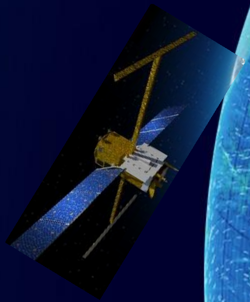
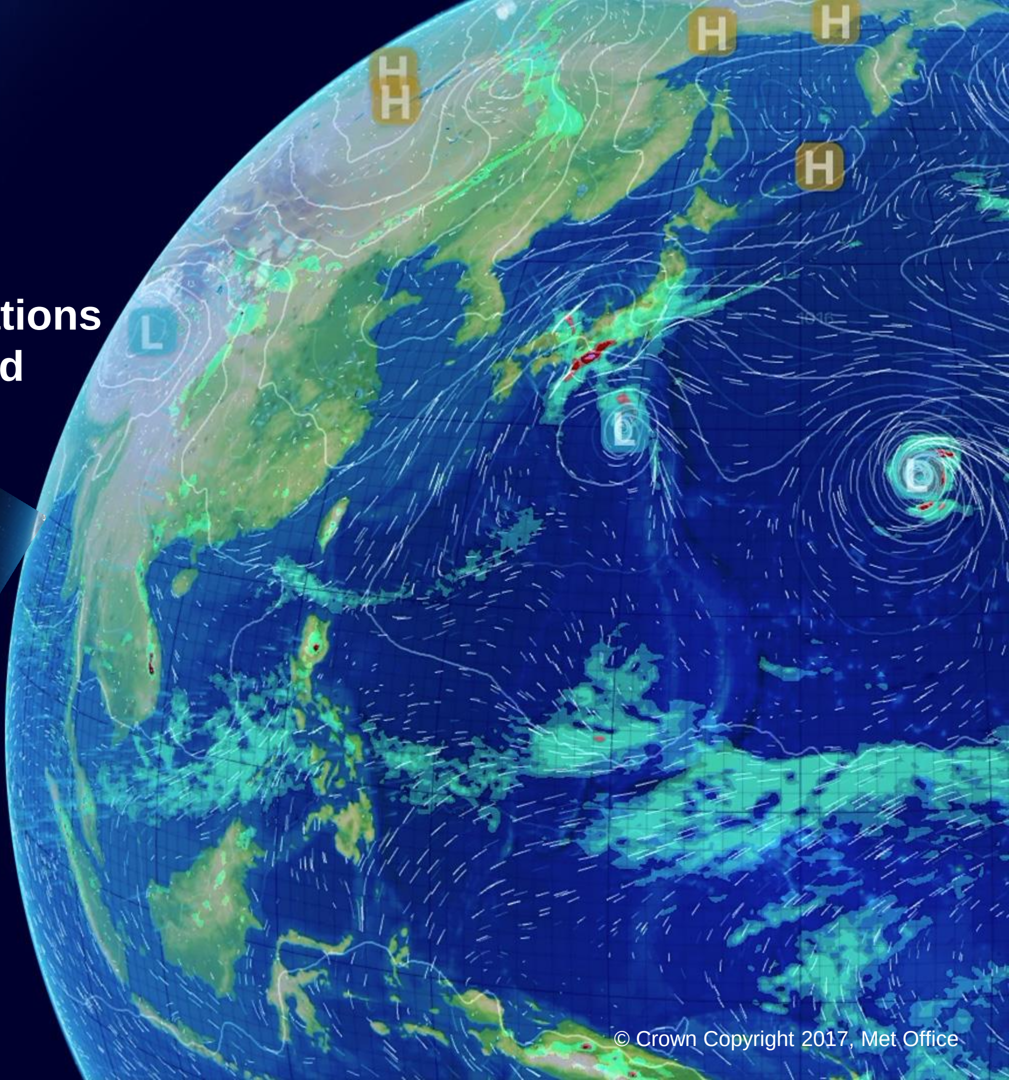
Assimilating wide-swath altimeter observations in a high-resolution shelf-seas analysis and forecasting system





