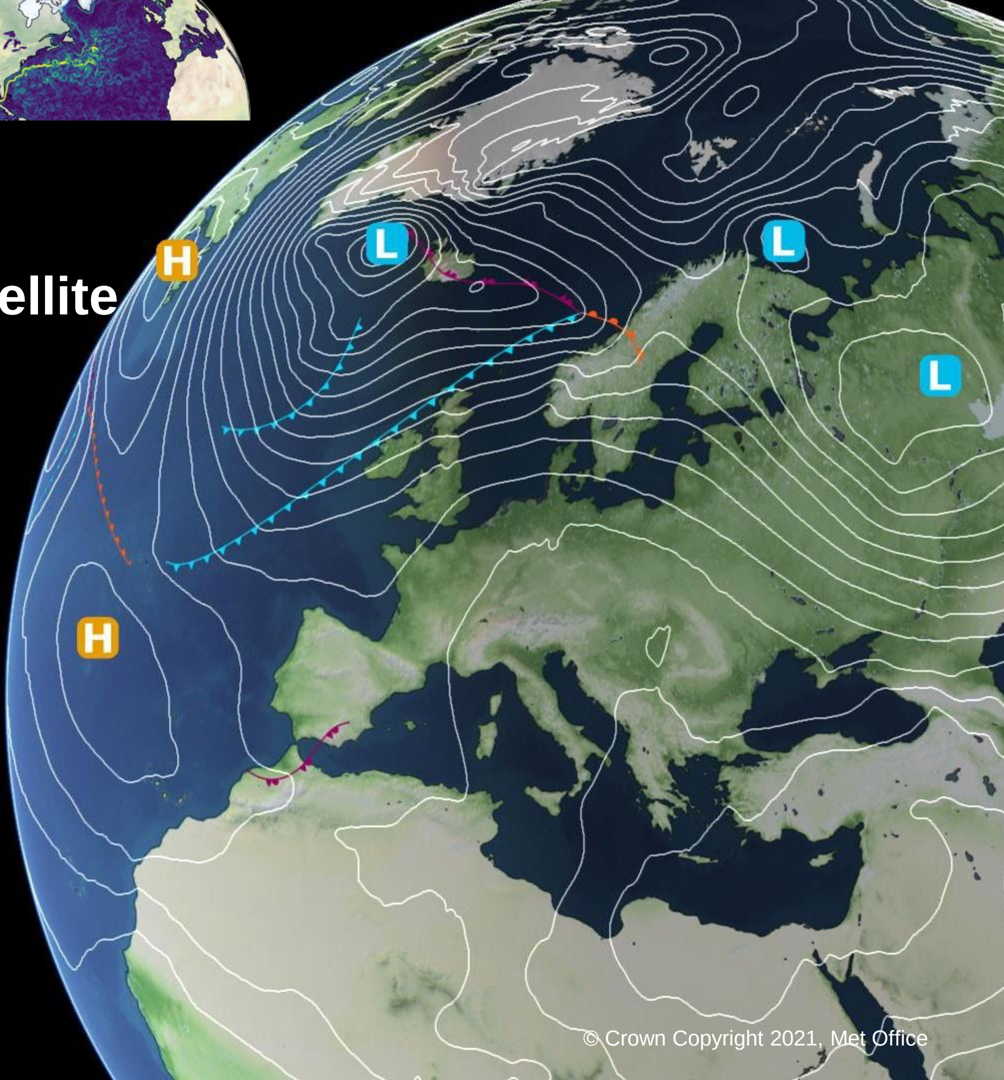
Met Office

esa

A-TSCV
Assimilation of Total Surface Current Velocities

Developing the assimilation of satellite total surface current velocities



Matt Martin[1], Jennifer Waters[1], Robert King[1], Mike Bell[1]

Elisabeth Remy[2], Isabelle Mirouze[3]

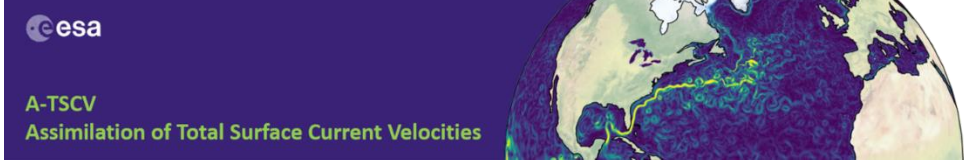
Lucile Gaultier[4], Clement Ubelmann[5]

Craig Donlon[6].

1. Met Office, UK
2. Mercator Ocean International, France
3. Cap Gemini, France
4. OceanDataLab, France
5. OceanNext, France
6. European Space Agency/ESTEC, Netherlands

© Crown Copyright 2021, Met Office

Met Office



This presentation describes work in progress.

We have done quite a bit of work on the data assimilation development and are about to start on the main experiments.

It seems a good time to solicit feedback on the approaches taken.

Contents

Met Office

1. Motivation and project overview

Total Surface Current Velocity

The ocean total surface current velocity (TSCV) is defined as:

- the Lagrangian mean velocity at the instantaneous sea surface, corresponding to an effective mass transport velocity at the surface [Marié et al. (2020)]
- or TSCV is defined as the velocity of a water parcel in contact with the atmosphere at any given location and time [ESA (2019)]

The TSCV is the result of a combination of different forces including:

- Frictional stress of the wind acting on the sea surface.
- Ocean surface wave-induced inertia and pressure gradient, leading to Stokes drift.
- Coriolis force related to the Earth's rotation.
- Large scale (>10 km) pressure gradients due to variations in surface elevation (gravitation, including tides, atmospheric pressure, local topography) and to variations in density, including the effects of stratification.

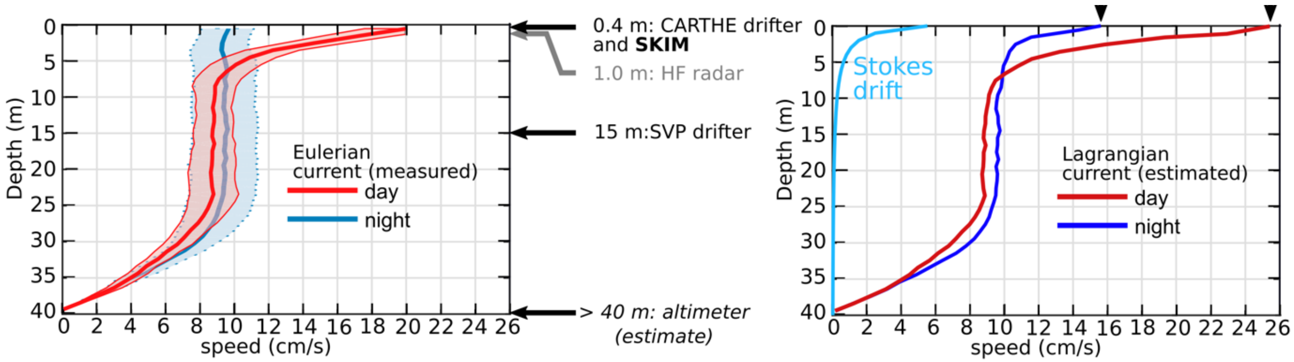
The long-term average velocity of particles at the ocean surface is well described by the sum of the three terms:

- The geostrophic currents, U_g, arising from the pressure gradients.
- The Ekman, or mean wind-driven, component, U_E.
- The wave-induced Stokes drift, U_S

Shorter time-scale processes also affecting the TSCV include tides and near-inertial oscillations driven largely by variable wind-stress (Kim and Kosro, 2013).

Depth variations of currents in the upper ocean

The depth of the surface layer representative of the TSCV in the upper ocean depends on the vertical density stratification and varies between approximately 0.1 m and 10s of metres.



[taken from the SKIM report for mission selection]
from a surface acoustic Doppler current profiler attached to a 50-m drogued drifter

Motivation

- Accurate forecasts of **total surface current velocities (TSCV)** are important for various applications, e.g.:
  - Search and rescue
  - Oil spill monitoring/forecasting
  - Tracking marine plastic
  - Coupled ocean/atmosphere forecasting

- Various satellite missions have been proposed to measure TSCV globally (e.g. SKIM, SEASTAR, WaCM).
- Global coverage TSCV data would provide information about ageostrophic velocities, not observed globally by other observing systems, as well as providing much improved coverage for the geostrophic velocities (compared to that available from the existing altimeter constellation).

- Demonstrating the potential impact of that type of data in global ocean forecasting systems will help the case for satellite agencies to move forward with these type of missions, and help define the requirements for such missions.
- It should also help us understand and improve our assimilation and forecasting systems.

Met Office

Existing measurements of near-surface currents

- Direct measurements of the TSCV are currently not available ***with global coverage***.
  - In coastal regions HF radars (e.g. Morley et al., 2018) provide TSCV measurements.
  - Surface drifters have global coverage and can be used to infer near-surface currents. Usually drogued at 15 m depth so don’t measure the TSCV.
  - Some drifters have been deployed to measure TSCV (including Stokes drift) but not widespread.
  - ADCPs are available in some regions (e.g. tropical Pacific) but have limited spatial coverage.

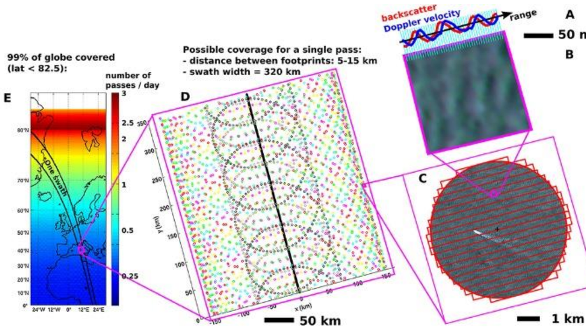
- Some products are available which provide information on the surface currents. GlobCurrent (Rio et al., 2014) and OSCAR (Dohan, 2017) datasets combine geostrophic velocities inferred from satellite altimeters, Ekman currents inferred from scatterometer satellite data, as well as using surface drifter-derived currents.

