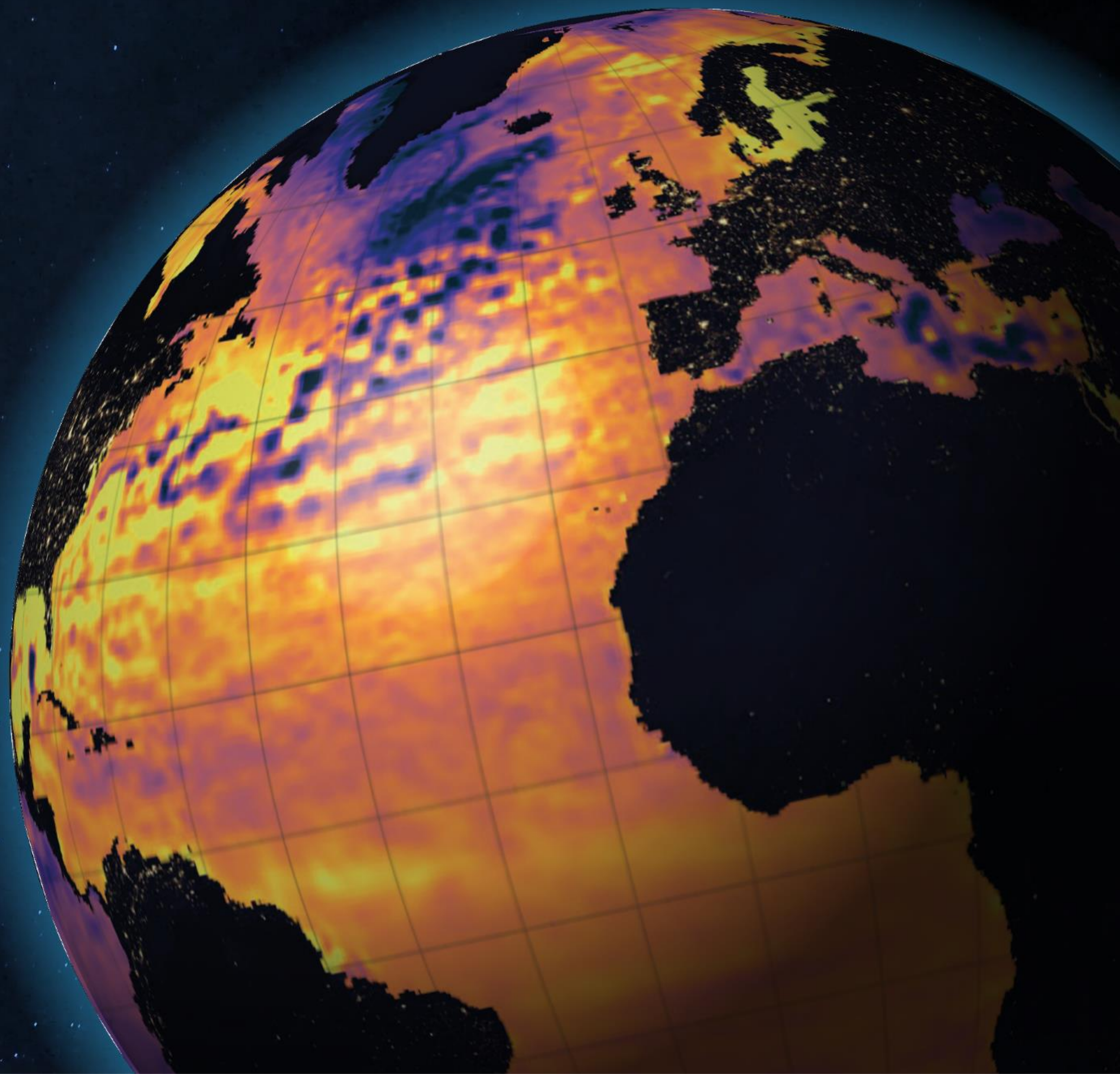
Ocean Predict

SYMPOSIUM OP'24

In partnership with unesco Intergovernmental Oceanographic Commission

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Challenges in simulating sea ice: insights from HighResMIP runs



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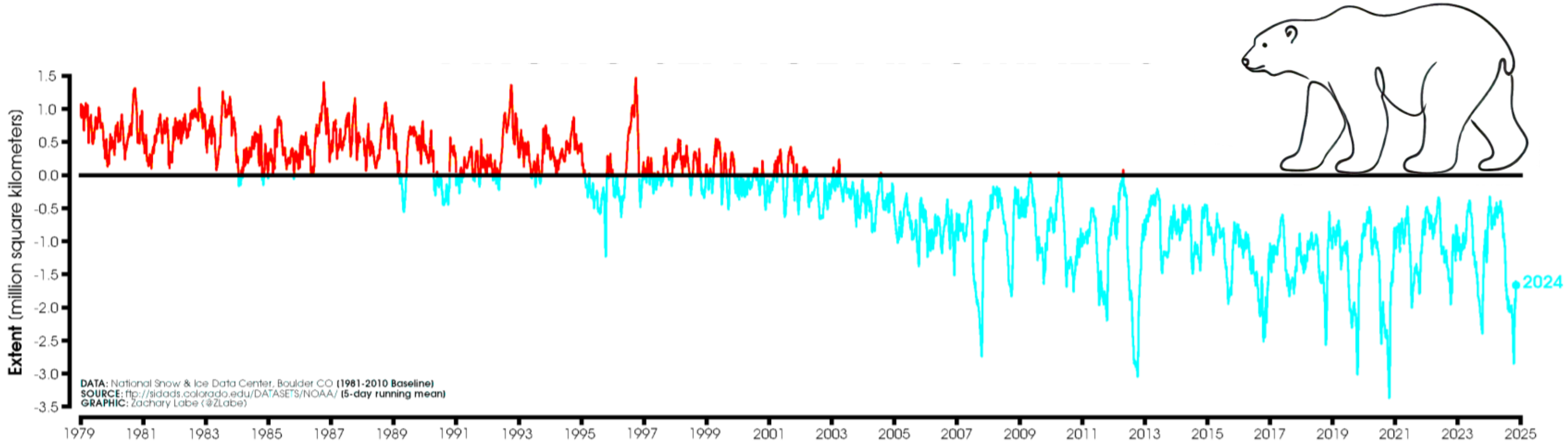
cmcc Centro Euro-Mediterraneo sui Cambiamenti Climatici

Foundation Euro-Mediterranean Center on Climate Change

CRiceS

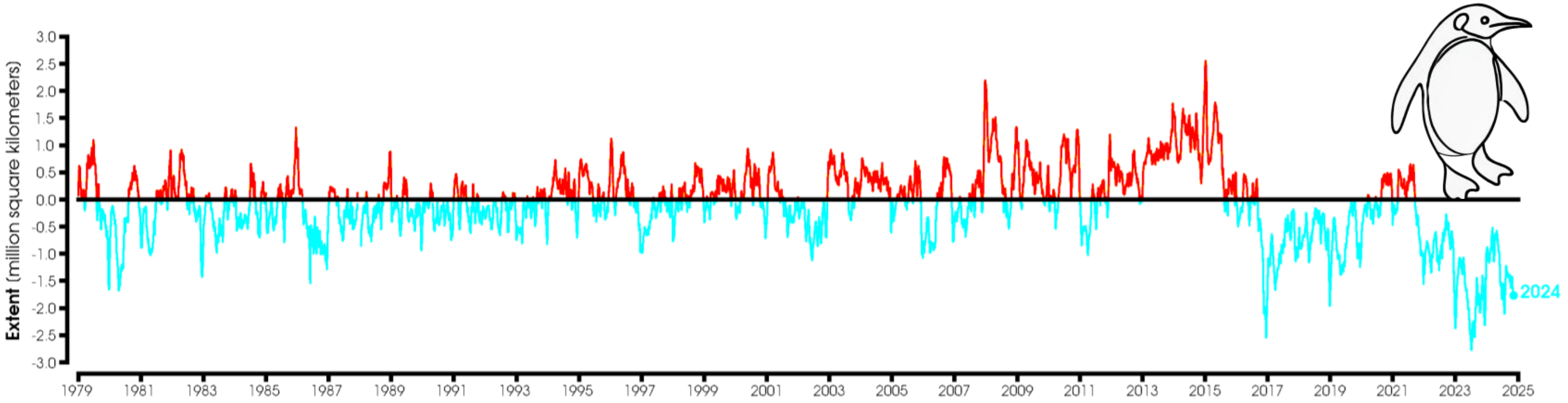
Arctic vs Antarctic variability

The Arctic has been warming either twice, more than twice, or even three, four times as fast as the globe on average, since 1979. Glaring evidence of climate change, the **Arctic sea ice has shown a clear decline.**



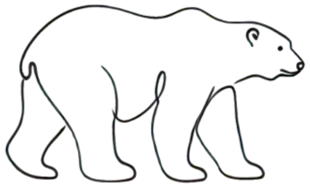
Arctic ↑ and Antarctic ↓ sea ice extent anomalies stretching from January 1979 to November 2024. Anomalies are calculated using a 5-day running mean from a climatological baseline of 1981-2010.

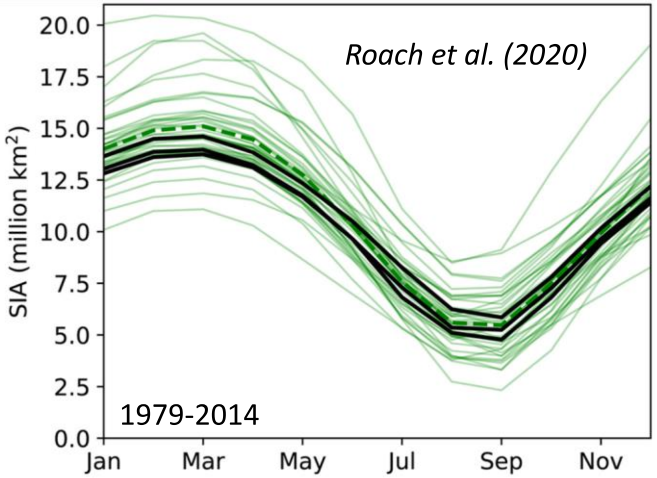
Antarctic sea ice has not. Instead, Antarctic sea ice has shown substantial year-to-year variability. With a modest expansion and a regime shift in 2016, the highest maximum and lowest minimum extents on record for Antarctic sea ice happened within a few years of each other.

