Attribution of the Earth's Energy Imbalance and implications for the future

(Some pointers, no conclusions)

Gavin Schmidt (NASA GISS) Jun 3rd 2026

History of EEI predictions and modeling

The tortuous path from Hansen to Loeb

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!

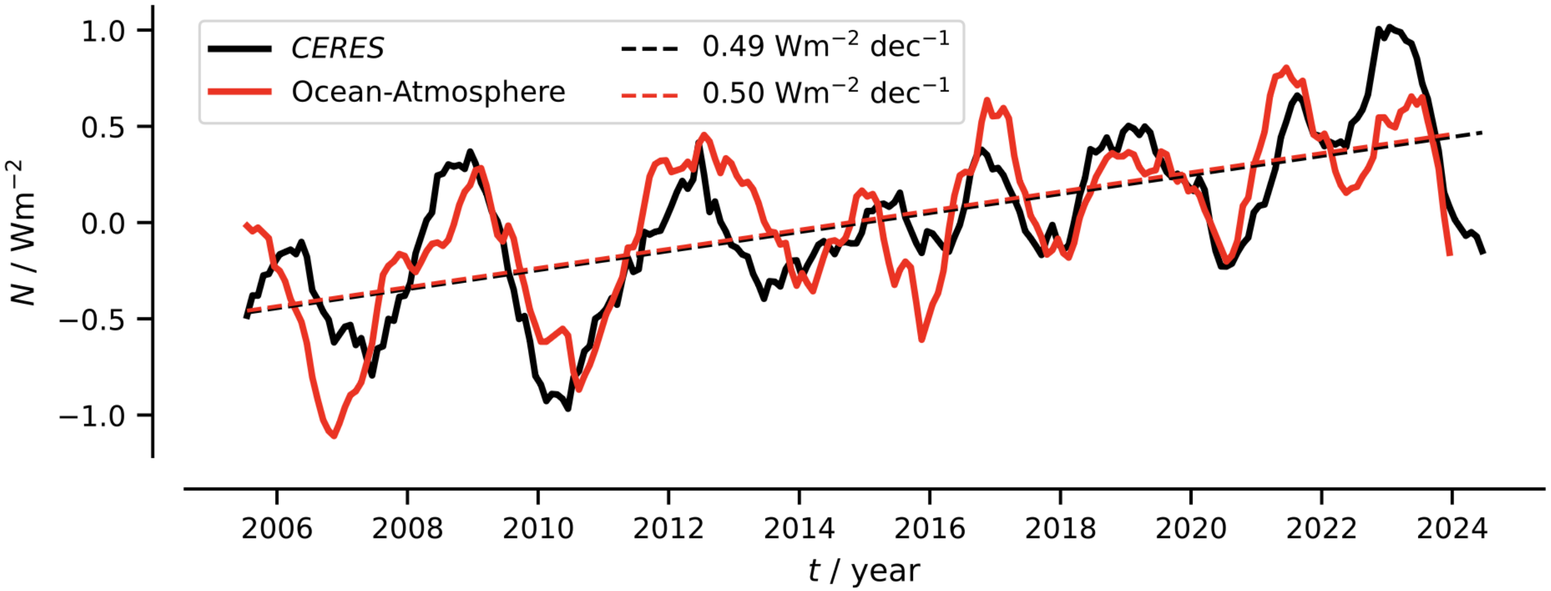
- Measurement shifts (CTDs/XRF/Argo)
- Data sparsity in southern ocean + pre-1970s

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 hard to attribute

Enter CERES…

- CERES from 2003 long enough to provide trends of EEI change (not absolute value)
- Calibration to OHC record (via Johnson + Lyman/Mayer etc)

