ECMWF SynObs OSES

Impact of ocean observations in Ocean Reanalysis and Seasonal Forecasts

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ECMWF SynObs OSES 4 S2S Experimental design

ORA: provision of initial conditions → FC: Ensemble of coupled forecasts

Common Period: 2001-2023

Latest prototype of ORAS6*:
- ¼ degree, NEMO4-SI3,ERA5 hourly forcing

Reforecasts Period: 2001-2023
Model: proto-SEAS6 (49r1) with low res atmosphere (Tco199)

Seasonal: May and Nov starts, 25 ens. 7 month range

Experiments
CNTL: as REF but 80%
NoInsitu: as CNTL but no Insitu data
No Argo: as CNTL but no Argo
Half Argo: as CNTL but 50% Argo
No Mooring: as CNTL but no moorings
No SST: as CNTL but no SST
No Alti: as CNTL but no altimeter
No SIC: as CNTL but no sea-ice
Free: No DA. Only surface fluxes
SSTonly: As free but assimilating only SST

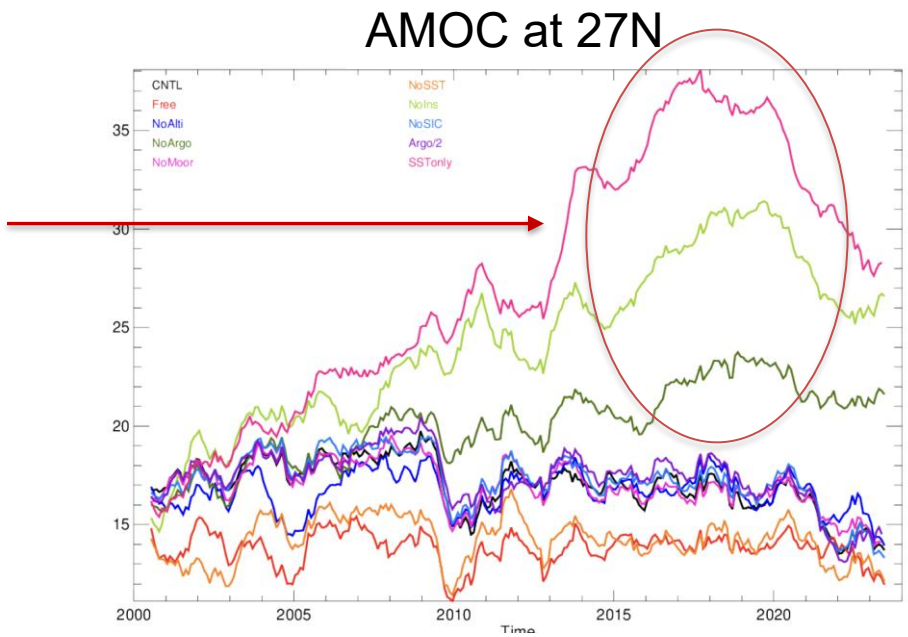
Analysis:

ORA:
- Climate indicators
- Maps of differences in mean
- Statistics of relative differences

FC:
- Maps of differences in mean
- Statistics of relative differences
- Fit to obs
- Skill for area average indices

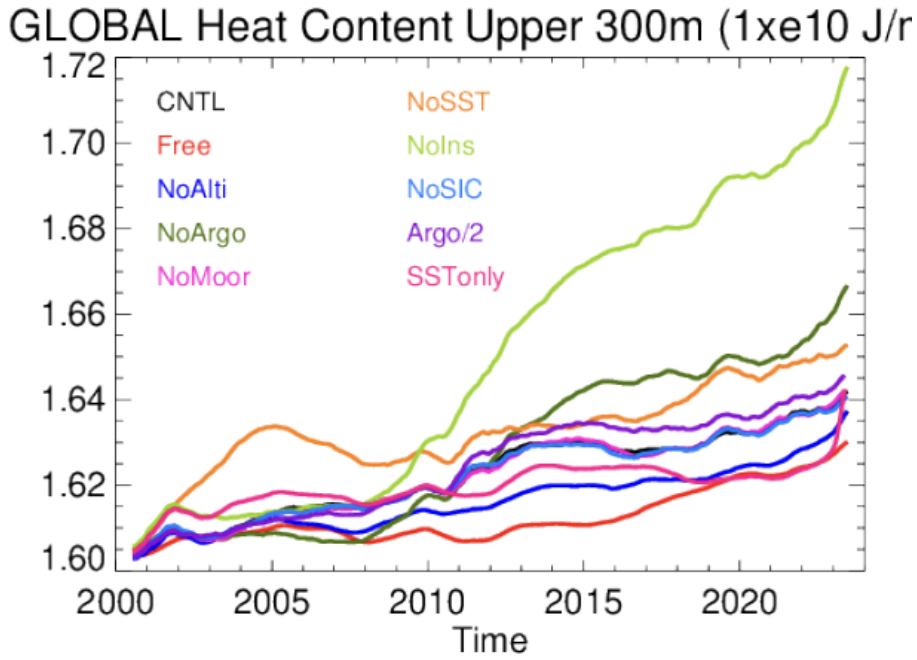
Impact on ORA climate indices

AMOC: NoInsitu, NoArgo, SSTonly
Produce unrealistically high AMOC=>
need of subsurface insitu



OHC:
NoInsitu unrealistically high OHC
Free underestimates OHC
NoSST outlier before Argo is present in Southern Ocean

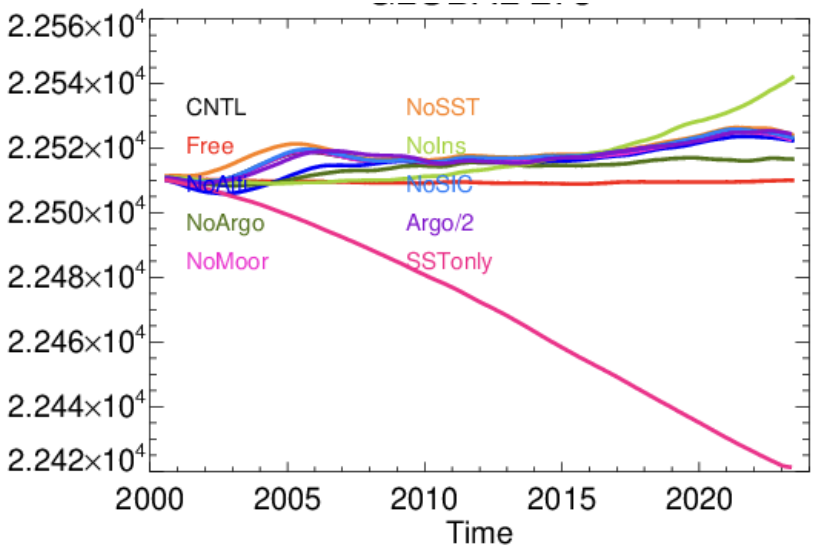
The vertical distribution of heat and steric height is also affected (not shown)



Impact on ORA :

Salinity content: SSTonly
Produce unrealistic decline in Salinity=> **need additional observations to constrain the salinity field**

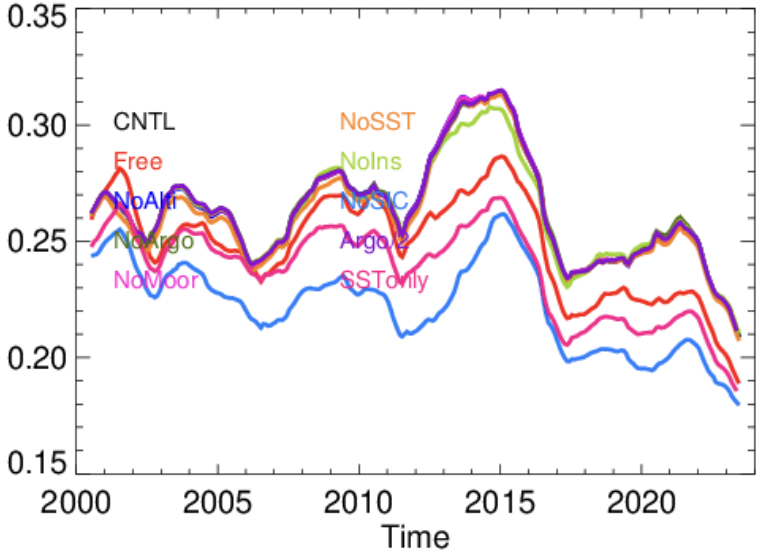
Total Salinity content



Sea Ice properties:
Need SIC observations the Sea-Ice properties (concentration and thickness)

