Historical and future projection simulations by the global coupled E3SMv1.0 model as used in CMIP6

https://gmd.copernicus.org/preprints/gmd-2021-312/

Xue Zheng[1], Qing Li[2], Tian Zhou[3]

Qi Tang[1], Luke Van Roekel[2], Jean-Christophe Golaz[1],

Hailong Wang[3], and Philip Cameron-Smith[1]

[1]Lawrence Livermore National Laboratory, Livermore, CA 94550

[2]Los Alamos National Laboratory, Los Alamos, NM 87545

[3]Pacific Northwest National Laboratory, Richland, WA 99352

E3SM All Hands, February 17th, 2022

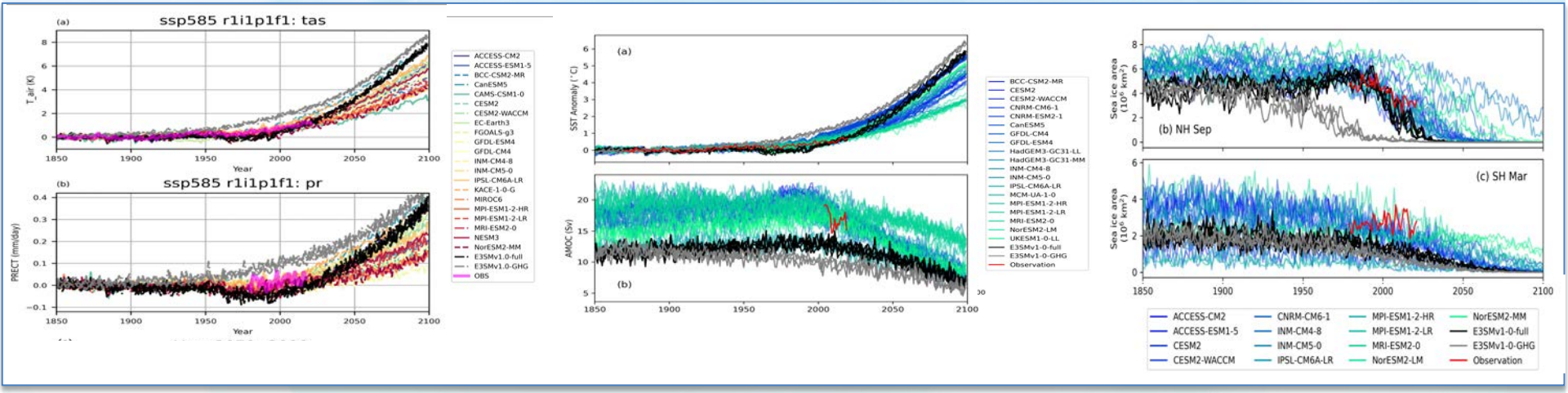
This work was performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. LLNL-JRNL-826361.

Introduction

- The Scenario Model Intercomparison Project (ScenarioMIP, Tebaldi *et al.,* 2021)
- ScenarioMIP High-Emission SSP5-8.5 Experiment (*five ensemble members*)
- CMIP6 DECK historical experiment (*five ensemble members*)
- Two sets of GHG-only simulations (*three ensemble members*)
  - **DECKv1b_H1_hist-GHG**: well-mixed greenhouse-gas (GHG)-only historical simulations
  - **DECKv1b_P1_SSP5-8.5-GHG**: well-mixed GHG-only future projection simulations initialized by hist-GHG simulations
- Main goals for this manuscript
  - Document global and regional responses of atmosphere, ocean, sea-ice and land runoff in the high-emission scenario simulated by E3SMv1.0
  - Describe regional responses of climate components in the GHG-only experiment relative to the all-forcing experiment

