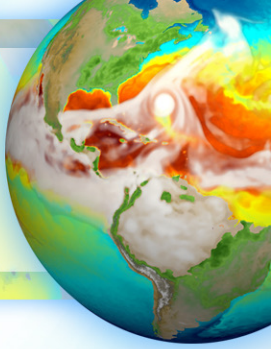
Climate responses to emissions reductions due to COVID-19



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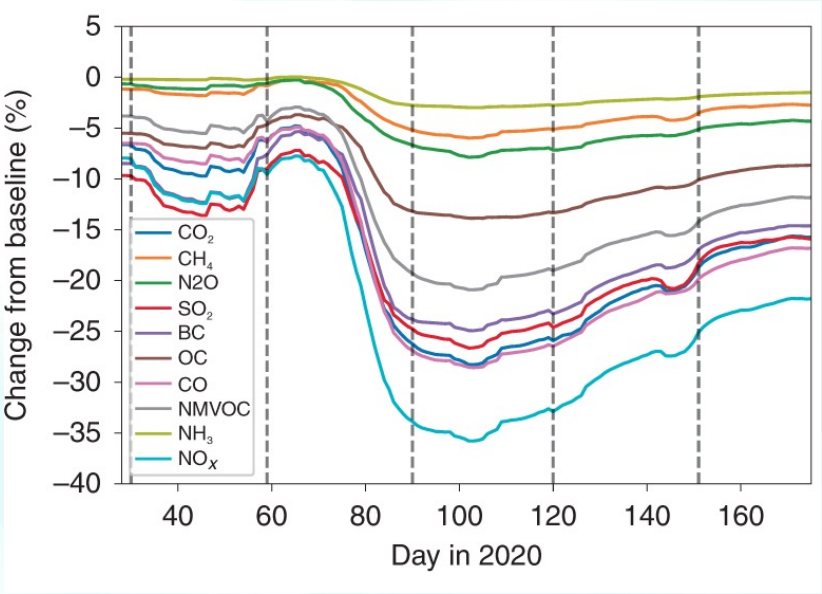
Background and motivation



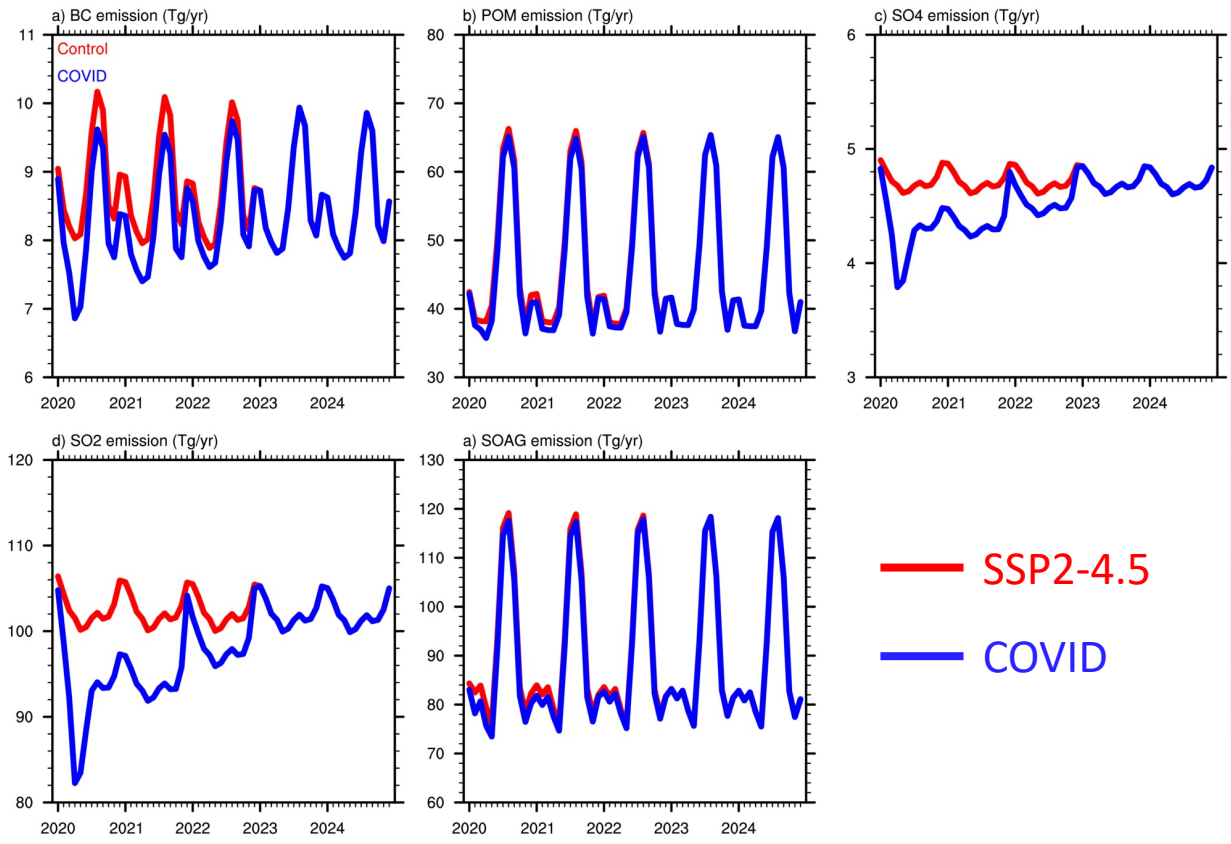
Global emission reductions estimated from mobility data during February-June 2020 (Forster et al., 2020)

- COVID-19 lockdown and restrictions led to sudden large reductions in emissions of GHGs and air pollutants
- Forster et al. (2020) found a short-term cooling (warming) associated with less GHGs (aerosols) based on a simple energy balance model
- Yang et al. (2020) show a surface warming effect over several NH continental regions in 2020 due to fast responses via aerosol-radiation and aerosol-cloud interactions based on AGCM simulations
- How about climate responses involving both fast and slow processes?

