Real Time Ocean Forecast System (RTOFS): A high resolution operational ocean forecast system for the Atlantic

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EMC/NCEP/NWS/NOAA

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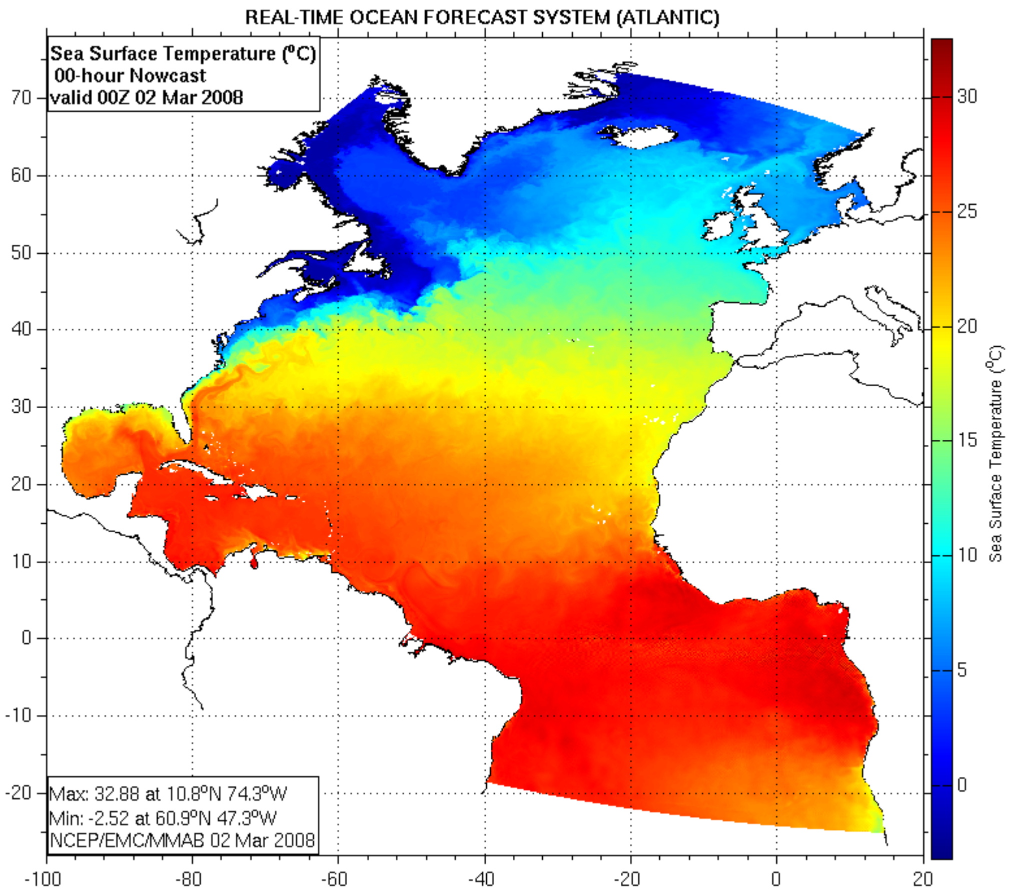
RT-OFS (Atlantic): Project Description

- RTOFS (Atlantic) is the first of a series of ocean forecast systems at the National Weather Service based on HYCOM. Part of the development of this system was done under a multi-institutional HYCOM Consortium funded by NOPP.

- HYCOM is the result of collaborative efforts among the University of Miami, the Naval Research Laboratory (NRL), and the Los Alamos National Laboratory (LANL), as part of the multi-institutional HYCOM Consortium for Data-Assimilative Ocean Modeling funded by the National Ocean Partnership Program (NOPP) to develop and evaluate a data-assimilative hybrid isopycnal-sigma-pressure (generalized) coordinate dynamical ocean model.

RTOFS (Atlantic): domain



RTOFS (Atlantic): Outline

- Dynamical Model
- Data Assimilation
- Daily operations and product distribution
- Comparison with observations

Dynamical Model: HYCOM

- Primitive equation with free surface.
- State variables: Temperature, Salinity, Velocity, Sea surface elevation.
- Vertical mixing and vertical viscosity: GISS

Dynamical Model: configuration

- **Horizontal grid:** orthogonal telescopic, dx/dy~1
- **Bathymetry:** ETOPO2 (NGDC)
- **Coastal boundary**: blend of bathymetry and coastline datasets (NGDC)
- **Surface forcing:** GDAS/GFS (NCEP)
- **River outflow/runoff:** blend of observations (US rivers USGS) and climatology (RIVDIS)
- **Initialization:** T,S from blended regional coastal climatologies (Gulf of Maine, Mid and South Atlantic Bights, Gulf of Mexico) and HYDROBASE; sea surface elevation and barotropic velocity from climatology (for low frequency) and tidal model (TPX06)
- **Body Tide**: eight tidal constituents

Treatment of Low Frequency Boundary Conditions

Internal Mode:

a) **Extrapolation of velocity fluxes for advection and momentum**

b) **Relaxation of Mass Fields T, S and P (interface thickness) in the buffer zones**

$$T^k_{t+1} = T^k_t + \Delta t \, \mu \, (\theta^k_t - T^k_t)$$

$$S^k_{t+1} = S^k_t + \Delta t \, \mu \, (\theta^k_t - S^k_t)$$

$$P^k_{t+1} = P^k_t + \Delta t \, \mu \, (\theta^k_t - P^k_t)$$

where θ represents climatology, k is the layer and μ^{-1} is the relaxation time scale.

The width of buffer zones and values of μ^{-1} are defined a priori.

Low Frequency Boundary Conditions

Tracking of external mode (normal transports, elevations)

Normal transports and elevations determined from T,S climatology and Mean Dynamic Topography.

- Absolute geostrophic velocity determined by either
  i) assuming a level of no motion, or
  ii) constrained by the sea surface elevation from Maximenko & Niller, 2005

The boundary conditions for each boundary are then defined as:

(one invariant formulation)

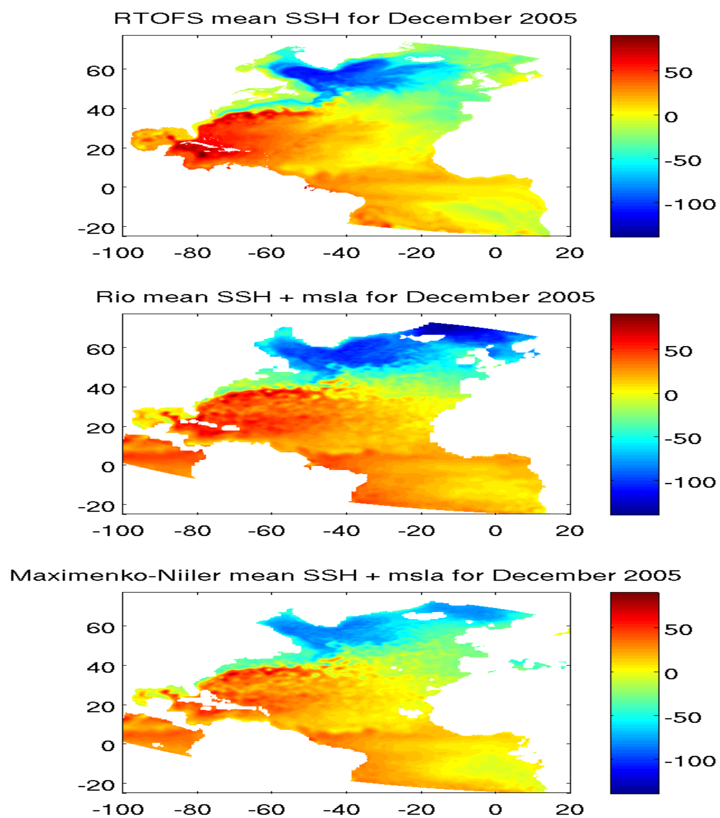
$$U_1^{k+1} = U_{obs} + (g/h)^{1/2} * W * (\eta_{obs} - \eta_1^k)$$

$$\eta_1^{k+1} = W * \eta_{obs} + (1-W) * \eta_1^k$$

where W is a prescribed weight.

Open boundaries for RTOFS

Mean Dynamic Topography from data collected and analyzed by Maximenko & Niiler et al. (GRL, 2003) using near-surface velocity observations from ARGOS drifters (1992-2002).



Low Frequency Boundary Conditions

Two invariant formulation:

If $\gamma = (g/h)1/2$ and U_{ext} is the linear extrapolated velocity at the boundary, the 2 invariants are defined as:

$$\Gamma^o_- = U_{ext} - \gamma\ \eta_b \quad ; \quad \Gamma^o_+ = U^o_{b-1} + \gamma\ \eta^o_b$$

where η is the free surface height and "o" signifies observed variables and "b" denotes boundary point.

Data Assimilation: objectives

- Improve the estimate of sub-surface ocean structures based on remotely sensed observations of sea surface height, sea surface temperature, in situ temperature and salinity; and model estimates.
- Improve the joint assimilation of SSH, SST, T and S in a high resolution ocean forecast system.

Data assimilation: Observations

- SST: in situ, remotely sensed [AVHRR, GOES]
- SSH: remotely sensed [JASON, GFO, ENVISAT]
- T&S: ARGO, CTD, XCTD, moorings.

Data assimilation: Algorithms

Overall employ 3DVar = 2D (along model layers)x1D(vertical).

2D assumes Gaussian isotropic, inhomogeneous covariance matrix using recursive filtering (Purser et al., *MWR, 2002*)

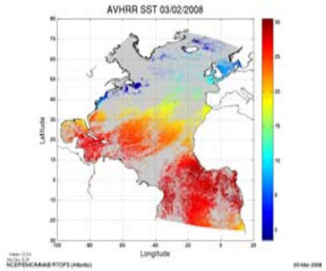
1D vertical covariance matrix.

- Constructed from coarser resolution simulations
- SST extended to model defined mixed layer.
- SSH lifting/lowering main pycnocline.
- S&T lifting/lowering below the last observed layer.

