The Wind Effect on Chesapeake Bay Destratification and Hypoxia

Ping Wang, Harry Wang,
Lewis Linker & Richard Tian

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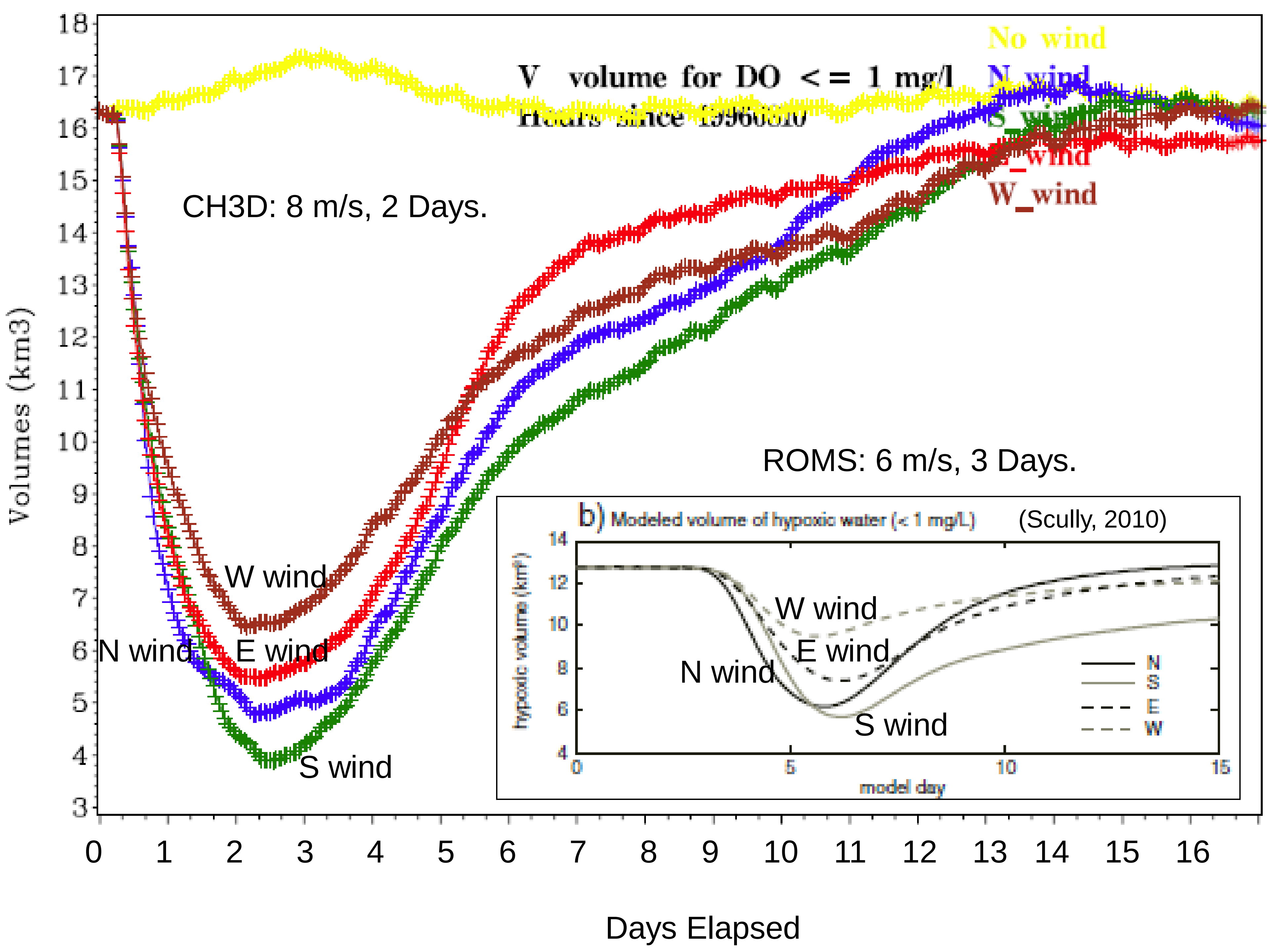
Introduction

- The effect of wind on circulation and Chesapeake Bay anoxia has been recognized by several researchers, however, different opinions exist on the extents of wind’s effect: e.g., the inter-annual variability of hypoxia is mainly controlled by wind or by nutrient loads.

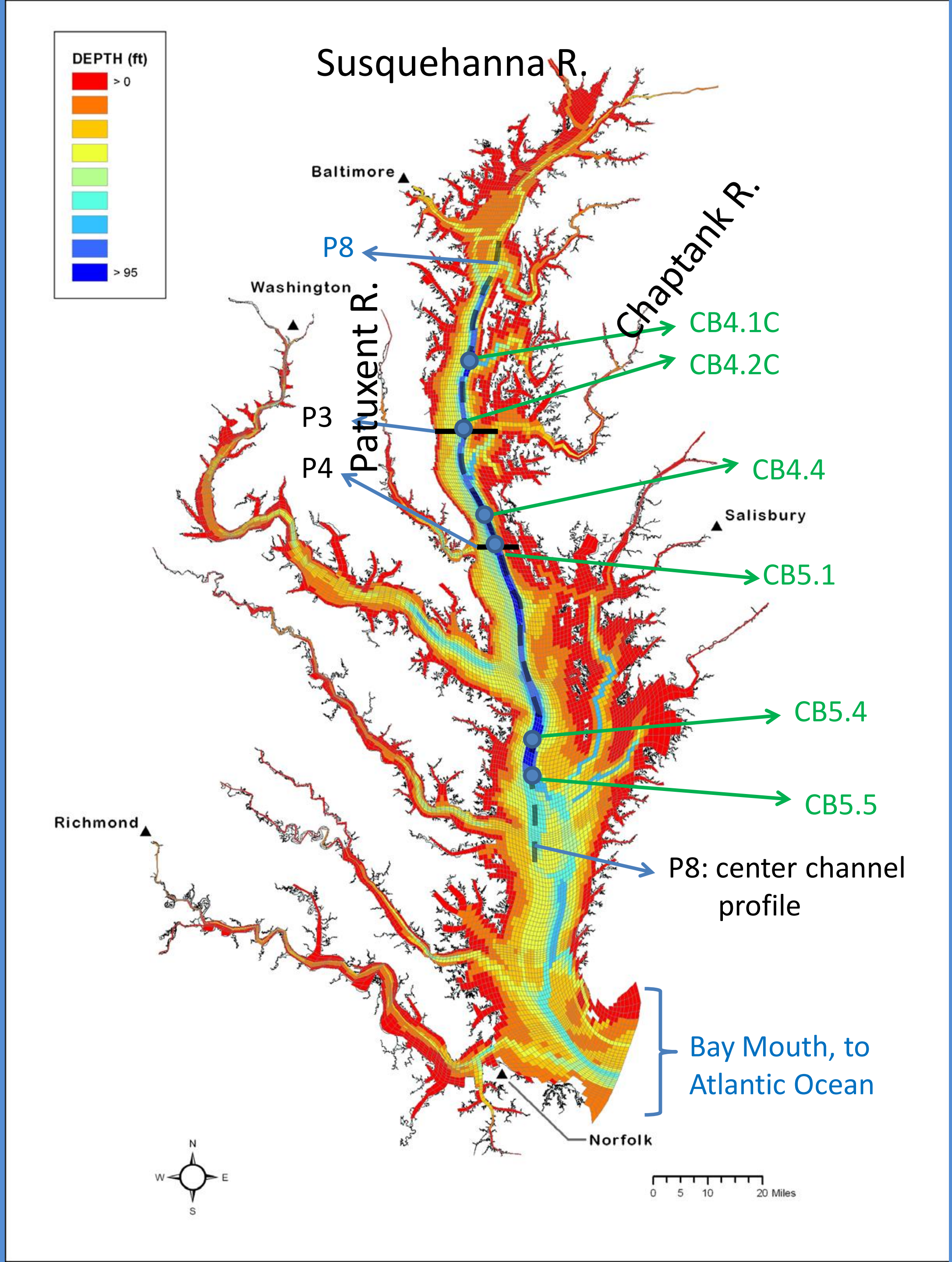
* How do the observed data and the simulations by the Chesapeake Bay regulatory model, i.e., the coupled CH3D_hydrodynamic & ICM_WQSTM, indicate the wind effect on hypoxia?

