Effects of mesoscale ocean flows on multidecadal climate variability

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photo: Landsat 8

Motivation and Research Question

- CMIP5 models (all with non-eddying oceans) underestimate multi-decadal variability. [1]

- When changing from diffusive to turbulent oceans, model biases reduce and eddies provide a source of internal noise that can excite existing modes of variability and new modes of variability emerge (e.g. through eddy—mean flow interaction).

What is the effects of resolving mesoscale eddies on simulating multidecadal variability?

Method

- comparing low frequency variability of two 250 year CESM1 simulations (one eddy-resolving, one not):
  1. SST indices and patterns compared with observed SSTs patterns
  2. ocean heat content changes between the simulations
  3. surface heat fluxes spectra between the simulations

name	ocean	atm.	detrending	source
HIGH	0.1°	0.5°	quadratic	CESM1.04
LOW	1°	1°	quadratic	CESM1.12
HIST		—	two-factor [2]	HadISST

Table: Simulations and observations.

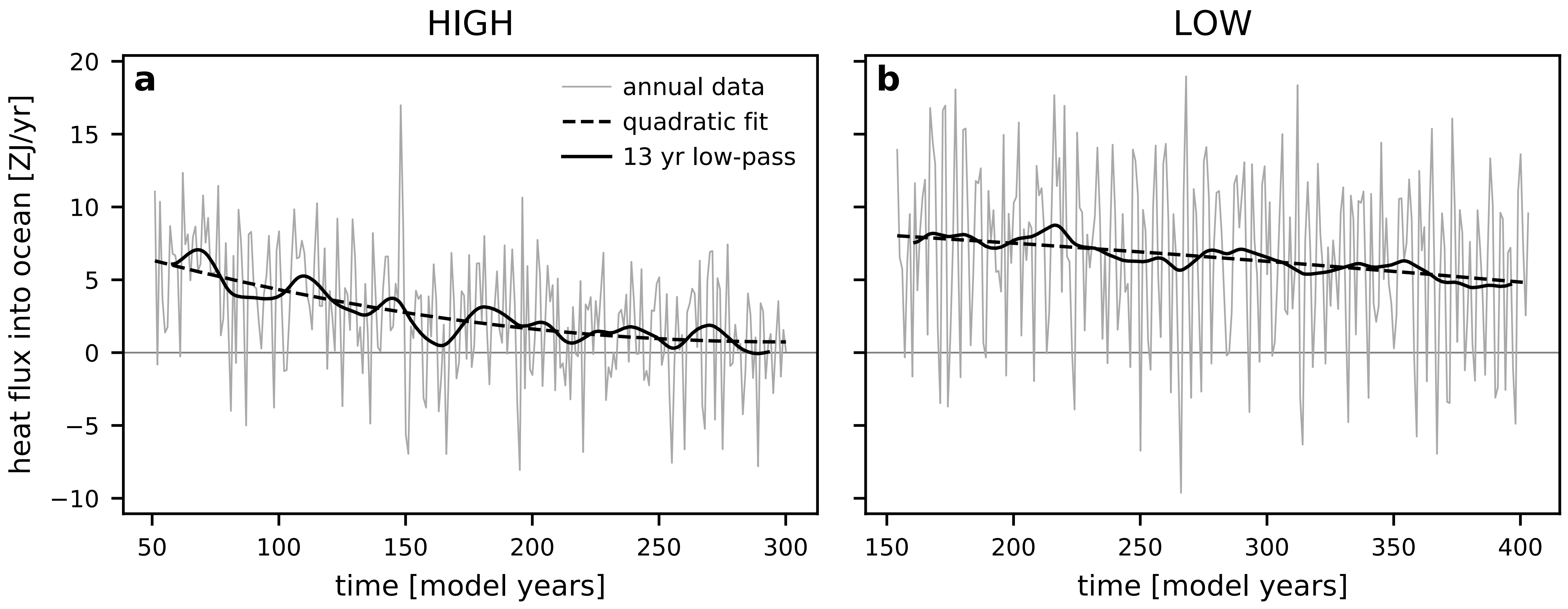


Fig: Heat flux into ocean showing equilibration of simulations with quadratic trend and low pass filtered variability.

