The role of ocean processes in predictability of sea surface temperatures in the subpolar North Atlantic

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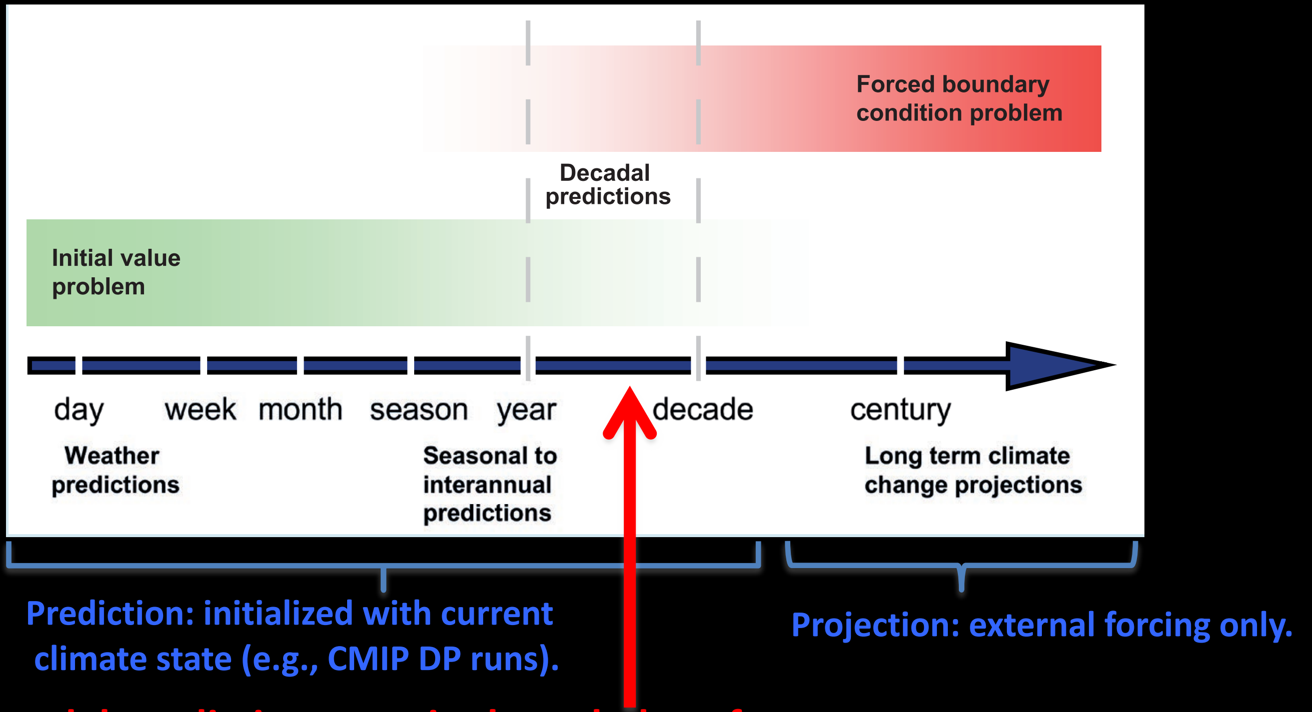
Climate predictions are needed on all time scales



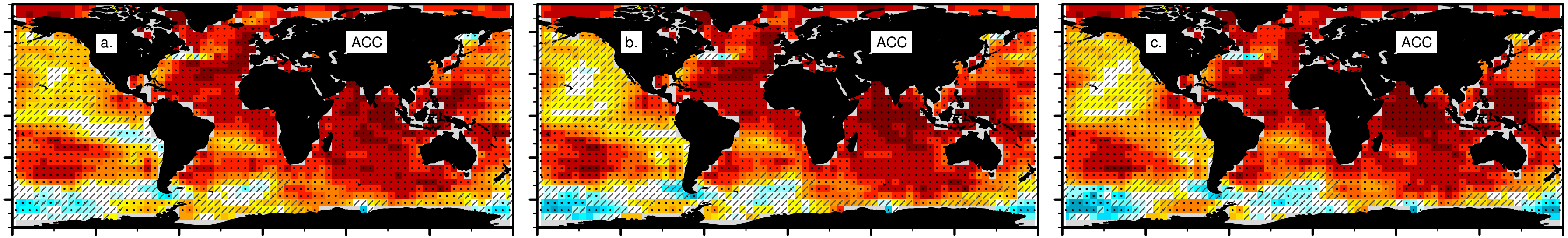
Interannual to decadal predictions require knowledge of:

