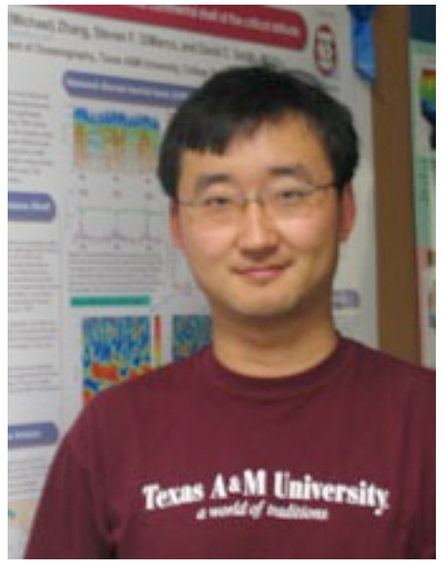
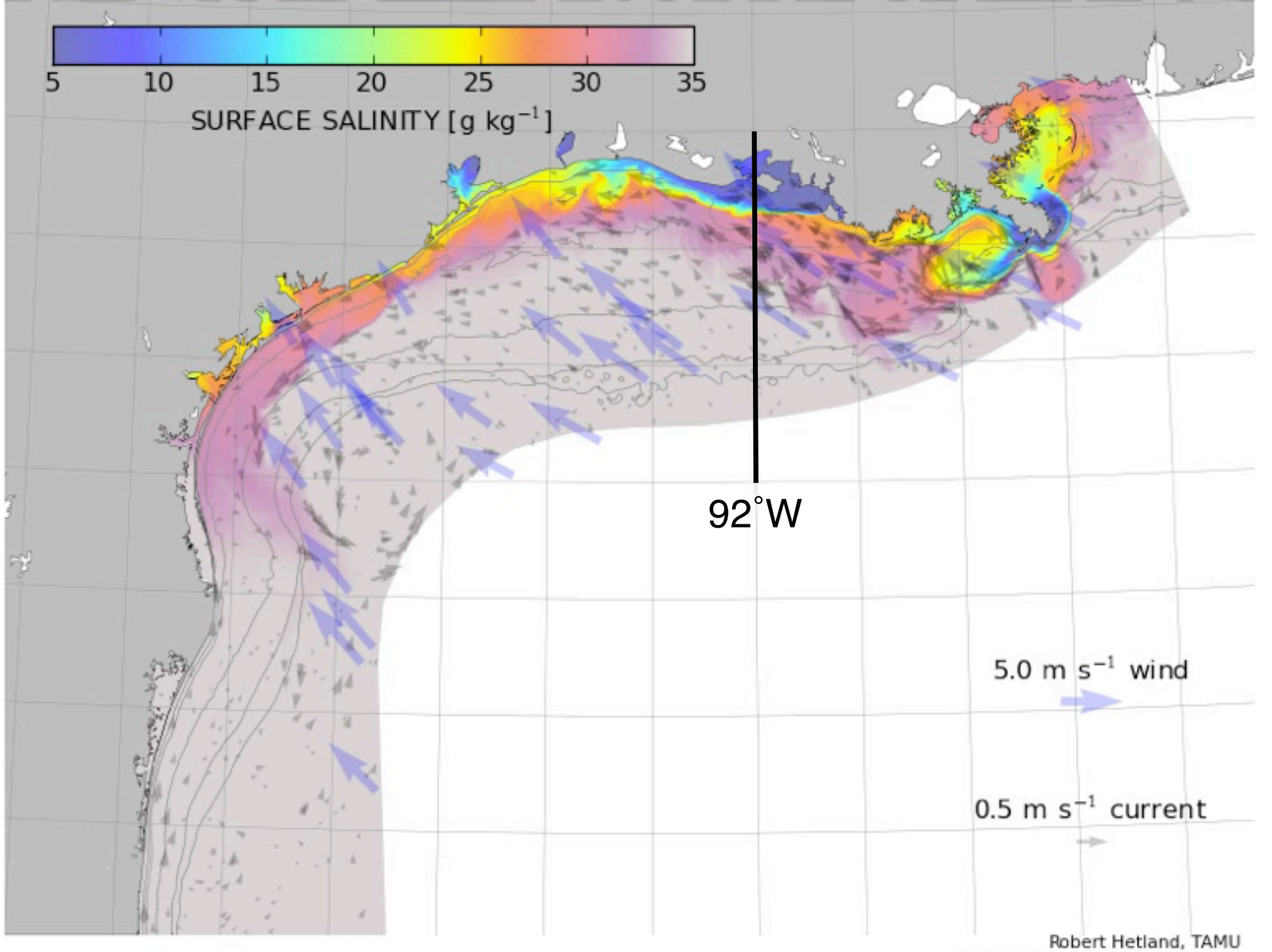
Modeling circulation on the Texas-Louisiana continental shelf

Rob Hetland
Xiaoqian Zhang




5
10
15
20
25
30
35
SURFACE SALINITY [g kg^{-1}]
92°W
5.0 m s^{-1} wind
0.5 m s^{-1} current
Robert Hetland, TAMU
Mechanisms Controlling Hypoxia
2008 Apr 01 04:00 GMT
Mississippi River Discharge
30,000 m^3 s^{-1}
20,000
10,000

25 m

50 m

75 m

100 m

15 m s⁻¹

10

5

Wind Speed

25 km

−0.50 −0.25 0.00 0.25 0.50

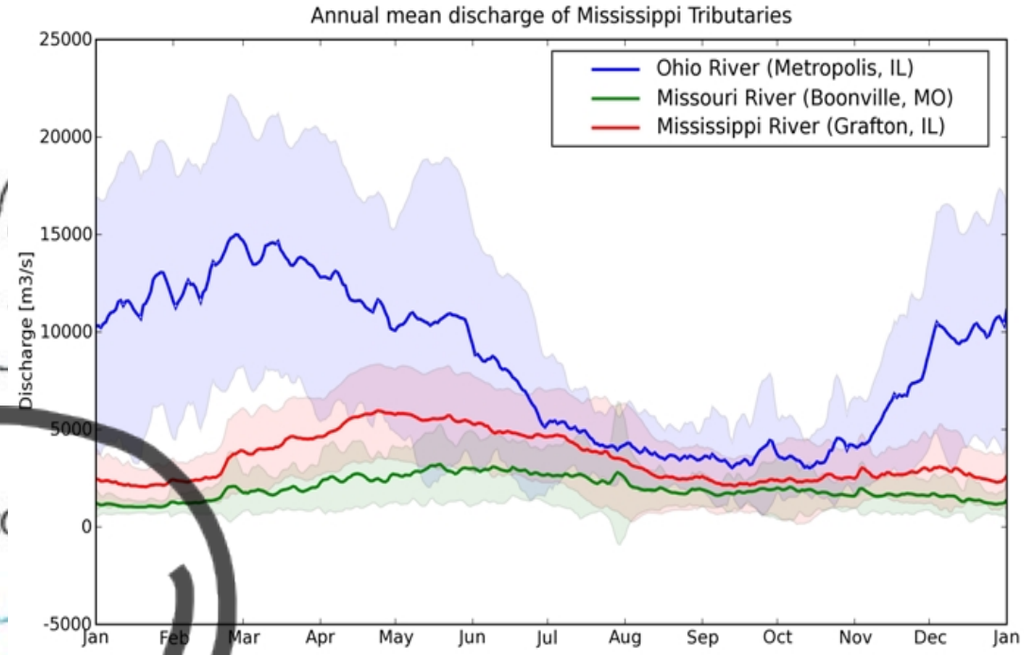
Along-shore velocity [m s^{-1}]

2008 May 01 12:00 GMT

Mississippi River Discharge 30,000 m^3 s^{-1}

20,000

10,000



Meade et al. (1995)
USGS Circular 1133

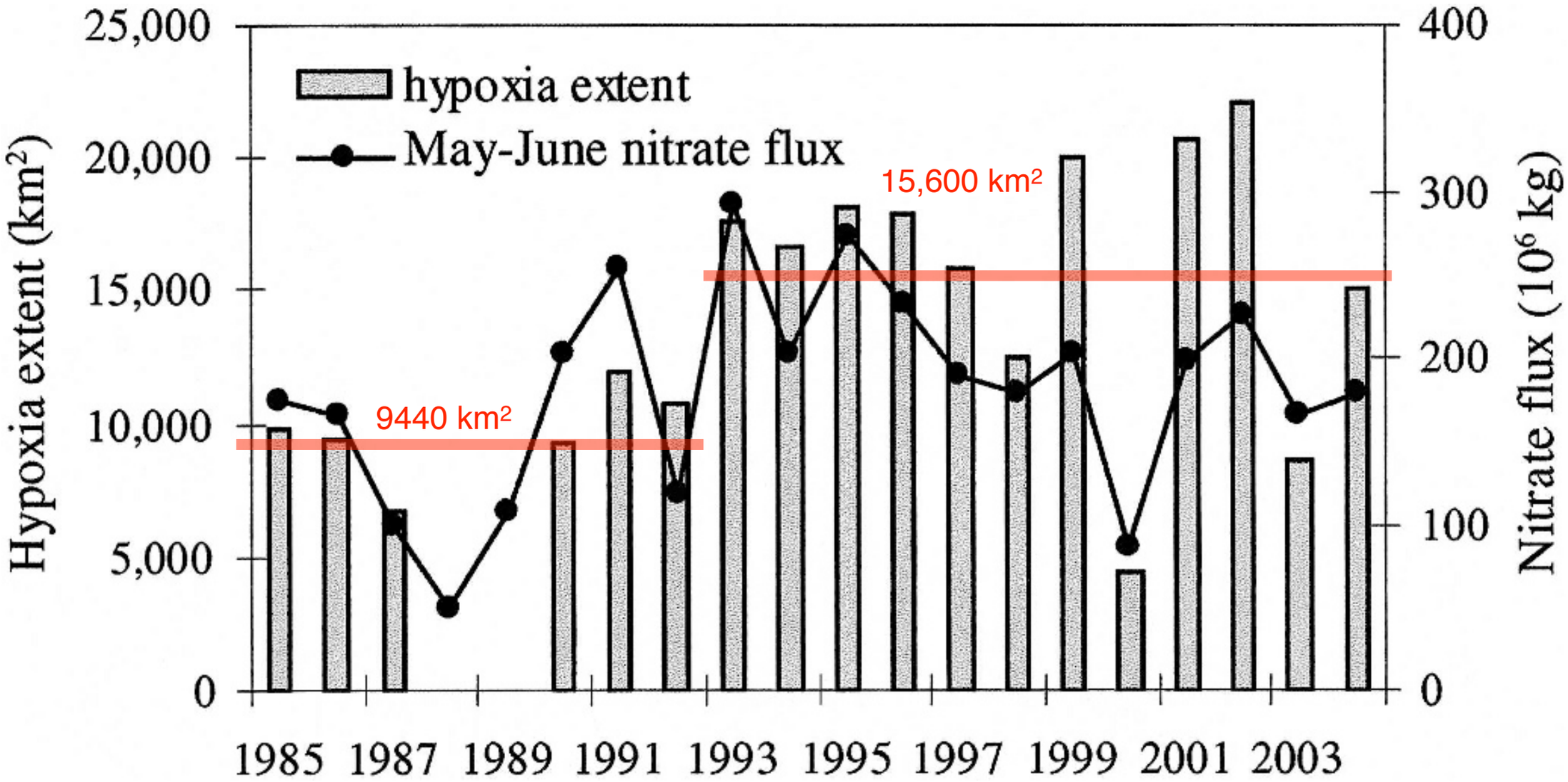
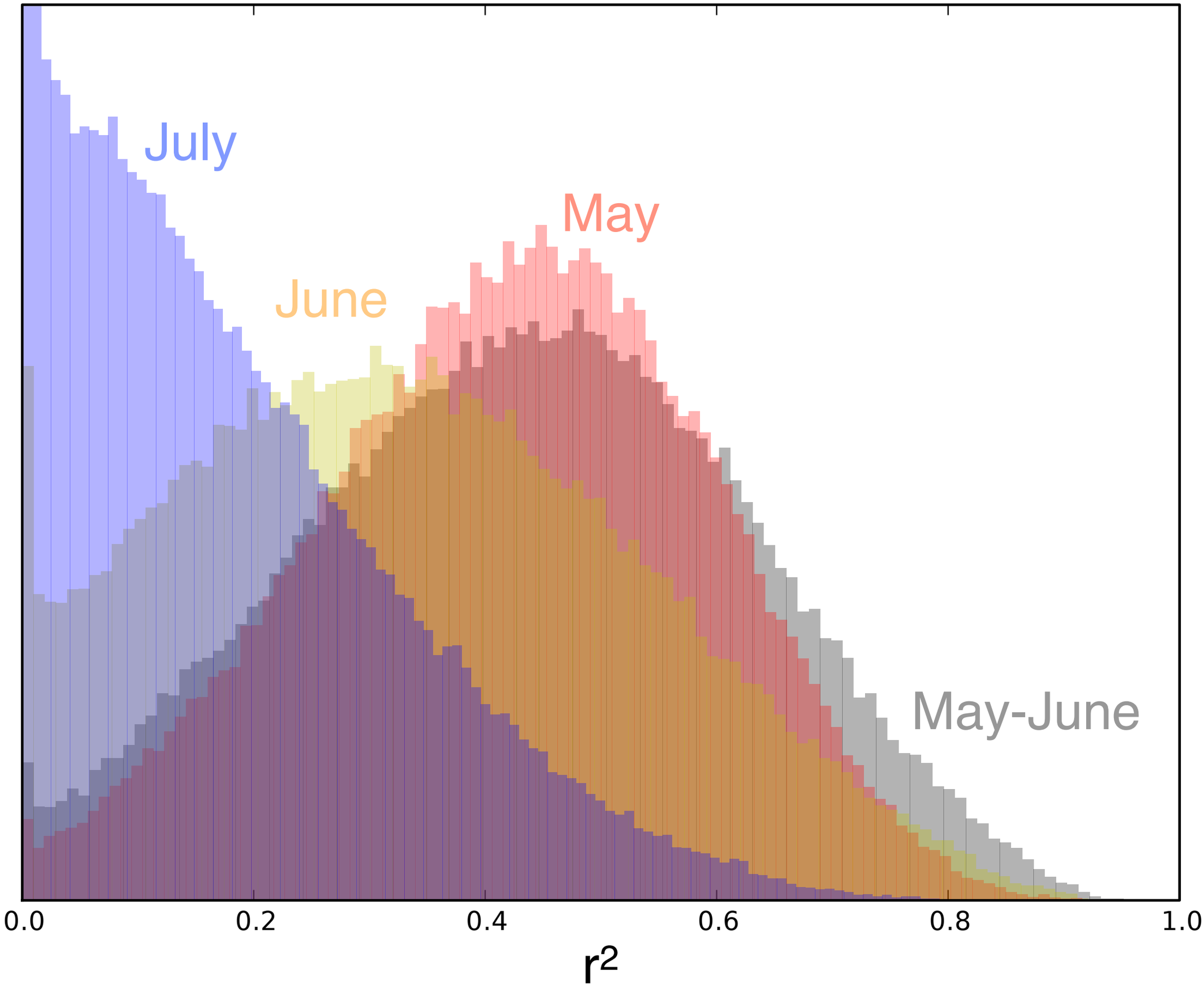
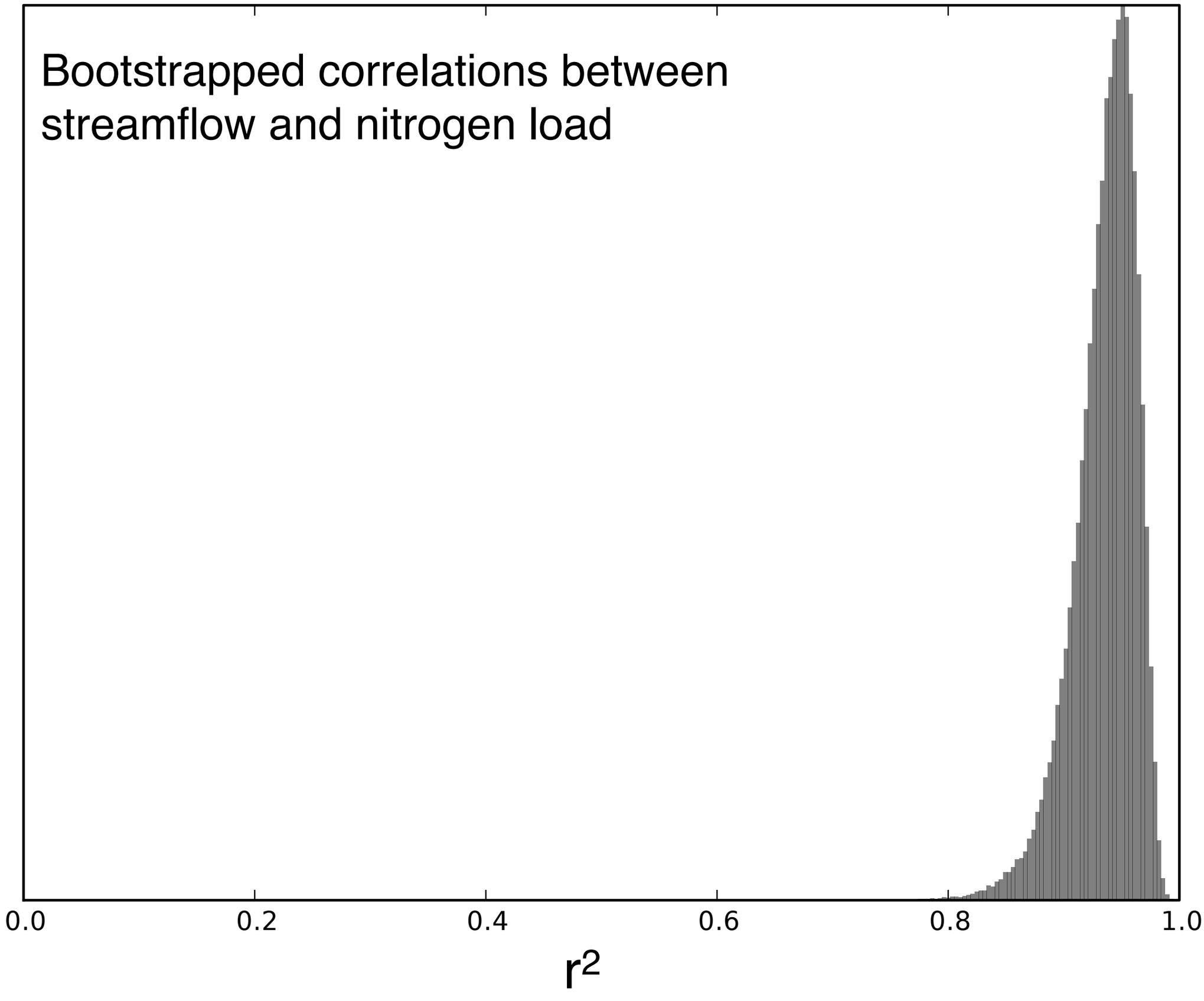