Modes of multidecadal variability

mode	name	area (see maps)	method
AMV	Atlantic Multidecadal Variability	[70°W,0°E]x[0°N,60°N]	SST avg.
PMV	Pacific Multidecadal Variability	[20°N,70°N]	1st principal component
SOM	Southern Ocean Mode [3]	[50°W,0°E]x[50°S,30°S]	SST avg.

Table: The three modes of multidecadal variability used. (PMV==PDO)

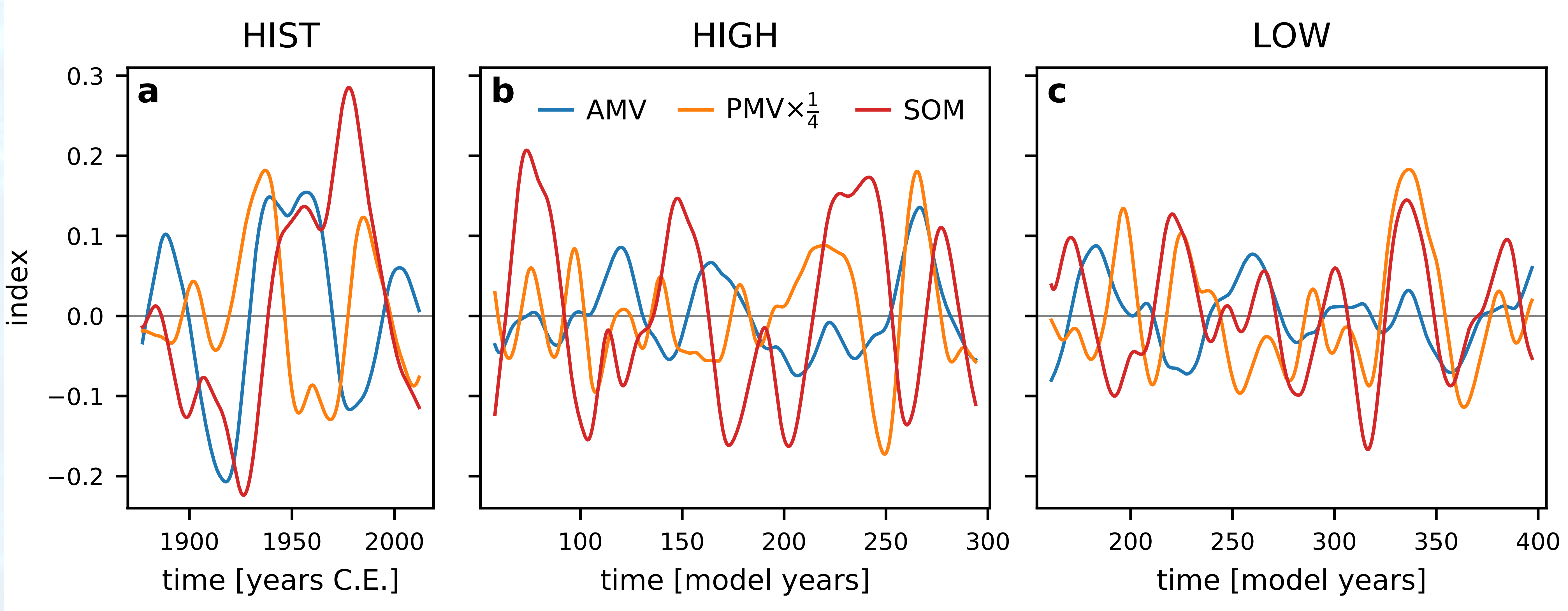


Fig: Lowpass filtered time series of SST indices.

