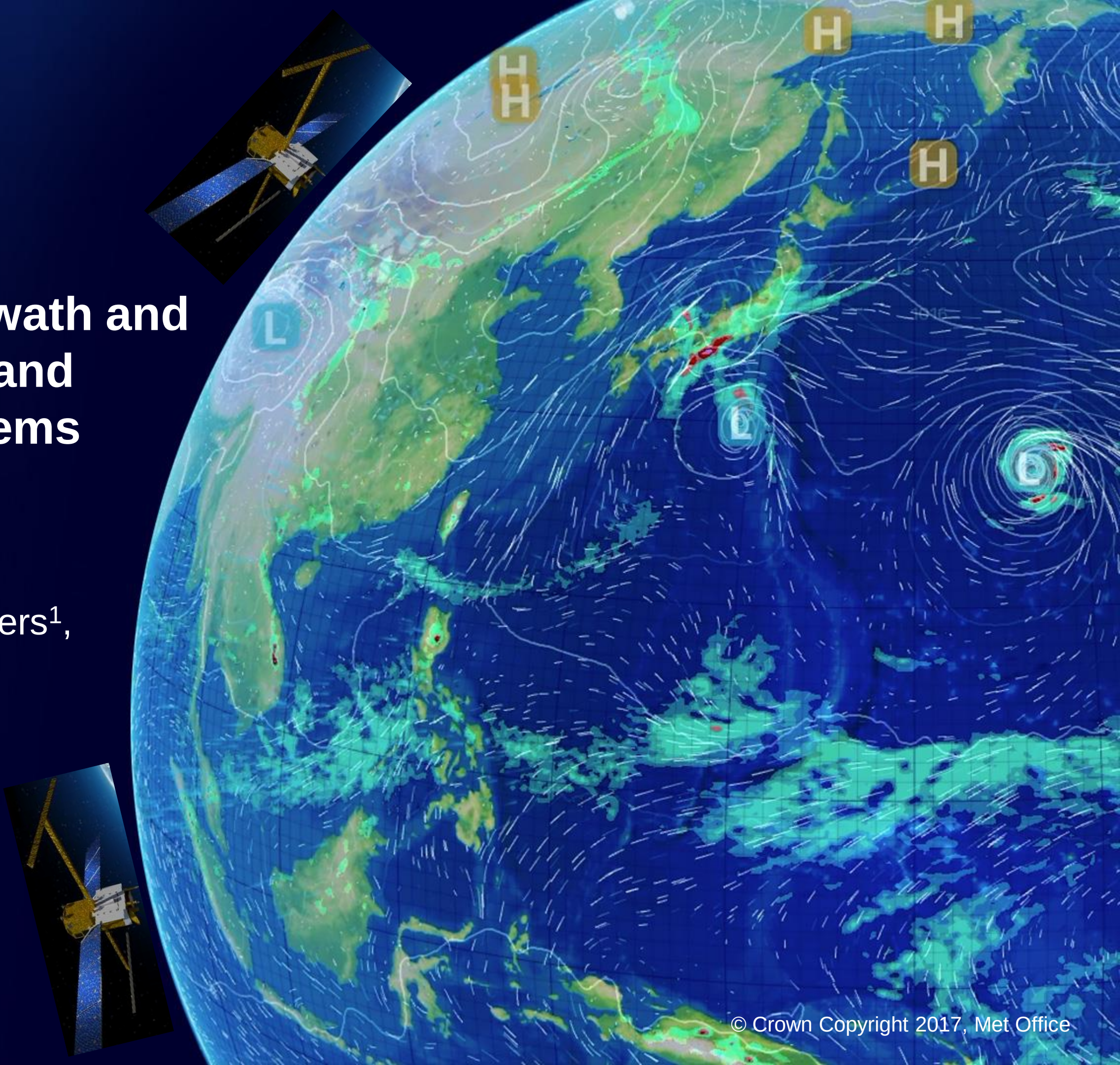
Met Office

# The impact of upcoming wide-swath and along-track altimeters in global and regional ocean forecasting systems




Robert King[1], Matthew Martin[1], Jennifer Waters[1], Lucile Gaultier[2], Clément Ubelmann[3]

1. Met Office
2. OceanDataLab, France
3. OceanNext, France

# Motivation

Altimetry routinely assimilated in operational systems, but

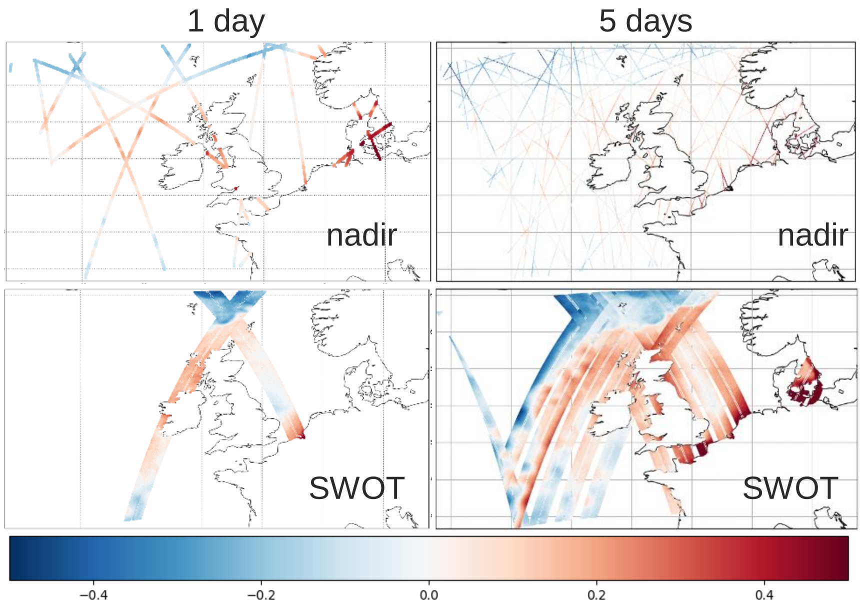
- Large gaps between tracks**, long repeat cycles** (10–35 days)
- Along-track obs have high sampling frequency (~7 km), but feature **resolution only ~100 km** (Xu and Fu, 2013).

