Initalization of prediction systems with ocean observations

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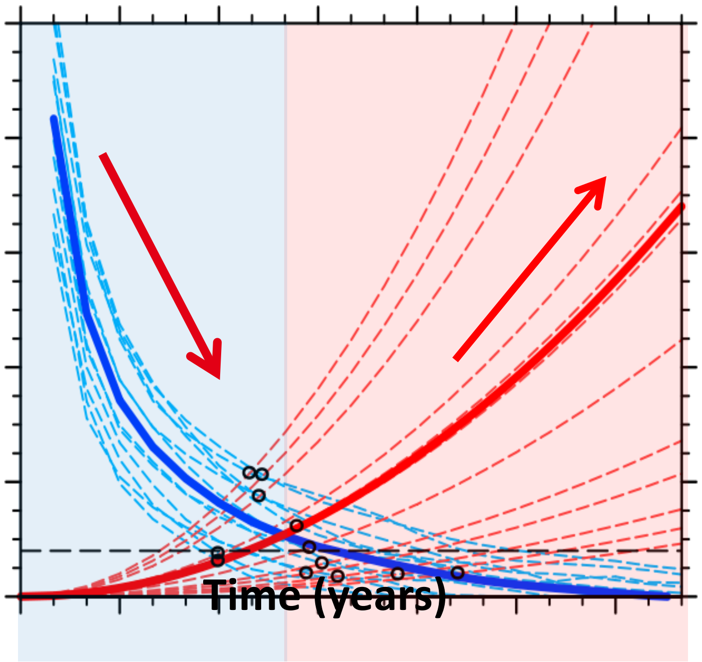
Initialization vs external forcing

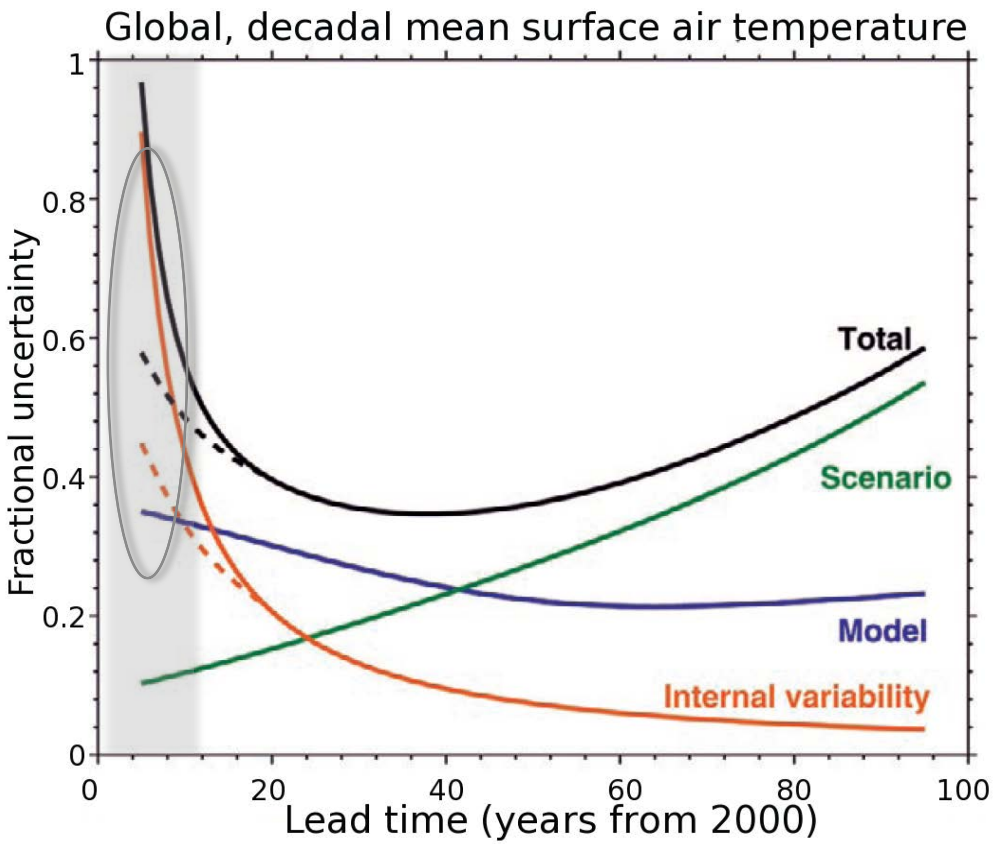
Importance of initialization



Importance of external forcing

Branstator and Teng, 2012

Uncertainty and initialization



Hawkins and Sutton, 2009

--- based on the results from Smith et al. (2007)

Importance to develop Initialized decadal predictions to reduce uncertainty from

- internal variability component
- model-related component

Decadal prediction is initial-boundary value problem

weather forecasts for a few days ahead

decadal predictions for a few years ahead

climate change projections from few years to centuries

Initial-value problem
(detailed knowledge of the initial state)

Boundary-value problem
(radiative forcing)

- ***source of predictability:***
  - fast varying atmospheric circulation

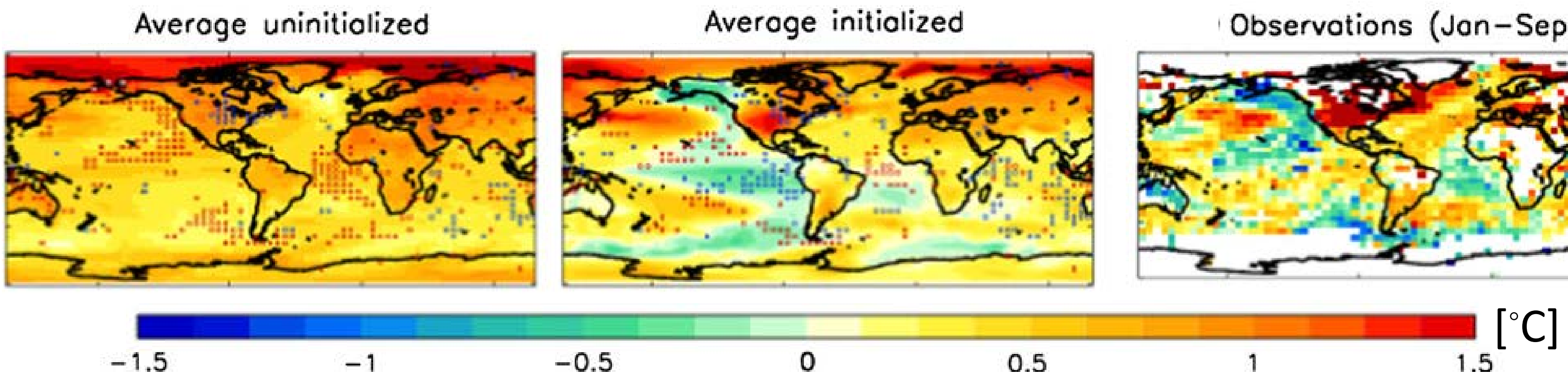
- ***source of predictability*:**
  - slow components of the natural climate variability, e.g. **ocean**
  - forced component of the climate system

source of predictability:

- forced component of the climate system
- do not take into account internal variability

