1C03.5 ID:3997INVITED/INVITÉ

Observed and modeled interacting jets and eddies in the North Pacific Ocean

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Acknowledgements to Jim Richman, NRL Stennis Space Center,
Yu-heng Tseng, National Taiwan University

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DieCAST Global Model Setup

Images & animations at www.edfl.as.ntu.tw/research/diecast

* Northern boundary at 69.77 deg N, southern boundary at 69.94 deg S.

* Model is purely z-level using an Arakawa "a" grid with interpolated "c" grid advection velocity;
* Grid dimensions: 1440 longitude X 792 latitude X 25 layers;
* Lateral resolution: 1/4 deg longitude, dy=dx (Mercator grid);
* Vertical resolution: linear + exponential grid. Top layer 13.3 m thick, bottom layer 891 m thick.
* Bathymetry is unfiltered etopo5 truncated at 5000m depth.
* Hellerman winds and Levitus '94 climatology;
* Dan Wright's nonlinear equation of state;

* All results shown are from year 17.

DieCAST Global Model Setup (cont'd)

* Numerics: all interpolations are rigorously fourth-order-accurate;

* Physics: hydrostatic, Boussinesq and rigid-lid approximations;

* Pacanoski and Philander (1982) Richardson number based vertical mixing except increased over steep bathymetry;

* Constant lateral viscosity and diffusivities (20 m-m/sec) except increased to 200 m-m/sec near lateral boundaries;

* Standard nonlinear bottom drag, free slip lateral boundaries;

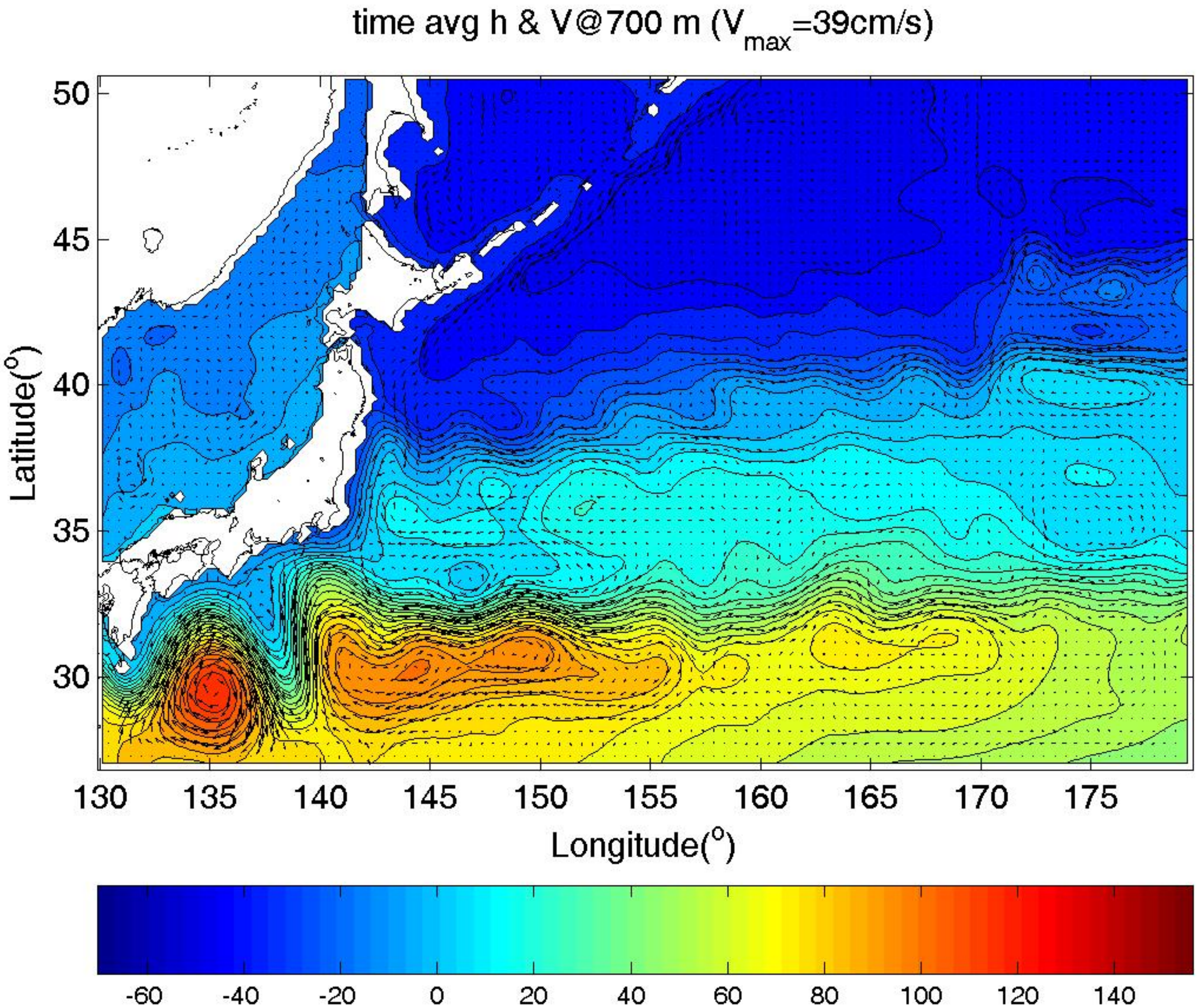
* Initial conditions at day 0: no flow, winter time climatology;

* Time step size: 10 minutes. Run time: 11 years per 100 days on a personal computer class processor, 240 years per 100 days on 32 processors of a parallel supercomputer forced by repeat annual cycle.

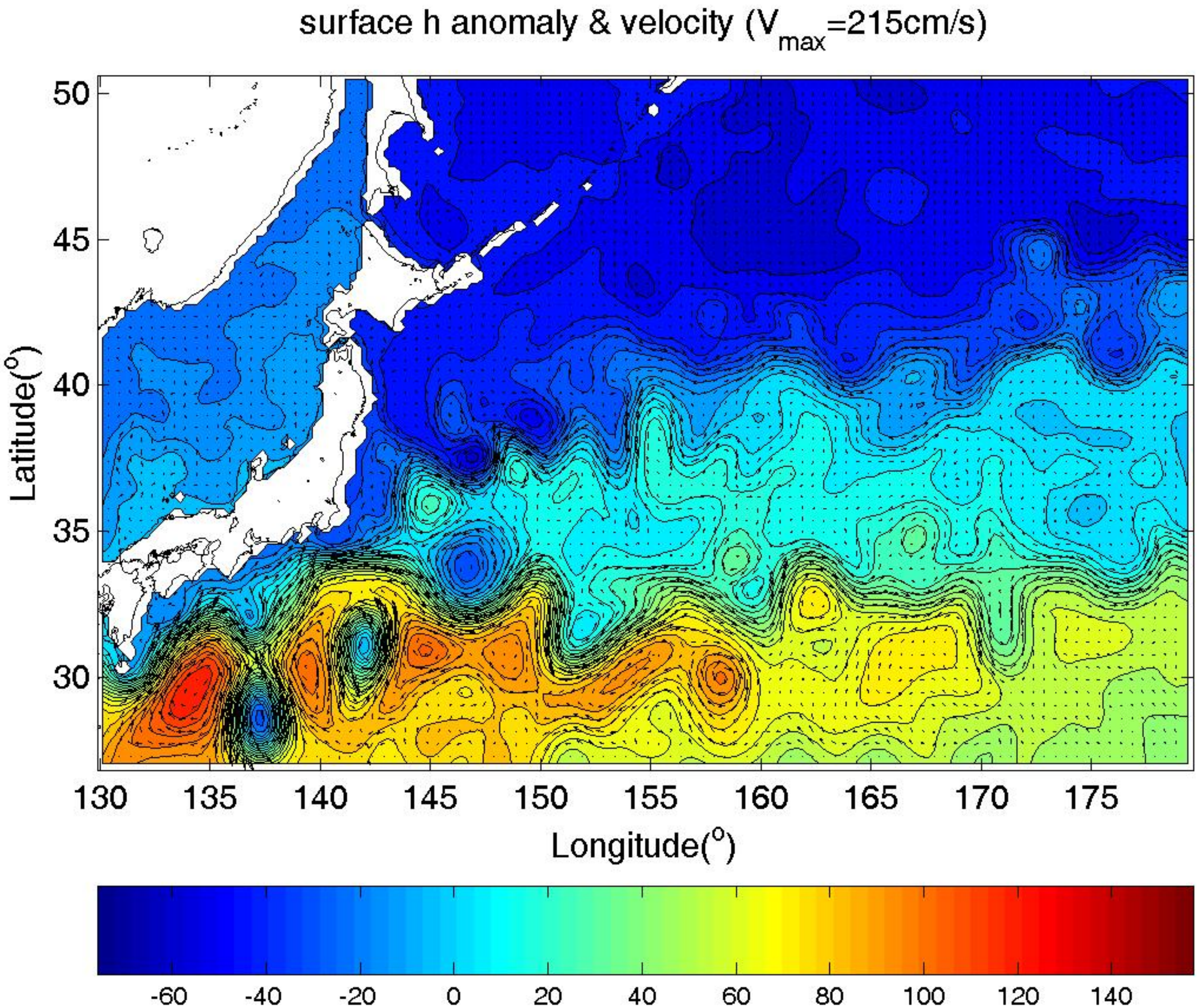
Layer interfaces and thicknesses

Layer	mid	top	bottom
1	6.46	0.00	13
2	20.5	13.3	28
3	36.3	28.2	45
4	54.3	45.0	64
5	75.0	64.3	86
6	98.9	86.5	112
7	126	112	142
8	159	142	178
9	198	178	220
10	244	220	270
11	298	270	330
12	364	330	401
13	442	401	488
14	537	488	592
15	652	592	717
16	790	717	870
17	958	870	1050
18	1161	1054	1279
19	1408	1279	1552
20	1709	1551	1883
21	2075	1883	2287
22	252	2287	2778
23	3063	2778	3378
24	3725	3378	4108
25	4532	4108	5000

KUROSHIO CURRENT



plot 1
* year 17 time average
* big meander during year 17
* primary and secondary Kuroshio Extension bifurcation
* third bifurcation over gap in Emperor Seamout chain
* from model having 4th-order-accurate numerics

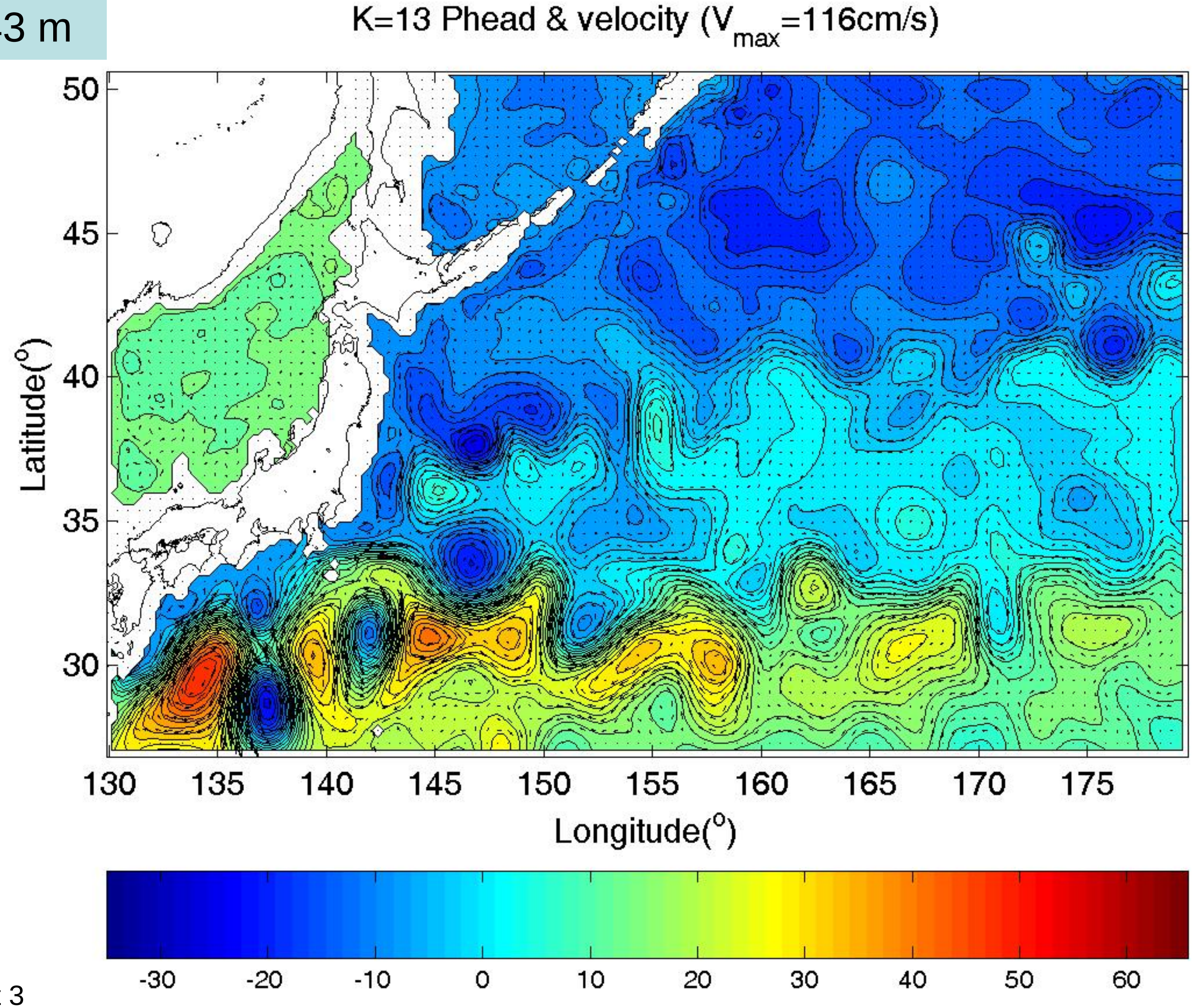


plot 2

* transient eddies transport and mix buoyancy between fronts
* buoyancy transport flattens intrafrontal region isopycnals thus giving much smaller mean flow than in the jets
* front spacings and eddy scales relate to internal Rossby radius of deformation
* jets are intense and penetrate far eastward

* from model having 4th-order-accurate numerics

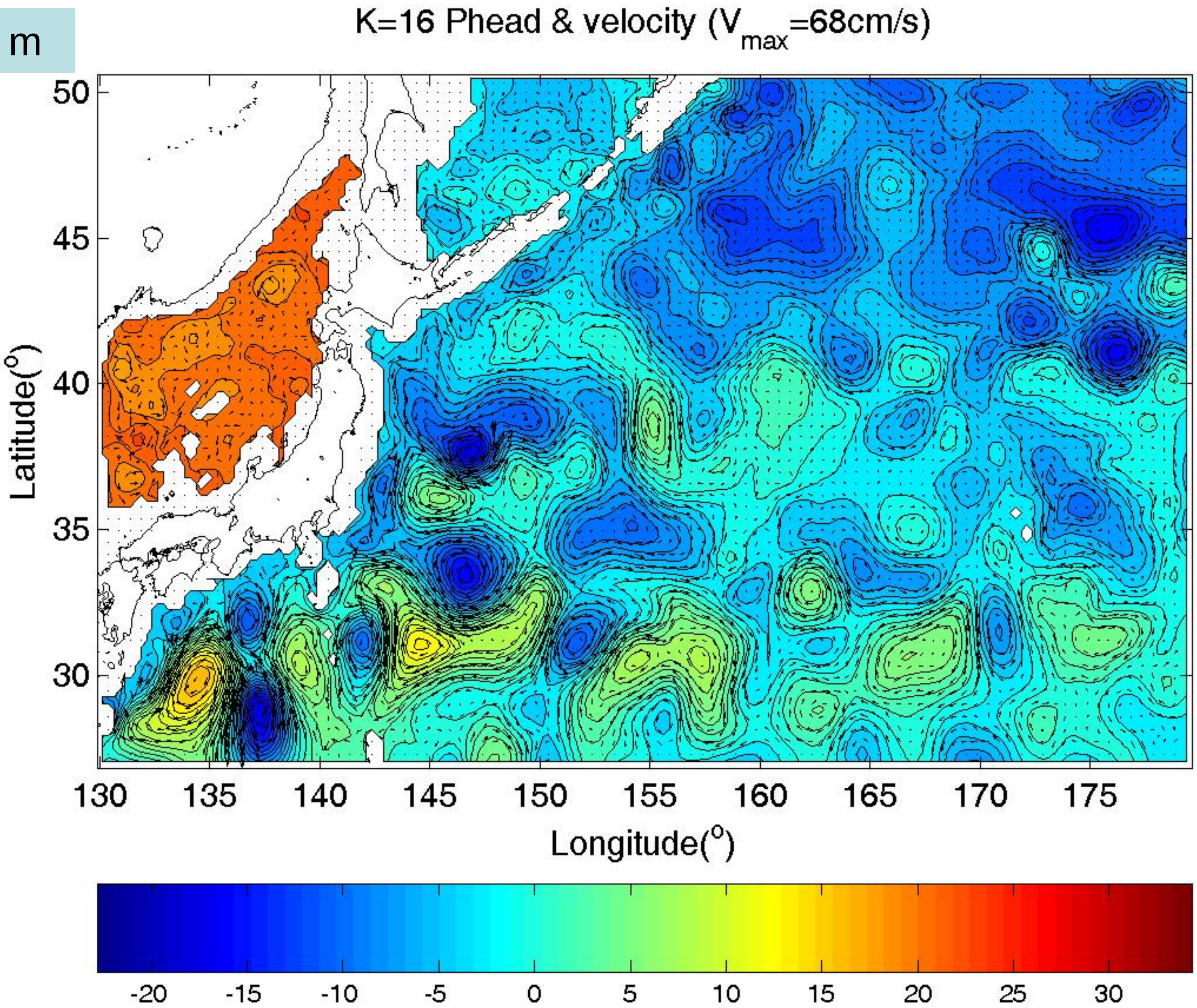
443 m



plot 3

* transient eddies transport and mix buoyancy between fronts
* front spacings are related to eddy scales (internal Rossby radius)
* jets are intense and penetrate far eastward
* from model having 4th-order-accurate numerics

