Implementing the EnKF into NorESM

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Motivation

• Climate model initialization important for seasonal to decadal timescales *Smith et al. 07*, *Keenlyside et al. 08*, *Pohlman et al.09*

• Multivariate initialization/update can be strongly beneficial (See poster by *Tiesche et al.*)

The Ensemble Kalman Filter advanced data assimilation method tested:

- •Operationally on coupled ocean-ice model (*Lisæter 03*, *Bertino et al. 08*)
  - •TOPAZ system (Arctic marine core service in MyOcean, poster by *Bertino et al.*)
- •Operationally on atmospheric model (*Houtekamer et al. 05*)
- •Used to estimate soil moisture (*Reichle et al 02a*)
- •For parameter estimation on Earth System Model of Intermediate Complexity (*Annan et al. 05*, *Hargreaves et al. 04* …)

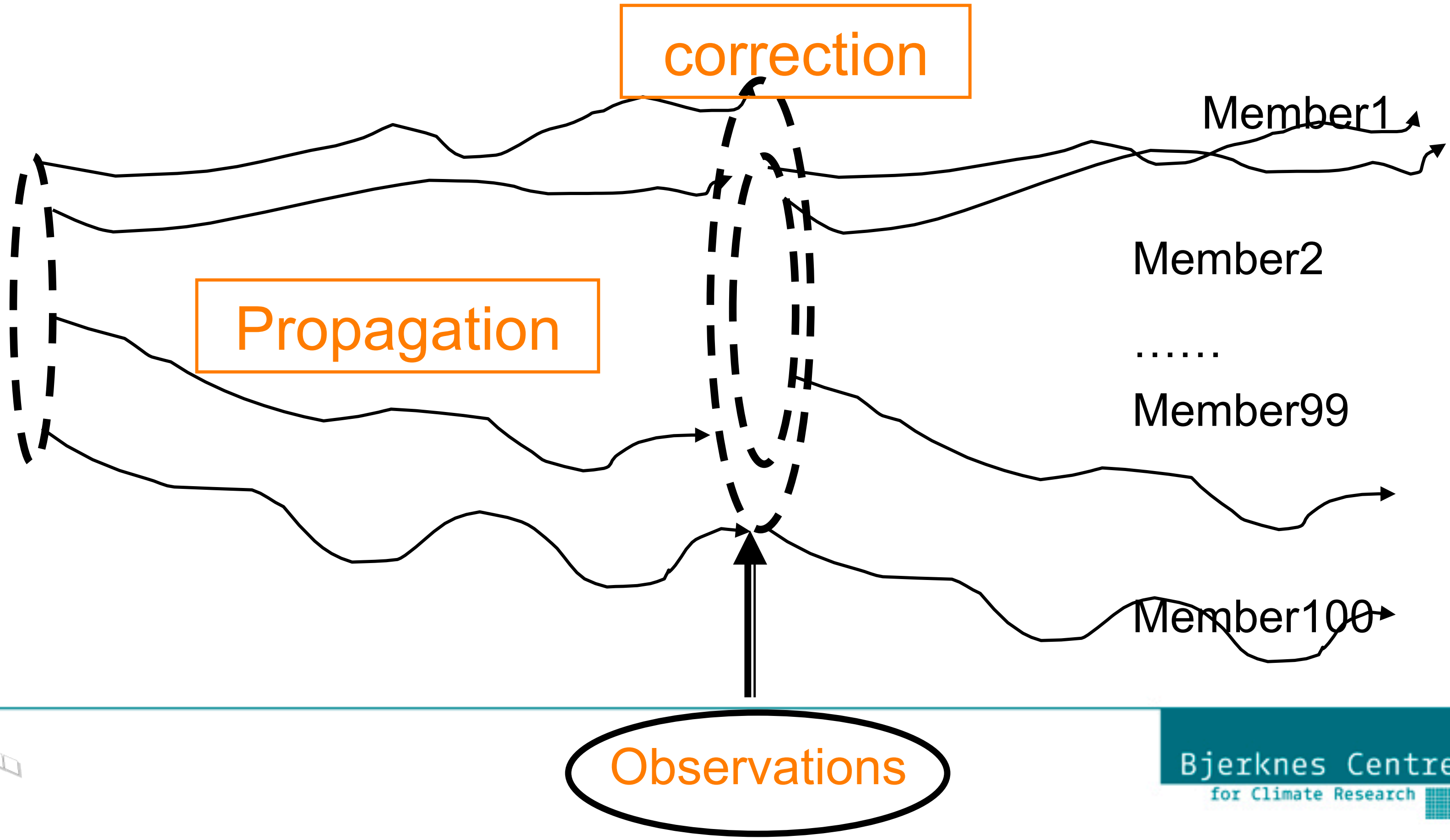
Test the EnKF for the first time with a full Earth System Model (NorESM), we start with the ocean component

