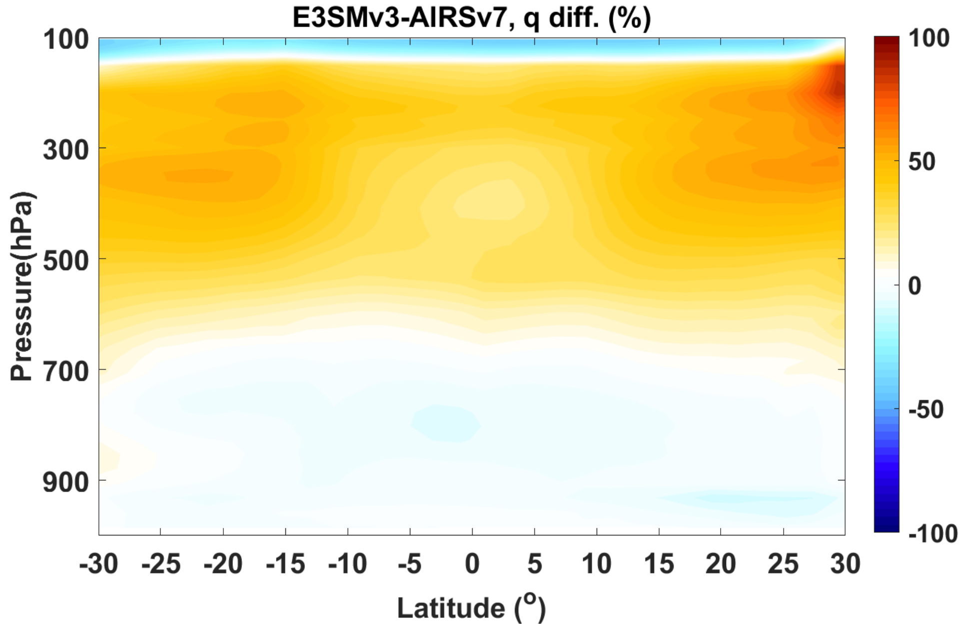


MERRA-2 – AIRS v7

2003-2021 mean
Different color scale as previous page



