Improved Representation of Eddies in Fine Resolution Forecasting Systems Using Multi-Scale Data Assimilation of Satellite Altimetry

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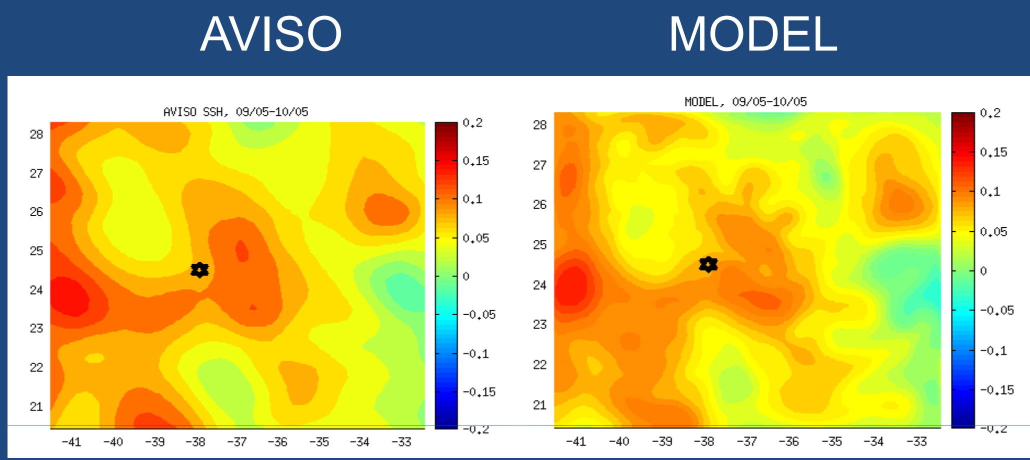
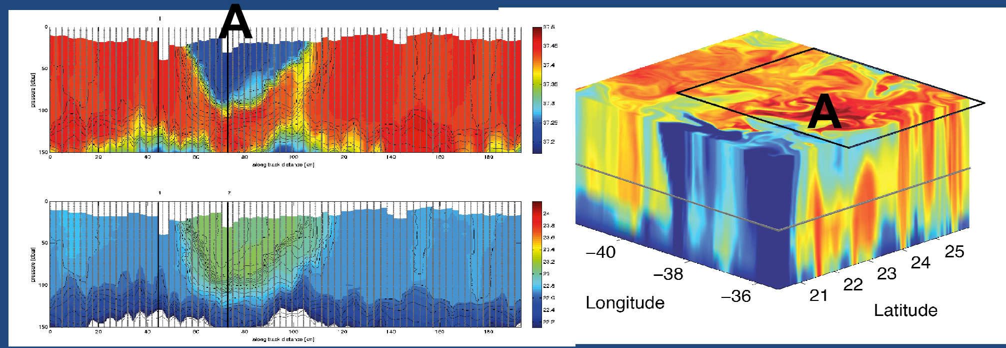
Impact of Altimetry Data in Real-Time Mesoscale Prediction during the SPURS Field Campaign

- The assimilation of the altimetry data played a significant role in the prediction of mesoscale eddies (OSTST 2013)
- The model encouragingly showed an ability of predicting submesoscale features (OSTST 2014)
- Today's topic: how the assimilation altimetry data improves representation of eddies down to tens of km



2012 Fall, Model Predicted Mesoscale Eddies

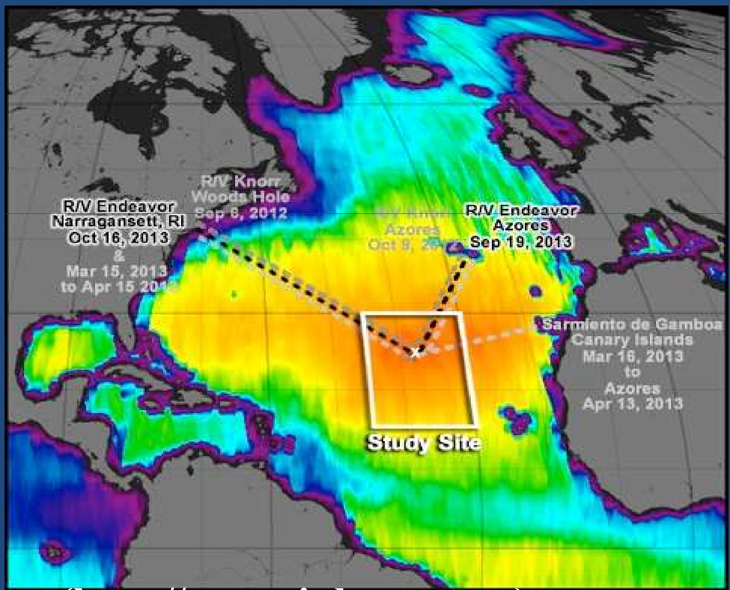


2013 Spring, Model Predicted Sub-mesoscale features

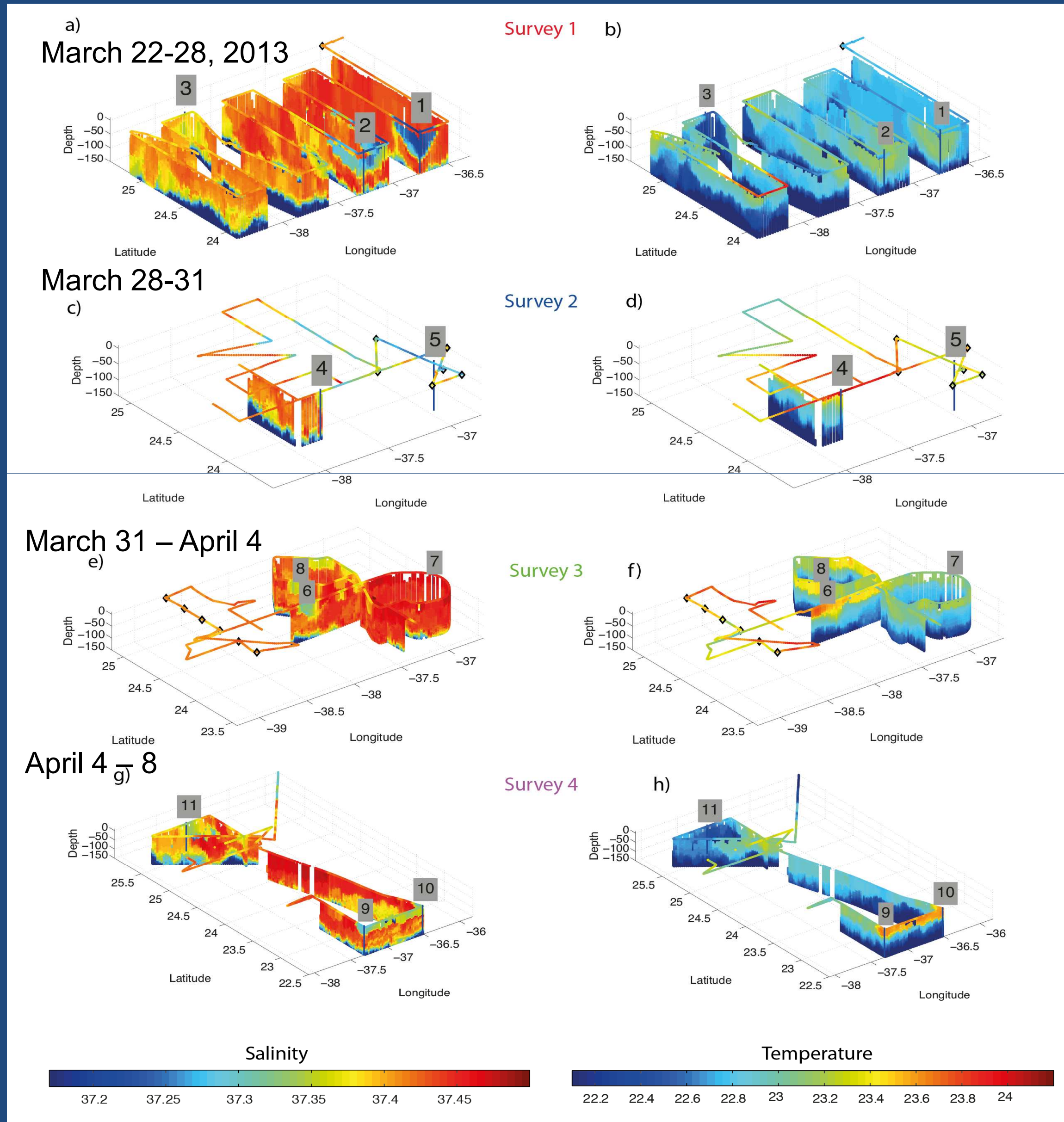
Busecke et al. (2014)