Ensemble Kalman Filter

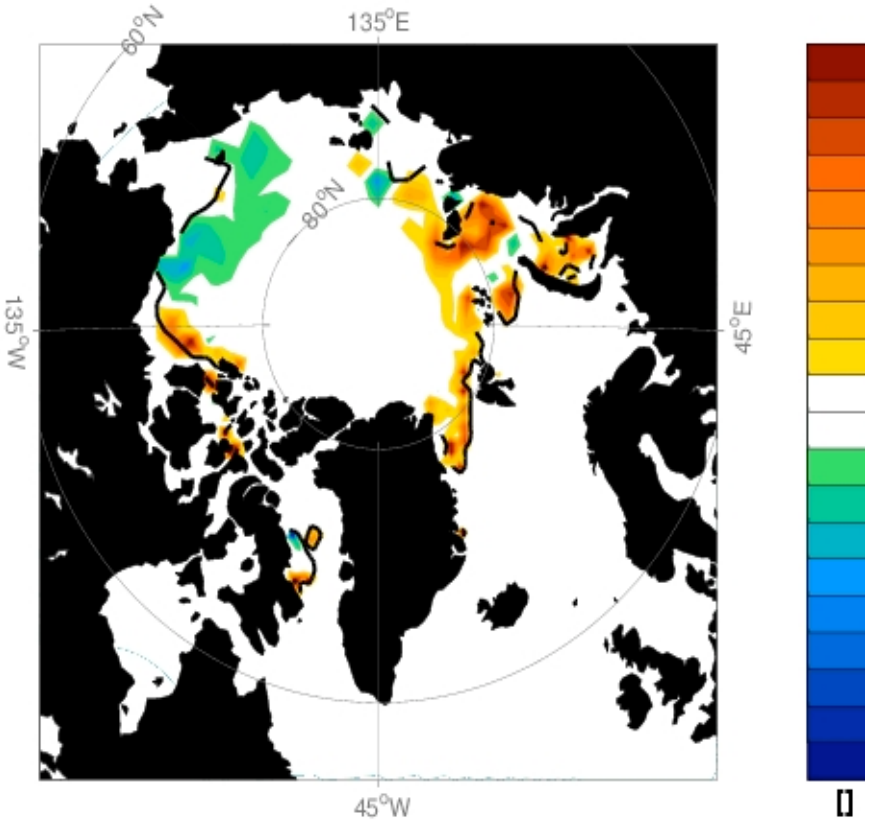
Statistic method based on ensemble (Monte-Carlo methodology)

Sequential data assimilation method:

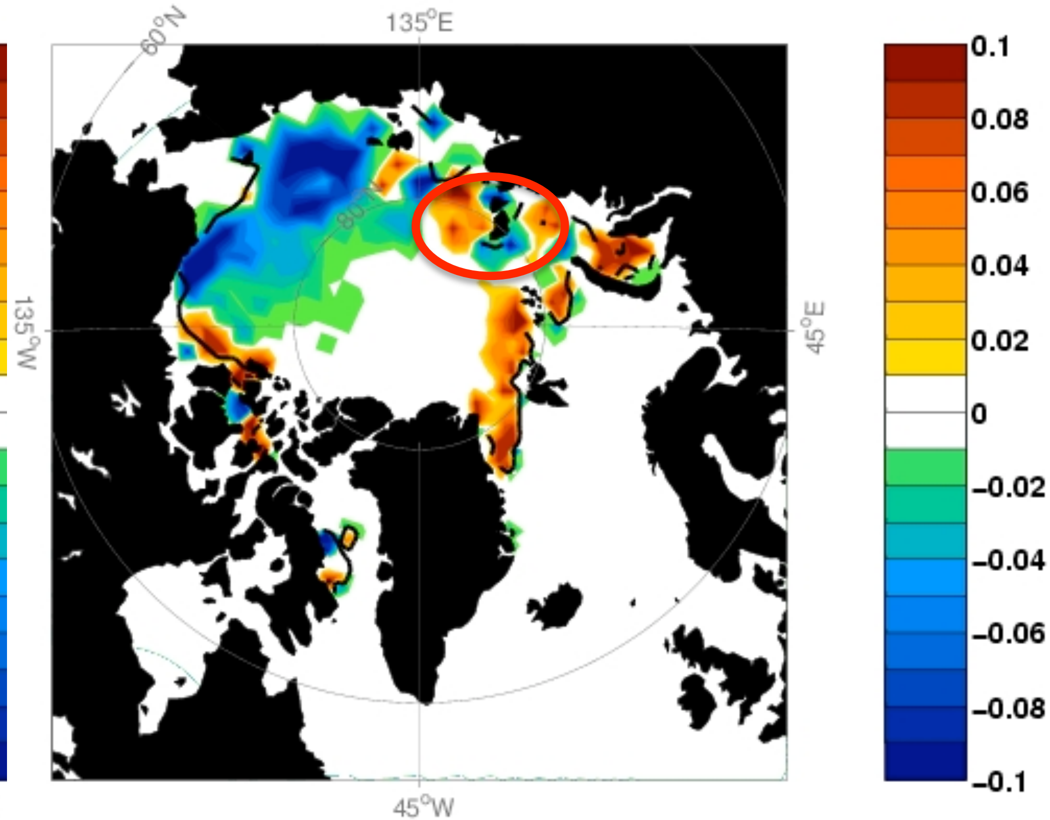
- Propagation step (Ensemble spreads in chaotic region → proxy for error)
- Correction step (Estimate optimal model state from [model, error] [obs, error])



Flow dependence
Ice concentration salinity



Ice concentration update



Surface salinity update

[Lisæter et al. 2003]

Conservation of properties
Evensen (2003)

Update equation

$X^a = X^f + K\,(d - HX^f\,)$

– Factorize by X^f

$X^{a'} = X^{f'}\,.\,T$

T: Transform matrix (nens,nens)

Kalman gain:

