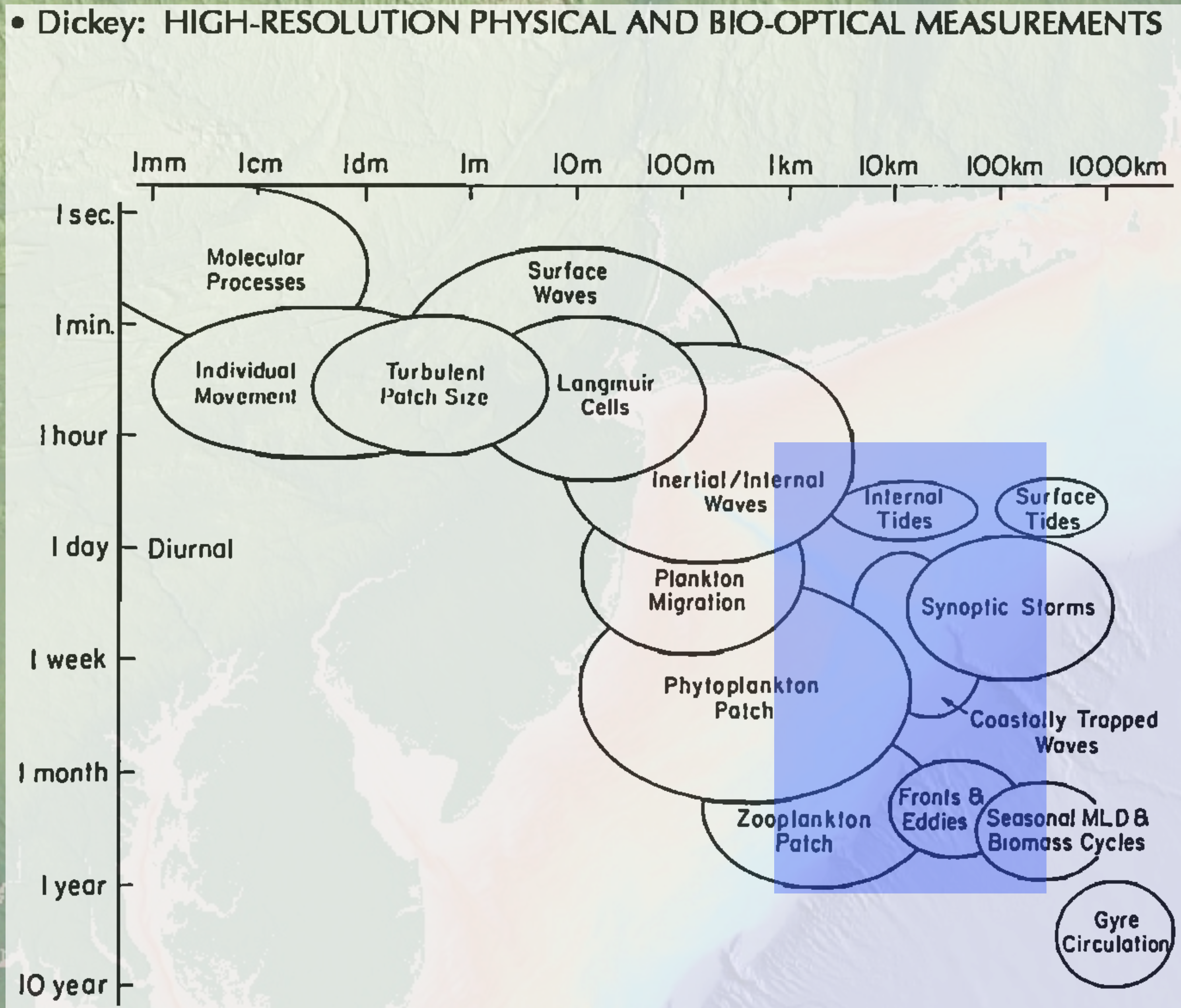
Surface transport and cross-shelf exchange processes on the New Jersey Shelf

Donglai Gong

WHOI AOPE Seminar

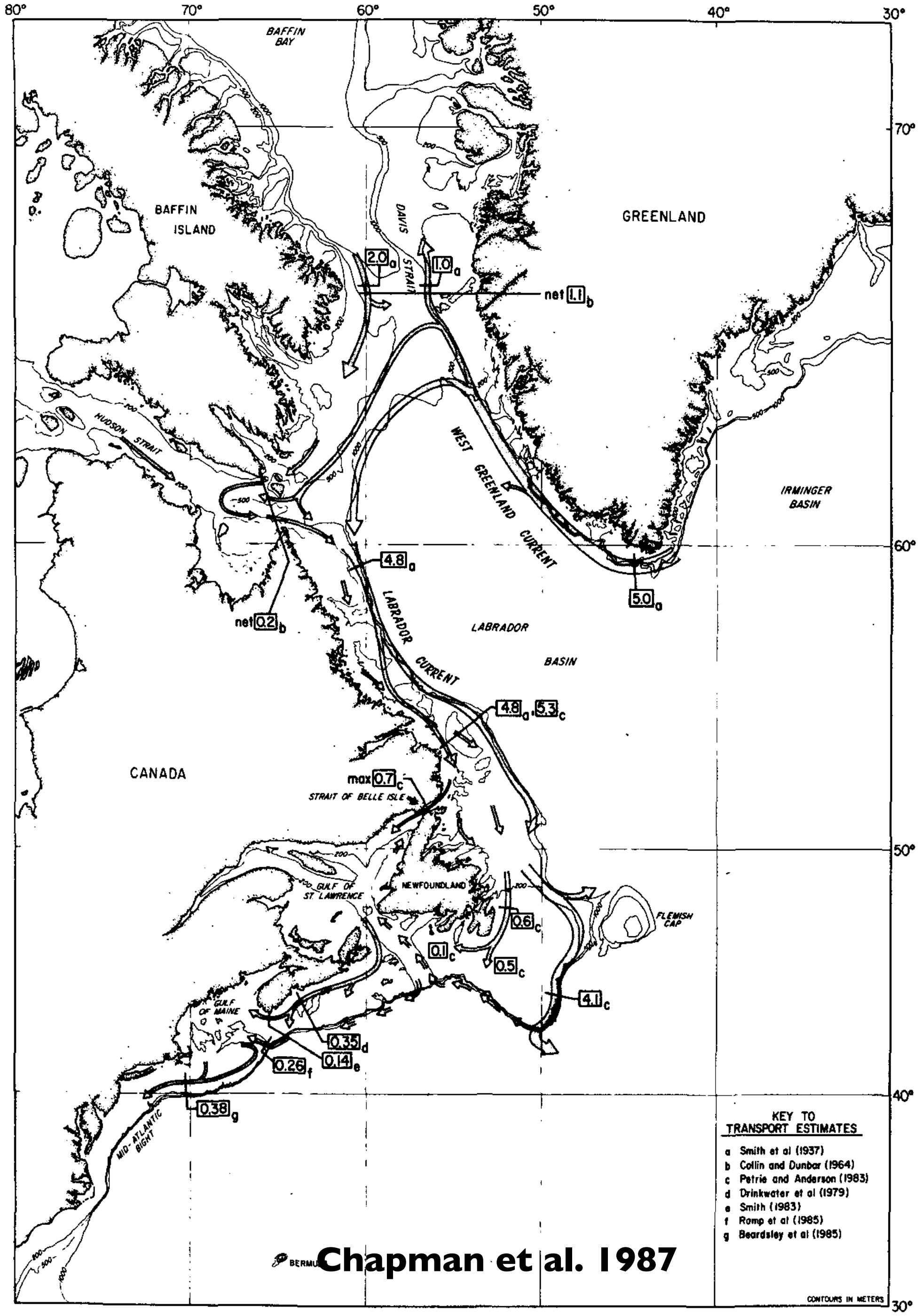
2010-01-27

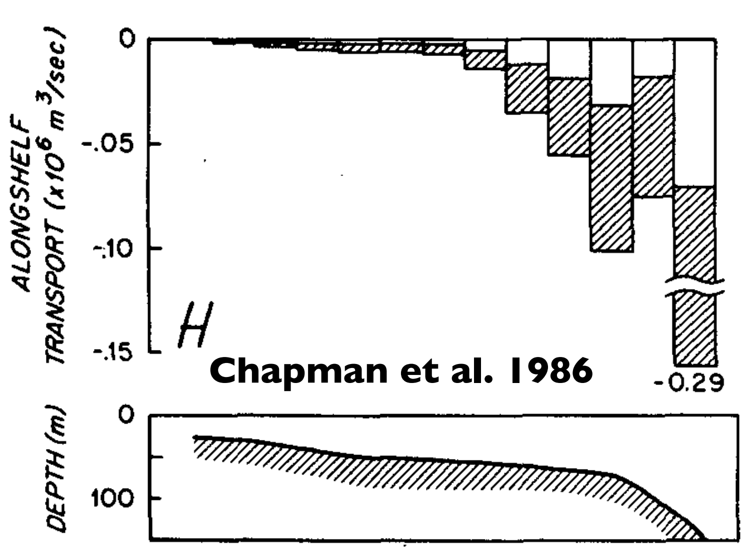


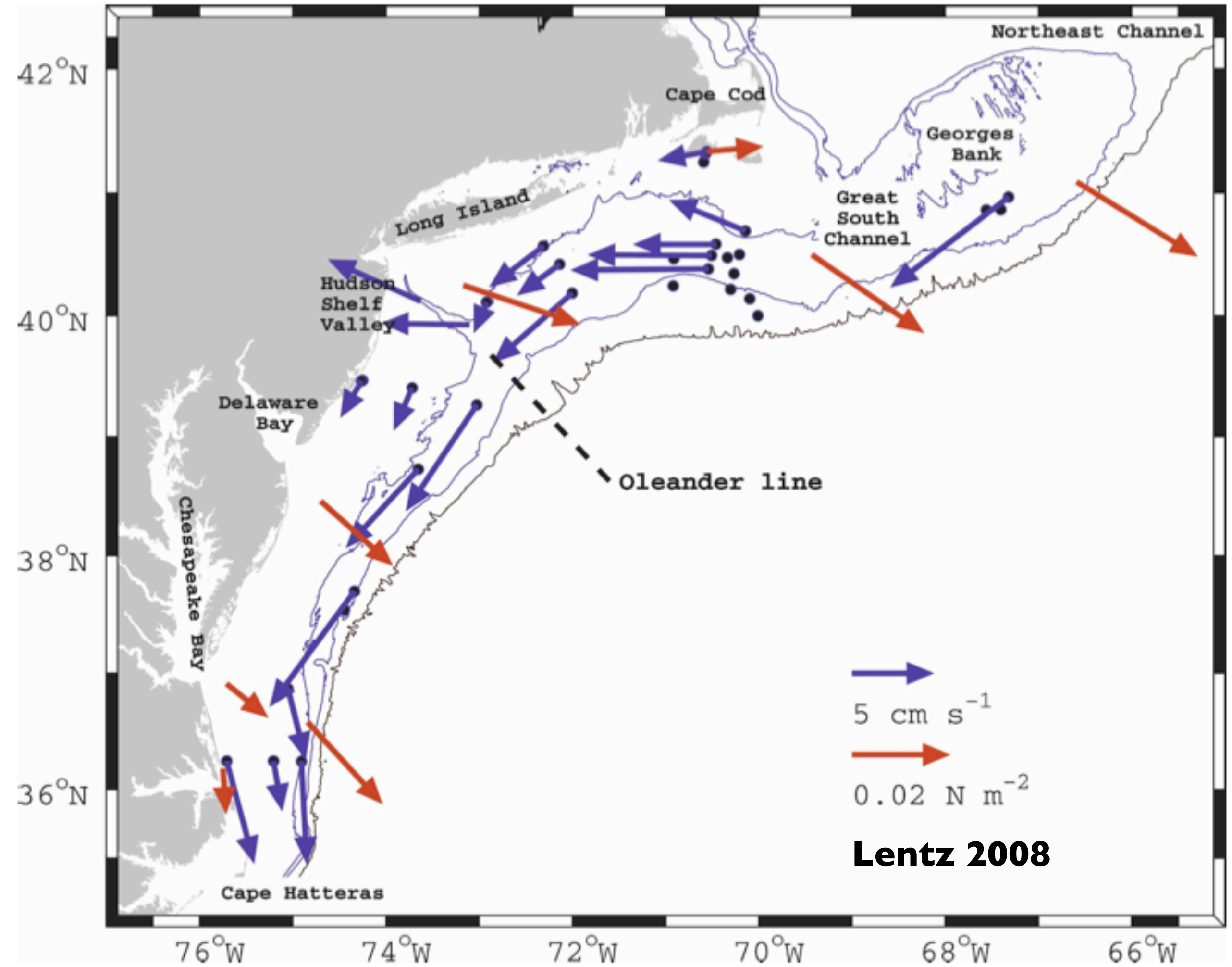
tides
winds
seasons
topography
river discharge
large scale flow
coastally trapped w.
internal tides/waves
WCR, frontal eddies
synoptic storms

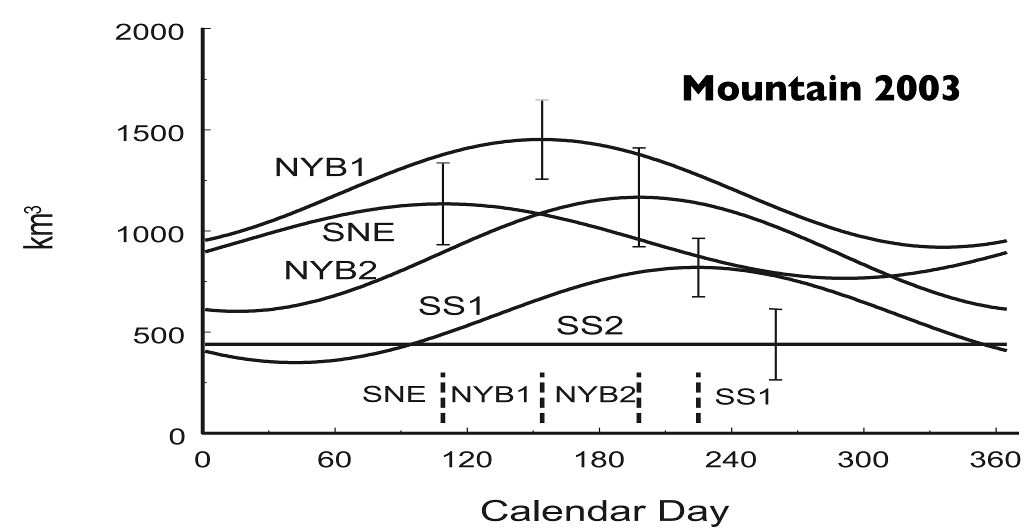
Transport
and mixing of
heat and salt

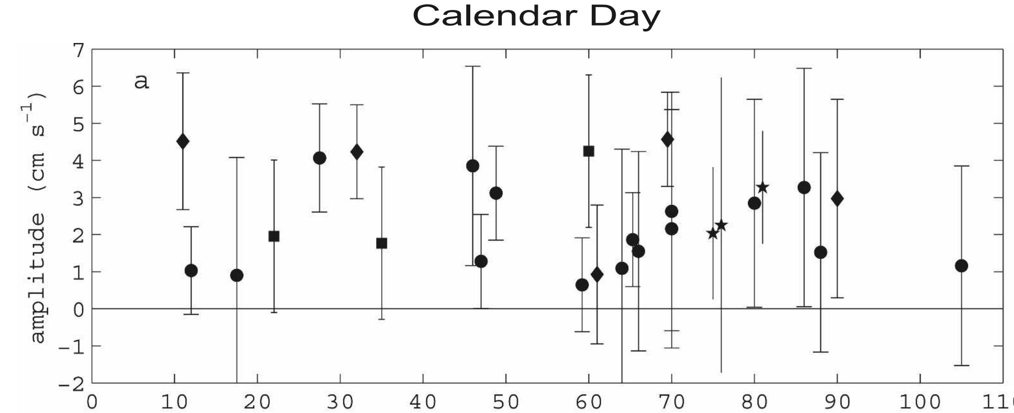
biological productivity,
dispersion of pollutants,
fisheries


BAFFIN BAY
BAFFIN ISLAND
GREENLAND
DAVIS STRAIT
HUDSON STRAIT
WEST GREENLAND CURRENT
IRMINGER BASIN
LABRADOR CURRENT
LABRADOR BASIN
CANADA
STRAIT OF BELLE ISLE
GULF OF ST LAWRENCE
NEWFOUNDLAND
FLEMISH CAP
GULF OF MAINE
MID-ATLANTIC BIGHT
KEY TO TRANSPORT ESTIMATES
a Smith et al (1937)
b Collin and Dunbar (1964)
c Petrie and Anderson (1983)
d Drinkwater et al (1979)
e Smith (1983)
f Ramp et al (1985)
g Beardsley et al (1985)
CONTOURS IN METERS
Chapman et al. 1987

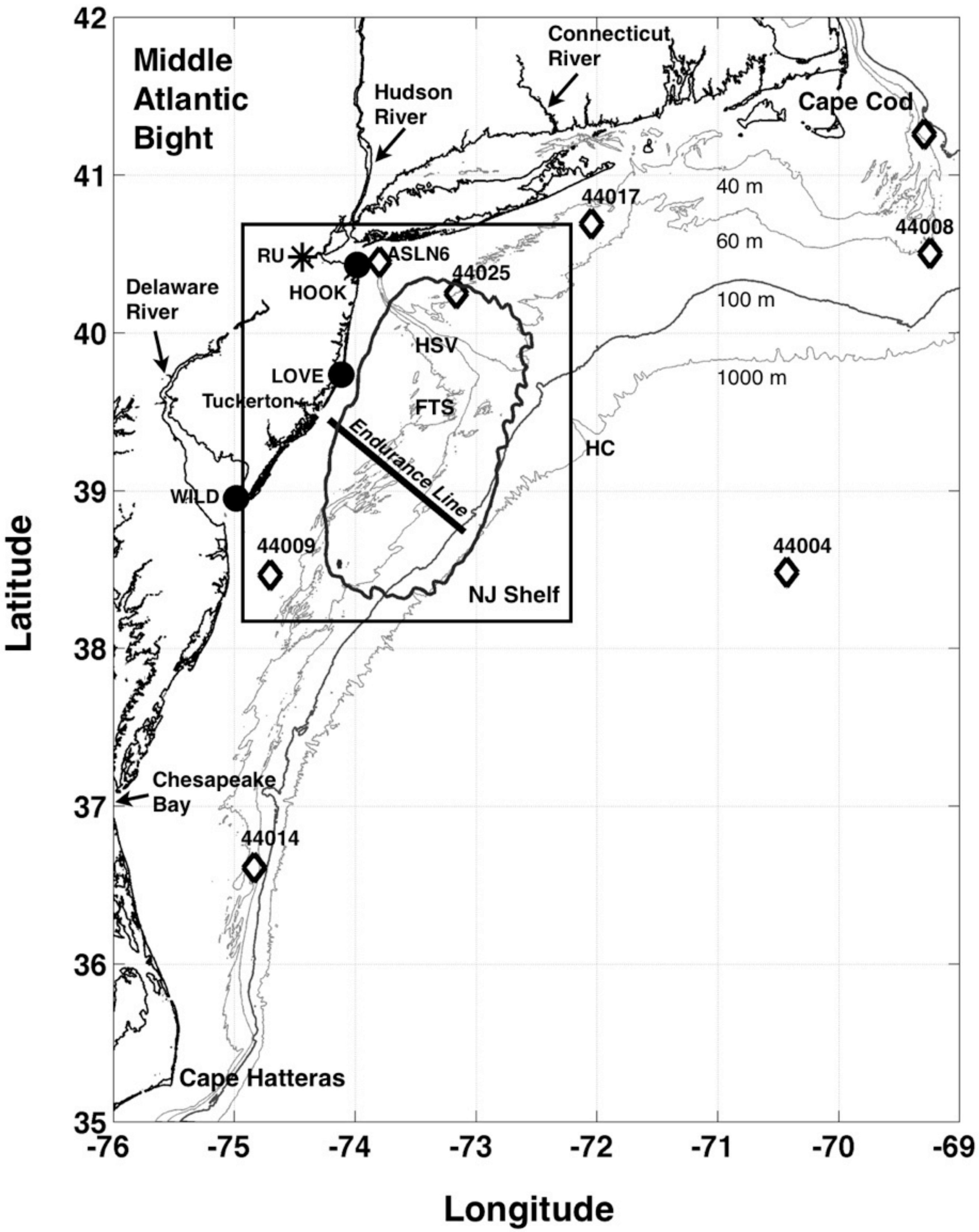

ALONGSHELF TRANSPORT (x10^6 m^3/sec)
0
-.05
-.10
-.15
-0.29
H
Chapman et al. 1986
DEPTH (m)
0
100


Northeast Channel
Cape Cod
Georges Bank
Great South Channel
Long Island
Hudson Shelf Valley
Delaware Bay
Oleander line
Chesapeake Bay
Cape Hatteras
5 cm s^-1
0.02 N m^-2
Lentz 2008
42°N
40°N
38°N
36°N
76°W
74°W
72°W
70°W
68°W
66°W


Mountain 2003
km^3
NYB1
SNE
NYB2
SS1
SS2
SNE NYB1 NYB2 SS1
Calendar Day

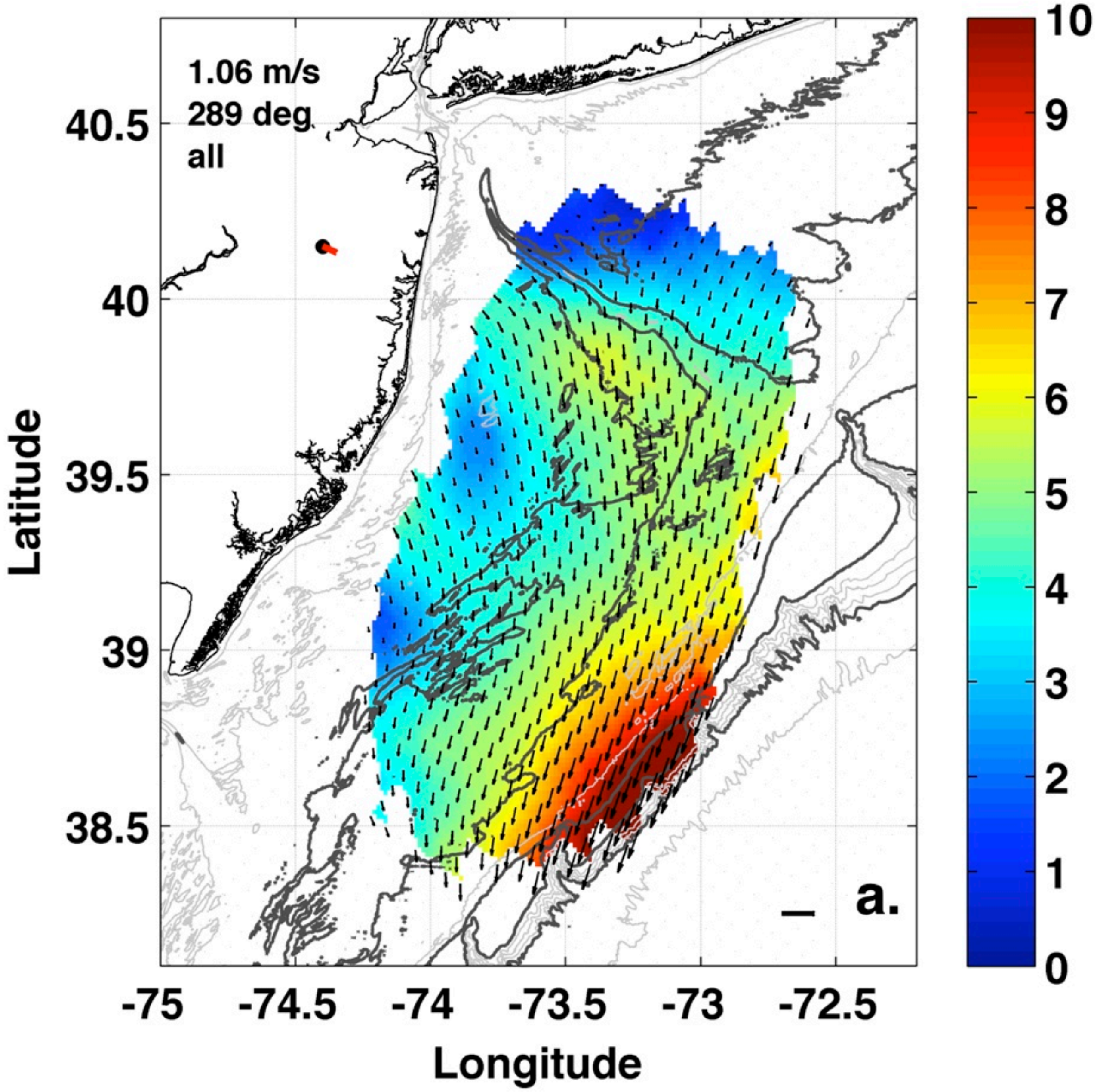

a
amplitude (cm s^-1)
Lentz 2008

Guiding Questions

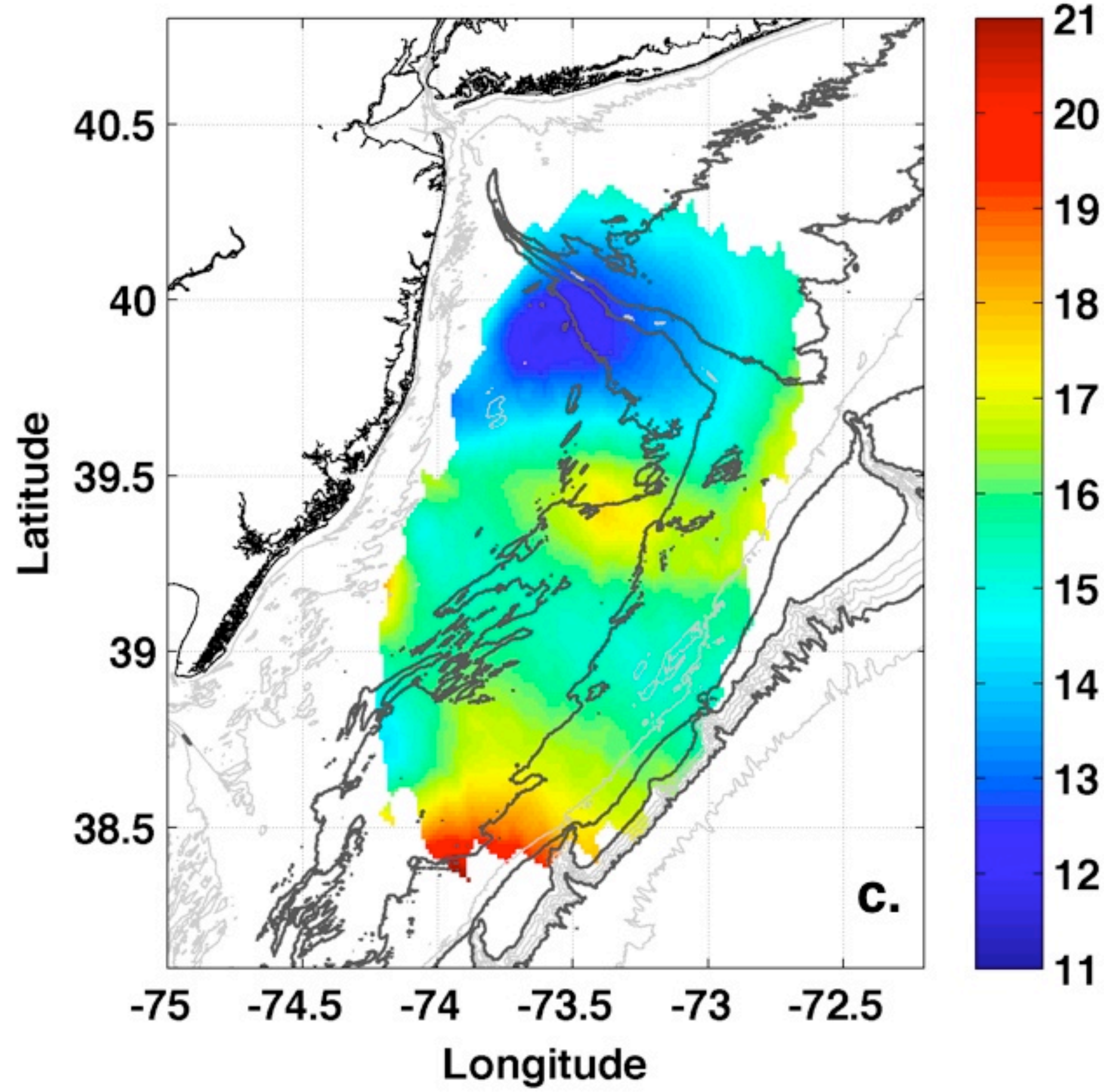


- Mean & background flow of the New Jersey Shelf? Effect of shelf topography?
- What is the seasonal meteorological condition and flow pattern on the shelf?
- How are material transported from the innershelf to the outershelf? Cross-shelf and along-shelf transport pathways? What is the residence time scale?
- How is surface shelf flow correlated with wind forcing, dependence on stratification?

