Assimilating along-track SLA data using the EnOI in an eddy resolving model of the Agulhas system

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NANSEN-TUTU CENTRE
MARINE ENVIRONMENTAL RESEARCH

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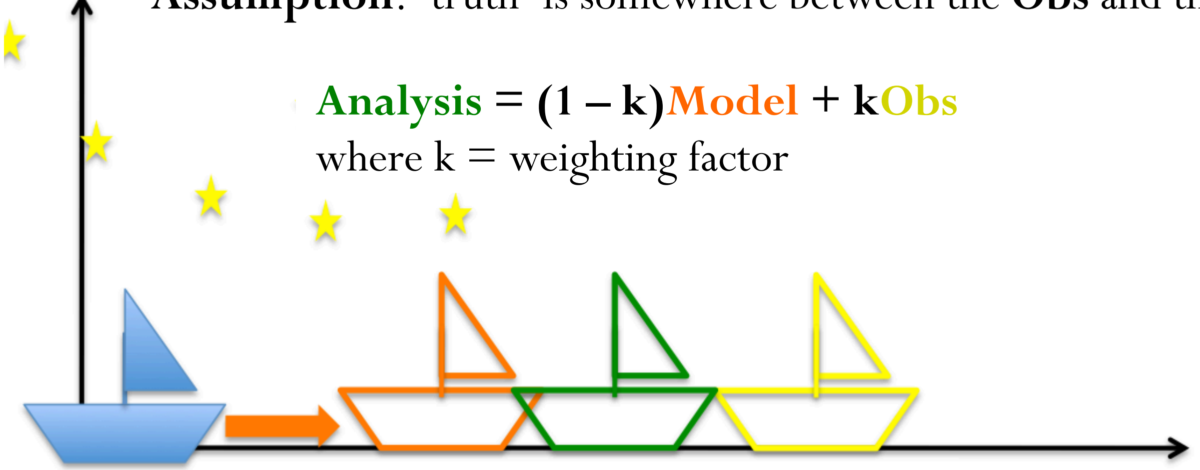
Objective

- Merge observations with a dynamical model to estimate the “true” ocean state.
- Models may have the correct dynamics and variability but they cannot be “accurate” because of the chaotic behaviour of the ocean circulation.
- Model errors arise from the **initial state**, **boundary conditions** & **numerical schemes**
- Data assimilation **uses observations** to **improve** the **initial state**

Assumption: “truth” is somewhere between the **Obs** and the **Model**

Analysis = (1 – k)Model + kObs
where k = weighting factor



The accuracy of the **Analysis** is determined by a combination of the variance in the **Model** and the variance in the **Obs**.

In a real application

Problem 1:

- Observations are sparse
- Models:
  - Are 3-dimensional
  - Are multivariate (multiple variables change in relation to each other)
  - Require consistent updates (computationally expensive)

Problem 2:

- Accuracy of the observations are not well known
- Do observations and models represent the same thing?
  (differences in temporal and spatial resolution, e.g. along-track data vs gridded data)

Problem 3:

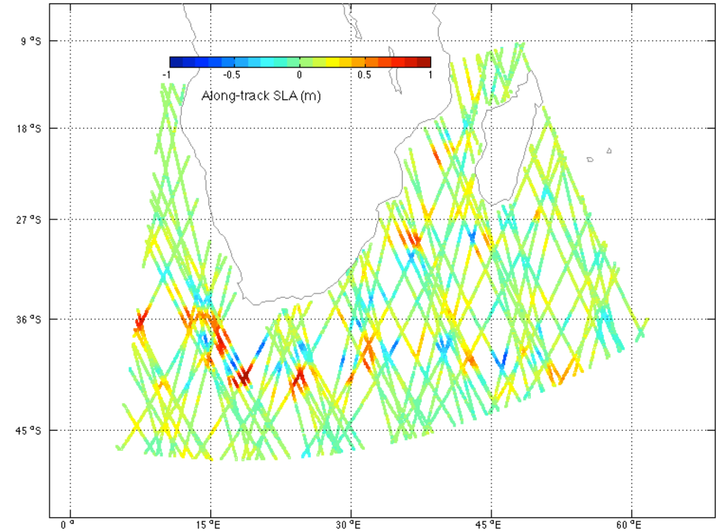
- The correction provided by the assimilation method **must be in equilibrium** with the model dynamics

Objective

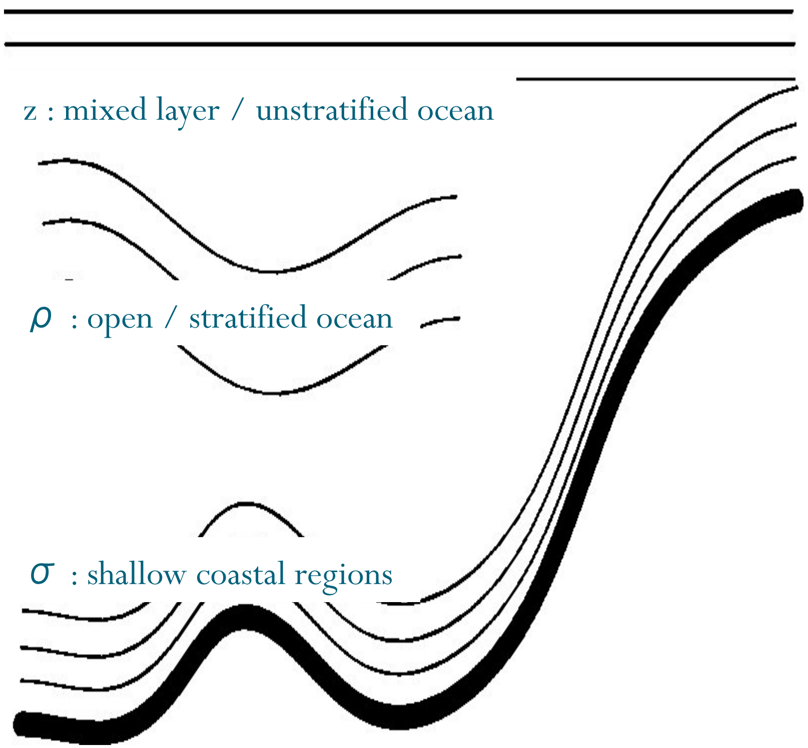
Assimilate along-track sea level anomaly (SLA) data into HYCOM with the Ensemble Optimal Interpolation (EnOI)

