Assimilation of total surface current velocities in the Met Office ocean forecasting system for the ESA A-TSCV project

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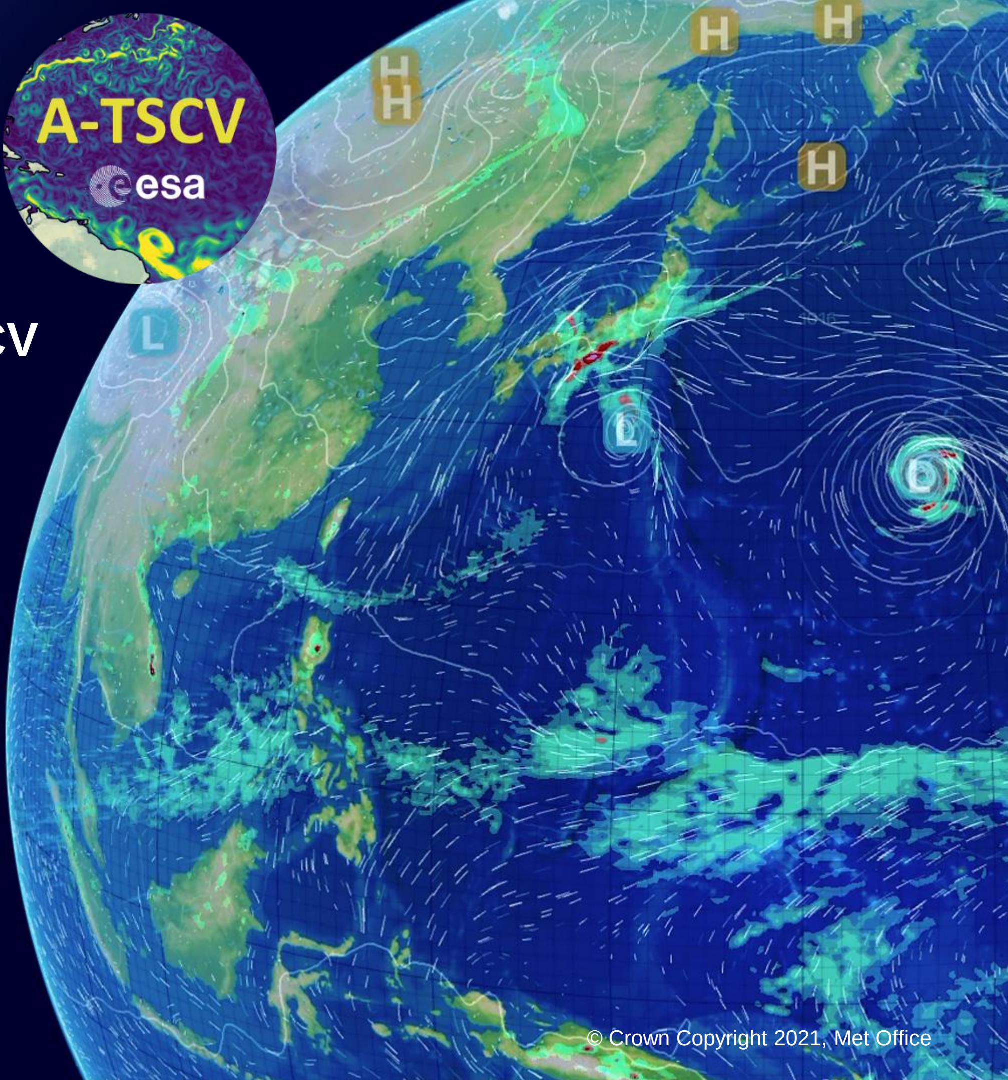

Implementing TSCV assimilation

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FOAM system overview

	UKMO – FOAM system
Ocean model	NEMO-CICE at ¼ degree
Data Assimilation Scheme	NEMOVAR 3DVar-FGAT scheme with multivariate balance.
Implementation of increments	IAU over 1 day.

Control

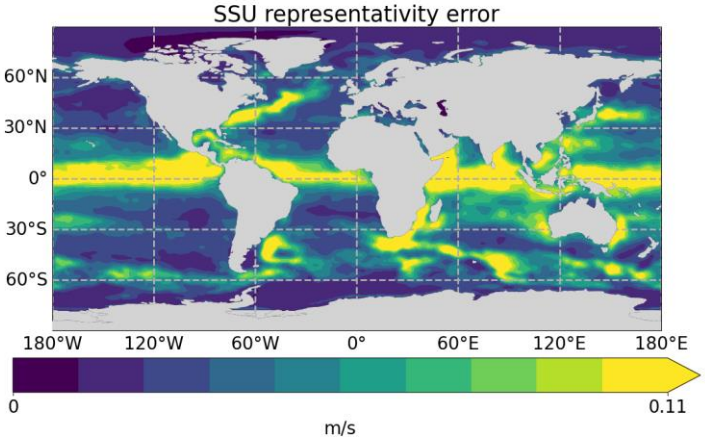
- Observations generated from Nature Run for standard obs types
- No assimilation of velocity observations but adjustments are made to the velocities through the balance relationship (geostrophic balance)
- No velocity balance at the equator

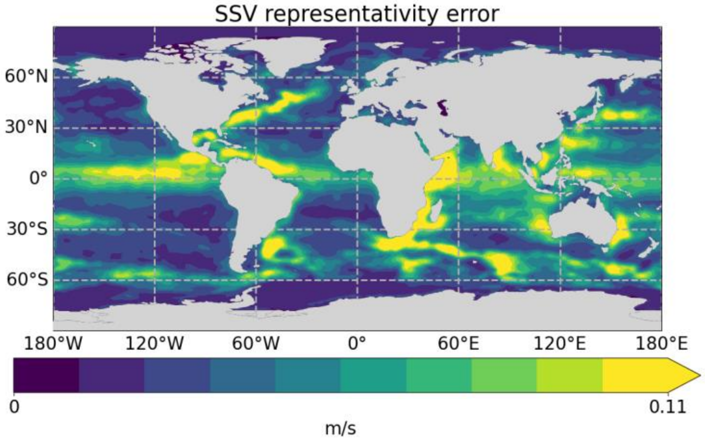
TSCV Assim Exp

- additional observations:
  - TSCV L2
- Both balanced (geostrophic) and unbalanced (ageostrophic) increments are produced for velocity. The geostrophic component gets transferred to the other variables though the balance relationships.
- New bkg error covariances are defined for unbalanced U and V
- New representativity obs error variances estimated for SSU and SSV

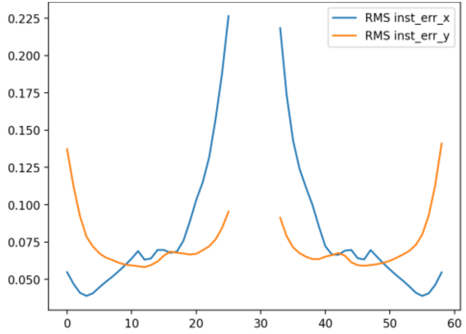
TSCV Observation Errors

- Estimated representativity errors for surface U and V by comparing the variability in the surface velocities for FOAM and the Nature run over a year.
- Added a constant mapping error ~2.5cm/s (along swath radial currents -> 2D currents along swath)





- Instrument error produced by Skimulator and depend on position across the track



Velocity Background Error Covariances in FOAM: Horizontal

- specifying background error covariance for the unbalanced (ageostrophic) velocities.

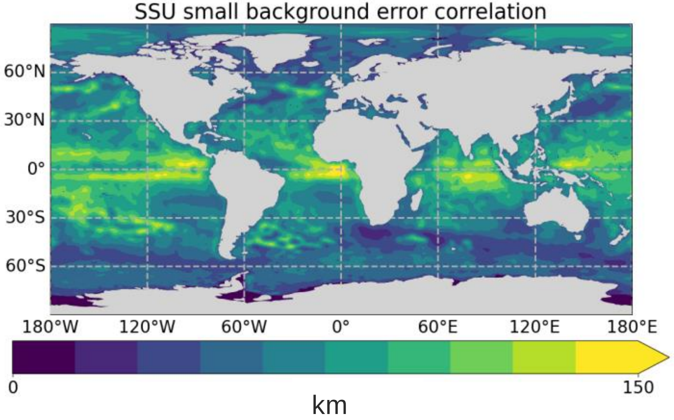
$$B = B_1 + B_2$$

- In NEMOVAR we need to specify the background error standard deviations and correlations at each model point
- NMC method: uses 48 hour and 24 hour forecast difference fields, valid at the same time, as a proxy for the background error.
- Using a previous two-year run of the 1/4° FOAM system.
- Removed the balanced component of the velocities from the forecast field differences to allow us to calculate “unbalanced” velocity error covariances.
- Performed a function fitting to determine the correlation length-scales.