- External forcing
- Initial conditions
  - Chaotic nature of troposphere (~ 2 week predictability horizon)
  - Knowledge of slower parts of climate system (ocean, cryosphere, land surface, stratosphere)

Predictability of Sea Surface Temperatures

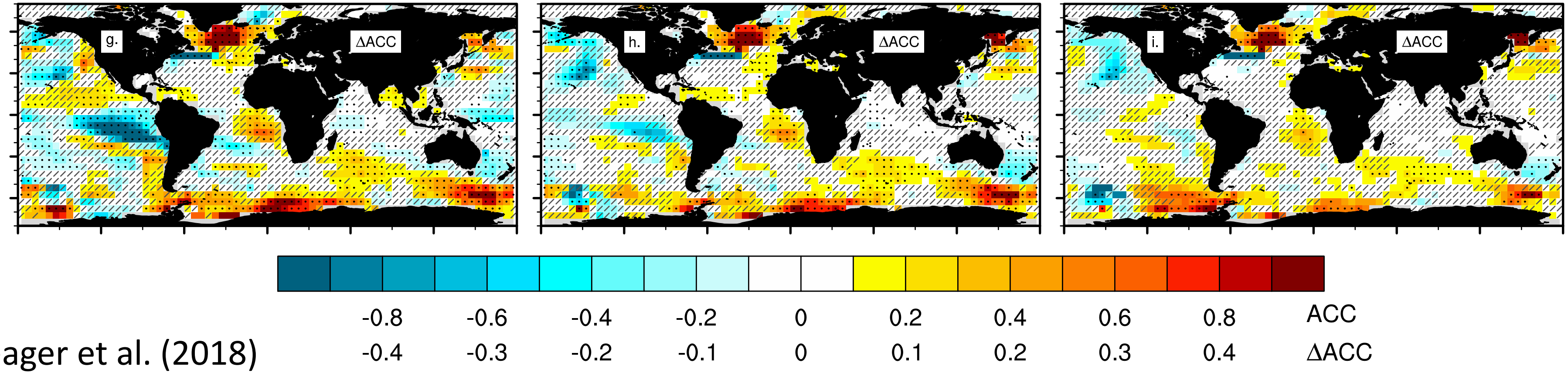
Anomaly correlation coefficient (ACC) for SST for CESM1-DPLE (40 members Init Nov. 1, 1954-2015) relative to ERSSTv5

Year 1-5 | Year 3-7 | Year 5-9



Difference in ACC between initialized (CESM-DPLE) and uninitialized (CESM1-LE) simulations

Year 1-5 | Year 3-7 | Year 5-9



Yeager et al. (2018)

Predictability of subpolar North Atlantic Sea Surface Temperatures

The subpolar North Atlantic is a region where ocean initialization increases skill of interannual to decadal SST predictions? (See also: Smith et al., 2019; Karspeck et al., 2014)

Why is the subpolar North Atlantic a region where internal SST variations are predictable?

1. **Deeper mixed layer depths (MLD) result in higher predictability.**
   Null hypothesis of SST variability (Frankignoul & Hasselmann, 1977)

$$\frac{dT}{dt} = F - \frac{T}{\tau} \qquad \tau = \frac{\rho_o \, c_p \, D}{\alpha}$$

D=MLD, α=Damping parameter (~ 20 W m^2 K^{-1})

2. **Seasonal remergence of SST anomalies enhances predictability (Deser et al., 2003; Coetlogon and Frankignoul, 2003).**

