U.S. GODAE: Global Ocean Prediction with the Hybrid Coordinate Ocean Model (HYCOM)

Community Effort: NRL, U. of Miami, Los Alamos, NOAA/NCEP, NOAA/AOML, NOAA/PMEL, PSI, FNMOC, NAVOCEANO, SHOM, LEGI, OPeNDAP, UNC, Rutgers, USF, Fugro-GEOS, Orbimage, Shell, ExxonMobil

Objectives and Goals

- A broad partnership of institutions that will collaborate in developing and demonstrating the performance and application of eddy-resolving, real-time global and basin-scale ocean prediction systems using HYCOM
- To be transitioned for operational use by the U.S. Navy at NAVOCEANO and FNMOC and by NOAA at NCEP

Opportunities

- NOAA/Navy collaboration and cooperation ranging from research to the operational level
- Global model outputs available to the community at large
- Strong participation of the coastal ocean modeling community in using and evaluating boundary conditions from the global and basin-scale ocean modeling prediction systems

HYCOM

- HYCOM is the result of a very effective collaboration between the U. of Miami, NRL/Stennis, and the Los Alamos National Laboratory.
- HYCOM has been configured globally (up to 1/4º ~30km mid-latitude resolution) and basin-scale (up to 1/12º ~7km mid-latitude resolution)

HYCOM 2.1

(collaboration between the U. of Miami, NRL, and LANL)

http://hycom.rsmas.miami.edu

- Halos for MPI to automatically support periodic boundaries
- Support nested-domain open boundaries
- Fully global (Pan-Am grid)
- Alternative mixed layer models
- Orthogonal curvilinear grids
- Passive tracers, floats
- NPZD model
- NetCDF output files
- User's manual and guide available

HYCOM 2.2 to be released in Fall 2004 – new features include alternate advection schemes, new diagnostics,…

HYCOM

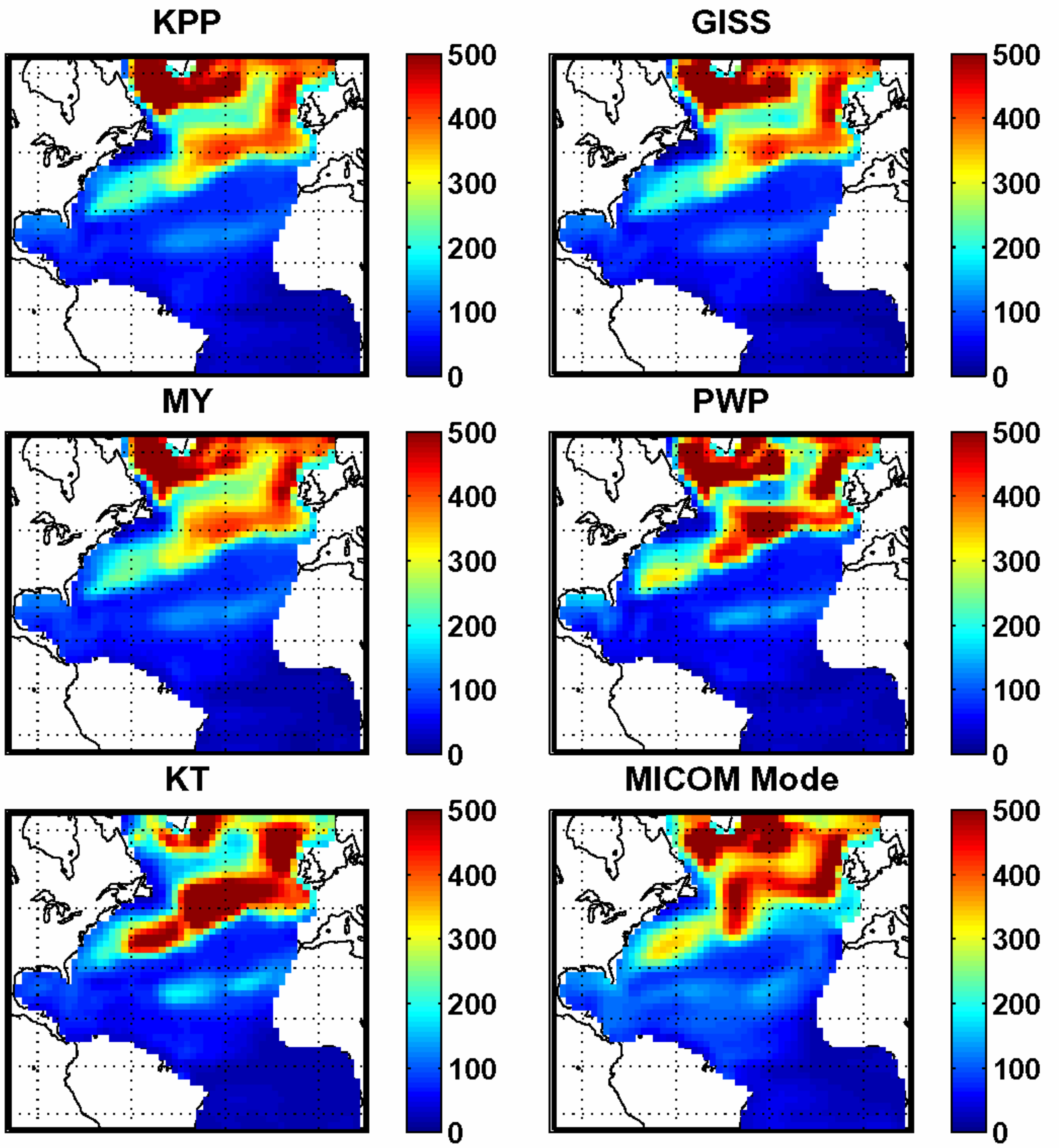
The capability of assigning additional coordinate surfaces to the oceanic mixed layer allows for sophisticated closure schemes in HYCOM:

- Continuous Vertical Mixing Models (surface to bottom)
  - K-Profile Parameterization, i.e., KPP (default)
  - Mellor-Yamada level 2.5 turbulence closure
  - Canuto/GISS level 2 turbulence closure
- Slab Mixed Layer Models
  - Kraus-Turner
  - Price-Weller-Pinkel dynamical instability model
- Compared in low-resolution climatological Atlantic simulations [Halliwell, 2004, available on HYCOM web site]

HYCOM

February Mixed Layer Thickness

- Domain
  - Atlantic Ocean, 20°S to 62°N
  - 2° horizontal spacing
  - 22 σ_2 vertical coordinates
- Forcing
  - Climatological annual cycle forcing derived from COADS
- 20-year spinup from Levitus climatology
- One-year analysis

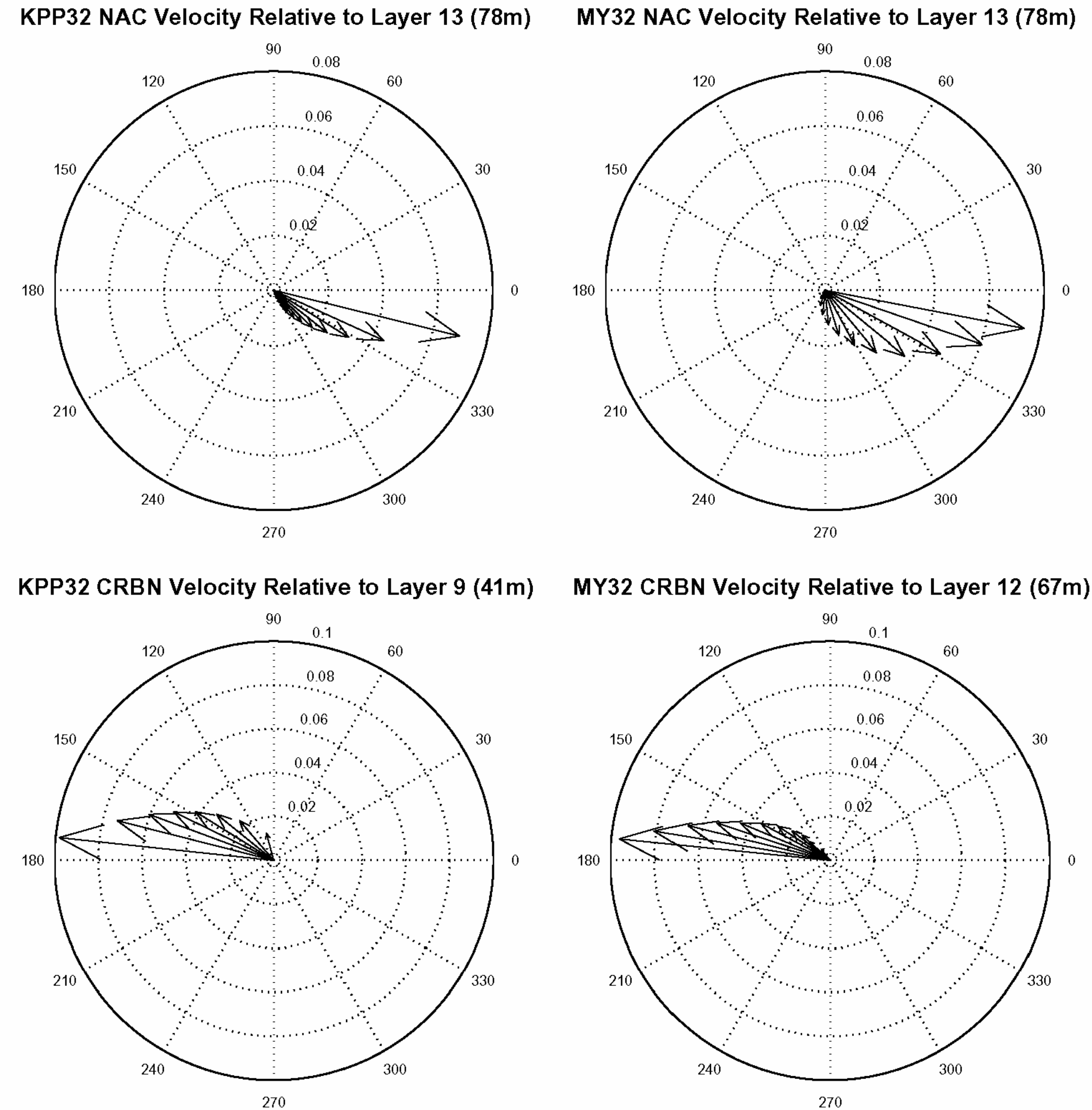


HYCOM

Surface Ekman Layer (Winter)

TOP: Westerlies
Bottom: Trade Winds

Left: KPP
Right: Mellor-Yamada



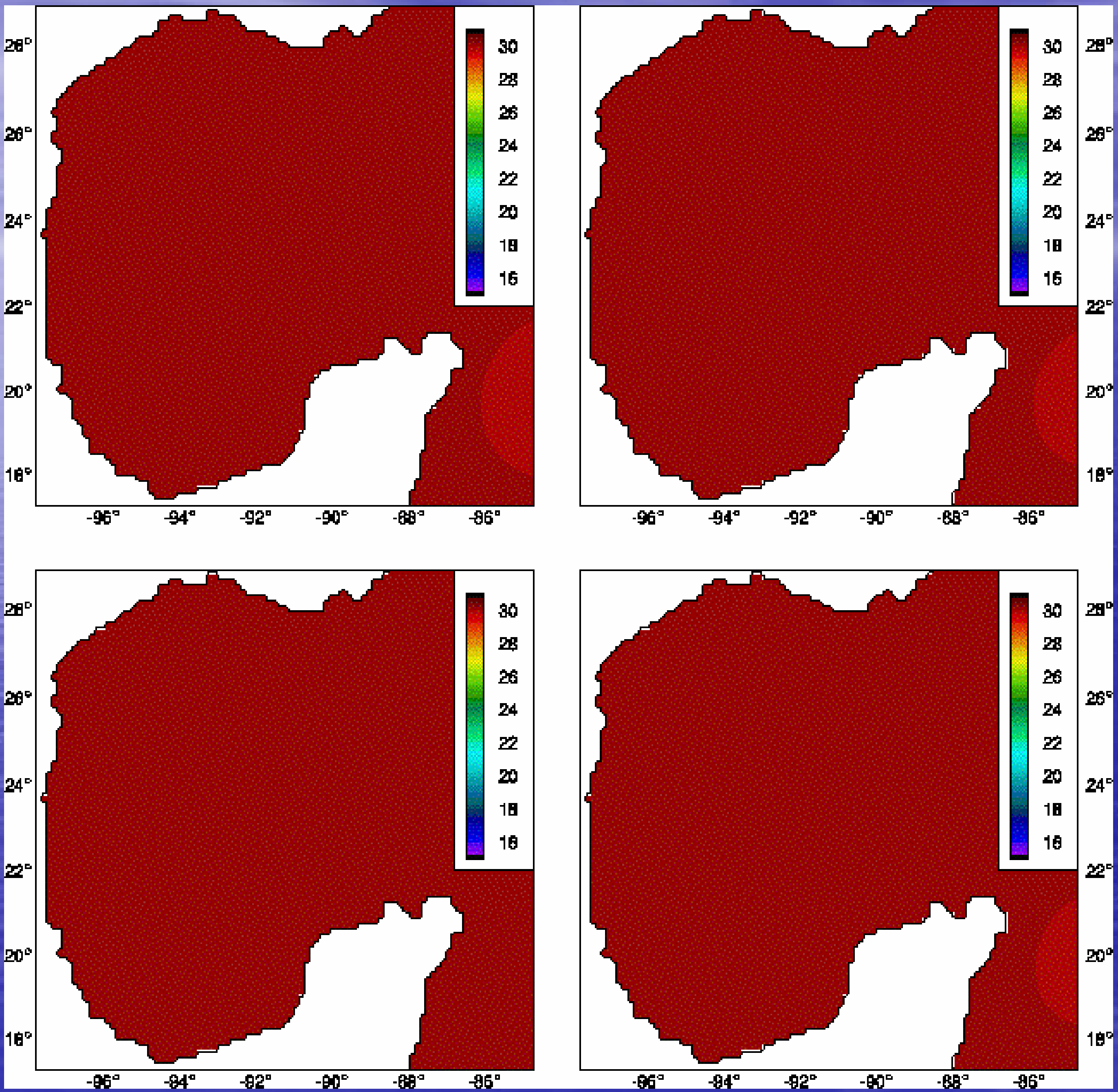
Vertical Mixing Scheme Evaluation Summary

- The largest observed differences among the vertical mixing choices result from:
  - Penetrating shortwave radiation
  - Shear instability mixing below the mixed layer
- KPP mixing chosen as the default mixing scheme
  - Parameterizes more physical processes than other schemes
  - Performed well in tests
- Other mixing algorithms allow one to determine the sensitivity of scientific results to vertical mixing

Effects of the entrainment closure on the mixed layer response during a hurricane

Gaspar

KPP



MY2.5

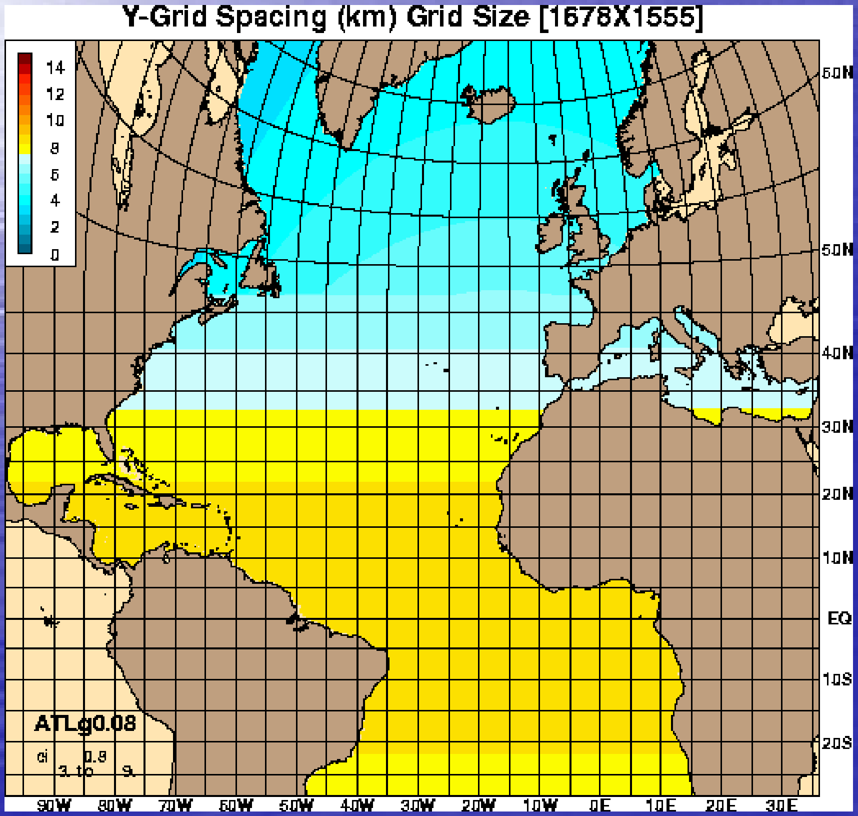
PWP

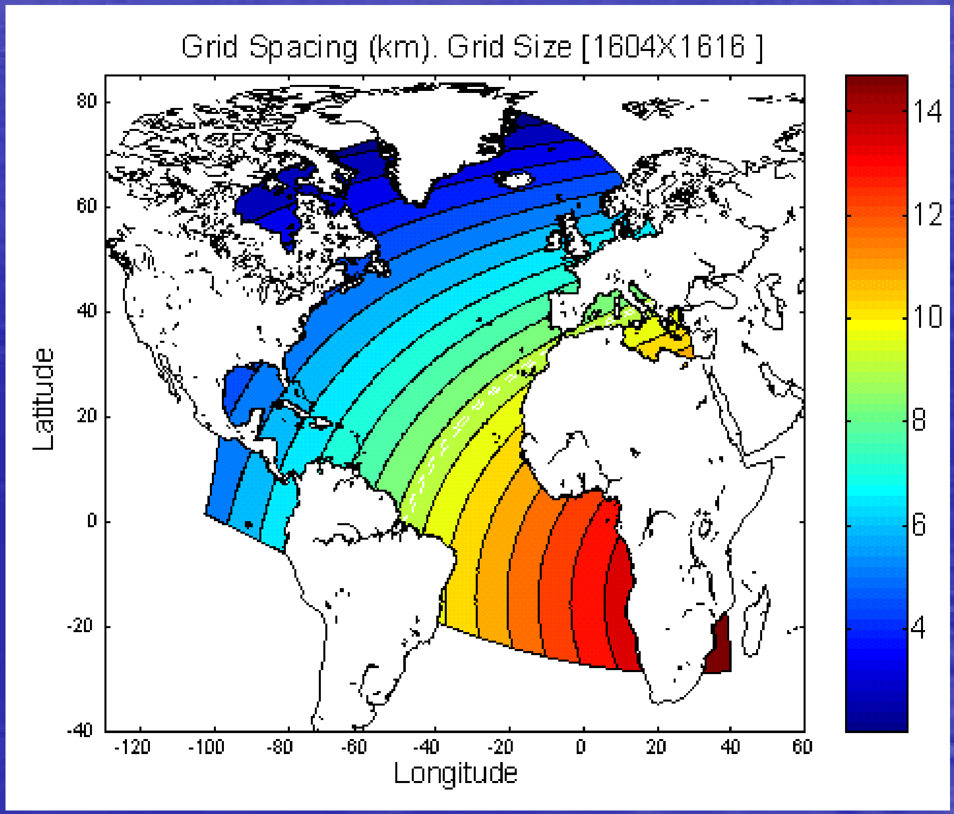
Data Assimilation

- Several techniques are either in place or under development
- Vary in sophistication and computational requirements
- Both the SEEK (Single Evolutive Extended Kalman) filter and ROIF (Reduced Order Information Filter) are being evaluated. The SEEK filter has been implemented in the 1/3º Atlantic configuration and will be evaluated in the 1/12º configuration this summer.