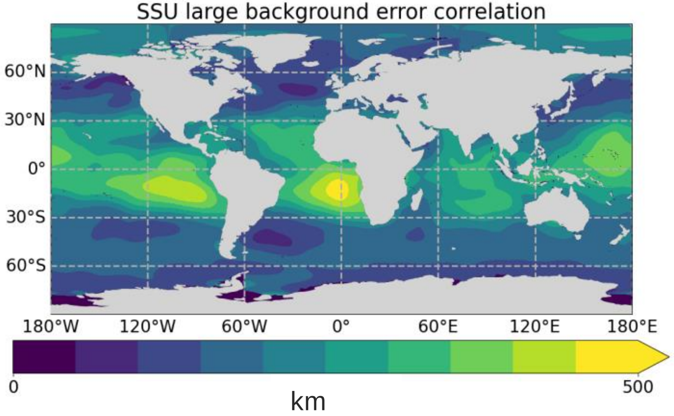
Background Velocity Error Covariances in NEMOVAR: Horizontal

Correlation length scales

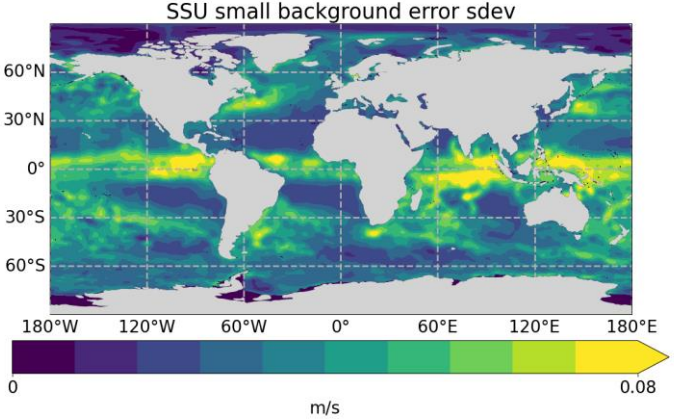
B_1

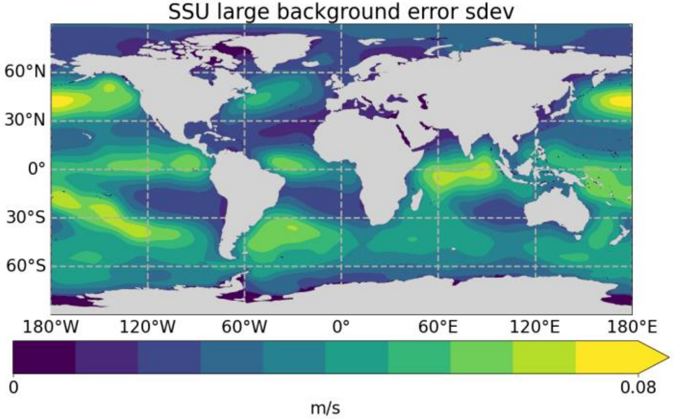


B_2



$D^{1/2}$



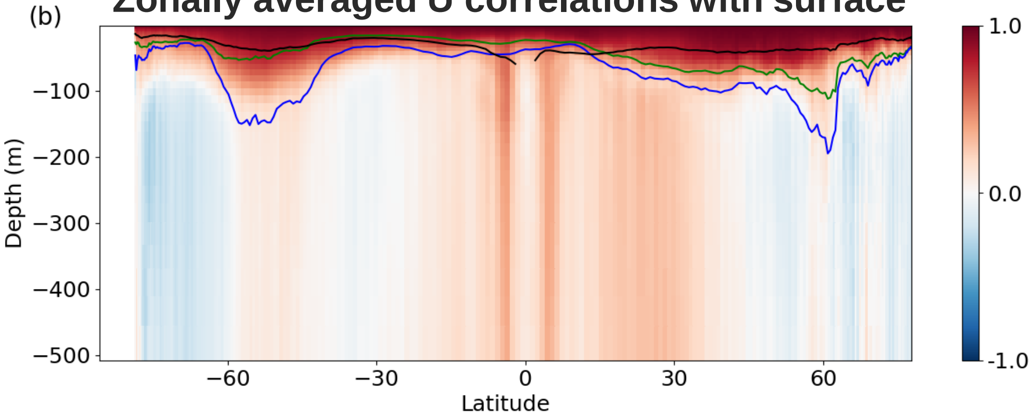


The correlation scales are fixed but the background error standard deviations vary seasonally

Background Velocity Error Covariances in NEMOVAR: vertical

- In NEMOVAR we use a mixed layer depth parameterisation to define the vertical correlation length scales for T and S
- The vertical correlations at the surface are equal to the local Kara mixed layer depth
- We use a similar approach to parameterise U and V scales.
- Compared the vertical correlation length-scales at the surface estimated from the NMC method with different mixed layer depth definitions
- Found that a different density based mixed layer depth best parameterised the vertical scales for U and V
- The same density based mixed layer depth is also used as the scale to taper the surface U and V standard deviations with depth, although a longer scale of 150m is used near the equator.

__ Kara mixed layer depth: depth at which the density has increased equivalent to a temperature difference of 0.8 degrees at the surface
__Density mixed layer depth: shallowest depth where density increases by 0.01 kgm-3 relative to 10m density
__ Ekman depth



Global results

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OSSE experiments

Experiment	Fluxes	Assim SST	Assim T/S profiles	Assim SSH	Assim SIC	Assim TSCV	TSCV Errors
Control	ERA5	✓	✓	✓	✓		
A-TSCV_no Err	ERA5	✓	✓	✓	✓	✓	mapping only (approx. 2cm/s)
A-TSCV_Instr Err	ERA5	✓	✓	✓	✓	✓	Mapping error + Instrument error

All TSCV Observations are thinned to a spatial resolution of 20km in the along and across track directions.

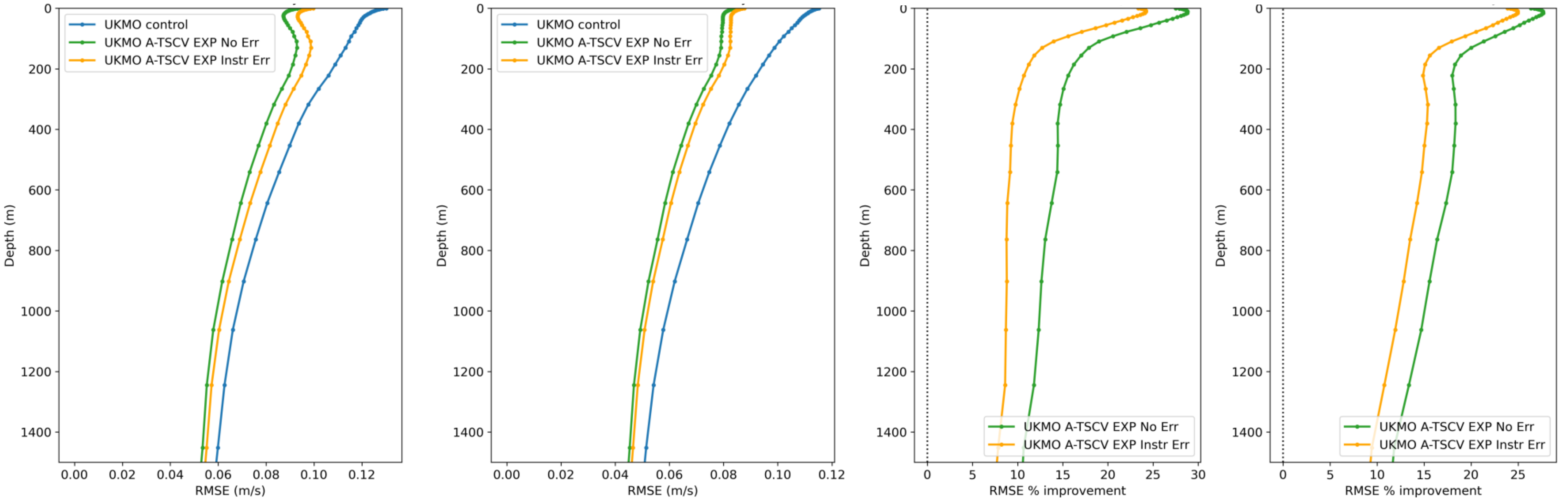
Global statistics: 25th Feb – 30th Dec Velocities

U RMSE

V RMSE

U RMSE % improvement

V RMSE % improvement

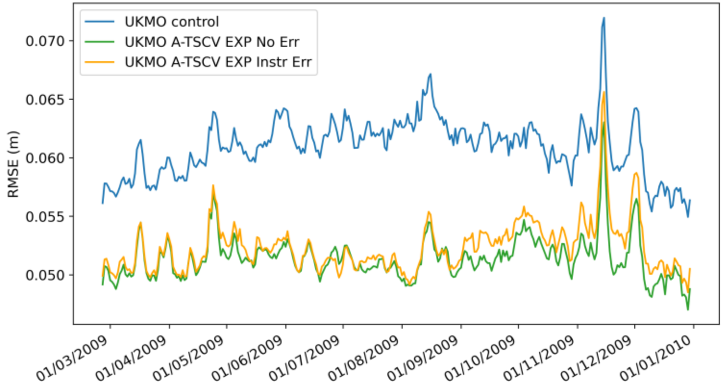


Note, these RMSE statistics are calculated against the NR (i.e the “truth”)