Proposed missions to measure TSCV

Various satellite missions are being proposed to measure TSCV globally such as SKIM (Ardhuin et al., 2019), SEASTAR (Gommenginger et al., 2019) and WaCM (Rodríguez et al., 2019).

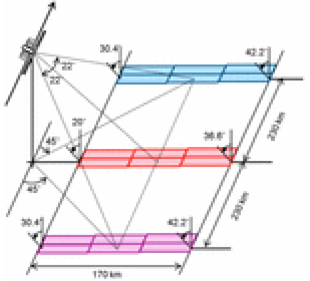
SKIM [This mission was proposed for ESA’s EE-9 mission, but was not selected]

- Conically scanning, multi-beam Doppler radar altimeter/wave scatterometer that would measure the surface velocity vector and ocean wave spectra across a 320-km swath.
- “Aim to have RMS accuracy of 0.07 m/s for each velocity component for wavelengths larger than 100 km, and time scales over 15 days.”



SEASTAR [one of 4 candidate missions for EE-11 – if selected, launch in 2031-32]

- Along-Track Interferometry (ATI), whereby the line-of-sight motion of the ocean surface is measured from the Doppler shift between two SAR images acquired within a few milliseconds of each other in a single satellite overpass. Both components of the TSCV retrieved in a single pass and would produce a single-sided 170 km swath. Focussed on shelf and coastal seas and marginal ice zones.
- “Accuracy requirements for current vectors at 1 km resolution are 0.1 m/s and 20°.”



Project overview

- The **ESA A-TSCV project**[1] will use observing system simulation experiments (OSSEs) to test the assimilation of satellite TSCV data.

- Two operational global ocean forecasting systems are being developed to assimilate these data in a set of coordinated OSSEs:
  - the FOAM system run at the Met Office
  - the Mercator Ocean International (MOI) system.

- **The main aims of the project are to:**
  1. **develop and test the assimilation methodology for total surface currents.**
  2. **provide feedback on the observation requirements for future satellite missions.**

[1]https://oceanpredict.org/science/projects/a-tscv

Planned OSSE overview (1)

- The nature run is a 1/12° model-only run of NEMO/LIM (v3.1) which was used in the AtlantOS project (Gasparin et al., 2019), forced by operational ECMWF IFS fluxes.
- Standard observation data types (SST, SIC, T/S, SLA) have been simulated from the nature run with errors added (method also described in Gasparin et al., 2019).
- TSCV data has been simulated from the nature run, also using wave data from a run of WWIII which was forced using ECWMF IFS fluxes and surface currents from the NEMO nature run.
- Full OSSE experiments will be carried out for 1 year:

1-year OSSEs	SST, in situ T,S and Sea Ice	SLA	TSCV
OSSE0	No	No	No
OSSE1	Yes	Yes	No
OSSE2	Yes	Yes	Yes (no error)
OSSE3	Yes	Yes	Yes
OSSE4	Yes	No	Yes (no error)

Met Office

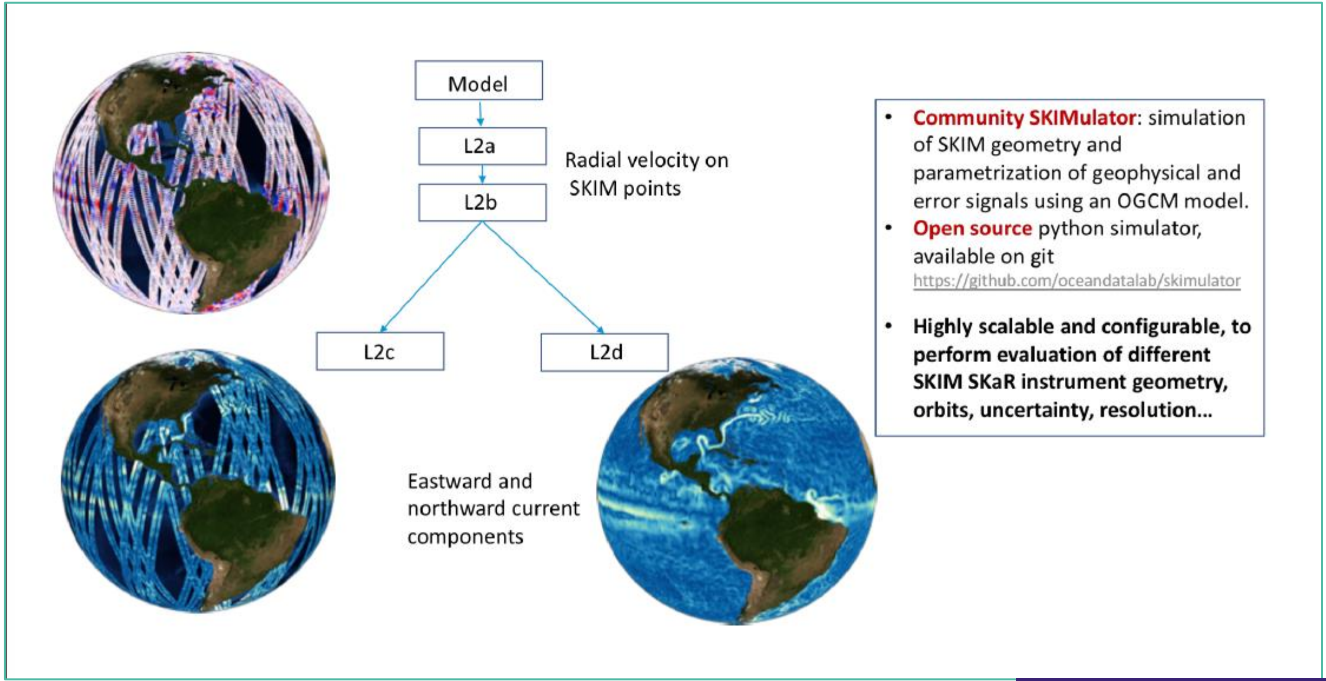
Planned OSSE overview (2)

- Initial tests of the TSCV assimilation will be carried out using idealised, widely-spaced observations.
- Short, one-month experiments will be carried out using the full set of data (with and without TSCV assimilation) to perform some initial testing and tuning.
- Both Met Office and Mercator Ocean forecasting systems will be run at 1/4° resolution, with different initial conditions to nature run, forced by ERA5 fluxes, using NEMOv3.6. But they differ significantly in their DA approach.

	FOAM	MOI
Assimilation scheme	NEMOVAR 3D-VAR FGAT (Waters et al., 2015)	SEEK filter with a fixed basis (Lellouche et al., 2018)
Assimilation window	1 day	7 days
Background error covariances	Spatially and seasonally varying error variances at the surface and flow-dependent parameterisation for the sub-surface error variances. Combination of two length-scales for the horizontal error correlations while vertical error correlations are based on the mixed-layer depth.	Defined through an ensemble of model anomalies from an historic model run. Spatially and weekly varying error covariances following the model “climatology”.
Multivariate Balance	Multi-variate relationships defined through linearised physical balances (Weaver et al., 2005)	Model covariance matrix based on a reduced basis of multivariate model anomalies.
Model	NEMO v3.6 and CICE, 1/4°, 75 levels	NEMO v3.6 and LIM3, 1/4°, 50 levels
Surface forcing	ERA-5	ERA-5

Generation of TSCV observations

- Using the SKIMulator tool: https://github.com/oceandatalab/skimulator
- We plan to assimilate the L2c data – eastward (u) and northward (v) components of the currents on the swath.



2. Implementing the assimilation of TSCV data

Focus on the Met Office system here

Overview of NEMOVAR incremental 3DVar-FGAT

Run NEMO for 1-day and calculate the innovations at the nearest model time-step to the obs time:

$$\mathbf{d} = \mathbf{y} - H(\boldsymbol{x}^f)$$

H is the observation operator, $\boldsymbol{x}^f$ is the model forecast.

Minimise the cost function:

$$J(\boldsymbol{\delta w}) = \frac{1}{2}\boldsymbol{\delta w}^T\boldsymbol{B}^{-1}\ \boldsymbol{\delta w} + \frac{1}{2}(\mathbf{HK}^{\boldsymbol{b}}\boldsymbol{\delta w} - \mathbf{d})^T\boldsymbol{R}^{-1}\ (\mathbf{HK}^{\boldsymbol{b}}\boldsymbol{\delta w} - \mathbf{d})$$

$\boldsymbol{\delta w}$ is the increment to the control vector, and $\boldsymbol{\delta w^a}$ is the control vector increment after minimisation

$\mathbf{K}^b$ is the multivariate balance operator [$\boldsymbol{x} = K^b(\boldsymbol{w})$] linearised around $\boldsymbol{x}^f$

$\boldsymbol{\delta x^a} = \mathbf{K}^b\boldsymbol{\delta w^a}$ are the analysis increments

$\mathbf{H}$ is the observation operator linearised around $\boldsymbol{x}^f$

$\boldsymbol{B}$ and $\boldsymbol{R}$ are the background and observation error covariances

Apply the increments to NEMO over 1-day by adding $\frac{\mathbf{1}}{\boldsymbol{N}}\boldsymbol{\delta x}^a$ on each of the $\boldsymbol{N}$ timesteps.