Mean

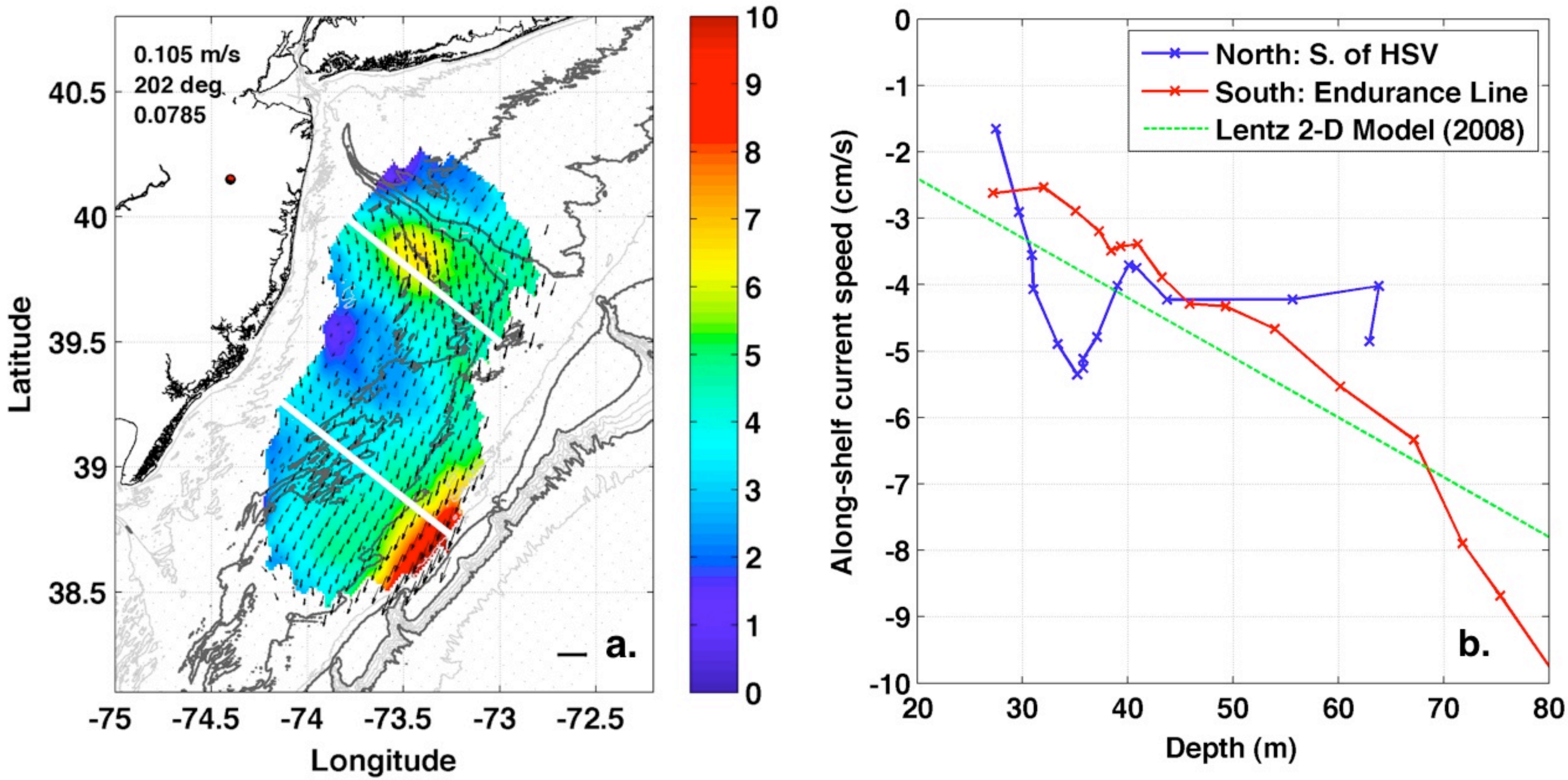


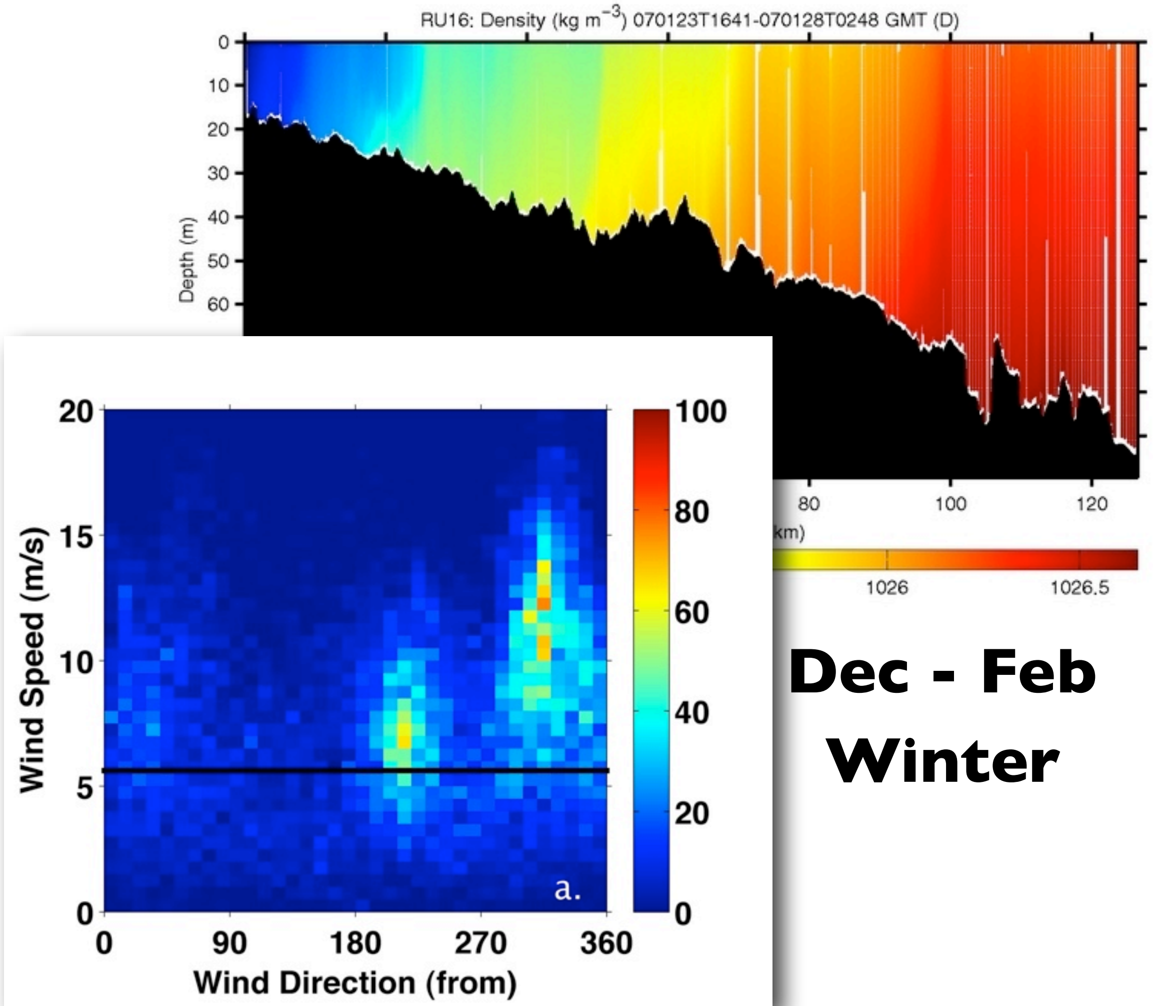
Std Dev.

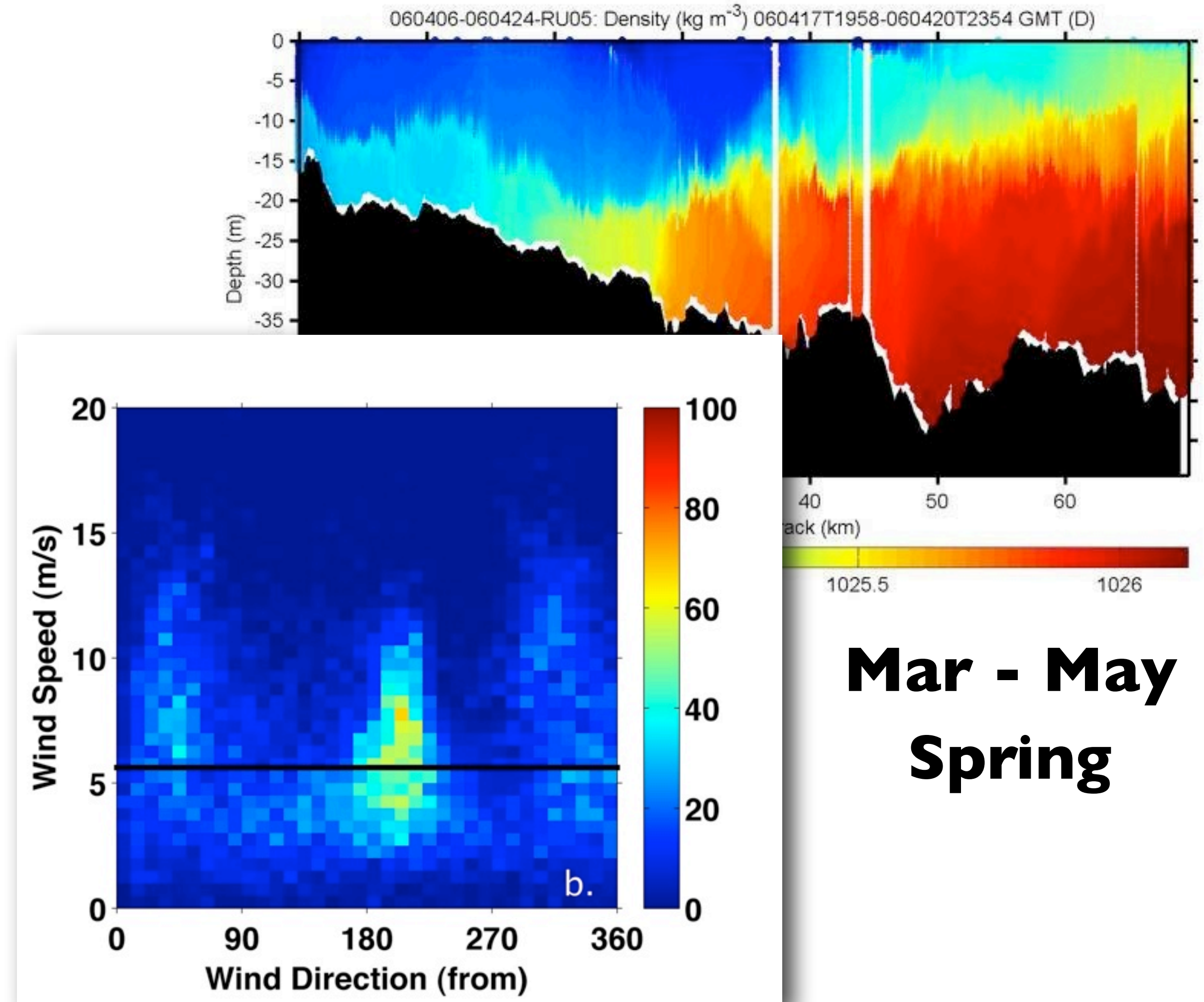


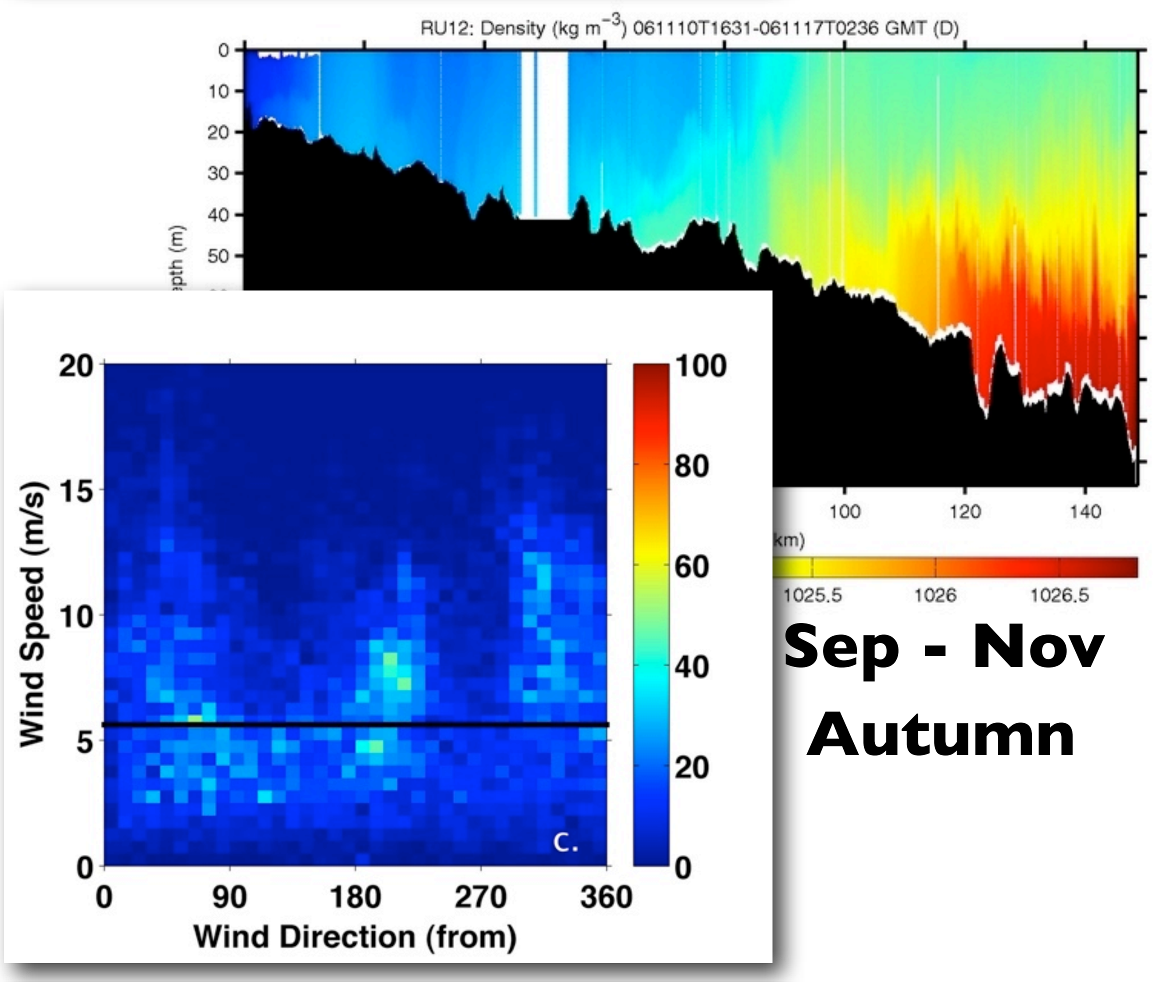
"Seasonal Climatology of Wind Driven Circulation on the NJ Shelf"
Gong, Kohut, Glen. in press.

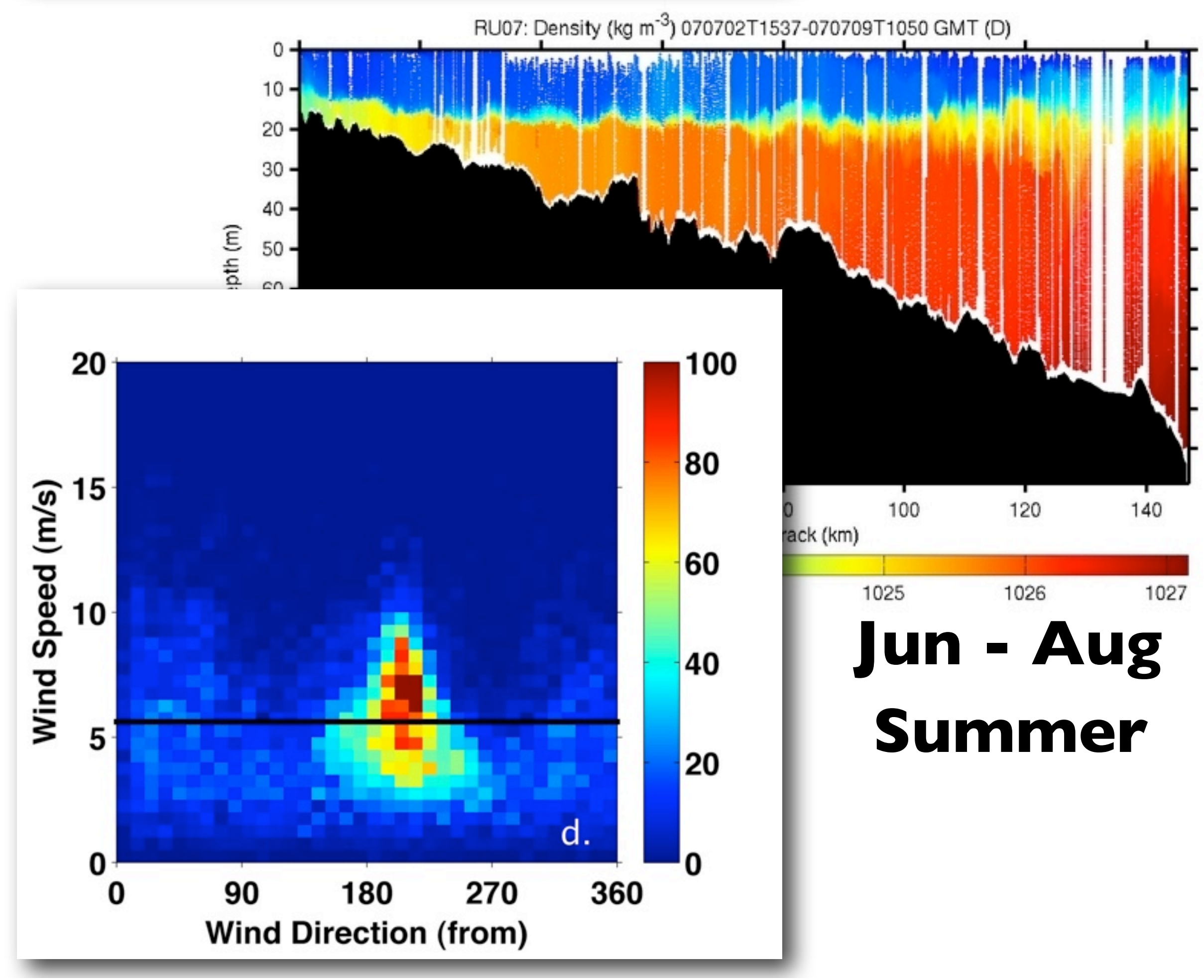
Background no-wind flow



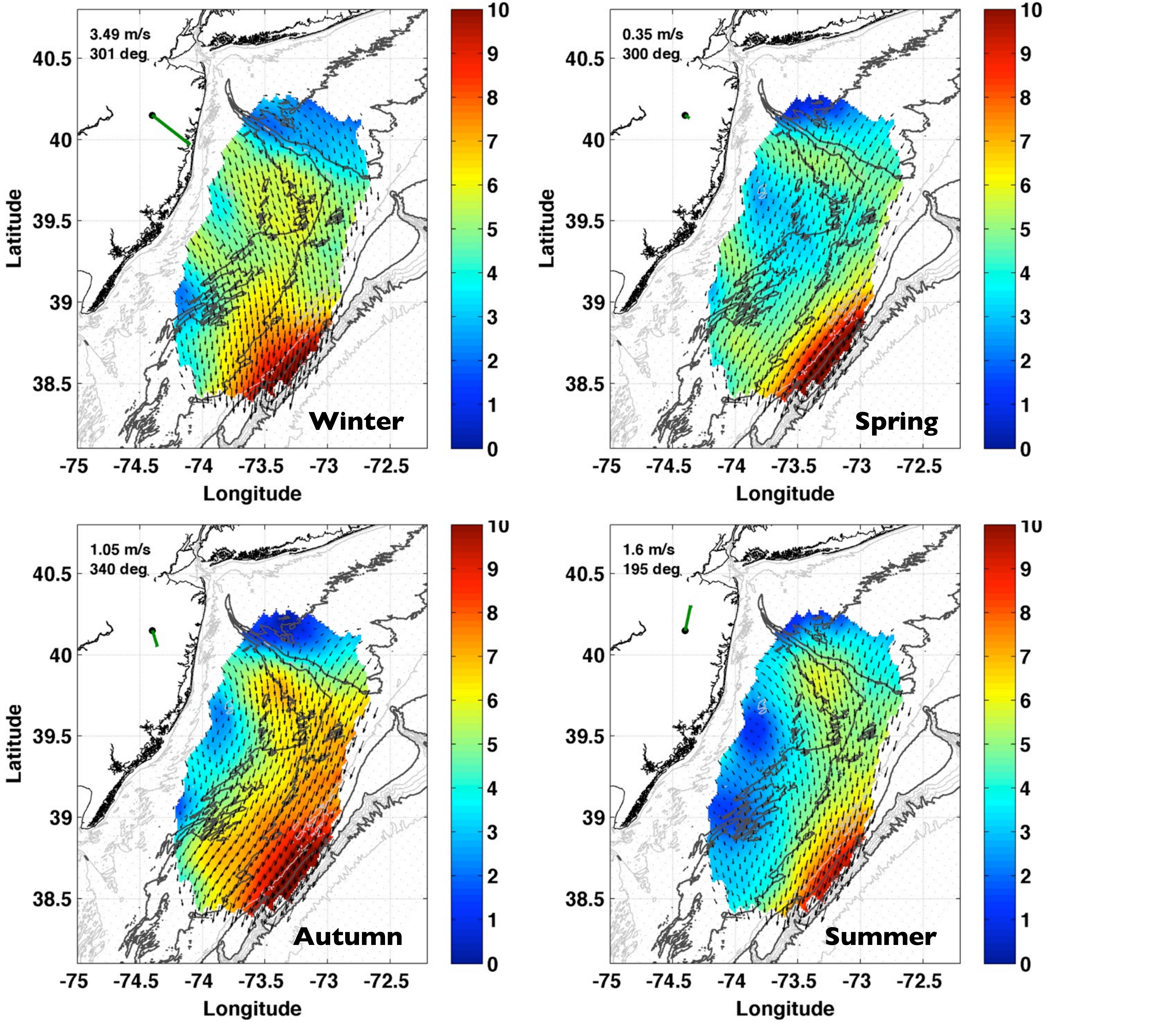

RU16: Density (kg m-3) 070123T1641-070128T0248 GMT (D)
Depth (m)
Wind Speed (m/s)
Wind Direction (from)
a.
Dec - Feb
Winter

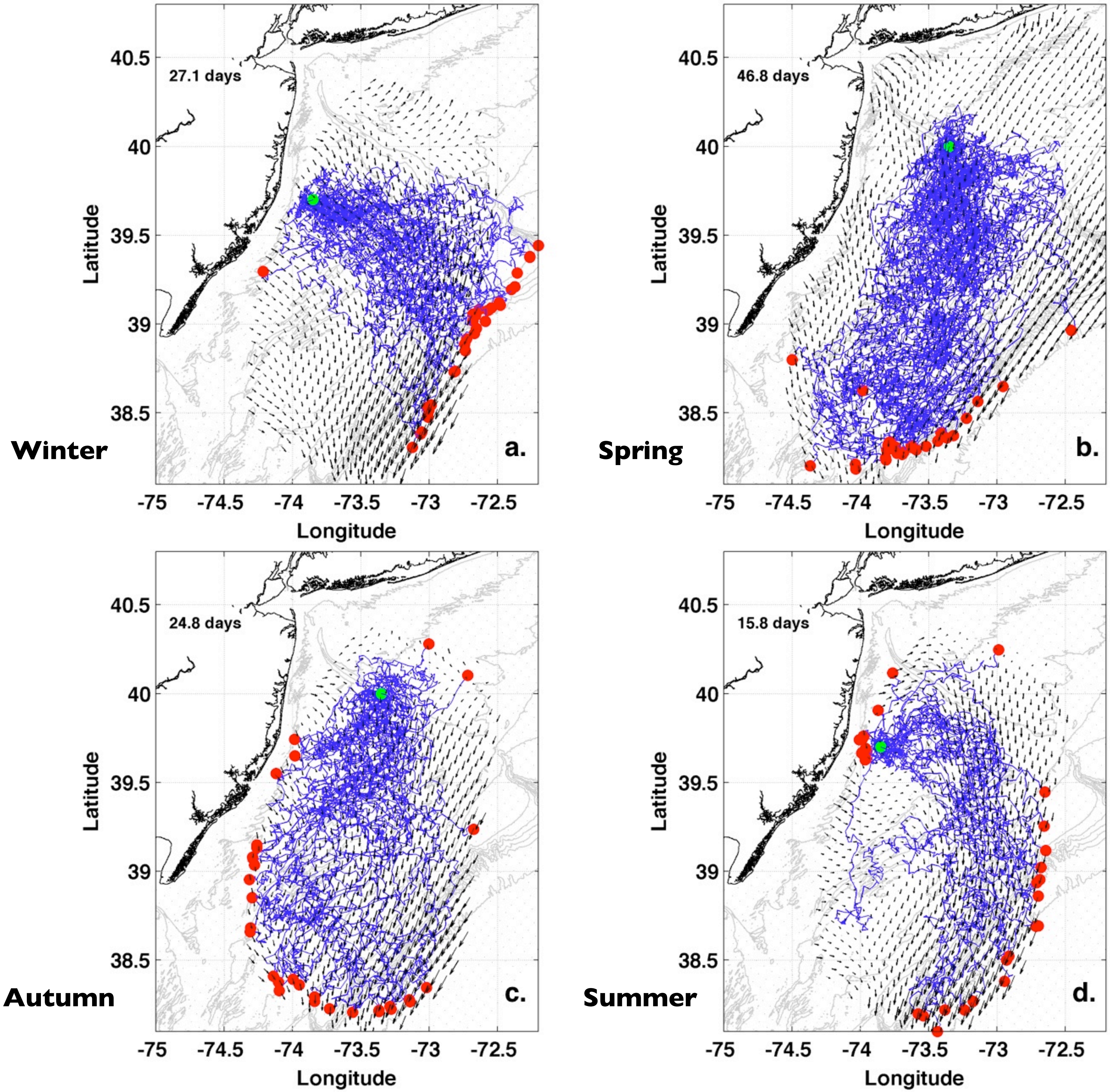

060406-060424-RU05: Density (kg m-3) 060417T1958-060420T2354 GMT (D)
Depth (m)
Wind Speed (m/s)
Wind Direction (from)
b.
Mar - May
Spring


RU12: Density (kg m-3) 061110T1631-061117T0236 GMT (D)
Wind Speed (m/s)
Wind Direction (from)
c.
Sep - Nov
Autumn


RU07: Density (kg m-3) 070702T1537-070709T1050 GMT (D)
Wind Speed (m/s)
Wind Direction (from)
d.
Jun - Aug
Summer

NJ Shelf Seasonal Mean Current (2002 - 2007)




27.1 days
Winter
a.
46.8 days
Spring
b.
24.8 days
Autumn
c.
15.8 days
Summer
d.
Latitude
Longitude
40.5
40
39.5
39
38.5
-75
-74.5
-74
-73.5
-73
-72.5