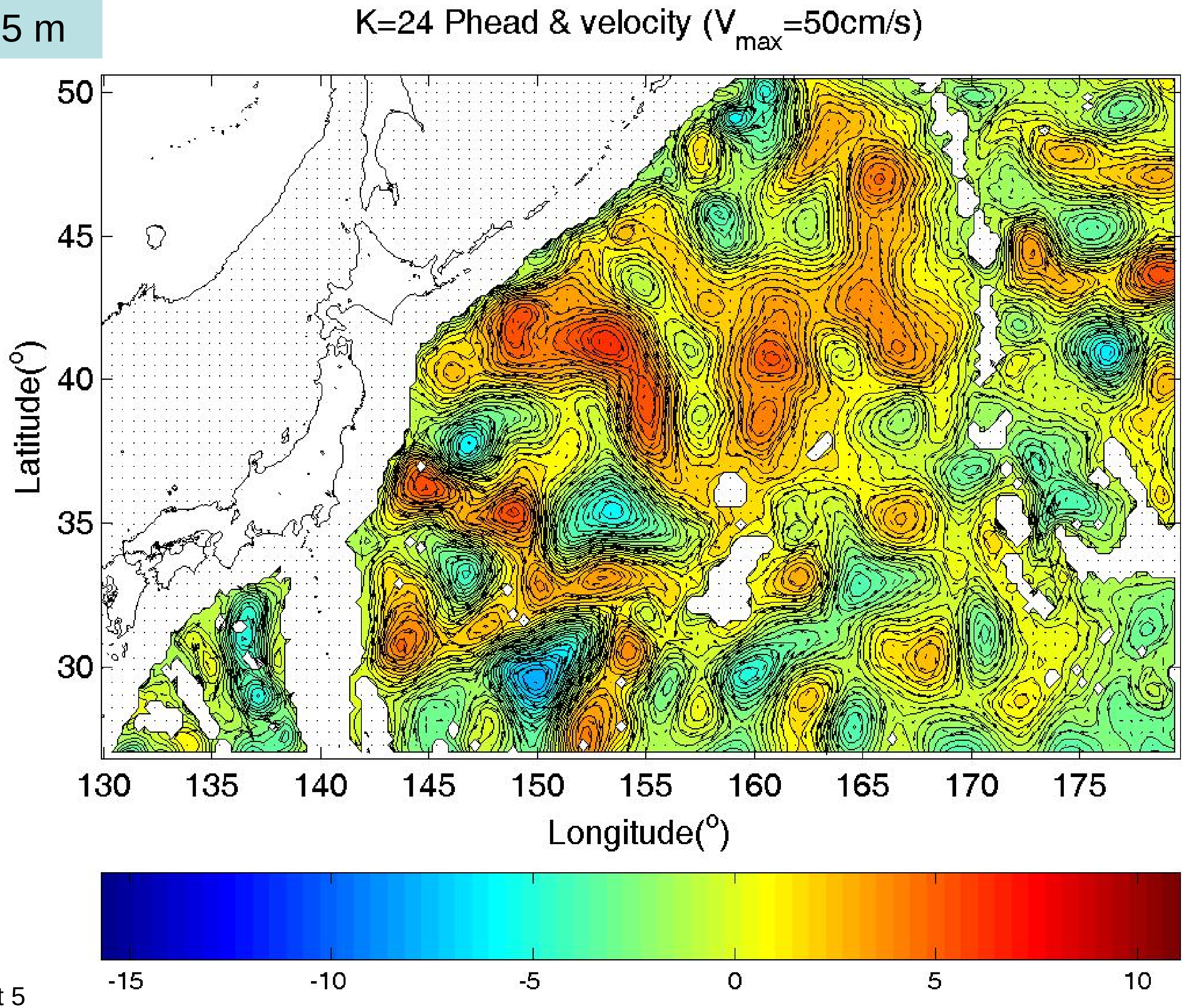
790 m



plot 4

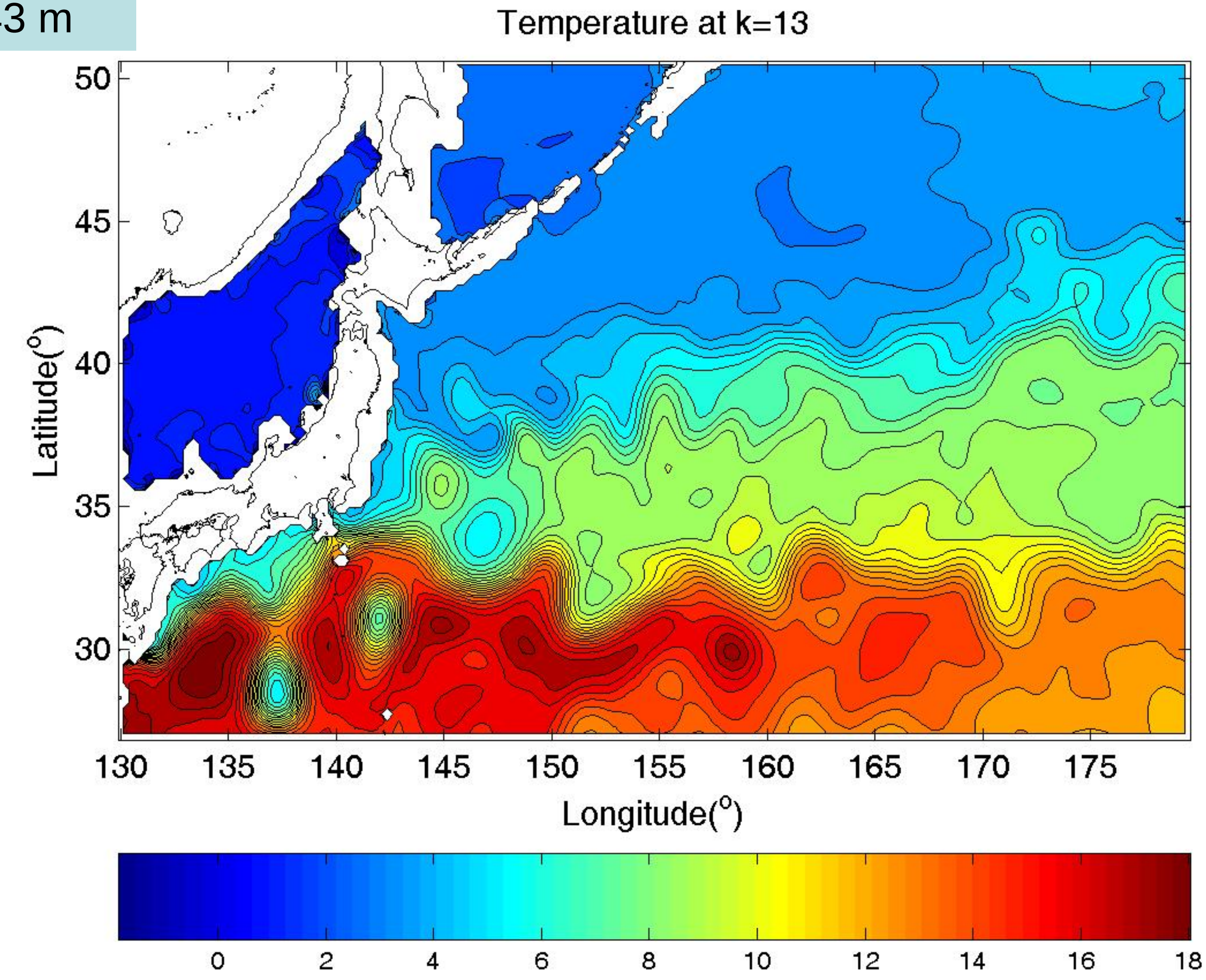
* deep flow is turbulent
* eddy activity aligns with surface fronts
* from model having 4th-order-accurate numerics

3725 m



plot 5
* abyssal flow is turbulent
* note Izu Ridge and Emperor Seamount locations
* from model having 4th-order-accurate numerics

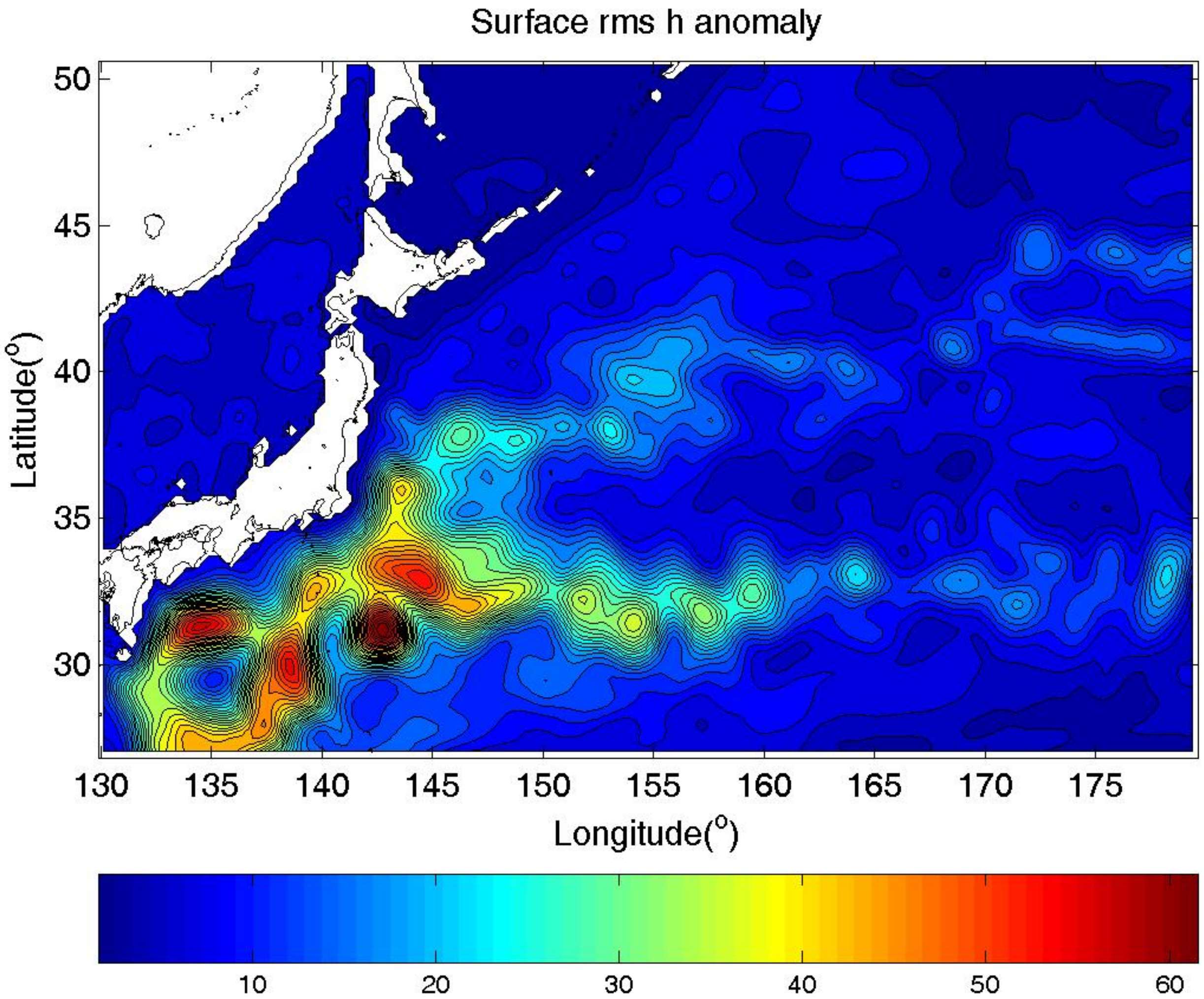
443 m



plot 7

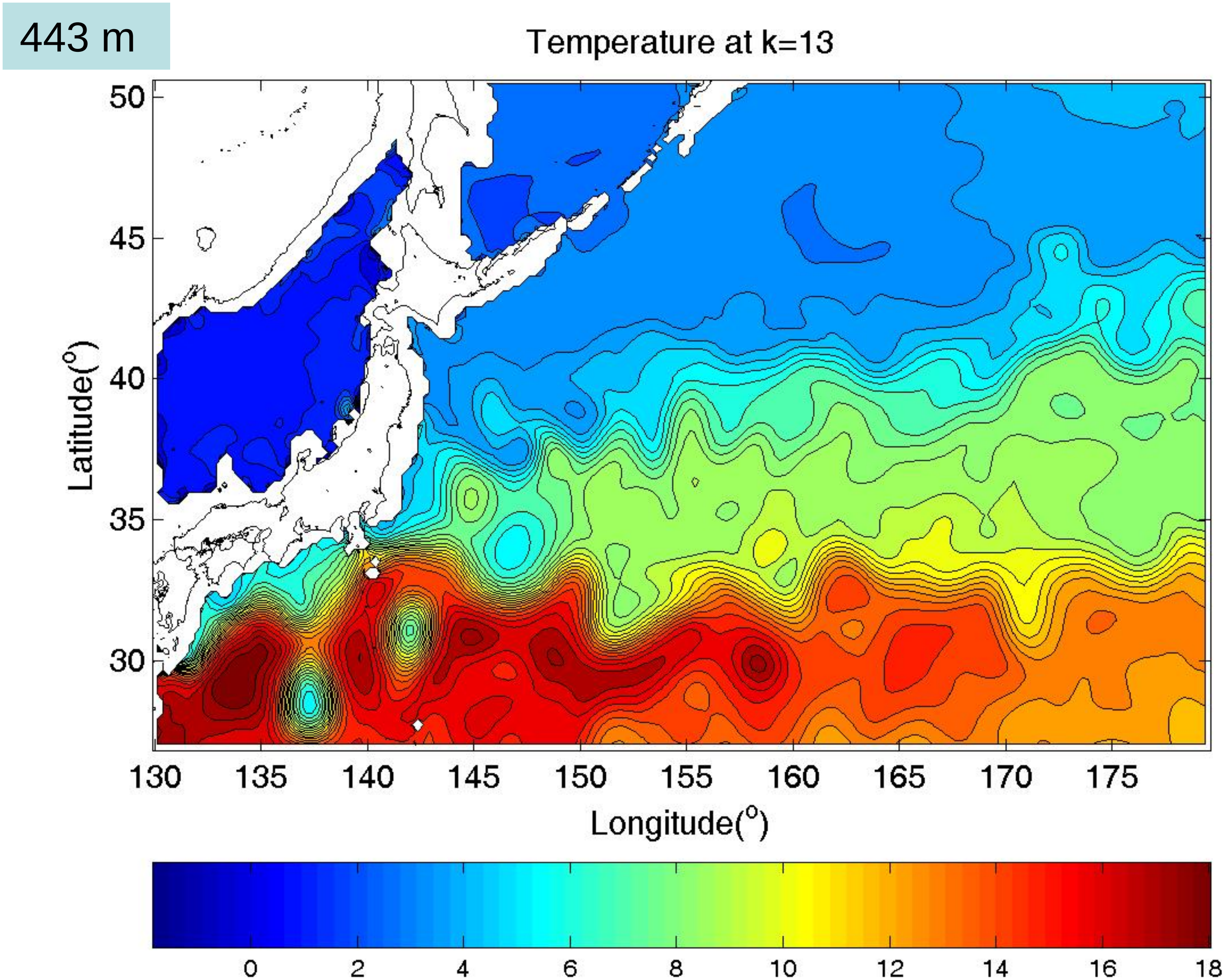
* temperature fronts are very intense: note 3 bifurcations;

* cold- and warm- core eddies are pinched off from big front meanders
* from model having 4th-order-accurate numerics.



plot 6

* root mean squared surface height anomaly deviation from year 17 average validated by satellite altimetry;
* biggest along bifurcated Kuroshio Extension jets; in snapshots, mean jets obscure this fact;
* the jets are energy source leading to intra-jet pinched off eddies having scale near the internal Rossby radius of deformation;
* available potential energy is released downstream of main KE separation (after Kuroshio separates from shelf-slope bathymetry near intersection of Izu Ridge with Honshu);
* buoyancy transport by eddies flattens intra-jet density surfaces, and maintains fronts and associated jets;
* bifurcation near Emperor Seamount gap is marginally resolved by satellite altimetry;
* from model having 4th-order-accurate numerics

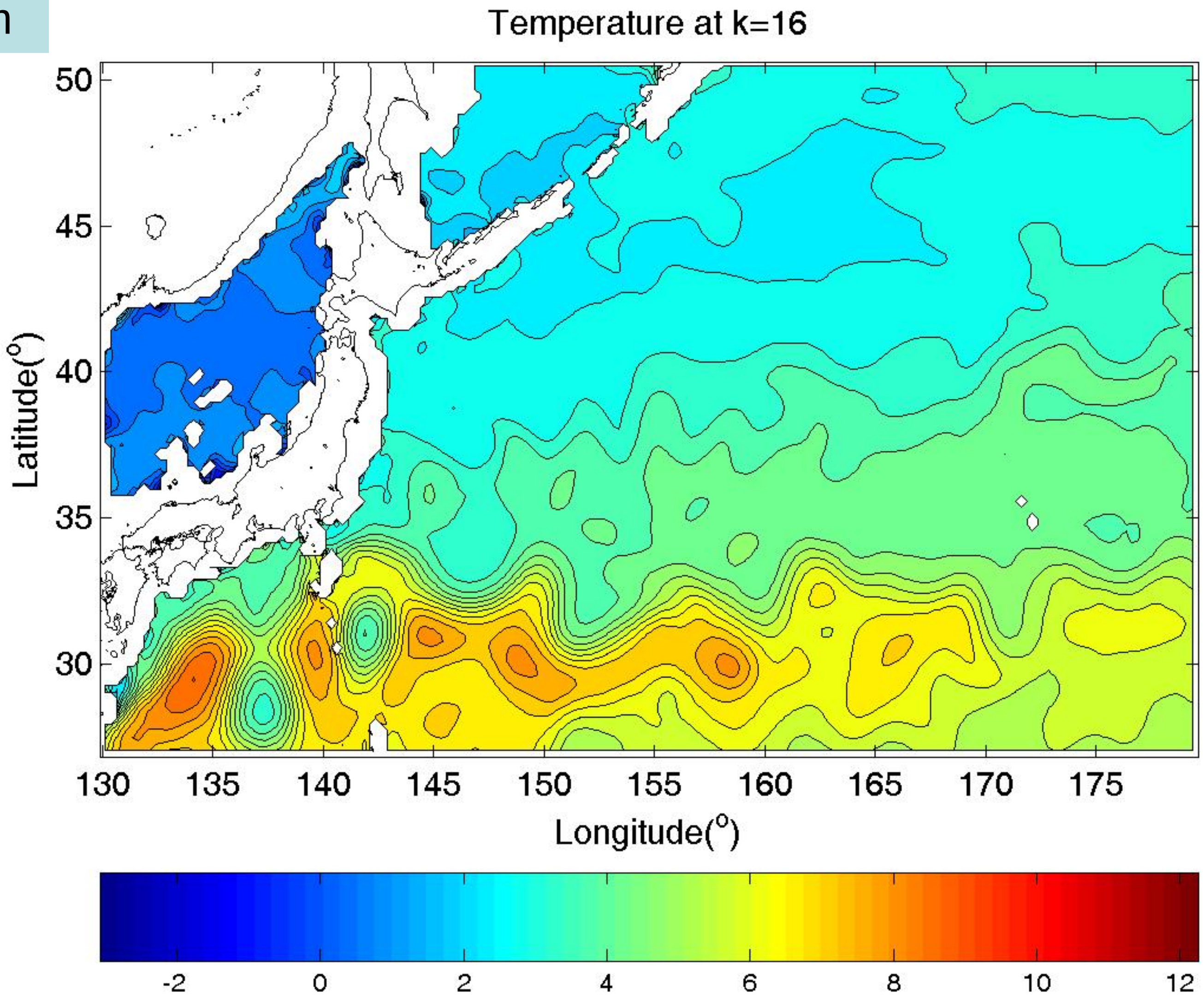


plot 7

* temperature fronts are very intense: note 3 bifurcations;

* cold- and warm- core eddies are pinched off from big front meanders
* from model having 4th-order-accurate numerics.