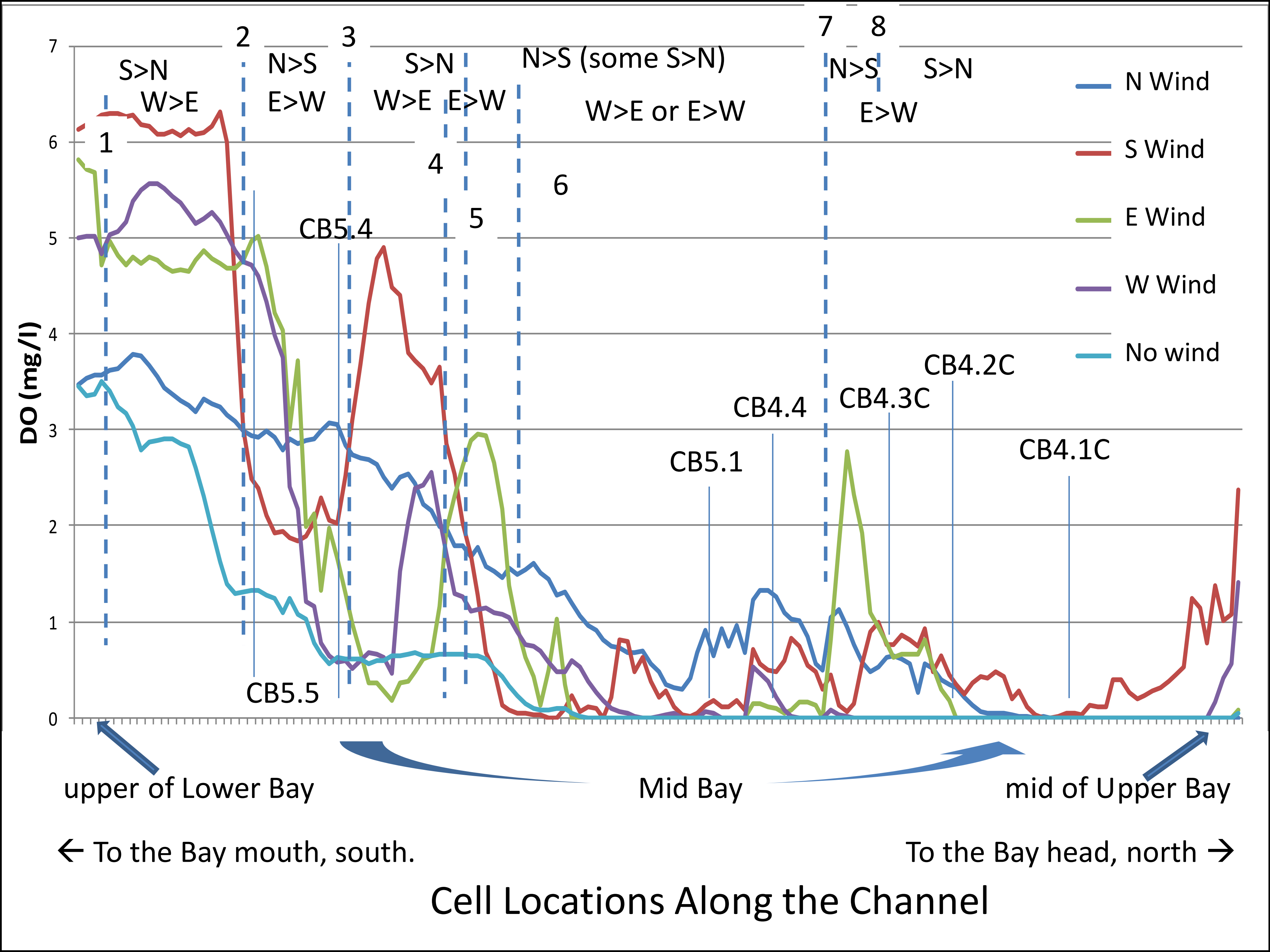
Findings

- Wind can significantly erode destratification and hypoxia.
- Under a specific wind speed, destratification and hypoxia reduction are different by different wind directions. Longitudinal and cross-channel speeds, and channel bathymetry play significant roles.
- The extents of eroding stratification and hypoxia by different wind directions diff, however, strengths of wind, i.e., speed, is more important.
- The inter-annual variability of hypoxia is mainly controlled by nutrient load, while episodic winds cause hypoxia variation in different sampling cruises or months in a summer.

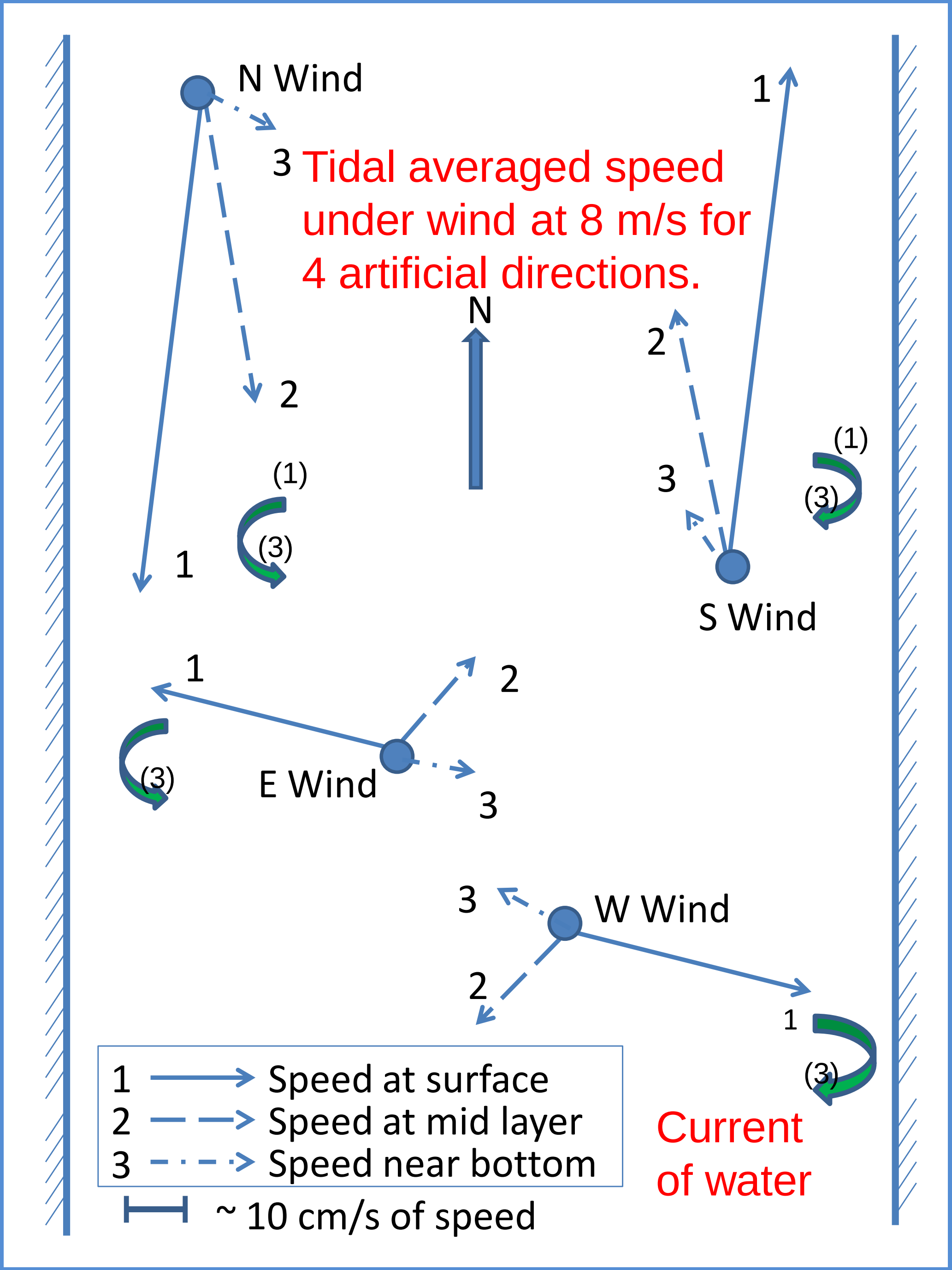


V volume for DO <= 1 mg/l
No wind
N_wind
S_wind
E_wind
W_wind
CH3D: 8 m/s, 2 Days.
ROMS: 6 m/s, 3 Days.
W wind
N wind
E wind
S wind
Volumes (km3)
Days Elapsed
b) Modeled volume of hypoxic water (< 1 mg/L)
(Scully, 2010)
hypoxic volume (km³)
model day
N
S
E
W