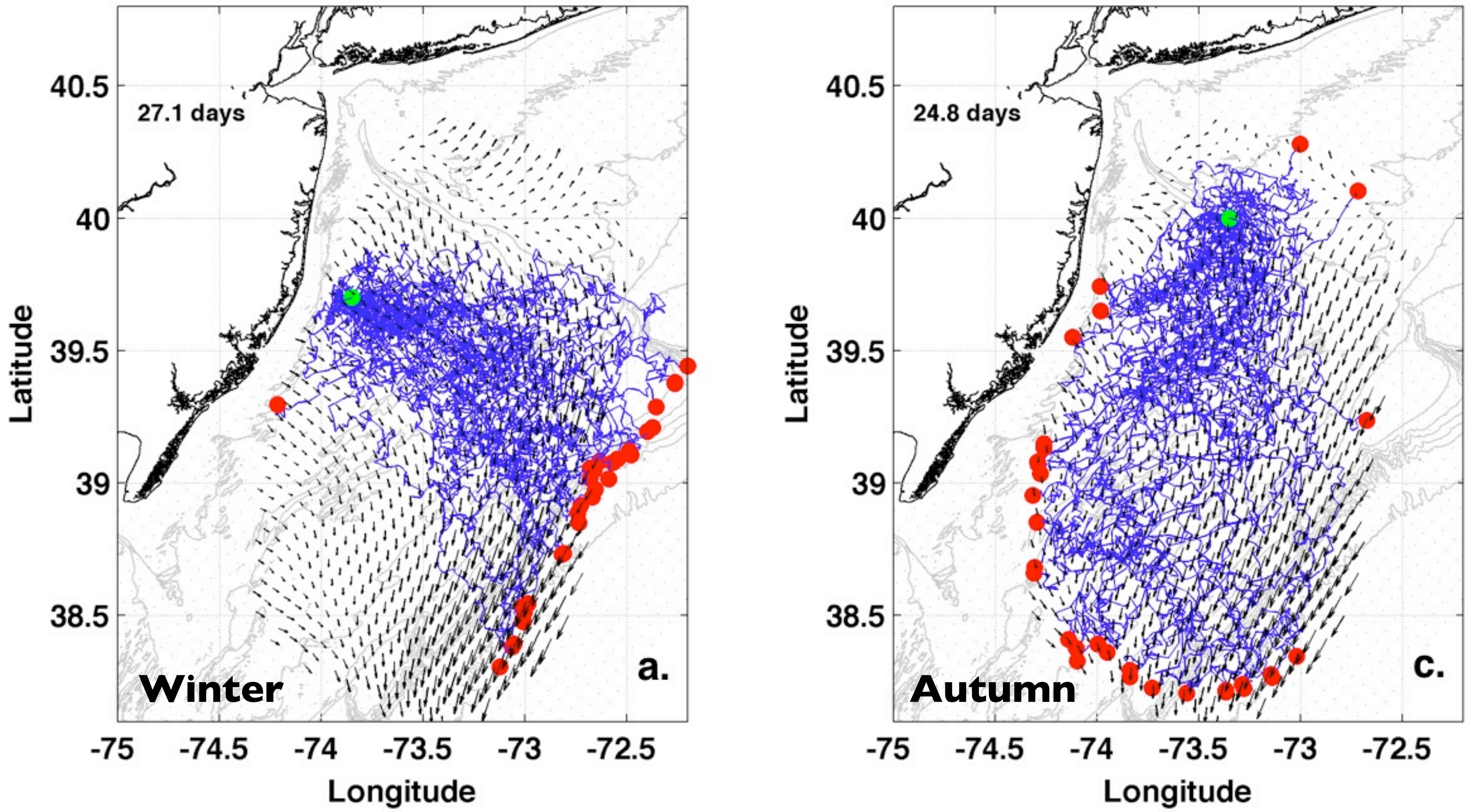
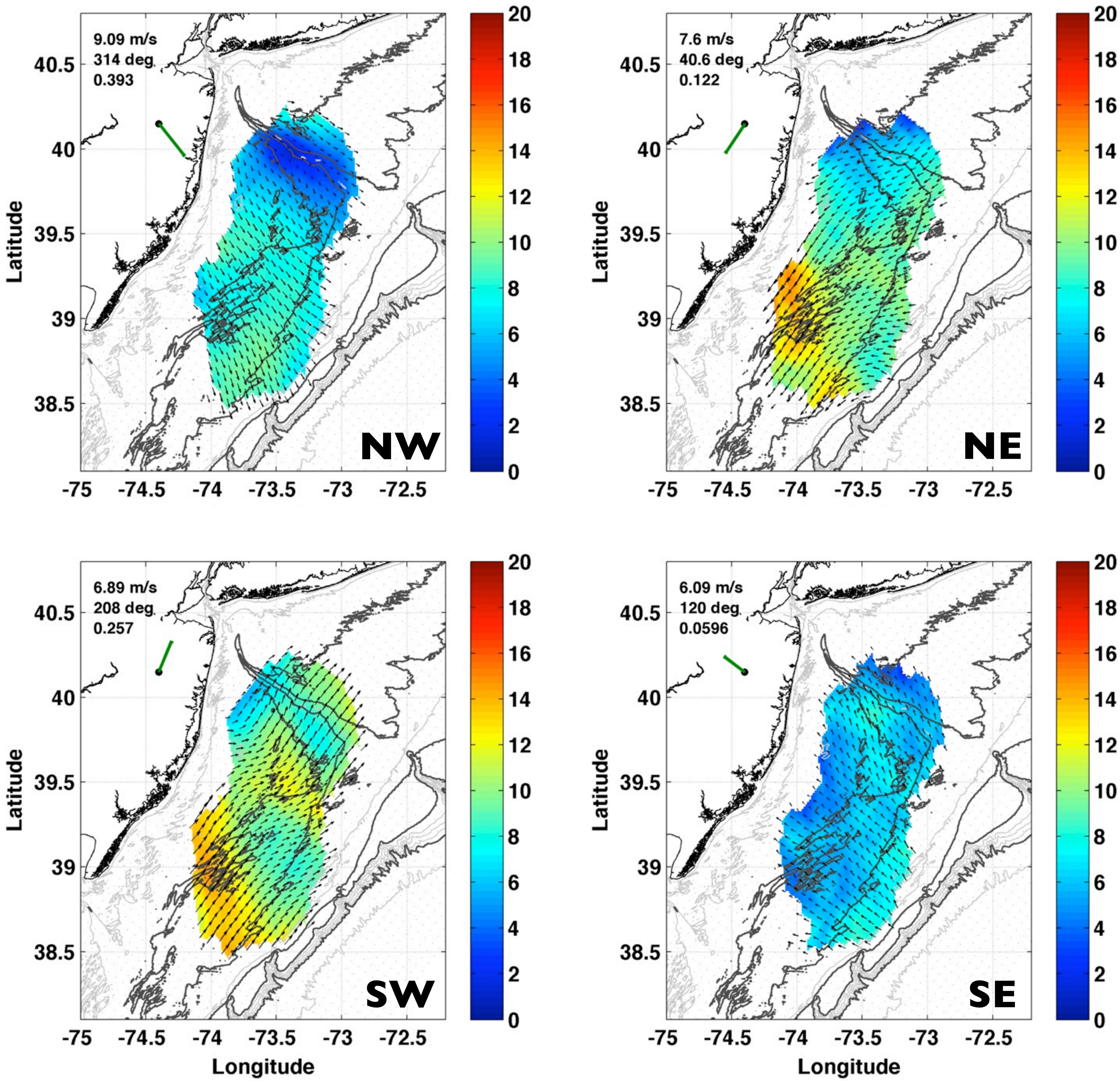


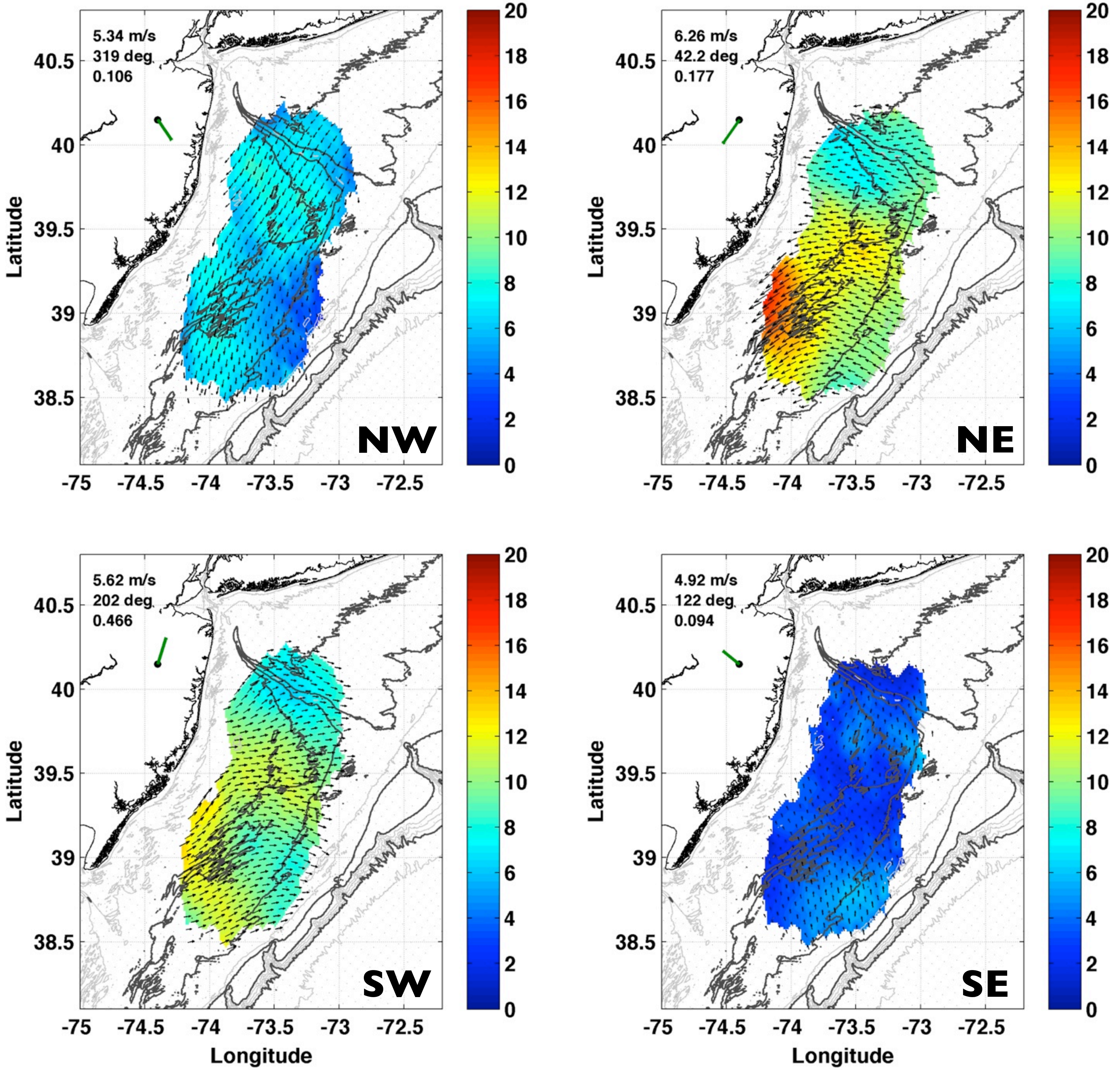
Table 4. Cross-shelf drifter time (days), speed (km/wk) and fraction reaching 60 m isobath

Drifter Time	Jun 06	Sep 06	Dec 06	Mar 07	Dist to 60m
Site N	13.6	30.7	23.9	36.1	97
Site C	13.3	20.5	17.4	24.8	82
Site S	12.9	13.1	14.9	27.6	67
Drifter Speed	Jun 06	Sep 06	Dec 06	Mar 07	Dist to 60m
Site N	49.9	22.1	28.4	18.8	97
Site C	43.2	28.0	33.0	23.1	82
Site S	36.4	35.8	31.5	21.4	67
Fraction to 60m	Jun 06	Sep 06	Dec 06	Mar 07	Dist to 60m
Site N	0.27	0.09	0.73	0.39	97
Site C	0.68	0.17	0.99	0.71	82
Site S	0.77	0.25	1.00	0.45	67

Mean Current based on Wind (Winter)



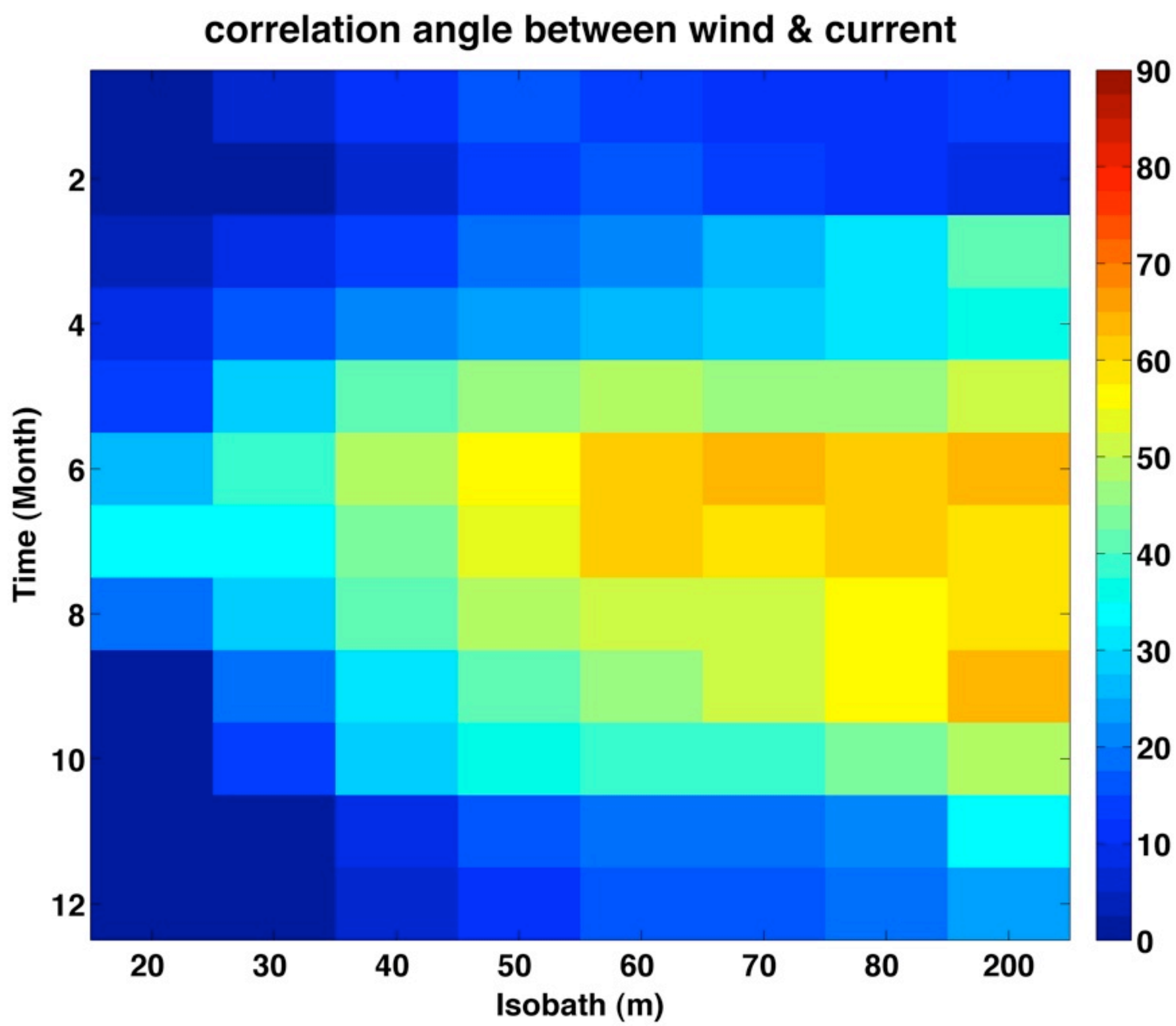
Mean Current based on Wind (Summer)



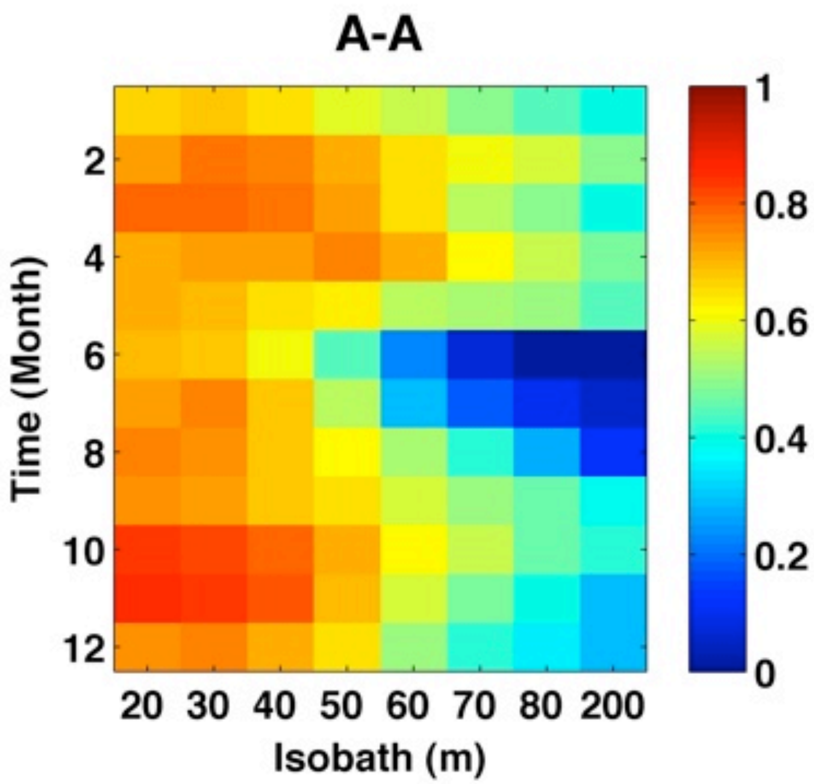
Wind-Current correlation & variability

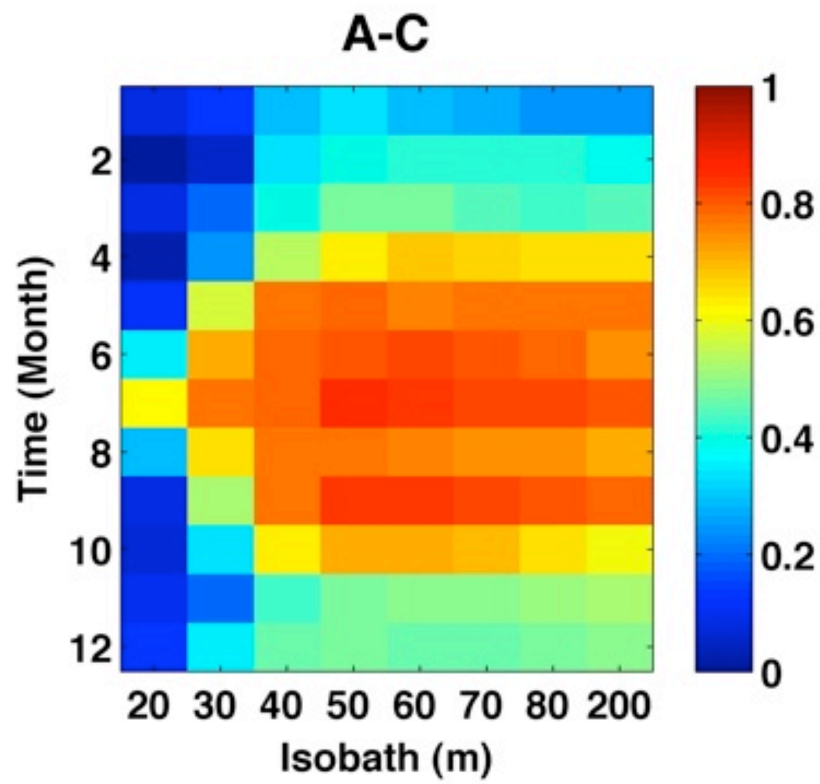
Table 3. Relative Variability of detided CODAR currents: R.M.S. / Mean

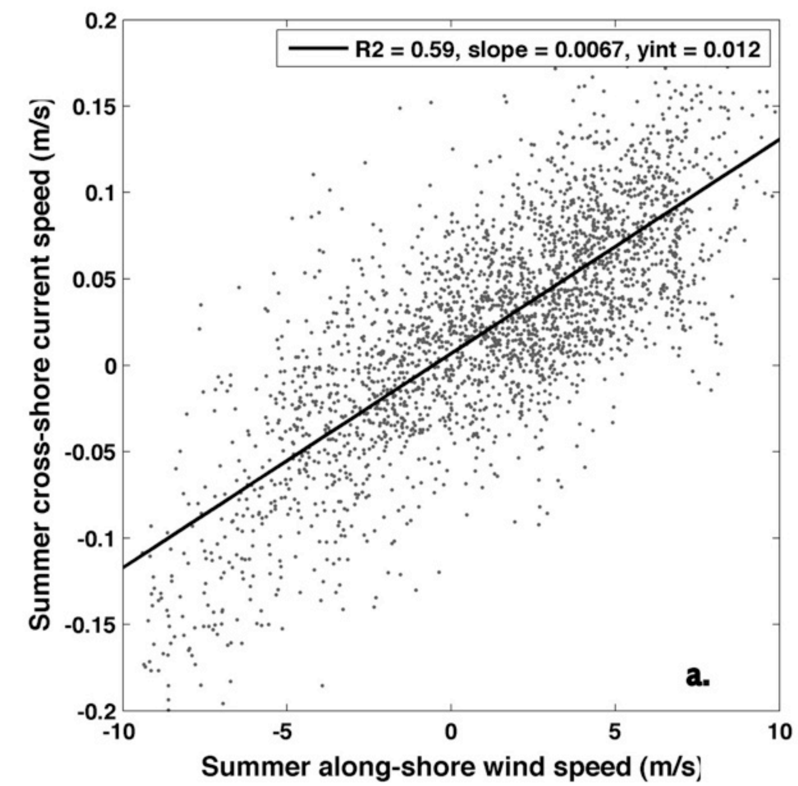
RMS/Mean	Summer	Winter	Spring	Autumn	All
All Dir.	4.9	2.6	3.0	3.0	3.3
NW	1.9	1.4	1.4	1.6	1.6
NE	1.3	0.9	0.9	1.1	1.1
SW	1.7	1.7	1.8	1.8	1.8
SE	6.8	1.8	3.7	3.0	3.5

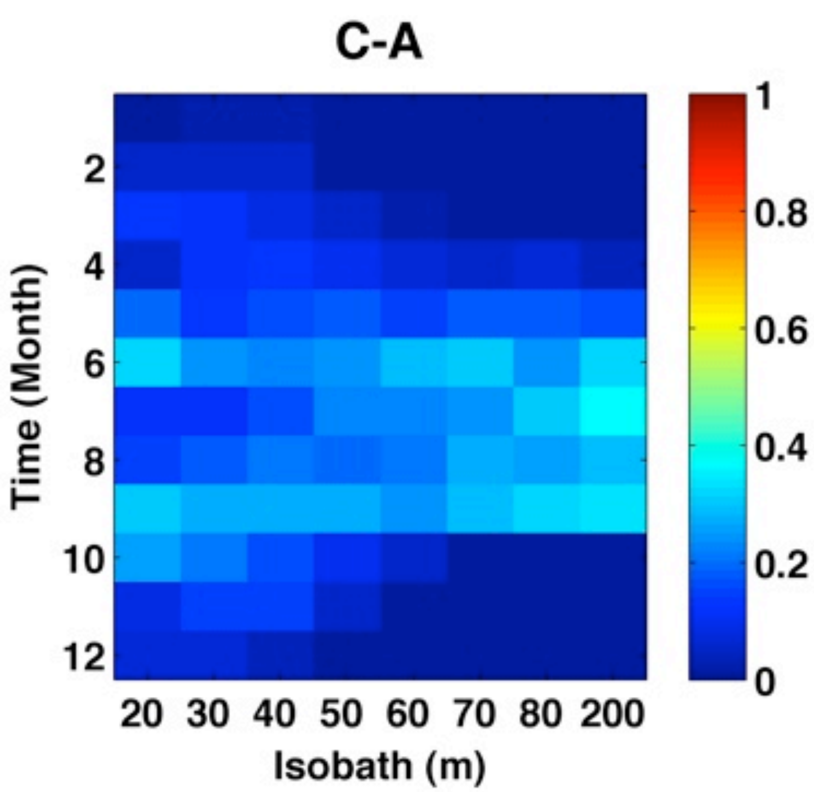


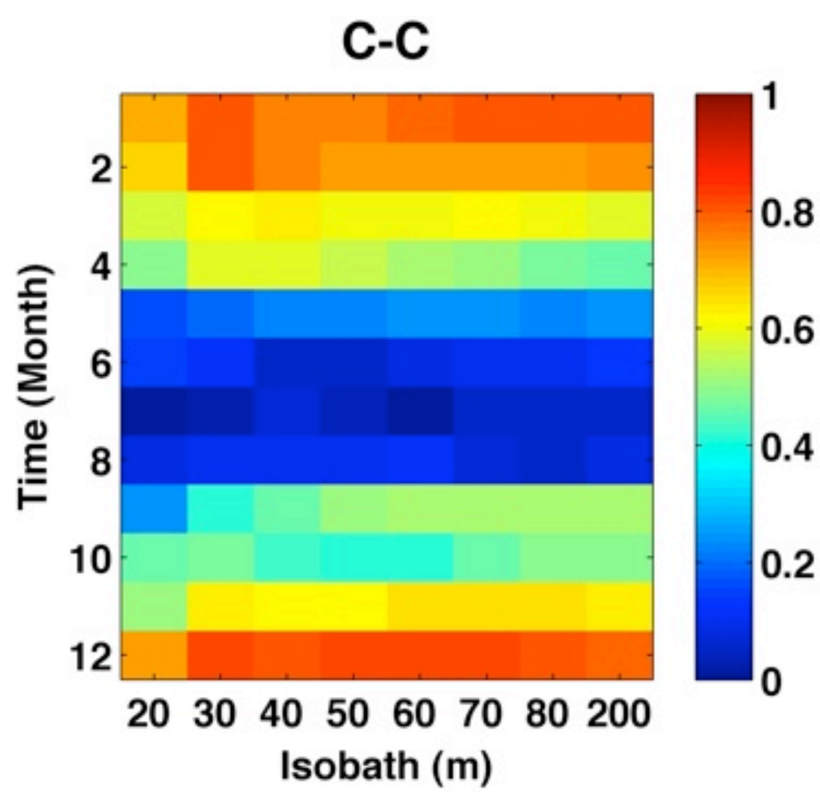
Cross-correlation of Wind and Current (along Geographic Axes)

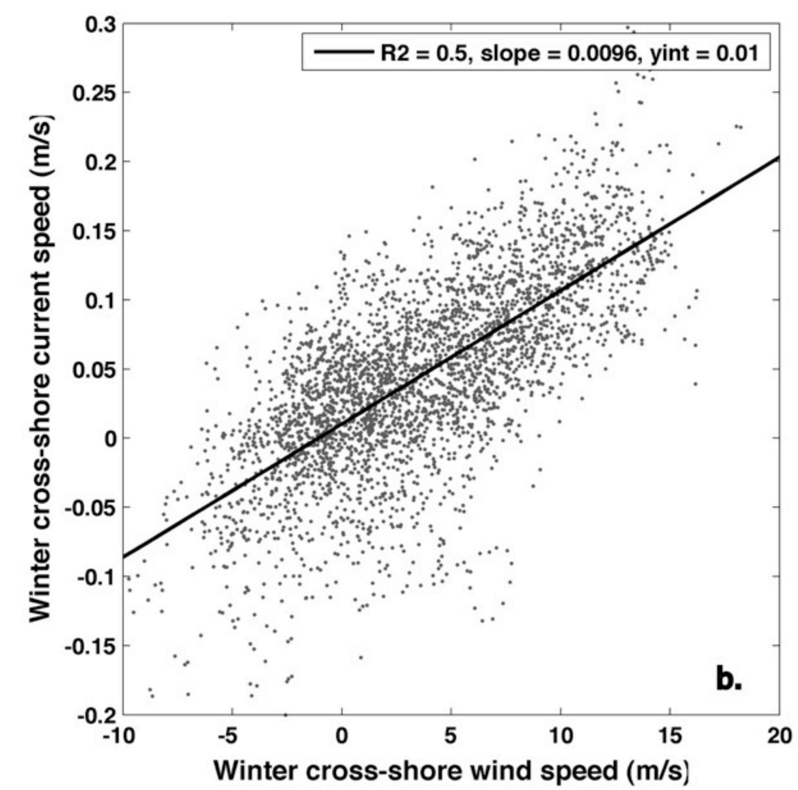








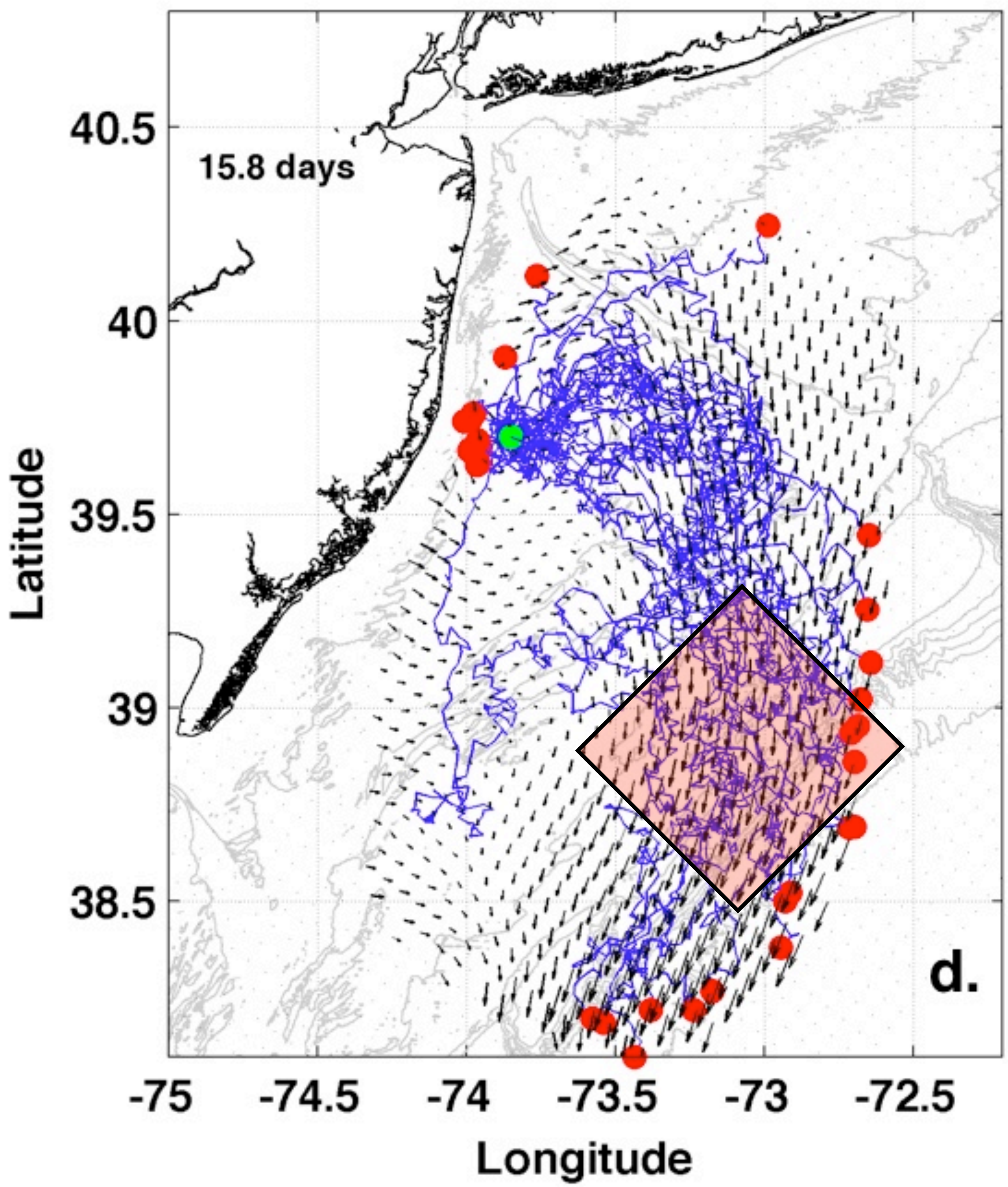




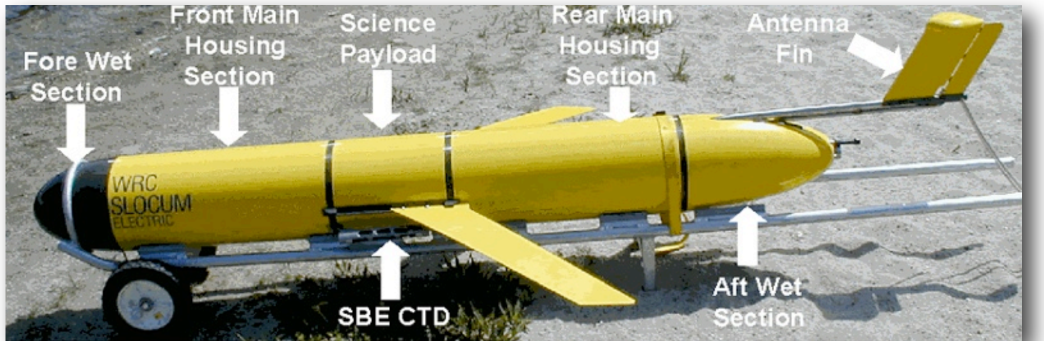
shelf surface flow summary

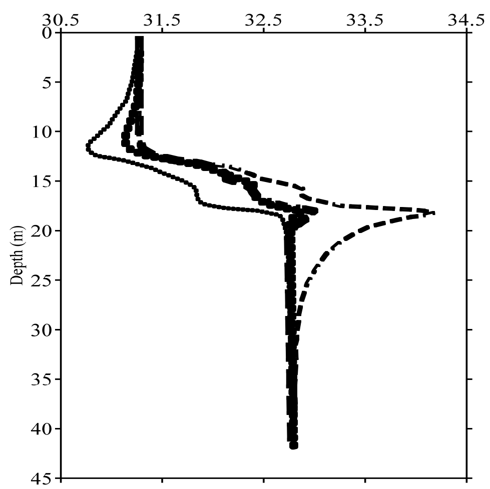
- Downshelf, offshore mean surface flow. Significant variability about the mean.
- Background flow under low wind conditions is consistent with previous MAB shelf observation/models. HSV influences downshelf flow behavior.
- Flow mainly cross-shelf (offshore) during stratified and mixed seasons, and mainly along-shelf (downshelf) during transition seasons. the residence time is on the order of 1-5 weeks.
- Surface flow is wind driven. Along-shore wind and cross-shelf flow is strongly correlated in summer, cross-shore winds and cross-shelf flow is strongly correlated in winter.