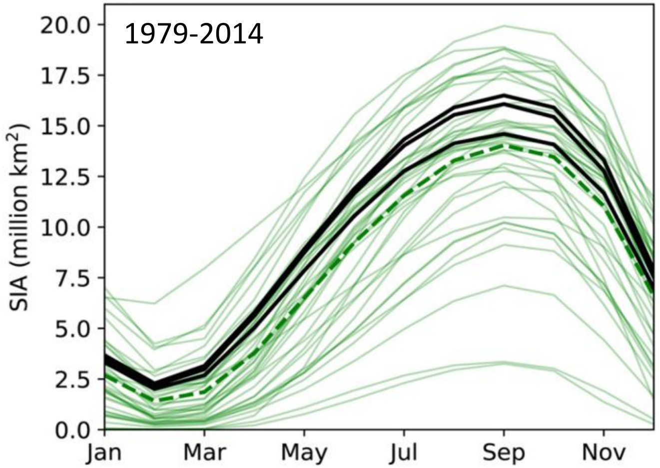


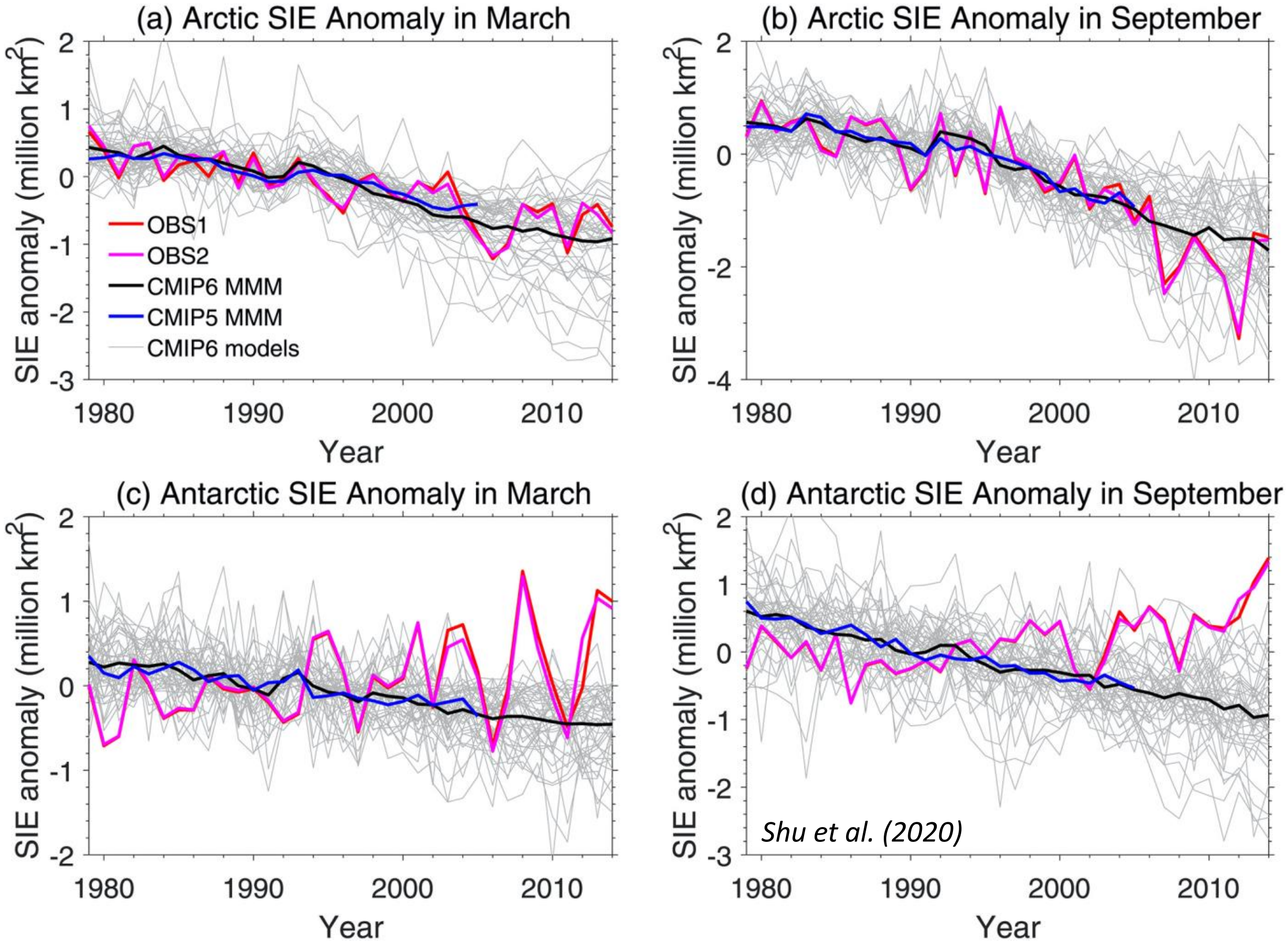
Background and Motivation

Mean ISIA seasonal cycle for the CMIP6









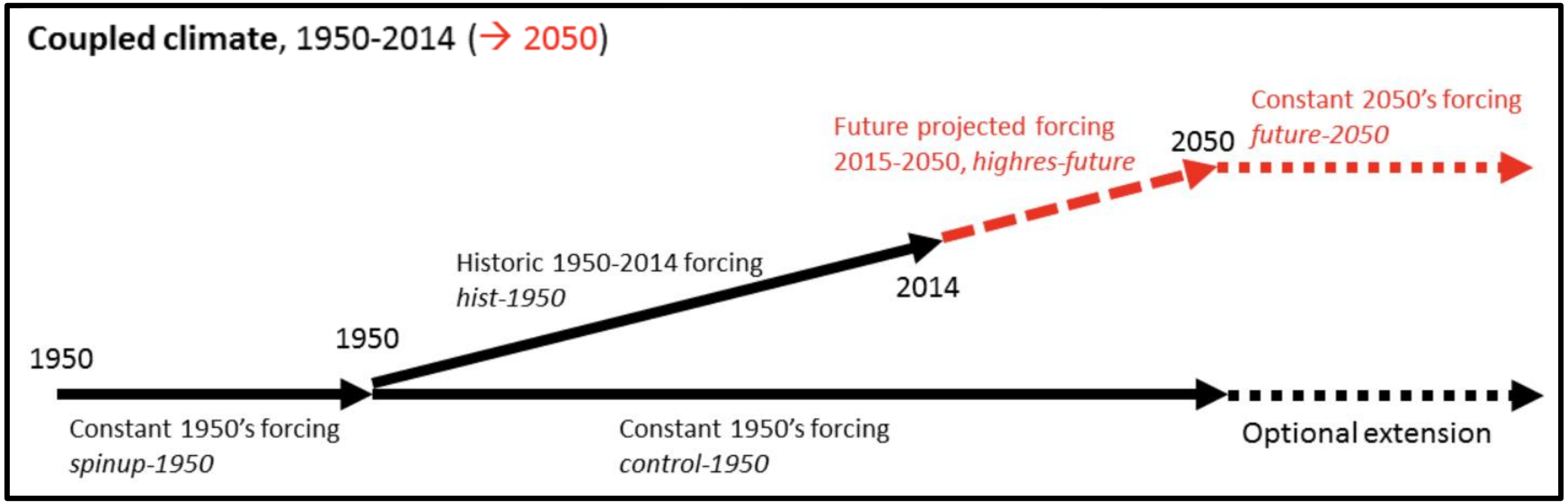
- **Similar temporal evolution of the MMM SIEs from CMIP6 and CMIP5 from 1979 to 2005**
- **Substantial inter-model spread among coupled climate models**
- ***Differences in observed products***

HighResMIP

The High Resolution Model Intercomparison Project (HighResMIP, *Haarsma et al. 2016*) was a CMIP6-endorsed MIP and applied, for the first time, a multi-model approach to the systematic investigation of the impact of the horizontal resolution. A coordinated set of experiments was designed to assess both a standard and an enhanced horizontal resolution simulation in the atmosphere and ocean.

Tier 2: Coupled runs 1950-2050

Spin-up: 50-year spin-up from EN4 ocean climatology with constant 1950's forcing
Control: 100 years with the 1950s forcing
Historic: 1950-2014 with historic forcing
Future: 2015-2050 under the SSP585 forcing scenario



High-Res Impacts

The increased horizontal resolution is widely considered to reduce biases in model simulations

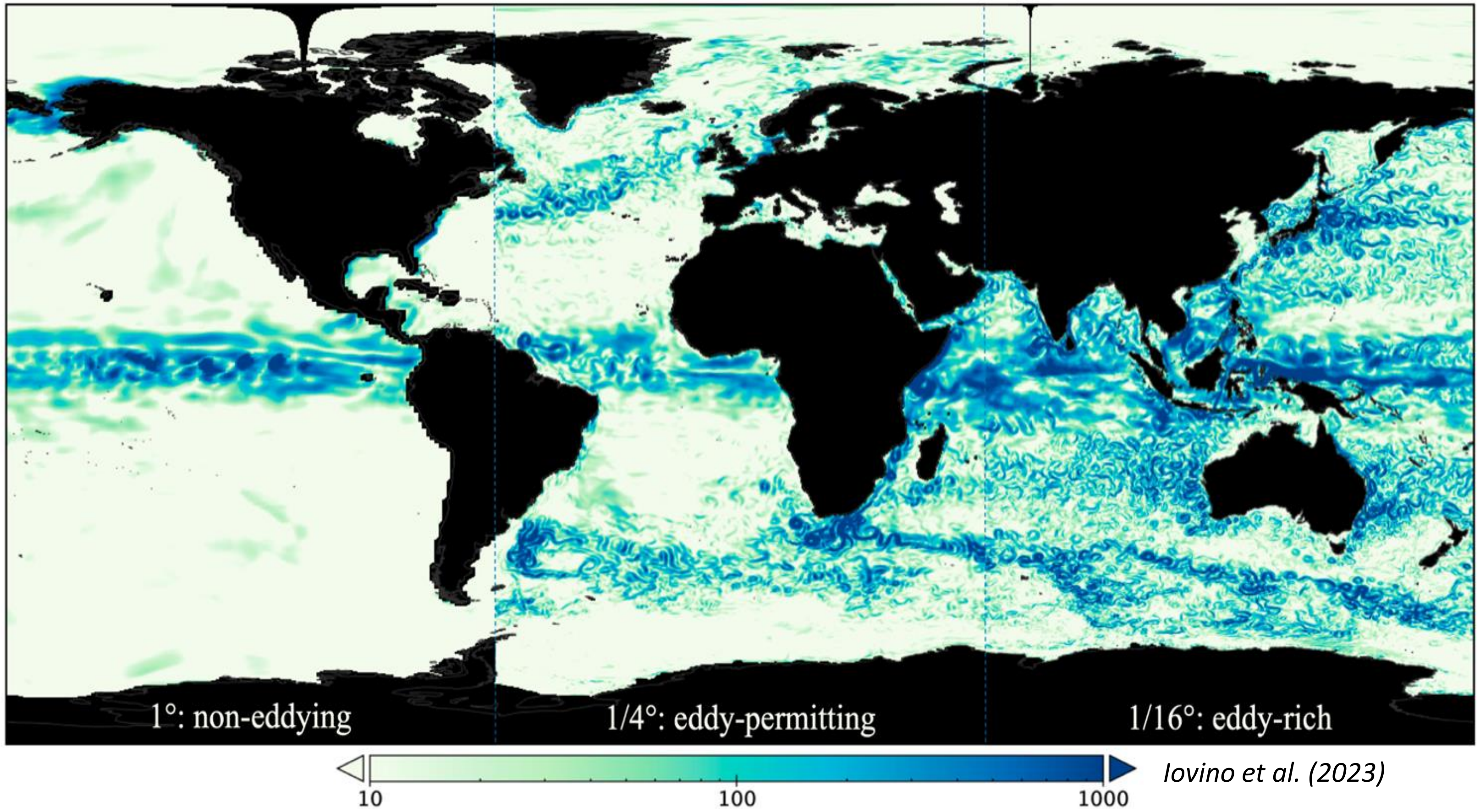
The oceanic and atmospheric mesoscale features are better resolved affecting the realism of large-scale climate representations in the model simulations

Atlantic meridional heat transport

Antarctic Circumpolar Current

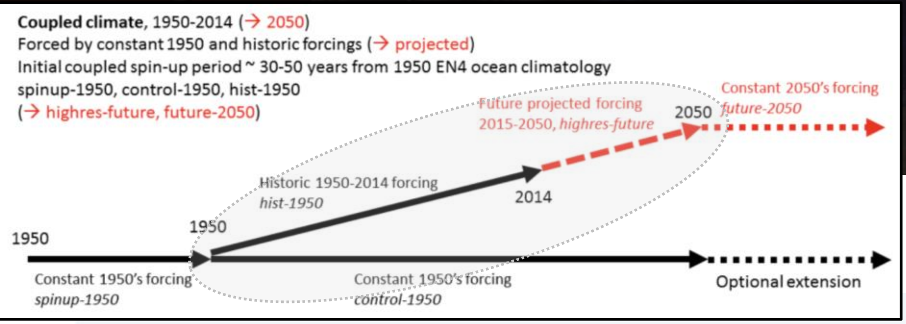
SH circumpolar jet stream position

precipitation over Antarctic ice sheets



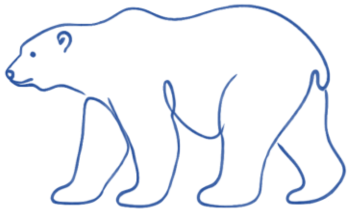
Iovino et al. (2023)

Does the *eddy-permitting* horizontal resolution improve the representation of sea ice in the recent past and future?