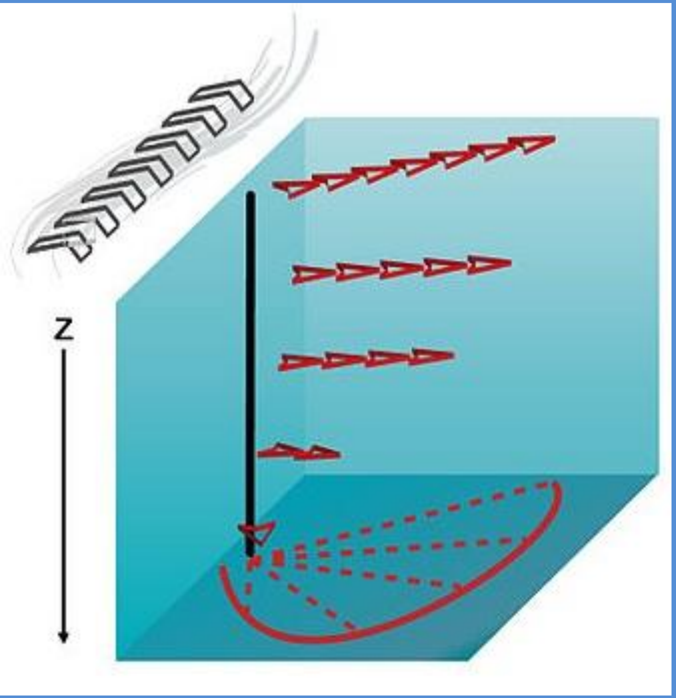

DEPTH (ft)
> 0
> 95
Susquehanna R.
Baltimore
P8
Washington
Patuxent R.
Chaptank R.
CB4.1C
CB4.2C
P3
P4
CB4.4
Salisbury
CB5.1
CB5.4
CB5.5
Richmond
P8: center channel profile
Bay Mouth, to Atlantic Ocean
Norfolk
N
W
E
S
0 5 10 20 Miles

