Accuracy and Dissipation Issues in Ocean Modeling

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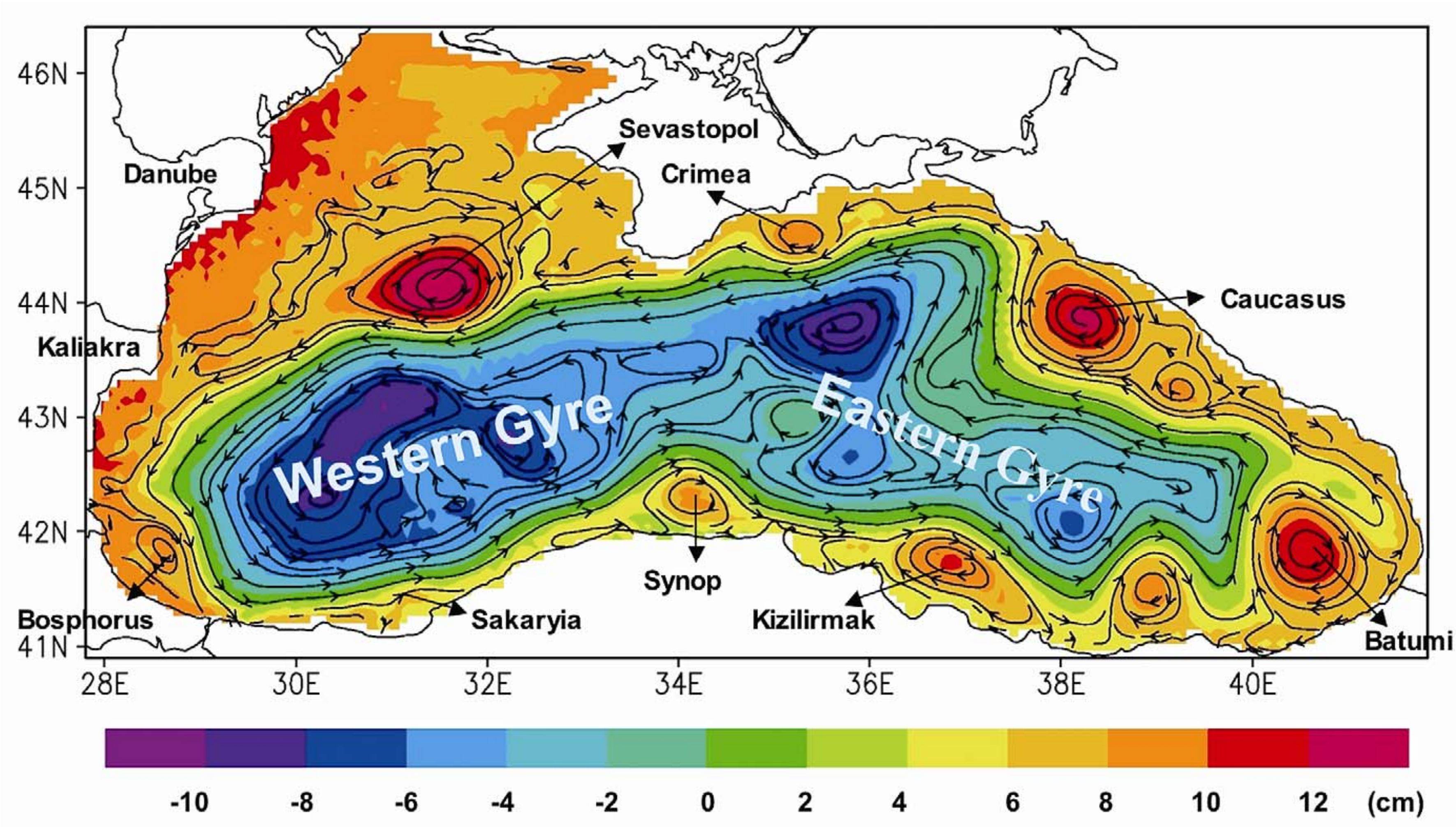
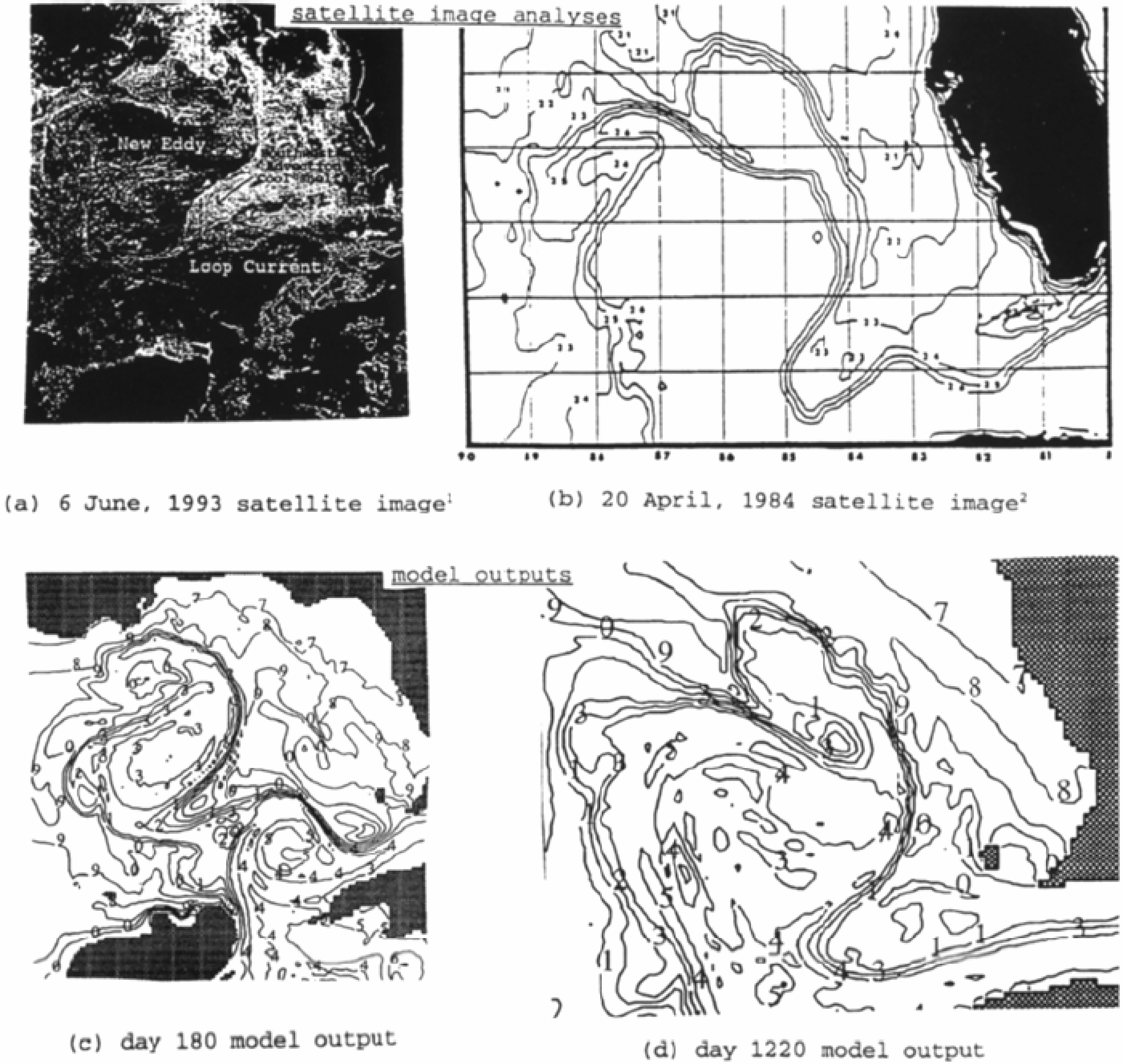
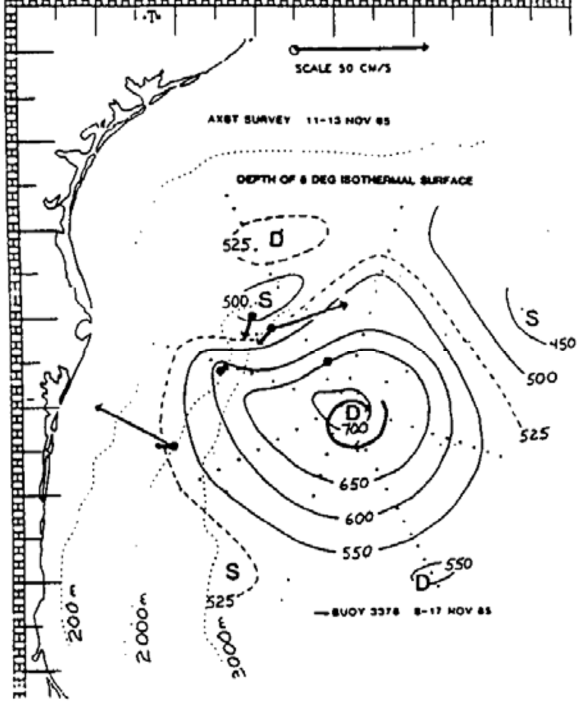
International Workshop on Numerical Ocean Prediction

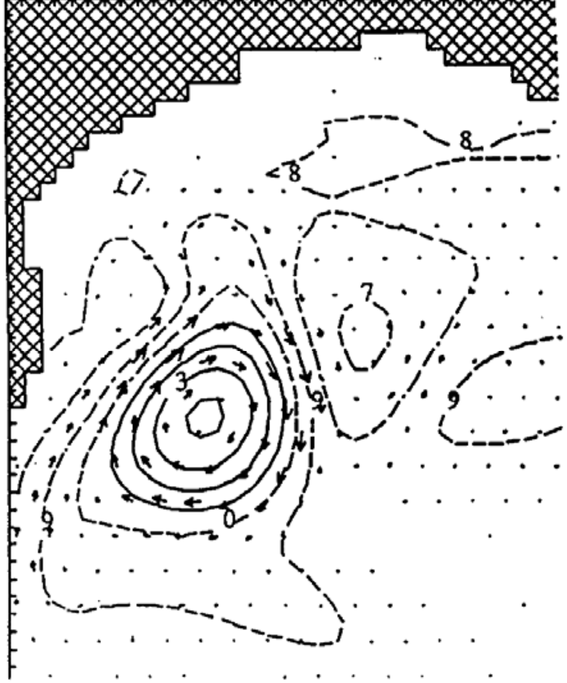


46N
45N
44N
43N
42N
41N
28E
30E
32E
34E
36E
38E
40E
Sevastopol
Danube
Crimea
Caucasus
Kaliakra
Western Gyre
Eastern Gyre
Synop
Bosphorus
Sakaryia
Kizilirmak
Batumi
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
(cm)



A comparison of analyzed satellite surface temperatures (top panels) and snapshots of the top layer (10 m depth) model temperature (bottom panels).

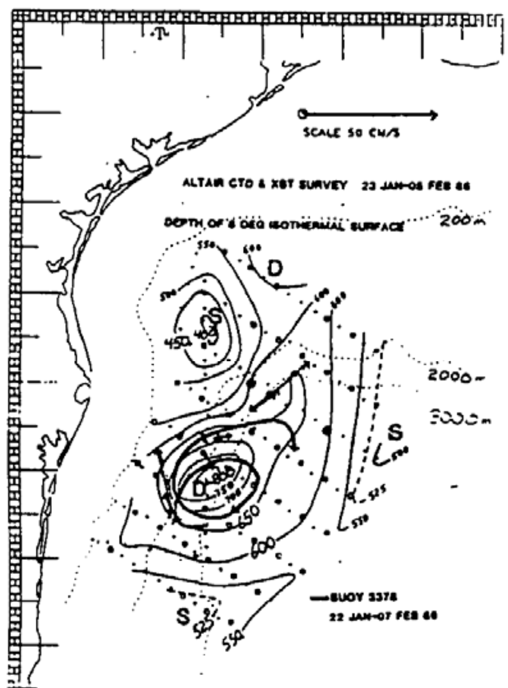


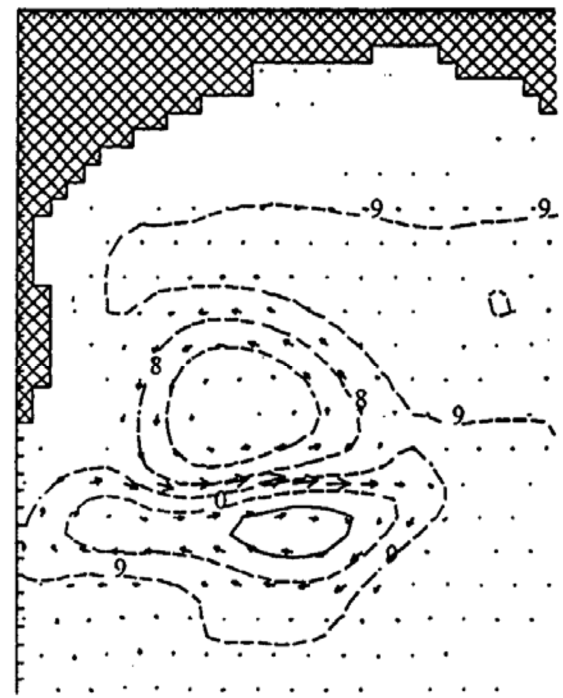


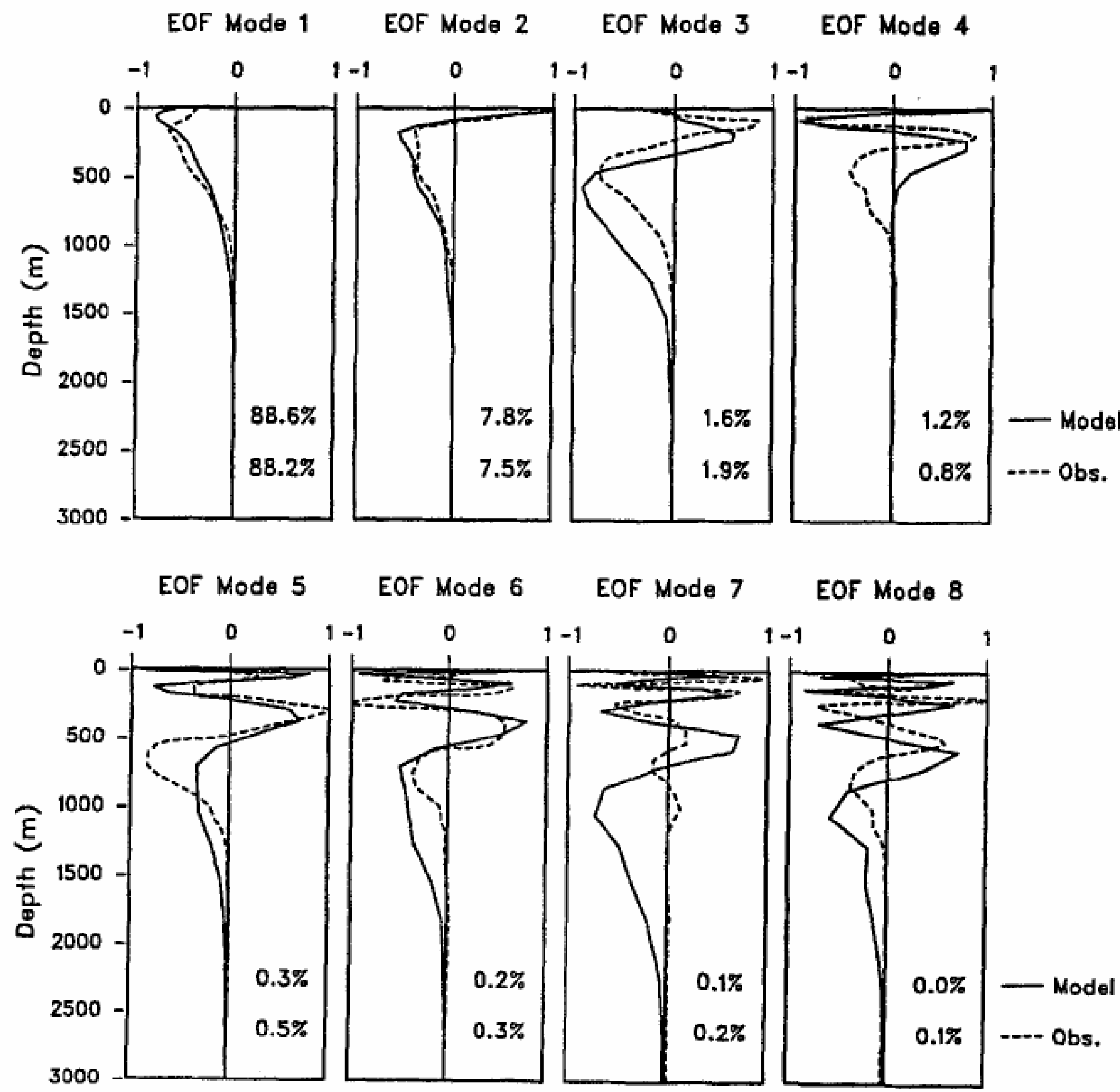
LEFT: Observations (Brooks and Kelly, 1986) depth of 8℃ isotherm.

Right: Model Results (top layer pressure and velocity)

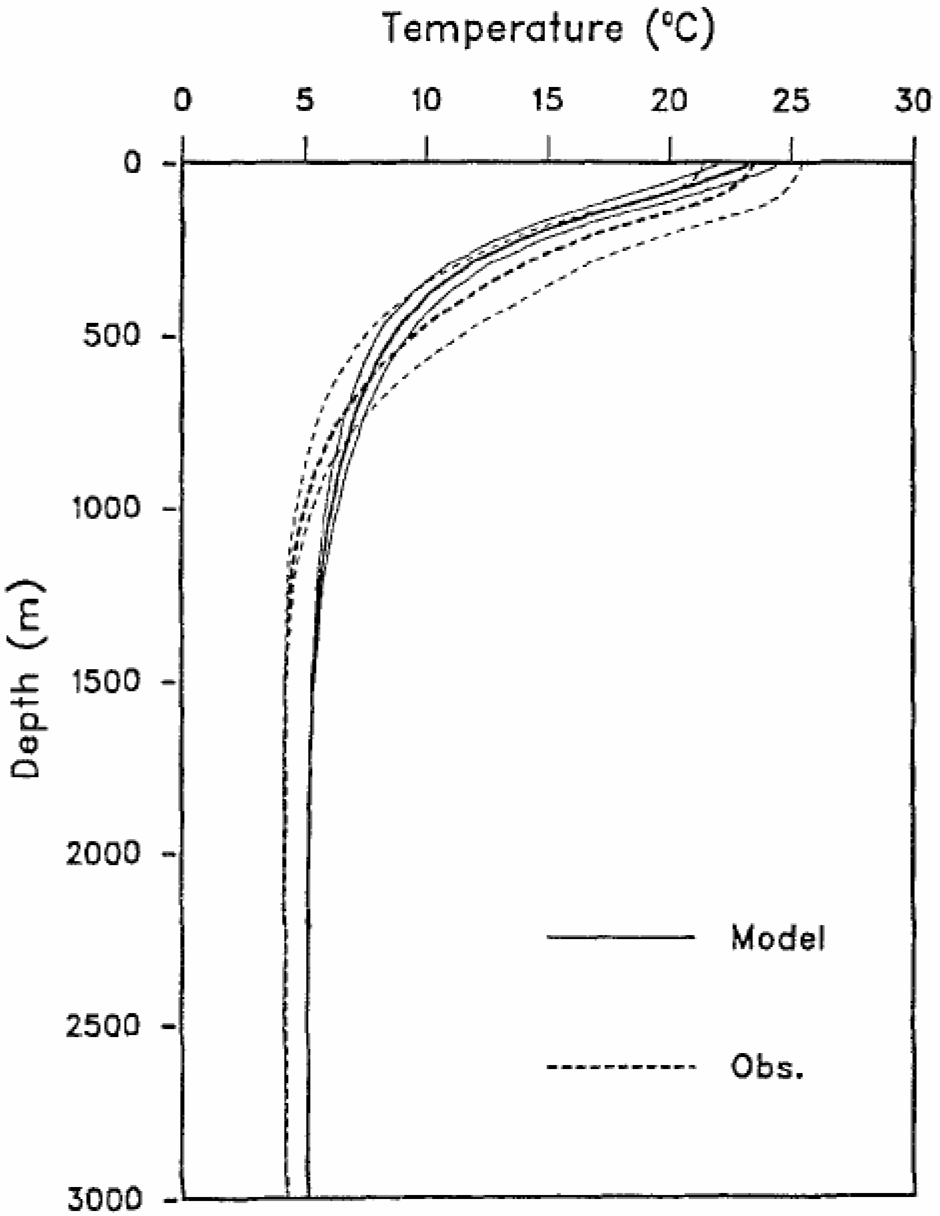
Paired eddy formation near the western GOM shelfbreak: observations and model results with no data assimilation. The observations are 80 days apart. The model results are 75 days apart (days 1935 and 2010 from Case B3). The maximum velocity in the region shown in the model results is about 50 cm s^{-1}.