Overview of NEMOVAR incremental 3DVar-FGAT

Run NEMO for 1-day and calculate the innovations at the nearest model time-step to the obs time:

$$\mathbf{d} = \mathbf{y} - H(\boldsymbol{x}^f)$$

H is the observation operator, $\boldsymbol{x}^f$ is the model forecast.

Minimise the cost function:

$$J(\boldsymbol{\delta w}) = \frac{1}{2}\boldsymbol{\delta w}^T \boldsymbol{B}^{-1}\ \boldsymbol{\delta w} + \frac{1}{2}(\mathbf{HK}^{\boldsymbol{b}}\boldsymbol{\delta w} - \mathbf{d})^T \boldsymbol{R}^{-1}\ (\mathbf{HK}^{\boldsymbol{b}}\boldsymbol{\delta w} - \mathbf{d})$$

$\boldsymbol{\delta w}$ is the increment to the control vector, and $\boldsymbol{\delta w^a}$ is the control vector increment after minimisation

$\mathbf{K}^b$ is the multivariate balance operator [$\boldsymbol{x} = K^b(\boldsymbol{w})$] linearised around $\boldsymbol{x}^f$

$\boldsymbol{\delta x^a} = \mathbf{K}^b \boldsymbol{\delta w^a}$ are the analysis increments

$\mathbf{H}$ is the observation operator linearised around $\boldsymbol{x}^f$

$\boldsymbol{B}$ and $\boldsymbol{R}$ are the background and observation error covariances

Apply the increments to NEMO over 1-day by adding $\frac{\mathbf{1}}{\boldsymbol{N}}\boldsymbol{\delta x}^a$ on each of the $\boldsymbol{N}$ timesteps.

Observation operator

- Observation operator code has been added to NEMO which:
  - reads in TSCV data
  - interpolates the model values to the observation locations at the nearest model time-step
  - rotates the model velocities from the model grid reference frame to the eastward/northward values.
- The same changes were added to the NEMOVAR observation operator and its adjoint coded.

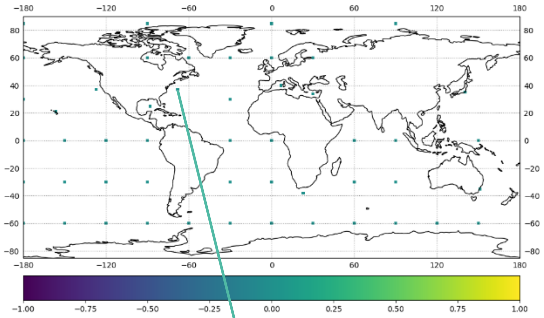
Testing functionality using idealised widely-spaced observations.

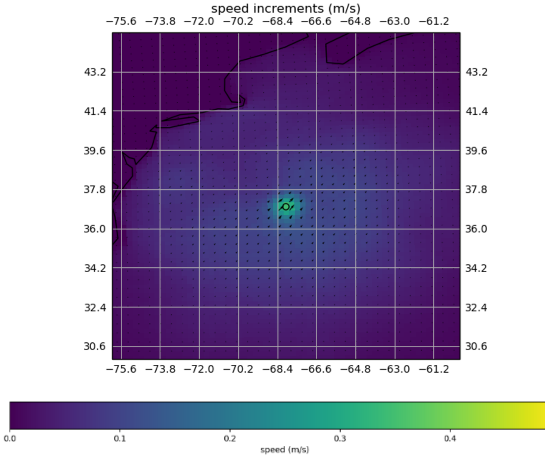
Error covariance settings (just for testing):

- TSCV observation error standard deviations set to 0.2 m/s.
- Surface background error standard deviations set to 0.2 m/s.

Innovations (obs-minus-background) set to 0.5 m/s for u and v

=> increments should be 0.25 m/s for u and v (0.35 m/s in N-E direction).





Overview of NEMOVAR incremental 3DVar-FGAT

Run NEMO for 1-day and calculate the innovations at the nearest model time-step to the obs time:

$$\mathbf{d} = \mathbf{y} - H(\boldsymbol{x}^f)$$

H is the observation operator, $\boldsymbol{x}^f$ is the model forecast.

Minimise the cost function:

$$J(\boldsymbol{\delta w}) = \frac{1}{2}\boldsymbol{\delta w}^T\boldsymbol{B}^{-1}\ \boldsymbol{\delta w} + \frac{1}{2}(\mathbf{HK}^{\boldsymbol{b}}\boldsymbol{\delta w} - \mathbf{d})^T\boldsymbol{R}^{-1}\ (\mathbf{HK}^{\boldsymbol{b}}\boldsymbol{\delta w} - \mathbf{d})$$

$\boldsymbol{\delta w}$ is the increment to the control vector, and $\boldsymbol{\delta w}^{\boldsymbol{a}}$ is the control vector increment after minimisation

$\mathbf{K}^{b}$ is the multivariate balance operator [$\boldsymbol{x} = K^b(\boldsymbol{w})$] linearised around $\boldsymbol{x}^f$

$\boldsymbol{\delta x}^{\boldsymbol{a}} = \mathbf{K}^b\boldsymbol{\delta w}^{\boldsymbol{a}}$ are the analysis increments

$\mathbf{H}$ is the observation operator linearised around $\boldsymbol{x}^f$

$\boldsymbol{B}$ and $\boldsymbol{R}$ are the background and observation error covariances

Apply the increments to NEMO over 1-day by adding $\frac{\mathbf{1}}{\boldsymbol{N}}\boldsymbol{\delta x}^{a}$ on each of the $\boldsymbol{N}$ timesteps.

Control vector and balance

The variables included in the control vector are: $\boldsymbol{\delta}\mathbf{w} = \begin{bmatrix} \delta T \\ \delta S_u \\ \delta SSH_u \\ \delta u_u \\ \delta v_u \\ \delta SIC \end{bmatrix}$ $\left(\boldsymbol{\delta x} = \begin{bmatrix} \delta T \\ \delta S \\ \delta SSH \\ \delta u \\ \delta v \\ \delta SIC \end{bmatrix} = \begin{bmatrix} \delta T \\ K_{S,T}\delta T + \delta S_u \\ K_{SSH,\rho}\delta\rho + \delta SSH_u \\ K_{u,p}\delta p + \delta u_u \\ K_{v,p}\delta p + \delta v_u \\ \delta SIC \end{bmatrix}\right)$

(plus other terms associated with variational bias correction)

- The balanced components of the velocity increments are geostrophically balanced with the pressure increments calculated using the T/S/SSH increments. So with the standard global observing system (without velocity data), the velocity increments are purely geostrophic.
- Including the assimilation of velocity data allows adjustments to both the geostrophic and ageostrophic velocities.The adjustment of geostrophic velocities by the velocity data will result in increments to T/S/SSH.
- In the cost function on the previous slide, $\boldsymbol{B}$ only needs to specify the univariate components of the error covariances for the control vector (unbalanced) variables.

- Aside: ideally the control vector variables should be uncorrelated with each other. u and v are correlated, so we have started a PhD looking into other options for specifying control variables for velocities.

Overview of NEMOVAR incremental 3DVar-FGAT

Run NEMO for 1-day and calculate the innovations at the nearest model time-step to the obs time:

$$\mathbf{d} = \mathbf{y} - H(\boldsymbol{x}^f)$$

H is the observation operator, $\boldsymbol{x}^f$ is the model forecast.

Minimise the cost function:

$$J(\boldsymbol{\delta w}) = \frac{1}{2}\boldsymbol{\delta w}^T \boldsymbol{B}^{-1}\ \boldsymbol{\delta w} + \frac{1}{2}(\mathbf{HK}^{\boldsymbol{b}}\boldsymbol{\delta w} - \mathbf{d})^T \boldsymbol{R}^{-1}\ (\mathbf{HK}^{\boldsymbol{b}}\boldsymbol{\delta w} - \mathbf{d})$$

$\boldsymbol{\delta w}$ is the increment to the control vector, and $\boldsymbol{\delta w^a}$ is the control vector increment after minimisation

$\mathbf{K}^b$ is the multivariate balance operator [$\boldsymbol{x} = K^b(\boldsymbol{w})$] linearised around $\boldsymbol{x}^f$

$\boldsymbol{\delta x^a} = \mathbf{K}^b \boldsymbol{\delta w^a}$ are the analysis increments

$\mathbf{H}$ is the observation operator linearised around $\boldsymbol{x}^f$

$\boldsymbol{B}$ and $\boldsymbol{R}$ are the background and observation error covariances

Apply the increments to NEMO over 1-day by adding $\frac{\mathbf{1}}{\boldsymbol{N}}\boldsymbol{\delta x}^a$ on each of the $\boldsymbol{N}$ timesteps.

Background error covariances

- Need to specify background error covariance for the unbalanced (ageostrophic) velocities.
- We use a combination of 2 Gaussian correlation functions to represent the horizontal correlations [Mirouze et al., 2016].
- Each of the two components has an associated weight (which are temporally and spatially varying).

- NMC method: uses 48 hour and 24 hour forecast difference fields, valid at the same time, as a proxy for the background error. Using data from a previous two-year run of the 1/4° FOAM system.
- We 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 (2 scales in the horizontal, 1 scale in the vertical) and the background error standard deviations associated with each of the horizontal scales.
- We only calculate isotropic covariances which are the same for u and v.
- Constant horizontal length-scales and seasonally varying variances (for each component) were estimated.
- Vertical correlations, and the way the variances vary with depth will be parameterized so that they are flow dependent.

