Development of a global ocean ensemble data assimilation and prediction system at the Met Office.

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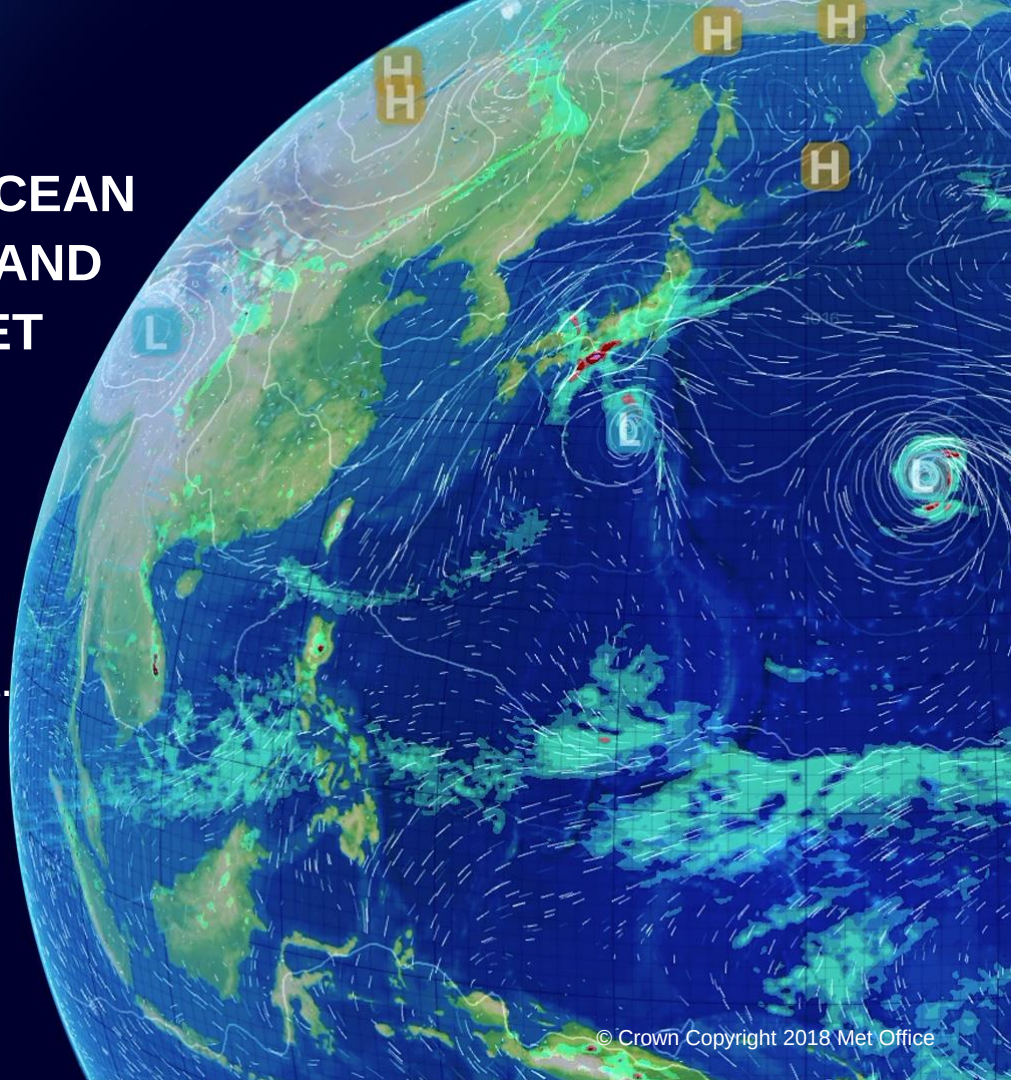


Introduction

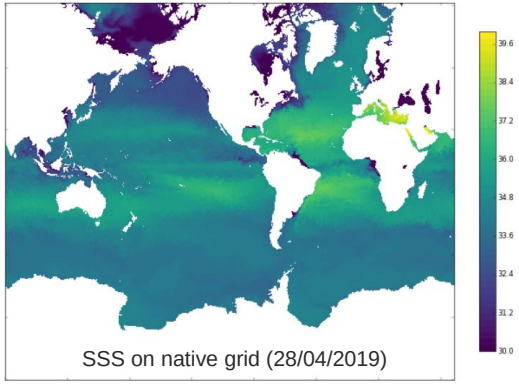
- At the Met Office we are in the process of developing a global ensemble ocean prediction system that includes assimilation.

- Eventually, the ensemble system will allow us to:
  - Perform ensemble forecasts/hindcasts of the ocean.
  - Run coupled ensemble forecasts/hindcasts of the ocean and atmosphere.
  - Use ensemble forecast error information in a hybrid data assimilation scheme. See the talk by Dan Lea.