Model intercomparison on climate responses to COVID-restrictions on emissions (CovidMIP) (Lamboll et al., 2020, GMDD)

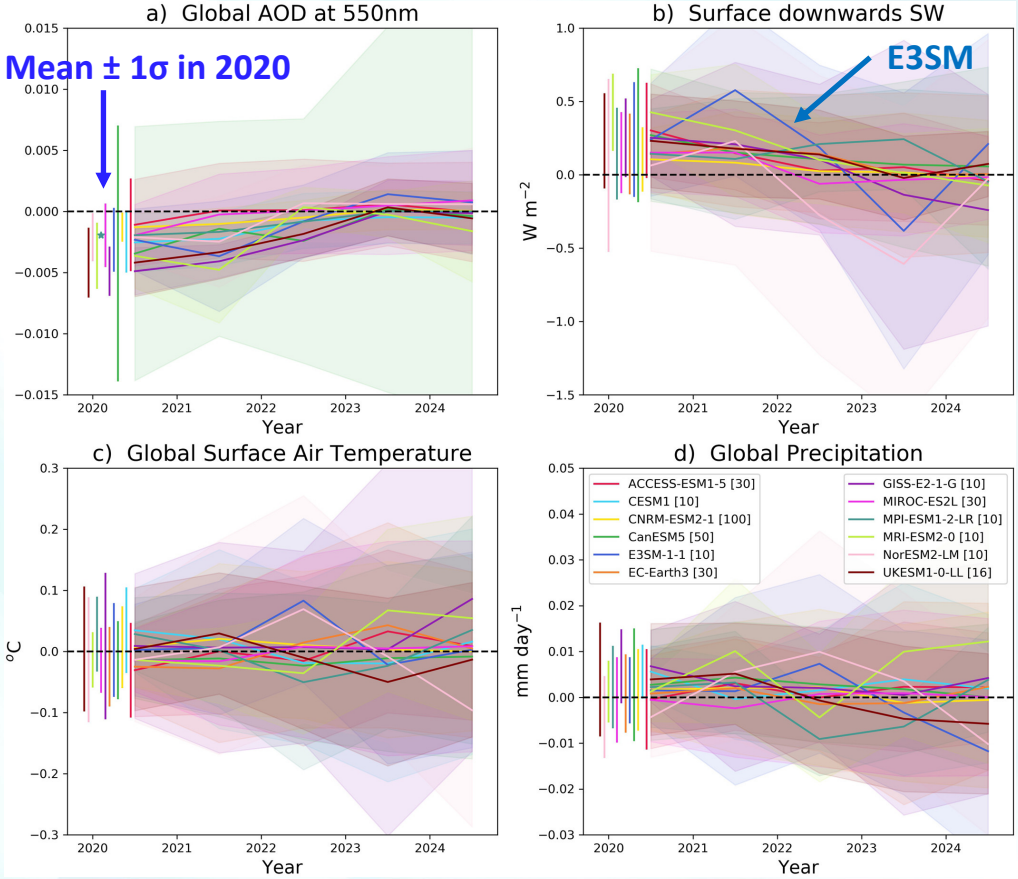
- What is the impact of emissions reductions on climate?
  - Well mixed GHGs (CO_2, CH_4, N_2O) and aerosol/precursors (SO_2, BC, OC, NMVOC, NO_x, NH_3)
- How do different recovery scenarios look?
  - Fossil stimulus (longer term increases in fossil emissions relative to baseline **SSP2-4.5**)
  - Moderate and strong green stimulus (longer term reductions in fossil emissions)
- E3SM participation
  - Near-term impact of COVID-lockdown emissions reductions
    - Branched from SSP2-4.5 at 1 Jan 2020 for 5 years
    - 10 ensemble members with perturbed initial conditions
  - Long-term impact of recovery scenarios
    - Branch from SSP2-4.5 at 1 Jan 2020 for 30 years (10 ensemble members)

Aerosol and precursor gas emissions reductions



- Emissions of aerosols and precursor gases are reduced in 2020-2022; mostly in SO_2 and BC
- Reductions in well mixed GHGs (CO_2, CH_4 and N_2O) also follow the protocol
- No change in land use
- NOx, NH_3 and O_3 changes are not considered in E3SMv1 simulations

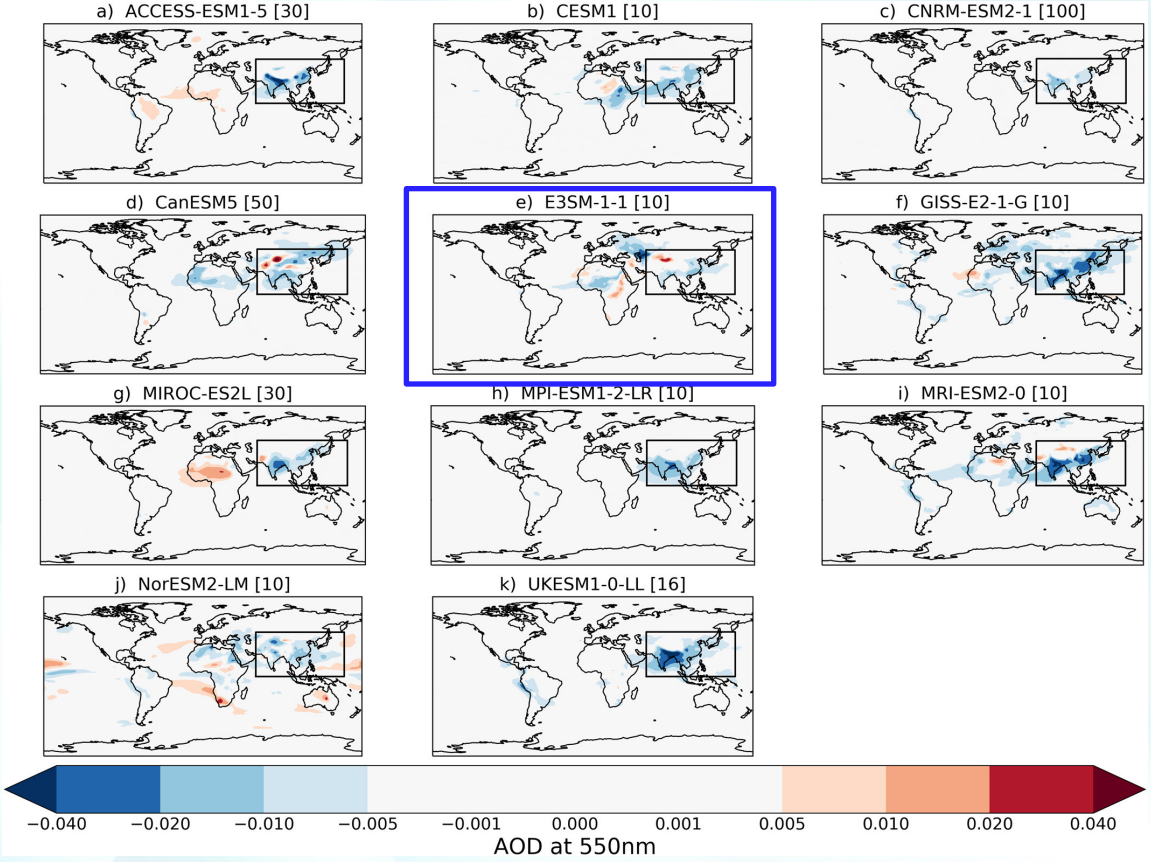
Modeled global mean changes due to COVID