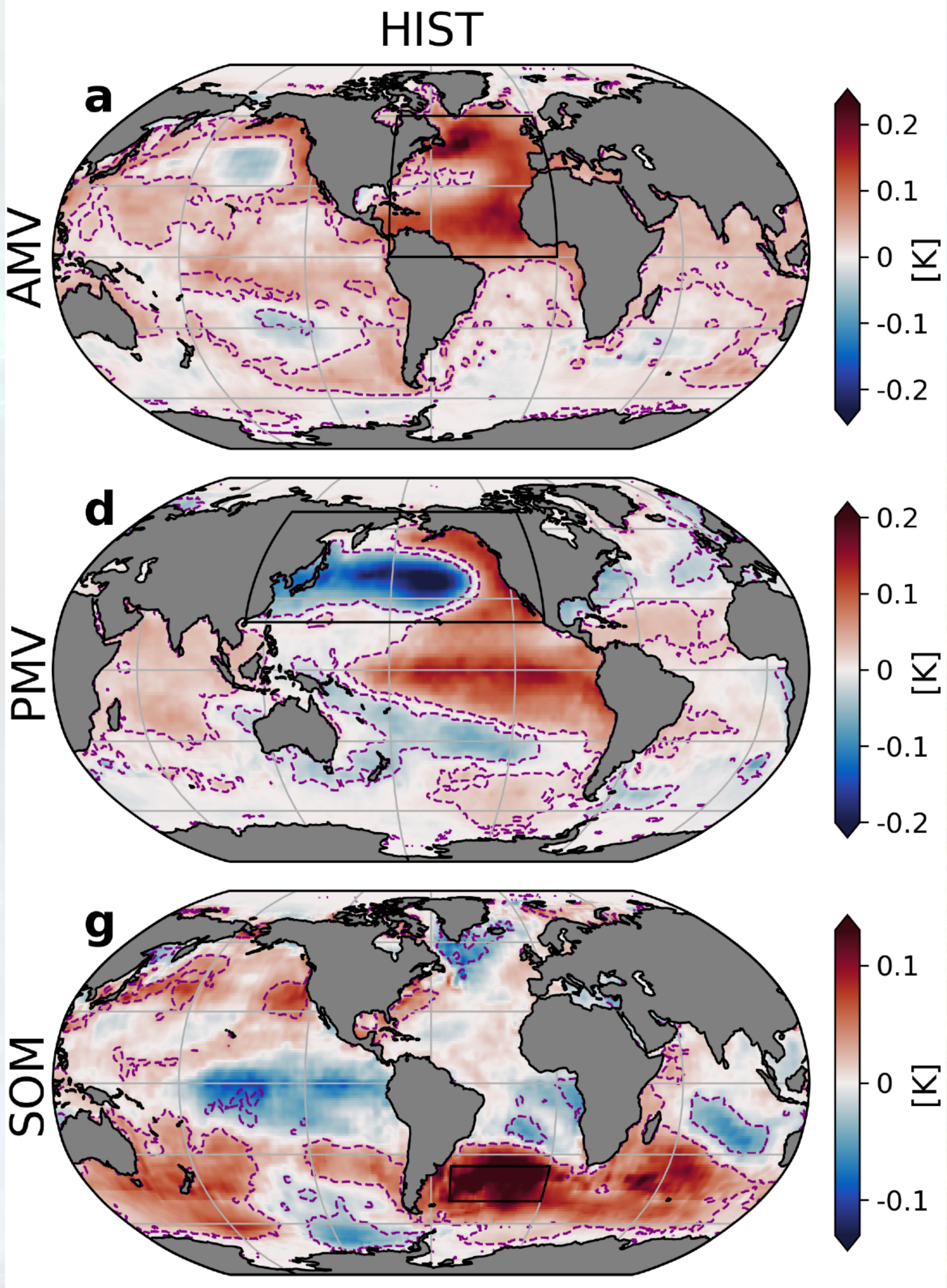