Historical and SSP5-8.5 all-forcing experiment

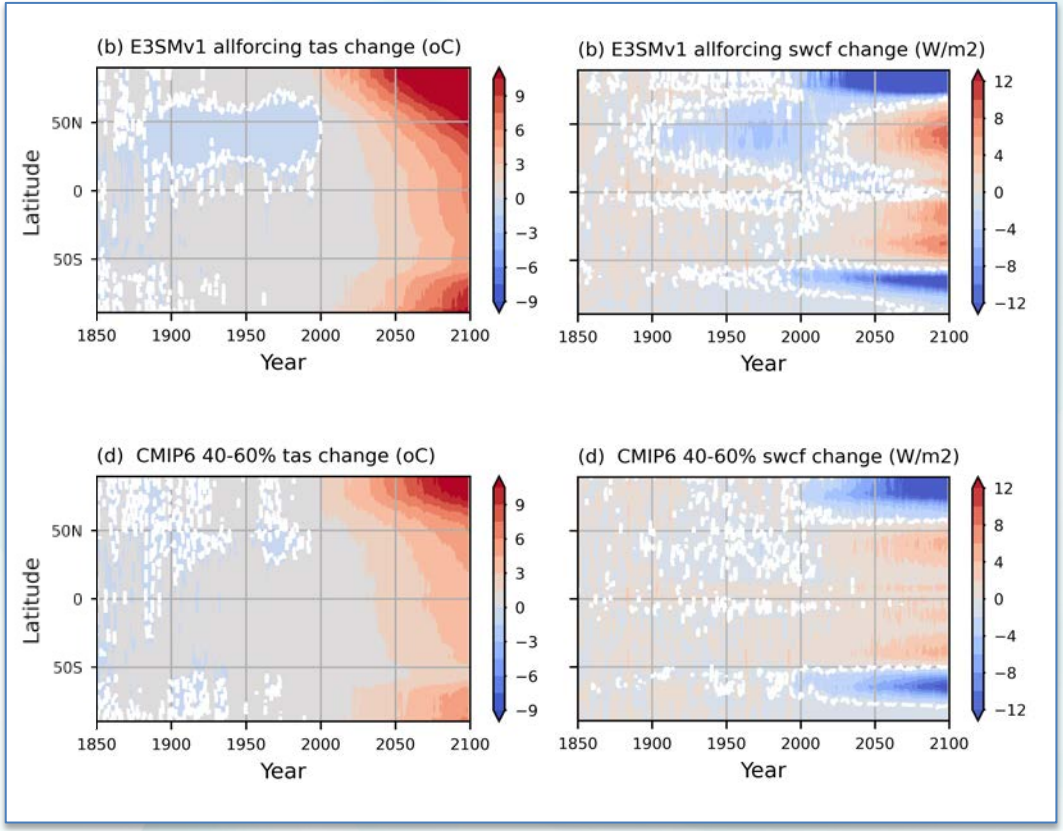
- Ensemble means from five ensemble members
- Global and regional responses from atmosphere, ocean, sea-ice and land runoff



Comparing E3SMv1.0 with other CMIP6 models:

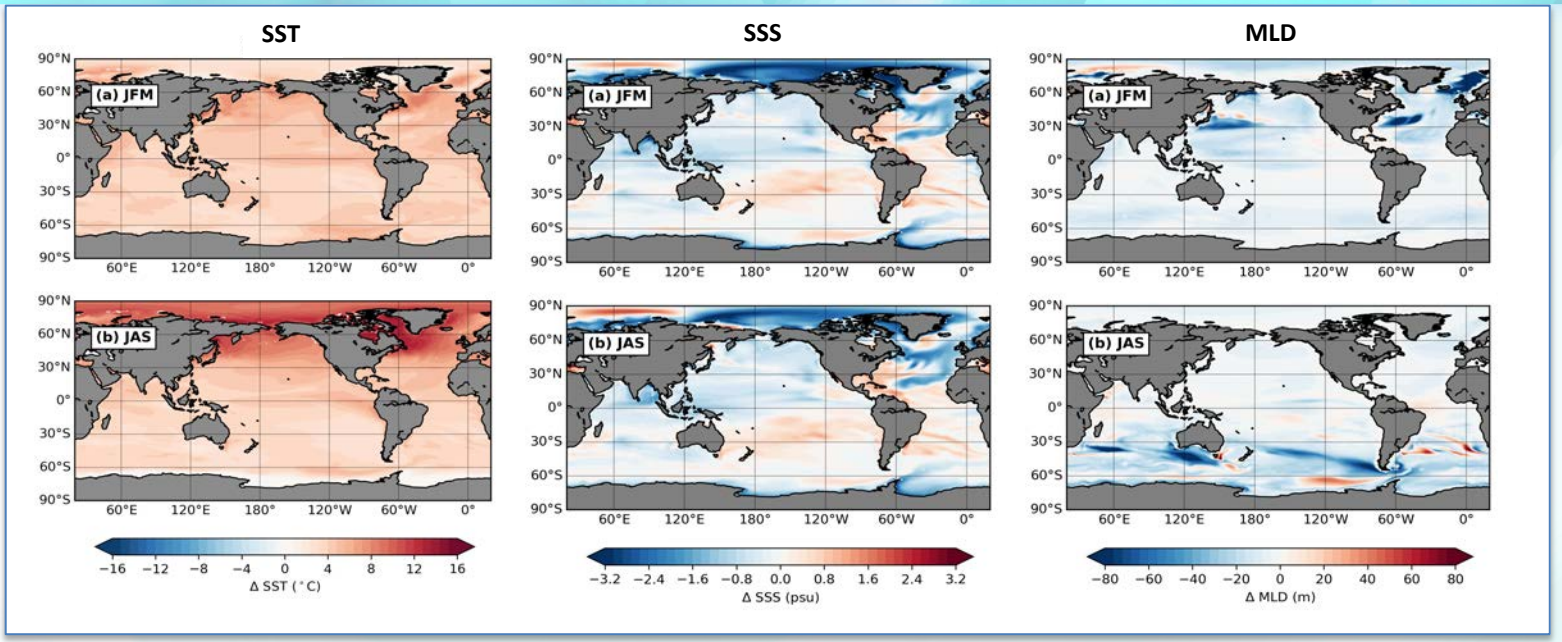
- The surface warming is strong by the end of the 21st century under the high-emission SSP5-8.5 scenario (black links).
- The annual mean AMOC is overly weak with a slower change from 11Sv to 6Sv.
- The sea ice, especially in the Northern Hemisphere, decreases rapidly.

