Impact of Model Resolution on Biases, Climate Simulations and Predictions in the Southern Ocean

Ping Chang , Stephen G. Yeager, Gokhan Danabasoglu, Gaopeng Xu, Qiuying Zhang, Pedro DiNezio, Fred S. Castruccio, Nan Rosenbloom
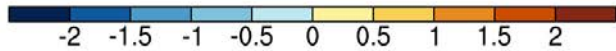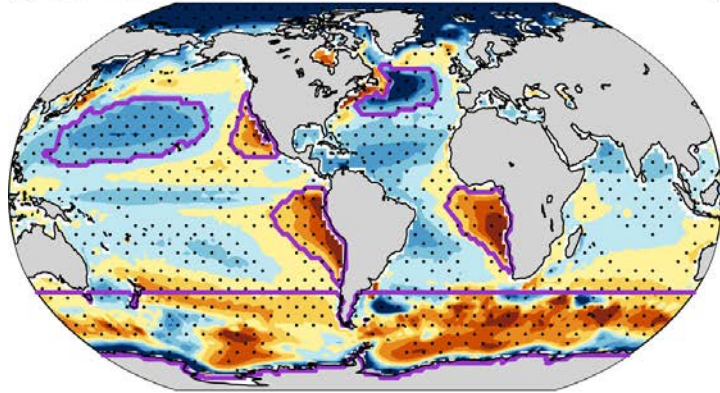
2023 US CLIVAR Summit, July 31-August 2, Seattle, WA
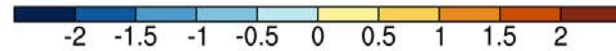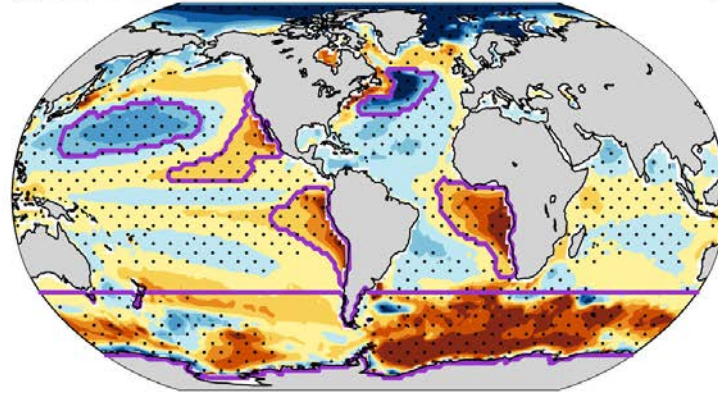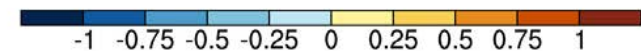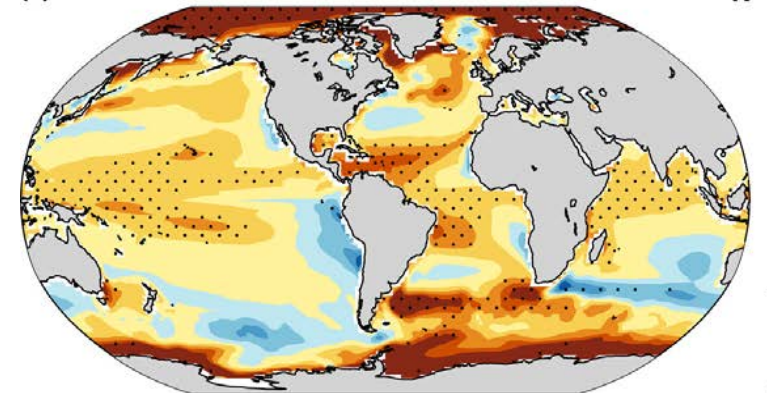
SST Bias in CMIP5 and CMIP6

(a) SST Bias in CMIP5

(b) SST Bias in CMIP6

(c) Difference in SST Biases (CMIP6-CIMP5)

Zhang et al (2023). GRL, https://doi.org/10.1029/2022GL100888
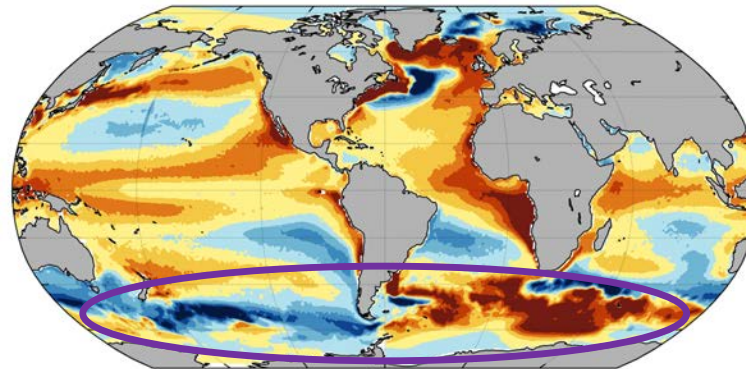
SST Bias in CESM1 and CESM2

CESM1 (LENS)
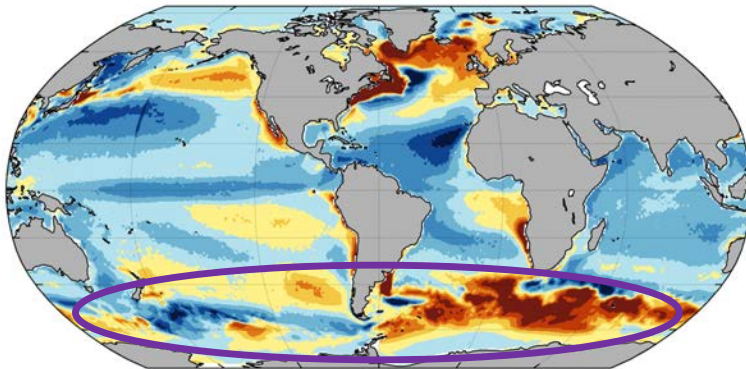
CESM2

CESM2-CESM1
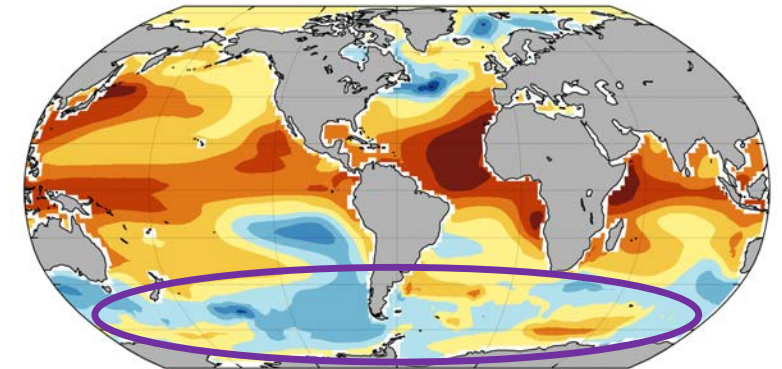
Courtesy of Gaopeng Xu (also see Danabasoglu et al. (2020), JAMES, https://doi.org/10.1029/2019MS001916)

