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Potential impact of assimilating total surface current velocity data in the Met Office's global ocean forecasting system

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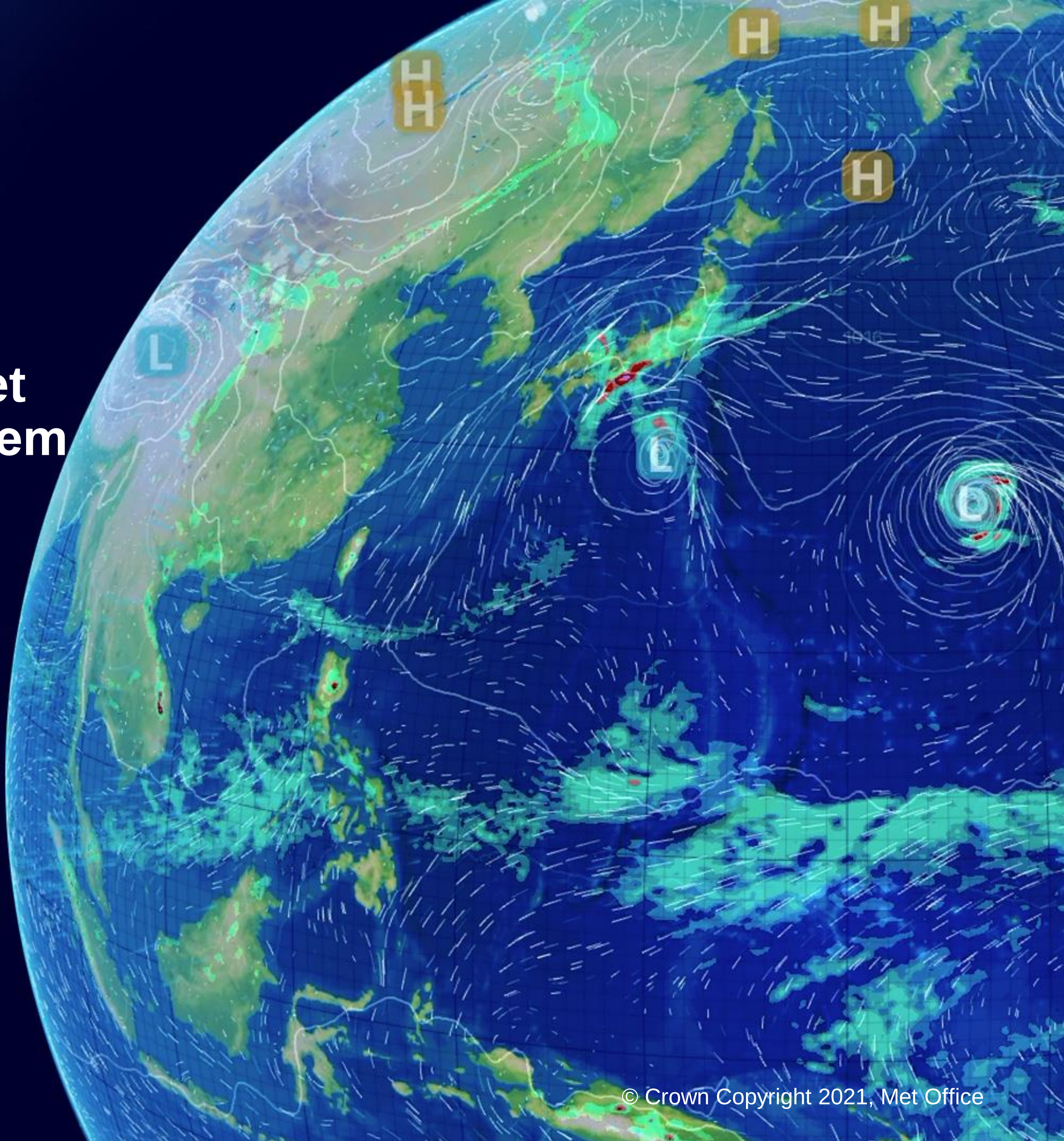

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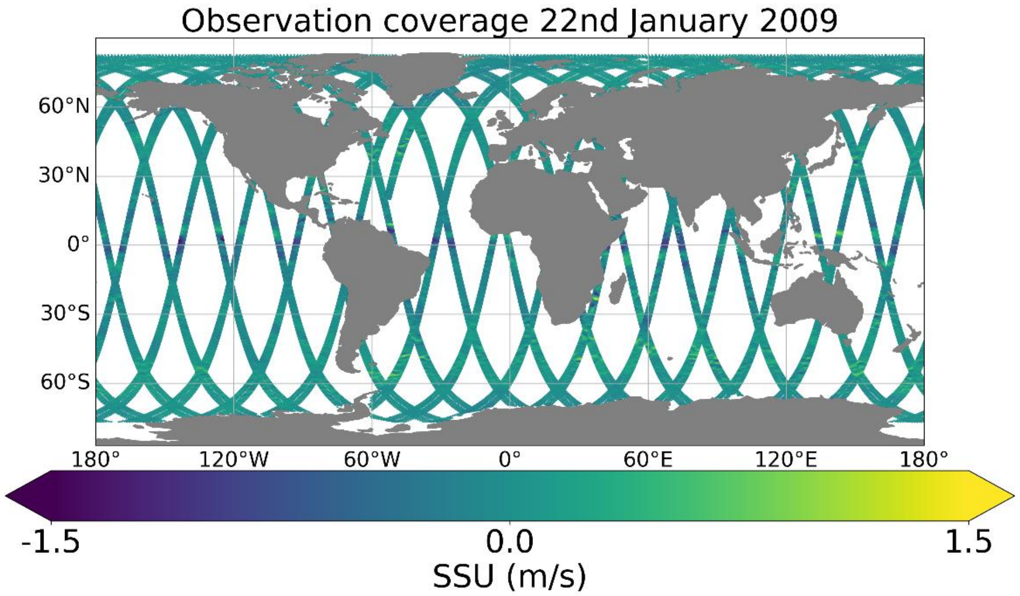
Introduction