Robert King, Matthew Martin

18th May 2021

AMM15 - Shelf-Seas Analysis and Forecasting System

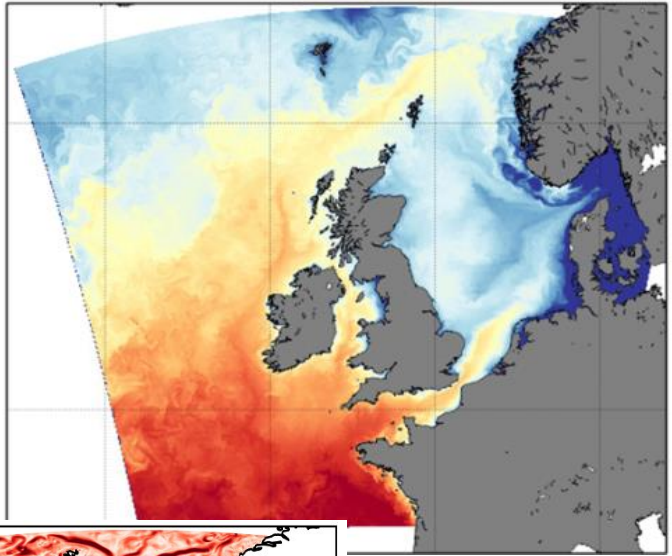
Latest configuration of the North-West European Shelf ocean forecasting system which delivers forecast products to CMEMS (NWS-MFC).

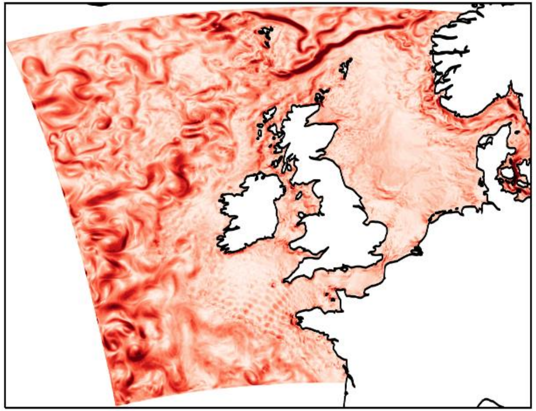
Ocean model is NEMOv3.6 in the AMM15 configuration

- 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

Along-track Altimetry

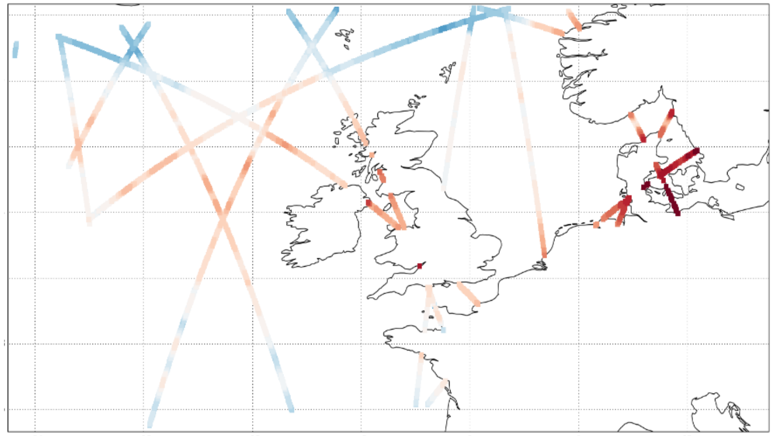
SLA observations are routinely assimilated in operational global ocean analysis and forecasting systems.

Existing observations provide limited spatial and temporal resolution.

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

Already sub-optimal for the initialisation of mesoscale features in the current generation of operational ocean prediction systems.

With the move to higher-resolutions, this disparity between the observed and modelled scales will increase.