HighResMIP

Modeling group	Model configuration	Ensemble group	Nominal ocean res. (°)	Nominal atm. res. (km)	Model components	
					Ocean + sea ice	Atmosphere
CMCC (Cherchi et al., 2019)	CMCC-CM2 HR	HR$_{all}$	0.25	100	NEMO3.6+CICE4.0	CAM4
	CMCC-CM2 VHR	HR$_{all}$	0.25	25		
CNRM and CERFACS (Voldoire et al., 2019)	CNRM-CM6-1 LR	LR	1	250	NEMO3.6+GELATO6	ARPEGE6.3
	CNRM-CM6-1 HR	HR, HR$_{all}$	0.25	100		
ECMWF (Roberts et al., 2018)	ECMWF-IFS LR	LR	1	50	NEMO3.4+LIM2	IFS cycle43r1
	ECMWF-IFS MR	HR, HR$_{all}$	0.25	50		
	ECMWF-IFS HR	HR, HR$_{all}$	0.25	25		
EC-Earth Consortium (Haarsma et al., 2020)	EC-Earth3P LR	LR	1	100	NEMO3.6+LIM3	IFS cycle36r1
	EC-Earth3P HR	HR, HR$_{all}$	0.25	50		
Met Office (Williams et al., 2018)	HadGEM3 LL	LR	1	250	NEMO3.6+CICE5.1	UM
	HadGEM3 MM	HR, HR$_{all}$	0.25	100		
	HadGEM3 HM	HR, HR$_{all}$	0.25	50		
MPI (Müller et al., 2018)	MPI-ESM HR	HR$_{all}$	0.4	100	MPIOM1.6.3	ECHAM6.3
	MPI-ESM XR	HR$_{all}$	0.4	50		
AWI (Sidorenko et al., 2015; Semmler et al., 2017)	AWI-CM-1 LR	LR	24–110 km	250	FESOM	ECHAM6.3
	AWI-CM-1 HR	HR, HR$_{all}$	10–60 km	100		
NCAR (Hurrell et al., 2020; Meehl et al., 2019)	CESM1-CAM5-SE-LR	LR	1	100	POP2	CAM5.2
	CESM1-CAM5-SE-HR	HR, HR$_{all}$	0.25	25		



SIC from satellite datasets (NOAA/NSIDC CDR v4; EUMETSAT OSISAF)

SIT and SIV from PIOMAS

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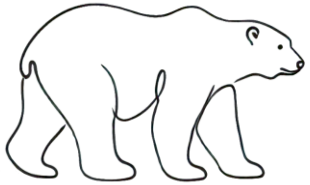
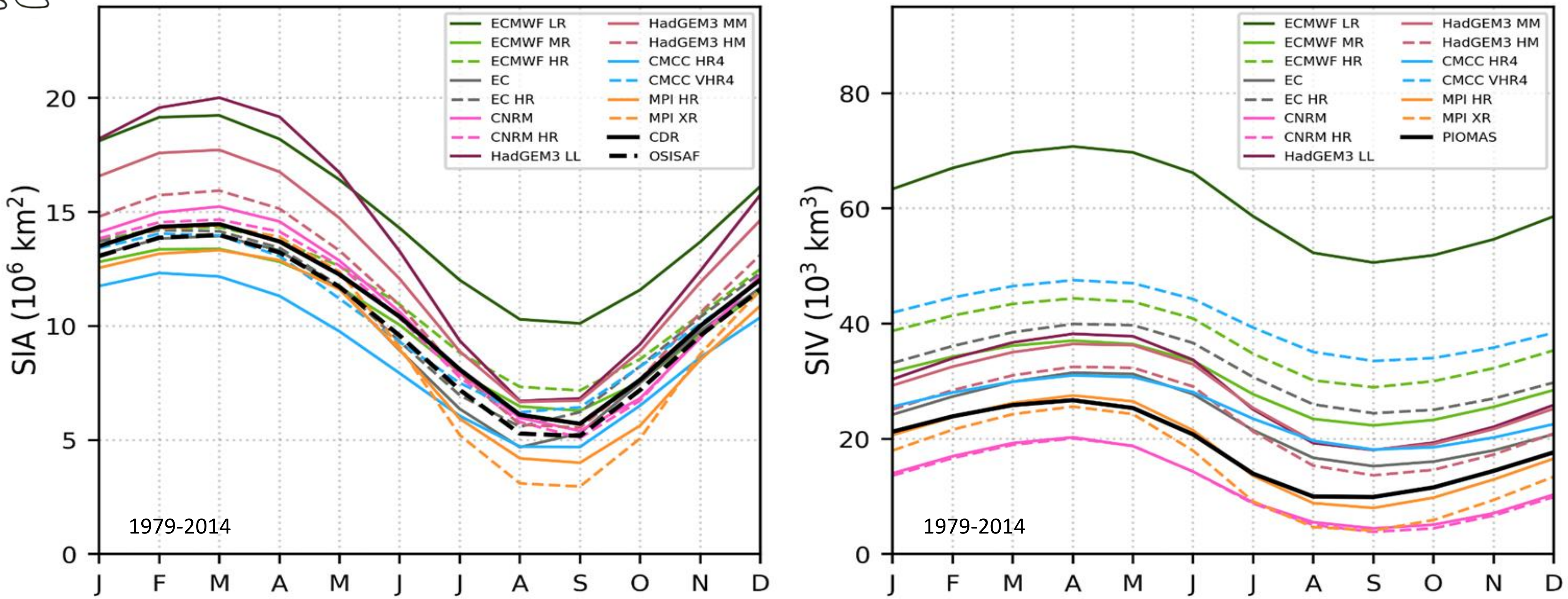
Historical period 1979-2014



Mean seasonal cycle in SIA and SIV from HighResMIP hist-1950 outputs

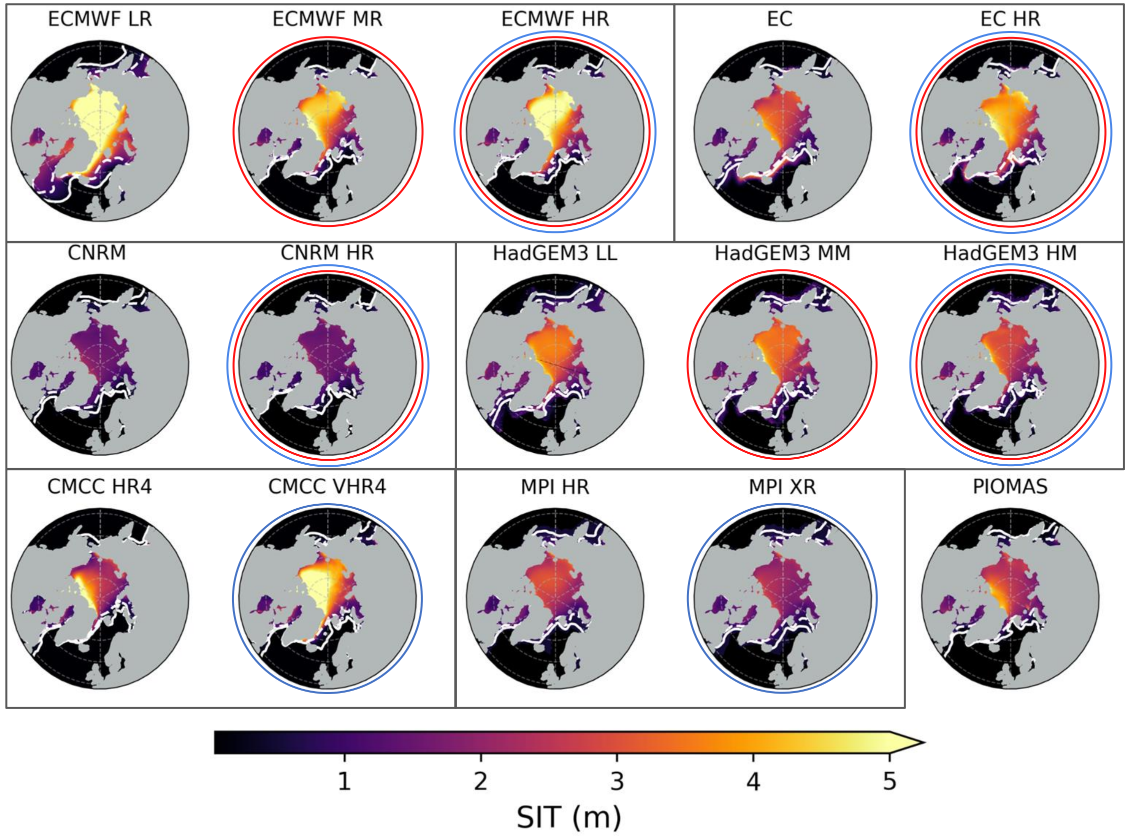


- **Reduced bias in winter SIA with finer ocean resolution *(impact on seasonal cycle amplitude)***
- **No systematic effect of resolution on sea ice volume**