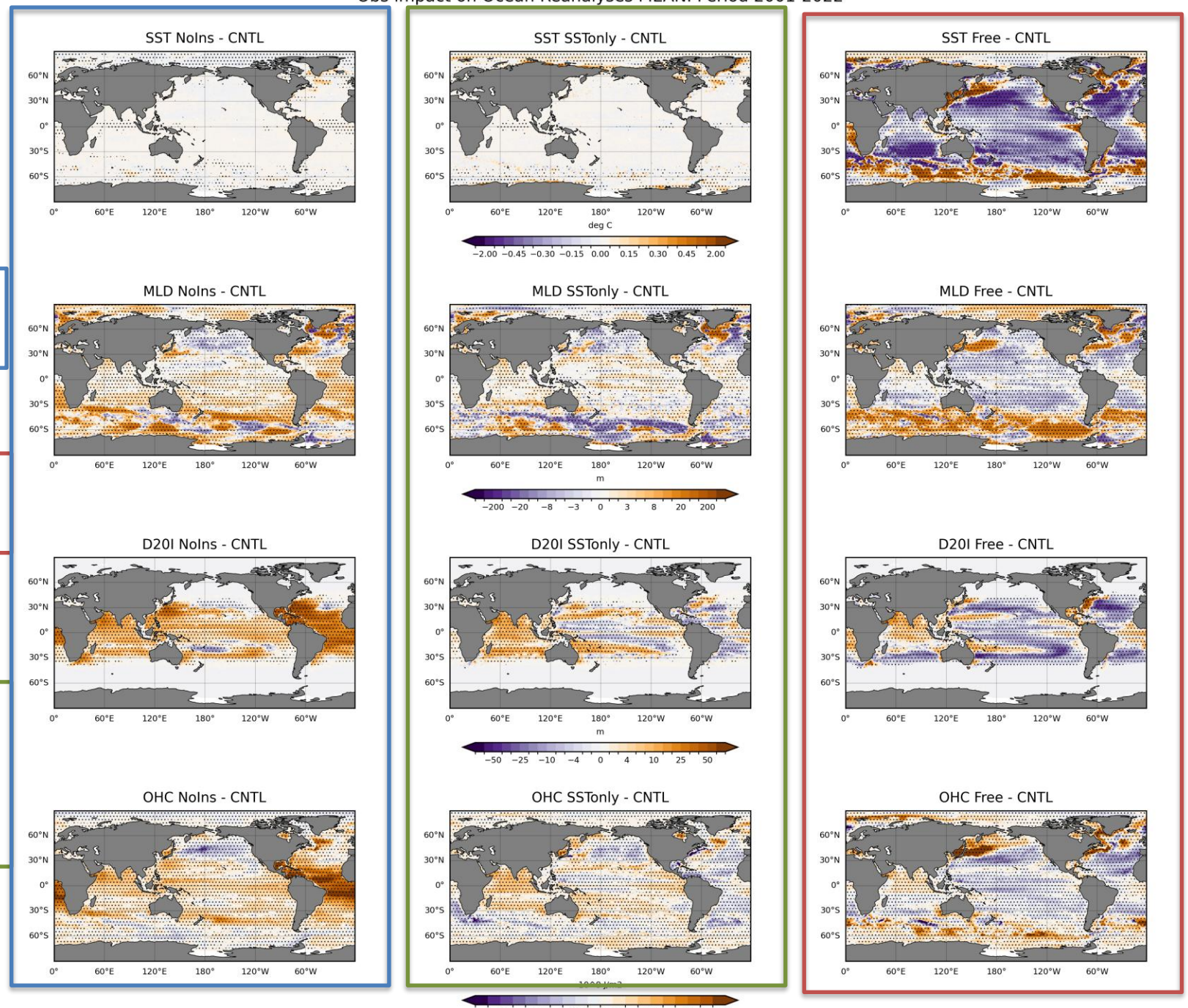
For instance, in Antarctic withdrawing SIC information produces **thicker ice:** : Free, NoSIC and SSTonly have thicker ice than the rest of experiments.

Antarctic Sea Ice Thickness



ORA Spatial maps: Impact on mean state

Obs impact on Ocean Reanalyses MEAN. Period 2001-2022



NoIns (left column) produces huge warming in tropical ocean (subsurface), especially in the Atlantic. Deeper mixed layers in NA-SPG

Free (right column) has colder tropical ocean with shallow mixed layers, warmer WWB with deeper mixed layers. Colder tropical, but magnitude less than NoIns.

SSTonly (middle column) in tropical ocean shows less differences w.r.t CNTL than NoIns, indicating that the excess warming comes from the altimeter assimilation.

SSTonly impact is larger in Indian Ocean and NA-SPG

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ORA: Relative differences

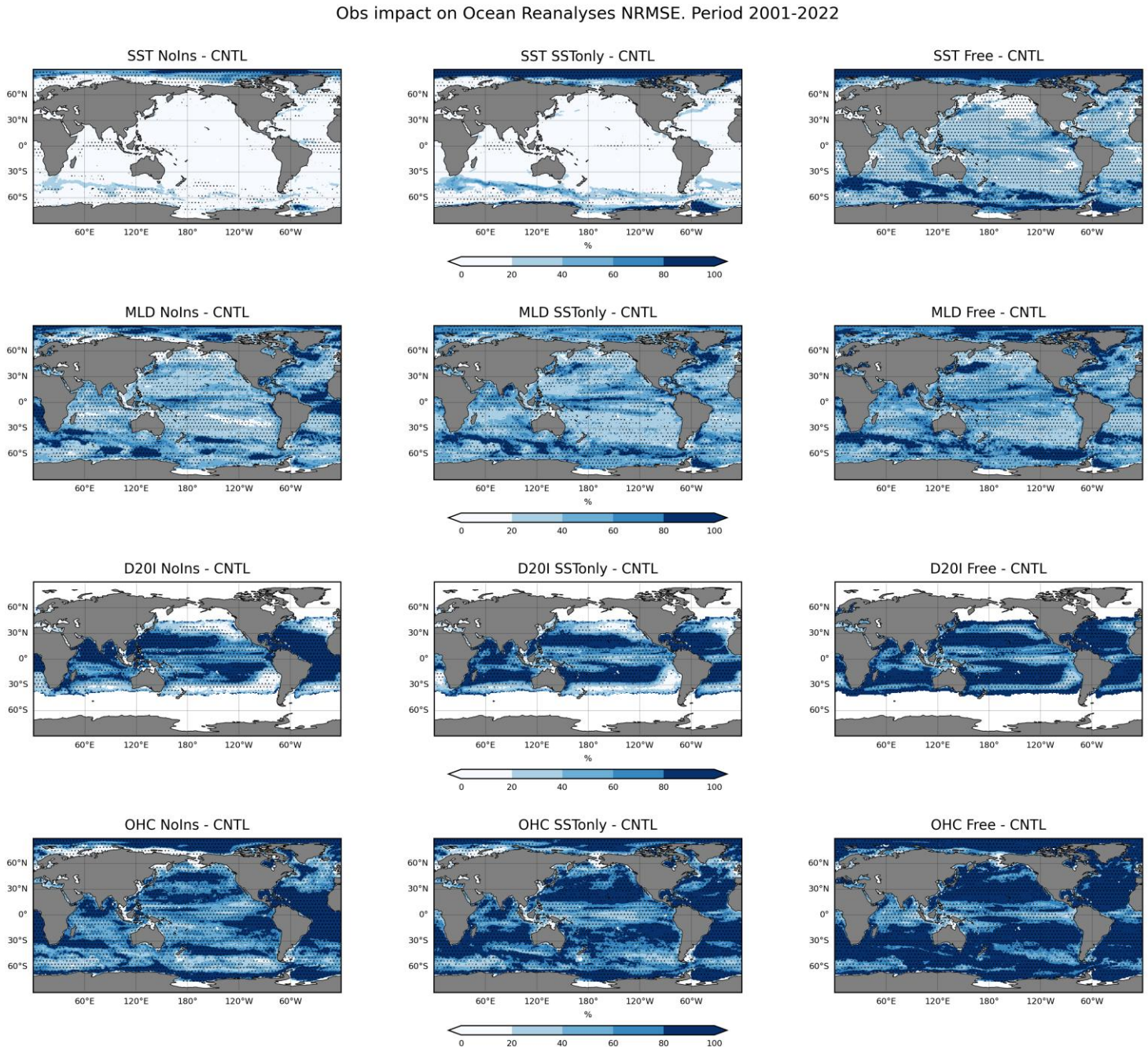
$$NRMSE = \frac{\sigma_{OSE-CNTL}}{\sigma_{CNTL}}$$

In a perfect reanalysis context (e.g. CNTL = Truth) this is equivalent to normalized error

For OHC and D20I the relative differences > **40 %** of variability (seasonal + interannual) in most of the ocean.