790 m



plot 8

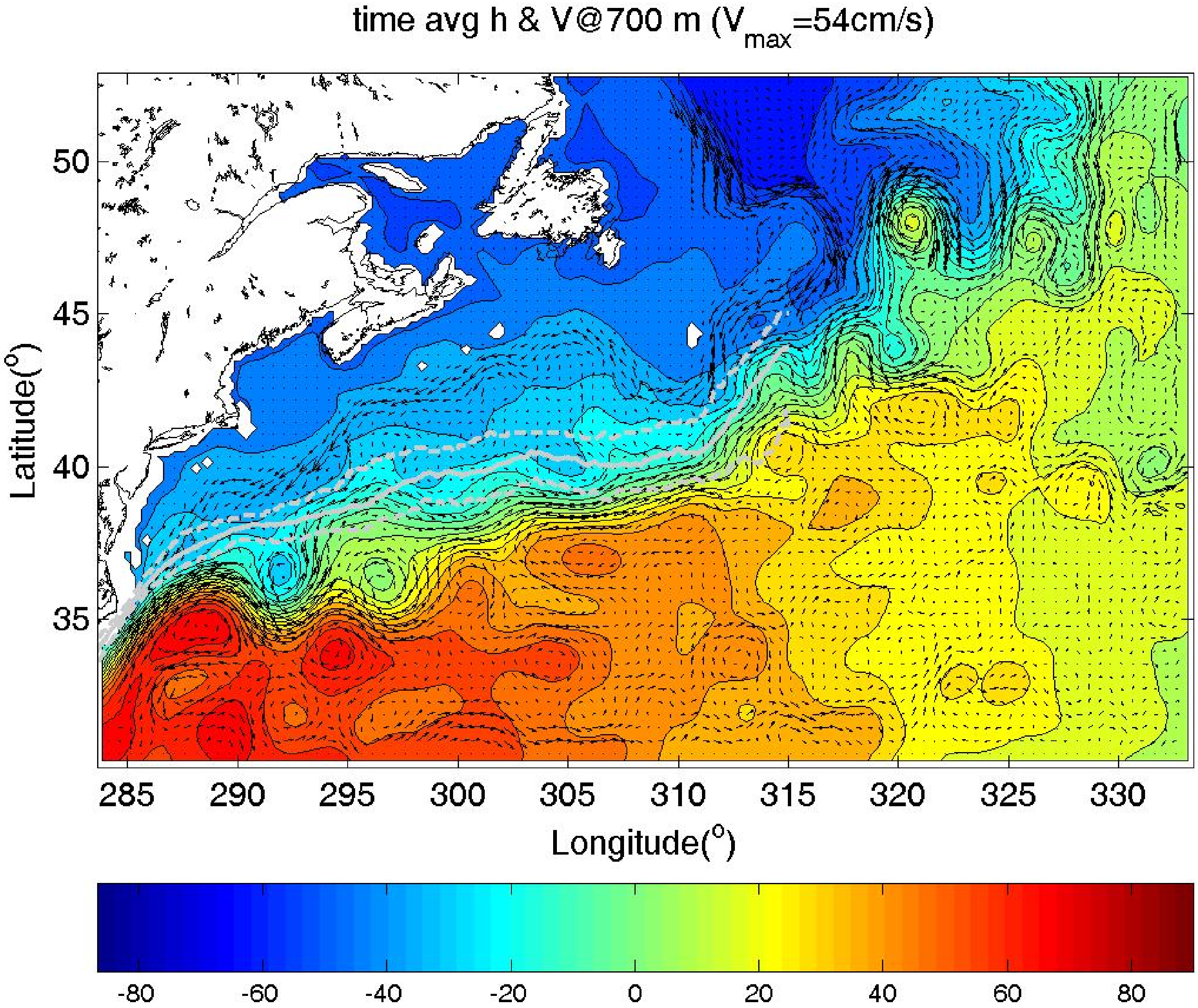
* temperature fronts are clear even at depth
* cold- and warm- core eddies are pinched off from big front meanders
* eddy locations are well correlated throughout the water column indicating dominance by primary empirical orthogonal function as in Gulf of Mexico and other regins of the global ocean
* from model having 4th-order-accurate numerics

GULF STREAM

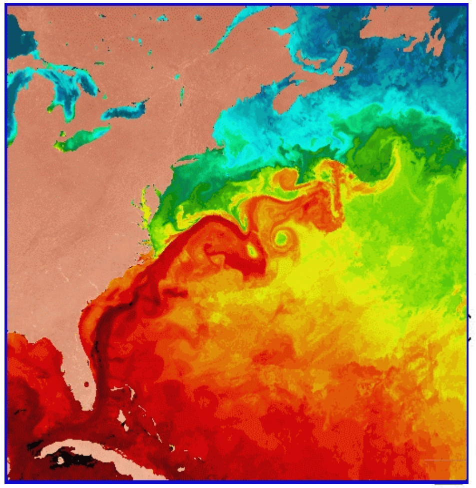
In order to flow westward past the abutment and ventilate the New York Bight, which is a necessary part of GS separation dynamics, the thin narrow
DWBC must be vigorous -- AND -- deep (because GS is weaker at deep levels).

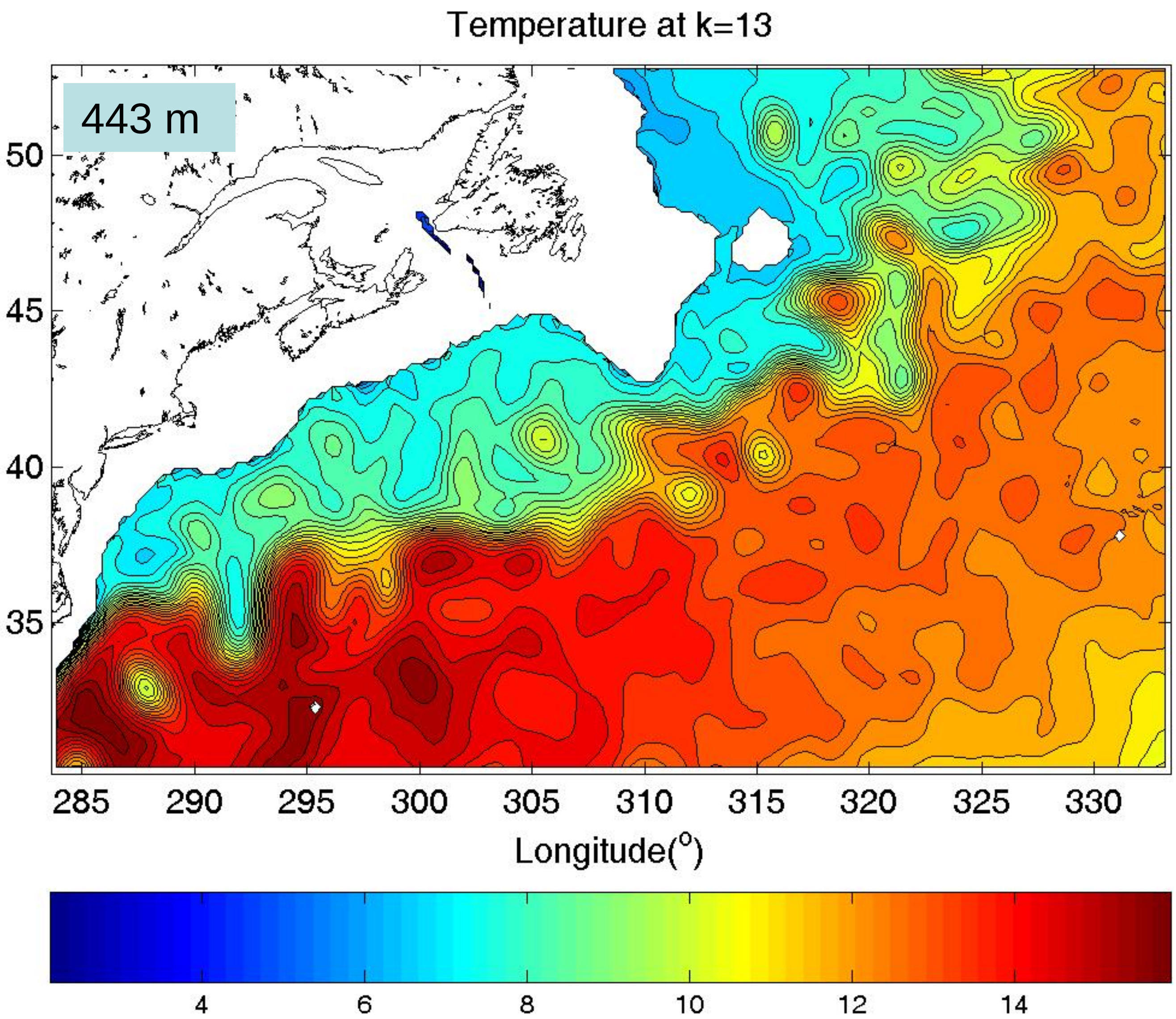
The shelf-slope current is nearly broken at southern tip of the Grand Banks; which is a critical point of DWBC/GS/bathymetry interaction.

This finding is based on a model that uses FULL AMPLITUDE real bathymetry and directly simulates water mass transformations and resulting slantwise convection. The abyssal flow is thought to
have even more important effect on the GS path (Hurlburt and Hogan, 2008).



plot 1
* year 17 time avg 700m depth velocity crosses under the time average
surface GS indicating strongly baroclinic flow.

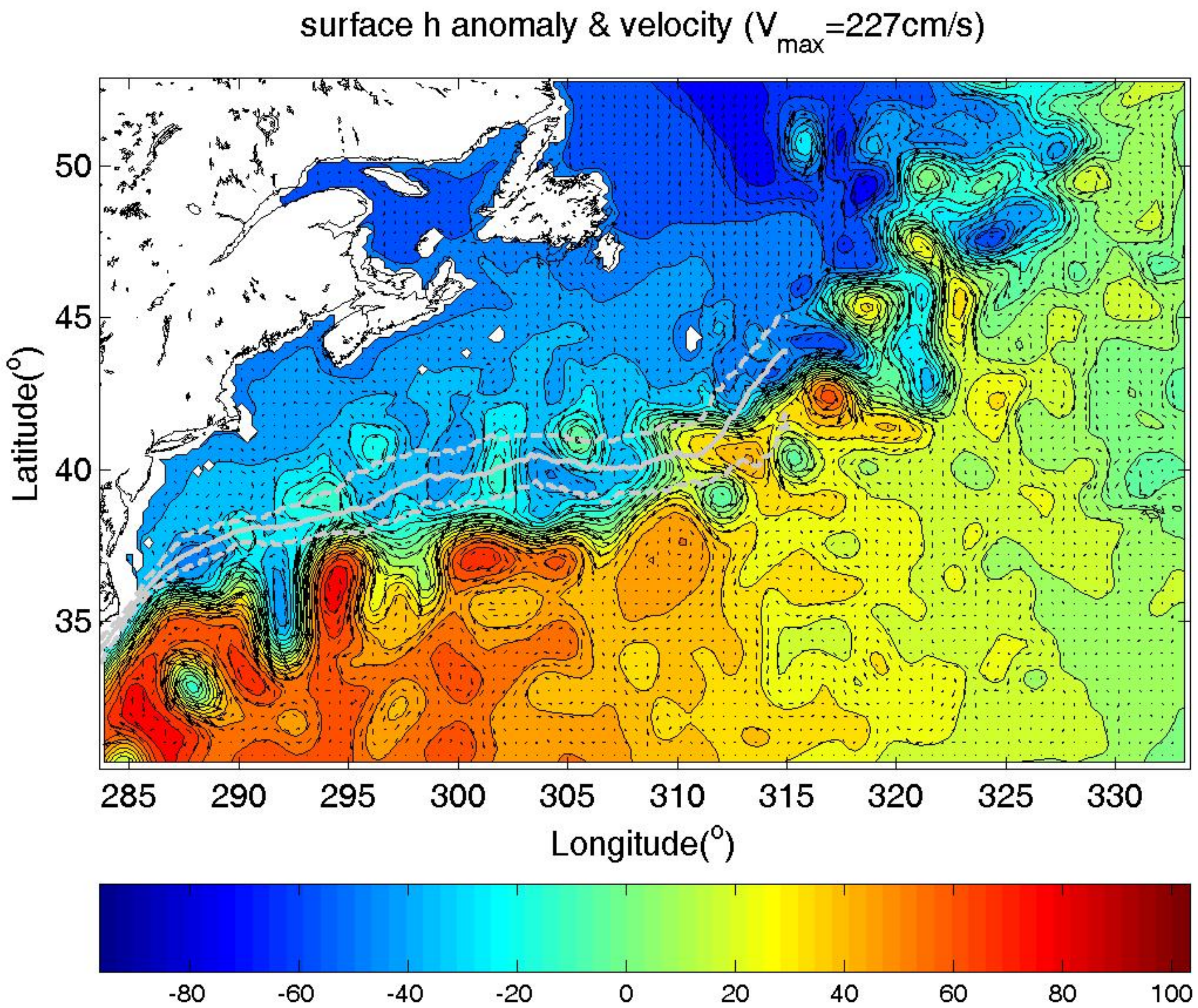




http://sam.ucsd.edu/sio210/gifimages/sst_brown.gif

plots 7

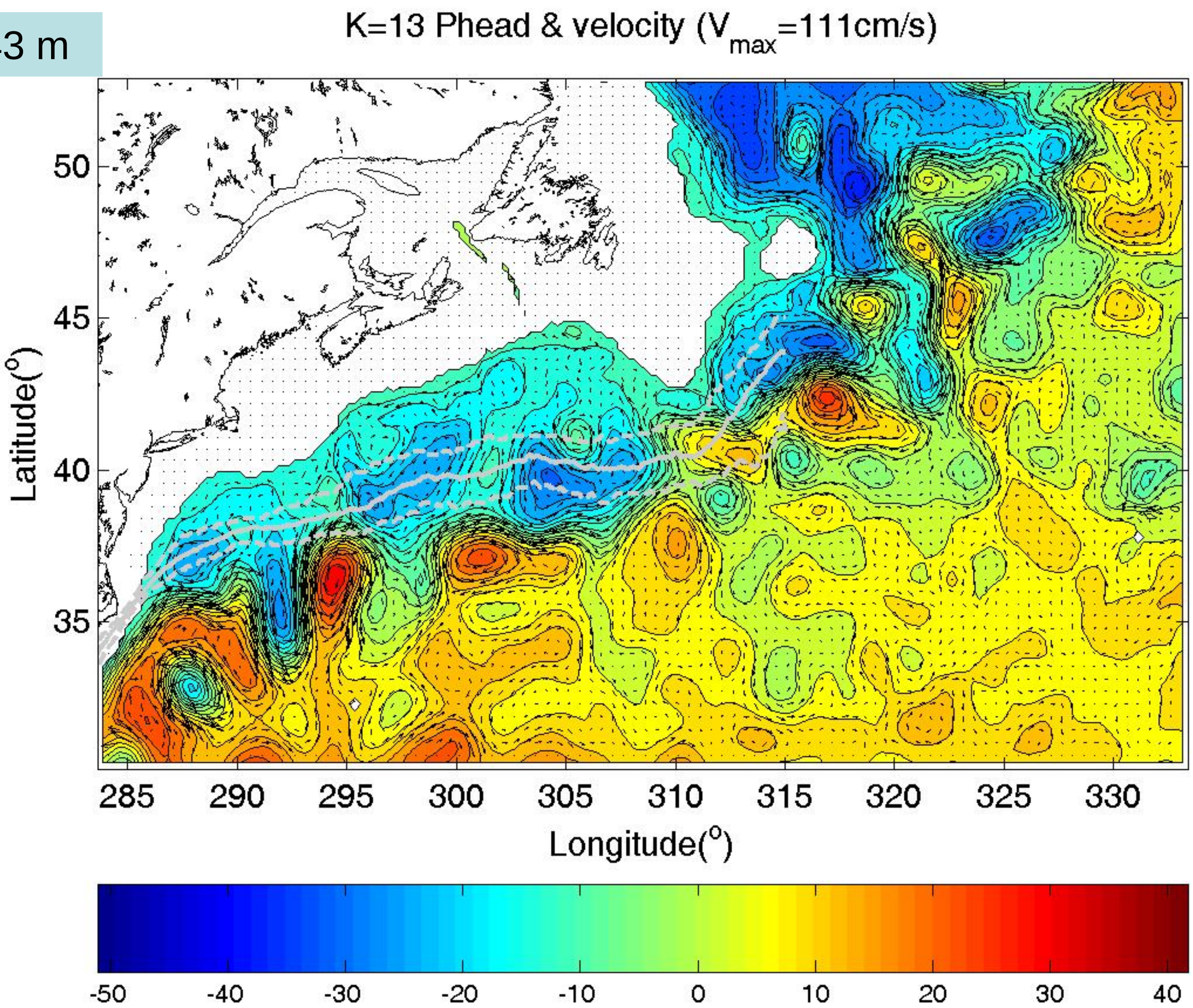
* strong deep temperature fronts (even tighter than GS jets)
* ubiquitous vigorous warm- and cold- rings
* from model having 4th-order-accurate numerics



plot 2

* end points of GS path -- near major deep Grand Banks abutment and Cape Hatteras abutment -- are close to observations.
* vigorous meanders and pinched off warm- and cold- core rings
* warm core rings ventillate southern Labrador Sea with GS water
* from model having 4th-order-accurate numerics