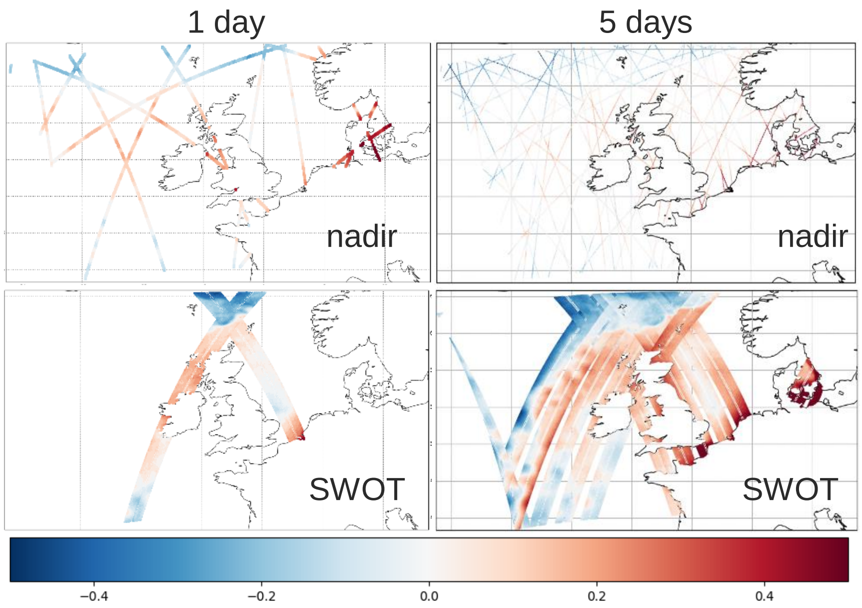
Example daily observation coverage over AMM15 domain from 4-altimeter constellation.

Wide-swath Altimetry

Upcoming wide-swath altimetry missions (SWOT and COMPIRA) will provide a step-change in ability to observe ocean mesoscale.

SWOT mission

- scheduled to launch in November 2022
- 120 km wide swath with a 20 km central gap
- combined with a nadir altimeter
- aim is an effective resolution of ~15 km with ~2 km sampling (Morrow et al., 2018)
- 21 day repeat cycle (average revisit of 11 days)