- Ensemble mean (±1σ) of anomalies, relative to baseline ssp2-4.5, from 12 individual ESMs (E3SM in blue)
- All models show a reduction in AOD, mostly greater than 1σ in 2020; AOD recovers by 2023.
- Positive surface downwelling SW in 2020-2021
- Global mean SAT and precipitation have a very small change
- E3SM does show a warming and increase in precipitation in 2020-2022

(Jones et al., 2021)

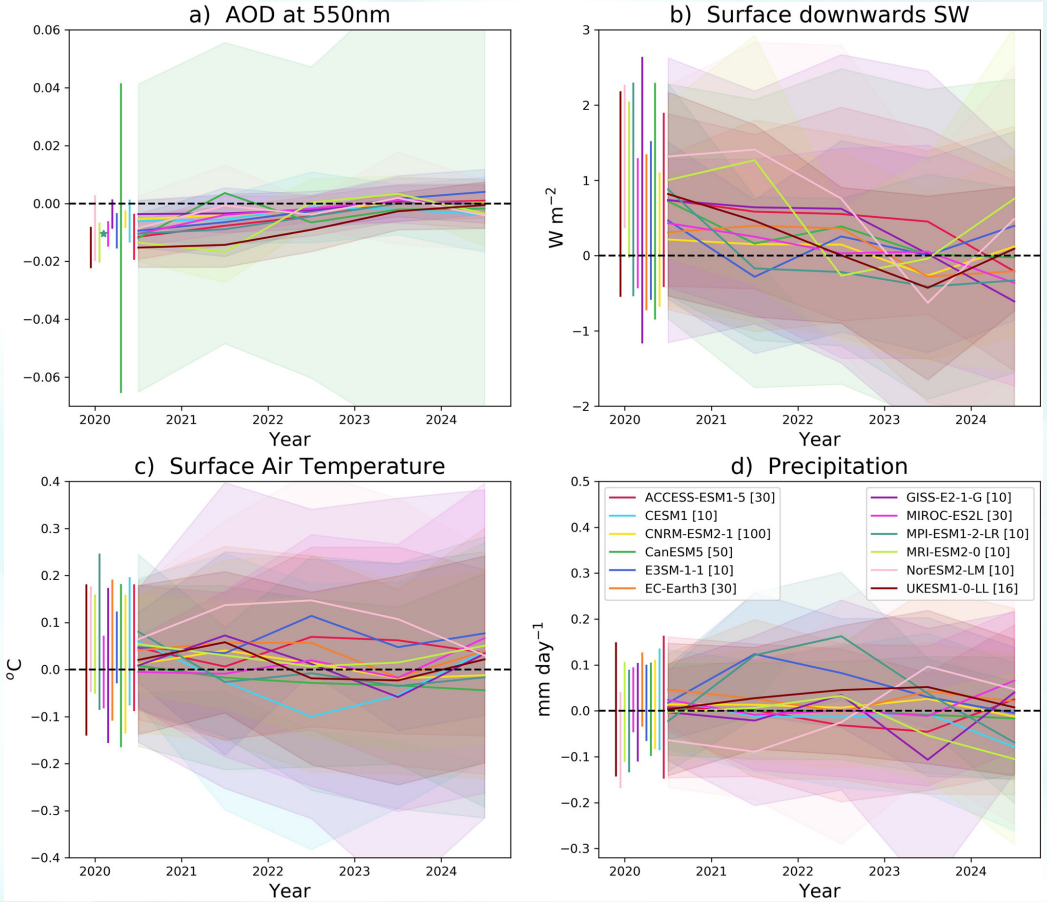
Regional AOD changes in the ESMs



- ESMs agree that the largest mean (**2020-2024**) AOD reductions are in Asia
- E3SM doesn't have a strong AOD reduction
- Patches of AOD increases most likely due to changes in circulation and dust emissions
- Does the regional AOD reductions have a more significant impact on climate in Asia?

(Jones et al., 2021)

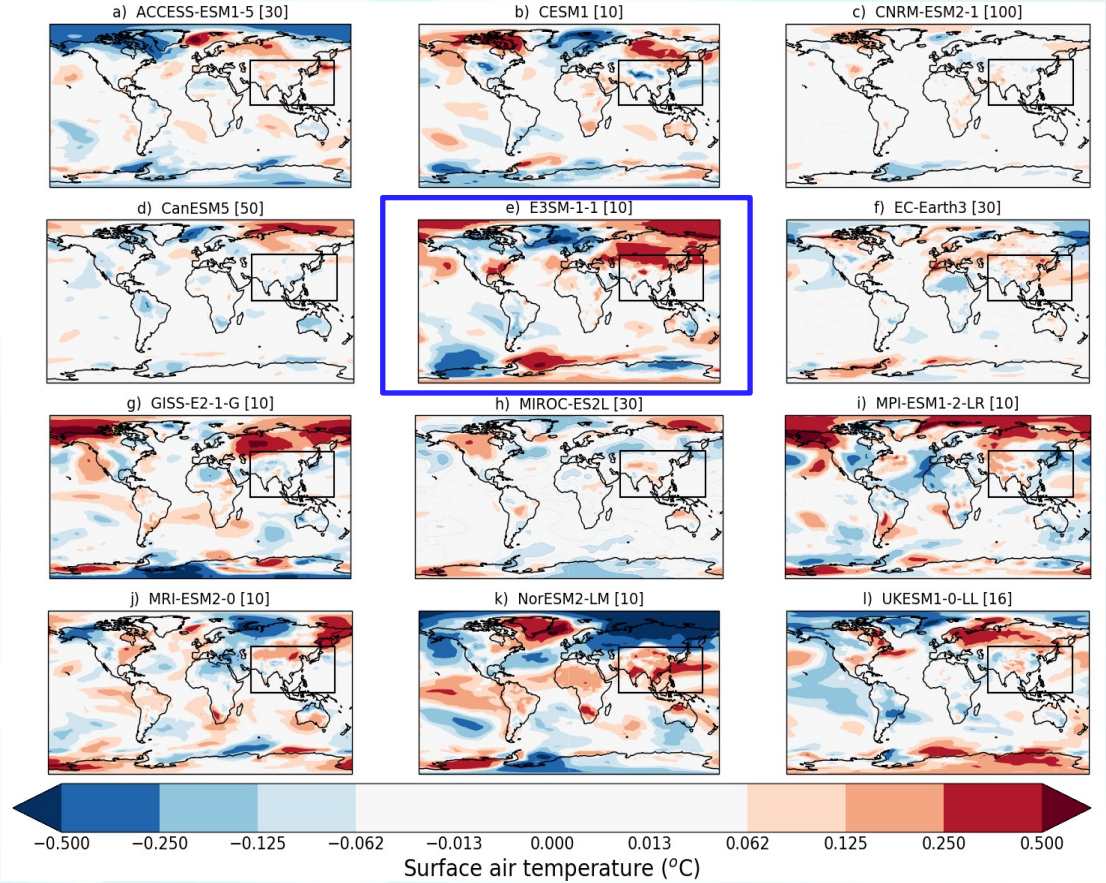
Mean changes in eastern and southern Asia



