SYMPOSIUM OP'24 ADVANCING OCEAN PREDICTION SCIENCE FOR SOCIETAL BENEFITS

# Assessing the impact of present and future altimeter constellations in the Met Office global ocean forecasting system

***Robert King, Daniel Lea, Matt Martin, Jennifer Waters.***
*Met Office, Exeter, UK.*

## Introduction

Satellite altimeter measurements of Sea Level Anomaly (SLA) are a crucial component of current operational ocean forecasting systems. The launch of the SWOT wide-swath altimeter mission is bringing a step change in our observing capacity with 2D mesoscale structures now able to be observed over the global ocean. Future altimeter constellations are likely to include multiple wide-swath altimeters. Here we present results from two studies using the Met Office's global ocean analysis and forecasting system, FOAM, looking at (1) the impact of possible future altimeter constellations, and (2) preliminary results from assimilating real SWOT data.

## 1. OSSEs: Impact of 2 wide-swath altimeters (WiSAs) vs 12 nadir altimeters

- There are plans to include more than one WiSA on board the Sentinel-3 Next Generation (S3-NG) operational mission (likely to be flying around 2030).
- Different combinations of nadir and swath altimeters were being considered by ESA for S3-NG and the aim of this work was to contribute information about the impact of different altimeter constellations on operational ocean forecasts.
- The main two options studied were (i) a constellation of 12 nadir altimeters, and (ii) a constellation of 2 WiSA satellites. See Fig. 1 for example of the coverage on 1 day.

Model and data assimilation (DA) system used in FOAM:
- 1/12° global ocean/sea ice model (NEMO/CICE)
- NEMOVAR 3DVar-FGAT DA scheme assimilating SST, SLA, T/S profiles, SIC

Nature run (NR): 1/12° resolution, different NEMO version & parameter settings, different surface forcing, different initial conditions.

Simulated observations taken from the NR:
- SST, T/S profiles, SIC simulated from NR with realistic observation errors generated.
- SLA data generated from NR using SWOT simulator.
- Nadir errors based on errors in real data from Sentinel-3 and Jason-3.
- WiSA errors included only uncorrelated components (KaRIn noise and residual path delay error).
- WiSA data is in a 120km wide swath at 2 km resolution averaged to generate super-obs at 10 km resolution. Obs removed when significant wave height > 8 m.

| Experiments | Model configuration | Atmospheric forcing | Assimilated observations | | | | |
|---|---|---|---|---|---|---|---|
| | | | Standard obs | S6 | S3A&B | 12xS3 | 2xWiSA |
| Nature run | NEMOv3.1/LIM, ORCA12 | real-time ECMWF | - | - | - | - | - |
| Control | NEMOv3.6/CICE, ORCA12 | ERA-5 | Y | Y | Y | - | - |
| NADIR | NEMOv3.6/CICE, ORCA12 | ERA-5 | Y | Y | - | Y | - |
| 2WISA | NEMOv3.6/CICE, ORCA12 | ERA-5 | Y | Y | - | - | Y |

Table: List of experiments run for 7 months in 2009. The Control expt has similar RMSEs to the operational FOAM system (not shown).

Conclusions:
- Both constellations have clear positive impact on accuracy of the analysis (Figs. 2-4) with largest impact in western boundary currents and Antarctic Circumpolar Current.
- In Gulf Stream region, SSH is more constrained by NADIR than 2WISA (Fig. 3). WiSA data can provide good analysis of the SSH in the vicinity of the data on a particular day, but there will be several days at any given location which are not sampled by the data, during which time the errors in the model will grow.
- Effective spatial resolution of daily SSH fields shows a clear improvement over the Control at mid- to high-latitudes (Fig. 5).
- Larger impact on all variables from 12 nadirs than 2 WiSAs in FOAM. Note, similar experiments in the MOI system showed more impact from 2 WiSAs.
- FOAM has 1-day DA window. Total number of obs in a single DA window is similar between the 2 constellations but 12 nadir altimeters sacrifices high spatial resolution for higher temporal resolution and more even sampling, while the 2WISA constellation has high spatial resolution but with much larger gaps between individual swaths.
- Note that no spatially-correlated errors were included in the WiSA data simulated here. Further expts showed difficulties assimilating data with such errors. Methods to model these in the DA are needed.
- ESA have now chosen to develop a solution involving both nadir and wide-swath altimeters.