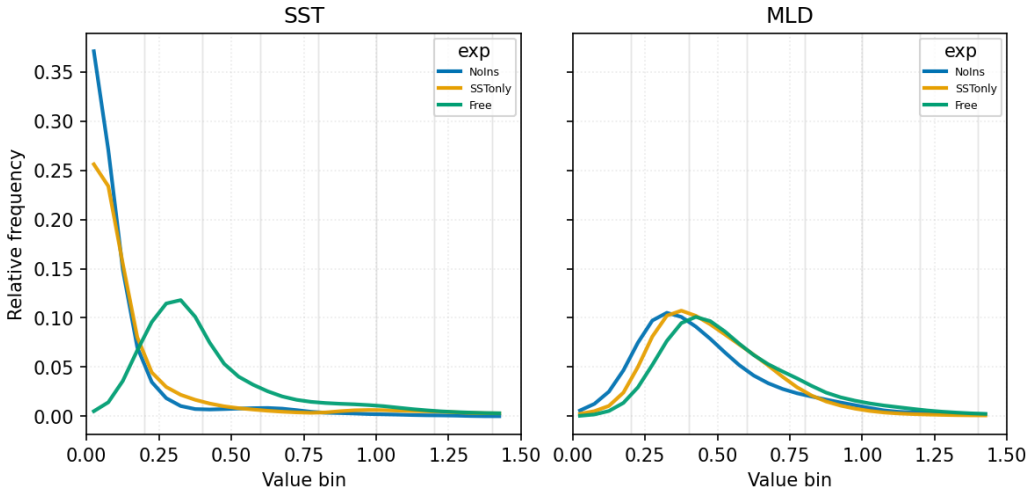
For MLD, relative differences exceed **20%** of interannual variability if most of the ocean, with largest values along frontal areas and Warm Pool regions.

NoIns produces huge differences in the Tropical Atlantic >80%

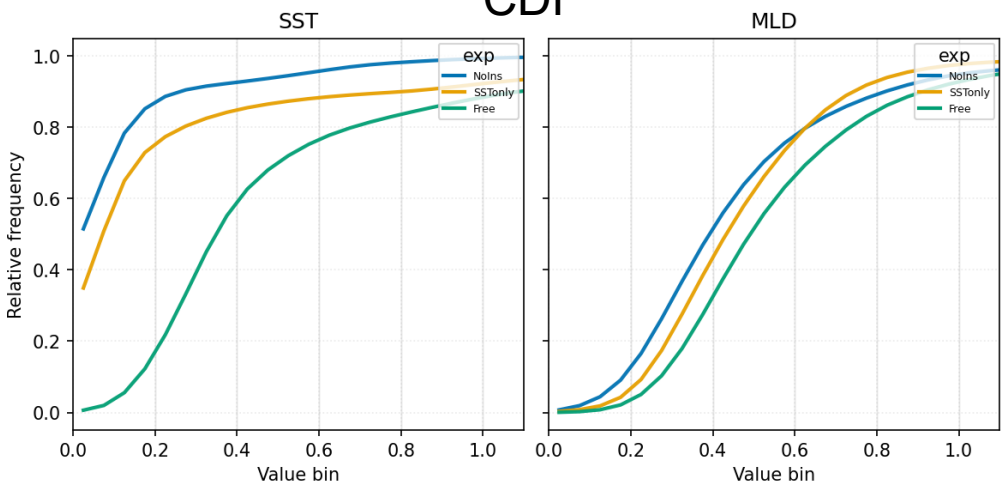


Observation impact on ORA: Relative difference PDF/CDF/InvPDF by spatial aggregation

PDF



CDF



Different behaviour in different variables

In what follows we show Inv-CDF as area fraction
Wider shapes indicate larger discrepancy.

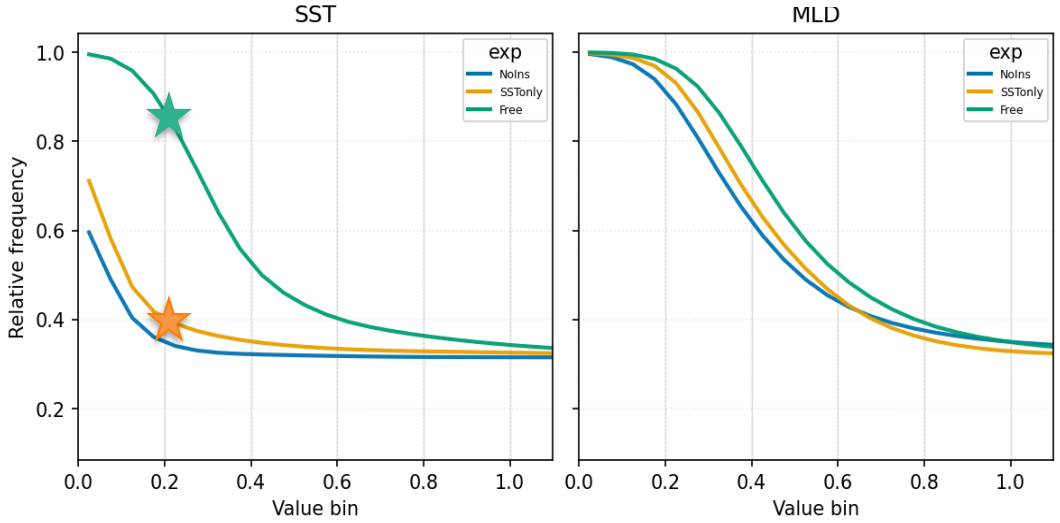
PDF(x)=Probability of NRMSE = x.
Here Probability = area fraction

CDF(x)= Probability of NRMSE <= x

Inv-CDF(x)= Probability of NRMSE > x (Inv-CDF=1-CDF)

Note: Integral of Inv-CDF = E[x]

