# On the Development of a Numerical Ocean Prediction System for the Atlantic Based on HYCOM

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*Federal University of Bahia (UFBA)*

*Collaboration: E. Chassignet, A. Srinivasan, A. Wallcraft*

UFBA

centro de pesquisa em geofísica e geologia
Desde 1969

The present work is part of the activities of the

**Research Network on Oceanographic Modeling and Observation**


anp
COMPROMISSO COM INVESTIMENTO EM PESQUISA & DESENVOLVIMENTO

UFRJ

UFBA

USP

FURG

PETROBRAS

*www.rederemo.org*
(under construction)

# REMO Goals

- To do research in physical oceanography over the Tropical and South Atlantic with emphasis in the region along the Brazilian shore
- Develop technology in ocean modeling, data assimilation, forecasting and observation
- Implement an operational numerical ocean forecast system for the regions of interest with ROMS, POM and HYCOM in the Brazilian Navy – Directorate of Hydrography and Navigation (DHN)
- Support off-shore oil production by Petrobras, navigation, environmental monitoring, military activities, etc.
- Support trainning and education

Cluster Netuno in NCE/UFRJ 256 nodes with a total of 2048 Intel Xeon 2.66GHz processors and 4 TB of distribute memory in partneship with the Research Network in Applied Geophysics.

Each participating institution has its computational facilities for REMO with about 40 processors.

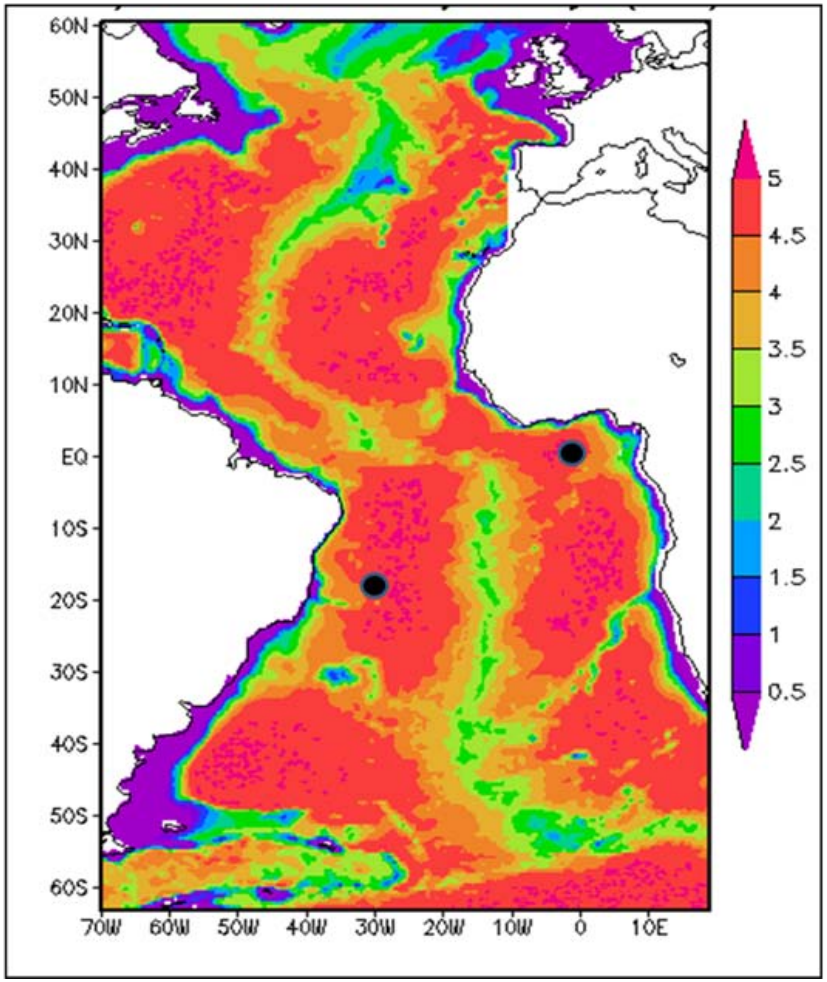
In UFBA, we have a SGI with 8 cores Intel Xeon Quad-core 3GHz 16 GB RAM, 12 TB storage upgrading to 48 TB this month.


Moored buoys developed in UFRJ and deployed by the Brazilian Navy (DHN)

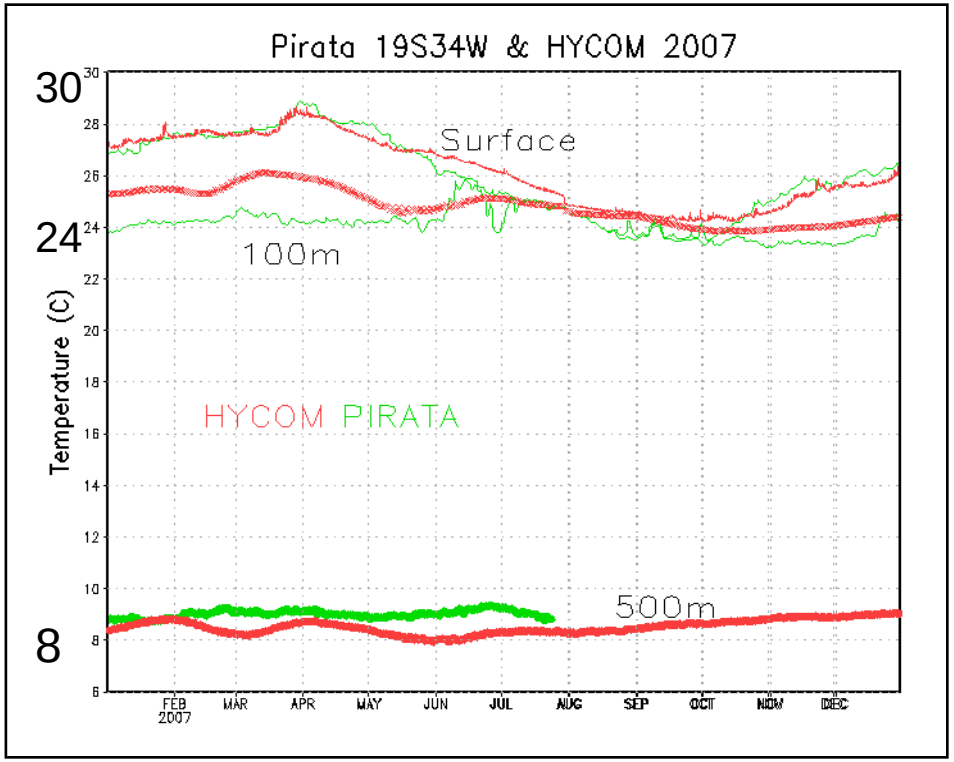
# Preliminary steps toward operational forcasts with HYCOM

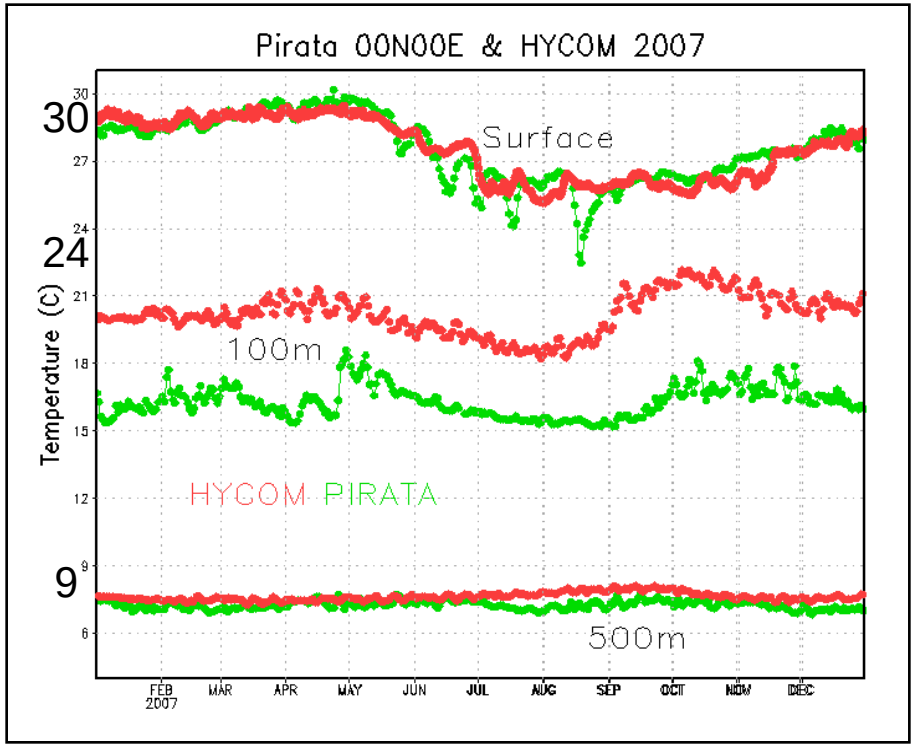
- 30 year spin-up run (1/3º resolution and 22 layers) from rest with Levitus T-S climatology forced with COADS climatological data of precipitation, 2m air temperature, 2m air mixing ratio, surface wind stress, longwave and shortwave radiation at the surface

- 4 years during 2007 with NCEP atmospheric reanalysis

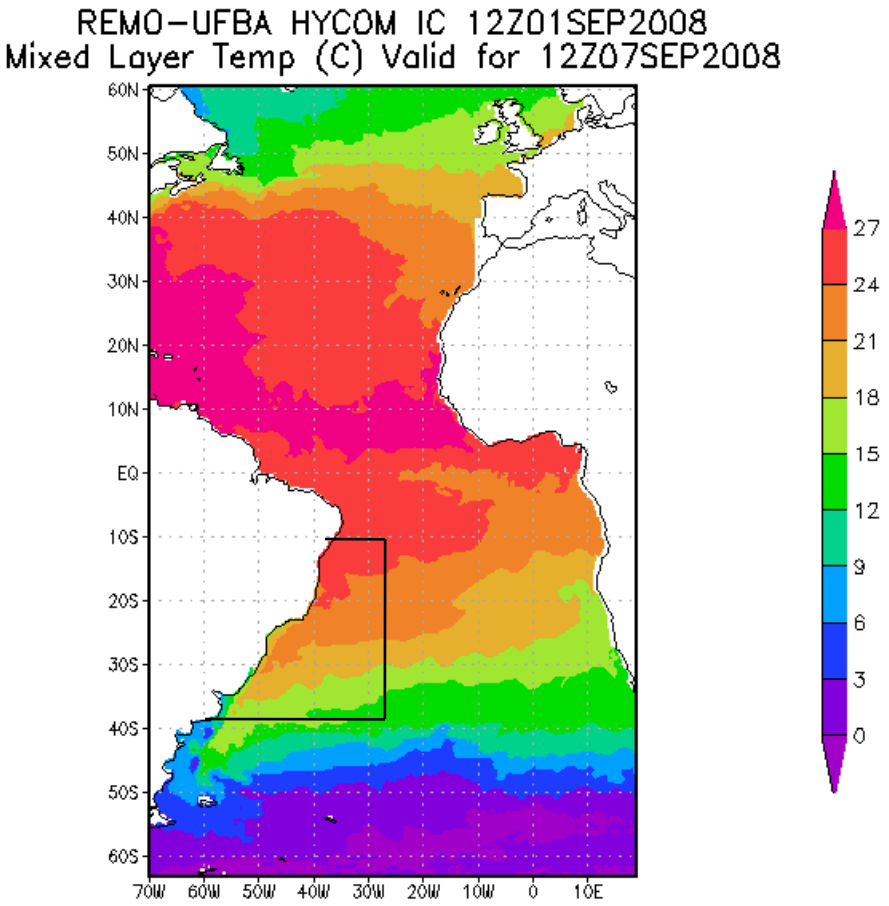


- The 2007 had strong warm bias in the equatorial thermocline, but close to Brazilian shore they were much better.