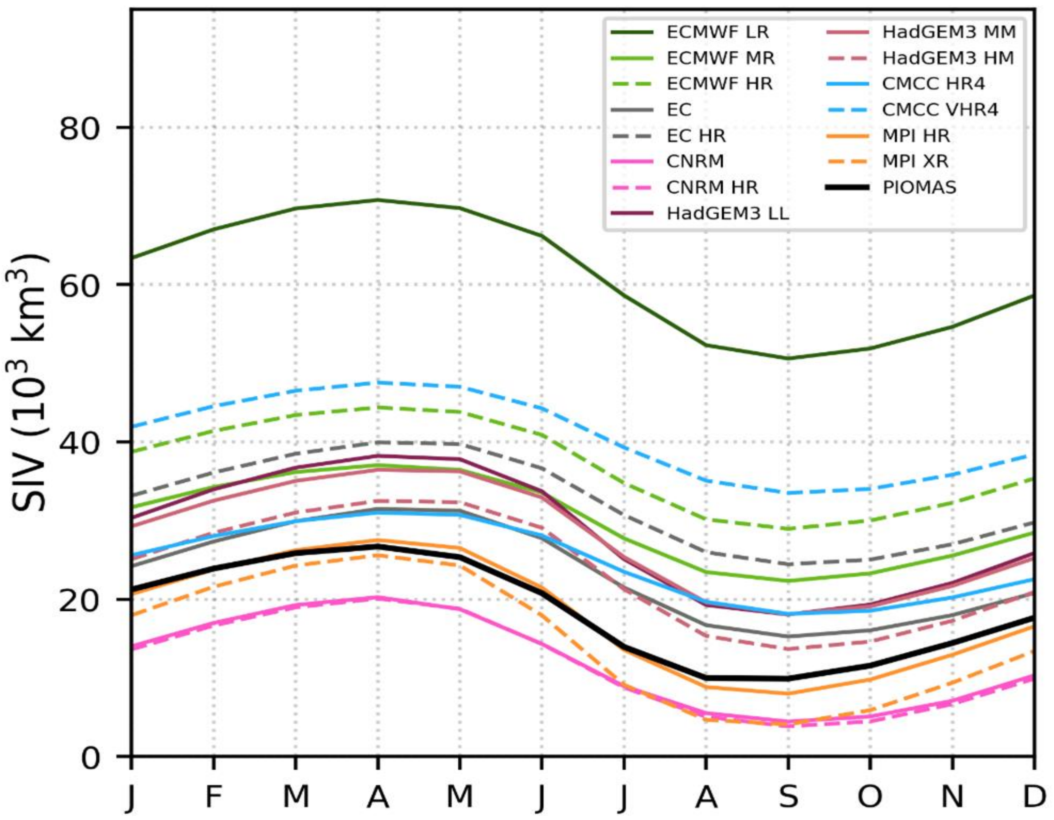
Historical period 1979-2014

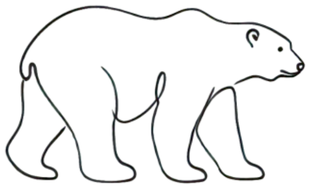
increase in ocean resolution
increase in atmosphere resolution

Spatial pattern of March SIT and sea ice edges (15 and 80%)



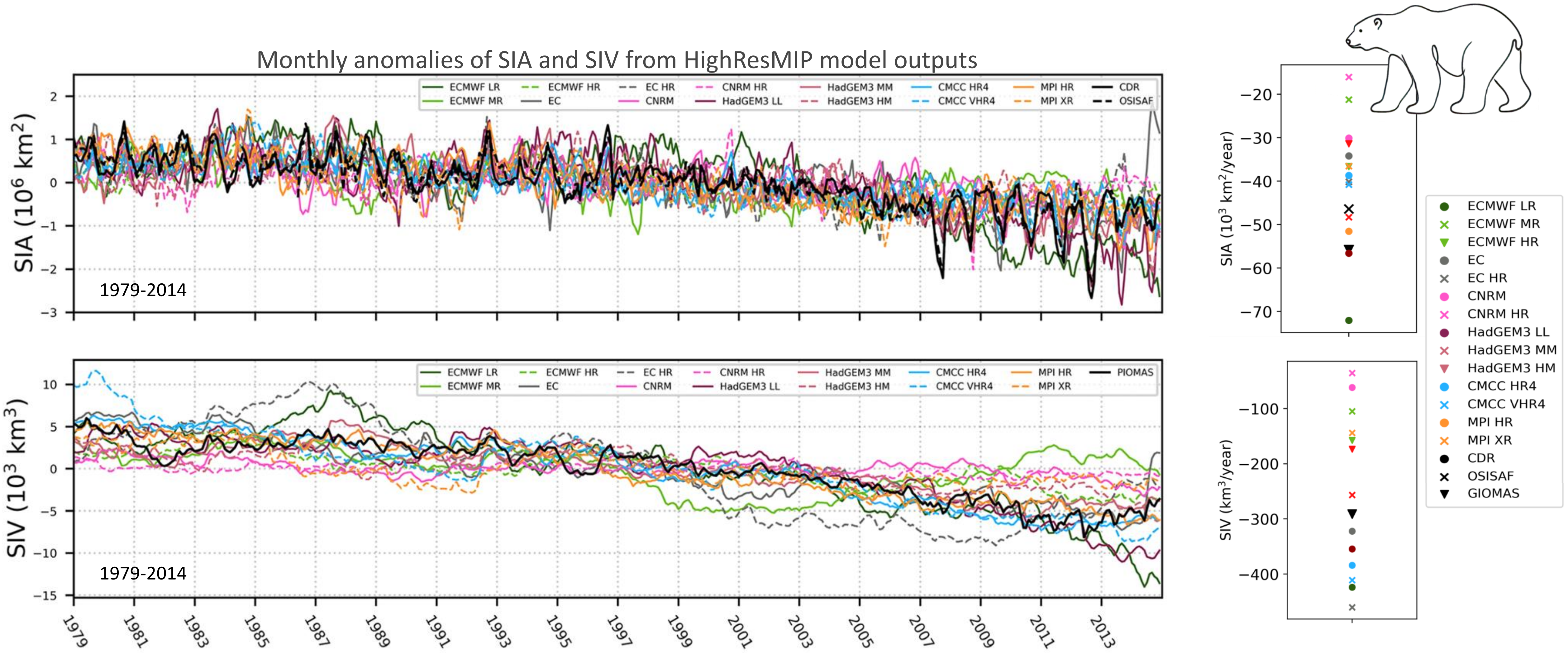
Mean seasonal cycle in SIV from hist-1950





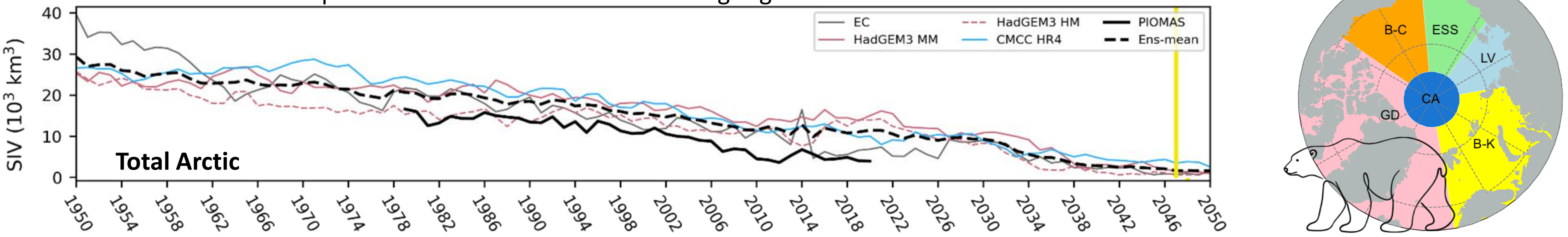
- **Reduced bias in winter SIA with finer ocean resolution *(impact on seasonal cycle amplitude)***
- **No systematic effect of resolution on sea ice volume**

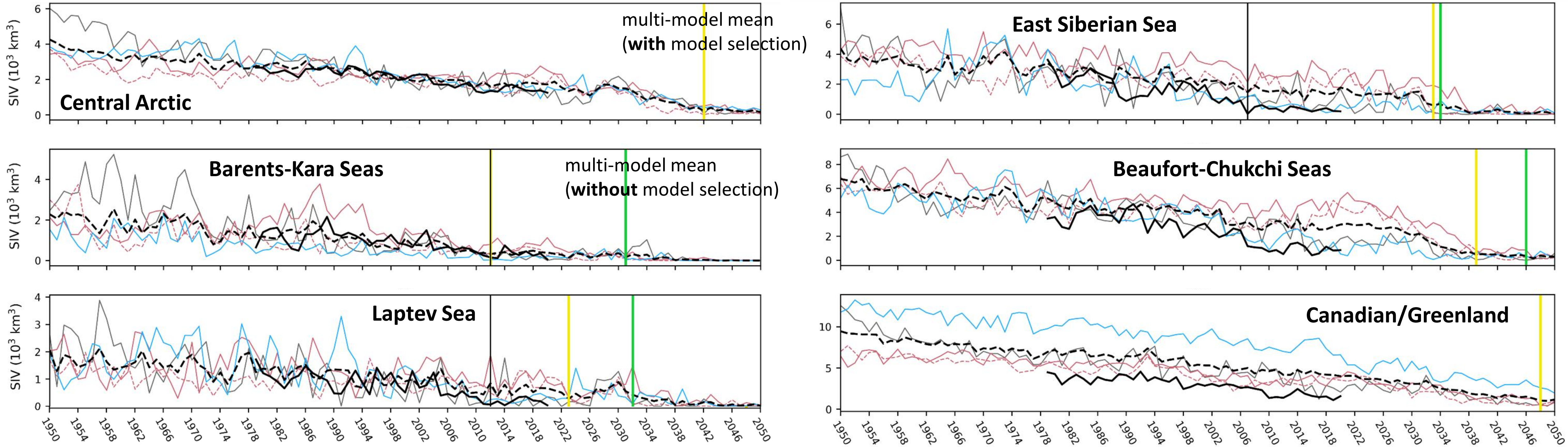
Interannual variability and trends



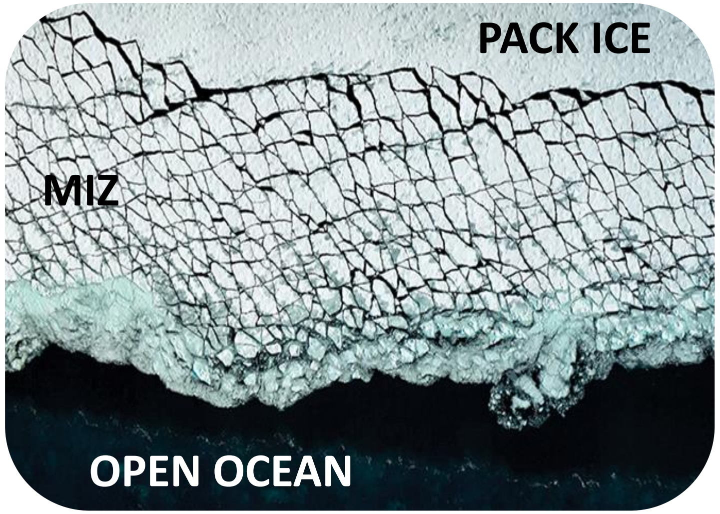
- **There is a tendency for less-pronounced SIA negative trends with finer ocean resolution**
- **No systematic effect of resolution on sea ice volume trends**

Time series of September SIV from 1950 to 2050 using HighResMIP historical and future runs





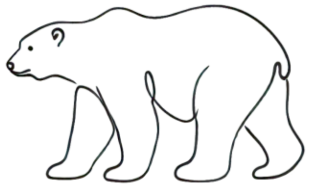
Changes in the structure of sea ice cover