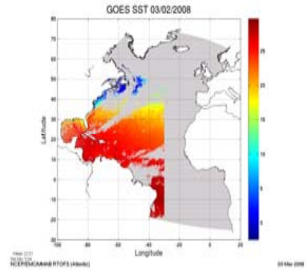
SST Assimilation

Data

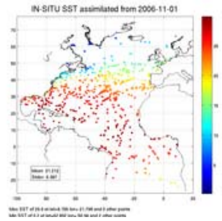
AVHRR



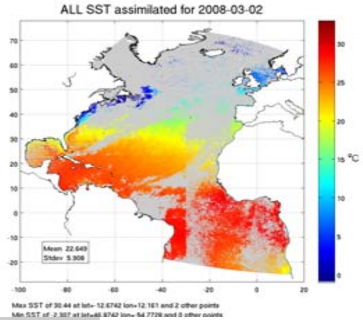
GOES



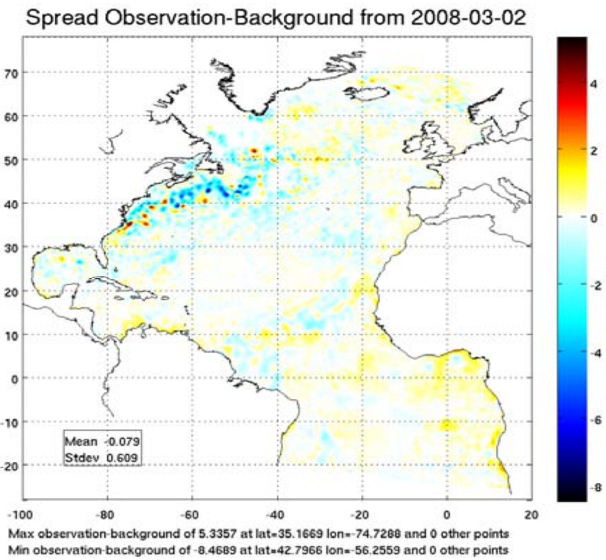
IN-SITU



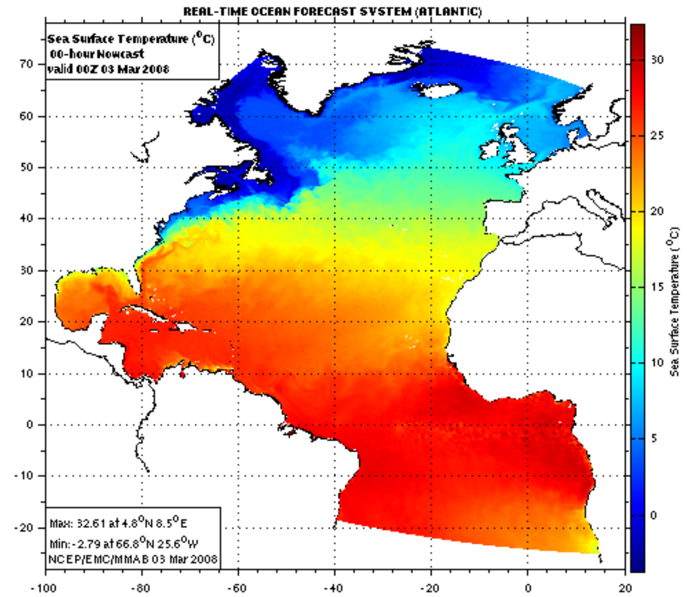
ALL



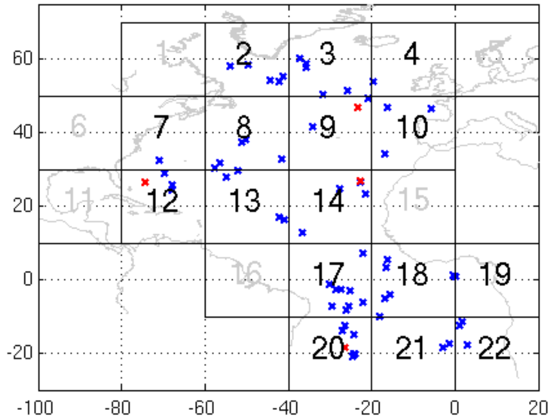
Observation - Background

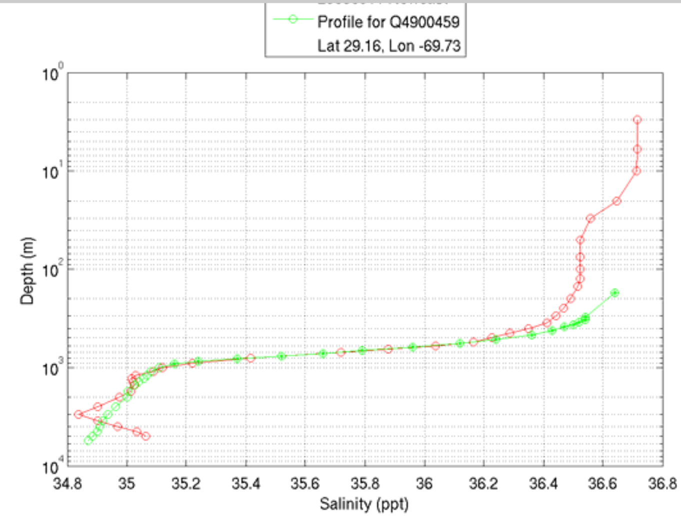


Assimilated Field

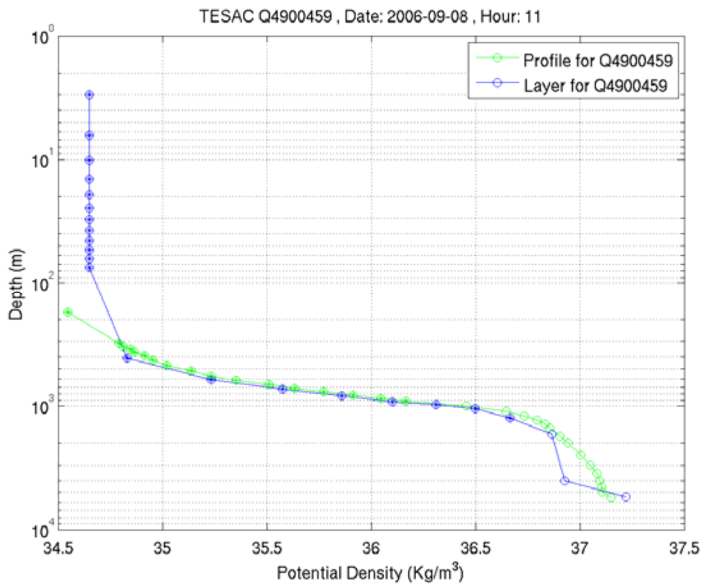


Z to LAYER

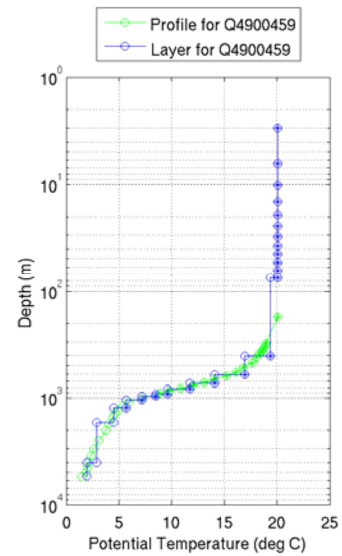


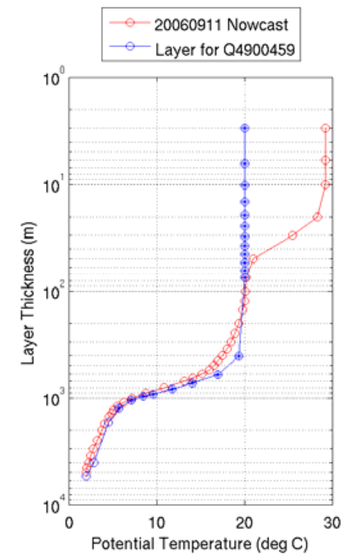


Data



Profile
To
Layers





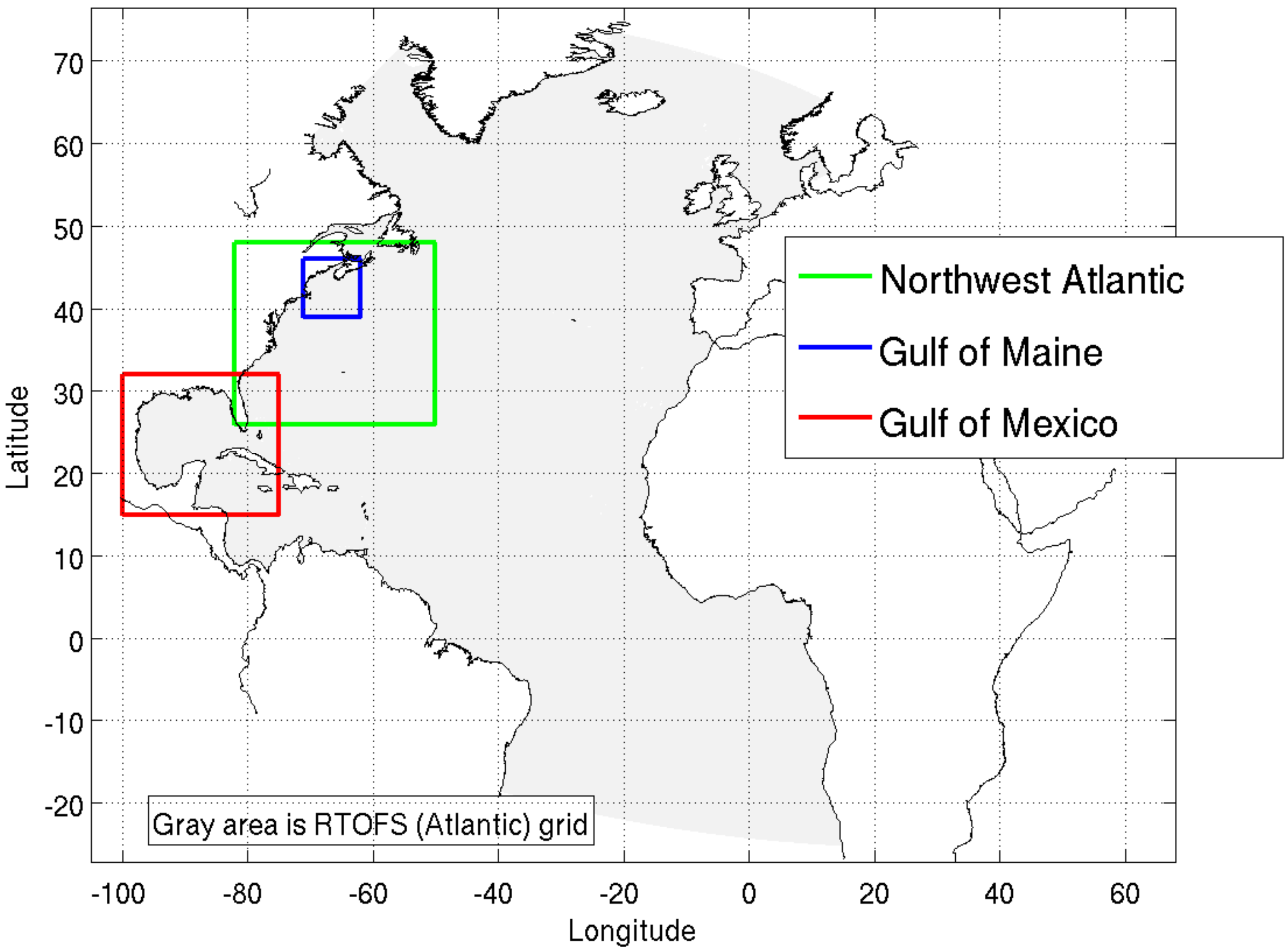
Daily Products

- Once daily (issued at 04Z)
  - Nowcast 1day
  - Forecast 5 days

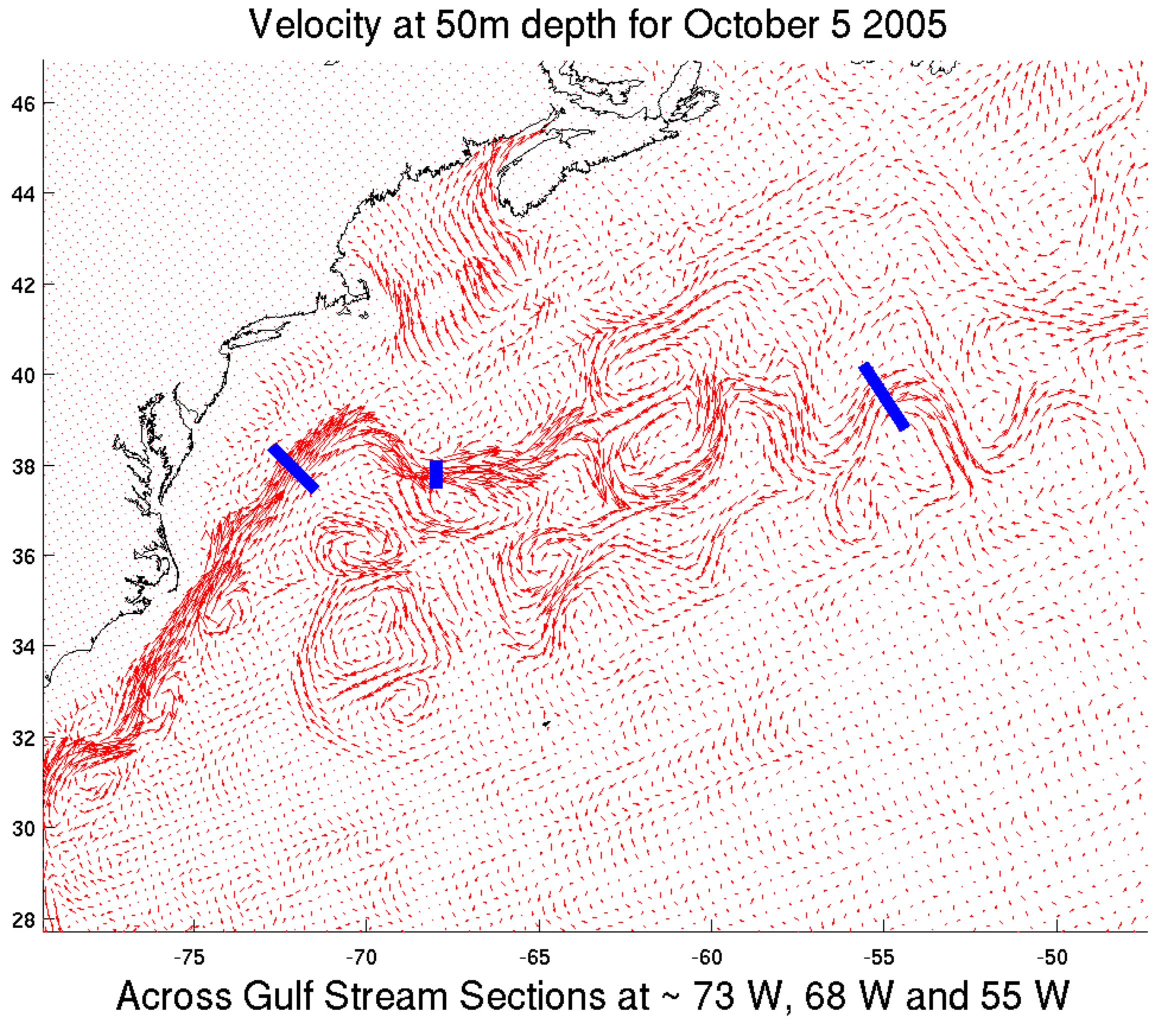
- Grib files for nowcast and forecast
  - Hourly surface T,S,U,V, SSH, barotropic velocity, mixed layer depth
  - Hourly interpolated fields on a regular lat-lon grid.
  - Daily T,S,U,V,W, SSH for 40 depths and for 26 layers

- Product distribution
  - NCO servers (ftpprd)
  - NOMADS [sub-setting] (full data server functions)
  - MMAB Web server (ftp, graphics)
  - NODC deep archives

