Investigating the potential of SST assimilation for ocean state estimation and climate prediction

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Introduction

Decadal climate prediction studies have often implemented using rather crude initialization approaches. While they have served to demonstrate the promise of decadal climate prediction, improvements can be achieved through more optimal use of observations and models. Here we apply an advanced data assimilation scheme – the Ensemble Kalman Filter – to assimilate sea surface temperature anomalies into a climate model. We demonstrate the skill of the system as a reanalysis and also in predictions for the period 1950-2010.

2. NorCPM

Norwegian Earth System Model + Ensemble Kalman Filter Data Assimilation

Based on the Community Earth System Model version 1 (CESM1)

- Atmospheric chemistry
- CAM
- CICE
- CLM
- River routing
- NorESM-O
- HAMOCC
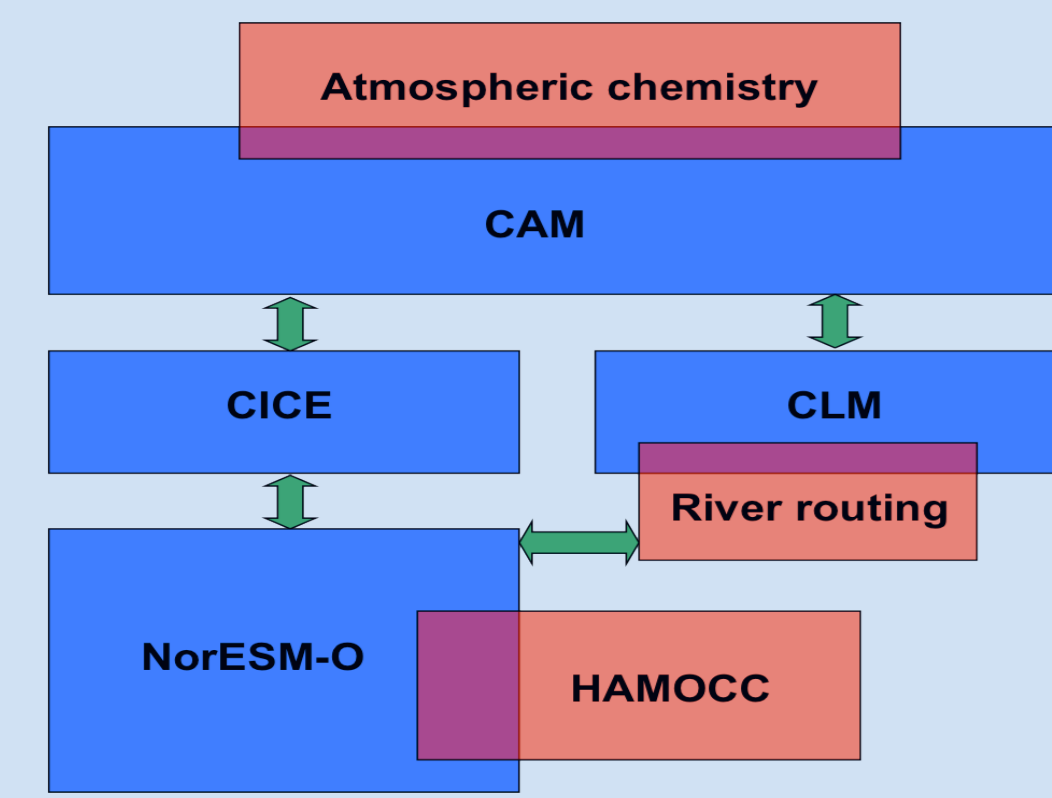
- Sequential Monte-Carlo method with **propagation** and **correction** step
- Forecast = Ensemble mean
- Forecast uncertainty = ensemble standard deviation
- Ensemble covariance used to update the **full water column** from the observations (e.g., SST)
- **More information extracted** from sparse observations

