Development of a Harmful Algal Bloom Model in Support of New Water Quality Standards for Chlorophyll for the James River

Preliminary Water Quality Model calibration

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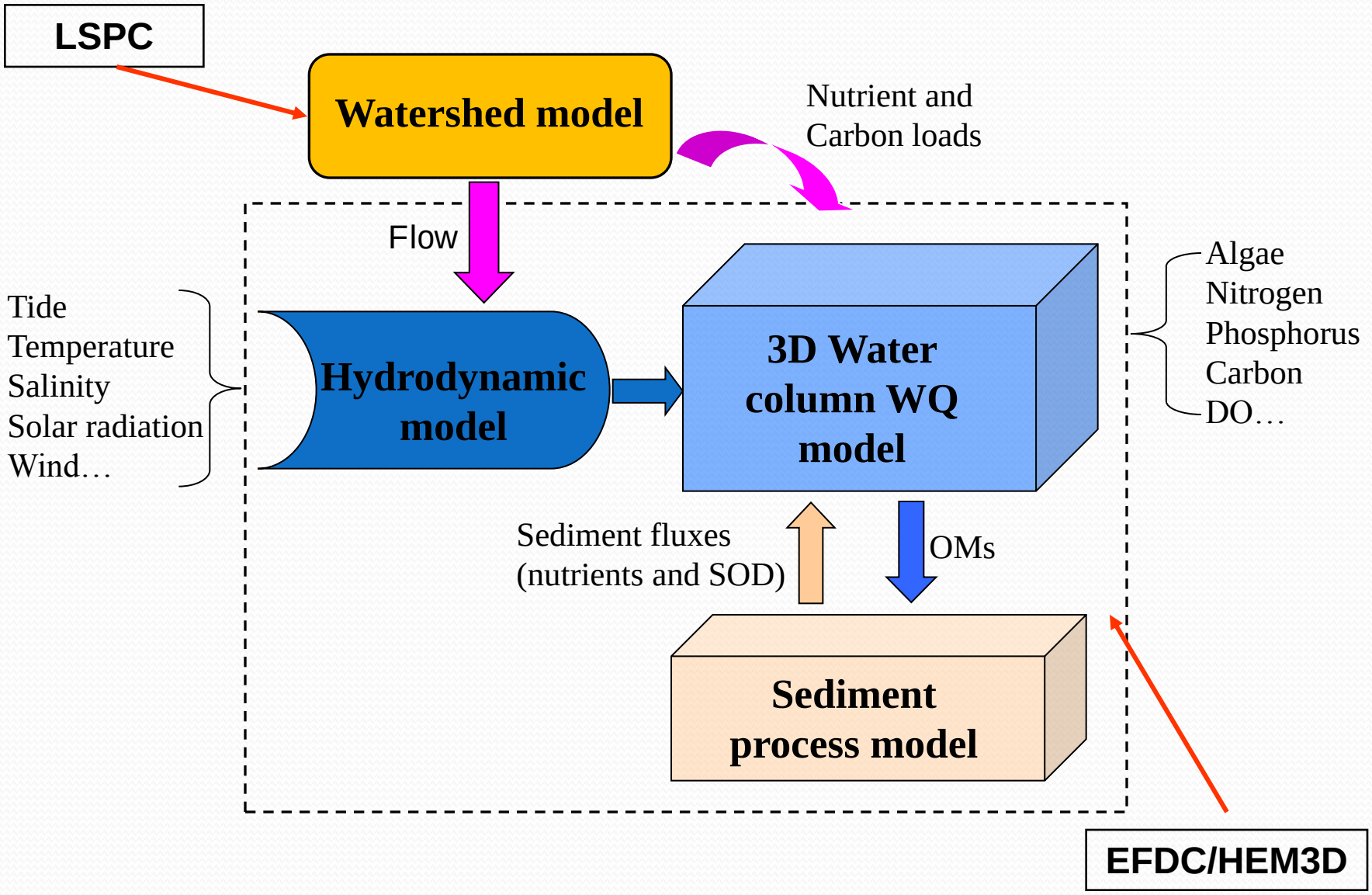
Outline

- Introduction
- Model description and configuration
- Model skill assessment
- Model key parameter consideration
- Model Calibration results
- Discussions

Model Grid

Horizontal :3368 cells
Vertical: 8 layers
Kilometers
0 4.5 9 18 27 36
Richmond
WILLIAMSBURG
PETERSBURG
Hampton
Chesapeake
Portsmouth

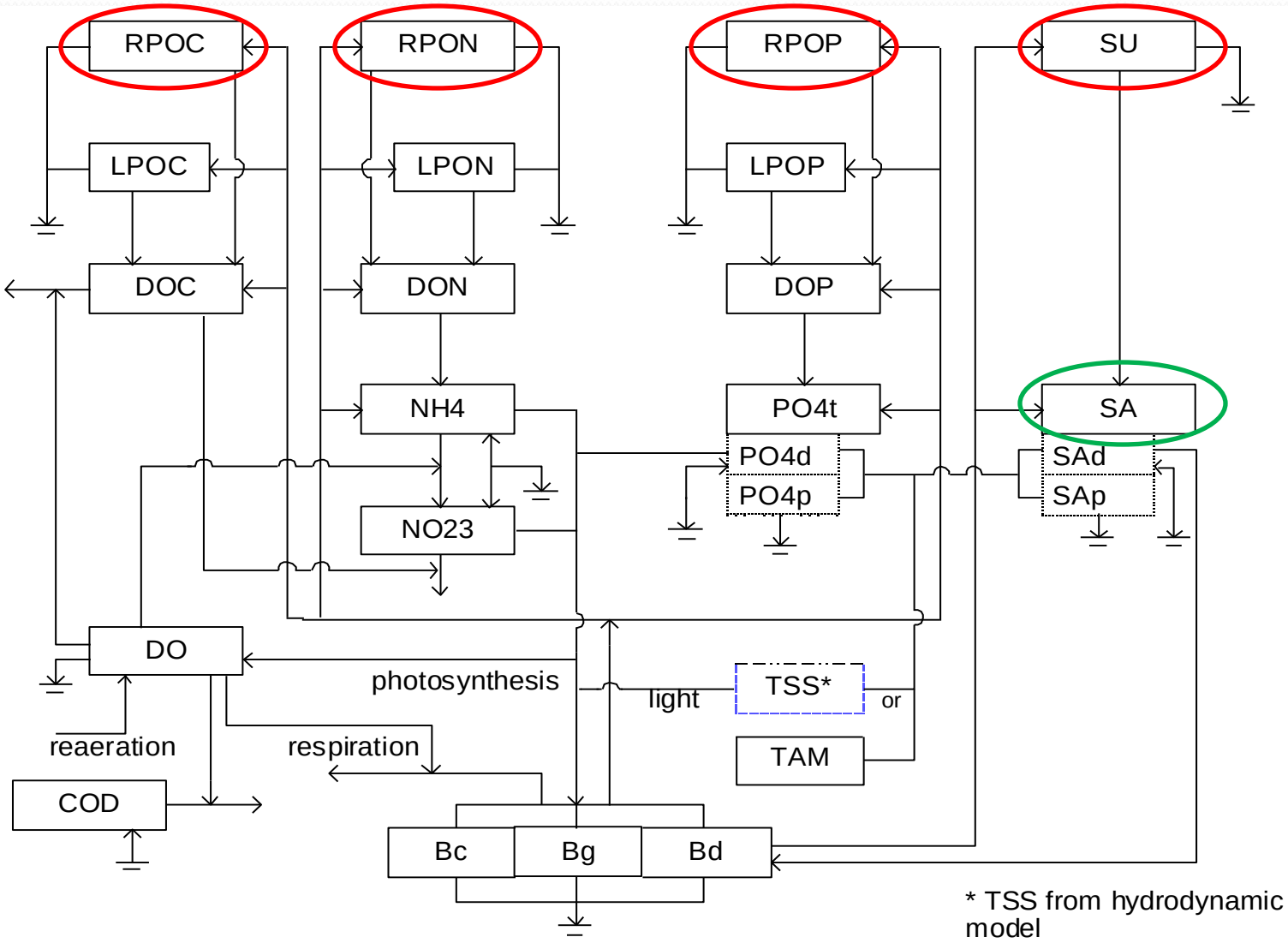
Modeling Approach



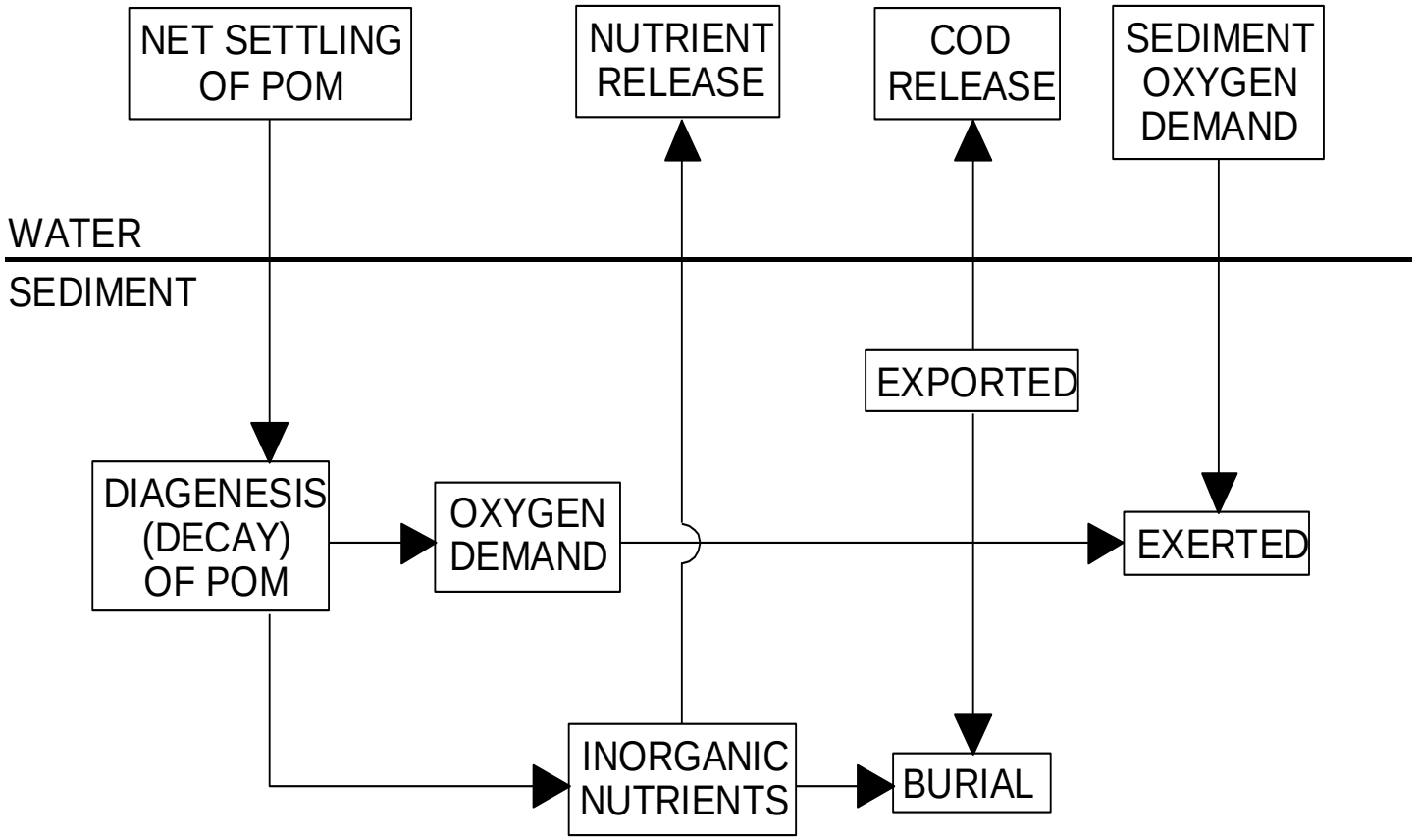
EFDC/HEM3D Model Descriptions

- Boundary Fitted Curvilinear Grid
- Sigma coordinates in vertical
- Eutrophication model is similar to the early version of Bay water quality model
  - Without zooplankton, SAV, and benthos
- Bottom sediment diagenesis model is similar to DiToro and Fitzpatrick's model the Chesapeake Bay water quality model

EFDC Water Quality model Schematic



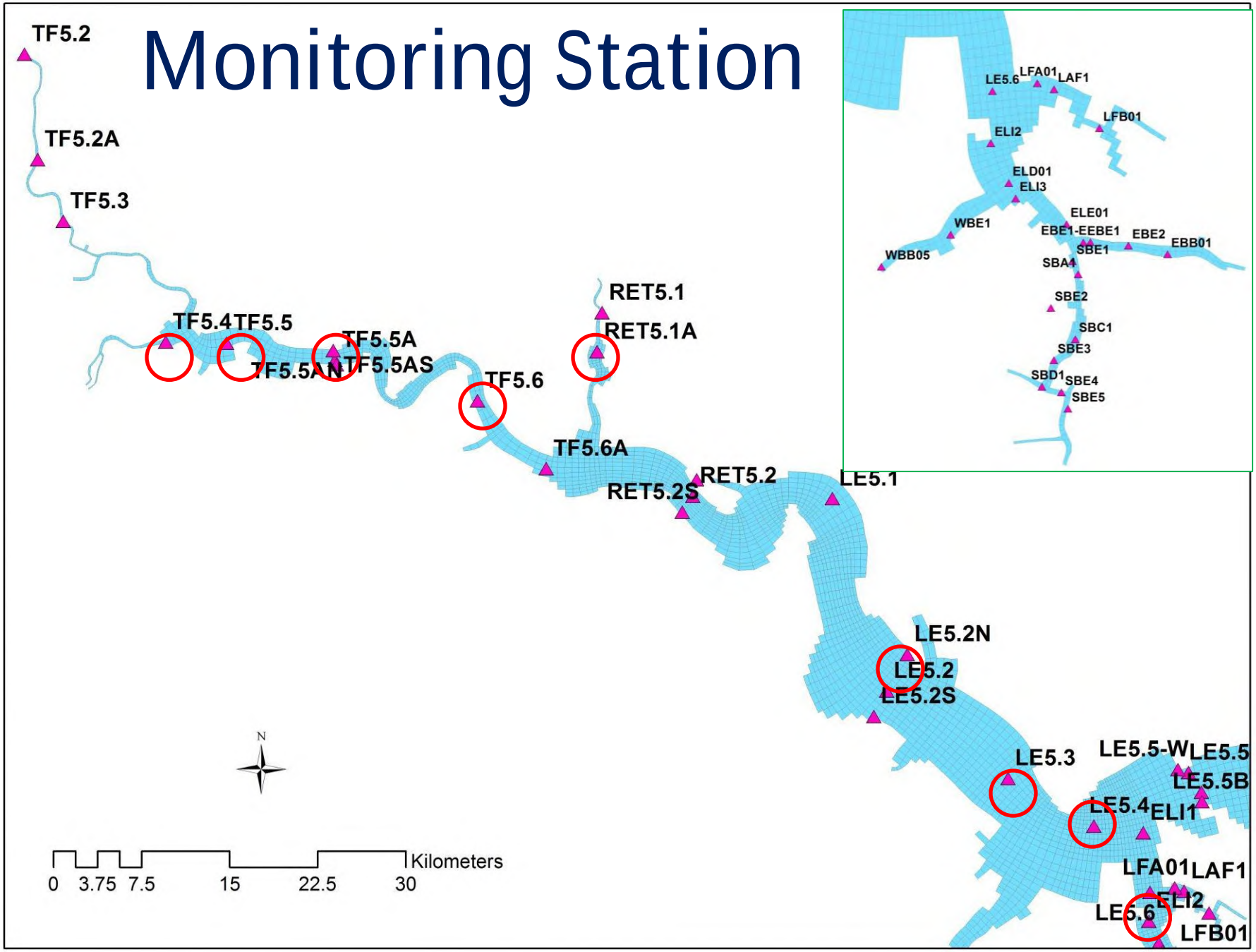
Sediment Diagensis Model Schematic



Model Configuration

- Flow and loadings use LSPC daily model outputs
  - POC, DOC, PON, DON, NH4, NO23, POP, DOP, PO4, and DO
  - POC, DOC, PON, DON, POP, and DOP are based on ratio to total organics
  - SA uses constant concentration times flow
- Open boundary condition uses Chesapeake Bay model outputs
  - Bay model outputs have same state variables
- Solar radiation uses hourly observations at Norfolk and Richmond stations
- Hourly observed wind data are used for computing aeration
- Suspended solids use spatially and temporally interpolated results based on observations
- Initial condition for bottom sediment diagensis model
  - Repeat simulations until it reach dynamic equilibrium