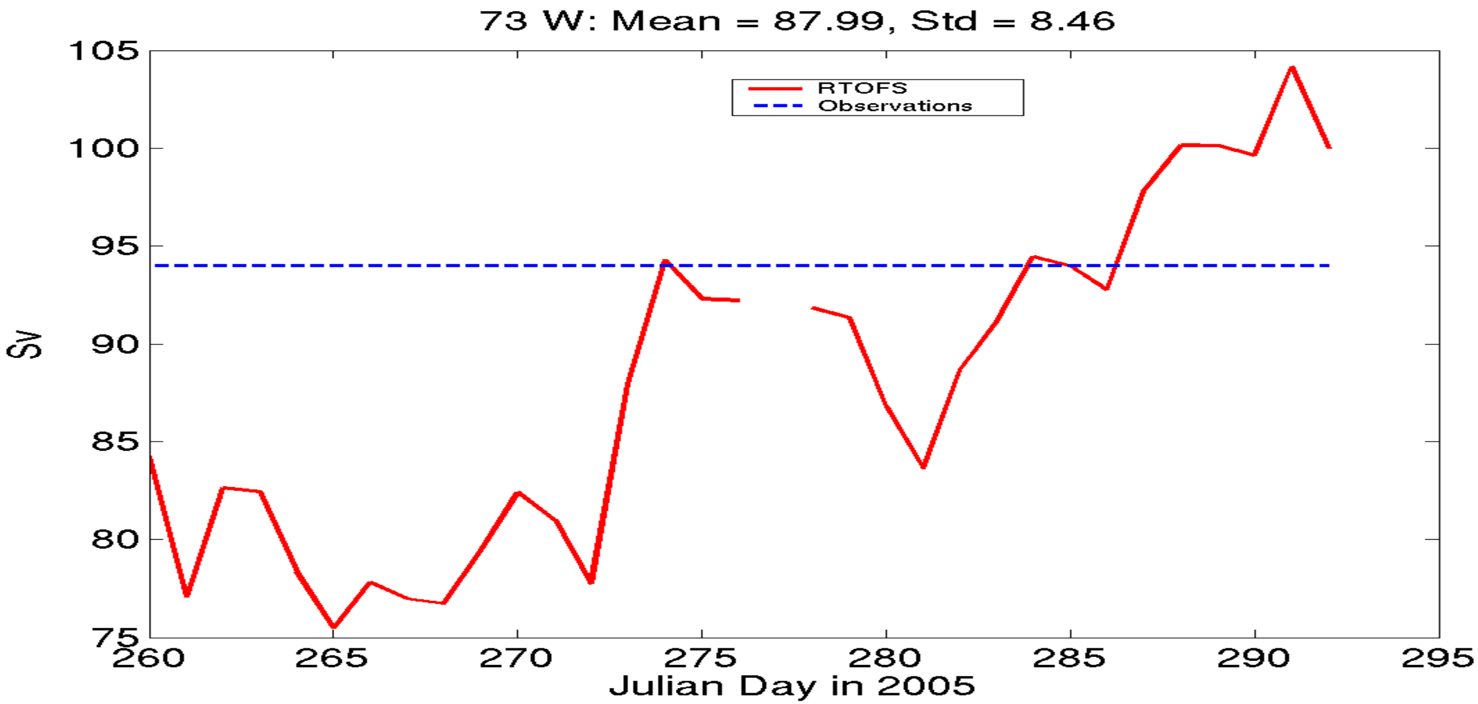
Comparisons in selected regions



Comparison of cross Gulf Stream section transports at 73 W, 68 W and 55 W with historical data

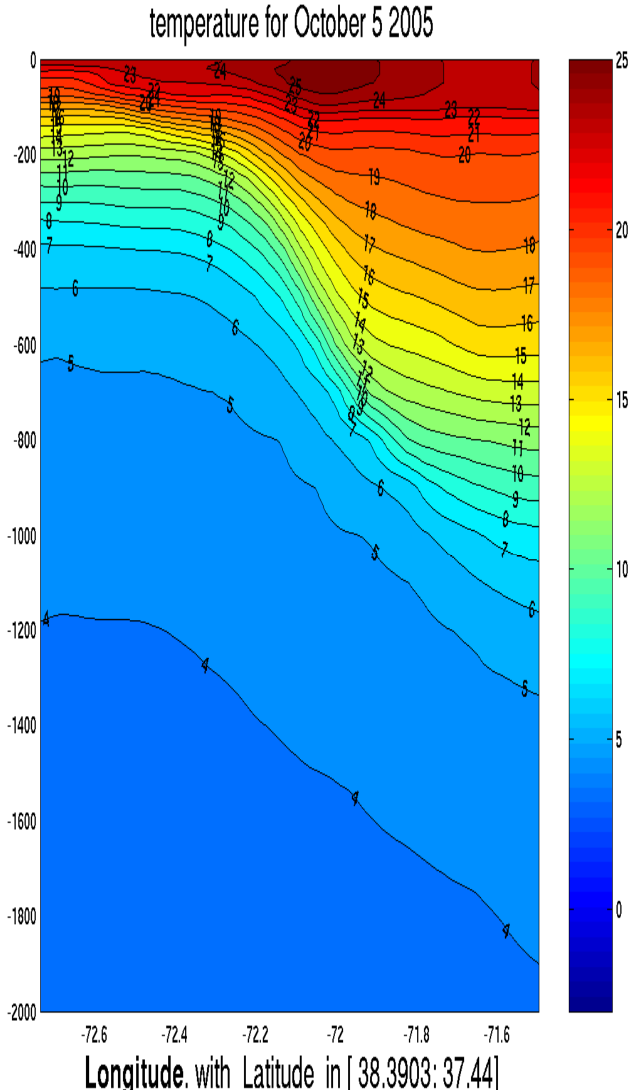


Gulf Stream Transport at 73 W in "cross-stream" coordinates



Observed Mean ~ 94 Sv (Leaman et al., JPO, 1989)

Transect at 73 W



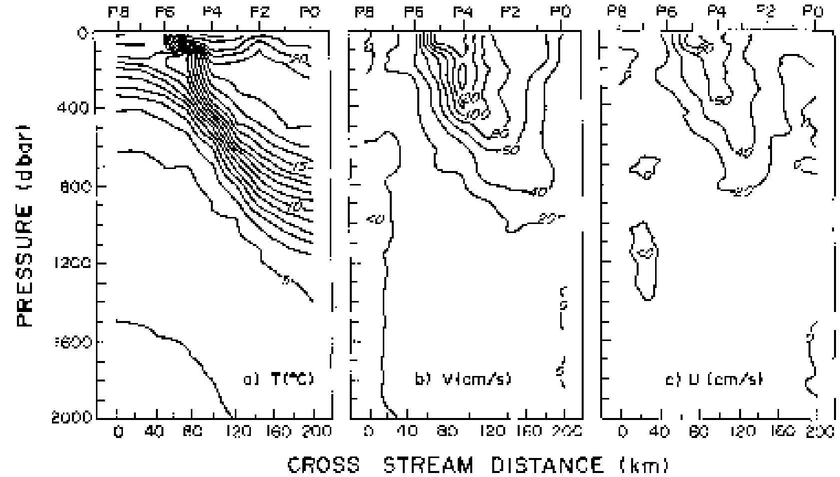
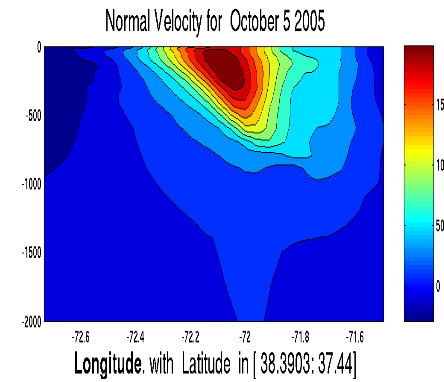
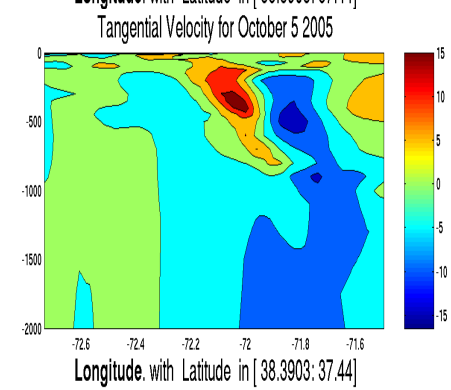


FIG. 4. Sections of temperature and velocity in the transect coordinate system for March 1982: (a) temperature; (b) the component of velocity perpendicular to the transect; (c) the component parallel to the transect (positive values indicate flow in the direction 141°T).

Halkin and Rossby, JPO 1987

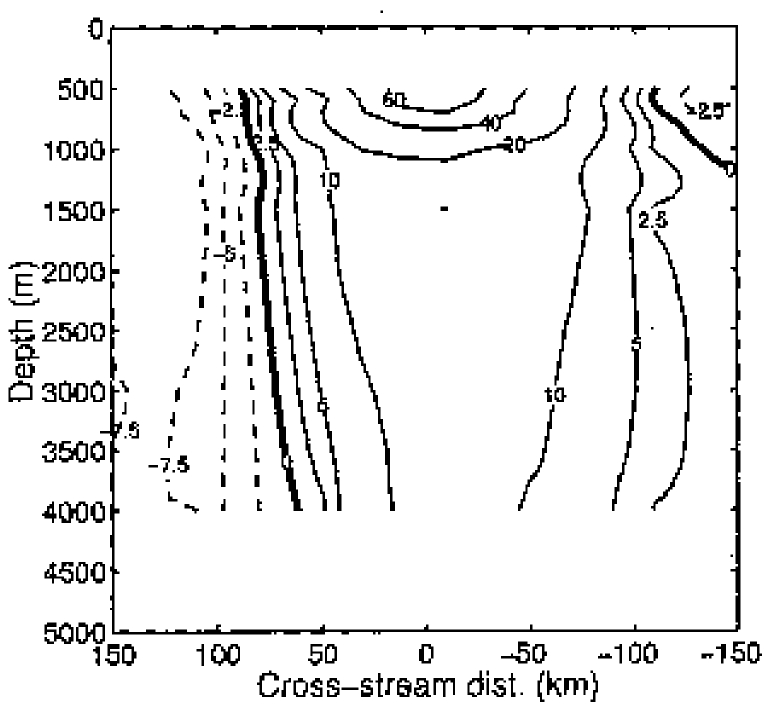


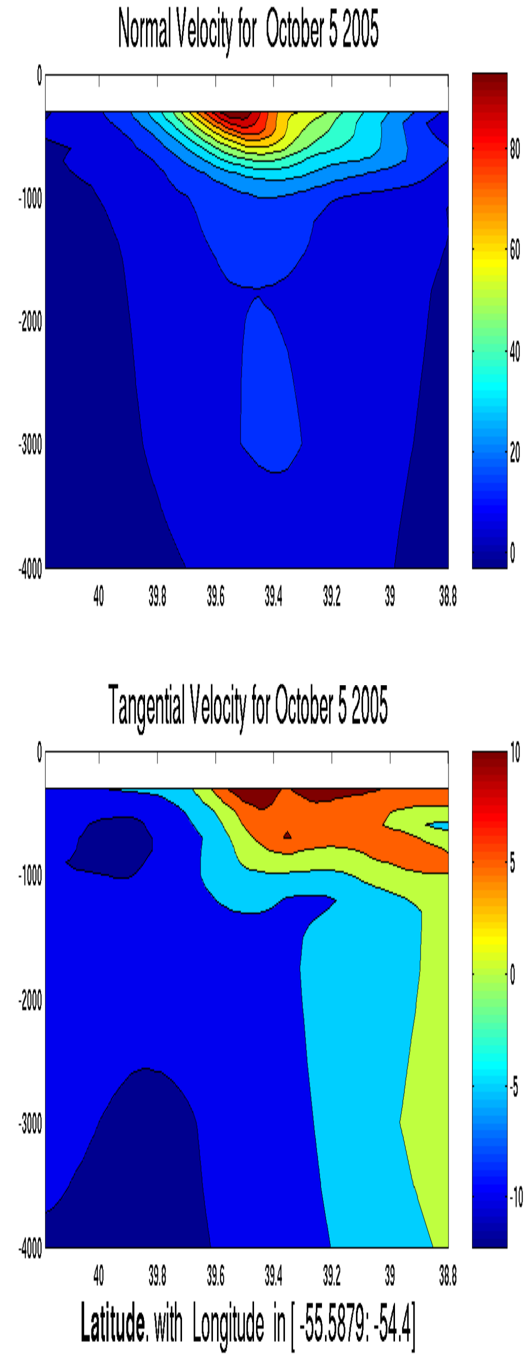


RT-OFS (Atlantic)