The time evolution of zonal mean Tair and SW cloud radiative effect



A continuous cooling and an enhanced negative SWCRE before 2000
A rapid warming in the Arctic and a clear warming asymmetry between NH and SH after 2000
Strong negative SWCRE change in the Arctic

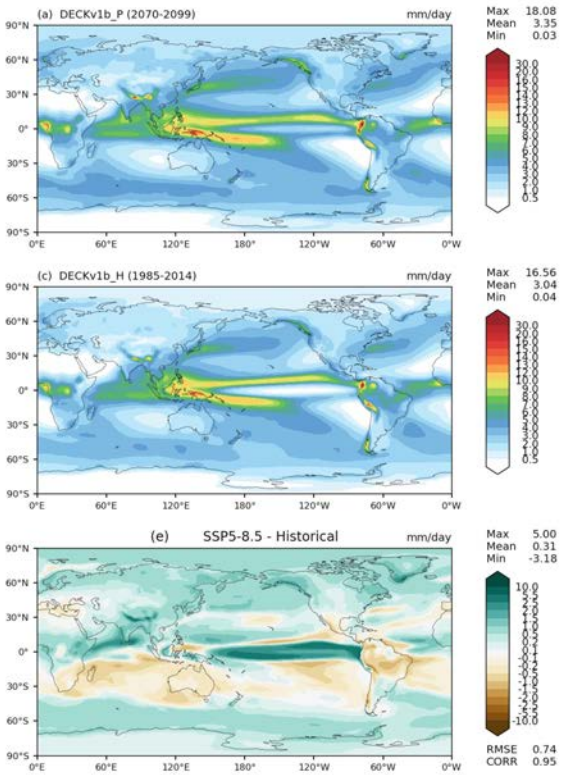
No signal of such a continuous cooling and enhanced negative SWCRE
Weaker polar amplification



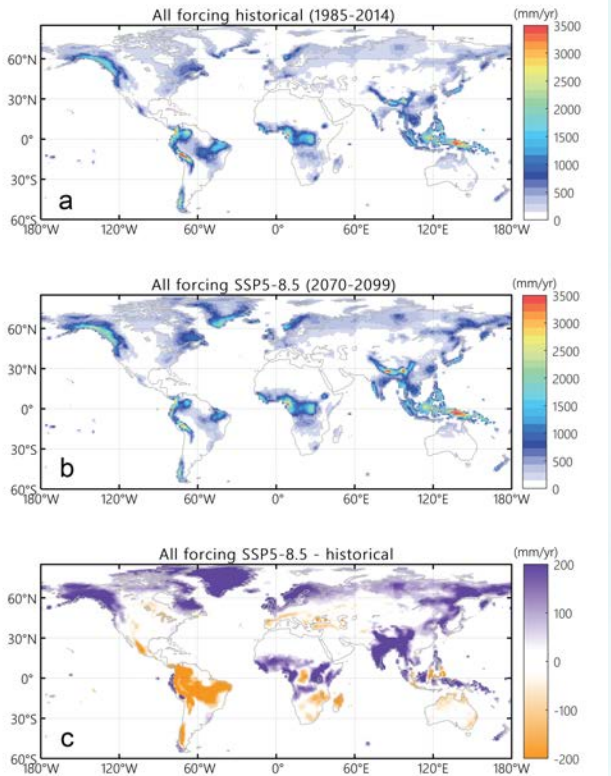
- Between the period of 2070-2099 and 1985-2014:
  - SST increases > 2°C everywhere with local changes > 10°C
  - A strong freshening in the Arctic and the North Atlantic
  - The oceanic mixed layer generally shoals throughout the global ocean

A strong polar amplification

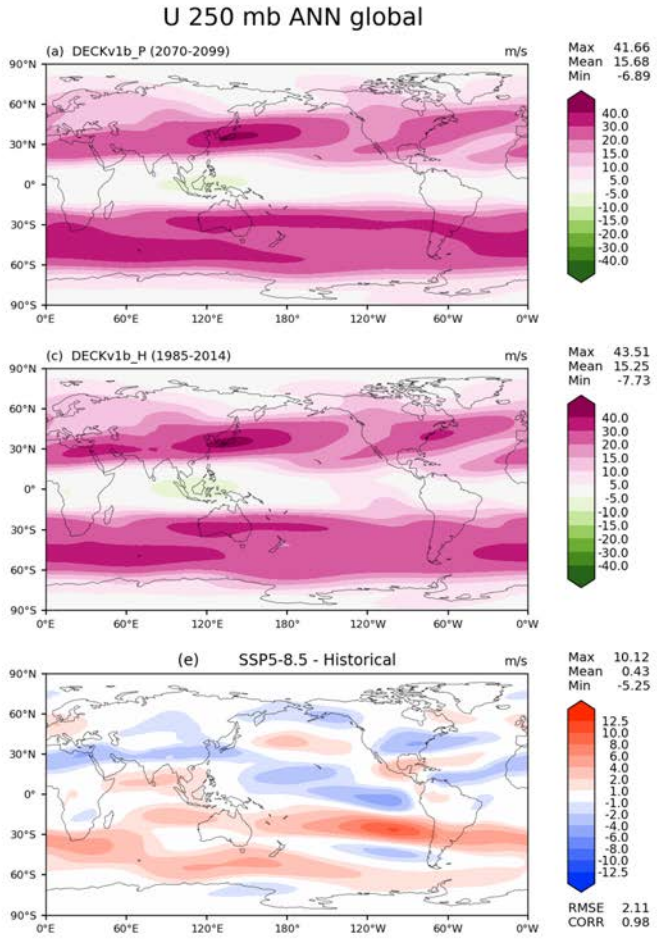
Precipitation



Runoff



- The global pattern of the precipitation changes
- Annual runoff predicted by ELMv1 is highly correlated to the precipitation changes

