National Aeronautics and Space Administration
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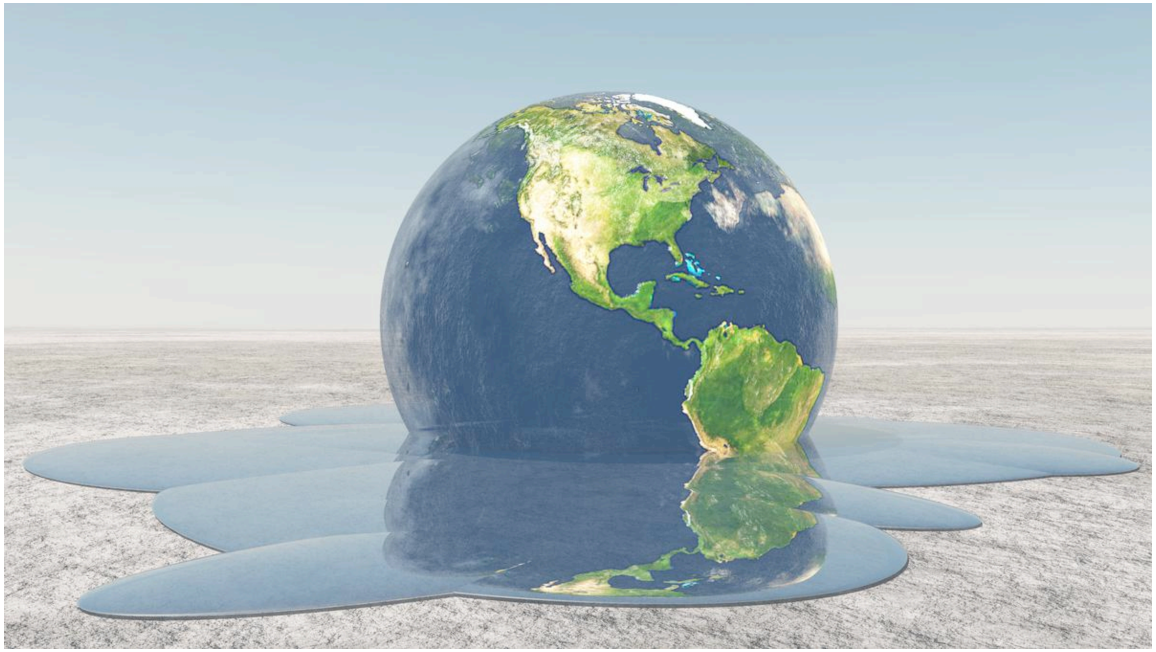
Goddard Space Flight Center
Sciences and Exploration Directorate
Earth Sciences Division

The importance of the Earth's Energy Imbalance in model predictions



Gavin Schmidt
NASA Goddard Institute for Space Studies

An increasing EEI is a robust prediction from climate models given anthropogenic forcings over the last 150 years

- Direct link between EEI and climate sensitivity (modulo forcings)

Impact expected to be seen in Ocean Heat Content rise but systematic issues have taken two decades to resolve!

- Measurement shifts (CTDs/XRF/Argo)
- Data sparsity in southern ocean + pre-1970s

CERES data is now long enough to provide independent checks on rate of change AND SW/LW split

- But comparisons with models are still in flux
- Net changes seem to match, but LW/SW split post 2015 is very different

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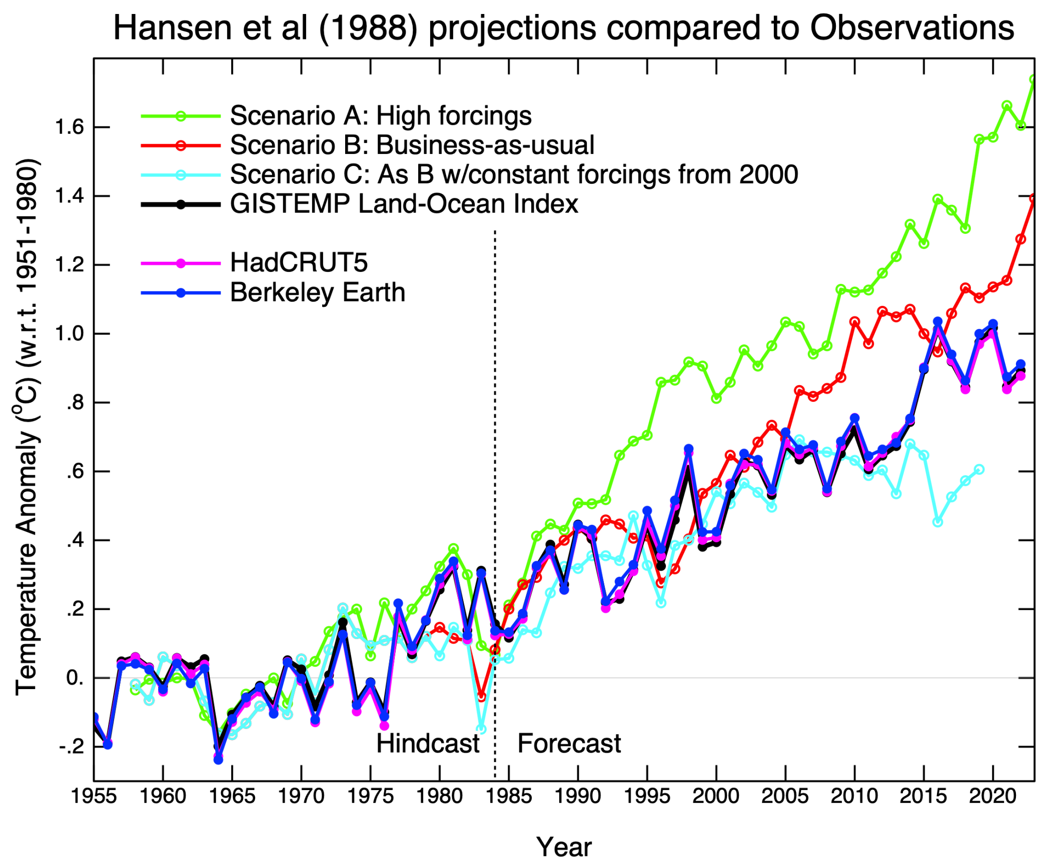
1980s understanding

First transient GCM simulations (1984+)

Given anthropogenic forcings, EEI initially increases, and then decreases as (if) new equilibrium is achieved

Magnitude of EEI and time to equilibrium depends on climate sensitivity (Hansen et al., 1985)



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How would we know we were getting the answer right for the right reasons?

We also stress the importance of measuring the rate of heat storage in the ocean. As discussed earlier and by *Hansen et al*. [1985], on the time scale of a few decades there is not necessarily a great difference in the surface temperature response for a low climate senitivity (say 1.5°–2°C for doubled CO_2) and a high climate sensitivity (say 4°–5°C for doubled CO_2). However, the larger climate sensitivity leads to a higher rate of heat storage in the ocean. Since theoretical derivations of climate sensitivity depend so sensitively on many possible climate feedbacks, such as cloud and aerosol optical properties [*Somerville and Remer*, 1984; *Charlson et al*., 1987], the best opportunity for major improvement in our understanding of climate sensitivity is probably monitoring of internal ocean temperature. Such measurements would be needed along several sections crossing the major oceans. In principle, the measurements would only be needed at decadal intervals, but continuous measurements are highly desirable to average out the effect of local fluctuations.

Hansen et al (1988)

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In 1999, the OHC rise was a key point in global warming 'debate'

6. Planetary disequilibrium

Hansen: Earth is out of radiative equilibrium with space by at least approximately 0.5 W/m^2 (absorbing more energy than it emits).

Comments: This is the most fundamental measure of the state of the greenhouse effect. Because the disequilibrium is a product of the long response time of the climate system, which in turn is a strong function of climate sensitivity, confirmation of the disequilibrium provides information on climate sensitivity and an indication of how much additional global warming is "in the pipeline" due to gases already added to the atmosphere.

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But there were big issues!