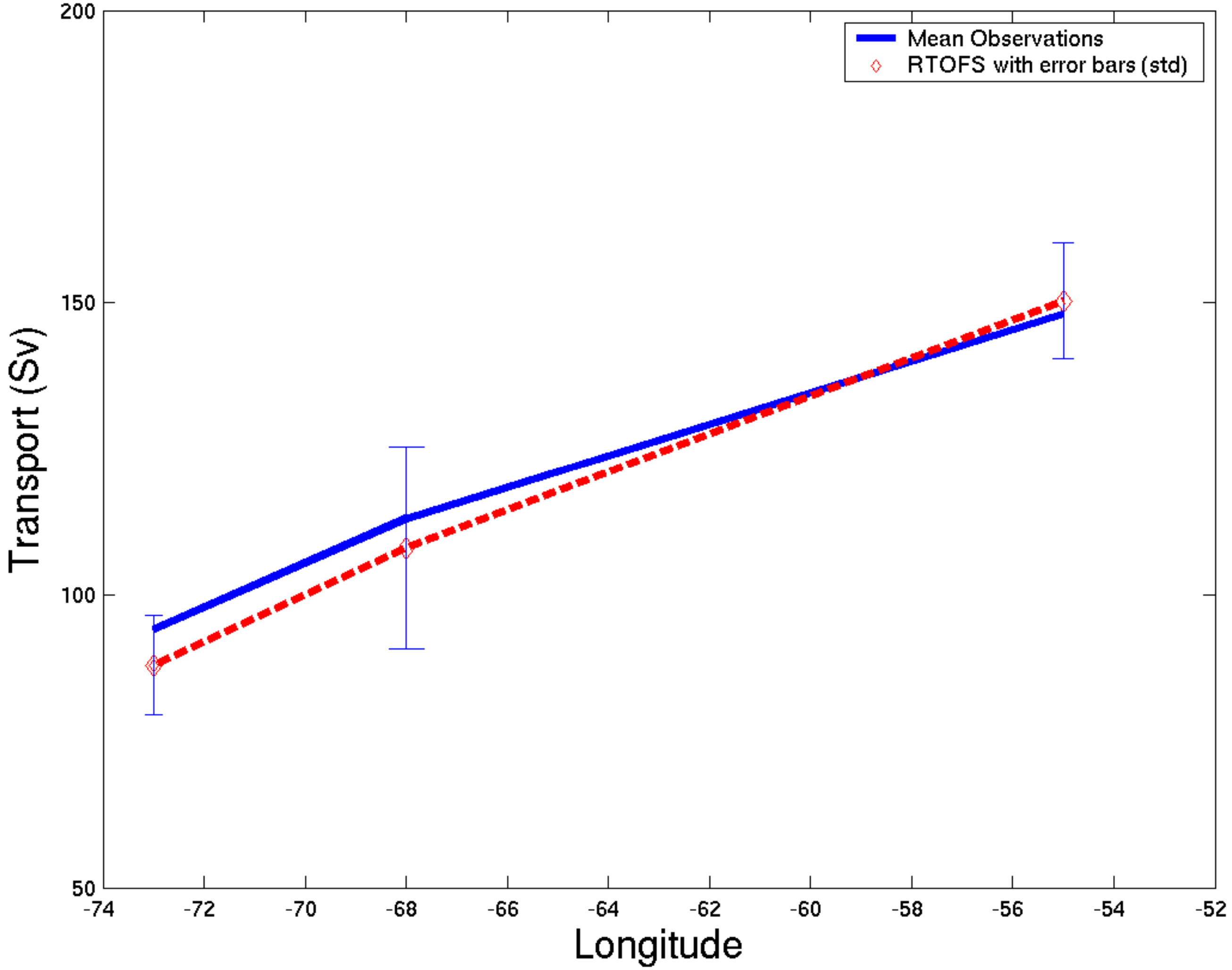
Transect at 55 W

Bower and Hogg, JPO 1996

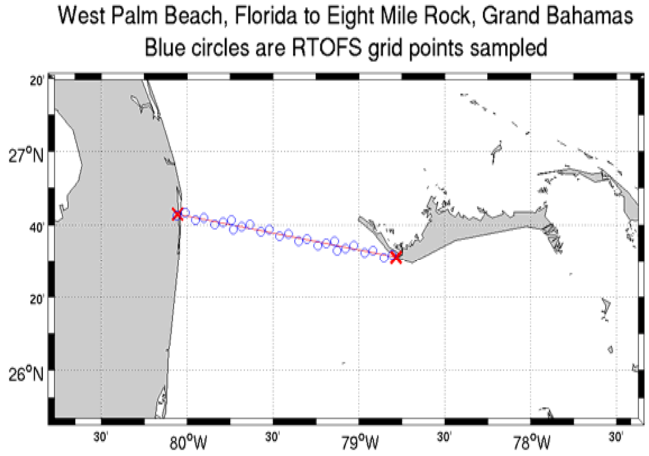


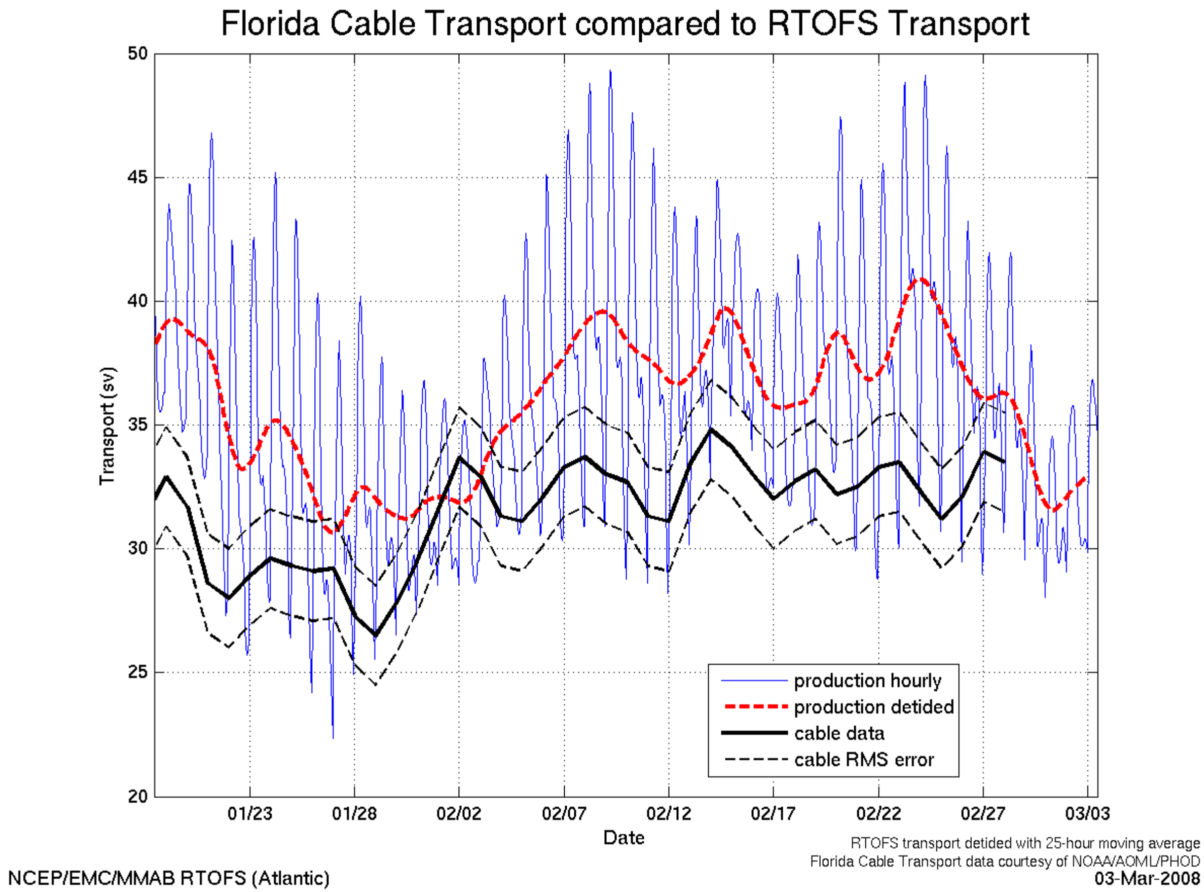


Gulf Stream Transport



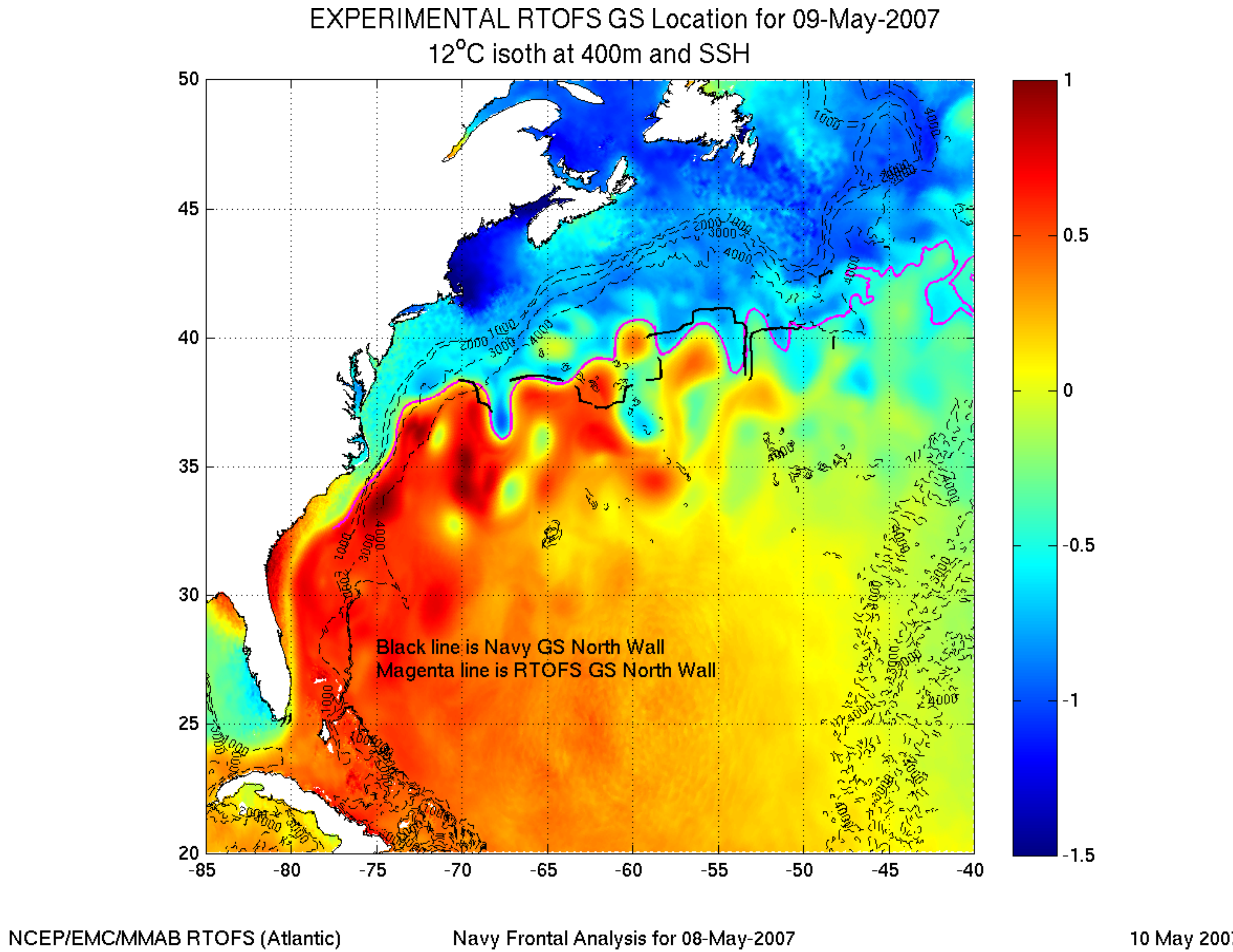
Florida Current Transport





Gulf Stream Transports Summary

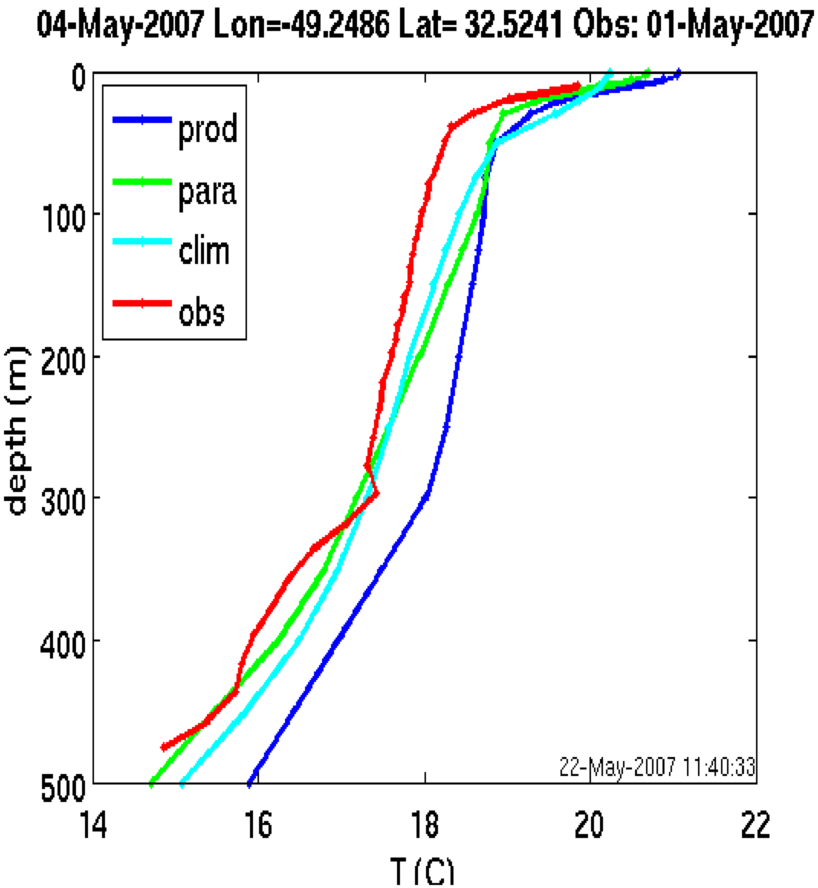
- The observed eastward increases in the Gulf Stream transport and its barotropic component are well matched in the mean by the RT-OFS.
- The observed slanted velocity profiles in stream coordinates are captured by the model.
- Model Florida Current transport tends to overestimate observations (4-5 Sv) and its variability is usually off phase (few days), but in general it preserves the observed variability pattern.



