Impact of sea surface temperature observations on an eddy-resolving ocean reanalysis of the Agulhas

An Observing System Experiment using HYCOM and the EnOI

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5th GODAE OceanView Coastal Ocean and Shelf Seas Task Team International Coordination Meeting
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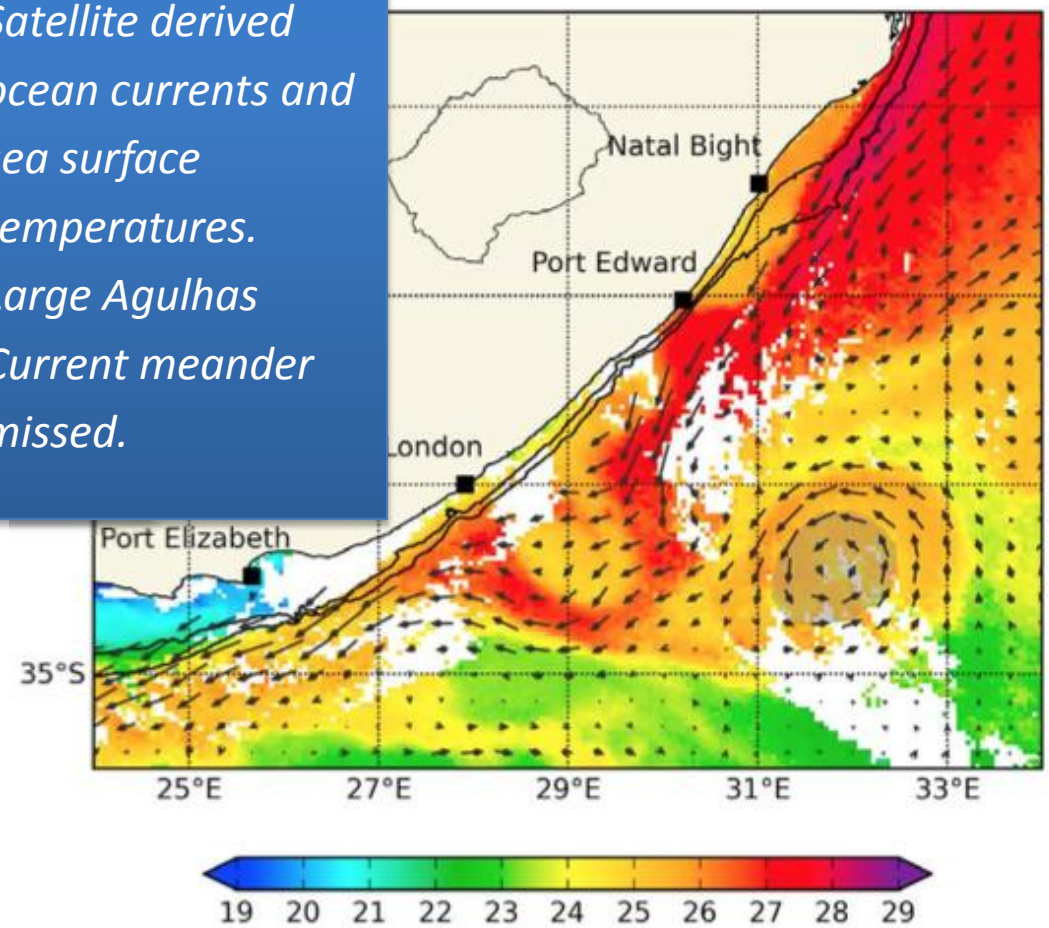
Objective

Satellite derived ocean currents and sea surface temperatures. Large Agulhas Current meander missed.



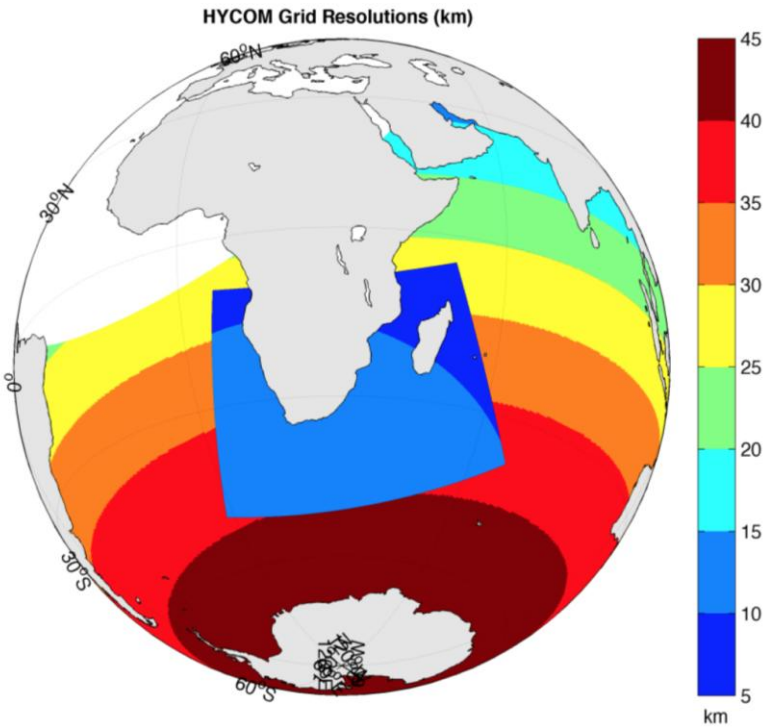
Courtesy of Marjolaine Krug

In the absence of a coherent in situ and satellite based observing system:

1. Develop accurate, high resolution, ocean reanalysis and forecasting systems.
2. Advance South Africa's operational oceanography capabilities.
3. Improve quantitative understanding of how the Agulhas Current influences the oceanography of the coastal and shelf sea regions through mesoscale and submesoscale processes.

Regional Hybrid Coordinate Ocean Model

- Version 2.2.37 (NERSC version)
- 1/10° (±10km) regional HYCOM
- 30 hybrid layers
- Boundary conditions from Indian & Southern Ocean HYCOM
- Forcing: ERA-interim reanalysis
- Monthly river discharges from TOTAL Runoff Integrating Pathways (TRIP, Oki and Sud 1998)
- Rivers are treated as a negative salinity flux with an additional mass exchange (Schiller and Kourafalou 2010)
- EnOI data assimilation



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Ensemble Optimal Interpolation

Why use the EnOI?

1. Low computational cost
2. Small sampling error (large ensemble)
3. 3D-Multivariate, preserves model consistency
4. Seasonally adjusted ensemble to account for seasonal and inter-annual variability

Observing system experiments:

1. Along-track sea level anomaly data from satellite altimeters (Backeberg et al., 2014)
2. Along-track SLA **<u>+ OSTIA sea surface temperatures</u>**

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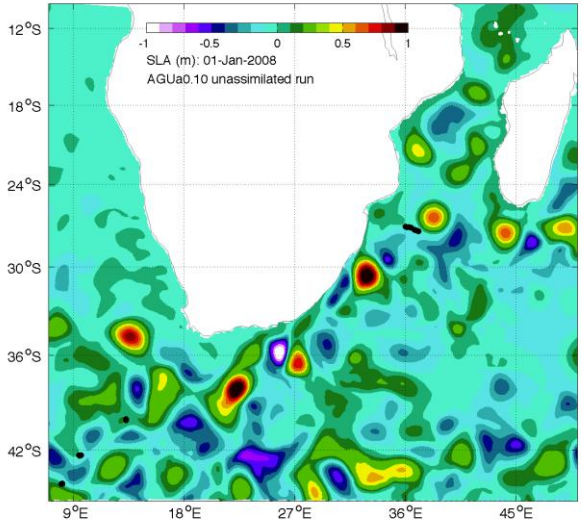
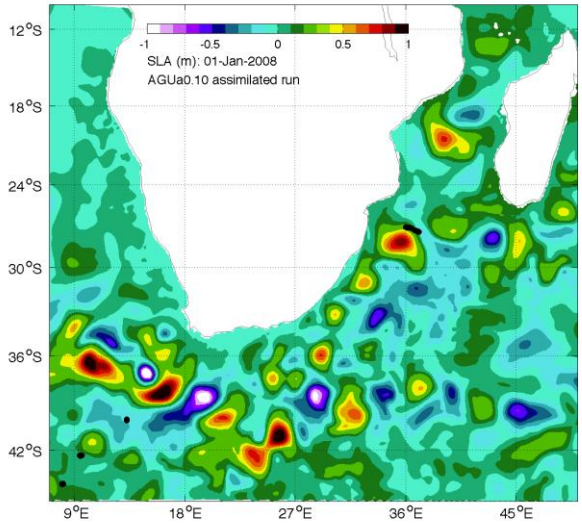
Conclusions from assimilating along-track SLA

(Backeberg et al., 2014)

