NOAA CPO CVP Webinar Series on
AMOC Mechanisms & Decadal Predictability
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Estimation of the Externally Forced Climate Change SST Signal and Its Impact on the SST Atlantic Multidecadal Variability

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Statistical estimation of externally forced signal

Category I

Multi-model ensemble (e.g. CMIP ensemble) approach to infer the anthropogenic climate change signal in the observation (e.g. Ting et al. 2009; Delsole et al. 2011)

Category II

Relying on the statistics of a single observational dataset (e.g. Trenberth and Shea 2006).

Approach of this study

- Treat each simulation of a large ensemble (n≥30) as if it is a single observational dataset.
- Apply seven different commonly used methods in the category II.
- Compare the result to the “true” externally forced signal based on the ensemble mean.
- Target variable: ***Annual mean SST for 1940-2015***.

Two different large Ensemble (LE) simulations

- **CESM1-LE**: Community Earth System Model v.1 (Kay et al. 2015)

  40 ensemble members, ~1° atmosphere & ocean, 1920-2100

- **IPSL-CM5-LE**: IPSL Climate Model v.5 (Dufresne et al. 2013)

  30 ensemble members, ~2° atmosphere & ocean, 1940-2020

* Each member is initialized with slightly different initial conditions, while the external forcing, e.g. greenhouse gases and volcanic eruptions, are specified identically among the ensemble members.

  ➜ Ensemble mean = response to the external forcings

  Deviation from the ensemble mean = natural climate variability of each member

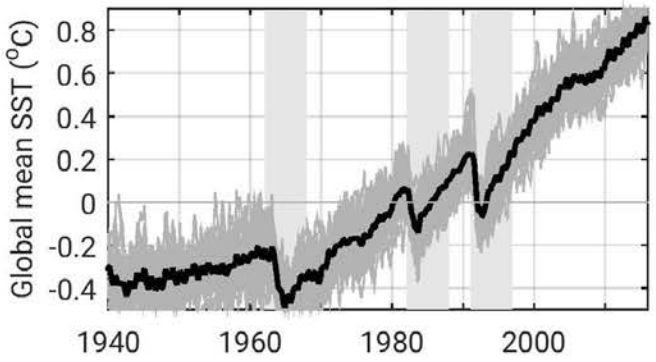
Two different large Ensemble (LE) simulations

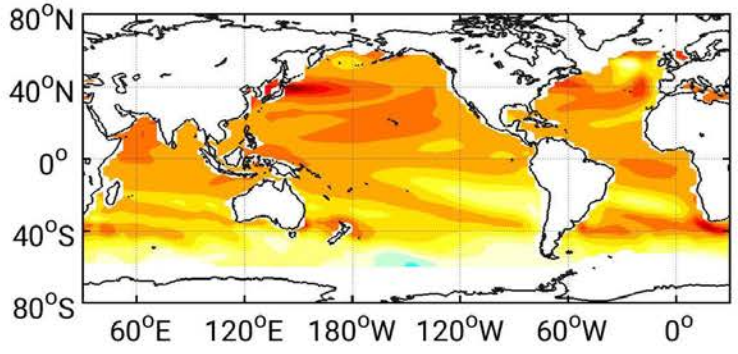
Global mean SST

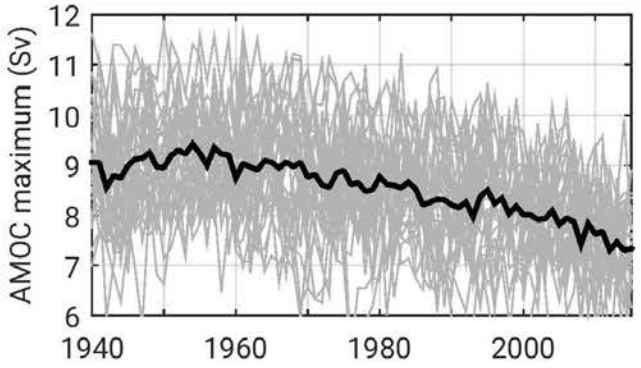
SST regression on global mean SST (using ensemble mean fields)