Initializing climate predictions with ocean observations

Temperature anomaly for 2012



Uninitialized predictions use

- external forcing

Initialized predictions use

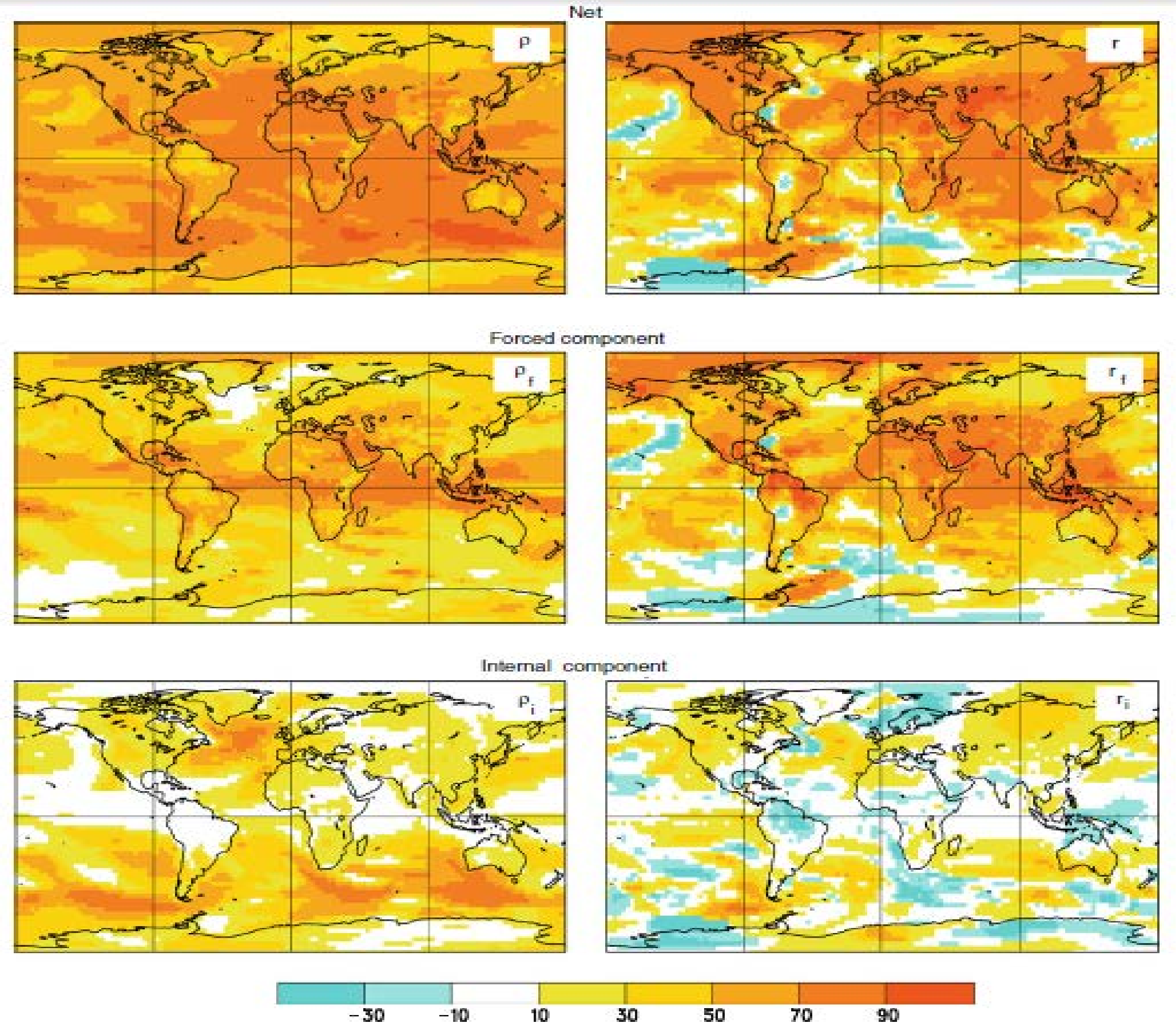
- external forcing and
- initialization with Ocean observations

Decadal predictions

predict natural internal variability over the next few years through knowledge of the observed climate state

Figure from Smith et al., 2012

Potential predictive skill and actual correlation skill for temperature, years 1–5



Boer et al, 2013

Ongoing Issues

- Learn from seasonal forecasts, work toward seamless predictions (WCRP).
- Extract information from decadal predictions useful for societies (WCRP GC, climate services).
- Improve initialization procedures (requires observations!)
- Expand to initialize all climate components.
- Improve quality of initial conditions (state estimation, CLIVAR).
- Deal with model uncertainties (similar to SI, WCRP).
- Understanding mechanism! (CLIVAR RF)

Previous experience on ocean initialization

- **First decadal prediction studies had mostly ocean initialization in focus**

Table 11.1 | Initialization methods used in models that entered CMIP5 near-term experiments. (Figures 11.3 to 11.7 have been prepared using those cor

CMIP5 Near-term Players Name of modeling centre (or group)	CMIP5 official model id	AGCM	OGCM	Initialization Atmosphere/Land	Ocean	Sea Ice	Anomaly Assimilation?
(*) Beijing Climate Center, China Meteorological Administration (BCC) China	BCC-CSM 1.1	2.8°L26	1°L40	No	SST, T&S (SODA)	No	No
(*) Canadian Centre for Climate Modelling and Analysis (CCCMA) Canada	CanCM4	2.8°L35	1.4° × 0.9°L40	ERA40/Interim	SST (ERSST&OISST), T&S (SODA & GODAS)	HadISST1.1	No
(*) Centro Euro-Mediterraneo per I Cambiamenti Climatici (CMCC-CM) Italy	CMCC-CM	0.75°L31	0.5°–2° L31	No	SST, T&S (INGV ocean analysis)	CMCC-CM climatology	No
(*) Centre National de Recherches Météorologiques, and Centre Européen de Recherche et Formation Avancées en Calcul Scientifique (CNRM-CERFACS) France	CNRM-CM5	1.4°L31	1°L42	No	T&S (NEMOVAR-COMBINE)	No	No
National Centers for Environmental Prediction and Center for Ocean-Land-Atmosphere Studies (NCEP and COLA) USA	CFSv2-2011	0.9°L64	0.25–0.5°L40	NCEP CFSR reanalysis	NCEP CFSR ocean analysis (NCEP runs) NEMOVAR-S4 ocean analysis (COLA runs)	NCEP CFSR reanalysis	No
(*) EC-EARTH consortium (EC-EARTH) Europe	EC-EARTH	1.1°L62	1°L42	ERA40/Interim	Ocean assimilation (ORAS4/NEMOVAR S4)	NEMO3.2-LIM2 forced with DFS4.3	No (KNMI & IC3) yes (SMHI)
(*) Institut Pierre-Simon Laplace (IPSL) France	IPSL-CM5A-LR	1.9 × 3.8° L39	2°L31	No	SST anomalies (Reynolds observations)	No	Yes
(*) AORI/NIES/JAMSTEC, Japan	MIROC4h MIROC5	0.6°L56 1.4°L40	0.3°L48 1.4°L50	No	SST, T&S (Ishii and Kimoto, 2009)	No	Yes
(*) Met Office Hadley Centre (MOHC) UK	HadCM3	3.8°L19	1.3°L20	ERA40/ECMWF operational analysis	SST, T&S (Smith and Murphy, 2007)	HADISST	Yes, also full field
(*) Max Planck Institute for Meteorology (MPI-M) Germany	MPI-ESM-LR MPI-ESM-MR	1.9°L47 1.9°L95	1.5°L40 0.4°L40	No	T&S from forced OGCM	No	Yes
(*) Meteorological Research Institute (MRI) Japan	MRI-CGCM3	1.1°L48	1°L51	No	SST, T&S (Ishii and Kimoto, 2009)	No	Yes
Global Modeling and Assimilation Office, (NASA) USA	GEOS-5	2.5°×2° L72	1°L50	MERRA	T&S from ocean assimilation (GEOS iODAS)	GEOS iODAS reanalysis	No
(*) National Center for Atmospheric Research (NCAR) USA	CCSM4	1.3°L26	1.0°L60	No	Ocean assimilation (POPDART) Ocean state from forced ocean-ice GCM	Ice state from forced ocean-ice GCM (strong salinity restoring for POPDART)	No
(*) Geophysical Fluid Dynamics Laboratory (GFDL) USA	GFDL-CM 2.1	2.5°L24	1°L50	NCEP reanalysis	Ocean observations of 3-D T & S & SST	No	No
LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences; and CESS, Tsinghua University China	FGOALS-g2	2.8°L26	1°L30	No	SST, T&S (Ishii et al., 2006)	No	No
LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences China, Tsinghua University China	FGOALS-s2	2.8°L26	1°L30	No	T&S (EN3_v2a)	No	Yes

