Eddies in the Rotating Annulus and Gulf Stream Region

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with valuable contributions from

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Outline

1. Validation of the model used for the Gulf Stream and rotating annulus simulations;

2. Isotherm flattening (reflects eddy available potential energy conversion to eddy kinetic energy):
   a) north of modeled Gulf Stream;
   b) in the modeled annulus interior flow with free-slip and non-slip rigid lid approximation;

3. The annulus value for teaching, research and model validation.

The DieCAST ocean model

- rigorously 4th-order-accurate numerics
- hydrostatic and non hydrostatic versions
- rigid-lid approximation (free-slip/non-slip)
- nearly seamless nesting/two-way-grid-coupling

DieCAST/MEDiNA model validation

We now extend the validation of the DieCAST ocean model (already well validated in many demanding applications) using results from our in-press JGR/Oceans paper

- Strait of Gibraltar water mass exchange;
- Mediterranean Overflow Water (MOW) depth penetration; and
- one-kilometer-depth warm salty MOW jet path

MEDiNA model: Bathymetry (km) and sub-domains

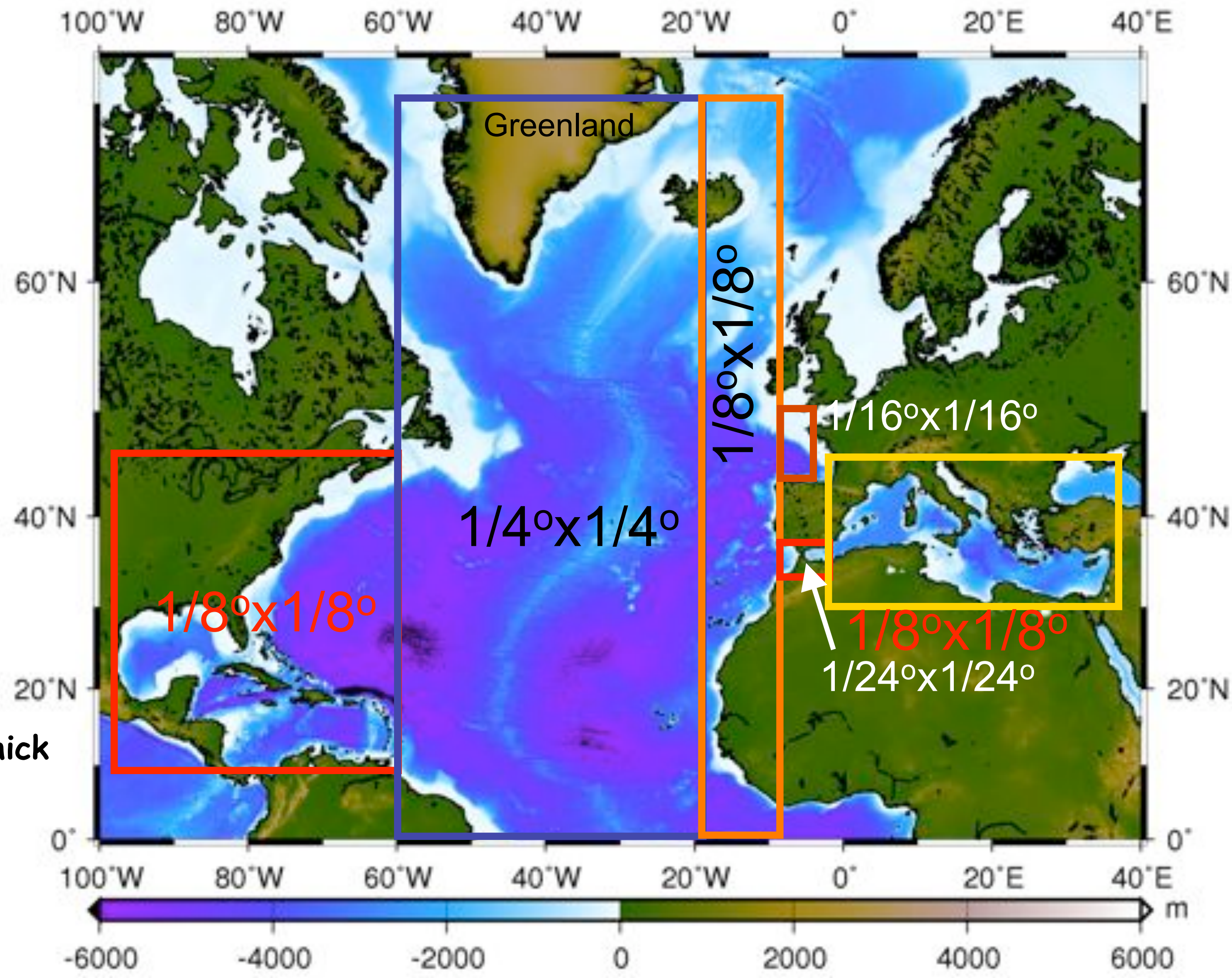
Six domain:

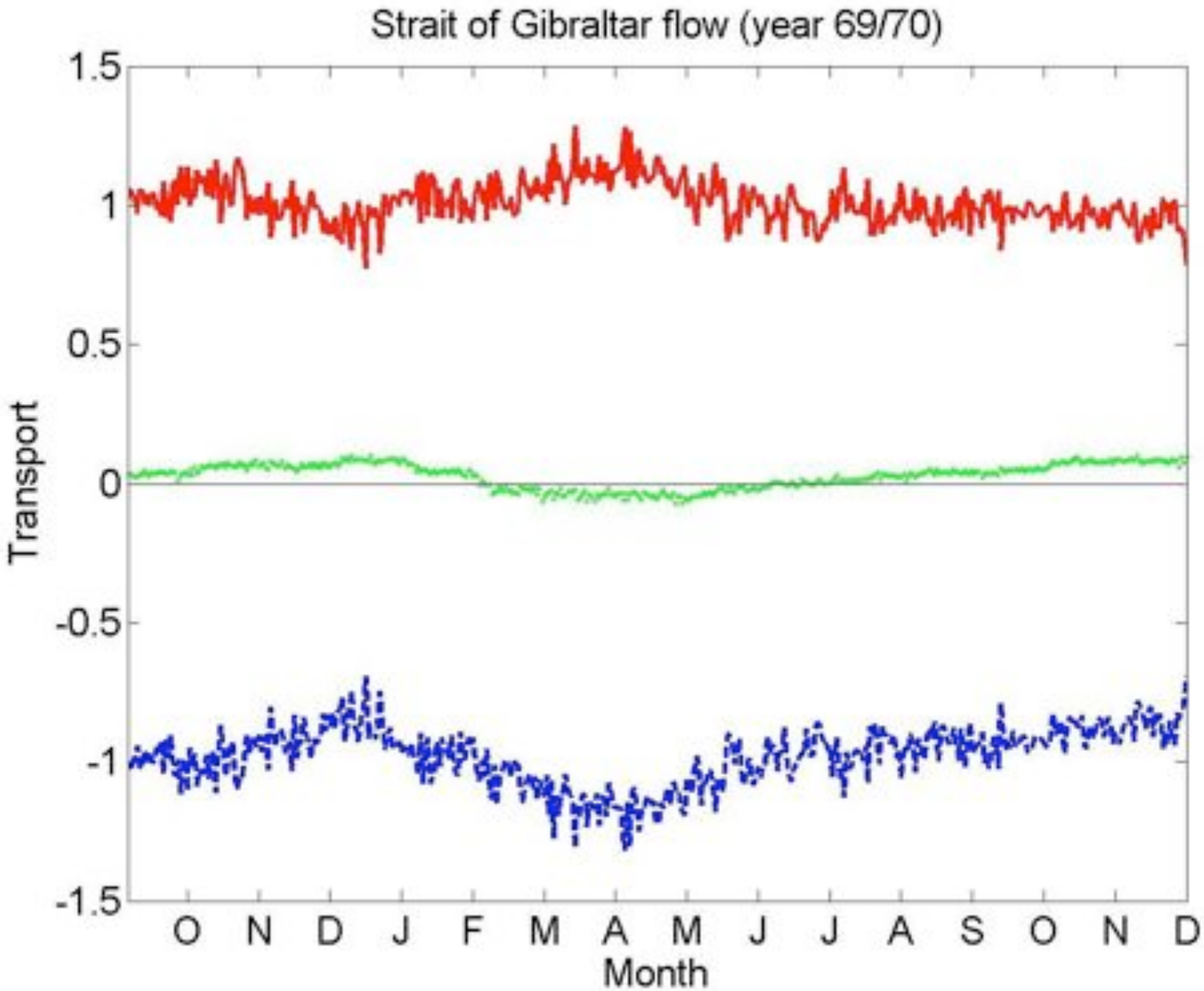
- GOM (1/8°) 304x336
- NAB (1/4°) 162x398
- IBE (1/8°) 100x794
- VIS (1/16°) 60x158
- GIB (1/24°) 125x107
- MED (1/8°) 316x157

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

Theory, observation and modelling

Strait of Gibraltar domain

Western Alboran Gyre (WAG)

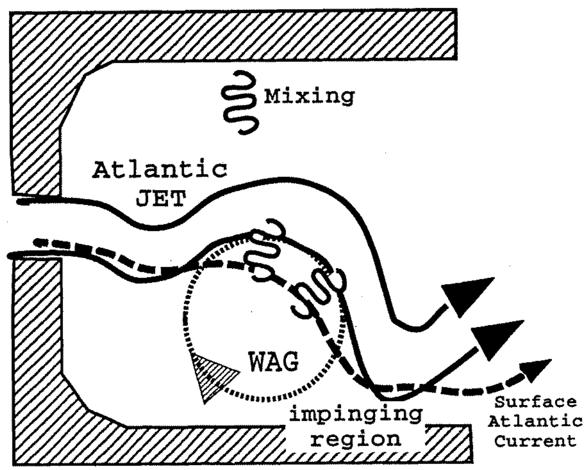
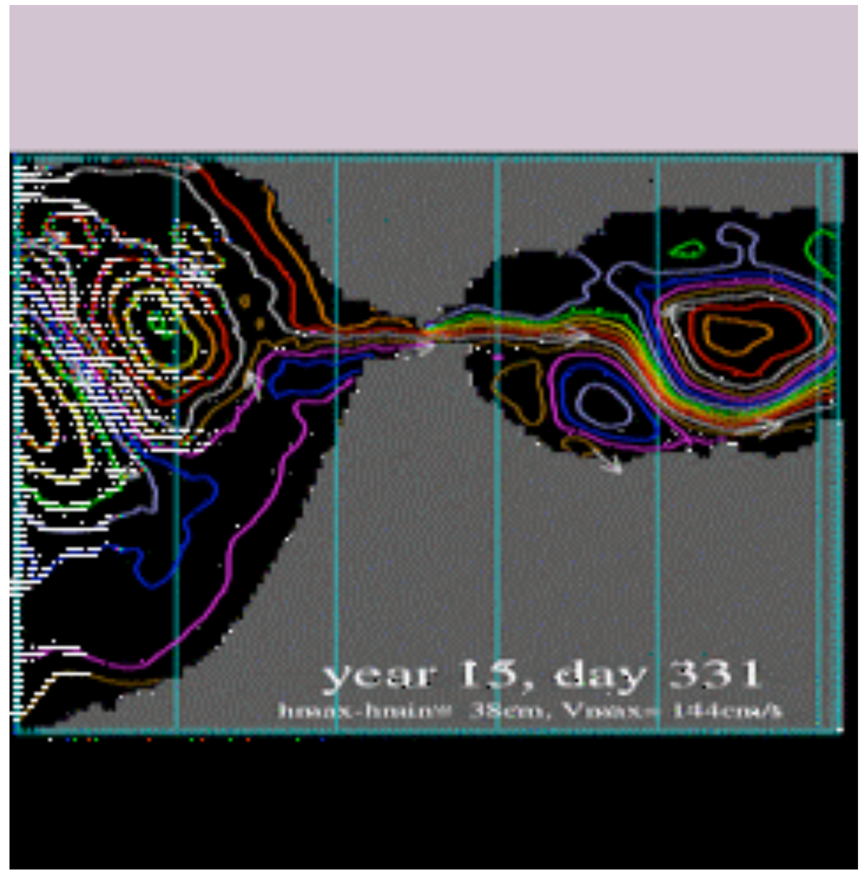
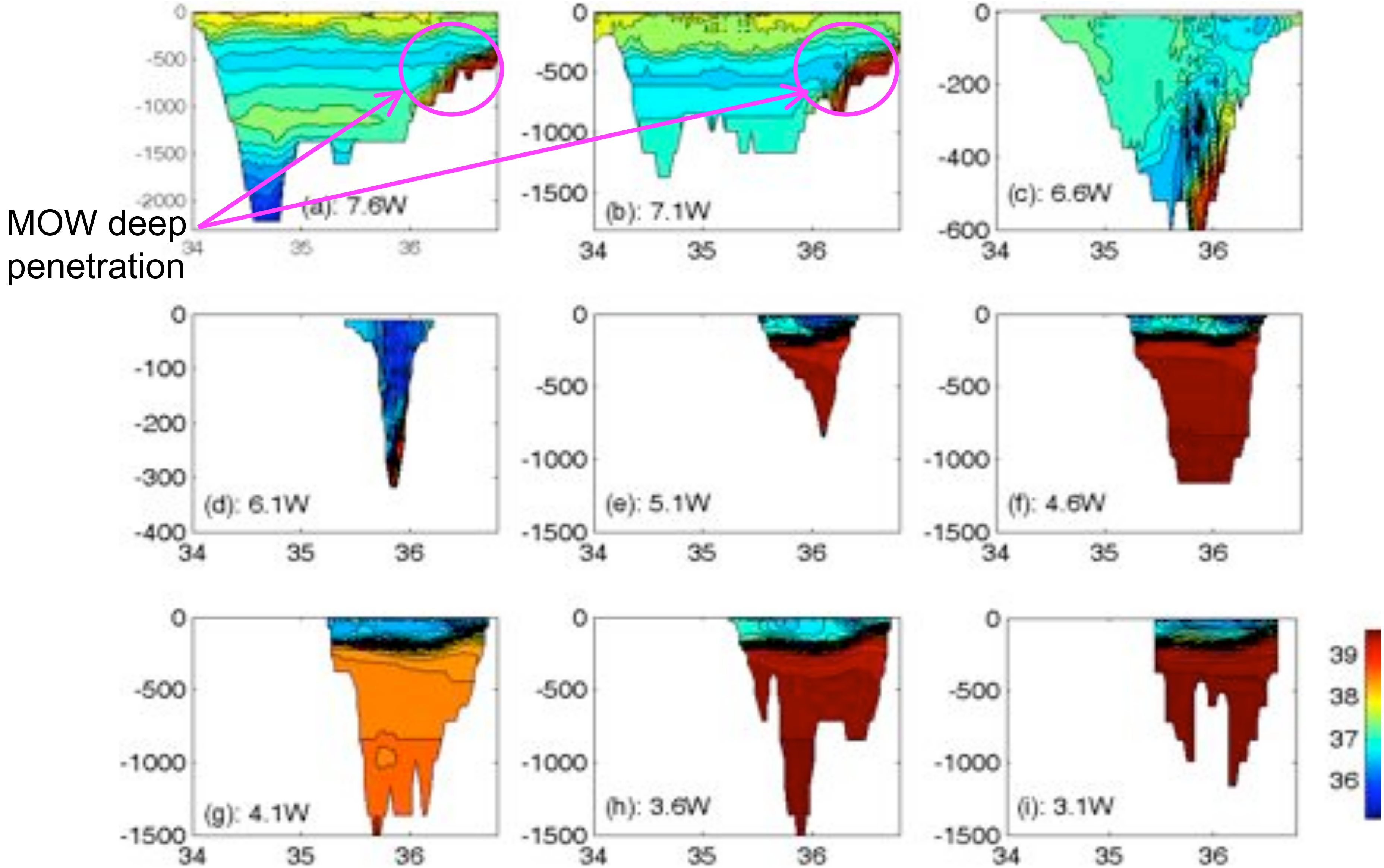