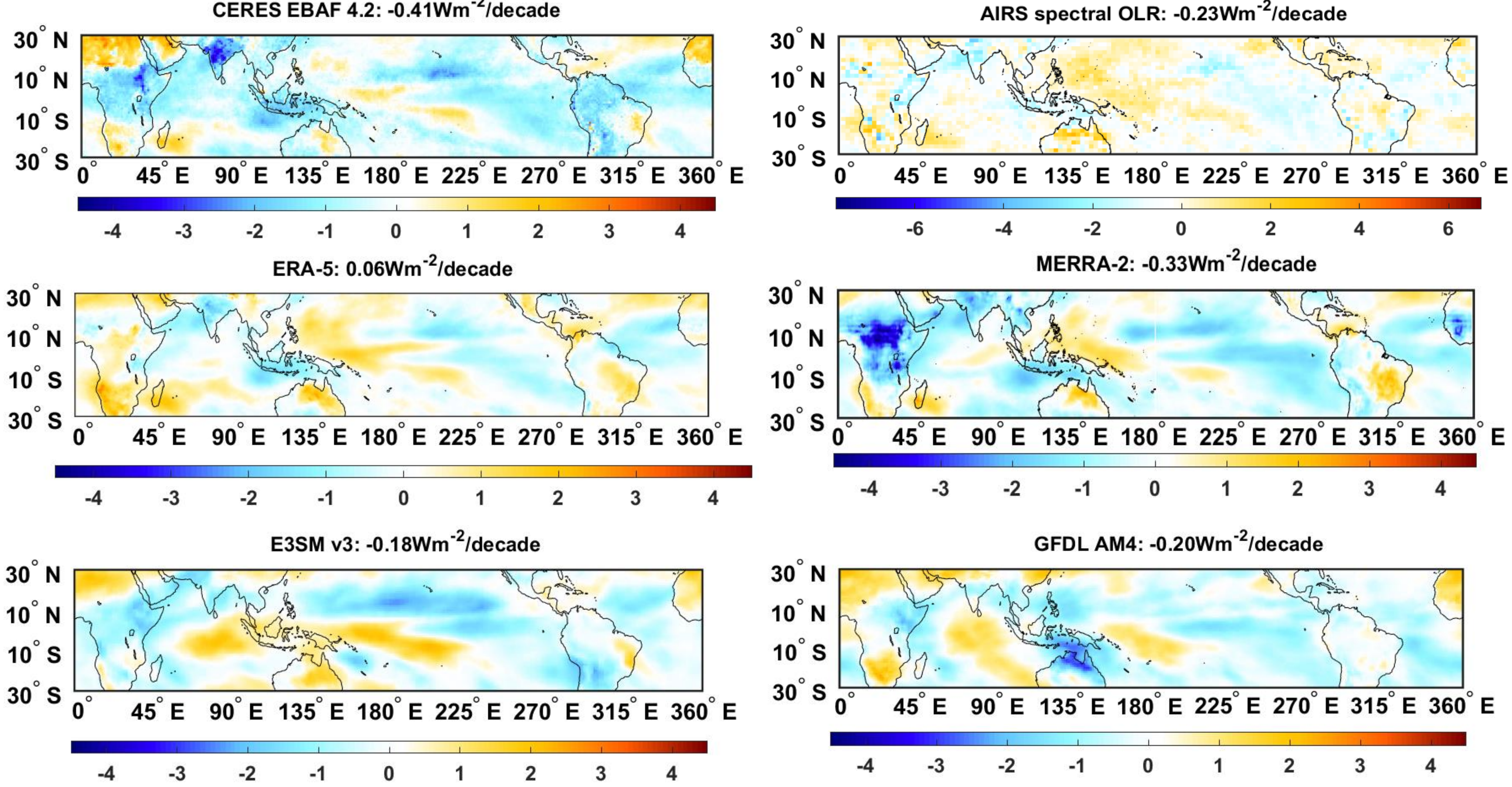
E3SM v3 – AIRS v7



ERAF 4.2 cloud free: -0.35±0.31
total region: -0.41±0.27

Trend of clear-sky OLR (LW