Ocean in-situ observations and ECMWF forecasts

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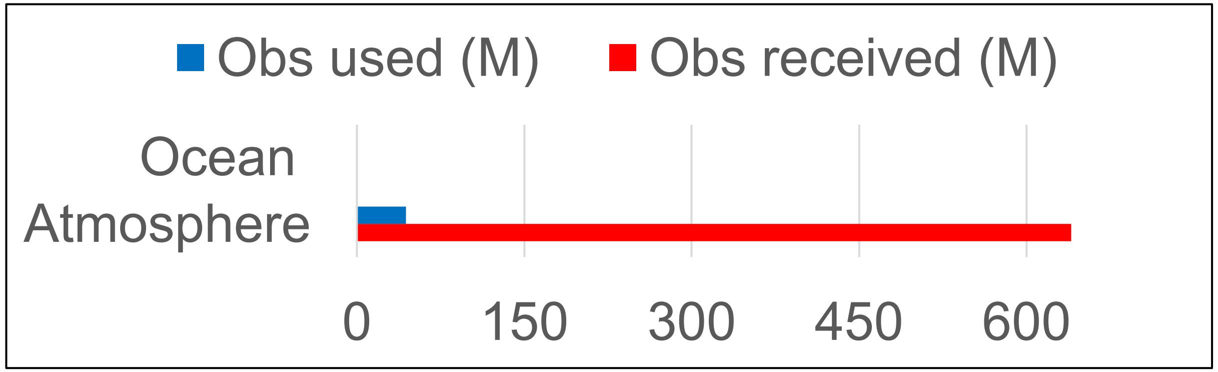
ECMWF

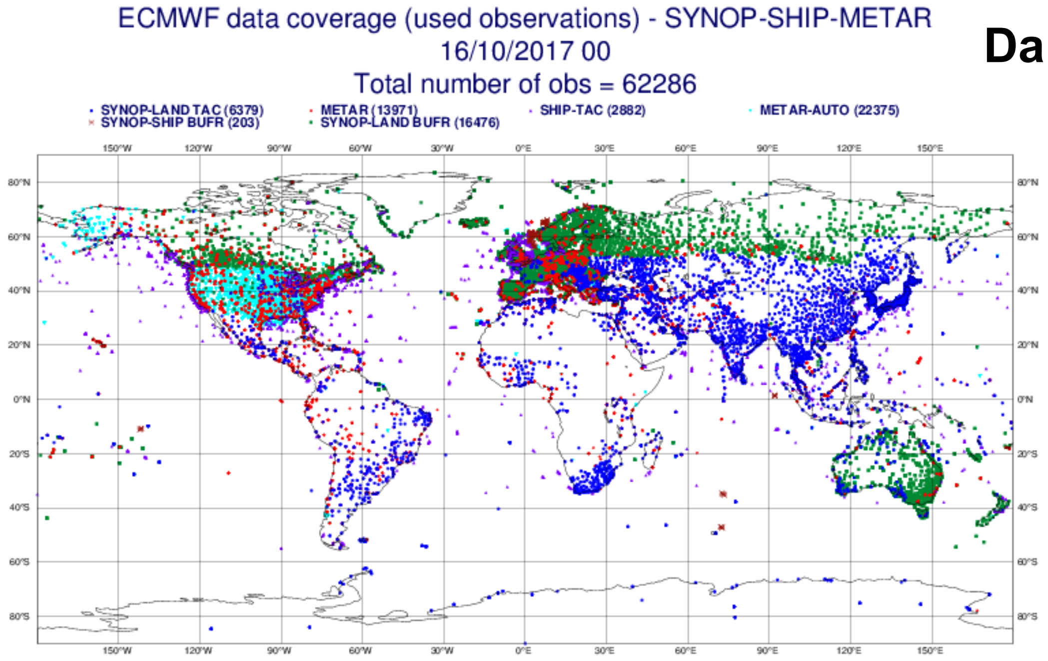
Why do we do ocean data assimilation

- **Forecasting: initialization of coupled models**
  - NWP, monthly, seasonal, decadal
  - Seasonal forecasts need calibration
- **Towards coupled DA system (weakly -> quasi-strong -> strong …)**
- **Climate application: reconstruct & monitor the ocean *(re-analysis)***
- ***Verification/evaluation/co-design of Global Ocean observing network (OSE/OSSE)***
- **Other applications**
  - Commercial applications (oil rigs, ship route …), safety and rescue, environmental (algii blooms, spills)

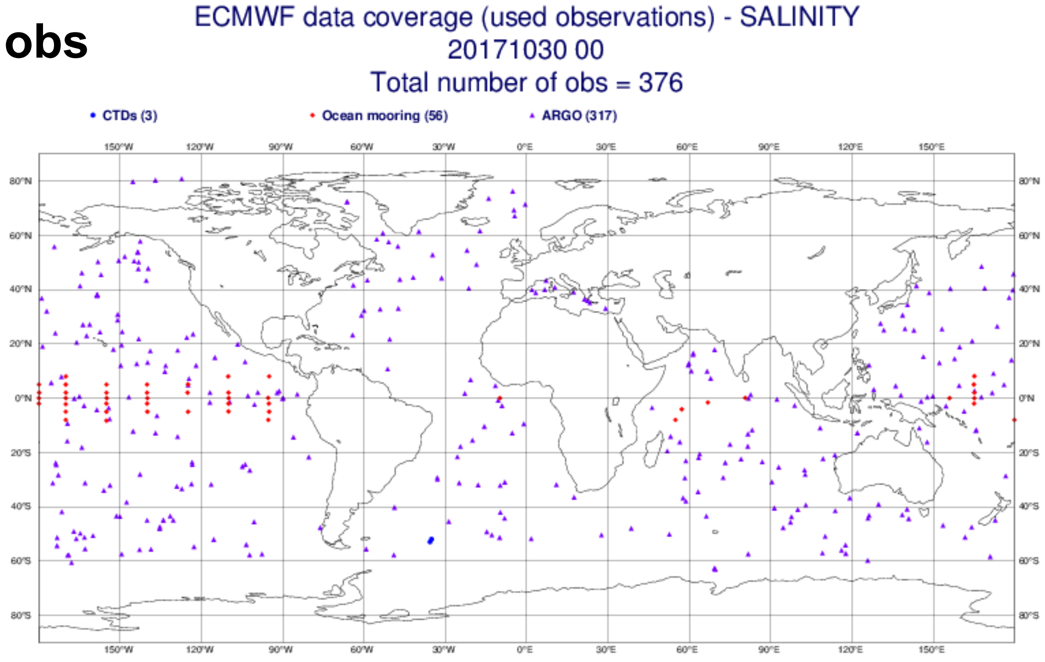
Ocean is a data sparse system



Ocean observation is about 1/1000 to 1/10000 smaller than Atmospheric observation

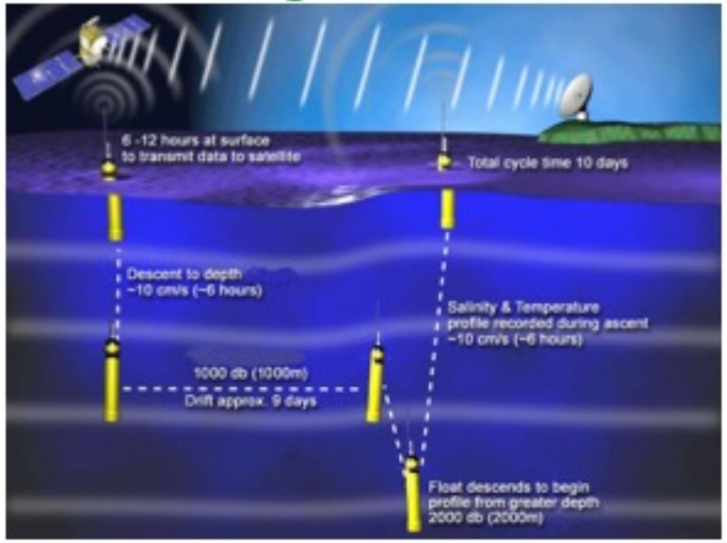


Daily obs



Ocean in-situ observations

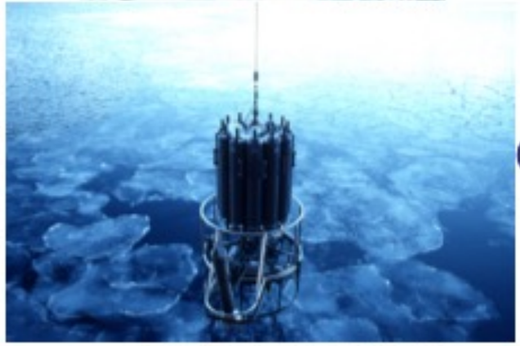
Argo floats



Argo operational cycle.
[Argo 2018]

Ship based observations

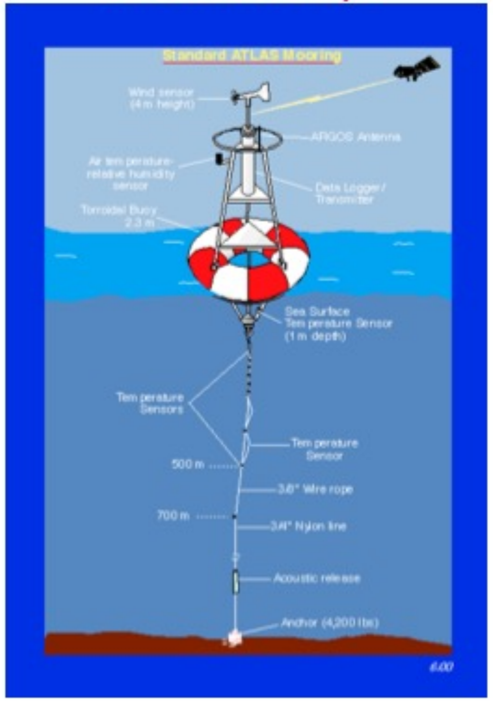
XBT



CDT

[CSIRO 2001]

Moored buoys



[PMEL 2018]

Mammals!

