# Understanding Ocean Processes during VOCALS-
# A data assimilation framework

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with data provided by:
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# Motivation

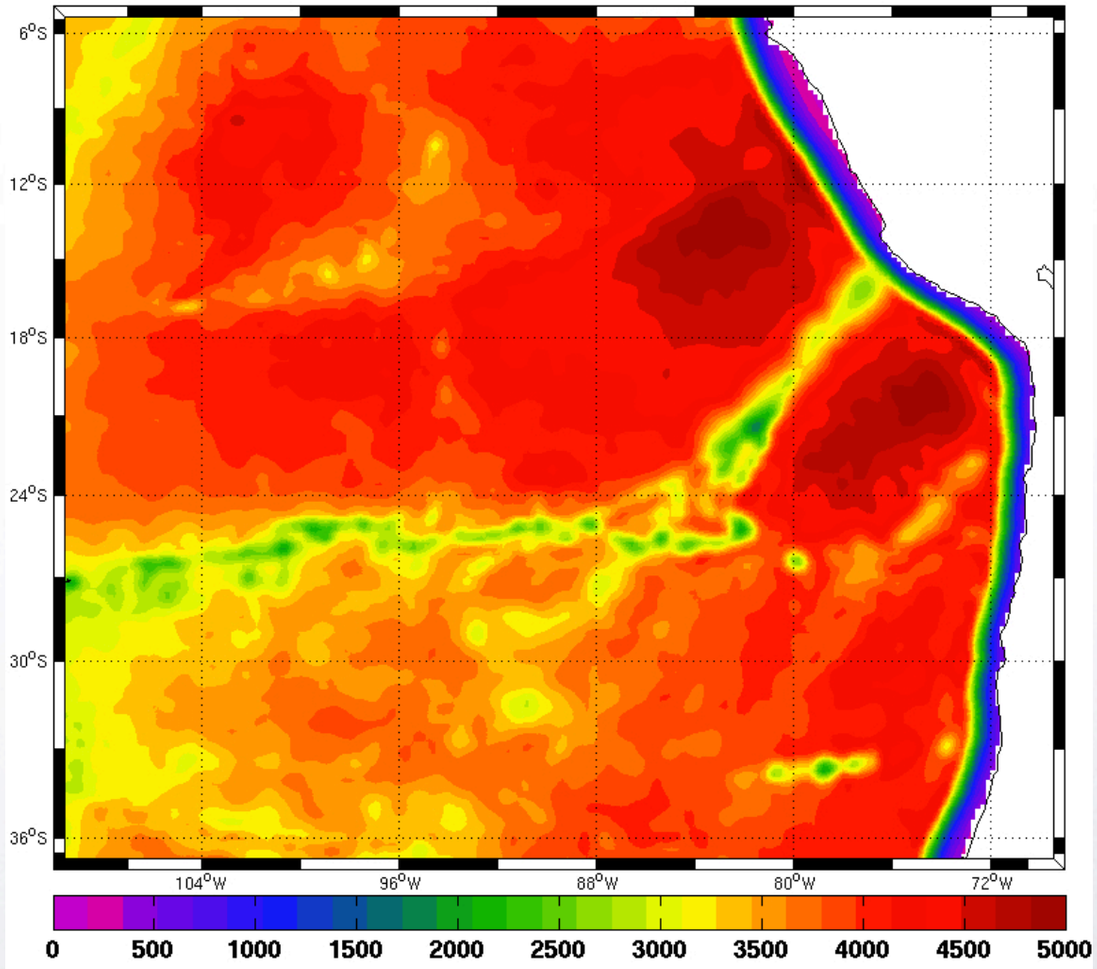
- Diagnose the **physical balances and sensitivities** of the ocean circulation fields.

- **Assimilate** the data from **mesoscale oceanic surveys** of the VOCALS observations in a regional ocean modeling system (ROMS).

- **Understand** the **biological response,** as well as the **heat transport** processes observed during VOCALS-REx**.**

# Model Configuration: Outer Domain

- 110° W to 69° W and 5° S to 37° S
- Horizontal resolution of 20 km
- 32 vertical levels.
- 7 years climatological spin-up and then annual forcing with 2007-08 winds from QuikSCAT, heat fluxes from NCEP or bulk fluxes from NCEP.