Figure 3. Sketch of the upper circulation (0-200 m) in the western Alboran basin. The surface Atlantic current, characterized by a salinity minimum, may enter into the western Alboran gyre (WAG) crossing the isolines of dynamic height anomaly produced by the deeper density gradients of the gyre. After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

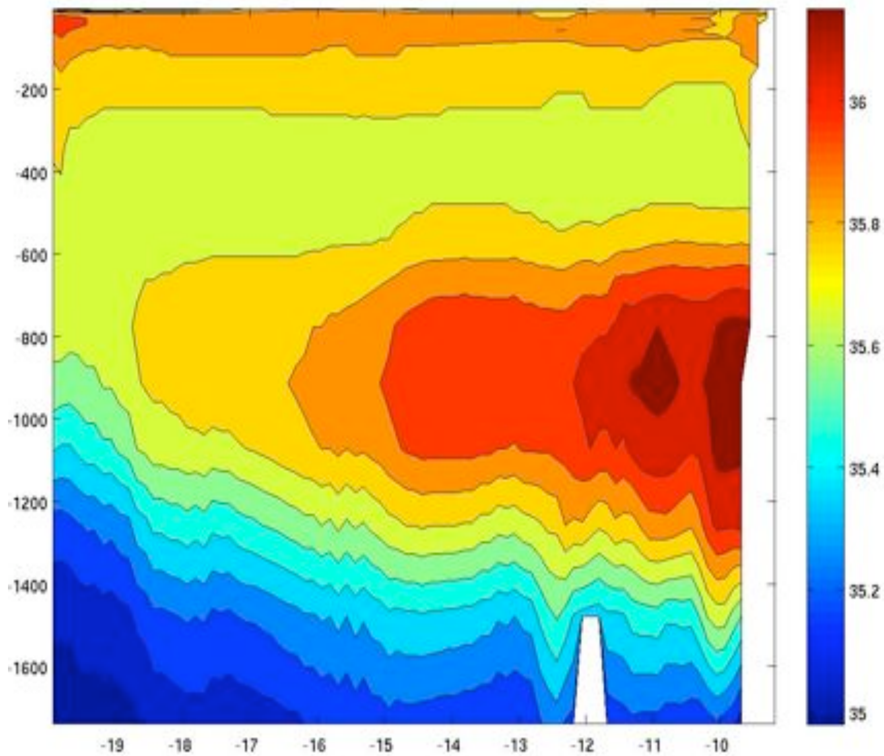
Viúdez, Pinot and Haney (1998)