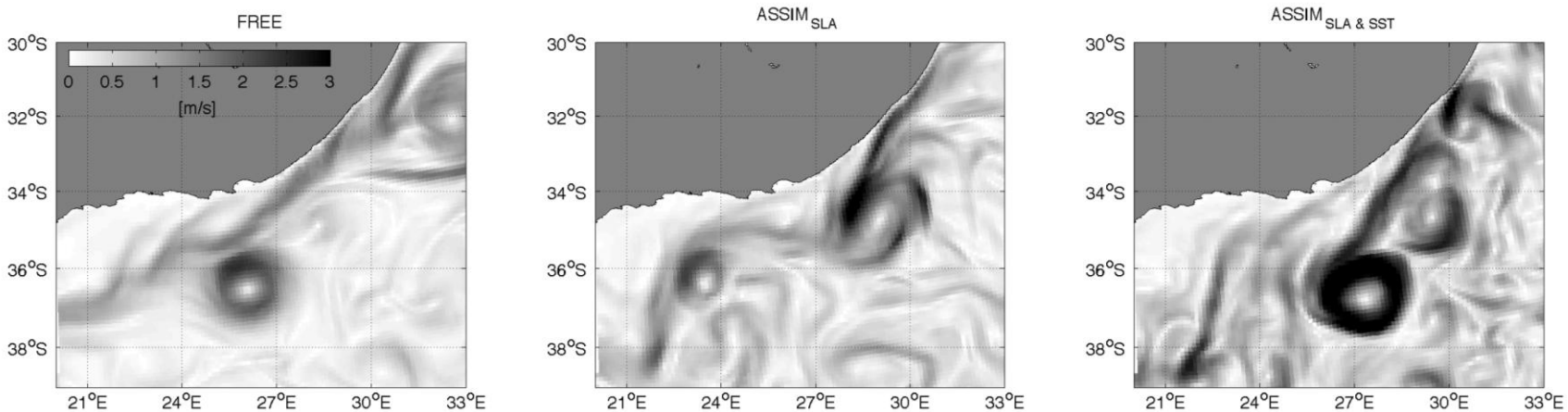
- **Characterisation of mesoscale dynamics is improved**, and the model errros are reduced – positioning and timing of mesoscale features is significantly improved.
- **"Globally", cannot beat a persistence forecast based on Aviso.**
- **Aviso significantly underestimates EKE in the region.**
- **Assimilating 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.





OSE: Along-track SLA + OSTIA SST

Daily average surface velocities from (a) FREE, (b) $ASSIM_{SLA}$ and (c) $ASSIM_{SLA\ \&\ SST}$ for 26 March 2009.



$ASSIM_{SLA\ \&\ SST}$ introduces smaller scale dynamics in the model.

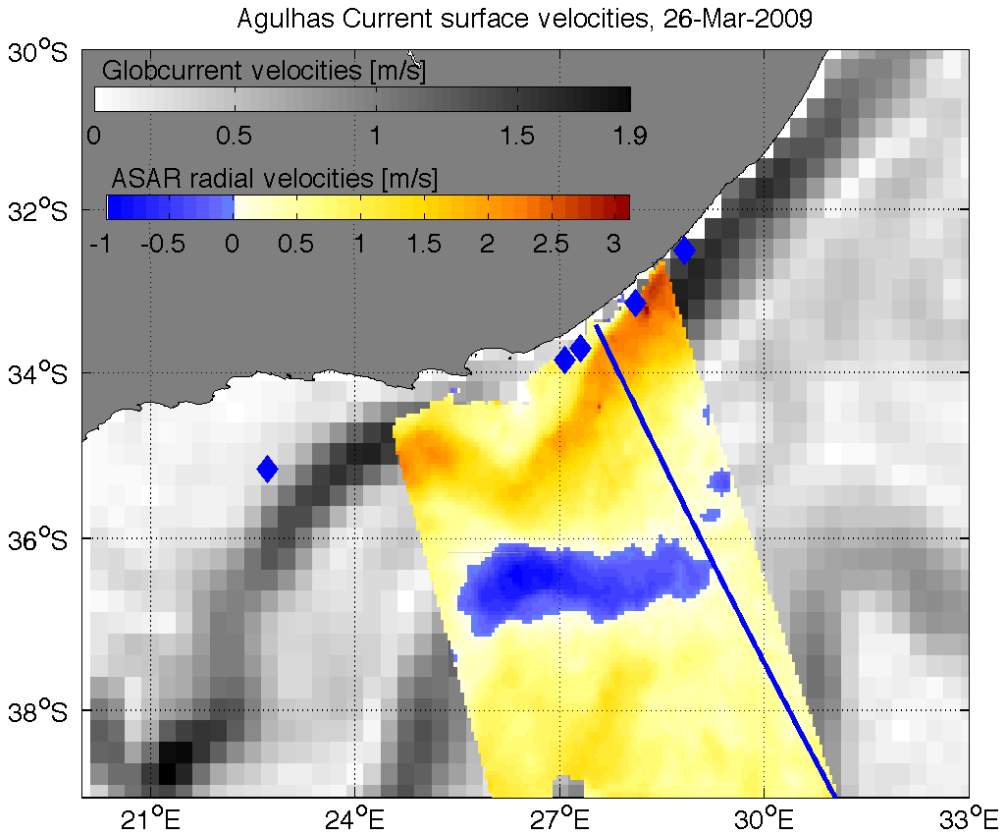
Objective

1. Understand the response of including OSTIA SST in the assimilation.
2. Quantify the impact on simulating the Agulhas Current and its variability.
3. Does the bias reduction from assimilating SST lead to feedback in the dynamical behaviour of the model?

Data sources for evaluation

Snapshot of Agulhas Current surface velocities from

1. Globcurrent daily surface velocities (including the Ekman wind component) (gray colour scheme),
2. ASAR instantaneous radial velocities (red-yellow-blue color scheme),
3. ADCP current measurements (blue diamonds).
4. Along-track SLA from Jason-1 / -2 track 96 (blue line)



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Comparison against ASAR

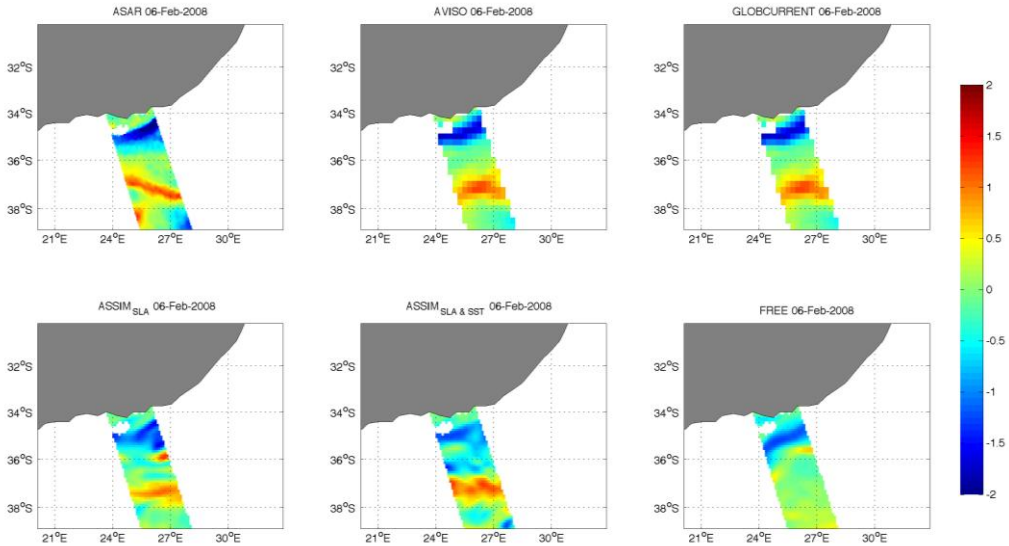
From ASAR, data where the incidence angle is less than 30 degrees is excluded (Rouault et al., 2010) – due to swath edge errors.

For each ASAR over-pass masks indicating missing values were created for each of the gridded products.

Then the radial velocity component was calculated for the remaining data as:

$$vel_{radial} = u \times \cos(\xi \times \frac{\pi}{180}) - v \times \sin(\xi \frac{\pi}{1800})$$

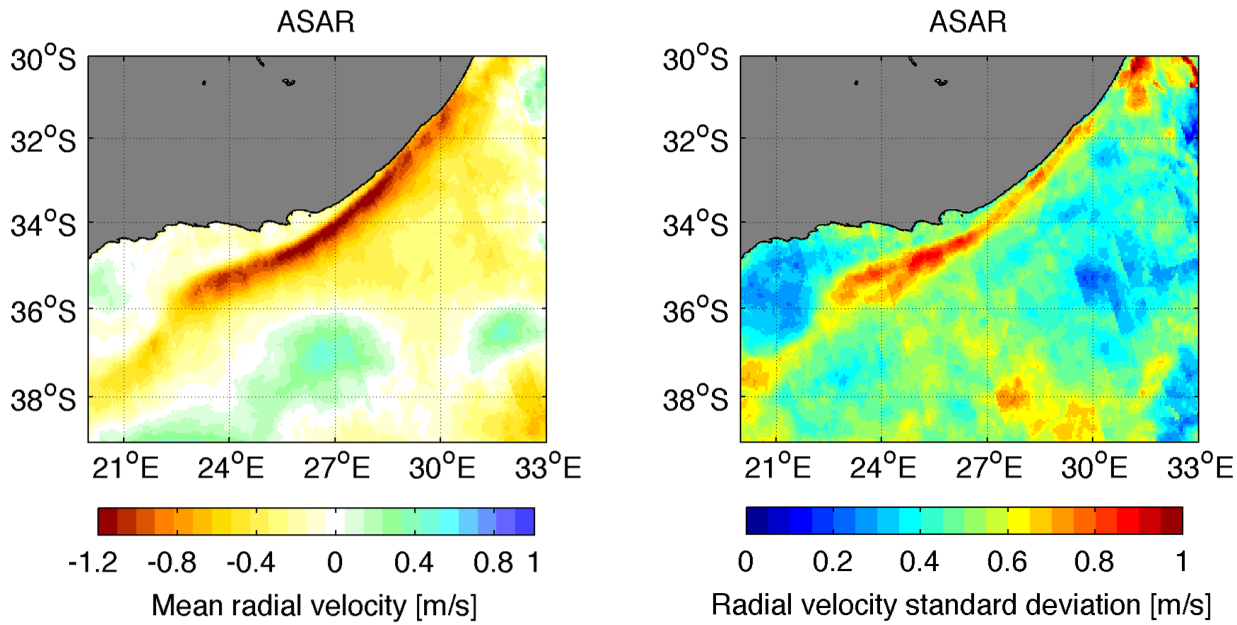
where ξ is the ASAR track angle.



