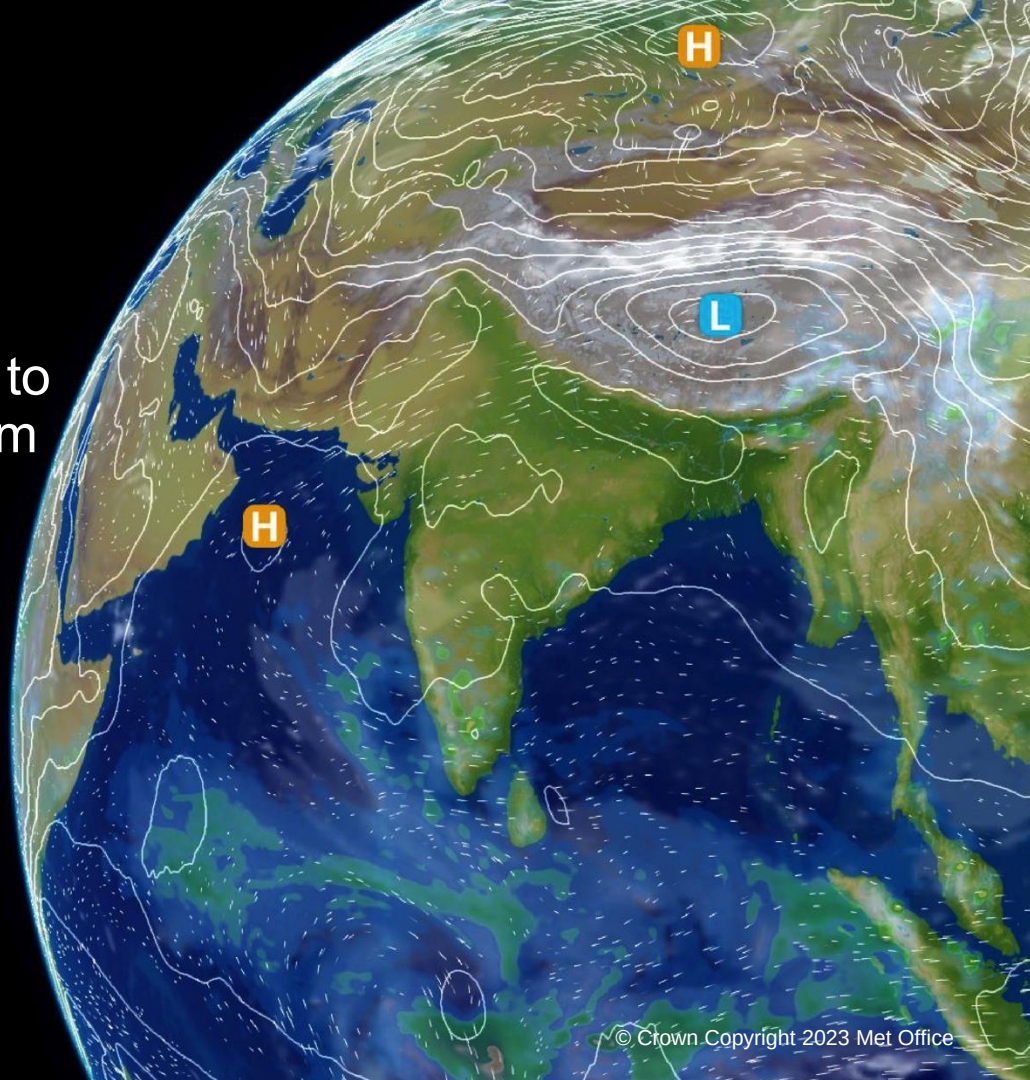
Adding ocean ensemble capability to the Met Office coupled NWP system

Dan Lea, Matt Martin, Martin Price, Jonah Roberts-Jones, Warren Tennant, and Chris Harris



Met Office

Ministry of Earth Sciences

Newton Fund

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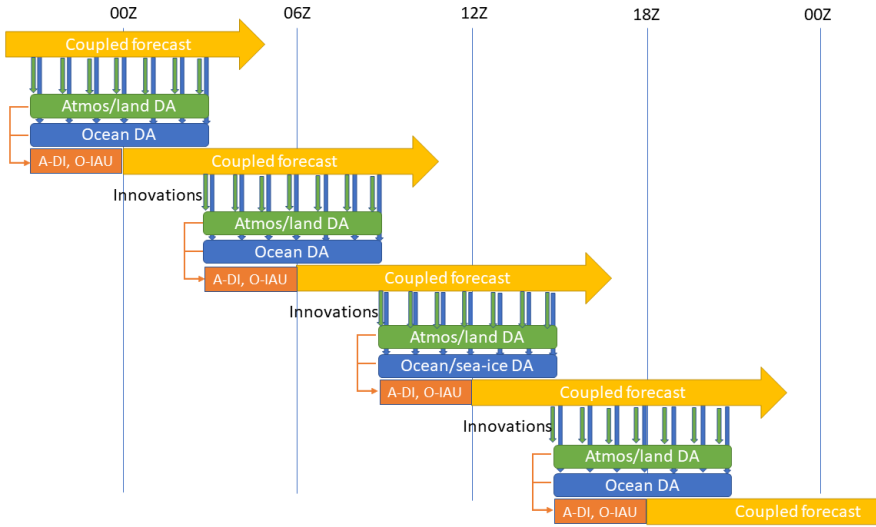
Building on previous work

- Coupled DA (which we developed) has evolved into the global coupled NWP system.
- More recently funded by WCSSP India we have developed an ocean ensemble system (in an ocean only system) which includes observation and model peturbations, and uses flux perturbations from the Met Office MOGREPS system
- The coupled NWP system does include a coupled ensemble system, but the ocean component is initialised from (the single) deterministic analysis. The spread in the ocean ensemble is therefore very small. An artifical SST perturbation is applied to the atmosphere ensemble to account for this.
- We have worked to improve on this by implementing our ocean ensemble work into the coupled NWP system



Summary of coupled NWP system and our developments

Atmosphere operationally at a higher resolution N1280/N640 our trials were at lower resolution to make them cheaper to run