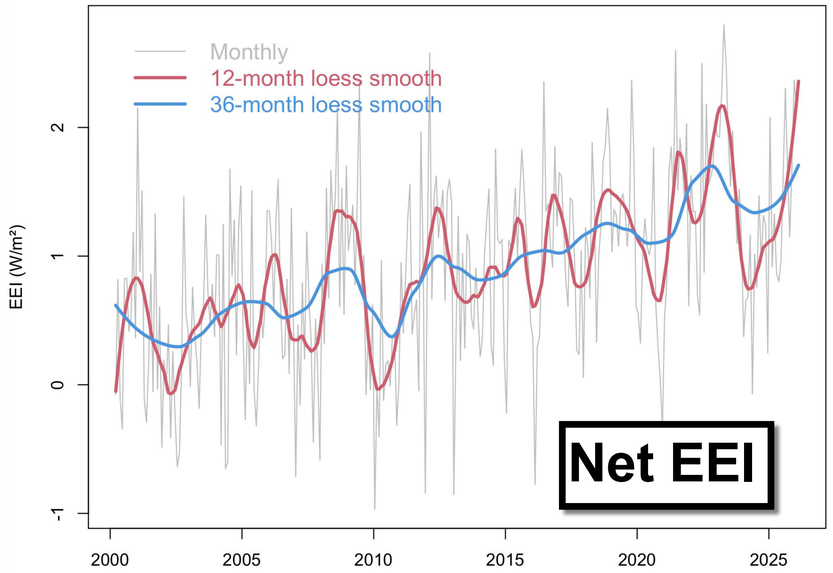


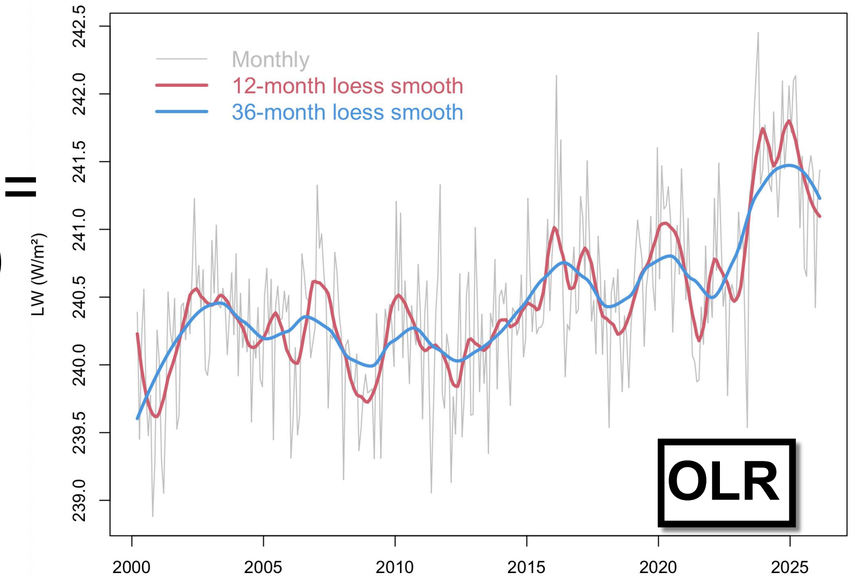
- All good, no?

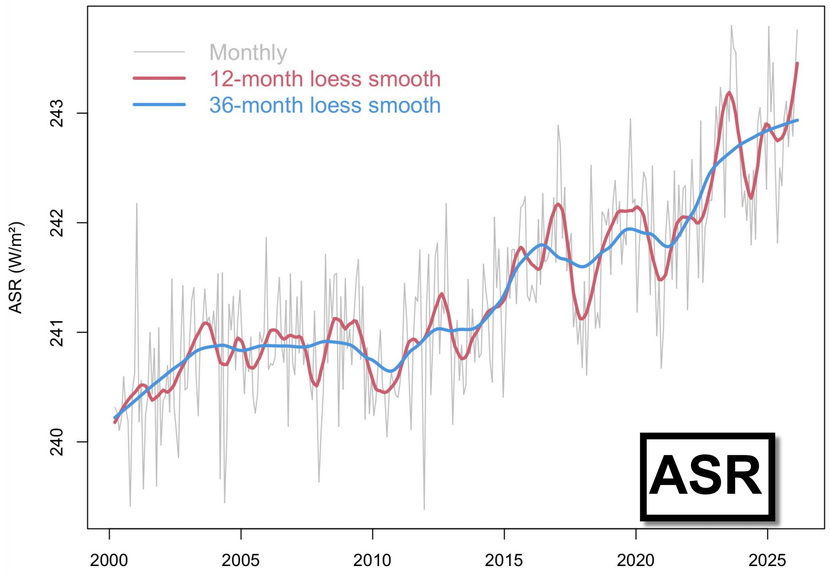
Stevens et al (2026) after Mayer et al (2026)

CERES has new info though…

- CERES splits EEI change into LW and SW components.
- ENSO variability (if you squint)
- LW follows SAT
- Large trend in SW (ASR = Absorbed Solar Radiation)



