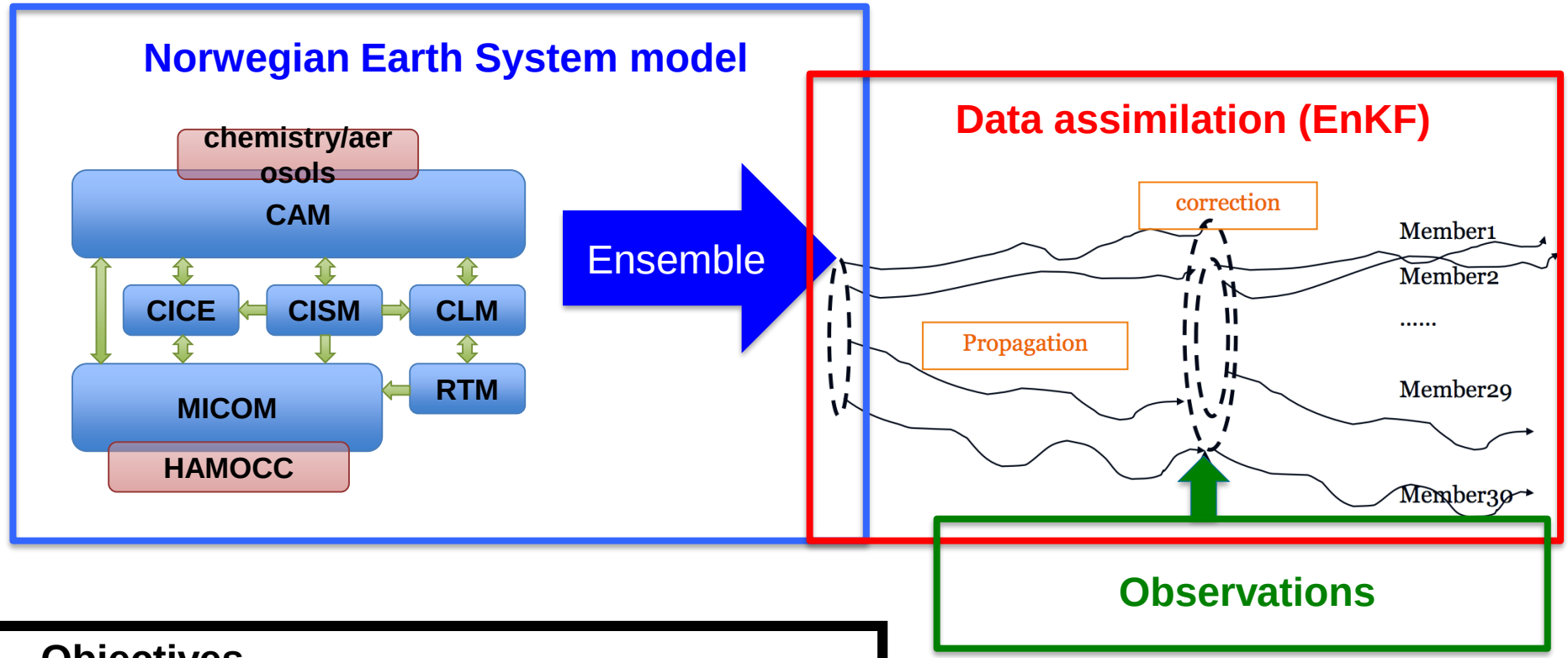
Bjerknes Centre for Climate Research

Approaches to reduce model bias and improve climate prediction

F. COUNILLON, N. KEENLYSIDE, M. DEVILLIERS, S. KOSEKI, *M.-L. SHEN*, *G. DUANE*,
I. BETHKE, T. TONIAZZO

UNIVERSITY OF BERGEN uni Research NERSC Nansen Center, Bergen HAVFORSKNINGSINSTITUTTET INSTITUTE OF MARINE RESEARCH

Norwegian Climate Prediction Model (NorCPM)

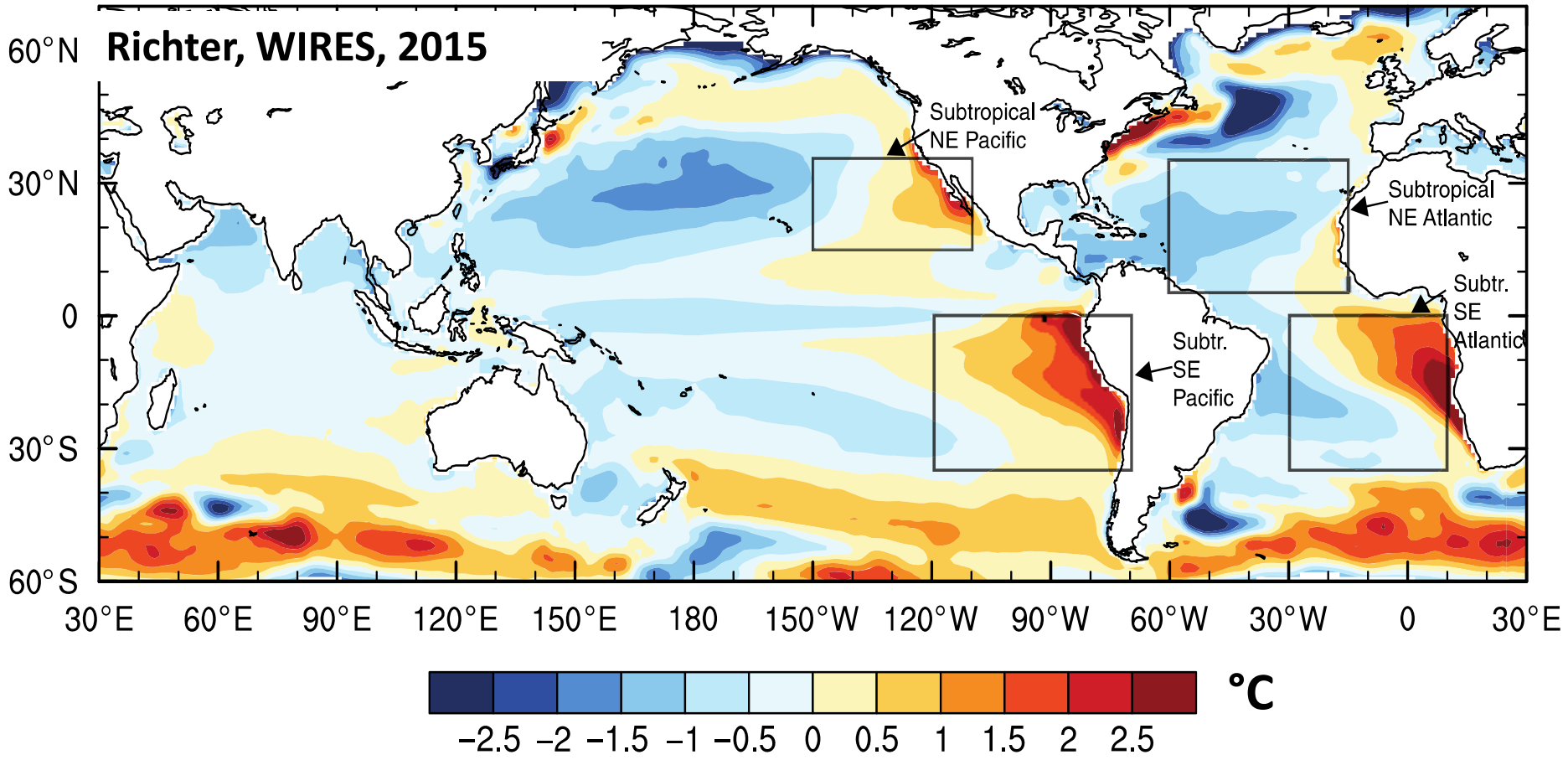


Objectives

- **Long climate reconstructions** (reanalysis)
- **Skillful and reliable climate prediction**

CMIP6 Decadal Prediction Project
Climate Services

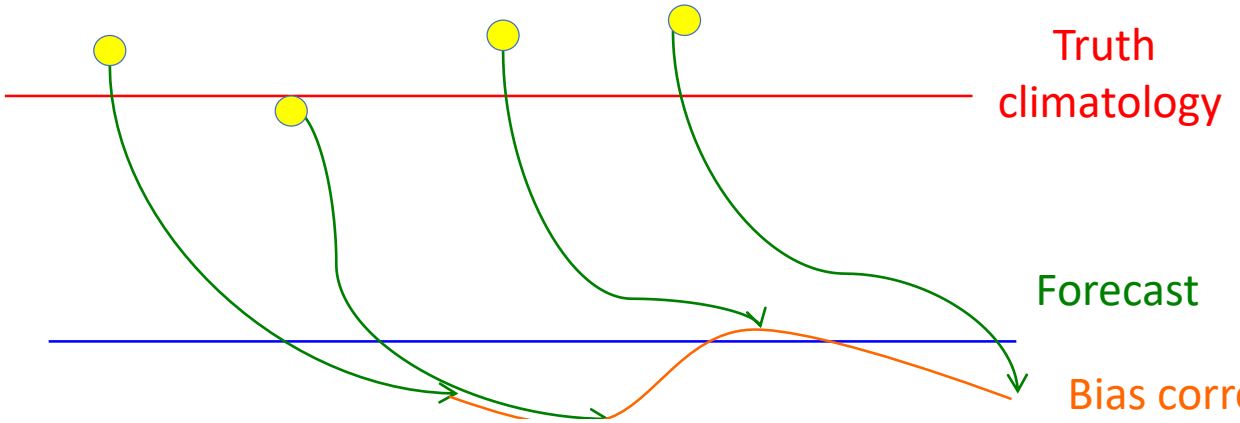
Persistent model biases – dramatic improvement unlikely soon

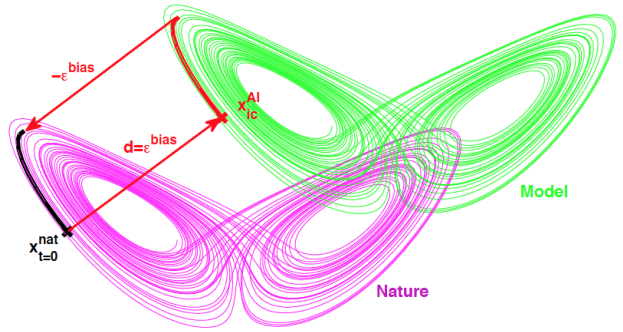


- **Bias is often larger than the signal we analyze or predict**
- **Observation network is too small to constrain it**

