Impact of the Ocean In-situ Observations on the ECMWF Subseasonal and Seasonal Forecasting Systems

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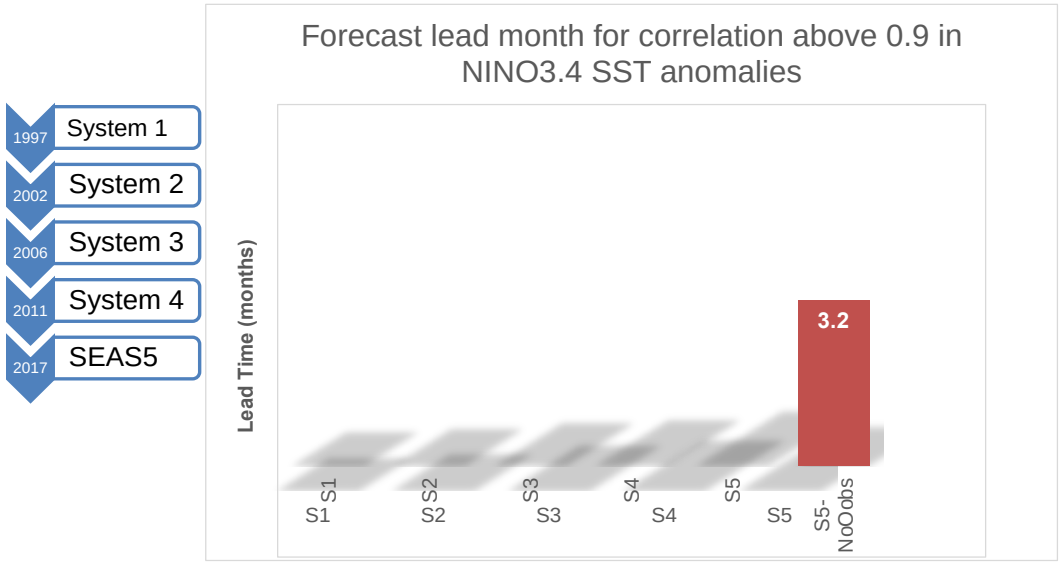
20 years or progress in ENSO prediction at ECMWF

and contribution of ocean observations



OUTLINE

- Experimental Setup
- Impact on ocean initial conditions
- Impact on the atmospheric state at seasonal time scales
- Impact on atmospheric state at sub-seasonal time scales
- Conclusions

Experimental design

ORA: provision of initial conditions

FC: Ensemble of coupled forecasts

Period: 1993-2015, 5 ens members
As ORAS5 except for :
lower resolution(~1º, 42 levels)
No Altimeter - No bias correction
All ORA have strong SST constrain

Reforecasts Period: 1993-2015
Model: as operations at low resolution ocean (1º , 42 levels)
Seasonal: May and November starts, 15 ens. Members.
Low resolution atmosphere (Tco199)
Subseasonal: Starts every month, 5 ens. members (Tco399)

Experiments
REF: SST, all Insitu
NoArgo: As REF, No Argo
NoInsitu: As REF, No Insitu
NoInsituAtl: As REF, but No Insitu in Atlantic

Evaluation methodology:

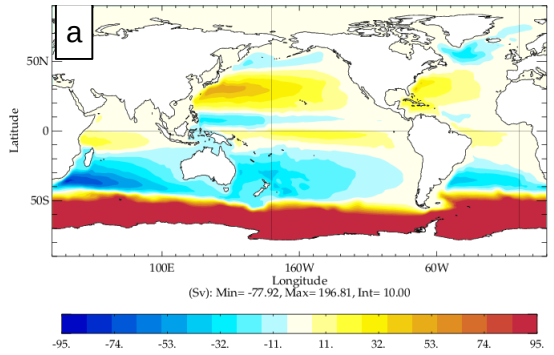
- Differences in the mean state of atmospheric and ocean forecast variables
- Impact on bias and errors

First time that we look at impact of ocean observations on atmospheric variables

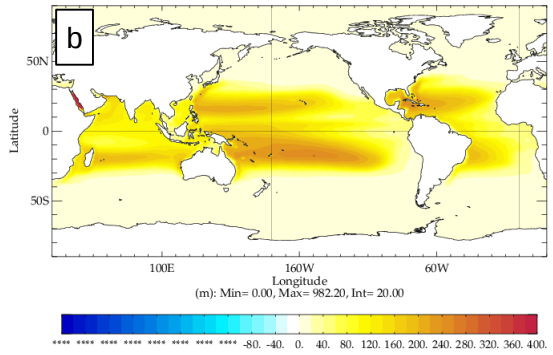
First a look at the mean differences on ocean initial conditions