Sub-optimal for the initialisation of mesoscale features

- Disparity between observed and modelled scales will increase as model resolution increases

Future constellations planned and SWOT due for launch

- SWOT scheduled to launch in November
- 120 km swath, 15km effective resolution (Morrow et al., 2018), 21 day repeat cycle




*Example coverage of 4-satellite constellation of nadir altimeters compared to SWOT.*

# Preparing for future altimeters

**Aim is to prepare for SWOT and to inform planning of future altimeter constellations**

**WiSA vs multiple Sentinel-3 altimeters in a Global System**

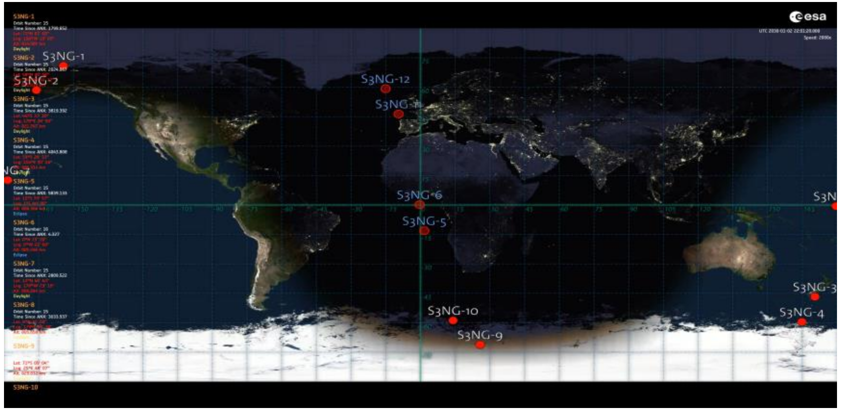
- On-going project comparing impact of two proposed scenarios
  - 2 Wide-Swath Altimeters (2xWiSA) flying along-side Sentinel-6
  - 12 Sentinal-3-like SAR altimeters flying along-side Sentinel-6.

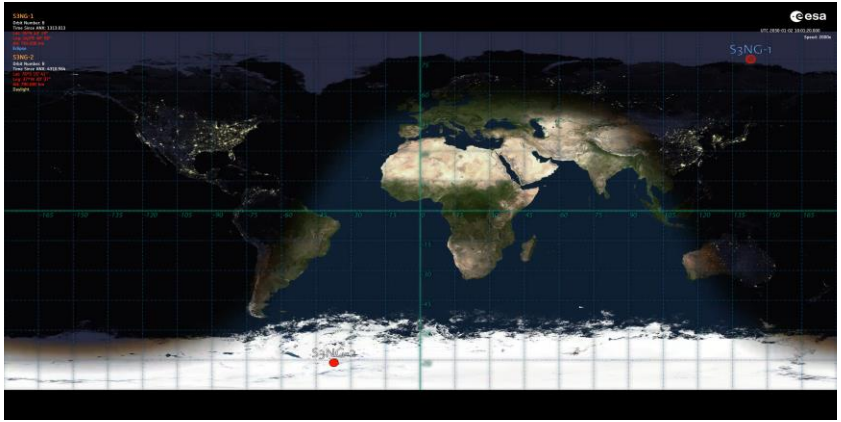
**Assimilating SWOT in a Regional Ocean Forecasting System**

- Looked at impact in 1.5km North-West European Shelf System
- Investigated simple methods to limit effects of correlated errors.

**Challenges**

- Making best use of both in situ and altimeter observations
- Uncertain magnitude of correlated errors – problematic for DA