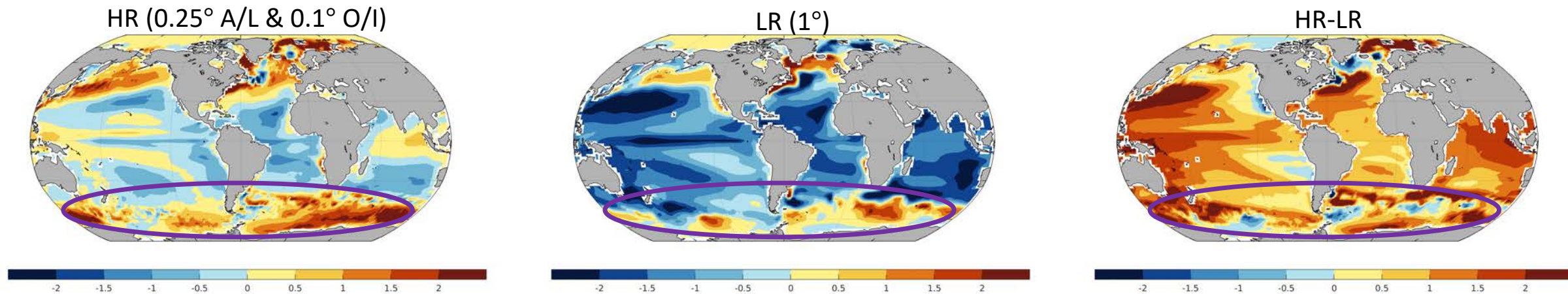# SST Bias in HighResMIP

HighResMIP: CNRM-CM6-1, EC-Earth3P, ECMWF-IFS, HadGEM3-GC31, MPI-ESM1-2, CESM1.3; 100-year 1950-CTRL and 1950-2050 TNST
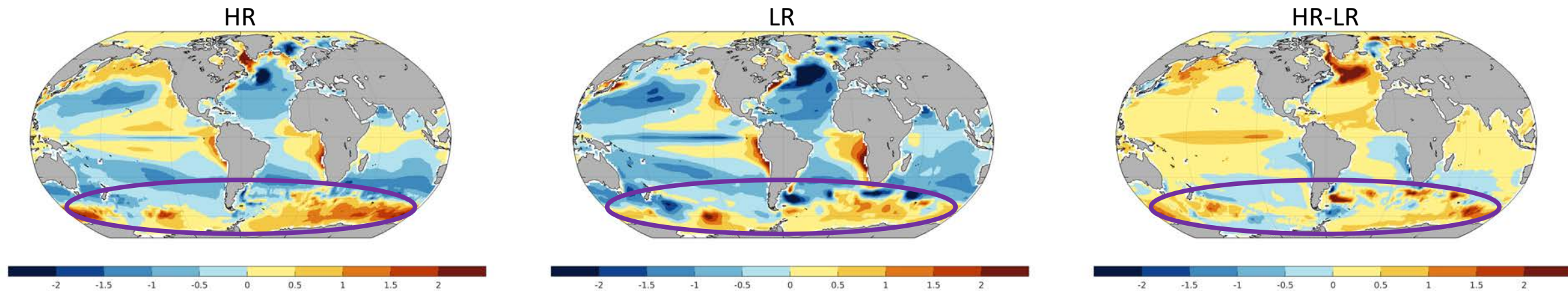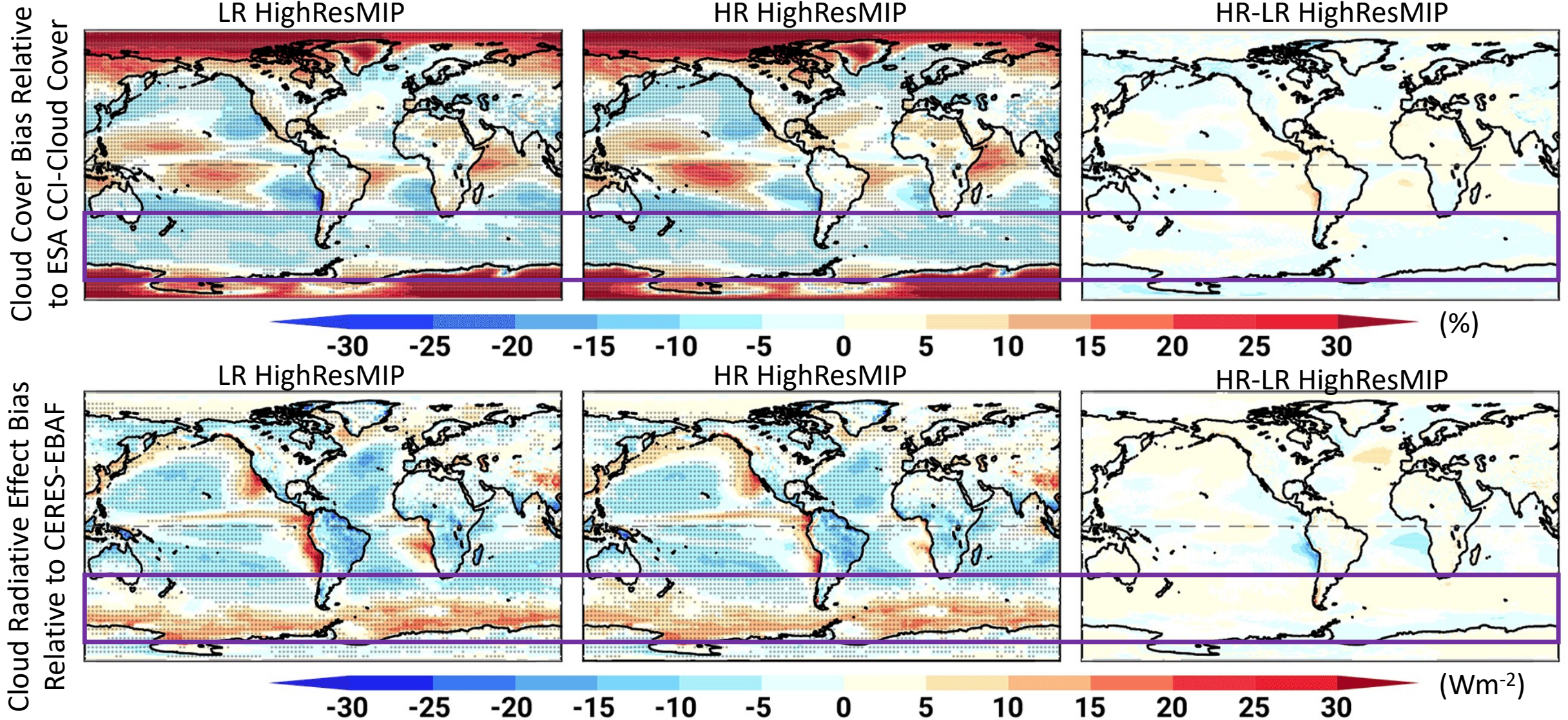