Configuration of the Prediction Systems

- Basin-scale (NRL/Miami and NOAA)



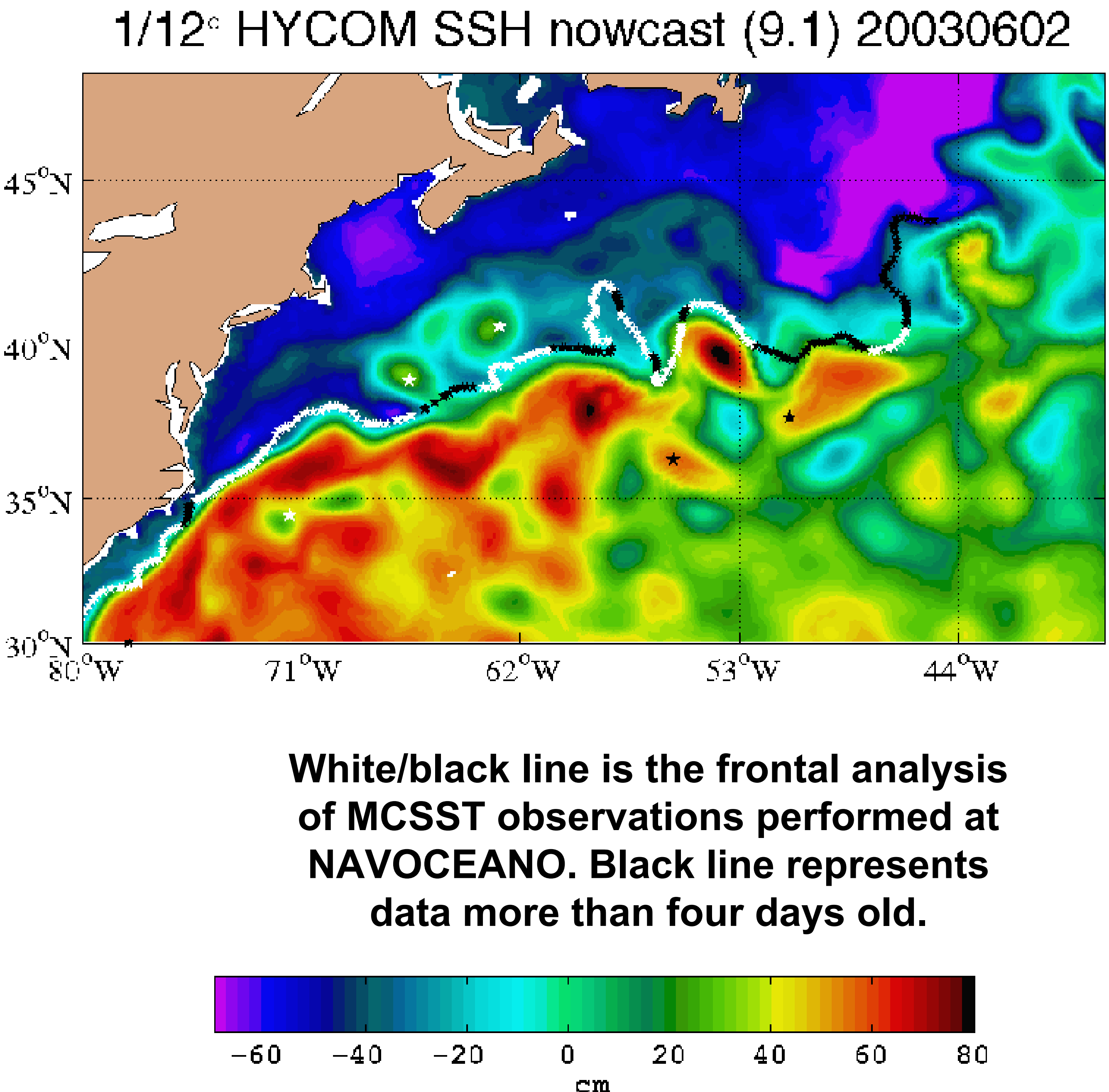


PRESENT SYSTEM

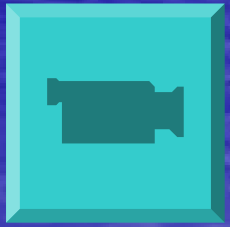
- **A near real-time nowcast/forecast system with the 1/12° Atlantic model**
  - **. Assimilates the satellite altimeter analysis from the MODAS operational system at NAVOCEANO**
  - **. Mean SSH from the 1/12° MICOM (ECMWF)**
  - **. Vertical projection via the Cooper and Haines technique (1996, JGR)**
  - **. Relaxation to the MODAS SST analysis**
- **Automated scripts to run the system from the preprocessing of the forcing fields to the post processing of the results**

http://hycom.rsmas.miami.edu

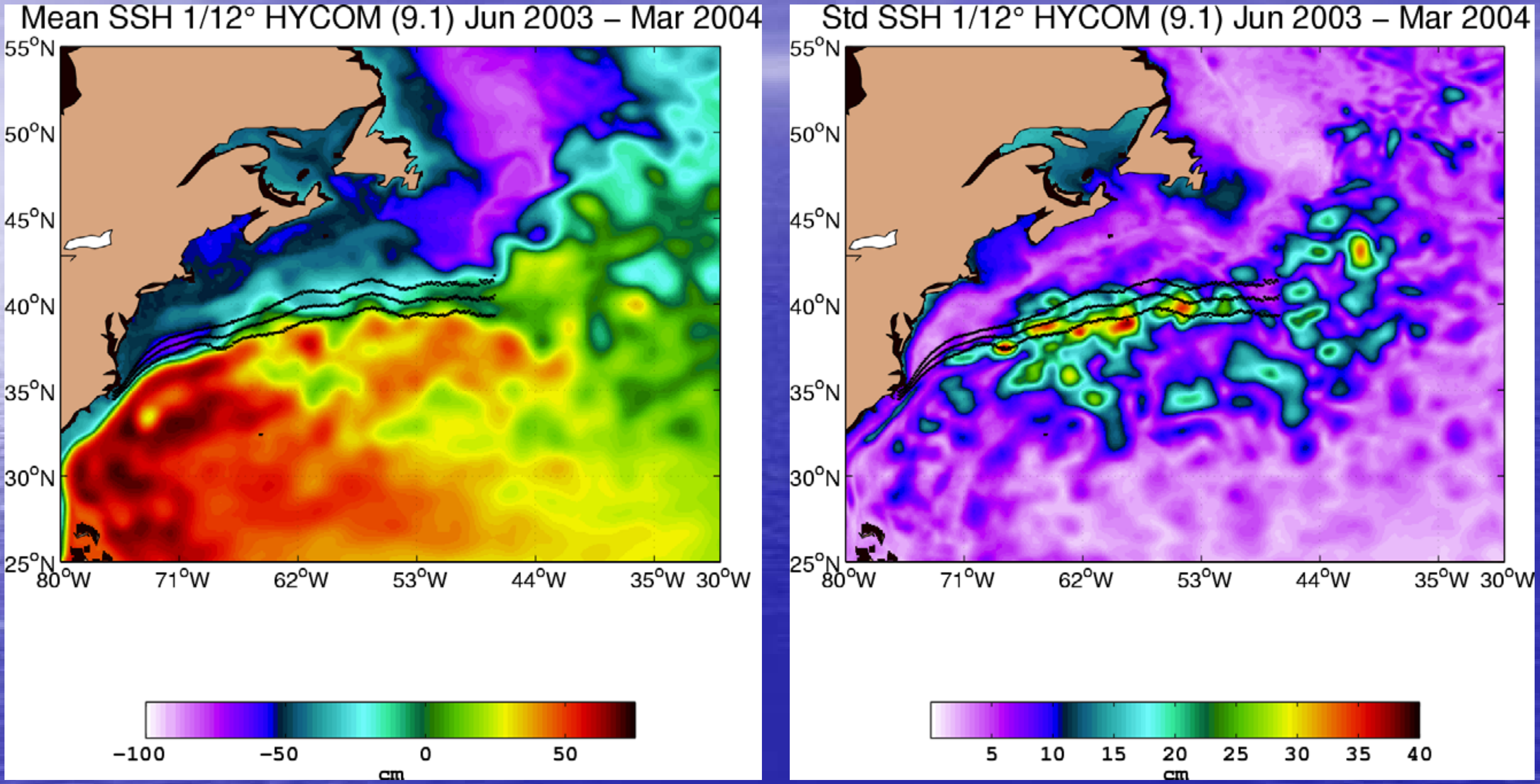
SSH in Gulf Stream region



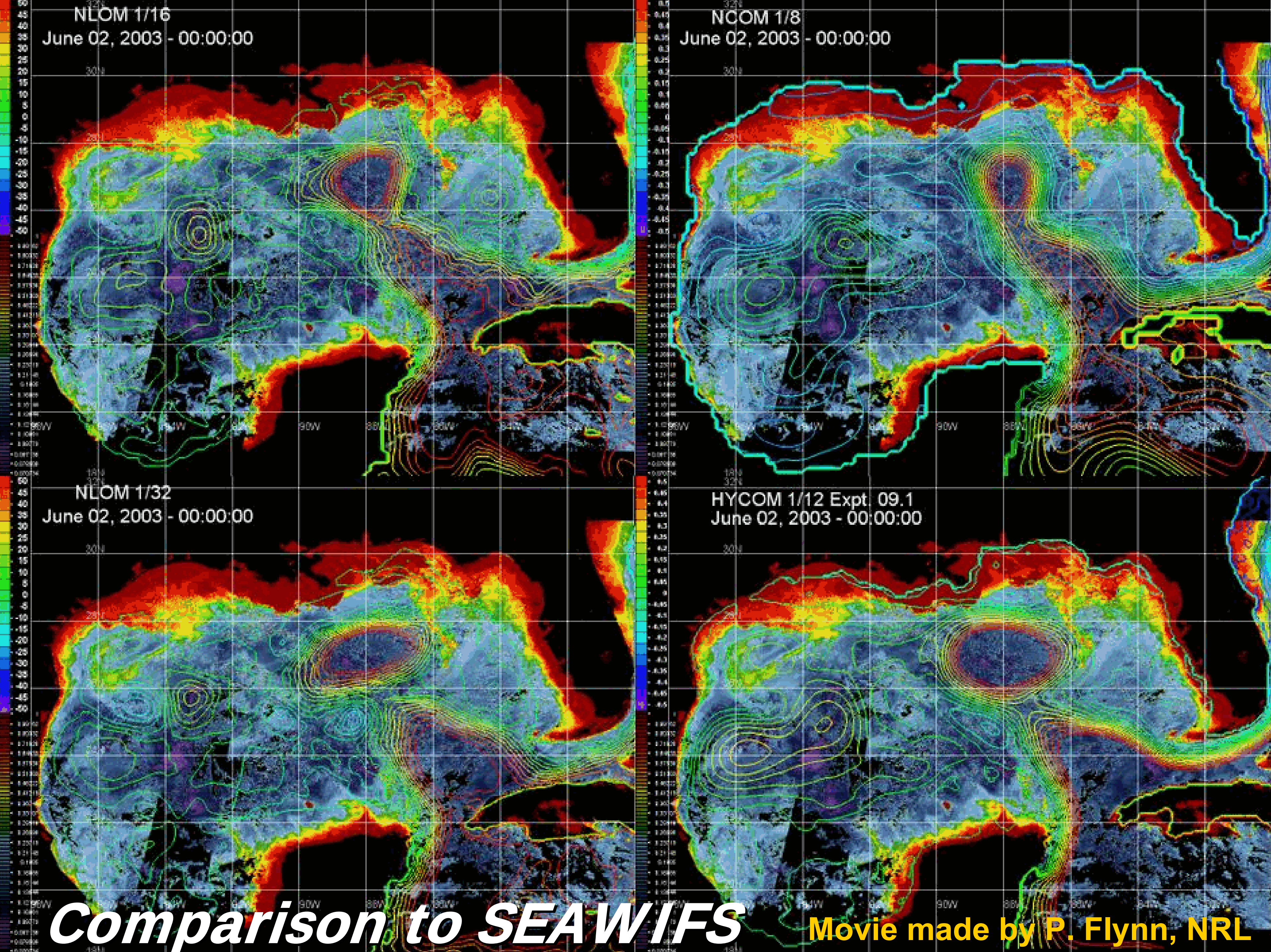
White/black line is the frontal analysis of MCSST observations performed at NAVOCEANO. Black line represents data more than four days old.



1/12° Atlantic HYCOM
SSH mean and RMS in the Gulf Stream region



Black line is the mean and standard deviation of the frontal position determined from SST observations

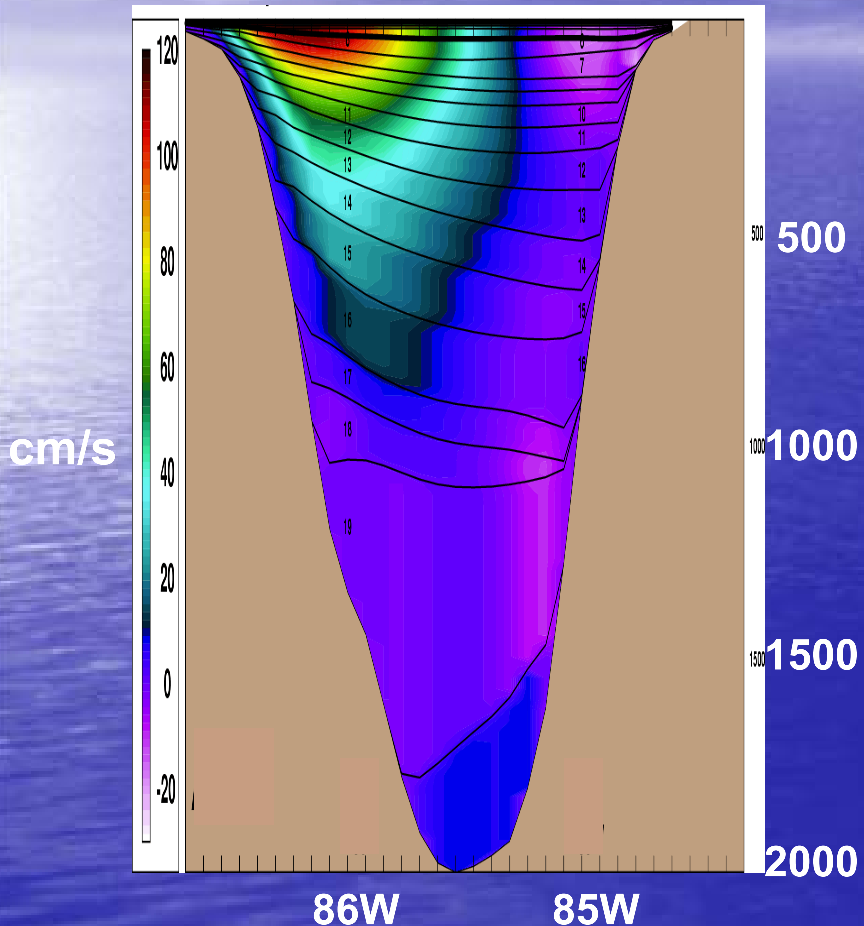


Comparison to SEAWIFS

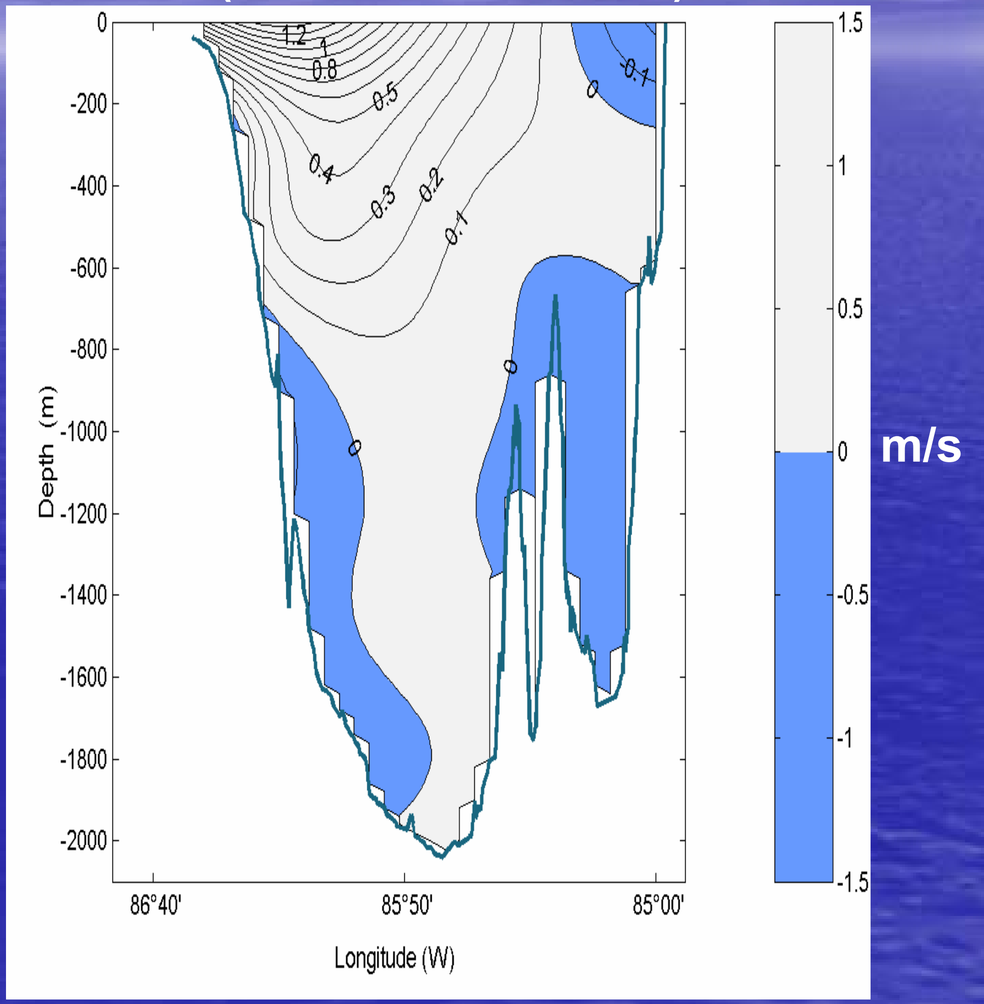
Movie made by P. Flynn, NRL

Yucatan Channel Normal Velocity

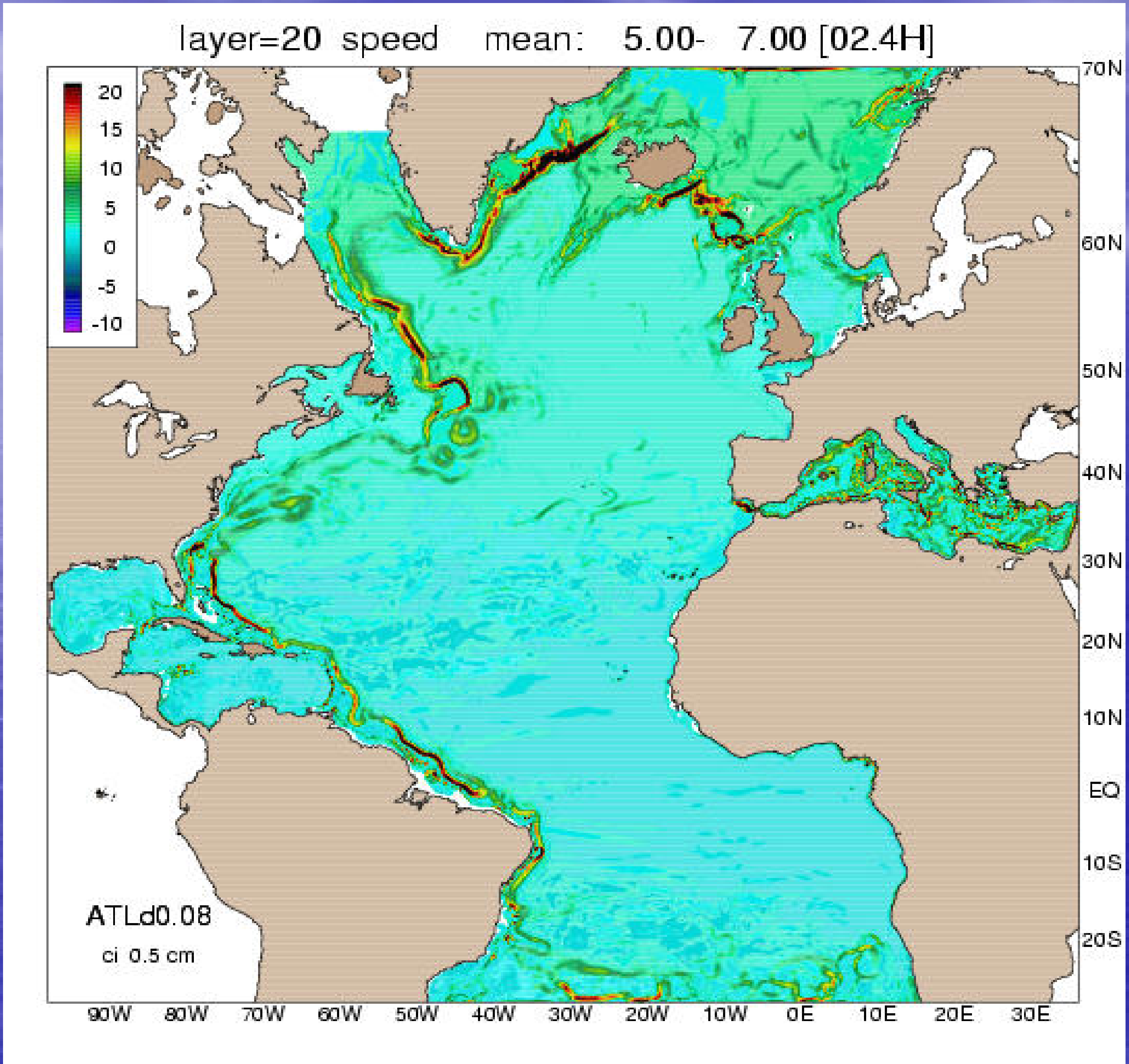
1/12° ATL HYCOM 1-Year Mean



Observed Mean 8/1999-6/2000
(Abascal et. al, 2003)