$K = X^f\,X'^{fT}\,H^T\,.$

$(\,H\,X'^f\,X'^{fT}\,H^T + R\,)^{-1}$

Ensemble X, anomalies $X' = X - \overline{X}$

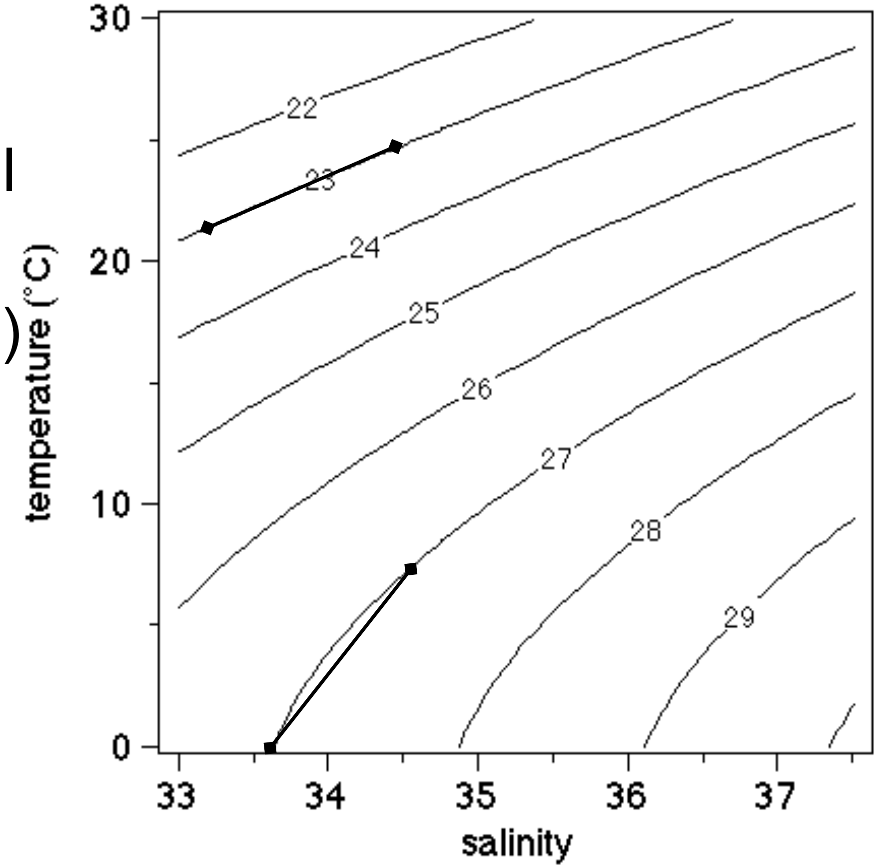
The transform T ensures conservation of the linear properties (geostrophic balance)

What about non-linear properties

- Density is nonlinear in (T,S)
- Combinations of T and S in isopycnal layer

→ artificial cabelling (Counillon et al. 08)

- *Remains small if update is small…*



T-S diagram from M. Tomczak, Flinders

Ensemble Kalman Filter

Strengths:

- Accounts for arbitrary model errors and observation errors.
- Multivariate data assimilation method
- Flow dependent updates (vary with space and time)
- Provides confidence indices of the forecast (predictability)
- Handles non-linear systems simply, no need for an adjoint

Weaknesses:

- Costly. Need an ensemble of 50-100 members (comparable to 4D-var)
- The linear update can introduce non-physical/dynamical initial state

Experiment

Test-configuration of NORESM:

- Atmospheric forcing from NCEP
- MICOM with coarse resolution (2.4^o)
- No ice dynamics

Observation:

- Reynolds SST (~100 km resolution)

EnKF:

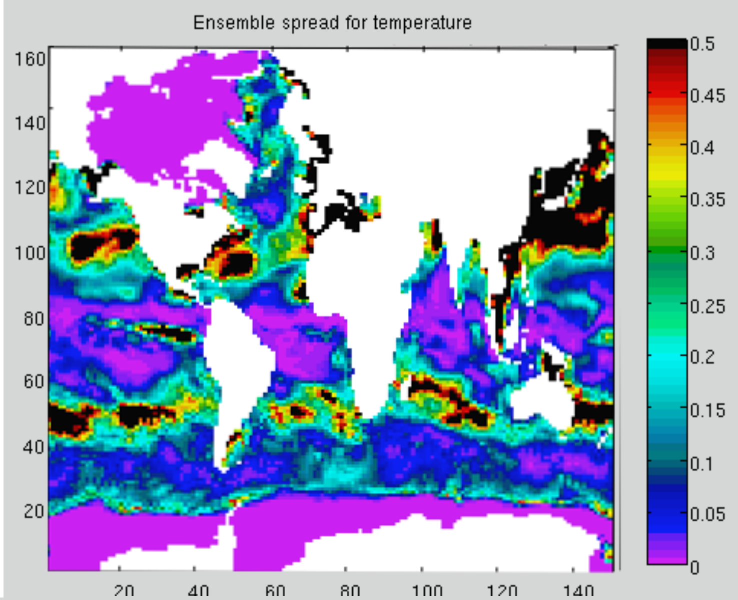
- 40 members
- Local analysis
- Monthly assimilation cycle

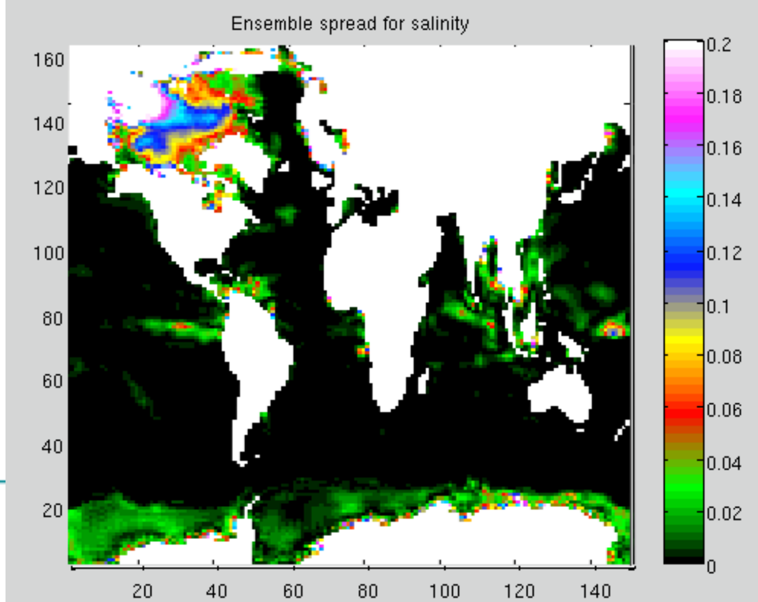
Run the model from 1990-1993 with monthly assimilation, and continue from 1993-1996 without assimilation