- Why SLA?
  - Sea level anomaly signals in the Agulhas system are strong
- Why the EnOI ?
  - Low computational cost DA (run one forecast member, historical ensemble represents the forecast error)
  - Small sampling error (large ensemble)
  - 3D-Multivariate

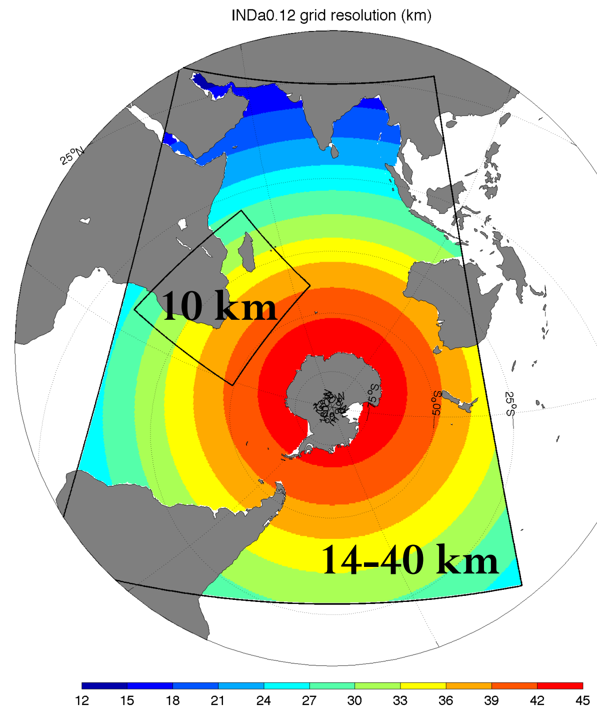
  → Preserves model consistency
  - Demonstrated in dynamically similar regions:
    - Gulf of Mexico (Counillon et al., 2009a,b; Srinivasan et al., 2011)
    - Australian regional ocean (Oke et al., 2005, 2007)
    - South China Sea (Xie et al., 2011)
- Why HYCOM?



Hybrid Coordinate Ocean Model



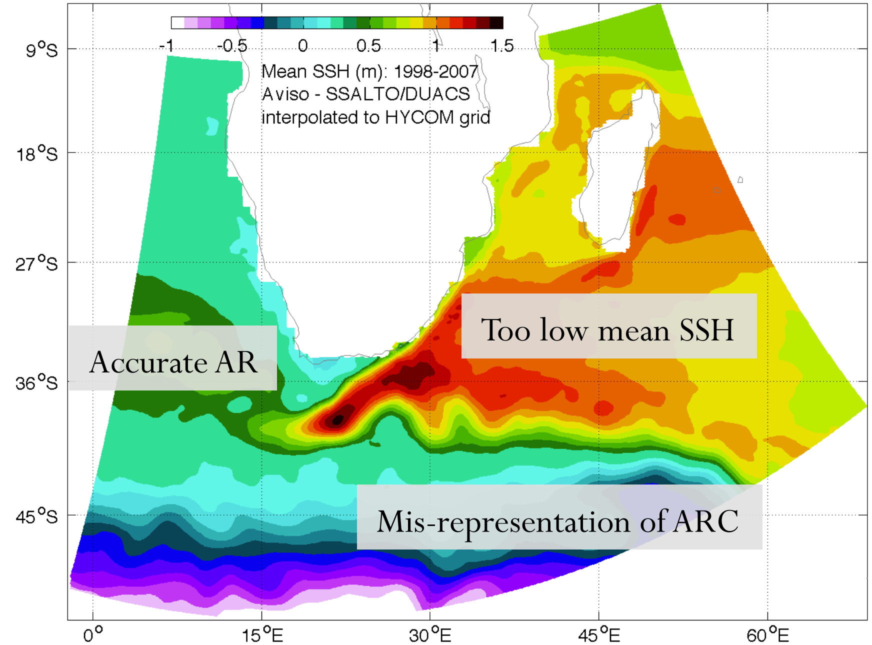
- Isopycnal (layered) coordinate system
- Ability to change to fixed-grid coordinate system when needed
- Adaptive vertical grid conveniently resolves regions of vertical density gradients, e.g. thermocline & surface fronts

