Decadal prediction of North Atlantic subpolar gyre SST in CMIP6
-formerly-
Windows of opportunity in decadal predictions of North Atlantic SST

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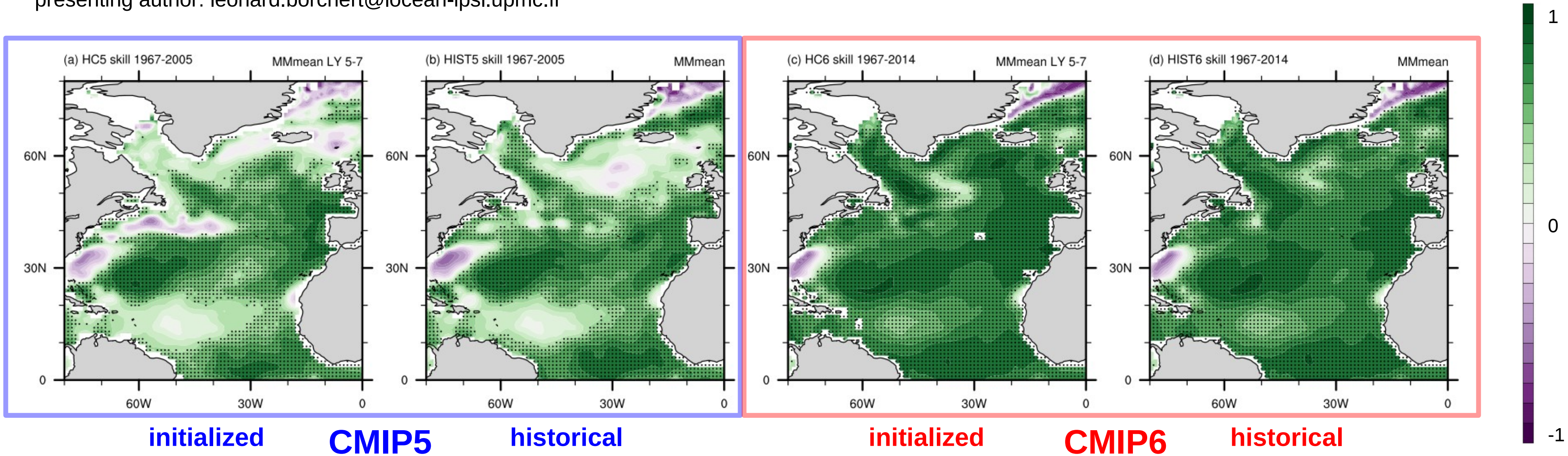