1/12° Atlantic HYCOM



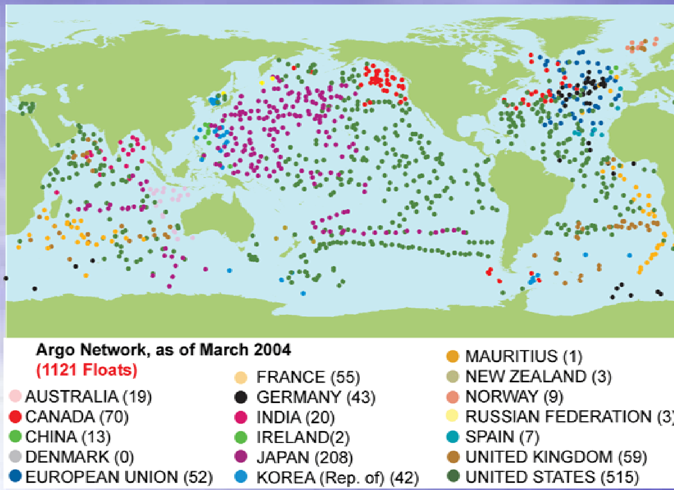
Deep Western Boundary Current

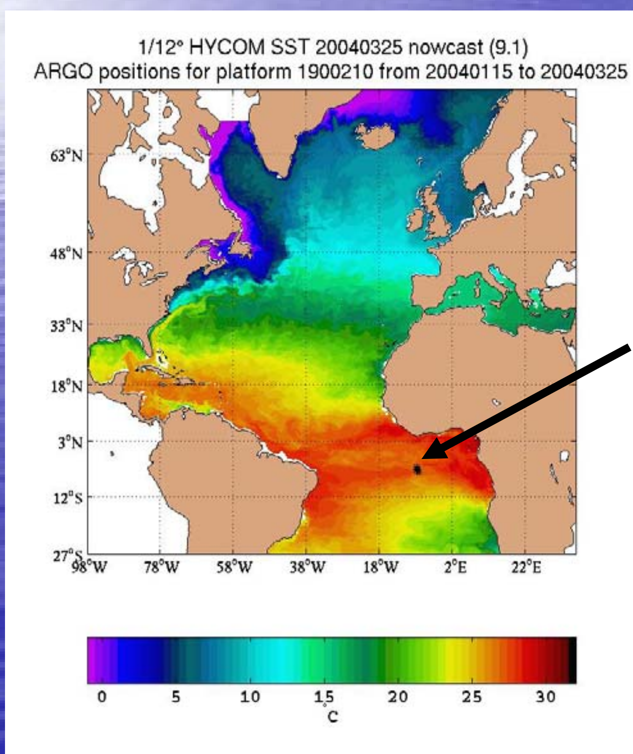
Comparison to vertical profiles

- ARGO profiles (T(z) & S(z)) (weekly)
- PIRATA buoys (weekly)
- MEDS data (monthly)
- Statistics in different regions of the Atlantic domain