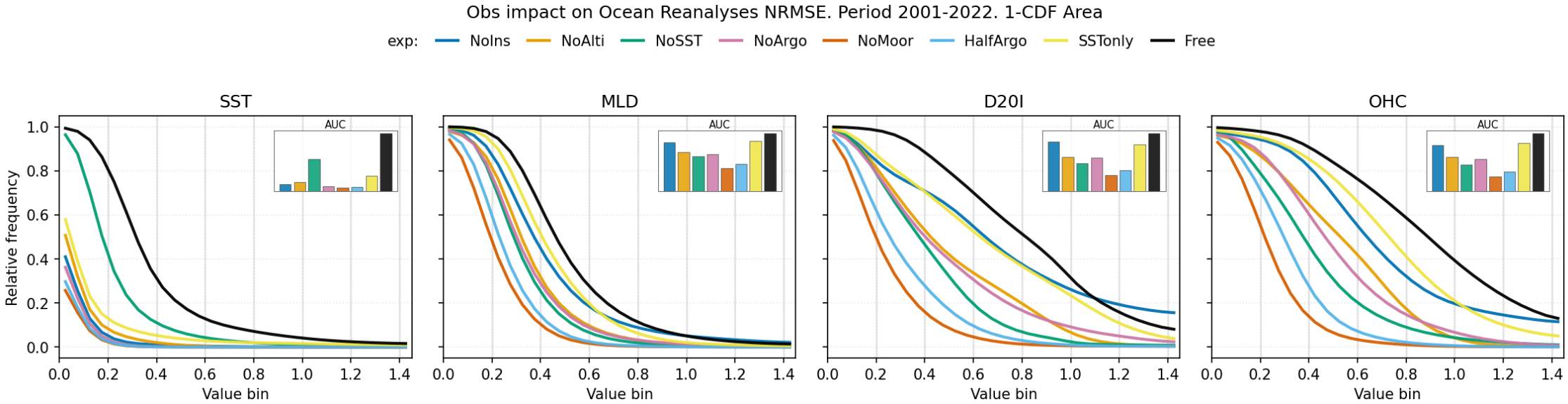
Inv-CDF Area



★ In Free, ~ 85% of area has SST normalized errors > 20% of variability

★ In SSTonly, ~40% of area has SST normalized errors > 20% of variability

Observation impact on ORA summary using Inv-CDF Area fraction

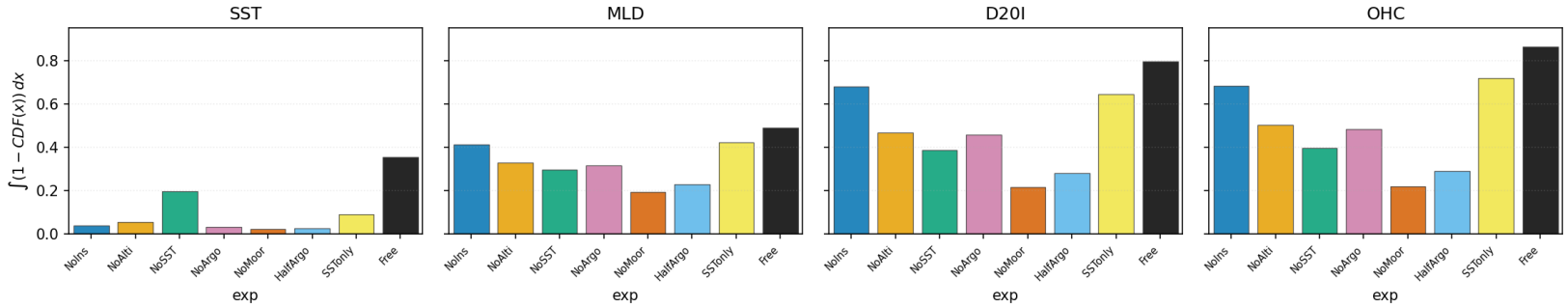


NoSST is the experiment with largest impact in SST (but not as much as Free), indicating that other observing systems help to constrain SST.Its impact MLD, OHC, D20 is commensurable with NoArgo

NoIns SSTonly and NoArgo have largest impact on MLD, OHC (with >30% of area with errors > 100% in upper OHC

NoMoor and HalfArgo show the smaller differences (as expected), but sill its impact on OHC/MLD errors is equivalent

- > 60% of area with errors > 20%
- ~40% of areas with errors larger than 40%



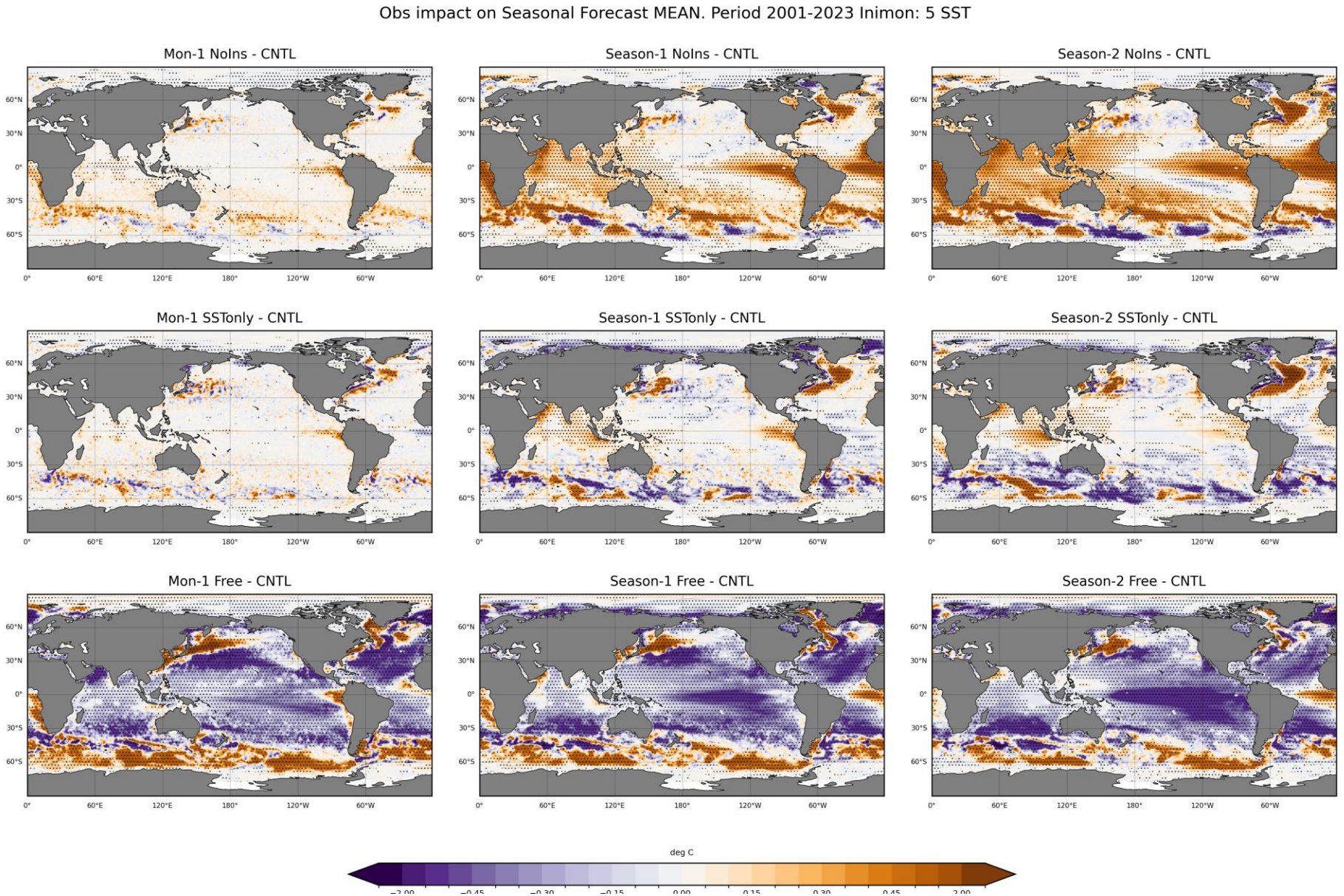
Average RMSE

Summary so far

- ORA-OSES:
  - Without Insitu climate signals unrealistic (OHC, Salt content, Steric Height, AMOC…). This is more acute when assimilating altimeter data.
  - Sea Ice assimilation needed to constrain ice properties
  - Spatial aggregation of normalized RMSE has been used to quantify observation impact.
    - SST absolutely needed to constrain SST, but insitu also helps to constrain the surface
    - Without Insitu there is large discrepancy in OHC, MLD, D20. (~ 60% of ocean area exhibiting errors > 80%)

What about impact on seasonal forecasts?