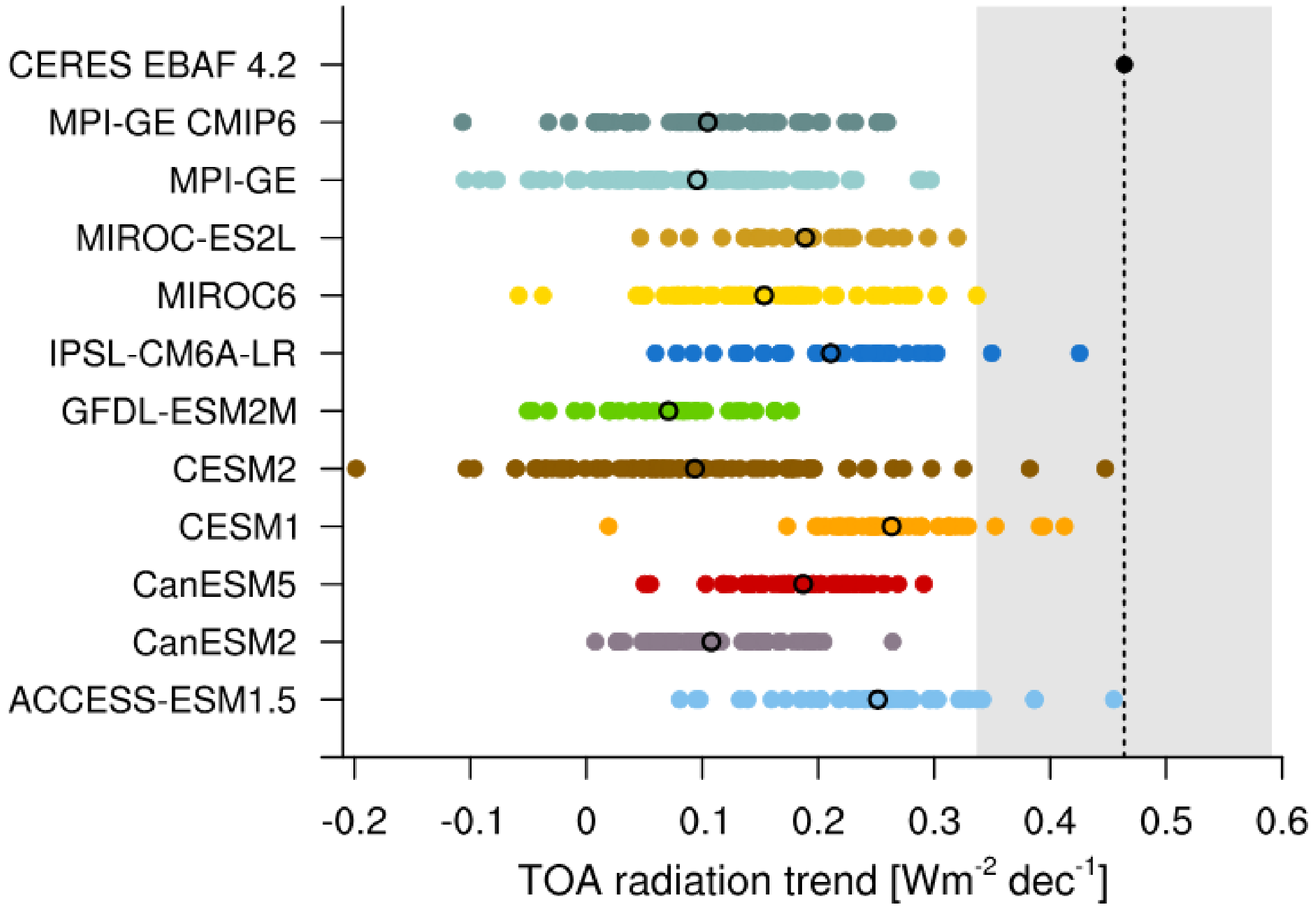




Update from EBAF4.2 to 02/26

2020's

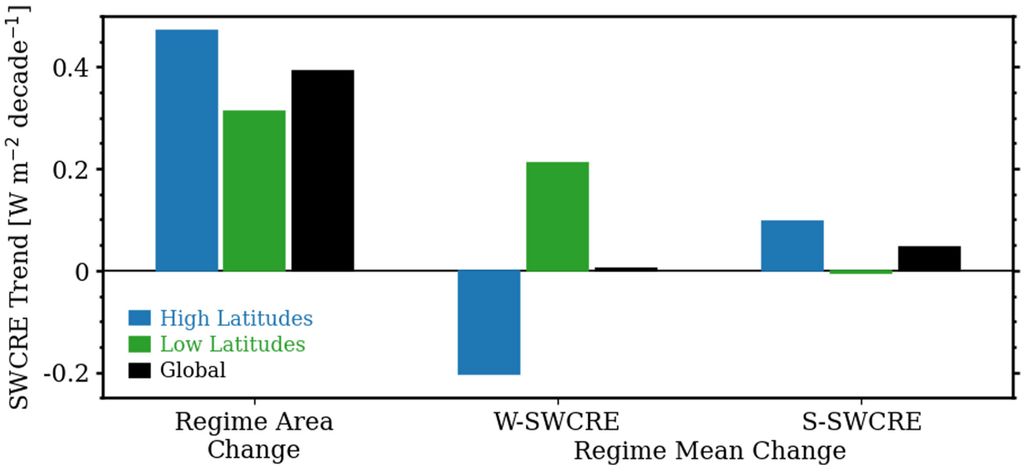
- CMIP6 models show similar net (slight underestimate), SW trends are not large enough.
- Large spread in coupled models due to internal variability