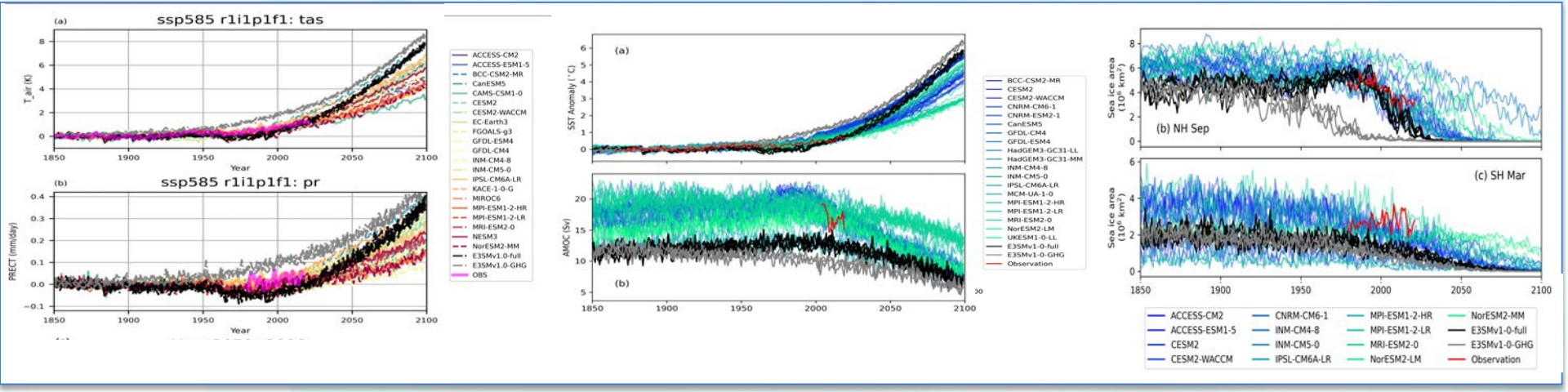


The response of the atmospheric circulation

- The subtropical edges of the Hadley cell in both hemispheres shift poleward in the warmer climate.
- The poleward shift is larger in the Southern Hemisphere.

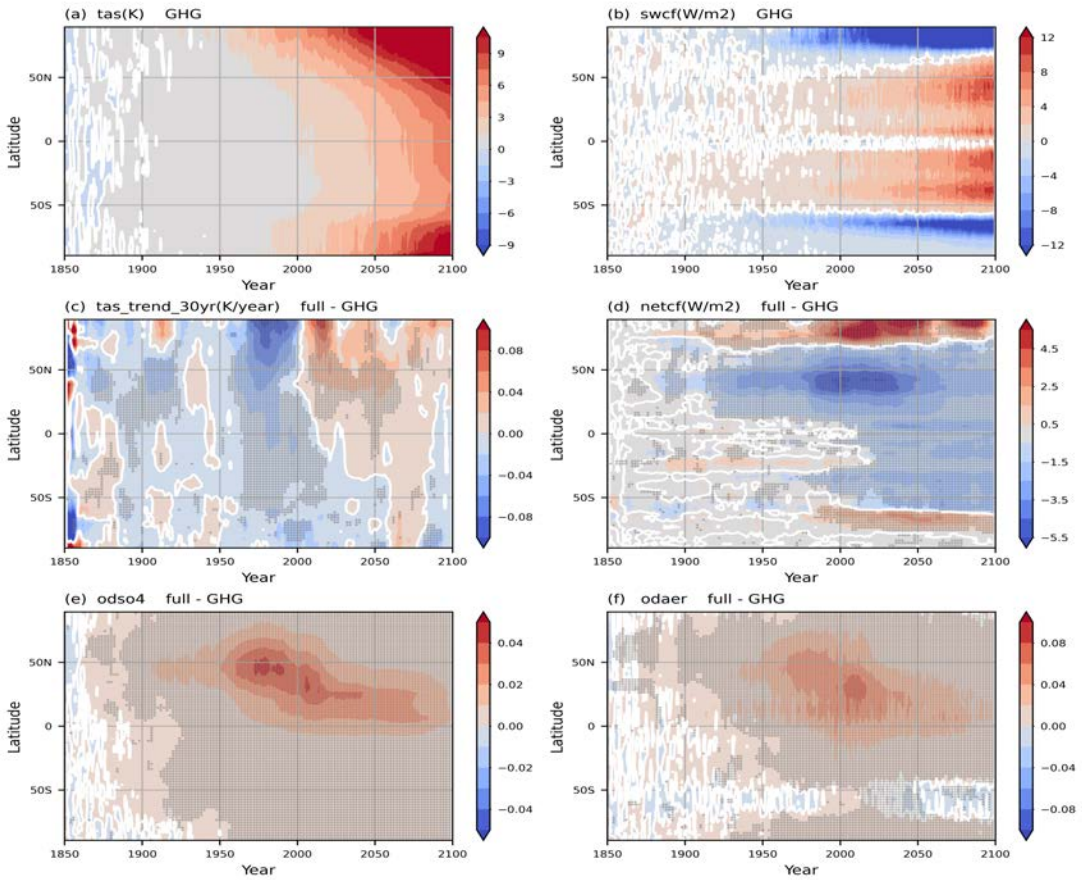
GHG-only Historical and Future Projection Experiment