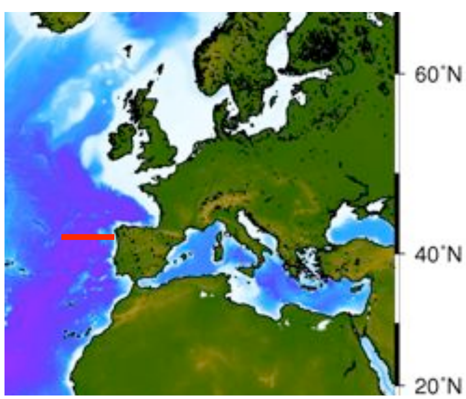


Salinity at different longitudes

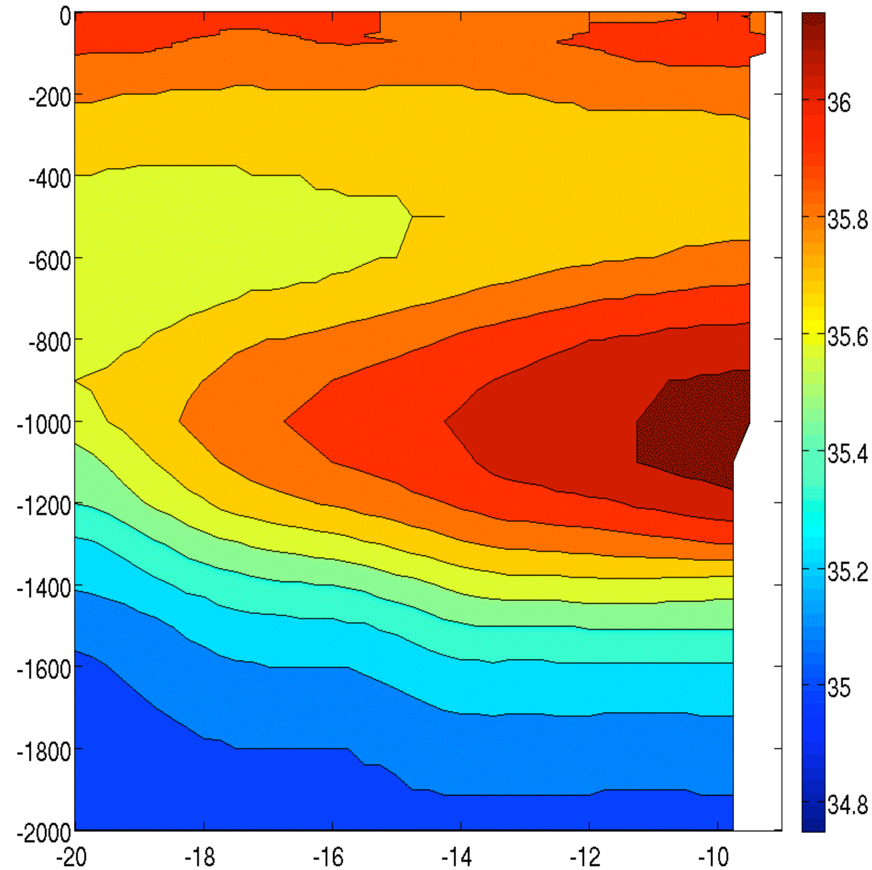


Vertical/longitudinal salinity section at 43°N





Annual averaged model results

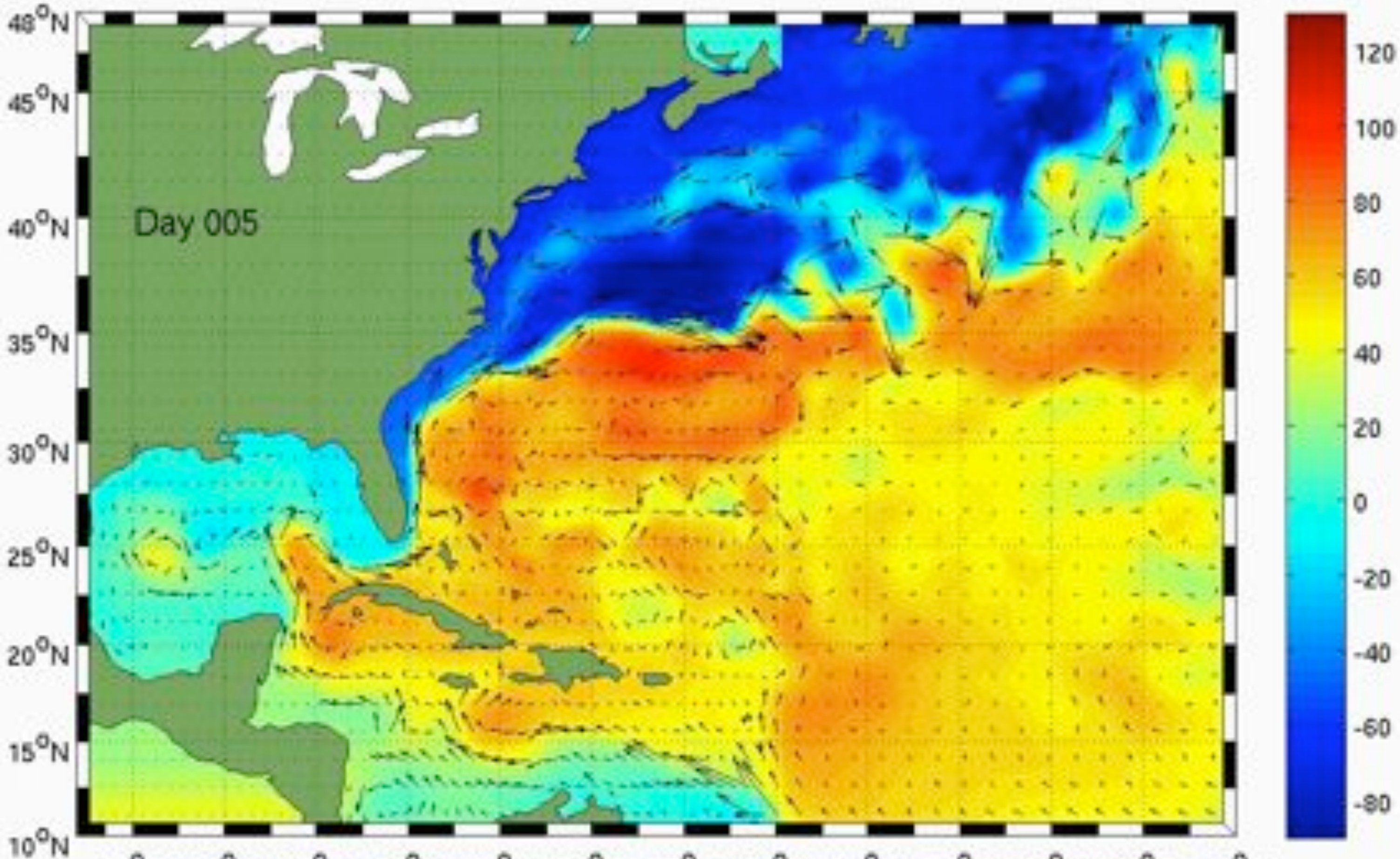


U. S. Navy's GDEM climatology

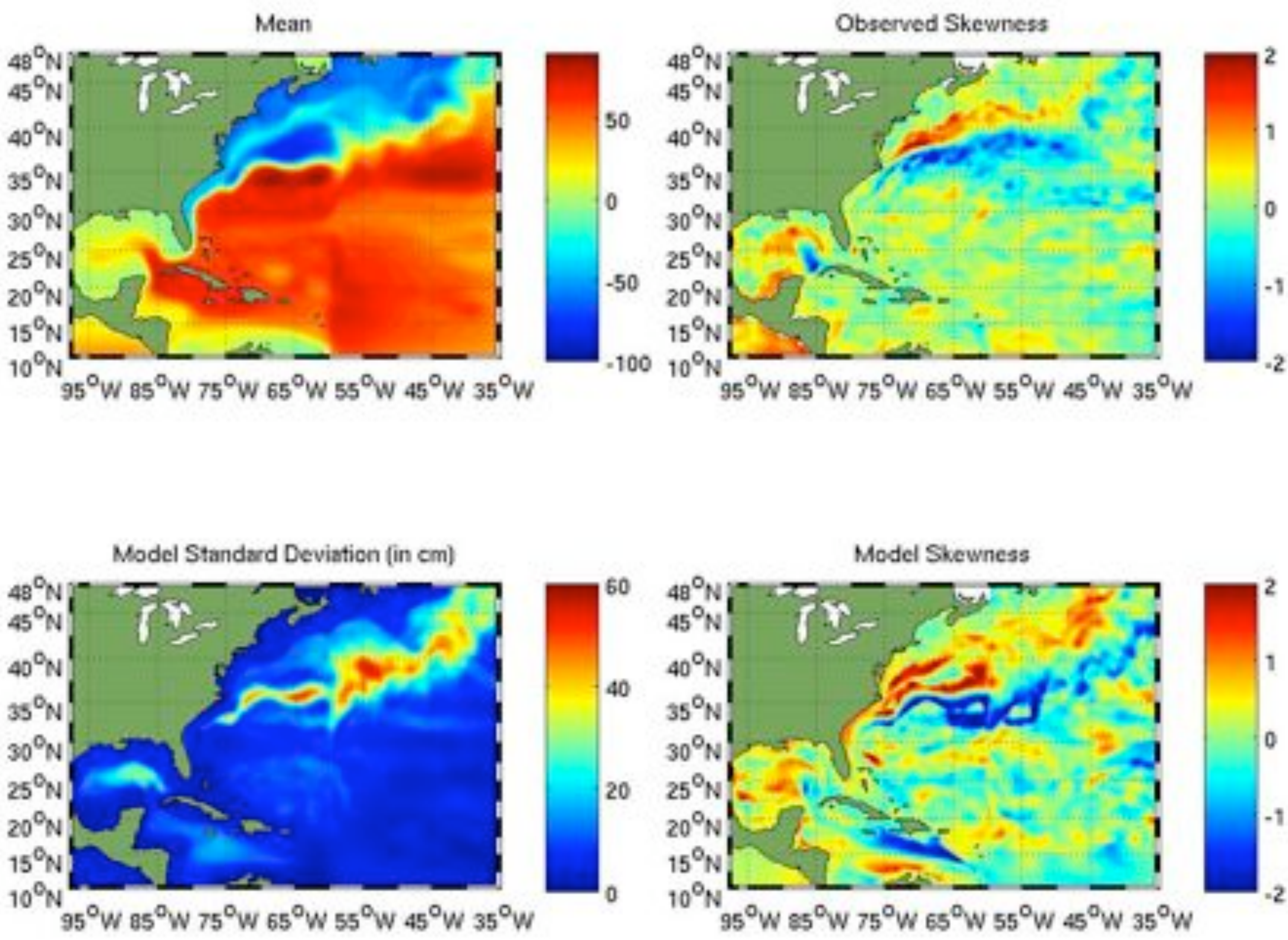
DieCAST/MEDiNA model validation