Example of the synthetic over-passes created for the the gridded products

Mean radial velocities and standard deviation

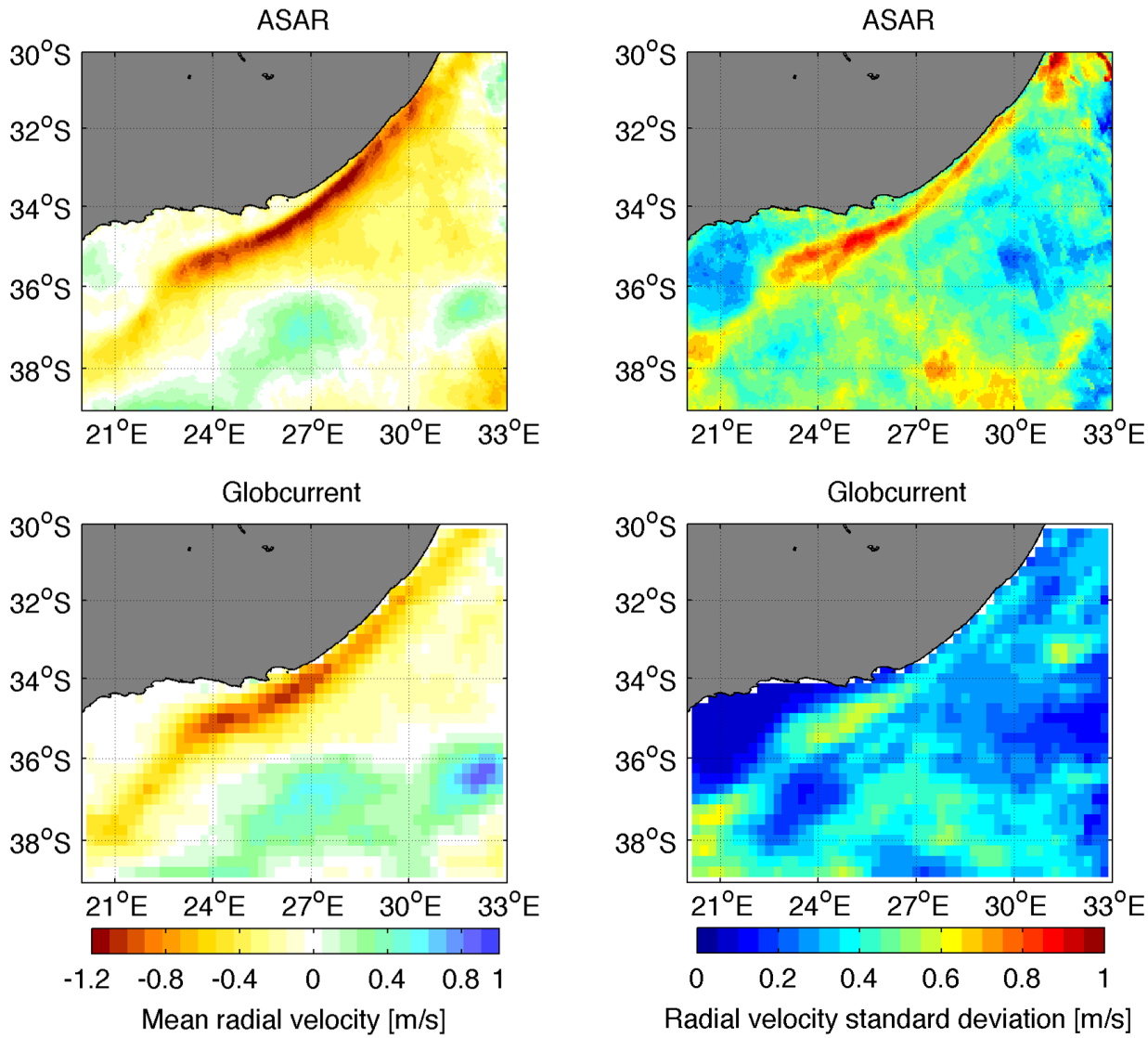
The synethic over-passes were averaged for available data for 2008 and 2009.



Mean radial velocities and standard deviation

Globcurrent

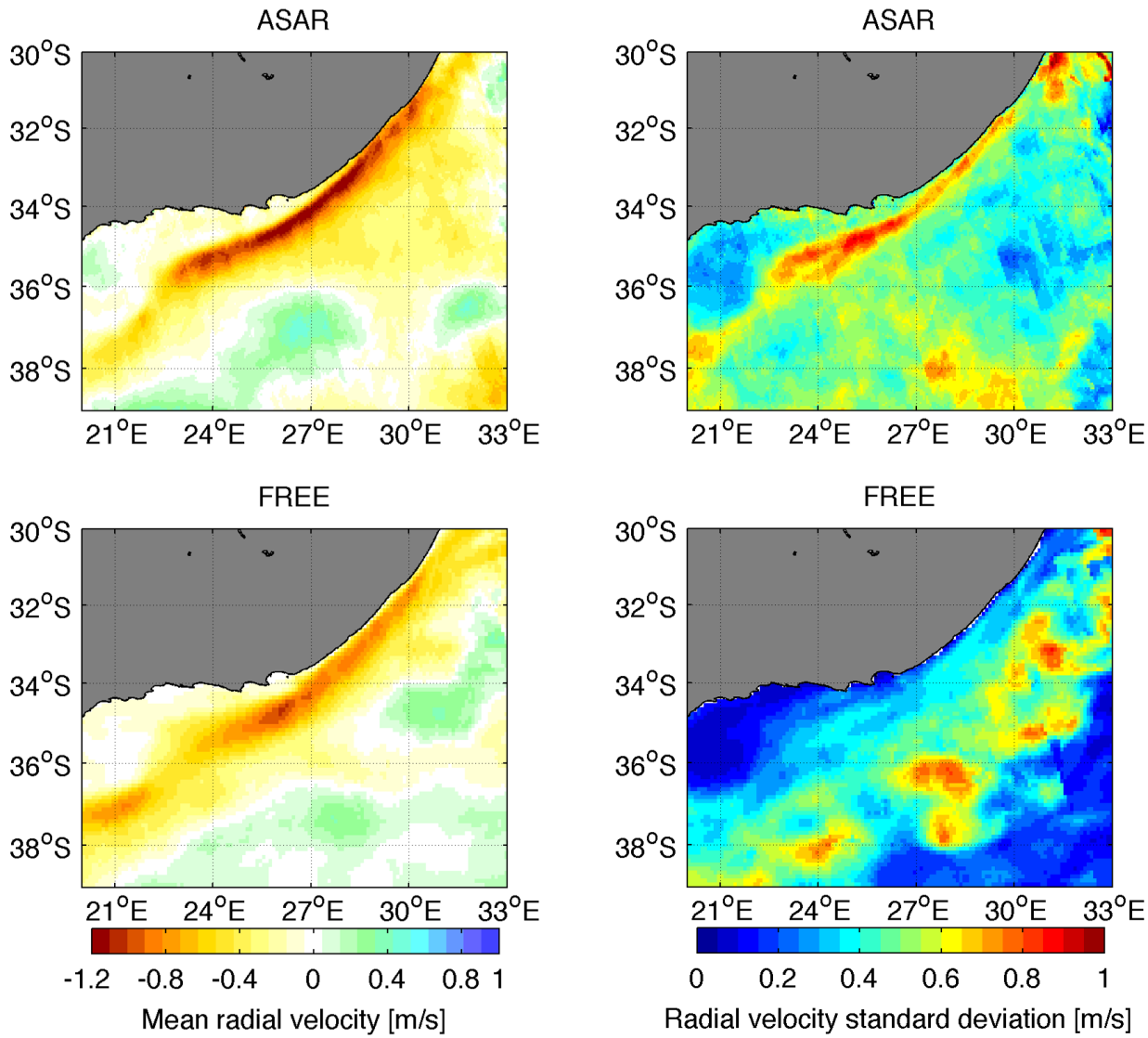
1. Underestimates mean radial velocity – especially in northern Agulhas Current.
2. Underestimates variability in the current core.