- At the present time we have:
  - An ensemble of 3DVars with 37 members (limited by the number of atmospheric states available for forcing).
  - Atmospheric forcing coming from the Met Office's MOGREPS-G ensemble atmospheric system.
  - Each ocean member assimilating perturbed observations using a 3DVar-FGAT scheme.
  - No pertubations of physics or inflation.

The ocean (and ice) model

The Forecasting Ocean Assimilating Model (FOAM)



SSS on native grid (28/04/2019)

Ocean Model: NEMO Vn3.6

Sea ice model: CICE Vn5.1

Resolution: ORCA025 extended tri-polar grid (~1/4 degree resolution); 75 vertical levels

Analysis update: Daily

Data assimilation scheme: 3DVar-FGAT (First Guess At Appropriate Time) using the NEMOVAR code base. Increments applied using an IAU scheme.

Assimilated observations: Satellite SST (various sources), drifting buoy SST, ARGO profiles, Satellite Altimetry (various sources). sea-ice concentration, data from ships, fixed moorings.

Assimilation length scales: Spatially varying function of Rossby radius (short scale) and 4 degree scale (long scale) in horizontal. Mixed layer parameterisation in vertical.

Atmospheric forcing.

All ensemble members use the CORE bulk formulation to apply atmospheric forcing with forcing updates every:
Wind: hourly
Other forcing: 3 hourly

The forcing applied to the model can be split into 3 types:

1.

Forcing from the Met Offices full resolution NWP system (the UM).

Used to force the single member Ocean ‘control’.

Resolution: N1280 (~10km)

Atm assimilation: Hybrid 4DVar

2.

Forcing from the Met Offices atmospheric ensemble system the Met Office Global Regional Ensemble Prediction System–Global (MOGREPS-G)

Up to 18 members can be forced with this data

Resolution: N640 (~20km)

Atm assimilation: ETKF (until later this year)

MOGREPS-G uses a combination of the ETKF and inflation techniques to ensure a good spread of members

Every assimilation cycle MOGREPS-G is re-centred on the high resolution NWP system (until later this year).

3.

Forcing from lagged MOGREPS-G data.

We use 6 hour lagged data

Up to 18 members can be forced with this data

Resolution: N640 (~20km)

Atm assimilation: ETKF

Total possible members: 1+18+18=37

Observation perturbations.

In each ensemble member perturbations can be added to observations of SST, SLA, sea ice concentration, and T&S profiles.

We use two independent methods, which can be combined, to perturb the observations

$$y'(lon, lat) = y(lon + \varepsilon_{lon}, lat + \varepsilon_{lat}) + \varepsilon_{value}$$

Position perturbation

- Based on ideas developed at ECMWF (Zuo et al. [2018])
- Designed to simulate representativity error
- The statistics of Ɛ are not well known but are currently set at 0.1º, both in latitude and longitude.

Value perturbation

- Good at simulating measurement error
- The statistics of Ɛ are based on our (imperfect) estimates of the obs errors. Ɛ varies between observation platform.
- Presently we do not specify any vertical or horizontal correlations.

y: Observation y': Perturbed observation ε: Random number of specified distribution

Observation perturbations.

We have tested our setup in a set of 4 experiments:

Experiment	Run length	Observation perturbations
mogreps_cntl	March to May 2018	Value perturbation only. Globally constant statistics based on global mean of measurement error + representativity error.
ens_obsperts_2	March 2018	Value perturbations only. Spatially and seasonally varying statistics of measurement error + representativity error.
ens_obsperts_3	March 2018	Position perturbations only. 0.1º Standard deviation.
ens_obsperts_4	March to May 2018	Position and value perturbations. Value pertubations based on measurement error only. 0.1º Standard deviation for position pertubations.

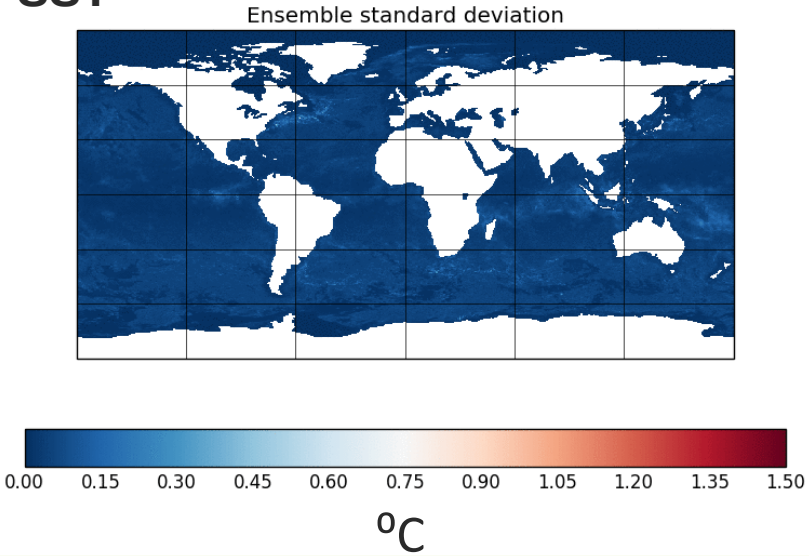
Ensemble Spread.