These MOW results prove that -- contrary to ocean modeling literature -- well designed 4th-order-accurate p**urely Z-level models** that are robust using low dissipation and no instant convective adjustment **can accurately simulate density currents.**

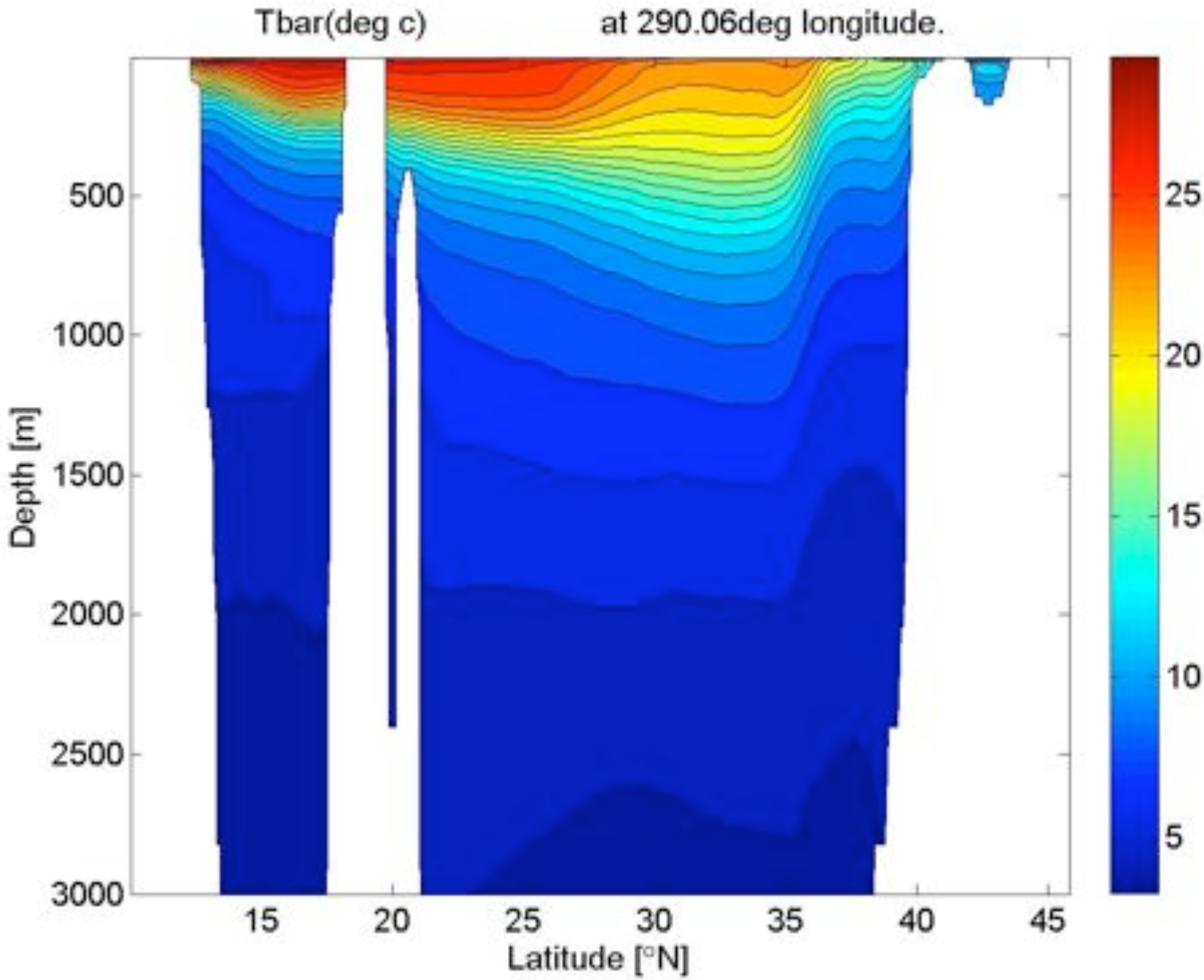
The annulus cold wall boundary layer is an extreme density current.



