North Atlantic and Pacific Ocean Model Boundary Flows

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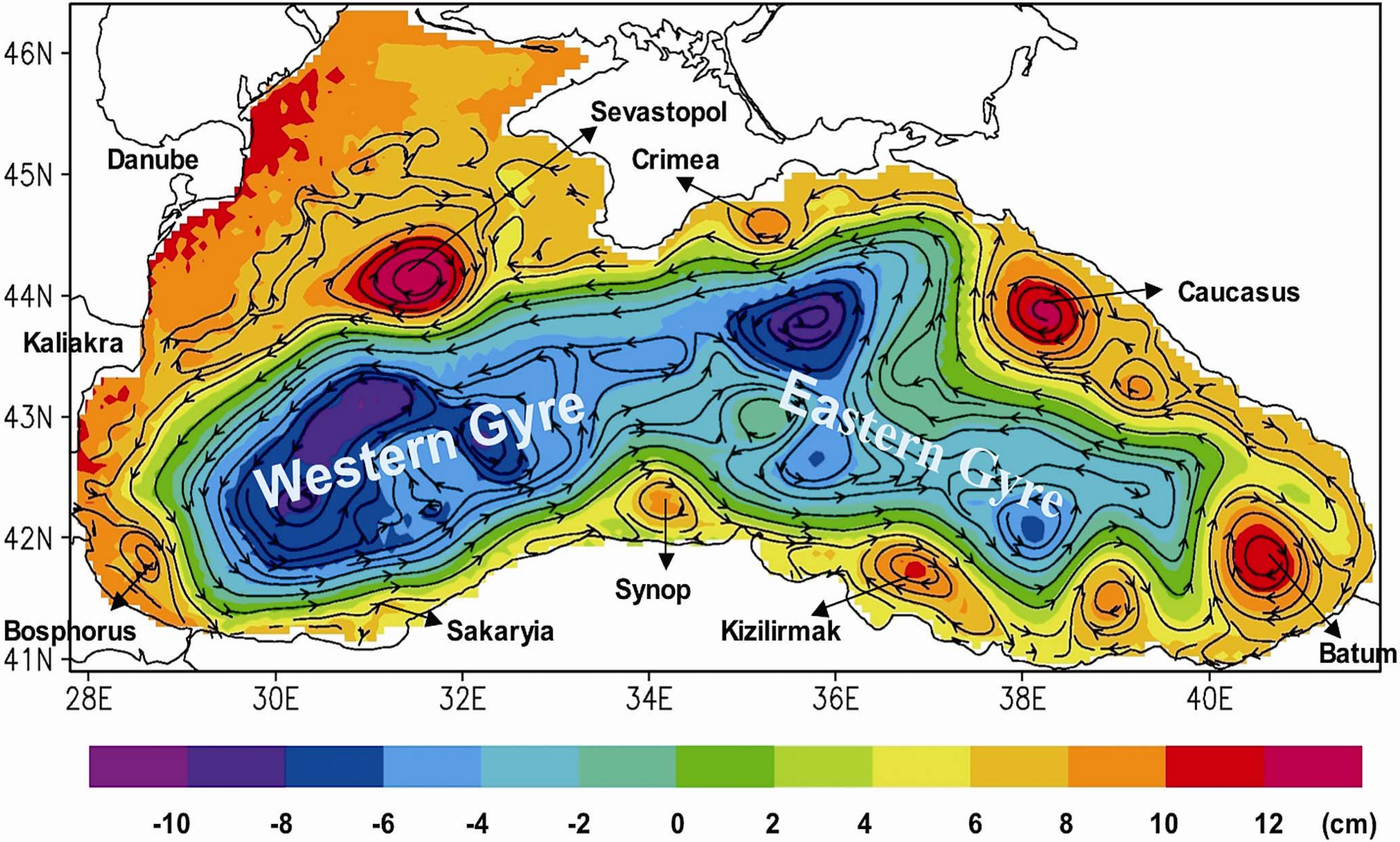
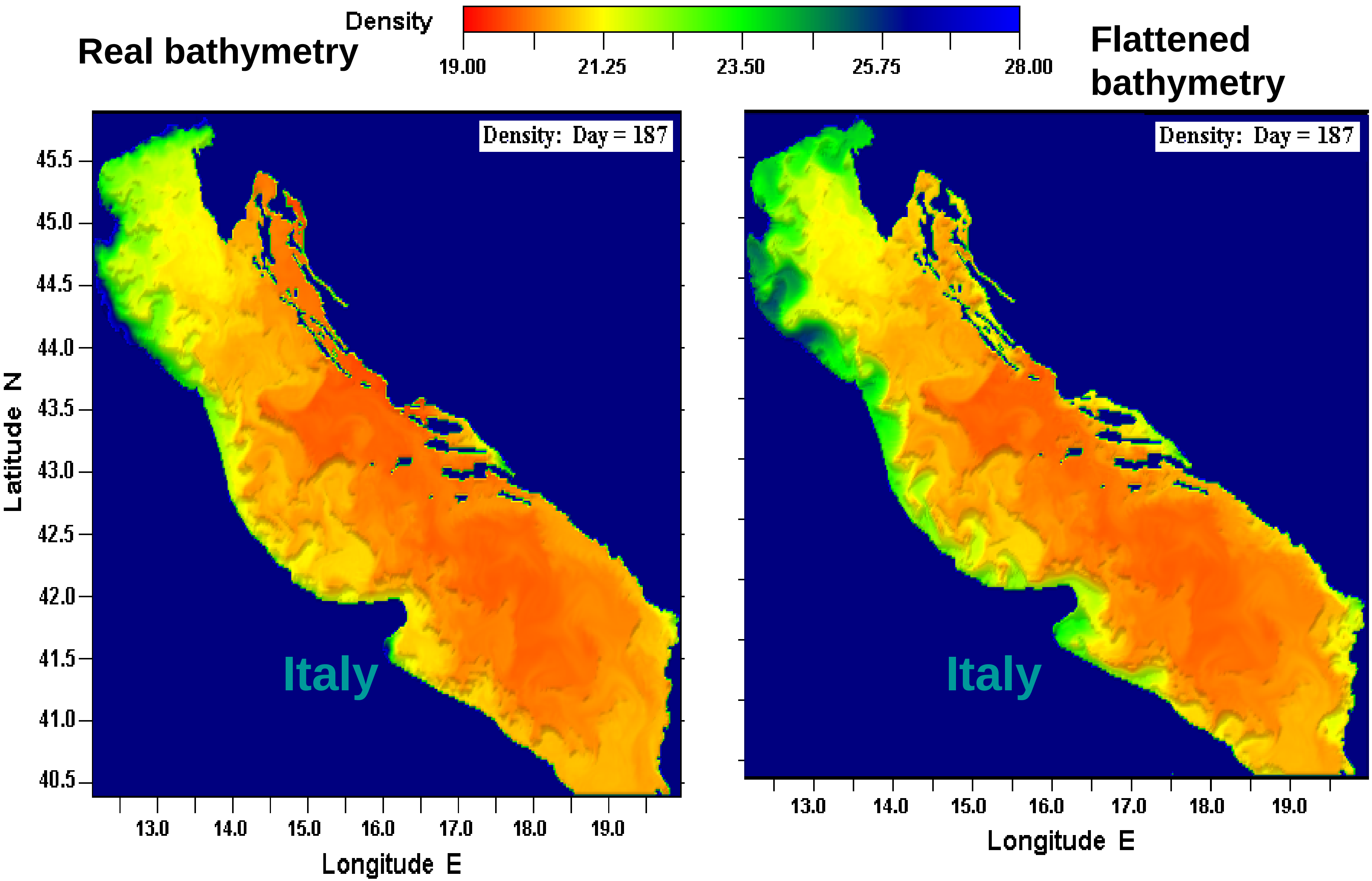
BERKELEY LAB

Surface height and velocity snapshot from Black sea modeling review paper by Emil Stanev



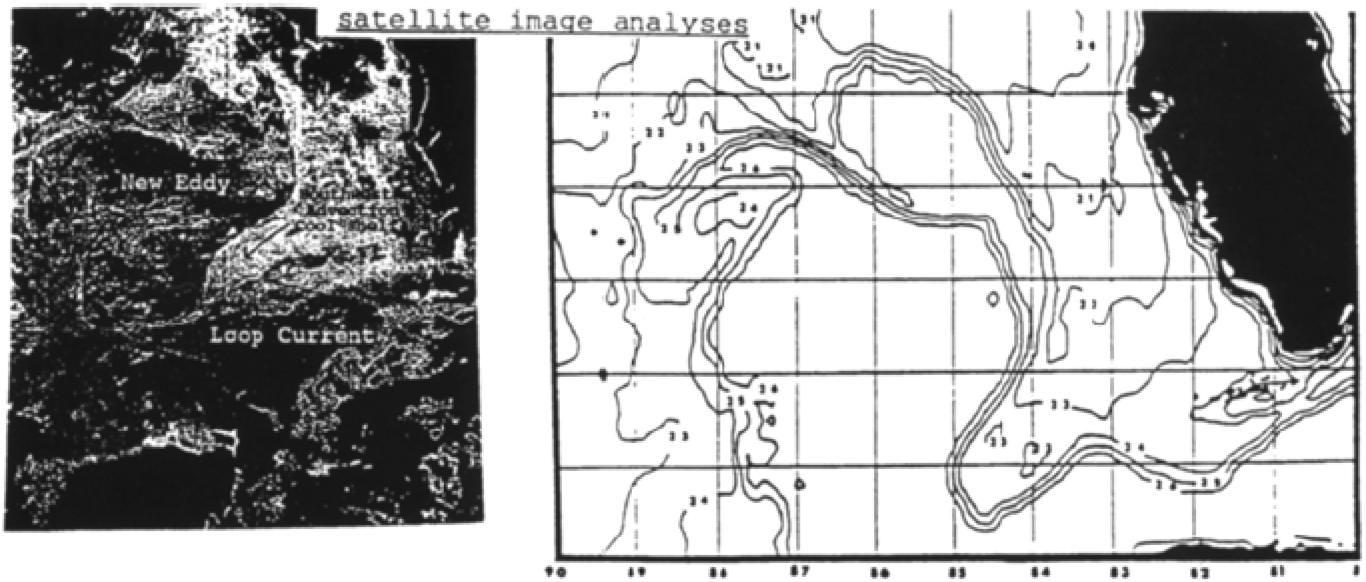
Ref: Stanev, E., 2005.

Adriatic Sea studies

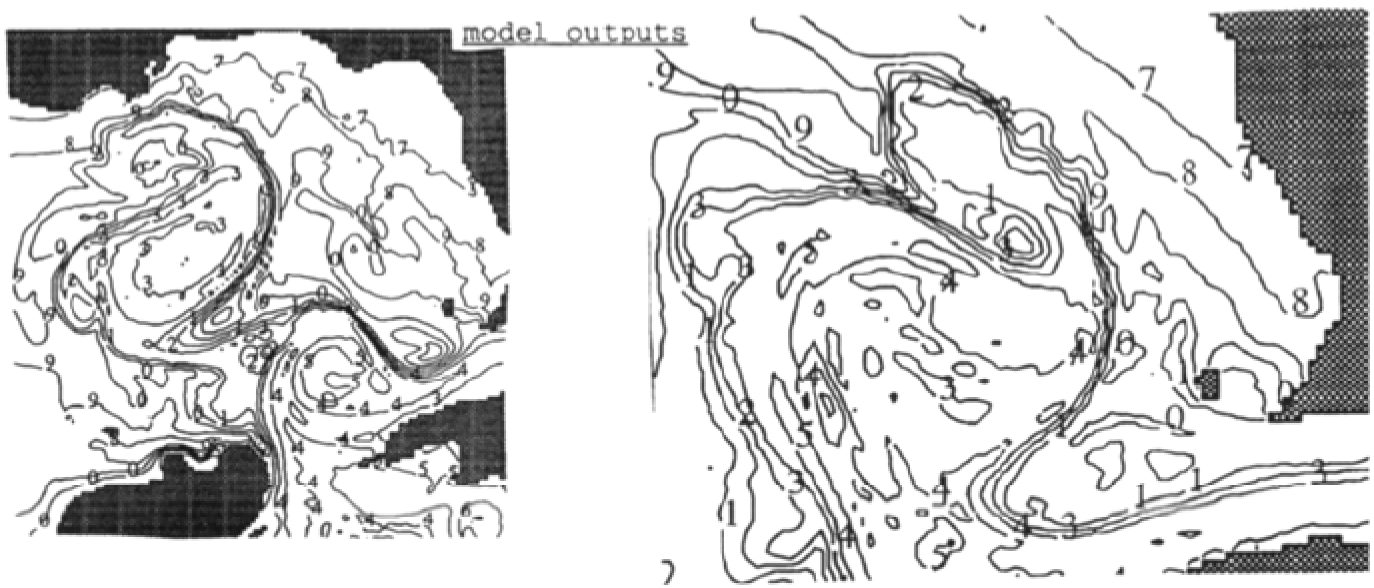


Cushman-Roisin et al, JGR, 2006.

The next five slides compare early 1990's single-grid Gulf of Mexico simulations with remote and *in situ* observations, and shed light on highly nonlinear boundary effects. These are mostly from a single 1/12 deg resolution simulation of the Gulf of Mexico and western Caribbean Sea running on a vintage SGI workstation having about 1/100 the speed of a modern personal computer.



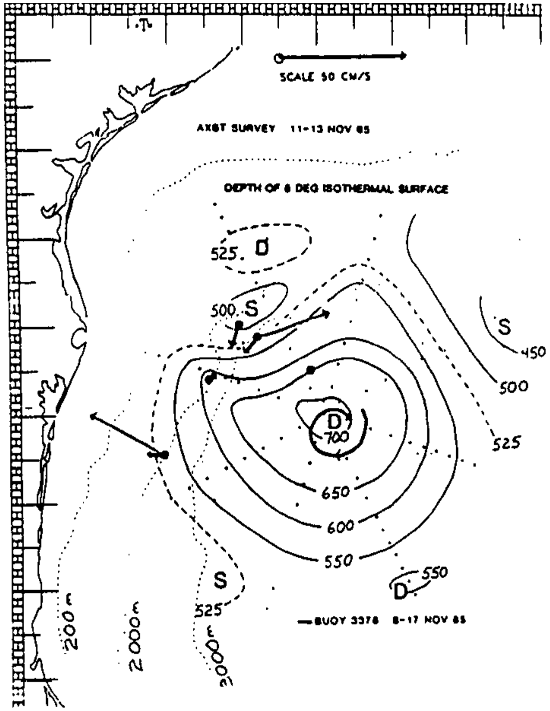
(a) 6 June, 1993 satellite image[1]   (b) 20 April, 1984 satellite image[2]

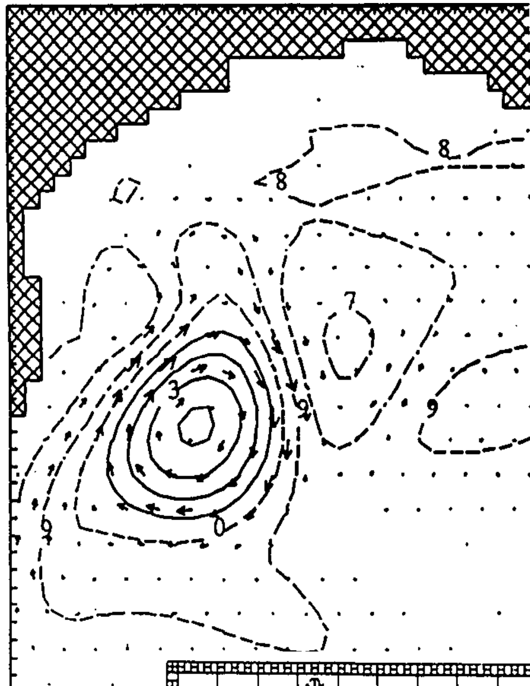


(c) day 180 model output   (d) day 1220 model output

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

Ref: Dietrich, D., 1997

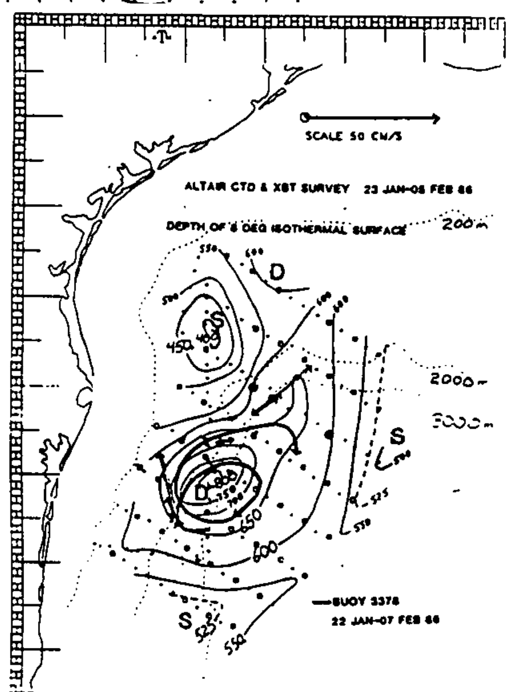


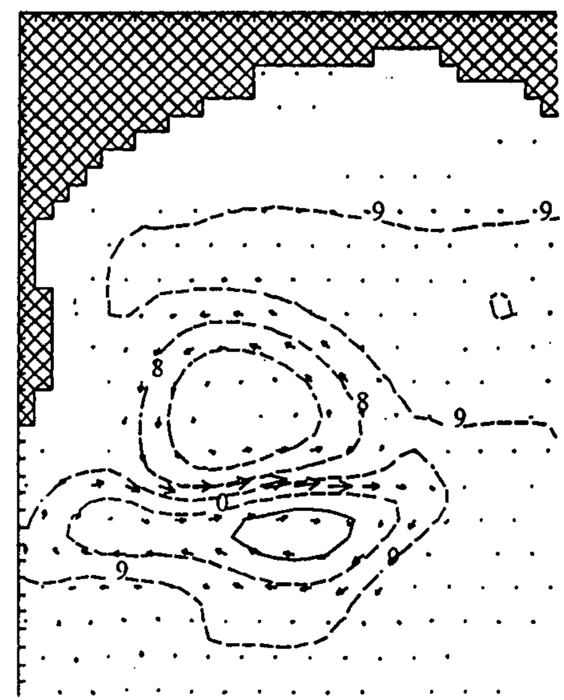


LEFT: Observations (Brooks and Kelly, 1986) depth of 8℃ isotherm.

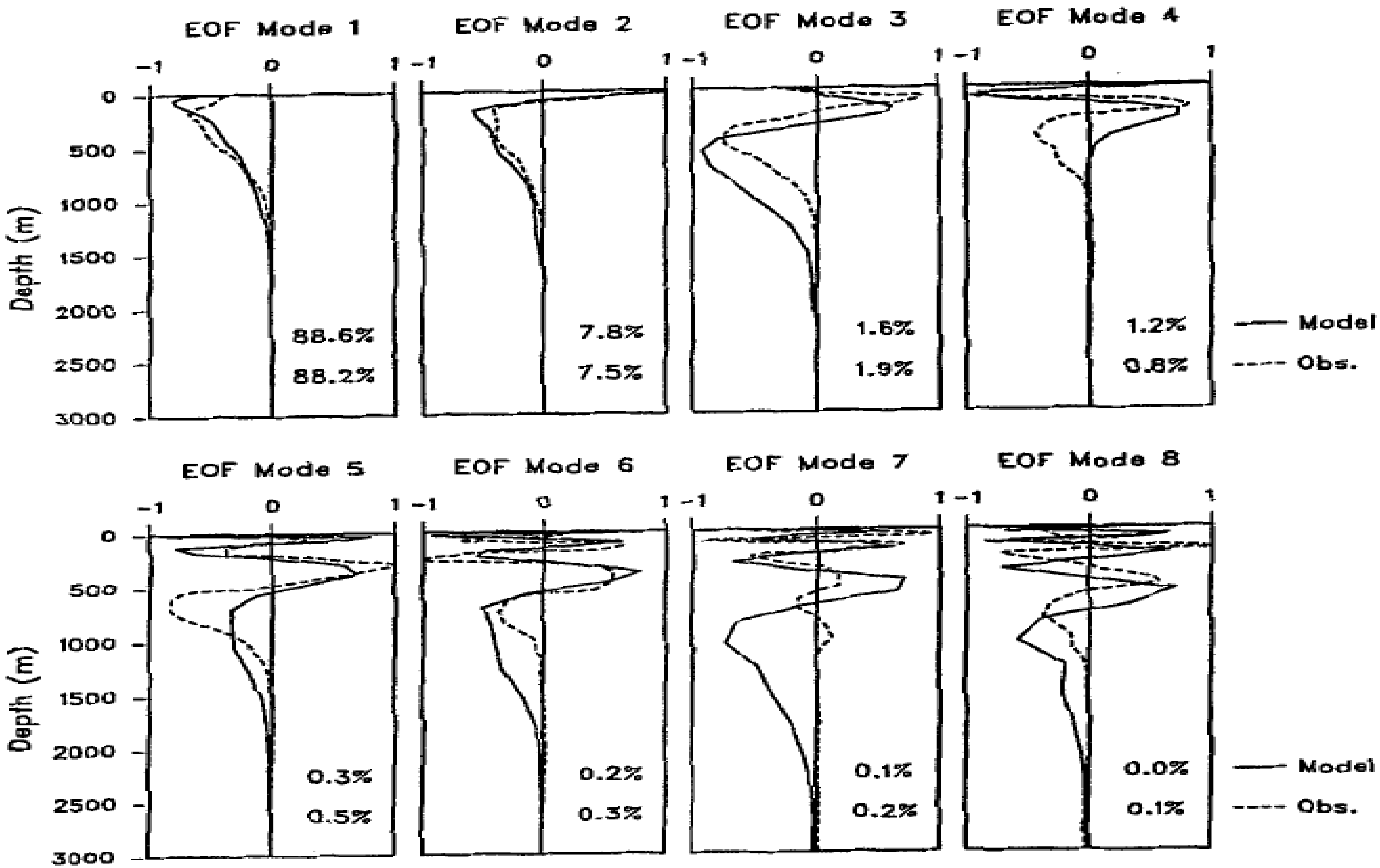
Right: Model Results (top layer pressure and velocity).

Dietrich, D.E., 1997

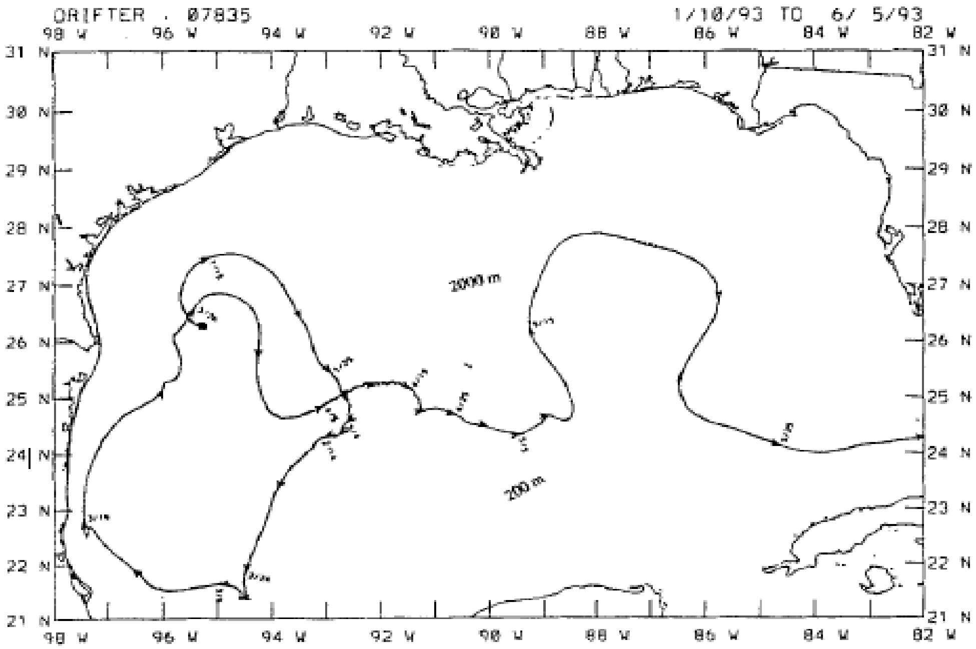


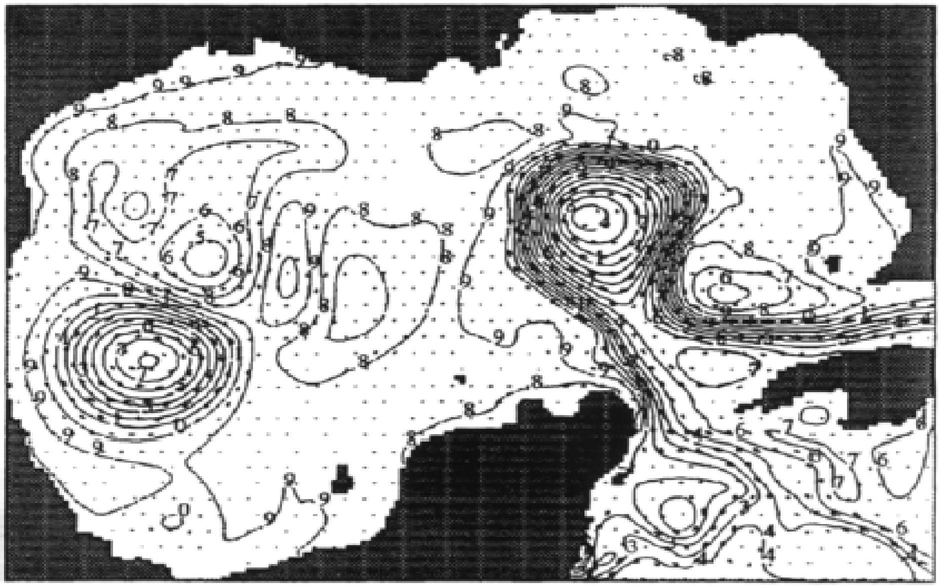


Paired eddy formation near the western GOM shelfbreak: observations and model results with no data assimilation. The observations are 80 days apart. The model results are 75 days apart (days 1935 and 2010 from Case B3). The maximum velocity in the region shown in the model results is about 50 cm s^{-1}.



