Trends in CERES, MODIS and NASA ModelE over the past 22 years: Which trends are caused by aerosol and/or cloud feedbacks

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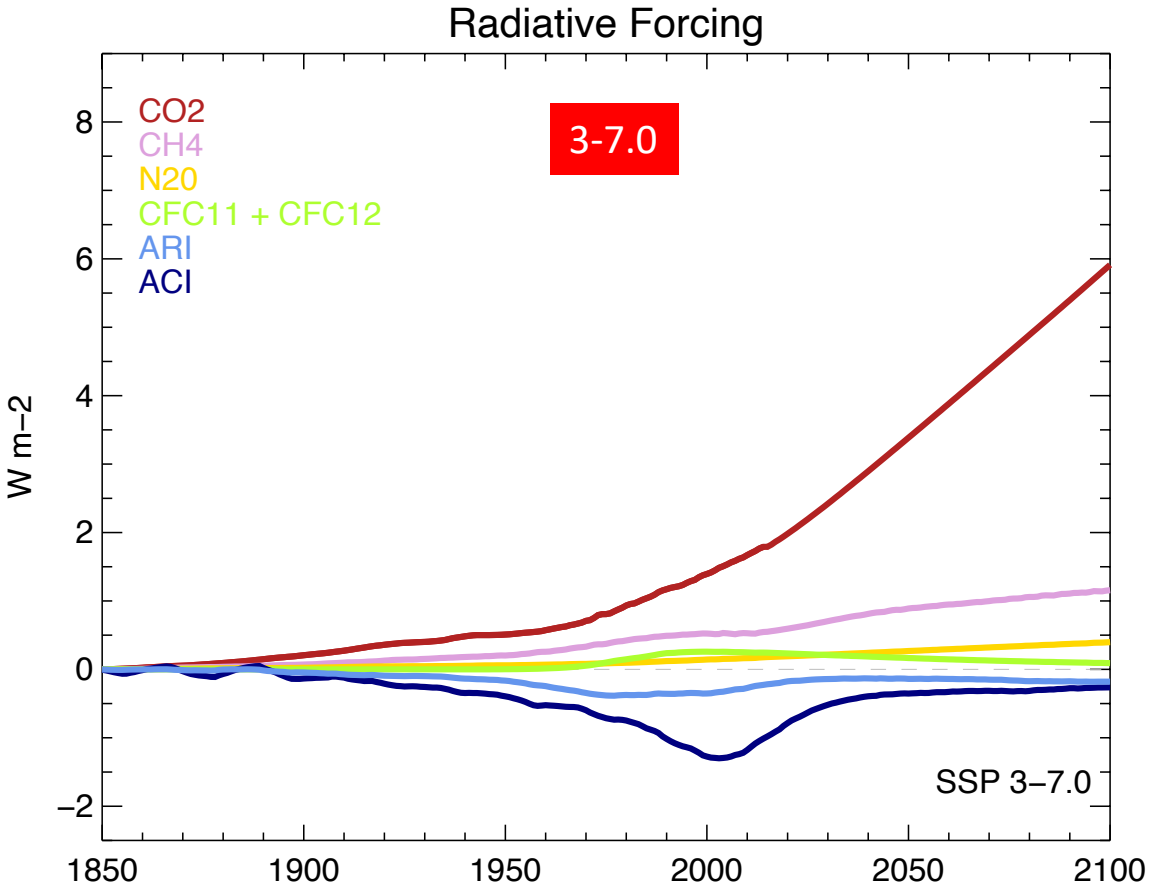
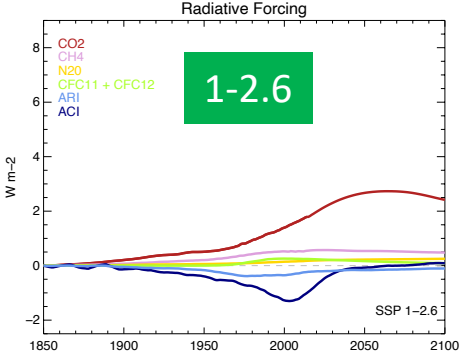
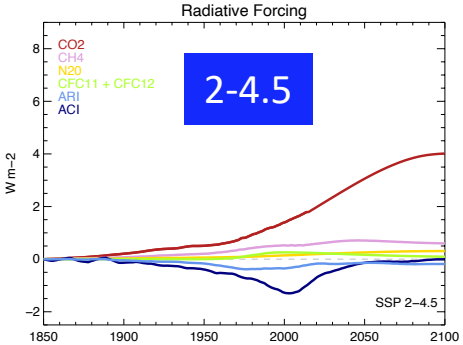
NASA Goddard Institute for Space Studies, New York, NY

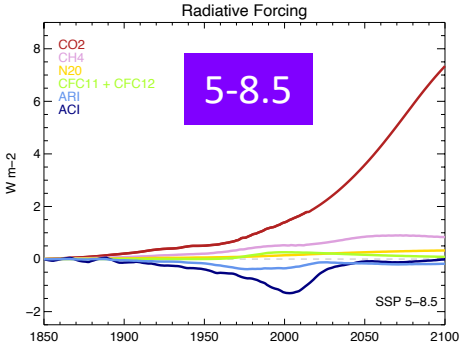
CERES Science Team Meeting Oct 2023

Historical Aerosol and GHG forcings: based on CMIP6



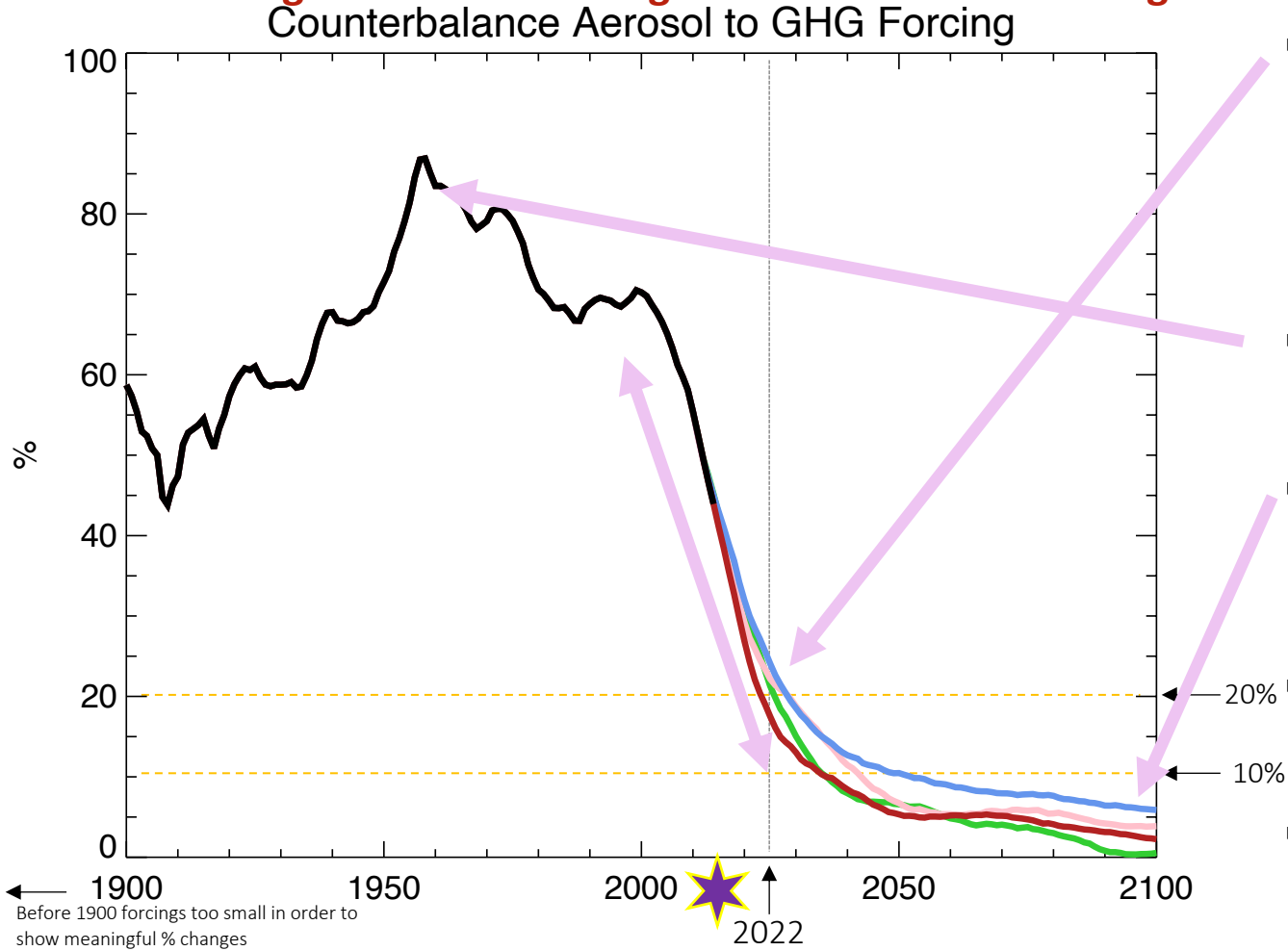






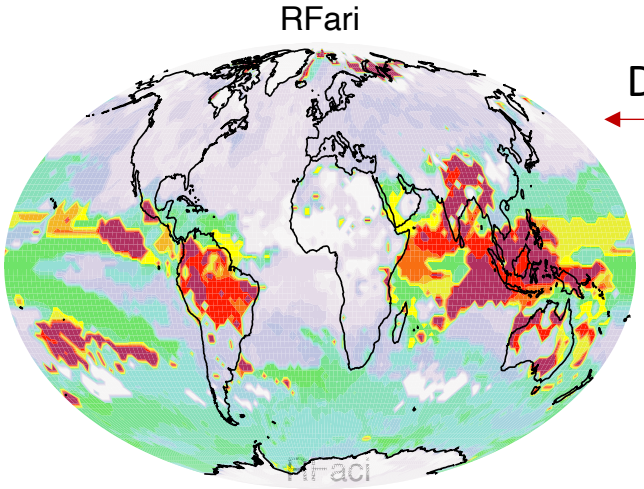
Percentage of aerosol forcing in relation to GHG forcing