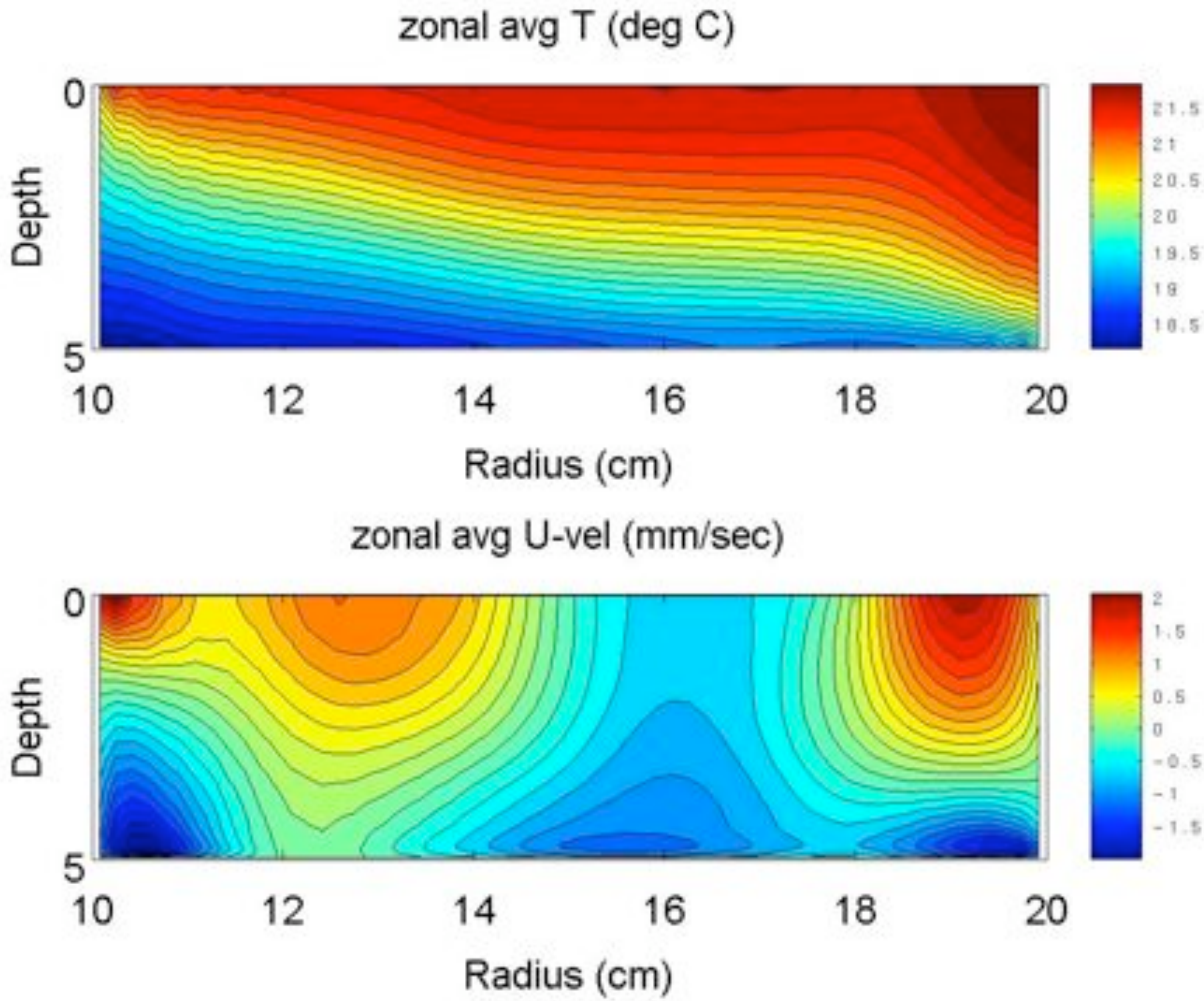
Day 005
48°N
45°N
40°N
35°N
30°N
25°N
20°N
15°N
10°N
95°W
90°W
85°W
80°W
75°W
70°W
65°W
60°W
55°W
50°W
45°W
40°W
35°W
120
100
80
60
40
20
0
-20
-40
-60
-80



