Hydrodynamic and Water Quality Modeling for Chester River using SCHISM/HEM3D

by

Harry Wang*, Joseph Zhang, Zhengui Wang, and Fei Ye

Virginia Institute of Marine Science, College of William and Mary
Gloucester Point VA 23062
Ph: 804-684-7215;email: hvwang@vims.edu

Presentation for EPA Chesapeake Bay Program, 4/4/2017

Outline:

I. Hydrodynamic modeling in the Chester River

1) model domain and topography
2) salt intrusion and temperature
3) wind wave and suspended sediment

II. Water quality processes -

1) phytoplankton dynamics
2) oxygen dynamics

III. A PH dependent phosphorus release scheme

IV. Conclusion

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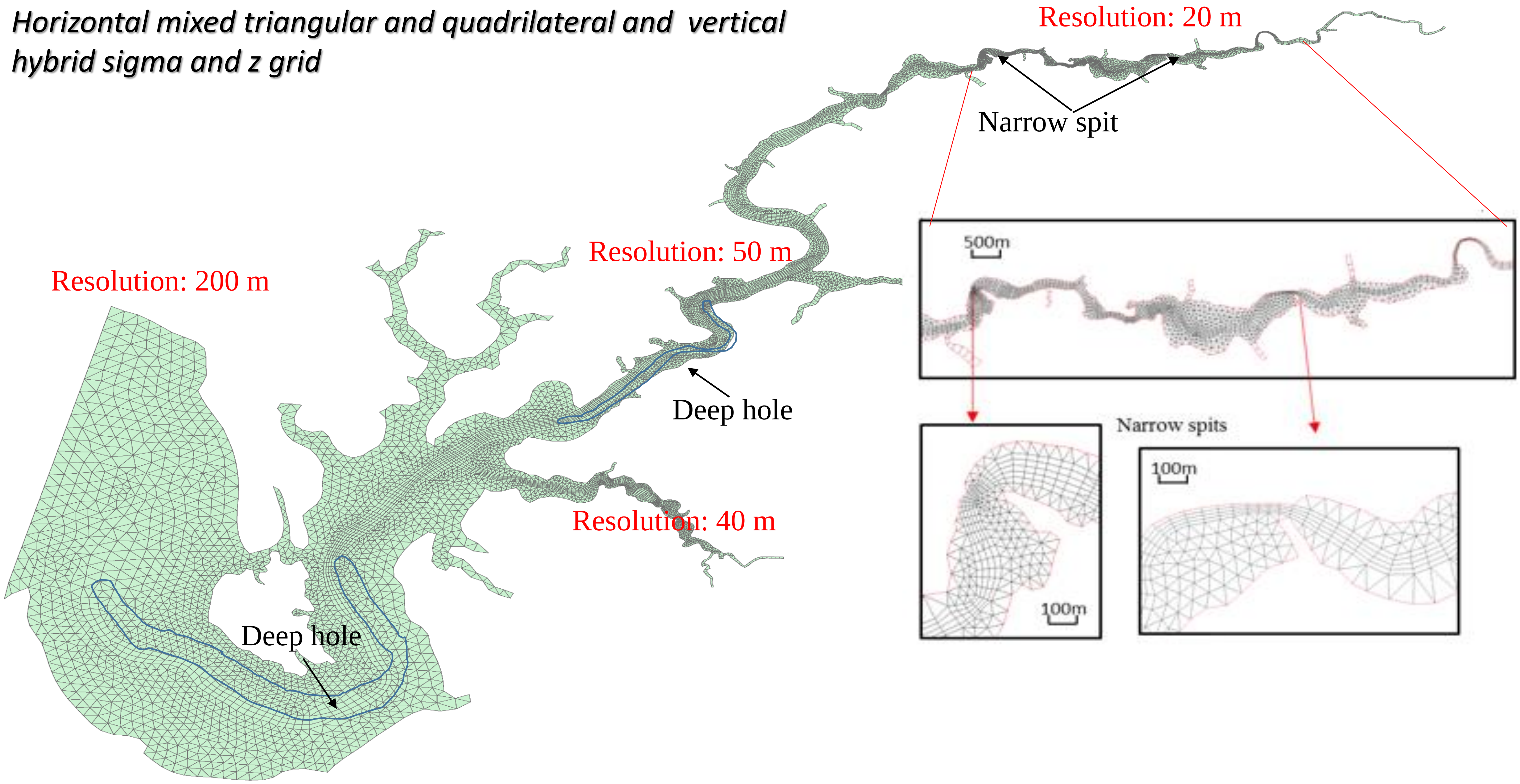
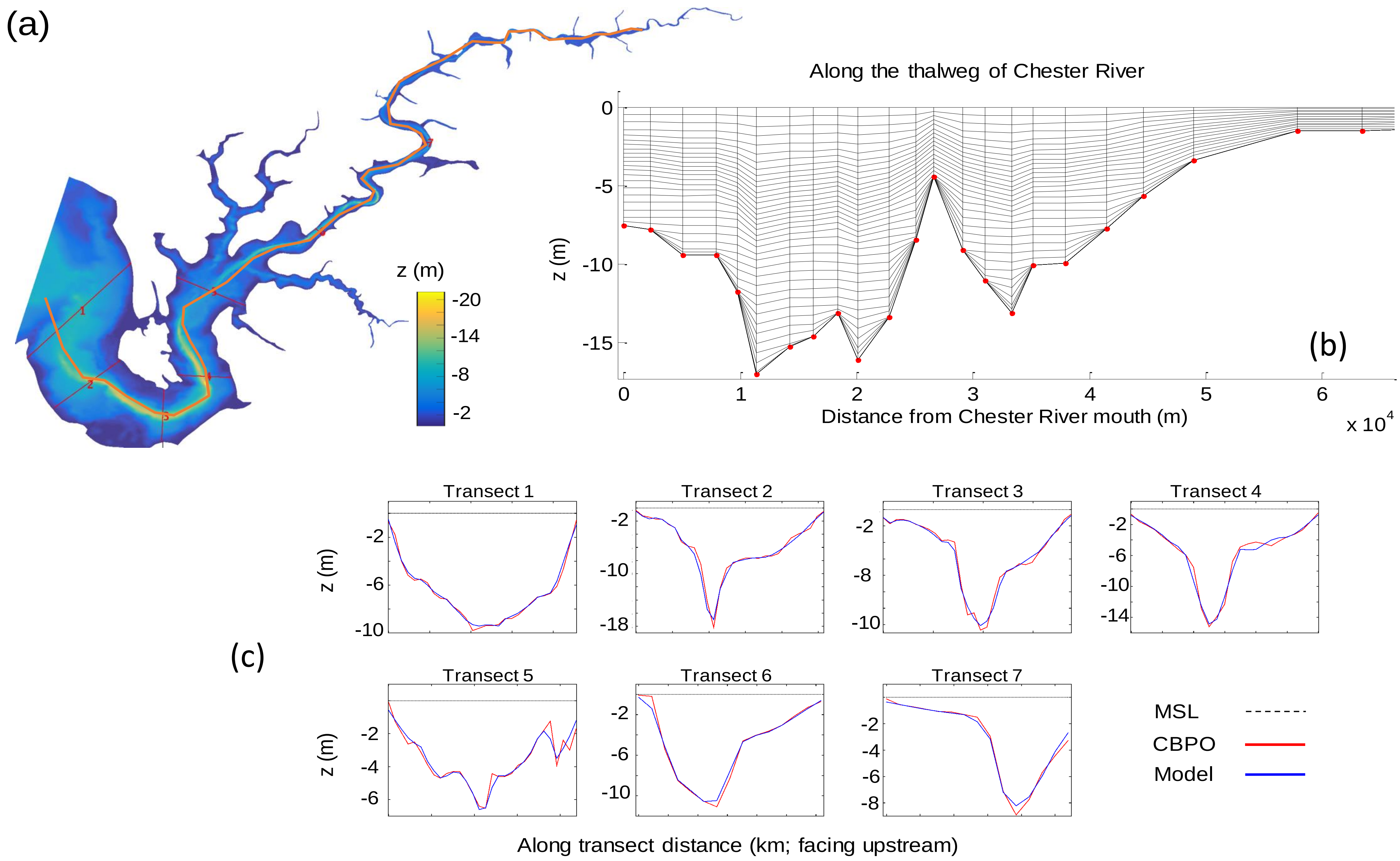
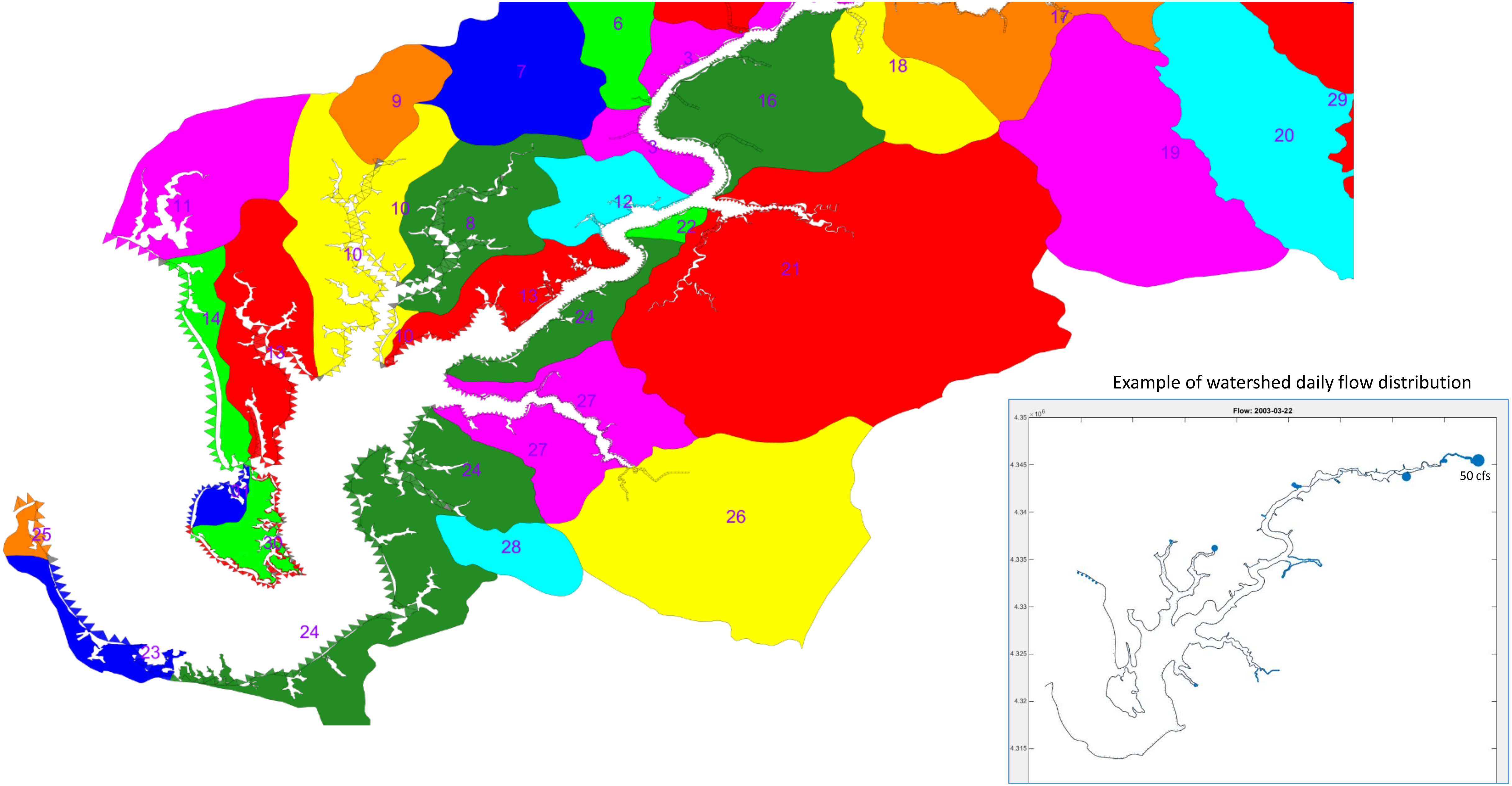
I. Hydrodynamic modeling

Horizontal mixed triangular and quadrilateral and vertical hybrid sigma and z grid



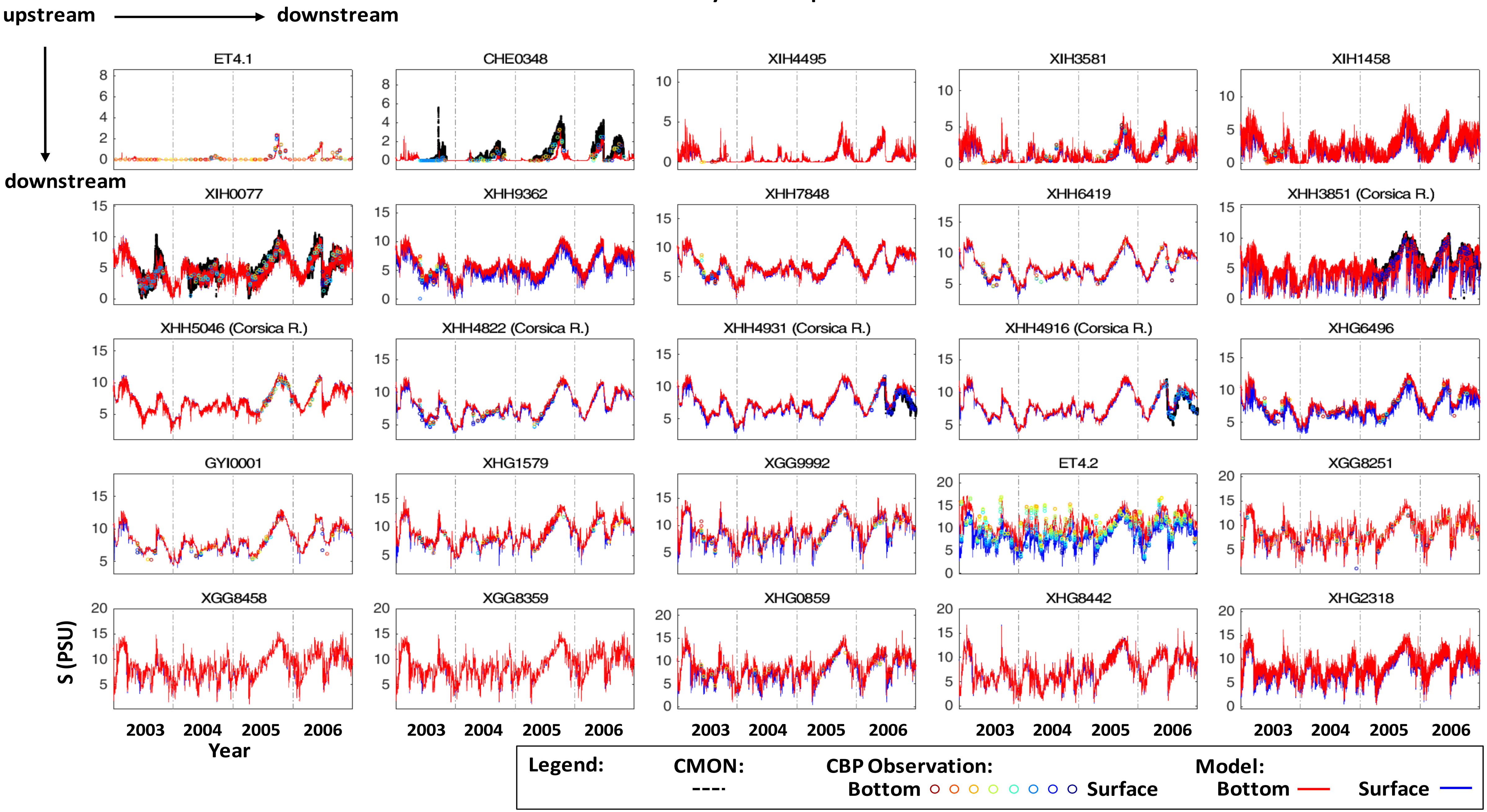

(a)
z (m)
-20
-14
-8
-2
Along the thalweg of Chester River
0
-5
-10
-15
z (m)
0
1
2
3
4
5
6
Distance from Chester River mouth (m)
x 10^4
(b)
(c)
Transect 1
Transect 2
Transect 3
Transect 4
Transect 5
Transect 6
Transect 7
z (m)
MSL
CBPO
Model
Along transect distance (km; facing upstream)