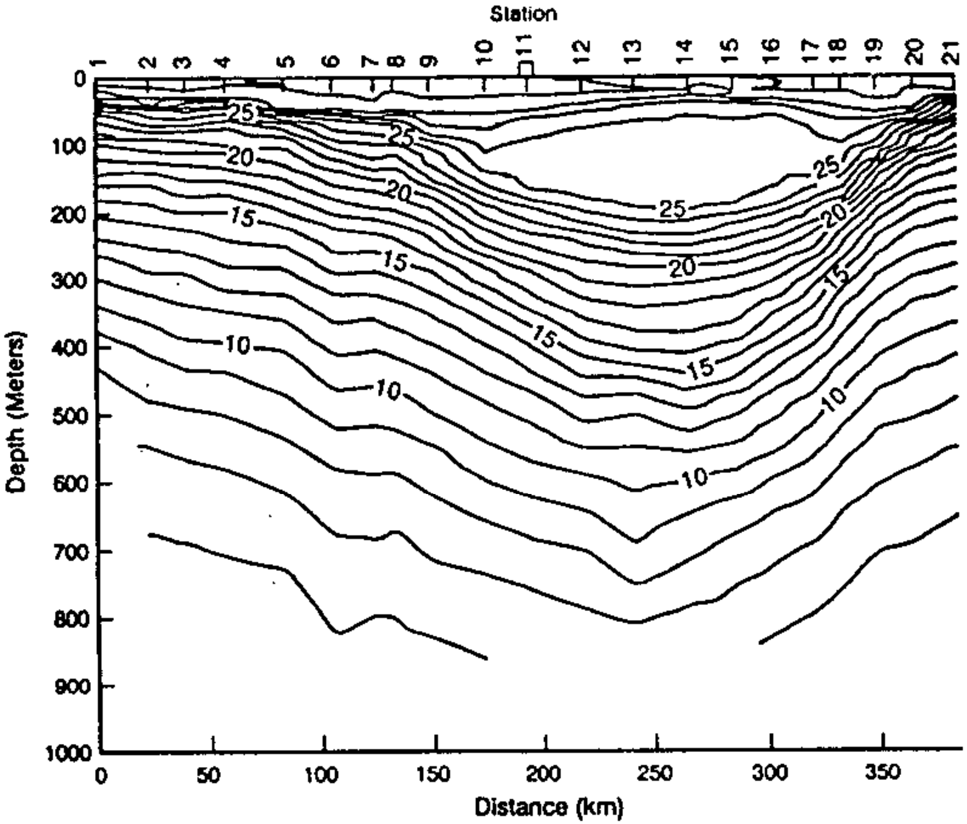
A comparison of the vertical EOF modes of the model (solid) with those derived from observations (dashed). The percent of total variance represented by each EOF mode is given in each panel, with the observations value located above the model value. (Dietrich, D.E., 1997).



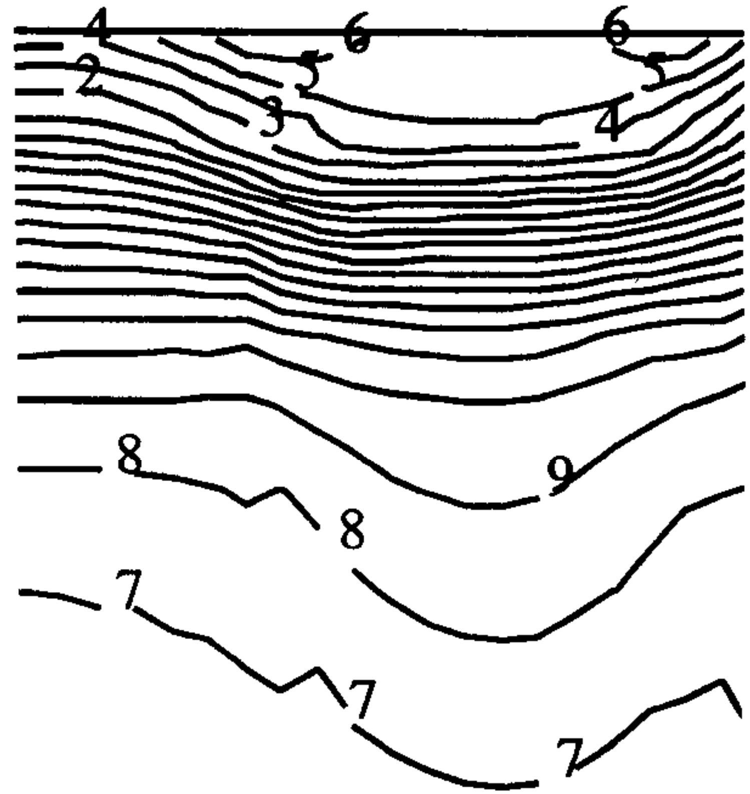


5A0/ 20 P(eq. fsa, cm) and Vel(cm/sec) at day 566, depth= 10.0 m. Pdif=100.5, Vmax=194.6

The top panel shows a drifter trajectory (from P Hamilton), while the bottom panel shows the top layer model pressure and velocity fields at day 566. (Dietrich, D.E., 1997).



OBSERVATIONS
(from Forristall, et al, 1992)



SOMS MODEL RESULTS
at day 1920

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°.

Six grid MEDINA model with Bathymetry (km)

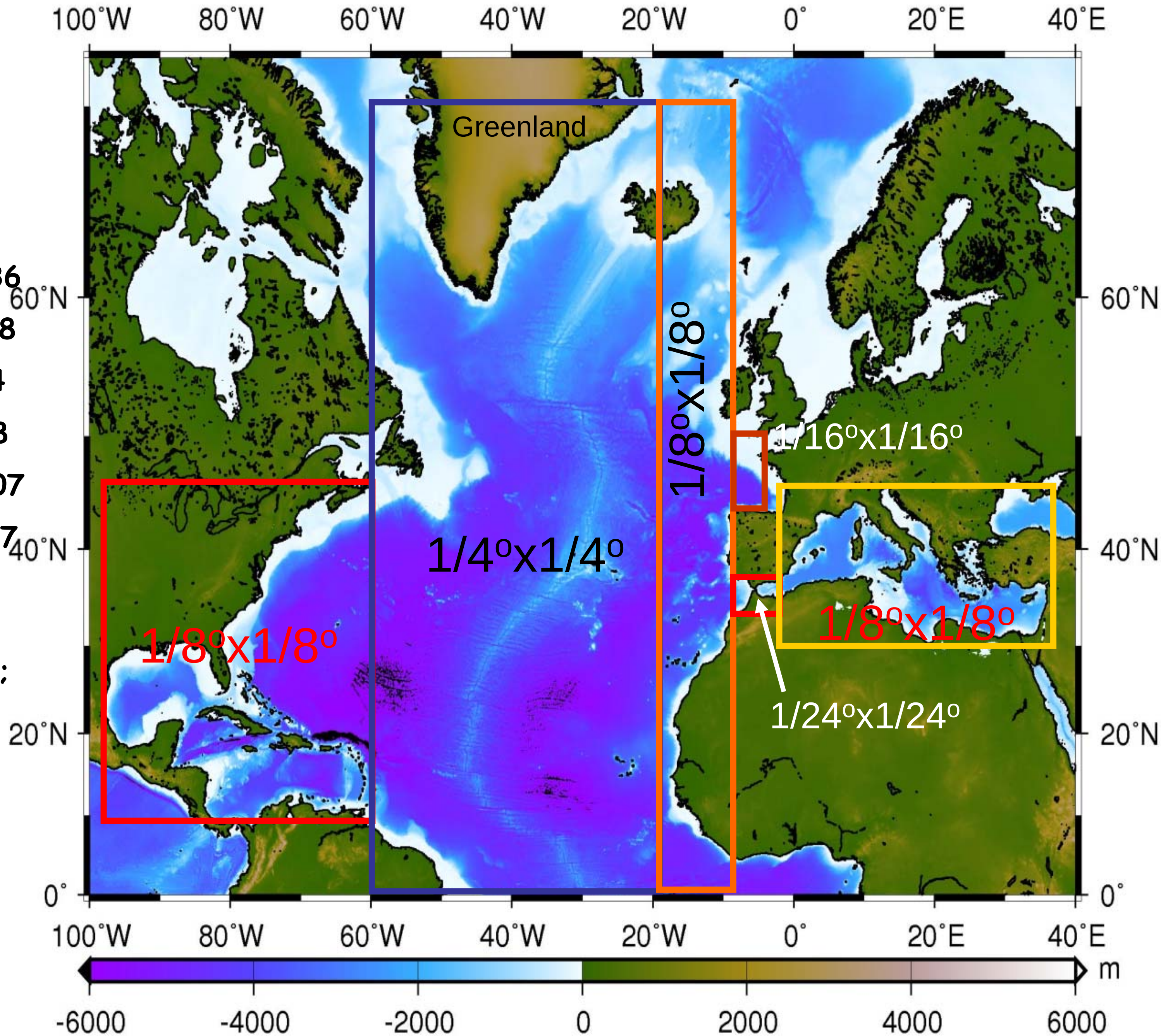
Six domains:

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

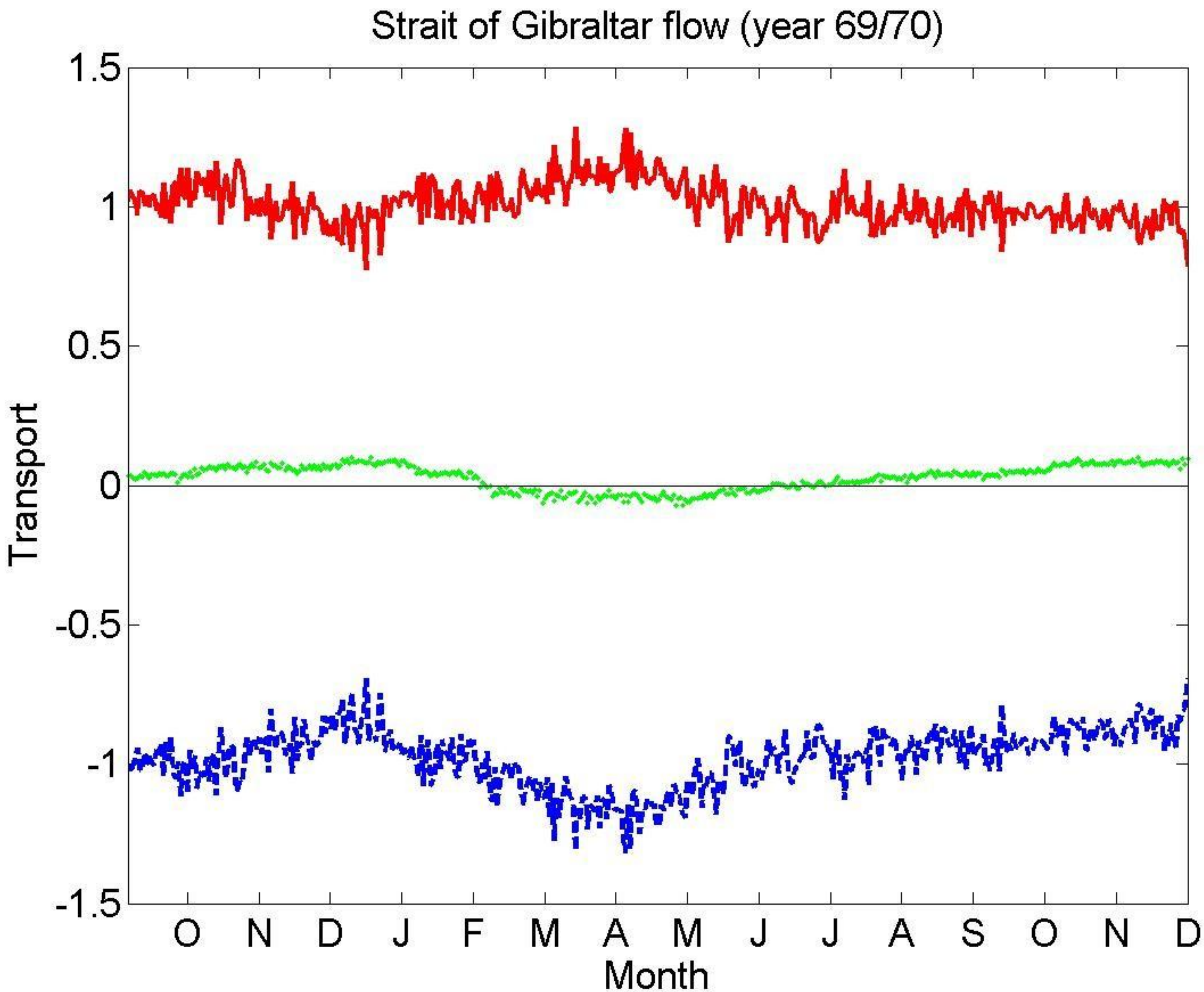
30 vertical layers;

Top layer 11 m thick;

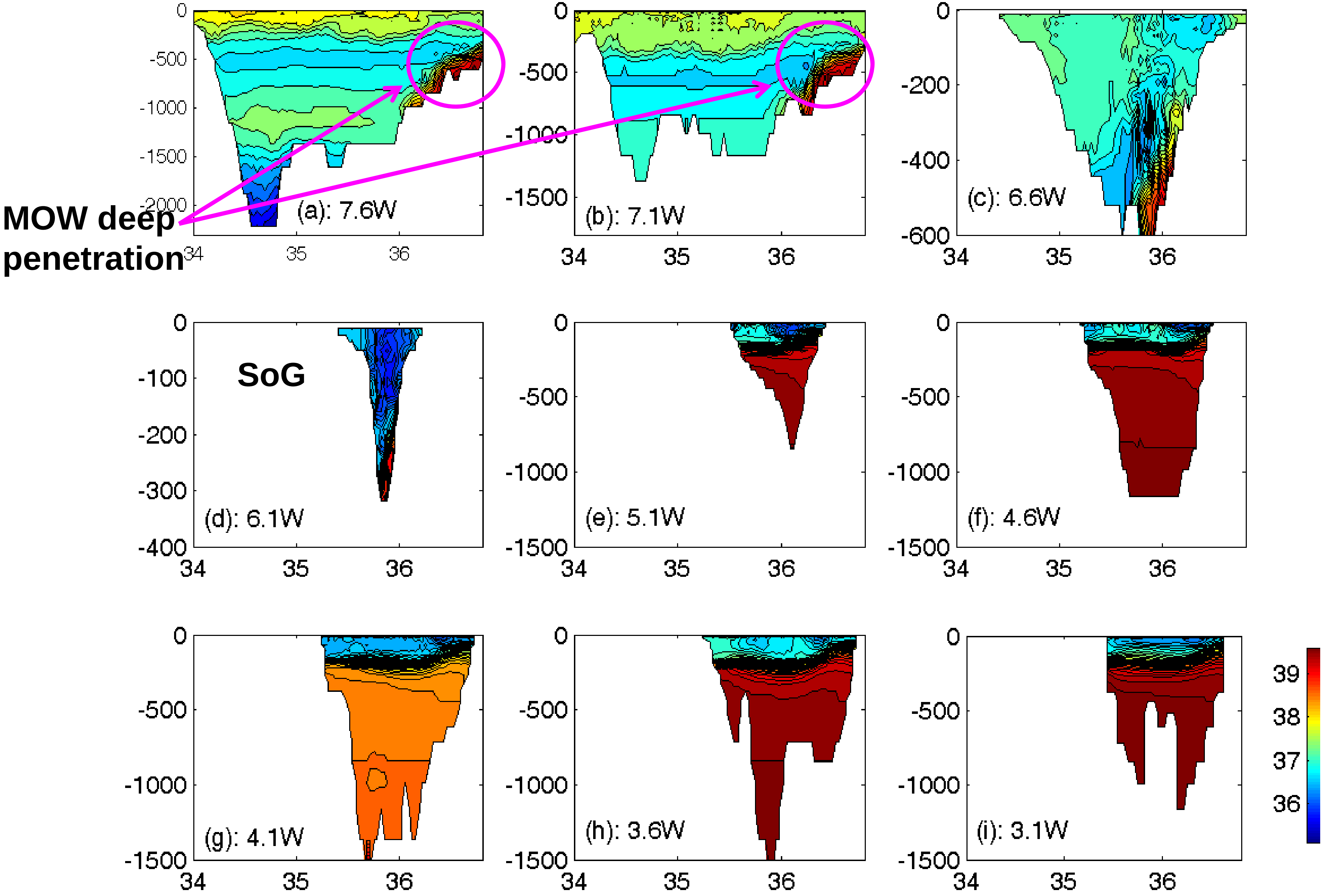
Bottom layer 750 m thick



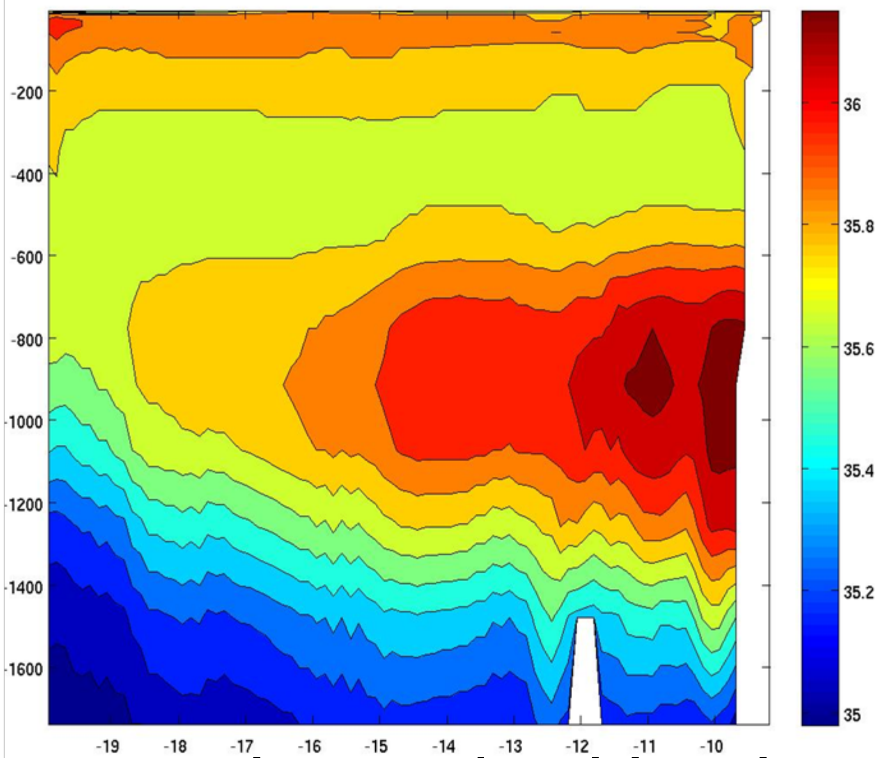
Modeled eastward, westward and net flow through Strait of Gibraltar



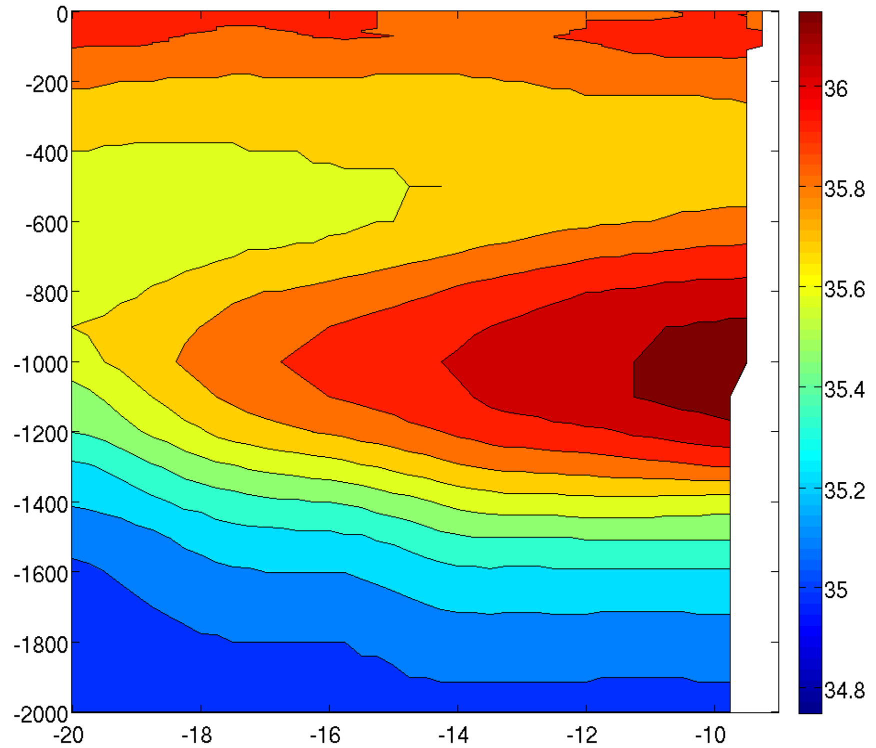
Meridional salinity sections at various longitudes



Vertical/longitudinal salinity section at 43°N



Annual averaged model results



U. S. Navy's GDEM climatology

(courtesy S. Piacsek)

The MOW equilibrium depth is sensitive to sub-gridscale modes that mix MOW with ambient less dense North Atlantic water as it edges down-slope, until it reaches a level where the densities are nearly matched.

At this equilibrium level, some of the MOW spreads laterally offshore as a lens of salty, warm water seen in slide 13.

The sub-gridscale mixing effects are emulated by the Pacanowski and Philander Richardson number based scheme.

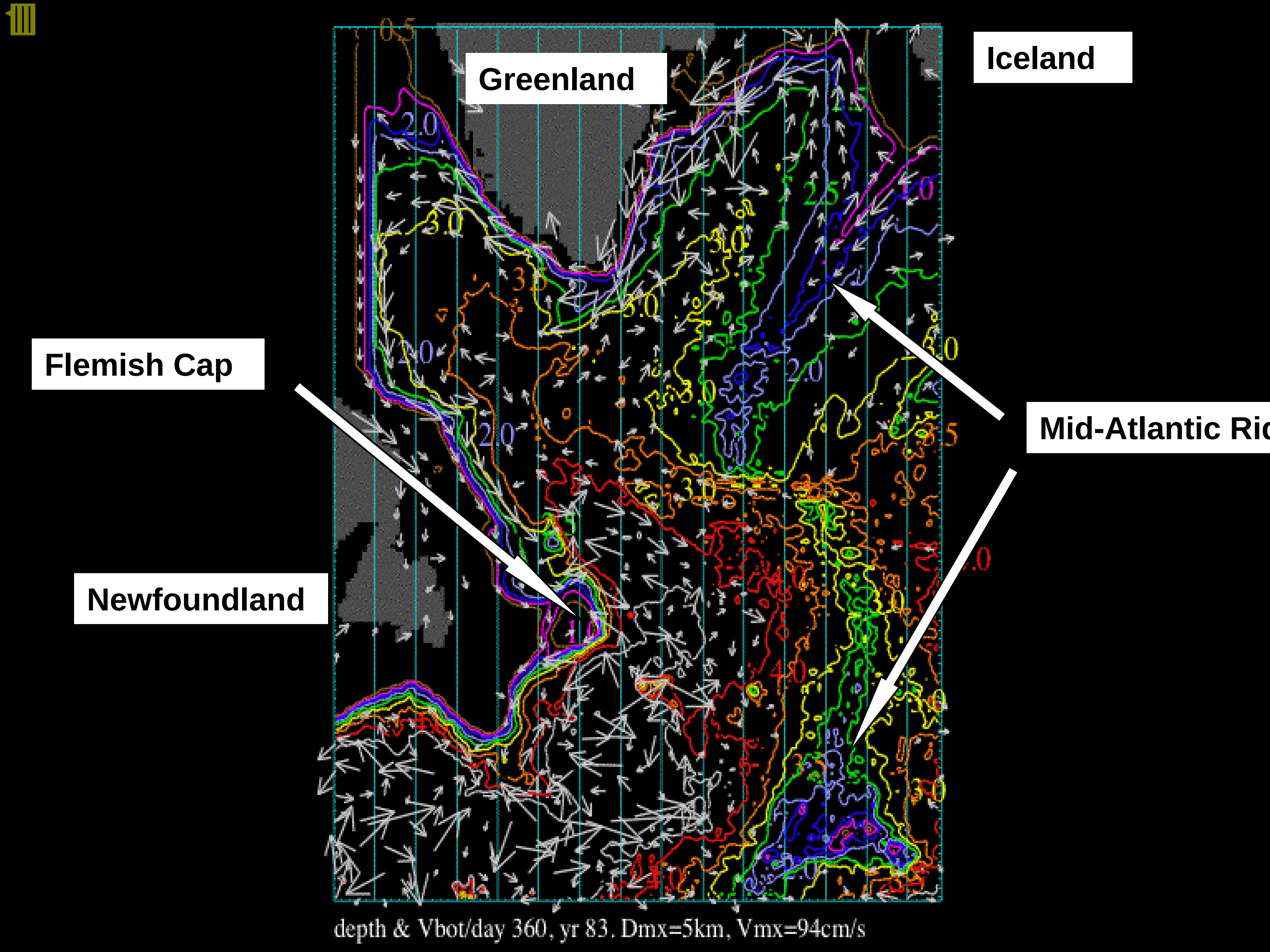
Thus, the results shown in slides 12 and 13 imply that the Pacanowski and Philander Richardson-number based vertical mixing gives remarkably realistic simulation of MOW dilution and depth penetration.