[MEOP et al. 2015]

New observations types are emerging: gliders, Deep Argo, BioArgo, drifter, saildrone …

Saildrone mission to the Gulf Stream

Video credit
@saildrone

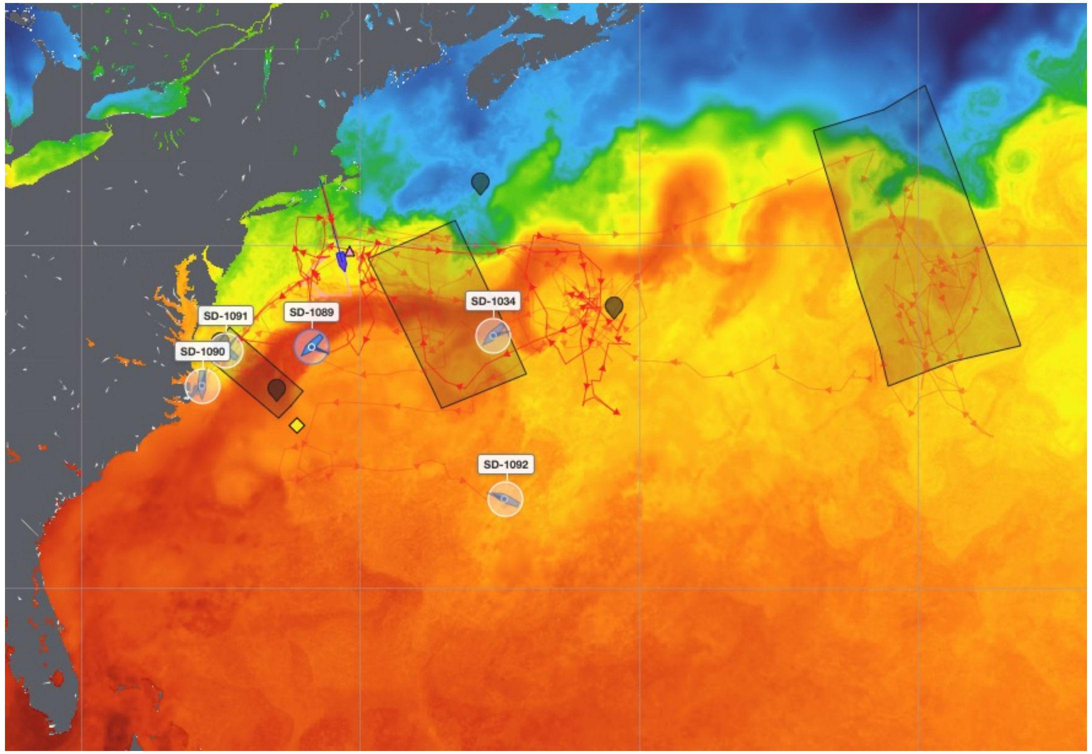
Funded by Google.org Impact Challenge for Climate

Collaboration with University of Rhode Island

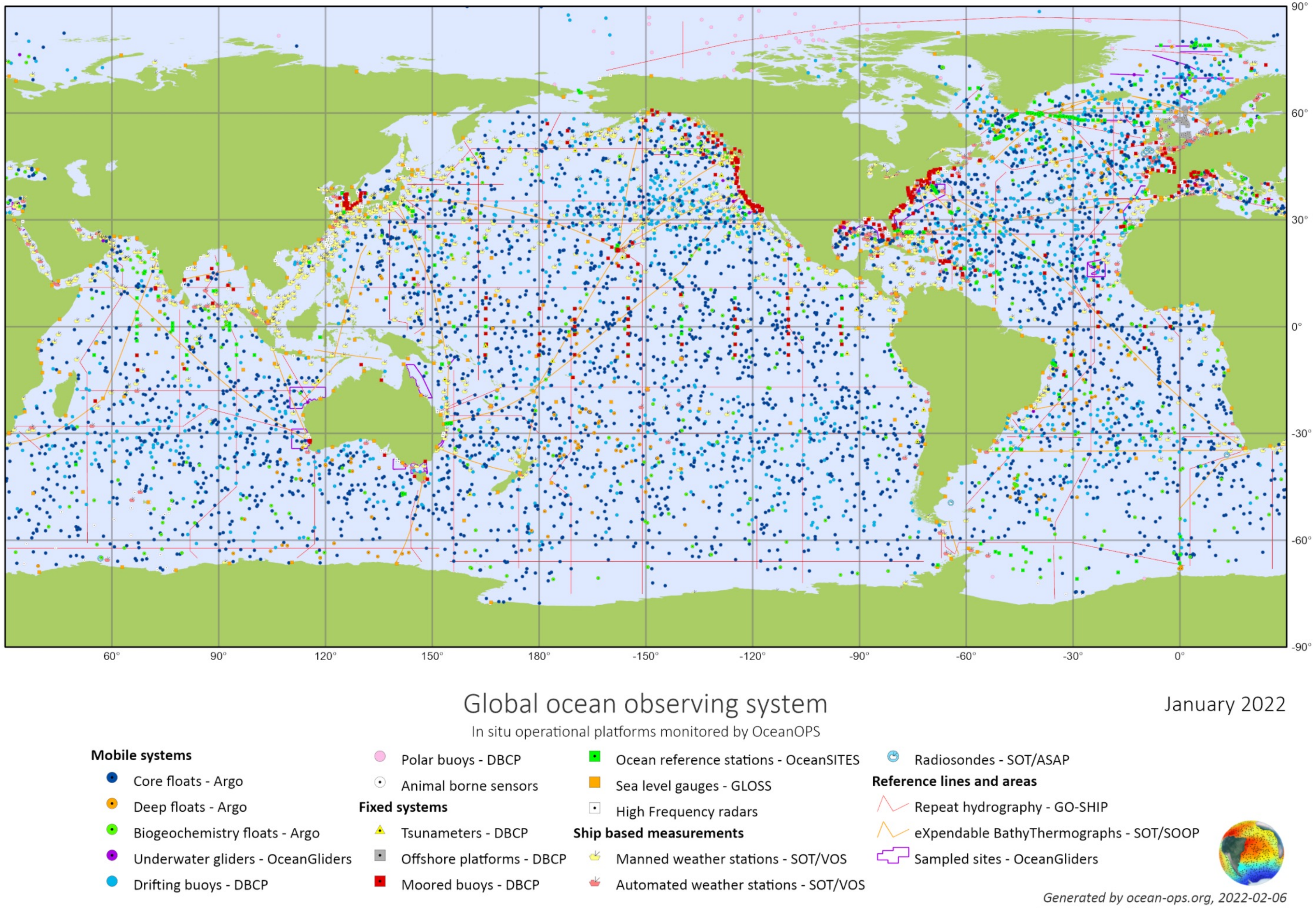
- their main interest is carbon fluxes

Goals:

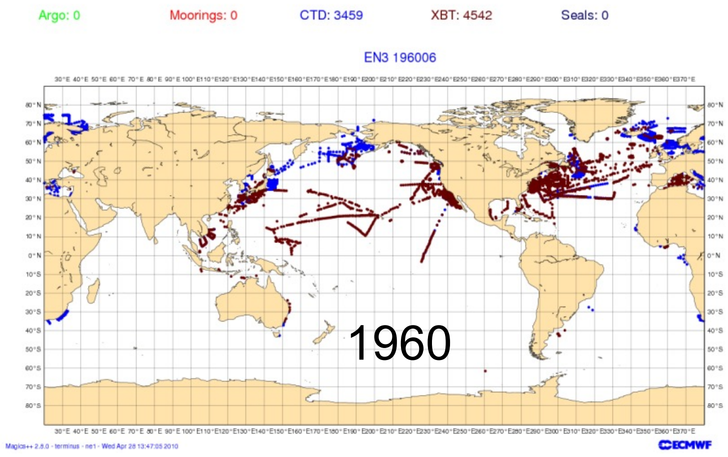
- Can we have USVs in the GS over the winter?
- Can we identify sources of biases in the ¼ degree model used at ECMWF?
- Provide a new community dataset for open use

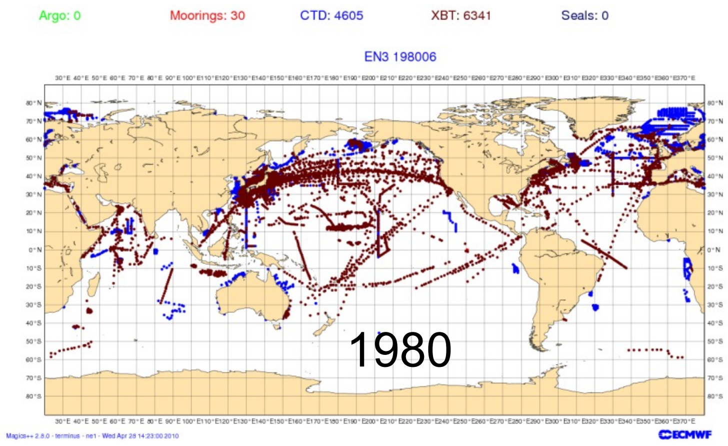


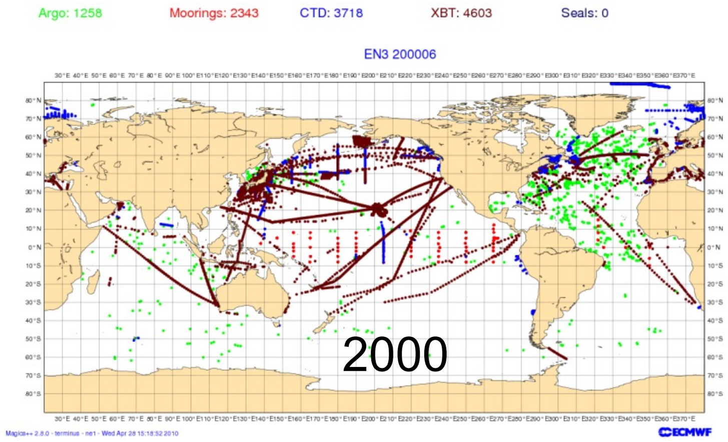
The Global Ocean Observing System (GOOS)