broadband) from 2003 to 2021

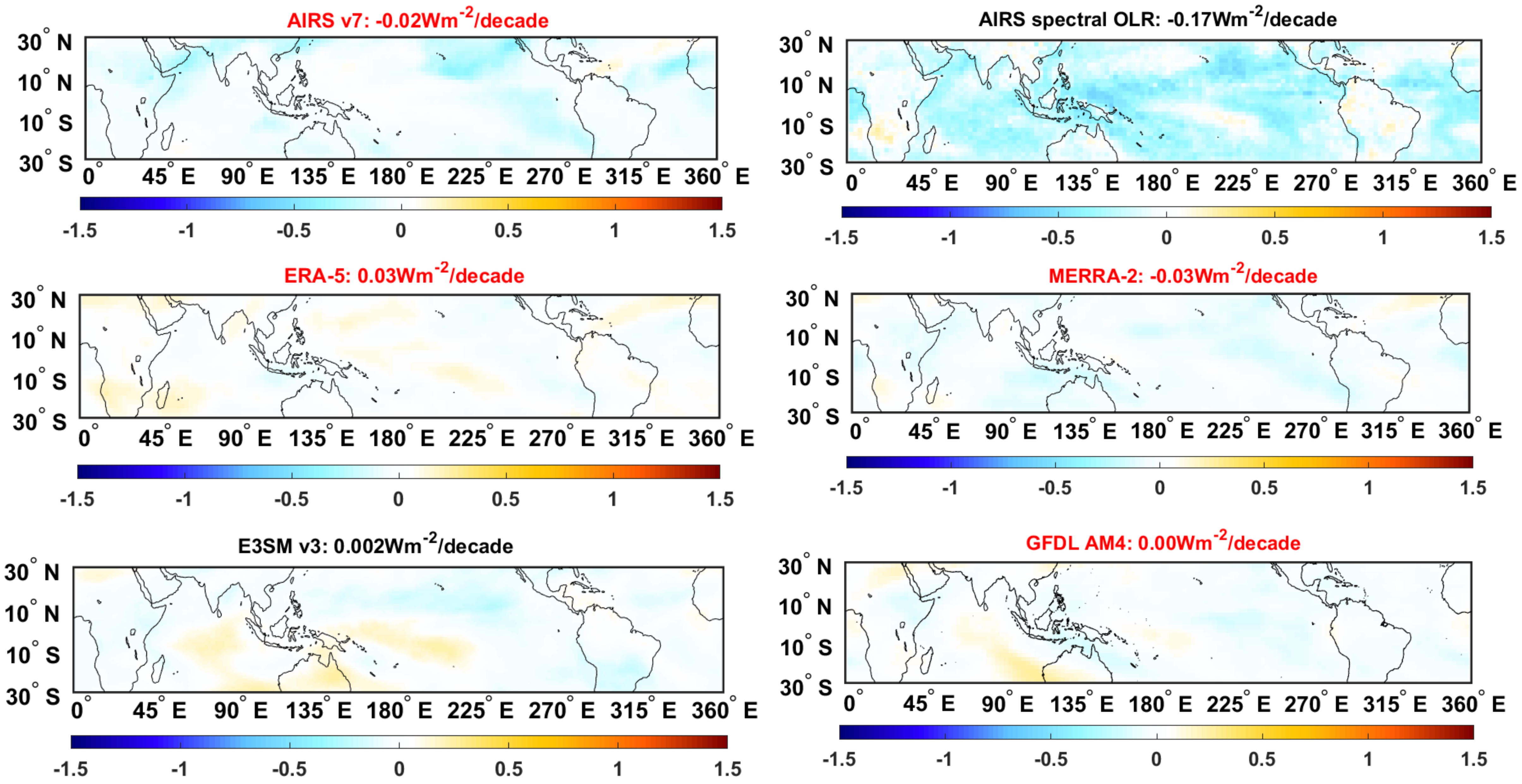
Previous EBAF trend of $-0.36 Wm^{-2}$ is from 2004 to 2021



