Met Office

Assessing the impact of assimilating Total Surface Current Velocities in global ocean forecasting systems

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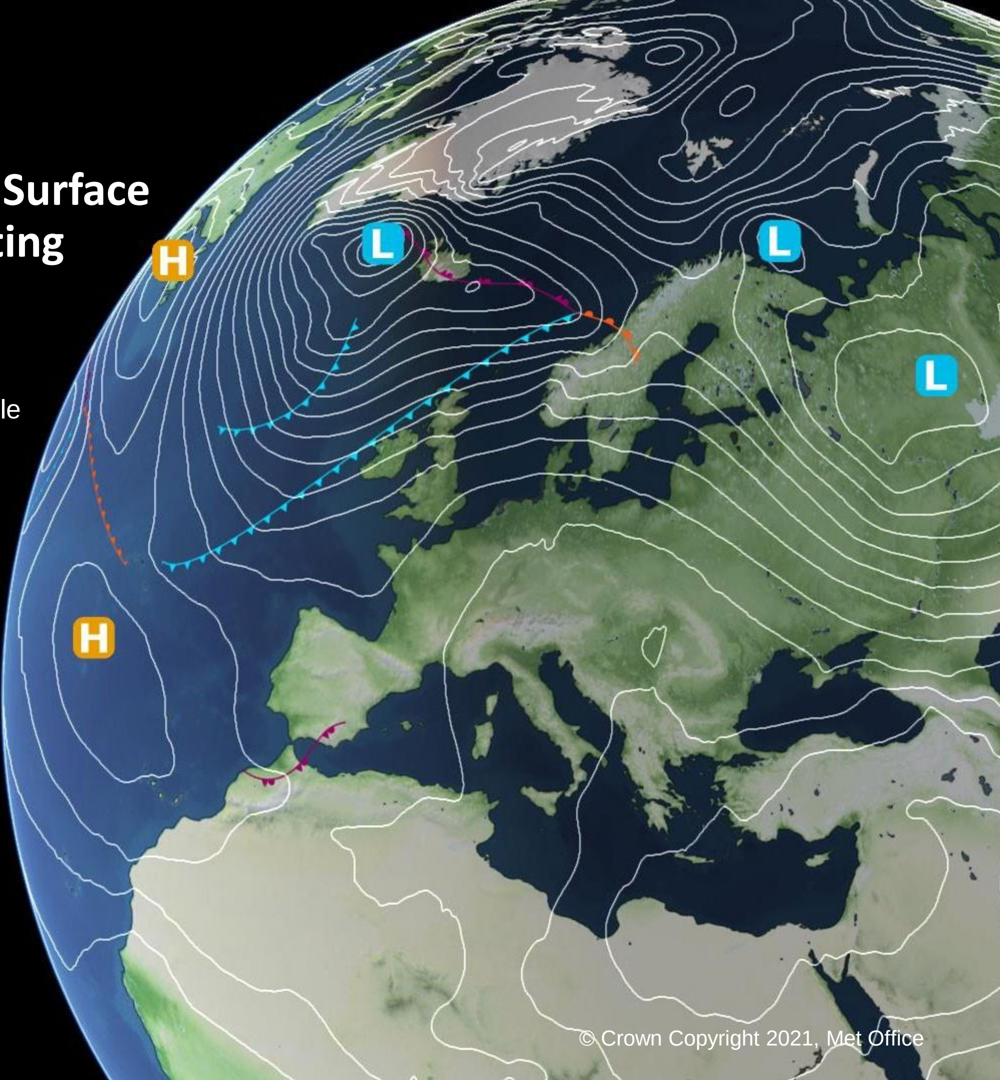
3. OceanDataLab, France
4. DATLAS, France
5. European Space Agency/ESTEC, Netherlands

DA-TT meeting, Rome, May 2023

A-TSCV esa



Contents

1. Introduction and experiment design

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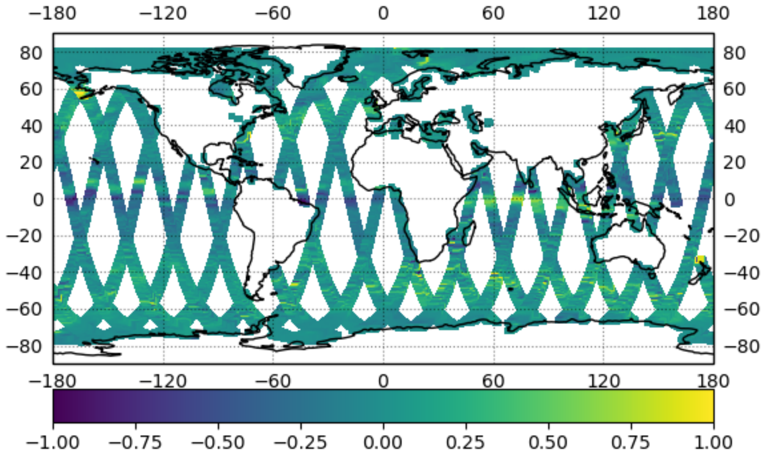
Introduction

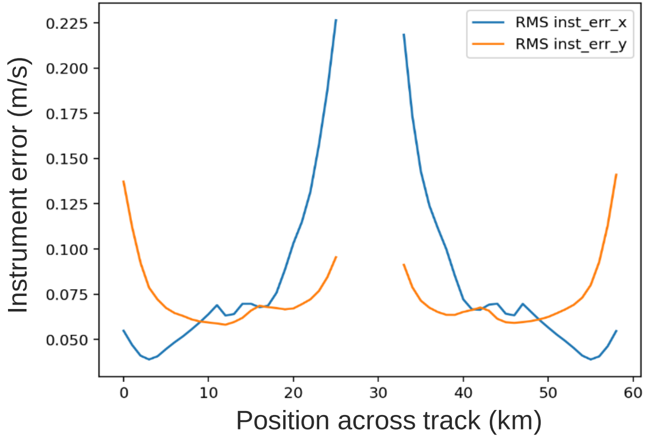
- Accurate forecasts of total surface current velocities (TSCV) are important for many users, e.g. search and rescue, ship routing, tracking marine plastic and for coupled forecasting.
- Various satellite missions are being proposed to measure TSCV globally (e.g. SKIM, SEASTAR, Odysea)
- The **ESA A-TSCV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



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

Simulated TSCV observations

- Observations of TSCV were generated using the Skimulator tool developed by OceanDataLab
- Used a NEMO 1/12 nature run, including an associated wave model run (WWIII).
- Swath data of the u/v components were generated with various different error components in the outputs including:
  - Mapping error (going from radial currents to u/v).
    Global average ~2.5 cm/s.
  - Random component of the instrument errors
    Instrument errors vary across-track →



  - Large correlated components of the (wave doppler) errors.
    Not included in the experiments here.
  - Data produced with ~5 km posting then sub-sampled
    (1/4 in MetO and ½ in MOI)

Experiments

- Experiments run for 21st Jan – 31st Dec 2009.
- Free-running nature run is used as the "truth" for generating observations and for assessing results.
- OSSE runs then carried using lower resolution assimilative systems at MOI and Met Office.

Models:

	Nature Run	Mercator Ocean	Met Office
OGCM	NEMO 3.1	NEMO 3.6	NEMO 3.6
Horizontal grid/resolution	1/12° ORCA grid	¼° ORCA grid	¼° ORCA grid
Vertical grid	50 levels	50 z-levels with partial steps, linear free surface	75 z-levels with partial steps, non-linear free surface
Wind/current coupling coefficient	50%	50%	100%
Ice model	LIM	LIM3	CICE
Atmospheric forcing	ECMWF IFS	ERA5	ERA5

Experiments:

Experiment	Assim SST	Assim T/S profiles	Assim SSH	Assim SIC[1]	Assim TSCV	TSCV Errors
Control	✓	✓	✓	✓		
A-TSCV no_err	✓	✓	✓	✓	✓	Mapping only
A-TSCV instr_err	✓	✓	✓	✓	✓	Mapping error + Instrument error

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2. Data assimilation systems

Observations and DA schemes

	Mercator Ocean	Met Office
Observations assimilated		
In situ T/S profiles	Argo, tropical moorings, drifters and XBT	Argo, tropical moorings, drifters and XBT
Altimetry	S3-A, S3-B, CryoSat and AltiKa	S3-A, S3-B, CryoSat and AltiKa
Sea ice concentration	-	L3 SSMI/S
TSCV	L2-C	L2-C
SST	L4 (OSTIA like maps)	L2
Data assimilation scheme		
Data Assimilation Scheme	SEEK filter with a fixed basis.with 7-day time window	NEMOVAR 3DVar-FGAT scheme with 1-day time window.
Forecast error covariances	Based on an ensemble of model anomalies from an historic model run.	Statistical and parametrised estimates.
Multi-variate relationships	Model covariance matrix based on a reduced basis of multivariate model anomalies.	Linearised physical balances.
Implementation of increments	IAU over 7 days.	IAU over one day.