- Accurate forecasts of total surface current velocities (TSCV) are important for many users including search and rescue, ship routing, tracking marine plastic and for coupled forecasting.
- Various satellite missions have been proposed to measure TSCV globally (e.g. SKIM, SEASTAR, Odysea)
- The **ESA A-TSCV project**[1] used observing system simulation experiments (OSSEs) to test the impact of assimilating satellite TSCV data from a skim like satellite.
- Two operational global ocean forecasting systems were developed to assimilate these data and the impact assessed in a set of coordinated OSSEs:
- FOAM system run at the Met Office (UKMO)
- Mercator Ocean International (MOI) system
- We present results from the impact of TSCV assimilation in the Met Office system



Aims of the project: to test the assimilation methodology and provide feedback on the observation requirements for future satellite missions.

1. https://oceanpredict.org/science/cross-cutting-projects/a-tscv

OSSE design

- OSSEs assimilation **synthetic** observations generated from a Nature Run
- Nature Run (NR) – High resolution, free-running model run
- Synthetic observations with realistic obs errors were generated from the NR for all standard data types as well as the new observations expected from SKIM-like satellite missions.
- NR is treated as our "truth" and is used to assess the OSSEs

	Nature Run	FOAM
OGCM	NEMO 3.1	NEMO 3.6
Horizontal grid/resolution	1/12° ORCA grid	¼° ORCA grid
Vertical grid	50 levels	75 z-levels with partial steps, non-linear free surface
Wind/current coupling coefficient	50%	100%
Ice model	LIM	CICE
Atmospheric forcing	3h ECMWF IFS	ERA5
Assimilation	None	NEMOVAR 3DVar-FGAT scheme with multivariate balance. Increments applied with 24 hour IAU.

Our assimilative runs differ from the NR through:

- Different fluxes
- Different restarts
- Different resolutions
- Different NEMO versions
- Different wind/current coupling coeff

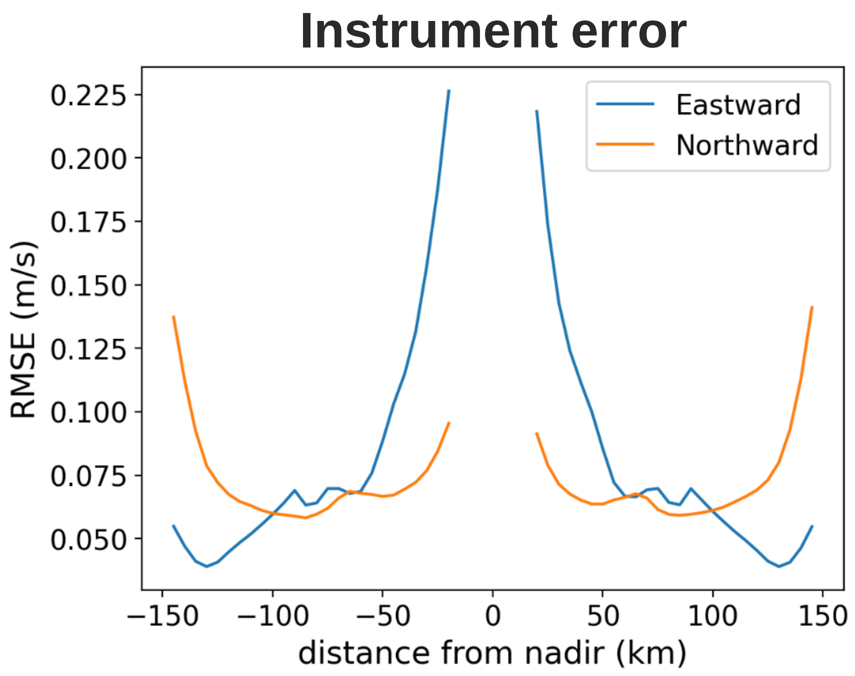
Experiments

Experiment	Assim SST	Assim T/S profiles	Assim SSH	Assim SIC	Assim TSCV	TSCV Errors
Control	✓	✓	✓	✓		
A-TSCV_no Err	✓	✓	✓	✓	✓	mapping only (approx. 3cm/s)
A-TSCV_Instr Err	✓	✓	✓	✓	✓	Mapping error + Instrument error

Experiments are run 21st January – 31st December

In control no assimilation of velocity observations but adjustments are made to the velocities through the balance relationship (geostrophic balance)

When TSCV assimilated both balanced (geostrophic) and unbalanced (ageostrophic) increments are produced for velocity. The geostrophic component gets transferred to the other variables though the balance relationships.