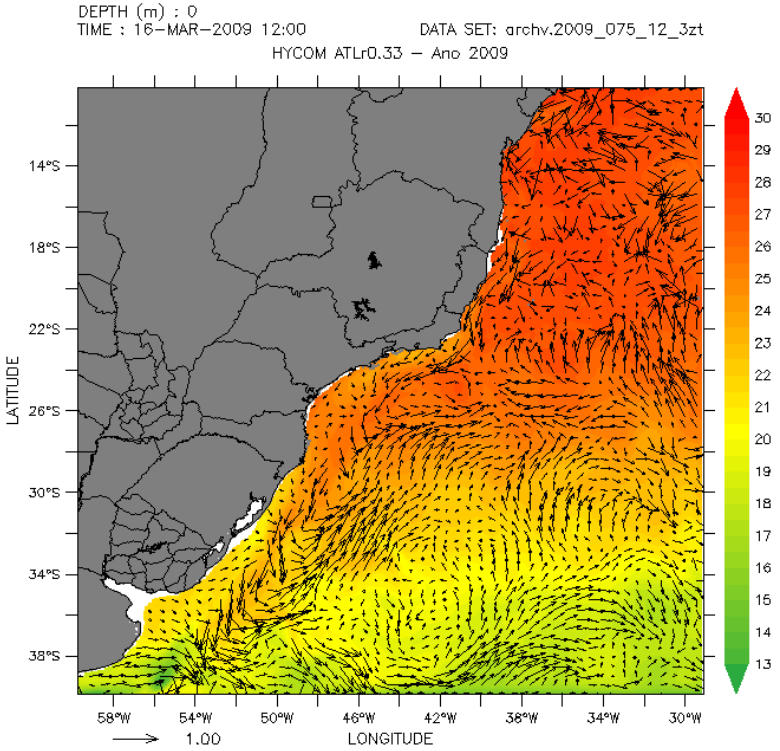


On Sep 1, 2008 daily 7-day forecasts without assimilation forced by NCEP GFS 1º resolution were initiated. The 24 h ocean forecast was saved as the the restart file for the next 7-day forecast




On 15 March 2009 pre-operational forecast swith HYCOM 1/12 º version 2.1.34 and Mellor and Ezer assimilation scheme (M&E) were initiated.

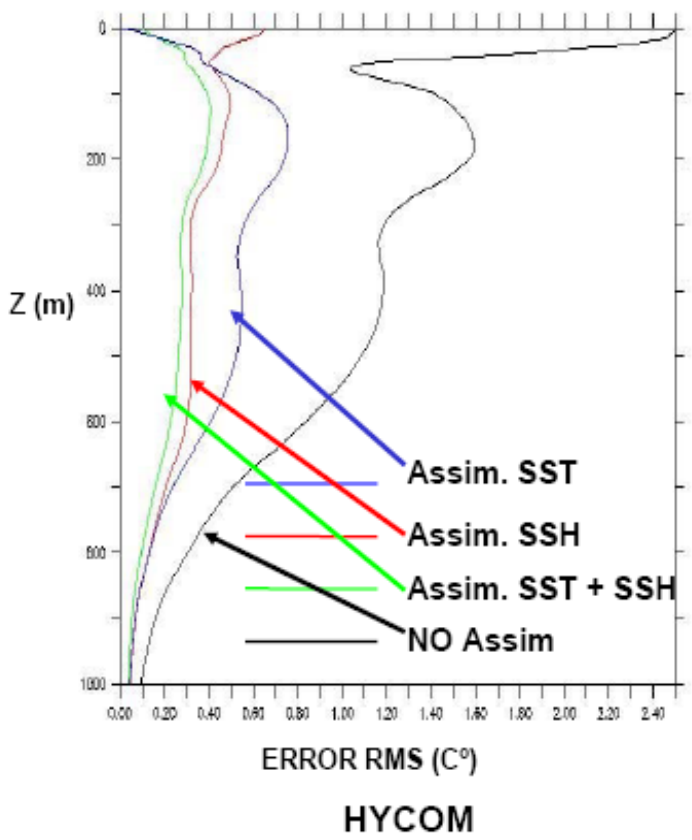



Temperatura e Correntes Superficiais

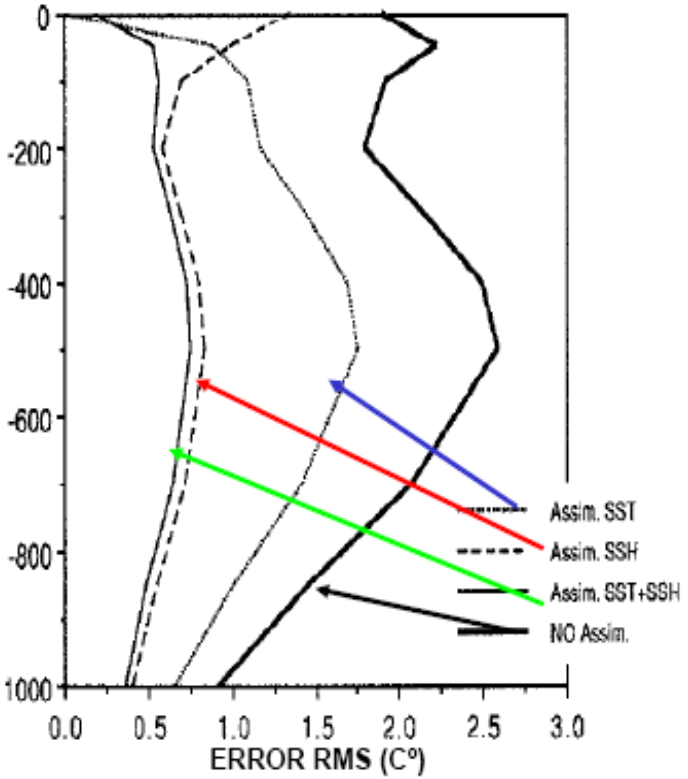
# Assimilation with prescribed weights and synthetic data of T and S

## Assimilation in z-coordinates

### Time mean of Error RMS



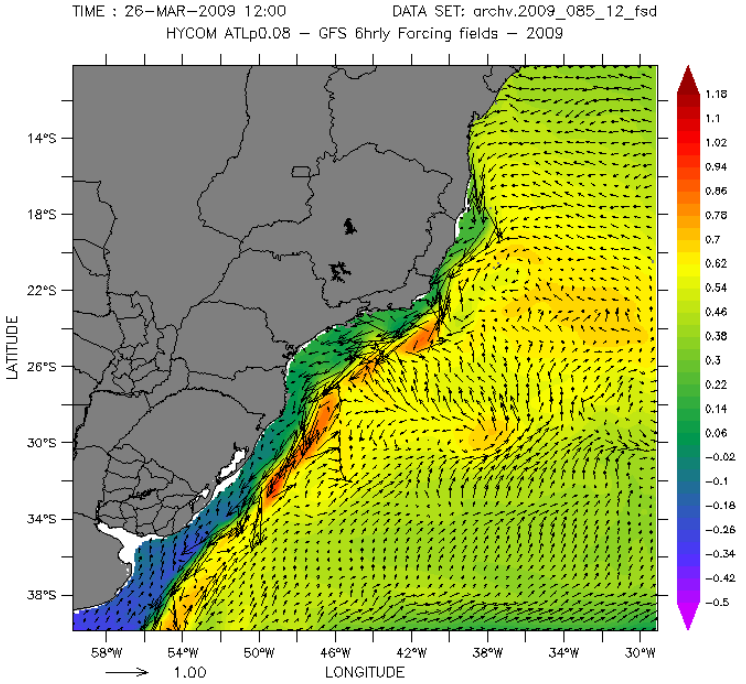

HYCOM




Gulf Stream region, EZER E
MELLOR (1997)

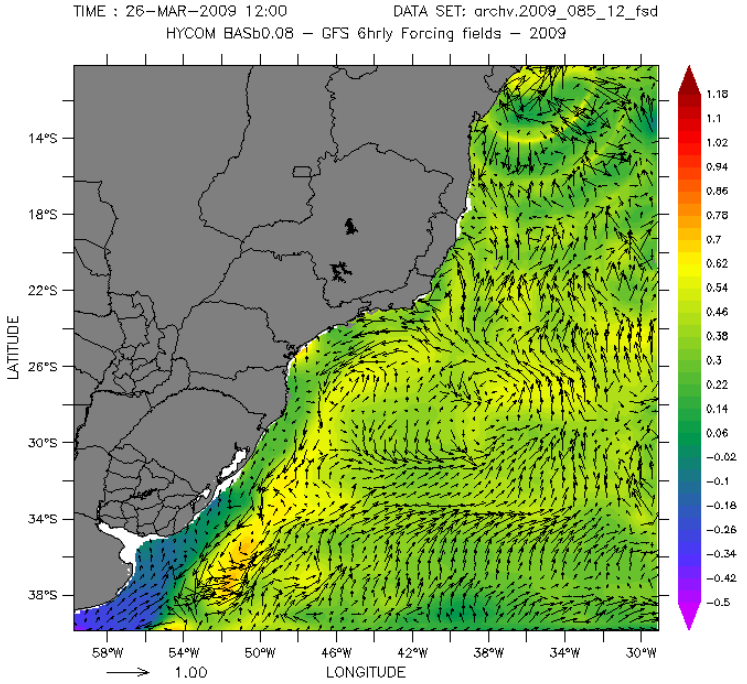


*(Oliveira, Campos e Tanajura, LOM 2007)*



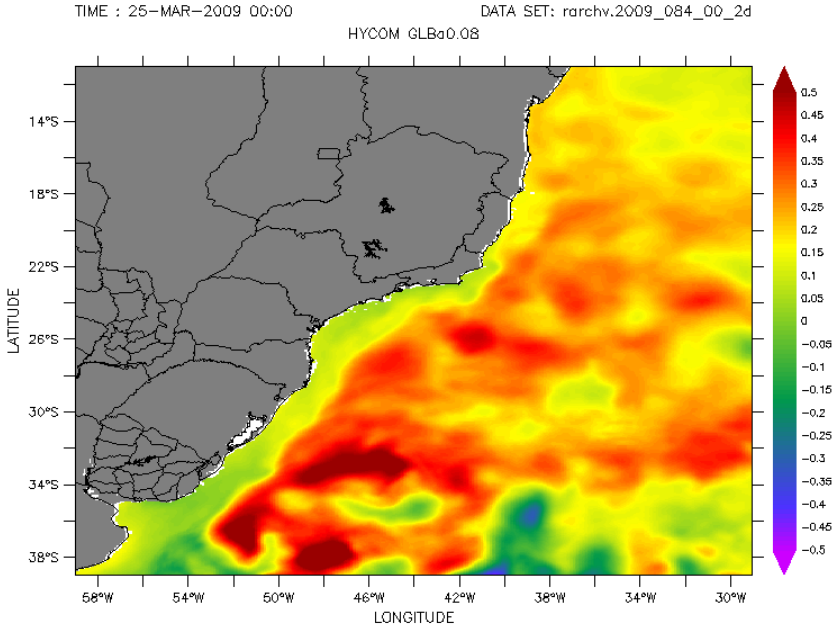

Elevacao e Correntes Superficiais

Improvement of SSH and surface circulation when M&E scheme was used.