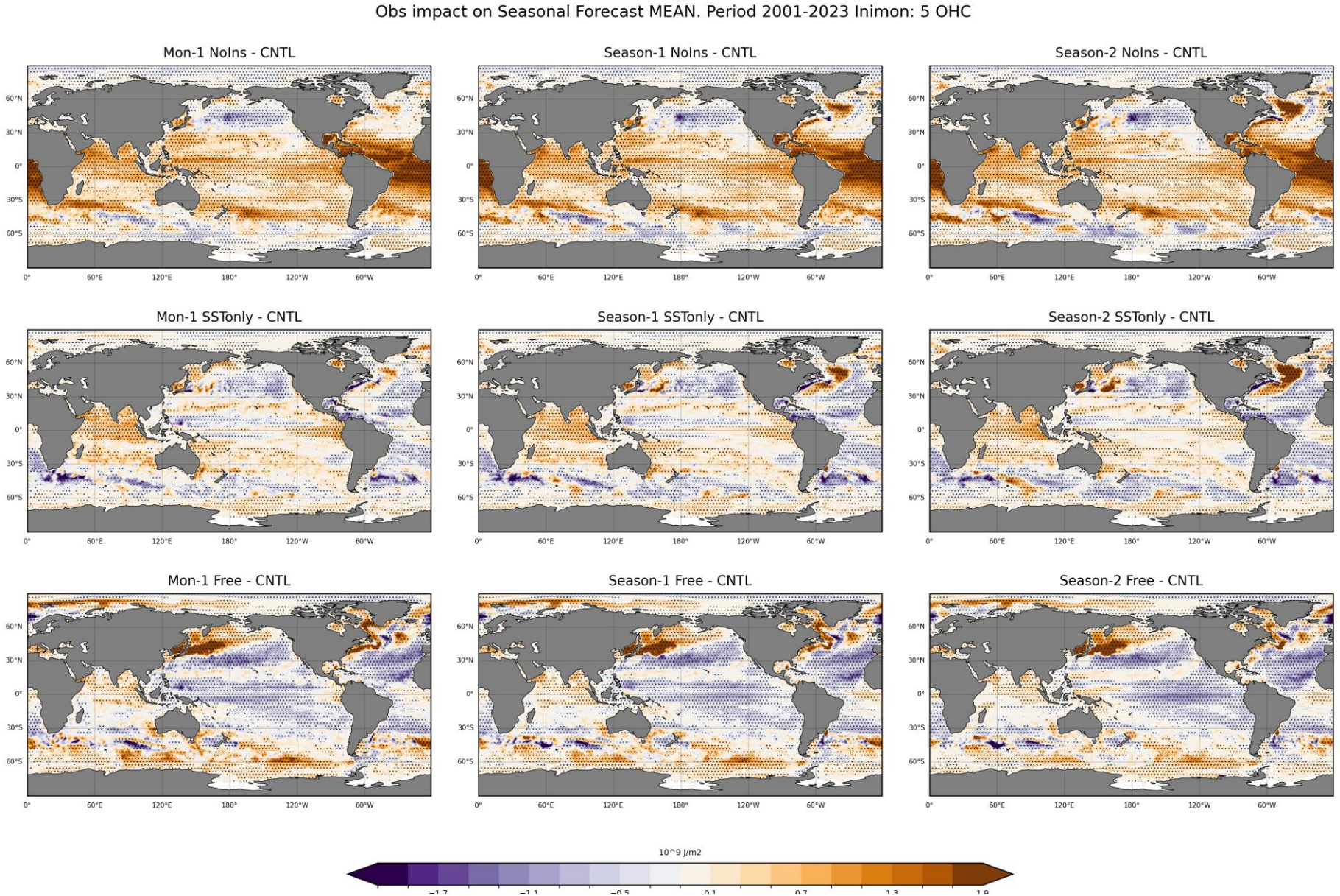
Impact on FC ocean variables mean state: SST



Growing modes:

- Tropics: ENSO,TropAtl, IOD,
- North Atlantic SPG
- Kuroshio and Gulf Stream extensions: Fast growth.

Impact on FC ocean variables mean state OHC



Signal on OHC mostly responsible for impact on SST forecasts?

OHC: quite persistent, except for growth in

- NA-SPG in NoIns and SSTonly
- Equatorial Pacific

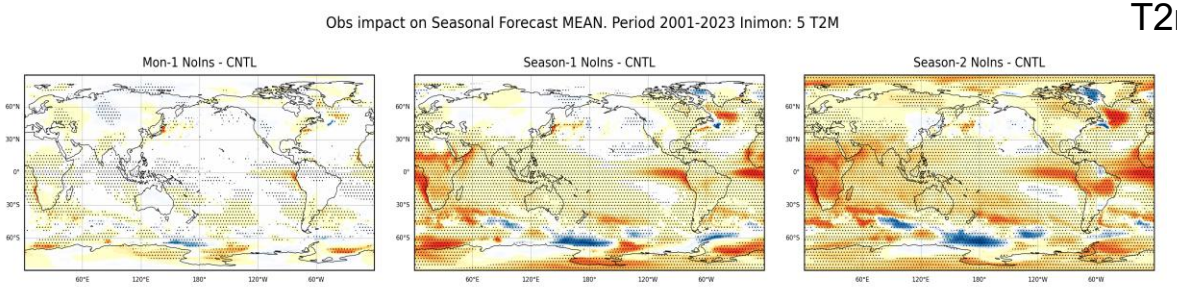
At mid latitudes, not all OHC signal appears on SST. It depends on the seasonality of the MLD (not shown)

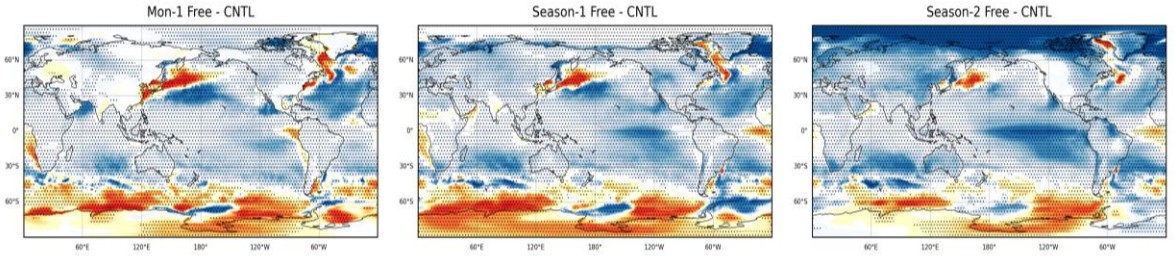
Impact on atmospheric variables mean: May starts