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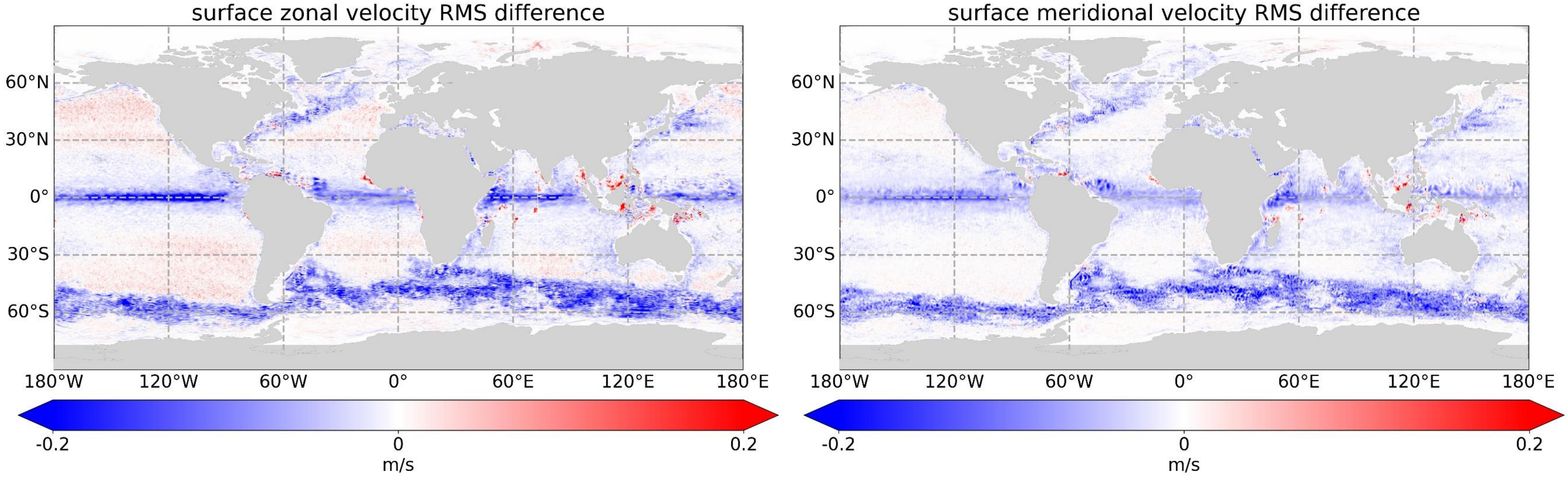
Impacts: surface velocities

Blue indicates an improvement in RMSE with TSCV assimilation

Spatial plot of A-TSCV_Instr_Err RMSE minus control RMSE



RMSE calculated for 25th Feb – 31st Dec

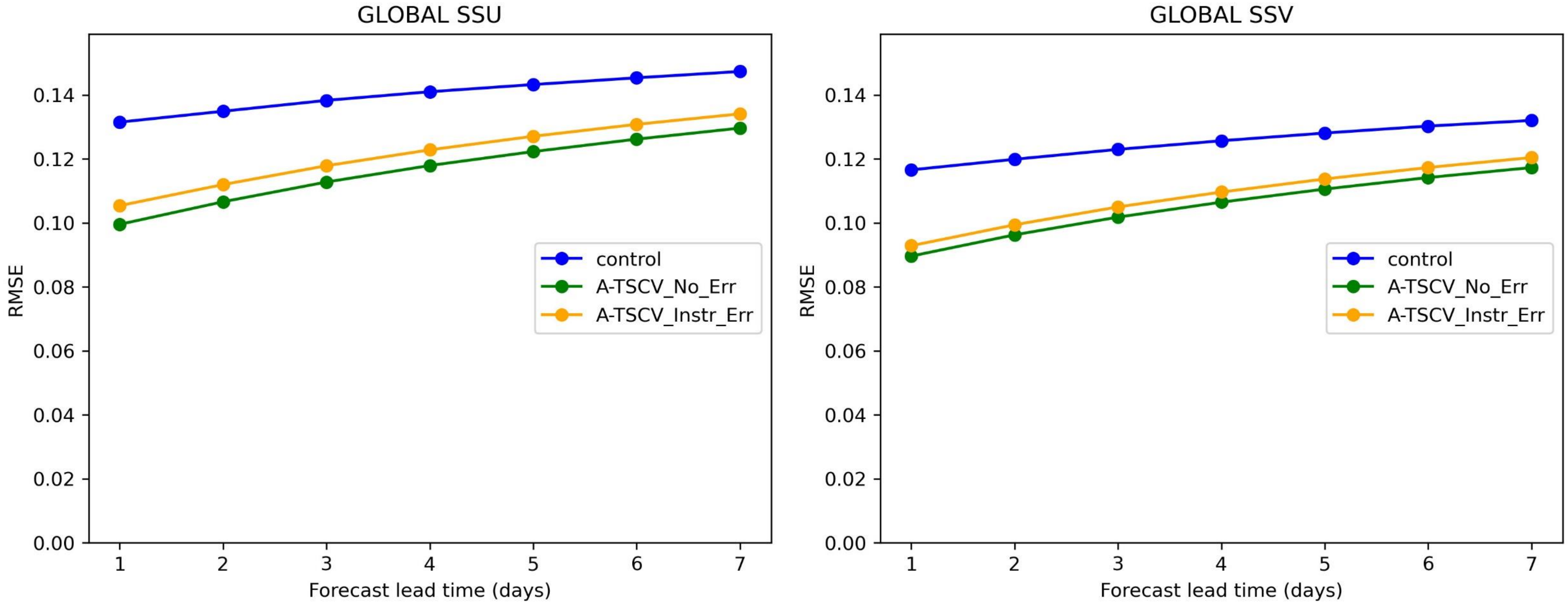
Largest improvements in the WBCs, ACC and equatorial region

23% improvement in global RMSE

Some degradation in the middle of the gyres for zonal velocity: due to low signal to noise in this region