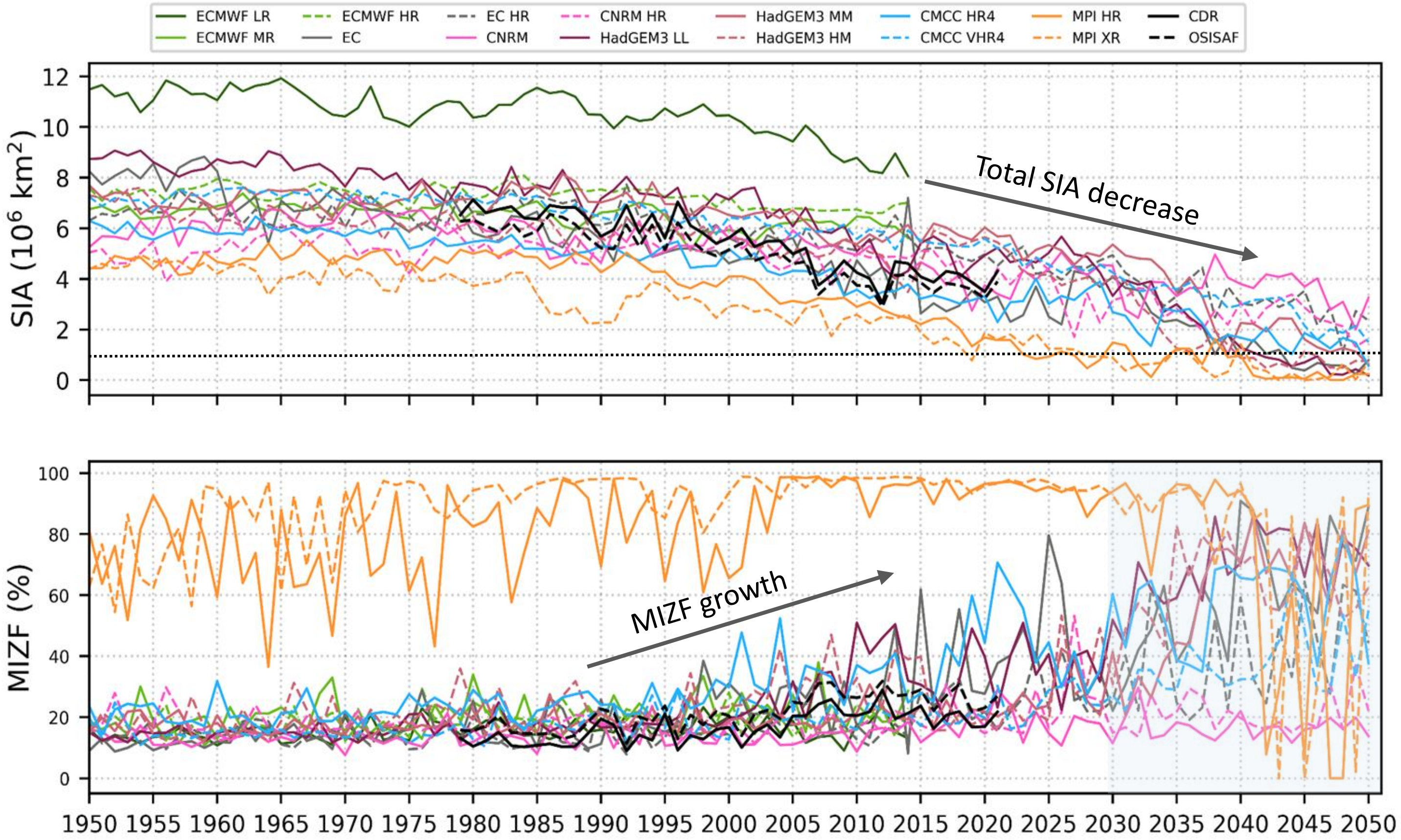
Marginal Ice Zone (MIZ) defined as

- *the part of the ice cover which is close enough to the open ocean boundary to be affected by its presence (Wadhams 1986);*
- *a dynamic and biologically active region that transitions from the dense inner pack ice zone to the open ocean.*

***MIZF** - the percentage of the Arctic sea ice cover that is MIZ (15-80% SIC; Horvat, 2022)*

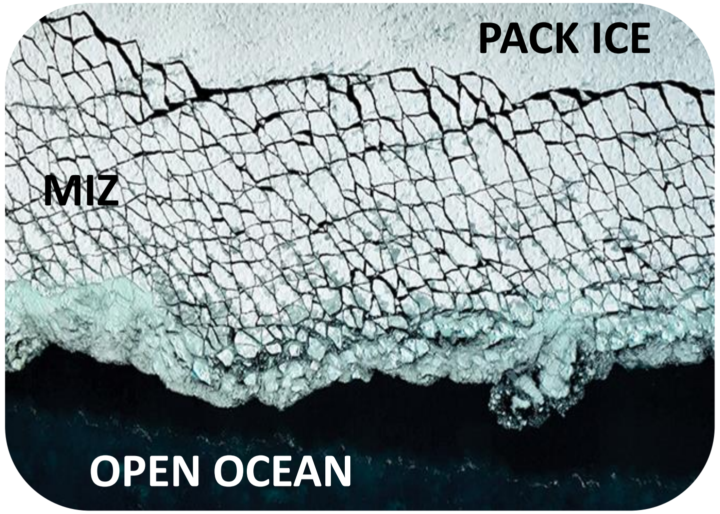


September total SIA and MIZF time series over 1950-2050

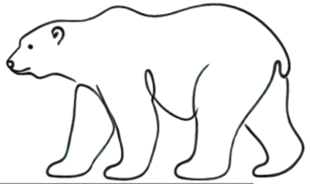


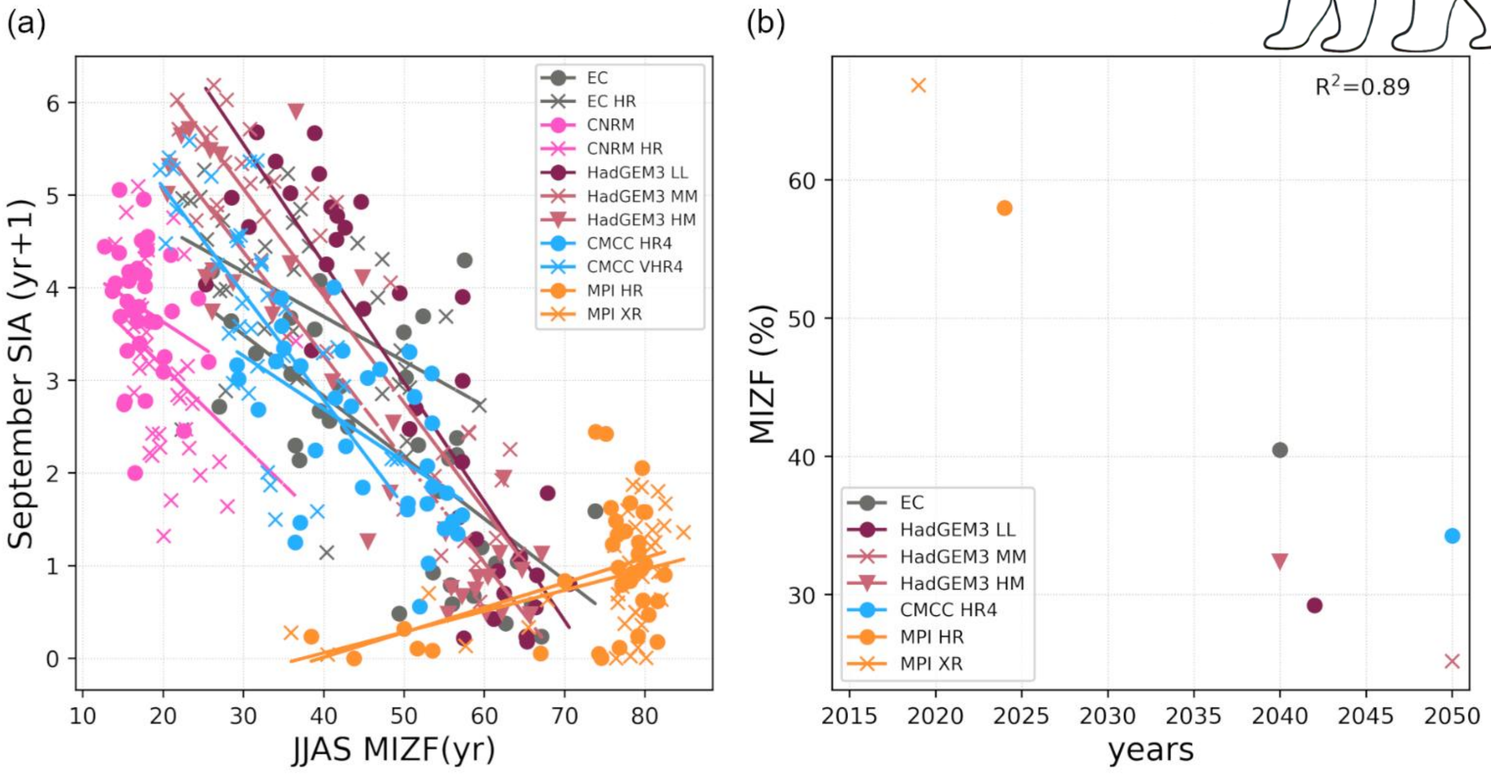
- **MIZ-dominance by 2050**

Changes in the structure of sea ice cover



- **The larger the summer MIZF the lower the September SIA the following year**
- **With higher initial MIZF, the September sea ice disappears earlier**
- **The MIZ might act as a predictor of future sea ice conditions in the model simulations**

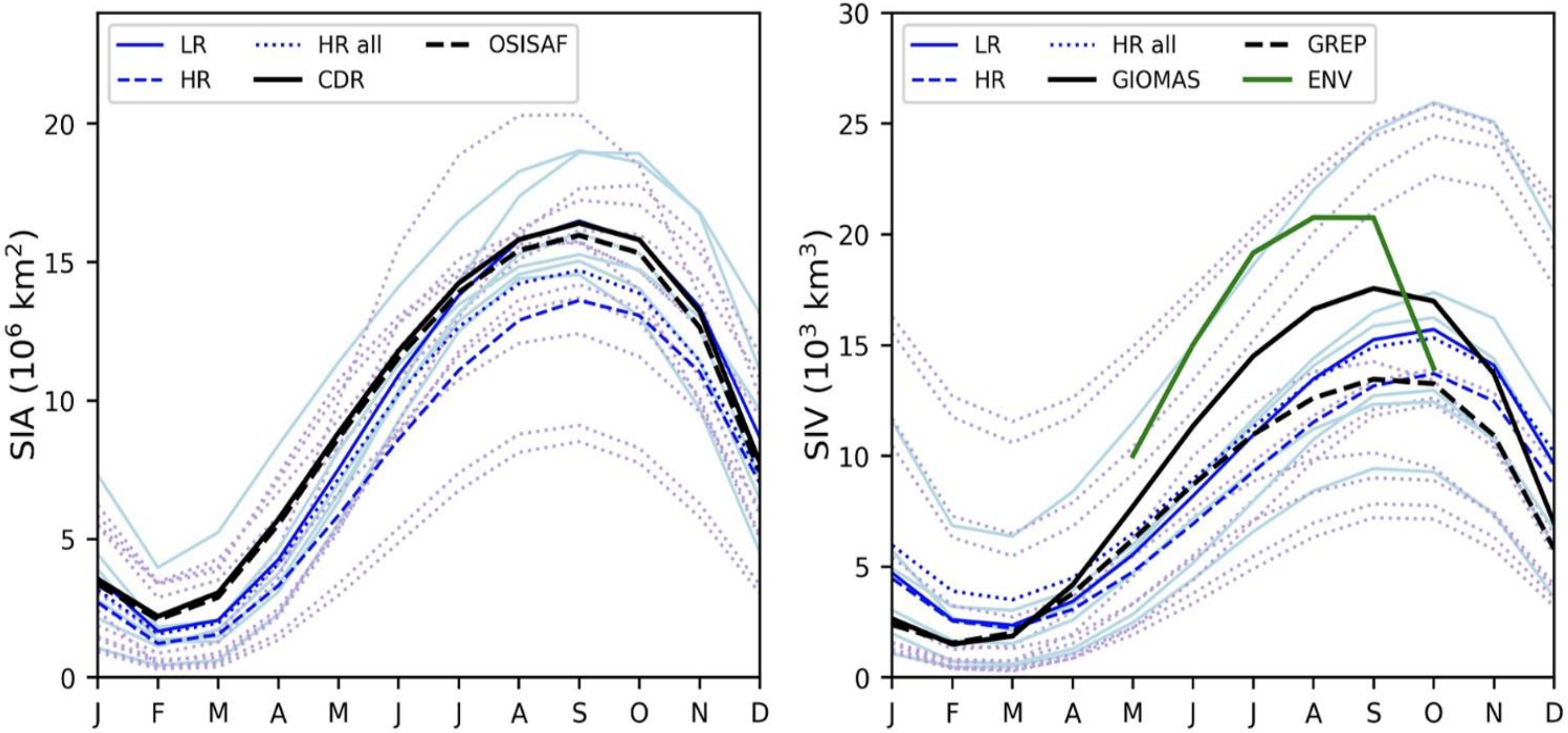




a) June, July, August, and September (JJAS) MIZF mean versus September SIA with a 1-year lag, from 2015–2050