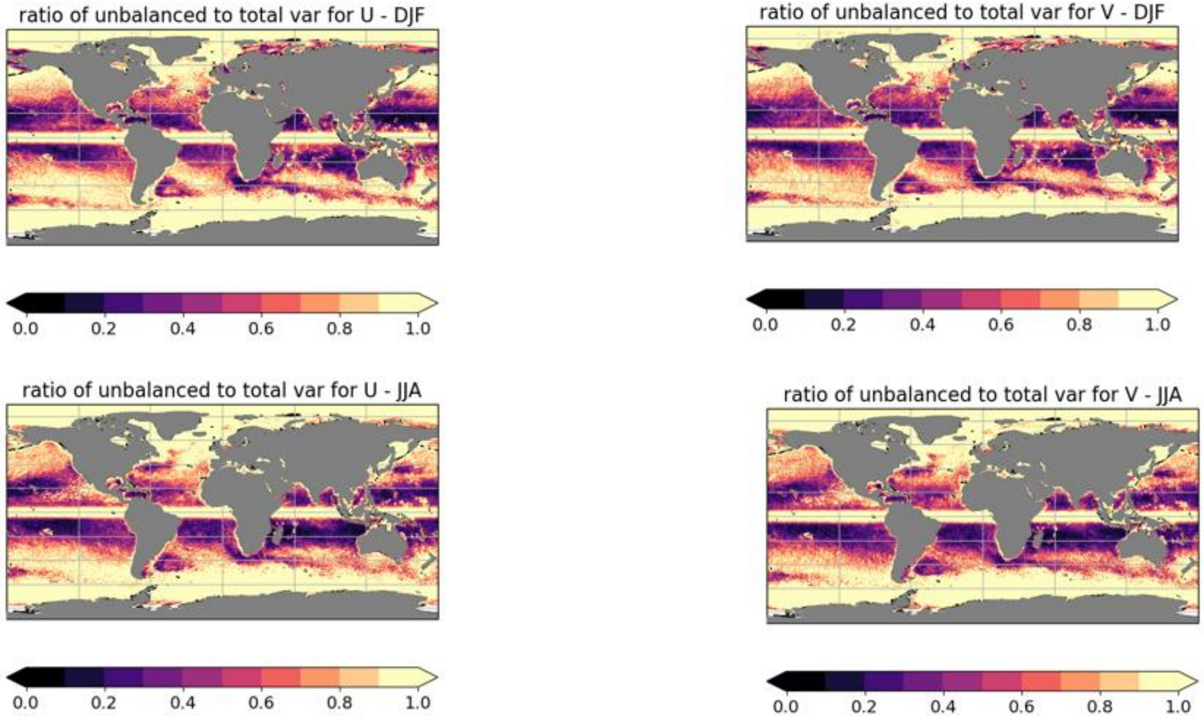
Met Office

Importance of the ageostrophic component of the background error

Ratio of the ageostrophic TSCV error variance to the total TSCV error variance

DJF

JJA

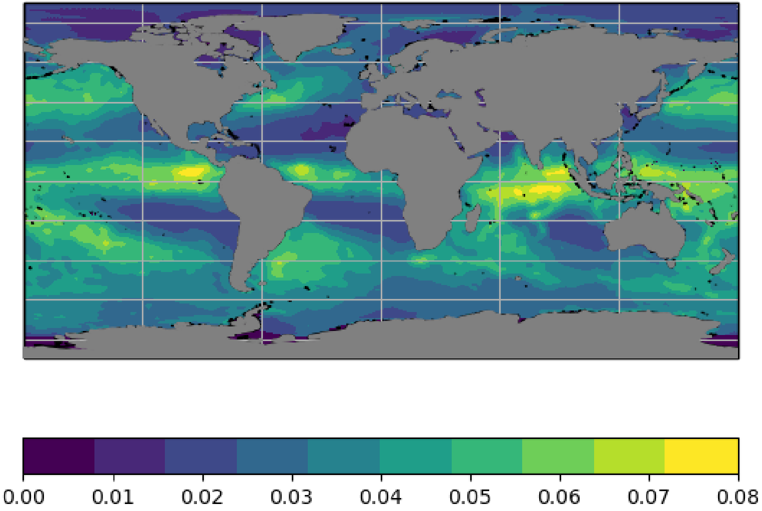


U component

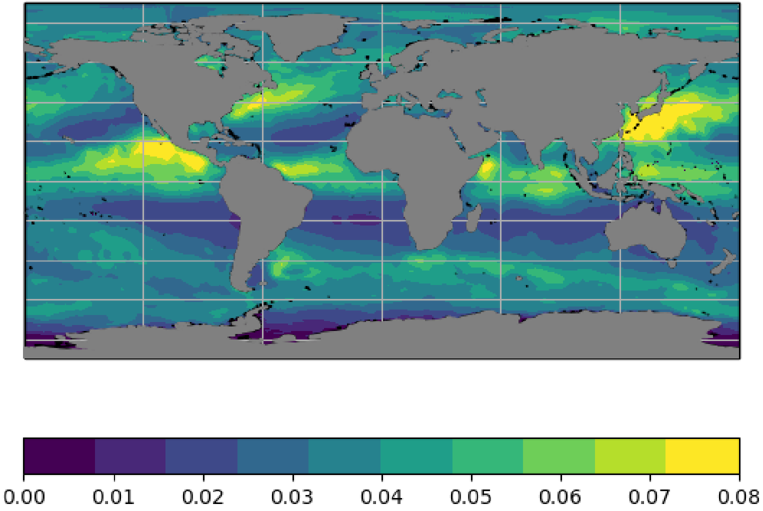
V component

Ageostrophic velocity background error standard deviations (small + large scale component)

DJF

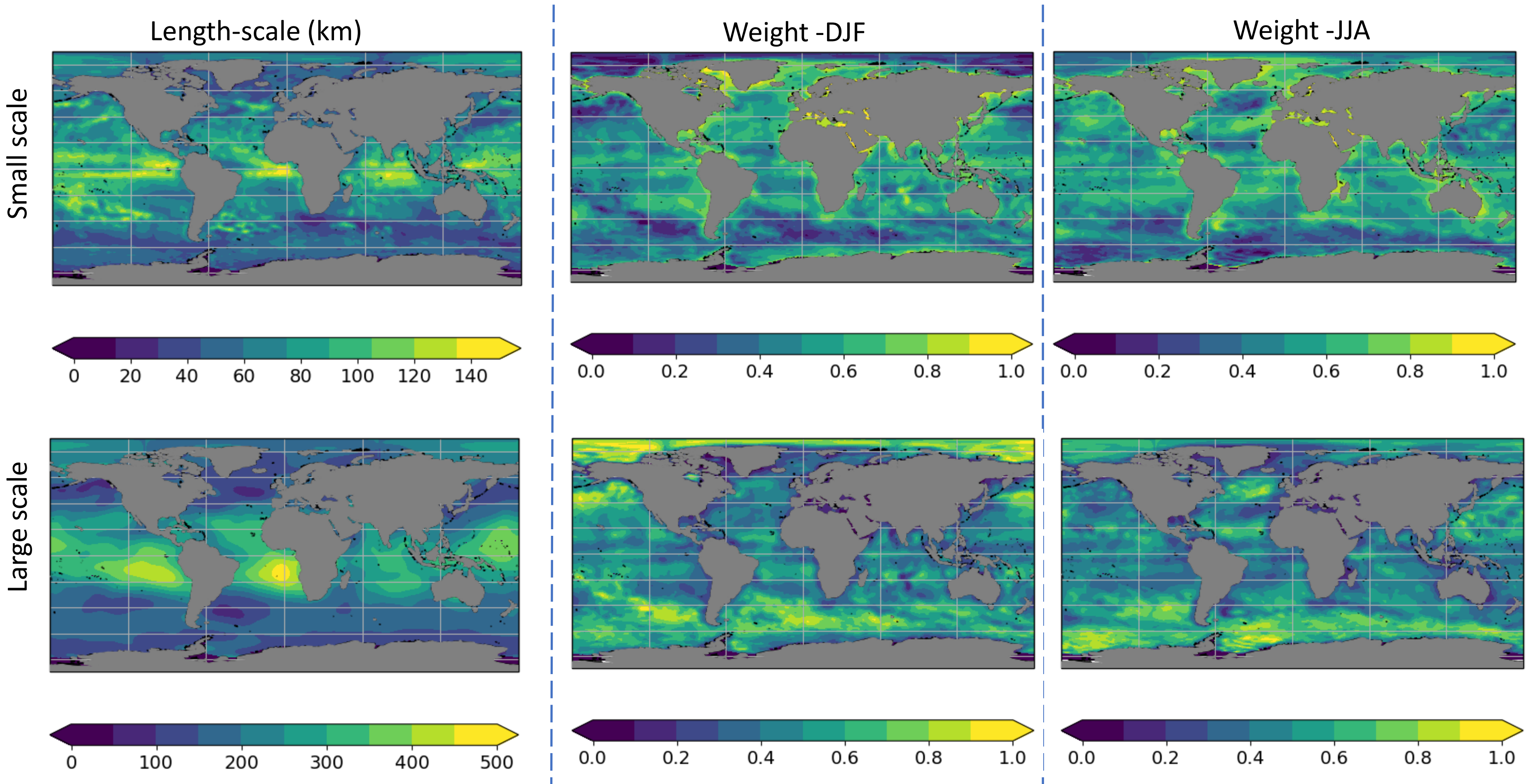


JJA



- Larger background errors in the western boundary currents, the tropics and regions of high winds.
- Some seasonal variations, e.g. in Eastern Pacific,

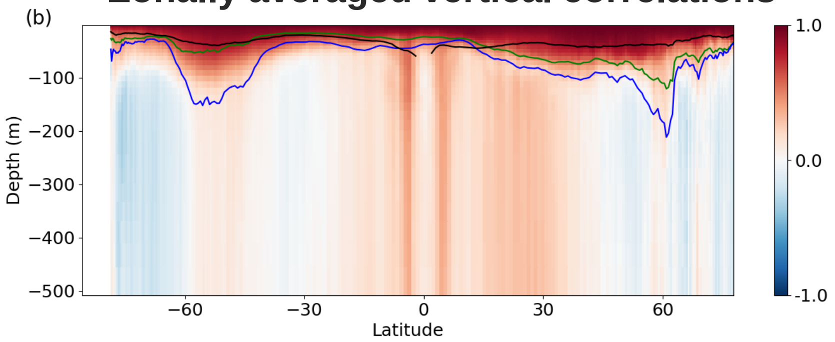
Ageostrophic velocity error correlation scales and their weights



Ageostrophic velocity vertical background error correlations

- Temperature and salinity vertical background error correlations are parameterised in NEMOVAR using the Kara et al. (2003) definition of mixed layer depth (blue line) and are dependent on the background model state.
- Should we use a similar parameterisation for the vertical length-scales of ageostrophic velocity?
- Vertical NMC ageostrophic velocity background error correlations were compared to 2 mixed layer depth definitions and the Ekman depth.
- The Ekman depth, and a shallower mixed layer depth better represent the error correlation scales of unbalanced velocities.