How is bias handled currently

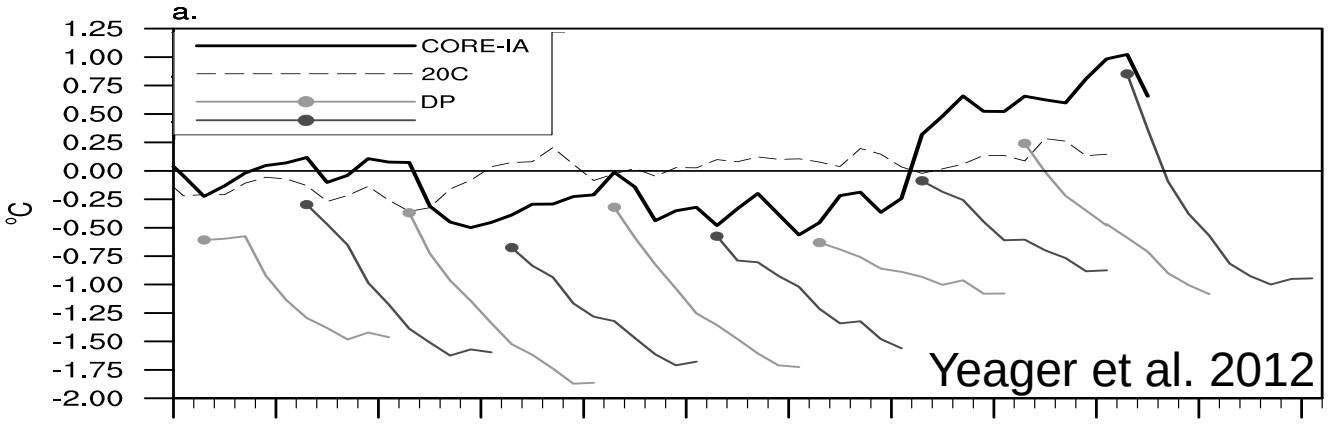
Full field assimilation





Observations

Raw CCSM4 predictions of SPG heat content anomalies



Good:

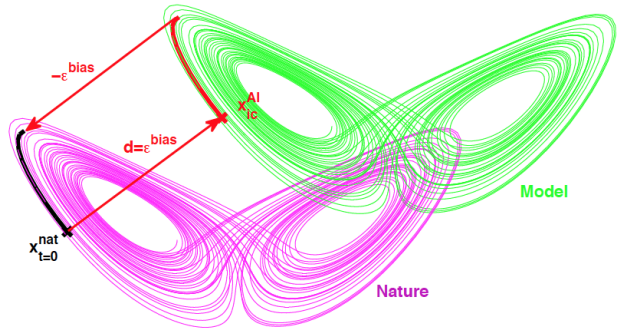
- Mean state is close to the truth
- If drift independent from signal, shock does not matter

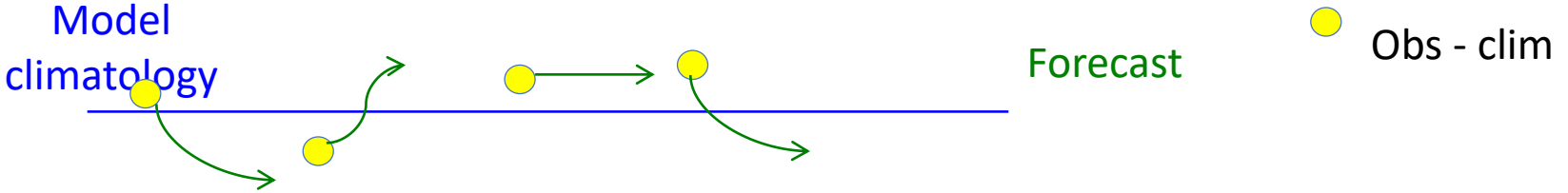
Bad:

- Large shock
- propagate the bias from observed variables to non observed variables (sparse inhomogeneous obs)

How is bias handled currently

Anomaly assimilation





Good:

- Less assimilation shock (no need for post processing)

Bad:

- Covariance are still biased
- Mean state influence the solution

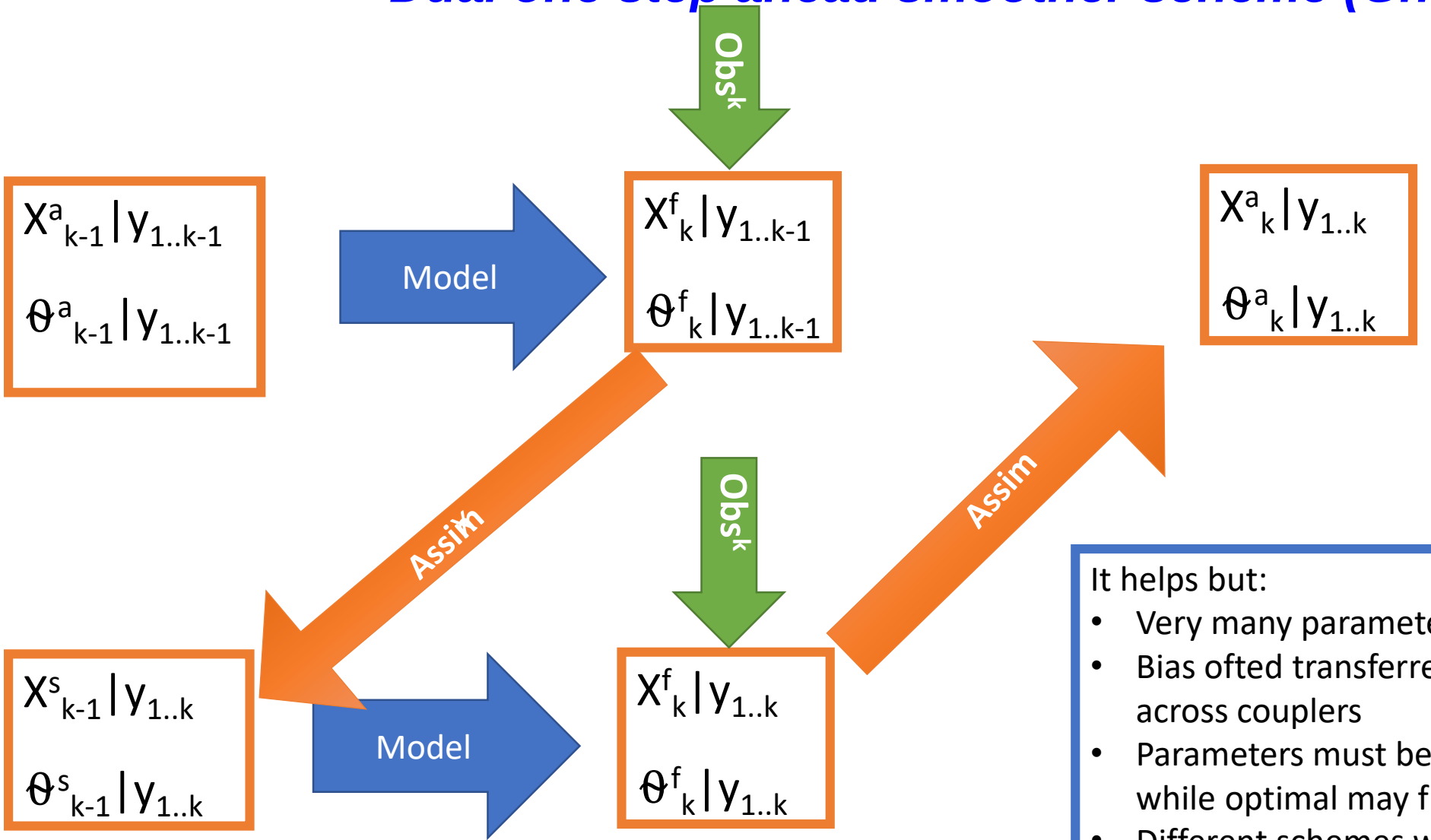
Outlines

We are considering 3 approaches to handle the model bias:

- Parameter estimation
- Flux correction method
- Supermodelling

Parameter estimation

Dual one step ahead smoother scheme (Gharamti et al. 2017)



It helps but:

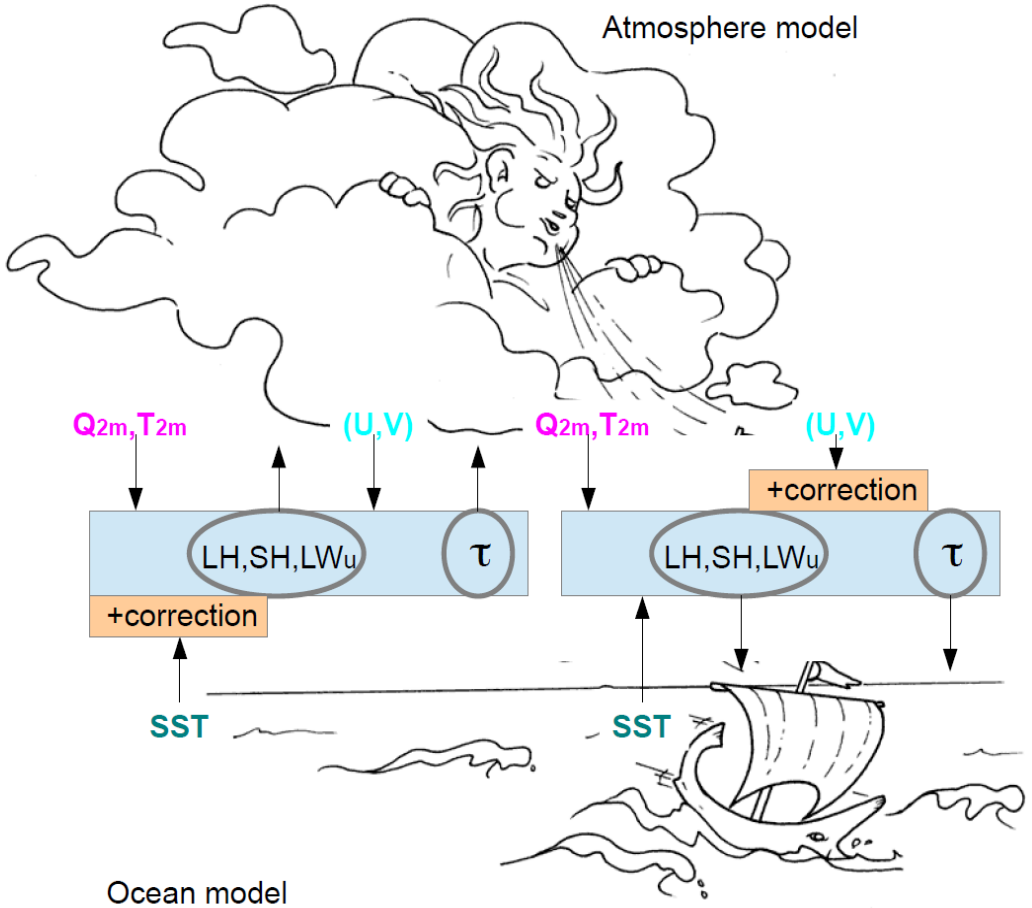
- Very many parameters and little obs
- Bias ofted transferred from different model across couplers
- Parameters must be fixed for climate simulation while optimal may fluctuate
- Different schemes works better in different condition/regions (not just the parameter value)