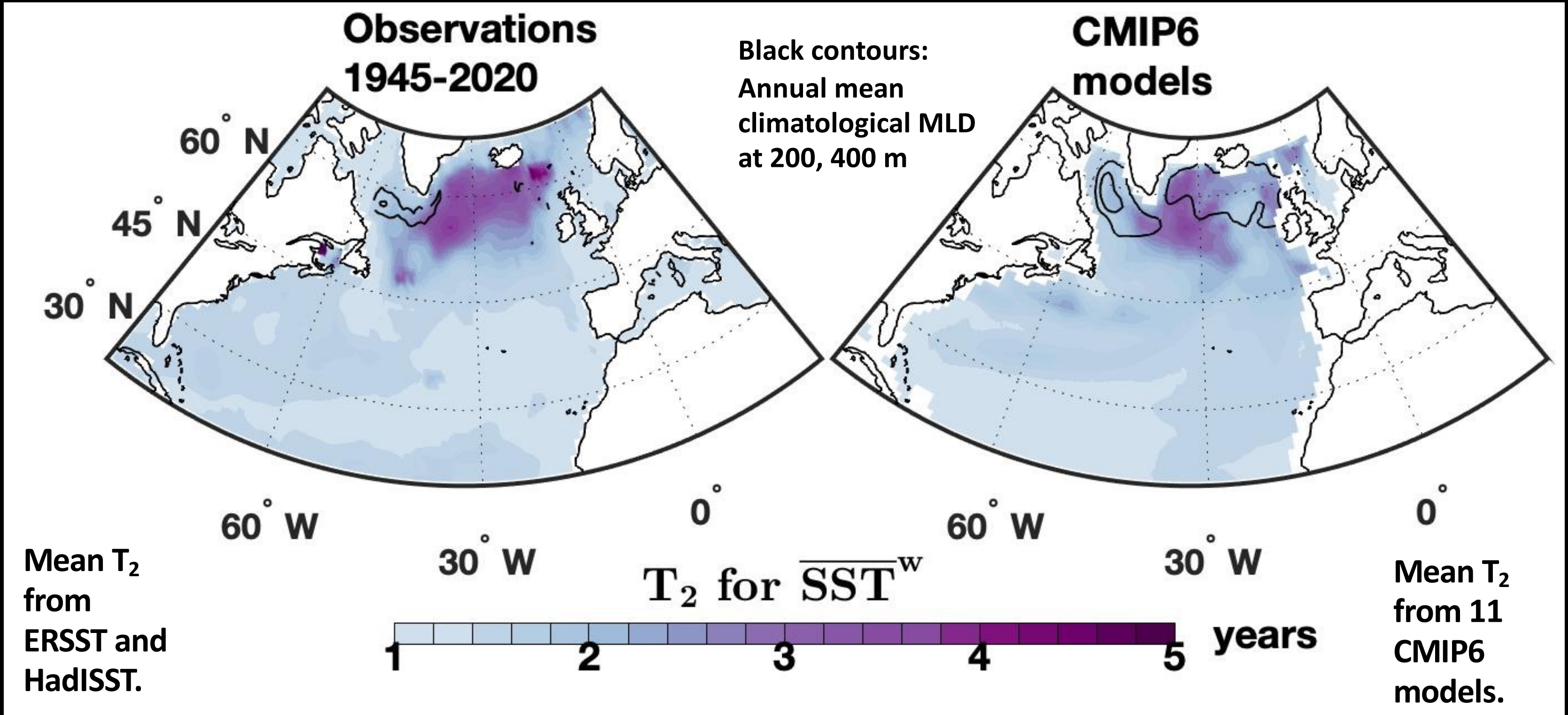
3. **Slow changes in the ocean circulation enhance predictability.**

   - **Variations in Atlantic Meridional Overturning Circulation (e.g., Yeager & Robson, 2017)**
   - **Changes in strength & position of subtropical & subpolar gyres (Reintges et al., 2020).**

Quantifying predictability of internal SST variations

1. Compare skill of ensemble of initialized predictions to that of ensemble of uninitialized projections (external forcing only).
2. Statistical measures of predictability of SST
   - Can be estimated from observations or control/historical simulations of models (Branstator et al., 2012, DelSole et al., 2013; Newman, 2013).
   - Measure discussed in this talk: decorrelation timescale (DelSole, 2001)
     - $T_2 = \sum_{k=-\infty}^{\infty} \rho_k^2,$ where ρ_k is the autocorrelation function at lag k .
     - Wintertime SST from observations and models:
       - Gridded SST observations (1945-2020, HadISST, ERSST): regress out global mean SST to remove forced signal.
       - Preindustrial control integrations (500 years +)
       - Historical large ensembles (1920-2021): remove ensemble mean to remove forced signal. Work in progress.