Observed Mesoscale and Sub-Mesoscale Features During SPURS

Salinity Processes in the Upper Ocean Regional Study (SPURS)

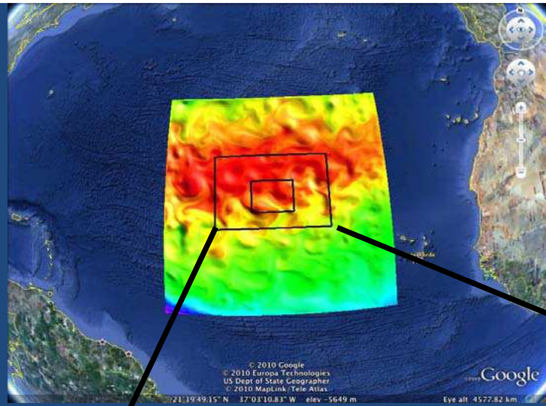


(http://spurs.jpl.nasa.gov)

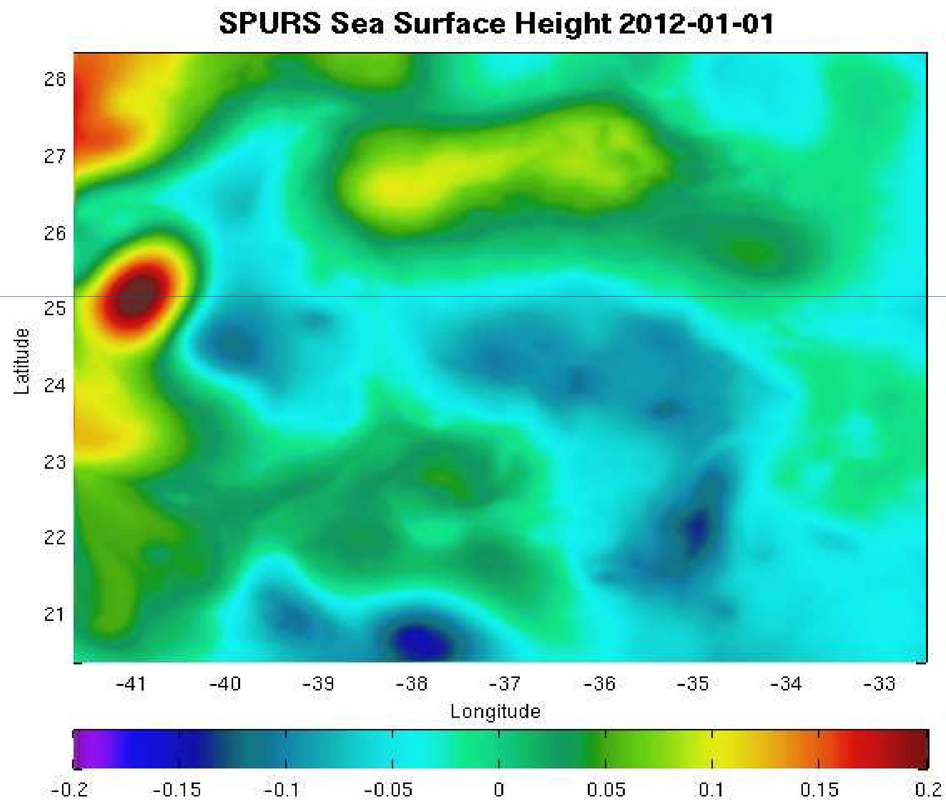


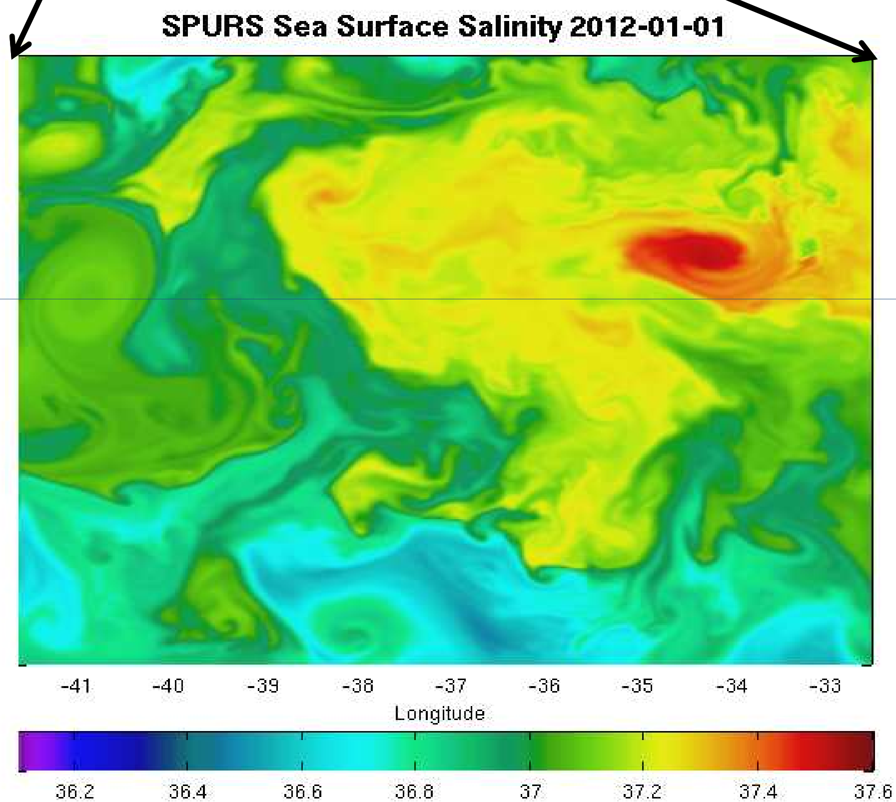
Focus on the maximum sea surface salinity (max-SSS) area

