Variational data assimilation of along-track altimeter data in the Mid Atlantic Bight (Northeast US coast)

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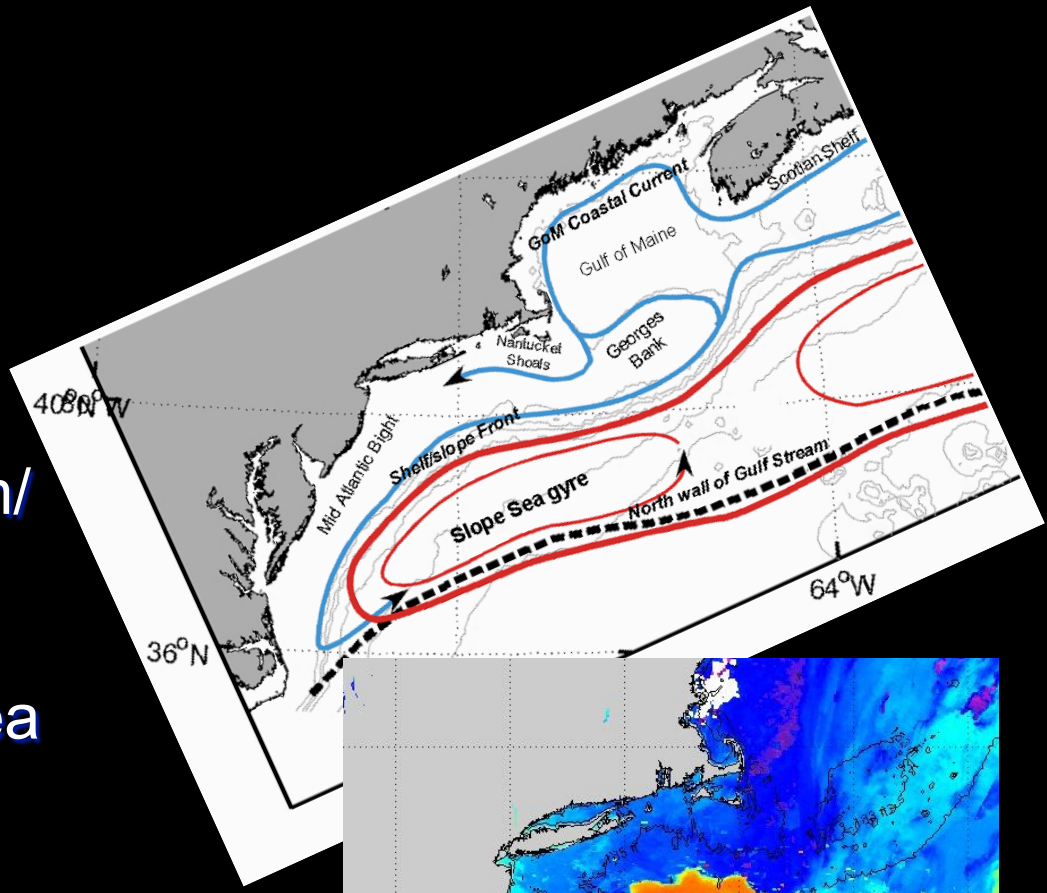
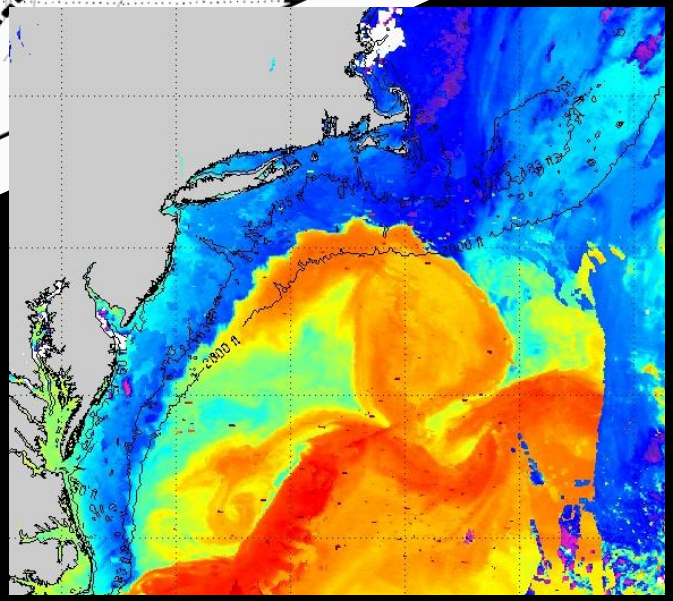
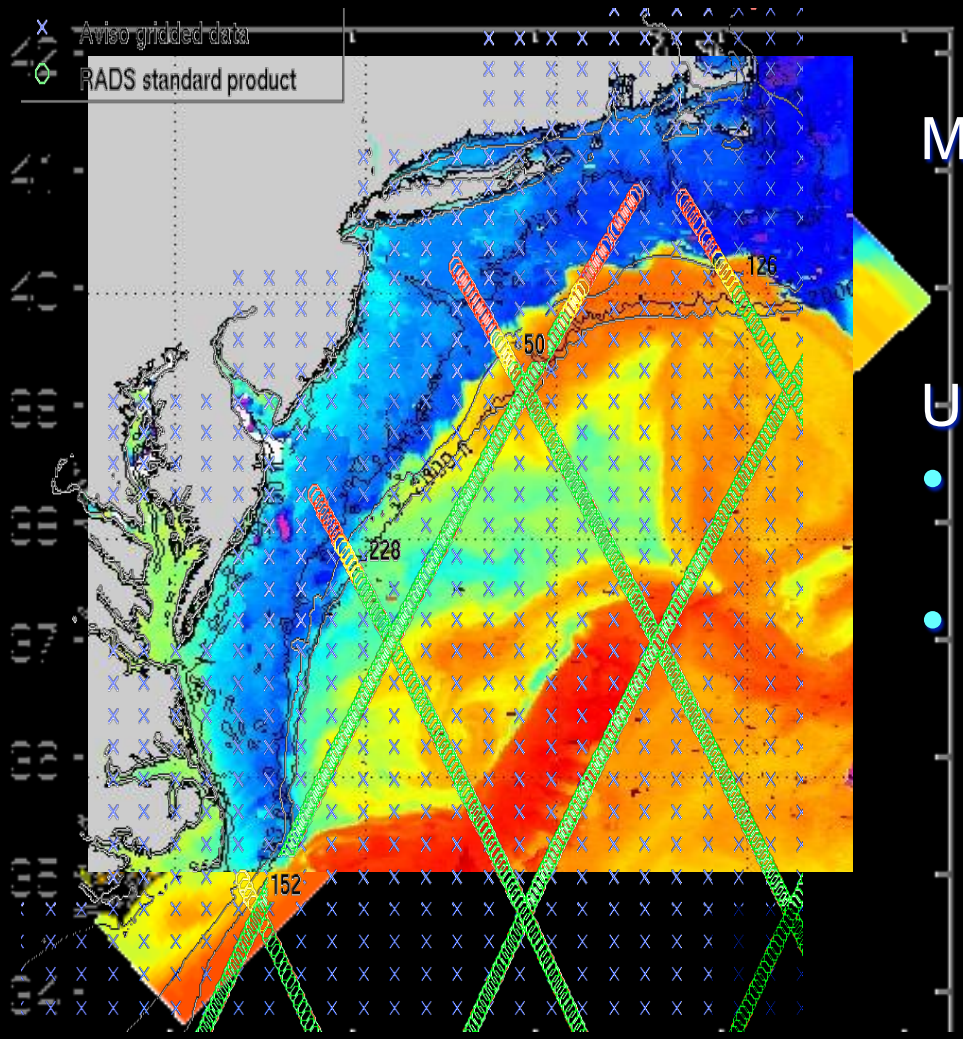
The Mid Atlantic Bight (MAB)

- wide shallow shelf separated from Gulf Stream by the Slope Sea
- Shelf/Slope Front (~0.3 m/s) at shelf edge
- Gulf Stream rings frequently enter Slope Sea and impact shelf
- Strong tides
- Shelf variability highly affected by atmospheric forcing