	Atmosphere	Land	Ocean	Sea-ice
Deterministic model configuration	N640 (∼20 km) UM	N640 (∼20 km) JULES	1/4° (∼25 km) NEMO	1/4° (∼25 km) CICE
Ensemble model configuration	N320 (∼40 km) UM	N320 (∼40 km) JULES	1/4° (∼25 km) NEMO	1/4° (∼25 km) CICE
Ensemble data assimilation approach	Ensemble of 4DEnVars with RTPP	EKF	Ensemble of 3DVars or hybrid-3DEnVars with perturbed observation values and positions	Ensemble of 3DVars with perturbed observation values and positions
Stochastic model perturbations	SPPT, SKEB	Breeding method	SPP, SPPT, SKEB	–
Ensemble inflation	Additive inflation and RTPS	–	RTPS (when hybrid-3DEnVar activated)	–

Table 1: Summary of the coupled ensemble system and developments made to the ocean/sea-ice components (which are in red text). Note that the operational atmosphere/land resolution is N1280 (∼10 km) for the deterministic forecast and N640 (∼20 km) for the ensemble.

Coupled NWP trials

Trials run from 1 Dec 2019 – 29 Feb 2020 – All coupled ocean, land, ocean, sea ice systems.

Experiments:

Control - as with the existing coupled NWP system (SST pert 2x)

OEn3DVar - 3DVar ensemble trial (0 SST pert)

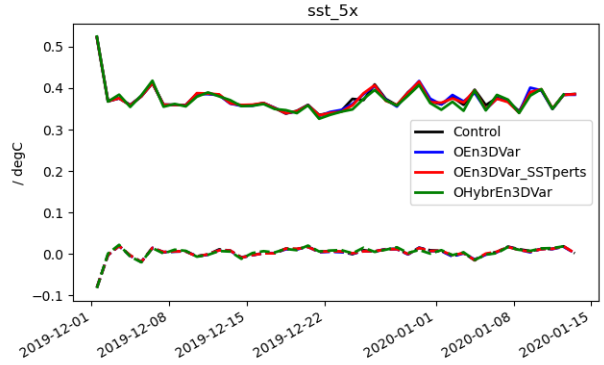
OEn3DVar SSTperts - 3DVar ensemble with SST perturbation ON reduced (SST Pert 1.8x)

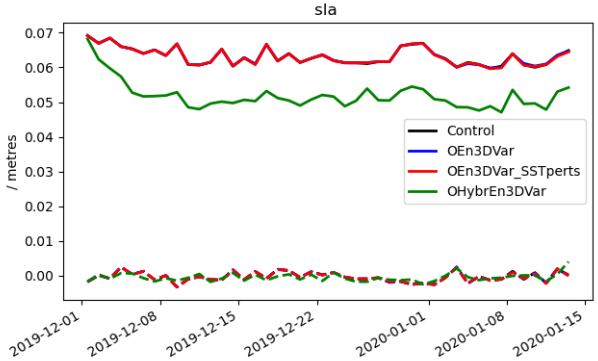
OHybrEn3DVar - Hybrid 3DVar ensemble (0 SST pert)

The *control* and *SSTperts* experiments have SST perturbations applied which are taken from the OSTIA daily mean variability (quite large and should always higher than the SST forecast error).

Ocean stats

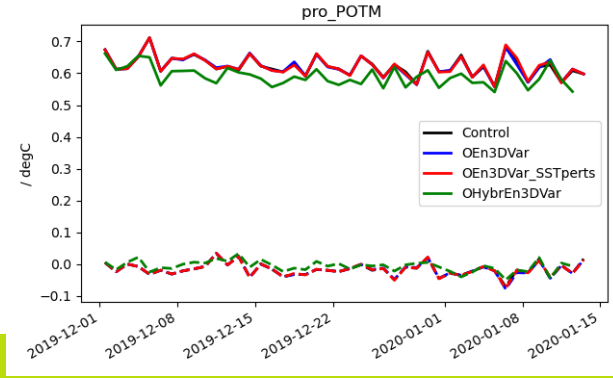
Deterministic: SST, SSH, prof T, S innovations