TSCV data assimilation set up

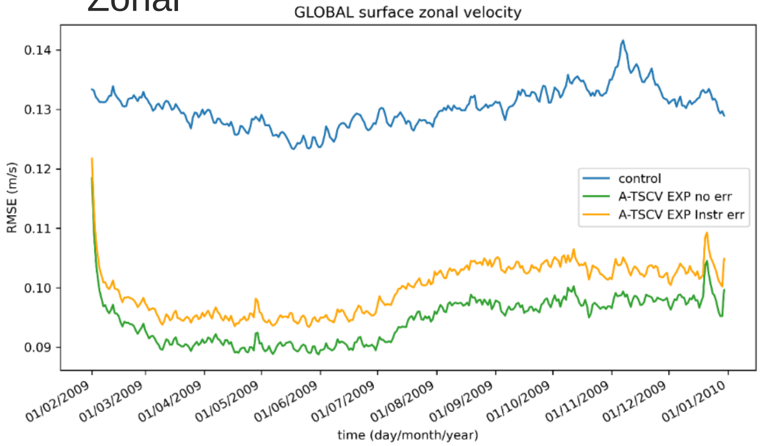
- Met Office DA developments described in a previous DA-TT technical seminar :
  - Estimated background error covariances for the unbalanced (ageostrophic) components of the velocity using NMC method with data from a previous 2-year reanalysis.
  - Spatially and seasonally varying estimates of the background error variances at the surface and a parametrisation for how they vary below the surface.
  - Estimates of the horizontal correlation length-scales.
  - Vertical length-scales parameterised using a mixed-layer depth.
  - Representation errors calculated by comparing variability of 1/12 and ¼ models.
  - Developed a way to initialise the inertial oscillations to try to improve the ageostrophic currents.

- MOI error covariances for TSCV are based on the same information already available, using anomalies generated from a historical run. Uses the same representation errors as MetO.

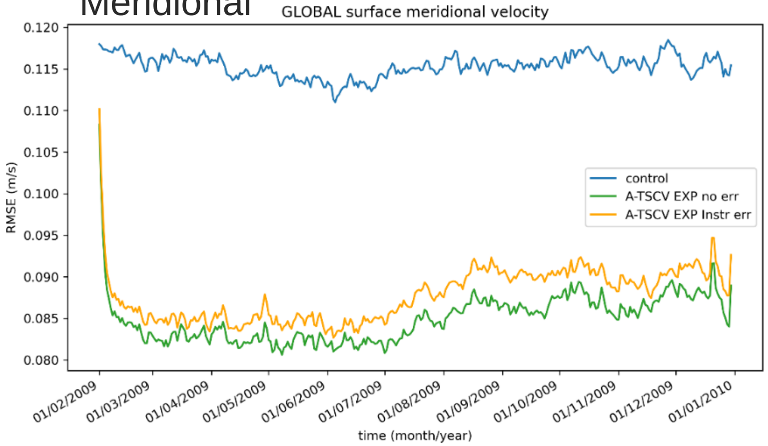
3. Impacts of surface current assimilation

Impact on global surface current RMSE timeseries

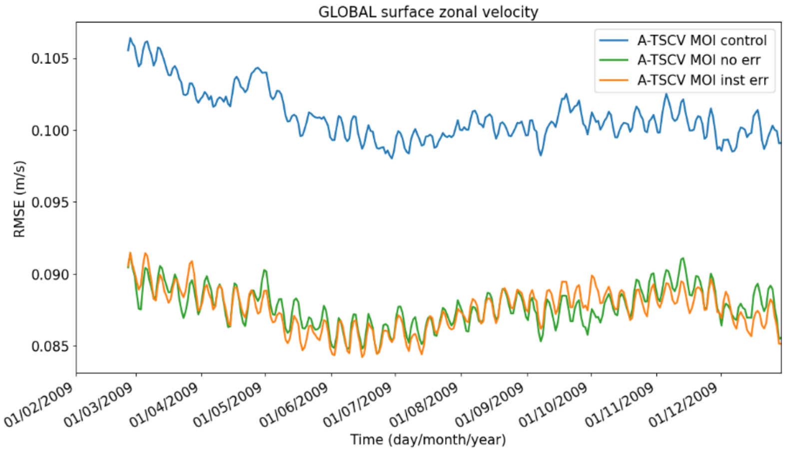
Zonal



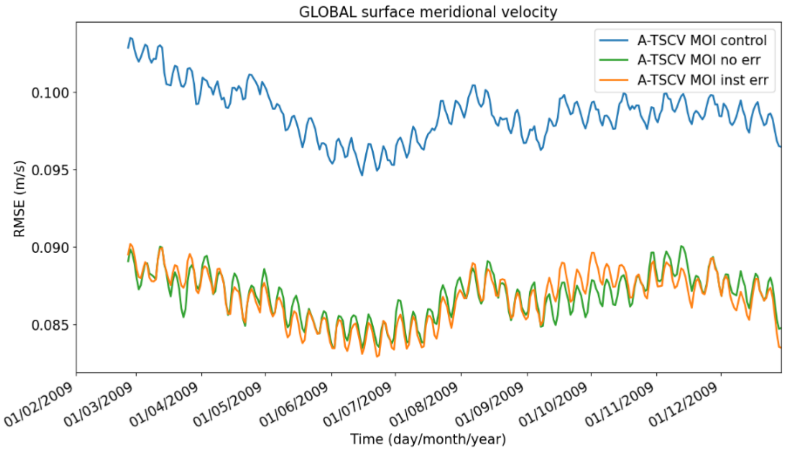
Meridional



MetO



MOI



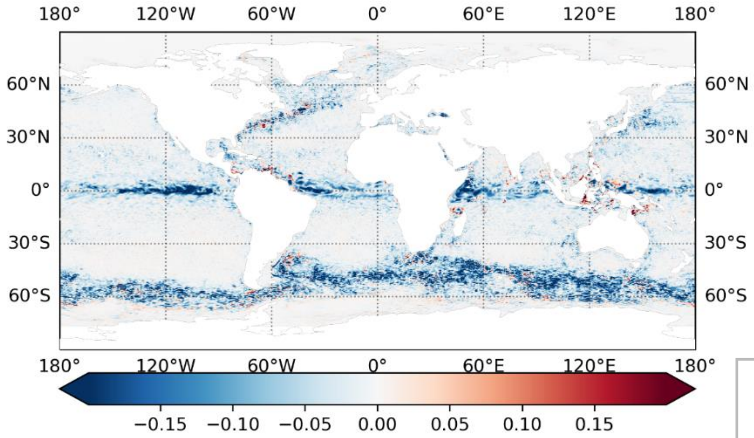
Impact on surface velocity RMSE - July

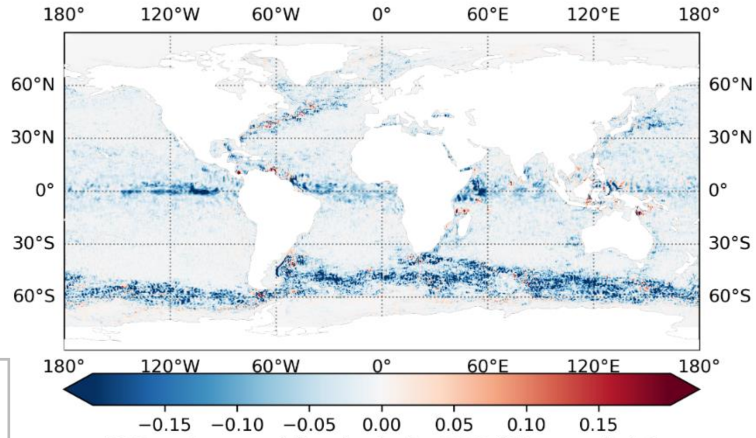
Blue/red -> reduction/increase in RMSE (m/s) compared to control

Zonal

Meridional

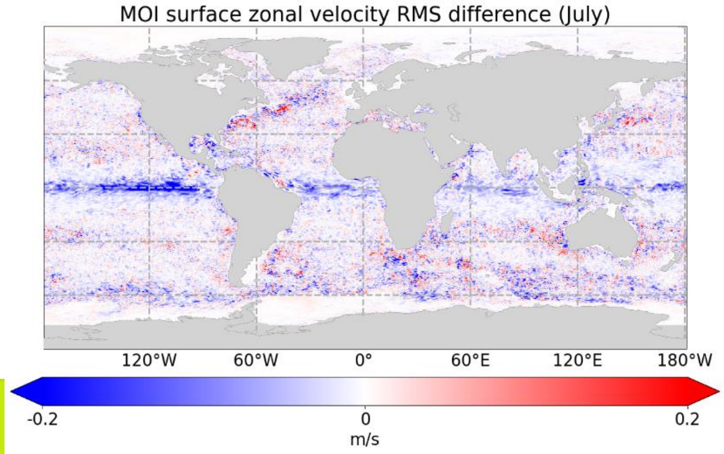
MetO

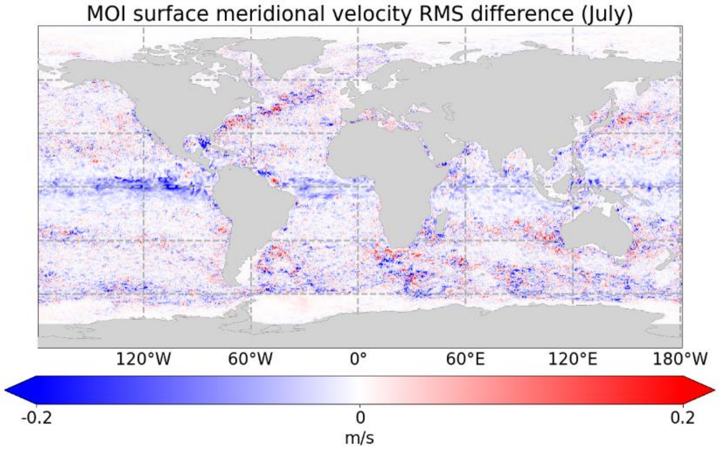




- Large improvements in equatorial region, WBCs, ACC.