- Strong model agreement in the regional AOD changes (3 times stronger reductions than the global mean in 2020)
- The regional surface downwelling SW reduction in 2020 is also 3 times stronger than the global mean
- Most models indicate a less than **0.1ºC** warming, smaller than 1σ across ensemble members
- Less agreement on precipitation changes; E3SM and CanESM5 show a strong increase, likely related to circulation changes

(Jones et al., 2021)

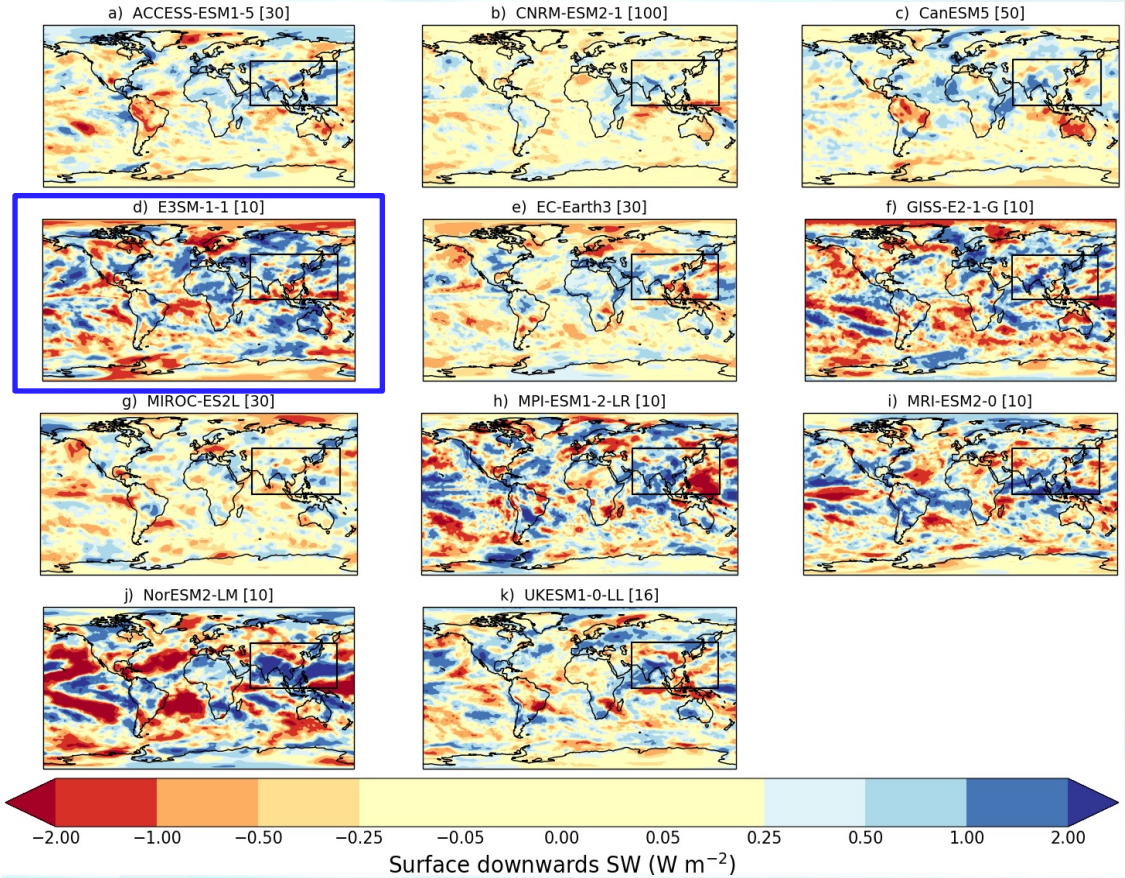
Strong regional warming and cooling signals



- Several models, including E3SM and CESM, simulate a strong warming over northern Asia
- ACCESS-ESM and NorESM show strong cooling there
- Mixed signals for high latitudes as well
- Radiation and/or heat transport

(Jones et al., 2021)

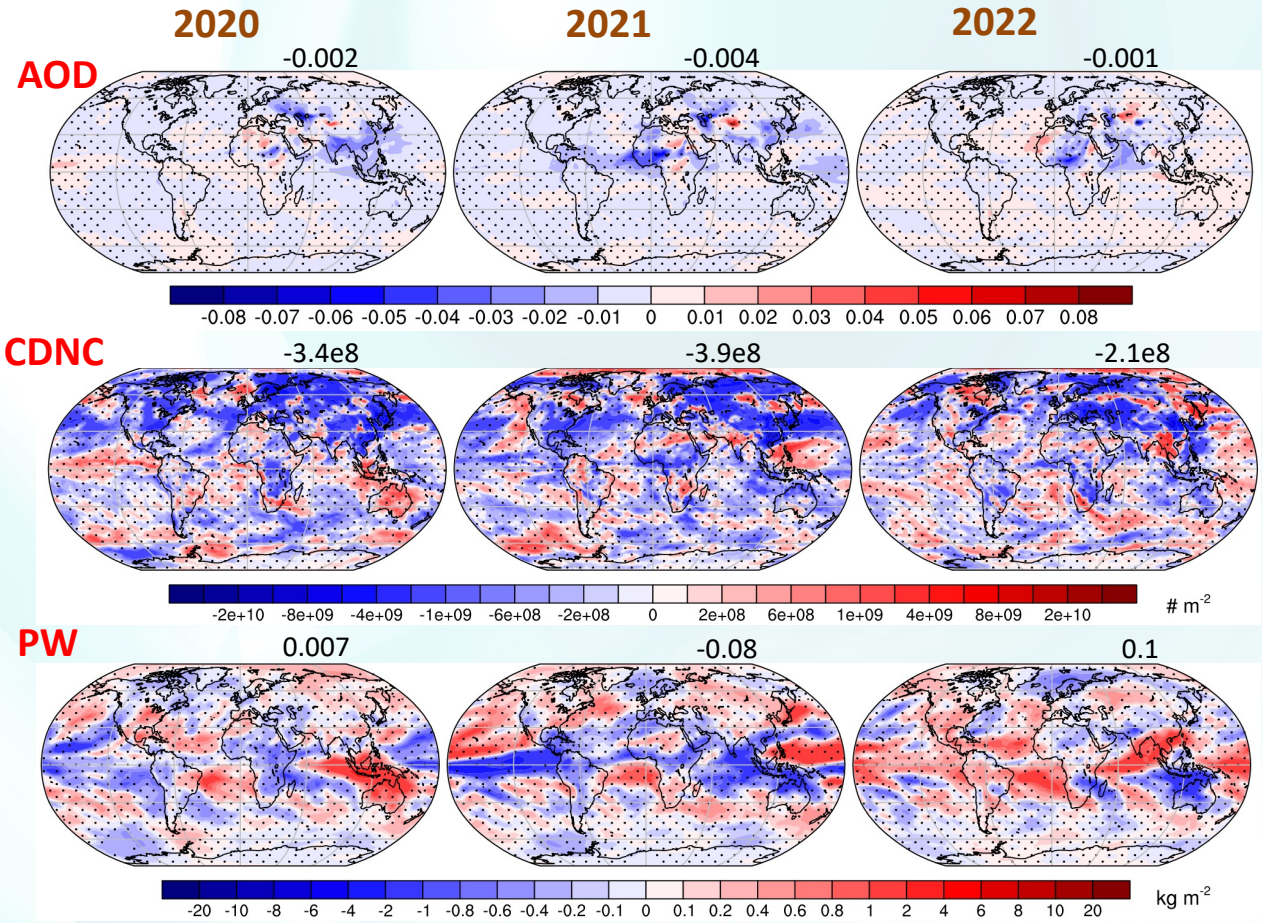
Changes in surface downwelling SW radiation



