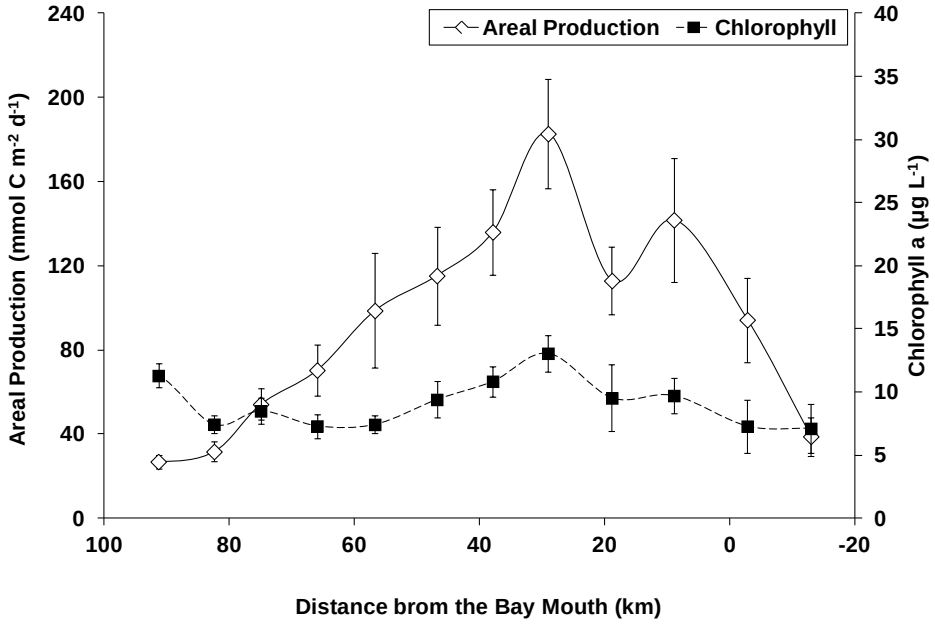
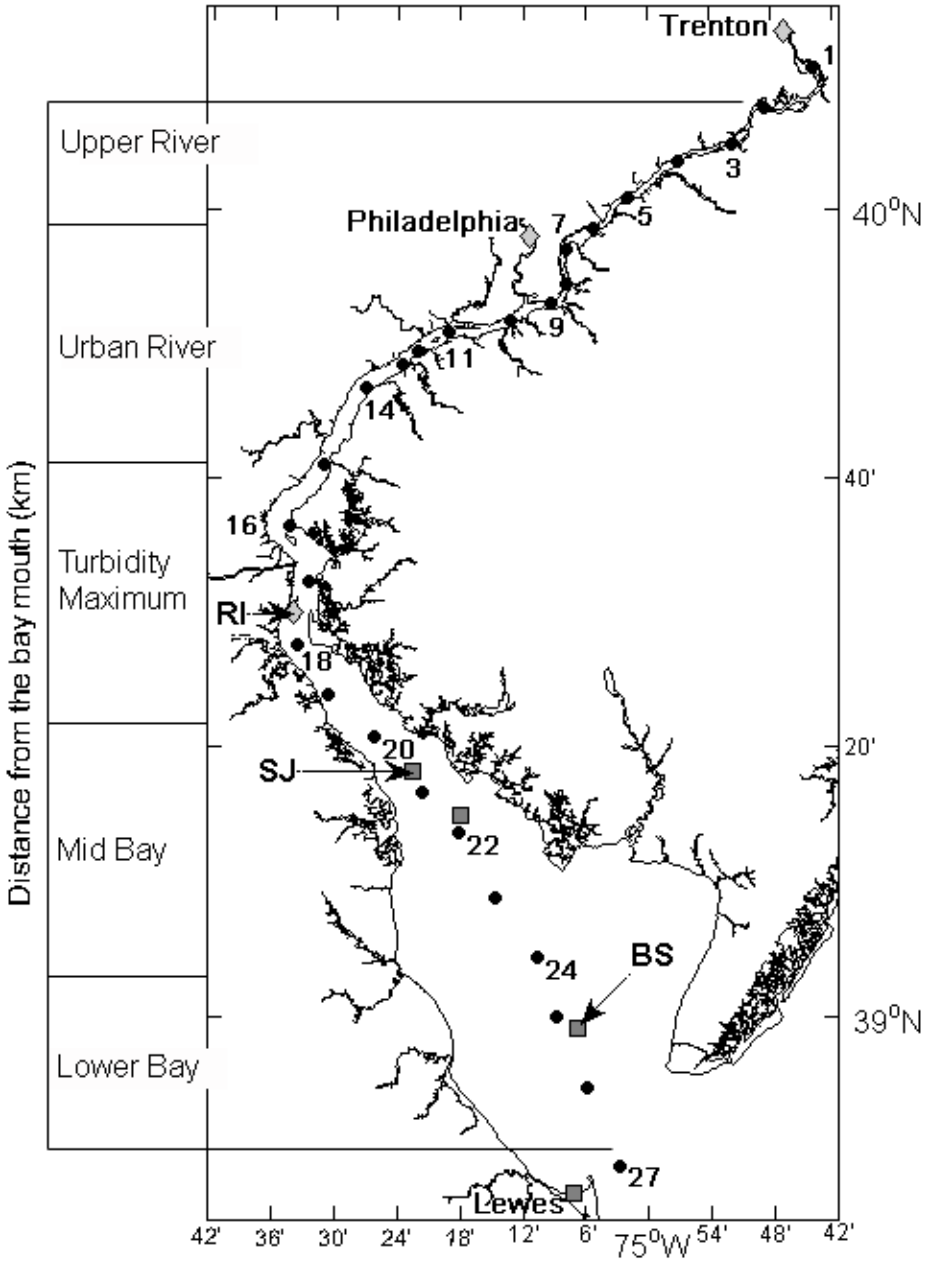
What Controls the Lower Delaware Bay Primary Production in the Summer: Wind-Driven Coastal Upwelling or Discharge Variability?

Y.G. Voynova and J.H. Sharp

January 30, 2013


Areal Production
Chlorophyll
Areal Production (mmol C m-2 d-1)
Chlorophyll a (µg L-1)
Distance brom the Bay Mouth (km)
240
200
160
120
80
40
0
40
35
30
25
20
15
10
5
0
100
80
60
40
20
0
-20


Trenton
Upper River
Urban River
Turbidity Maximum
Mid Bay
Lower Bay
Philadelphia
RI
SJ
BS
Lewes
Distance from the bay mouth (km)
1
3
5
7
9
11
14
16
18
20
22
24
27
40°N
40'
20'
39°N
42'
36'
30'
24'
18'
12'
6'
75°W
54'
48'
42'

Outline

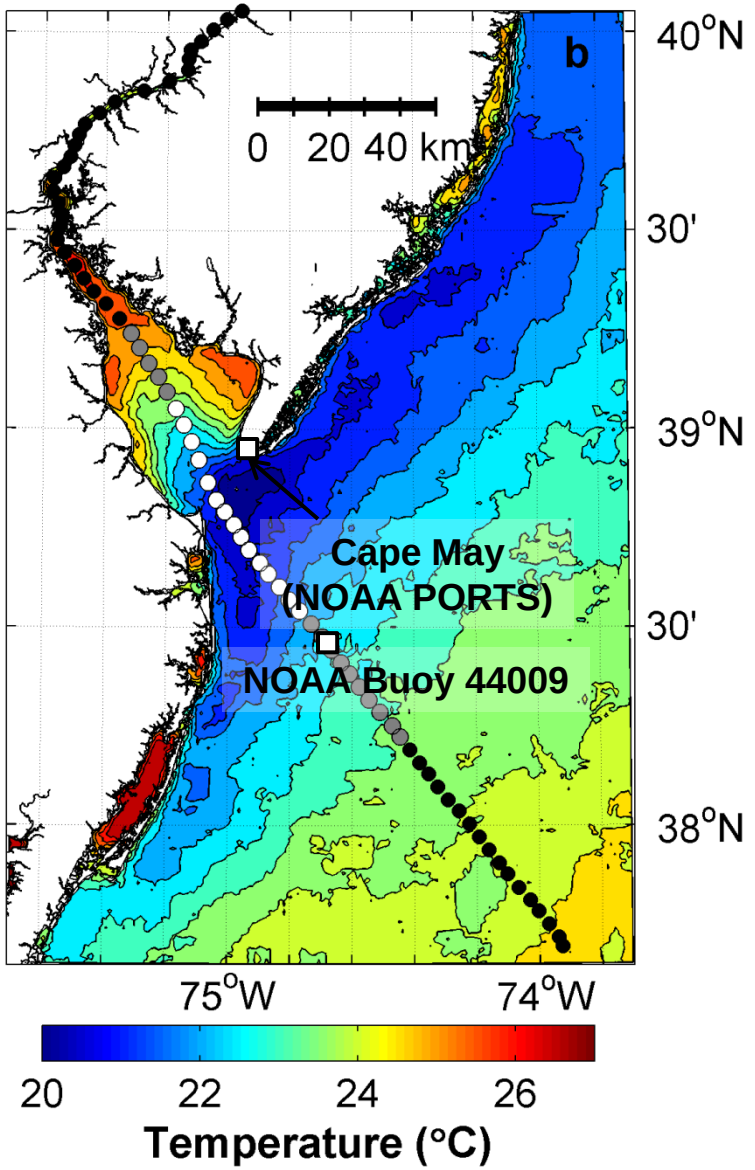
1. Wind-Driven Upwelling

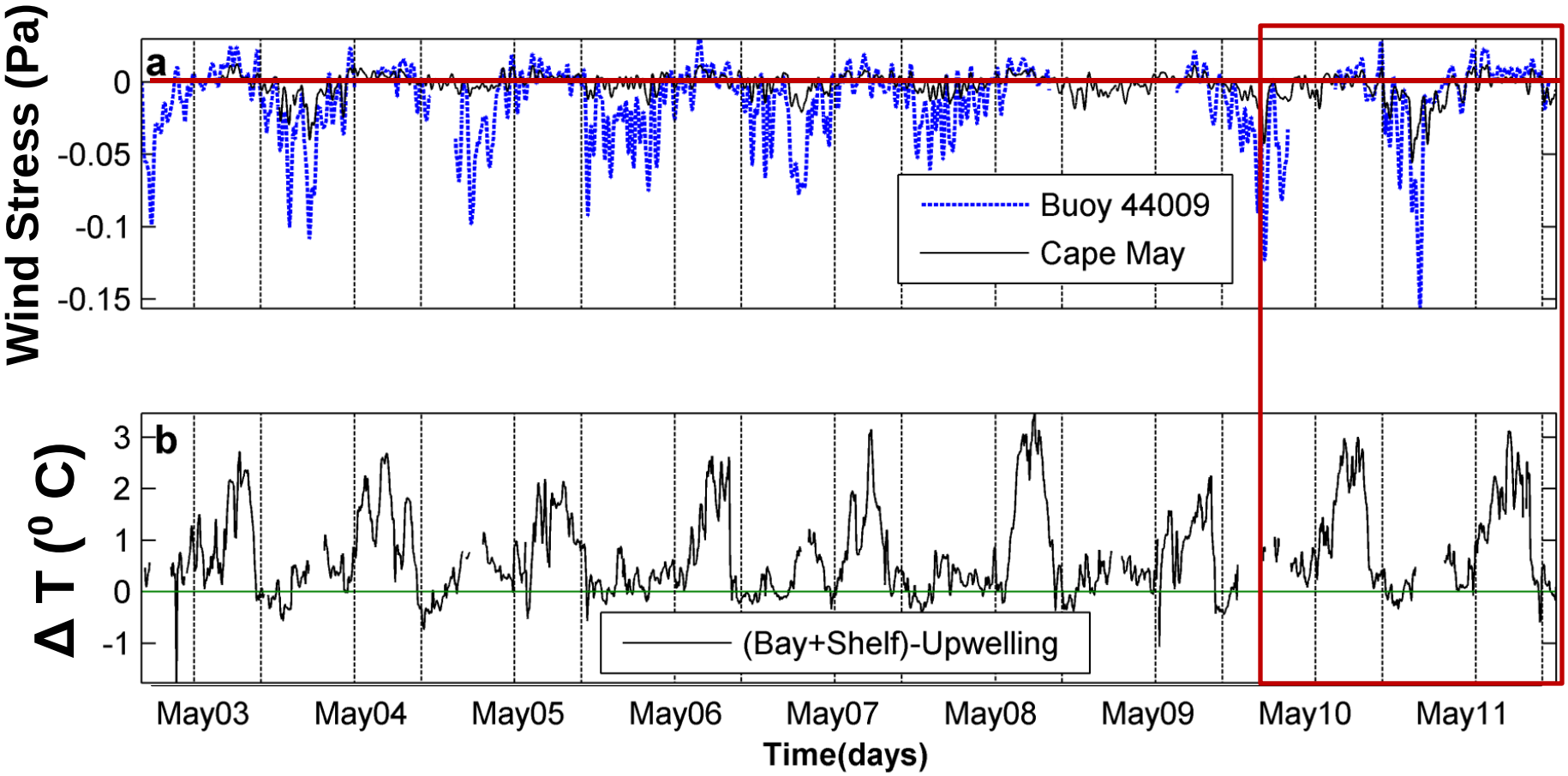
2. Discharge Variability

3. Biogeochemical Response (Ferry Monitoring)
   - 2010: May-July
   - 2011: July-October

4. Conclusion

Sea Surface Temperature (AVHRR) June-August, 2008





Summer winds (May-September) are strongly correlated to upwelling index ($R^2 > 0.8$)