Mean radial velocities and standard deviation

FREE

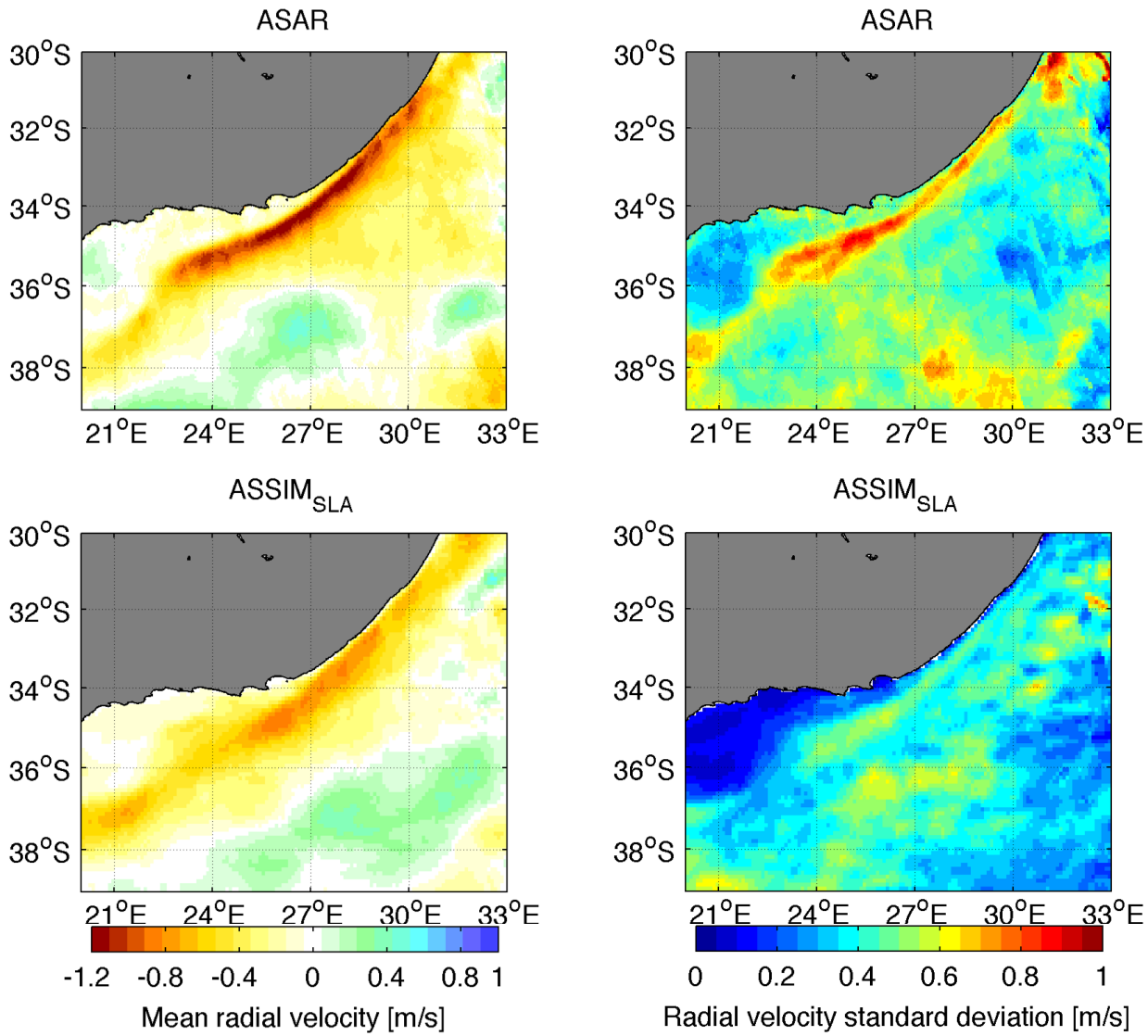
1. Weaker, broader, Agulhas Current.
2. Underestimates variability in the core of the current.
3. Exaggerated variability offshore of the Agulhas Current – related to the (inaccurate) regular passage of too many eddies.



Mean radial velocities and standard deviation

ASSIM$_{SLA}$

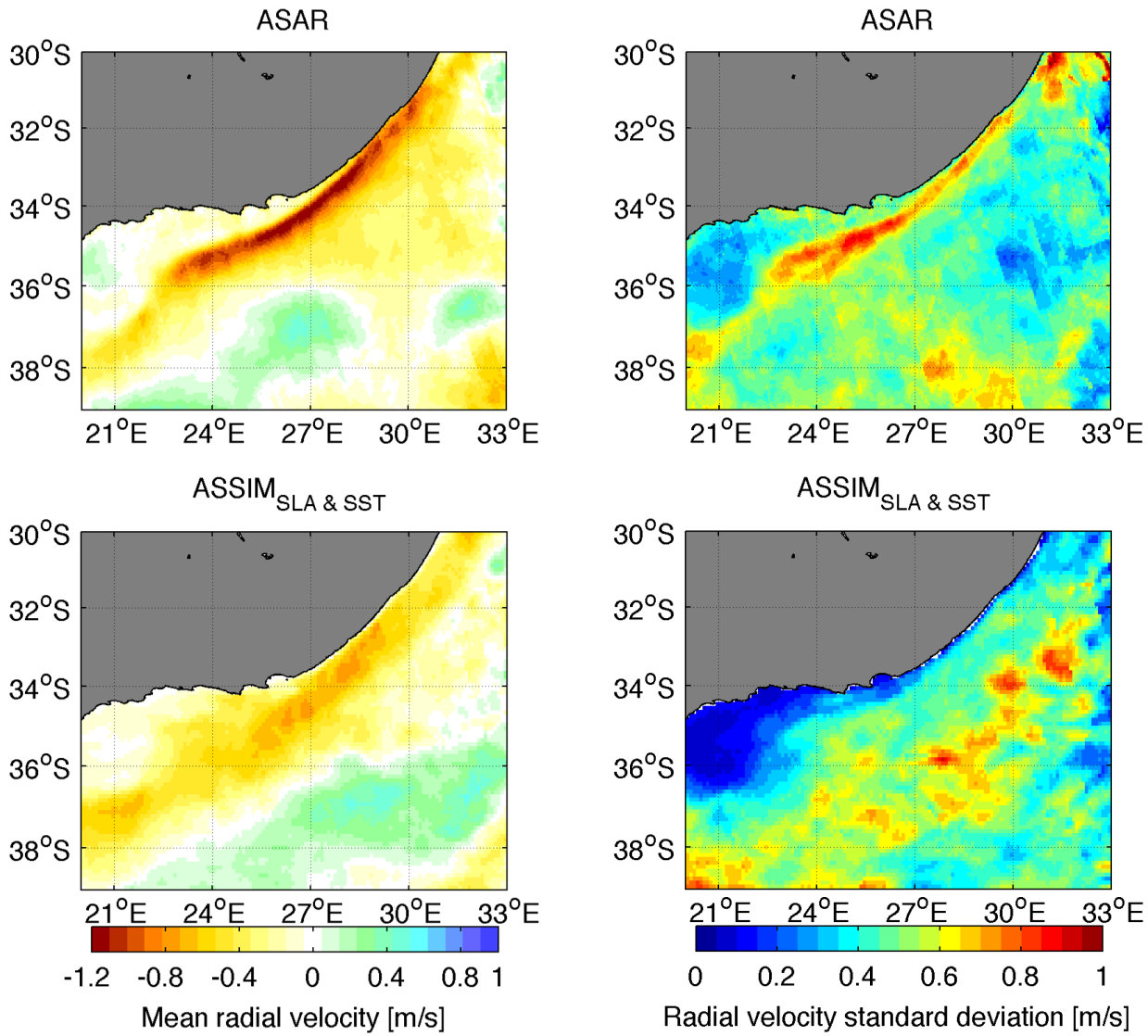
1. Further weakened and widened current.
2. Improved variability in the core of the current.
3. Reduced variability offshore of the Agulhas Current.