2005-2015 mean

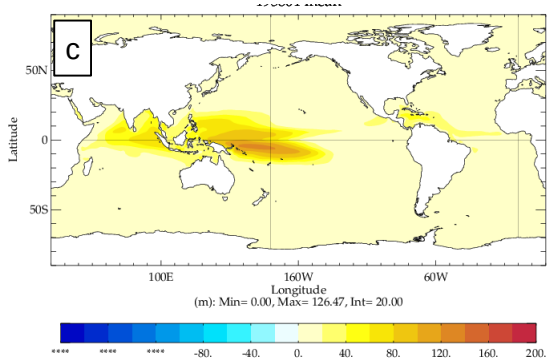
Barotropic Stream Function
Ref



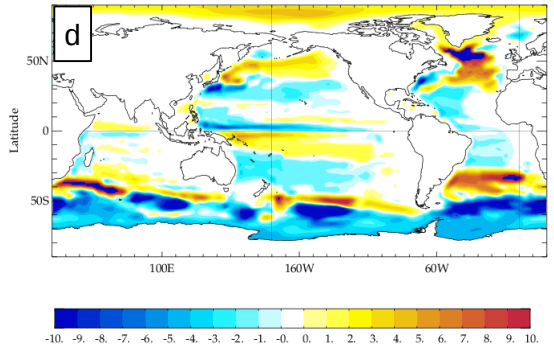
Depth 20-C Isotherm
Ref



Depth 28-C Isotherm
Ref



NoInsitu - Ref



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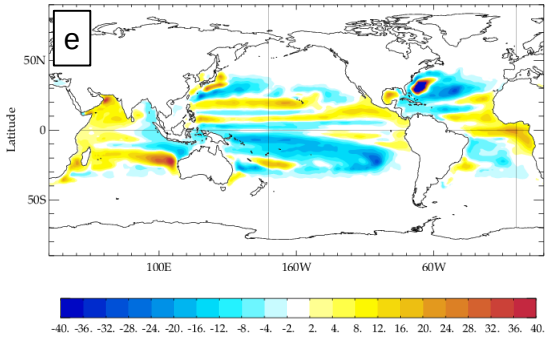

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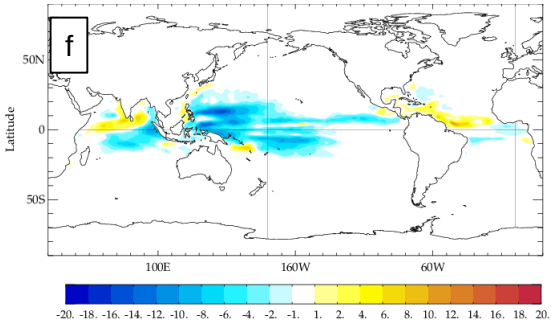


In-situ observations have an impact on:

- The global circulation (BSF) –large memory-potential to impact multiyear forecasts
- Thermocline depth (D20)- potential to impact seasonal forecasts (several months adjustment time)
- Warm pool (D28) and mixed layer (not shown)- potential to impact monthly forecasts

ECMWF

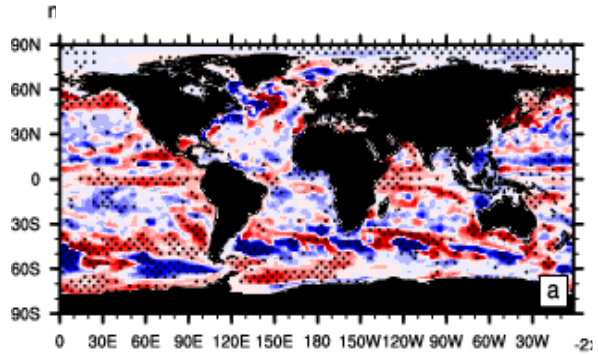
From Initial condition differences to Seasonal Forecast differences: Ocean Heat Content

May starts 2005-2015 JJA verification

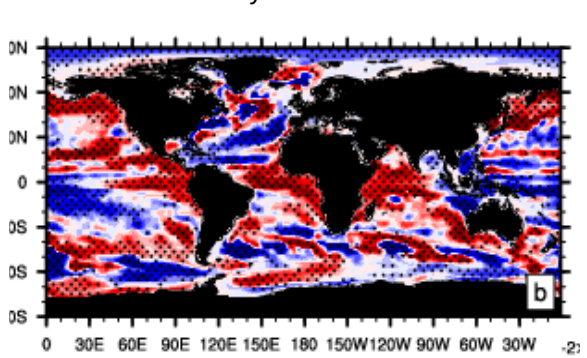
Mean difference on Ocean Initial Condition