Maximum AMOC @ ~40◦N

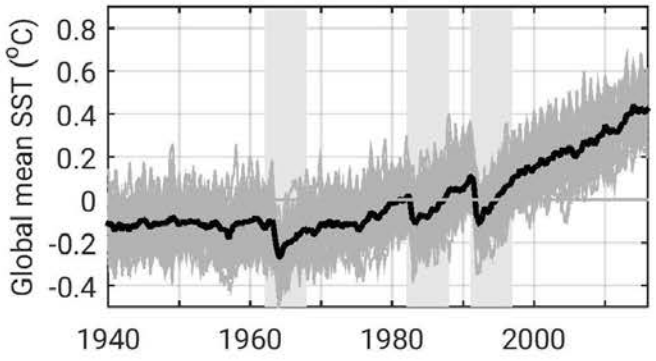
IPSL-CM5-LE

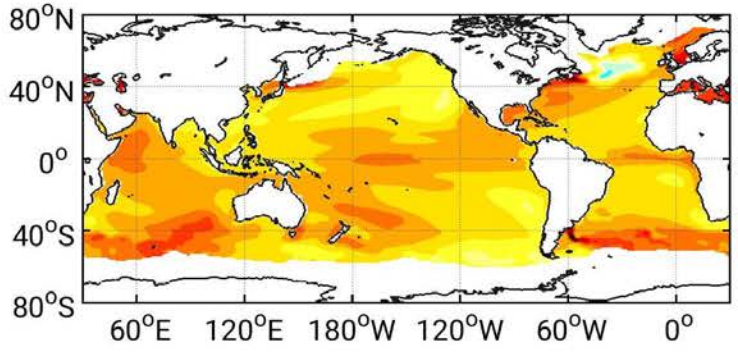


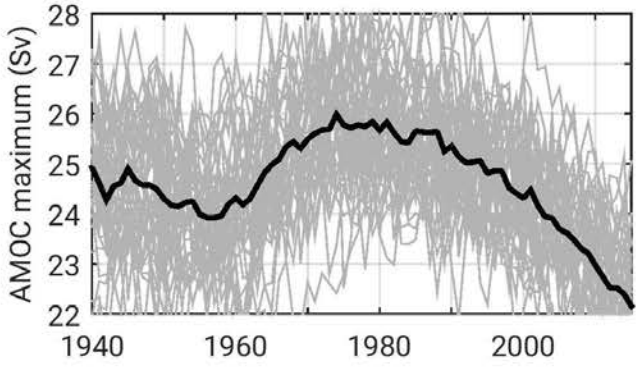


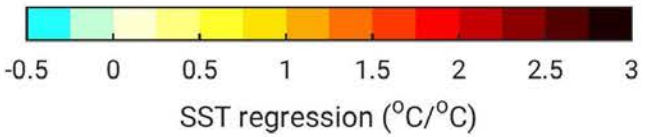


CESM1-LE









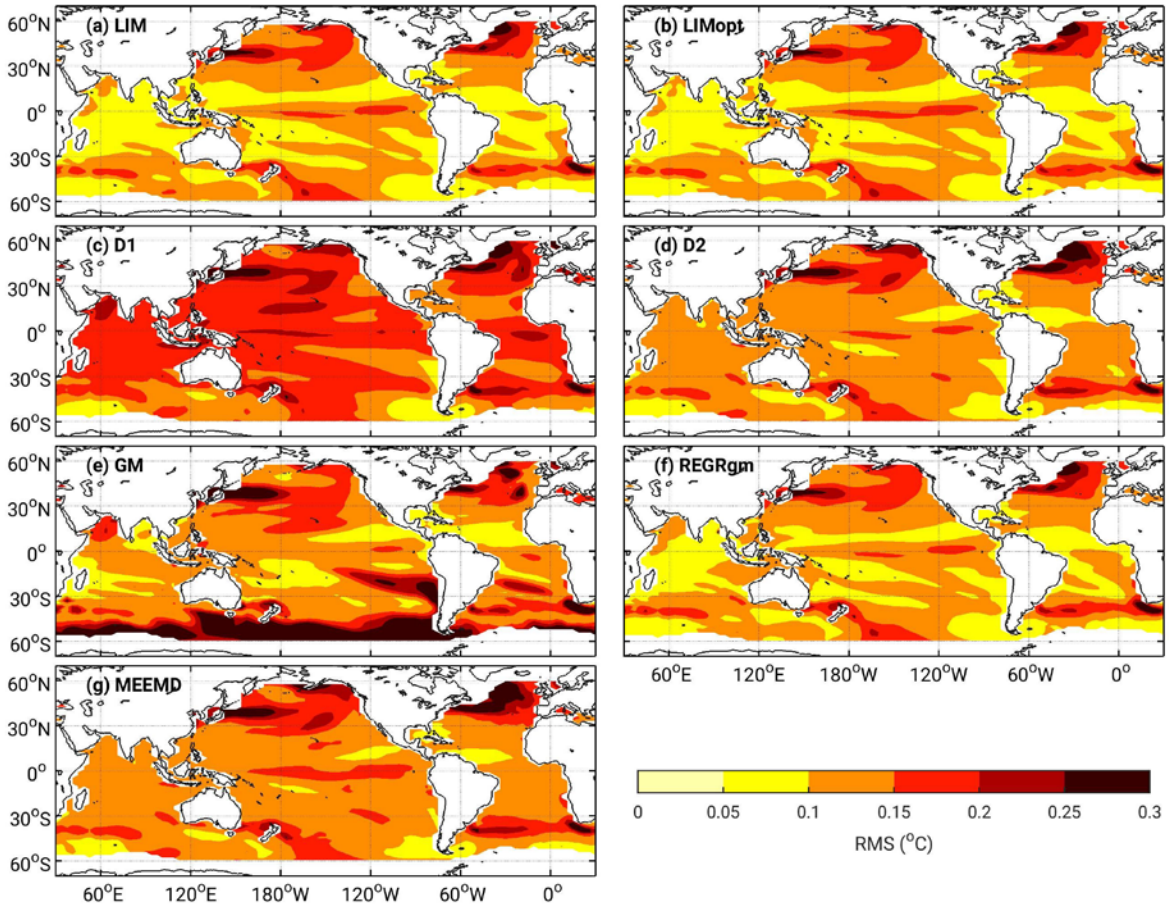
Grey curves: each member / Black curves: Ensemble mean

