CESM Workshop 2023
June 13, 2023

Reduced Southern Ocean Warming Enhances Global Skill and Signal-to-Noise in an Eddy-Resolving Decadal Prediction System

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This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

A Comparison of HR and LR Decadal Prediction Systems

CESM Decadal Prediction Large Ensemble (**DPLE**; Yeager et al., *BAMS*, 2018)

vs.

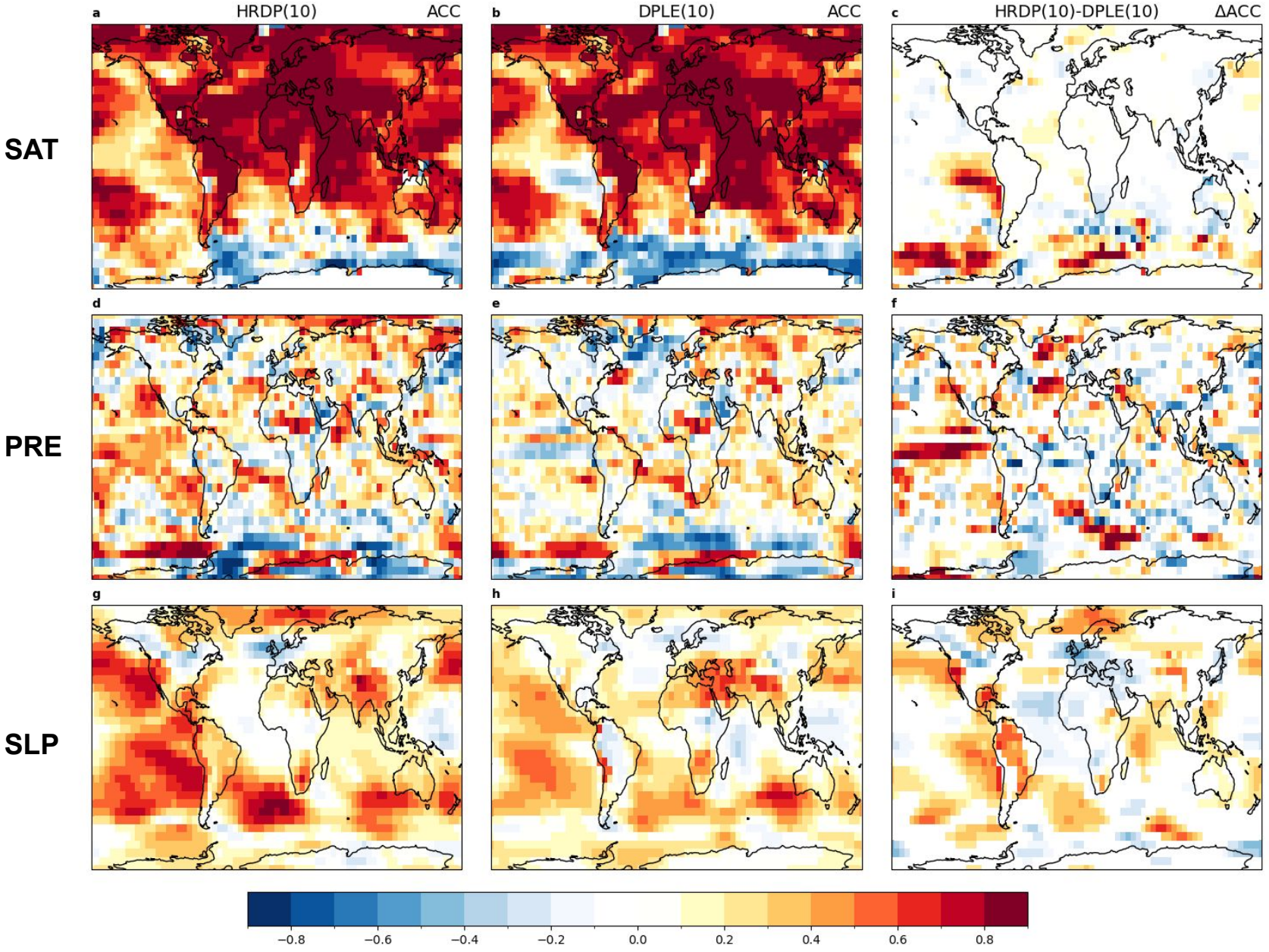
CESM High-Resolution Decadal Prediction (**HRDP**)

	HR	LR
	HRDP	**DPLE**
Model ocean atmosphere land sea ice	CESM1.3 POP2 (0.1°, 62L) CAM5-SE (0.25°, 30L) CLM4 (0.25°) CICE4 (0.1°)	CESM1.1 POP2 (1°, 60L) CAM5-FV (1°, 30L) CLM4 (1°) CICE4 (1°)
Forcing	CMIP5 RCP8.5	CMIP5 RCP8.5
Initialization ocean atmosphere land sea ice	Full field FOSI (0.1°, OMIP2) JRA55 HighResMIP Tier1 FOSI (0.1°, OMIP2)	Full field FOSI (1°, OMIP1ish) N/A N/A FOSI (1°, OMIP1ish)
Hindcasts start date init years length	N=21 Nov 1st 1976,1978,…,2016 62 mon	N=64 Nov 1st 1954-2017 122 mon
Ensemble Size	10	40
Total Sim-years	~1,000	~27,000
Normalized Cost	100	1

Yeager et al. (*npj Clim Atm Sci,* 2023, in review)

FY1-5 ACC (Annual)

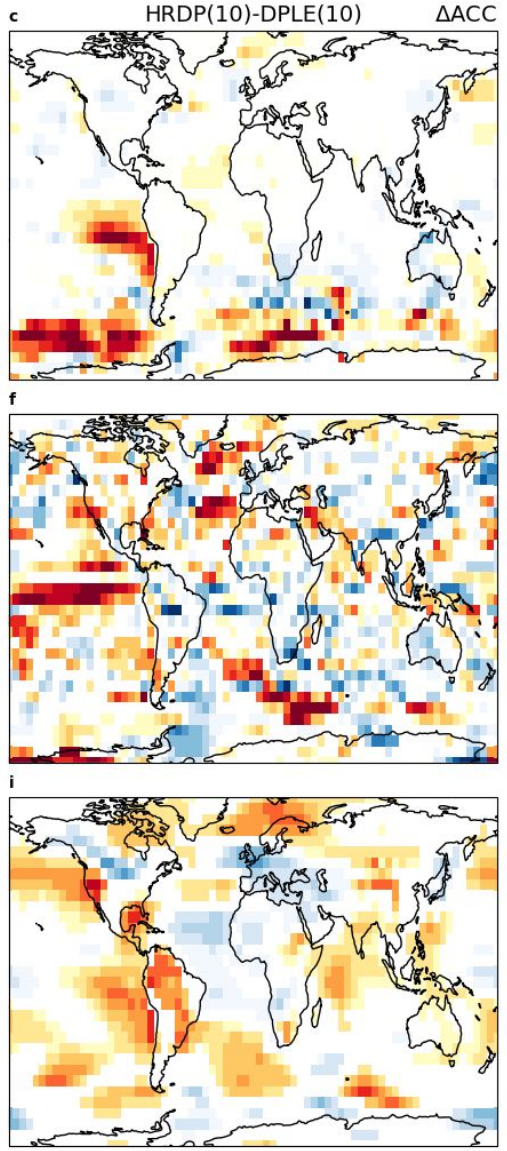
- All fields remapped to 5°x5°
- Verification Data:
  - CRU-TSv4.05+HadISST1
  - GPCPv2.3
  - ERA5
- DPLE resampled to match HRDP (10-member, N=21)
- Skill & skill difference plotted only where significant (p<0.1)
- Regional variation, but overall skill improvement for SAT, PRE, & SLP



FY1-5 ACC (Annual)

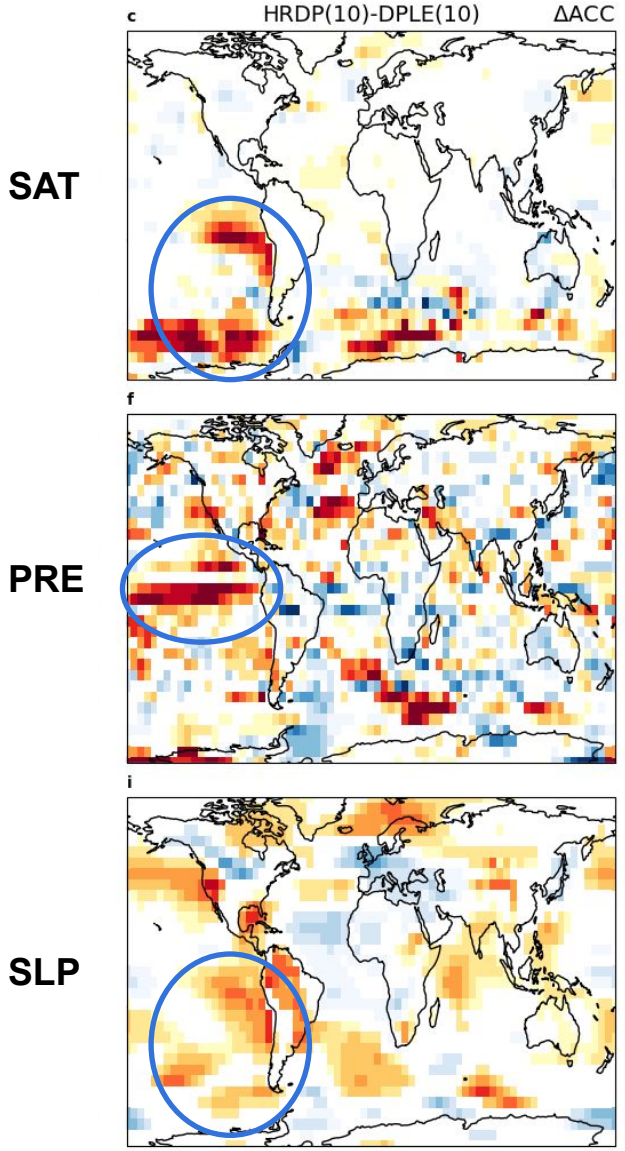
SAT		PRE		SLP	
26% +0.24	23% -0.13	25% +0.44	17% -0.38	30% +0.34	9% -0.26