Ç

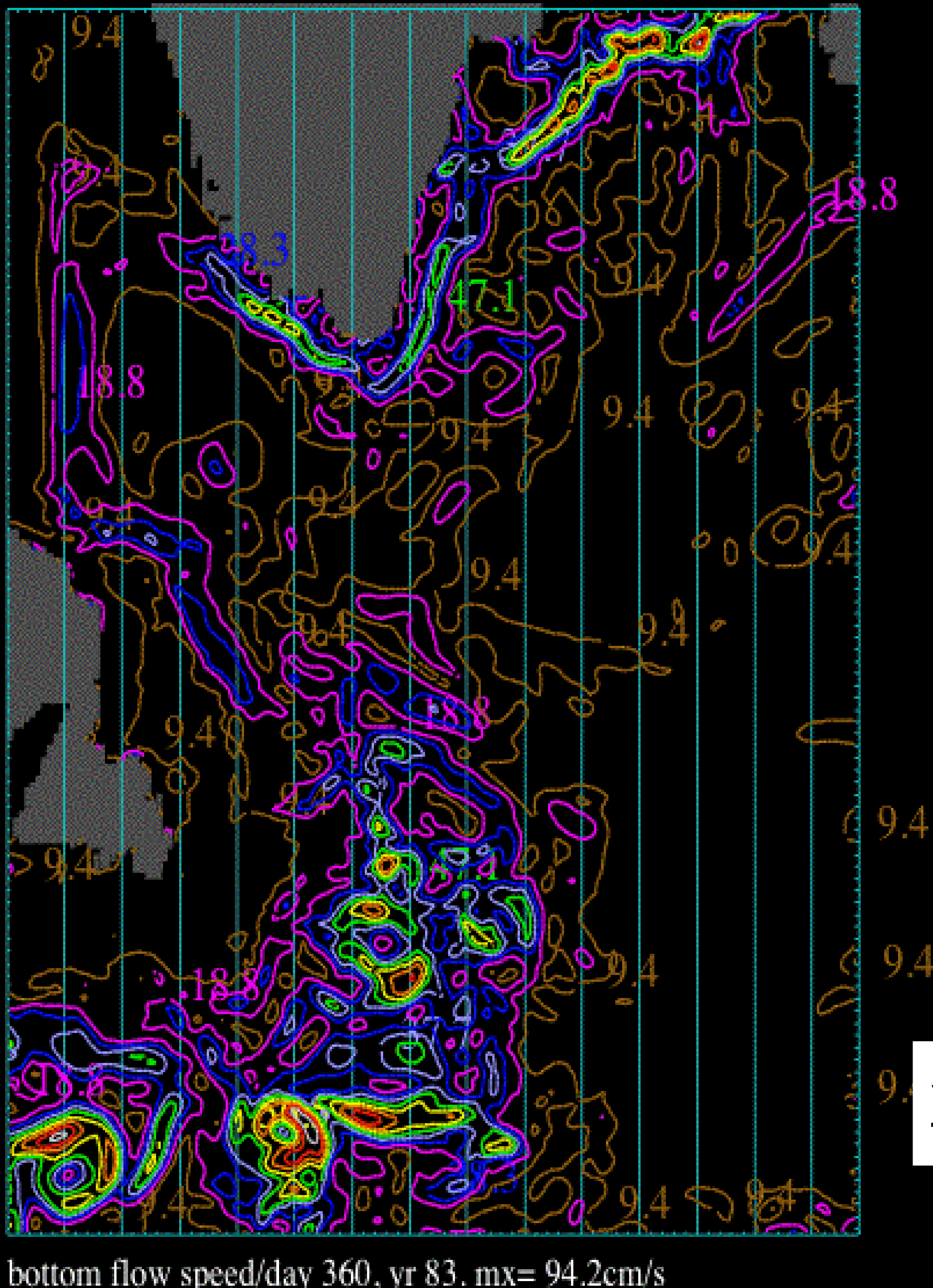
The next 8 slides show results from the 1/4 deg resolution central North Atlantic grid of the MEDINA model zoomed to the Gulf Stream region.

The western boundary is at 60^{o} W, which is the interface of between the central grid and the $1/8^{o}$ resolution western grid (see slide 10).

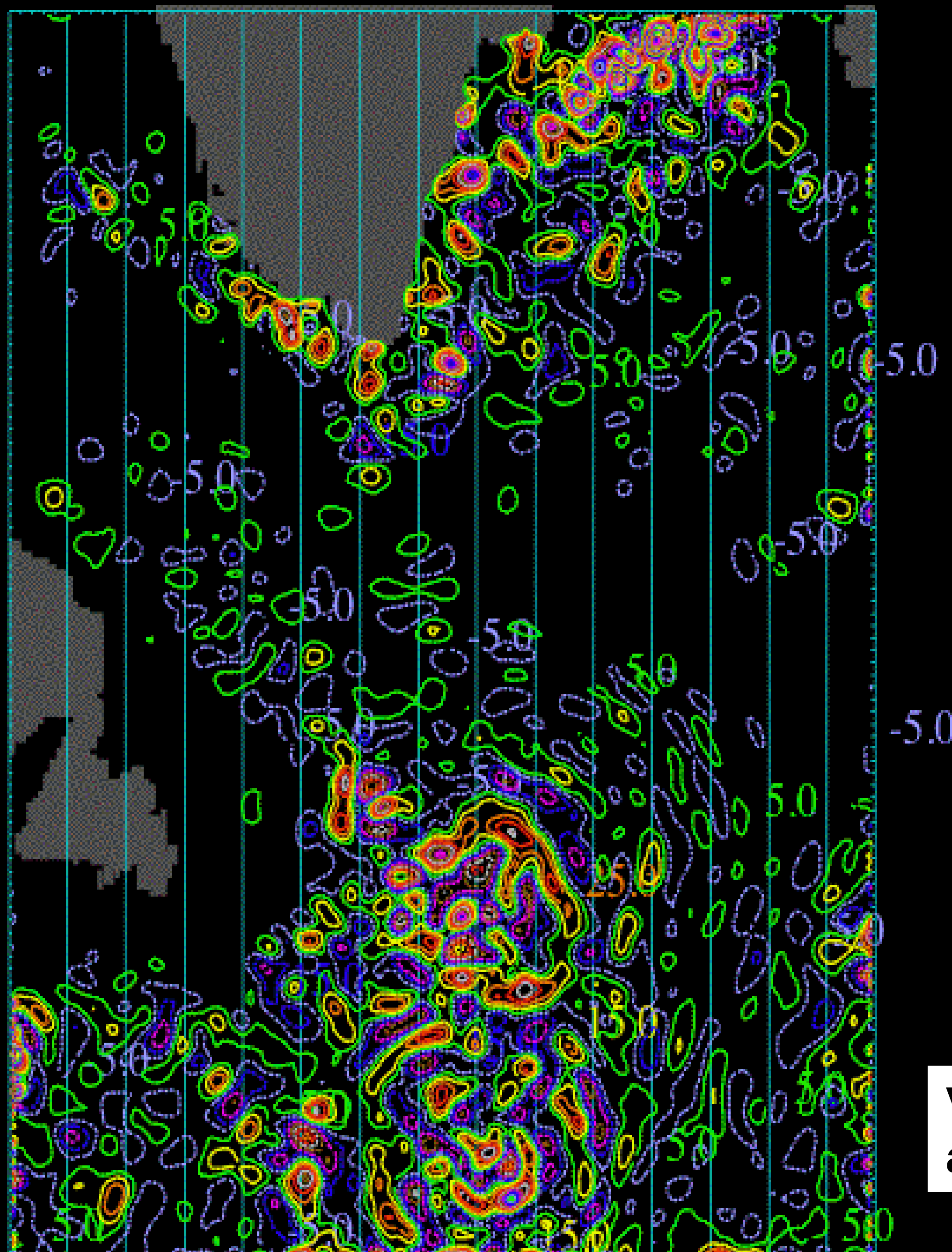
At the end of this talk, an animation will show the nearly seamless behavior of the flow across this intergrid boundary; even fine-scale marginally resolved warm- and cold- core rings pass cleanly across this intergrid boundary.



Greenland
Iceland
Flemish Cap
Newfoundland
Mid-Atlantic Ric
depth & Vbot/day 360, yr 83. Dmx=5km, Vmx=94cm/s



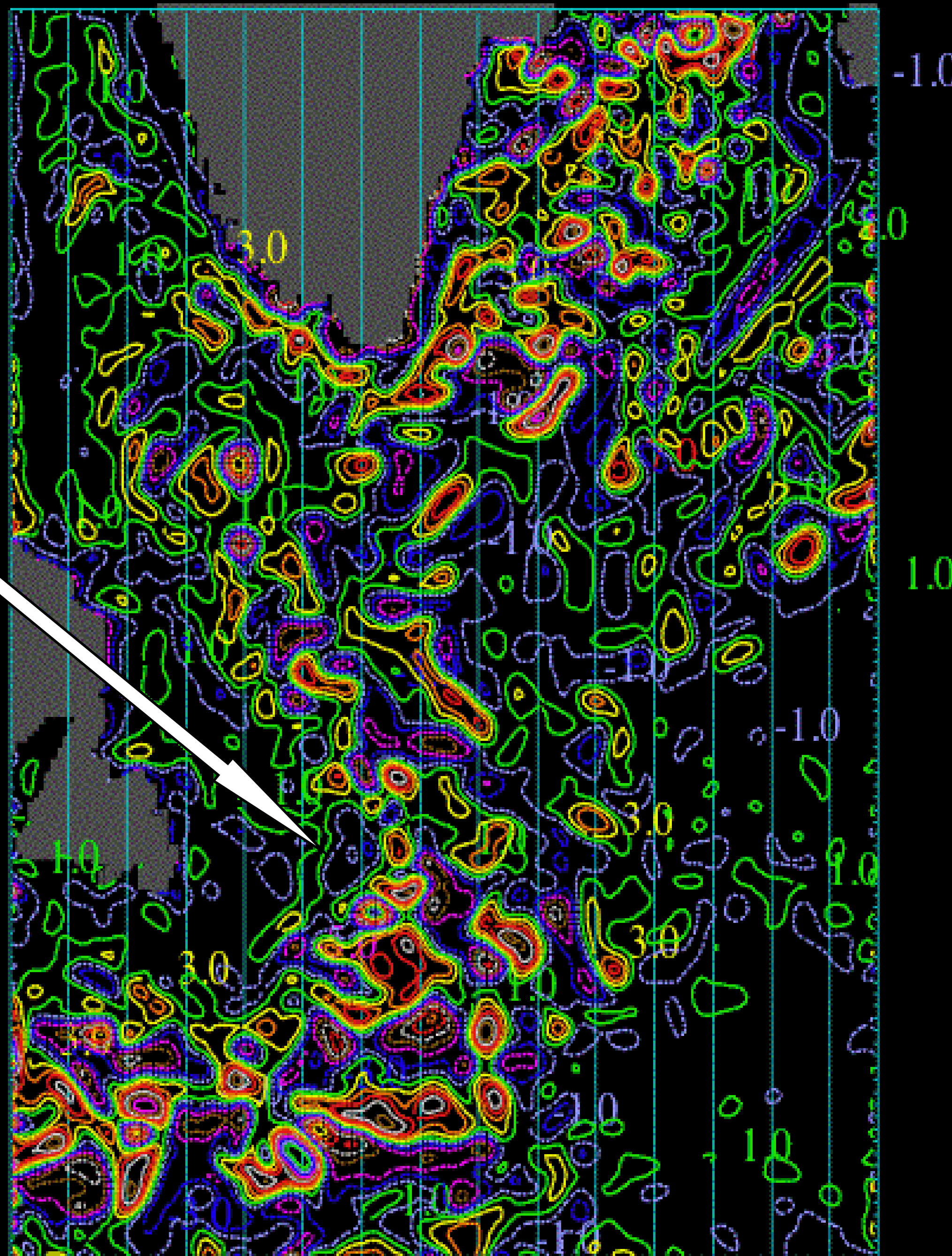
Speed of bottom flow (cm/s)



wbot(m/day)/day 360, yr 83. mn=-370, max=534

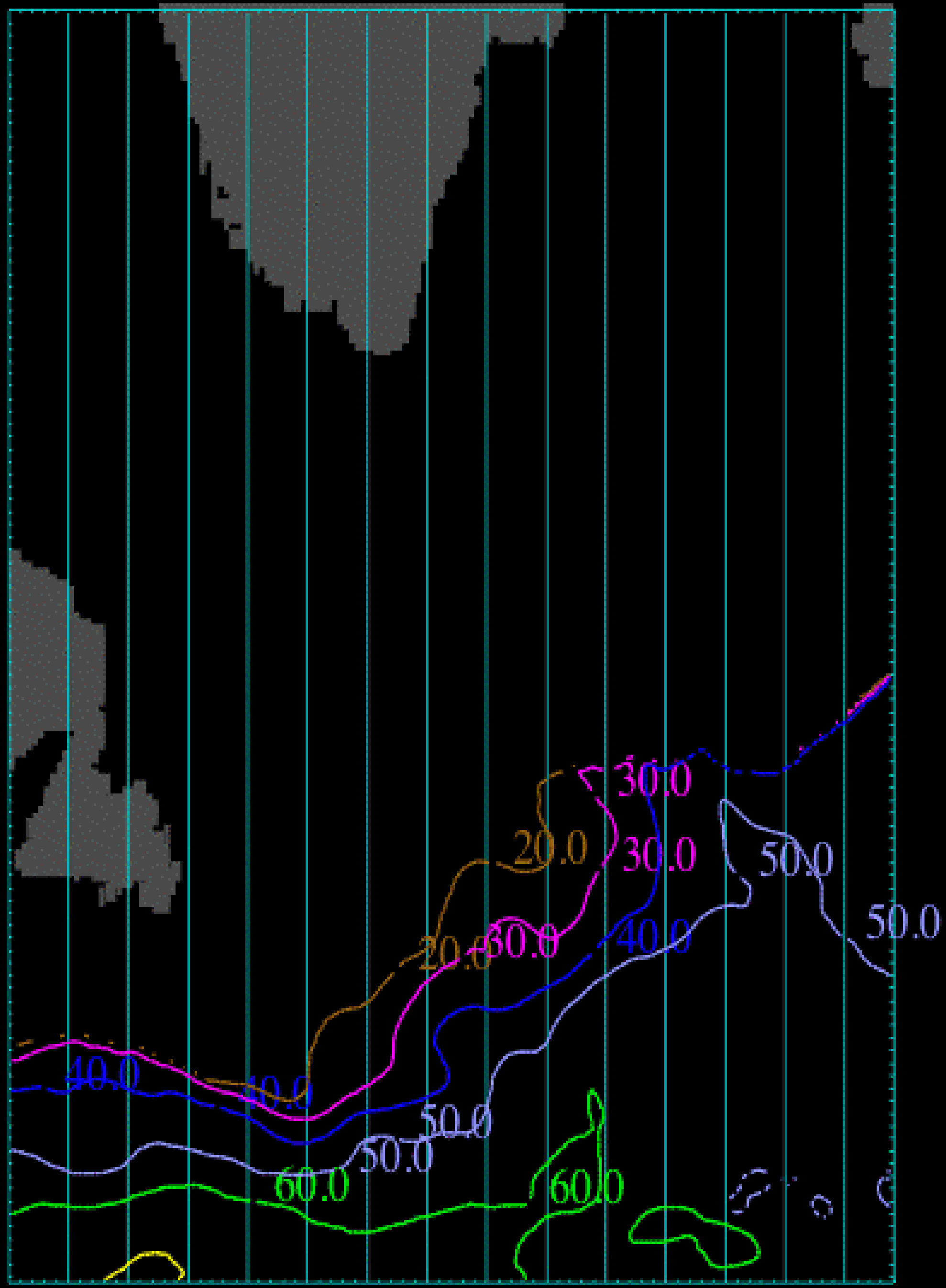
Vertical velocity at 670 m or less

Flemish Cap



vort(rad/wk)/day 360, yr 83. z=5m. mn=-21.6, mx=25.6

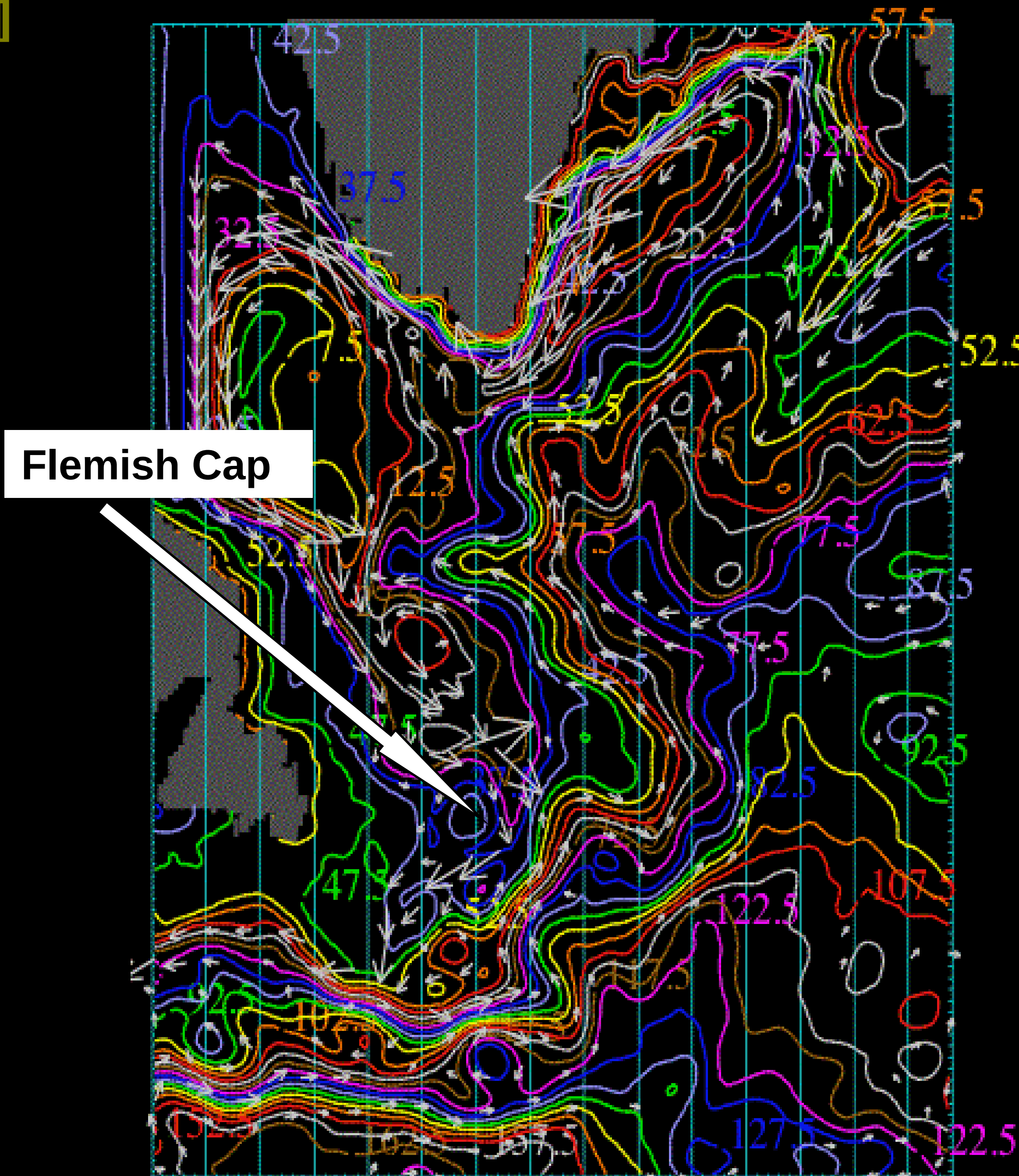
Top layer relative vorticity



avg 12 deg depth/days 0-120, yr 83. mx=71.0decameters

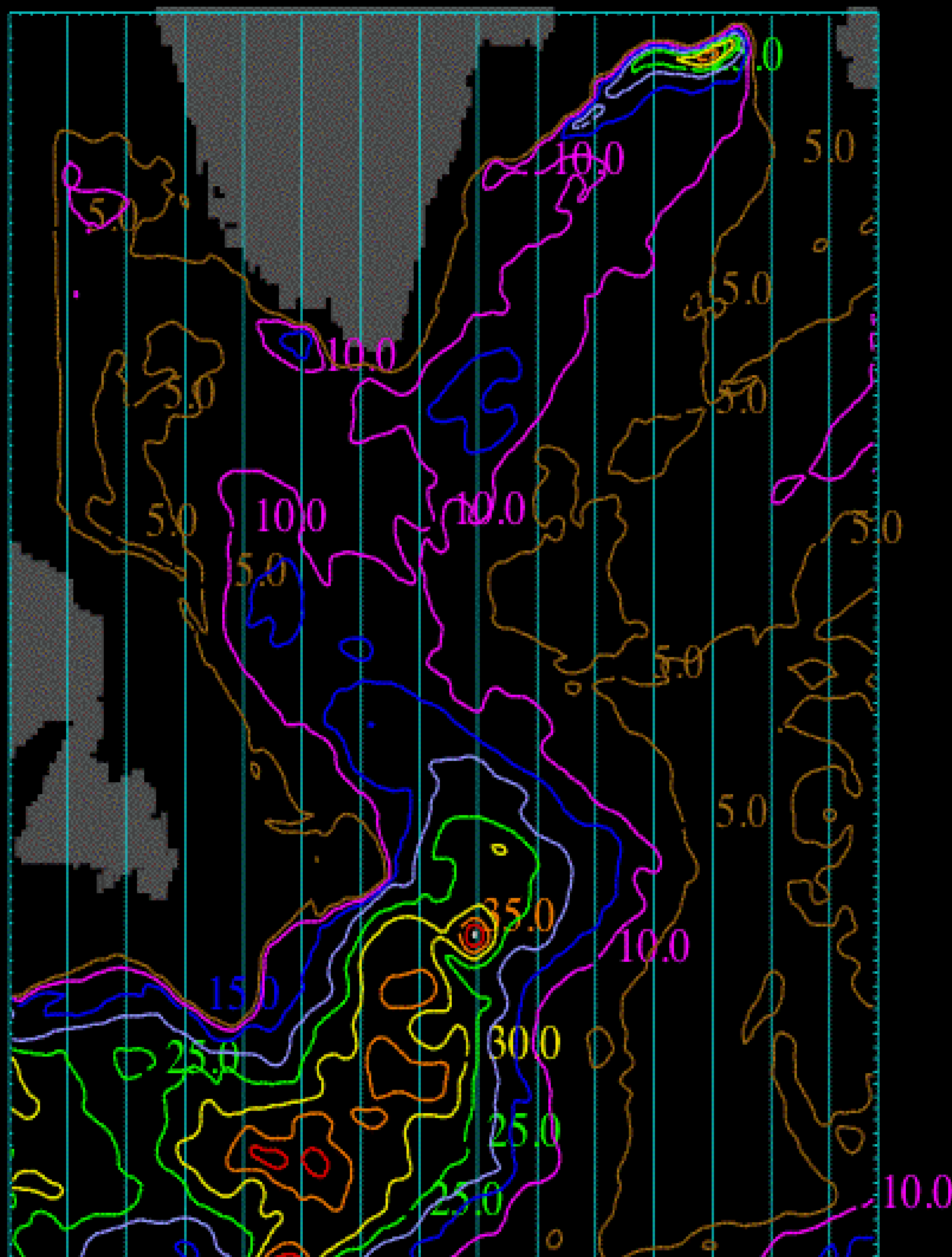
Depth of 12º temperature surface, showing path of Gulf Stream extension.