March in ens_obsperts_4

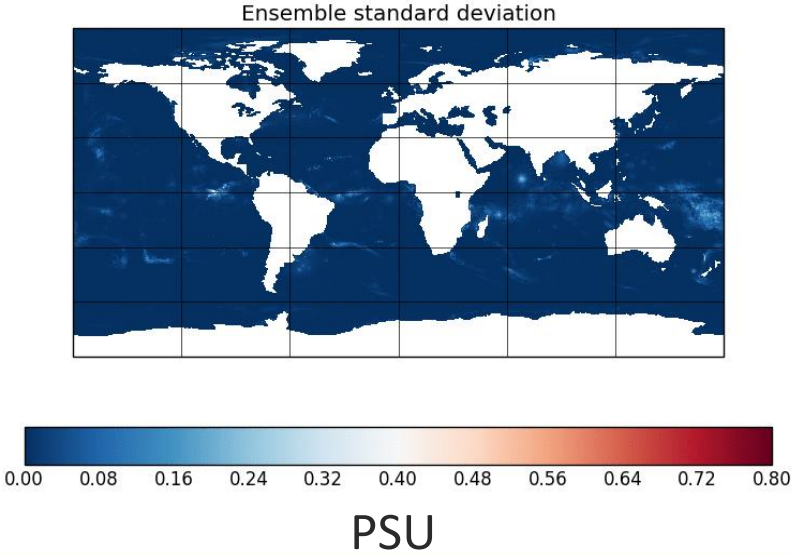
- Spin-up clearly visible
- As are day to day variations in the spread (errors of the day).

- Also seen are weather effects which would not be present if we just perturbed the forcing.