Bauer et *JAMES*, 2022



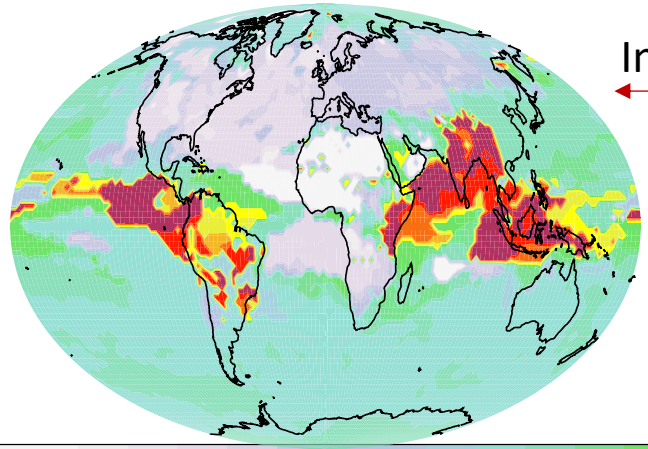
- Aerosols ability to counterbalance GHG forcing on the global scale is today below the level of the beginning of the last century.
- During peak aerosol years, aerosols balanced up to 80% of GHG forcings
- By the end of this century, 2100, aerosols counterbalance GHG between 0% -5%
- Dramatic drop in relevance of aerosol forcing in the past 20 years.
- Individual SSP almost irrelevant.

Timing of maximal Aerosol Forcing:



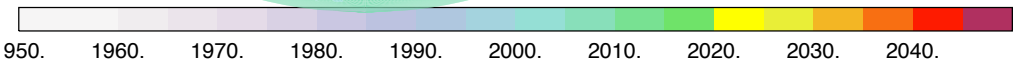
Direct aerosol forcing

RFari follows aerosol loads and (not shown AOD)

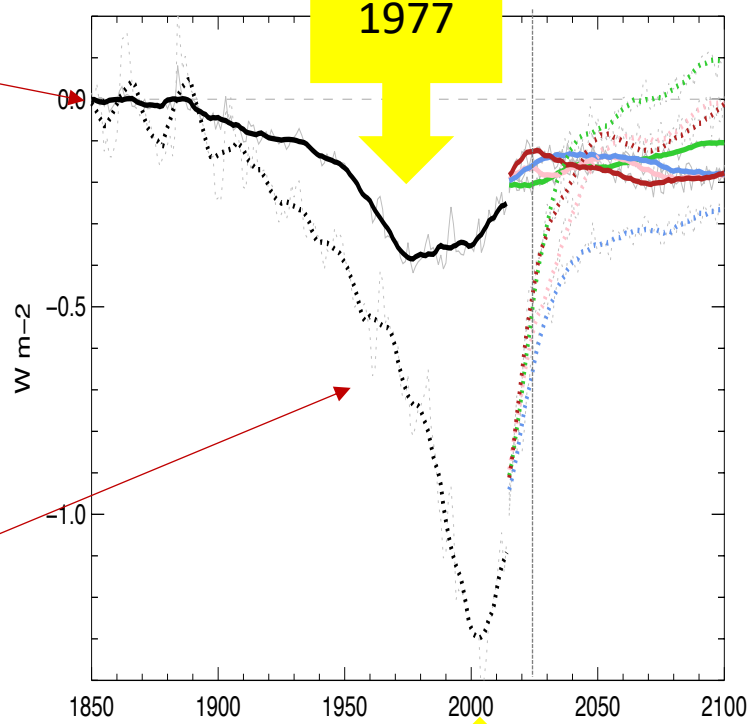


In-Direct aerosol forcing

RFaci maximal impact does occur later than max RFari



RFari 1977



RFaci 2007

Indirect forcing is 4 times larger than direct

Question to sort out here:

How do the changing trends in Aerosol and GHG forcing impact EEI.

Prior studies looking at CMIP models and EEI:

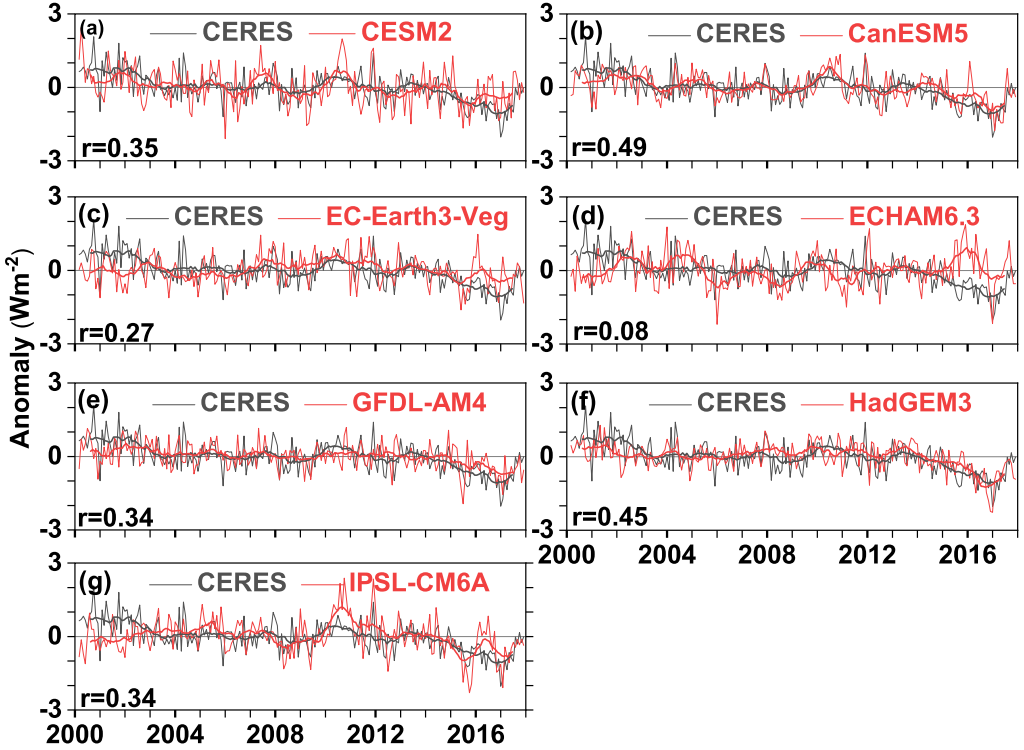
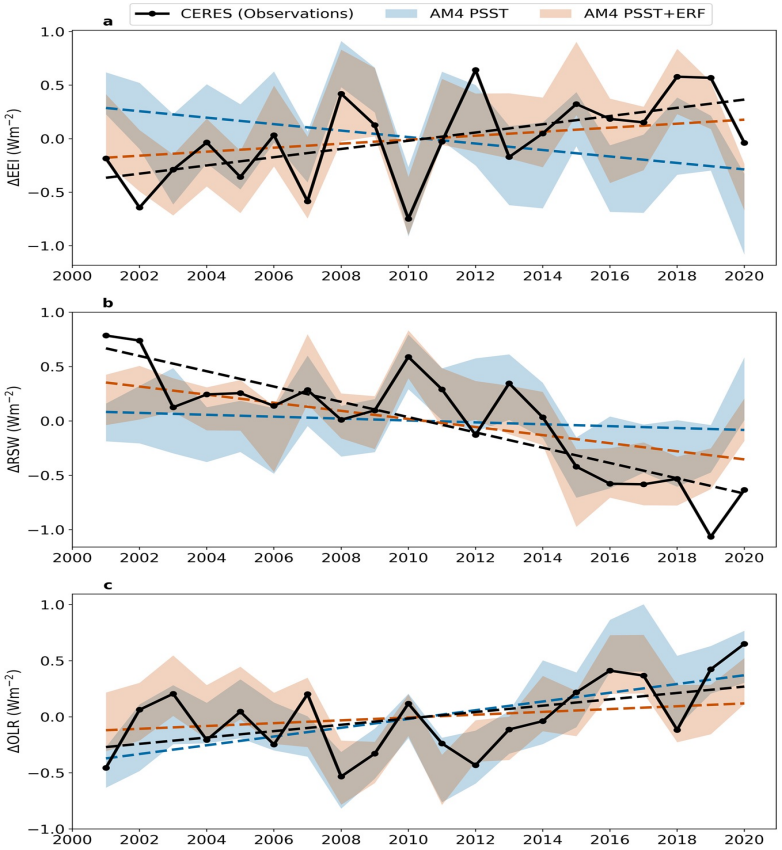
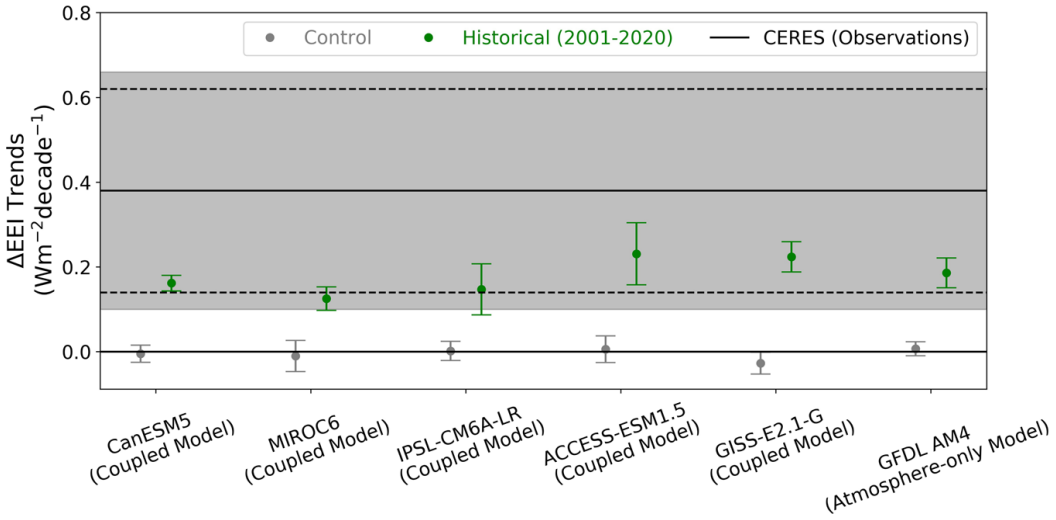