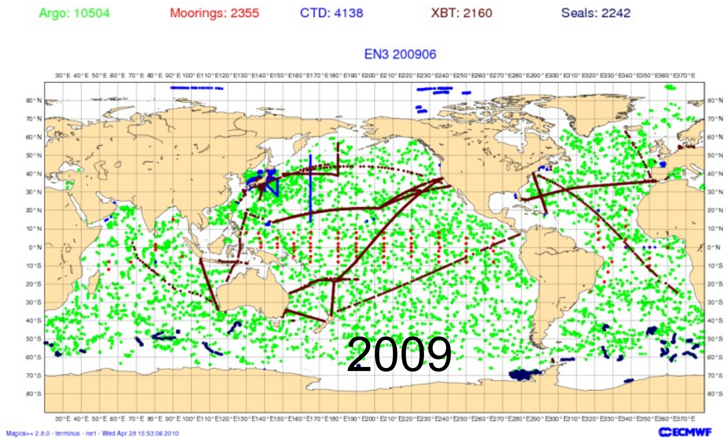


Temporal evolution of GOOS









- Very uneven distribution of observations.
- Southern ocean poorly observed until ARGO period.

Use of in-situ observations: data assimilation

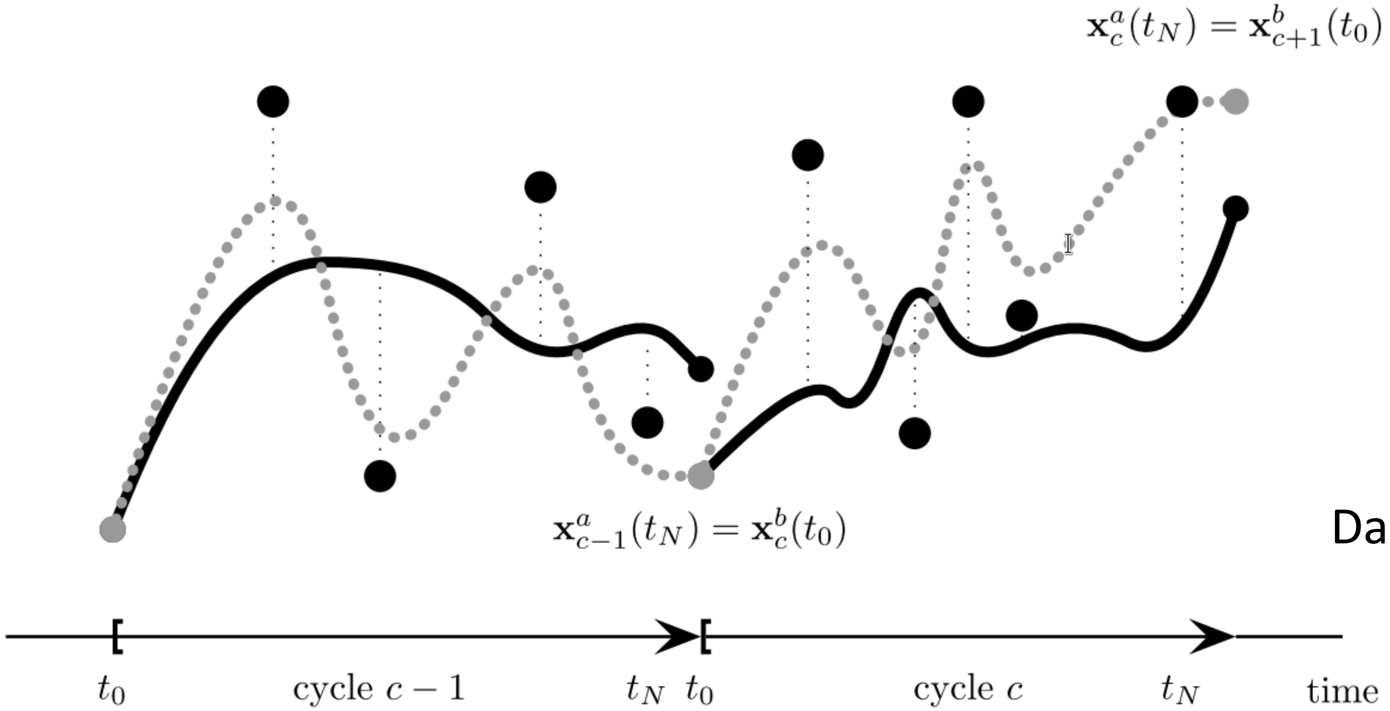
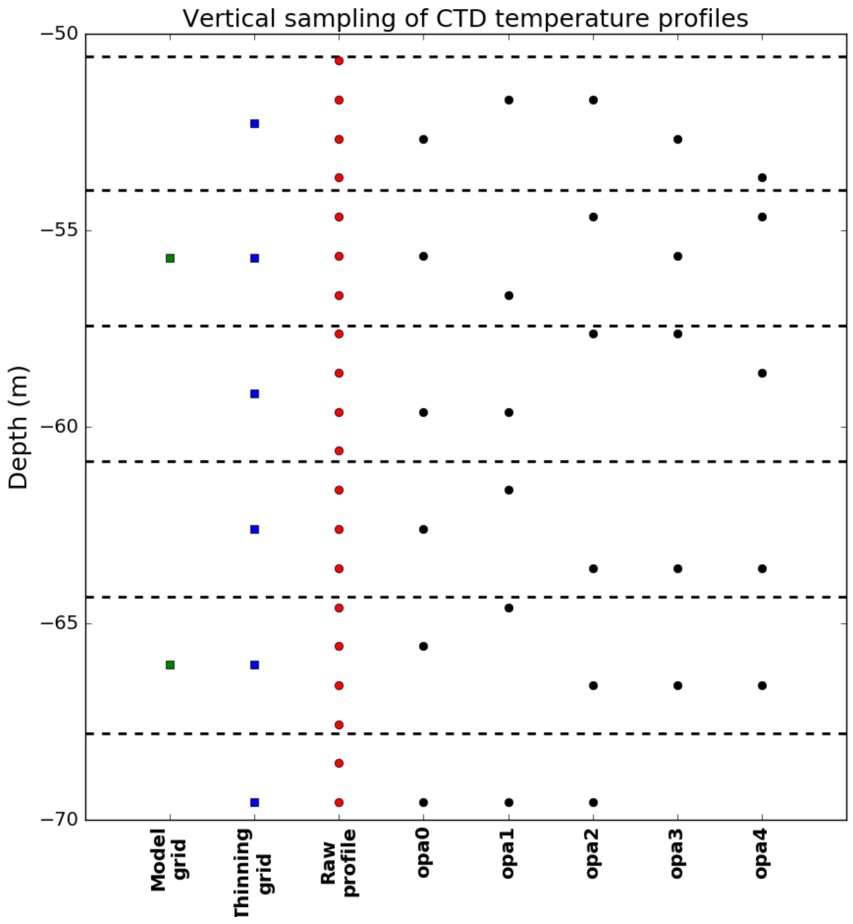


Figure 1: Schematic illustration of the procedure used to cycle 3D-Var. On each cycle c, the model is integrated from t_0 to t_N starting from a background initial condition $\mathbf{x}_c^b(t_0)$ (grey dots) to produce the background trajectory $\mathbf{x}_c^b(t_i)$ (black solid curve). The difference between the observations $\mathbf{y}_{c,i}^o$ (black dots) and their background counterpart ($\mathbf{H}_{c,i}\mathbf{x}_c^b(t_i)$) is computed (represented by the vertical thin dotted lines) for use in the 3D-Var FGAT minimization. After minimization, the model integration is repeated from the same initial condition ($\mathbf{x}_c^b(t_0)$) but with the analysis increment applied using IAU. This produces the analysis trajectory $\mathbf{x}_c^a(t_i)$ (grey dashed curve). The updated model state $\mathbf{x}_c^a(t_N)$ at the end of cycle c is then used as the background initial condition for the next cycle $c+1$ (grey dots).

Daget et al 2009

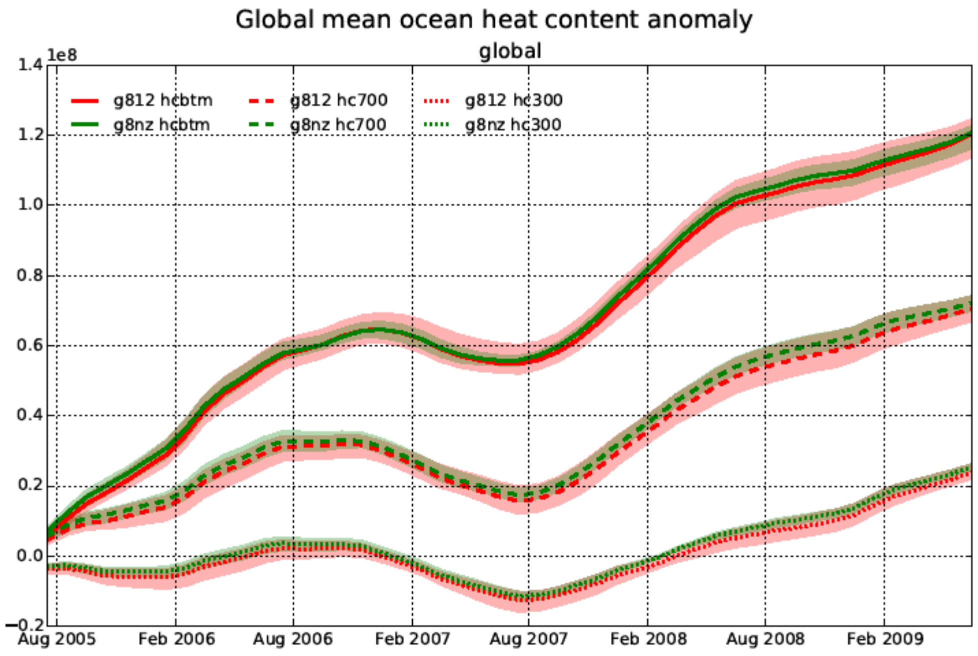
Use of in-situ observations: ensemble generation

In-situ observation profiles can be perturbed to generation ensemble analyses, by perturbing
- location of observations (horizontal + vertical)
- value of observations



+ other obs Pert.