# Global OSSEs –
# comparing 12 nadir vs 2 WiSA altimeters

Met Office

# Global OSSEs – 12nadir vs 2xWiSA

**OSSE design**

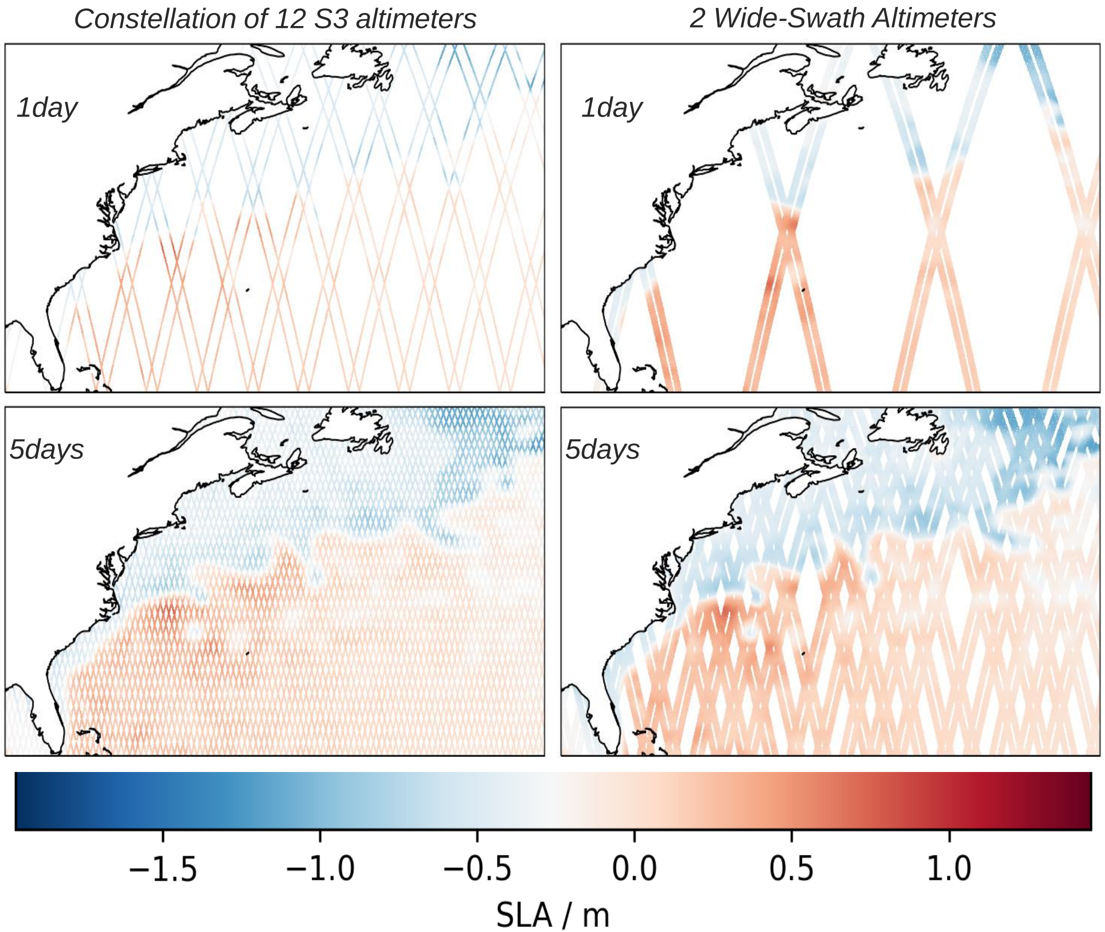
- Similar set-up as described in previous talk by J Waters.
- 1/12º Nature Run (NR), previously assessed by Gasparin et al. (2018)
- Observations simulated from NR with realistic errors, inc. SST, in situ T/S, SLA
- WiSA obs simulated with KaRIn and residual WetTropo errors. Not yet with correlated phase/roll errors.
- OSSE experiments: ¼º NEMO model, NEMOVAR DA, different initial conditions and fluxes.
- Mercator running coordinated experiments with which we will compare.

| Expt | Fluxes | Std Obs | S3A, S3B, | S6 | 12 x S3 | 2 x WiSA |
|---|---|---|---|---|---|---|
| Nature Run | ERA-I | | | | | |
| Control | ERA-5 | ✓ | ✓ | ✓ | | |
| NADIR | ERA-5 | ✓ | | ✓ | ✓ | |
| WISA | ERA-5 | ✓ | | ✓ | | ✓ |

# Global OSSEs – 12nadir vs 2xWiSA

**OSSE design**

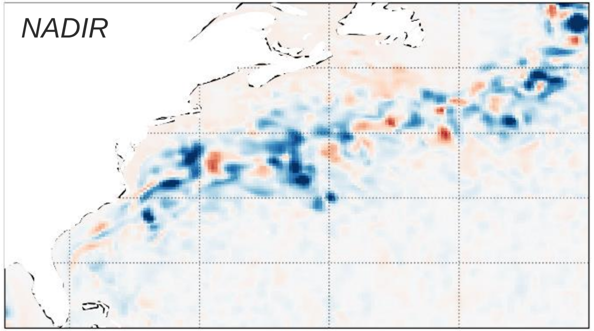
- Similar set-up as described in previous talk by J Waters.
- 1/12º Nature Run (NR), previously assessed by Gasparin et al. (2018)
- Observations simulated from NR with realistic errors, inc. SST, in situ T/S, SLA
- WiSA obs simulated with KaRIn and residual WetTropo errors. Not yet with correlated phase/roll errors.
- OSSE experiments: ¼º NEMO model, NEMOVAR DA, different initial conditions and fluxes.
- Mercator running coordinated experiments with which we will compare.