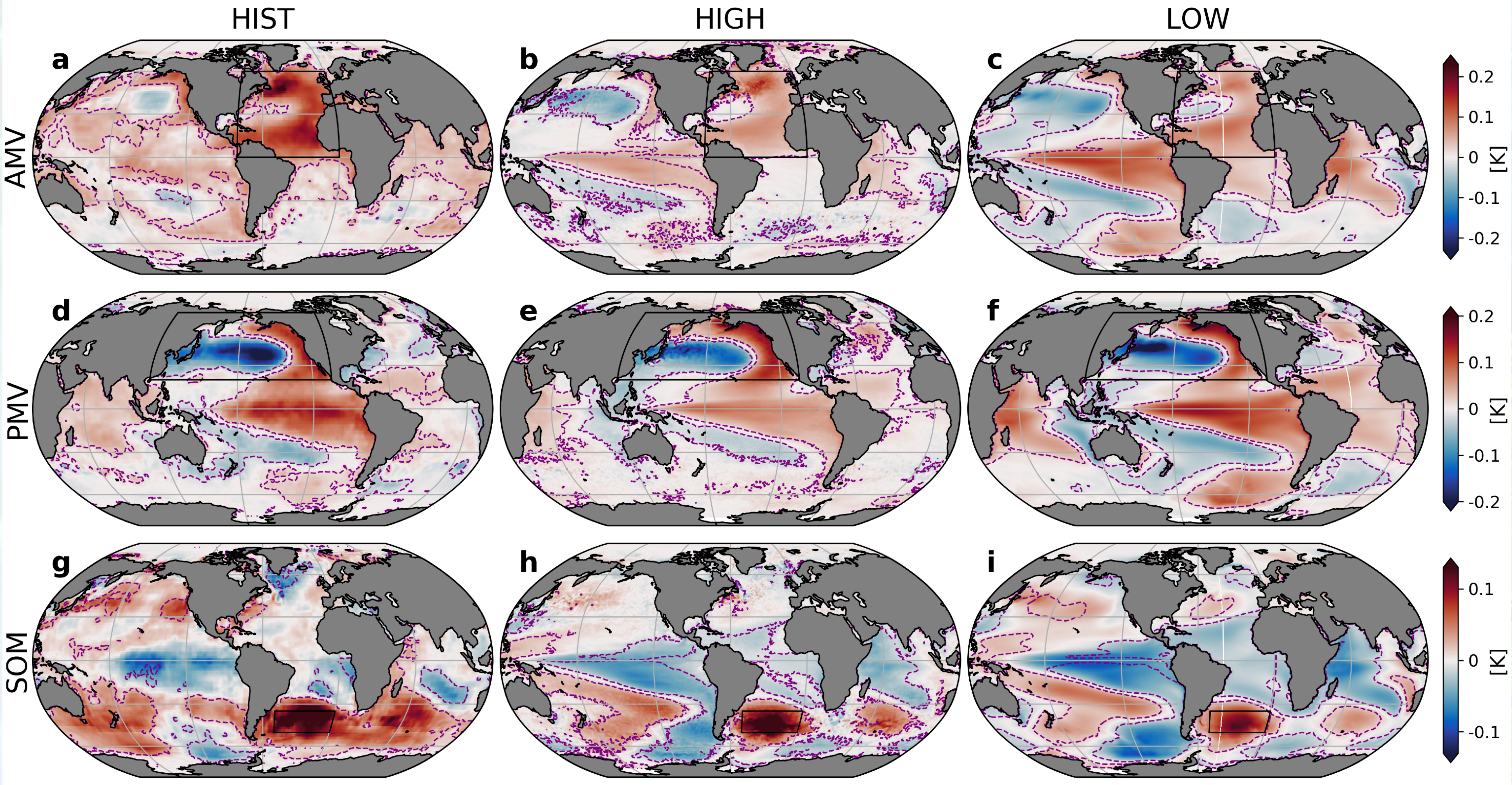