Monitoring Station



Model Skill Assessment Criteria

- Model-data graphic comparison
  - Direct comparison
  - Scatter plots
  - Accumulative distribution
  - Error distribution
- Statistics
  - Correlation (R)
  - Root-mean-square error (ER)
  - Model Skill (SS, WS)
  - Mean error (ME)
  - Absolut mean error (AME)
  - Relative error (RE)
- Processes
  - Primary production
  - Respiration
  - Net ecosystem metabolism

$$= \frac{\quad}{{}_{=1}(\quad - \quad)^2}$$

$$= 1 - \frac{{}_{=1}(\quad - \quad)^2}{{}_{=1}(\quad - \quad)^2}$$

$$= 1 - \frac{{}_{=1}(\quad - \quad)^2}{{}_{=1}(\quad - \quad)^2}$$

$$\mathrm{ME} = {}_{=1}(\quad - \mathrm{O}\ )/\mathrm{N}$$

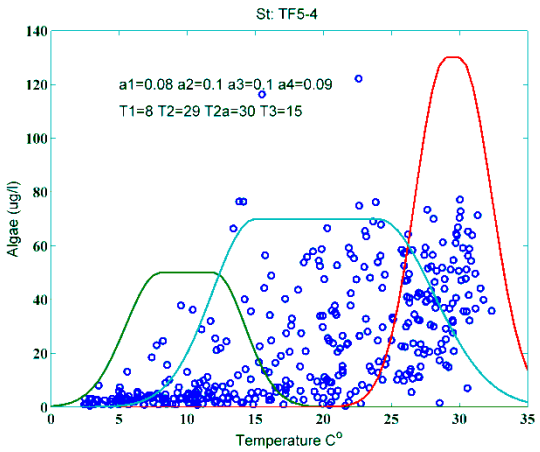
$$\mathrm{AME} = {}_{=1}|\quad - \mathrm{O}\ |/\mathrm{N}$$

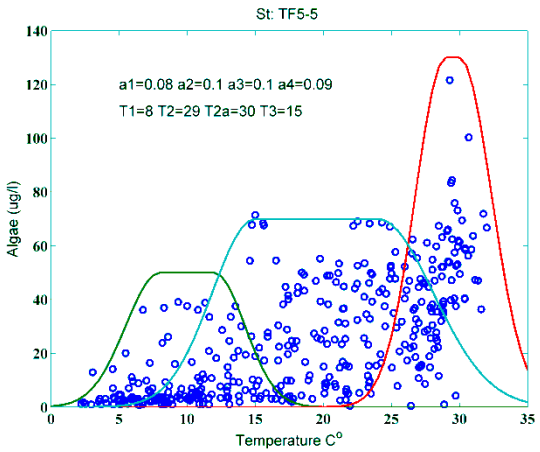
$$= \frac{{}_{=1}|\quad - \quad|}{{}_{=1}}$$

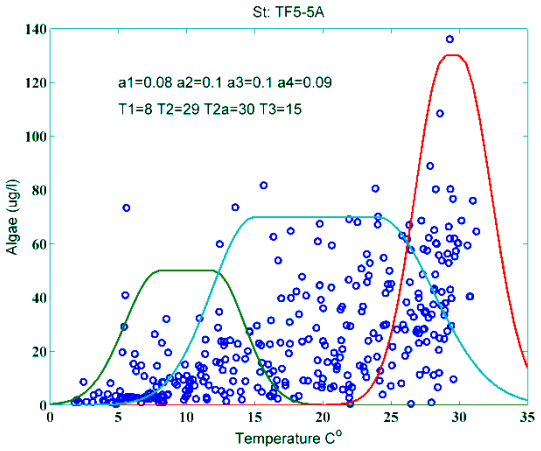
Parameter Considerations

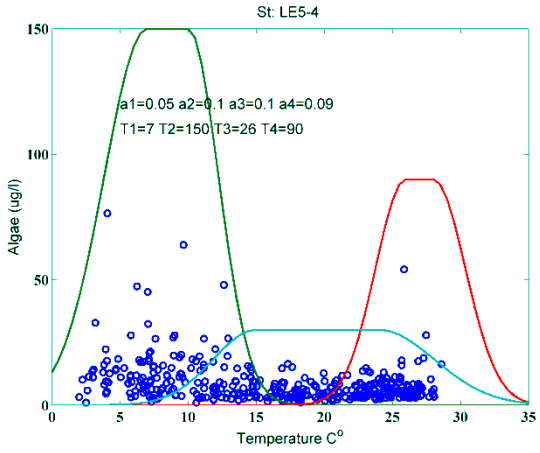
- Phytoplankton species
  - Tidal fresh: cyanobacteria, diatoms, green algae
  - Tidal water: diatom, green algae
  - Motility is applied in the mesohaline zone based on salinity
- Temperature
- Light
- Carbon – Chla ratio
- Other parameters
  - Same order as Bay model