Different Spatial Scales
- Salinity Finer Structures



- ROMS model
- 3-km resolution
- 50 levels
- 6-hourly GFS atmospheric forcing



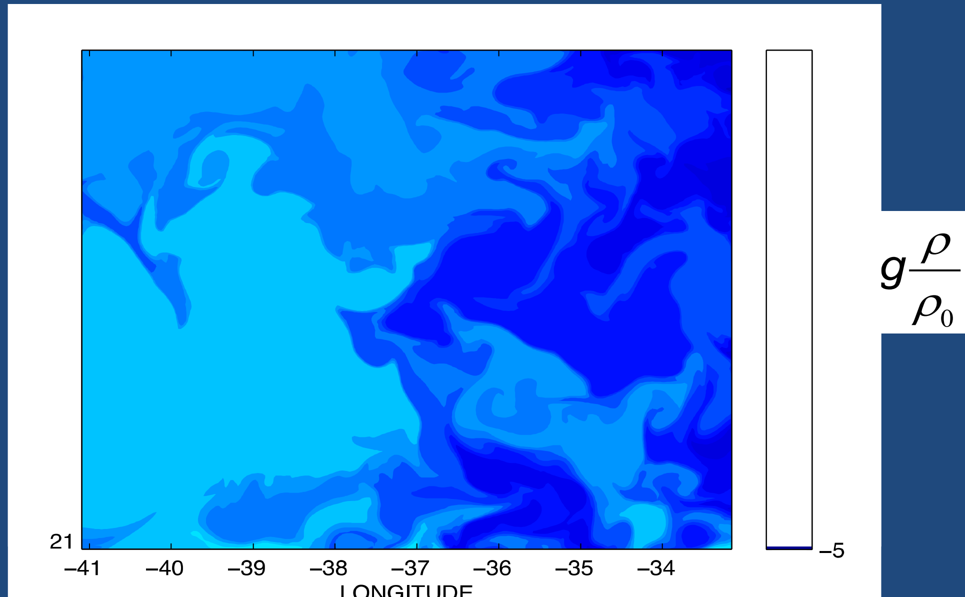


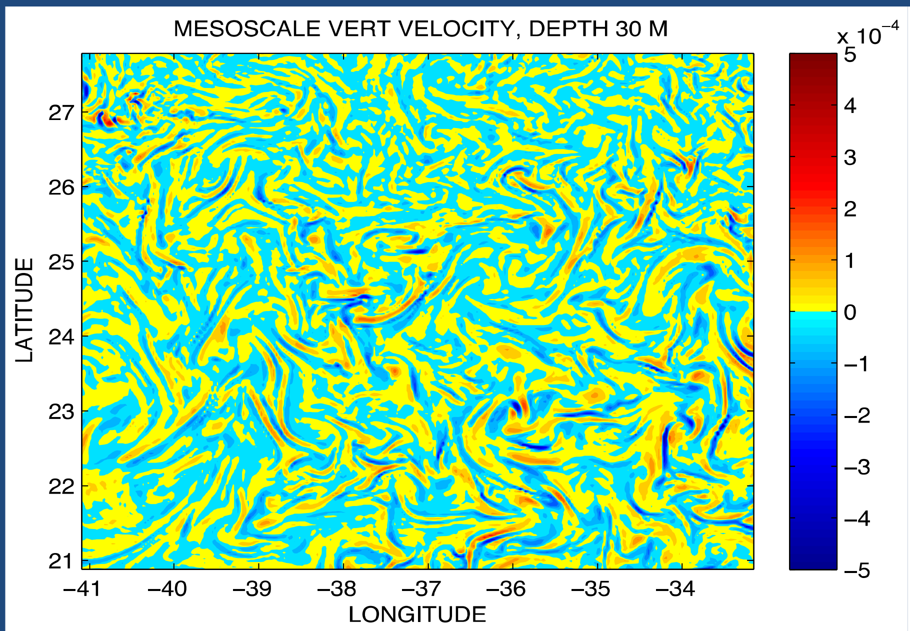
Mesoscale and Sub-Mesoscale Characteristics

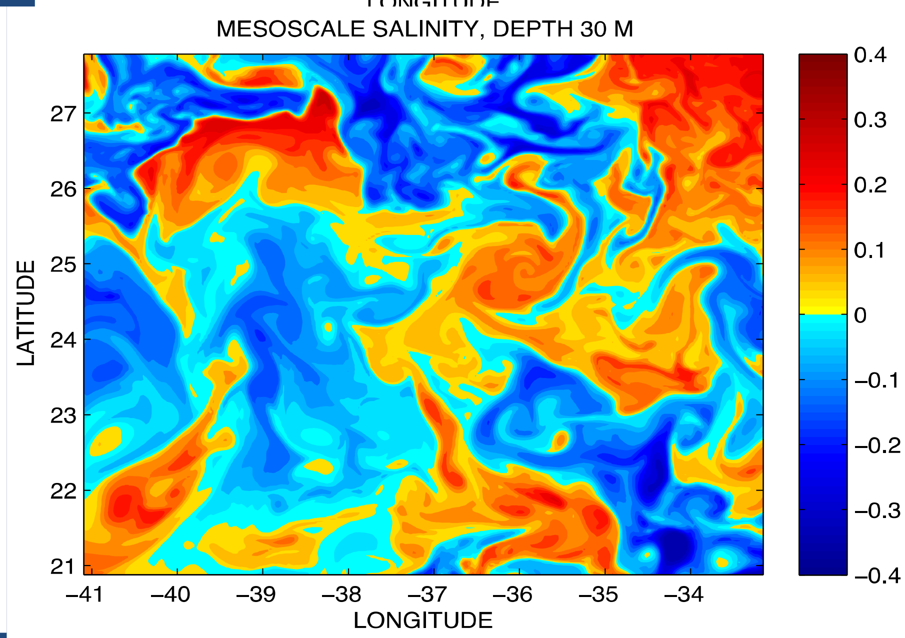
Remove

- **Two monthly mean**
- **Zonal Mean**

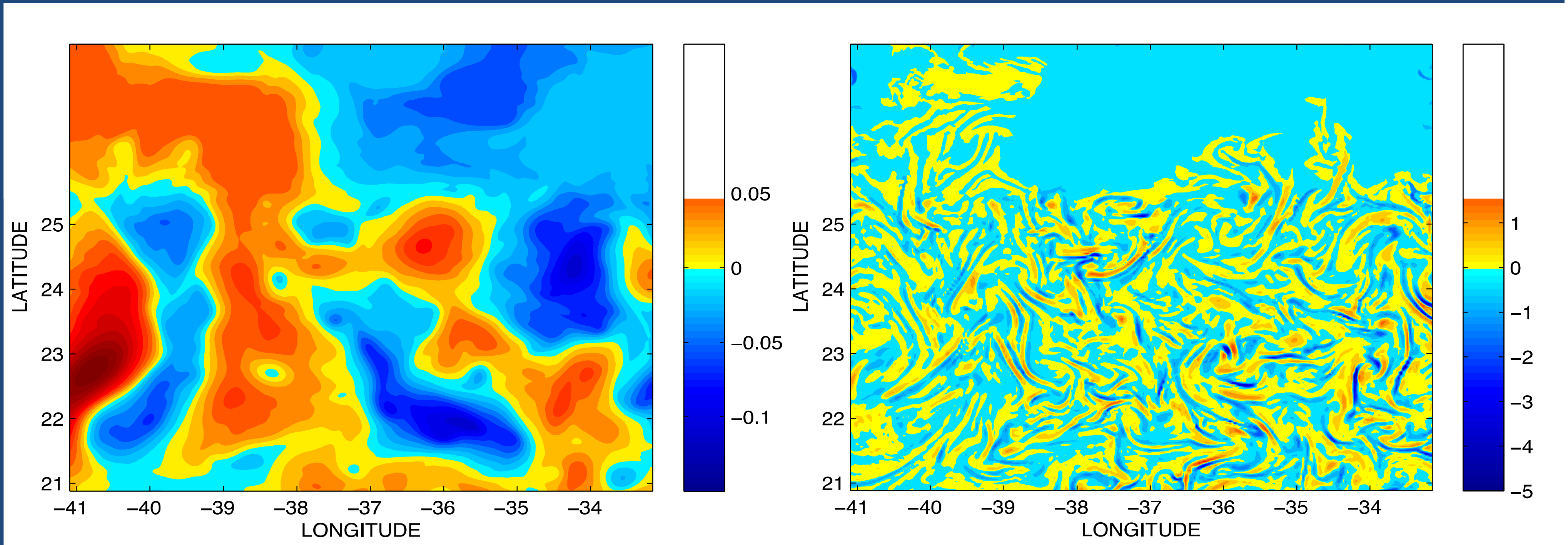
April 6, 2013





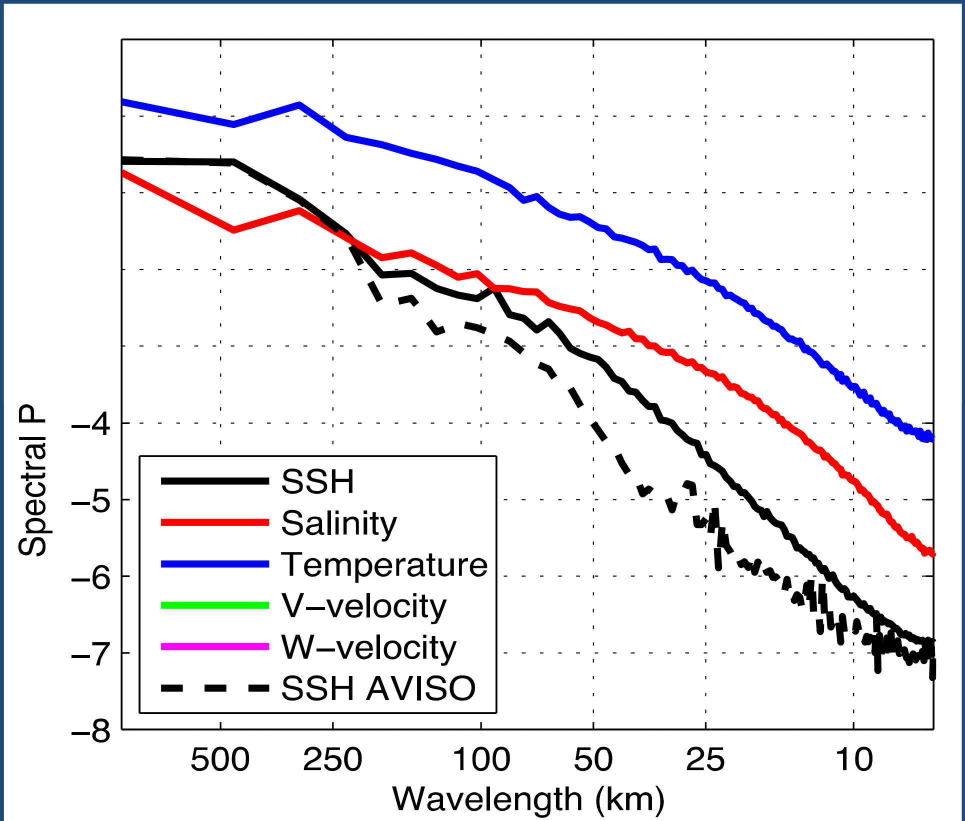


Mesoscale SSH Fronts
Responsible for Submesoscale Vertical Velocity



Implication to data Assimilation: Constraints on mesoscale eddies partially constrain submesoscale features ?