Voynova et al.,
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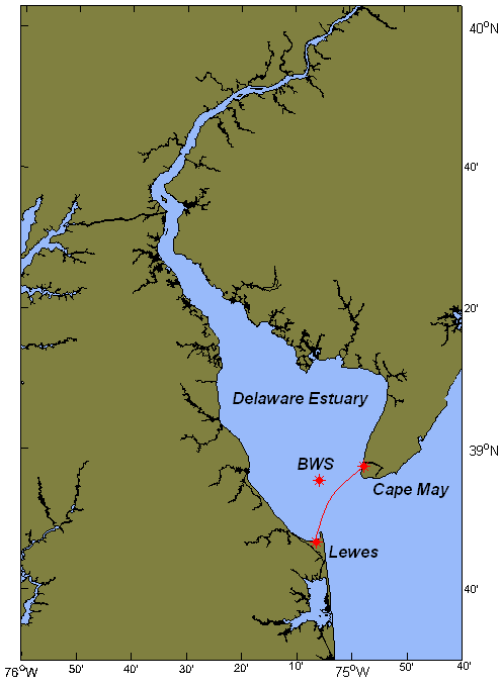
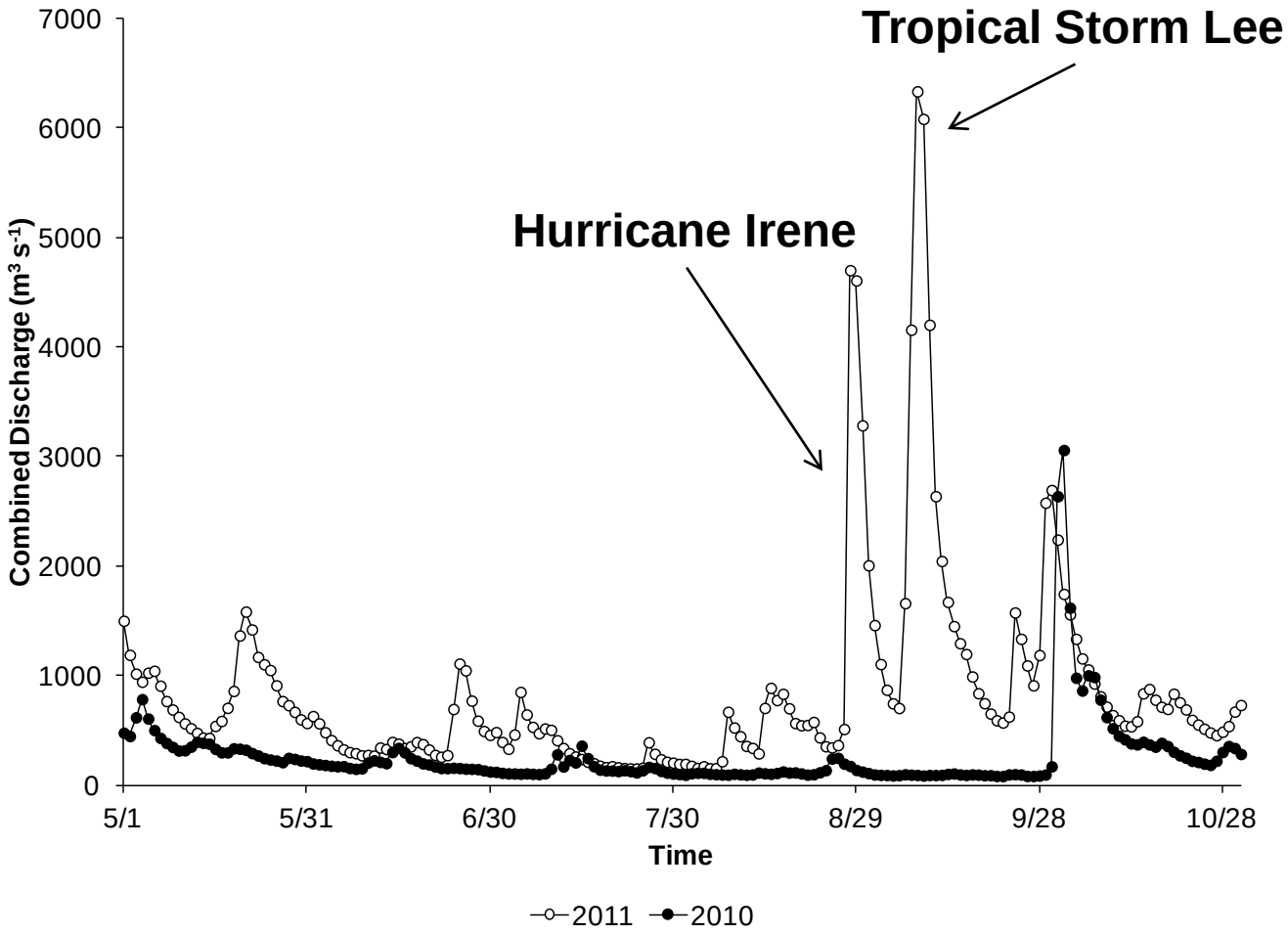
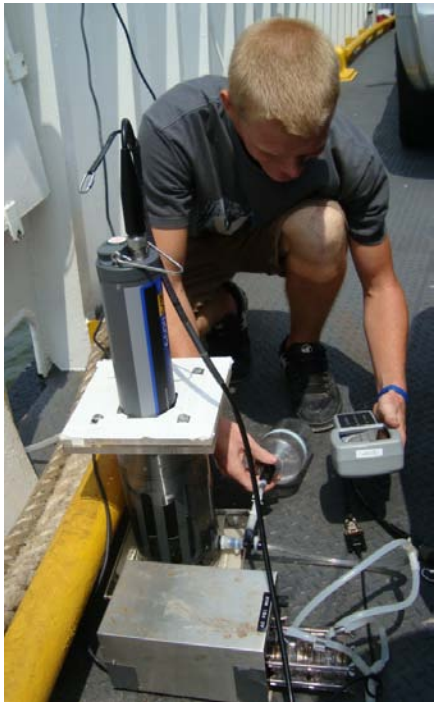
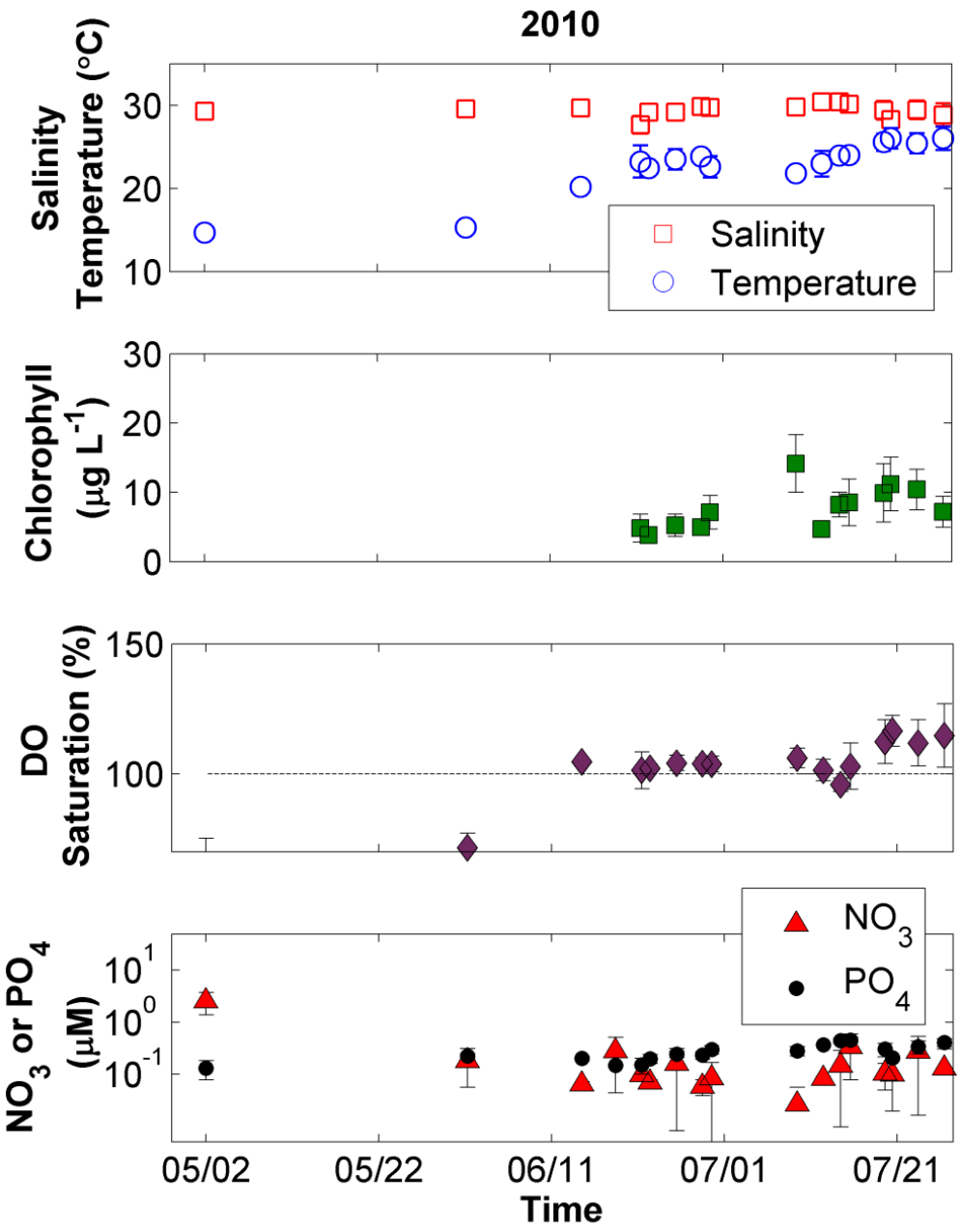

40°N
40'
20'
39°N
40'
Delaware Estuary
BWS
Cape May
Lewes
76°W
50'
40'
30'
20'
10'
75°W
50'
40'

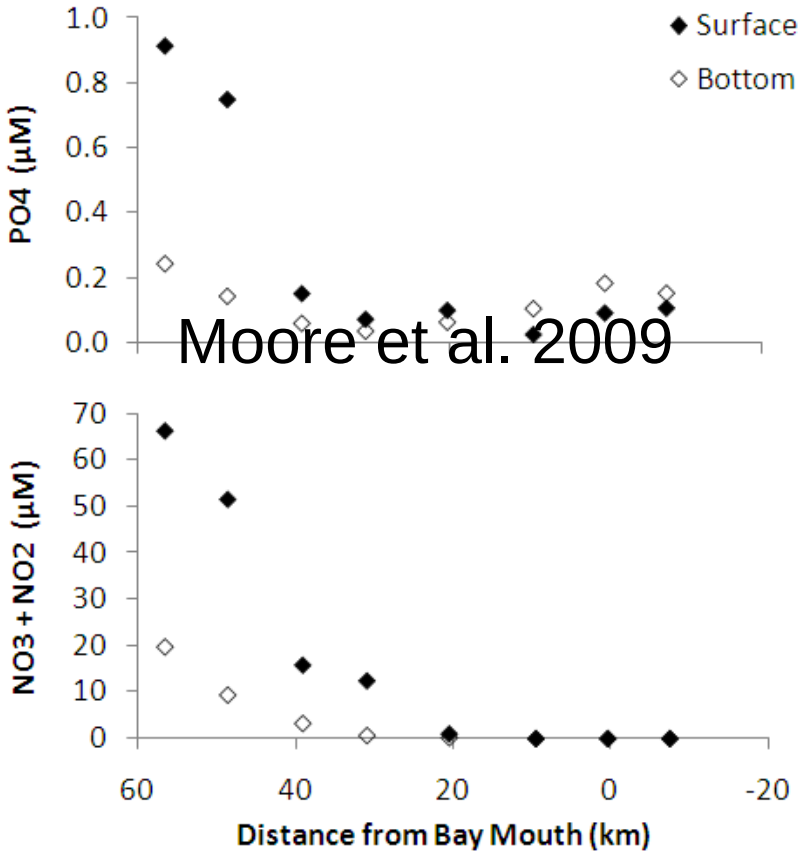

Tropical Storm Lee
Hurricane Irene
Combined Discharge (m³ s⁻¹)
7000
6000
5000
4000
3000
2000
1000
0
5/1
5/31
6/30
7/30
8/29
9/28
10/28
Time
2011
2010