correction
Member1
Member2
......
Member29
Propagation
Member30
Observations
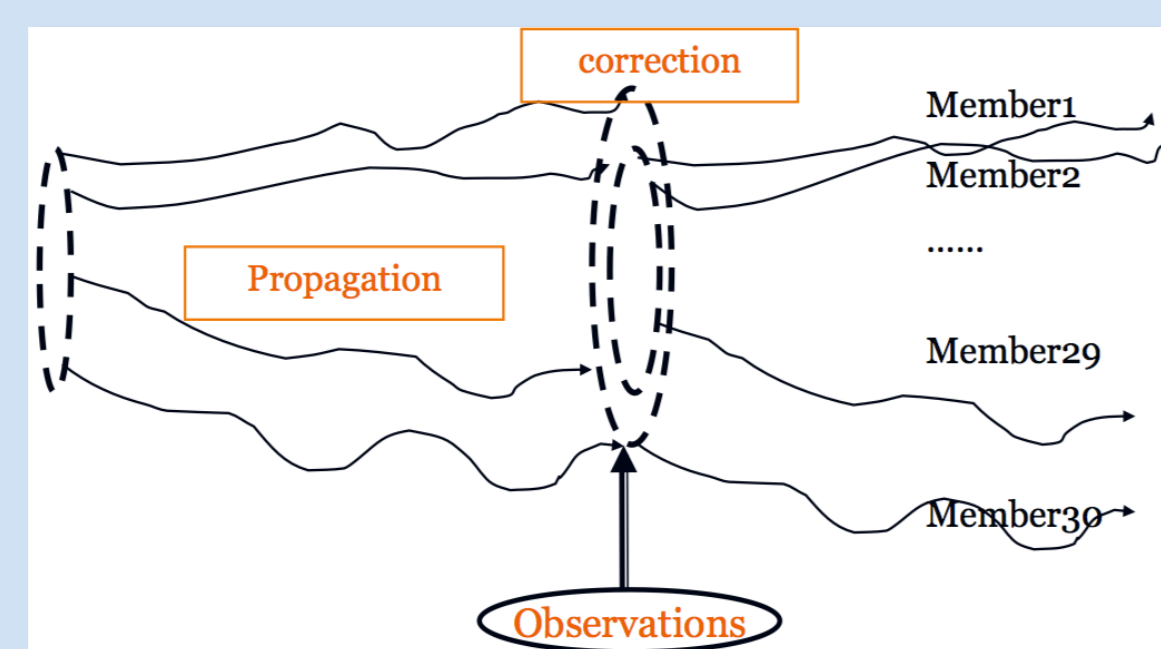
NorESM-O is an isopycnic coordinate ocean model with a bulk mixed layer on top, and is based on MICOM
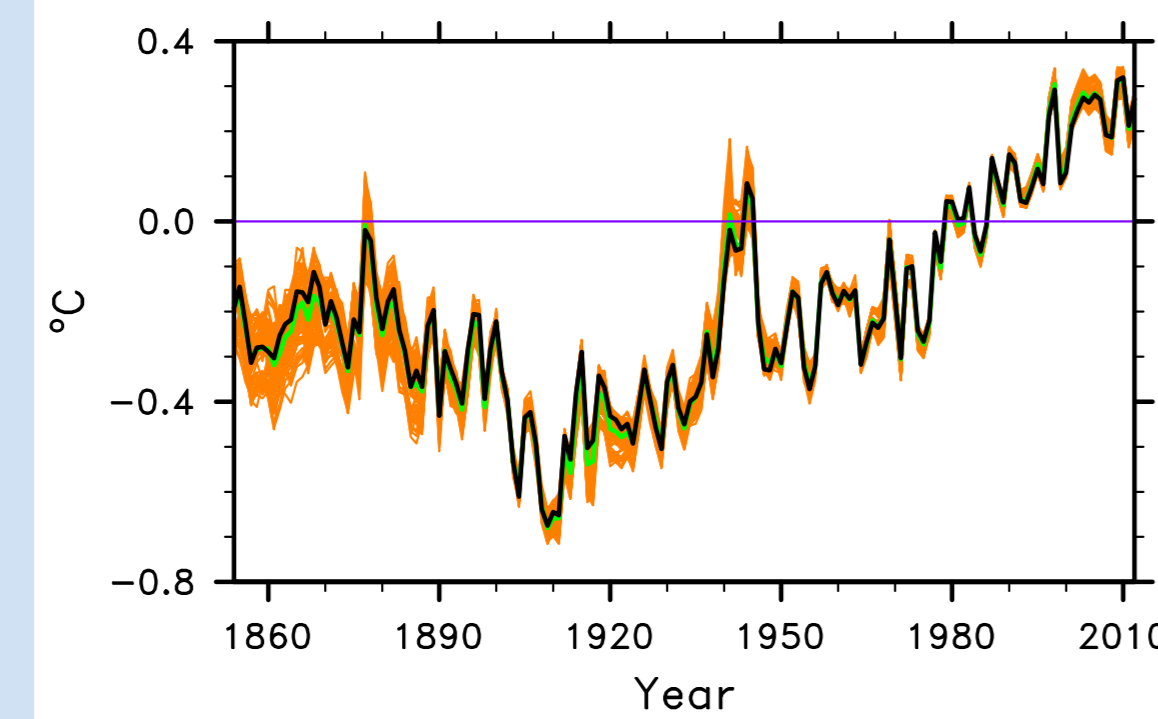
3. Experiments