- Increased SW in the Asia box, but with patches of decreases
- Larger spatial variability when ensemble number is smaller; Influence of cloud changes
- High-latitude surface radiative warming and cooling
- Reduced SW and warming in the Arctic in E3SM and other models indicate LW and heat transport changes
- Here shows the 2020-2024 mean, but there are interannual and seasonal variations

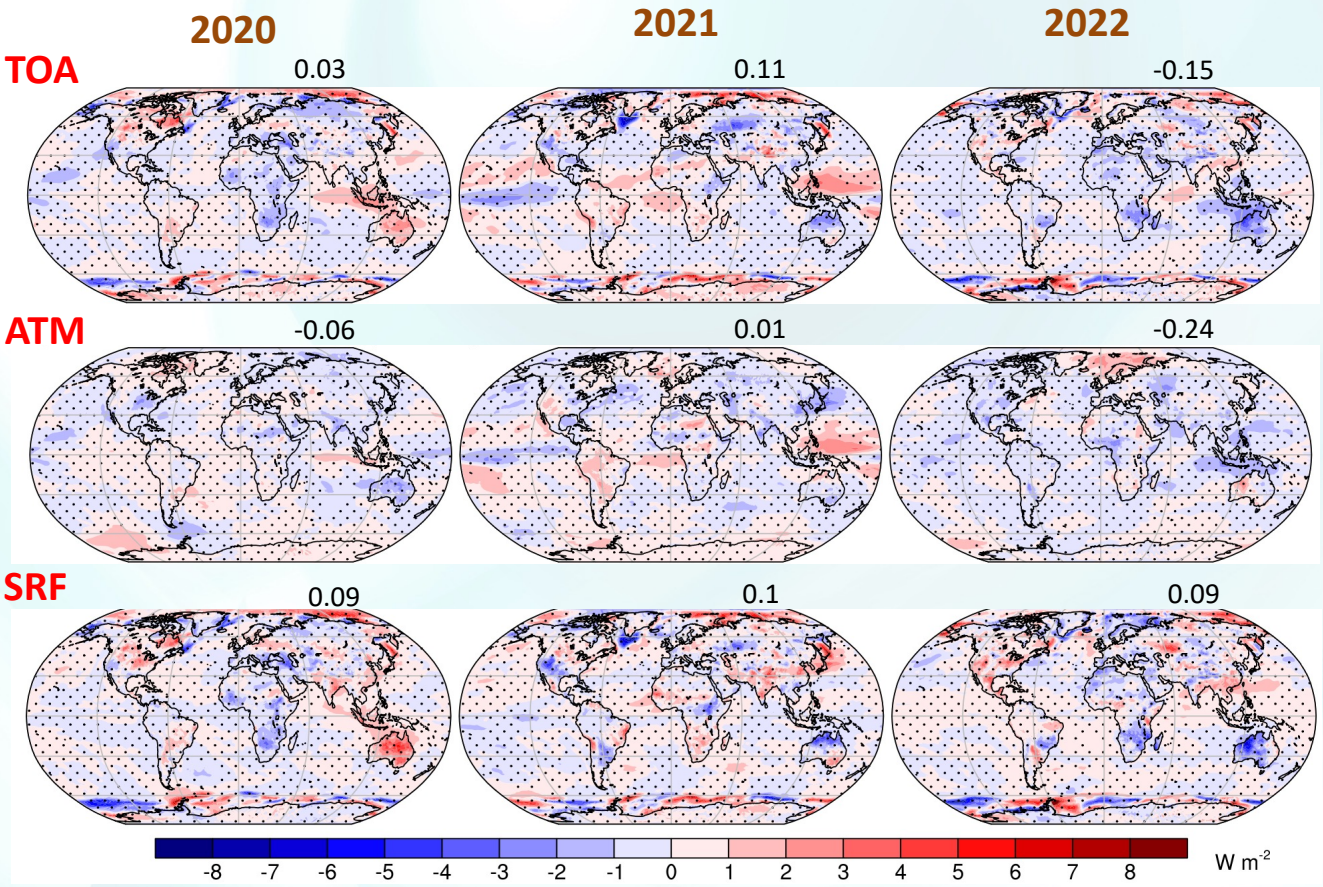
(Jones et al., 2021)