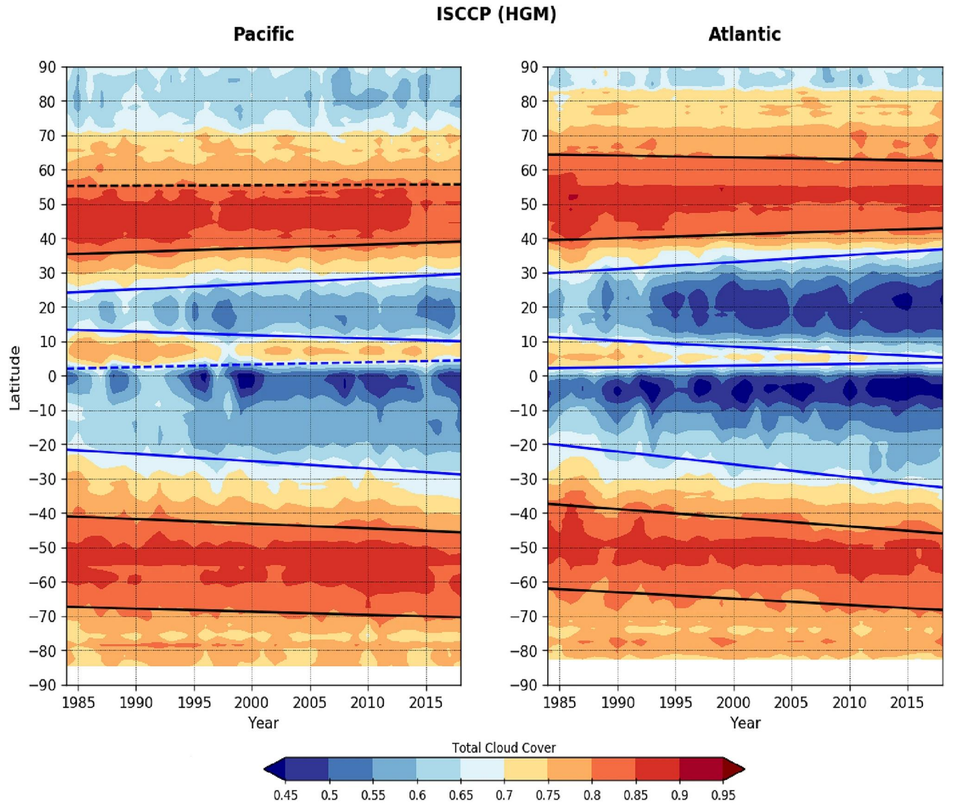


Olonsheck and Rubenstein (2024)

Cloud observations?

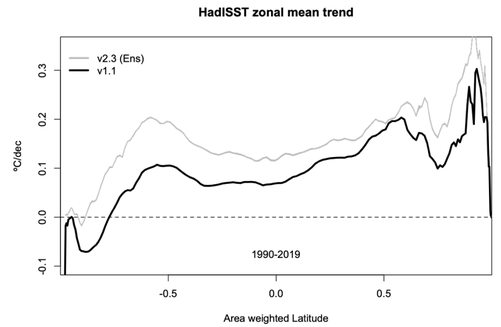
- Cloud trends over the ocean are now significant
- Mostly driven by dynamic feedbacks associated with expansion of Hadley circulation, poleward shift in mid-latitude storm tracks
- Might explain ~70% of the CERES SW trend





Tselioudis et al (2024;2025)

Are we comparing like-with-like?



CMIP6 simulations are ‘historical’ to 2014, scenarios from 2015

- Multiple updates to historical emissions/SST now available
- Post 2014 history has not matched scenarios:
  - Hunga Tonga, Pandemic, China clean-up, IMO regulations

Missing components in ESMs may make a small difference to comparisons

- No inclusion of changing melt terms for mountain glaciers, ice sheets/shelves in CMIP6
- Shallow soil layers mean missing deep soil heat sinks
- Incomplete energy budgets in AGCMs?
- More important for absolute EEI than trend…

Are there any non-climate drifts in CERES?