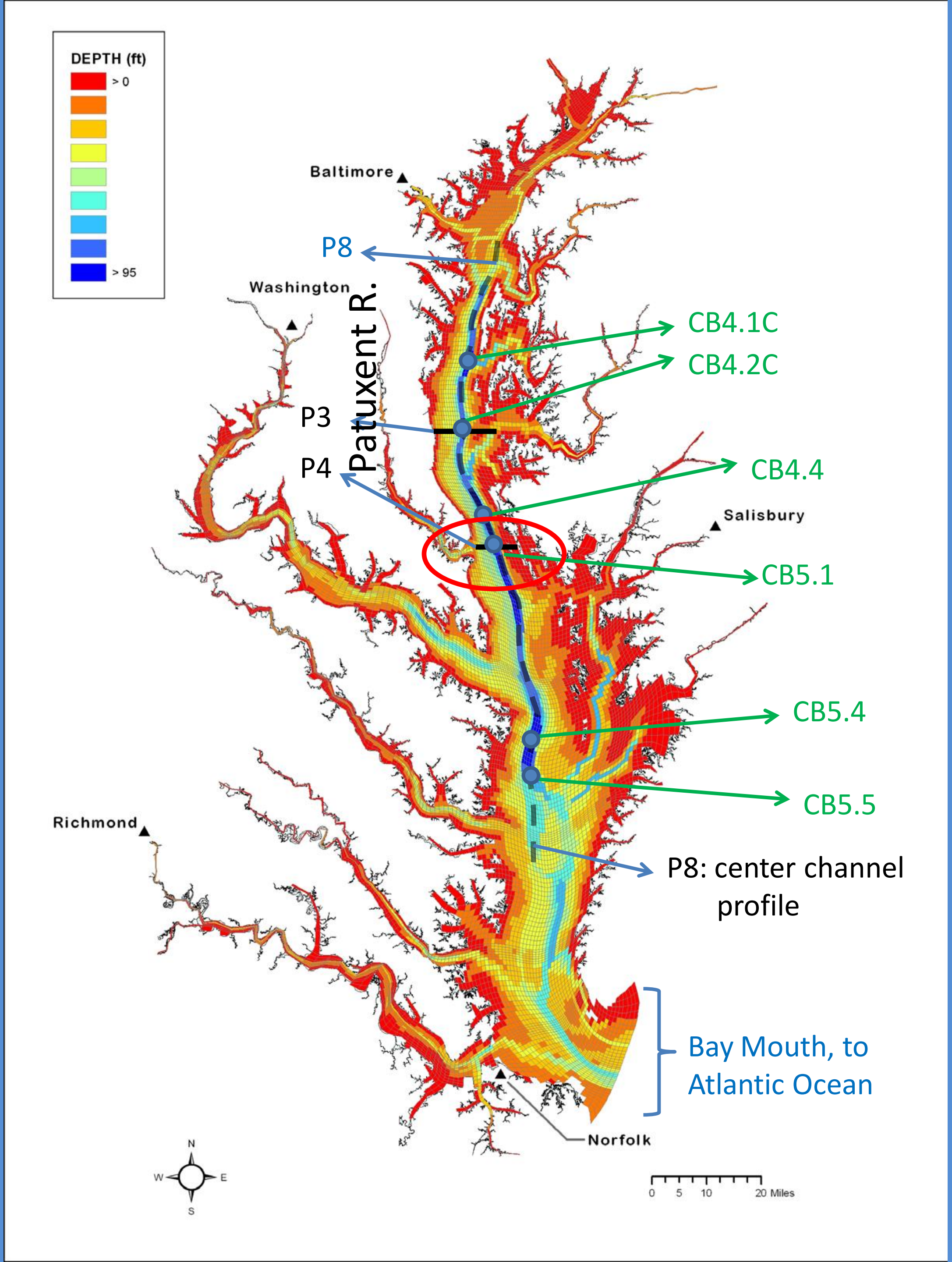


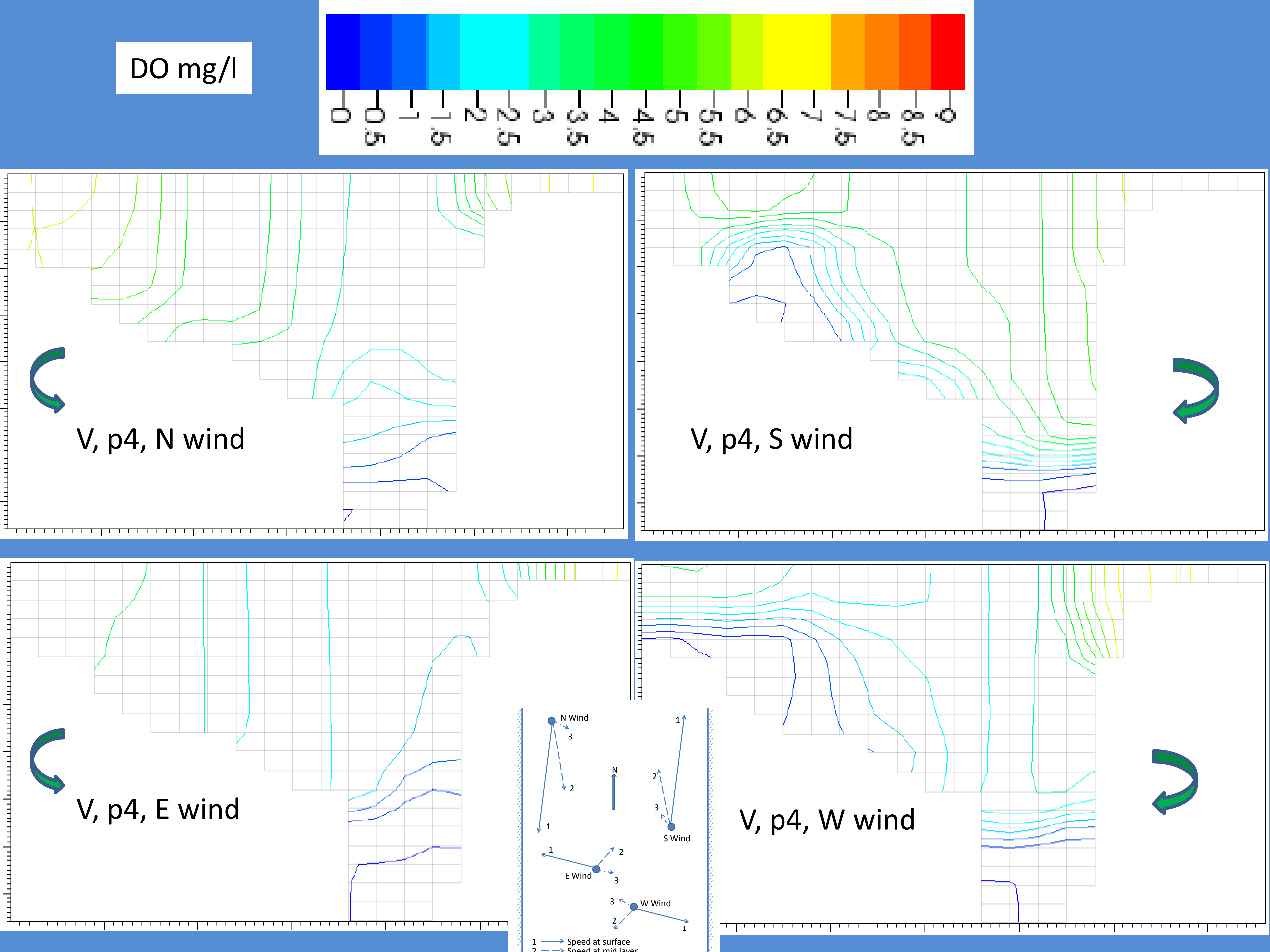
DO (mg/l)
0
1
2
3
4
5
6
7
1
2
3
4
5
6
7
8
S>N
W>E
N>S
E>W
S>N
W>E
E>W
N>S (some S>N)
W>E or E>W
N>S
E>W
S>N
CB5.4
CB5.5
CB5.1
CB4.4
CB4.3C
CB4.2C
CB4.1C
N Wind
S Wind
E Wind
W Wind
No wind
upper of Lower Bay
Mid Bay
mid of Upper Bay
← To the Bay mouth, south.
To the Bay head, north →
Cell Locations Along the Channel

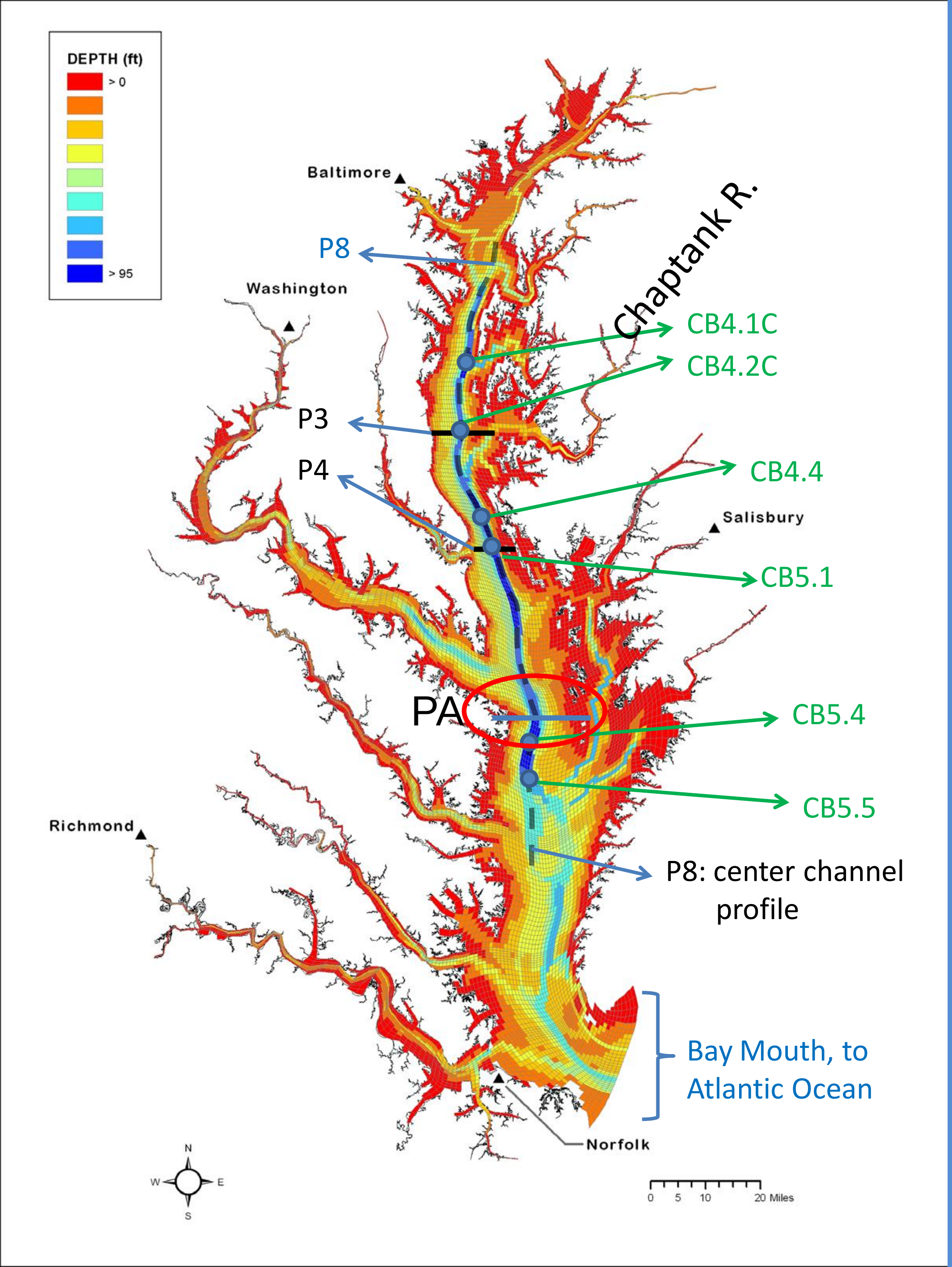


The direction of bottom current is mainly controlled by return flow from the bank besides the estuarine circulation, instead of the Ekman spiral. Therefore, channel bathymetry has significant effect on cross channel circulation.