Manual Ferry Sampling System

- Continuous sampling (YSI sonde)
  - temperature, salinity, chlorophyll, DO saturation, turbidity, pH
- Discrete samples
  - nutrients, chlorophyll, DOC/TDN



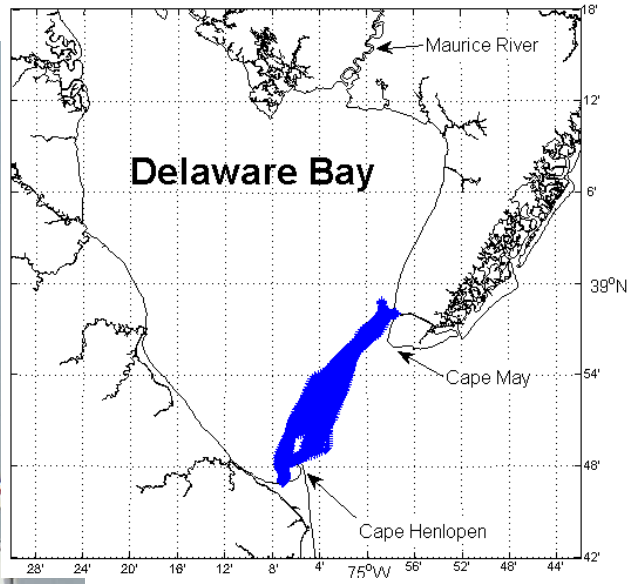


Moore et al. 2009

Met Station

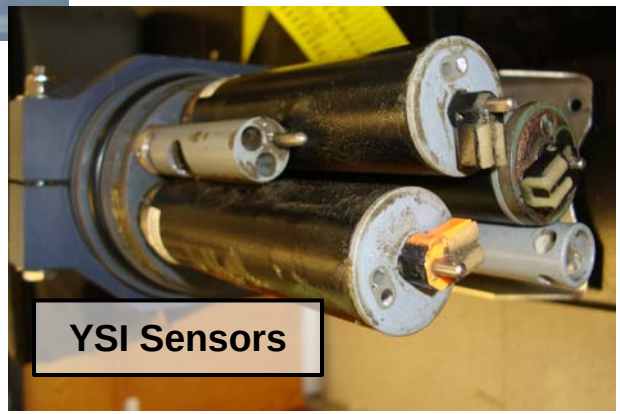
The met station above the pilothouse measures air temperature, pressure, wind speed and direction.

Monitoring System

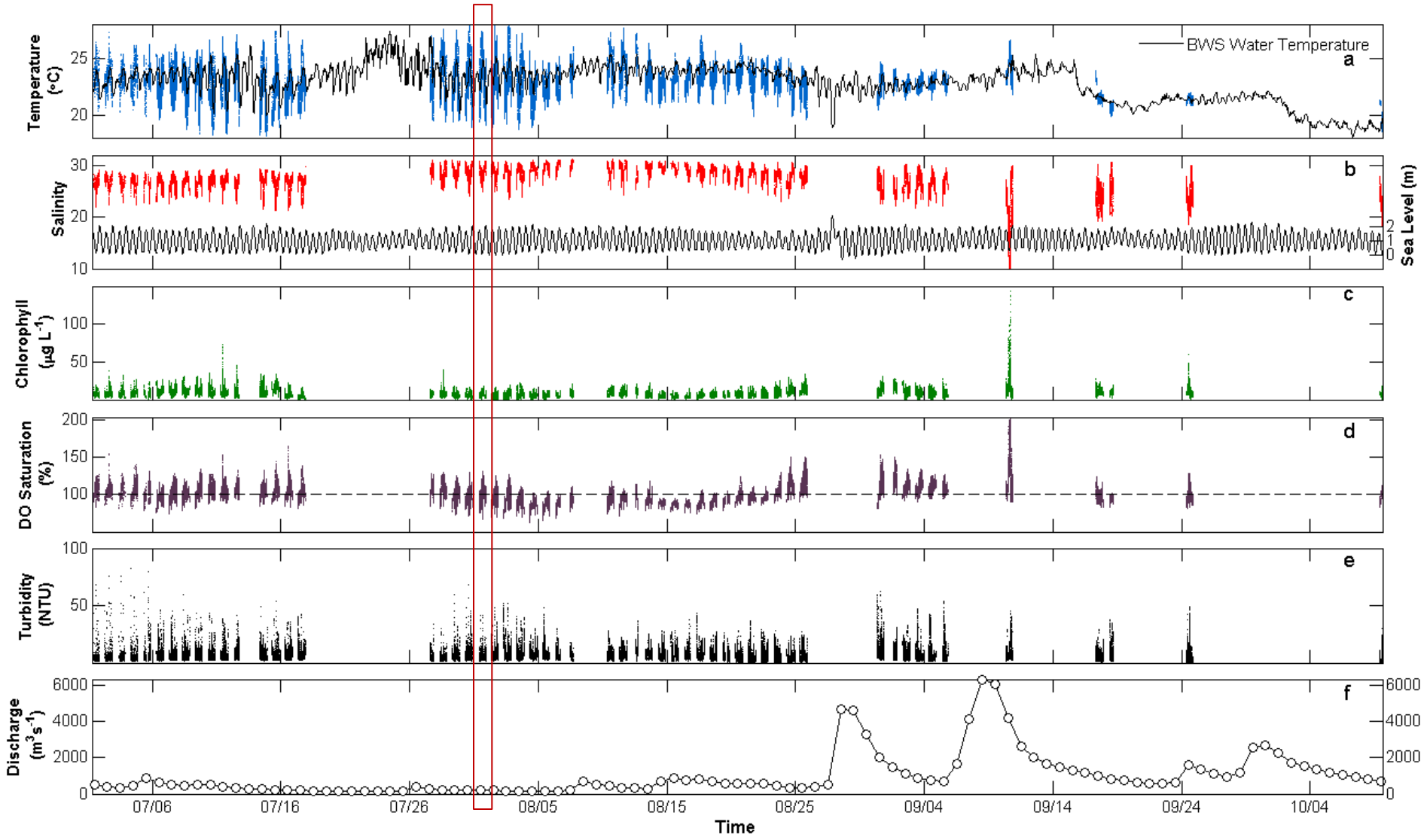


Inflow & Outflow Valves

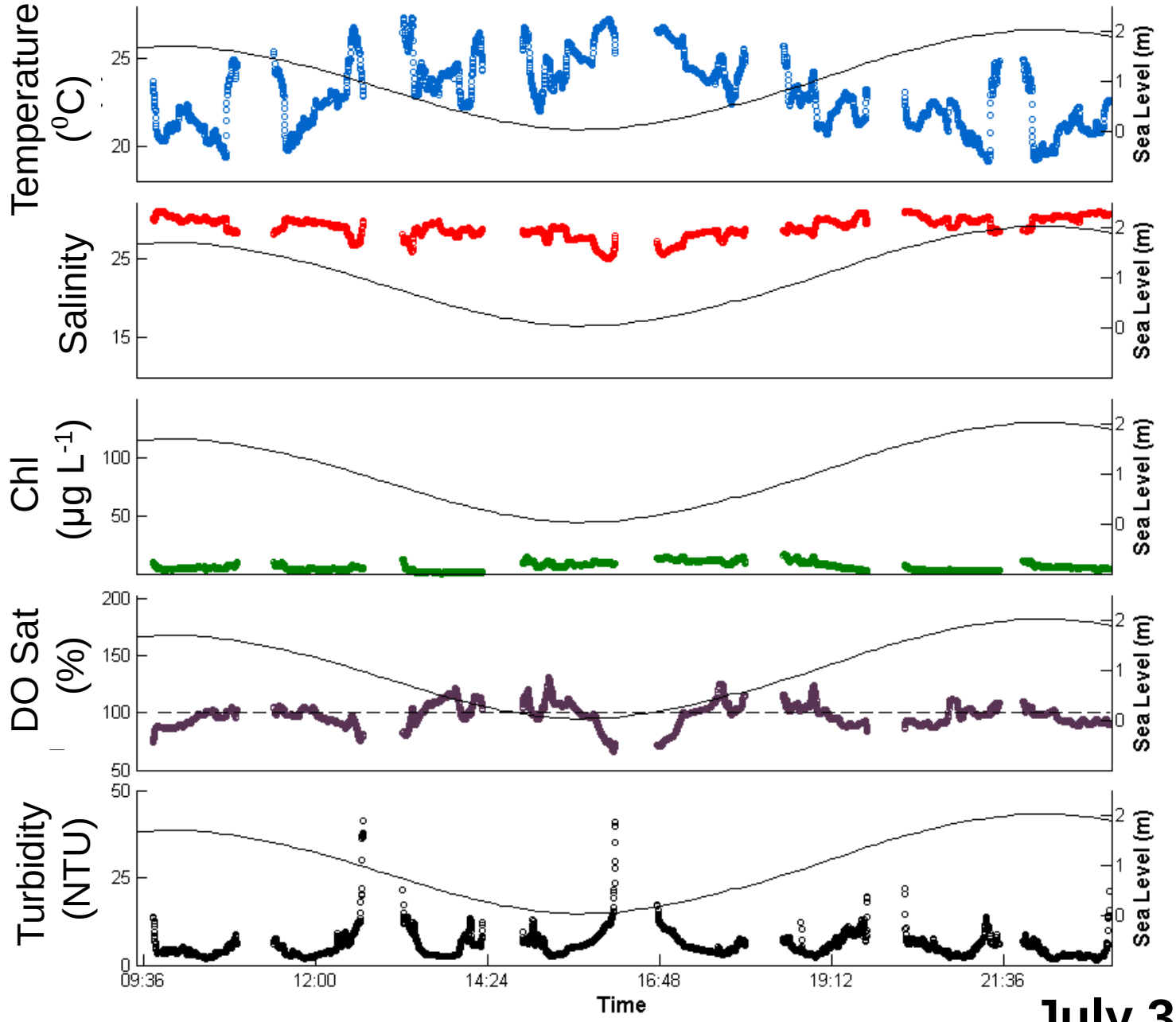
Water Quality Sensors



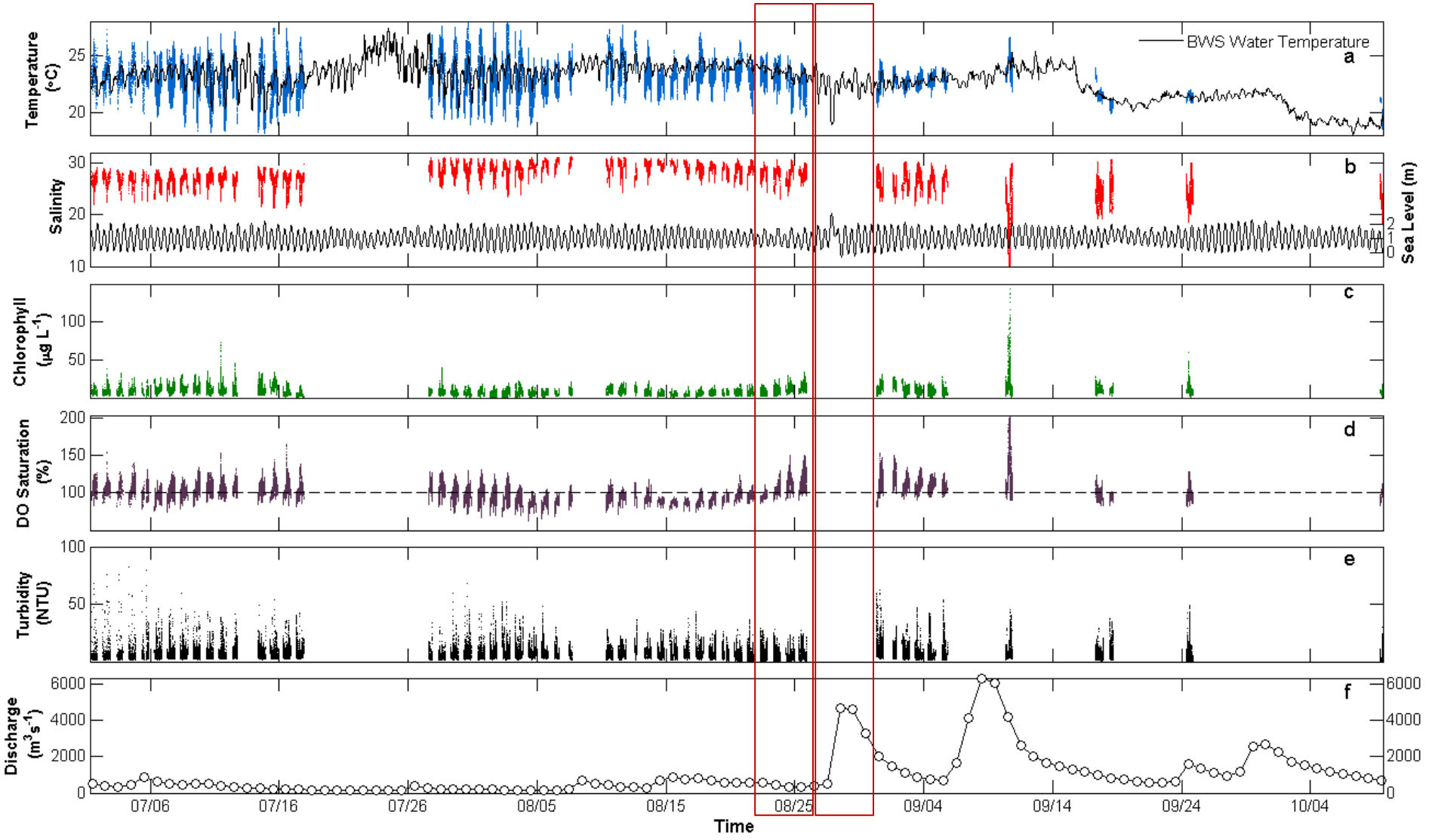
YSI Sensors

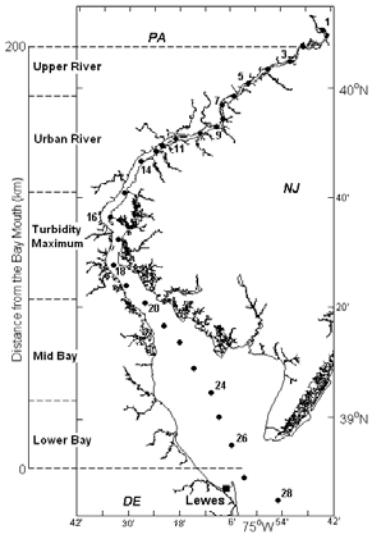

Temperature (°C)
BWS Water Temperature
a
Salinity
b
Sea Level (m)
Chlorophyll (µg L-1)
c
DO Saturation (%)
d
Turbidity (NTU)
e
Discharge (m3s-1)
f
07/06
07/16
07/26
08/05
08/15
08/25
09/04
09/14
09/24
10/04
Time