A methodology to correct mean state biases: Anomaly coupled model

Standard flux correction techniques were abandoned because they alter (damp) variability

Here :

- correction estimated with the coupled system
- Estimation is iterative

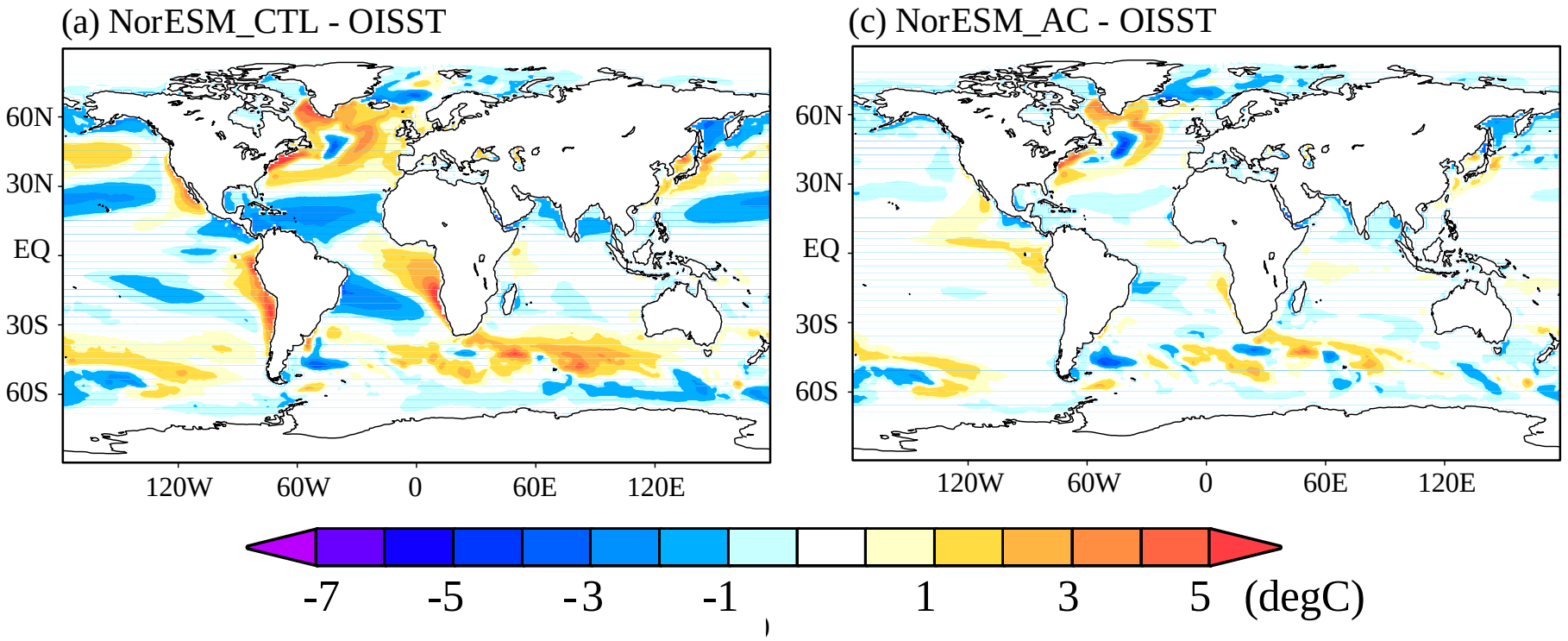


Correction added to quantities exchanged between atmosphere and ocean

Courtesy: Thomas Toniazzo

A methodology to correct mean state biases: Anomaly coupled model

An alternative method referred to as anomaly coupling has been implemented and tested with NorESM (Toniazzo and Koseki, 2018)

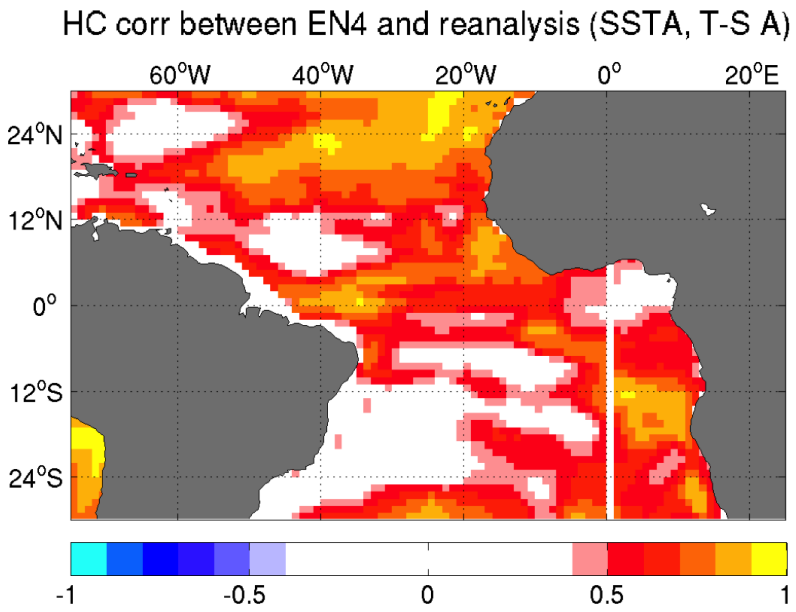


The anomaly coupling approach reduces strongly the bias in the tropics

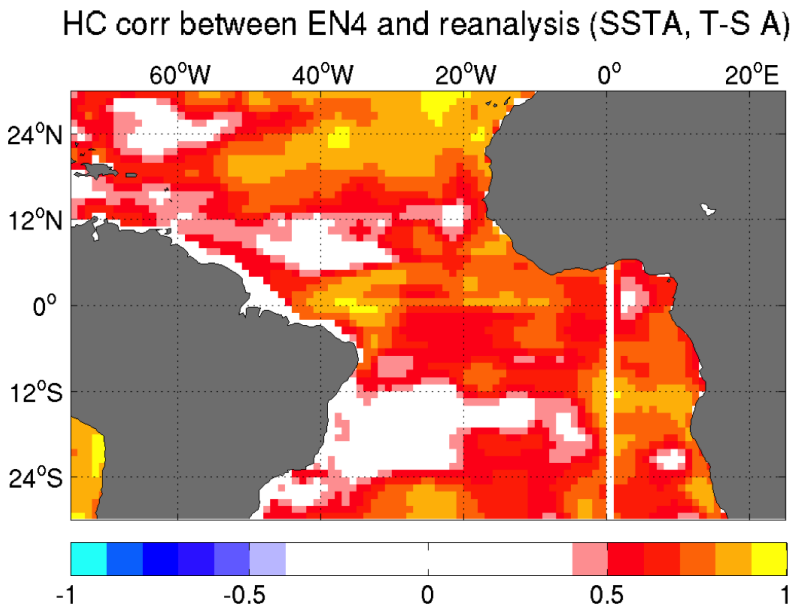
Reduced biases enhances

Comparison of reanalysis with objective analysis

NorCPM reanalysis

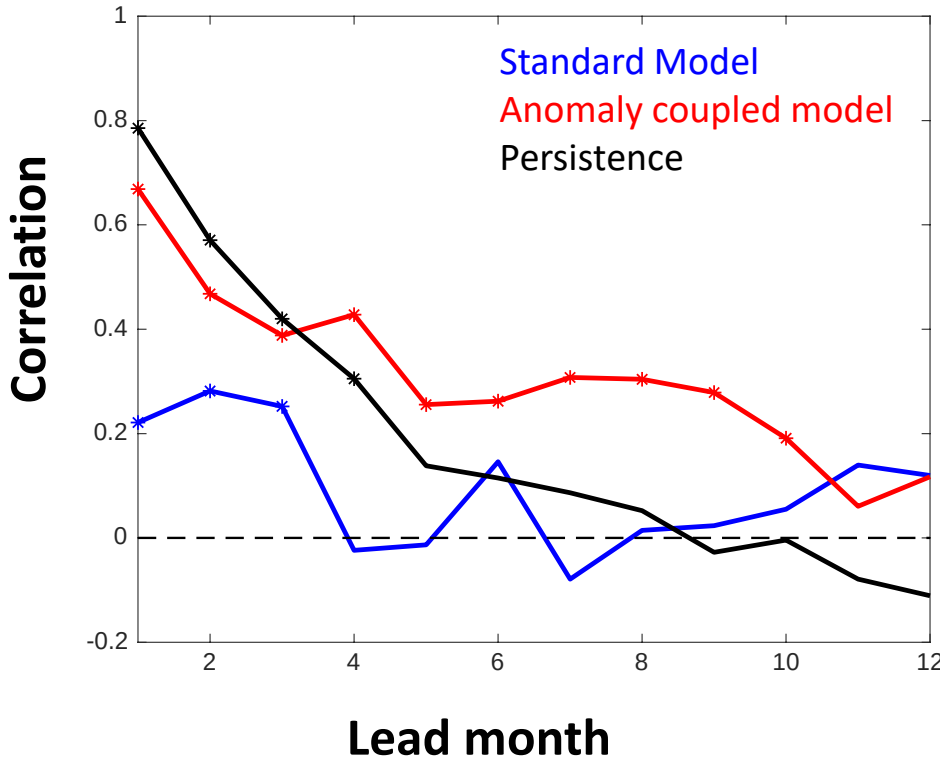


NorCPM anomaly coupled reanalysis



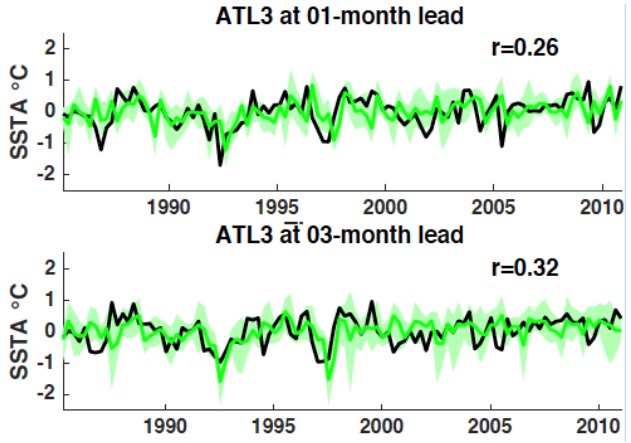
Higher match with assimilated observation in the Tropical Atlantic