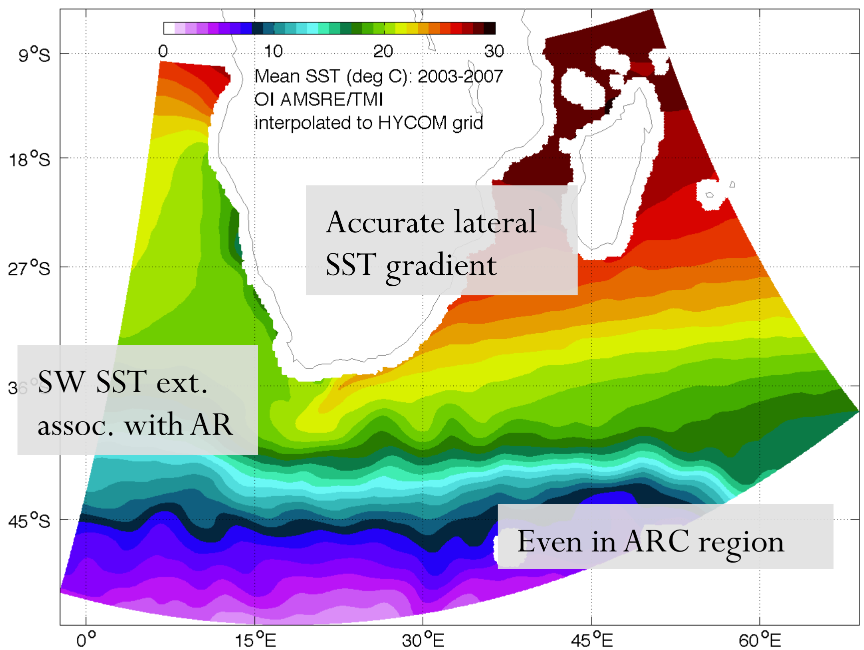


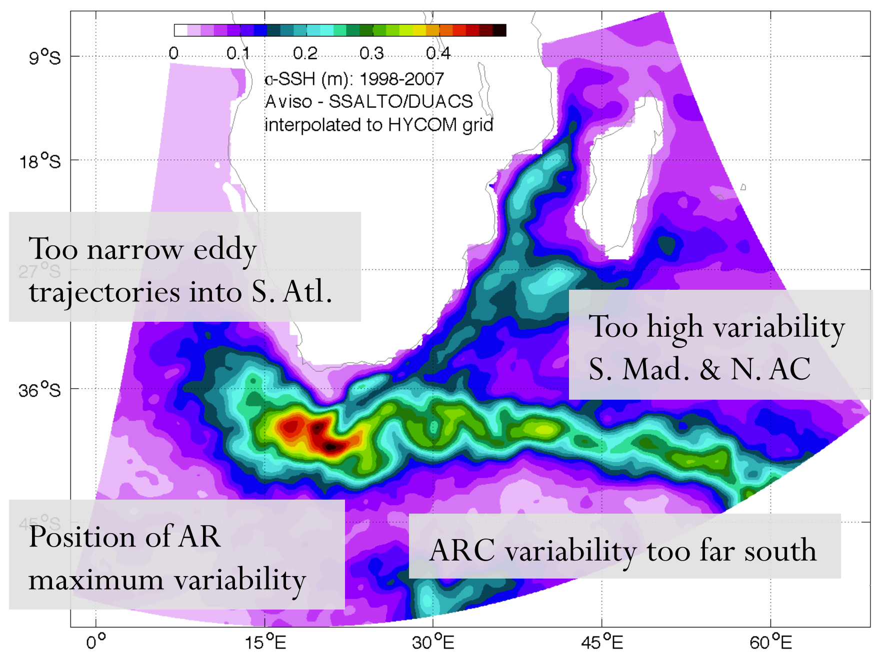
- Regional implementation in Agulhas (1/10th degree resolution) shown to provide a reasonable representation of the salient oceanographic features of the region.
- See Backeberg et al., 2008, 2009 & 2010.

About the EnOI

- Climatological variability (from a historical ensemble) represents the instantaneous forecast error (Ergodicity).
- Historical ensemble is composed of a hindcast simulation from a dynamical model

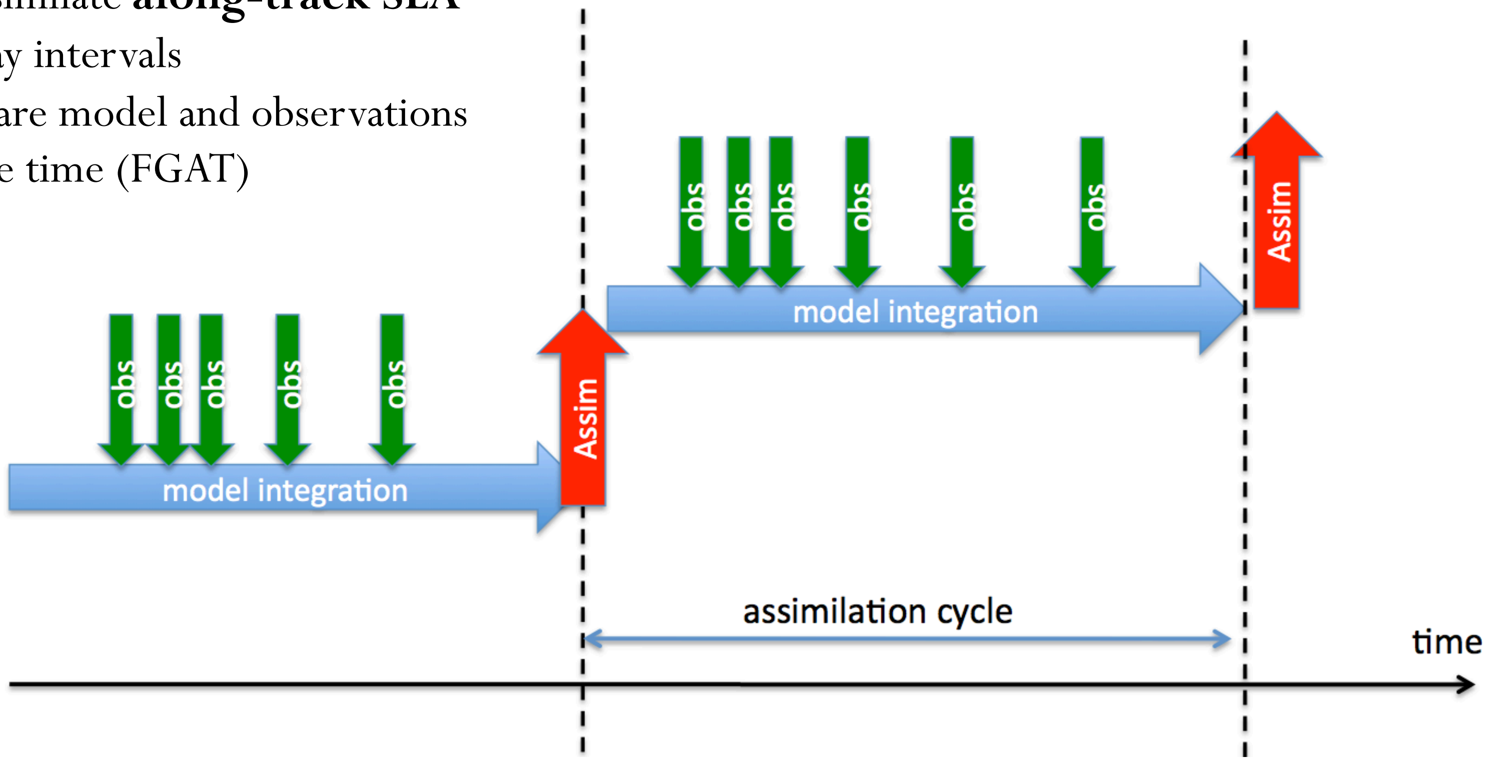






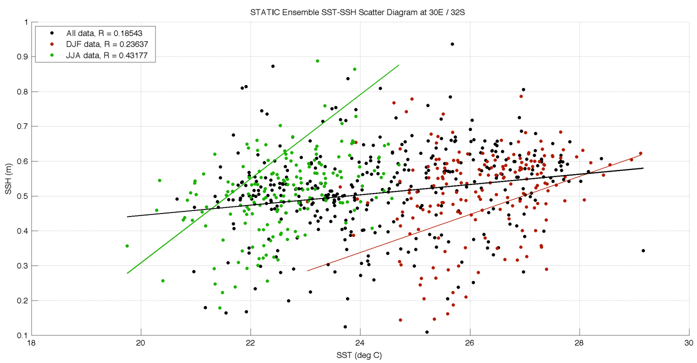
Assimilation cycle

- Observations are sparse in time.
- It is therefore impractical to stop the model each time a new observation becomes available.
- A common approach is to gather observations in batches and assimilate these at given intervals.
- We assimilate **along-track SLA** at 7-day intervals
- Compare model and observations at same time (FGAT)



Dealing with seasonal variability

- Historical (static) ensemble takes into consideration the main circulation features, the topography, but does <u>not vary with time</u>.
- Seasonal & interannual variability may impact the correlation.