July 31, 2011

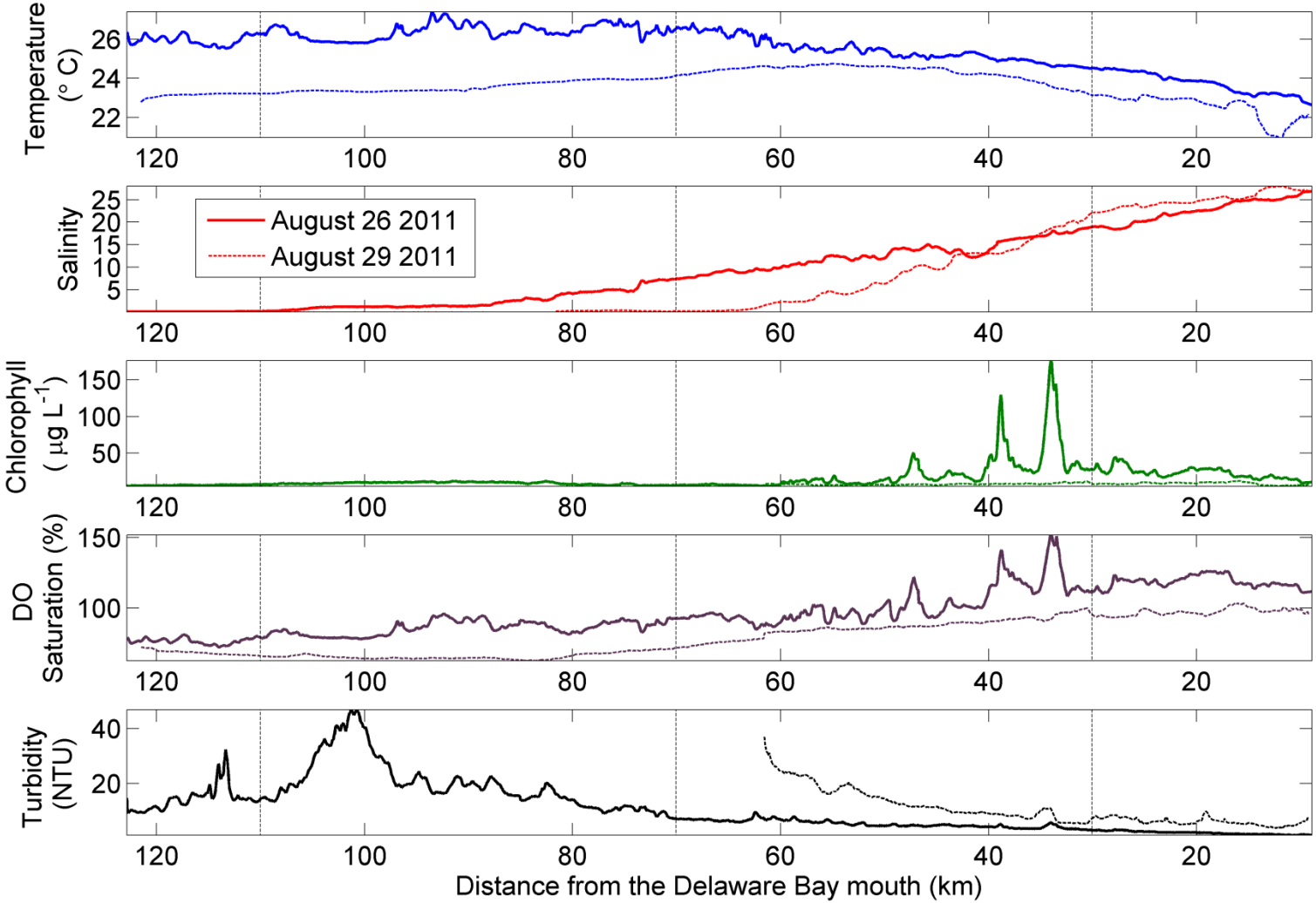

Temperature (°C)
Salinity
Chl (µg L-1)
DO Sat (%)
Turbidity (NTU)
Sea Level (m)
09:36
12:00
14:24
16:48
19:12
21:36
Time

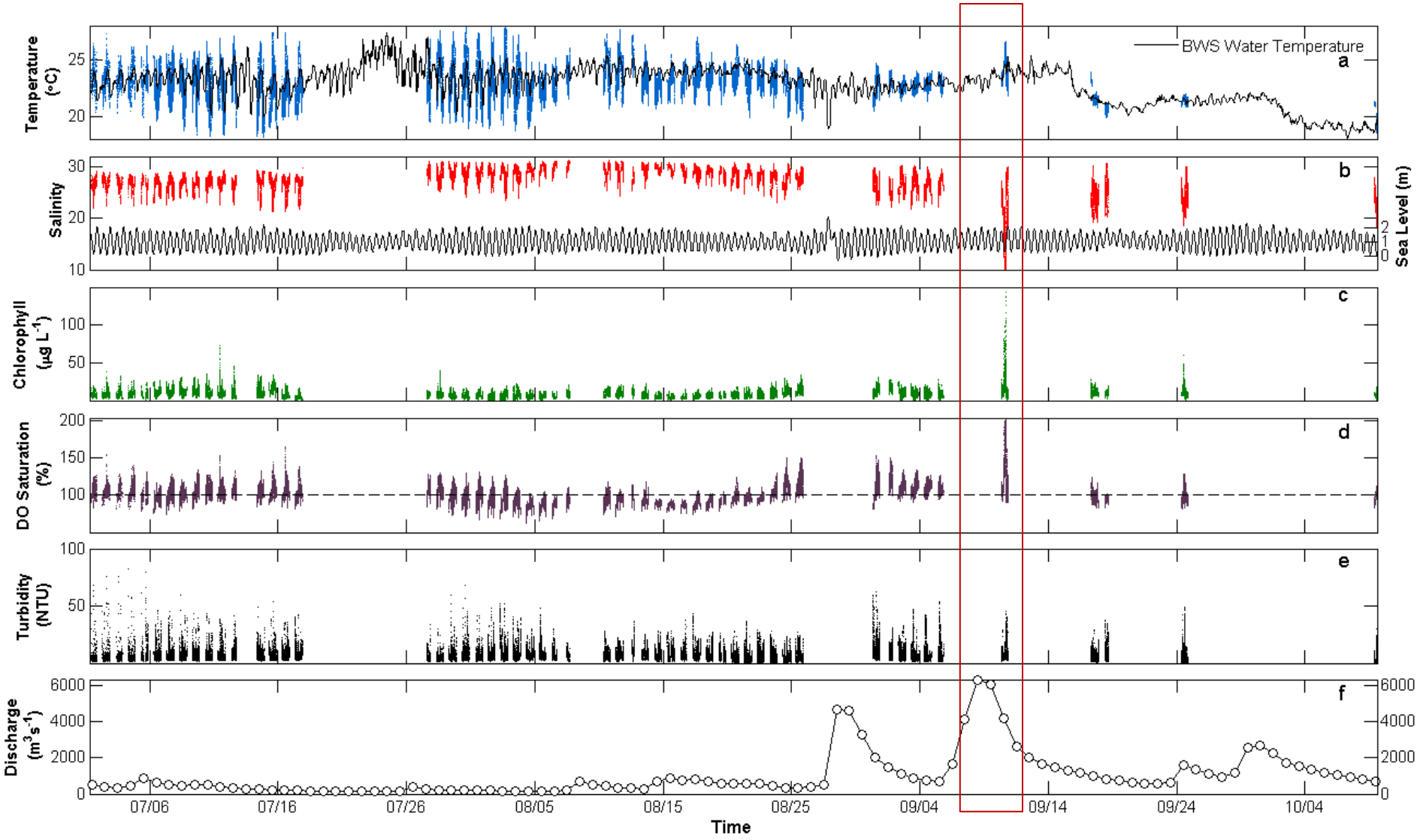
July 31, 2011

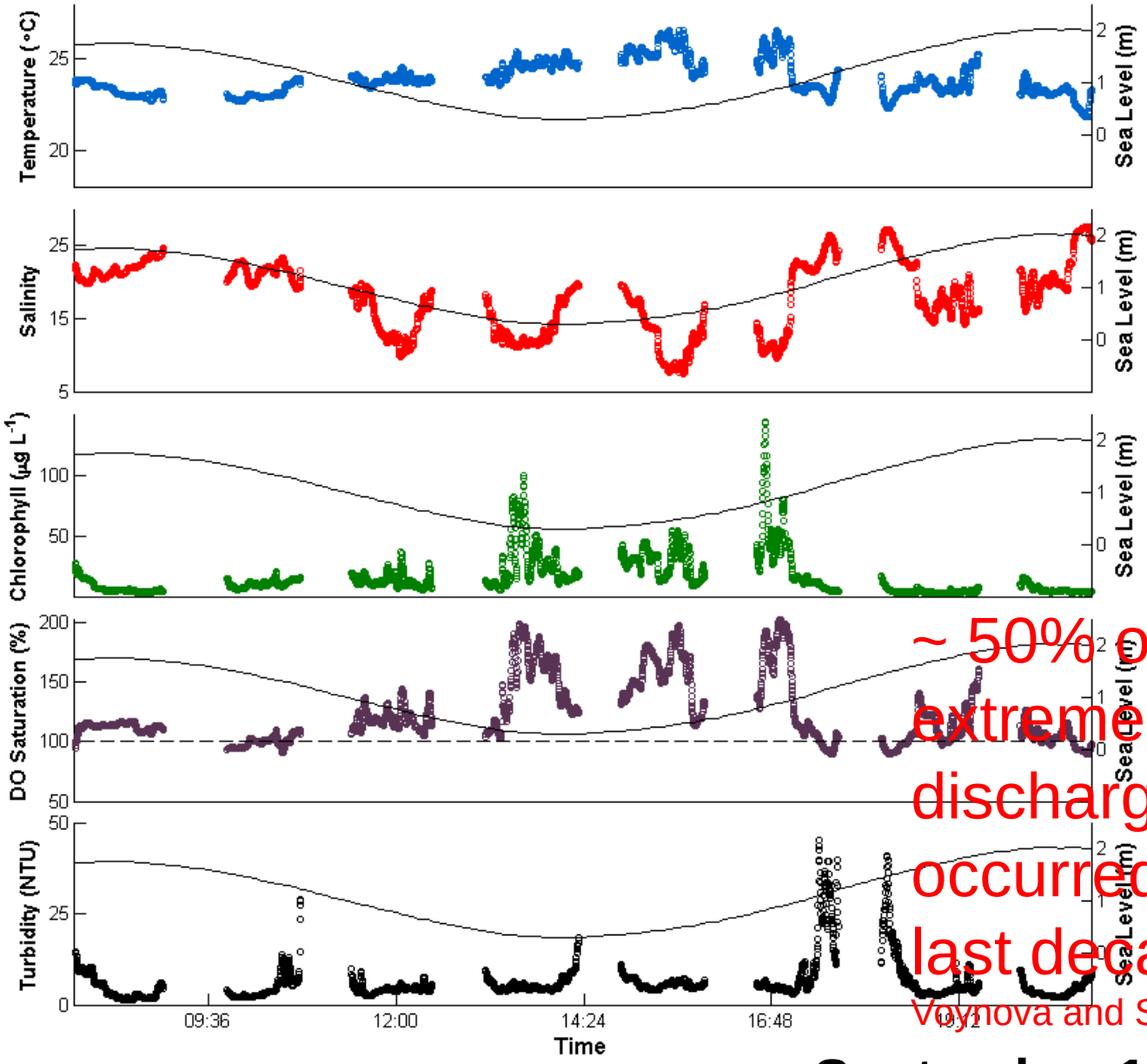

Temperature (°C)
25
20
BWS Water Temperature
a
Salinity
30
20
10
b
Sea Level (m)
2
1
0
Chlorophyll (µg L-1)
100
50
c
DO Saturation (%)
200
150
100
d
Turbidity (NTU)
100
50
e
Discharge (m3 s-1)
6000
4000
2000
0
f
07/06
07/16
07/26
08/05
08/15
08/25
09/04
09/14
09/24
10/04
Time