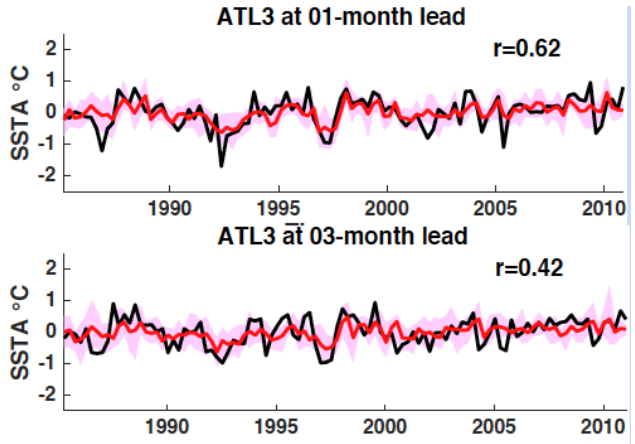
Reduced biases enhances seasonal prediction skill for the Atlantic Niño



But skill is poor :

- Mechanism of predictability improved but still misrepresented in some season
- Tendency to dampen the variability of the signal

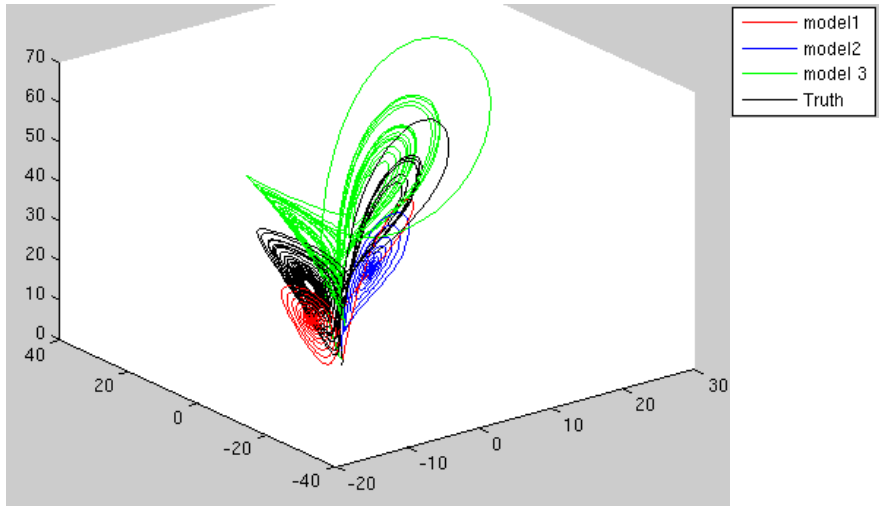




Super modelling
An example with L63

	σ	ρ	β
Truth	10	28	8/3
Model 1	13.25	19	3.5
Model 2	7	18	3.7
Model 3	6.5	38	1.7

$$\dot{x} = \sigma(y - x)$$
$$\dot{y} = x(\rho\text{-z})\text{-y}$$
$$\dot{z} = xy\text{-}\beta z$$



A super model add connections to the other imperfect models

Example:

$$\dot{x_1} = \sigma_1(y_1 - x_1) + C_{12}^x(x_2 - x_1) + C_{13}^x(x_3 - x_1)$$

Nudging to other supermodel

In **training phase** you use observations to estimate the nudging coefficients (and constrain the state during)

In **verification phase** the coefficient are frozen and the system can be use as a new dynamical system

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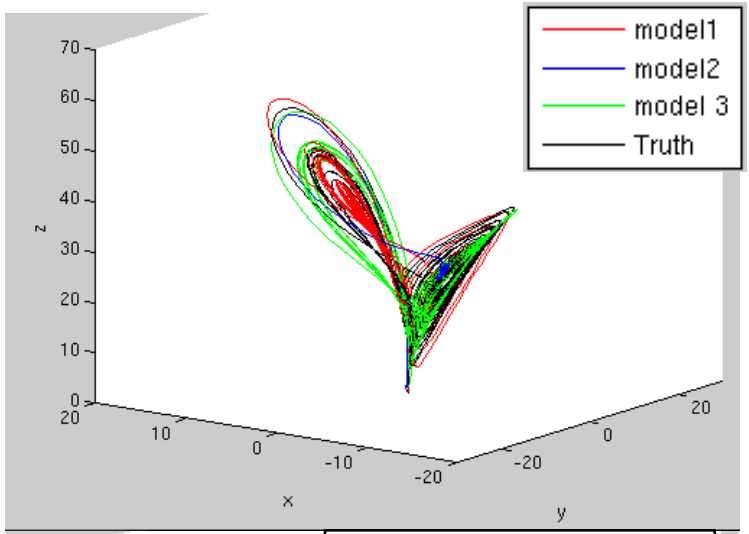
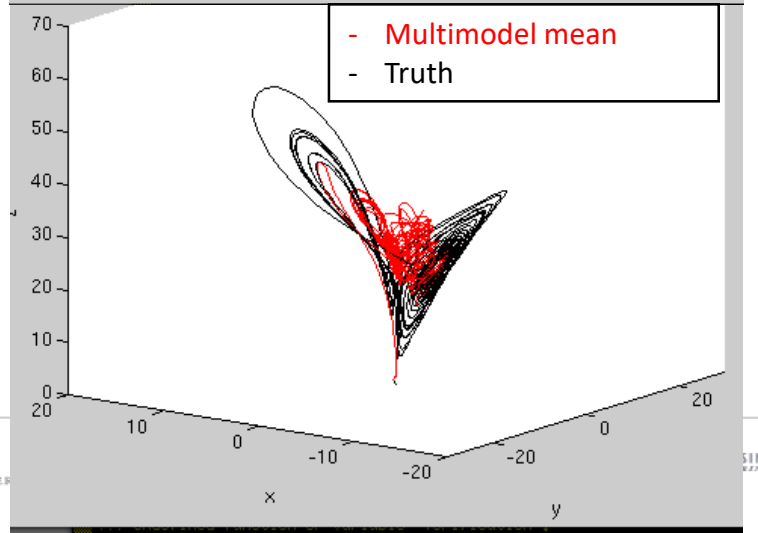
Super ensemble