The blue contour represents the GS core.

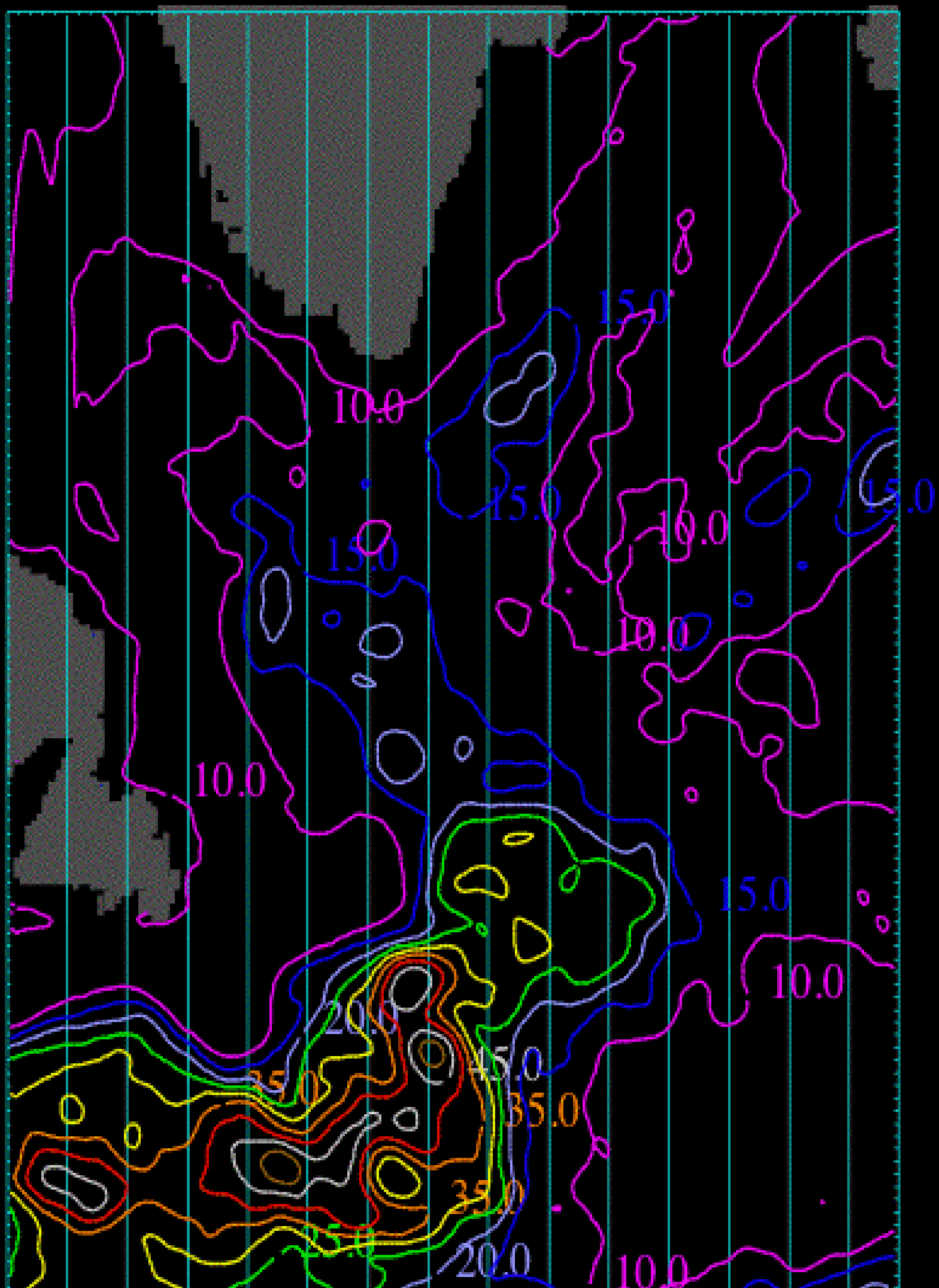


time avg h & V@1000m/days 0-120, yr 83. Hmx-Hmn=168cm, Vmx=59cm/s

Time-mean sea surface height anomaly with 1000m velocity vectors.



RMS velocity deviation from mean at 1000m (cm/s).

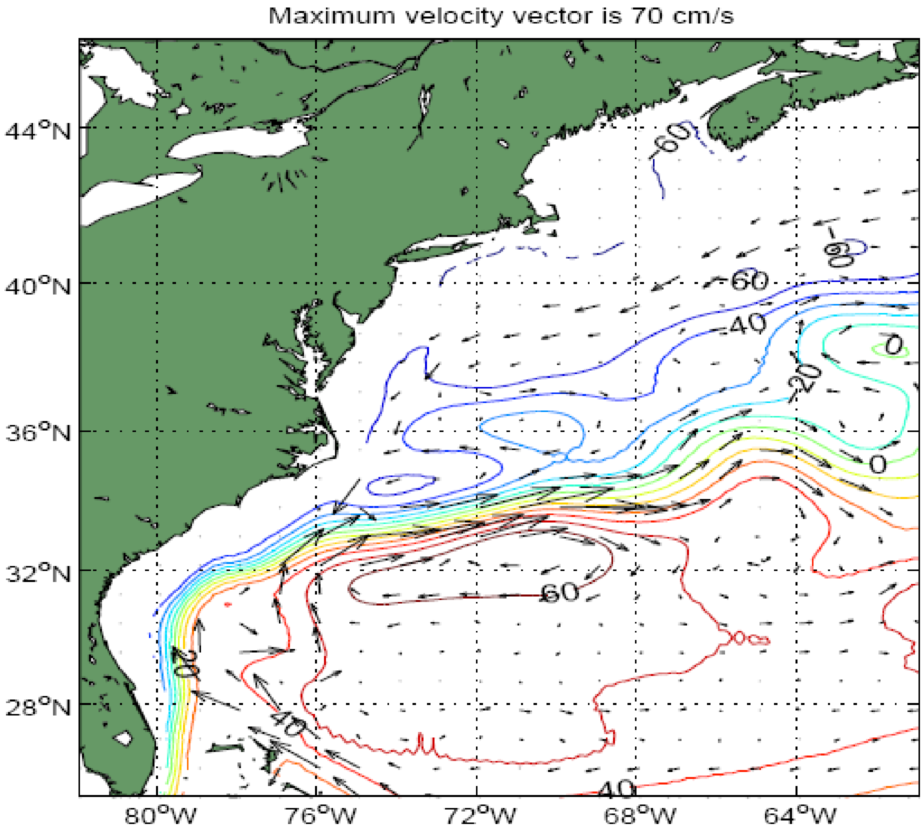


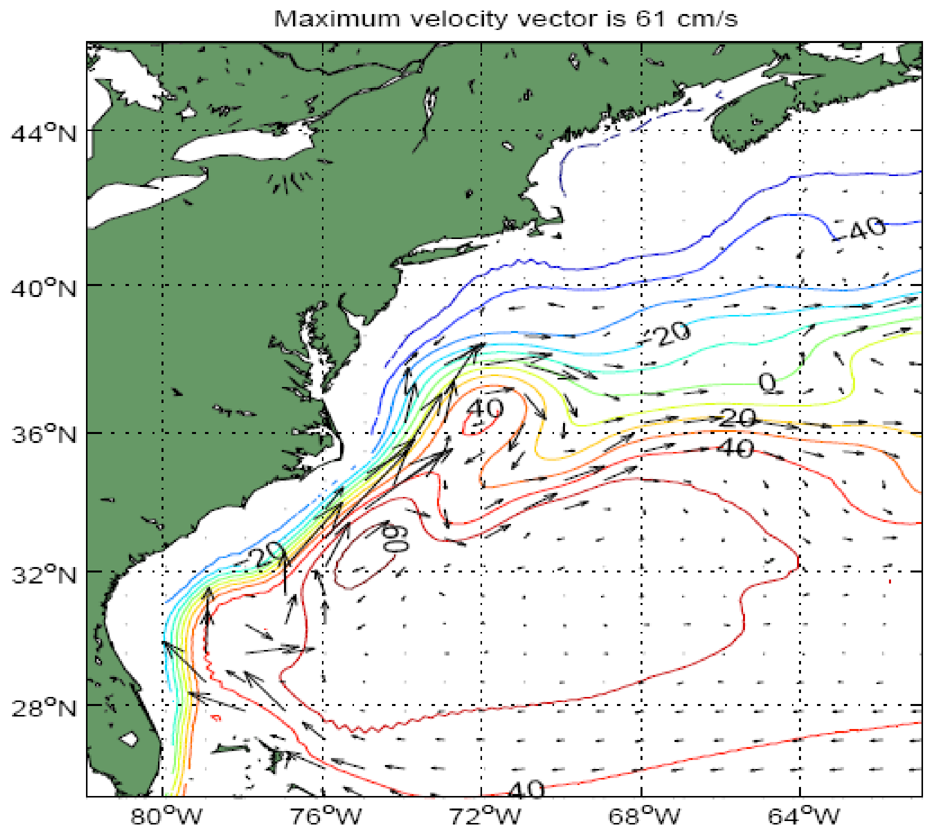
eddy rms h(2nd moment)/days 0-120, yr 83. mx=53.6cm

RMS sea surface height deviation from average (cm).

SUMMARY OF CENTRAL GRID RESULTS

Slides 20-27 showed that the Labrador Sea is strongly ventilated by the Gulf Stream northern branch and eddies that it energizes. This keeps it ice free during winter and makes it a major water mass transformation region.

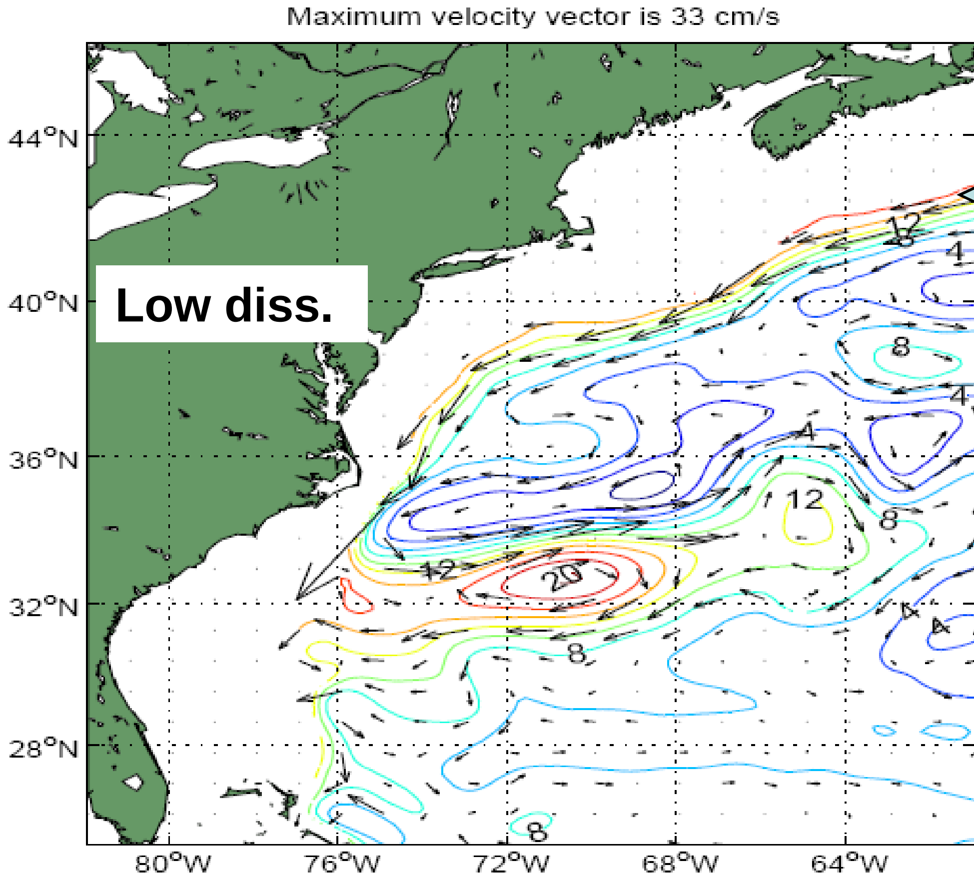


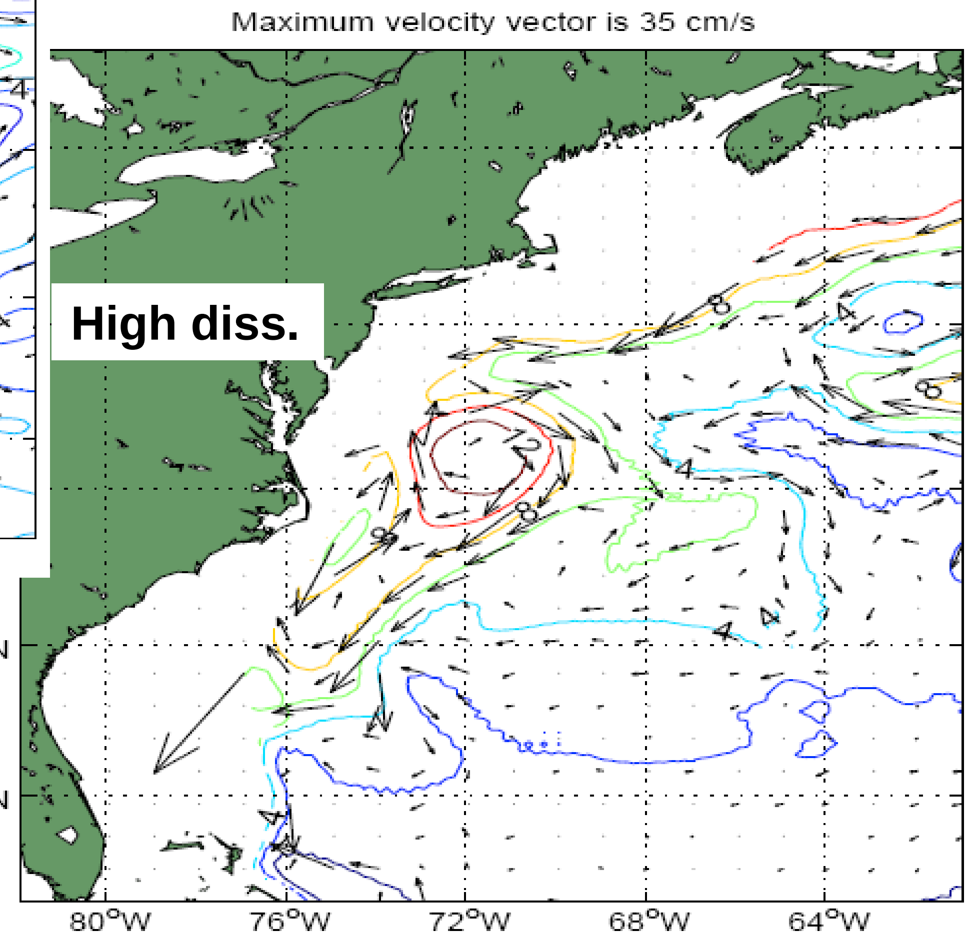


Twenty years mean sea surface height (cm) and 700 m depth velocity vectors in the 1/6 degree resolution western domain. Viscosities are 20 – 60 m^2/s (Top) and 50 – 150 m^2/s (bottom).

Dietrich et al., GRL, 2004).

Density current coming from northern seas

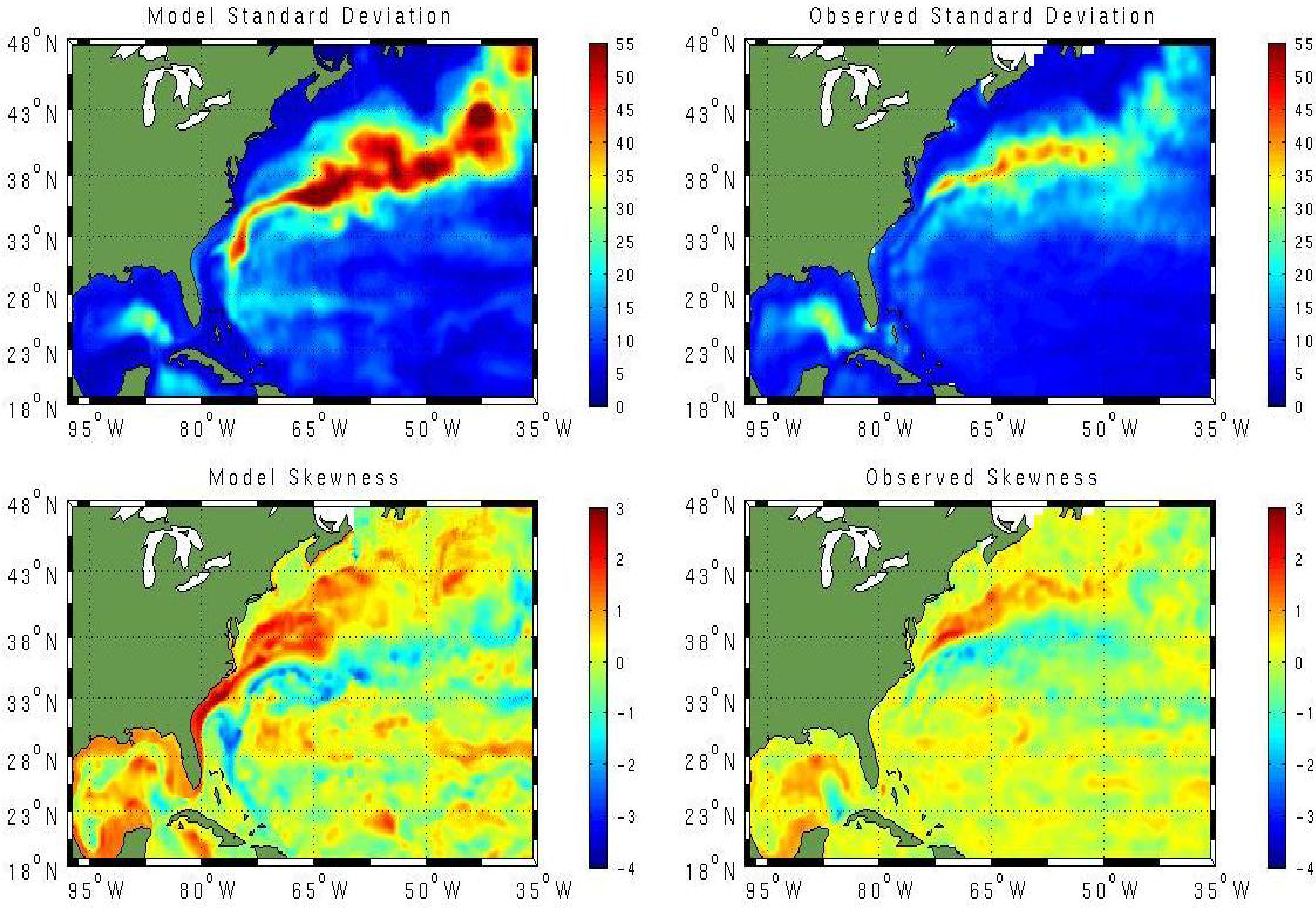


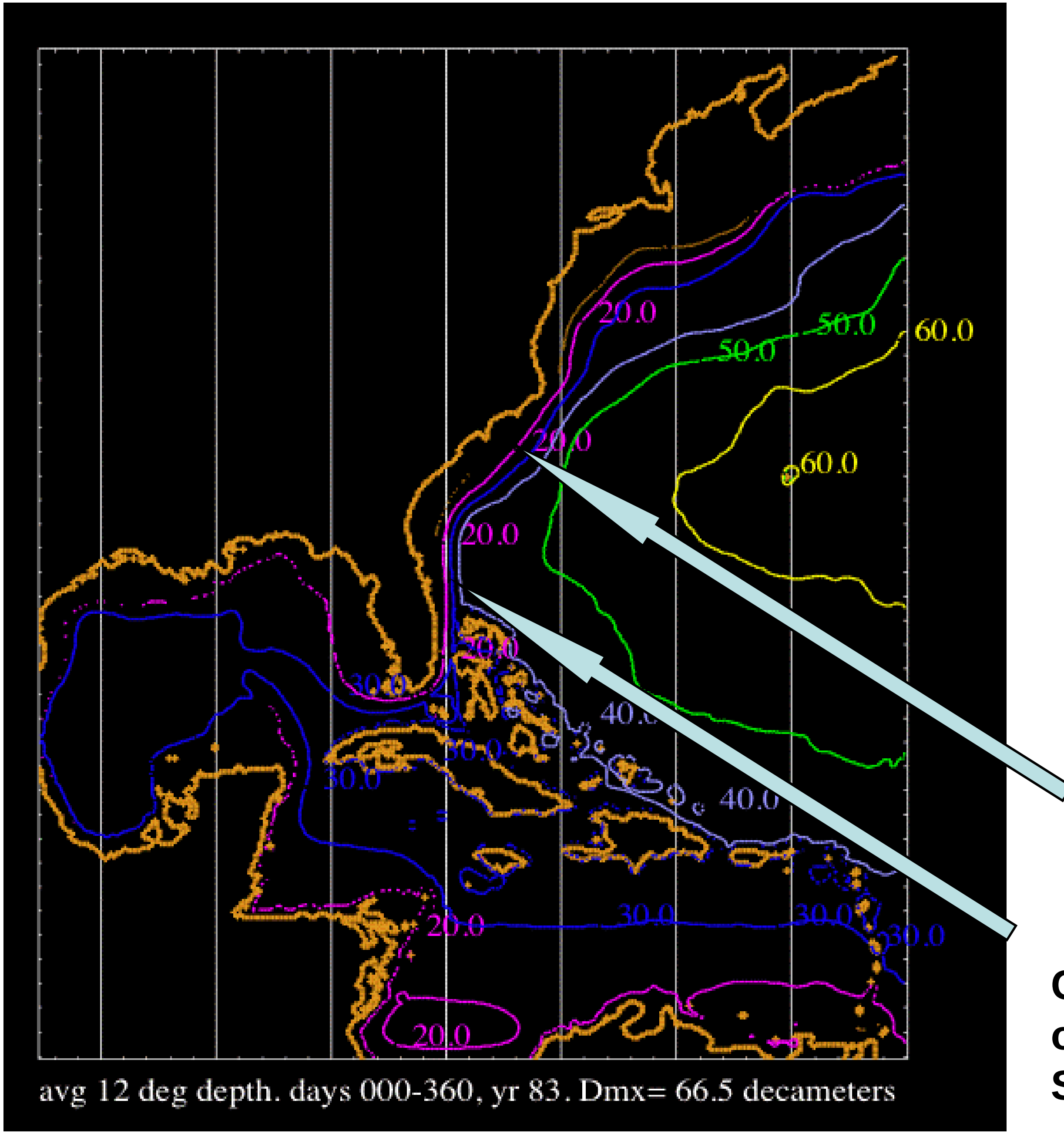


Twenty year mean pressure (cm) and velocity vectors in the 1/6 degree resolution western domain at level 1474m. Viscosities are 20 – 60 m^2/s(Top) and 50 -150 m^2/s(bottom).

Dietrich et al., GRL, 2004).

MEDINA Low Dissipation results (in prep.)