Historical simulation

- Period: 1860 to 2010
- Ensemble size: 30 member
- Historical external/RCP8.5 forcing

Historical reanalysis

- Period: 1950 to 2010
- Ensemble size: 30 member
- Assimilation of anomaly SST from HadISST2
- Assimilation middle of month
- Historical external/RCP8.5 forcing
- NorESM – ME version (CMIP5)
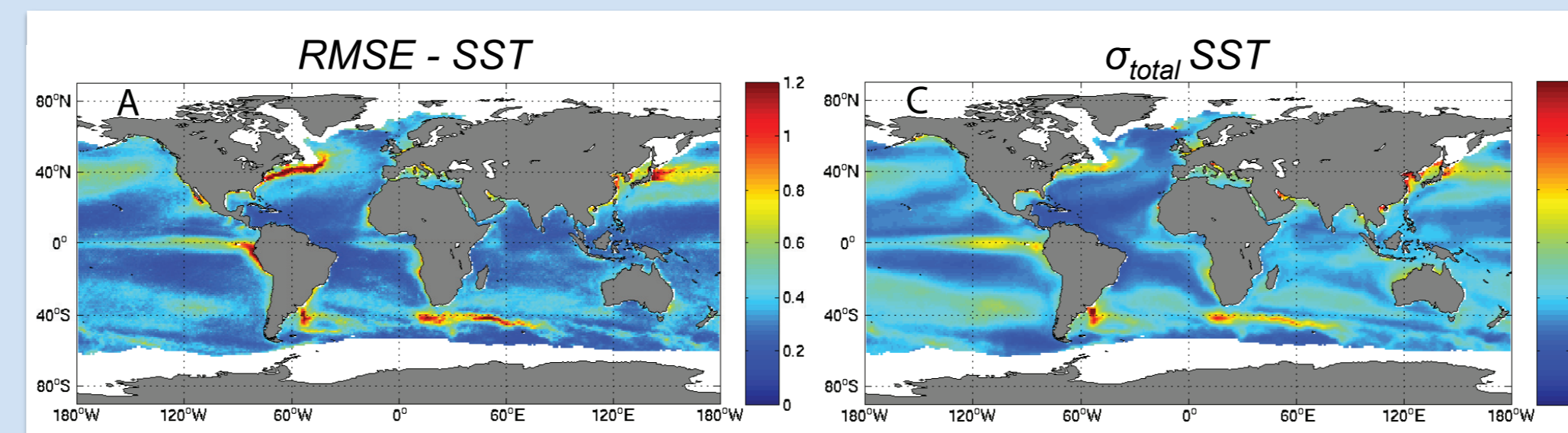 — atmosphere: 1.9ºx2.5º, 26 levels
  — ocean: 1º, 53 levels