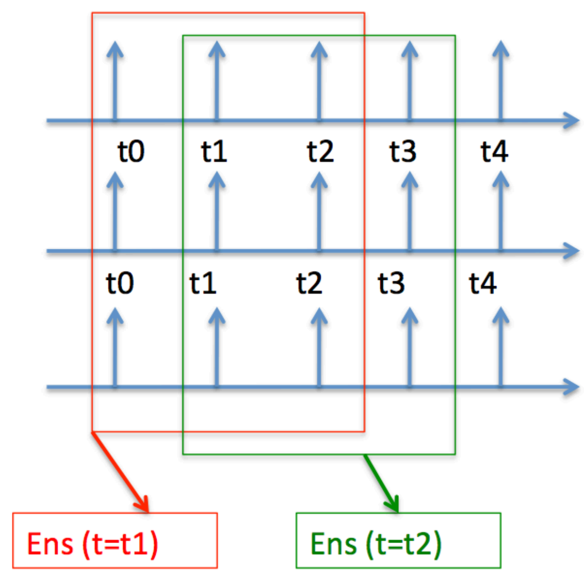
In the Agulhas

- A correlation exists when considering DJF / JJA data only (e.g. green & red lines).
- Seasonal variability will impact the correlation matrix of the EnOI.
- Therefore we need to adjust the ensemble to limit the seasonal signal.

Seasonally adjusted ensemble

- Ensemble consists of model states from the same season centered in a 60-day running window.
- Each ensemble consists of 120 members.

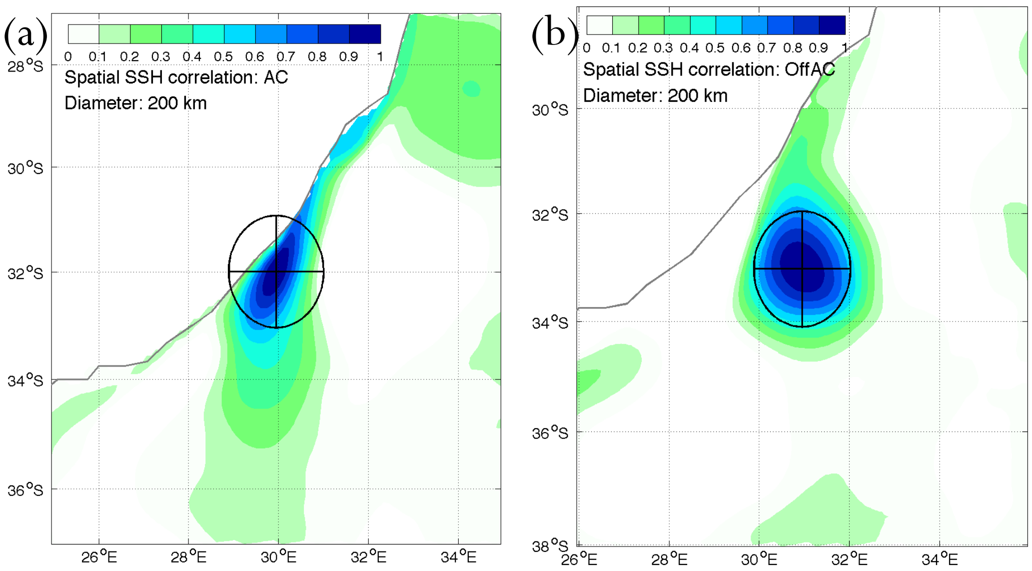
(Xie et al., 2011)



Localisation radius

Need to constrain the influence of an observation to a prescribed local area.

E.g. it seems unrealistic that an observation in the Agulhas should contribute towards resolving an eddy upstream - to the northeast in the below Fig. (a).



Method: look at the spatial correlation and choose a scale that fits the feature you want to correct (e.g. eddy).

Innovation is weighted with a smoothing function depending on the distance between the observation and the model.

Localisation radius = 400 km

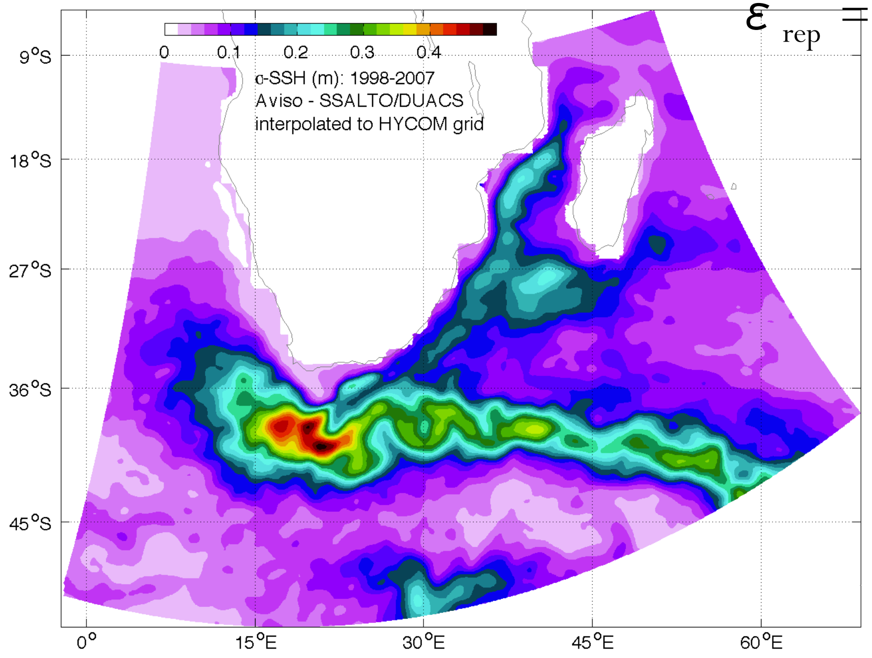
Model – observation inconsistencies

- Inconsistencies arise for e.g. when the model and the observations have different resolutions.
- An additional term is introduced (Oke et al., 2008):

$$\varepsilon_{obs}^2 = \varepsilon_{inst}^2 + \varepsilon_{rep}^2$$

ε_{inst} = instrument error given by provider (e.g. ~3cm for SLA)