Zonally averaged vertical correlations

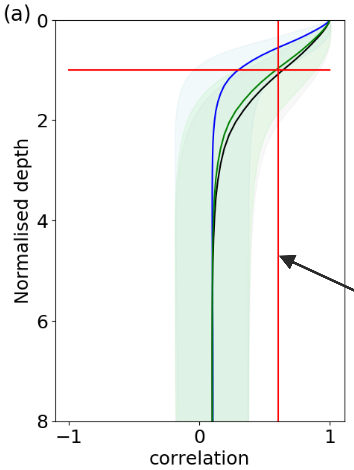


Mld_kara – depth at which density has increased equivalent to a temperature of 0.8

Mld_Rho – shallowest depth where density increases by 0.01kg/m3

Ekman depth – Calculated from the model's vertical viscosity (max value in each water column)

Globally averaged



The plot shows the vertical correlations estimated from the NMC method, as a function of "normalised depth" (normalised by the local MLD or Ekman depth), averaged over the globe.

Value of a Gaussian function when z=L

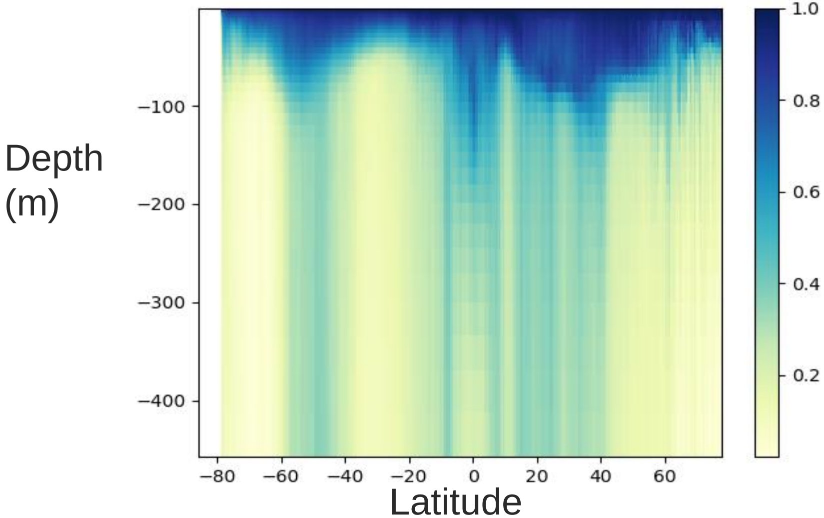
Parametrisation for the vertical ageostrophic velocity standard deviations

Need to define a flow dependent parameterisation to reduce the surface standard deviation with depth, we're using the following equation:

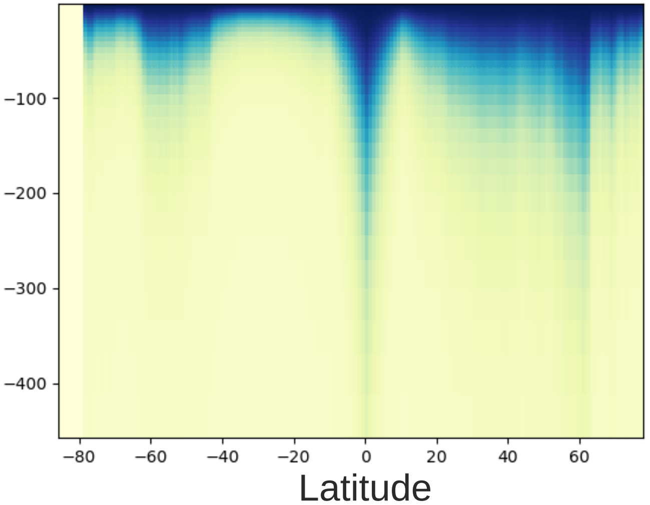
$$zcoef(z) = 0.05 + 0.95(1 - \tanh[\ln\frac{z}{L}])/2$$

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

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



Parameterisation (zcoef)



Summary of background error covariances

- Ageostrophic component of the velocity forecast errors is large in most regions.
- Background error standard deviations are specified based on seasonally varying estimates from the NMC method at the surface and are reduced with depth based on a parameterization.
- Specify constant horizontal length-scales based on the NMC estimates for the two components.
- The weight given to each component varies seasonally.
- Vertical correlation length-scales are parametrized based on the mixed layer depth in the background.

Overview of NEMOVAR incremental 3DVar-FGAT

Run NEMO for 1-day and calculate the innovations at the nearest model time-step to the obs time:

$$\mathbf{d} = \mathbf{y} - H(\boldsymbol{x}^f)$$

H is the observation operator, $\boldsymbol{x}^f$ is the model forecast.

Minimise the cost function:

$$J(\boldsymbol{\delta w}) = \frac{1}{2}\boldsymbol{\delta w}^T \boldsymbol{B}^{-1}\ \boldsymbol{\delta w} + \frac{1}{2}(\mathbf{HK}^{\boldsymbol{b}}\boldsymbol{\delta w} - \mathbf{d})^T \boldsymbol{R}^{-1}\ (\mathbf{HK}^{\boldsymbol{b}}\boldsymbol{\delta w} - \mathbf{d})$$

$\boldsymbol{\delta w}$ is the increment to the control vector, and $\boldsymbol{\delta w^a}$ is the control vector increment after minimisation

$\mathbf{K}^b$ is the multivariate balance operator [$\boldsymbol{x} = K^b(\boldsymbol{w})$] linearised around $\boldsymbol{x}^f$

$\boldsymbol{\delta x^a} = \mathbf{K}^b \boldsymbol{\delta w^a}$ are the analysis increments

$\mathbf{H}$ is the observation operator linearised around $\boldsymbol{x}^f$

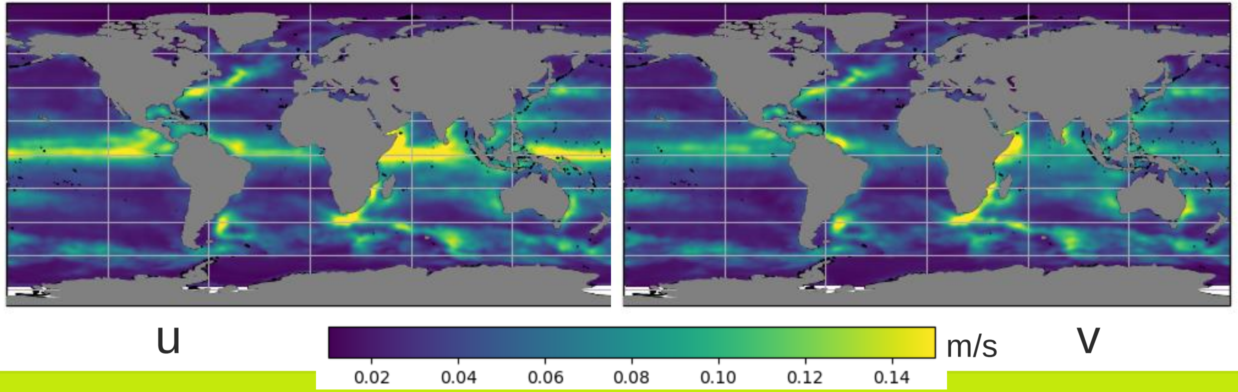
$\boldsymbol{B}$ and $\boldsymbol{R}$ are the background and observation error covariances

Apply the increments to NEMO over 1-day by adding $\frac{\mathbf{1}}{\boldsymbol{N}}\boldsymbol{\delta x}^a$ on each of the $\boldsymbol{N}$ timesteps.

Observation error covariances

- $\boldsymbol{R}$ will be specified by combining estimates of measurement errors and representation errors.
- Measurement errors are supplied with the data by the SKIMulator.
- Representation errors are due to the different resolution of nature run (1/12°) and OSSE (1/4°)
- Real TSCV data is likely to have significant error correlations but these will not be included here, either in the data or in the specification of $\boldsymbol{R}$.

Representation error standard deviations estimated by comparing the variability of model free runs of ORCA12 and ORCA025 over one year



Overview of NEMOVAR incremental 3DVar-FGAT

Run NEMO for 1-day and calculate the innovations at the nearest model time-step to the obs time:

$$\mathbf{d} = \mathbf{y} - H(\boldsymbol{x}^f)$$

H is the observation operator, $\boldsymbol{x}^f$ is the model forecast.