State of observational databases:

- incomplete digitization, undeveloped methods, large spatial gaps, multiple measurement systems

Coupled climate modeling:

- Deep ocean drifts due to insufficient spin up, energy leaks (non-physical sinks/sources), uncertain forcings
- Connection between EEI and OHC uptake

Relationship between heat flux at TOA and Surface

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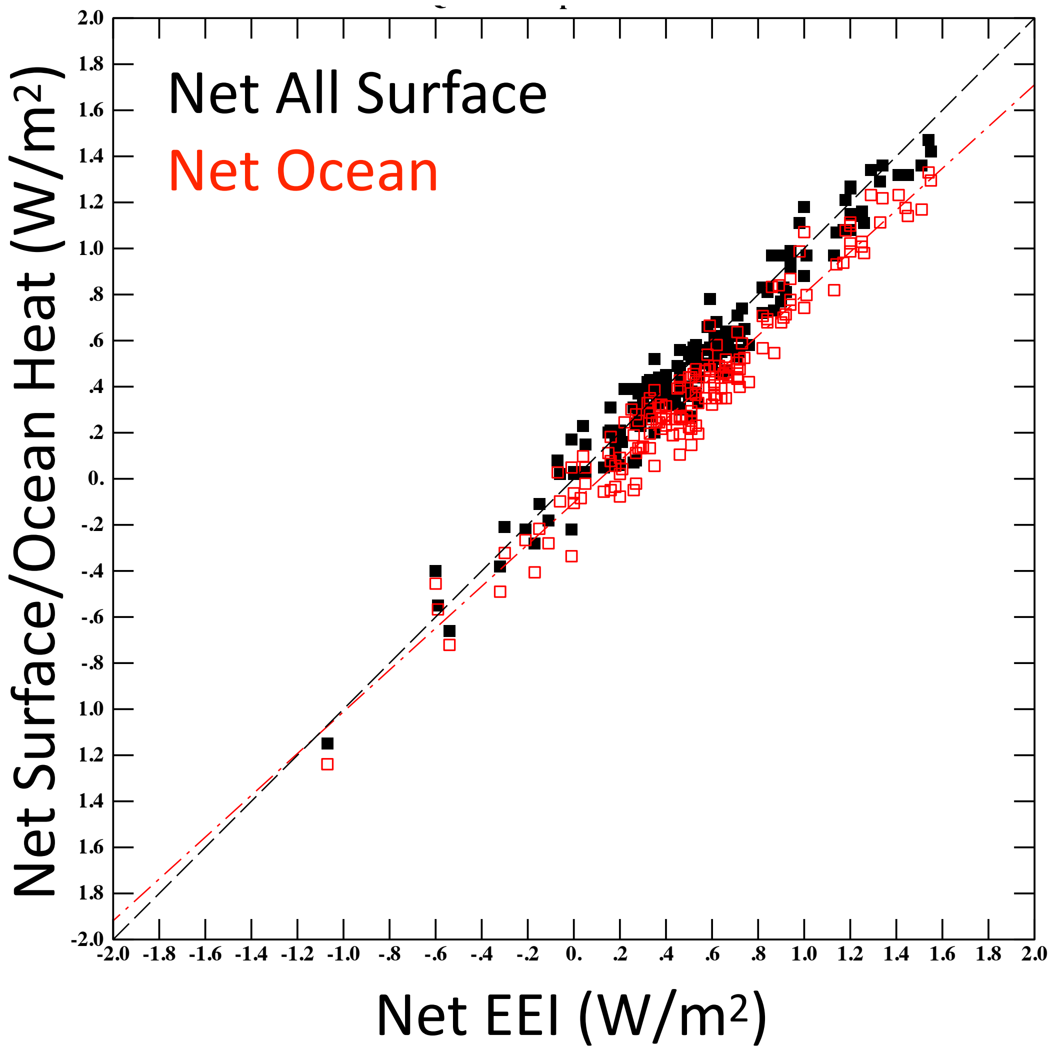

TOA to Surface: 93%

TOA to Surf Ocn: 91%

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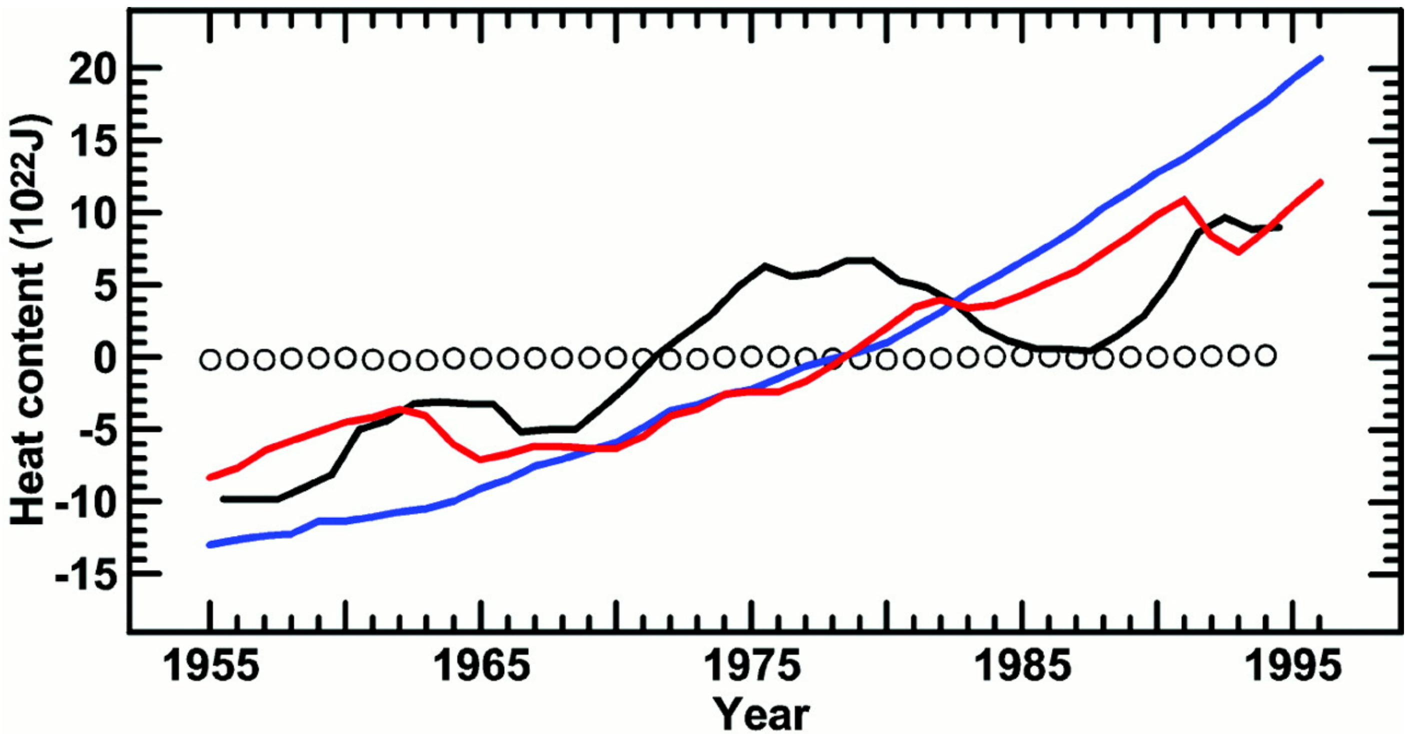
Validation?