Annual changes in AOD, cloud drop number, and moisture in E3SM



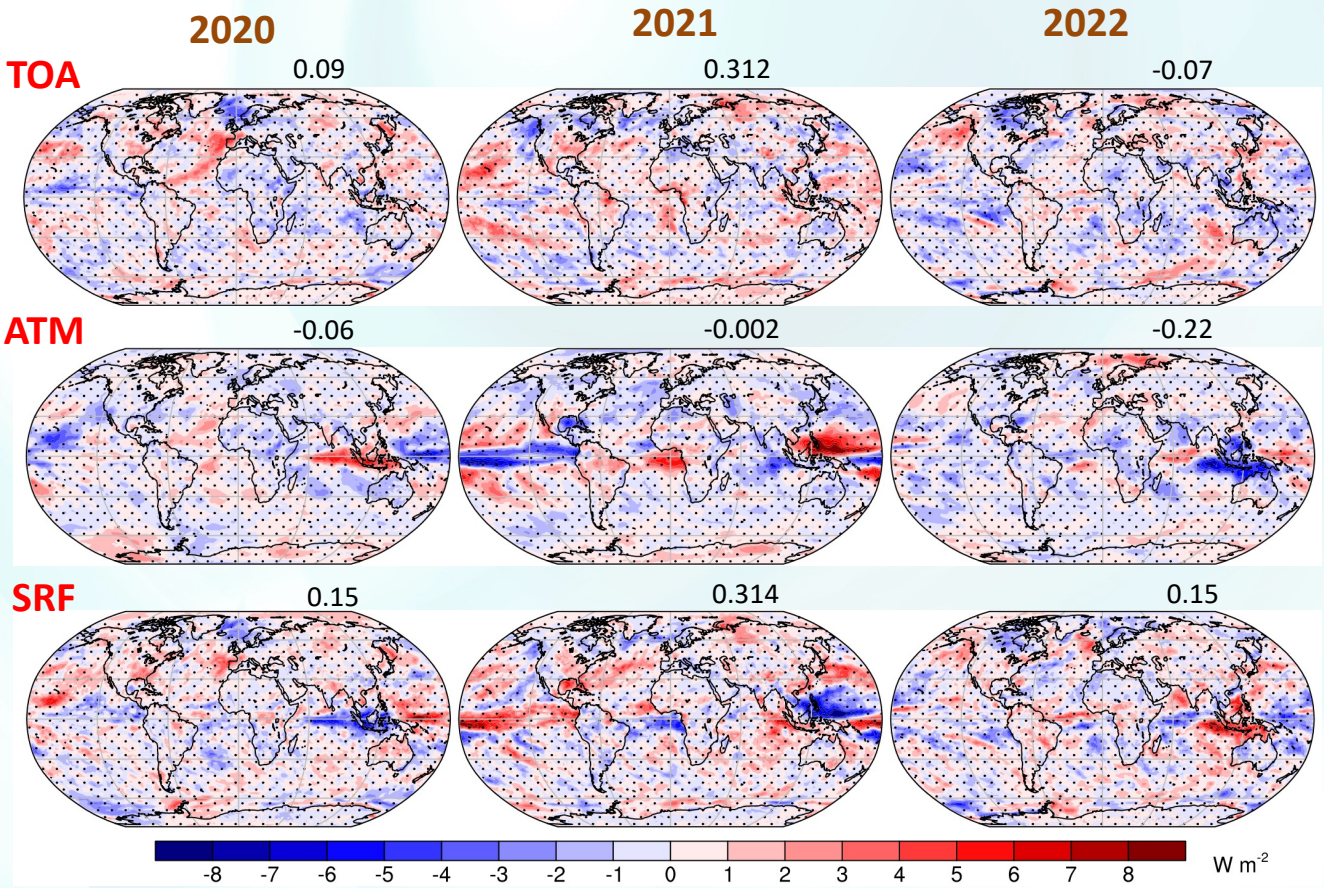
- Significant reductions in anthropogenic AOD, but also large changes in dust
- Cloud drop number reduced in NH, consistent with aerosol changes
- Increases in precipitable water in NH
- Strong moisture convergence/divergence in some regions

E3SM changes in clear-sky net radiative flux



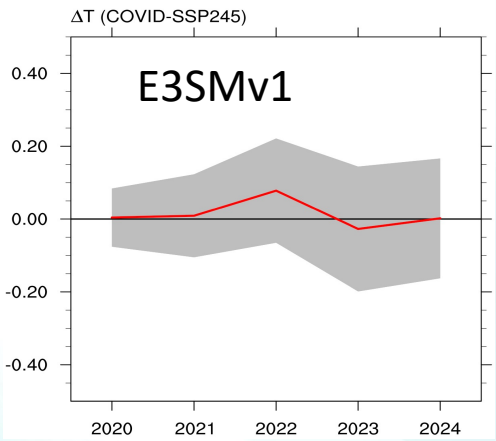
- Surface and atmospheric warming is consistent with net radiative forcing
- Strong regional changes related to moisture (tropics) and aerosols (mid-latitudes and deserts)

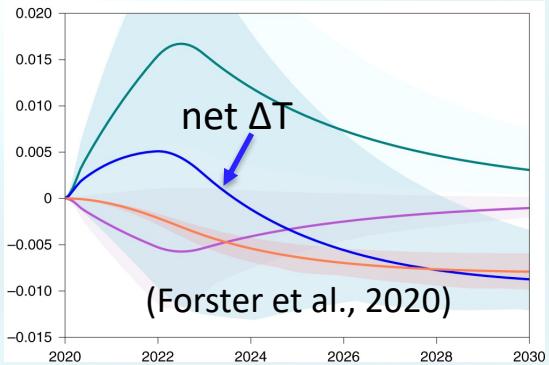
E3SM changes in all-sky net radiative flux

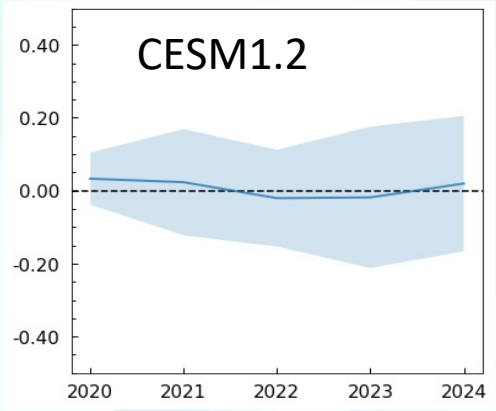


- Surface warming is consistent with net radiative forcing
- Strong regional (tropics) changes related to moisture and clouds