Impacts: surface velocities

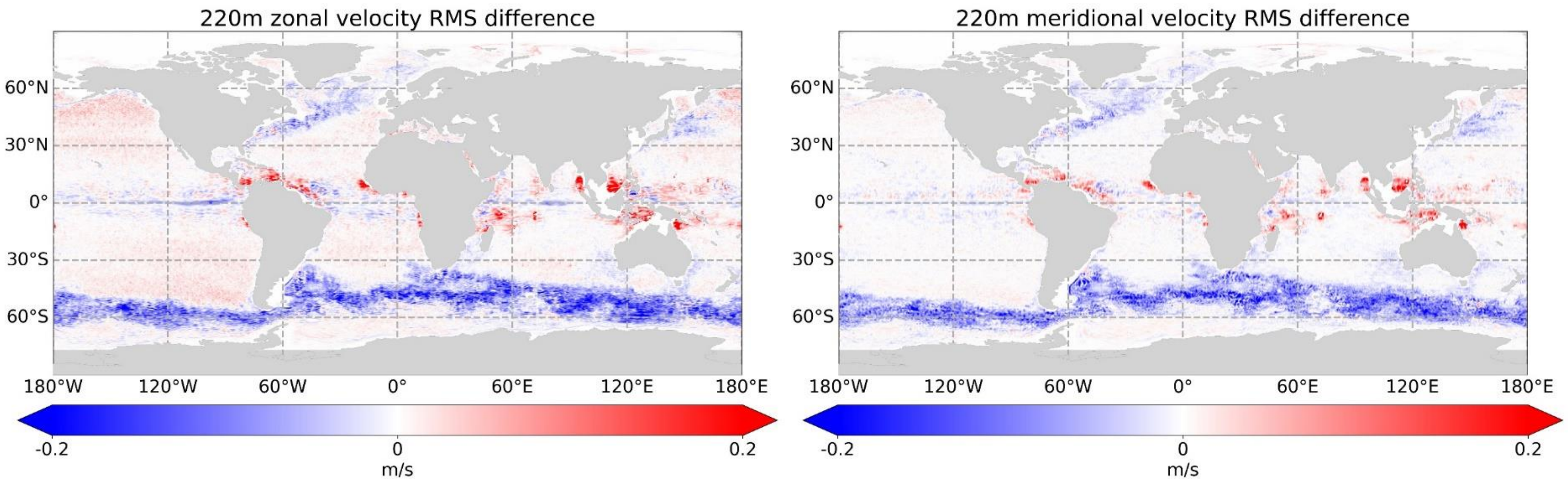
Forecast RMSE



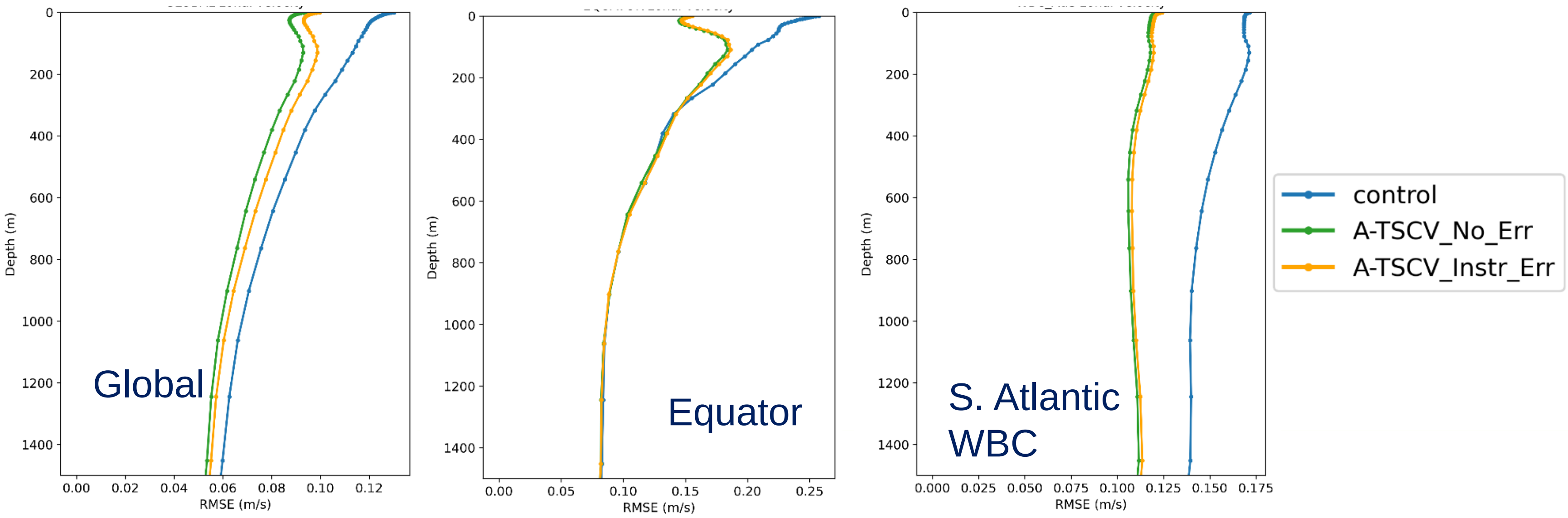
- 7 day forecasts run every 7 days between 25th Feb – 30st Dec
- Forecast RMSE demonstrates benefit of TSCV assimilation of surface velocity is retained through a 7 day forecast

Impacts: subsurface velocities

Spatial plot of A-TSCV_Instr_Err RMSE minus control RMSE: 220m



Zonal velocity RMSE



- Largest improvements in the ACC
- Improvements in the WBCs and equatorial region
- Degradations in the tropics in regions with complex salinity structure – prescribed multivariate balance not appropriate here
- Globally, velocity RMSE improved down to at least 1500m
- Deep improvements are seen in the WBC regions
- Improvements at the equator are down to ~300m
- Larger improvements globally when instrument error not included –> improving obs error specification to reduce impact in regions with low signal to noise