initialized CMIP5 historical

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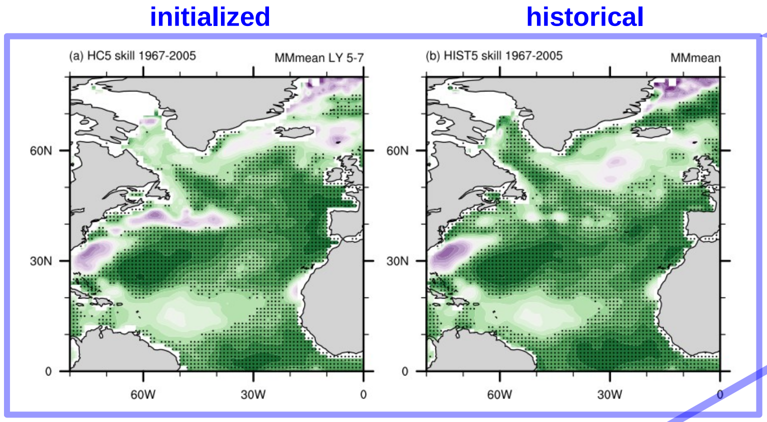
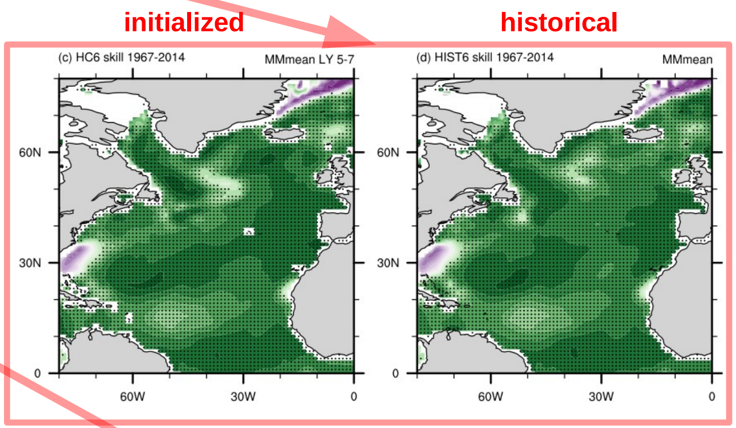
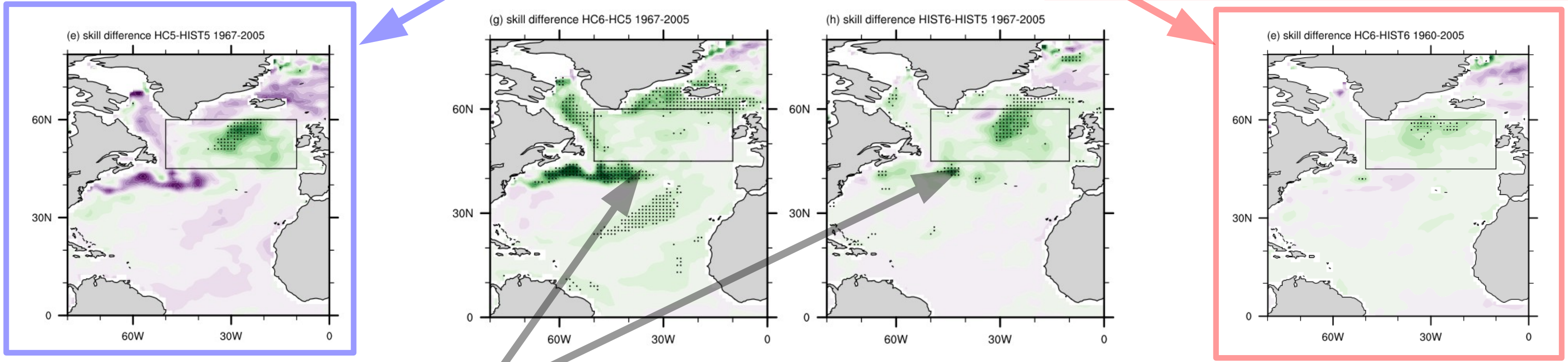
The correlation of North Atlantic SST to observation improves from CMIP5 to CMIP6



Model initialization improves the correlation stronger in CMIP5 than in CMIP6





In the subpolar gyre region, the reduced correlation improvement through initialization is due to the improved historical simulation

I want to learn more!

Overview

We use a multimodel ensemble consisting of 58 models for the period since 1960 to examine if observed decadal North Atlantic SST variations are captured in these models. Initialized decadal hindcast simulations from the 6th phase of the Coupled Model Intercomparison Project (CMIP) show better prediction skill for North Atlantic SST than equivalent simulations from the 5th CMIP phase. Similarly, CMIP6 non-initialized historical simulations reproduce observed decadal-scale North Atlantic SST variations better than their CMIP5 equivalent. A reduced improvement of correlation skill from initialization for SST in the subpolar gyre (SPG) region in CMIP6 can be traced back to very good agreement between CMIP6 historical simulations and observations since the 1980s, that we do not find for CMIP5 historical simulations. This agreement is at least partly caused by a realistic response of CMIP6 models to natural (i.e. volcanic and solar) forcing. Model initialization continues to be valuable for capturing the amplitude of change in decadal SPG SST predictions in CMIP6.