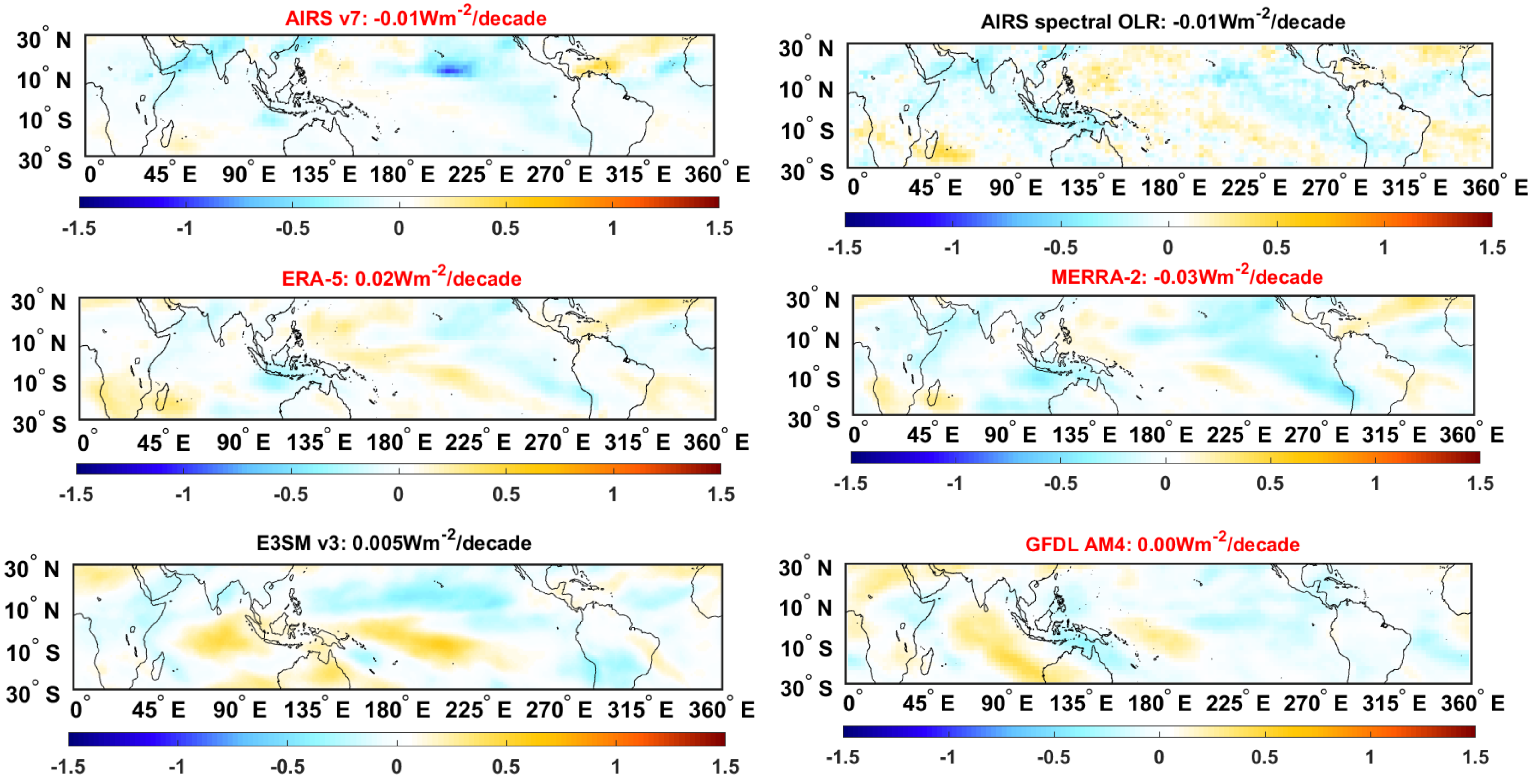
Red color denotes from kernel calculation