NoIns -CNTL

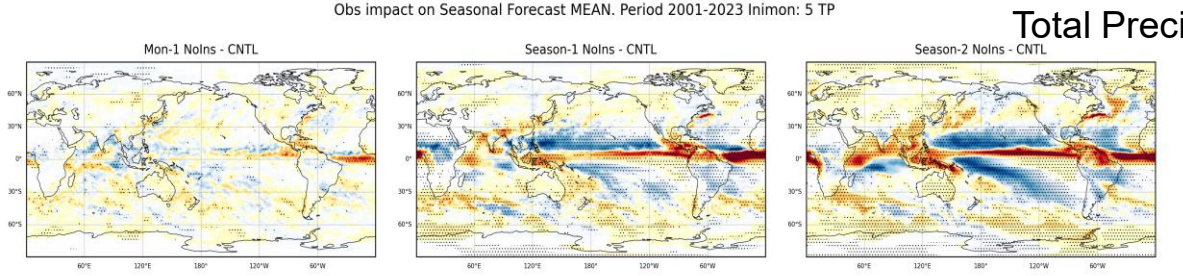
Free - CNTL

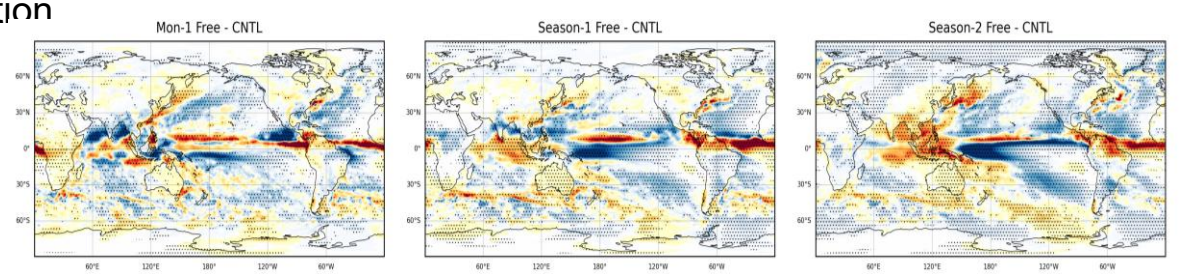
T2m



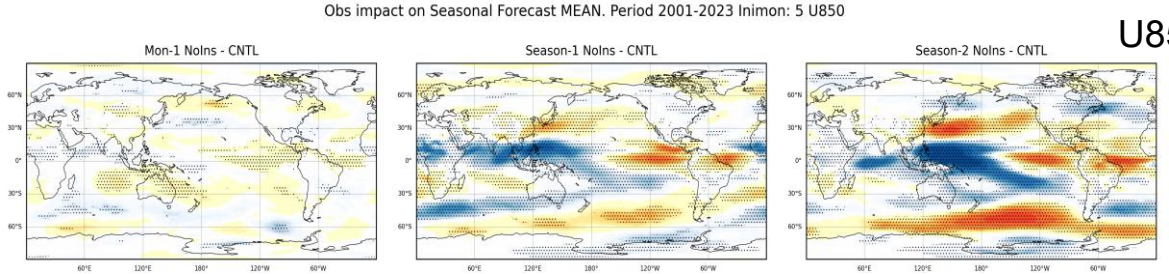


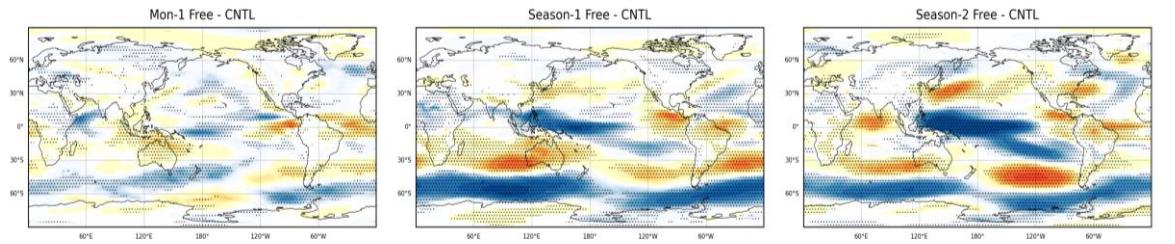
Total Precipitation





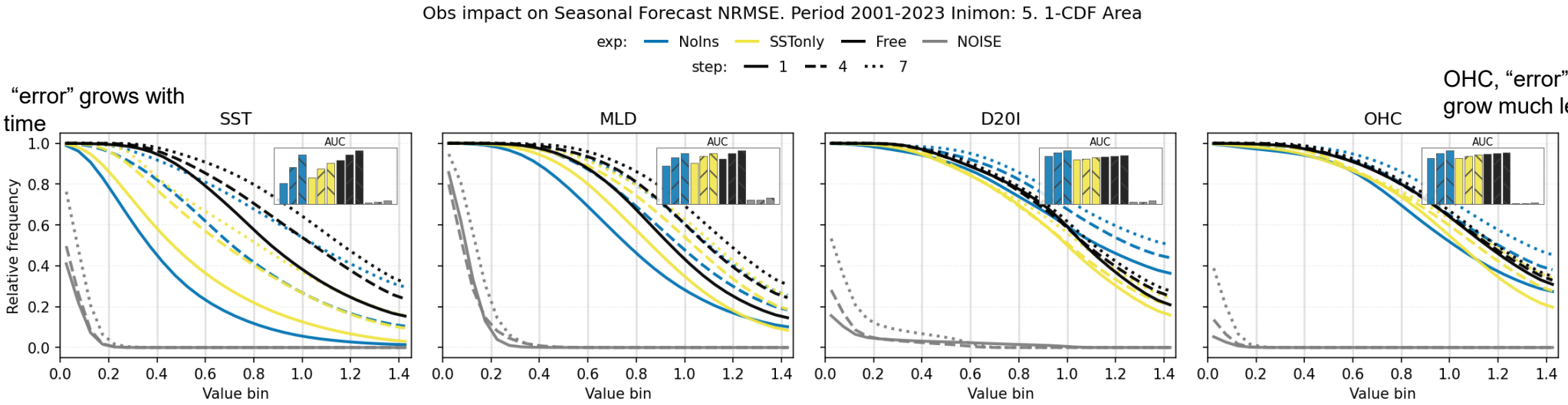
U850





Large impact on T2m, Precip, Circulation (winds), with opposite sign in NoIns and Free
Impact grows with lead time.

Summary of impact using Inv-CDF Area fraction. Perfect model assumption



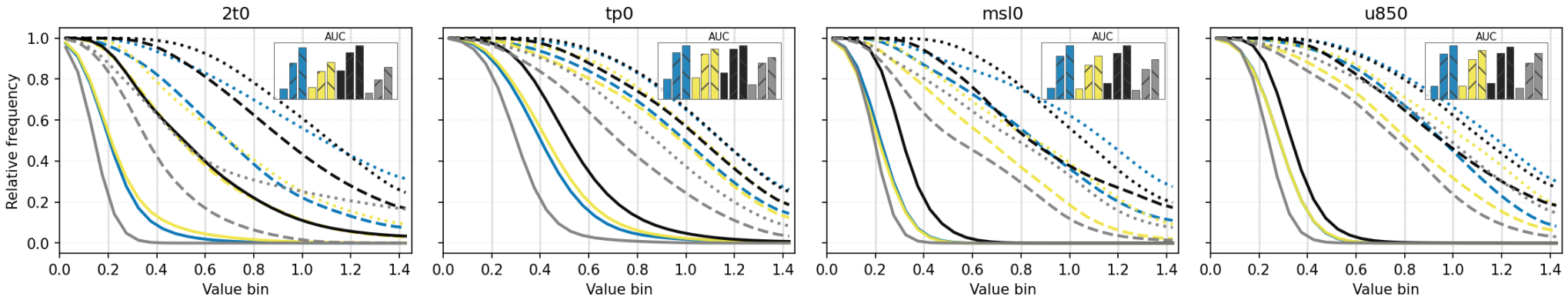
SST "error" grows with lead time

OHC, "error" does not grow much lead time

Ocean

Grey curve/bars: sample noise

Atmosphere less predictable => sample noise growth is larger than in ocean, so detecting observation impact is more challenging



Atmos

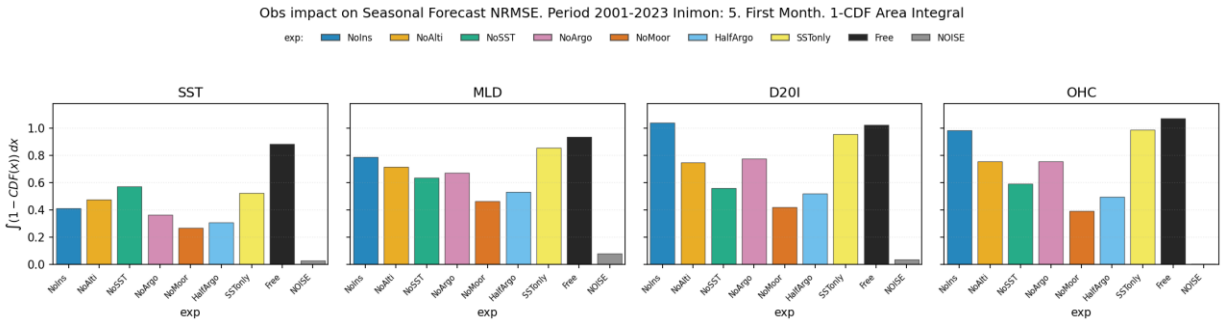
In the atmosphere variables, the "error" in the ocean initial conditions grows with lead time and propagates to all variables. "Error" grows with lead time, but so does the ensemble spread

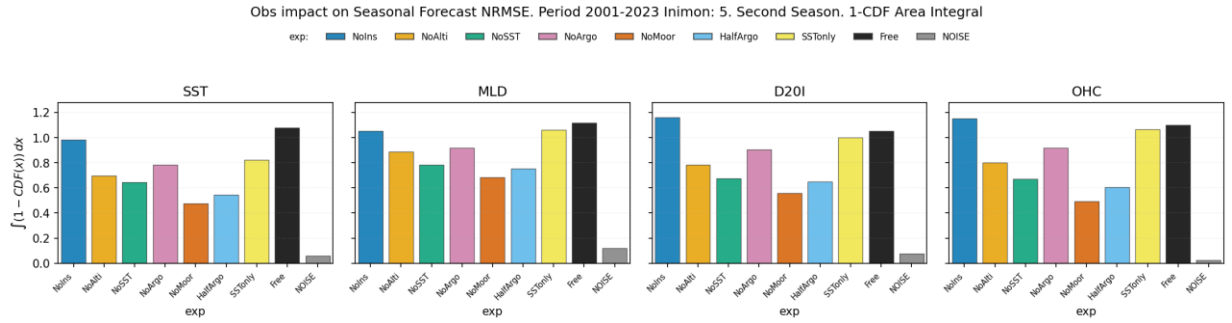
All experiments: First month and Second Season.