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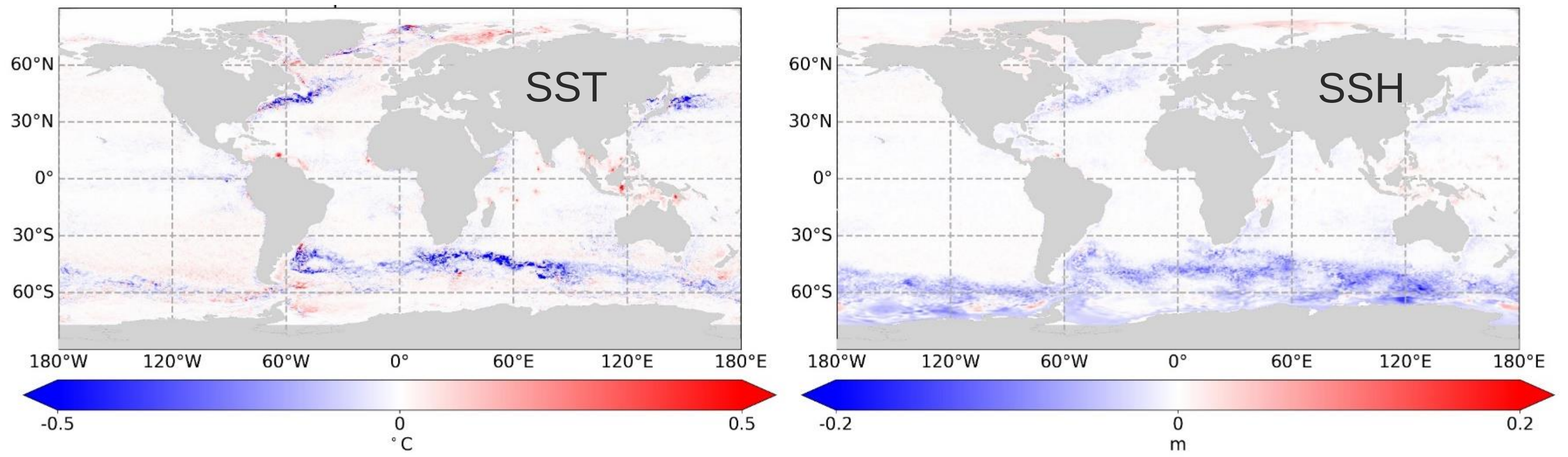
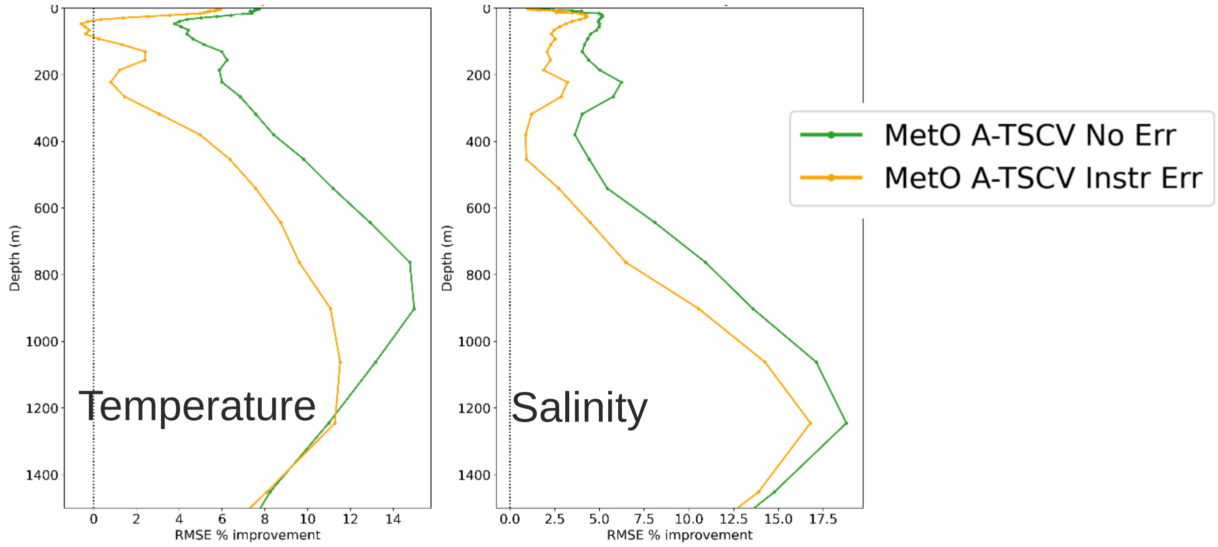
Impacts: temperature, salinity and SSH