7 different statistical estimates of externally-forced annual mean SST

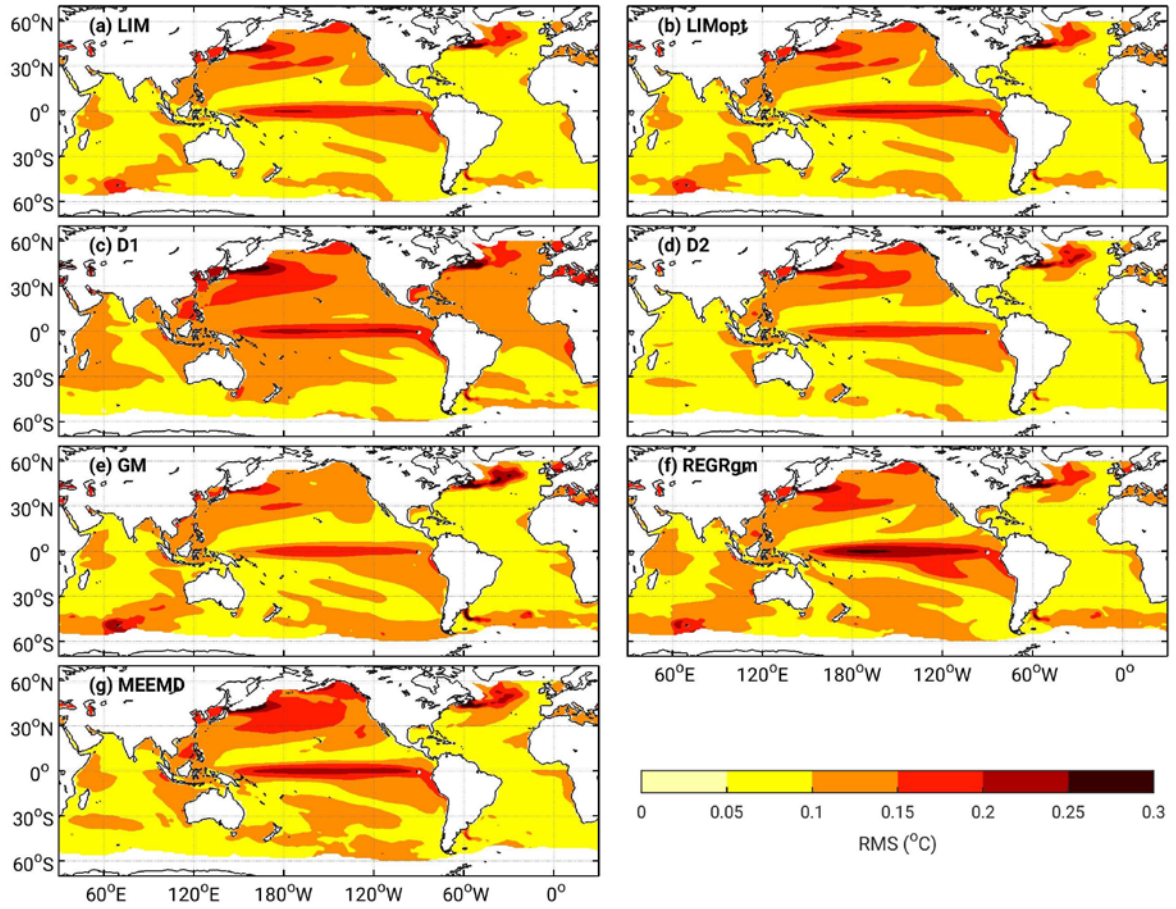
0. **EnsAvg**: Ensemble average at each grid ➡ *considered as the truth*
1. **D1**: 1st order linear trend at each grid of each member
2. **D2**: 2nd order trend at each grid of each member (Enfield and Sid-Serrano 2010)
3. **GM**: Global mean time series of each member (Trenberth and Shea 2006)
4. **REGRgm**: Linear regression at each grid on the GM (Ting et al. 2009)
5. **LIM**: First damped mode of the linear inverse model decomposition (Marini and Frankignoul 2013)
6. **LIMopt**: Fastest growing mode using the optimal perturbation filter based on the linear inverse model with τ_e=2.5 yrs & τ_1=20 yrs (Solomon and Newman 2013)
7. **MEEMD**: Multidimensional ensemble empirical mode decomposition (Ji et al. 2014)

Ensemble mean of the RMS differences between the estimated forced SST in each member and the truth