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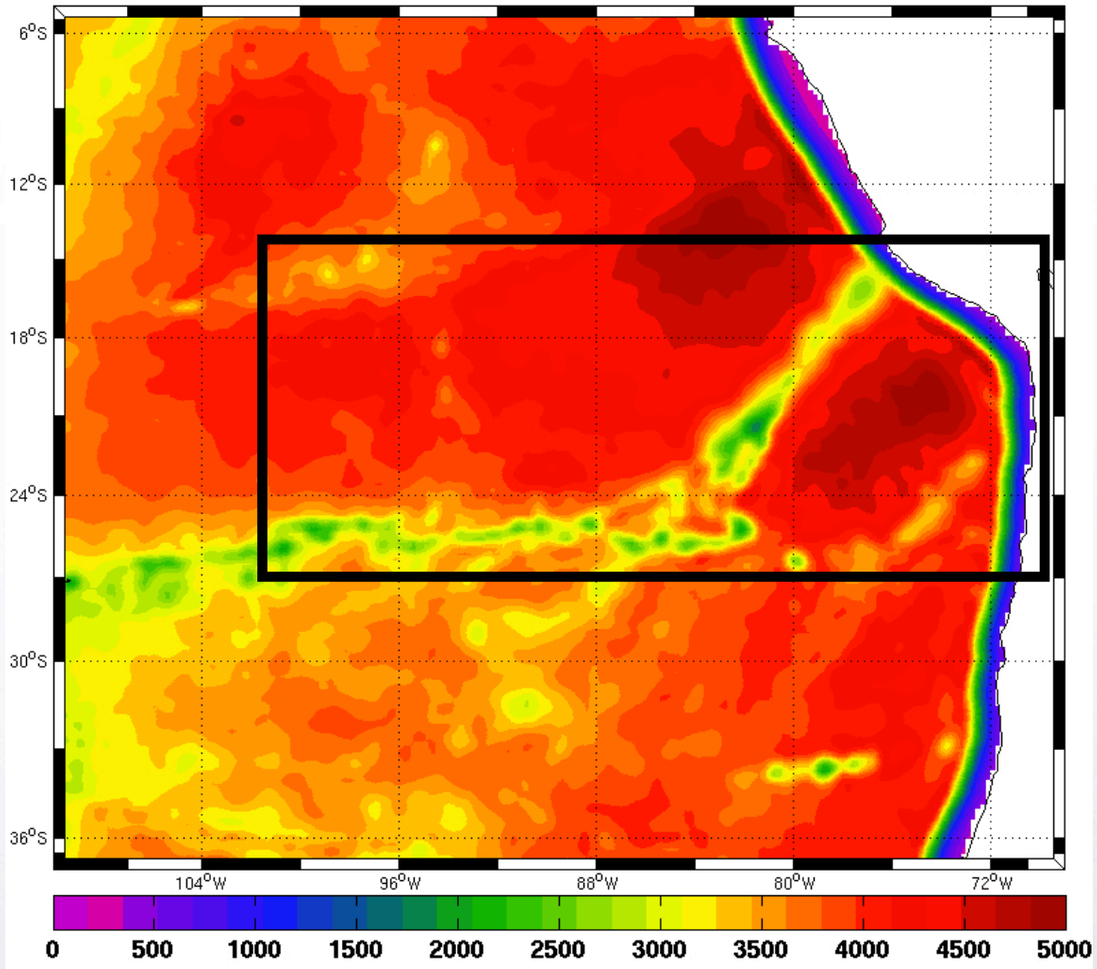
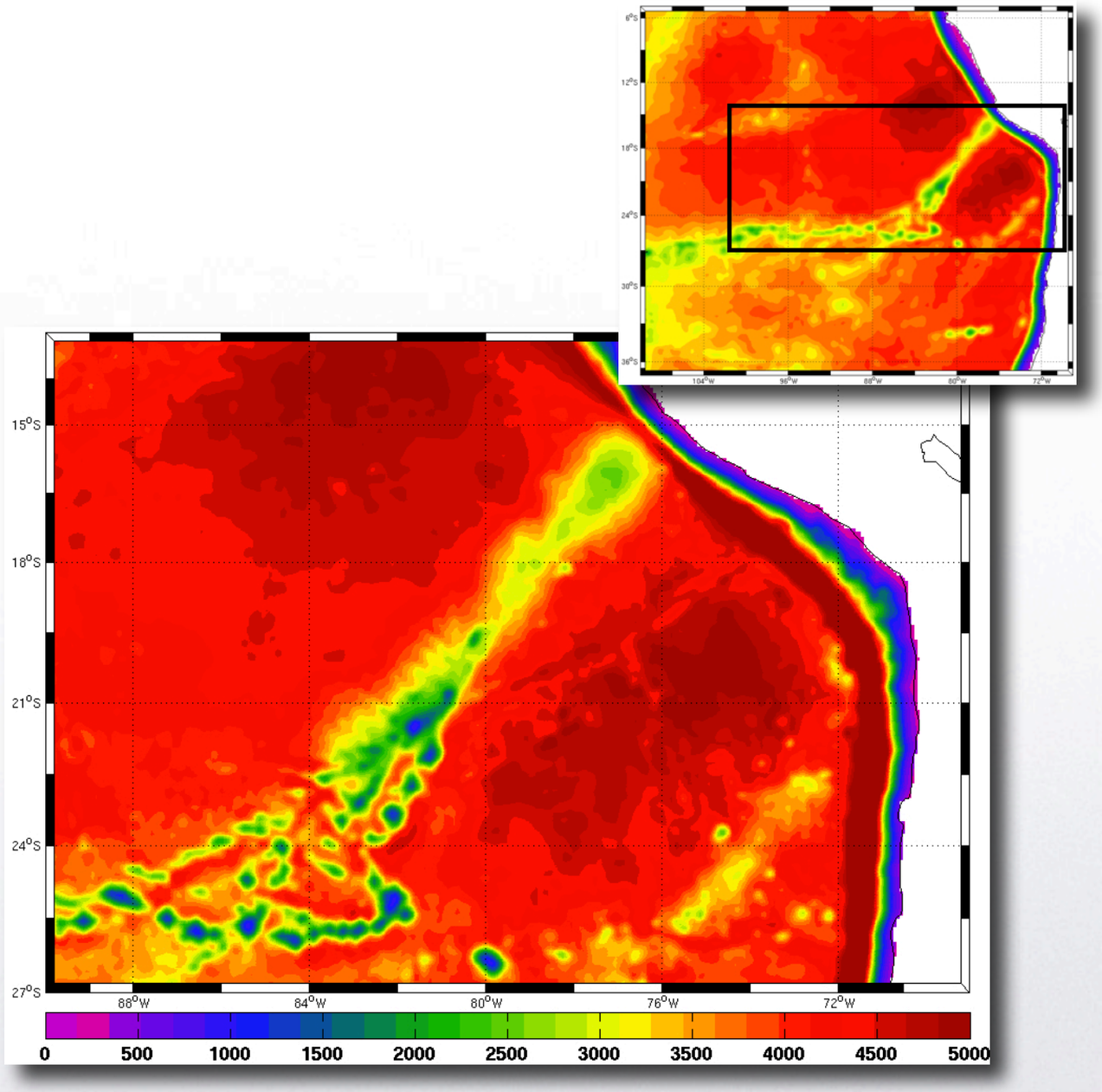


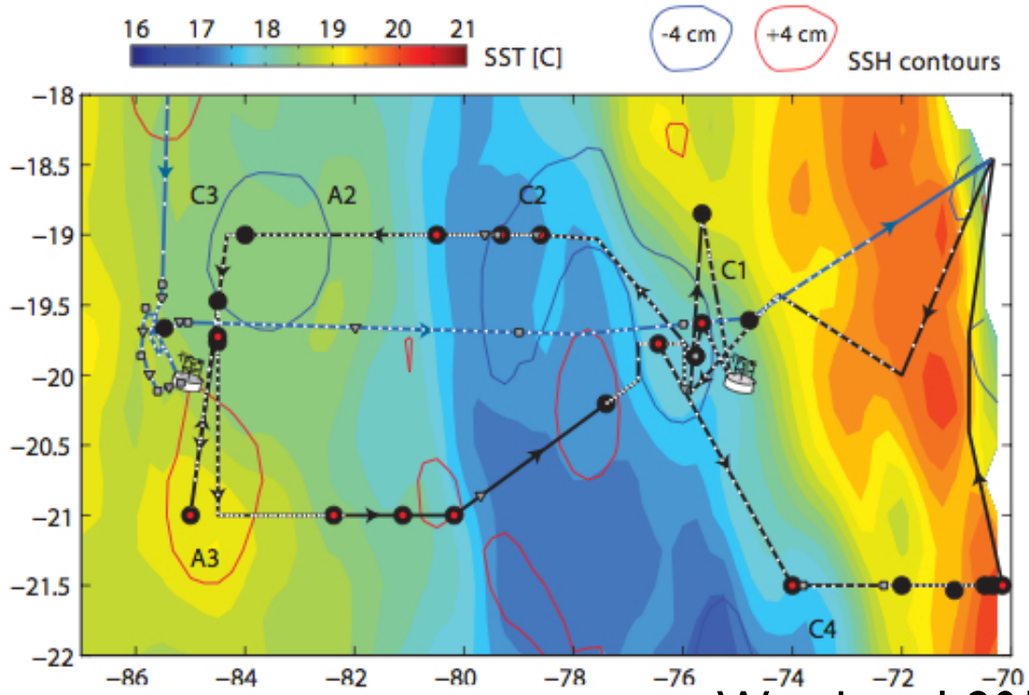
# Model Configuration: Inner Domain

- 90° W - 69° W, 13° S - 27° S
- Horizontal resolution of about 7 km.
- 32 vertical levels.
- At open boundaries, the inner-domain solution was constrained to match the solution of the outer domain.