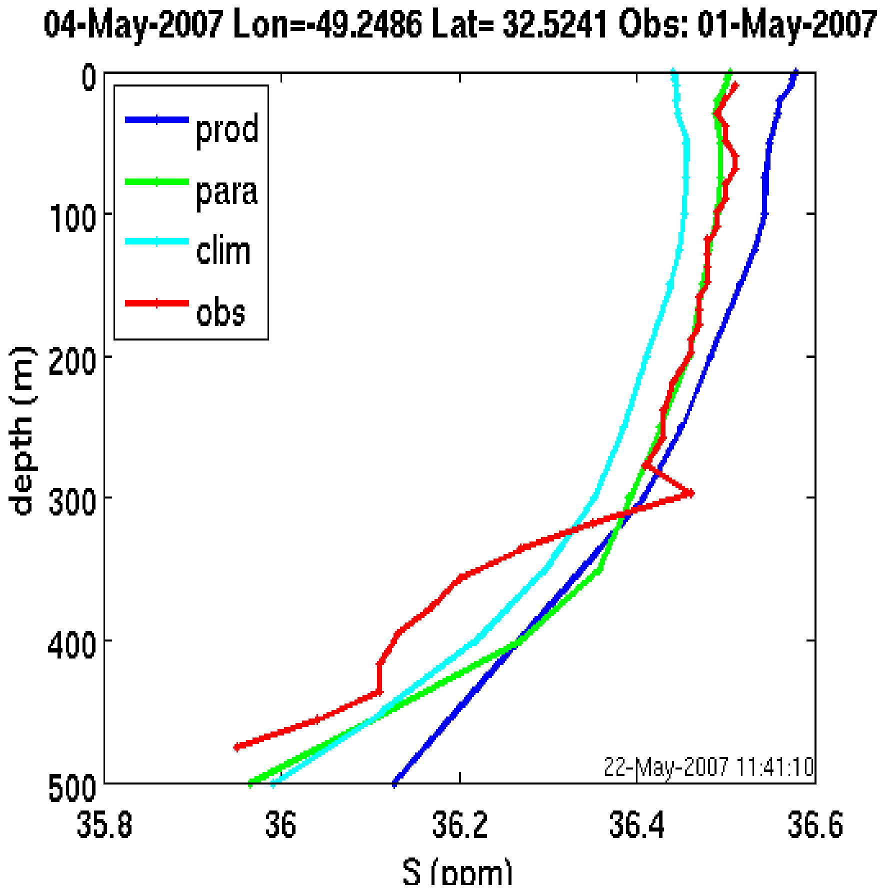
North Wall of the Gulf Stream (in magenta), Navy Analysis (in black) superposed on model SSH.

Location: Sargasso Sea (middle Atlantic)

POTENTIAL TEMP

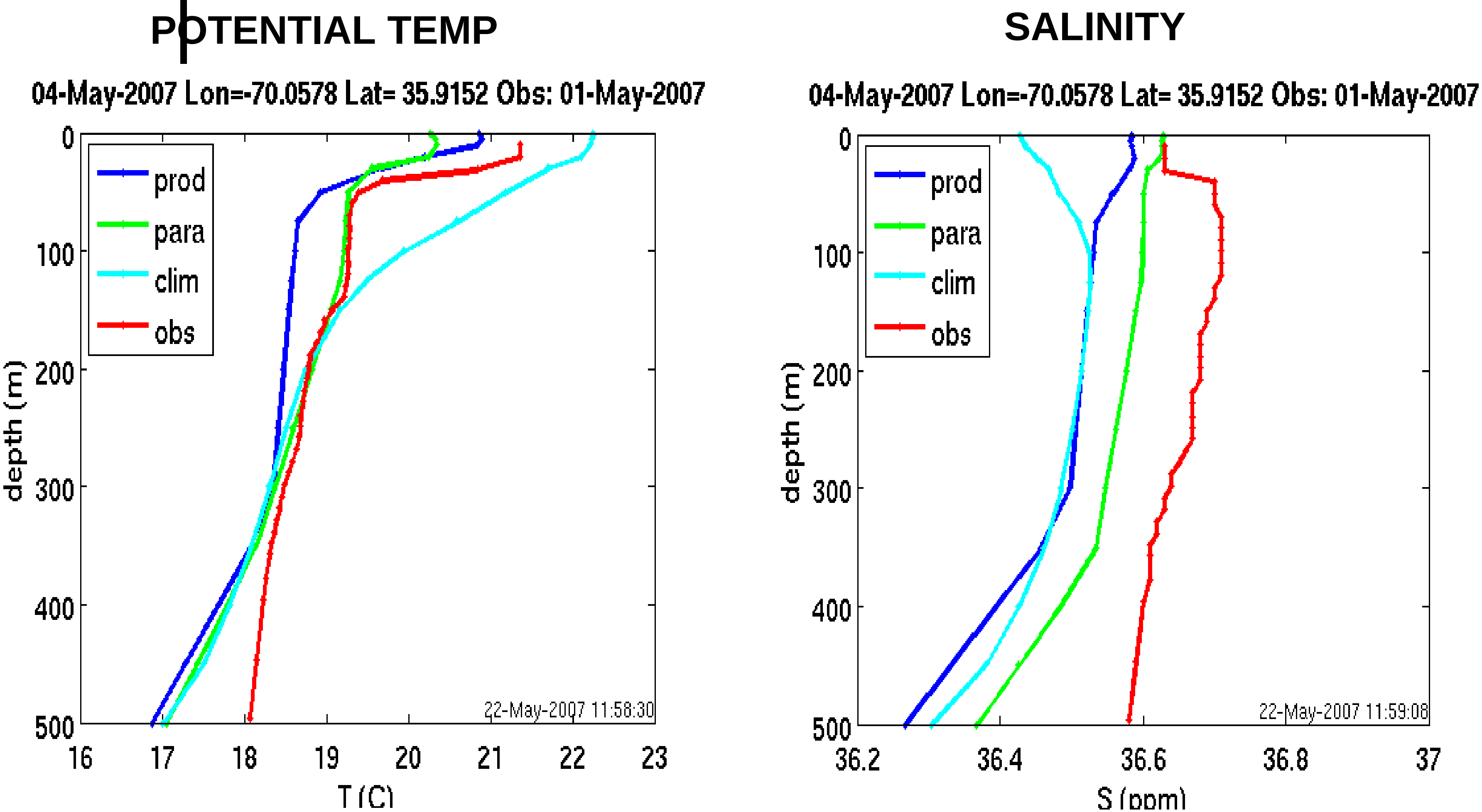


SALINITY



prod (SST assimilation only), para compared to a CTD profile (obs) and climatology (clim). prod is warmer and fresher than para and the CTD data.

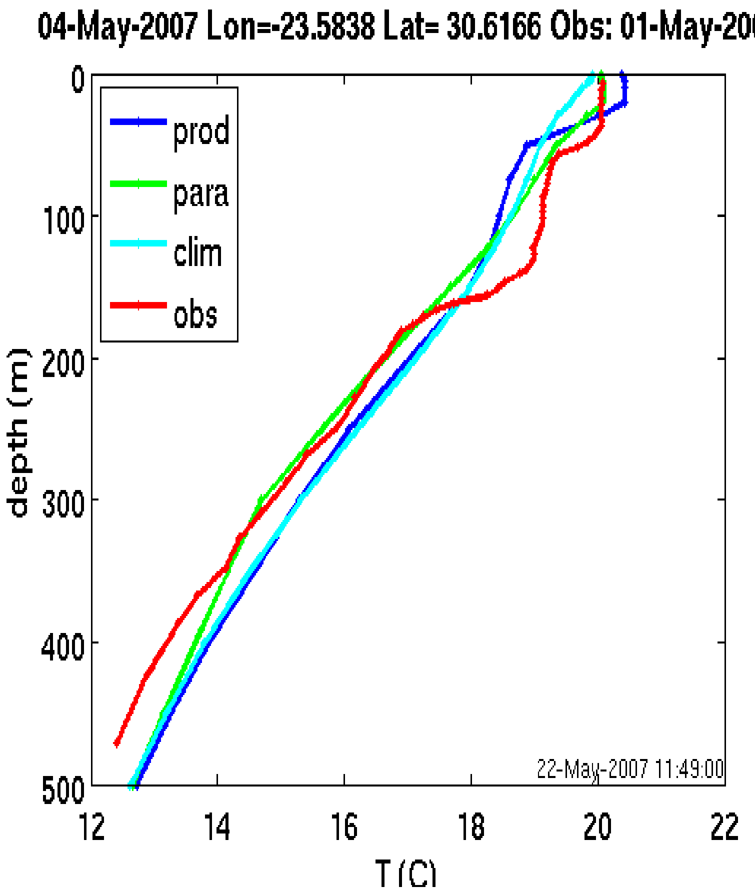
Location: Gulf Stream region



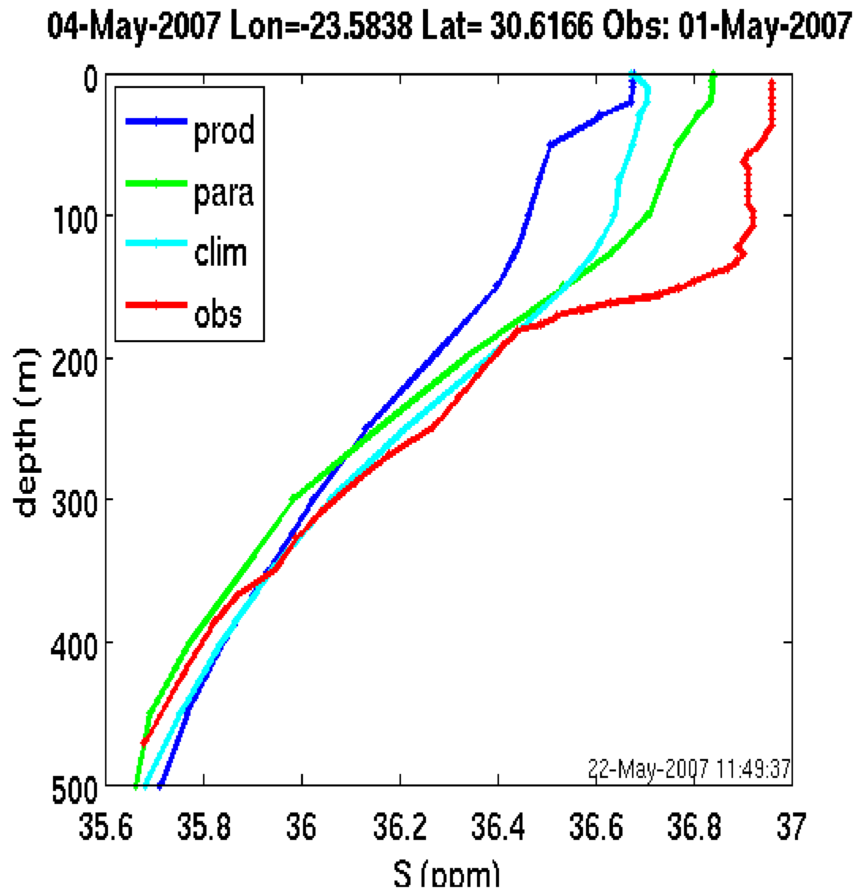
Prod (SST assimilation only), para compared to a CTD profile (obs) and climatology (clim). para is colder and fresher as compared to prod and CTD.

Location: Near Azores (eastern Atlantic)