Fig. 1. M–J nitrate flux by the Mississippi River (at St. Francisville, Louisiana) and extent of seasonal hypoxia in the Gulf of Mexico between 1985 and the present. The hypoxic zone reached 40 km² in 1988; no data is available for 1989.

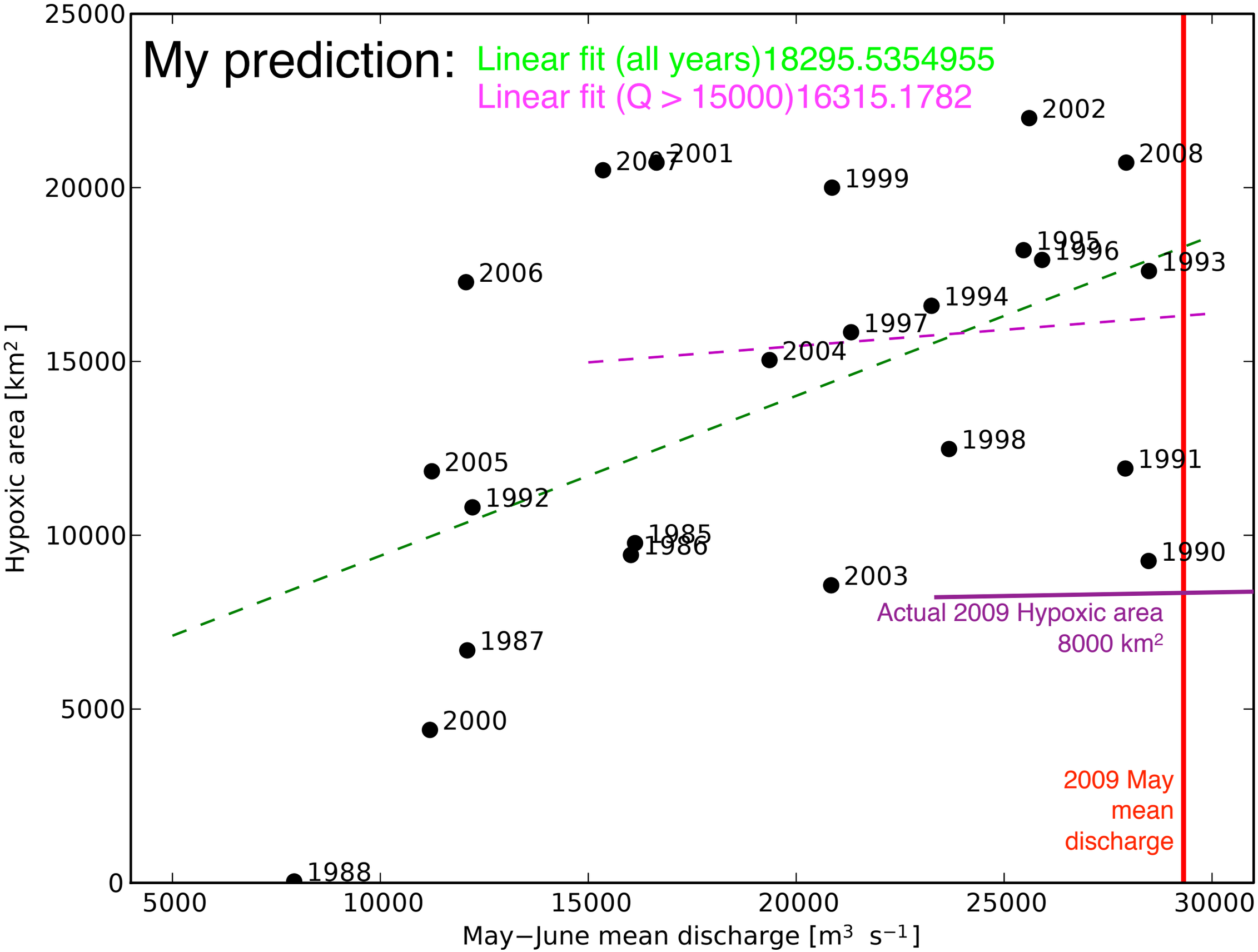
Donner and Scavia (L&O, 2007)

Bootstrapped correlation between nutrient load and hypoxic area

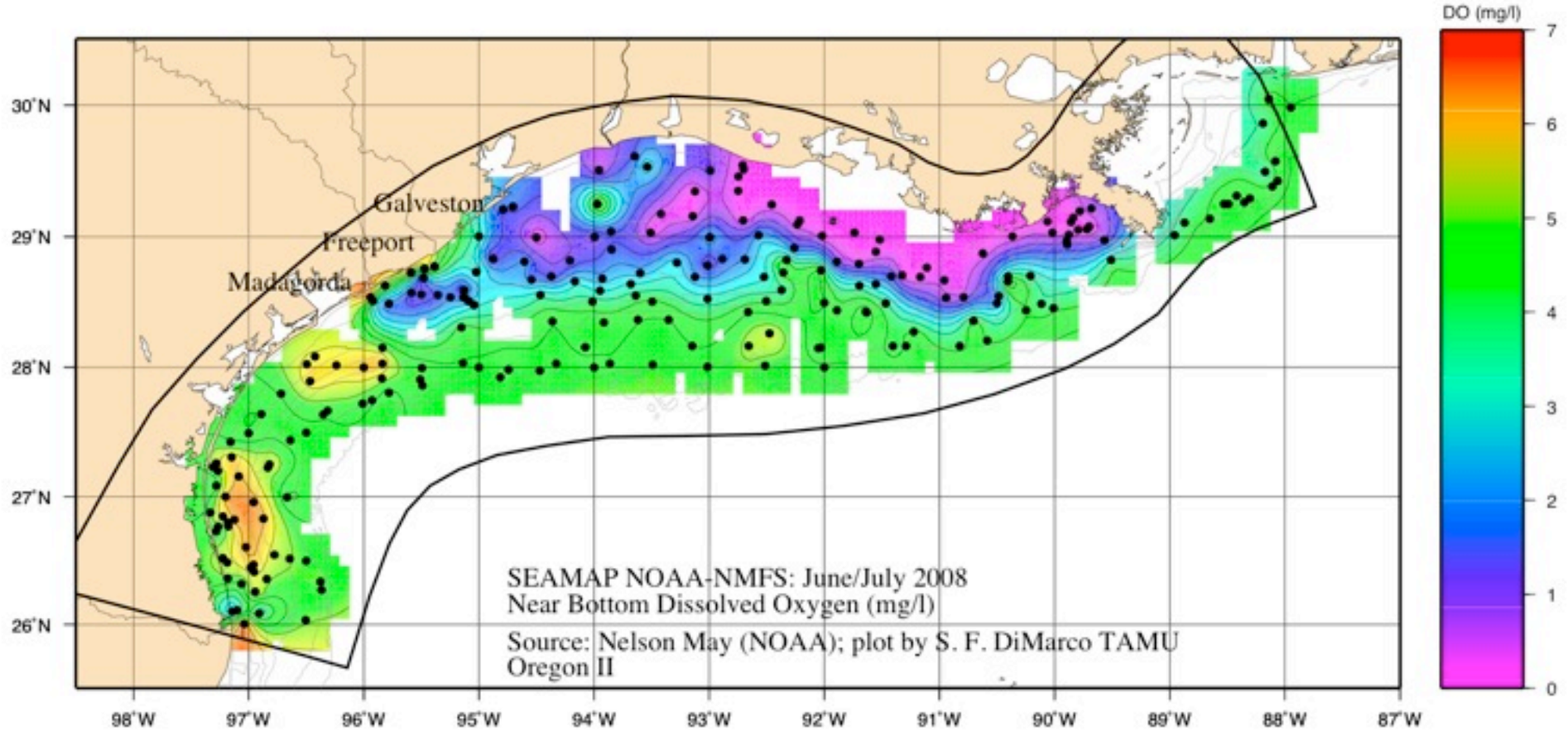



Bootstrapped correlations between
streamflow and nitrogen load
0.0
0.2
0.4
0.6
0.8
1.0
r2