Mid-Atlantic Bight ROMS Model for IS4DVAR

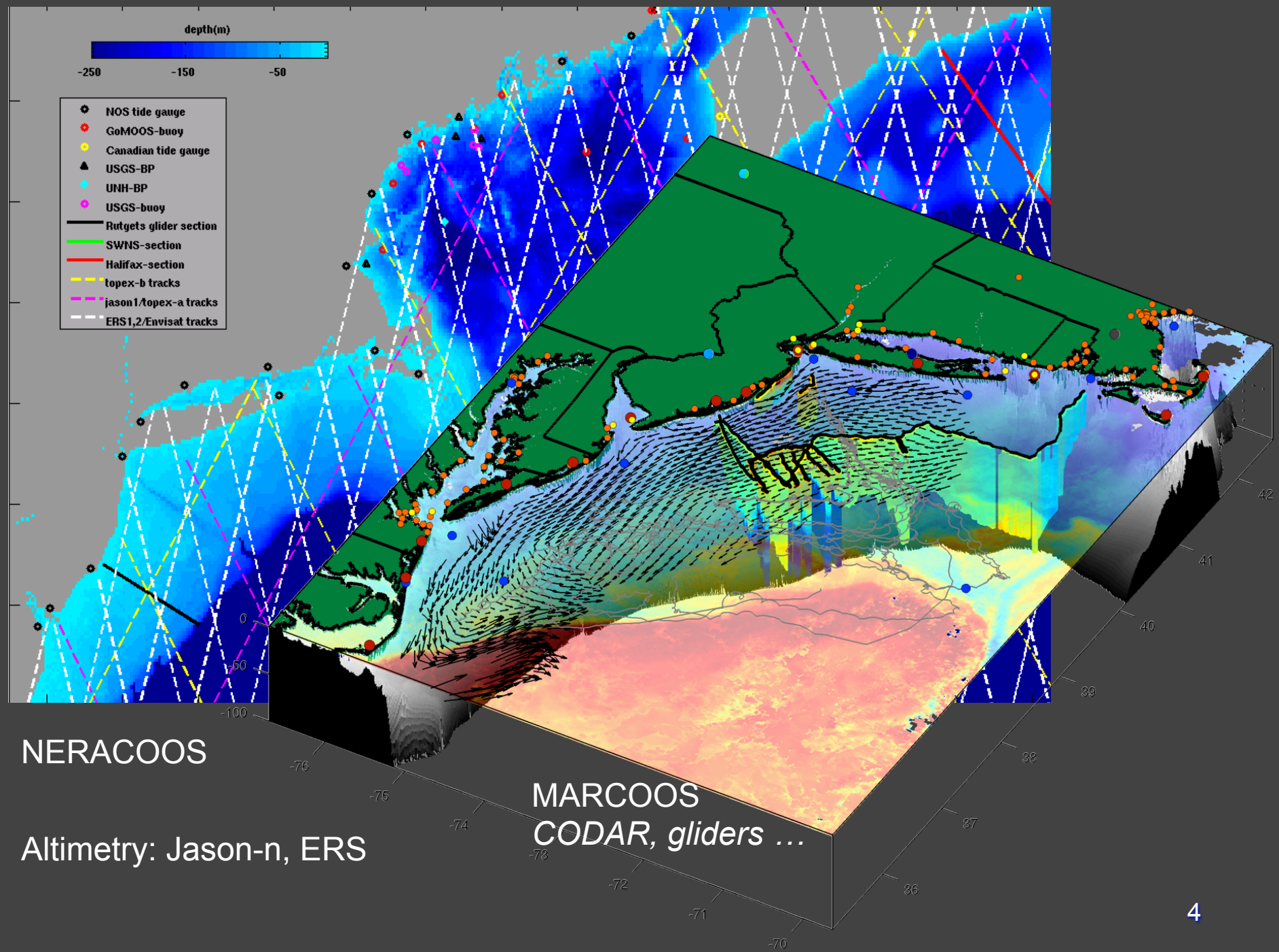


eddies are resolved by multi-satellite SLA gridded products

MAB *SLA* is more anisotropic with shorter length scales due to flow-topography interaction

Use along-track altimetry:

- 4DVar uses the data at time of satellite pass
- model "grids" along-track data by simultaneously matching observations and dynamical constraints

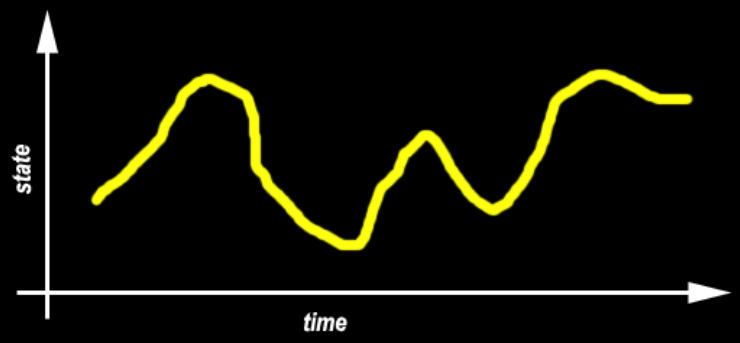


NERACOOS

Altimetry: Jason-n, ERS

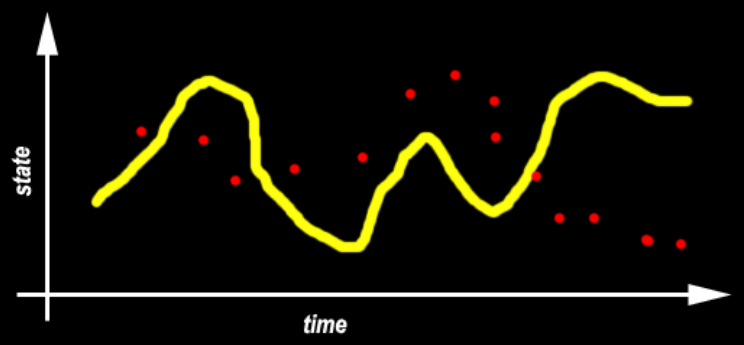
MARCOOS
CODAR, gliders …

Incremental Strong-constraint 4Dimensional Variational (IS4DVAR) Data Assimilation



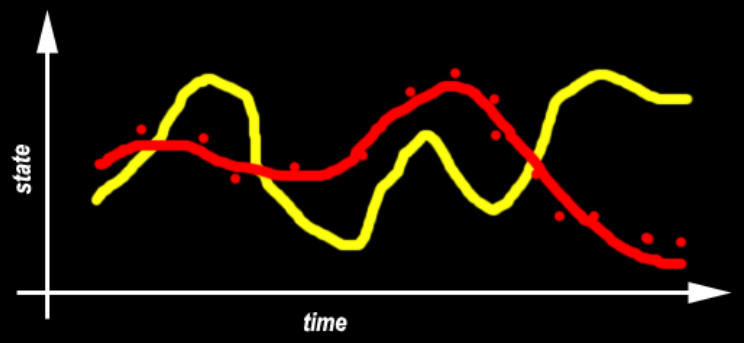
- Given a first guess (a forward trajectory)

Incremental Strong-constraint 4Dimensional Variational (IS4DVAR) Data Assimilation



- Given a first guess (a forward trajectory)…
- And given the available data…

Incremental Strong-constraint 4Dimensional Variational (IS4DVAR) Data Assimilation



- Given a first guess (a forward trajectory)…
- And given the available data…
- What are the changes (or increment) to the IC so that the forward model fits the observations in a given period of time (assimilation window)?

For a single observation (e.g. SSH at one grid point)

the increment is given by:

$$\delta \mathrm{x} = \mathrm{c}\ \mathrm{B}\ \mathrm{M}^T \mathrm{e}$$

For a single observation (e.g. SSH at one grid point) the increment is given by:

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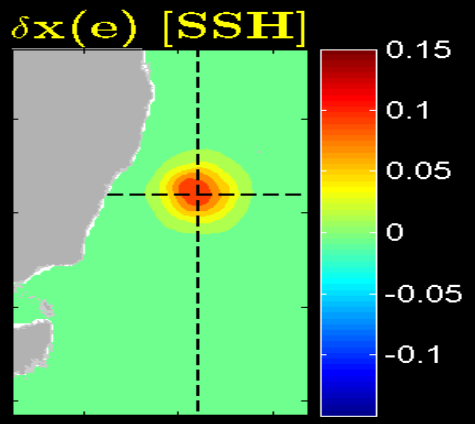
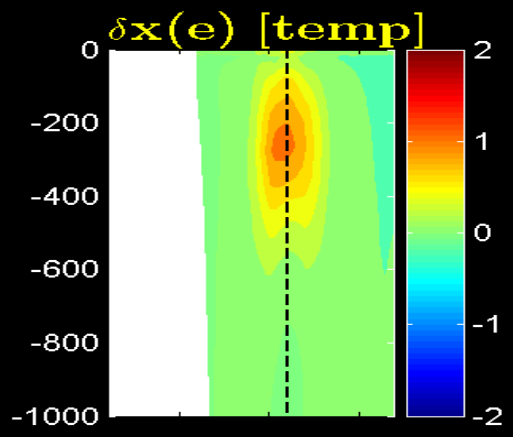
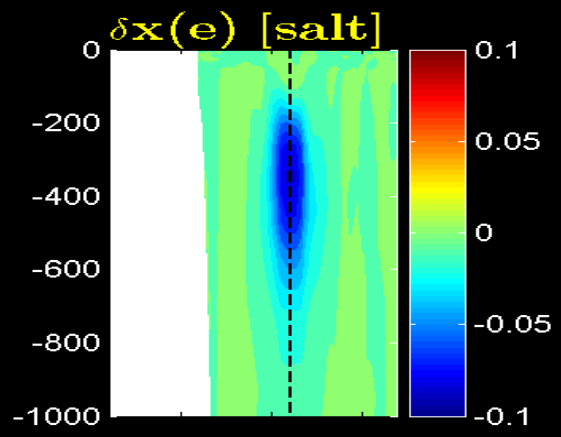
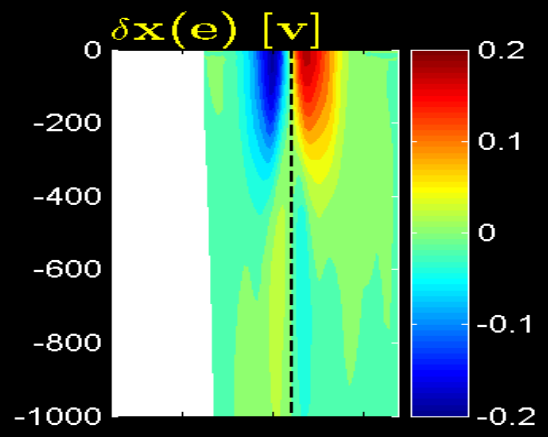