Watershed delineation and loading

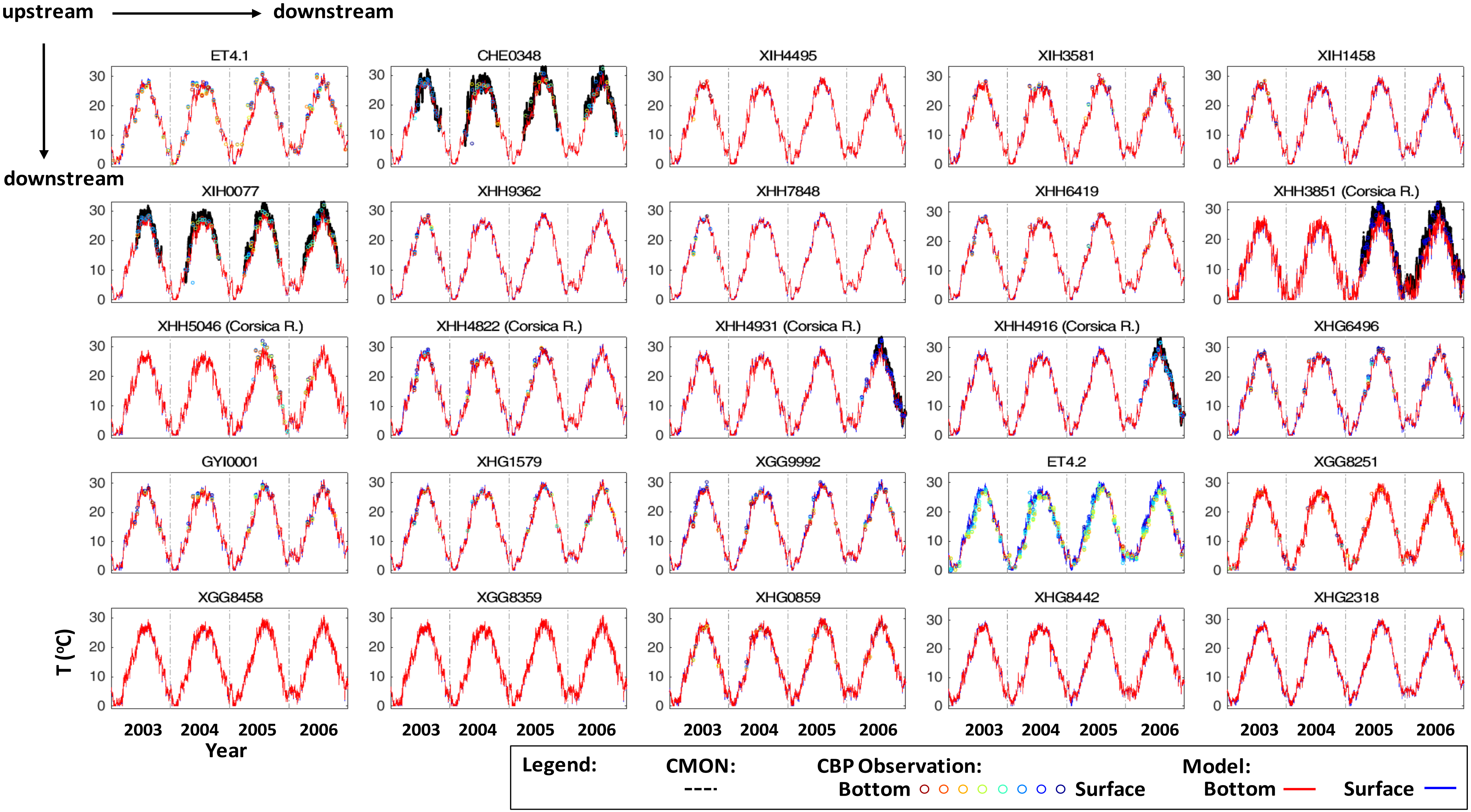


Example of watershed daily flow distribution

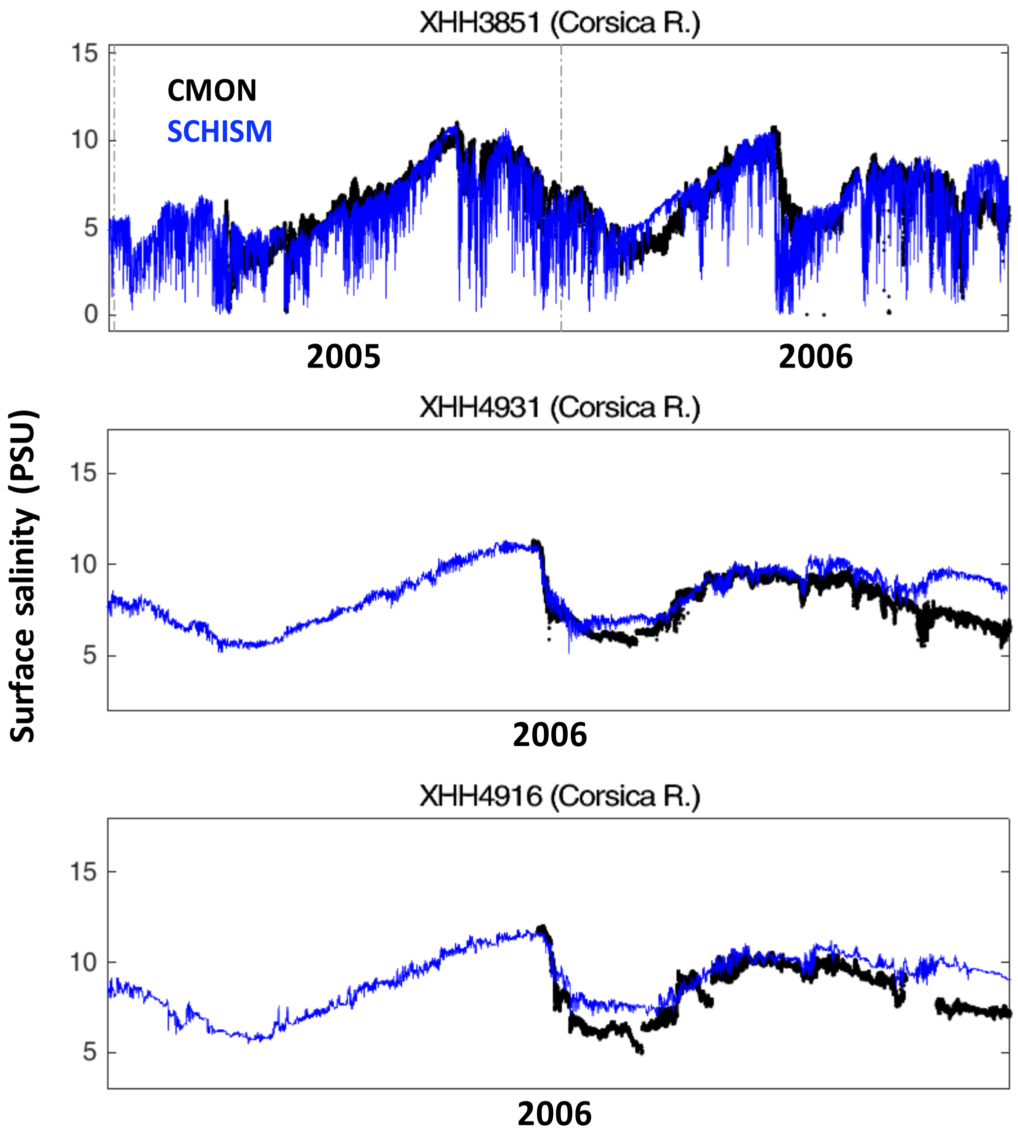
Salinity Comparison



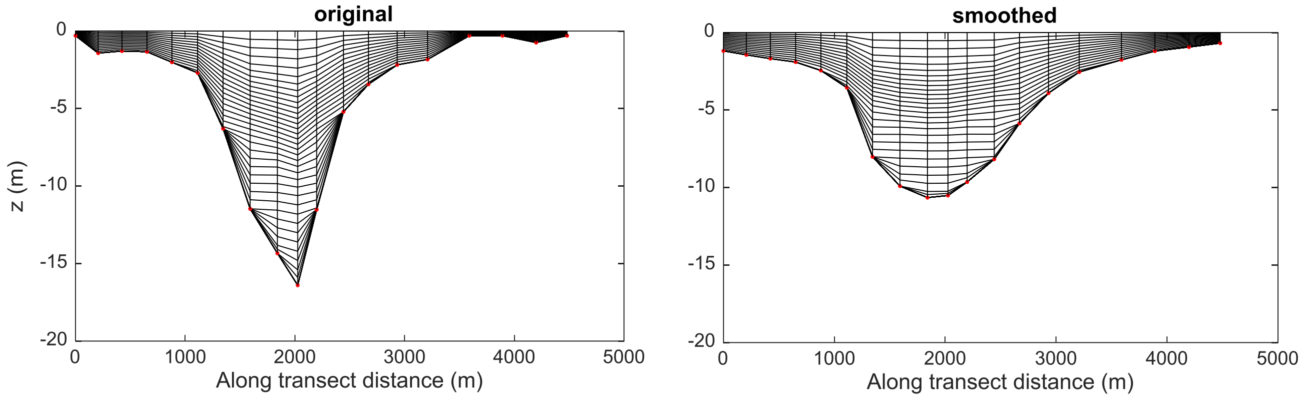
Temperature Comparison

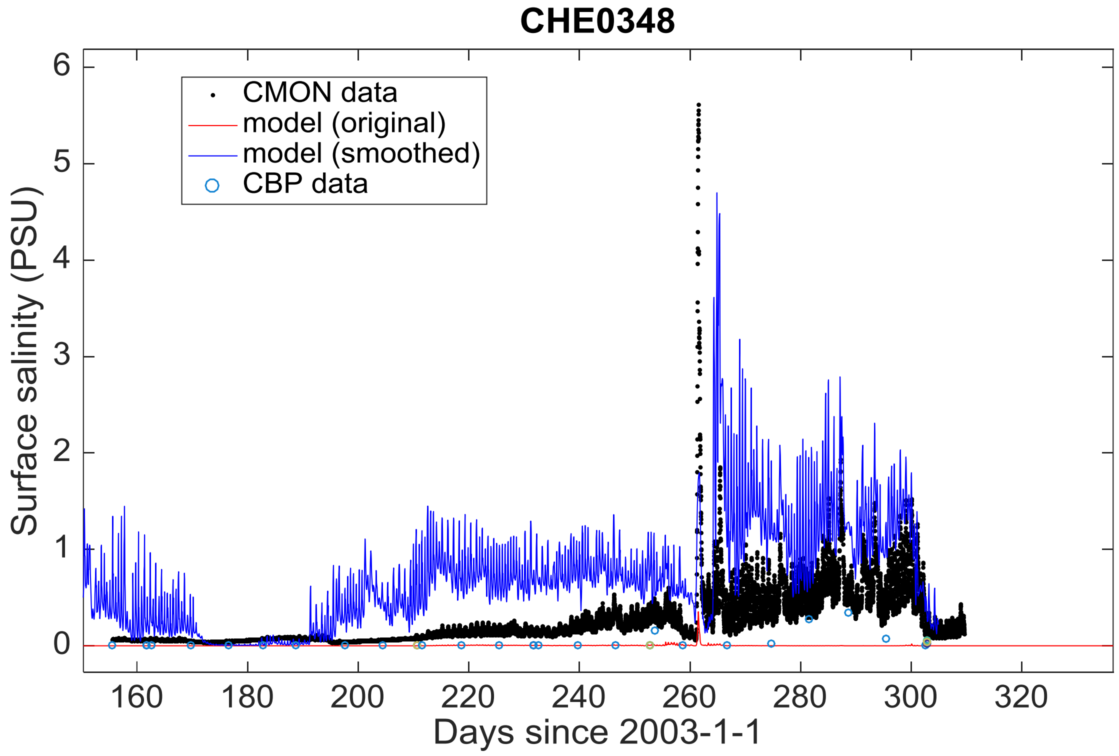


Comparison with Cmon salinity data



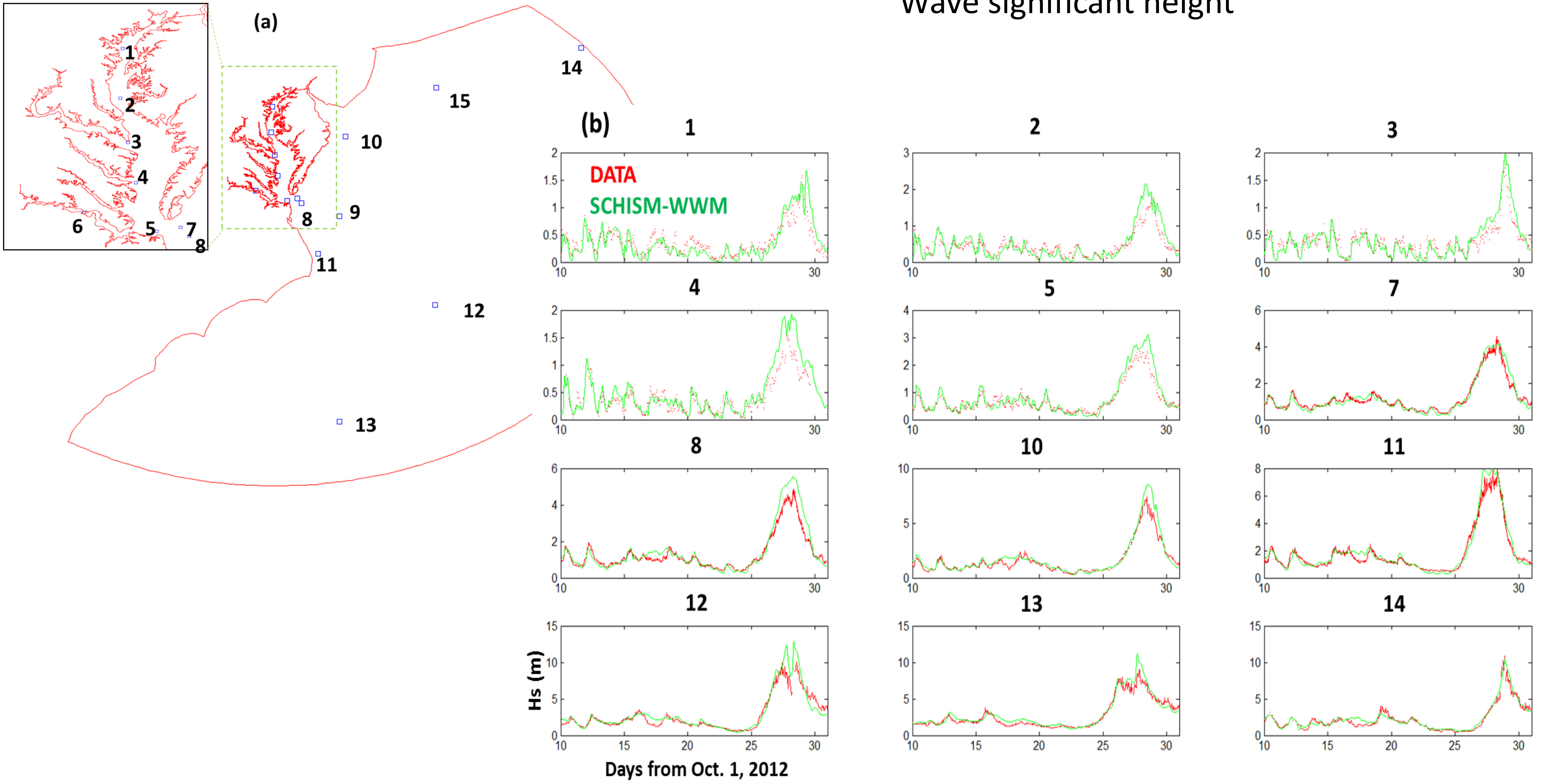
Sensitivity to the cross-sectional discretization