Before and after Hurricane Irene



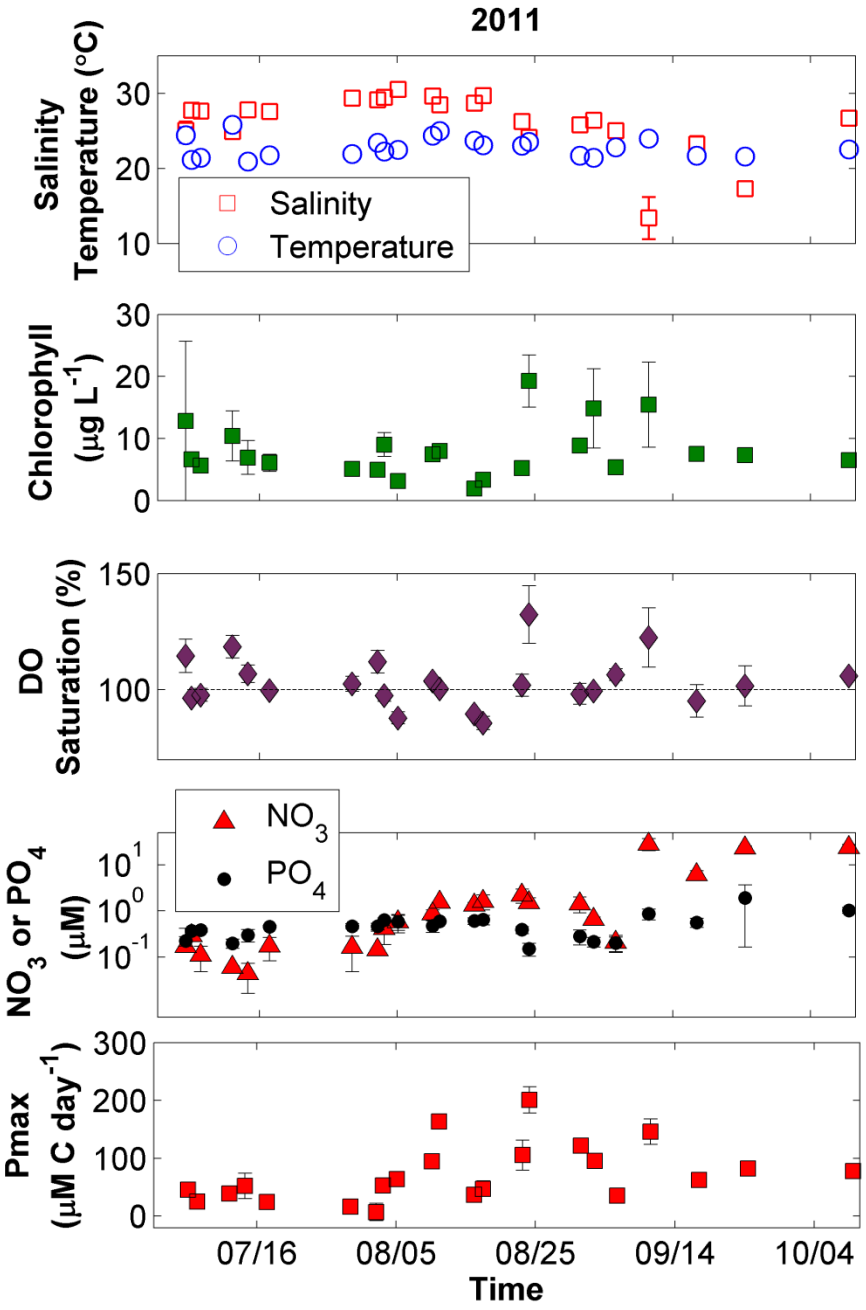

Temperature (°C)
BWS Water Temperature
a
Salinity
b
Sea Level (m)
Chlorophyll (μg L-1)
c
DO Saturation (%)
d
Turbidity (NTU)
e
Discharge (m3s-1)
f
07/06
07/16
07/26
08/05
08/15
08/25
09/04
09/14
09/24
10/04
Time



~ 50% of the extreme discharges occurred in the last decade

Vaynova and Sharp, 2012

September 10, 2011


2011
Salinity
Temperature (°C)
30
20
10
Salinity
Temperature
Chlorophyll
(µg L-1)
30
20
10
0
DO
Saturation (%)
150
100
NO3 or PO4
(µM)
NO3
PO4
10^1
10^0
10^-1
Pmax
(µM C day-1)
300
200
100
0
07/16
08/05
08/25
09/14
10/04
Time

- In the summer when discharge is low, upwelling controls lower bay biogeochemistry and sustains moderately high primary production

- Elevated discharge causes nutrient influx, and stimulates phytoplankton production and growth in the lower bay

- Cape May-Lewes Ferry is an excellent platform to study the lower bay biogeochemistry

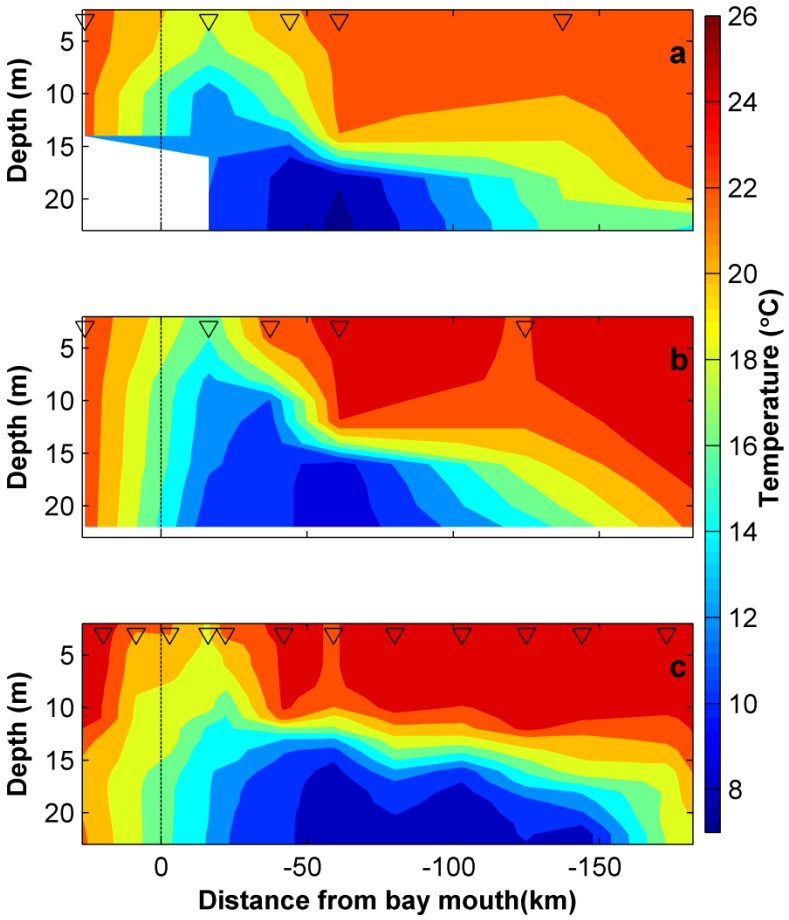
Acknowledgements

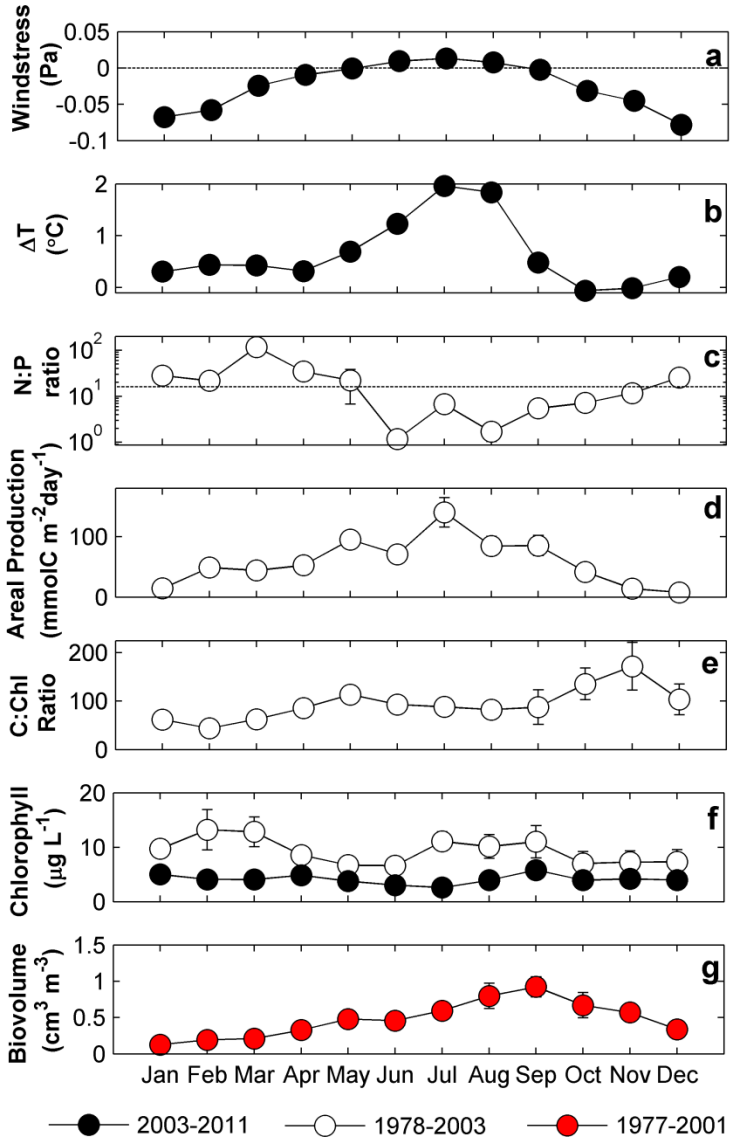
- Funding

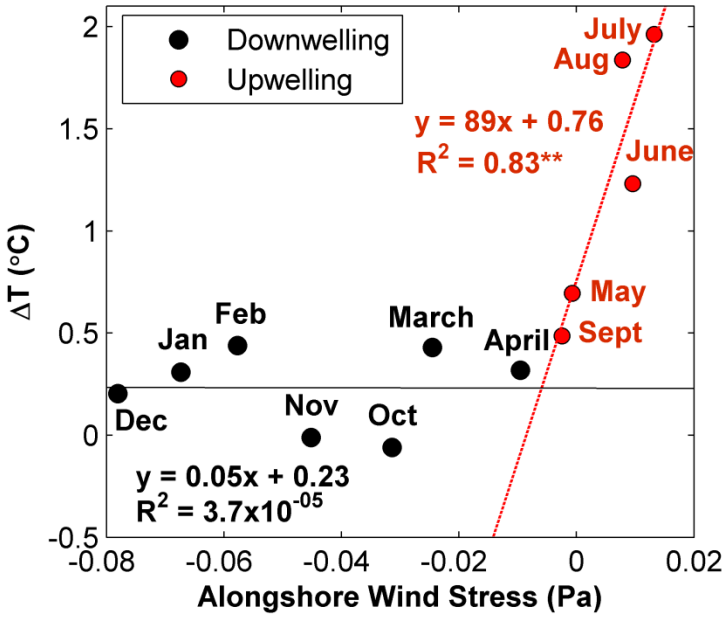
- Cape May-Lewes Ferry staff and crew
  - N. Fisher, H. Gehrke, R. Brown, J. Gillespie, B. Greenling