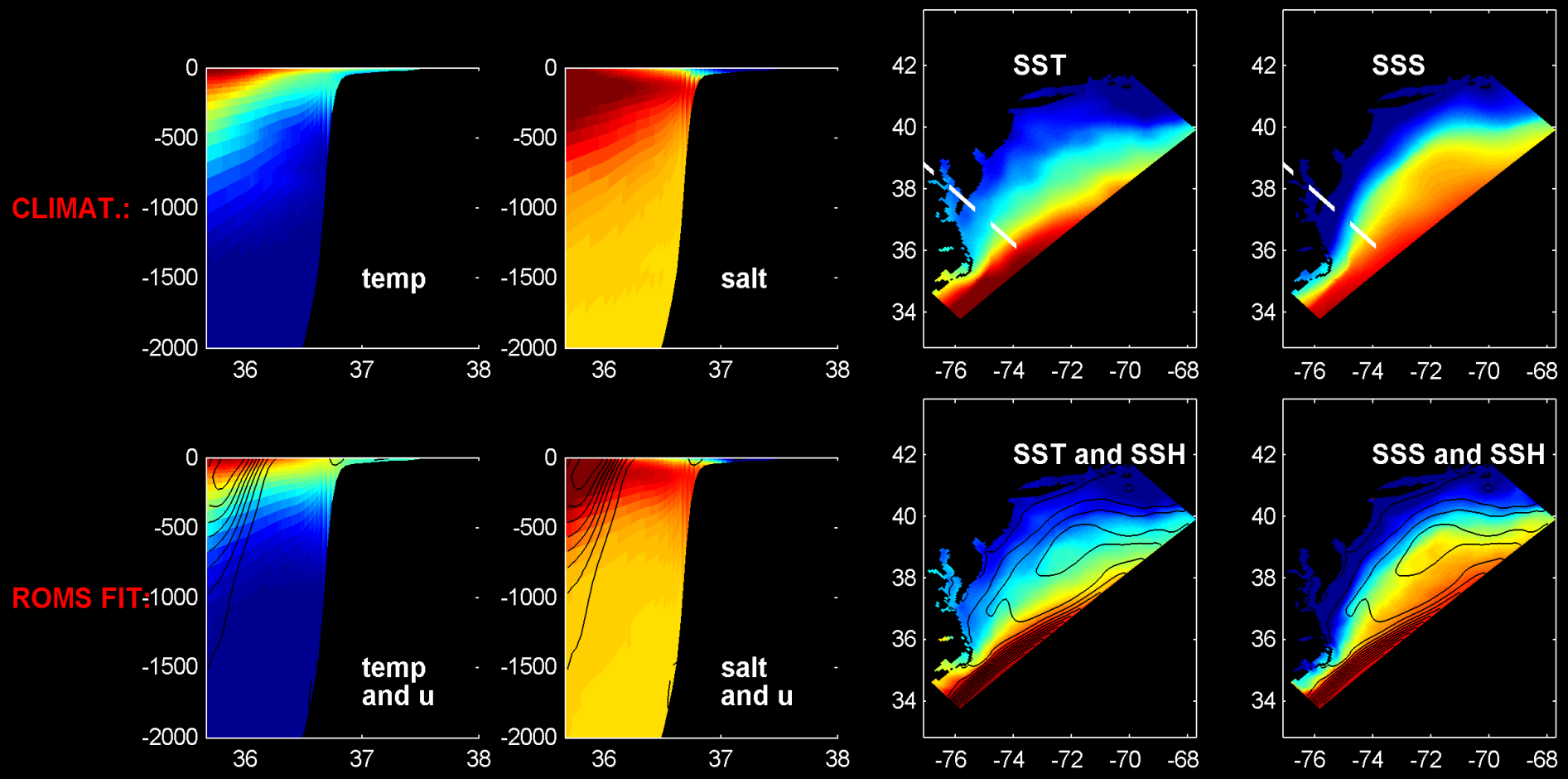


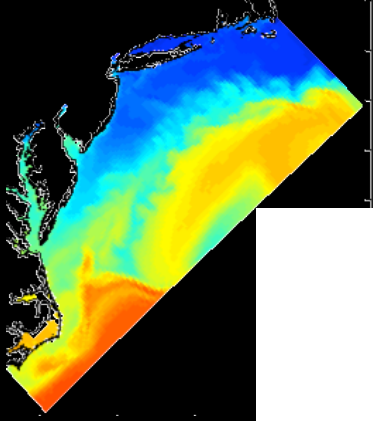




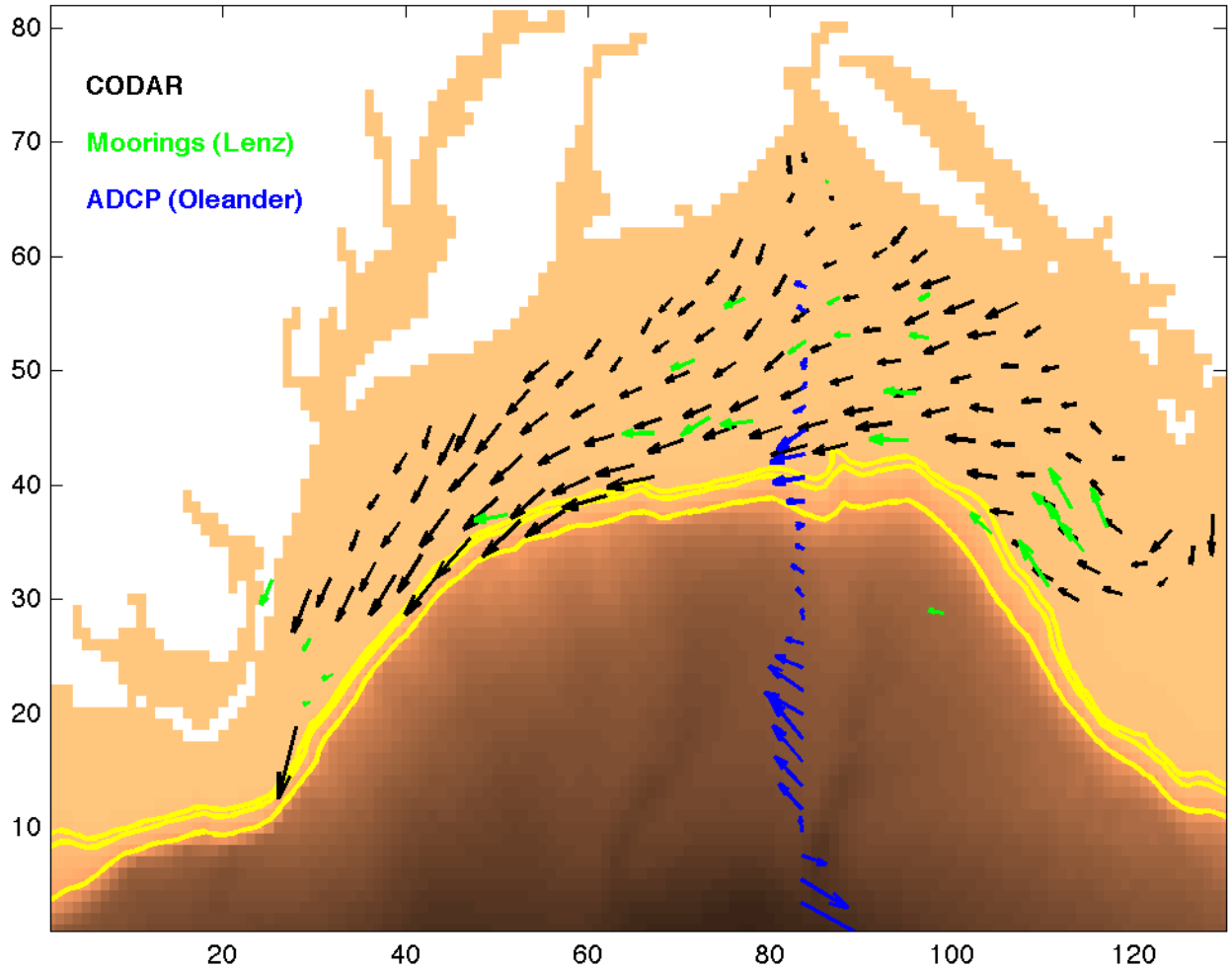
Mean Dynamic Topography (MDT) is computed by 4DVAR analysis of a regional 3-D T-S climatology computed from historical hydrographic data.

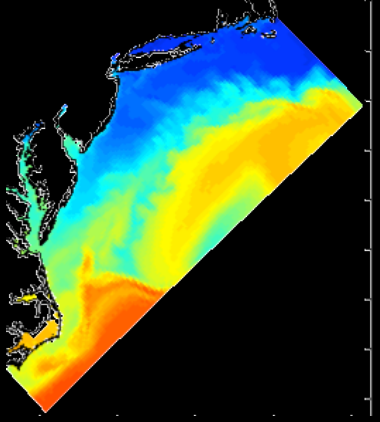
4DVAR analysis is forced with annual mean meteorology and open boundary conditions.