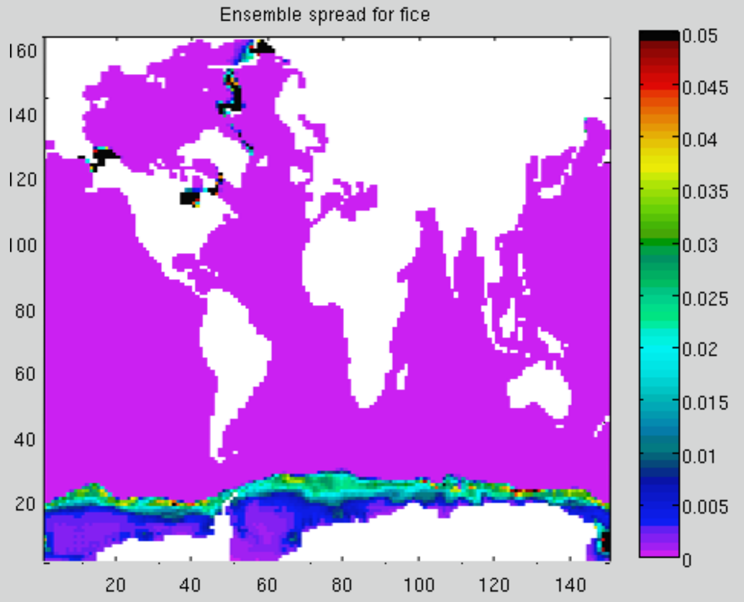
Uncertainty sources

Uncertain model parameters must be perturbed:

- •Atmospheric forcing (lag of date ±40 days)
- •Background vertical diffusion (0.14+-0.02)
- •Non-dimensional parameter in the eddy parameterization scheme (egc=1±0.25)
- •Efficiency factor for wind TKE generation entering the mixed layer depth parameterization (rm0=1.5±0.3)







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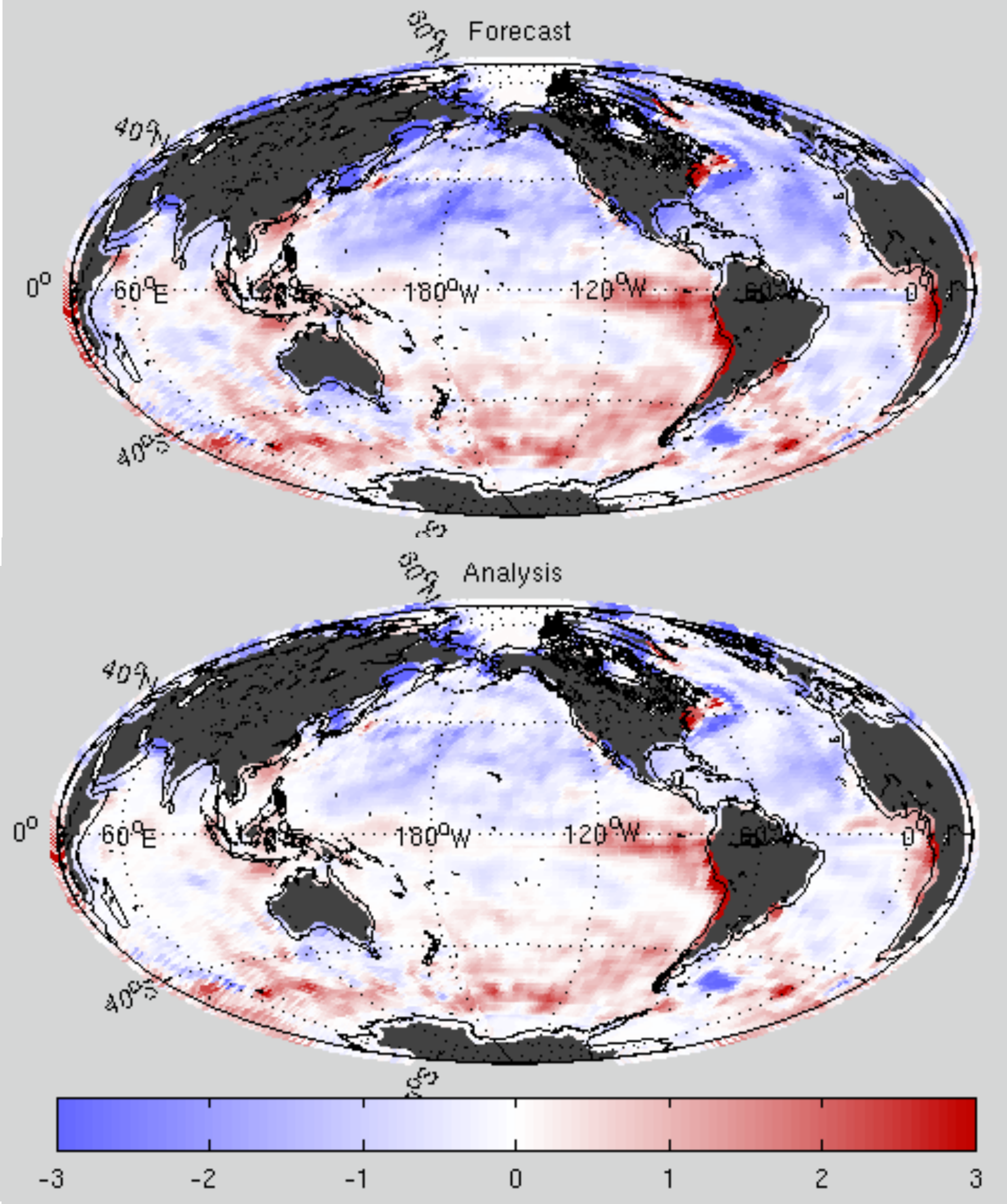
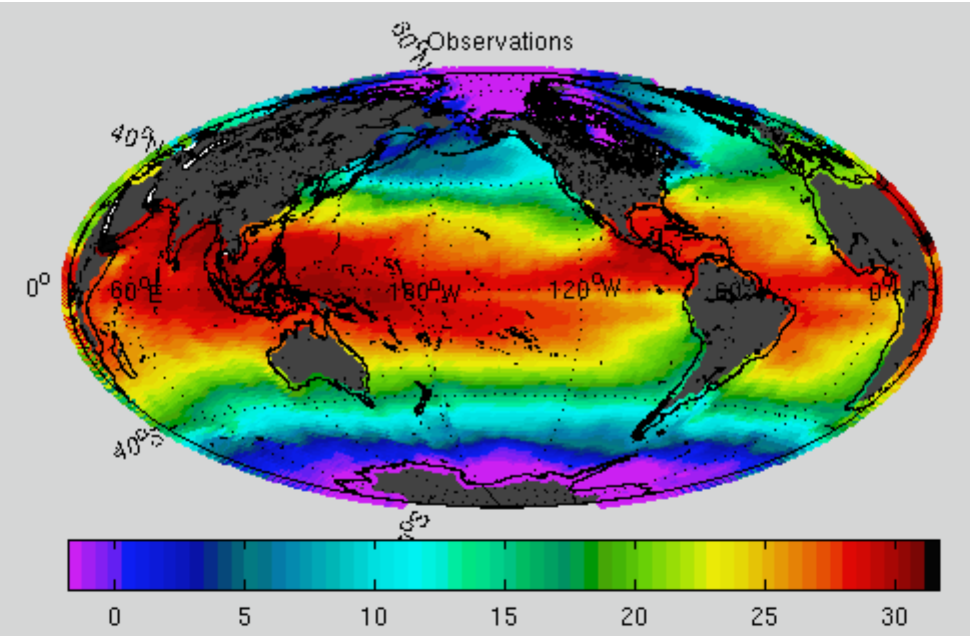
Assimilation update
Example