- Top: percentage of global (80°S-80°N) surface area where HRDP(10) ACC is significantly greater than (left, in black) or less than (right, in grey) DPLE(10) ACC.
- Bottom: Area-weighted mean ACC score differences



FY1-5 ACC (Annual)

★ Enhanced global skill is related to improved Southern Ocean evolution via a SO to tropical Pacific teleconnection



FY1-5 ACC (Detrended Annual)

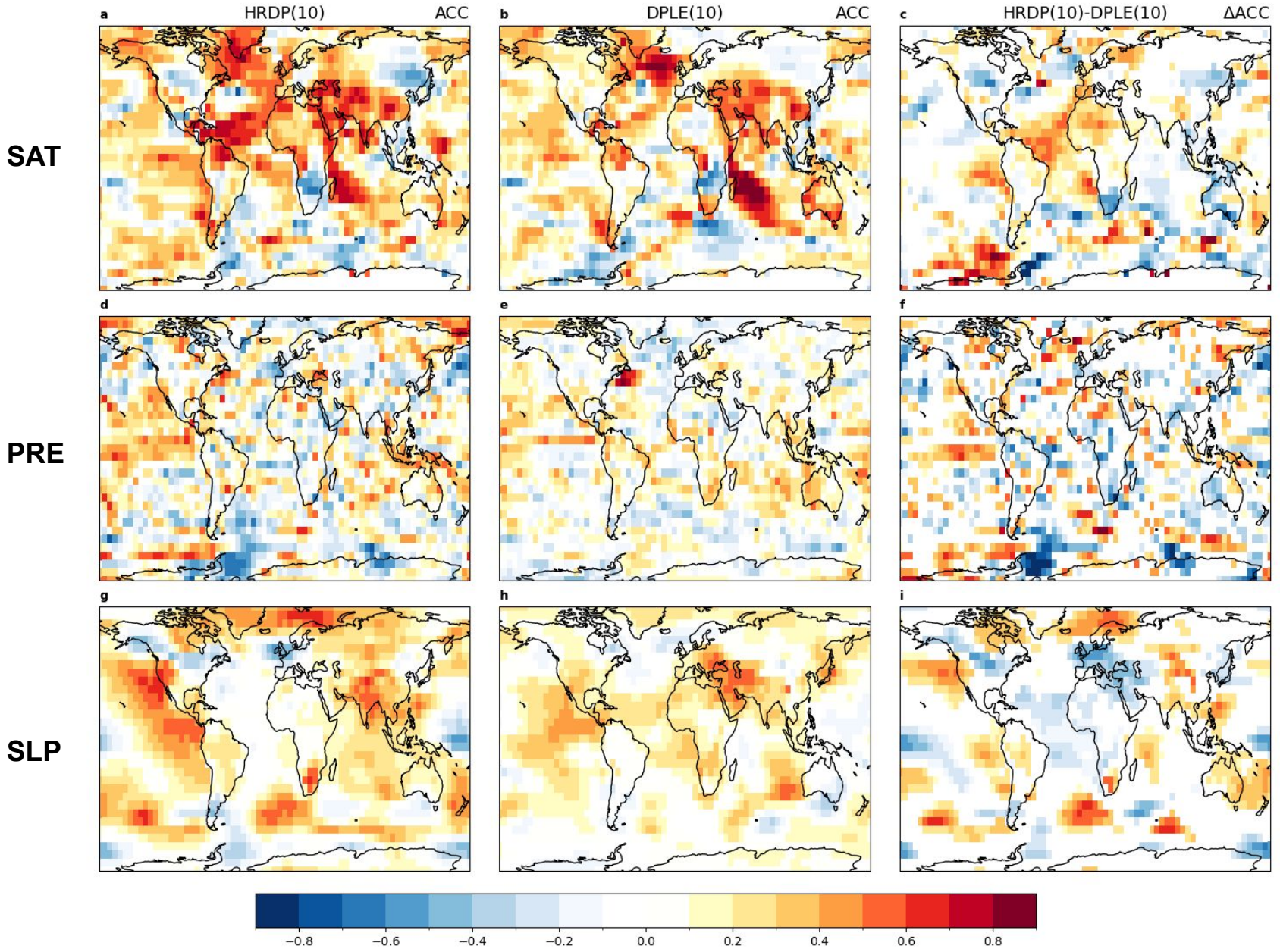
- Suggestion of a role for internal variability in skill improvement (not just improved response to external forcing)