- Differences in IncSW in CERES v. ‘Best estimate’ TSI (minor impact on Net, SW)
- Degradation in Aura/Terra SW sensor? (Impact on SW/LW split).

CERESMIP

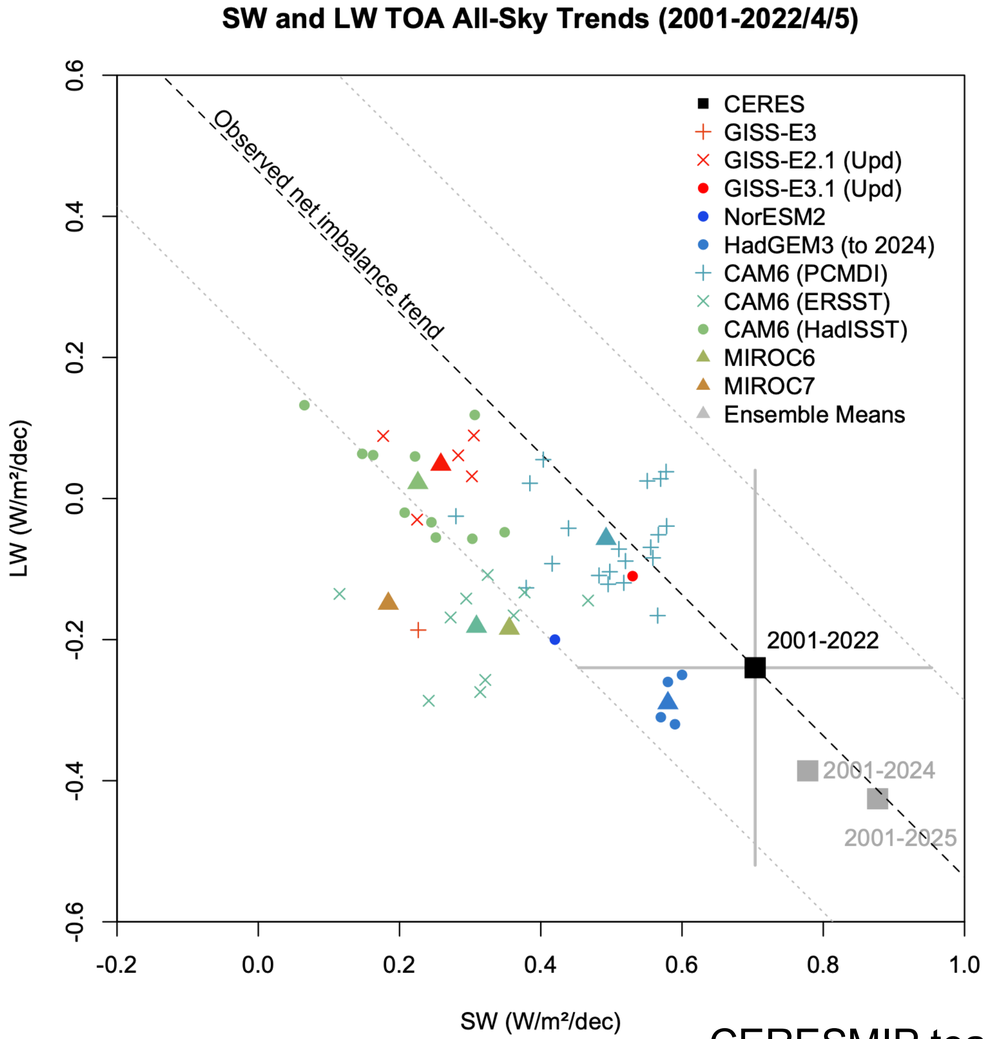
New CMIP6plus effort to focus on CERES data as a target

Update aerosol/SLCF to CMIP7 estimates to 2023

- AMIP-style from 1990, updated SST (Schmidt et al., 2023)
- Single-forcing ensembles
- Only really got started spring 2025

Initial results from some CMIP6 models

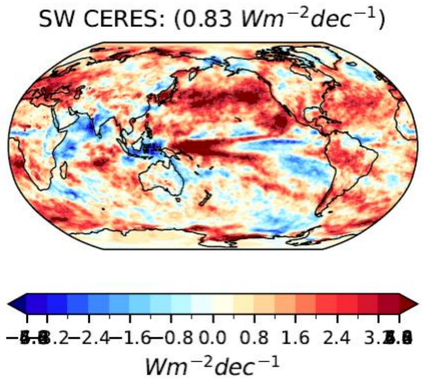
- Impact of SST product can be significant
- Some results from HadGEM3, GISS, MIROC, GFDL
- Improvement in Net, still 0.2 W/m^2 off from CERES SW