MOI





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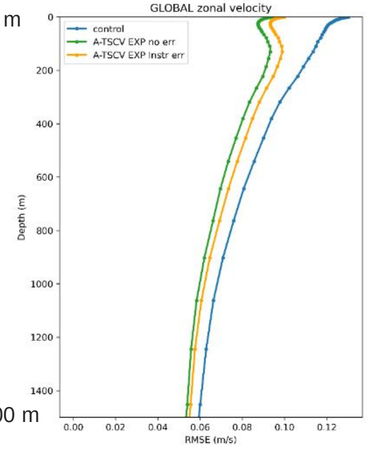
Impact on sub-surface global current RMSE

Zonal

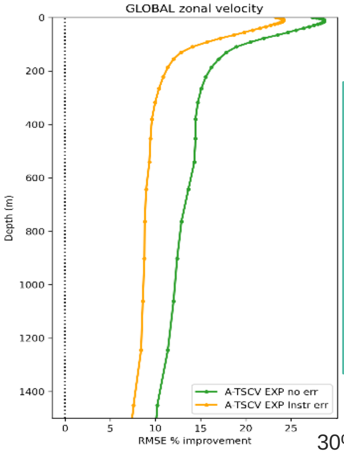
RMSE

0 m



1500 m

% reduction in RMSE



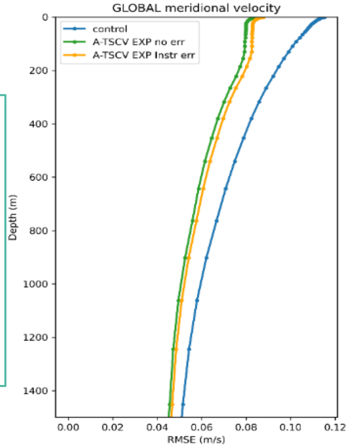
30%

MetO

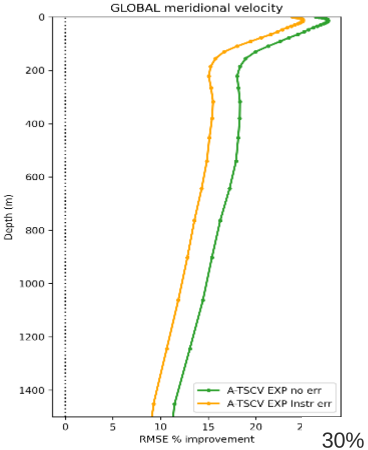
- Large +ve impact at all depths for u and v.
- Slightly less impact when instrument error included, but still ~25% reduction in RMSE at surface.

Meridional

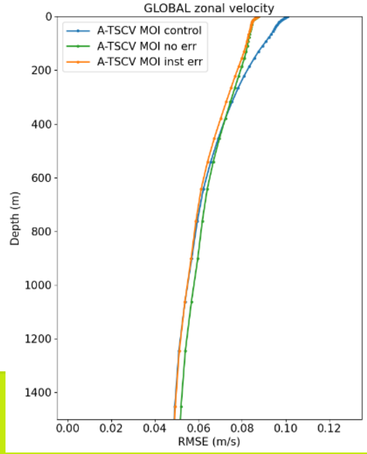
RMSE

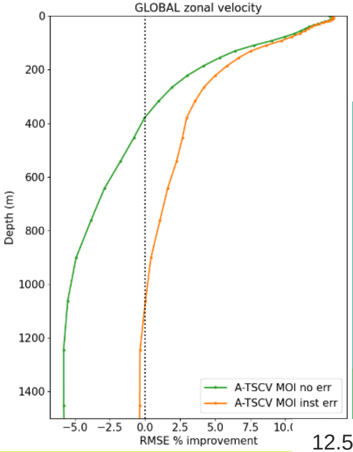


% reduction in RMSE



30%

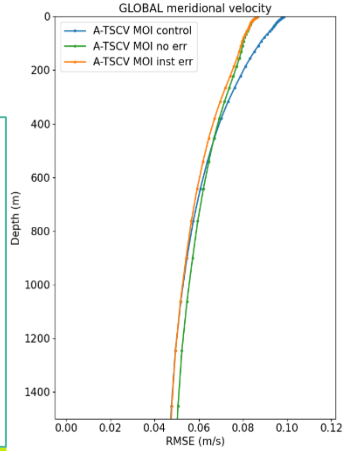


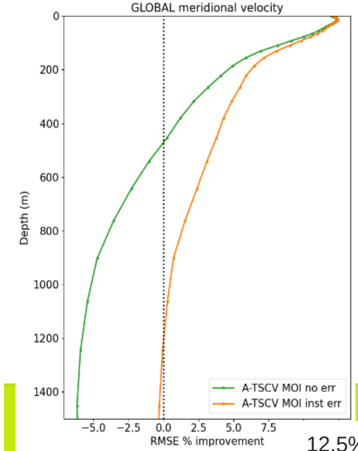


12.5%

MOI

- Large +ve impact near the surface.
- Some degradation at depth in MOI which is improved when instr error is added.
- Overfitting of TSCV obs due to less thinning?





12.5%

Impact on ~200m depth velocity RMSE - July

~200m depth zonal currents

Blue/red -> reduction/increase in RMSE (m/s) compared to control

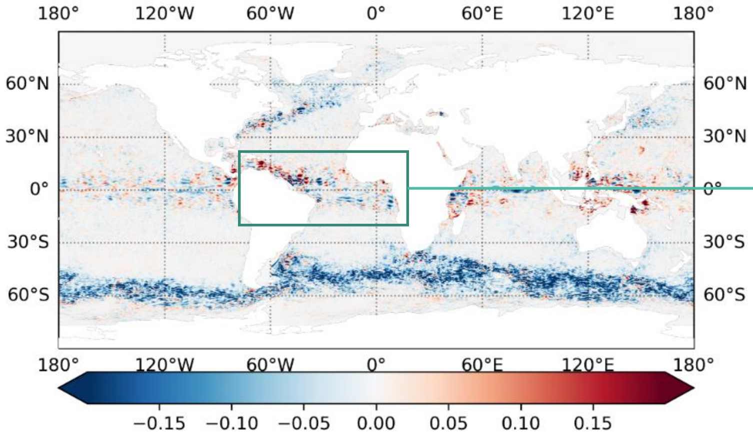
MetO:

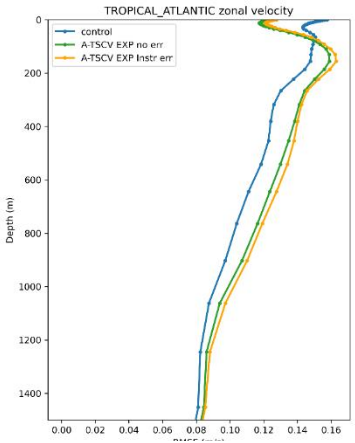
- Improvements at depth in ACC, Gulf Stream, Kuroshio, equatorial Indian Ocean.
- Degradation in tropics near some coasts, e.g. Amazon outflow, maritime continent, north of Madagascar.

- W. tropical Atlantic: issues with multivariate aspects, or vertical length-scales inappropriate?

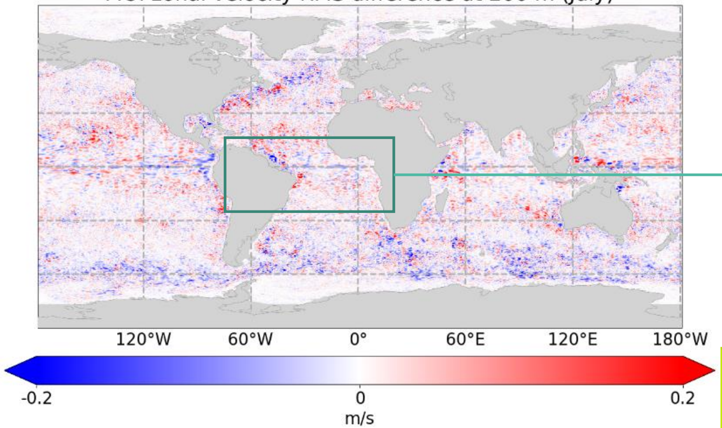
MOI:

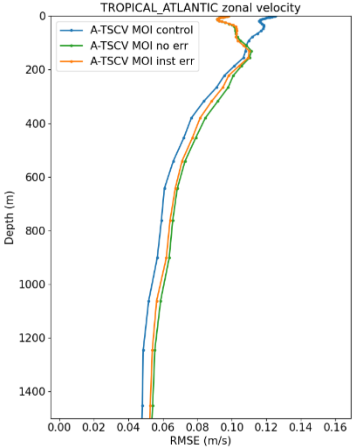
- Improvements in ACC, eastern tropical Pacific.
- Degradations in some regions, e.g. tropical N. Atlantic, west of Australia, eastern Pacific, Gulf Stream.