King, R. R., Martin, M. J., Gaultier, L., Waters, J., Ubelmann, C., and Donlon, C.: Assessing the impact of future altimeter constellations in the Met Office global ocean forecasting system, https://doi.org/10.5194/egusphere-2024-756, 2024.

## 2. Impact of real SWOT data on FOAM

- Preliminary experiments to show the impact of real SWOT data on FOAM have been carried out using a 1/4° resolution version of the global FOAM system.

| Experiment name | Assimilated observations |
|---|---|
| Control | SST, T/S profiles, SIC, nadir SLA data |
| SWOT | SST, T/S profiles, SIC, nadir SLA data + L3 SWOT data from Aviso |

- The SWOT observations were thinned within the swath with one observation every 10 km retained.
- Experiments were started in April 2023 and run through to end of April 2024 – results are shown from the period when SWOT was in its 21-day repeat orbit (from August 2023 onwards).
- No additional tuning of the data assimilation system has been carried out yet – the SWOT data are treated in the same way as other SLA data.

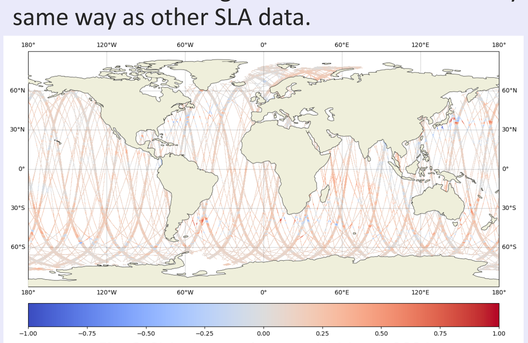


Fig. 6. SLA observations on 1st March 2024.

- The impact of SWOT is shown in Fig. 7.
- Reduction in SLA innovation RMS in energetic regions like the Gulf Stream, Kuroshio, Agulhas and Antarctic Circumpolar Current.
- Neutral impact on other variables.
- Timeliness of the L3 NRT SWOT data not adequate for operational assimilation at present.
- Further work includes testing the impact in global 1/12° system and regional 1.5 km system with reduced observation averaging.

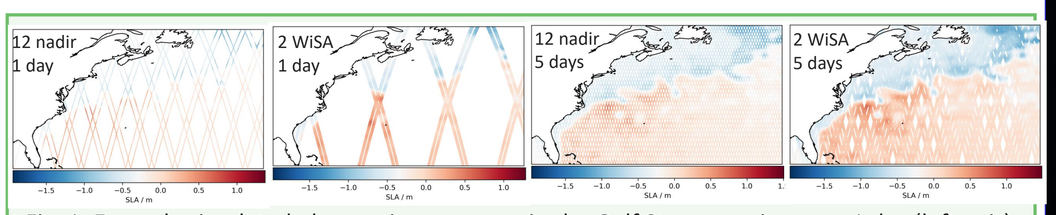


Fig. 1: Example simulated observation coverage in the Gulf Stream region over 1 day (left pair) and 5 days (right pair) from two altimeter constellation scenarios (12xnadir, 2xWiSA)