First Month

Ocean variables

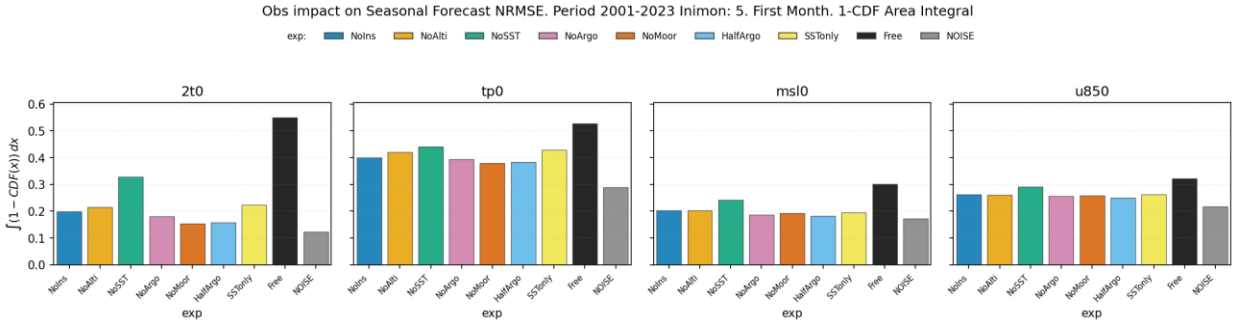
Second season

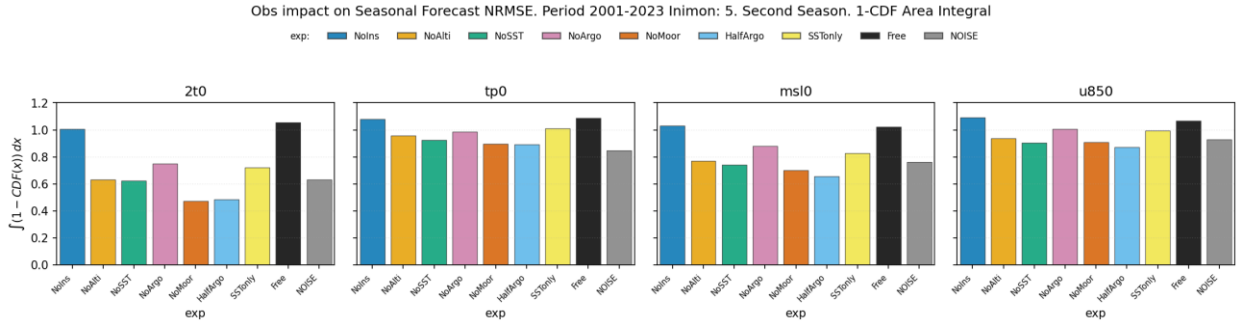




NoIns NoAlti NoSST NoArgo NoMoor HalfArgo SSTonly Free NOISE

Atmospheric variables



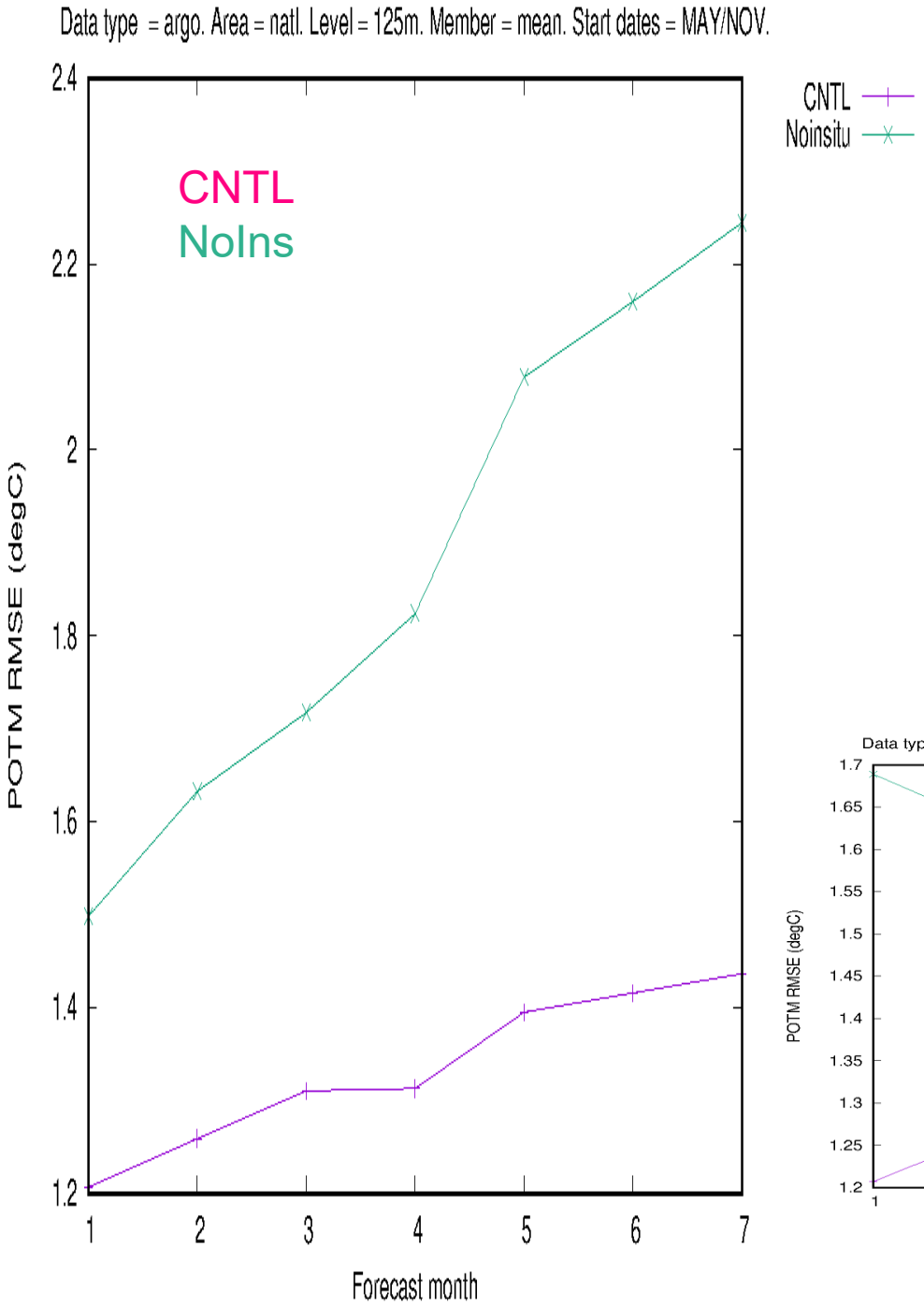


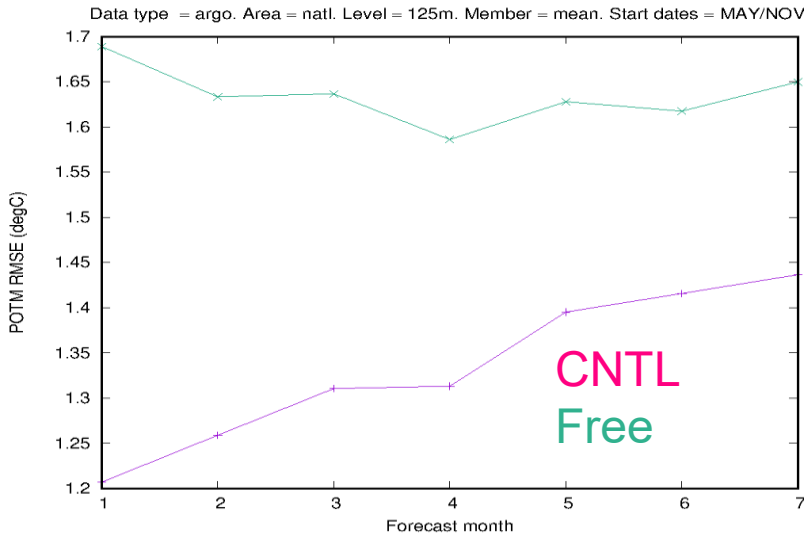
First month impact on atmospheric variables (other than t2m) is similar for all OSES (slightly larger for Free).
Note large impact on Precipitation

The impact grows with lead time, but so does the sample noise in atmospheric variables. In the 2nd season impact is still slightly larger than the noise. Note that NoInsitu errors ~ Free errors