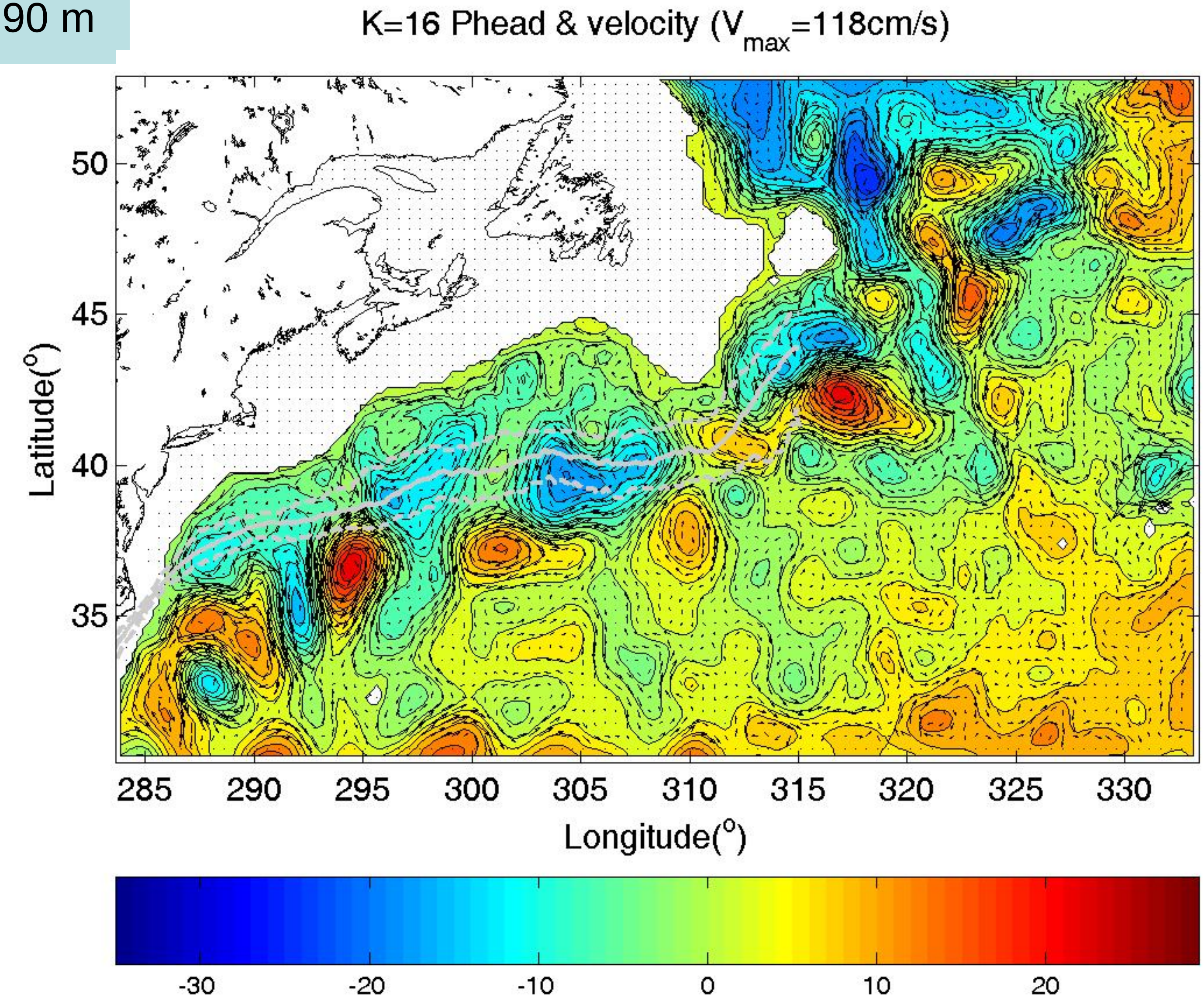
443 m



plot 3

* deep and abyssal GS region plots show GS recirculation and strong deep transient eddies.
* from model having 4th-order-accurate numerics

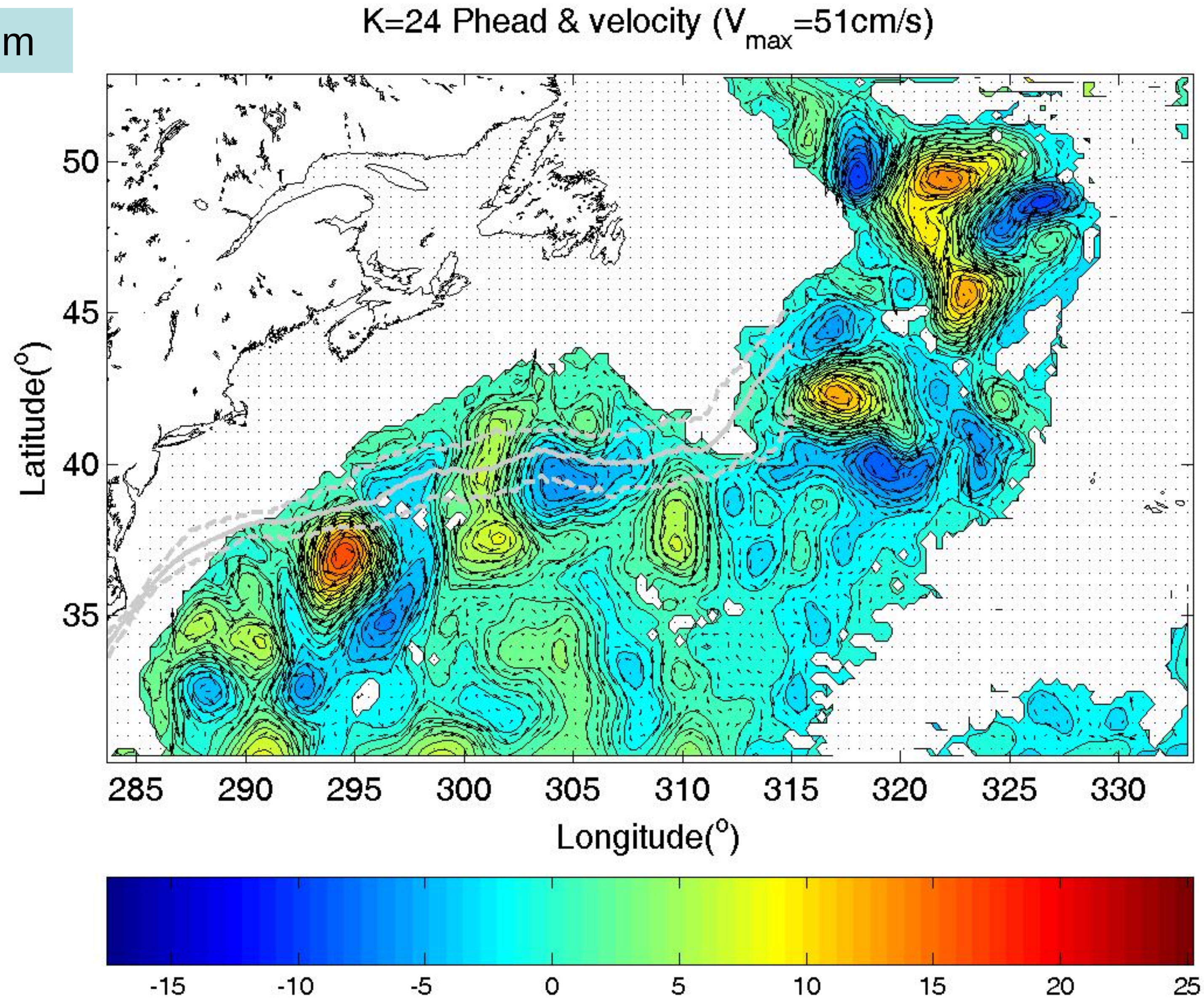
790 m



plot 4

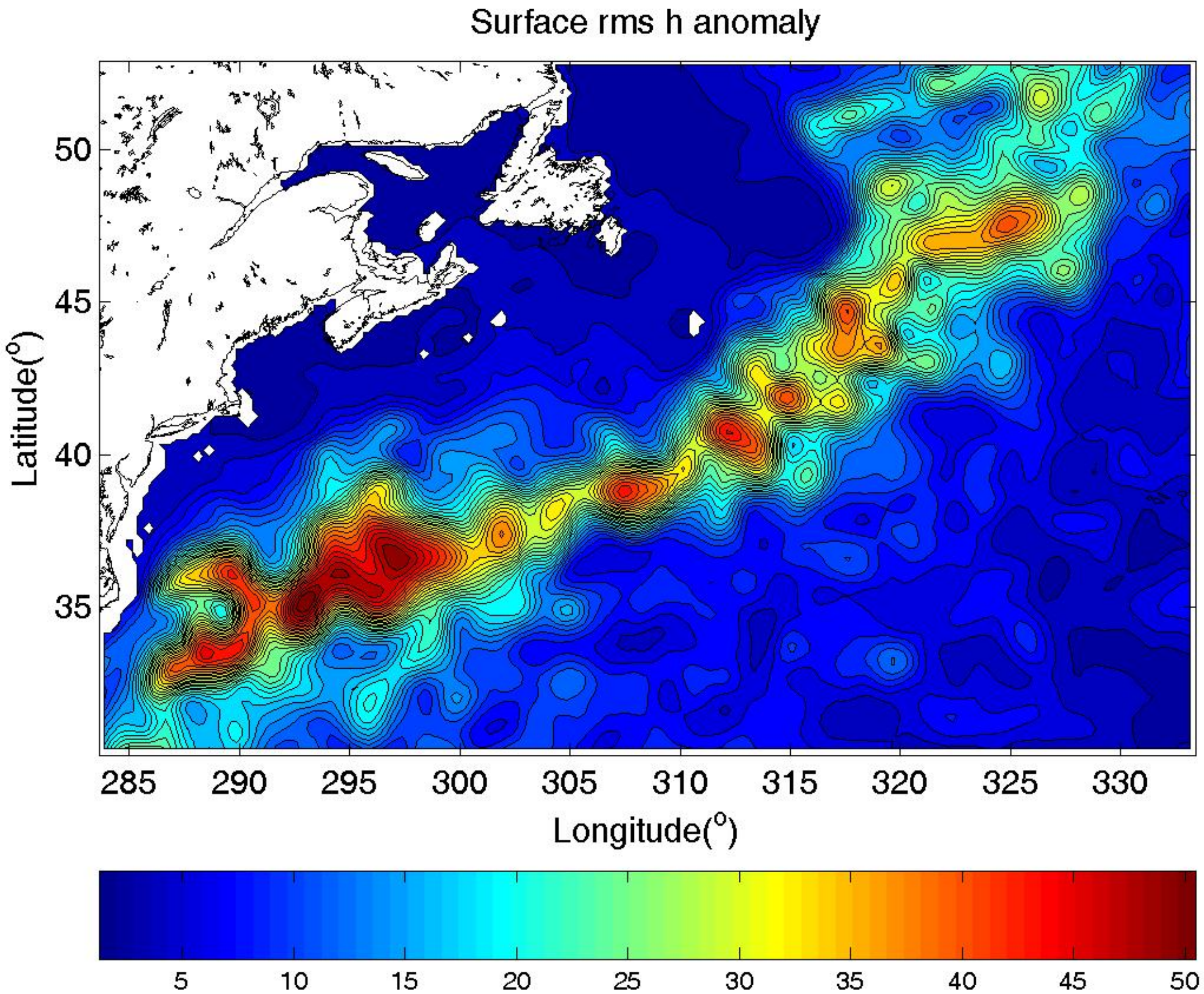
* deep and abyssal GS region plots show GS recirculation and strong deep transient eddies.
* from model having 4th-order-accurate numerics

3725 m



Plot 5

* deep and abyssal GS region plots show GS recirculation and strong deep transient eddies.
* from model having 4th-order-accurate numerics



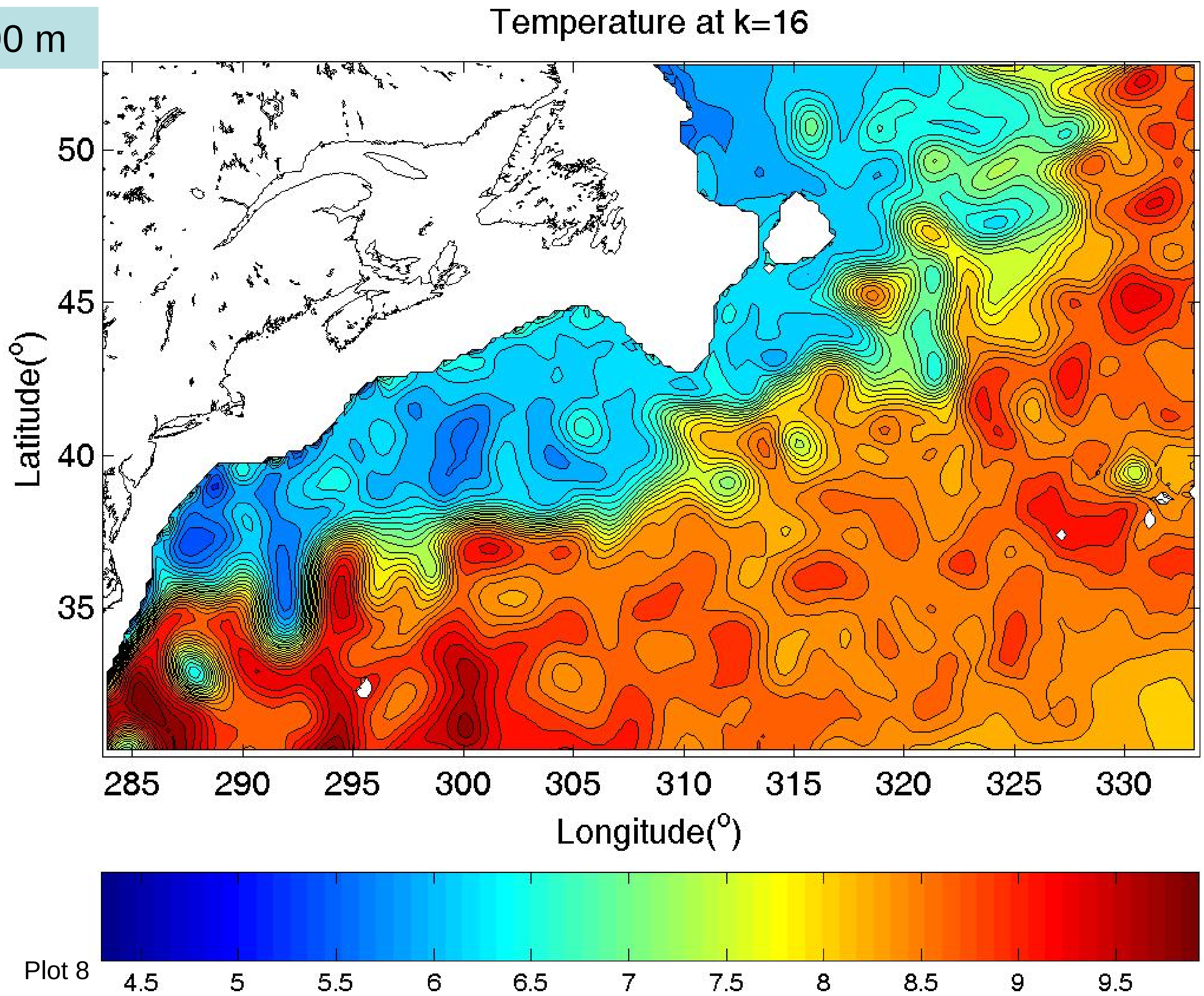
plot 6

* root mean squared sea surface deviation from its year 17 time average shows vigorous transients all along GS path;

* horse shoe shaped pattern near Cape Hatteras reflects warm- and cold- core rings that propagate westward after separating from the GS core;

* the transients are biggest in the GS core having big meanders from which warm- and cold- cores separate;
* meander scales similar to the internal Rossby radius of deformation and strong deep flow across the overlying GS core reflect baroclinic instability processes;
* from model having 4th-order-accurate numerics.

790 m



Plot 8

* strong deep temperature fronts (even tighter than GS jets)
* ubiquitous vigorous warm- and cold- rings
* from model having 4th-order-accurate numerics

GULF OF MEXICO

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Model results and publications shows its good potential value for applications relating to environmental effects of, and response to, the BP disaster.

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The original model leading to the modern version of the present ocean model was designed for risk assessment of nuclear waste disposal in the ocean bottom sediments. It included coupling of a deep sea bottom boundary layer model to an overlying ocean model in the Sandia Ocean Modeling System.

The original Gulf of Mexico studies using the modern version of the model are validated by a variety of observations including satellite altimetry.

The original model was two-way-coupled to an atmospheric hurricane model in the Gulf of Mexico, in a late 1990's study published in J. Atmos. Sciences (Nihat Cubukcu, et al.).

More recently:

1.

NATO sponsored coupling of a state-of-the-art oil plume model to a Black Sea adaptation of the present model to study hypothetical oil spills.

2.