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

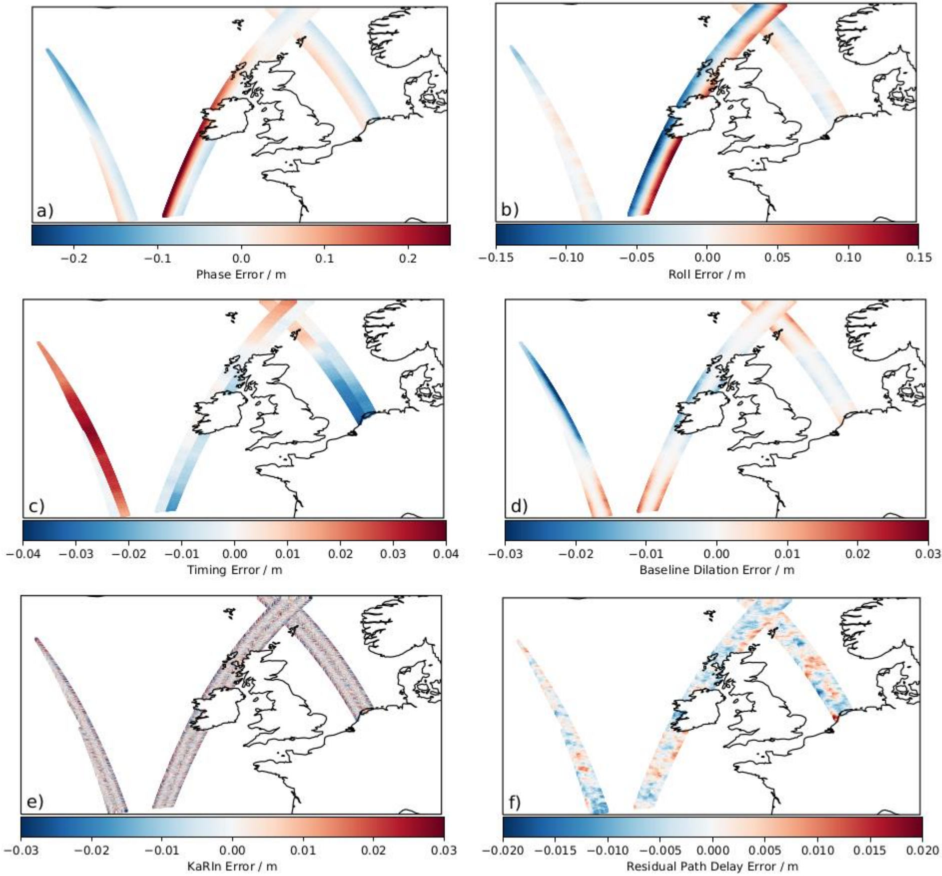
Wide-swath Altimetry

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



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).

OSSE set-up

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 <u>uncorrelated</u> 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

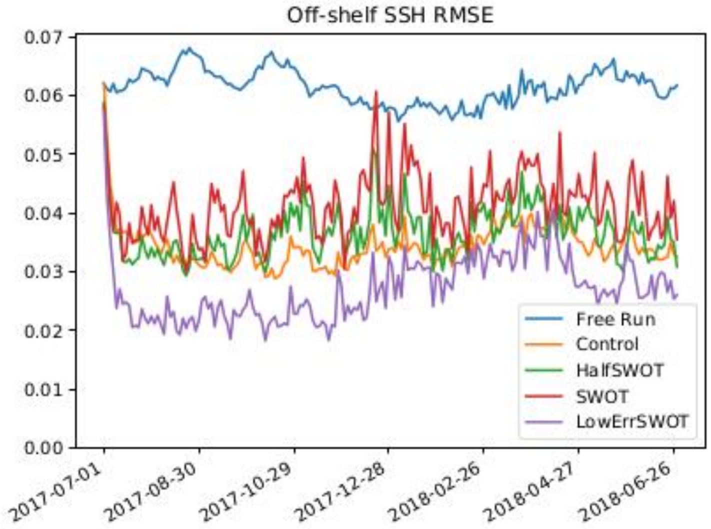
Results: Impact on SSH

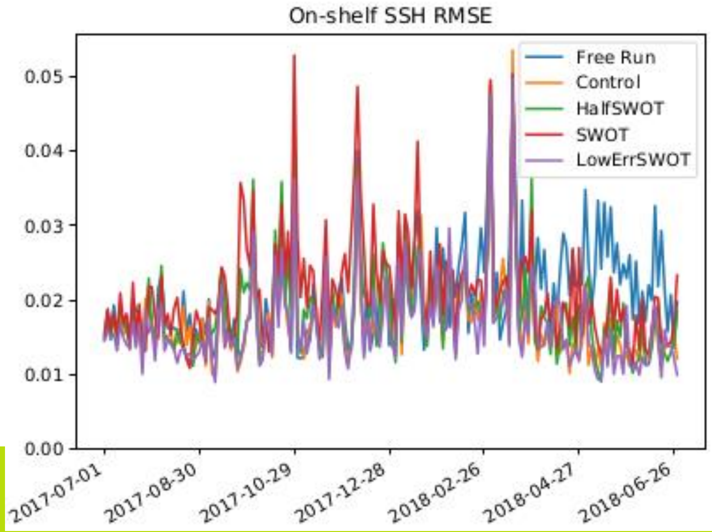
Off-shelf, assimilation has clear positive impact on SSH RMSE

- Assimilating SWOT with correlated errors degrades SSH bias and RMSE
  - HalfSWOT and SWOT increase RMSE by 8% and 22% relative to Control
  - LowErrSWOT reduces RMSE by 20% relative to Control

On-shelf modelled SSH variability is much lower

- In absolute terms, little difference in SSH RMSE b/w expts
- In percentage terms, impact is similar to that seen off-shelf
  - HalfSWOT and SWOT increase the RMSE by 6% and 24%
  - LowErrSWOT reduces RMSE by only 3% relative to the Control.