Figure 2. Deseasonalized anomalies in global mean TOA SW upward flux for CERES and each of the seven CMIP6 models considered in Table 1. Thin lines correspond to monthly anomalies; thick lines are 12-month running averages. Correlation coefficients (*r*) between model and observed monthly anomalies are also shown.

Loeb et al GRL 2020

Prior studies looking at CMIP models and EEI:





CERESMIP:
Looking at EEI in new versions of CMIP models using updated forcings until 2022, allowing analysis of 20 year CERES record.

Raghuraman et al, 2021

CMIP6 forcing stopped 2014 CERESMIP

frontiers | Frontiers in Climate

TYPE Methods
PUBLISHED 03 July 2023
DOI 10.3389/fclim.2023.1202161

OPEN ACCESS

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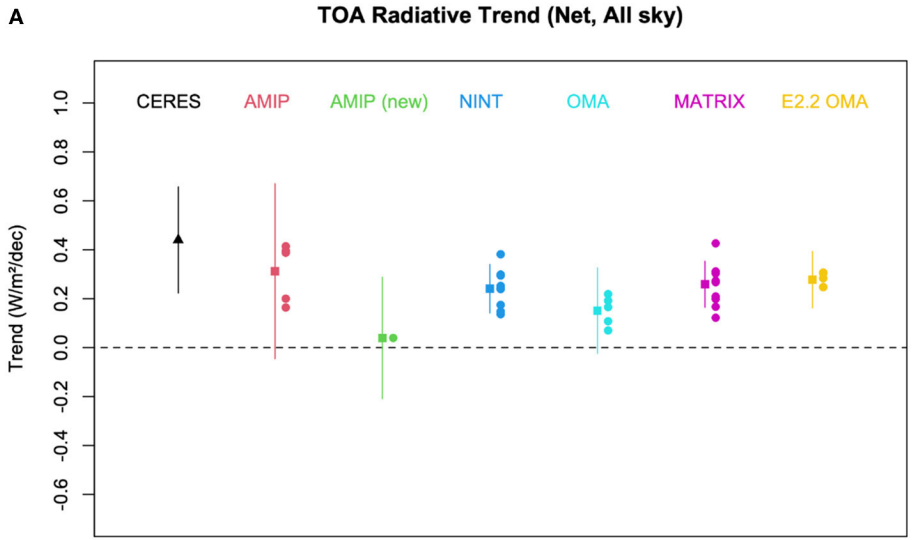
RECEIVED 07 April 2023
ACCEPTED 16 June 2023
PUBLISHED 03 July 2023

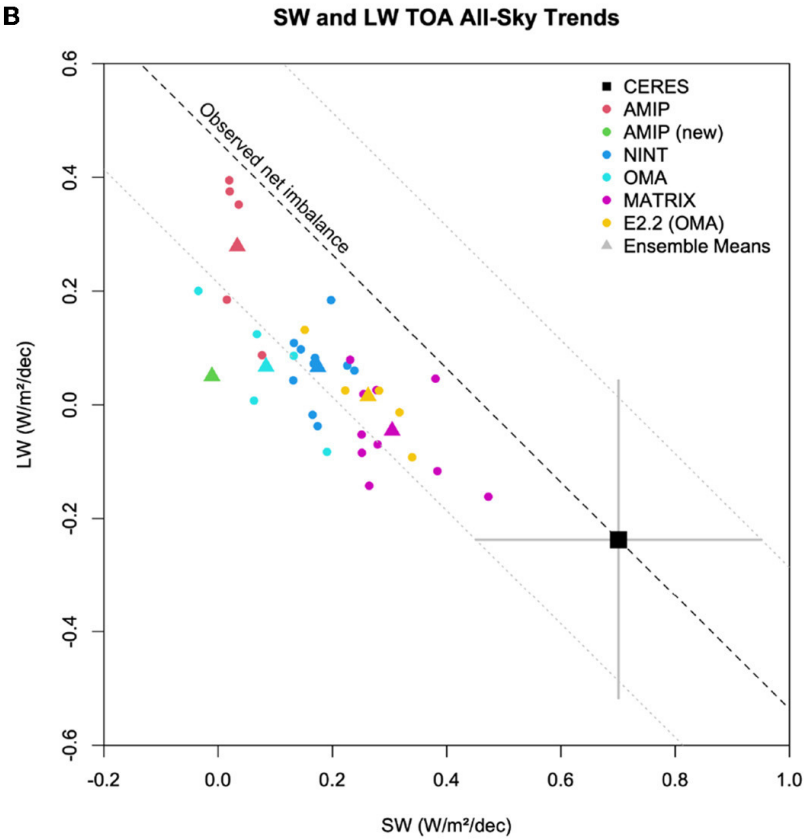
CITATION
Schmidt GA, Andrews T, Bauer SE, Durack PJ, Loeb NG, Ramaswamy V, Arnold NP, Bosilovich MG, Cole J, Horowitz LW,

CERESMIP: a climate modeling protocol to investigate recent trends in the Earth's Energy Imbalance

Gavin A. Schmidt[1]*, Timothy Andrews[2], Susanne E. Bauer[1], Paul J. Durack[3], Norman G. Loeb[4], V. Ramaswamy[5], Nathan P. Arnold[6], Michael G. Bosilovich[6], Jason Cole[7], Larry W. Horowitz[5], Gregory C. Johnson[8], John M. Lyman[8,9], Brian Medeiros[10], Takuro Michibata[11], Dirk Olonscheck[12], David Paynter[4], Shiv Priyam Raghuraman[10], Michael Schulz[13], Daisuke Takasuka[14,15], Vijay Tallapragada[16], Patrick C. Taylor[4] and Tilo Ziehn[17]

GISS Model E2.1/2 diversities in Simulating EEI





Schmidt et al Front clim 2023

GISS Model updates: GISS E3.1

NASA GISS E3.1:

- brand new version including new model physics, cloud microphysics, turbulence scheme, etc.