Fig: Regression maps on SST indices for detrended observations.

Regression patterns

- AMV: HIGH captures subpolar gyre maximum
- PMV: both HIGH and LOW have minimum too far west, HIGH reduces Atlantic correlation
- SOM: both HIGH and LOW capture wave number 3 pattern, but LOW likely coupled to other modes



- LOW: too strong coupling between all three modes, resembling hyper climate mode (c)≈(f)≈-(i) [4]

Ocean Heat Content

- HIGH: more vertically integrated, low frequency ocean heat content variability at all latitudes than LOW
- HIGH: Southern Ocean shows meridionally propagating anomalies, akin to Southern Ocean Mode , absent in LOW
- HIGH: Atlantic much larger subpolar gyre variability and strong coherent subtropical mode compared to LOW

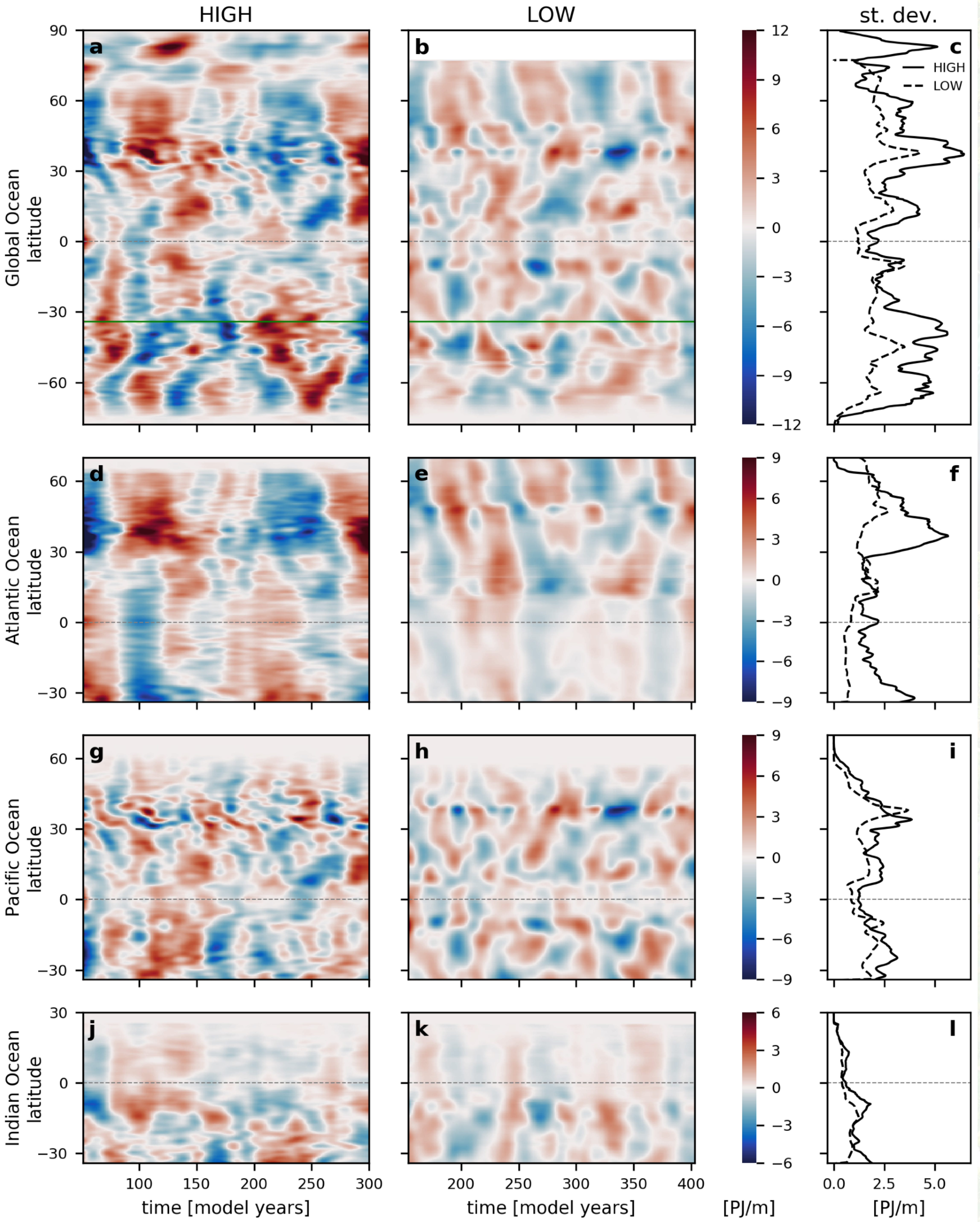


Fig: Hovmöller diagram of 250 year of depth integrated ocean heat content per basin in latitude. Right: standard deviation per depth level. All 13 year lowpass filtered. Note different color scales.

Ocean Heat Content

- HIGH : more OHC variability with deeper reaching anomalies especially in the Southern Ocean than LOW
- Atlantic: enhanced variability only between 500 m and 1200 m
- Pacific, enhanced variability does not appear in meridional Hovmöller diagram