Global Ocean Heat Content changes

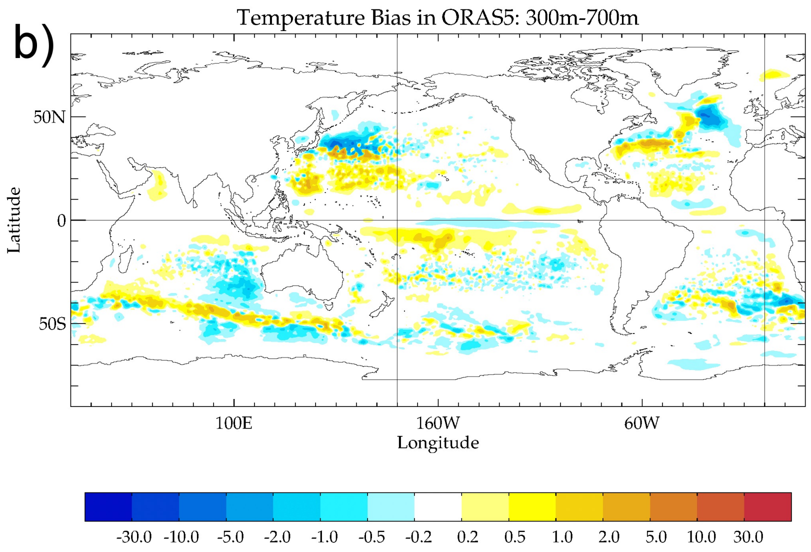


Use of in-situ observations: bias estimation

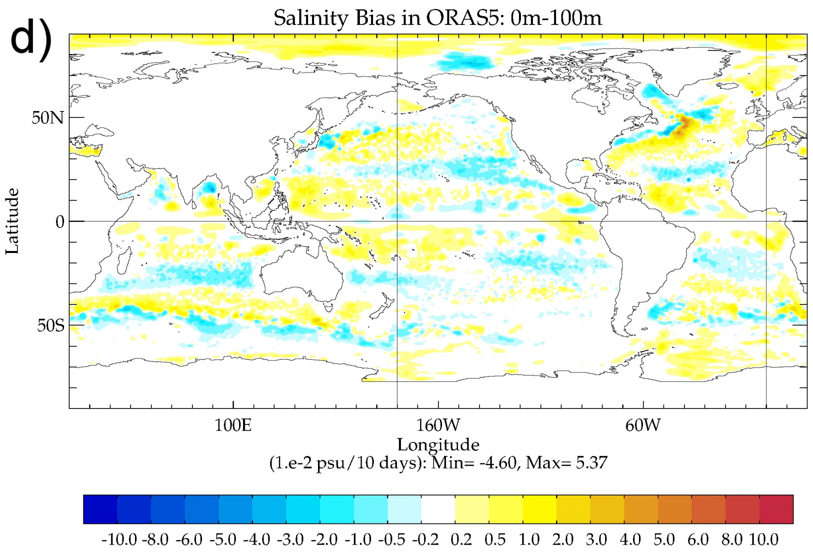
Ensemble-based model-forcing error estimation using in-situ observations and Ocean DA system

- A-priori bias term is estimated with assimilation increment from Argo period
- It is a way of using Argo information retrospectively

Temperature

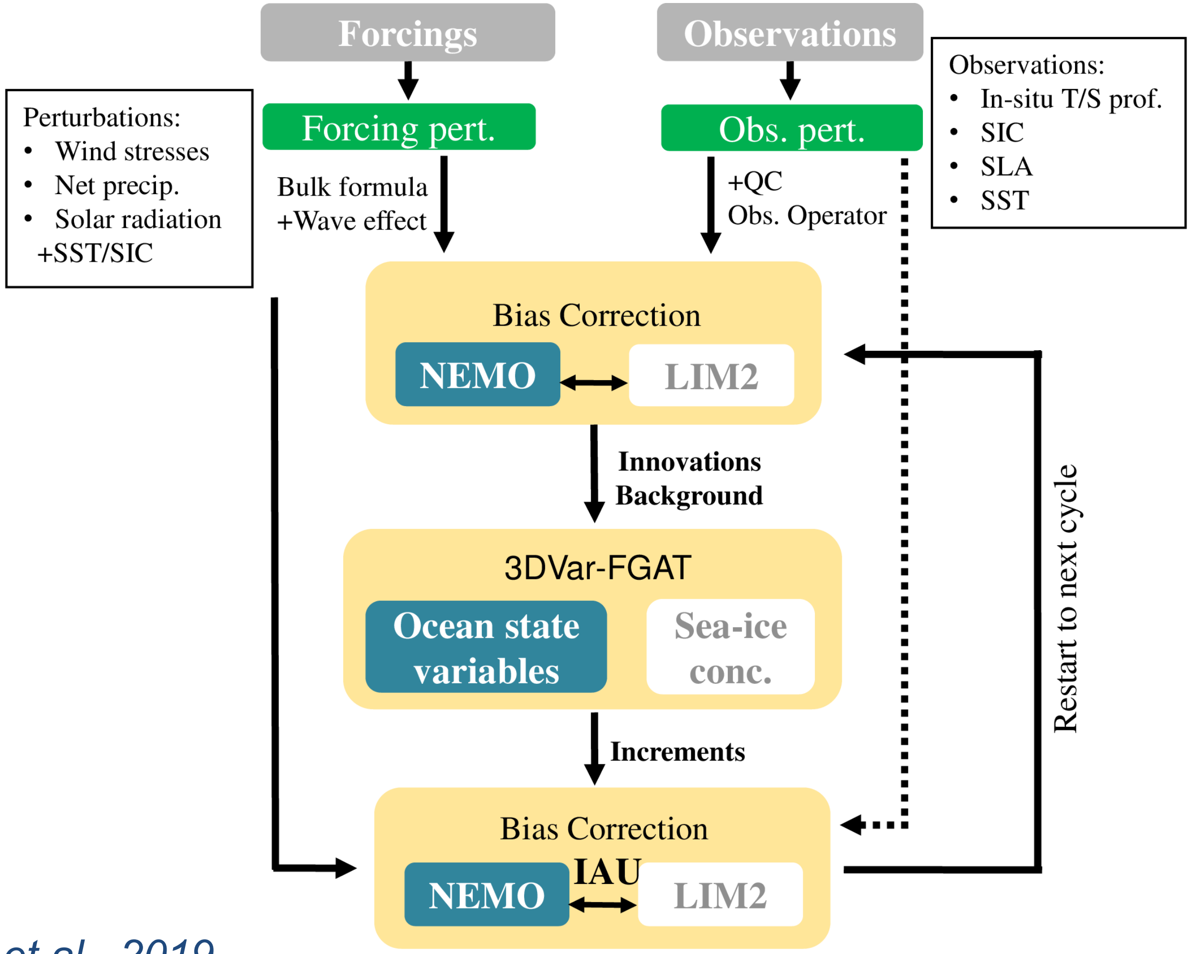


Salinity



Zuo et al., Ocean Science, 2019

ECMWF Ocean DA System



Zuo et al., 2019

Overview of the OCEAN5 setup

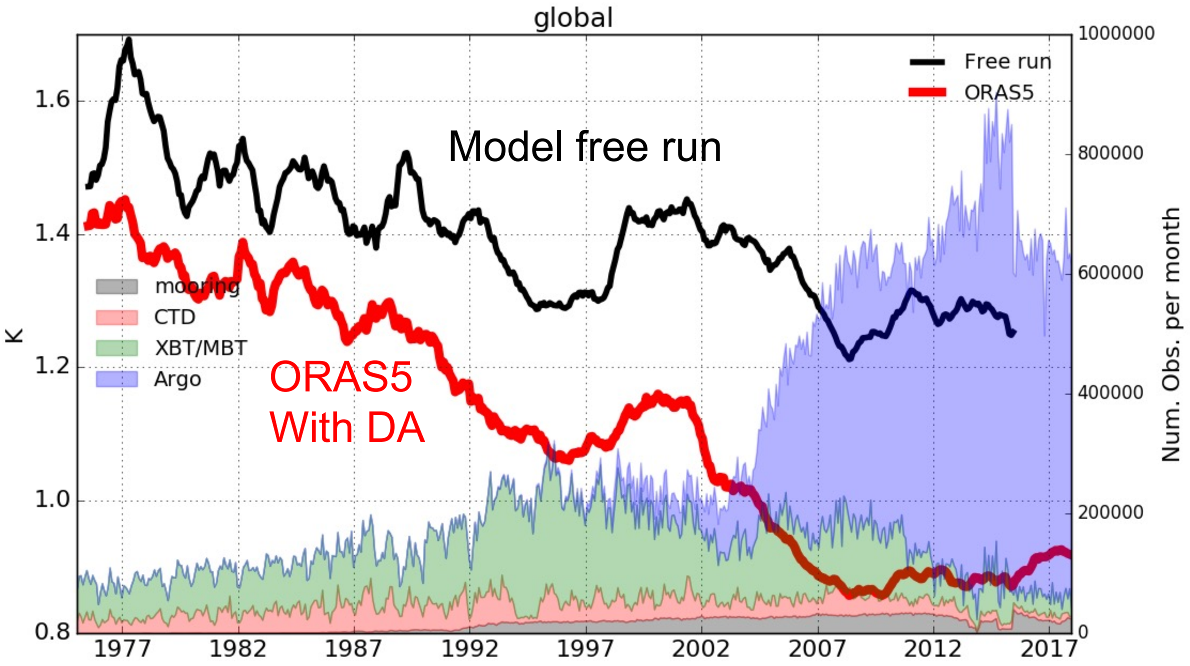
OCEAN5 is the 5th generation of ECMWF ocean and sea-ice ensemble reanalysis-analysis system (Zuo et al., 2018, 2019).