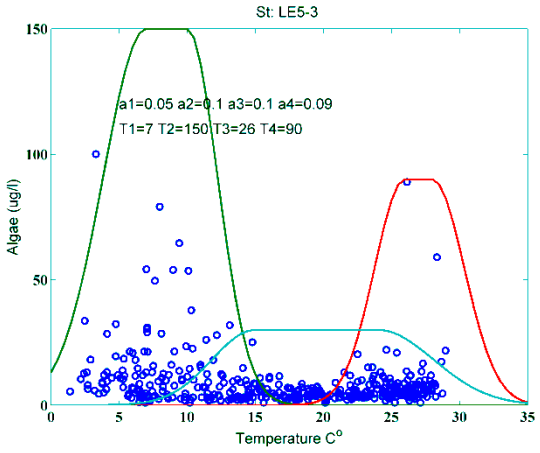
Temperature

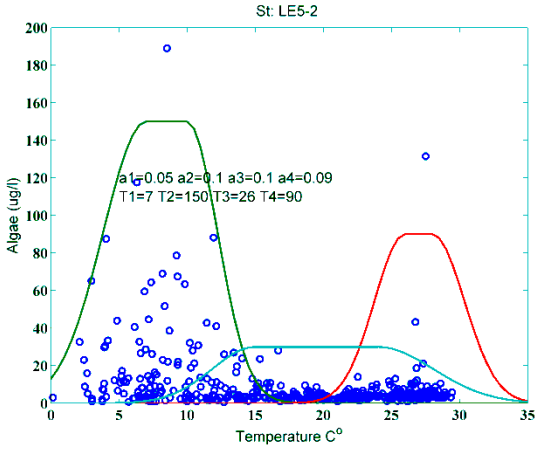




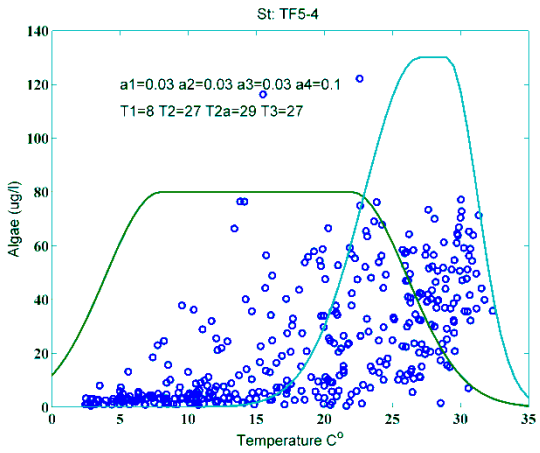


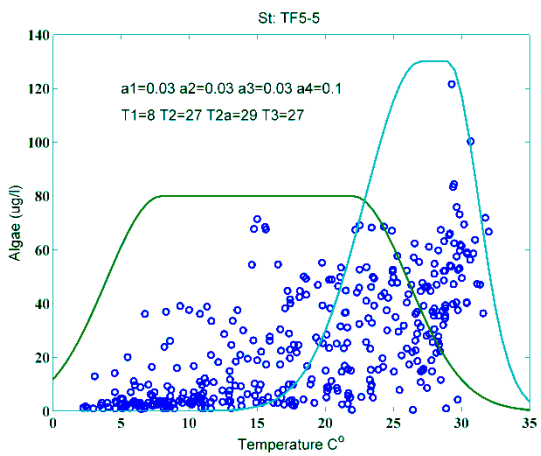


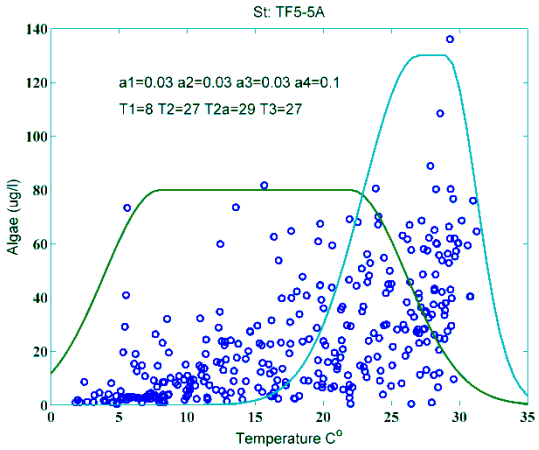


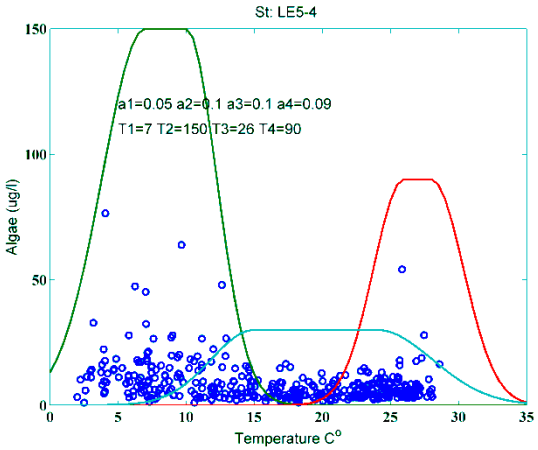


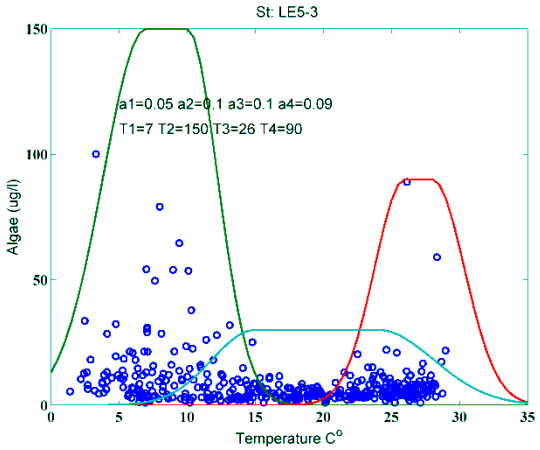
Temperature

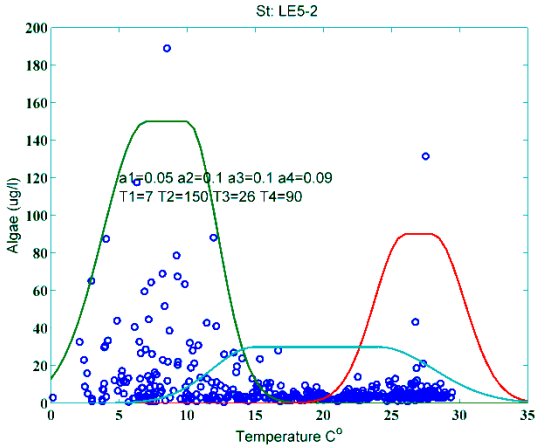






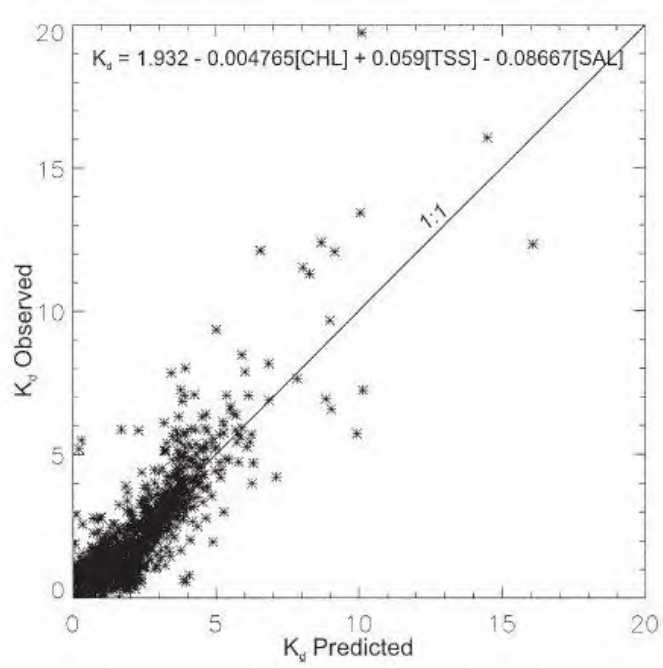


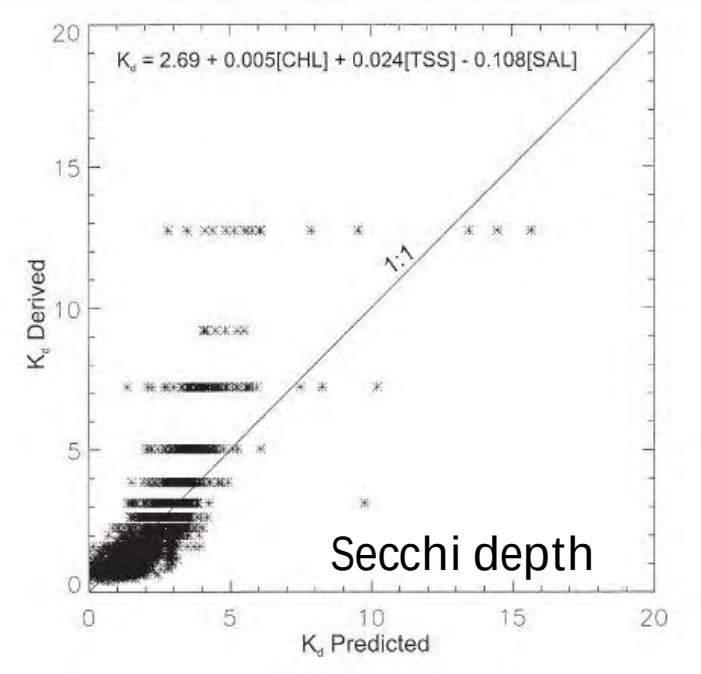




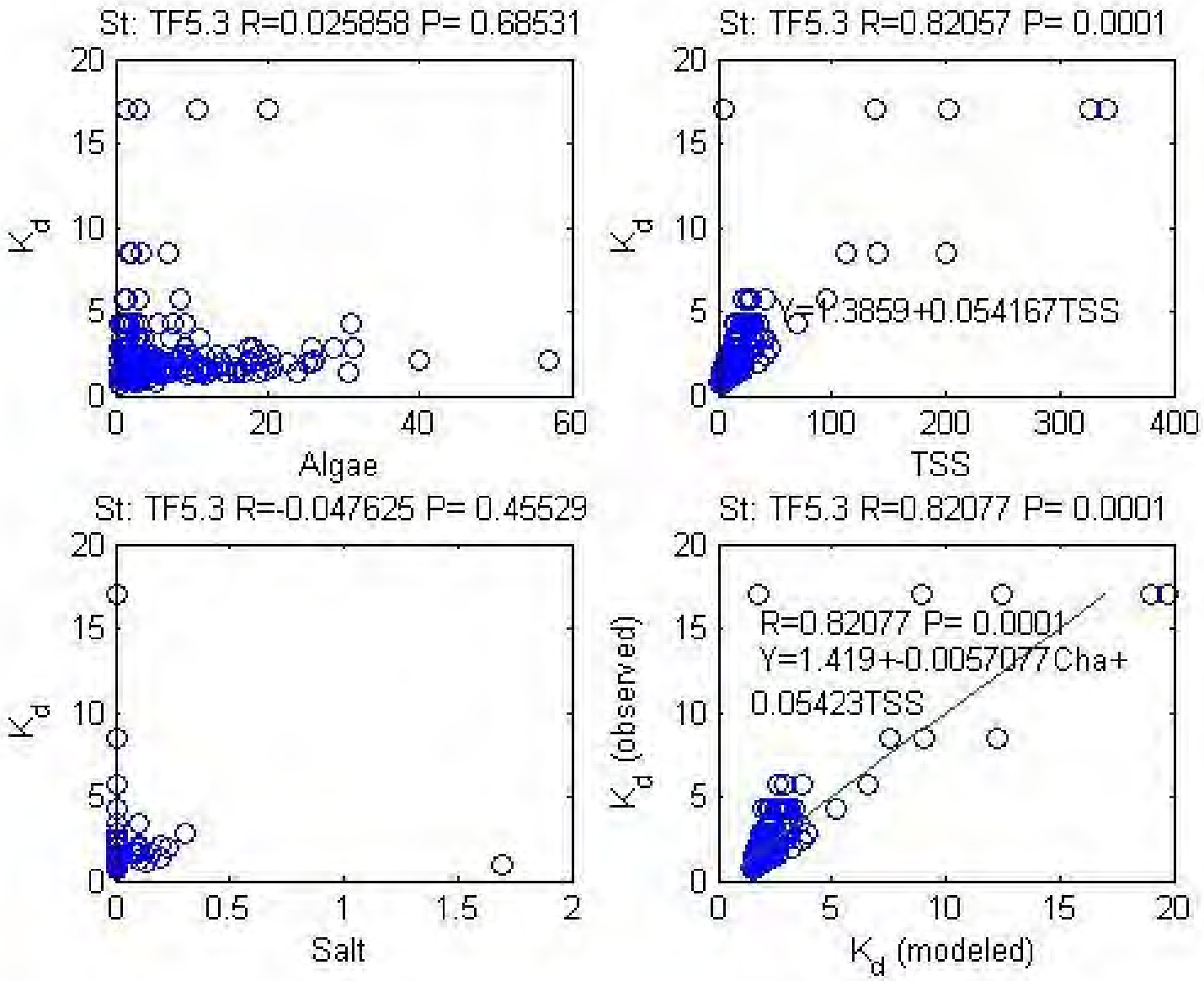
Light

- Light attenuation is expressed as a function TSS, Chl a, Salt, and background (Xu et al., 2005)

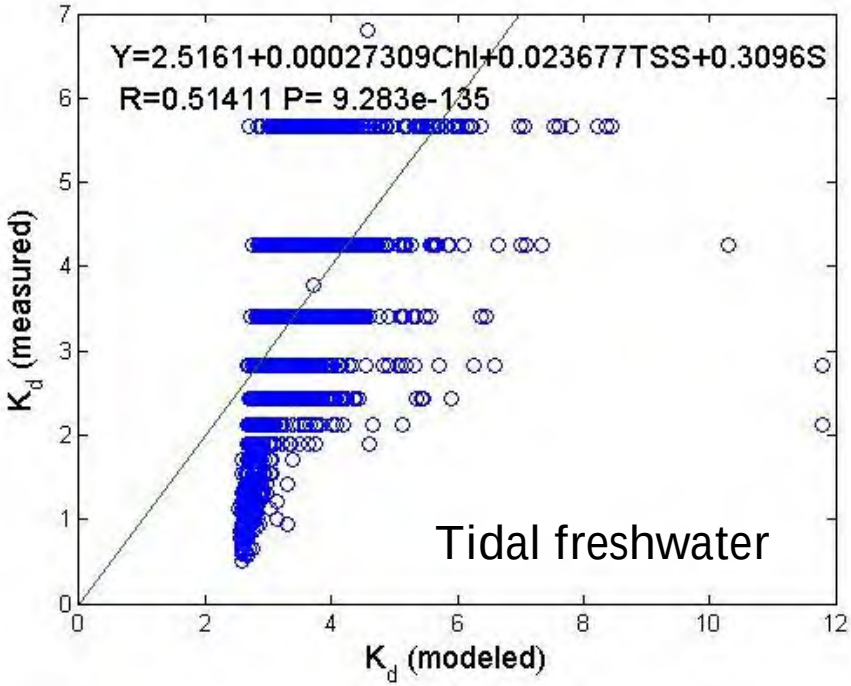


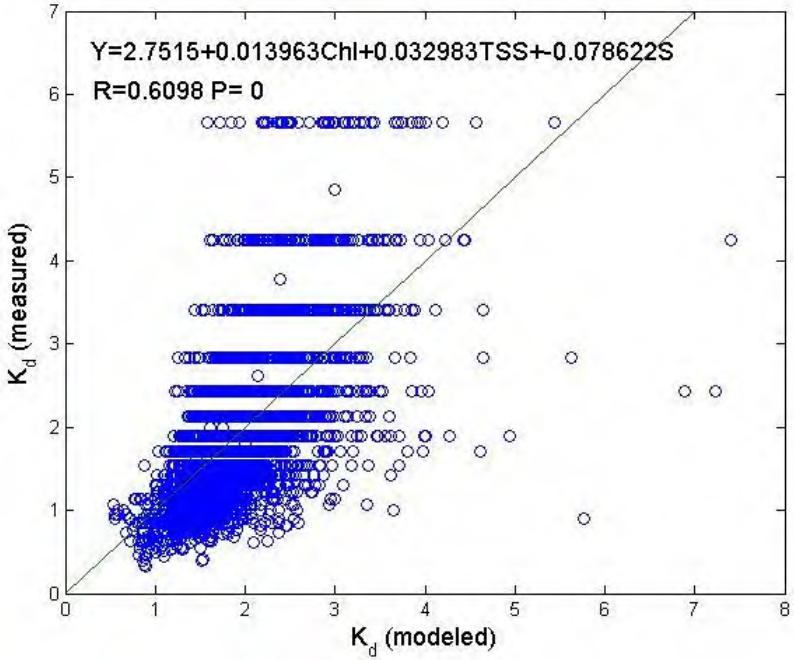


$Kd=1.19+0.3TSS^{(1/1.5)}+0.056*salinity+0.00027\ Chla$ EPA 2008


St: TF5.3 R=0.025858 P= 0.68531
Kd
Algae
St: TF5.3 R=0.82057 P= 0.0001
Y=1.3859+0.054167TSS
TSS
St: TF5.3 R=-0.047625 P= 0.45529
Salt
St: TF5.3 R=0.82077 P= 0.0001
R=0.82077 P= 0.0001
Y=1.419+-0.0057077Cha+
0.05423TSS
Kd (observed)
Kd (modeled)

Combine All Stations





C/Chla Ratio

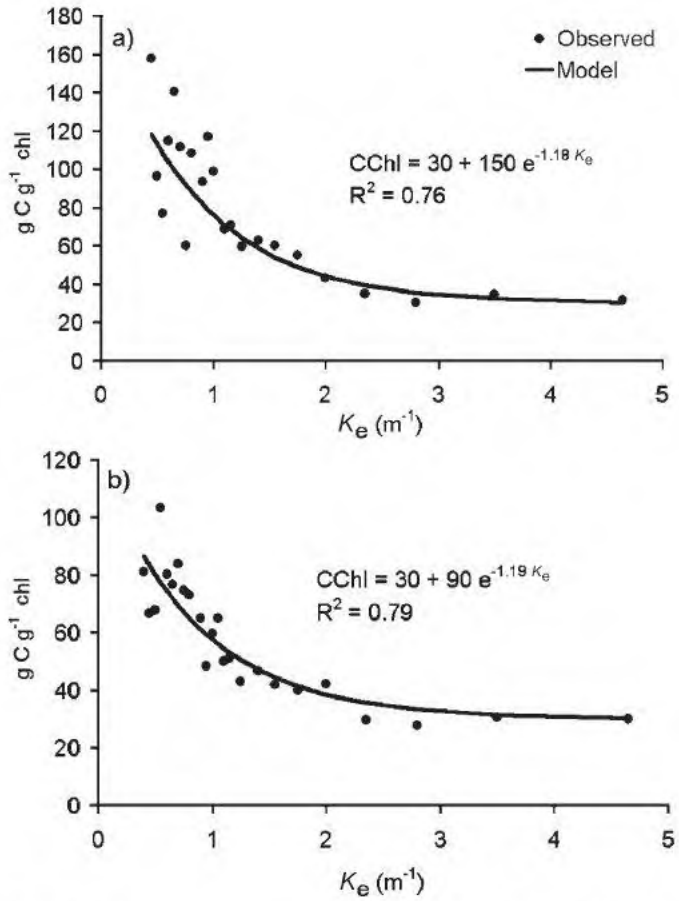
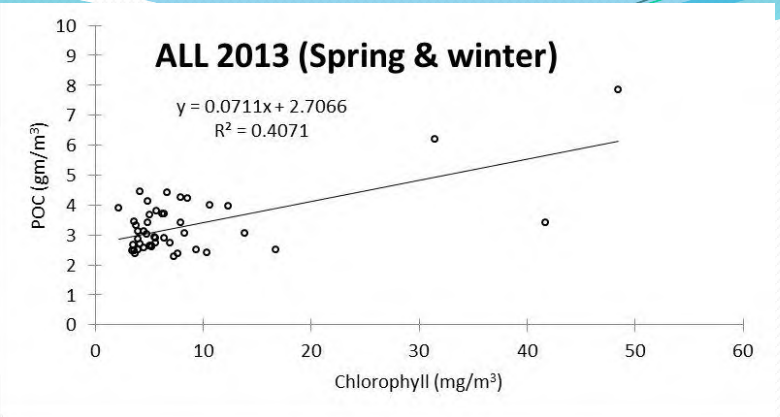
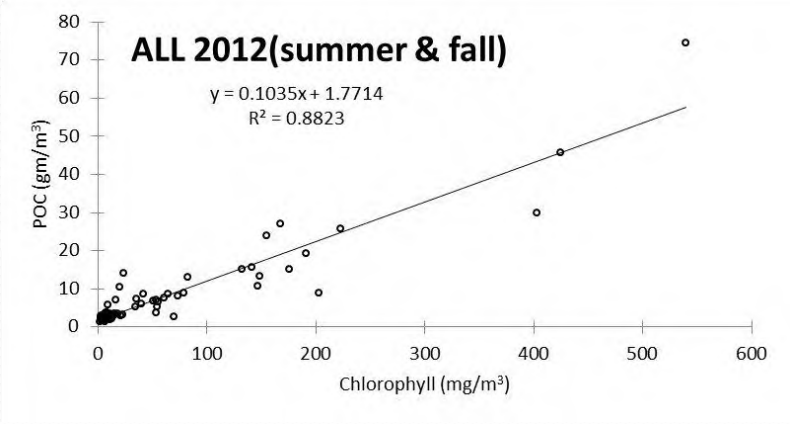


Fig. 3. Observed and modeled carbon:chlorophyll ratios (CChl) versus light attenuation for (a) spring and (b) summer algal groups



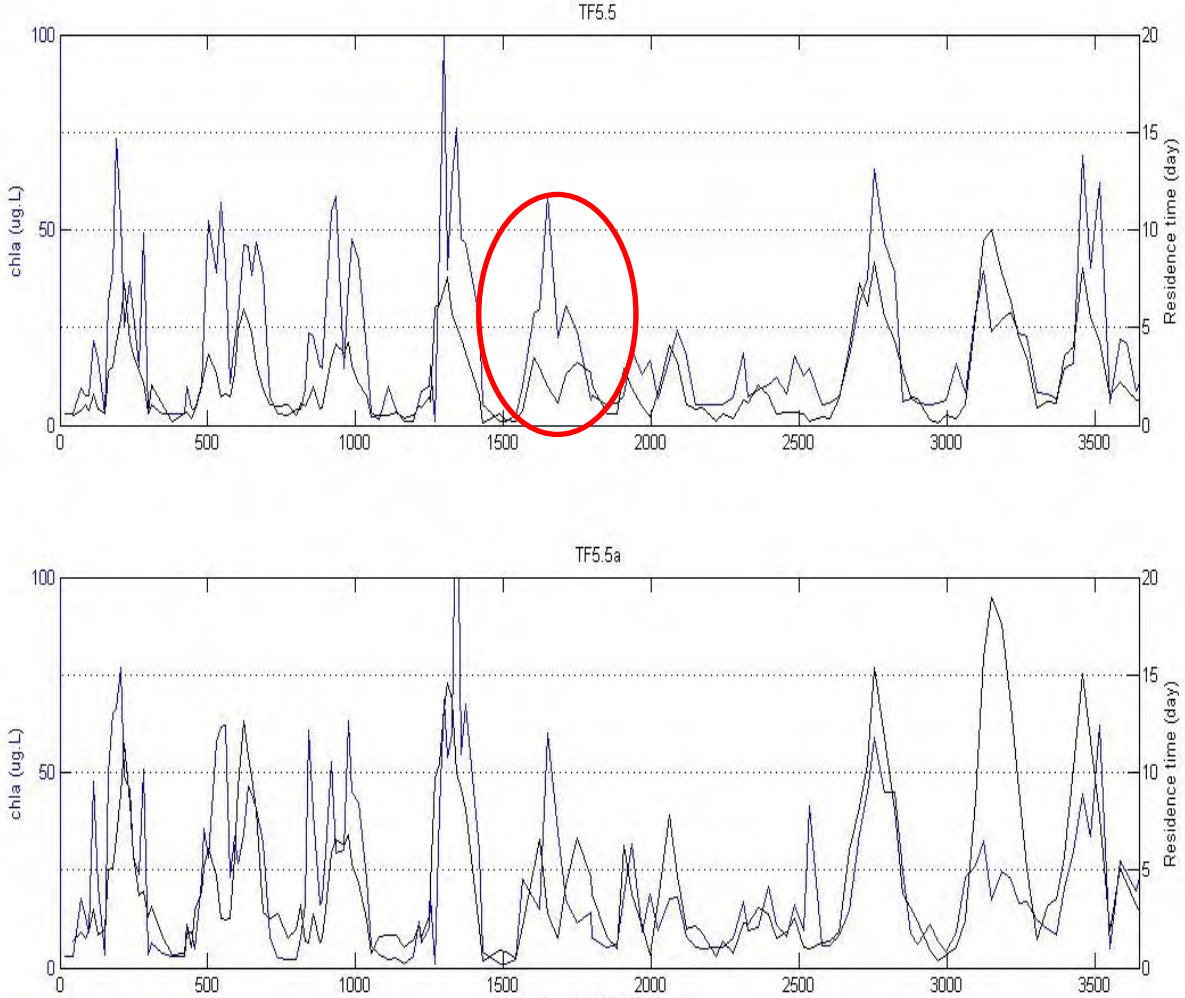


- Tidal freshwater: constant 40 ug/ug (Bukaveckas and Barry, 2011)
- Other region: constant ~60 ug/ug (summer), and 40 ug/ug (winter)