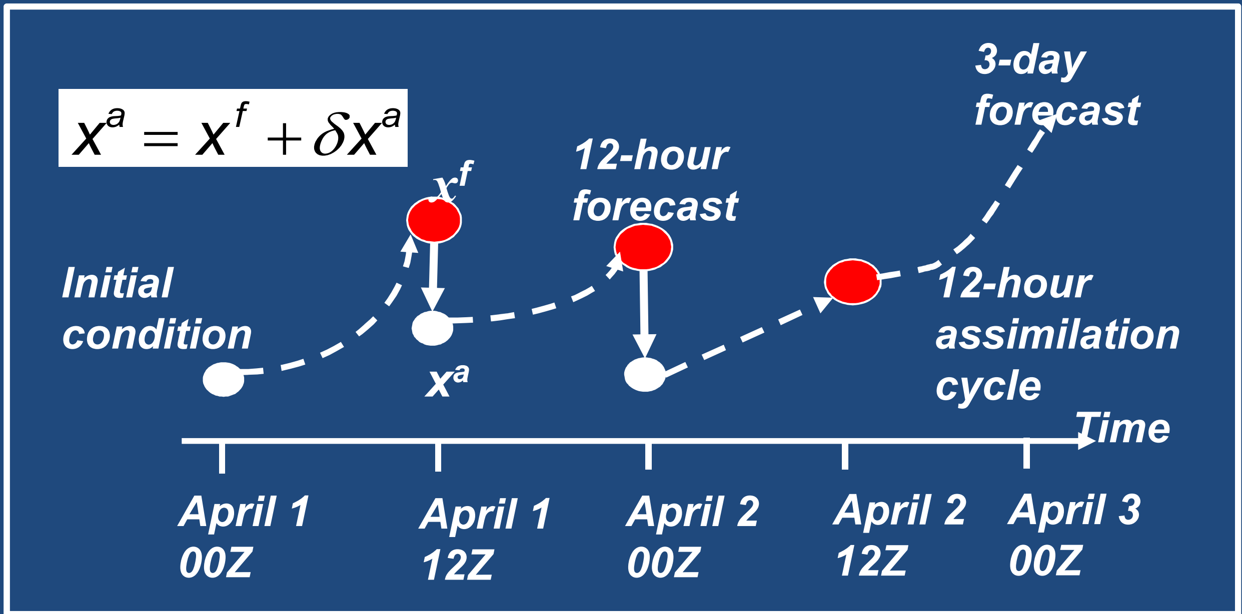
Improved Mesoscales and Mesoscales with Data Assimilation



Average from March 5 through April 5, 2013
(Scaled for plotting)

- The SSH analysis is close to AVISO for scale larger than 250 km.
- The model with data assimilation realistically reproduces submesoscale features observed from high resolution SSTs and SPURS measurements.
- The vertical velocities is largest at a scale of around 20 km (likely depending on 3-km resolution).

How Altimetry Data Impacts Small-Scale Analysis and Forecast



$$\delta x^a = K(\varsigma^o - H\varsigma^f)$$

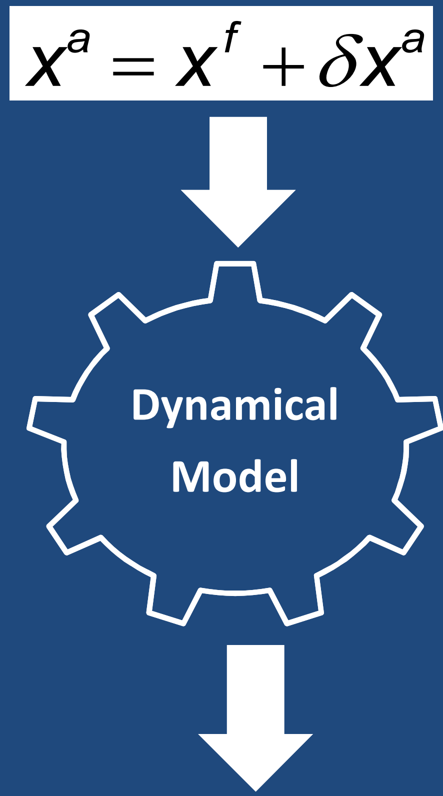
$\delta\varsigma^a, \delta T^a, \delta S^a, \delta\vec{V}^a$

Gain Matrix

Altimetry Data

Direct but smoothed constraint

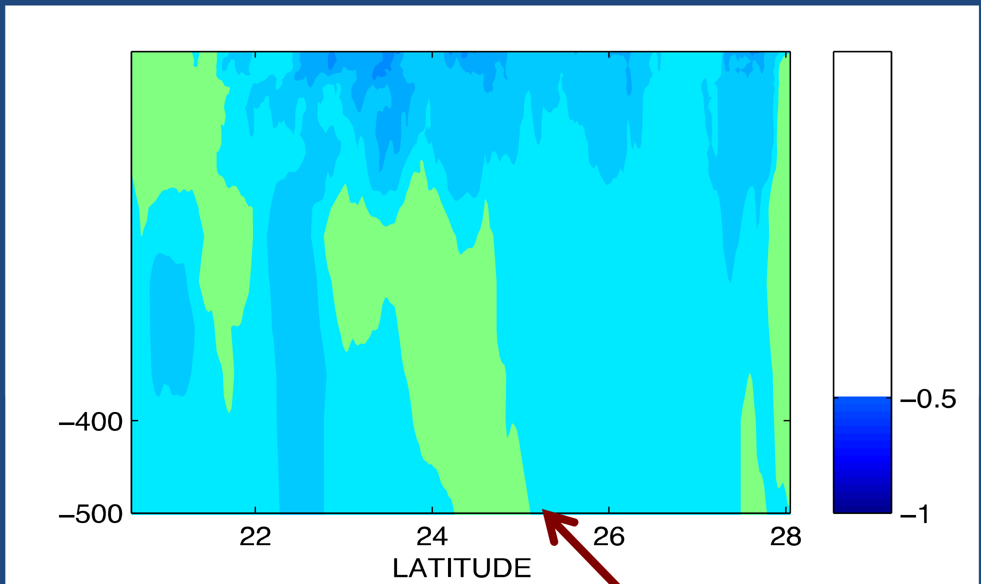
(Li et al., 2015, MWR; 2015, Ocean Dyn.)