IPSL-CM5-LE

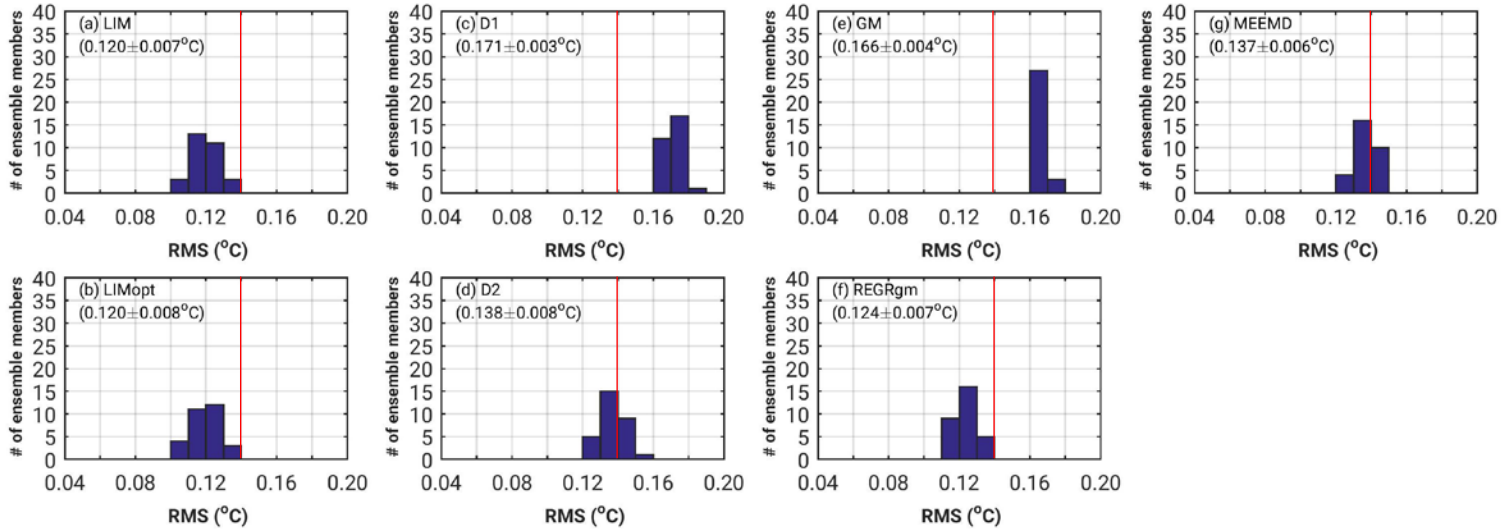


CESM1-LE



Global mean of RMS differences at each grid between the estimated forced SST in each member and the truth

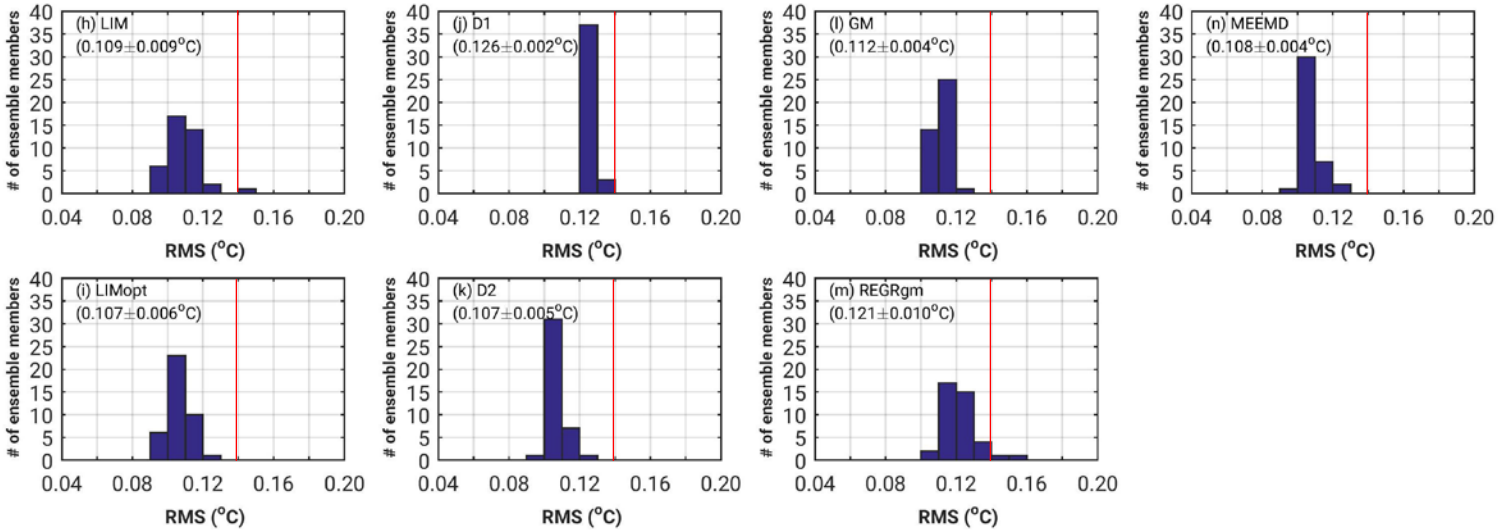
IPSL-CM5-LE



LIM, LIMopt *are superior.*

D1, GM are inferior

CESM1-LE



LIM, LIMopt*, D2, MEEMD are superior.*

Atlantic Multidecadal Variability (AMV) after removing the externally-forced signal