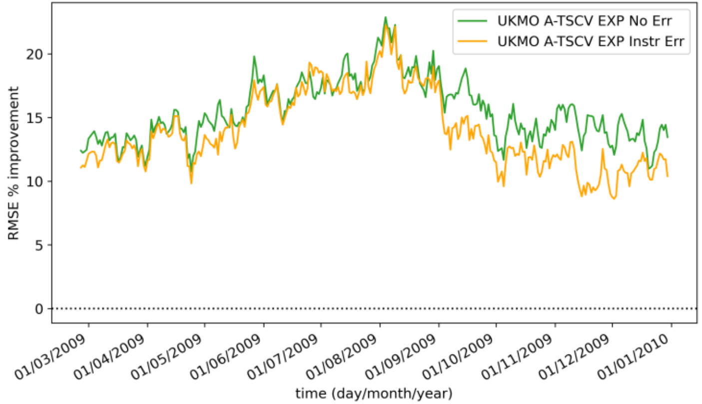
Global statistics: 25th Feb – 30th Dec

Other variables

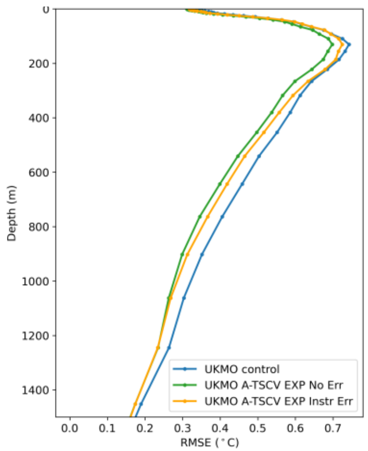
SSH RMSE



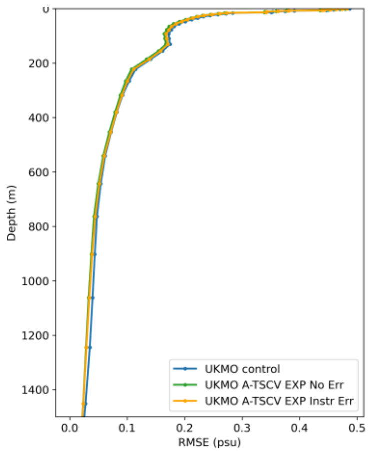
SSH RMSE % improvement



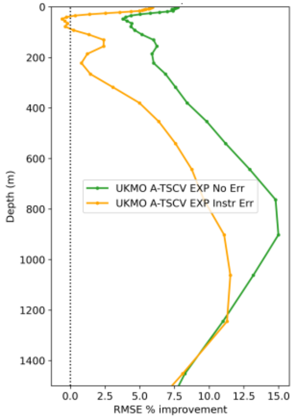
T RMSE

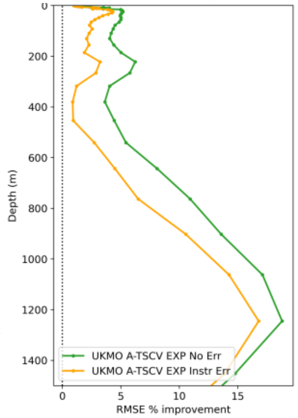


S RMSE



RMSE % improvement





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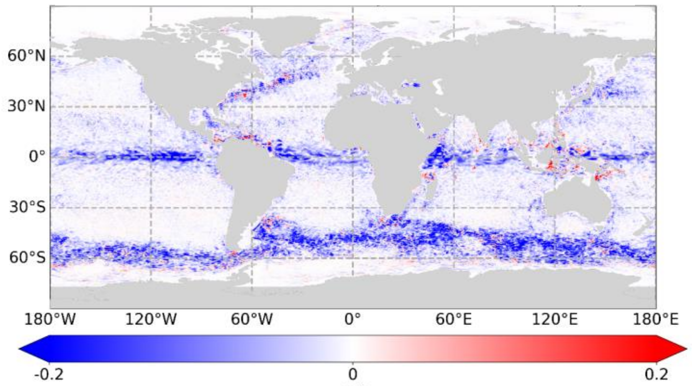
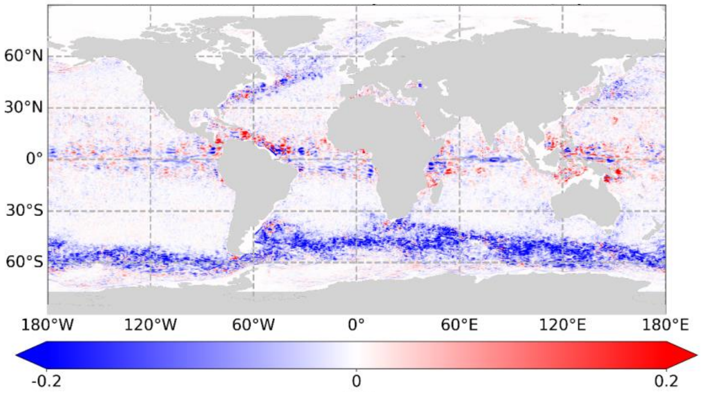
Difference in RMSE for the control and A-TSCV No Err: July 2009