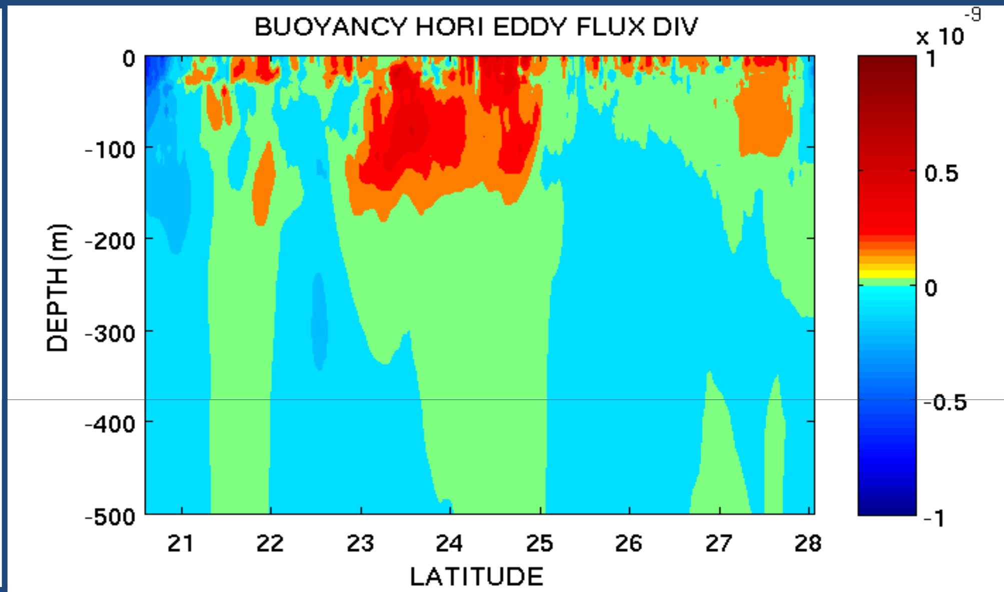


Model Produced Meso/Submesoscales

Partial constraint

SPURS Reanalsysis and Eddy Flux Analysis (1)
Horizontal Divergence



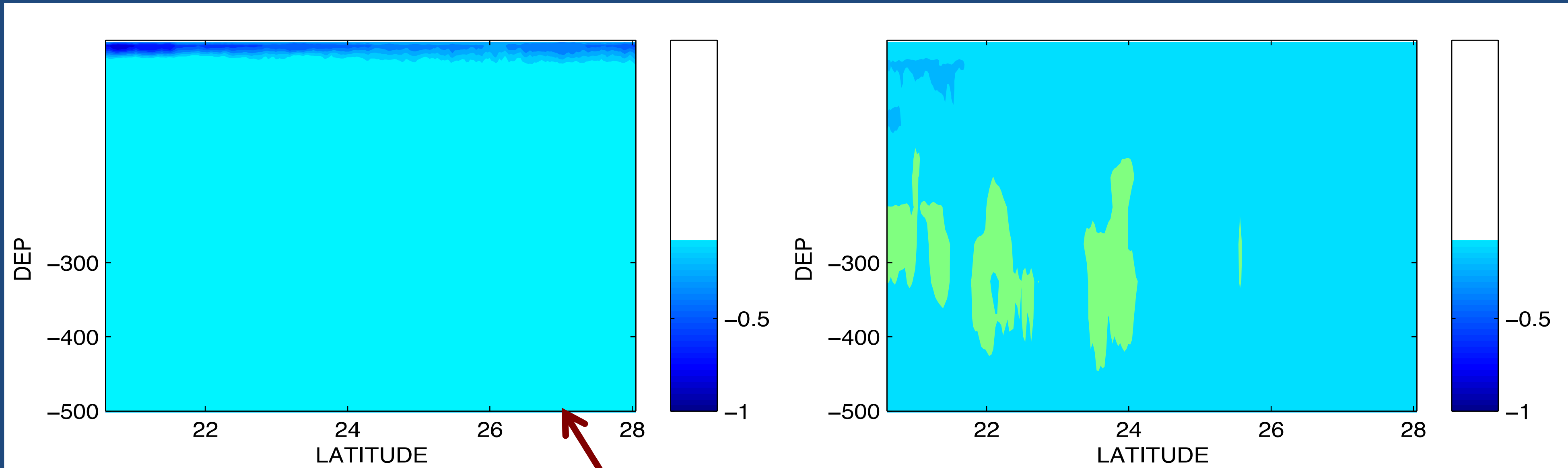


$$10^{-7}\, psu/s = 3.1\, psu/year$$

$$\frac{\partial \bar{s}}{\partial t} + \bar{u}\cdot\nabla\bar{s} + \bar{w}\frac{\partial \bar{s}}{\partial z} = \underline{-\nabla_H \cdot \overline{u's'}} - \frac{\partial \overline{w's'}}{\partial z} + \bar{S}$$

The eddy flux divergence fresh and stratify the maximize salinity are

SPURS Reanalsysis and Eddy Flux Analysis (2)
Vertical Divergence

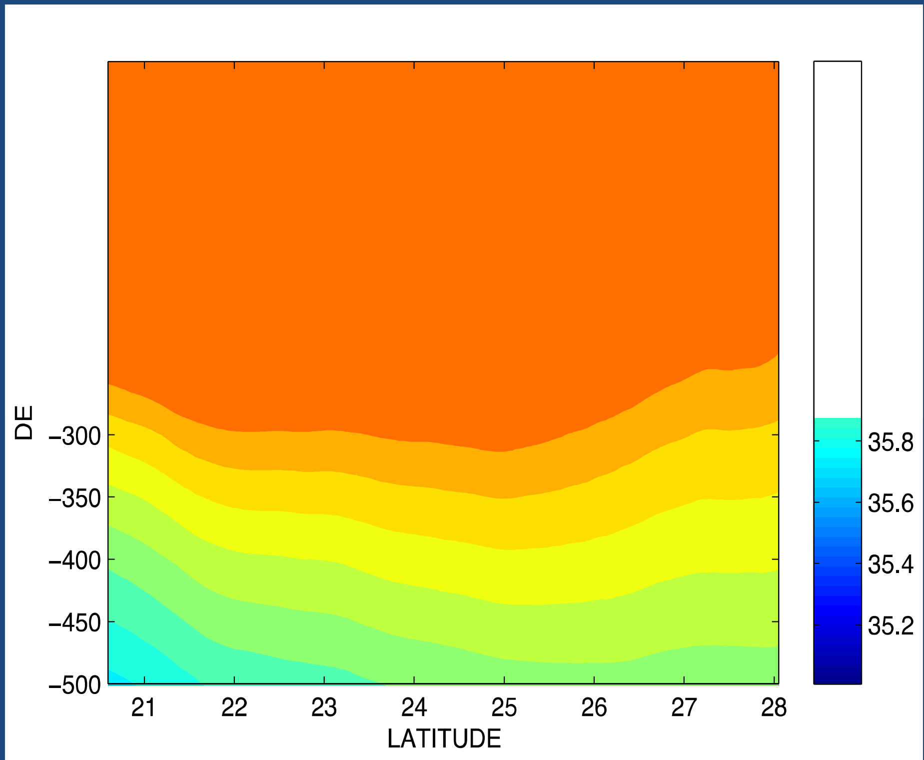


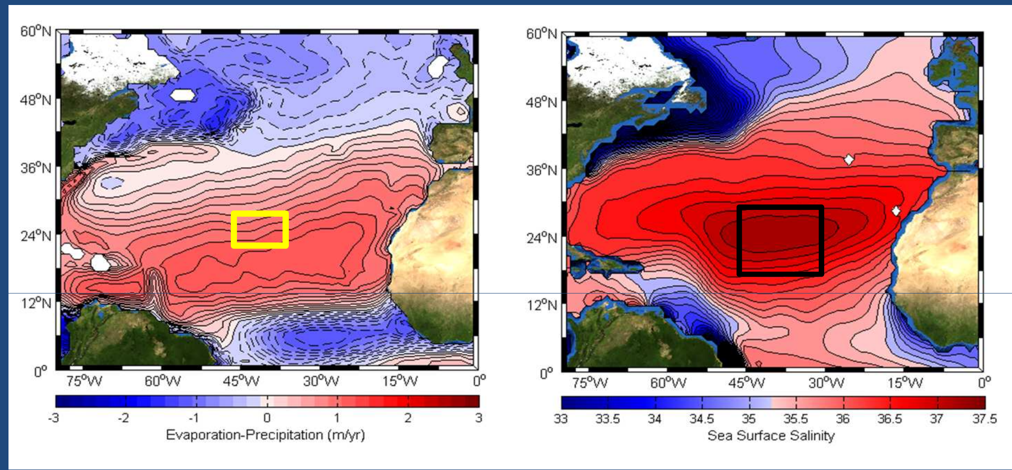
$$10^{-7}\, psu/s = 3.1\, psu/year$$

$$\frac{\partial \bar{s}}{\partial t} + \bar{u}\cdot\nabla\bar{s} + \bar{w}\frac{\partial \bar{s}}{\partial z} = -\nabla_H\cdot\overline{u's'} - \underline{\frac{\partial\overline{w's'}}{\partial z}} + \bar{S}$$

- **Strong submesoscale activities**
- **Rapid restratification**
- **Comparable to other regions?**

Salinity Budget for the Maximum Salinity (22.5ºN-25.5ºN)