- 1 st version with new physics and interactive tracer scheme, gases and aerosol microphysics (MATRIX)

Forcings:

- Sea Temperature and Sea Ice boundary conditions, PCMIP (here) HadISST (later)

- GHG until 2022

- CEDS Short lived climate forcer emissions until 2019 (const. thereafter) 2022 update coming end of this year (S. Smith, personal communication)

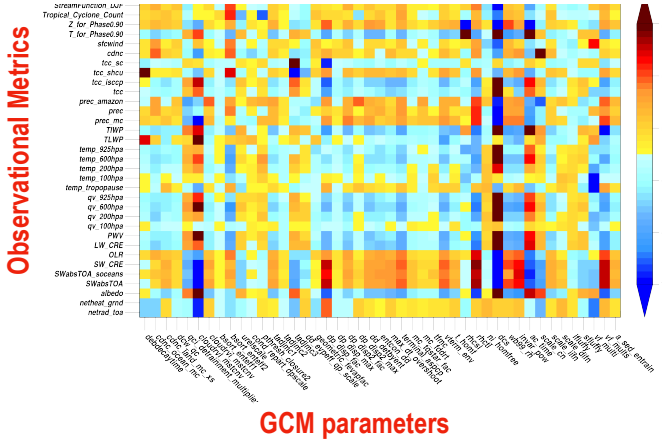
- Solar, volcanic, land-surface etc…

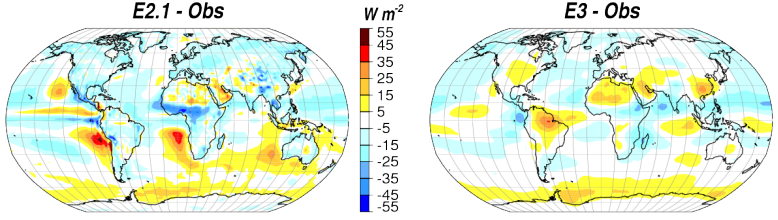
GISS Model updates: GISS E3

Model tuning in E3

- 45 parameters
- 36 observational targets (including uncertainty!)
- Latin hypercube sampling
- 450 simulations for 1 year
- ML emulator to efficiently search parameter space
- Iterative process including updating of priors and inclusion of SCM and LES results

Better physics and tuning make big improvements in skill

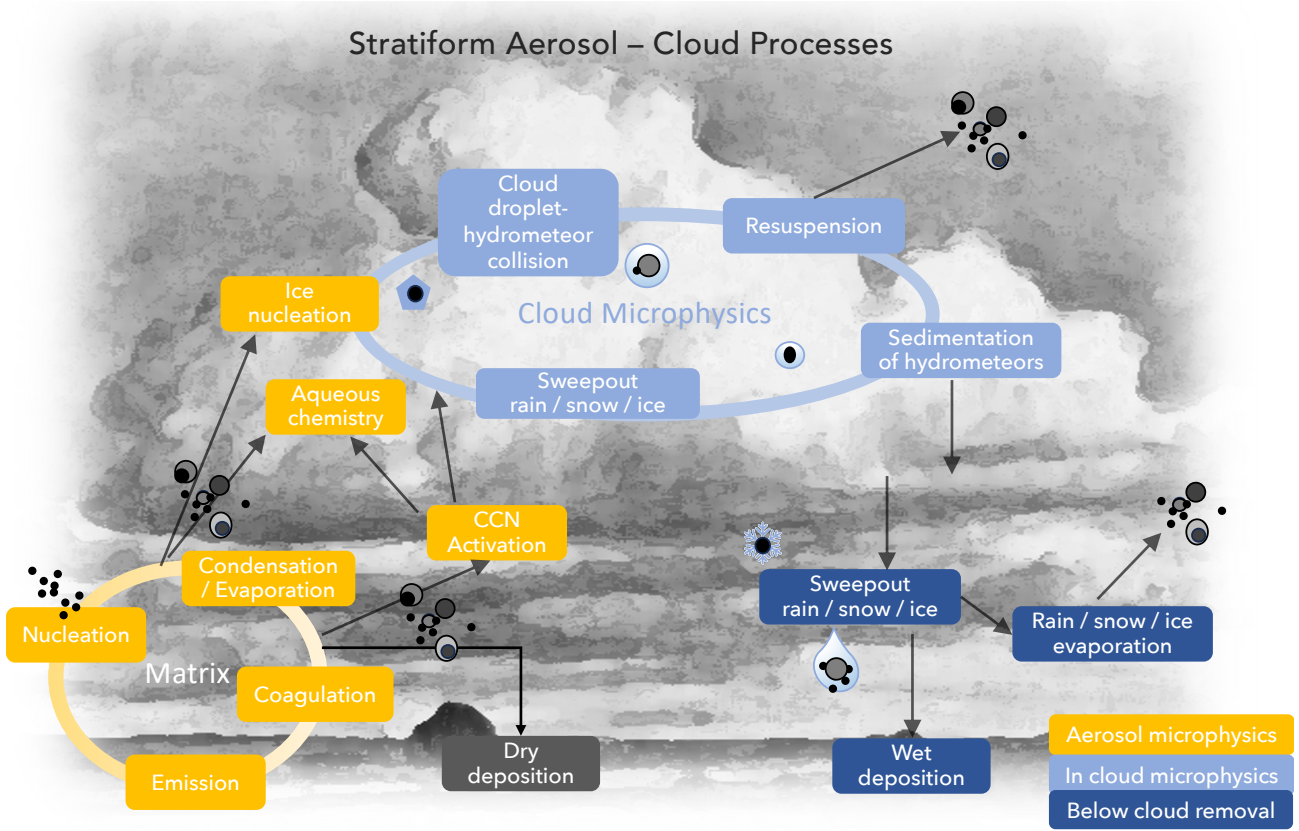




CERES AbsSW
Big improvements in marine cirrus, total cloud cover and precipitable water vapor

Elsaesser et al in prep.

GISS E3.1 Model updates: Aerosol – Cloud processes



This study:

NASA GISS E3.1 Model:

- Composition climate simulations, using MATRIX
- 2 x 2.5 resolution, 62 vertical layers (test version)
- Years simulated 1995 – 2022
- Base simulations, and single forcing experiments

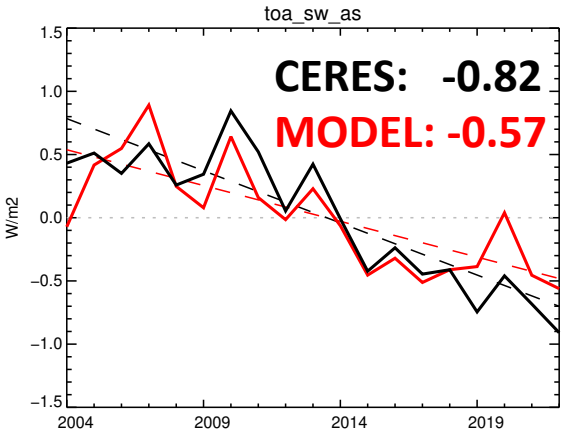
Forcings:

- Sea Temperature and Sea Ice boundary conditions, PCMDI (here) HadISST (later)
- GHG until 2022
- CEDS Short lived climate forcer emissions until 2019 (const. thereafter) 2022 update coming end of this year (S. Smith, personal communication), Biomass Burning until 2016
- Solar, volcanic, land-surface etc…

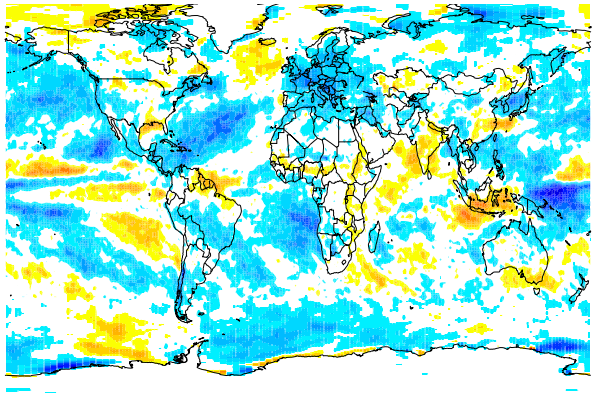
Satellite data:

- CERES EBAF vs. 4.2
- **MODIS: AOD,** Collection 6 Dark Target and Deep Blue combined product
- TERRA based Cloud droplet number concentrations (David Painemal, LARC)
- **MAC - LWP (Elsaesser et al J. of Clim. 2017):** The Multisensor Advanced Climatology of Liquid Water Path
- MAC – Precip. Water vapor

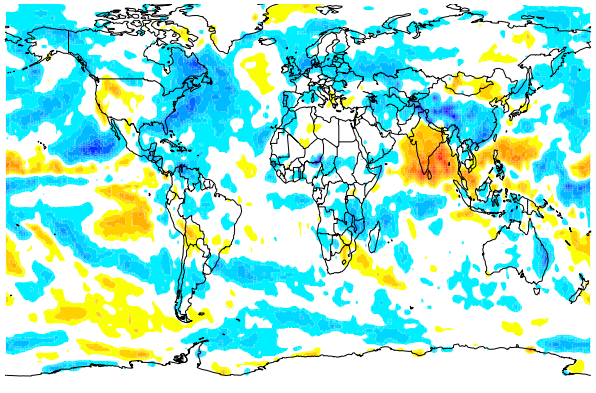
SW TOA all sky trend: slope W/m²/decade averaged between 60N - 60S