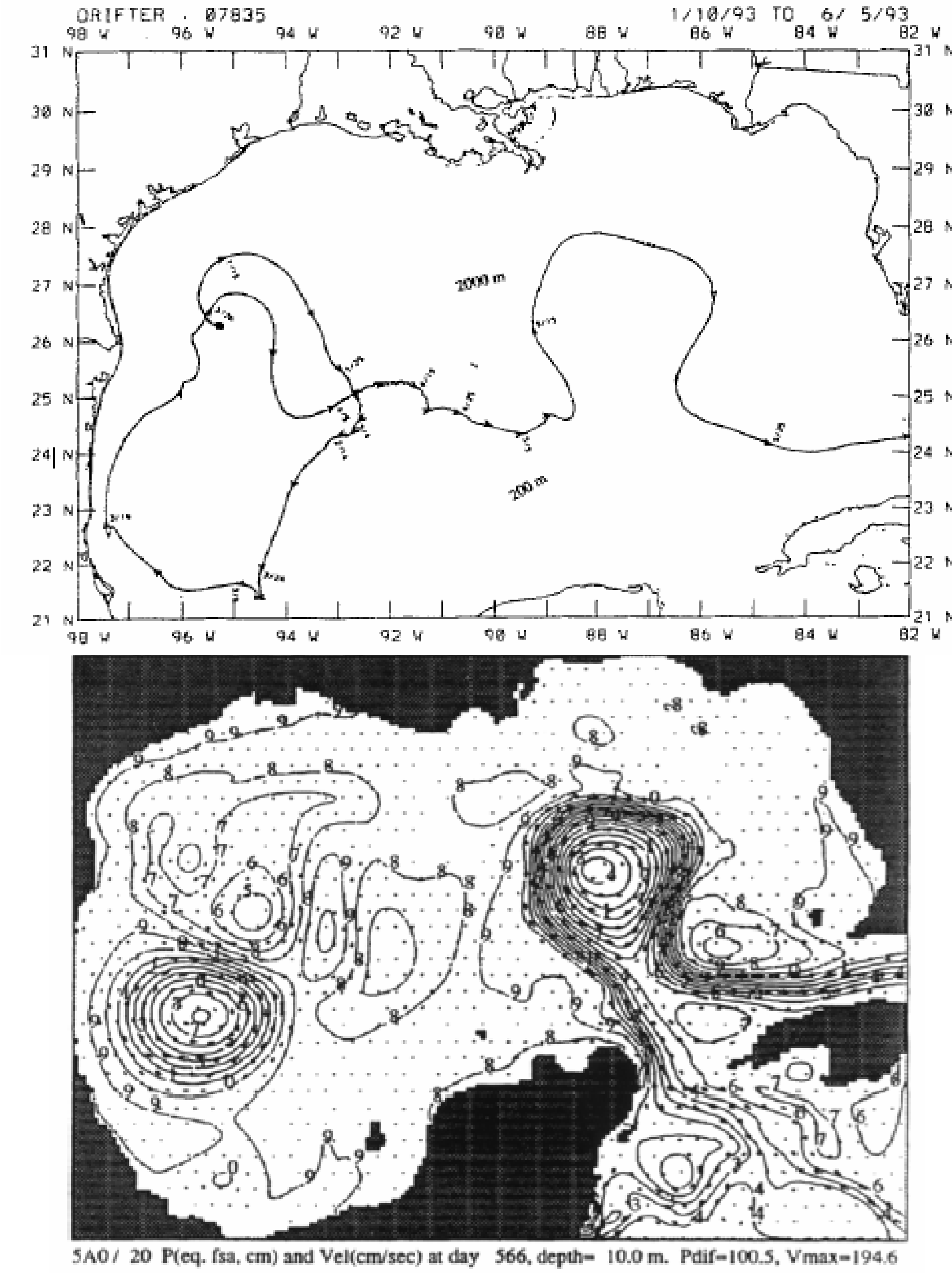




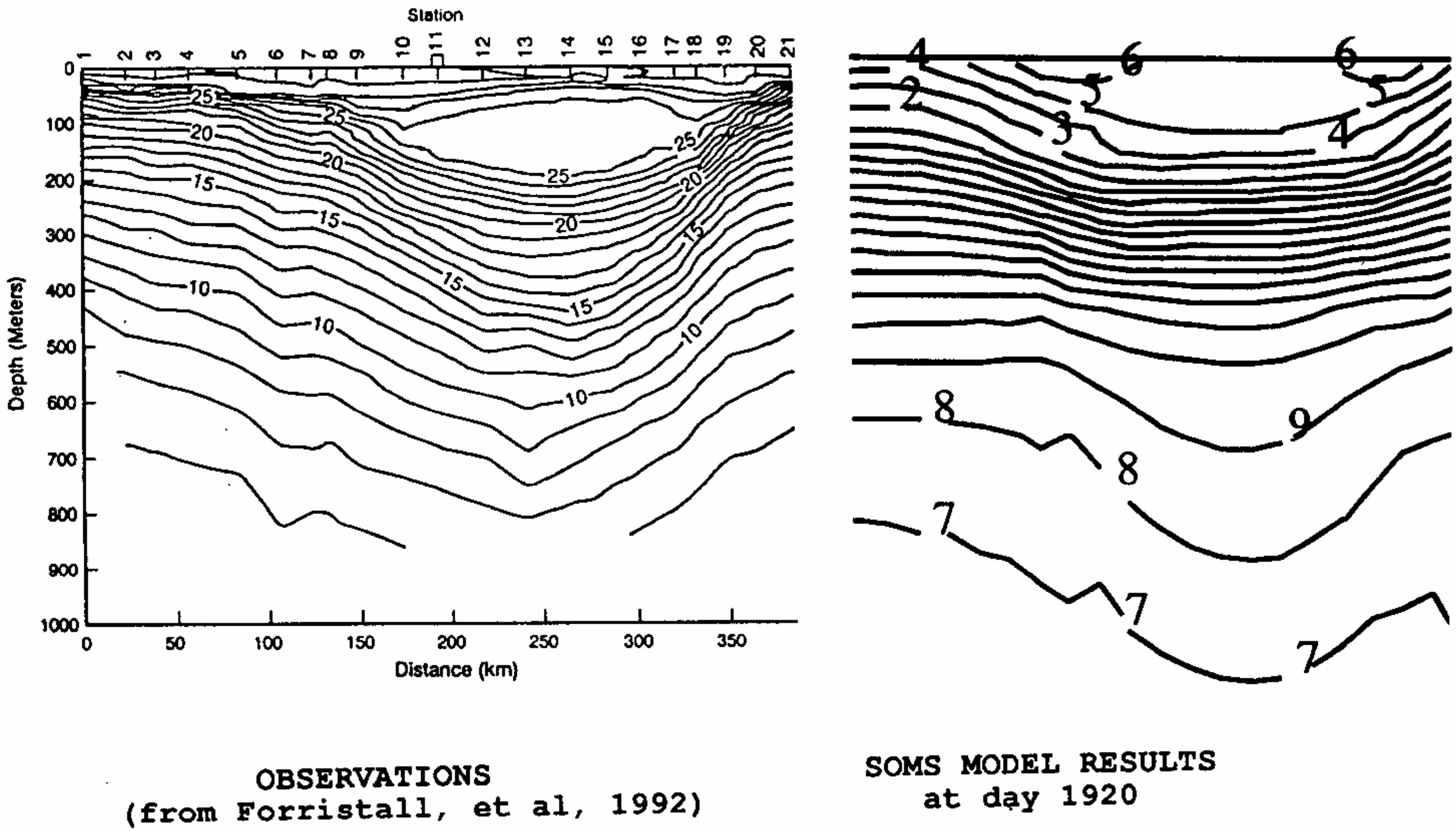
A comparison of the vertical EOF modes of the model (solid) with those derived from observations (dashed). The percent of total variance represented by each EOF mode is given in each panel, with the observations value located above the model value



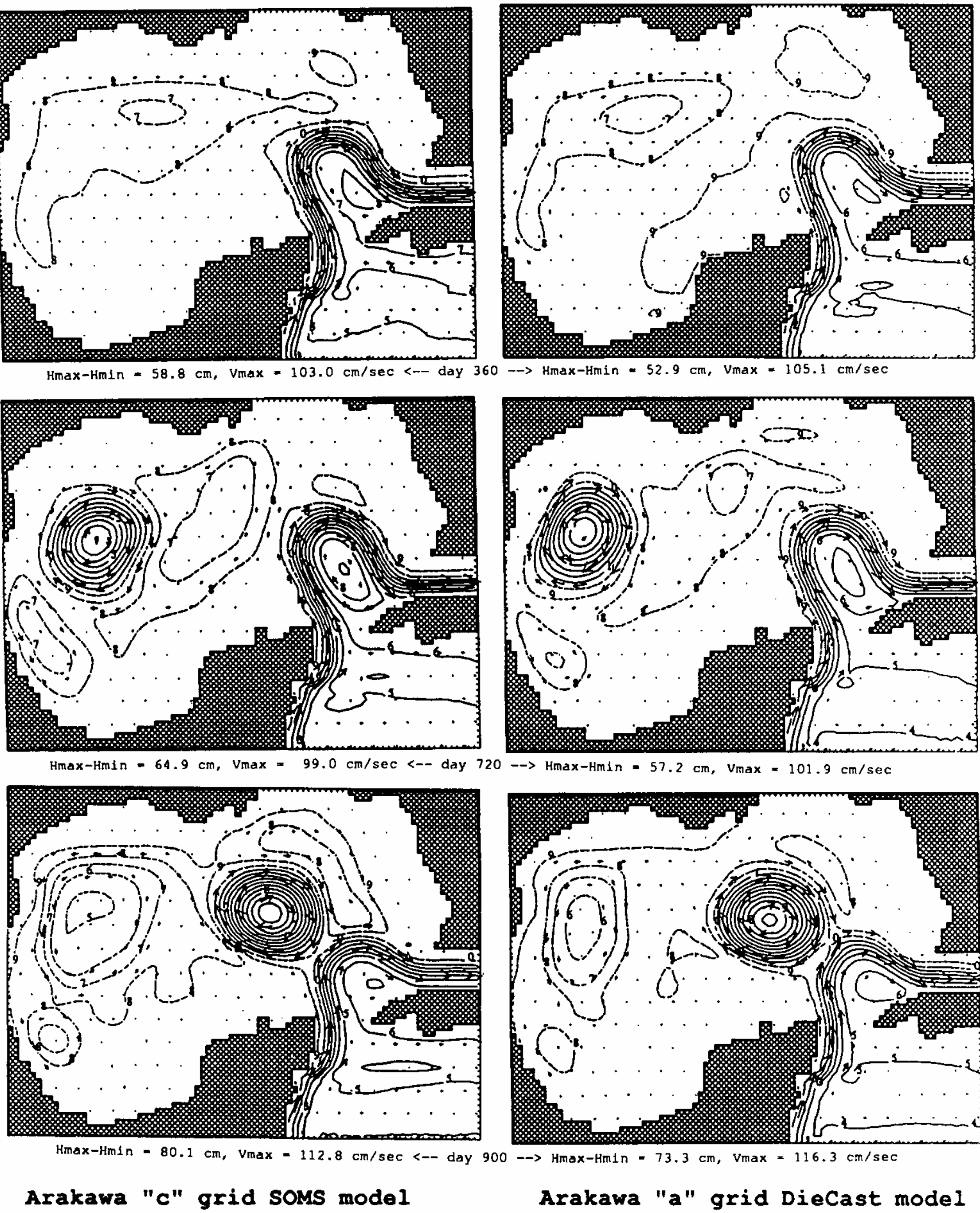
A comparison of model and observed winter time mean horizontally vertical temperature profiles. The standard deviations for both cases are also shown. The full history of available GOM observed profiles is used in this comparison



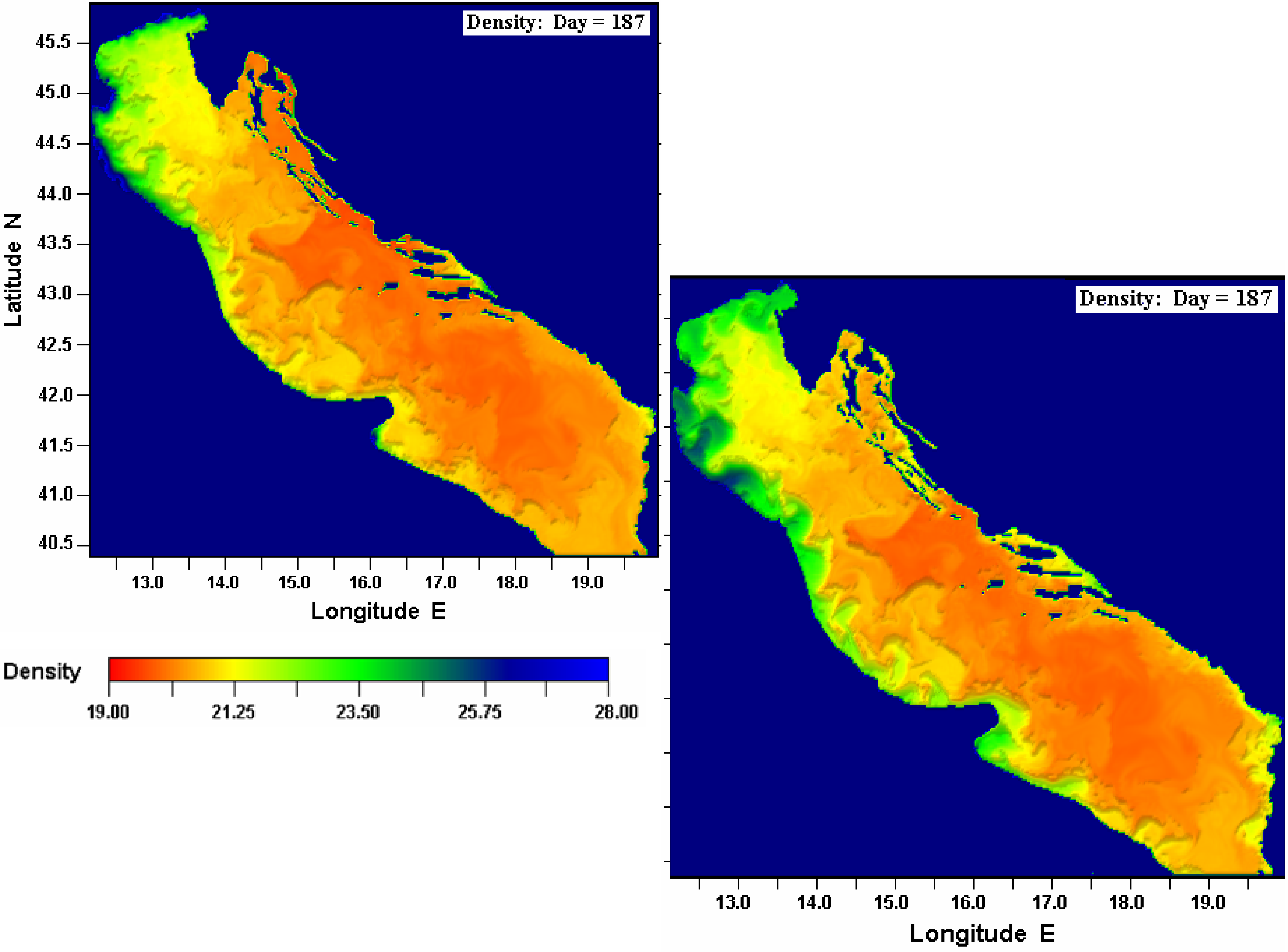
The top panel shows a drifter trajectory (provided by P Hamilton, while the bottom panel shows the top layer model pressure and velocity fields at day 566



Vertical cross-sections of temperature (℃) through a recently shed Loop Current eddy. The observations and model cross-sections have the same vertical and horizontal scales. The observations are from a NE-SW slice through the most thoroughly measured eddy ever. Model results are from a longitudinal-depth cross-section through the Loop Current core. The single-digit contour labels in the model output omit the 10's digit; thus e.g. the "6" isotherm near the top surface represents 26 ℃ while the "7" isotherm near 900 m depth represents 7 ℃.



Intercomparison of two models in the Gulf of Mexico. Rigid-lid pressure (converted hydrostatically to free surface height anomaly) contours and velocity vectors are shown.


Density: Day = 187
Latitude N
45.5
45.0
44.5
44.0
43.5
43.0
42.5
42.0
41.5
41.0
40.5
13.0
14.0
15.0
16.0
17.0
18.0
19.0
Longitude E
Density
19.00
21.25
23.50
25.75
28.00
Density: Day = 187
13.0
14.0
15.0
16.0
17.0
18.0
19.0
Longitude E

MEDiNA model: Bathymetry (km) and sub-domains

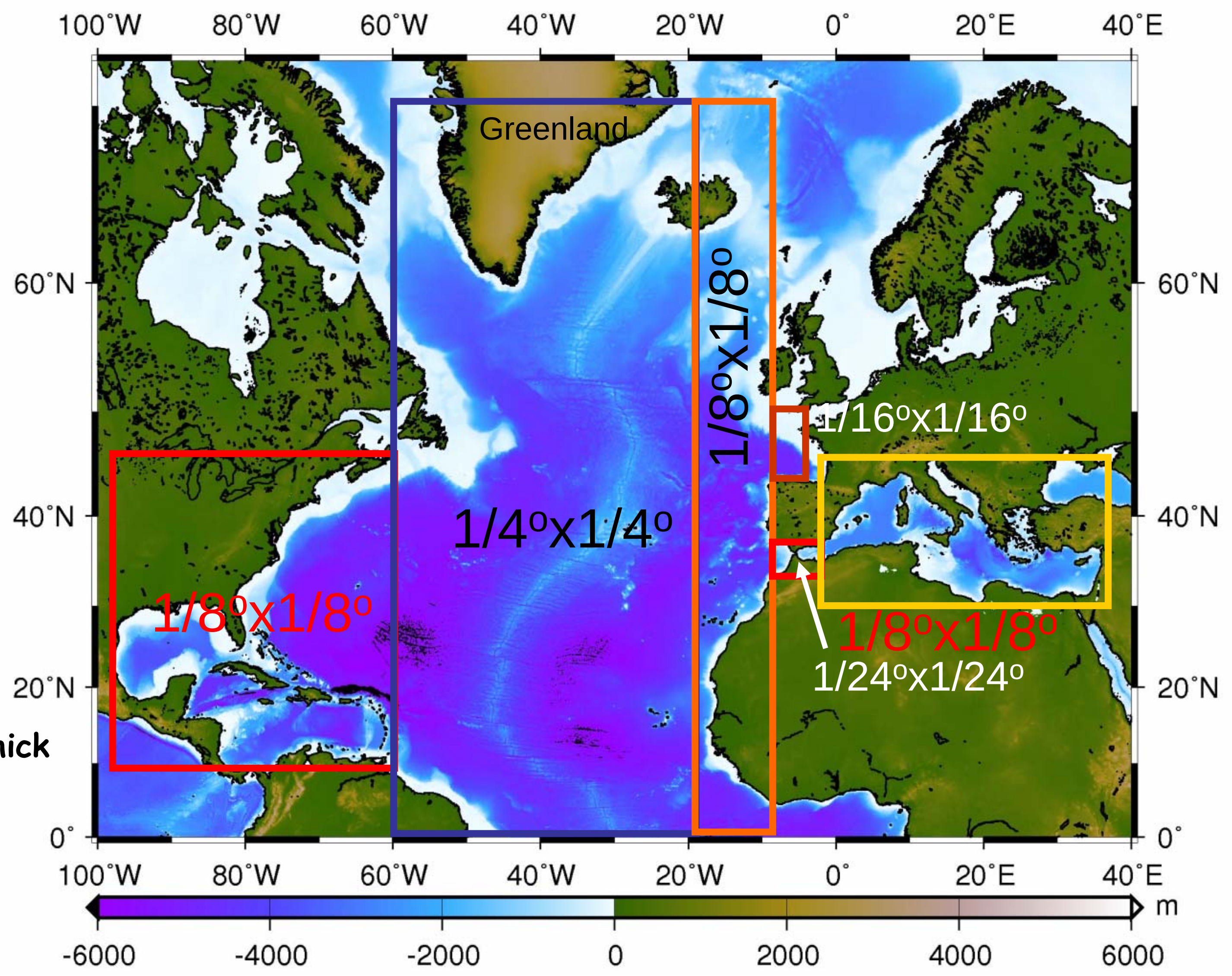
Six domain:

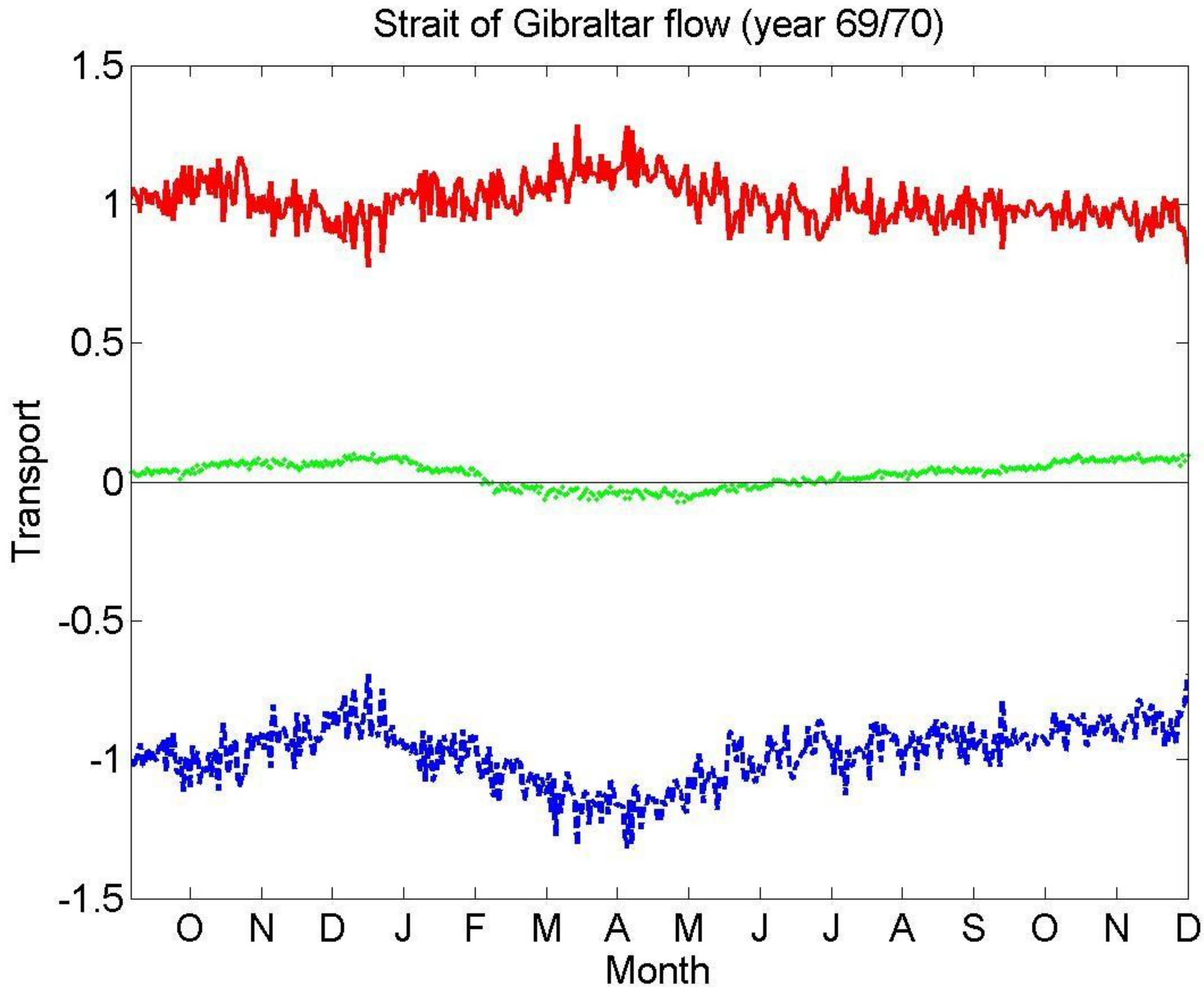
- GOM (1/8°) 304x336
- NAB (1/4°) 162x398
- IBE (1/8°) 100x794
- VIS (1/16°) 60x158
- GIB (1/24°) 125x107
- MED (1/8°) 316x157

30 vertical layers;

top layer 11 m thick;

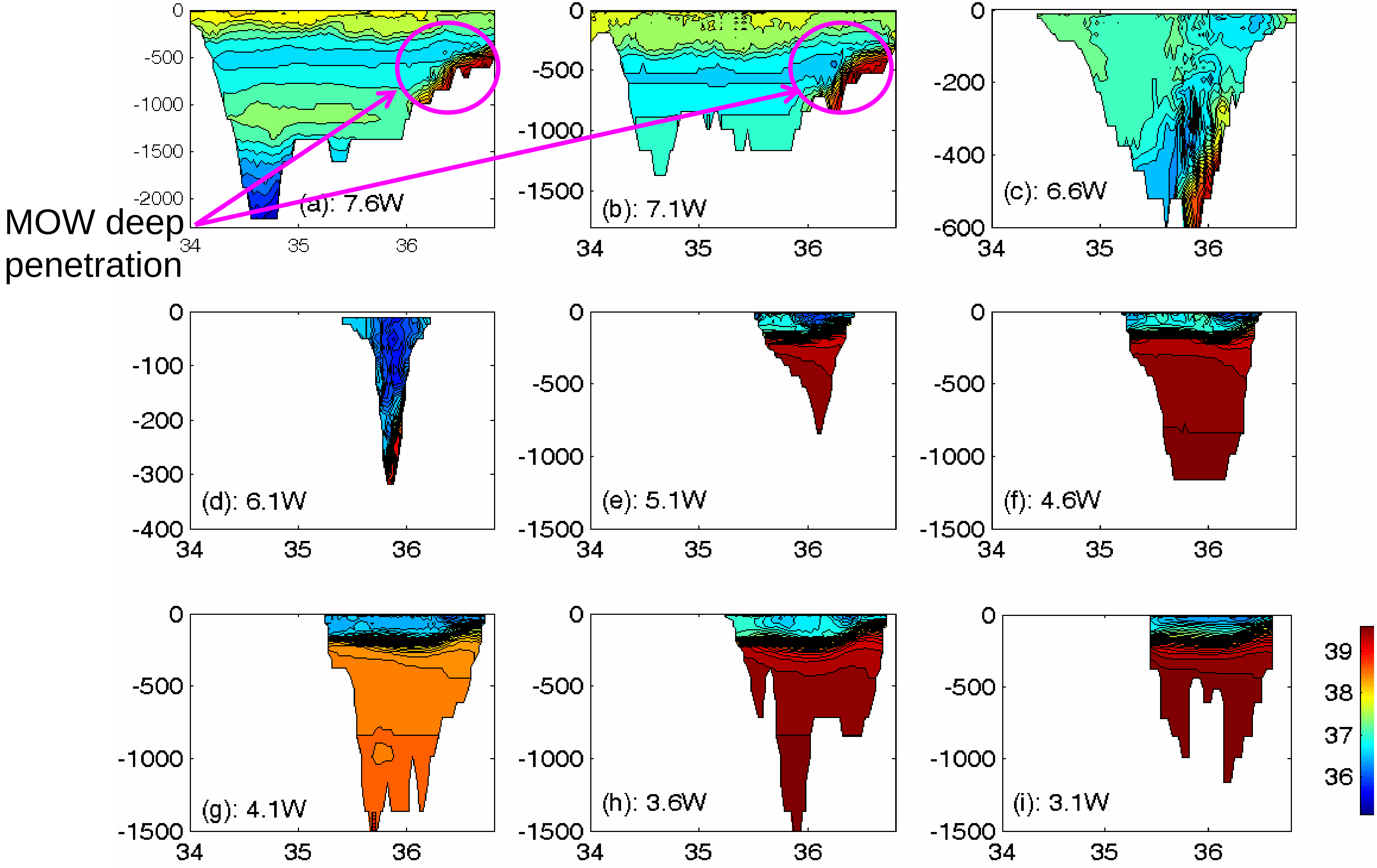
bottom layer 750 m thick



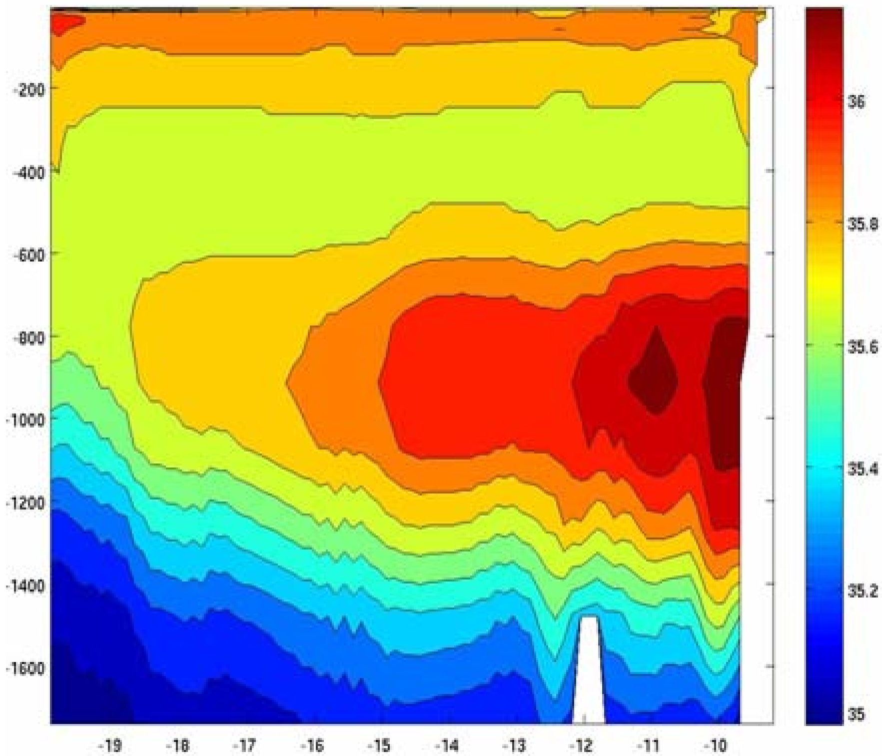


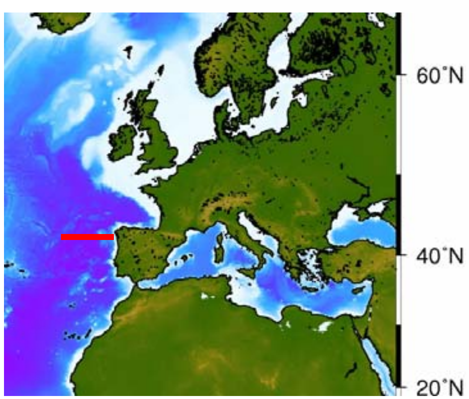
Strait of Gibraltar flow (year 69/70)
1.5
1
0.5
0
-0.5
-1
-1.5
Transport
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
Month