This display is structured into 5 topics:

1) Motivation

- Prediction of the climate system up to 10 years ahead, *decadal* prediction, is a particularly interesting scientific challenge as exemplified by the World Climate Research Program's Grand Challenge of Near-Term Climate Prediction (Boer et al., 2016)
- Such predictions require both knowledge of the forcing of the climate system, and of the state of the climate system at the start of the prediction. The latter is achieved by *initializing* decadal predictions from observed climate (e.g. Boer et al., 2016)
- Decadal predictions of North Atlantic sea surface temperature (SST), particularly in the subpolar gyre (SPG) region, have been identified as being of particular importance due to their impact on larger-scale climate (e.g. Dunstone et al., 2011)
- Research also focused on SPG SST because studies of CMIP5 models found particular improvement of the model's capability to predict decadal SPG SST variations through model initialization (e.g. Doblas-Reyes et al., 2013 ; Brune & Baehr, 2020)

Decadal predictions of North Atlantic SST have not been systematically examined in CMIP6.

- We therefore ask the following research questions:

1) How well do CMIP6 models predict North Atlantic SST on the decadal time scale, compared to CMIP5 models?
2) If there is a difference between CMIP5 and CMIP6, where does this difference originate?

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2) Model and methods

- We use a multi-model ensemble of simulations from a total of 58 models (see models)
- These simulations can be separated into several groups:
  - Historical simulations from CMIP6 (HIST6; 28 models)
  - Decadal hindcasts from CMIP6 (HC6; 6 models)
  - Historical simulations from CMIP5 (HIST5; 30 models)
  - Decadal hindcasts from CMIP5 (HC5; 5 models)
  - Simulations from the CMIP6 Detection and Attribution MIP (DAMIP; Gillett et al., 2016) to isolate individual historical forcings from greenhouse gases (hist-GHG), anthropogenic aerosols (hist-aer), and natural forcing (i.e. volcanoes & sun, hist-nat) (9 models each)
- For observations, we use the Hadley Centre Ice and Sea Surface Temperature (HadISST) data set (Rayner et al., 2003)

- SST from all models were remapped to a regular lat-lon grid prior to analysis
- We use yearly averages smoothed with a 3-year running mean in all analyses, focusing on lead years 5-7 in decadal hindcasts
- We analyze the multi-model mean (one-model-one-vote) for each of the groups defined above
- The time periods considered here are 1967-2014 for the CMIP6 data, and 1967-2005 for CMIP5
- The North Atlantic subpolar gyre (SPG) is defined as the region 50-10W, 45-60N
- Prediction skill is quantified using anomaly correlation coefficient (ACC; Jolliffe & Stephenson, 2012) and mean square skill score (MSSS; Smith et al., 2019)
- Significance is defined as exceeding the 95th percentile of a distribution created by randomly resampling the underlying time series with replacement 500 times

3) Decadal prediction skill for North Atlantic SST in CMIP6

i. A comparison of CMIP5 and CMIP6

- CMIP6 models show higher correlation to observations than CMIP5 models (fig. 1a-d)
- This is true for initialized and historical runs

- Skill improvement in the SPG region through initialization is higher in CMIP5 than in CMIP6 (fig. 1e,f)
- The **reduced improvement through initialization in CMIP6** compared to CMIP5 can be attributed to the **high skill in the CMIP6 historical simulations** (fig. 1g,h).

- **What causes the improvement of CMIP6 historical simulations compared to CMIP5?**

The multimodel ensemble in this analysis consists of those 5 (6) CMIP5 (CMIP6) models that provide yearly initialized decadal hind casts.