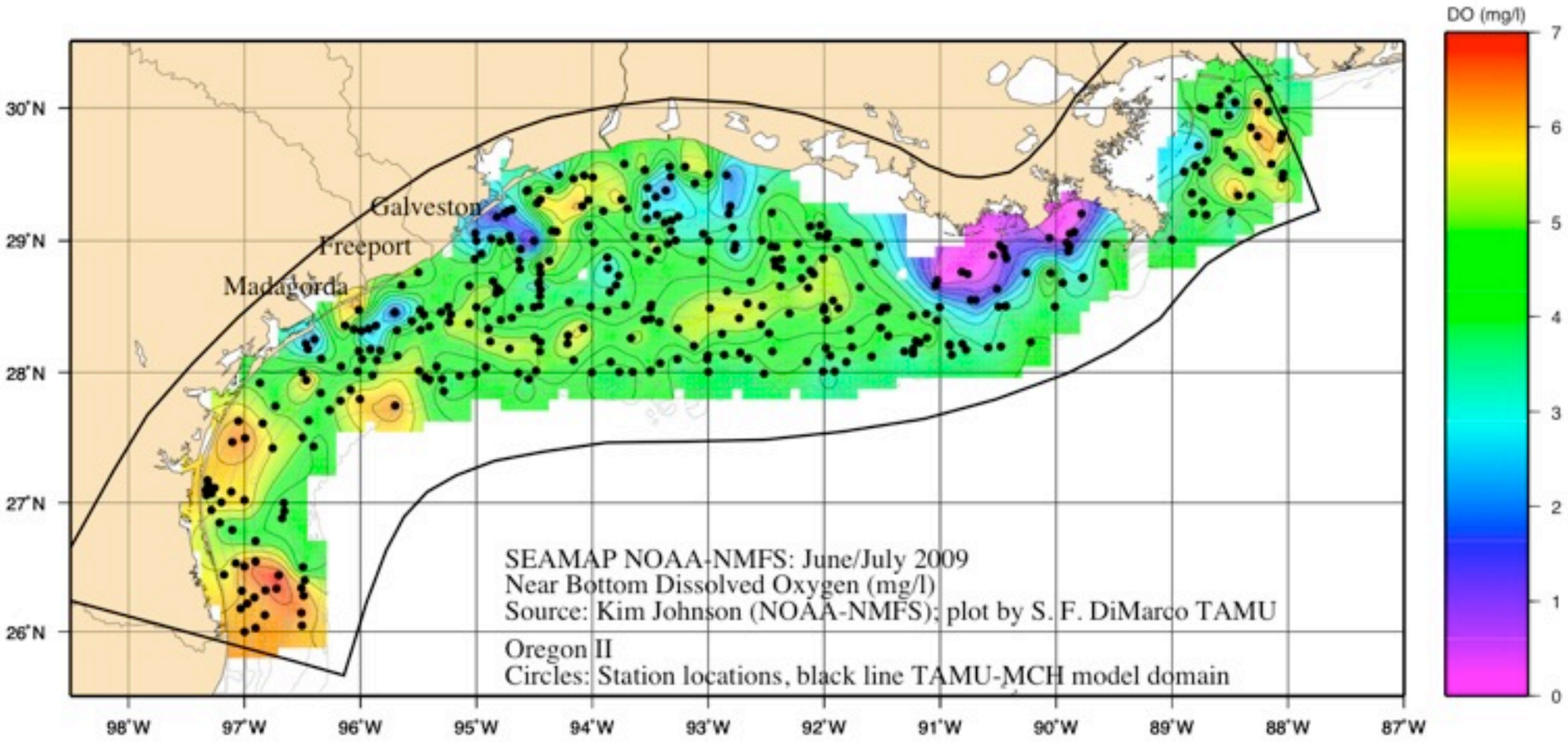
Statistical predictions of 2009 hypoxic area



2008


DO (mg/l)
7
6
5
4
3
2
1
0
30°N
29°N
28°N
27°N
26°N
98°W
97°W
96°W
95°W
94°W
93°W
92°W
91°W
90°W
89°W
88°W
87°W
Galveston
Freeport
Madagorda
SEAMAP NOAA-NMFS: June/July 2008
Near Bottom Dissolved Oxygen (mg/l)
Source: Nelson May (NOAA); plot by S. F. DiMarco TAMU
Oregon II

2009


DO (mg/l)
7
6
5
4
3
2
1
0
30°N
29°N
28°N
27°N
26°N
98°W
97°W
96°W
95°W
94°W
93°W
92°W
91°W
90°W
89°W
88°W
87°W
Galveston
Freeport
Madagorda
SEAMAP NOAA-NMFS: June/July 2009
Near Bottom Dissolved Oxygen (mg/l)
Source: Kim Johnson (NOAA-NMFS); plot by S. F. DiMarco TAMU
Oregon II
Circles: Station locations, black line TAMU-MCH model domain

5 10 15 20 25 30 35

SURFACE SALINITY [g kg^{-1}]

2008

5

0.5

2008 May 02 08:00 GMT

Mecha

Mississippi River

5 10 15 20 25 30 35

SURFACE SALINITY [g kg^{-1}]

2009

5.0 m s^{-1} wind

0.5 m s^{-1} current

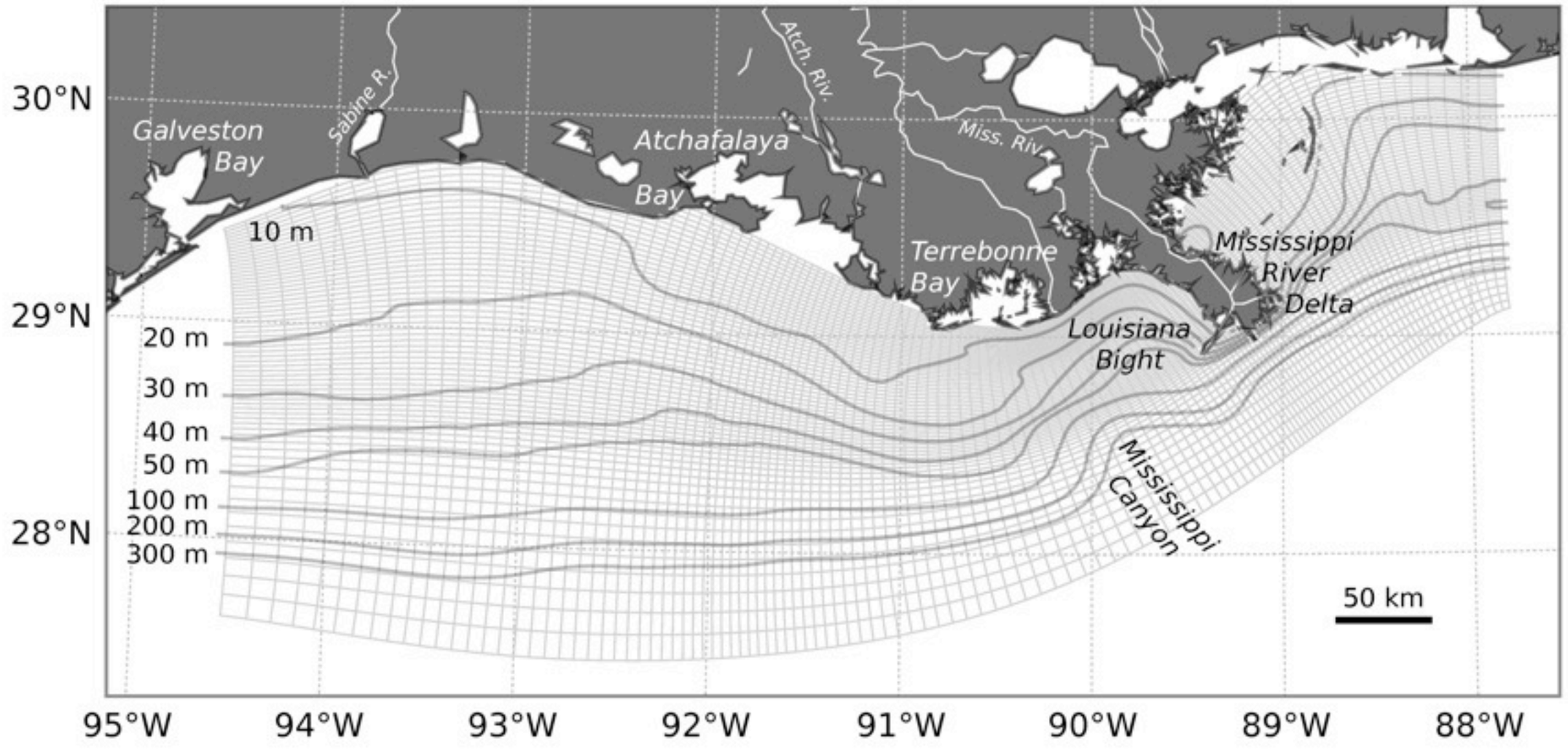
Robert Hetland, TAMU
Mechanisms Controlling Hypoxia

2009 May 02 00:00 GMT

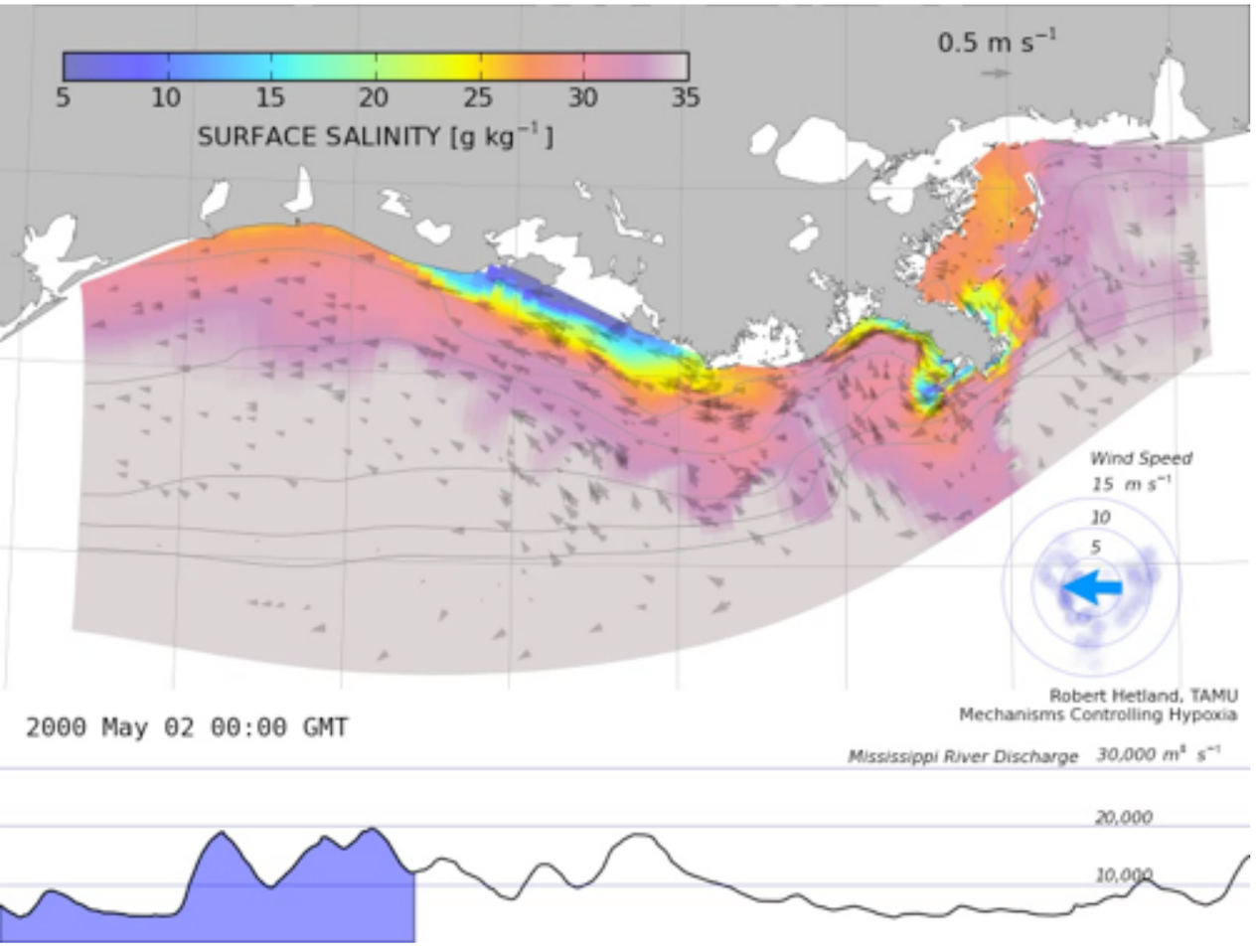
Mississippi River Discharge *30,000 m^3 s^{-1}*