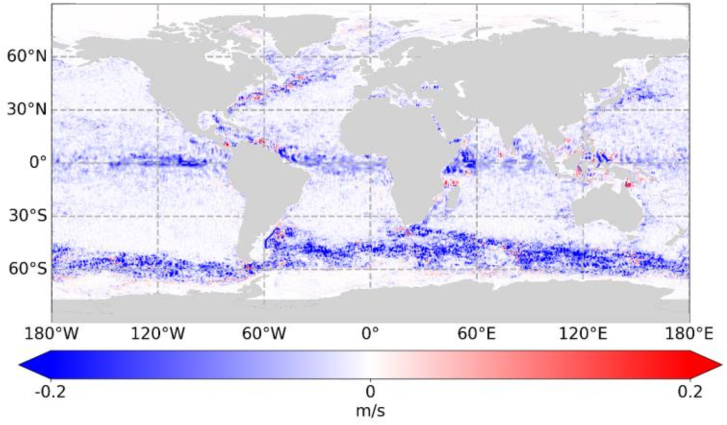
U RMS difference 0m



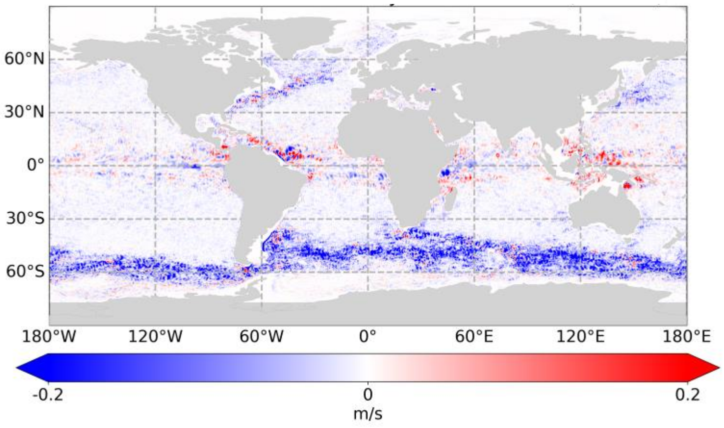
U RMS difference 220m



V RMS difference 0m

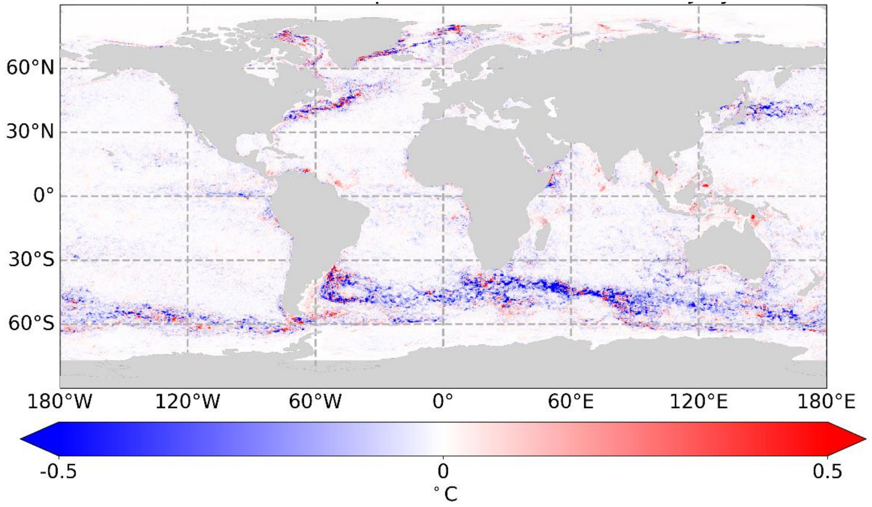


V RMS difference 220m

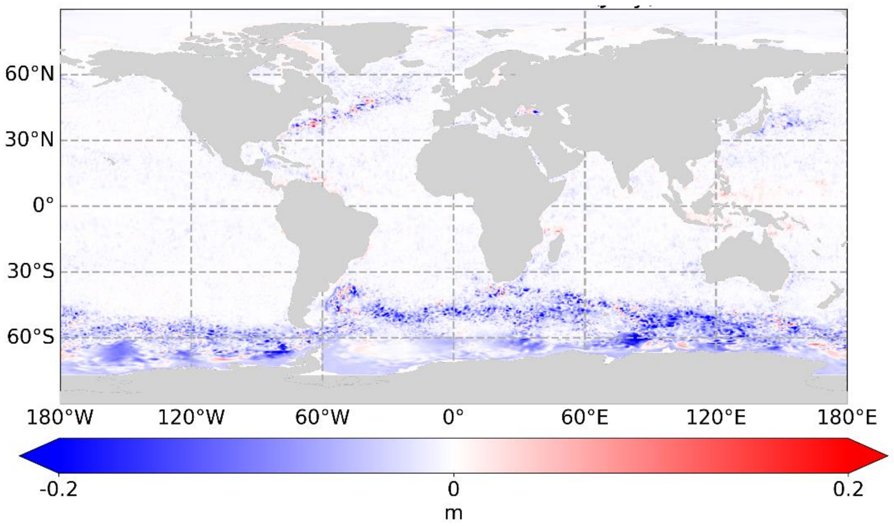


Difference in RMSE for the control and A-TSCV No Err: July 2009

SST RMS difference



SSH RMS difference



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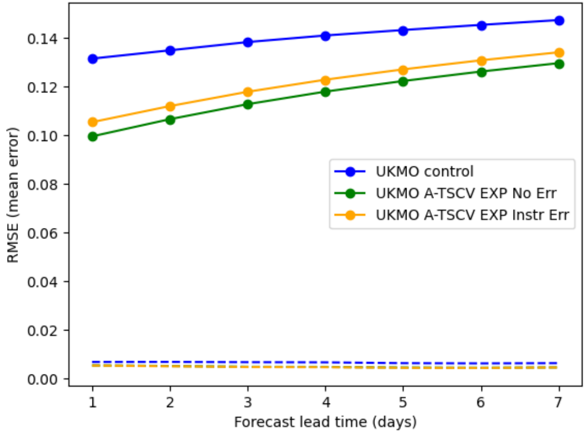
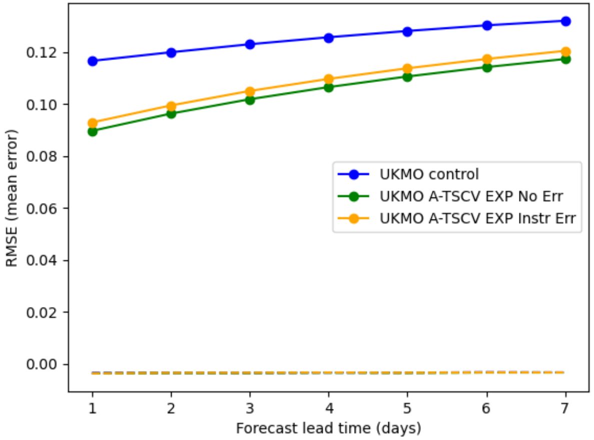
Global Forecast Results

Surface U



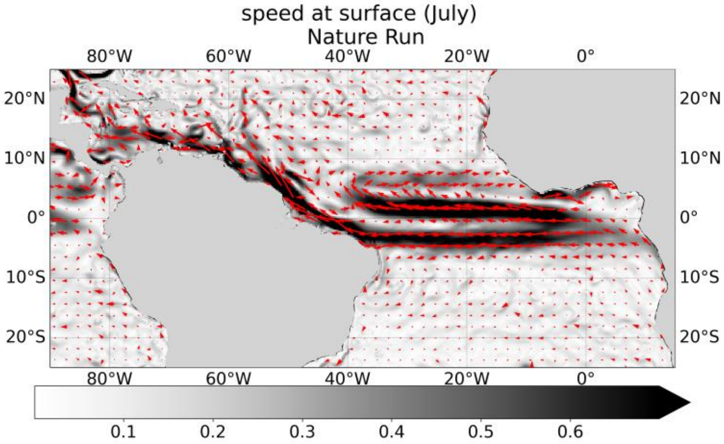
Surface V

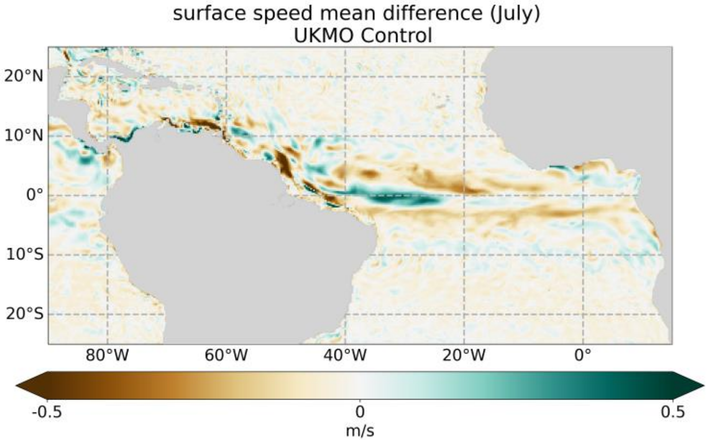


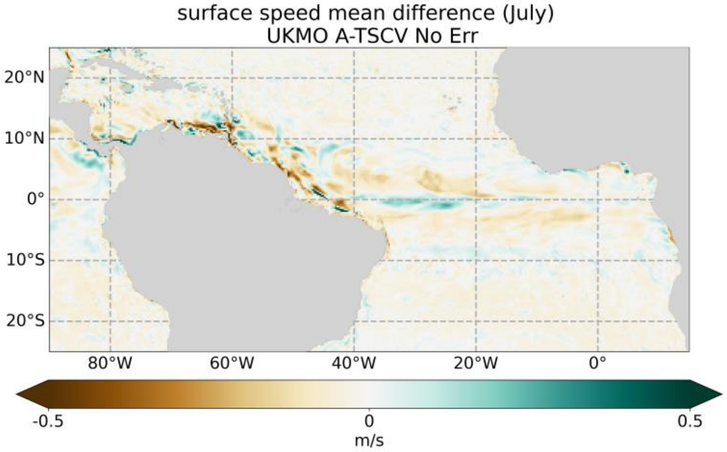
Ran 7 day forecasts every 7 days between 25th Feb and 30th of Dec.