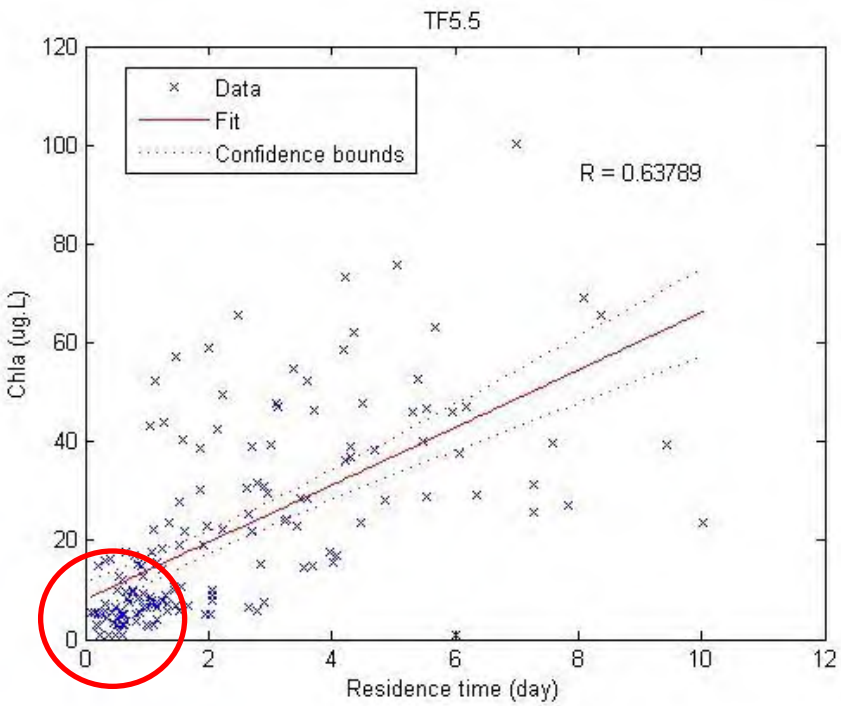
Cerco and Noel, 2004

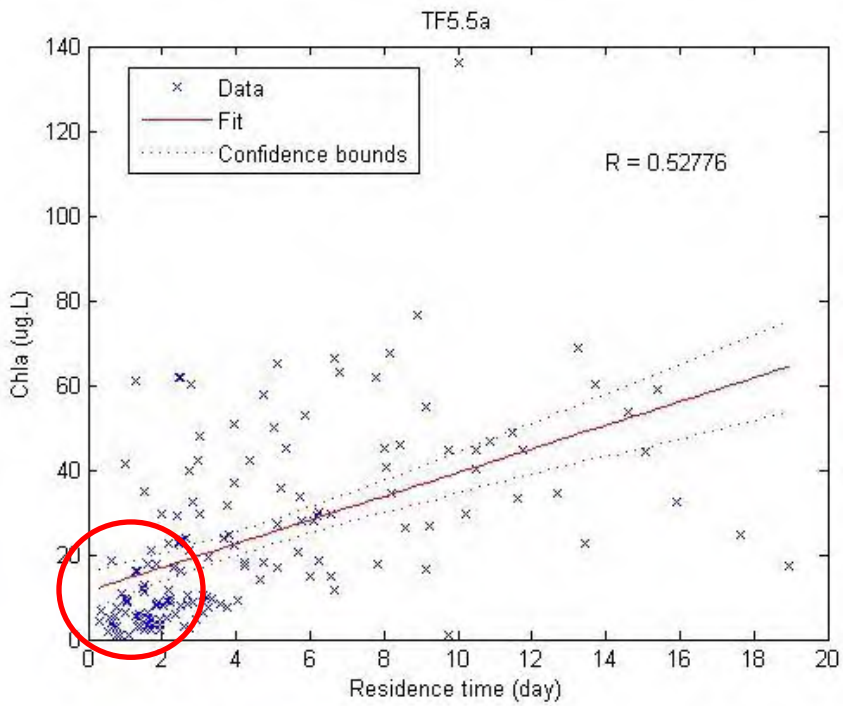
Net Growth Rate

Residence Time vs. Phytoplankton

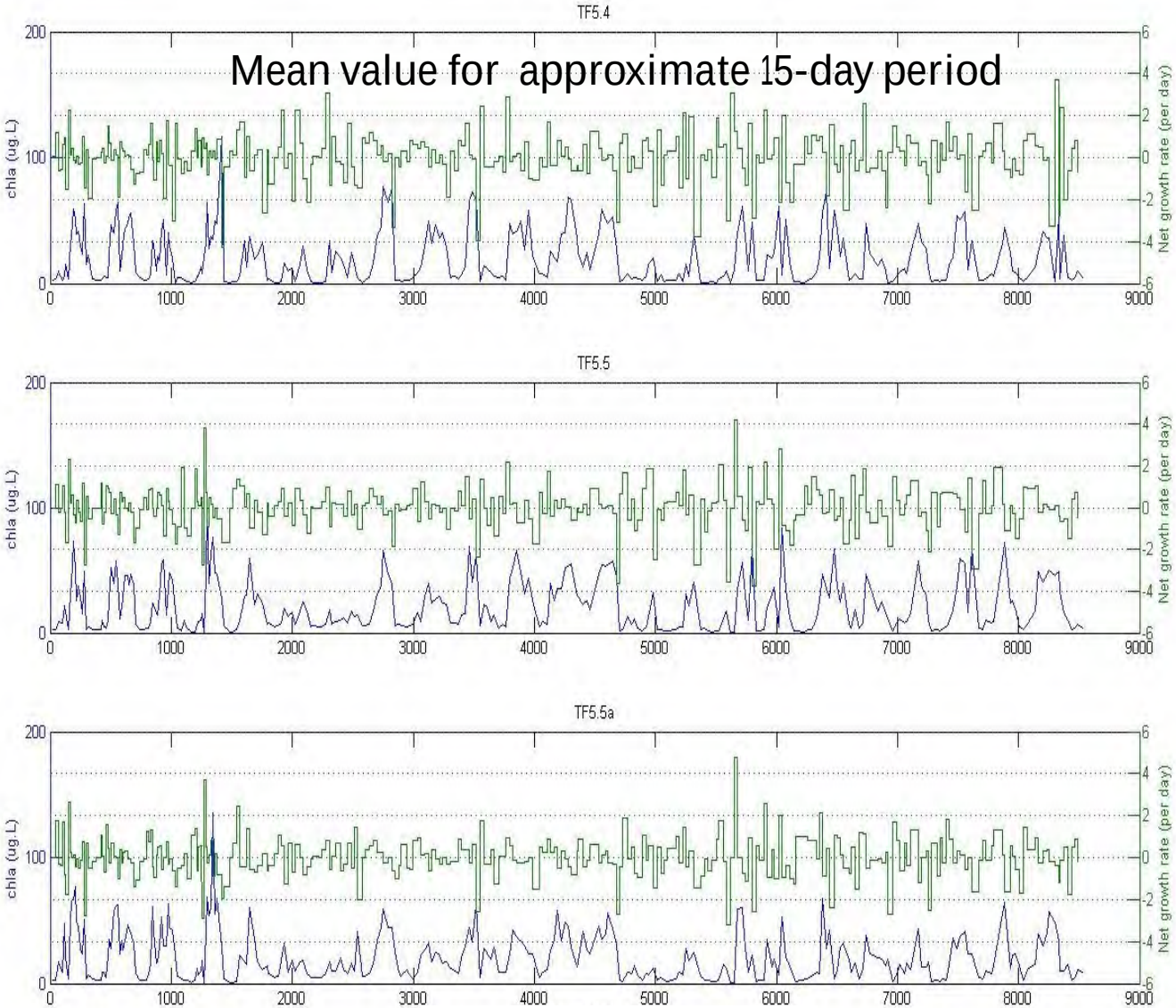


Residence Time vs. Phytoplankton



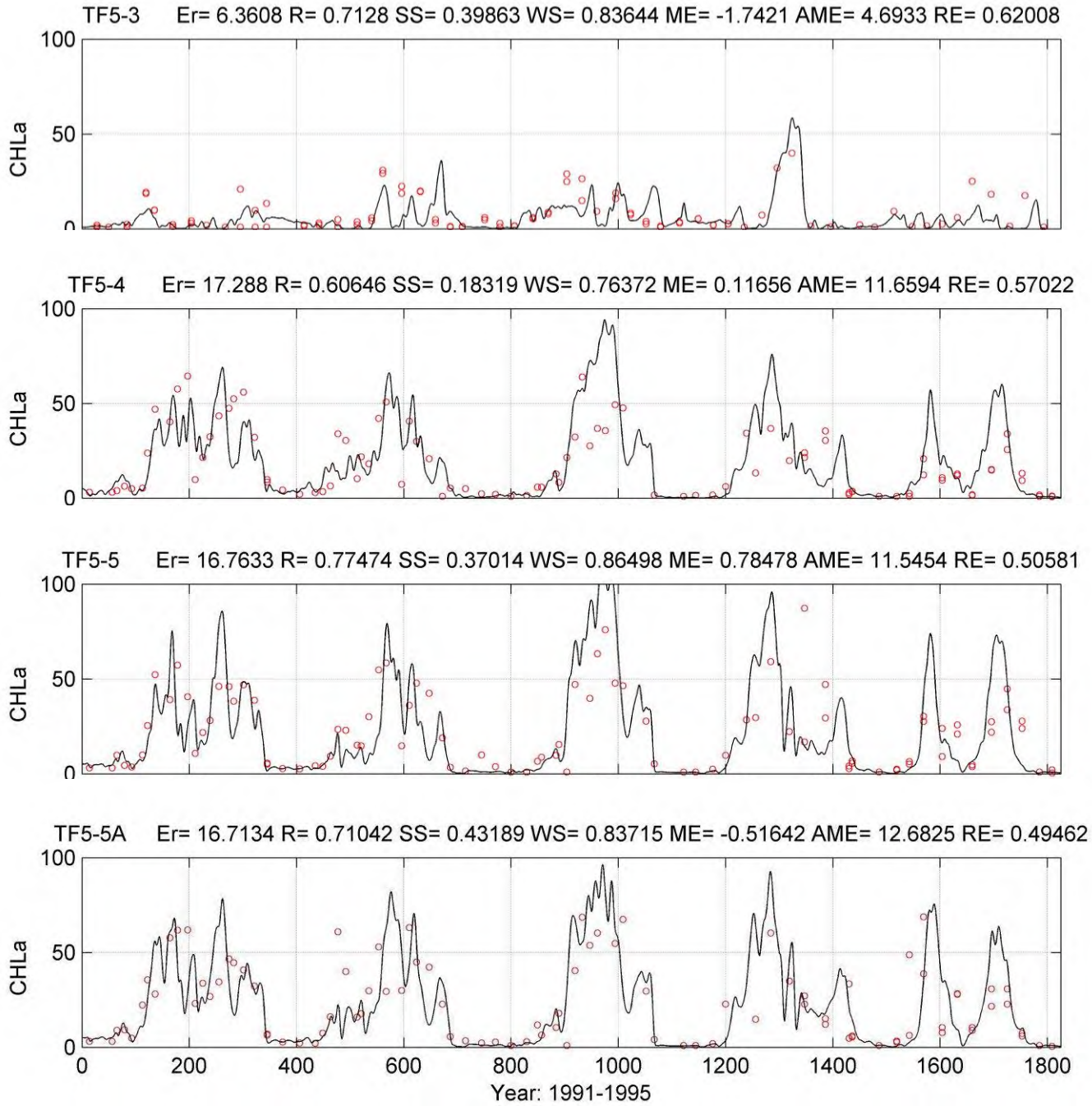


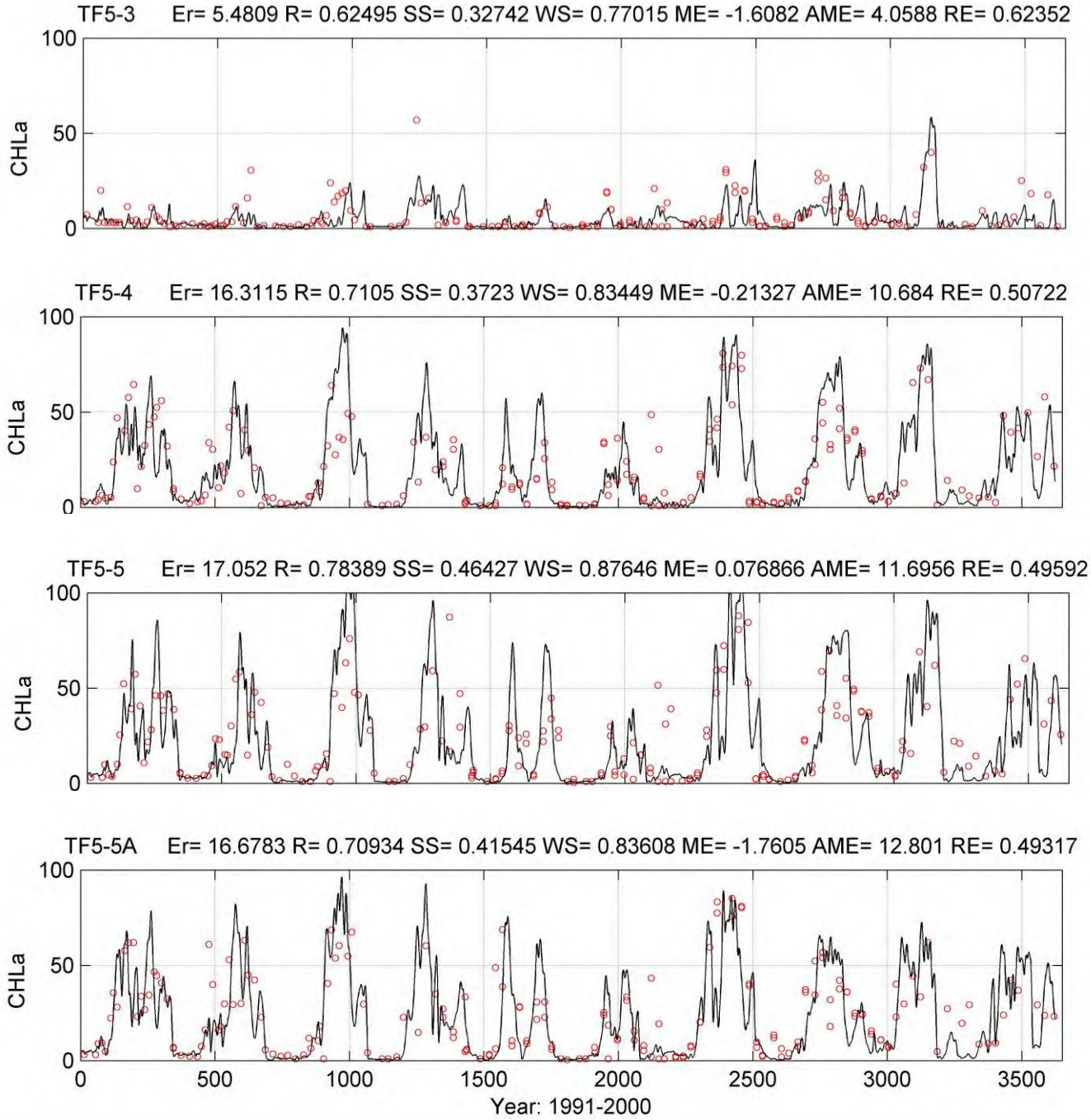
Estimation of Net Growth Rate



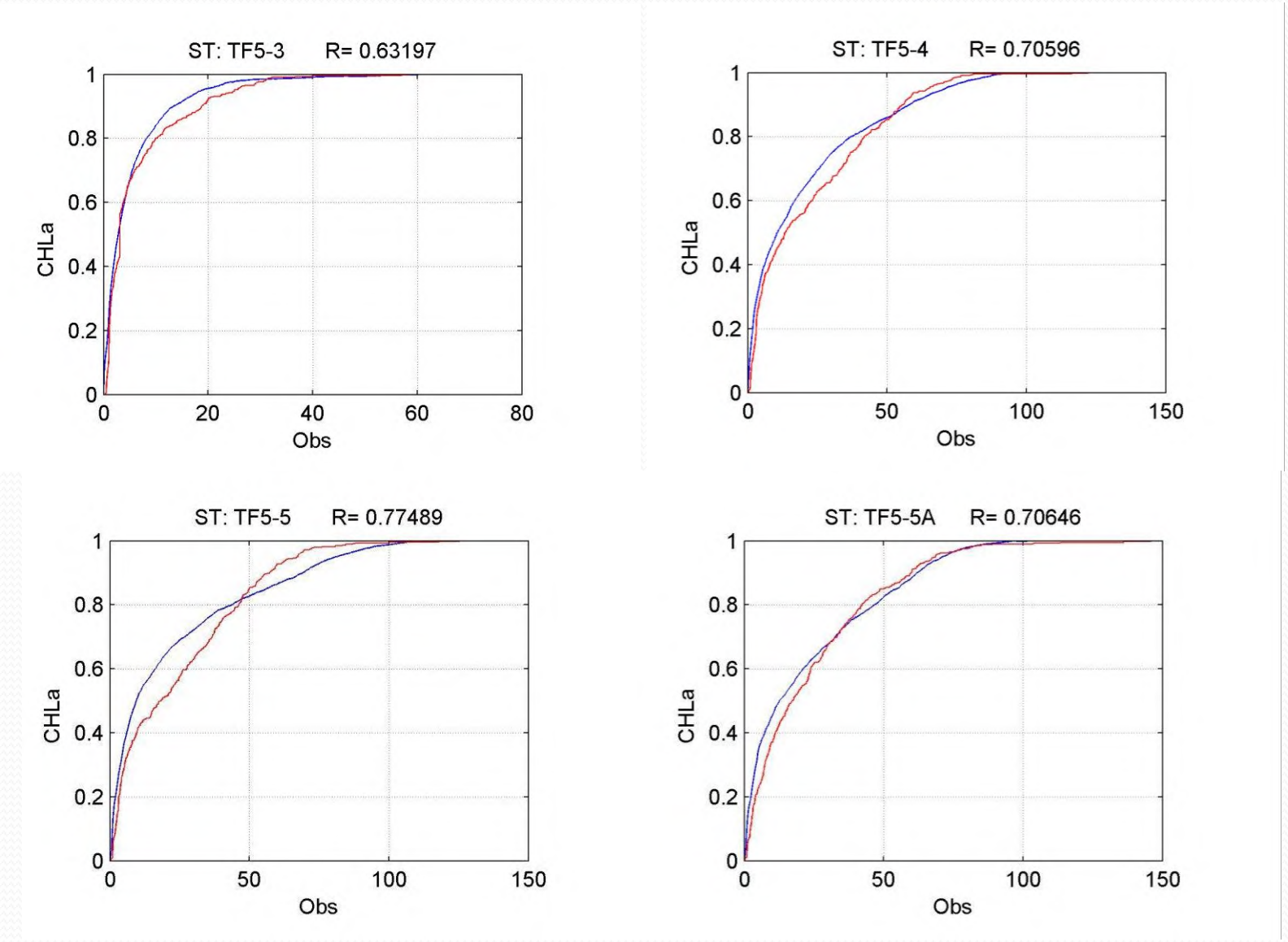
Tidal Freshwater

- Calibration period is from 1991-2000

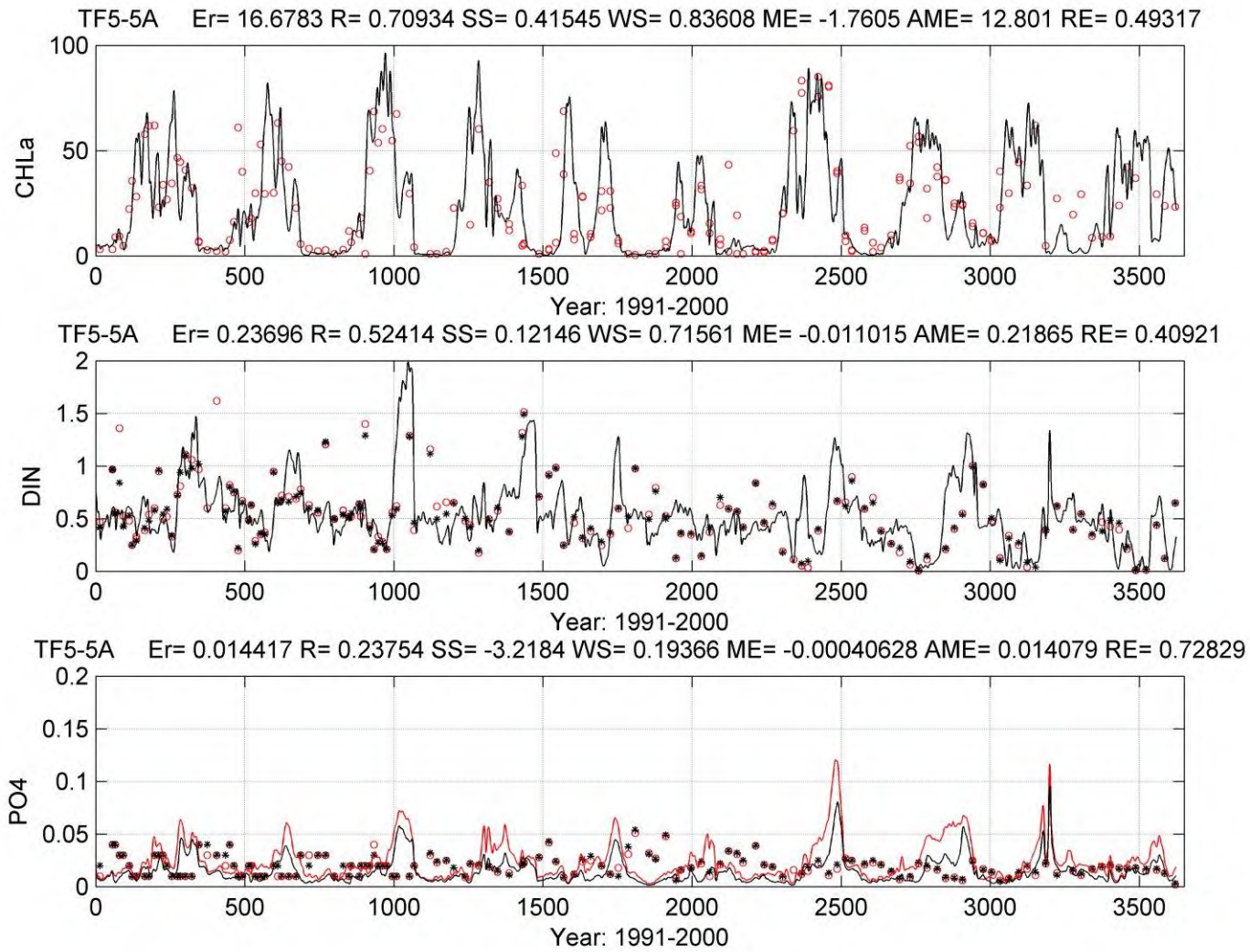

TF5-3 Er= 6.3608 R= 0.7128 SS= 0.39863 WS= 0.83644 ME= -1.7421 AME= 4.6933 RE= 0.62008
TF5-4 Er= 17.288 R= 0.60646 SS= 0.18319 WS= 0.76372 ME= 0.11656 AME= 11.6594 RE= 0.57022