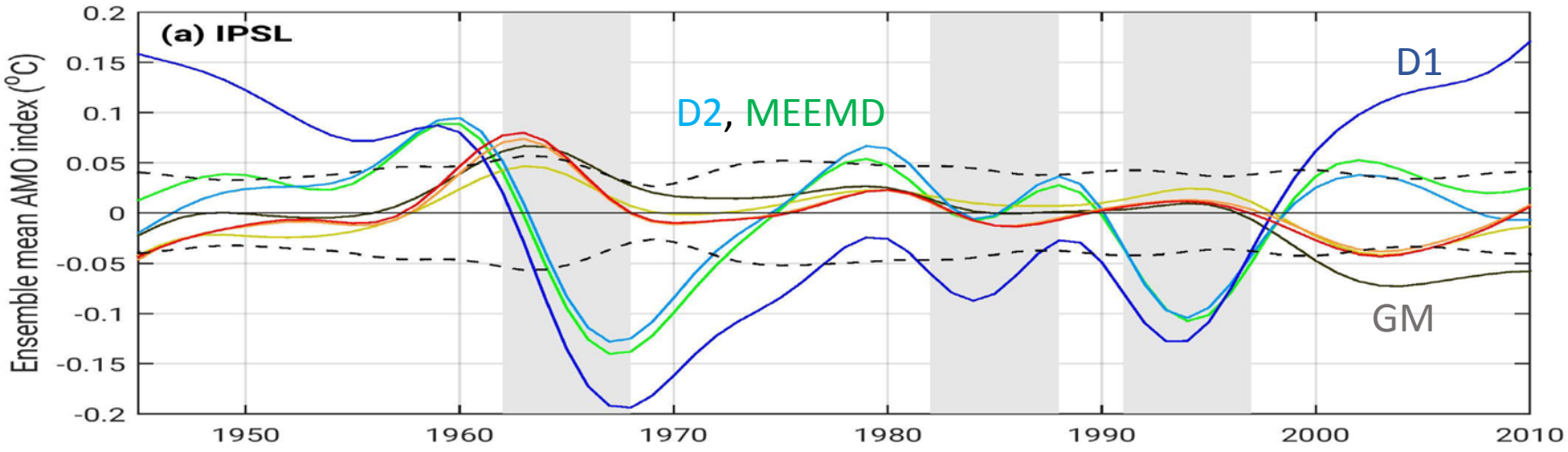
- **AMV index**:
  10-yr low-pass filtered time series of mean SST in 0-60°N, 0-80°W after removing the externally forced signal using the different methods.

- **AMOC index**:
  10-yr low-pass filtered time series of AMOC maximum near 40°N after removing the ensemble mean time series.

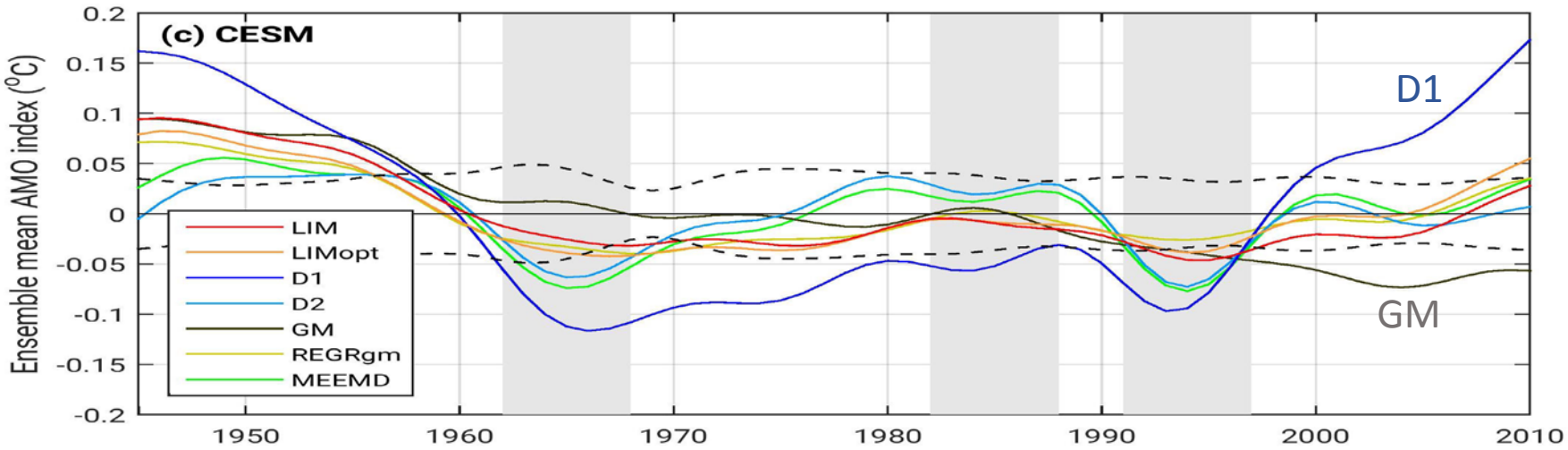
AMV indices: How well are the externally-forced signals removed?

Ensemble mean of AMV indices (should be near zero within error bars)