Table from Kirtman et al 2013, IPCC AR5

Ocean initialization approaches for decadal predictions

Flux correction:

initial conditions = observed anomalies + observed climatology and heat/freshwater/momentum flux correction

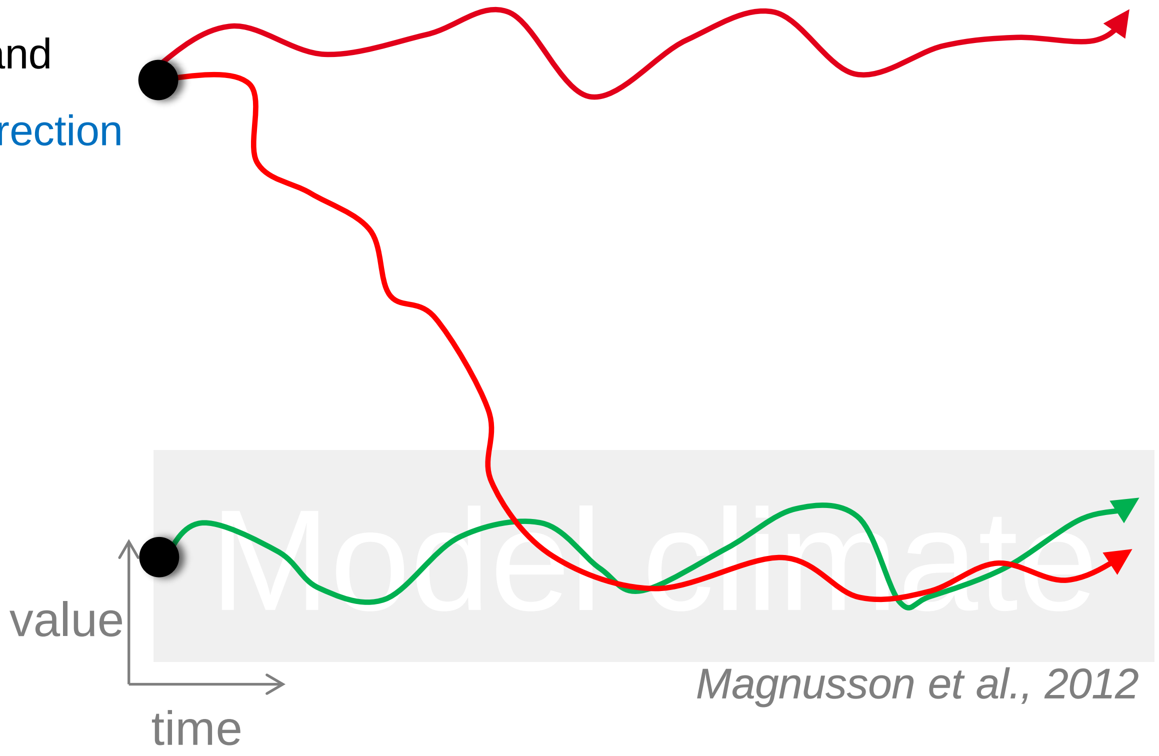
Full state initialization:

initial conditions = observed anomalies + observed climatology

Anomaly initialization:

initial conditions = observed anomalies + model climatology

Commonly used



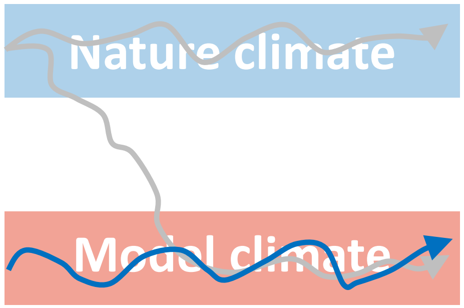
Magnusson et al., 2012

Anomaly initialization: pros and cons

(Pierce et al., 2004, Smith et al. 2007, Pohlmann et al. 2009, Magnusson et al 2013)

Aims/Benefits

- avoids model drift
- avoids non-linear effects of model drift like initialization shocks



Magnusson et al., 2013

Drawbacks

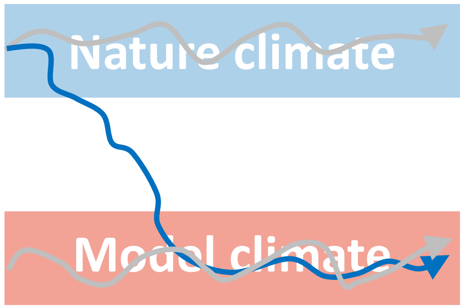
- large errors are allowed in the mean model climatology
- non-stationary bias (past experience applied to the future: mean state)
- initialization shocks (imbalance between initial conditions and model dynamics)

Full field initialization: pros and cons

(Troccoli and Palmer 2007, Doblas-Reyes et al. 2011, Magnusson et al 2013, Polkova et al 2014)

Aims/Benefits

- initial condition represents the "actual" observed state
- "Actual" state leads to more realistic adjustment/climate dynamics.