Decorrelation timescales for wintertime SST



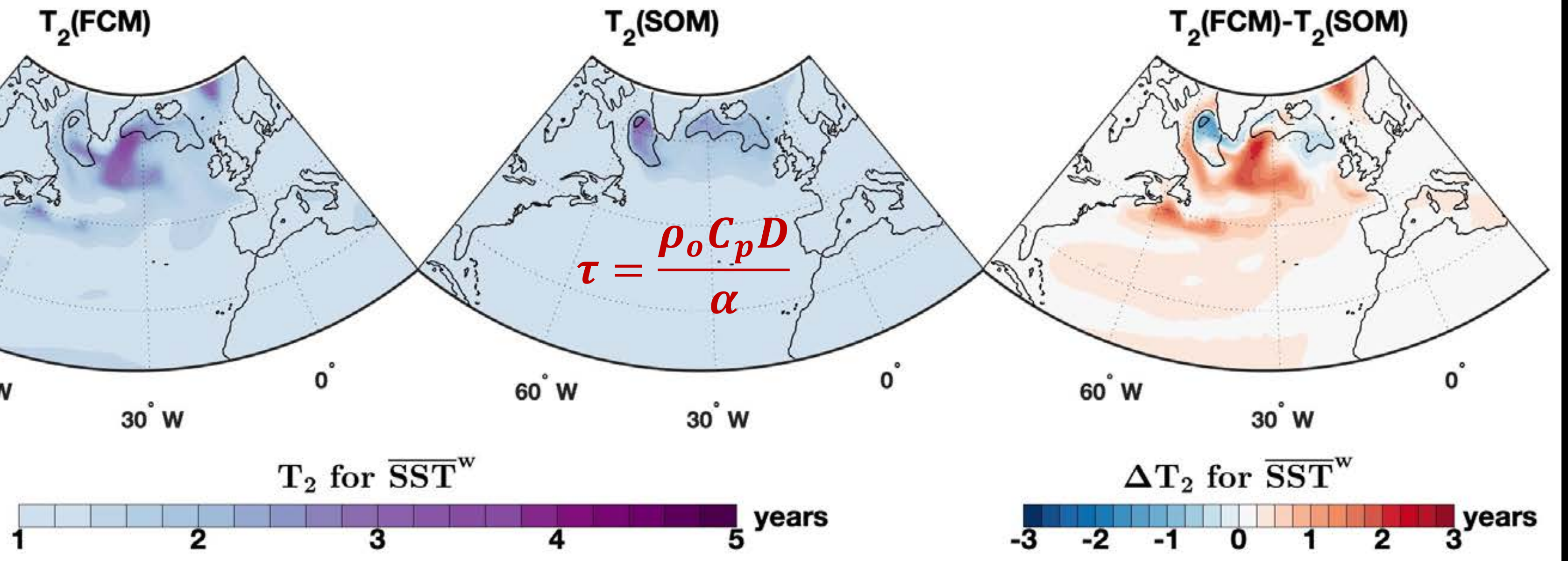
GFDL ESM4, CESM2, CESM2-FV2, CESM2-WACCM-FV2, MRI-ESM2-0, MPI-ESM1-2-HR, MPI-ESM-1-2-LR, MPI-ESM1-2-HAM, BCC-CM2-MR, HadGEM3, UKESM1-0-LL, FGOALS-g3

Exclude models with ice covered Labrador Sea.

- T_2 is longest in the subpolar North Atlantic (Buckley et al., 2019).
- T_2 is highest southeast of Greenland, despite modest MLDs in this region.
- T_2 is low in the Labrador Sea despite deep MLDs.

Impact of ocean dynamics on predictability of wintertime SST

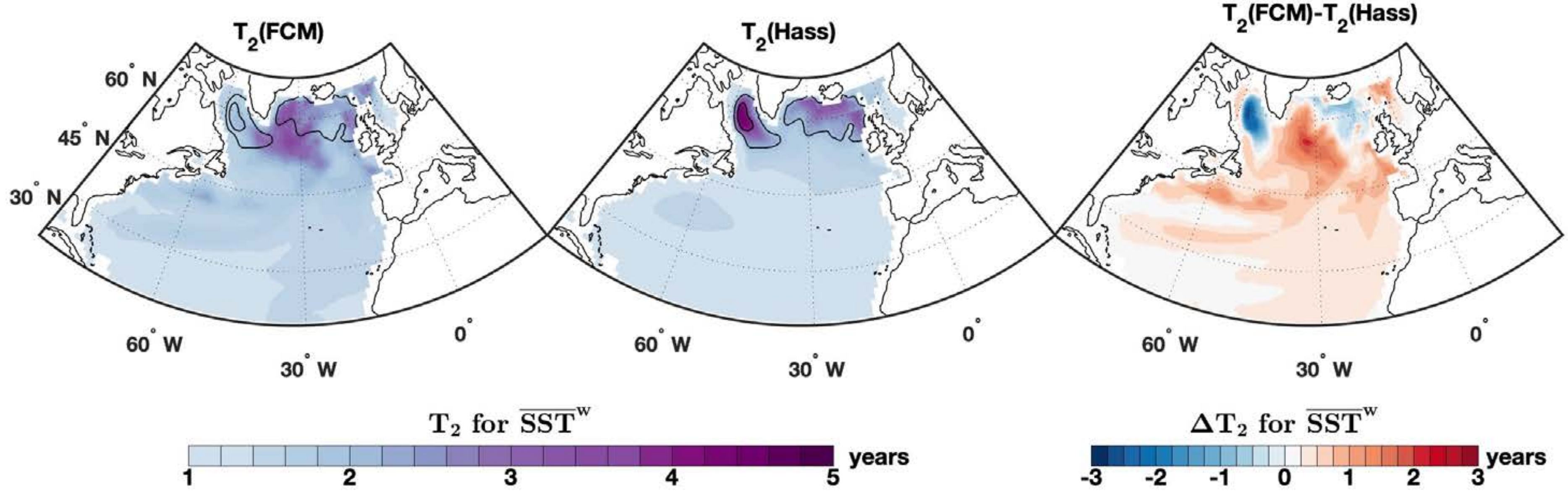
Compare T_2 from preindustrial control simulations of CESM1 fully coupled model (FCM) and model in which atmosphere coupled to motionless slab (SOM). Slab depth=annual mean MLD.