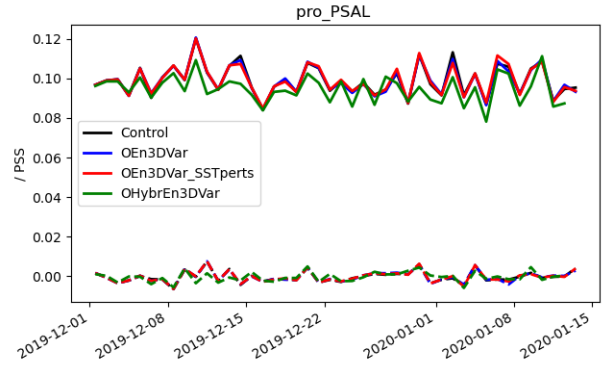




RMS

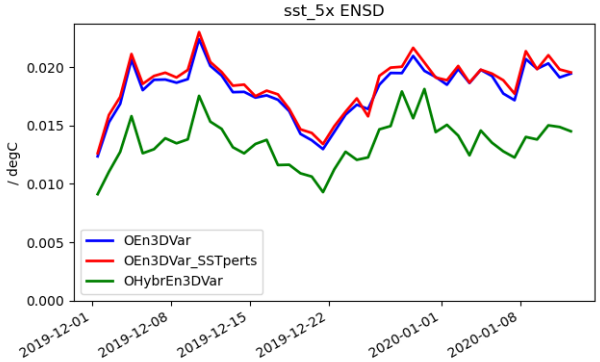
mean

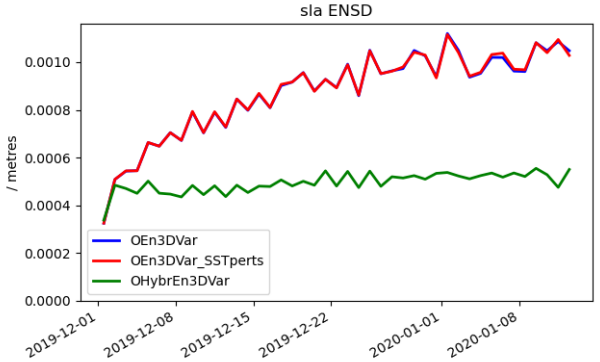


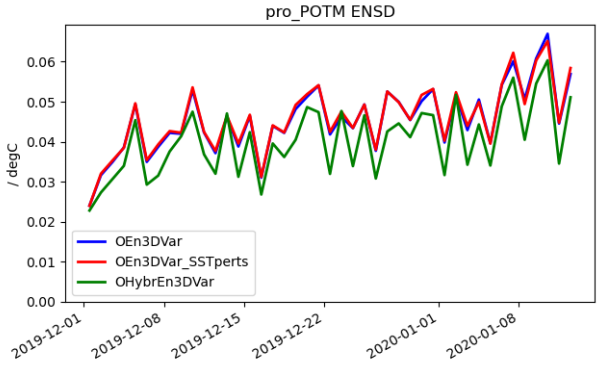


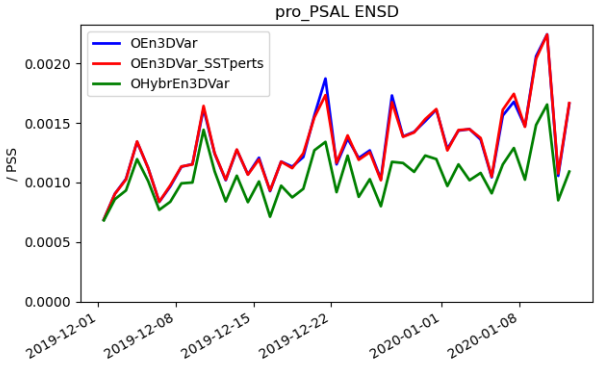
Ocean stats

Ensemble spread for SST, SSH, prof T, S







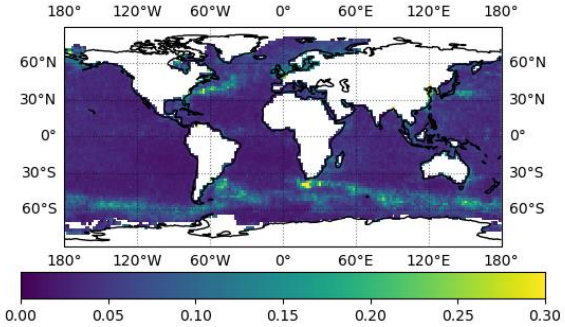


Ocean spatial plots

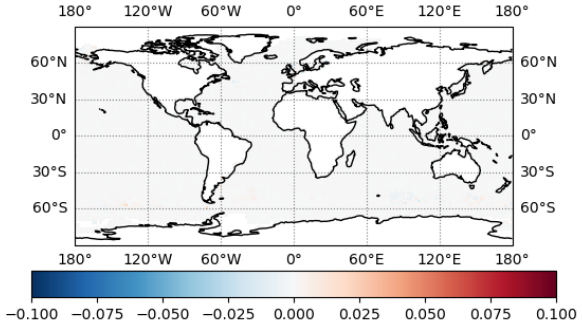
SLA ensemble mean RMSE and std dev (spread) / m

Ens. mean RMSE

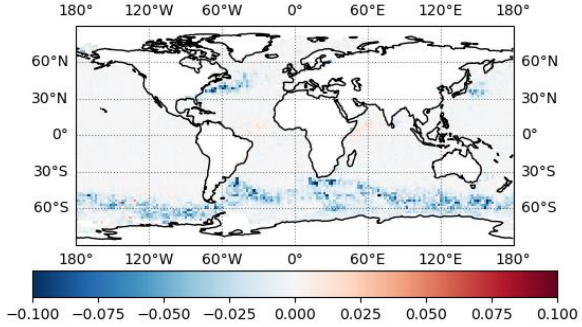
OEn3DVar



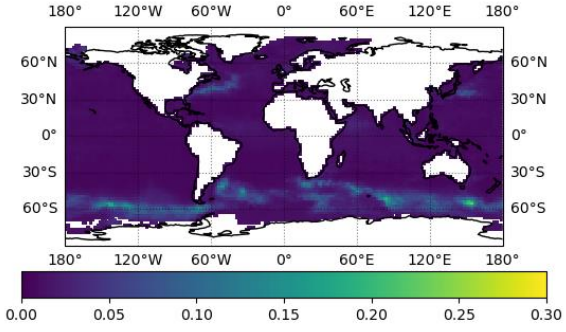
OEn3DVar SSTperts (diff)

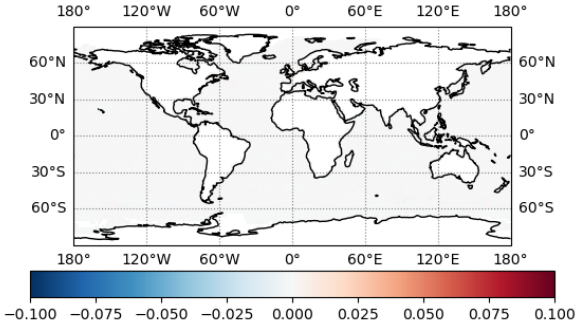


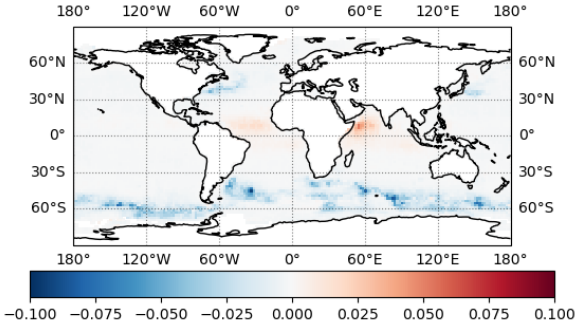
OHybrEn3DVar (diff)