Magnusson et al., 2013

Drawbacks

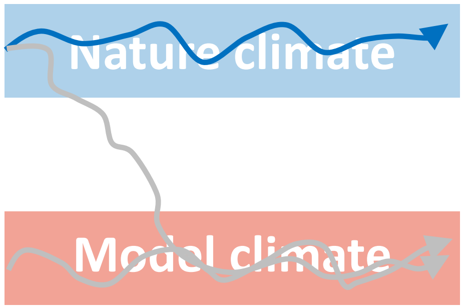
- model drift (development of systematic errors, loss of predictability)
- conditional bias (start date dependent)
- initialization shocks (imbalance between initial conditions and model dynamics)

Flux correction is a work around systematic model biases

(seasonal: Rosati et al 1997; Spencer et al 2007, Manguello and Huang 2009, decadal: Magnusson et al 2013, Polkova et al 2014)

Aims/Benefits

- initial condition represents the "actual" observed state
- corrects the mean state and seasonal cycle
  - might improve amplitude of variability
  - might improve predictive skill for non-corrected variables



Magnusson et al., 2013

Drawbacks

- construction of relevant correction terms in not straightforward:
  - remaining model drift (in non-corrected variables, e.g. AMOC)
  - may lead to incorrect model response to external forcing
  - initialization shocks
  - non-stationary bias

Difference between the forecast and the reanalysis for lyrs3–10: (a) SST bias and (b) cross-section of the equatorial temperature bias

anomaly initialization | U flux correction | UH flux correction

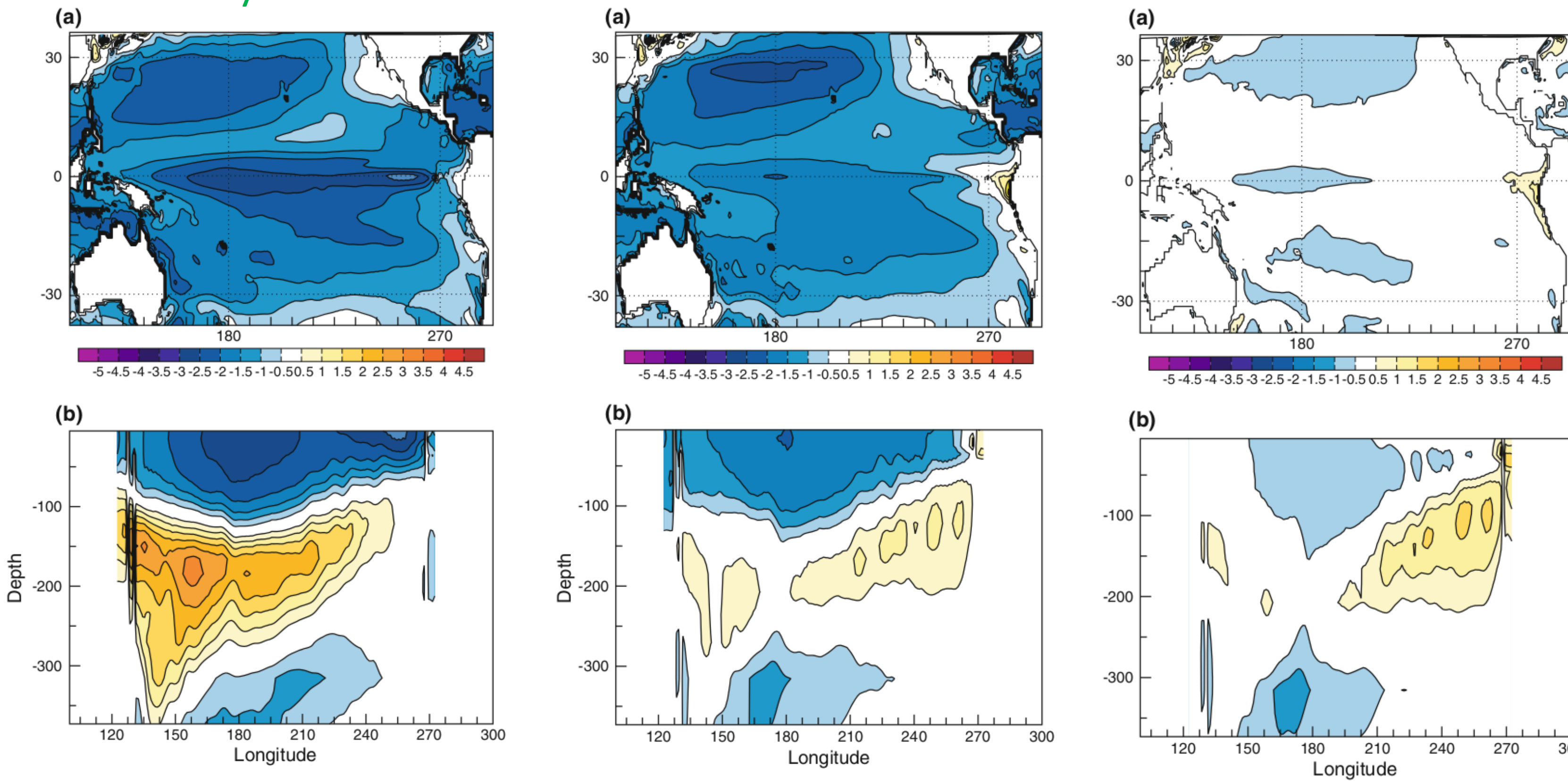


Figure from Magnusson et al., 2013

Ocean State Estimate

- Combine ocean observations with ocean circulation models to obtain more accurate estimates than either can provide alone.
- Use the results to study the changing ocean circulation and its interaction with the remaining climate system.
- Use results to initialize coupled forecasts; requires actual climate observations.

- Several approaches exist; mostly least squares fitting approaches aiming to reduce a quadratic model-data misfit.
- Some are just SST/SSS nudging; but the memory sits subsurface.

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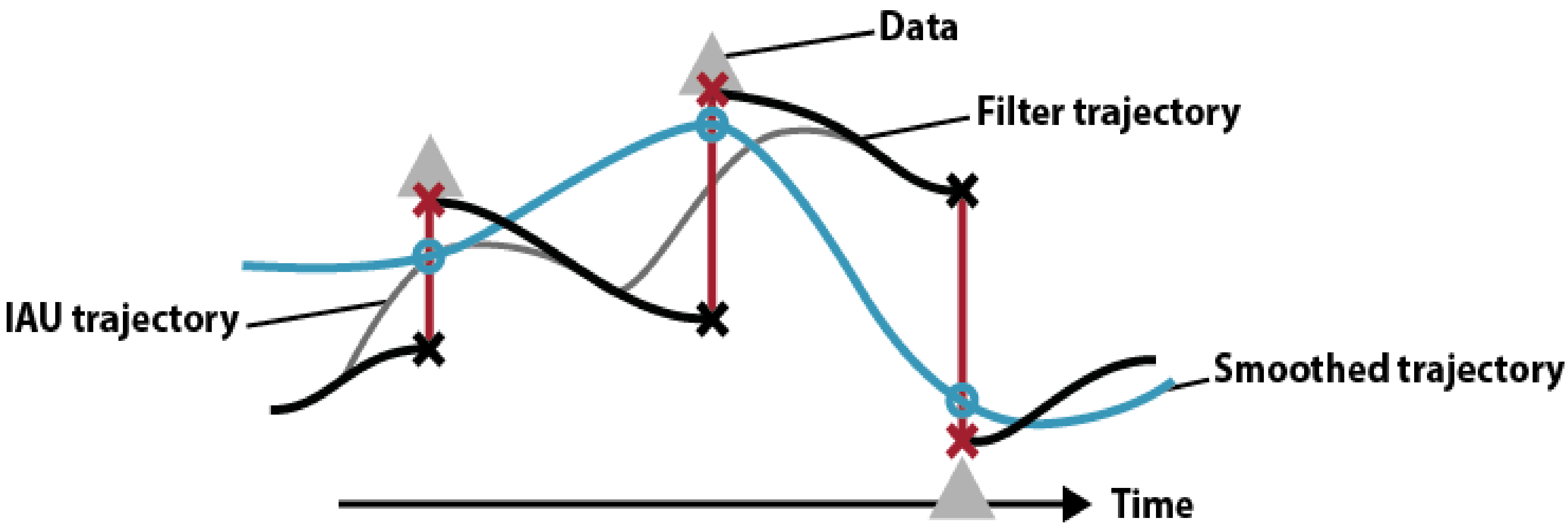
Approaches