Mean of unconnected models

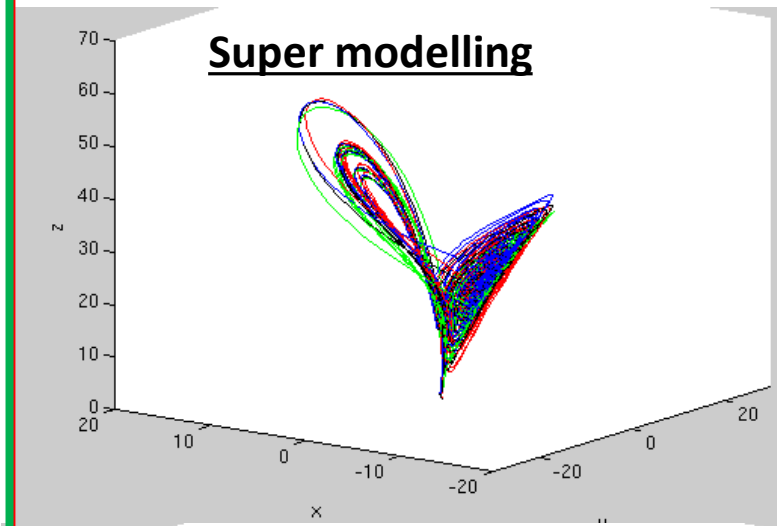


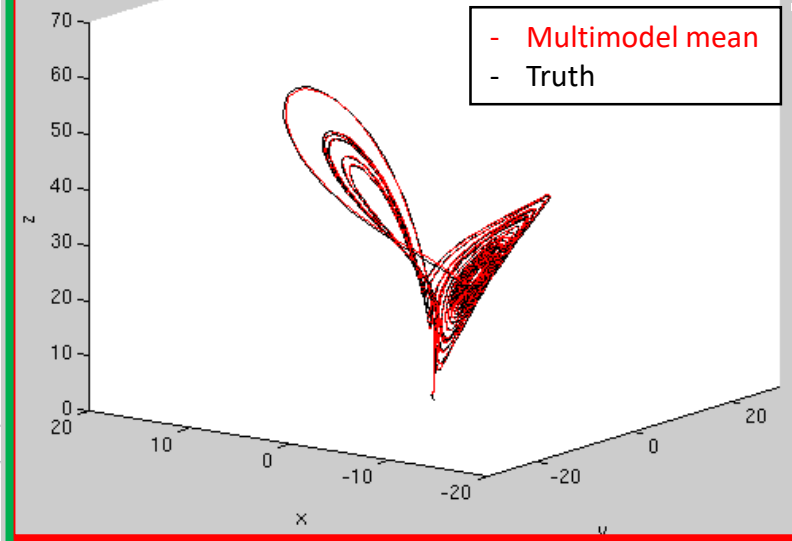


Supermodel

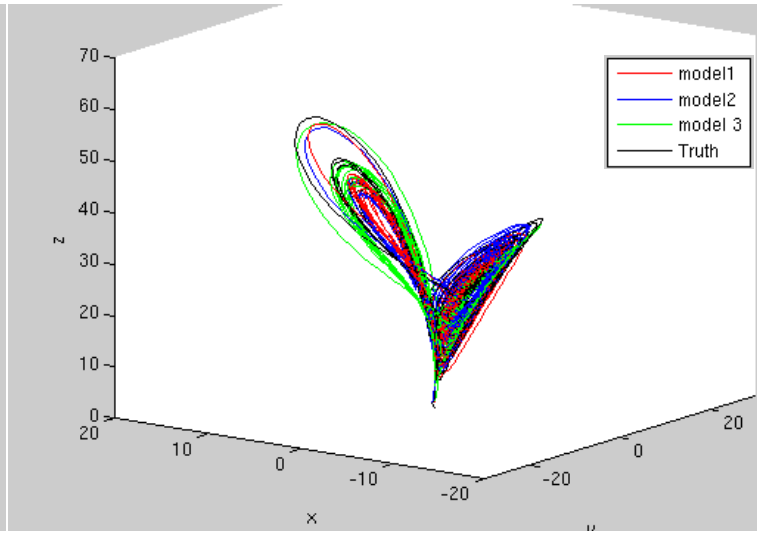
Training

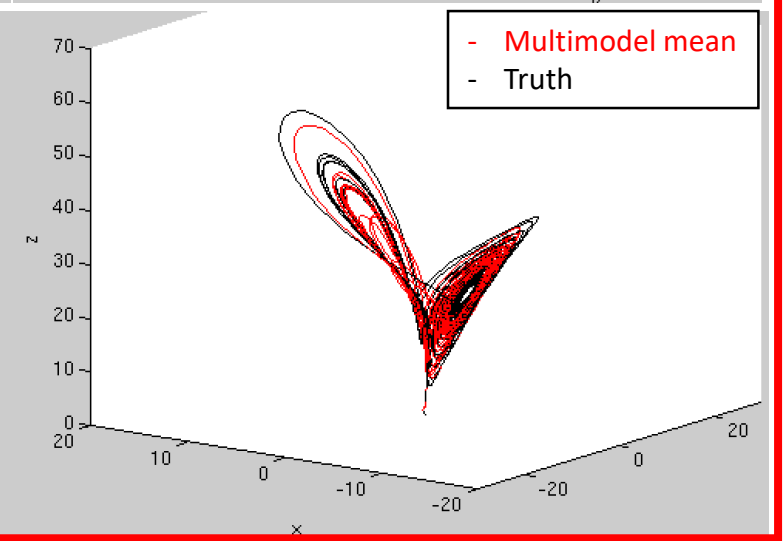
Super modelling



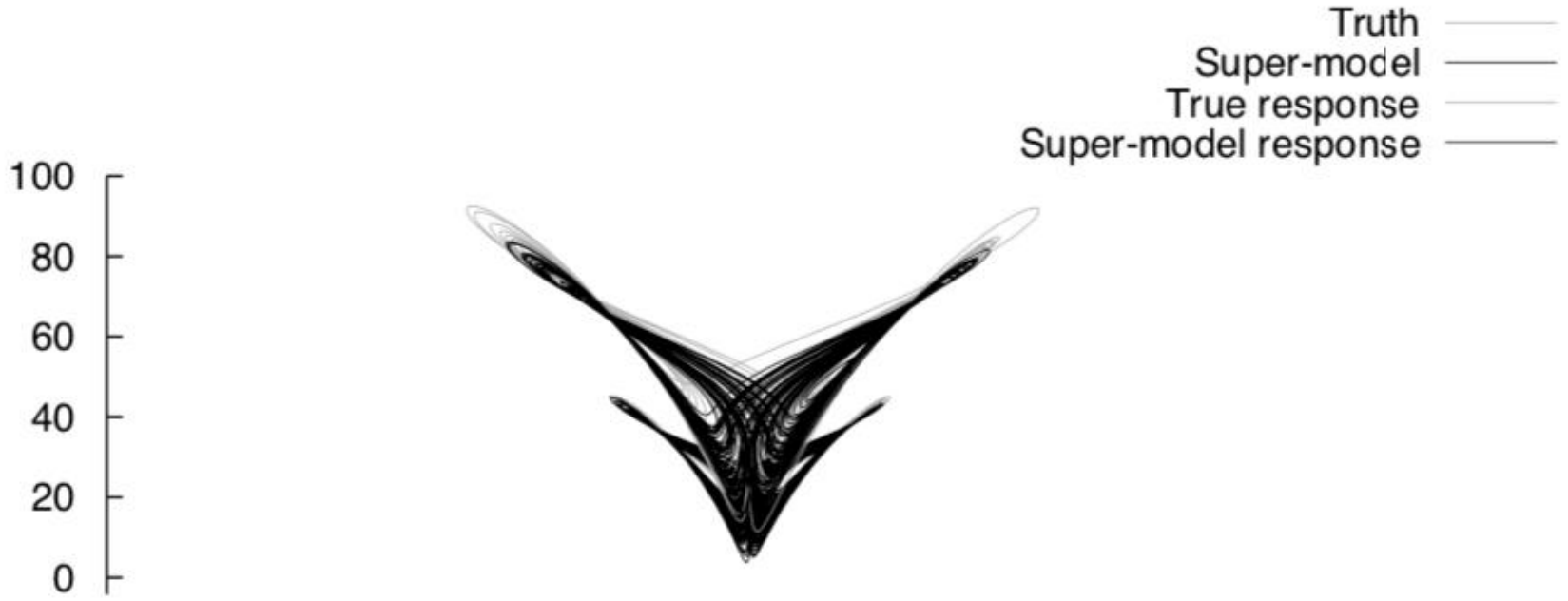


Verification





Super modelling
An example with L63

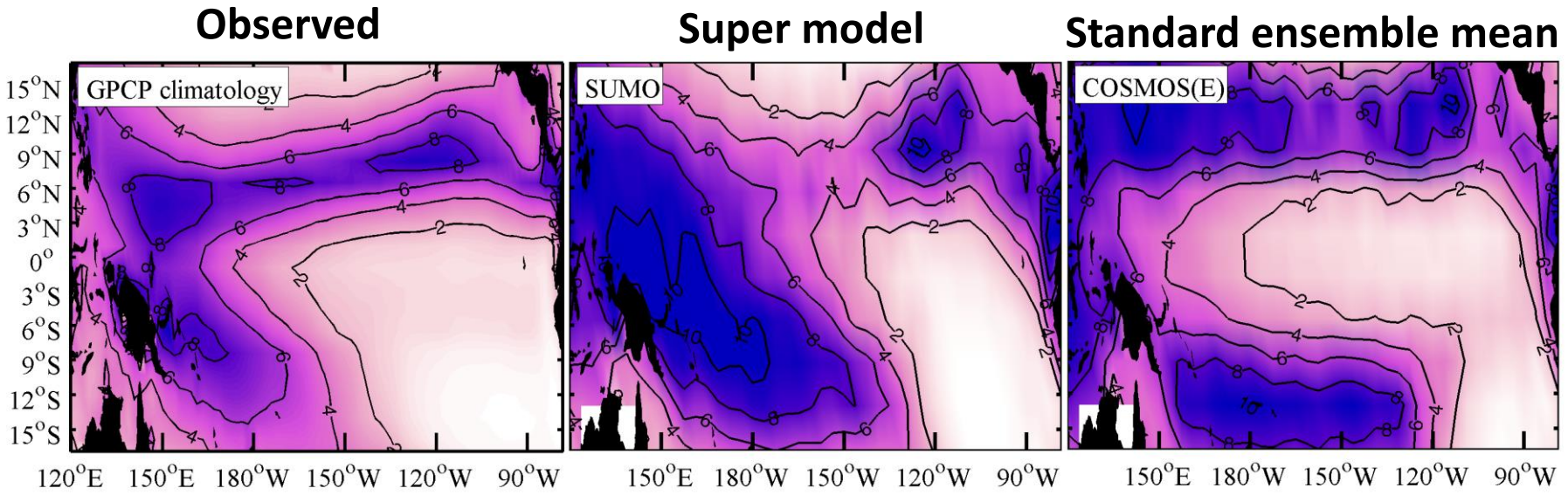


Supermodel still working if you double the parameter rho in all model (climate change like simulation)

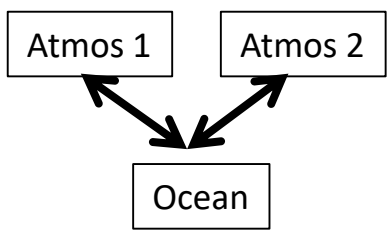
Super modelling

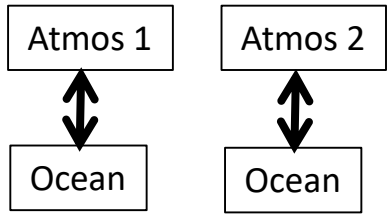
A first attempt with GCM

Climatological Precipitation in Tropical Pacific



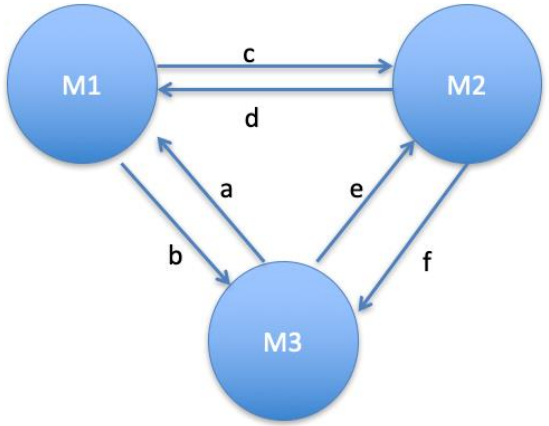
(Shen et al. 2016, 2017)





Super modelling
Different flavour

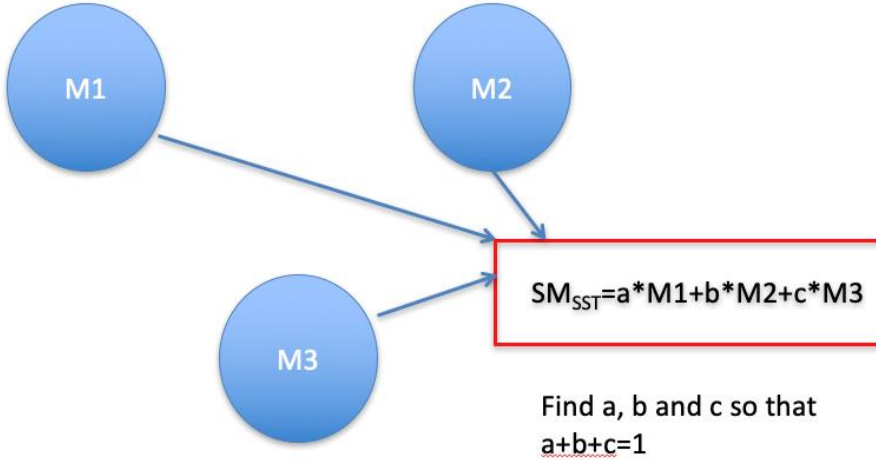
Connected Supermodel



a,b,c,d,e,f are nudging coefficients (>0 < 100)