b) Timing of the first ice-free Arctic year versus JJAS MIZF in 2015

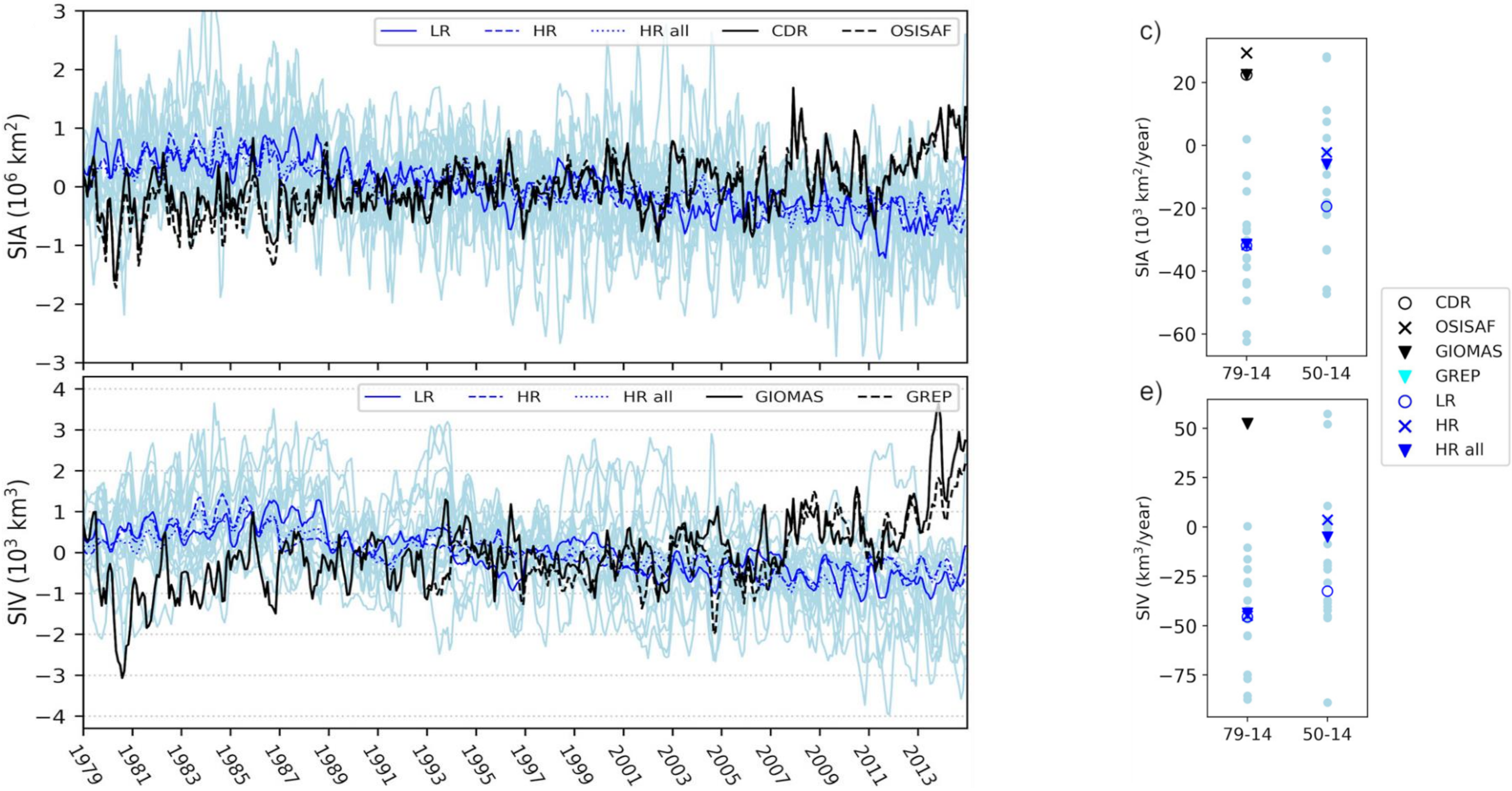
Seasonality of sea ice area and volume



Envisat SIV is computed from Envisat sea-ice thickness multiplied by NSIDC CDR sea ice concentration for the period 2003–2011

- **For SIA, Low Resolution is closer to satellite products compared to High Resolution ensembles**
- **ENVISAT has an earlier seasonal peak than ocean reanalyses**

Interannual variability and trends over 1979-2014



- **The models do not capture the overall positive trend in SIA and SIV** (except one)
- **Less-pronounced negative trends in annual mean SIA and SIV with higher ocean resolution**

Take-home messages

- Coupled climate models can adequately reproduce historical seasonal variability in SIA and SIV, although they exhibit a **large inter-model spread**, particularly in Antarctica. All models can simulate sea-ice loss in recent years in the Arctic while they generally fail to reproduce the overall expansion trend in Antarctica.

- There is **no systematic relationship between ocean/atmosphere grid resolutions and sea ice representation**: the impact of horizontal resolution rather depends on the analysed ice characteristic and the model used. However, the refinement of the ocean mesh has a more prominent effect than the atmosphere. *Given the high computational cost of high-resolution simulations, the focus of the modelling community might evolve firstly towards improving the sea ice model physics and parameterisations.*

- This study suggests the necessity to distinguish between **sea ice classes (MIZ/pack ice, FYI/MYI)** to investigate present and future sea ice changes and assess the quality of numerical systems. The proper simulation of the MIZ is fundamental for robust predictions/projections of sea ice conditions. *Given that the marginal ice zone will dominate the Arctic sea ice cover soon, the model physics might require adaptation to a new sea ice regime.*

Ocean Predict

- Selivanova, Julia, Iovino, D., Cocetta, F., 2024. *Past and future of the Arctic sea ice in High-Resolution Model Intercomparison Project (HighResMIP) climate models.* The Cryosphere 18, 2739–2763. https://doi.org/10.5194/tc-18-2739-2024

- Selivanova, J., Iovino, D., Vichi, M., 2024. *Limited Benefits of Increased Spatial Resolution for Sea Ice in HighResMIP Simulations.* Geophysical Research Letters 51, e2023GL107969. https://doi.org/10.1029/2023GL107969

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ECMWF ensemble members

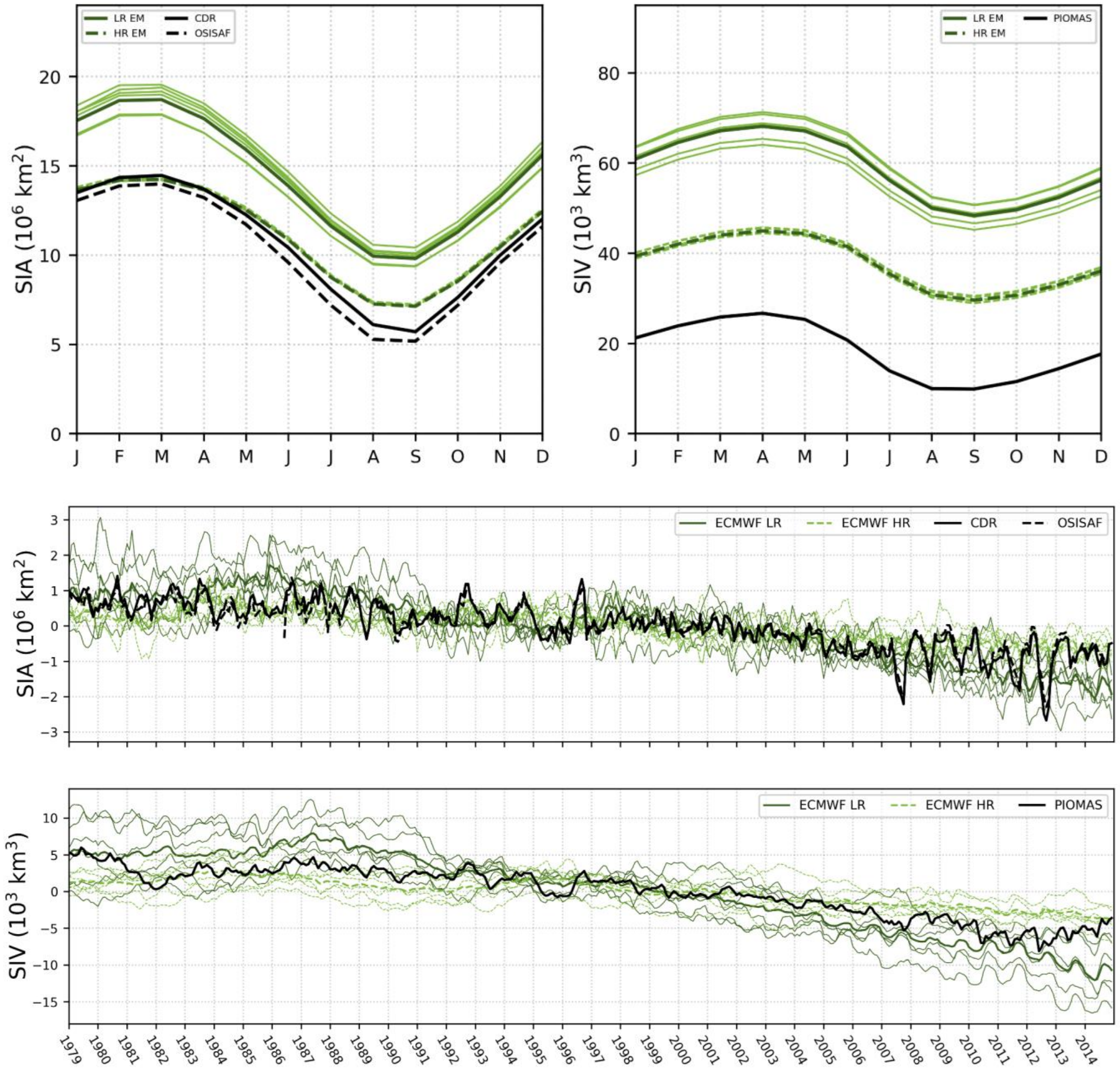


Table S1. Linear trend in SIA and SIV and their standard deviations for ensemble members of ECMWF LR and HR simulations for 1979-2014.