Ens. spread







For difference plots red bigger, blue smaller

SST ensemble spread

Control starts off each cycle with zero ocean ensemble spread

Including the ocean ensemble allows a more realistic ensemble spread to build up

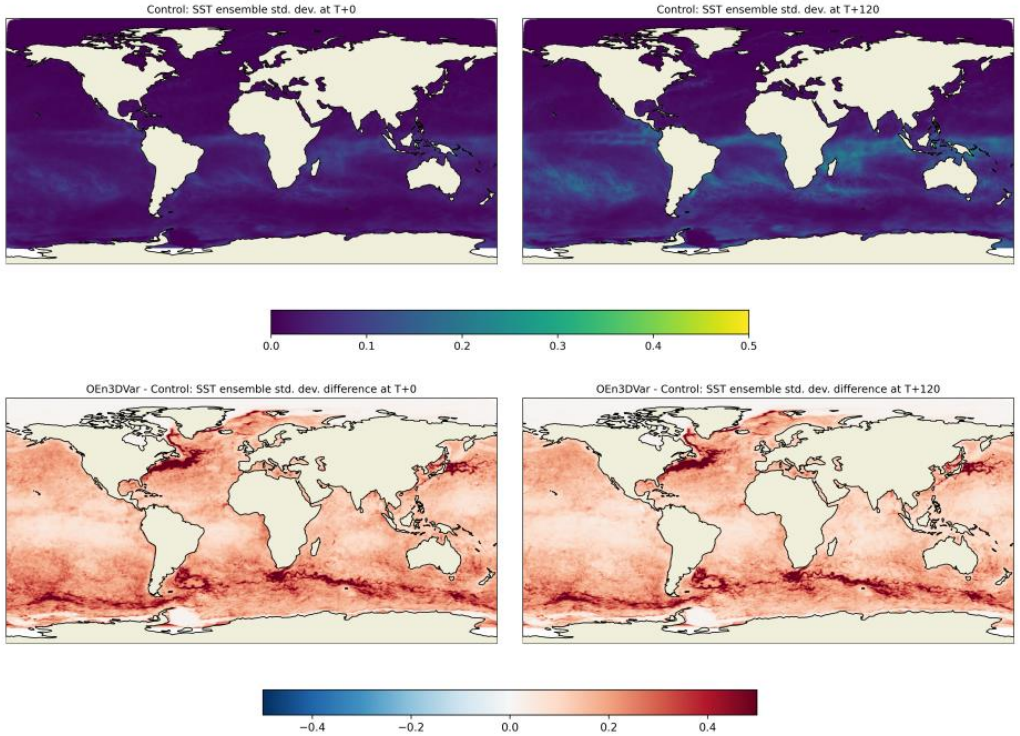


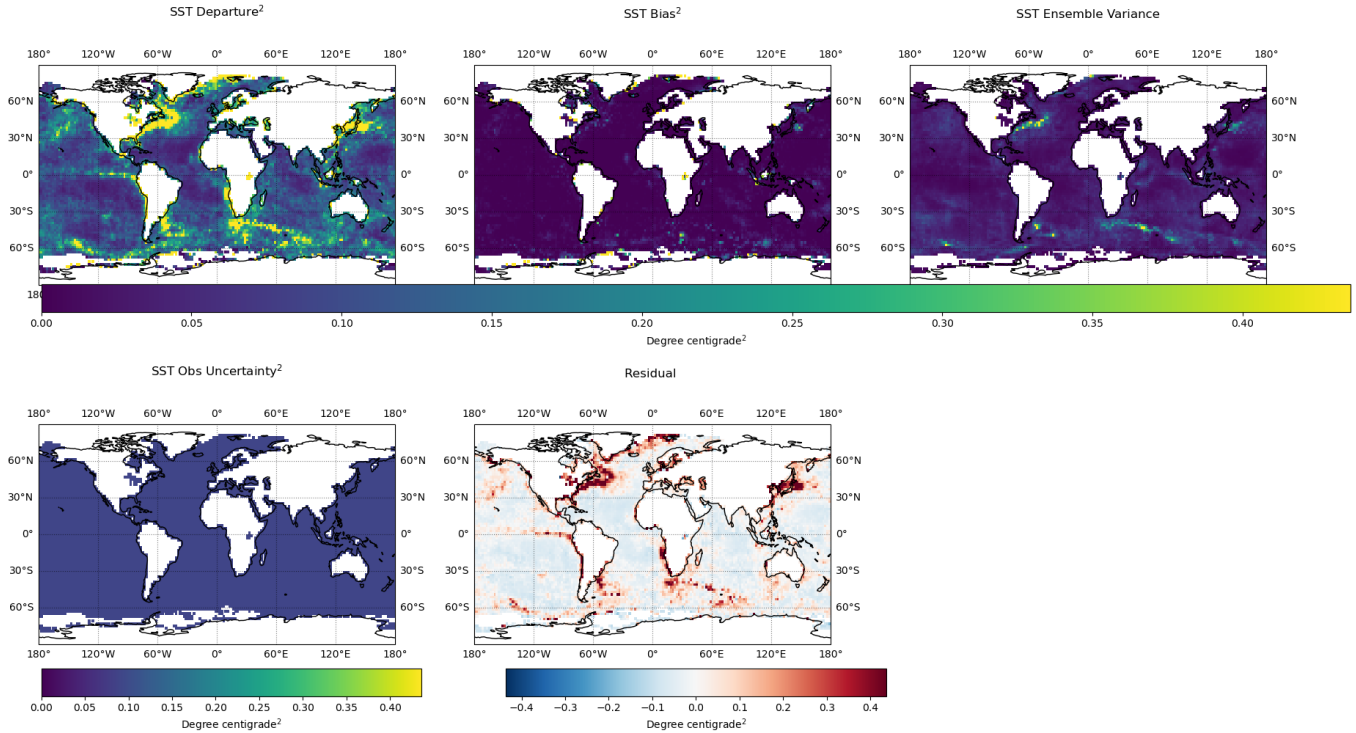
Figure 4: SST ensemble standard deviation (C) at T+0 (left) and T+120 (right) averaged over forecasts initialised between 1st – 15th January 2020. Top plots: *Control*, bottom plots: *OEn3DVar–Control*.