Levitus et al (2001) show rise in OHC, but with large decadal variability

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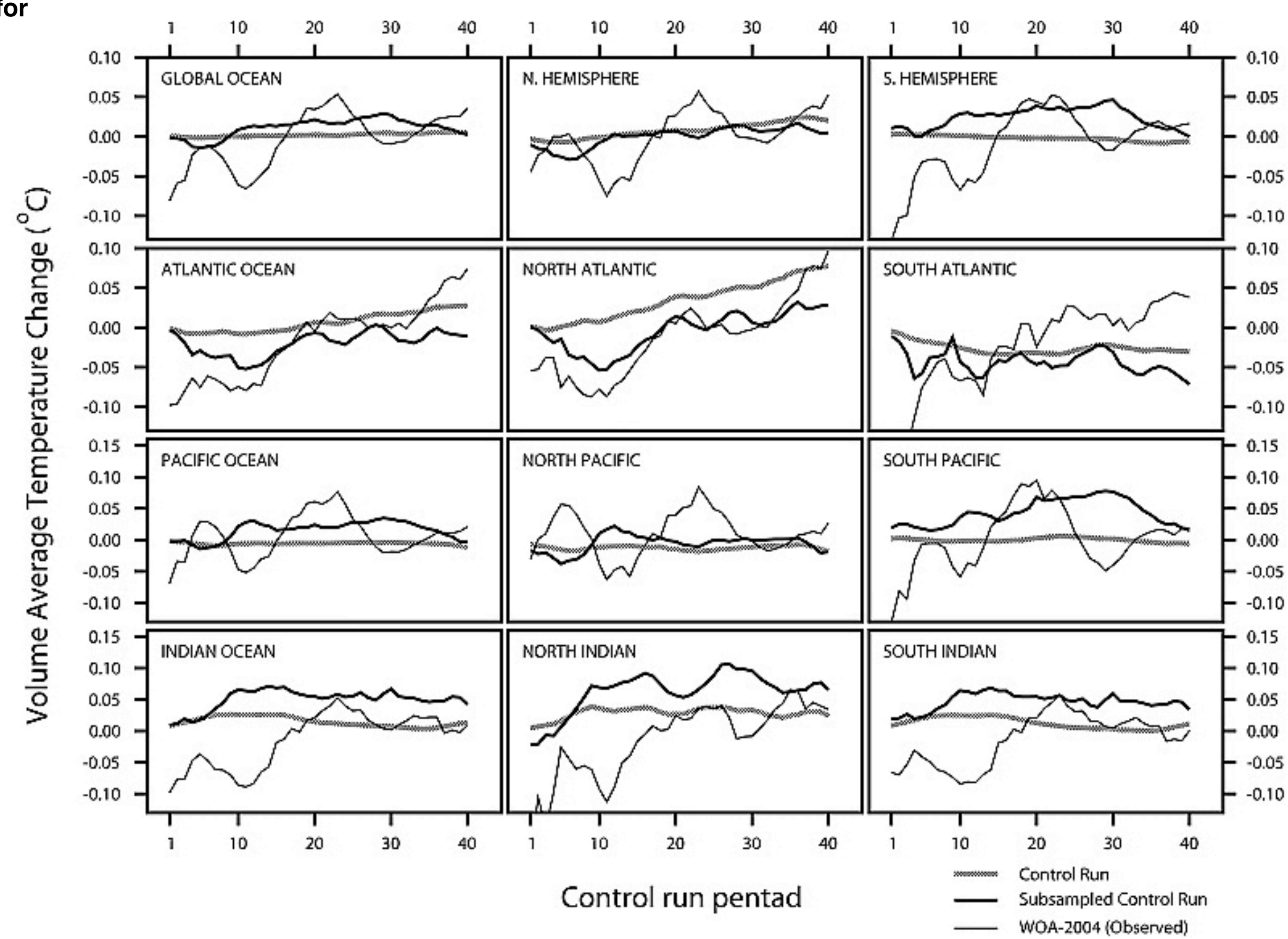
Validation?



AchutaRao et al (2006) found that not even spatial sampling in climate models could generate the inferred decadal variability from the obs.

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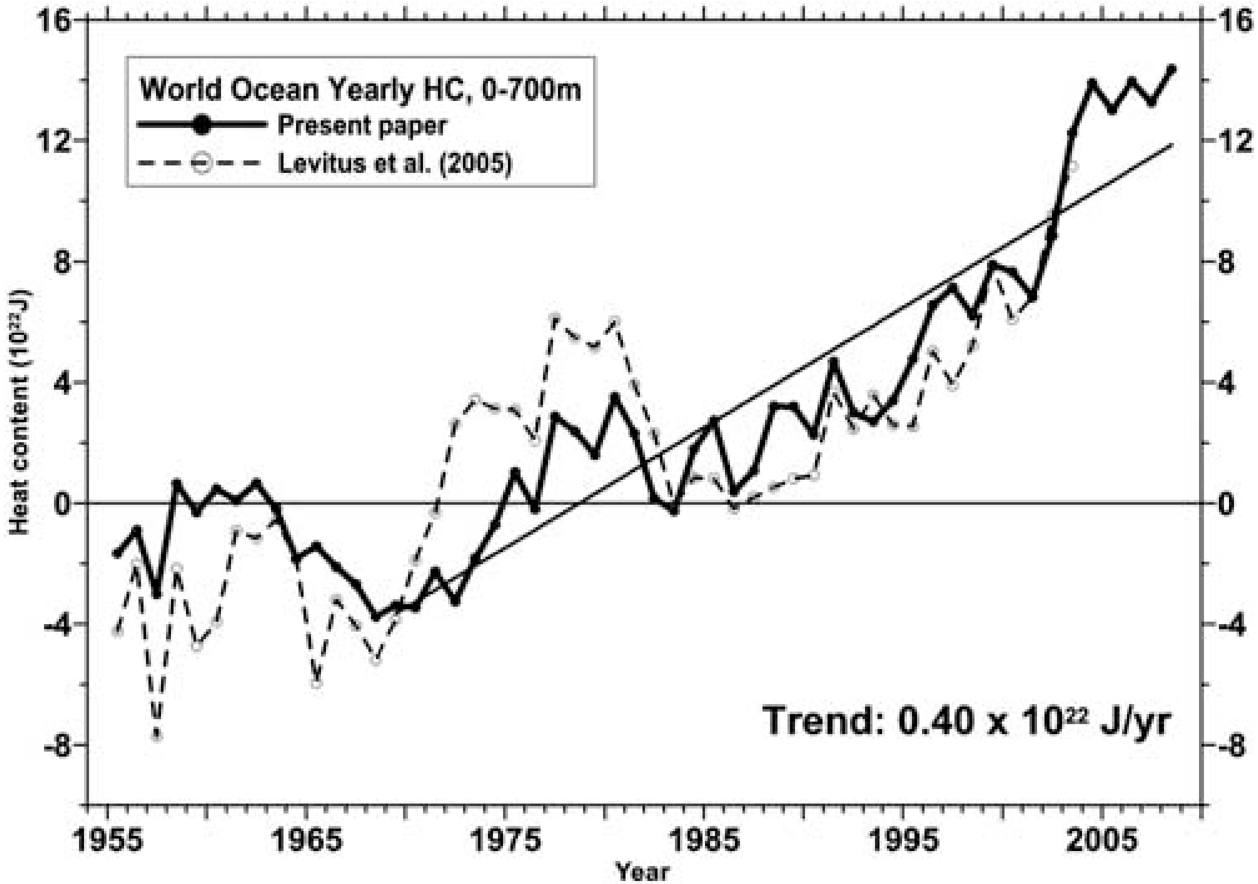
Validation?



Levitus et al (2008) adopted corrections for XBT artifacts reduces variance. OHC rise clearer (also Domingues et al, 2008).

Beginning of Argo + GRACE era!