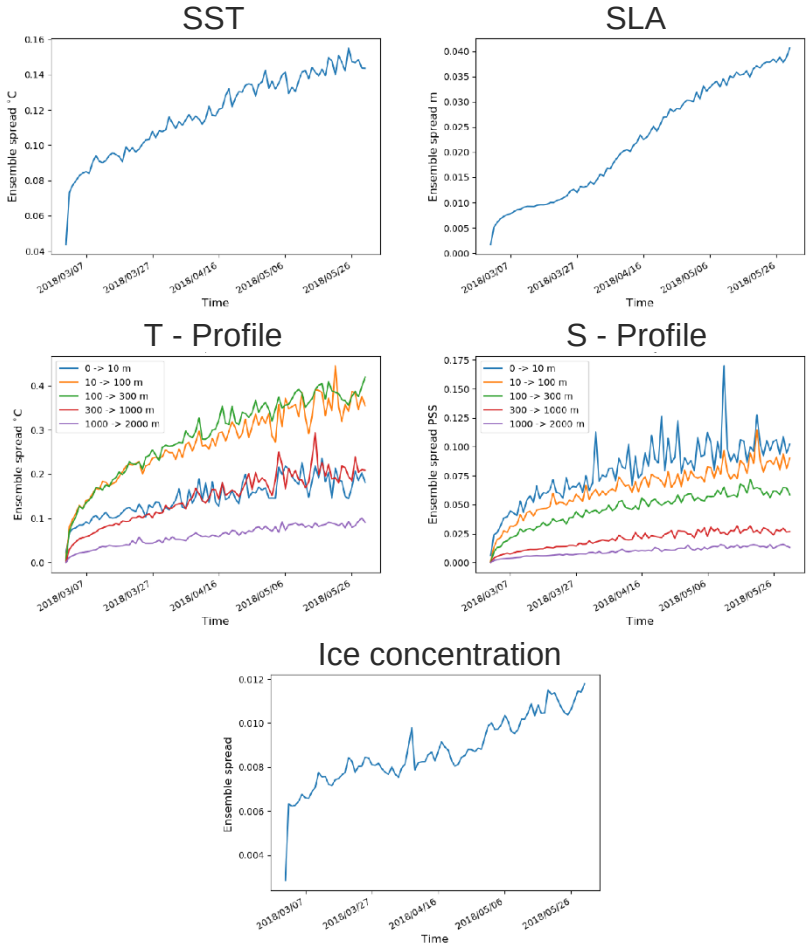
SST



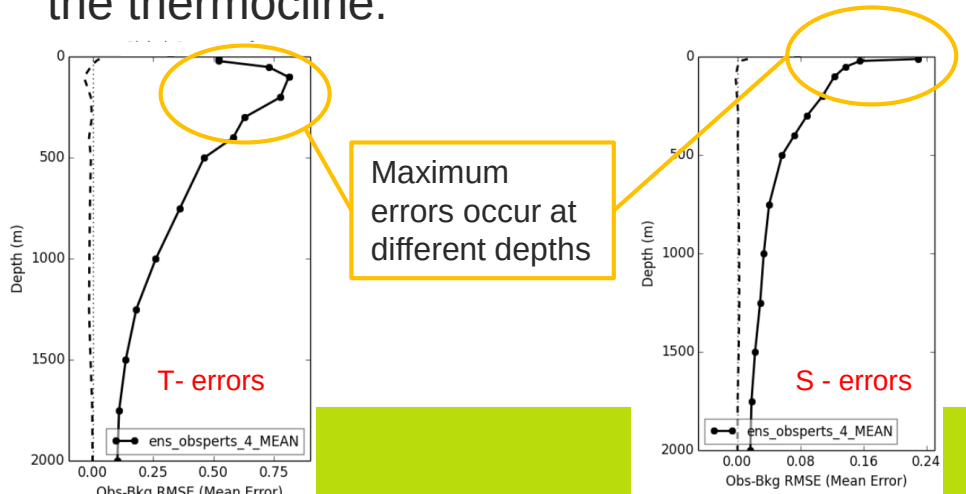
SSS



Ensemble spread and spin-up



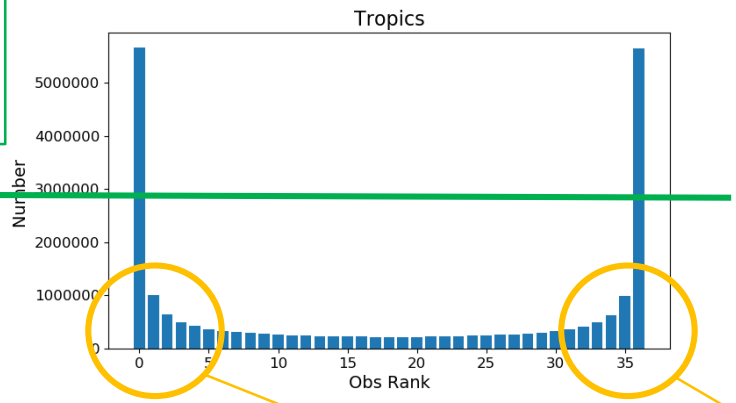
- All variables are still spinning up after 3 months.
- Spread decreases with depth for salinity.
- For temperature spread is maximum near the thermocline.