Spatial plot of A-TSCV_Instr_Err RMSE minus control RMSE



Global RMSE % improvement relative to the control

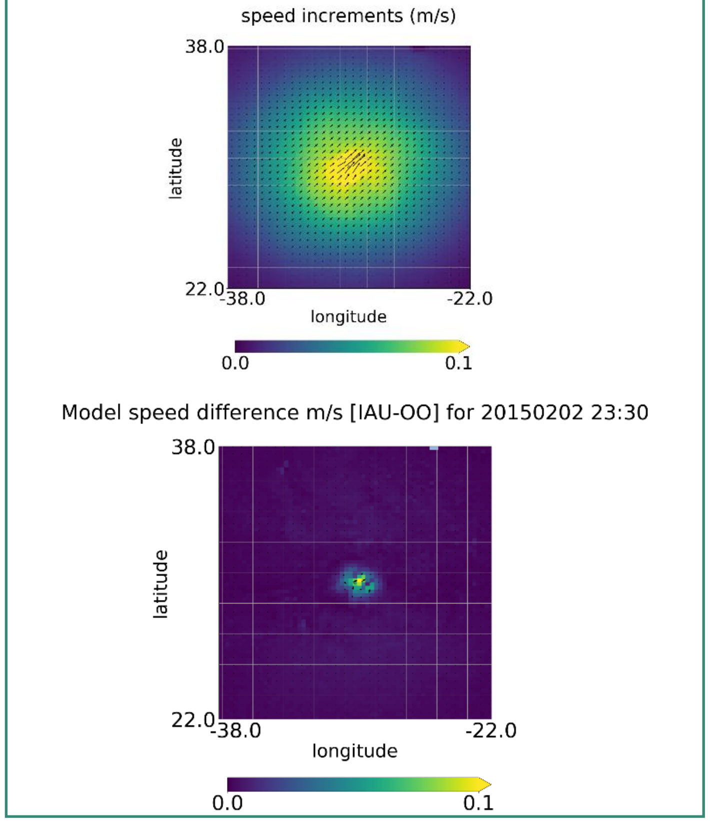


- Global SSH improved by 14% and global SST improved by 6% with TSCV assimilation
- Improvements to SST and SSH in WBCs and ACC
- Experiment assimilating TSCV with instrument error produces improvements to global T near the surface and below 100m
- Experiment assimilating TSCV without instrument error improves global T down to 1500m
- Global S improved down to 1500m

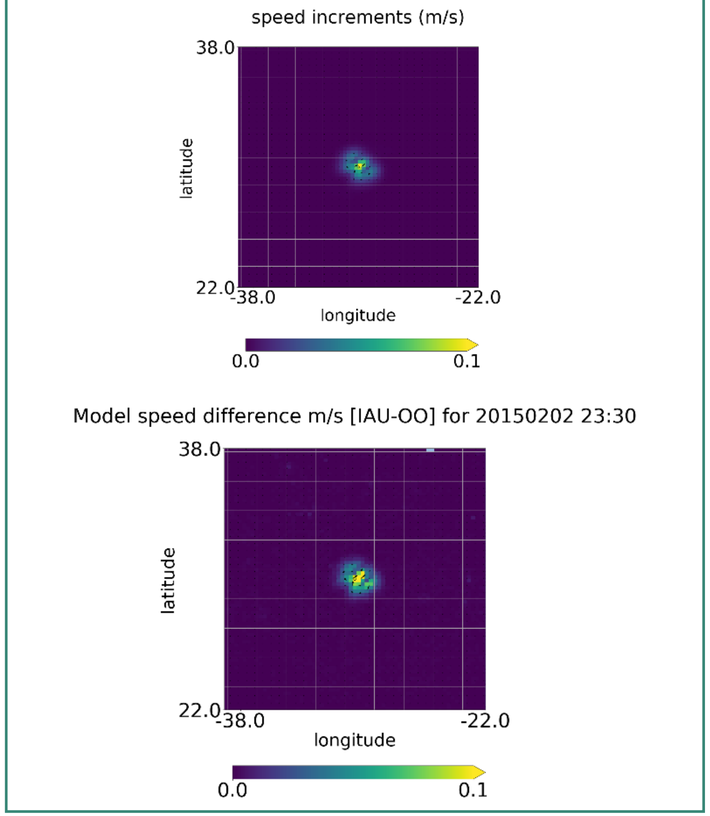
Good improvements with TSCV assimilation