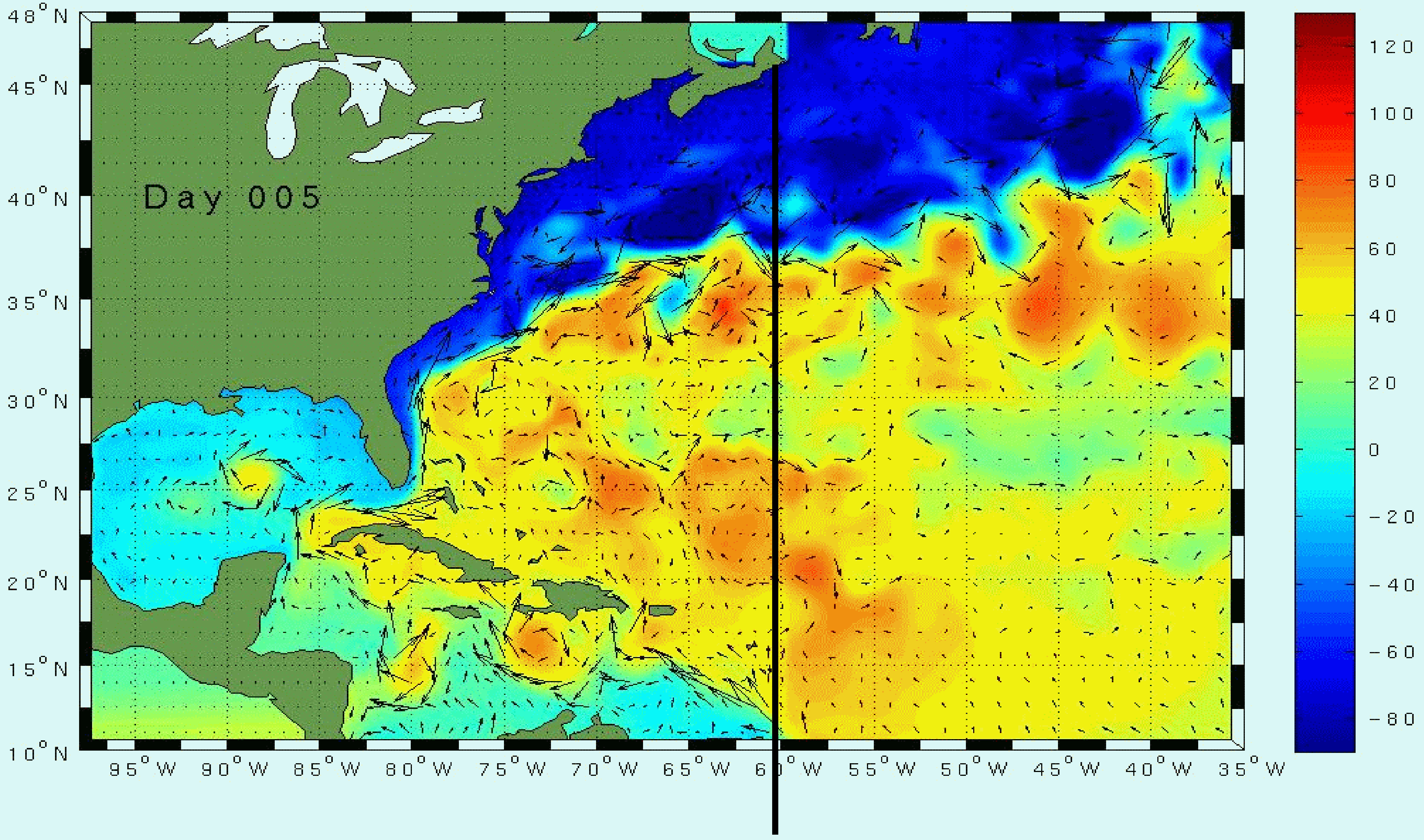




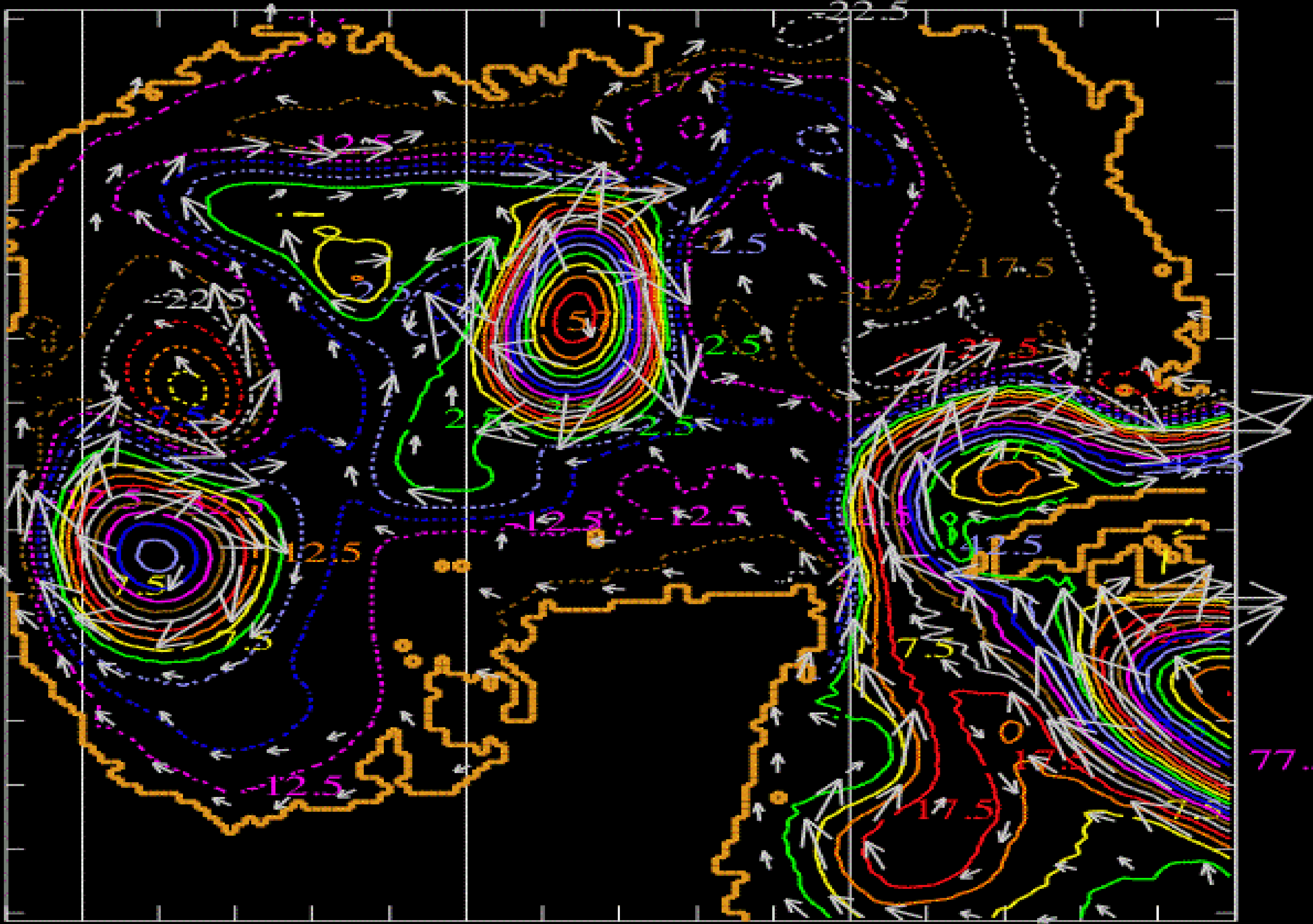
MEDINA year 83 mean depth of 12º temperature surface. The grey contour delineates the path of the Gulf Stream.

Confluence of water east of Bahamas with Florida Strait water.

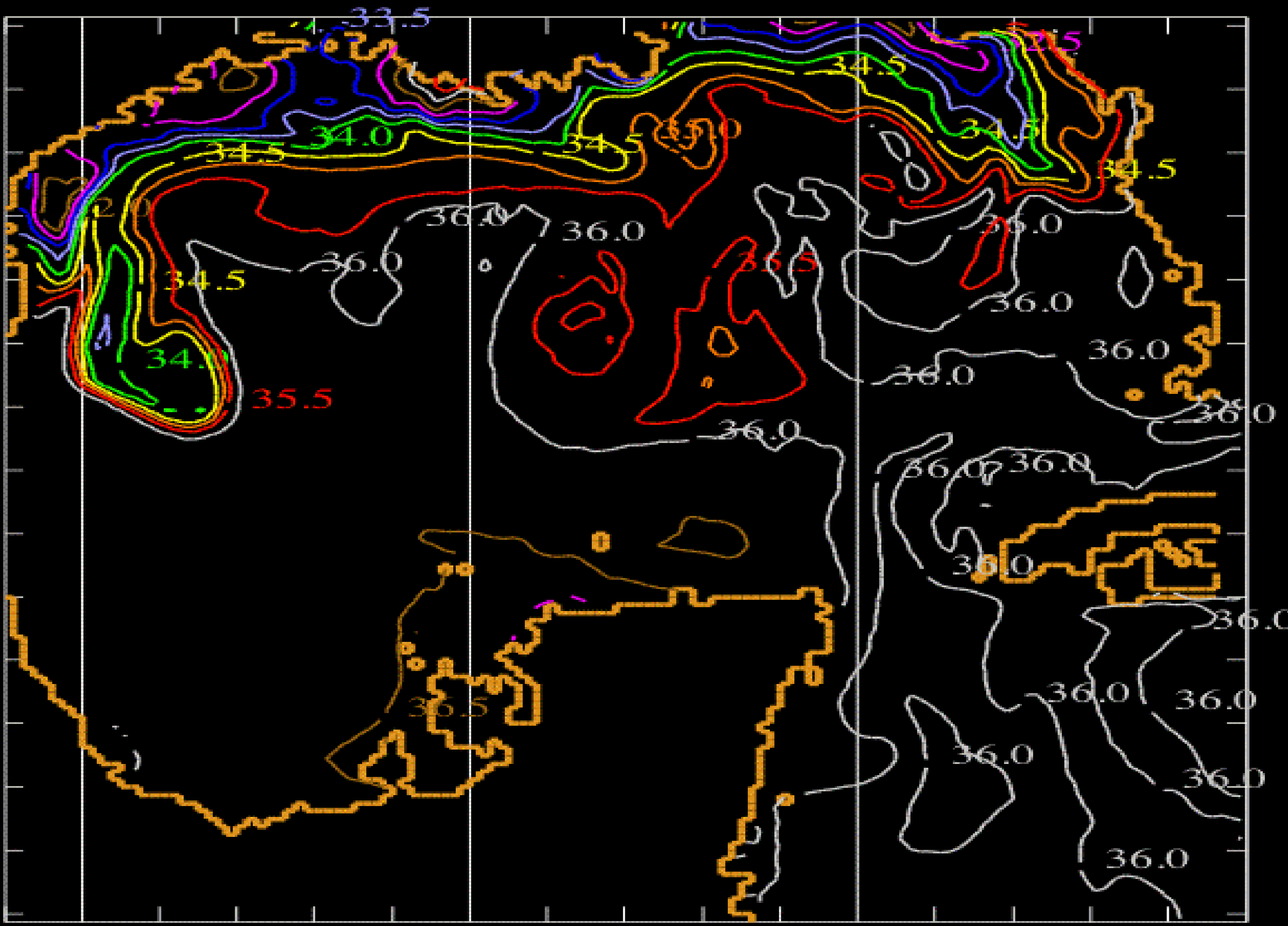
Gulf Stream animation across the inter-grid boundary



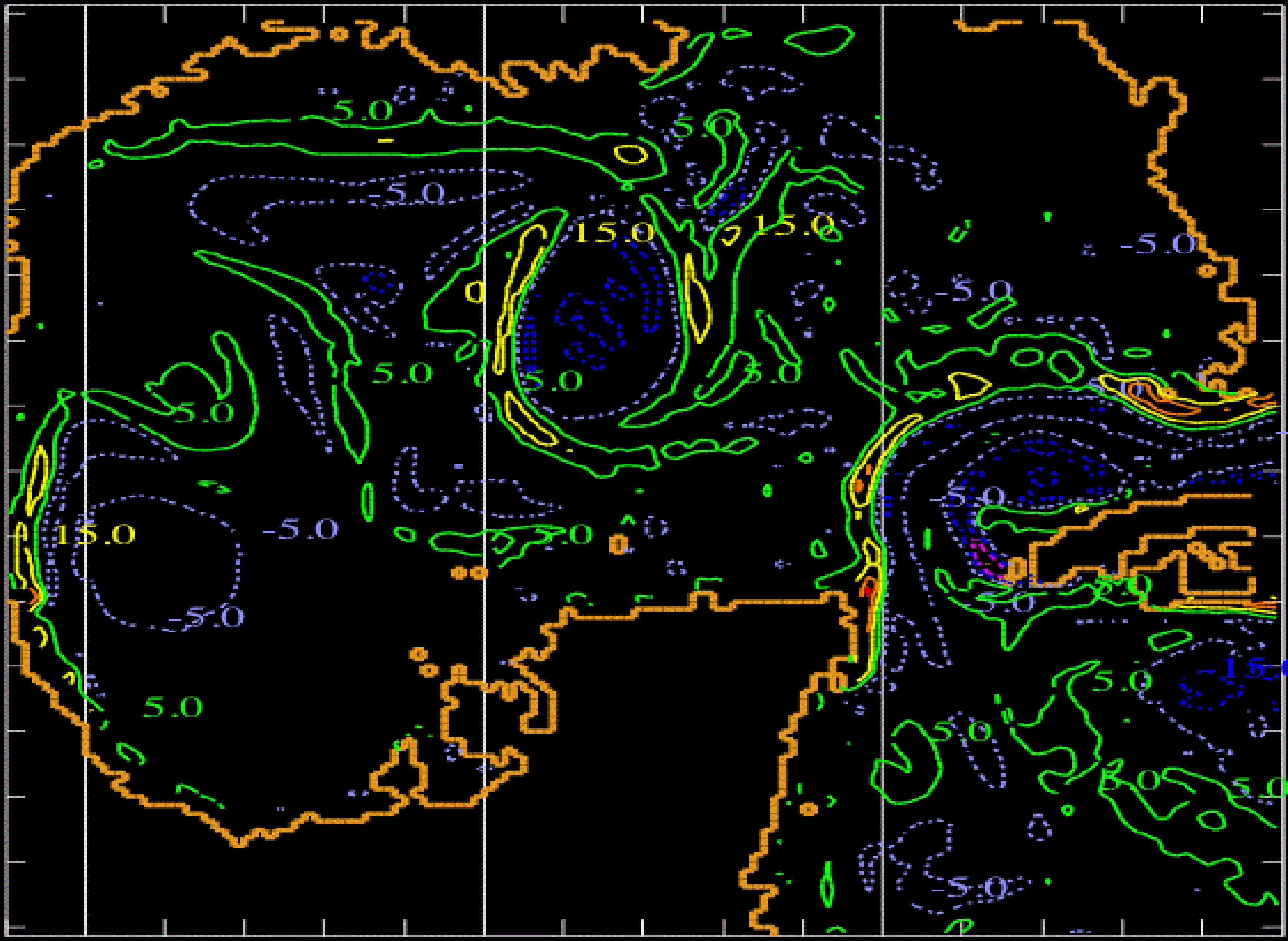
1/8º resolution **1/4º resolution**



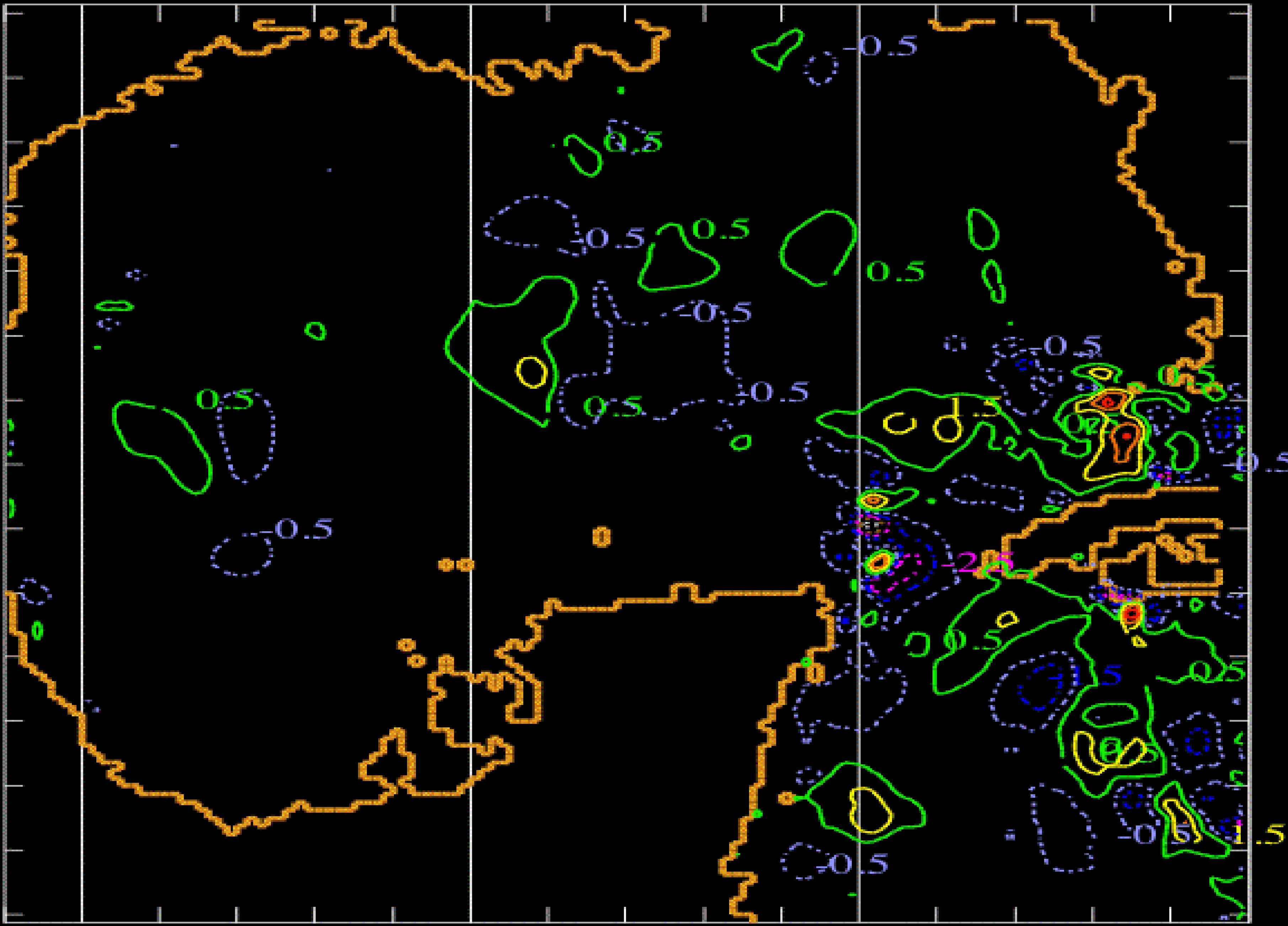
h & V. day 120, yr 83. z=5m. Hmx-Hmn=147cm, Vmx=173cm/s



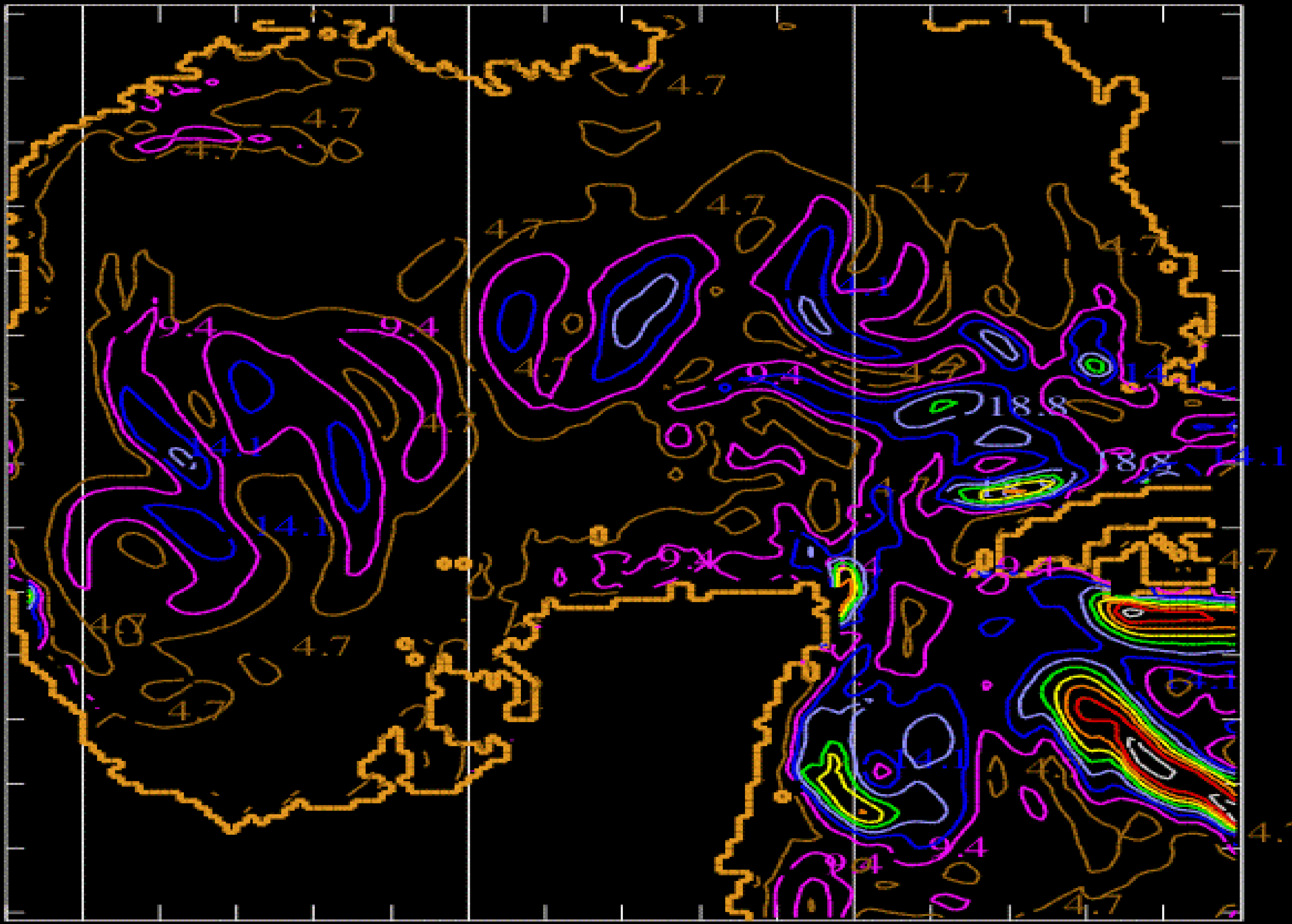
S(ppt). day 120, yr 83. z=5m. Smn=30.7, Smx=37.2



vort(rad/wk). day 120, yr 83. z= 5m. mn=-36.1, mx=37.4



w @ bottom or 670m, dm/day. day 120, yr 83. mn=-5.2, mx=4.5



deep flow speed. day 120, yr 83. Cmx=46.9cm/s

See attached file anim.gif for animation

Concluding remarks

Well validated results from a survey of basin scale simulations by the DieCAST ocean model, including the Gulf of Mexico, Black Sea, Adriatic Sea, and six-grid MEDIterranean Sea and North Atlantic (MEDINA model) have been shown. All simulations were done on a personal computer using no data assimilation.