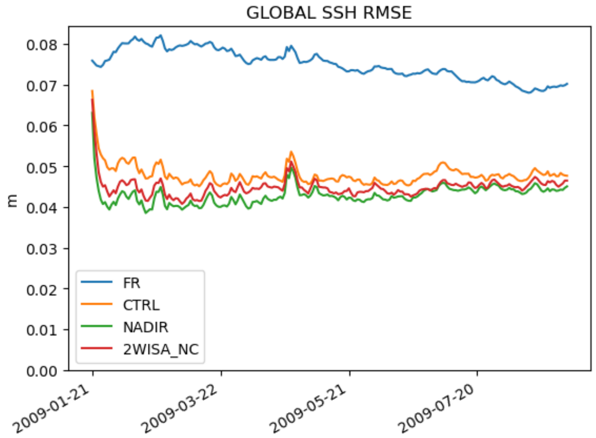


# Impact on SSH

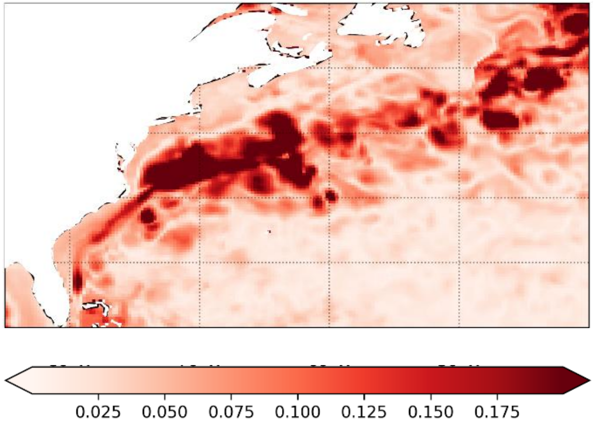
**Initial assessment**

- Both NADIR and WISA experiments reduce SSH RMSE compared to Control
  - RMSE reduction of 6.5% (WiSA) and 10% (NADIR)
  - Greatest improvement in WBCs
  - Next compare observation coverage and increments over these regions to understand why NADIR seems superior.

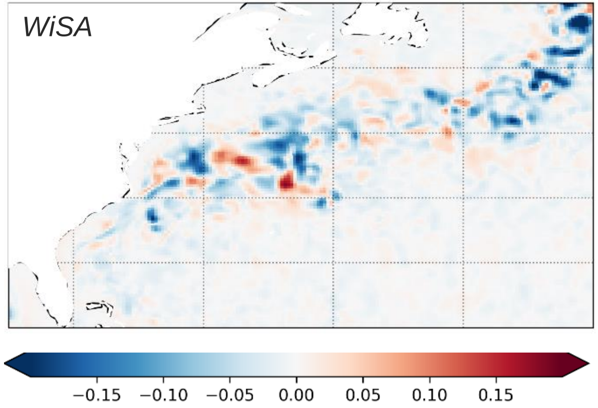



***SSH RMSE*** *(compared to truth) for the Free Run (blue), Control (orange), NADIR (green), and WISA (red) runs.*




*Control Run: May 2009* ***SSH RMSE*** *(compared to NR/truth)*

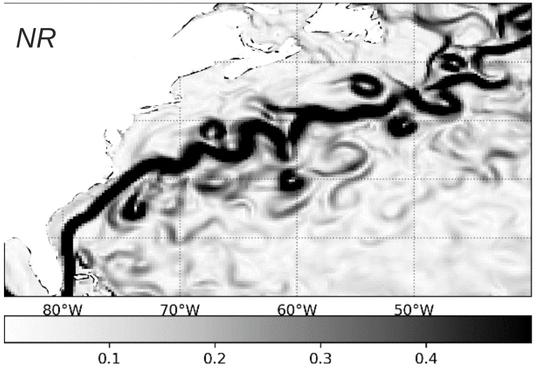



***SSH RMSE difference*** *(May 2009 compared to control, blue shows reduction in RMSE)*

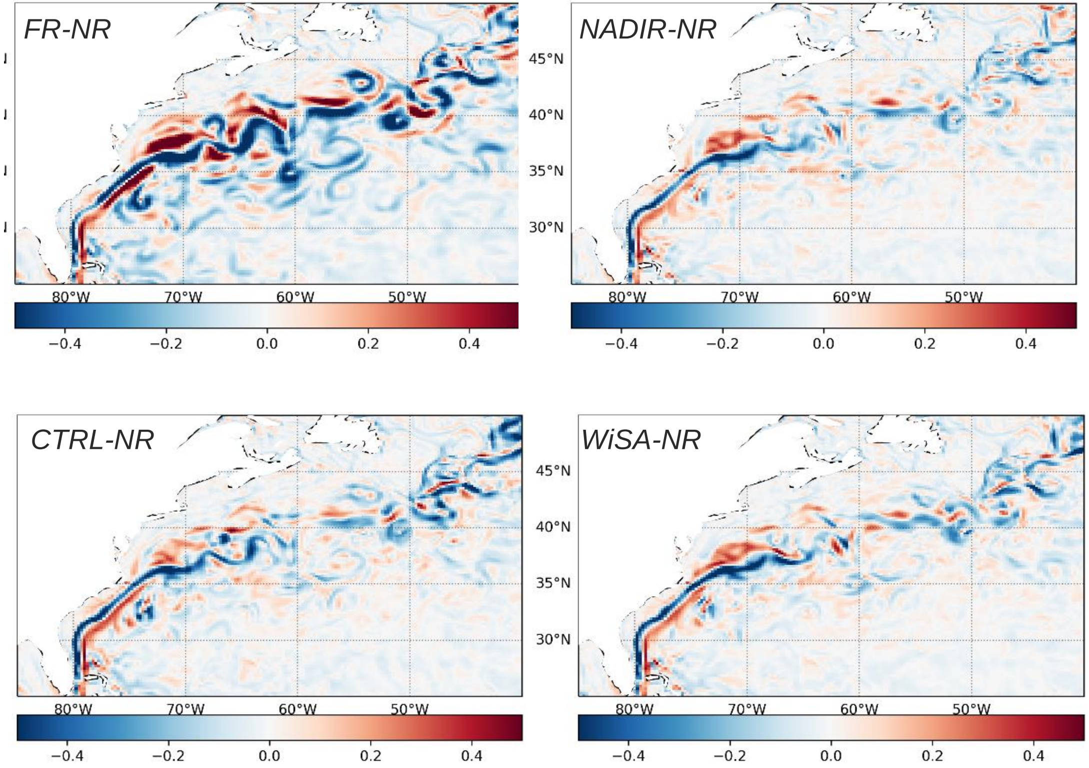
# Impact on Surface Currents

**Monthly mean surface current speed error**

- Free Run missing most of the well-defined eddies
- Better represented in Control
- Gulf Stream Extension better represented by WiSA and NADIR experiments.