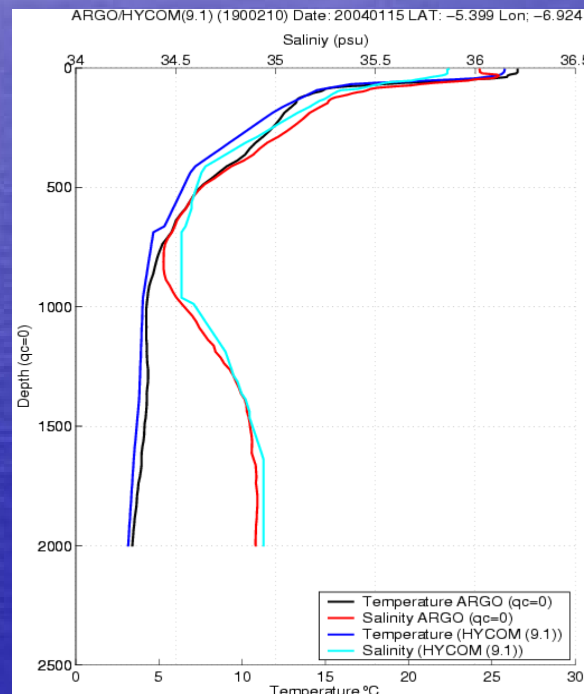
ARGO profiles

http://w3.jcommops.org/cgi-bin/WebObjects/Argo

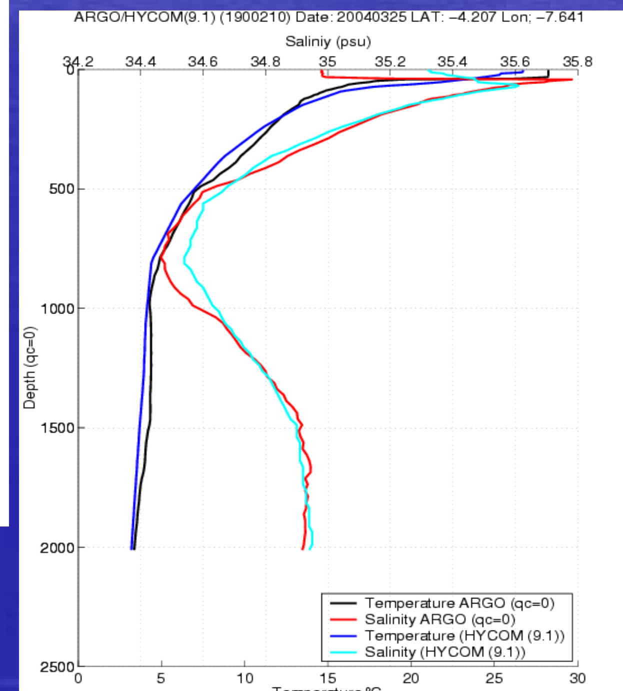




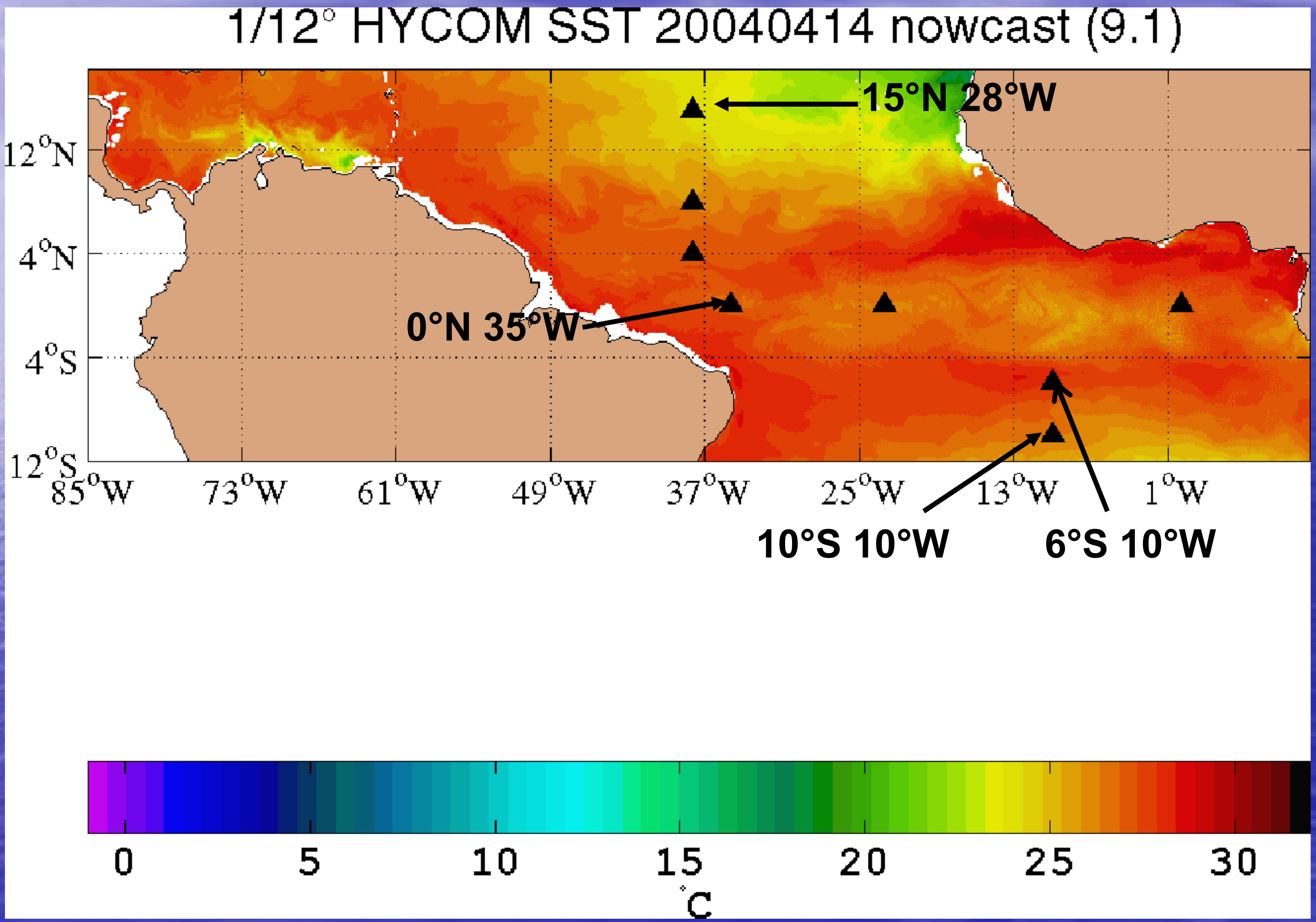
15 January 2004
5.399°S, 6.924°W



25 March 2004
4.207°S, 7.641°W

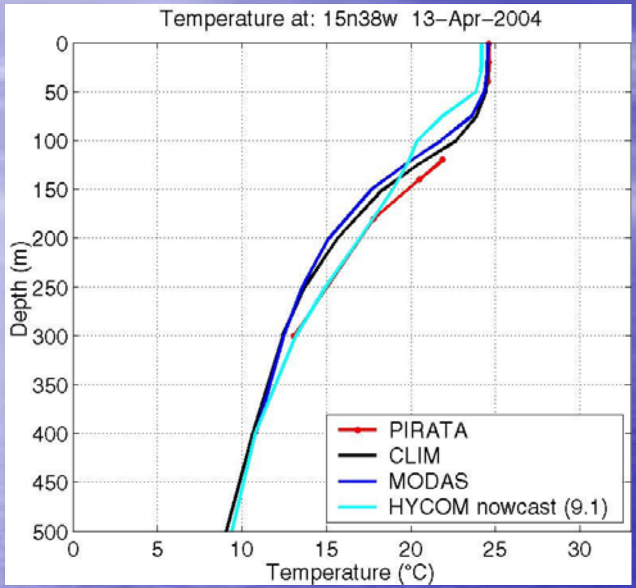


POSITIONS OF PIRATA BUOYS

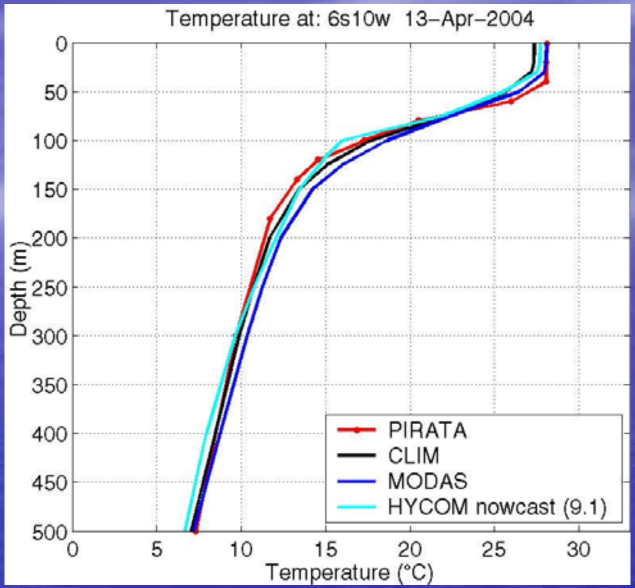


PIRATA BUOYS 13 April 2004

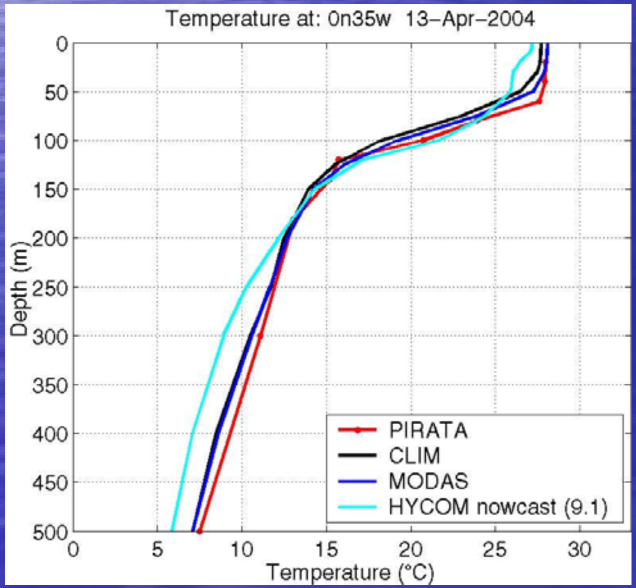
15°N 28°W



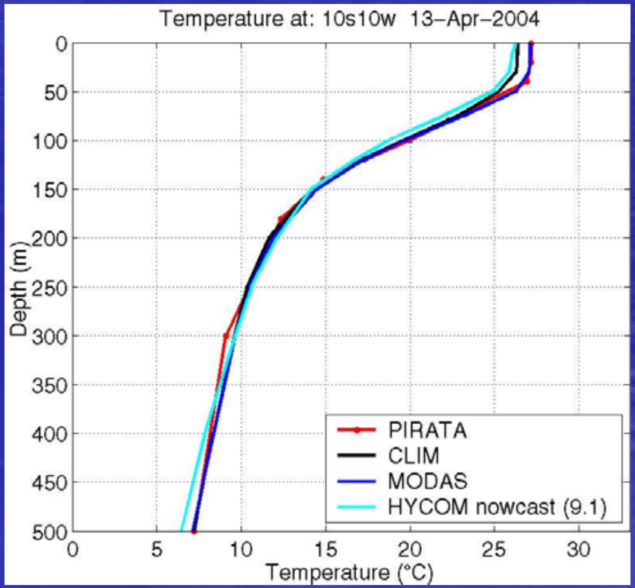
6°S 10°W



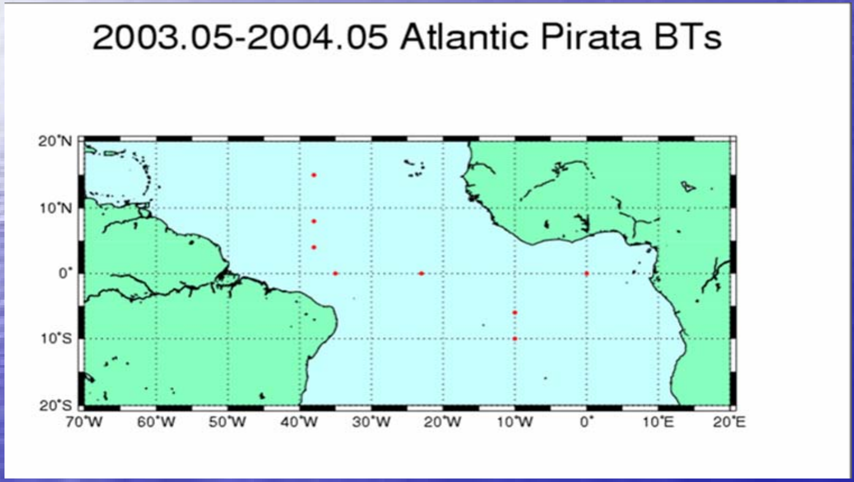
0°N 35°W

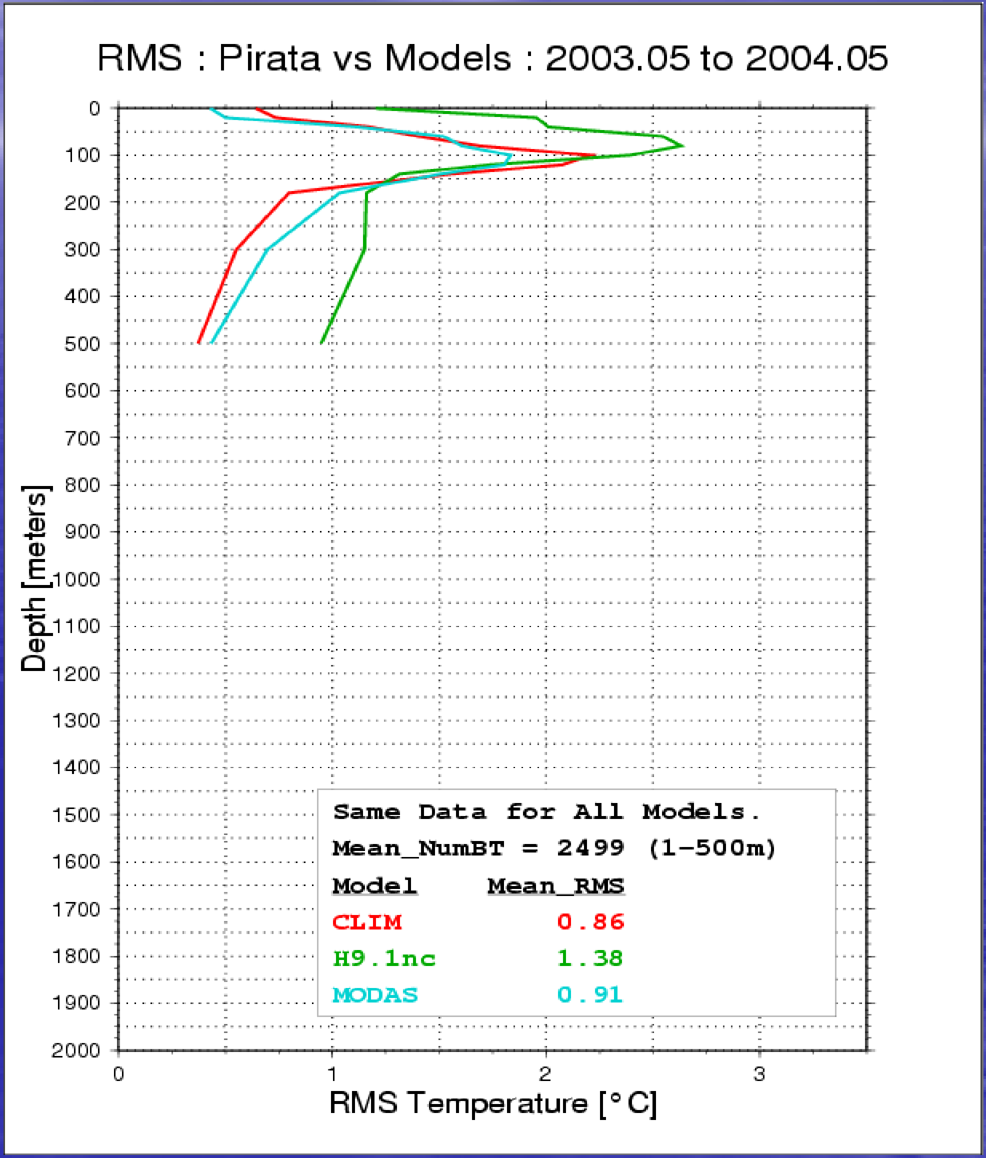


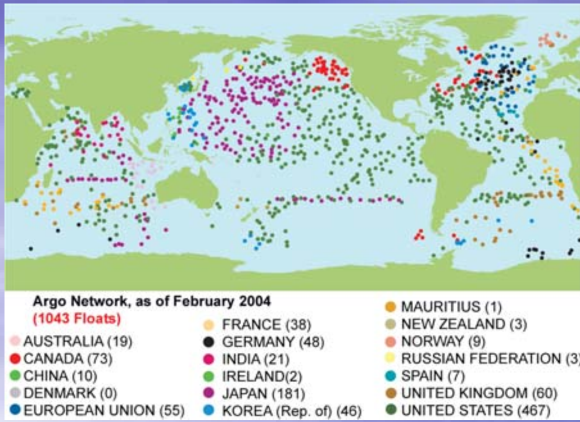
10°N 10°W



Statistics of PIRATA profiles May 2003 – May 2004

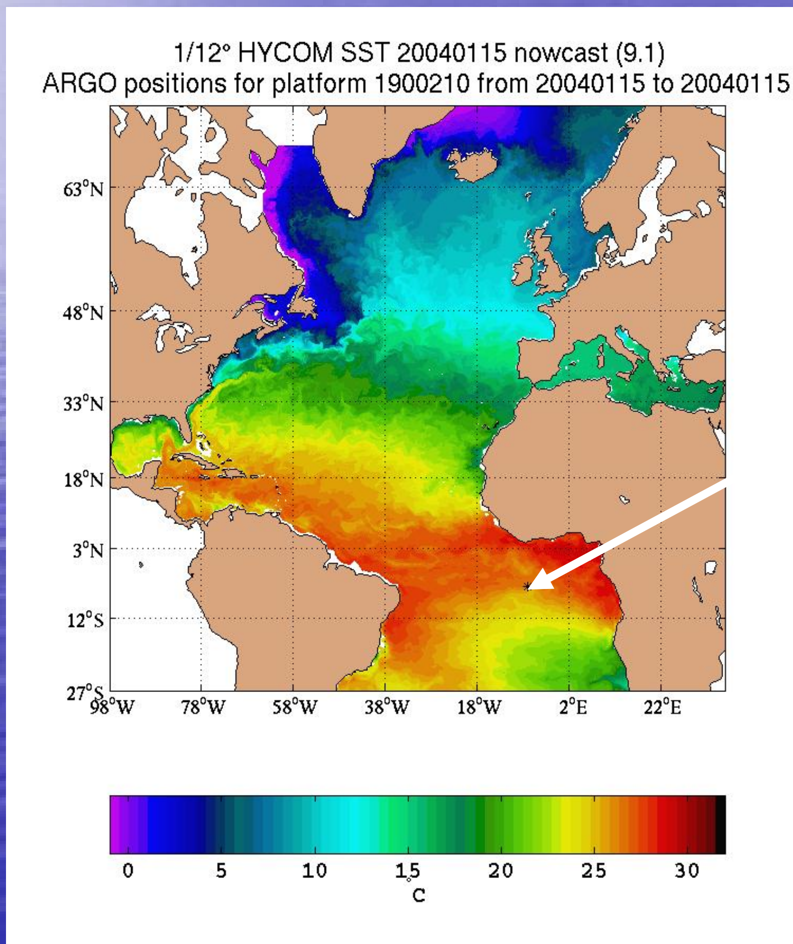


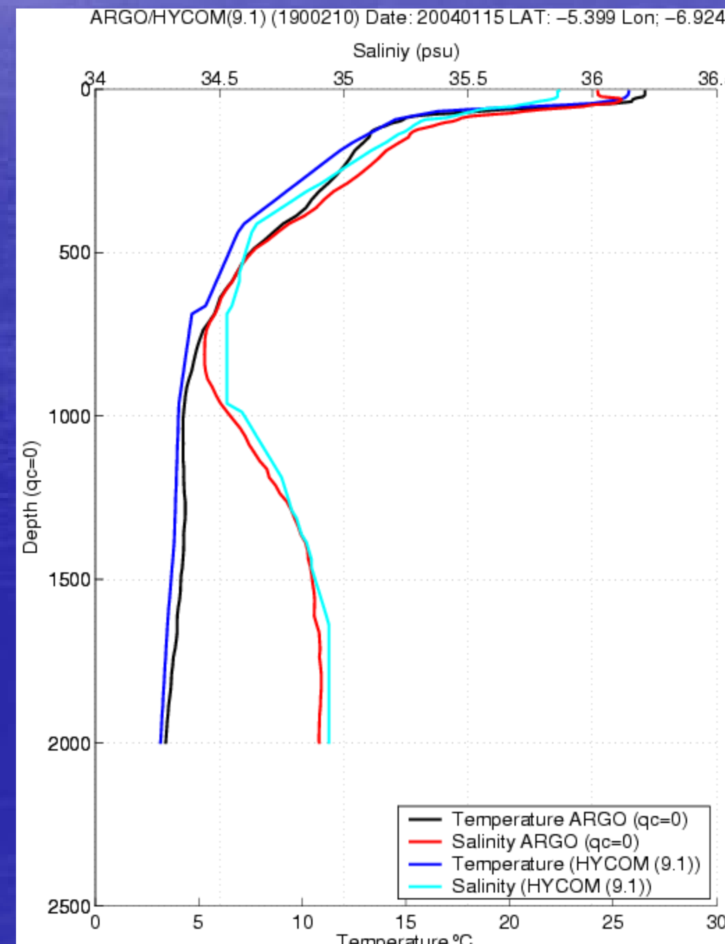




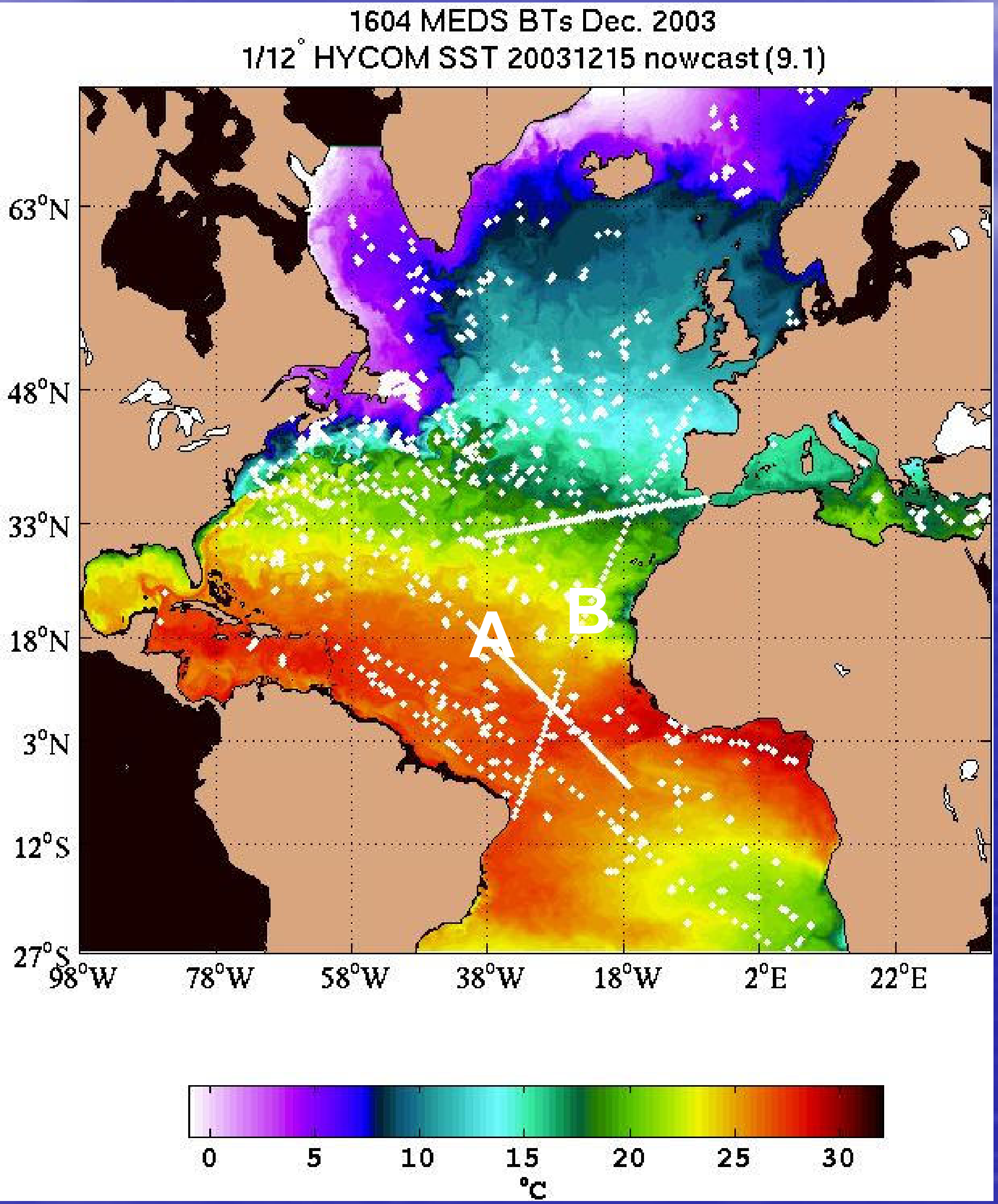
ARGO profiles

15 January 2004 5.431°S, 6.924°W

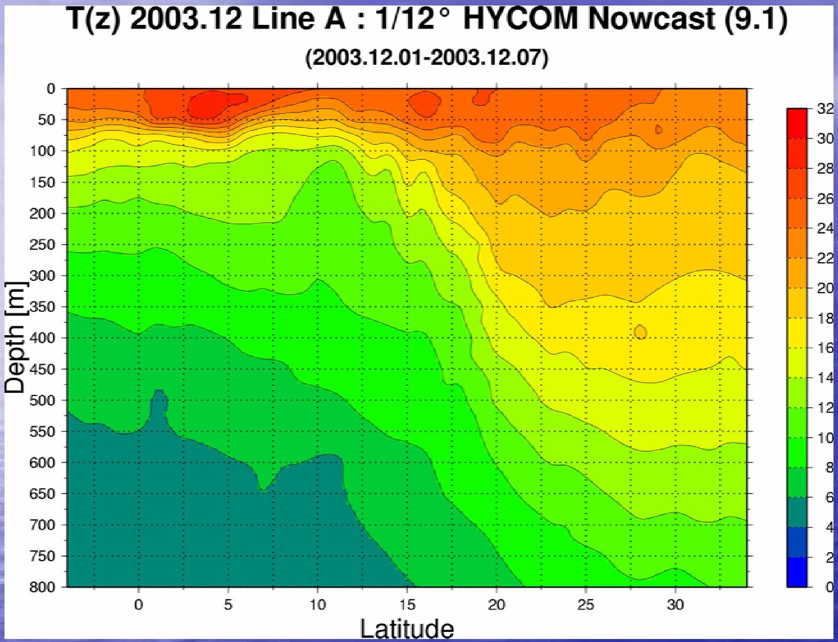


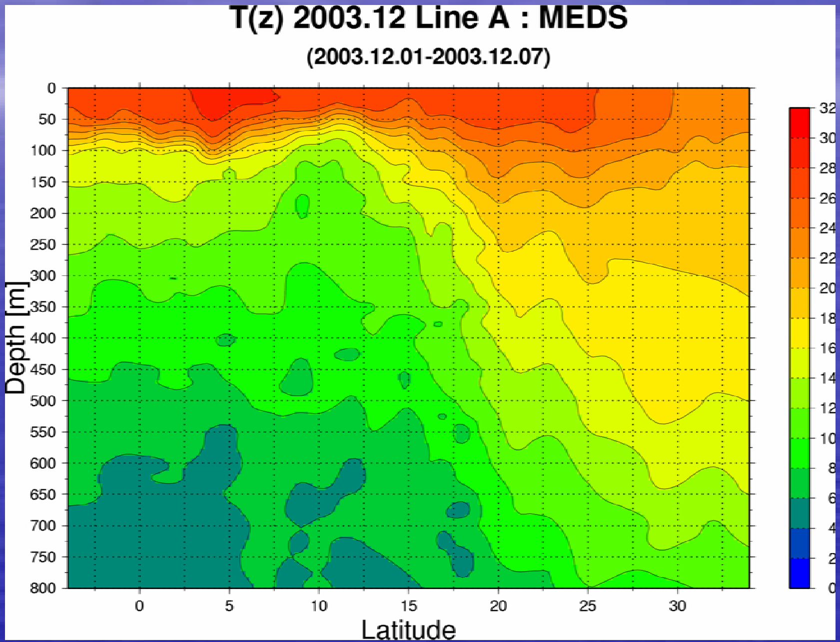


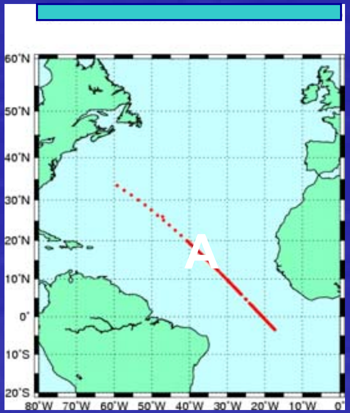
MEDS BT positions December 2003



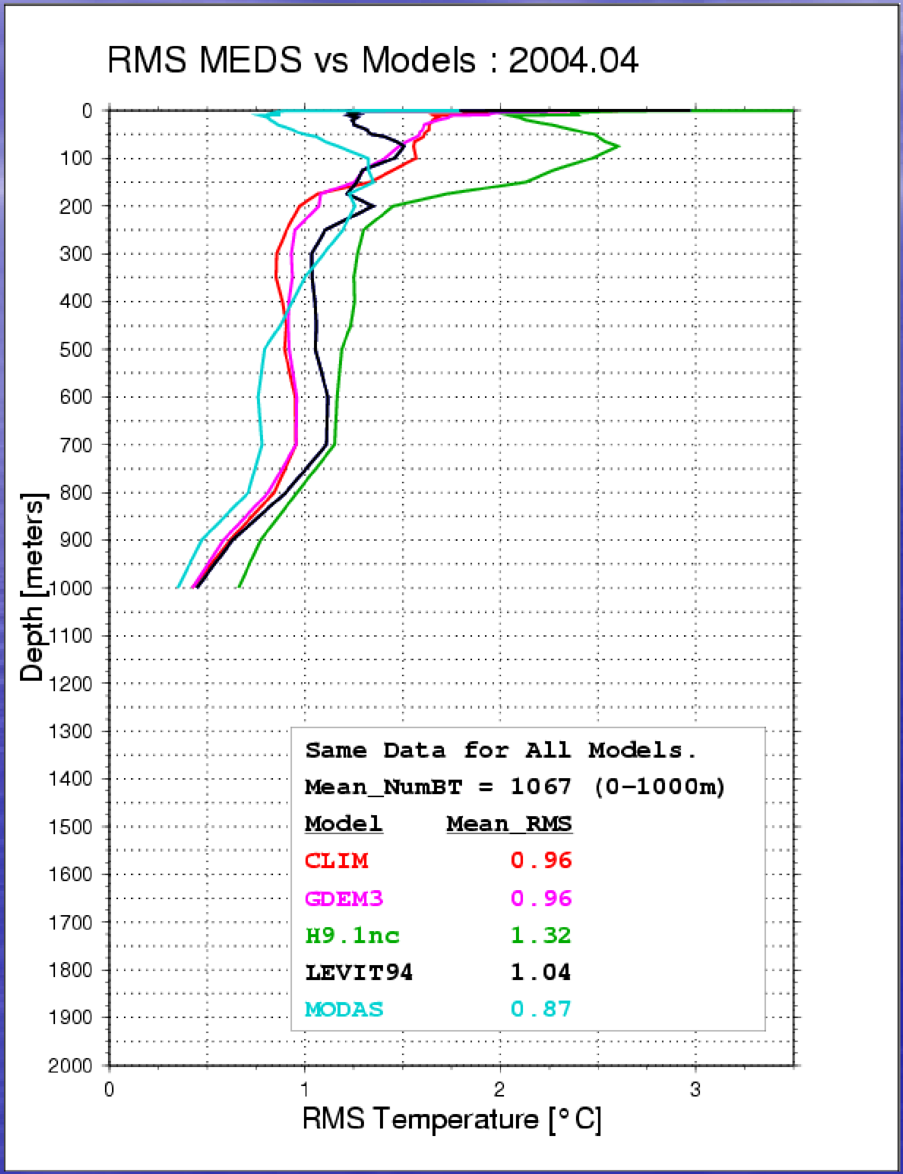
MEDS BT sections







Profile BTs statistics April 2004



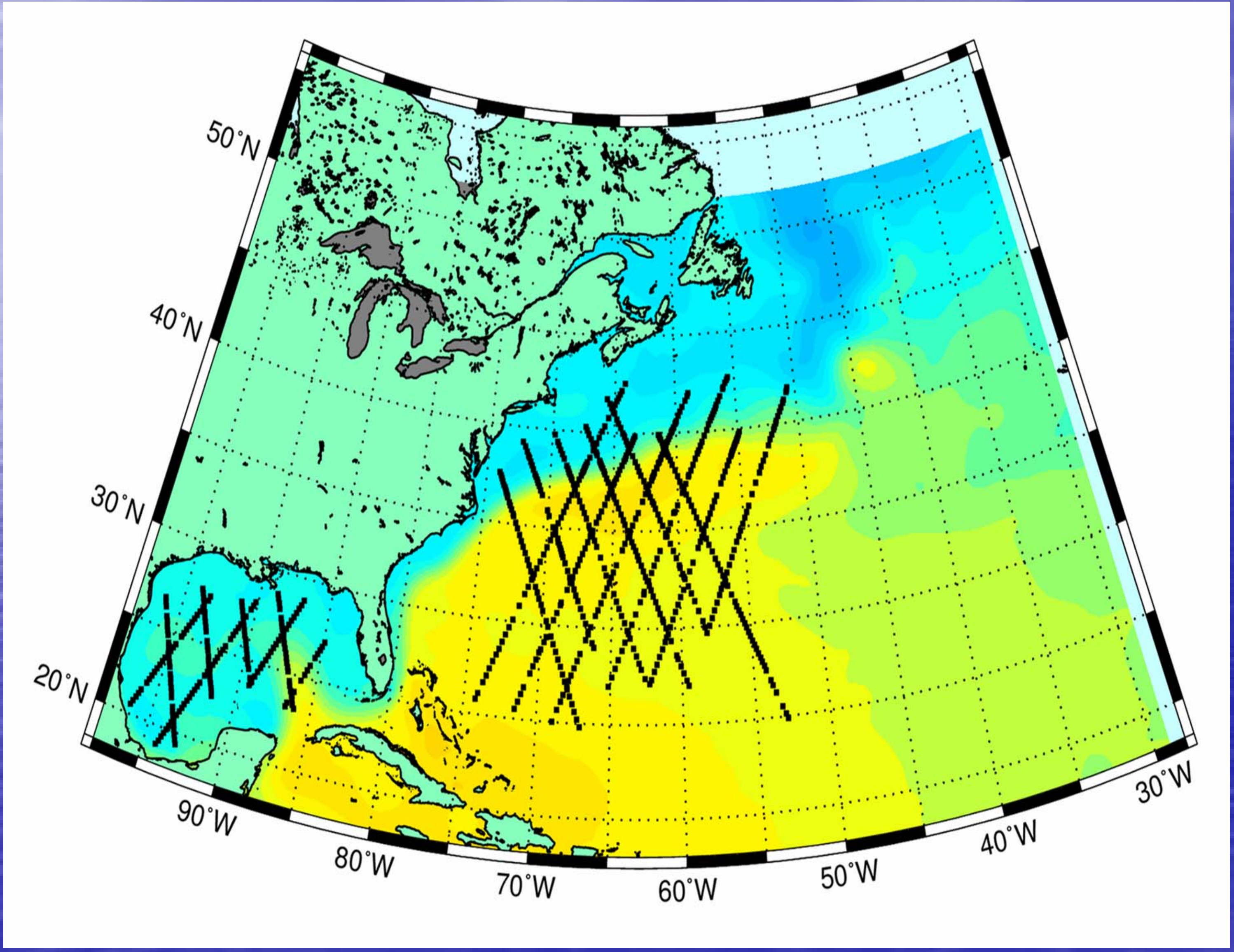
Near Future

- <u>New 5m coastline</u>
- Upgrade assimilation
  - MVOI (Multi-Variate Optimal Interpolation) with assimilation of vertical profiles
  - SEEK (Singular Evolutive Extended Kalman filter)
  - ROIF (Reduced Order Information Filter)