Results illustrated the nonlinear geophysical fluid dynamics involved in a variety of flow configurations, including: vortex shedding in the wakes of island and coastal abutments; frontal eddies; river plume meanders; baroclinic instability; and downslope density current penetration. Notable results include:

1. **Accurate simulation of model-challenging thin, narrow intense shelfslope jet of Mediterranean Overflow Water, and the deep salty, warm current that it feeds, which affects the deep North Atlantic salt and heat balance.**

2. **Realistic eddy ventillation of the Labrador Sea by eddies that are energized by the Gulf Stream interaction with the Labrador density current in the 1/4 deg resolution central North Atlantic grid.**

Concluding remarks (cont'd)

This success is due to:

a) **Using raw unfiltered bathymetry.**

b) **Low dissipation and 4th-order-accurate numerical approximations on a non-staggered Arakawa "a" grid.**

c) **NOT invoking instant convective adjustment or other highly dilusive subgridscale vertical mixing parameterization.**

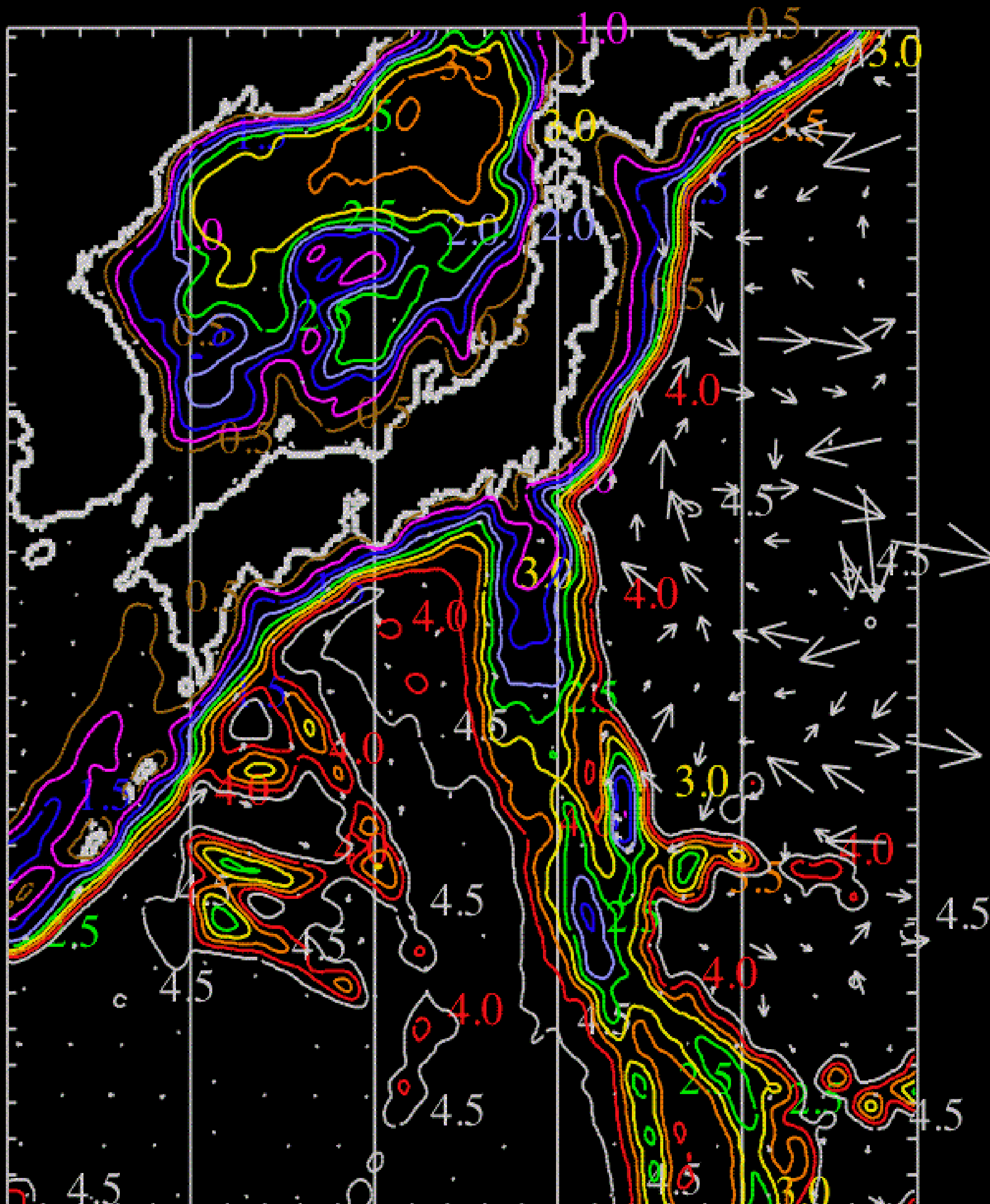
Based on results shown in this presentation, conventional wisdom that:

a) **density currents cannot be accurately simulated by z-level models; and**

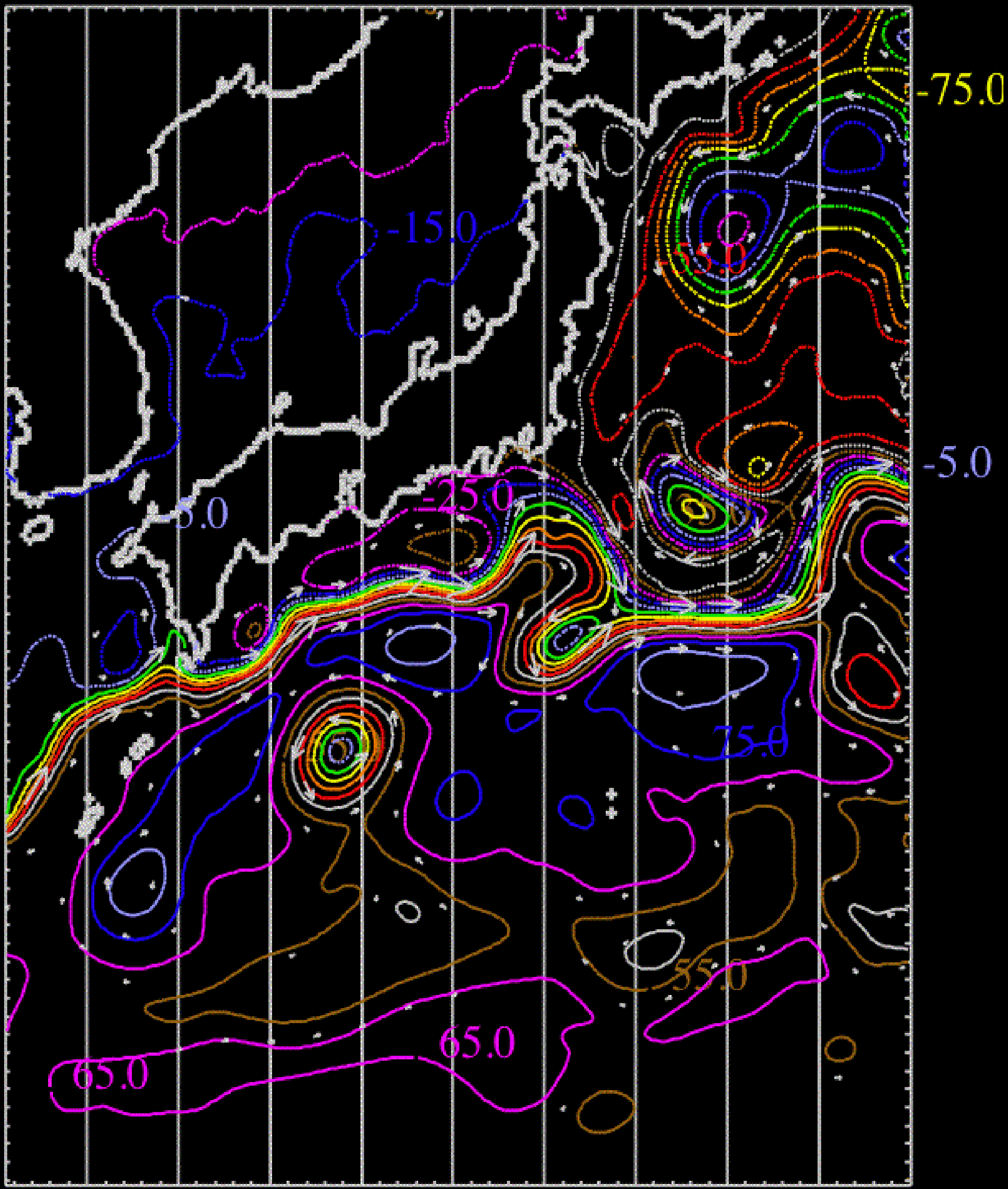
b) **reasonable eddy amplitudes, distribution and interaction with the general circulation require at least 1/10 deg resolution**

may be premature and too pessimistic.

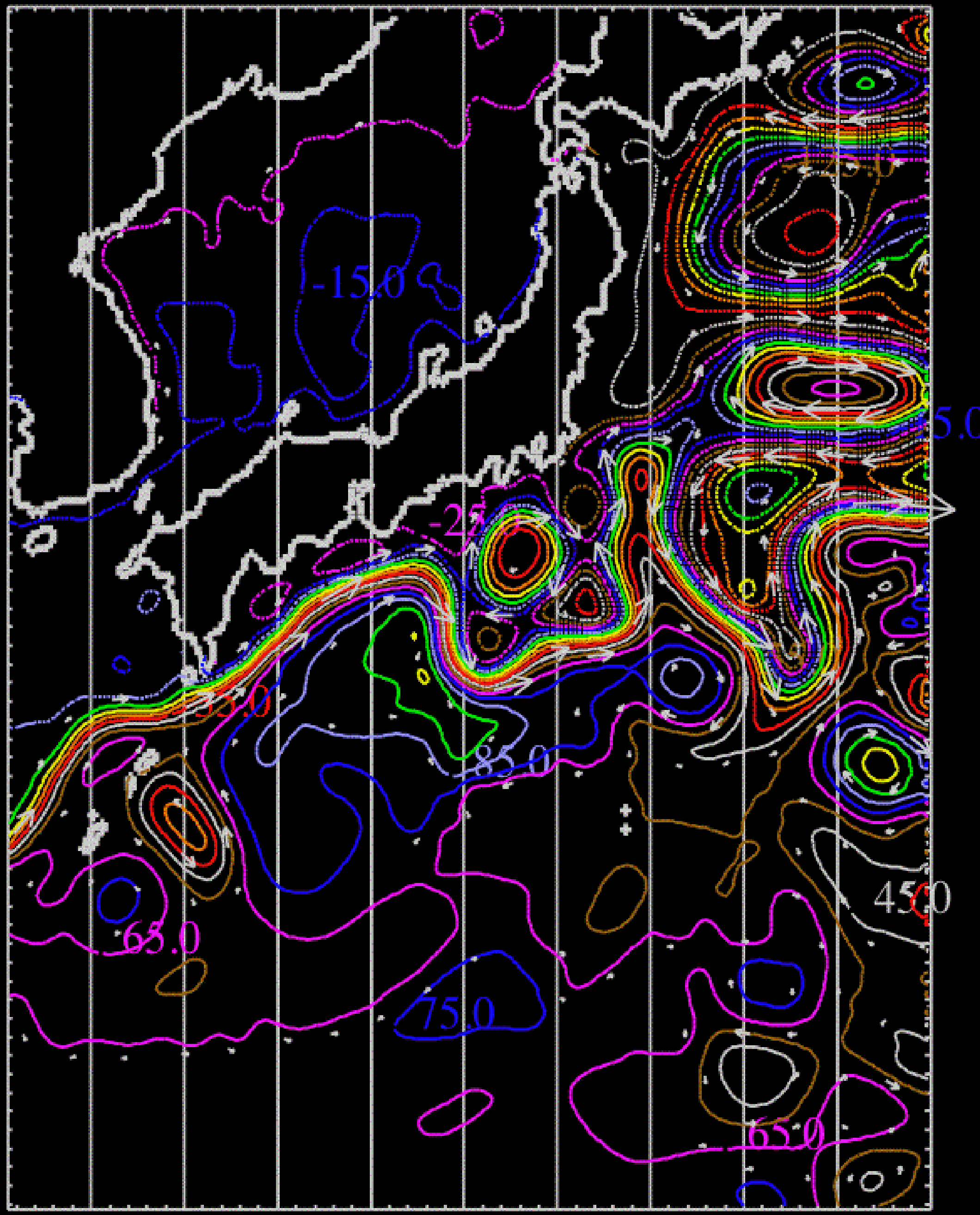
The End



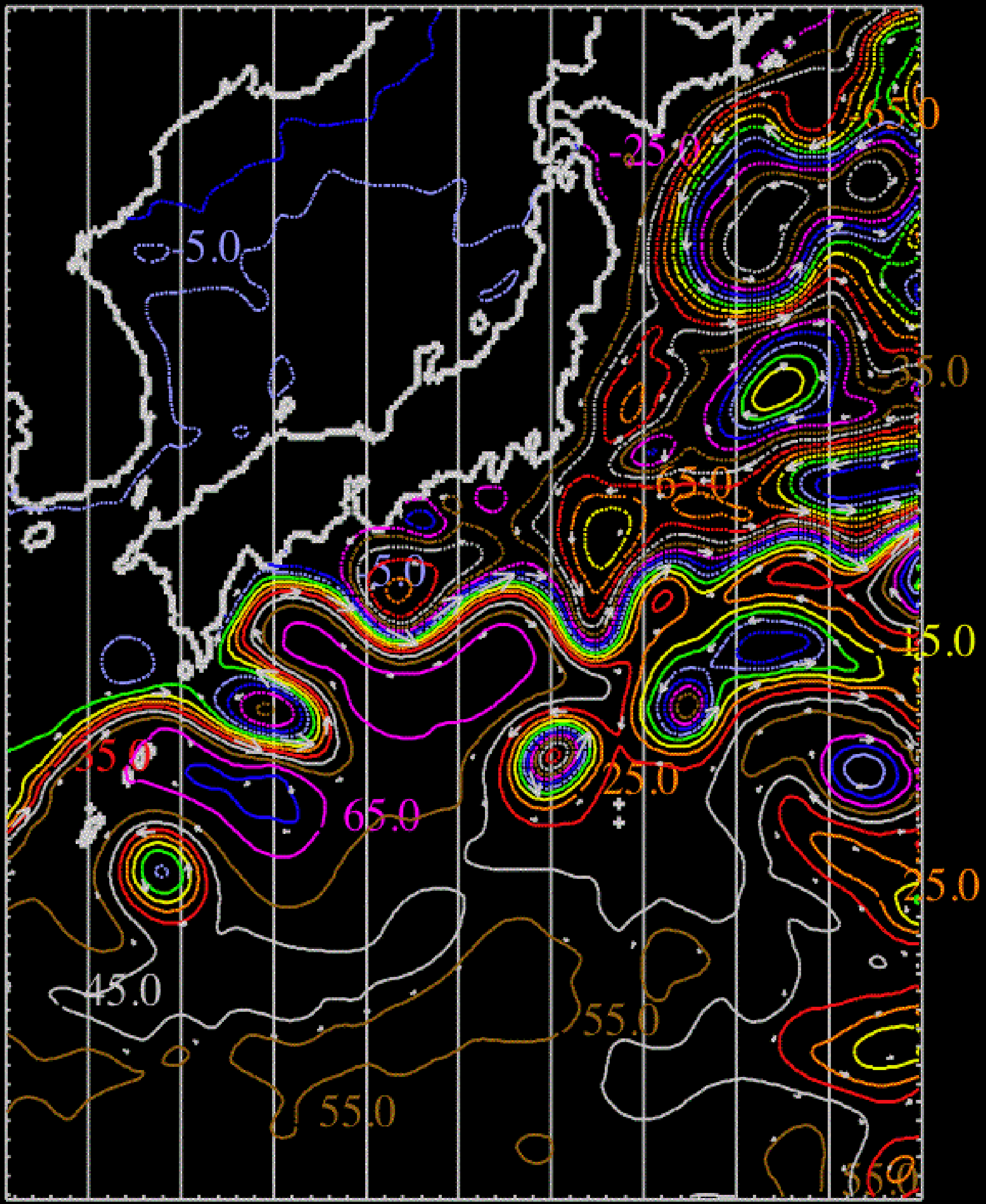
depth & Vbot @ day 360, yr 23. Dmx= 5km, Vmx= 64cm/s



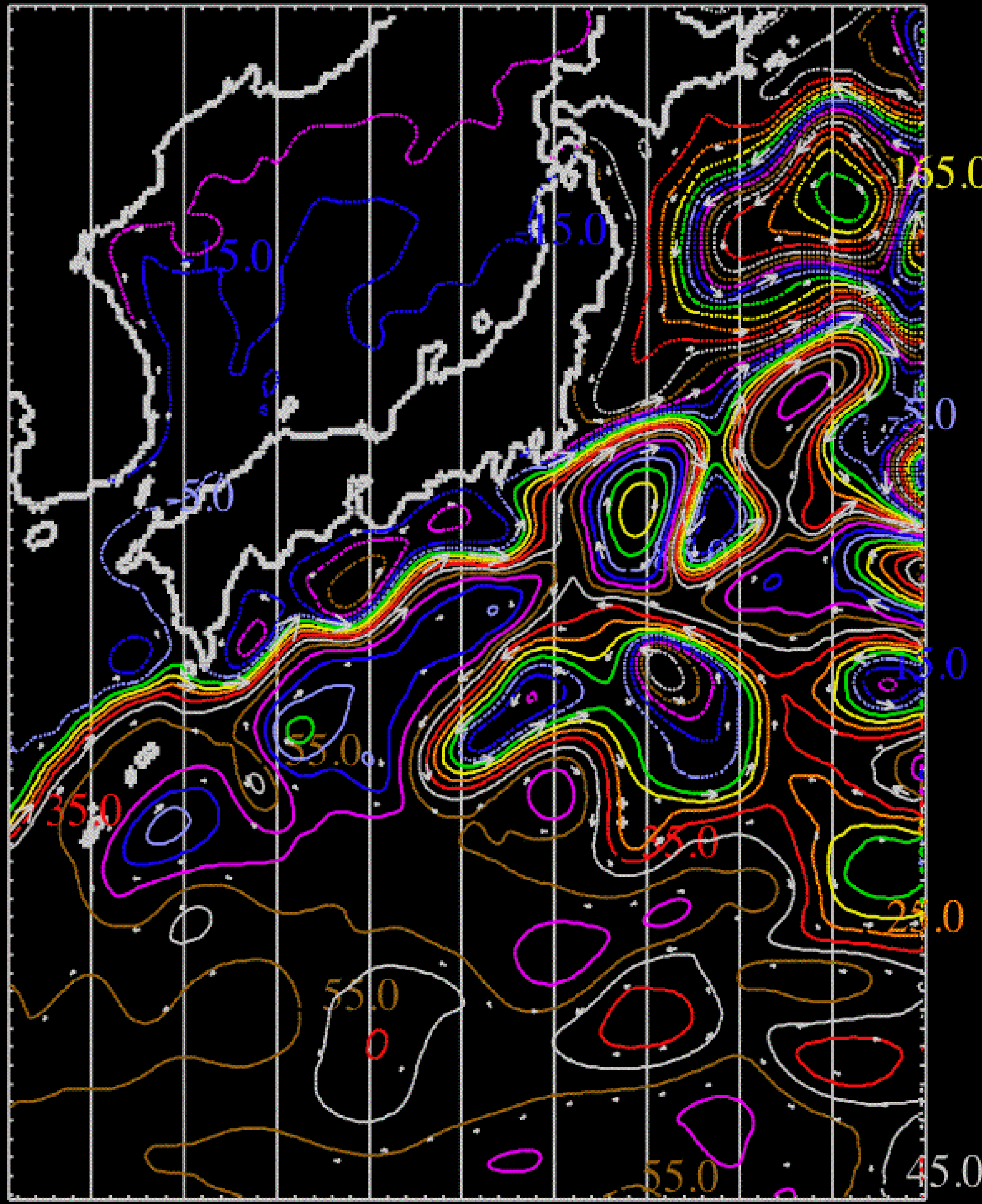
NORPAC1:h & V @ day 70, yr 23. z= 21m. Hmx-Hmn= 213cm, Vmx= 190cm/s



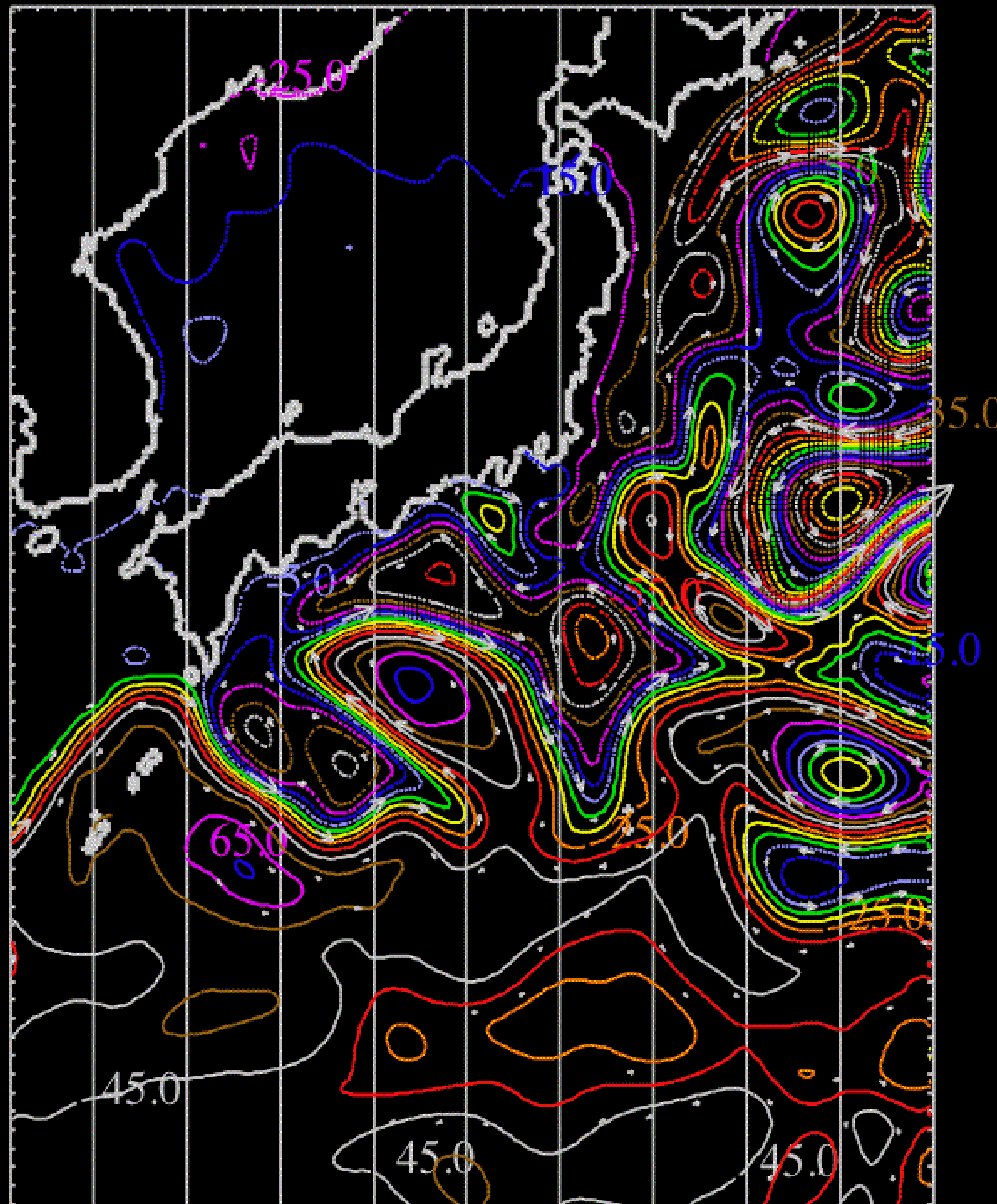
NORPAC1:h & V @ day 180, yr 23. z= 21m. Hmx-Hmn= 267cm, Vmx= 210cm/s



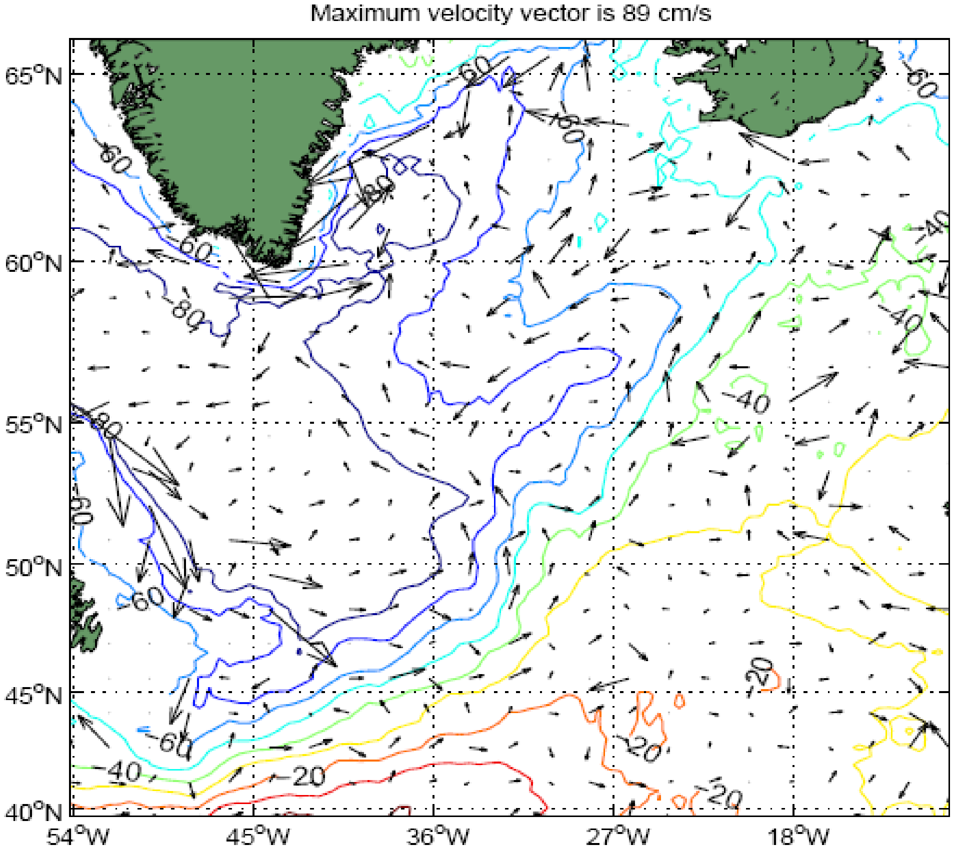
NORPAC2:h & V @ day 180, yr 23. z= 21m. Hmx-Hmn= 257cm, Vmx= 264cm/s