IPSL-CM5-LE

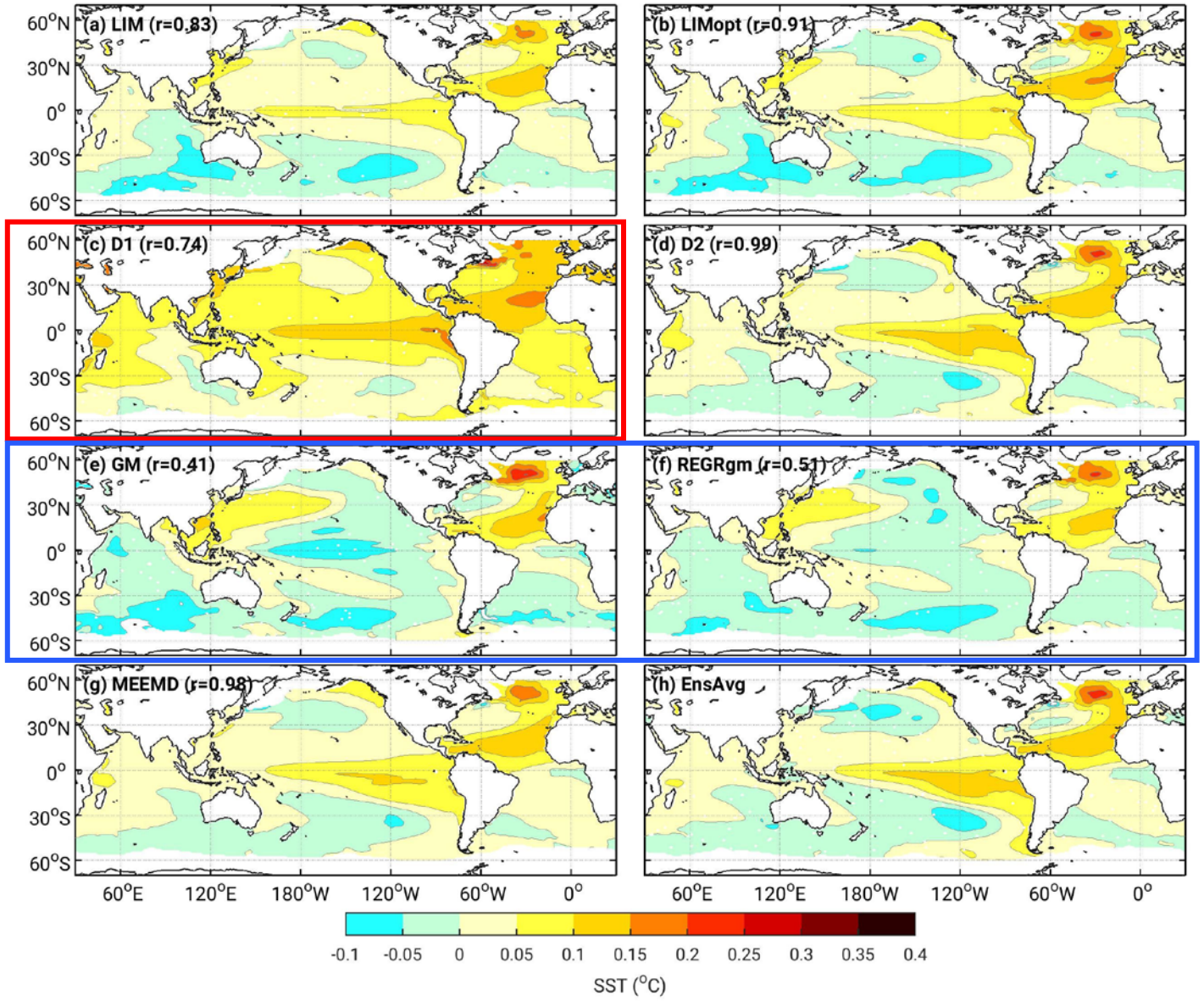


CESM1-LE



- - - - 95% confidence interval based on ensemble spread around the ensemble mean

Ensemble mean of SST regressions on AMV indices



CESM1-LE

In North Atlantic,
all the methods are reasonable except D1.

In Pacific,
only the GM and REGRgm exhibit cooling in tropics.

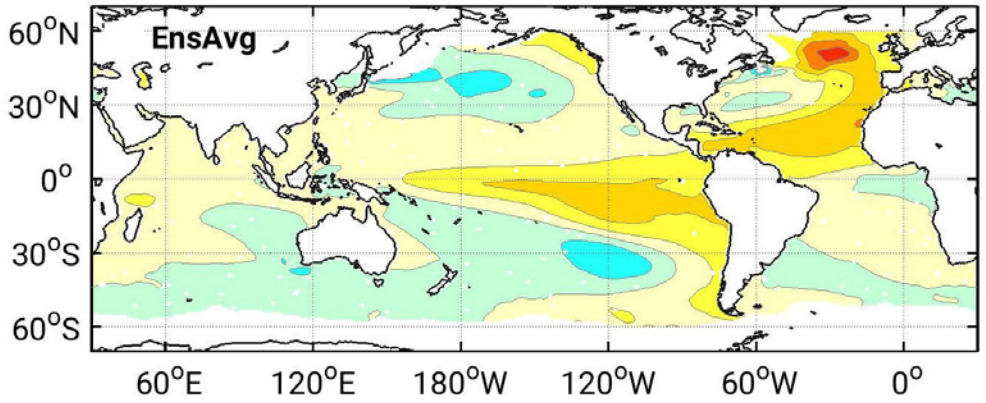
Similar result for the IPSL-CM5-LE.

Spatial correlation (*r*) calculated globally against the EnsAvg AMO pattern (h) is given in each panel.