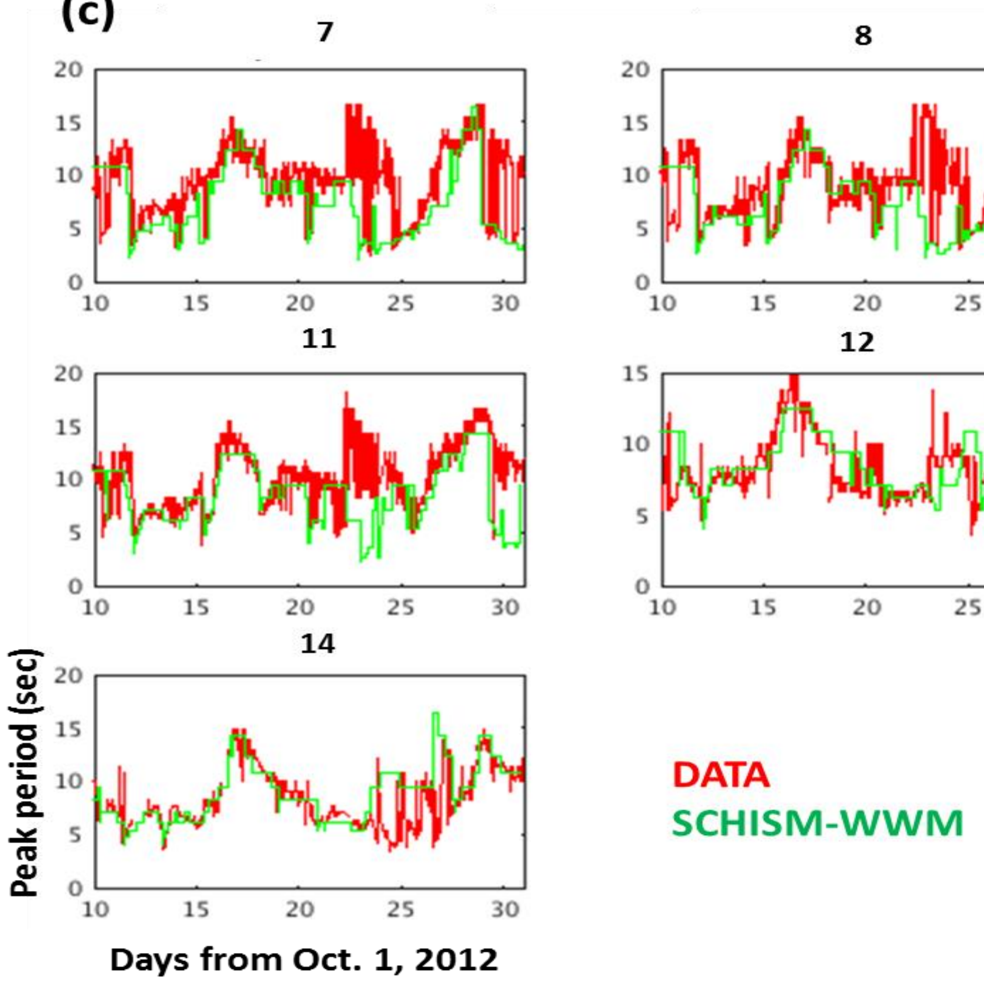


Wind wave modeling

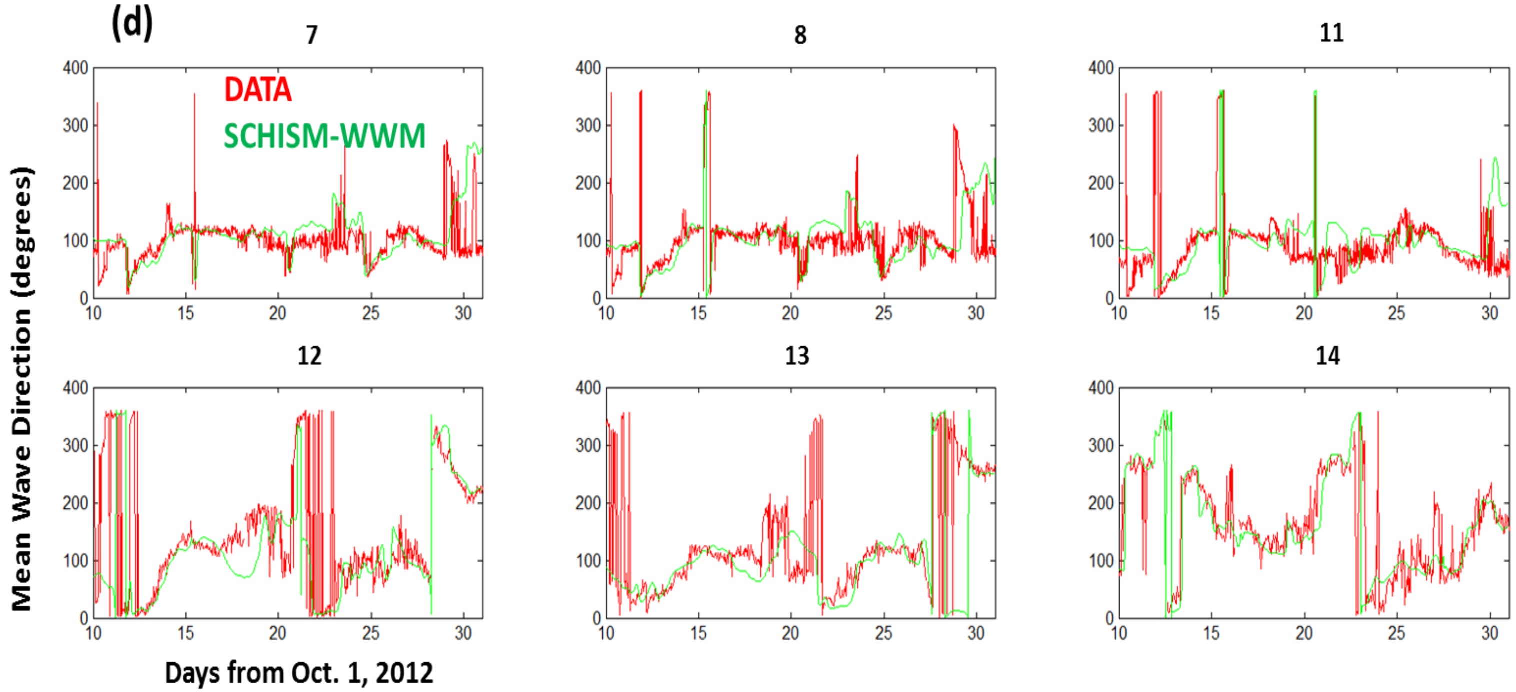
Wave significant height



Peak wave period

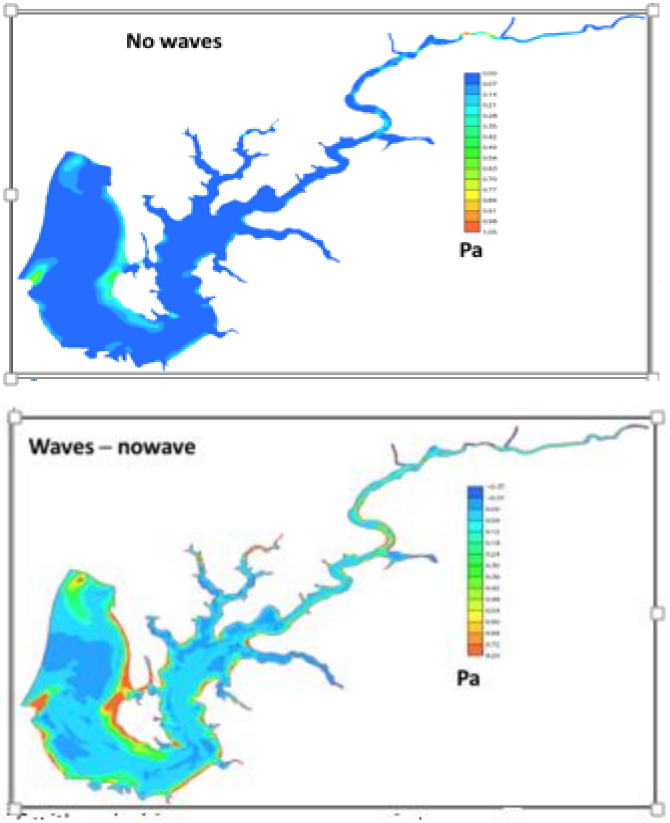


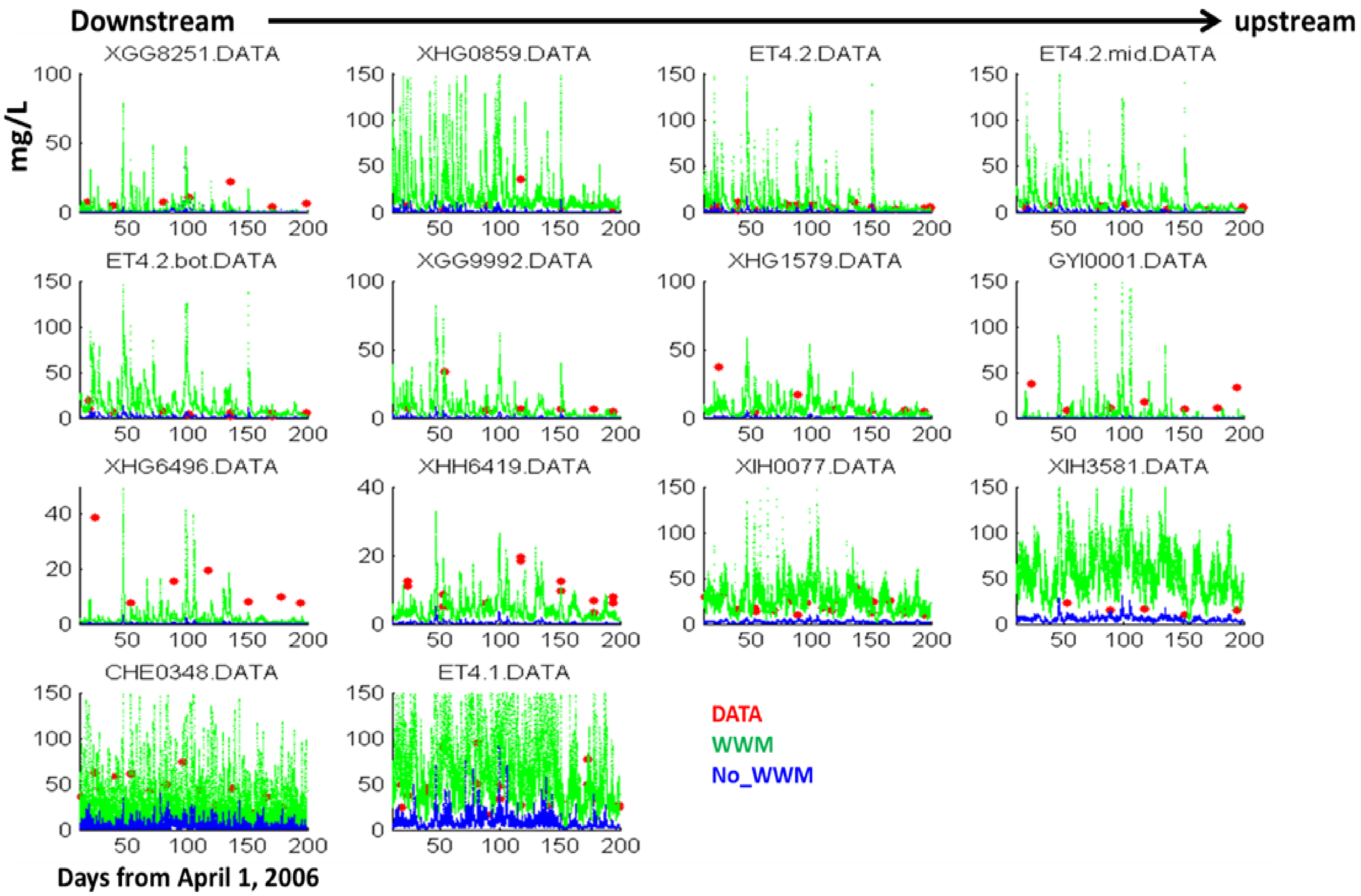
Wave direction



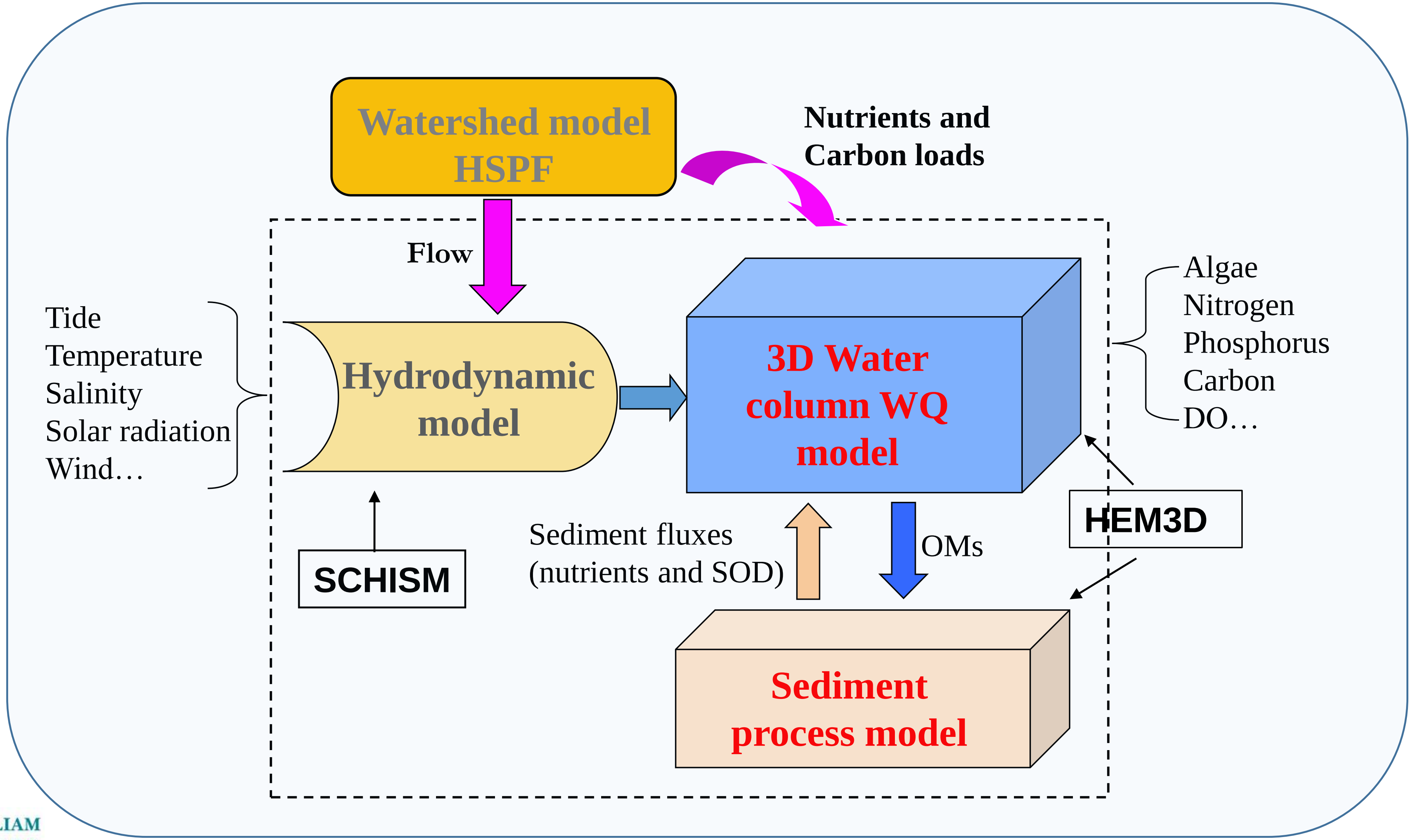
Averaged bottom shear stress

Inorganic component of TSS





II. Water quality processes



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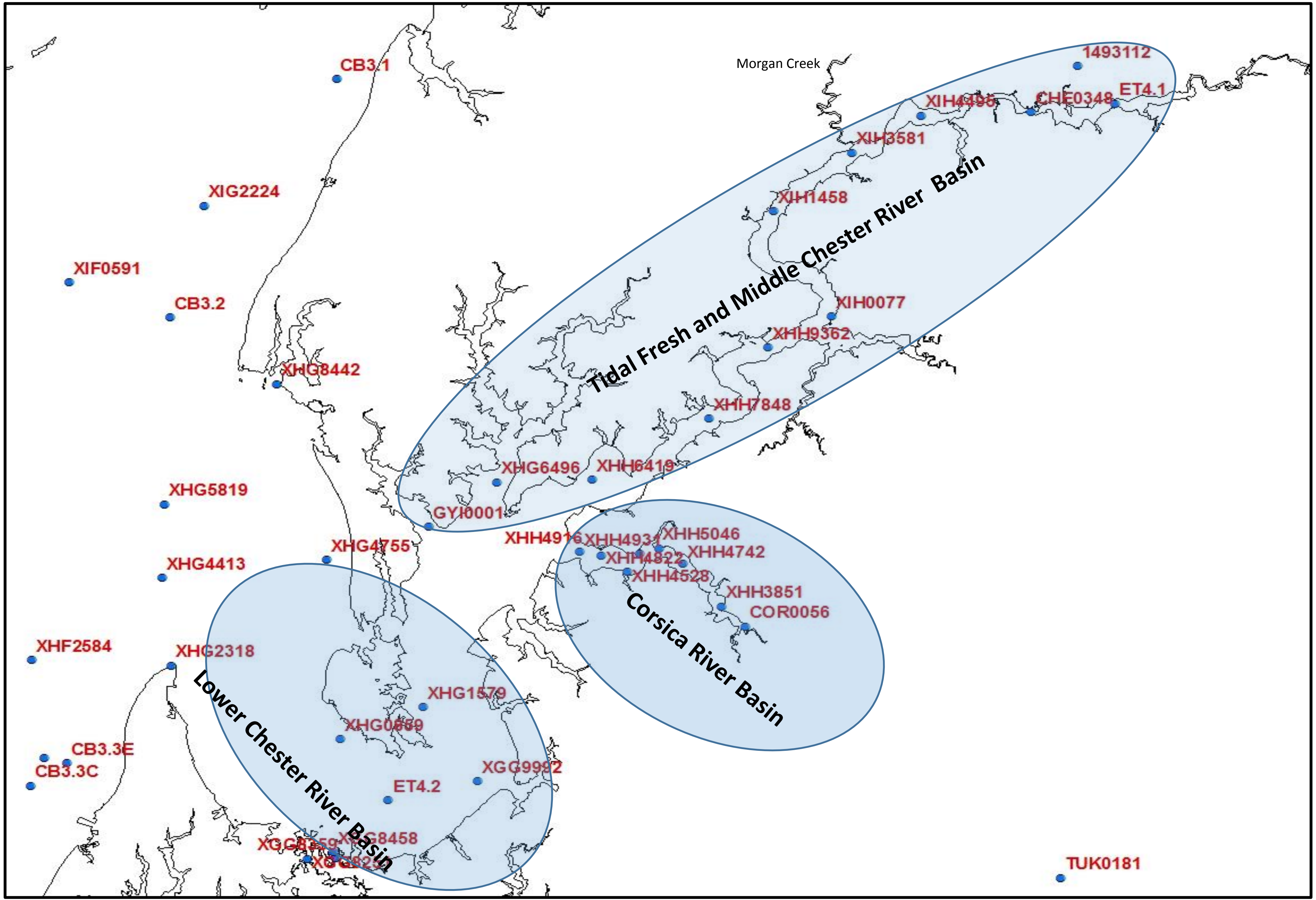
Field Station Map

Divided into three major basins

1. Tidal fresh and middle Chester River basin
2. Corsica River basin
3. Lower Chester River basin

(used later for presenting modeling results)



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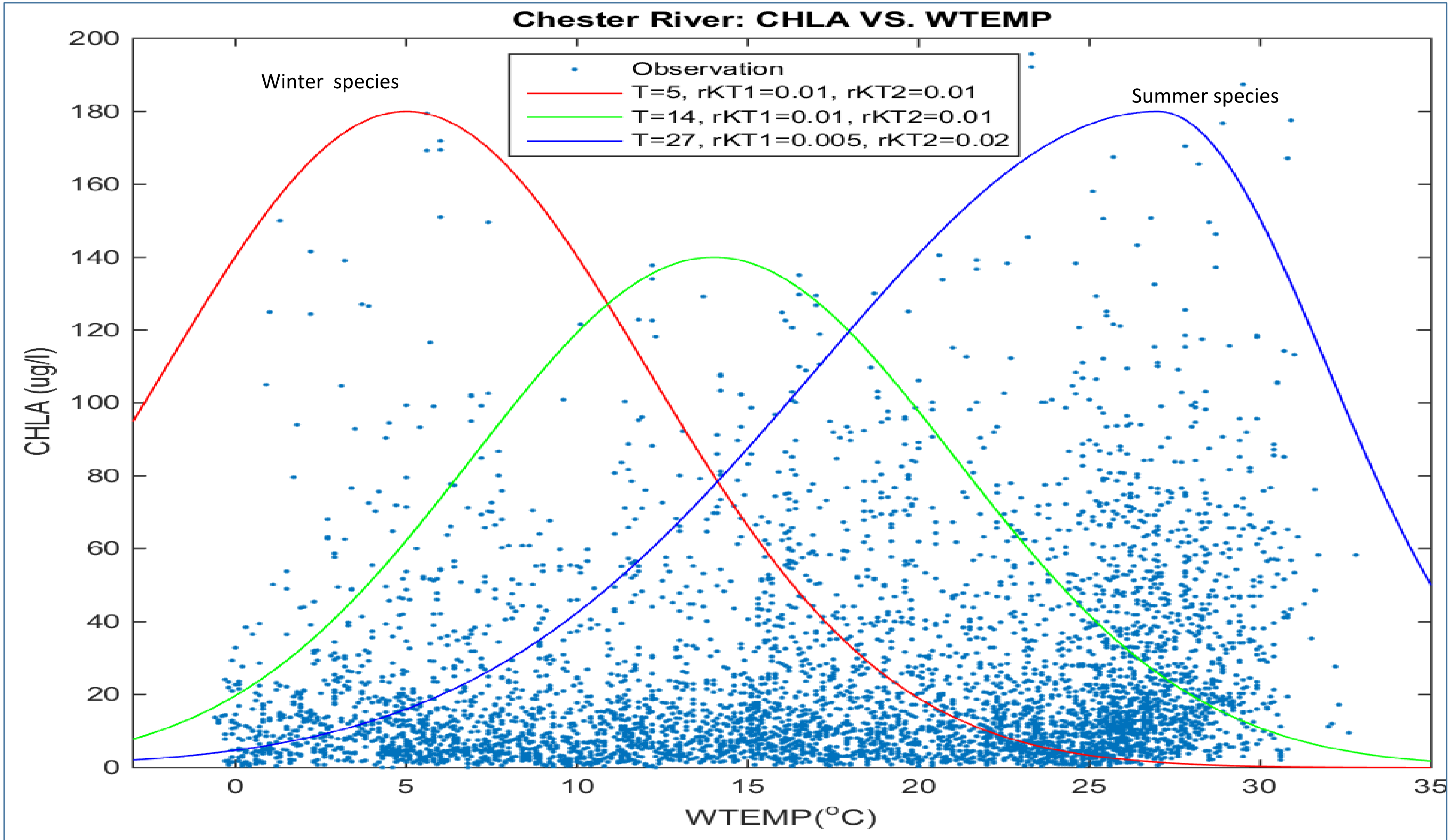