- Ocean: NEMOv3.4
- Sea-ice: LIM2
- Resolution: ¼ degree with 75 levels
- Assimilation: 3DVAR-FGAT
- 5 ensemble members

Observations impact on the ocean state estimation

Temperature RMSE: 0-1000m

~65% of the total RMSE reduction comes from assimilating in-situ data



MRB: moored buoy
OSD: CTD sonde
XBT: Expendable bathythermograph
PFL: Argo float

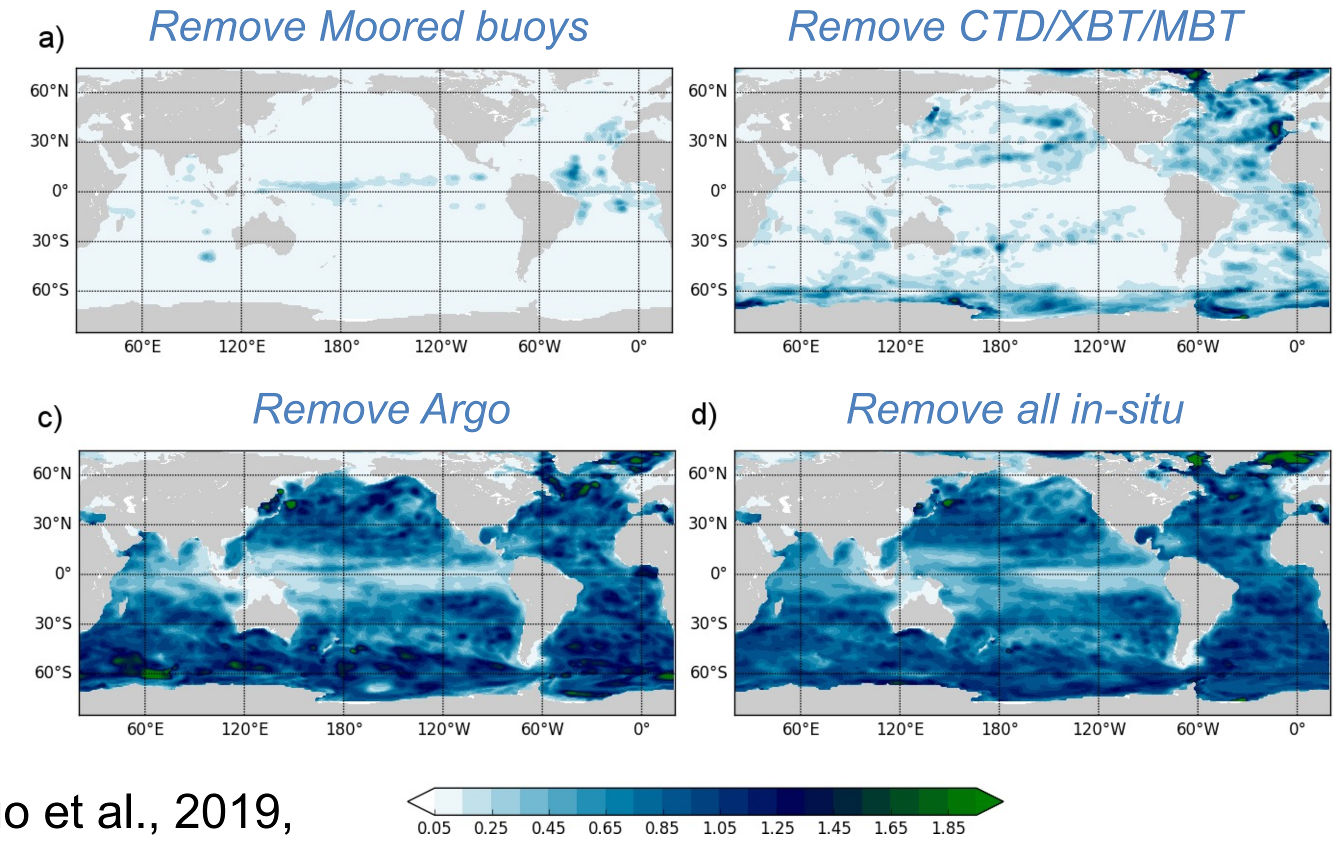
Mean: 2005-2014

	T RMS reduction	S RMS reduction
In-situ	65%	90%
Bias-corr.	14%	10%
SST	18%	negative
Altimeter	3%	neutral

Assimilation of ocean in-situ observations helps to constrain the 3D ocean, therefore providing better estimation of the ocean initial condition for the coupled forecasting system

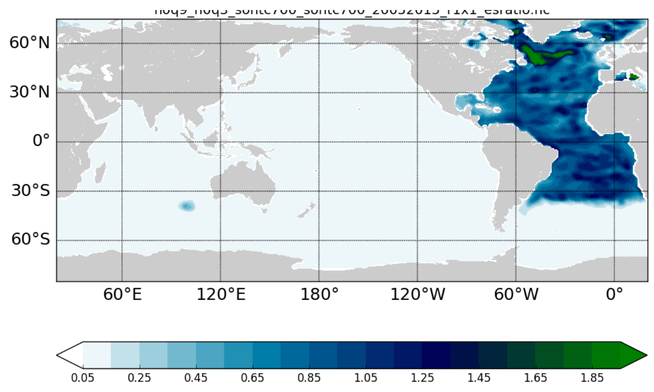
Global OSE with the ECMWF system

Maps of normalized RMSD of Temperature (upper 700m) in OSEs



RMSD w.r.t a reference reanalysis, in which all in-situ data are assimilated.

Remove in-situ only in Atlantic

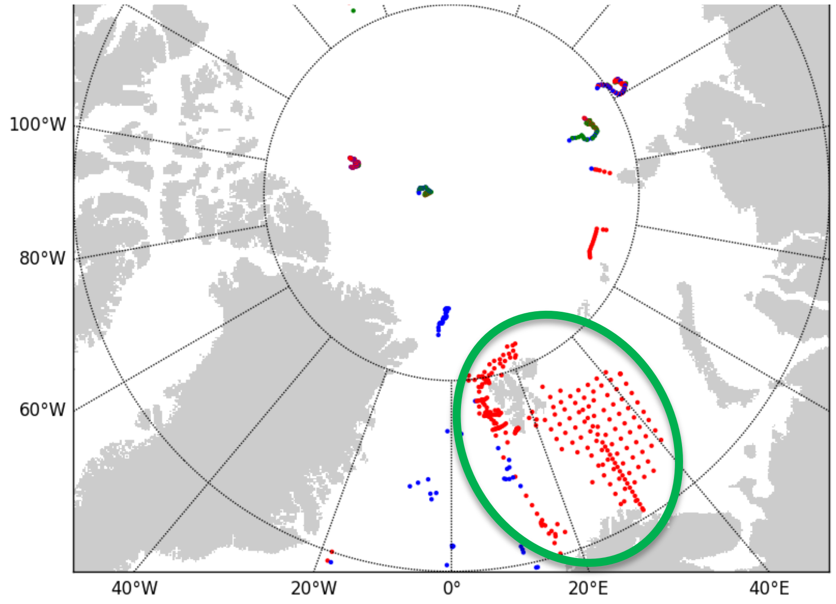


Zuo et al., 2019, Ocean Science

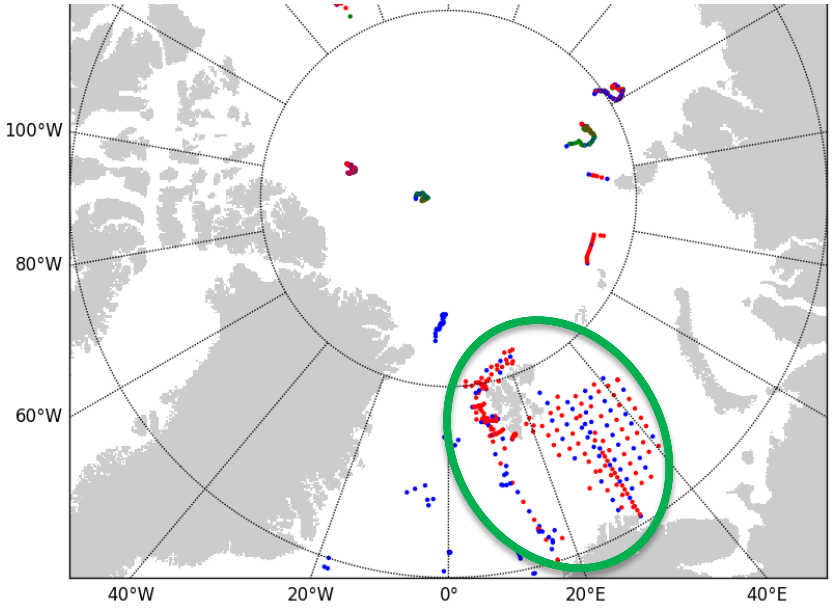
OSE with ECMWF system

From 2000-2012 and focus on the Arctic region (sensitive to the inflow of warm Atlantic Water)

rej500m



rej50m



In-situ observation QC results in the Arctic region when using different shallow water rejection depths: (left) 500m and (right) 50m