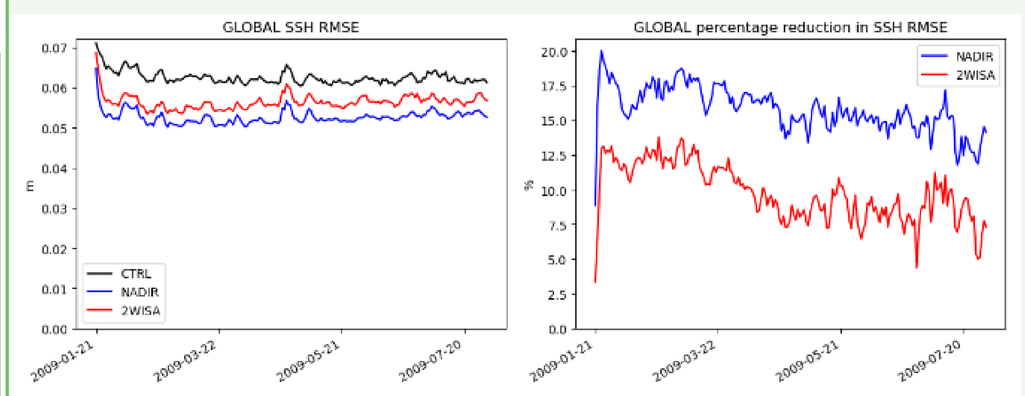


Fig. 2: Globally-averaged SSH RMSE (left) and % reduction in the SSH RMSE compared to the CTRL expt (right). NADIR expt reduction ~16% compared to ~10% in the 2WISA expt.

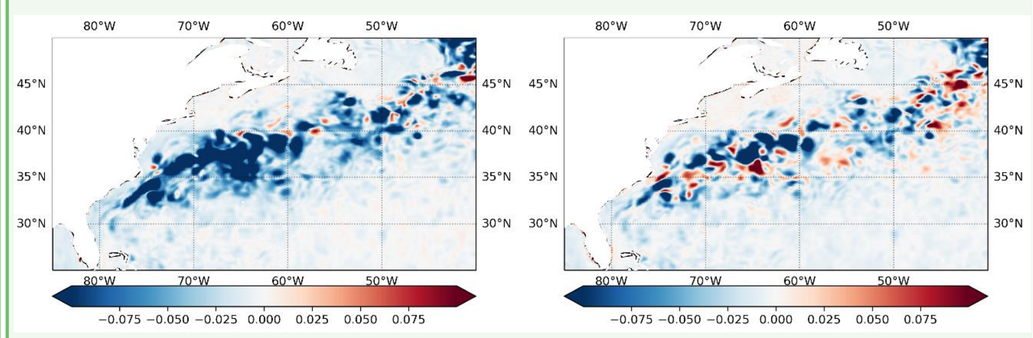


Fig. 3: Monthly SSH RMSE difference (July 2009) compared to the Control for the NADIR (left) and 2WISA (right) runs for the Gulf Stream region. -ve values => reduction in RMSE for the expt (NADIR or 2WISA) ref the Control.

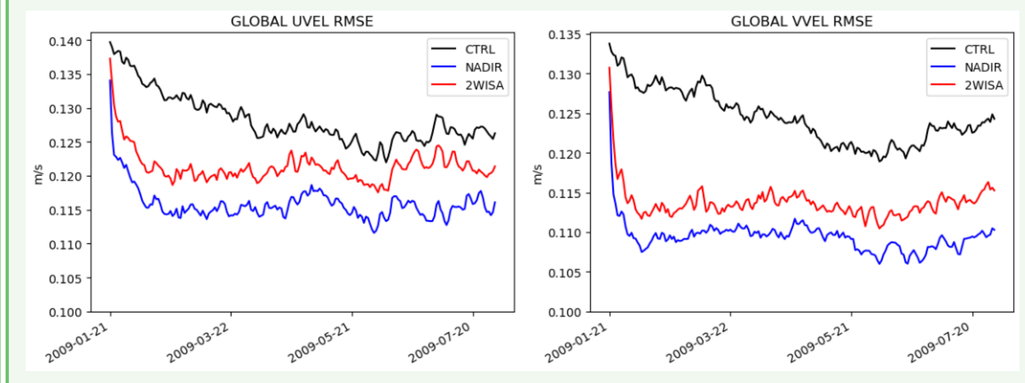


Fig. 4: Globally-averaged time-series of the u- and v-components of surface current velocity RMSE for the Control, NADIR, and 2WISA runs.