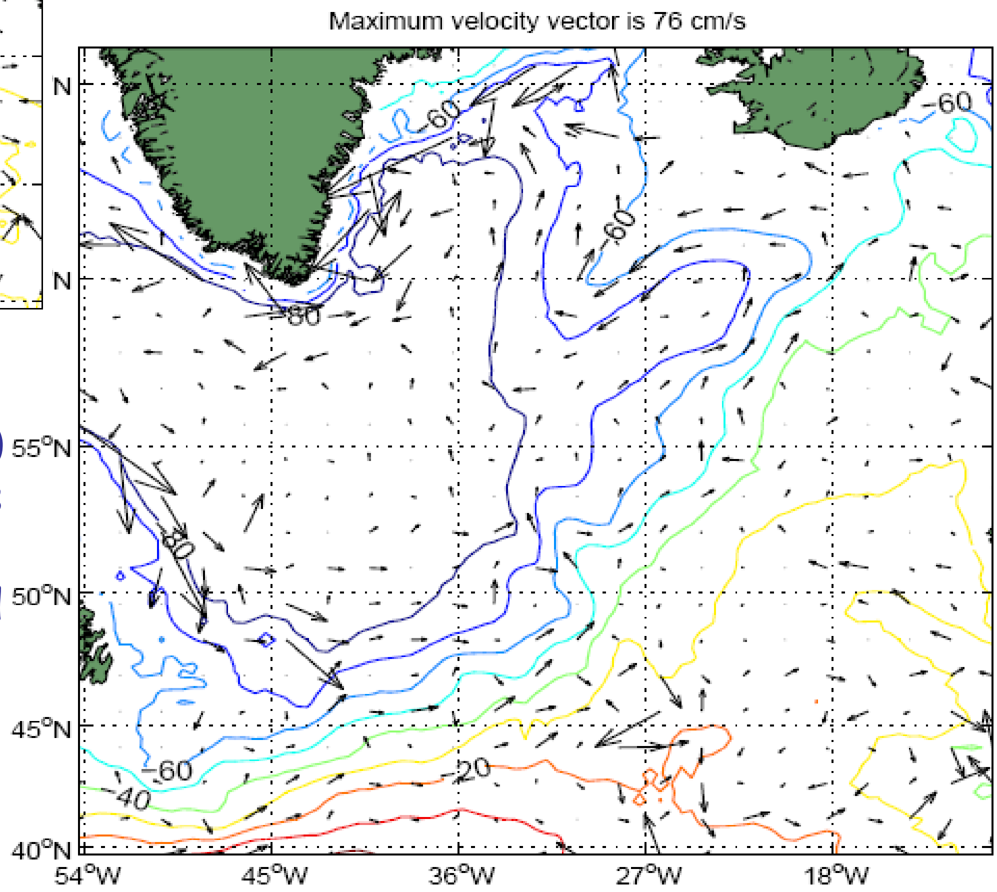


NORPAC1:h & V @ day 275, yr 23. z= 21m. Hmx-Hmn= 354cm, Vmx= 232cm/s



NORPAC2:h & V @ day 275, yr 23. z= 21m. Hmx-Hmn= 296cm, Vmx= 274cm/s





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)

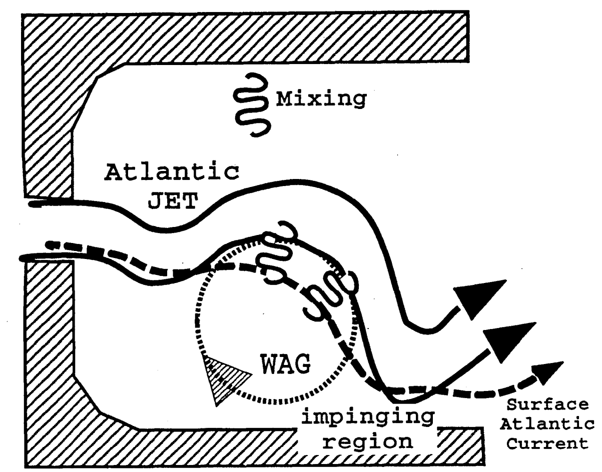
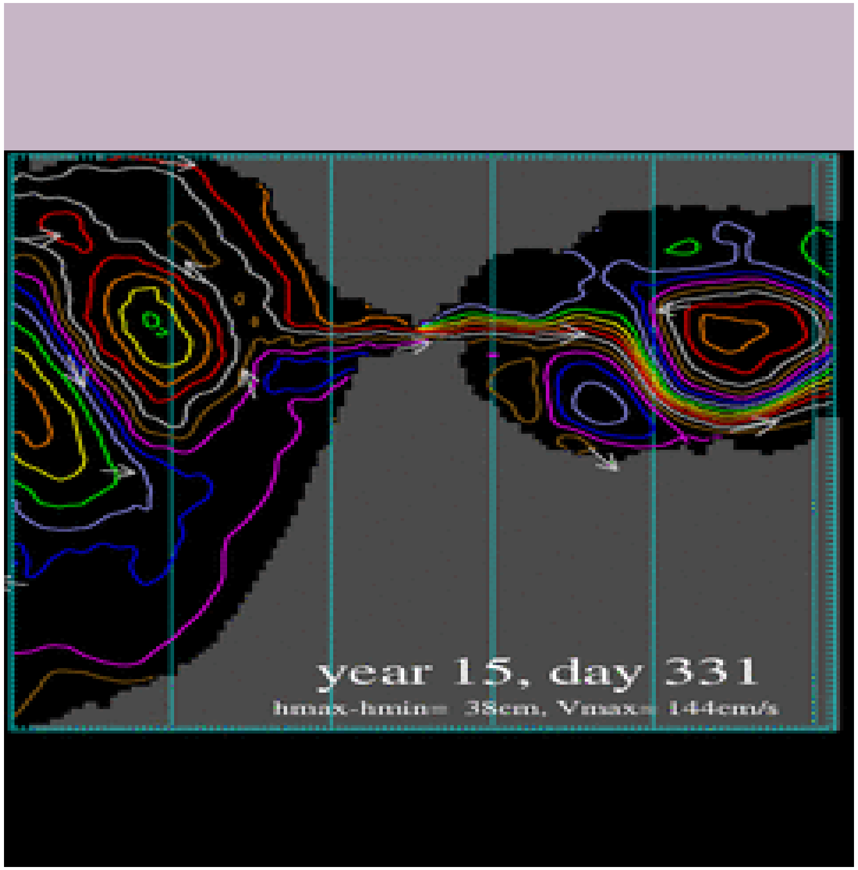


Figure 3. Sketch of the upper circulation (0-200 m) in the western Alboran basin. The surface Atlantic current, characterized by a salinity minimum, may enter into the western Alboran gyre (WAG) crossing the isolines of dynamic height anomaly produced by the deeper density gradients of the gyre. After 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)



MODEL USED IN THIS OCEAN-MODEL-BASED STUDY

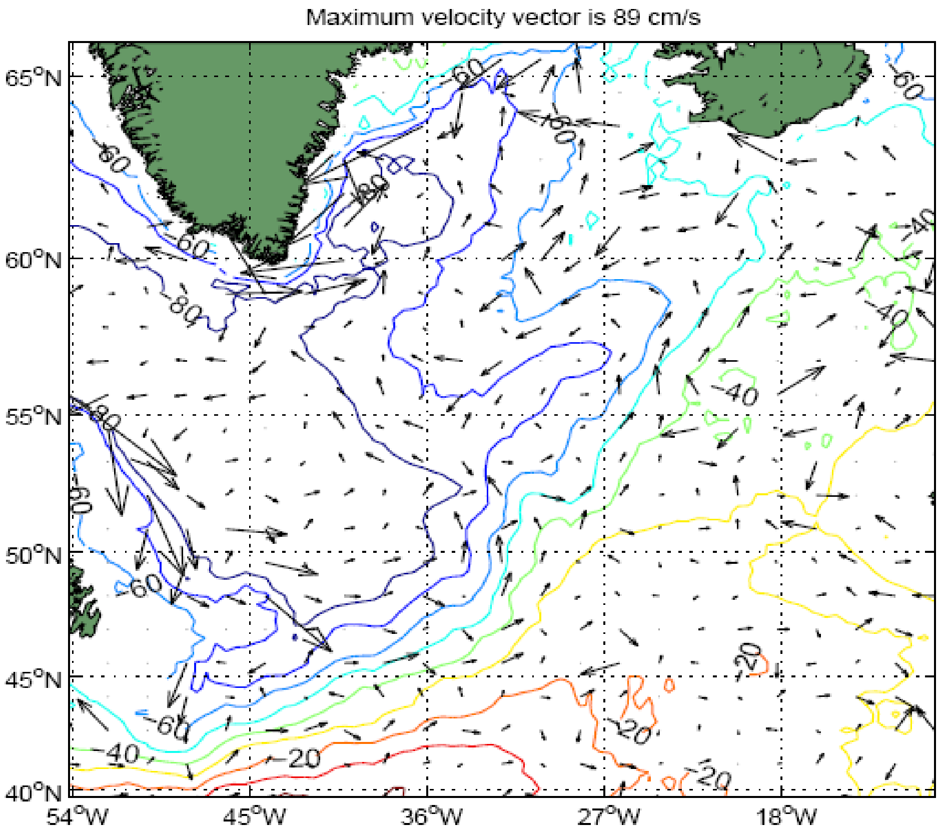
- The hydrostatic version of the DieCAST ocean model used in this study is a z-level model using 4th-order-accurate approximations and a reduced dispersion incompressibility algorithm on a semi-collocated control volume grid.

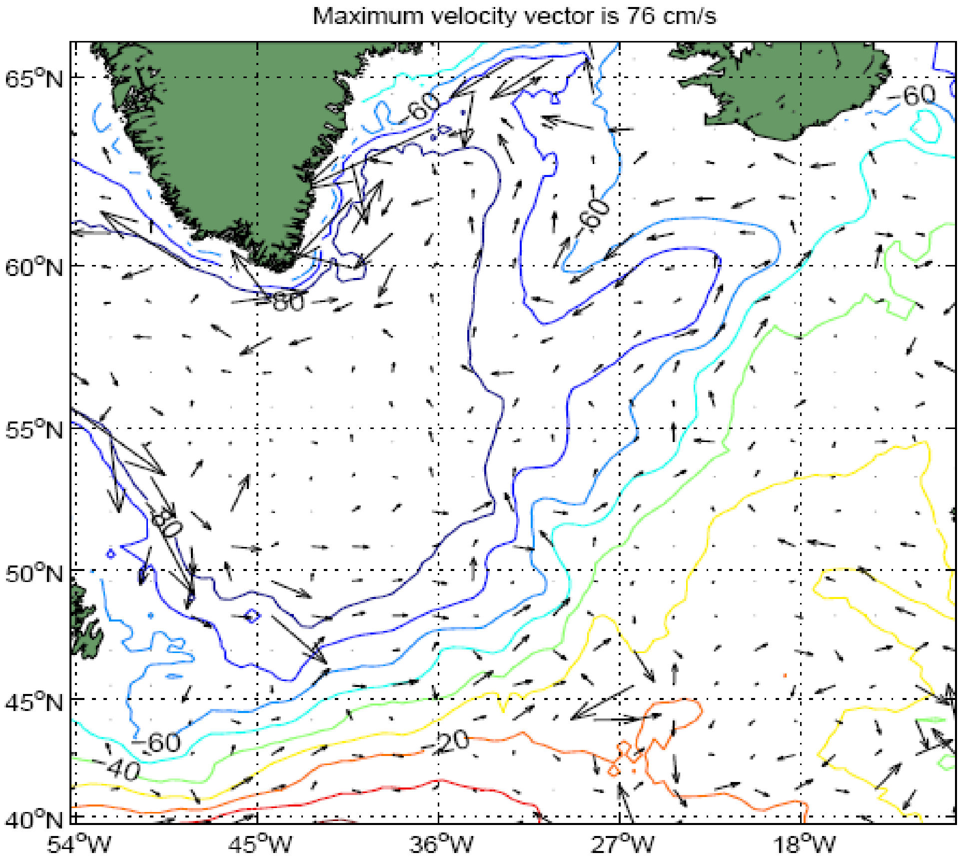
- Multiple-grid coupling technique (the resolution ranges from 1/24° to 1/4°). -NEW!

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

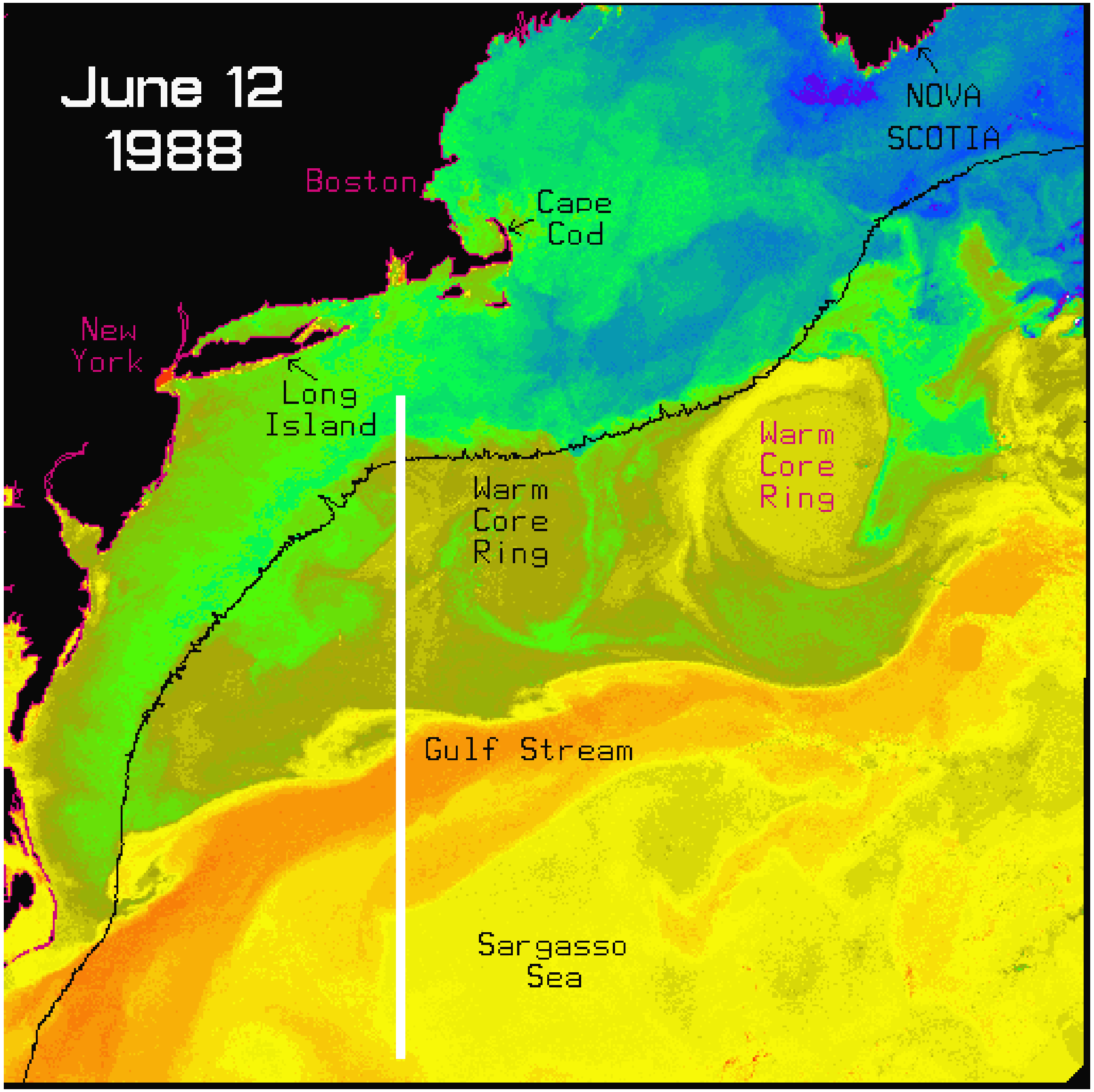
- Multi-domain Parallelization is currently underway

This slide shows dissipation effects based on results from the original two-grid North Atlantic simulation, taken from (Dietrich et. al 2004, AGU-highlighted paper).





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 (left) and 50 – 150 m^2/s (right)



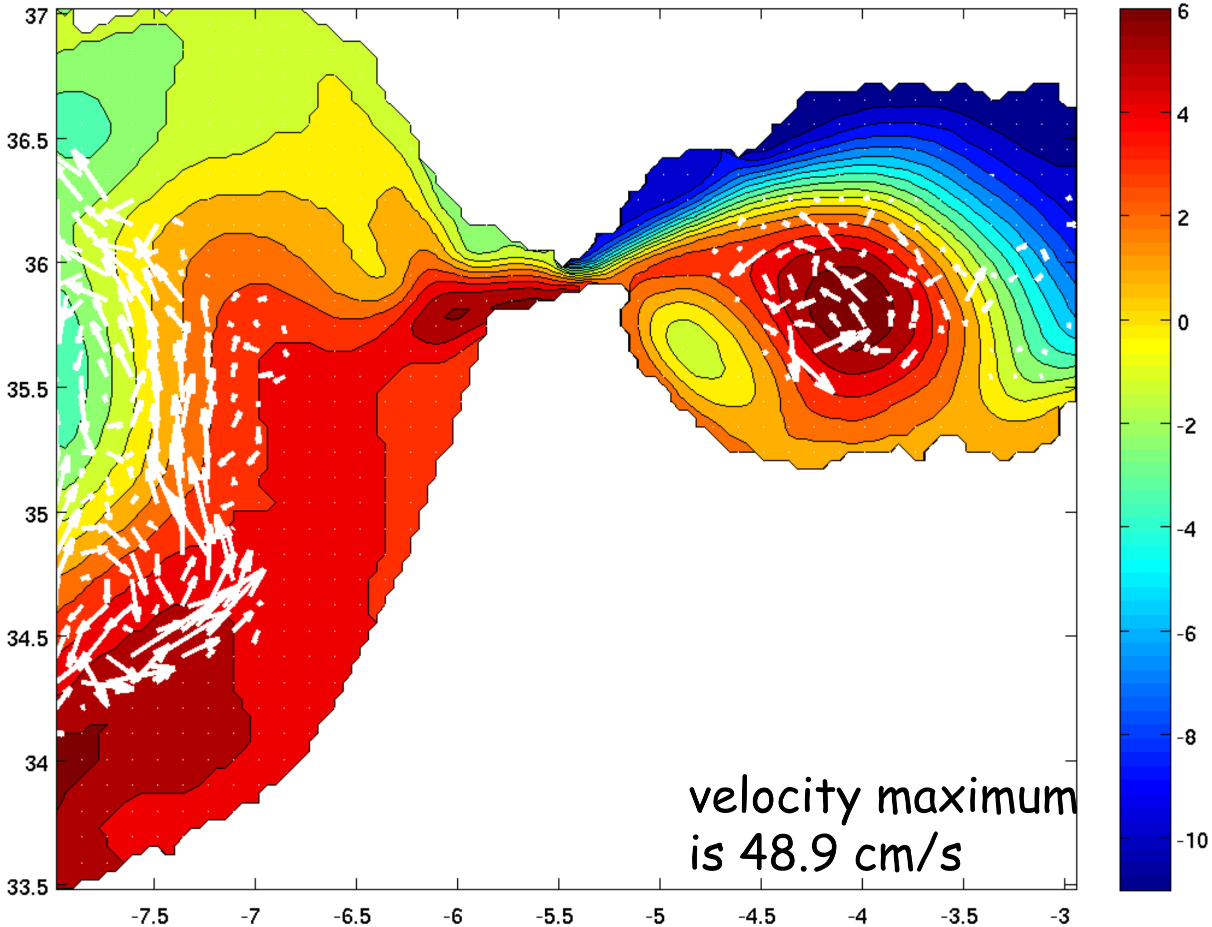
The core of the Gulf Stream ranges between 25 and 28 deg C. The yellow water south of the stream is ~ 23 deg C and the green water off Long Island is ~ 14 deg C. The blue water around Nova Scotia is ~ 5 deg C. The black line is the 1000 m isobath. The white line is located at 72°W (courtesy Amy Schubert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

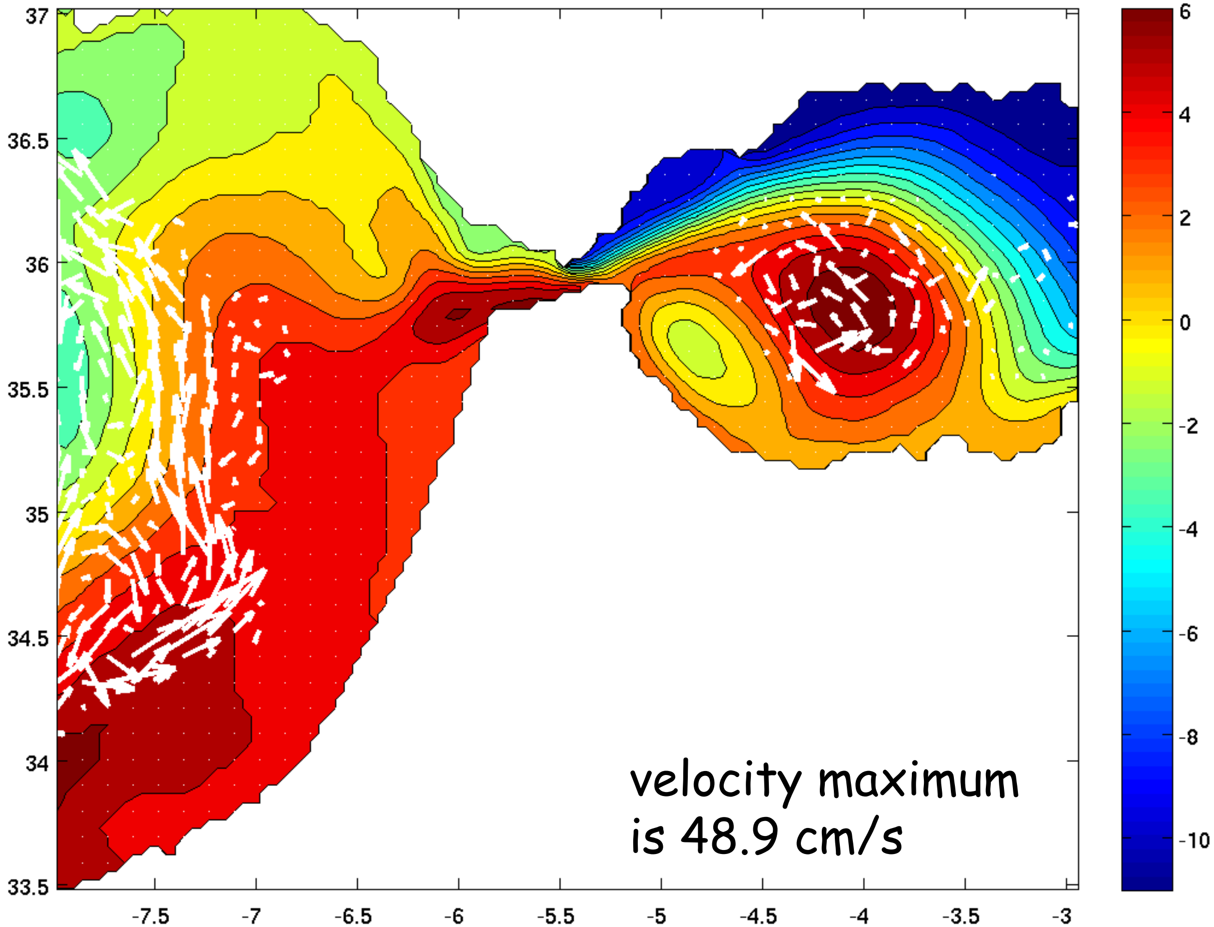


Annual averaged sea surface height and velocity vectors (1000m)

Dietrich et al. (2007)