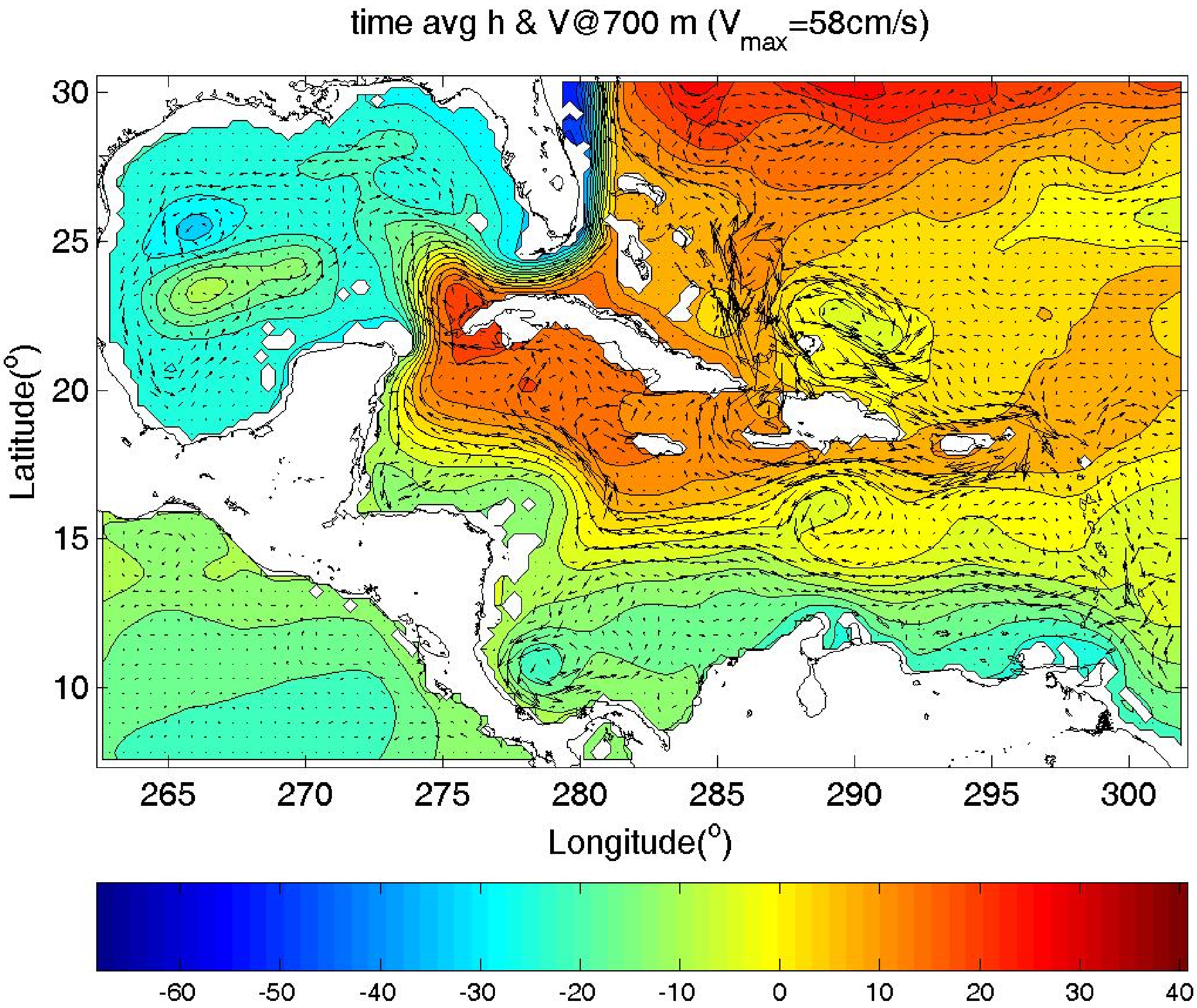
Motivated by the Prestige oil spill disaster in deep water near the NW corner of the Iberian Peninsula, the Marcelino Botin Foundatation (ran by Santander Bank) sponsored simulation of the coupled Mediterranean Sea and North Atlantic Ocean using the present model. This was done using 6 two-way coupled grids. The six grids include an ultra high resolution Strait of Gibraltar region grid.
The model accurately simulated the *model-challenging* deep Mediterranean Overflow Water depth penetration and the path of the deep lense of warm, salty water fed by the MOW, around the entire Iberian Peninsula.

3.

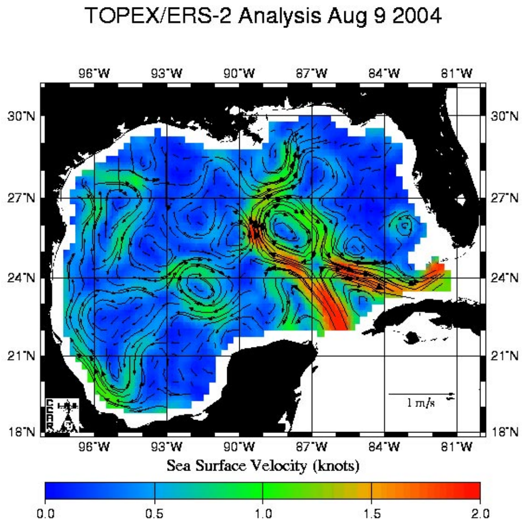
The model simulation of the East China Sea response to typhoon Kai-tak was well validated by the accurately simulated 9 deg C cooling of the surface water caused by wind forced upwelling of thermocline water and turbulent mixed layer.

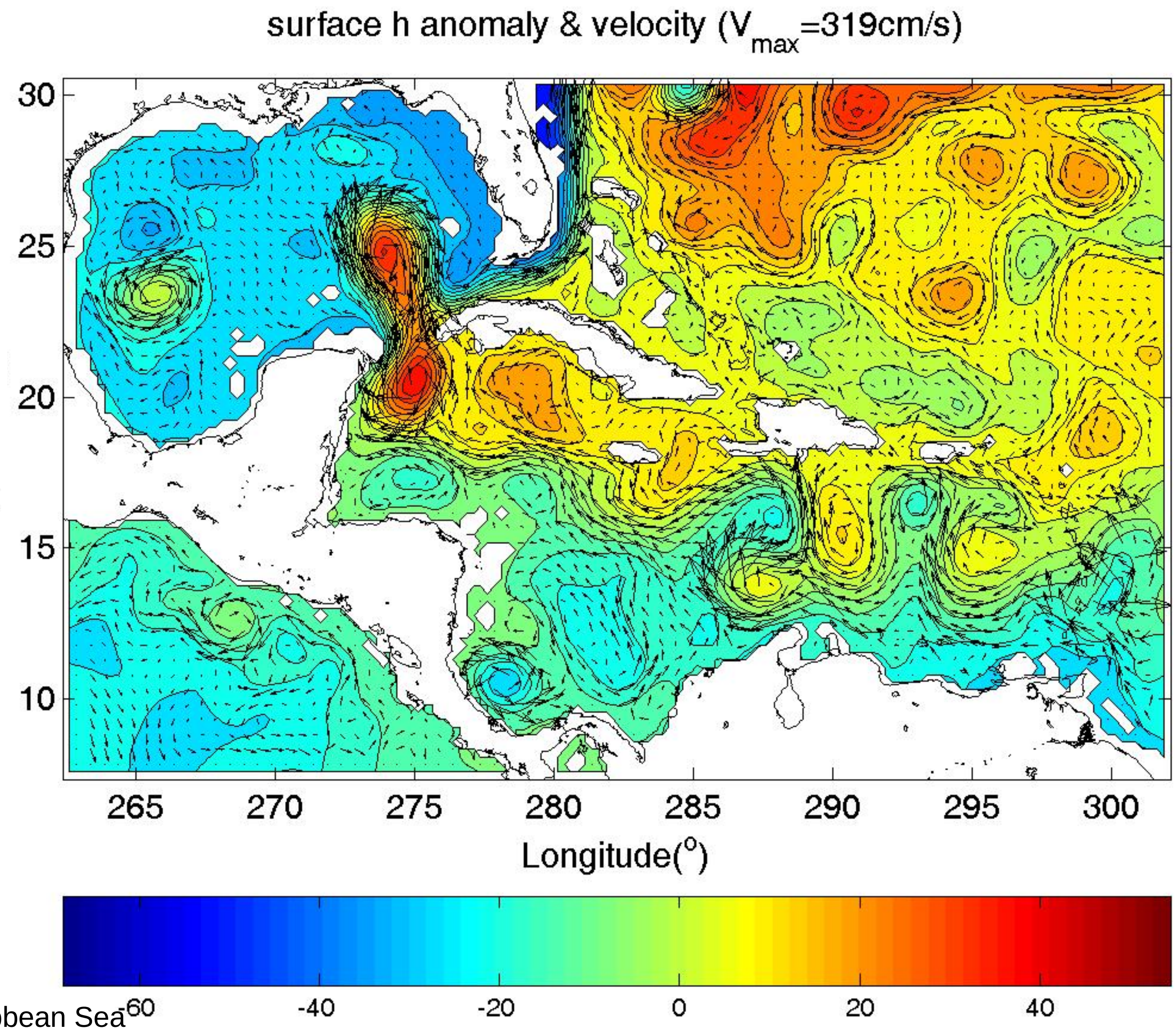
4.

The Canadian version of the present model, CANDIE, has multiple publications relating to hurricane response.



plot 1 (skipped in talk)
* year 17 time average
* from model having 4th-order-accurate numerics

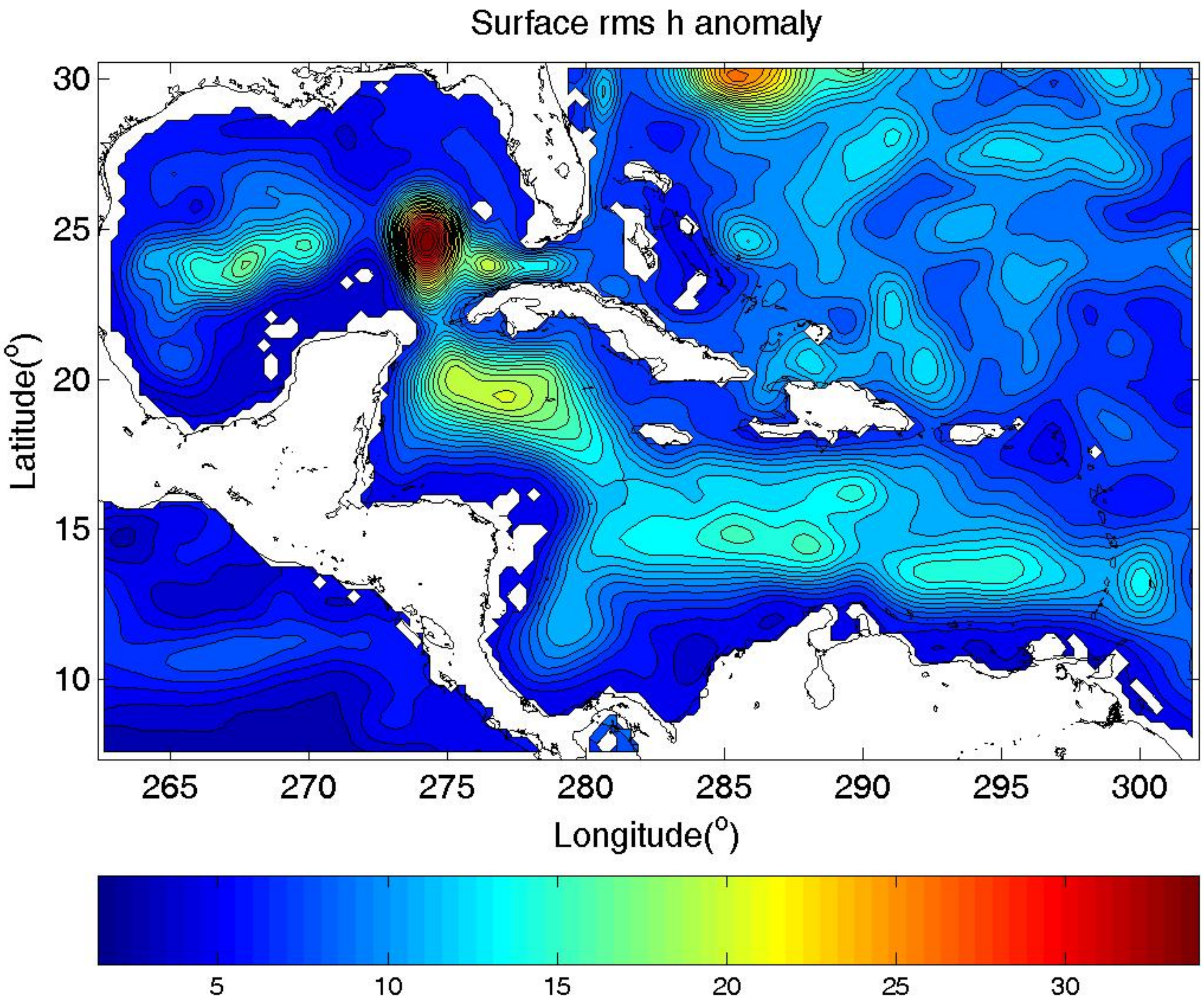




http://www.jpl.nasa.gov/news/profiles.cfm?profile=609

plot 2

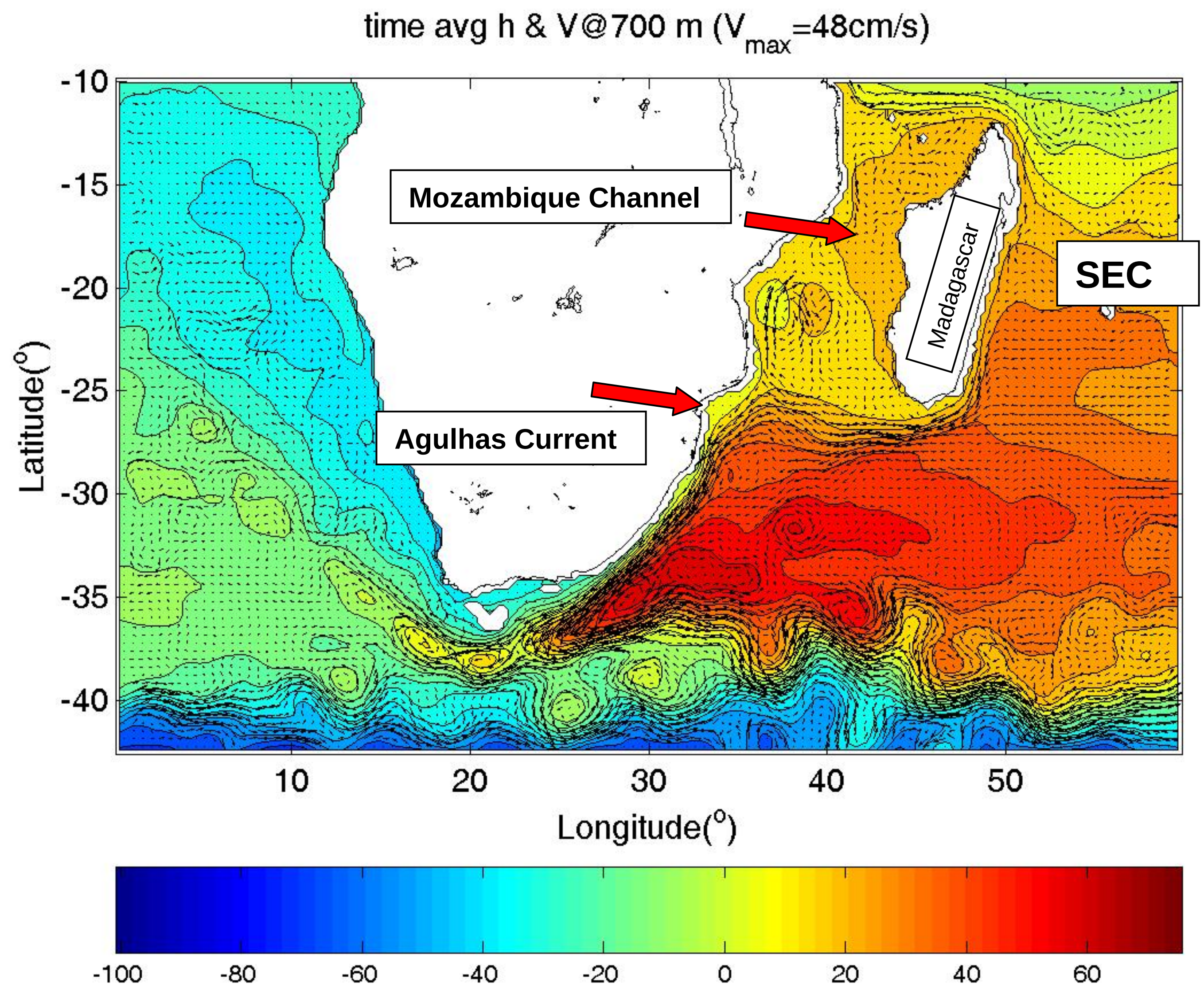
* anticyclonic eddies in Caribbean Sea
* cyclonic flow in southwestern Caribbean Sea
* Loop Current
* paired old Loop Current eddy and cold core eddy in western GOM
* Loop Current frontal eddy extends toward BP disaster site-- this is similar to what is happening now!



plot 3

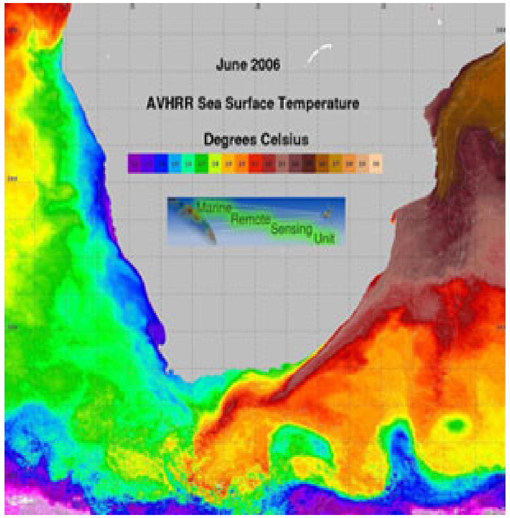
* root mean squared surface height deviation from its year 17 average
* trail of old shed LCE
* trail of Caribbean Sea anticyclones
* from model having 4th-order-accurate numerics

AGULHAS CURRENT

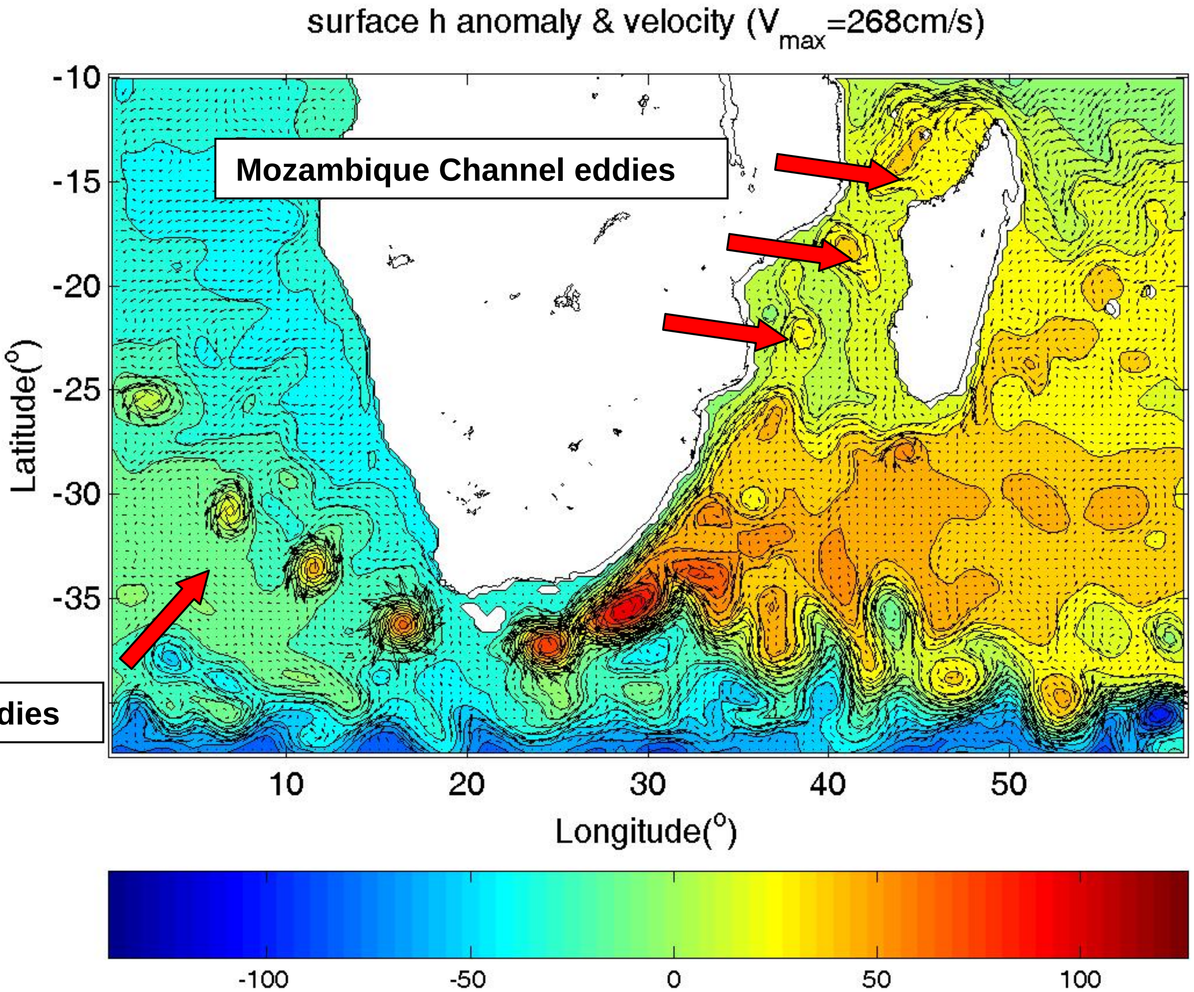


plot 1

* year 17 time average
* South Equatorial Current bifurcates at Madagascar east coast stagnation point
* northern branch bifurcates again at African coast
* front at north edge of Agulhas rings path
* Antarctic Circumpolar Current along south edge
* from model having 4th-order-accurate numerics