Salinity at different longitudes

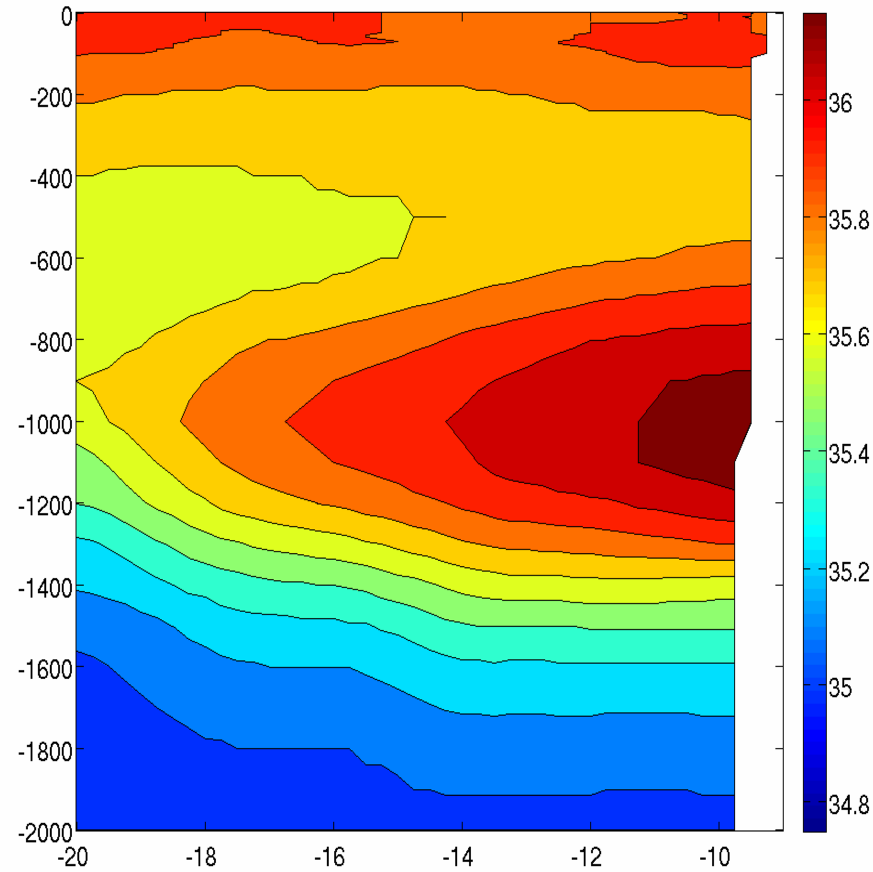


Vertical/longitudinal salinity section at 43°N

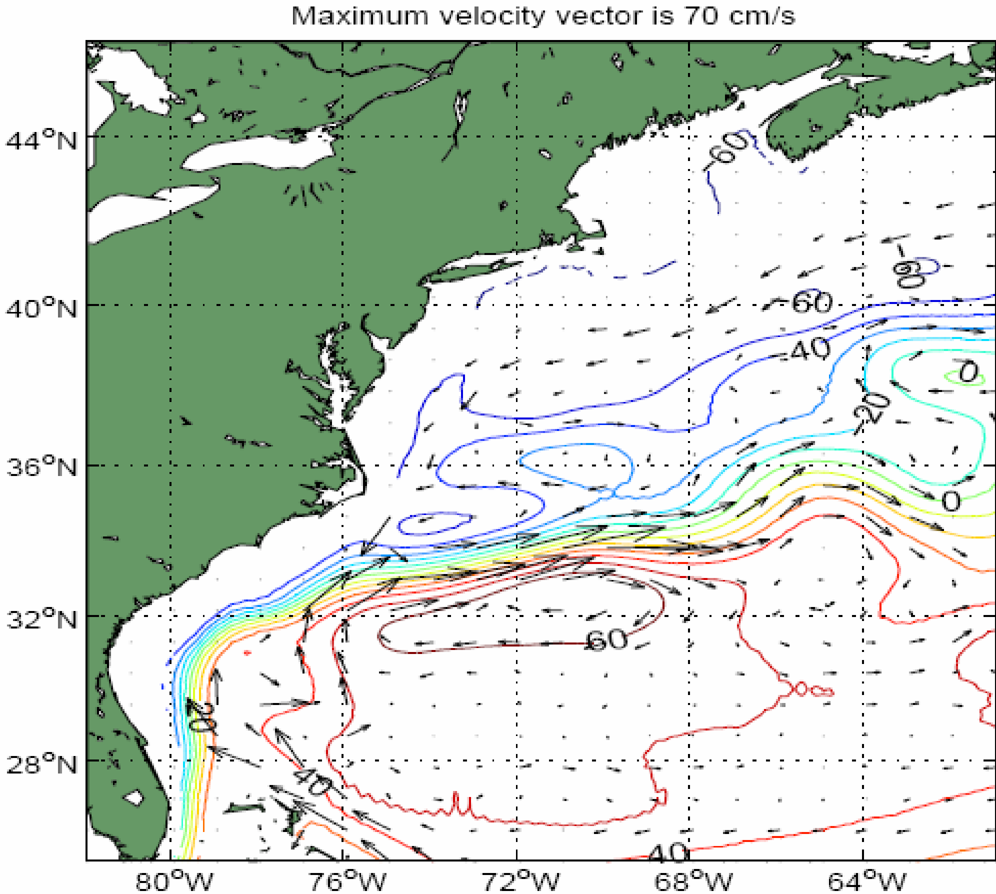


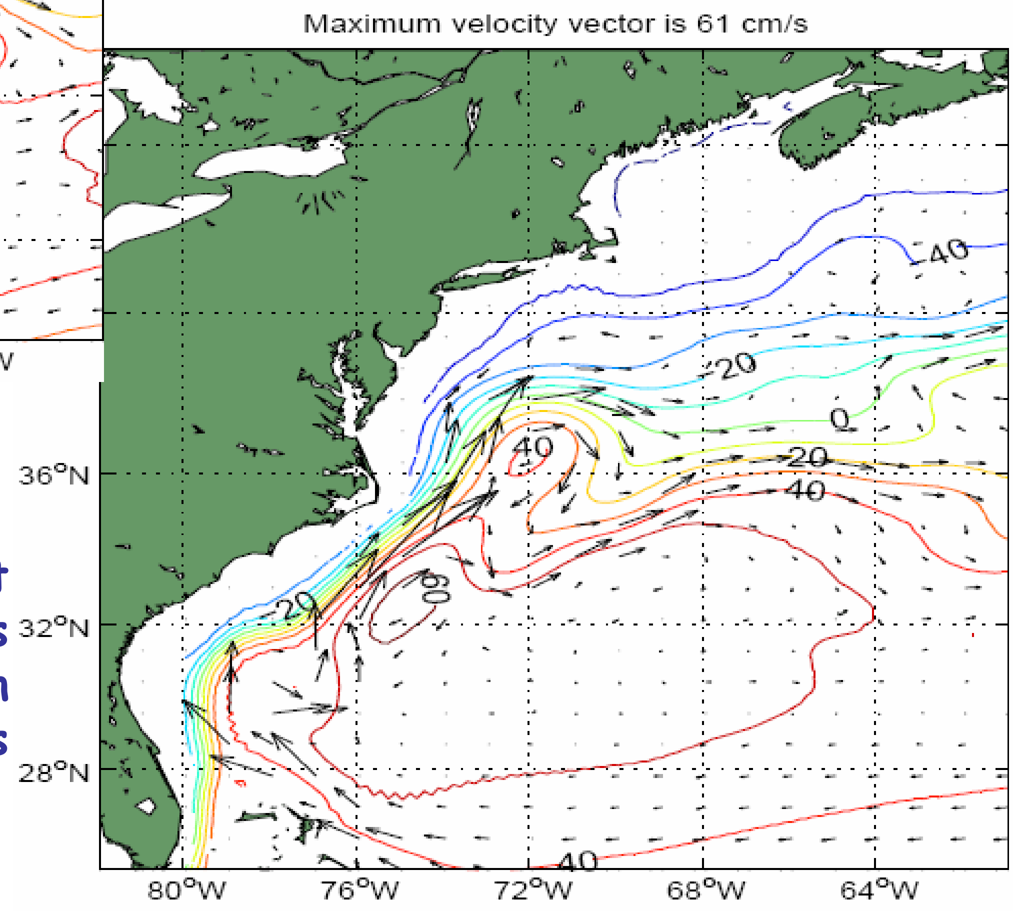


Annual averaged model results

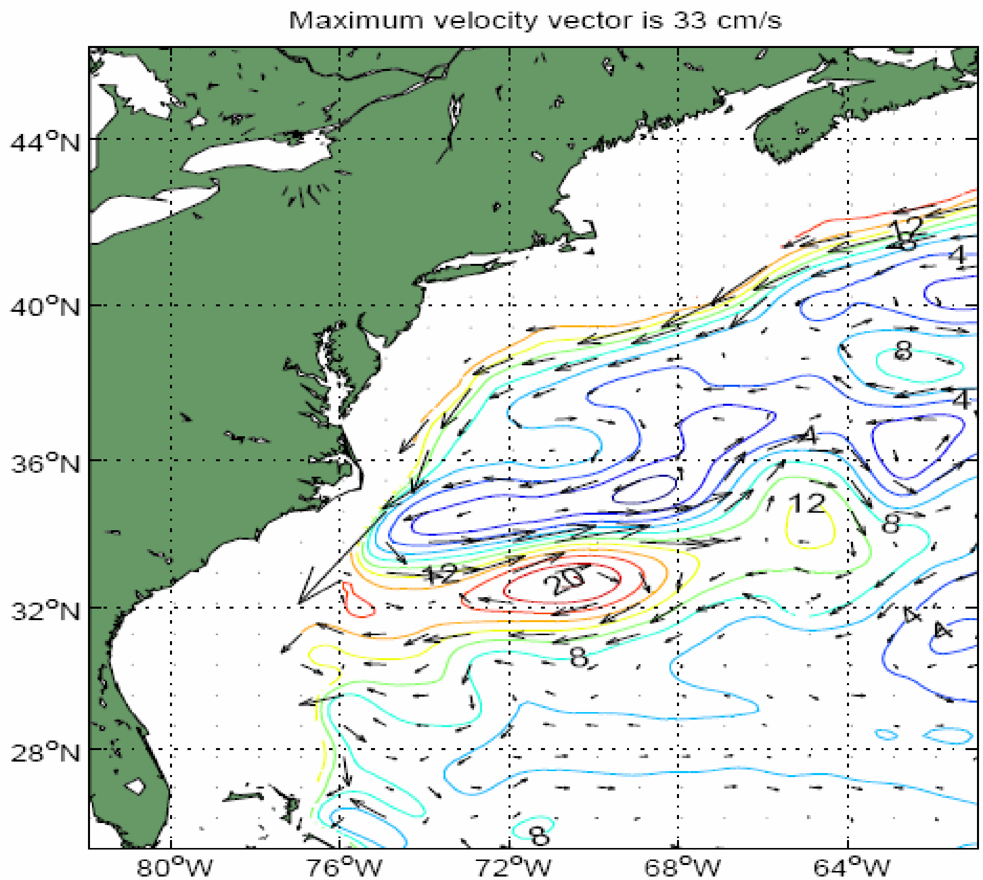


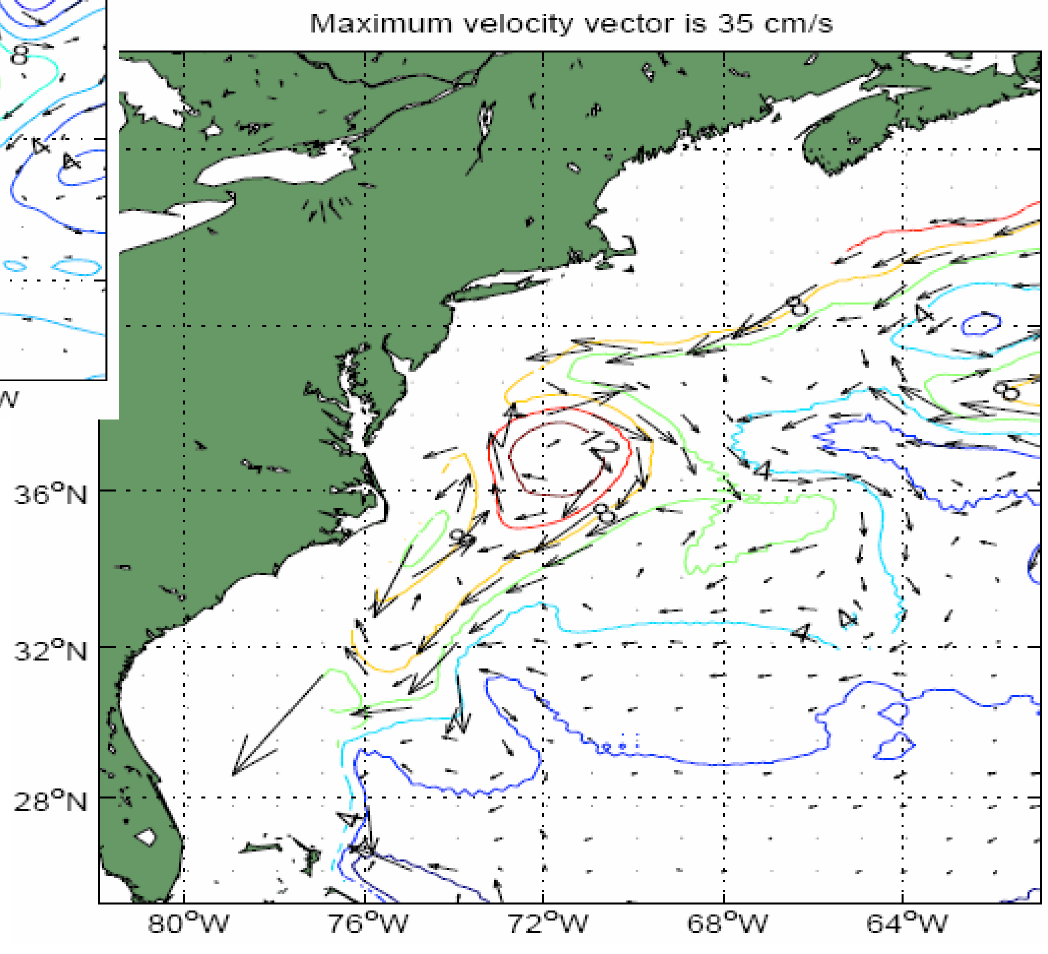
U. S. Navy's GDEM climatology



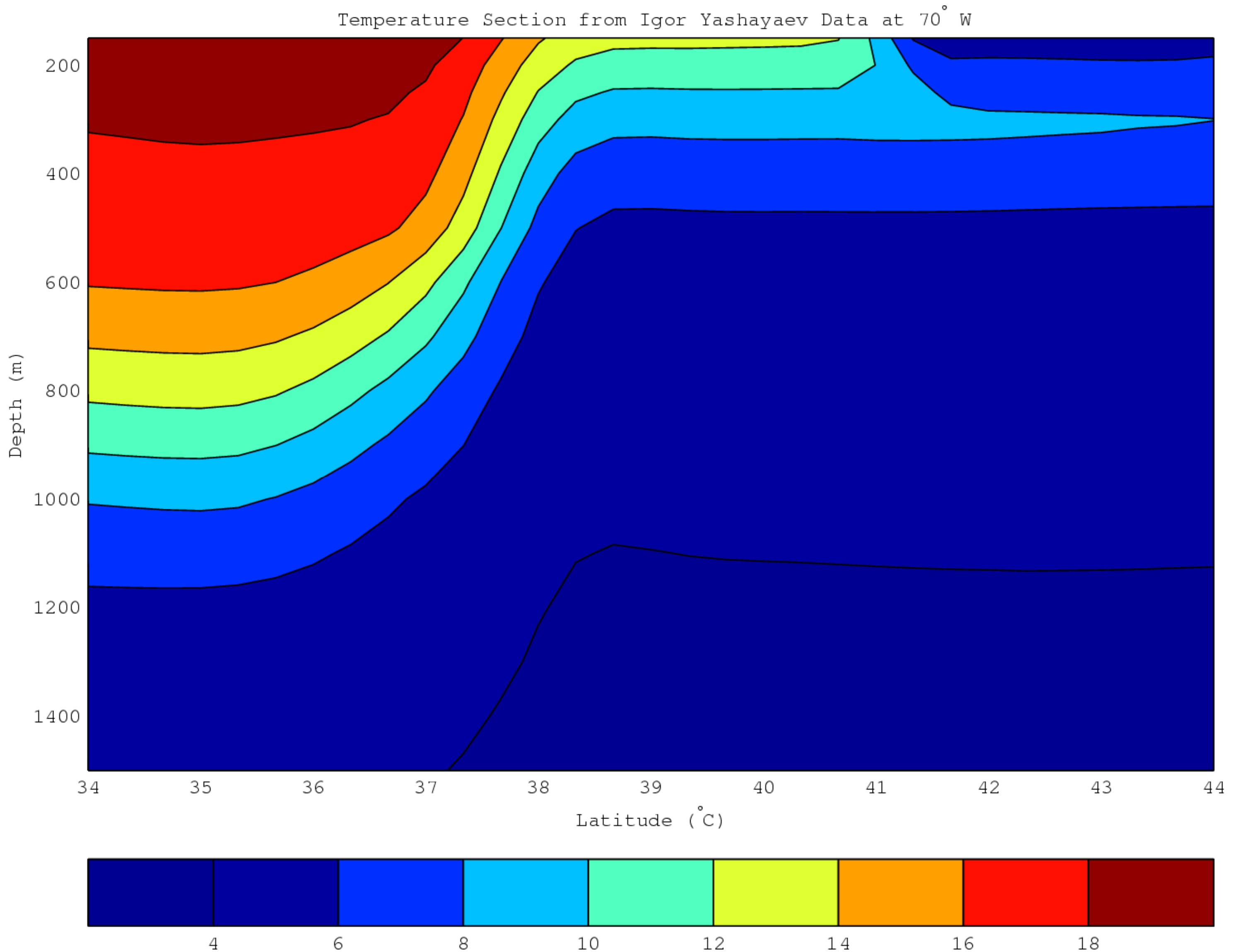


Twenty years mean sea surface height (cm) and 700 m depth velocity vectors in the 1/6 degree resolution western domain. Viscosities are 20 – 60 m^2/s (Top) and 50 – 150 m^2/s (bottom)

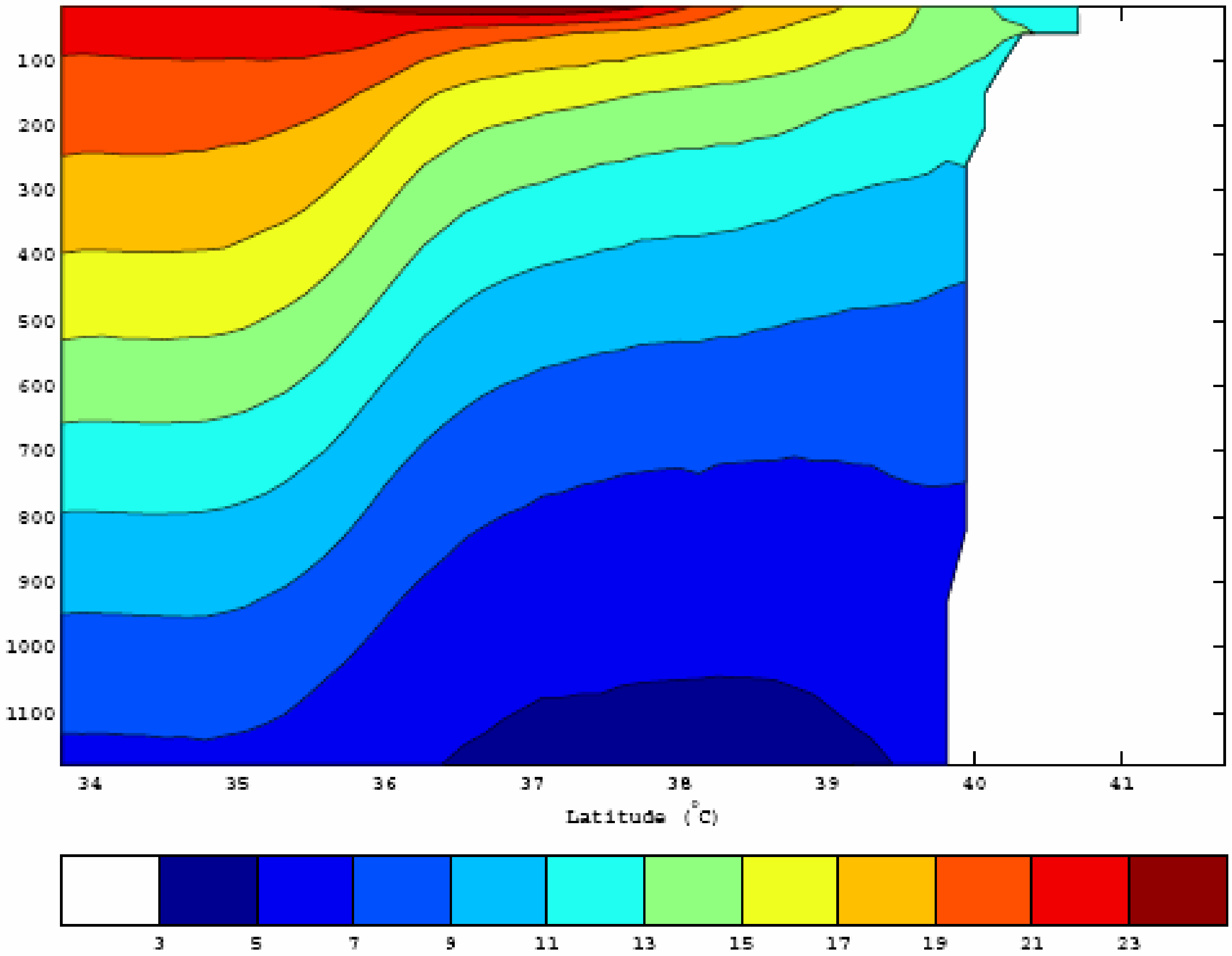




Twenty year mean pressure (cm) and velocity vectors in the 1/6 degree resolution western domain at level 1474m. Viscosities are 20 - 60 m^2/s(Top) and 50 -150 m^2/s(bottom)

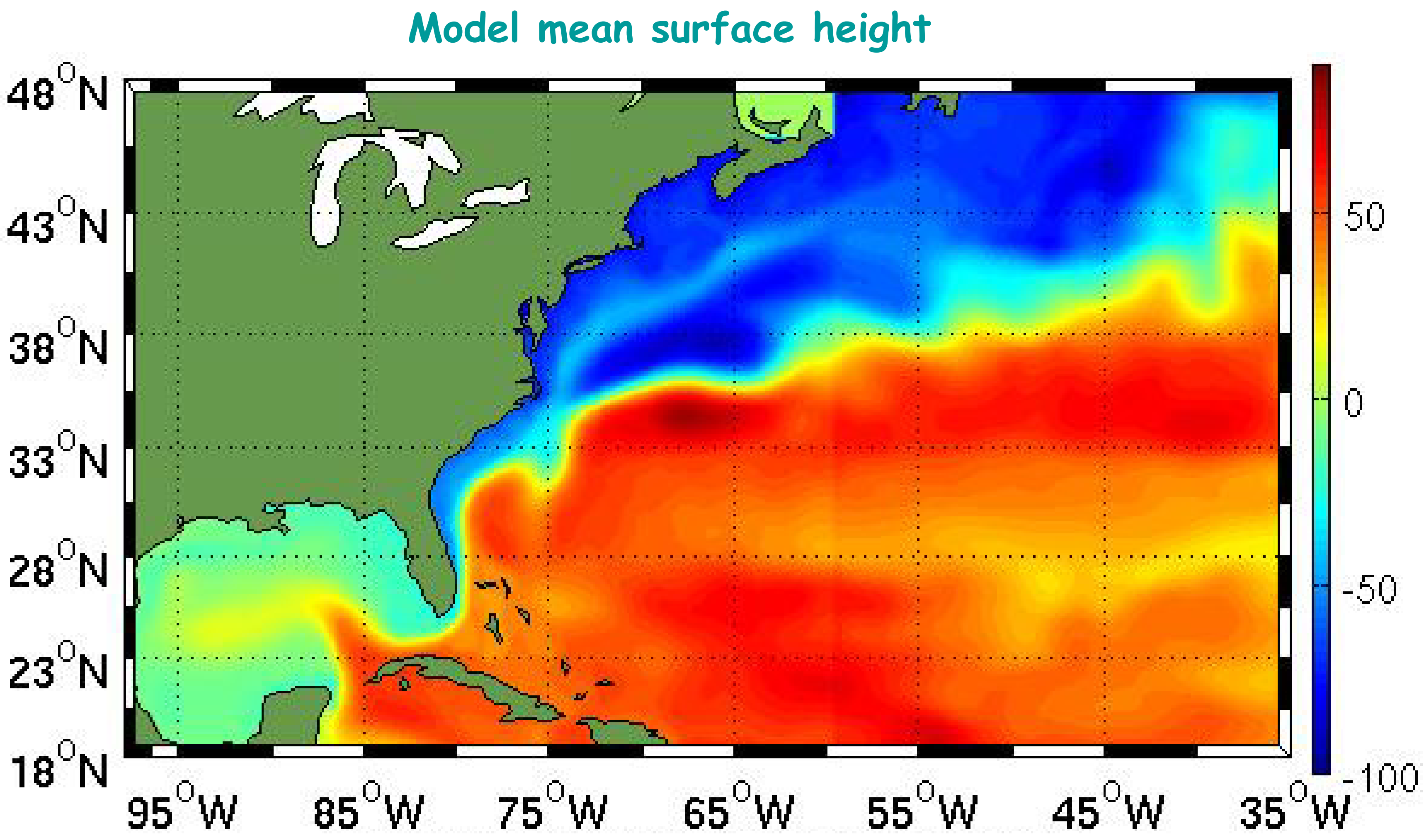


Temperature Section from Igor Yashayaev Data at 70° W
Depth (m)
200
400
600
800
1000
1200
1400
34
35
36
37
38
39
40
41
42
43
44
Latitude (°C)
4
6
8
10
12
14
16
18

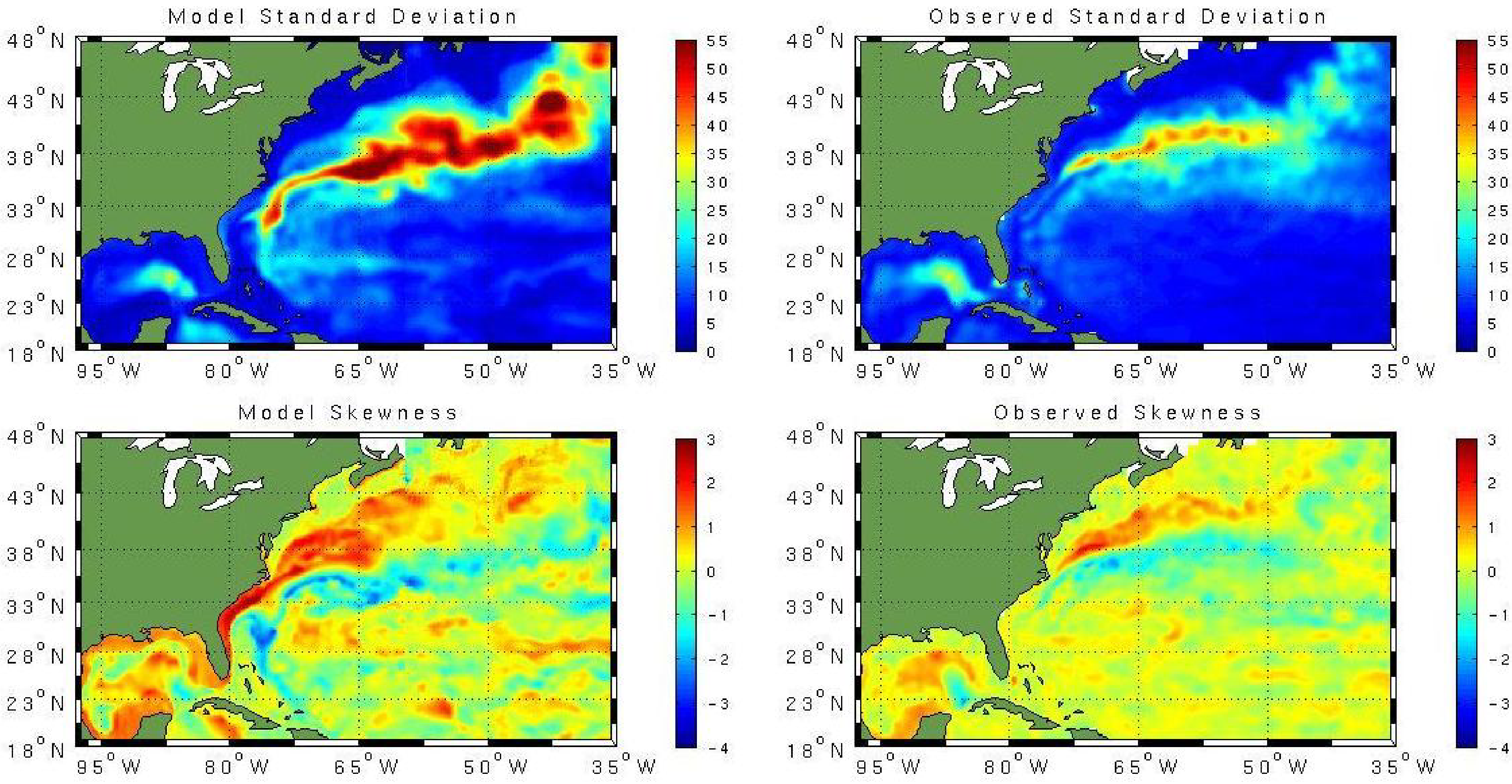


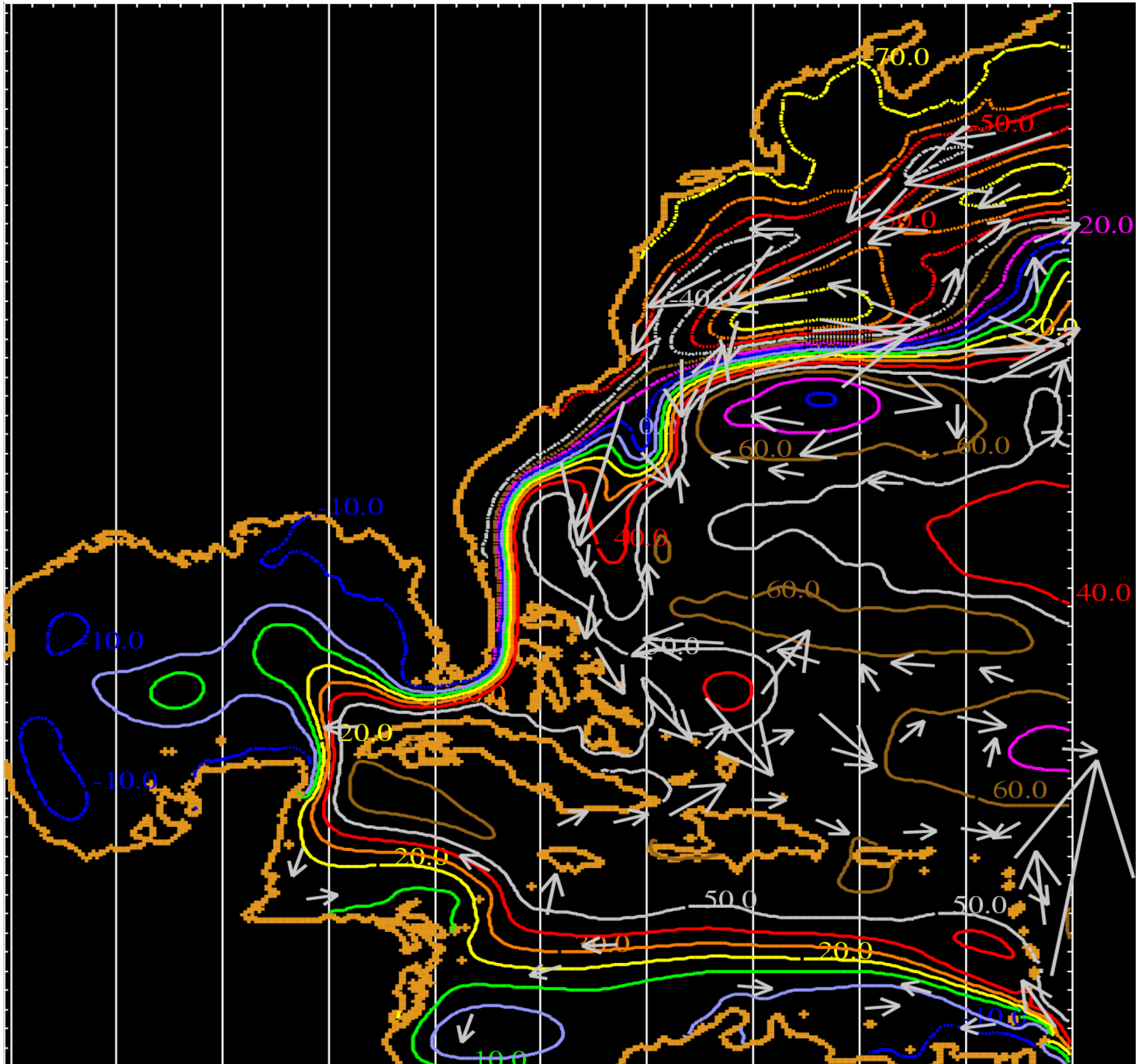
DieCAST vertical cross-section at longitude 70 W of time-averaged temperature (℃)