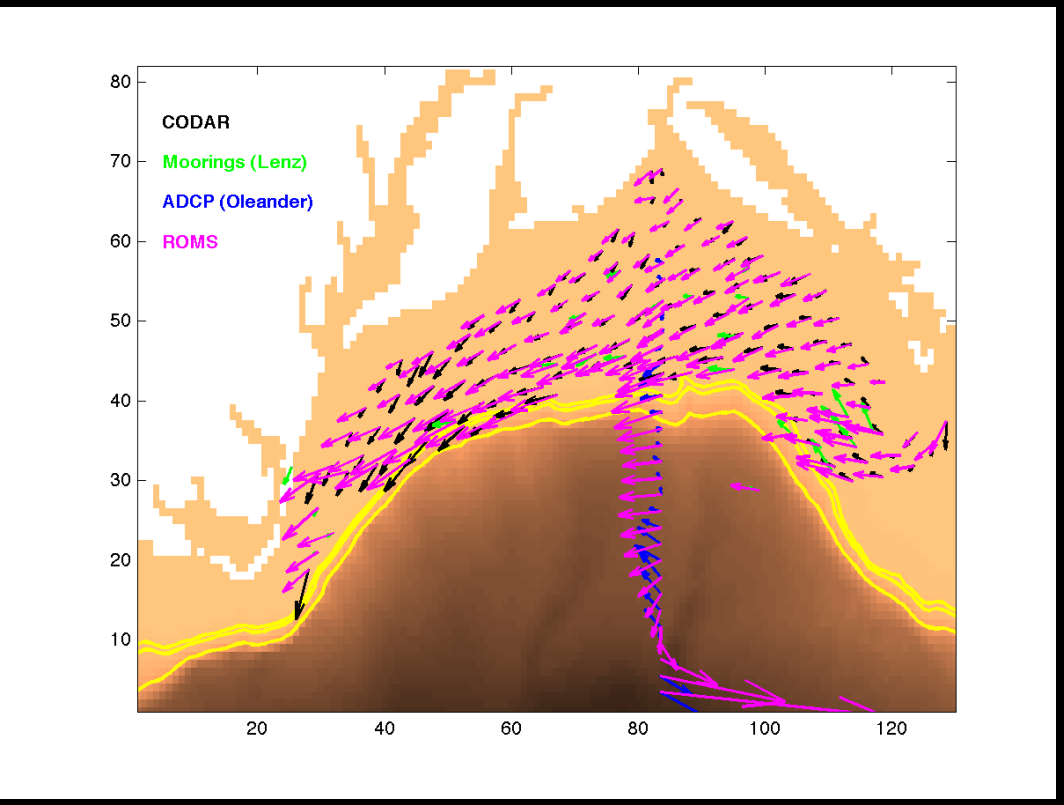
Observed mean surface currents

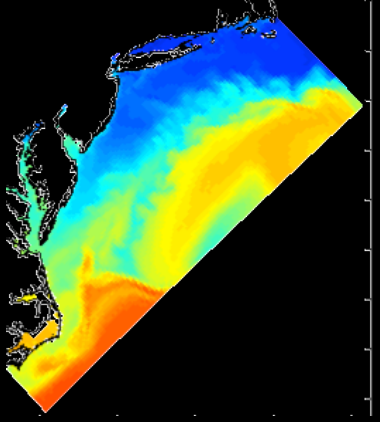




ROMS vs observed mean surface currents

ROMS given mean T and S

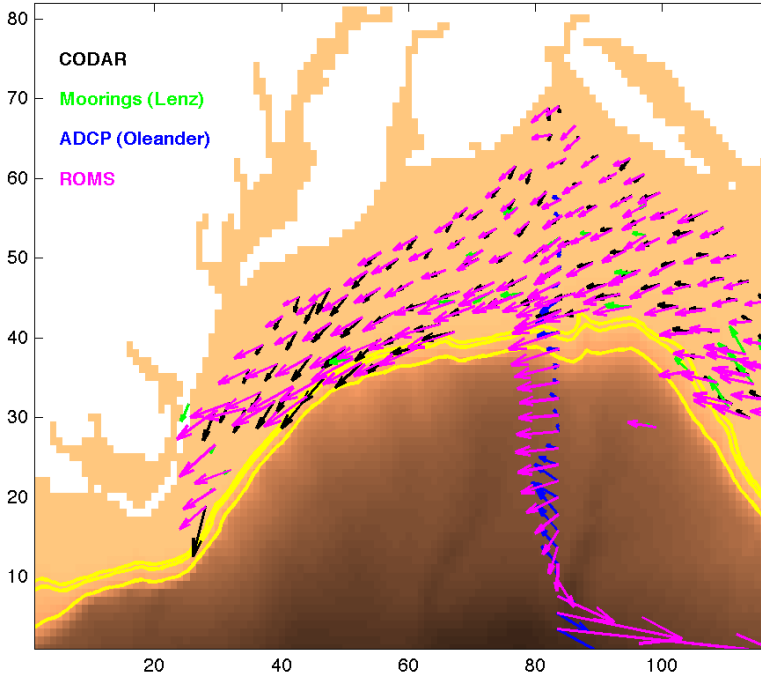


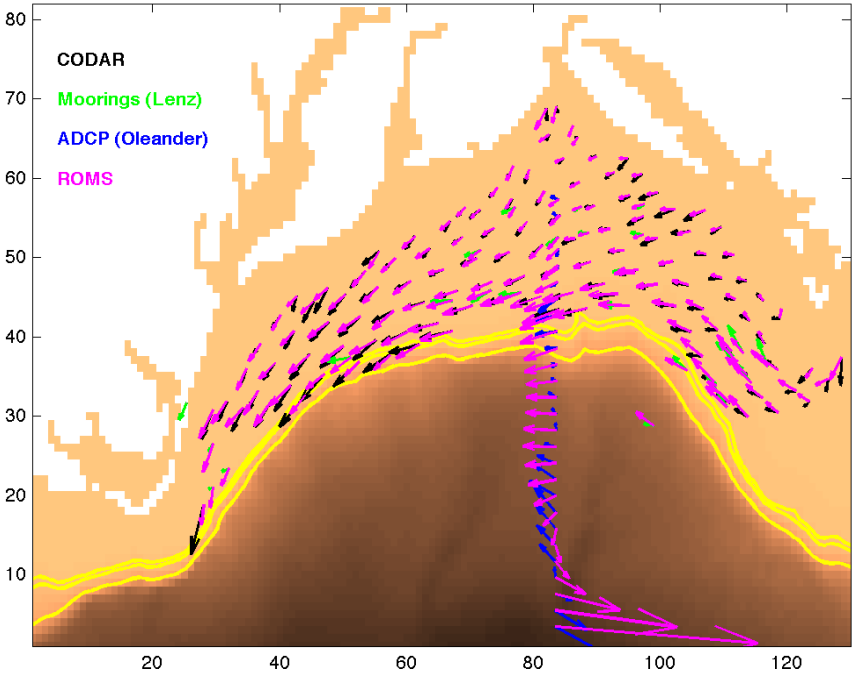


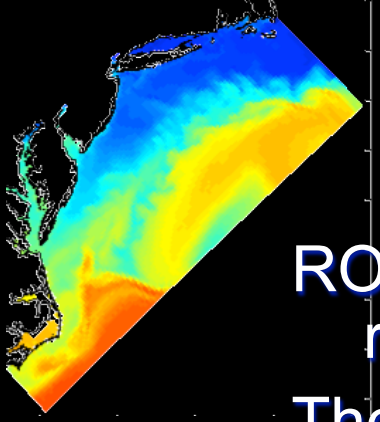
ROMS vs observed mean surface currents

ROMS given mean T and S

ROMS given mean T, S and CODAR surface velocity







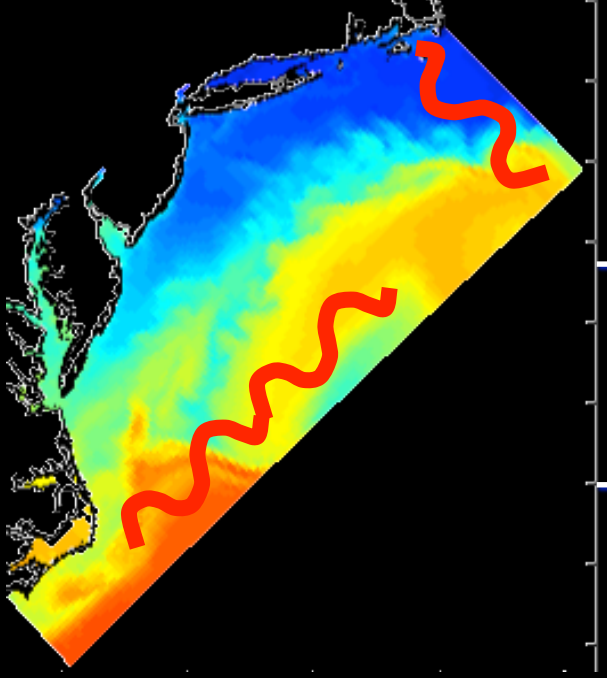
High frequency variability: model and data issues

ROMS includes high frequency variability typically removed in altimeter processing (tides)

The IS4DVAR cost function, J, samples this high frequency variability, so it must be either (a) removed from the model or (b) included in the data

Our approach:

- Run 1-year ROMS (no assimilation) forced by boundary TPX0.7 tides; compute ROMS tidal harmonics
- use de-tided along-track altimetry
- add ROMS tides to de-tided altimeter data
- thus the *observations* are *adjusted* to include model tide
- assimilate – high frequency mismatch of model and altimeter is minimized and cost function is, presumably, dominated by sub-inertial frequency dynamics



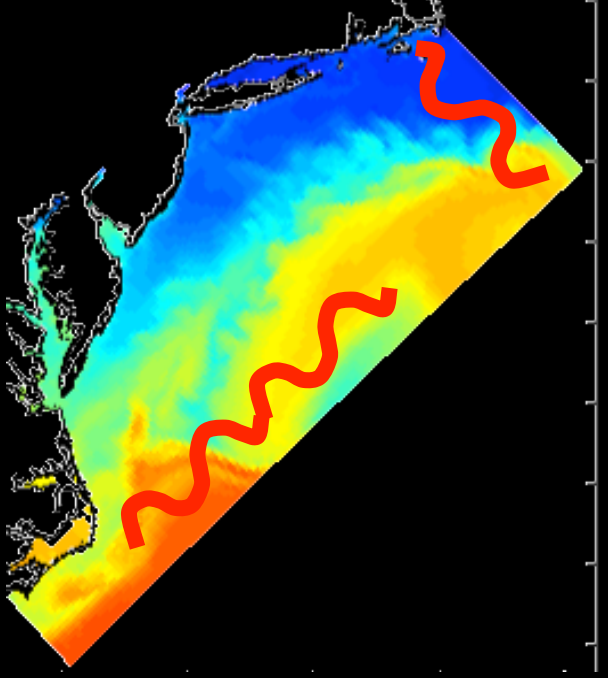
High frequency variability: model and data issues

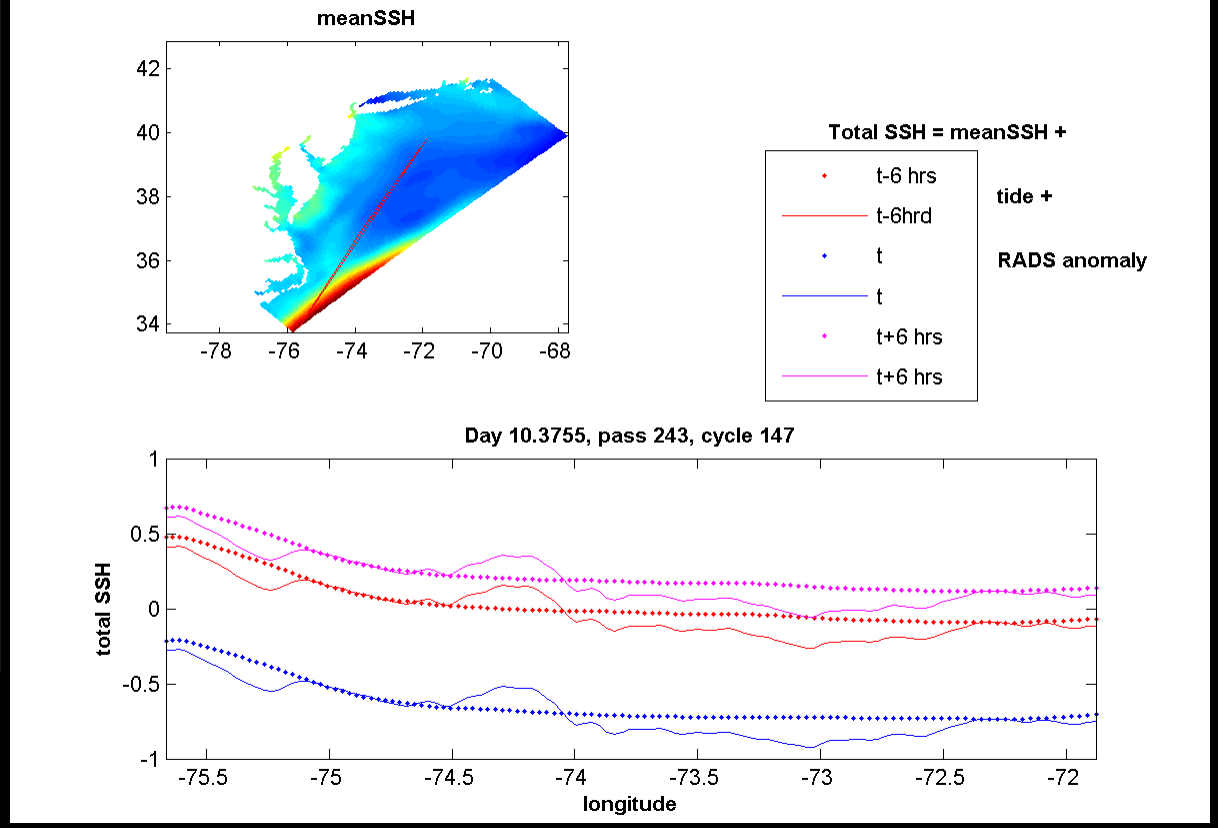
The adjoint model can erroneously accommodate too much of the SLA model-data misfit in the barotropic mode