  SAT: southeastern Pacific (SEP), Subtropical Atlantic, Pacific SO

  PRE: Eastern Trop Pac

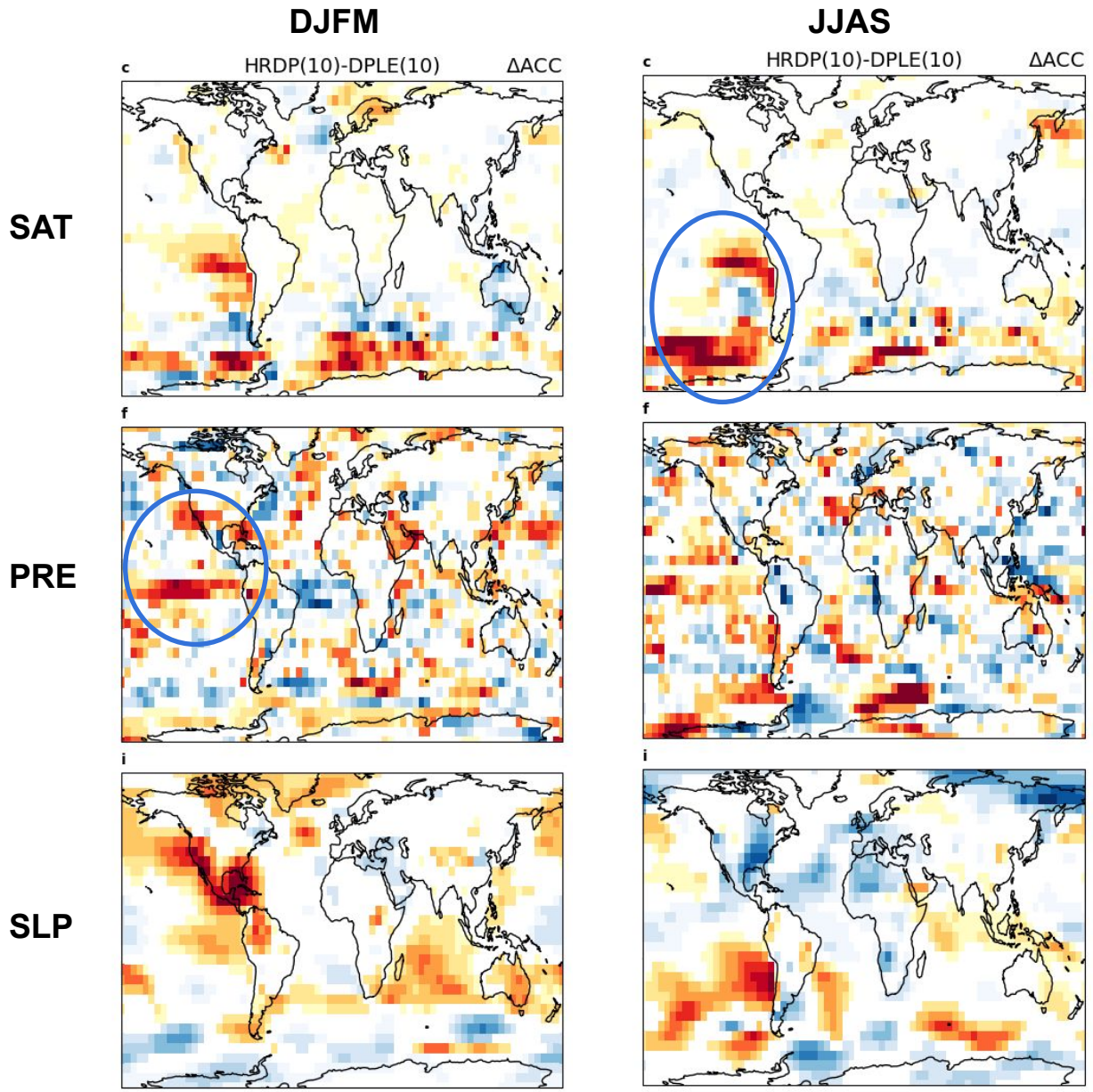
  SLP: NAM

- A more sophisticated removal of forced signal yields similar results



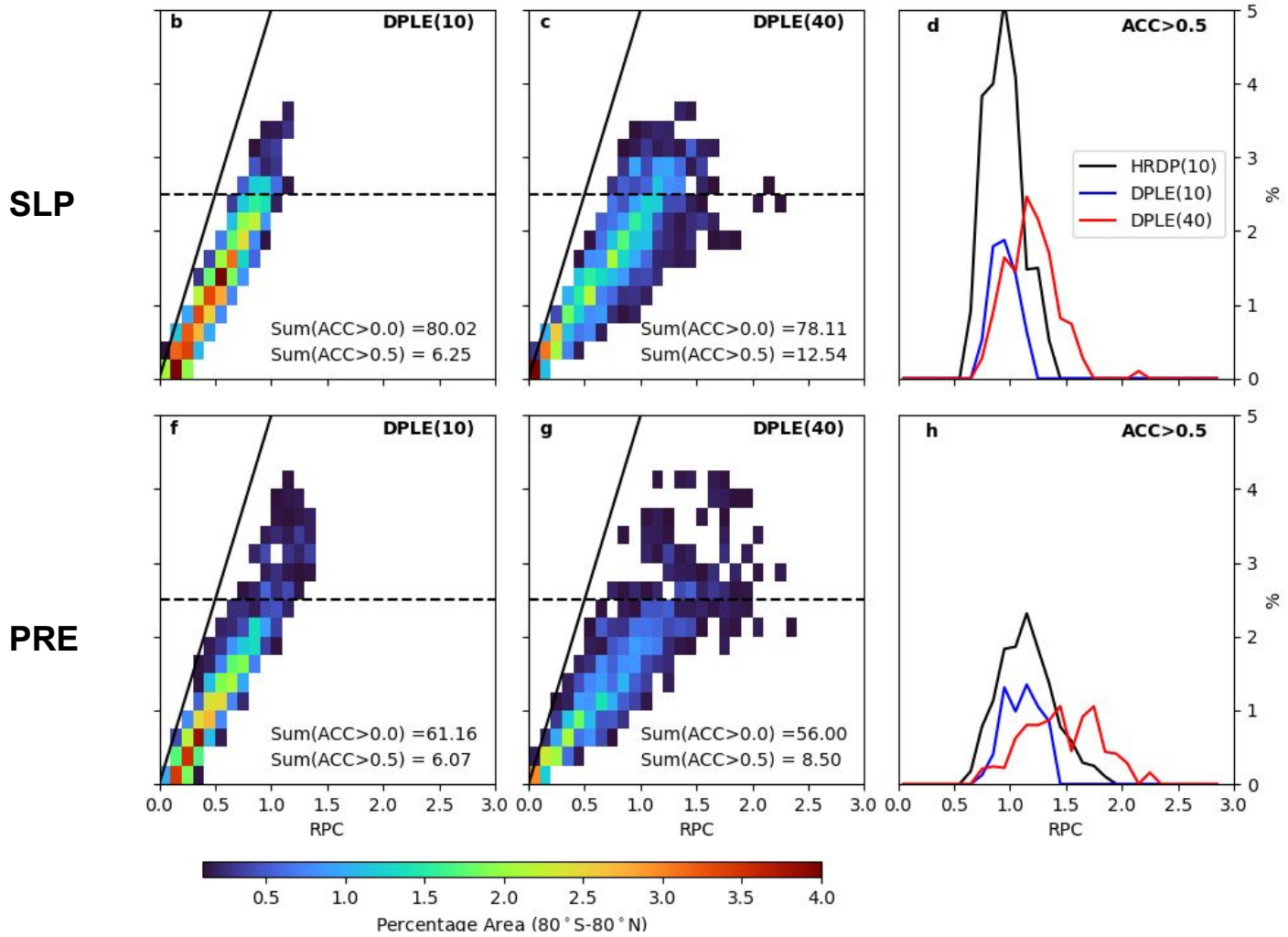
FY1-5 ACC (DJFM, JJAS)

- Overall skill improvement seen in all seasons (except SLP in NH summer)
- East Pacific/Southern Ocean SAT skill shows largest improvement in austral winter
- Better prediction of convective precip in Eastern Trop Pacific in DJFM likely contributes to large-scale improvements in DJFM



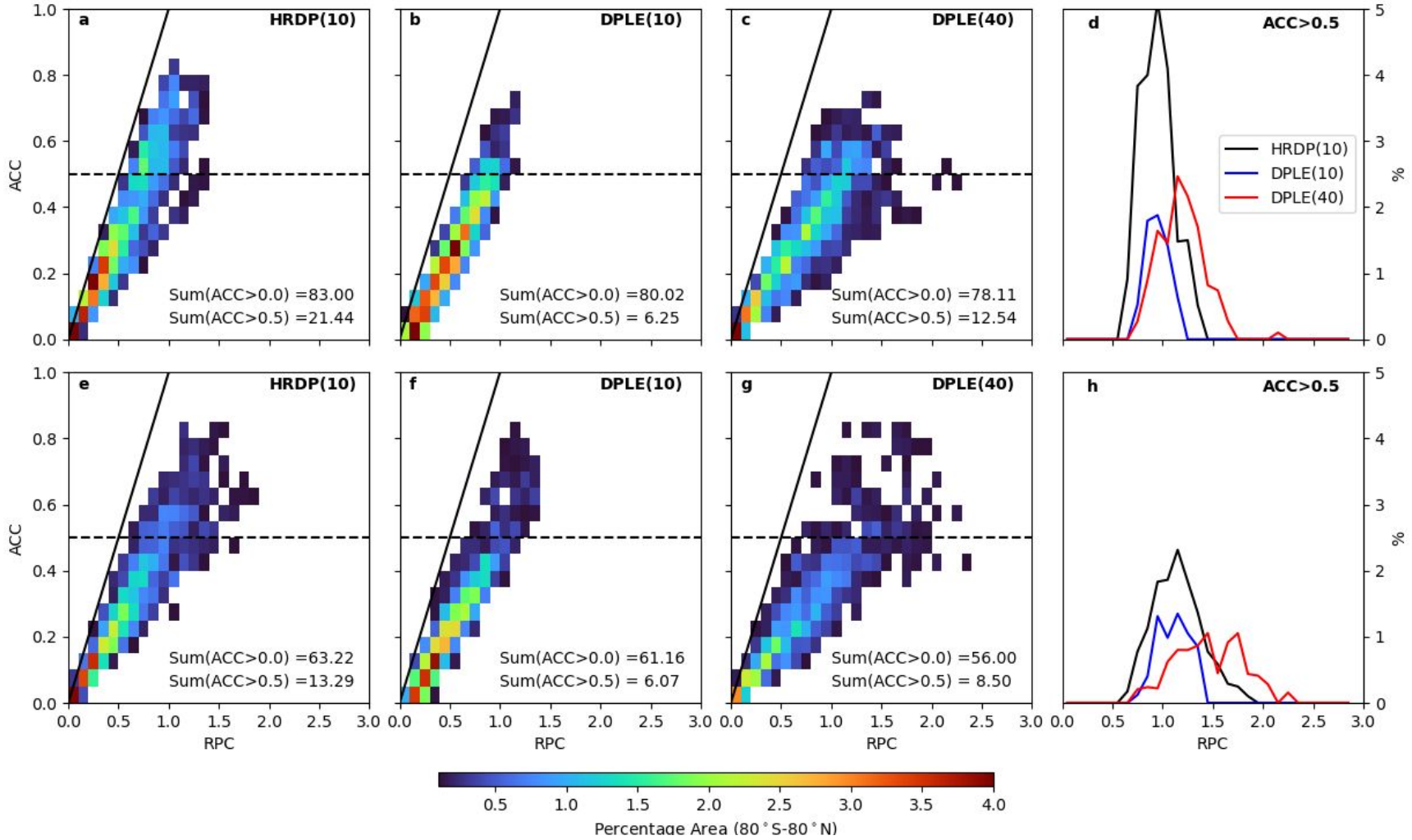
Improved Signal-to-noise in HRDP

- Signal-to-noise paradox when RPC = ACC/S2T > 1 (Scaife&Smith 2018)
- Global (80°S-80°N) skill metric joint pdf's
- Skill increase in DPLE(40) compared to DPLE(10), but at expense of RPC>1



Improved Signal-to-noise in HRDP

- Despite “noisier” physics (ocean eddies + eddy-sensitive atmosphere), S2T in HRDP is not degraded relative to DPLE(10) and is higher compared to DPLE(40)
- Much larger areas of high skill (ACC>0.5) combined with RPC~1