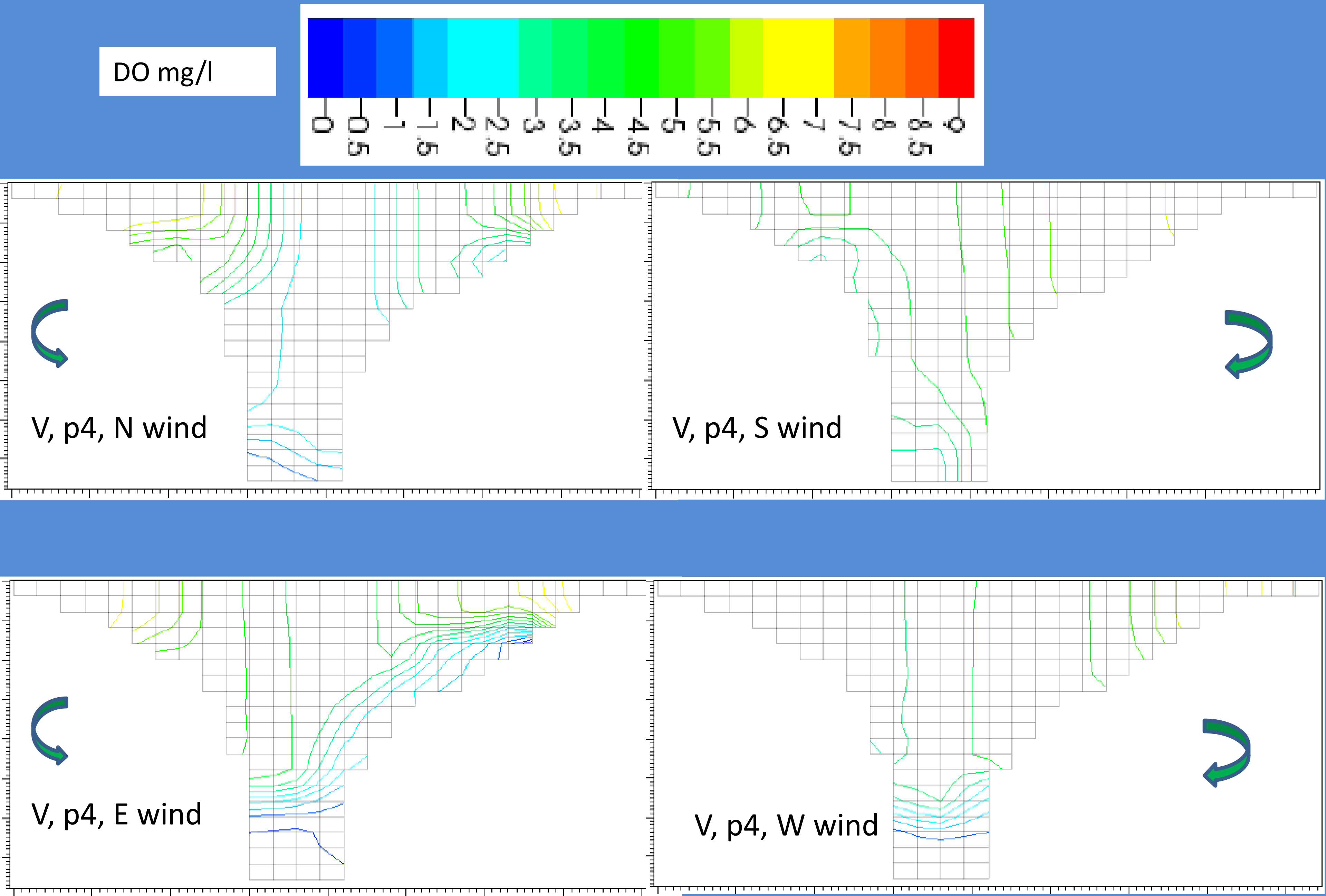


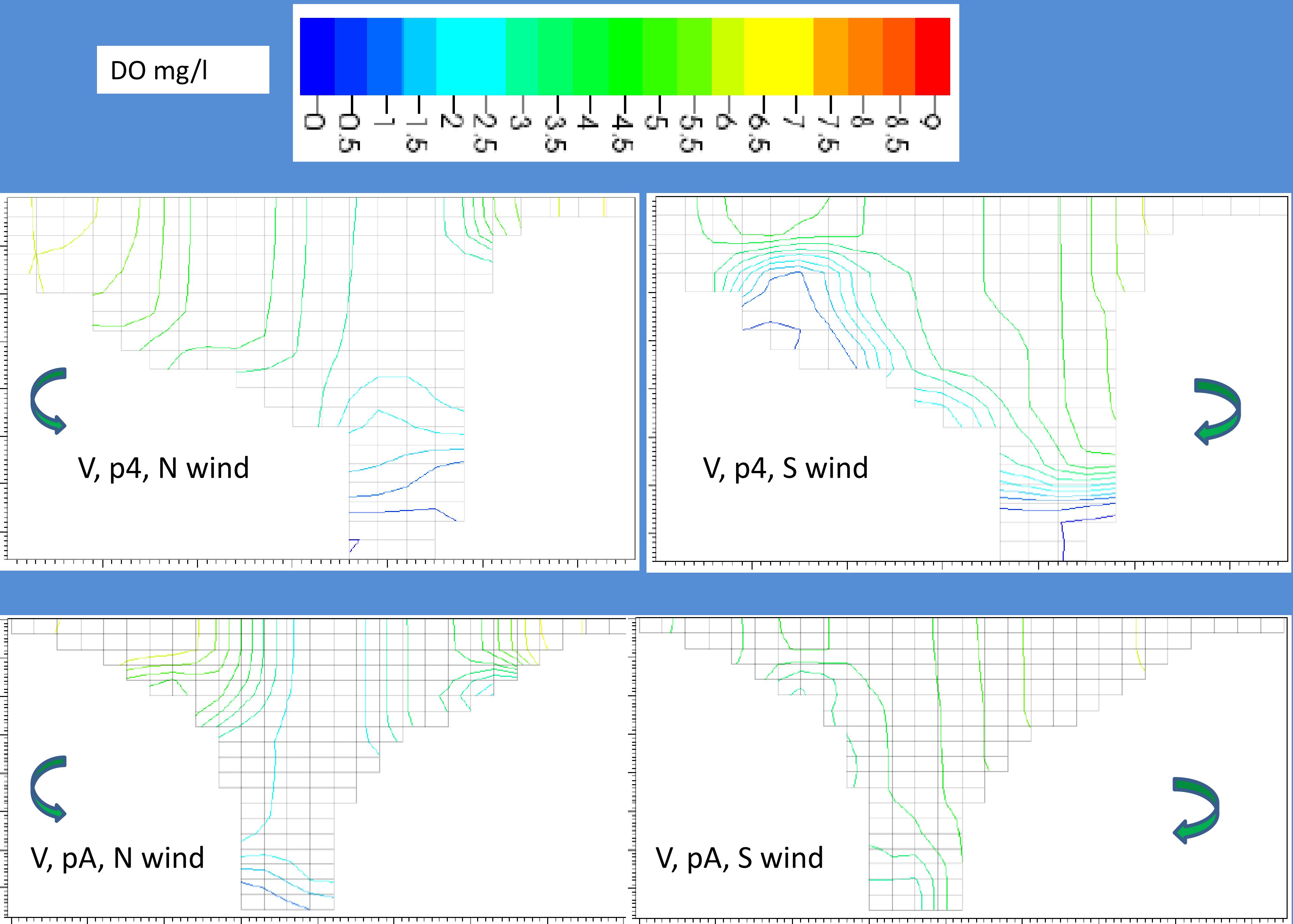

DEPTH (ft)
> 0
> 95
Baltimore
Washington
Patuxent R.
P8
CB4.1C
CB4.2C
P3
P4
CB4.4
Salisbury
CB5.1
CB5.4
CB5.5
Richmond
P8: center channel profile
Bay Mouth, to Atlantic Ocean
Norfolk
N
W
E
S
0 5 10 20 Miles


DO mg/l
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
V, p4, N wind
V, p4, S wind
V, p4, E wind
V, p4, W wind
N Wind
S Wind
E Wind
W Wind
N
1 Speed at surface