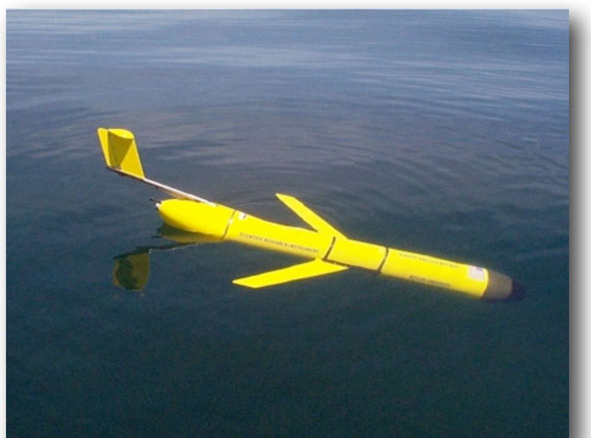
Summer 2006

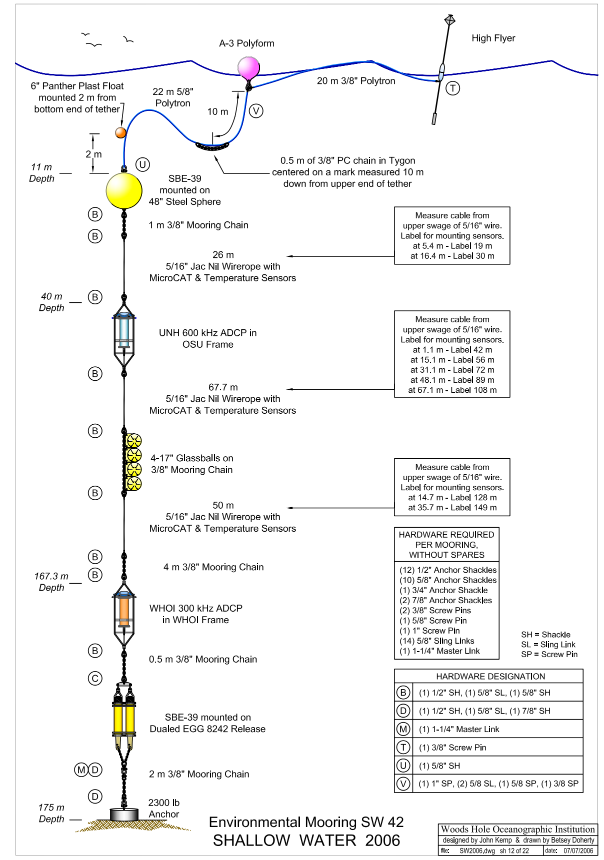

15.8 days
d.
Latitude
40.5
40
39.5
39
38.5
Longitude
-75
-74.5
-74
-73.5
-73
-72.5

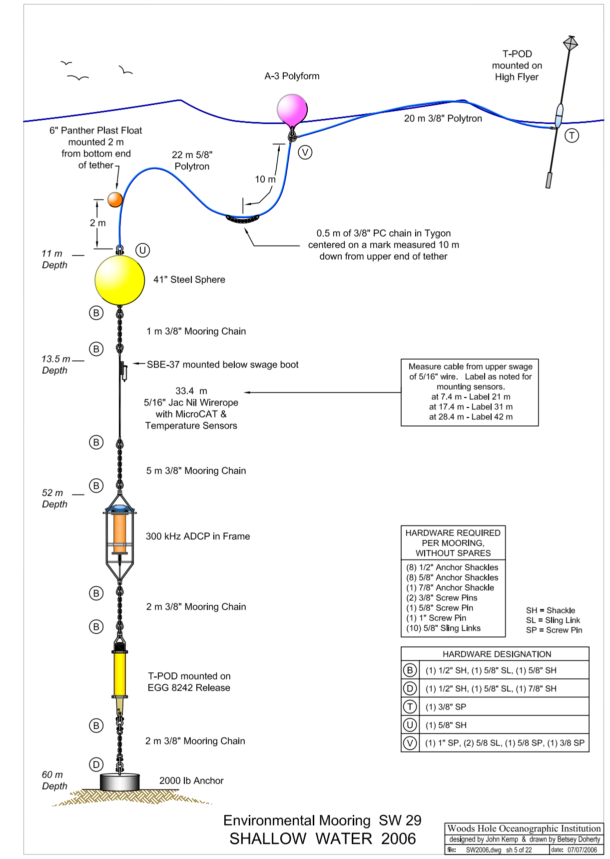
Gliders & Moorings (SW06)

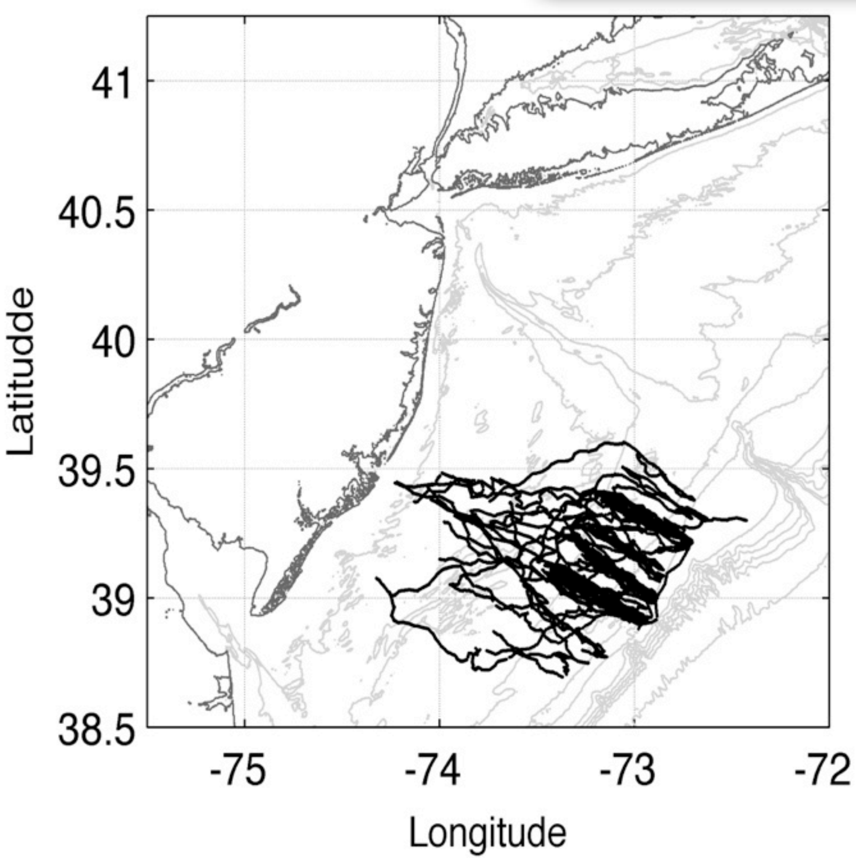




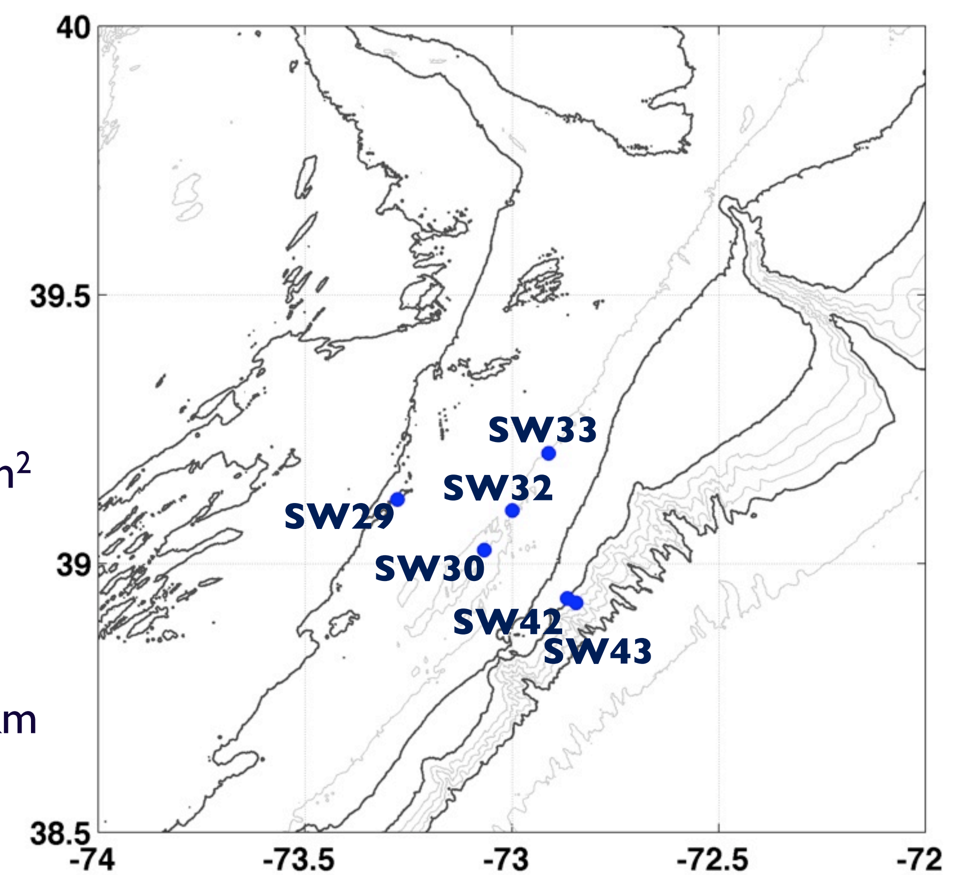


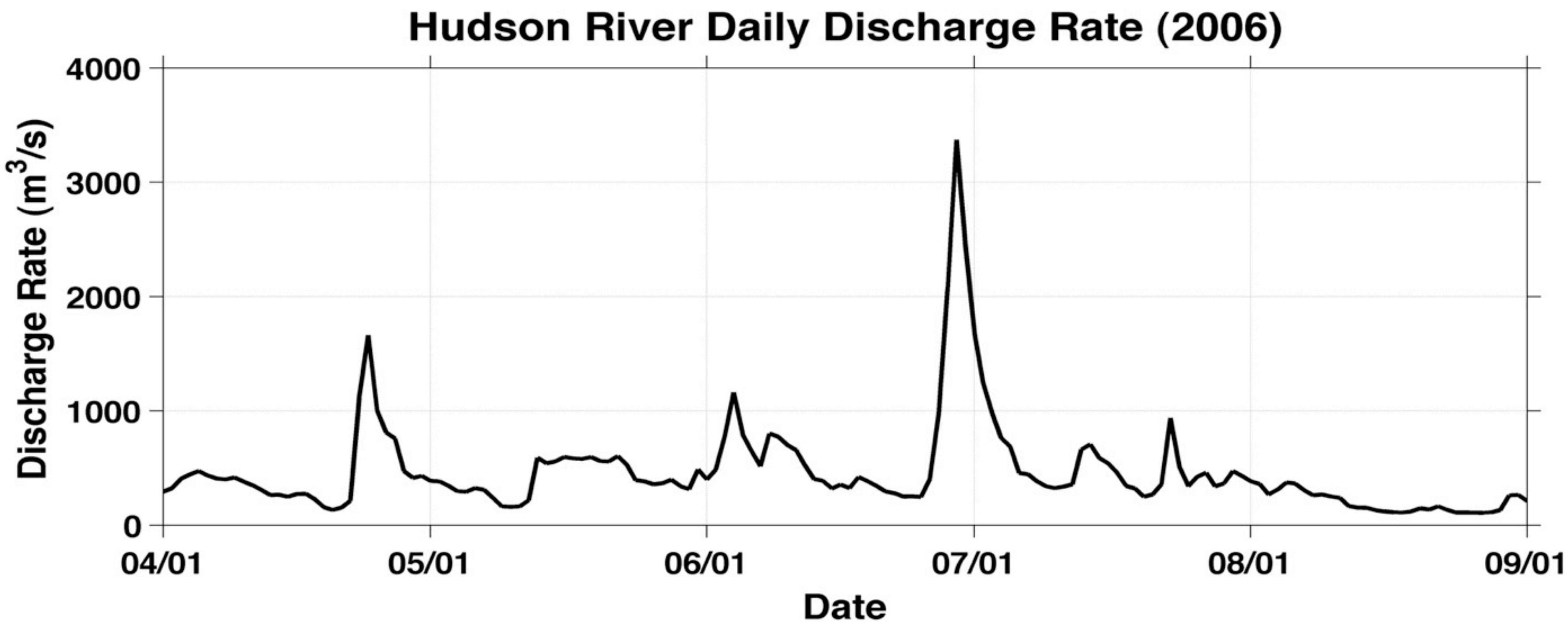


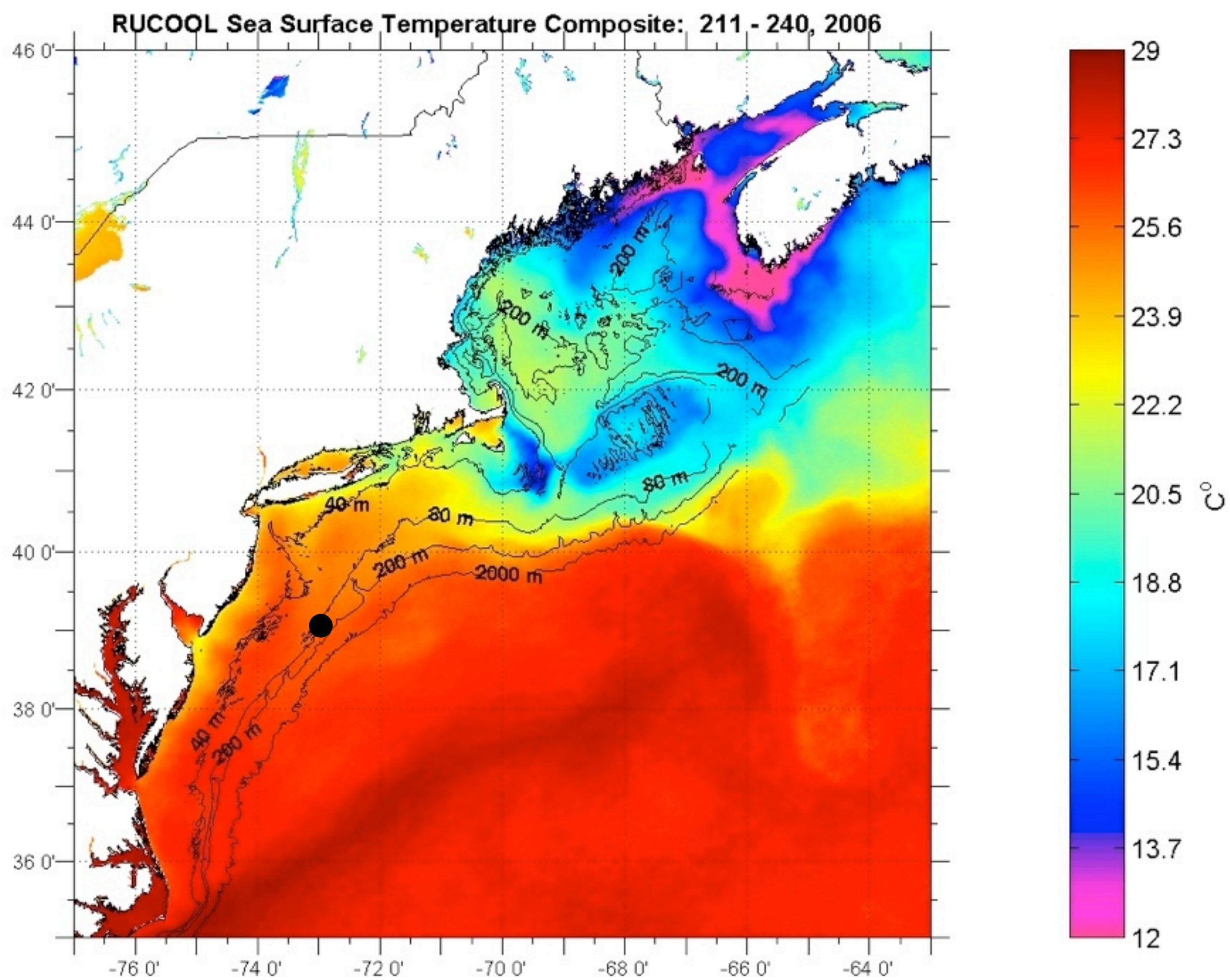


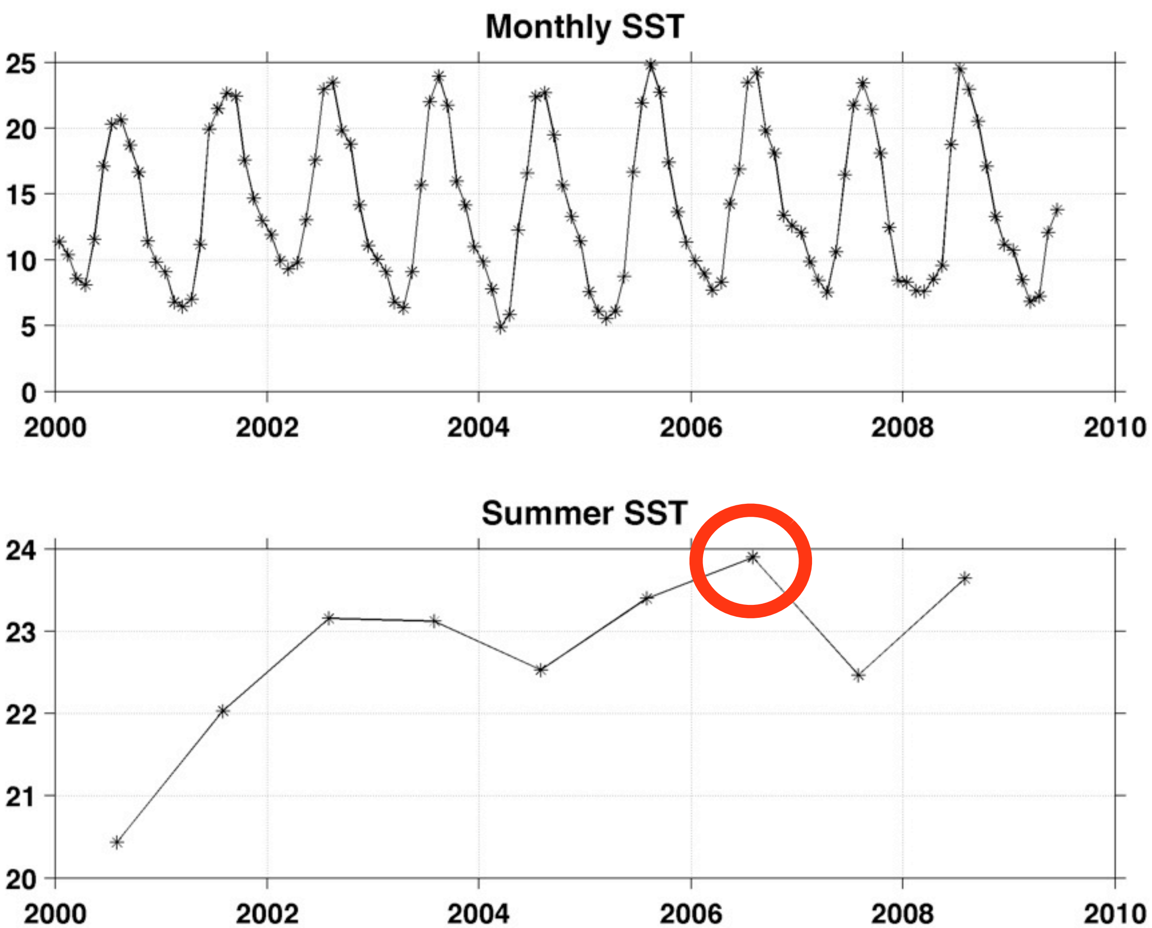


- Hi-res. oceanographic sampling of the outershelf using gliders, moorings, ships (July 19 - Oct 2, 2006)
- South of Hudson Canyon, 100 × 100 km^2 between 30 & 100 m isobaths
- 17 deployments, 356 glider days, 6683 km flown, 51933 CTD casts



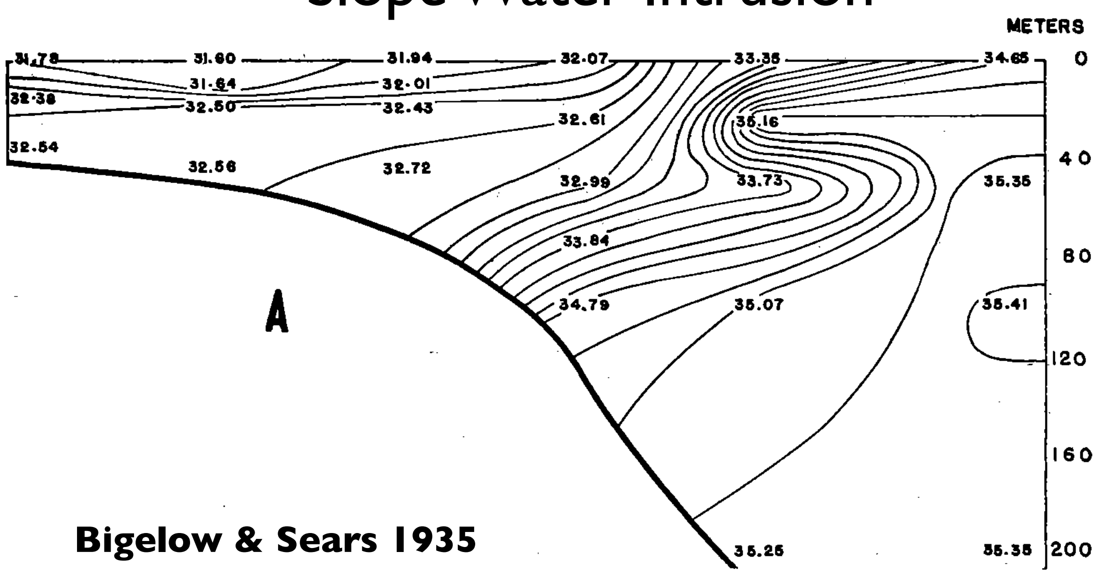

Hudson River Daily Discharge Rate (2006)
Discharge Rate (m3/s)
4000
3000
2000
1000
0
04/01
05/01
06/01
07/01
08/01
09/01
Date


RUCOOL Sea Surface Temperature Composite: 211 - 240, 2006
46 0'
44 0'
42 0'
40 0'
38 0'
36 0'
-76 0'
-74 0'
-72 0'
-70 0'
-68 0'
-66 0'
-64 0'
200 m
40 m
80 m
2000 m
29
27.3
25.6
23.9
22.2
20.5
18.8
17.1
15.4
13.7
12
C°

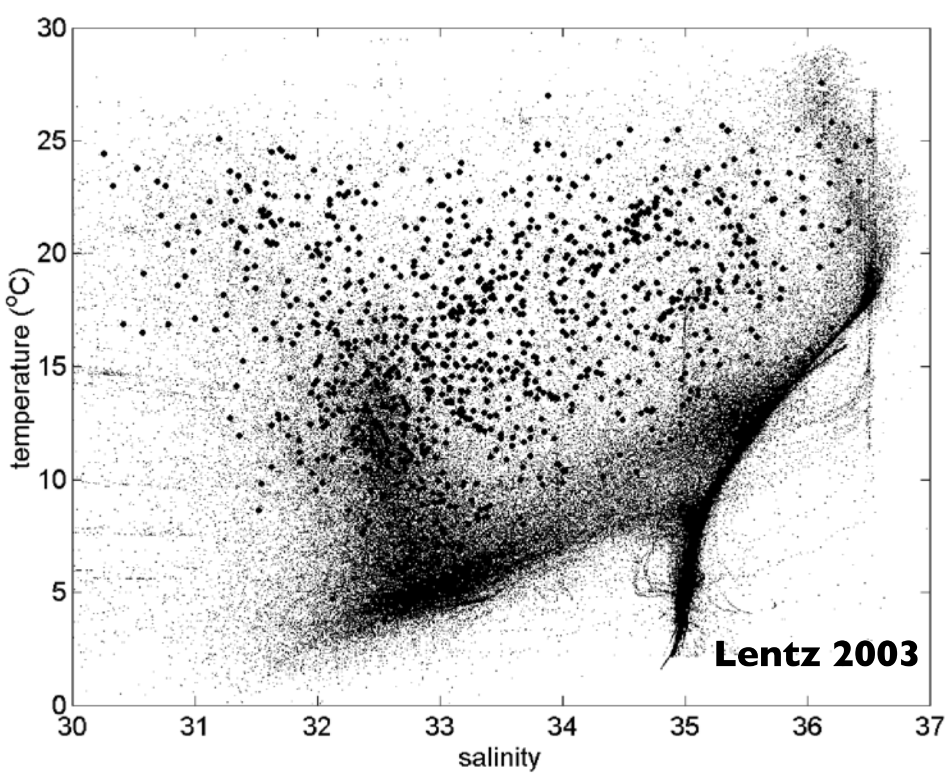

Monthly SST
25
20
15
10
5
0
2000
2002
2004
2006
2008
2010
Summer SST
24
23
22
21
20
2000
2002
2004
2006
2008
2010