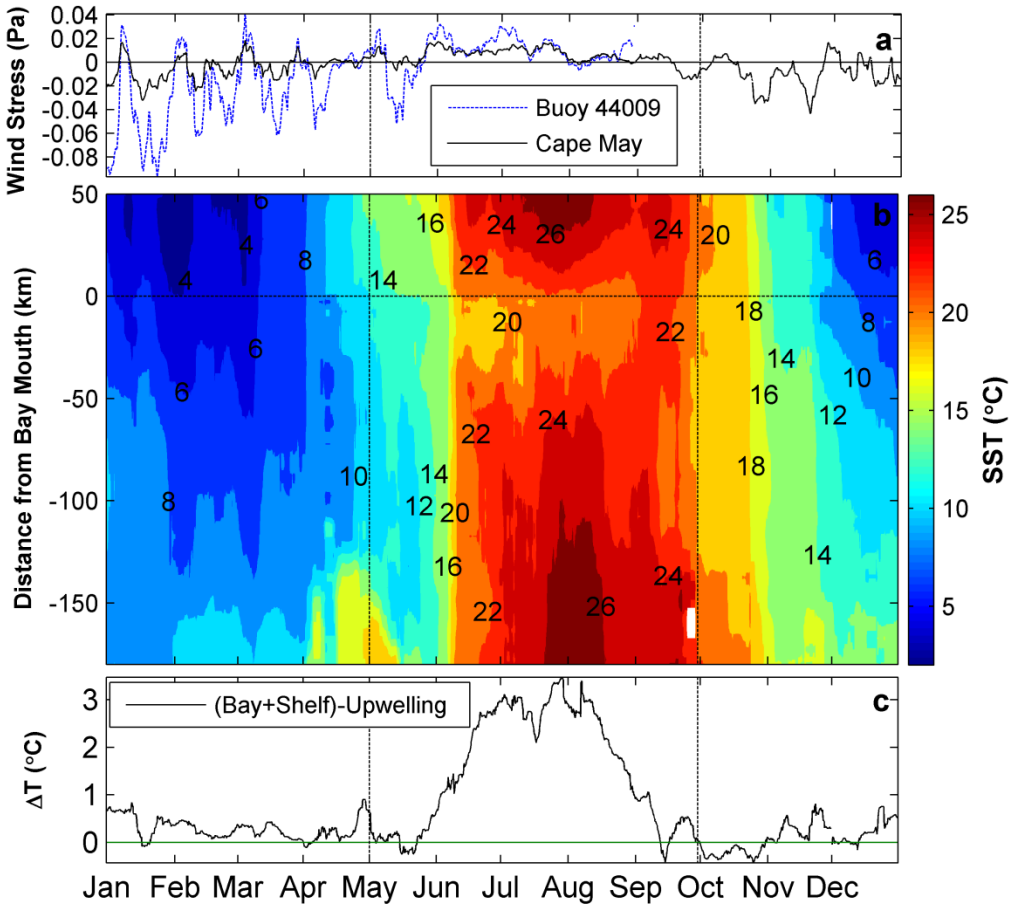
- Sharp Lab
  - A. Nelson, C. Thibodeaux, K. Peeler

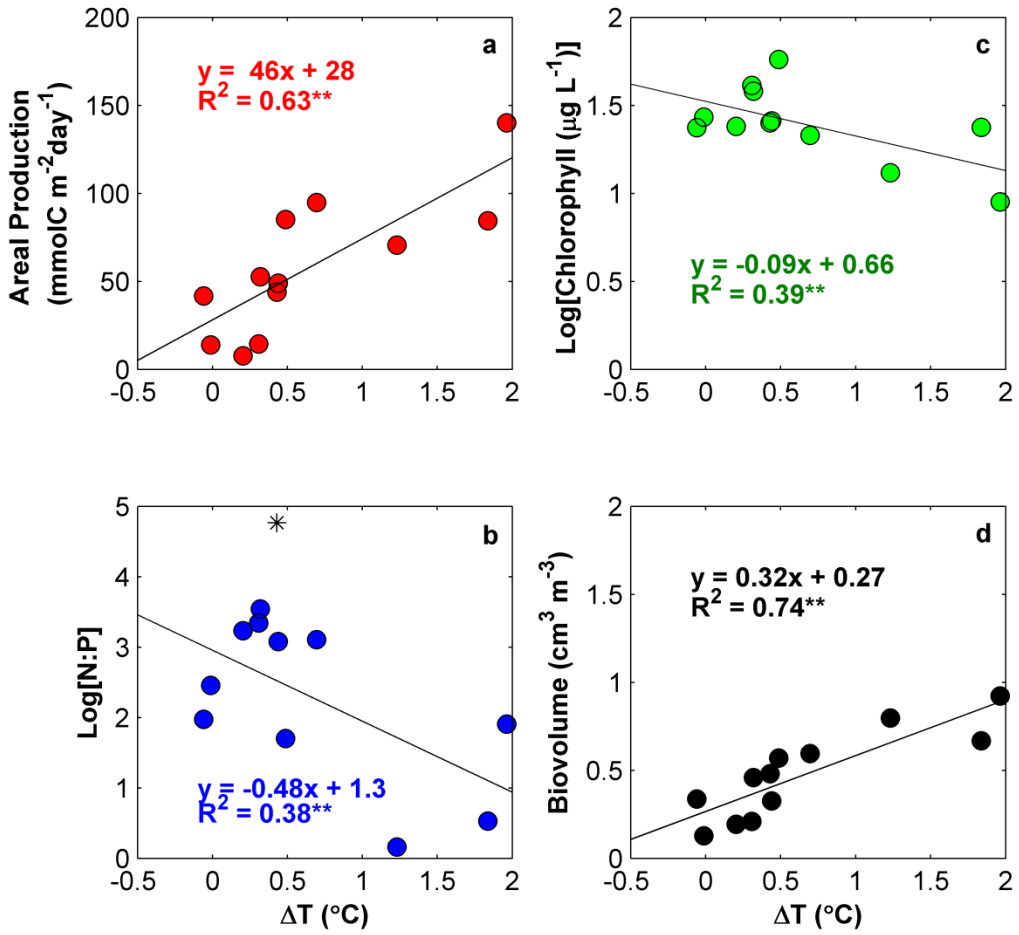
- Collaborators
  - M. Oliver, C. Heyer (YSI), C. Sommerfield, R. Chant (RU)
- *RV Hugh R. Sharp* crew & MOB staff
- M. Buckey, F. Pimenta, B. Ullman
- NOAA NDBC and NOAA PORTS


a
b
c
Depth (m)
5
10
15
20
0
-50
-100
-150
Distance from bay mouth(km)
Temperature (°C)
26
24
22
20
18
16
14
12
10
8

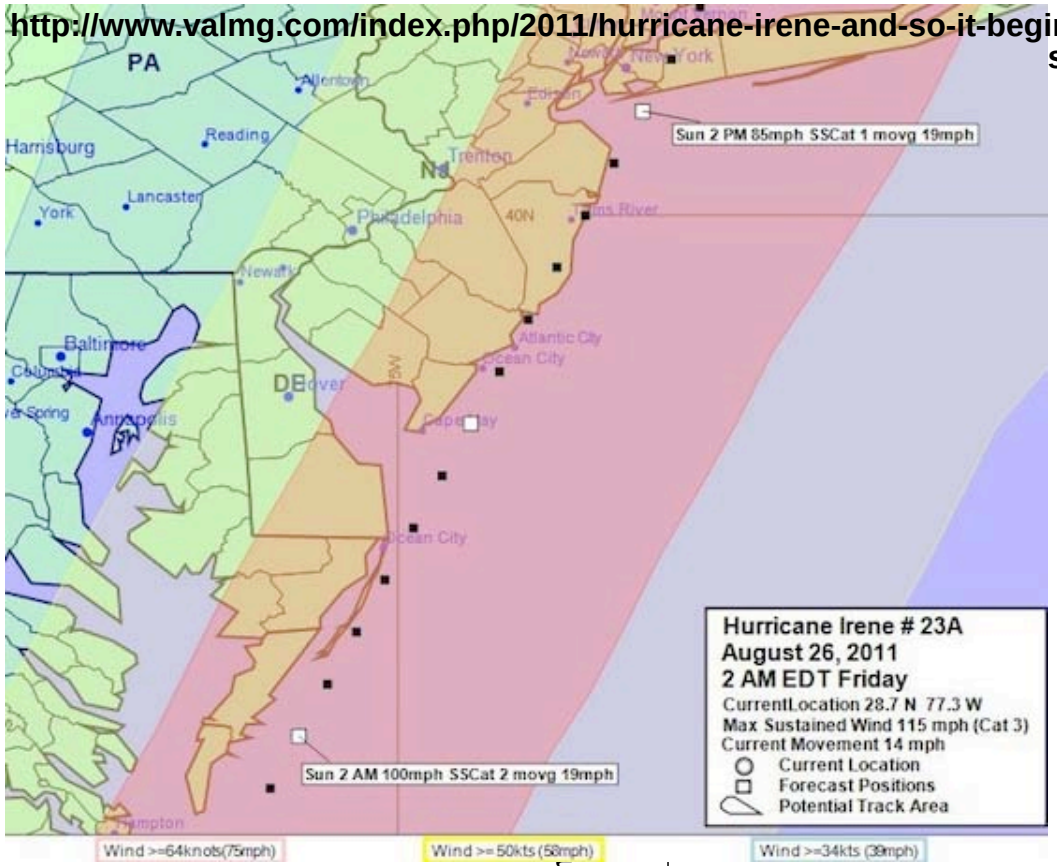

Windstress (Pa)
0.05
0
-0.05
-0.1
a
ΔT (°C)
2
1
0
b
N:P ratio
10^2
10^1
10^0
c
Areal Production (mmolC $m^{-2}day^{-1}$)
100
0
d
C:Chl Ratio
200
100
0
e
Chlorophyll ($\mu g\ L^{-1}$)
20
10
0
f
Biovolume ($cm^3\ m^{-3}$)
1.5
1
0.5
0
g
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2003-2011
1978-2003
1977-2001

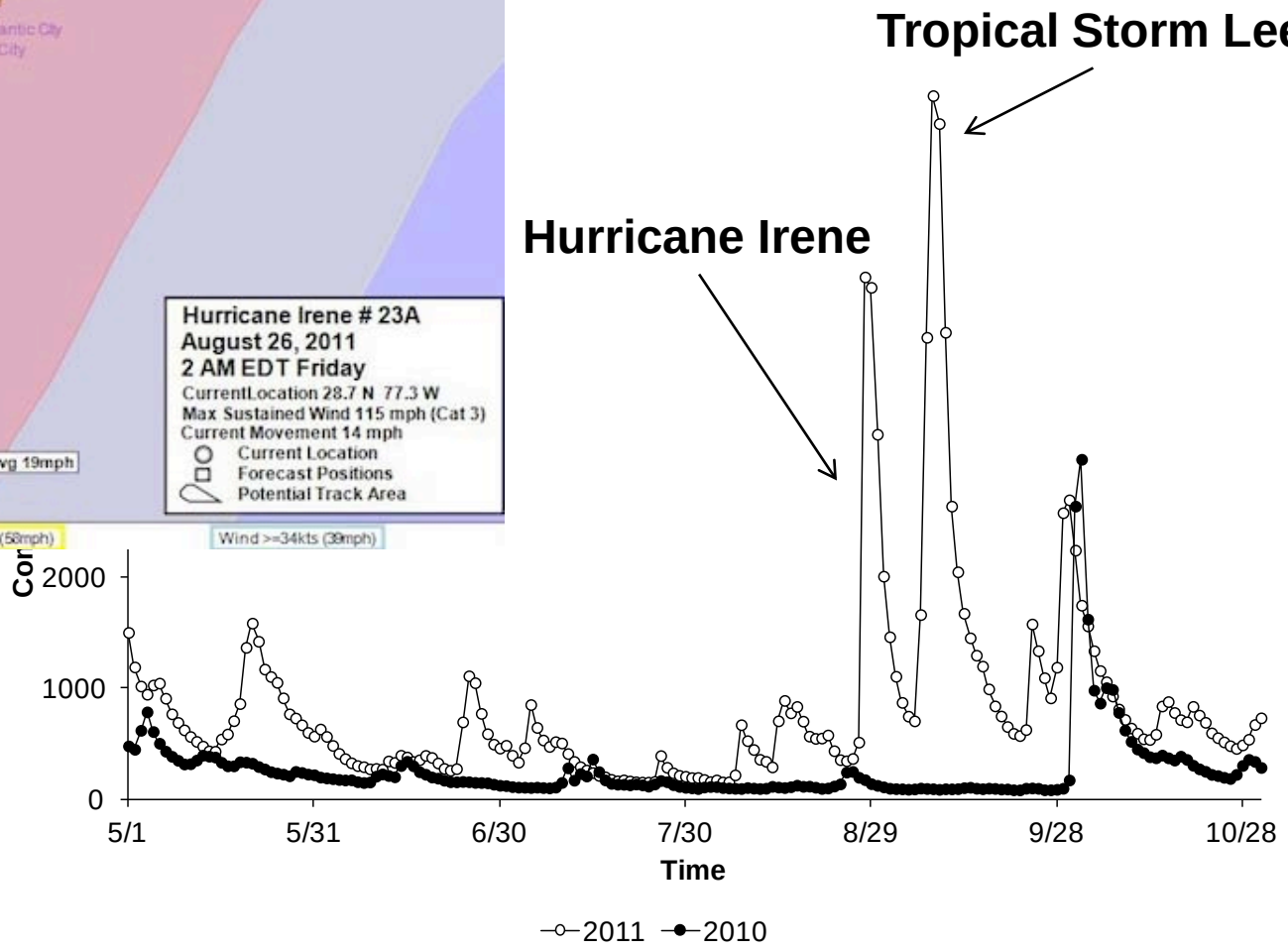

Downwelling
Upwelling
July
Aug
June
May
Sept
April
March
Feb
Jan
Dec
Nov
Oct
y = 89x + 0.76
R2 = 0.83**
y = 0.05x + 0.23
R2 = 3.7x10-05
ΔT (°C)
Alongshore Wind Stress (Pa)