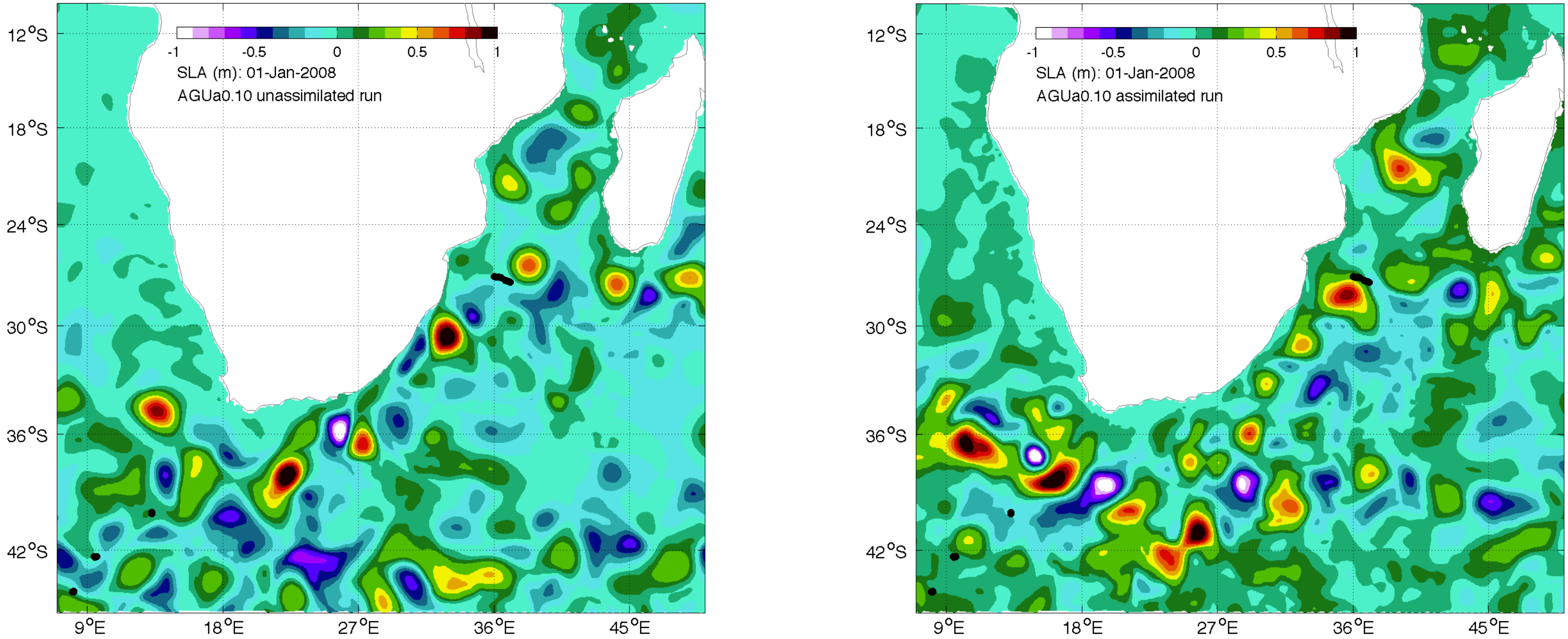
ε_{rep} = representativity error accounting for the different resolutions between the model and observations



Use a proxy of ε_{rep} approximated by the observed SSH variability.

Can assume the error to be large in regions of high variability

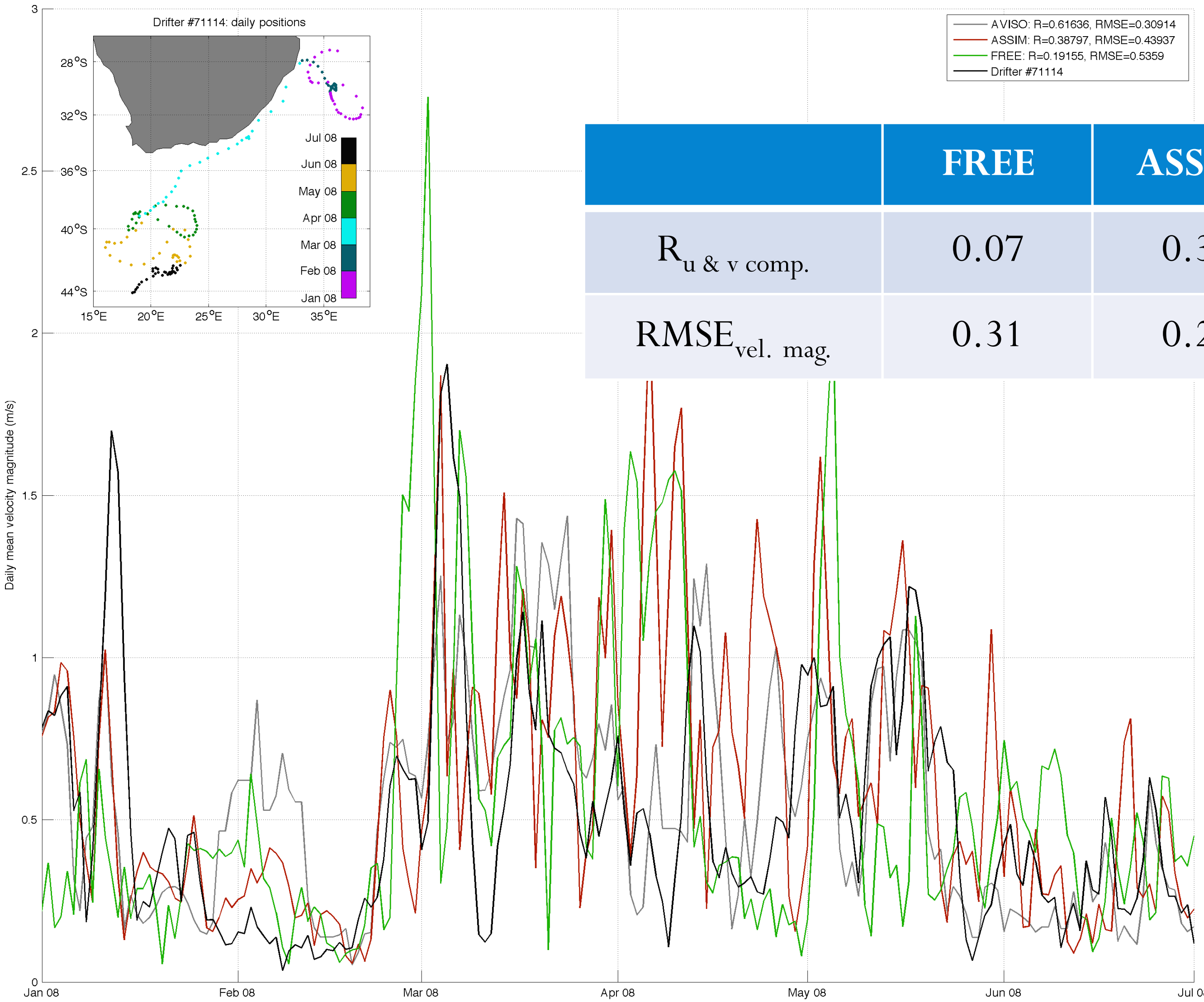
Daily simulated SLA and observed drifter positions