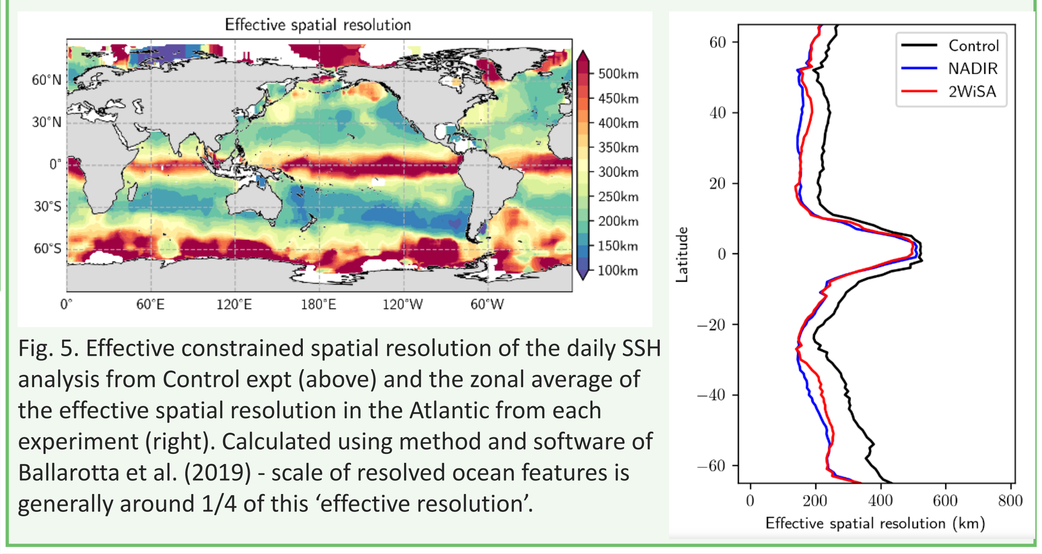


Fig. 5. Effective constrained spatial resolution of the daily SSH analysis from Control expt (above) and the zonal average of the effective spatial resolution in the Atlantic from each experiment (right). Calculated using method and software of Ballarotta et al. (2019) - scale of resolved ocean features is generally around 1/4 of this 'effective resolution'.

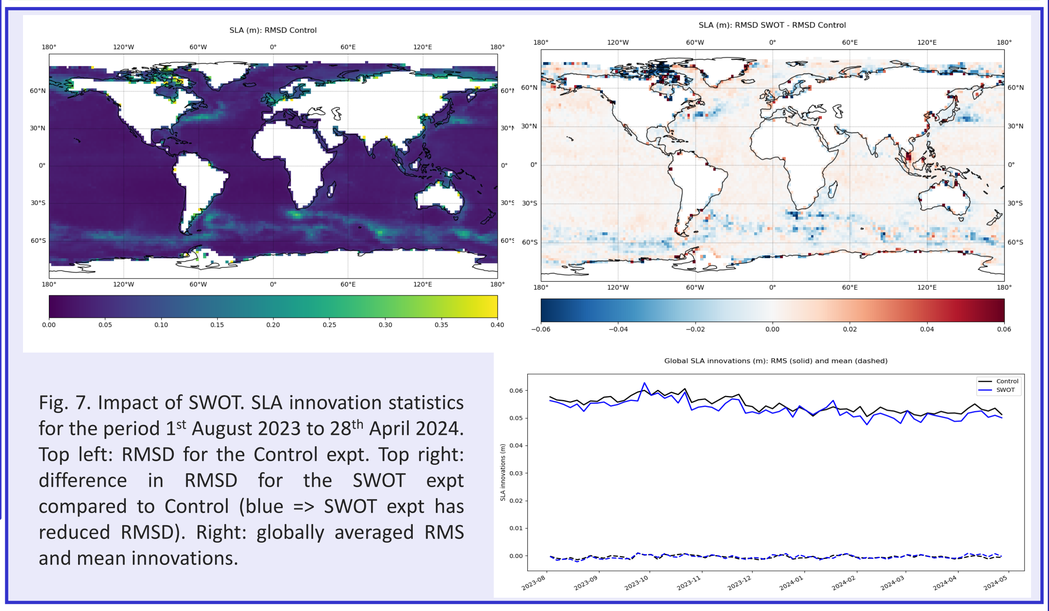


Fig. 7. Impact of SWOT. SLA innovation statistics for the period 1st August 2023 to 28th April 2024. Top left: RMSD for the Control expt. Top right: difference in RMSD for the SWOT expt compared to Control (blue => SWOT expt has reduced RMSD). Right: globally averaged RMS and mean innovations.



Ocean Predict In partnership with unesco Intergovernmental Oceanographic Commission 2021 2030 United Nations Decade of Ocean Science for Sustainable Development