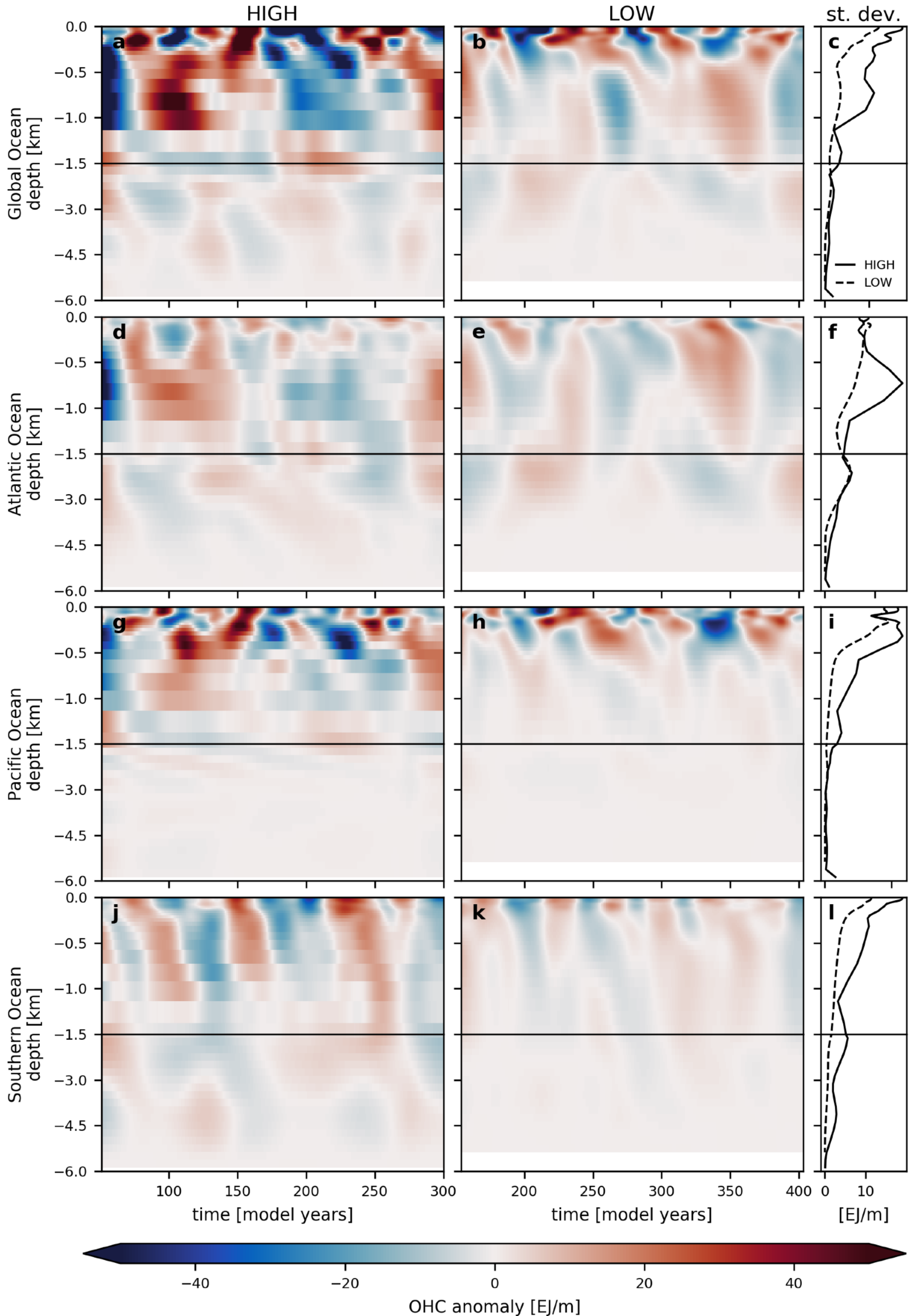