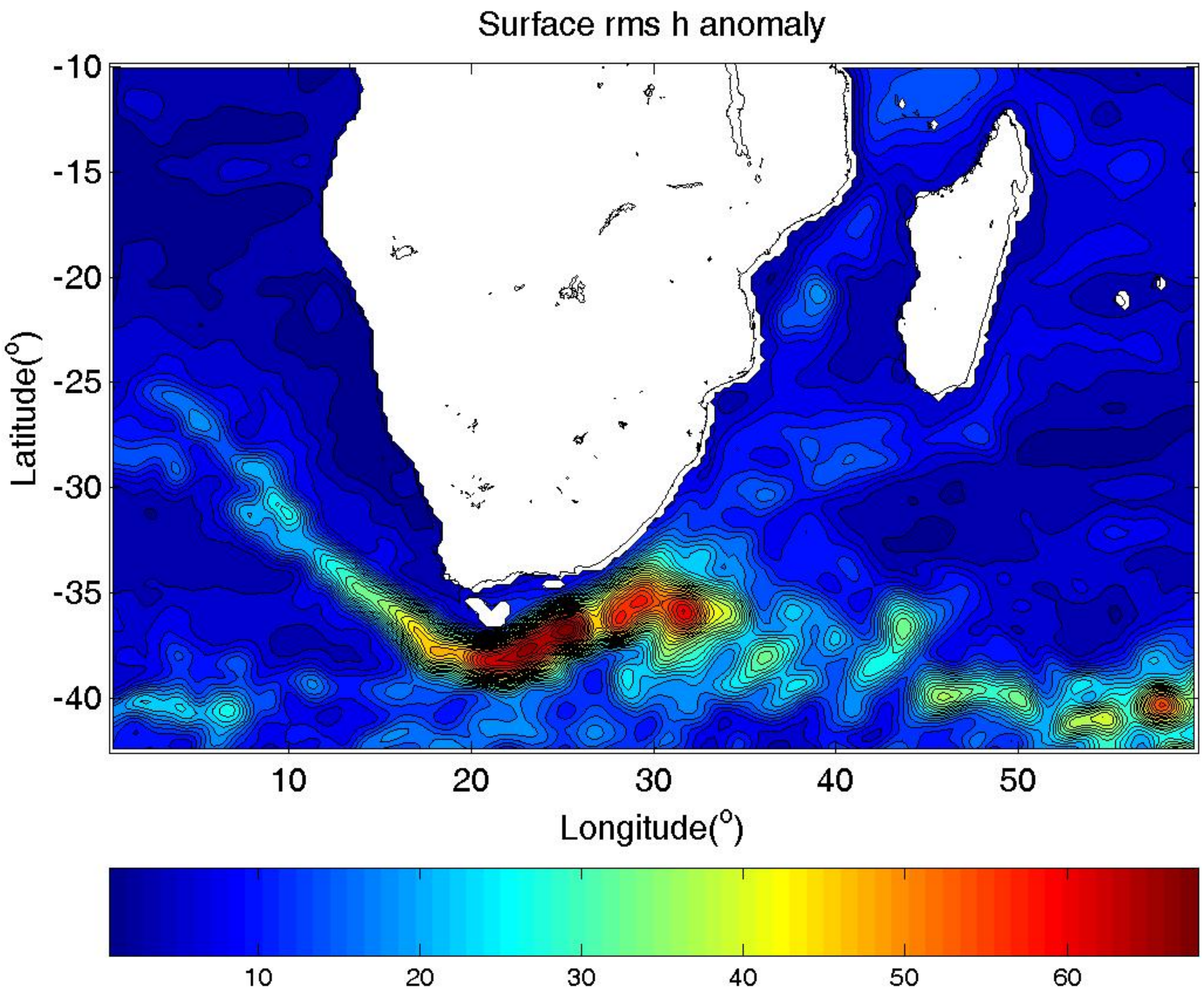
http://sea.uct.ac.za/



Agulhas retroflection eddies

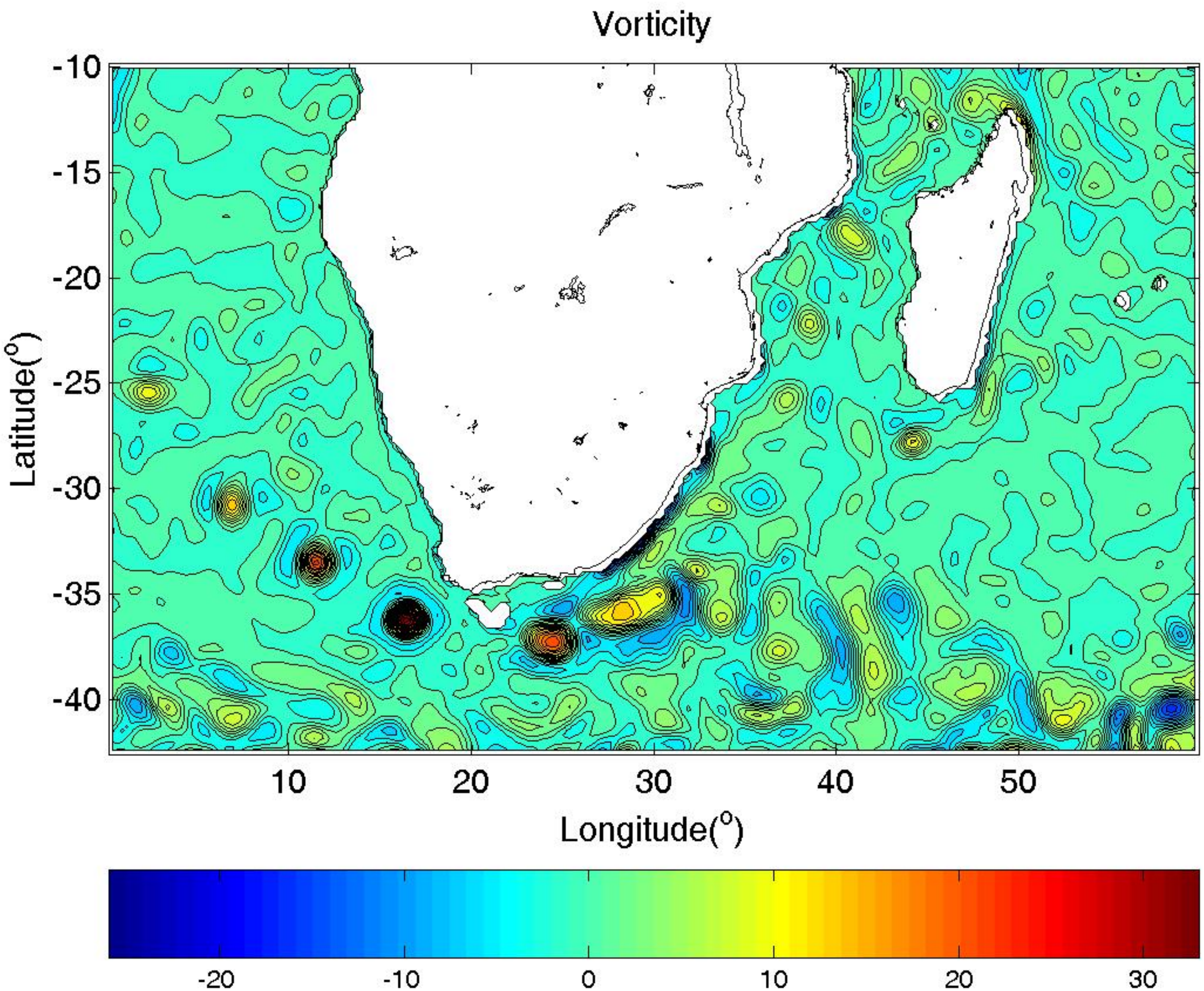
plot 2

* South Equatorial Current bifurcates at Madagascar east coast stagnation point
* warm core rings break away from Agulhas Current south of Capetown
* warm core eddies spin off northern tip of Madagascar and propagate southward in the Madagascar Channel
* channel eddies are bottom-drag-generated island wake recirculation eddies that quickly approach Mozambique coast, elongate and turn southward; they also carry earth vorticity southward (increases their intensity)
* Antarctic Circumpolar Current near 41 S interacts with Agulhas Current
* similar to island wake vortices (e.g. Barbados) and to headland wake vortices that dominate the Black Sea -- both accurately modeled by the present model
* from model having 4th-order-accurate numerics



plot 3

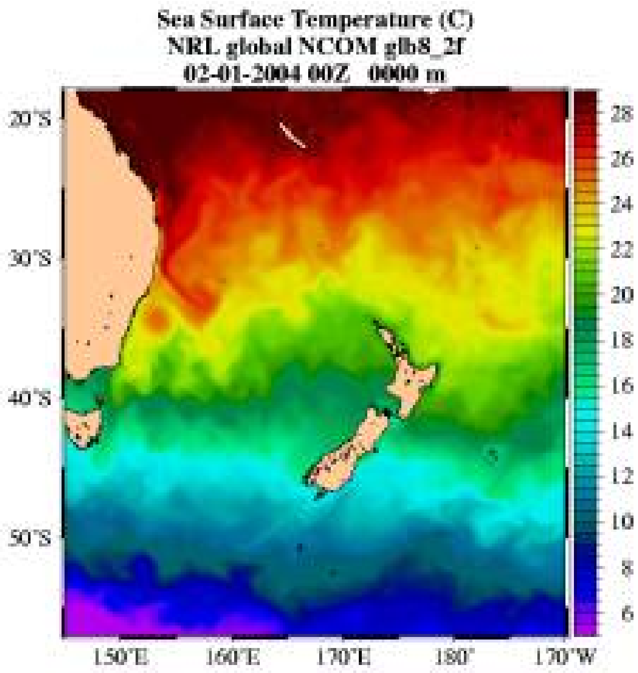
* Mozambique Channel eddies affect Agulhas Current warm core rings and thus North Atlantic thermohaline circulation at 1/4 deg resolution:
* notably the model accurately simulates the Mozambique Channel eddies that are thought to affect the Agulhas Current, due to its robust, 4th order accurate numerics.

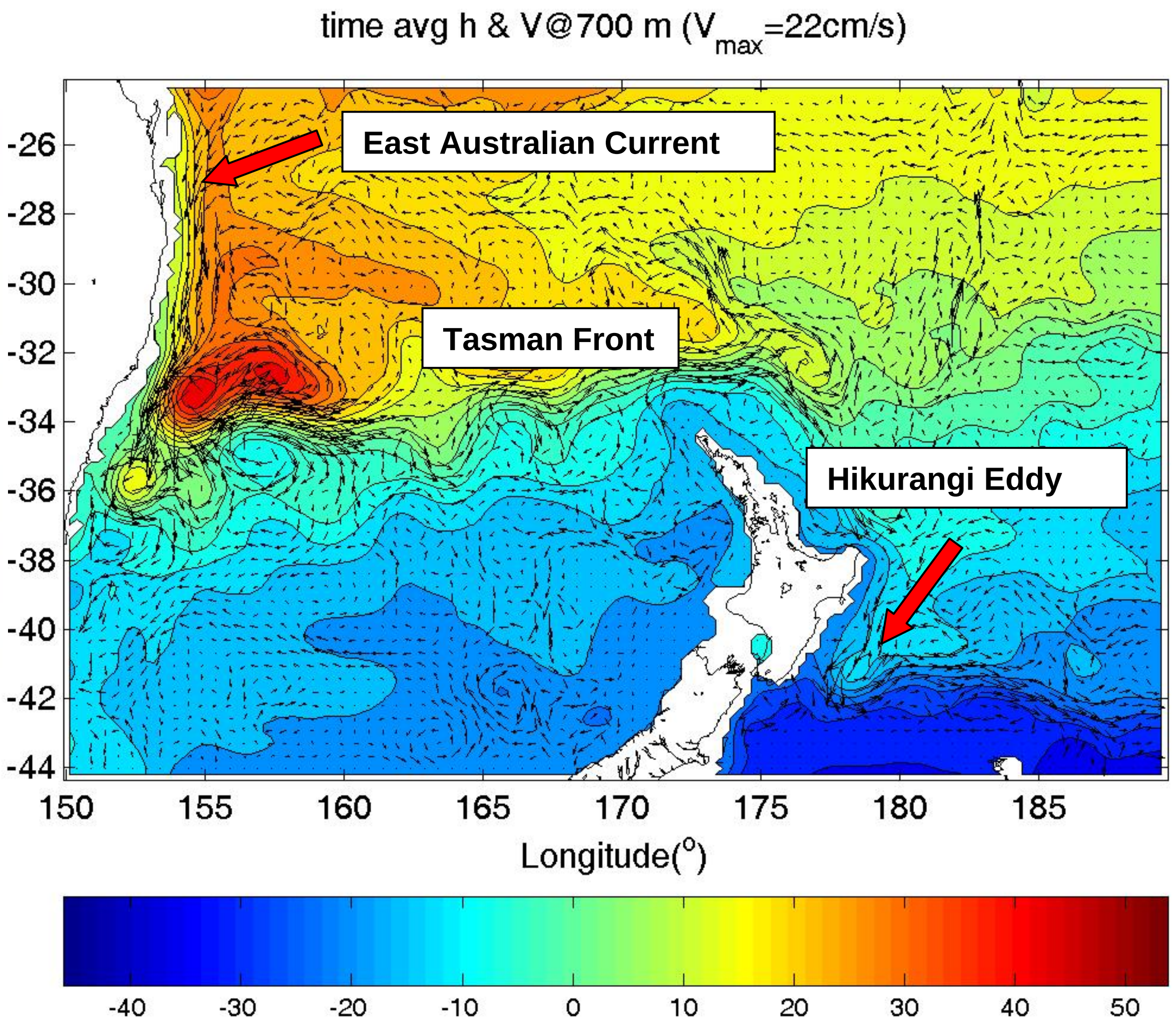


plot 4 (may be skipped in talk)

* vorticity plot emphasizes the richly detailed robust features simulated by the present 1/4 deg resolution global model
* from model having 4th-order-accurate numerics