Results: correcting ageostrophic velocities

Total increments



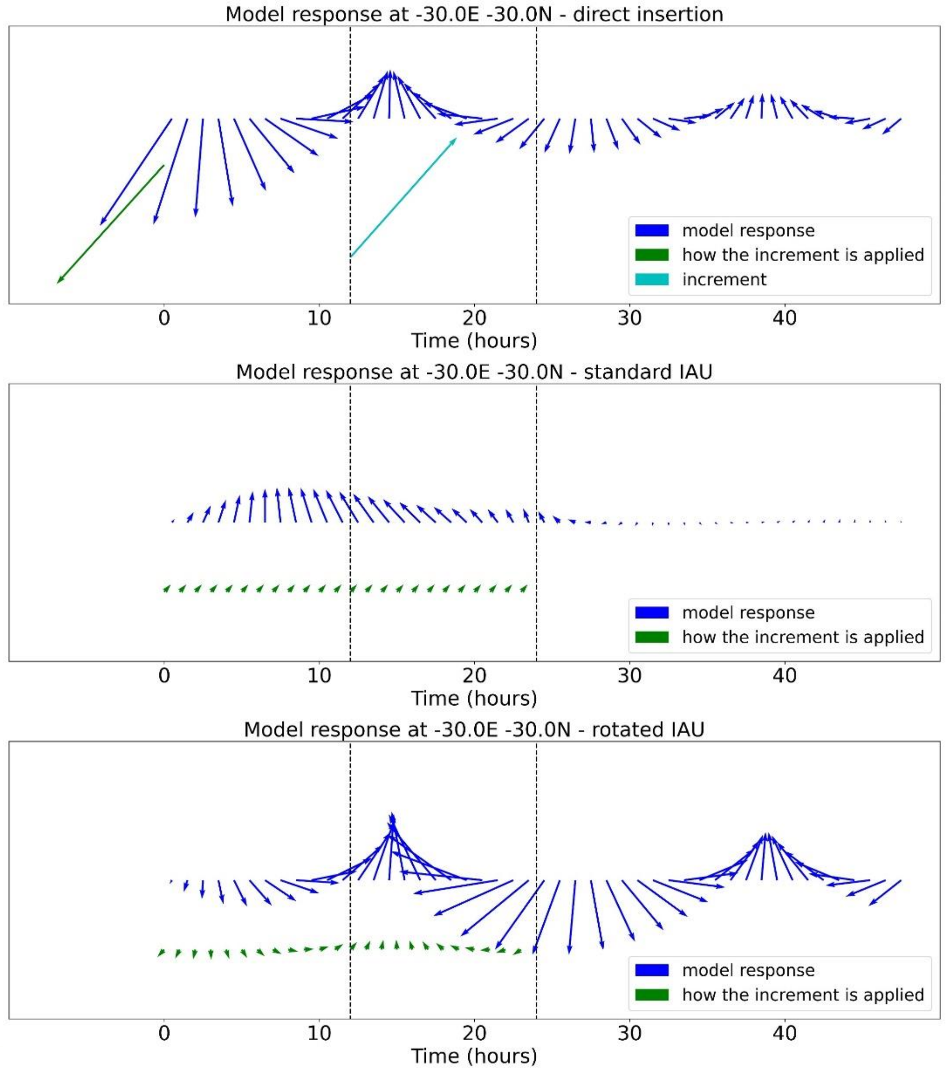
Balanced increments only



- The ageostrophic or unbalanced component of velocity increment is not being properly retained in the model
- Away from the equator and boundaries, Near Inertial Oscillations (NIOs) are a large component of the ageostrophic velocities.
- Localised wind changes cause NIO oscillations in the ocean currents at the inertial period: ~24 hours at 30N, ~14 hours at 60N
- Applying the increments using a 24 hour IAU dampens the NIO model response.
- When the NIOs are spurious this dampening effect is useful (Raja et al; 2024), but it restricts our ability to correct NIOs when we have valuable information.

Results: correcting ageostrophic velocities

- Model response to a single ageostrophic increment in the NW direction valid at 12 hours
- This is the model response at 30S where the inertial period is ~24 hours.
- A rotated IAU has the potential to initialises NIOs in the model with the phase and magnitude of the unbalanced ageostrophic velocity increments.



Model response when **direct insertion** is used. Note that the increment is rotated to 0 hours so it can be applied at the start of the time window.

Model response when **IAU** is used.

Model response when the **IAU** is used but the applied increments are **rotated at each time step** by the inertial period

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Conclusions

- Significant improvement to global surface velocity RMSE statistics with TSCV assimilation:
    - ~23% improvement in RMSE, 4 day gain in forecast accuracy
- Largest improvements in the WBCs, ACC and equatorial currents
- Subsurface velocities improved down to 1500m in the WBCs and 300m near the equator
- Global temperature and salinity improved at most depths
- Some degradations in the middle of the gyre where the signal to noise in the TSCV observations is low and some degradations in tropical regions with complex salinity structures
- Some further tuning of the background and observation error covariances should improve results in these regions
- Away from the equator, improvements are largely due to geostrophic corrections, ageostrophic increments are not well retained in the model
- Idealised experiments: not all processes represented in simulated TSCV and full error budget not included
- **We have the capability to assimilate simulated TSCV observations and they have the potential to significantly improve the prediction of the ocean state in global ocean forecasting systems. The results from this study support the case for future satellite missions with TSCV observing capabilities**
- In addition, the results from this study have demonstrated that we are able to successfully assimilate velocity observations in our global system - this has motivated new work looking at drifter derived velocity assimilation.

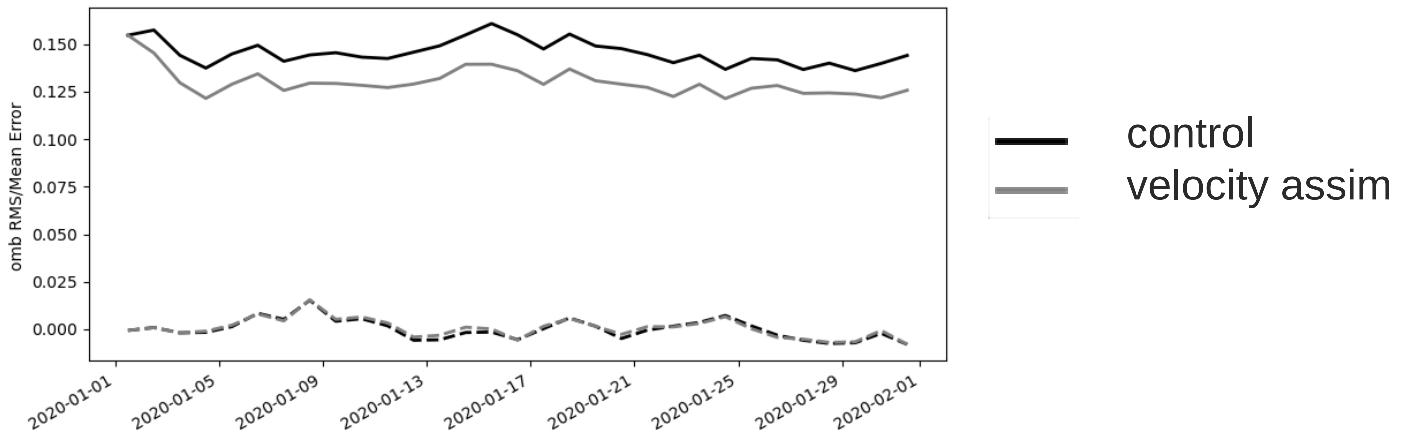
Future work: Drifter Velocity Assimilation

Performed some preliminary experiments assimilating CMEMS 6 hourly drifter derived velocities.