Original

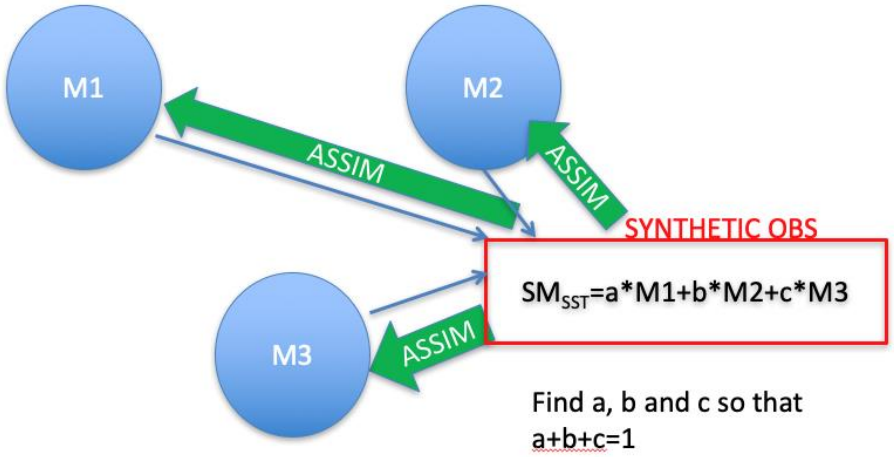
Weighted Supermodel



Find a, b and c so that a+b+c=1

Less parameter to estimate

Centralized Supermodel



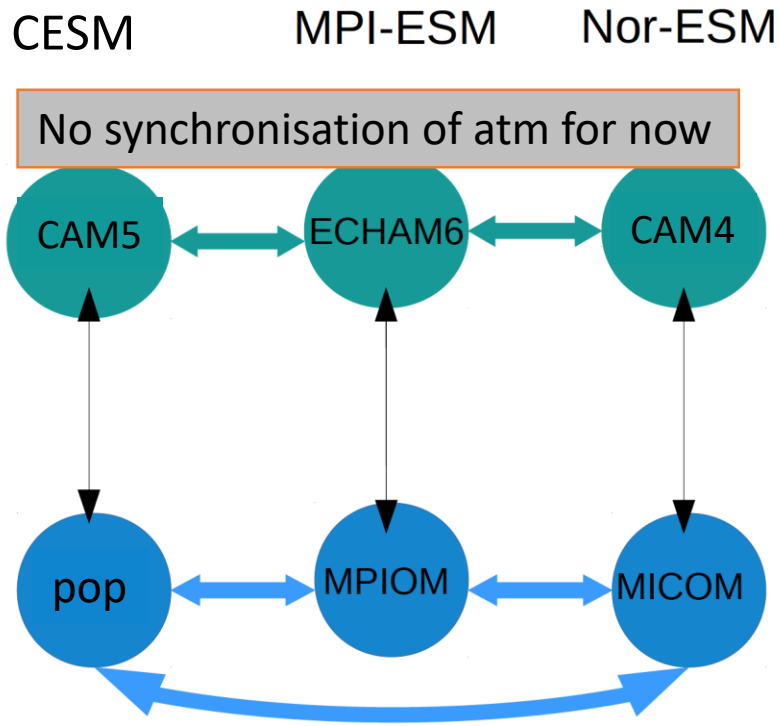
Find a, b and c so that a+b+c=1

Independent of resolution and grid
And running speed of each model

Optimal coefficients can be estimated:

- Online
- A posteriori to minimize mean error, variance, curtosis
- Forecast error

Super modelling for an earth system model



We use DA to synchronise the system and ensure dynamical consistency and multivariate updates

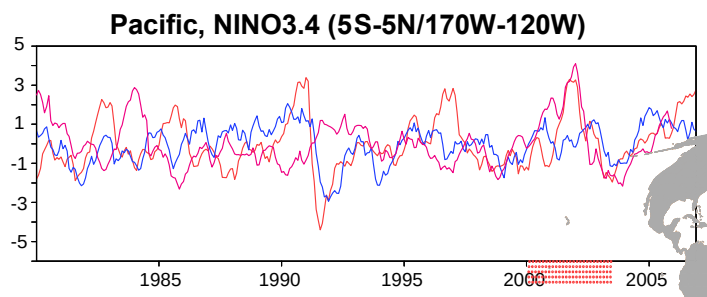
- We generate synthetic observations (Here mean of models SST, every month) that are assimilated into each individual models (with the EnOI)
- The three models are then propagated
- Possible to assimilate real data in addition

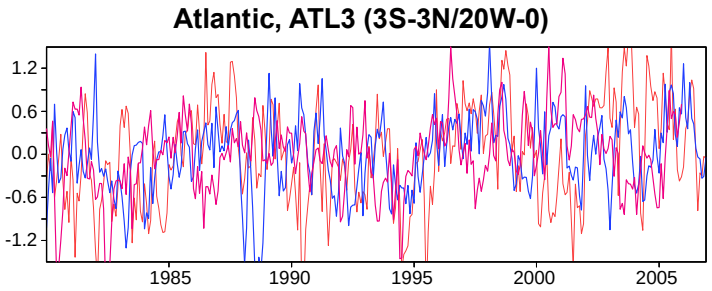
Can the centralized scheme works ?_

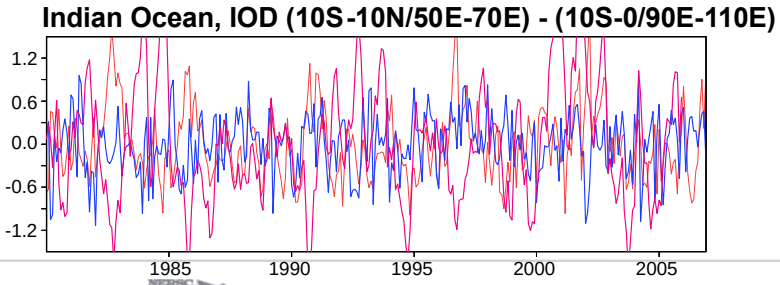
- Does the models synchronized ?
- Is internal variability damped ?

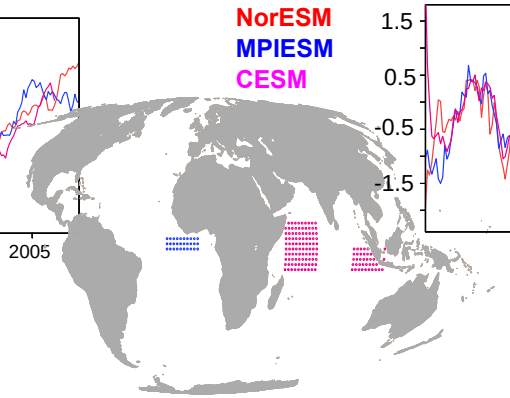
Is variability synchronised ?