Ocean ensemble reliability

SST reliability of OEn3DVar SSTperts

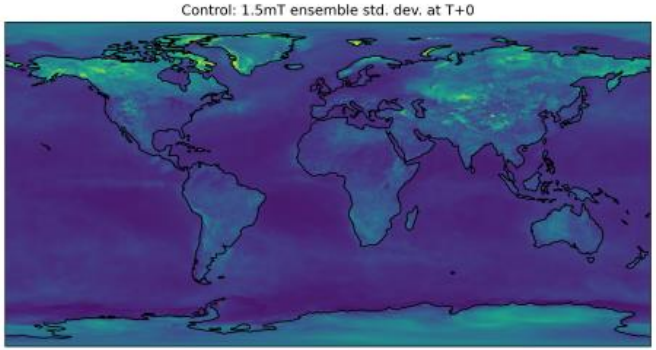
Residual (a consistency test) suggests the ensemble spread is a bit low in some locations.

(The spread was about twice this in the previous uncoupled/ocean only ensemble experiments)

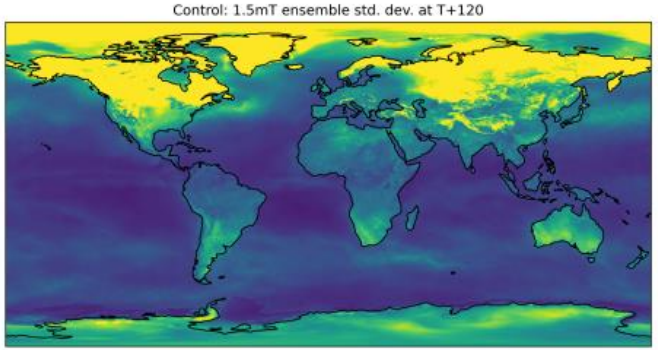


Atmospheric 1.5 m air temperature ensemble spread Control

Analysis/0 days

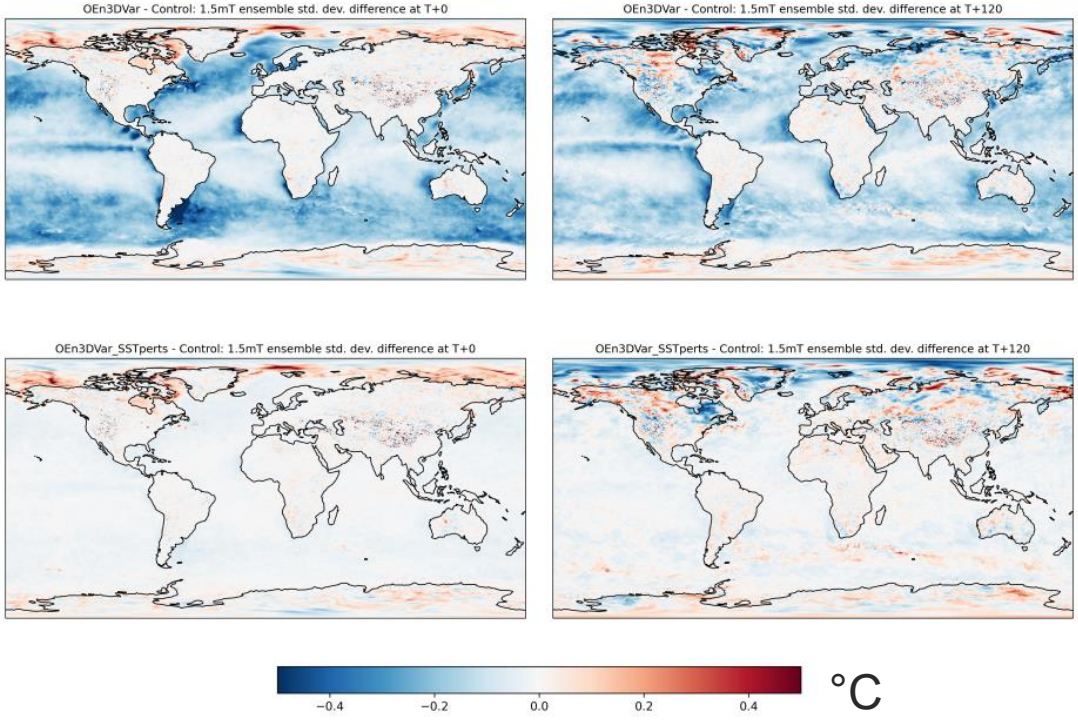


5 day forecast

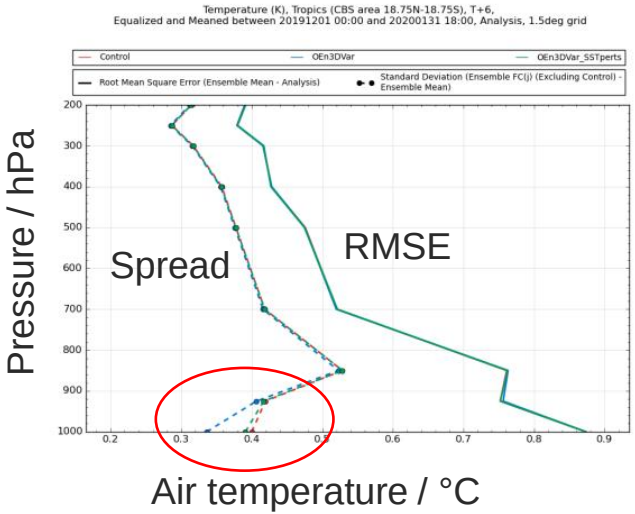


°C

Air temperature spread - OEn3DVar & OEn3DVar vs Control