- Atmospheric Responses
- Ocean and Sea-ice Responses
- Land Responses



Compared with the all-forcing experiment

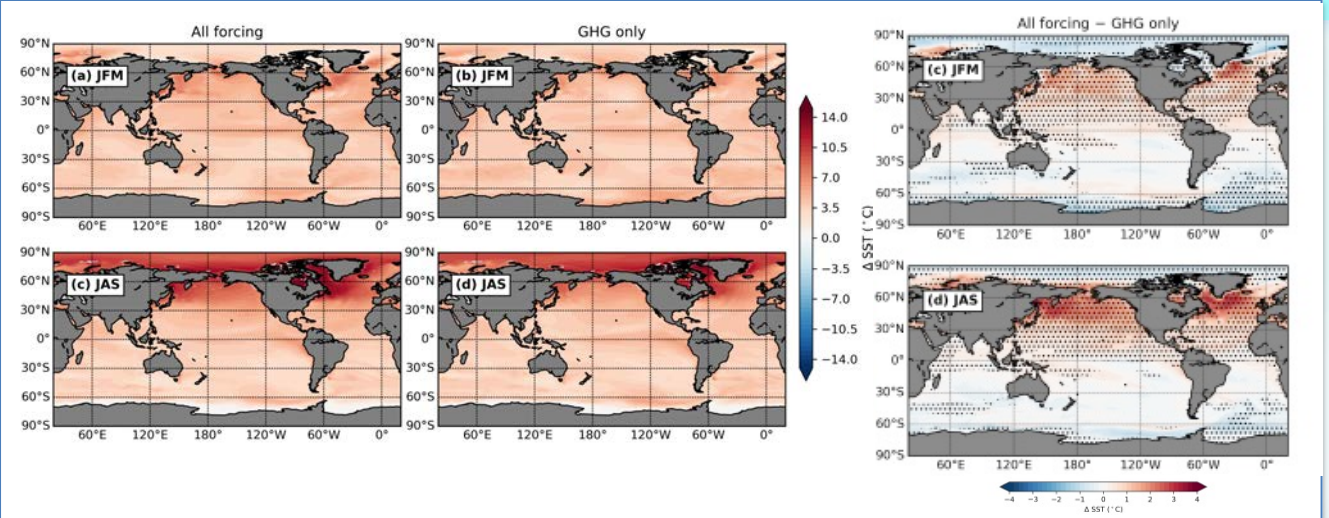
- the climate in the GHG-only experiment warms more rapidly in the historical simulations
- the AMOC is further weakened
- the sea-ice amount is less after 1950, especially in the Northern Hemisphere

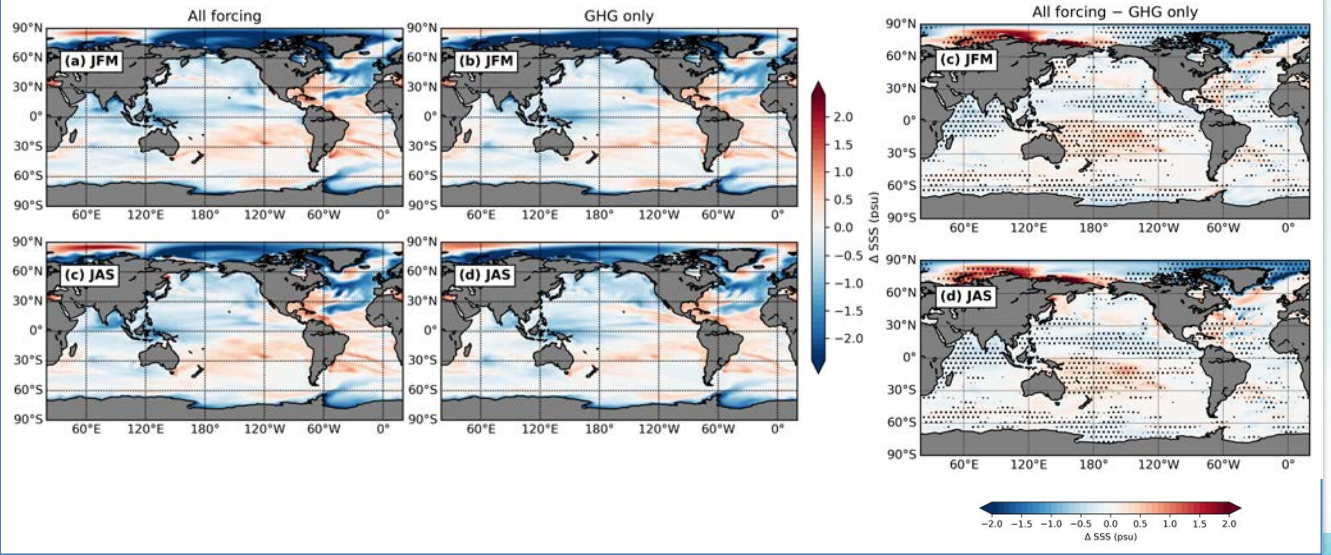


No signal of cooling and enhanced SWCRE cooling effect in the Northern Hemisphere