Stammer et al., 2016

Ocean Reanalyses Intercomparison Project (Balmaseda et al. 2015)

Product	Institution	Configuration	Control method	Reference
ARMOR3D	CLS	**1/3° product (T/S)**	OI (T/S/SST)	Guinehut et al (2012) & Mulet et al (2012)
CFSR	NOAA NCEP	1/2° MOM4 coupled	3DVAR (T)	Saha et al (2010)
C-GLORS05V3	CMCC	1/2° NEMO3.2	3DVAR (SLA/T/S/SST/Ice)	Storto et al (2011)
ECCO-NRT	JPL/NASA	1° MITgcm	KF-KS (SLA/T)	Fukumori et al. (2002)
ECCO-v4	MIT/AER/JPL	0.4-1° MITgcm	4DVAR (SLA/SSH/T/S/SST)	Wunsch & Heimbach (2013); Speer and Forget (2013)
EN3 v2a	UK Met Office	**1° product (T/S)**	OI (T/S)	Ingleby & Huddleston (2007)
GECCO2	Hambourg University	1x1/3° MITgcm	4DVAR (SLA/T/S/SST)	
ECDA	GFDL/NOAA	1/3° MOM4 coupled	EnKF (T/S/SST)	Zhang et al (2007) & Chang et al (2013)
GloSea5	UK Met Office	1/4° NEMO3.2	3DVAR (SLA/T/S/SST/ice)	
MERRA Ocean	GSFC/NASA/GMAO	1/2° MOM4	EnOI (SLA/T/S/SST/ice)	
GODAS	NOAA NCEP	1°x1/3° MOM3	3DVAR (SLA/T)	Behringer (2007)
G2V3	Mercator Océan	1/4° NEMO3.1	KF+3DVAR (SLA/T/S/SST/ice)	
K7-ODA	JAMSTEC/RIGC	1° MOM3	4DVAR (SLA/T/S/SST)	Masuda et al (2010)
K7-CDA	JAMSTEC/DrC	1° MOM3 coupled	4DVAR (SLA/SST)	Sugiura et al (2008)
LEGOS	LEGOS	**1/4° product (SL)**	OI+EOF (SLA/SSH)	Meyssignac et al (2012)
NODC	NODC/NOAA	**1° product (T/S)**	OI (T/S)	Levitus et al (2012)
PEODAS	CAWCR (BoM)	1°x2° MOM2	EnKF (T/S/SST)	Yin et al (2011)
ORAS4	ECMWF	1° NEMO3	3DVAR (SLA/T/S/SST)	Balmaseda et al (2013) & Mogensen et al (2012)
MOVE-C	MRI/JMA	0.3-1° MRI.COM2 coupled	3DVAR (SLA/T/S/SST)	Fuji et al (2009)
MOVE-G2	MRI/JMA	0.3°-1° MRI.COM3	3DVAR (SLA/T/S/SST)	Toyoda et al (2013)
MOVE-CORE	MRI/JMA	0.3°-1° MRI.COM3	3DVAR (T/S)	Tsujino et al (2011) & Danabasoglu et al (2013)
SODA	University of Maryland and Texas A&M University	0.4x1/4° POP2.1	OI (T/S/SST)	Carton & Giese (2008)
UR025.4	University of Reading	1/4° NEMO3.2	OI (SLA/T/S/SST)	Haines et al (2012)
SLCCI	ESA	**1/4° product (SL)**	OI (SLA)	

CLIVAR Exchanges 64 (2014) and special issue of Clim.Dyn.

- Ocean heat content *(Palmer et al 2014)*
- Sea level *(Hernandez et al 2014)*
- Steric sea level *(Storto et al 2014, 2015)*
- Surface heat fluxes *(Valdivieso et al 2014)* and transports
- Mixed layer depth *(Toyoda et al 2014, 2015)*
- Salinity *(Alves et al 2014)*
- Depth of 20°C isotherm *(Hernandez et al 2014)*
- Sea ice *(Smith et al 2014)*
- AMOC

These variables will be available through http://icdc.zmaw.de/

Monthly global steric sea level

Storto et al., 2015

rify- ing dataset for the full signal (COR), the seasonal signal (COR S
i.e. interannual signal removed) and the inter-annual signal (COR I
i.e. seasonal signal removed) is also shown