Elevacao e Correntes Superficiais

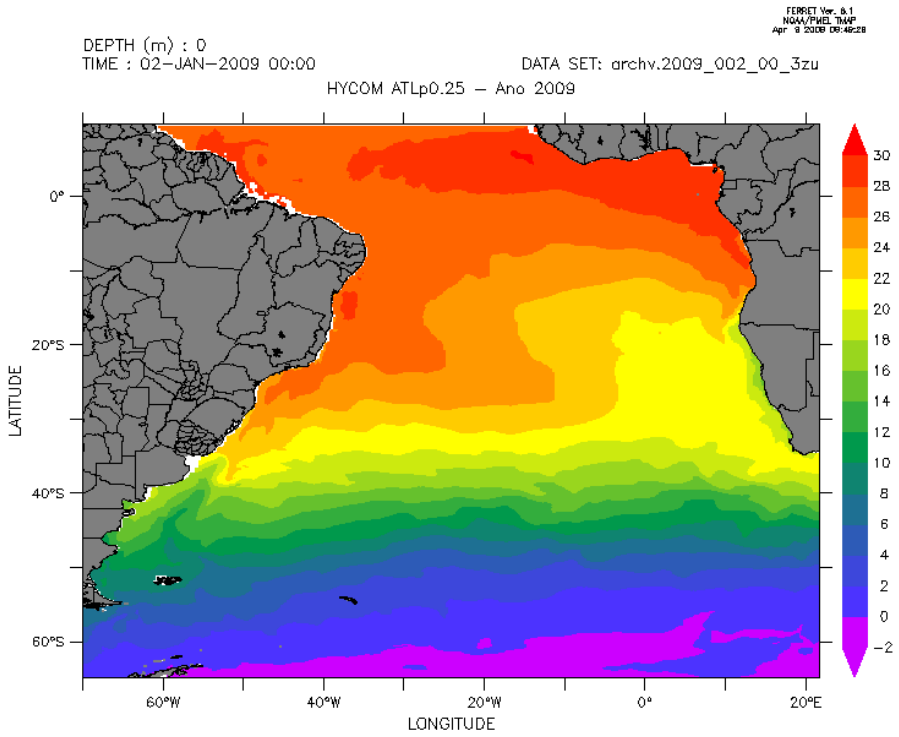
HYCOM+NCODA




SSH (m)

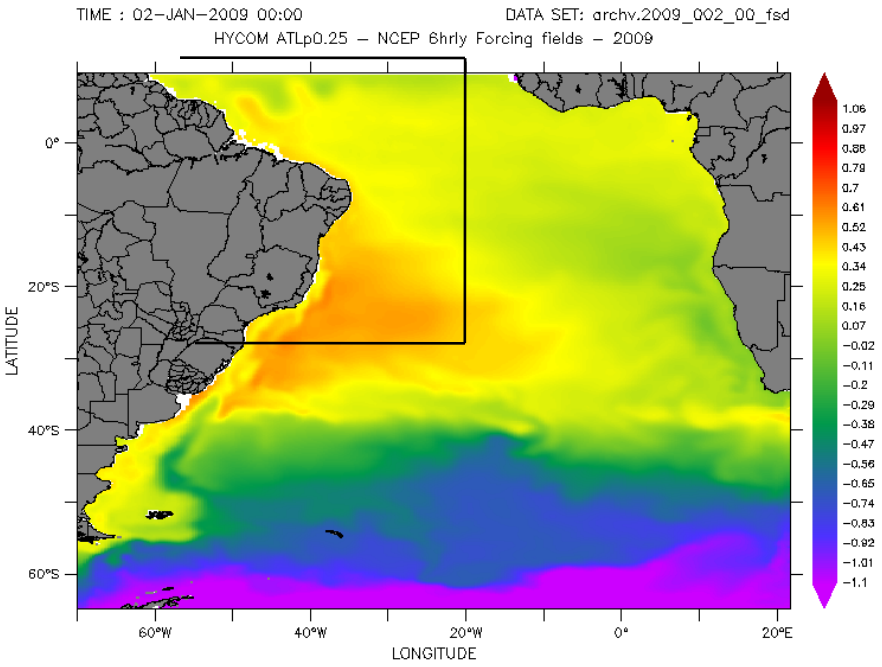
In March 2009 we began to test HYCOM version 2.2.14 with 1/4° and 1/12° with 21 layers.

Temperature



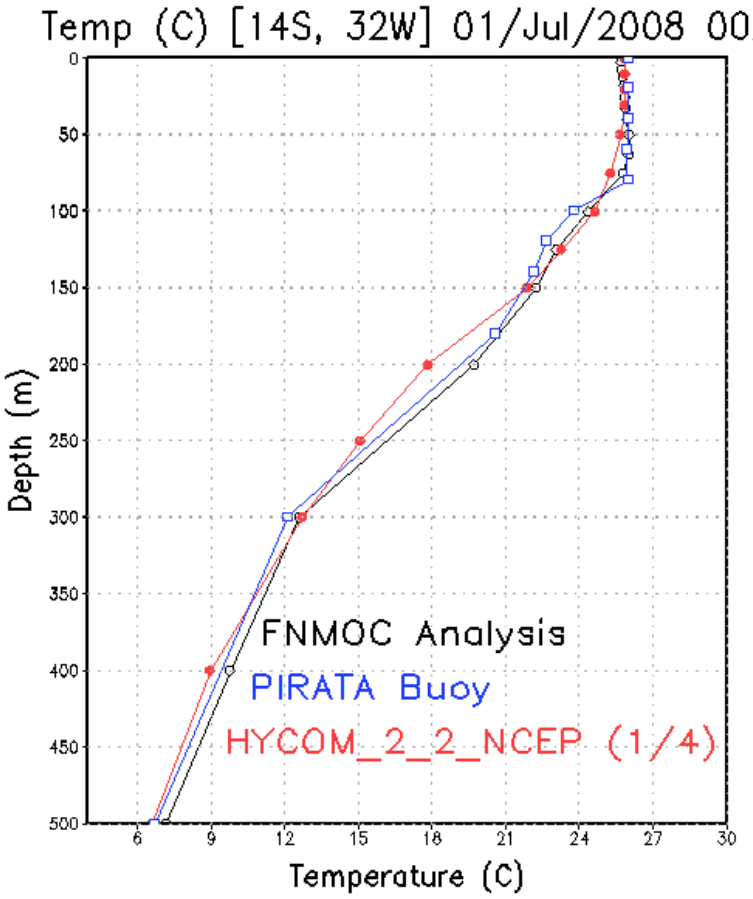

Temperatura

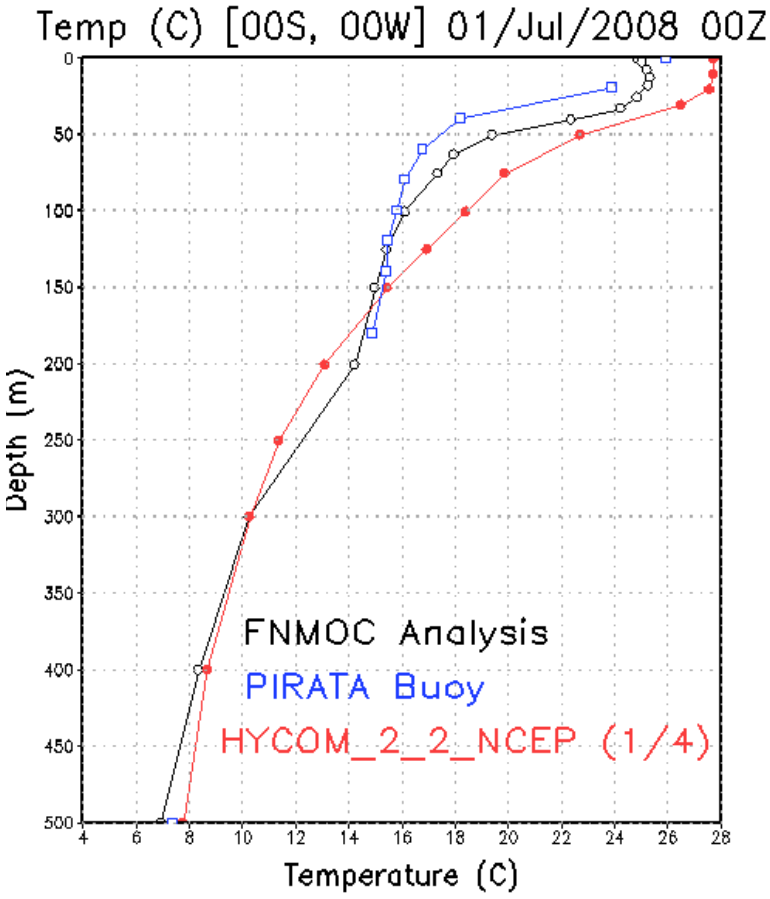
SSH



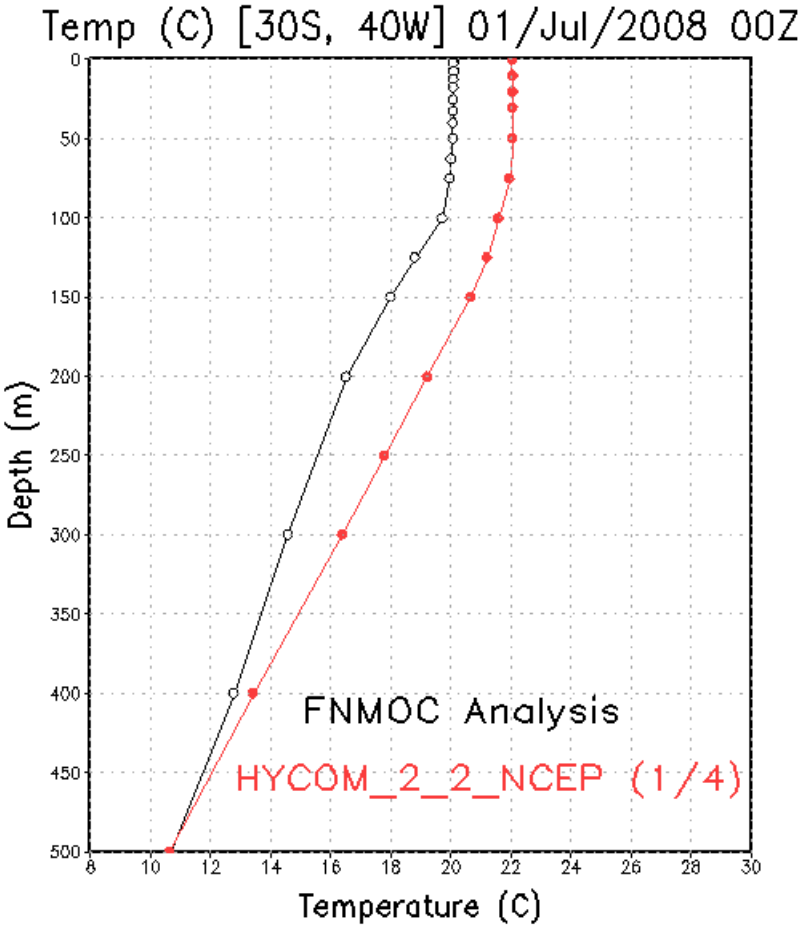

SSH

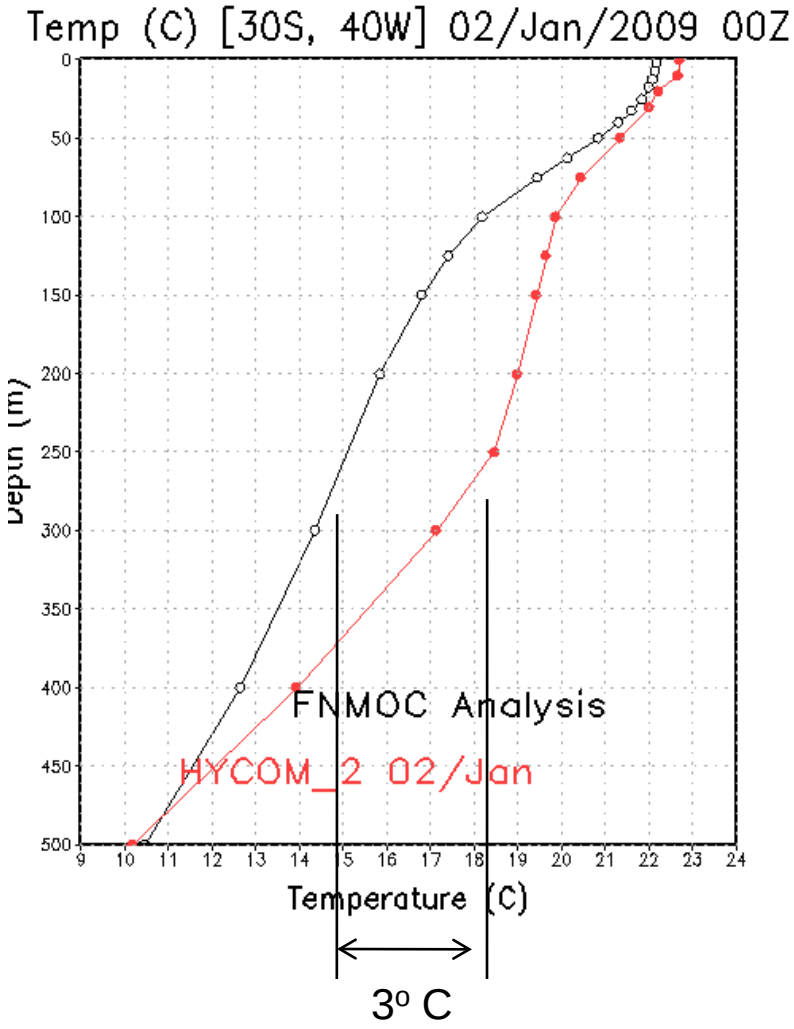
Comparison of 1/4º HYCOM 2.2.14 with PIRATA mooring data and FNMOC analysis