Mean SSH Bias

- Compare several model mean and climatological sea surface heights (13 different means to date)
- Combine satellite altimeter and XBT data along the satellite tracks
- Determine the “best” mean to be used in the assimilation

BT Survey Data



Northwestern Atlantic Results

Table 1: **NWA MDT Analysis** [B]

Grid Name	AVG AbsDev [cm]
GBL NLOM RS 1/16°	5.9357
ATL Niiler 1/2°	6.5357
GBL Niiler 1/2°	6.7500
GBL MODAS 1/8°	7.1500
GBL NLOM RS 1/32°	7.5000
ATL MICOM ECMWF 1/12°	7.7571
GBL RIO 1°	7.7714
ATL RIO 1°	8.7929
NWA Kelly 1°	8.8143
GBL NLOM 1/32°	9.2857
ATL NLOM 1/64°	9.8000
GBL NLOM 1/16°	9.9357
ATL MICOM COADS 1/12°	12.0571
ATL HYCOM 1/12°	12.9857
ATL HYCOM 1/3°	16.1071

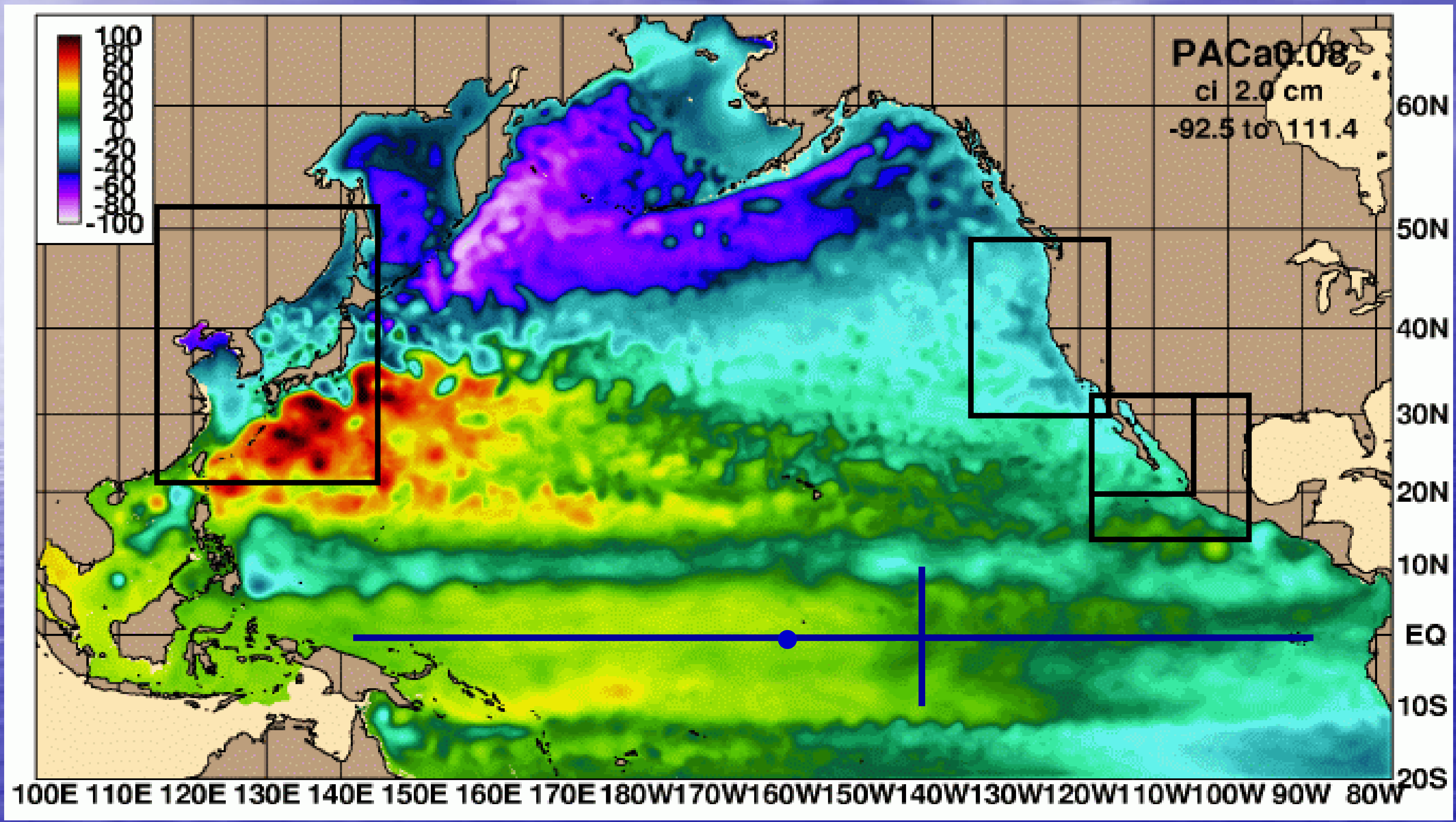
Pacific HYCOM Model Configuration

- Horizontal grid: 1/12° equatorial resolution (2294 x 1362 grid points, 6.5 km spacing on average)
- 20°S to 65.8°N
- 20 vertical coordinates
- KPP mixed layer model
- Surface forcing: (wind stress, wind speed, thermal forcing, precipitation, relaxation to climatological SSS)
- Monthly river runoff (254 rivers)
- Buffer zone: ~3° band along southern and eastern boundary with relaxation to monthly climatological (GDEM3) T and S

• Closed boundaries along 20°S, in the Indonesian throughflow region and in the Bering Strait

1/12° Pacific HYCOM Basin-scale Circulation

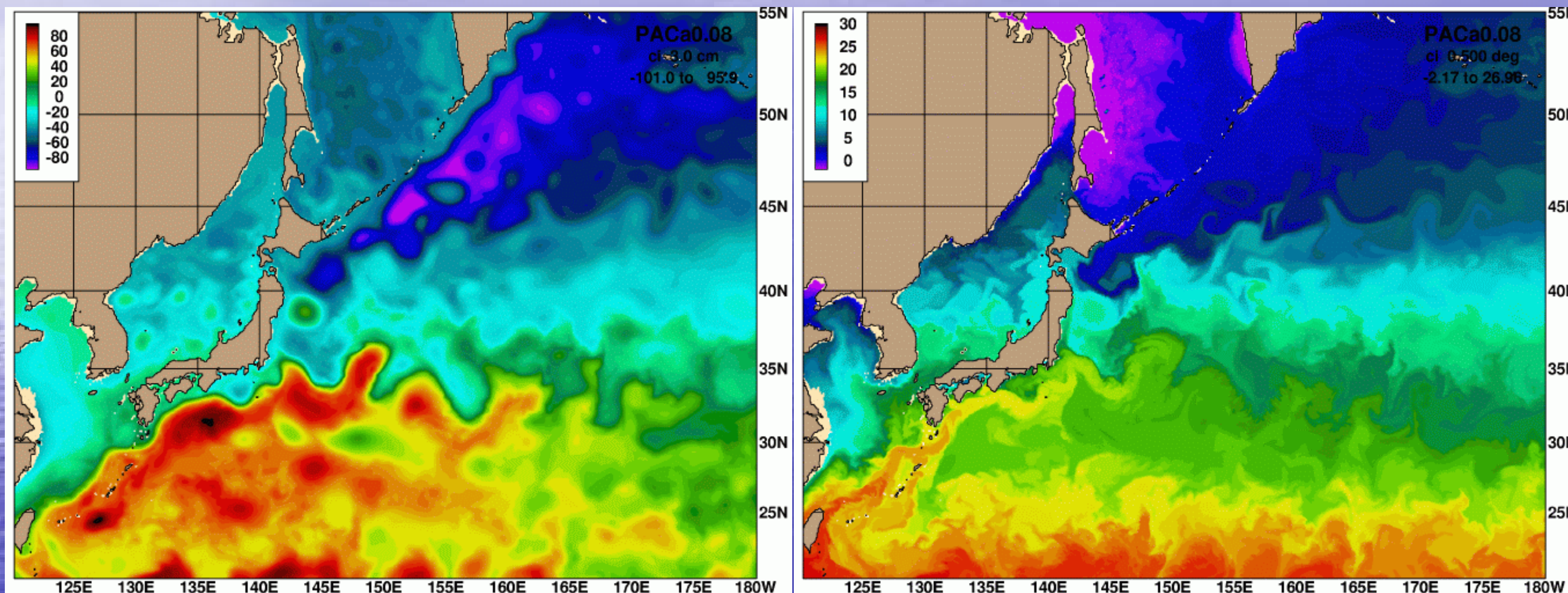
SSH Snapshot – 2 January 1991



Nesting strategy: 1-day updating in the buffer zone at the boundaries using T, S, P, u and v from the Pacific model

1/12° Pacific HYCOM

Zoom on the Kuroshio
SSH and SST Snapshot – 21 March

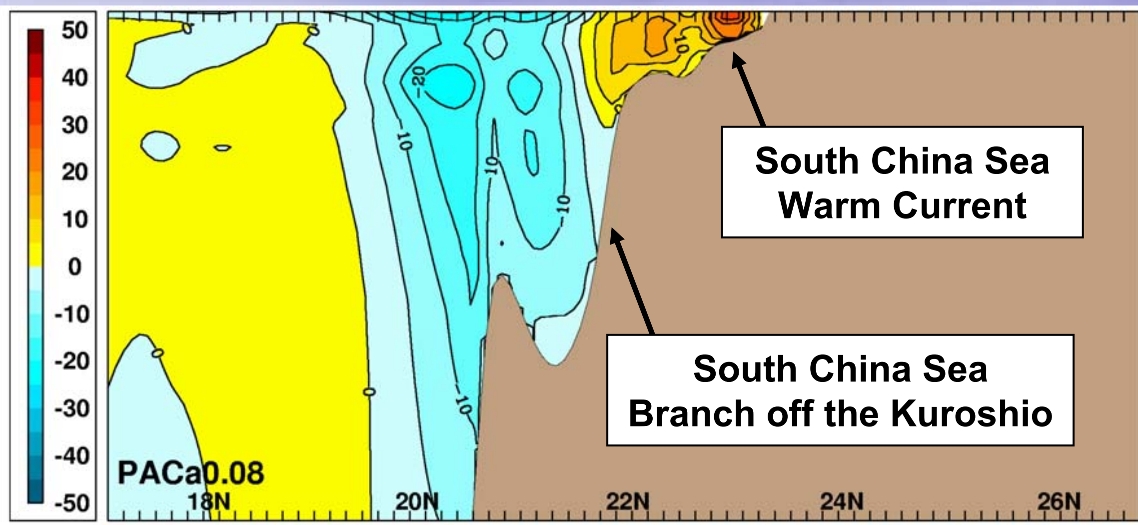


Forced with high frequency climatological ECMWF winds and thermal forcing

South China Sea Warm Current (SCSWC) Feeding the Taiwan Strait

SCSWC flows counter to the prevailing monsoon winds

Mean Zonal Velocity vs. Depth (top 500m) Along 117°E



blue = westward, orange = eastward

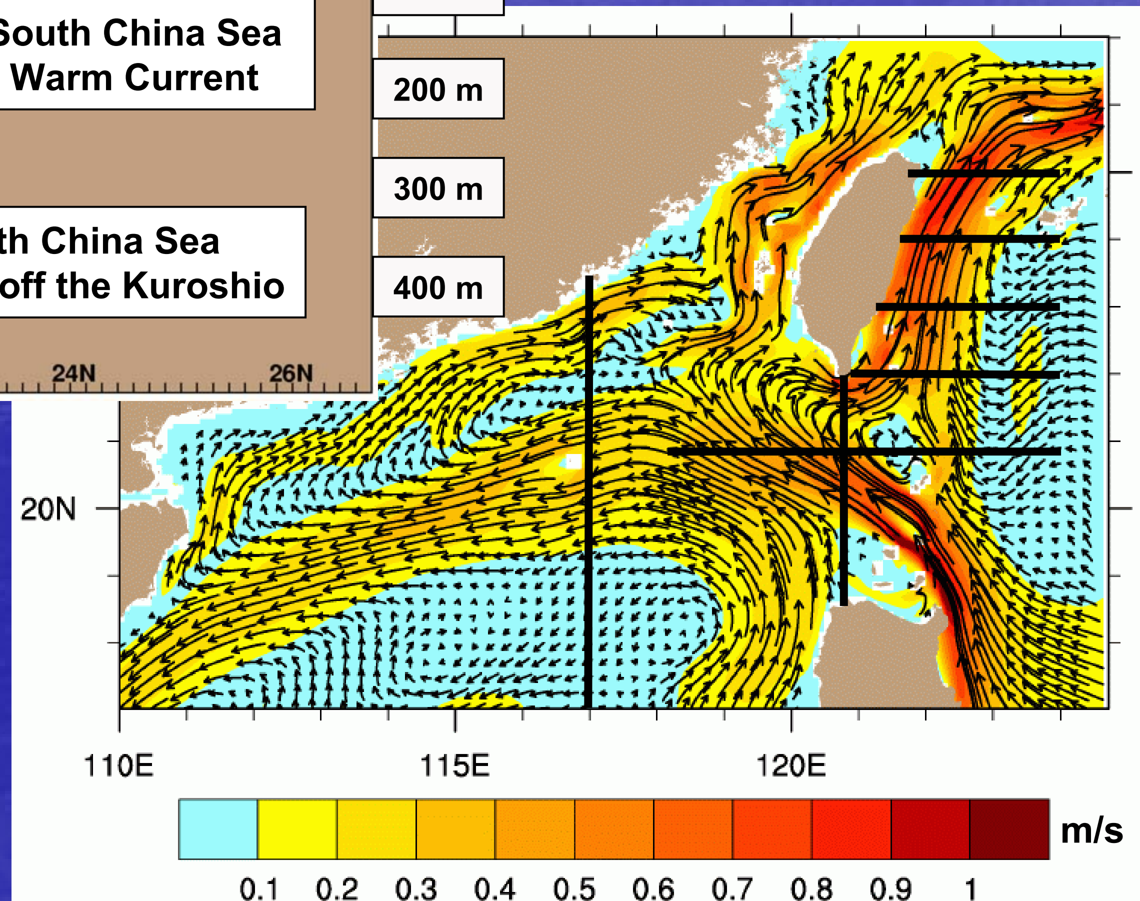
100 m

200 m

300 m

400 m

Mean Surface Layer Currents & Speed

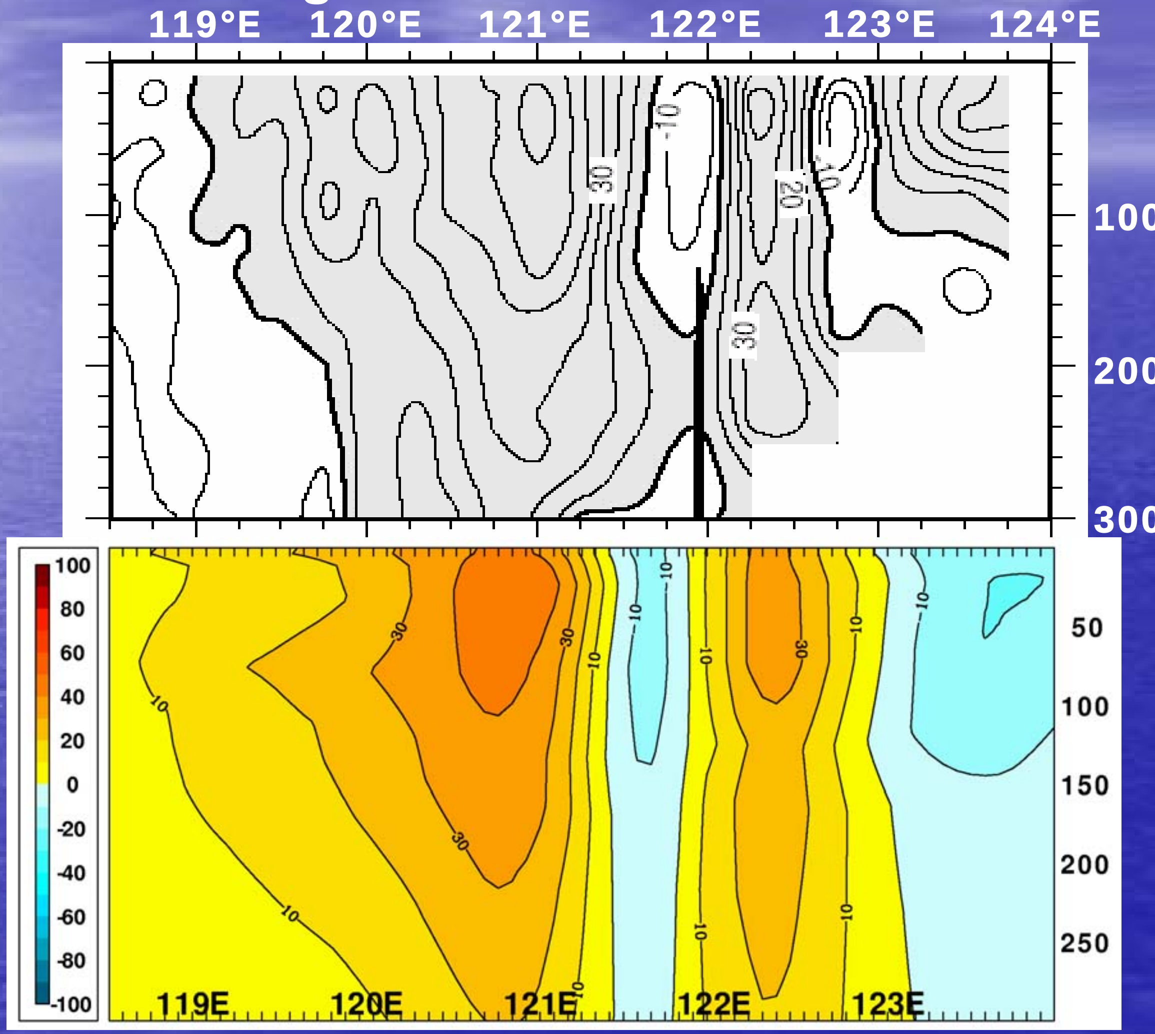


Results from a 1/12° Pacific HYCOM simulation forced with climatological ECMWF winds and heat fluxes