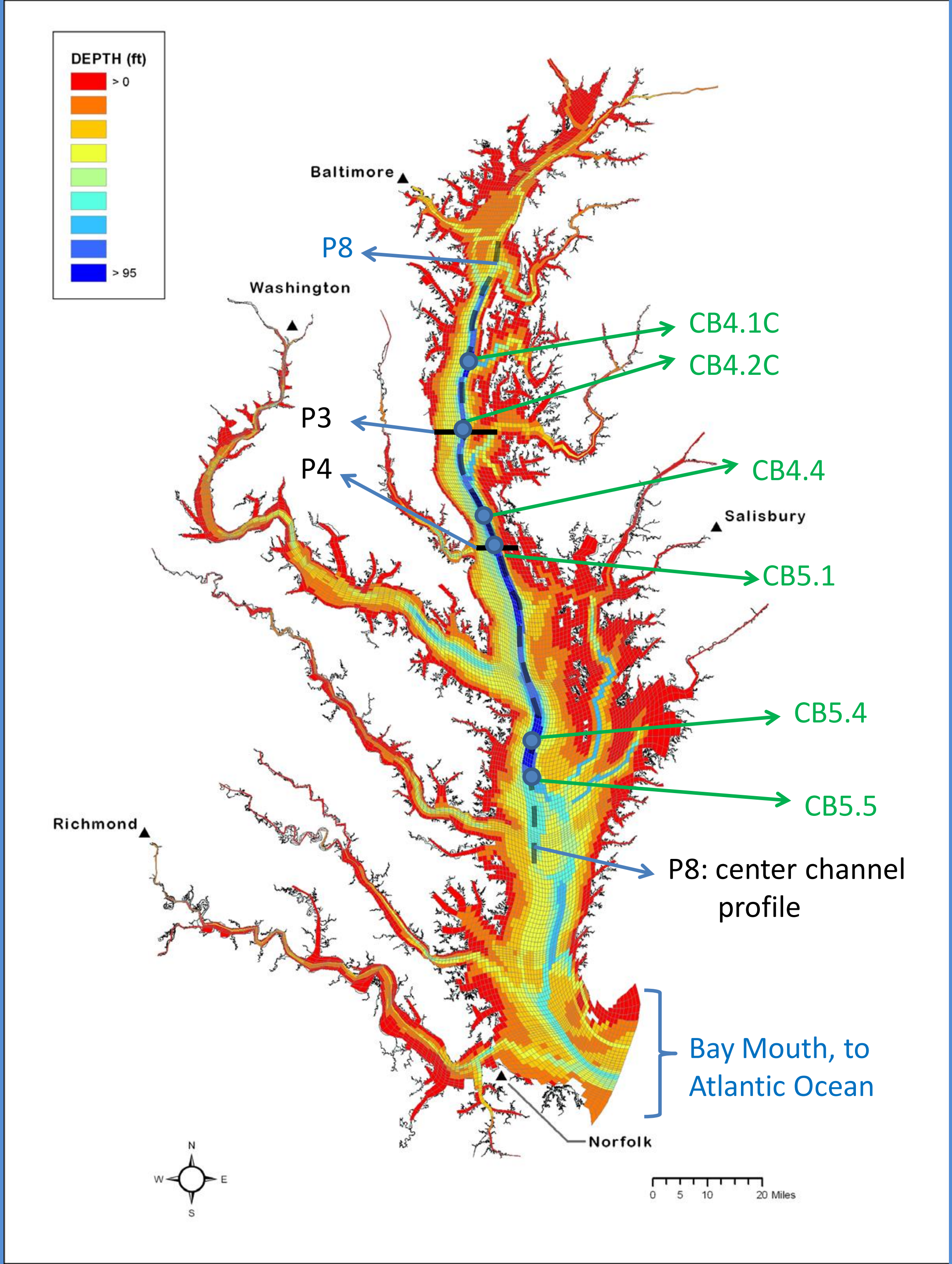


DEPTH (ft)
> 0
> 95
Baltimore
Washington
Salisbury
Richmond
Norfolk
Chaptank R.
P8
CB4.1C
CB4.2C
P3
P4
CB4.4
CB5.1
PA
CB5.4
CB5.5
P8: center channel profile
Bay Mouth, to Atlantic Ocean
N
W
E
S
0 5 10 20 Miles

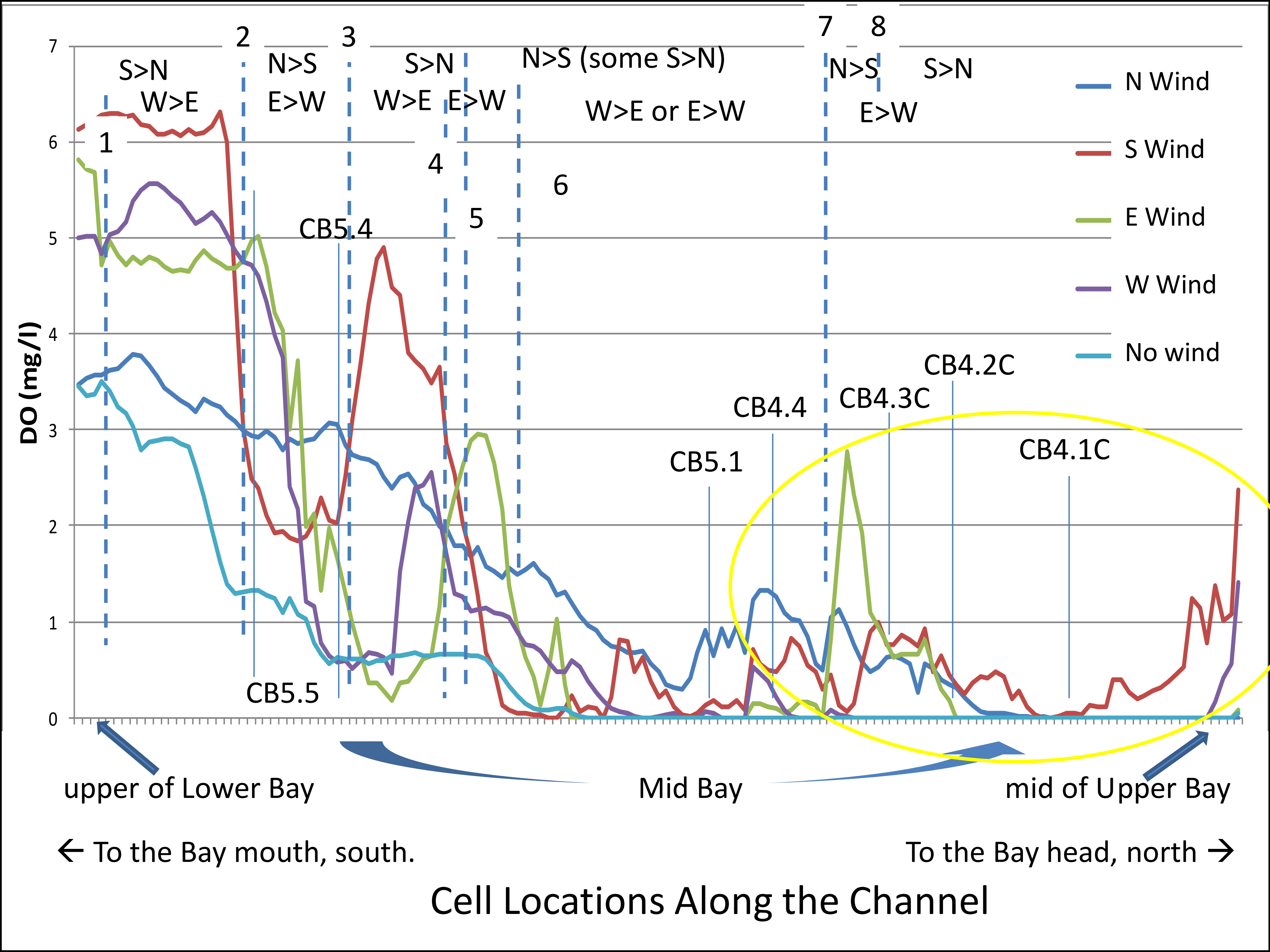

DO mg/l
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
V, p4, N wind
V, p4, S wind
V, p4, E wind
V, p4, W wind



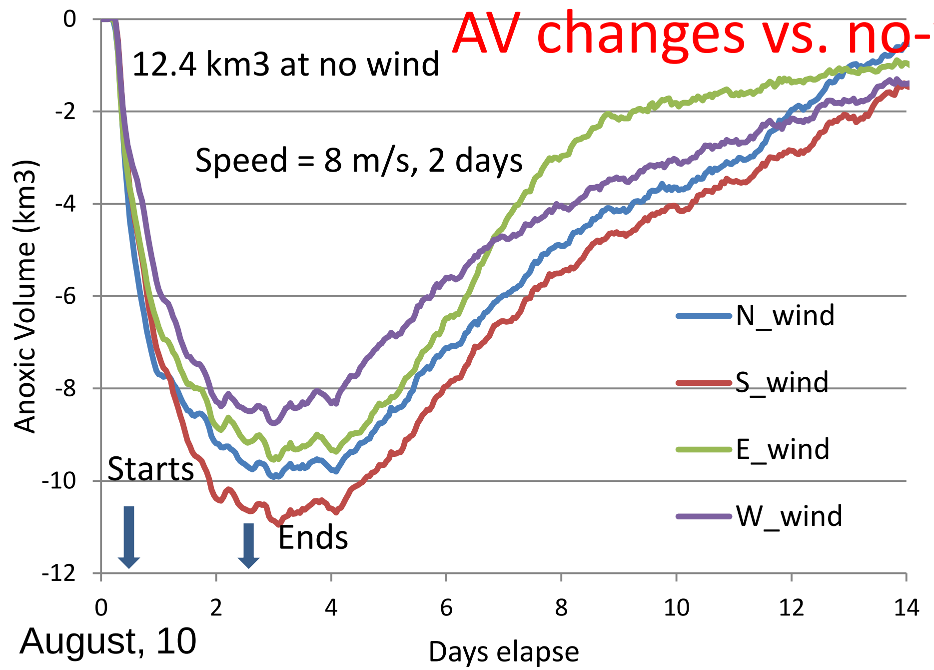
DO mg/l
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
V, p4, N wind
V, p4, S wind
V, pA, N wind
V, pA, S wind