# Comparison of 1/4º HYCOM 2.2.14 with FNMOC analysis

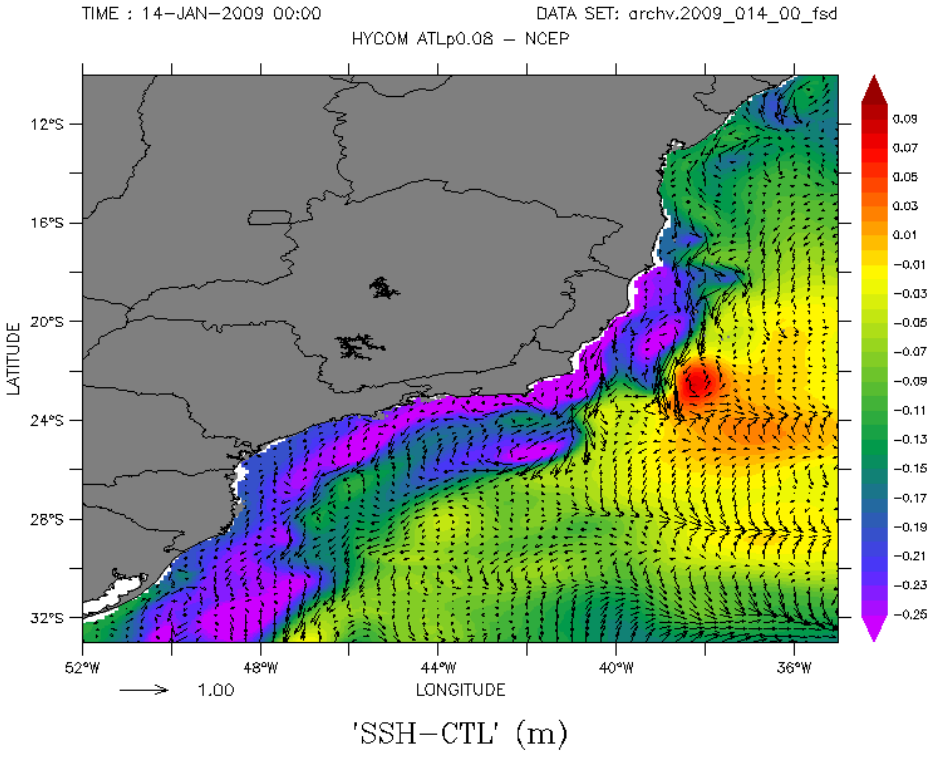


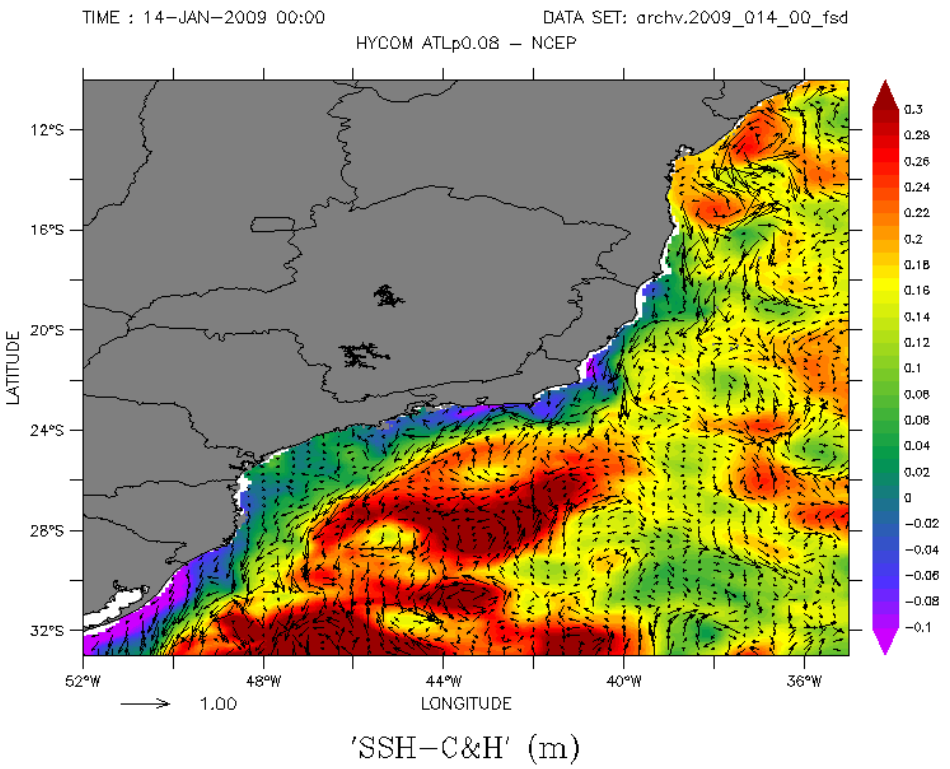
A correction of SSH was implemented using Cooper and Haines (C&H).

SSH given to C&H = SSH mean from HYCOM + SSHA from FNMOC

## Control



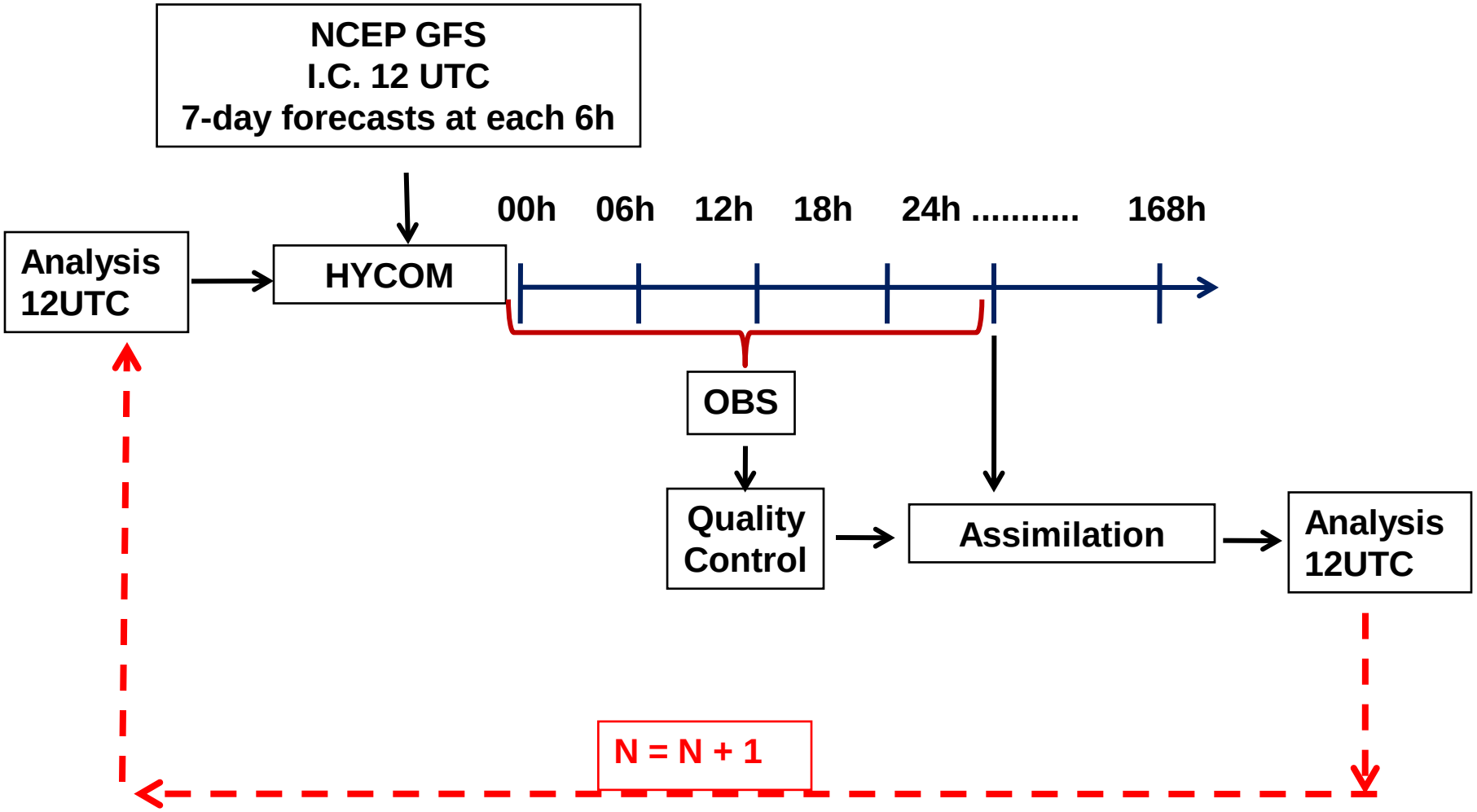

## Cooper & Haines



# Present situation of the pre-operational system

- 1/4$^{o}$ and 1/12$^{o}$ of HYCOM 2.2.14 with C&H
- 1/4$^{o}$ and C&H is running in DHN-Brazilian Navy
- The Mellor and Ezer scheme is under implementation in DHN-Brazilian Navy
- A data assimilation system is under development to assimilate PIRATA and ARGO data profiles
- We need to go to an assimilation cycle for SSH, SST and in situ data

# The Assimilation Cycle



# Data Assimilation: Theory (*Tanajura & Belyaev Appl.Math Model. 2009*)

The following problem is considered:

Find the optimal estimation or analysis $\hat{\varsigma}(t,x)$ of the true value such that

$$E(\hat{\varsigma}-\varsigma)=0$$

$$E(\hat{\varsigma}-\varsigma)^2=\min E(\omega-\varsigma)^2$$

for any estimation $\omega$.

Restricting the class of the analysis to the linear estimation w.r.t to model and observations, the analysis can be sought as

$$\hat{\varsigma}(t,x)=\varsigma_m(t,x)+\int_0^t\sum_{i=1}^{N(\tau)}\alpha(\tau,x,x_i)\theta(\tau,x_i)d\tau$$

$\varsigma_m(t,x)$ is the model background state

$$\theta(\tau,x_i)=\varsigma_o(\tau,x_i)-H_i\varsigma_m(\tau)$$

$x$ is the analysis grid point and $x_{i,}$ is the observational points. $N(\tau)$ is the number of points of observations at time $\tau$ .