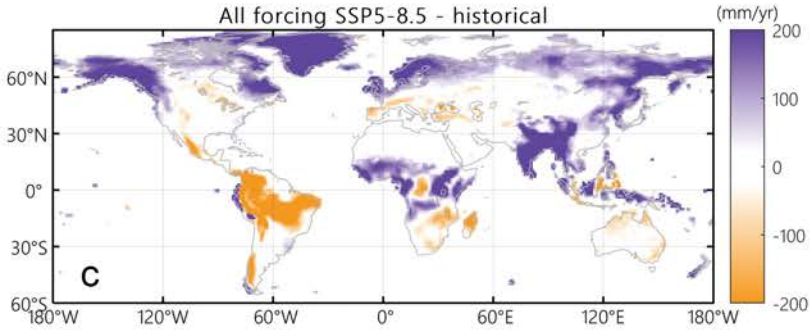
An extra strong CRE cooling effect over the high aerosol-loading regions in the all-forcing historical experiment

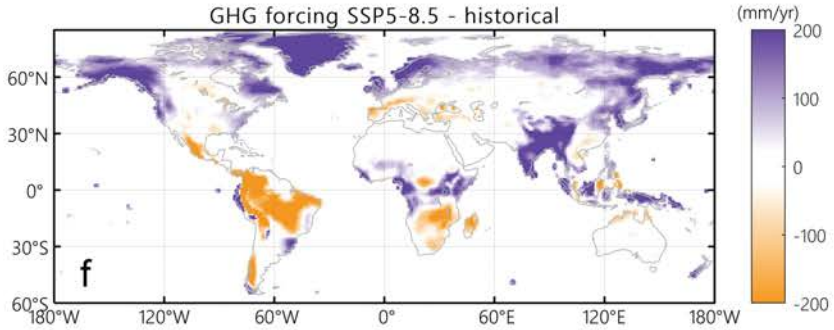
The unmasking of the aerosol effects





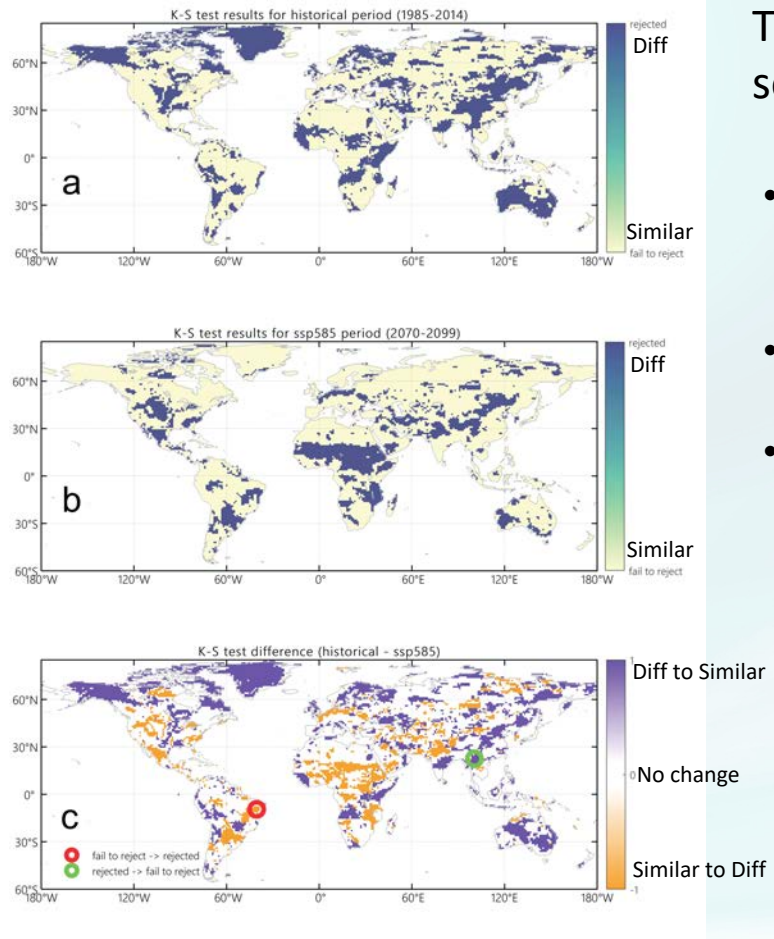
GHG emissions dominate the global pattern of the SST and SSS changes. Other forcings may affect the magnitude of regional changes





The changes in land runoff between the period of 2070-2099 and 1985-2014:

- GHG-only forcing leads to a greater decline in future runoff than all forcing in southern North America, southern Africa, and eastern Asia
- GHG-only forcing tends to have less runoff increase in the future than the all-forcing experiment



The Kolmogorov–Smirnov (K-S) tests for the time series of runoff.