0.42 my^{-1} **0.15 my^{-1}**

$$\frac{\partial \bar{s}}{\partial t} + \bar{u}\cdot\nabla\bar{s} + \bar{w}\frac{\partial \bar{s}}{\partial z} = \underline{-\nabla_H \cdot \overline{u's'}} - \frac{\partial \overline{w's'}}{\underline{\partial z}} + \bar{S}$$

Mesoscale **Submesoscale**

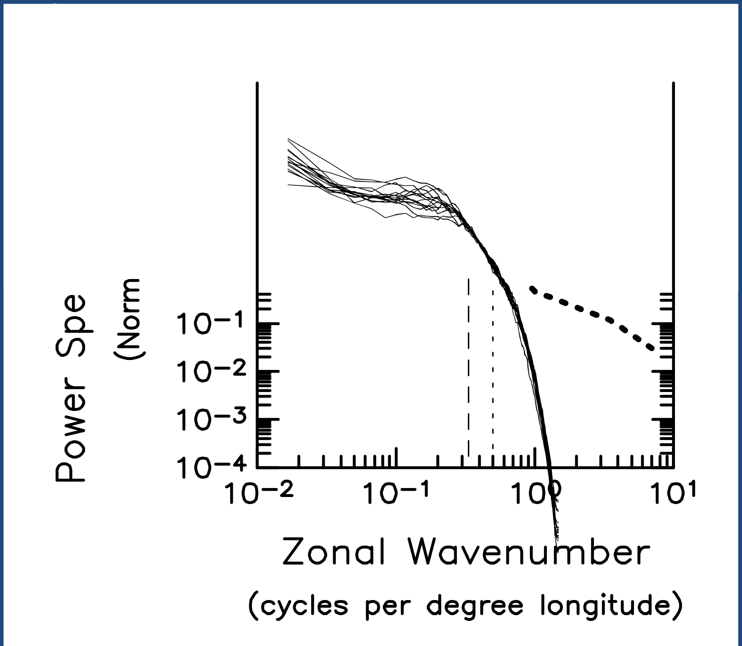
Summary

1. The assimilation of altimetry data constrains eddies larger than 200 km and also improves the representation of submesoscales down to tens of km.
2. Near surface, salinity and buoyancy have considerably stronger submesoscale features, which are subject to submesoscale vertical velocities associated with mesoscale SSH fronts.
3. Reanalysis has been produced for SPURS with the assimilation of altimetry data.
4. The eddy flux divergence analysis from the reanalysis shows that both mesoscale and submesoscale flux divergences account for a significant part of the salinity budget in the maximum salinity area.

Back up

How Does the Altimetry Data Impacts Representation of Meso-Scale Eddies in Data Assimilation?

AVISO vs Along Track



(Chelton et al, 2011)

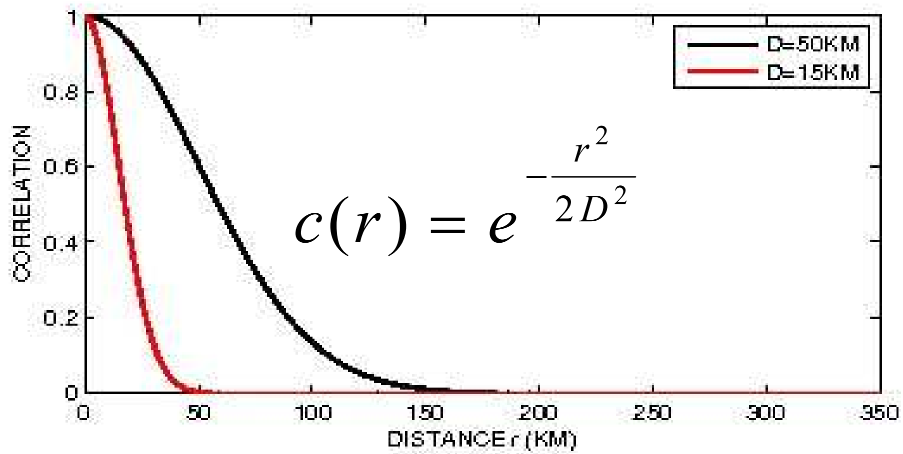
In Data Analysis

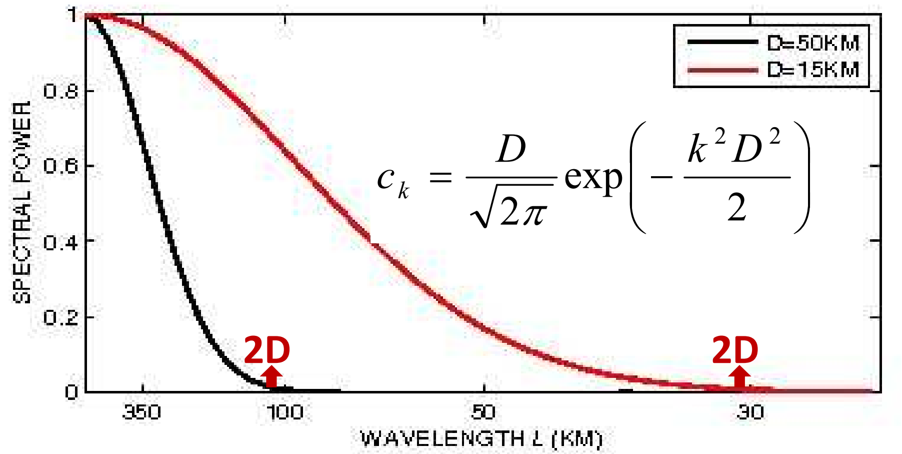
- Eddies down to 100 km along track (?)
- Eddies down to 200 km in 2D maps, with reduced amplitudes approaching 200 km (e.g., Chelton et al., 2011)
- Difference between the OI maps from four and two altimeters as large as 10 cm (Pascual et al., 2006)

In Data Assimilation

- Frontogenesis deterministic conditioned on the accurate placement of the mesoscale (Jacobs, 2014).

Multi-Scale 3DVAR with Background Error Covariance of Multi-Decorrelation Length Scales





$$x = x_L + x_S$$

$$B = B_L + B_S$$

$$\min_x J(\delta x) = \frac{1}{2}\delta x^T (B_L + B_S)^{-1} \delta x + \frac{1}{2}(H\delta x - \delta y)^T R^{-1}(H\delta x - \delta y)$$

Low resolution obs

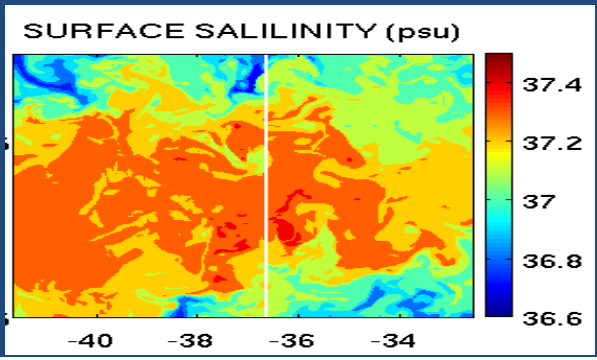
$$\min_{\delta x_L} J(\delta x_L) = \frac{1}{2}\delta x_L{}^T B_L^{-1} \delta x_L + \frac{1}{2}(H\delta x_L - \delta y)^T \left(H B_S H^T + R\right)^{-1} (H\delta x_L - \delta y)$$