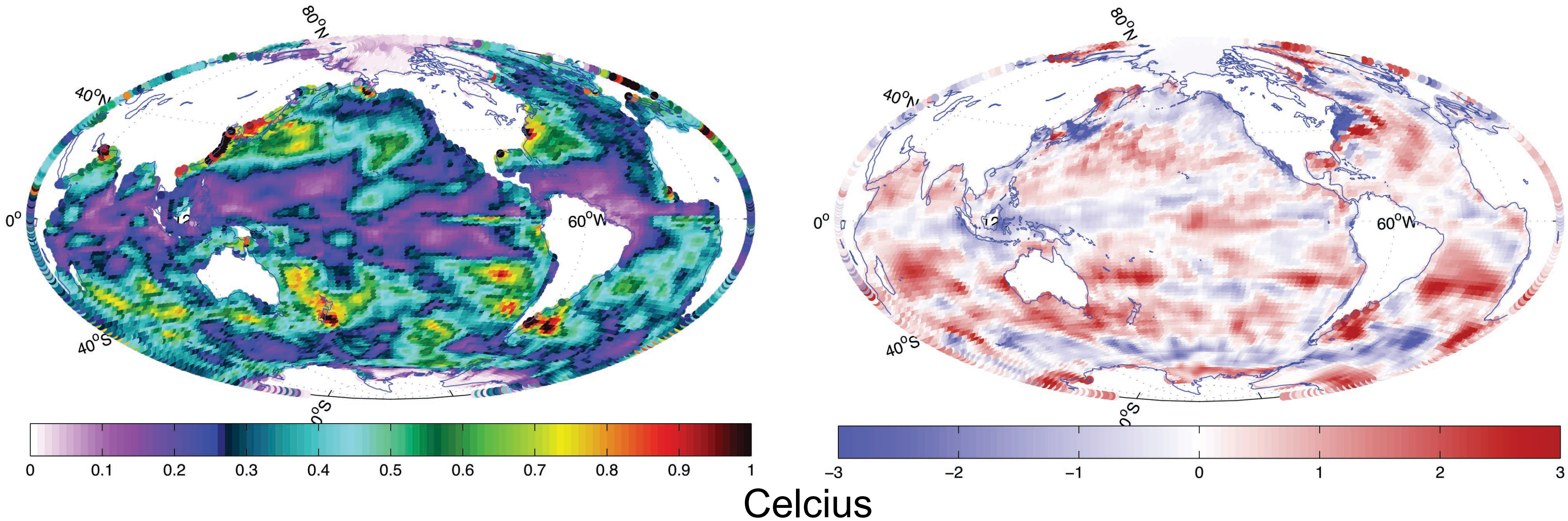
Single assimilation example





Predictability?