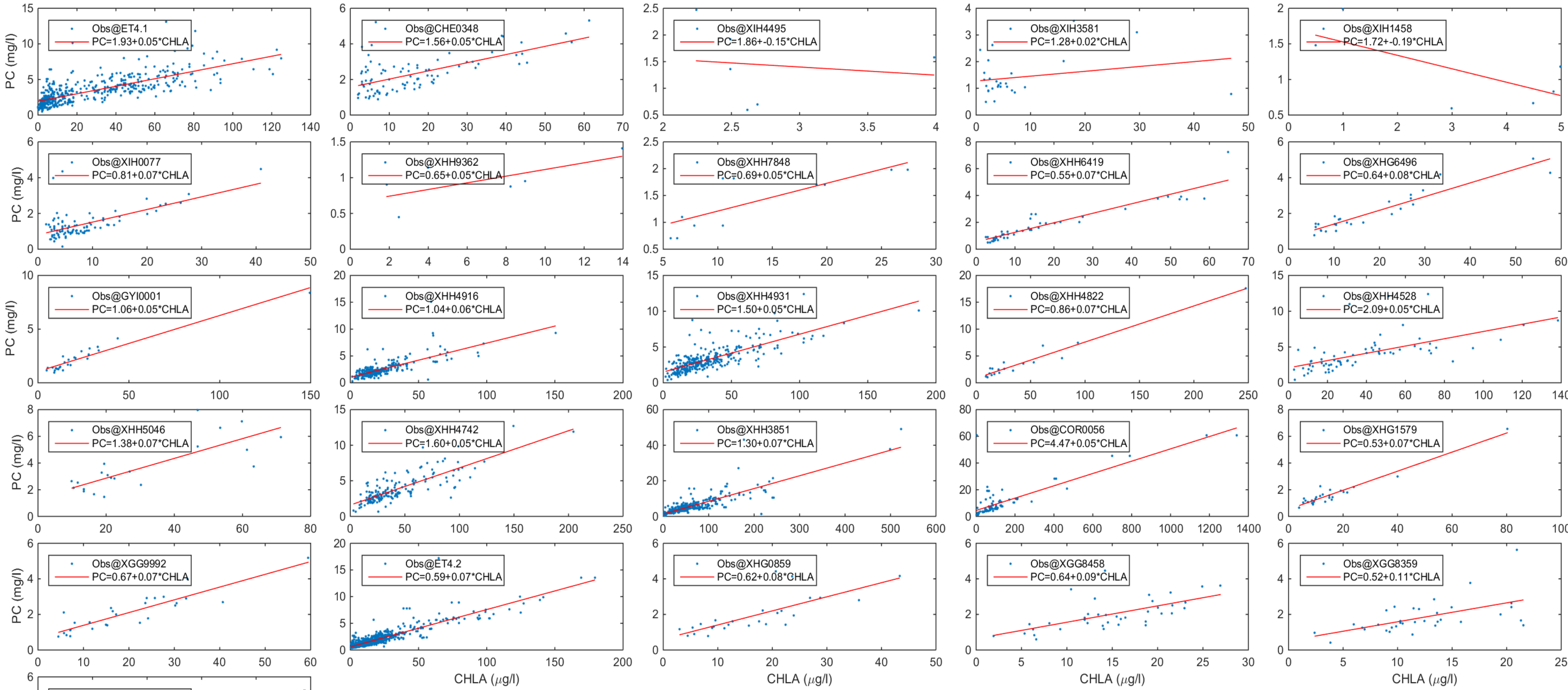
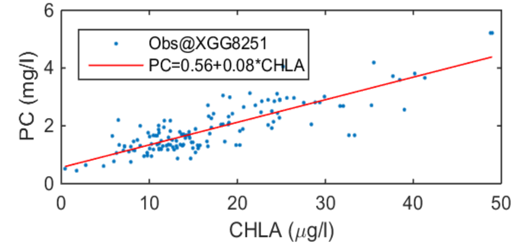
Parameter specification

a. Optimal temperature for algal bloom







b. Carbon to Chla Ratio

1). The analysis shows that the slope of Chla:C is about (50 – 70 in mg/l unit) in Chester River

2). A constant value of Chla to Carbon ratio =59 is used.

c. Light attenuation

The formulation for light attenuation is as follows:

$$Ke = a_0 + a_1 * \mathrm{CHLA} + a_2 * \mathrm{TSS}$$

Ke: light attenuation (m^{-1})

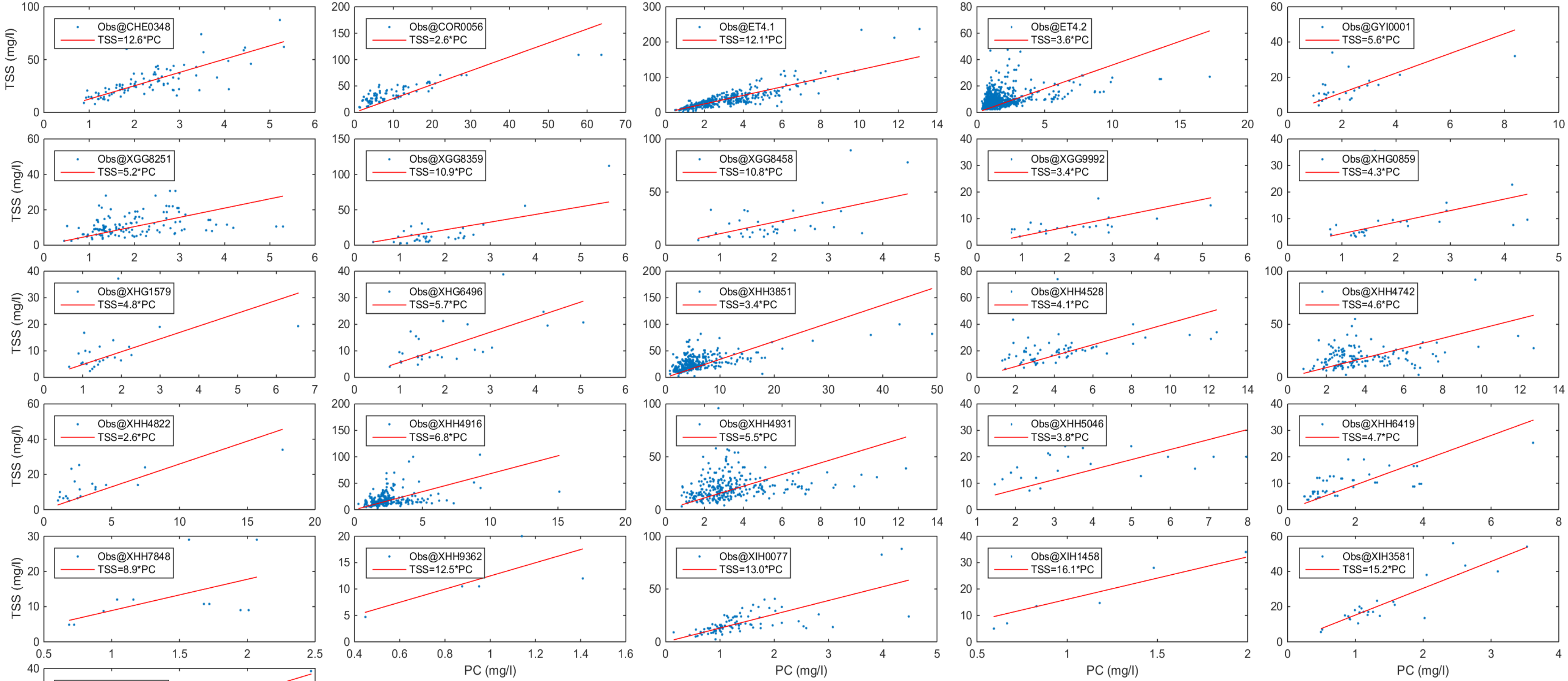
a_0: background attenuation (m^{-1})

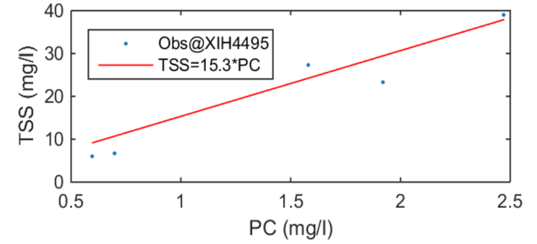
a_1 : attenuation coefficient for CHLA ($\frac{m^2}{mg}$)

a_2 : attenuation coefficient for TSS ($\frac{m^2}{g}$)

where a0=0.26 ; a1=0.017; a2=0.07;