MOW deep penetration

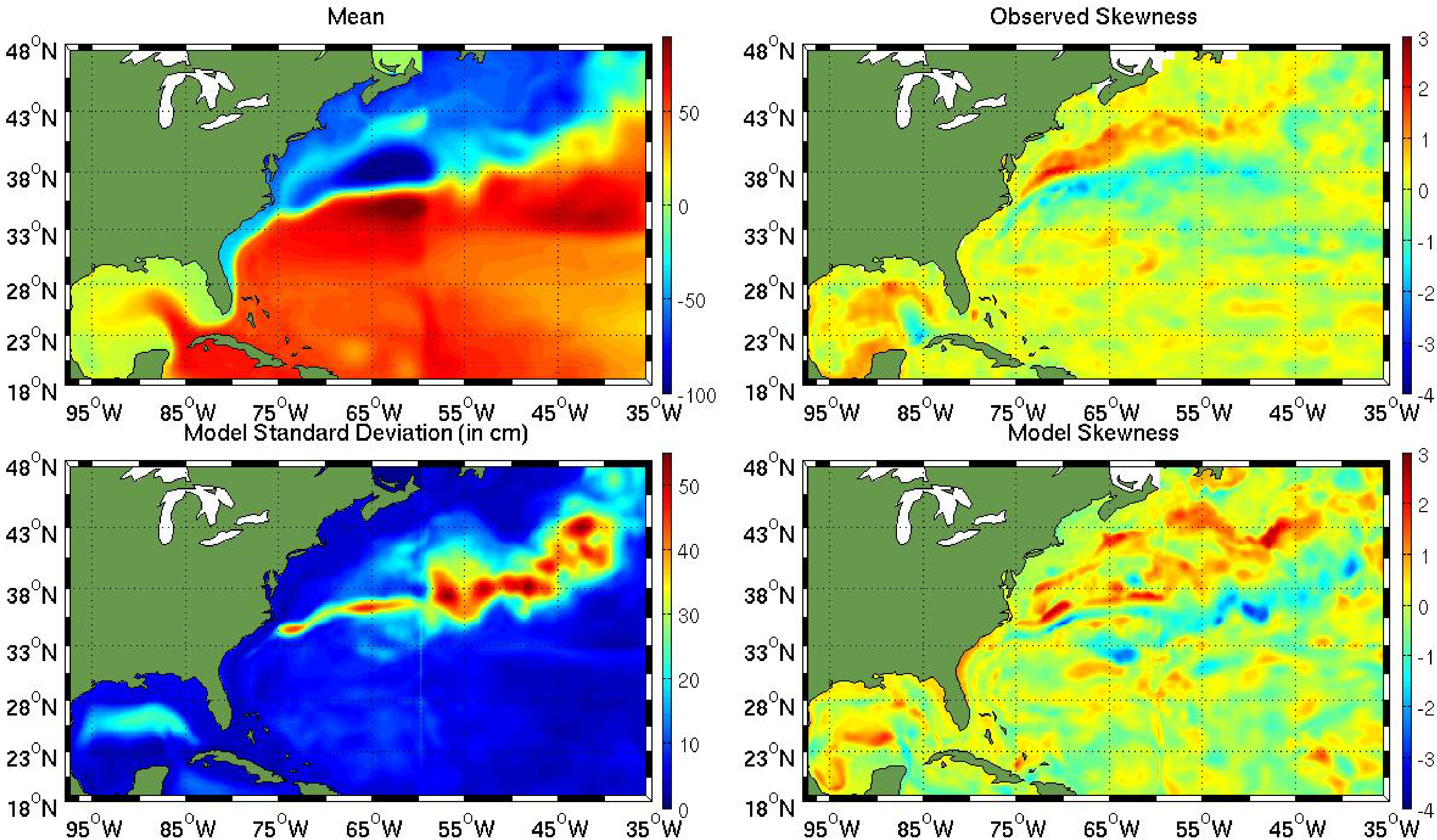
Strait of Gibraltar domain



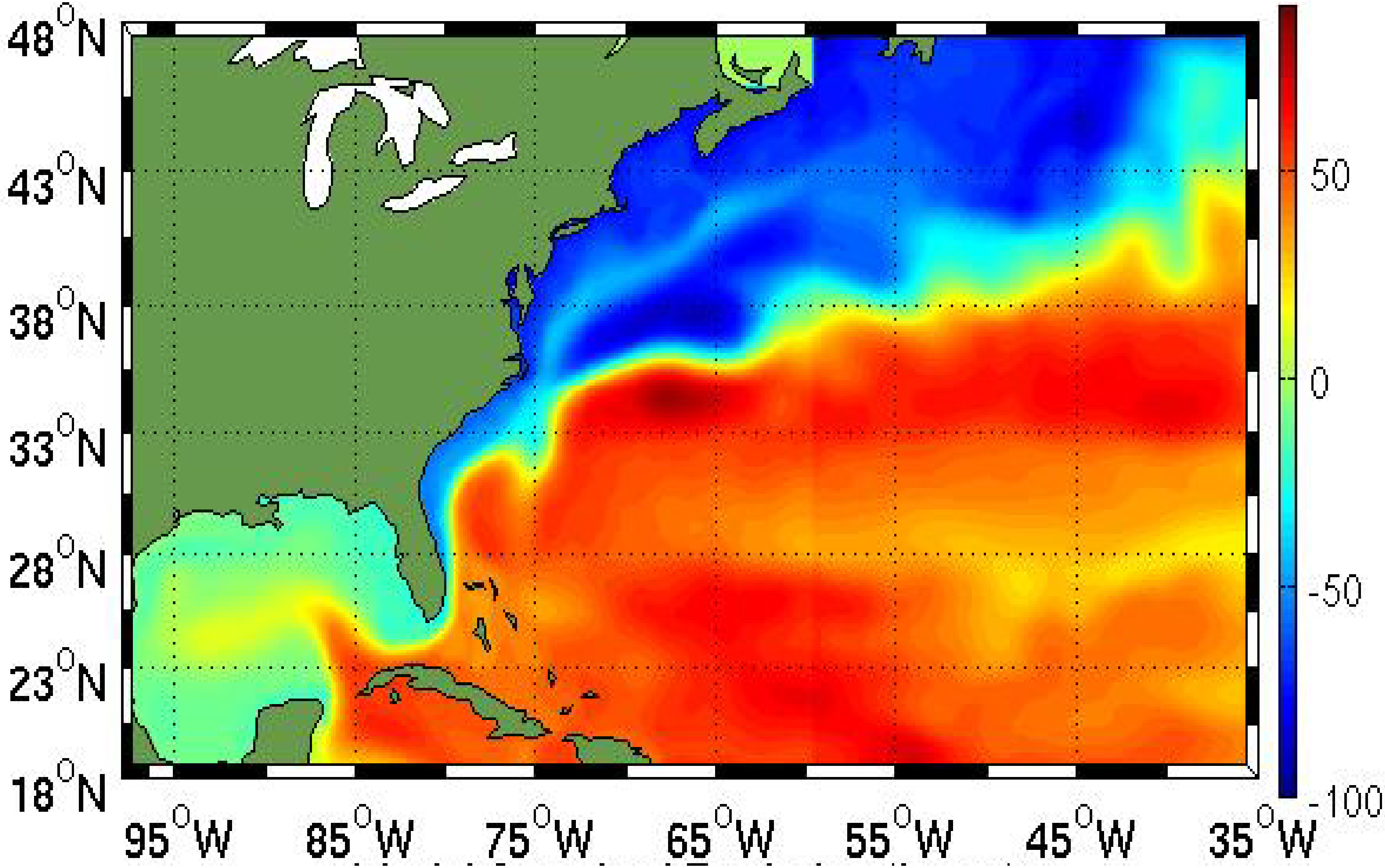
velocity vectors (1000m)

Tseng and Dietrich (2006)

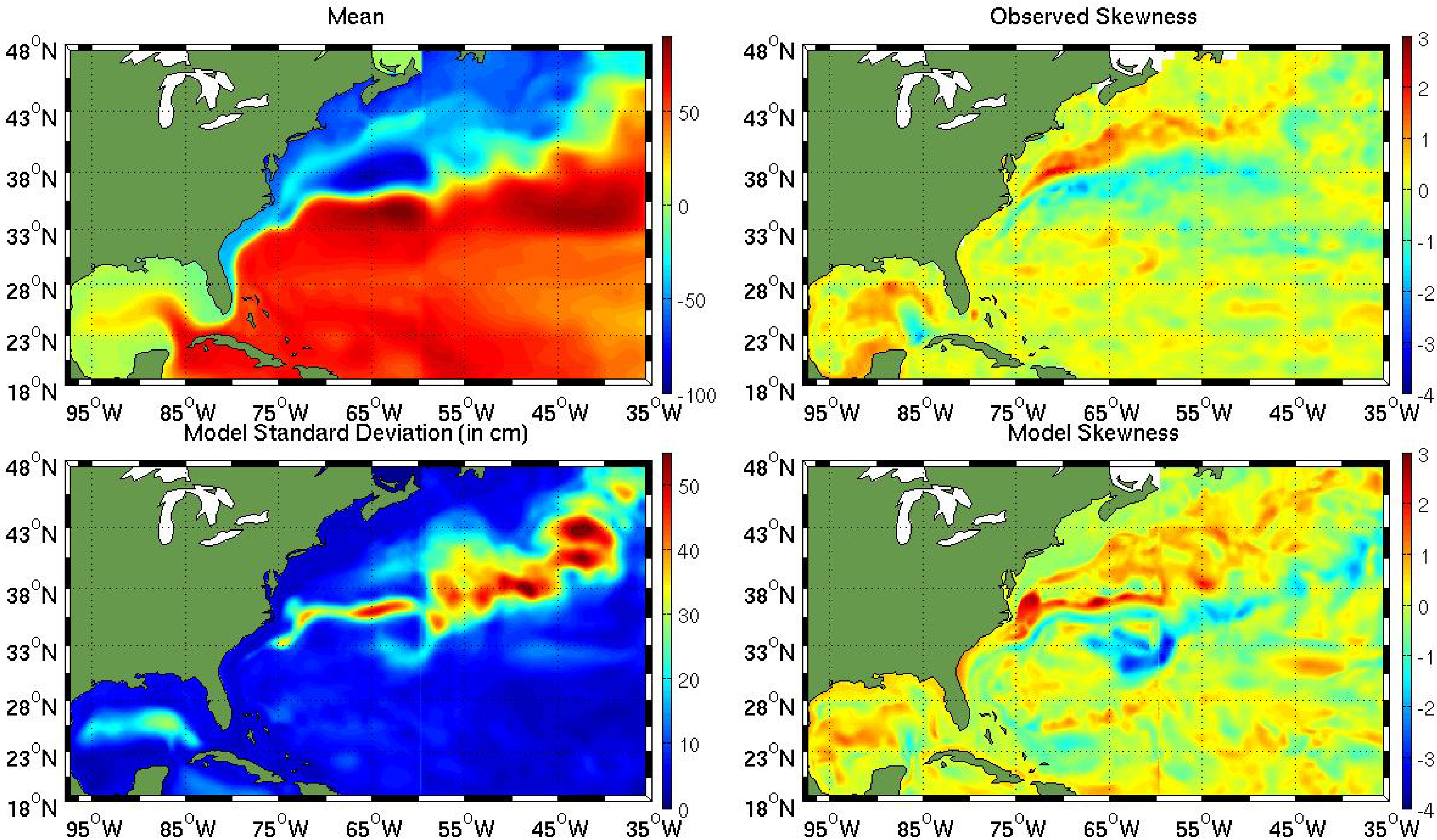
Moderate Dissipation Run



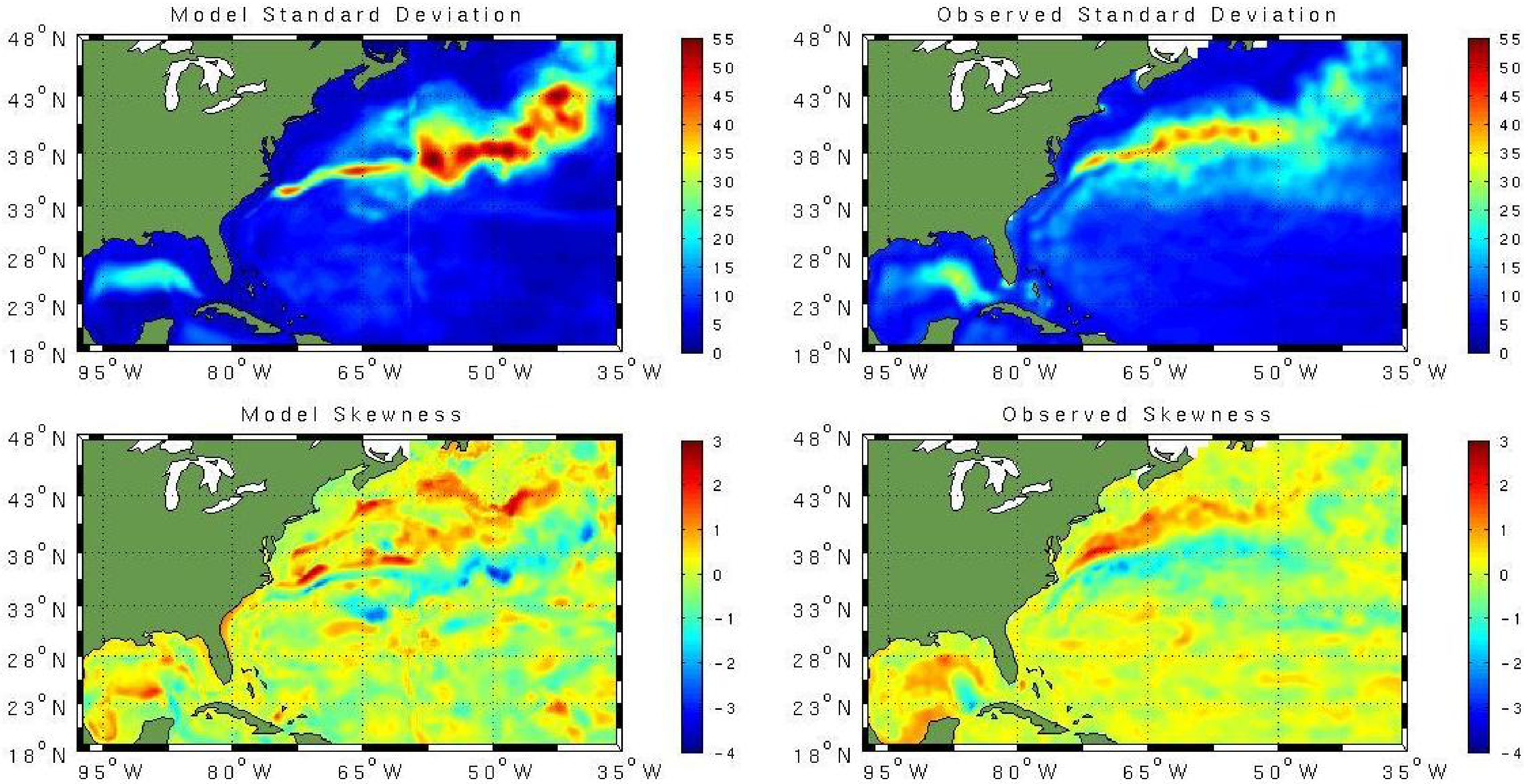
Low Dissipation Run: Model mean surface height



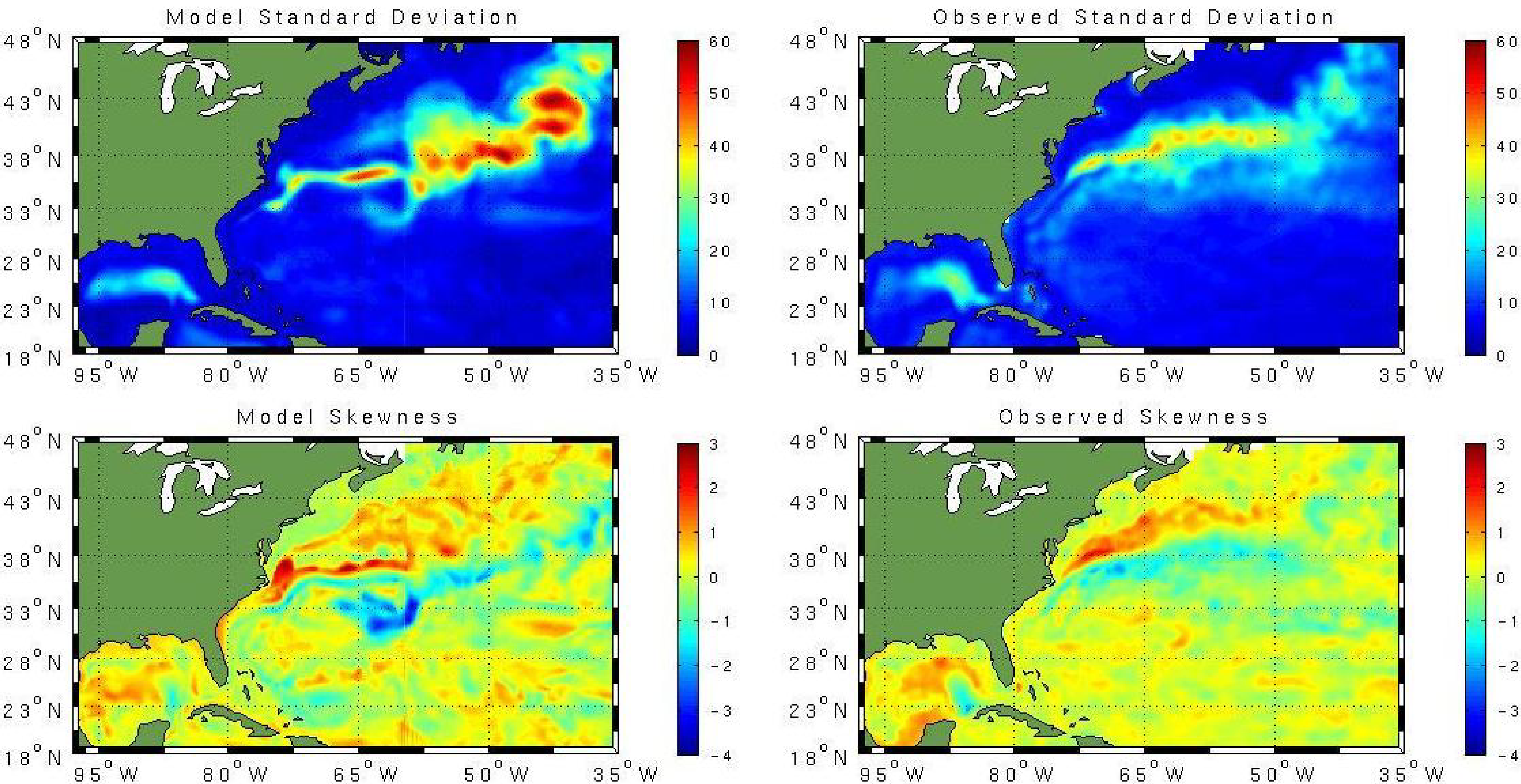
High Dissipation Run

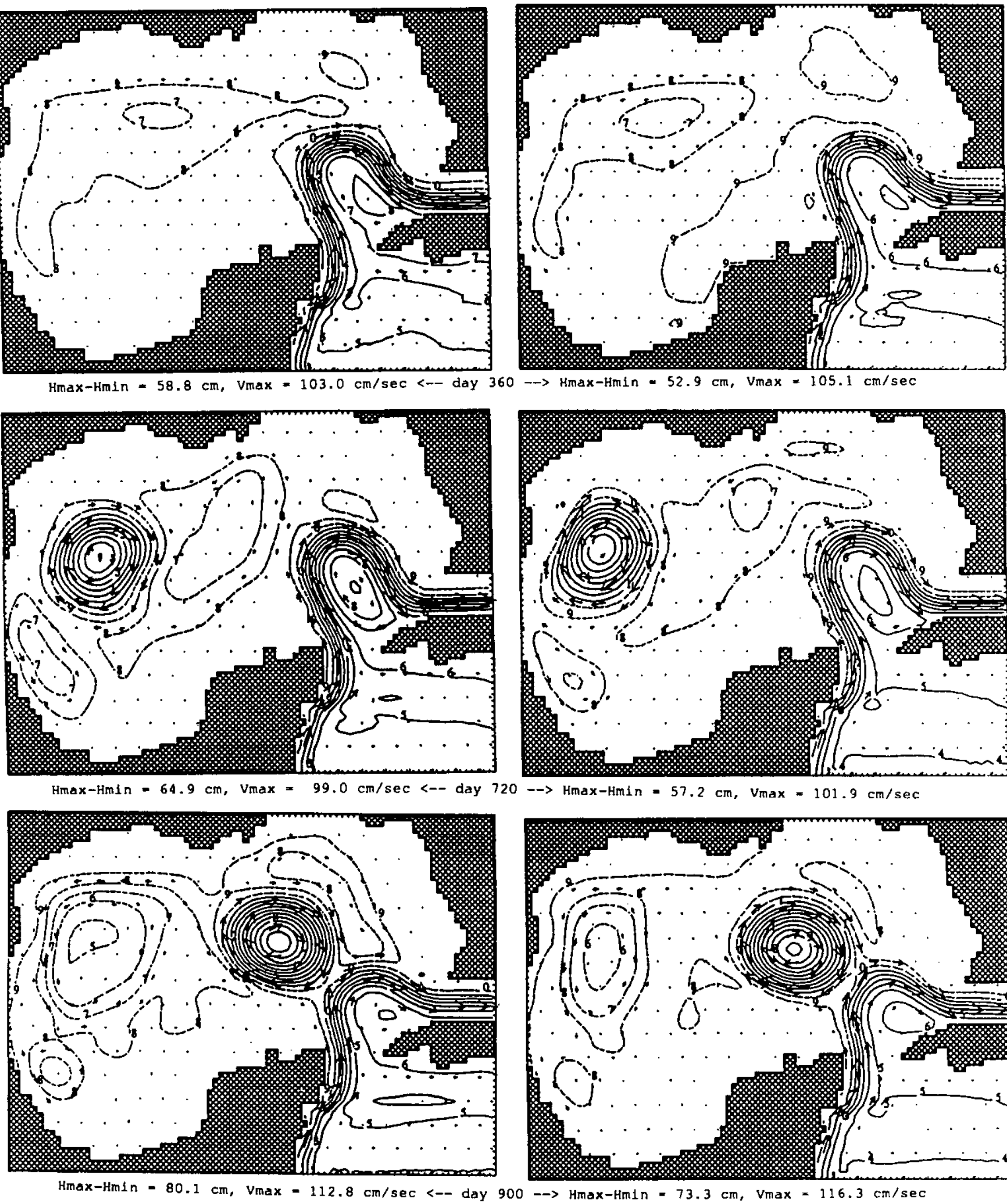


Moderate Dissipation



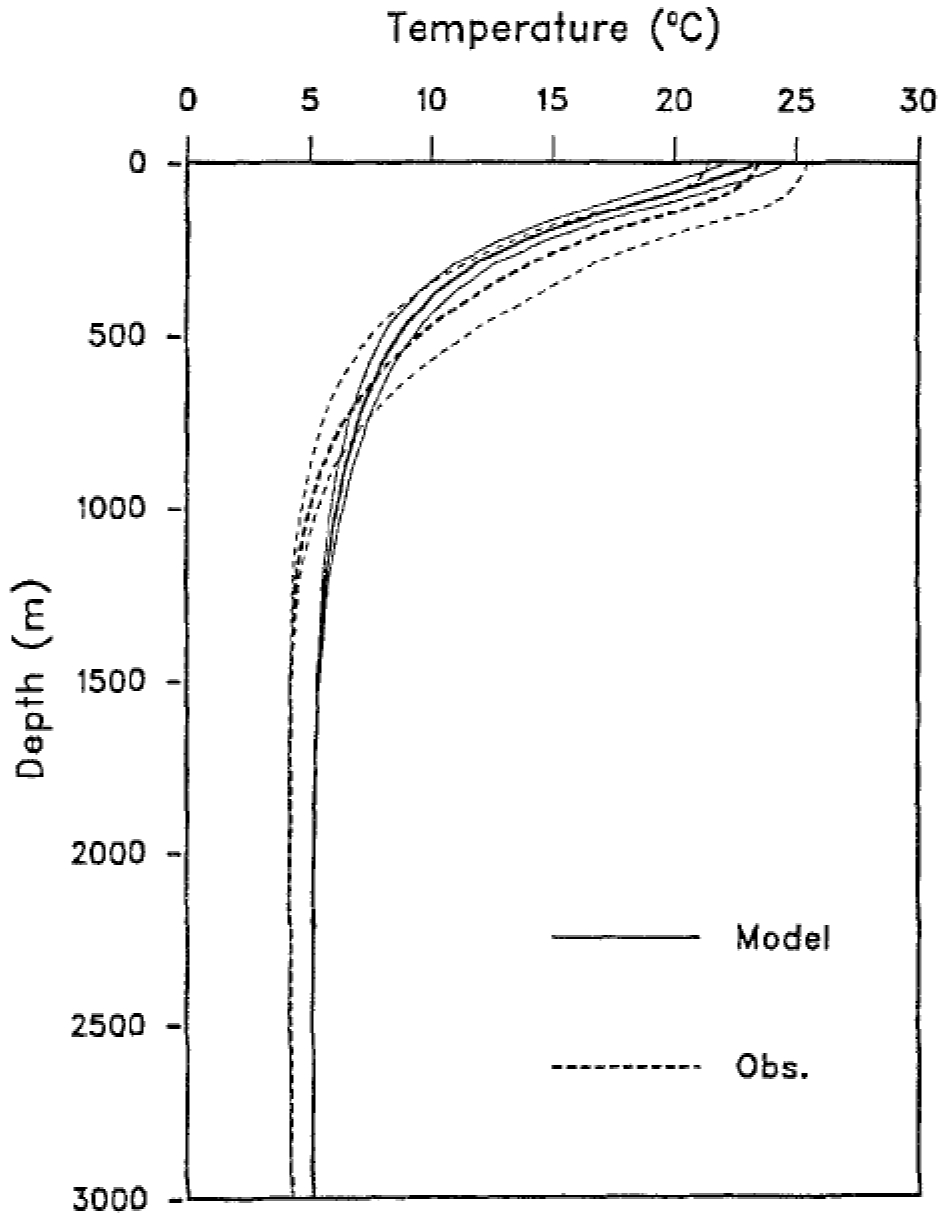
High Dissipation





Arakawa "c" grid SOMS model **Arakawa "a" grid DieCast model**

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.



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