Mean radial velocities and standard deviation

ASSIM$_{\text{SLA \& SST}}$

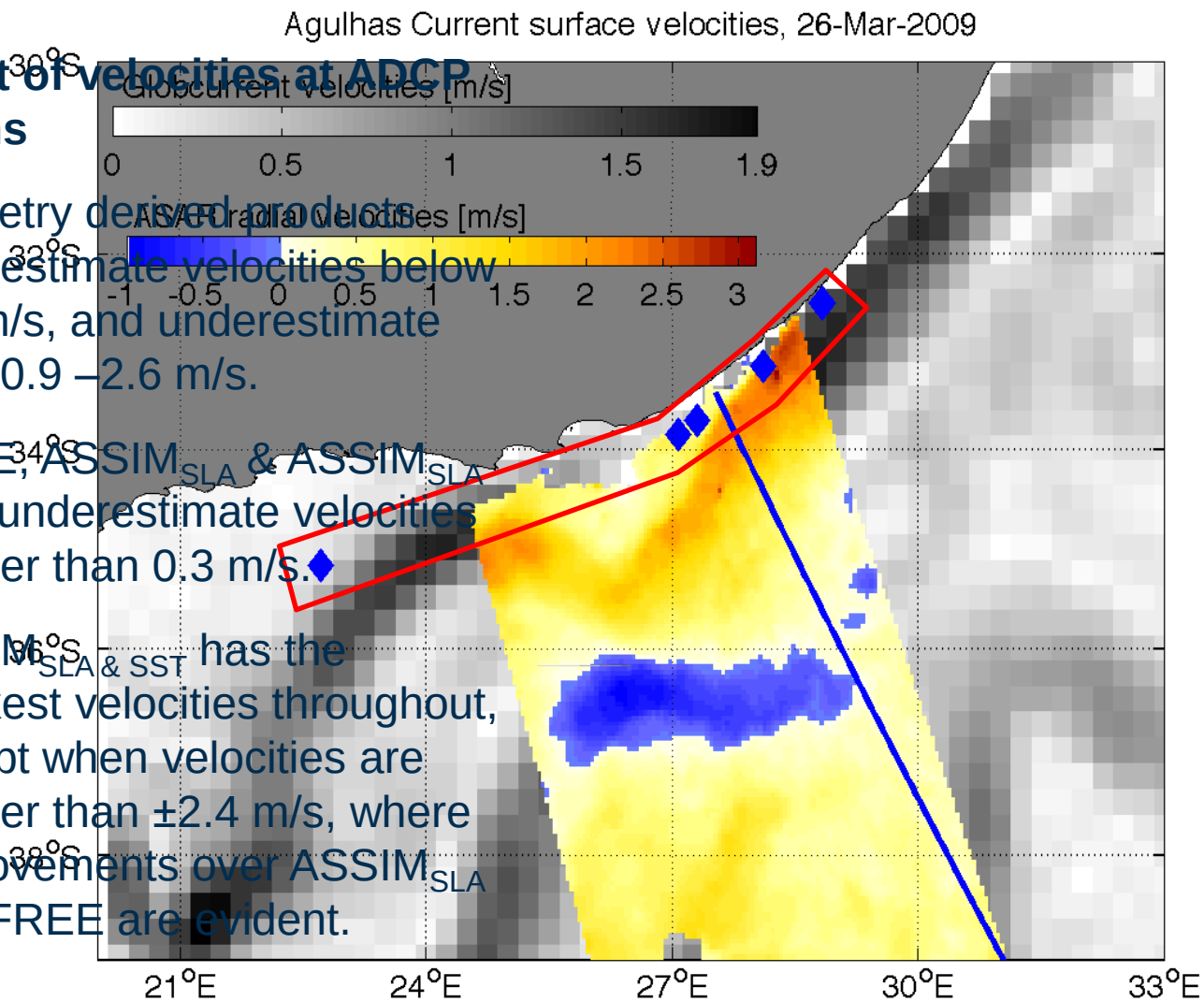
1. Even further weakened and widened current.
2. Variability in the core of the current stays more or less the same.
3. Increased variability offshore of the Agulhas Current.

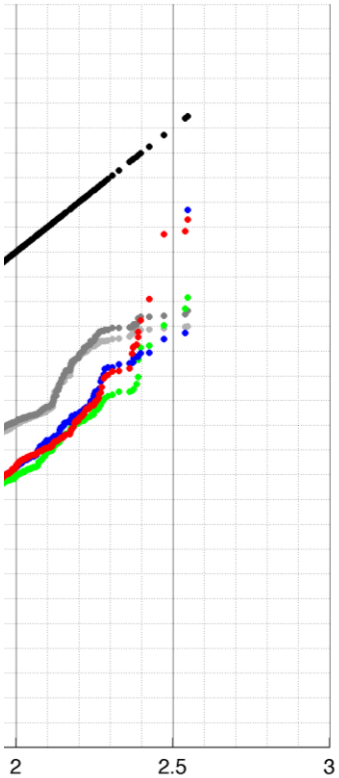


Comparison against ADCP data

Q-Q plot of velocities at ADCP locations

- Altimetry derived products over-estimate velocities below 0.9 m/s, and underestimate from 0.9 – 2.6 m/s.
- FREE, $ASSIM_{SLA}$ & $ASSIM_{SLA\ \&\ SST}$ underestimate velocities greater than 0.3 m/s.
- $ASSIM_{SLA\ \&\ SST}$ has the weakest velocities throughout, except when velocities are greater than ±2.4 m/s, where improvements over $ASSIM_{SLA}$ and FREE are evident.





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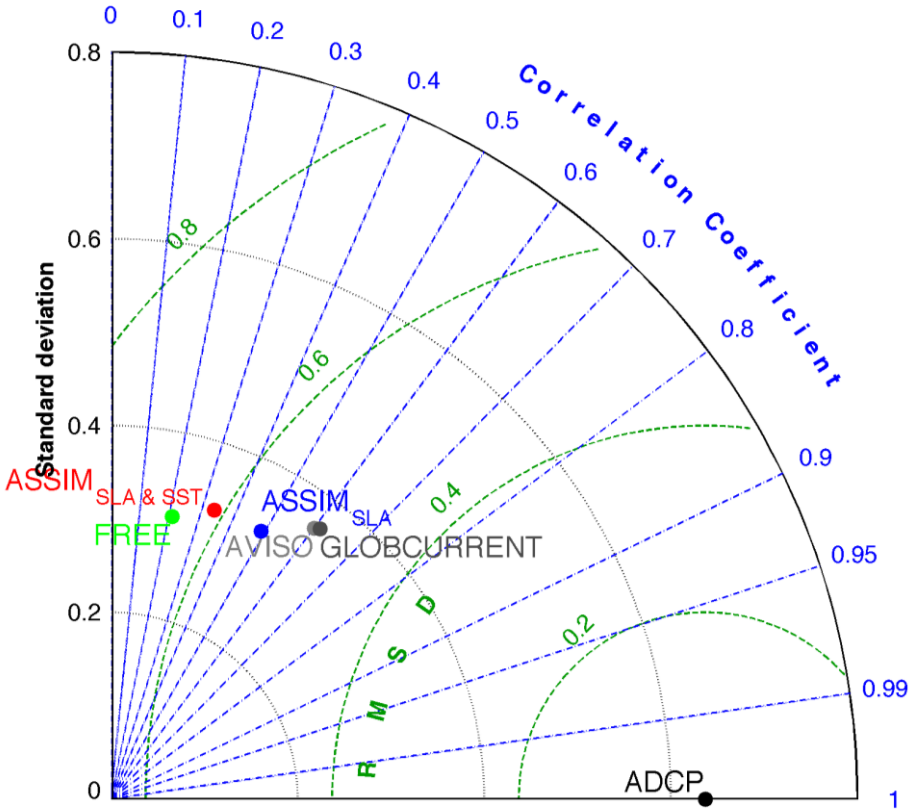
Taylor Diagram – ”global” comparison

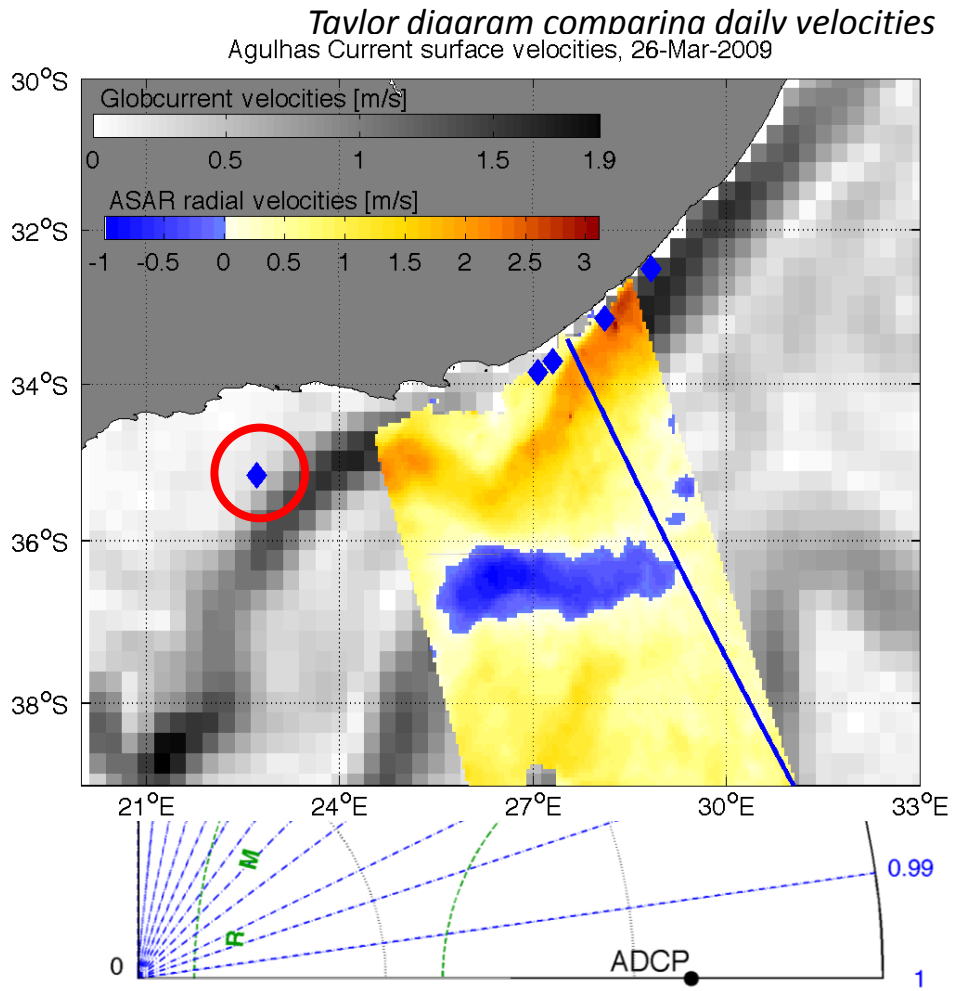
- Levels of variability (standard deviation) from altimetry products are too low compared to ADCP (expected).
- $ASSIM_{SLA}$ has similar levels of variability (standard deviation) compared to altimetry products, but reduced correlation and larger RMSD.
- $ASSIM_{SLA\ \&\ SST}$ has higher levels of variability, but reduced correlation and larger RMSD compared to $ASSIM_{SLA}$.