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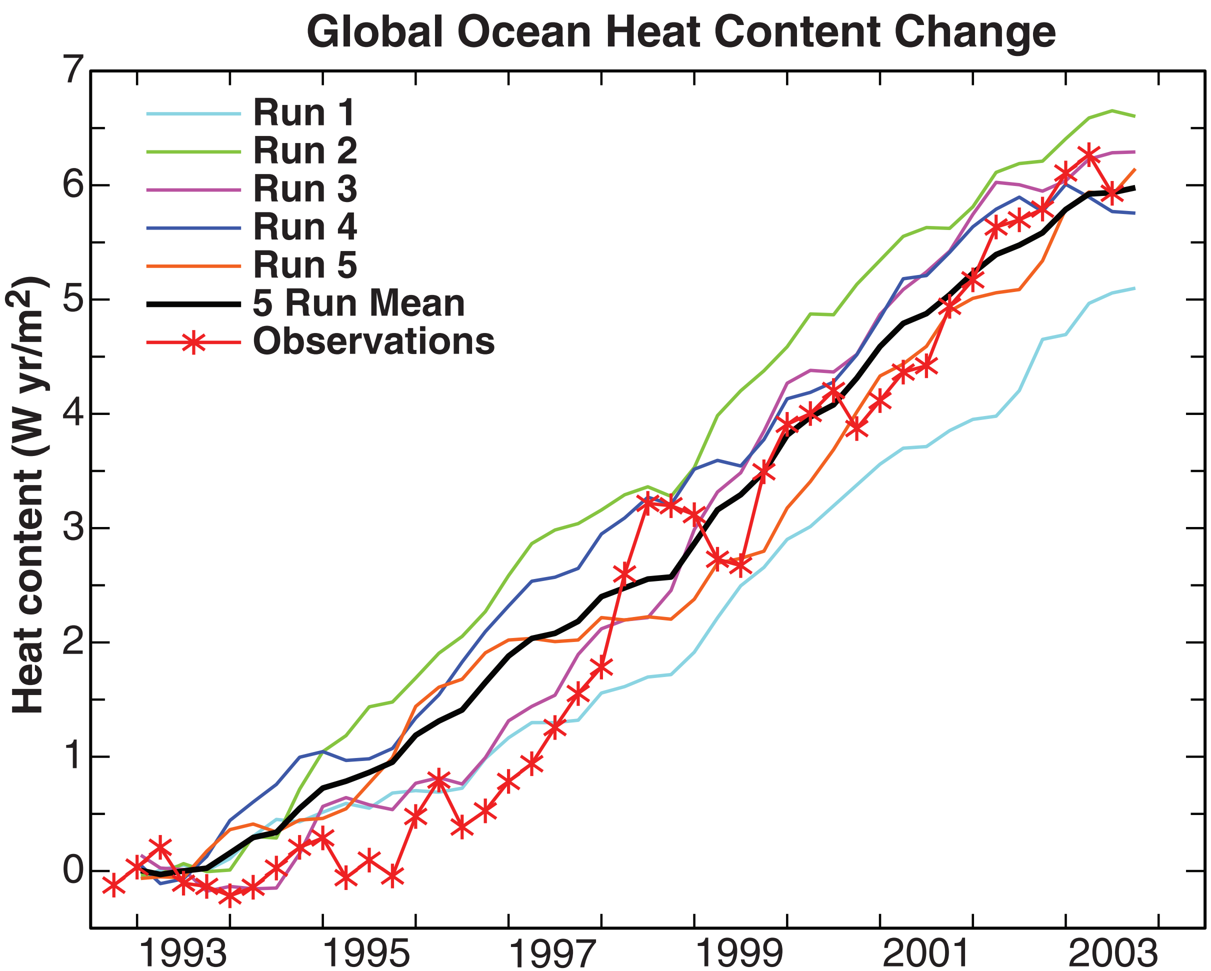
Fig. 2. Ocean heat content change between 1993 and 2003 in the top 750 m of world ocean. Observations are from (*20*). Five model runs are shown for the GISS coupled dynamical ocean-atmosphere model (*8*, *9*).



Hansen et al (2005)

By AR5, clearer picture had emerged

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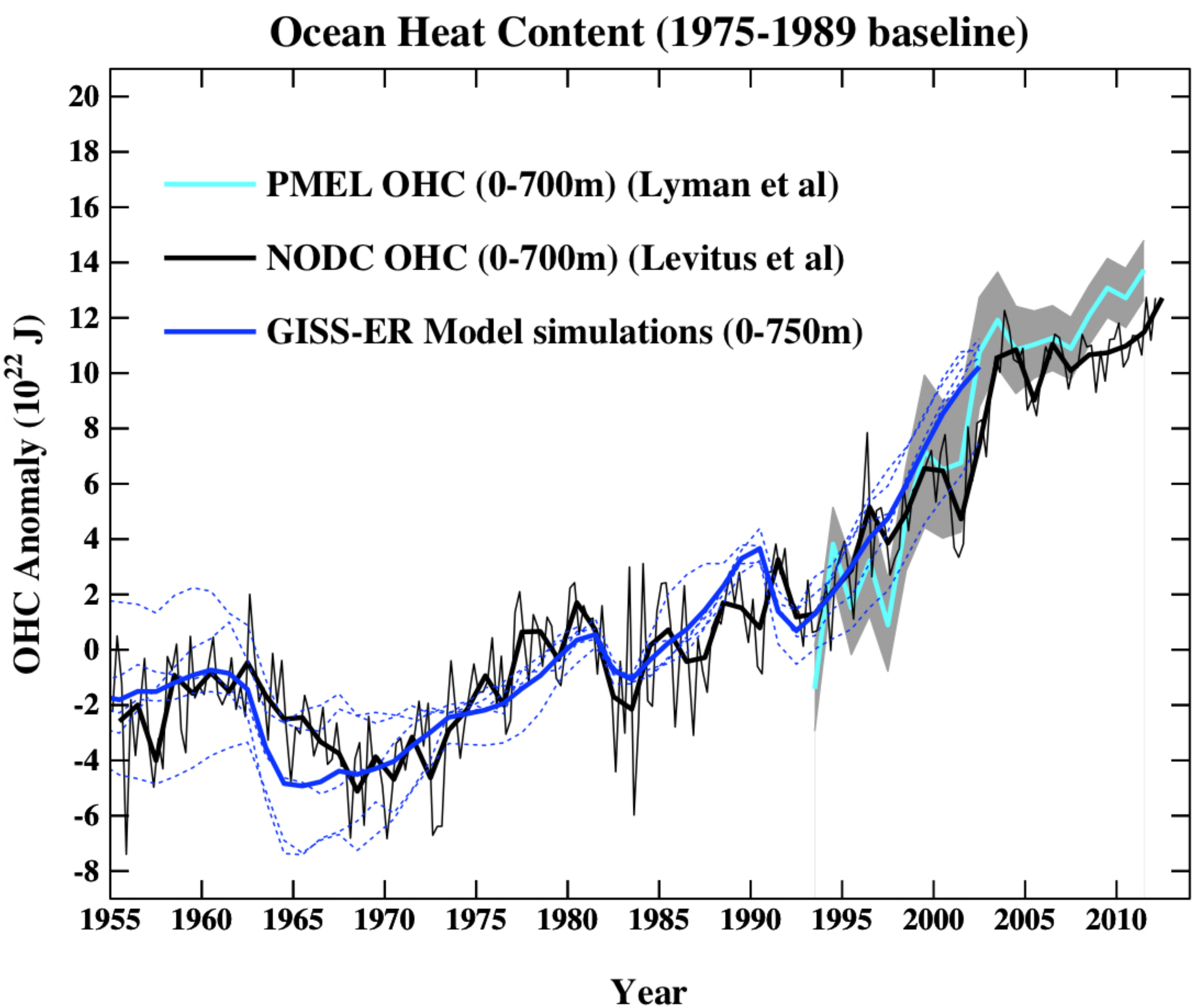