Beyond Perfect model statistics, we can also look at fit to observations

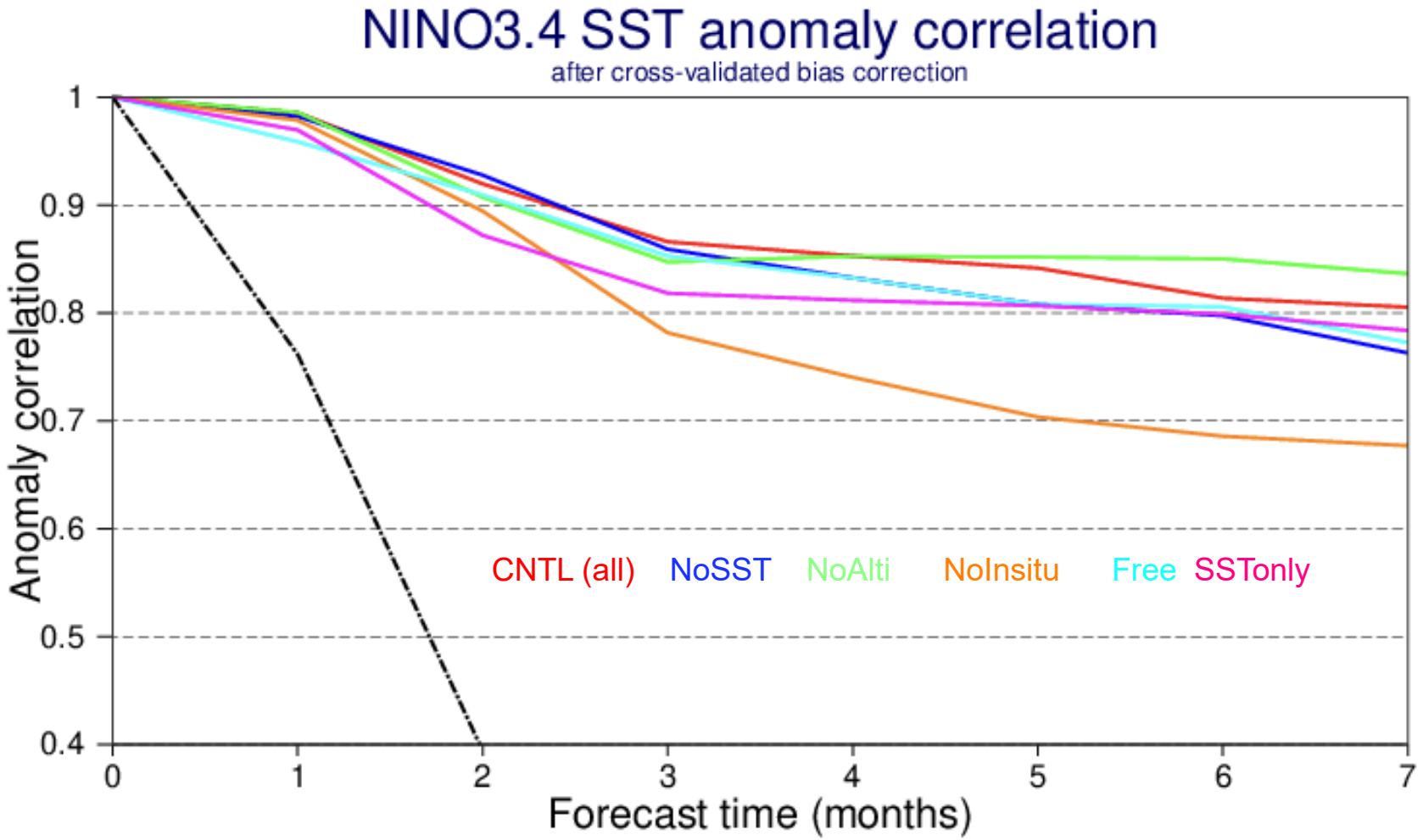
Error Growth in North Atlantic at 125m, fit to Argo temperature





The error growth in NoIns is much faster than in CNTL and that in Free

FC OSES: Skill (ACC). 2001-2023. May Starts



Most OSES worse that CNTL except for NoAlti , which is better than CNTL at longer lead times

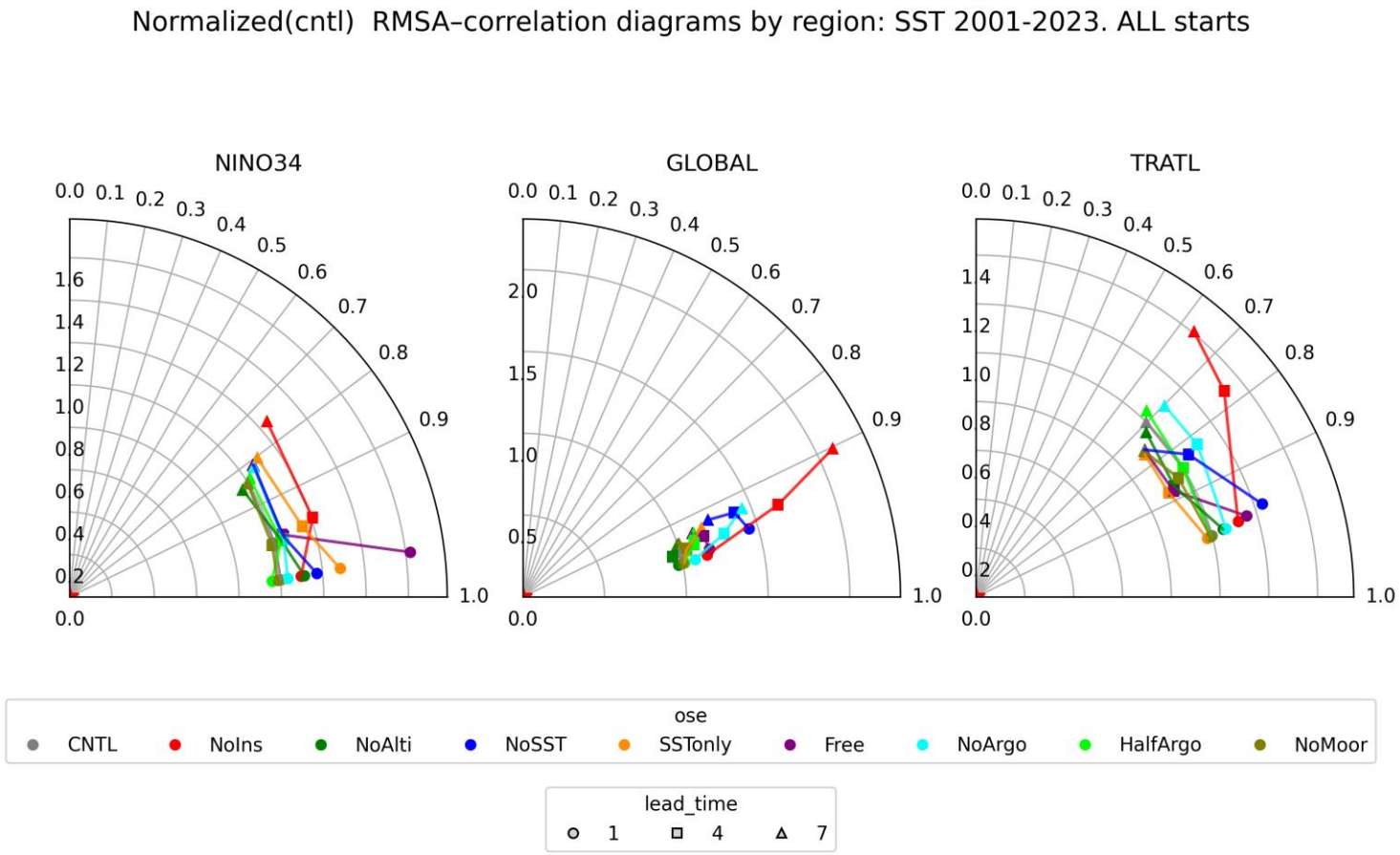
NoIns is the worst, followed by SSTonly

Normalized RMSA-Correlation diagrams

Radius: RMS/RMS(CNTL)
Control follows the circumference with radius 1, with decreasing correlation values with lead time

Any points outside unit circle worse than CNTL

Most of the OSES worse than CNTL at 1 month lead, but then differences collapse with time, except for **NoIns**



Summary

- ORA-OSES:
  - Without Insitu climate signals are unrealistic (OHC, Salt content, Steric Height, AMOC…). This is more acute when assimilating altimeter data.
  - Sea Ice assimilation needed to constrain ice properties
  - Spatial aggregation of normalized RMSE has been used to quantify observation impact.
    - SST absolutely needed to constrain SST, but insitu also helps to constrain the surface
    - Without Insitu there is large discrepancy in OHC, MLD, D20. (~ 60% of ocean area exhibiting errors > 80%)

- FC-OSES:
  - Physical considerations: (1) there are error growing modes in Tropics, NASPG, Kuroshio. (2) Strong seasonality in the response, i) with larger error growth in May starts and i) impact of subsurface more noticeable during the winter. (3) The impact on ocean variables more noticeable than in atmospheric variables (less sampling noise/more predictability). (4) Impact is non local, mediated by atmospheric bridge. Importance of uniform distribution of observations.
  - Under prefect model assumption, the impact of ocean observations ranges from 20% to > 100%. NoInsitu can be worse than Free at longer lead times.
  - Data is available for comparison of forecasts with observations, at observation location.
  - ENSO skill is clearly degraded without in-situ observations
  - The skill for SST in the first month is degraded in all OSEs.