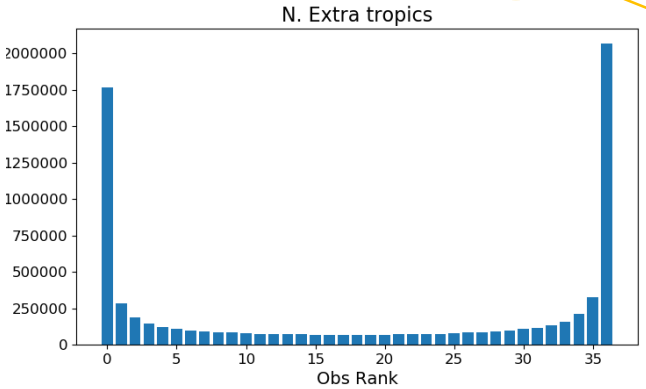
Histograms of observation rank

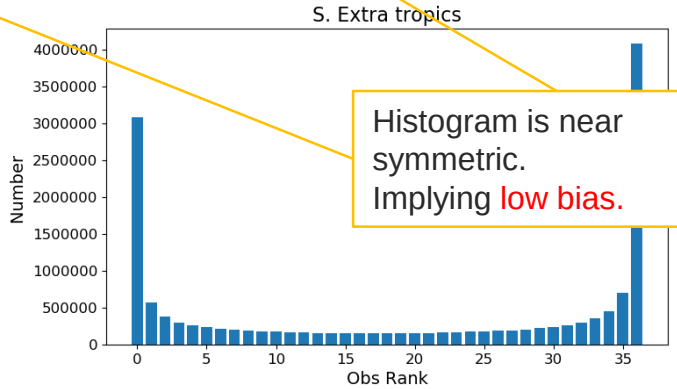
May 2018 in mogreps_cntl

Histogram is U-shaped, not flat.
Therefore the ensemble is under-spread



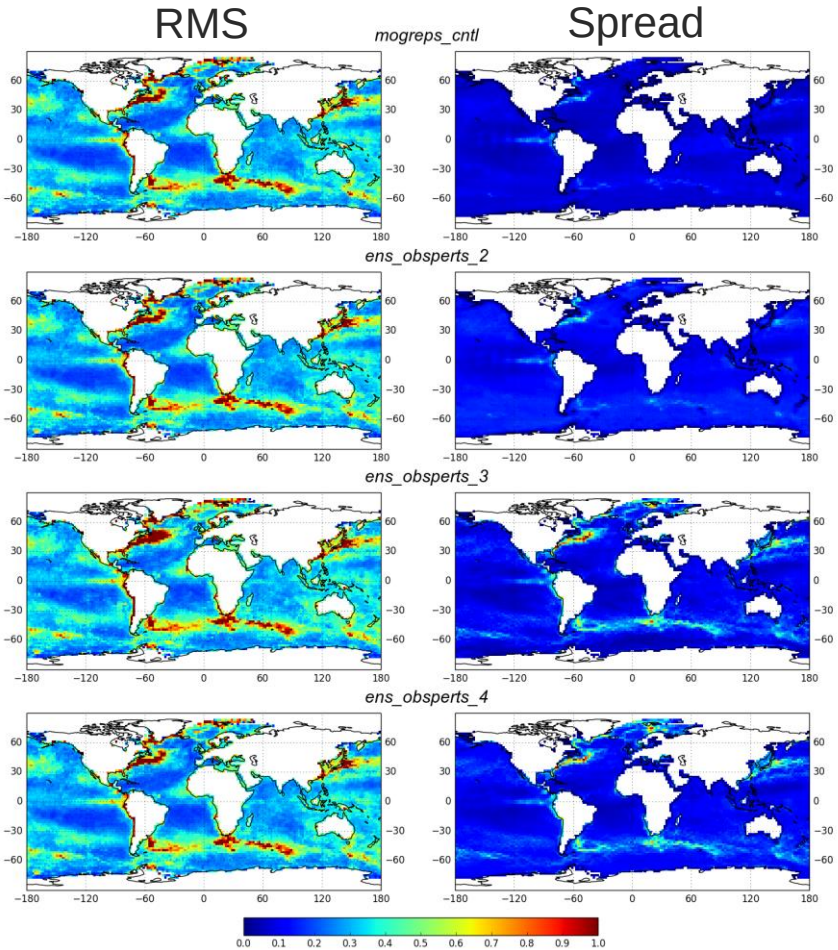
These histograms are for SST obs, but are representative of the results for other variables.





Histogram is near symmetric.
Implying low bias.

SST RMS Vs Ensemble Spread (March)



RMS is the RMS of the observations minus ensemble mean.

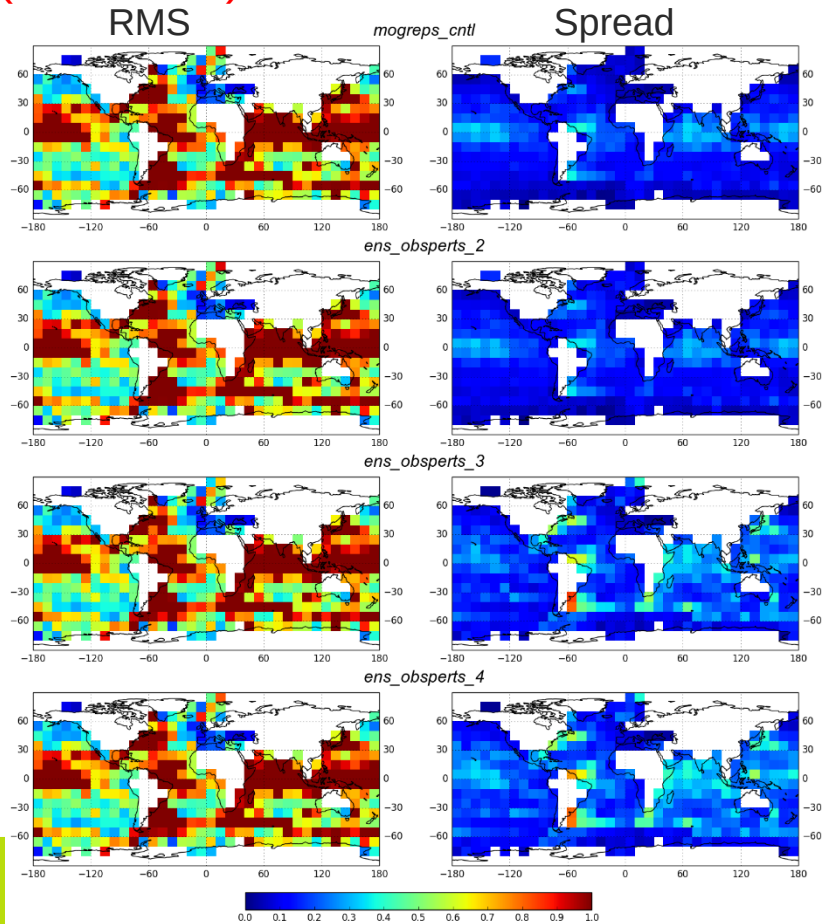
In a well spun-up system, the RMS should be the sum of the ensemble spread and observation error.