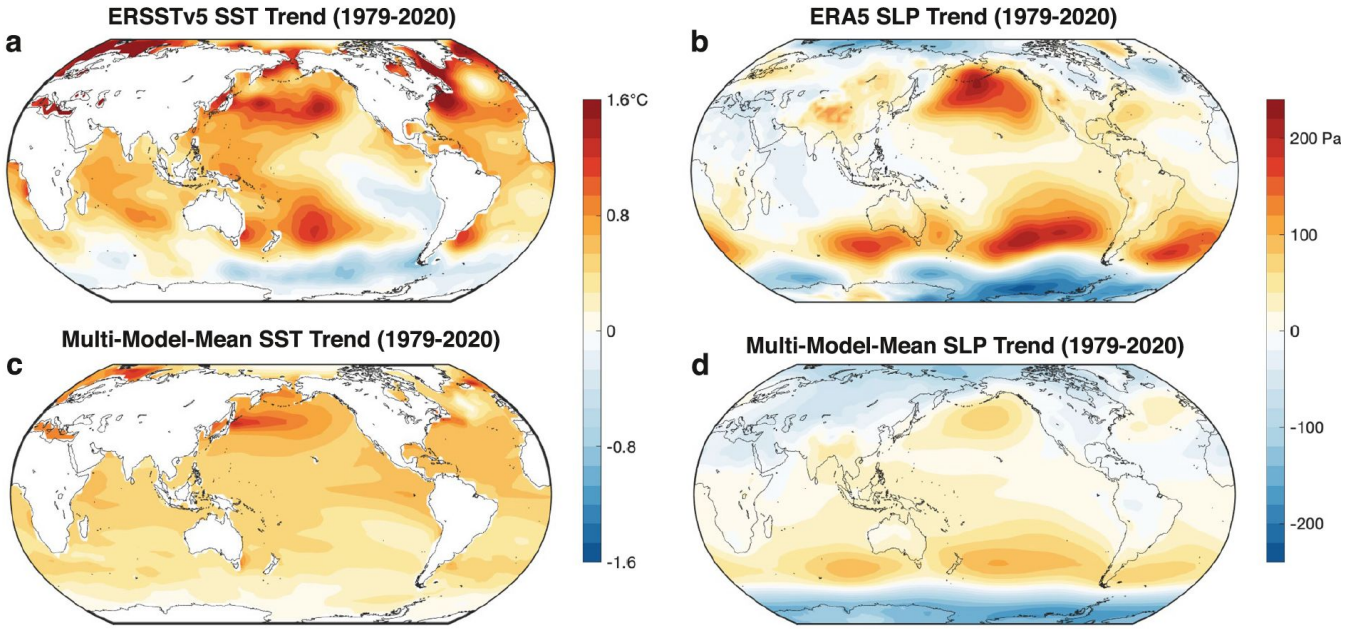


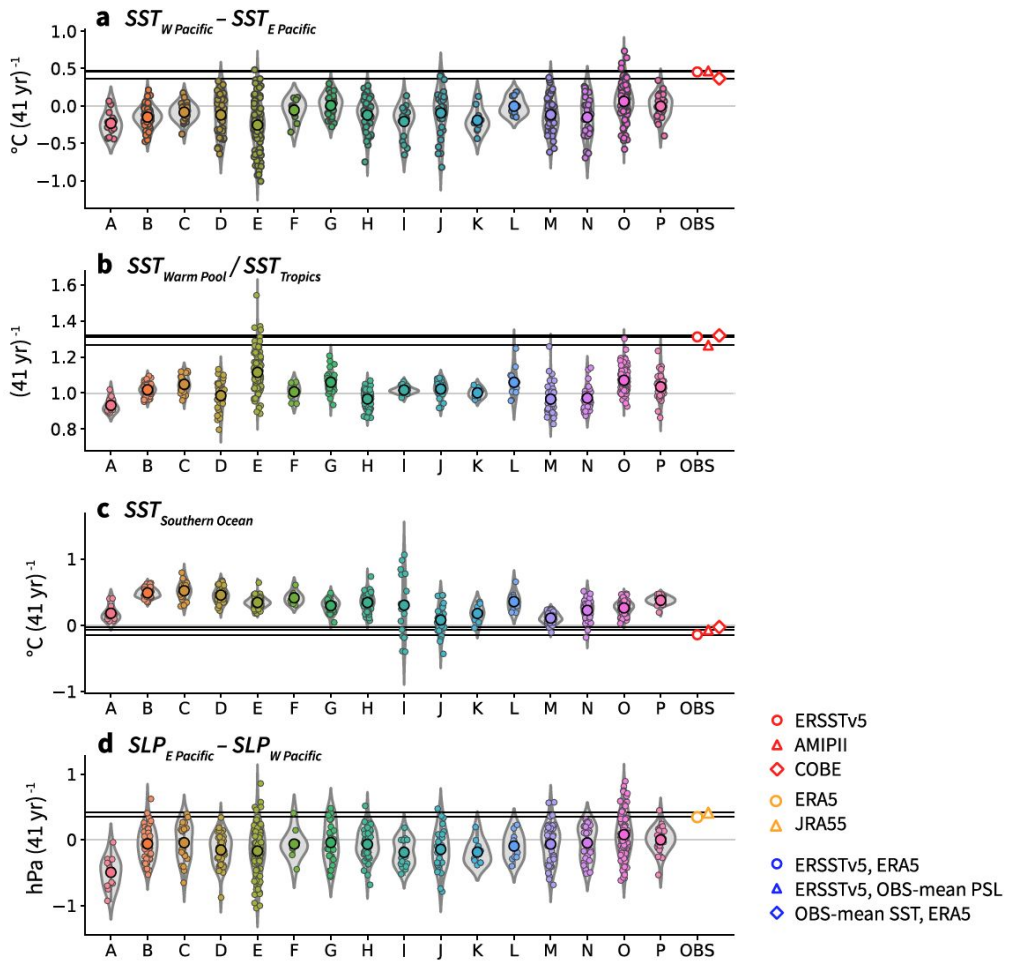
High-resolution enhances skill more than a quadrupling of ensemble size, and without introducing widespread signal-to-noise paradox

2022

Systematic Climate Model Biases in the Large-Scale Patterns of Recent Sea-Surface Temperature and Sea-Level Pressure Change

Robert C. J. Wills[1], Yue Dong[2], Cristian Proistosecu[3], Kyle C. Armour[1,4], and David S. Battisti[1]



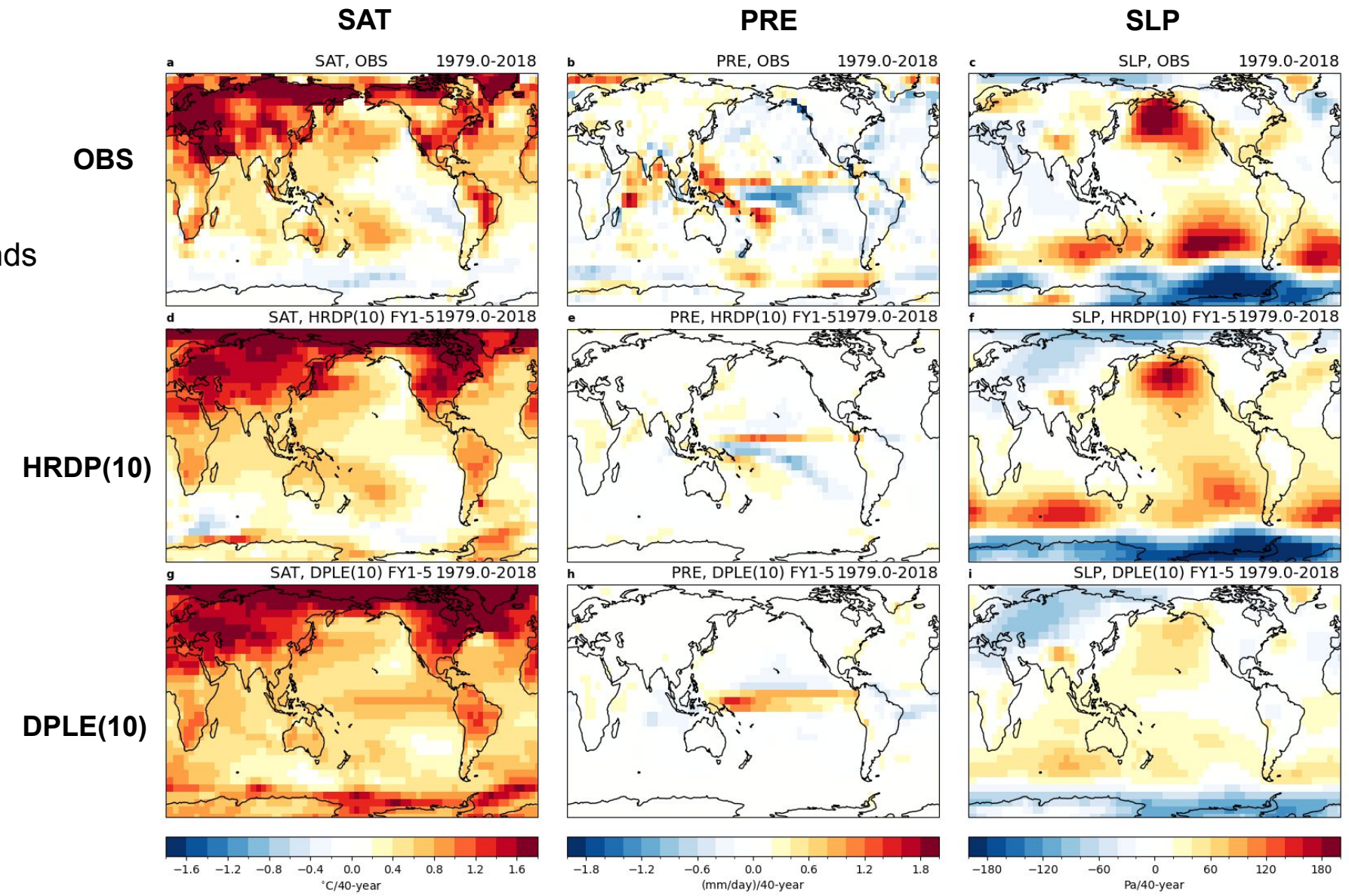


- Observed trends over recent decades:
  - enhanced West Pac warming
  - East Pac cooling
  - strengthened Walker circulation
  - Southern Ocean cooling

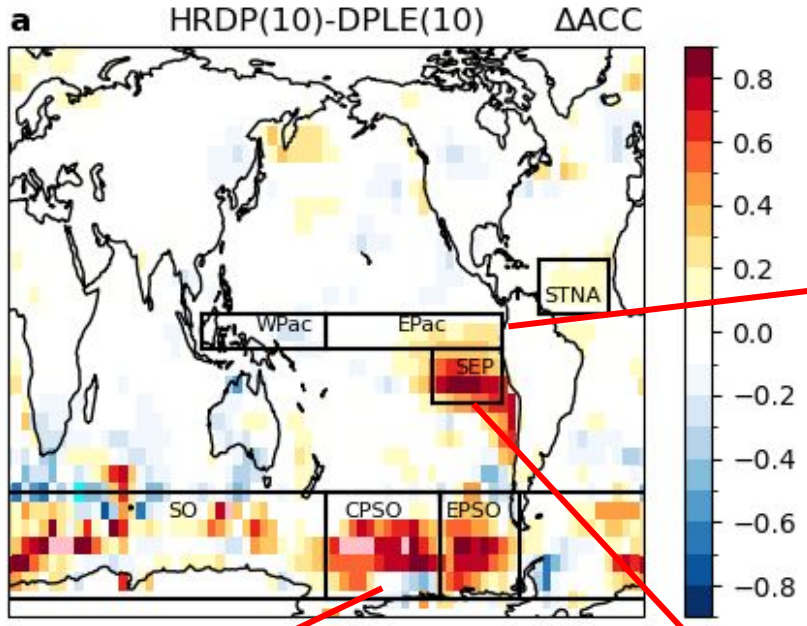
- CMIP5 & CMIP6 large ensembles :
  - enhanced East Pac warming
  - weakened Walker circulation
  - Southern Ocean warming
- Unlikely due to internal variability, suggests biased response to external forcing