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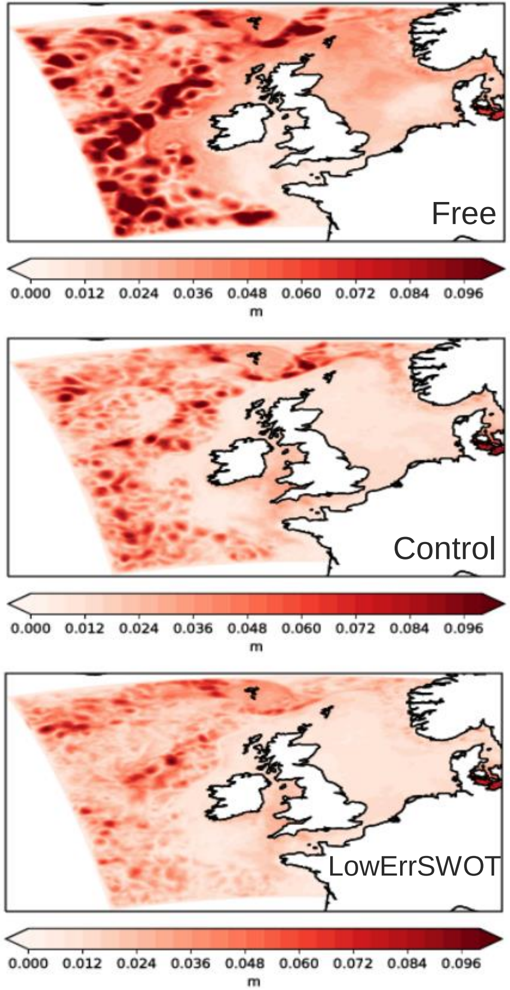
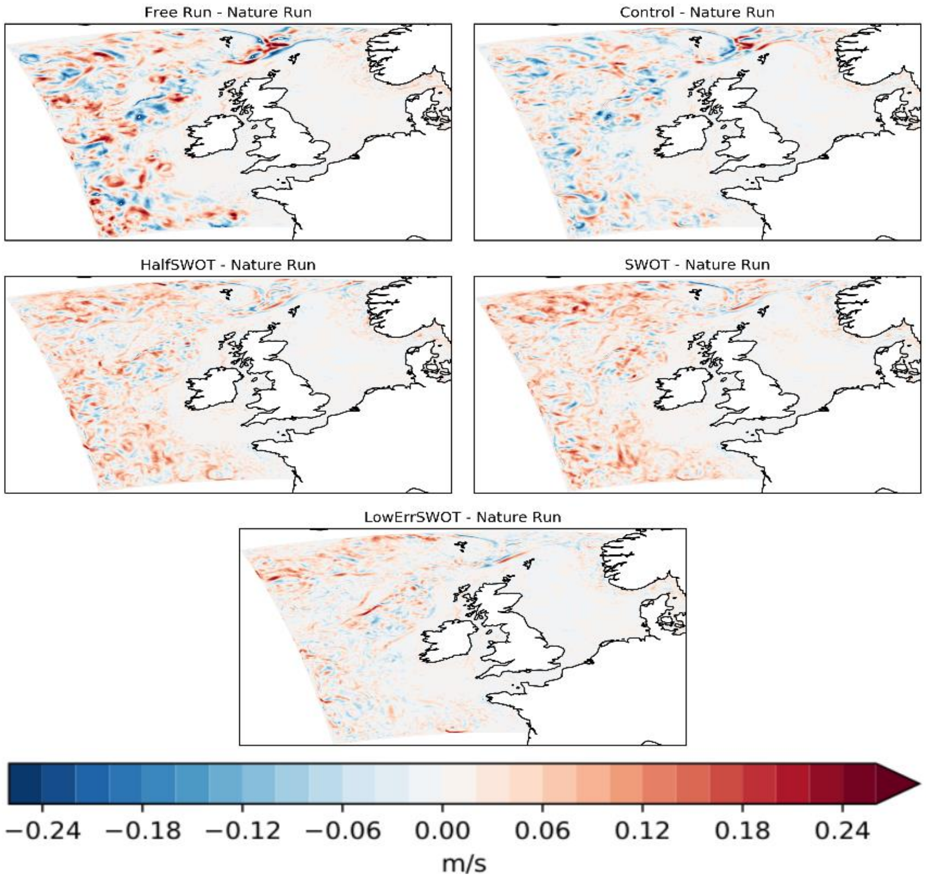
Improvement in eddy positions clear from maps of monthly mean SSH RMSE.