Black contours: mean MLD/SOM depth at 200, 400 m

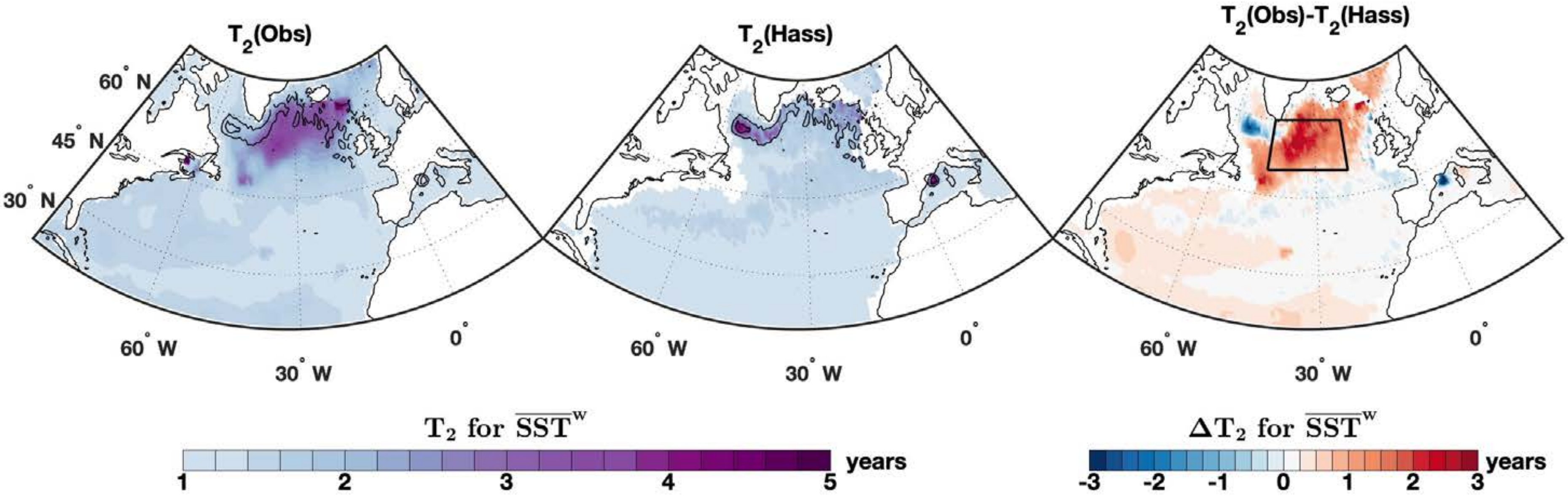
- Ocean dynamics reduce T_2 in the Labrador Sea.
- Ocean dynamics increase T_2 in the central subpolar gyre and southeast of the Grand Banks.

CMIP6 models: comparison to the Hasselmann model



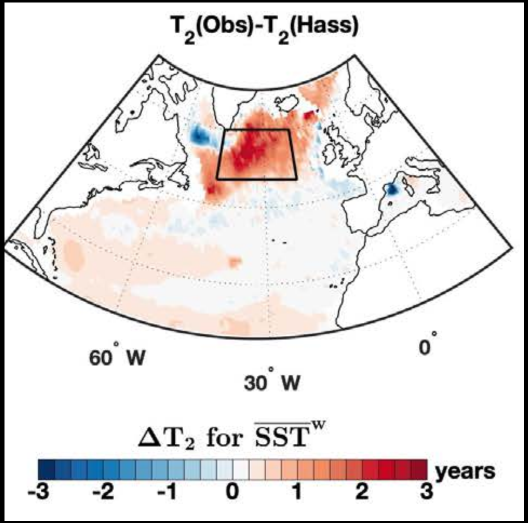
- Labrador Sea: T_2 in CMIP6 models is less than predicted by Hasselmann model, suggesting ocean dynamics reduce predictability in the Labrador Sea.
- Central subpolar gyre and southeast of the Grand Banks:
  - T_2 in CMIP6 models is larger than predicted by Hasselmann model, suggesting ocean dynamics increases predictability in these regions.