Minimise the cost function:

$$J(\boldsymbol{\delta w}) = \frac{1}{2}\boldsymbol{\delta w}^T\boldsymbol{B}^{-1}\,\boldsymbol{\delta w} + \frac{1}{2}(\mathbf{HK}^{\boldsymbol{b}}\boldsymbol{\delta w} - \mathbf{d})^T\boldsymbol{R}^{-1}\,(\mathbf{HK}^{\boldsymbol{b}}\boldsymbol{\delta w} - \mathbf{d})$$

$\boldsymbol{\delta w}$ is the increment to the control vector, and $\boldsymbol{\delta w}^{\boldsymbol{a}}$ is the control vector increment after minimisation

$\mathbf{K}^b$ is the multivariate balance operator [$\boldsymbol{x} = K^b(\boldsymbol{w})$] linearised around $\boldsymbol{x}^f$

$\boldsymbol{\delta x}^{\boldsymbol{a}} = \mathbf{K}^b\boldsymbol{\delta w}^{\boldsymbol{a}}$ are the analysis increments

$\mathbf{H}$ is the observation operator linearised around $\boldsymbol{x}^f$

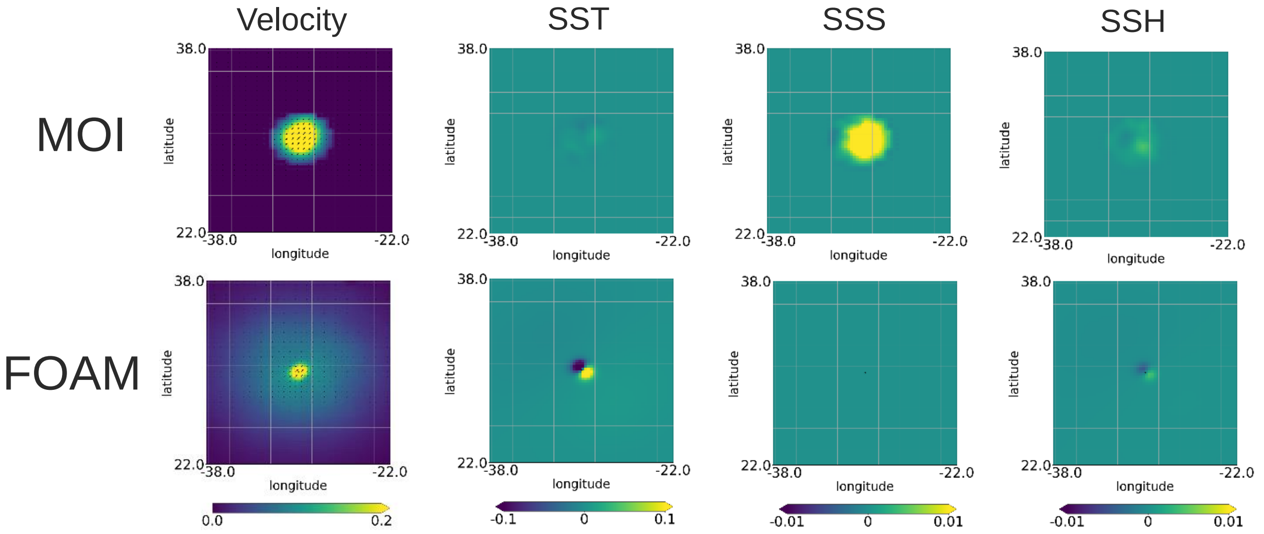
$\boldsymbol{B}$ and $\boldsymbol{R}$ are the background and observation error covariances

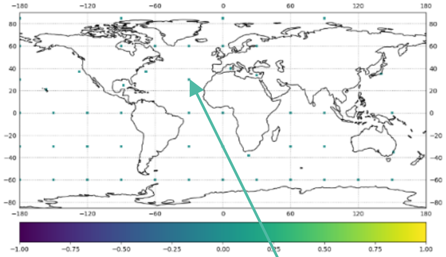
Apply the increments to NEMO over 1-day by adding $\frac{\mathbf{1}}{\boldsymbol{N}}\boldsymbol{\delta x}^a$ on each of the $\boldsymbol{N}$ timesteps.

Idealised observation experiments

- We defined a set of widely-spaced (~30° apart) innovations of TSCV of 0.5 m/s in u & v and assimilated them.

Increments



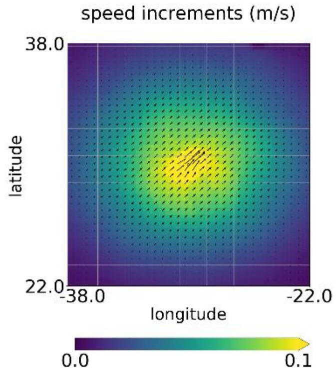


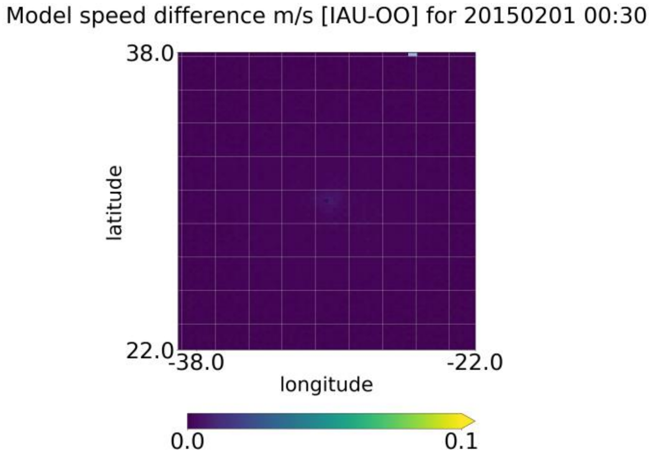
An innovation of 0.5 m/s in u and v is specified in the mid North Atlantic, **valid at 12UTC**.

- MOI and FOAM systems give quite different increments to the velocity.
- The multivariate relationships give very different increments to other surface variables.
- The following focusses only on the FOAM system to examine how the velocity increment is retained when added to the model.

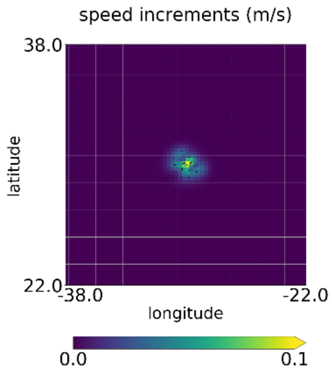
Model response to increments in FOAM

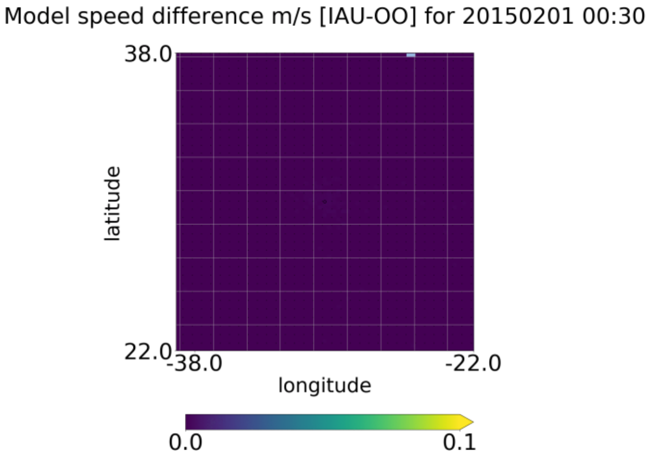
Total increments





Balanced increments only



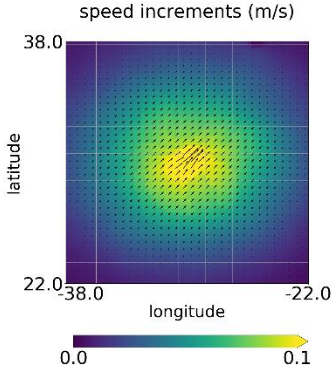


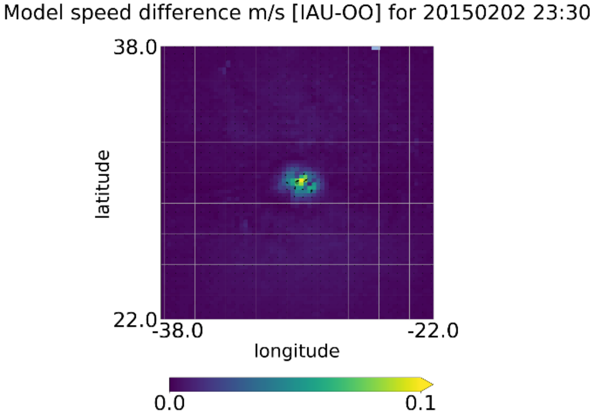
- In NEMOVAR the velocity increments are a combination of balanced/geostrophic and unbalanced/ageostrophic components.
- Balanced increments are the geostrophic component
- Animations show difference between a run which adds in the increments, and a free run.
- Showing differences for 1-day of the IAU and then 1-day forecast.