TF5-5 Er= 16.7633 R= 0.77474 SS= 0.37014 WS= 0.86498 ME= 0.78478 AME= 11.5454 RE= 0.50581
TF5-5A Er= 16.7134 R= 0.71042 SS= 0.43189 WS= 0.83715 ME= -0.51642 AME= 12.6825 RE= 0.49462
CHLa
100
50
0
0
200
400
600
800
1000
1200
1400
1600
1800
Year: 1991-1995

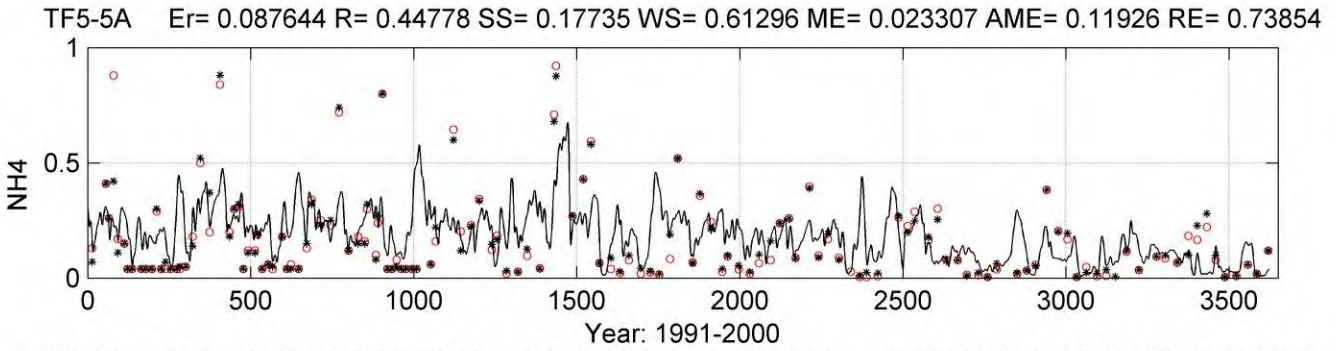

TF5-3 Er= 5.4809 R= 0.62495 SS= 0.32742 WS= 0.77015 ME= -1.6082 AME= 4.0588 RE= 0.62352
TF5-4 Er= 16.3115 R= 0.7105 SS= 0.3723 WS= 0.83449 ME= -0.21327 AME= 10.684 RE= 0.50722
TF5-5 Er= 17.052 R= 0.78389 SS= 0.46427 WS= 0.87646 ME= 0.076866 AME= 11.6956 RE= 0.49592
TF5-5A Er= 16.6783 R= 0.70934 SS= 0.41545 WS= 0.83608 ME= -1.7605 AME= 12.801 RE= 0.49317
CHLa
100
50
0
0
500
1000
1500
2000
2500
3000
3500
Year: 1991-2000