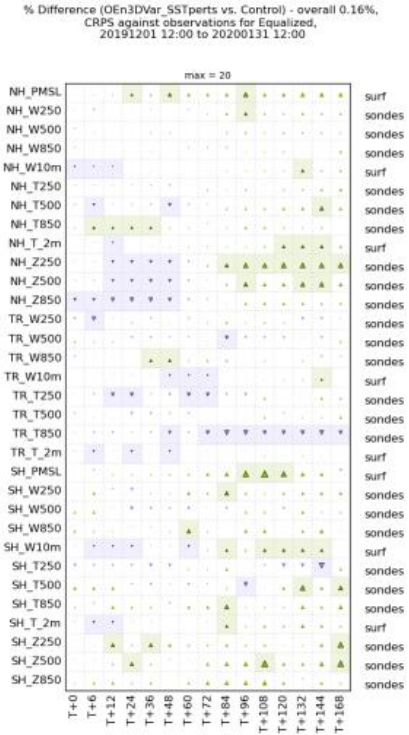


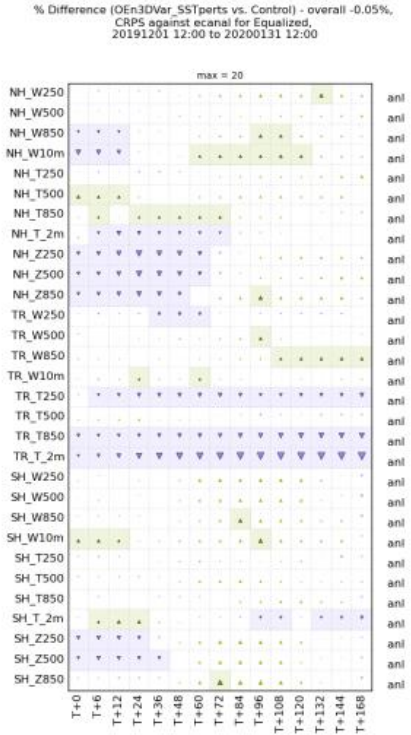
Low spread over the ocean using the ocean ensemble. But much higher spread with SST perturbations added.



OEn3DVar_SSTperts Atmosphere ensemble CRPS scorecards

Vs Observations





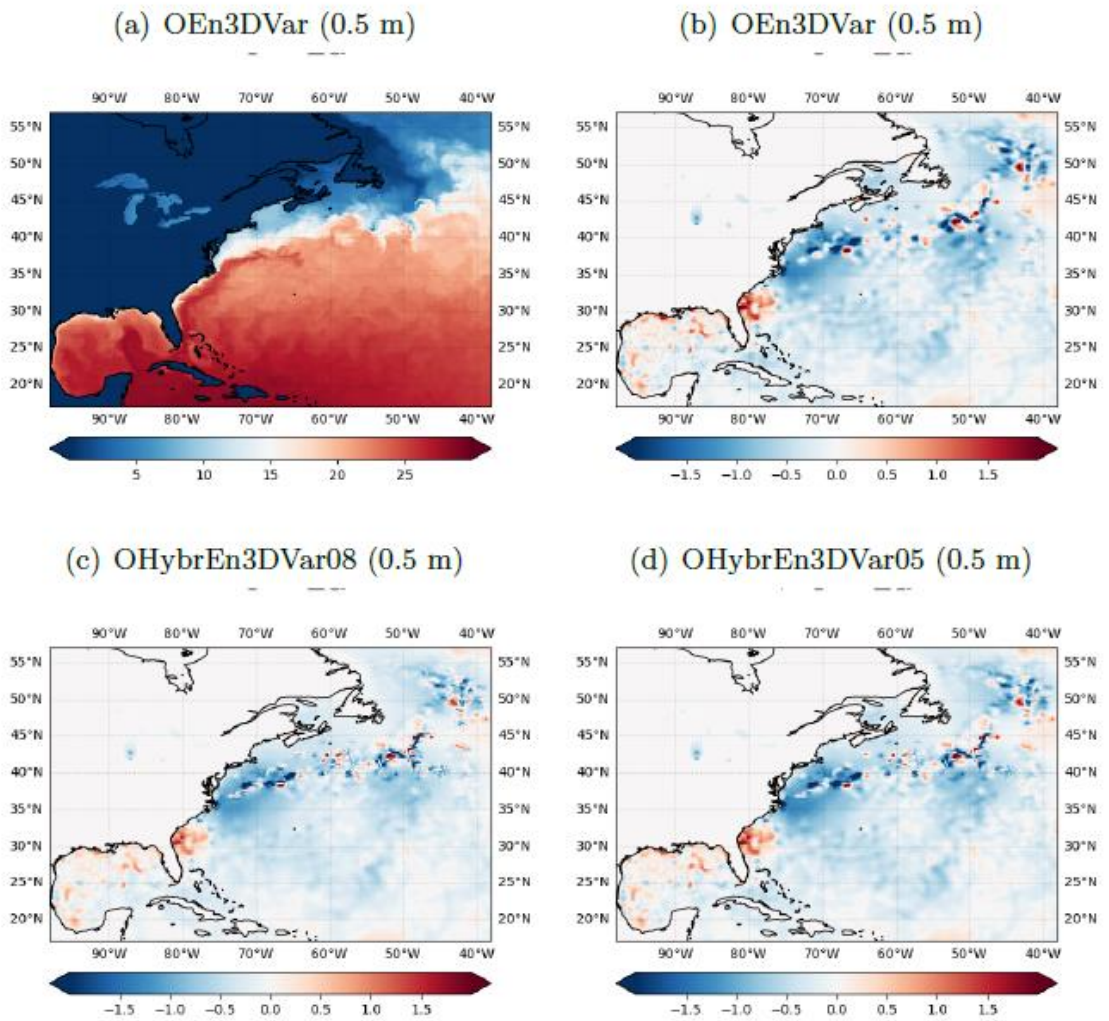
Vs ECMWF analysis

Mixed results
Better than without the SSTperts (not shown).
Some things to work on to improve the results.

Hybrid DA

$B = (1 - \beta) B_{mod} + \beta B_{ens}$

$B_{ens} = L^{o} X^{T} X$



Hybrid DA

OHybrEn3DVar08 (ensemble weight β = 0.8)

OHybrEn3DVar05 (β = 0.5)