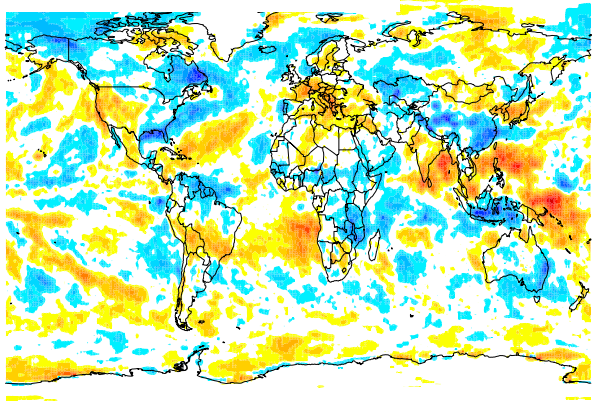
CERES



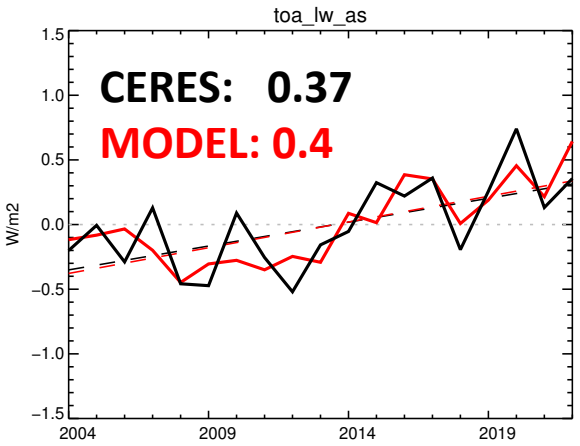
MODEL



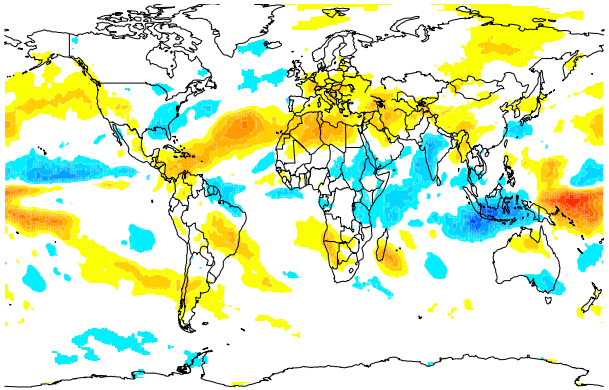
MODEL – CERES



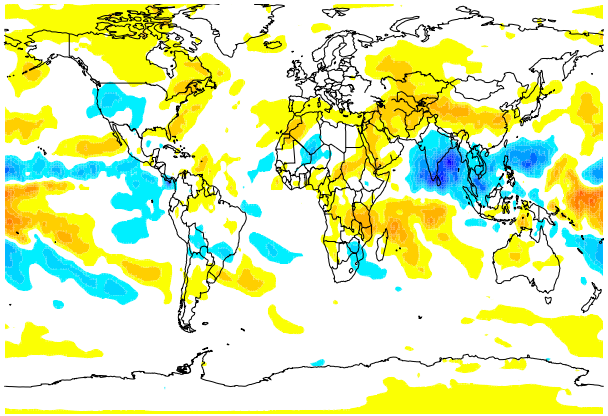
LW TOA all sky trend: slope W/m²/decade averaged between 60N - 60S



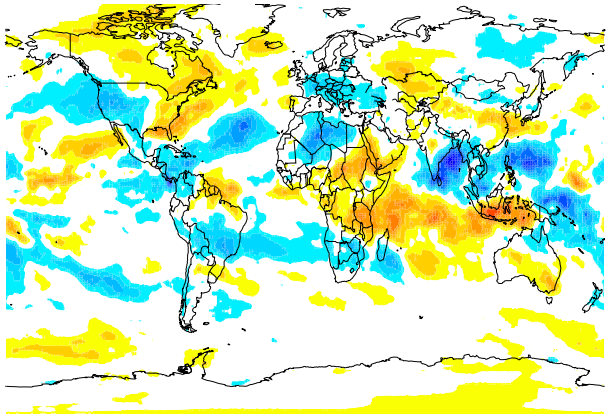
CERES

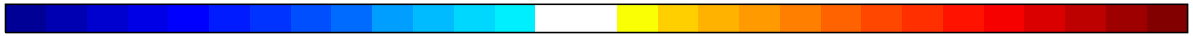


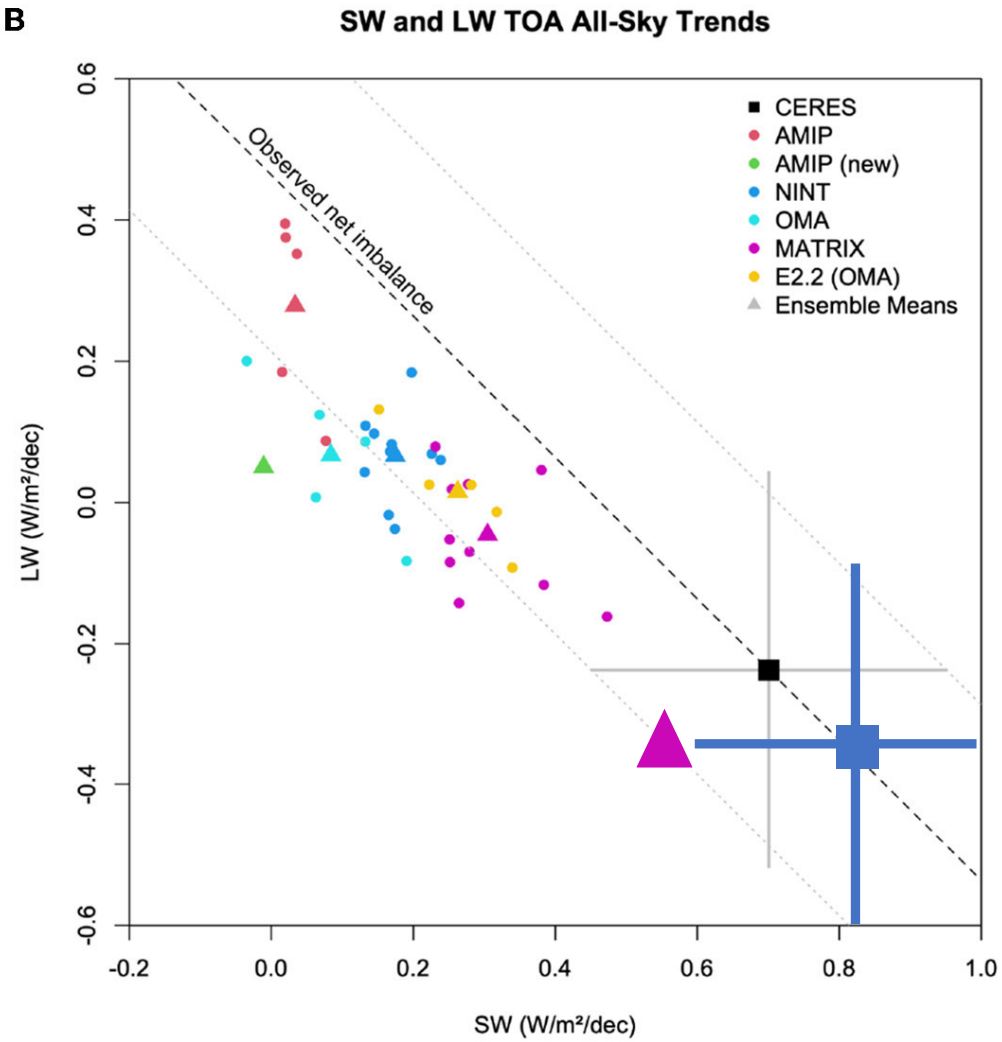
MODEL



MODEL – CERES







Not really apples to apples:
60N/60S
2004-2022 average.
Model had ozone forcing hiccup in 2001

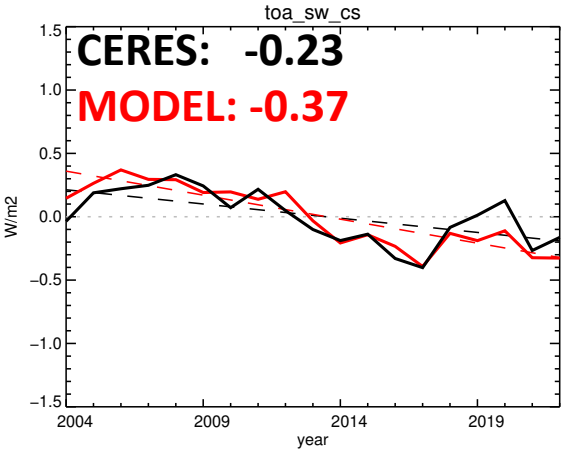
CERES

MATRIX E3.1

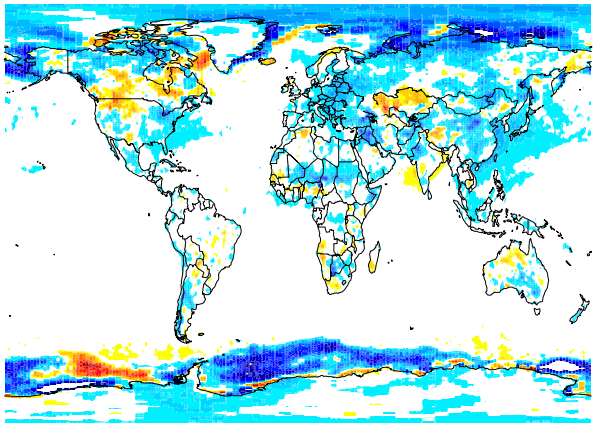
Summary:

- New updated forcings reproduce previously found results: Models underestimate the observed trends in Earth Energy Imbalance. Improved trends in SW and LW all sky fluxes, but still similar bias in Net. Net all sky trend about half in model compared to CERES, but at least for the right reasons.
- Problems caused by model and not forcings?