Mean difference on seasonal forecasts

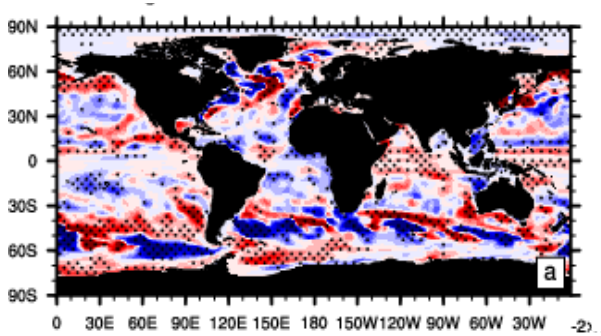
NoArgo-Ref: May Initial Conditions



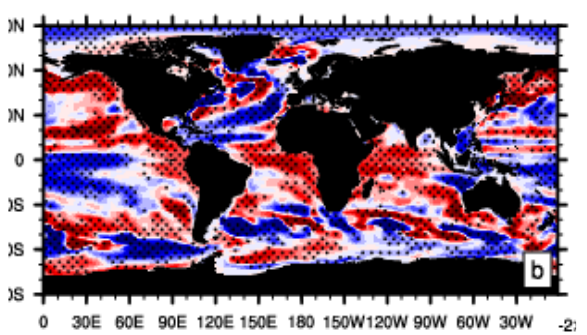
NoInsitu-Ref: May Initial Conditions

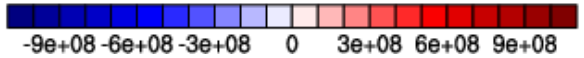


NoArgo-Ref: FC JJA



NoInsitu-Ref: FC JJA





Ocean Heat Content Upper 300m

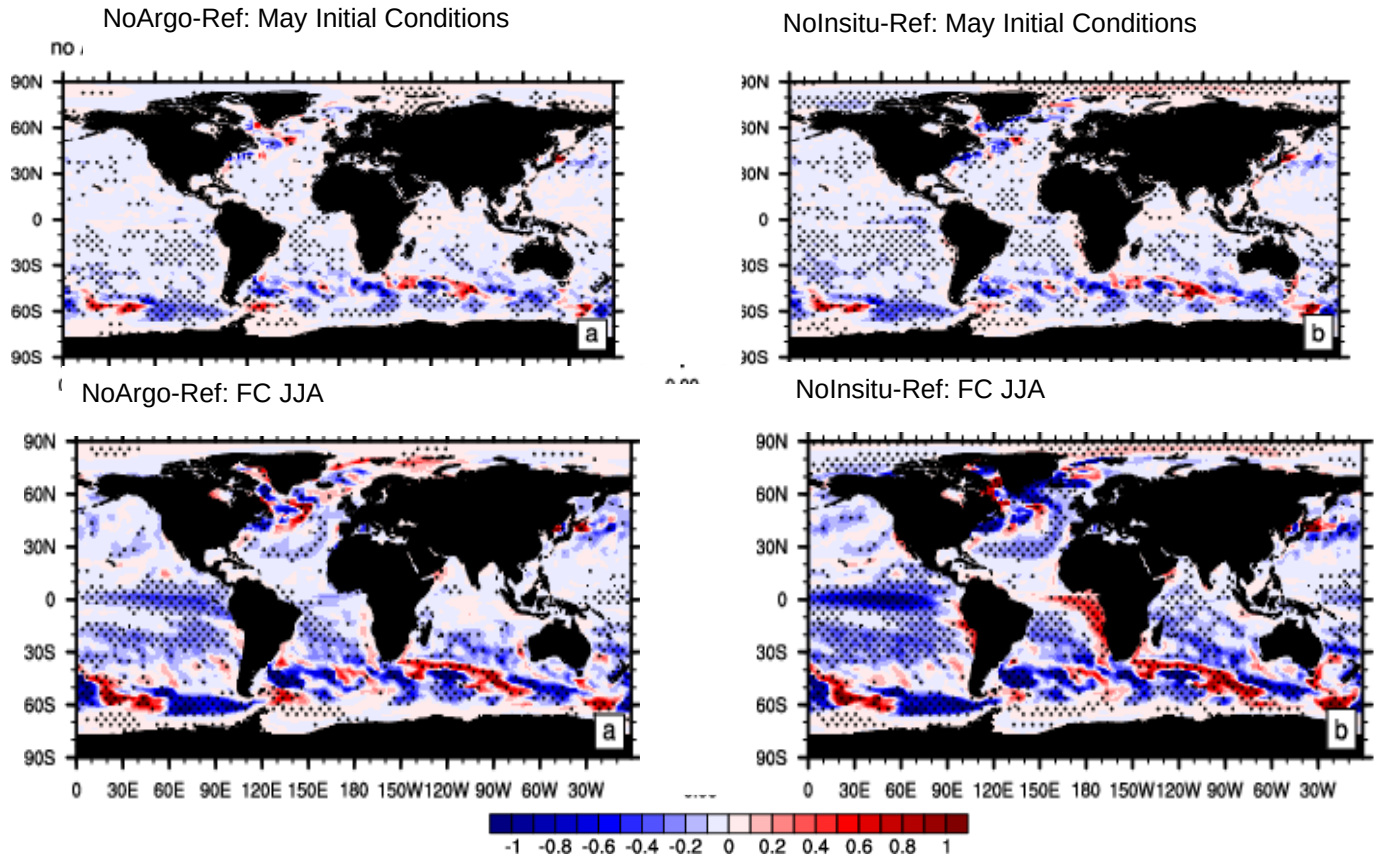
- Differences in OHC initial conditions largely remain into forecast, with the exceptions associated with Equatorial dynamics
- NoInsitu impact on Initial Conditions larger than NoArgo. Due to memory of observation impact and experiment design (e.g. all experiments start in 1993, so the contribution of Insitu prior to Argo period is visible in results)