***Surface current speed monthly mean***
*(May 2009)*

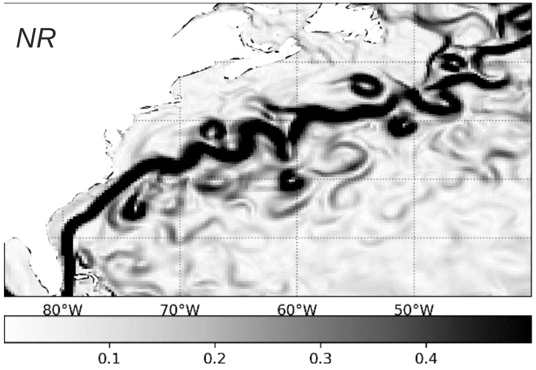



***Surface current speed monthly mean error***
*(May 2009 compared to Nature Run)*

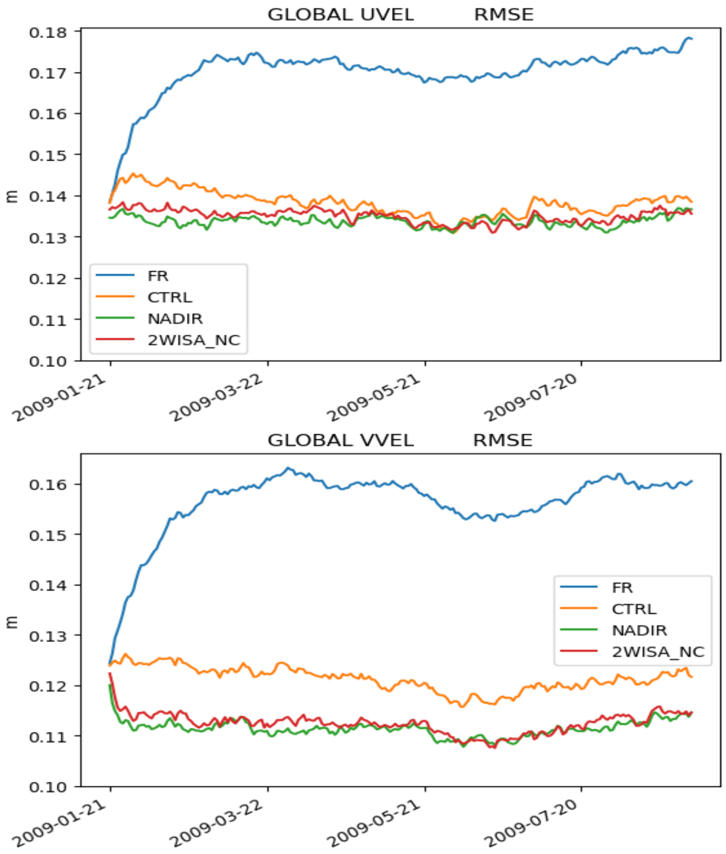
# Impact on Surface Currents

**Monthly mean surface current speed error**

- Free Run missing most of the well-defined eddies
- Better represented in Control
- Gulf Stream Extension better represented by WiSA and NADIR experiments.
- U RMSE reduces by ~1%
- V RMSE reduces by ~5%




***Surface current speed monthly mean***
*(May 2009)*




***U/V surface current speed RMSE***

# Regional OSSEs – assessing the potential impact of SWOT

Met Office

# Regional OSSEs

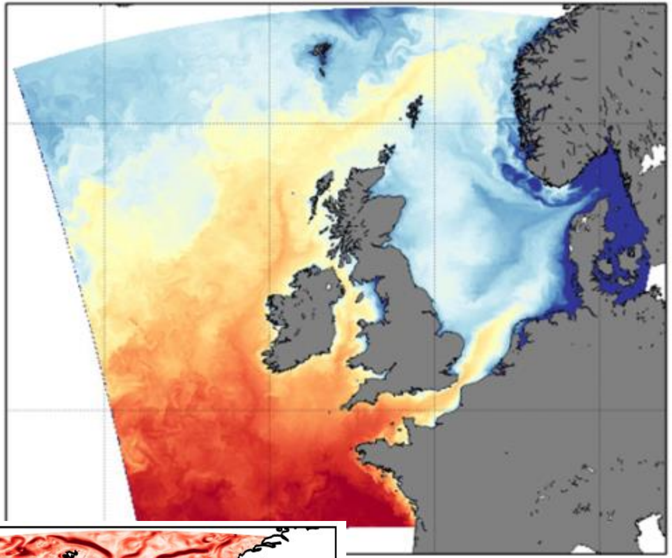
Latest configuration of the North-West European Shelf ocean forecasting system which delivers forecast products to Copernicus (NWS-MFC).