Regional Results

Tropical Atlantic: July

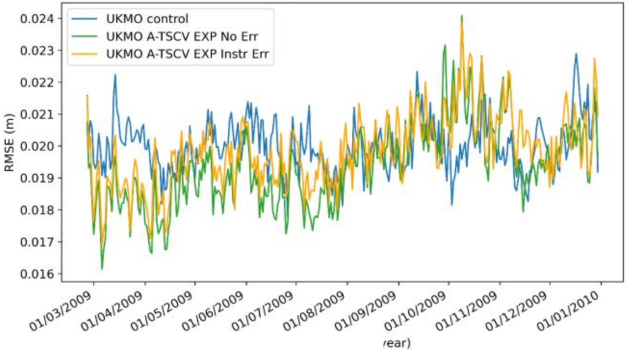


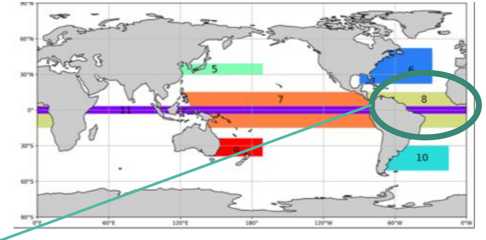




Tropical Atlantic

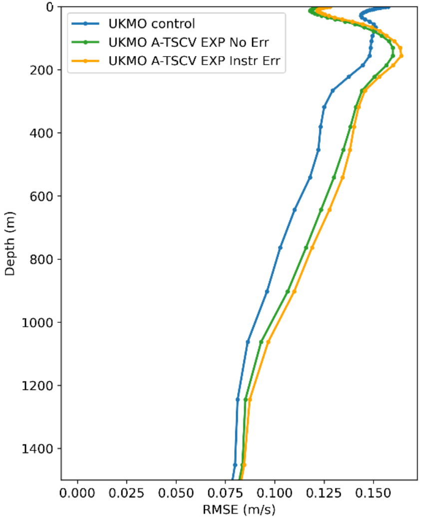
SSH RMSE



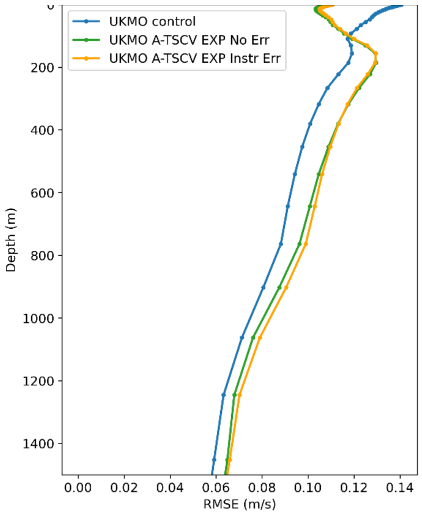


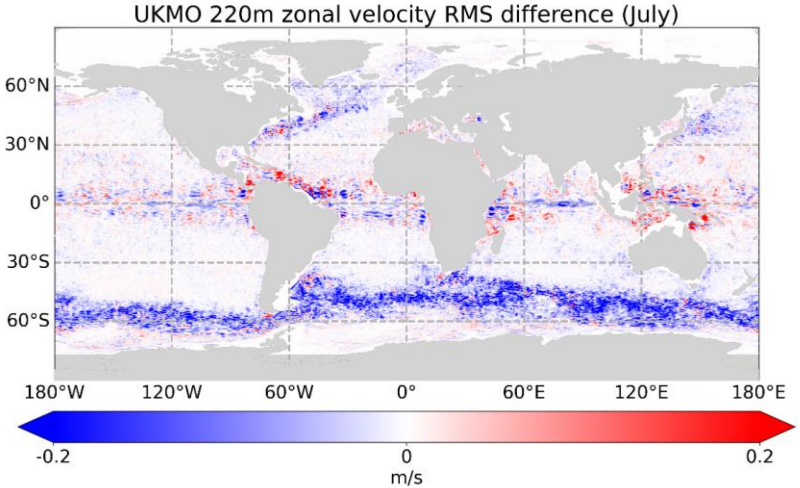
Subsurface degradations to U RMSE in the Tropical Atlantic primarily occur in the Amazon outflow region – known deficiency in this region which appears to be exacerbated by extra obs sampling.

U RMSE

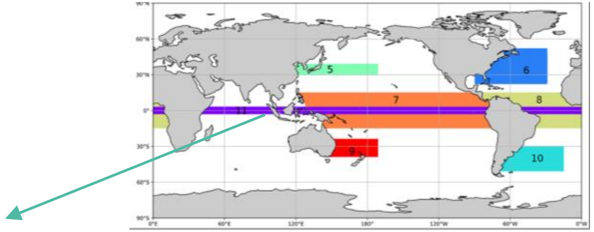


V RMSE

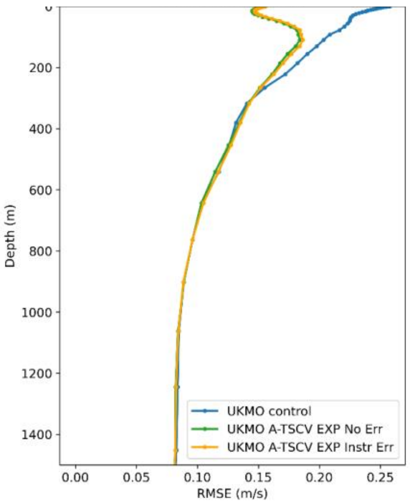




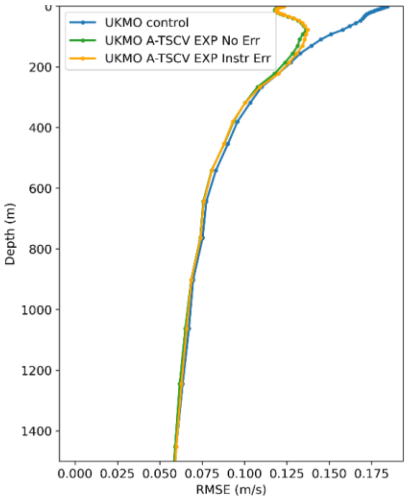
Equatorial region



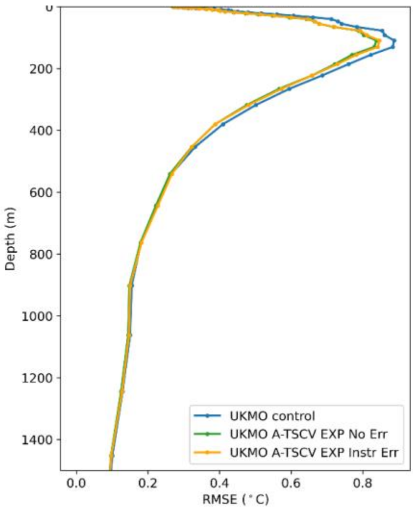
U RMSE



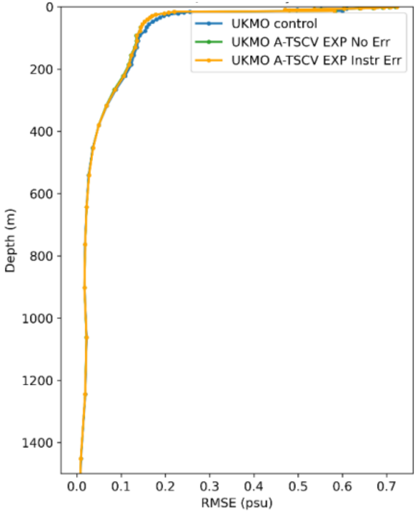
V RMSE



T RMSE

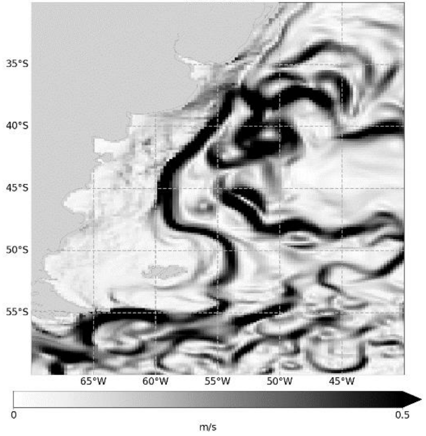
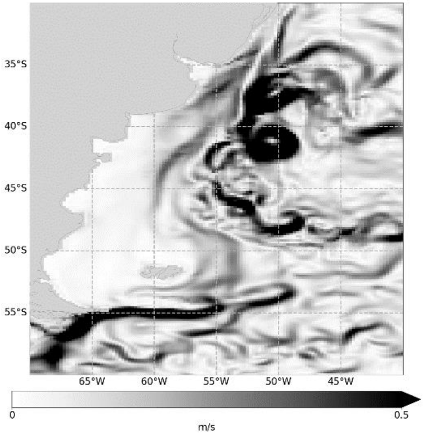
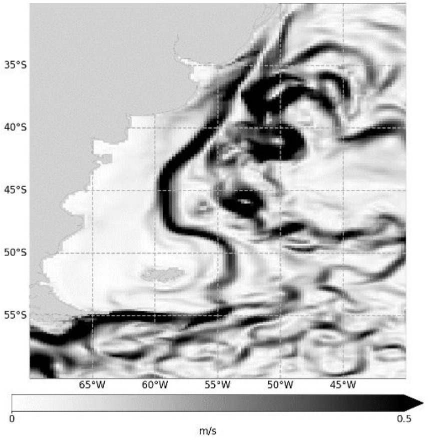
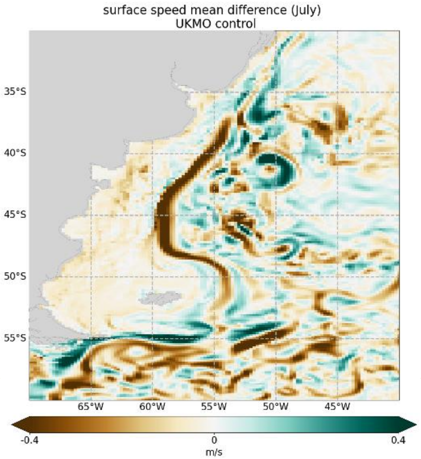
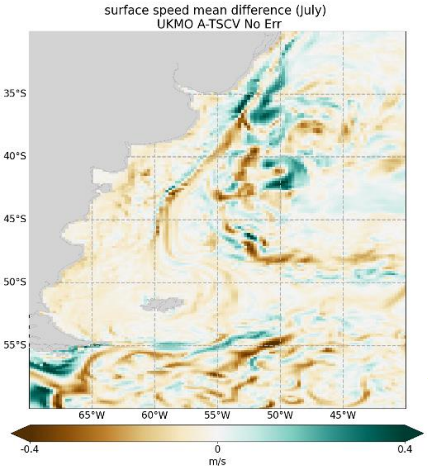


S RMSE



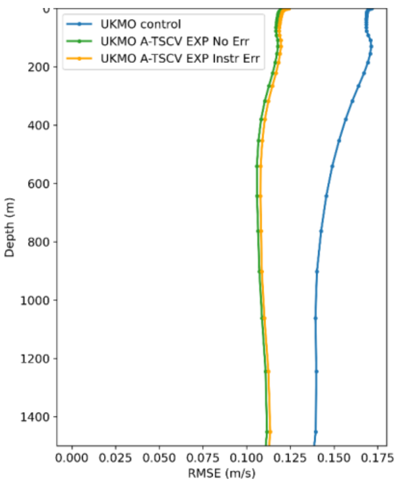
The degradation at depth is not seen in the equatorial region – the degradations are primarily in the tropics away from the equator and are in regions with large fresh water input (e.g Amazon outflow, Indonesian archipelago)