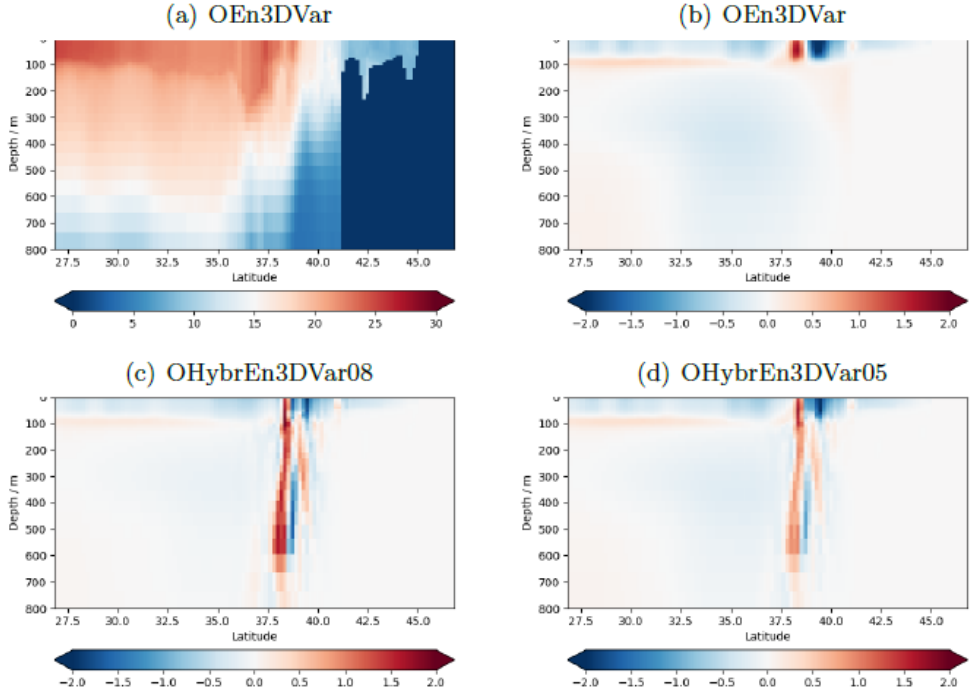


Figure 42: Vertical sections, on the first cycle, of background temperature from north to south across the Gulf Stream at 66°W (in °C) and vertical sections of ocean temperature increments (°C), at the same location and time, comparing hybrid-3DEnVar experiments and 3DVar for the unperturbed ensemble member.

Hybrid DA

OHybrEn3DVar08 (ensemble weight β = 0.8)

OHybrEn3DVar05 (β = 0.5)

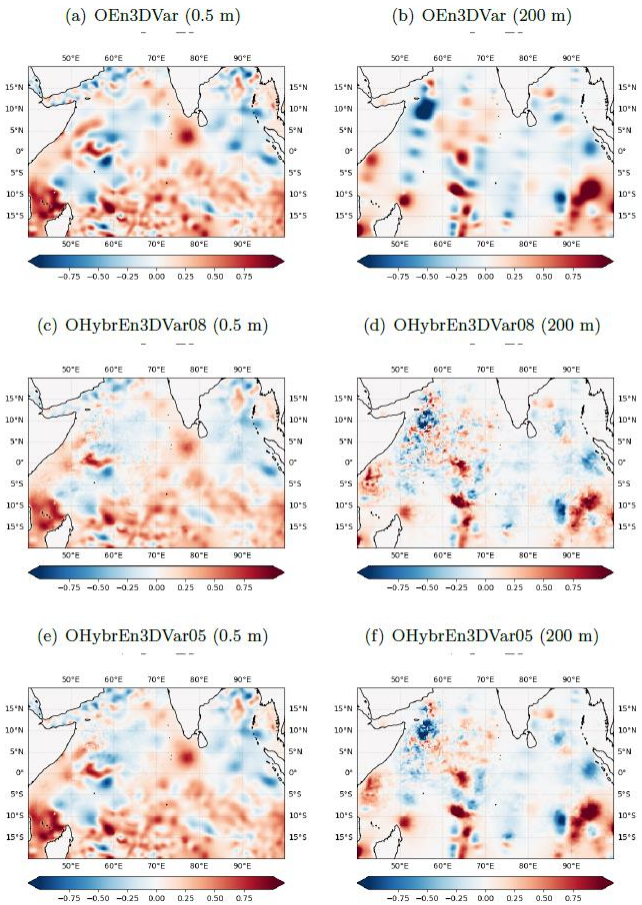


Figure 43: Temperature increments at the surface and at 200 m (in °C), on the first cycle, comparing hybrid EnVar experiments and 3DVar for the unperturbed ensemble member.

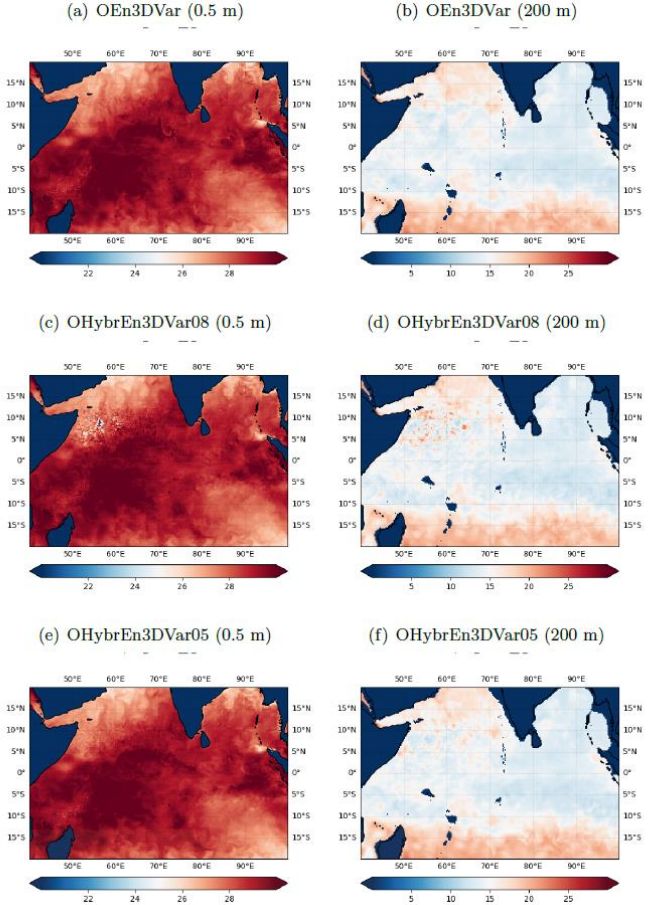


Figure 44: Ocean model temperature at the surface and at 200 m depth (in °C) comparing hybrid EnVar experiments and 3DVar for the unperturbed ensemble member.