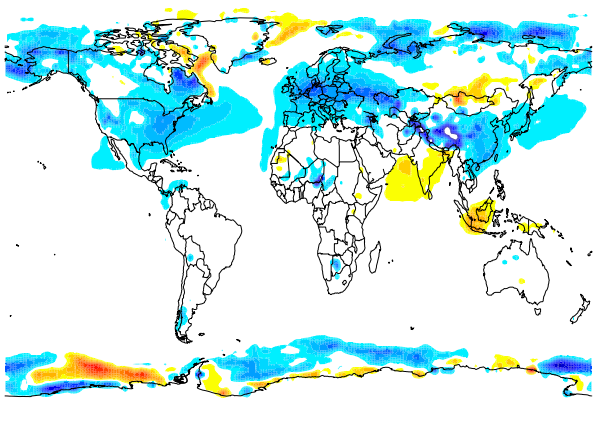
SW TOA clear sky trend: slope W/m²/decade averaged between 60N - 60S



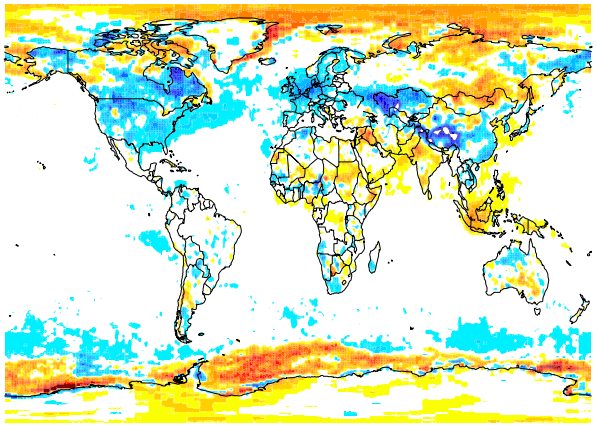
CERES

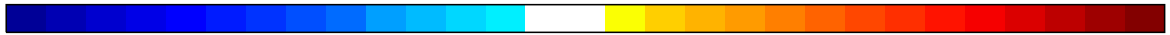


MODEL

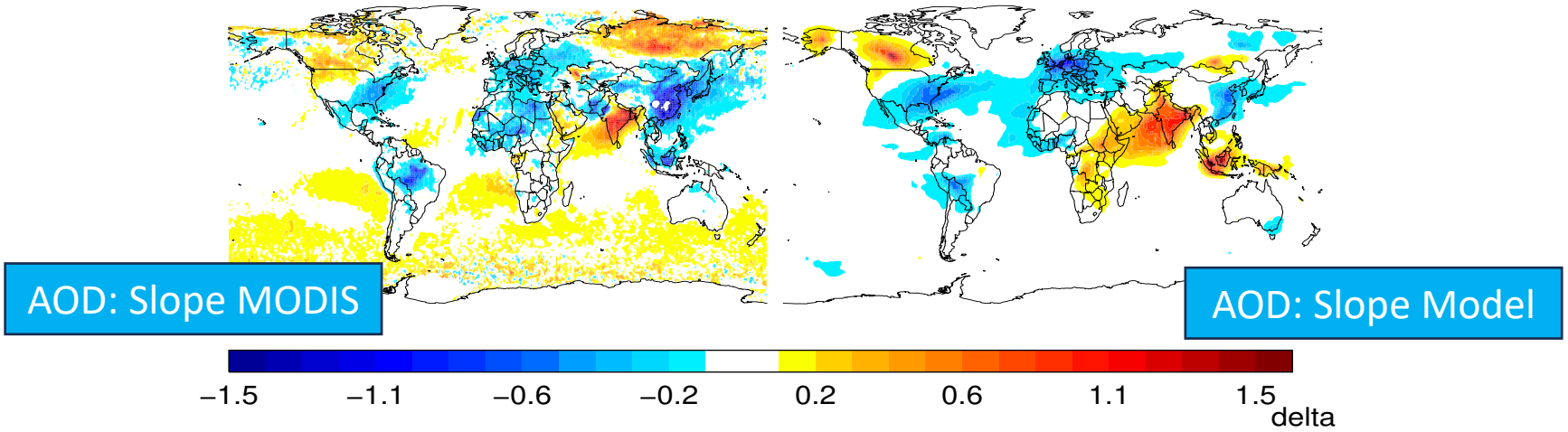


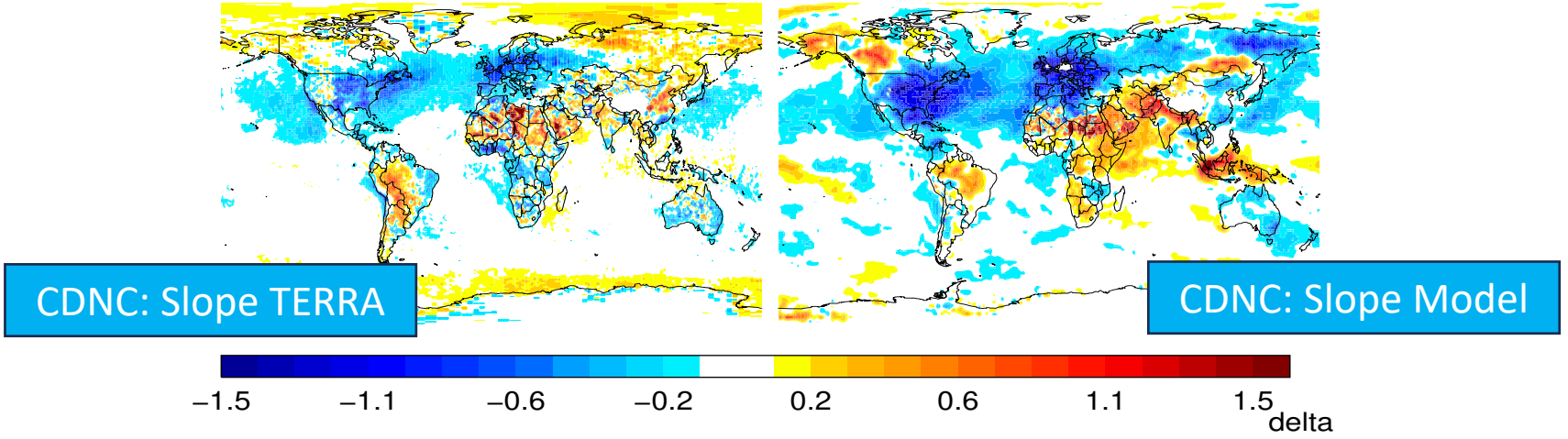
MODEL – CERES





Aerosol Impacts on EEI:





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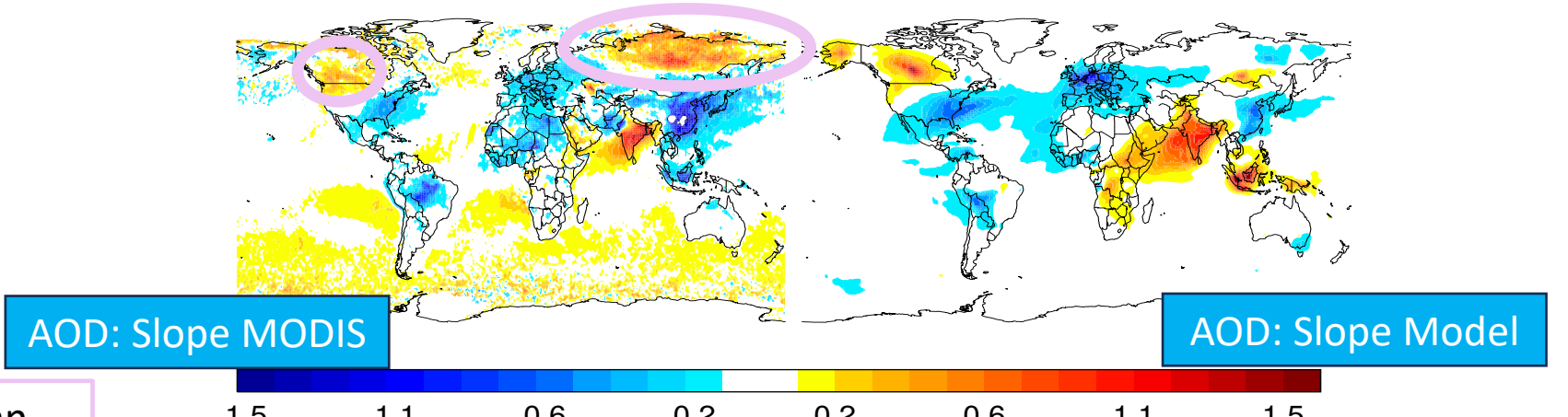
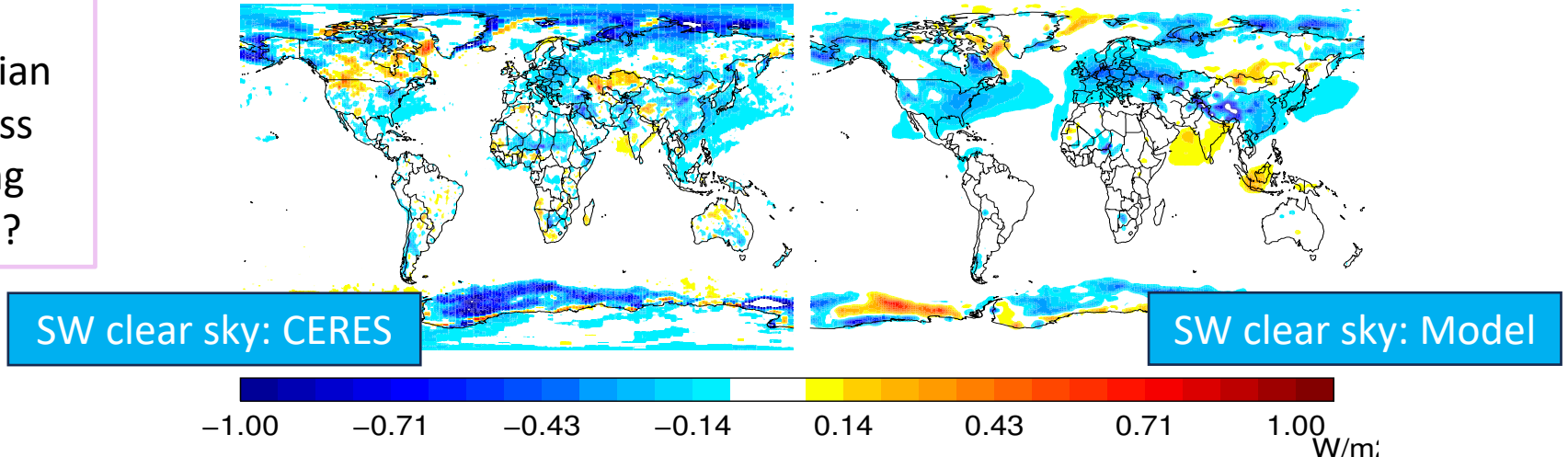
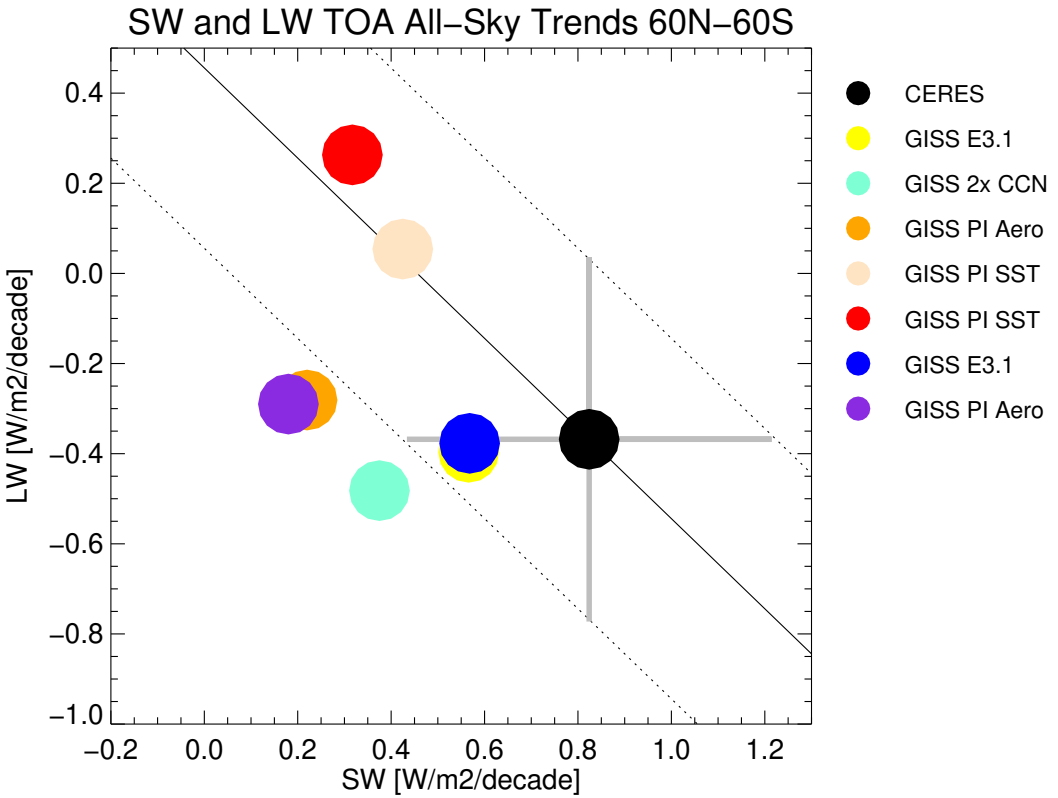


Siberian vs. Canadian Biomass burning smoke?



Aerosol Impacts on EEI: Sensitivity Experiments



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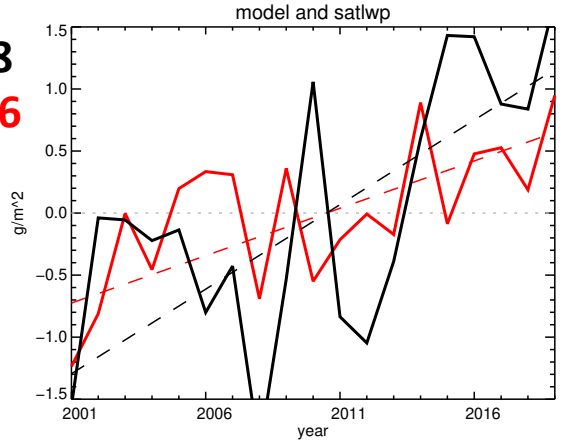
- Problems caused by model and not forcings?
- High latitude forcing dataset SIC evaluation needed.
- Aerosol results are preliminary, as we are waiting for updated emissions. Recent Biomass Burning events might change results.
- Correct AOD results lead to larger CDNC trends compared to TERRA CDNC by Painemal. Study sampling, and processes.
- Aerosol impact on forcing slightly too high, and shows impact in EEI.
- Overall expectation that we will be able to represent aerosol effects very well.

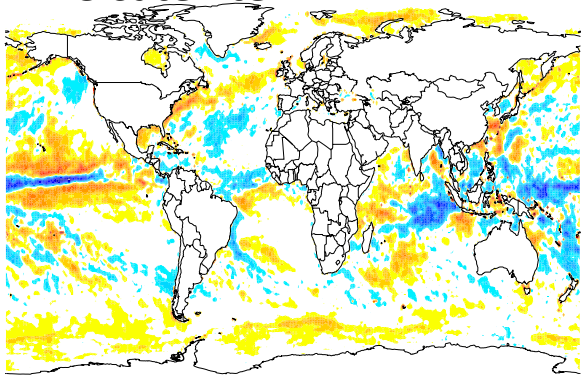
LWP trend: slope g/m²/decade averaged between 60N - 60S