South Atlantic West Boundary Current: July

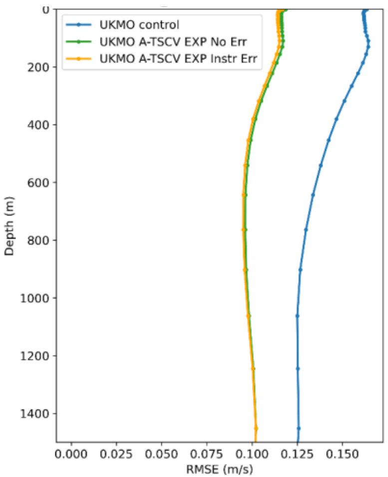
	NR	Control	A-TSCV No Err
Monthly mean surface speed			
Monthly mean error in surface speed			

South Atlantic Western Boundary current

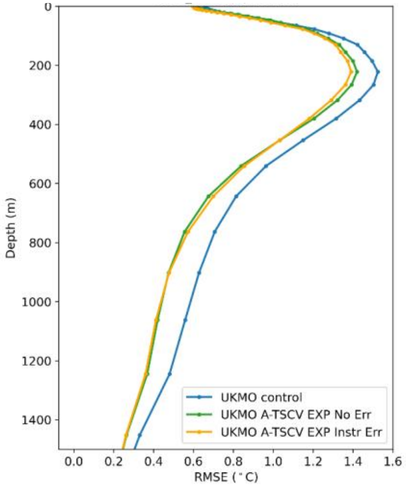
U RMSE



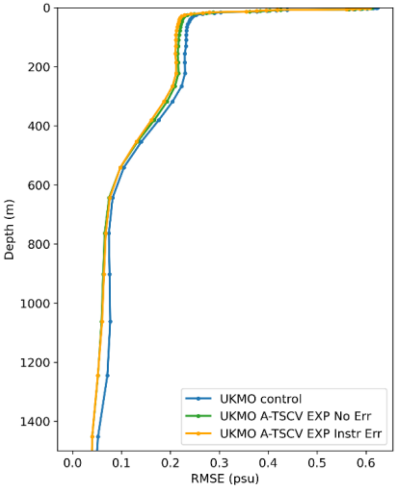
V RMSE



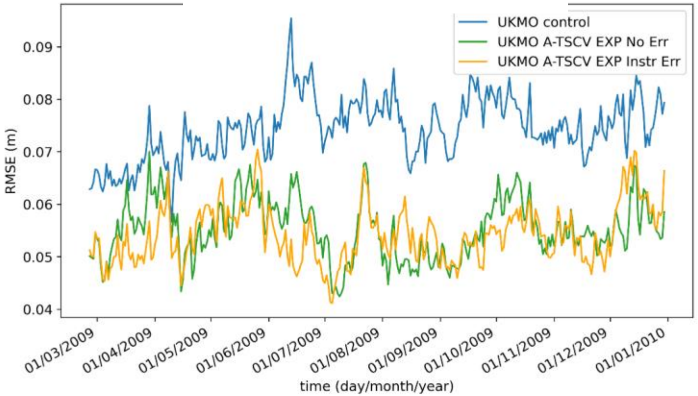
T RMSE



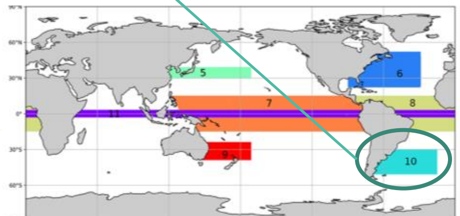
S RMSE



SSH RMSE



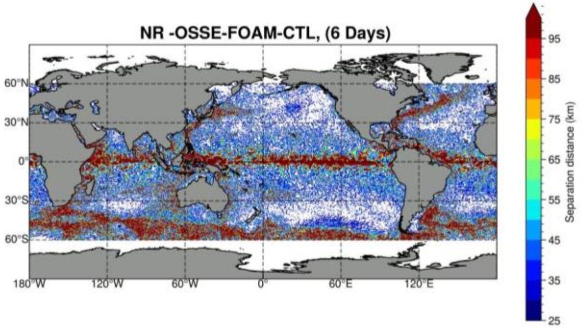
- SSH RMSE improved by ~2cm
- Velocities improved by ~30% near surface
- Velocities improved by ~20% at 1500m