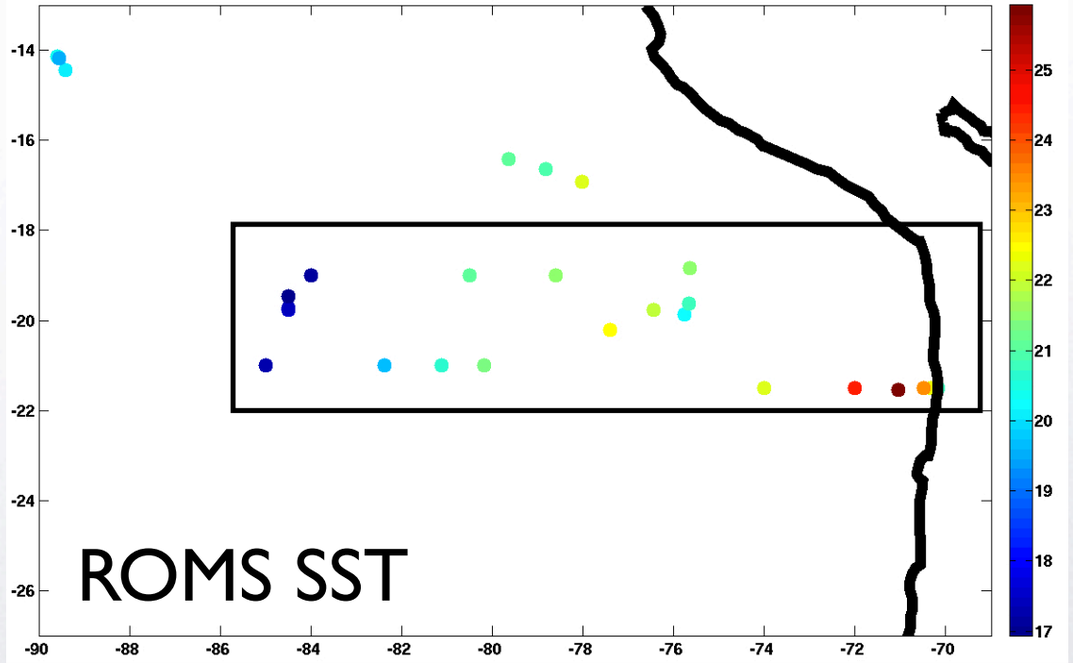


# Assimilated Data

- Ron Brown CTD data (Temp., Salinity) (35 CTD Casts)
- SST (AVHRR along track), SSH (Topex-Poseidon) (gridded AVISO)
- ARGO Profiles




Wood et al. 2011

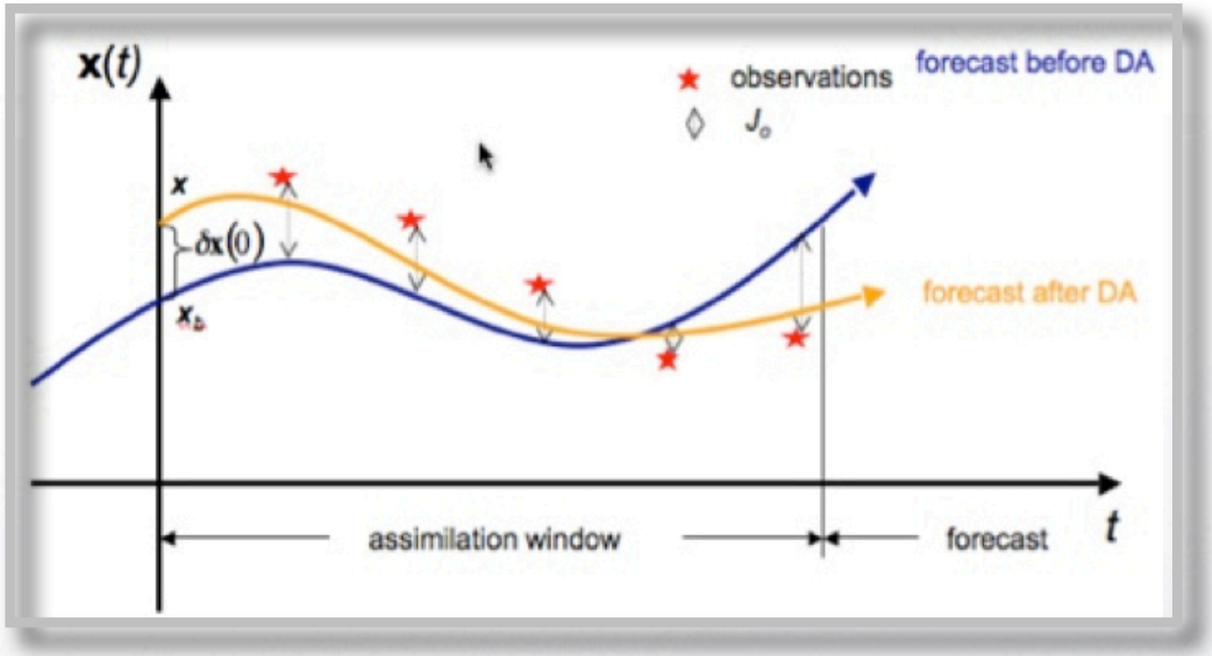


# What is our Data Assimilation strategy?

# Incremental Strong Four Dimensional Variational Analysis (IS4DVAR)

*We want to estimate a new state which is close to the observations, yet dynamically consistent.*

*The new estimated state minimizes the cost function which is combination of two terms.*



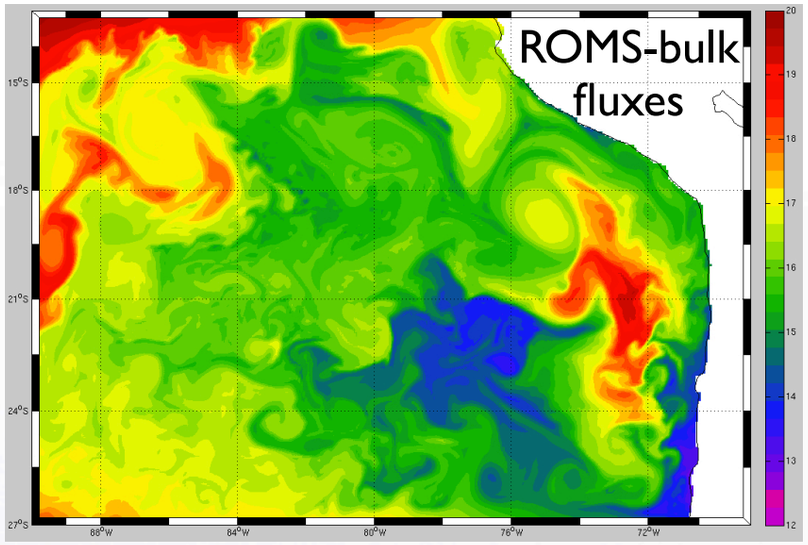

$$J(\delta \mathbf{x}(0)) = \frac{1}{2}\underbrace{\delta \mathbf{x}(0)^T \mathbf{B}^{-1} \delta \mathbf{x}(0)}_{J_b} + \frac{1}{2}\underbrace{\sum_{i=1}^{N} \{\mathbf{H}_i(\mathbf{x}_i + \delta \mathbf{x}_i) - \mathbf{y}_i\}^T \mathbf{O}_i^{-1} \{\mathbf{H}_i(\mathbf{x}_i + \delta \mathbf{x}_i) - \mathbf{y}_i\}}_{J_o}$$

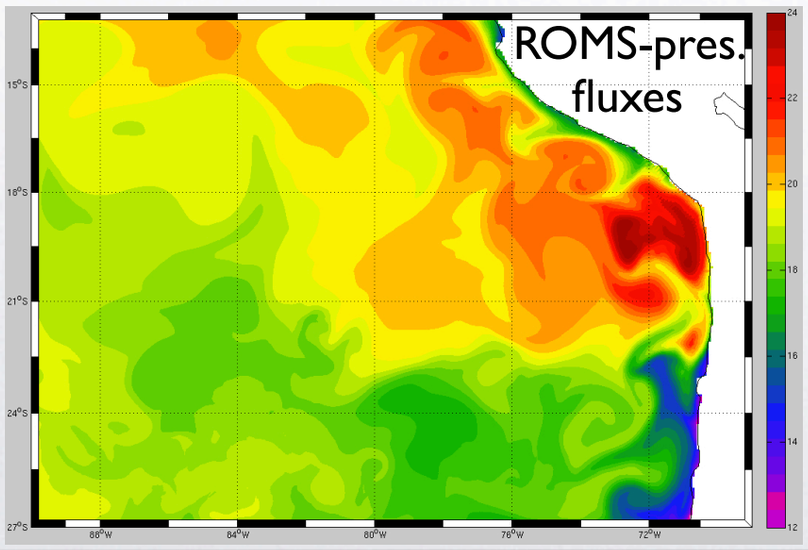
Background

Misfit to Obs.