1) CHLA is calculated from the model.
2) TVSS is estimated based by PC (particulate carbon)





d. TVSS estimation from PC

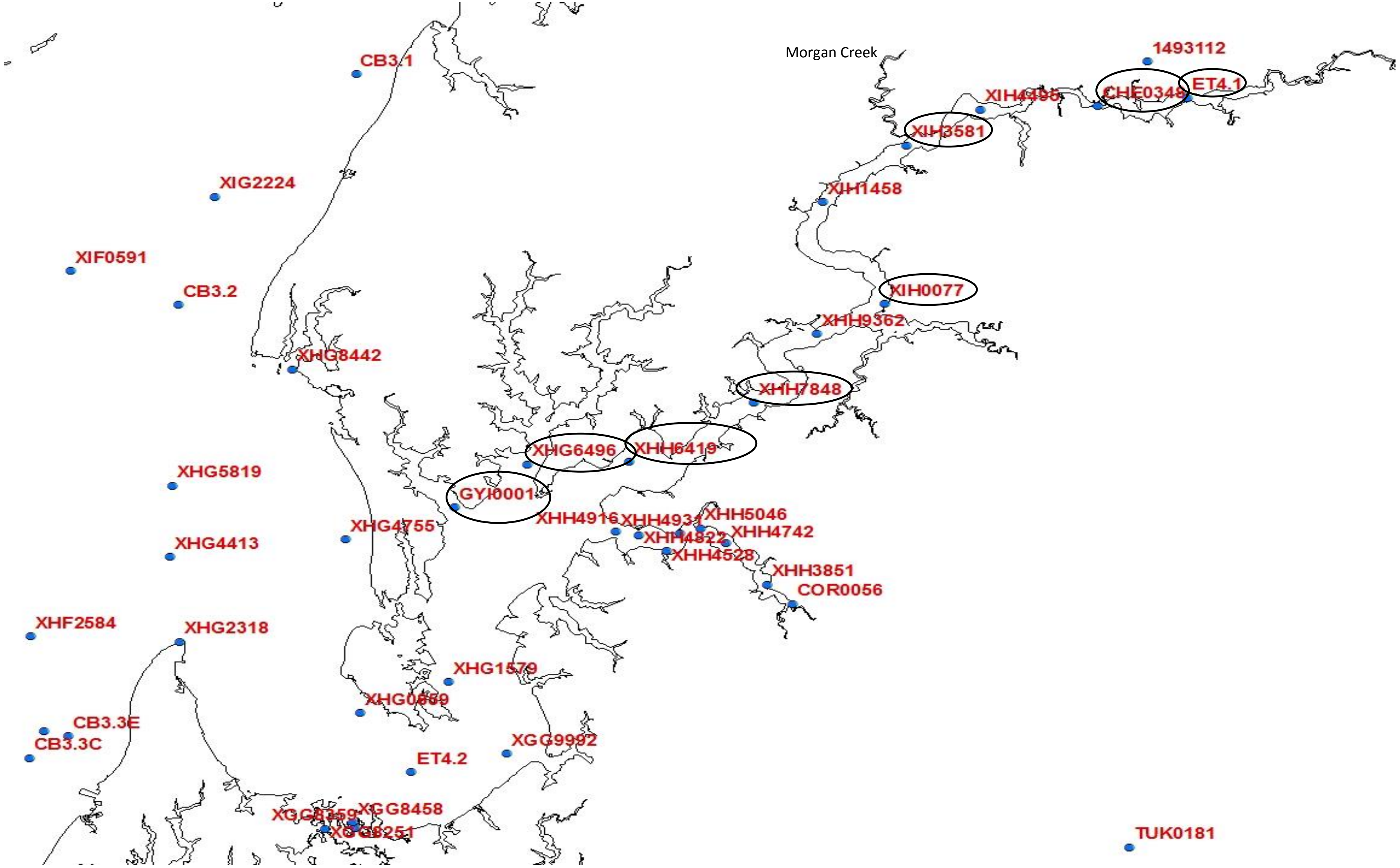
1). The regression was made between of PC versus $TVSS$ for every stations

2). This relation is interpolated in the whole domain

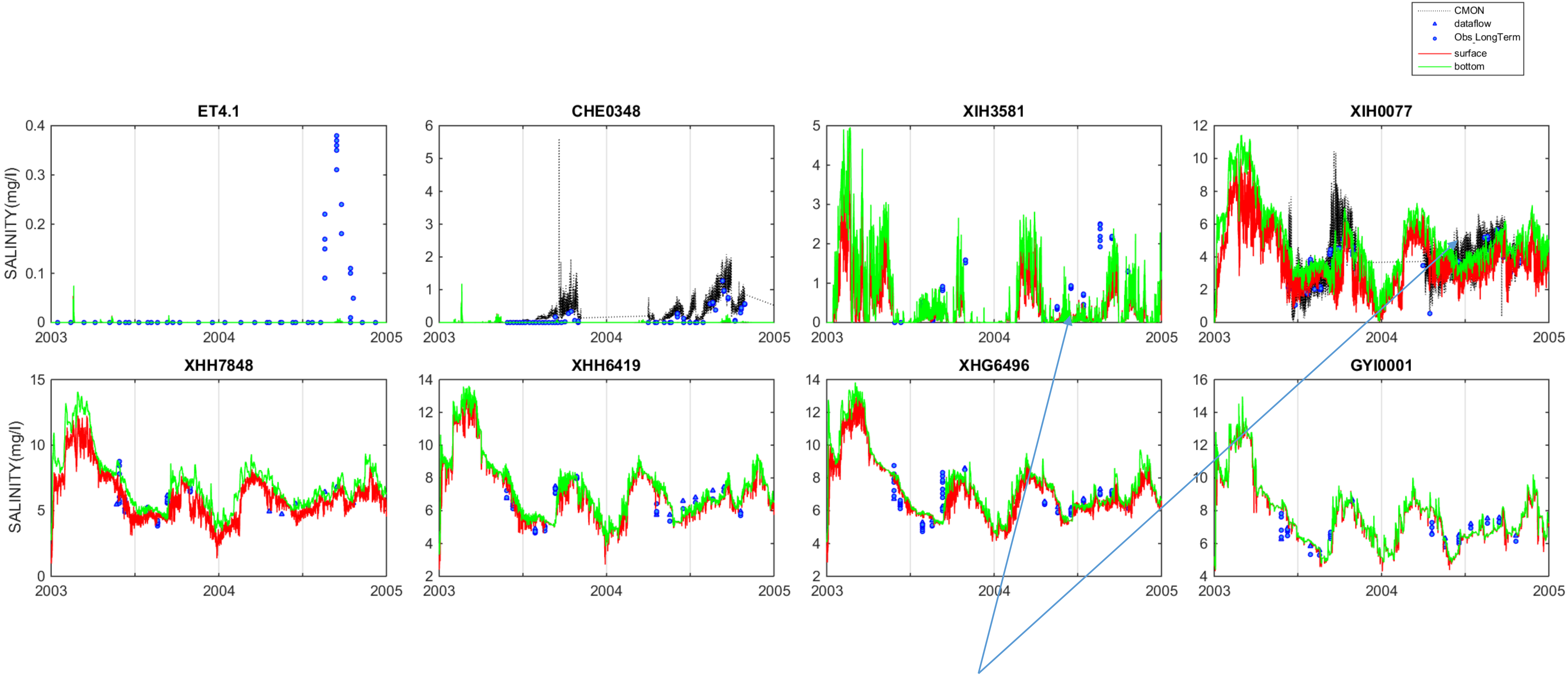
3)* Eventually, TSS is the addition of TVSS and Inorganic sediment from SCHISM

Water quality modeling results

1. The water quality model is executed directly coupling with SCHISM. The time step used for both model is 120 sec.
2. Simulating period 2003 and 2004

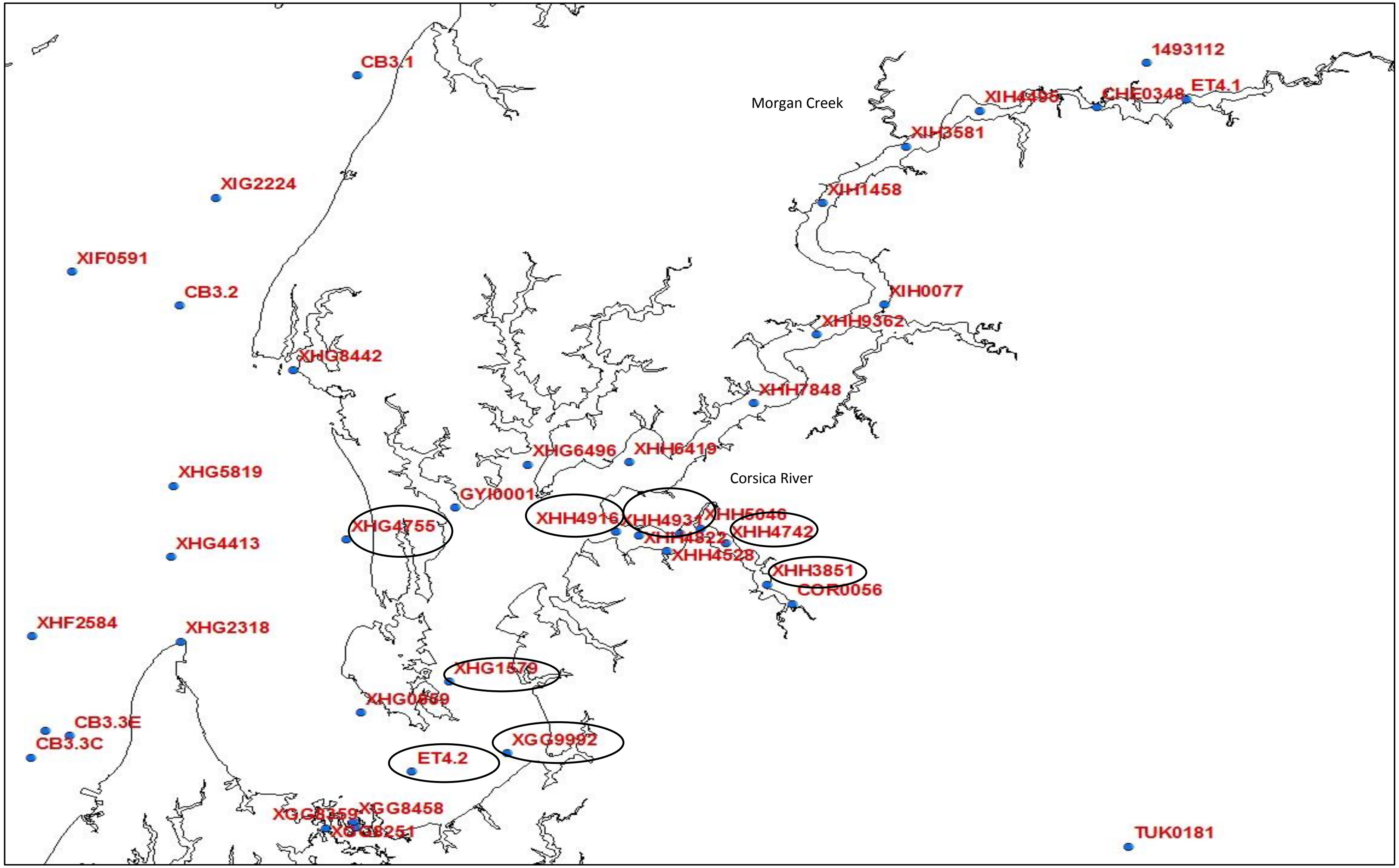


Salinity in the tidal fresh and middle Chester River

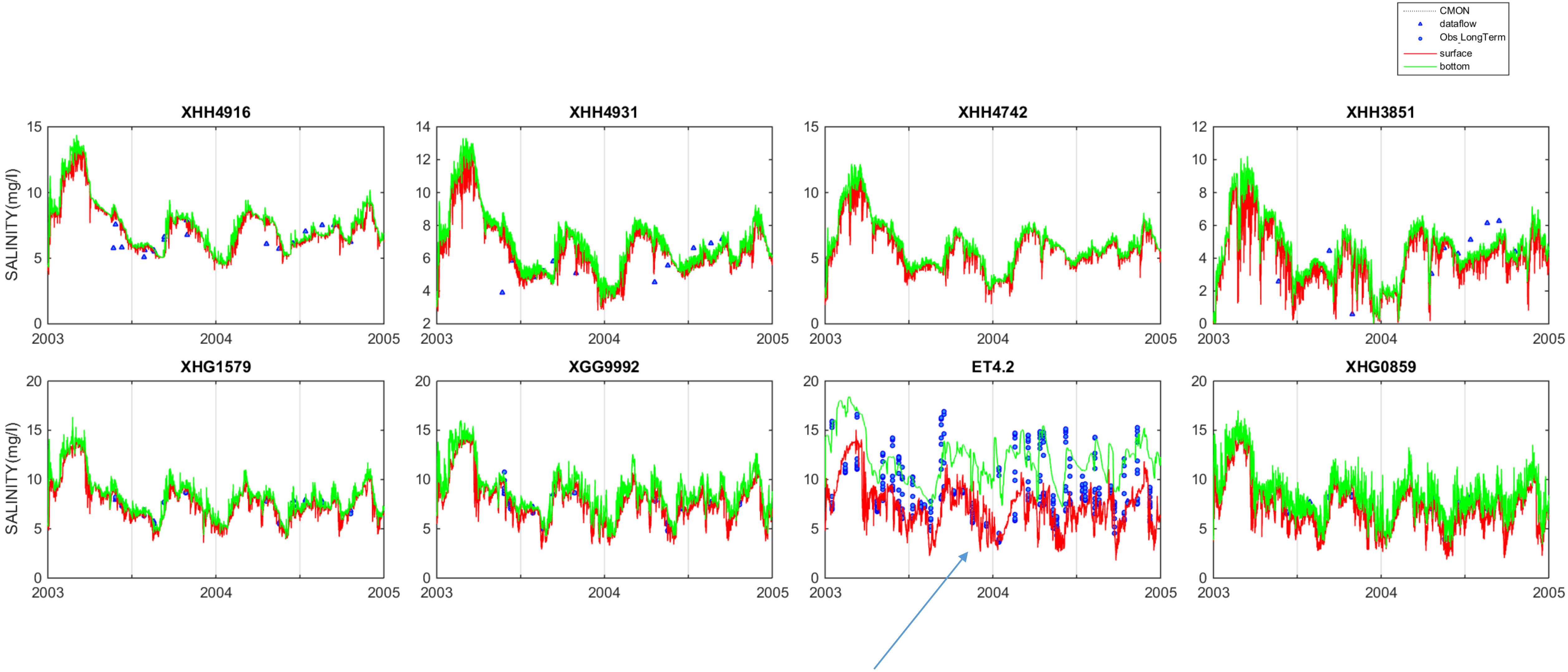


Salt intrusion prediction was better using coupled upper Bay open boundary condition