20,000

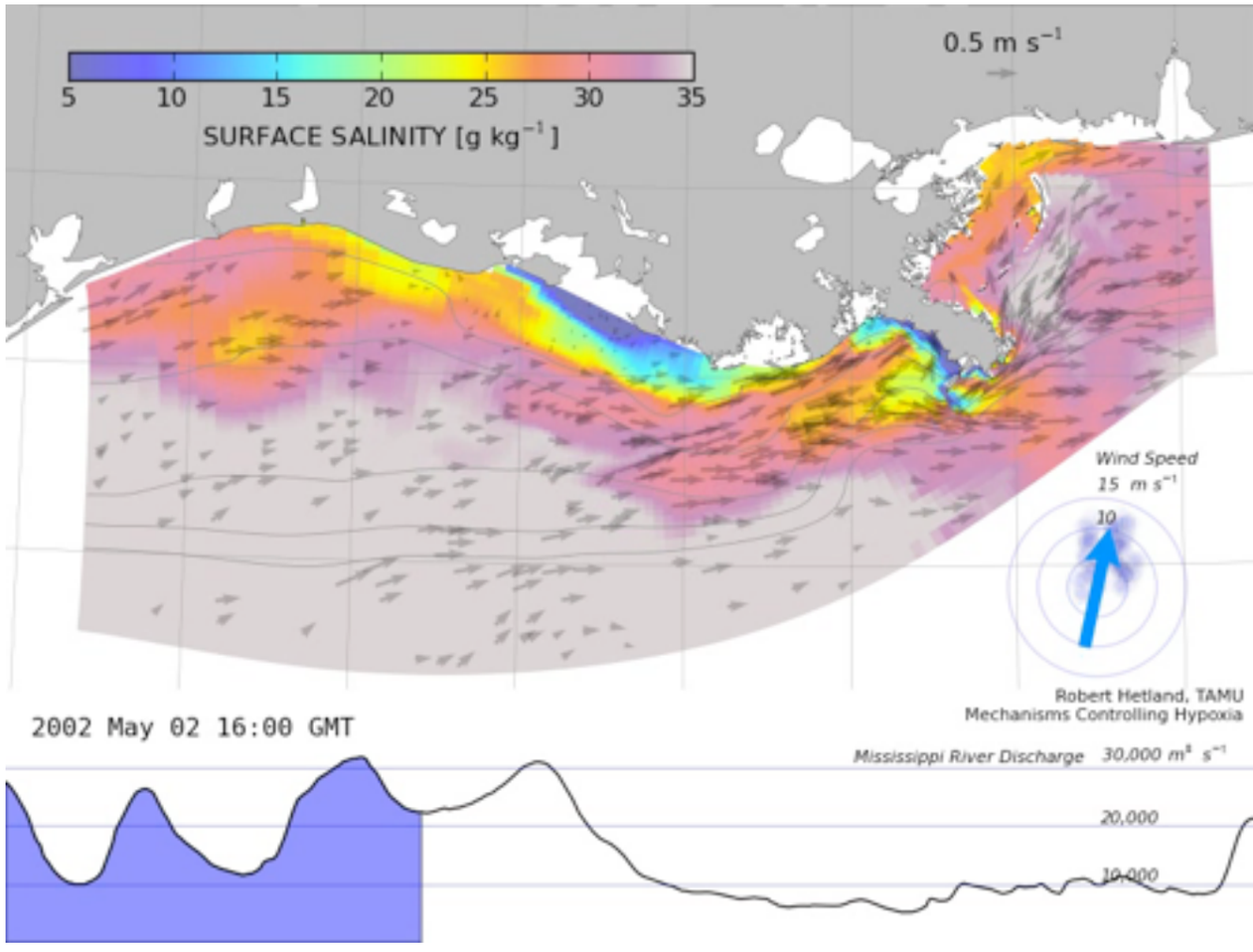
10,000

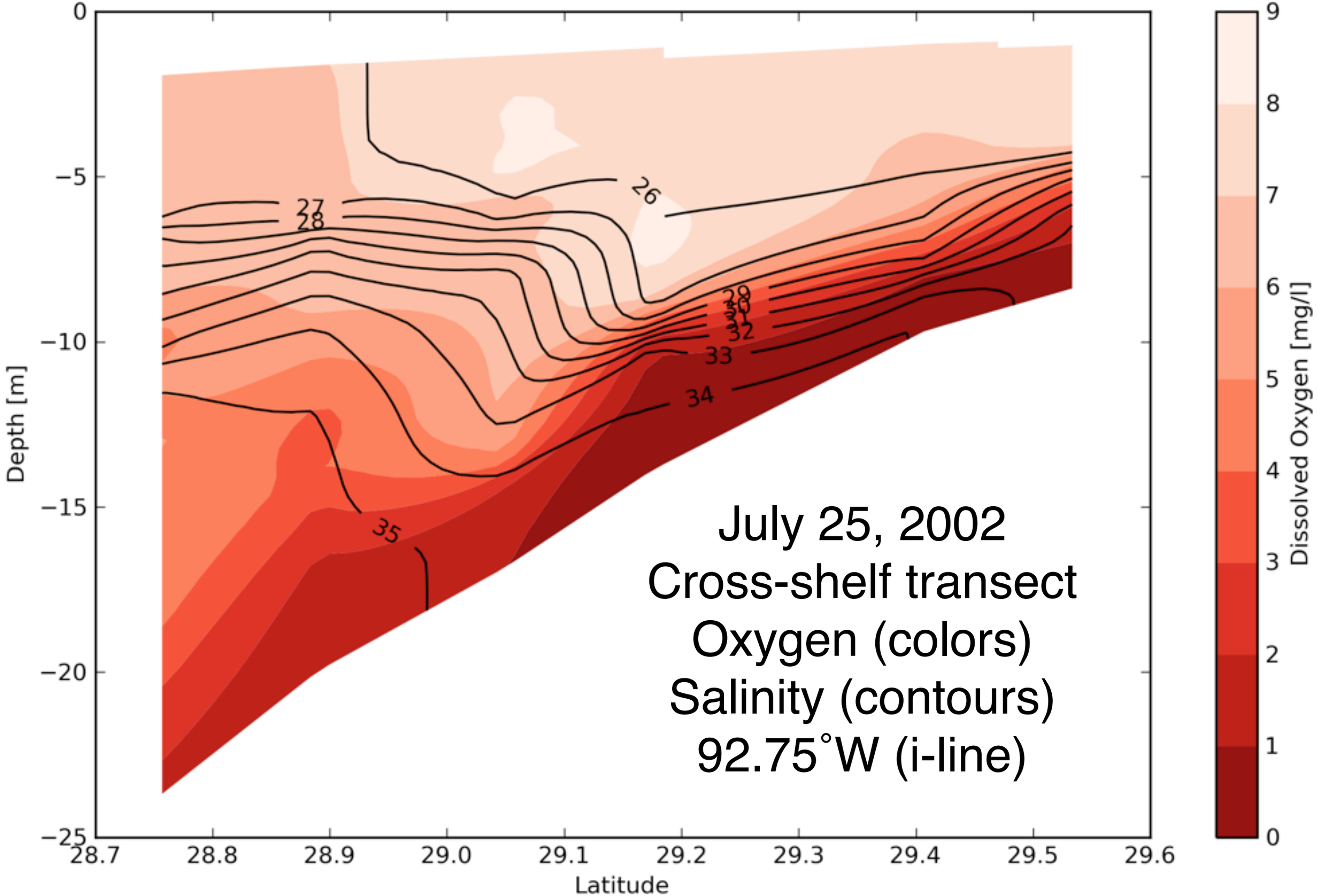

30°N
29°N
28°N
95°W
94°W
93°W
92°W
91°W
90°W
89°W
88°W
Galveston Bay
Sabine R.
Atchafalaya Bay
Atch. Riv.
Miss. Riv.
Terrebonne Bay
Mississippi River Delta
Louisiana Bight
Mississippi Canyon
10 m
20 m
30 m
40 m
50 m
100 m
200 m
300 m
50 km