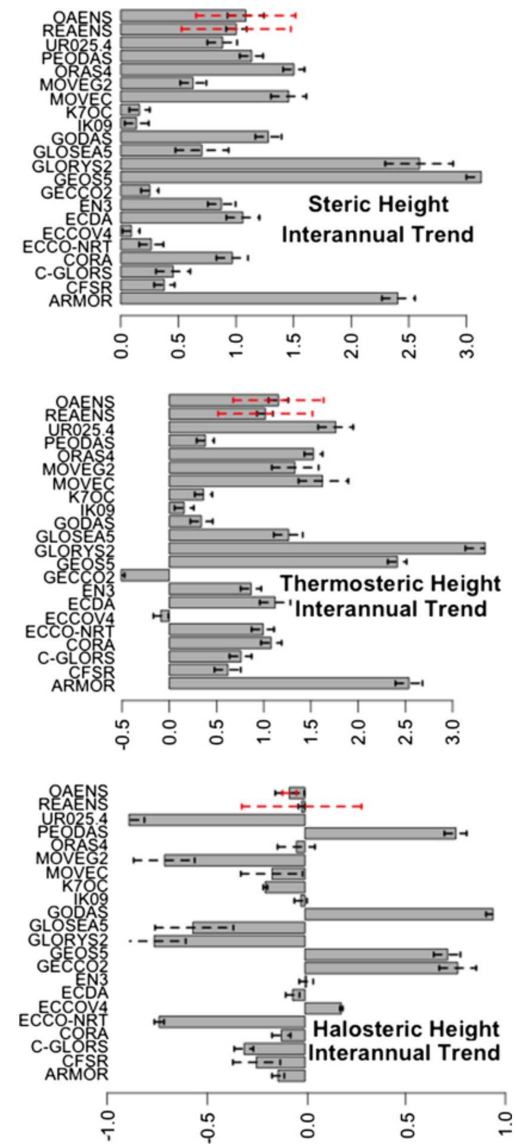
1993-2010

line trends

total

thermosteric

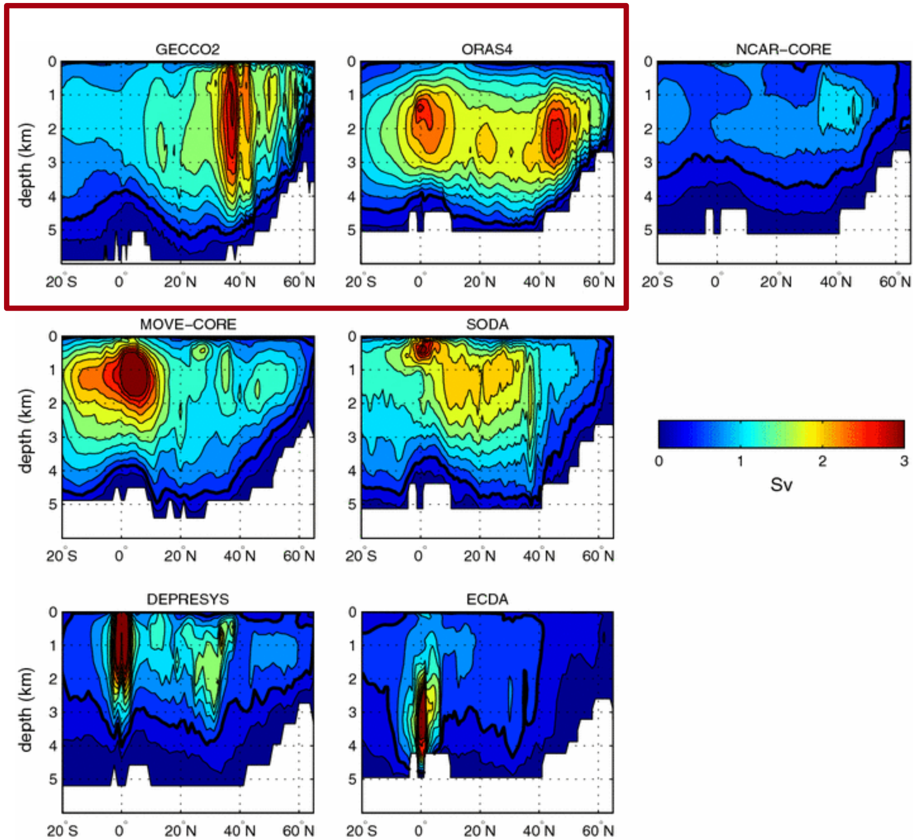
halosteric



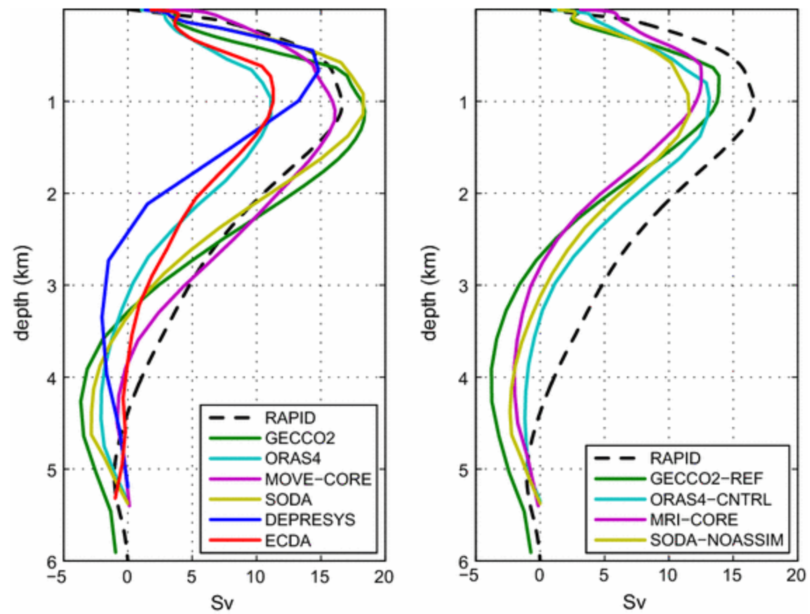
r^{-1}

Fig. 8 Global sea level linear trends (1993–2010) from all the products, the ensemble mean of reanalyses (REANS) and objective analyses (OAENS) for the steric (*top panel*), thermosteric (*middle panel*) and halosteric (*bottom panel*) sea level, with the 95 % confidence level calculated using a bootstrap algorithm. Units are mm year^{-1}

Comparison of the AMOC in ocean reanalysis products by *Karspeck et al 2015*



STD of the annual-mean, linearly detrended stream function from 1960 to 2007



Depth profiles of the time-mean AMOC at 26.5°N during 2005–2014

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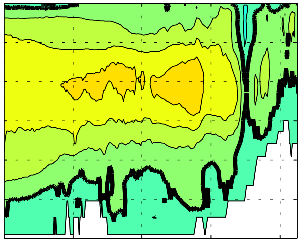
AMOC Estimates:

Linear Trends



Karspeck et al., 2015

se) circulation trends. Bold line is

the zero contour. Contour interval is 0.5 Sv/decade.

Coupled data assimilation procedure

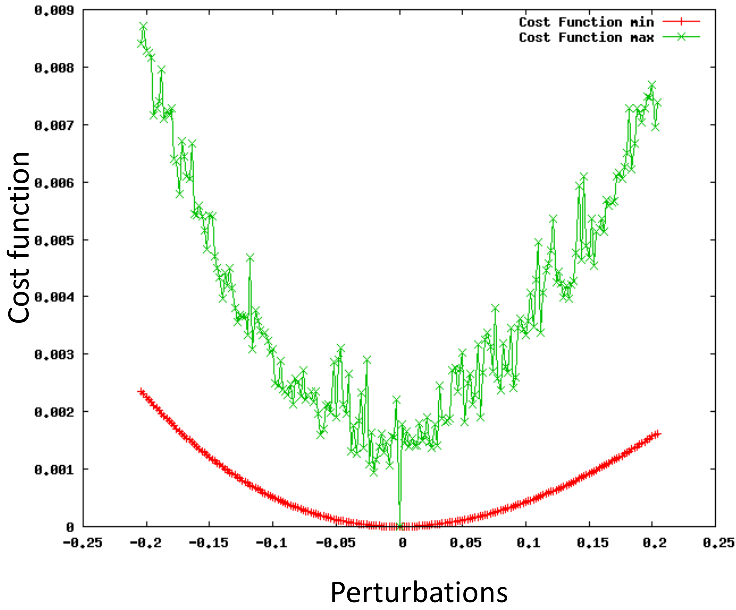
- Coupled data assimilation (CDA) has a potential for
  - reducing coupling shock and providing balanced initial conditions *(examples: Mulholland et al 2015)*
  - reducing model drift by optimizing model parameters through parameter estimation *(examples: Liu et al 2014)*

- CDA is still in the early stage of development *(Stammer et al 2016, Haines 2011)*