SST Bias in CESM1-HR

CESM1.3 with SE-CAM5: 650-year PI-CTRL, 1850-2100 hist+RCP8.5, 2x1920-2100 hist+RCP8.5, 1970-2022 10-member decadal predictions, …
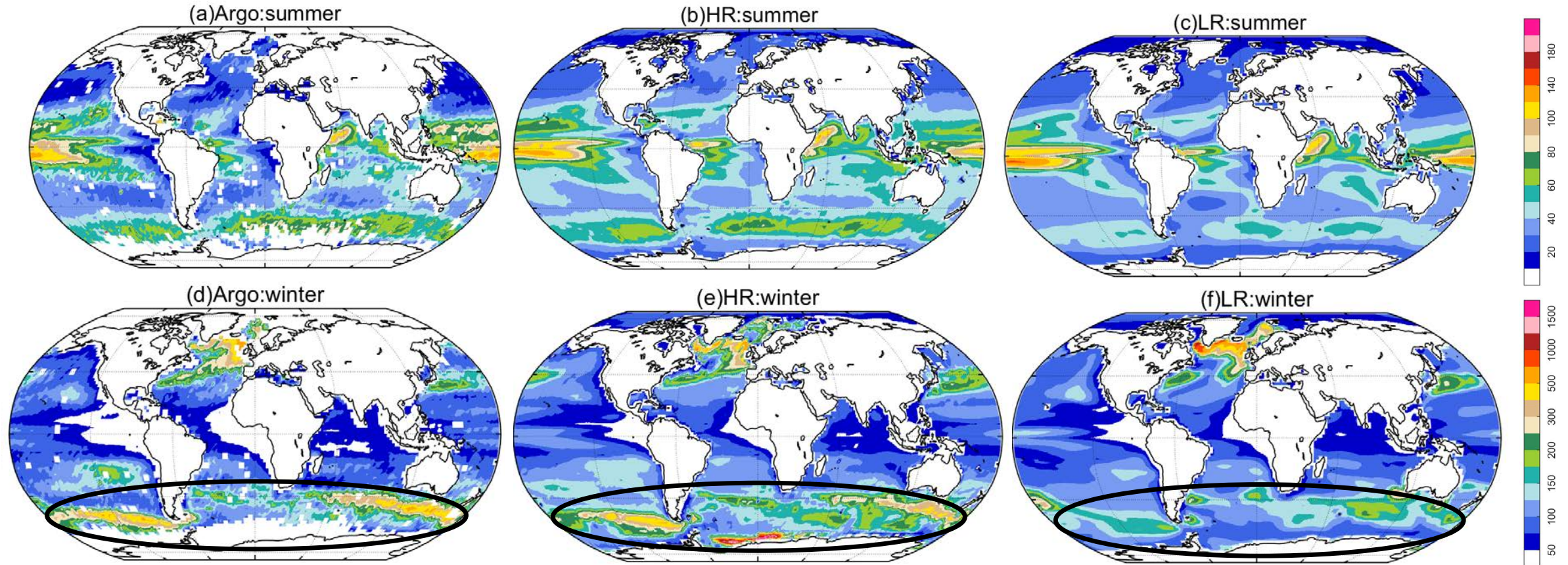

Courtesy of Qiuying Zhang

Cloud Cover and Radiative Effect in HighResMIP

Moreno-Chamaro et al. (2022), GMD, https://doi.org/10.5194/gmd-15-269-2022

Mixed Layer Depth in CESM1-HR and -LR
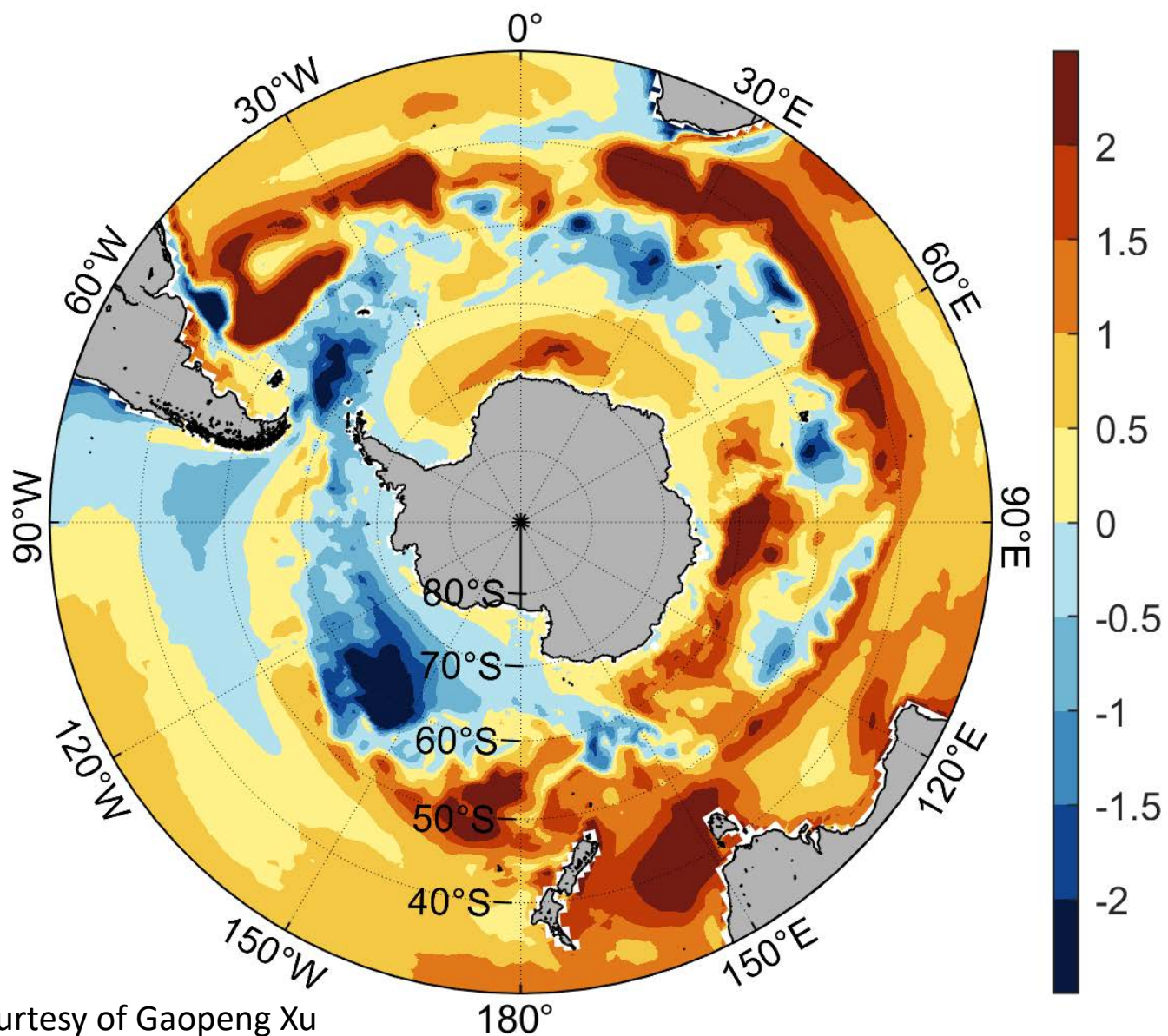

Chang et al. (2020), JAMES, https://doi.org/10.1029/2020MS002298

HR simulates more realistic mixed layer depth (MLD), particularly the winter MLD in the Southern Ocean and in the subpolar North Atlantic, despite of the same vertical resolution and vertical mixing parameterization.