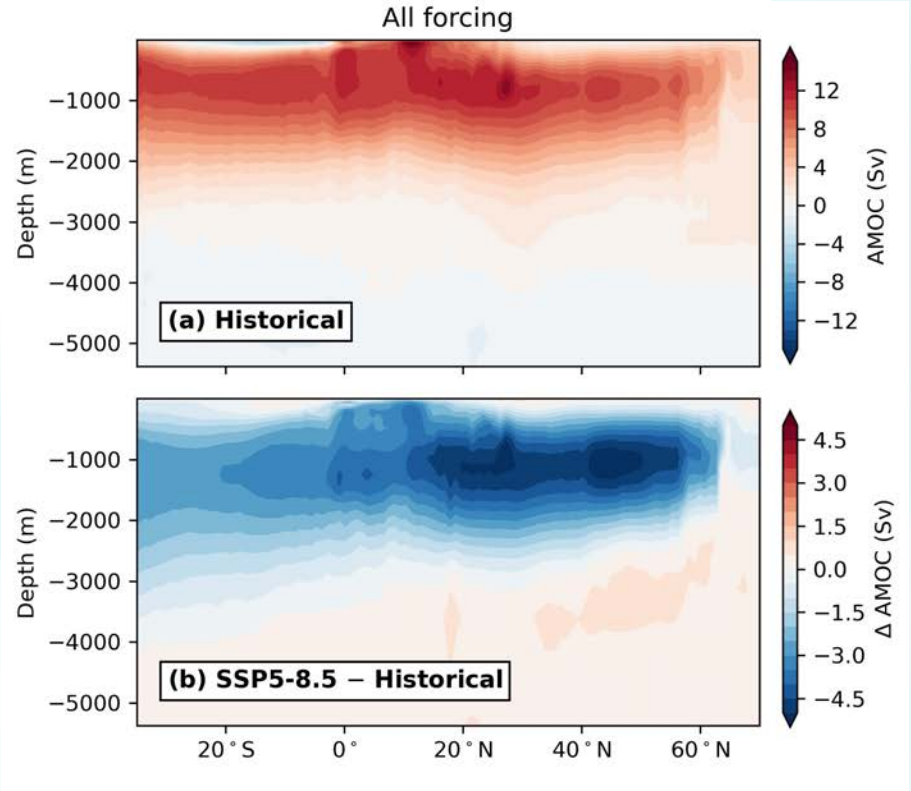
- In (a), the time evolution of land runoff becomes different in areas like Greenland, Australia, central and northwest of North America, and eastern Asia.
- In (b), the difference in local runoff enlarges in most areas except in Greenland, Australia, and Alaska.
- Overall, the runoff distributions from the all-forcing experiment and GHG-only experiment tend to be more similar during the future period than during the historical period.

Summary

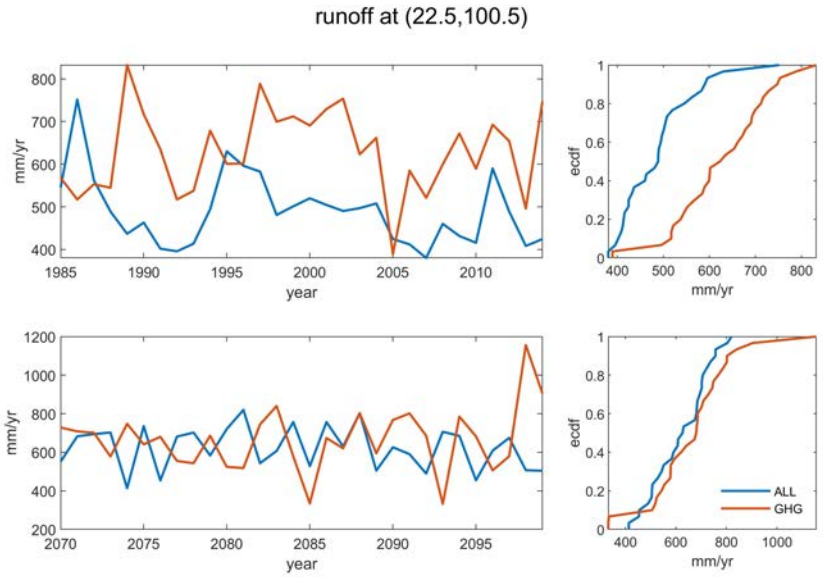
- E3SMv1.0 is one of the CMIP6 models with the largest surface warming by the end of the 21st century under the high-emission SSP5-8.5 scenario.
- A significant polar amplification of surface warming in E3SMv1.0, which is associated with increased clouds, a weaker AMOC, reduced SSS, lower sea ice concentration, and faster sea ice melting in the Arctic.
- The transient accelerated warming in the all-forcing experiment during the first half of the 21st century is likely caused by the unmasking of the aerosol effects due to the decline of the aerosol loading in the future projection period.
- While the oceanic climate response is largely controlled by the GHG forcing, the land runoff response is impacted primarily by forcings other than GHG, e.g., southern North America, southern Africa, central Africa, and western Asia. However, the impact of GHG forcing grows and becomes dominant in the future climate projection period.