Comparison of CMIP3 models to ocean data in 2012

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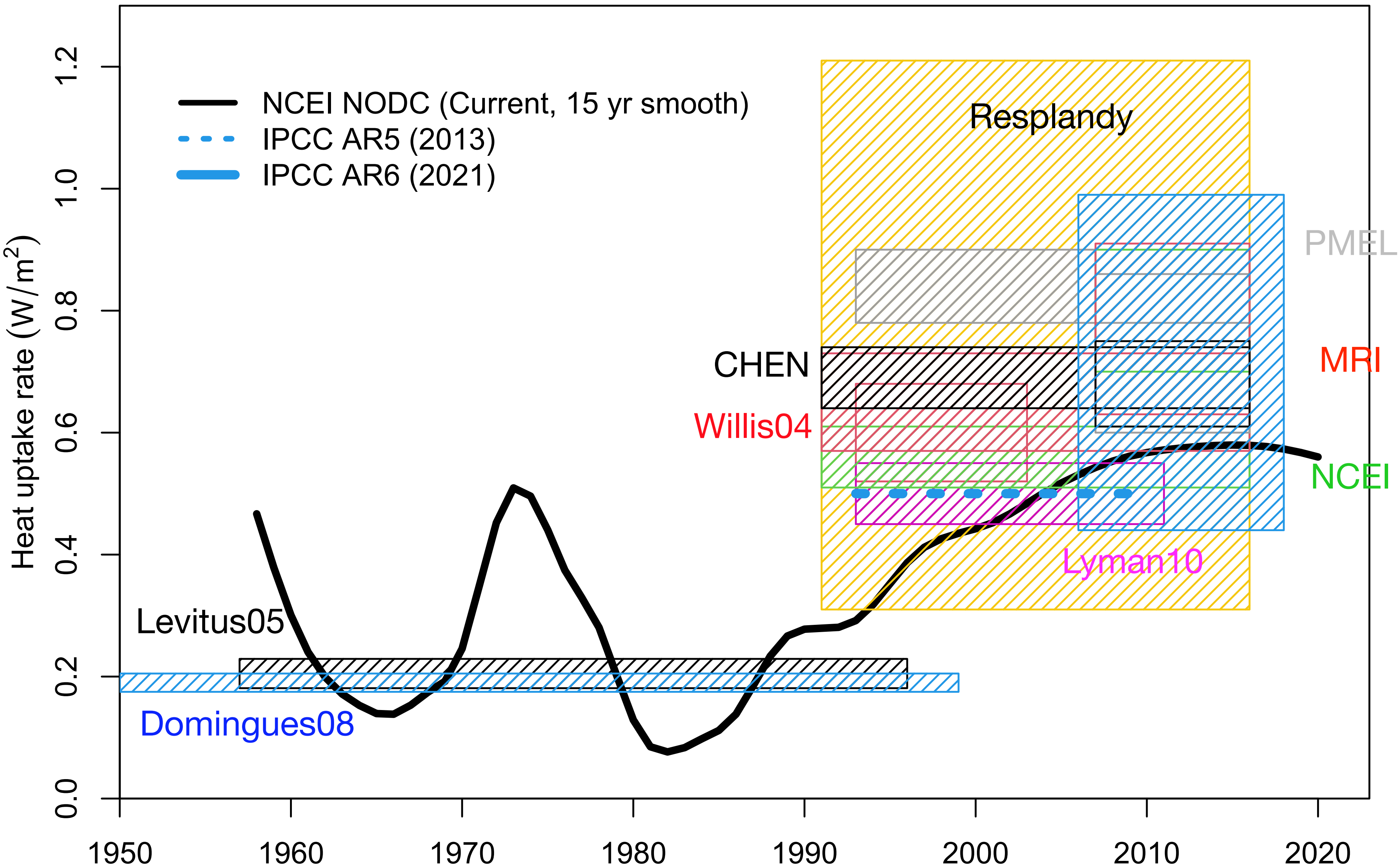
Ocean heat uptake estimates over time

(averaged over whole surface)



All good, no?

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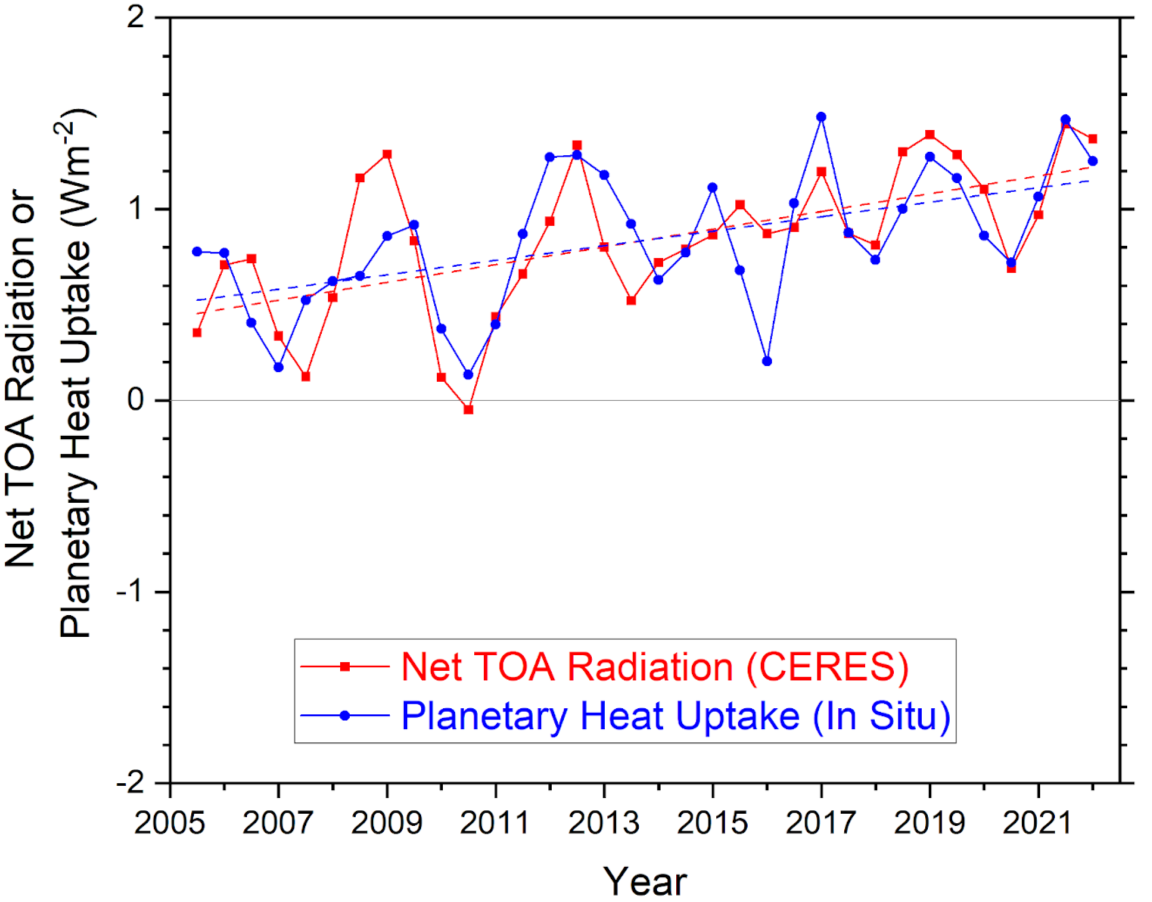
CERES from 2003 to present

- Trends in EEI match OHC (calibrated to absolute value)
- Also SW/LW breakdown



Update of Loeb et al (2021)

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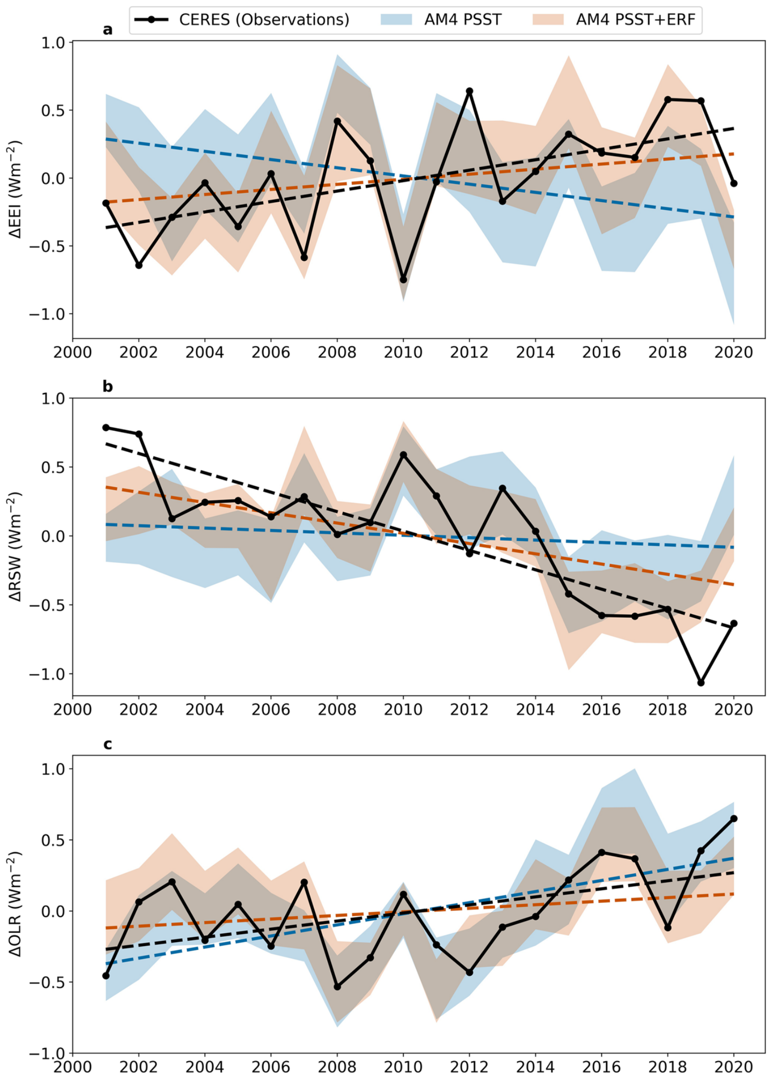
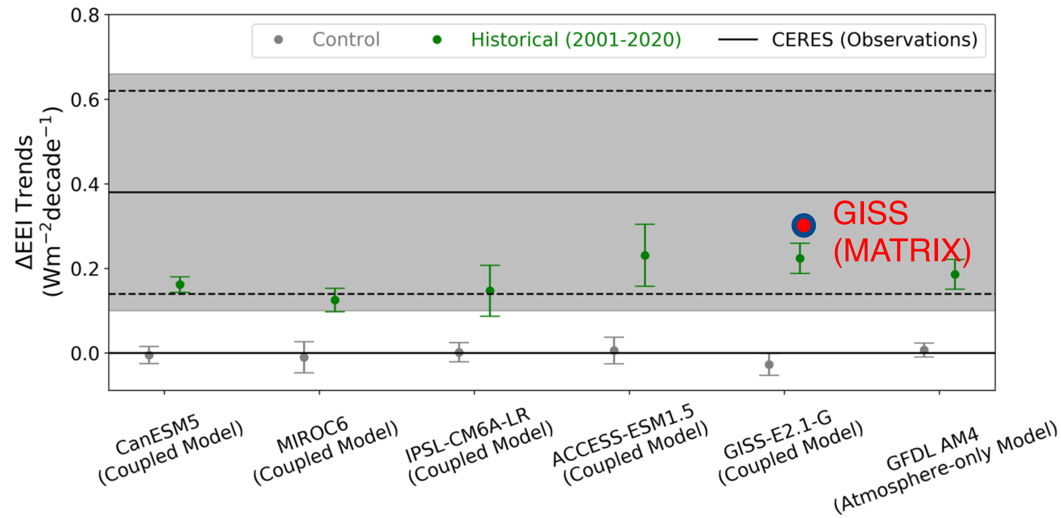
CERES observations show dramatic shifts in SW and LW TOA