Timing and placement of mesoscale features is realistic

- ANALYSIS: The observed drifters move around the simulated circumference of the SLA features.
- FREE: Very little coherence between drifter movement and the simulated SLA features.

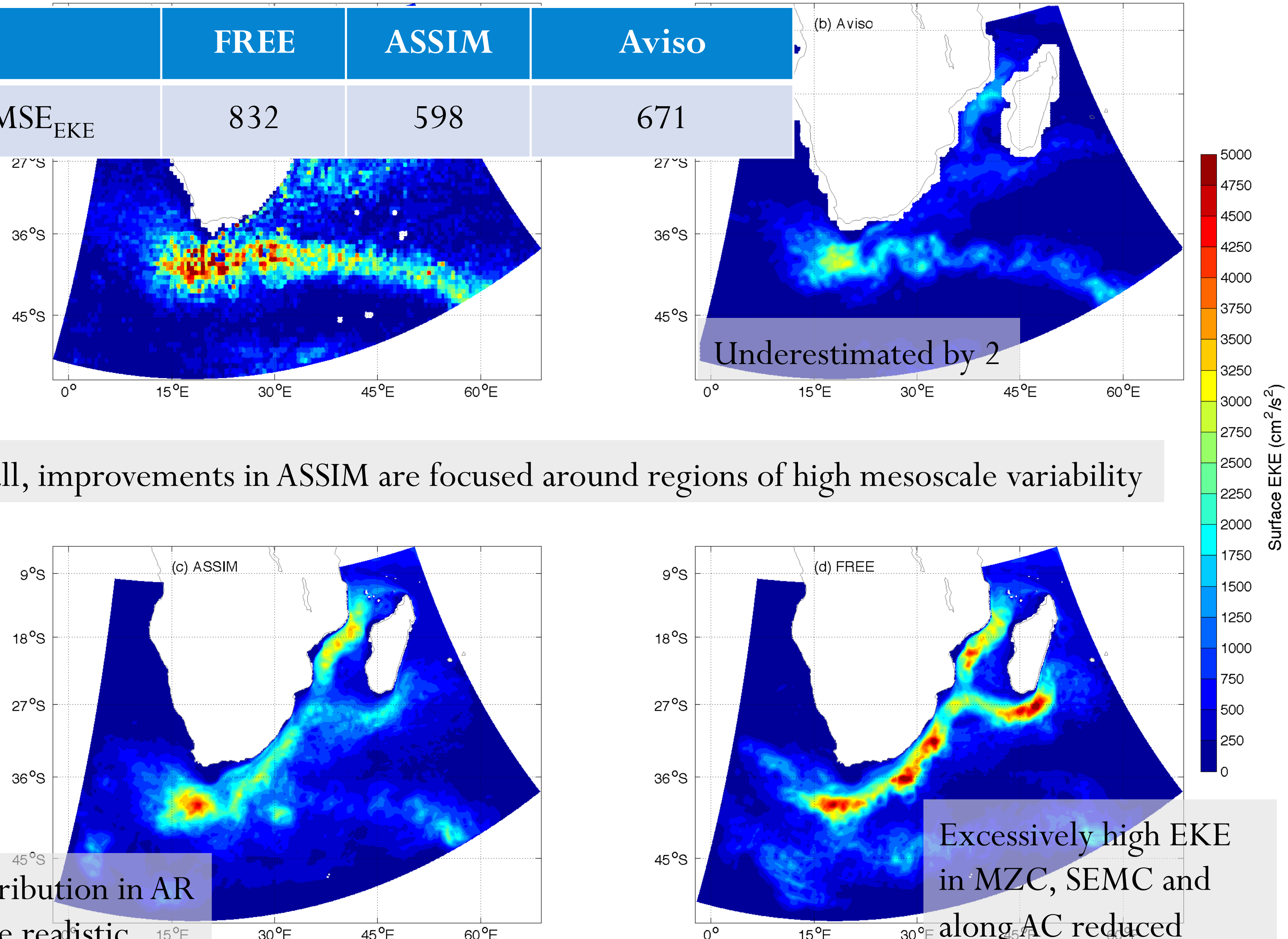
Comparison to drifter velocities



	FREE	ASSIM	Aviso
$R_{u\ \&\ v\ comp.}$	0.07	0.33	0.91
$RMSE_{vel.\ mag.}$	0.31	0.26	0.18

Drifter derived EKE comparison

	FREE	ASSIM	Aviso
$RMSE_{EKE}$	832	598	671



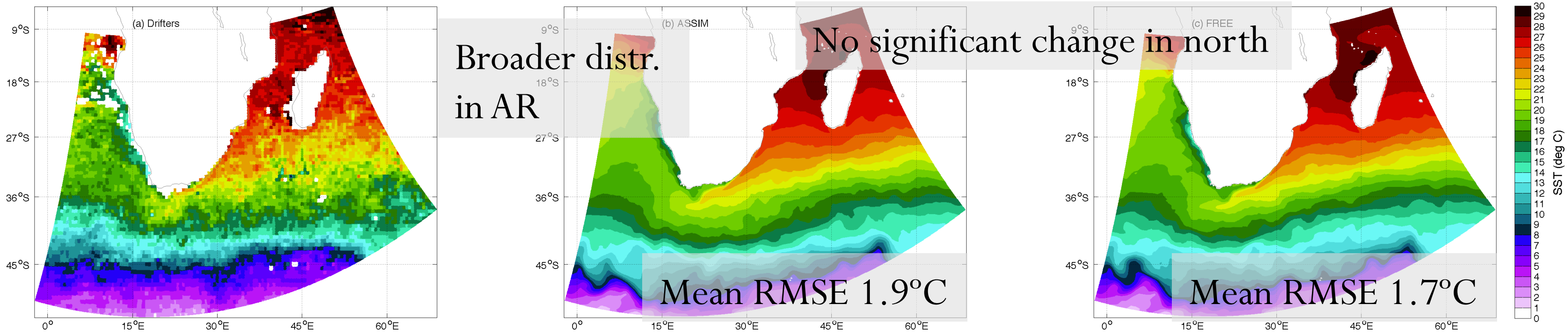
Underestimated by 2

Overall, improvements in ASSIM are focused around regions of high mesoscale variability