This sends gravity wave at $\sqrt{gh}$ along the model perimeter

Our approach:

- Repeat (duplicate) the altimeter SLA observations at
  t = -6 hour, t=0 and t = +6 hour
  but with appropriate time lags in the added tide signal
- These data cannot easily be matched by a $\sqrt{gh}$ wave
- We are effectively acknowledging the temporal correlation of the sub-tidal altimeter SLA data





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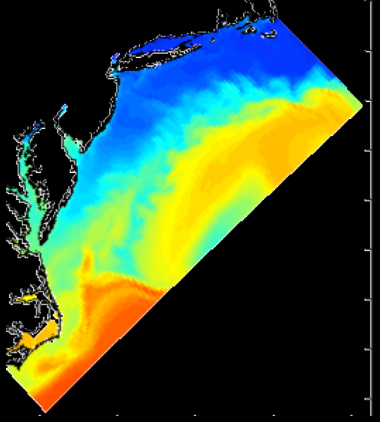
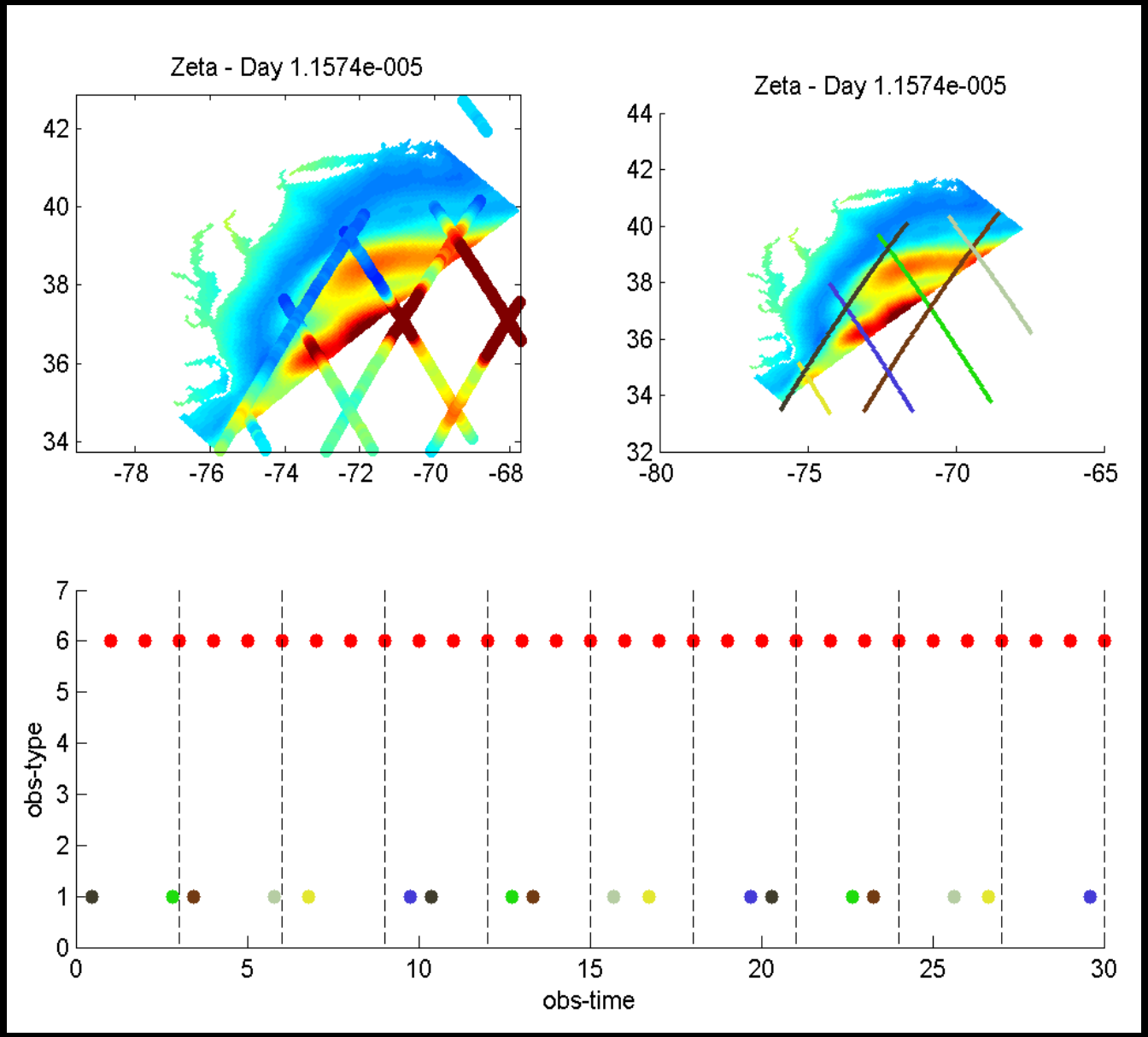
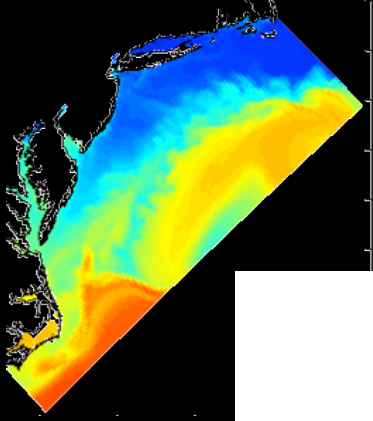