- Big decreases in reflected SW
- Increases in outgoing LW
- AMIP/CMIP models have some coherence
- Best match with GISS-E2.1 (MATRIX)?



Raghuraman et al, 2021

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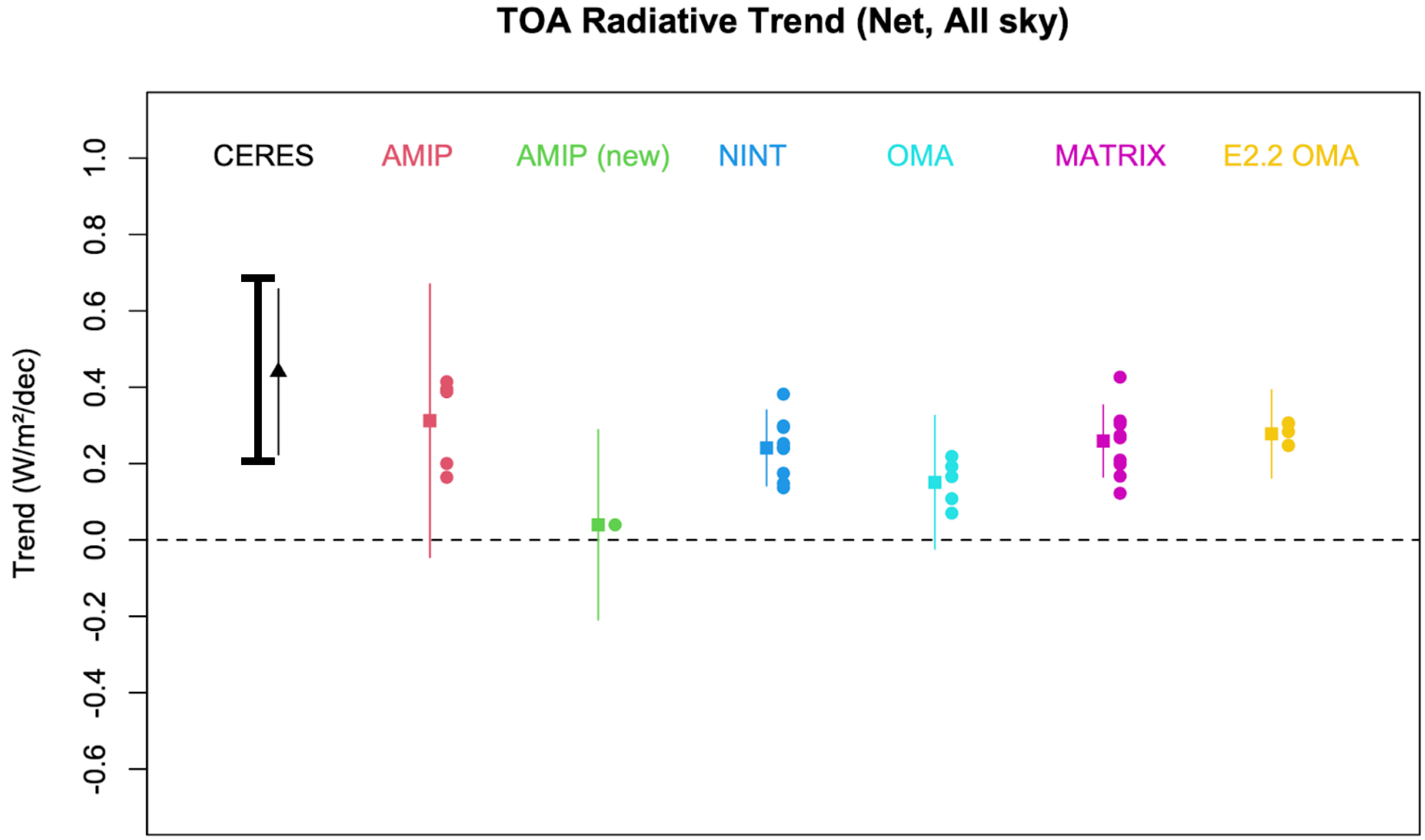
Net trends plausible match to GISS climate model expectations