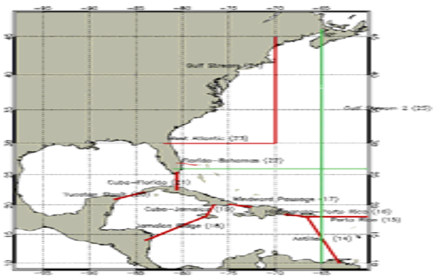
POTENTIAL TEMP



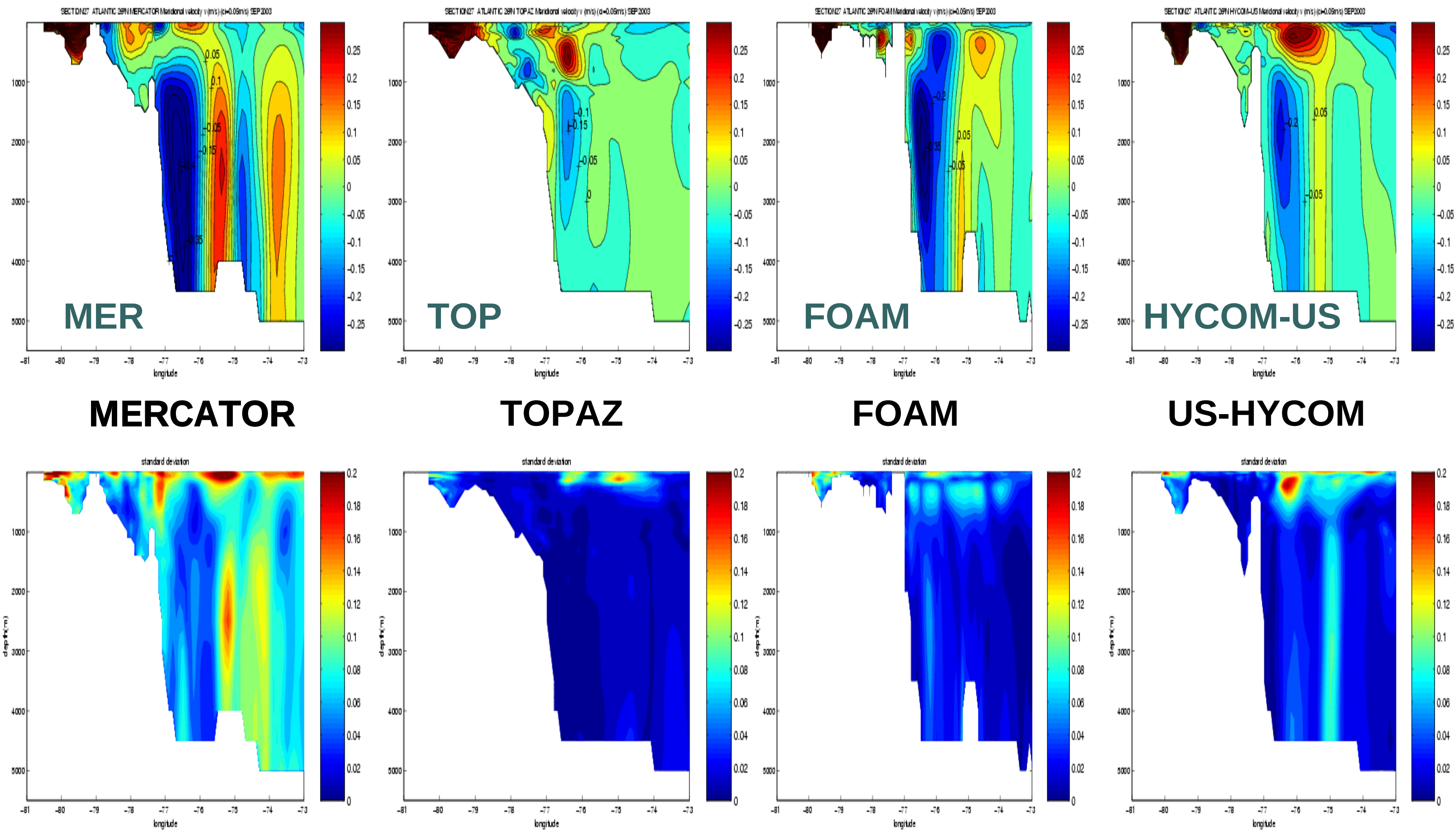
SALINITY



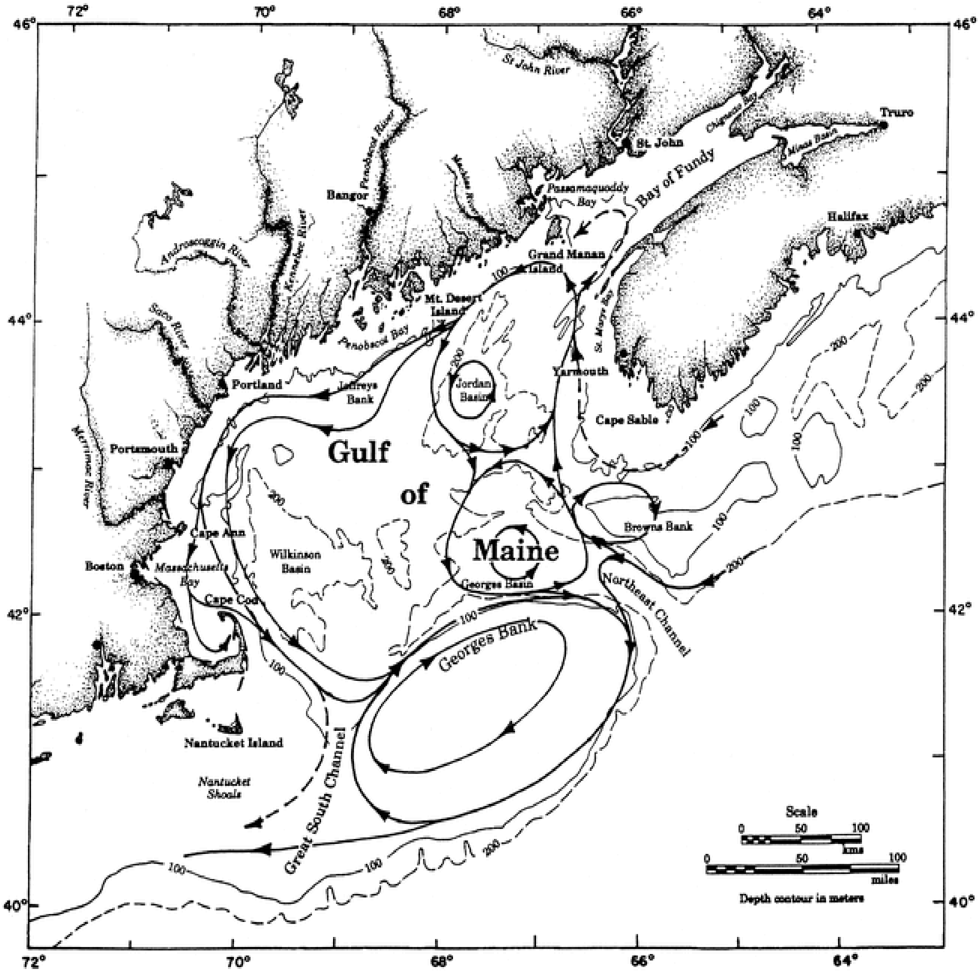
prod (SST assimilation only), para compared to a CTD profile (obs) and climatology (clim). Both para and prod do not capture the thermocline well.



Results from three other models showing the location and strength of DWBC at 27 N.

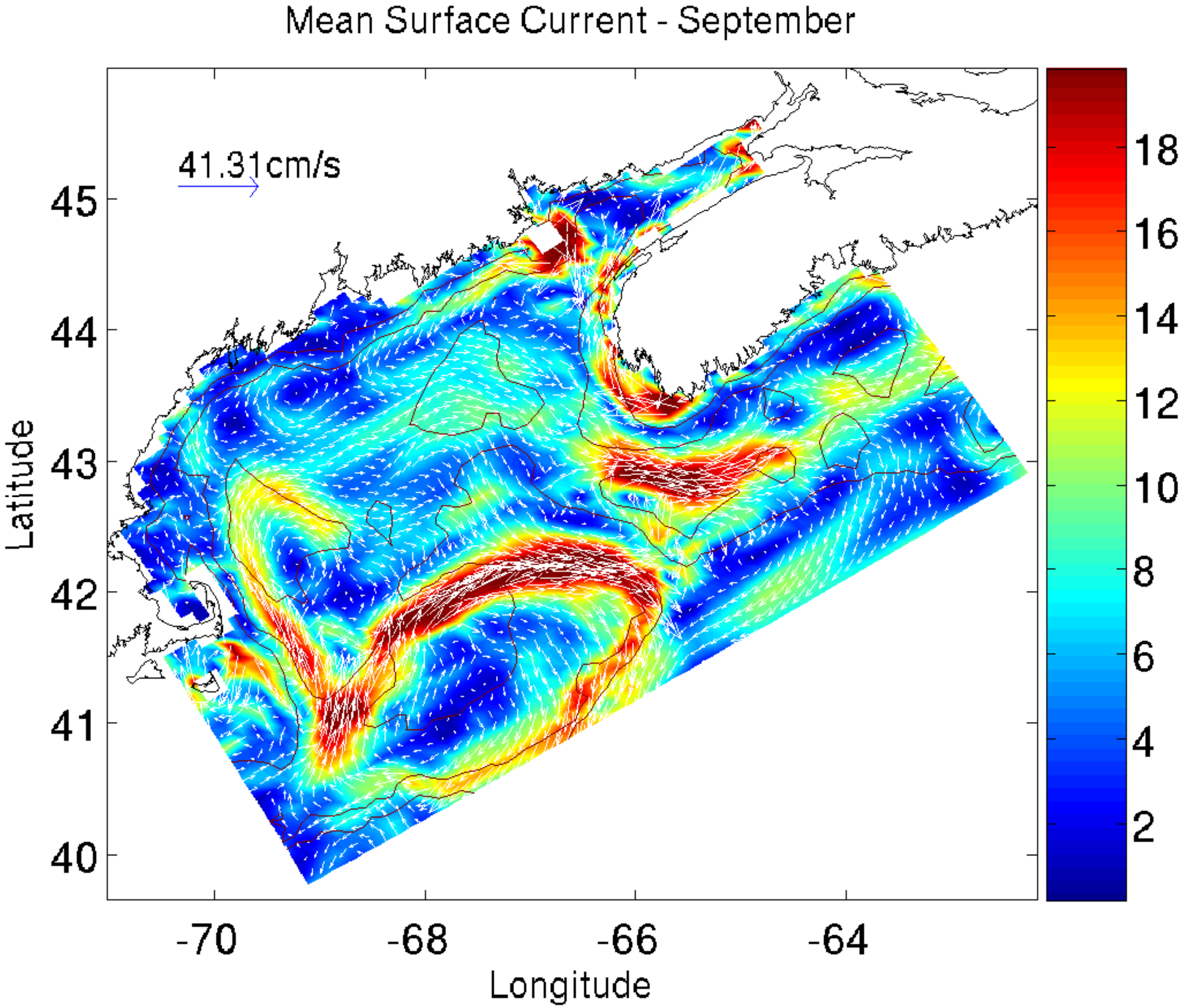


Gulf of Maine Surface Circulation



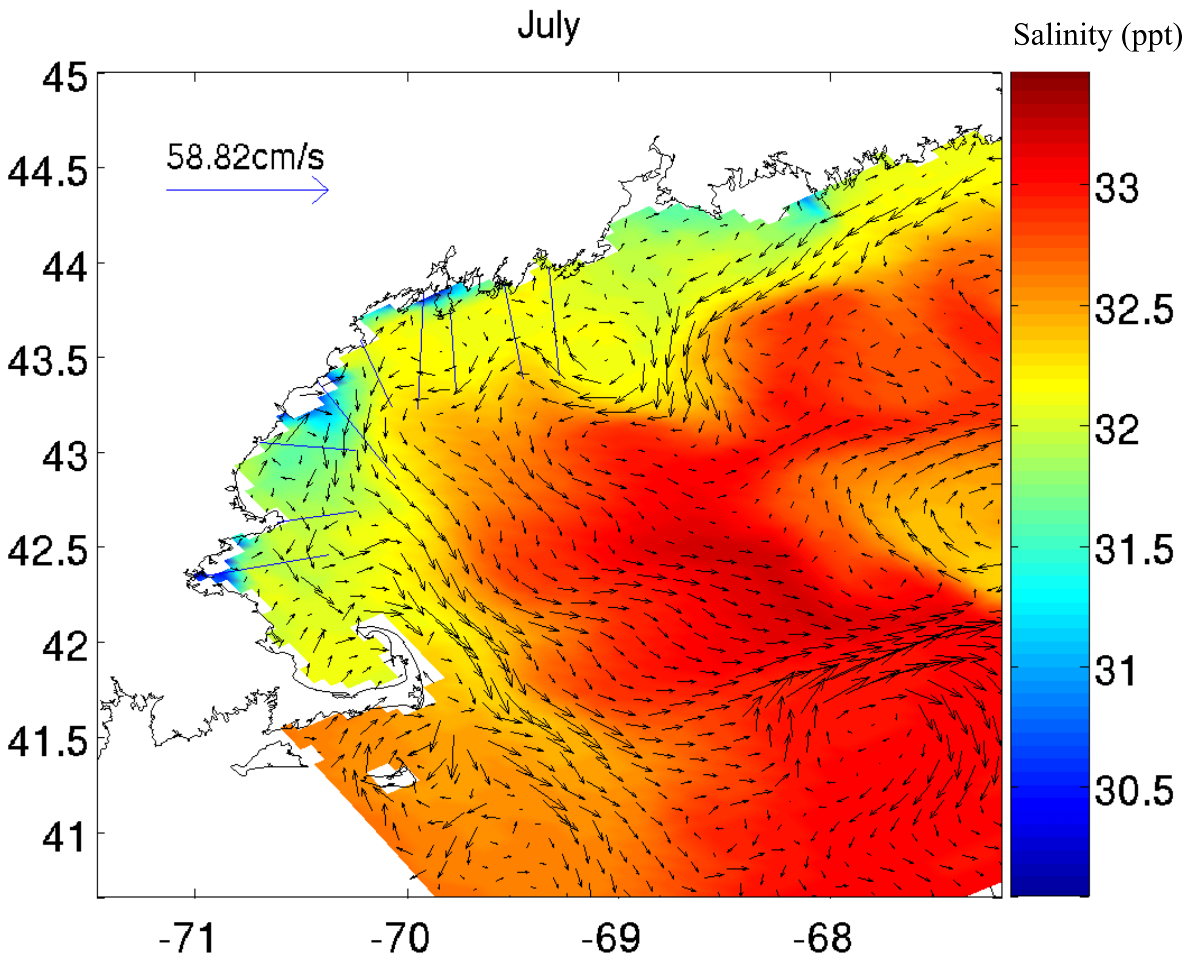
Xue, H., F. Chai, and N.R. Pettigrew (JPO 2000)