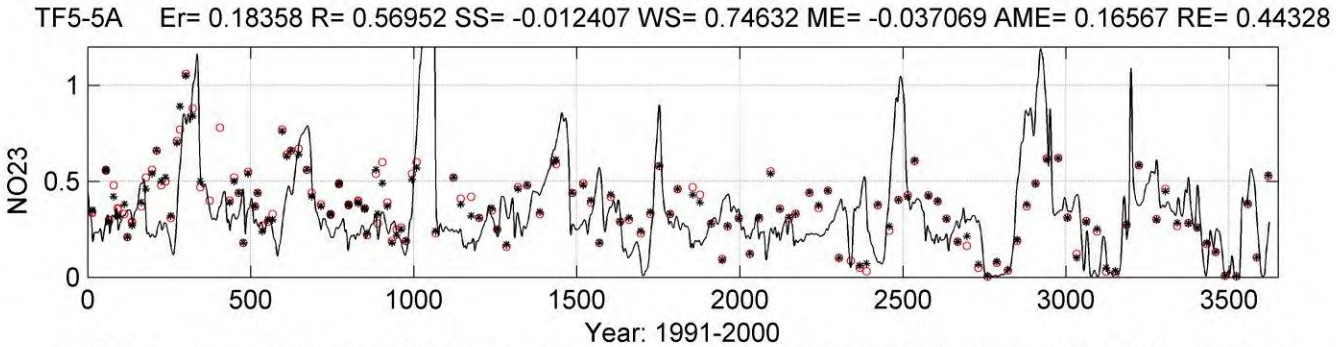
Accumulative Distribution

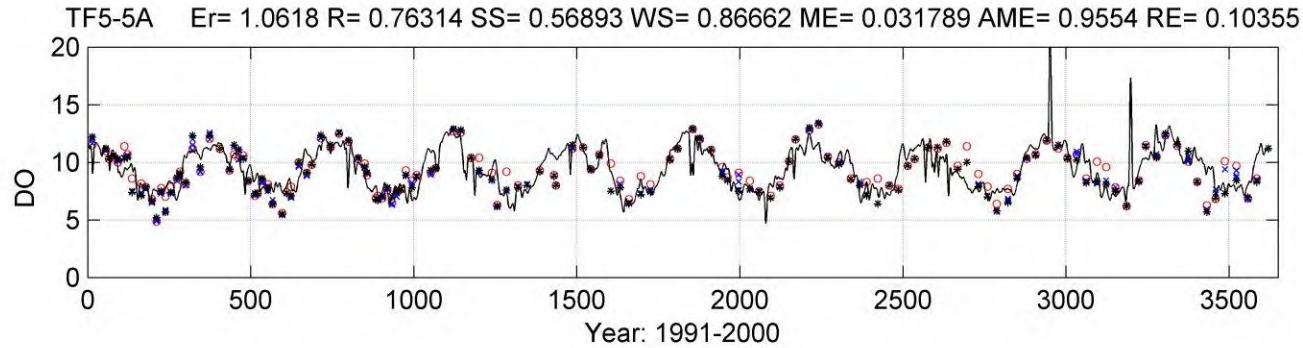


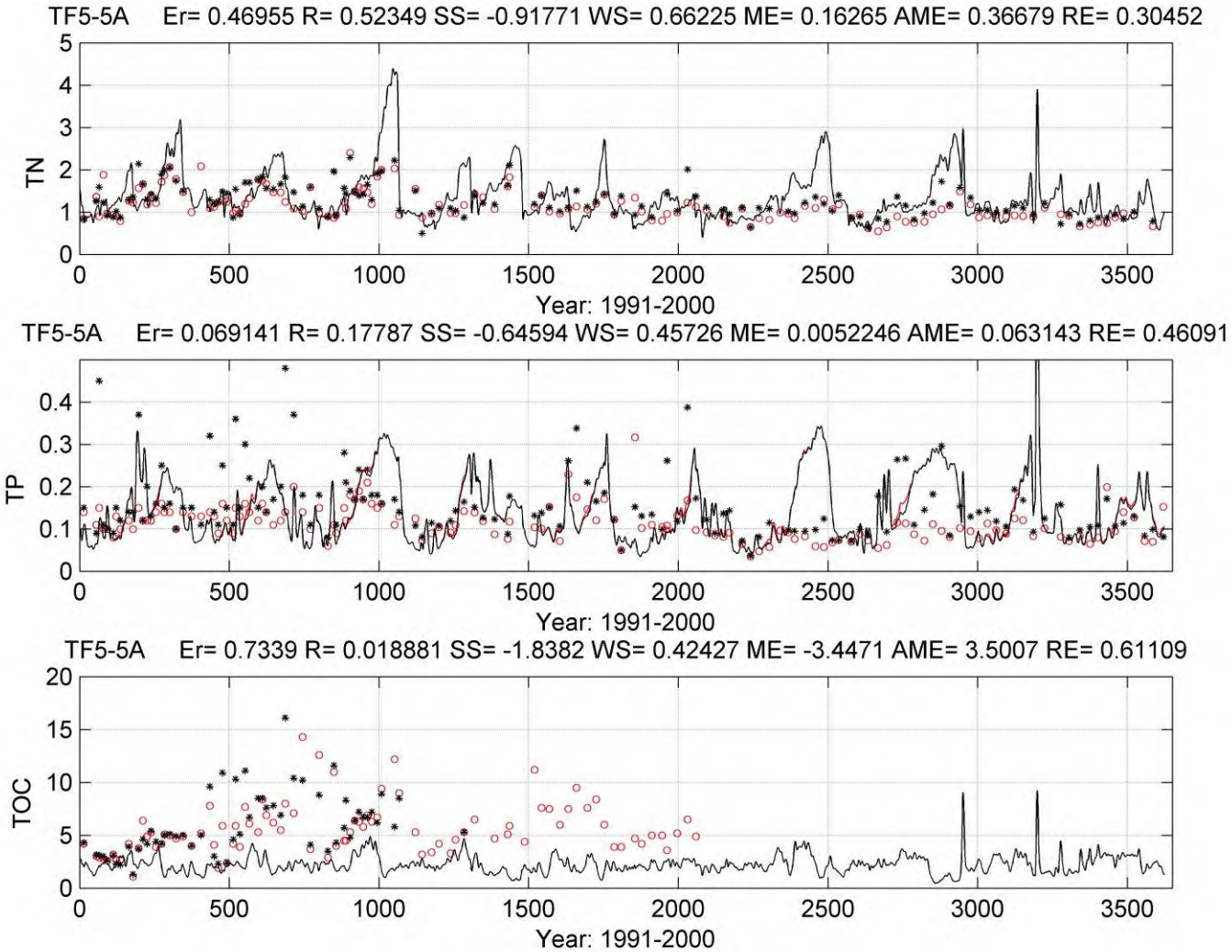
10-Year Simulation Results

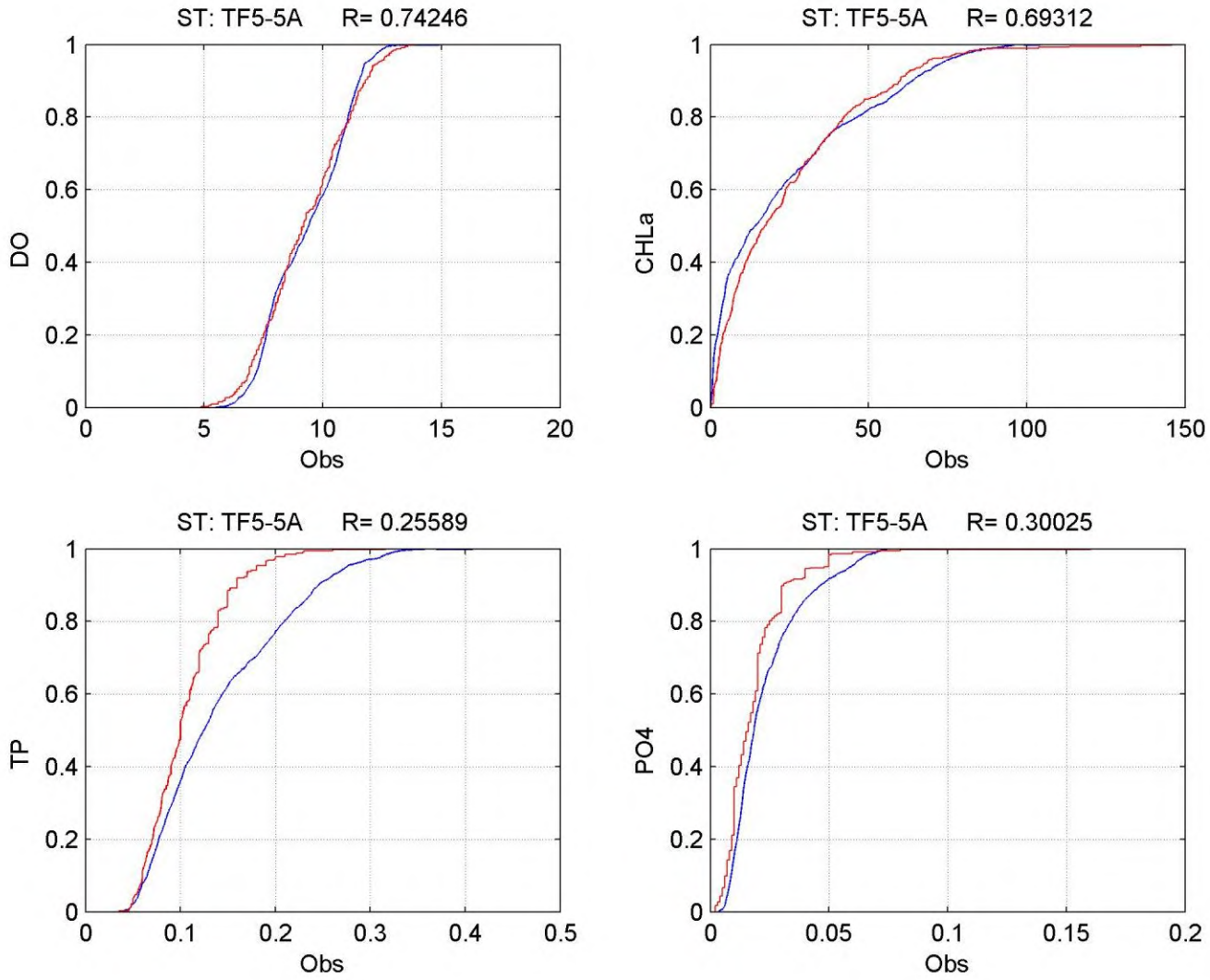


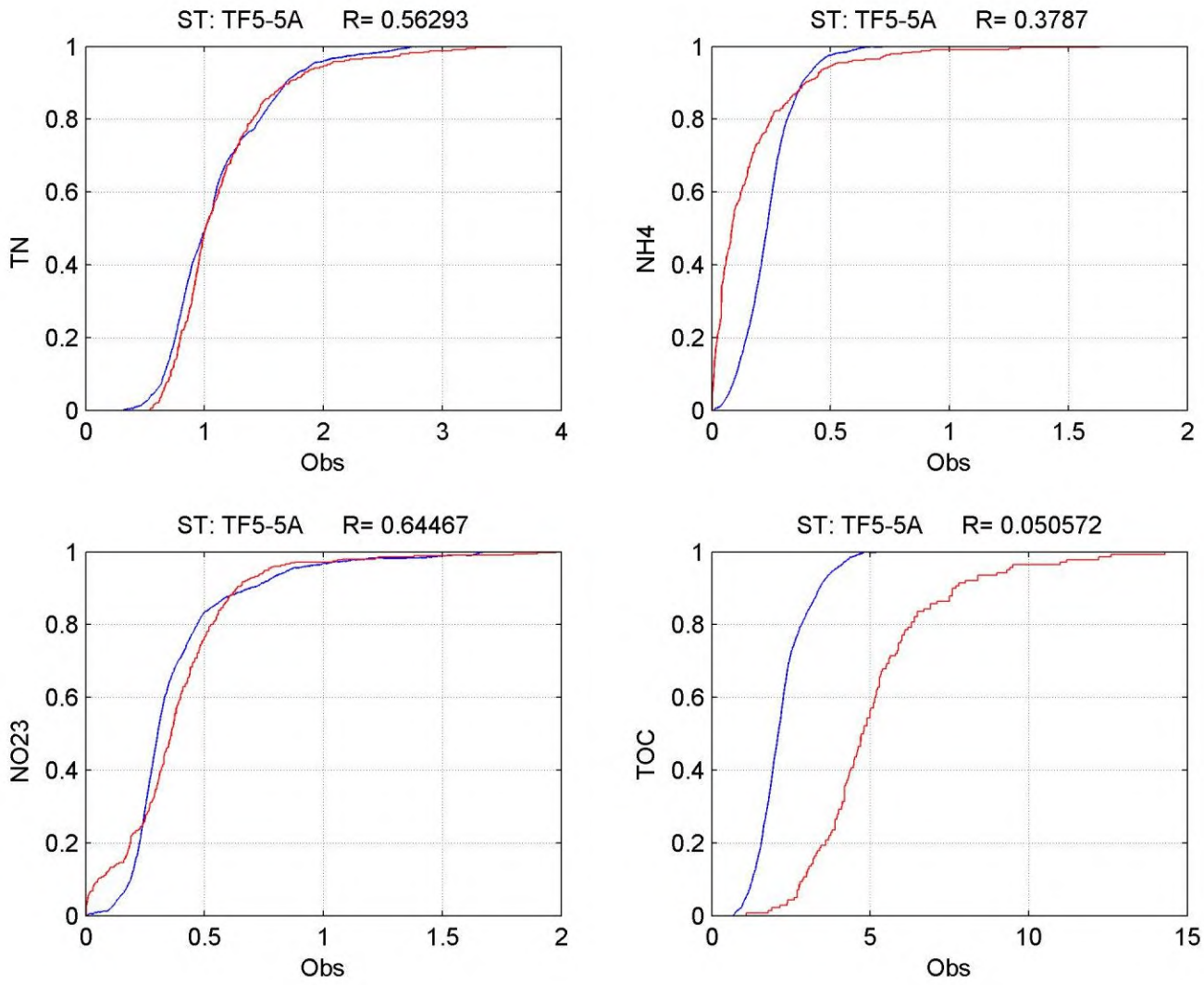

TF5-5A Er= 0.087644 R= 0.44778 SS= 0.17735 WS= 0.61296 ME= 0.023307 AME= 0.11926 RE= 0.73854
NH4
Year: 1991-2000


TF5-5A Er= 0.18358 R= 0.56952 SS= -0.012407 WS= 0.74632 ME= -0.037069 AME= 0.16567 RE= 0.44328
NO23
Year: 1991-2000

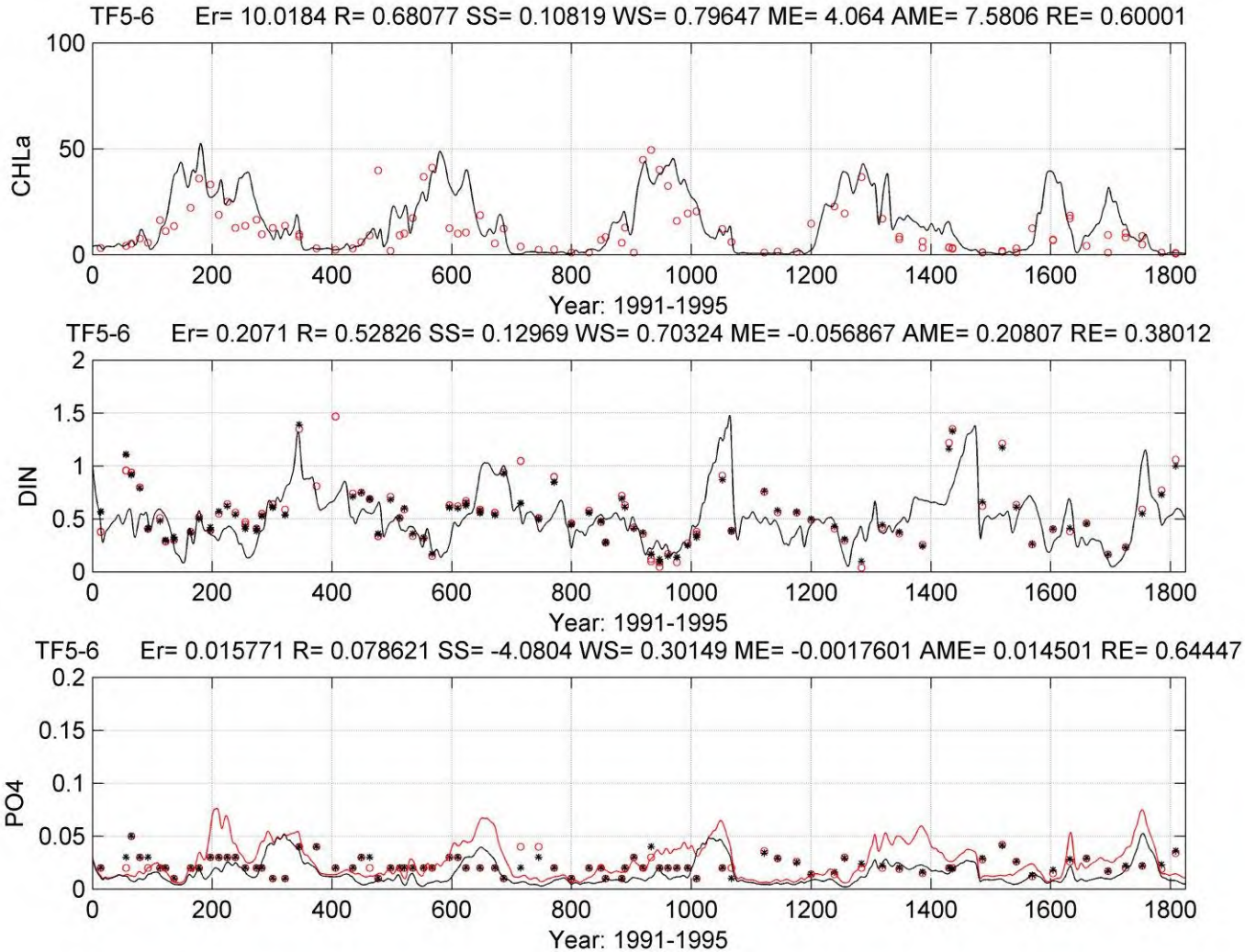

TF5-5A Er= 1.0618 R= 0.76314 SS= 0.56893 WS= 0.86662 ME= 0.031789 AME= 0.9554 RE= 0.10355
DO
Year: 1991-2000

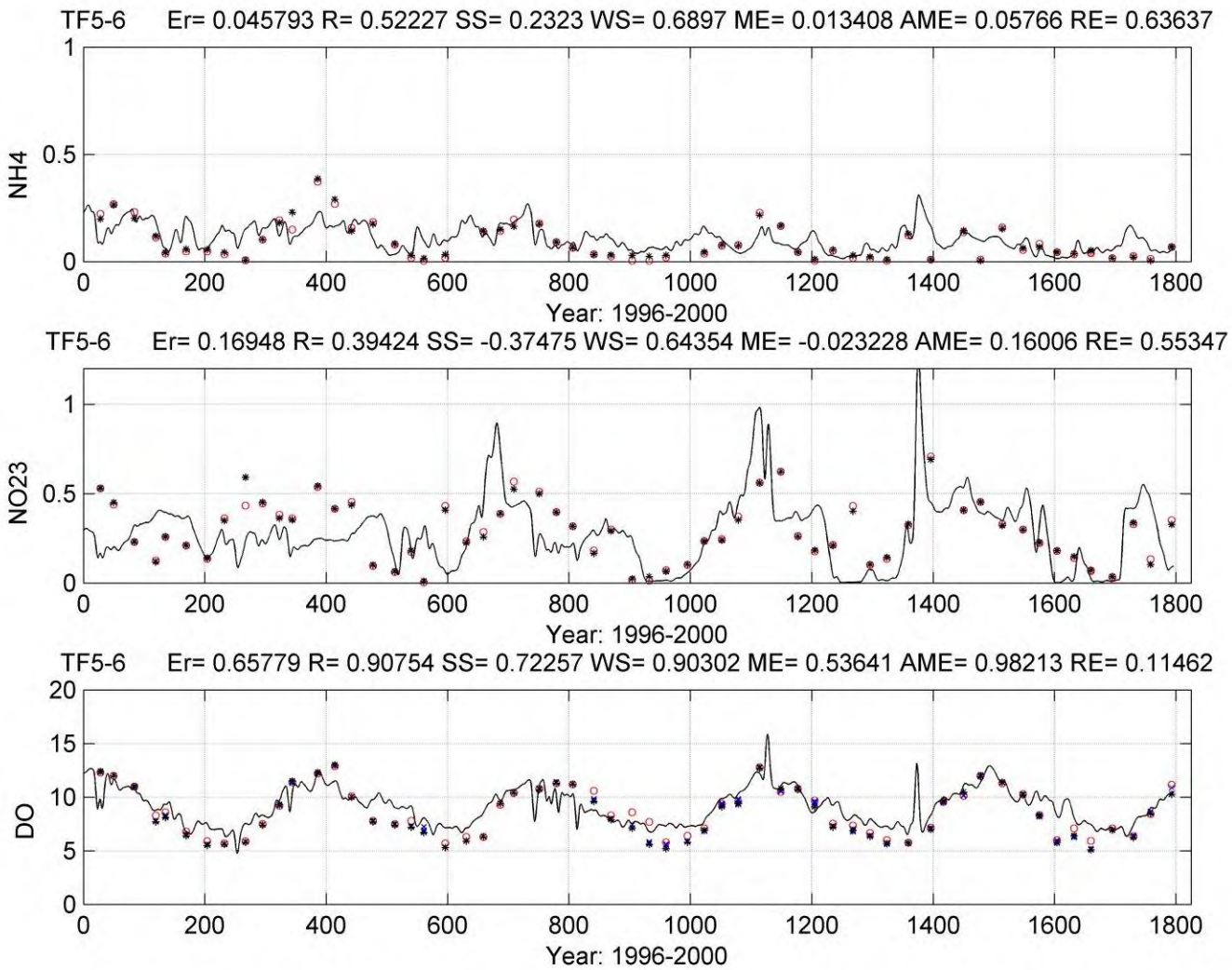

TF5-5A Er= 0.46955 R= 0.52349 SS= -0.91771 WS= 0.66225 ME= 0.16265 AME= 0.36679 RE= 0.30452
TN
Year: 1991-2000
TF5-5A Er= 0.069141 R= 0.17787 SS= -0.64594 WS= 0.45726 ME= 0.0052246 AME= 0.063143 RE= 0.46091
TP
Year: 1991-2000
TF5-5A Er= 0.7339 R= 0.018881 SS= -1.8382 WS= 0.42427 ME= -3.4471 AME= 3.5007 RE= 0.61109
TOC
Year: 1991-2000