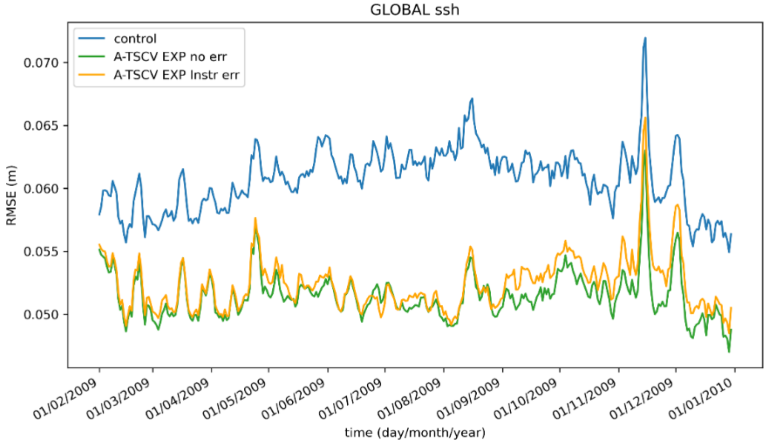


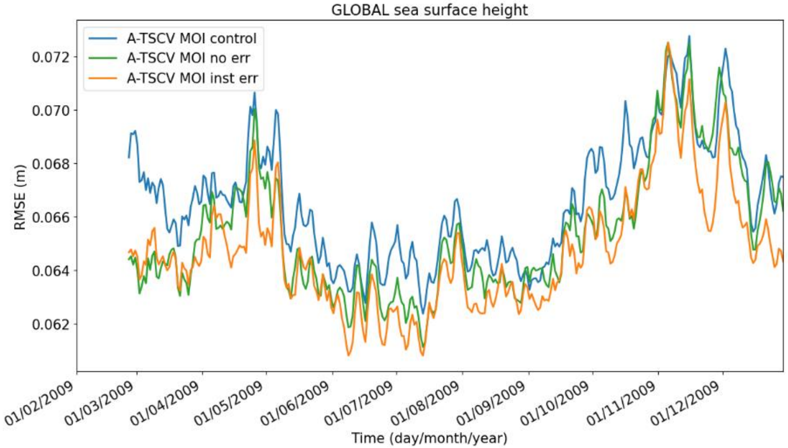
MOI zonal velocity RMS difference at 200 m (July)





Impact on global SSH RMSE



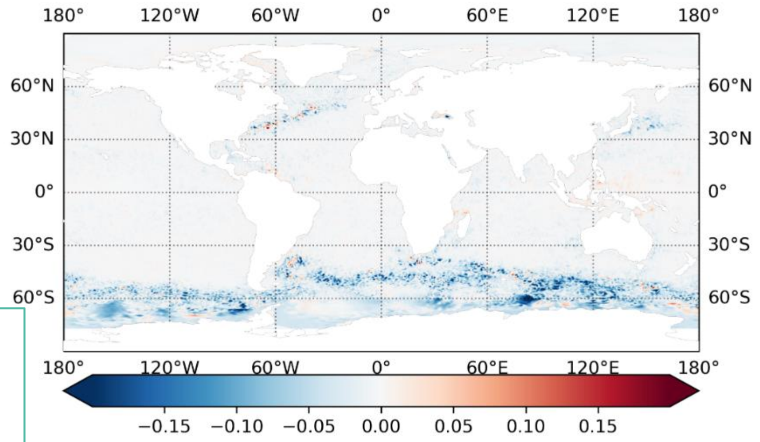


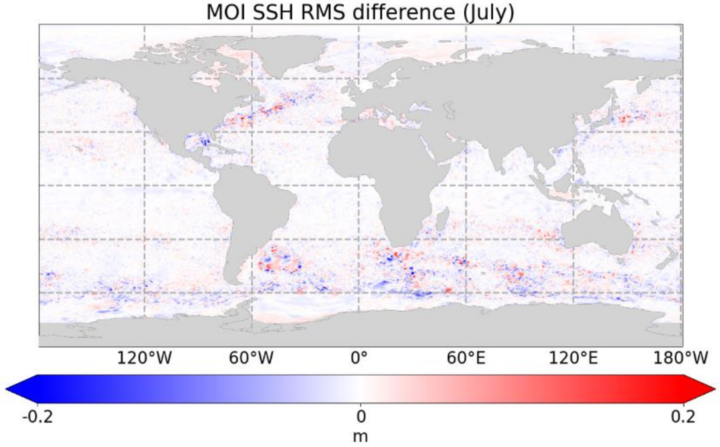
MetO

- Largest impact in ACC and WBCs
- Less impact on SSH in MOI system than MetO.
- Some improvements in tropical Pacific in MOI not seen in MetO

MOI

Change in SSH RMSE (July)