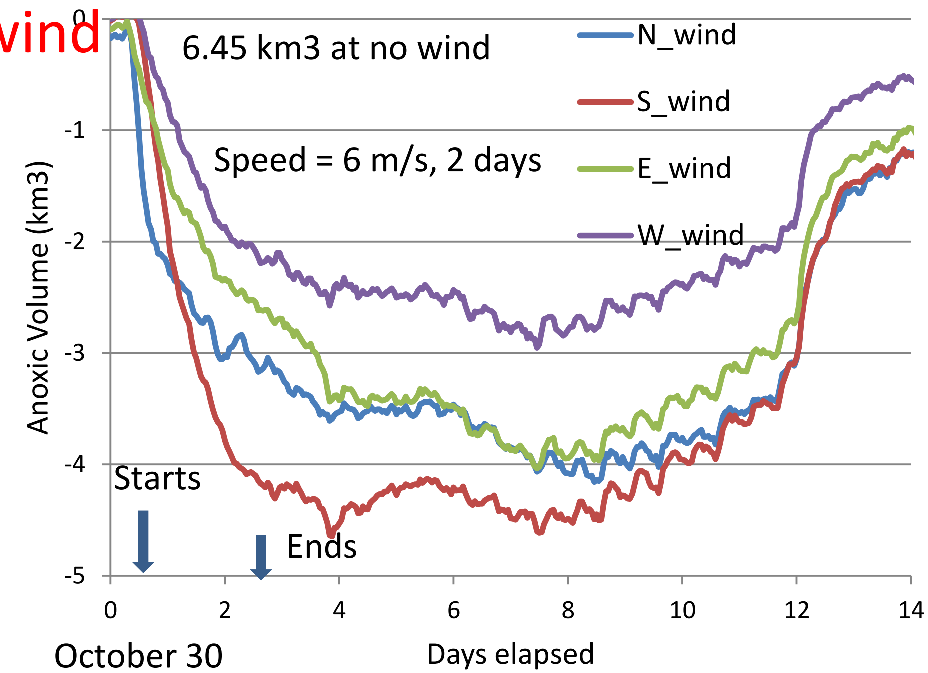


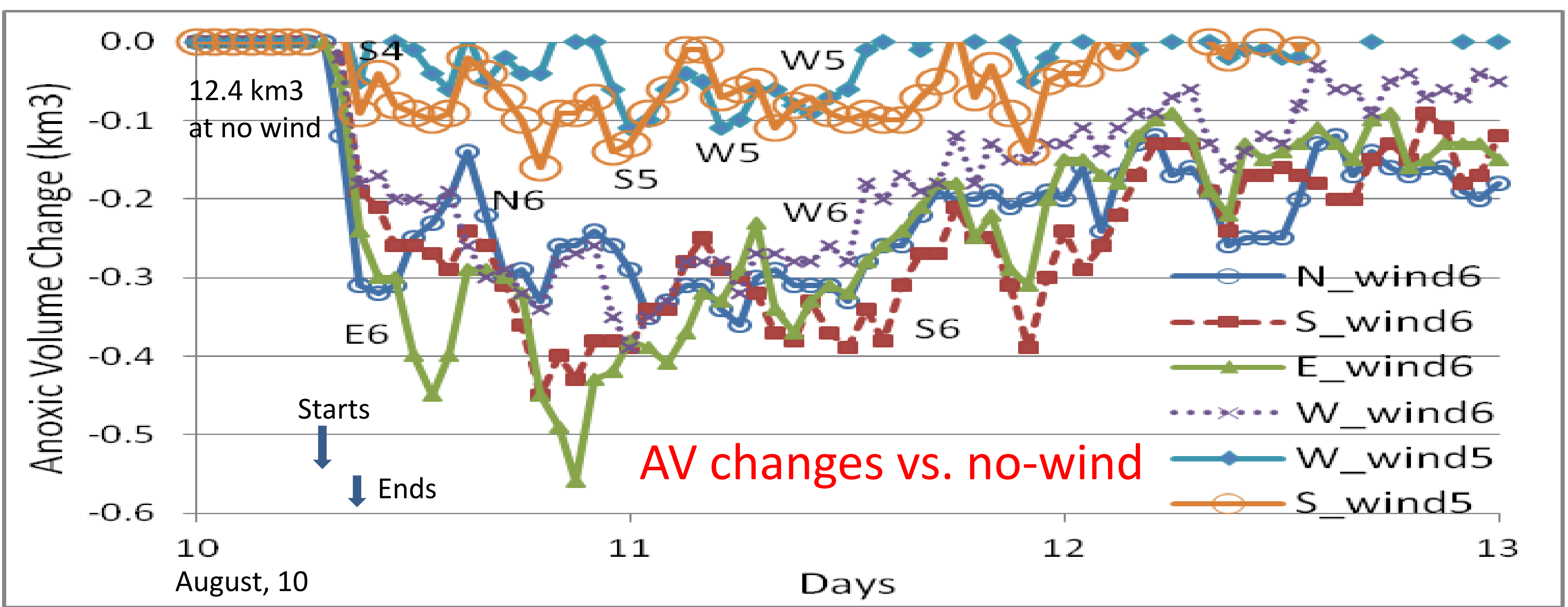
DEPTH (ft)
> 0
> 95
Baltimore
Washington
Salisbury
Richmond
Norfolk
P8
CB4.1C
CB4.2C
P3
P4
CB4.4
CB5.1
CB5.4
CB5.5
P8: center channel profile
Bay Mouth, to Atlantic Ocean
N
W
E
S
0 5 10 20 Miles