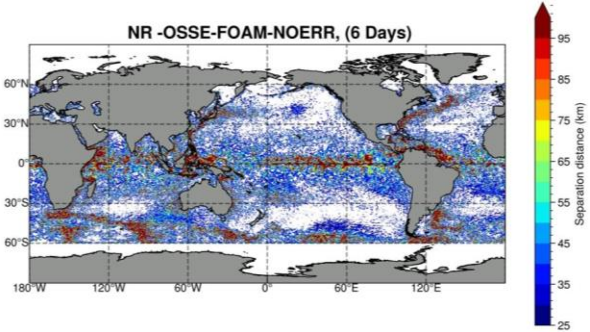


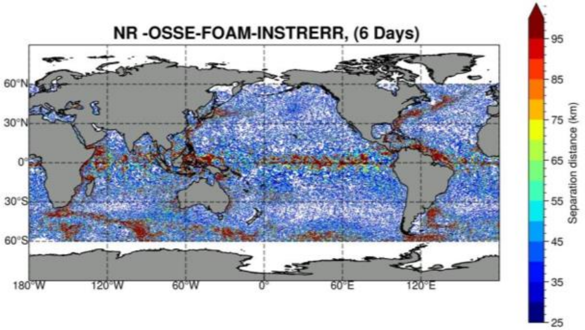
Lagrangian Assessment

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

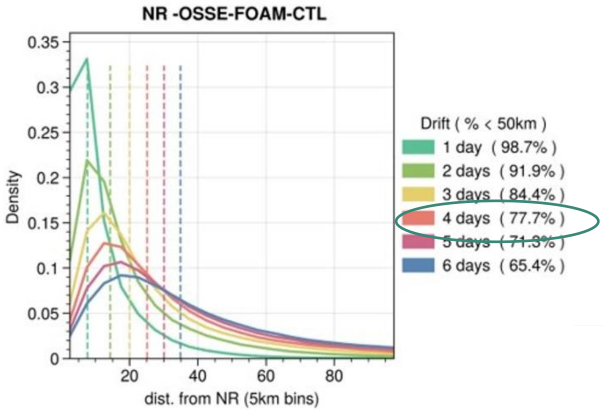
particle separation after 6 days

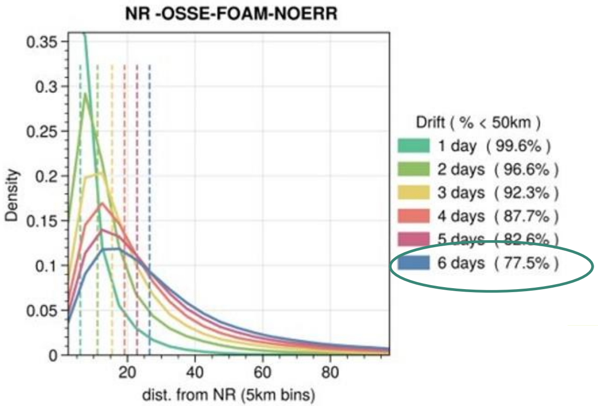


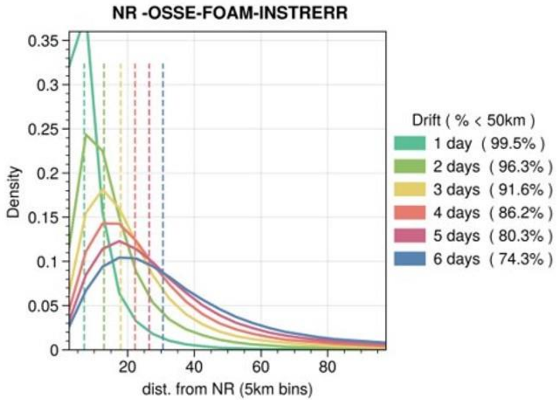




Histograms of the distance



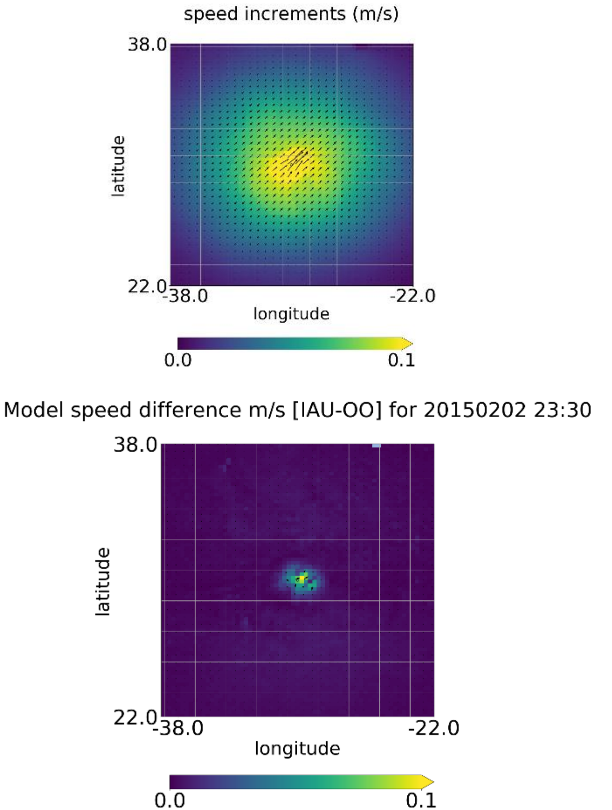




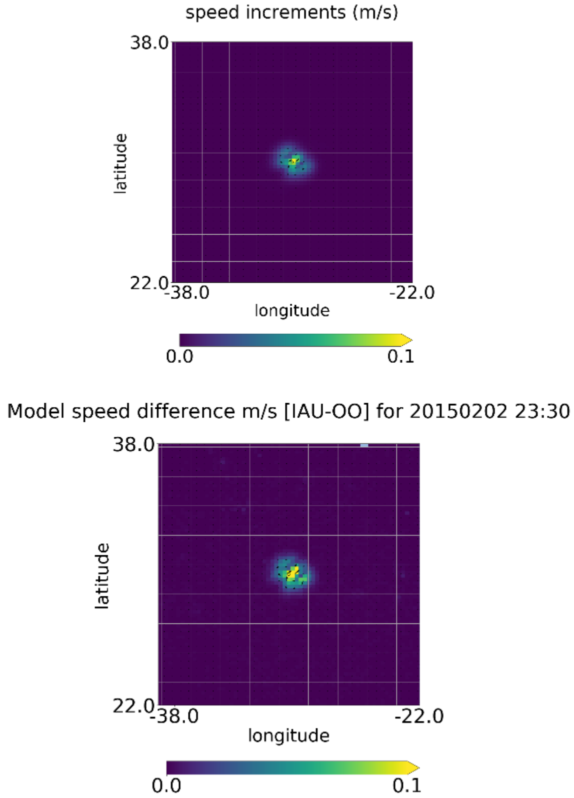
Correcting inertial oscillations

Model response to increments in FOAM: end of 24 hour forecast

Total increments



Balanced increments only



- The ageostrophic or unbalanced component of the increment is not being properly retained in the model

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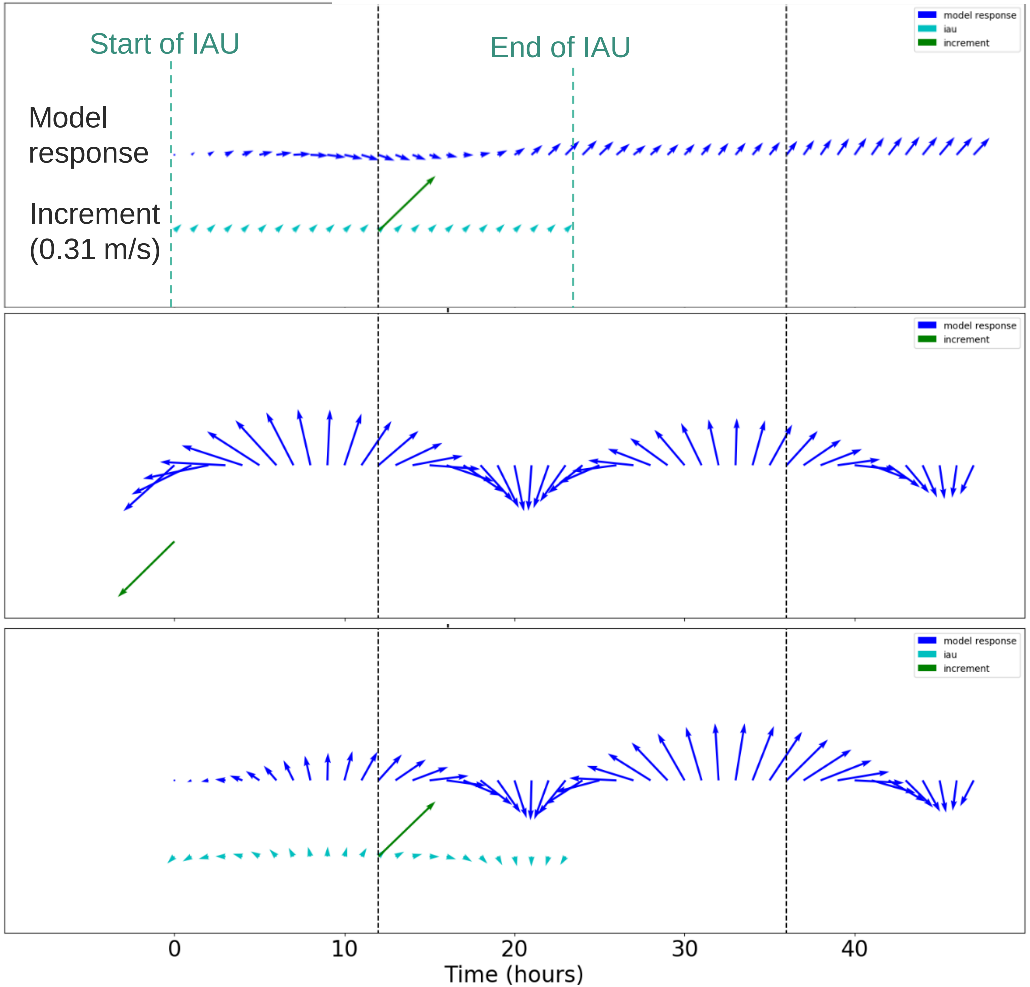
- Away from the equator and boundaries, inertial oscillations are a large component of the ageostrophic velocities.
- Increments are not be well retained in regions where near inertial oscillations dominate
    - When the IAU is used to apply an ageostrophic velocity increment, the model responds by rotating the applied increment at the inertial frequency. Meanwhile, the IAU continues to apply the increment in the direction of the original increment. This means that the applied increment on subsequent time steps can act to cancel each other out.

Model response at 30W, 30N

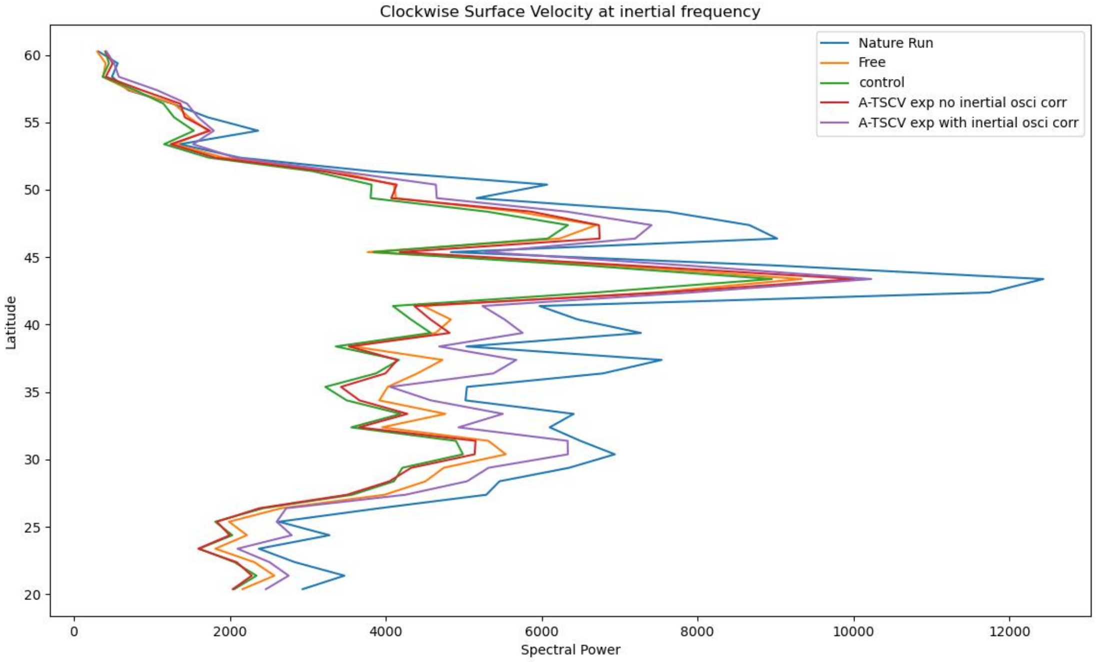


Experiment	Fluxes	Assim SST	Assim T/S profiles	Assim SSH	Assim SIC	Assim TSCV	IAU
Standard A-TSCV exp	ERA5	✓	✓	✓	✓	✓ Only assimilating descending tracks below 60 degrees	Standard IAU
Correct Inertial Oscillation exp	ERA5	✓	✓	✓	✓	✓ Only assimilating descending tracks below 60 degrees	Rotated IAU

Only Descending tracks below 60 are used to remove cross-overs and allow us to generate a time analysis field for the velocity increments.