Processes affecting shelf-slope exchange

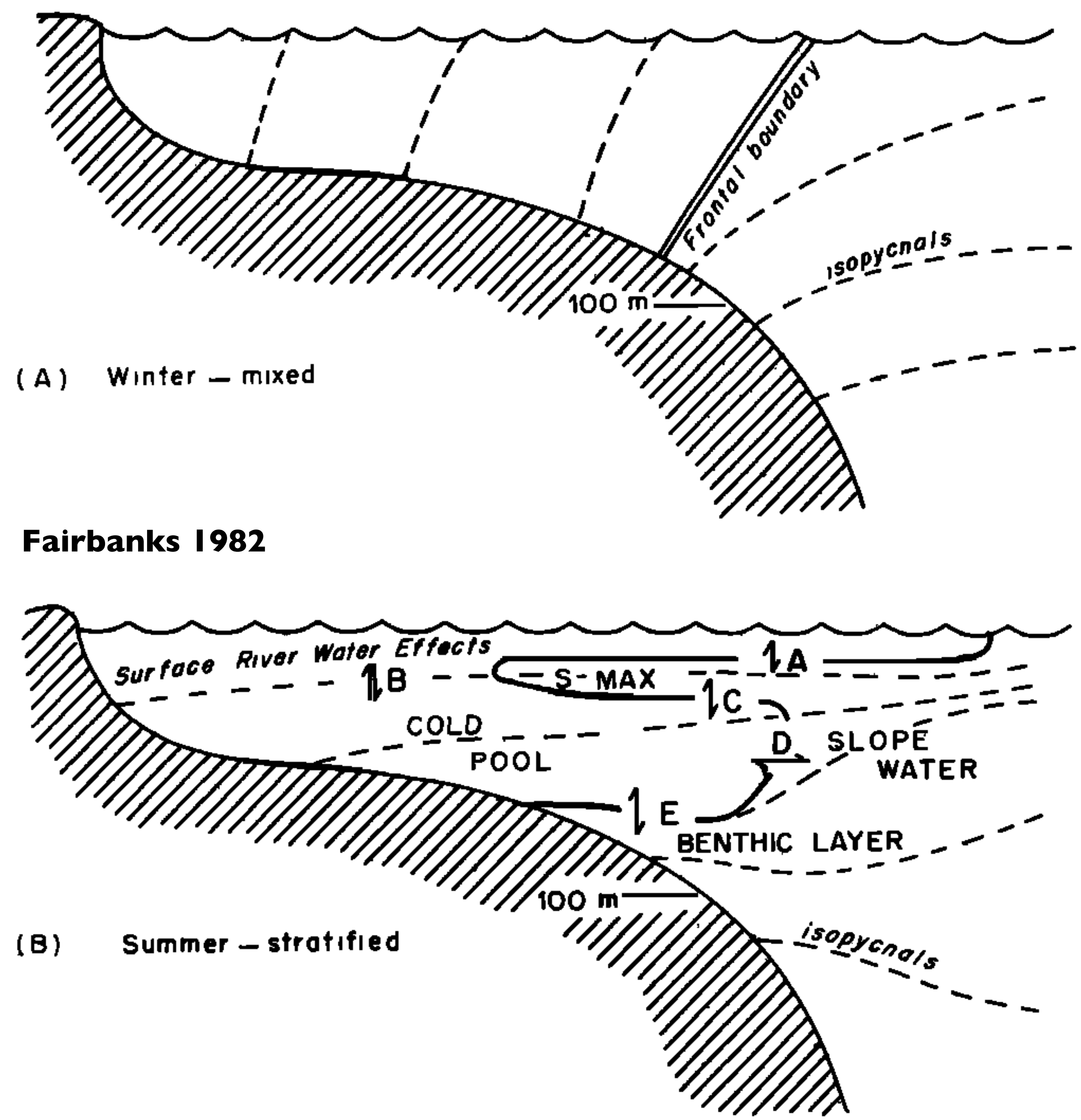
Slope Water Intrusion



Bigelow & Sears 1935

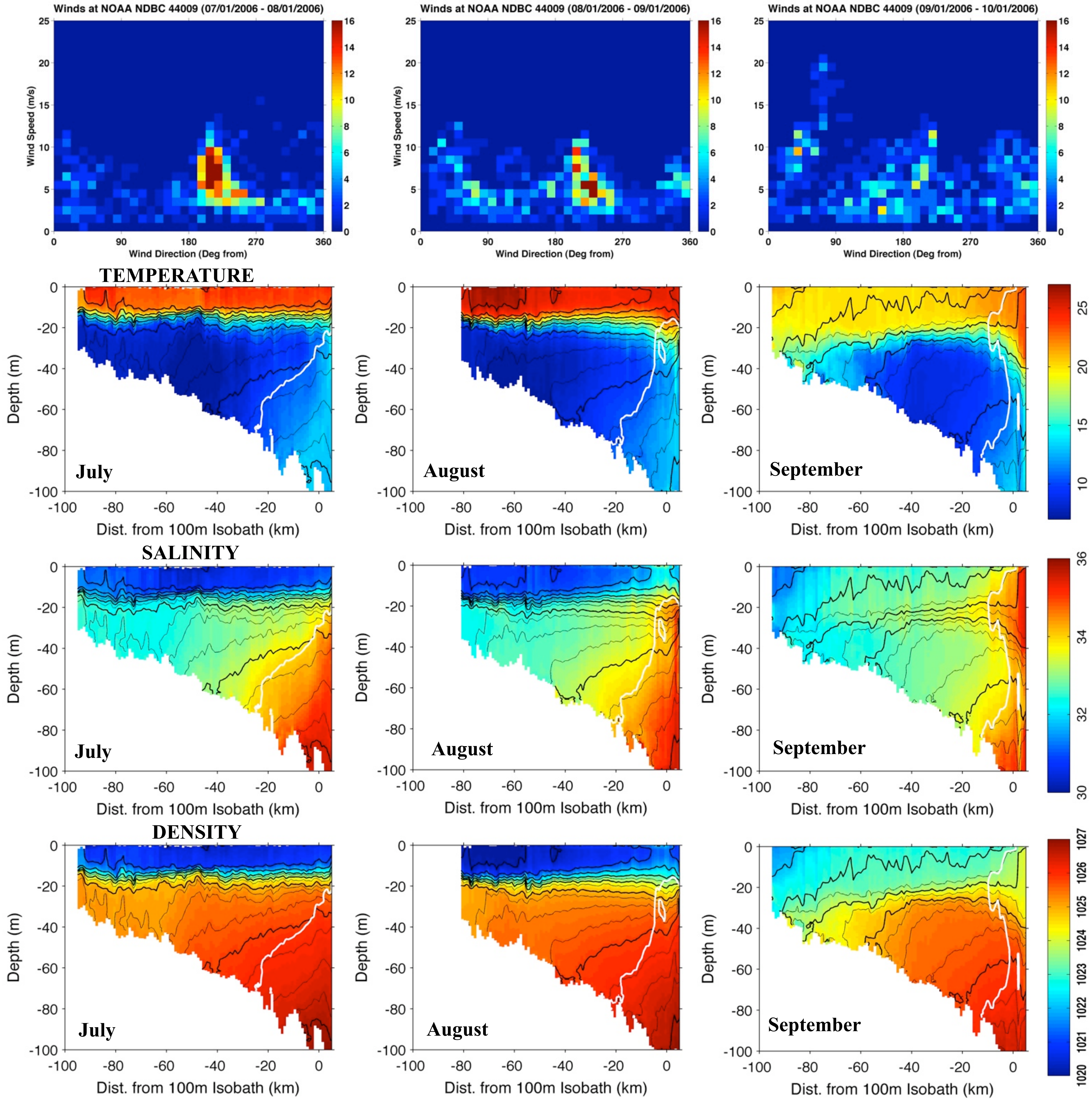


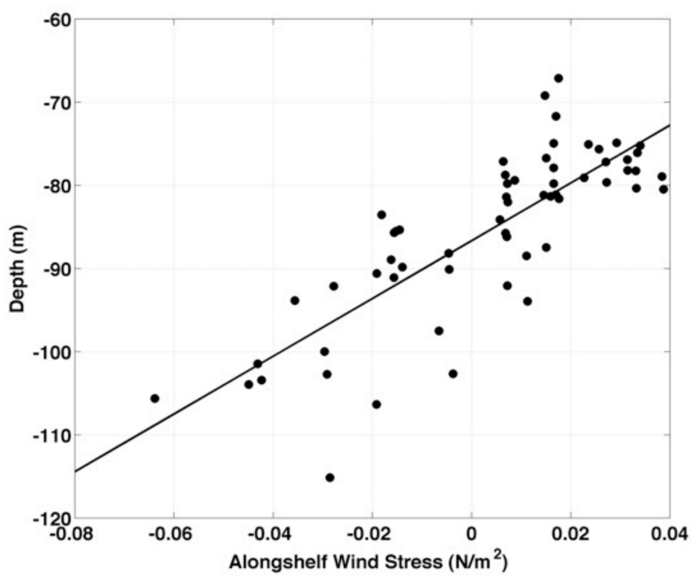
Lentz 2003



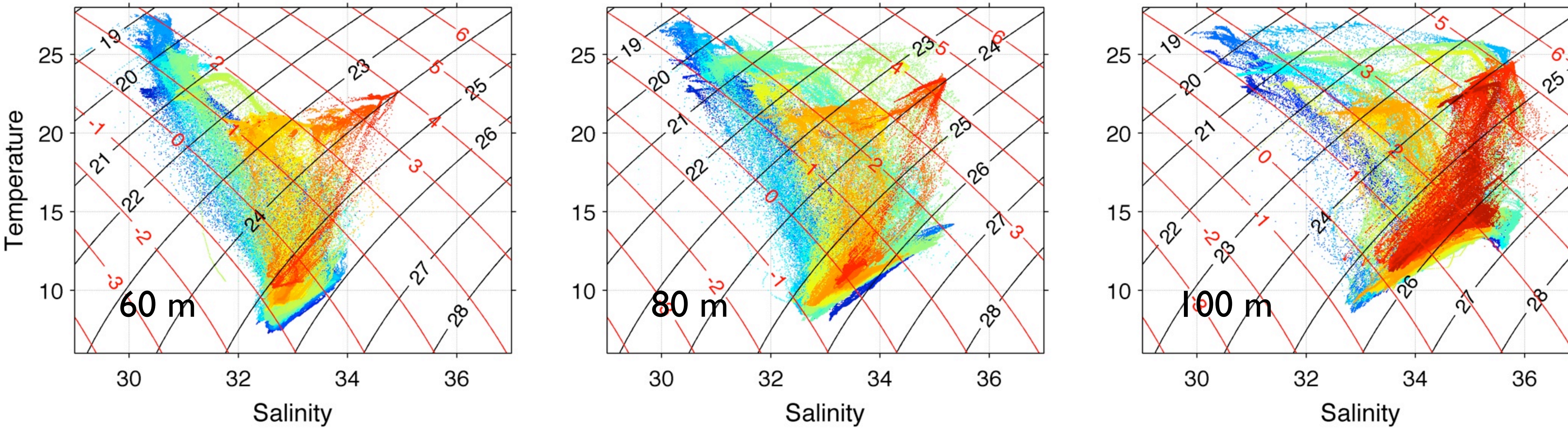
Fairbanks 1982

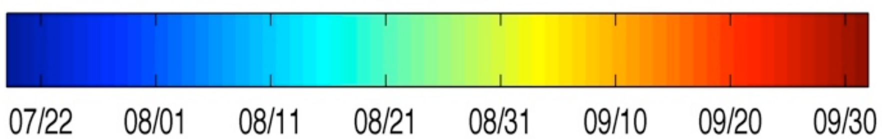
NJ Shelf Winds and Hydrography (2006)





Location of the foot of the shelf-slope front vs. alongshelf wind stress for summer 2006 on NJ Shelf





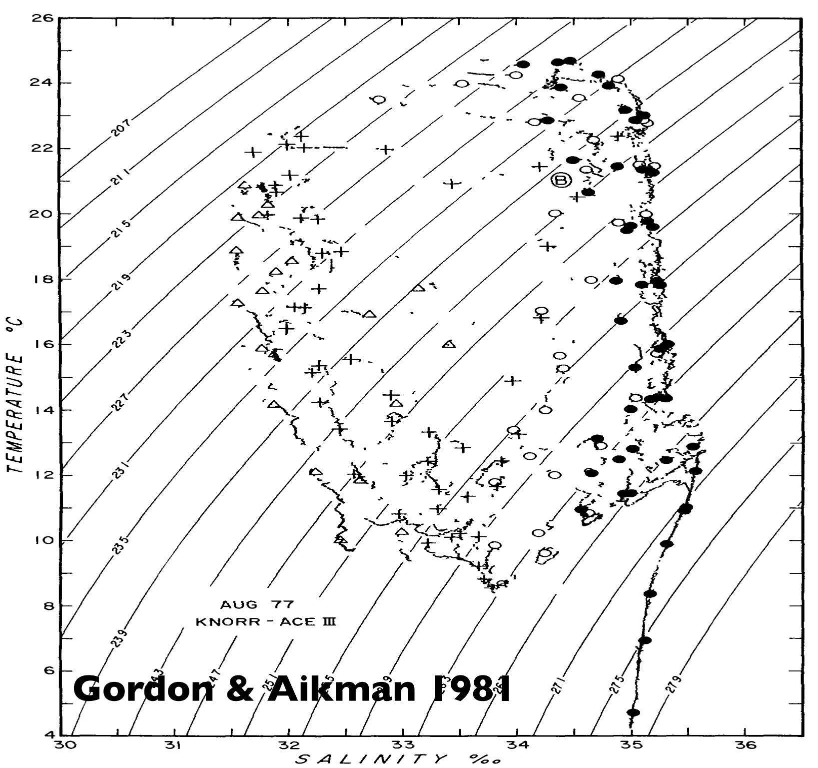
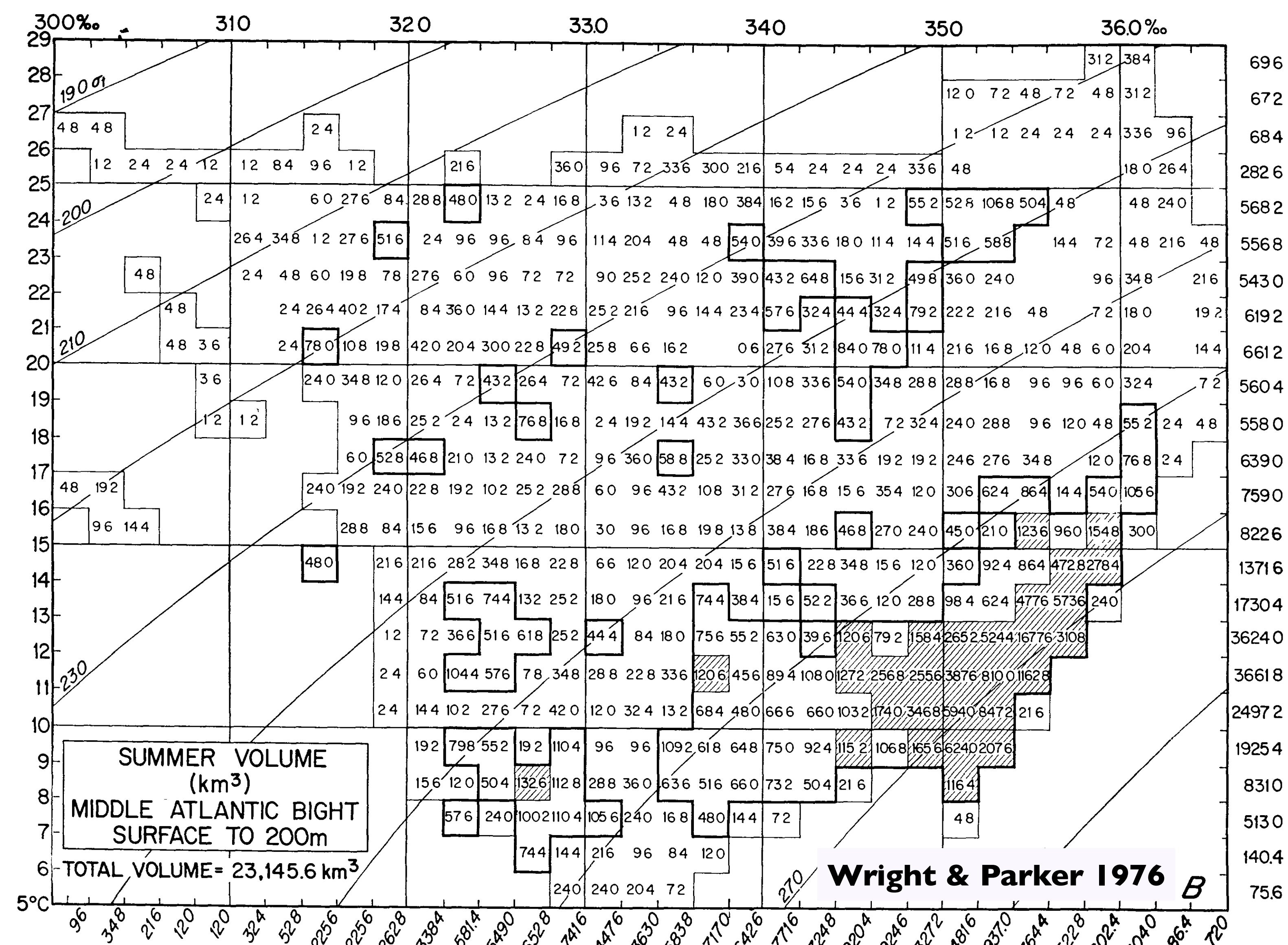
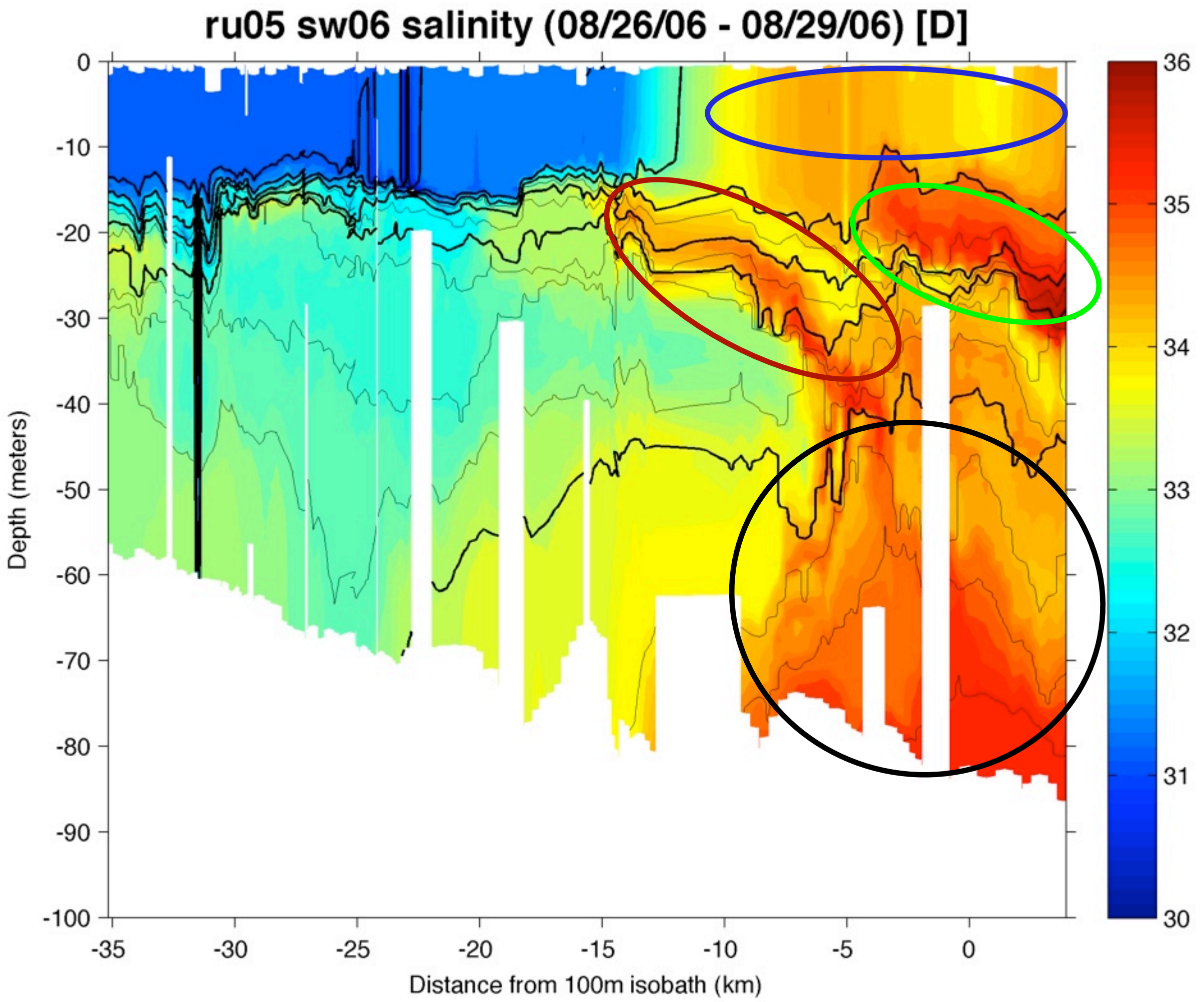
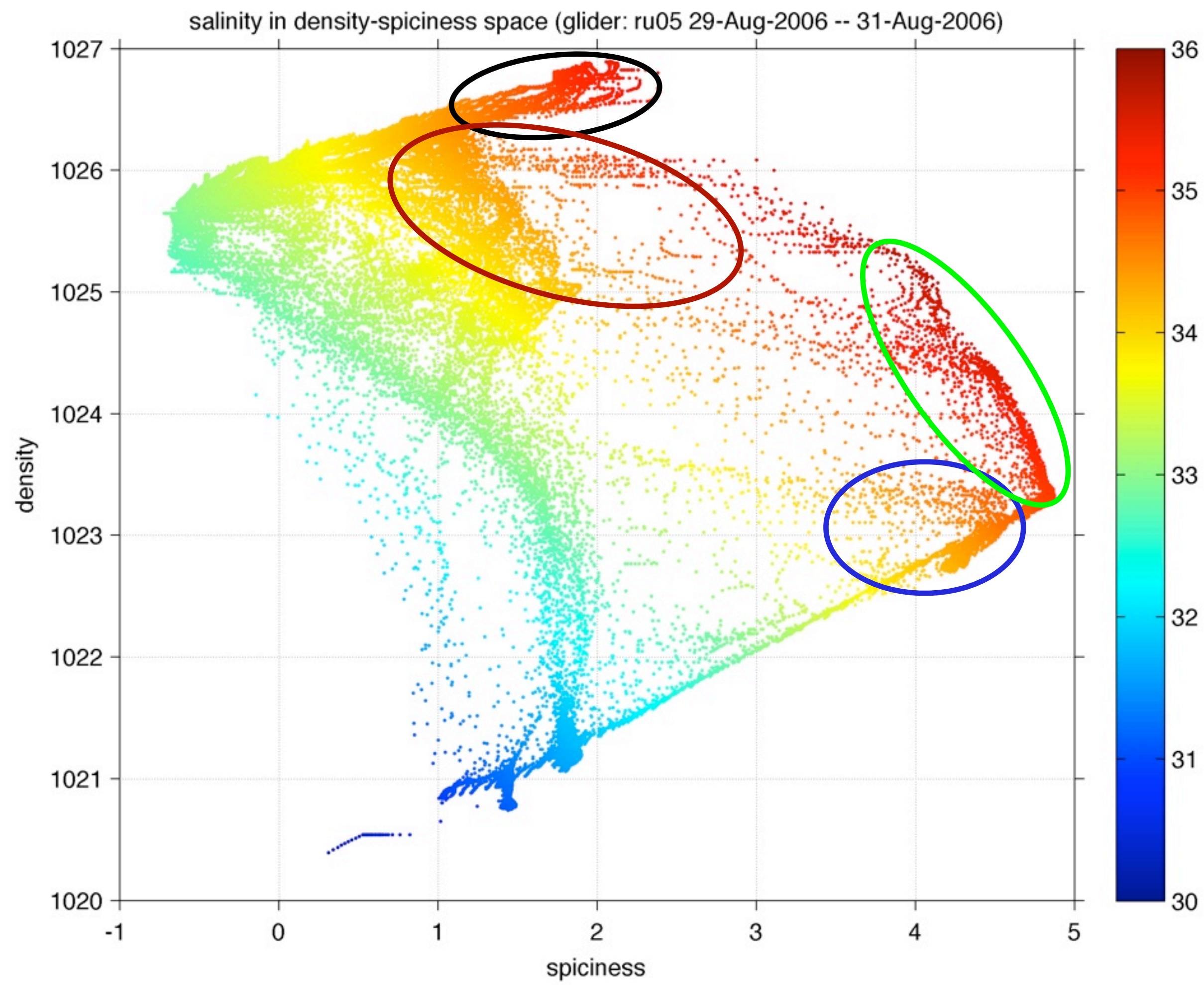


Fig. 6. As Fig. 3, but for August 1977, *Knorr* ACE III. (B—Pycnocline *S*-max.)







Surface: $S \geq 34$, den ≤ 1024, no $S < 34$ water in the upper 5 meters

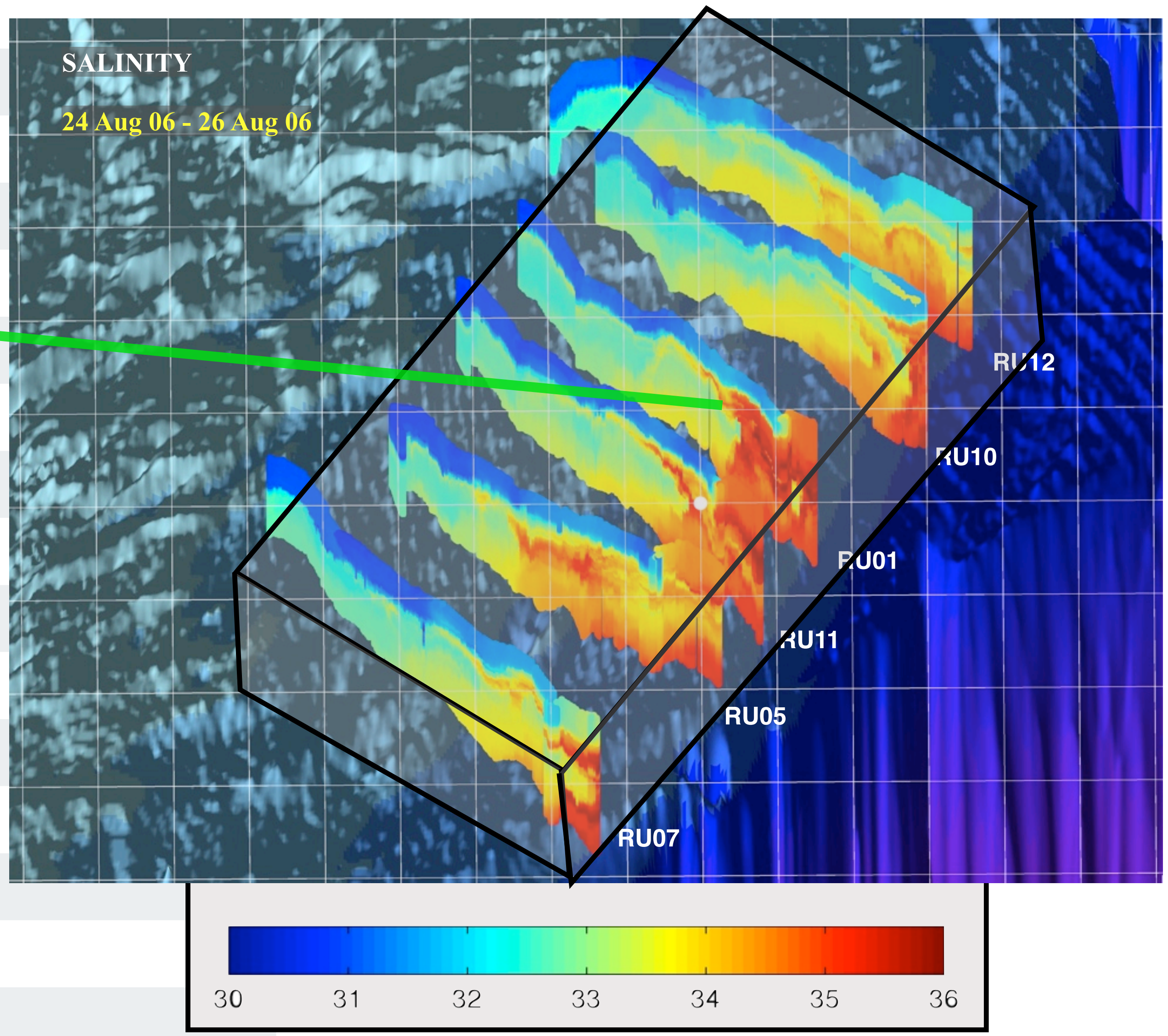
Pycnocline: $S \geq 34$, $1022 \leq$ den ≤ 1025.7, spiciness > 3.4, $z \leq -10$m

Sub-Pycnocline: $S \geq 34$, $1024.5 \leq$ den ≤ 1026.2, $1 \leq$ spiciness ≤ 3.2

Bottom: $S \geq 34$, $1026.2 \leq$ den, $0.5 \leq$ spiciness ≤ 3

Outershelf Salt Budget

Intrusion Salt Budget	
Intrusion Types	Salt Fraction
Aug 24-26 Sect.	
Surface	0.025
Pycnocline	**0.135**
Sub-pycnocline	**0.153**
Bottom	0.612
Slope/Total	0.36
Mean SLW Salinity	34.73
Aug Avg. 2D	
Surface	negl.
Pycnocline	negl.
Sub-pycnocline	0.13
Bottom	0.79
Slope/Total	0.26
Mean SLW Salinity	34.57



Definitions:

Surface: $S \geq 34$, den ≤ 1024, no $S < 34$ water in the upper 5 meters

Pycnocline: $S \geq 34$, $1022 \leq$ den ≤ 1025.7, spiciness > 3.4, $z \leq -10$m

Sub-Pycnocline: $S \geq 34$, $1024.5 \leq$ den ≤ 1026.2, $1 \leq$ spiciness ≤ 3.2

Bottom: $S \geq 34$, $1026.2 \leq$ den, $0.5 \leq$ spiciness ≤ 3

Cross-shelf Salt Balance...