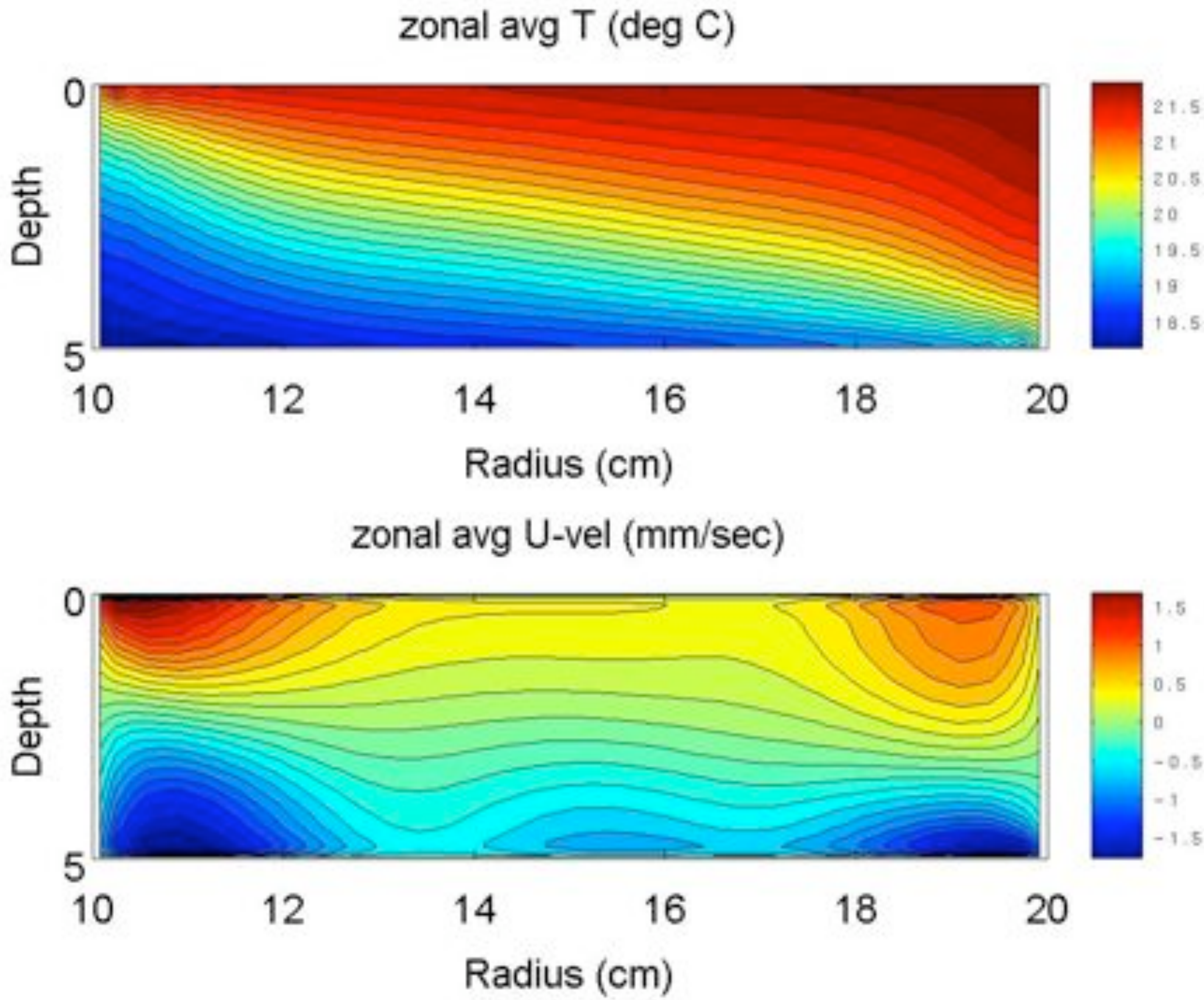
Mean
Observed Skewness
Model Standard Deviation (in cm)
Model Skewness
48°N
45°N
40°N
35°N
30°N
25°N
20°N
15°N
10°N
95°W 85°W 75°W 65°W 55°W 45°W 35°W
50
0
-50
-100
2
1
0
-1
-2
60
40
20
0


Tbar(deg c)
at 290.06deg longitude.
Depth [m]
Latitude [°N]
500
1000
1500
2000
2500
3000
15
20
25
30
35
40
45
25
20
15
10
5