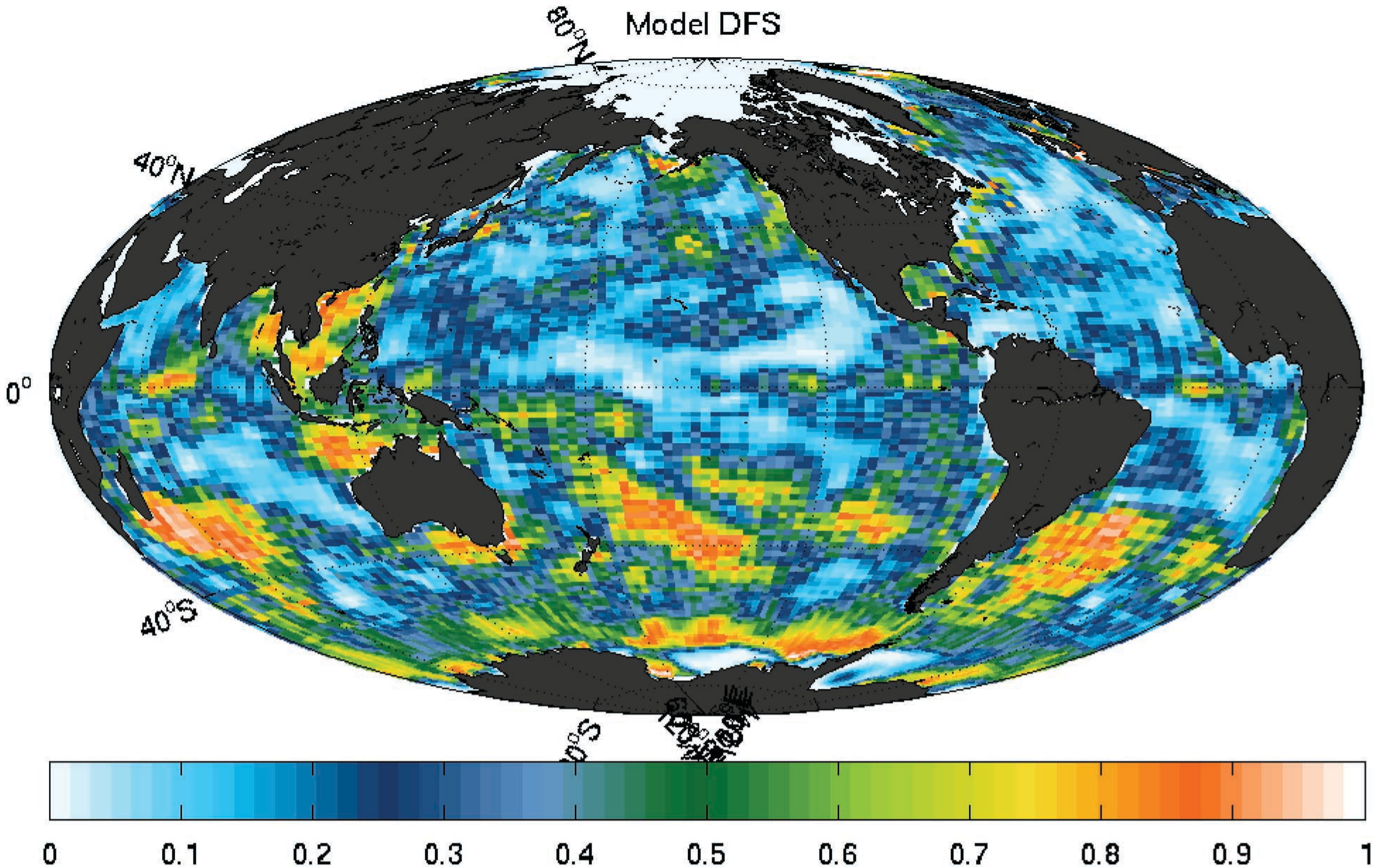
The ensemble spread of SST is representative of the forecast error. Example in December 1991