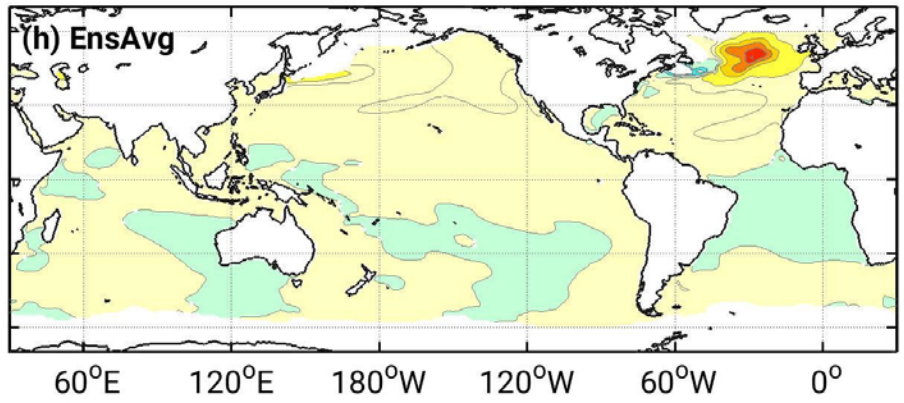
AMV pattern vs. AMOC SST fingerprint *(only for the EnsAvg)*

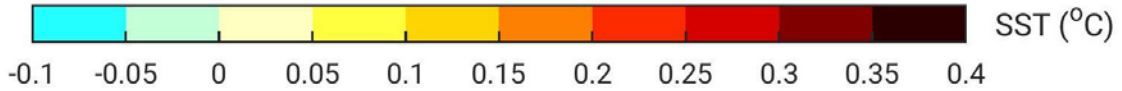
CESM1-LE

AMV pattern



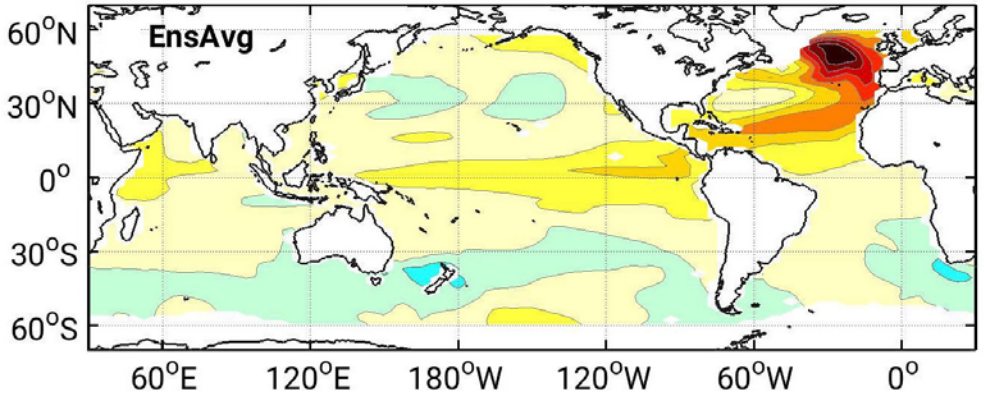
AMOC SST fingerprint (lag=2 yrs)



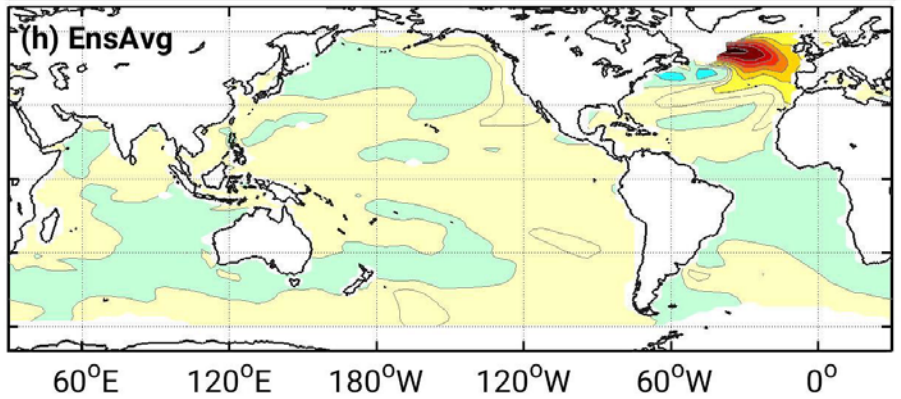


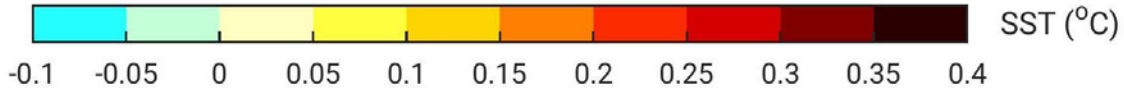
IPSL-CM5-LE

AMV pattern



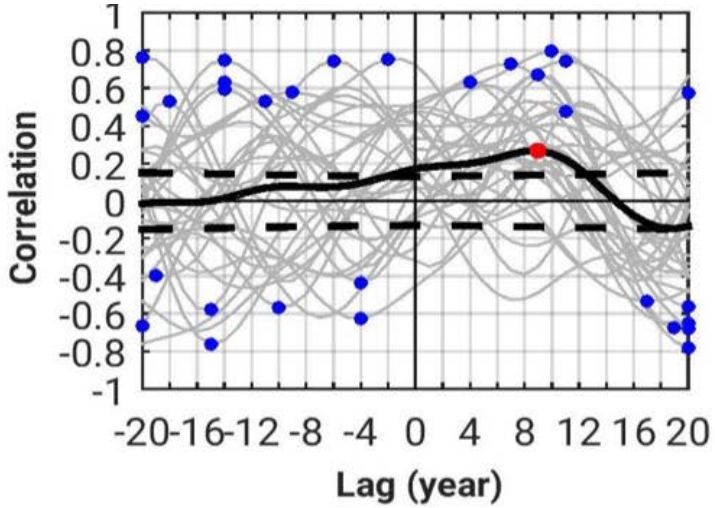
AMOC SST fingerprint (lag=9 yrs)