Velocity Cross-section Along Luzon Strait

Sb-ADCP data (top) vs. 1/12° Pacific HYCOM (bottom) in the upper 300 m

Section along 21°N between 118.5°E and 124.0°E



Northward velocity western core: 60+ cm/s

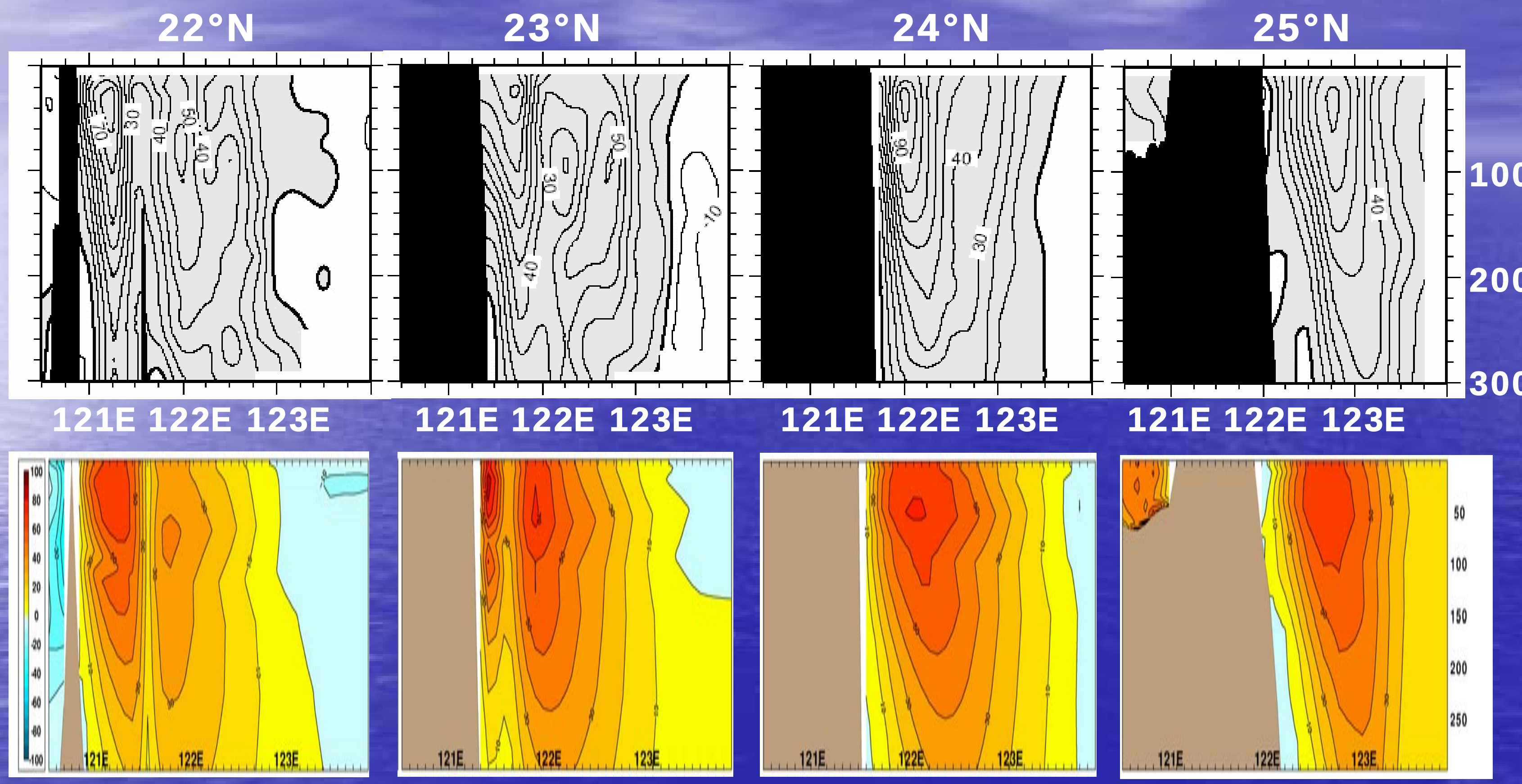
Northward velocity western core: 40+ cm/s

1991-2000 mean shipboard ADCP data from Liang et al. (2003, DSR Pt. II)
6 year mean from HYCOM forced with high-frequency ECMWF winds and thermal forcing
No ocean data assimilation in HYCOM

Velocity Cross-sections East of Taiwan

Mean ADCP data (top) vs. 1/12° Pacific HYCOM (bottom) in the upper 300 m

Sections at 22°N, 23°N, 24°N and 25°N

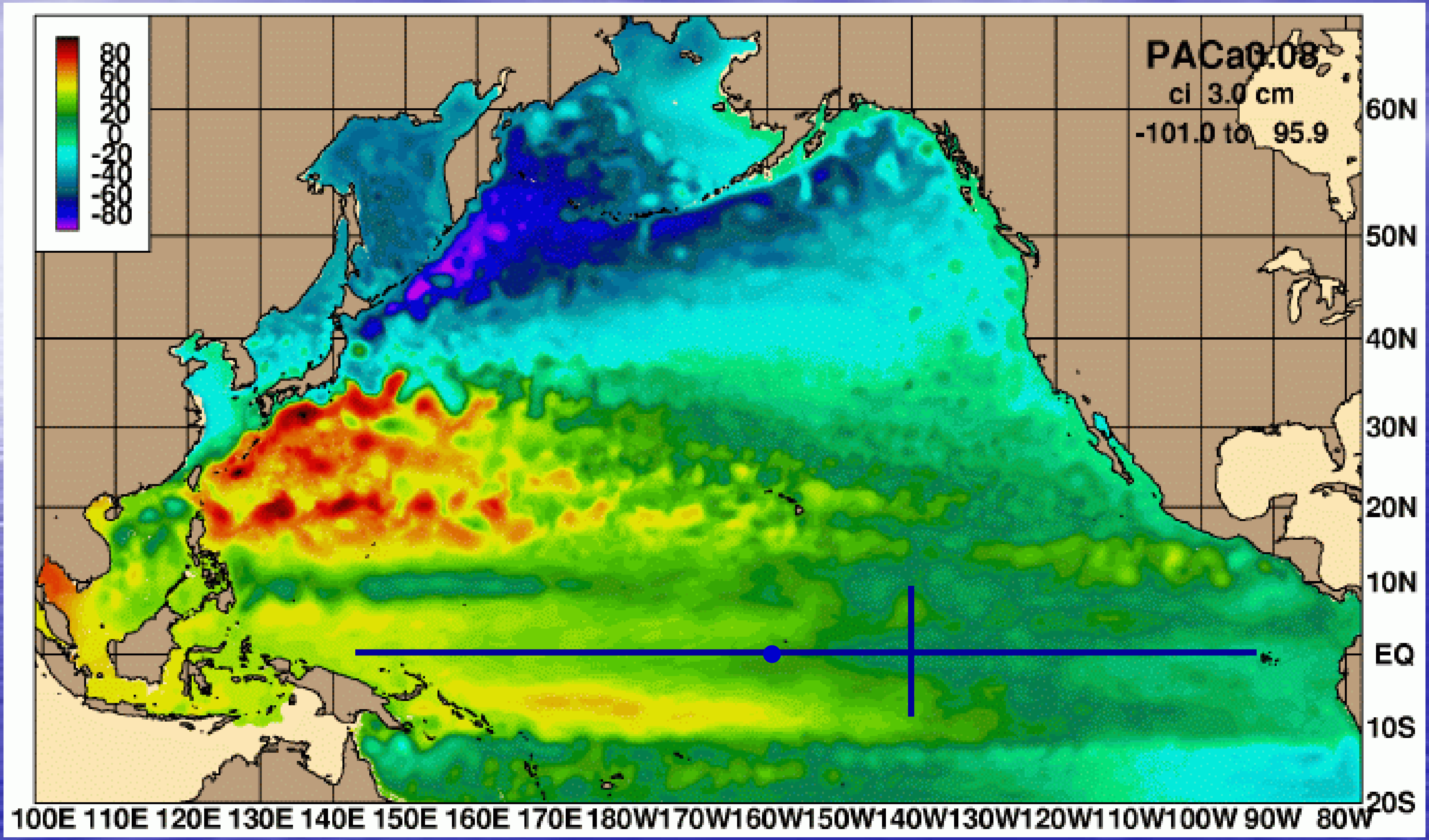


1991-2000 mean shipboard ADCP data from Liang et al. (2003, DSR Pt. II)
6 year mean from HYCOM forced with high-frequency ECMWF winds and thermal forcing
No ocean data assimilation in HYCOM

Note how the two-core Kuroshio merges into a single jet in both the observations and HYCOM from the south to north along the Taiwan coast

1/12° Pacific HYCOM Basin-scale Circulation

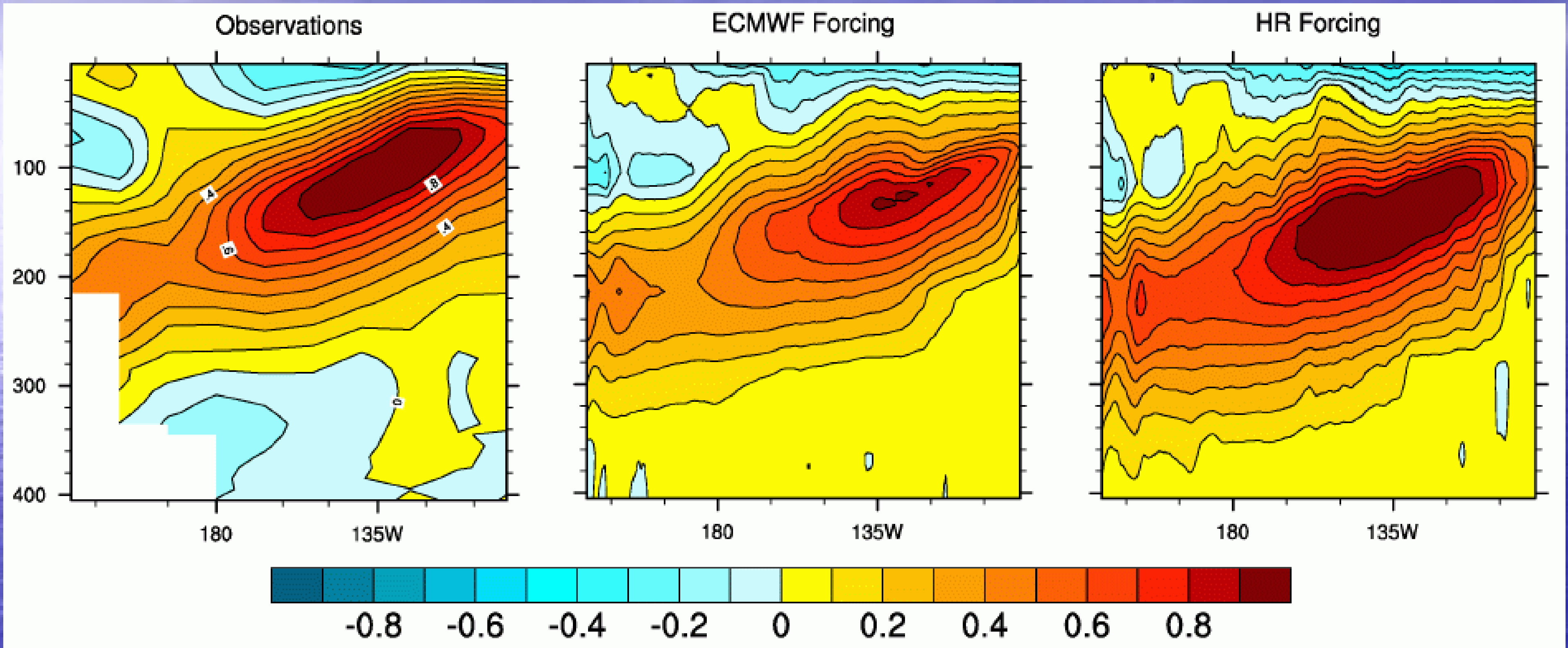
SSH Snapshot – 21 March



Forced with high frequency climatological ECMWF winds and thermal forcing

Velocity Cross-section Along the Equator

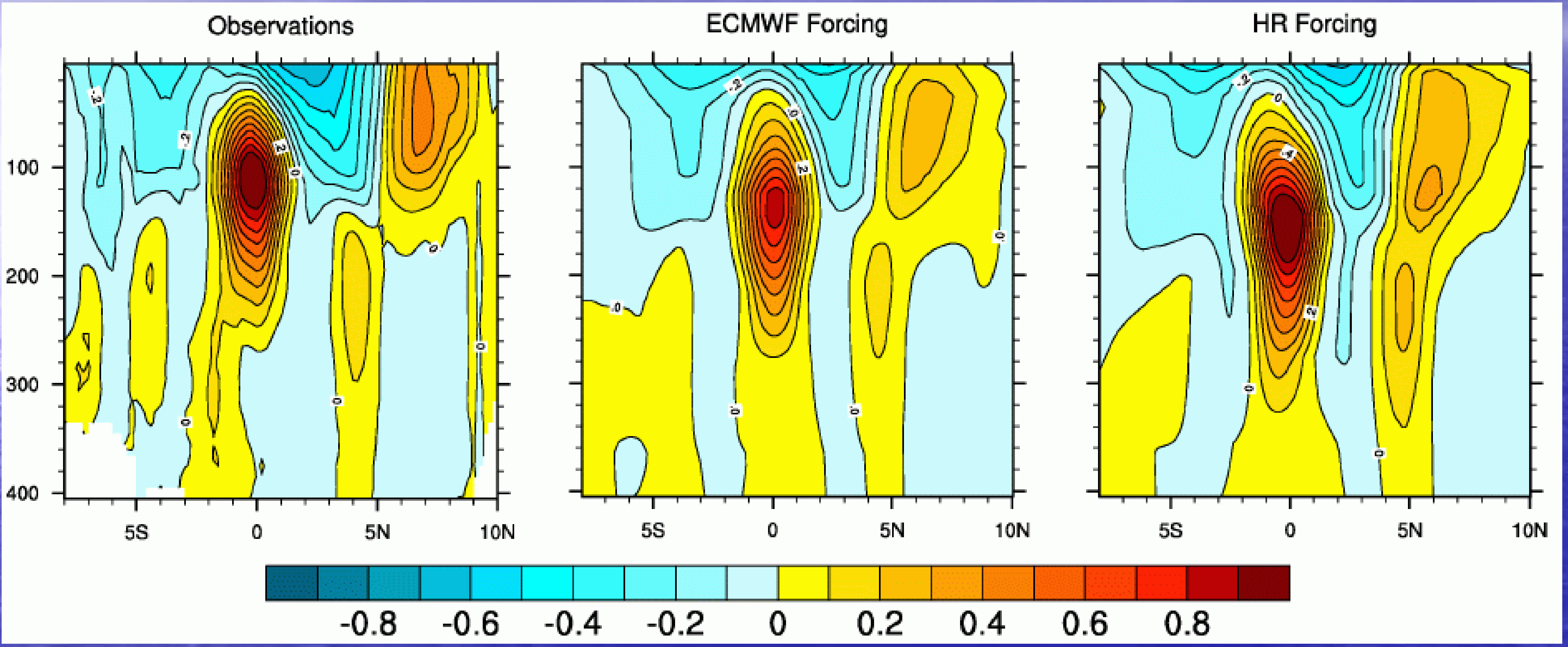
Observations (left) vs. 1/12° Pacific HYCOM (middle, right) in the upper 400 m
Section between 143°E and 95°W



Observations based on CTD/ADCP data from Johnson et al. (2002, Prog. Oceanogr.)
HYCOM forced with ECMWF (middle) or Hellerman and Rosenstein (right) winds
No ocean data assimilation in HYCOM

Velocity Cross-section Across the Equator at 140°W

Observations (left) vs. 1/12° Pacific HYCOM (middle, right) in the upper 400 m
Section between 8°S and 10°N

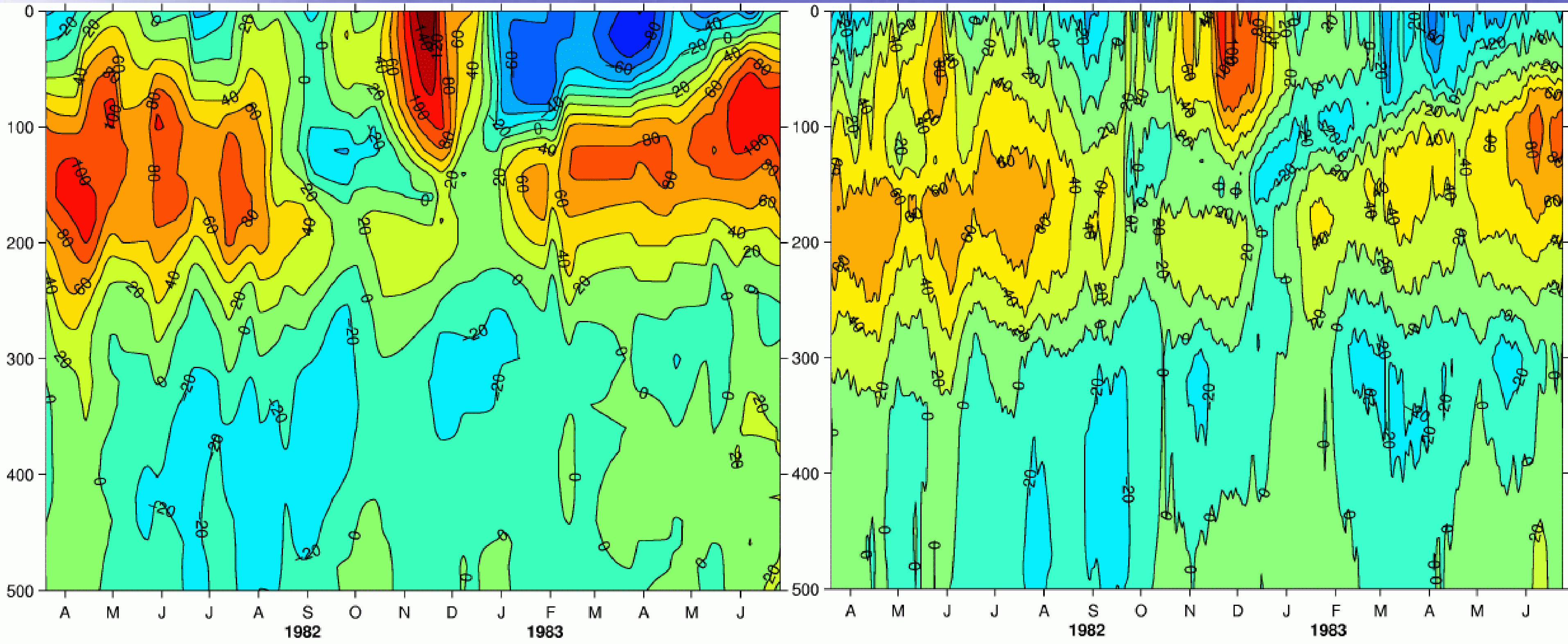


Observations based on CTD/ADCP data from Johnson et al. (2002, Prog. Oceanogr.)
HYCOM forced with ECMWF (middle) or Hellerman and Rosenstein (right) winds
No ocean data assimilation in HYCOM