	1979-2014 SIA trend (10^3 km^2/yr)	1979-2014 SIV trend (km^3/yr)
ECMWF-IFR LR1	-72.08 ± 16.9	-423.86 ± 68.3
ECMWF-IFR LR2	-44.68 ± 13.5	-238.32 ± 82.8
ECMWF-IFR LR3	-134.19 ± 14	-801.13 ± 65.3
ECMWF-IFR LR4	-92.77 ± 12	-666.2 ± 34.3
ECMWF-IFR LR5	-40.13 ± 8.8	-608.42± 64.6
ECMWF-IFR LR6	-94.85 ± 11.5	-225.26 ± 63
ECMWF-IFR LR Ens	**-80.3 ± 9.1**	**-493.85 ± 49.2**
ECMWF-IFR HR1	-36.66 ± 7.6	-157.49 ± 34.4
ECMWF-IFR HR2	-40.78 ± 8.9	-209.46 ± 50.9
ECMWF-IFR HR3	-36.92 ± 8.1	-260.7 ± 58.7
ECMWF-IFR HR4	-32.45 ± 6.2	-157.08 ± 47.4
ECMWF-IFR HR5	-31.95 ± 13.7	-88.3 ± 61.8
ECMWF-IFR HR6	-11.29 ± 8.7	-32.03 ± 49.1
ECMWF-IFR HR Ens	**-31.81 ± 5**	**-150.85 ± 22.8**

CNRM ensemble members

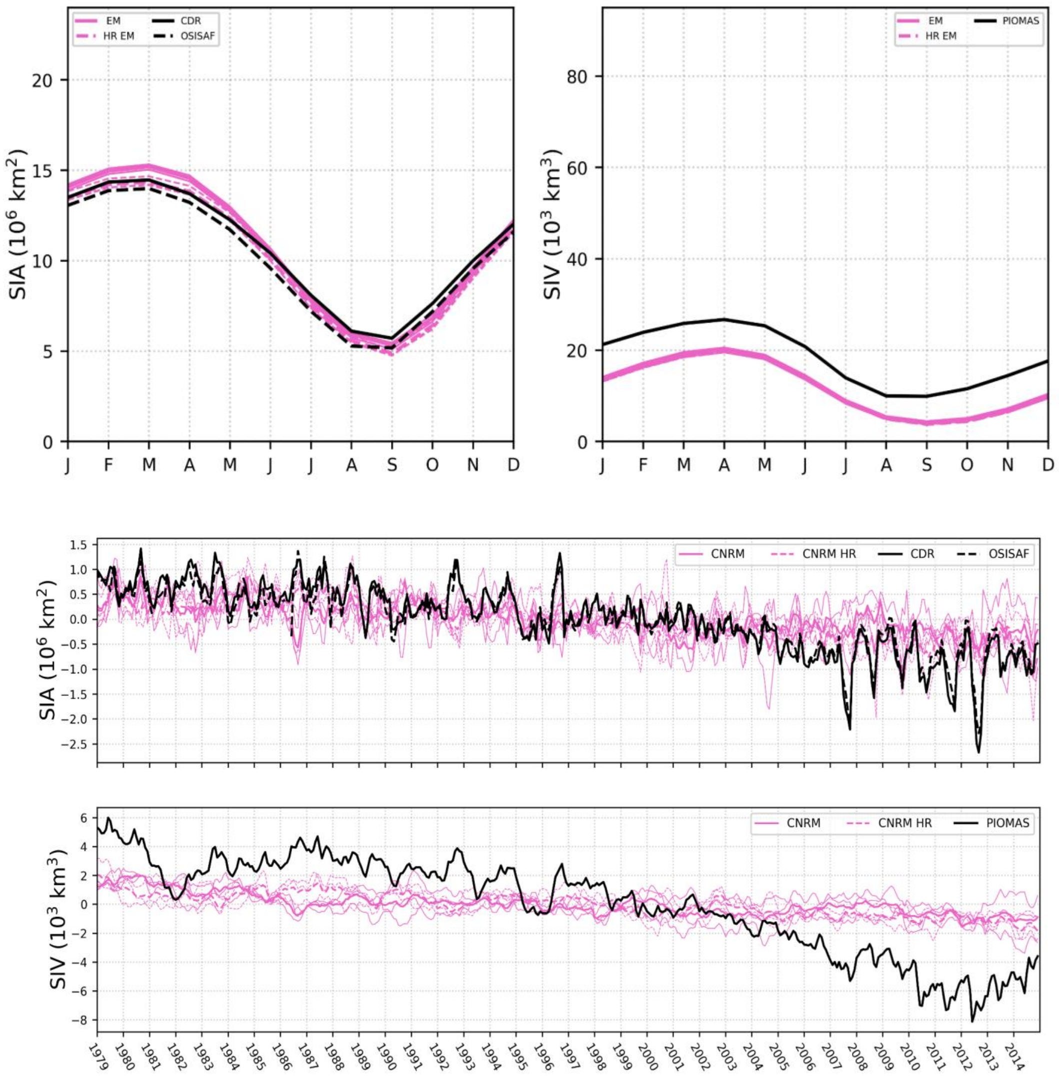
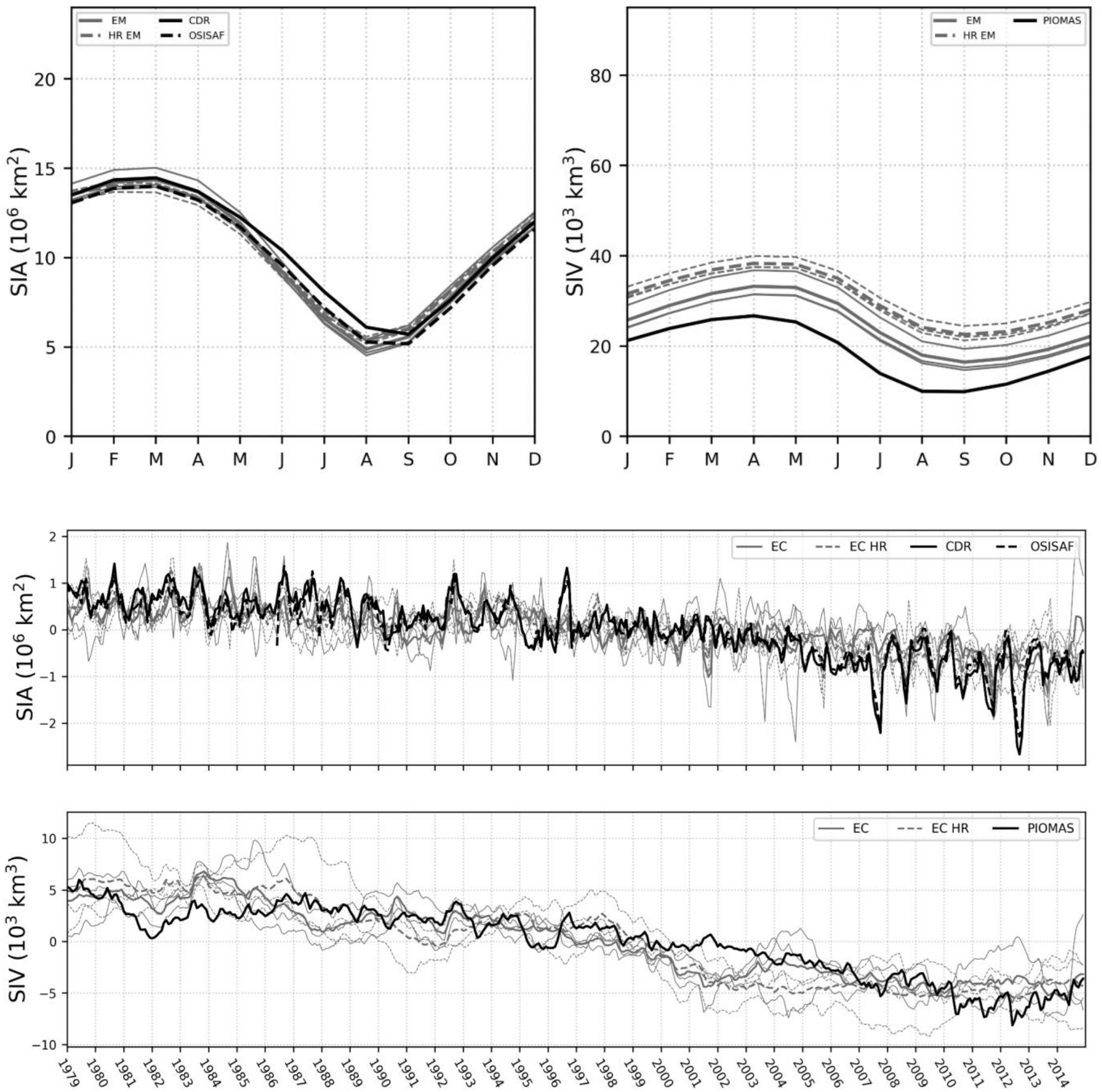


Table S2. Linear trend in SIA and SIV and their standard deviations for ensemble members of CNRM LR and HR simulations for 1979-2014.

	1979-2014 SIA trend (10^3 km^2/yr)	1979-2014 SIV trend (km^3/yr)
CNRM LR 1	-29.83 ± 8.9	-61.89 ± 23.6
CNRM LR 2	-16.29 ± 8.9	-53.95 ± 22.1
CNRM LR 3	-14.19 ± 9.6	-56.77 ± 24.2
CNRM LR Ens	**-20.1 ± 4.4**	**-57.54 ± 12.3**
CNRM HR1	-15.94 ± 7.9	-35.58 ± 15.9
CNRM HR2	-36.1 ± 7.2	-70 ± 19
CNRM HR3	-39.94 ± 6.3	-94.53 ± 13.6
CNRM HR Ens	**-30.67 ± 4**	**-66.7 ± 10.1**

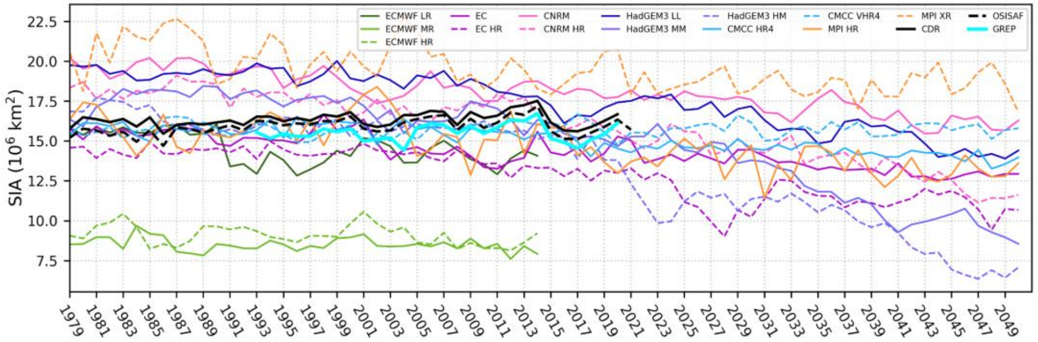
EC-Earth ensemble members

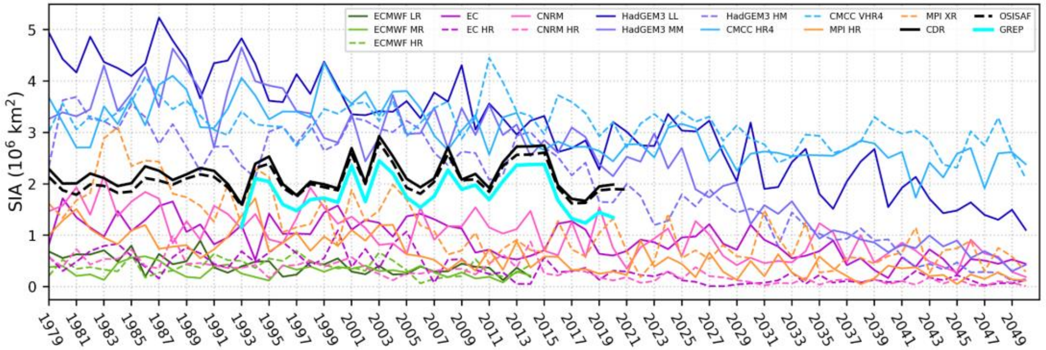


	1979-2014 SIA trend (10^3 km^2/yr)	1979-2014 SIV trend (km^3/yr)
EC-Earth3P LR 1	-34.2 ± 9.47	-322.28 ± 31.8
EC-Earth3P LR 2	-40.31 ± 7.8	-394.77 ± 58.4
EC-Earth3P LR 3	-19.87 ± 9.7	-224.19 ± 55.3
EC-Earth3P LR ens	**-31.46 ± 4.4**	**-313.77 ± 31.3**
EC-Earth3P HR 1	-40.13 ± 8.8	-460.47 ± 97.5
EC-Earth3P HR 2	-19.25 ± 6.9	-211.62 ± 59.7
EC-Earth3P HR 3	-50.26 ± 8.5	-427.92 ± 43.3
EC-Earth3P HR ens	**-36.55 ± 4.9**	**-366.67 ± 41.1**