Note: the change in plotting scale from the last slide

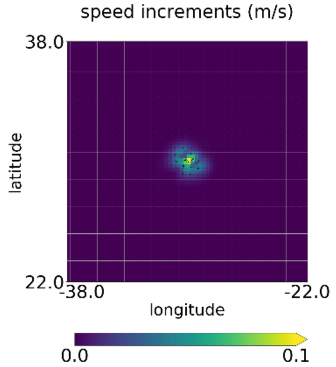
Model response to increments in FOAM: end of 24 hour forecast

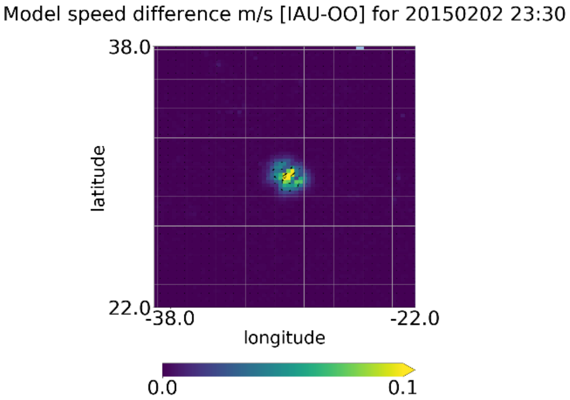
Total increments





Balanced increments only





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

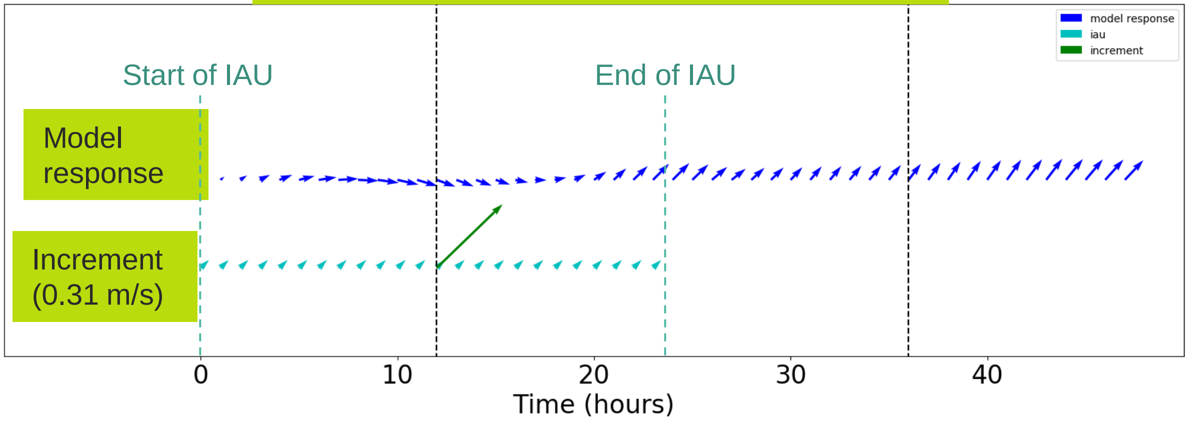
Impact of ageostrophic velocity increments

- Away from the equator, inertial oscillations are a large component of the ageostrophic velocities.
- The inertial period is given by $T = \frac{2\pi}{f}$, where f is the Coriolis parameter, e.g. at 30N the inertial period is approximately 24 hours

- If we apply the ageostrophic velocity increments using IAU the model responds by rotating the applied increment on subsequent time steps.
- 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.

This figure shows how the surface model velocity (at the obs location) responds to an ageostrophic velocity increment.

Model response at 30W, 30N



Applying ageostrophic velocity increments

- We propose to rotate the ageostrophic component of the increments using the following equations for an increment $(\delta u_1, \delta v_1)$ at time t_1 :

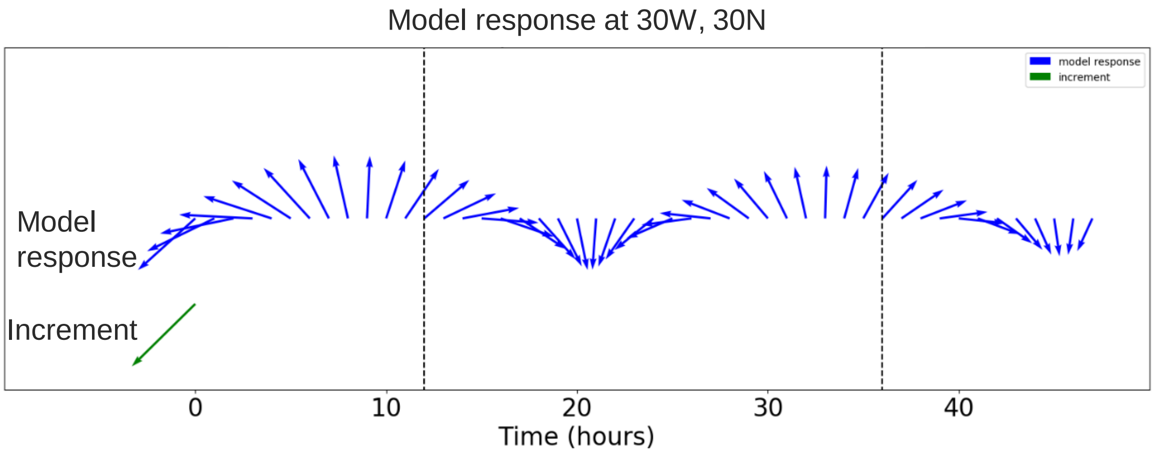
$$\delta u(t) = \delta u_1\, cos\big(f(t-t_1)\big) + \delta v_1\, sin\big(f(t-t_1)\big)$$
$$\delta v(t) = \delta v_1\, cos\big(f(t-t_1)\big) - \delta u_1\, sin\big(f(t-t_1)\big)$$

- The increments could either be rotated to be valid at one particular time during the day and applied directly then.
- Or we could follow the approach of the IAU and rotate and apply a fraction of the ageostrophic u/v increments on each time-step of the day.
- This requires us knowing the validity time of the increments. In the idealised obs case we only have one observation locally so it is easy.
- With the full set of pseudo SKIM data, we propose to pre-select observations so that they are all valid at a similar time locally, output a gridded field of the increments' validity time, then use this as $t_1(x, y)$ in the above equations.

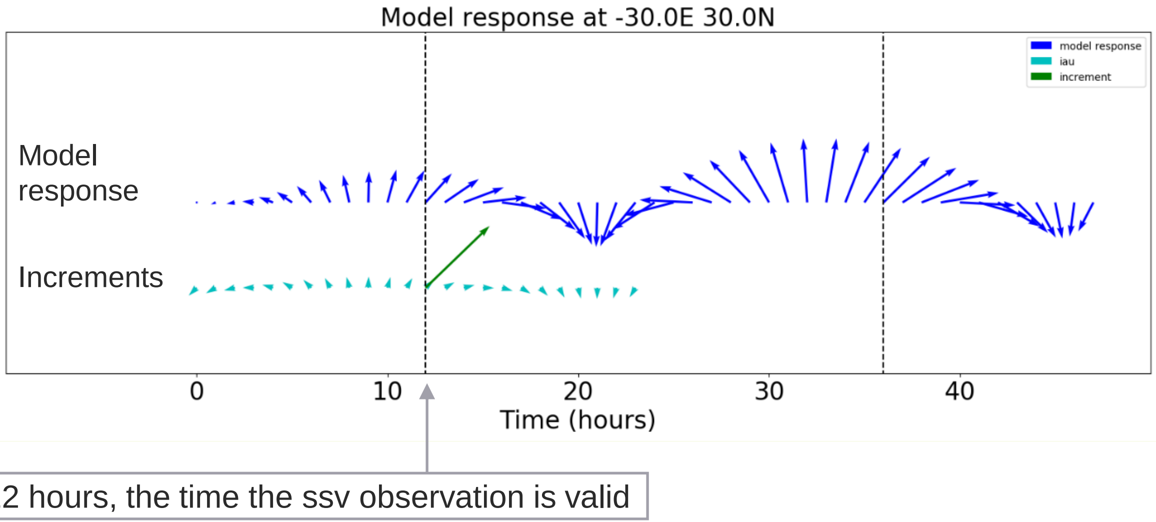
- [4DVar would be a better approach, but with a 3DVar system the above approach should allow us to make better use of the information in TSCV data.]

Impact of rotated ageostrophic velocity increments

Model response when **direct insertion** is used. Note that the increment is rotated to 0 hours so it can be applied at the start of the time window.

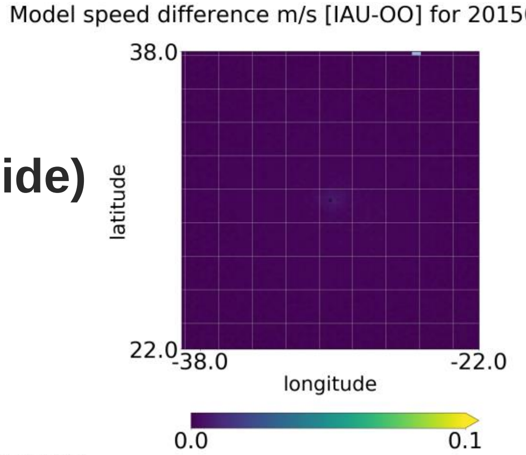


Model response when the **IAU** is used but the applied increments are **rotated at each time step** by the inertial period