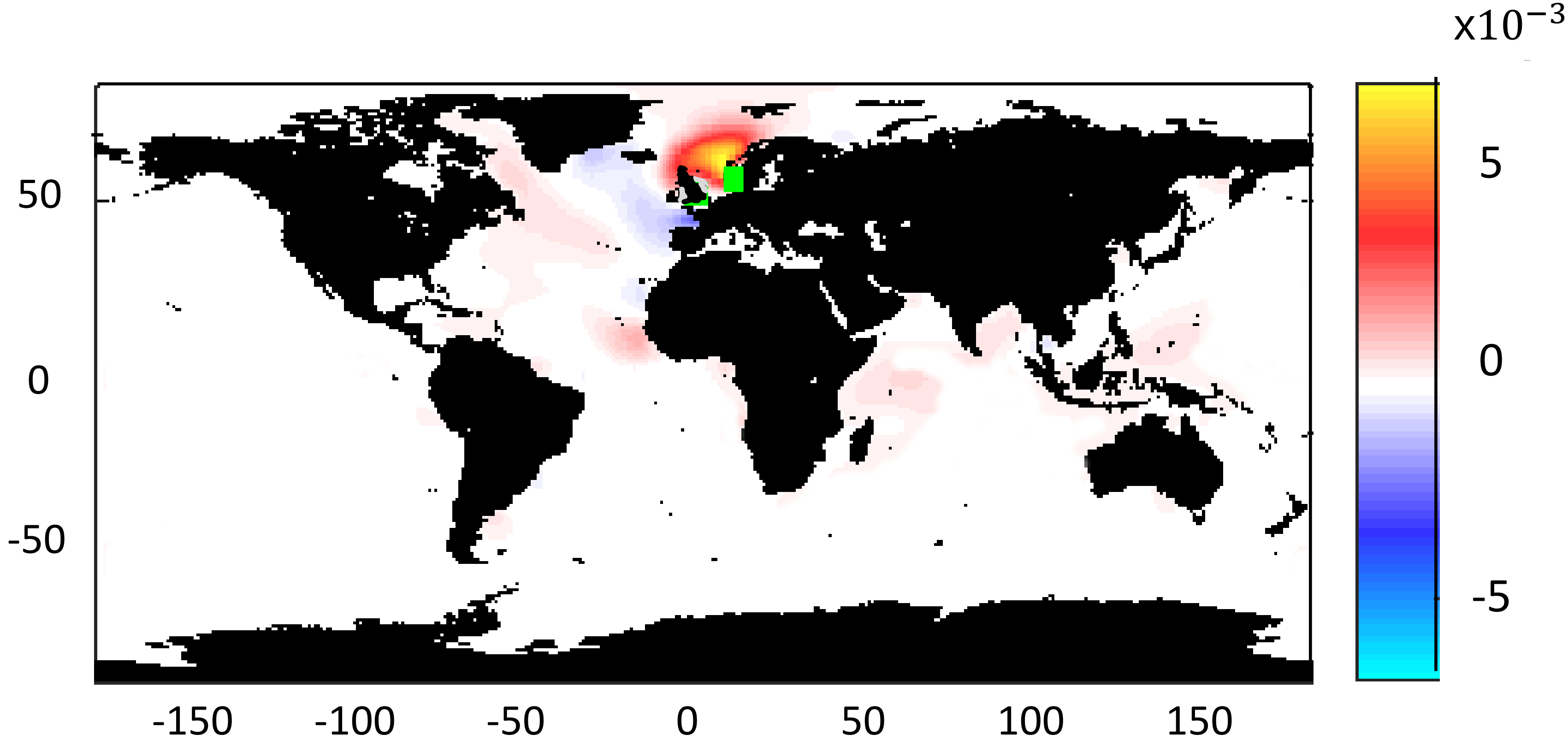
- First CDA products:
  - 4 CDA products (based on 3D-VAR, 4D-VAR and EnKF) are considered in the Ocean Reanalyses Intercomparison Project *(Balmaseda et al. 2015)*
  - Recent CDA product from ECMWF *(CERA based on incremental 4D-VAR; Laloyaux et al 2015)*

Toward coupled data assimilation product

- The CEN Earth System Assimilation Model is a numerical Earth System Model built by coupling MITgcm to Plasim.
- Adjoint of the CESAM generated through automatic differentiation of the model's source code by TAF *(Blessing et al 2014).*
- Challenges:
  - nonlinearity of the climate system limits the length of the assimilation window.
- Currently, sensitivity studies are on its way.

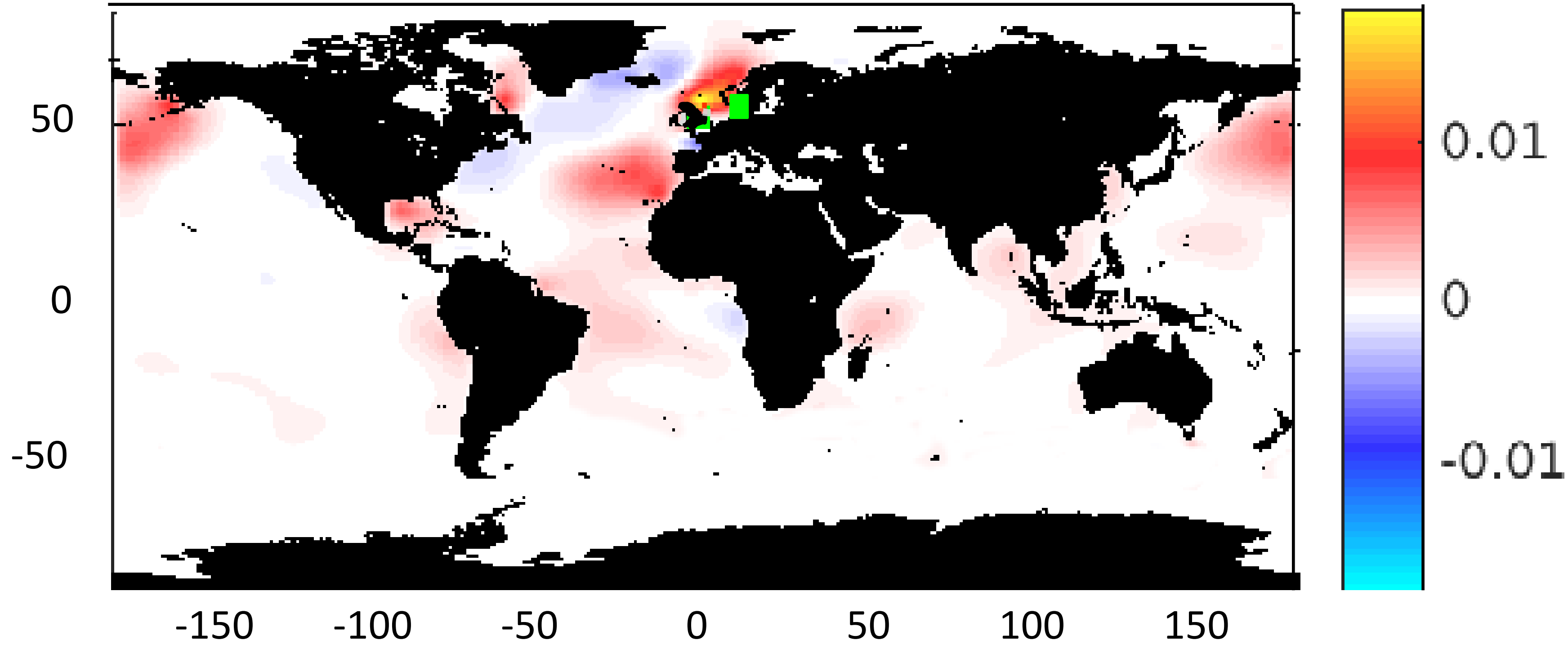


NLT sensitivity to SST (kinematic phase)