Distribution in AR more realistic

Excessively high EKE in MZC, SEMC and along AC reduced

Drifter SST comparison



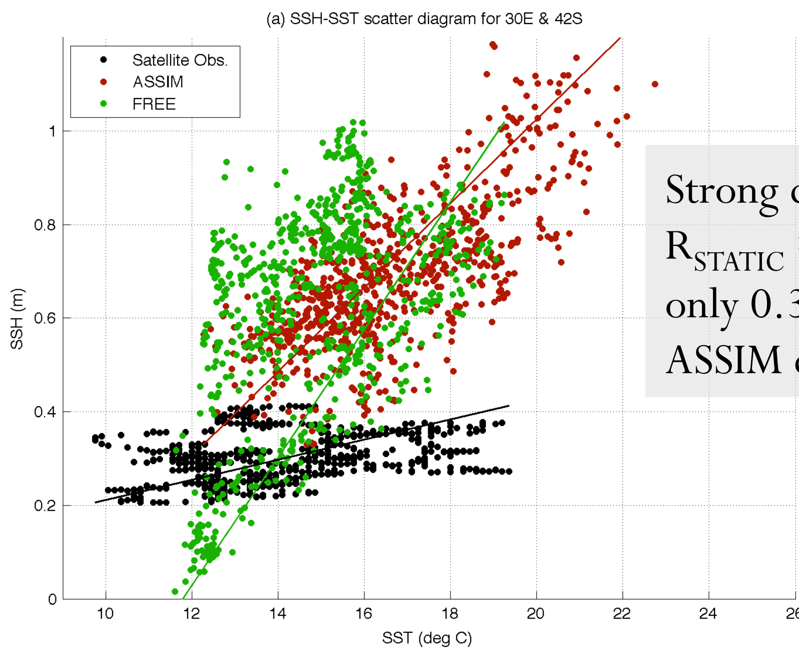
Broader distr. in AR

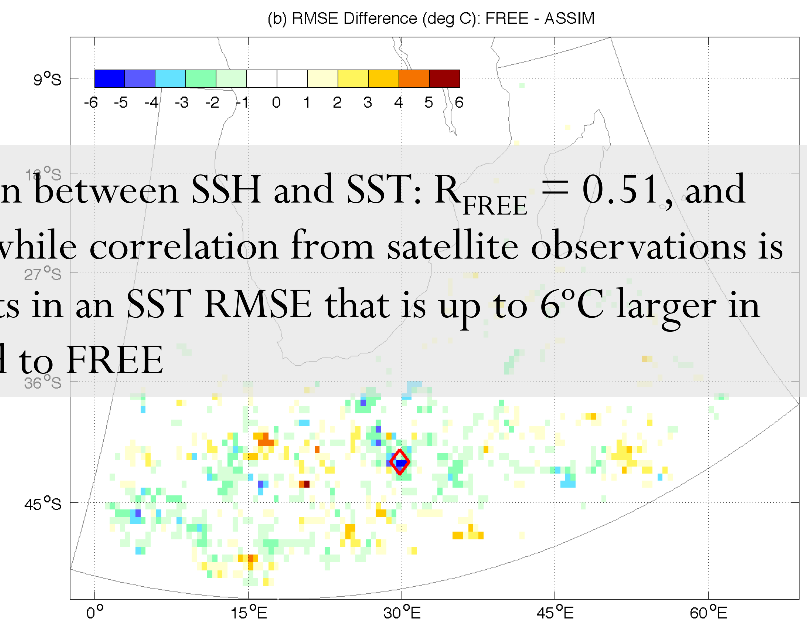
No significant change in north

Mean RMSE 1.9°C

Mean RMSE 1.7°C

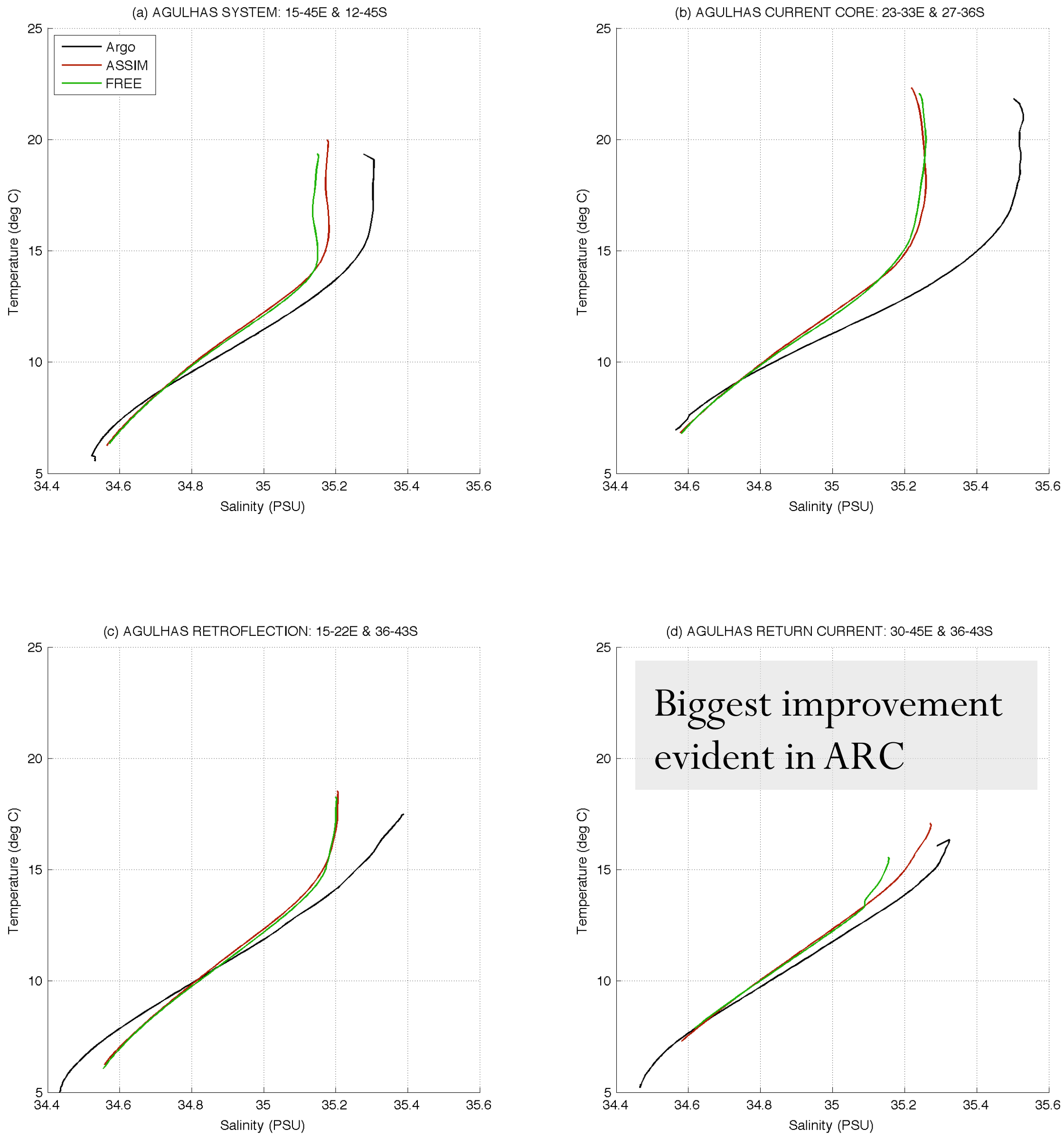
Poorly resolved dynamics of the ARC in the free–running HYCOM results in an incorrect multivariate correlation during the assimilation.