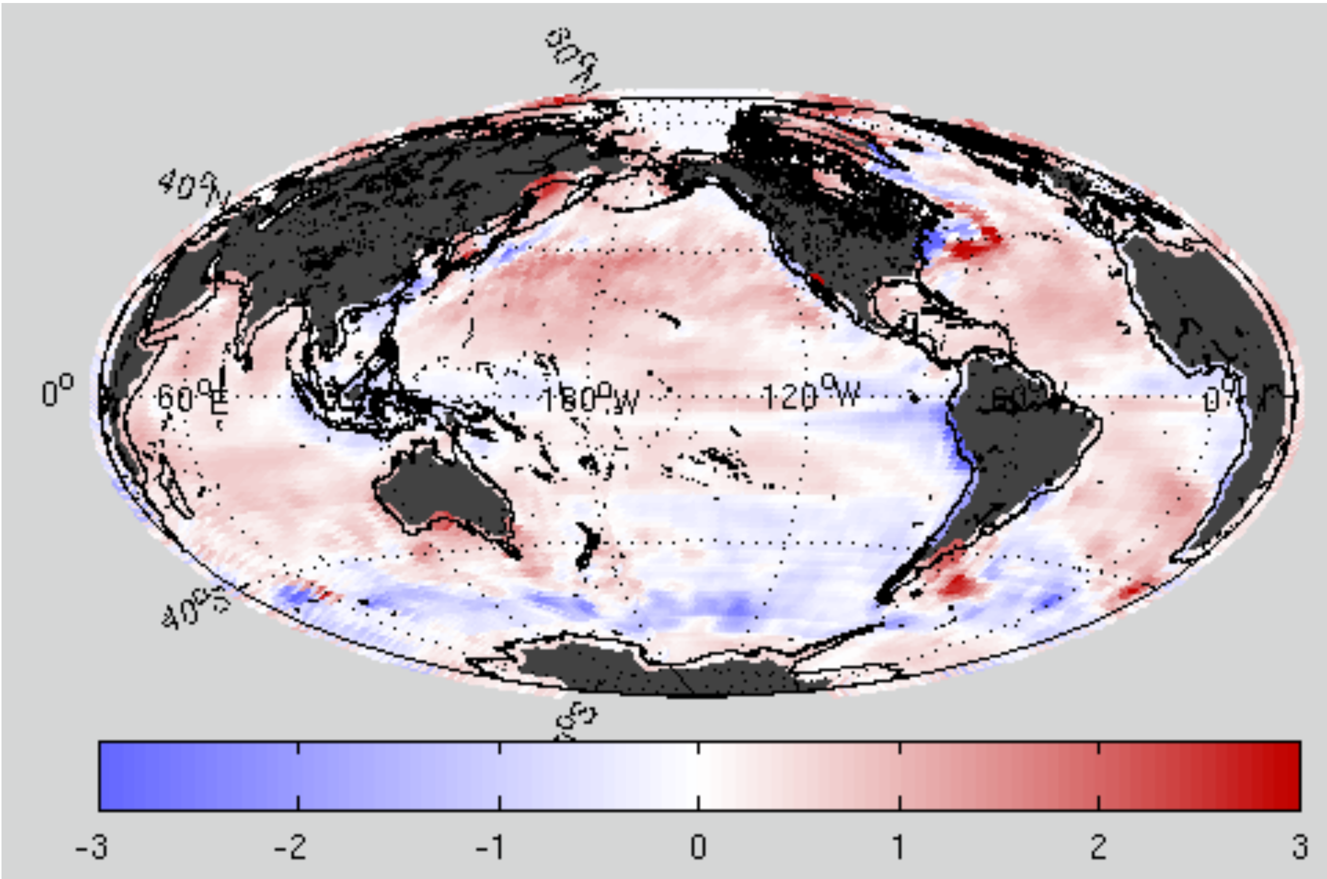
Assimilation update
Useful diagnostic

Degrees of Freedom of Signal: DFS=trace(KH)
Measure of sensitivity to observations at given time and location