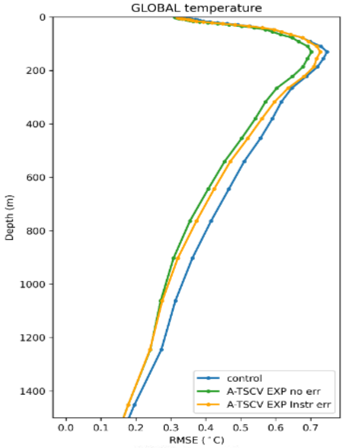




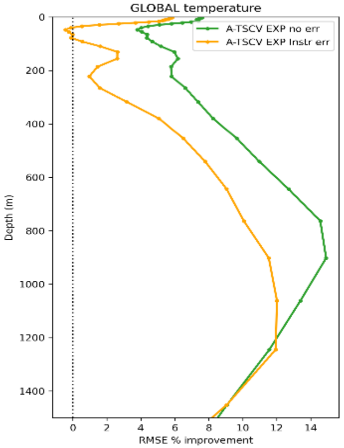
Impact on global sub-surface T/S RMSE

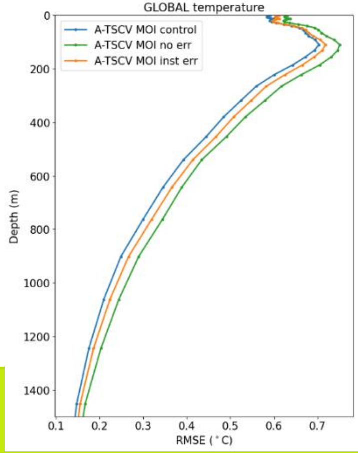
Temperature

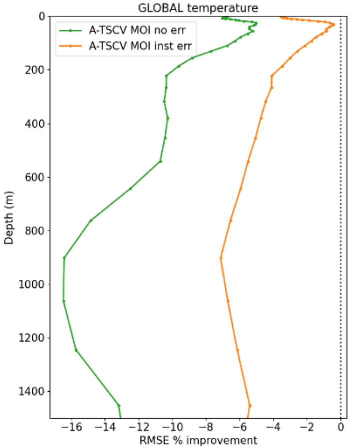
RMSE



% reduction in RMSE







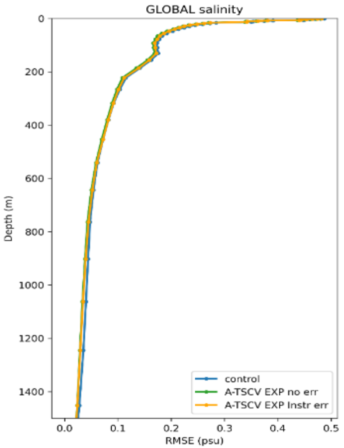
MetO

- Large improvements in T/S in MetO
- Degradation to T/S in MOI system

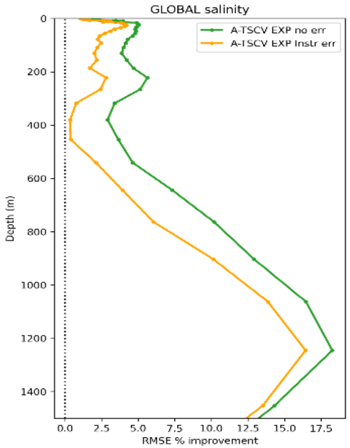
MOI

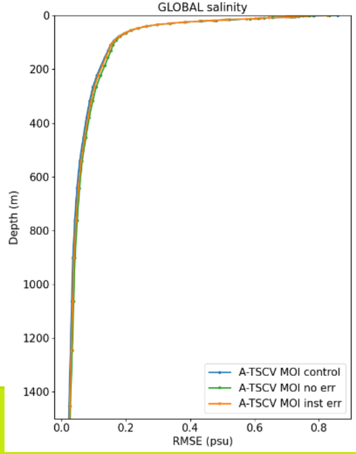
Salinity

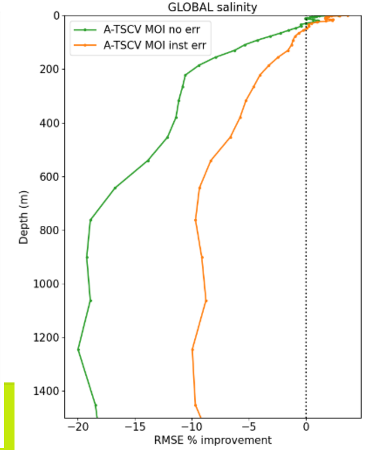
RMSE



% reduction in RMSE

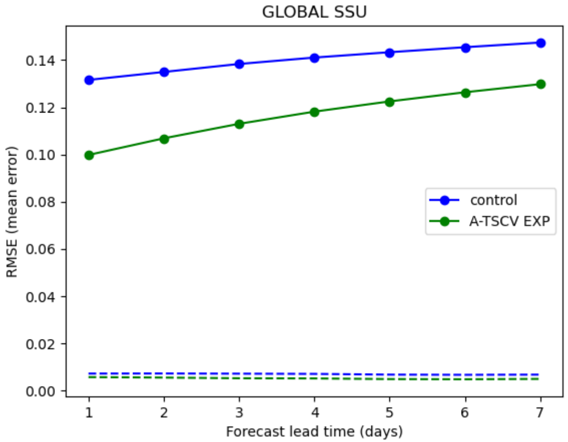


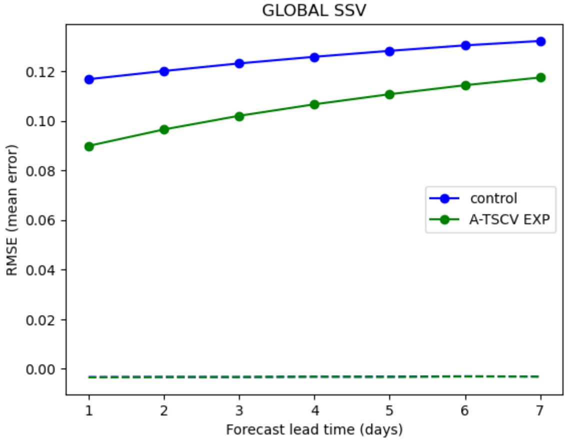




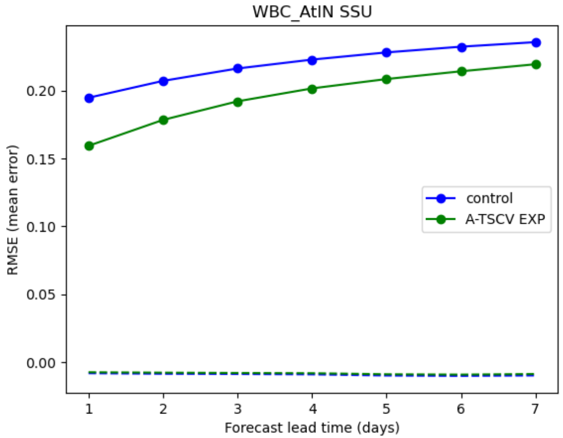
Forecast lead time RMSE plots – MetO system

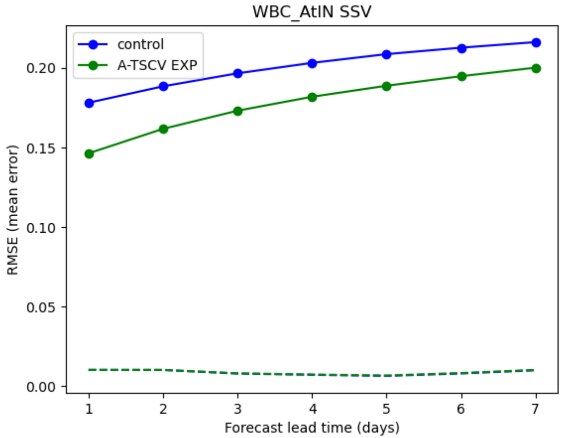
Global



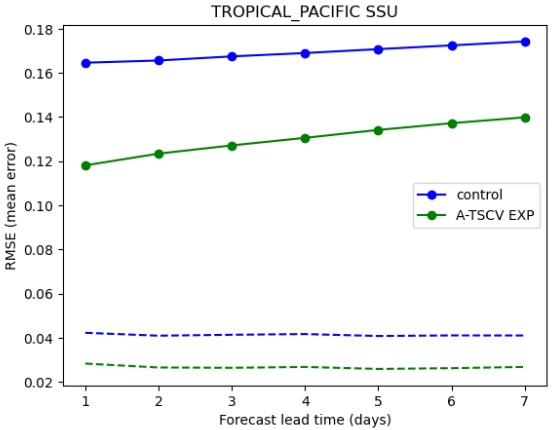


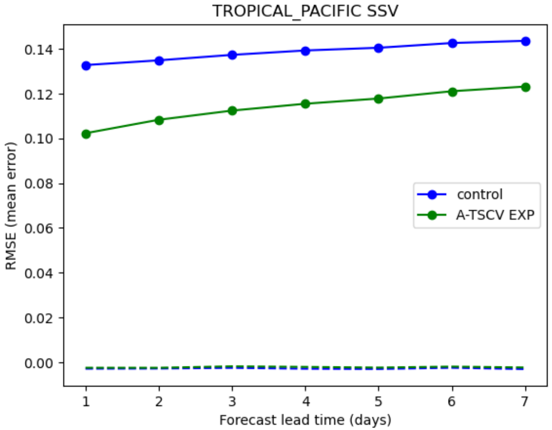
Gulf stream





Tropical Pacific

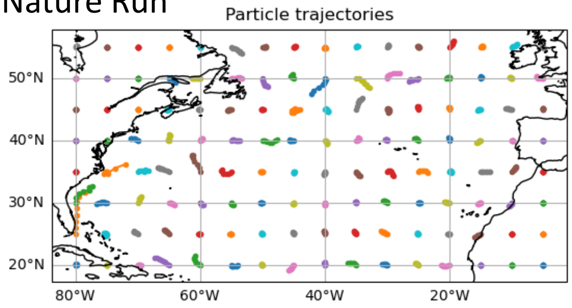




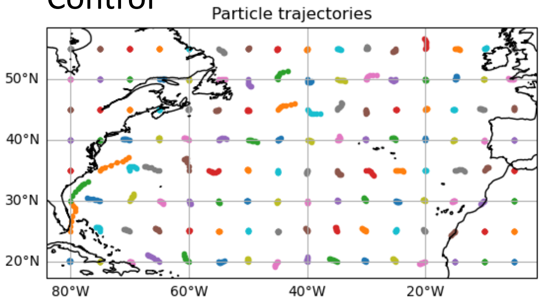
Lagrangian assessment N. Atlantic – Met Office

Met Office

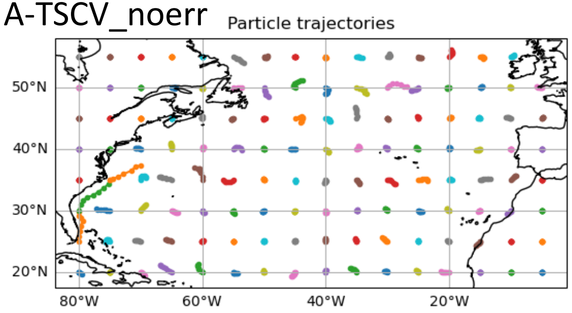
Nature Run



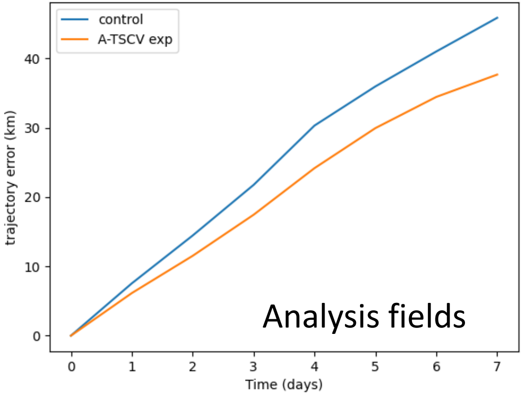
Control

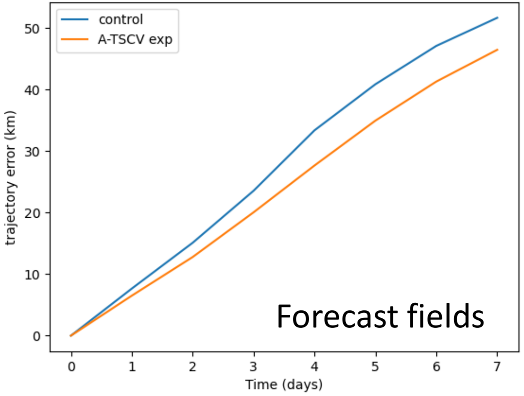


A-TSCV_noerr



- OceanParcels package used to propagate particles over 7 days (with 2-hourly time-step) between 9th – 16th Sep 2009
- Particles seeded every 5 degrees in the North Atlantic
- ~15% (analysis) and 10% (forecast) improvement in distance error after 7 days

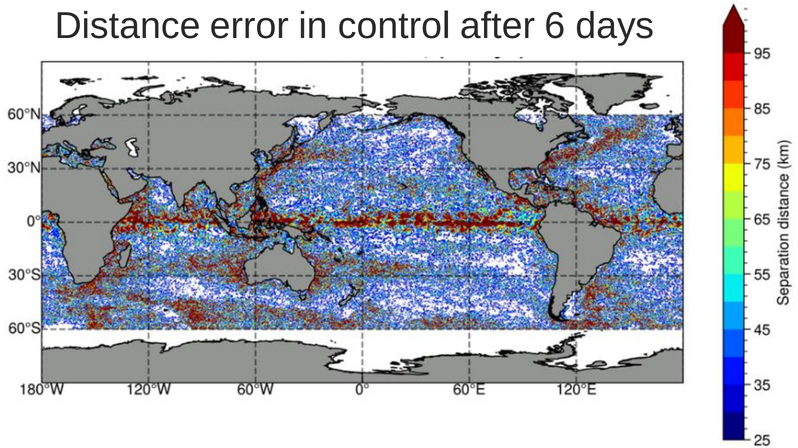




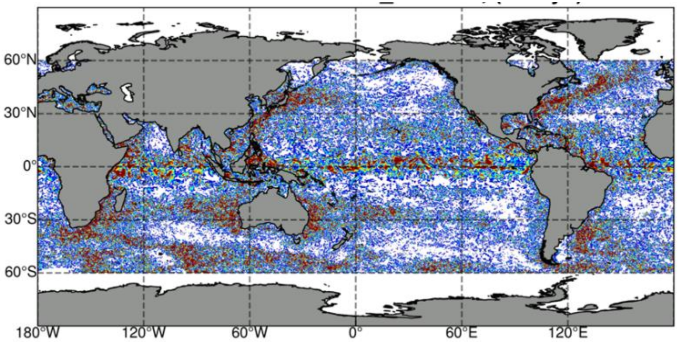
Mean divergence of particles in the experiments vs Nature run