OSE with ECMWF system

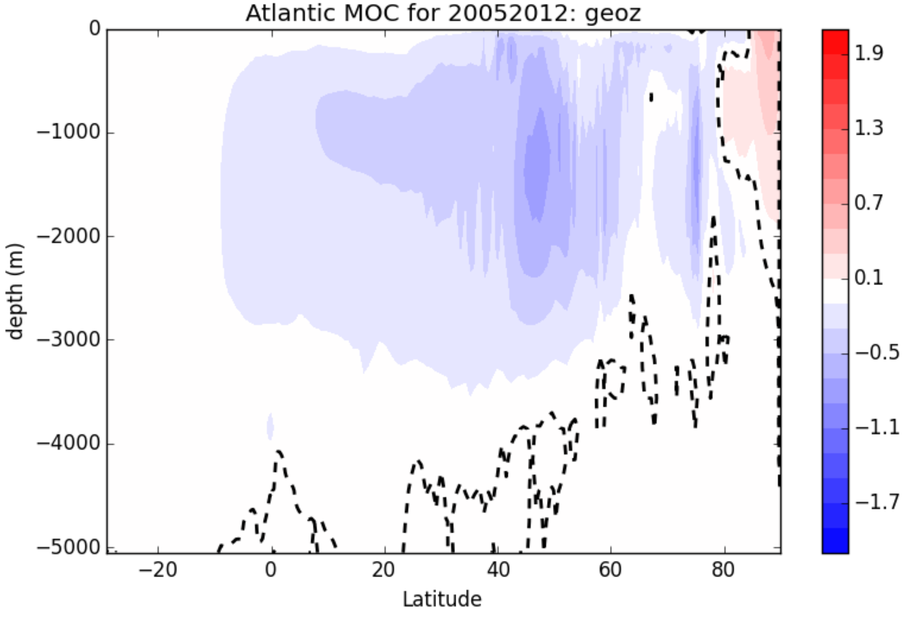
Assimilation of additional in-situ obs in the shallow water area leads to

slows down the AMOC slightly.

Increases the inflow of warm Atlantic water into the Arctic regions

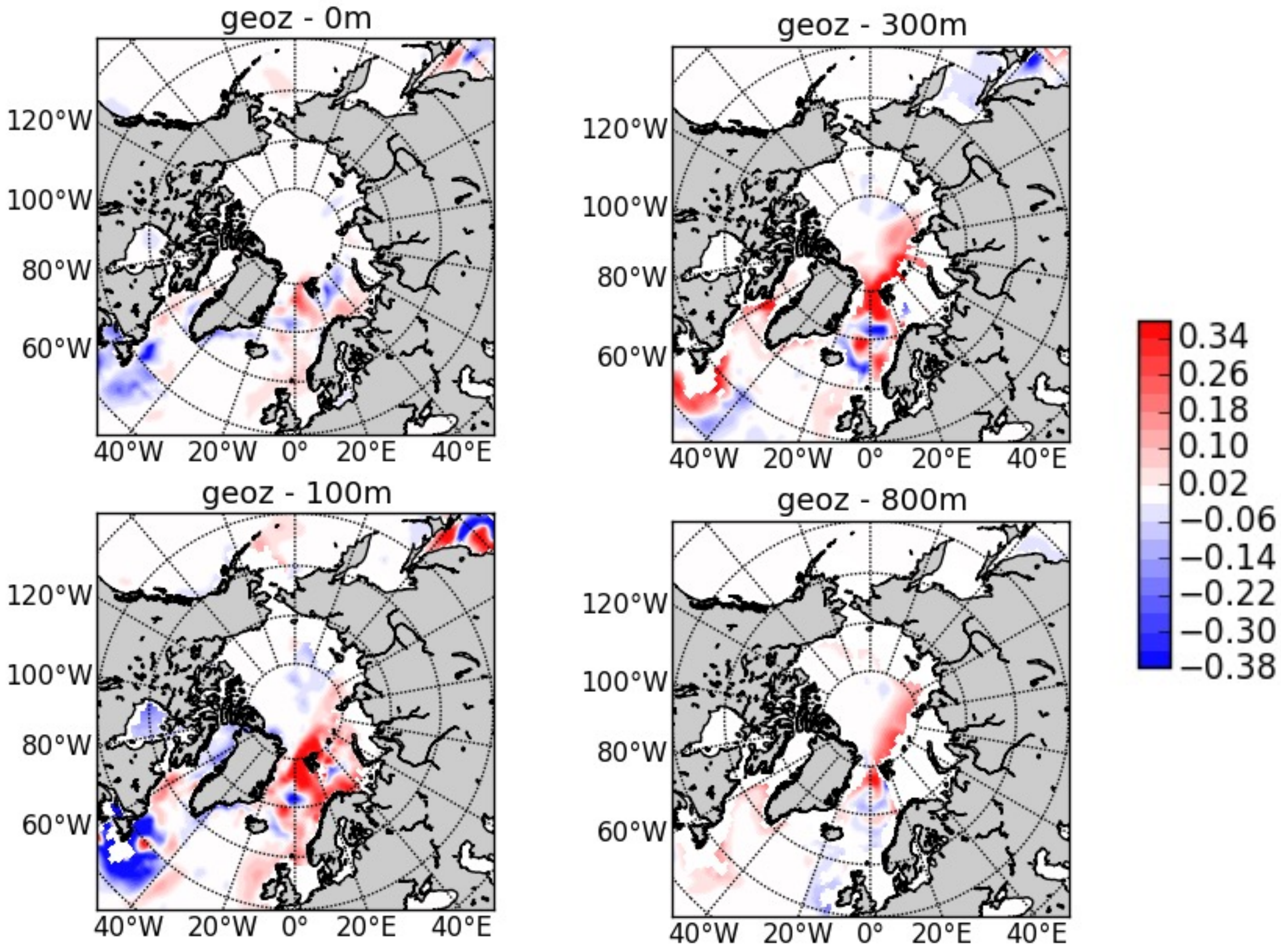
AMOC differences

(2005-2012: rej50m - rej500m)



Temperature differences

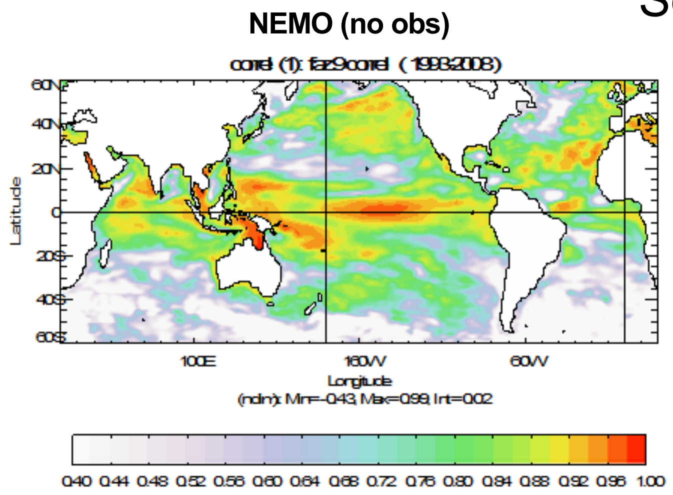
(2005-2012: with – without shallow water obs)

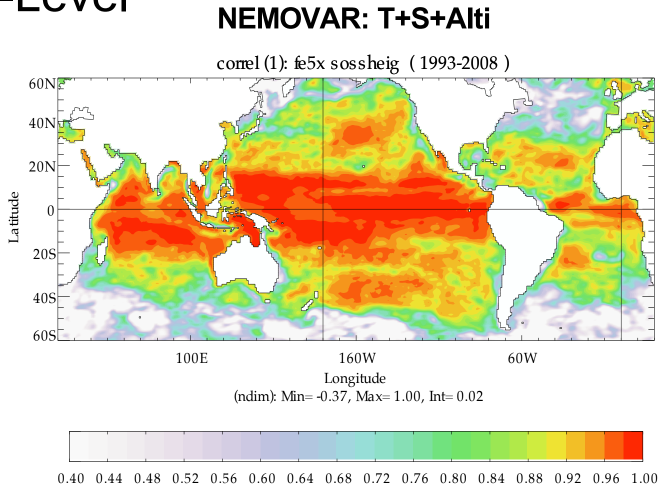


Impact on NWP: initialization the coupled forecasting system

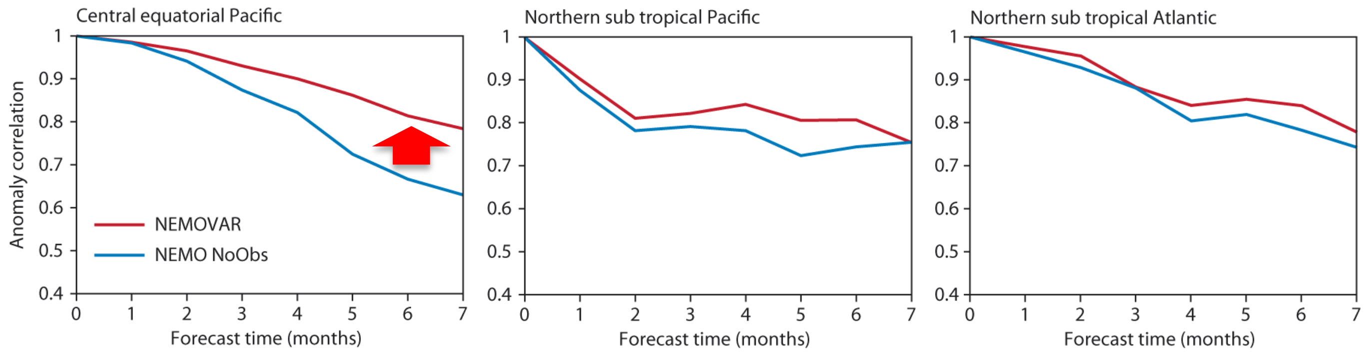
A proper initialisation played a key role in the performance of coupled forecasts