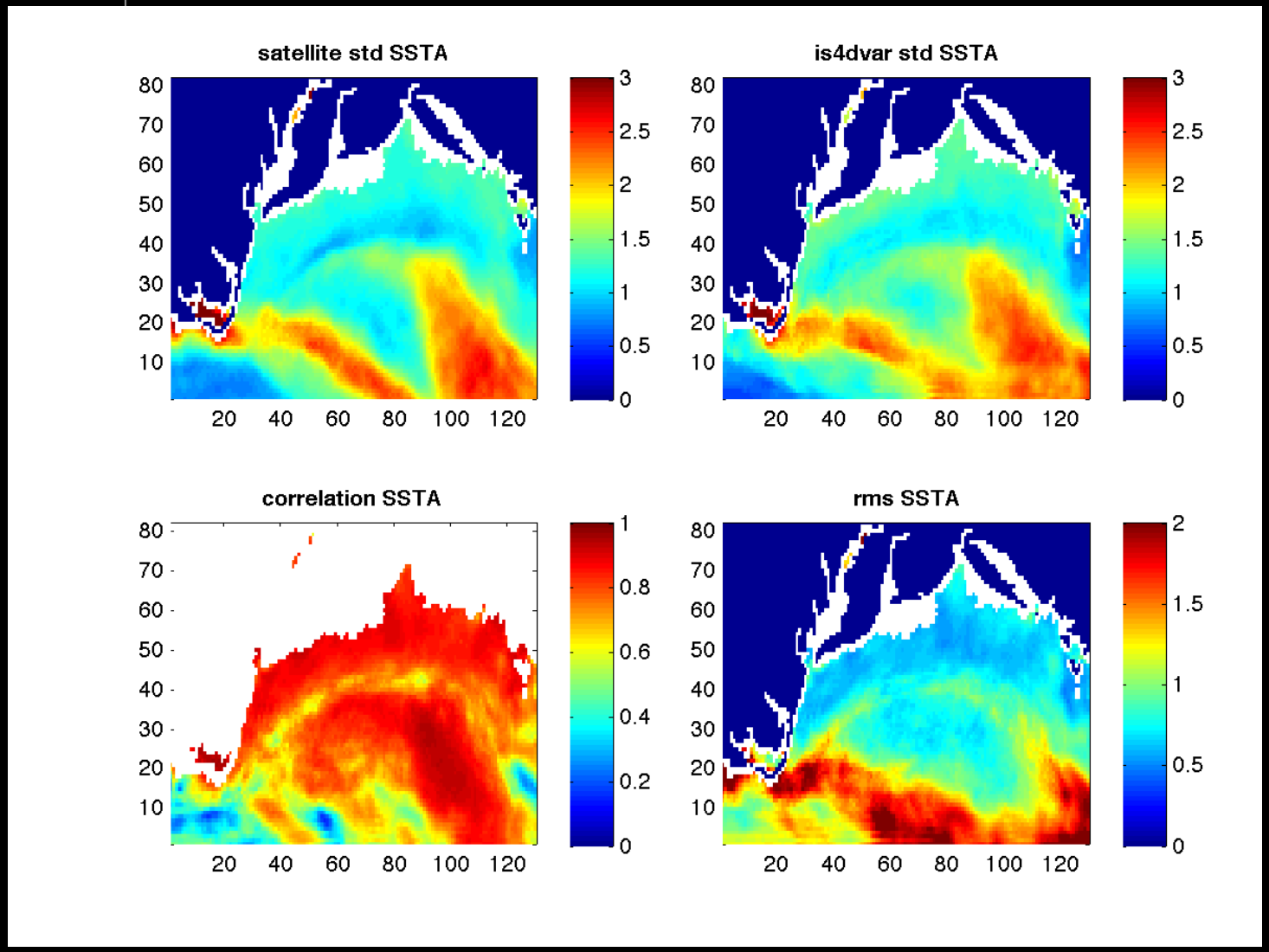
Sequential assimilation of SLA and SST



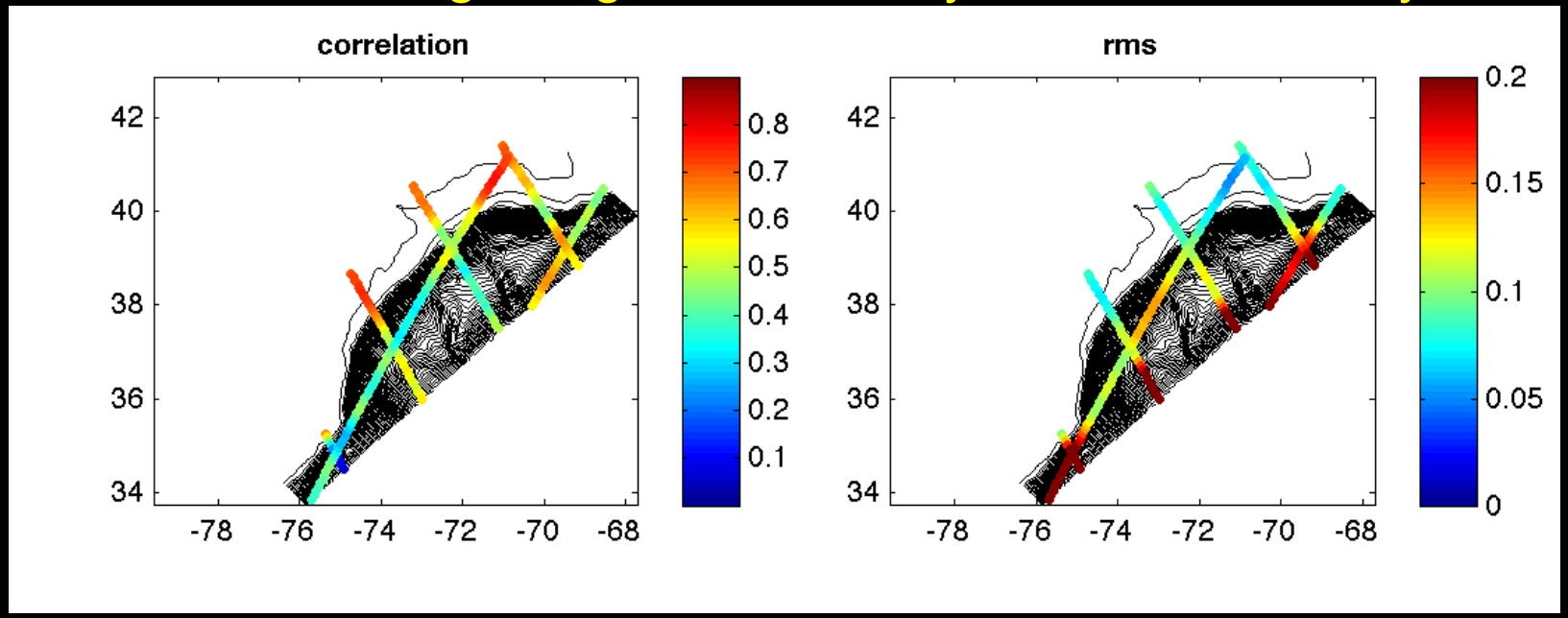
- Reference time is days after 01-01-2006
- 3-day assimilation window (AW)
- Daily MW+IR blended SST (available real time)
- SSH = Dynamic topography + ROMS tides + Jason-1 SLA (repeated three times)
- Seasonal T and S climatology
- For the first AW we just assimilate SST to allow the tides to ramp up.



Skill in hindcasting mesoscale SST by the assimilation system



Skill in hindcasting alongtrack SSHA by the assimilation system



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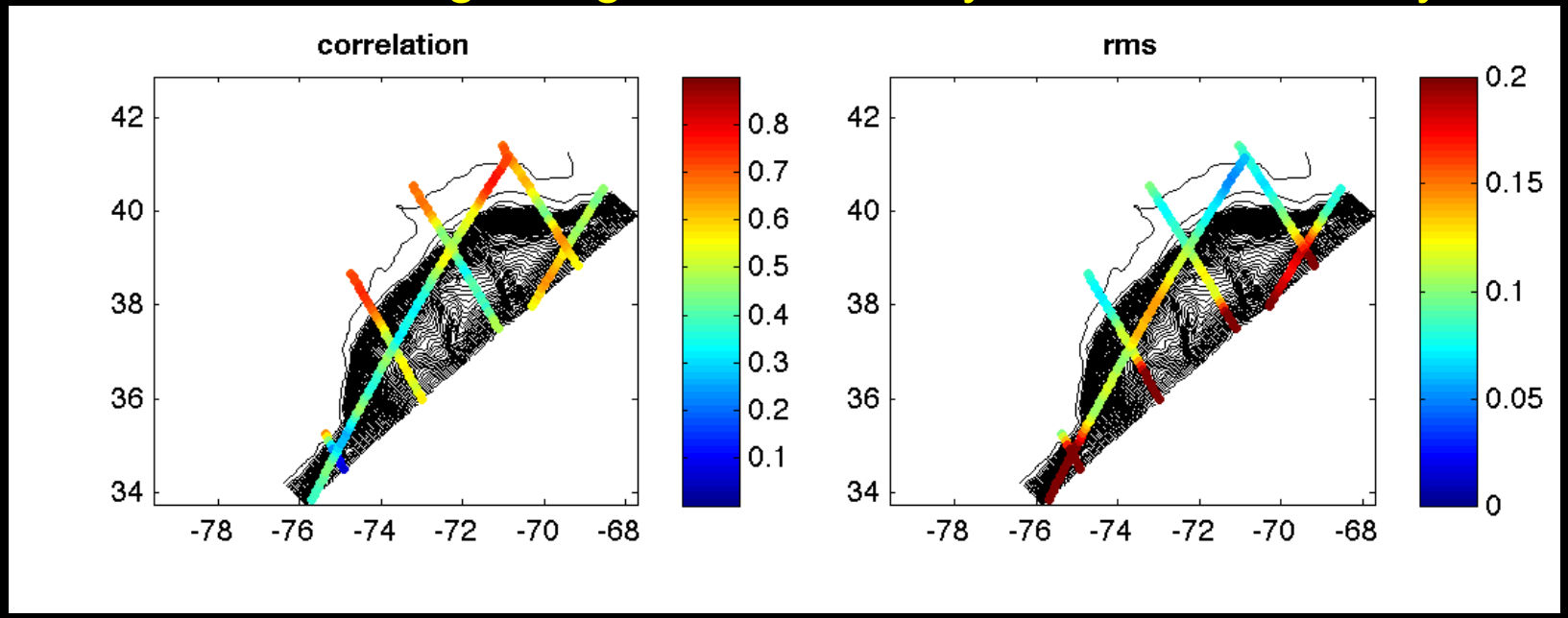
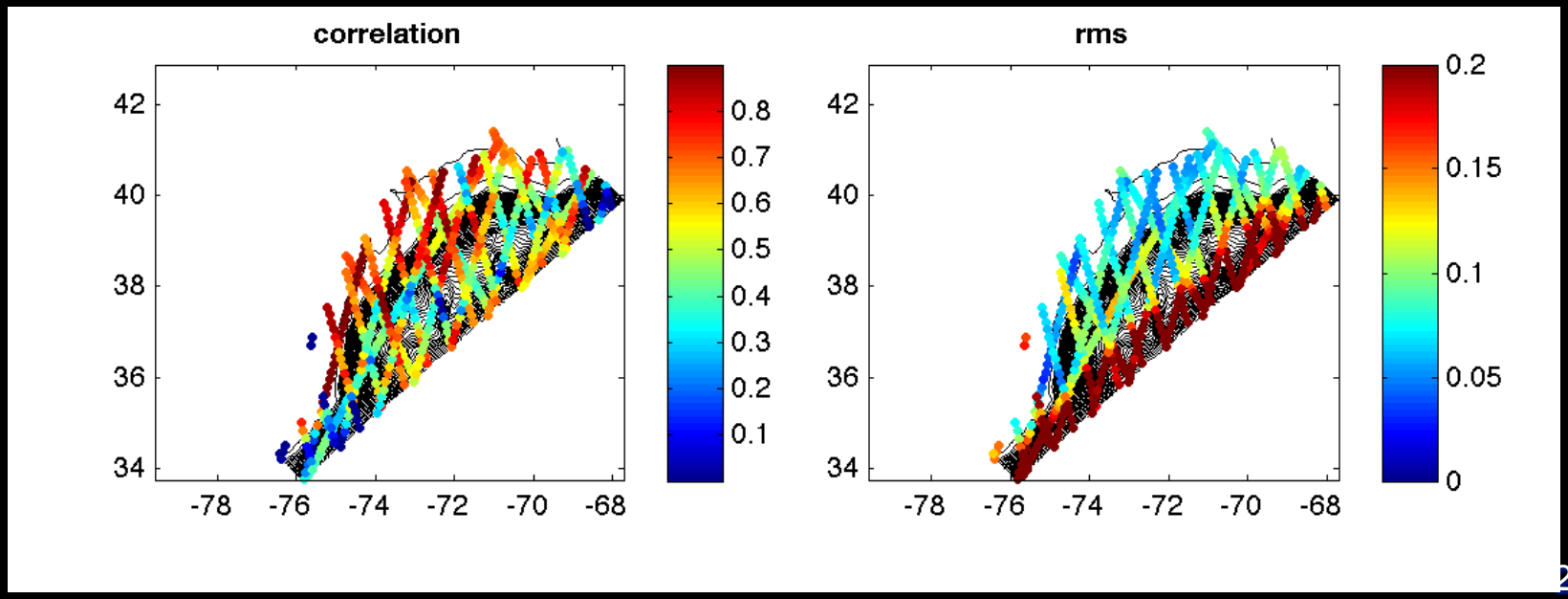
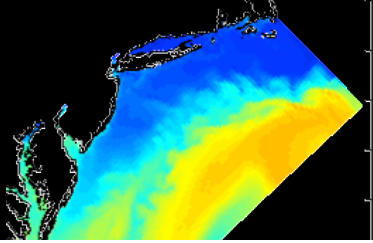
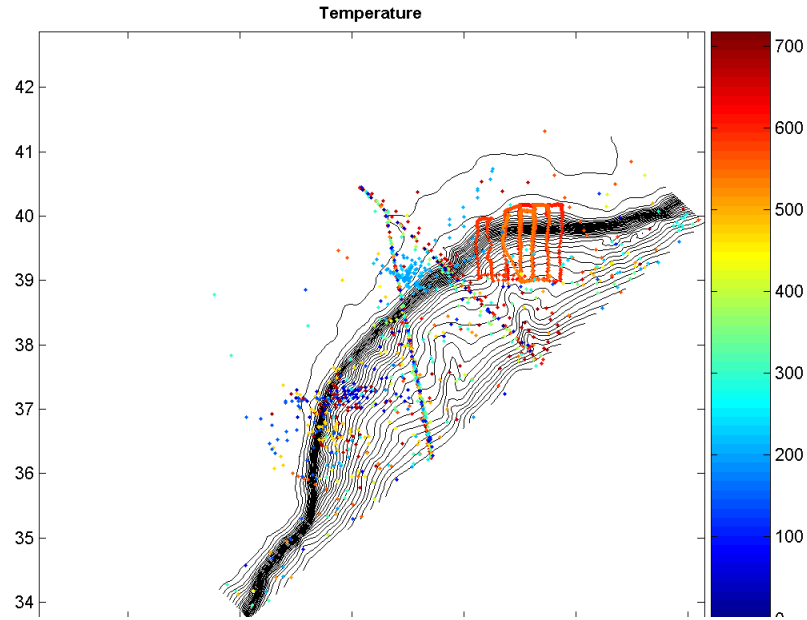
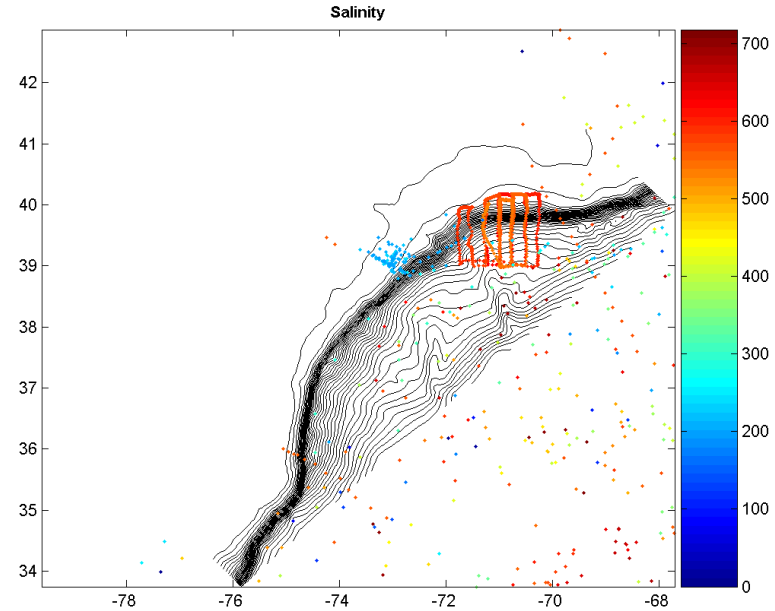