From Initial condition differences to Seasonal Forecast differences: Sea Surface Temperature

May starts 2005-2015 JJA verification

Mean difference on Ocean Initial Condition

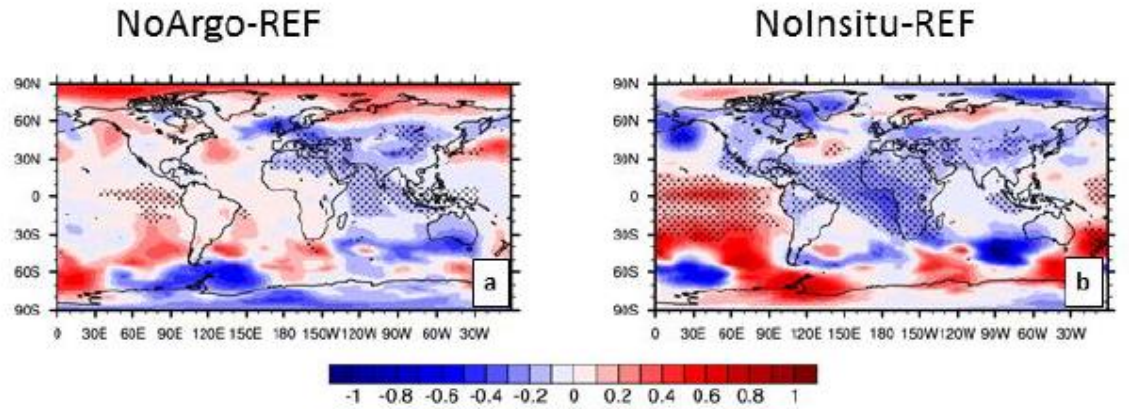
Mean difference on seasonal forecasts



- Impact of observations visible in SST initial condition. Impact small but significant.
- **Fast**: Removing observations induces overall cooling in forecasts (likely Mixed layer processes?. Note different sign of impact between SST and OHC in Indian Ocean)
- **Medium** : Strong dynamical cooling in Pacific cold tongue by removing observations.
- **Slow:** In Extratropics and gyres, impact on SST Forecast resembles the impact on OHC initial conditions