Ocean Mixed Layer Processes
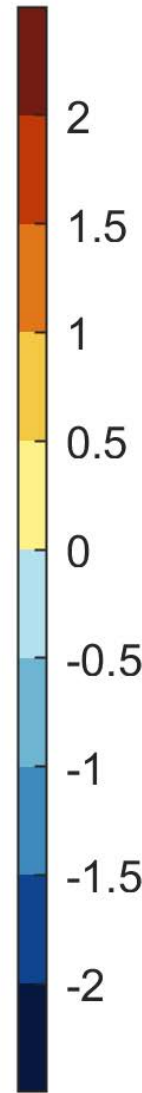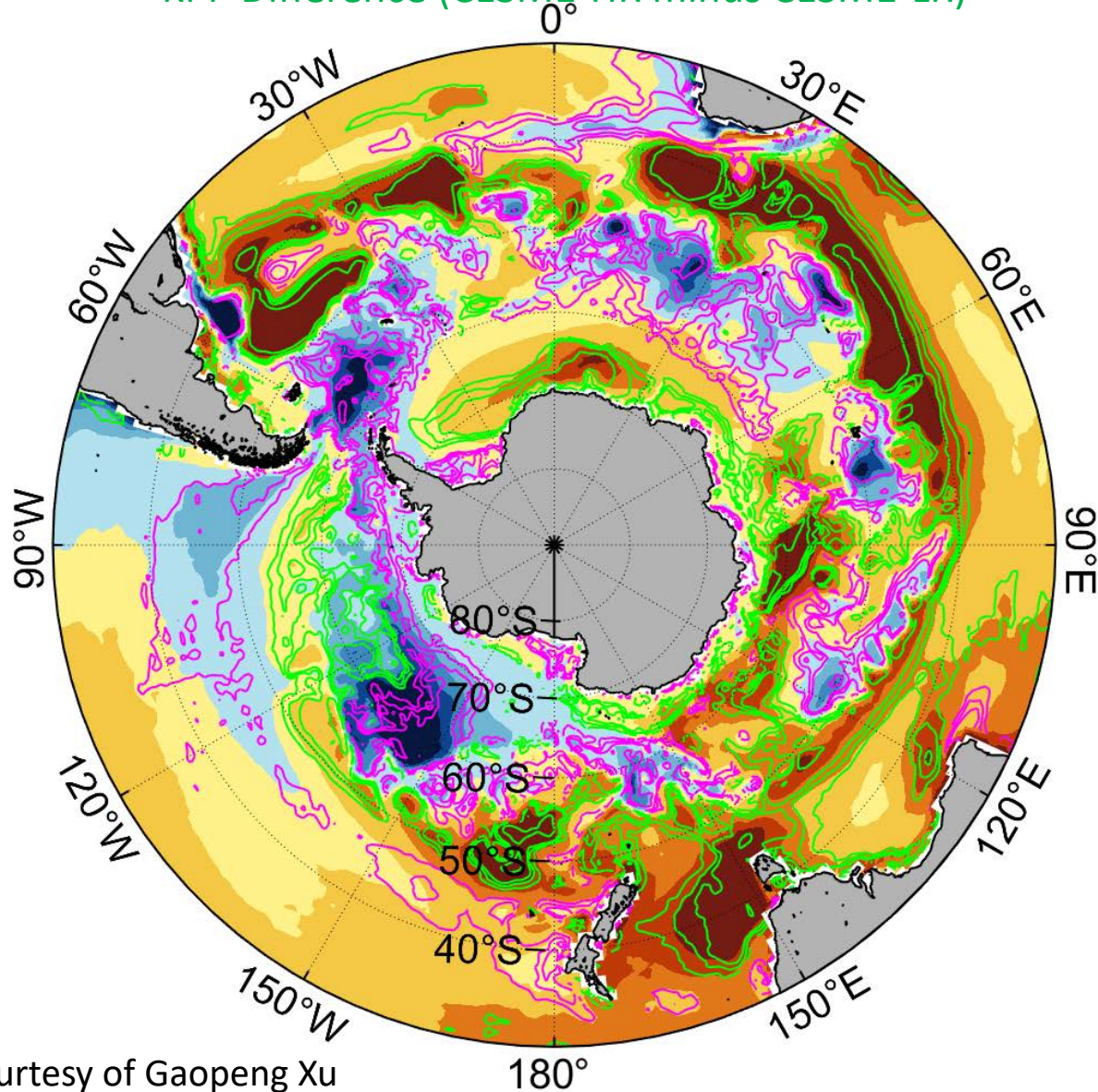
SST Difference (CESM1-HR minus CESM1-LR)

Courtesy of Gaopeng Xu

Ocean Mixed Layer Processes
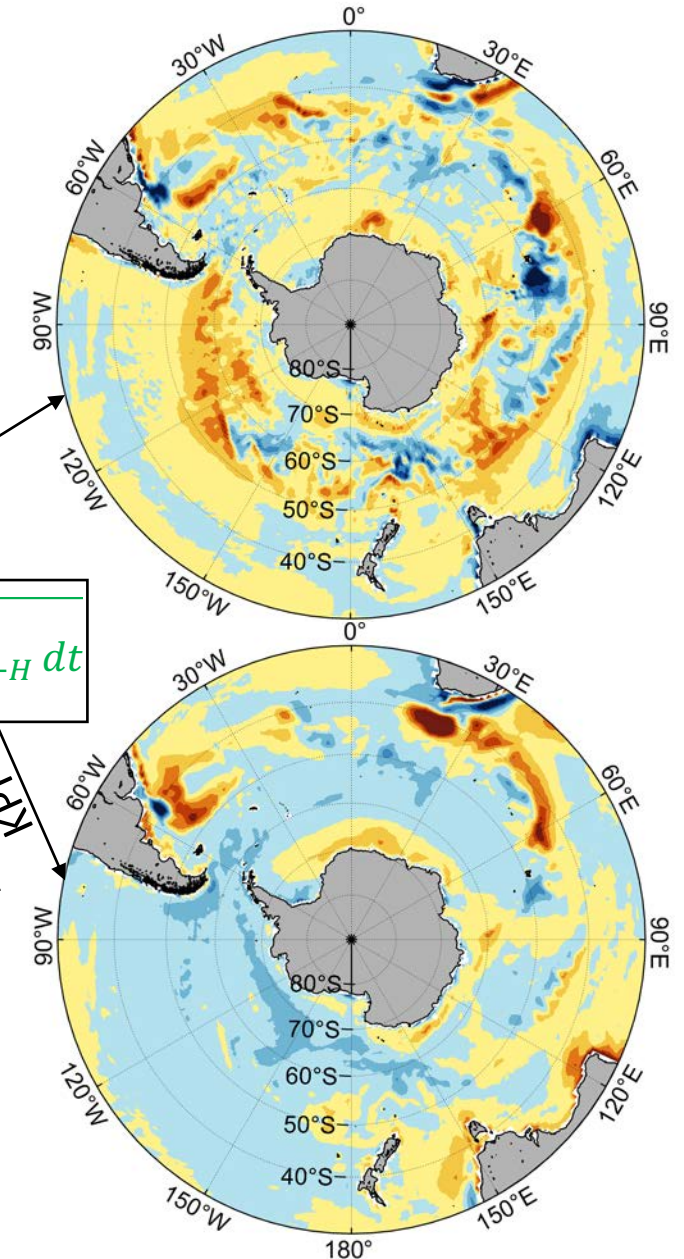
SST Difference (CESM1-HR minus CESM1-LR)