Stations selected in Corsica River and lower Chester River

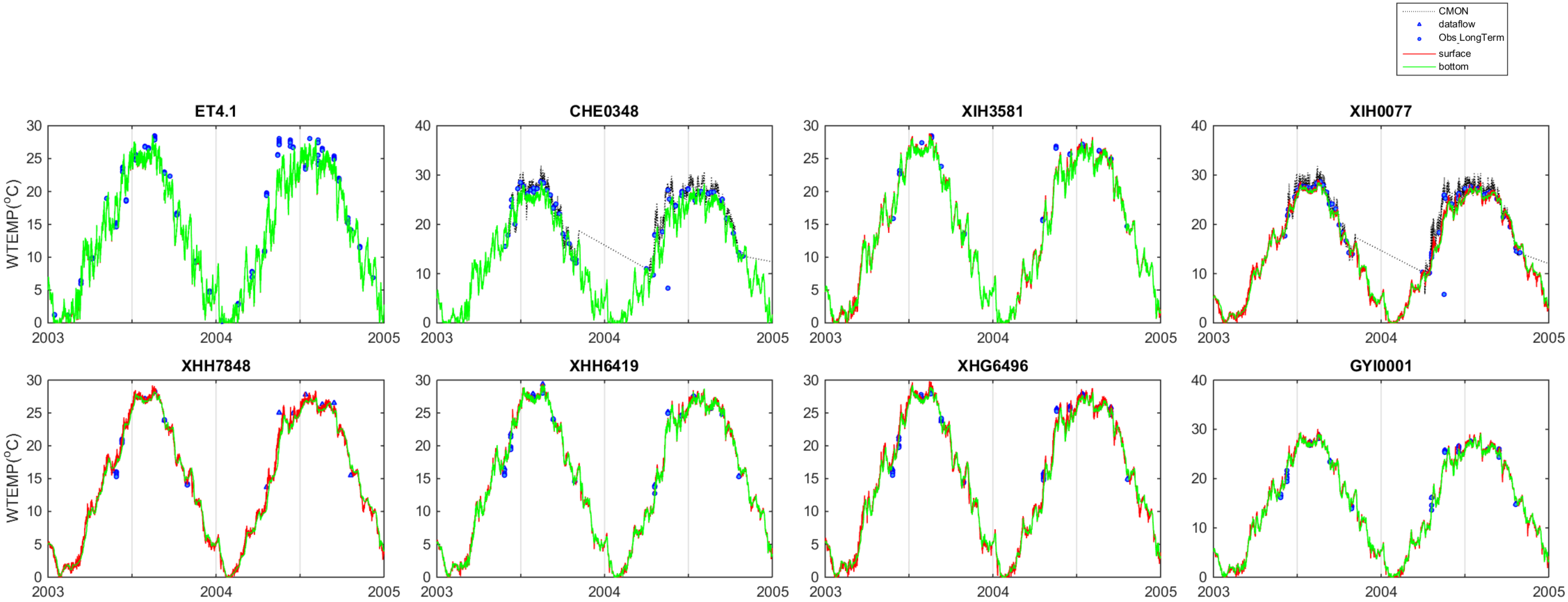


Salinity in the Corsica River and lower Chester River

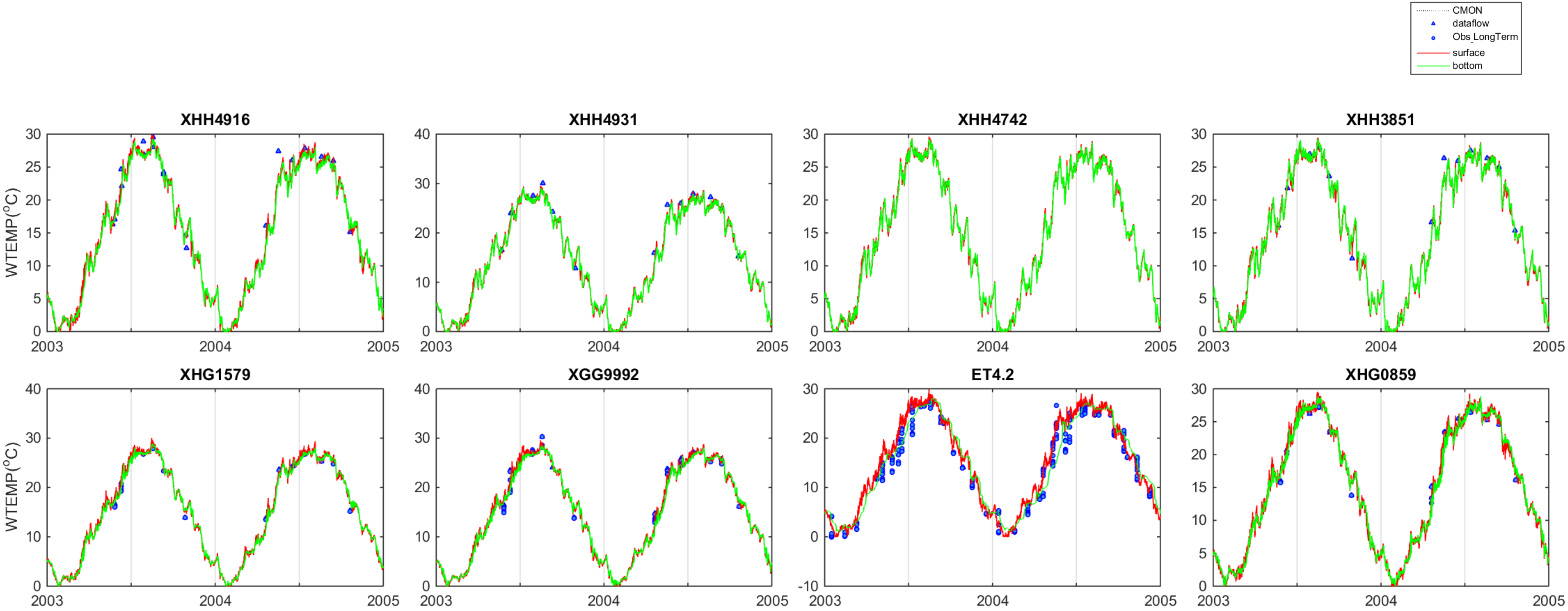


Salt intrusion prediction was better using coupled upper Bay open boundary condition

Temperature in the tidal fresh and middle Chester River

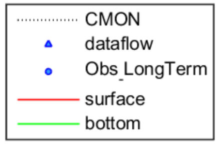


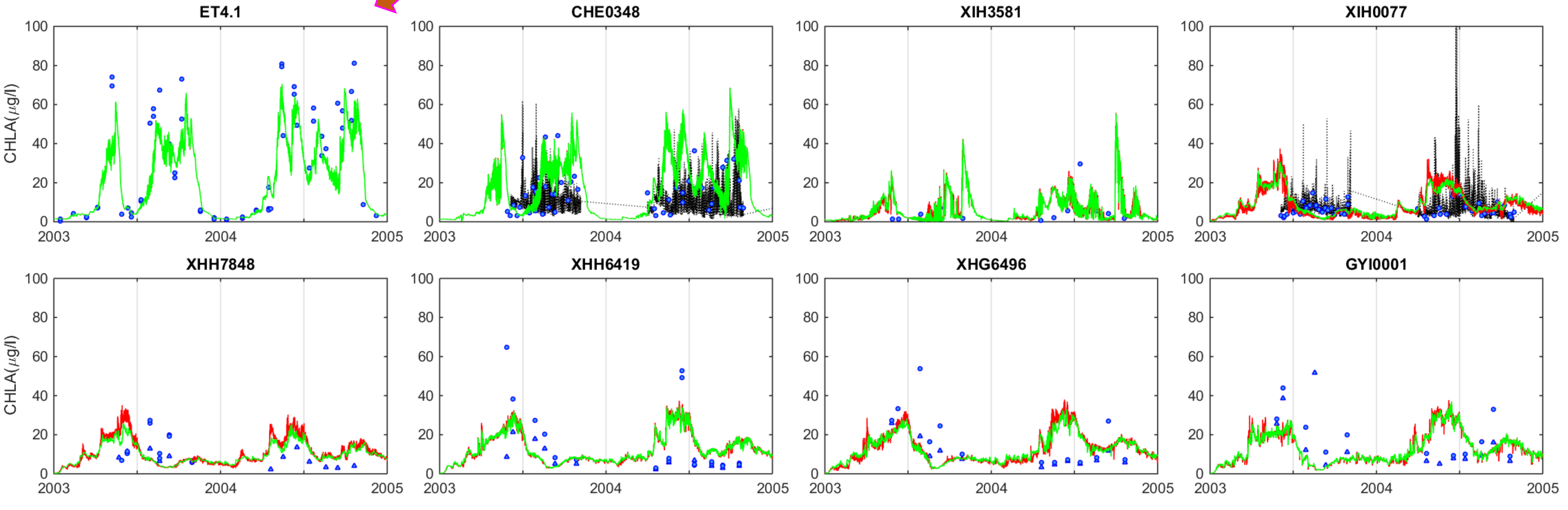
Temperature in the Corsica River and lower Chester River



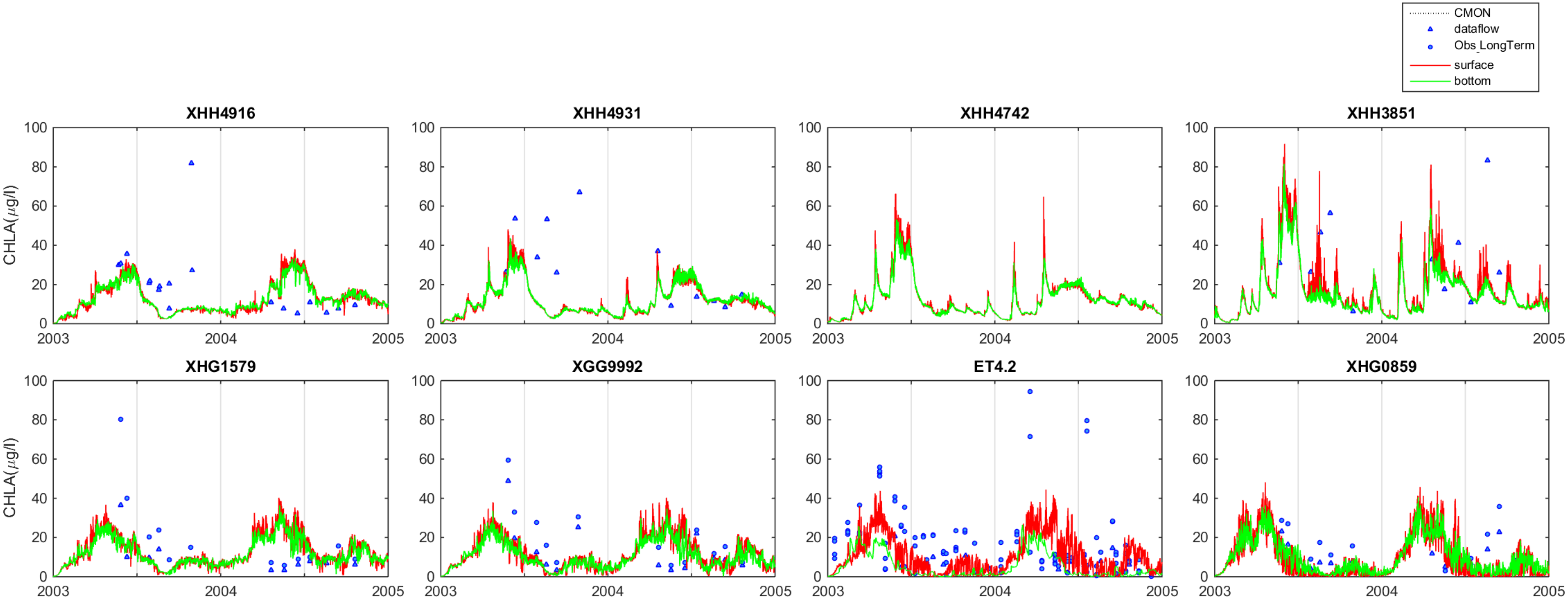
Chlorophyll in the tidal fresh and middle Chester River

Likely Cyanobacteria

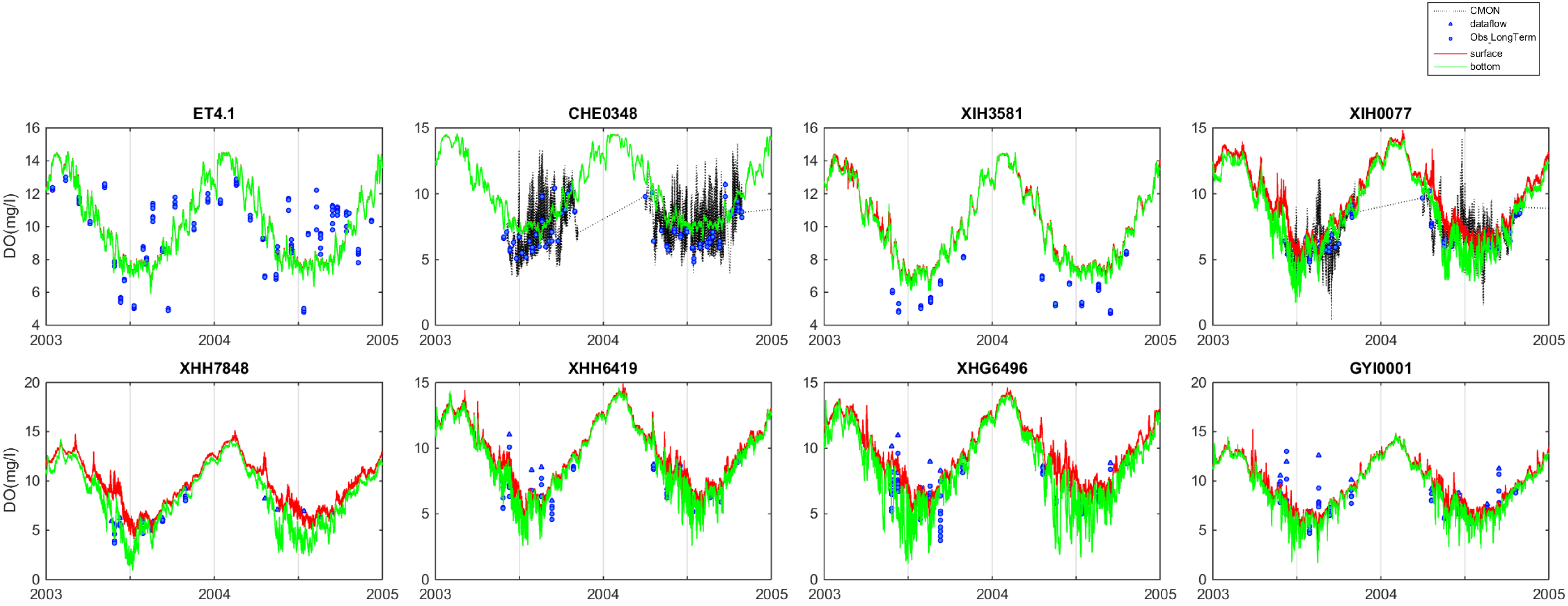




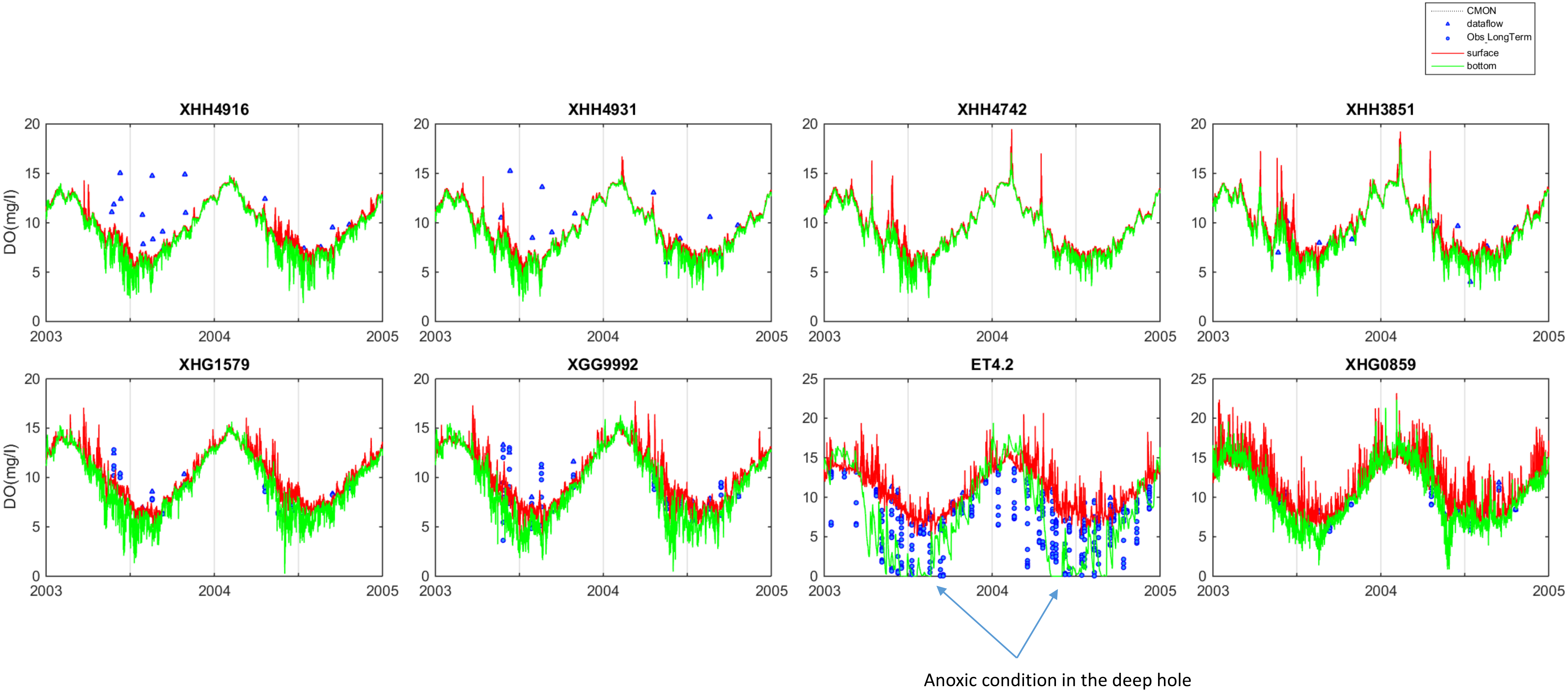
Chlorophyll in the Corsica River and lower Chester River