The weigths $\alpha_i = {}_{,}\alpha(\tau, x, x_i)$ are unknown, and they should be determined using the minimum variance condition. This condition is equivalent to calculate $\alpha_i$ such that $\partial / \partial \alpha_i \, E(\hat{\varsigma} - \varsigma)^2 = 0$

If $E(\zeta) = \zeta_m$ , the formula above is equivalent to solving the Wiener-Hopf equation:

$$K(t, x, x_i) = \int_0^t \sum_{j=1}^{N(\tau)} \alpha(\tau, x, x_j) K(t - \tau, x_i, x_j) d\tau$$

$K(t, x_i, x_j)$ is the covariance function of the errror calculated by

$$K(t, x_i, x_j) = E\theta(t, x_i)\theta(t, x_j) - E\theta(t, x_i) E\theta(t, x_j)$$

$K(t, x_i, x_j)$ is parameterized as $K(t, x_i, x_j) = \sum_{i=1}^{N(t)} \theta_i^2 \Big/ (N-1) R_{ij}$

where $R_{ij}$ is the dimensionless distance between observational points $x_i$ and $x_j$

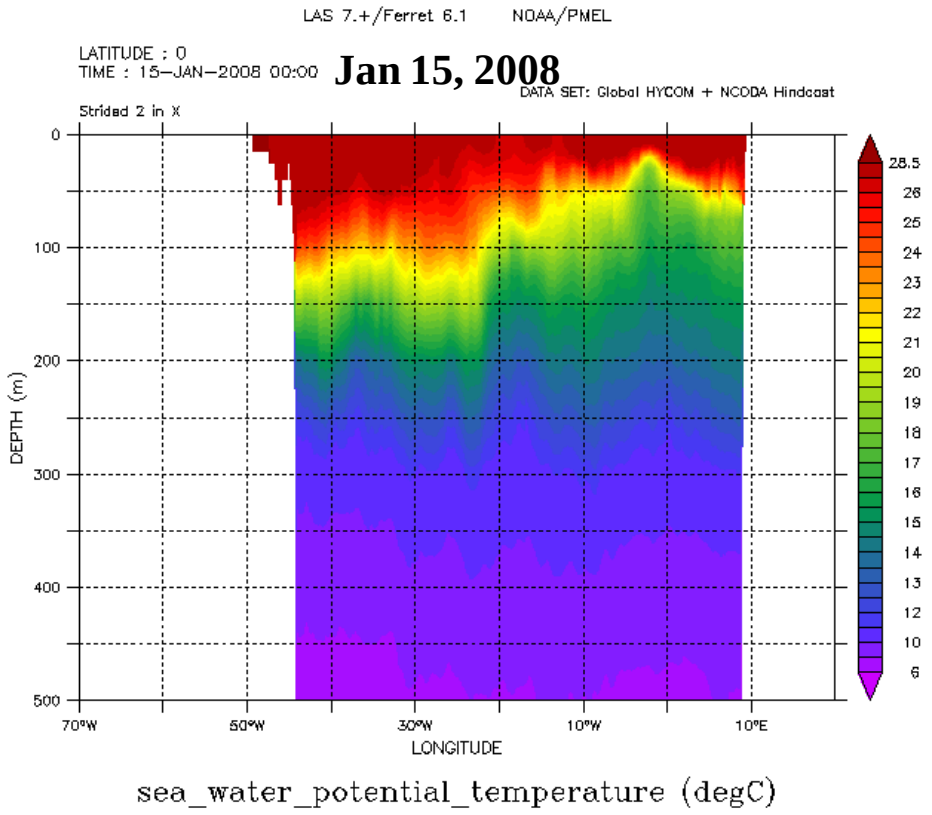
$K(t, x_{,} x_j)$ is estimated using the Fokker-Planck equation and histogram technique

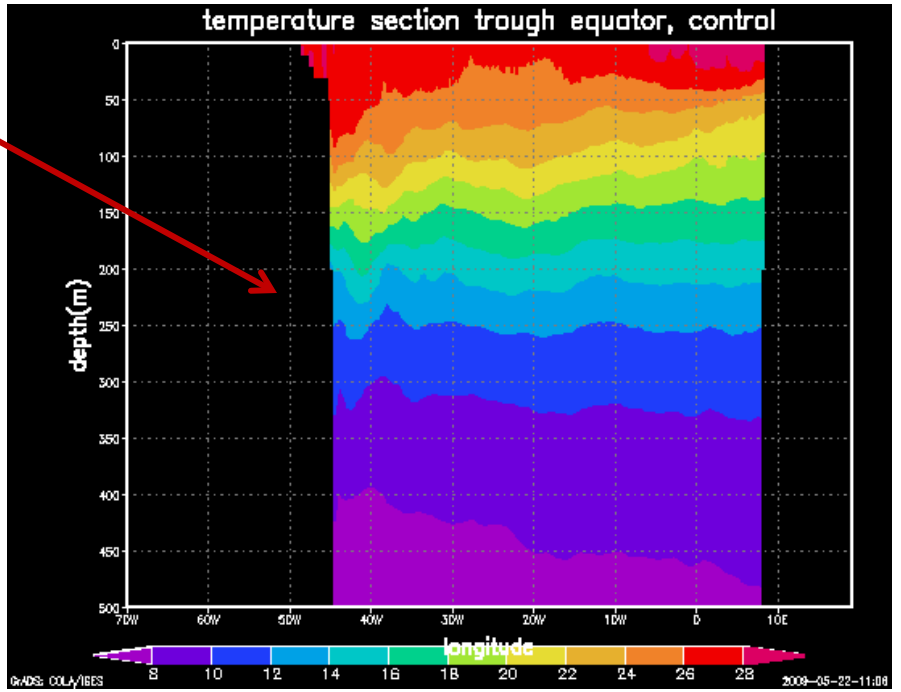
Since the model is not unbiasied, the model bias is estimated a priori in each time step by

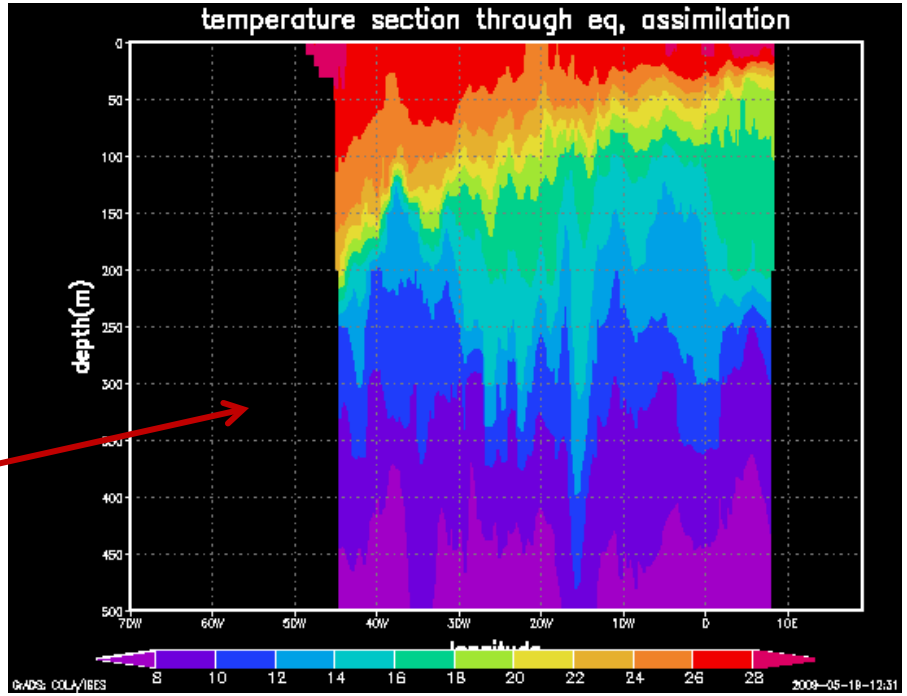
$$Bias_i(t) = \sum_{i=1}^{N(t)} \theta_i \Big/ N$$