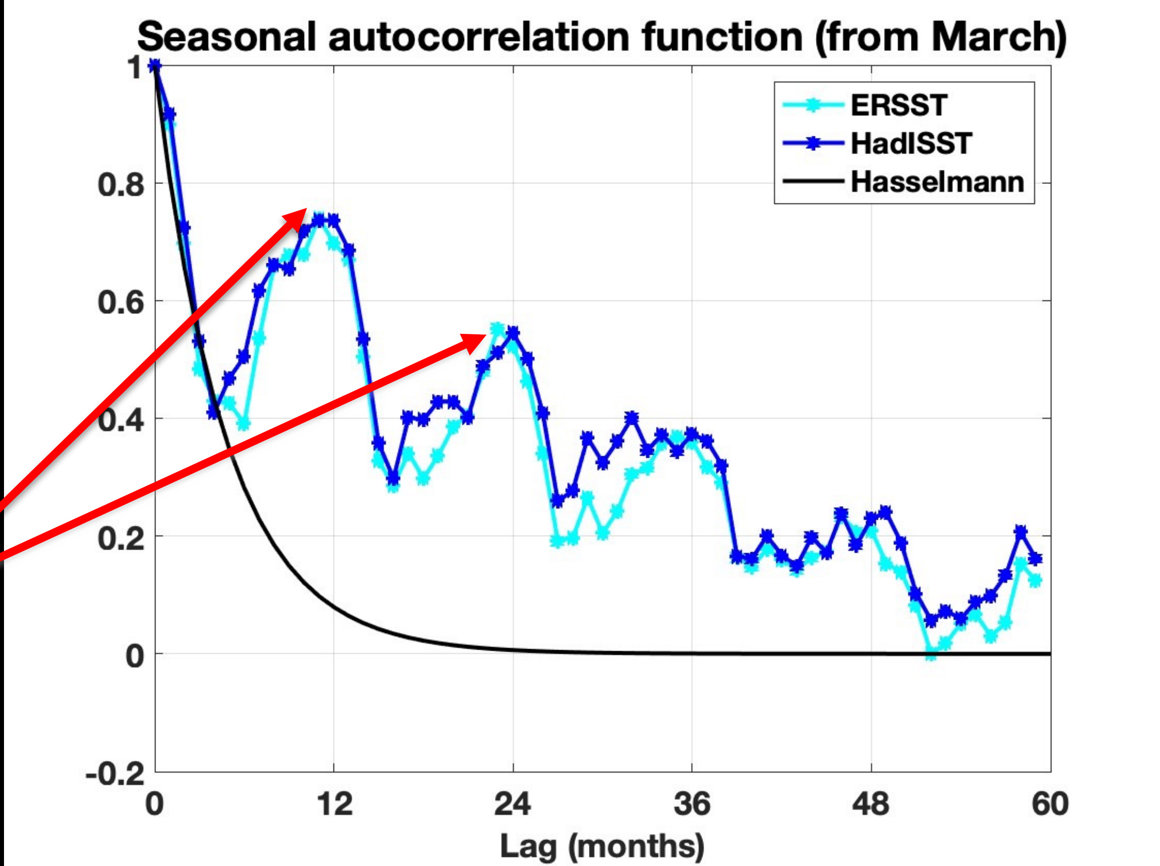
Observations: comparison to the Hasselmann model



- Labrador Sea: T_2 in observations is less than predicted by Hasselmann model, suggesting ocean dynamics reduce predictability in the Labrador Sea
- In central subpolar gyre: T_2 in observations is larger than predicted by Hasselmann model, suggesting ocean dynamics increases predictability in these regions.