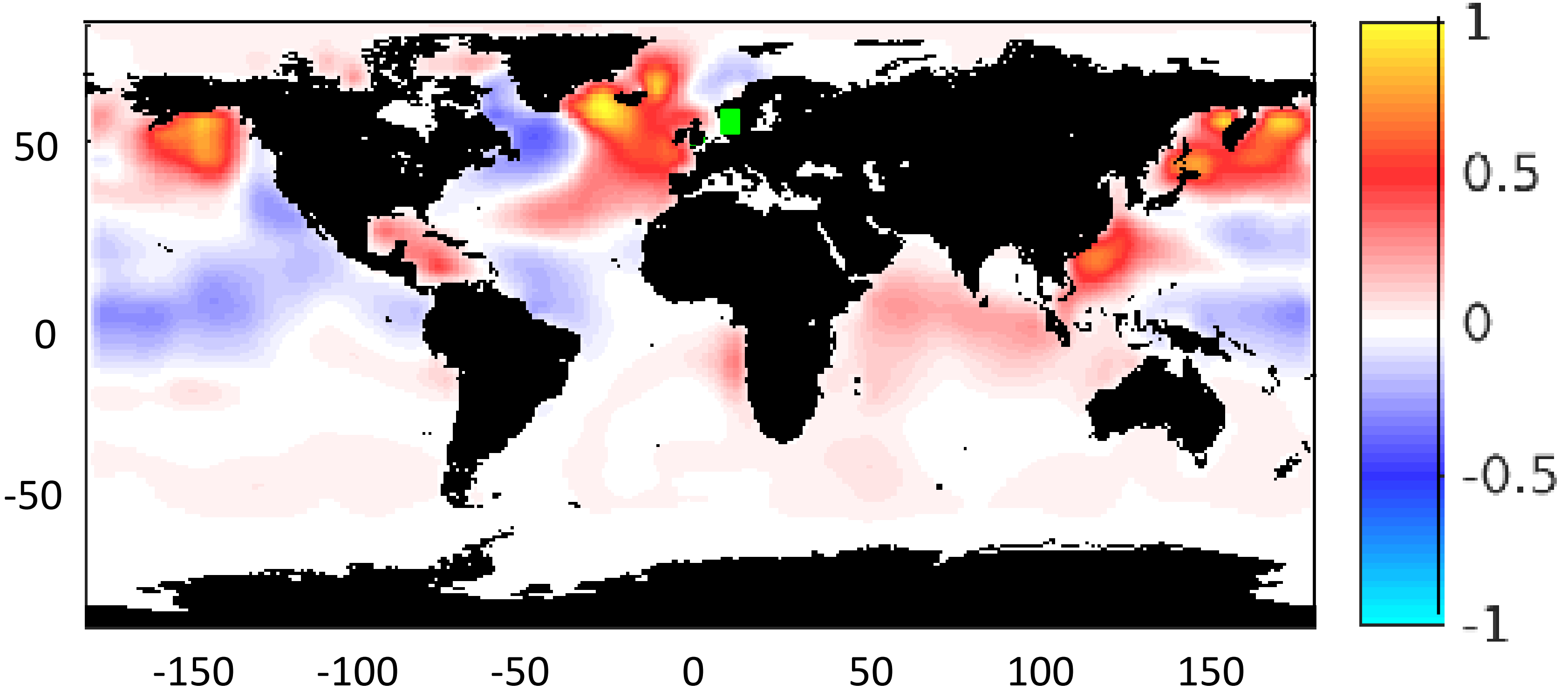
The 5 member-ensemble mean of averaged sensitivity of the near land air temperature over Northern Europe to SST (between days 3-5) of backward integration. The air temperature is the mean over the last day.

NLT sensitivity to SST(intermediate phase)



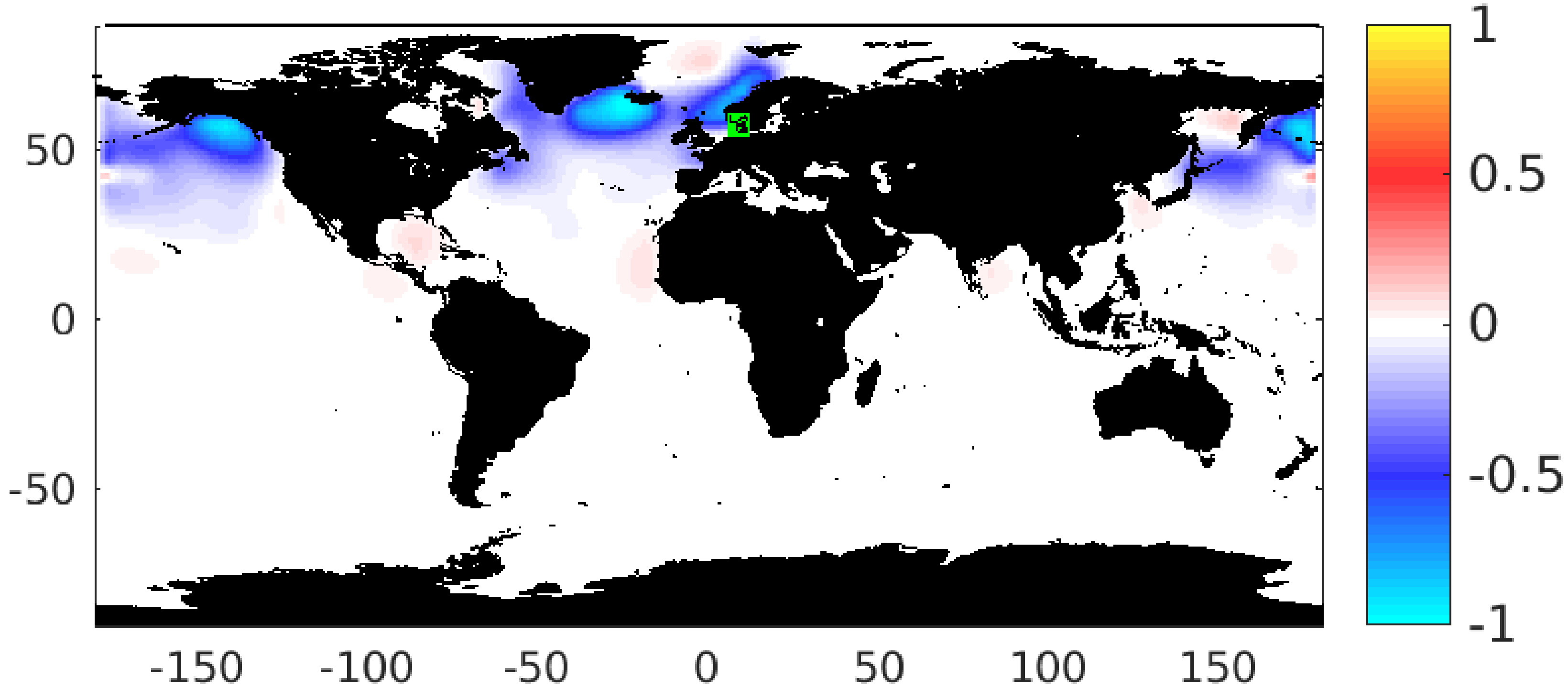
The 5 member-ensemble mean of averaged sensitivity of the near land air temperature over Nothern Europe to SST (between days 13-15) of backward integration. The air temperature is the mean over the last day.

NLT sensitivity to SST(dynamic phase)



The 5 member-ensemble mean of averaged sensitivity of the near land air temperature over Northern Europe to SST (between days 33-35) of backward integration. The air temperature is the mean over the last day.

SSS sensitivity



The 5 member-ensemble mean of averaged sensitivity of the near land air temperature over Northern Europe to SSS (between days 33-35) of backward integration. The air temperature is the mean over the last day.

Summary and Conclusion

- Initializing climate predictions with ocean observations is essential for skillful predictions.
- Requires ocean observations on a regular basis. Not only the most recent data are important, but actually a sustained system.
- Initial conditions from other climate components gain attention as well.
- We need to improve the way we use existing observations through model improvements; can involve flux corrections.
- Ocean/climate observations are essential for model improvements through parameter estimation and this fact will need to be further explored.