**Control**

# HYCOM+NCODA



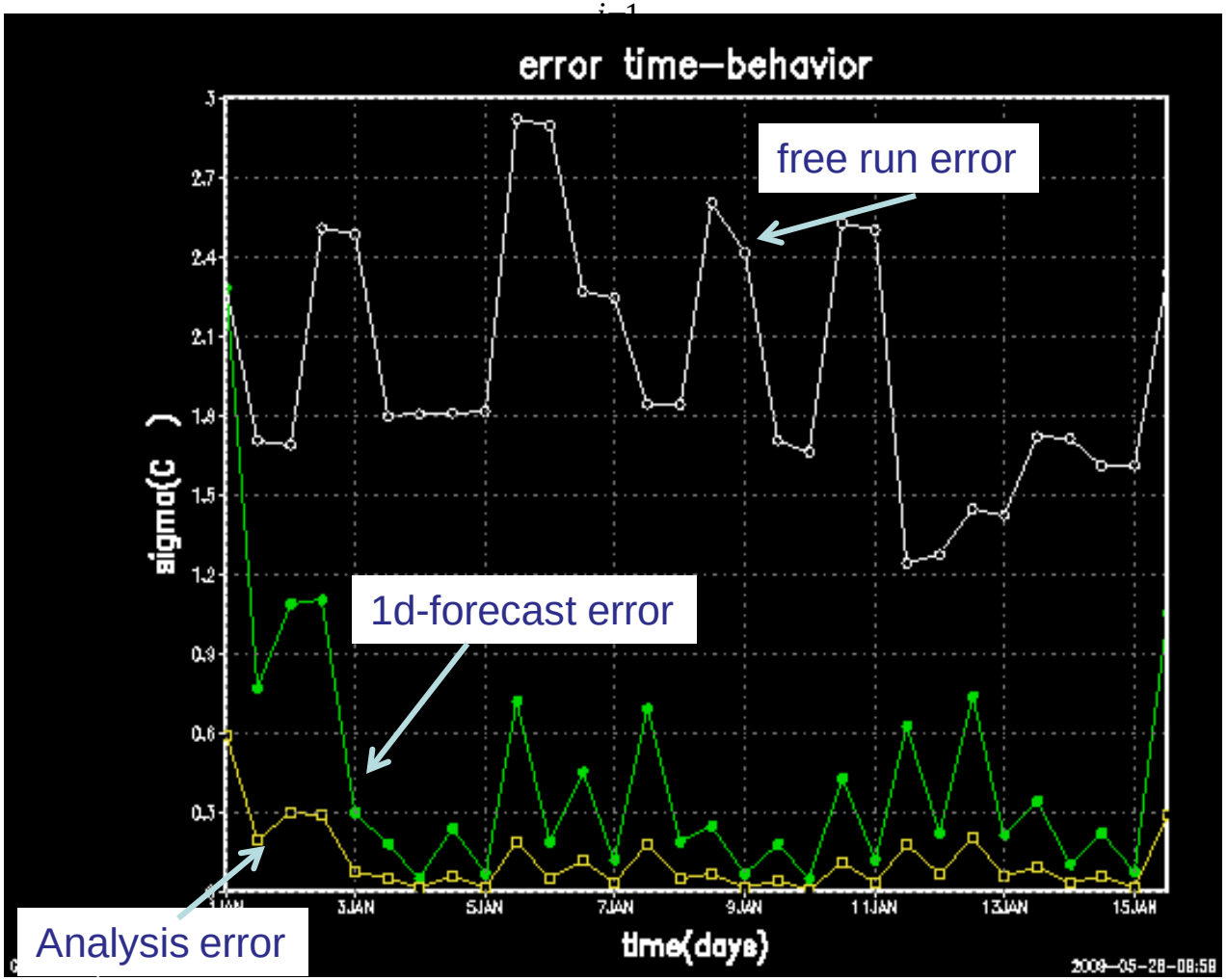



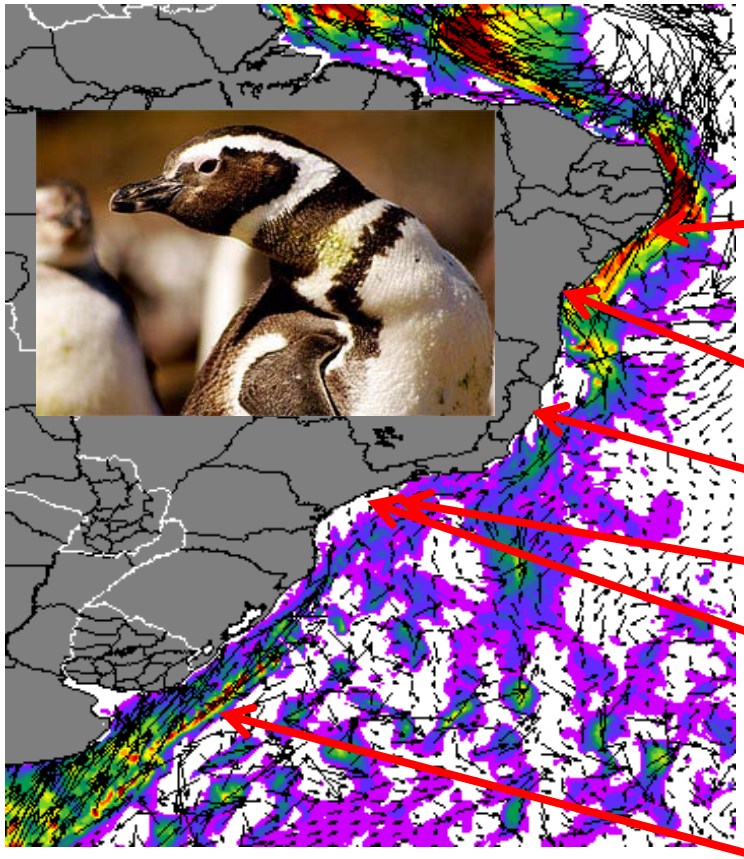

**ARGO and PIRATA Assimilation**

# 1-15 Jan 2008 Assimilation run
# Pirata observation – HYCOM 1/3°

$$\sigma_a^2 = (N-1)^{-1} \sum_{i=1}^{N} (\zeta_{oi} - H_i \zeta_a)^2$$



# Anomalous 2008 Winter-time Penguins Travel Towards Tropical South Atlantic



## Penguin Reports on the News

**September 2008**

Paraíba = 05

Sergipe = 26

Alagoas = 14

**17-31 July 2008**

Salvador = 370

Espírito Santo = 220

São Paulo = 200

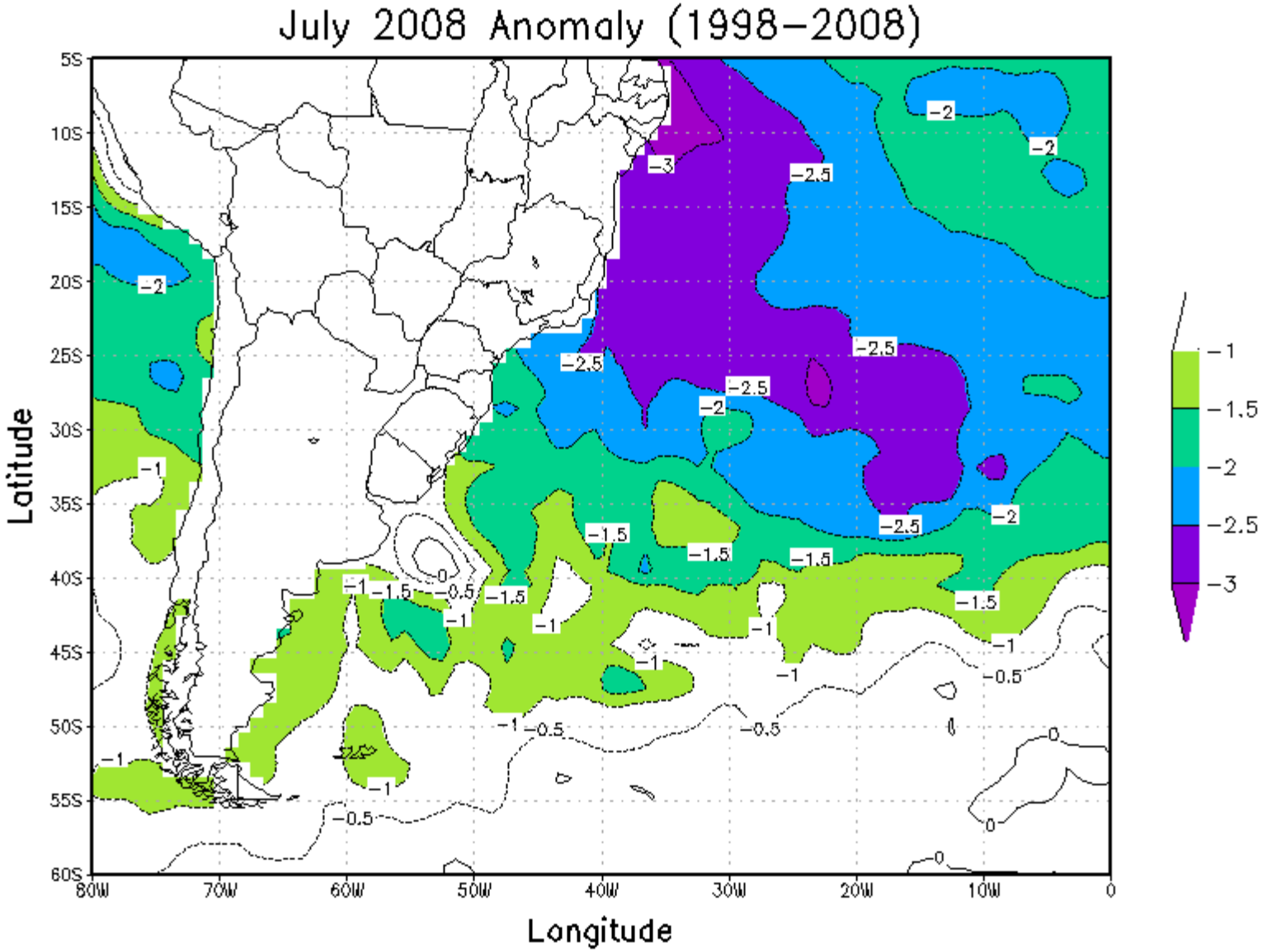
**25 June 2008**

02 Penguins São Sebastião-SP

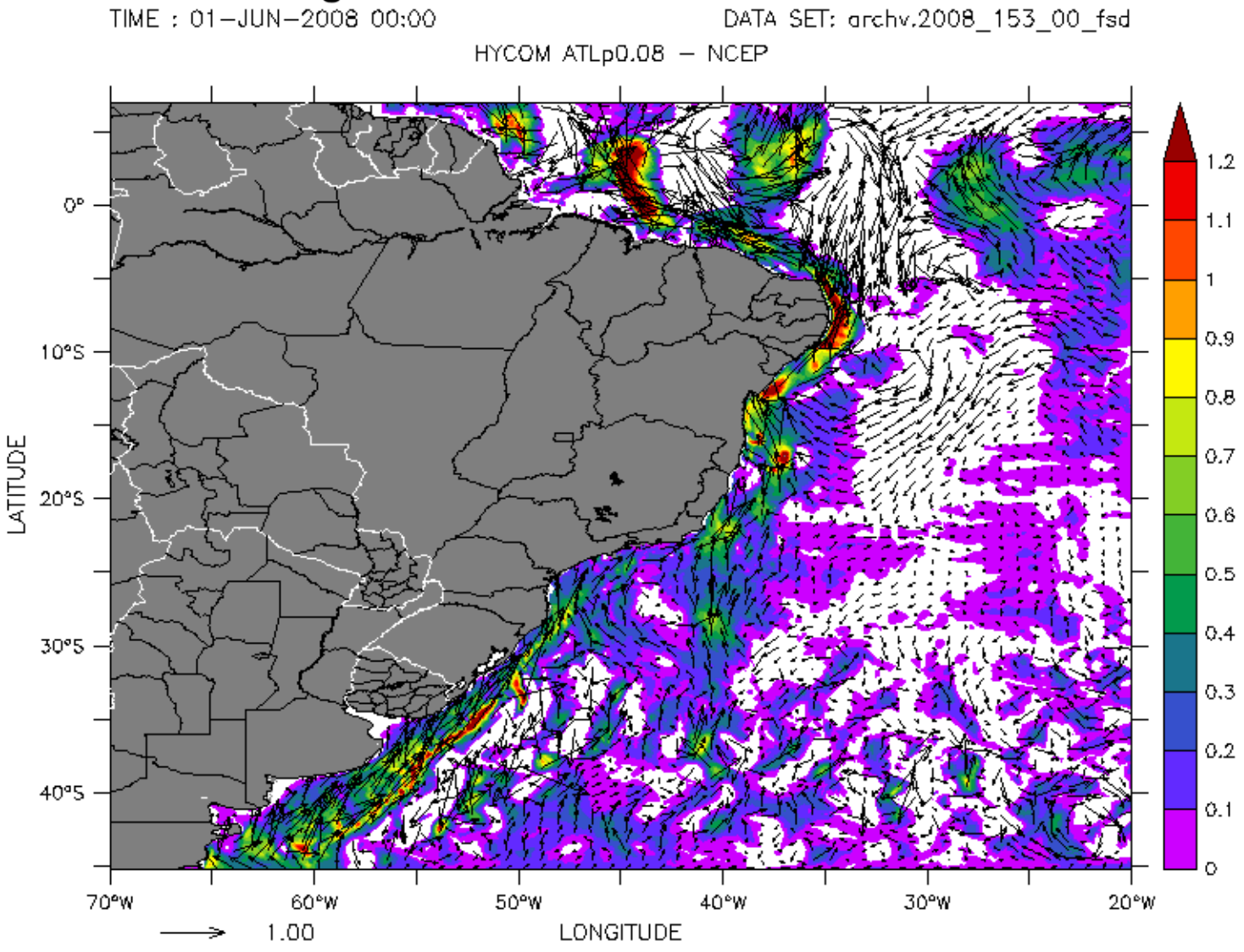
**08 June 2008**

About 65 penguins, mostly dead, appeared near the Uruguay coast

**SST cold anomalies were identified to move northward along Brazlian shore from April to July 2008. Cooler areas were located near the coast of Espirito Santo, Bahia, and the northeast states in July 2008.**



# HYCOM 1/12 grid

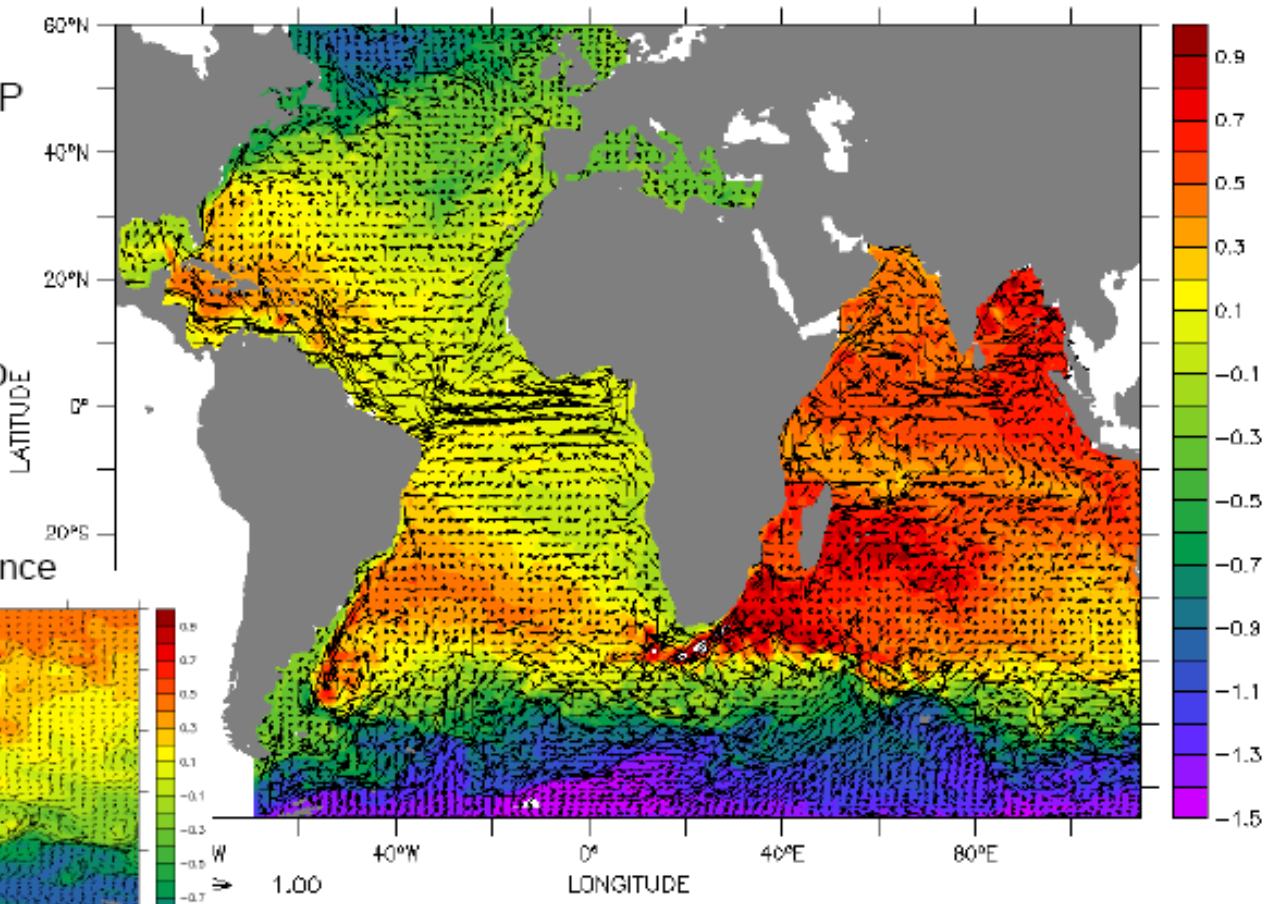



mixl. v-velocity [03.0H] (m/s)