Strong correlation between SSH and SST: $R_{FREE} = 0.51$, and $R_{STATIC} = 0.43$, while correlation from satellite observations is only 0.30. Results in an SST RMSE that is up to 6°C larger in ASSIM compared to FREE

Comparison to Argo

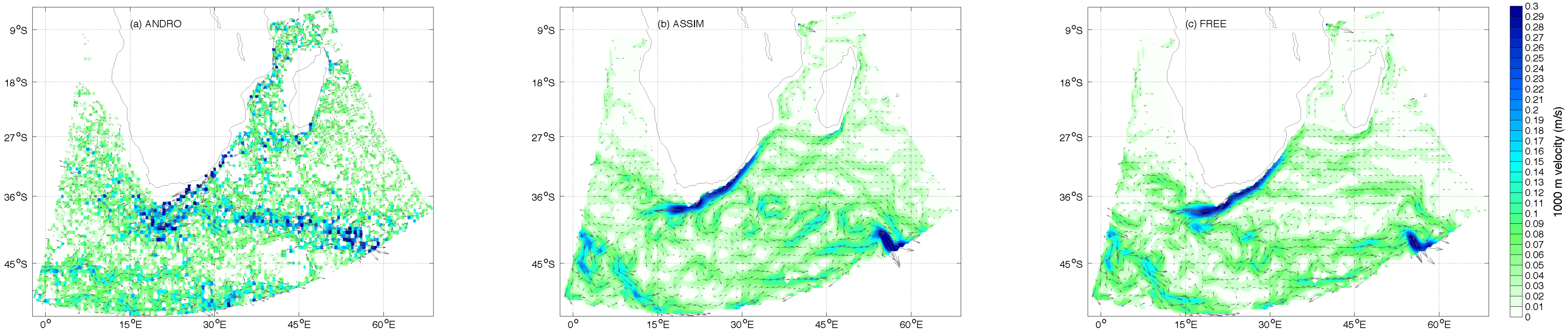


Biggest improvement evident in ARC

Assimilating along- track SLA data has a positive impact on water masses in the range of T>15°C and S>35.1 PSU, aligning these more closely with the observed Argo profiles. These temperature ranges are associated with Indian Central Water (IWC), a subtropical water mass that typically resides in the upper 500m.

ARC SST bias, offset the water associated with bias of the static ensemble are corrected.

Deep (1000m) velocities



	FREE	ASSIM
$R_{u\ \&\ v\ comp.}$	0.18	0.21
$RMSE_{vel.\ mag.}$	0.065	0.061

Improved the sub-surface velocities at about 1000 m.

The 1000m velocities associated with the Agulhas Return Current are corrected, shifting these further north.

On the other hand, the Agulhas Return Current in ASSIM is too discontinuous and not as strong as suggested by observations.

RMSE	FREE	ANALYSIS	Aviso
$R_{\text{drifter u \& v comp.}}$	0.07	0.33	0.91
$RMSE_{\text{drifter vel. mag.}}$ (m/s)	0.31	0.26	0.18
$RMSE_{\text{drifter EKE}}$ (cm^2/s^2)	832	598	671
$RMSE_{\text{drfiter SST}}$ (°C)	1.7	1.9	
$R_{\text{Argo u \& v comp.}}$	0.18	0.21	
$RMSE_{\text{Argo 1000 m vel. mag.}}$ (m/s)	0.065	0.061	

- **Characterisation of mesoscale dynamics is improved**, and the model errros are reduced – positioning and timing of mesoscale features is significantly improved.
- **Cannot beat a persistence forecast based on Aviso.**
- **Aviso significantly underestimate EKE in the region.**
- **Assimilating altimetry observations improves both the water mass properties as well as the velocities at 1000 m.**
- **SST distribution is slightly degraded** – due to a SSH bias in the static ensemble resulting in an incorrect correlation with SST, a slight warming is introduced in places of the Agulhas Return Current.

Next steps

- ~~Assimilate along-track sea level anomaly data from satellite altimeters in HYCOM using the EnOI~~.
- Improve the numerical model.
- Testing the impact of a proxy for the absent time correlation in the EnOI.
- Assimilate satellite sea surface temperatures.
- Assimilate Argo profiling float .
- Implementation of the Ensemble Kalman Filter assimilation scheme in HYCOM of the Agulhas, and assimilation of satellite and in-situ ocean observations.
- Validation of the ocean data assimilation system against independent (unassimilated observations) and inter-comparison with global operational products, e.g. those provided by MyOcean, BlueLink and the HYCOM consortium.

Thank you