Disappearance of the Equatorial Undercurrent During the 1982-83 El Niño

Zonal velocity on the Equator at 159°W

Adapted from Firing at al. (1983) | 1/12° Pacific HYCOM



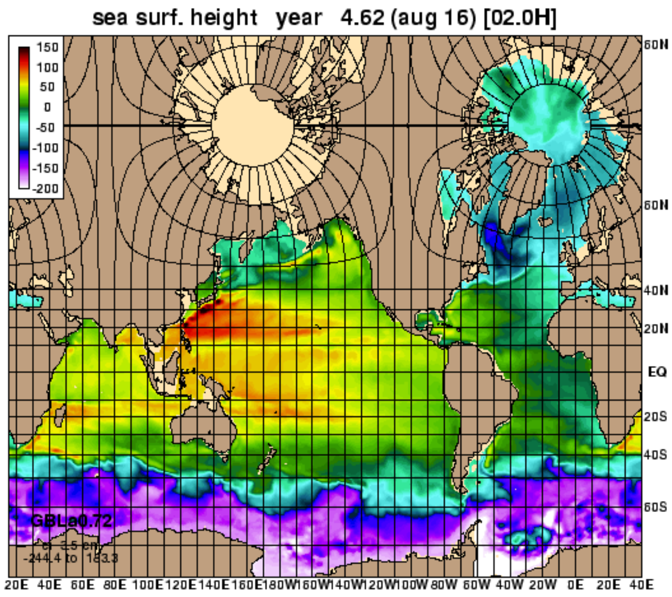
Yellow/red = eastward flow, blue = westward flow

HYCOM forced with interannual ECMWF winds and heat fluxes

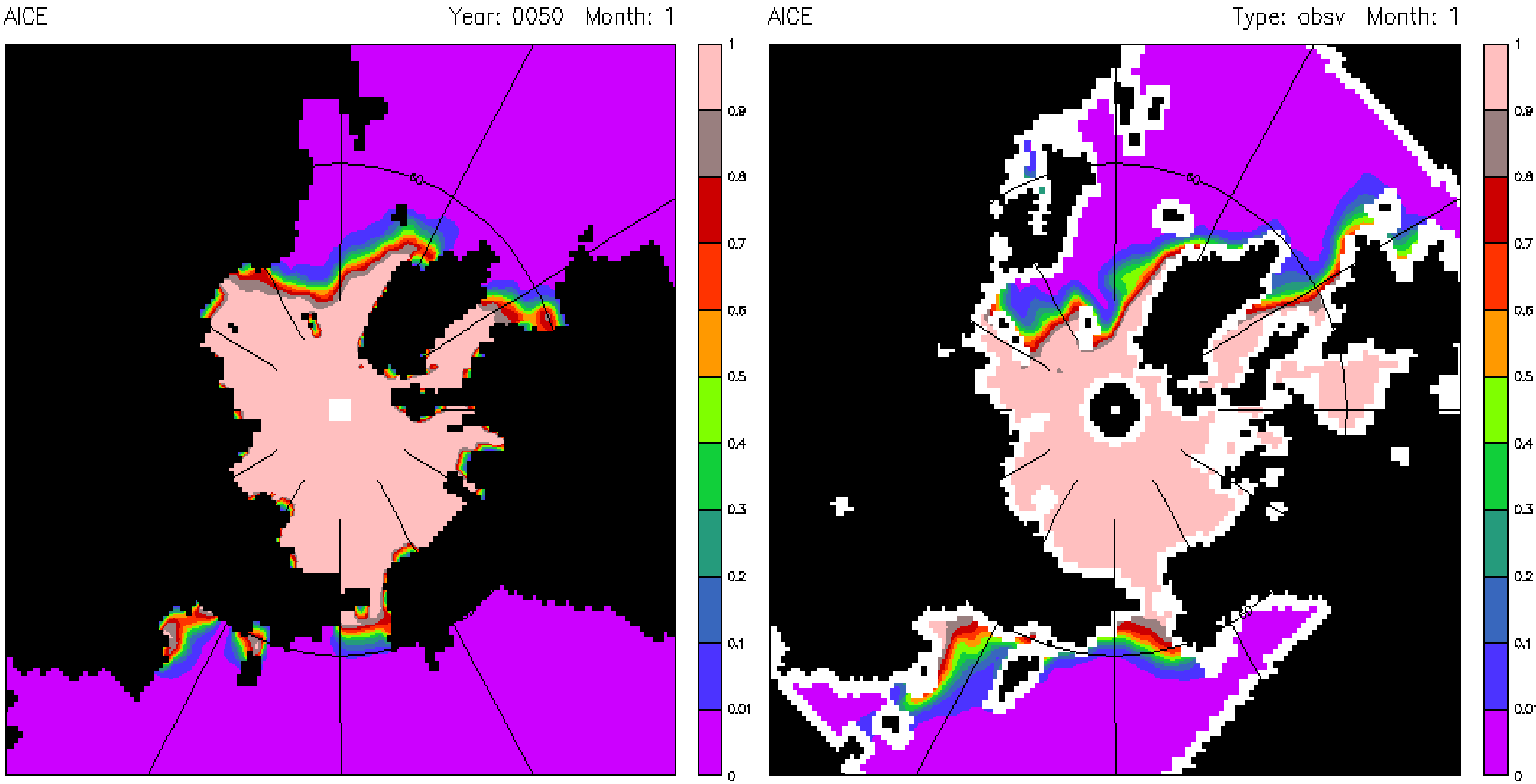
No oceanic data assimilation

Configuration of the Prediction Systems

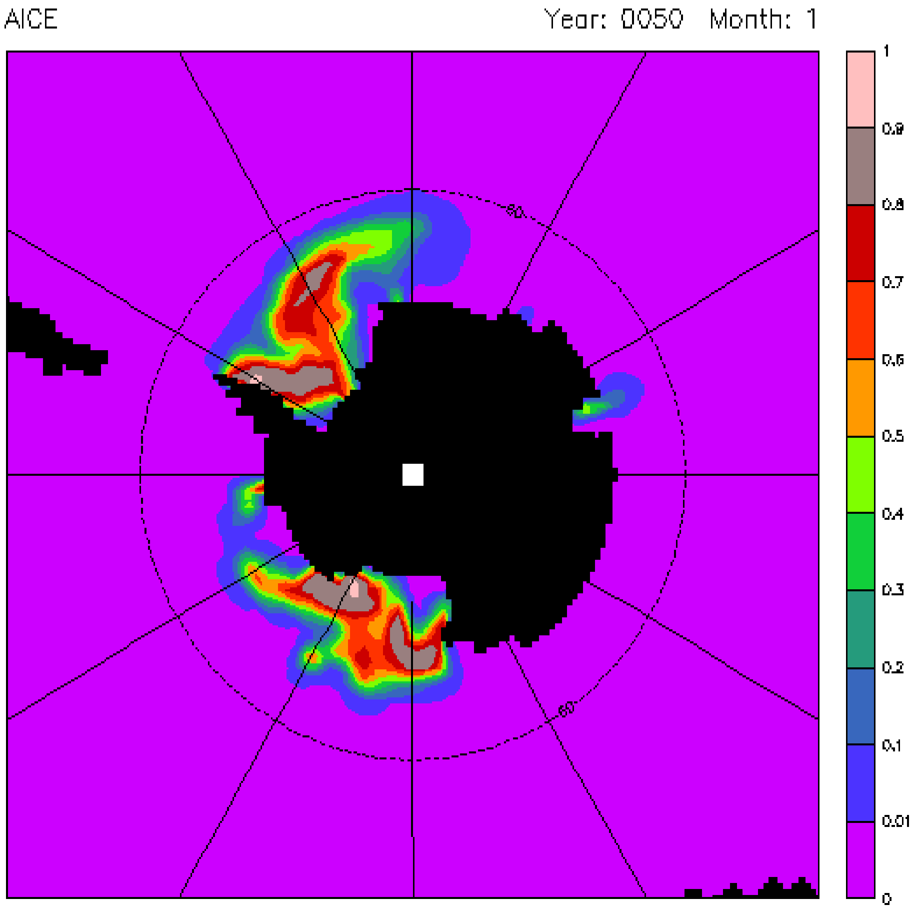
- Global
  - Sea Ice Options
    - Energy loan
    - 4-layer thermodynamic (Russel et al., 2000)
    - Los Alamos CICE
  - Target
    - 1/12º for NAVOCEANO
    - 1/4º (~20 km) for FNMOC (ocean component of coupled ocean-atmosphere)

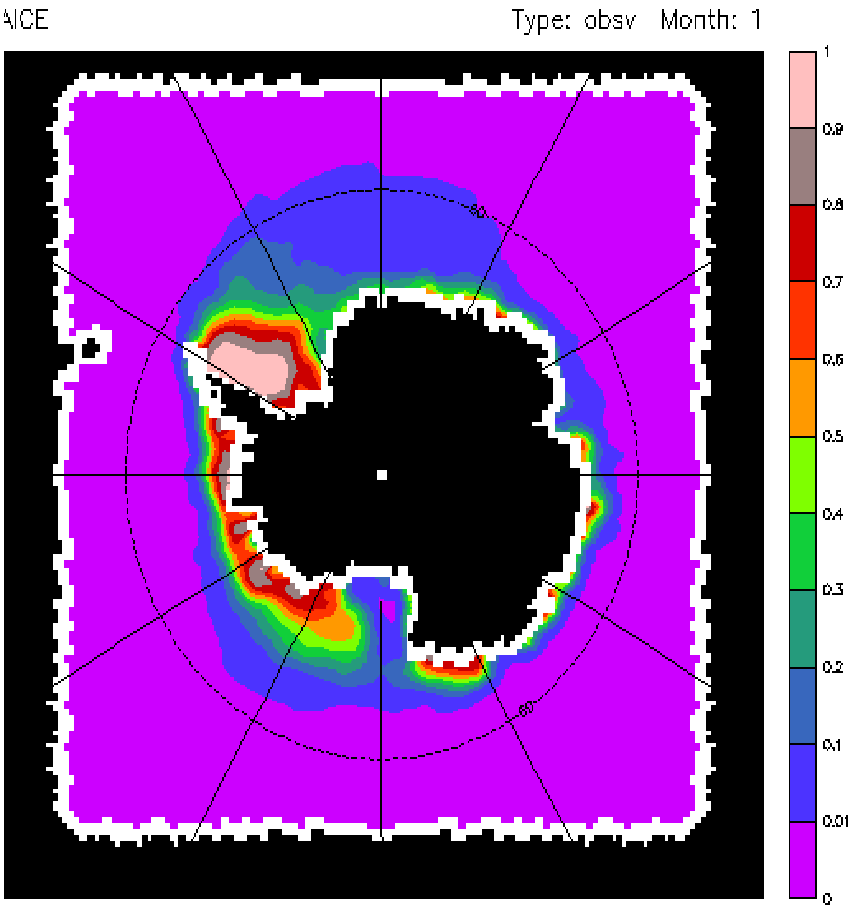


Monthly Sea Ice Coverage (NH)



Monthly Sea Ice Coverage (SH)

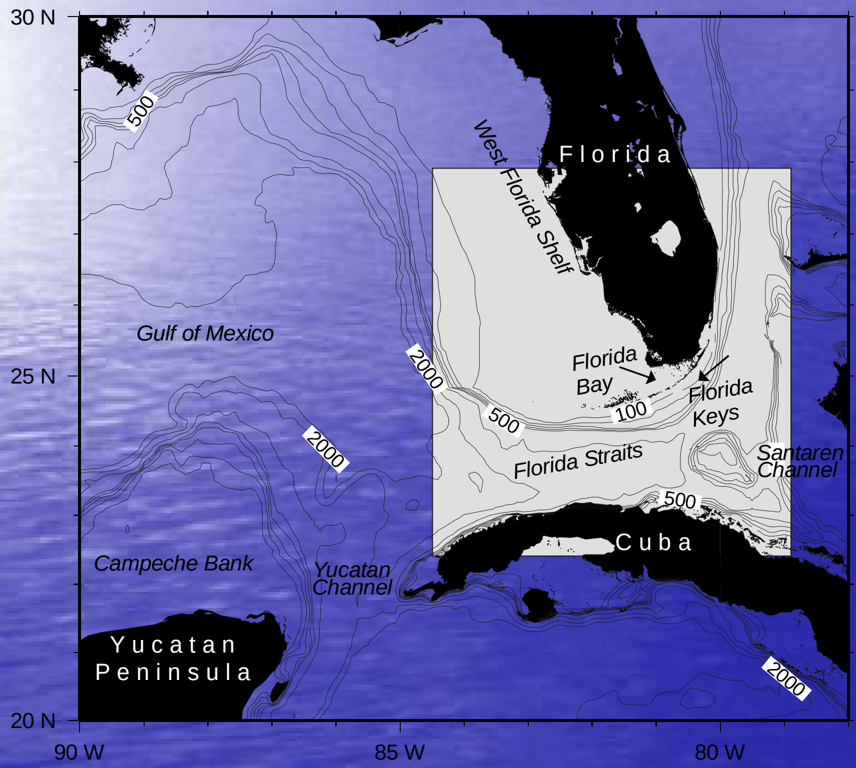


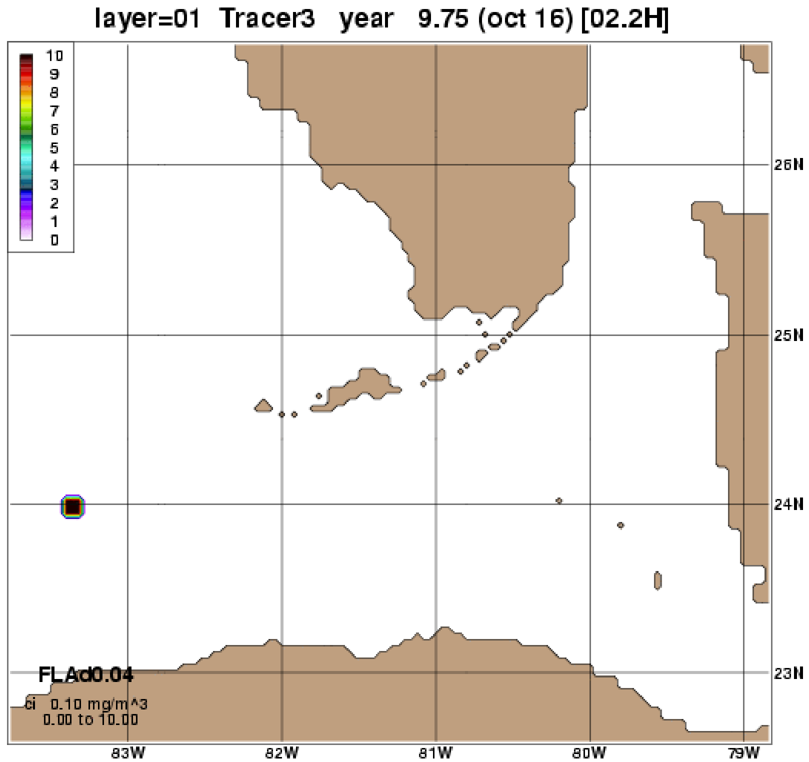


Product Evaluation

- Assessment of the outputs by comparison to independent observations
- Strong involvement of coastal ocean modeling groups to use and evaluate boundary conditions provided by the global and basin HYCOM real time prediction system outputs