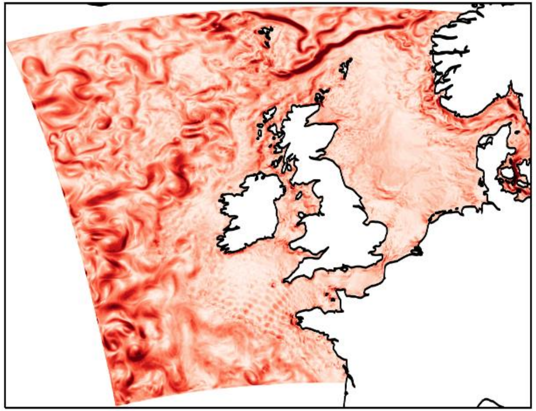
Ocean model is NEMOv3.6 in the AMM15 configuration

- Eddy-resolving **1.5km resolution**, 51 vertical sigma levels,
- Tidal, wind- and pressure-forced model
- Coupled to WaveWatchIII wave model

Data assimilation scheme is NEMOVAR

- **3DVar FGAT with 24-hour assimilation window**
- Multi-scale background errors, multivariate balances.
- Assimilates SST (L2 satellite and in situ), T/S profiles (Argo, moored buoys, gliders, ships, XBTs, marine mammals), and SLA
- Here we assimilate SLA throughout the domain (operational system is currently restricted to deep water)





*Example AMM15 SST and surface current speed*

# Regional OSSEs

**OSSE design**

Nature Run uses AMM15 with different surface forcing and different initial conditions.

Control OSSE assimilates only the existing network of (simulated) observations

Additional experiments with existing network plus

- SWOT with uncorrelated errors
- SWOT data with all expected sources of error
- Restricted SWOT data – full/half swath width, no/5km/20km SWOT obs averaging

| Experiment | Std Obs | Swath width | SWOT errors | Superob radius |
|---|---|---|---|---|
| Nature Run | - | - | - | - |
| Free Run | - | - | - | - |
| Control | Y | - | - | - |
| LowErrSWOT | Y | Full | Uncorrelated | - |
| SWOT | Y | Full | All | - |
| HalfSWOT | Y | Half | All | - |
| SWOT_5km | Y | Full | All | 5 km |
| SWOT_20km | Y | Full | All | 20 km |
| HalfSWOT_5km | Y | Half | All | 5 km |
| HalfSWOT_20km | Y | Half | All | 20 km |

# Impact on SSH

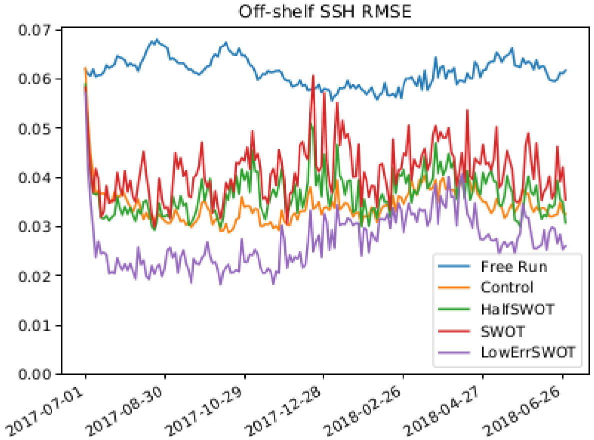
Off-shelf, assimilation has clear positive impact on SSH RMSE

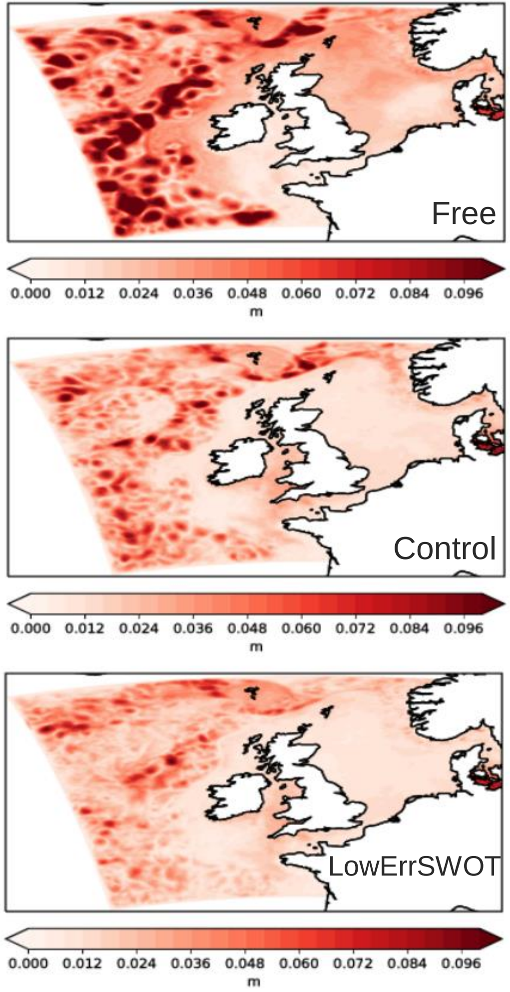
- **Without correlated errors (LowErrSWOT) RMSE down by 20%** relative to Control

- Assimilating SWOT with correlated errors degrades SSH bias and RMSE
  - RMSE increases by 22% with full swath and by 8% with half-swath (HalfSWOT)

Improvement in eddy positions clear from maps of monthly mean SSH RMSE.