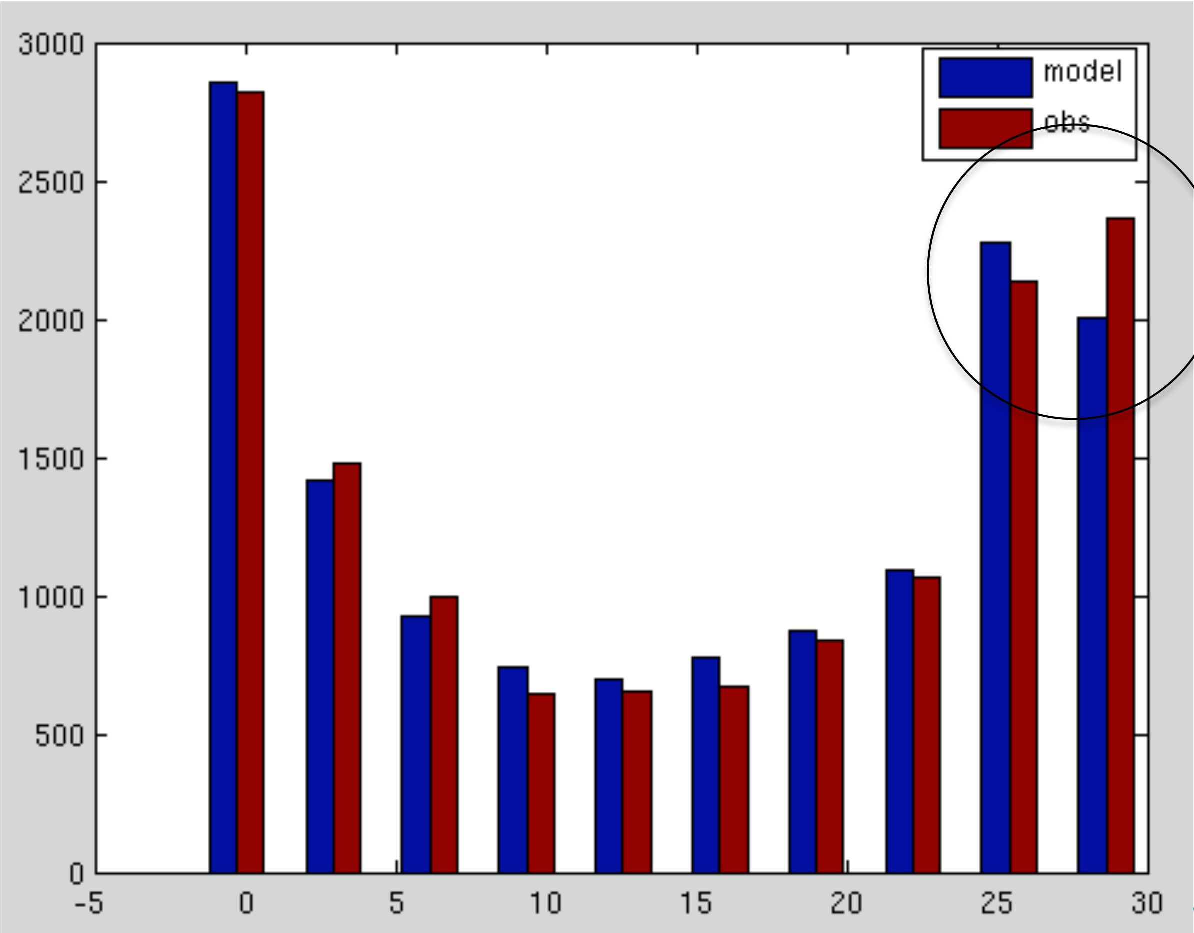
Example
December 1992



Assimilation update
SST mean innovation



Model limitation



Model underestimates
High SST values

The EnKF is not originally designed to handle biases.
→can estimate the bias

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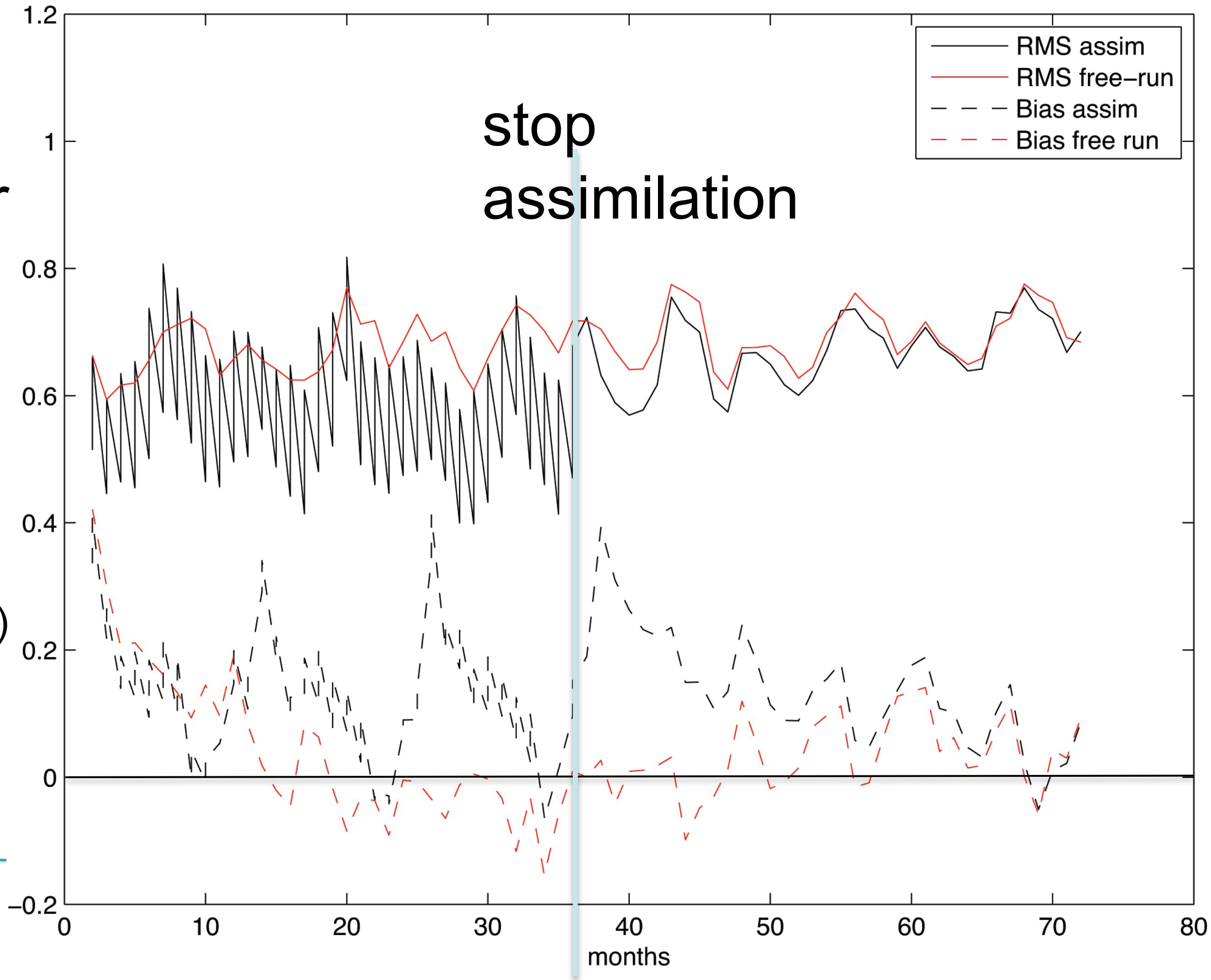
Assimilation experiment

Data assimilation reduces the SST error post-assimilation:

7 % the first year
3 % the second year
1% the third year

Data assimilation increase bias: technical aspects of the perturbation system (year switch)



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Conclusion

- •Implemented the Ensemble Kalman Filter within the framework of NorESM
- •Primary test run with monthly assimilation of SST in a non-coupled version:
  - Data assimilation reduces the RMS of SST during assimilation
  - Benefit remains for ~2 years after observation are no-longer assimilated
  - →Benefit extend far beyond the memory window of SST
    - →Multivariate changes has longer memory than SST (interior water masses, Energy)
- •There is a bias likely related to the perturbation system

Future perspectives

•Test the EnKF with the fully coupled NorESM
•Tuning the EnKF parameterization for better efficiency (loc radius, inflation)
•EnKF can be used for bias estimation.
→ Do not correct model where changes cannot be sustained
→expect to reduce increase post assimillation
•Use the EnKF for parameter estimation
→ Estimate uncertain model parameters
•Assimilate more observations as in TOPAZ (Argo and ITP T/S profiles, sea-ice concentrations, SSH, SST, sea ice drift)

•**Expected Problems:**
- •Multivariate update for coupled system is challenging when time scale are completely different
- •Evaluate change-of-variables for improving conservation issues