June 2018 average SSH RMSE

Results: Impact on Surface Currents

- 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).

Results: Impact on Surface Currents

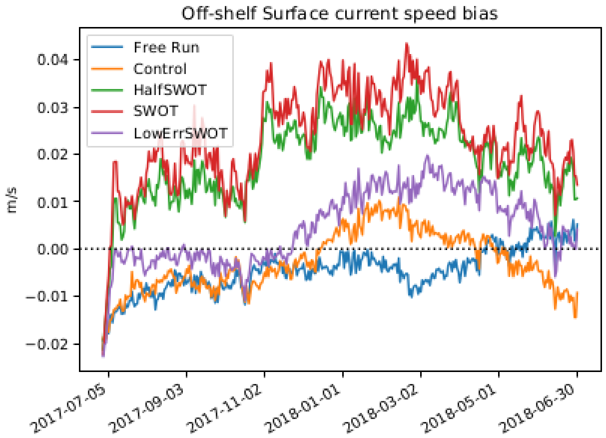
Off-shelf

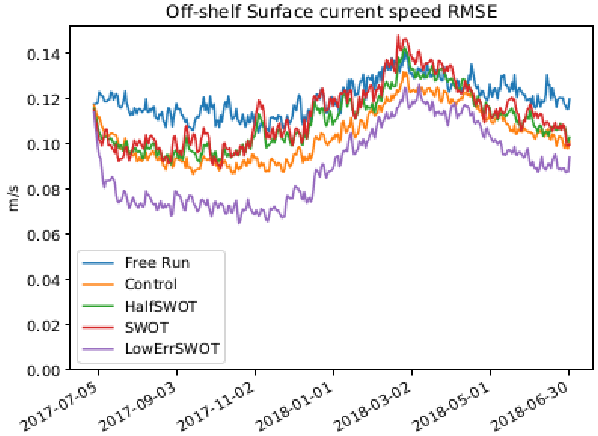
- HalfSWOT and SWOT increase surface current speed errors by 6% and 9%
- LowErrSWOT reduces RMSE relative to the Control by 13% (varies seasonally, peak reduction of ~20%).

On-shelf

- differences smaller in absolute terms
- HalfSWOT and SWOT increase surface current speed errors by 6% and 13%
- LowErrrSWOT has a negligible impact relative to the Control.

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.





Results: impact of averaging observations

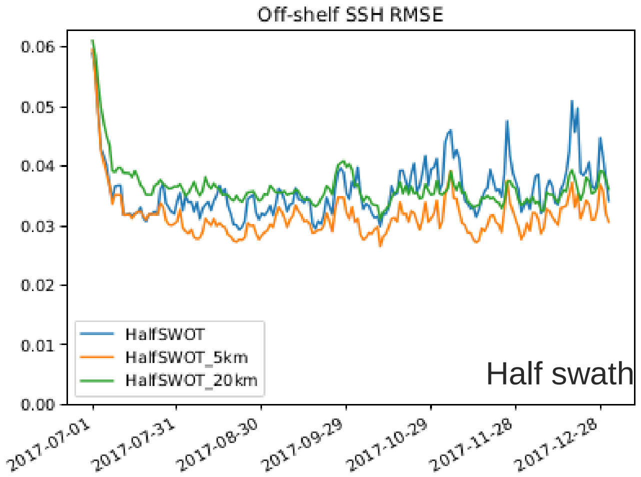
SWOT can clearly have a large impact without correlated errors.