Lagrangian assessment global (+/- 60° lat) – MOI

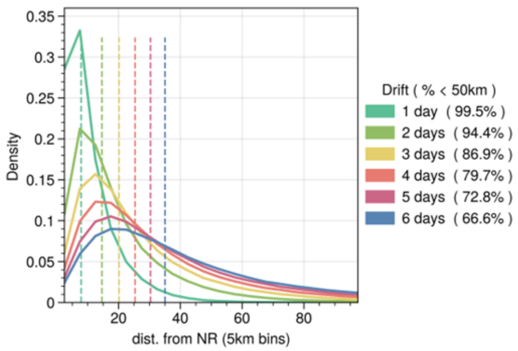
Distance error in control after 6 days



Distance error in A-TSCV_noerr after 6 days

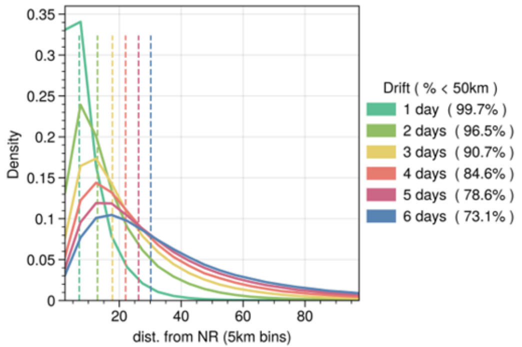


PDFs of distance error in control



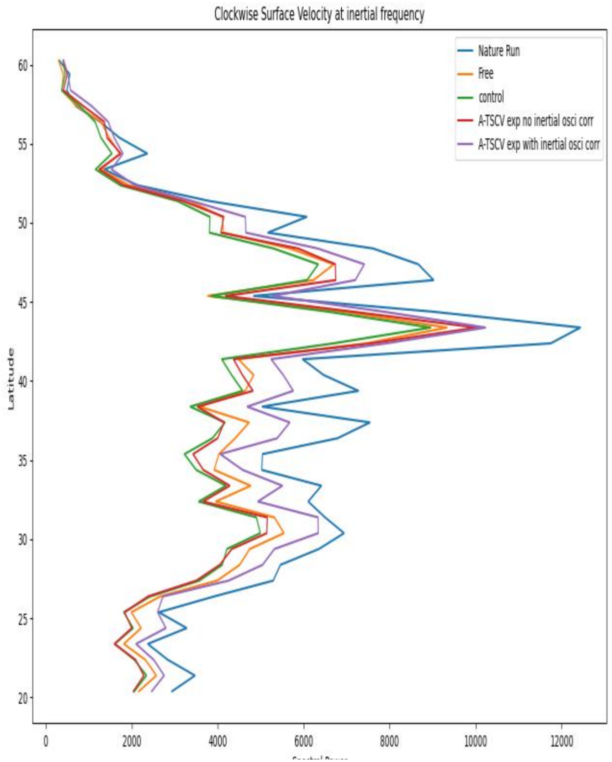
- On average, there is a 5 km improvement after 6-day drift when TSCV data are assimilated.
- The proportion of parcels with a distance error <50 km is improved by 10% after drifting during 6 days thanks to TSCV data. This represents a one-day gain.

PDFs of distance error in A-TSCV_noerr

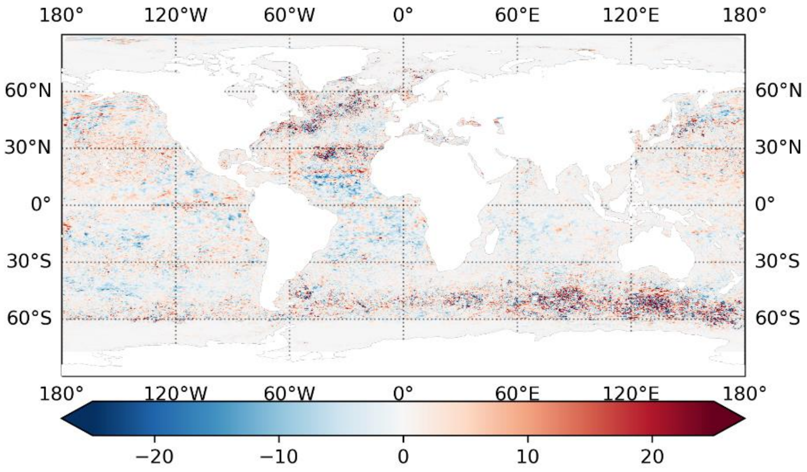


Inertial oscillations initialisation - MetO

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



Percentage difference in SSU RMSE between experiments with and without the inertial oscillations correction – February 2009



Blue shows region where RMSE is improved with the inertial oscillation correction

Spectral temporal analysis of the clockwise component of the surface velocities along latitudinal bands

4. Summary and requirements

Summary (1)

Coordinated set of OSSEs show large impacts from TSCV data in both systems:

- ~12% (MOI) to ~25% (MetO) reduction in global surface current RMSE. Largest impact in equatorial regions, ACC and western boundary currents.
- Significant impact on sub-surface currents down to ~200 m in MOI and at least 1500 m in MetO system (much of the deeper impact is in ACC region in MetO system). Some negative impacts in tropical fresher regions (e.g. Amazon outflow, maritime continent) on currents below 100-200 m depth. Perhaps related to issues with e.g. multivariate issues, or vertical length-scales?
- Knock-on improvements on SSH RMSE in extra-tropics (but not much impact at the equator, except a small improvement there in MOI). In MetO ~15% reduction in global SSH RMSE.
- Temperature RMSE reduced at most depths in MetO system. In MOI system it is degraded, particularly below mixed layer. Perhaps related to multivariate relationships, or over-fitting data (e.g. not enough obs thinning).
- MetO forecasts retain the (geostrophic) surface currents information well and surface currents are improved significantly throughout 7-days.
- Improvements of 10-15% in distance errors after 6-7 days shown when assessing Lagrangian surface currents.
- Inertial oscillations hard to initialise using 3D DA algorithms. Some improvements in MetO system.

Met Office

Summary (2)

- Systems able to make good use of TSCV data which gives information different to SSH satellites (not just improved sampling of geostrophic component, though that is a factor too):
  - Equatorial region + high latitudes where SSH data hard to assimilate effectively to correct currents.
  - Ageostrophic currents, e.g. inertial oscillations.
- Further work to improve the DA which could allow even more impact from TSCV data: sub-surface propagation in MOI system, issues in Amazon outflow, initialising inertial oscillations, control variables in the DA.
- Data assimilated here has not contained the full correlated errors expected from the TSCV satellite data. Methods to deal with those will be required to make good use of real data.

- Final part of the project is to define the requirements from the operational ocean forecasting community for future satellite missions:
  - Accuracy; resolution; sampling; important regions; timeliness.
  - Need for estimates of the uncertainties: random uncorrelated, random correlated, bias.
- We welcome inputs on these requirements from ocean DA community.

- A-TSCV workshop at MOI (hybrid virtual/in-person) in Toulouse, 13th June. Registration deadline is 12th May!

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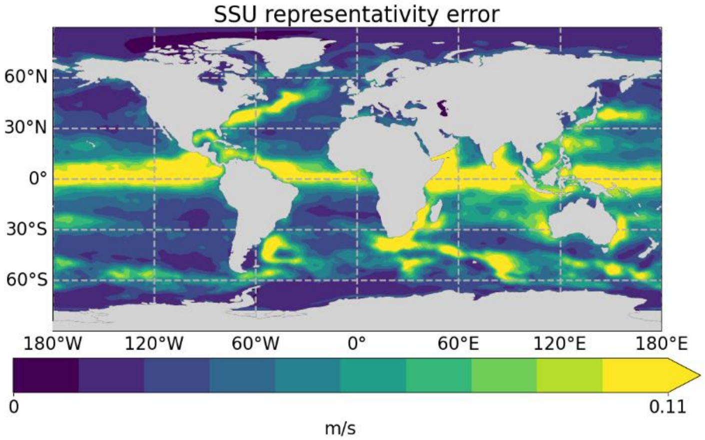
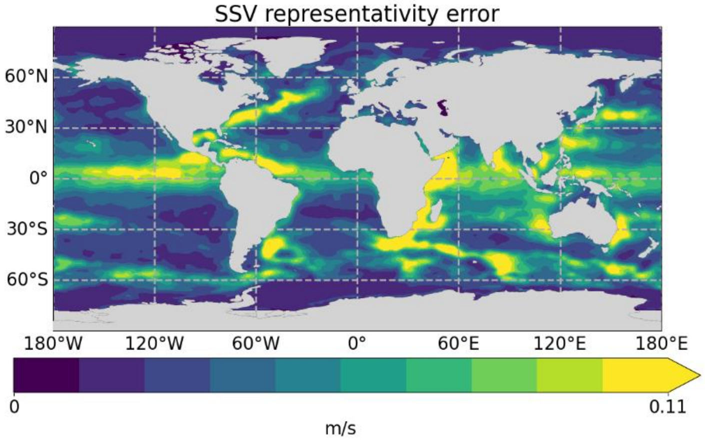
Thank you

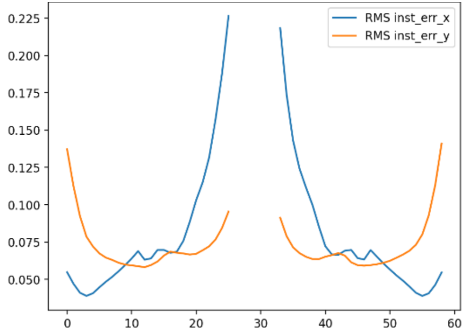
TSCV Observation Errors

- 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





- 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.

$$B = D^{1/2} C D^{1/2} \quad \text{and} \quad B = B_1 + B_2$$

- 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.