MAC: 1.18

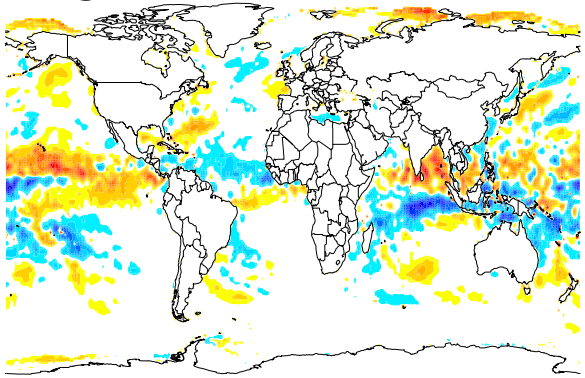
MODEL: 0.66



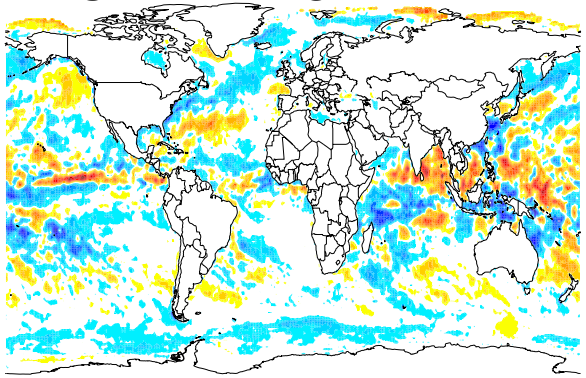
MAC-satellite

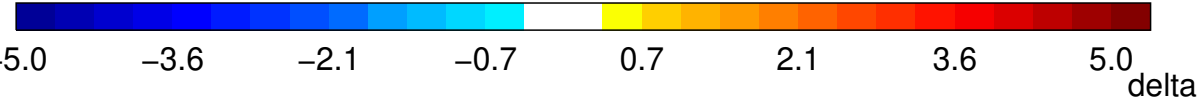


MODEL



MODEL – MAC

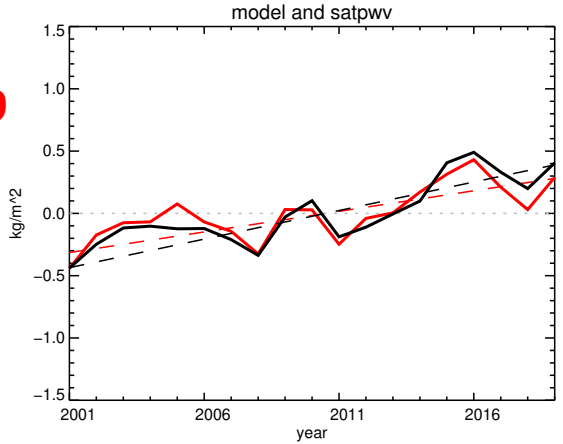




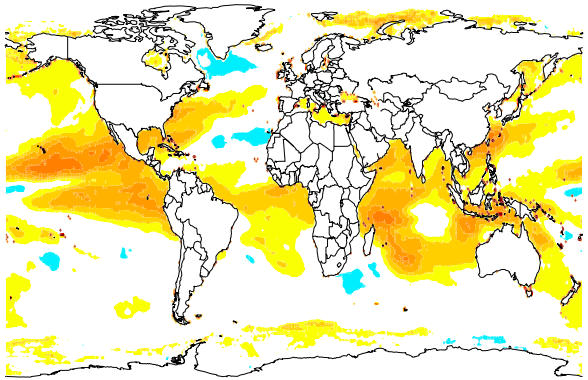
Precip. Water vapor trend: kg/m^2/decade averaged between 60N - 60S

MAC: 0.40

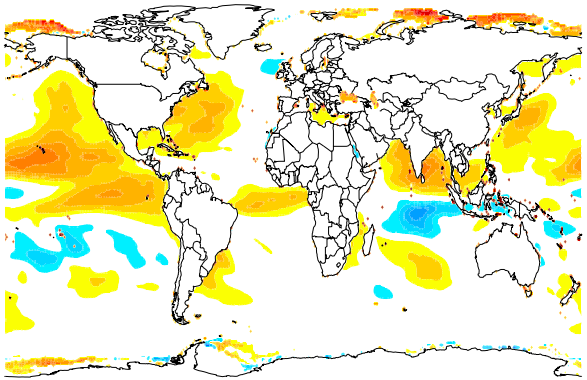
MODEL: 0.29



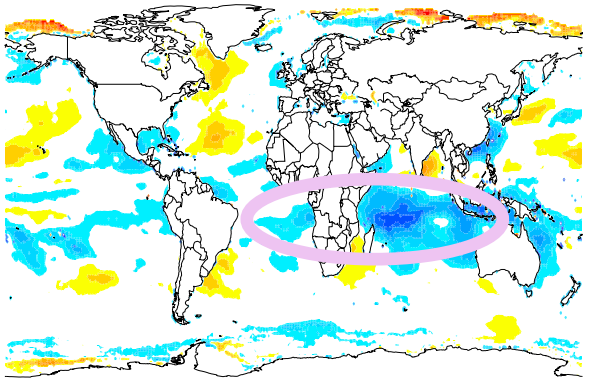
MAC-satellite

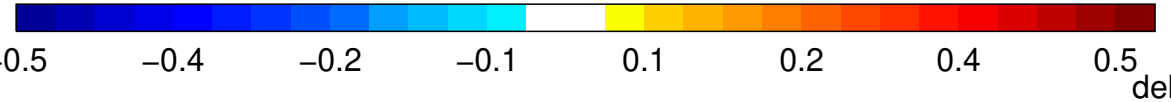


MODEL



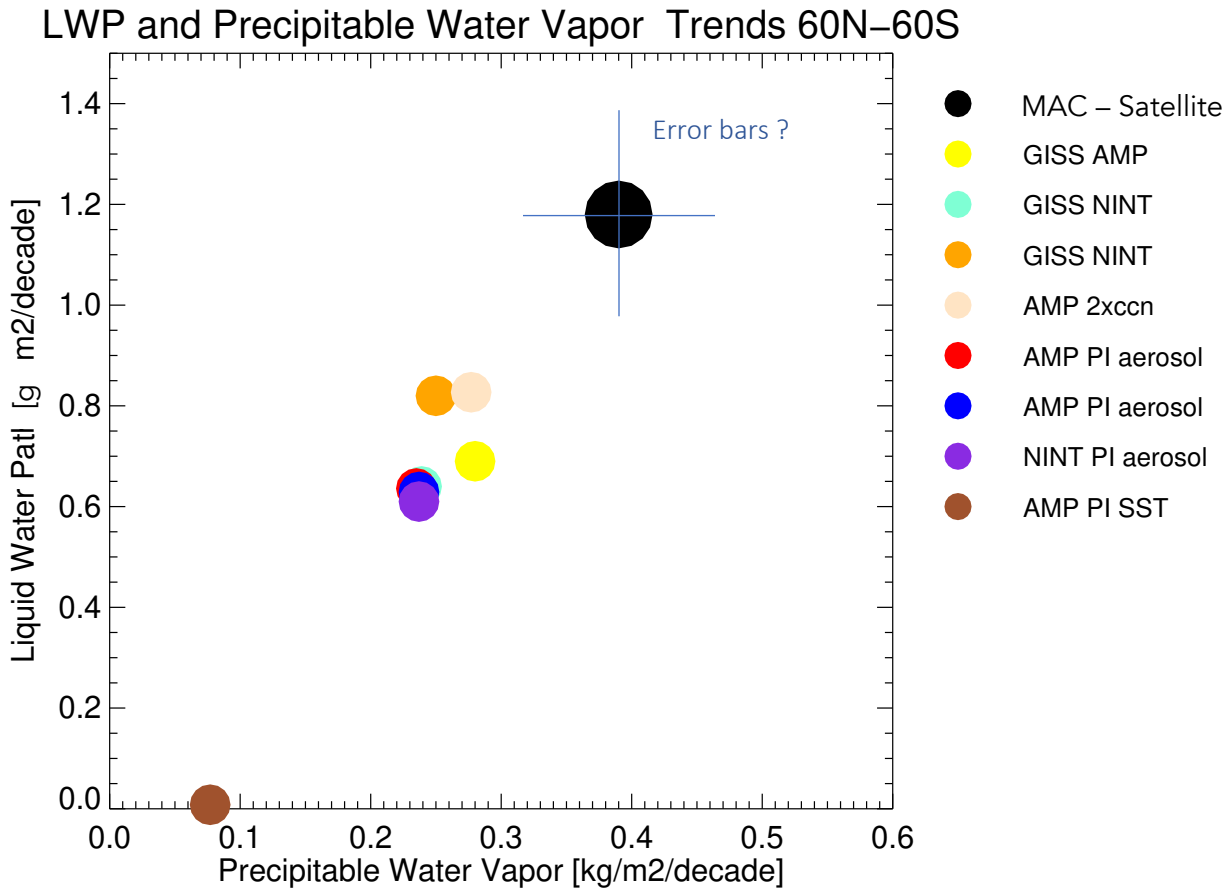
MODEL – MAC





Matches LW all sky bias

Cloud Impacts on EEI:



Summary:

- New updated forcings reproduce previously found results: Models underestimate the observed trends in Earth Energy Imbalance. Improved trends in SW and LW all sky fluxes, but still similar bias in Net. Net all sky trend about half in model compared to CERES, but at least for the right reasons.
- Problems caused by model and not forcings?
- Aerosol results are preliminary, as we are waiting for updated emissions. Recent Biomass Burning events might change results.
- Correct AOD results lead to larger CDNC trends compared to TERRA cdnc by Painemal. Study sampling, and processes.
- Aerosol impact on forcing slightly too high, and shows impact in EEI.
- LWP and Precipitable water vapor show significant trends. The model only reproduces about 60% of the trend.
- Updated aerosol emissions will only explain a small change to this bias.
- Studying more cloud trend behavior, and using more observational products.
- With the goal to understand cloud EEI effects by SST/SIC, GHG and SLCF behavior.

Lessons learned:

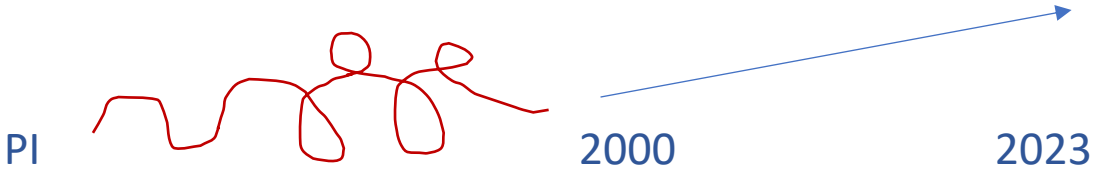
- New updated forcings (not fully updated yet) and model reproduce previously found results: Models underestimate the observed trends in Earth Energy Imbalance, but much better in individual LW and SW effects. We are on the right path!

Further analysis:

- Much deeper processes analysis needed for the brand new model E3.1
- Ozone, CCN, CDNC etc.
- Deeper understanding of cloud feedbacks caused by GHG vs SLCF
- Working with more observational products to evaluate trends.

CERESMIP:

- Still waiting for updated forcings until 2022
- Possibly starting sensitivity experiments at the beginning of CERES period?



Acknowledgement of funding by NASA ACMAP and MAP