Regional Model around Florida Bay

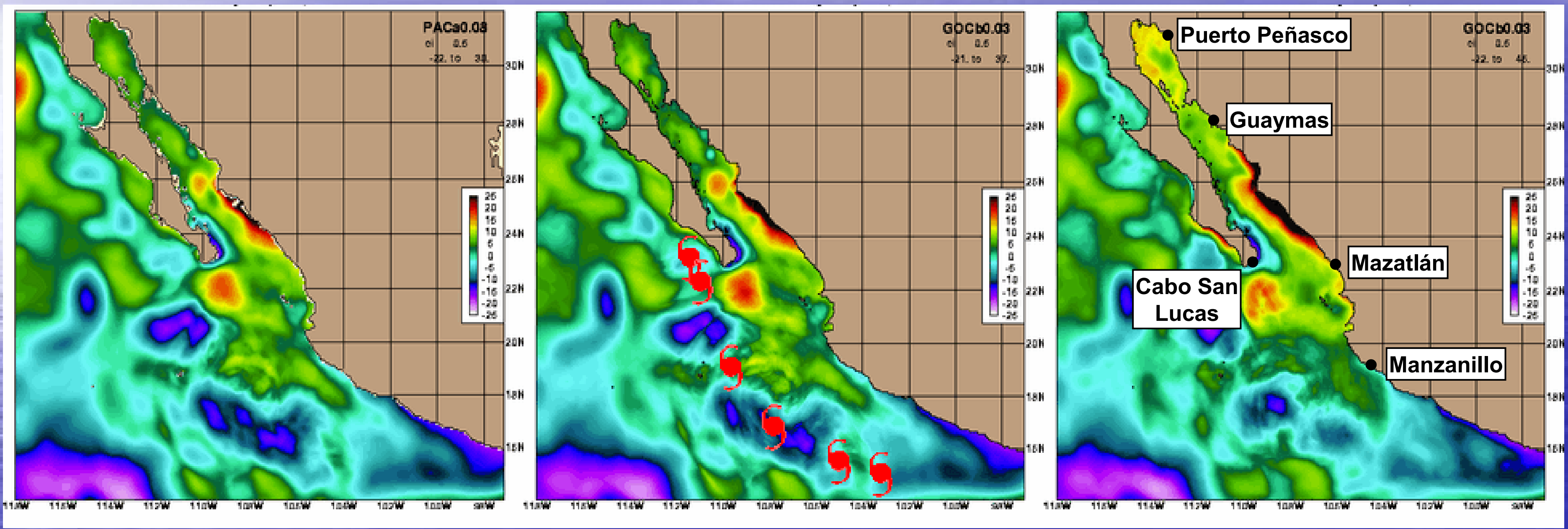




HYCOM Response to Hurricane Juliette

SSH anomaly – 29 September 2001 00Z

1/12.5° PAC | 1/37.5° GOC | 1/37.5° GOC

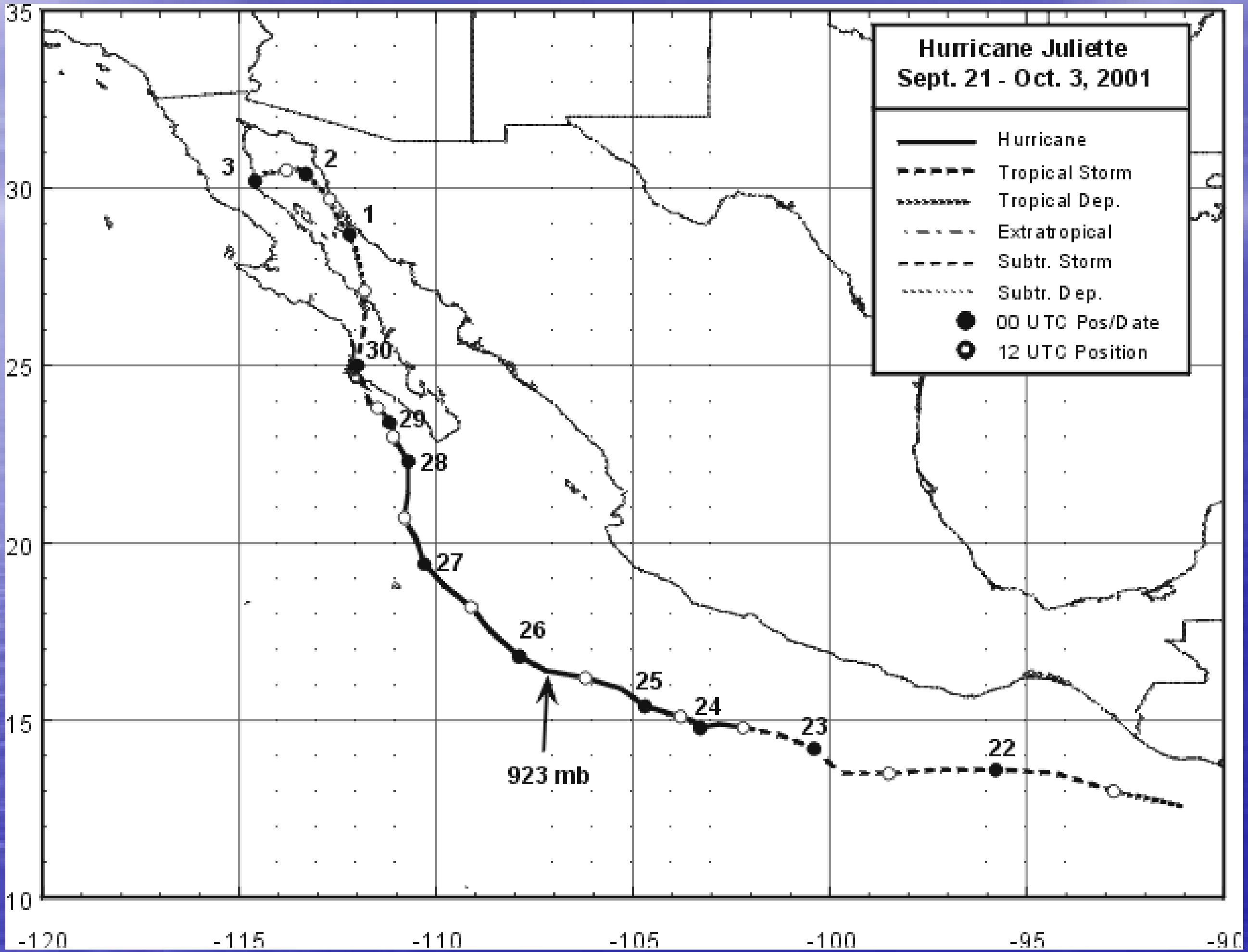


1.0° NOGAPS wind forcing | 1.0° NOGAPS wind forcing | 27 km COAMPS wind forcing

No ocean data have been assimilated into the models

Hurricane position at 24-hr intervals through 29 September

1/12° Pacific HYCOM – 6-hourly NOGAPS



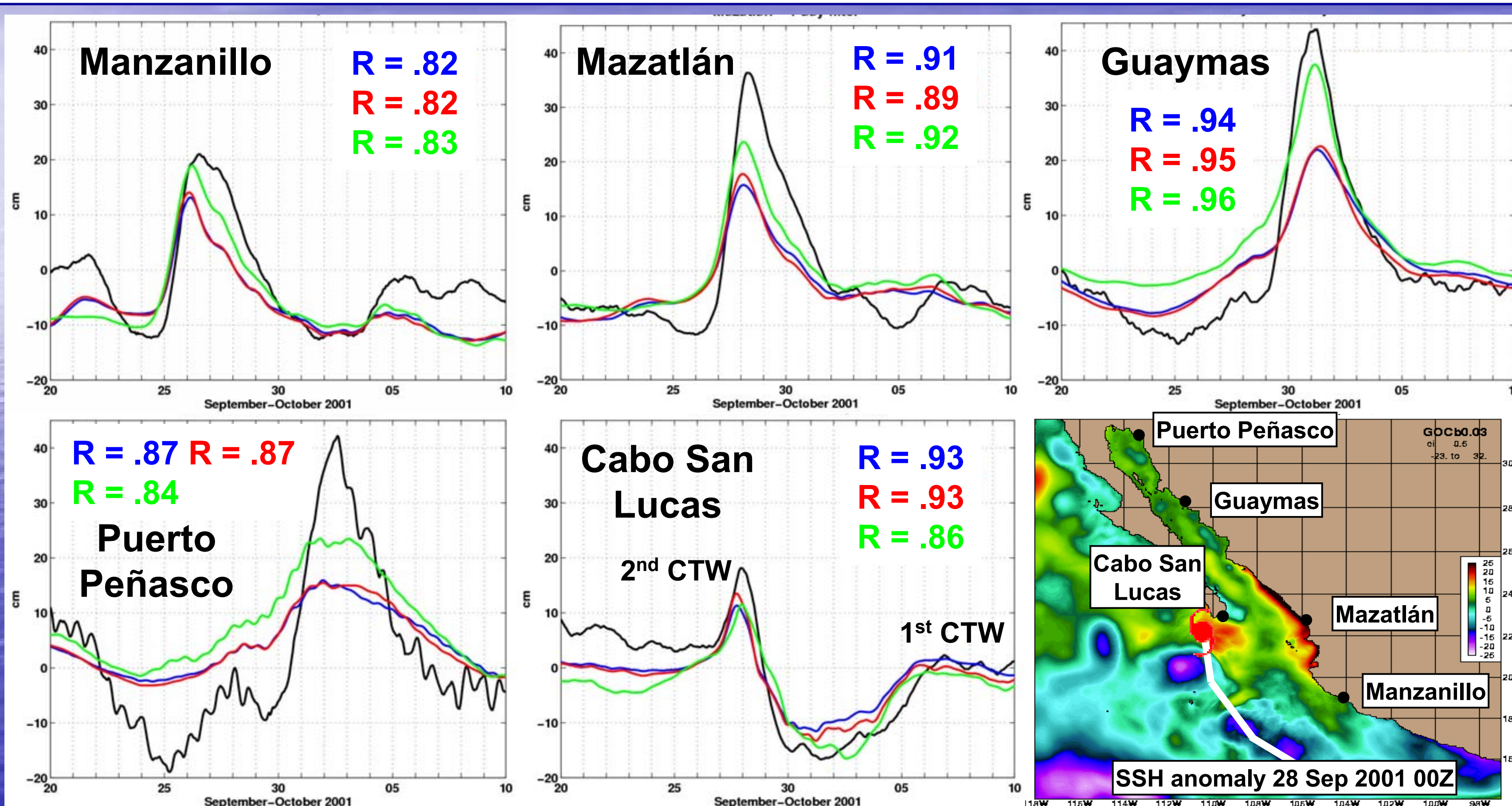
SST

SSH

Impact of Hurricane Julliette

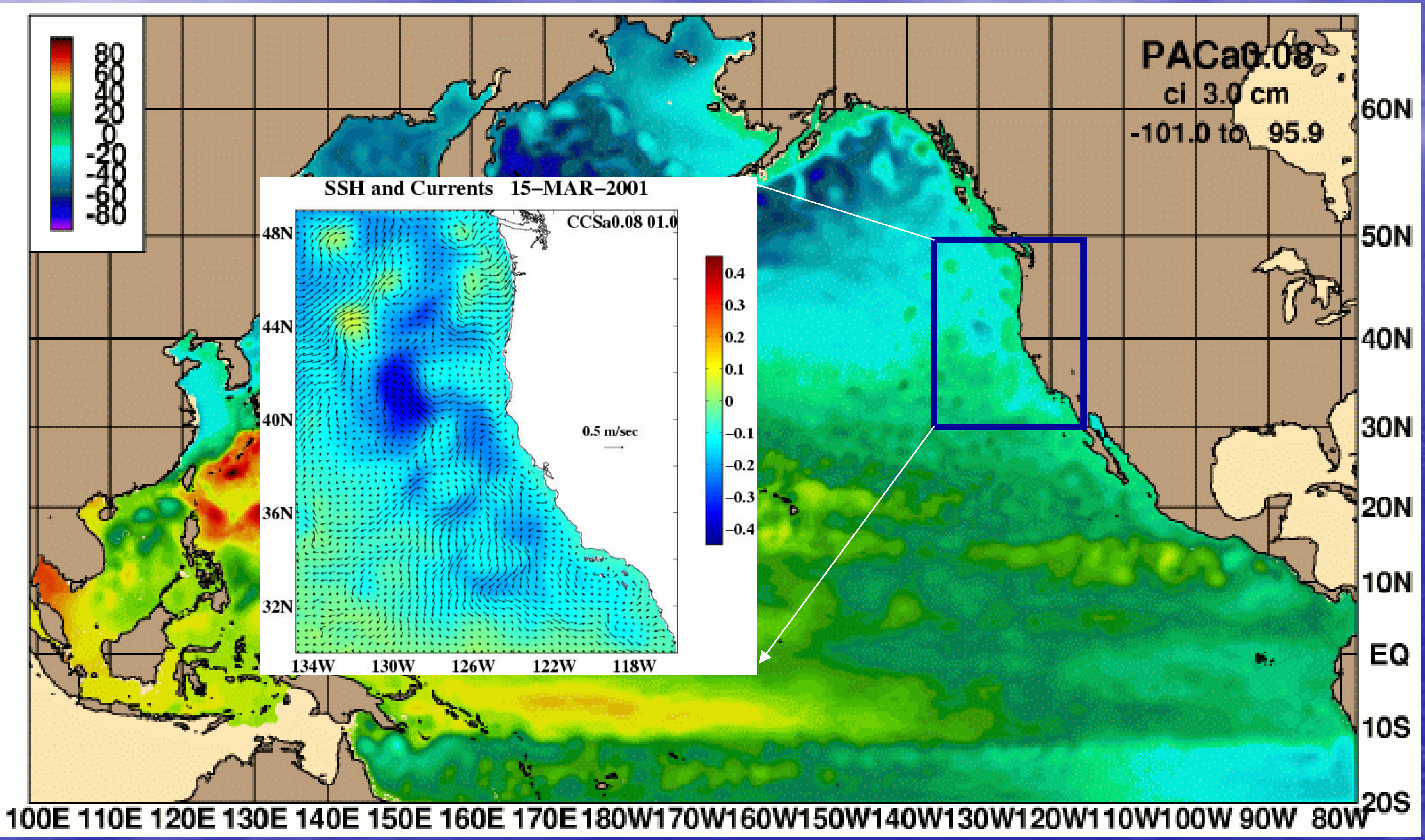
Observed Versus Modeled Sea Level Anomaly Along the Mexican Coast Associated With the Coastally Trapped Waves (CTW) Generated by Hurricane Juliette: 20 Sept- 10 Oct 2001

Tide gauge data 1/12° Pacific - NOGAPS 1/37.5° GOC – NOGAPS 1/37.5° GOC − COAMPS



No ocean data were assimilated into the models. De-tided tide gauge data were provided by the University of Hawaii and the Secretaría de Marina de México (Mexican Navy). A 1-day running mean filter was applied to all time series.

1/12° Pacific HYCOM Basin-scale Circulation with nested US West Coast HYCOM

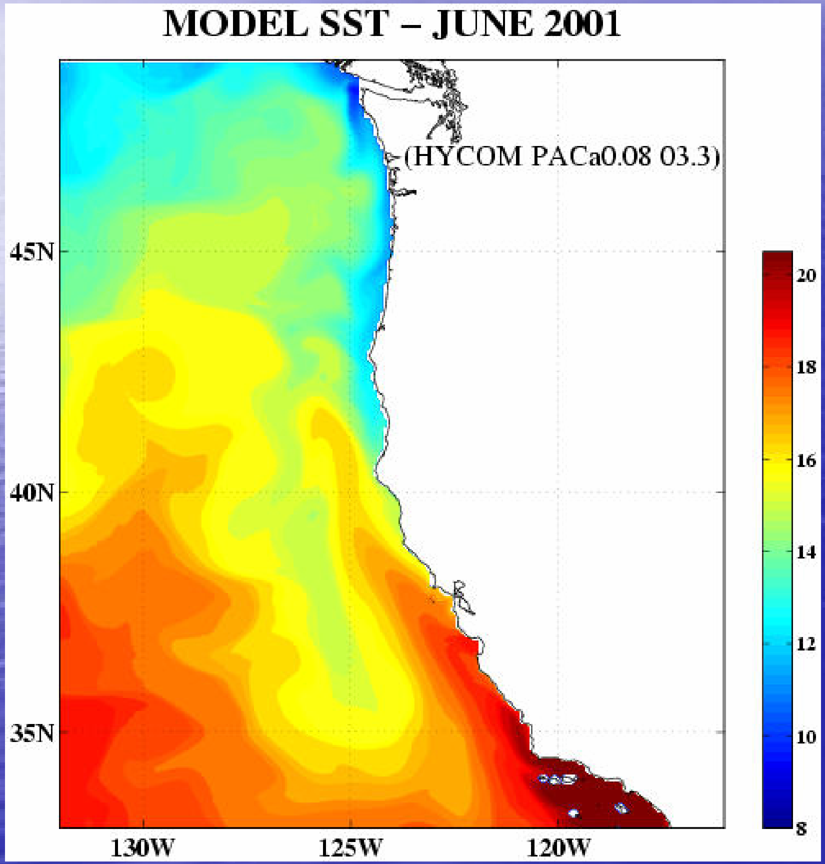


Forced with high frequency ECMWF winds and thermal forcing

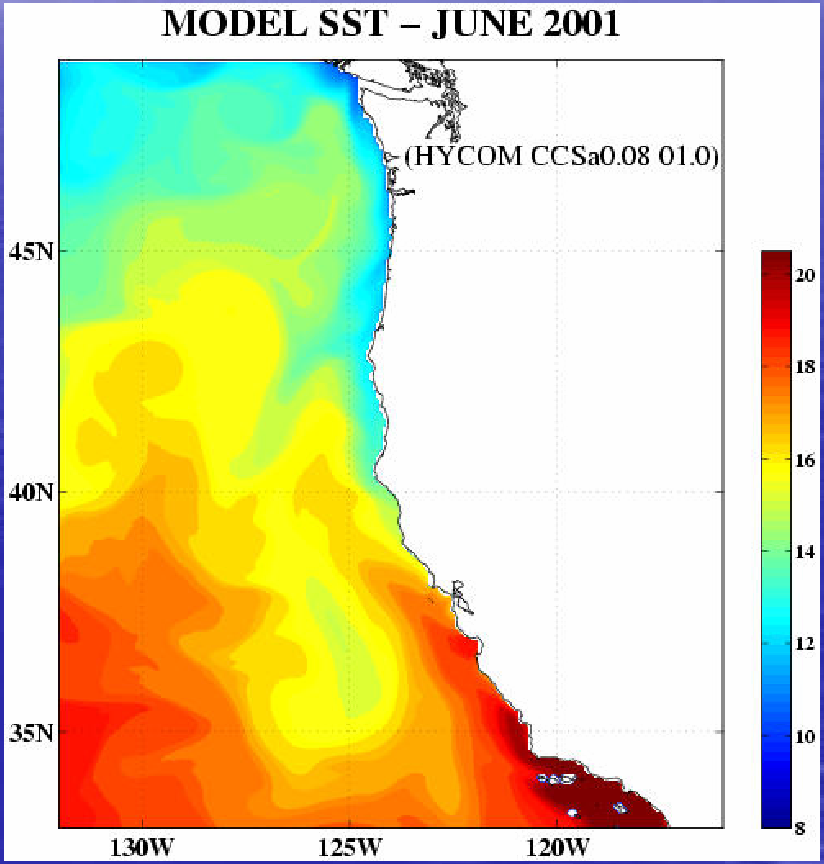
SSH Snapshot – 21 March

1/12° Pacific HYCOM Basin-scale Circulation with nested US West Coast HYCOM

Pacific Basin HYCOM



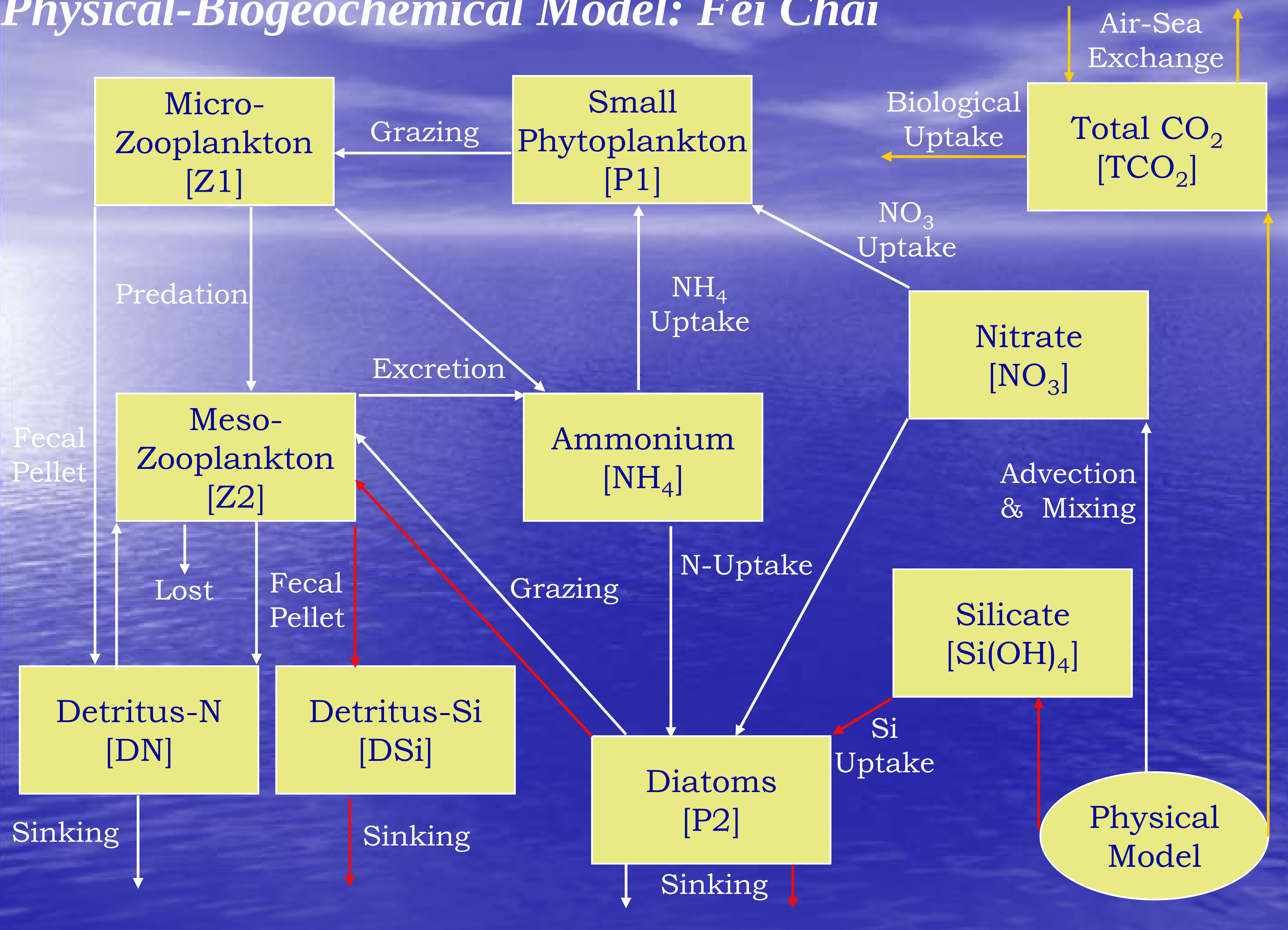
Nested US West Coast HYCOM



Nested HYCOM uses same resolution and forcing as Pacific HYCOM to test bc.

Simulation begins on January 1, 2001; no data assimilation is included.

Physical-Biogeochemical Model: Fei Chai



Model Outputs

- Are available to the community at large within 24 hours via ftp and the Miami Live Access Server (LAS)
- Strong collaboration with NOAA/PMEL (S. Hankin) and OPeNDAP (P. Cornillon) to enhance the LAS and to provide an efficient distribution of the model outputs
- Comparison with other GODAE products (i.e. MERSEA collaboration)

http://hycom.rsmas.miami.edu