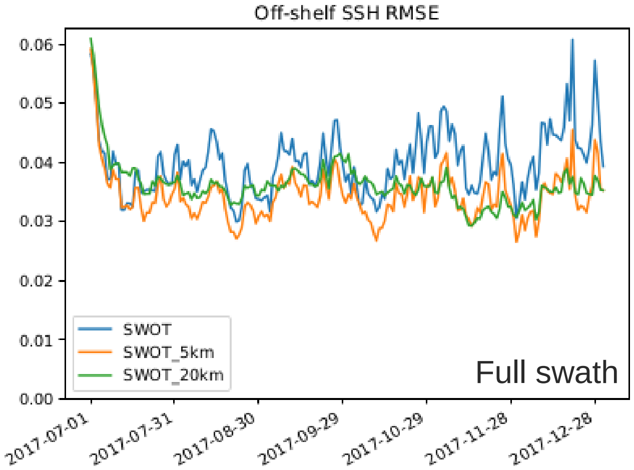
Limiting the data to the inner half of the swath can reduce some of the degradation caused by correlated errors.

Next 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.

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





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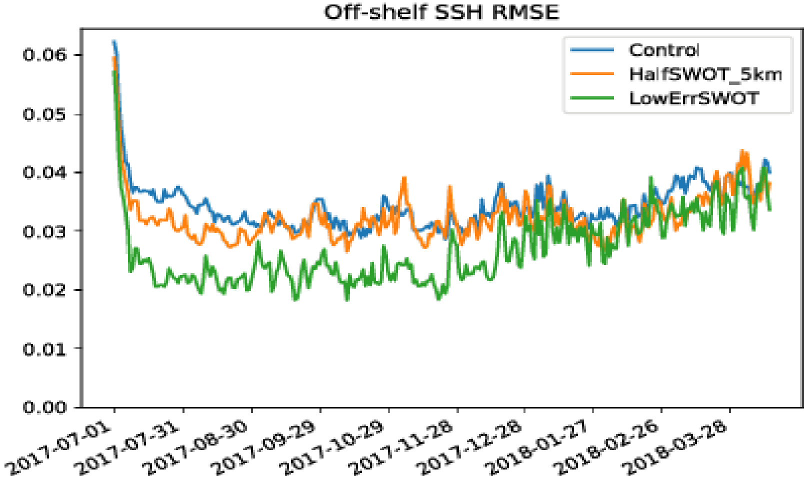

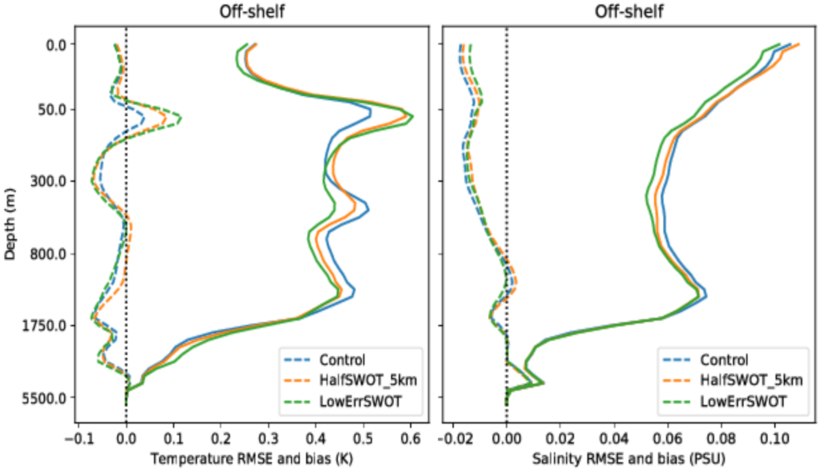

Conclusions & Outlook

Impact of assimilating wide-swath altimetry obs from upcoming SWOT mission assessed using OSSEs with a high-resolution shelf-seas model.

- Aim to highlight potential of swath altimeters and challenge in their use within an operational system
- Observations were simulated with realistic errors.

SWOT assimilation can significantly improve SSH, surface currents, and 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

We next aim to explore

- modelling obs error correlations using a diffusion operator (e.g., Guillet et al. 2019)
- treating correlated errors as a bias – some SWOT errors have predictable structure along/across track.
- whether SWOT assimilation can improve the surge component of the SSH signal