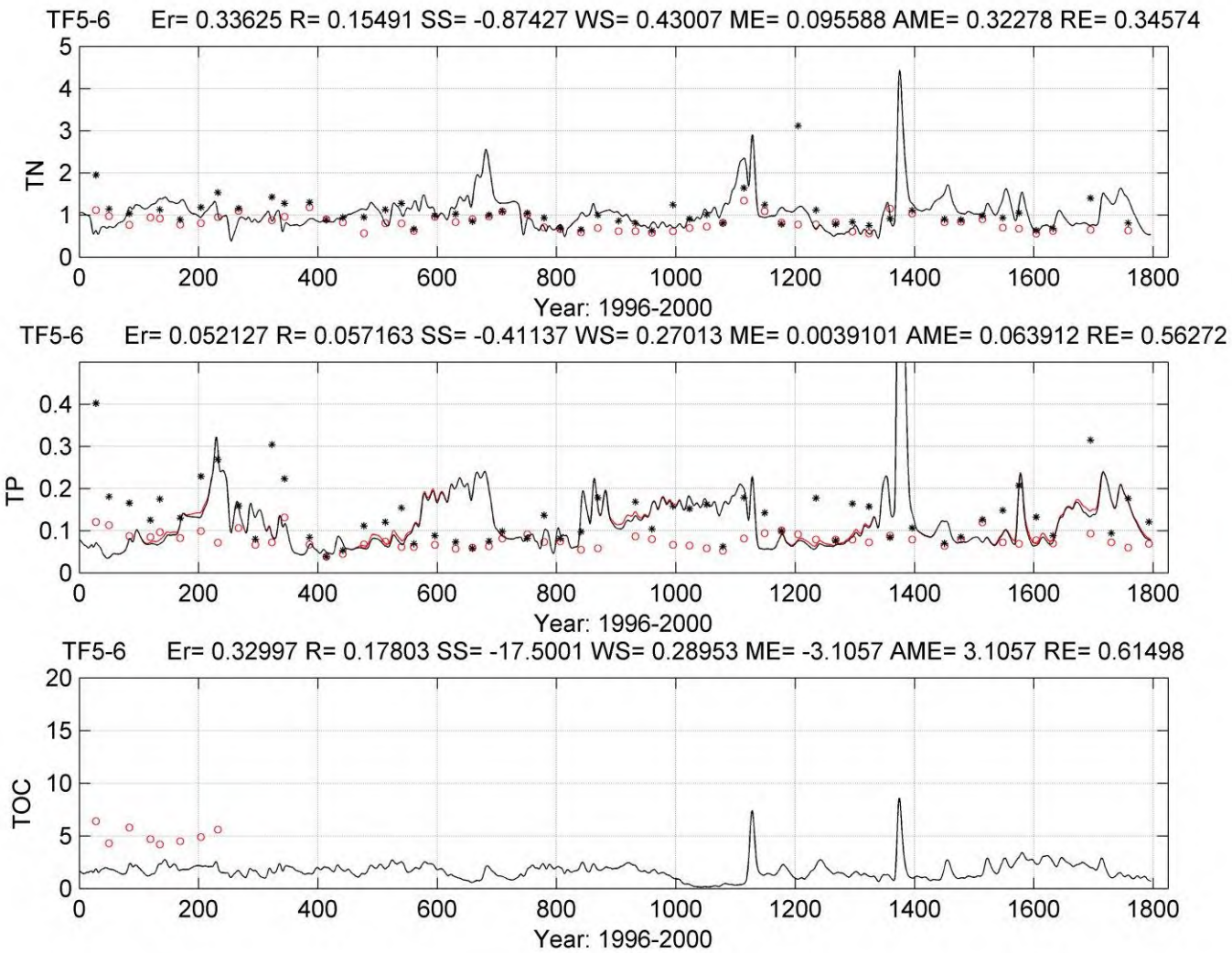

ST: TF5-5A R= 0.74246
DO
Obs
ST: TF5-5A R= 0.69312
CHLa
Obs
ST: TF5-5A R= 0.25589
TP
Obs
ST: TF5-5A R= 0.30025
PO4
Obs

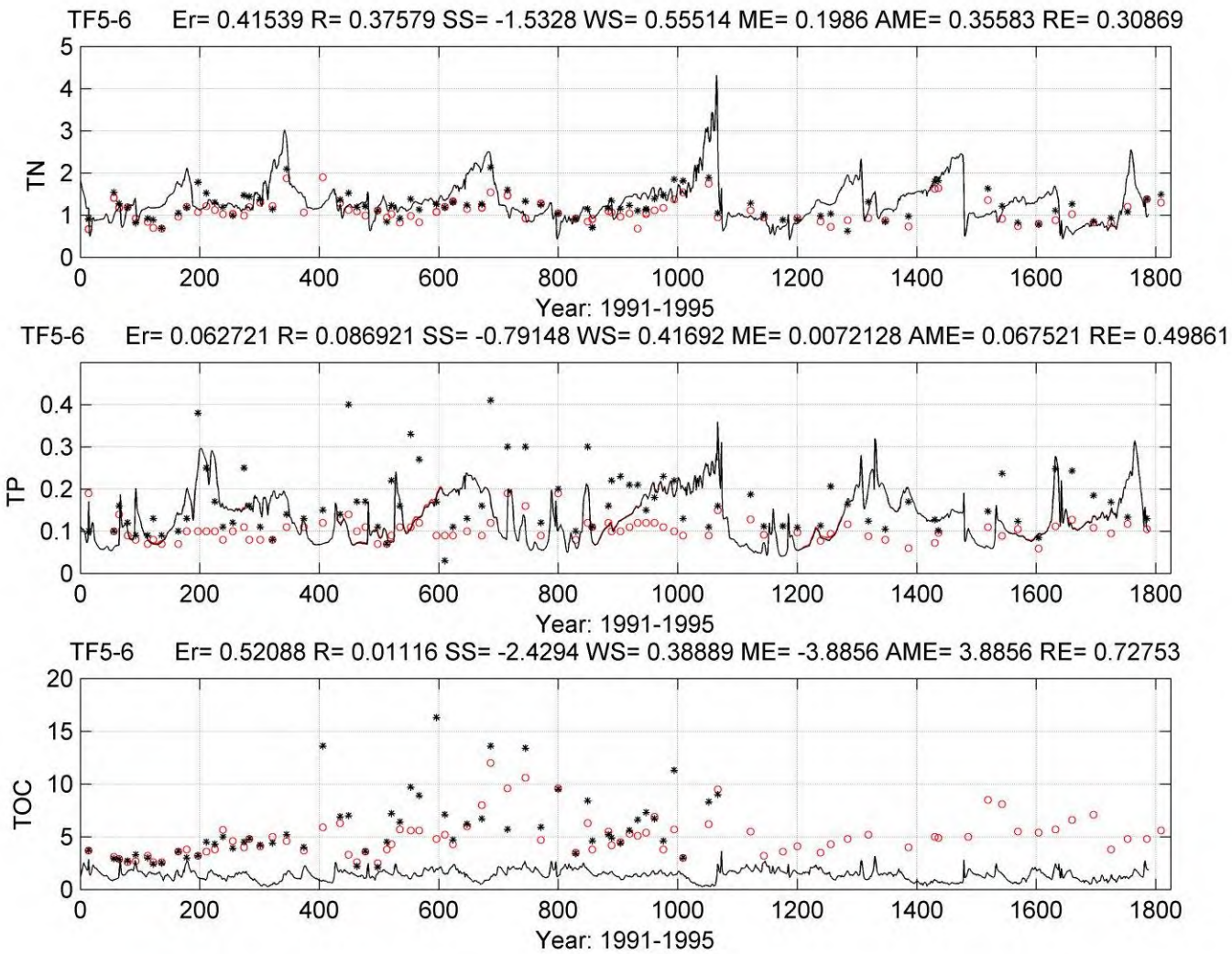

ST: TF5-5A R= 0.56293
TN
Obs
ST: TF5-5A R= 0.3787
NH4
Obs
ST: TF5-5A R= 0.64467
NO23
Obs
ST: TF5-5A R= 0.050572
TOC
Obs

Mesohaline

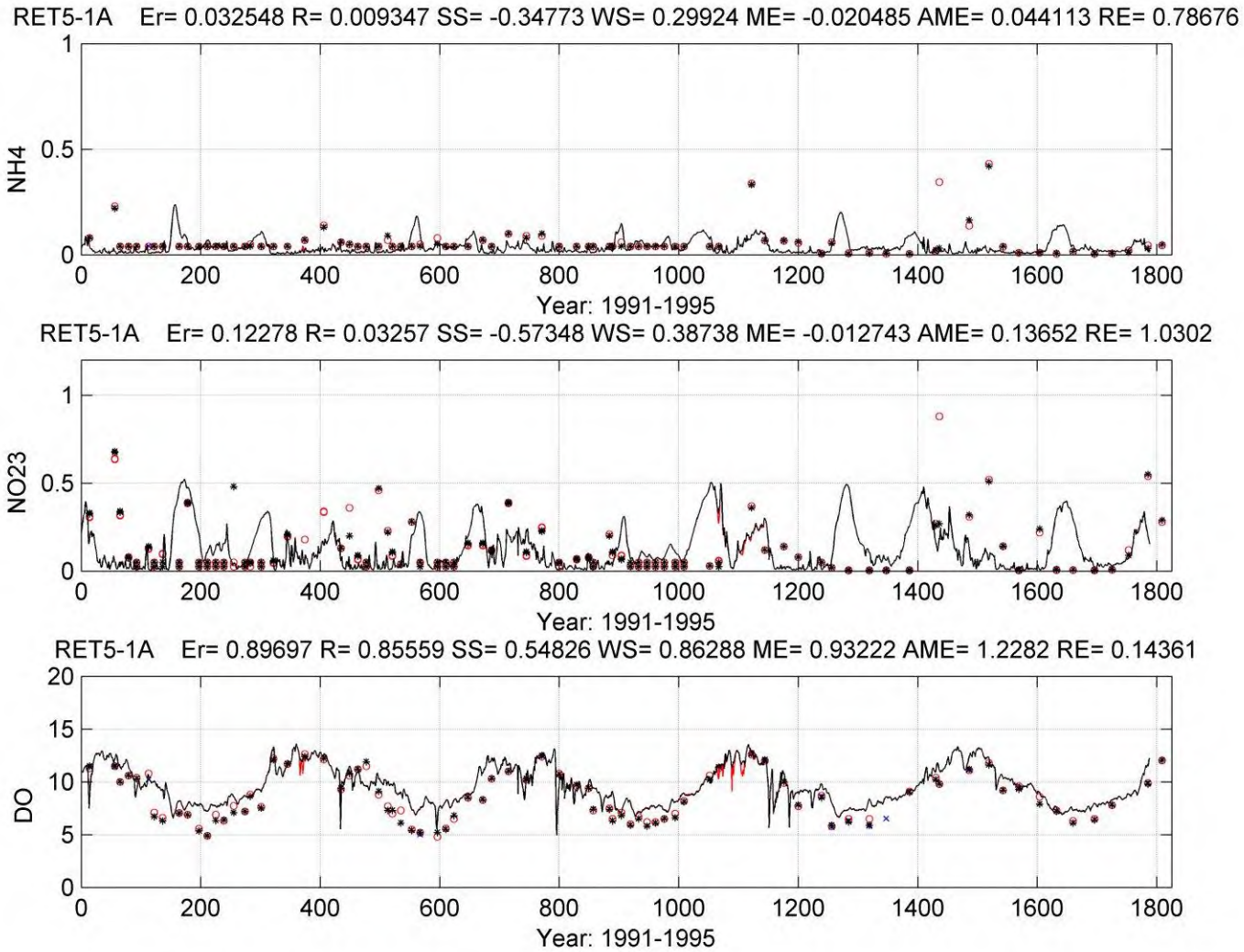

TF5-6 Er= 10.0184 R= 0.68077 SS= 0.10819 WS= 0.79647 ME= 4.064 AME= 7.5806 RE= 0.60001
CHLa
Year: 1991-1995
TF5-6 Er= 0.2071 R= 0.52826 SS= 0.12969 WS= 0.70324 ME= -0.056867 AME= 0.20807 RE= 0.38012
DIN
Year: 1991-1995
TF5-6 Er= 0.015771 R= 0.078621 SS= -4.0804 WS= 0.30149 ME= -0.0017601 AME= 0.014501 RE= 0.64447
PO4
Year: 1991-1995


TF5-6 Er= 0.045793 R= 0.52227 SS= 0.2323 WS= 0.6897 ME= 0.013408 AME= 0.05766 RE= 0.63637
NH4
Year: 1996-2000
TF5-6 Er= 0.16948 R= 0.39424 SS= -0.37475 WS= 0.64354 ME= -0.023228 AME= 0.16006 RE= 0.55347
NO23
Year: 1996-2000
TF5-6 Er= 0.65779 R= 0.90754 SS= 0.72257 WS= 0.90302 ME= 0.53641 AME= 0.98213 RE= 0.11462
DO
Year: 1996-2000