However, we know the system is under-spread

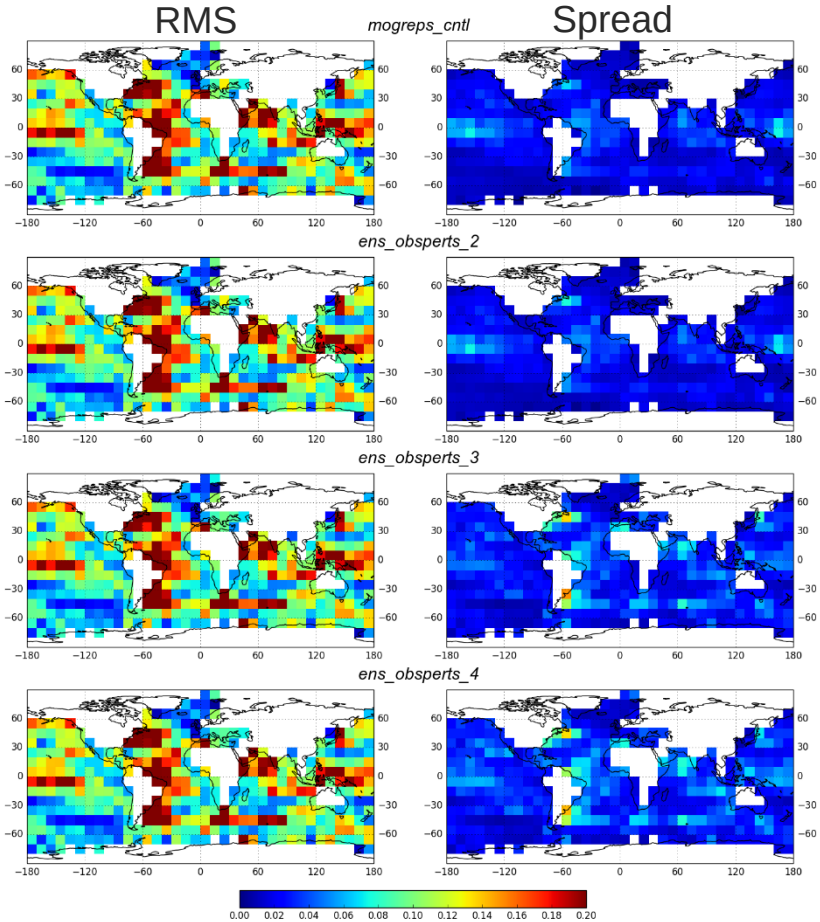
Position perturbations have had a bigger impact on spread than the value perturbations.

RMS Vs Ensemble Spread (March)

T (0 to 100m)