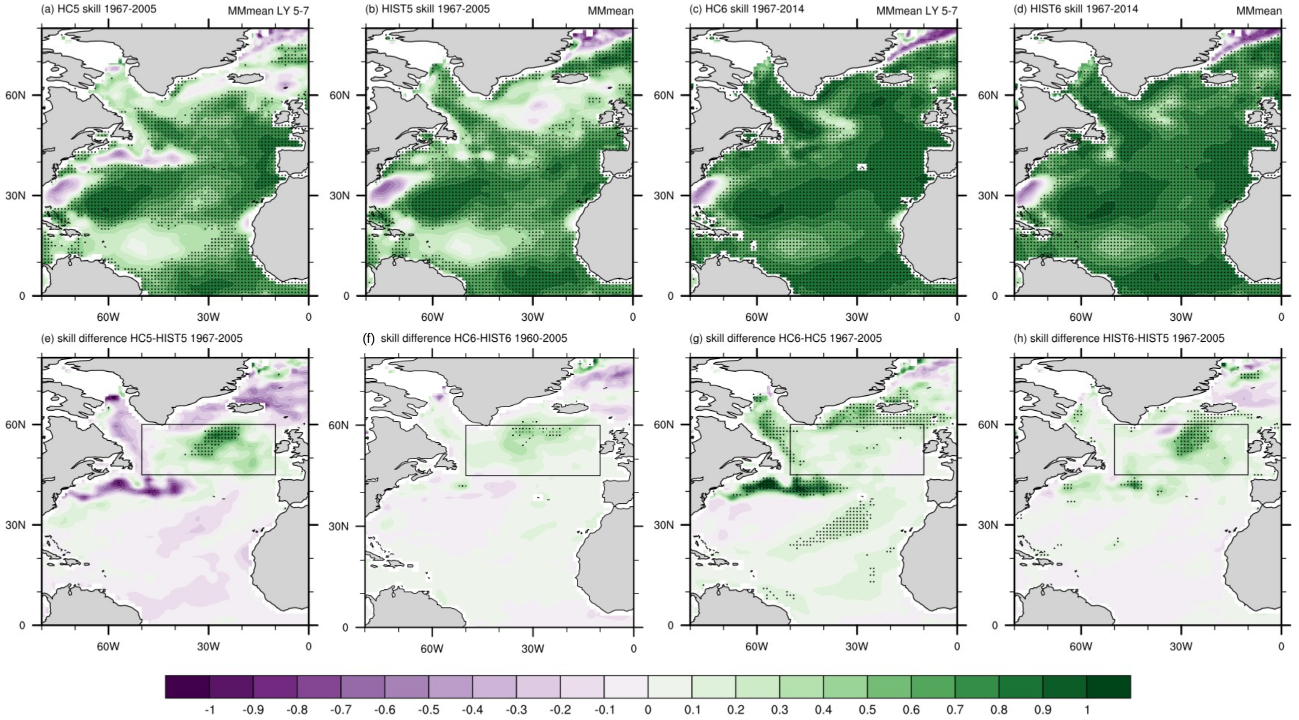

Figure 1: Multimodel ensemble mean decadal prediction skill for annual mean non-detrended SST, calculated by means of ACC at lead years 5-6 if applicable. Examined model systems are (a) CMIP5 initialized hindcasts, (b) CMIP5 historical simulations, (c) CMIP6 initialized hindcasts, (d) CMIP6 historical simulations. We also show the differences between (e) CMIP5 initialized hindcasts and historical simulations, (f) CMIP6 initialized hindcasts and historical simulations, (g) initialized hindcasts from CMIP6 and CMIP5, (h) historical simulations from CMIP6 and CMIP5. Stippling shows where correlation or correlation differences are significantly different to zero (at 95% confidence). The box outlined in black in (e-h) shows the area used to calculated the SPG index.

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3) Decadal prediction skill for North Atlantic SST in CMIP6

ii. A closer look at North Atlantic subpolar gyre (SPG) SST

- CMIP6 models show consistently higher (fig. 2a,b) and more robust (lower model spread; fig. 2c) skill than CMIP5 models for SPG SST.
- While there is only little impact of initialization on hindcast skill in CMIP6 for correlations (fig. 2a), initialization continues to be valuable to predict the full SST signal (fig. 2b)
- **Model sampling bias partly explains the skill difference** between CMIP5 and CMIP6 historical simulations (cf. fig. 1a,b)
- There is a **robust skill increase from CMIP5 to CMIP6** historical runs **after 1980**
- **Could the high skill in CMIP6 historical runs after 1980 be related to forcing?**