Wind Stress (Pa)
Buoy 44009
Cape May
a
b
c
Distance from Bay Mouth (km)
SST (°C)
ΔT (°C)
(Bay+Shelf)-Upwelling
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec


a
y = 46x + 28
R2 = 0.63**
Areal Production (mmolC m-2day-1)
c
y = -0.09x + 0.66
R2 = 0.39**
Log[Chlorophyll (µg L-1)]
b
y = -0.48x + 1.3
R2 = 0.38**
Log[N:P]
ΔT (°C)
d
y = 0.32x + 0.27
R2 = 0.74**
Biovolume (cm3 m-3)
ΔT (°C)

http://www.valmg.com/index.php/2011/hurricane-irene-and-so-it-begins/sep11.jpg

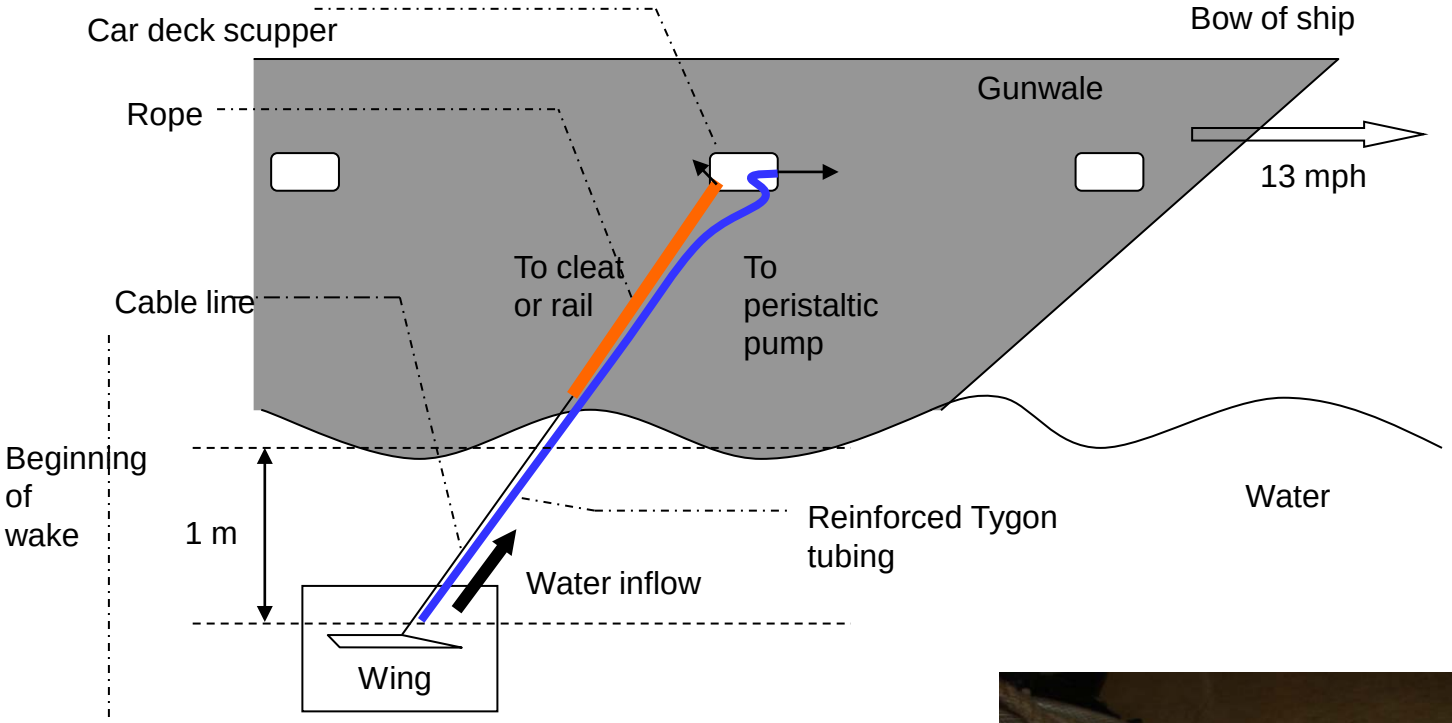


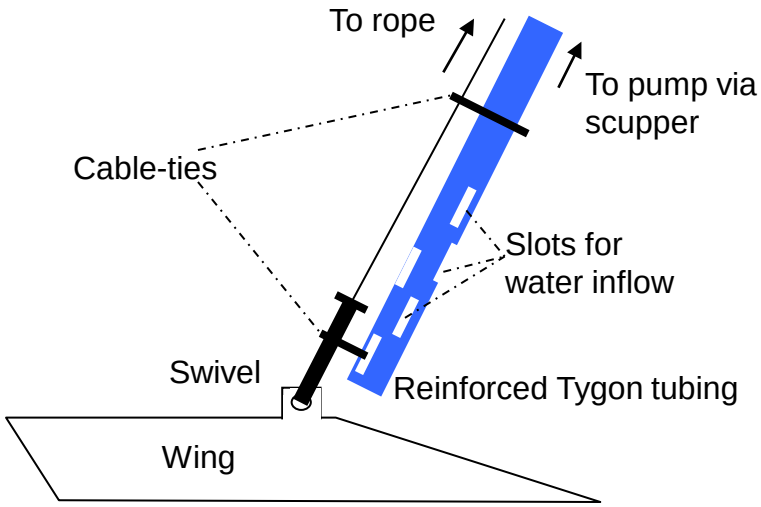


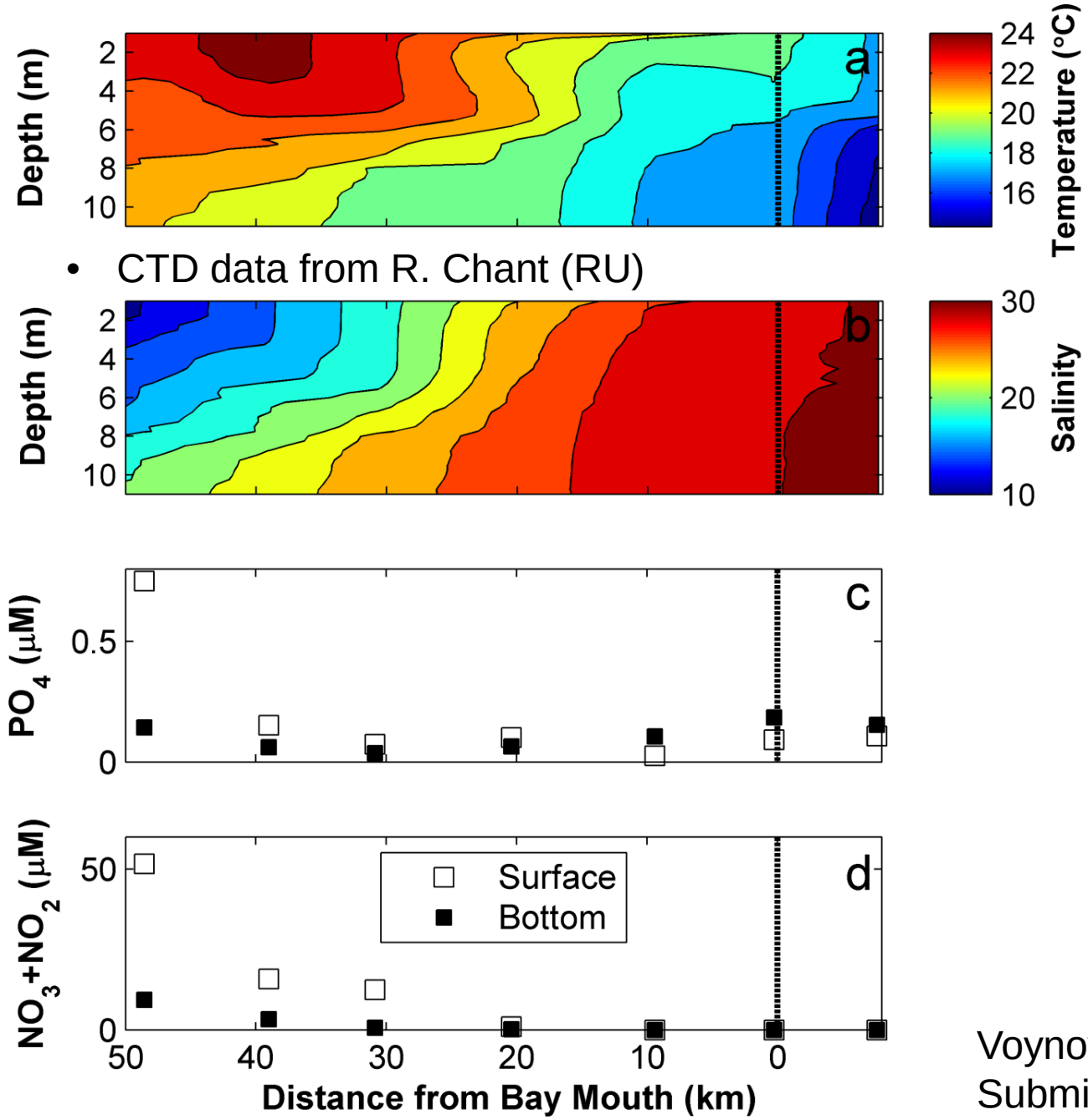
Very Large Discharges **Extreme Discharges**

Decades	>Average+3*SD		>Average+10*SD	
	Delaware	Schuylkill	Delaware	Schuylkill
10/1/1912–9/30/1921	70		1	
10/1/1921–9/30/1931	44		0	
10/1/1931–9/30/1941	71	61	6	4
10/1/1941–9/30/1951	71	47	1	3
10/1/1951–9/30/1961	66	54	2	3
10/1/1961–9/30/1971	16	35	0	0
10/1/1971–9/30/1981	77	80	0	6
10/1/1981–9/30/1991	53	55	0	1
10/1/1991–9/30/2001	69	71	0	2
10/1/2001–9/30/2011	113	105	12	13
Average for first 9 decades	60	58	1	3
Total number of discharges	650	508	22	32
% discharges in last decade	17	21	55	41
df	8	6	8	6
p value	0.0154	0.0124	0.0004	0.0014

Voynova and Sharp, 2012


Car deck scupper
Bow of ship
Gunwale
Rope
13 mph
To cleat
or rail
To
peristaltic
pump
Cable line
Beginning
of
wake
1 m
Water
Reinforced Tygon
tubing
Water inflow
Wing


To rope
To pump via
scupper
Cable-ties
Slots for
water inflow
Swivel
Reinforced Tygon tubing
Wing



- CTD data from R. Chant (RU)