Low Dissipation Run

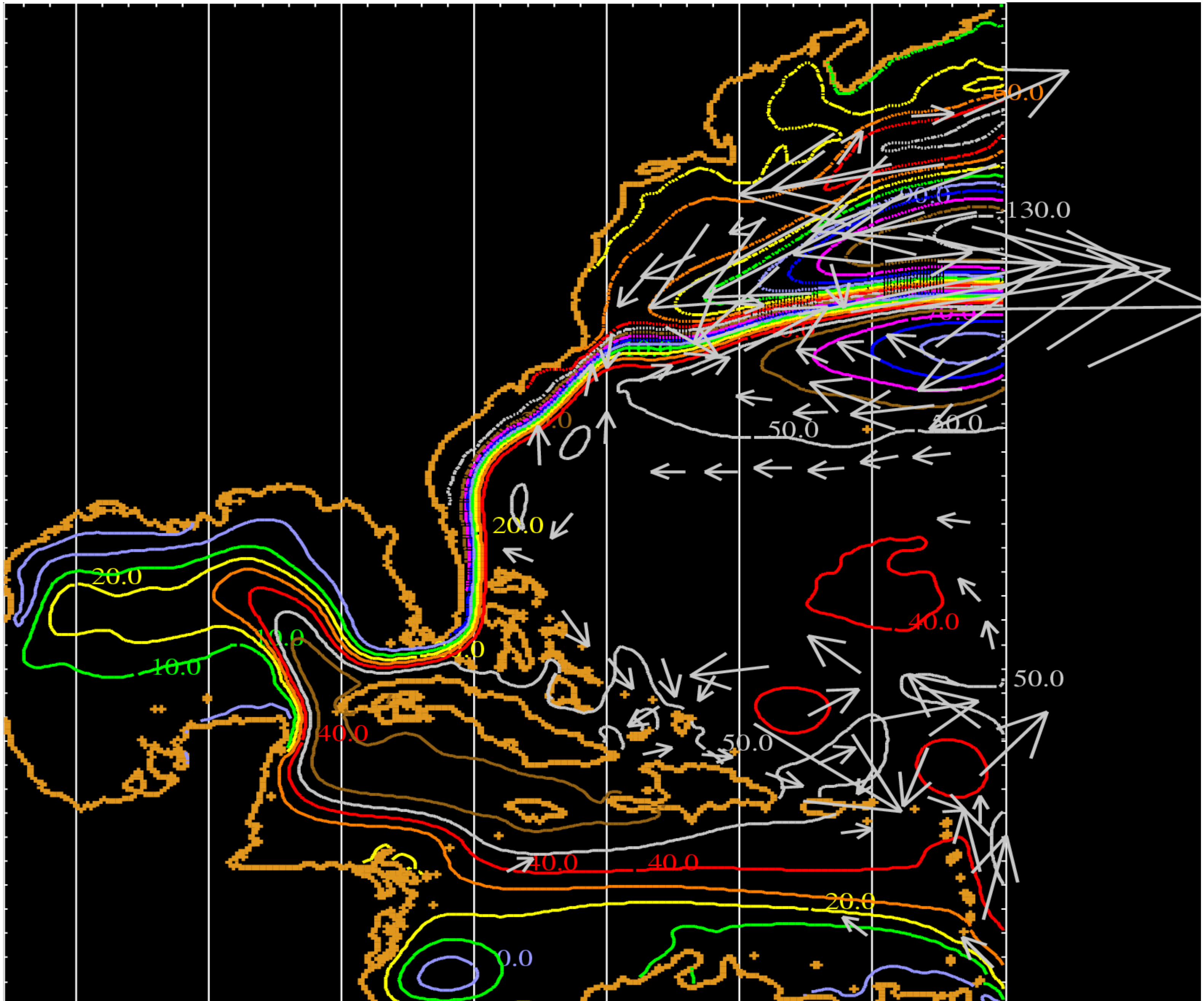


Low Dissipation



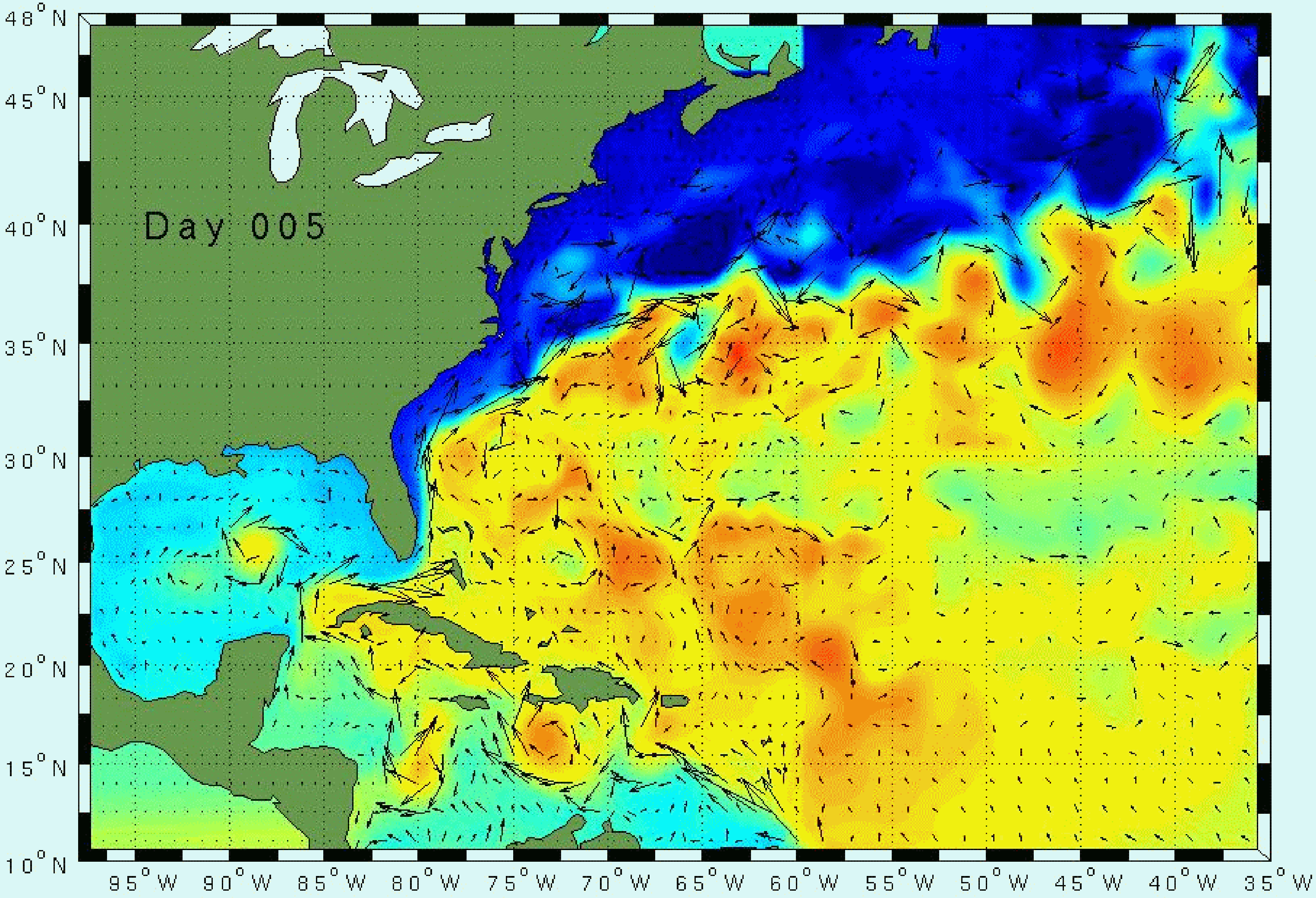


avg h & V@1000m/yr 78. Hmx-Hmn= 161cm, Vmx= 81cm/s



avg h & V@1000m/yr 80. Hmx-Hmn= 233cm, Vmx= 75cm/s

Low Dissipation Animation



CONCLUDING REMARKS

The results shown today from a model in multiple major ocean basin simulations strongly validate the model by comparison with a wide variety of observations. This validation is unambiguous, because no data assimilation is used. This includes amazingly accurate coastal and density current simulation in the framework of a purely z-level model. This shows the model's dynamic similarity to the real ocean, resulting from:

a) realistically low dissipation;

b) low numerical dispersion;

c) fourth-order-accuracy;

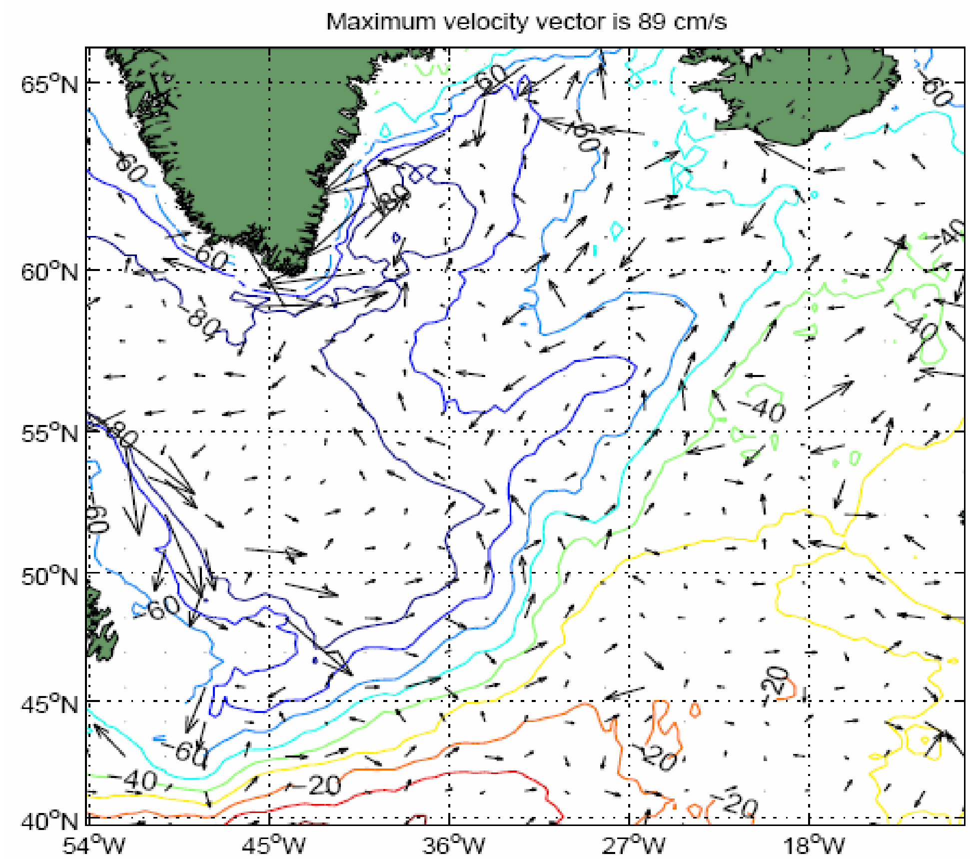
d) using raw unfiltered bathymetry; and

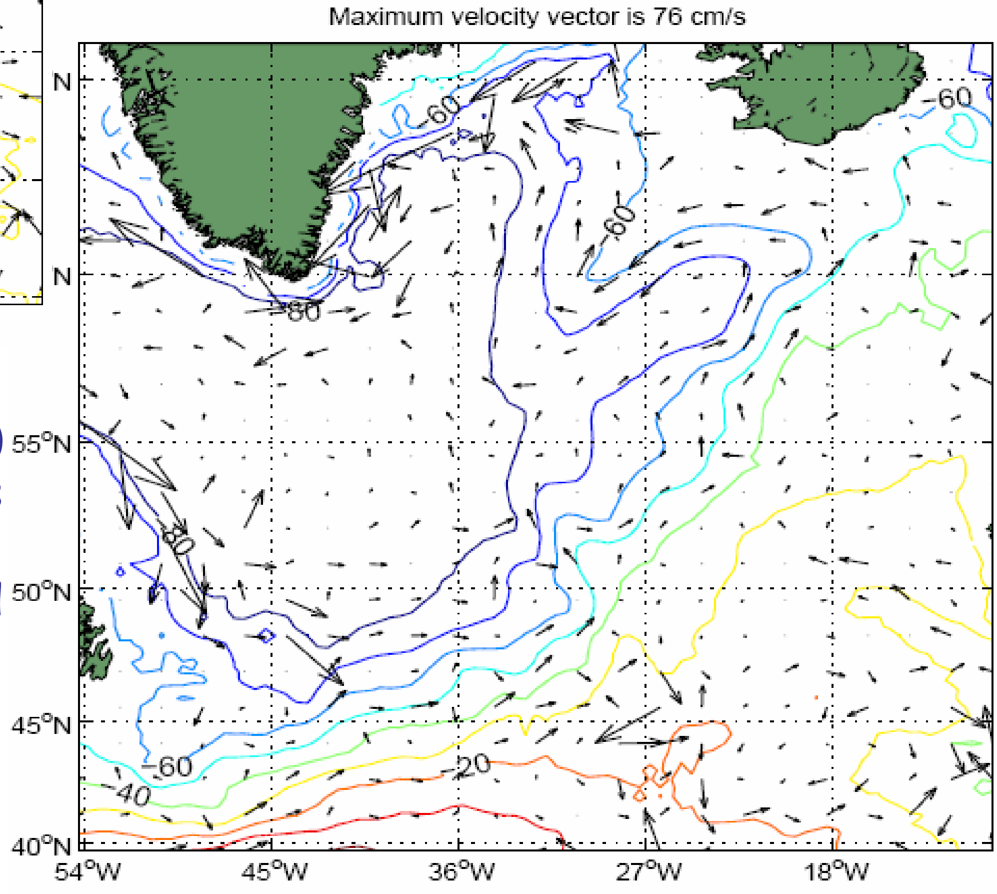
e) avoiding misuse of instant convective adjustment.

Besides the need for low dissipation, the need for accurate boundary conditions in long term simulations (no sponge layers!) is emphasized by model results.

Acknowledgement

The Marcelino Botin Foundation, National Taiwan University and AcuSea, Inc. supported this work. It also benefitted from many useful discussions with Harley Hurlburt, Steve Piacsek, Paul Martin, Bob Haney, Aaron Lai and too many others over the last 20 years to list here.





Twenty years mean surface height (cm) and 700 m depth mean velocity vectors in the Denmark Strait region. Viscosities are 20 – 60 m^2/s (Top) and 50 – 150 m^2/s

Theory, observation and modelling

Strait of Gibraltar domain

Western Alboran Gyre (WAG)

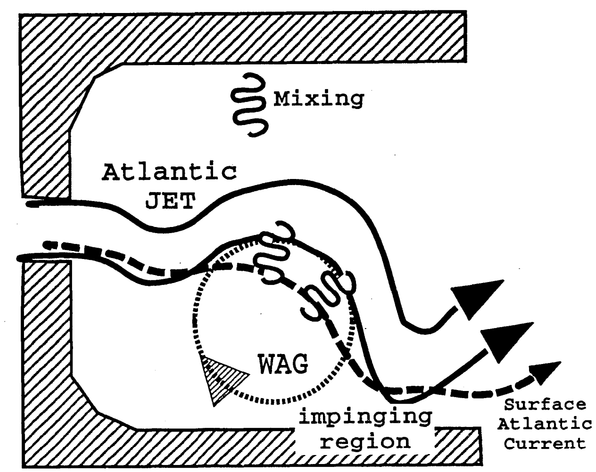
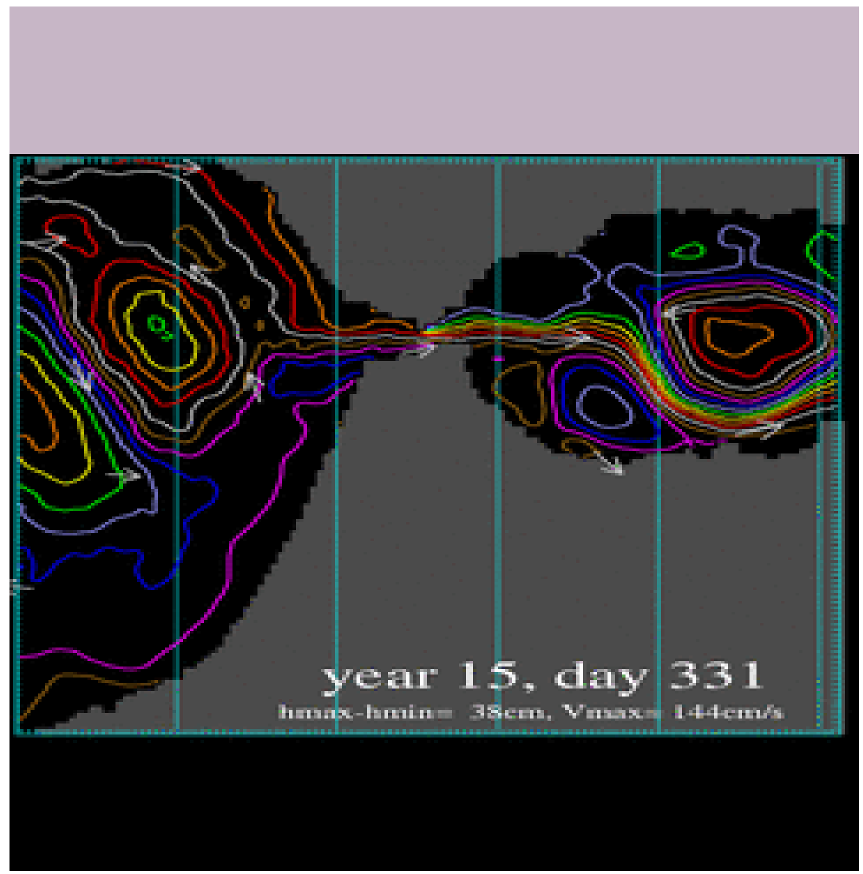
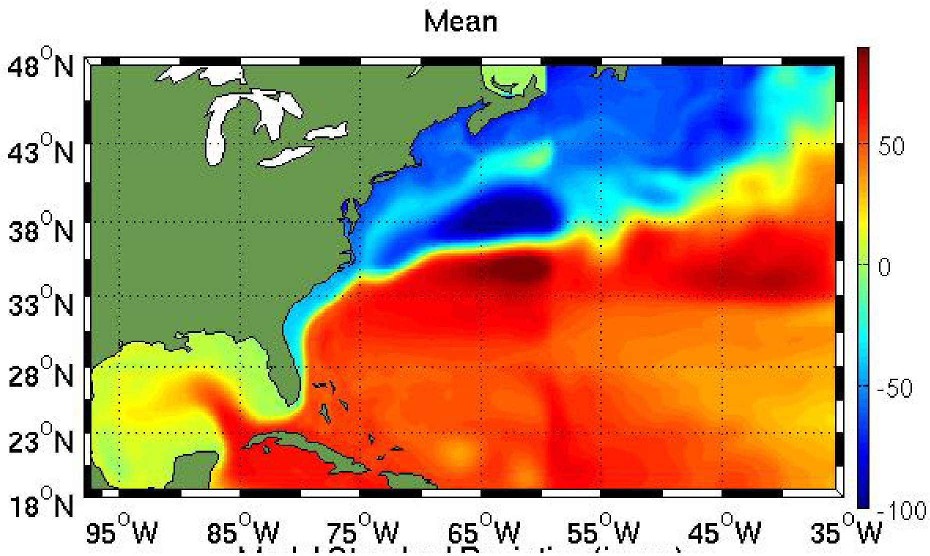


Figure 3. Sketch of the upper circulation (0-200 m) in the western Alboran basin. The surface Atlantic current, characterized by a salinity minimum, may enter into the western Alboran gyre (WAG) crossing the isolines of dynamic height anomaly produced by the deeper density gradients of the gyre. After mixing briefly with water in the core of the WAG, this surface Atlantic current leaves the WAG through the impinging region on the African coast.