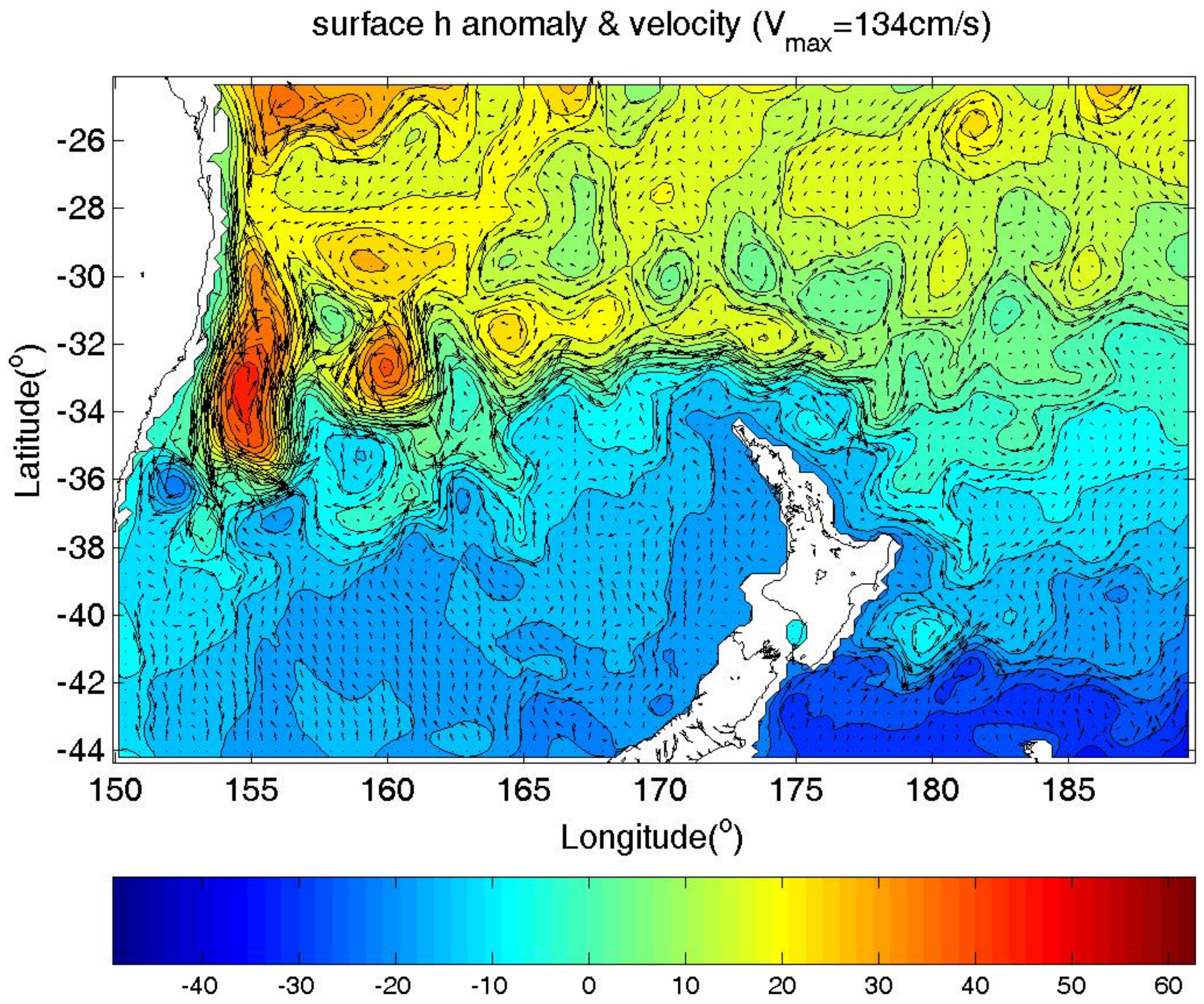
TASMAN SEA



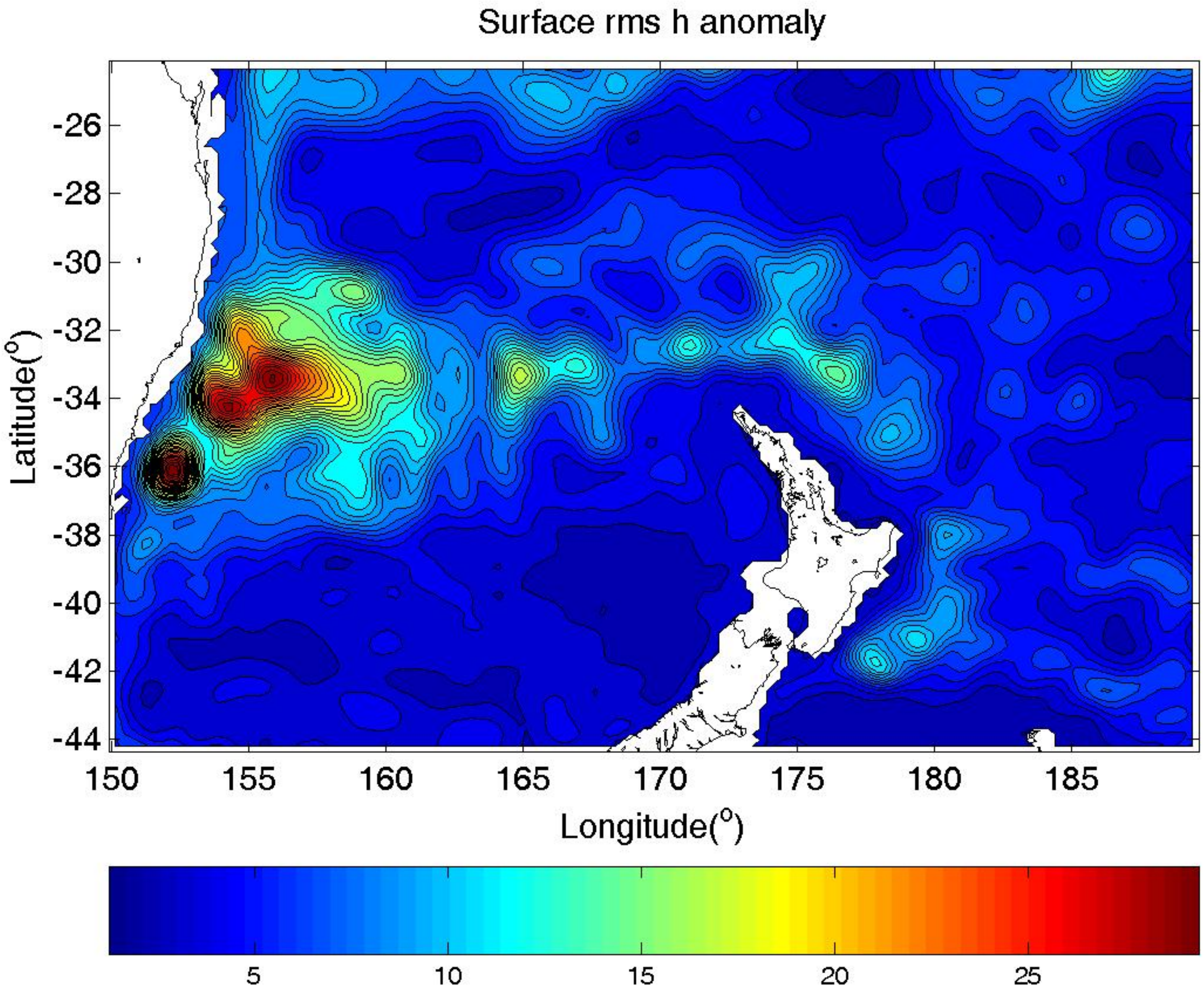


http://www2.science.unsw.edu.au/images/Newsoceanimage.jpg

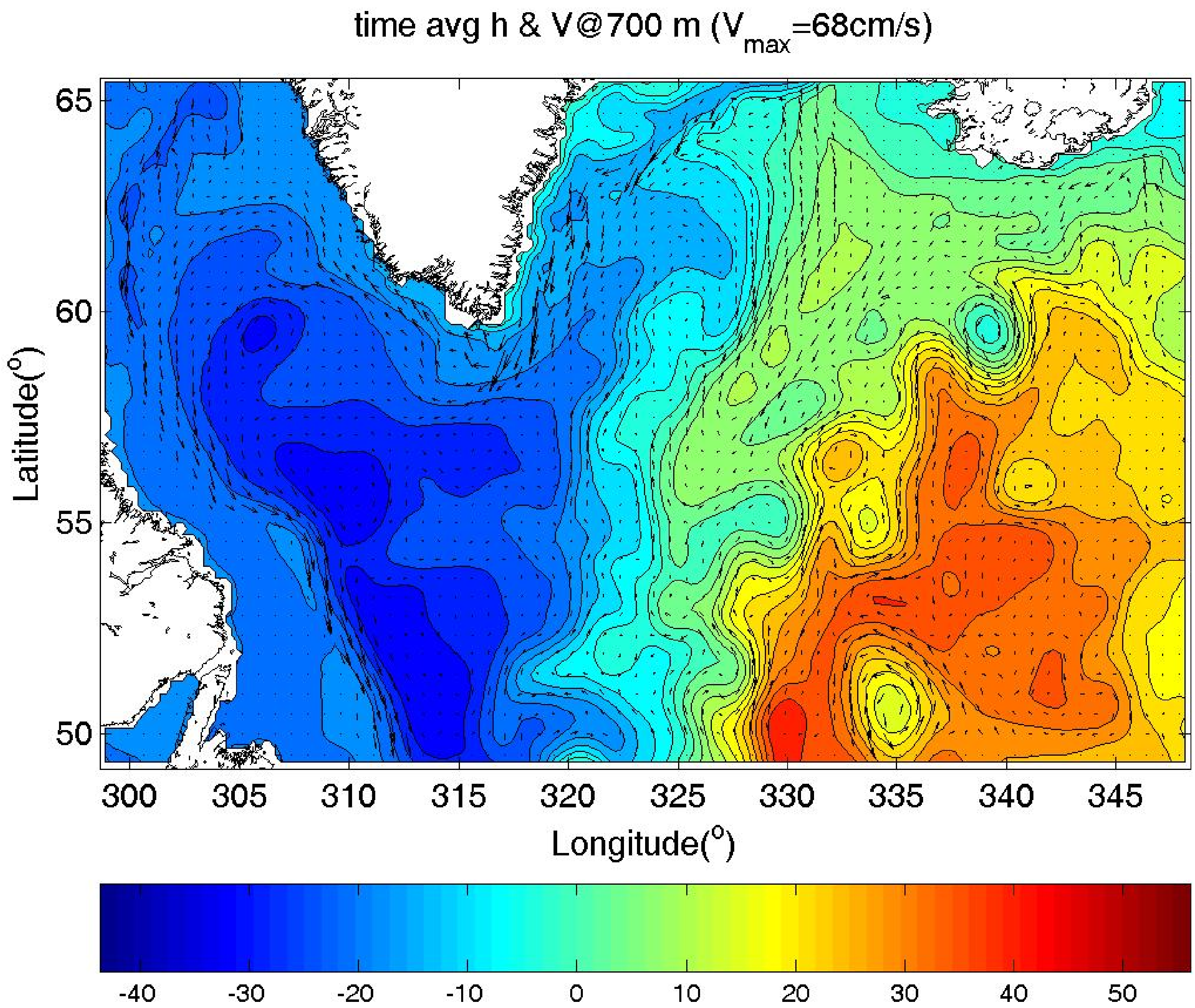
plot 1 (may be skip
* time average covers year 17
* East Australian Current shed warm core rings North Cape eddies
* bathymetry trapped Hikarangi Eddy near east end of Cook Strait
* from model having 4th-order-accurate numerics

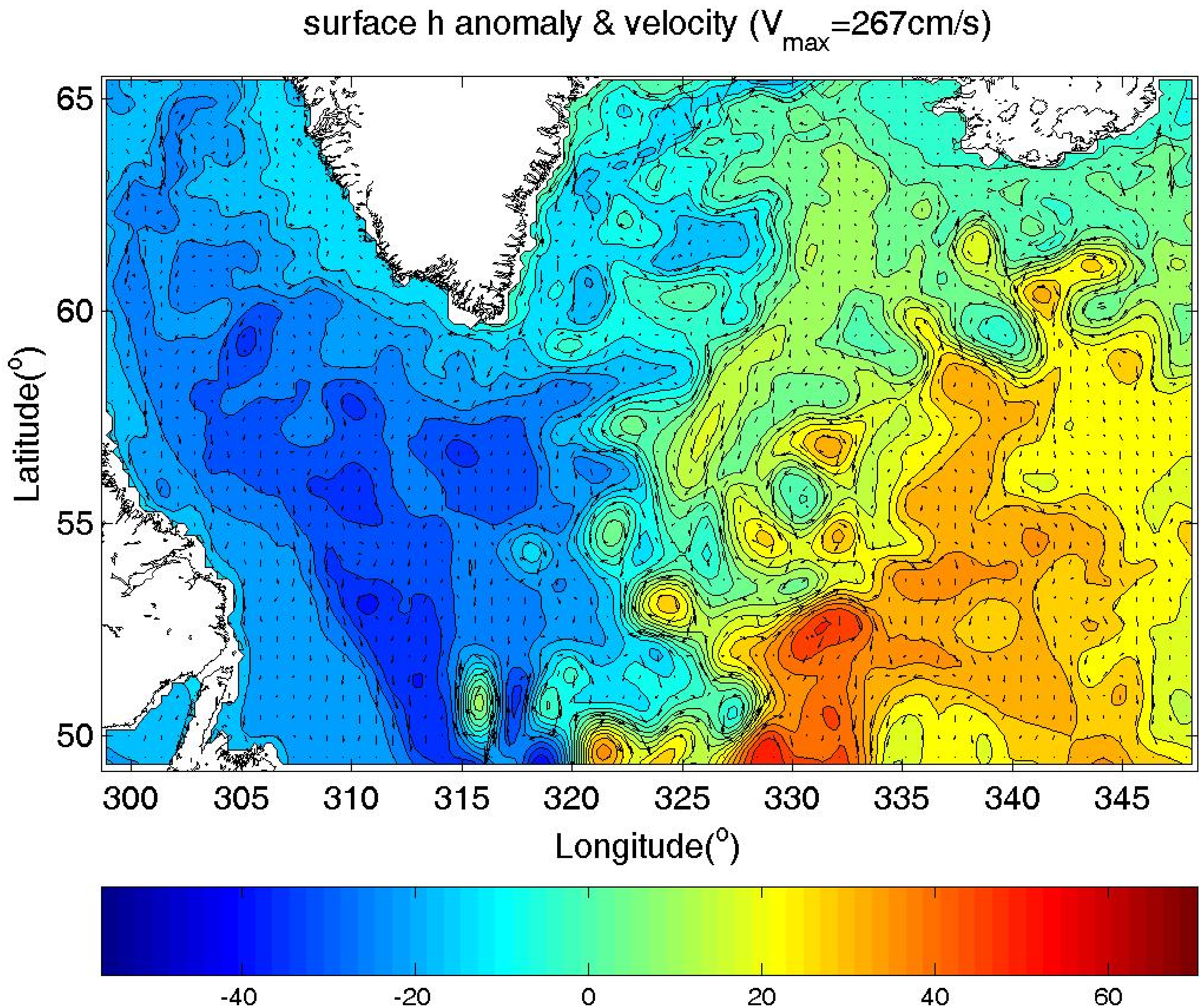


surface h anomaly & velocity (V_{max}=134cm/s)
-26
-28
-30
-32
-34
-36
-38
-40
-42
-44
Latitude(°)
150
155
160
165
170
175
180
185
Longitude(°)
-40
-30
-20
-10
0
10
20
30
40
50
60


Surface rms h anomaly
-26
-28
-30
-32
-34
-36
-38
-40
-42
-44
Latitude(°)
150
155
160
165
170
175
180
185
Longitude(°)
5
10
15
20
25

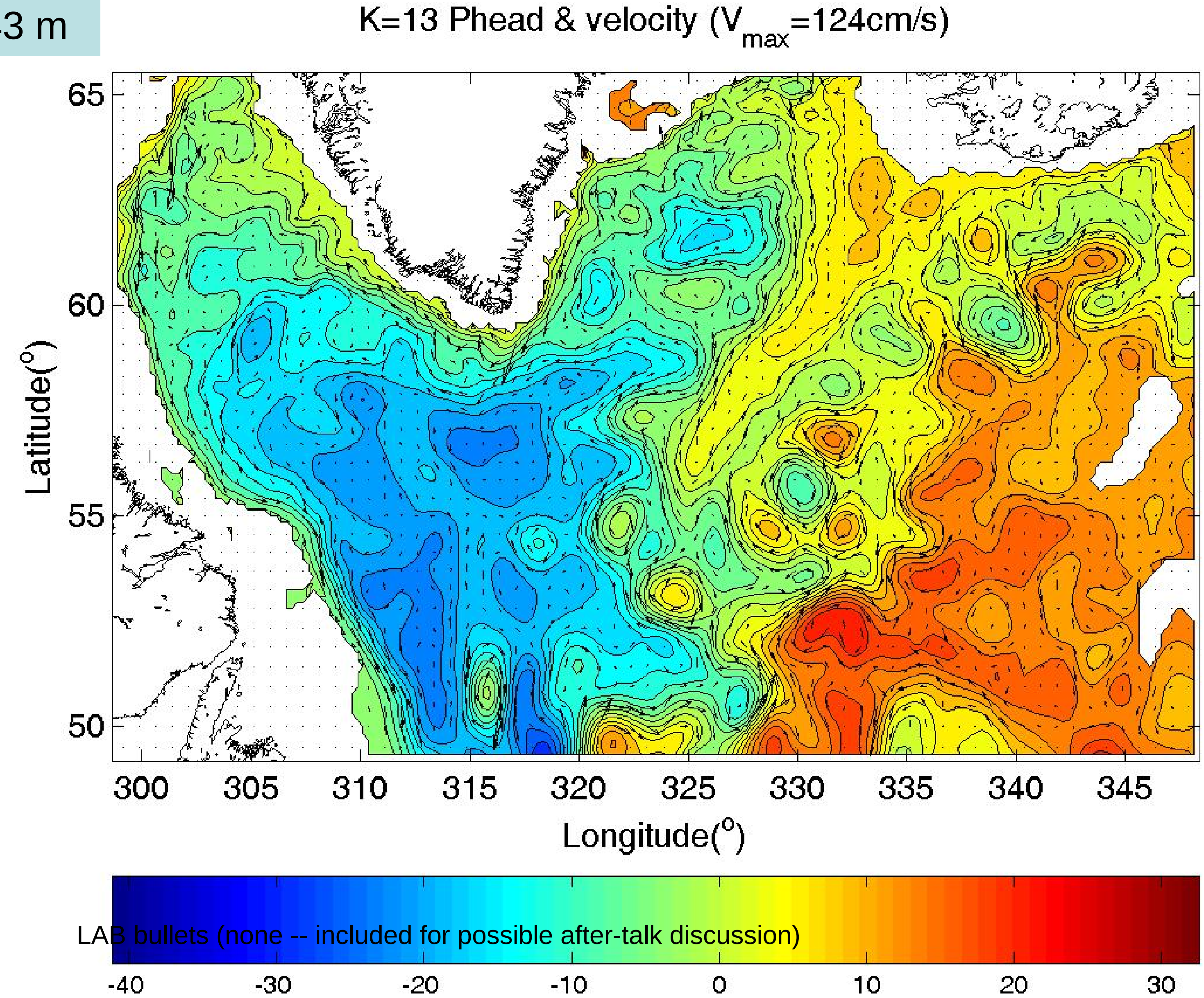
LABRADOR SEA


time avg h & V@700 m (V$_{max}$=68cm/s)
Latitude(°)
65
60
55
50
300
305
310
315
320
325
330
335
340
345
Longitude(°)
-40
-30
-20
-10
0
10
20
30
40
50