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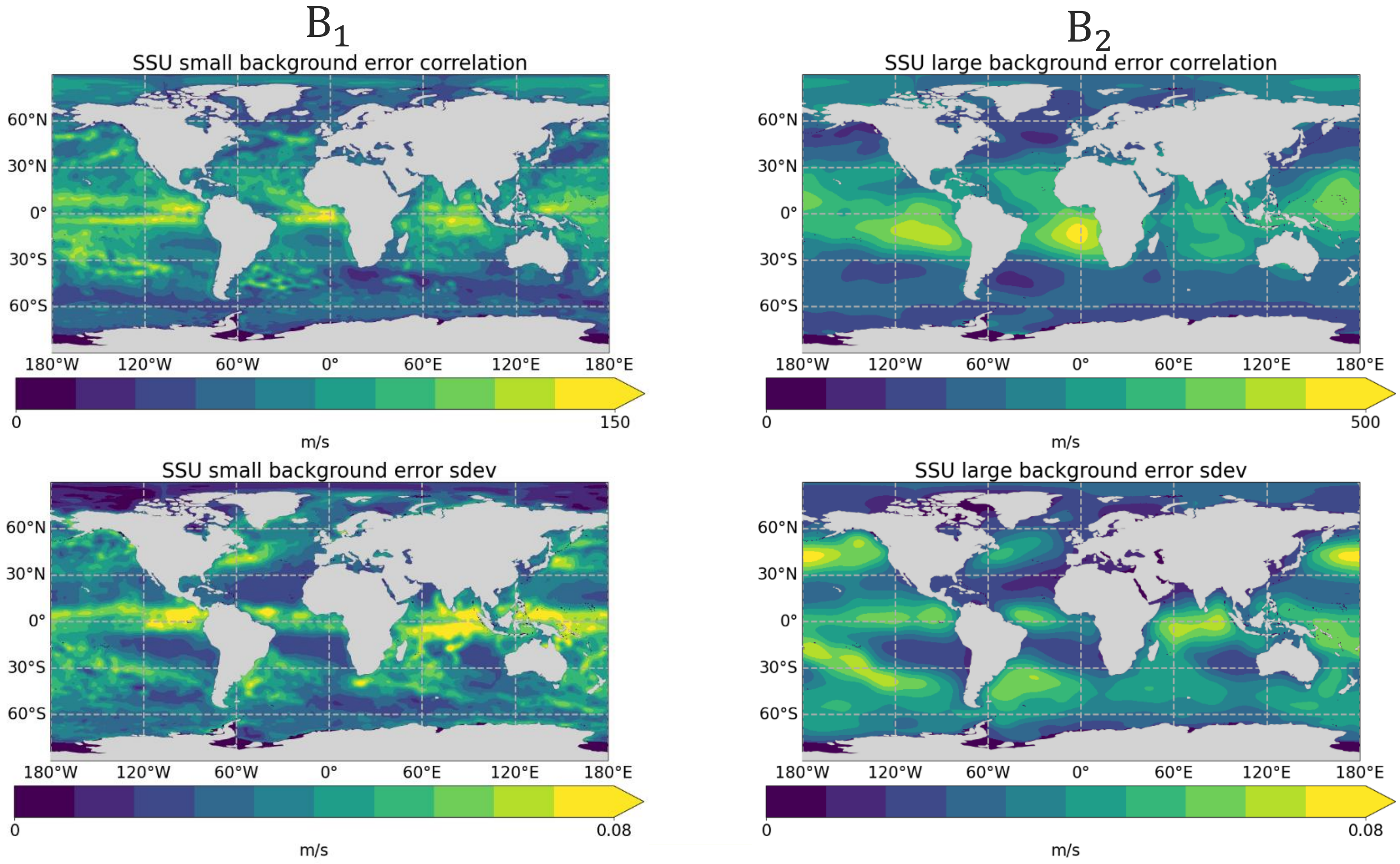
Background Velocity Error Covariances in NEMOVAR: Horizontal

Horizontal length-scales

Standard deviations

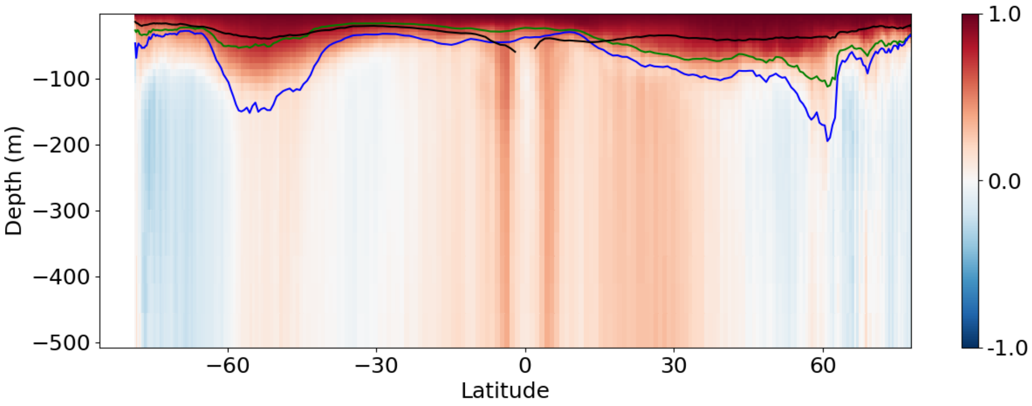


The correlation scales are fixed but the background error standard deviations vary seasonally

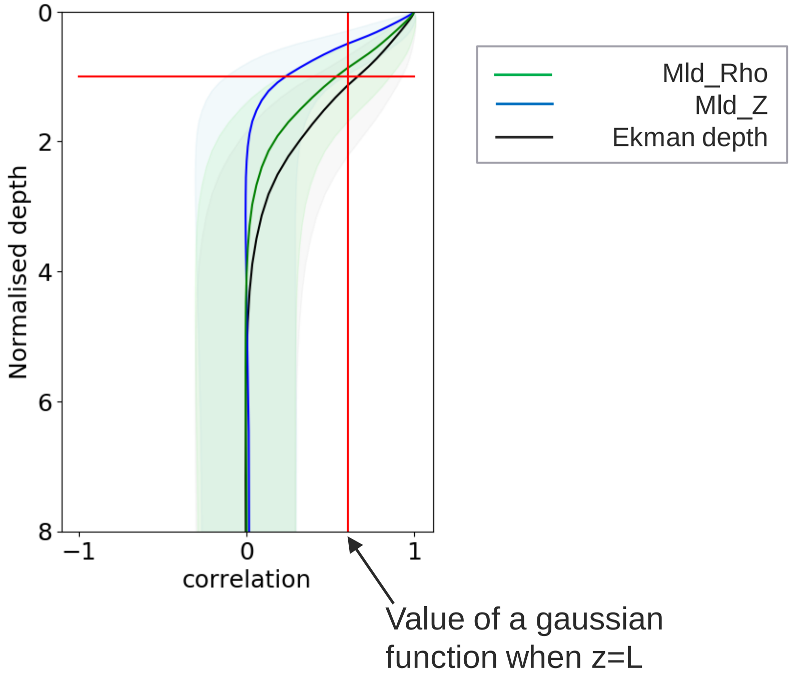
Background Velocity Error Covariances in NEMOVAR: vertical

Unbalanced U vertical background error correlations with the surface

Zonally averaged



Globally averaged



Parametrisation for the vertical U and V standard deviations

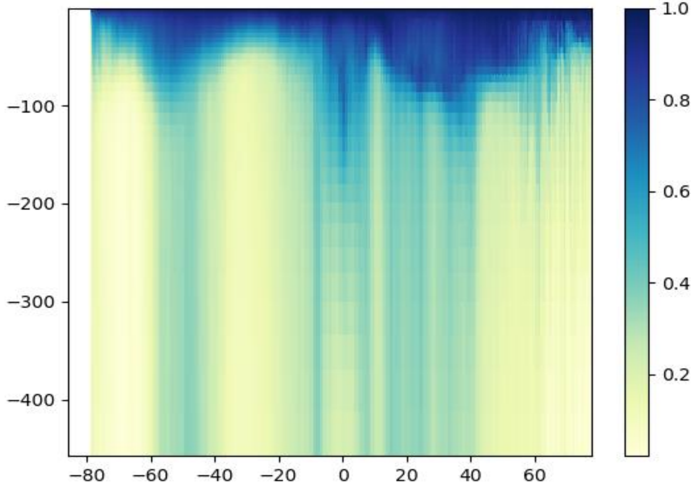
Need to define a parameterisation to reduce the surface standard deviation with depth, we're using an equation of the form:

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

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

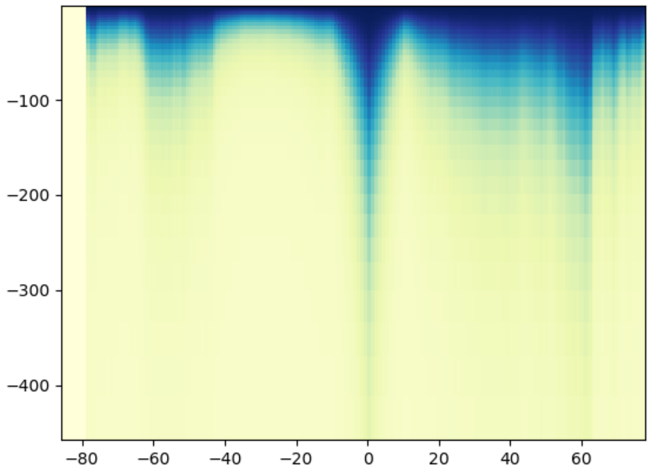
Zonal average of NMC unbalanced U background error standard deviation, normalised by the surface value.