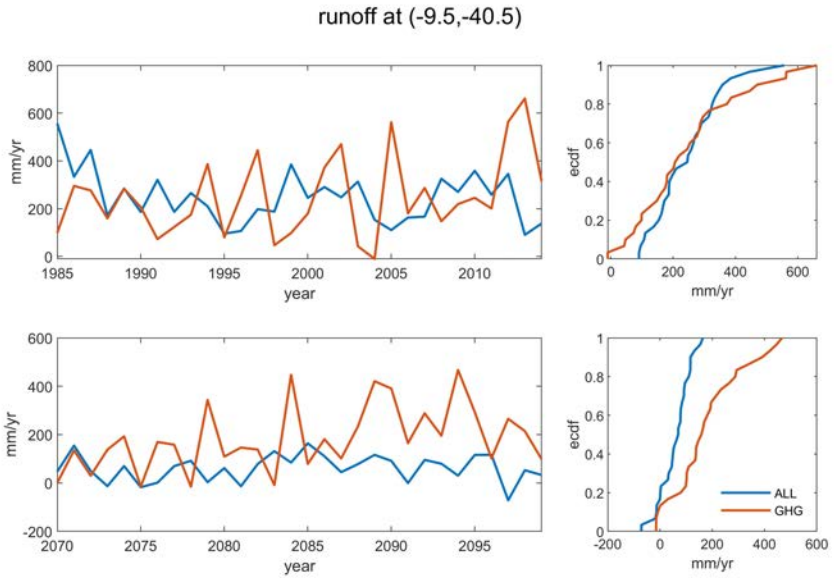
Thanks!

The ensemble averaged spatial pattern of the simulated AMOC



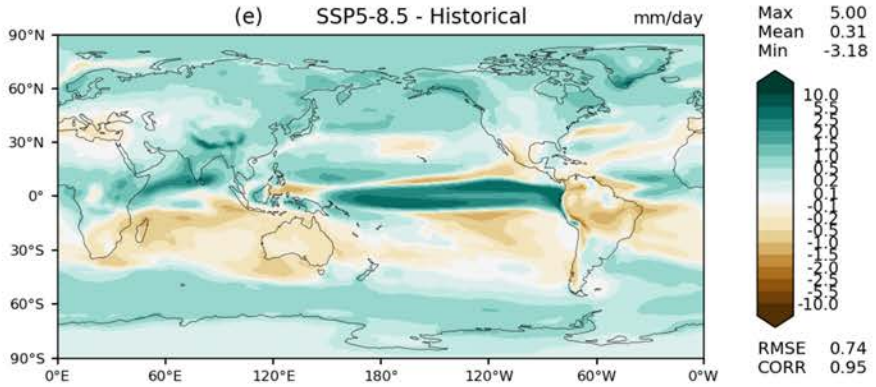
Besides the overall weakening, a strong AMOC weakening occurs at high-latitudes around 50°N.

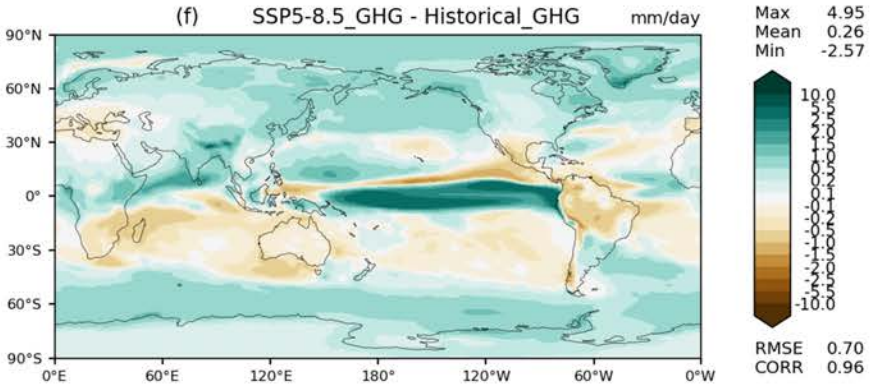




Different to Similar

Similar to Different


(e)
SSP5-8.5 - Historical
mm/day
Max 5.00
Mean 0.31
Min -3.18
RMSE 0.74
CORR 0.95
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°E
60°E
120°E
180°
120°W
60°W
0°W
10.0
5.5
3.0
2.5
2.0
1.5
1.0
0.5
0.2
0.1
-0.1
-0.2
-0.5
-1.0
-1.5
-2.0
-2.5
-5.5
-10.0


(f)
SSP5-8.5_GHG - Historical_GHG
mm/day
Max 4.95
Mean 0.26
Min -2.57
RMSE 0.70
CORR 0.96
90°N
60°N
30°N
0°
30°S
60°S
90°S
0°E
60°E
120°E
180°
120°W
60°W
0°W
10.0
5.5
3.0
2.5
2.0
1.5
1.0
0.5
0.2
0.1
-0.1
-0.2
-0.5
-1.0
-1.5
-2.0
-2.5
-5.5
-10.0