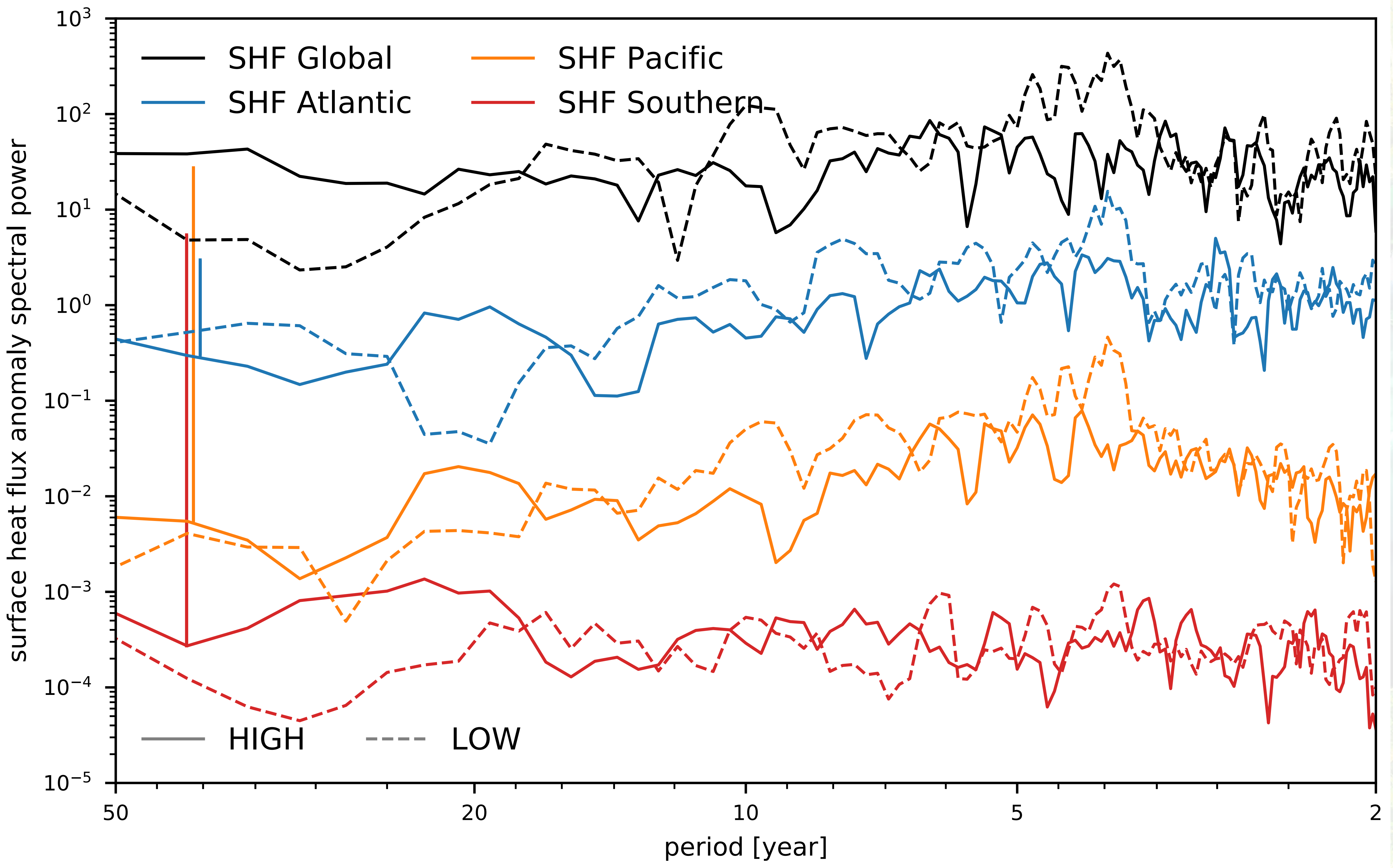