KPP Difference (CESM1-HR minus CESM1-LR)

$$\int_0^t \frac{\kappa_v}{H} \left(\frac{\partial T}{\partial z} - \gamma_x \right) |_{-H} \, dt$$
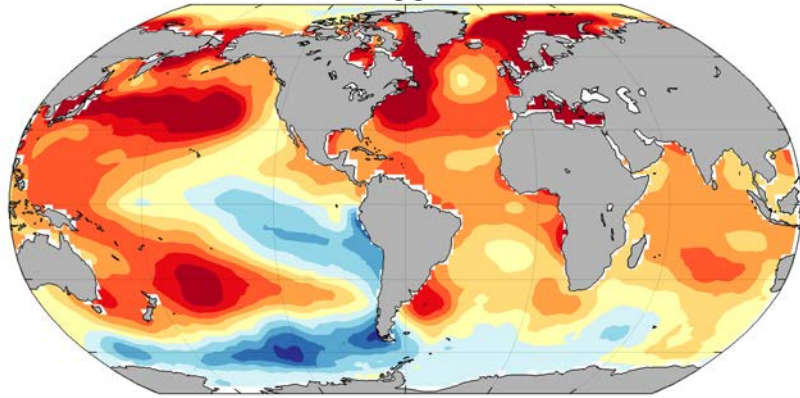
Local KPP
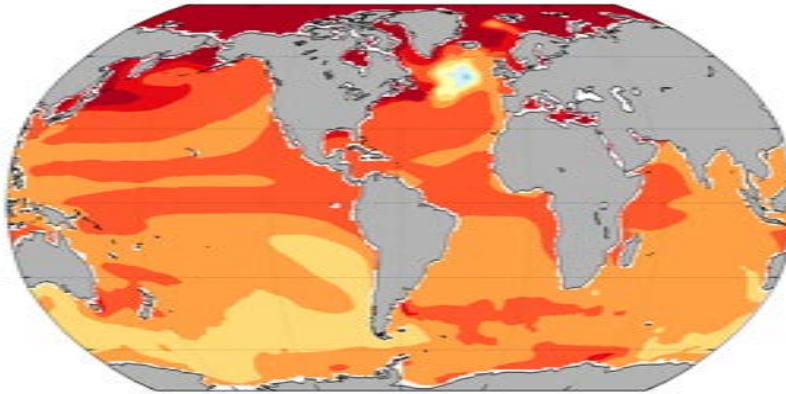
nonlocal KPP

Courtesy of Gaopeng Xu
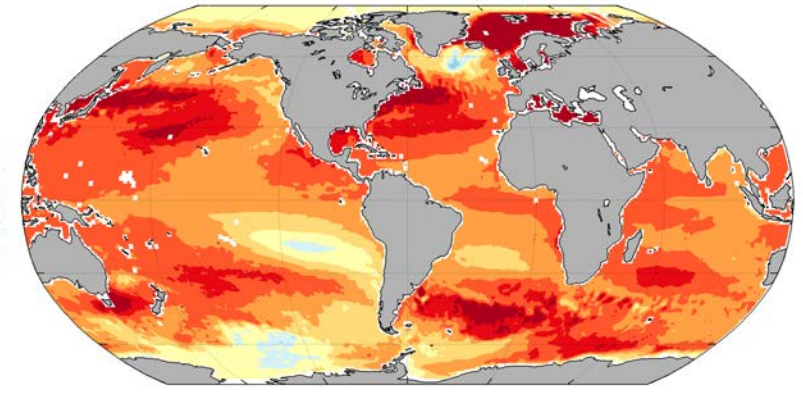
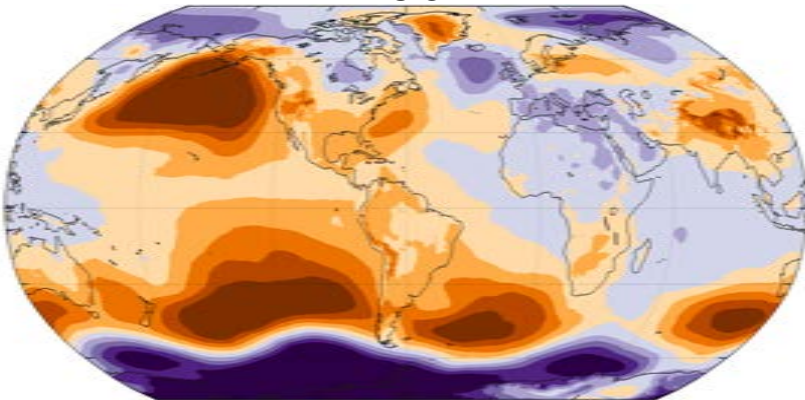# Linear Trend

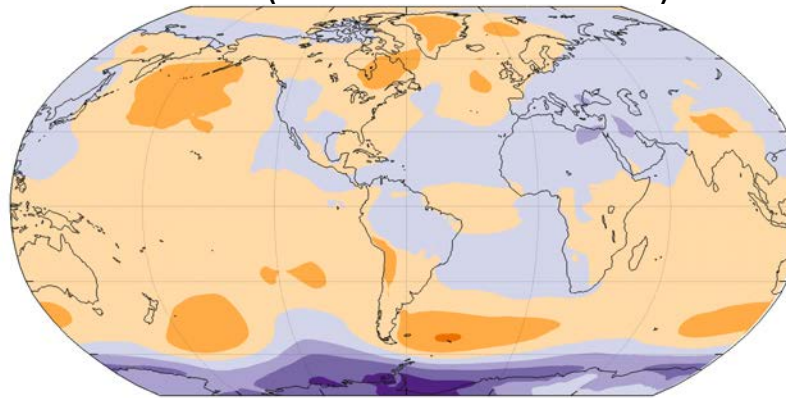DiNezio et al (2023, in preparation)

ERSST — LR SST (45 CESM1 + 34 CMIP6) — HR SST (4 CESM1 + 6 HighResMIP)