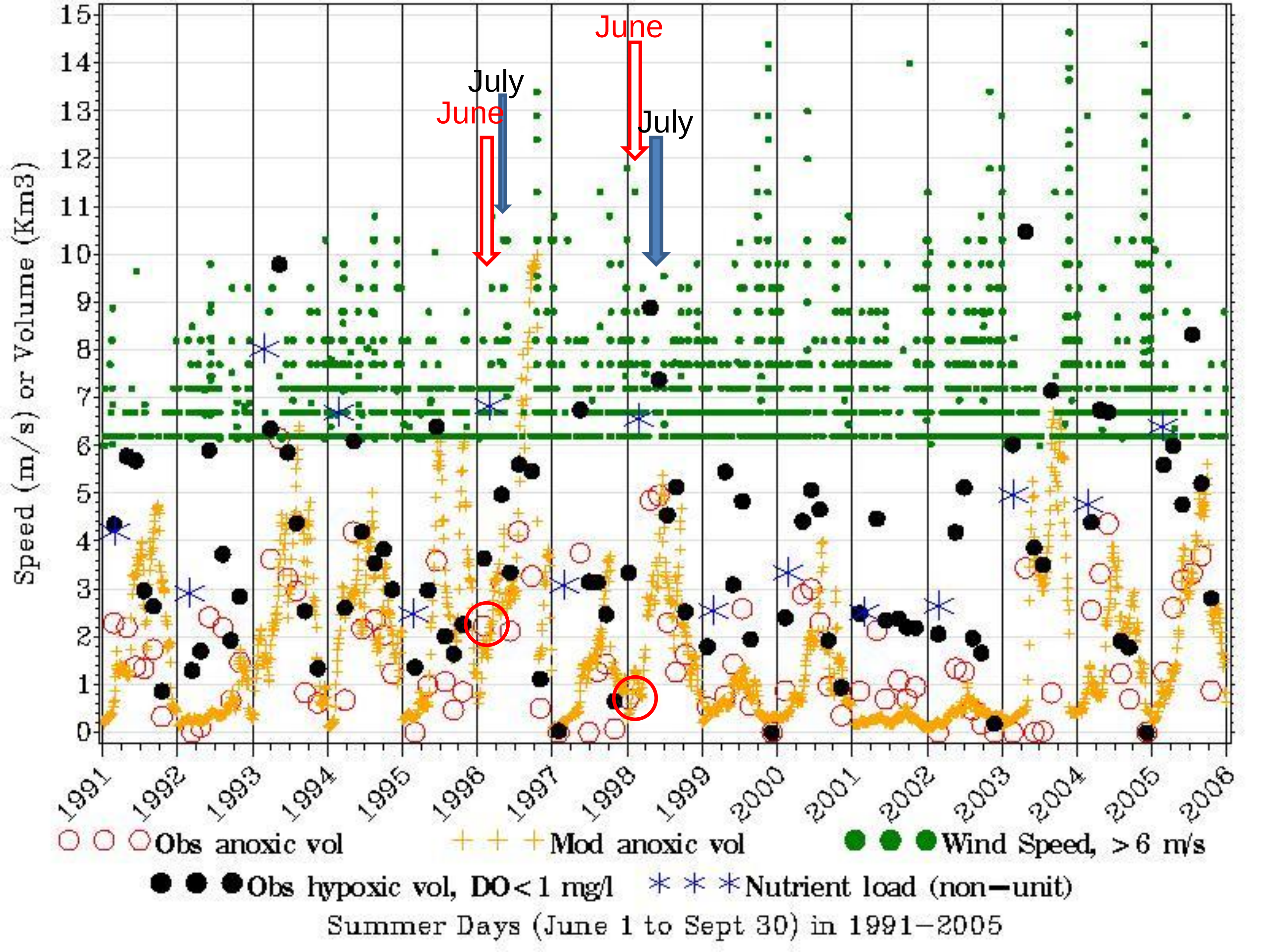


DO (mg/l)
0
1
2
3
4
5
6
7
1
2
3
4
5
6
7
8
S>N
W>E
N>S
E>W
S>N
W>E
E>W
N>S (some S>N)
W>E or E>W
N>S
E>W
S>N
CB5.5
CB5.4
CB5.1
CB4.4
CB4.3C
CB4.2C
CB4.1C
N Wind
S Wind
E Wind
W Wind
No wind
upper of Lower Bay
Mid Bay
mid of Upper Bay
← To the Bay mouth, south.
To the Bay head, north →
Cell Locations Along the Channel

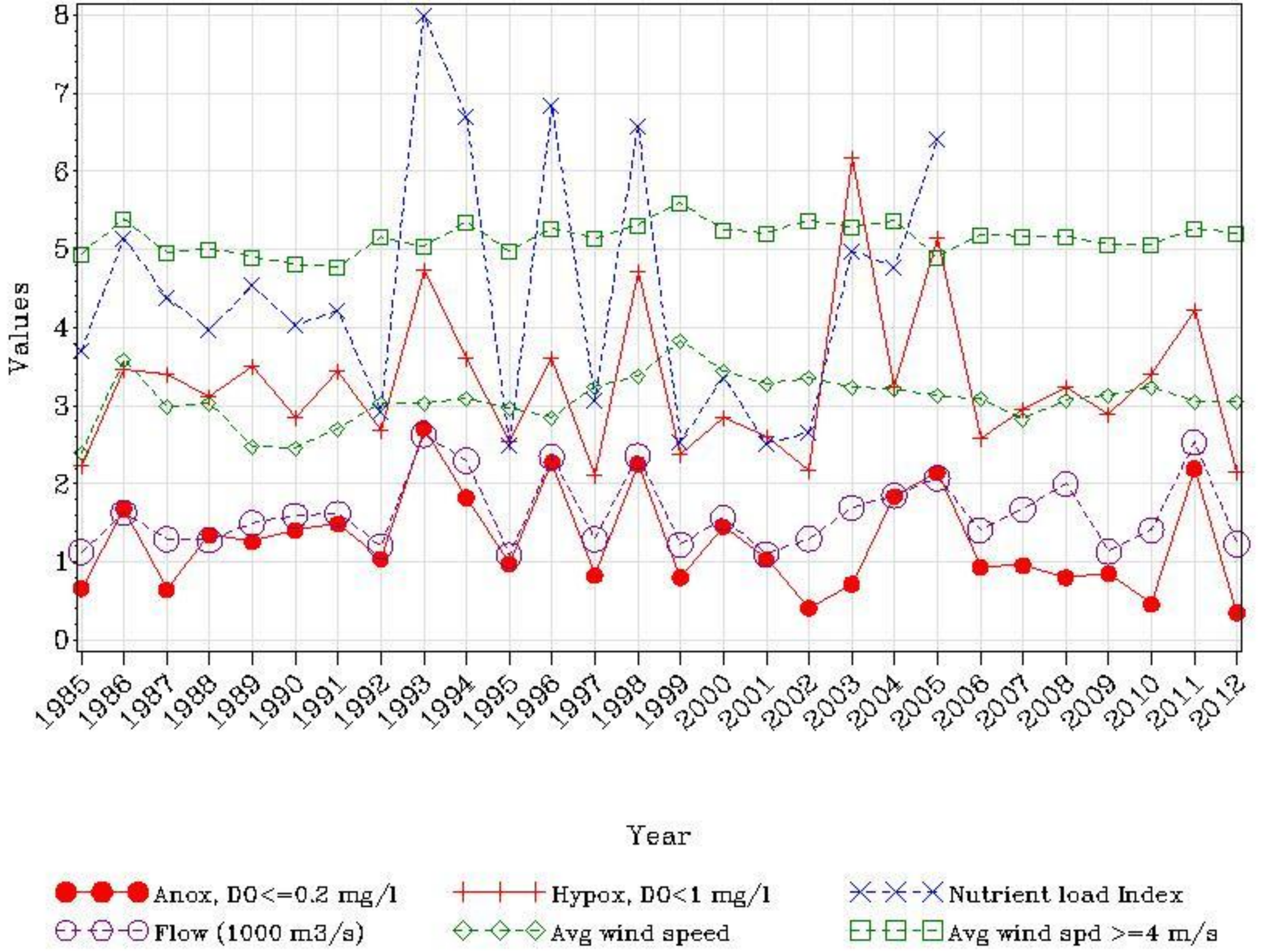

AV changes vs. no-wind
12.4 km3 at no wind
Speed = 8 m/s, 2 days
Anoxic Volume (km3)
0
-2
-4
-6
-8
-10
-12
Starts
Ends
N_wind
S_wind
E_wind
W_wind
0
2
4
6
8
10
12
14
August, 10
Days elapse


6.45 km3 at no wind
Speed = 6 m/s, 2 days
Anoxic Volume (km3)
0
-1
-2
-3
-4
-5
Starts
Ends
N_wind
S_wind
E_wind
W_wind
0
2
4
6
8
10
12
14
October 30
Days elapsed


12.4 km3
at no wind
Anoxic Volume Change (km3)
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
S4
W5
W5
S5
N6
W6
E6
S6
Starts
Ends
AV changes vs. no-wind
N_wind6
S_wind6
E_wind6
W_wind6
W_wind5
S_wind5
10
11
12
13
August, 10
Days



June
July
June
July
Speed (m/s) or Volume (Km3)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
Obs anoxic vol
Mod anoxic vol
Wind Speed, >6 m/s
Obs hypoxic vol, DO<1 mg/l
Nutrient load (non-unit)
Summer Days (June 1 to Sept 30) in 1991-2005



Values
Year
0
1
2
3
4
5
6
7
8
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Anox, DO<=0.2 mg/l
Hypox, DO<1 mg/l
Nutrient load Index
Flow (1000 m3/s)
Avg wind speed
Avg wind spd >=4 m/s

Conclusions

- Wind can reduce stratification and summer anoxic volumes significantly. Direct wind mixing, and lateral circulation (associated with longitudinal and cross channel straining) are the main factors for destratification by winds.

- The shape or bathymetry of cross channel is another factor that plays an important role in causing differential influences on wind-induced circulation among wind directions.

Conclusions (cont.)

- In general, south and north winds reduce more anoxic volume than east and west winds; south wind affects the most (because of stronger longitudinal straining and wind direct mixing), while west wind the least.

- Although the extents of eroding stratification and hypoxia are different for different wind directions, the strengths of wind (i.e., speed) over certain threshold is more important. Longer duration of strong wind also has a stronger impact.

Conclusions (cont.)

- Watershed load is the key factor controlling inter-annual hypoxia (r~0.85). While episodic strong wind can reduce hypoxia significantly, causing variations of hypoxia among months or different sampling cruises in a summer.

Thank you.