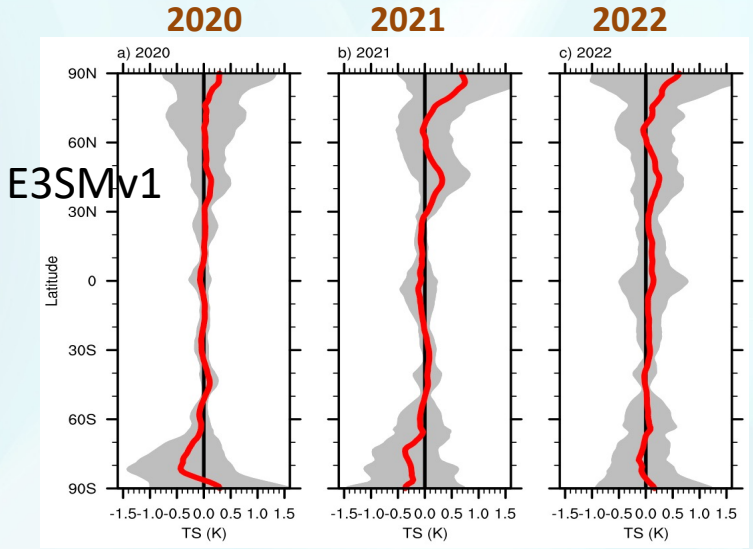
Comparison of ΔSAT in E3SM and CESM

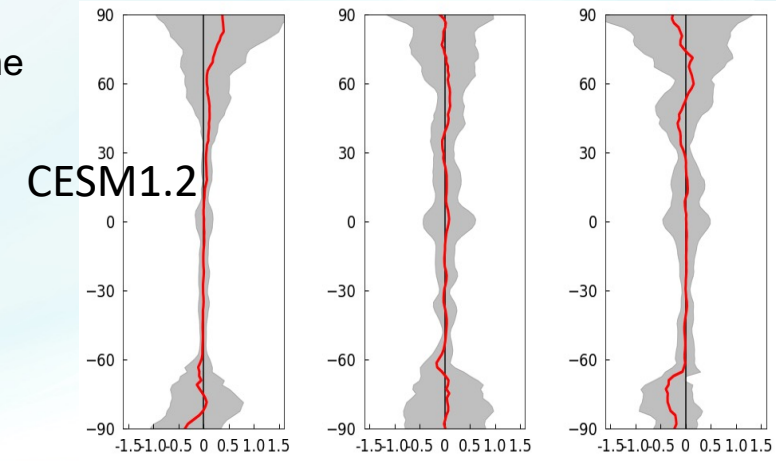




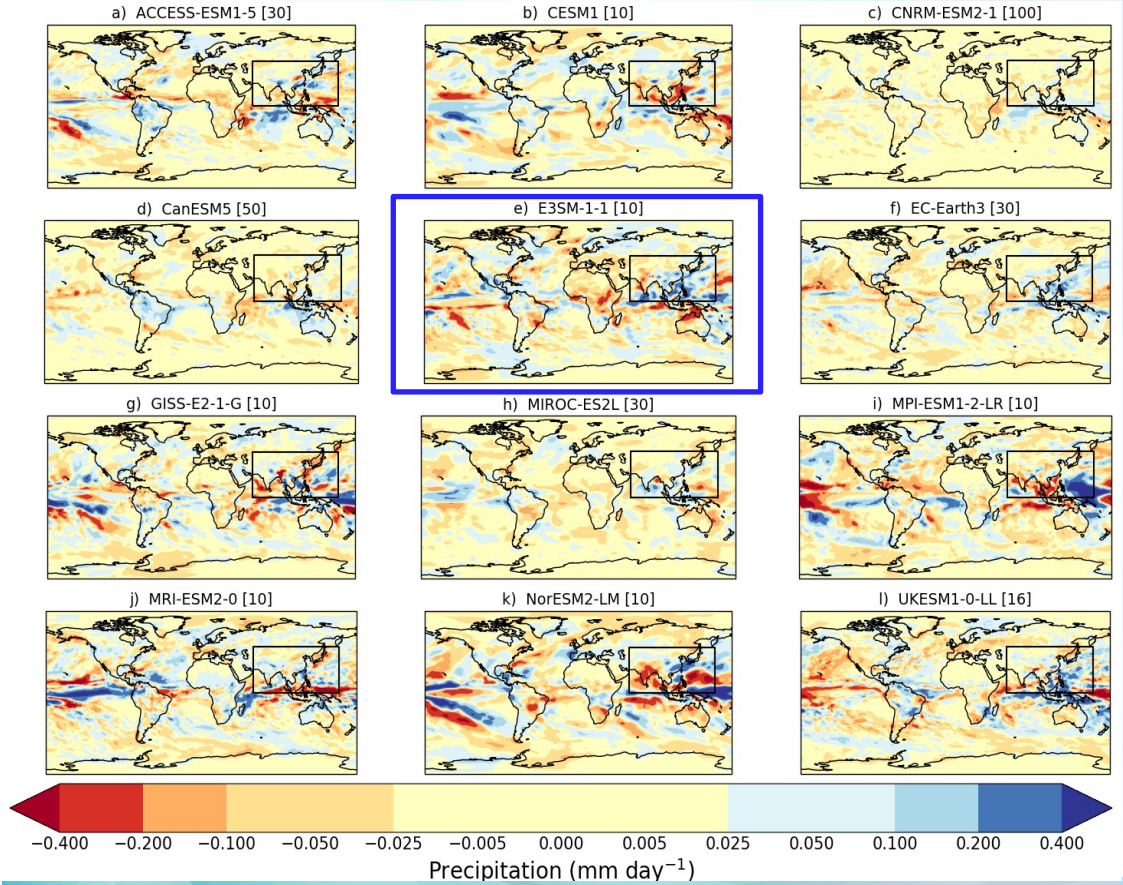


- E3SM does not show the fast warming in 2020 but captures the peak in 2022
- CESM has an immediate warming in 2020 but turns to cooling too soon, mostly at high latitudes
- E3SM shows persistent Arctic warming in 2020-2022





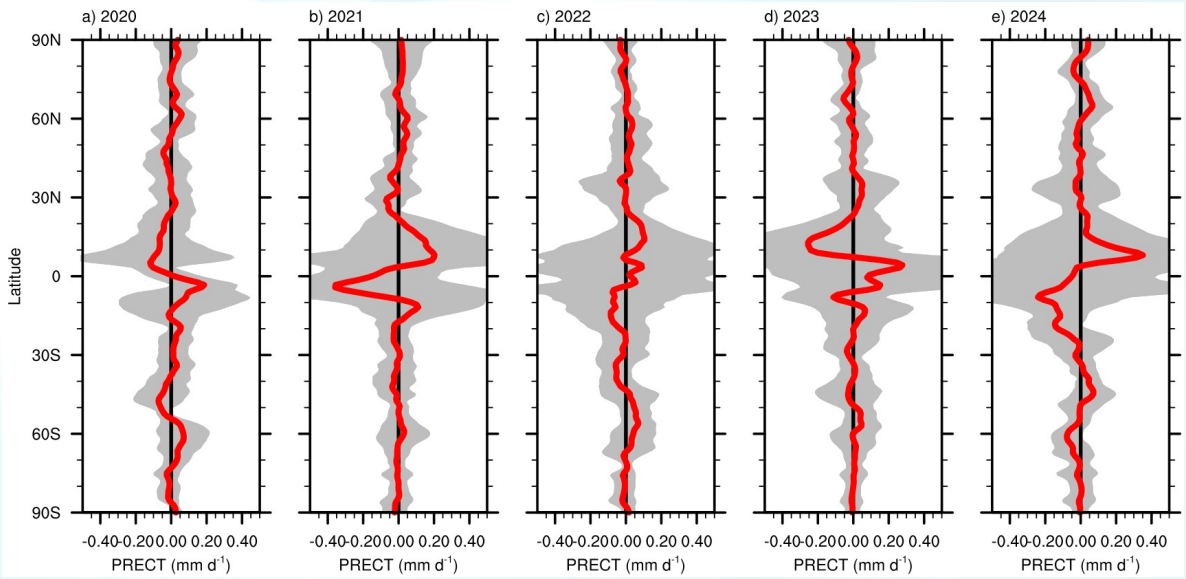
Regional patterns of precipitation change