Unconnected

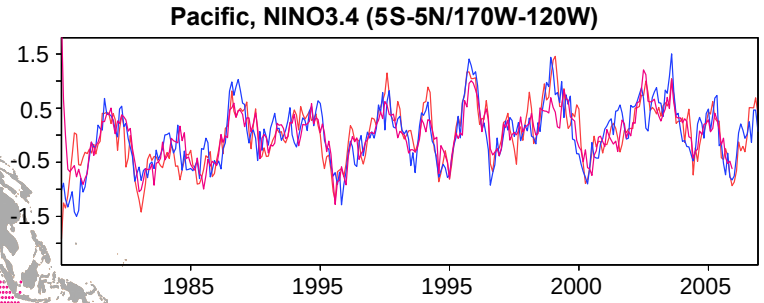


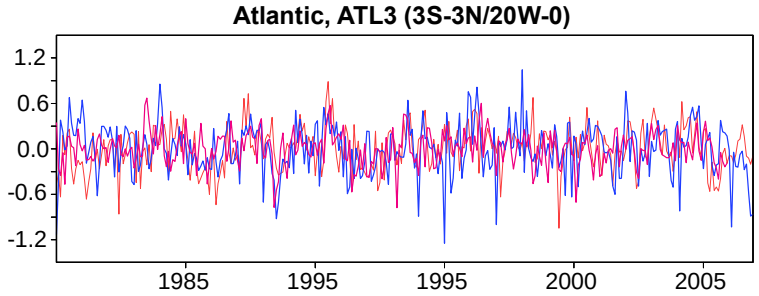


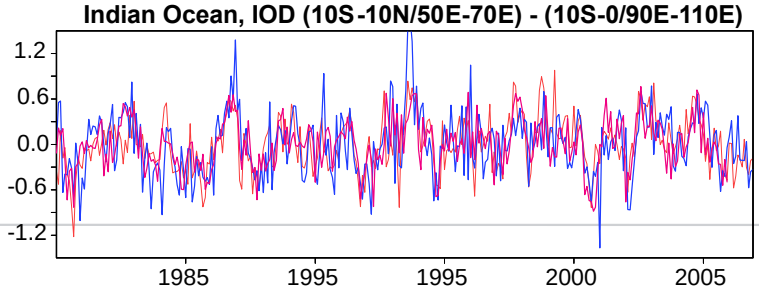




Supermodel

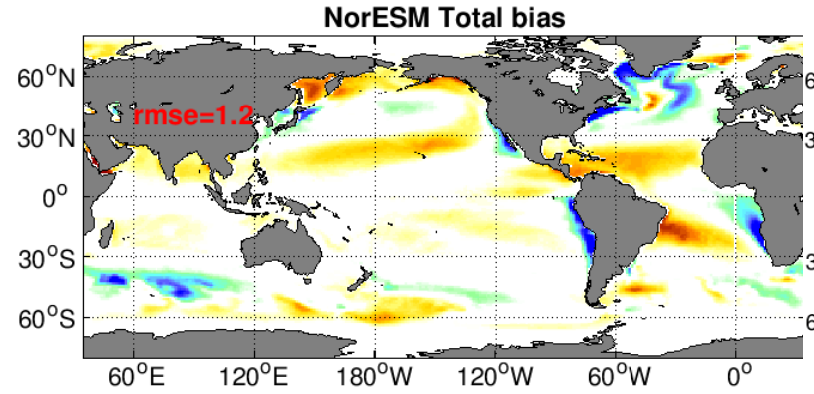


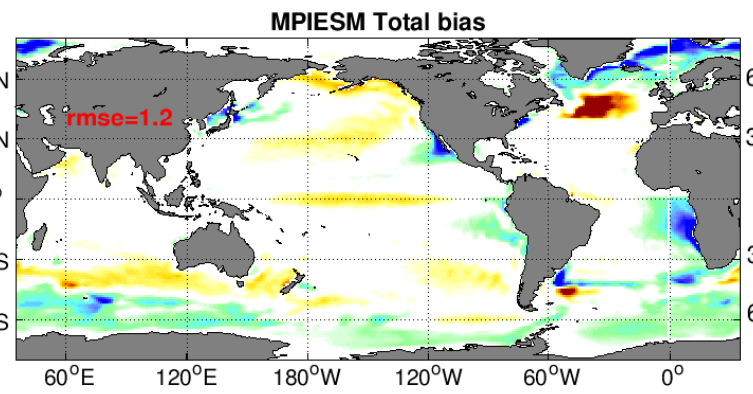


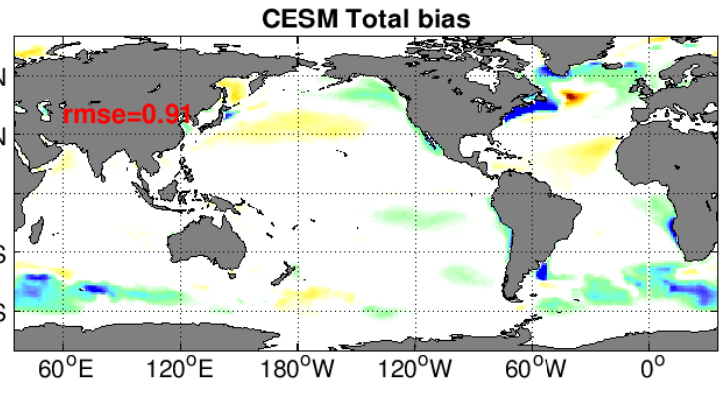


Is bias improved ?

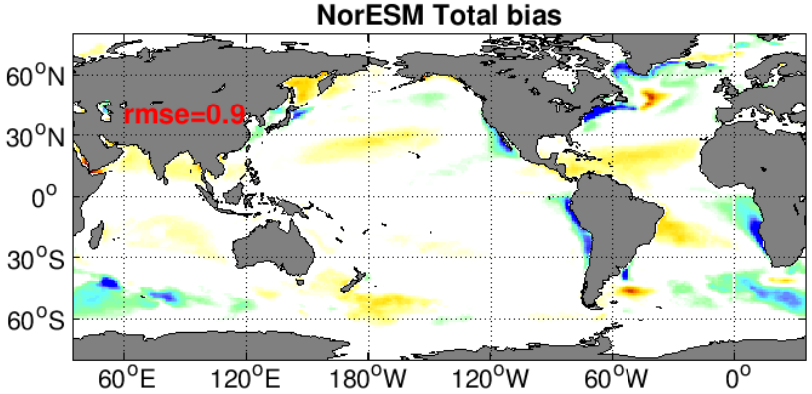
Unconnected

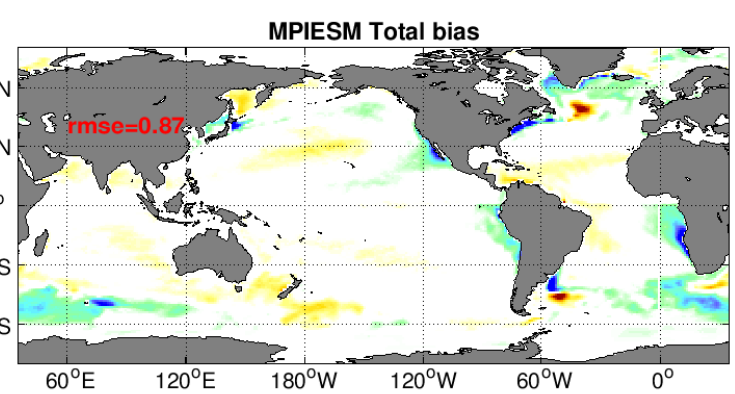


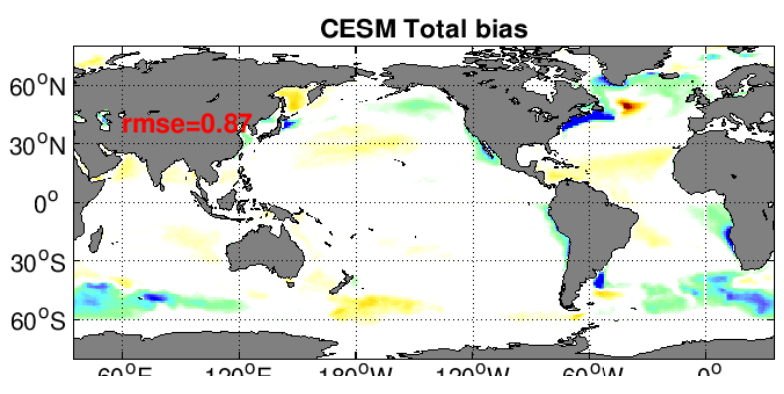




Supermodel



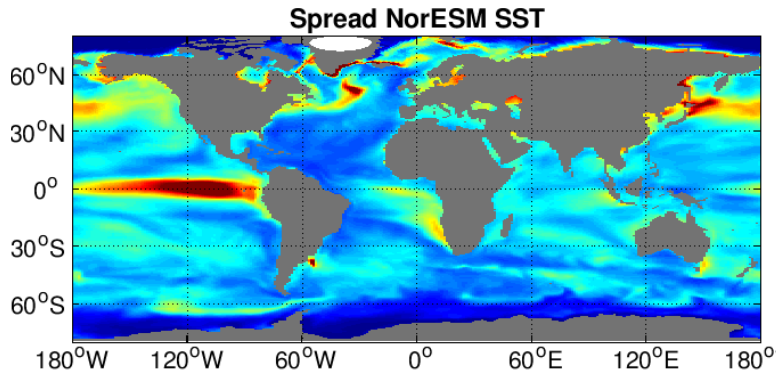


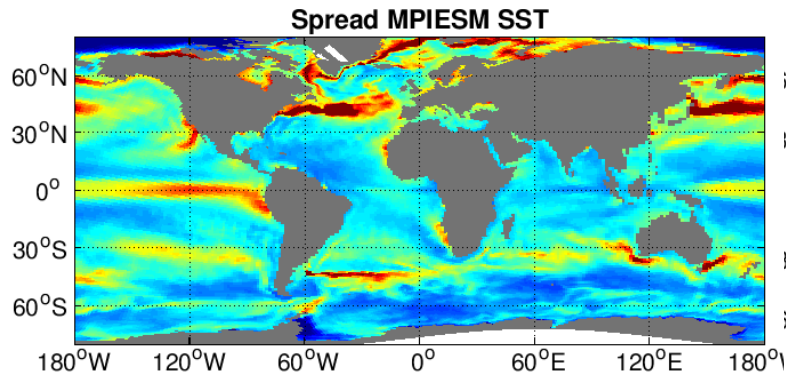


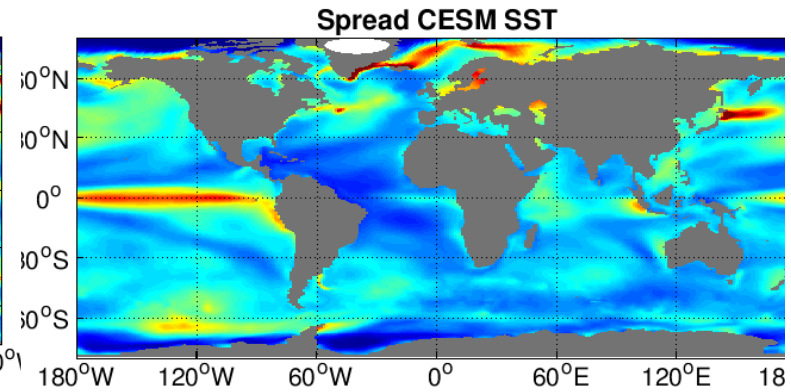
The bias of each model is reduced

Is variability damped ?