ERA5 SLP — LR SLP (45 CESM1 + 34 CMIP6) — HR SLP (4 CESM1 + 6 HighResMIP)
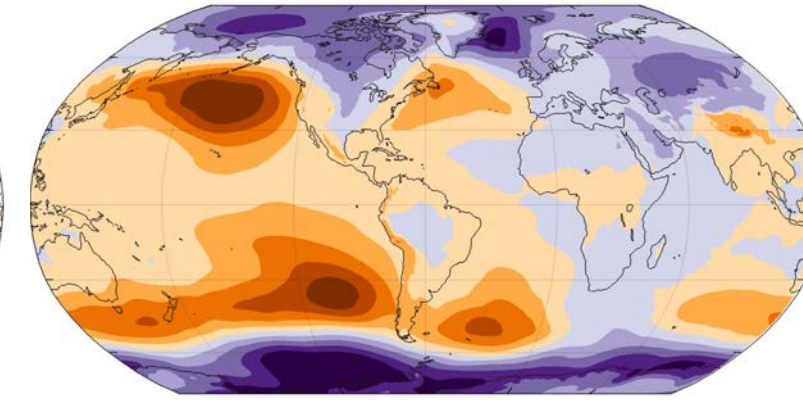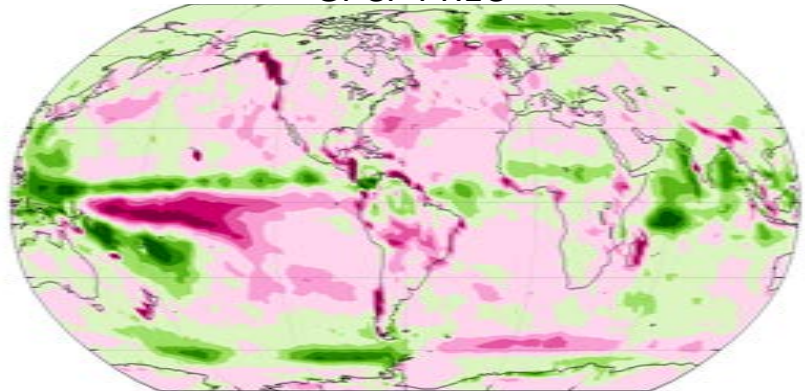
GPCP PREC — LR PREC (45 CESM1 + 34 CMIP6) — HR PREC (4 CESM1 + 6 HighResMIP)
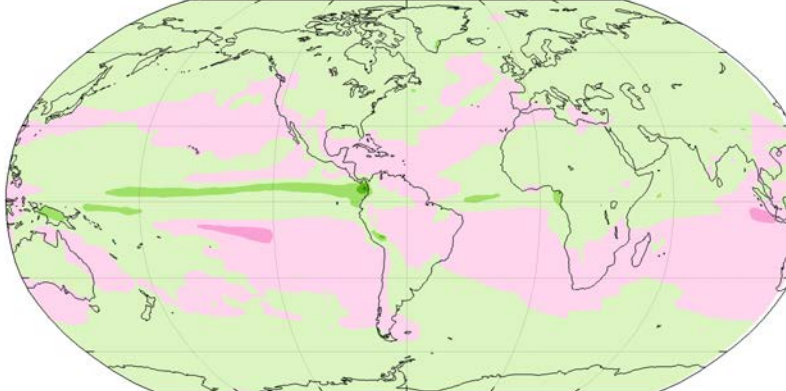
Multi-Year SST Prediction in CESM1-HR and -LR

From Yeager et al. (2023), njp Clim. Atmos. https://doi.org/10.21203/rs.3.rs-1792406/v1

Observed and Predicted Linear Trends

Yeager et al. (2023), njp Clim. Atmos. https://doi.org/10.21203/rs.3.rs-1792406/v1
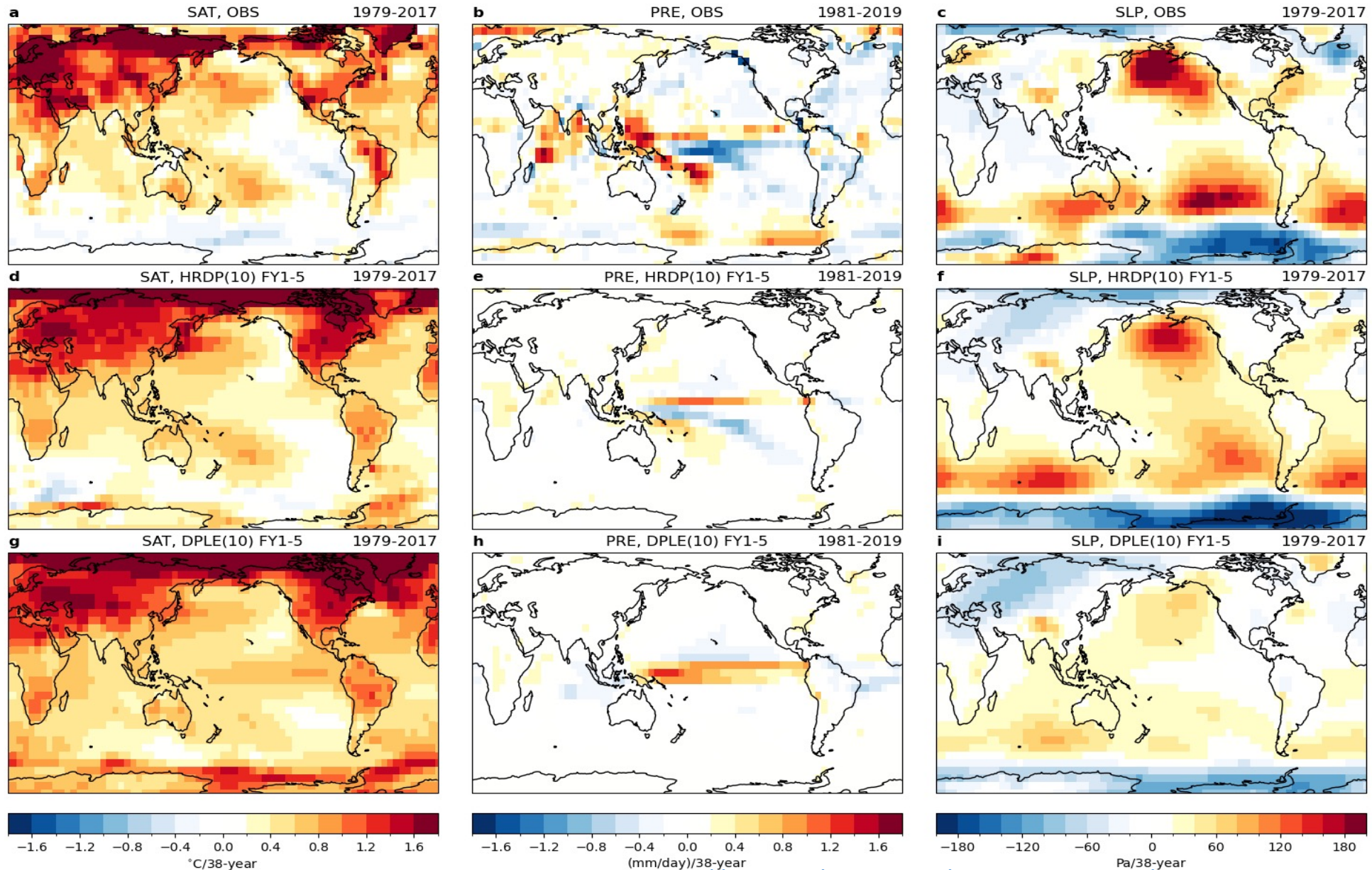
HR and LR Forced Ocean Sea-Ice (FOSI) Simulations