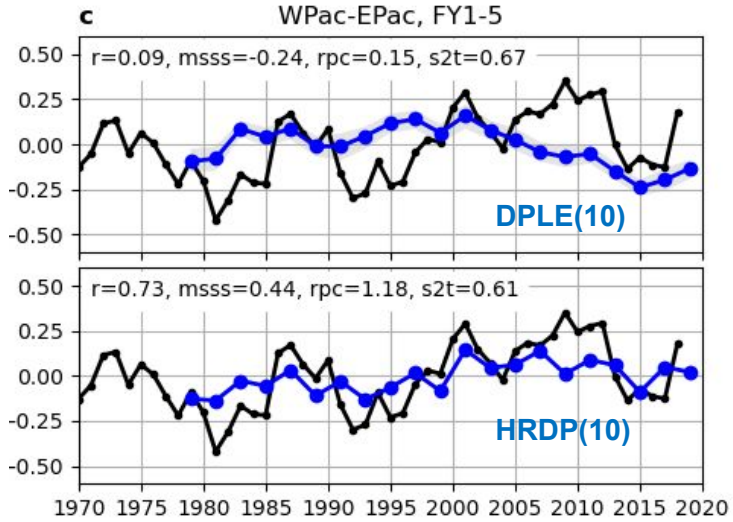
FY1-5 Trends

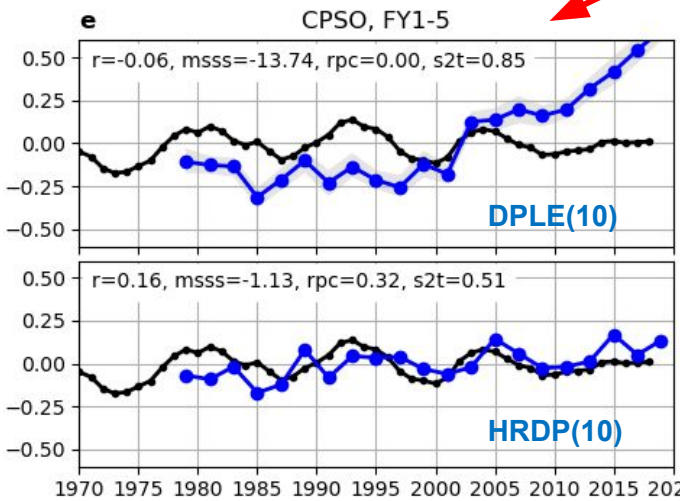
- HRDP(10) reproduces realistic trends
- DPLE(10) does not

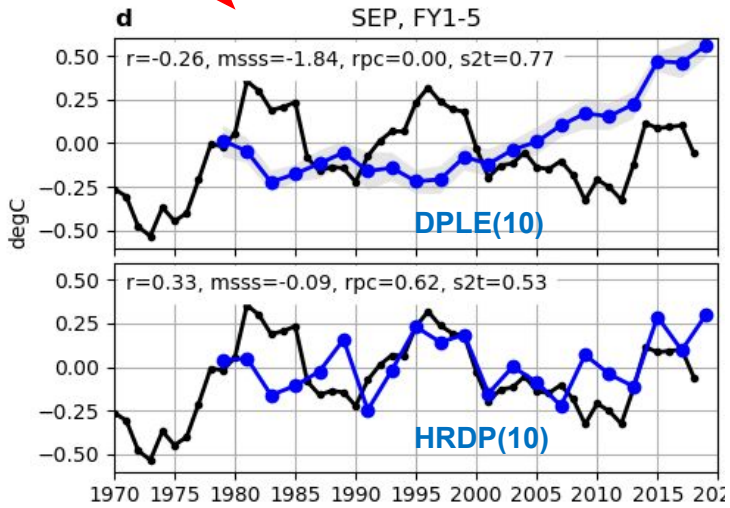


FY1-5
SAT Timeseries
(Annual)





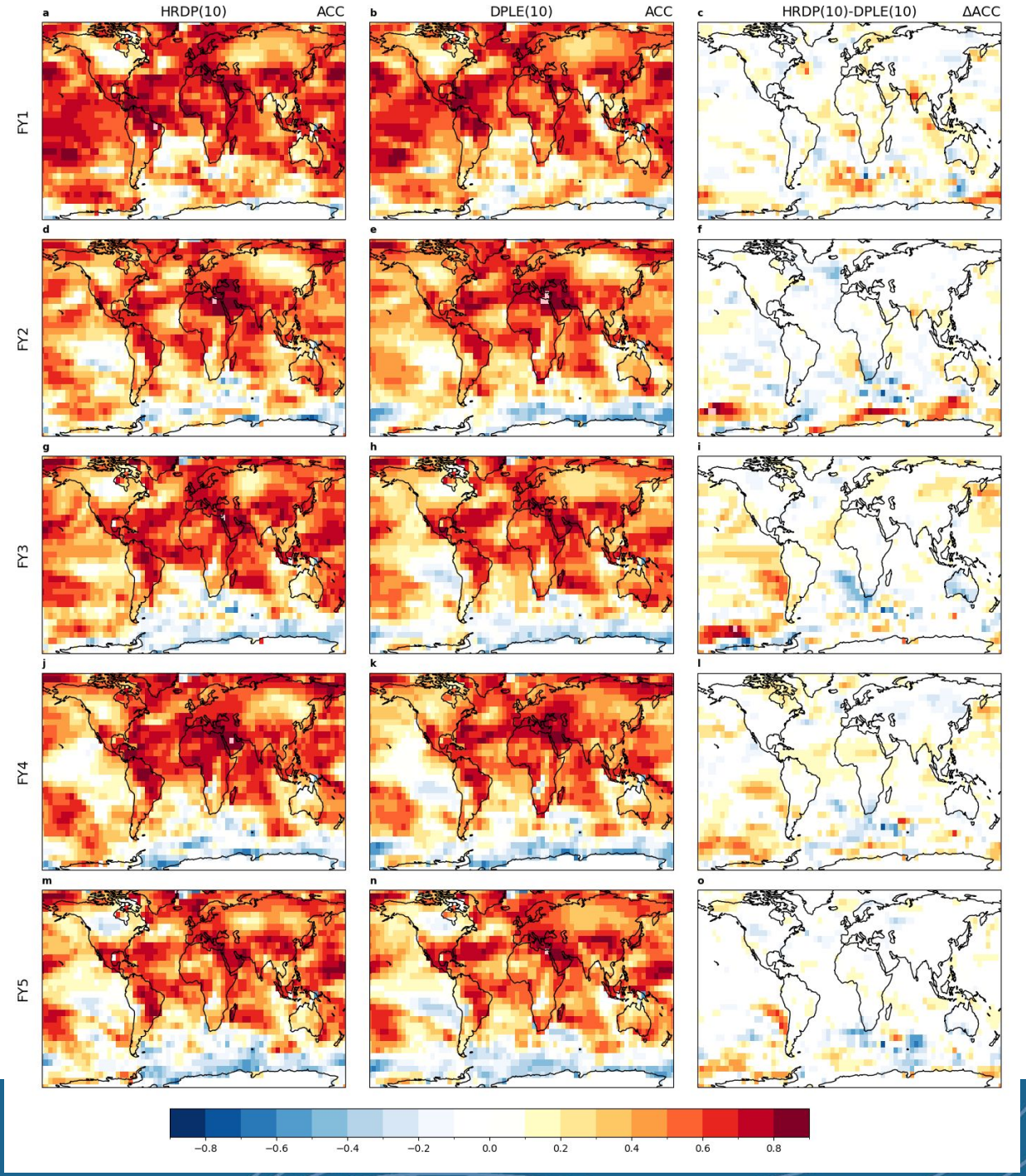




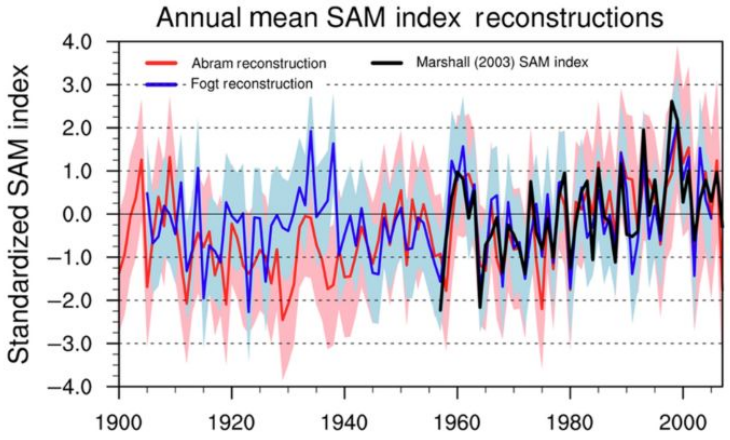
SAT ACC by FY

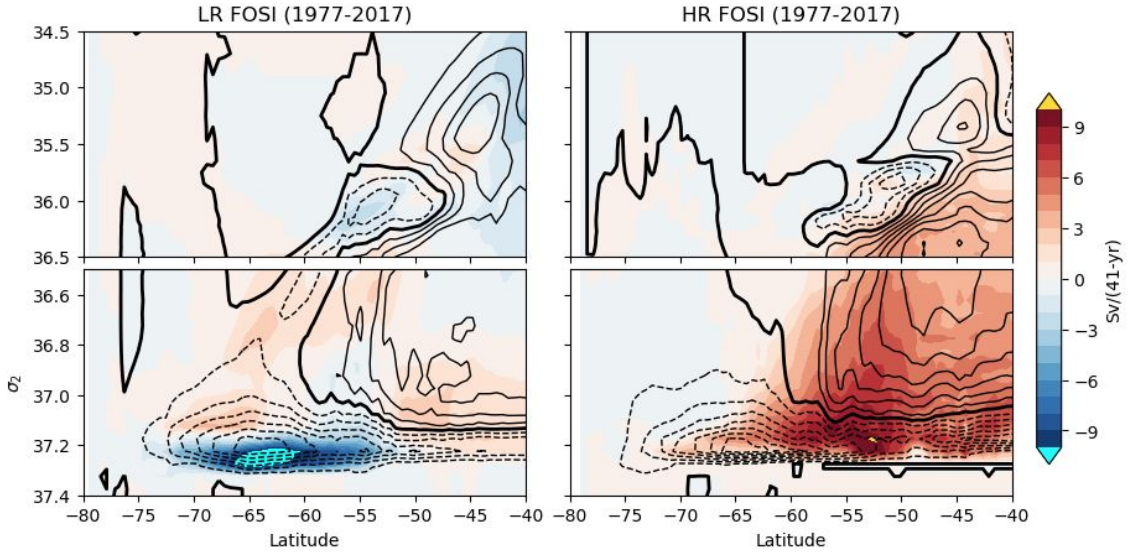
- HRDP(10) skill improvement in SO at early leads, but not in SEP