# Assimilation Experiment Setup

Model SST (Oct 14,2008)

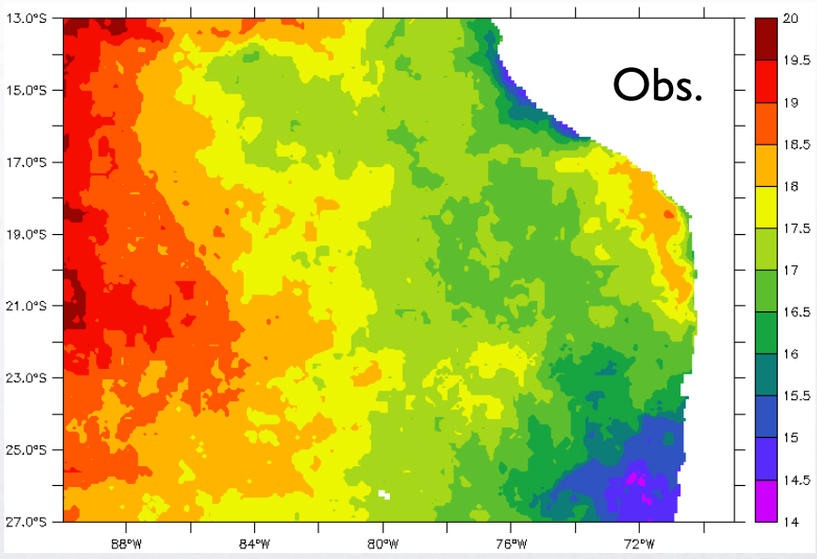


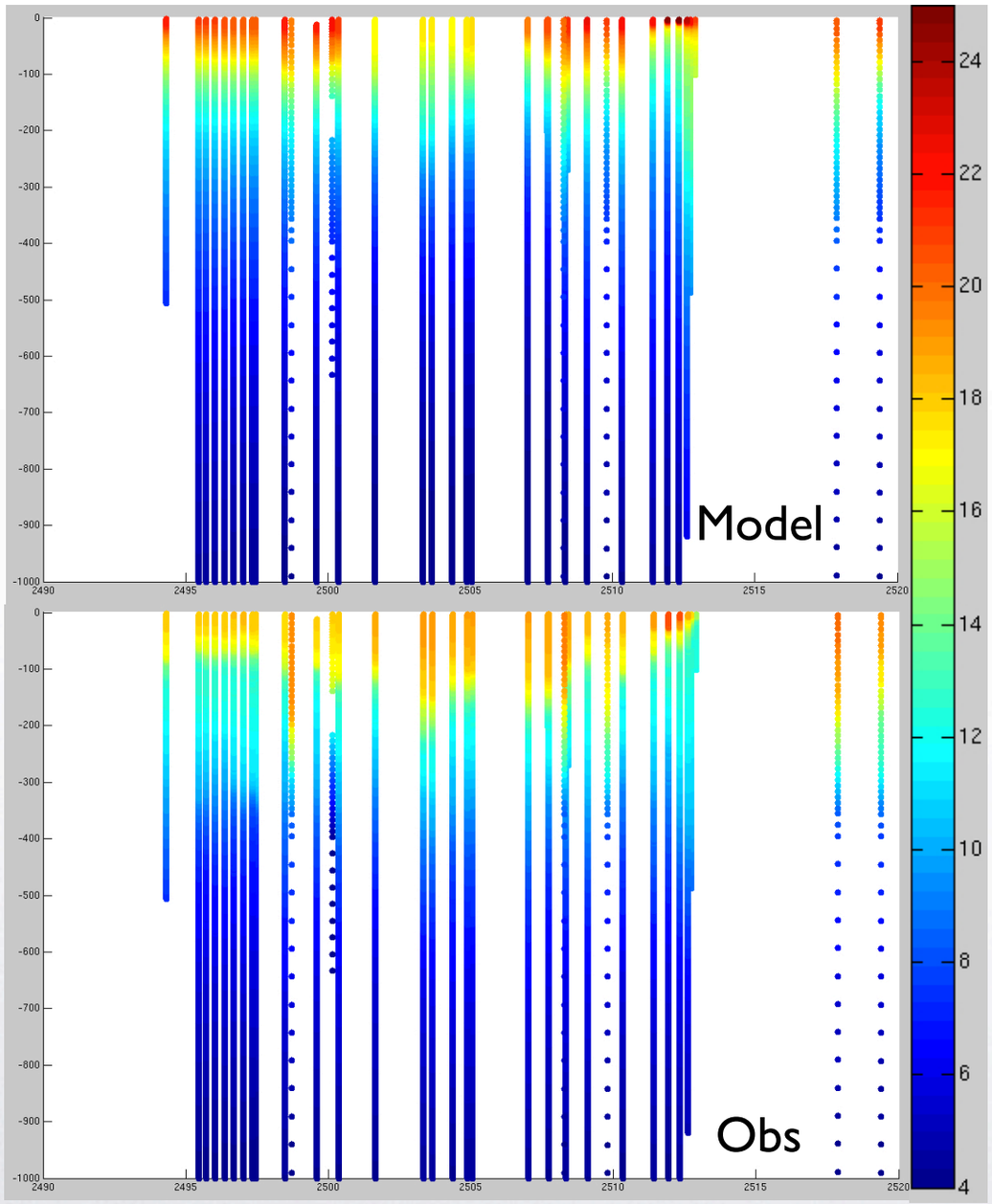




*Nonlinear model initial values are far away from observations to get a good estimate of the state using IS4DVAR.*

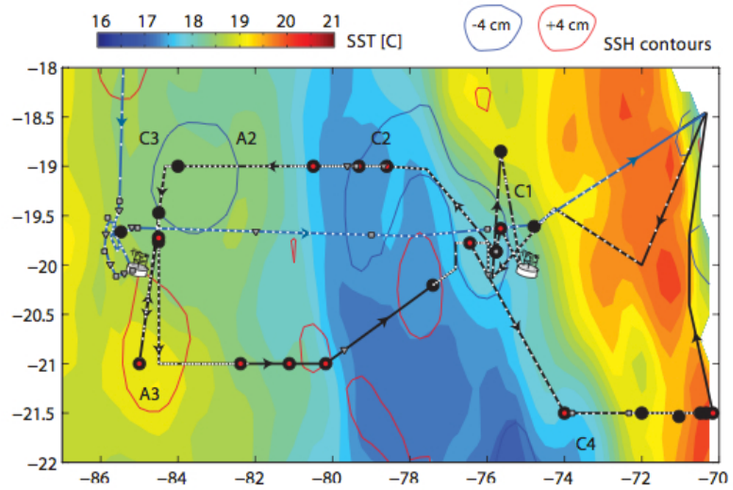
*Hence, data are assimilated for the pre-VOCALS months of Aug and Sep 2008 to get a better initial condition.*