2000
Smallest hypoxic area

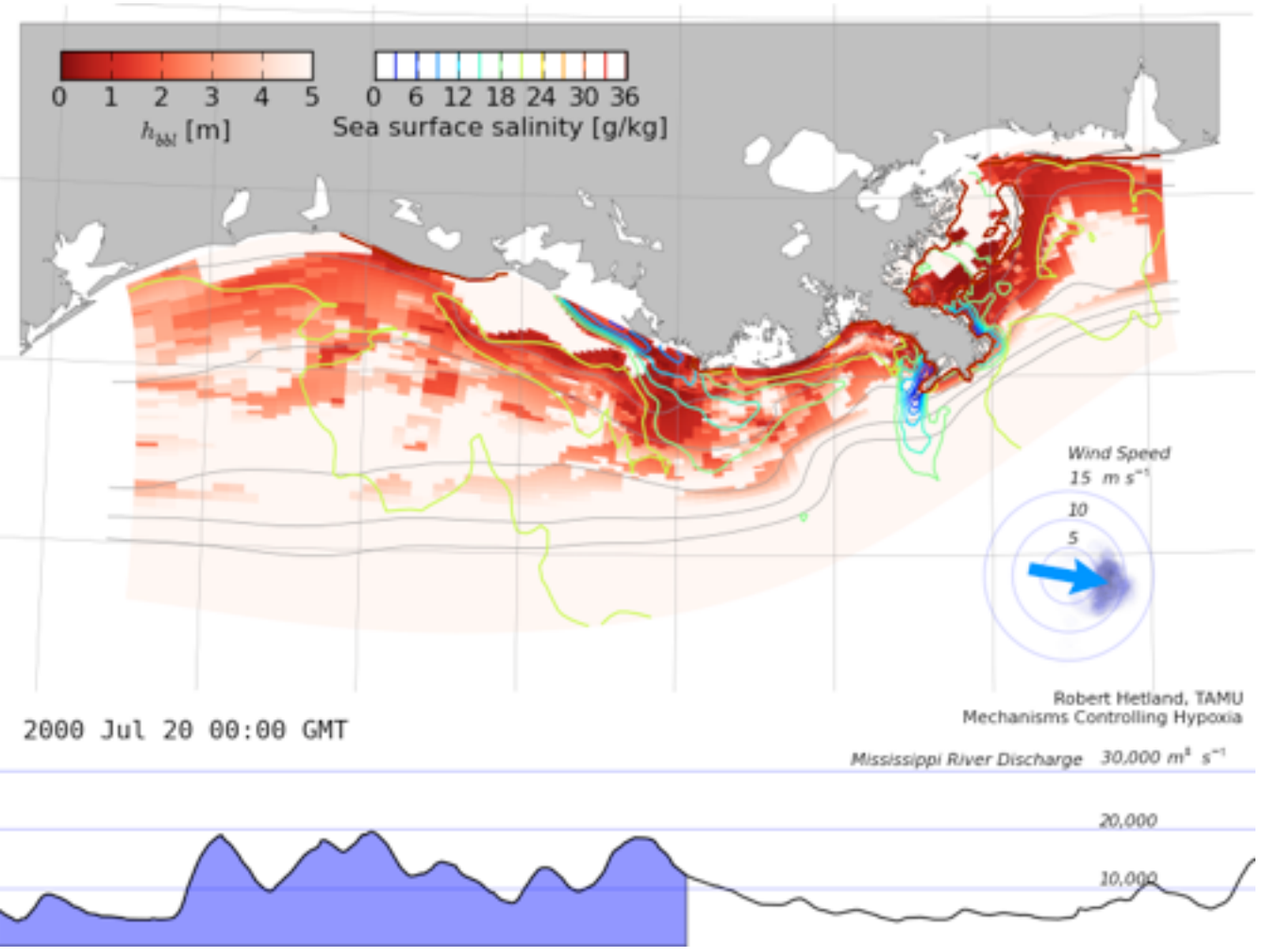


2002
Largest hypoxic area

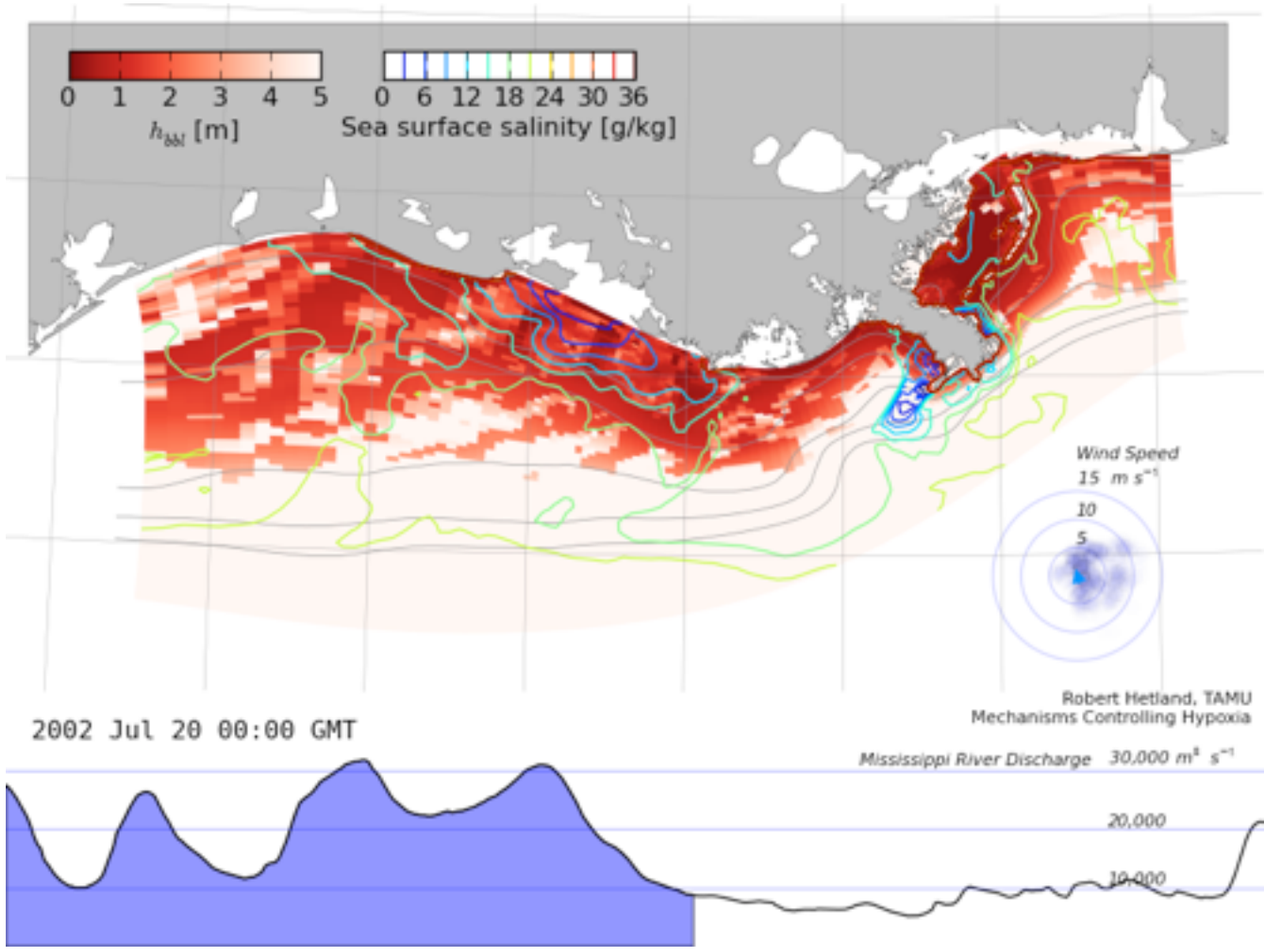


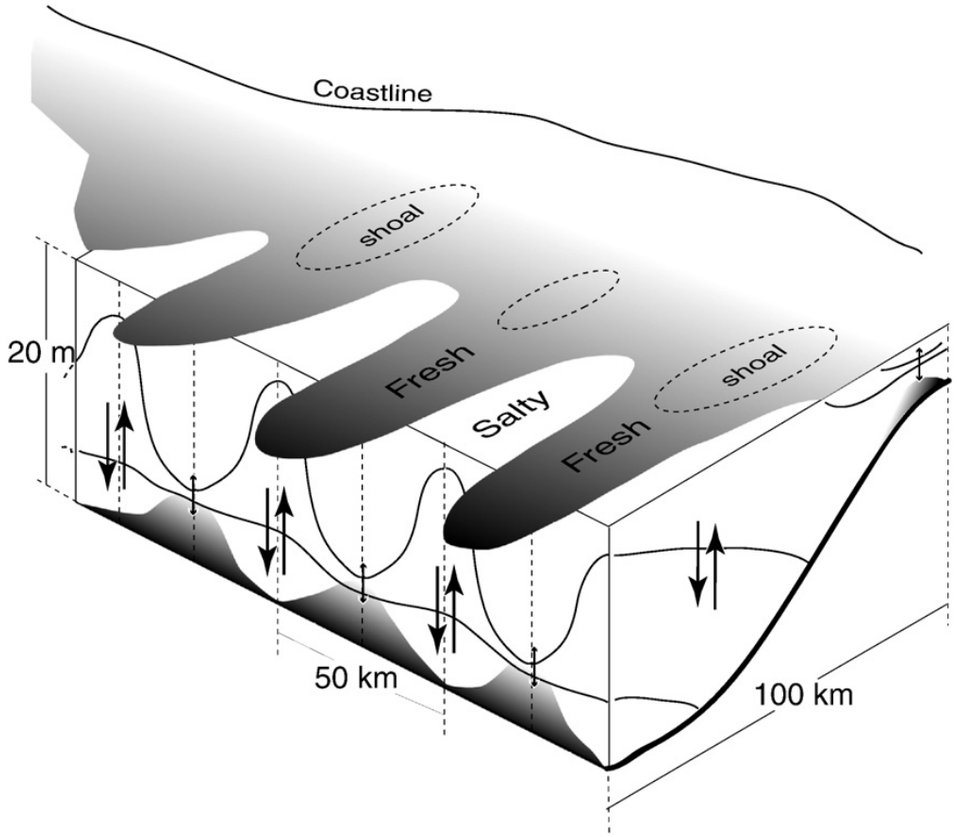

0
−5
−10
−15
−20
−25
Depth [m]
28.7
28.8
28.9
29.0
29.1
29.2
29.3
29.4
29.5
29.6
Latitude
26
27
28
29
30
31
32
33
34
35
9
8
7
6
5
4
3
2
1
0
Dissolved Oxygen [mg/l]
July 25, 2002
Cross-shelf transect
Oxygen (colors)
Salinity (contours)
92.75˚W (i-line)

2000
Low discharge year
Strong westerly winds

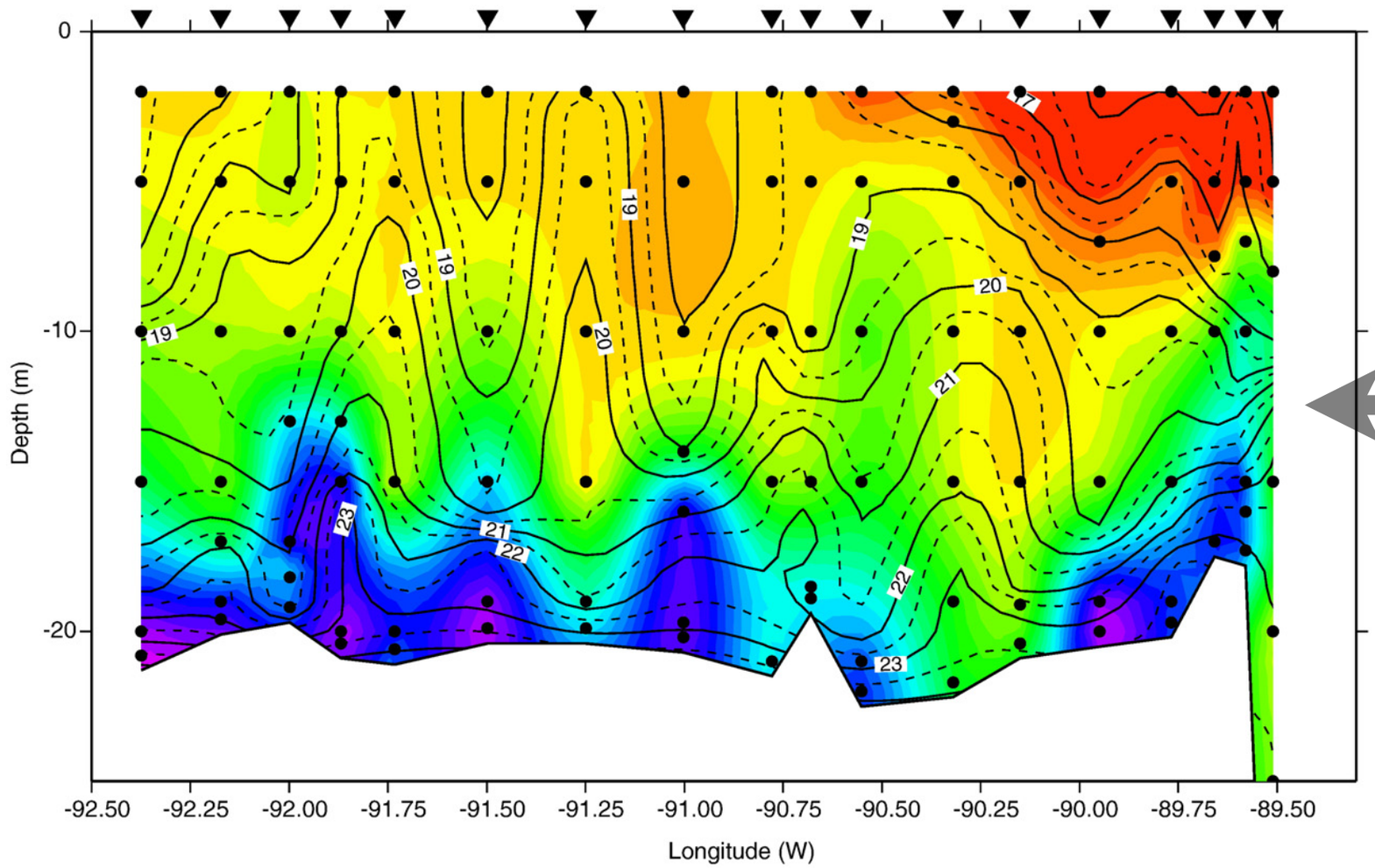


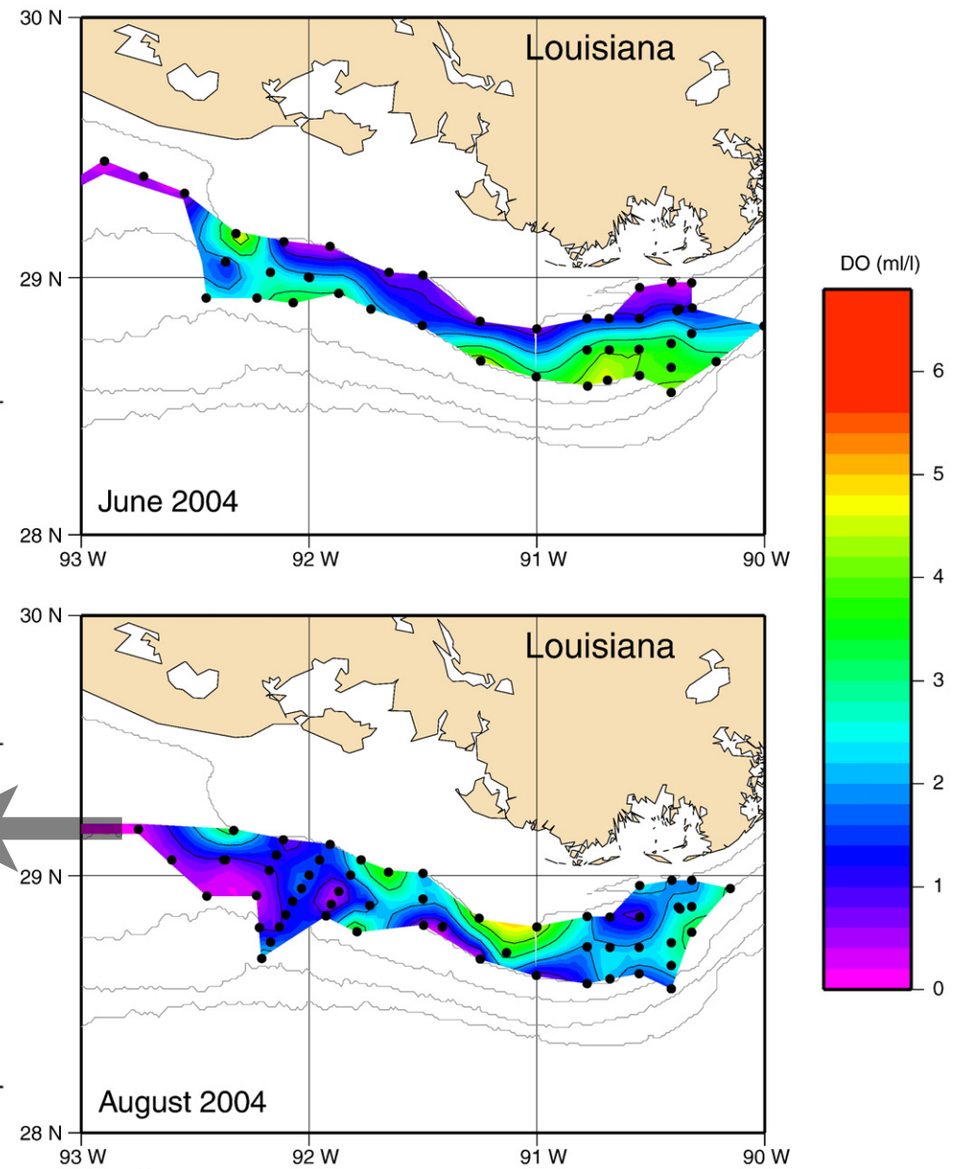
2002
High discharge year
Weak variable winds





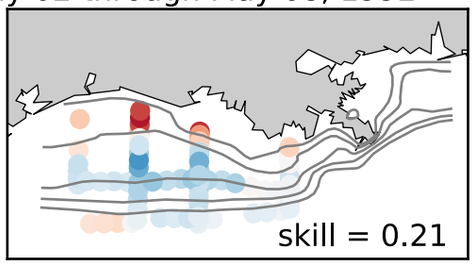
Spatial length scales of bottom hypoxia are O(10 km), and associated with small-scale bathymetric features.



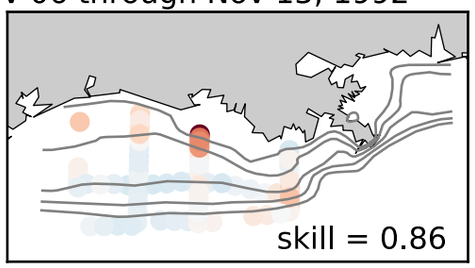


Dimarco et al. (JMS, 2010)