Impact of Ocean Observations impact Seasonal Forecast atmospheric mean state

MSLP

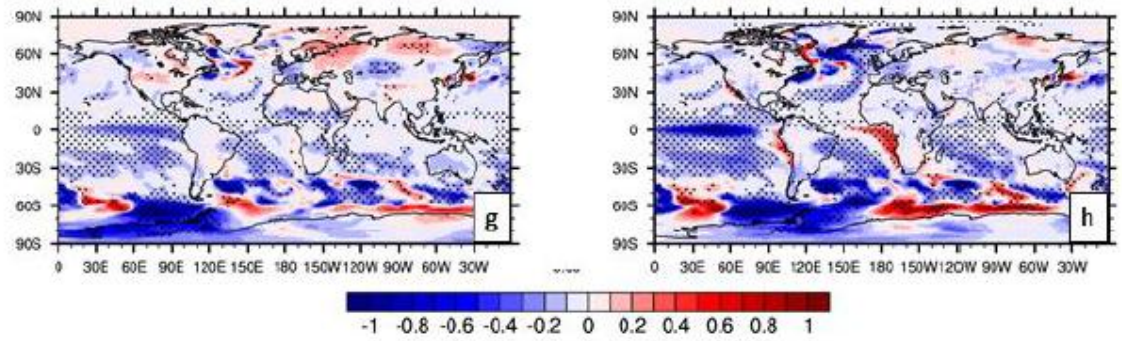


May starts 2005-2015
JJA verification

Top panels: Mean sea level pressure (MSLP)

- Tropical Pacific: increased MSLP over Cold Tongue Area, La Nina-like conditions, associated dryness in precip
- Tropical Indo-Atlantic: decrease in MSLP likely due to large scale SST gradients
- Extratropics: Likely due to teleconnections though some local impact due to Gulf Stream and subpolar gyre.

T2m



Bottom panels:

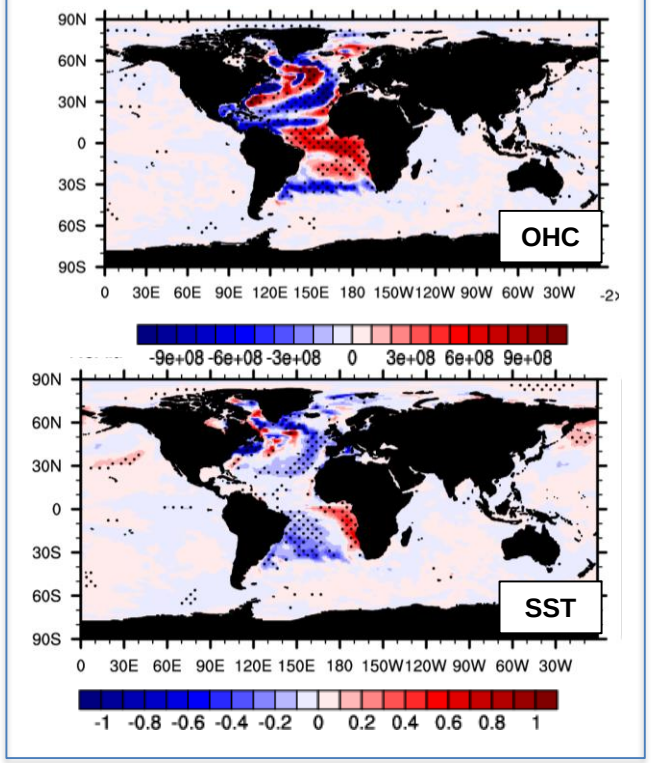
- T2m changes compatible with overall cooling in sea surface temperature
- NoInsitu impact is largely similar to NoArgo

Balmaseda et al. (in prep)

Note that while the amplitude of observation impact may be comparable to the forecast bias, the structure is not a 1-1 match.
In the Equatorial Pacific, removing observations enhances the cold bias and the high MSLP.
But over the Atlantic, removing the in-situ seems to improve the forecast bias in MLSP

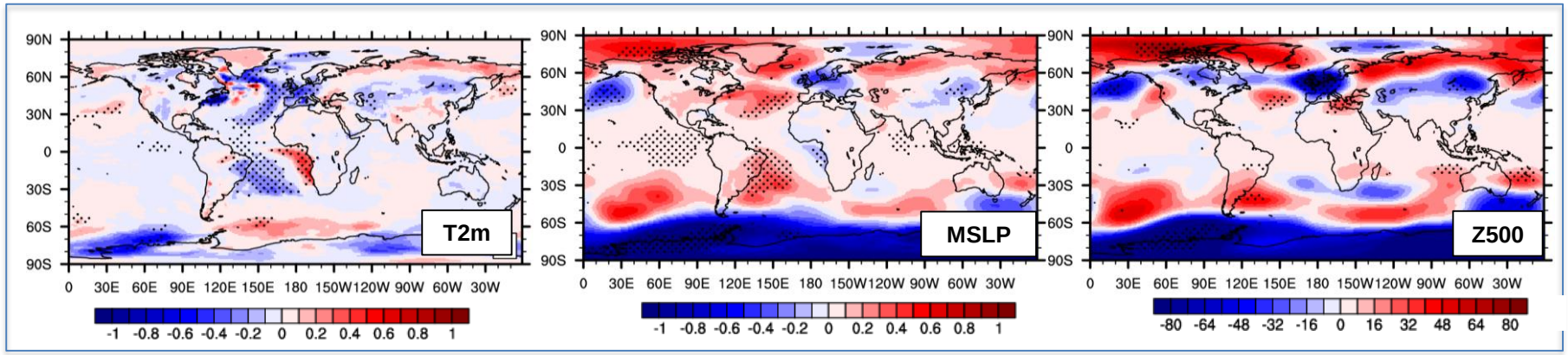
The impact of ocean observations is non-local: atmospheric bridge