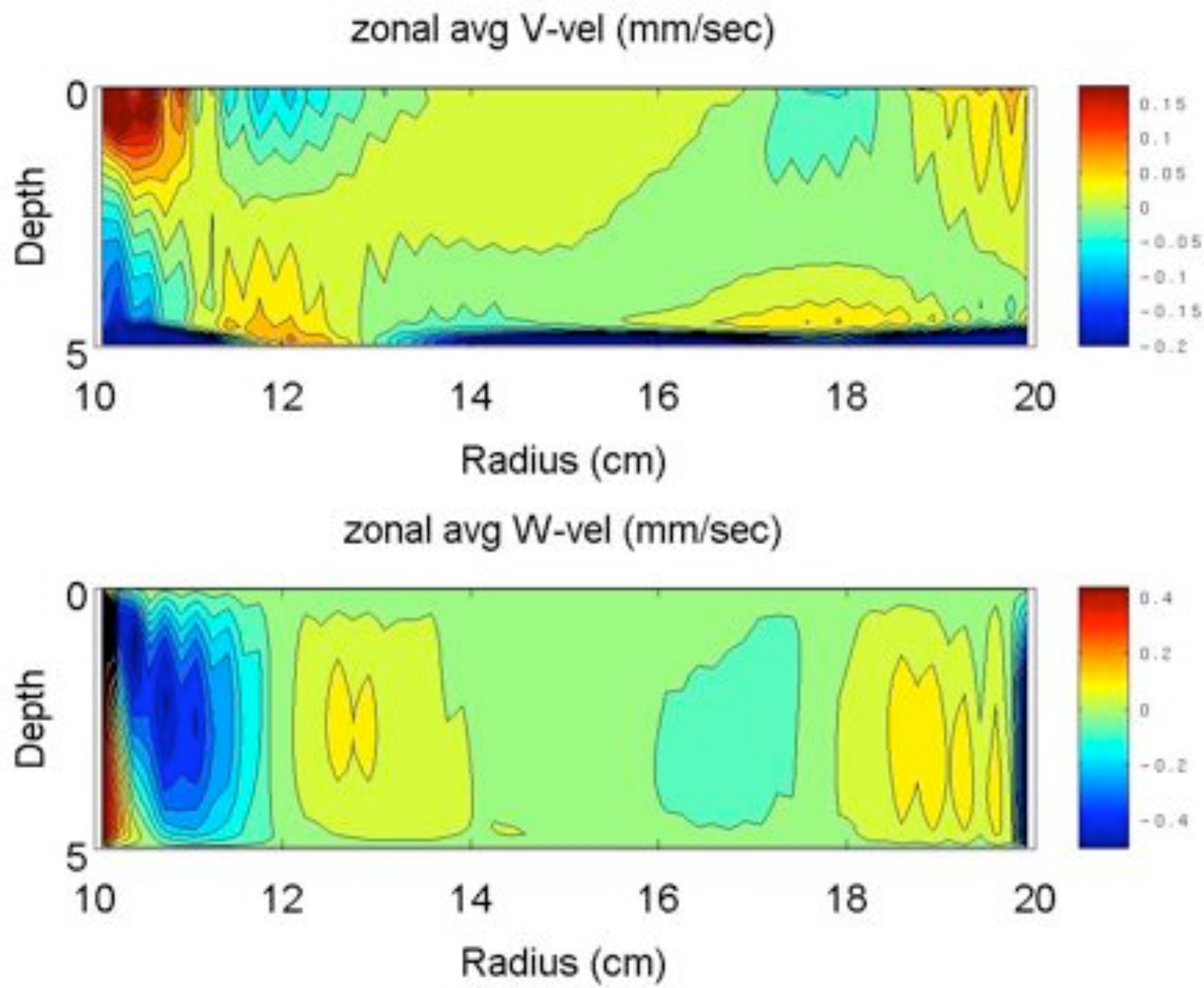
Free-slip T and U



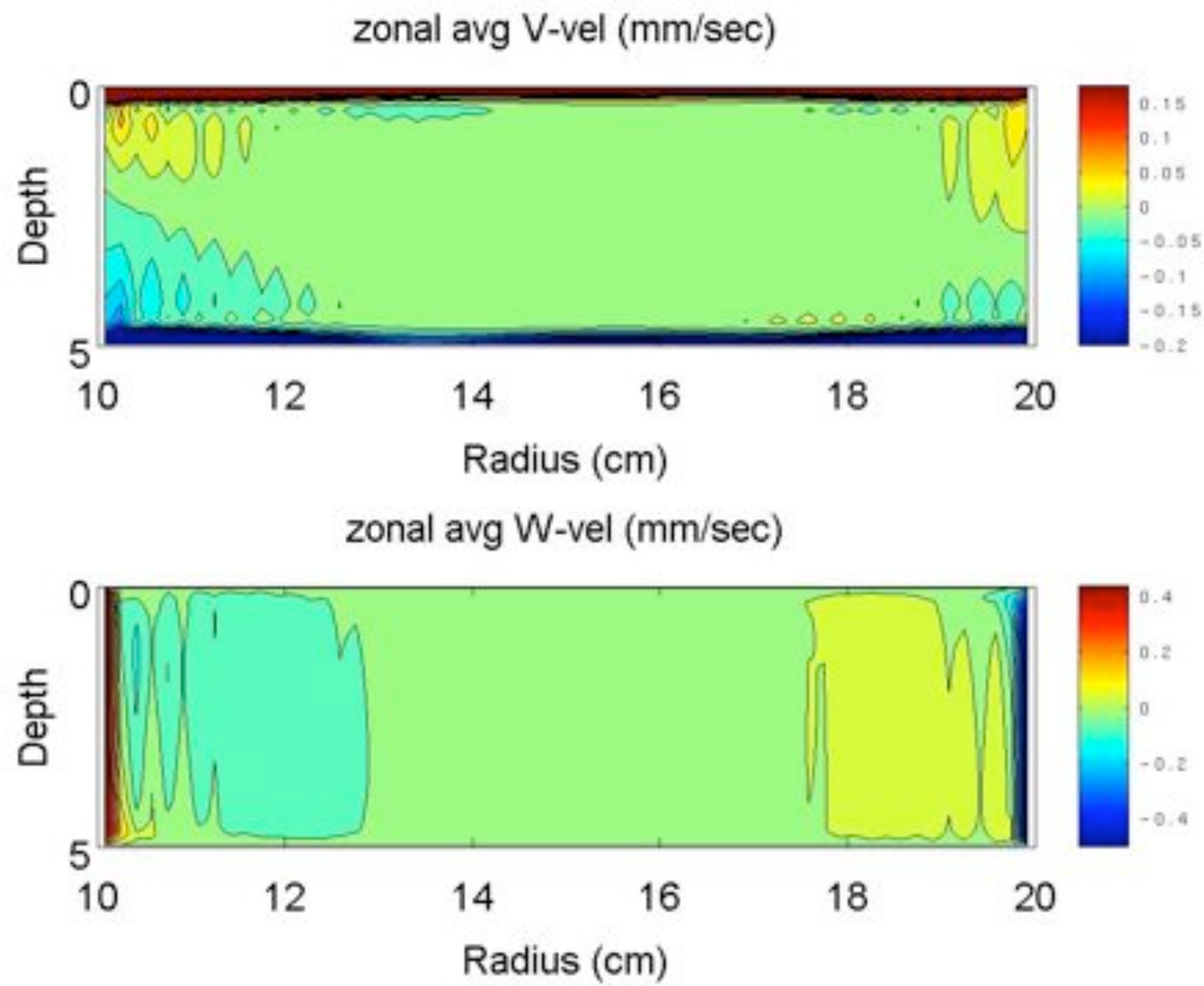
Non-slip T and U



Free-slip V and W



Non-slip V and W



Summary

- ❖Isotherm flattening north of the Gulf Stream and in the annulus has been simulated by the DieCAST ocean model.
- ❖The flattening reflects eddy APE conversion to eddy KE.
- ❖The ocean APE is externally maintained by radiation processes and is focused by the ocean-basin-scale circulation in the wedge-shaped region between the cold New England shelf slope density current and the warm Gulf Stream.
- ❖The annulus APE is externally maintained cold inner and warm outer sidewall boundaries.

VALUE OF THE ANNULUS EXPERIMENTS

- The annulus experiments are a valuable teaching and research tool because they include geophysically important baroclinic instability and boundary layer processes in a relatively easily understood and analyzed configuration.

- The annulus experiments are also ideal for **rigorous** validation and inter comparison of ocean models because:

  a) they are very well observed and accurately measured;

  b) their boundary conditions are accurately known;

  c) they include fundamental aspects of GFD in a simple configuration;

  d) their true molecular viscosity and diffusivities give Reynolds and Peclet numbers similar to those of ocean models commonly using eddy viscosity and diffusivity 5-6 orders-of-magnitude bigger than the laminar values.

- They are also ideal for **rigorous** inter comparison of data assimilation approaches.

FINAL REMARKS

The flat bottom of the conventional annulus experiments makes it easier to resolve boundary layers. A sloping bottom would require sigma-like coordinates in order to have comparably efficient bottom boundary layer (bbl) resolution, but that would give well known baroclinic pressure gradient errors requiring much more resolution outside of the bottom boundary layer. The thin-shell sub model approach used by my SOMS model (Dietrich, et al., 1987) from which the present Diecast model was derived -- which was reinvented by Beckmann and Doscher (1997) and by Ganadesekin, et al. -- is good way to resolve the bottom boundary layer over a sloping bottom. The UCLA model uses a continuum bottom fit approach that is analagous to my original SOMS thin-shell approach; this approach was suggested in my review of the widely cited "s-coordinate“ paper by Song and Haidvogel. The immersed boundary methodology applied in the DieCAST model framework by Yu-heng Tseng is another good alternative.

FUTURE WORK

The parallelized MPI version of DieCAST model is ready and can be used for:

- ❖ studies with the rotating annulus at higher resolutions
- ❖ simulations to compare with nonlinear geostrophic adjustment experiments conducted by Stegner at al. (JFM, 2004) of a circular density front in a rotating two-layer fluid.