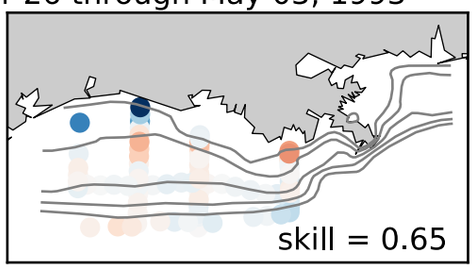
May 02 through May 08, 1992



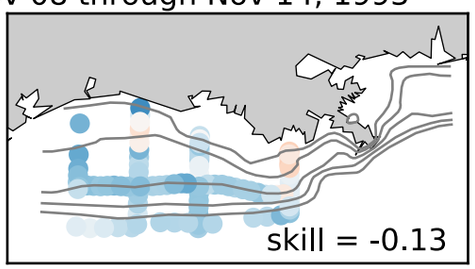
Nov 06 through Nov 13, 1992



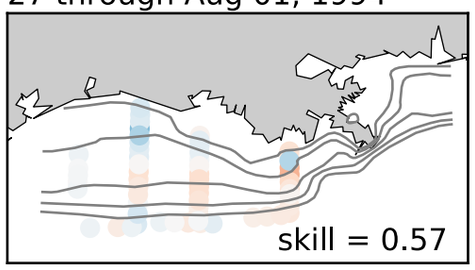
Apr 26 through May 03, 1993



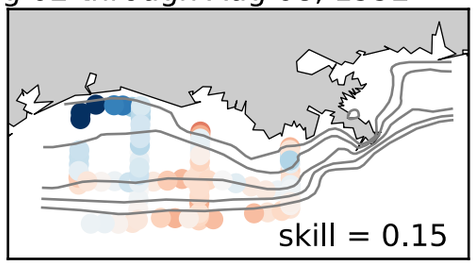
Nov 08 through Nov 14, 1993



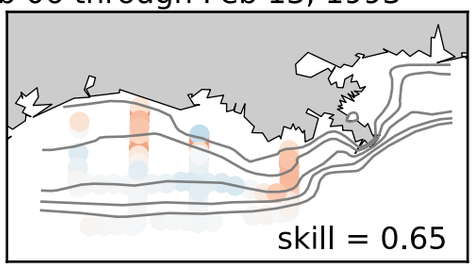
Jul 27 through Aug 01, 1994



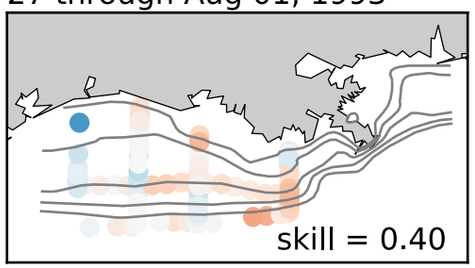
Aug 02 through Aug 08, 1992



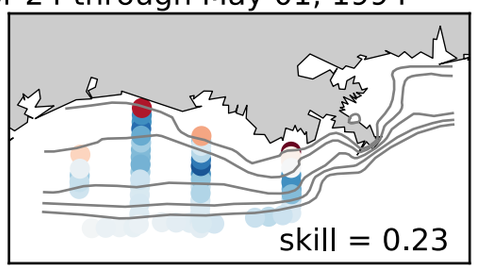
Feb 06 through Feb 13, 1993



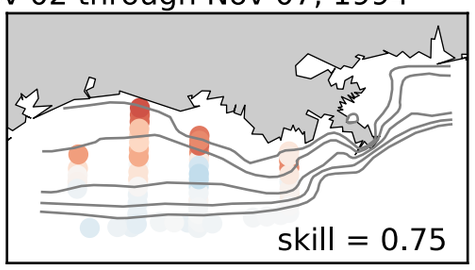
Jul 27 through Aug 01, 1993



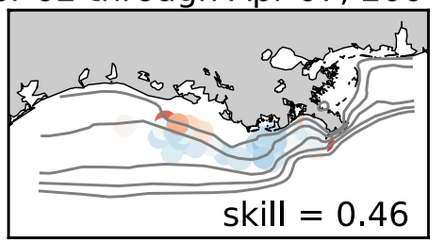
Apr 24 through May 01, 1994



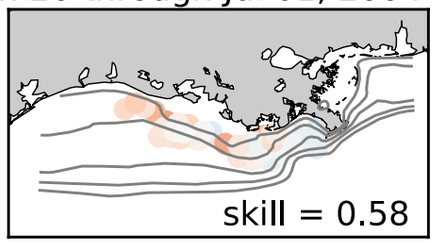
Nov 02 through Nov 07, 1994



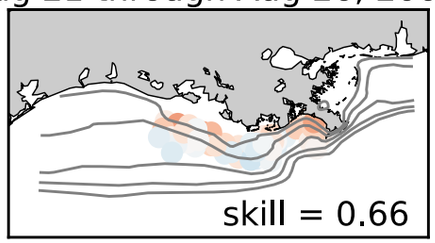
Apr 02 through Apr 07, 2004



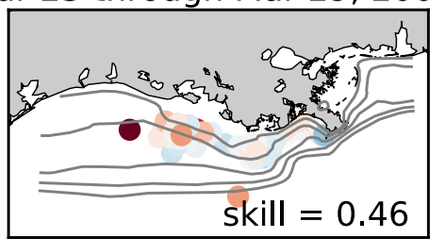
Jun 26 through Jul 01, 2004



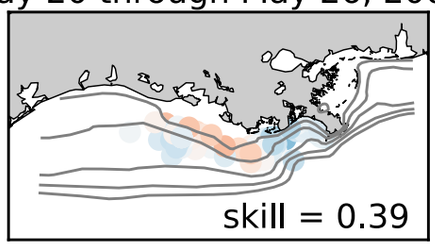
Aug 21 through Aug 26, 2004



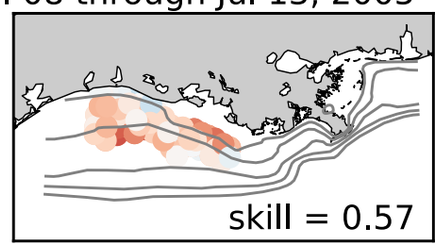
Mar 23 through Mar 29, 2005

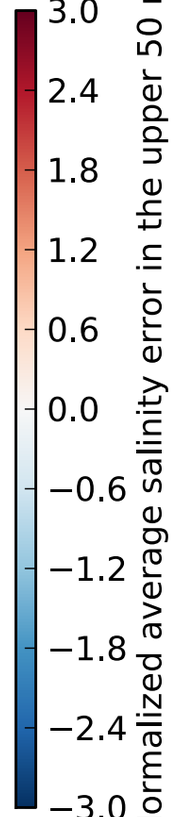


May 20 through May 26, 2005



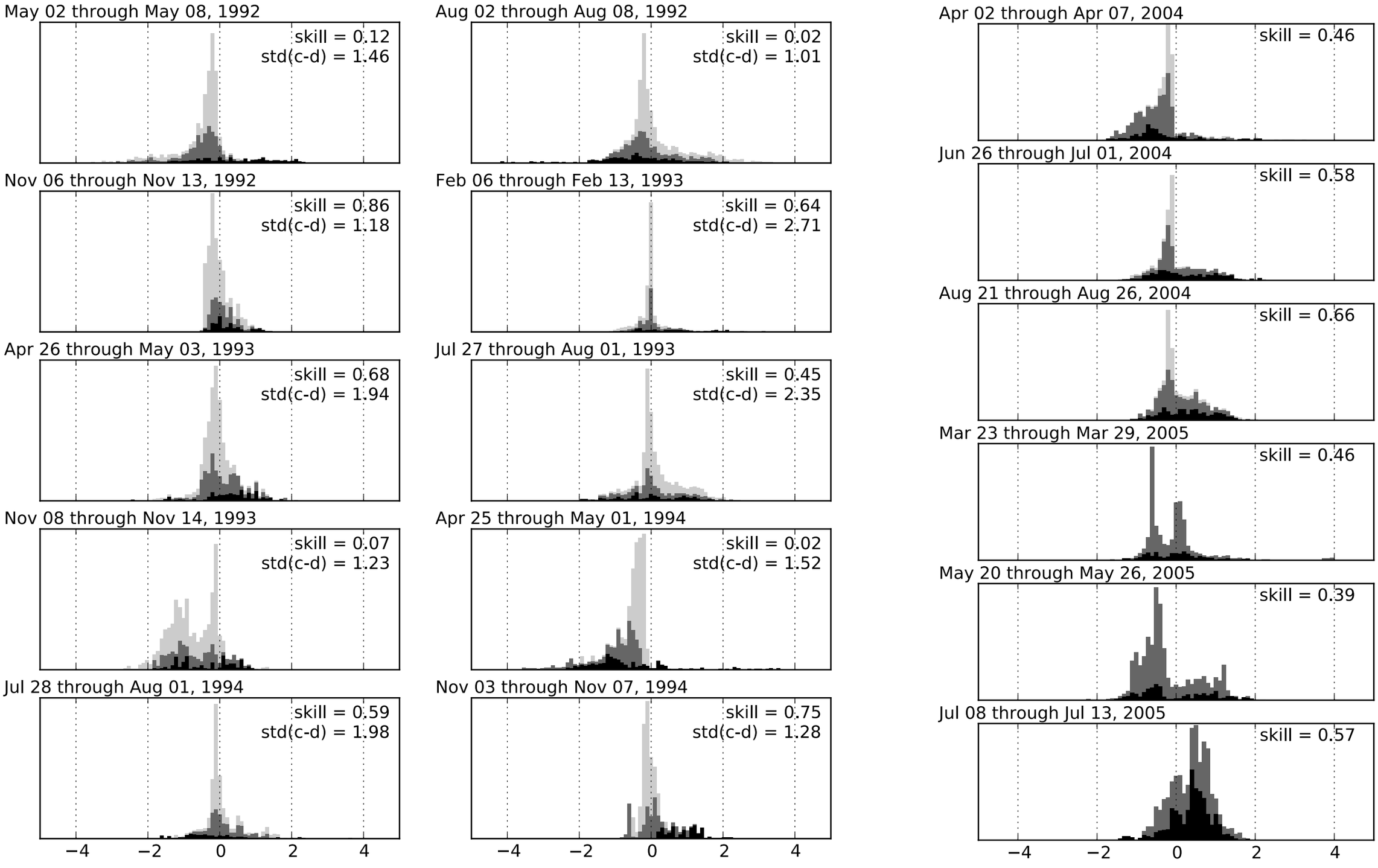