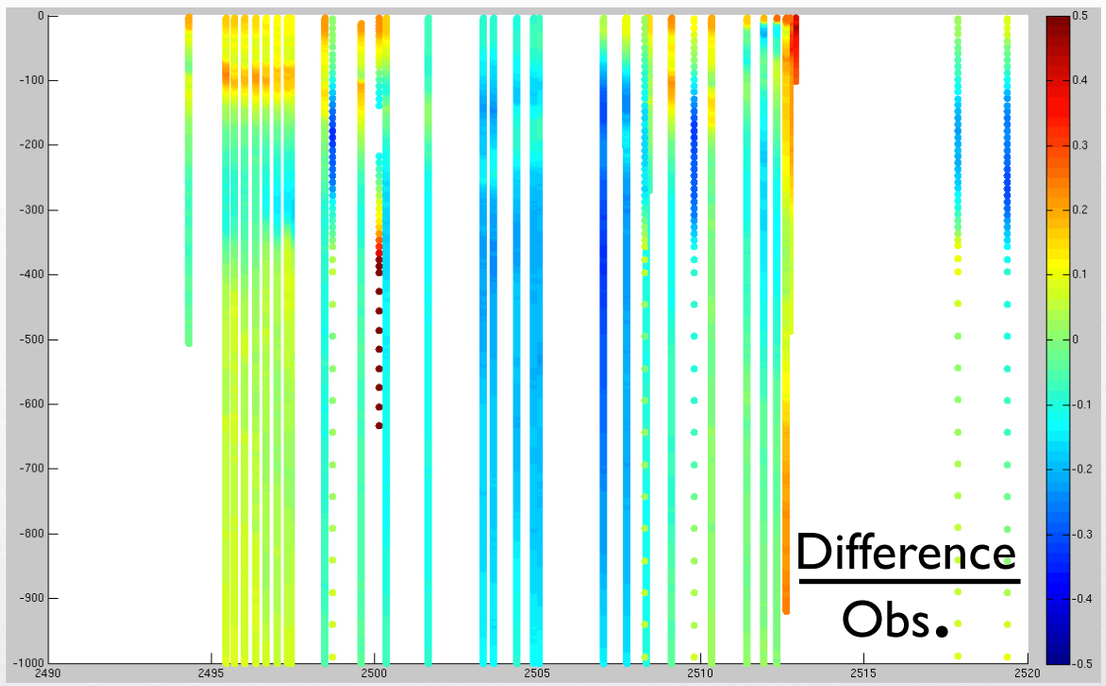
## SST for Oct. 14, 2008



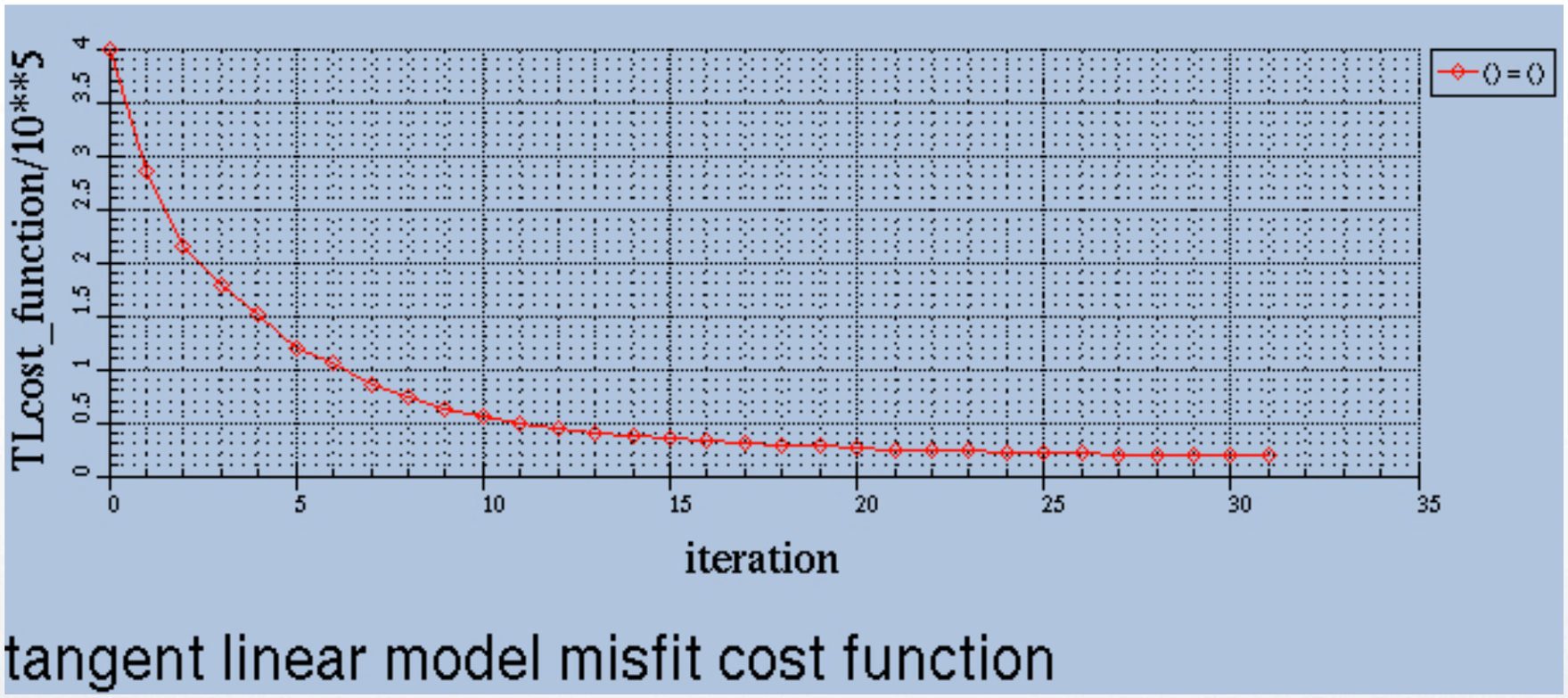



# Model vs Obs Profile



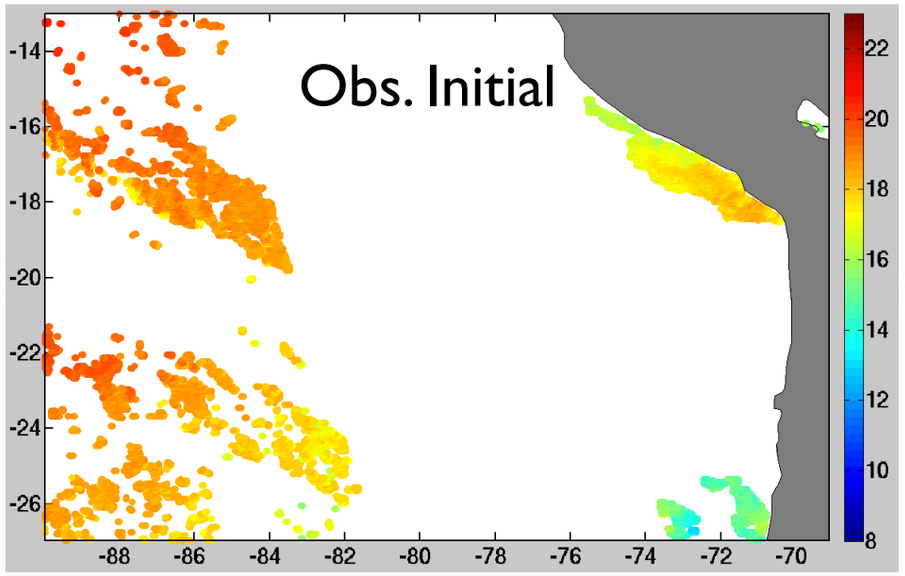



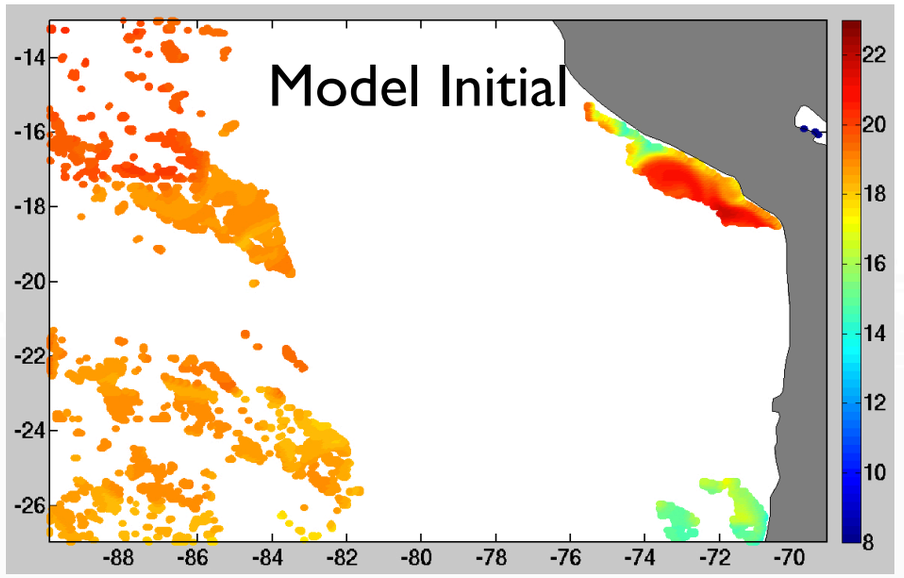
# Cost Function Reduction achieved in Aug 2008.