Decadal predictions

- Period: 1950 to 2006
- Ensemble size: 20 member
- Started every 2nd year
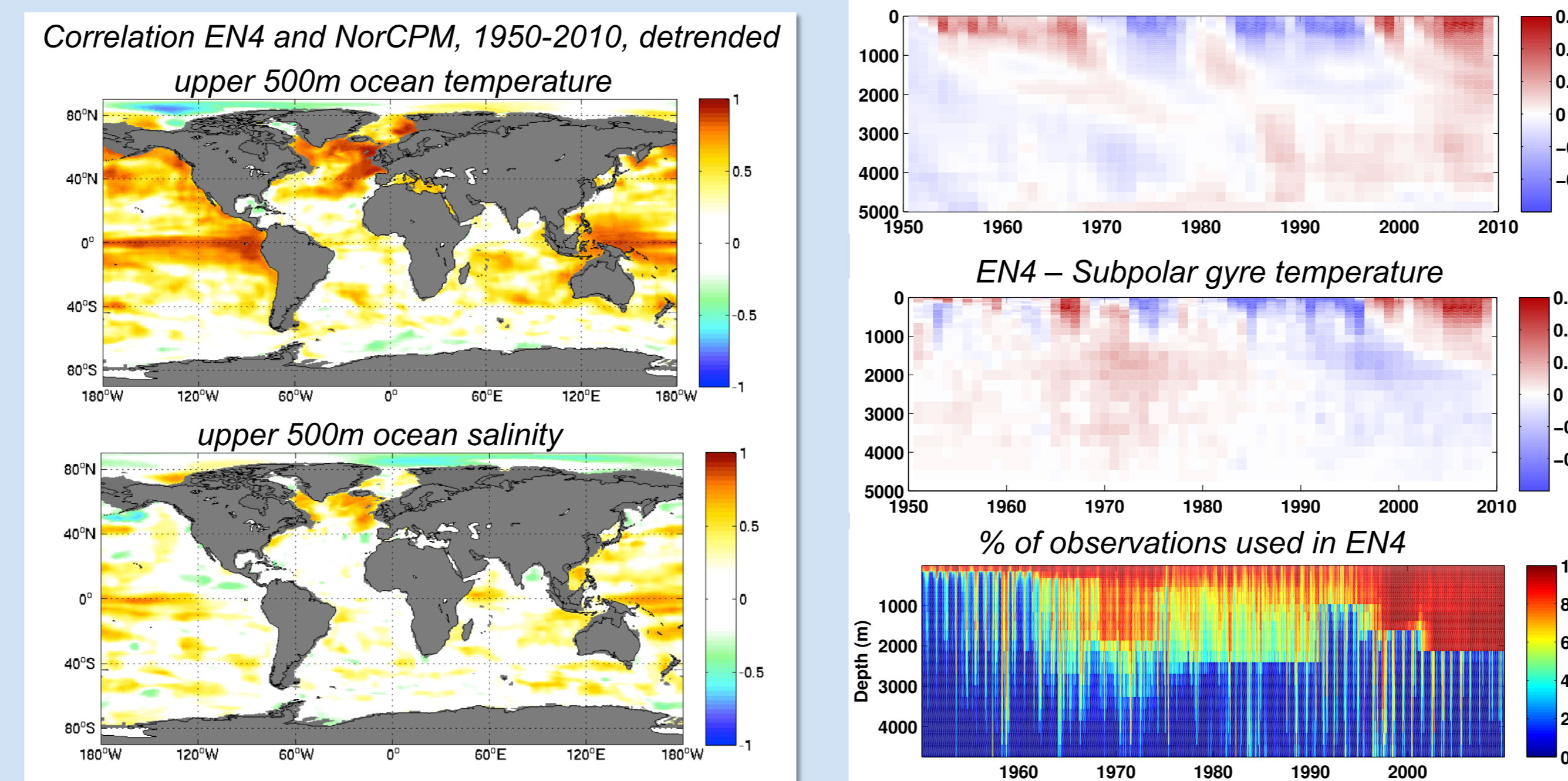- Run for ten years
- Historical external/RCP8.5 forcing

HadISST – Ensemble mean and spread representing uncertainty in the reconstructions
(b) SSTA (60S–60N)

4. Historical reanalysis

Reanalysis is well calibrated with the uncertainty ($\sigma_{tot} = \sqrt{\sigma_{obs}^2 + \sigma_{mod}^2}$) matching RMSE of SST.
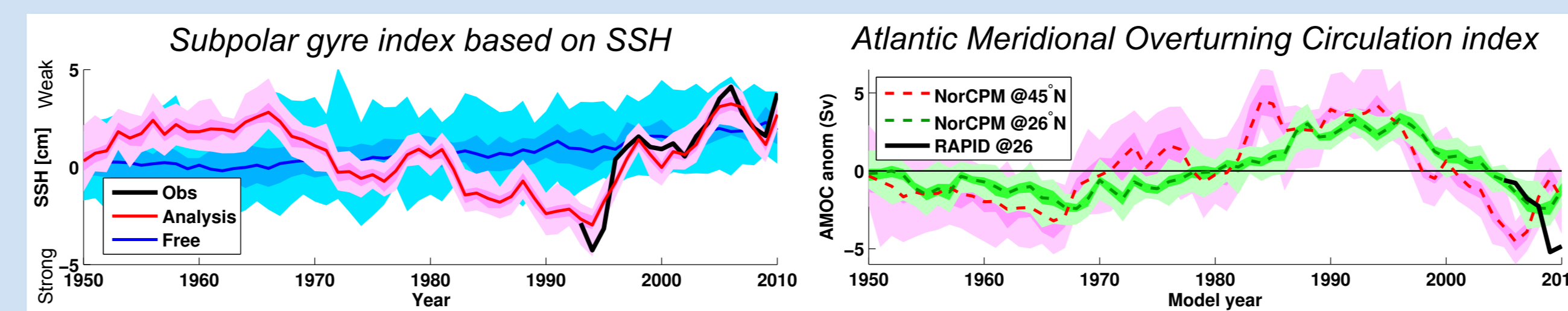
Analysis is also unbiased and ensemble spread stable.