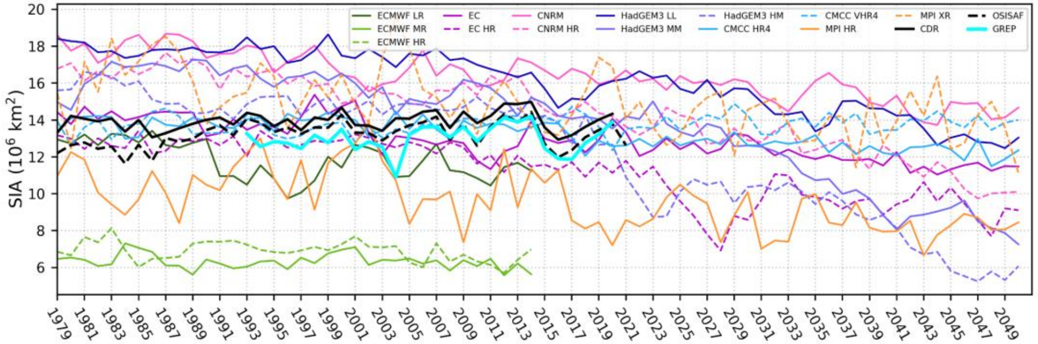
SIA time series 2015-2050, September and February

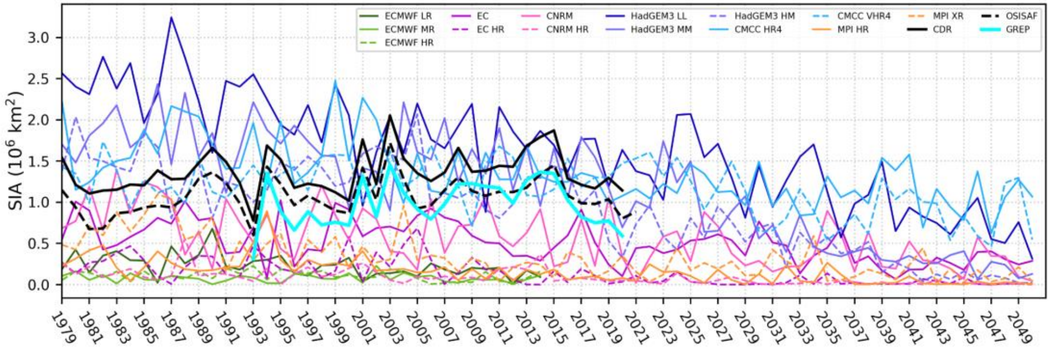
SIA



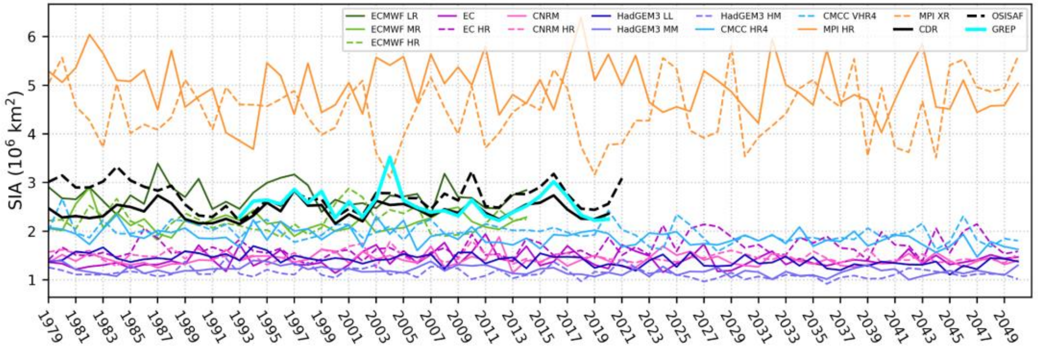


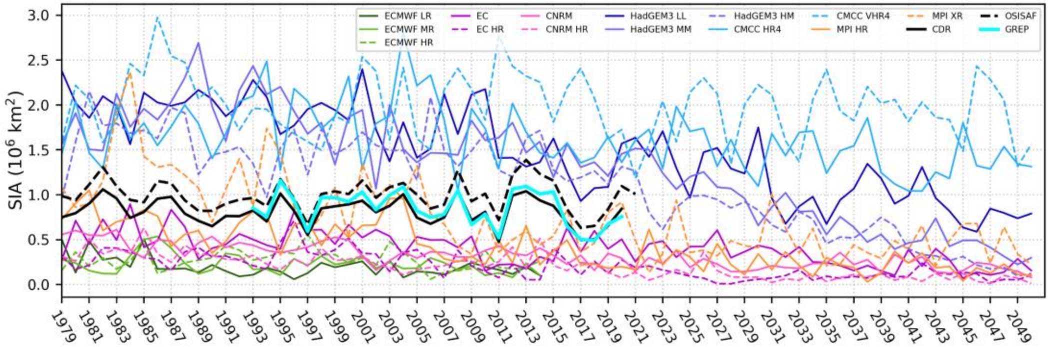
Pack



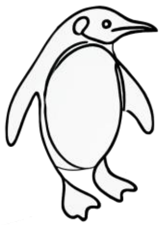


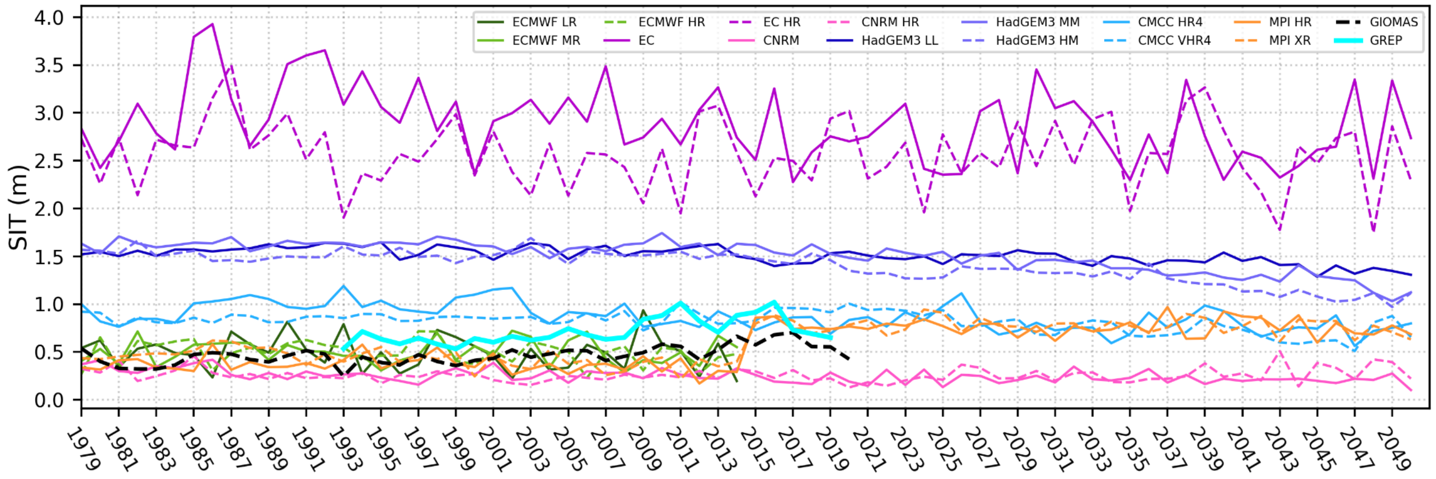
MIZ

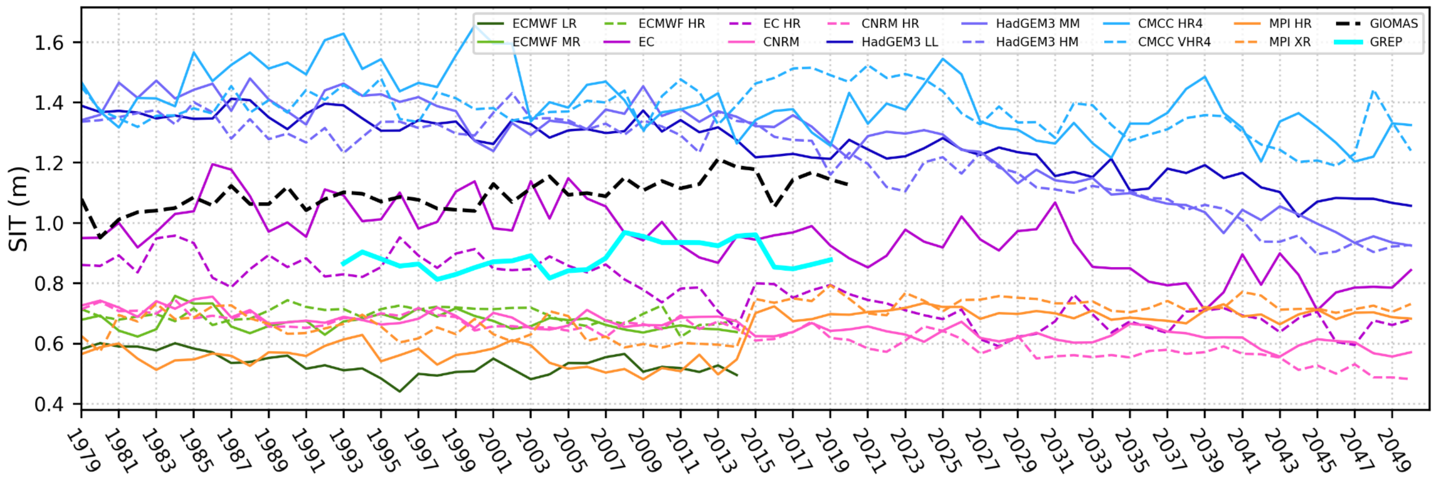




SIT time series 1979-2050, September and February







SIV time series 1979-2050, September and February