May Ocean Initial Conditions



NoInsitu Atlantic - Ref

Seasonal Forecasts verifying in JJA



The atmosphere responds to large scale SST gradients. As a consequence, at seasonal time scales:

A) differences in Atlantic SST are felt by the atmosphere at a global scale:

Note the significant impact on MSLP in the Tropical Pacific, the impact on T2m at the Pacific mid-latitudes.

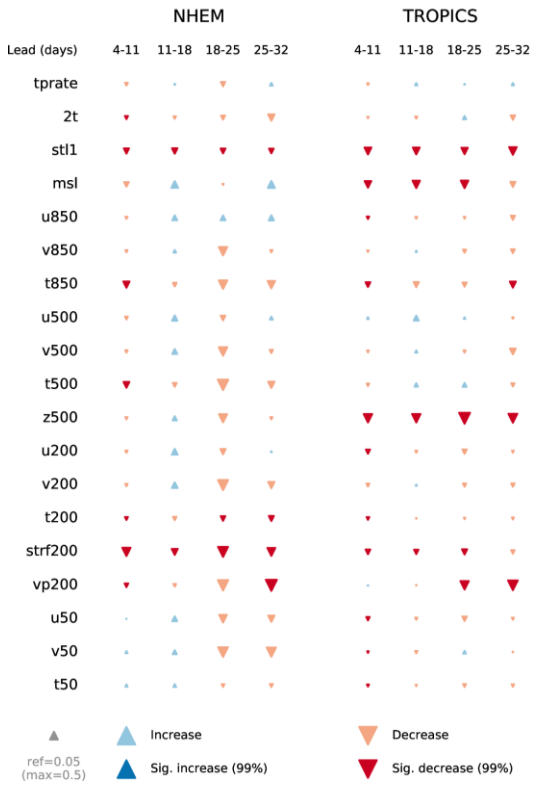
There are also some significant impact on the Southern hemisphere subtropical jet by Australia

B) The response to local SST may be modified by signals from other areas, creating interference:

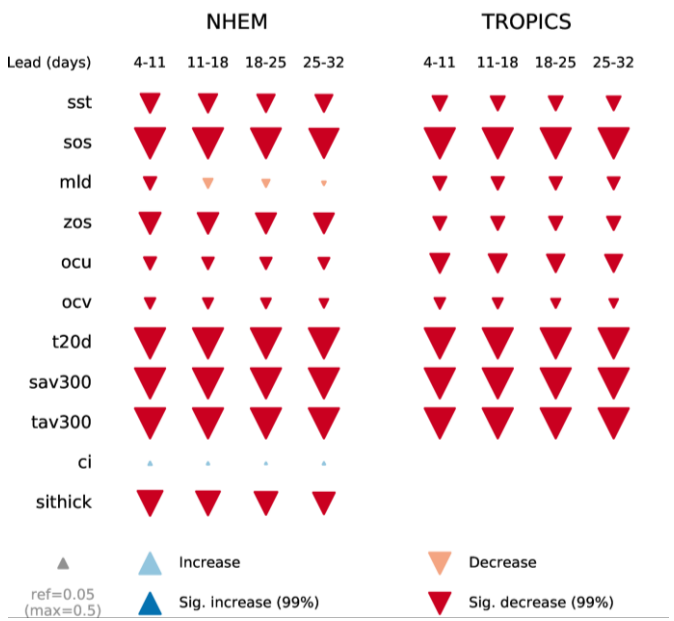
Note the MSLP response over the tropical Atlantic is very different between NoInsitu-global (previous slide) and NoInsitu-Atlantic