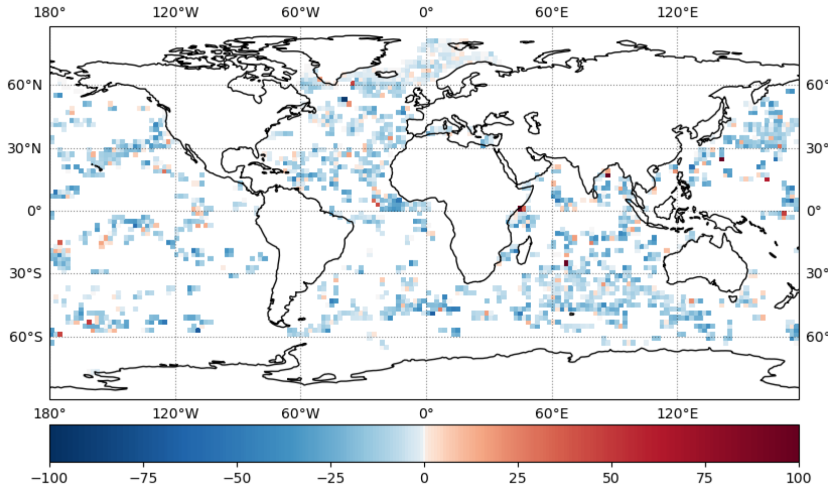
Global drifter velocity innovation RMSD statistics suggest that the velocity information can be successfully assimilated in global FOAM.

~11% improvement in zonal and meridional velocity RMSD.

Zonal velocity innovation RMS/mean error



% improvement in zonal velocity RMSD when drifter velocities are assimilated



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Thank You

Publications

Waters et al. 2024. Assessing the potential impact of assimilating total surface current velocities in the Met Office's global ocean forecasting system. Front. Mar. Sci., Volume 11, https://doi.org/10.3389/fmars.2024.1383522

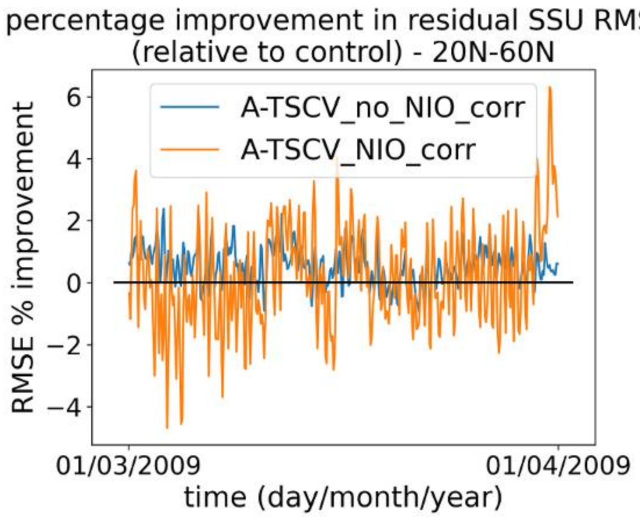
Mirouze et al. 2024. Impact of assimilating satellite surface velocity observations in the Mercator Ocean International analysis and forecasting global 1/4°system. Front. Mar. Sci. Volume 11, doi: 10.3389/fmars.2024.1376999

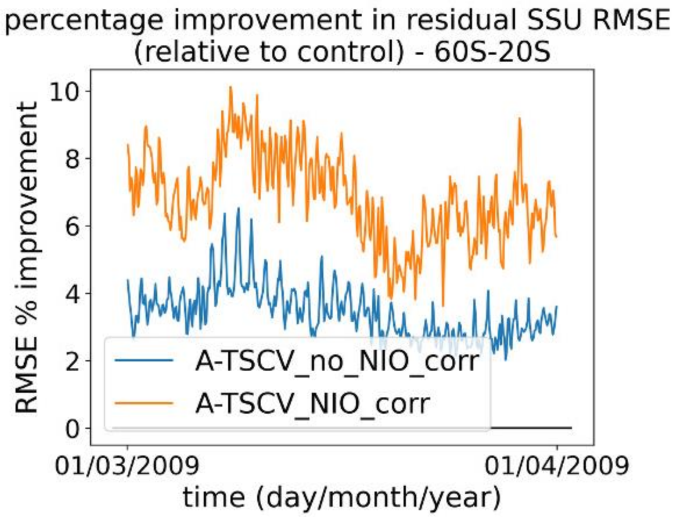
Waters et al. 2024. The impact of simulated Total Surface Current Velocity observations on operational ocean forecasting and requirements for future satellite missions.. Submitted to Front. Mar. Sci.

Extra slides

Results: correcting ageostrophic velocities

- Performed some preliminary tests using the rotated IAU approach to apply ageostrophic velocities in the OSSE framework
- Aim to initialises NIOs in the model with the phase and magnitude of the unbalanced ageostrophic velocity increments.
- Improved the sub-daily surface velocity RMSE in the Southern-Hemisphere, although results in the Northern-Hemisphere were more mixed.
- More development required to correctly make use of high frequency velocity information – 4DVAR might help





- Particles were seeded globally at a ¼ degree resolution and were propagated for 6 days from the 09/09/2009 using the model daily analysis velocity fields in OceanParcels.

- separation of the particles from the NR particles was calculated on each day

- after 6-days of drifting, position of objects would be estimated within 50 km of the NR position 74 % of the time with TSCV assimilation compared to 65/67 % of the time without.

Largangian assessment: Percentage of particles within 50km of the NR particles as a function of advection time