*__SSH RMSE__ (compared to truth) for the Free Run (blue), Control (orange), half-swath SWOT (green), full-swath SWOT (red), and full-swath w/o correlated errors (purple) runs.*



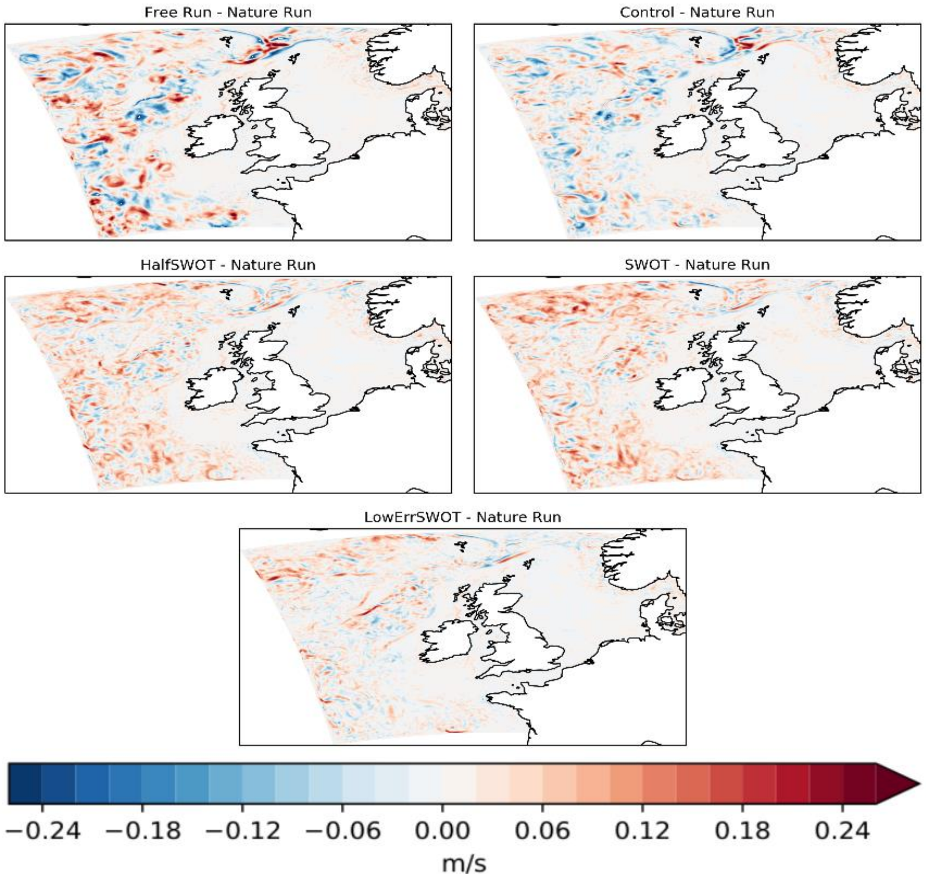




***June 2018 average SSH RMSE***

# Impact on Surface Currents

**Monthly mean surface current speed error**

- In Free run, many eddies and current meanders are misplaced
- Control run improves the positions of individual eddies and straightens the current through the Faroe-Shetland channel.
- LowErrSWOT further improves the simulation of the surface current features.
- However, average surface current speed erroneously increased when assimilating SWOT obs with correlated errors.




**Monthly (June 2018) mean surface current speed error (compared to Nature Run).**

# Impact on Surface Currents

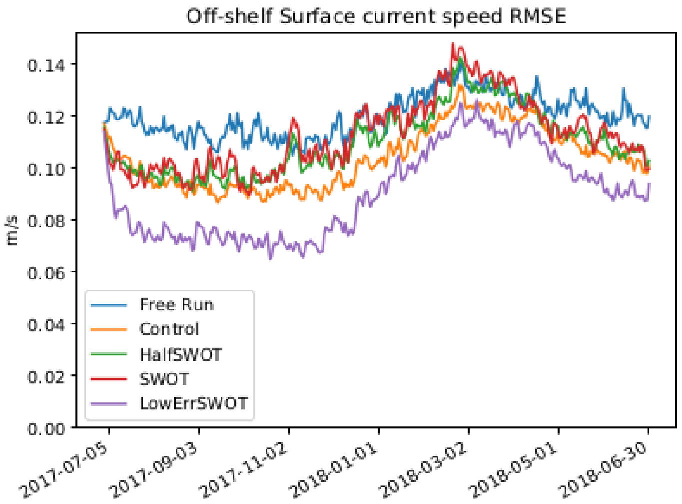
Off-shelf

- HalfSWOT and SWOT increase surface current speed errors by 6% and 9%
- LowErrSWOT reduces RMSE relative to the Control by 13% (varies seasonally, peak reduction of ~20%).

On-shelf

- differences smaller in absolute terms, but similar in percentage terms

Overall, the assimilation of SWOT observations can better initialise the position and strength of eddies and significantly reduce the surface current RMSE, but correlated SWOT errors lead to a bias toward faster surface currents.




***Surface current speed RMSE (compared to Nature Run).***

# Impact of averaging observations

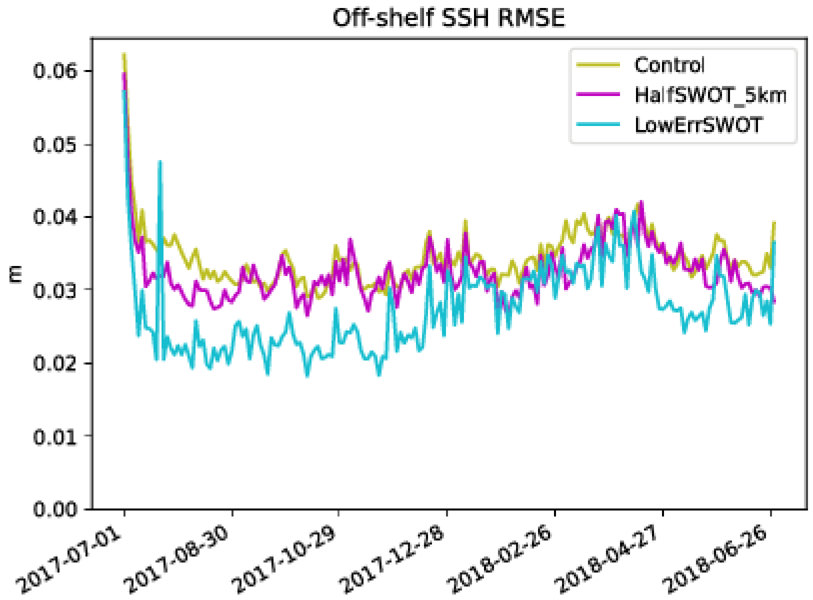
SWOT can clearly have a large impact without correlated errors.