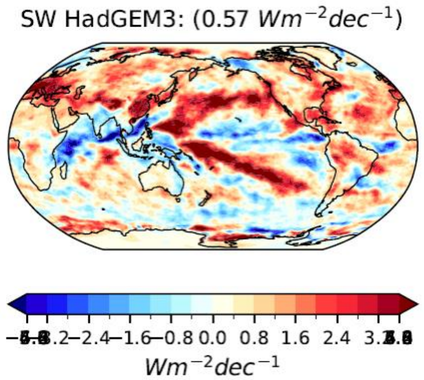


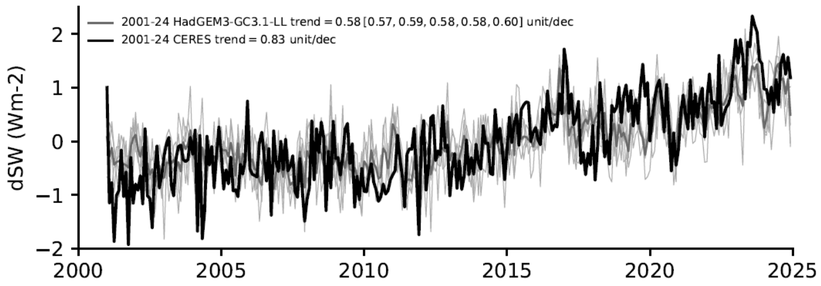
CERESMIP team

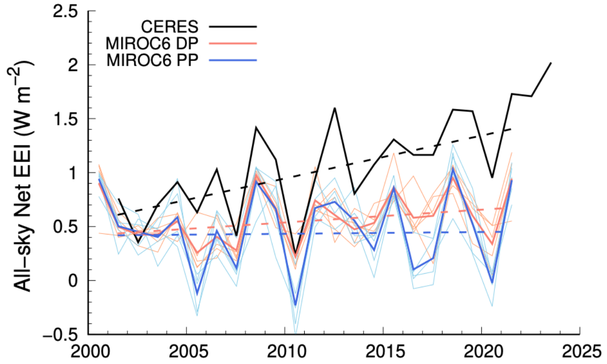
CERESMIP Initial results

- HadGEM3 seems to do ok on net, underestimate on SW (Tim Andrews, pers. comm)
- MIROC6 not showing net trend? (Takuro Michibata)
- GISS-E2.1 has reasonable cloud area trends in southern ocean, but not in tropics or NH. (Susanne Bauer/George Tselioudis)