Yeager et al. (2023)
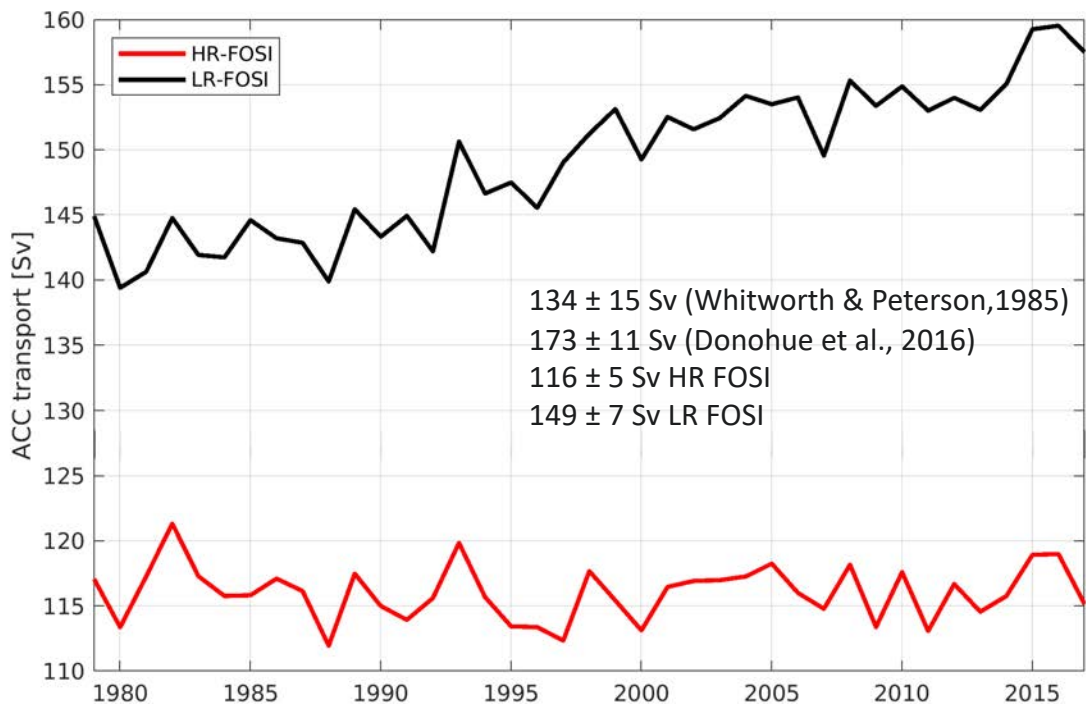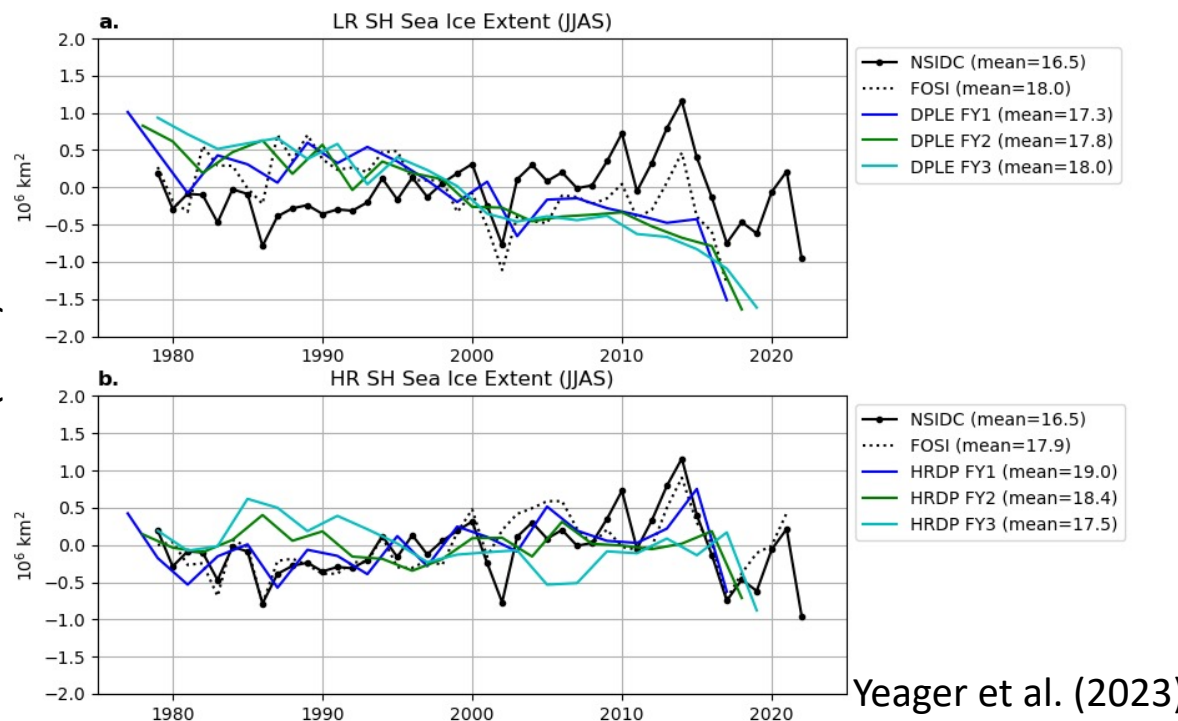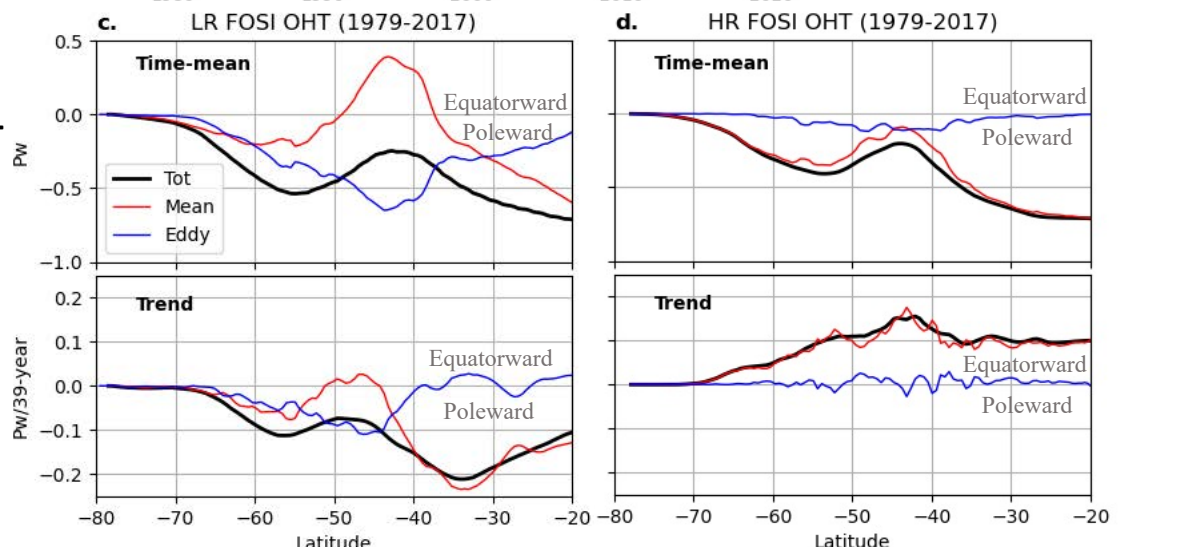
Summary