Global statistics - SST

NorCPM
RMSE
Observed spread
Ensemble spread
σ_{total}
Bias – red dashed

Free run
RMSE
Bias – green dashed


RMSE - SST   *σ_{total} SST*

Reanalysis constrains upper ocean heat and salinity content in the North Atlantic, North Pacific, and tropical Pacific. Profiles of temperature show good agreement in the extra-tropical North Atlantic down to 2000m.

Correlation EN4 and NorCPM, 1950-2010, detrended
upper 500m ocean temperature
upper 500m ocean salinity

NorCPM – Subpolar gyre temperature
EN4 – Subpolar gyre temperature
% of observations used in EN4

Reanalysis constrains ocean circulation in the North Atlantic. Variations in the strength of the subpolar gyre matching observations well.

Subpolar gyre index based on SSH
Obs
Analysis
Free

Atlantic Meridional Overturning Circulation index
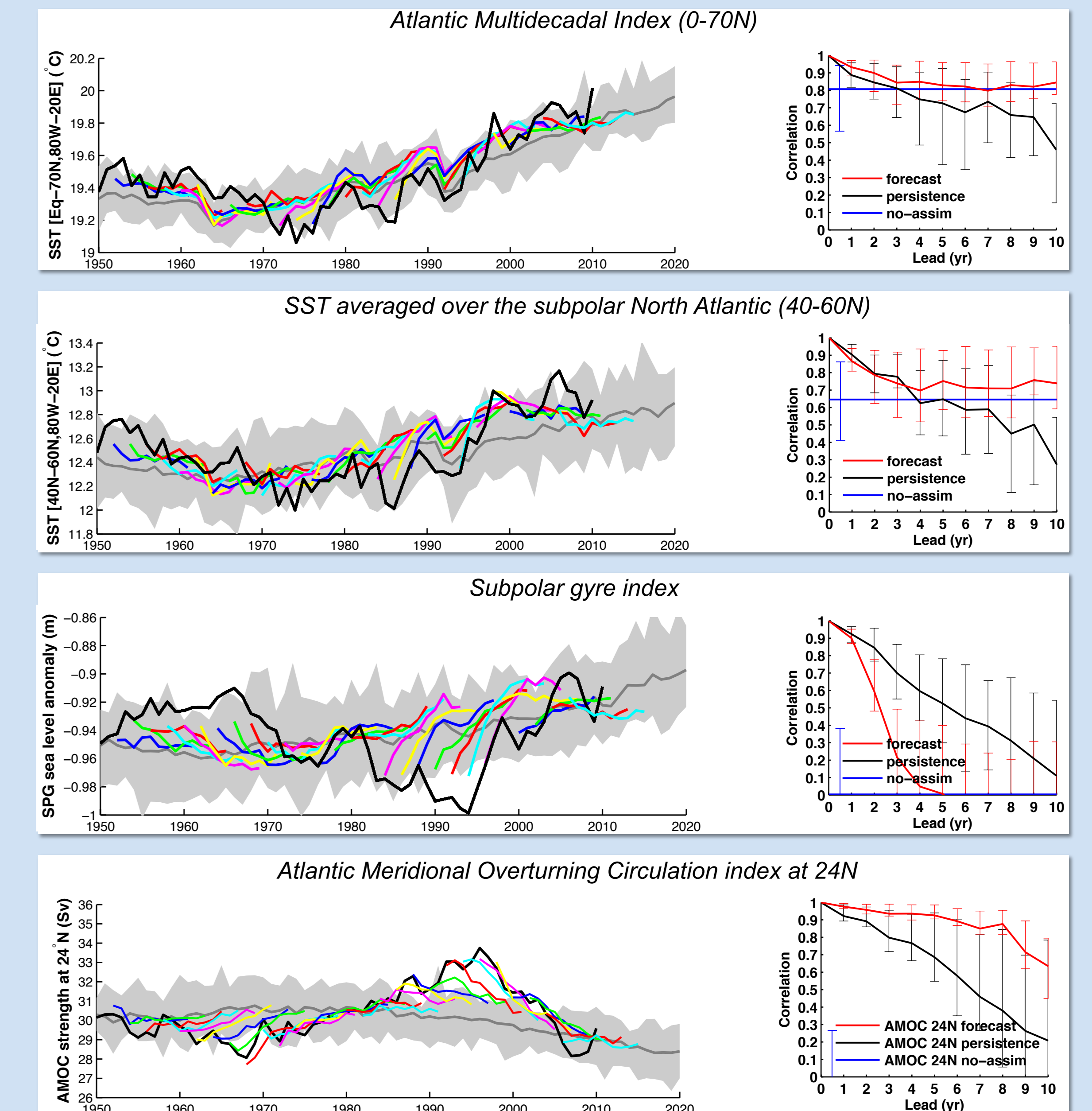NorCPM @45°N
NorCPM @26°N
RAPID @26