Sea-Level





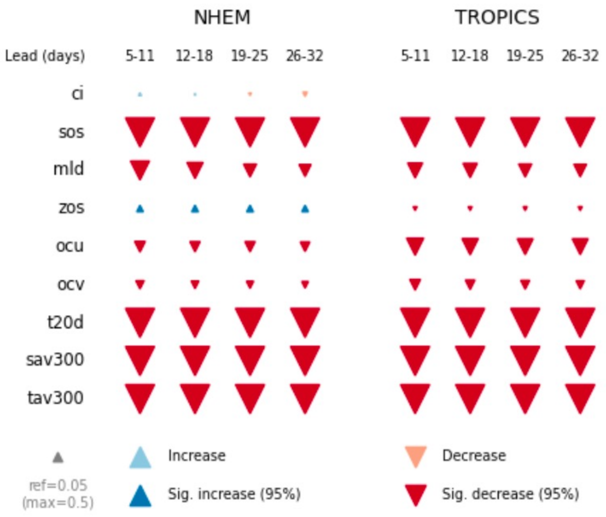
SST



Impact on NWP: medium to extended ranges

Significant degradation in ocean forecasts from week 1 to week 4 when removing in-situ observations in the ECMWF ocean DA system

Ocean forecasts bias scores

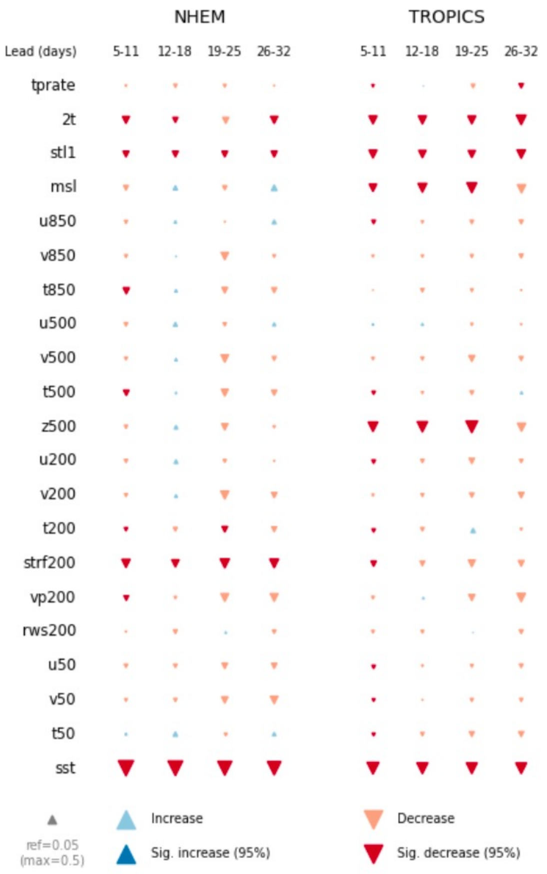


NoInsitu - Ref

Red : Degraded mean state compared to Reference fc

B B Sarojini et al., in preparation

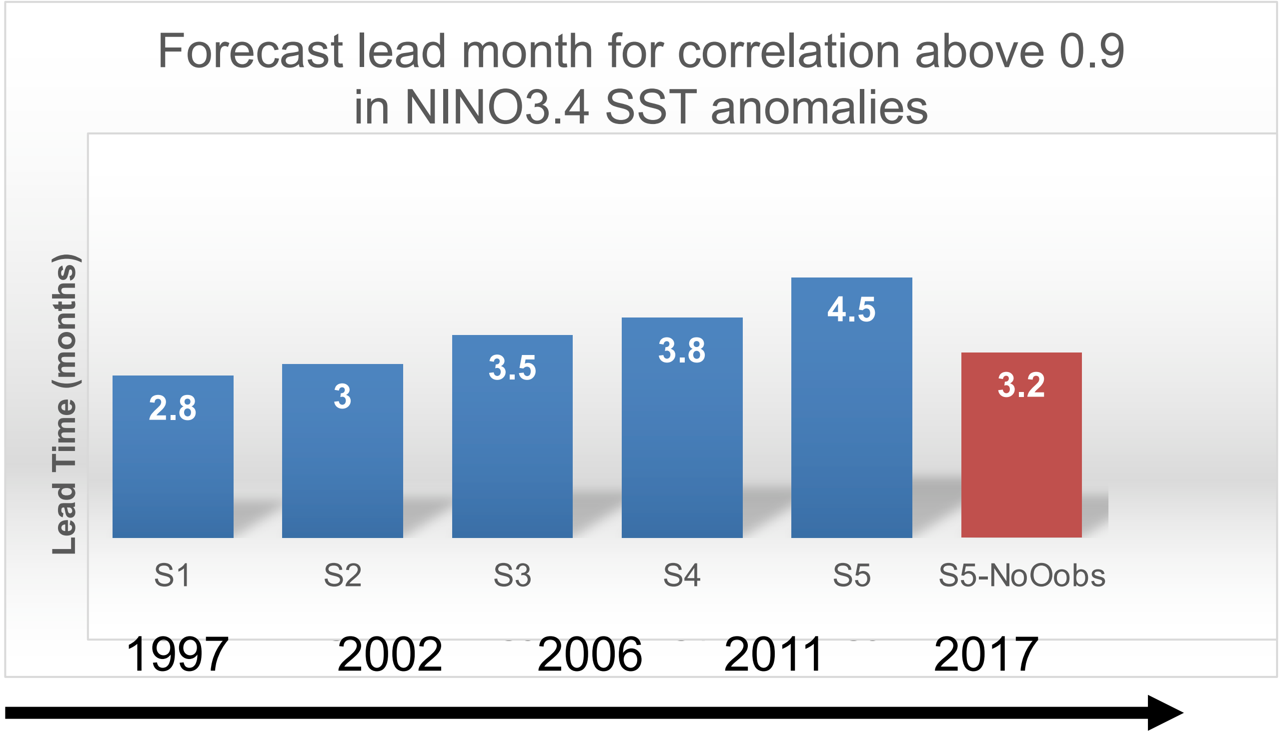
Atmoshperic forecasts bias scores



NoInsitu - Ref

Impact on NWP: seasonal forecasts

Ocean DA system provides ocean and sea-ice initial conditions for all ECMWF coupled forecasting system: (ENS, HRES, Seasonal). OCEAN5 also provides SST and SIC conditions for the ECMWF atmospheric analysis system (Browne et al., 2018)

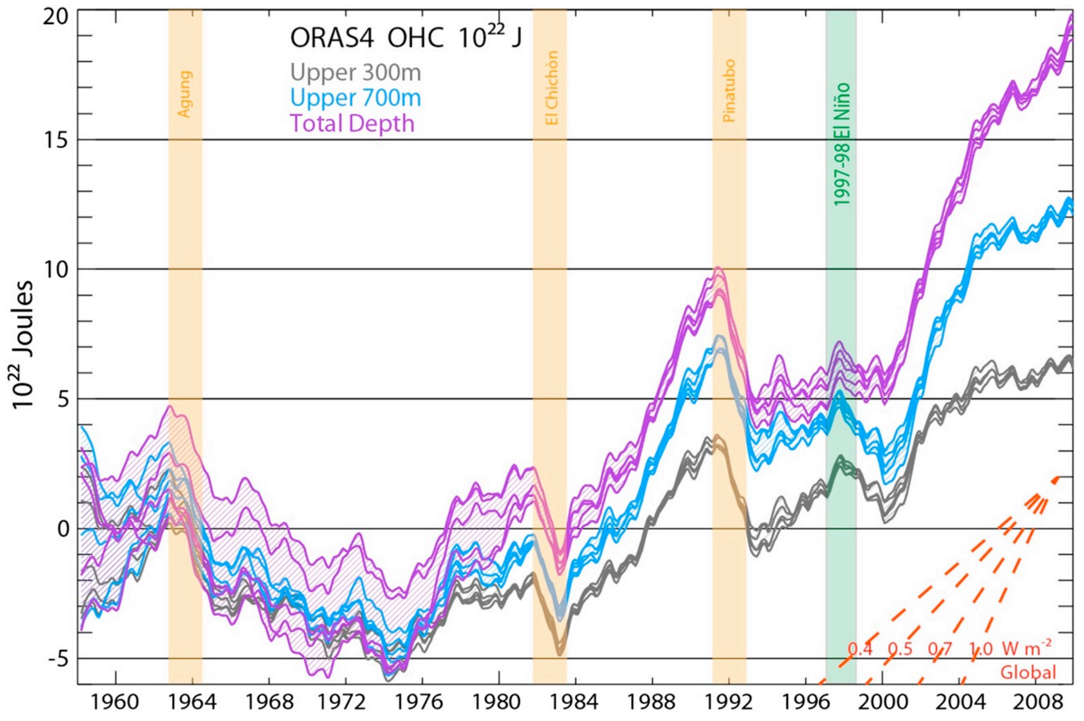


- Gain about 2 months in ENSO prediction
- Without Ocean observation and DA, we would lose about 15 years of progress.

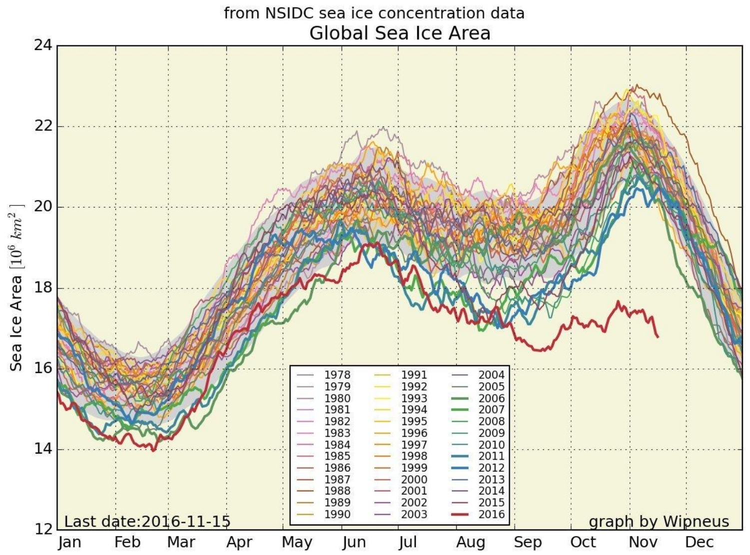
Application of Ocean DA: climate monitoring

ORAS4 suggests that there is more heat absorbed by the deeper ocean after 2004.