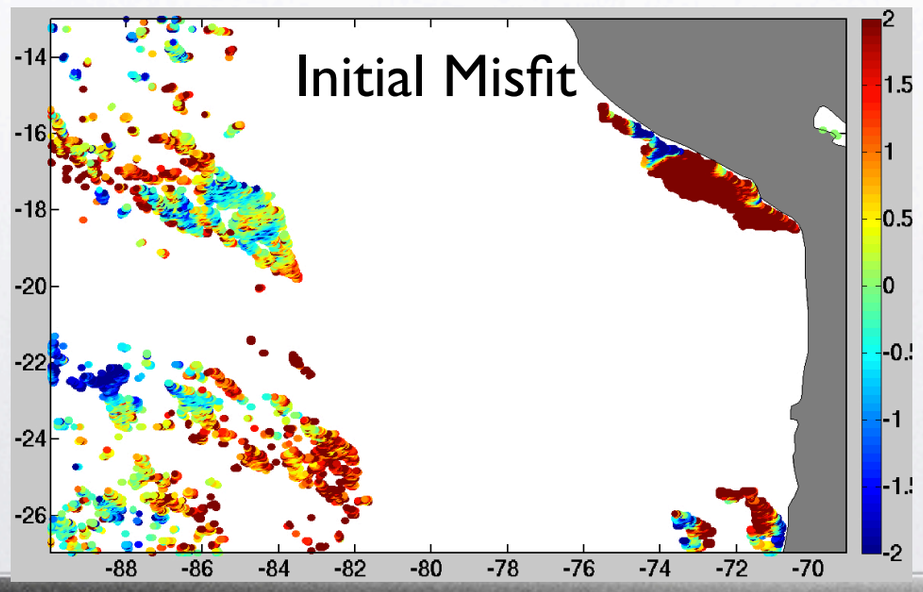


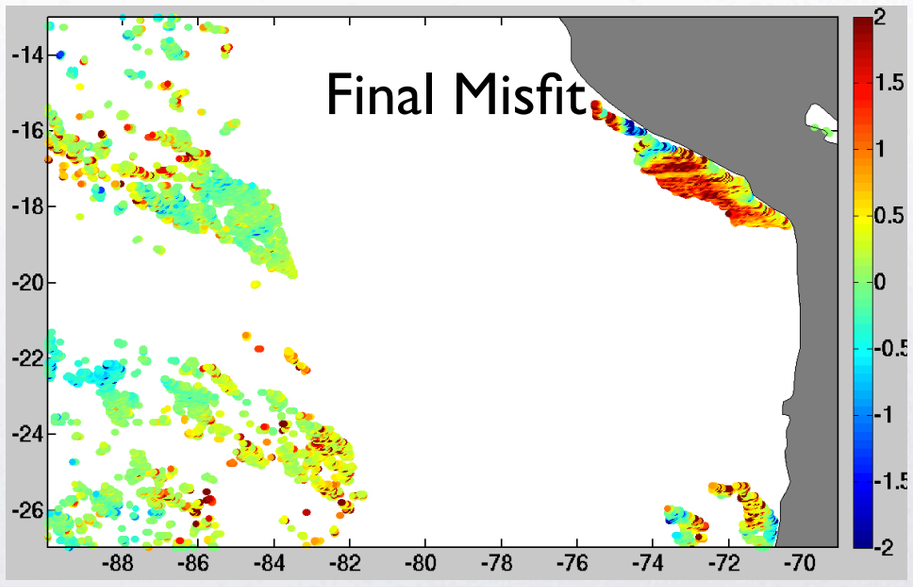

tangent linear model misfit cost function

# Comparison Plots (Aug 3, 2008)

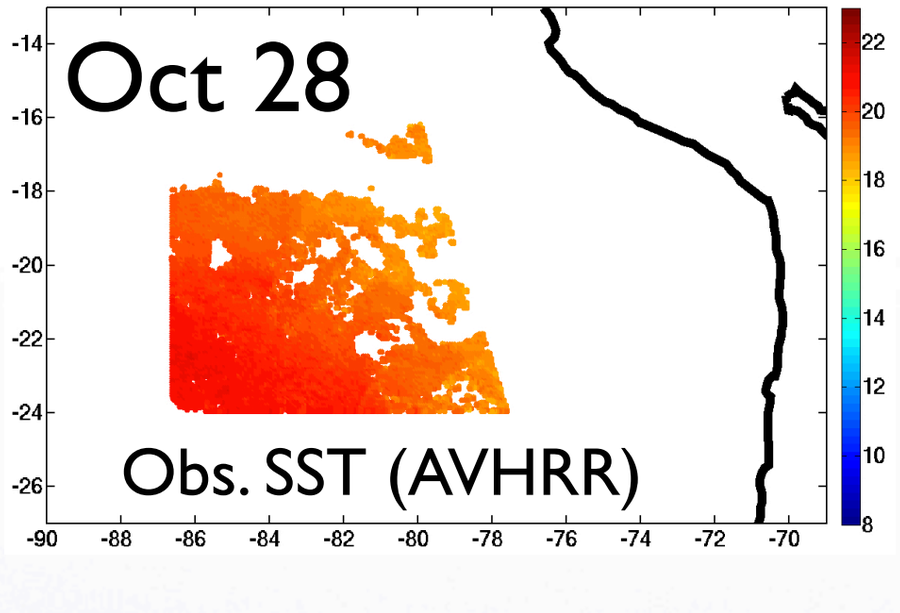


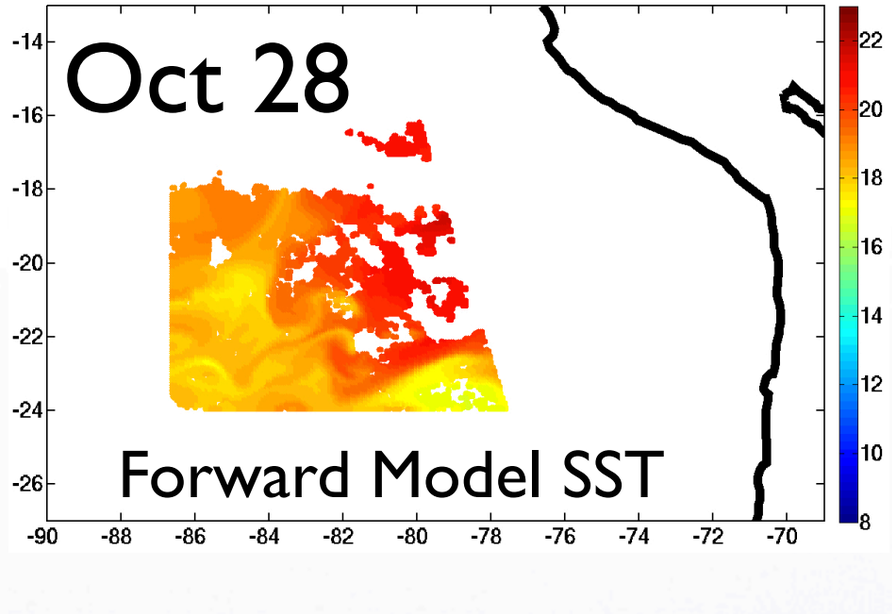



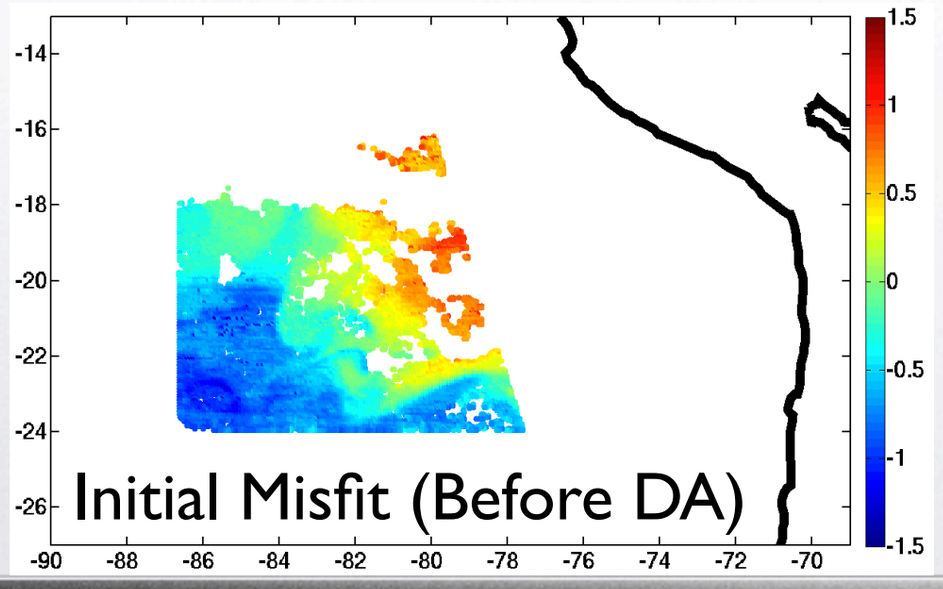



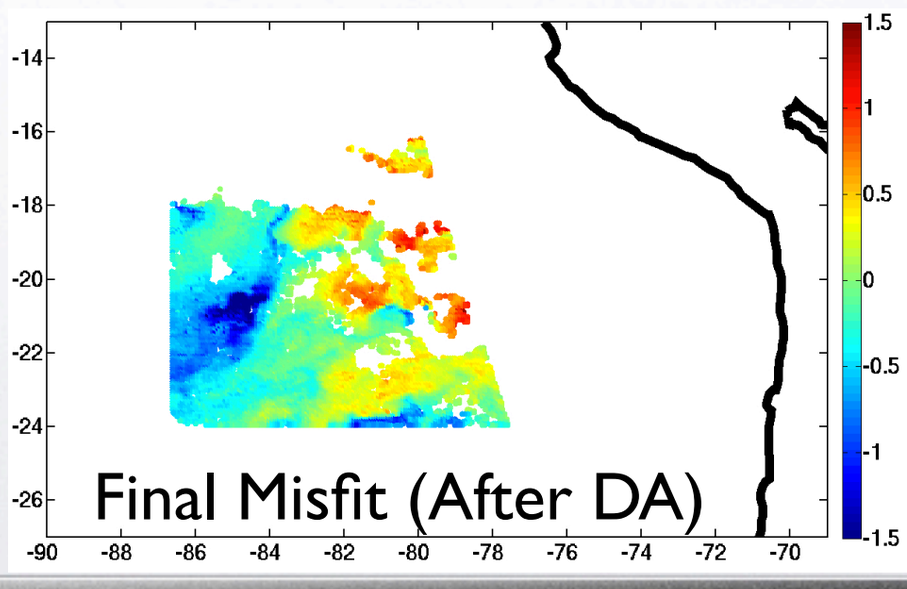



# Assimilation Results (Oct 14 - 31)



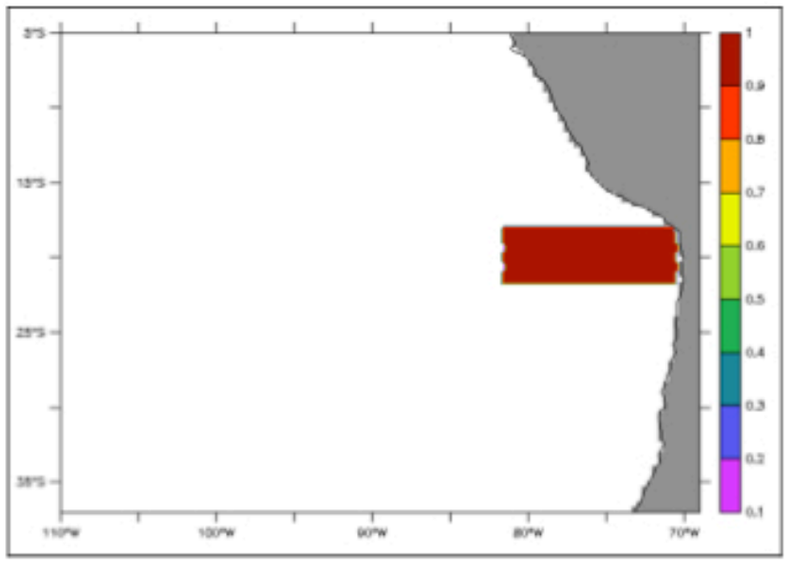



# Conclusions

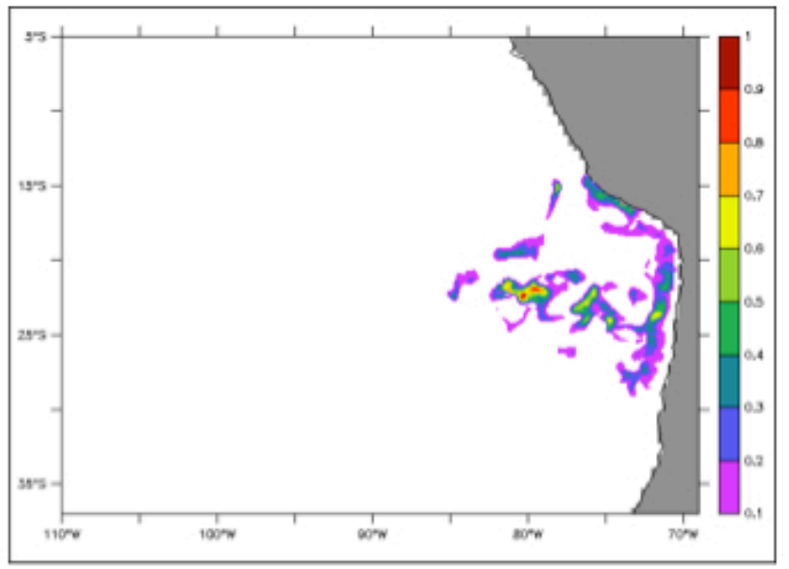
- The forward model has a warm bias in the surface and cold bias in the sub-surface that can be corrected with data assimilation.
- The model prior state needs to be improved so that it is closer to the observations so that the nonlinear data assimilation procedure can converge.

# Adjoint Sensitivity Expts.

(a)




(b)




(a) Initial state and (b) 90 day prior to the initial state percent ratio of the passive tracer concentrations close to the surface indicating a bifurcation in the jet-like structure of the Humboldt current.

# Proposed work

- Transport across VOCALS transect using ROMS adjoint calculations.
- Adjoint sensitivity experiments to locate the source of tracers into the VOCALS-Rex region.