Depth (m)



Latitude

Parameterisation (zcoef)

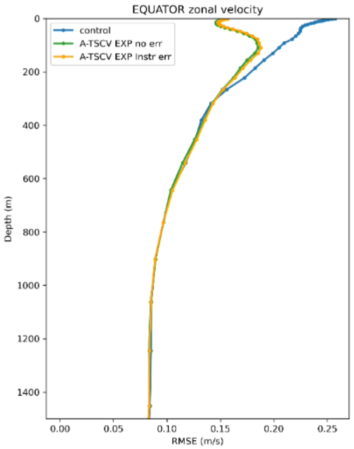


Latitude

Impact on velocity RMSE in the equatorial region

Zonal

Meridional



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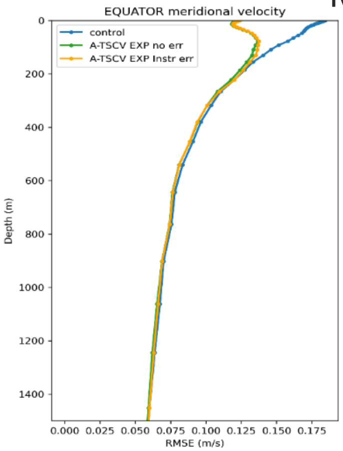
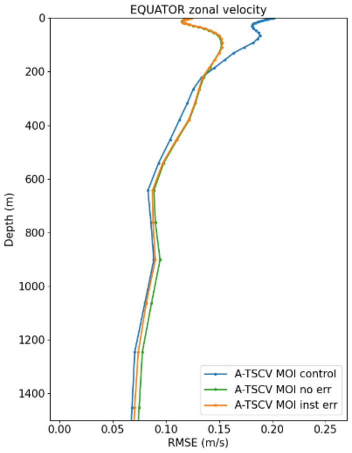
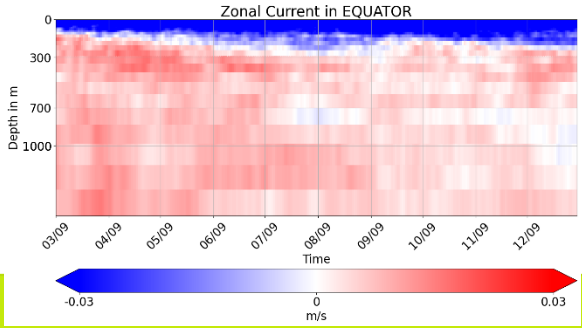
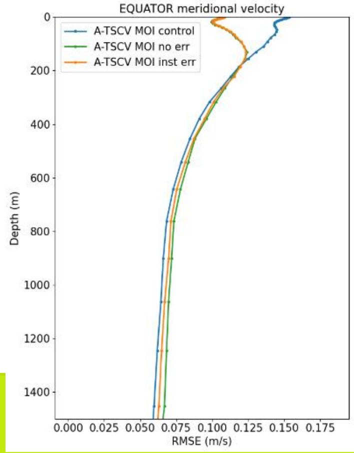


- Deeper impact in zonal than meridional
- Small degradations below ~200 m in MOI



MOI

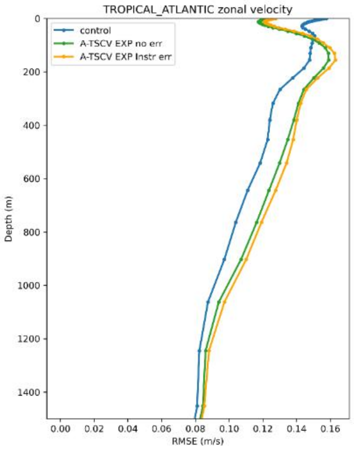


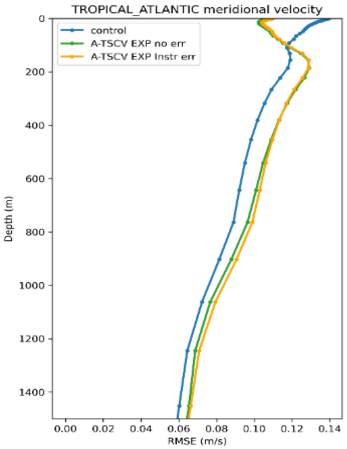


Impact on velocity RMSE in the Tropical Atlantic region

Zonal

Meridional

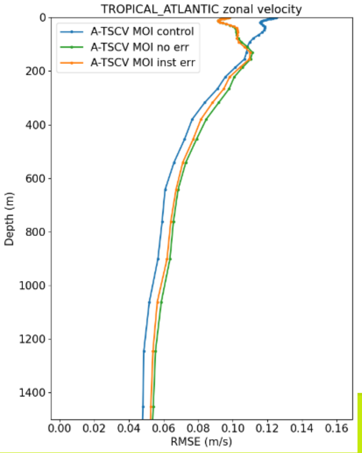


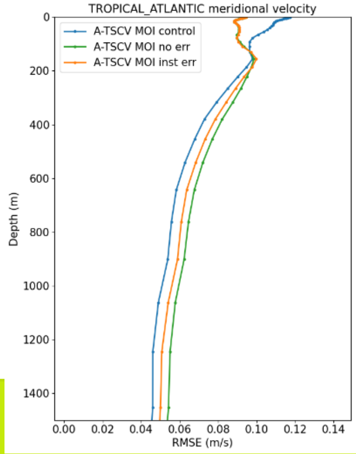


MetO

- Larger degradations below ~100 m in both systems.
- Issues with multivariate aspects here, or vertical length-scales inappropriate?

MOI

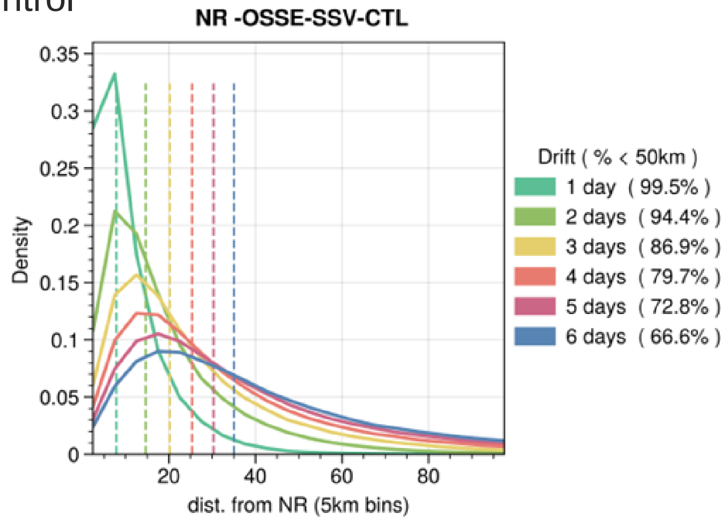




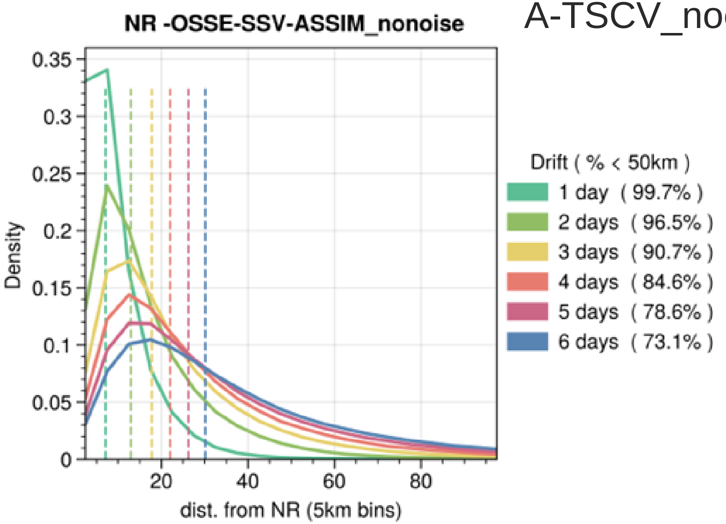
Lagrangian assessment – MOI

PDFs of distance error in control at different lead times

Control



A-TSCV_noerr



- On average, there is a 5 km improvement after 6-day drift when TSCV data are assimilated compared to control.
- The proportion of parcels with a distance less than 50 km is improved by 10% after drifting during 6 days thanks to TSCV data. This represents a one-day gain.