Taylor diagram comparing daily velocities from Globcurrent, AVISO, FREE, $ASSIM_{SLA}$ and $ASSIM_{SLA\ \&\ SST}$ to daily ADCP data



Taylor Diagram – eastern Agulhas Bank

- Comparison against ADCPs close to the coast is very tough comparison for both the models and altimetry products.
- Issues related to proximity to land grid cell in the model and boundary condition errors.
- Comparison between model and ADCP further offshore more promising.
  - $ASSIM_{SLA}$ (marginally) better correlation than satellite data
  - Both ASSIM experiments have higher variability



Preliminary conclusions

- Benefit of including OSTIA SSTs in assimilation is not clear
  - Widening and weakening of the Agulhas Current core
  - Unrealistically enhanced variability offshore of the Agulhas Current core
  - Poor comparison in Taylor diagrams
- OSTIA is known to overly smooth the SSTs
  - The assumption that the observations error is uncorrelated no longer holds.
  - In the assimilation framework, this is comparable to assimilating the same observations many times, meaning that we **over-fit the data.**

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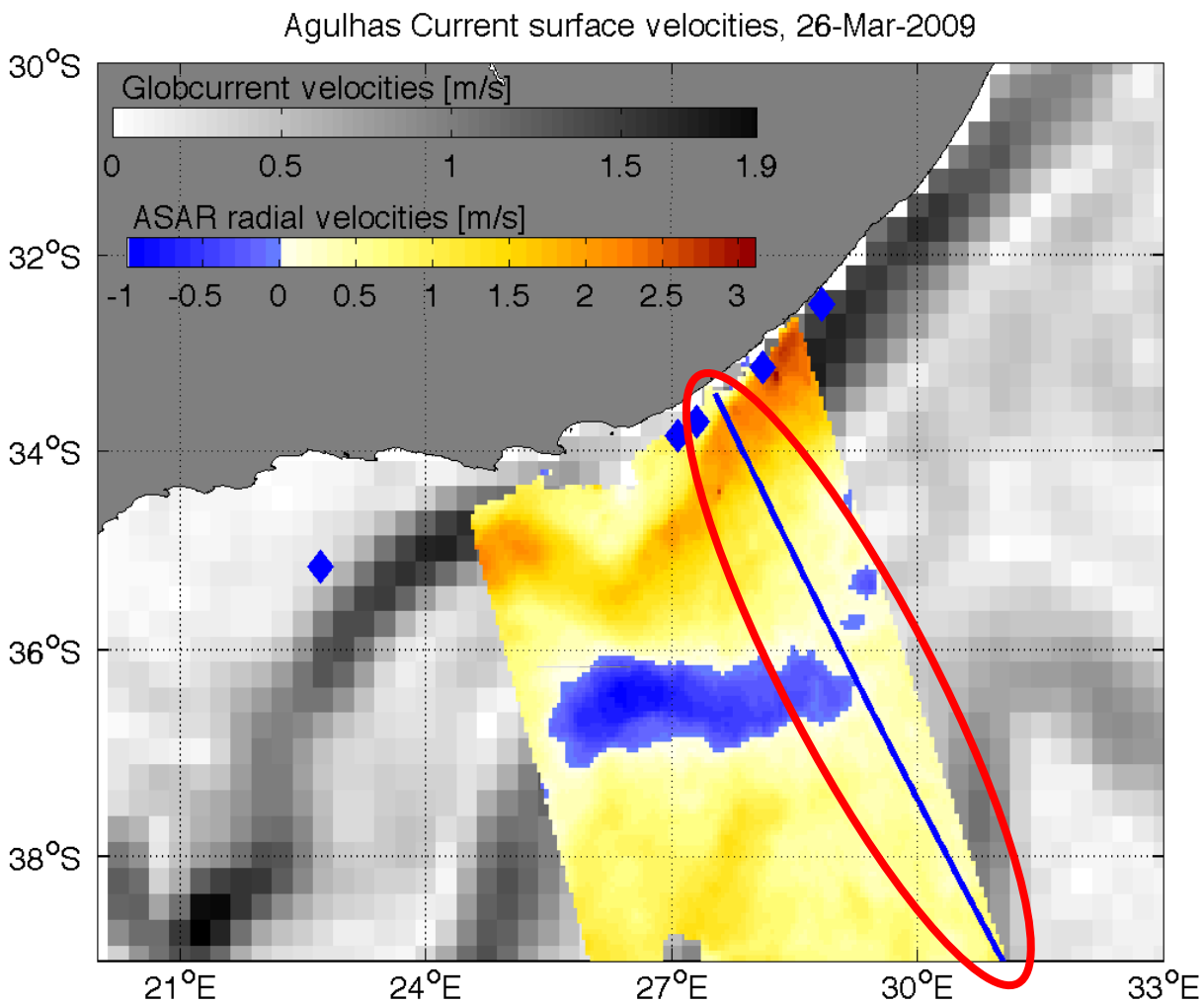
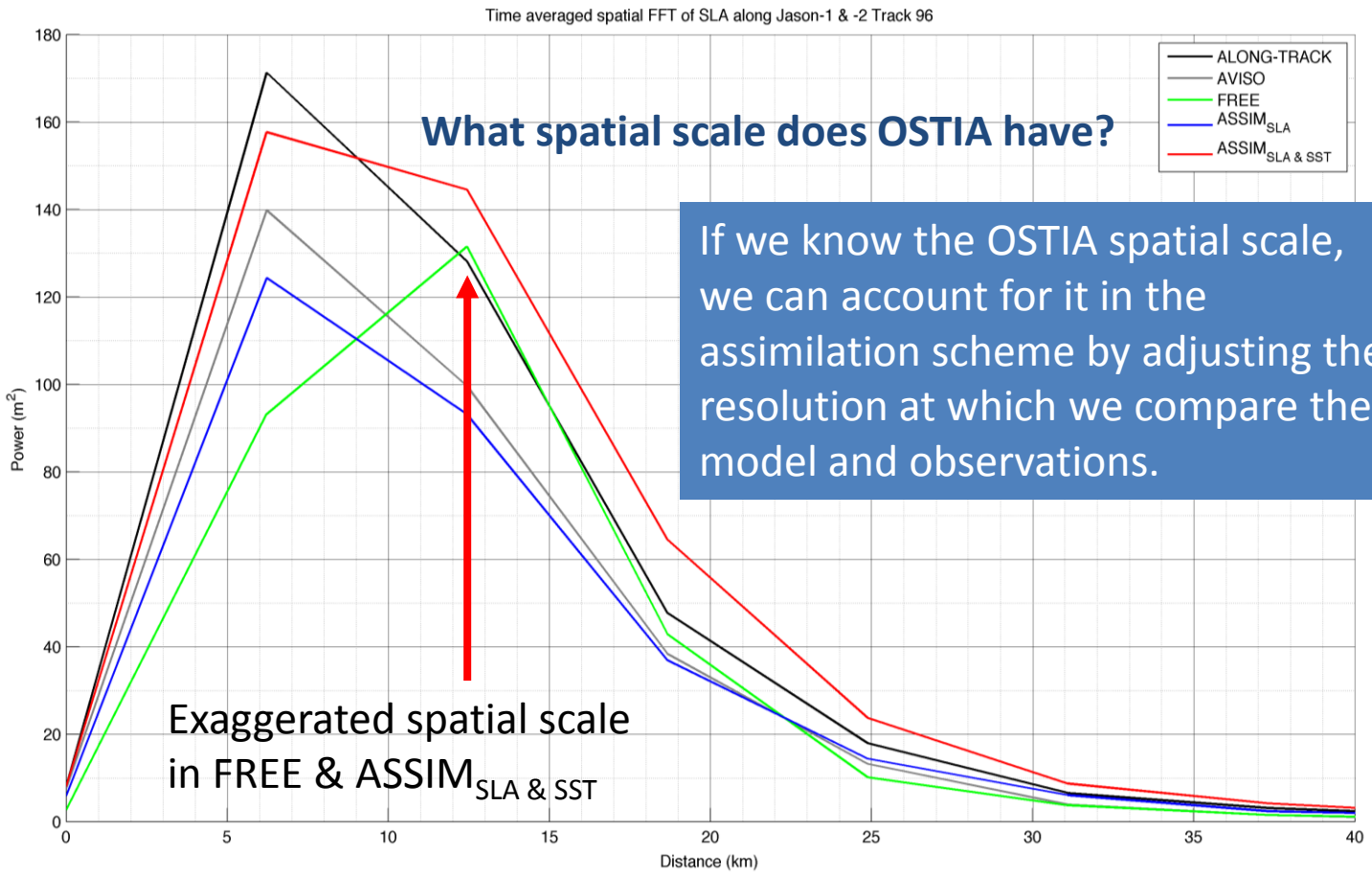
Future work

Analyse the spatial variability along Jason-1 & -2 track 96.