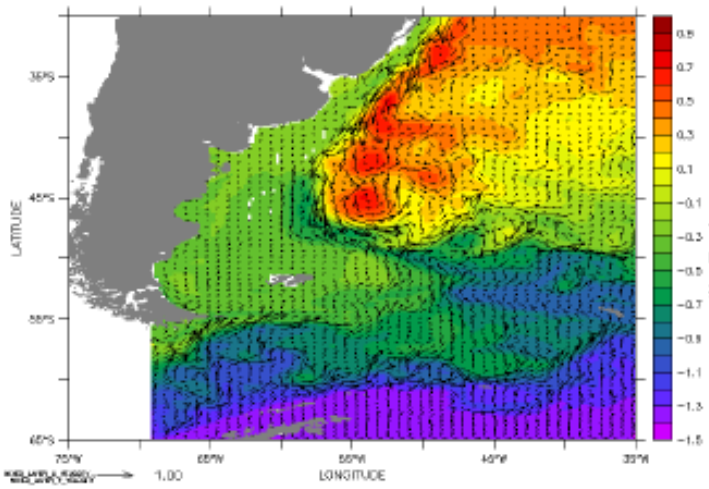
# New experiments with HYCOM *(E. Campos et al.)*

An implementation of HYCOM V 2.2 in the Atlantic-Indian basins, forced with 6-hours NCEP reanalysis products, is being run to investigate possible changes in the South Atlantic circulation associated with changes in the position of the zero wind-stress curl in the past 60 years.

HYCOM V2.2, with ¼-degree resolution – ETOPO 2 Bathymetry



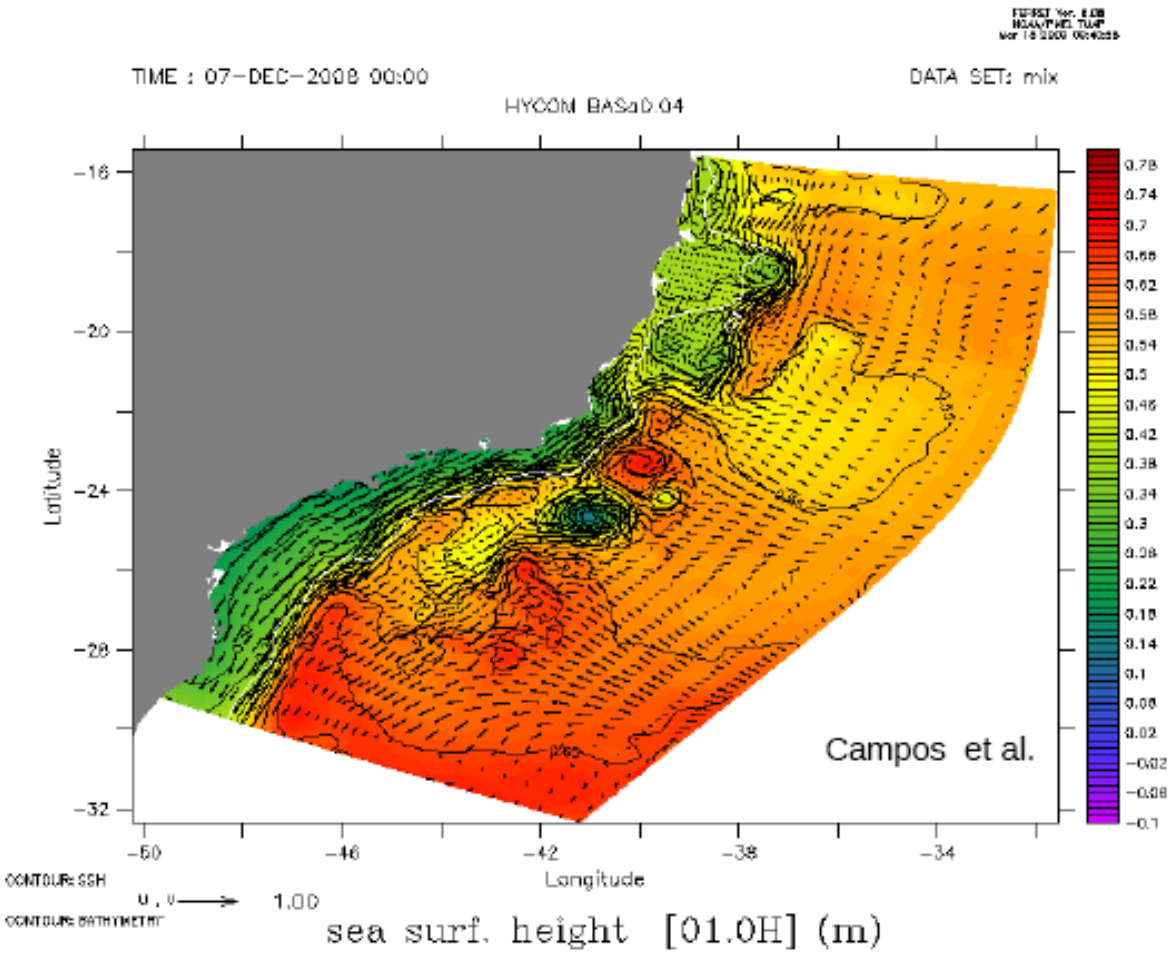

Brazil-Malvinas Confluence




*E Campos et al.*

**Motivation:**

In an unpublished study with NCEP reanalysis products since 1948, Lumpkin and Garzoli (pers. Comm.) have found indications of changes in the latitude of confluence fo the Brazil and Malvinas Currents, correlated with changes in the wind-stress curl.




Hindcast run, from Nov 27 thru Dec 31, 2008, with horizontal resolution up to a couple of km in the Cabo Frio Region.

The model shows the ability to reproduce quite well the mean values and the mesoscale variability of the Brazil Current.

Nesting of curvilinear grids with varying horizontal resolution is being used to increase model's efficiency in near coastal regions. In a preliminary attempt, HYCOM V2.2 is being made to nest a meso-scale grid near the Brazilian coast, run succesfuly in hindcast mode with SSH assimilation, tides and forced with dated atmospheric products.

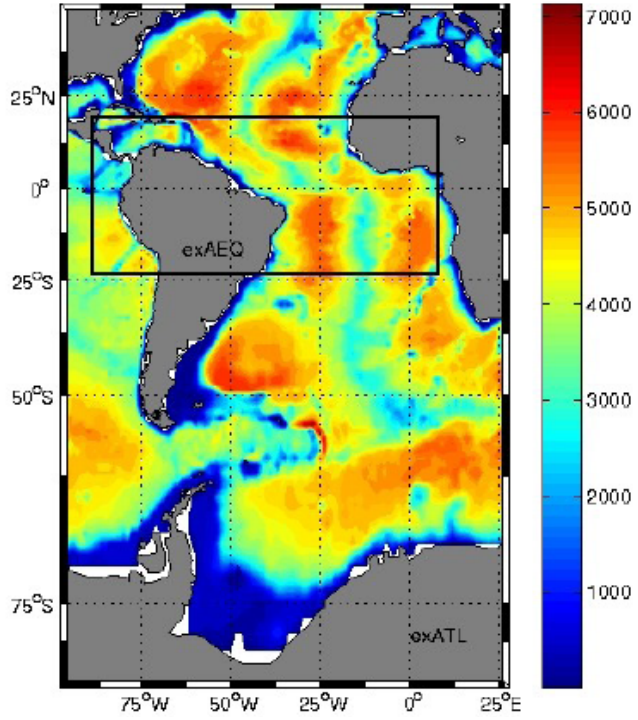
# A Numerical Study of the Influence of the Amazon River Plume in the Dynamics of the Western Equatotial Atlantic

*(G. Ruggiero & I. Soares)*

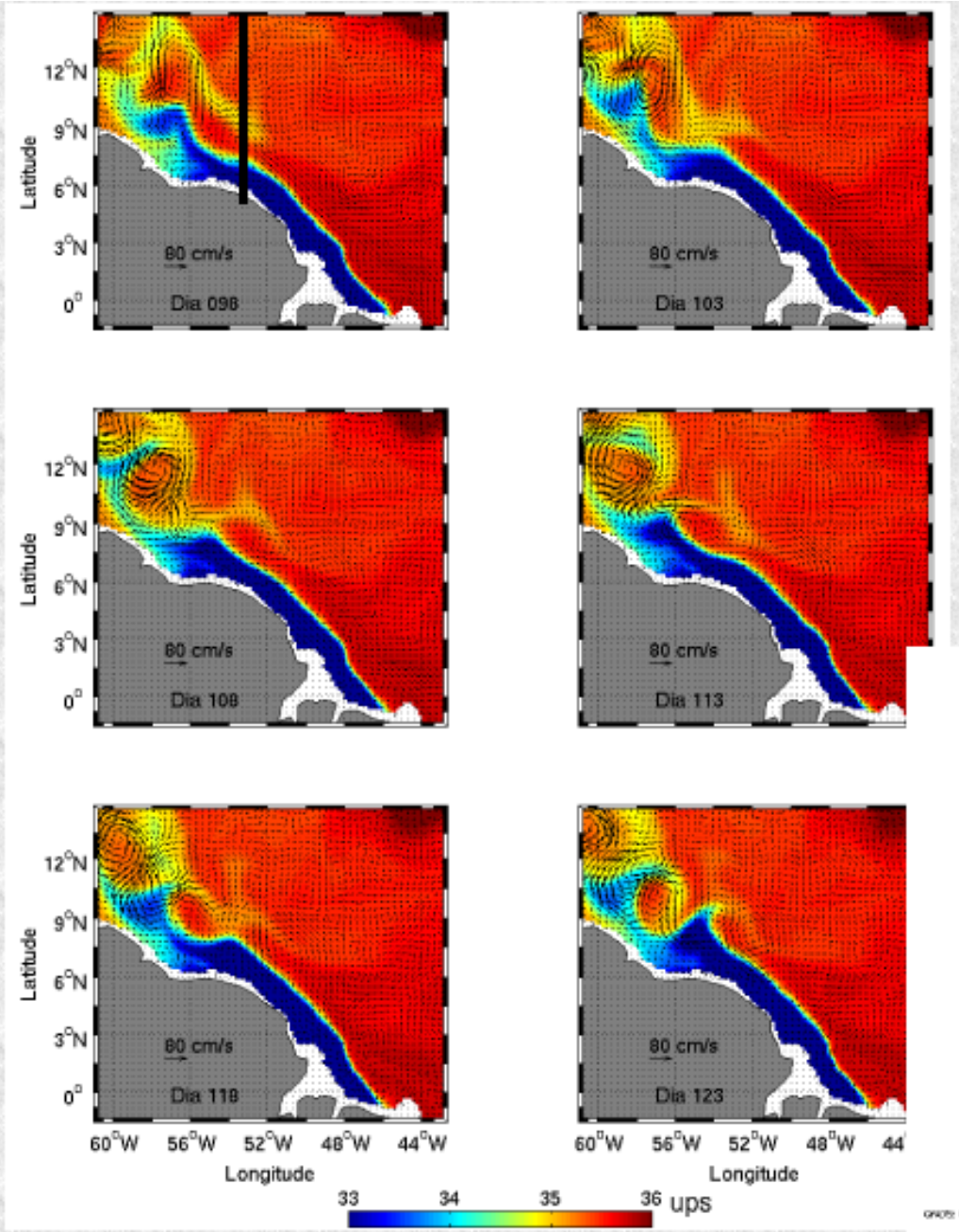
Universidade Federal do Rio Grande
Curso de Pós-Graduação em Modelagem Computacional