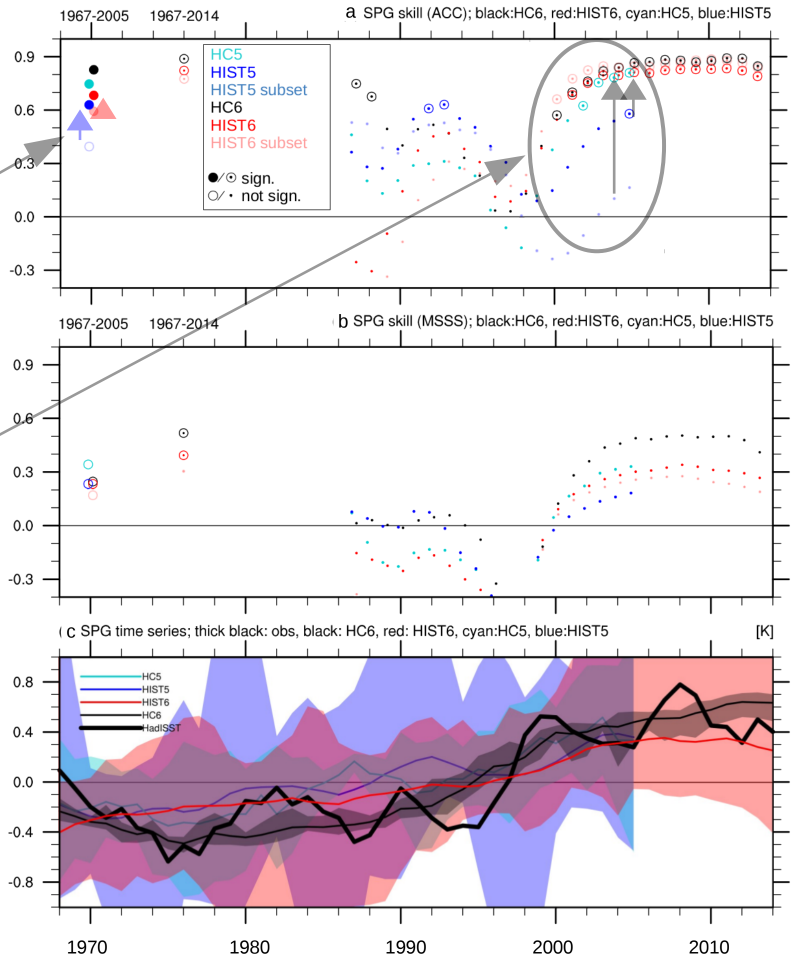

Figure 2: SPG SST skill evaluated using (a) ACC and (b) MSSS (methods). We show skill for the full multimodel ensembles of HC5 (cyan), HIST5 (blue), HC6 (black) and HIST6 (red). Skill for the HIST5 and HIST6 ensemble subsets used in fig. 1 are shown in shading. Circles/dots on the left show skill for the periods specified above. We also show skill for a rolling 20 year window (as in Brune et al., 2018), where the markers are positioned at the last year of the respective 20 year period. Full circles/circled dots indicate significant skill. (c) Time series of SPG SST anomalies in observations (thick black), HC5 (cyan), HIST5 (blue), HC6 (black), HIST6 (red). Shading indicates the spread of the individual model ensemble means included in the multimodel ensemble mean.