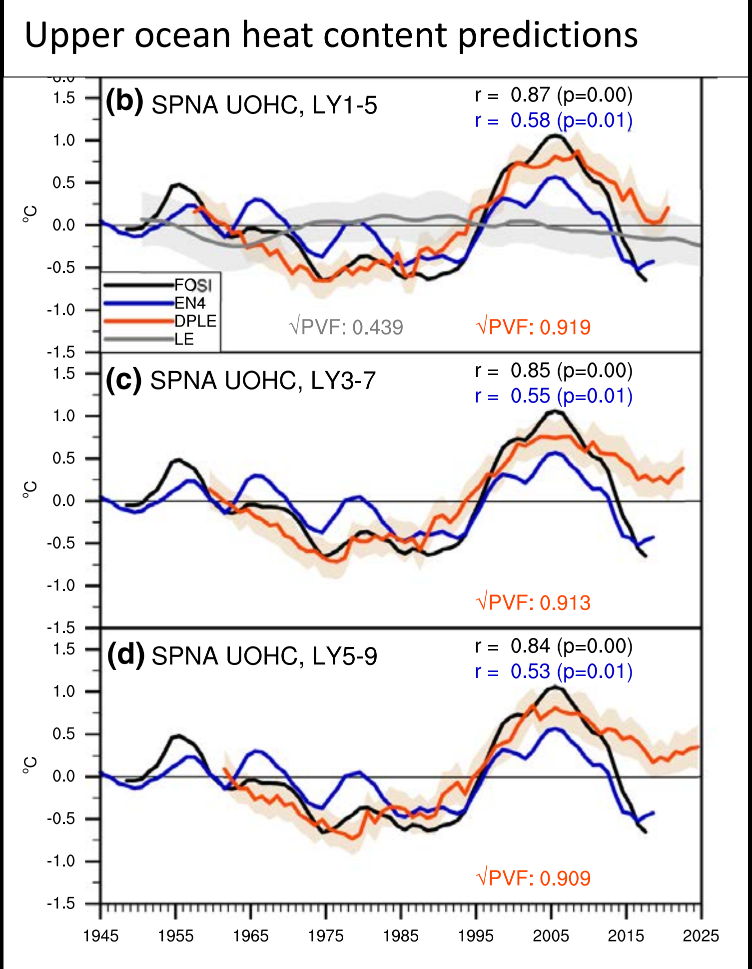
Predictability in central subpolar gyre: role of reemergence





Seasonal ACF suggests reemergence of wintertime SST anomalies in the central subpolar North Atlantic.

Initialized predictions of upper ocean heat content in subpolar gyre



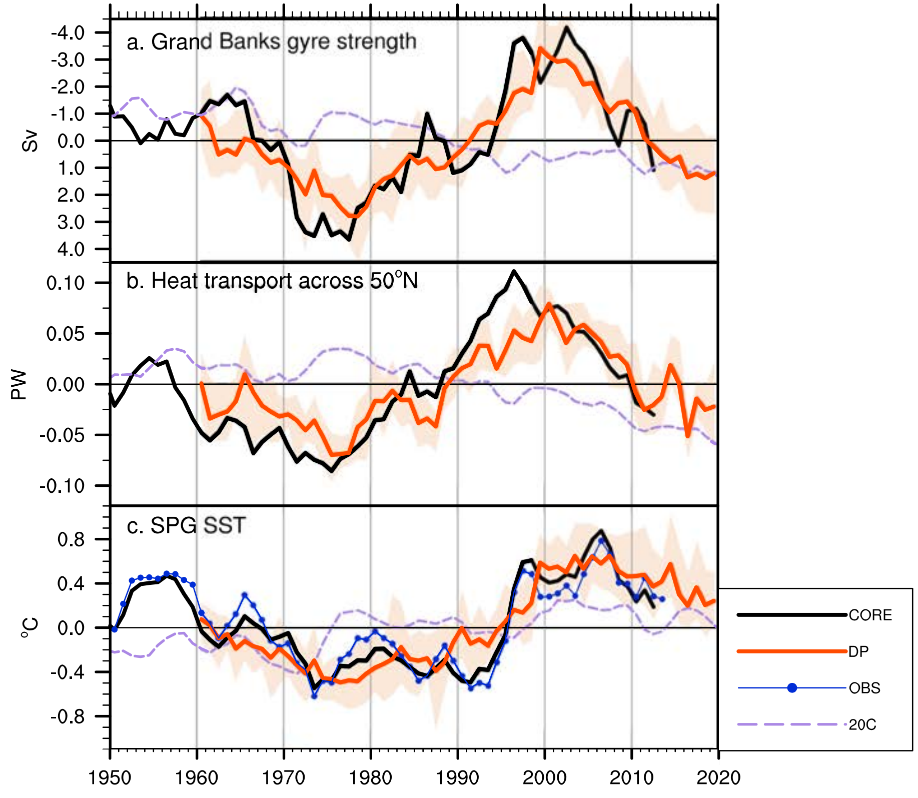
Running 5-year mean SPNA upper ocean heat content (UOHC, to 295 m depth) from

- **Blue: EN4 observations**
- **Black: reanalysis forced ocean-ice simulations (FOSI).**
- **Red: CESM decadal prediction large ensemble (DPLE)**
- **Grey: CESM-Large Ensemble (LE).**
- **The SPNA region is defined as 45°W–20°W, 50°N–60°N** (same box as previous slide).