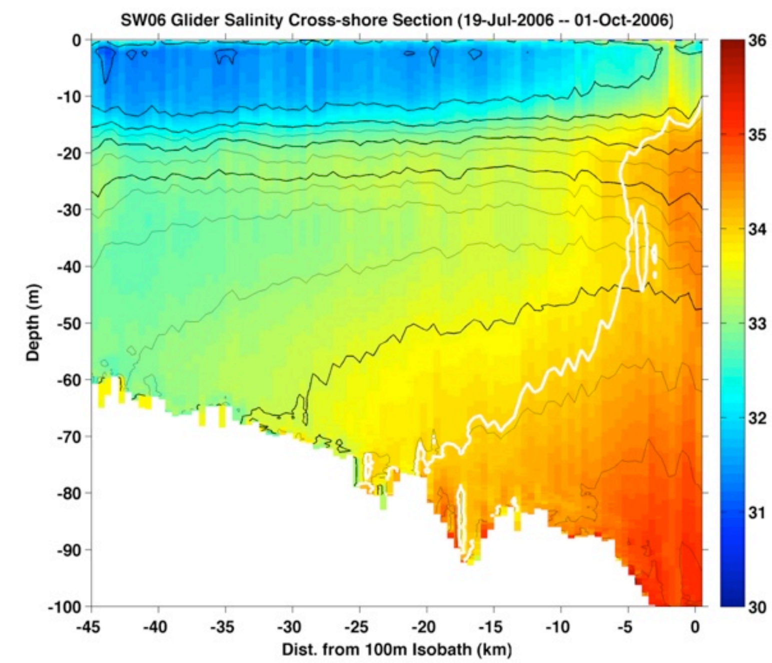
Salt advected offshore ≈ Salt 'diffused' onshore

$$\bar{U}\bar{S} = K\frac{d\bar{S}}{dx}$$

$$\bar{U} = \frac{\Delta VolTr_{sh}}{Area_{100}} = \frac{0.3\ Sv}{10^8\ m^2} = 0.003\ m/s \qquad \bar{S} = 33$$

$$\Delta VolTr_{sh} = TrN_{Flagg77/BB81} - TrS_{Biscaye94} \approx 0.5 - 0.2\ Sv = 0.3\ Sv$$

$$\bar{U}\bar{S} = 0.1\ m/s$$

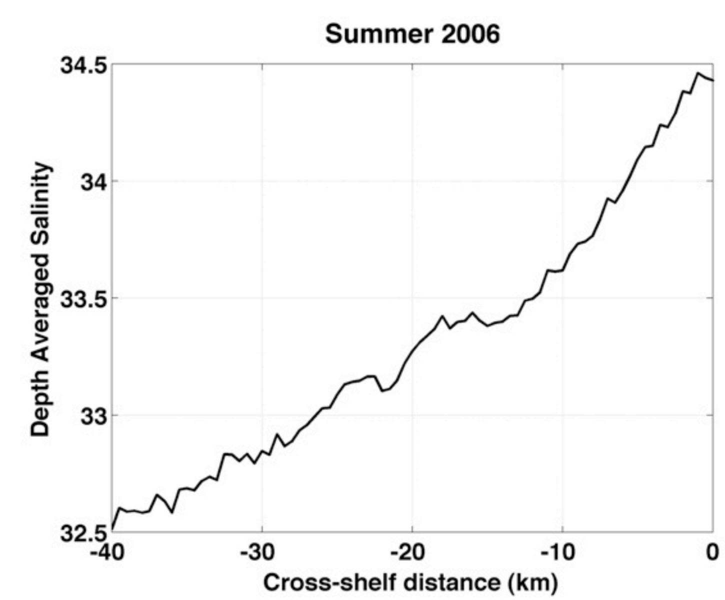


$$\frac{d\bar{S}}{dx} = \frac{1.0}{10\ km} = 10^{-4}\ m^{-1}$$

$$K_{Fischer80} \approx 3\times 10^5\ cm^2/s = 30\ m^2/s$$

$$K_{Stommel72} \approx 3\times 10^6\ cm^2/s = 300\ m^2/s$$

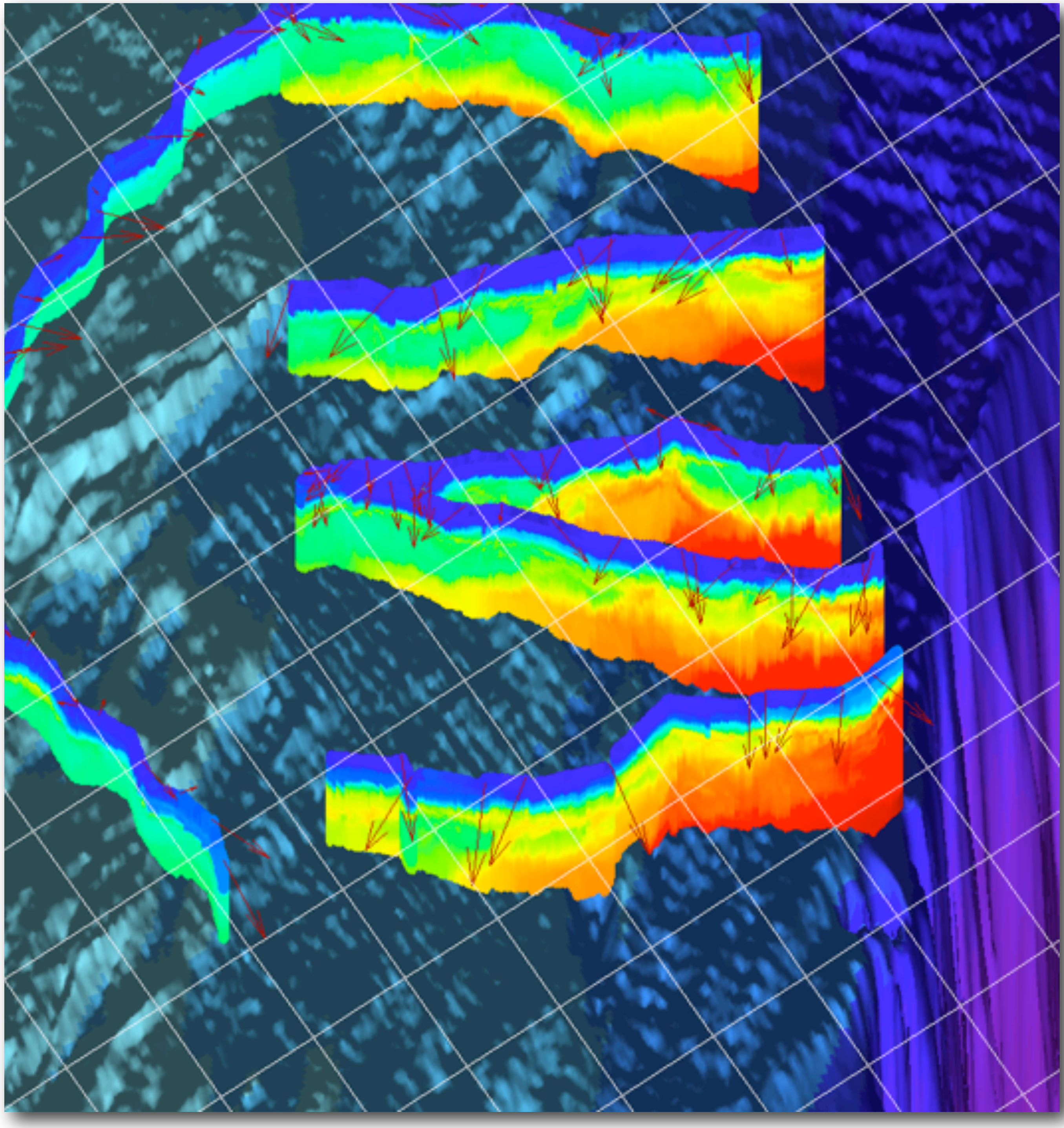
$$K\frac{d\bar{S}}{dx} \lesssim 0.03\ m/s$$

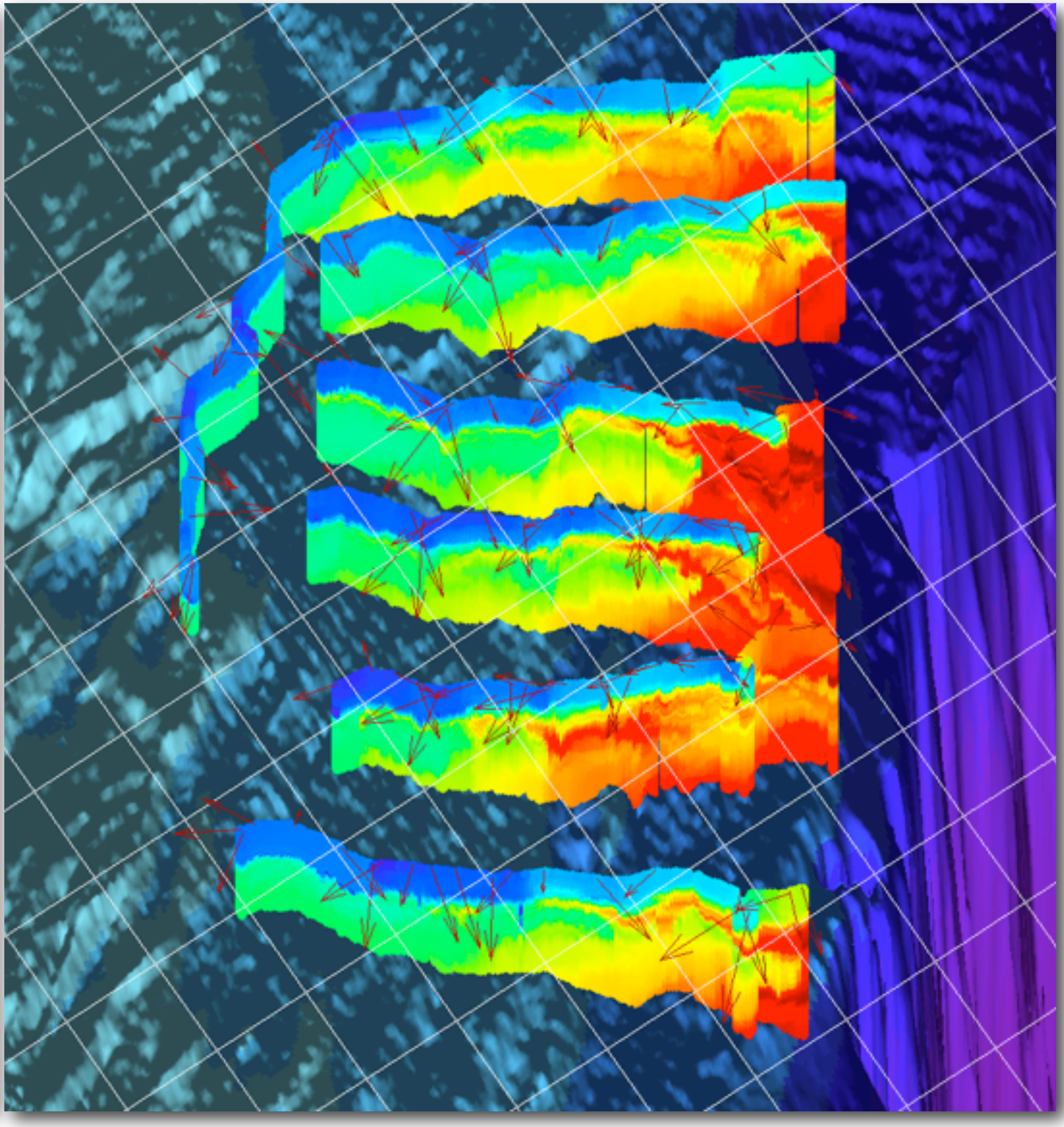


Slope water intrusions contribute up to 30% of the salt needed.

Weak Intrusion (Early Aug.)

Strong Intrusion (Late Aug.)



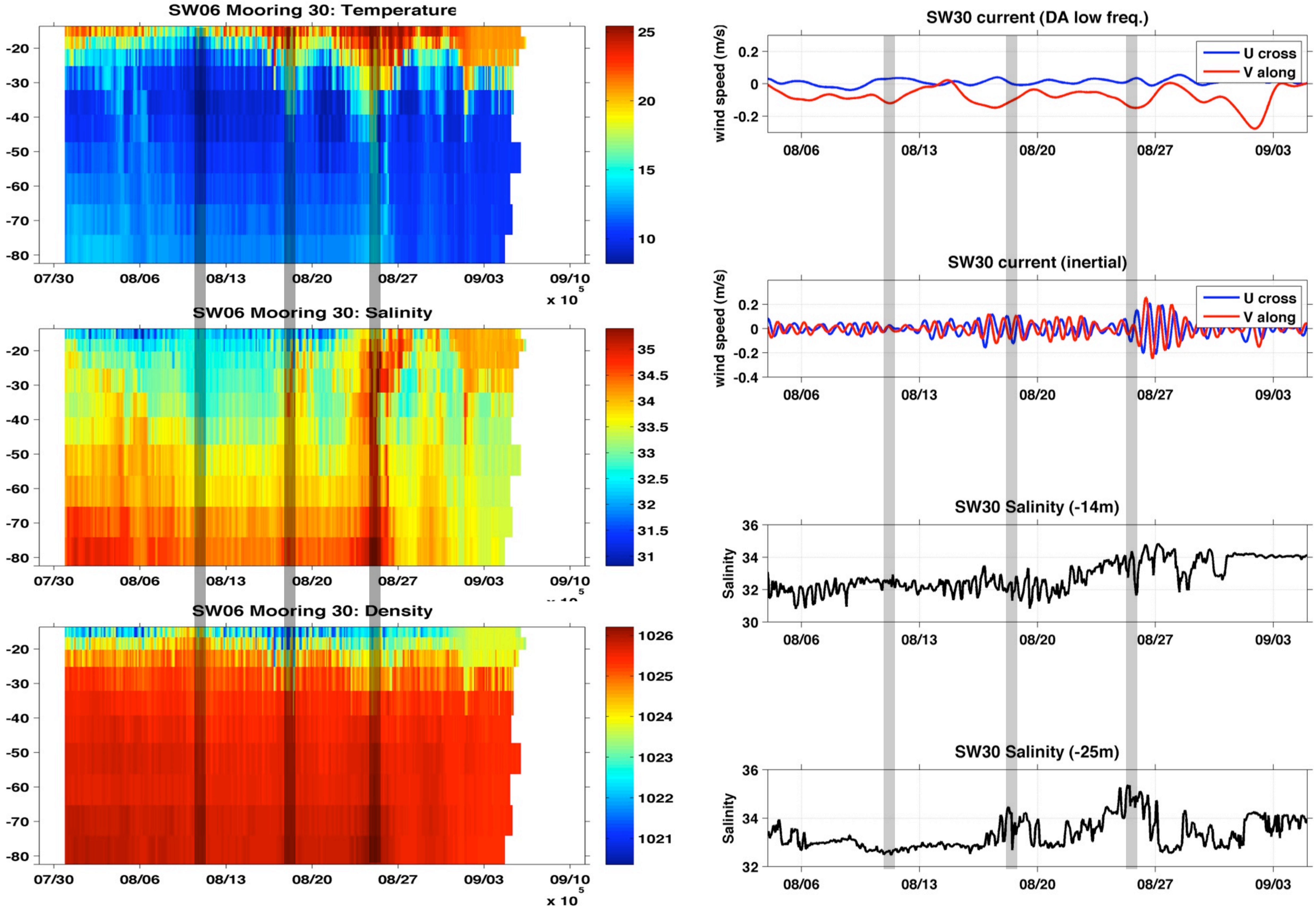


S = 33.19

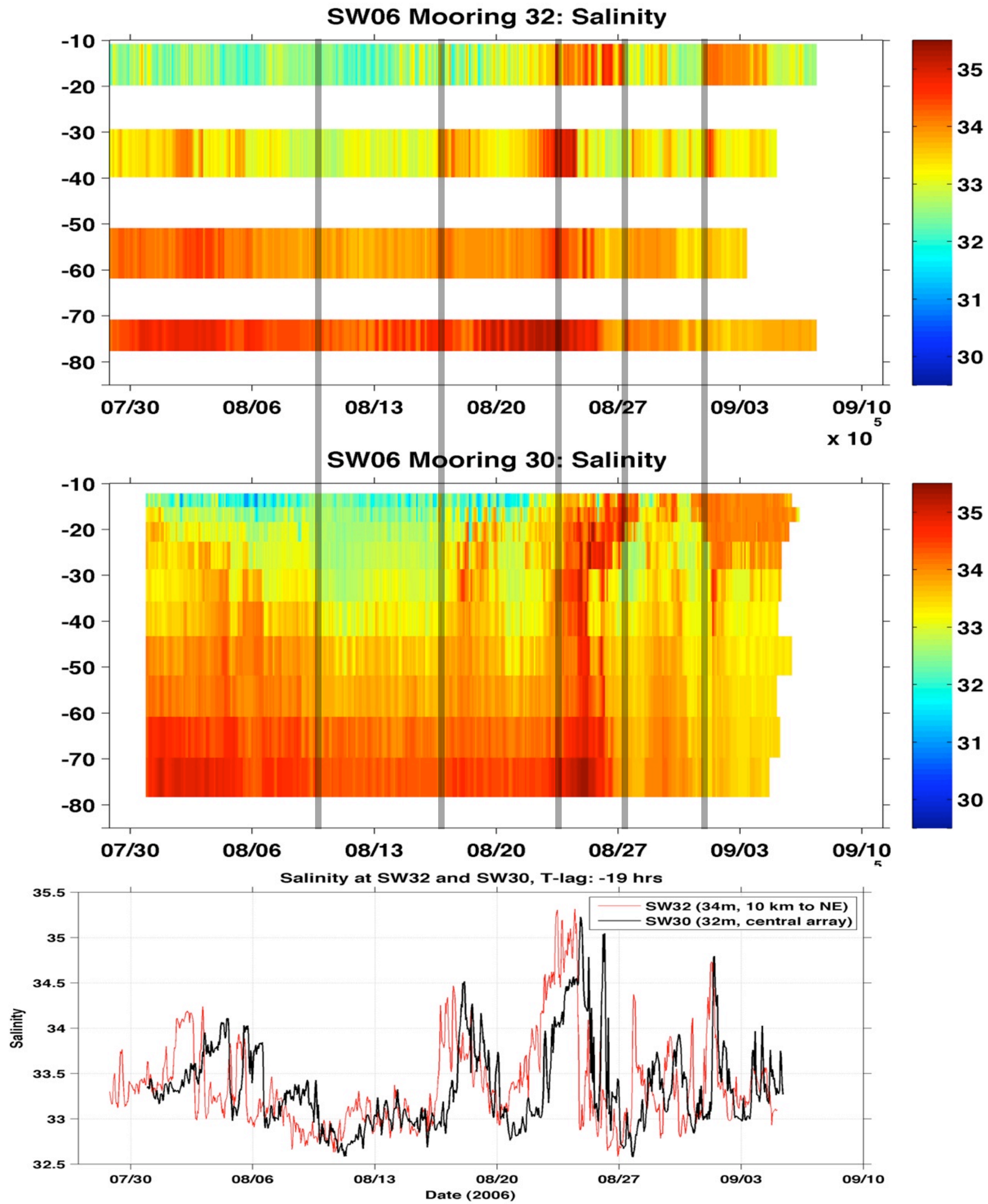
S = 33.35

$$\frac{dS_{Aug}}{dt} \times \frac{Vol}{Area_{100}} = 0.007\ m/s$$

$$\frac{dS_{Sep}}{dt} \times \frac{Vol}{Area_{100}} = 0.022\ m/s$$



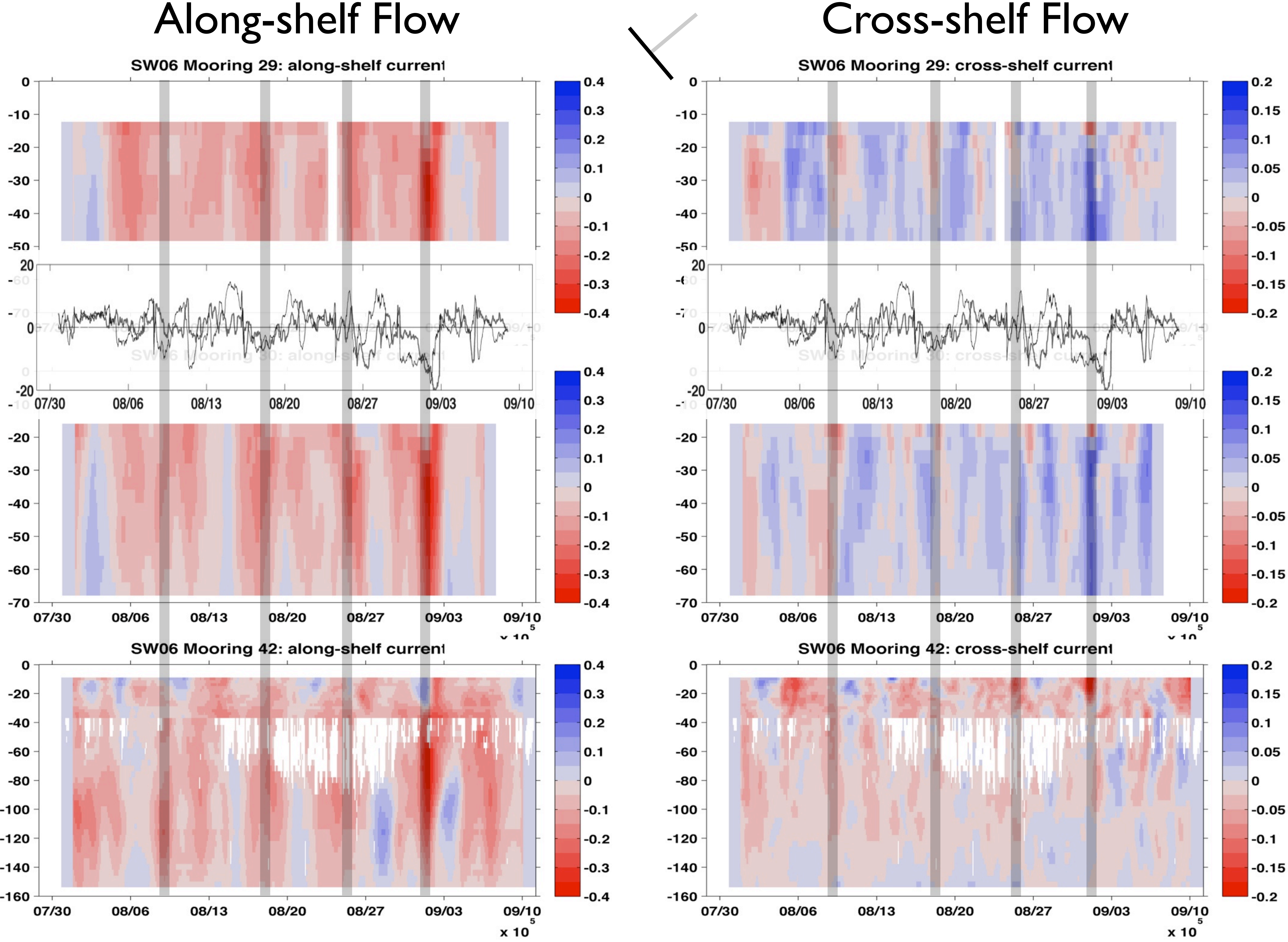
SW06 Mooring 30: Temperature
SW06 Mooring 30: Salinity
SW06 Mooring 30: Density
07/30
08/06
08/13
08/20
08/27
09/03
09/10
x 10^5
SW30 current (DA low freq.)
SW30 current (inertial)
wind speed (m/s)
U cross
V along
SW30 Salinity (-14m)
SW30 Salinity (-25m)
Salinity



SW06 Mooring 32: Salinity
-10
-20
-30
-40
-50
-60
-70
-80
07/30
08/06
08/13
08/20
08/27
09/03
09/10
x 10^5
35
34
33
32
31
30
SW06 Mooring 30: Salinity
Salinity at SW32 and SW30, T-lag: -19 hrs
SW32 (34m, 10 km to NE)
SW30 (32m, central array)
Salinity
Date (2006)

Along-shelf Flow

Cross-shelf Flow



SST: Slope Eddies

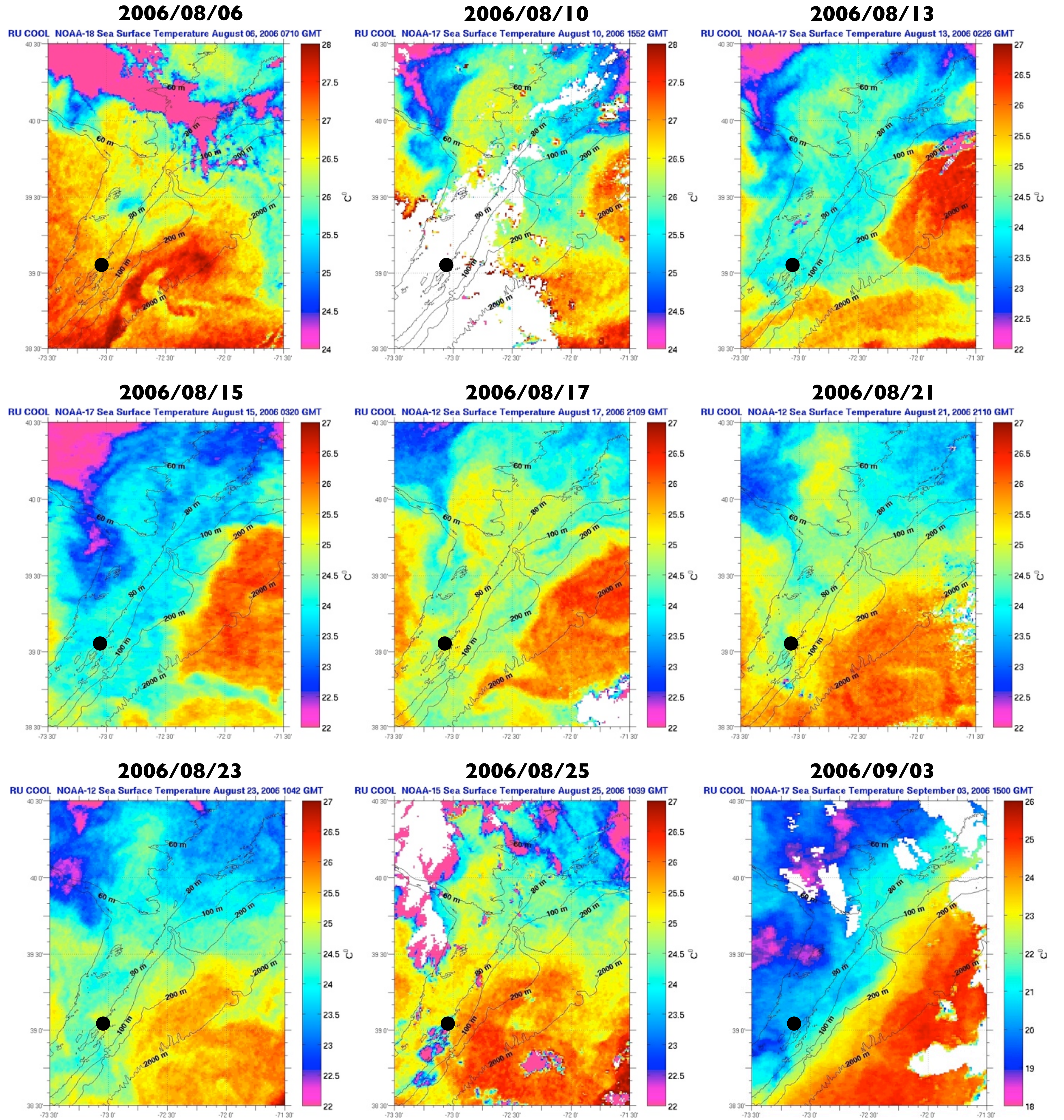
Two eddies near SW06:

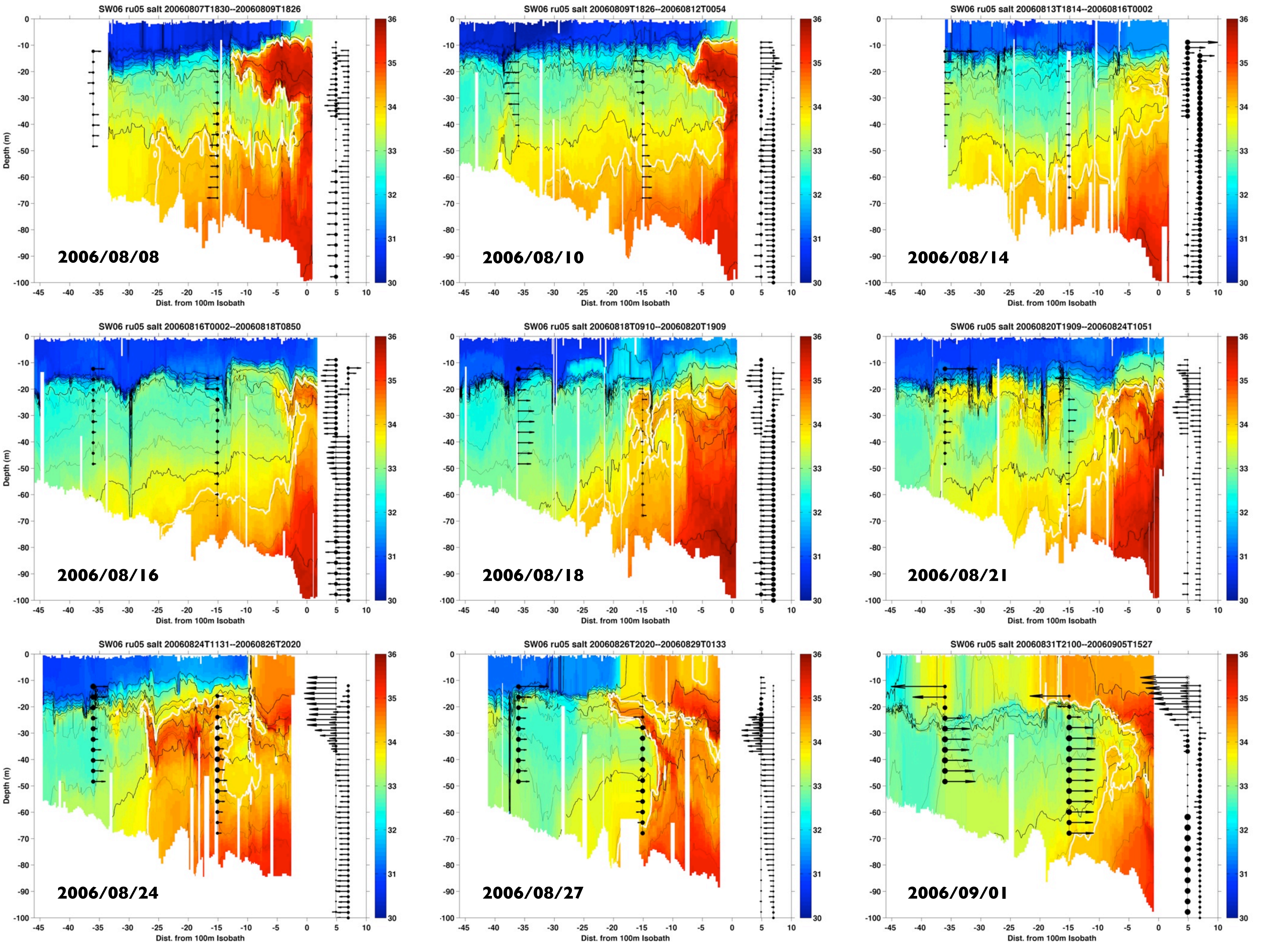
1: 8/06 - 8/10

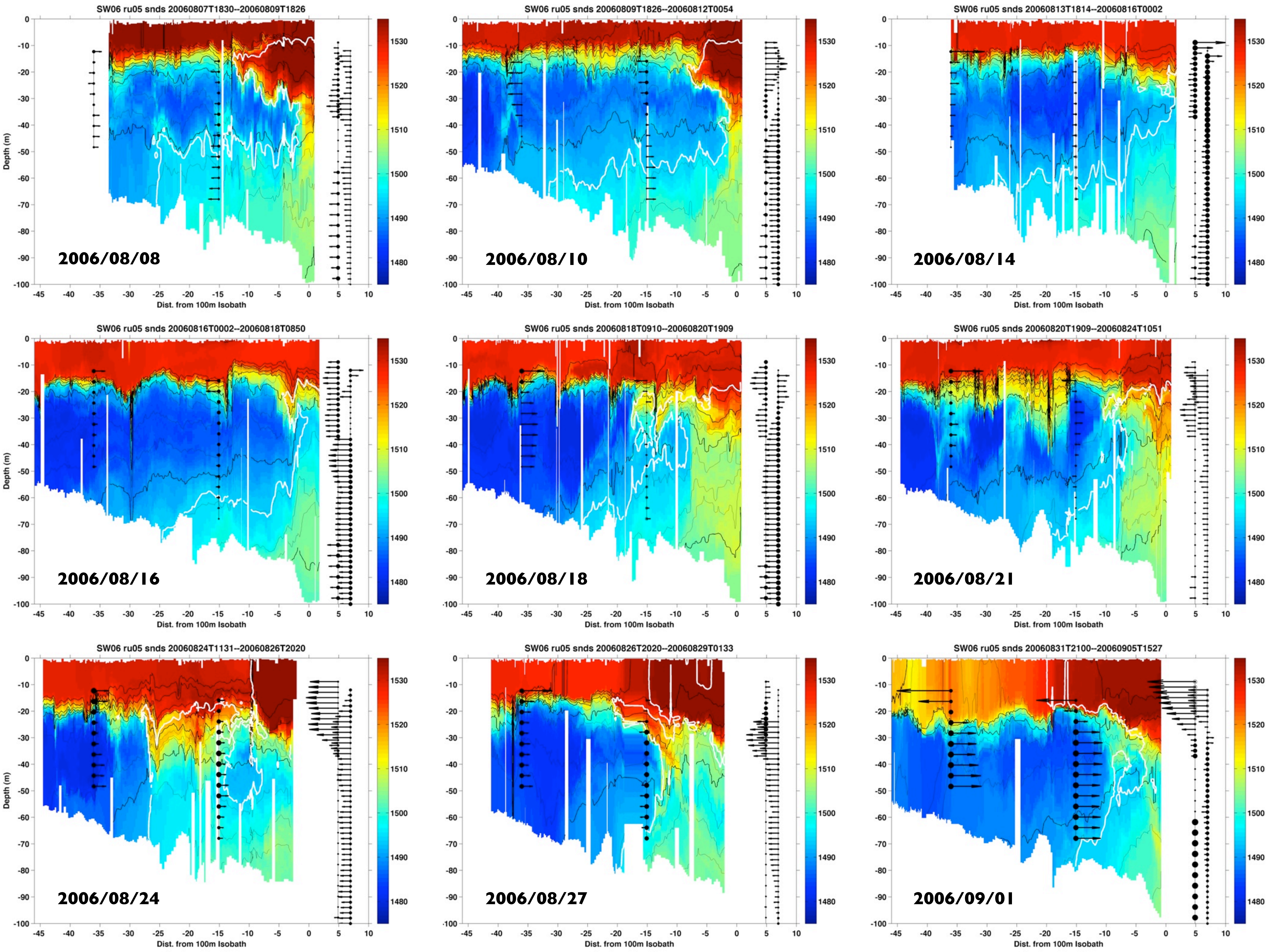
2: 8/22 - 8/27

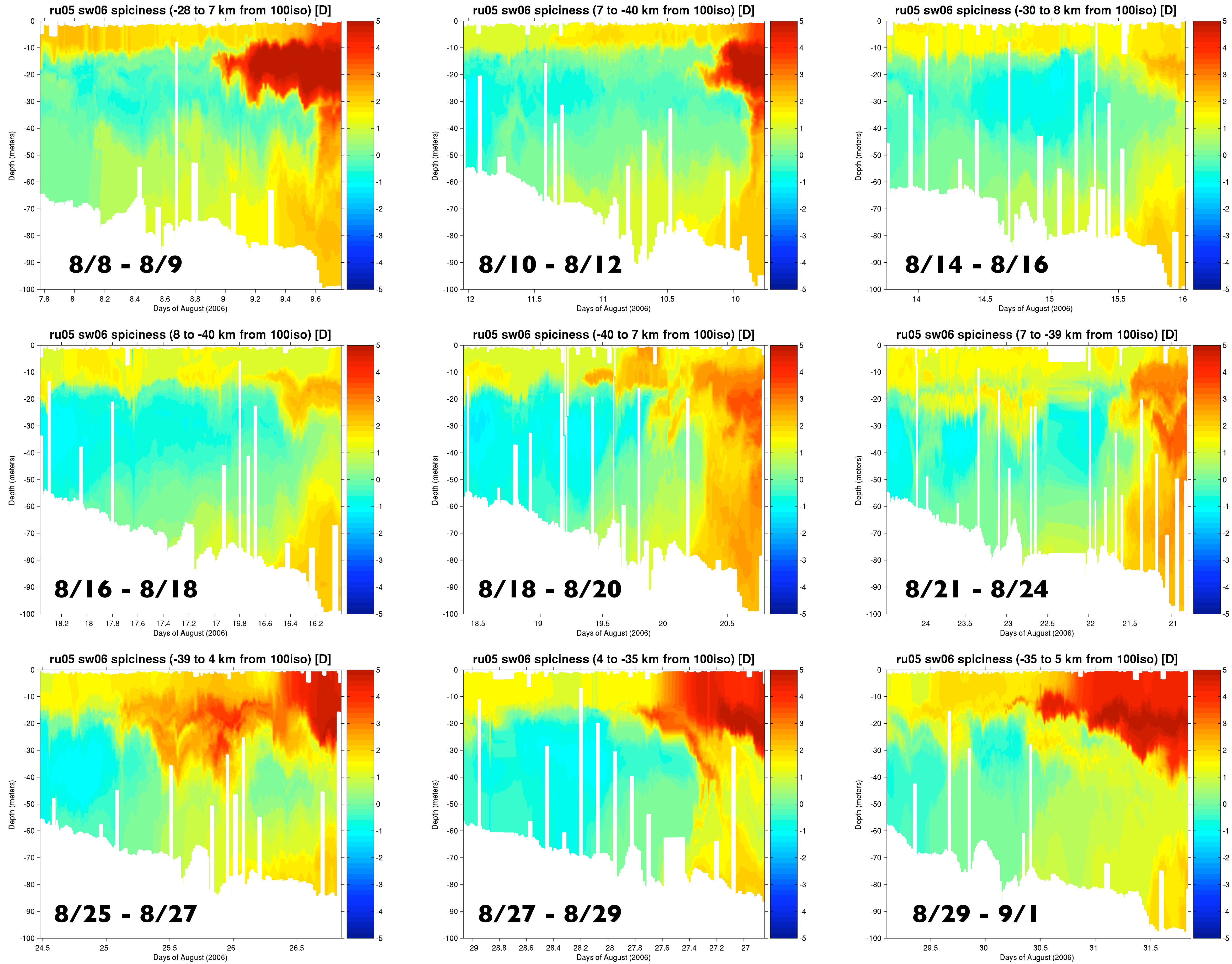
Radius: ~50 km

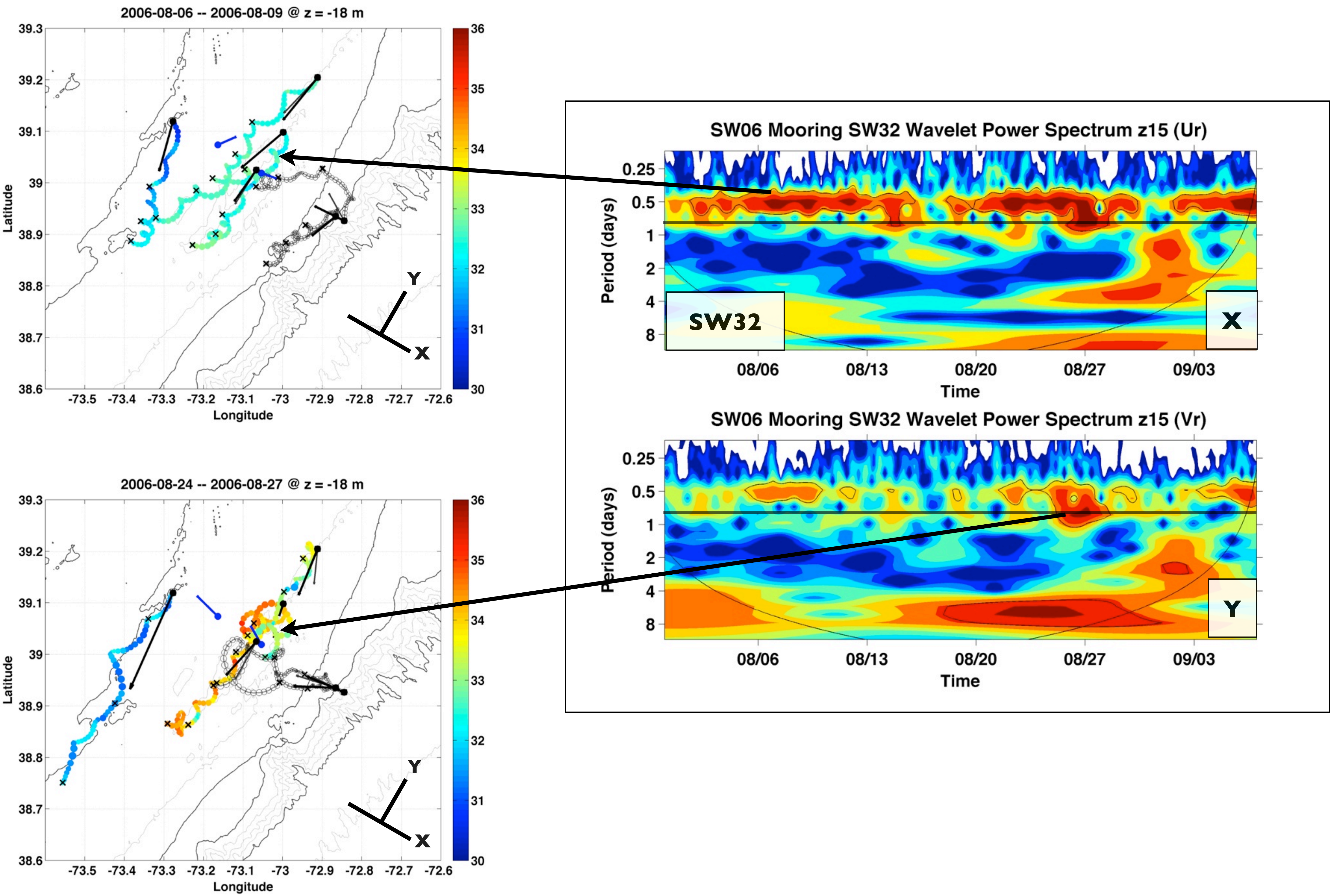
Speed: 22 - 9 cm/s

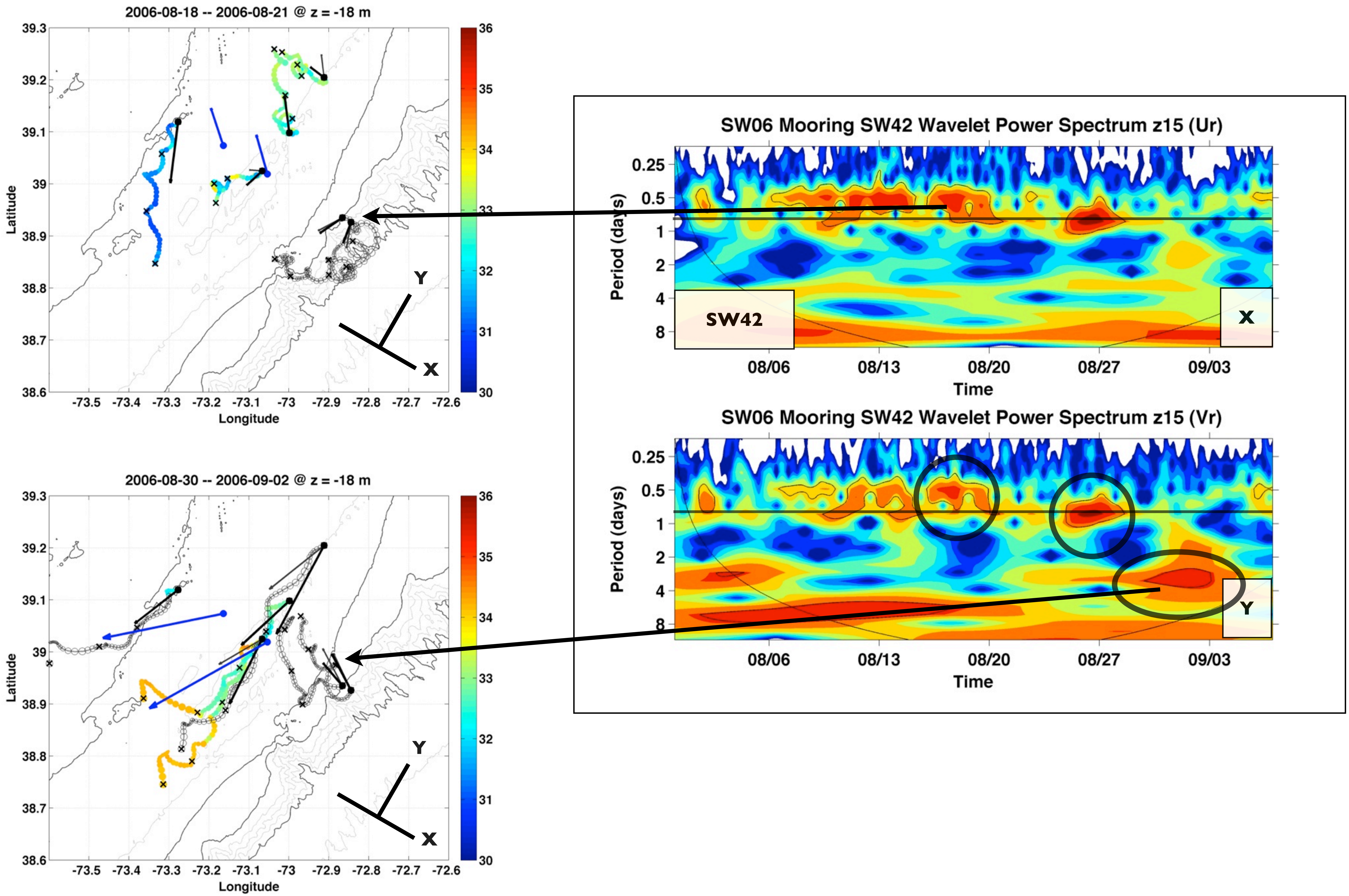


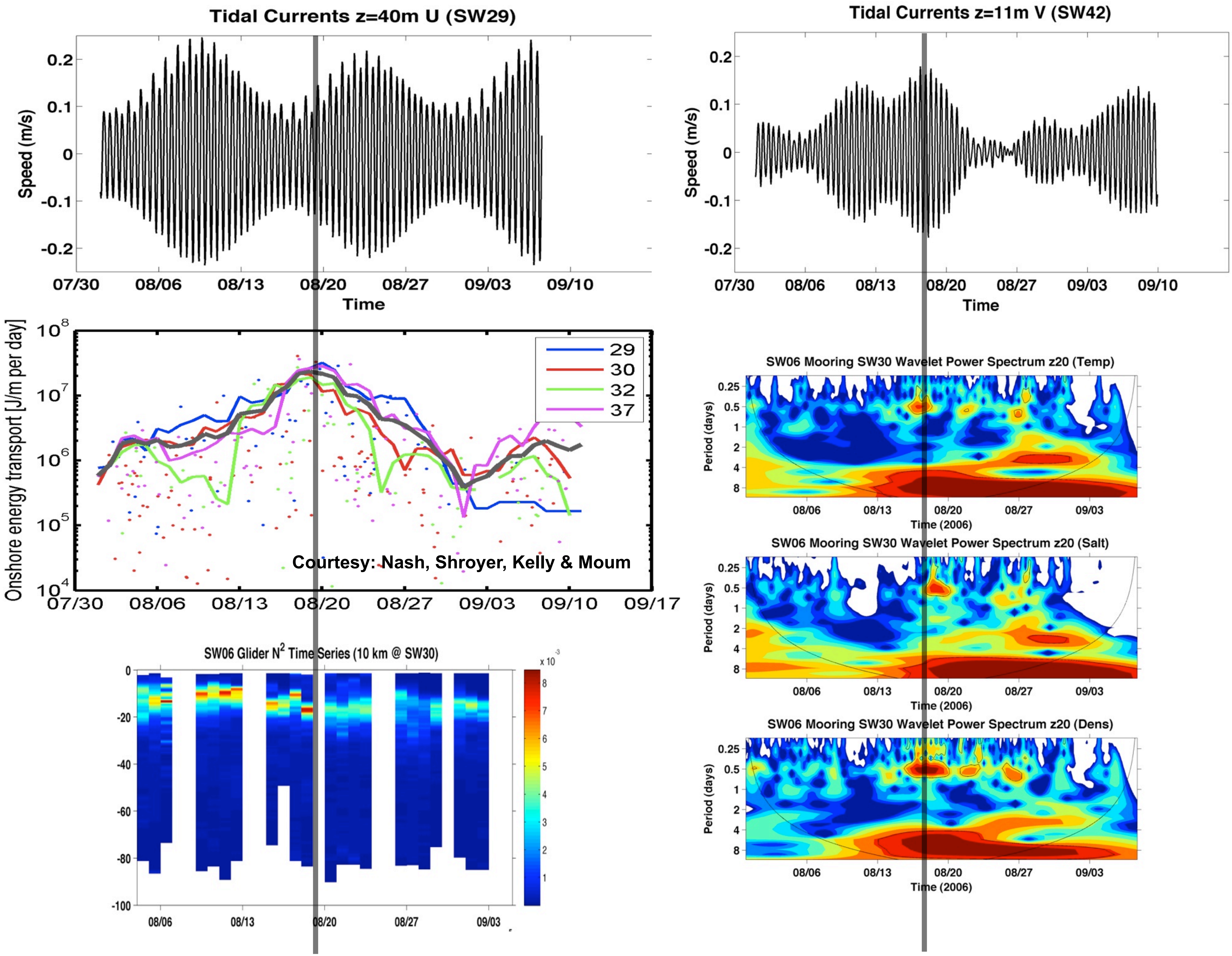

SW06 ru05 salt 20060807T1830--20060809T1826
2006/08/08
SW06 ru05 salt 20060809T1826--20060812T0054
2006/08/10
SW06 ru05 salt 20060813T1814--20060816T0002
2006/08/14
SW06 ru05 salt 20060816T0002--20060818T0850
2006/08/16
SW06 ru05 salt 20060818T0910--20060820T1909
2006/08/18
SW06 ru05 salt 20060820T1909--20060824T1051
2006/08/21
SW06 ru05 salt 20060824T1131--20060826T2020
2006/08/24
SW06 ru05 salt 20060826T2020--20060829T0133
2006/08/27
SW06 ru05 salt 20060831T2100--20060905T1527
2006/09/01
Depth (m)
Dist. from 100m Isobath


SW06 ru05 snds 20060807T1830--20060809T1826
2006/08/08
SW06 ru05 snds 20060809T1826--20060812T0054
2006/08/10
SW06 ru05 snds 20060813T1814--20060816T0002
2006/08/14
SW06 ru05 snds 20060816T0002--20060818T0850
2006/08/16
SW06 ru05 snds 20060818T0910--20060820T1909
2006/08/18
SW06 ru05 snds 20060820T1909--20060824T1051
2006/08/21
SW06 ru05 snds 20060824T1131--20060826T2020
2006/08/24
SW06 ru05 snds 20060826T2020--20060829T0133
2006/08/27
SW06 ru05 snds 20060831T2100--20060905T1527
2006/09/01
Depth (m)
Dist. from 100m Isobath
1530
1520
1510
1500
1490
1480


ru05 sw06 spiciness (-28 to 7 km from 100iso) [D]
8/8 - 8/9
ru05 sw06 spiciness (7 to -40 km from 100iso) [D]
8/10 - 8/12
ru05 sw06 spiciness (-30 to 8 km from 100iso) [D]
8/14 - 8/16
ru05 sw06 spiciness (8 to -40 km from 100iso) [D]
8/16 - 8/18
ru05 sw06 spiciness (-40 to 7 km from 100iso) [D]
8/18 - 8/20
ru05 sw06 spiciness (7 to -39 km from 100iso) [D]
8/21 - 8/24
ru05 sw06 spiciness (-39 to 4 km from 100iso) [D]
8/25 - 8/27
ru05 sw06 spiciness (4 to -35 km from 100iso) [D]
8/27 - 8/29
ru05 sw06 spiciness (-35 to 5 km from 100iso) [D]
8/29 - 9/1
Depth (meters)
Days of August (2006)

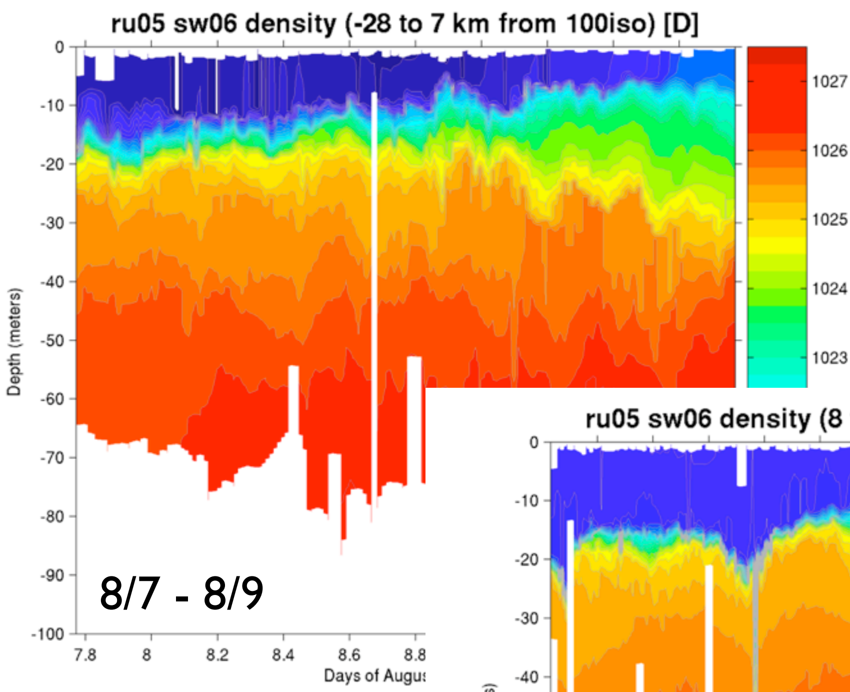

2006-08-06 -- 2006-08-09 @ z = -18 m
2006-08-24 -- 2006-08-27 @ z = -18 m
Latitude
Longitude
Y
X
SW06 Mooring SW32 Wavelet Power Spectrum z15 (Ur)
SW06 Mooring SW32 Wavelet Power Spectrum z15 (Vr)
Period (days)
Time
08/06
08/13
08/20
08/27
09/03
SW32
X
Y


2006-08-18 -- 2006-08-21 @ z = -18 m
Latitude
Longitude
2006-08-30 -- 2006-09-02 @ z = -18 m
Y
X
SW06 Mooring SW42 Wavelet Power Spectrum z15 (Ur)
Period (days)
Time
SW42
SW06 Mooring SW42 Wavelet Power Spectrum z15 (Vr)
08/06
08/13
08/20
08/27
09/03

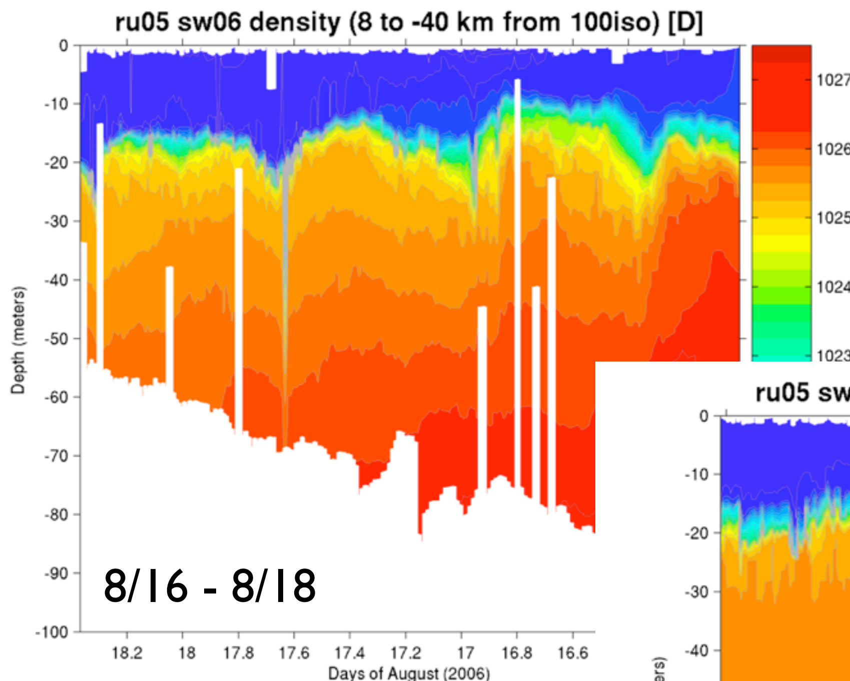


Tidal Currents z=40m U (SW29)
Speed (m/s)
Time
Tidal Currents z=11m V (SW42)
Speed (m/s)
Time
Onshore energy transport [J/m per day]
29
30
32
37
Courtesy: Nash, Shroyer, Kelly & Moum
07/30
08/06
08/13
08/20
08/27
09/03
09/10
09/17
SW06 Glider N^2 Time Series (10 km @ SW30)
x 10^-3
SW06 Mooring SW30 Wavelet Power Spectrum z20 (Temp)
Period (days)
Time (2006)
SW06 Mooring SW30 Wavelet Power Spectrum z20 (Salt)
Period (days)
Time (2006)
SW06 Mooring SW30 Wavelet Power Spectrum z20 (Dens)
Period (days)
Time (2006)

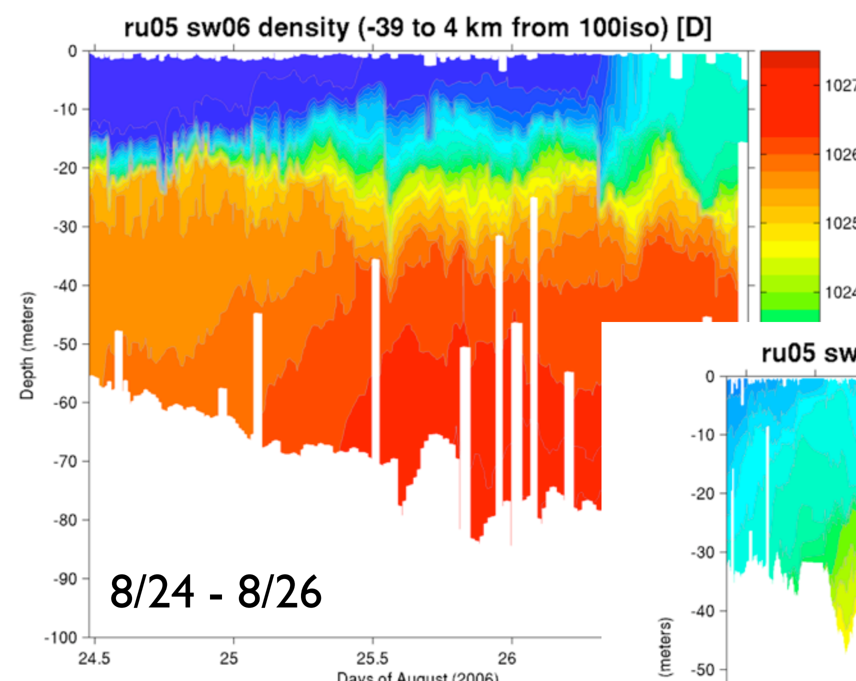
Evolution of Outershelf Hydrography & Stratification



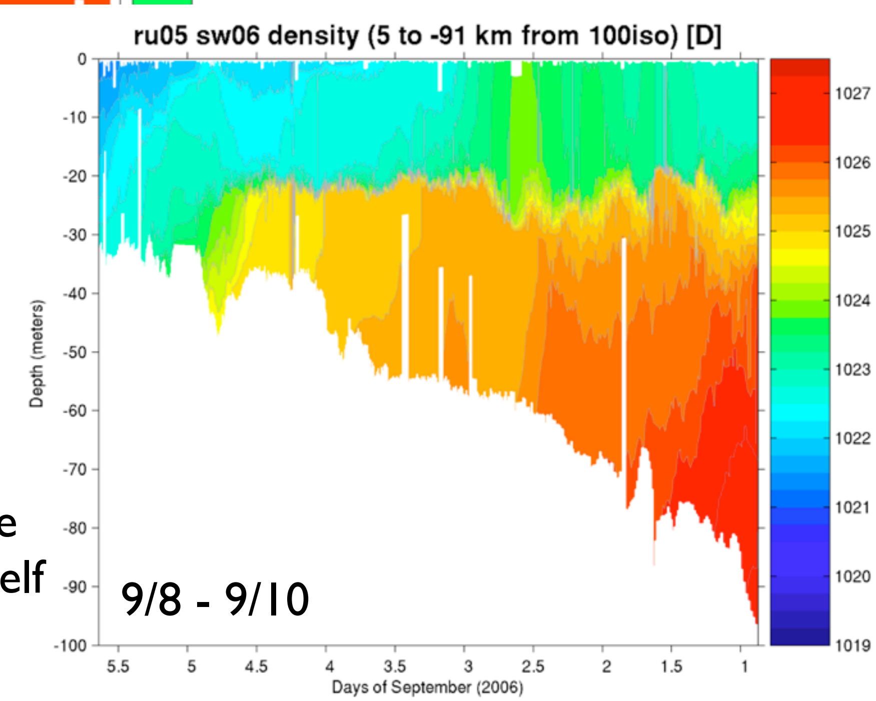
- Fresh surface layer due to river discharge
- strong diurnal tidal currents
- Slope eddy at the study site
- pycnocline weakened by intrusion / offshore eddy



- Peak NLIW activity period, neap barotropic tide
- large semidiurnal pycnocline oscillation (internal tides)
- Salty intrusion in the bottom layer, strengthening pycnocline



- Slope eddy at the shelfbreak
- inertial freq winds drives inertia currents
- Slope water intrusion pushes freshwater inshore
- Pycnocline begins to weaken



- Hurricane Ernesto moves through, shelf-slope front is reset
- Surface cools and become saltier, still stratified, weaker pycnocline
- intrusions decay over day time-scale, storm entrain salt on the shelf
- Minimum in NLIW activity during storm

What did we learn?