# Thank You

Scripps Institution of Oceanography
UCSD

# Adjoint Sensitivity

- Consider a model state vector described as $\Phi = (u, v, T, S, \zeta)^T$
- A cost function $J(\Phi)$ is defined as a function of the state vector $\Phi$.
- Small changes in $\Phi$ will reflect as changes in J.

$$\delta J = \left(\frac{\partial J}{\partial u}\right)\delta u + \left(\frac{\partial J}{\partial v}\right)\delta v + \left(\frac{\partial J}{\partial T}\right)\delta T + \left(\frac{\partial J}{\partial S}\right)\delta S + \left(\frac{\partial J}{\partial \varsigma}\right)\delta \varsigma$$

- Adjoint sensitivity can be defined as:

$$u^\dagger = \left(\frac{\partial J}{\partial u}\right),\ v^\dagger = \left(\frac{\partial J}{\partial v}\right),\ T^\dagger = \left(\frac{\partial J}{\partial T}\right),\ \text{etc}$$

- Hence it can be shown that the solution of the adjoint system also represents the system's sensitivity

$$\Phi^\dagger = (u^\dagger, v^\dagger, T^\dagger, S^\dagger, \varsigma^\dagger)^T$$

- Surface adjoint sensitivity of the South East Pacific ocean domain in an adjoint sensitivity test case was run for 90 days to test the sensitivity of the coastal region to surrounding coastal flows. Sensitivity to strong coastal upwelling and the Humboldt current was evident from the simulations.

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# Proposed work

- Adj. Sensitivity
- Obs. Impact.

# Forcing challenges

- Challenges for forcing and boundary conditions.
- Show Plots of initial condition with NCEP bulk flux forcing and QScat winds. Also see if you have the run with ERA.

# Data assimilation experiments

- Data assimilation of VOCALS cruise time intervals can be achieved using the inverse ROMS, a 4D variational data assimilation system for high-resolution (7 km resolution model) basin-wide and coastal oceanic flows.

- Sensitivity of the South East Pacific ocean circulation is studied using adjoint tracer calculations.

- Sensitivity studies also imply the possible impacts the various datasets will have in data assimilation experiments and also significantly indicate the predictability of the model.

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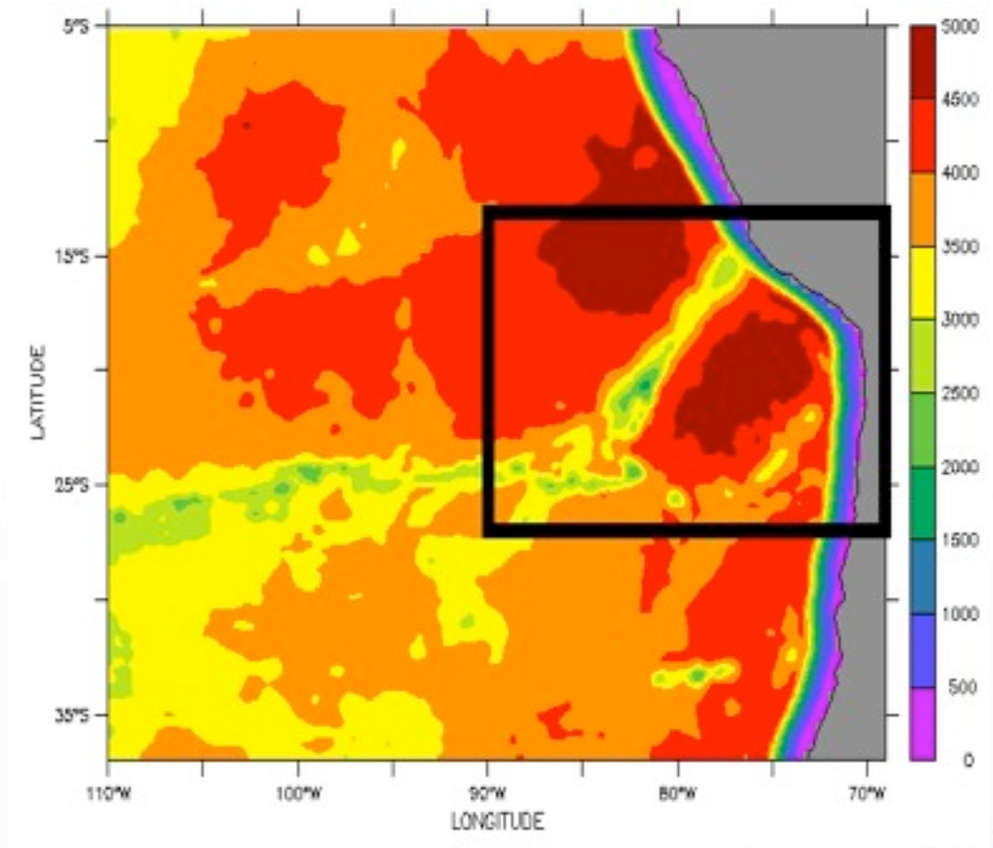
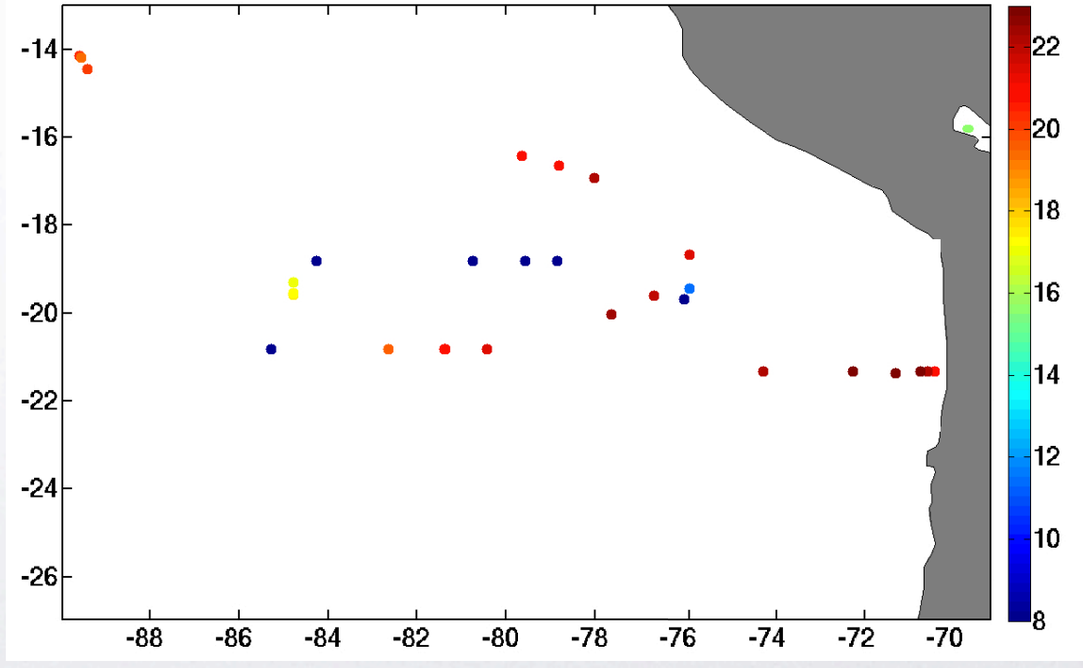
- Outer domain (110° W to 69° W and 5° S to 37° S)has a horizontal resolution of 20 km and has 32 vertical levels.

- Inner-domain (90° W - 69° W, 13° S - 27° S) has a horizontal resolution of about 7 km and is the focus of the present study.

- At open boundaries, the inner-domain solution was constrained to match the solution of the outer domain. Radiation conditions were imposed on the free- surface and vertically integrated velocity. No-slip conditions were imposed at all coastal boundaries on velocity, and zero gradient conditions on the free-surface and all tracers.




Contours of the bathymetry used in the ROMS outer and inner- domains for the South East Pacific ocean configuration of the model.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