Summary

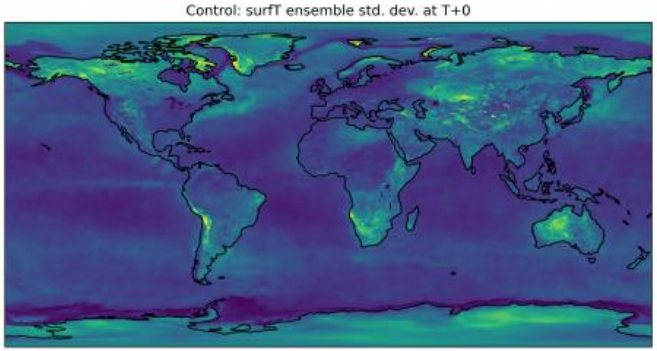
- We have included the ocean ensemble system in the coupled NWP suite
- For the most part it works well
- The ocean ensemble results are comparable to the standalone uncoupled ocean ensemble system. The hybrid DA approach delivers improved sea surface height and profile statistics.
- The atmosphere ensemble performance is gives similar results to the system without an ocean ensemble (we'd hope to demonstrate improved results in the future).
- We'd like to understand more about the need for additional SST perturbations for good atmosphere ensemble performance
- The sea ice ensemble needs attention (we have previously concentrated on the ocean)

Future work

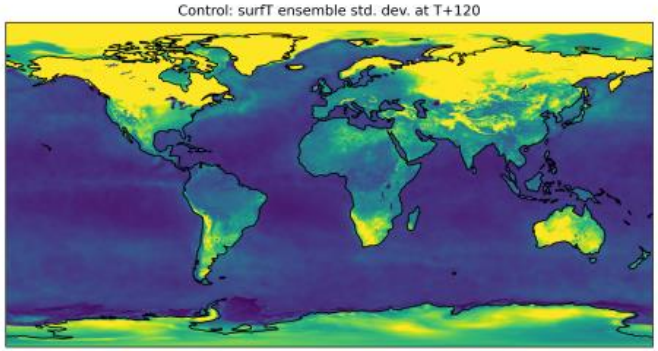
- Plan to increase the resolution of the ocean ensemble to 1/12 degree (including the DA). This will use the standalone uncoupled ocean ensemble system to start with.
- At higher ensemble weights (0.8) in the hybrid DA we get instability in the coupled NWP but not in ocean only runs – this may be to do with using a 6 hour vs 24 hour time window. This and other aspects will be investigated
- Continuing to develop the ocean ensemble in coupled NWP.
- Includes dedicated work to deal with sea ice – e.g. dealing with non-Gaussianity

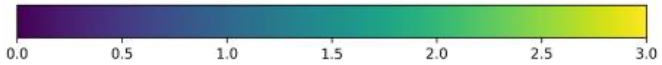
Atmosphere surface temperature ensemble spread - Control

Analysis/0 days



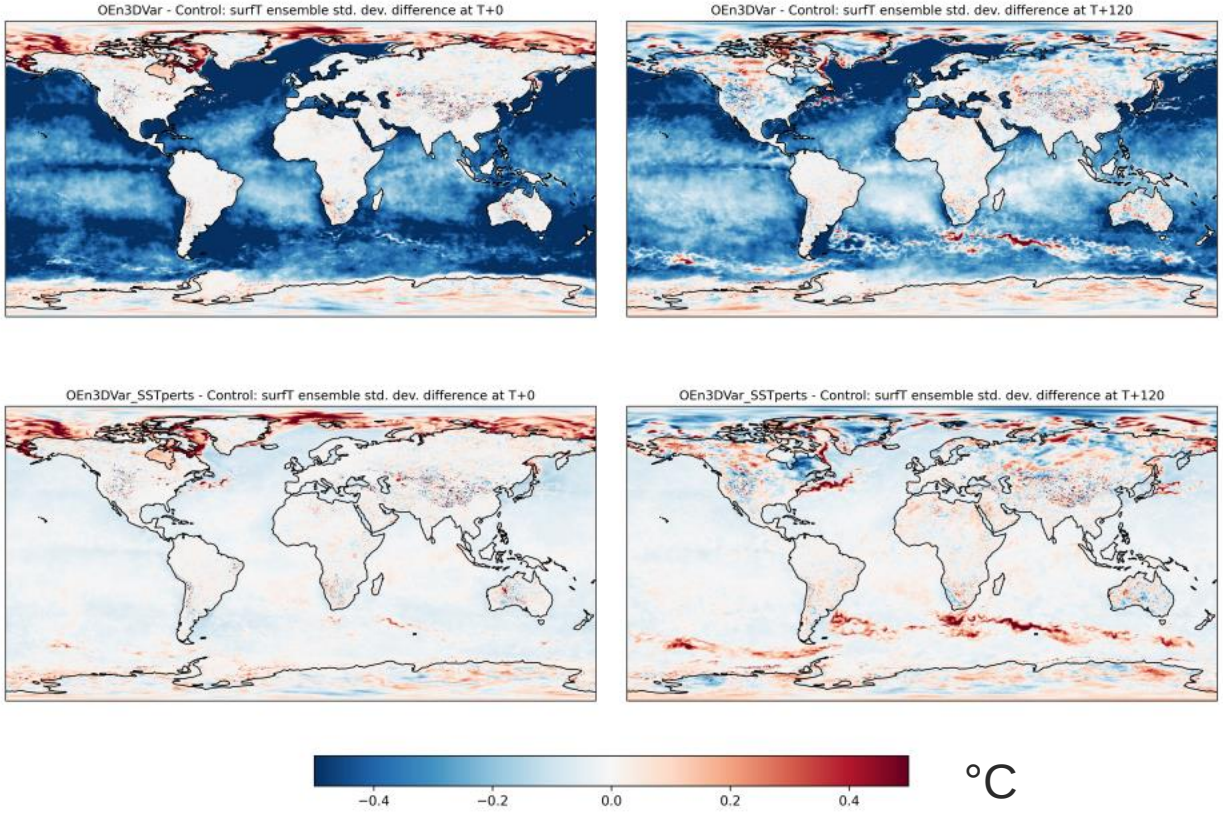
5 day forecast





°C

Atmosphere surface temperature ensemble spread – OEn3DVar & OEn3DVar vs Control



Spread over ocean much lower than control.

Much higher spread with SST perturbations added back in.