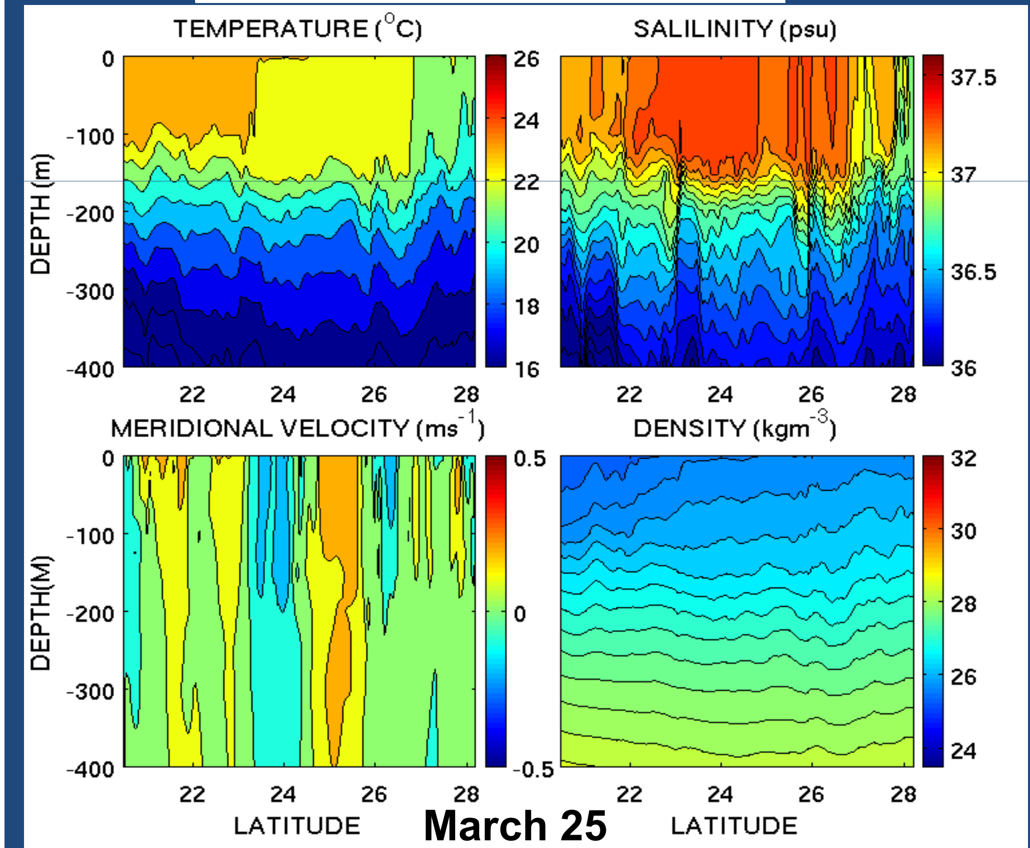
$$\min_{\delta x_S} J(\delta x_S) = \frac{1}{2}\delta x_S{}^T B_S^{-1} \delta x_S + \frac{1}{2}(H\delta x_S - \delta y)^T \left(H B_L H^T + R\right)^{-1} (H\delta x_S - \delta y)$$

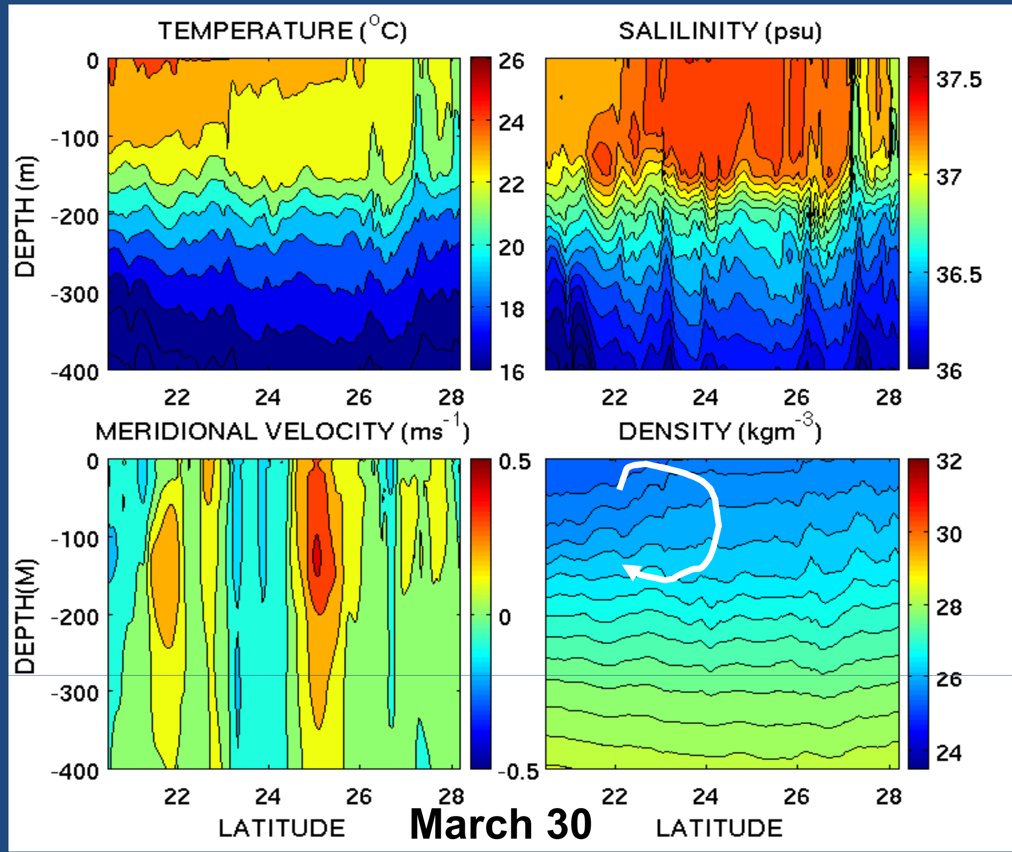
High resolution obs

(Li et al., 2014, JGR, MWR)

What Occurred ?