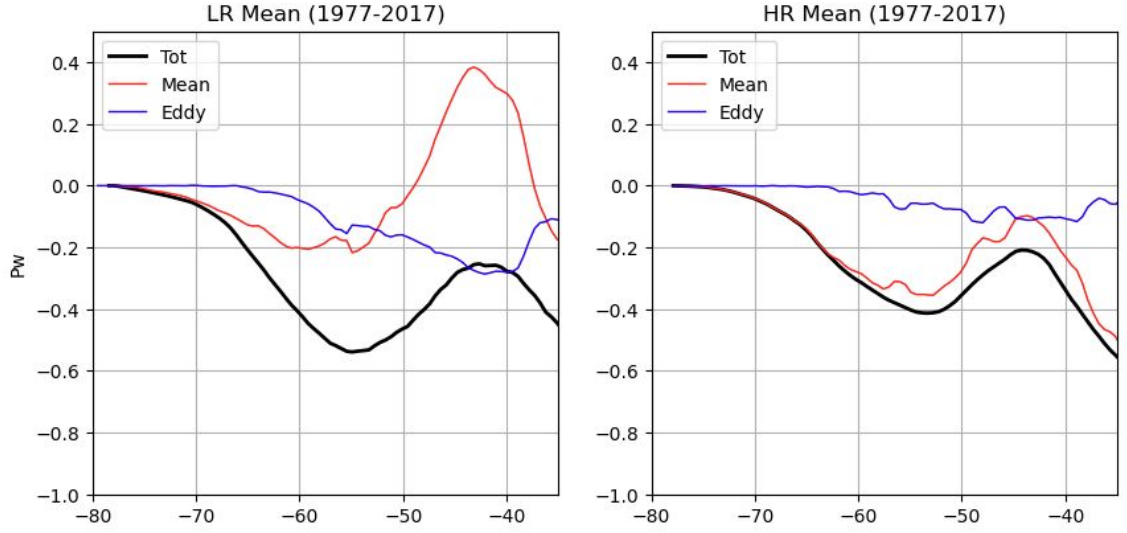
 SEP skill improvements derive from SO skill improvements, not the other way around

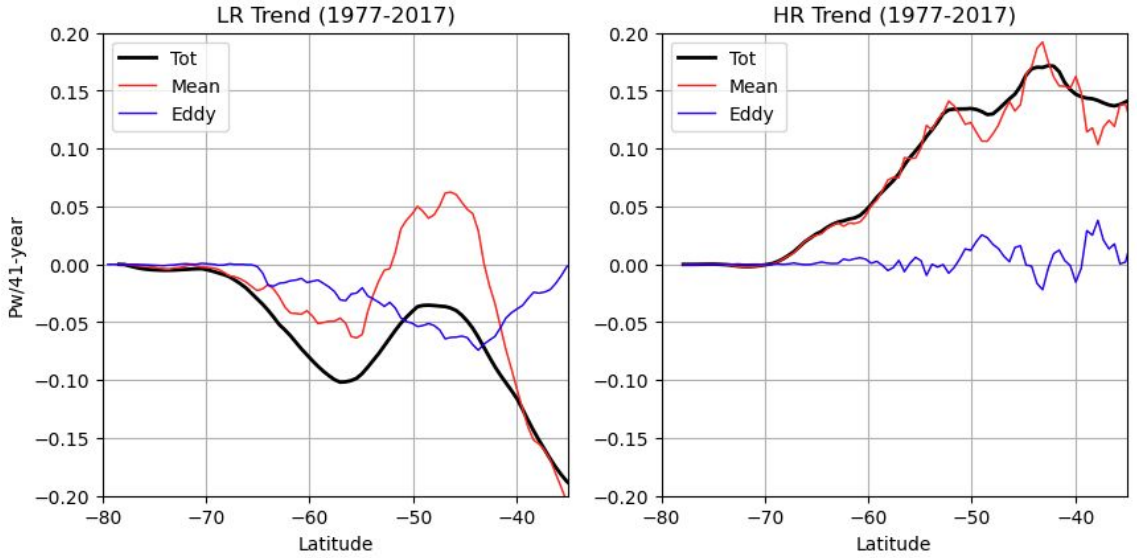


FOSI: Southern Ocean Response to SAM trend









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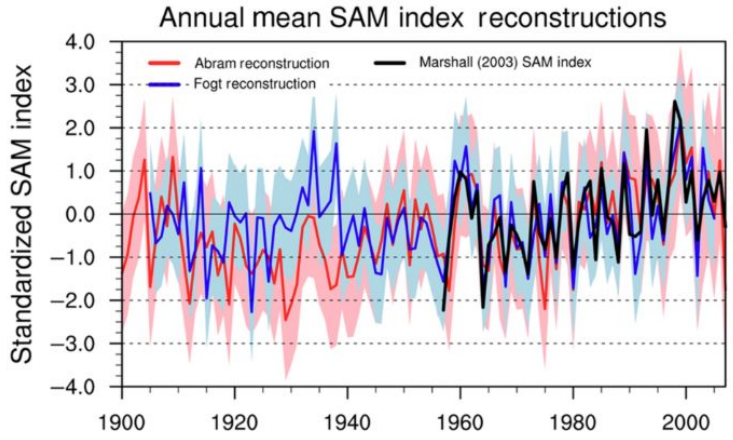