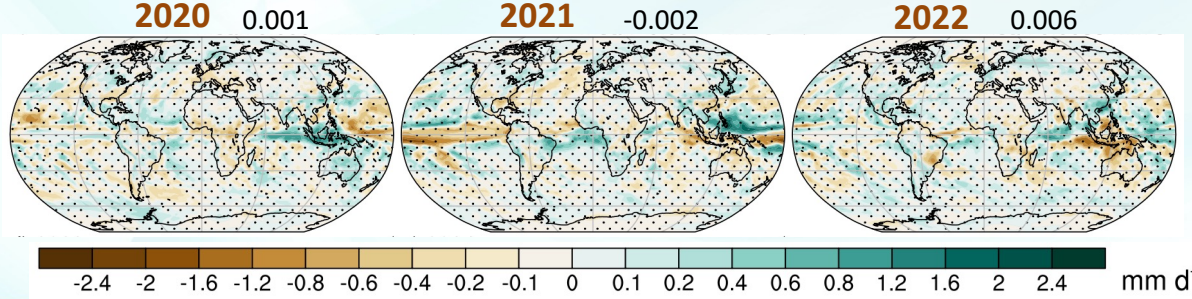


- Strong changes in the tropics, consistent with cloud forcing and surface radiation changes
- Some signals over East Asia and South Asia but not consistent across models
- Indicates strong internal variability of modes (NAO, ENSO, etc.)

(Jones et al., 2021)

Precipitation responses in E3SM



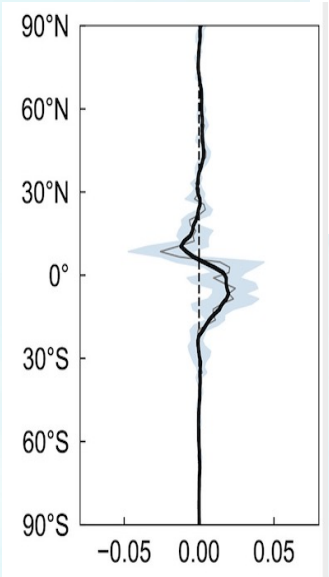


- Strong precipitation changes over the tropics, indicating a northward shift of ITCZ in 2021-2022, consistent with NH warming
- Change from 2020 onward indicates a dominant impact of oceanic responses
- ITCZ shift is reversed in 2023, also consistent with warming changes
- Significant regional changes in mid-latitudes

Comparison of precipitation changes between E3SM and CESM (CMIP vs. AMIP type)

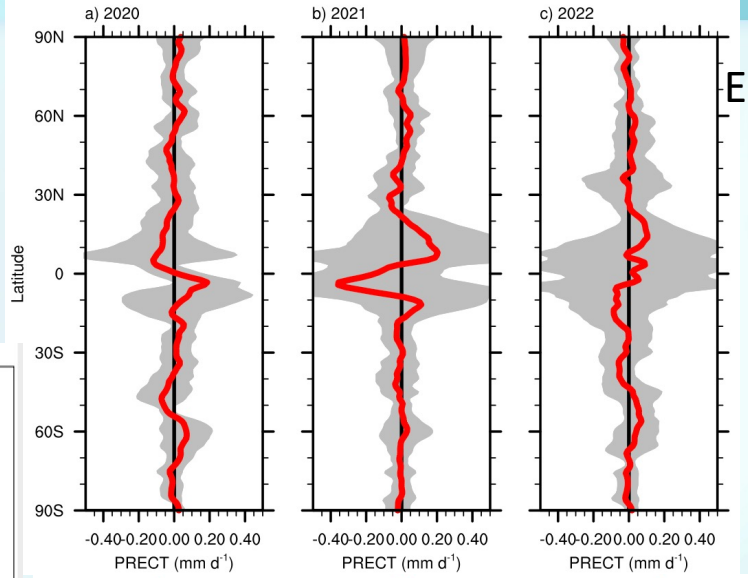
- Changes in ITCZ between E3SM and CESM are not exactly in phase
- AMIP simulations (Yang et al., 2020) show similar precipitation change in 2020 to E3SM
- Interestingly, signals of ITCZ in 2020 are less clear in CESM

CAM5

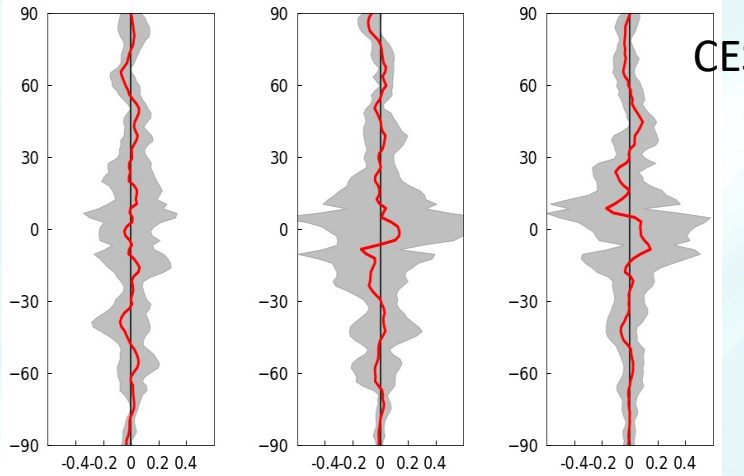


(Yang et al., 2020 GRL)

E3SM



CESM



Summary

- E3SM participated in the CovidMIP, as a result of very rapid response of the ESM community
- Initial results show interesting responses in aerosol loading, radiation, temperature and precipitation to the COVID lockdown and restrictions
- Regional responses on shorter timescales are much stronger than global means
- Further efforts in analyzing the simulations, especially the E3SM and CESM results on
  - Atmospheric circulation change and record-breaking 2020 summer precipitation anomaly over eastern China
  - Mechanisms behind the high-latitude changes in response to the COVID lockdown
  - Global dust lifecycle in response to the COVID lockdown

Additional information on the CovidMIP

- Current plans on papers/projects by participants:
  - https://drive.google.com/drive/folders/1m5WA9dpCL8o63ENOv_JH1JrzKlt200J-?usp=sharing
  - CovidMIP simulations are available on ESGF
  - https://wcrp-cmip.github.io/CMIP6_CVs/docs/CMIP6_experiment_id.html
  - Search “ssp245-cov” and you should see all 6 experiments
  - Thanks to Sterling Baldwin, Jill Zhang and Renata McCoy for helping publish the E3SM datasets on ESGF
    - DAMIP: https://esgf-node.llnl.gov/search/cmip6/?institution_id=E3SM-Project&activity=DAMIP
    - ScenarioMIP: https://esgf-node.llnl.gov/search/cmip6/?institution_id=E3SM-Project&experiment_id=ssp245
- SSP2-4.5 forcing conditions (input files) are available