Dissolve oxygen in the tidal fresh and middle Chester River

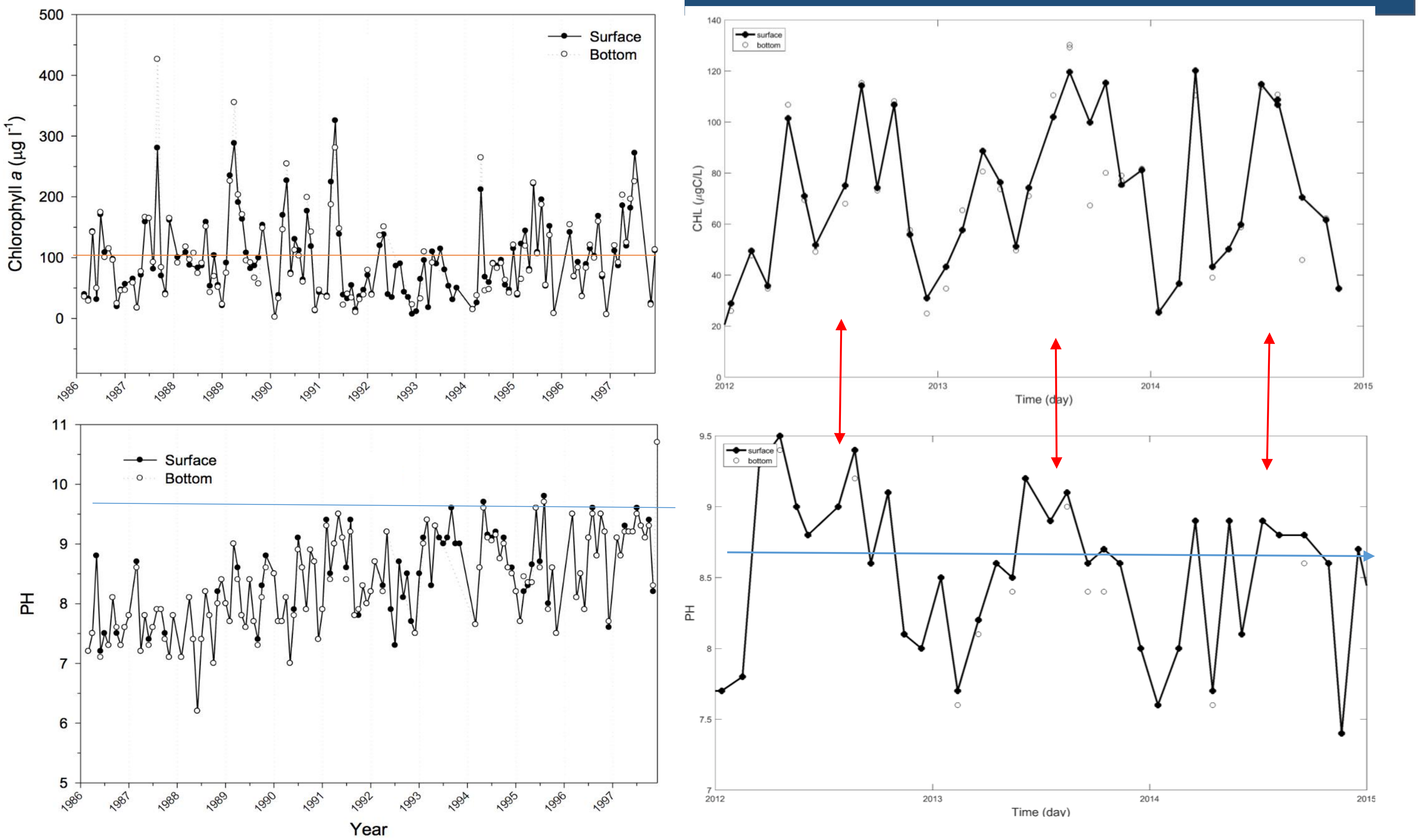


Dissolve oxygen in the Corsica River and lower Chester River

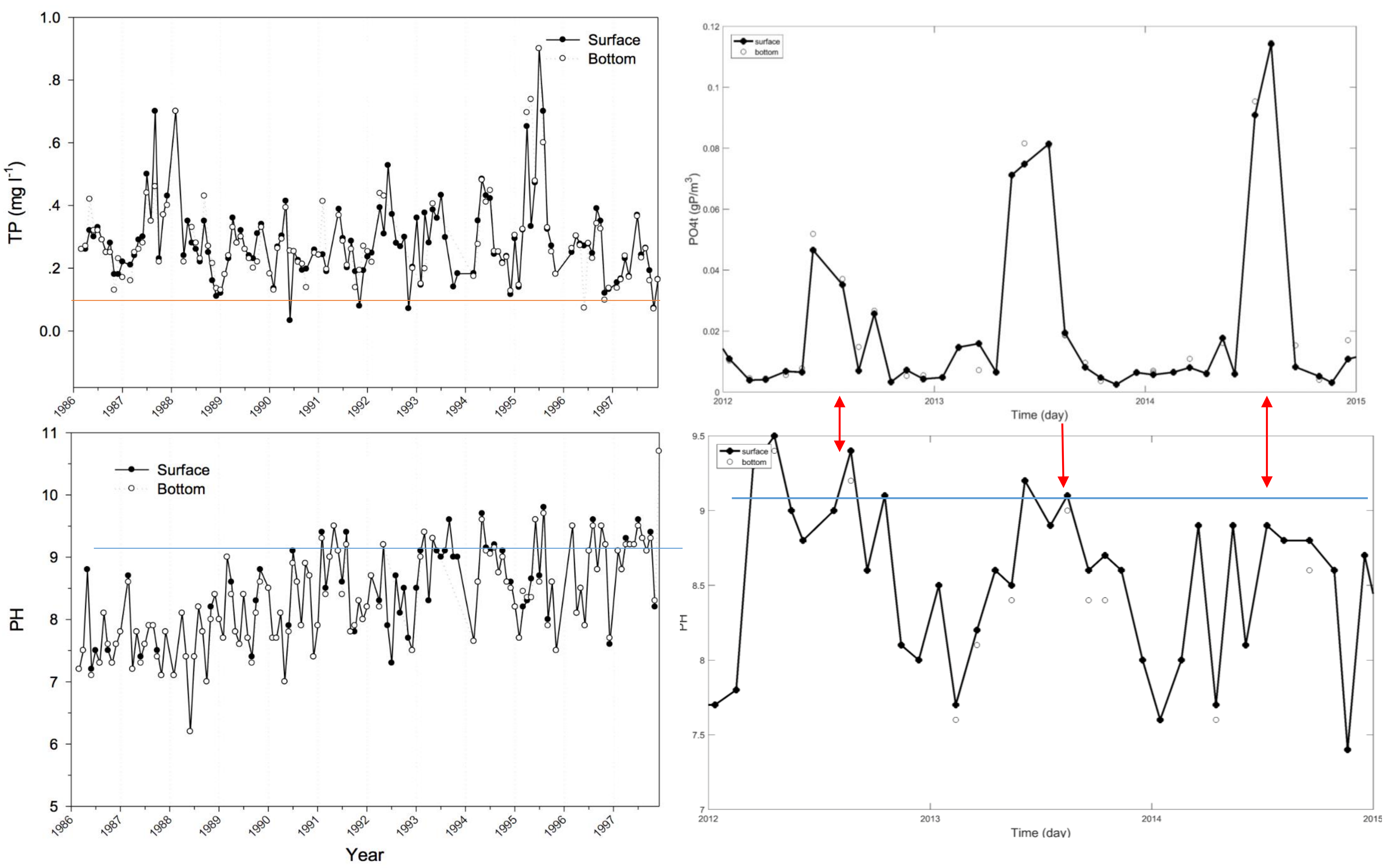


Ⅲ. A PH dependent phosphorus release scheme

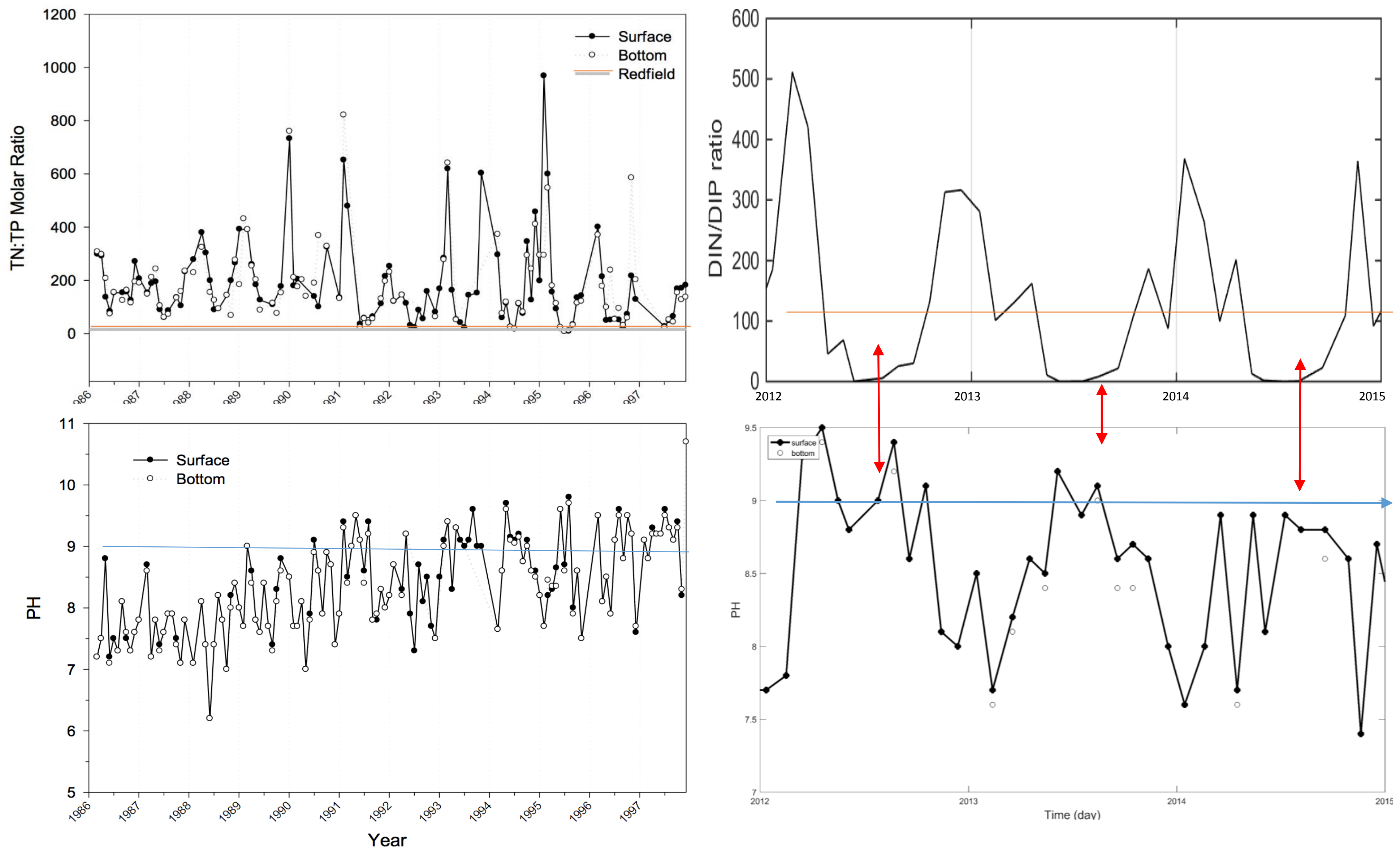
Observational evidence of high chlorophyll and pH in Back River