➢ Impact of Model Resolution on Southern Ocean (SO) Biases

- SO biases worsen from CMIP5 to CMIP6, particularly in warm SST and sea-ice extent
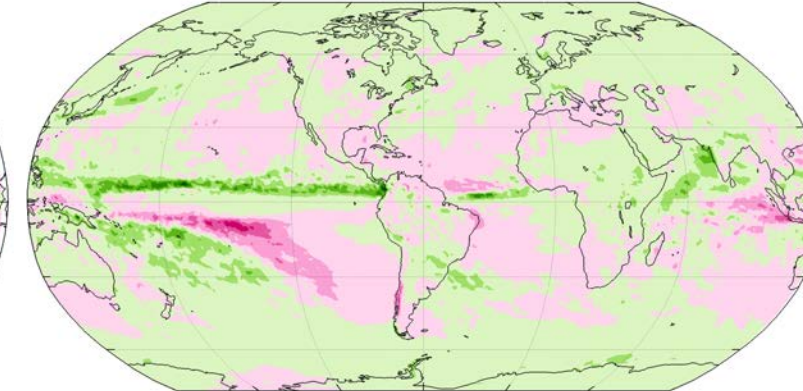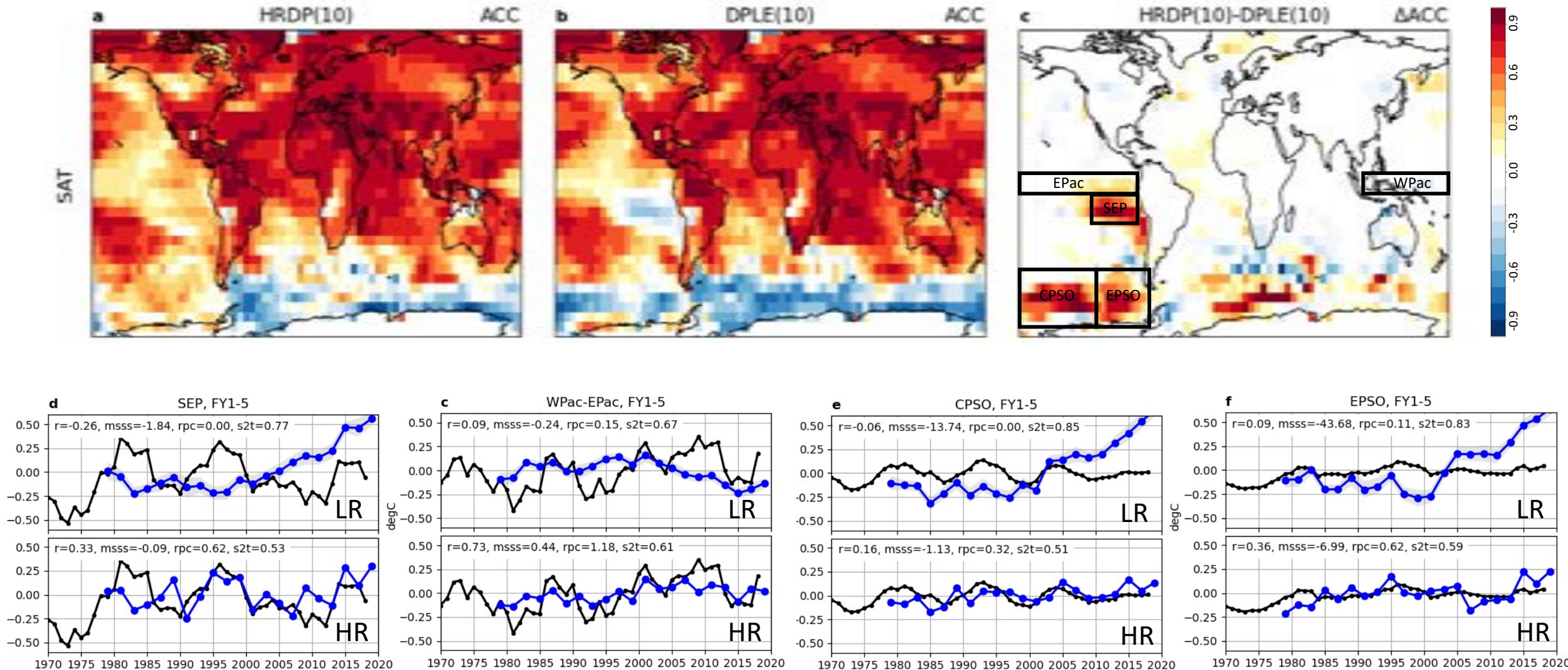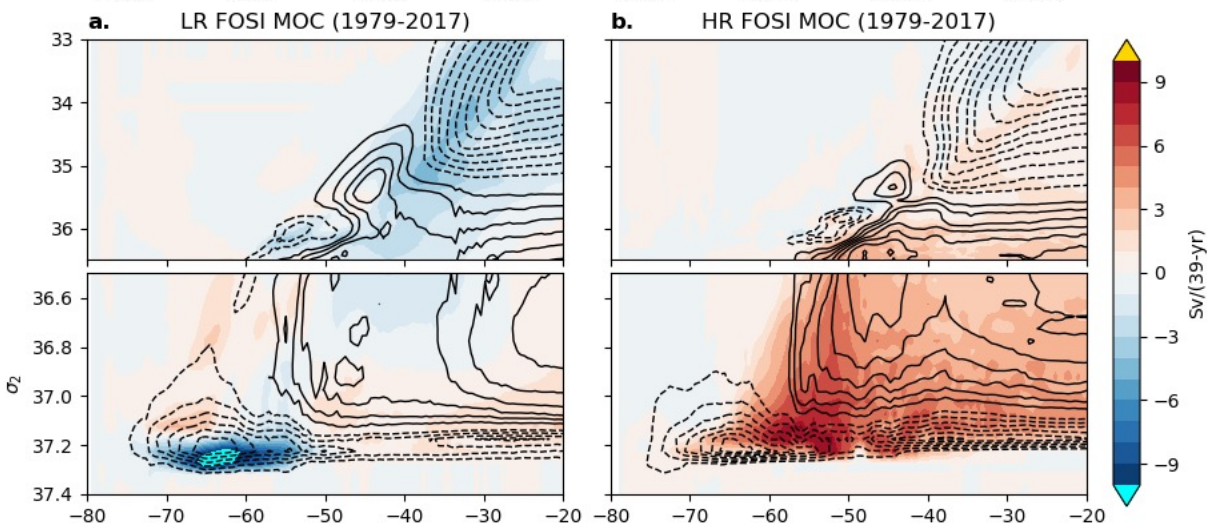- Increasing model horizontal resolution has a mixed impact on SO biases: improving mixed layer depth biases in austral winter but exacerbating warm SST and sea-ice biases
- Model resolution's effect on cloud cover and cloud radiative effect bias in the SO is limited, yet the worsened SST bias in HR correlates with changes in vertical turbulence mixing, suggesting a complex interplay among ocean eddies, vertical mixing, and air-sea fluxes, which requires further investigation

➢ Impact of Model Resolution on Climate Simulations and Predictions

- Increasing model horizontal resolution yields realistic SO anthropogenic changes despite SST and sea-ice biases, including strengthened westerlies, SST cooling trend, and sea-level pressure changes
- Increasing resolution also significantly enhances multi-year prediction skills for SO SST and SLP
- Findings prompt intriguing questions about the relationship between model bias, simulation, and prediction skill

➢ Importance of accurately representing SO eddies in climate models

- SO eddies play a pivotal role in compensating wind-driven meridional overturning and ocean heat transport, influencing the SO's response to climate change
- Eddy compensation differs between eddy-resolving and non-eddy-resolving climate models with parameterized eddy fluxes, potentially contributing to high- and low-resolution model disparities in simulating the SO's response to climate changes