Jul 08 through Jul 13, 2005

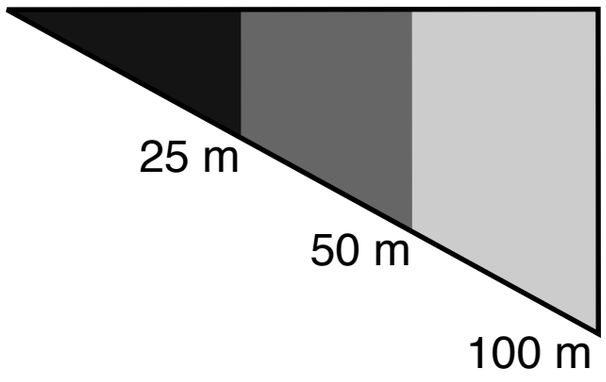




$$\frac{(m-d)}{\mathrm{std}(c-d)}$$

$$\mathrm{skill} = 1 - \frac{\sum (m-d)^2}{\sum (c-d)^2}$$

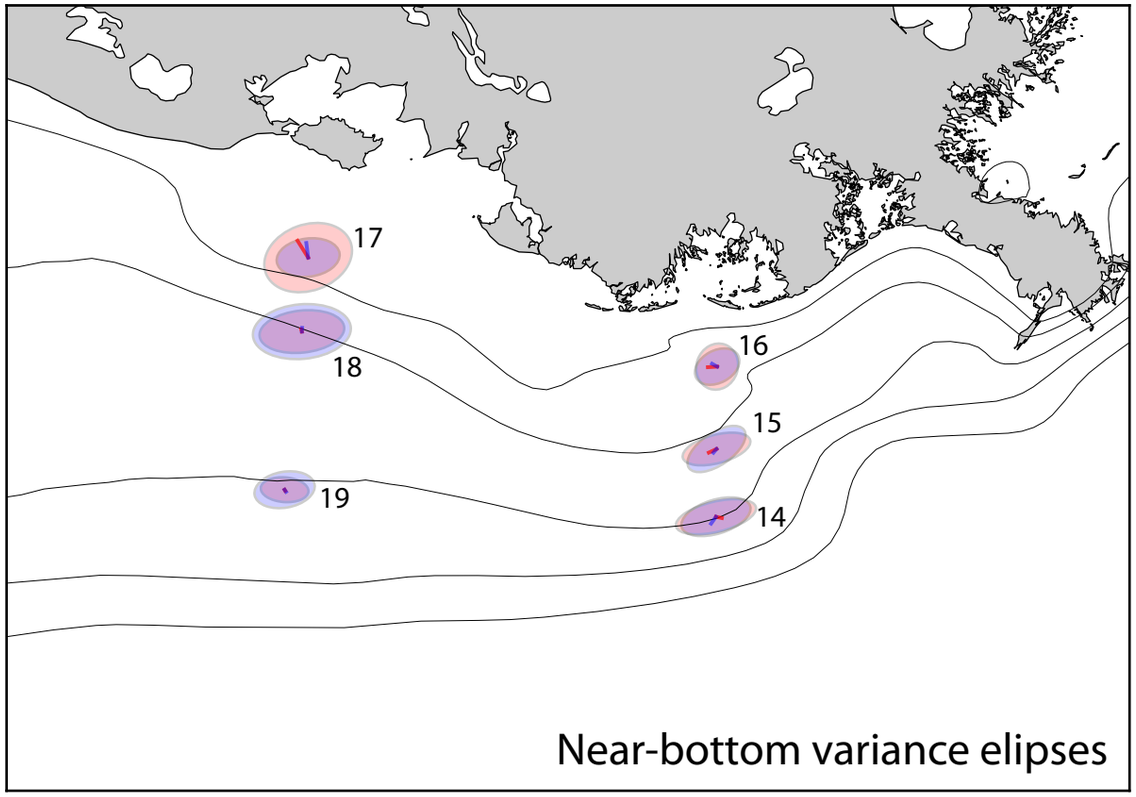




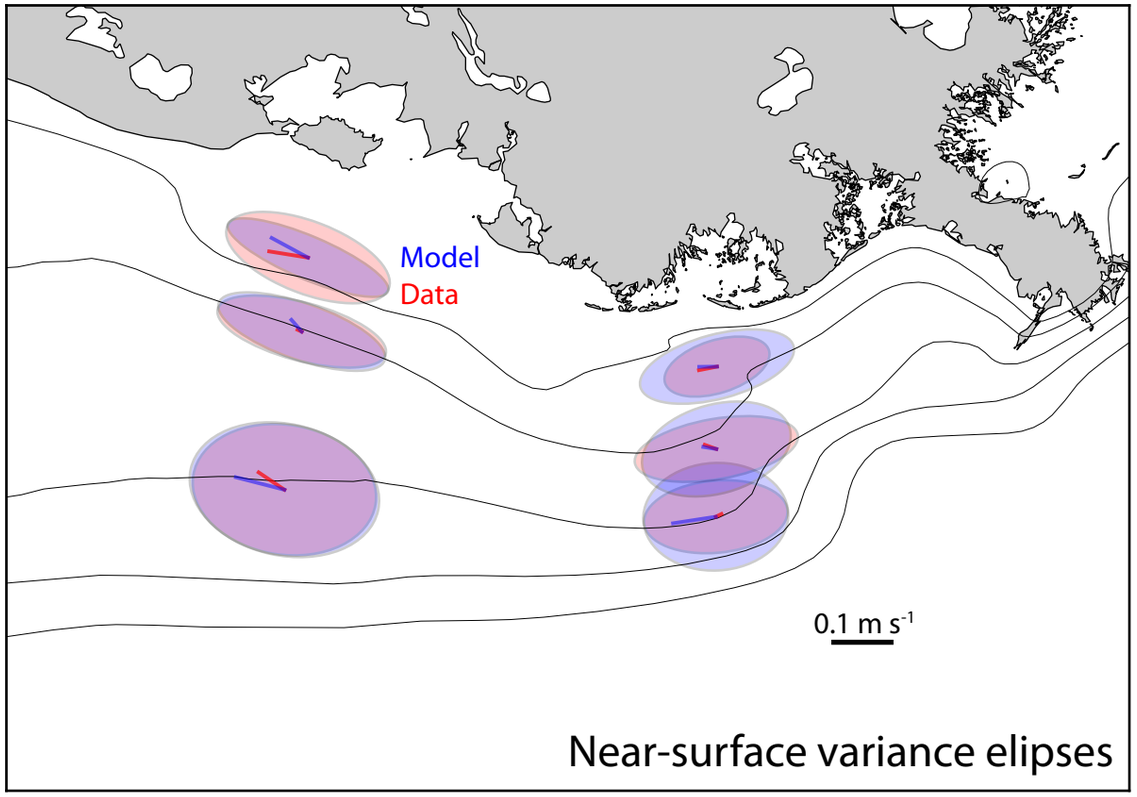
Normalized Salinity Error Histograms

$$\frac{(m-d)}{\mathrm{std}(c-d)}$$

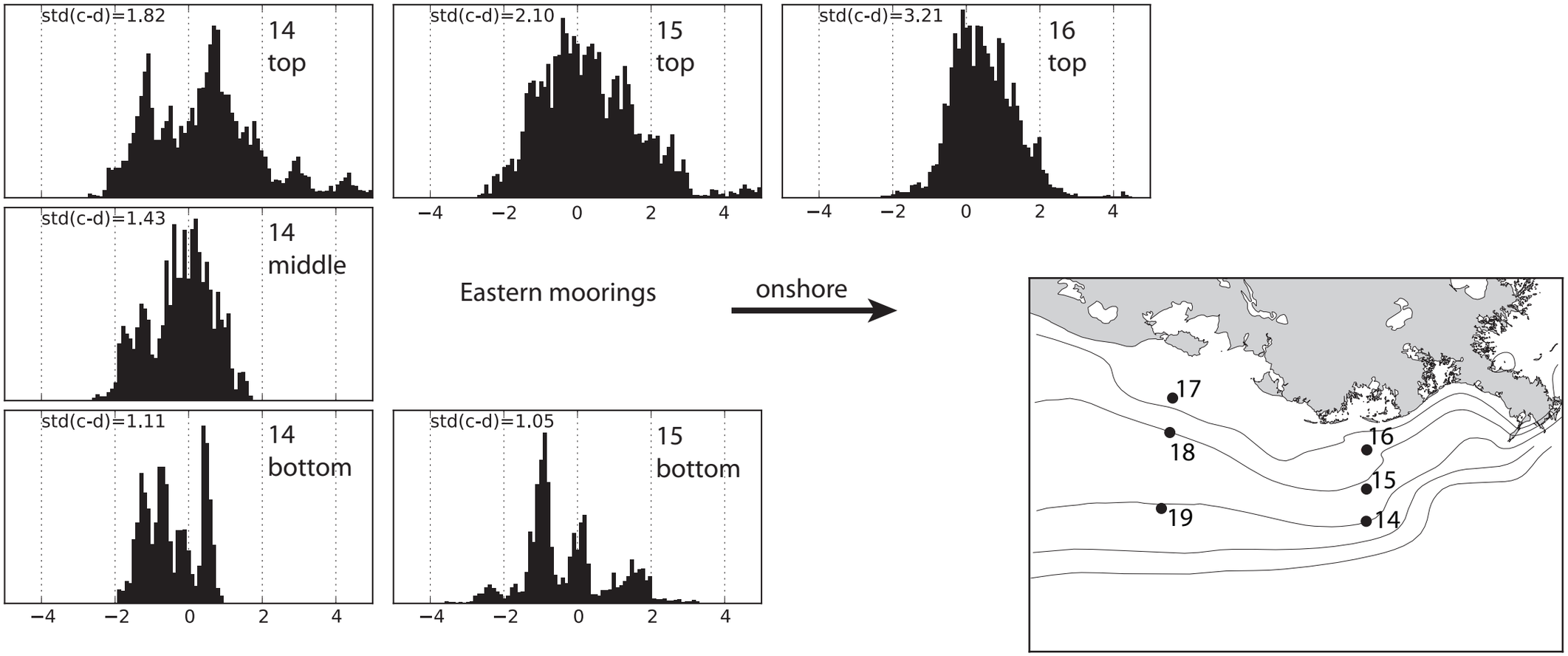
Note: std defined *with* mean

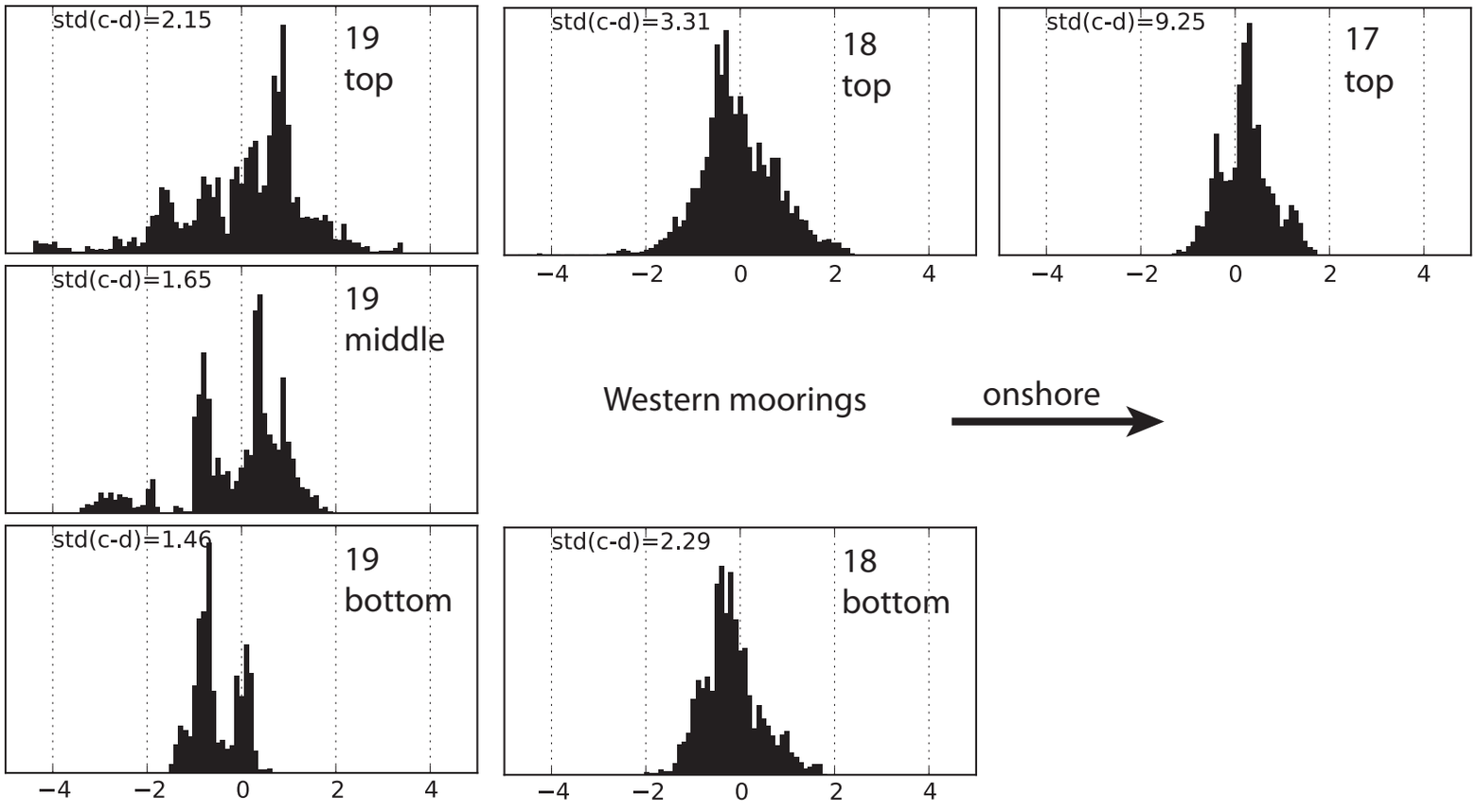


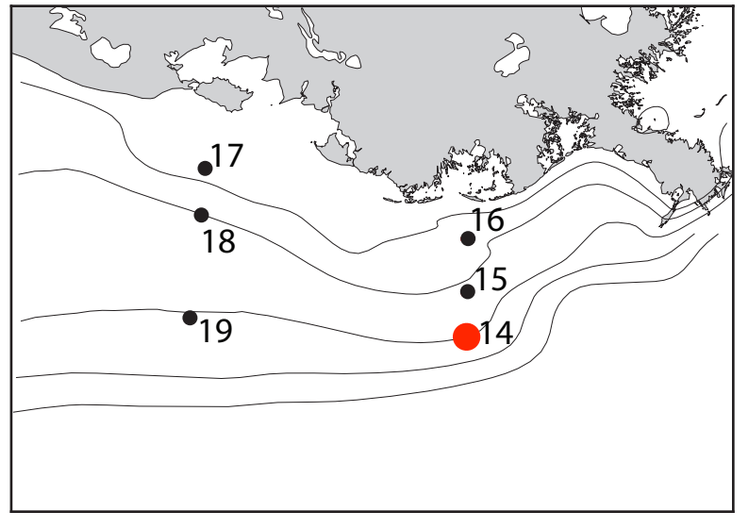
Near-bottom variance elipses



Near-surface variance elipses


std(c-d)=1.82
14
top
std(c-d)=2.10
15
top
std(c-d)=3.21
16
top
std(c-d)=1.43
14
middle
Eastern moorings
onshore
std(c-d)=1.11
14
bottom
std(c-d)=1.05
15
bottom
−4
−2
0
2
4
17
18
16
15
19
14

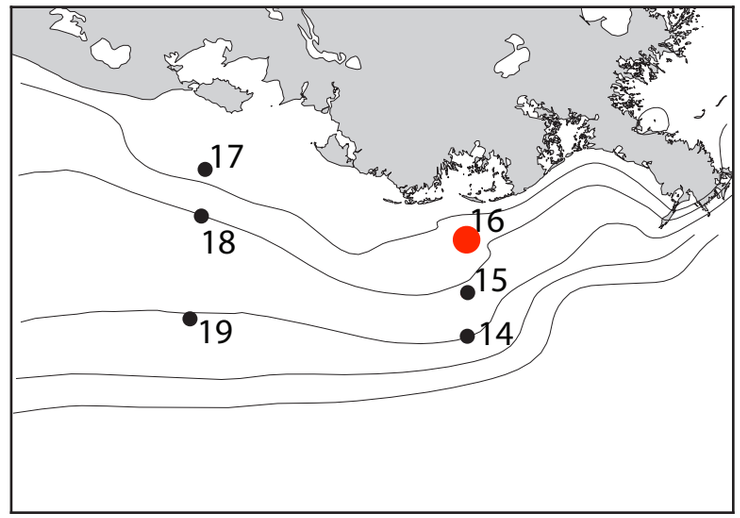

std(c-d)=2.15
19
top
std(c-d)=3.31
18
top
std(c-d)=9.25
17
top
std(c-d)=1.65
19
middle
Western moorings
onshore
std(c-d)=1.46
19
bottom
std(c-d)=2.29
18
bottom
−4
−2
0
2
4



Mooring 14t; skill = -1.753

38
36
34
32
30
28
26
24

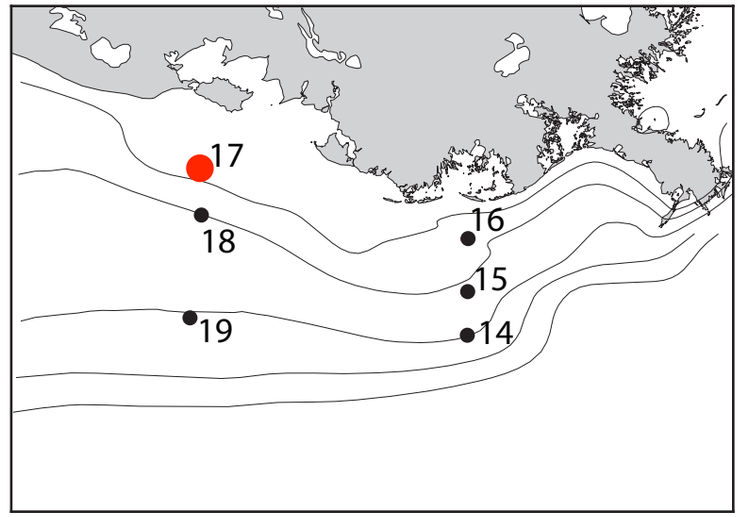
May 1992 Sep 1992 Jan 1993 May 1993 Sep 1993 Jan 1994 May 1994 Sep 1994