Impact on Extended Range: Biases

Atmosphere: NoInsitu-Ref



Ocean: NoInsitu-Ref

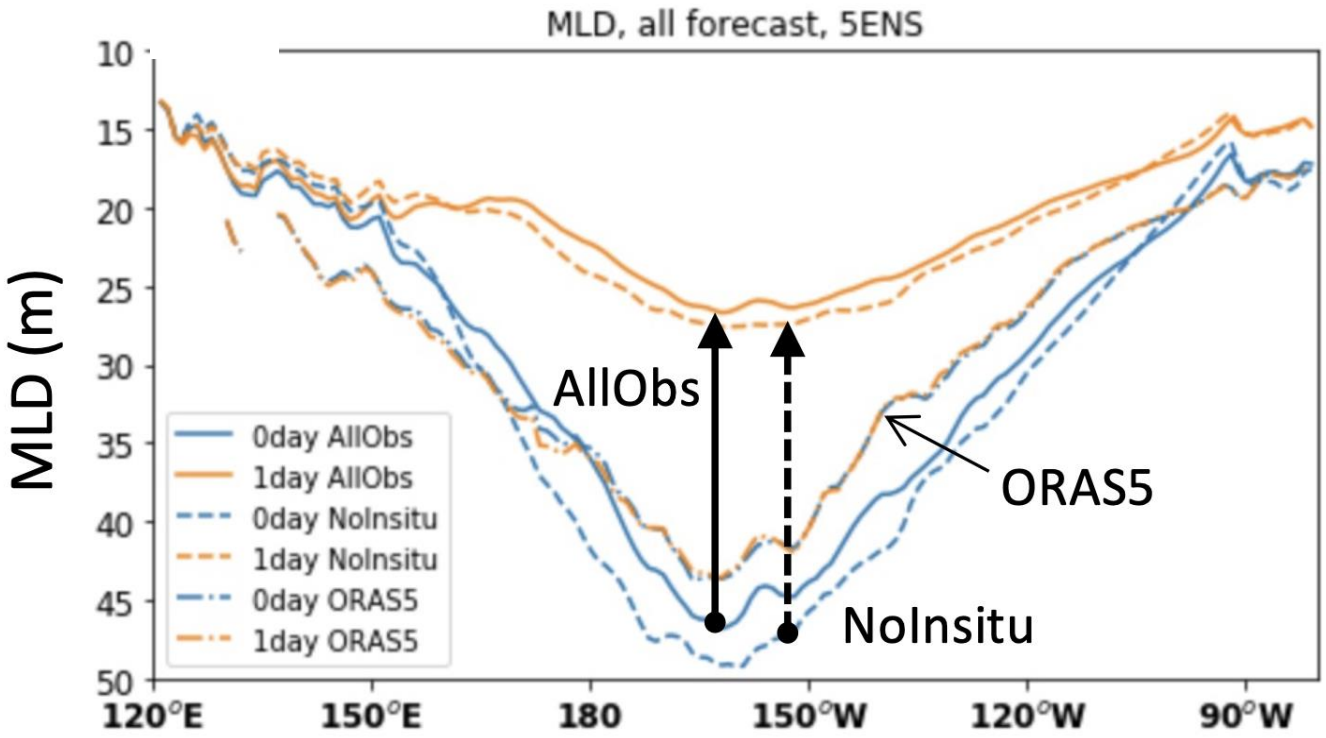


Red : Degraded mean state

Significant degradation in ocean surface and subsurface variables when removing observations From week 1 to week 4. Also impact on atmospheric biases

Although there is impact on atmospheric biases is difficult to show impact on skill

Ocean Mixed Layer Depth biases



Courtesy of Ho-Hsuan Wei

Initialization shock?

The mixed layer information disappears quickly in the first day into the forecast