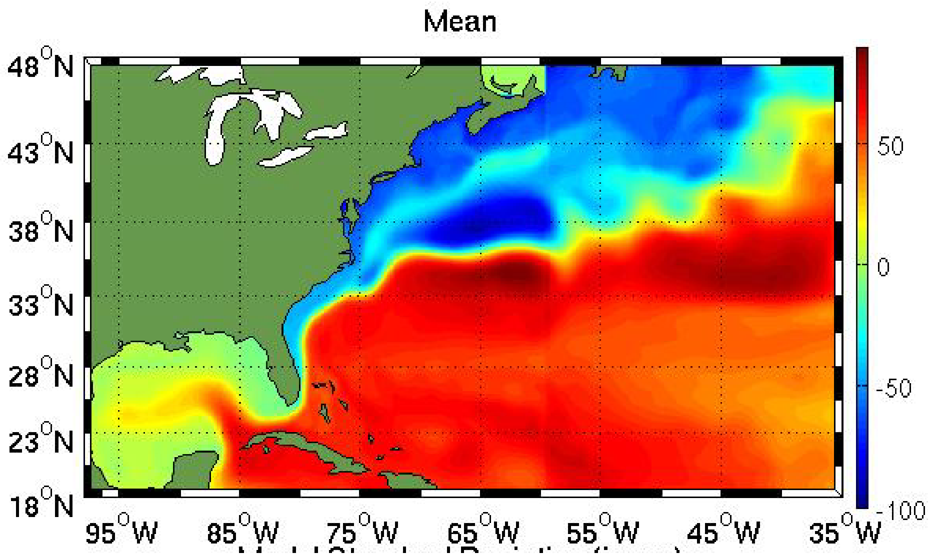
Viúdez, Pinot and Haney (1998)



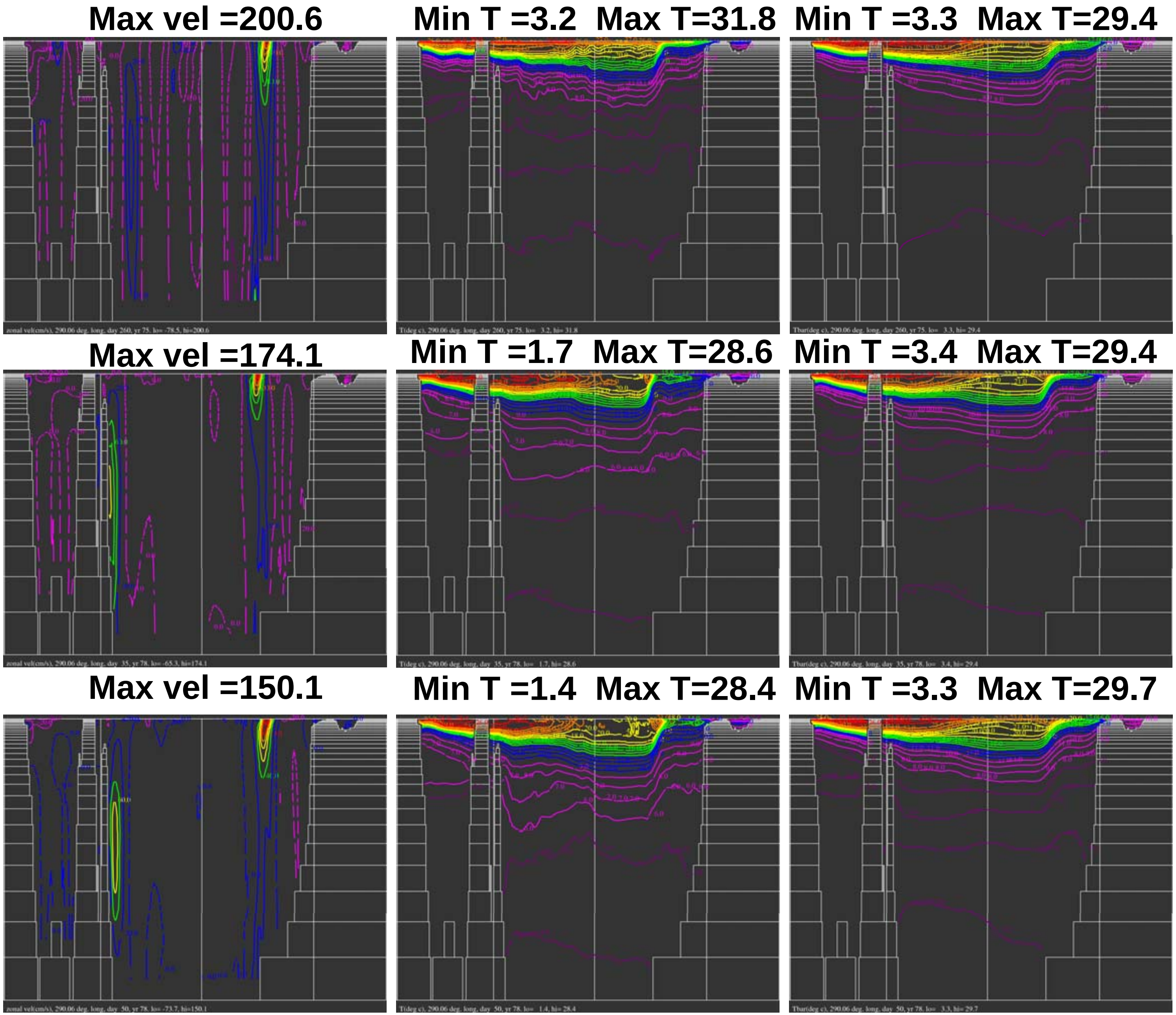
Moderate Dissipation Mean



High Dissipation Mean



	U velocity	Temperature	Time avgT
Low dissipation			
Medium dissipation			
High dissipation			



Abstract

Increasing HORIZONTAL eddy viscosity and diffusivity to parameterize baroclinic eddies increases isopycnal slopes between the GS and shelfslope density current, and reduces the observed isopycnal flattening that is important in nonlinear baroclinic eddy equilibration. However, unresolved internal waves may mix horizontal momentum VERTICALLY faster than implied by conventional vertical eddy viscosity (Polzin, et al., 2007) while giving less watermass mixing unless they break. Here, we explore using MUCH bigger than conventional VERTICAL eddy viscosity -- in the framework of a coupled Mediterranean Sea and North Atlantic Ocean model that is well validated by amplitudes and distributions of 2nd and 3rd moments of surface height compared to satellite altimetry, and by its accurate simulation of Mediterranean Overflow Water depth penetration and associated density current -- while using much smaller vertical eddy diffusivity to maintain the observed thin pycnocline. Vertical viscosity affects vertical transport of horizontal momentum and thus also vortex stretching by kinematic conditions at the bottom and dissipation by bottom drag.

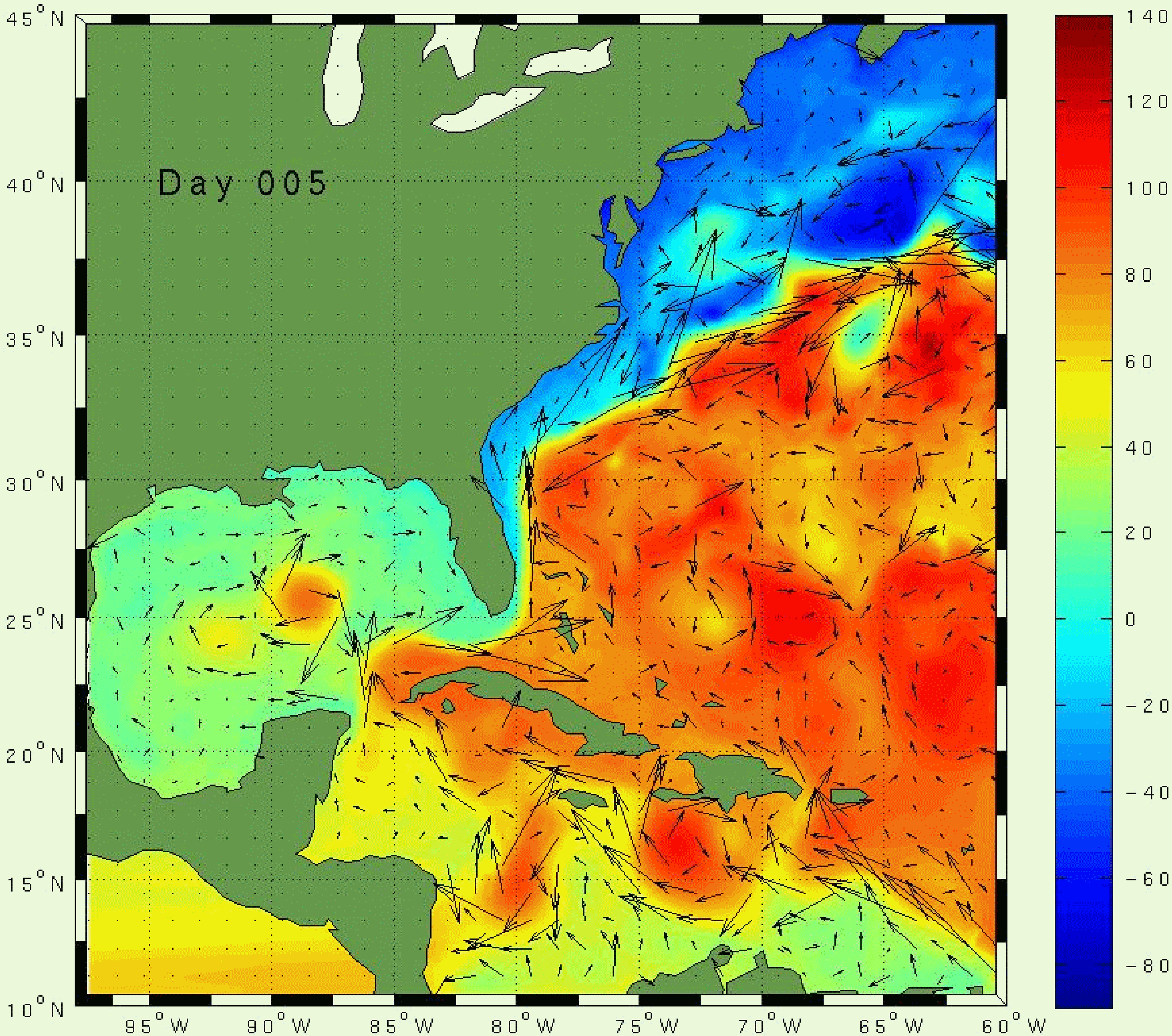
MODEL USED IN THIS OCEAN-MODEL-BASED STUDY

• The hydrostatic version of the DieCAST ocean model used in this study is a z-level model using 4th-order-accurate approximations and a reduced dispersion incompressibility algorithm on a semi-collocated control volume grid.

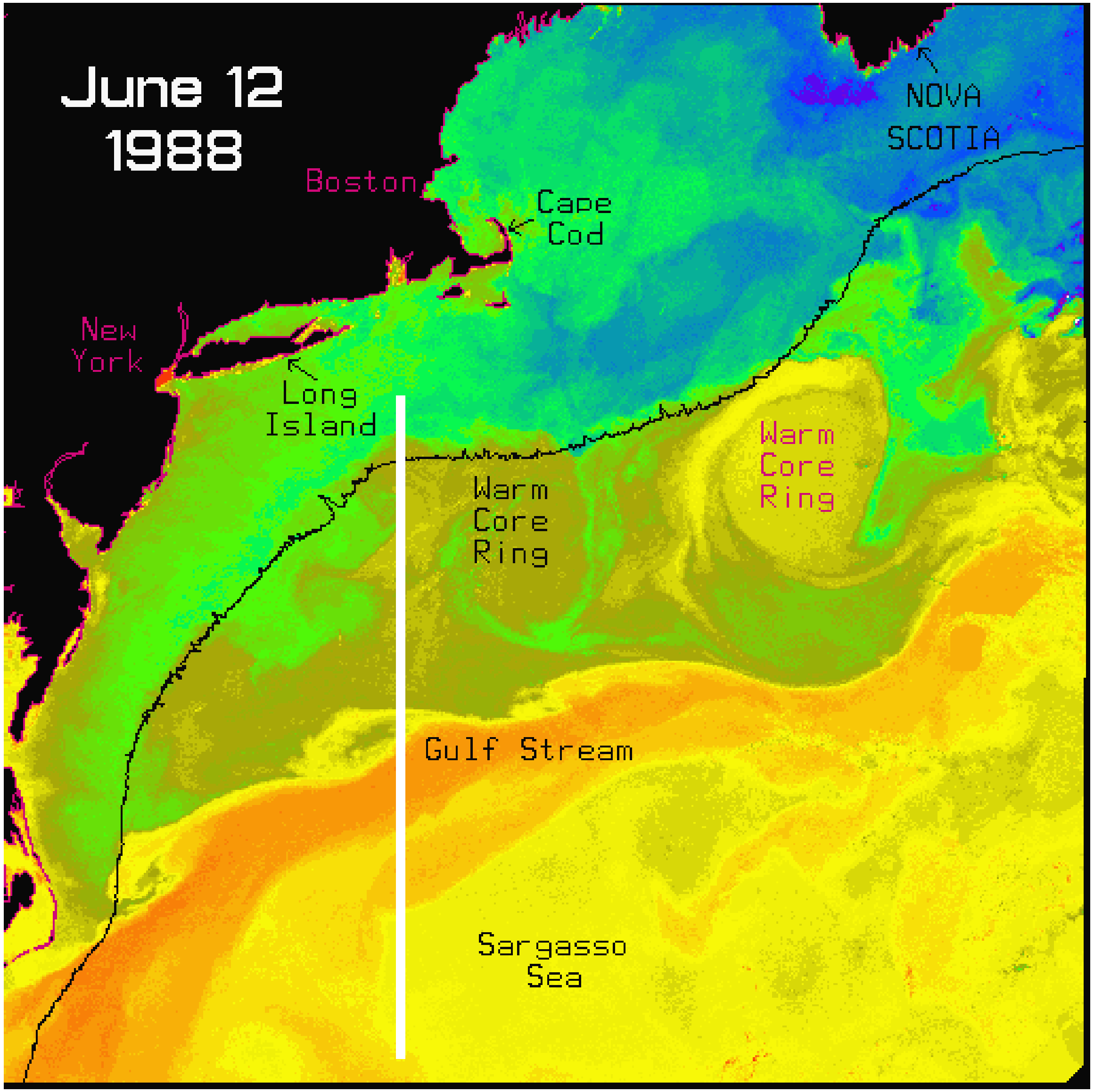
• Multiple-grid coupling technique (the resolution ranges from 1/24° to 1/4°). -NEW!

• MEDiNA model: preliminary results through year 20. Simulations were performed on a Dell 2.0 gigahertz P4 PC.

• Multi-domain Parallelization is currently underway



Day 005
45° N
40° N
35° N
30° N
25° N
20° N
15° N
10° N
95° W
90° W
85° W
80° W
75° W
70° W
65° W
60° W
140
120
100
80
60
40
20
0
-20
-40
-60
-80



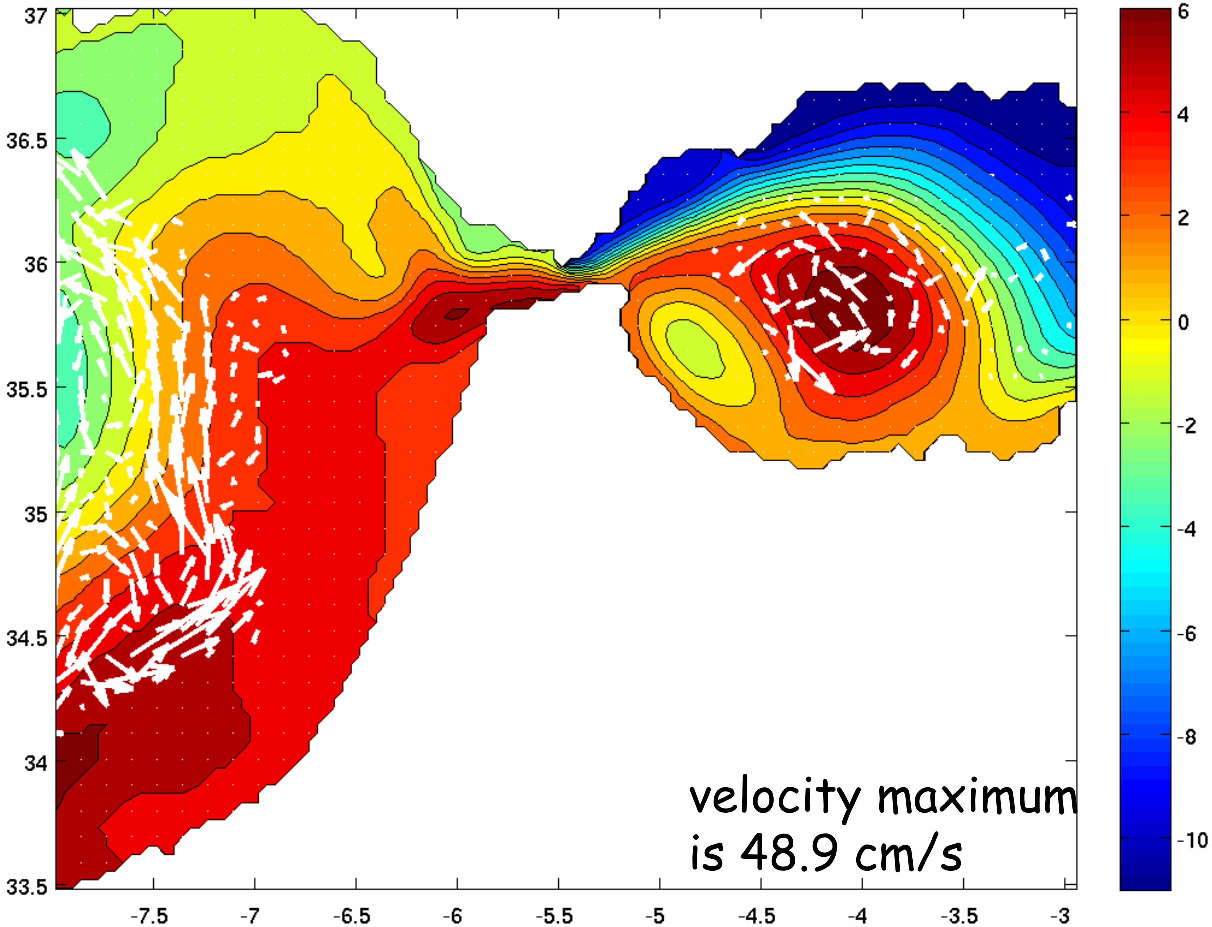
The core of the Gulf Stream ranges between 25 and 28 deg C. The yellow water south of the stream is ~ 23 deg C and the green water off Long Island is ~ 14 deg C. The blue water around Nova Scotia is ~ 5 deg C. The black line is the 1000 m isobath. The white line is located at 72°W (courtesy Amy Schubert and Peter Cornillon, URI).