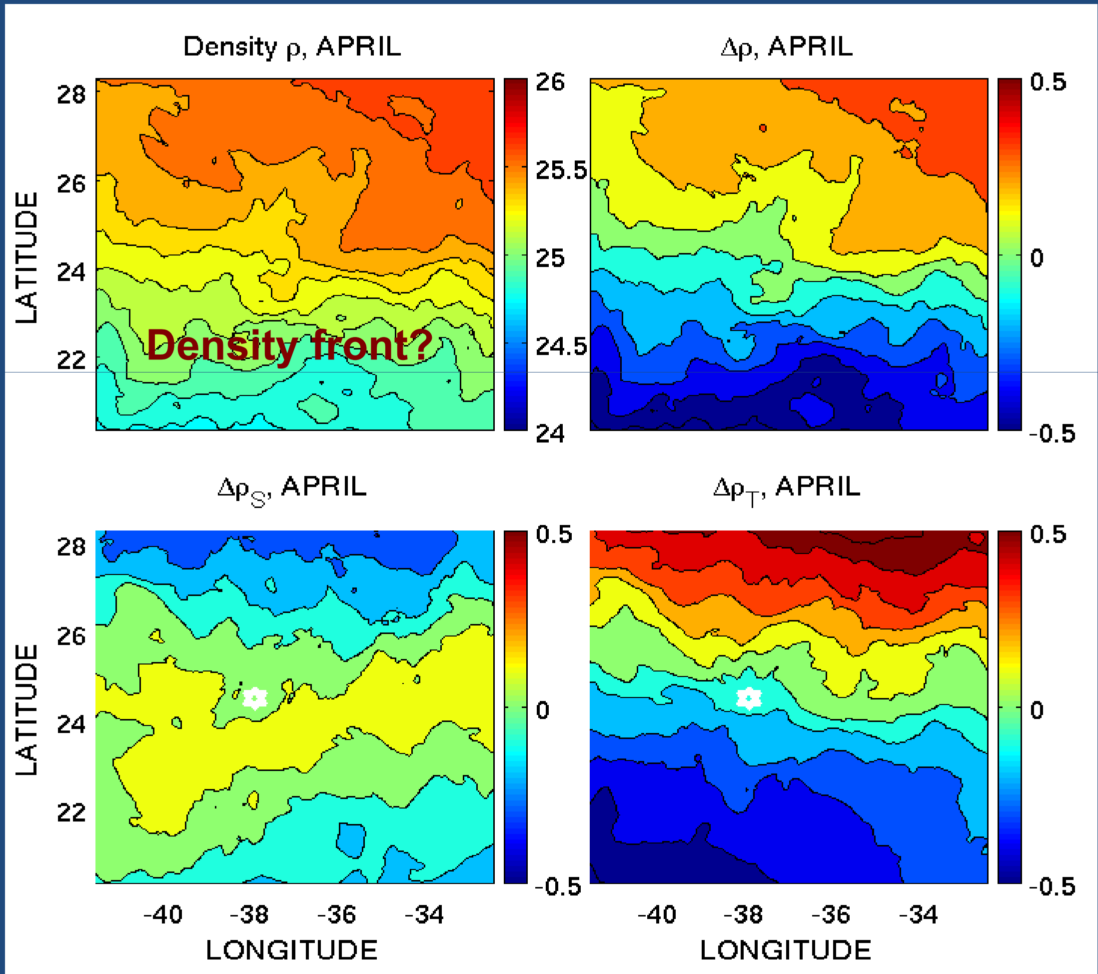


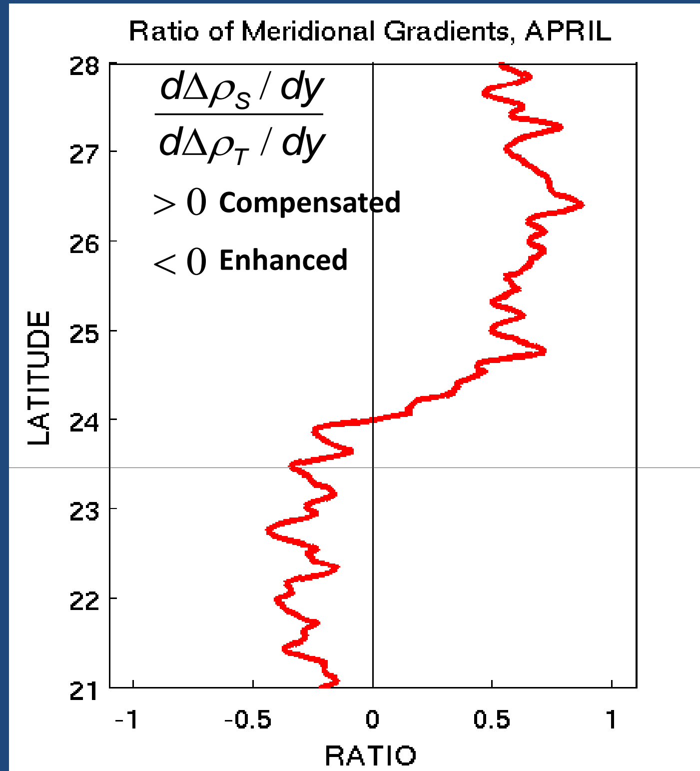




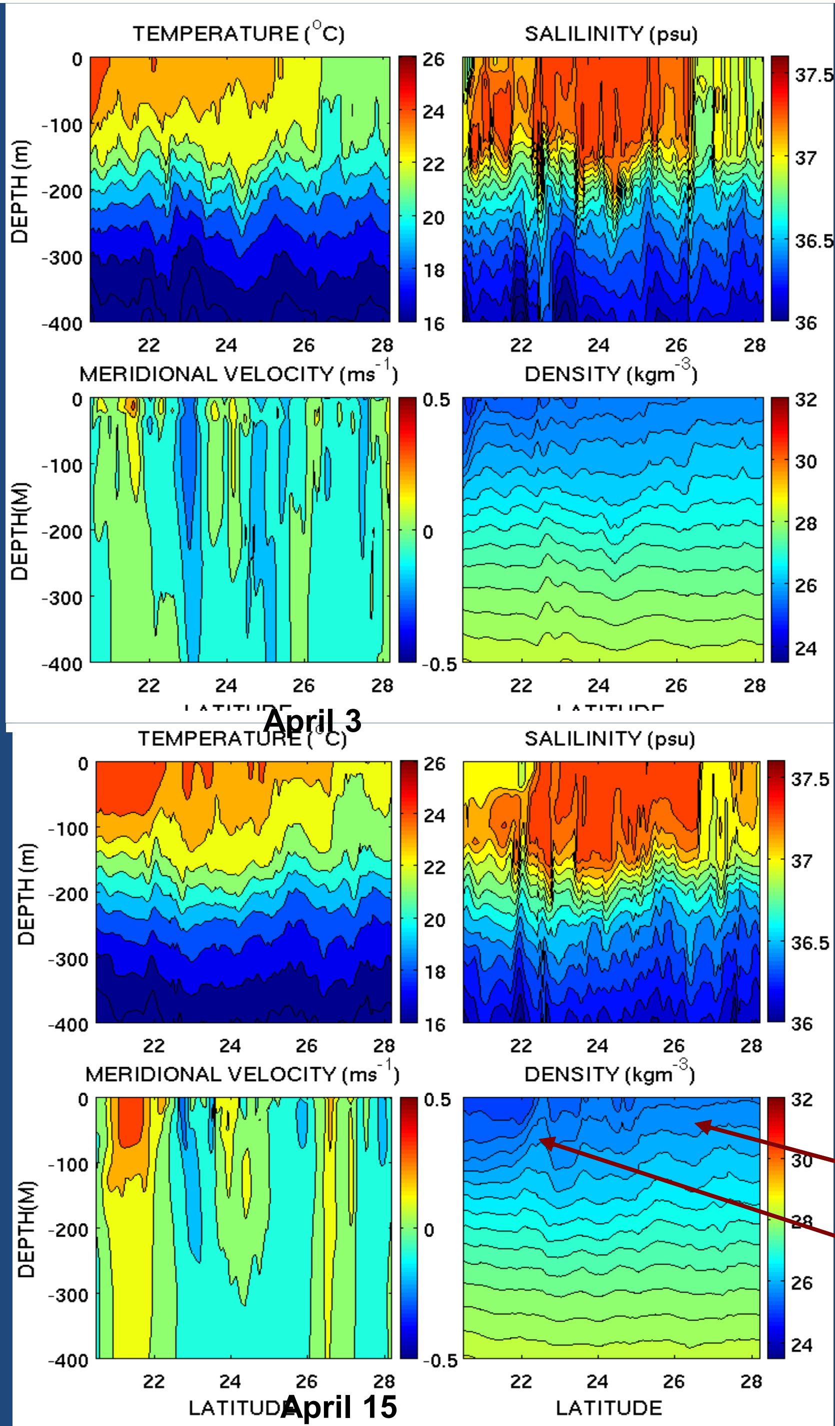
1. Fresher-warmer water intrusion
2. Intensification of mesoscale systems
3. Rapid stratification
4. Secondary circulation
5. Baroclinic instability

Baroclinity: Density Compensation and Enhancement

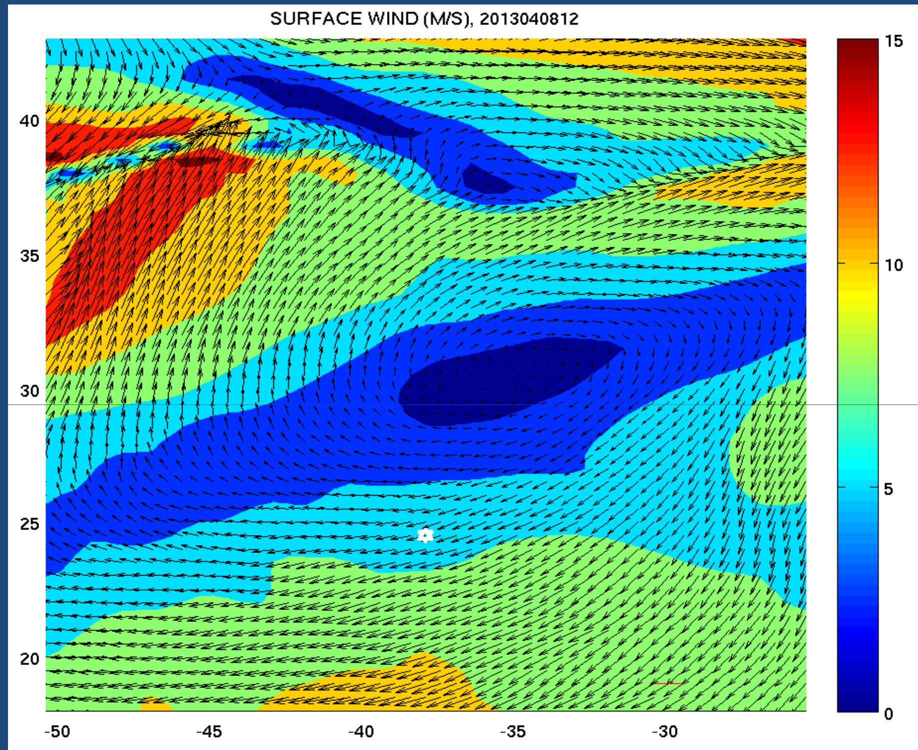




The density anti-compensation establishes intense density gradients and thus baroclinicity south of 24°N



Stratification: Up-Front Winds



- Up front winds
- Stratification
- Frontogenesis