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4) Forcing contribution to SPG SST prediction skill in CMIP6 historical simulations

- Skill of DAMIP simulations with isolated forcings illustrates how much observed variability is explained by the forcing
- The linear sum of the individual forcings is similar to the full historical signal, so this **decomposition is appropriate**

- Models generally do not agree about how much observed variability is explained by individual forcings (fig. 3c-h)

  Natural forcing explains a good amount of the **observed variability after 1980 in the CMIP6 ensemble mean** (fig. 3g)
- This is partly related to the reasonable reproduction of the mid-1990s warming in these simulations, which suggests a role of the Pinatubo eruption for that warming (fig. 3h)

The multimodel ensemble in this analysis consists of those 9 models that provide DAMIP simulations of hist-GHG, hist-nat and hist-aer

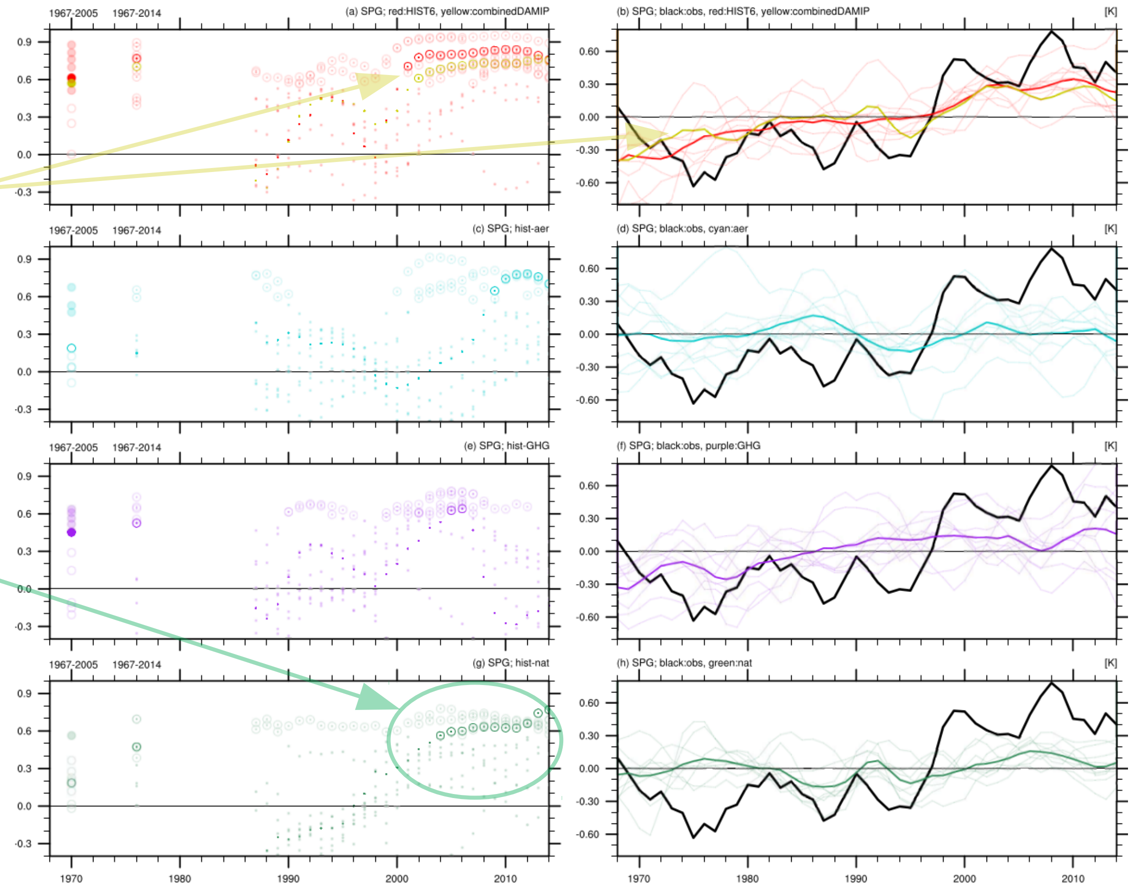
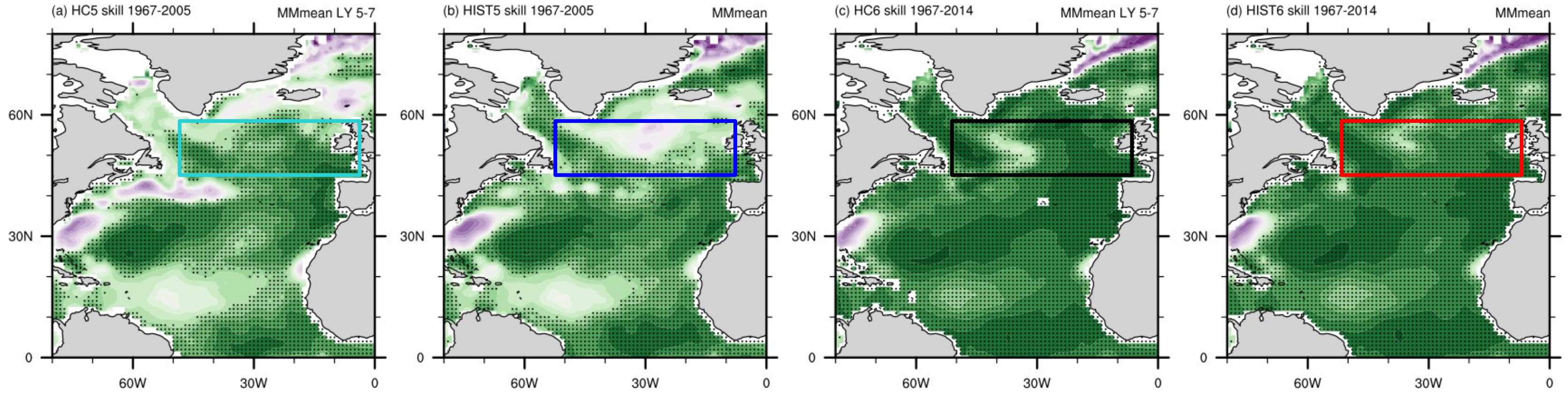