Limiting to inner half of swath can reduce some of the degradation caused by correlated errors.

Also looked at impact of super-obbing

- Tried 5km and 20km averaging radii
- 20km averaging improved both SWOT and HalfSWOT results
- 5km averaging gave best results.

So overall, best results with correlated errors when using half swath and 5km averaging (HalfSWOT_5km)




***Surface current speed RMSE (compared to Nature Run)*** *showing comparison of SWOT impact without correlated errors vs with correlated errors but restricted to inner half swath and with observation averaging.*

# Conclusions & Outlook

**Swot assimilation in our regional system can significantly improve SSH, surface currents, sub-surface T/S.**

- but correlated errors are a major issue
- Restricting swath width, stringent QC, and Super-obbing can extract some benefit from SWOT w/ correlated errors
- But more explicit treatment of correlated errors required to realise full potential of SWOT

**A 12-nadir altimeter constellation may have greater impact in our global system than 2 WiSAs**

- But need to assess full year of experiments and impact on subsurface
- And assess impact on small-scales

**Next aim to explore**

- Using power spectra to assess the minimum resolved length and time-scales in the analysed SSH fields
- Treating obs error correlations within our DA scheme (e.g., using a diffusion operator, Guillet et al. 2019)

Met Office

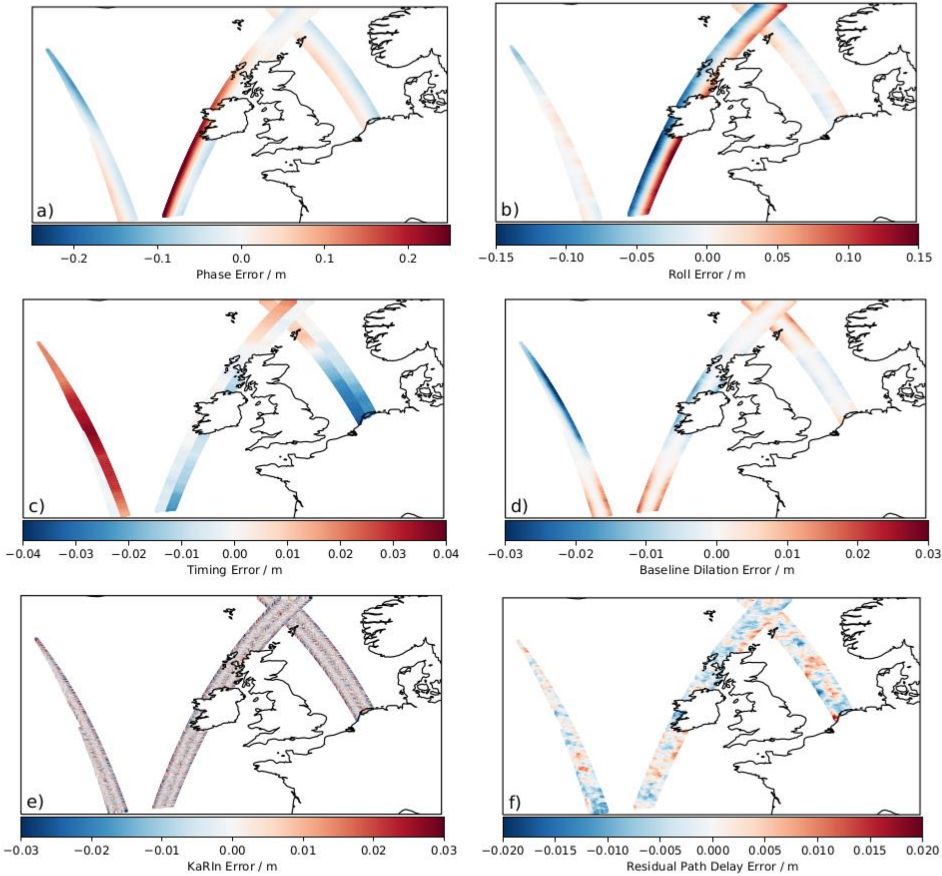
# Wide-swath Altimetry

Wide-swath altimetry observations will be subject to **large correlated geophysical and instrumental errors**.

- Presents a challenge for data assimilation schemes.
- These errors are significantly larger than that associated with current nadir SLA observations.
- Phase and roll errors in particular can introduce **spatially correlated errors in excess of 10 cm**.

| Error (cm) | RMSE | Extrema |
|---|---|---|
| All | 6.2 | 39 |
| Phase | 4.9 | 26 |
| Roll | 3.1 | 16 |
| Timing | 1.8 | 6 |
| KaRIn | 1.2 | 7 |
| Baseline Dilation | 0.6 | 4 |
| Residual Path Delay | 0.5 | 3 |
| All nadir | | |
| All | 1.4 | 6 |

*SWOT and nadir altimeter error statistics for 1-month of simulated observations (see King & Martin 2021).*




*Individual components of the SWOT errors for an example day. Note the difference in the scales for each error component. Created using the SWOTsimulator of Gaultier et al. (2016).*