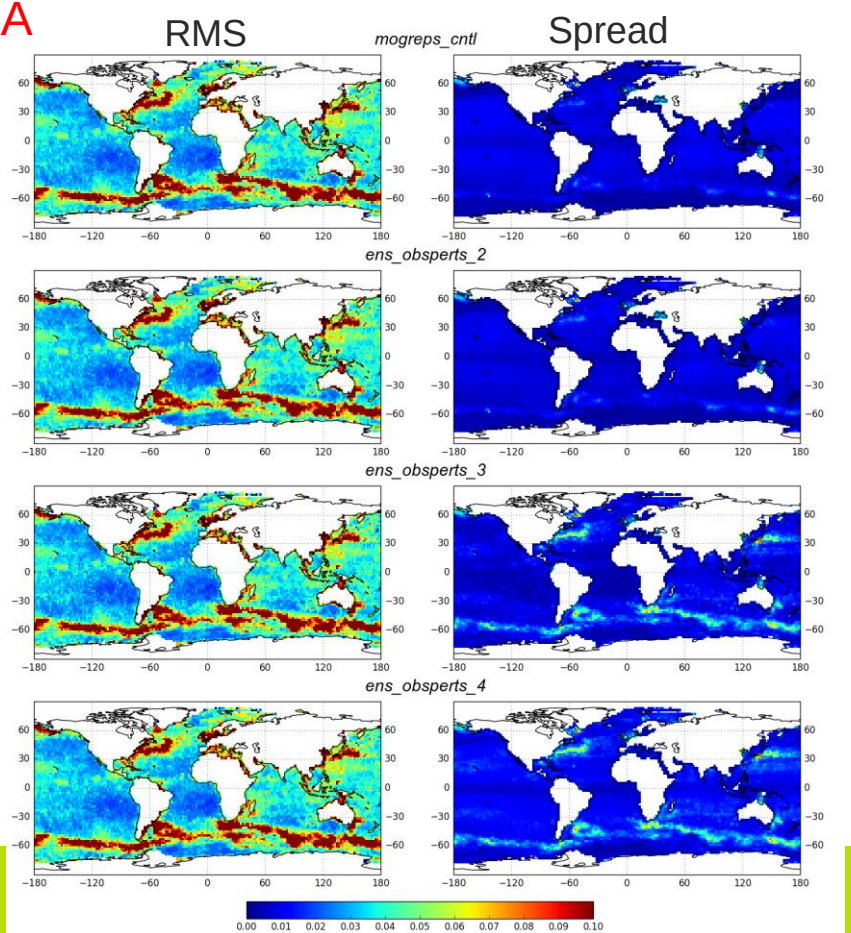


S (0 to 100m)

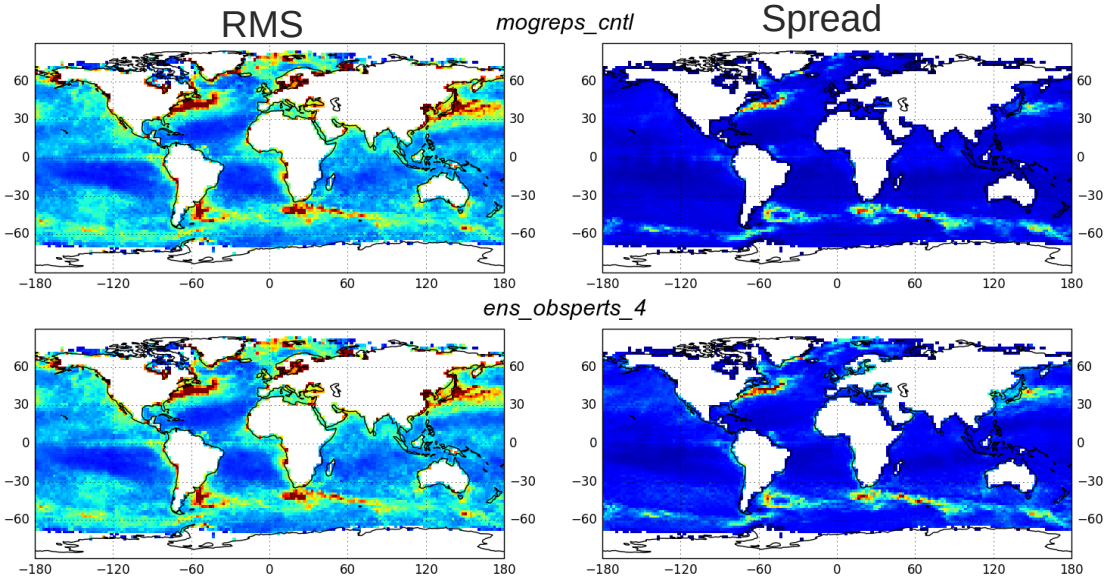


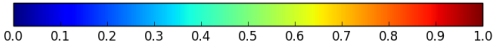
RMS Vs Ensemble Spread (March)

SLA



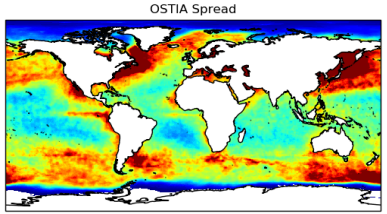
SST RMS Vs Ensemble Spread (May)





This is the SST spread seen by MOGREPS-G

It is the daily variability of the OSTIA analysis



Spread too large

Spread too small

Eventually we will want to couple the ocean ensemble system to MOGREPS-G.

At present the spread in SST is too small in our ensemble.

Conversely, the spread seen by the current uncoupled version of MOGREPS-G is almost certainly unrealistically large.