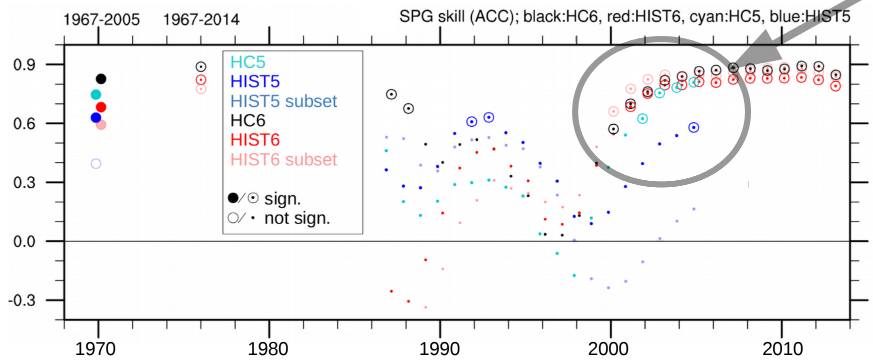
Figure 3: SPG SST in a 9-member multimodel ensemble from HIST6 (red) and DAMIP simulations for hist-GHG (purple), hist-aer (cyan), and hist-nat (green), as well as their linear sum (yellow). Ensemble means in solid colors, individual members in shading. (a,c,e,g) SPG SST prediction skill based on correlations. Circles/dots on the left show skill for the periods specified above. We also show skill for a rolling 20 year window (dots), positioned at the last year of the respective 20 year period. Full circles/circled dots indicate significant skill. (b,d,f,h) Time series of SPG SST anomalies in observations (thick black) as well as HIST6 or the DAMIP simulations. Weak lines show the single model ensemble means represented in the multimodel ensemble mean.