10-350 cm^{-1}

Black color denotes from Obs or model output



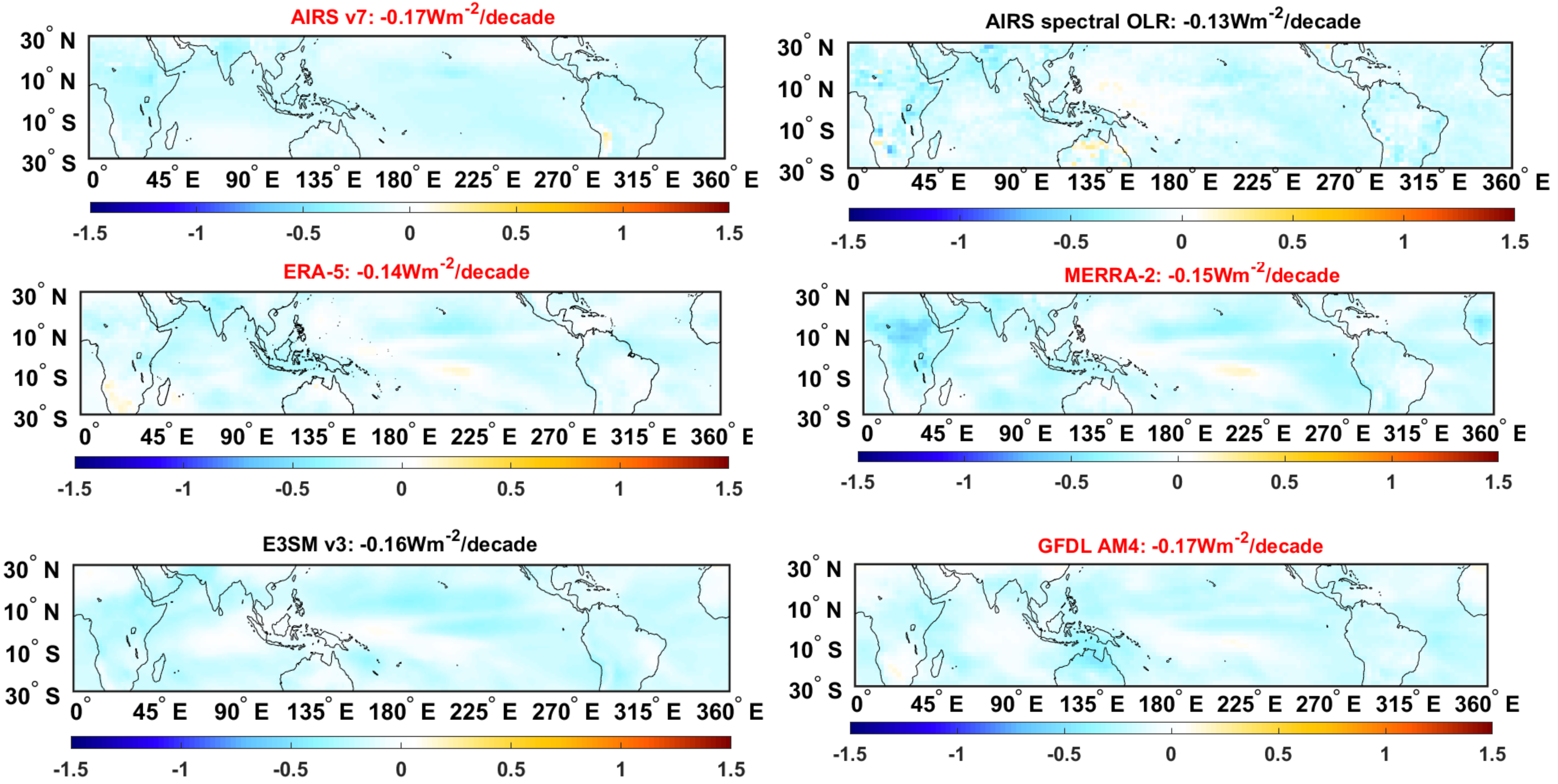
350-500 cm^{-1}



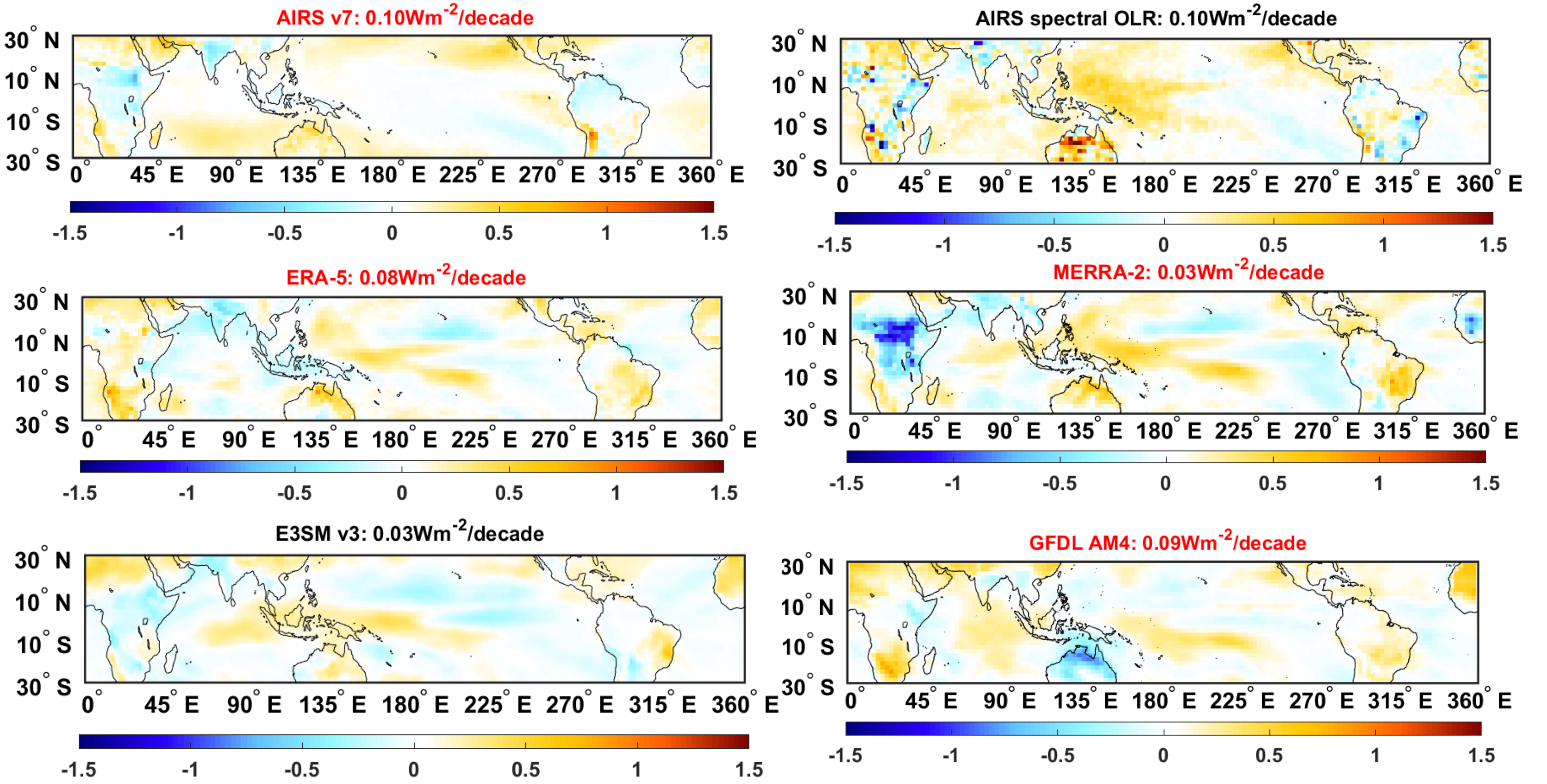
AIRS v7: -0.01Wm-2/decade
AIRS spectral OLR: -0.01Wm-2/decade
ERA-5: 0.02Wm-2/decade
MERRA-2: -0.03Wm-2/decade
E3SM v3: 0.005Wm-2/decade
GFDL AM4: 0.00Wm-2/decade
30° N
10° N
10° S
30° S
0° 45° E 90° E 135° E 180° E 225° E 270° E 315° E 360° E
-1.5 -1 -0.5 0 0.5 1 1.5