Comparisons with GISS-E2-1-G/H, GISS-E2-2-G, different aerosol treatments

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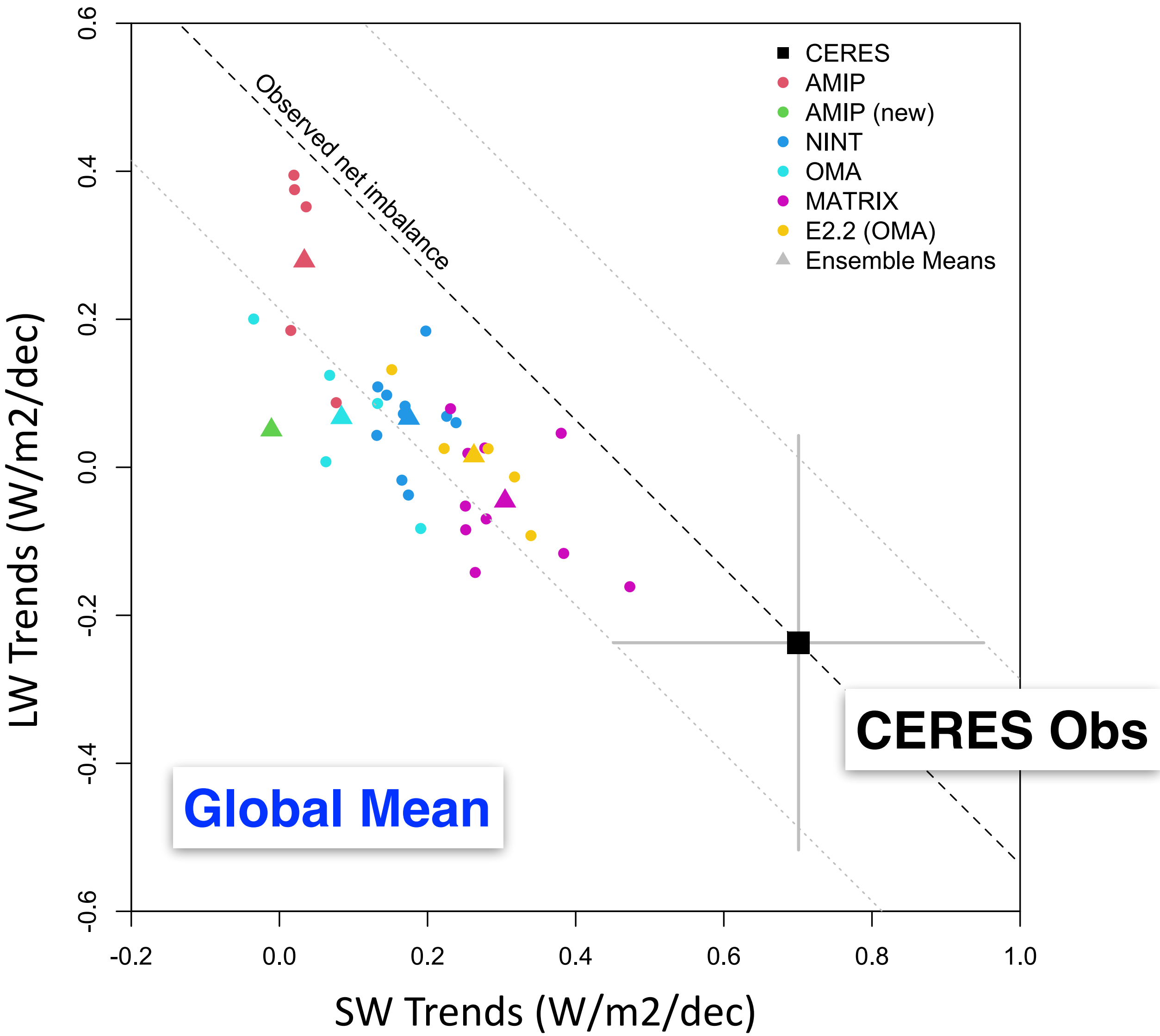
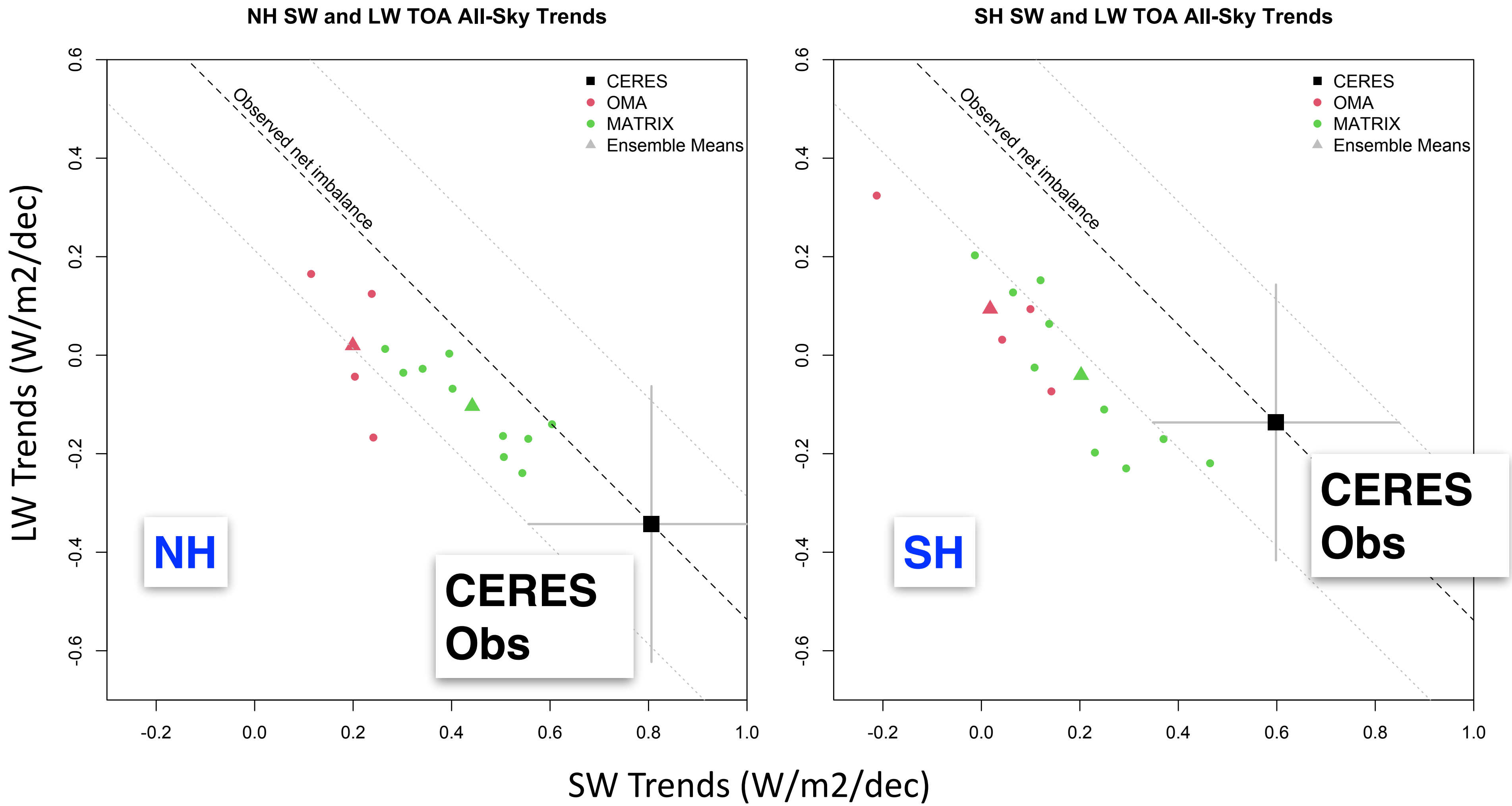
But LW/SW split in trends are way off!



Comparisons with GISS-E2-1-G/H, GISS-E2-2-G, different aerosol treatments

Some difference between hemispheres…



Divergence is mostly post-2014

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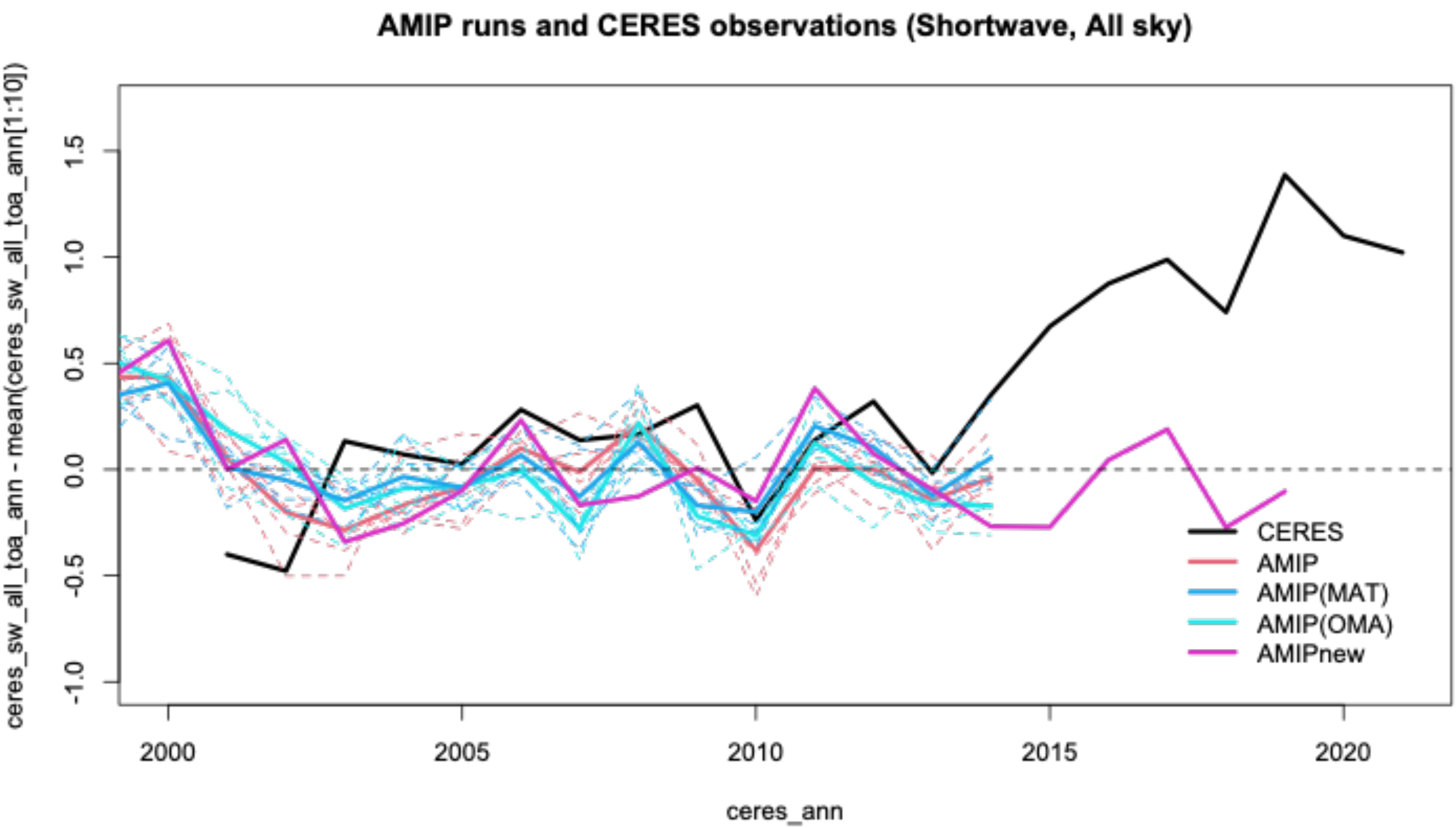