Evidence of high phosphorus and pH in Back River

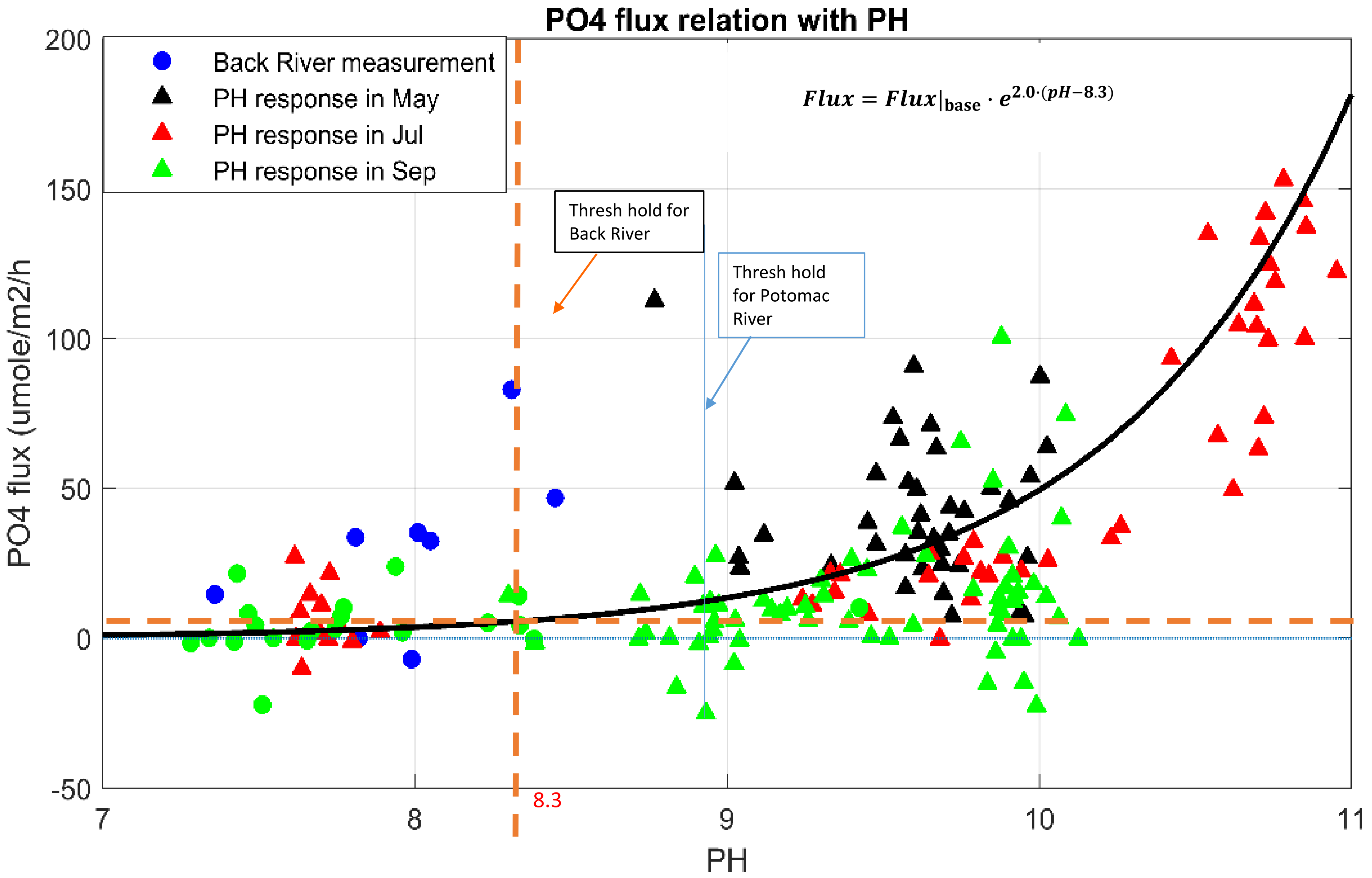


Evidence of high N:P ratio versus low pH in Back River

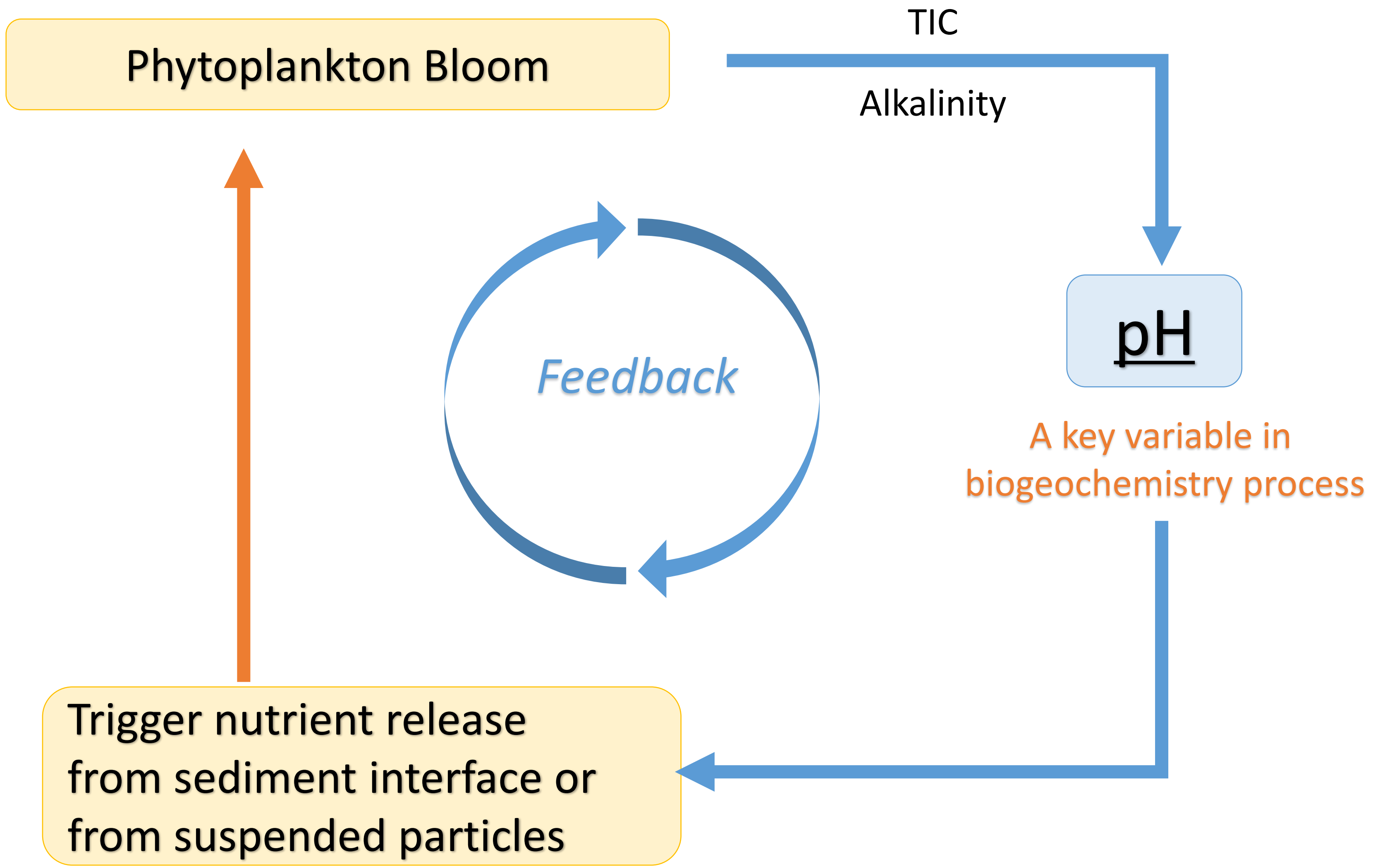


Effect of pH on phosphorus release in Back River

- PH indeed poses effect on phosphorus release in Back River with slightly lower thresh hold than that of Potomac River



The pH positive feedback loop is proposed as a mechanism for sustaining high algal biomass exceeding 100 -200 µg/l in Back River



Development of pH sub-model

Apply DIC and ALK from water quality model to the pH equation.

$$\frac{\partial \mathrm{DIC}}{\partial t} = \sum_x (R - G) * PB_x \quad + \frac{rKa * (CO2_{sat} - CO2)}{H} + rKHR * DOC$$

algal respiration and growth | reaeration | DOC transformation

$$+ \frac{SOD}{H * AOC} + rKCACO3 * (CA_{sat} - CA)\frac{\mathrm{mC}}{\mathrm{mCACO3}}$$

sediment release | caco3 formation/dissolution

$$\frac{\partial \mathrm{ALK}}{\partial t} = \sum_x \left\{ -\frac{15}{14} * PN_x * G * PB_x + \frac{17}{16} * (1 - PN_x) * G * PB_x \right\}$$

algal uptake of NH4 | algal uptake of NO3

$$* ANC_x * \frac{\mathrm{mCACO3}}{2 * \mathrm{mN}} - rNit * NH4 * \frac{\mathrm{mCACO3}}{\mathrm{mN}} + rKCACO3 * (CA_{sat} - CA)$$

nitrification | caco3 formation/dissolution

Development of pH sub-model

Carbon equilibrium

$$H_2CO_3 \overset{K_1^*}{\rightleftharpoons} HCO_3^- + H^+ \cdots\cdots (1)$$

$$HCO_3^- \overset{K_2^*}{\rightleftharpoons} CO_3^{2-} + H^+ \cdots\cdots (2)$$

Mass balance of inorganic carbon

$$DIC = [CO_2] + [HCO_3^-] + [CO_3^{2-}] \cdots\cdots (3)$$

Approximation of alkalinity

$$ALK \cong [HCO_3^-] + 2[CO_3^{2-}] + [B(OH)_4^-] + [OH^-] - [H^+] \cdots\cdots (4)$$

Water equilibrium

$$H_2O \overset{K_w^*}{\rightleftharpoons} H^+ + OH^-$$

Boron equilibrium

$$B(OH)_3 + H_2O \overset{K_B^*}{\rightleftharpoons} B(OH)_4^- + H^+$$

$$B_T = [B(OH)_3] + [B(OH)_4^-] = 4.16 \times 10^{-4} \times \frac{\text{Salinity}}{35}$$

4 equations
6 variables

Governing equation: 5th order algebraic equation

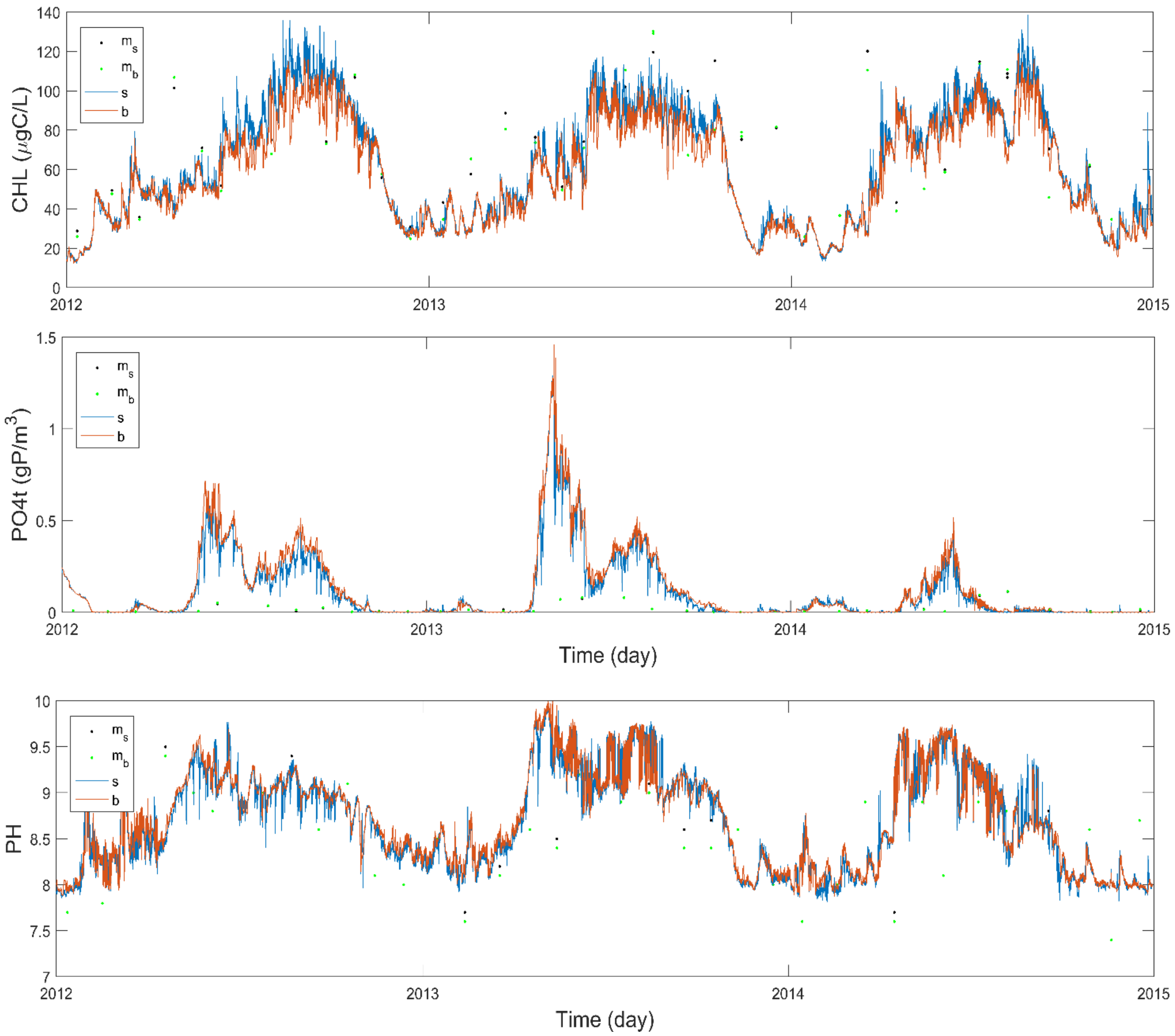
$$DIC \cdot (K_B^* + h) \cdot (K_1 h^2 + 2K_1K_2 h) - [ALK(K_B^* + h)h - K_B^* B_T h - K_W^*(K_B^* + h) + (K_B^* + h)h^2] \cdot (h^2 + K_1 h + K_1K_2) = 0$$

Numerically, solving the pH equation with Brent's Method

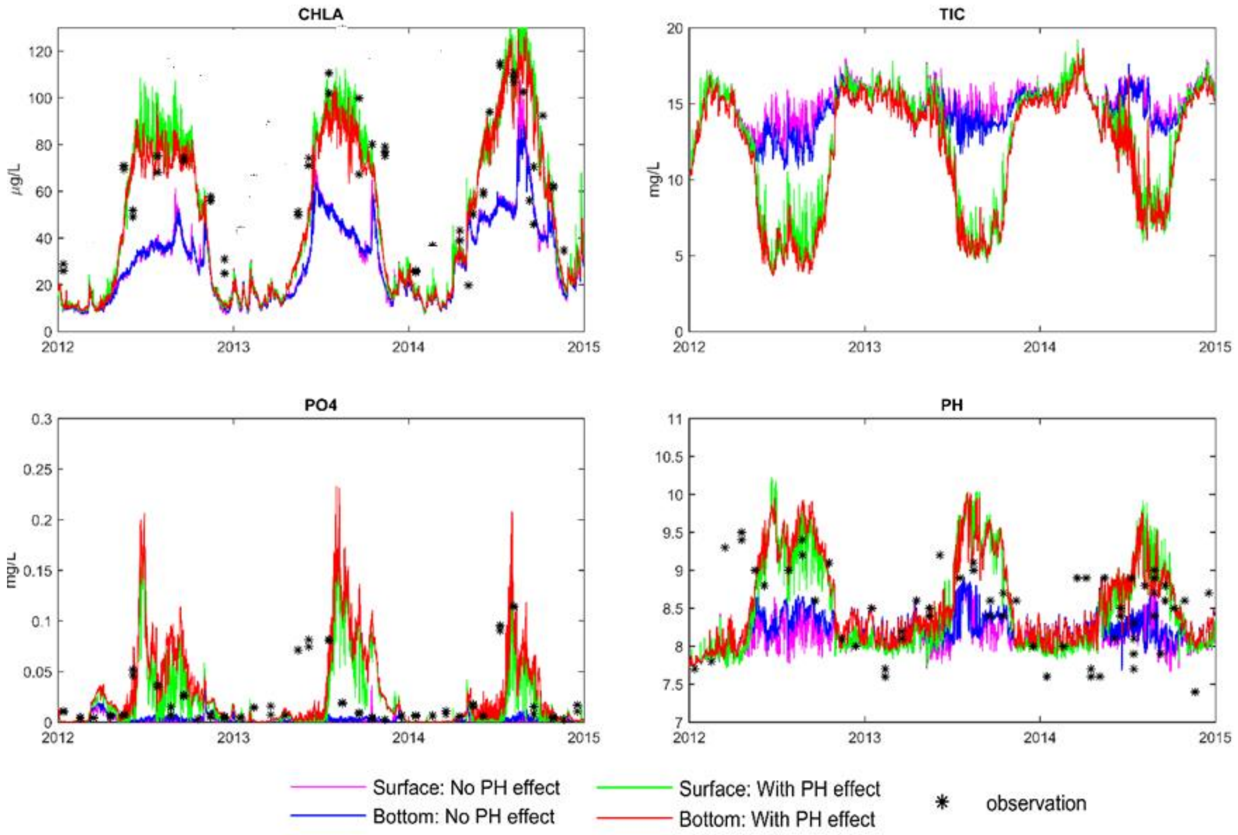
- **root bracketing and bisection** ➡ Stability
- **inverse quadratic interpolation.** ➡ Efficiency (8.60298358 × 10^{-7}s per operation)

Results:

- Base comparison and calibration



- Sensitivity with and without PH



IV. Conclusion

- The SCHISM hydrodynamic model goes a greater extent in treating the horizontal and vertical grids to ensure they reflect the real geometry truthfully.

- The modeled results of salinity and temperature compared very well with the observation when the coupled upper Bay open boundary condition was used.

- The simulation for the wind wave and inorganic sediment concentration showed the nearshore resuspension is important and can have significant impacts on the shallow water clarity.

- The water quality simulation was carried out based on the parameters derived from the rich data available. The TSS data was treated separately for the TVSS and inorganic suspended sediment. The latter was then provided by SCHISM.

Conclusion (con't)

- The results for the chlorophyll simulation indicated that there is a persistent higher concentration occurred in the fresh water portion of the Chester in the summer, which is likely the bloom due to Cyanobacteria. Its concentration, however, drops quickly when encountering with the brackish water downstream.

- The DO anoxic condition occurred only in the deep hole in the lower Chester.

- A PH dependent phosphorus release scheme was developed which could be important for the algal dynamics in the fresh portion of the estuary, such as Back River or Corsica River.

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