Quantifying perturbation and error growth: SST

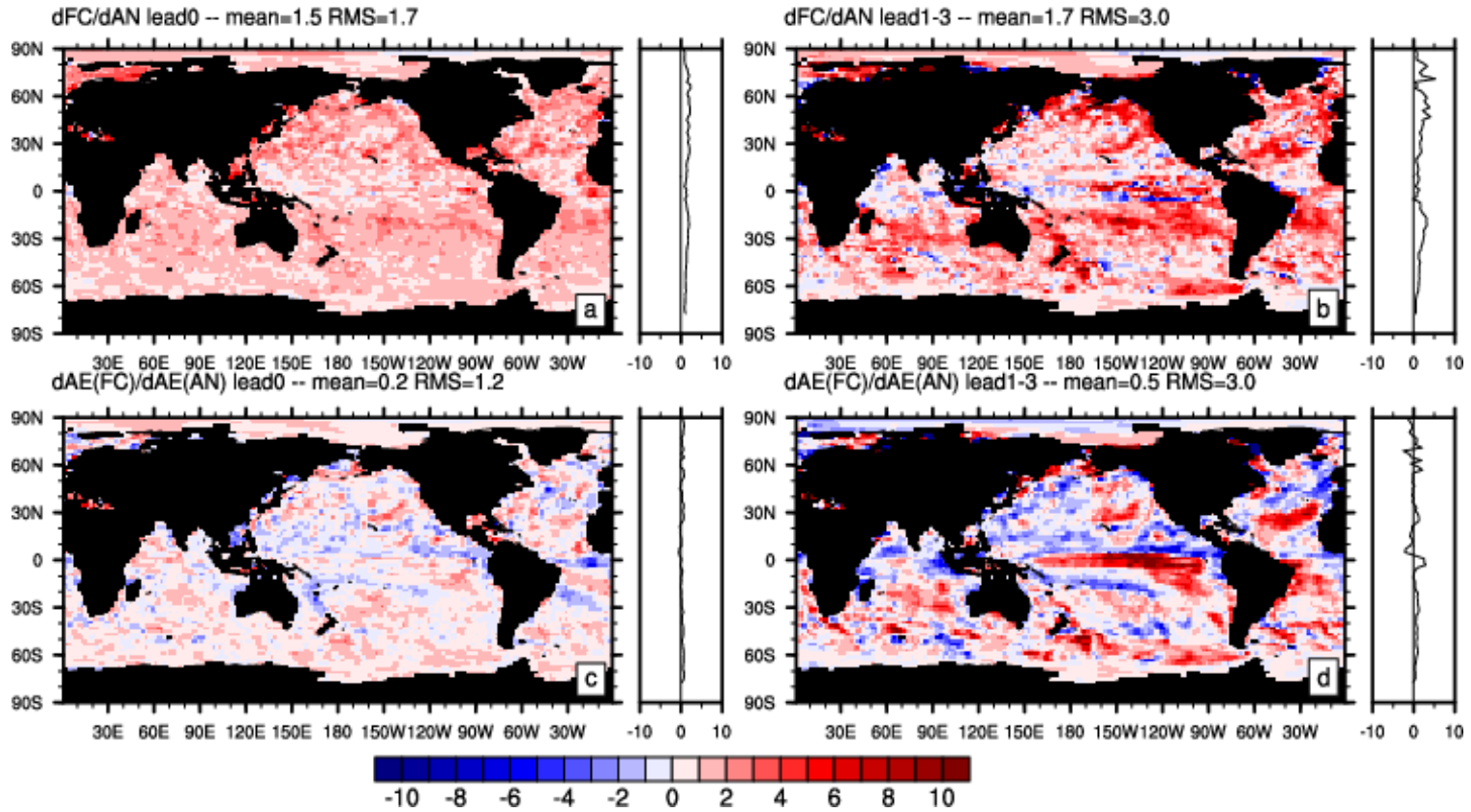
No Argo - REF

First month

Months 2-3-4

Sensitivity Metric:

May starts



$$\frac{\delta FC}{\delta AN}$$

$$\frac{\delta\,|FC - Obs|}{\delta|AN - Obs|}$$

Perturbation doubles size in many areas within the first month (month 0).
Growth is not uniform. At lead 2-3-4, error growth > 4 in some areas; in a few areas decreases or even reverses sign.
We also see that the perturbation and error growth have different patterns.

The extent to which these patters of error/perturbation growth can be applied to generic initial perturbation is still an open question

Lessons learnt

- **The in-situ ocean observations have a profound and significant impact on the mean state of forecast ocean and atmospheric variables, and can be classified into different categories:**

  1. Related to local air-sea interaction, a direct consequence of changes in the mixed layer in the ocean initial conditions, and visible in the early stages of the forecasts
  2. Related to different ocean dynamical balances, most visible in the Equatorial Pacific at time scales of 3-4 months
  3. Resulting from changes in large scale SST gradients; these are non-local, mediated by the atmospheric bridge, and depend on the differential impact of the observing system in different regions.

- **Interplay with model error:**
  - The impact does not always translate into improvements, since the bias in the model are not exclusively due to SST errors.
  - The information on ocean mixed layer initial conditions disappears at early stages of forecasts. Need to understand why.
- **Results highlight the importance of a homogenous/uniform and sustained ocean observing system at the global scale.**
- **A coordinated set of OSES 4 S2S is currently being discussed within SynObs contribution to the Ocean Decade**