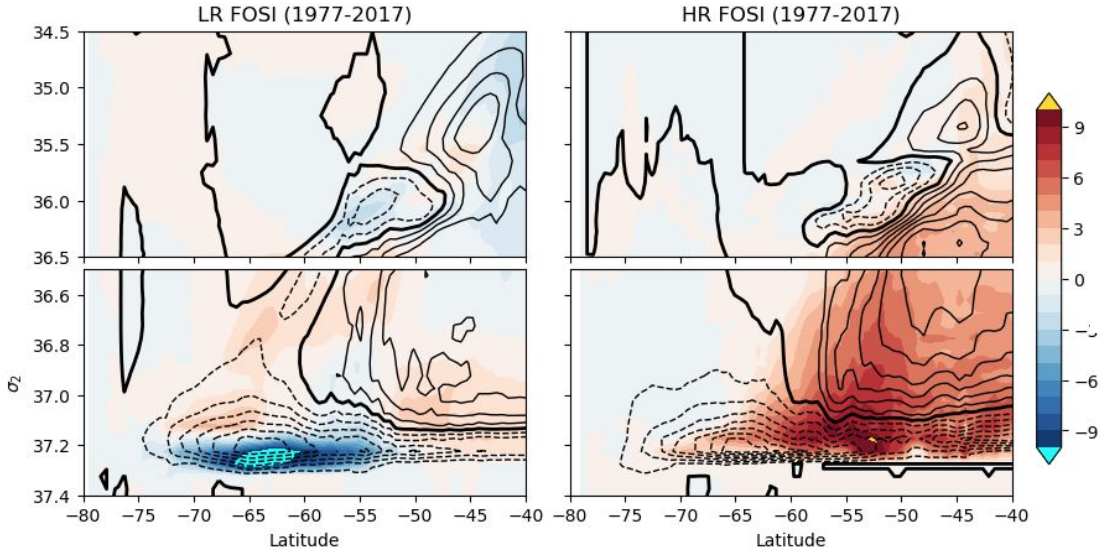

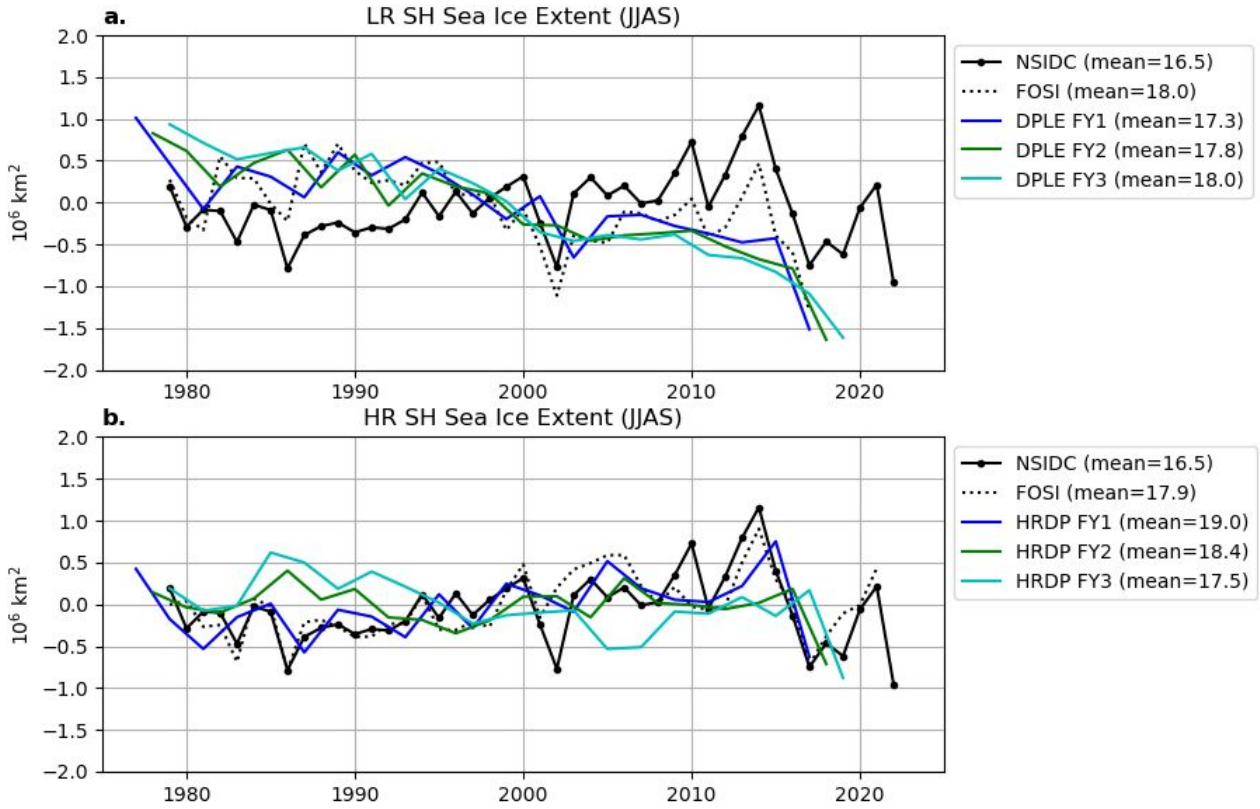

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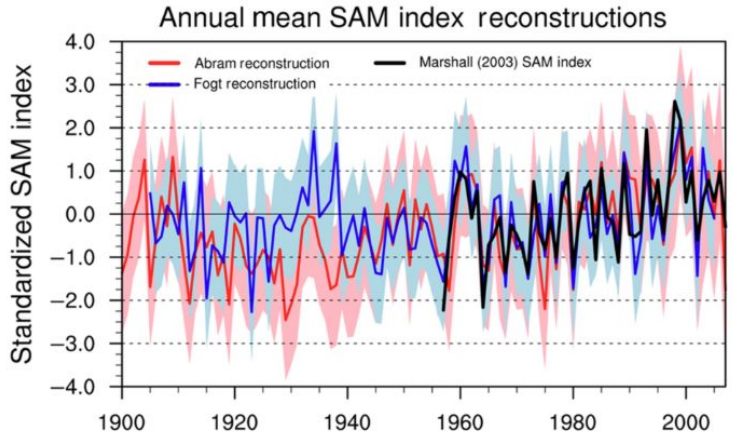
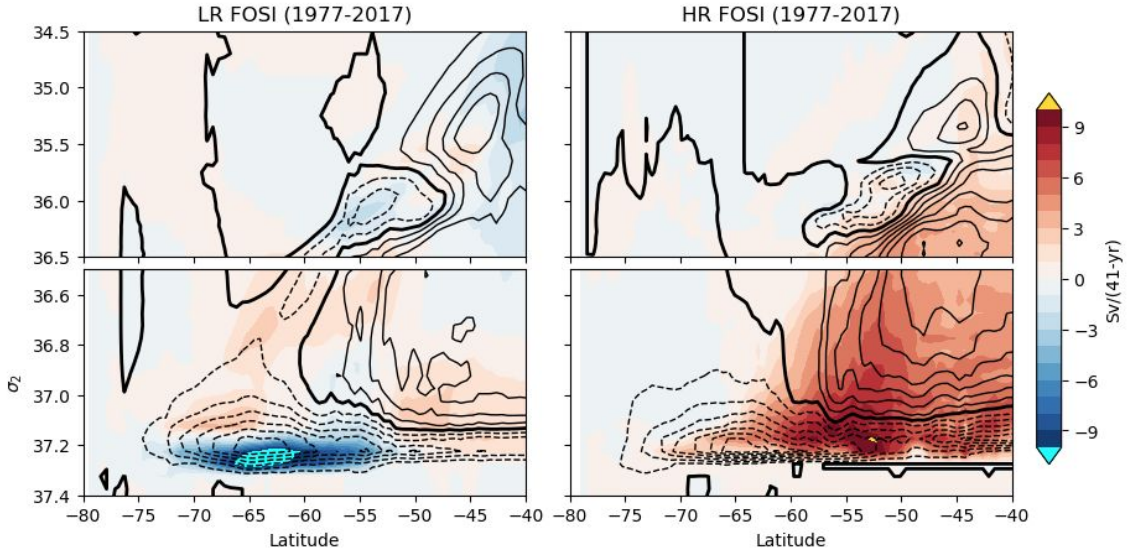
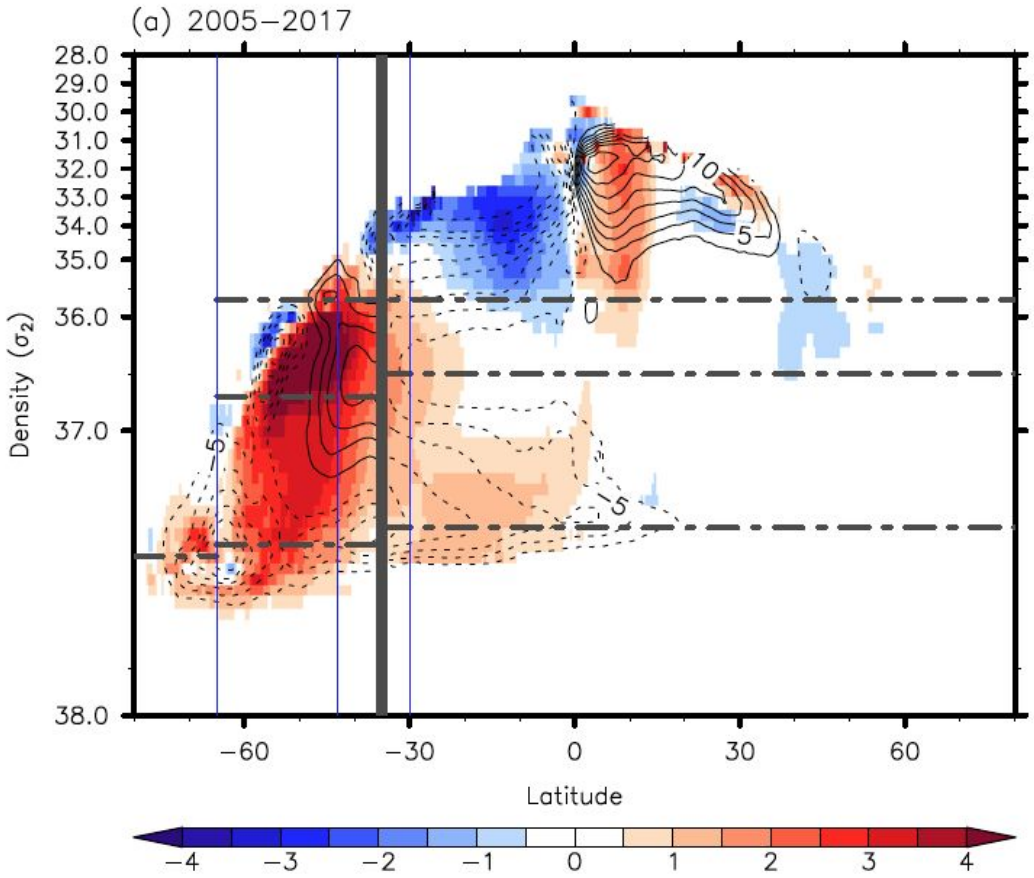




Observation-based Estimate
[(2005-2017) – (1955-1974)]:



Lee et al., 2023: Human-induced changes in the global meridional overturning circulation are emerging from the Southern Ocean, *Commun Earth Environ*, 4, 69, doi:10.1038/s43247-023-00727-3.

Summary

- A direct comparison of CESM1 HR/LR decadal prediction systems shows:
  - Overall skill improvement for SAT/PRE/SLP, although results vary from region to region
  - Better signal-to-noise characteristics (particularly, for SLP): higher S2T, RPC→1

- To first order, improved realism in HR appears to be related to improved Southern Ocean evolution (partly forced, partly internal) and associated teleconnections to the tropical eastern Pacific. Results offer new line of evidence in support of hypothesized role of Southern Ocean as a global climate pacemaker via its influence on the Tropics, building on numerous recent studies:

Zhang, Deser, Sun: Is There a Tropical Response to Recent Observed Southern Ocean Cooling? *Geophys Res Lett*, 2021

Chung, Kim, Timmermann, Ha, Lee, et al: Antarctic sea-ice expansion and Southern Ocean cooling linked to tropical variability, *Nat Clim Ch*, 2022

Dong, Armour, Battisti, Blanchard-Wrigglesworth: Two-Way Teleconnections between the Southern Ocean and the Tropical Pacific via a Dynamic Feedback, *J Clim*, 2022

Kim, Kang, Kay, Xie: Subtropical clouds key to Southern Ocean teleconnections to the tropical Pacific, *PNAS*, 2022

Wills, Dong, Proistosecu, Armour, Battisti: Systematic Climate Model Biases in the Large-Scale Patterns of Recent Sea-Surface Temperature and Sea-Level Pressure Change, *Geophys Res Lett*, 2022.

Summary

- We speculate that the eddy-resolving ocean model in HR is a key factor in global skill improvement via improved representation of SO (internal+external) processes in a region of high eddy activity, following:

Armour, Marshall, Scott, Donohoe, Newsom: Southern Ocean warming delayed by circumpolar upwelling and equatorward transport, *Nat Geoscience*, 2016

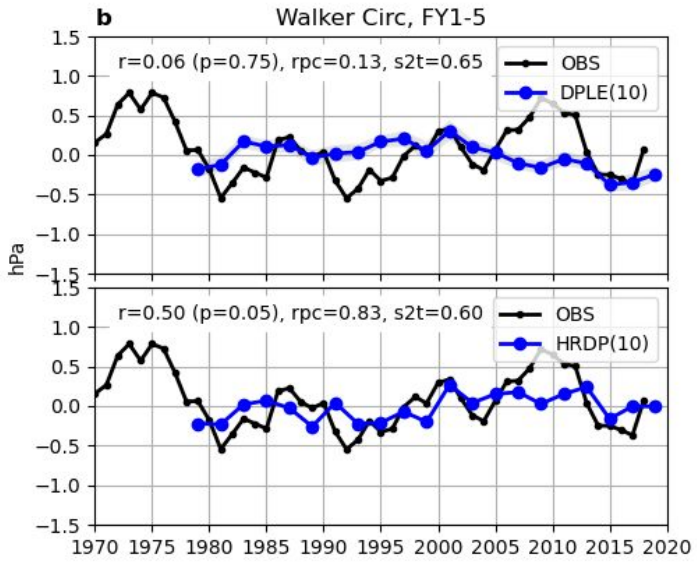
Rackow, Danilov, Goessling, et al: Delayed Antarctic sea-ice decline in high-resolution climate change simulations, *Nat Commun*, 2022