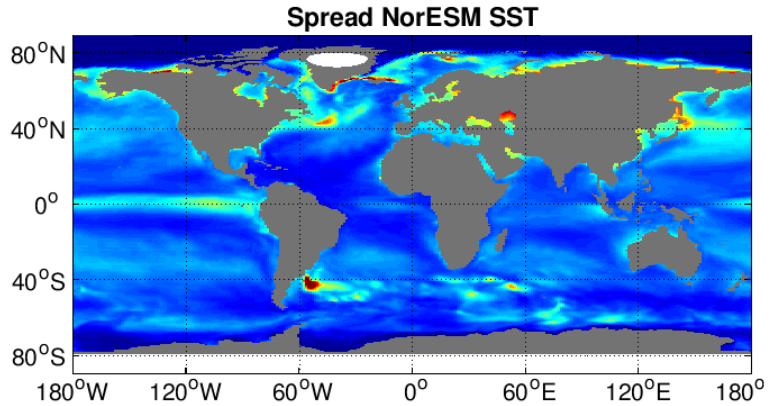
Unconnected

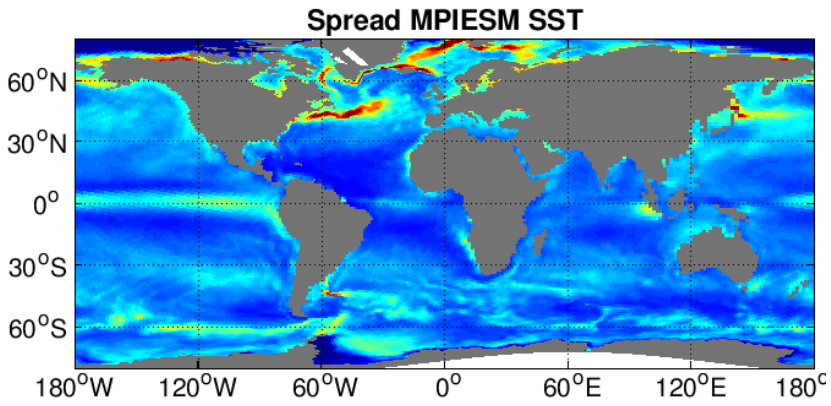


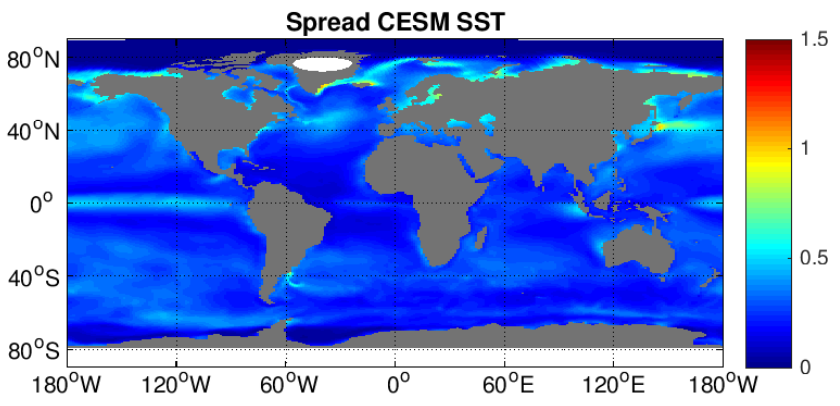




Supermodel

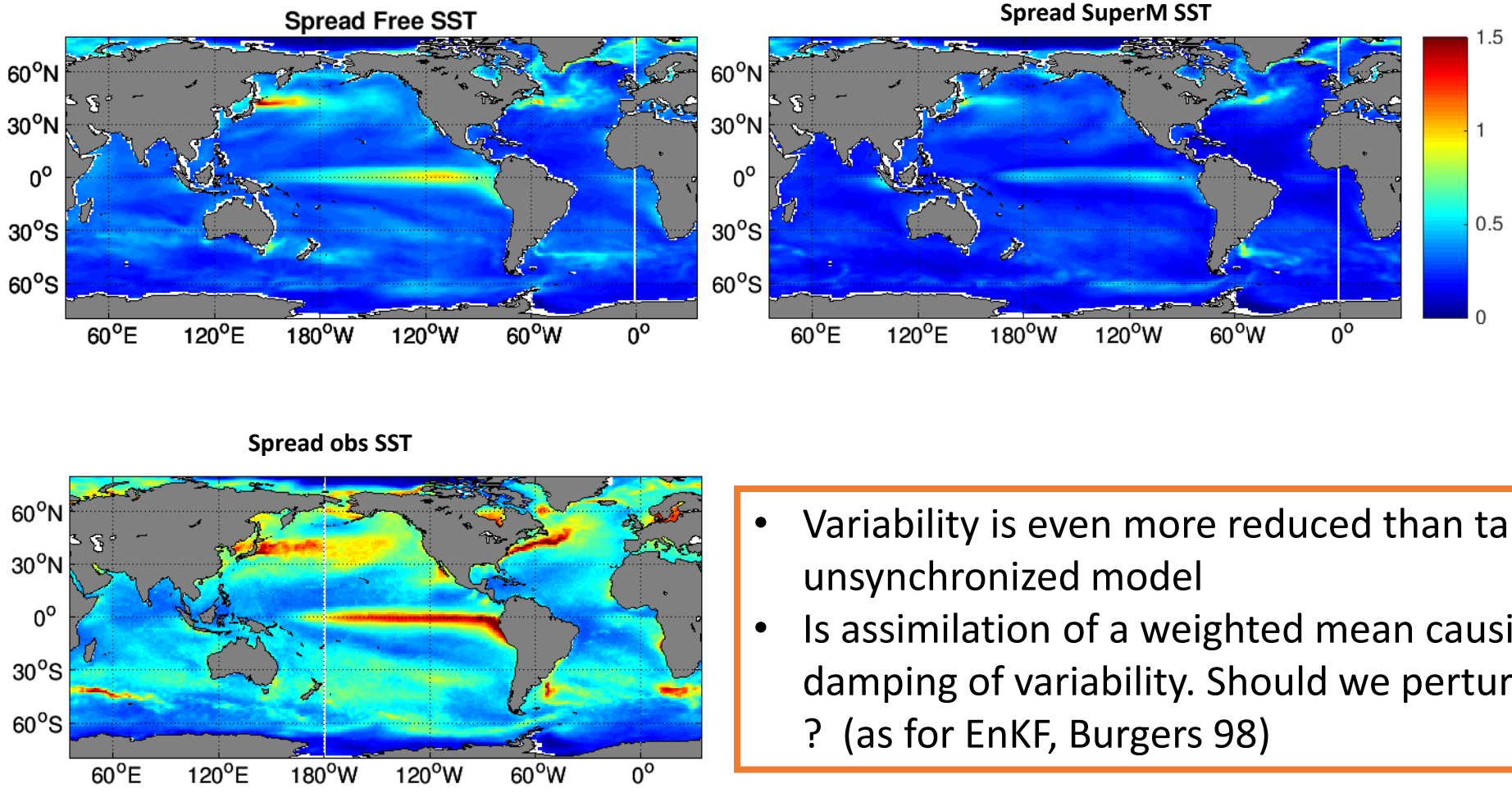






Variability is very <u>largely</u> reduced

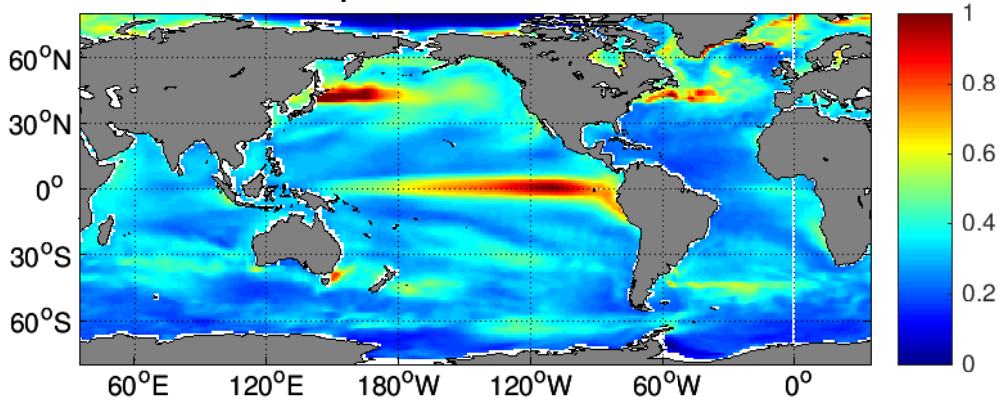
Is variability damped ?



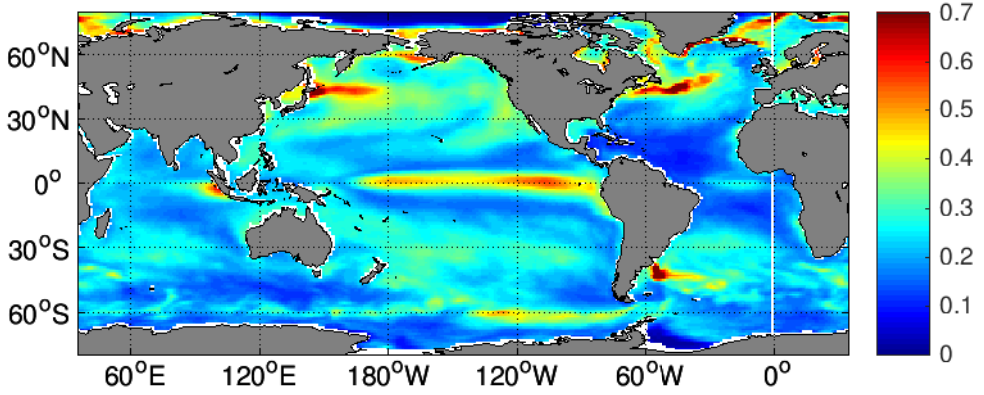
- Variability is even more reduced than taking the mean of unsynchronized model
- Is assimilation of a weighted mean causing an artificial damping of variability. Should we perturb the synthetic obs ? (as for EnKF, Burgers 98)

Is variability damped ?

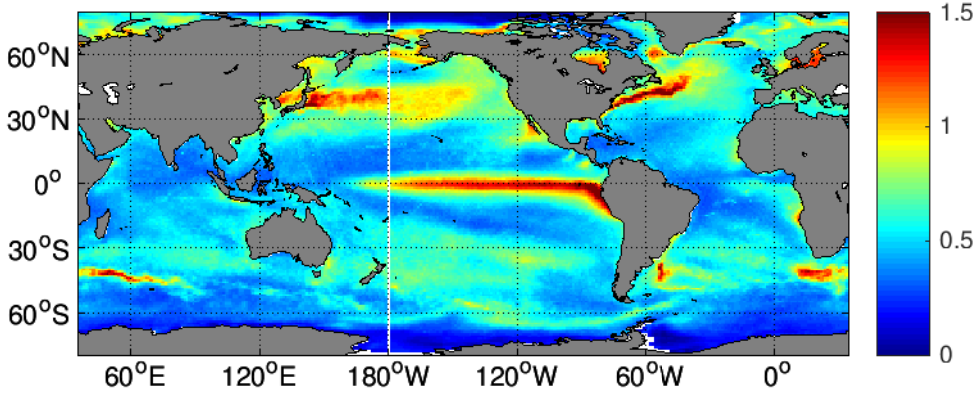
Spread Free SST



Spread SuperM SST



Spread obs SST



If we scale the amplitude, there seems to be a better spatial coherency with the obs

Conclusions

We are trying different techniques to reduce model bias and enhance prediction skill

- Parameter estimation using one step ahead smoother is being tested
- Anomaly coupling reduces bias and improved skill but fails to improve all mechanism of predictability and still tends to damp variability
- Supermodel allow a reduction of bias using models as black box
- It worked well with idealized model
- Show promising result for a GCM with two atmospheres
- When using DA to synchronised the model (new supermodeling scheme)
  - ESM are synchronised and bias reduced but variability totally damped
  - We will try the centralised supermodel with perturbed synthetic observations