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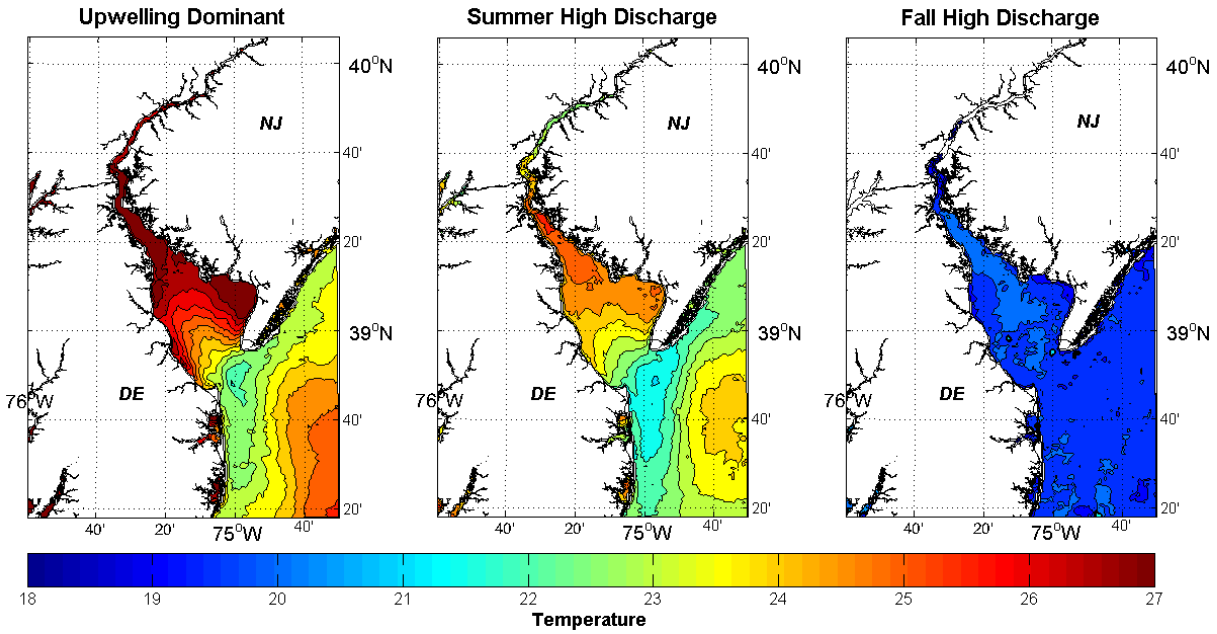
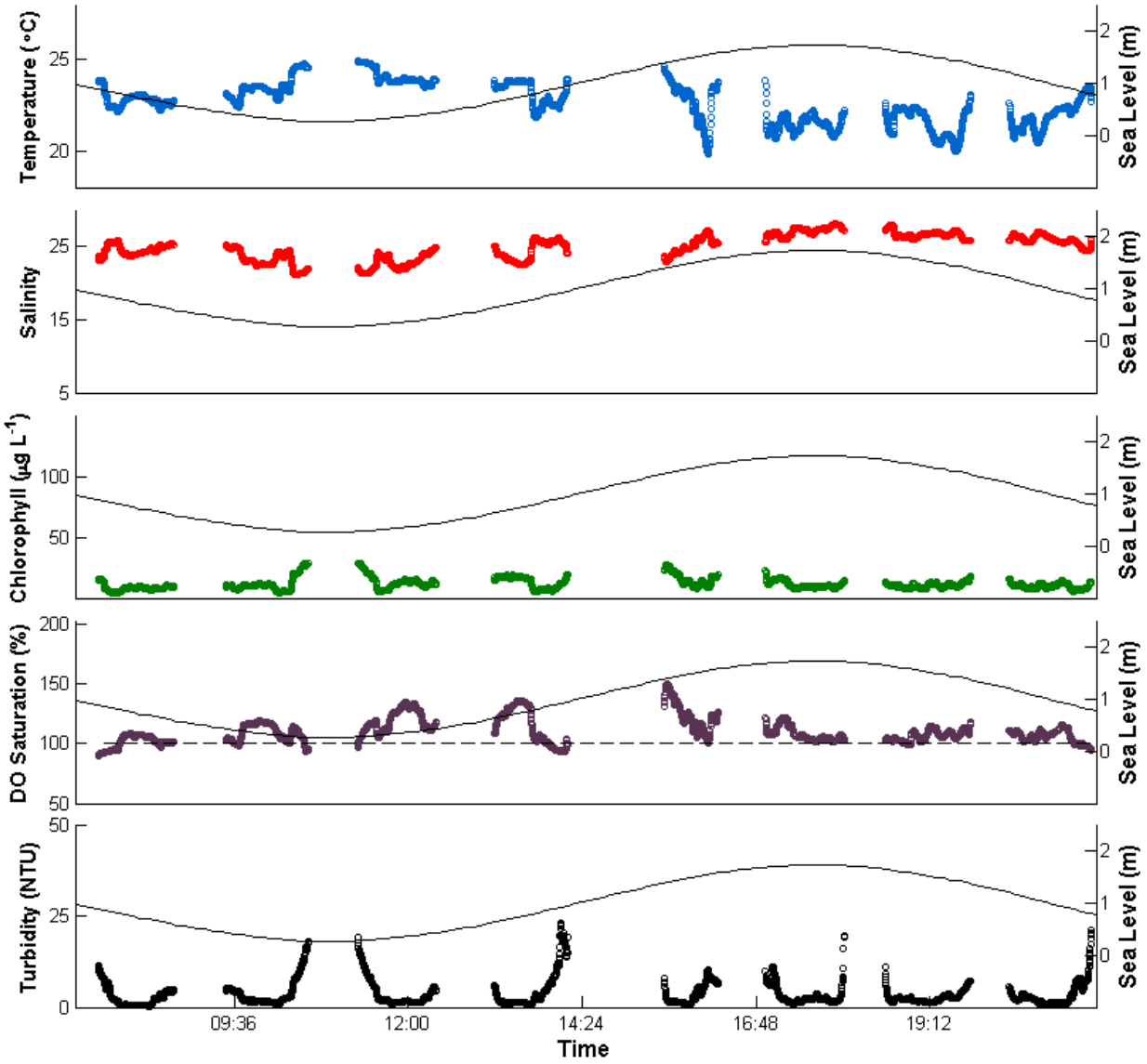
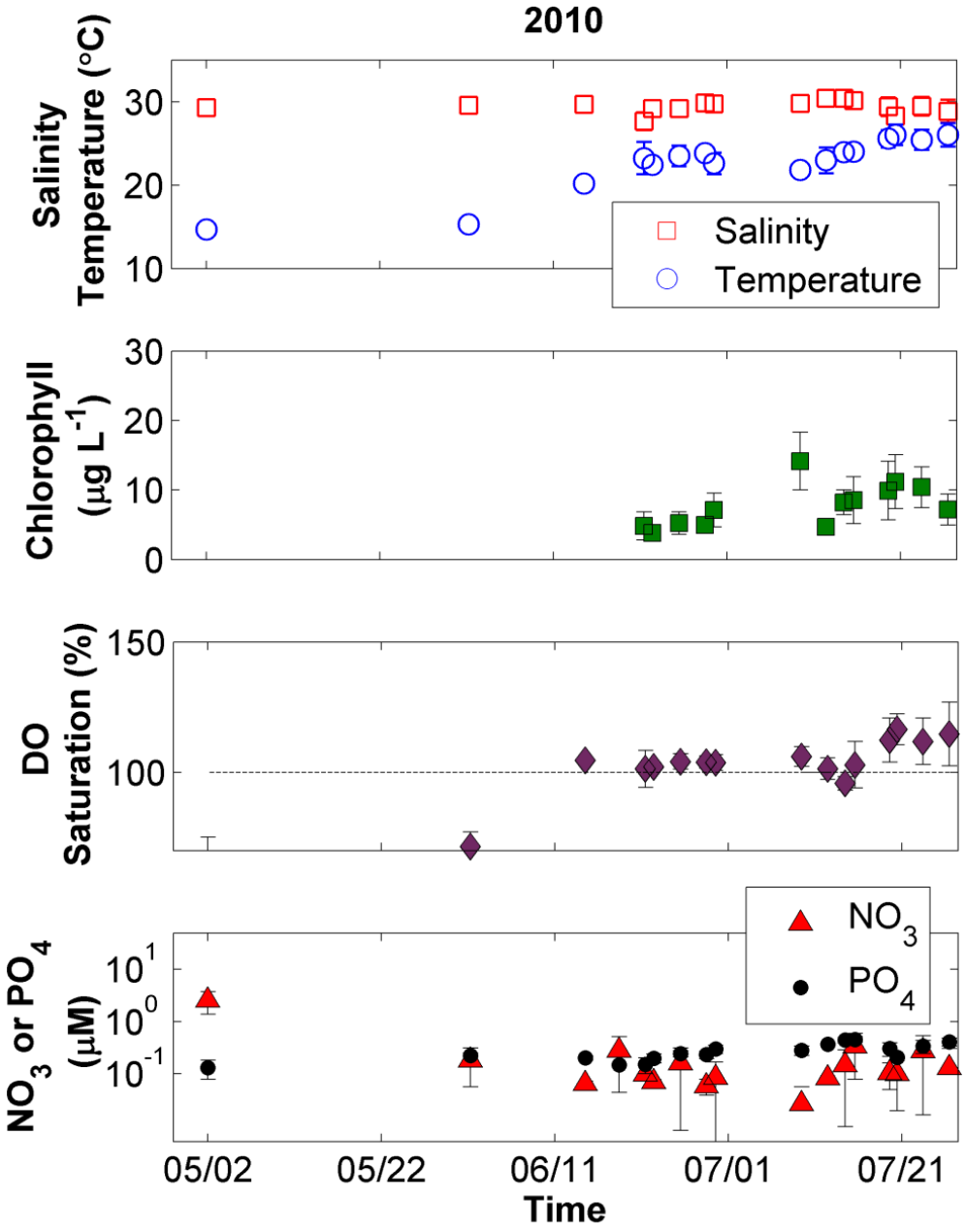
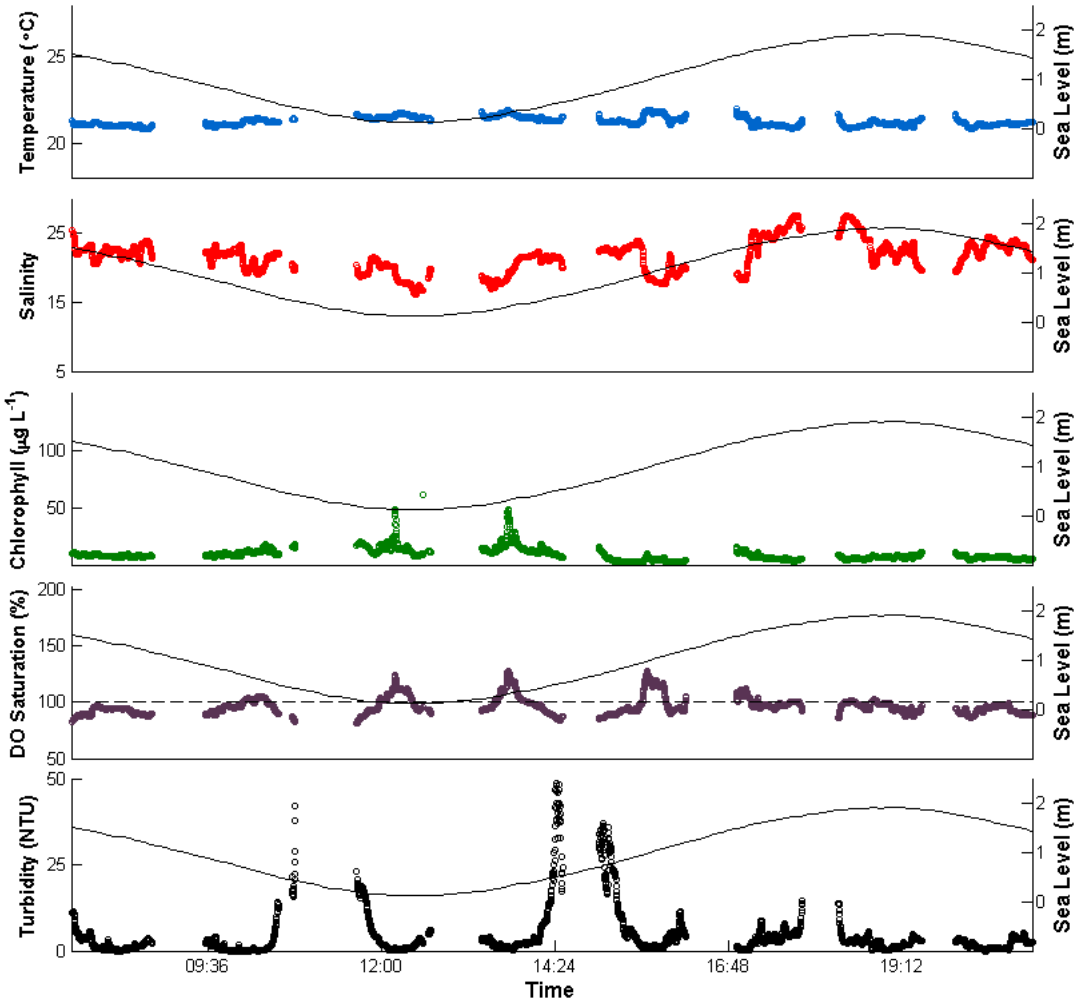


Season	Time Interval	Start Date	End Date	Combined Discharge ($m^3\ s^{-1}$)
Summer	**Upwelling Dominant**	July 1	Aug 10	345
	High Discharge	Aug 11	Sept 5	1264
	Extreme Discharge	Sept 6	Sept 10	4487
Fall	**High Discharge**	Sept 11	Oct 9	1319


Temperature (°C)
25
20
Sea Level (m)
2
1
0
Salinity
25
15
5
Chlorophyll (μg L-1)
100
50
DO Saturation (%)
200
150
100
50
Turbidity (NTU)
50
25
0
09:36
12:00
14:24
16:48
19:12
Time


2010
Salinity
Temperature (°C)
30
20
10
Salinity
Temperature
Chlorophyll
(µg L-1)
30
20
10
0
DO
Saturation (%)
150
100
NO3 or PO4
(µM)
10^1
10^0
10^-1
NO3
PO4
05/02
05/22
06/11
07/01
07/21
Time


Temperature (°C)
25
20
Salinity
25
15
5
Chlorophyll (µg L-1)
100
50
DO Saturation (%)
200
150
100
50
Turbidity (NTU)
50
25
0
Sea Level (m)
2
1
0
09:36
12:00
14:24
16:48
19:12
Time