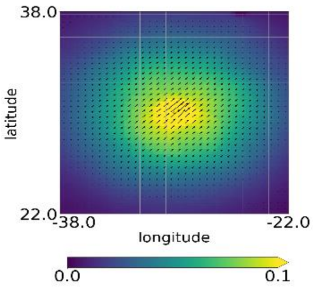


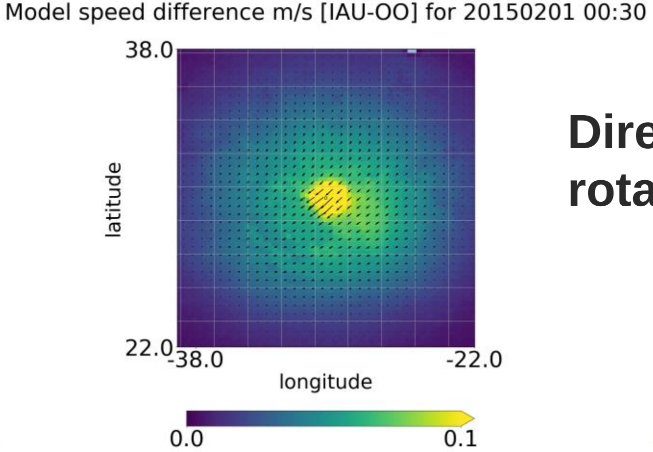
Model response to increments in FOAM

Standard IAU (from earlier slide)

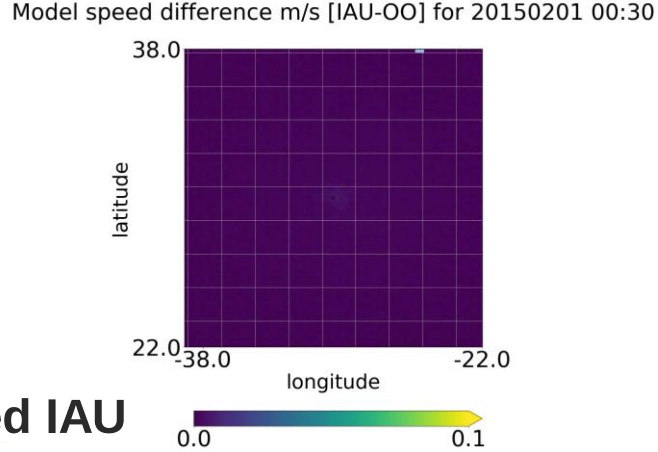


Velocity increment





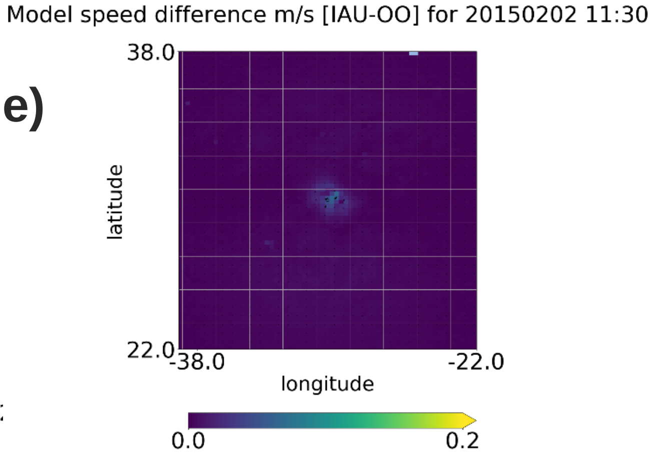
Direction insertion of rotated increments



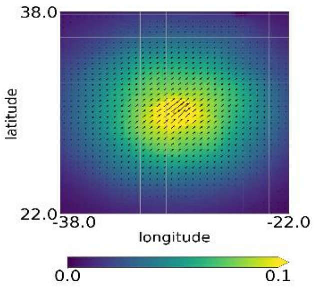
Rotated IAU

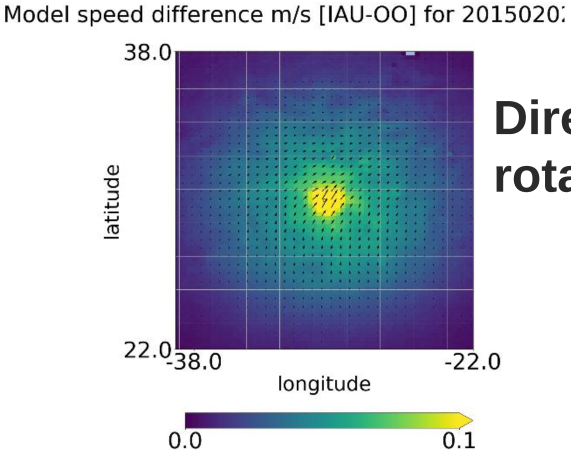
Model response to increments in FOAM – snapshot at 11:30UTC on the second day

Standard IAU (from earlier slide)



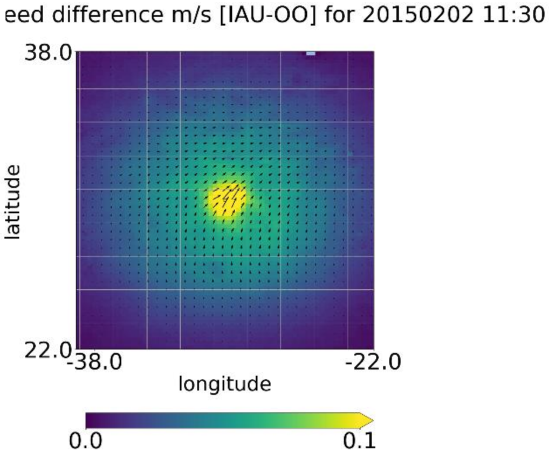
Velocity increment





Direction insertion of rotated increments

Rotated IAU



3. Summary and next steps

Summary

- The ESA A-TSCV project aims to assess the potential impact of satellite TSCV data in order to define requirements from operational ocean forecasting systems.

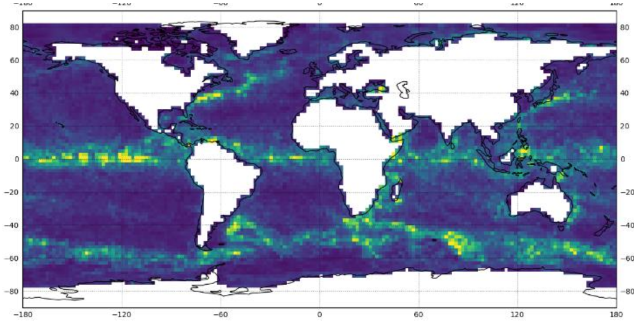
- We have developed the assimilation of TSCV data in the Met Office and Mercator Ocean systems.

- This included:
  - implementing an observation operator for TSCV
  - estimating background error covariances for the ageostrophic velocities
  - specifying observation error covariances
  - testing the use of a new rotated IAU scheme for assimilation of the ageostrophic velocity component.

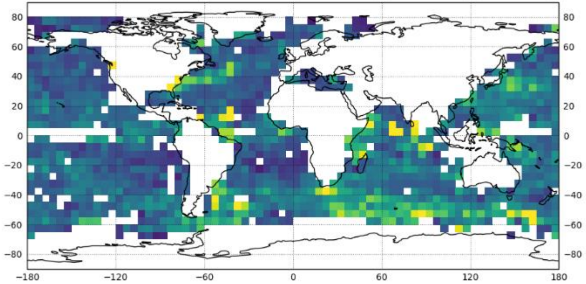
Future work

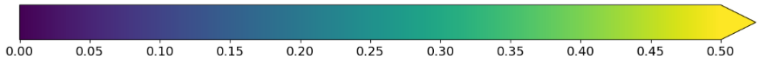
- The control runs have been set going and are being assessed.
- We are now just about to start some one month tests of the full assimilation of TSCV data from the SKIMulator.
- We will then run the full set of OSSEs in both Met Office and Mercator Ocean systems, and assess the impact of assimilating TSCV data.
- Provide feedback on the observation requirements for future satellite missions.
- We plan to hold a workshop later in 2022.

OSSE control run U RMSE of 1 m depth



Real system 15 m depth u RMSE compared to drifter-derived velocities from CMEMS (includes obs errors)





Questions?

For more information please contact

matthew.martin@metoffice.gov.uk

© Crown Copyright 2020, Met Office

- Ardhuin F et al. (2019): SKIM, a Candidate Satellite Mission Exploring Global Ocean Currents and Waves. Front. Mar. Sci. 6:209. doi: 10.3389/fmars.2019.00209
- Gasparin F, Guinehut S, Mao C, Mirouze I, Rémy E, King RR, Hamon M, Reid R, Storto A, Le Traon P-Y, Martin MJ and Masina S (2019) Requirements for an Integrated in situ Atlantic Ocean Observing System From Coordinated Observing System Simulation Experiments. Front. Mar. Sci. 6:83. doi: 10.3389/fmars.2019.00083
- Gommenginger C et al. (2019): SEASTAR: A Mission to Study Ocean Submesoscale Dynamics and Small-Scale Atmosphere-Ocean Processes in Coastal, Shelf and Polar Seas. Front. Mar. Sci. 6:457. doi: 10.3389/fmars.2019.00457
- Kim, S. Y., and P. M. Kosro (2013): Observations of near-inertial surface currents off Oregon: Decorrelation time and length scales, J. Geophys. Res. Oceans, 118, 3723–3736, doi:10.1002/jgrc.20235.
- Marié, L. et al. (2020): Measuring ocean total surface current velocity with the KuROS and KaRADOC airborne near-nadir Doppler radars: a multi-scale analysis in preparation for the SKIM mission, Ocean Sci., 16, 1399–1429, https://doi.org/10.5194/os-16-1399-2020.
- Mirouze, I., E.W. Blockley, D.J. Lea, M.J. Martin and M.J. Bell, 2016. A multiple length scale correlation operator with application to ocean data assimilation Tellus A, 68, 29744, http://dx.doi.org/10.3402/tellusa.v68.29744.
- Rodríguez E. et al.(2019): The Winds and Currents Mission Concept. Front. Mar. Sci. 6:438. doi: 10.3389/fmars.2019.00438