Analysis of the covariance matrix demonstrates its dynamical nature, as illustrated here for the Labrador Sea. SST observations influence the deep ocean in dynamic manner.

Correlation across the ensemble
SST and subsurface temperature
SST and subsurface salinity
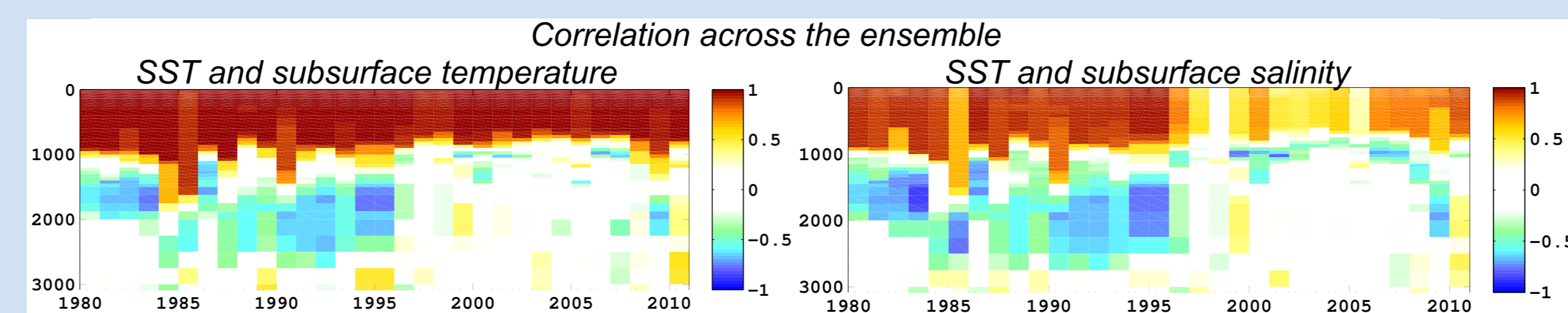
5. Hindcast experiments

Preliminary analysis of the North Atlantic regions shows NorCPM has marginally better skill in predicting extratropical SST than the historical simulation. There is also potential to predict AMOC at 24N. (Correlation computed against the reanalysis.)

Atlantic Multidecadal Index (0-70N)
forecast
persistence
no-assim

SST averaged over the subpolar North Atlantic (40-60N)
forecast
persistence
no-assim

Subpolar gyre index
forecast
persistence
no-assim

Atlantic Meridional Overturning Circulation index at 24N
AMOC 24N forecast
AMOC 24N persistence
AMOC 24N no-assim

Summary

- Weakly coupled data assimilation of SST anomalies has potential for skilful long-term reanalysis (1870 to present) in the North Atlantic, North Pacific, and tropical Pacific.
- Provides a potential to assess skill of decadal predictions over a much longer period that commonly considered.

Publications

- Counillon, F., I. Bethke, N. Keenlyside, M. Bentsen, L. Bertino, and F. Zheng, 2014: Seasonal-decadal prediction with the EnKF and NorESM: a twin experiment. Tellus A, 66, 21074
- Counillon F., I. Bethke, N. Keenlyside, Y. Wang, S. Billeau, M.-L. Shen and M. Bentsen, Flow dependent assimilation of SST in isopycnal coordinate with the Norwegian Climate Prediction, to be submitted

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