630-820 cm^{-1}

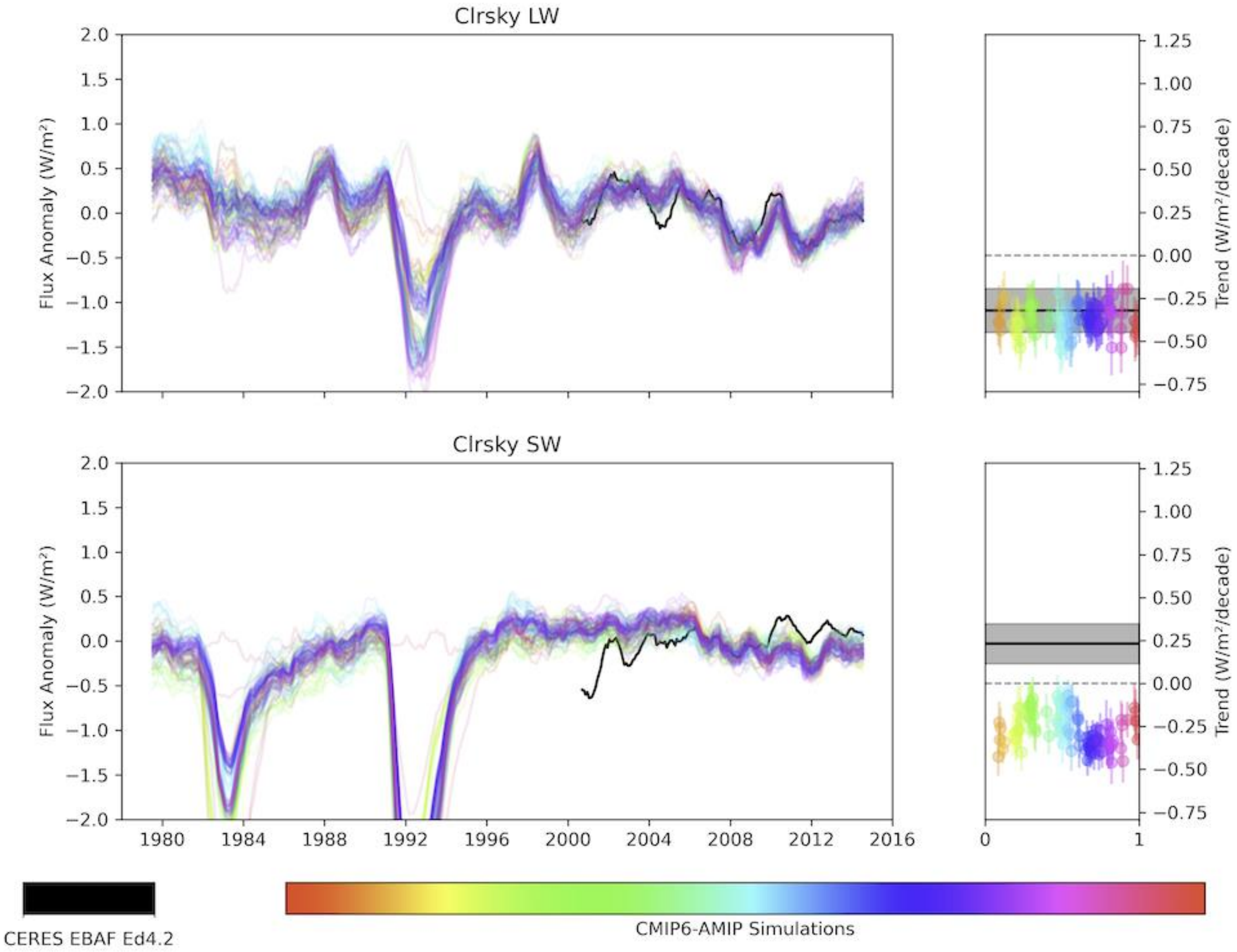
Contribution is almost from 700-820 cm-1



820-980 cm^{-1}



AIRS v7: 0.10Wm-2/decade
AIRS spectral OLR: 0.10Wm-2/decade
ERA-5: 0.08Wm-2/decade
MERRA-2: 0.03Wm-2/decade
E3SM v3: 0.03Wm-2/decade
GFDL AM4: 0.09Wm-2/decade
30° N
10° N
10° S
30° S
0°
45° E
90° E
135° E
180° E
225° E
270° E
315° E
360° E
-1.5
-1
-0.5
0
0.5
1
1.5



From Chongxing Fan and his GFDL collaborators