Future work

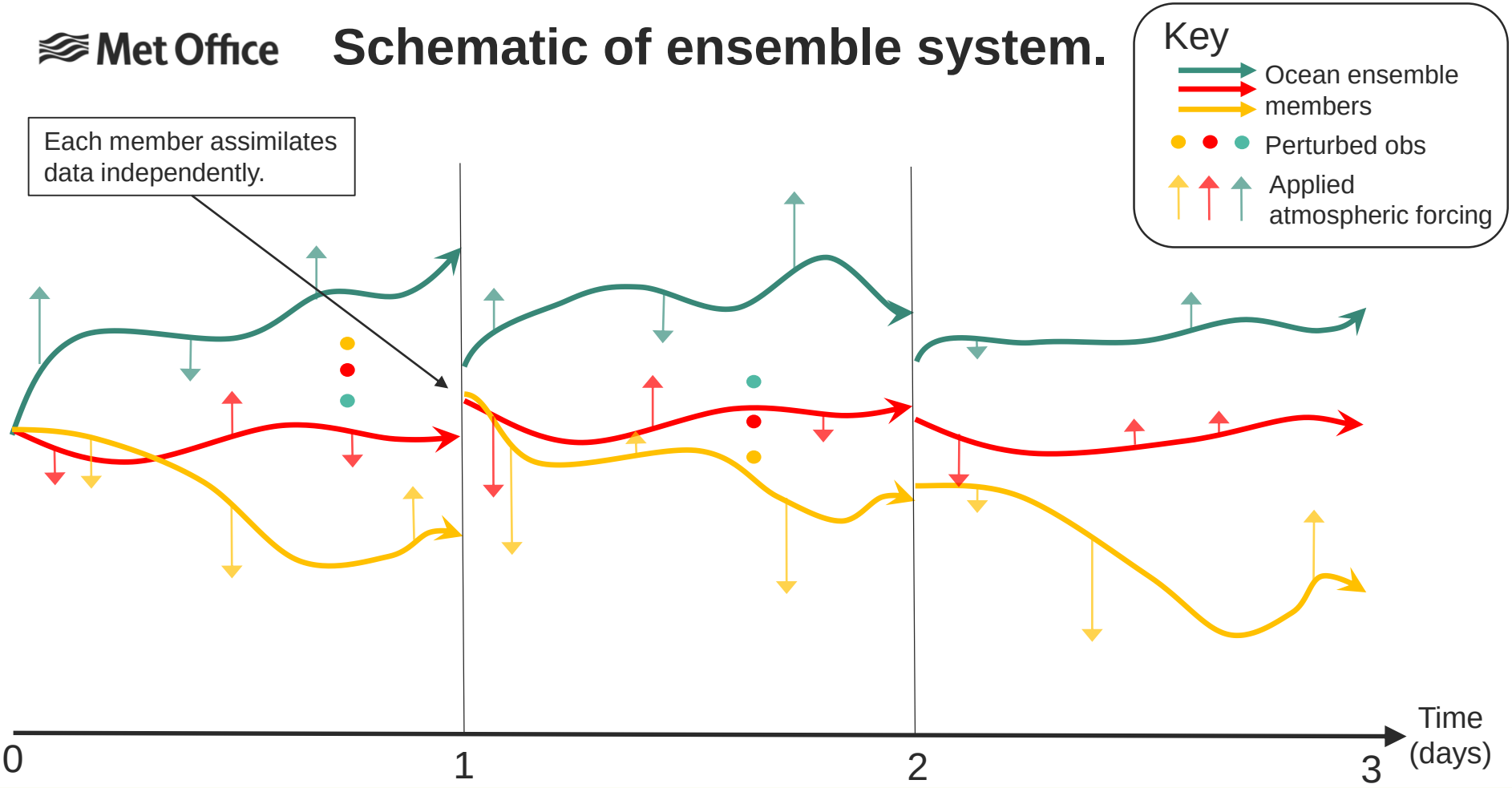
- Perform longer runs to see the ensemble system in equilibrium.
- Improve the spread by implementing inflation techniques and perturbations to model physics.
- Introduce hybrid ensemble DA methods to improve the analysis (see talk by Dan Lea)
- Couple the system with MOGREPS-G to give a full atmosphere-ocean ensemble system.
- Work is currently underway by Rob King (Met Office) and Sarah Zedler (National Oceanography Centre) on developing an ocean ensemble system in shelf seas.

Summary

- At the Met Office we have built an ocean ensemble data assimilation system with perturbed observations and MOGREPS-G forcing.
- It is planned, eventually, for the system to be used in a Hybrid variational/ensemble DA framework. And for the system to be coupled to MOGREPS-G
- At the present time the system appears under-spread. But it is relatively unbiased and shows the benefit of using a realistic atmospheric ensemble for forcing (rather than just perturbing the forcing).
- In our experiments, perturbed observation positions had a bigger impact on model spread than did perturbed observation values.
- Further improvements are planned (inflation, physics perturbations, hybrid DA) to improve the ensemble.

Met Office

Schematic of ensemble system.



Note: Although this diagram shows an instantaneous assimilation update. In practice we use an IAU scheme which is more gradual.