Model Setup

- Semi-enclosed basin with restoring to watermass climatology near latitudinal boundaries;
- fully-two-way-coupled multiple-grid (6 grids) approach;
- a new approach to develop and apply annual cycle surface heat and freshwater fluxes giving ENSEMBLE annual cycle surface conditions close to climatology;
- Unfiltered etopo5 bathymetry with DAMEE and Strait of Gibraltar upgrades;
- Hellerman annual cycle wind forcing;
- Levitus climatology initial conditions;
- Yashayaev surface climatology for surface heat and freshwater fluxes;
- An artificial shelf along closed northern boundaries to avoid unphysical vortex stretching caused by conventional vertical wall approach;
- laminar background viscosity and vertical diffusivities;

Theory, observation and modelling

Strait of Gibraltar domain

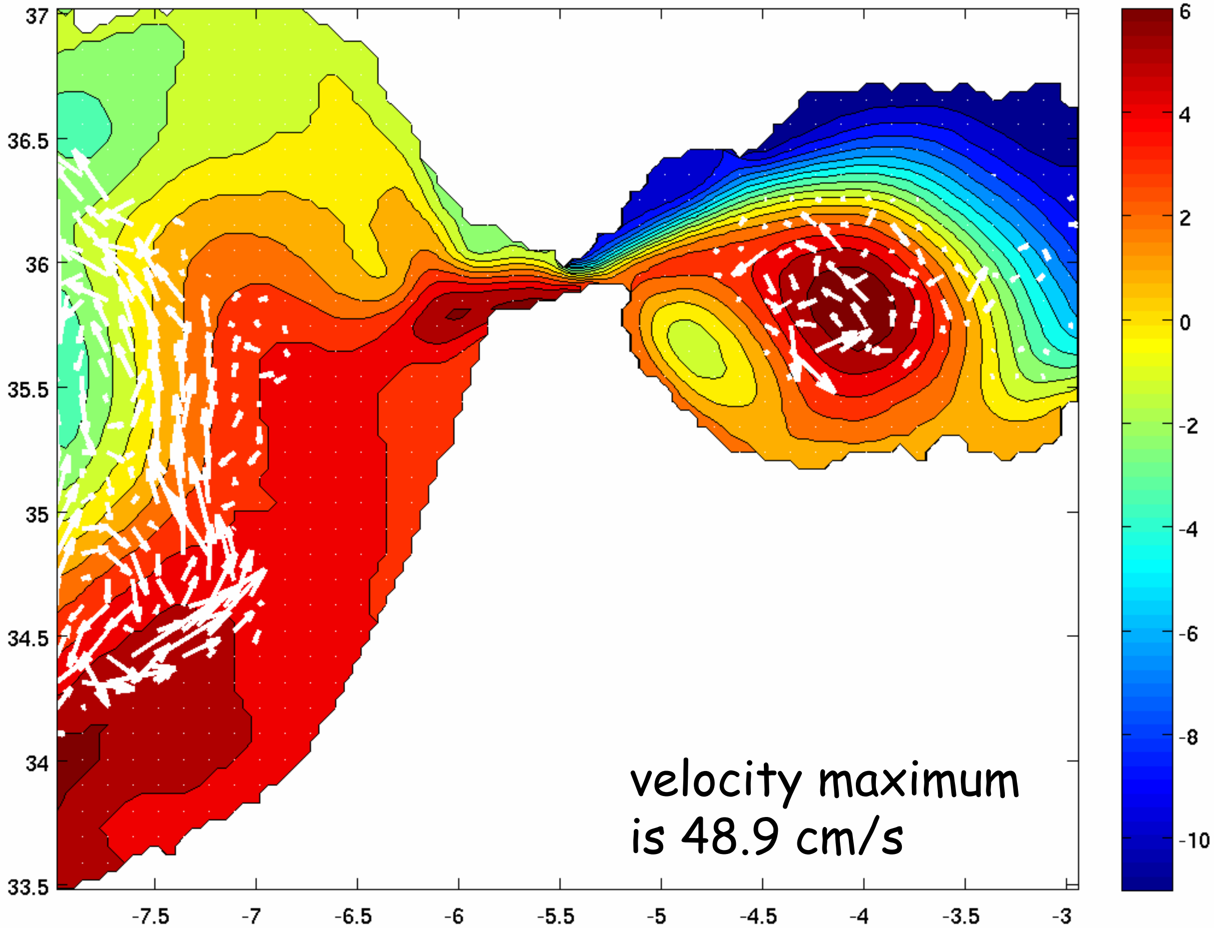


Annual averaged sea surface height and velocity vectors (1000m)

Dietrich et al. (2007)

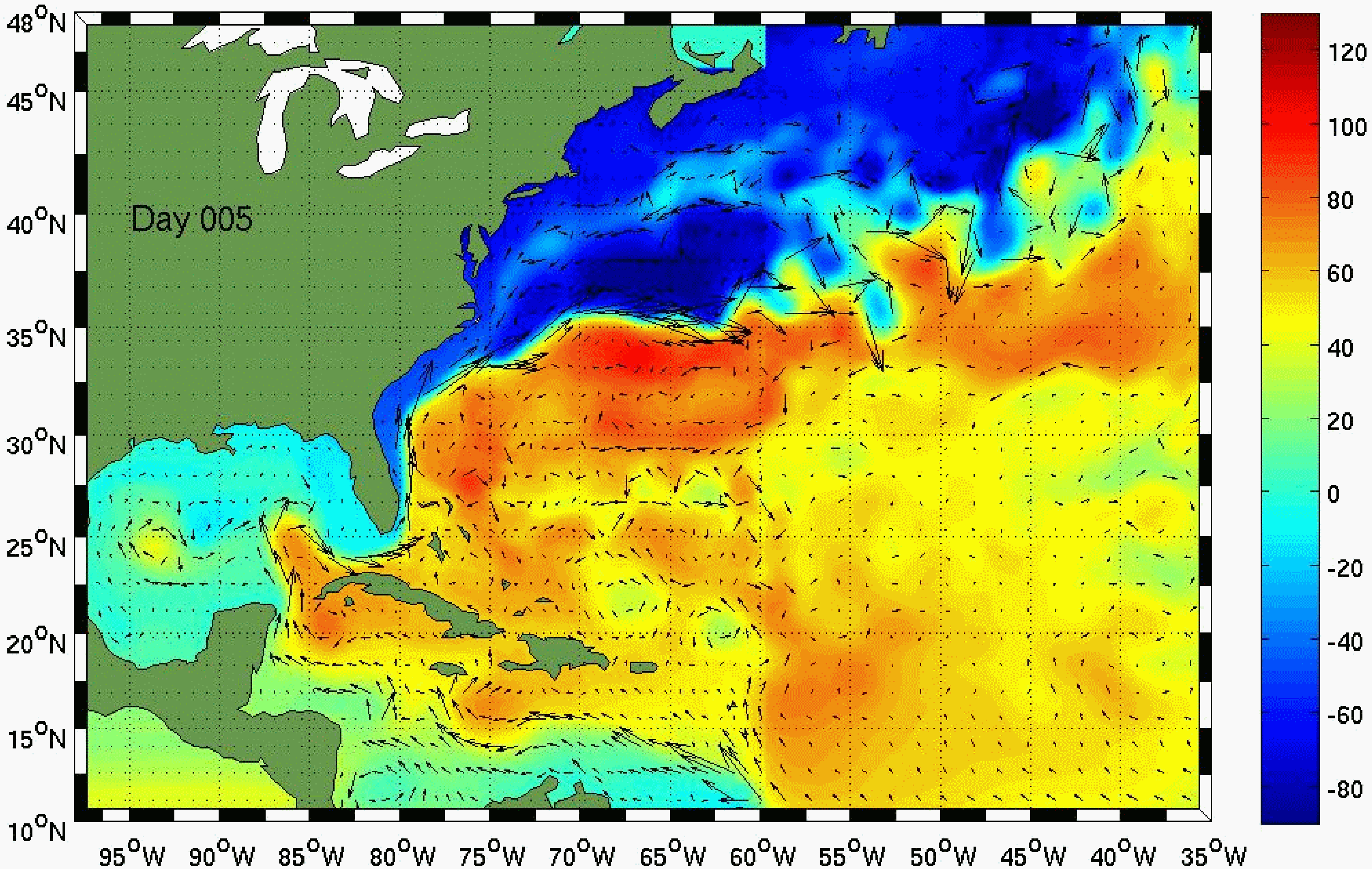
MOW deep penetration

Strait of Gibraltar domain



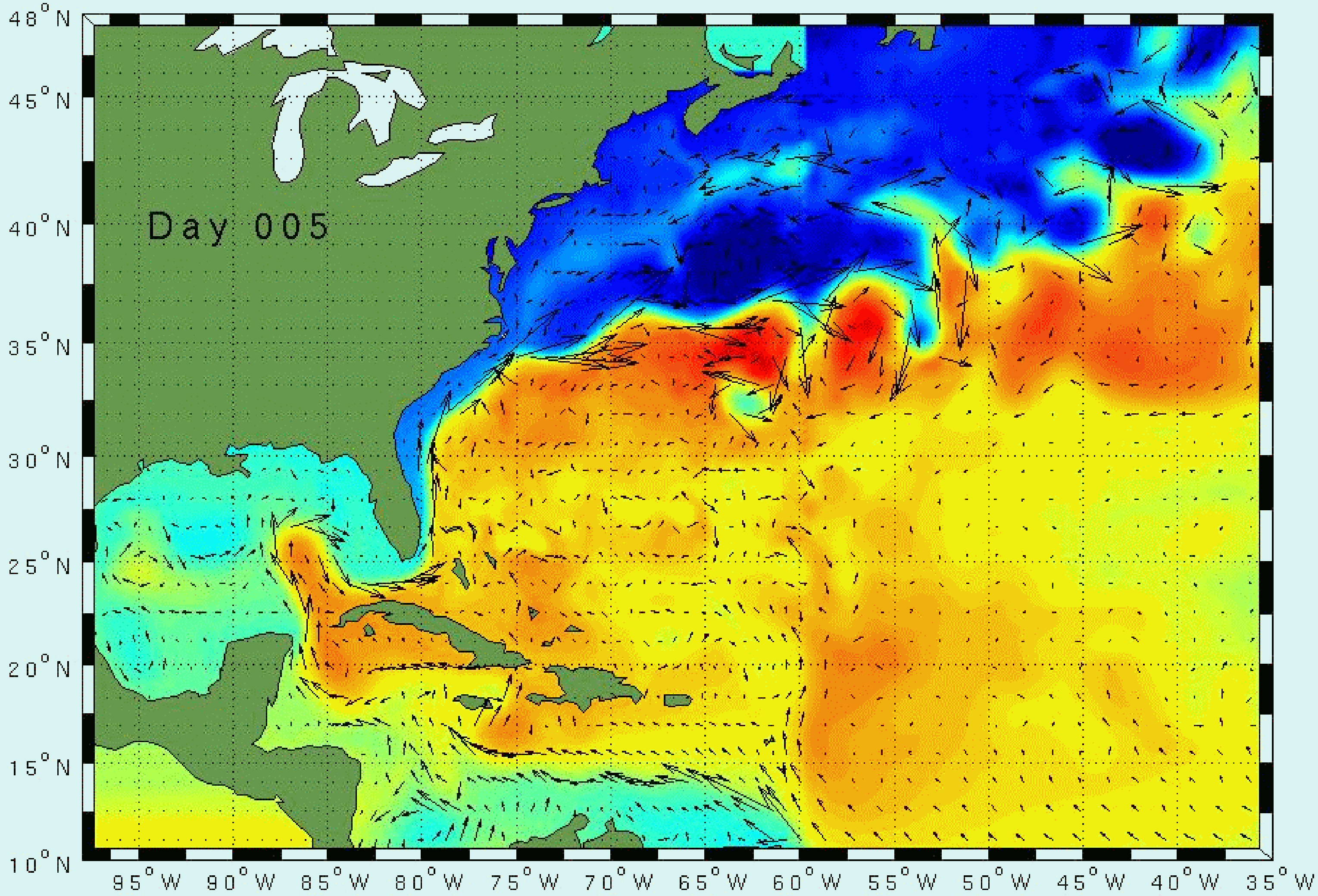
velocity vectors (1000m)

Tseng and Dietrich (2006)

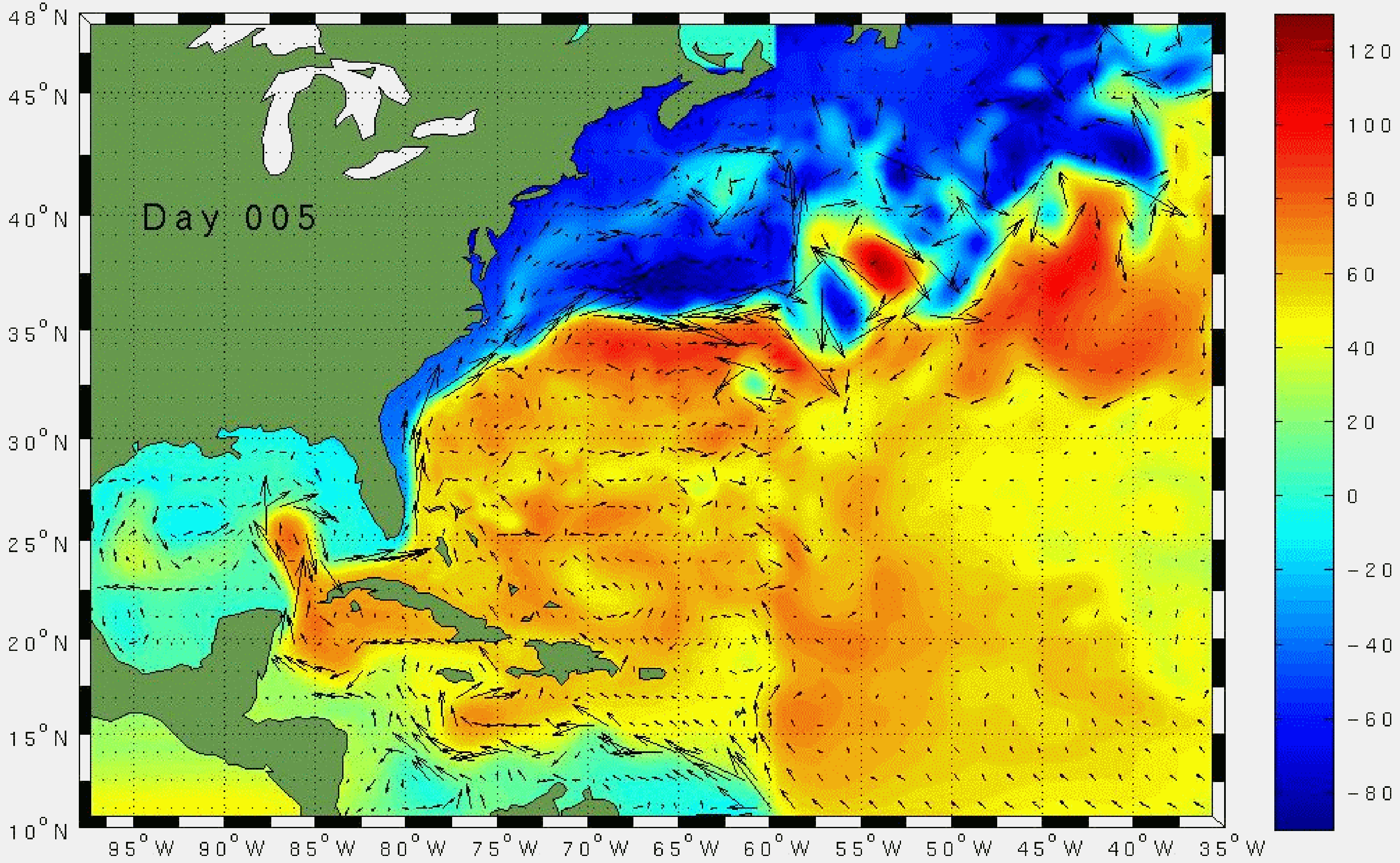


Day 005
48°N
45°N
40°N
35°N
30°N
25°N
20°N
15°N
10°N
95°W 90°W 85°W 80°W 75°W 70°W 65°W 60°W 55°W 50°W 45°W 40°W 35°W
120
100
80
60
40
20
0
-20
-40
-60
-80