Future work

Time averaged spatial FFT of SLA along Jason-1 & -2 track 96.



What spatial scale does OSTIA have?

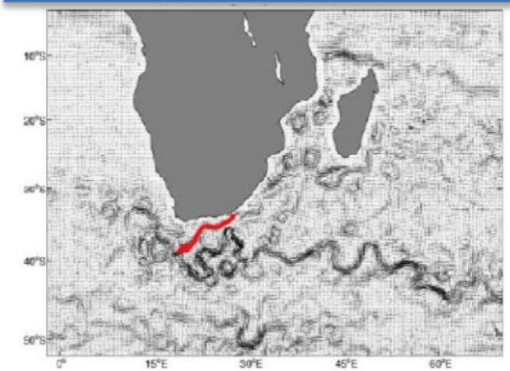
If we know the OSTIA spatial scale, we can account for it in the assimilation scheme by adjusting the resolution at which we compare the model and observations.

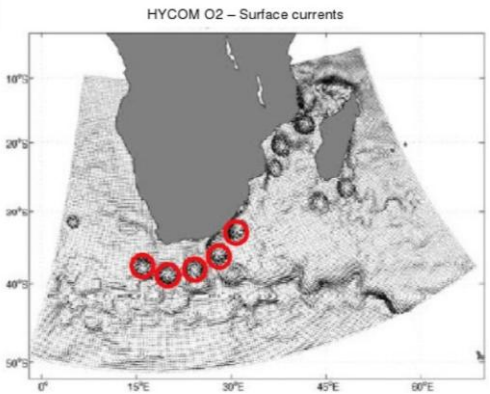
Exaggerated spatial scale in FREE & ASSIM$_{SLA\ \&\ SST}$

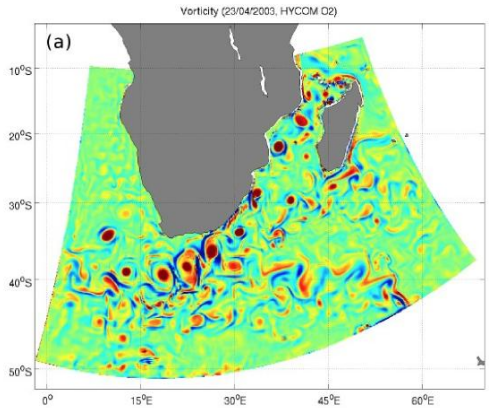
Future work

EnOI is sensitive to the skill of the free-running model

Satellite derived ocean currents

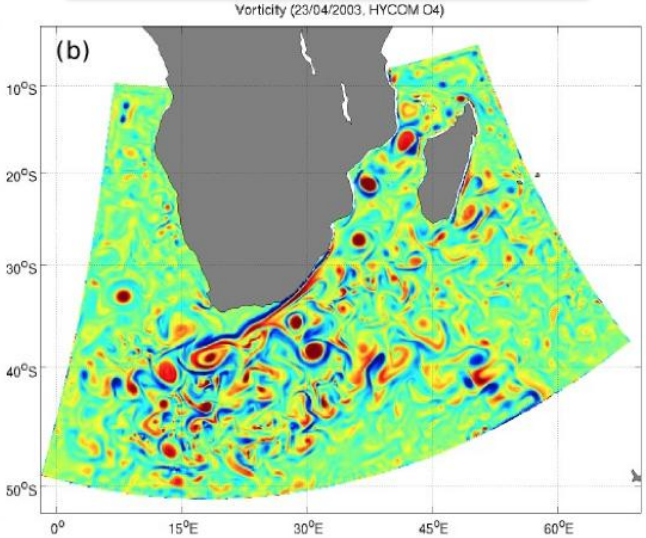






2nd order momentum advection

4th order momentum advection



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Thank you

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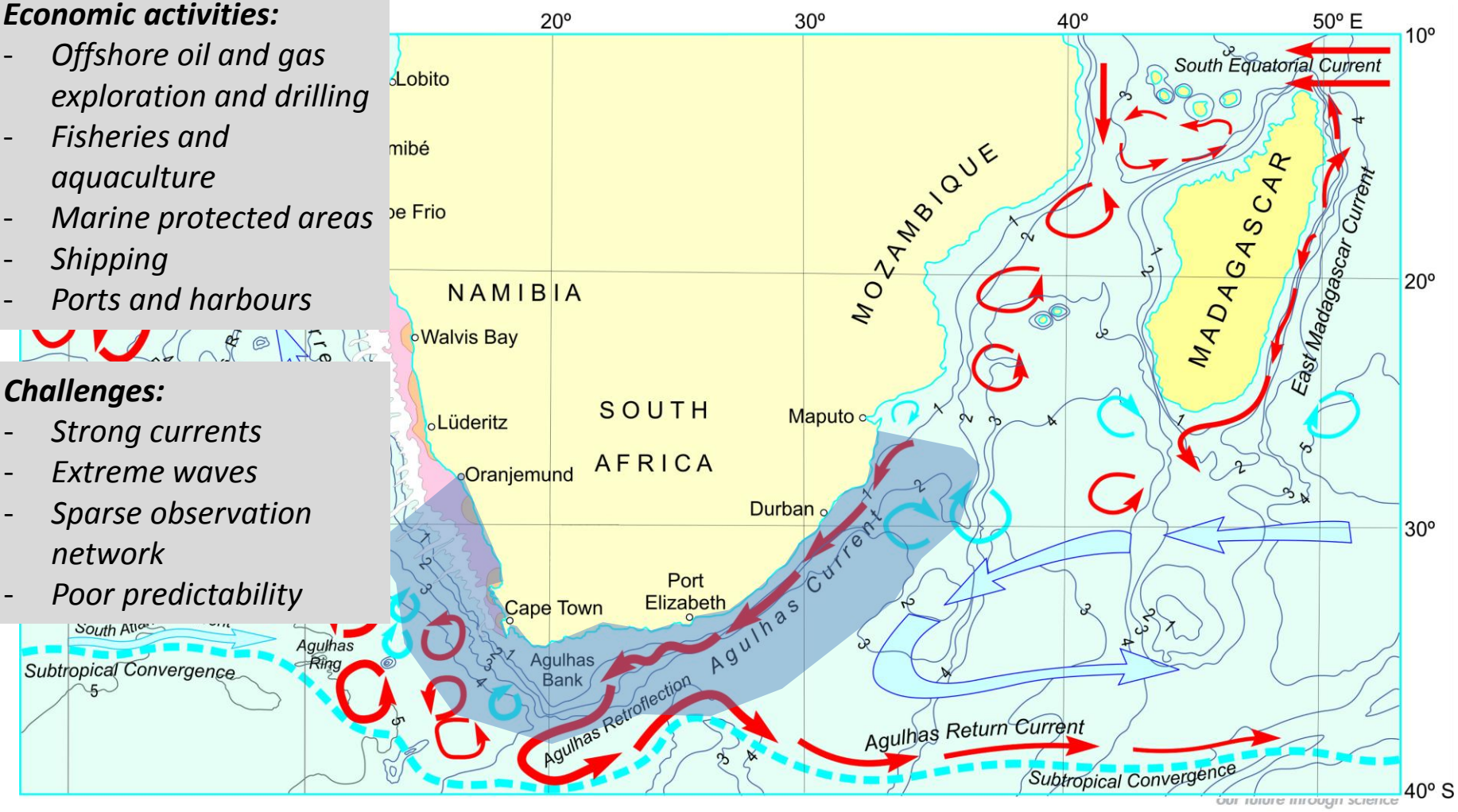
SA's EEZ and the Agulhas Current

Economic activities:

- *Offshore oil and gas exploration and drilling*
- *Fisheries and aquaculture*
- *Marine protected areas*
- *Shipping*
- *Ports and harbours*

Challenges:

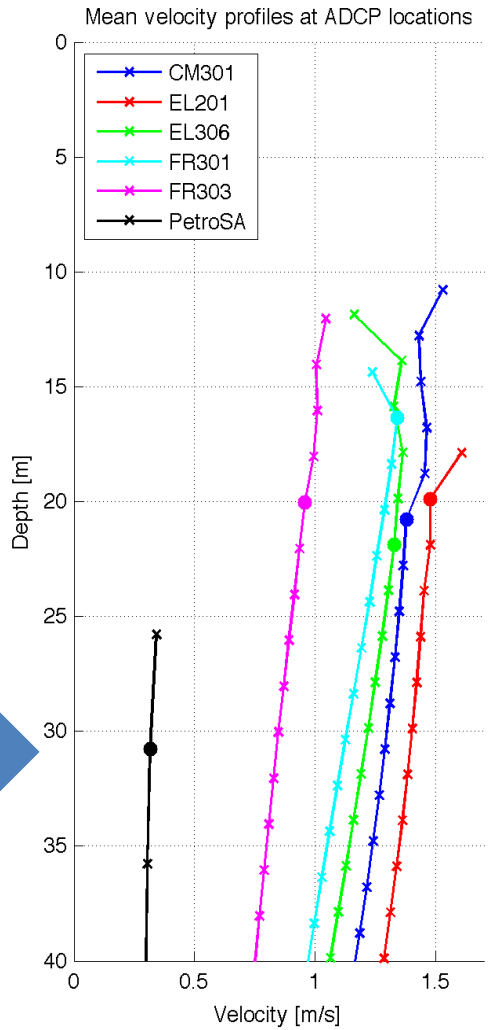
- *Strong currents*
- *Extreme waves*
- *Sparse observation network*
- *Poor predictability*



Comparison against ADCP data

The mean vertical velocity profiles at each of the ADCP locations indicates that the velocity drop off from the surface to the depth of the longest continues time series can reach up to 0.2 m/s.

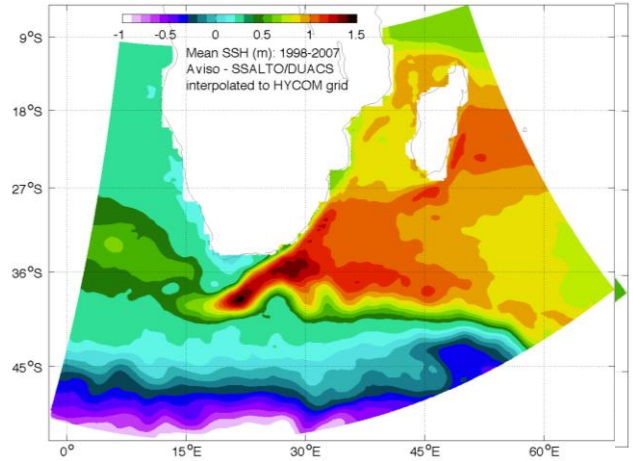
The drop off from 15m to 20m is negligible. For the comparison with the model simulations we use velocities from 15m depths for a more direct comparison to the Globcurrent product.

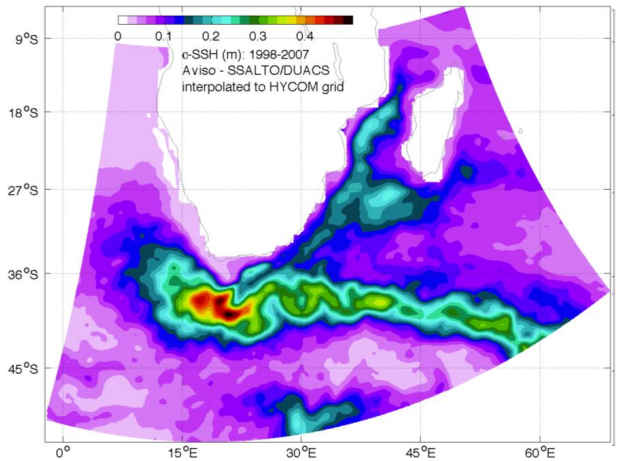


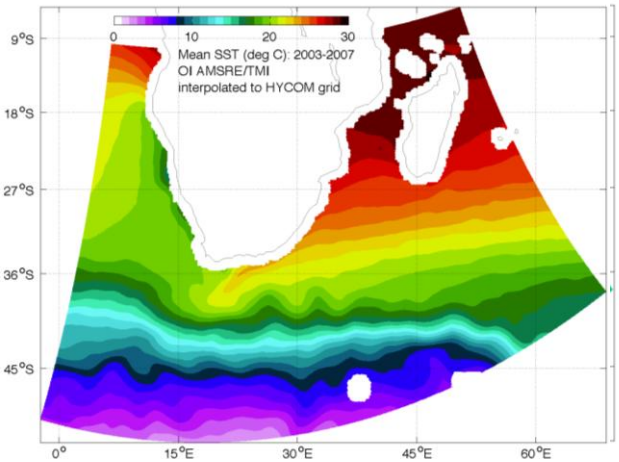
Mean ADCP velocity profile at mooring locations. 'x' mark the ADCP bin depths, and '•' mark the depth of the longest continuous times series, during the period 2008–2009, used in further analysis.

Static (Historical) Ensemble

- Hindcast simulation 1998-2007, data stored every 5 days.
- Reasonable representation of the mean circulation and variability, incl. location of retroflection.







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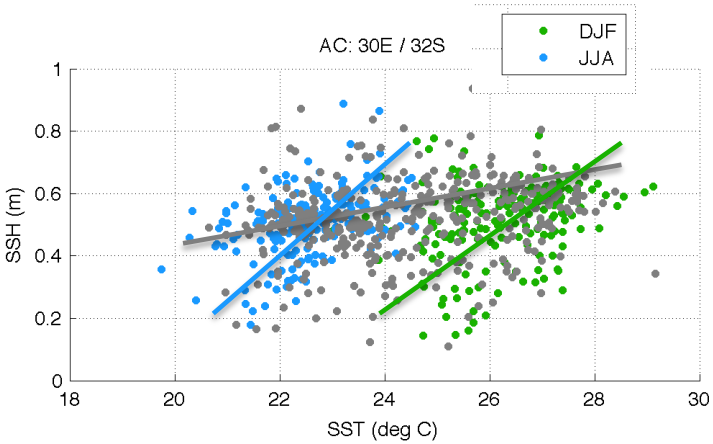
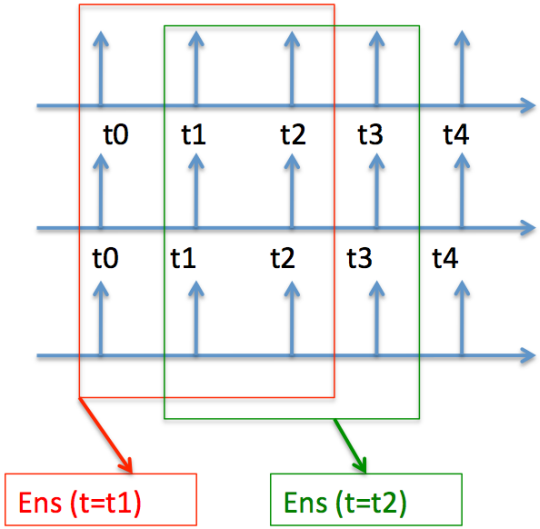
Dealing with seasonal variability

- 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 & blue 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.

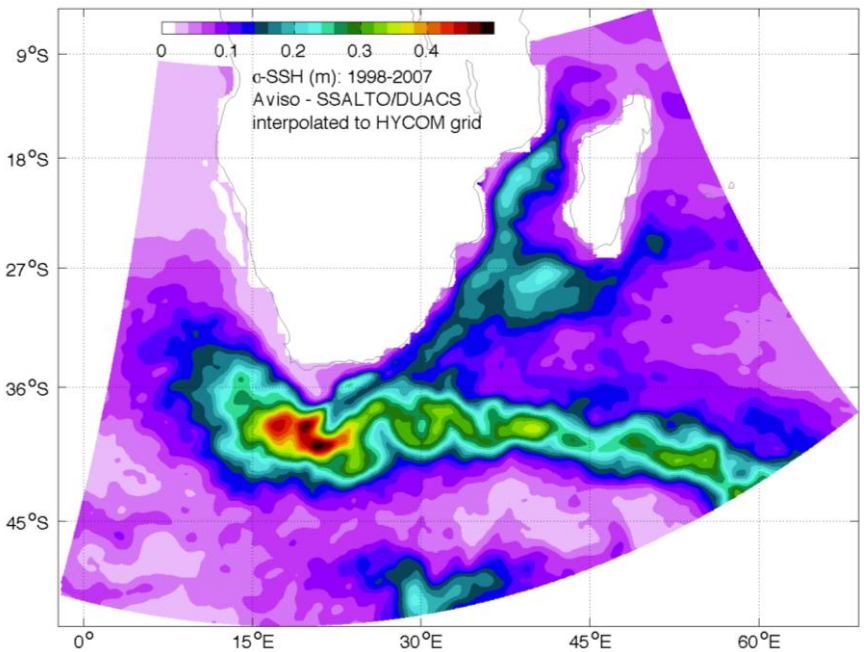
Model – observation inconsistencies

- 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 Aviso variability.

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

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 at 7-day intervals.