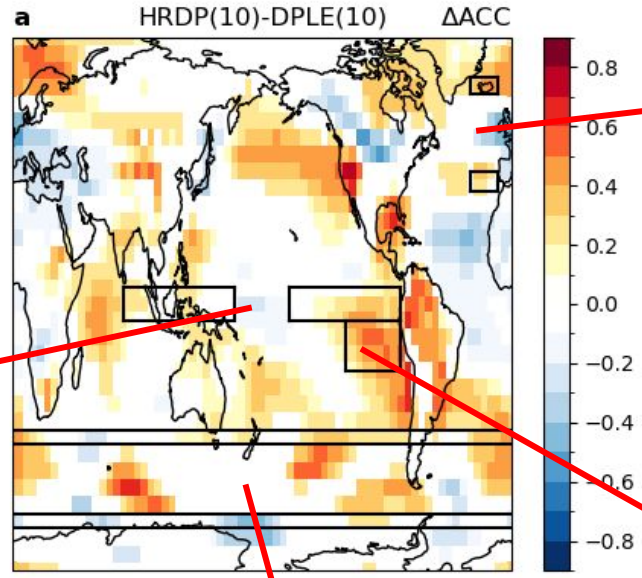
- Further investigation is needed to quantify relative roles of various process-level differences in contributing to improved prediction performance in HRDP, e.g.:
  - mesoscale air-sea interaction (present in HR, but absent in LR)
  - mean state bias reduction
  - improved SST/low-cloud feedbacks
  - response to forcing due to increased atmospheric resolution

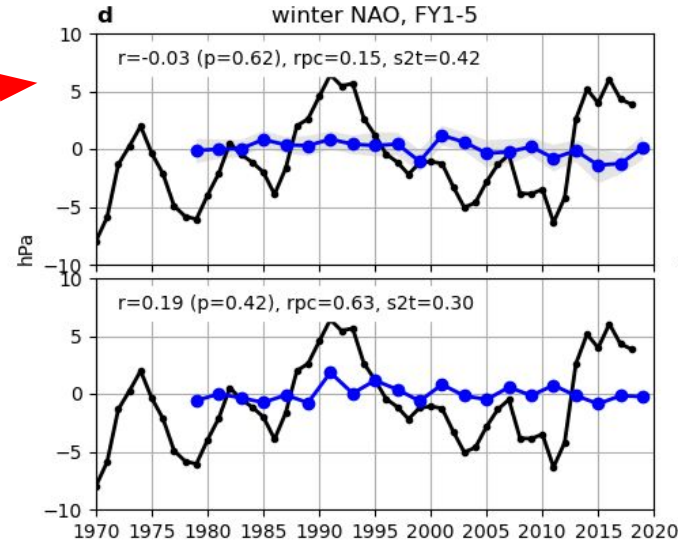
Yeager et al. (*npj Clim Atm Sci,* 2023, in review, https://doi.org/10.21203/rs.3.rs-1792406/v1)

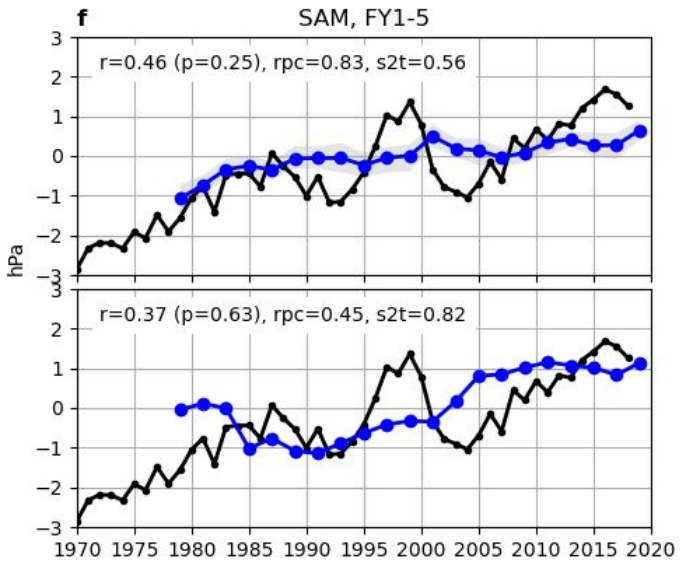
Extra Slides

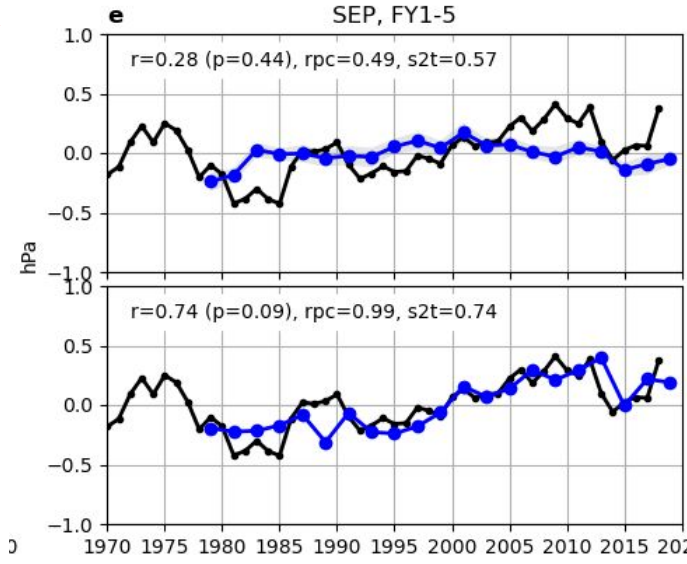
FY1-5
SLP Timeseries
(Annual)





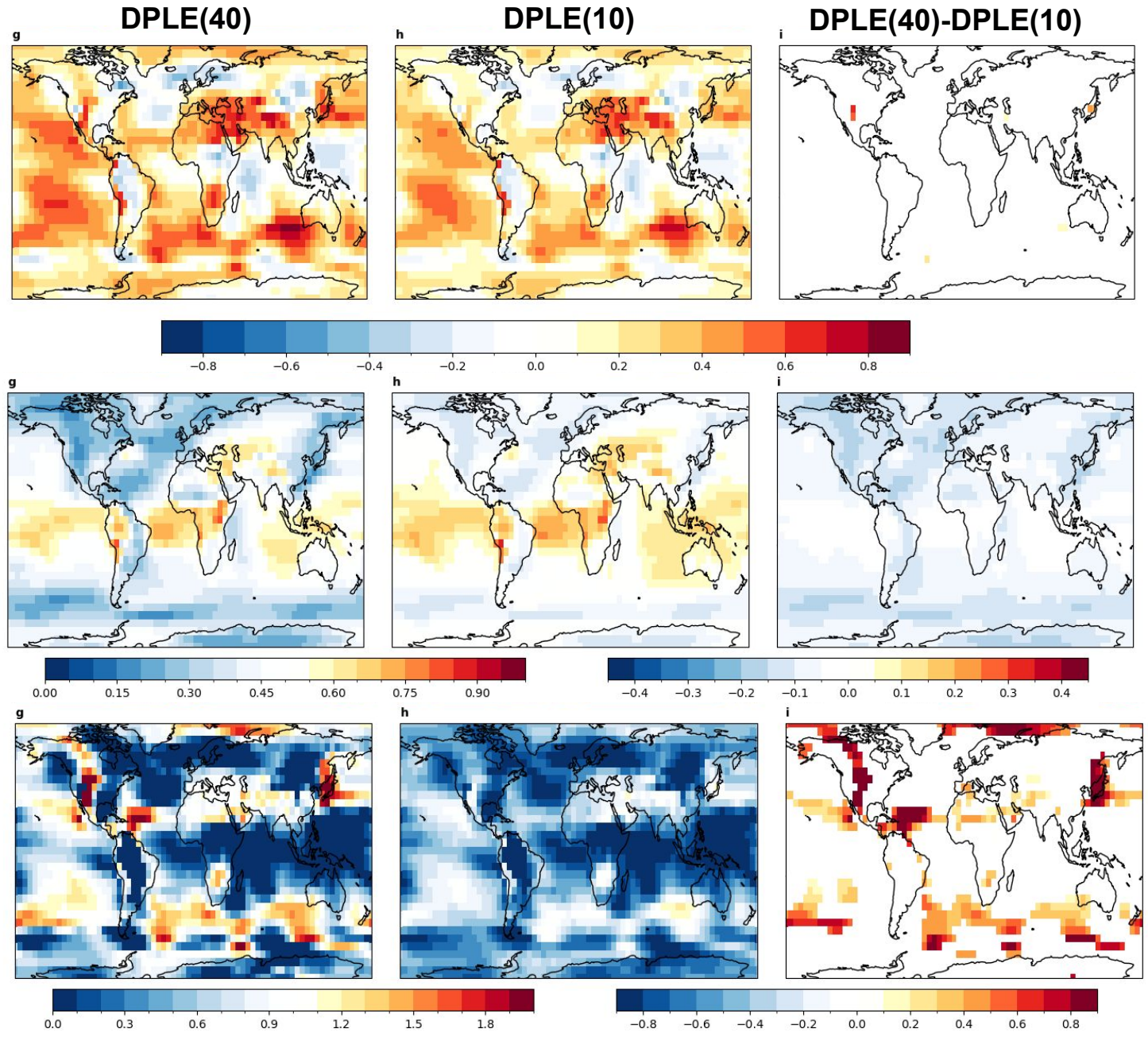






Signal-to-noise Paradox in DPLE

- FY1-5 annual SLP
- RPC = ACC/S2T (Scaife&Smith 2018)
- Slight ACC increase
- Larger S2T decrease
- RPC increase
- Skill increase with larger ensemble comes at the cost of RPC>1 in many regions



Improved Signal-to-noise in HRDP

- RPC closer to 1 in many regions (except GIN seas)
- High-resolution enhances skill more than a quadrupling of ensemble size, and without introducing widespread signal-to-noise paradox