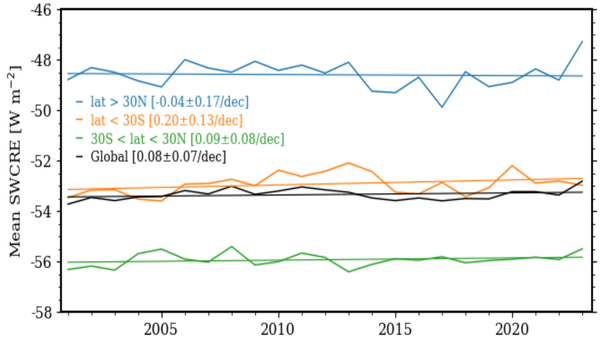




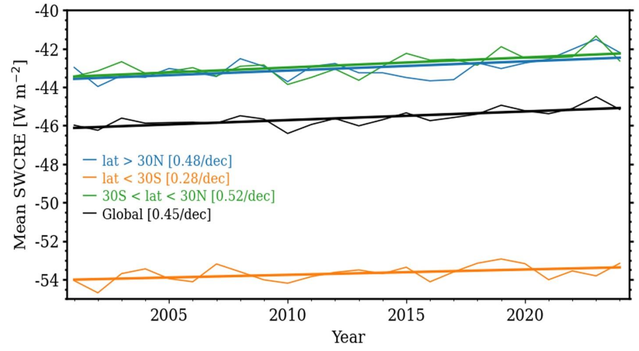




GISS E2.1

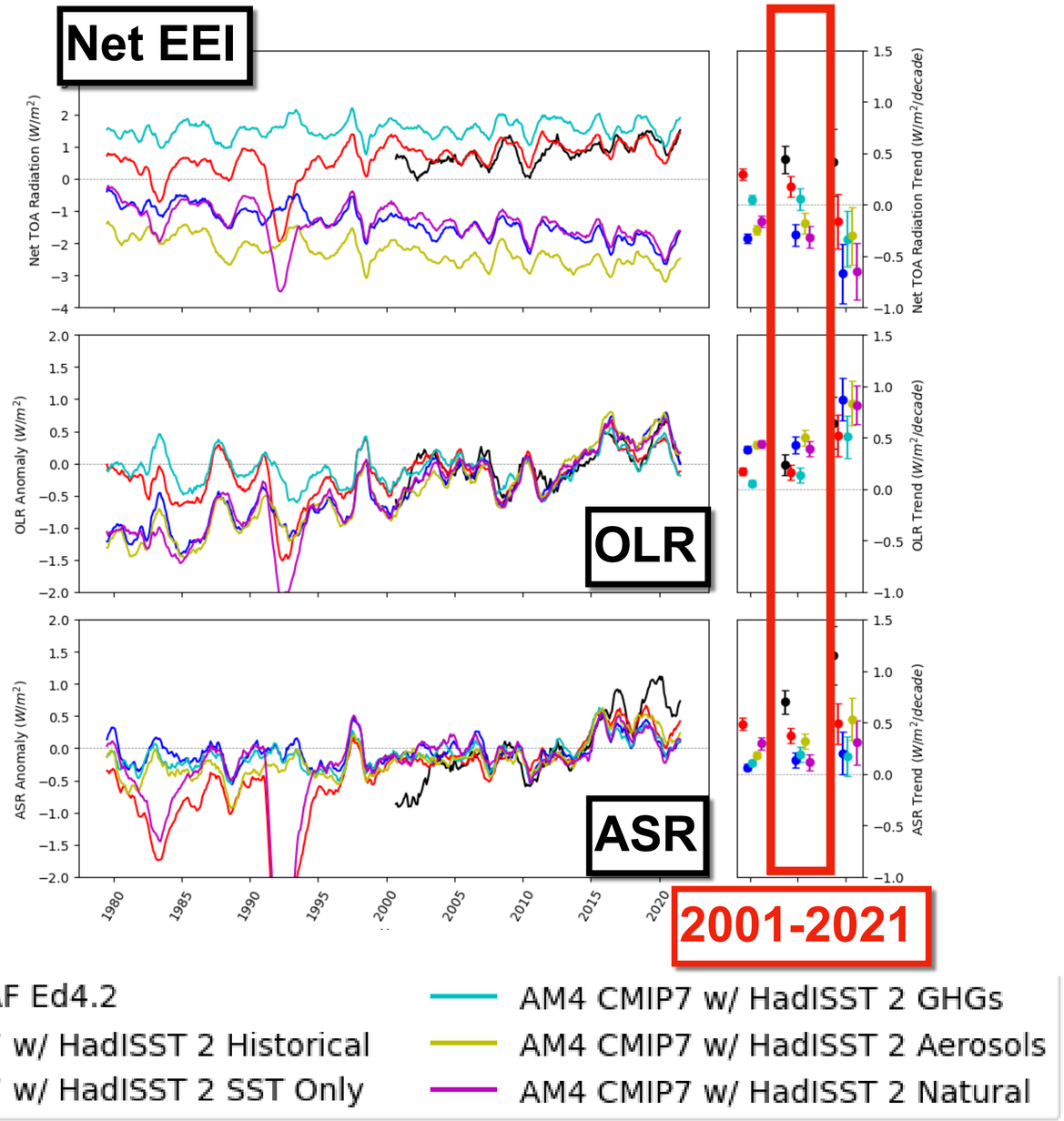


CERES



CERESMIP Initial results

- GFDL AM4 (Changing Fan, pers. comm)
- Recent Net trends good (slight underestimate)
- ASR trends underestimated, but Aerosol-only runs explain ~50% of trend (2001-2021)