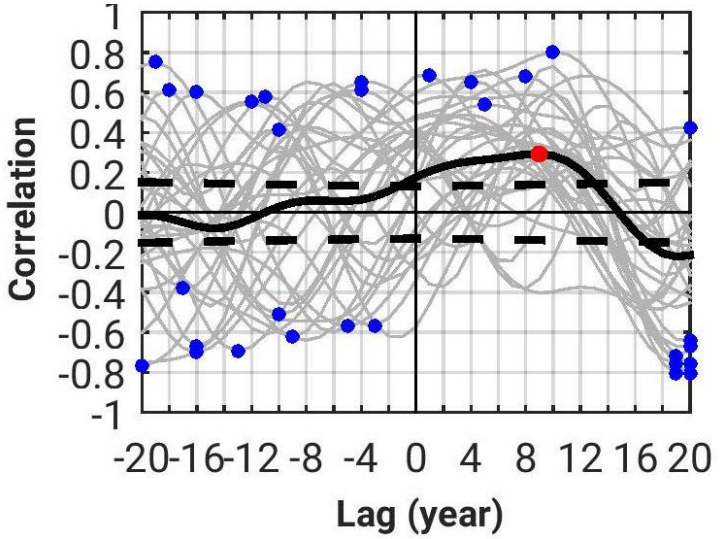




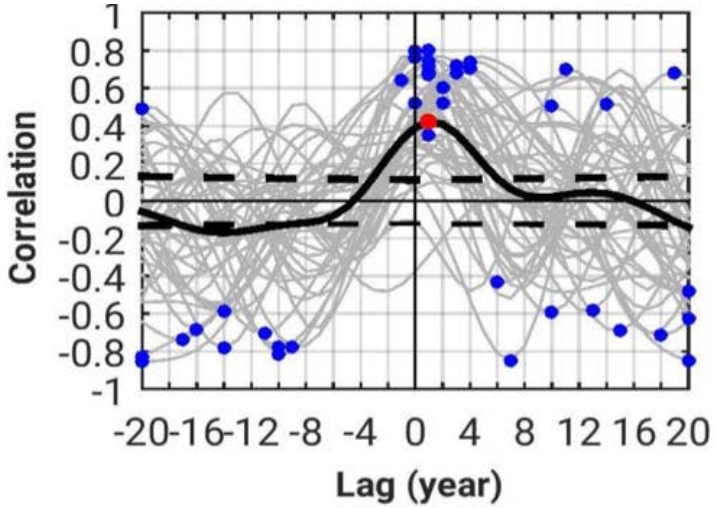
AMV index – AMOC index correlations *(only for the EnsAvg)*

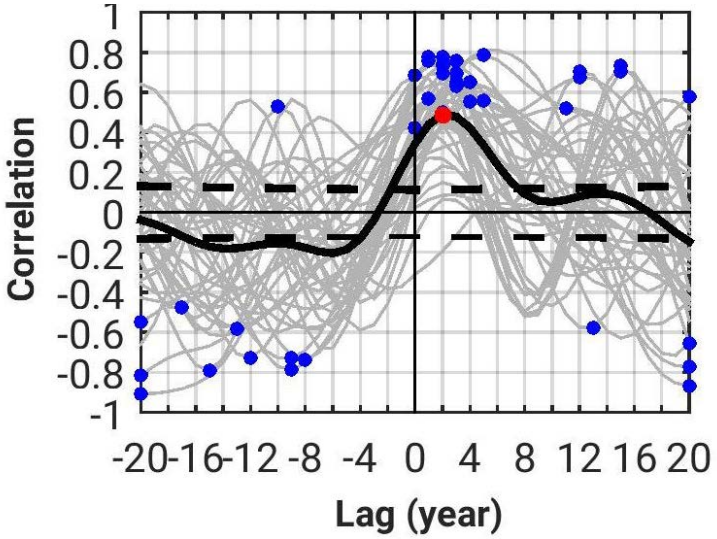
IPSL-CM5-LE





CESM1-LE





Black curves: Ensemble mean correlations (dashed: 95% confidence interval)

Gray curves: each member correlations

Blue/red dots: Maximum absolute values for each correlation.

AMV index vs.
Atlantic ocean heat transport @40◦N

Summary

- LIM and LIMopt perform most consistently better in separating the externally-forced SST signal, especially when assessed in the global domain.

- After removing the externally-forced signal, AMOC clearly leads AMV in the ensemble mean sense, but at the different lags between the CESM1-LE and IPSL-CM5-LE.

- However, the 76-year record length is probably too short to obtain a robust relationship between AMOC and AMV from individual ensemble member.

Thank you!