Fig: Hovmöller diagram of 250 year of ocean heat content per basin in depth. Right: standard deviation per depth level. All 13 year lowpass filtered.

Spectra

- HIGH surface heat flux low frequency spectral power is higher in Southern Ocean and globally
- due to larger spectral power in heat flux convergence in the atmosphere, there is more atmospheric variability at low frequencies



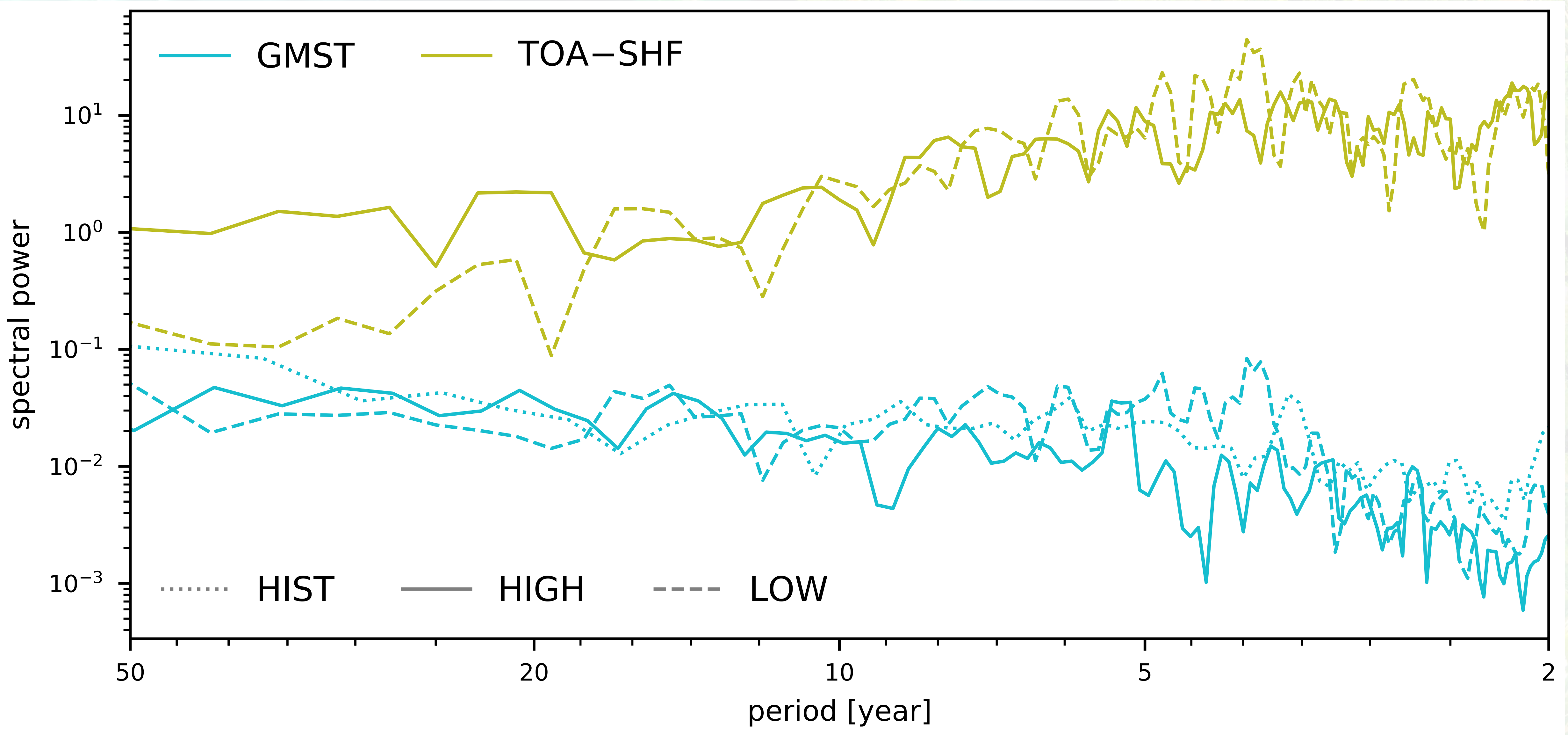


Fig: Multi-taper spectra of Surface Heat Fluxes (top), Global Mean Surface Temperature & atmospheric heat convergence (bottom).

Conclusions

- current climate models represent multidecadal variability poorly may thus underestimate low frequency surface temperature variability, affecting for example attribution
- CESM multidecadal variability is stronger with eddy-resolving ocean due to stronger vertical heat fluxes and new mode in Southern Ocean
- improved representation of modes could improve decadal predictability
- increased low frequency ocean heat content variability results in higher global mean surface temperature variability, leading us to expect stronger “hiatuses” and “accelerations” of anthropogenic warming trend
- detrending of observations and specific phasing of modes in only 150 year historical period remain issues, and we cannot estimate multidecadal variability in the ocean due to a lack of long observations
- ongoing work to assess effects of different model versions, atmospheric resolution, and vertical ocean resolution

references

[1] Cheung (2017: “Comparison of Low-Frequency Internal Climate Variability in CMIP5 Models and Observations”, doi: 10.1175/JCLI-D-16-0712.1

[2] Frankcombe et al. (2018): “On the Choice of Ensemble Mean for Estimating the Forced Signal in the Presence of Internal Variability”, doi: 10.1175/JCLI-D-17-0662.1

[3] Le Bars et al. (2016): “A Southern Ocean mode of multidecadal variability”, doi: 10.1002/2016GL068177

[4] Dommenget et al. (2008): “Generation of hyper climate modes”. doi: 10.1029/2007GL031087