- **5-year mean UOHC in SPNA is well predicted.**
- **Little degradation of skill with lead time.**
- **Rapid decrease in UOHC after 2015 not well predicted, see E. Maroon's talk.**

Yeager (2020)

Predictability in central subpolar gyre: role of ocean heat transport



Yeager et al (2015)

3 year running mean anomalies of:

(a) Grand Banks gyre strength

(b) Heat transport across 50ºN

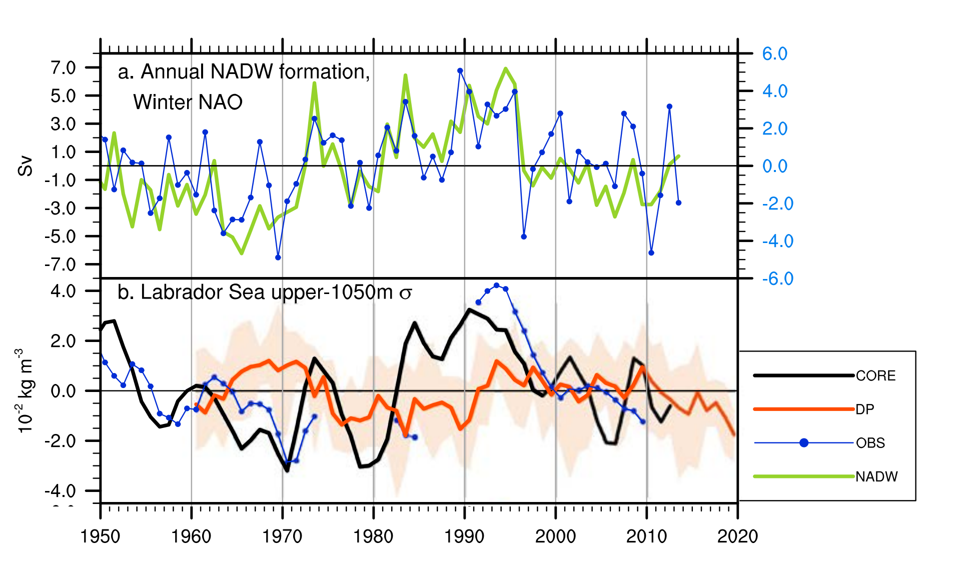
(c) Subpolar gyre SST (SPG SST)

- Black curves: reanalysis forced ocean-ice model (CORE).
- Blue curves: observational estimates
- Red curves: the CESM DP averaged over the 5–7 year forecast period.
- Purple dashed curves: ensemble mean of the six-member uninitialized CESM 20C simulations.

SST anomalies in subpolar North Atlantic:

- connected to ocean circulation anomalies near the Grand Banks.
- Ocean heat transport variations at 50ºN.

Initialized predictions show low skill in Labrador Sea



Yeager et al (2015)

Decadal predictions do not show skill in predicting Labrador Sea density.

a) Forcing and watermass formation:
- Blue line (right axis): winter NAO
- Green line (left axis): NADW formation rate

b) 3 year running mean anomalies of upper 1500 m Labrador Sea density.
- Black curves: reanalysis forced ocean-ice model (CORE).
- Blue curves: observational estimates
- Red curves: the CESM DP averaged over the 5–7 year forecast period.

Recap

1. **Atlantic SST predictability is longest in the subpolar gyre.**
2. **Ocean dynamics enhances SST predictability in central subpolar gyre.**
   - **Reemergence of SST anomalies (e.g., Duchez et al., 2016).**
   - **Variations in the Atlantic Meridional Overturning Circulation & gyre circulation (e.g., Keil et al., 2020).**
3. **Ocean dynamics reduces SST predictability in the Labrador Sea**
   - **Large, unpredictable interannual MLD variations reduce SST predictability.**
   - **Potential role for mixing processes, including lateral restratification by eddies (e.g., Jones and Marshall, 1997).**
   - **Strong atmospheric forcing by NAO (Yeager et al., 2012, 2012, 2020), which is largely unpredictable.**
     - **Note: recent studies suggest NAO may be more predictable than models indicate (Signal to noise paradox; e.g., Eade et al., 2014; Scaife & Smith, 2018).**

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