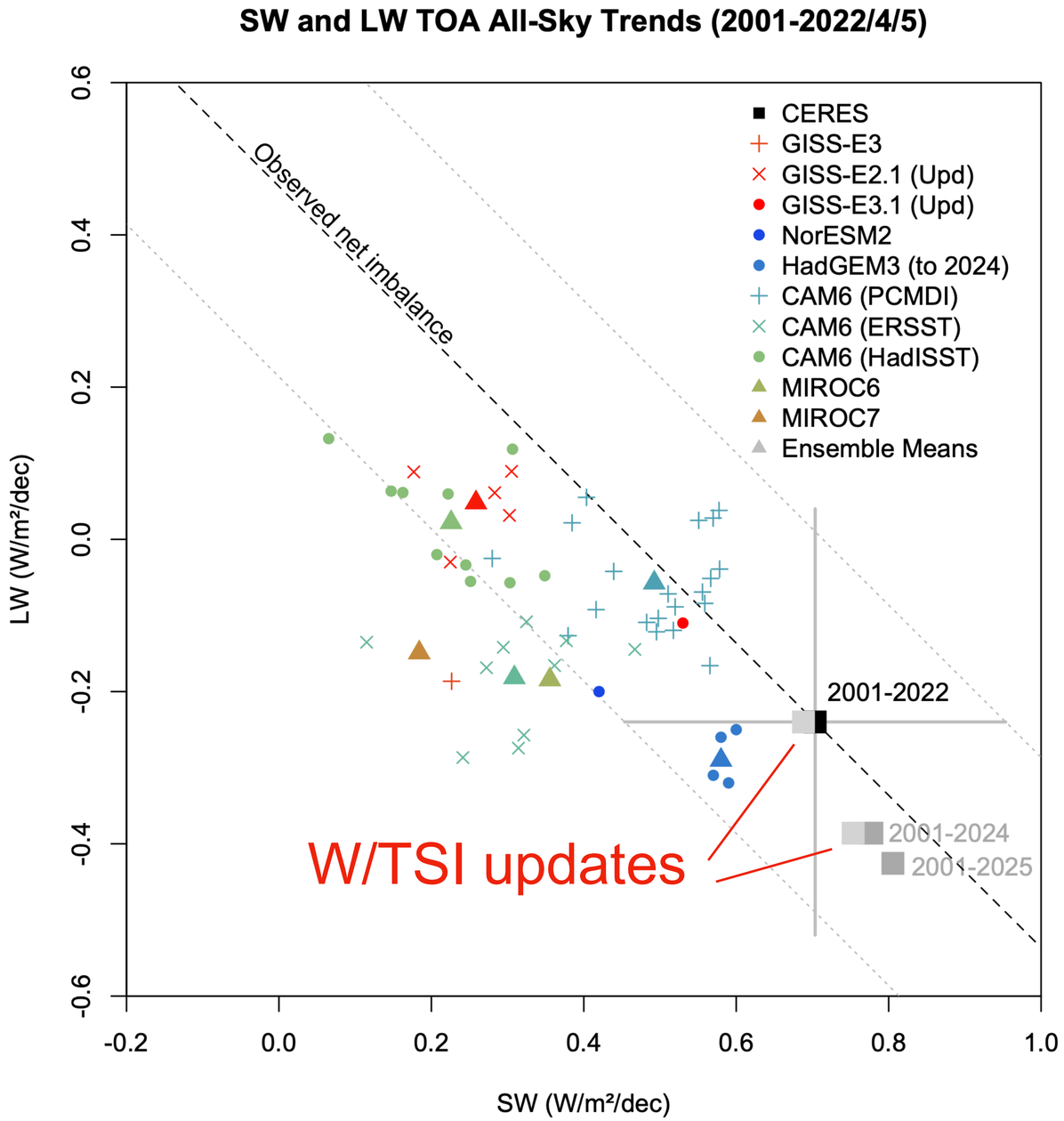
Attribution?

- Aerosol emissions (impacting SW via direct and indirect cloud effects): Chinese reductions (post 2008)/IMO regulations (post 2020)
- Cloud feedbacks to ongoing climate change (dynamic and thermodynamic)
- Surface albedo change (ice/snow/vegetation)
- Internal variability
- Instrument degradation/Processing
- Bottom up estimates from changes in emissions/(note that reanalyses don't have changing emissions)

- Needs regime/region-by-region analysis (to come!)
- Needs updated sea ice data/land use change
- Unlikely
- ?

Trends in incoming solar?

- CERES does not use community standard TSI (too slow), so possibility of mis-specification in between reprocessing.
- Would impact NET and SW trend.
- Impact of using Community TSI is however small.



Key open questions

Impact of aerosol emission changes on SW trends

- CERESMIP single-forcing runs to quantify

Process-level assessment of cloud feedbacks

- Dynamic (HC expansion), vs. thermodynamic
- Changes in high clouds have opposing impacts on SW/LW, limited impact on Net
- High ECS models have stronger +ve cloud feedbacks (therefore bigger SW trends)
  - Are they better? Specifics matter!
- This will be a main focus of CERESMIP analyses as simulations get completed

Quantification of model energy budget biases in trends?

- I think this is likely < 0.1 W/m^2/dec… but needs confirmation.

Non-climatic effects always possible - TBD

Implications for the future?

If models are underestimating sensitivity to aerosol effects?

- Underestimate of warming effects associated with aerosol decreases (but also excessive cooling in build up)

If models are underestimating cloud feedbacks?

- Underestimate of climate sensitivity

If imposed emissions and/or interactive emissions are wrong?

- Misspecification of forced trend and/or underestimate of composition feedbacks?

If there are biases in inferred observational trends?

- No implication for future climate change.

We shall see!