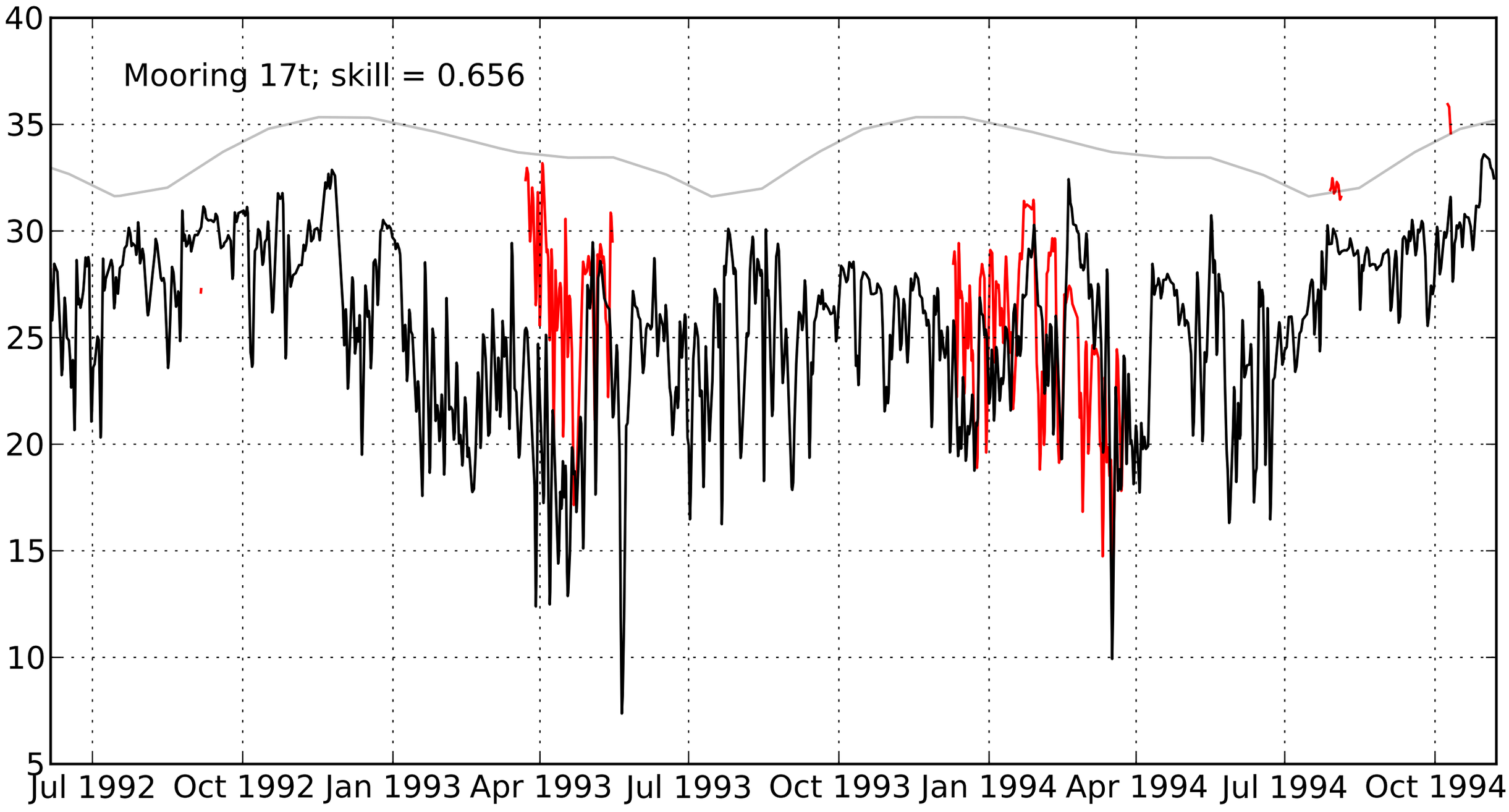


Mooring 16t; skill = 0.008

40
35
30
25
20
15

May 1992 Aug 1992 Nov 1992 Feb 1993 May 1993 Aug 1993 Nov 1993 Feb 1994 May 1994 Aug 1994


17
18
16
15
19
14


Mooring 17t; skill = 0.656
40
35
30
25
20
15
10
5
Jul 1992
Oct 1992
Jan 1993
Apr 1993
Jul 1993
Oct 1993
Jan 1994
Apr 1994
Jul 1994
Oct 1994

Bogden et al. (1996)

Basic model: Oct 27 response to local wind

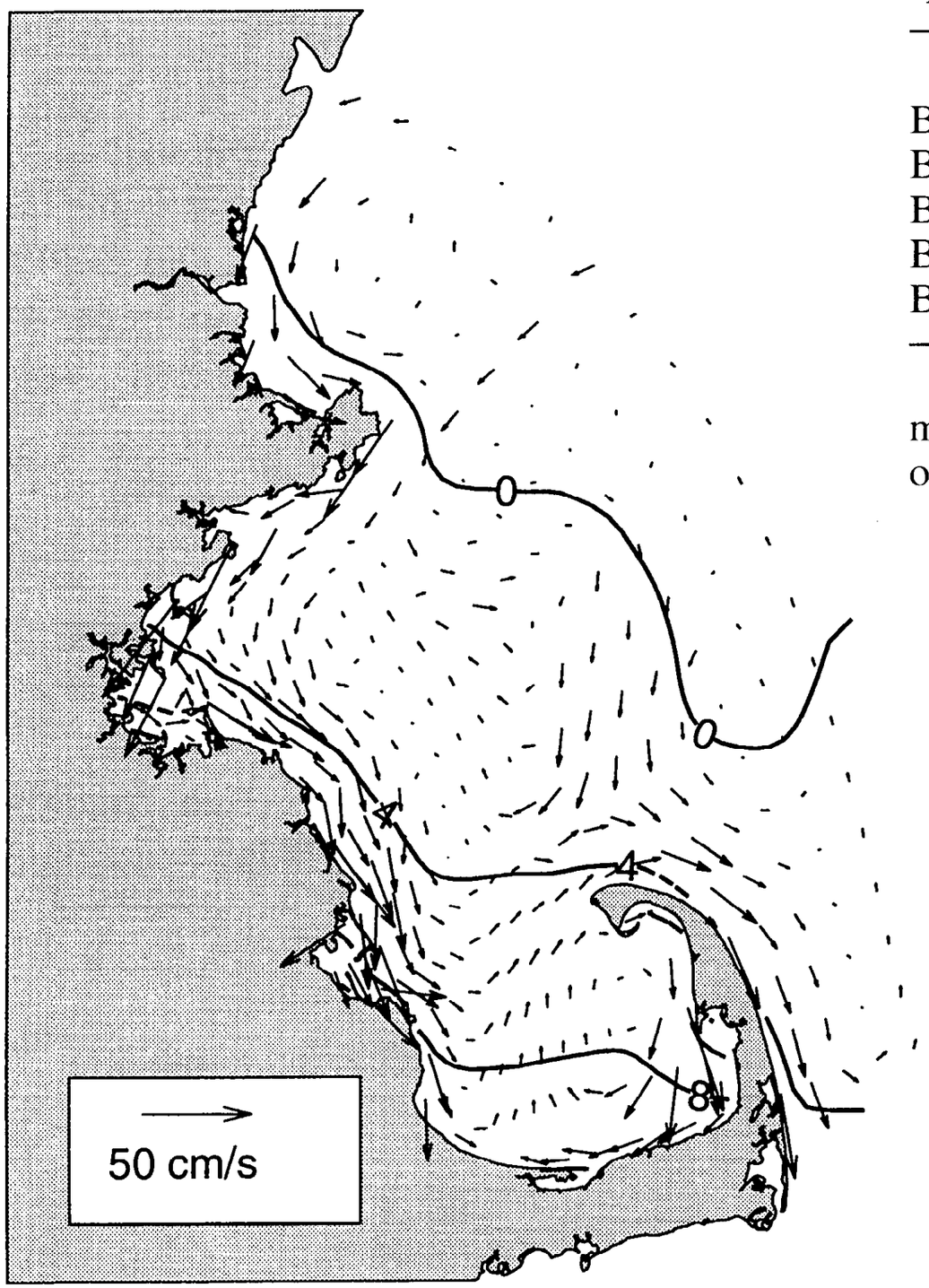


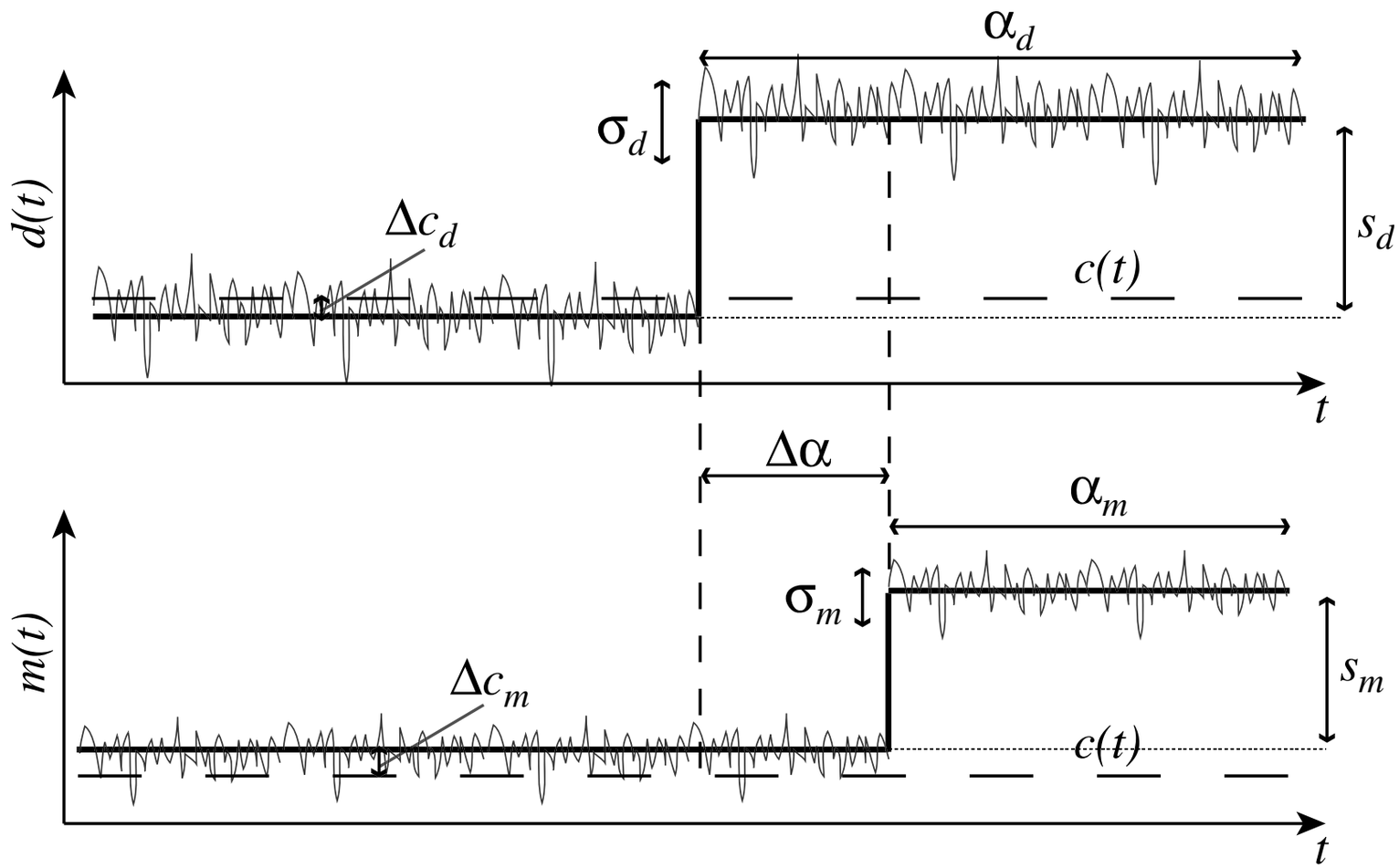
Table 2. Skills of the Local Wind-Driven Flow From the Basic Model (1) and of the Hierarchy of More Complete Primitive-Equation Models

Run	Dimensions	Momentum	Bottom Friction	Model Skill	rms, cm/s
(1)	2-D	linear	linear	0.27	0.21
BM-1	2-D	linear	linear	0.30	0.28
BM-2	2-D	linear	quadratic	0.27	0.40
BM-3	2-D	nonlinear	quadratic	0.25	0.43
BM-4	3-D	linear	quadratic	0.20	0.45
BM-5	3-D	nonlinear	quadratic	0.11	0.49

See text. The last column shows rms variation averaged over all measurement locations and times. For comparison, the rms variation of the data is $\sqrt{\mathbf{d} \cdot \mathbf{d}/N} = 0.57$ cm/s.

Increasing model complexity:

- increases variance
- decreases model skill



Perfect model
with same noise levels

$$\text{skill} = 1 - \frac{2}{\alpha(\frac{s}{\sigma})^2 + 1}$$

or

Perfect model
with different noise levels

$$\text{skill} = 1 - \frac{(\frac{\sigma_m}{\sigma_d})^2 + 1}{\alpha(\frac{s}{\sigma_d})^2 + 1}$$

Hetland (Ocean Mod, 2006)

Some kind of obvious statements intended to be profound

Decorrelation space and time scales are quite small

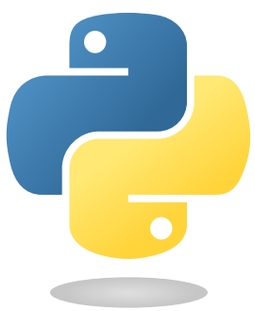
Observations do not resolve these scales adequately

Differences between simulation and observations of these features must be considered measurement error

The observation error covariance needs to have spatial scales larger than the measurement separation

While the observation error covariance is ridged at the small scales, the model is not – how to assimilate?

How to evaluate the parts of the model that could be improved, but are not well represented in the model?



python™

A modern scripting language, similar to Perl, Ruby, etc

- a high level language, with functions and classes
- many built in packages for text processing, networking

Python + numpy/matplotlib packages ≈ MATLAB™

- Many other scientific packages (like MATLAB™'s toolboxes)
- Many other plotting packages (unlike MATLAB™)
- NetCDF3 & NetCDF4 support, able to concatenate files.
- Able to call compiled FORTRAN and C (like MEX files, but much easier)
- Free, open source.

Everything you saw was created using Python

- Model setup, analysis, figures, and animations (with ffmpeg)