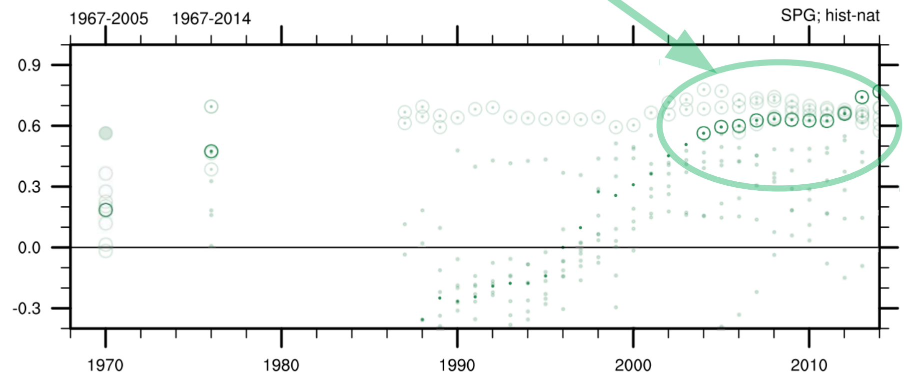
5) Synthesis/Conclusions

1) Decadal prediction skill for North Atlantic subpolar gyre SST is higher in CMIP6 than it was in CMIP5.



2) High skill in CMIP6 can be attributed to **high skill since the 1980s** from a good **response to natural forcing.**





Thank you for your interest. Please comment or contact us if you have questions!

Overview

List of models/ensemble sizes

Modelling Centre	Model	Ensemble size				
		CMIP6			CMIP5	
		Historical	Decadal hindcasts	DAMIP	Historical	Decadal hindcasts
AWI, Germany	AWI-CM1.1-MR	5				
BCC, China	BCC-CSM1.1				3	3
	BCC-CSM1.1-M				3	
	BCC-CSM2-MR	3		3		
	BCC-ESM1	3				
BSC, Spain	EC-EARTH	20				
CAMS, China	CAMS-CSM1.0	2				
CAS, China	FGOALS-f3-L	3				
	FGOALS-g3	5				
CCCma, Canada	CanCM4				10	5
	CanESM5	20		10		
CMCC, Italy	CMCC-CESM				1	
	CMCC-CM				1	
	CMCC-CMS				1	
CNRM, France	CNRM-CM5				10	
	CNRM-CM6-1	30		10		
	CNRM-ESM2.1	10				
CSIRO, Australia	ACCESS1.0				3	
	ACCESS3.0				3	
	CSIRO-Mk3-6.0				10	
E3SM-Project	E3SM1.0	5				
FIO, China	FIO-ESM2.0	3				
ICHEC, Ireland	EC-EARTH				14	
INM, Russia	INM-CM4				1	
	INM-CM5	10				
IPSL, France	IPSL-CM5A-LR				6	3
	IPSL-CM5A-MR				3	
	IPSL-CM6A-LR	30	10	10		
JAMSTEC, Japan	MIROC5				5	6
	MIROC-ESM				3	
	MIROC6	10	10	10		
LASG-CESS, China	FGOALS-g2				5	
MOHC, UK	HadGEM2-ES				5	
	HadGEM2-CC				3	
	HadCM3				10	
	HadGEM3-GC31-LL	4	10	4		
	HadGEM3-GC31-MM	2				
	UKESM1.0-LL	20				
MPI-M, Germany	MPI-ESM1.0-LR				3	3
	MPI-ESM1.2-LR	10				
	MPI-ESM1.2-HR	10	10			
MRI, Japan	MRI-CGCM3				3	
	MRI-ESM1				1	
	MRI-ESM2.0	5		5		
NASA-GISS, USA	GISS-E2-H				6	
	GISS-E2-CC				1	
	GISS-E2.1-G	10		5		
	GISS-E2.1-H	10				
NCAR, USA	CCSM4				6	
	CESM1.1-CAM5		20			
	CESM2	10				
NCC, Norway	NorESM1-M				3	
	NorESM2-LM	3		10		
	NorCPM1	30	10			
NIMR-KMA,Korea	HadGEM2-AO				1	
NOAA-GFDL	GFDL-ESM4	2				
NSF-NCAR, USA	CESM1-CAM5				3	
NUIST, China	NESM3	5				
UNSW, Australia	CSIRO-Mk3L-1.2				3	
Total members		281	70	67	134	20

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