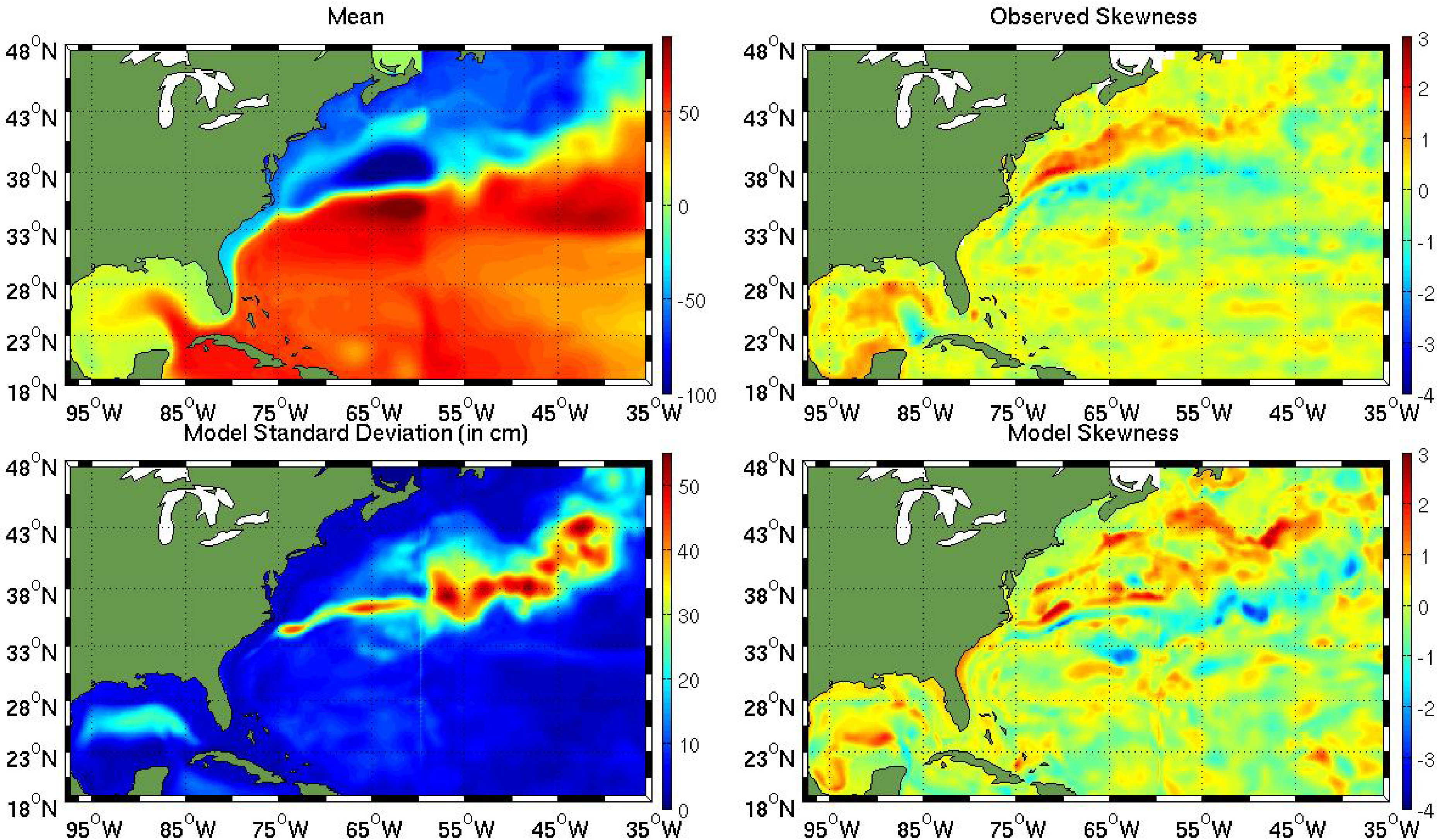
Moderate Dissipation Animation



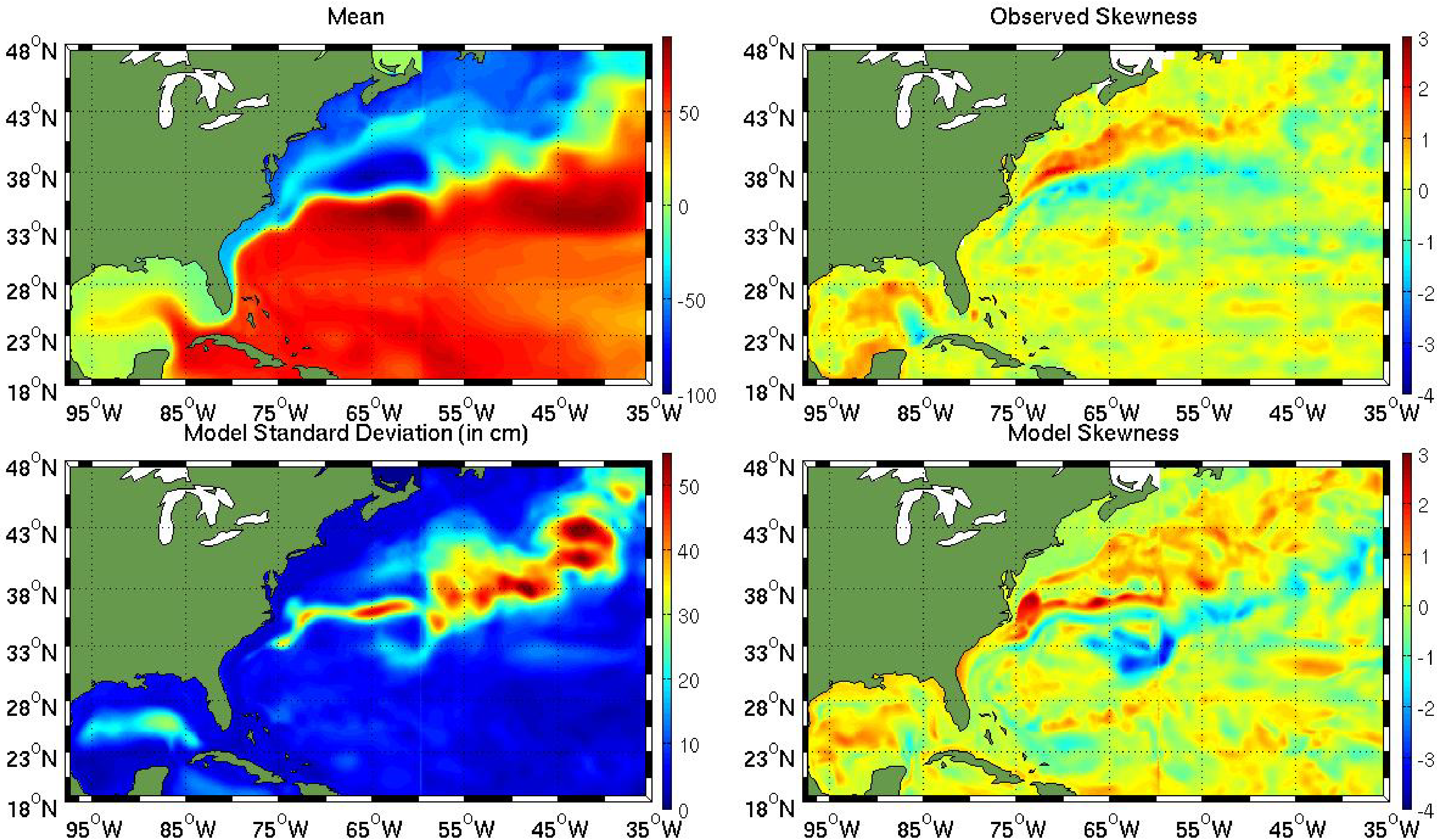
High Dissipation Animation



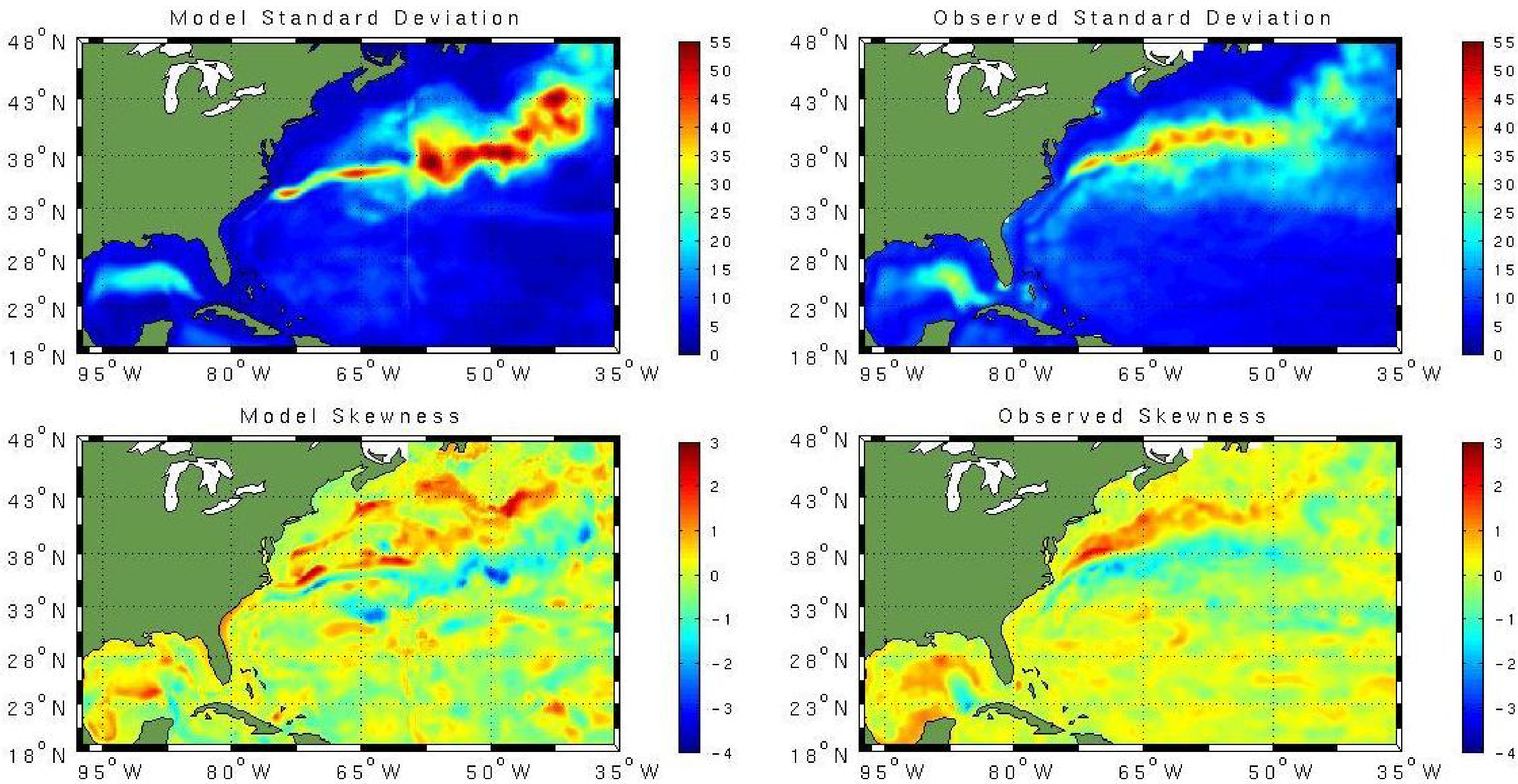
Moderate Dissipation Run



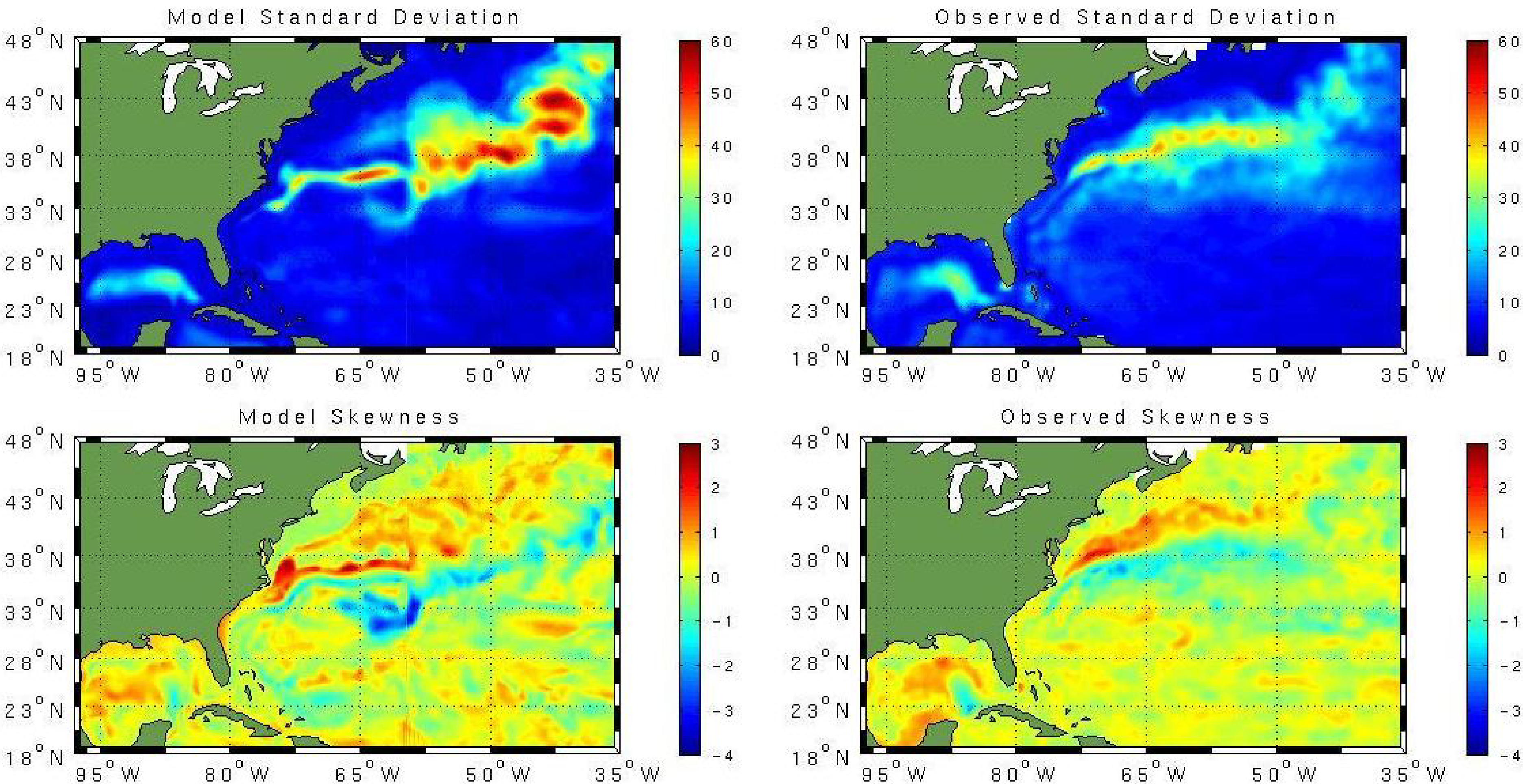
High Dissipation Run

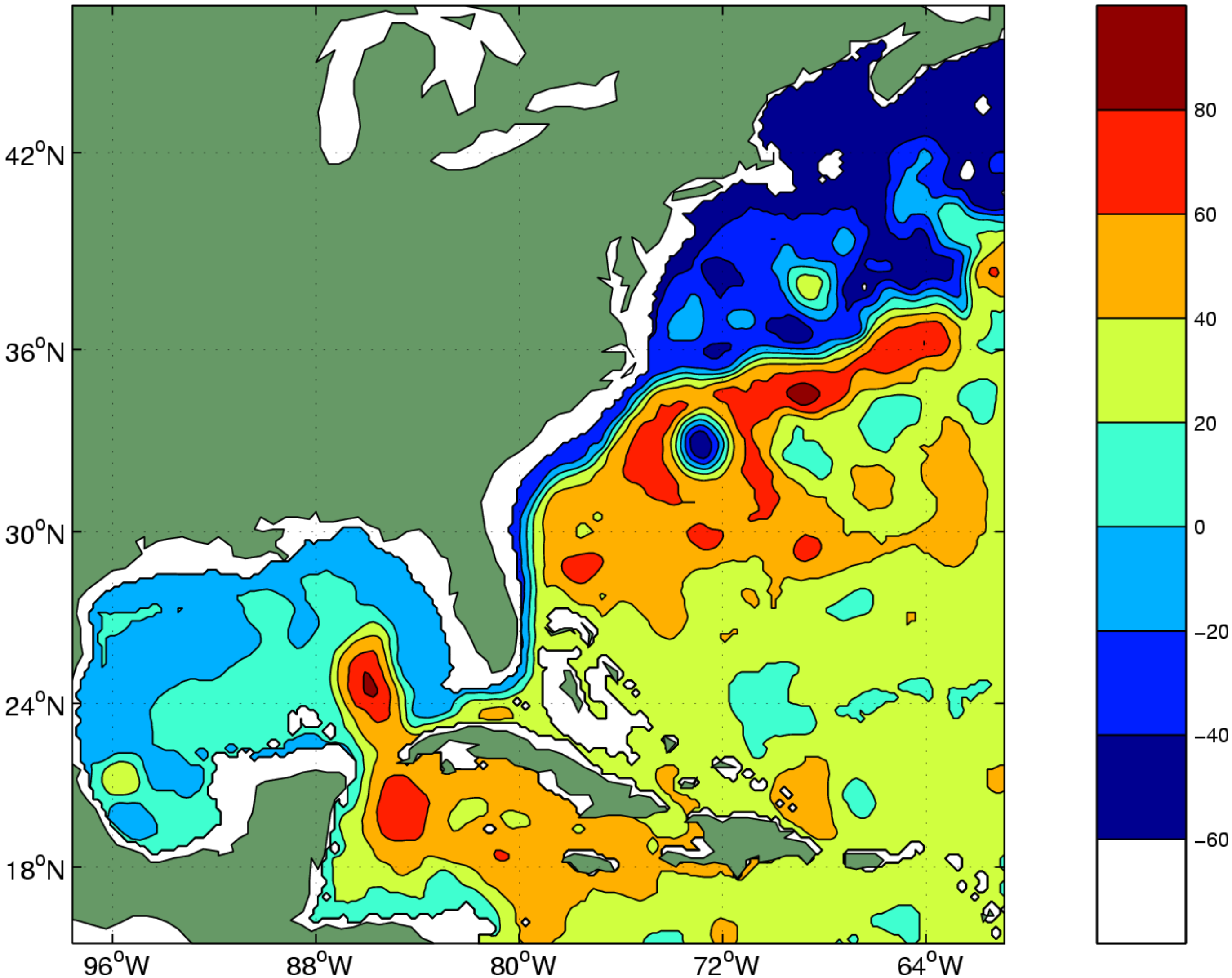


Moderate Dissipation

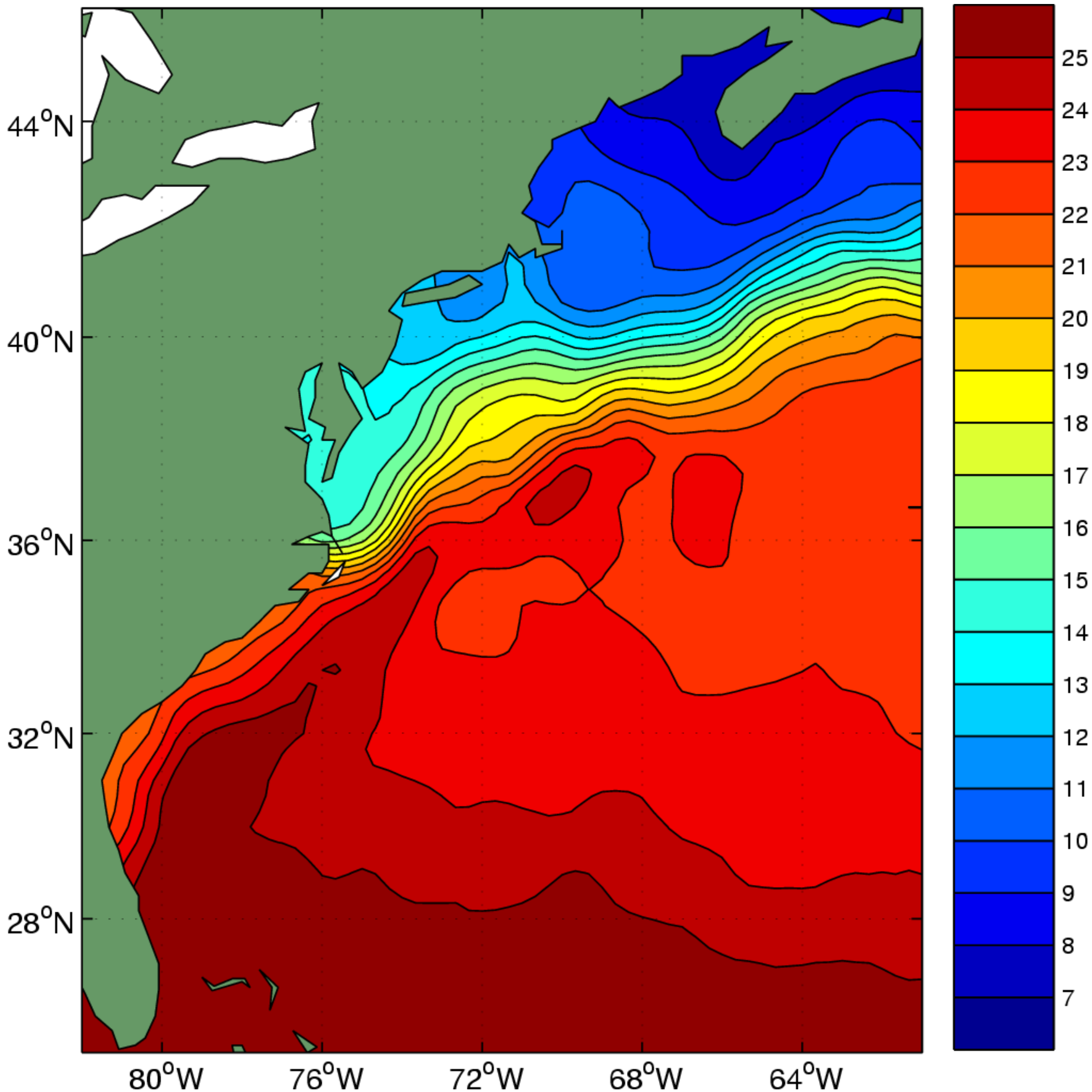


High Dissipation

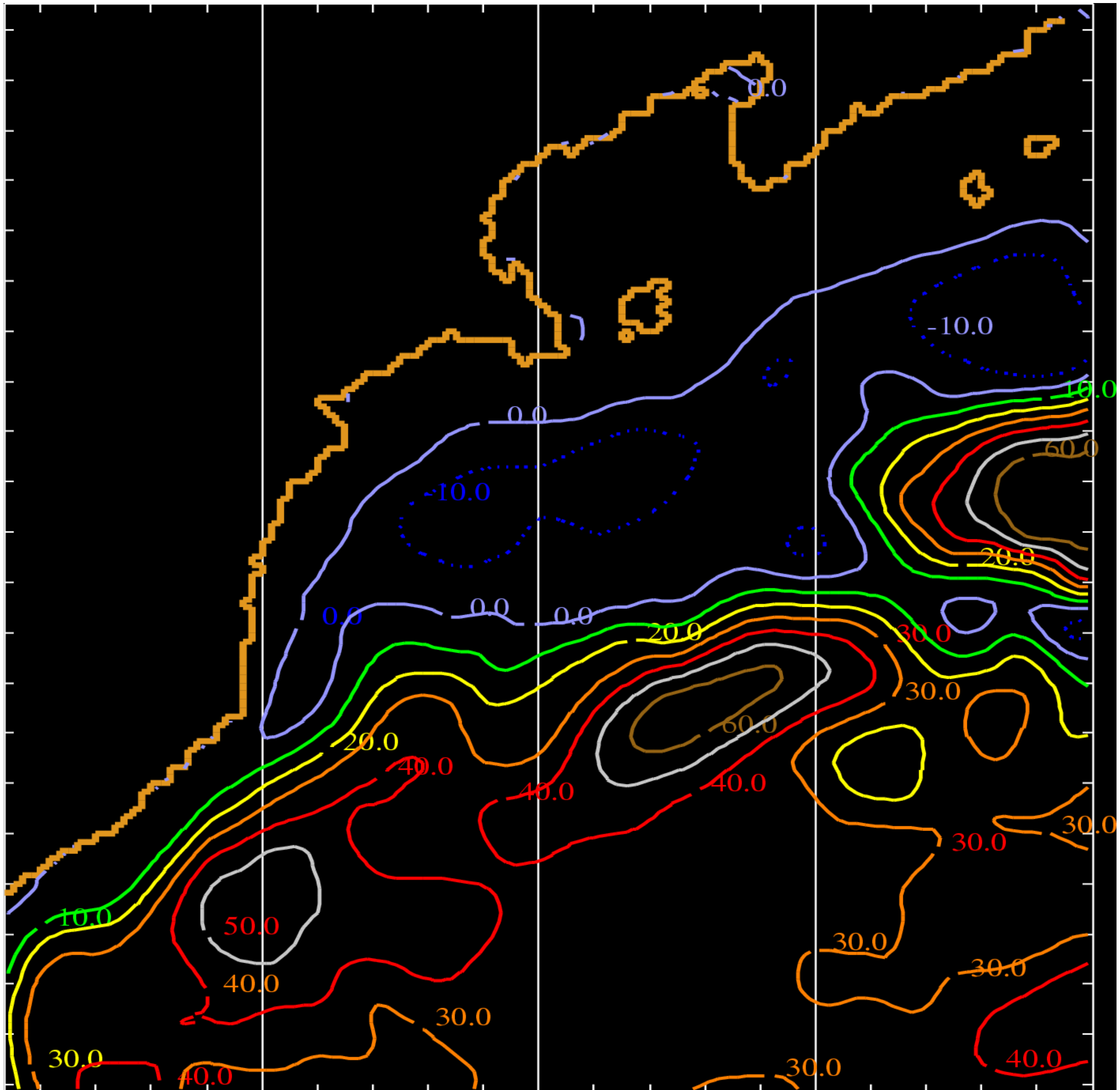




42°N
36°N
30°N
24°N
18°N
96°W
88°W
80°W
72°W
64°W
80
60
40
20
0
−20
−40
−60



44°N
40°N
36°N
32°N
28°N
80°W
76°W
72°W
68°W
64°W
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7



time avg streamfunction (Sverdrups), yrs 60-70. min= -19.5, max= 70.0

CONCLUDING REMARKS

A model that can accurately simulate the 2nd- and 3rd moments using climatological forcing with no data assimilation is desirable in forecast applications.

Using such model, Keith Thompson's frequency selective spectral nudging approach can keep the model on track with slow variations while having little effect on fast variations.

Veronis' Law:
"Do not assimilate data into a model that the model cannot simulate."

A final comment is that our 1- and 2- grid NORPAC (North Pacific and South China Sea) model is giving realistic results. It has a 1/12 deg MPI version running on 32 processors that uses an efficient message passing protocol to take advantage of modern supercomputers. It runs about one simulated month per day of clock time. Its two-grid version been applied successfully to simulate the observed 9(!) deg surface cooling resulting from a Y2K typhoon that churned and sucked up thermocline level water (subject of a talk by Professor Yu-heng Tseng at this meeting).

Summary

Using climatological forcing with no data assimilation, the six two-way-coupled grid MEDIterranean and North Atlantic ("MEDINA") adaptation of the DieCAST model:

- accurately simulates real density currents coming from the Strait of Gibraltar (MOW water) and the high latitude seas (Deep Western Boundary Current and its effects on the Gulf Stream);
- is validated by comparison with observed transient 2nd- and 3rd moment statistics in the energy intensive Gulf Stream region;
- gets realistic results almost everywhere in the modeled multi-basin domain in a 70-year simulation (so far) using a single personal computer processor;
- shows nearly seamless grid coupling even with no intergrid sponge layer;
- sheds light on the interaction of the DWBC and the Gulf Stream.