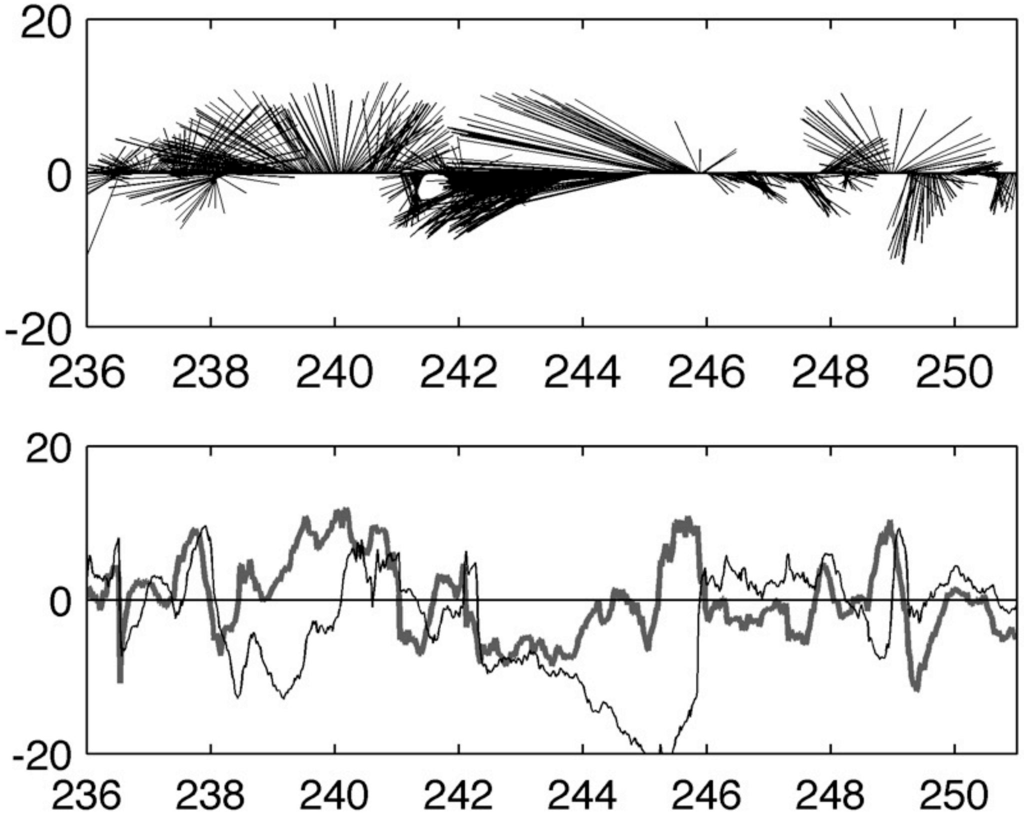
- Shelf-slope interface undergo significant intra-seasonal evolution. Along-shore wind & offshore forcings affect the vertical structure of the frontal interface.
- Slope water intrusions are common in late summer. 4 different types, some associated with slope water eddies. Cross-shore scale of 10-20 km, alongshelf scale of 15-30 km.
- Convergent cross-shore flow at the shelfbreak, intrusions are associated with tidal and inertial variability.
- Intrusions weaken outershelf stratification & contribute up to 30% of the outershelf salt budget.
- Barotropic and baroclinic tides not in phase. Internal wave activity highest during peak stratification and large internal tides.

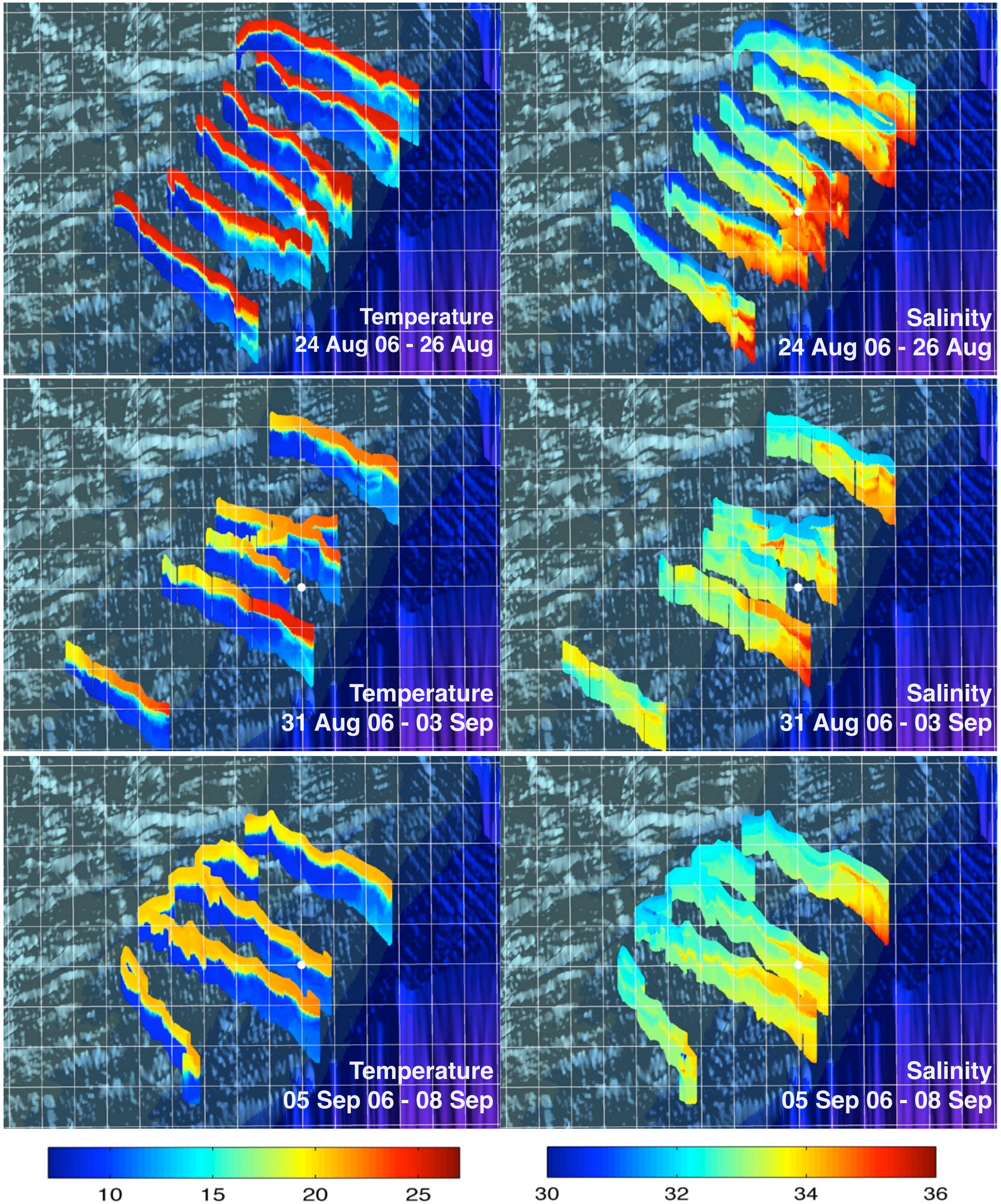
Future studies

- The transport and mixing of heat, salt and sediments on continental shelves due to energetic storms.
- Role of submarine canyons, channels and valleys in shelf-slope exchange.
- The cross-shelf exchange of heat and salt on the polar shelves.

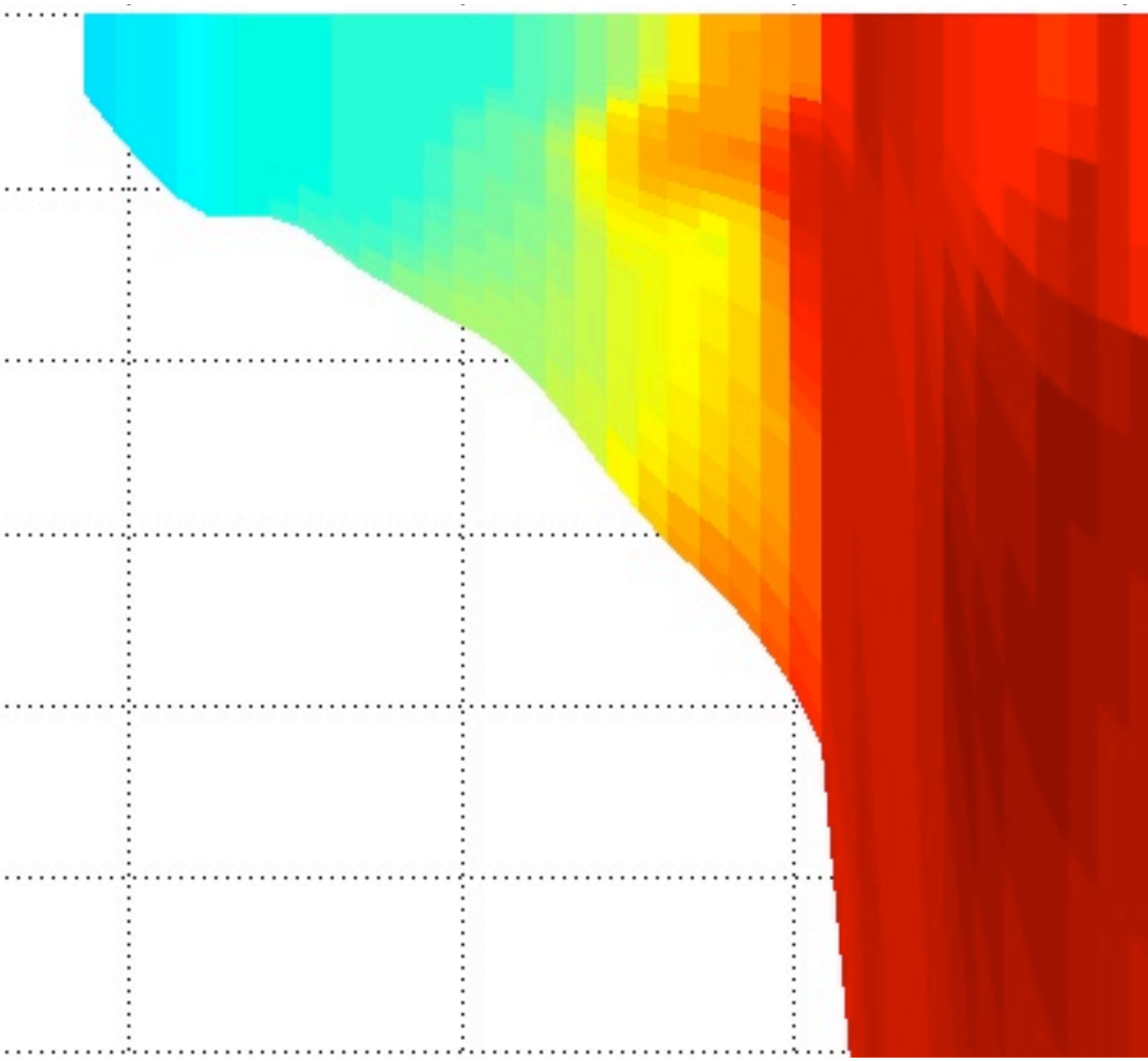
Observation ⟷ Modeling

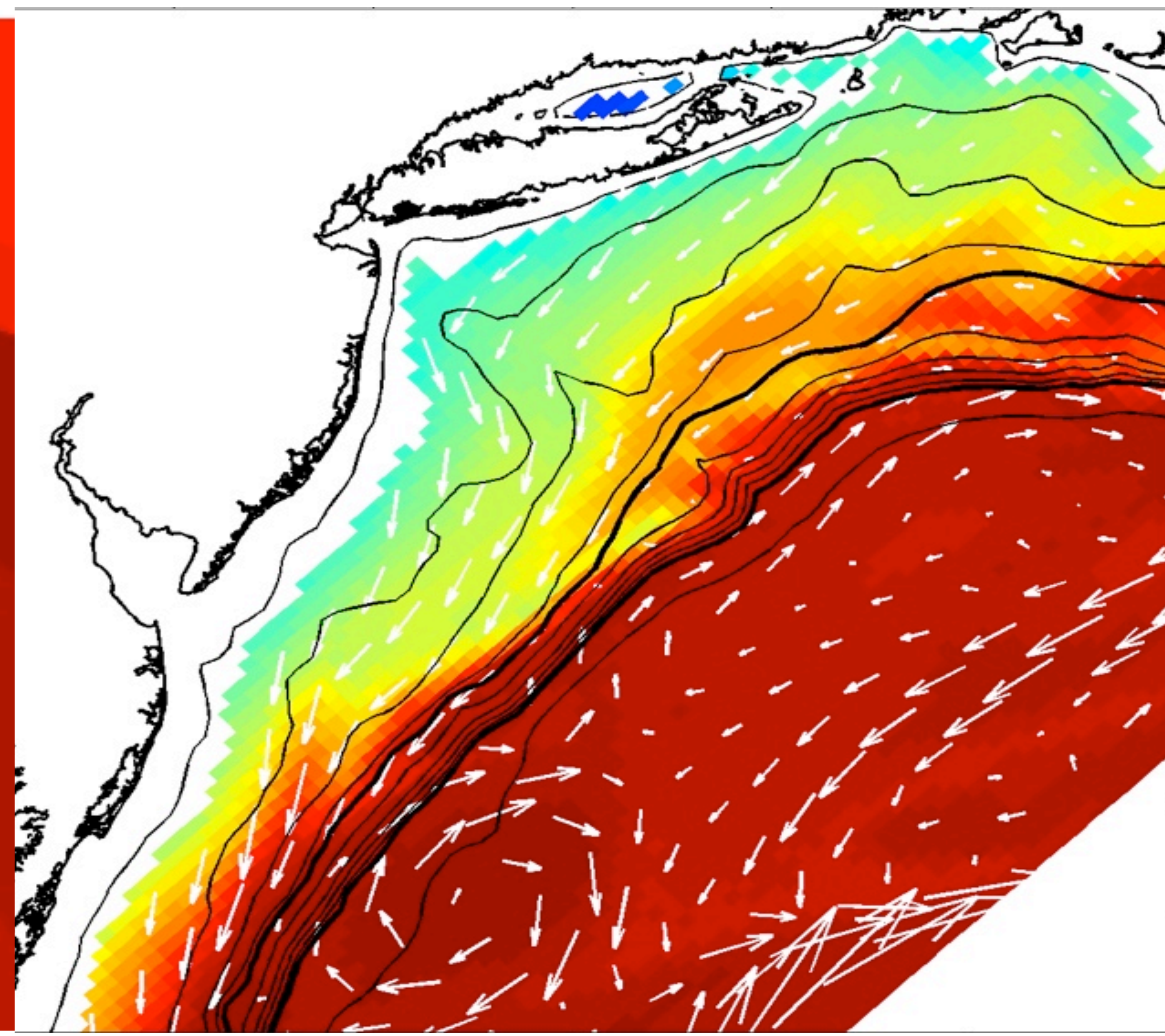
How do storms affect the shelf transport & mixing of heat and salt?





The role of shelfbreak canyons and shelf valleys in shelf-slope exchange?





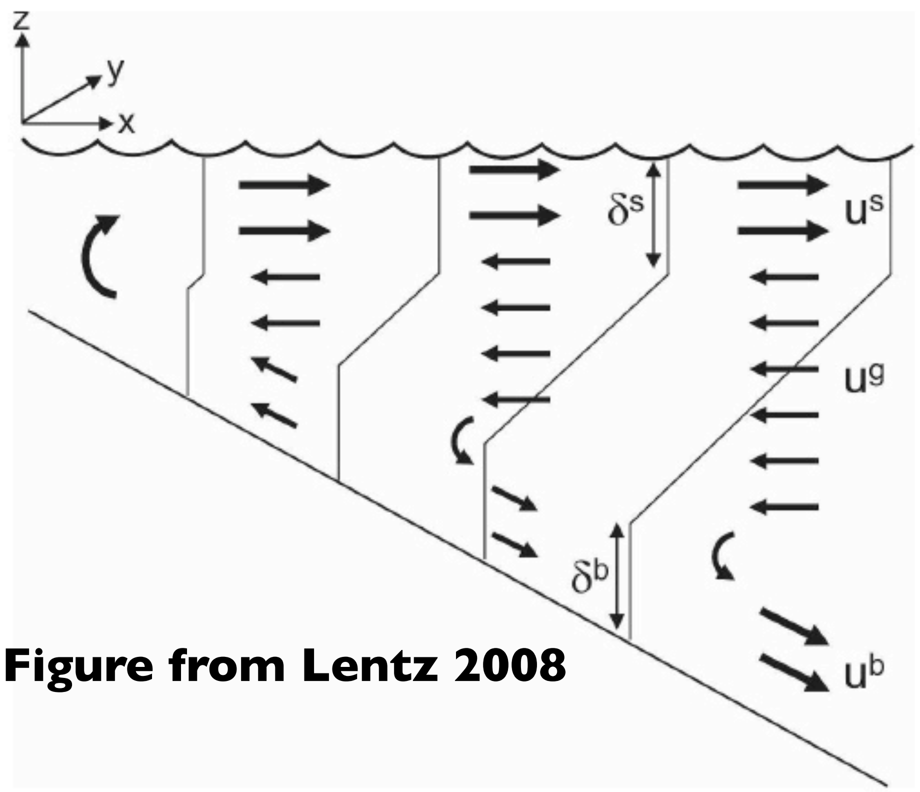
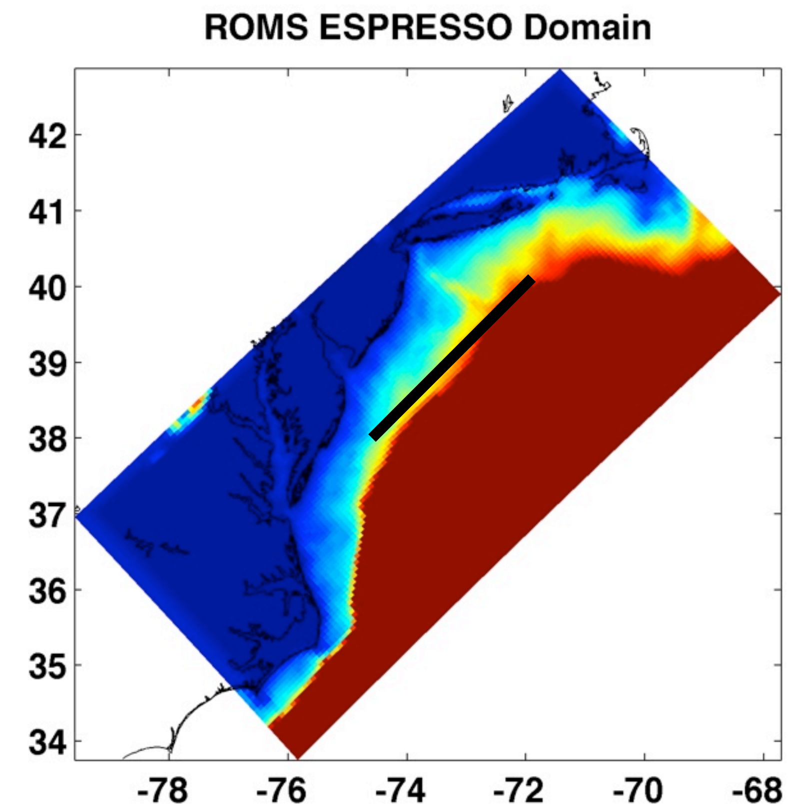
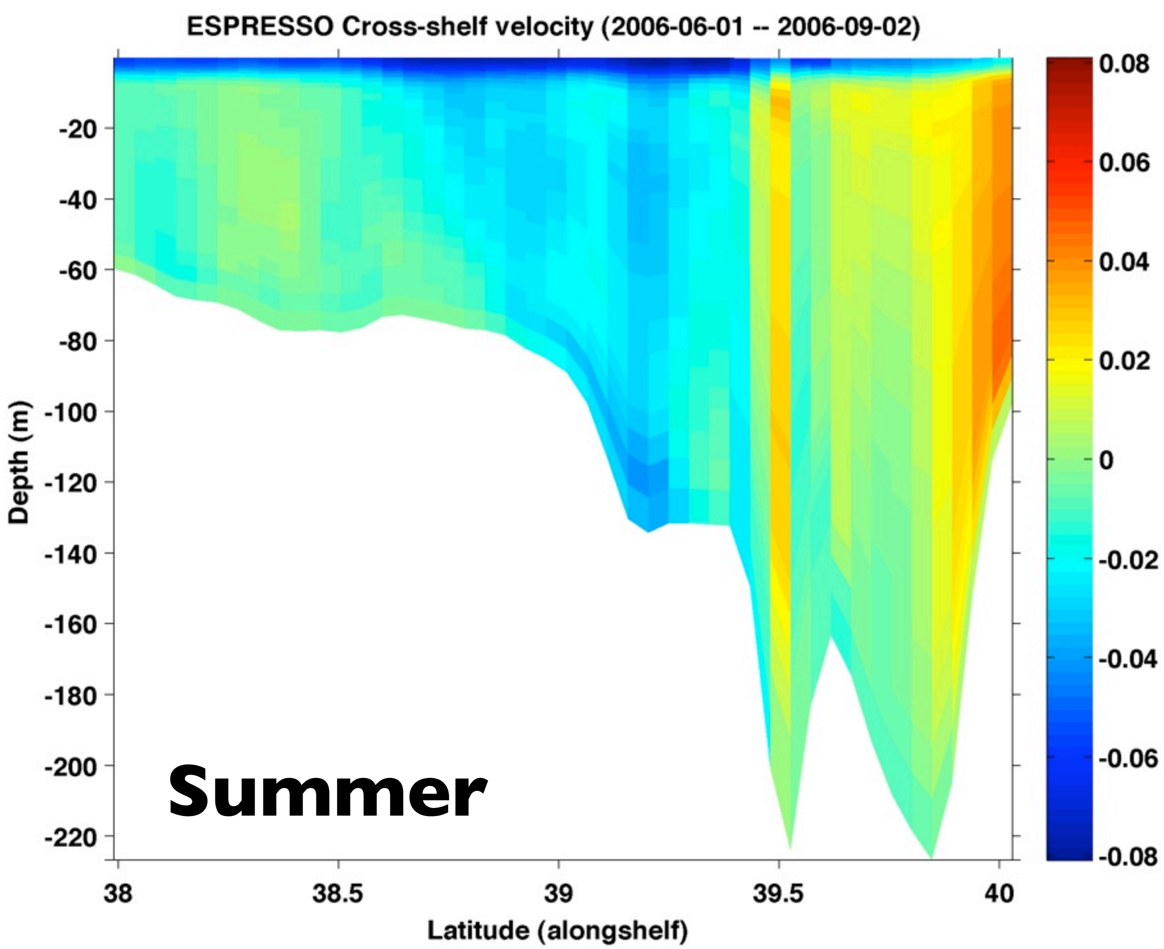
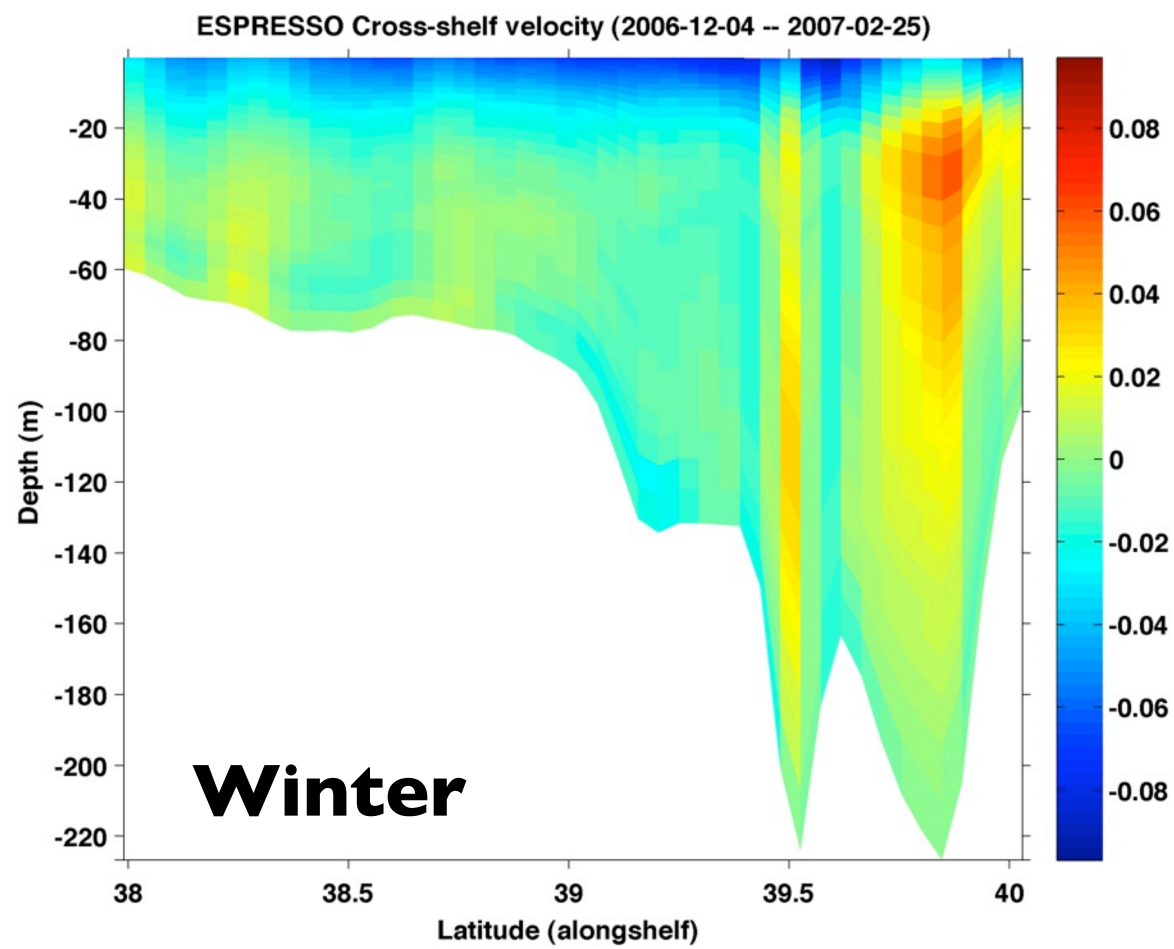


Figure from Lentz 2008







2 year ESPRESSO model run by Gordon Zhang & John Wilkin

Acknowledgements

Advisor: Scott Glenn

Thesis committee: Robert Chant, Glen Gawarkiewicz, Oscar Schofield, and John Wilkin

RUCOOL Operations Team

Collaborators at OSU & WHOI