Spectral power at the inertial frequency as a function of latitude – Feb 2009

Performed a spectral temporal analysis of the clockwise component of the surface velocities along latitudinal bands. At each latitudinal band we extracted the spectral power at the inertial period for that latitude. These are plotted below as a function of latitude



Conclusions and Future work

Conclusions

- Significant improvement to global velocity RMSE statistics with TSCV assimilation: ~25% at surface and ~10% at 1500m
- Global SSH RMSE is improved by ~15% or ~1cm
- 6 day gain in forecast accuracy for SSU and SSV
- Lagrangian assessment suggests a 2 day gain in number of particles with a separation distance of less than 50km from the NR
- When instrument err is included in the TSCV obs, results are generally similar but positive impact is slightly reduced.
- Improvements are largely in the WBC, ACC and along the equator, but some degradations are seen in tropical coastal regions where there is large fresh water input (e.g Amazon outflow, Indonesian Archipelago)
- Away from the equator, improvements are largely due to geostrophic corrections, ageostrophic increments are not well retained in the model
- Could potentially improve ageostrophic prediction by initialising the inertial oscillations with TSCV assimilation

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Future Work

- Further work to assess the impact and improve the assimilation of inertial oscillations

- Full correlated obs errors expected from a SKIM like satellite have not been included in this work.
    - Ongoing work by O. Goux (cerfacs) to include correlated observation errors in NEMOVAR should give us capability to deal with these correlated obs errors.

- Investigate improvements to the velocity control variables used in the DA. We could use velocity potential and streamfunction so that the variables are less correlated (see Laura’s presentation later).

Extra slides

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OSSE design

- **Nature Run**: 1/12° global ocean simulation with the Mercator Ocean real time system model without assimilation forced with 3 hourly ECMWF IFS fluxes.

- **OSSE experiments**: FOAM, 1/4° resolution, different initial conditions, NEMOVAR, ERA5 fluxes

Control

- Observations generated from Nature Run for:
  - SST L2
  - ARGOx1, XBT, Mooring, Drifters
  - SIC
  - SSH: Altika, Cryosat2, S3a, S3b
- Realistic observation errors add to simulated obs
- No assimilation of velocity observations but adjustments are made to the velocities through the balance relationship (geostrophic balance)
- No velocity balance at the equator
- Run period: 02/2009 – 12/2009

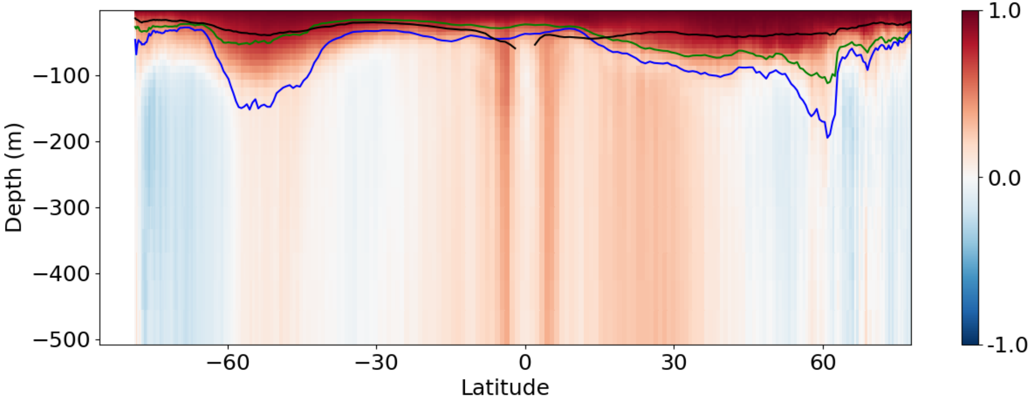
TSCV Assim Exp

- additional observations:
  - TSCV L2
- Both balanced (geostrophic) and unbalanced (ageostrophic) increments are produced for velocity. The geostrophic component gets transferred to the other variables though the balance relationships.
- New bkg error covariances are defined for unbalanced U and V
- New representativity obs error variances estimated for SSU and SSV

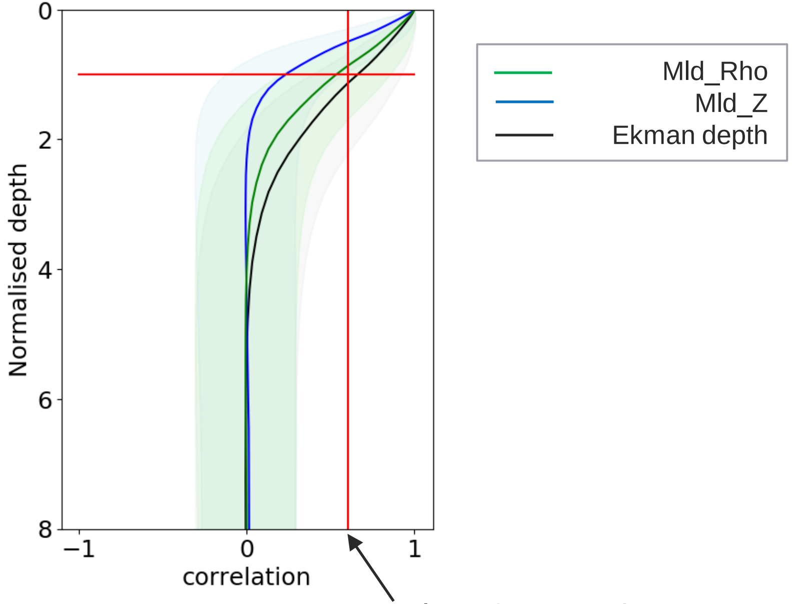
Background Velocity Error Covariances in NEMOVAR: vertical

Unbalanced U vertical background error correlations with the surface

Zonally averaged



Globally averaged



Value of a gaussian function when z=L

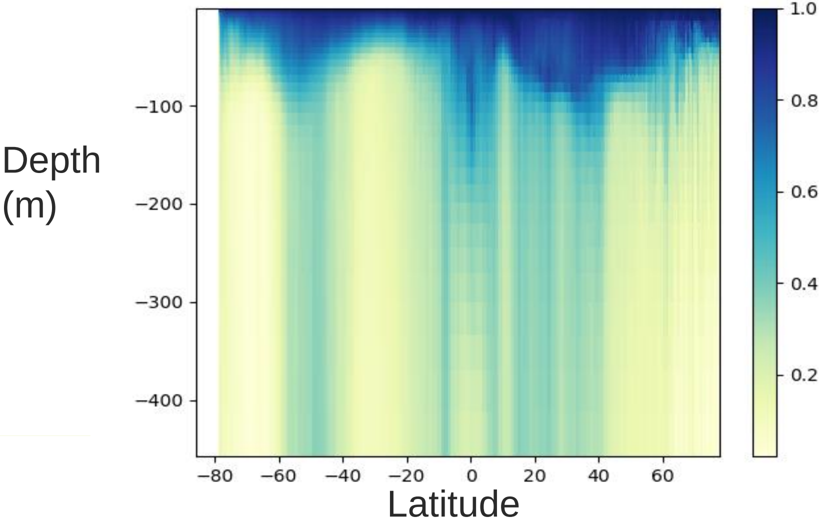
Parametrisation for the vertical U and V standard deviations

Need to define a parameterisation to reduce the surface standard deviation with depth, we're using an equation of the form:

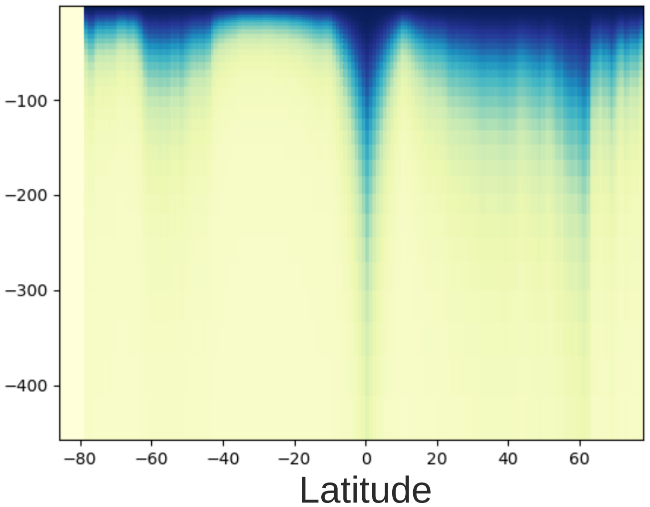
$$zcoef(z) = 0.05 + 0.95(1 - \tanh[\ln\frac{z}{L}])/2$$

Where L is a density based mixed layer depth but it ramped up to 150m at the equator.

Zonal average of NMC unbalanced U background error standard deviation, normalised by the surface value.



Parameterisation (zcoef)



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- To test the initialisation of the inertial oscillations in our TSCV OSSEs we need to know the time that the increments are valid for
- Ideally we would do this using 4D-VAR but not possible in our system
- Instead we calculate a field of TSCV increment times to be used in the inertial oscillation assimilation
- Need to avoid daily cross-overs in the TSCV observation data – only use the descending tracks and cap at 60 degrees N/S.