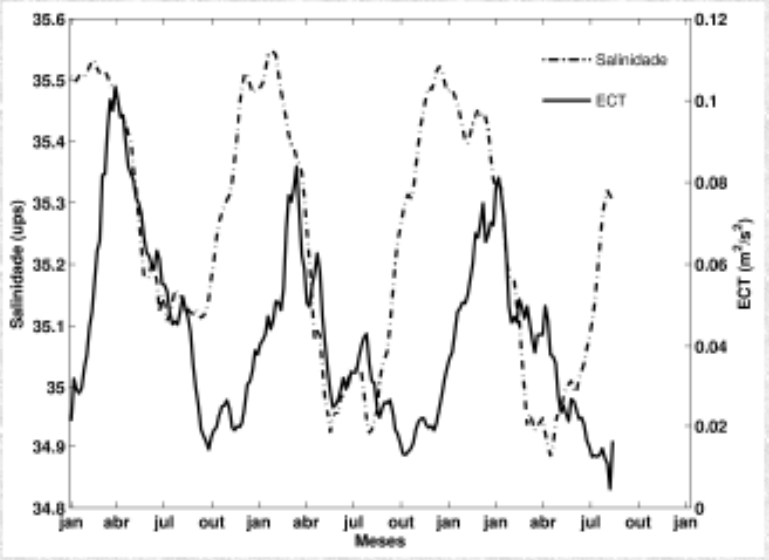
Estudo Numérico da influência da pluma do Rio Amazonas na dinâmica da porção oeste equatorial

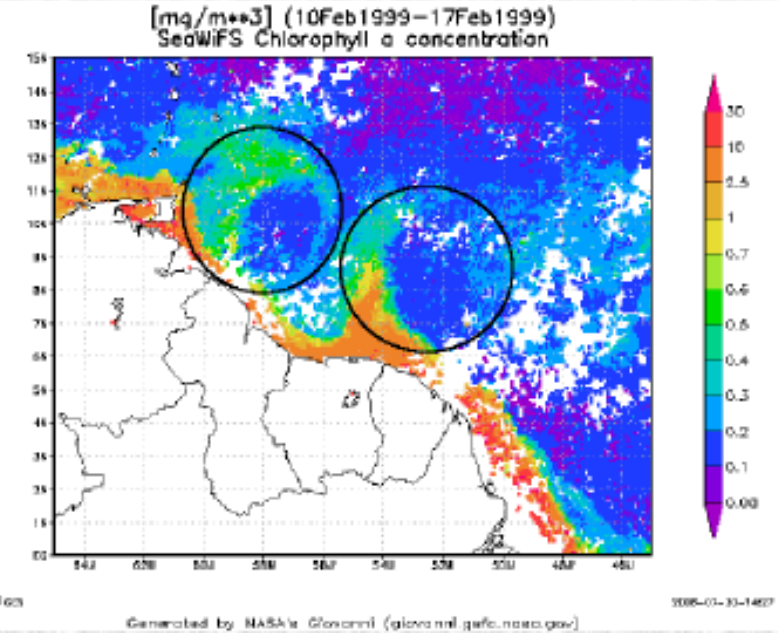
Mestrando: Giovanni Abdelnur Ruggiero
Orientador: Ivan Dias Soares
Co-orientador: Jeferson Ávila Souza



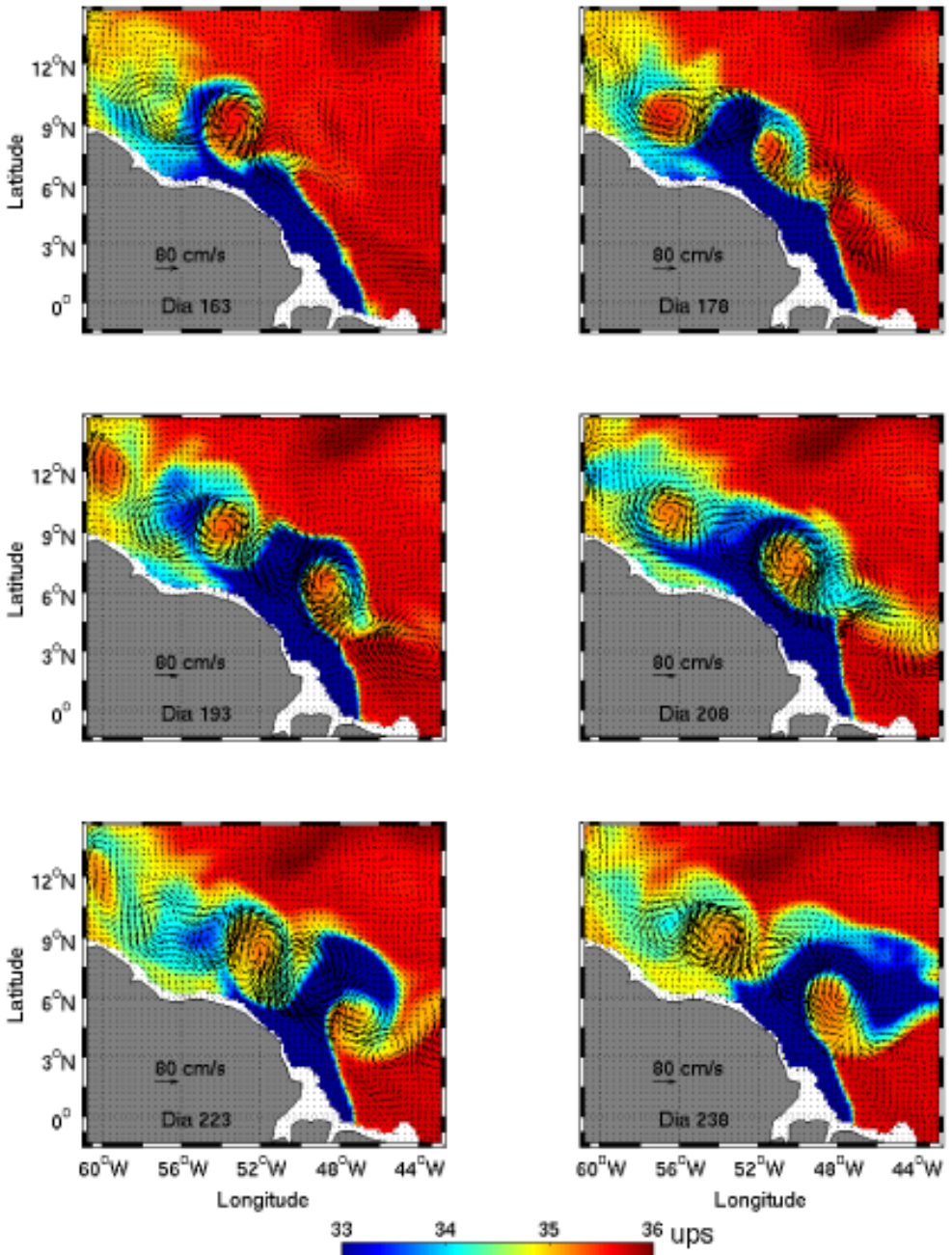
# NE Winds

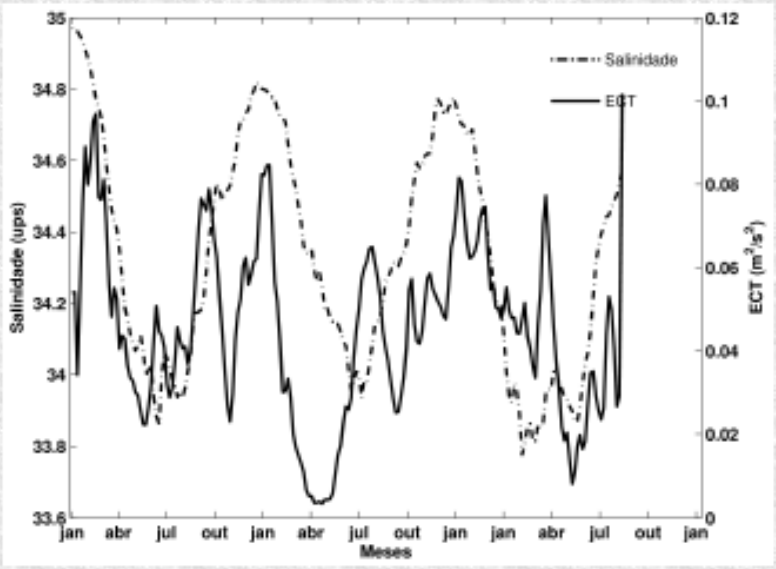

Latitude
12°N
9°N
6°N
3°N
0°
80 cm/s
Dia 098
Dia 103
Dia 108
Dia 113
Dia 118
Dia 123
60°W
56°W
52°W
48°W
44°W
Longitude
33
34
35
36 ups

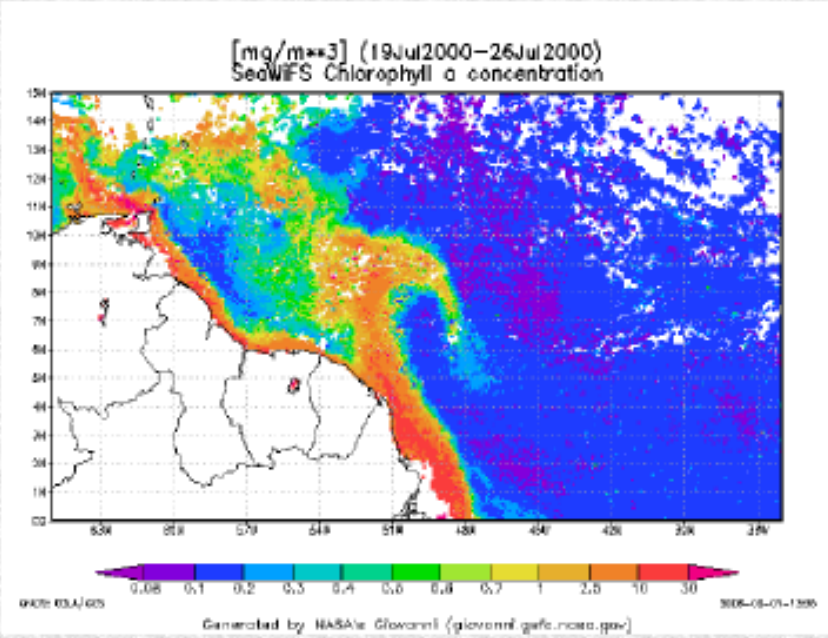

Salinidade
ECT
Salinidade (ups)
ECT (m²/s²)
Meses
jan
abr
jul
out


[mg/m**3] (10Feb1999-17Feb1999)
SeaWiFS Chlorophyll a concentration

# SE Winds


Latitude
Longitude
80 cm/s
Dia 163
Dia 178
Dia 193
Dia 208
Dia 223
Dia 238
12°N
9°N
6°N
3°N
0°
60°W
56°W
52°W
48°W
44°W
33
34
35
36 ups


Salinidade
ECT
Salinidade (ups)
ECT (m²/s²)
Meses
jan
abr
jul
out


[mg/m**3] (19Jul2000-26Jul2000)
SeaWiFS Chlorophyll a concentration
Generated by NASA's Giovanni (giovanni.gsfc.nasa.gov)

## Next Steps

- Implement an automatic data quality control system
- Implement the Extended Kalman Filter in the pre-operational forcast system
- Validate the forecasts taking the RMS w.r.t. observations (and independent data not used in the assimilation)
- Do experiments to look for a better model configuration including new domains, resolutions and lateral boundary conditions
- Investigate the physical processes associated with the Amazon and Tocantins rivers plume, the variability of the Brazil Malvinas Confluence, the bifurcation of the SEC, .....