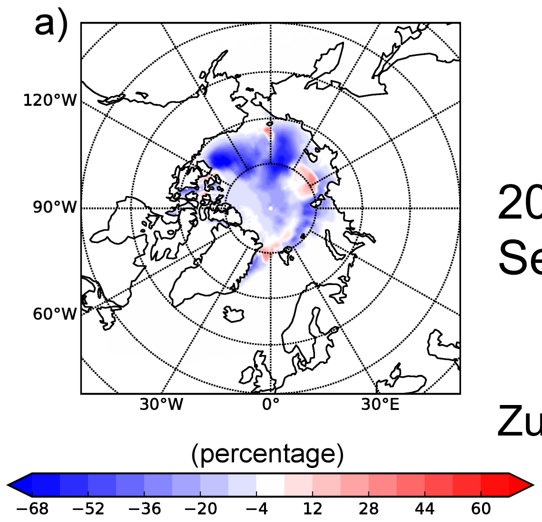
ocean heat content changes



Balmaseda et al., 2013



Sea-ice extent anomalies

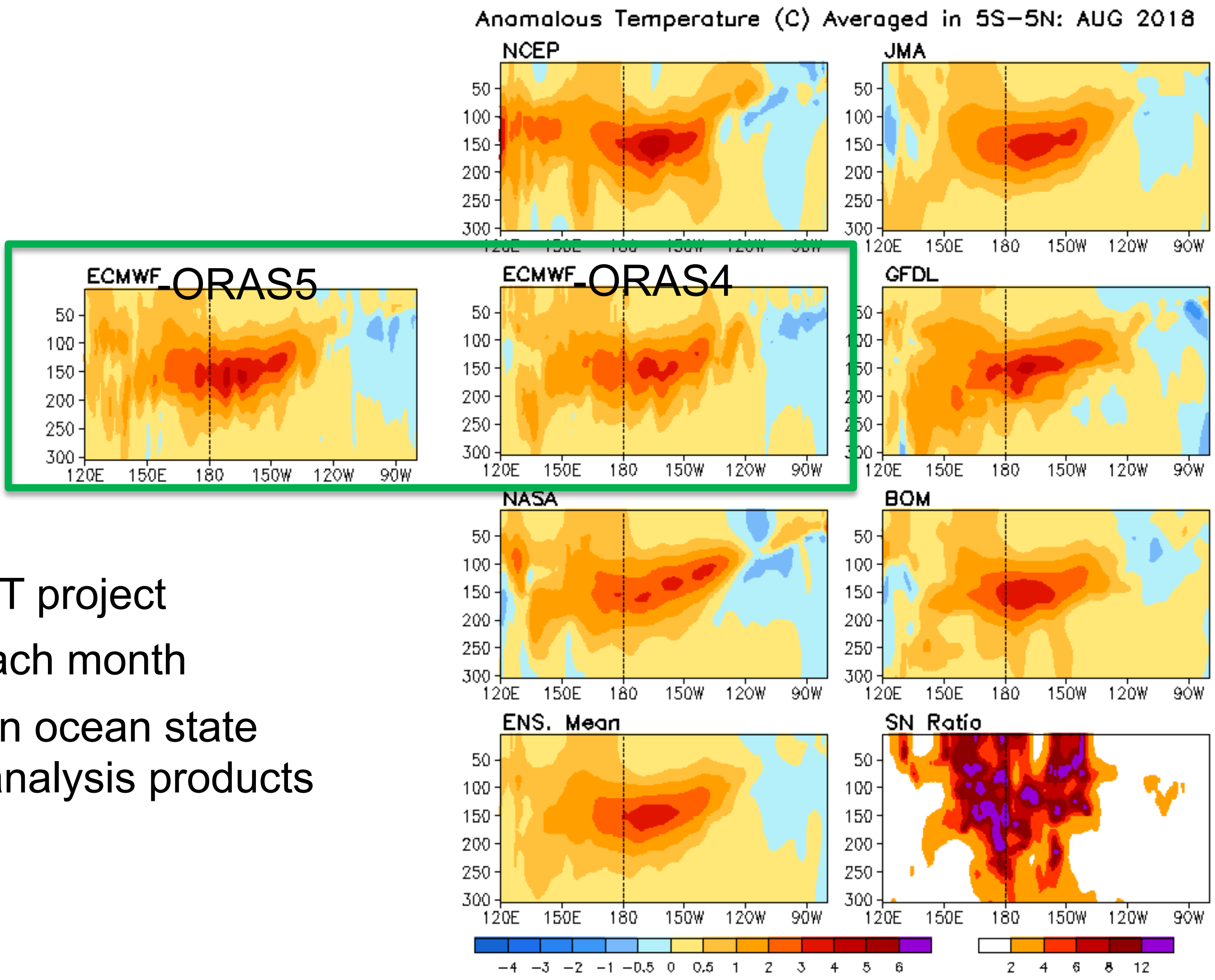


2016 September

Zuo & Lien, 2018

Application of ocean DA: RT monitoring

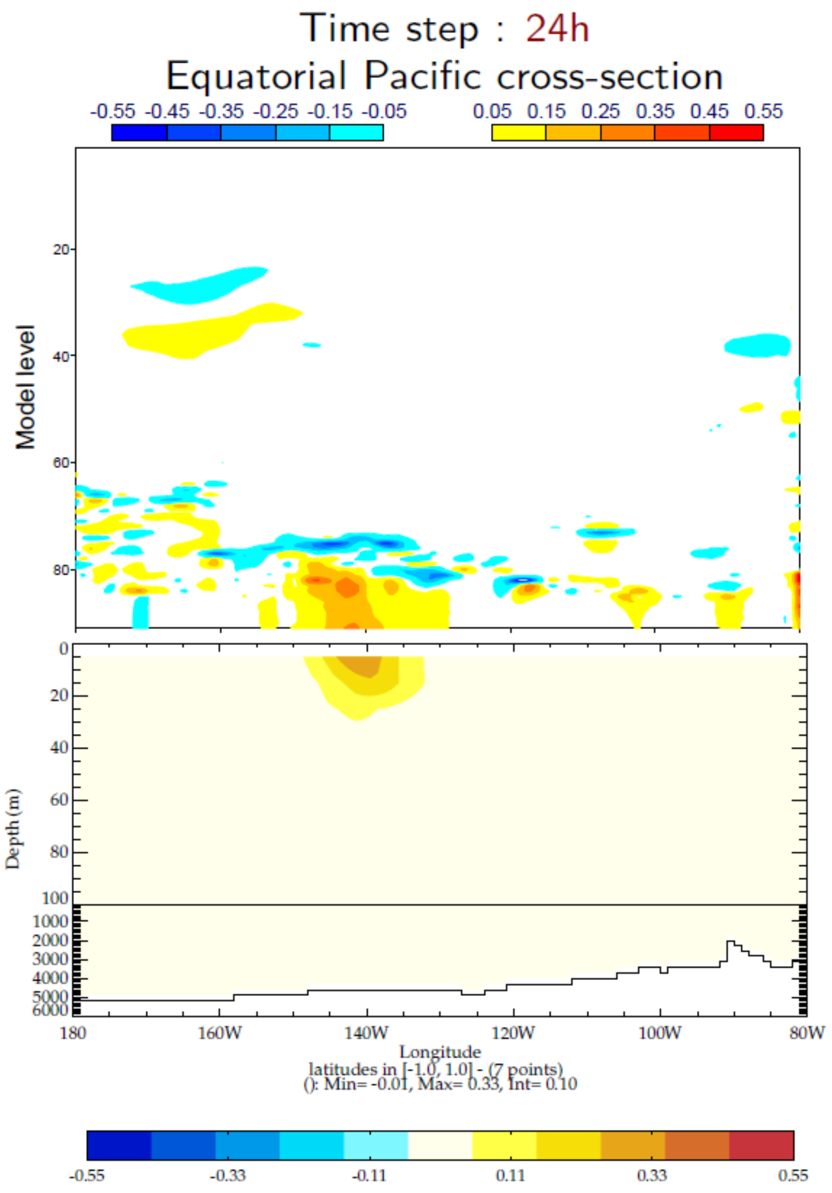
Real-Time monitoring of ENSO state Ref: 1981-2010



Contribution to the ORIP-RT project

- Update on the 1st day each month
- Compare the latest mean ocean state with 8 other RT Ocean analysis products

Application of Ocean DA: towards coupled DA



Atmosphere-ocean temperature cross-section

Ocean increment (assimilation of one temperature observation at 5-meter depth) spreads in the atmosphere during the model integration (outer loop)

Coupled analysis should be better balanced and consistent with respect to the coupled model

Summary

Assessment of ocean observation impact on ECMWF coupled forecasting system suggests

- Assimilation of ocean observations has a strong positive impact on the performance of ocean reanalysis, with almost 2/3 of the error reduction comes from in-situ data assimilation
- Removal of all ocean in-situ observations leads to significant degradation in forecasted ocean states from week 1 to week 4, and has a negative impact (~2 month skill) on seasonal forecasts of ENSO prediction
- Ocean in-situ observation plays an important role on estimation of model errors, and in calibration and reforecasts system
- Coordinated efforts on developing an experimental framework and analysis methodology for assessing observation impact in ODA and coupled forecasts are needed (see Fujii et al., 2019).

A consistent, homogenous and deep reaching global ocean observing network is absolutely essential for both operational NWP and climate monitoring services