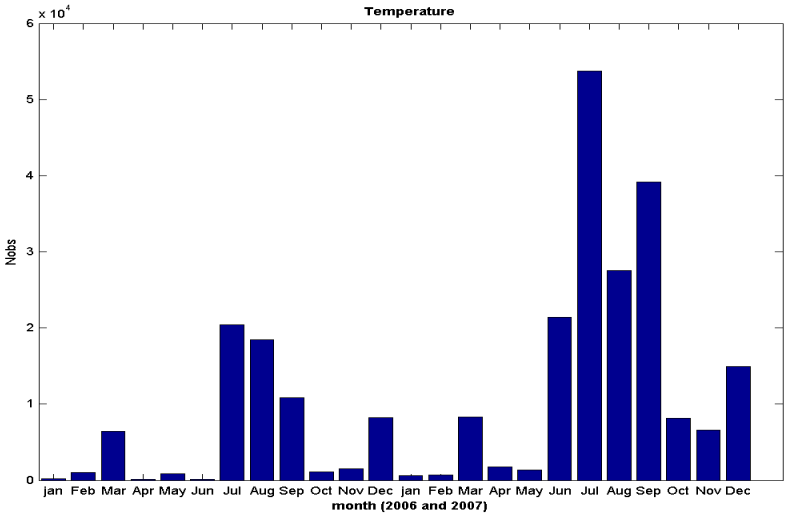


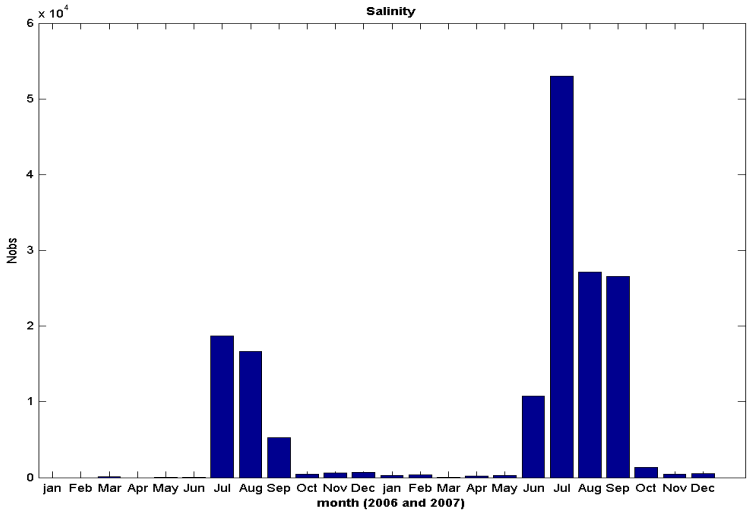


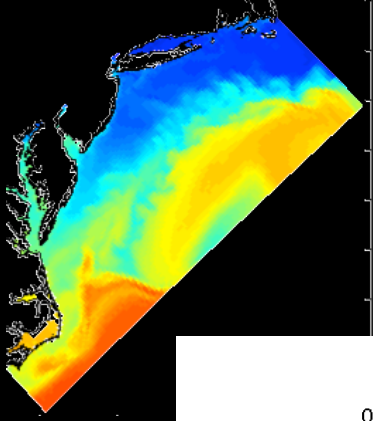
Large set of T and S observations from CTD, gliders, XBTs for 2006 (SW06) and 2007