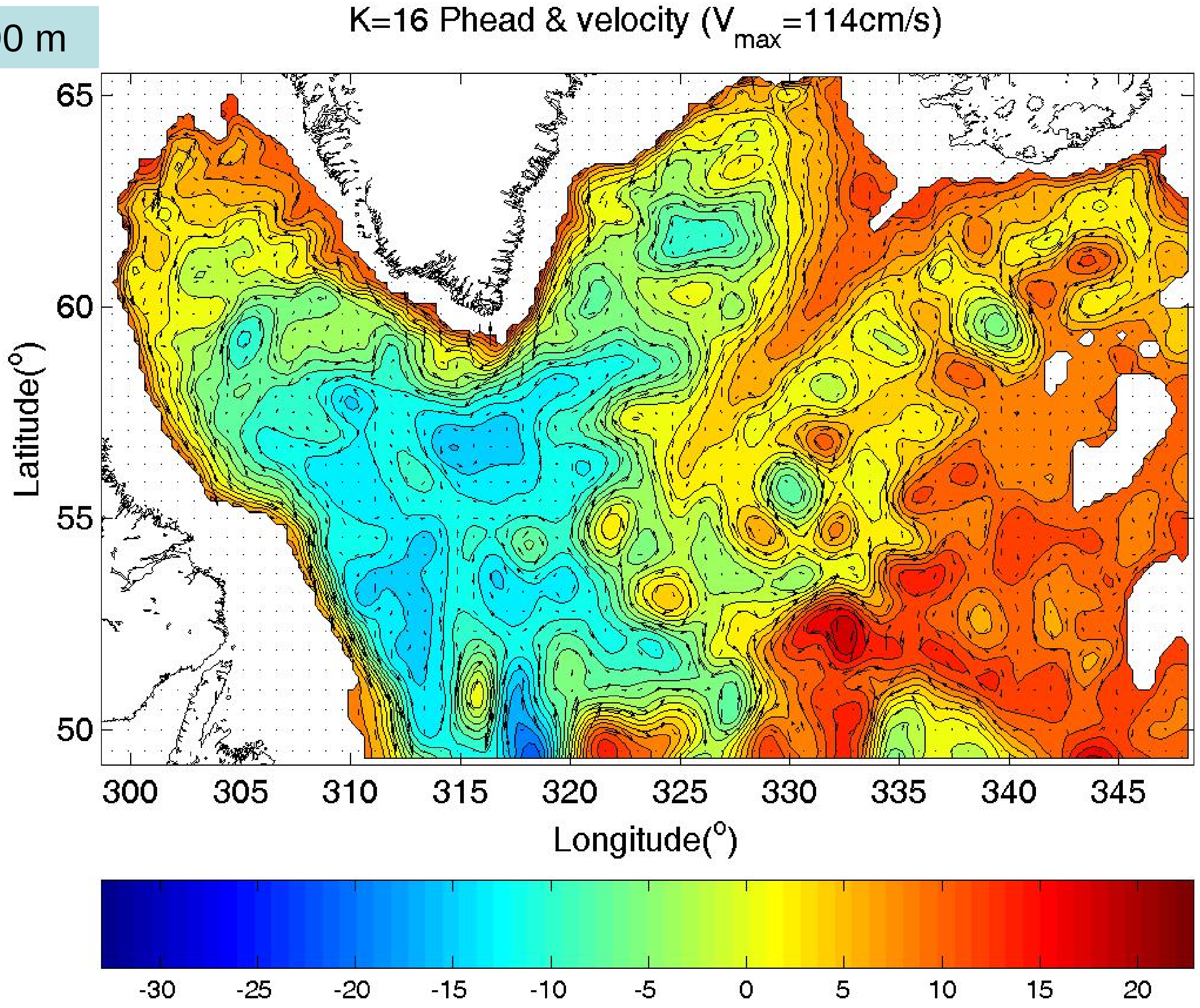
surface h anomaly & velocity (V$_{max}$=267cm/s)
Latitude(°)
65
60
55
50
300
305
310
315
320
325
330
335
340
345
Longitude(°)
-40
-20
0
20
40
60

443 m

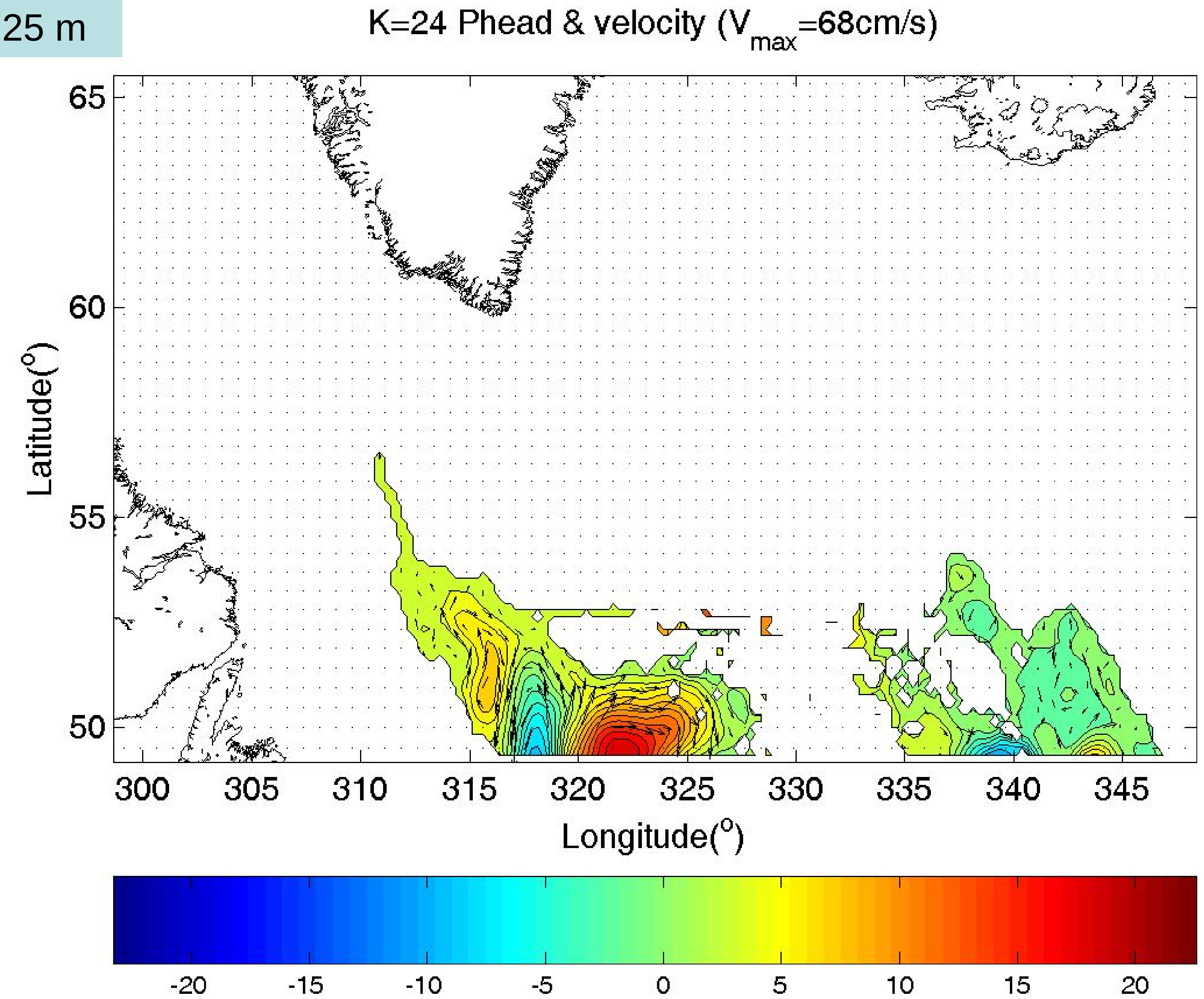


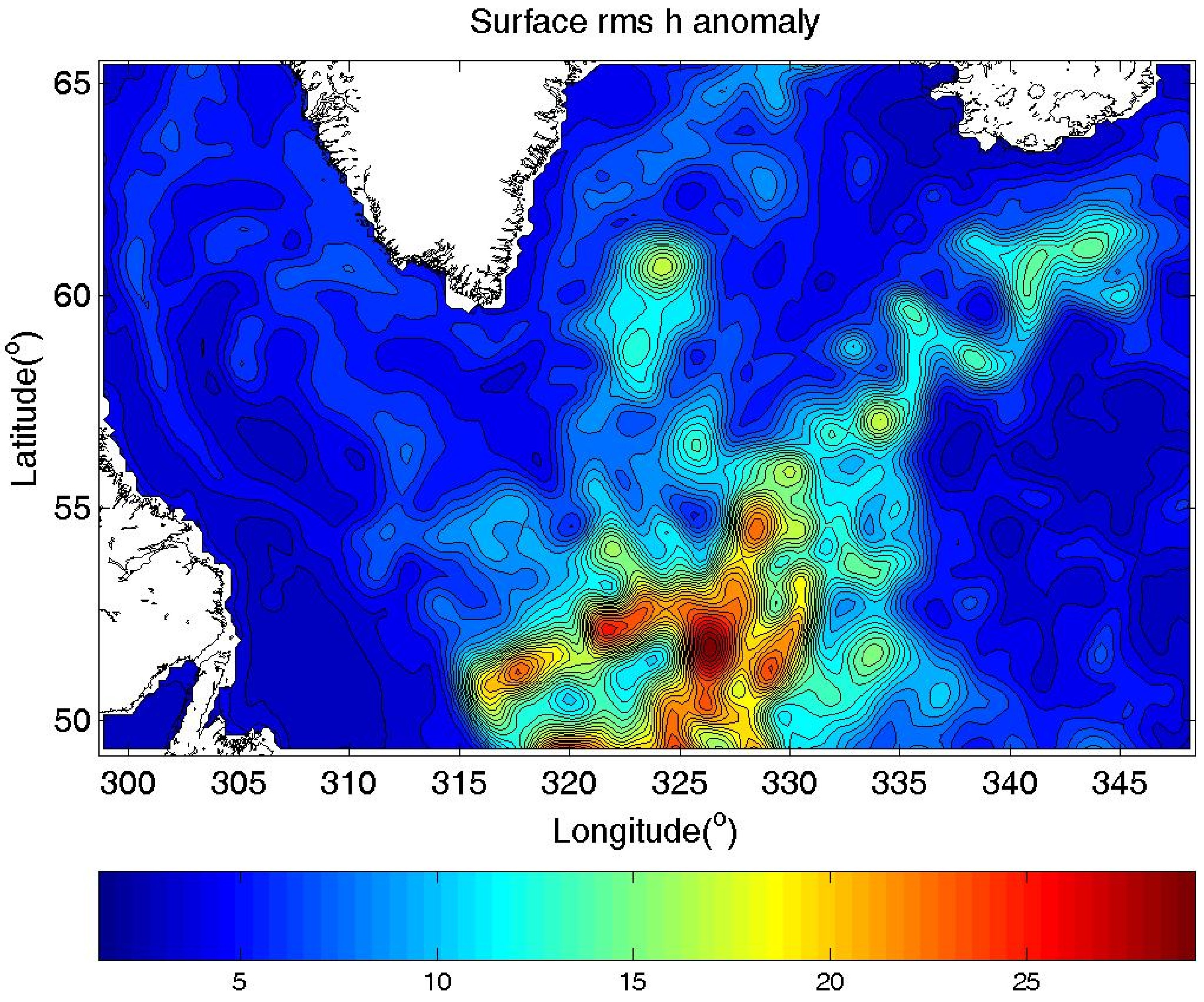
LAB bullets (none -- included for possible after-talk discussion)

790 m

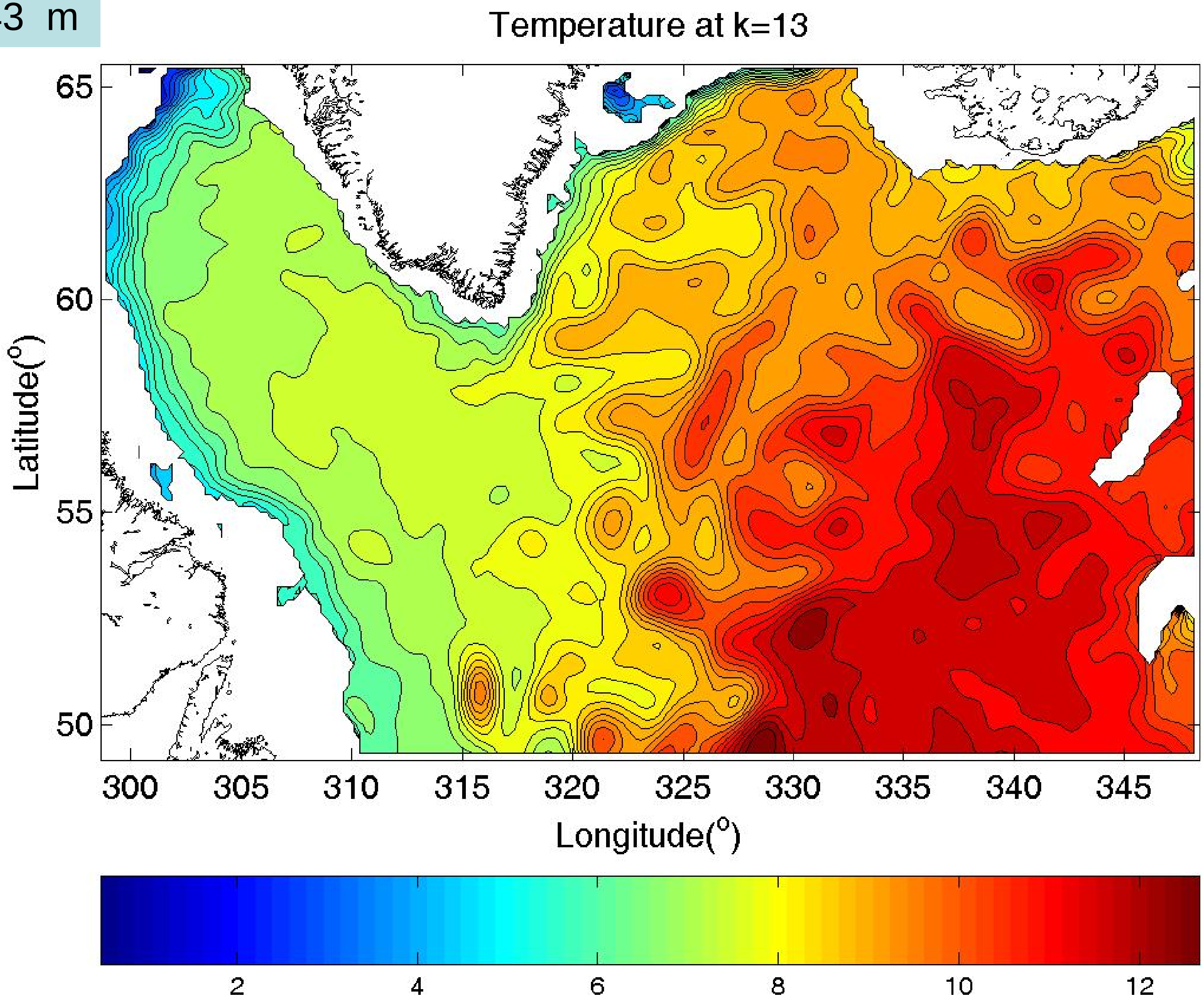

K=16 Phead & velocity (V_{max}=114cm/s)
65
60
55
50
Latitude(°)
300
305
310
315
320
325
330
335
340
345
Longitude(°)
-30
-25
-20
-15
-10
-5
0
5
10
15
20

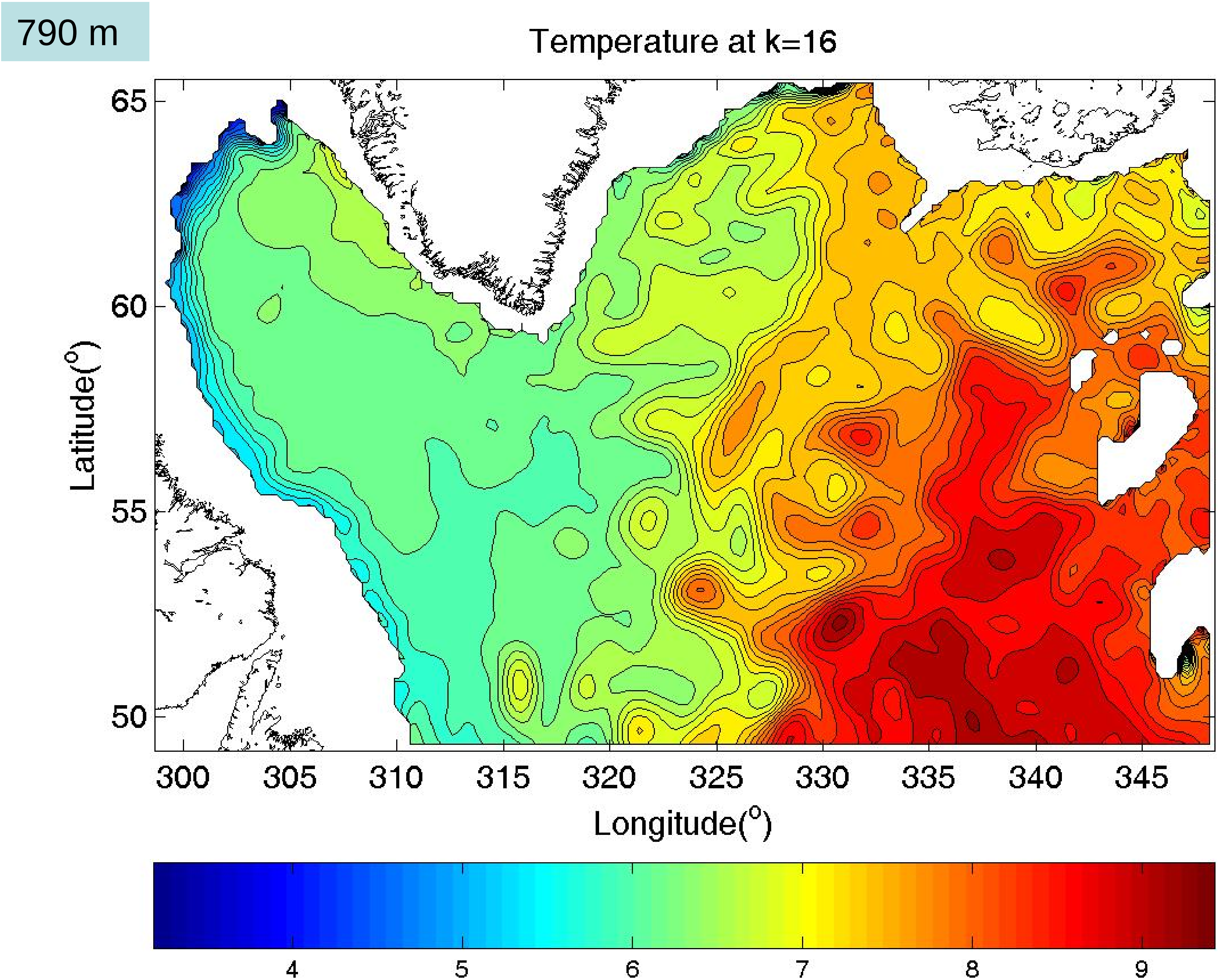
3725 m


K=24 Phead & velocity (V_{max}=68cm/s)
65
60
55
50
Latitude(°)
300
305
310
315
320
325
330
335
340
345
Longitude(°)
-20
-15
-10
-5
0
5
10
15
20


Surface rms h anomaly
65
60
55
50
Latitude(°)
300
305
310
315
320
325
330
335
340
345
Longitude(°)
5
10
15
20
25

443 m


Temperature at k=13
Latitude(°)
Longitude(°)
65
60
55
50
300
305
310
315
320
325
330
335
340
345
2
4
6
8
10
12


790 m
Temperature at k=16
Latitude(°)
65
60
55
50
Longitude(°)
300
305
310
315
320
325
330
335
340
345
4
5
6
7
8
9

END