Are aerosols to blame?

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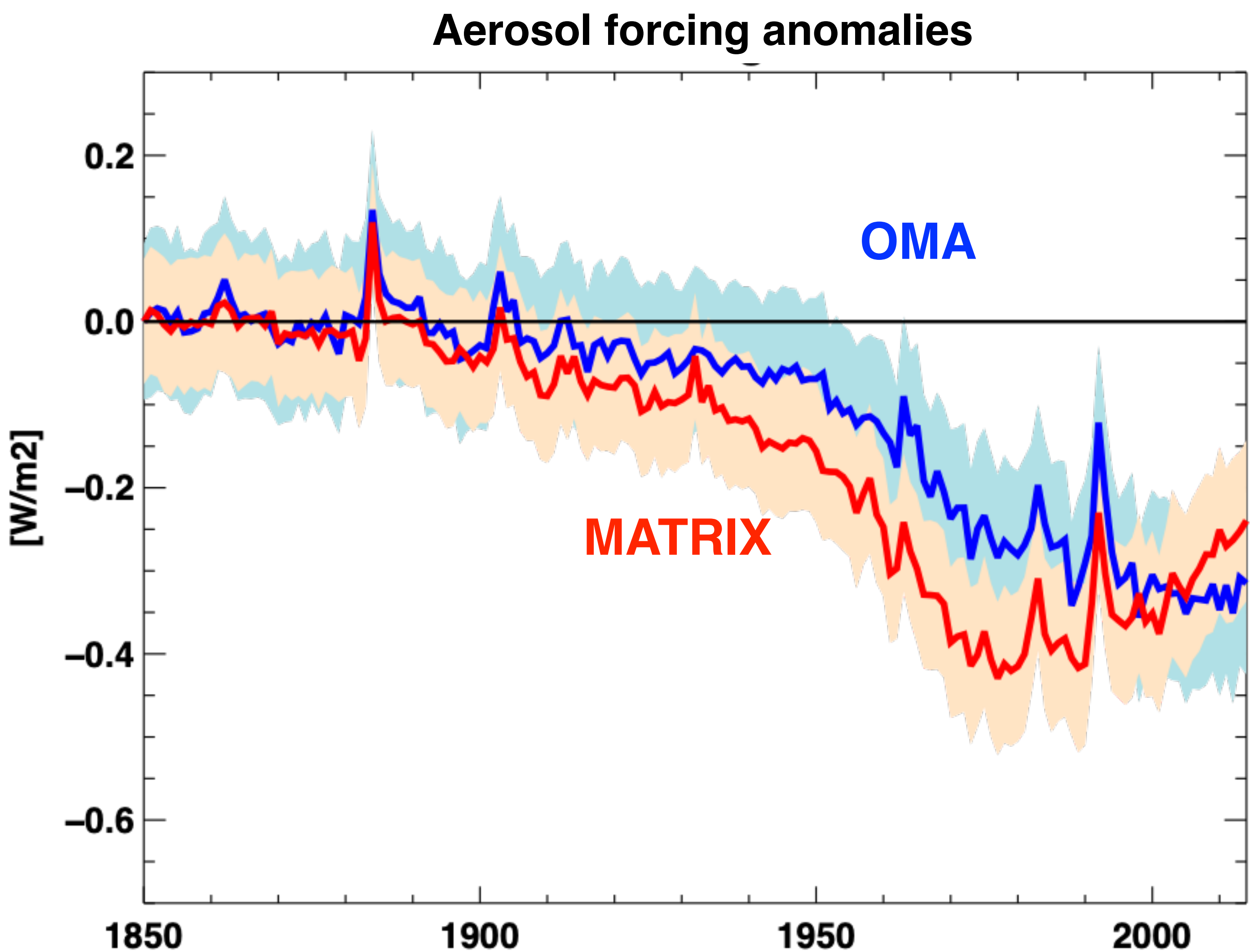

Bauer et al. (2020)

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What's happening?

Function of ENSO, COVID, aerosol changes?

Problem: AMIP runs in CMIP6 only go to 2014 and use out-of-date SSTs

- SW changes incl. cloud feedbacks, WV, aerosols and aerosol-cloud interactions
- LW changes incl. cloud feedbacks and surface emission change w/global warming

=> CERESMIP

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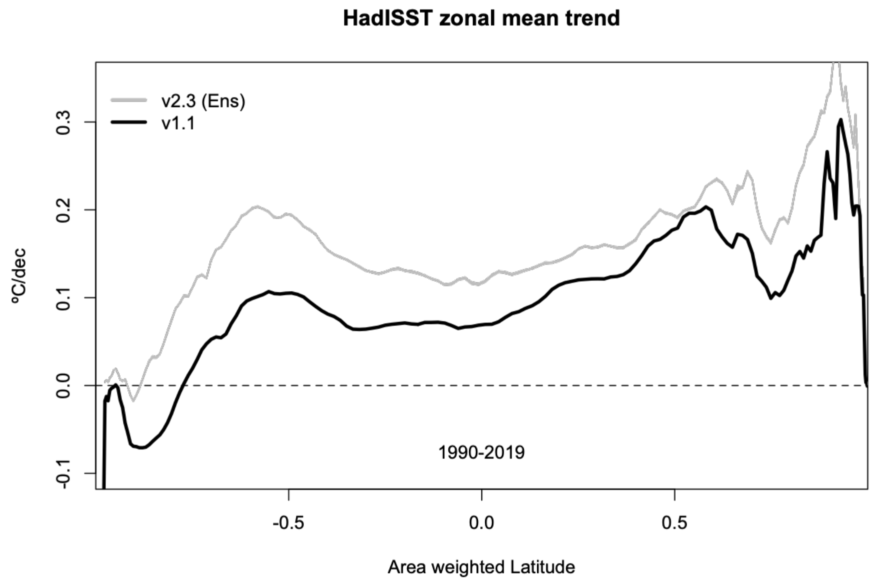
CERESMIP proposal

- Use AMIP-style runs from 1990 to present (cheap!)
- Update SST to HadISST v2.3 (or better) (currently to Jun 2020) (Not what is currently in Inputs4MIPs)
- Update CEDS to v2021_4_21 (to end 2019) (next version will include 2021)



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Requested diagnostics/Timeline

- Standard CMIP6 DECK output + COSP Cloud simulator
- Tier 1: All-forcing run
- Tier 2: Single forcings/Varying plausible aerosol input
- Runs to end-2019 can be done now.
- Runs including 2020+2021 need to wait on Hadley Centre/CEDS. Maybe by end 2023?

Predictions of an increasing net heat imbalance dating from the 1980s were correct

- Implies that warming is being driven by external forcing
- Climate sensitivity is non-negligible

New CERES results pose a challenge to existing models

New assessment of last two decades is needed.

- Updates to SST/SIC products
- Updates to aerosol and SLCF emissions
- Possible constraints on aerosol changes and cloud feedbacks.