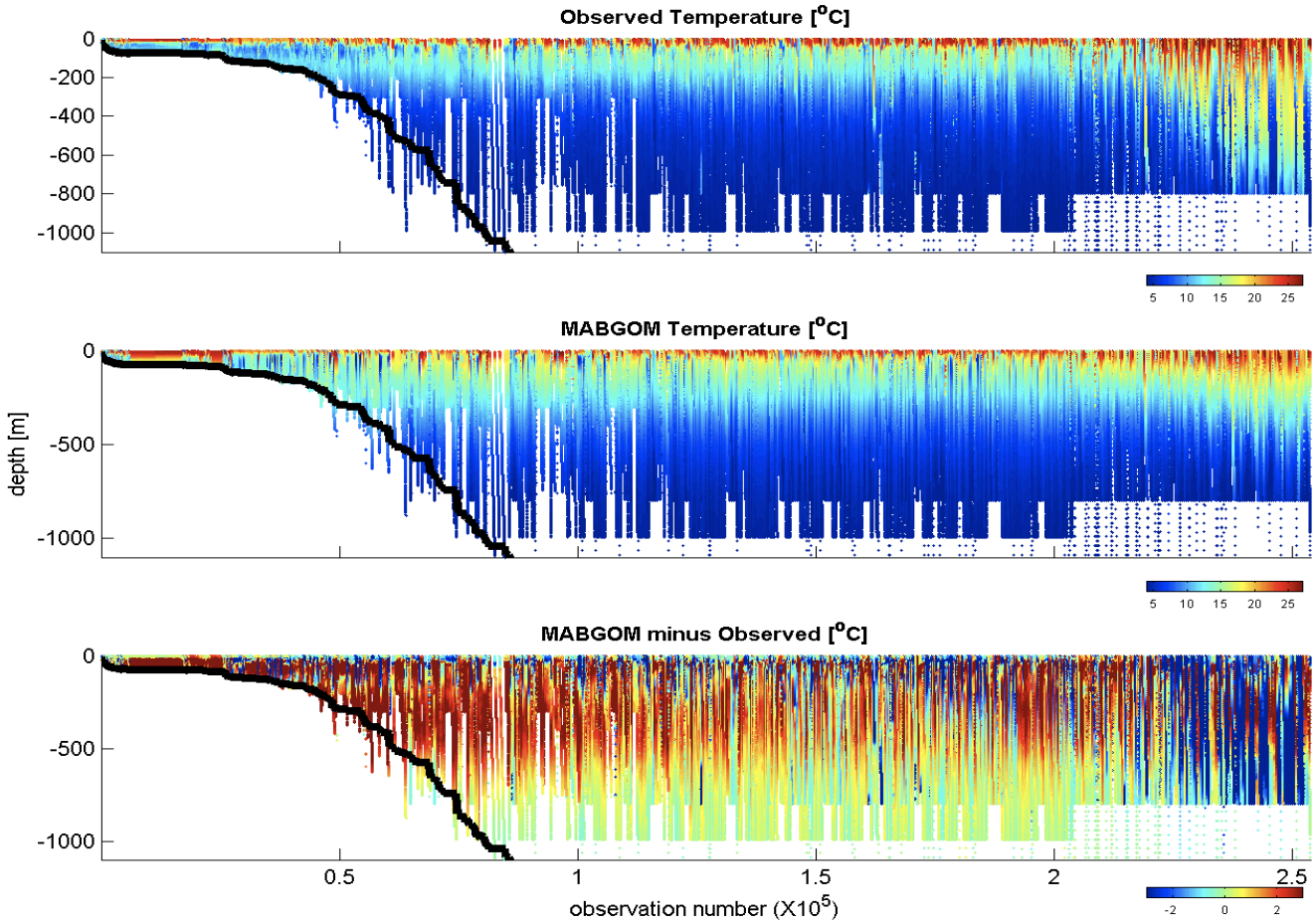


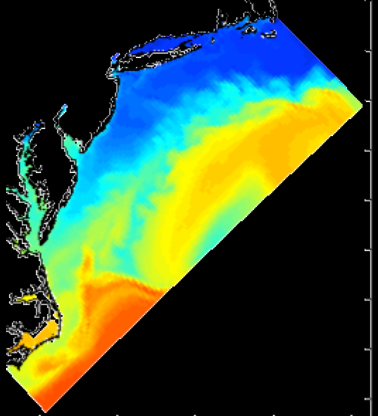




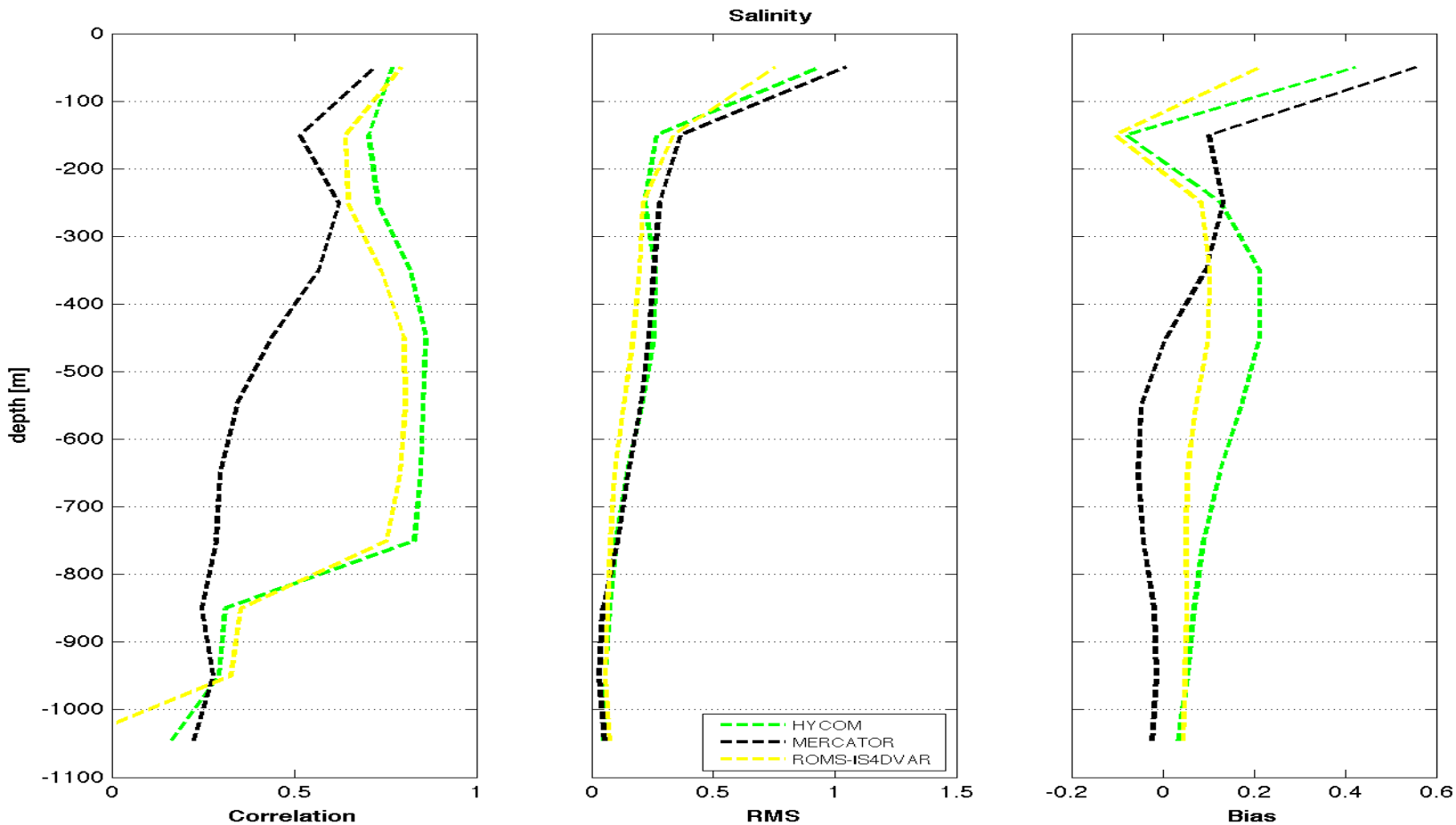


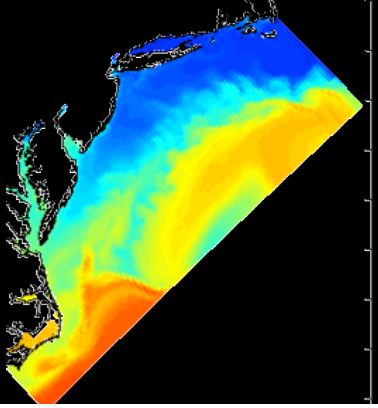
MABGOM, HYCOM and MERCATOR have strong errors when predicting all the observations



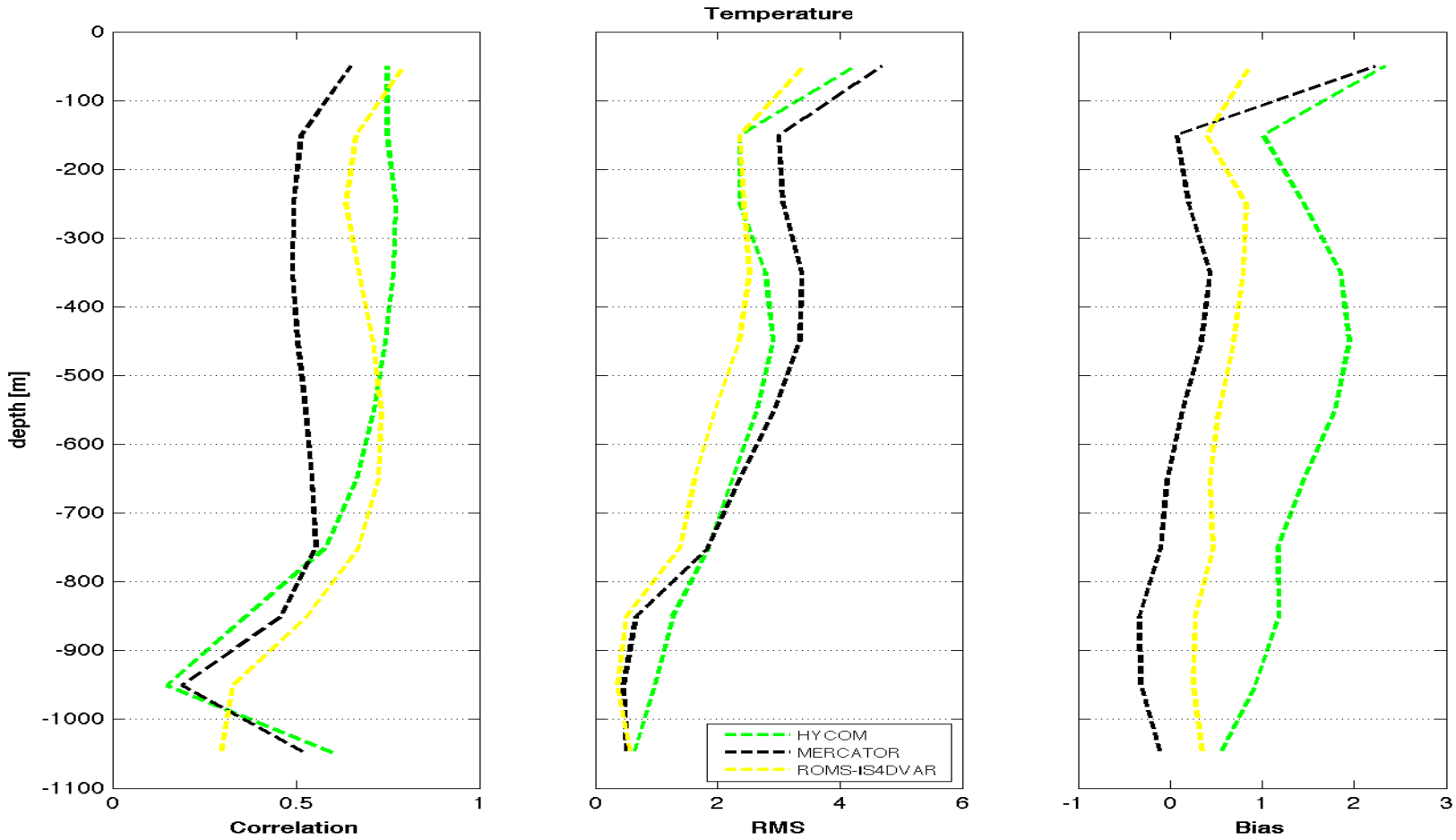


Skill in hindcasting the vertical structure of salinity. Note: this variables was not assimilated.





Skill in hindcasting the vertical structure of temperature. Note: this variable was not assimilated.



Final remarks

Variational methods are a very useful tool to combine model physics with coastal observations from different instruments such as reprocessed altimeter data, HF radars, CTD, gliders, etc.

Useful tool to provide gridded maps of SSH, ….and 3D state of the ocean.

We have demonstrated its applicability in a very complex coastal region (the MAB): strong tides, strong spatial gradients of temperature and salinity, wide shelf interacting with deep ocean eddies, etc.

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The system is working operational assimilating also CODAR surface currenys: To be shown is Lisbon

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