Mean Surface Current for September



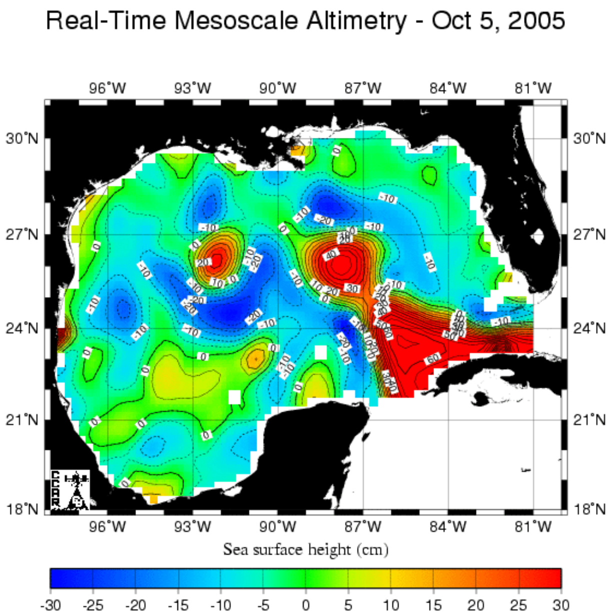
Freshwater Transport for July

Freshwater mean:
Data: 1338.9 m³/s
RTOFS: 1149.1 m³/s

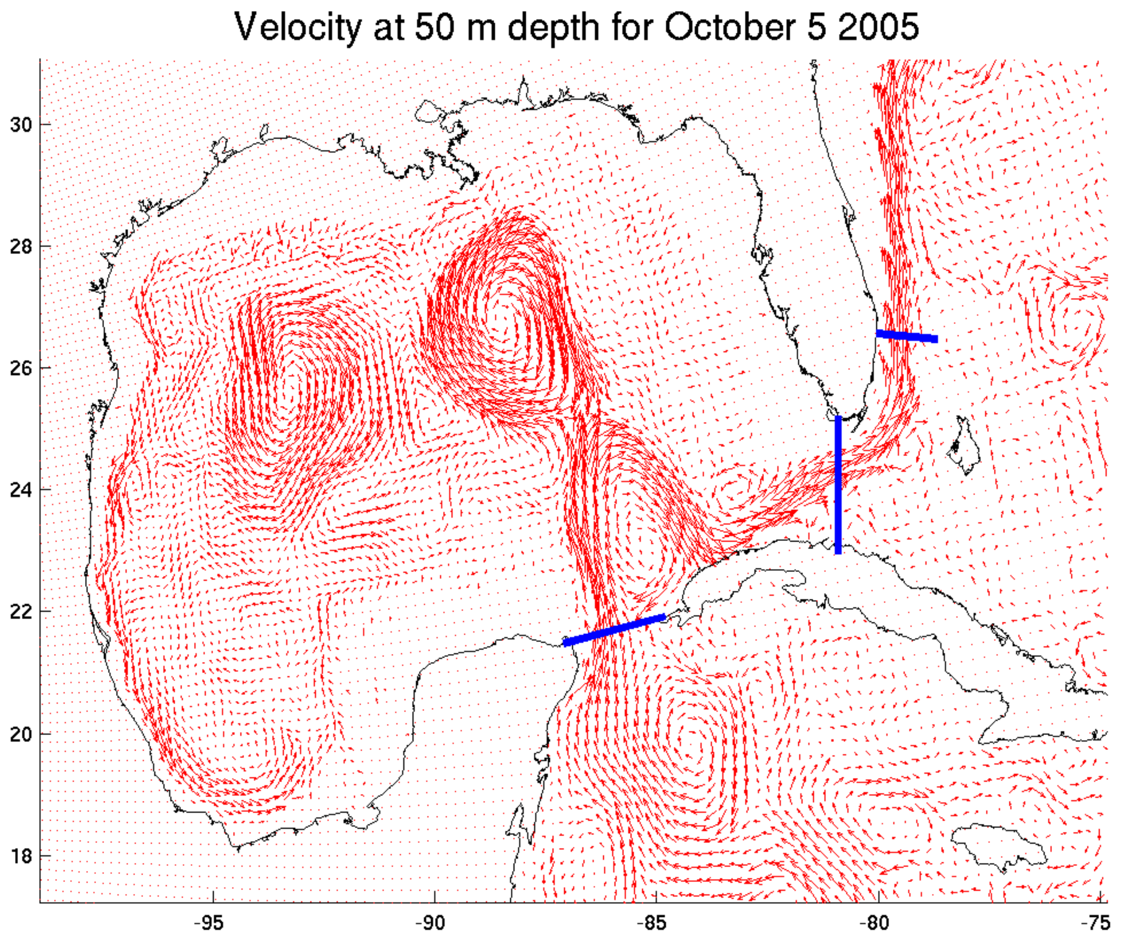


Data from Geyer et al., *Continental Shelf Research*, 2004.

Comparison of Loop Current /Florida Current transports with historical data

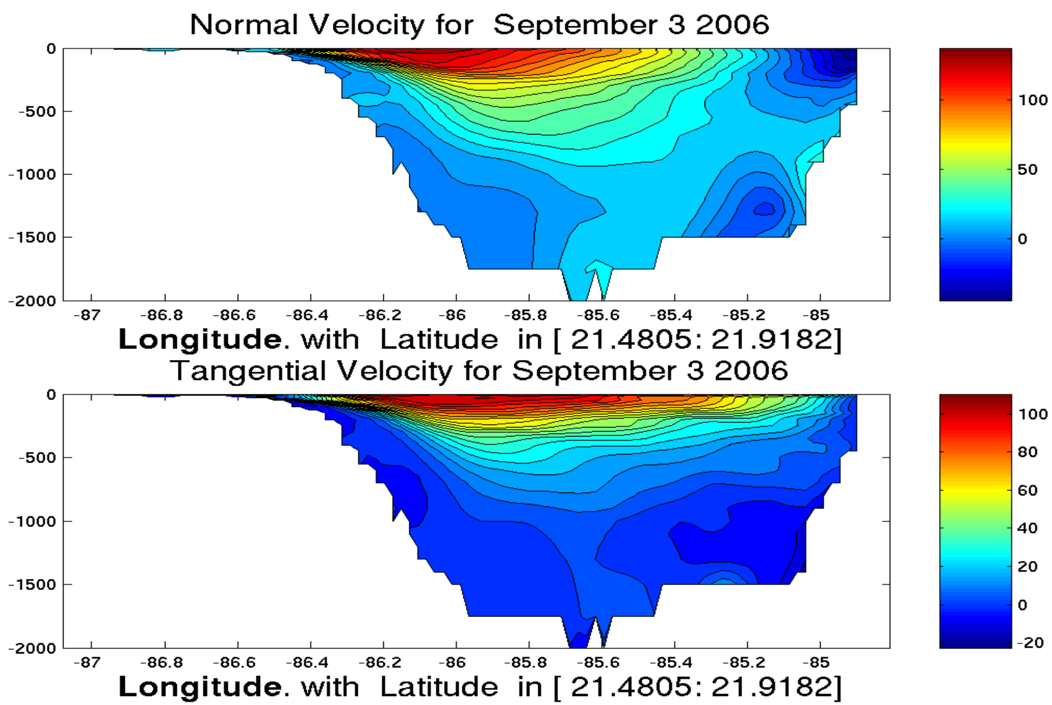


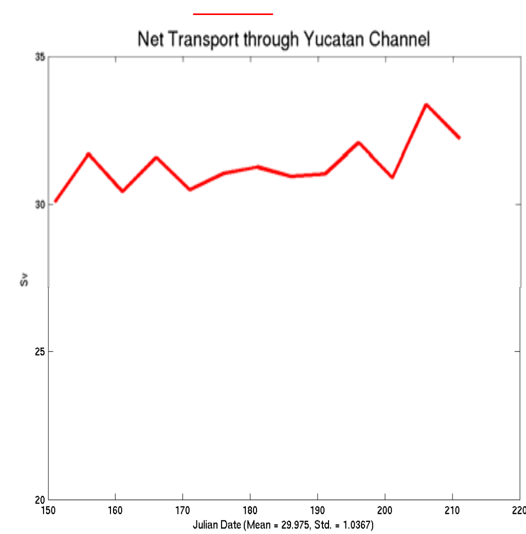
http://argo.colorado.edu



Location of Loop Current and Florida Current Sections

Transports across Yucatan Channel





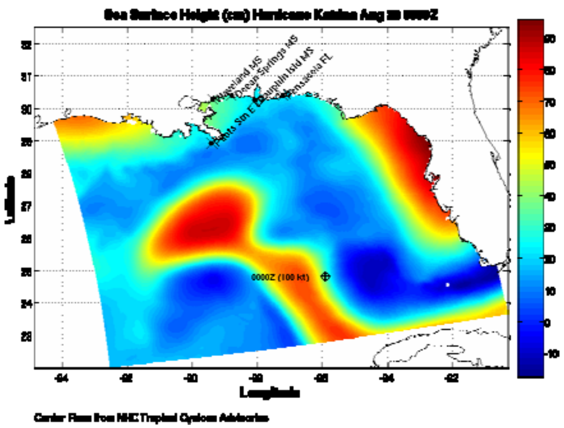
RTOFS Mean 31.18 Sv

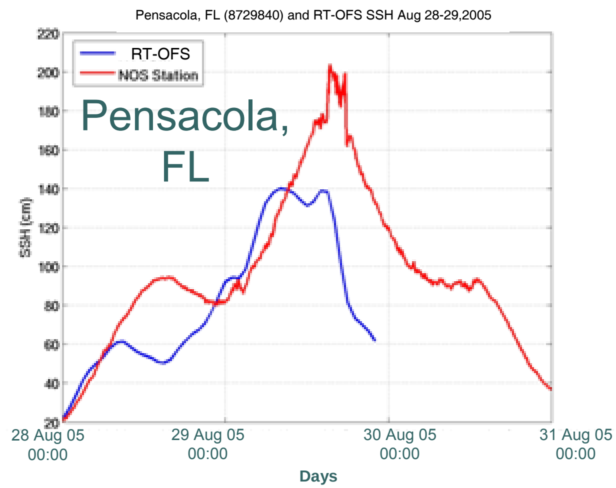
Std. 1.67 Sv

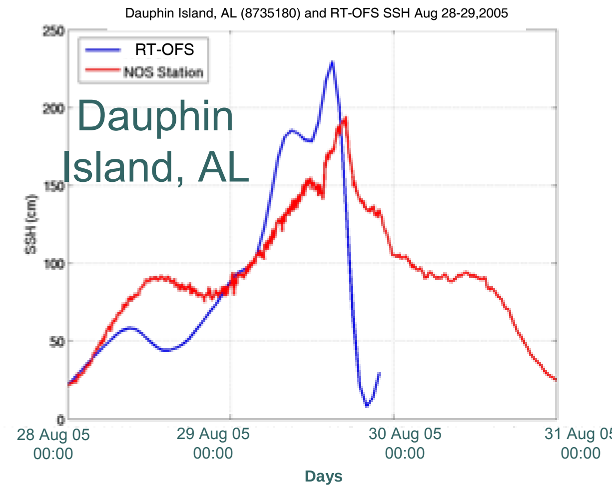
Observed Mean 23.8 Sv, Std 3.2 (Sheinbaum et al., JGR, 2002)

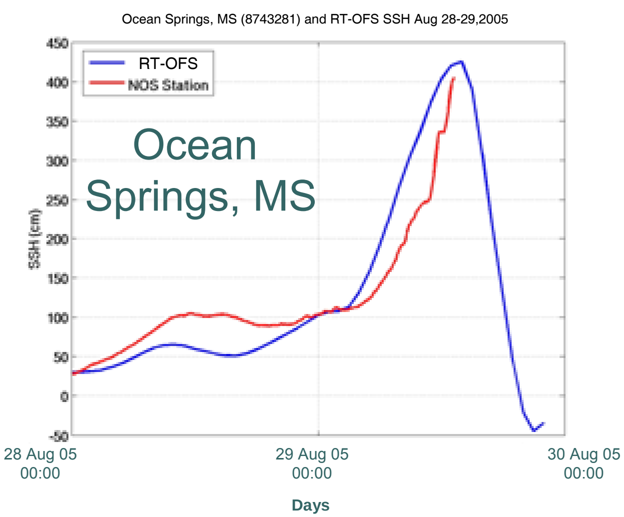
Observed Mean ~28 Sv (Roemmich, JGR, 1981)

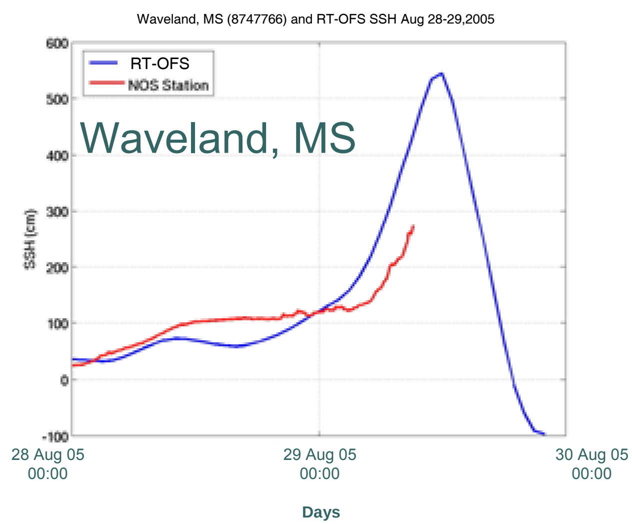
NOAA/NCEP Atlantic Ocean Forecast System Tide Gauge Comparisons for Hurricane Katrina

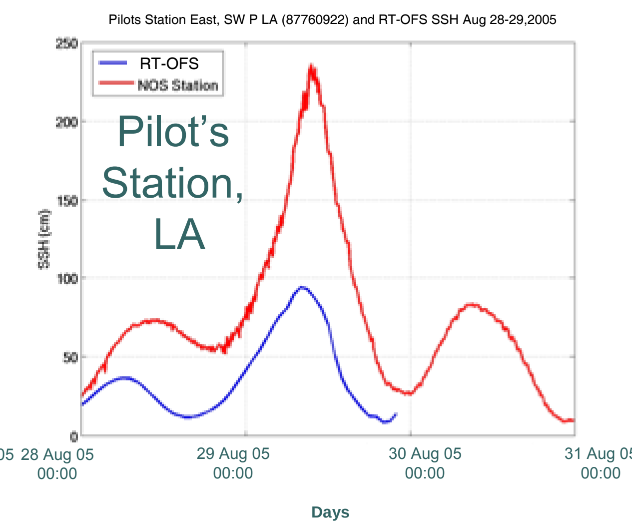












Freshwater (Salinity) Flux Algorithm

Experiment S1:

-- only provides dilution in the top layer

-- does not allow for changes to sea surface elevation due to river outflow volume changes

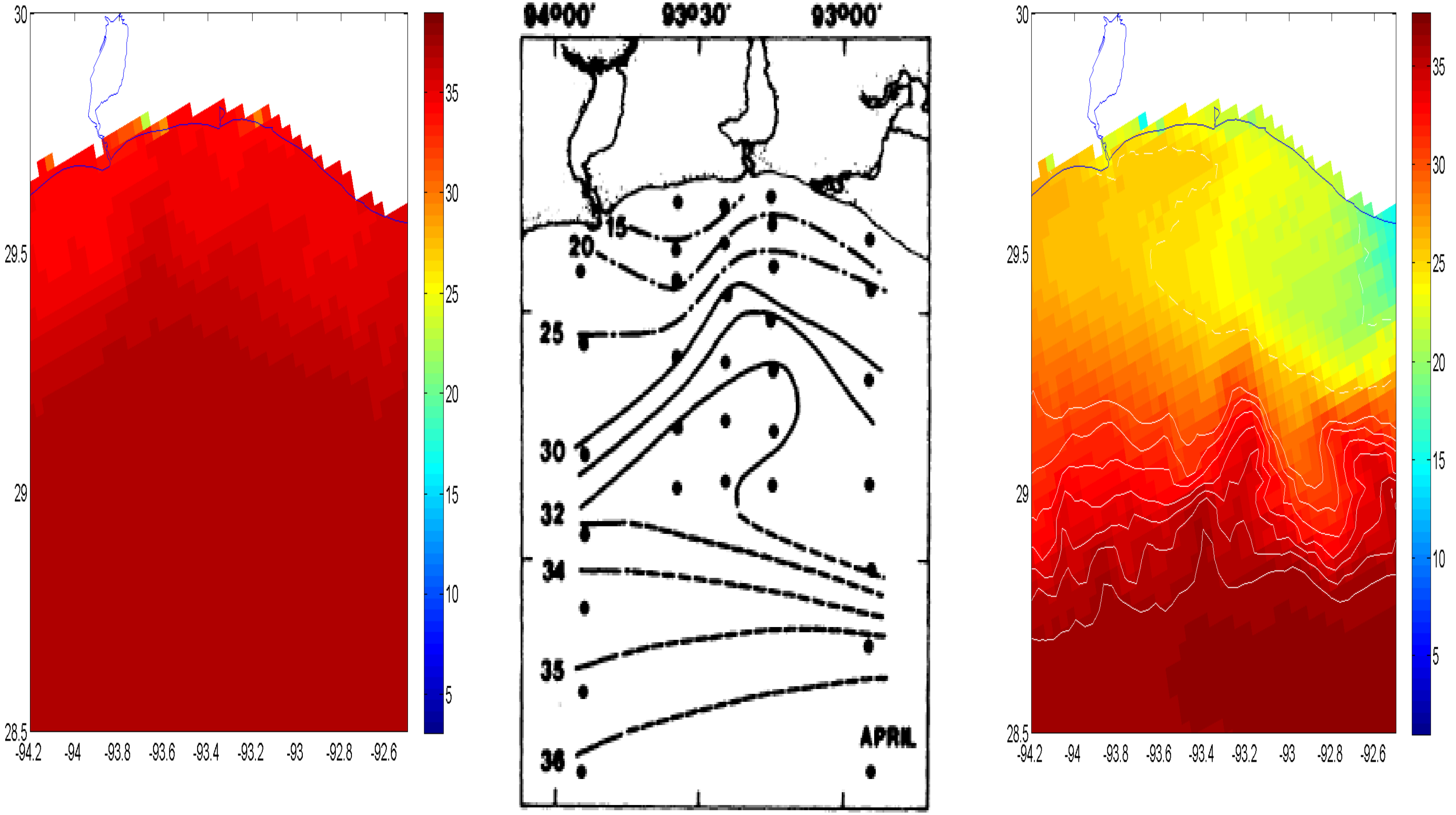
Experiment S2:

-- provides for dilution up to bottom so that:

1. minimum salinity bounded (> 1 ppt).
2. sea surface elevation adjusts due to river outflow volume changes.

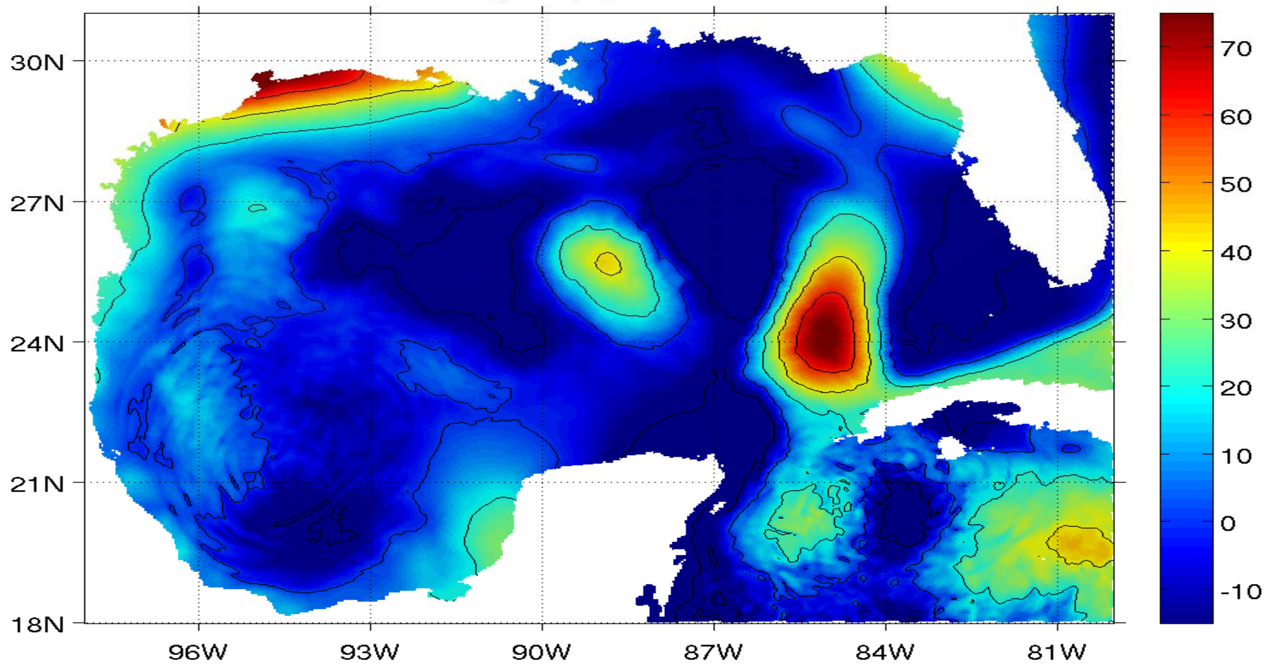
S1: Nowcast for 20070405

S2 Test: Nowcast for 20070405

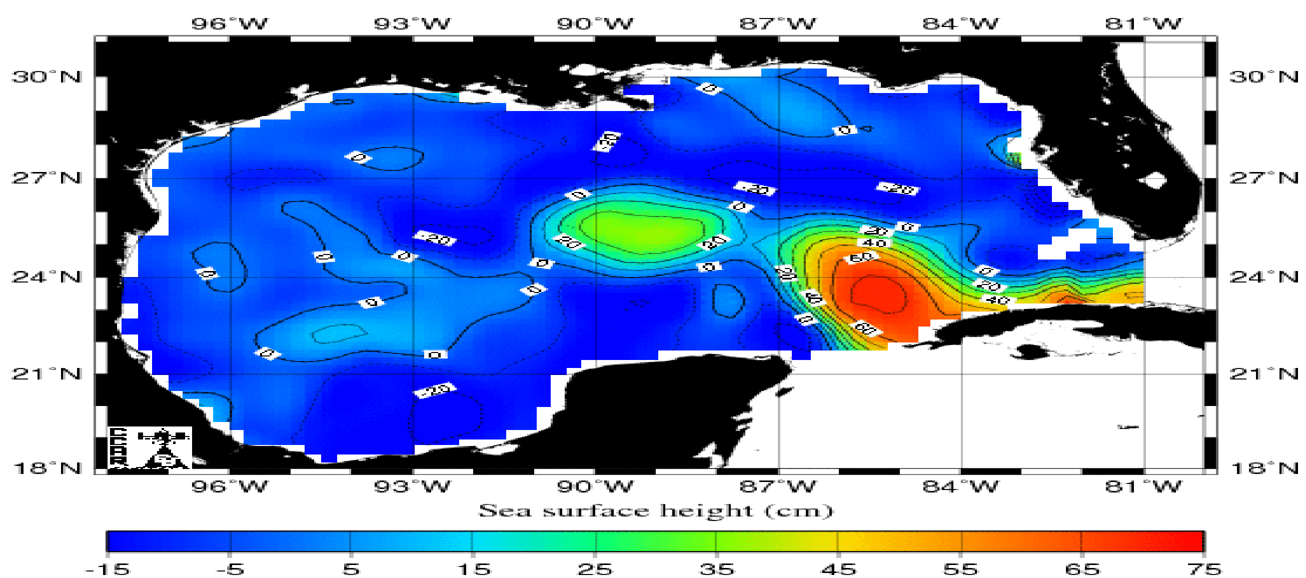


Surface Salinity map for S1 (left panel) and S2 Test (right panel) compared to surface salinity map near mouth of Mississippi based on conductivity sensors and current meters data (middle panel) collected from moorings near the LATEX coast in 1982 (Estuaries, Wiseman & Kelly, 1994). The offshore salinity front is non-existent in S1. In S2 test, it is weaker than the one observed and is located closer to the coast.

ASSIM: SSH (CM) @ N24hr 15-Oct-06



Real-Time Mesoscale Altimetry - Oct 15, 2006



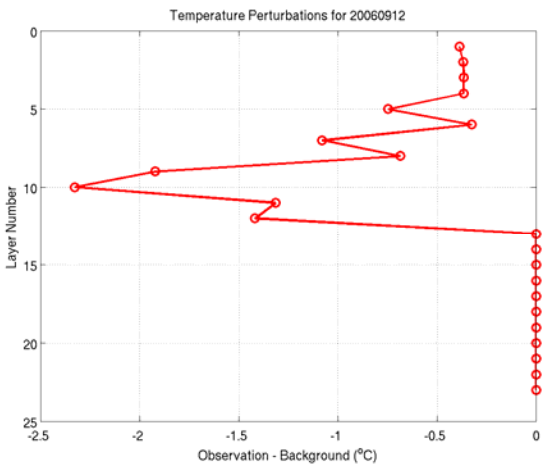
Future Applications of HYCOM based Ocean Forecast Systems to NWS Forecast Activities

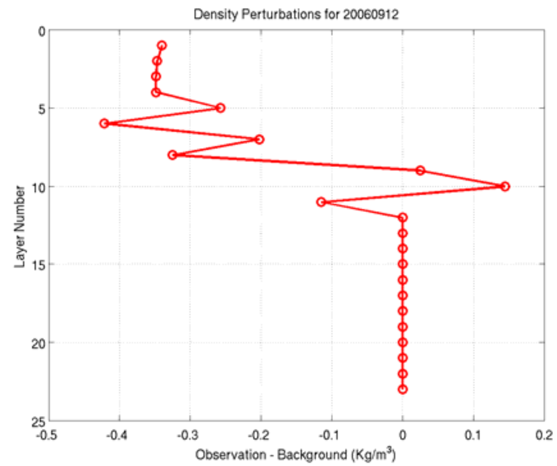
- HWRF-HYCOM coupled model
  - Ocean model component is a HYCOM with nested grids.
  - Initial conditions and boundary condition are mapped from RT-OFS (Atlantic) nowcast and forecast.

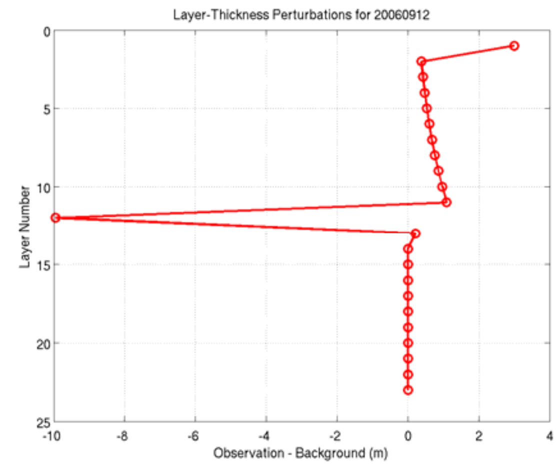
- Coupled Global Ocean Atmosphere Forecast System
  - Based on NEMS and HYCOM

- High Resolution Global Ocean Forecast System
  - In collaboration with NAVY
  - Delivery of fields for end-users and other regional model applications within and outside NOAA

CTD Assimilation (per layer)







Potential Temperature

Potential Density

Layer Thickness