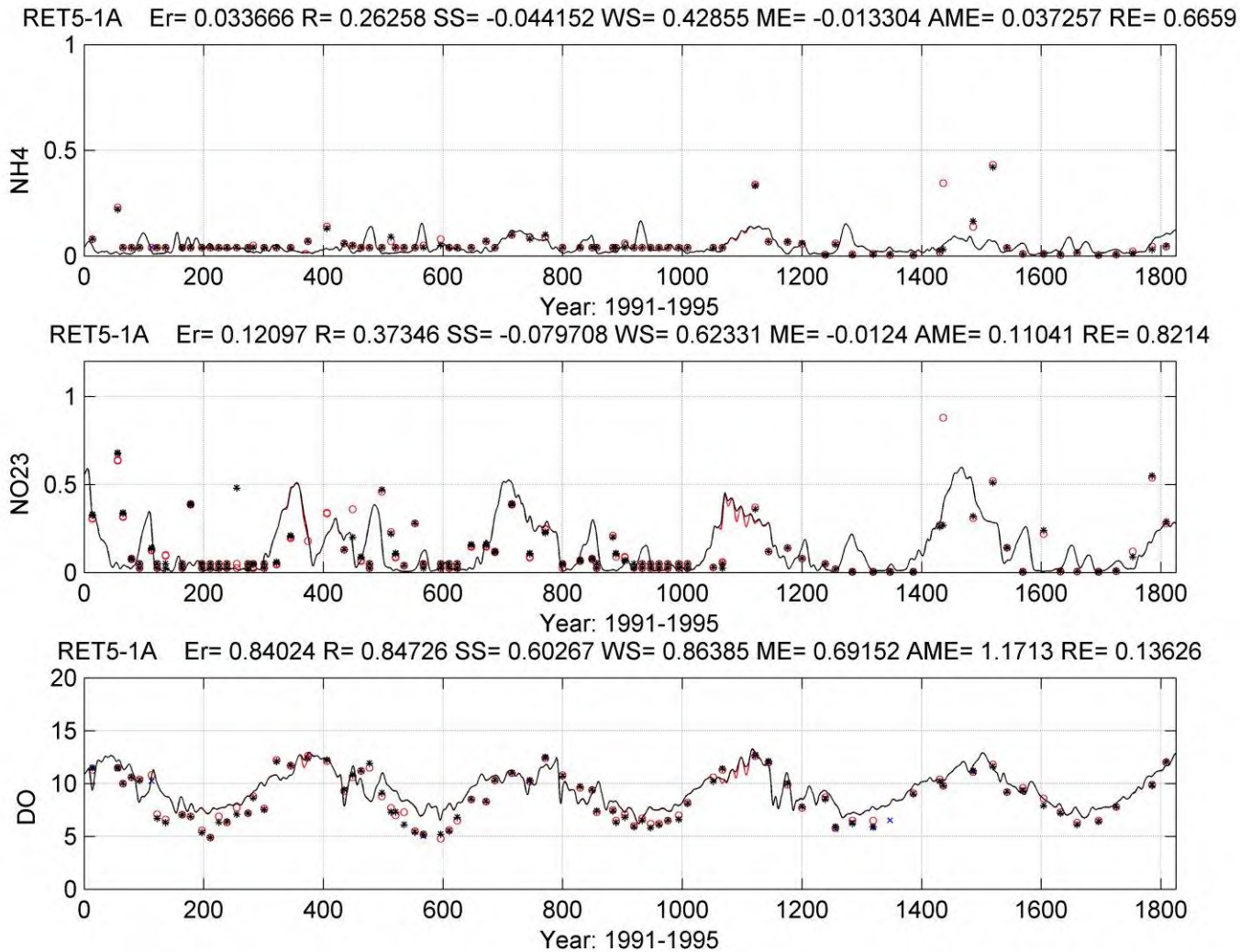

TF5-6 Er= 0.33625 R= 0.15491 SS= -0.87427 WS= 0.43007 ME= 0.095588 AME= 0.32278 RE= 0.34574
TN
Year: 1996-2000
TF5-6 Er= 0.052127 R= 0.057163 SS= -0.41137 WS= 0.27013 ME= 0.0039101 AME= 0.063912 RE= 0.56272
TP
Year: 1996-2000
TF5-6 Er= 0.32997 R= 0.17803 SS= -17.5001 WS= 0.28953 ME= -3.1057 AME= 3.1057 RE= 0.61498
TOC
Year: 1996-2000

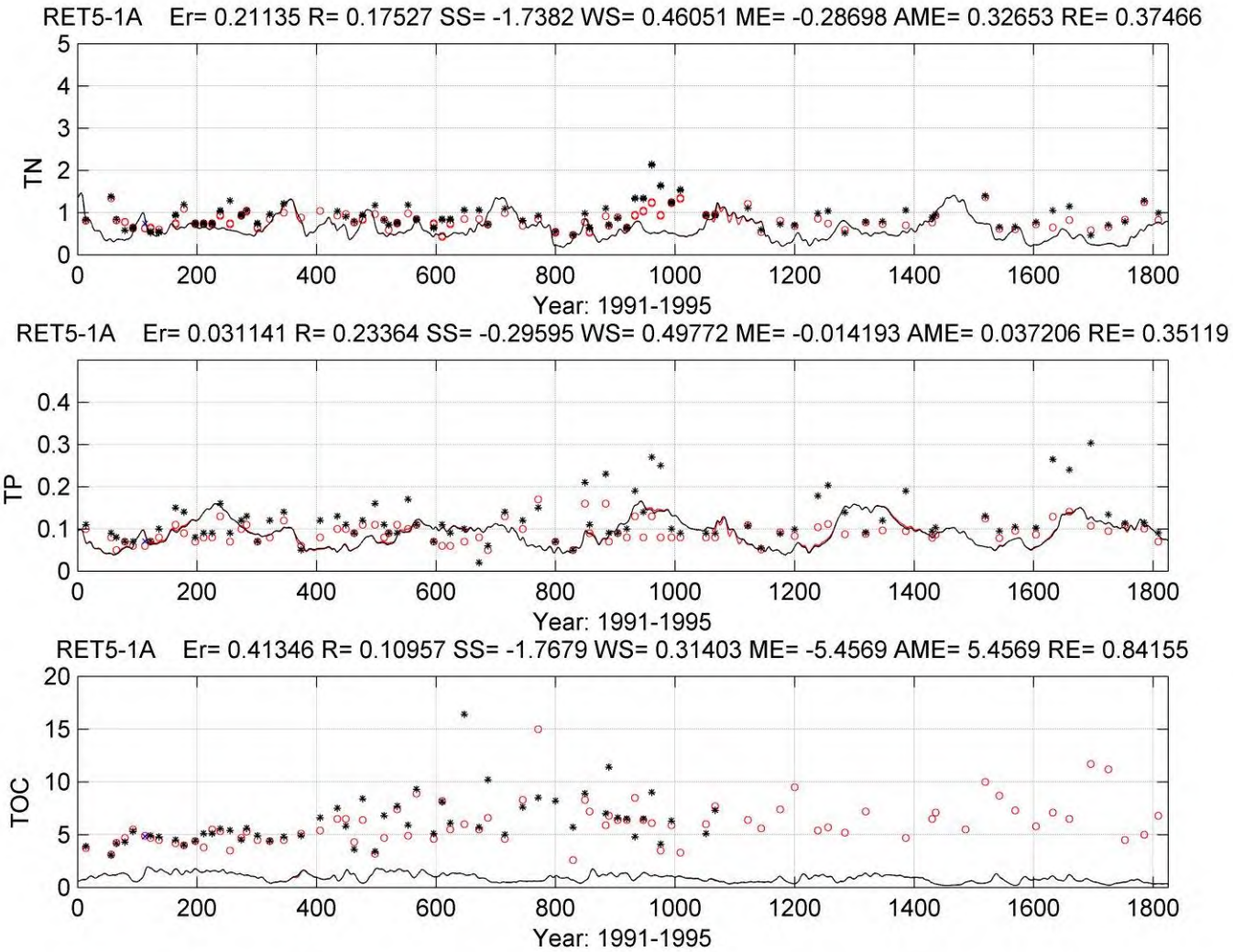

TF5-6 Er= 0.41539 R= 0.37579 SS= -1.5328 WS= 0.55514 ME= 0.1986 AME= 0.35583 RE= 0.30869
TN
Year: 1991-1995
TF5-6 Er= 0.062721 R= 0.086921 SS= -0.79148 WS= 0.41692 ME= 0.0072128 AME= 0.067521 RE= 0.49861
TP
Year: 1991-1995
TF5-6 Er= 0.52088 R= 0.01116 SS= -2.4294 WS= 0.38889 ME= -3.8856 AME= 3.8856 RE= 0.72753
TOC
Year: 1991-1995

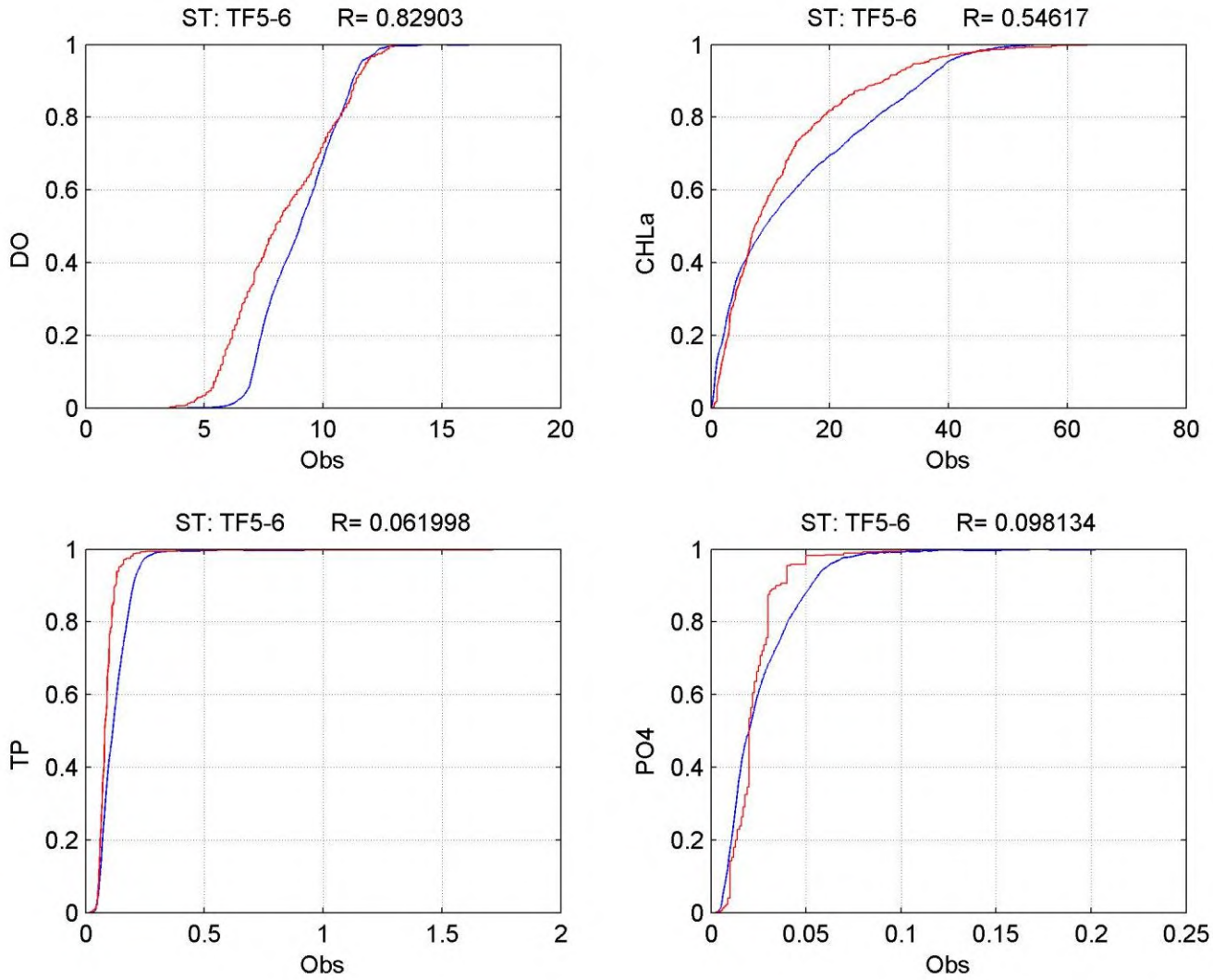
RET5-1A Er= 7.1851 R= 0.35875 SS= -0.19451 WS= 0.61514 ME= 1.4436 AME= 7.2046 RE= 0.47408
CHLa
Year: 1991-1995
RET5-1A Er= 0.14716 R= 0.0061019 SS= -0.54353 WS= 0.34179 ME= -0.029395 AME= 0.17369 RE= 0.93523
DIN
Year: 1991-1995
RET5-1A Er= 0.013013 R= 0.025999 SS= -3.1218 WS= 0.17757 ME= 0.0054962 AME= 0.011693 RE= 0.9958
PO4
Year: 1991-1995

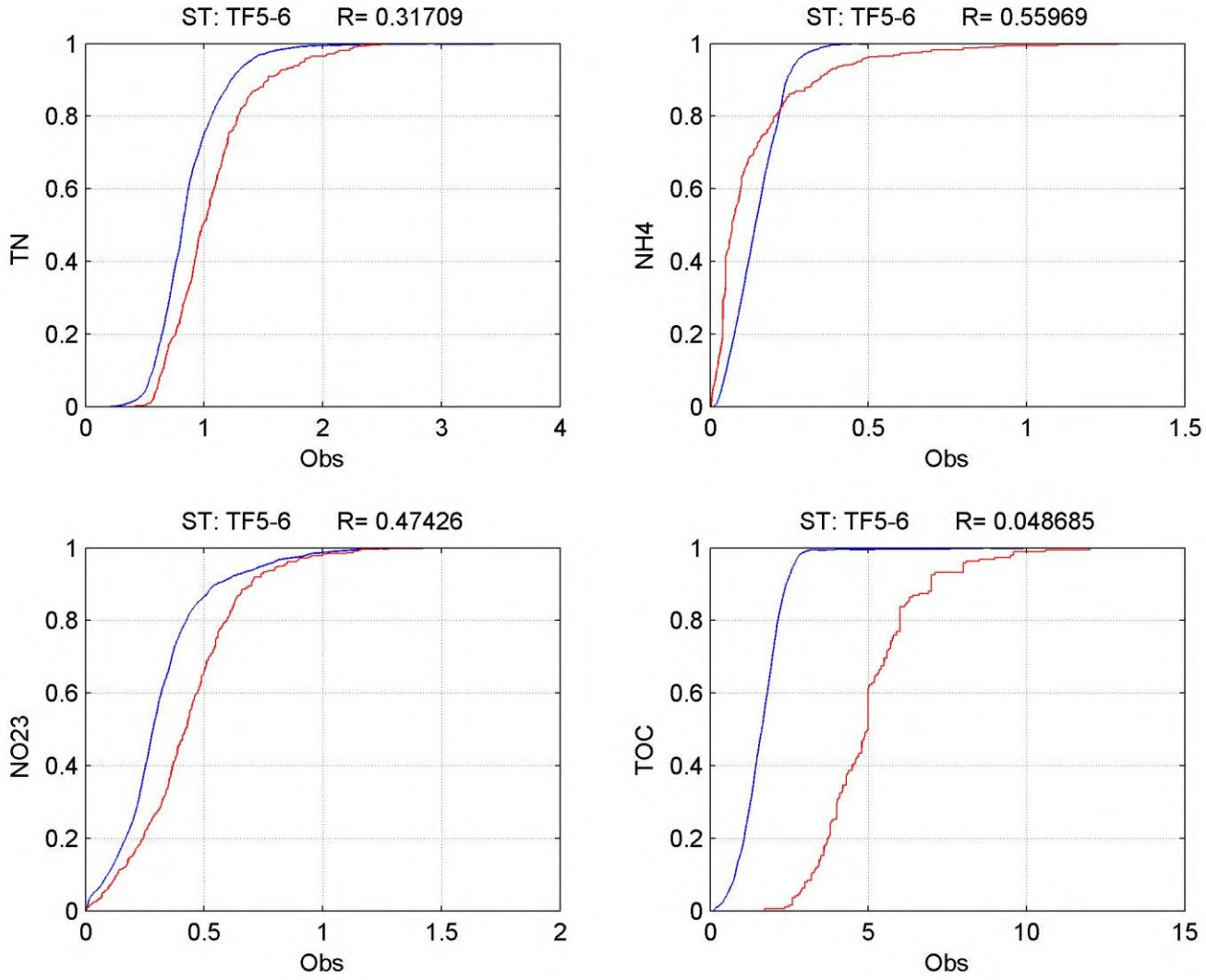

RET5-1A Er= 0.032548 R= 0.009347 SS= -0.34773 WS= 0.29924 ME= -0.020485 AME= 0.044113 RE= 0.78676
NH4
Year: 1991-1995
RET5-1A Er= 0.12278 R= 0.03257 SS= -0.57348 WS= 0.38738 ME= -0.012743 AME= 0.13652 RE= 1.0302
NO23
Year: 1991-1995
RET5-1A Er= 0.89697 R= 0.85559 SS= 0.54826 WS= 0.86288 ME= 0.93222 AME= 1.2282 RE= 0.14361
DO
Year: 1991-1995

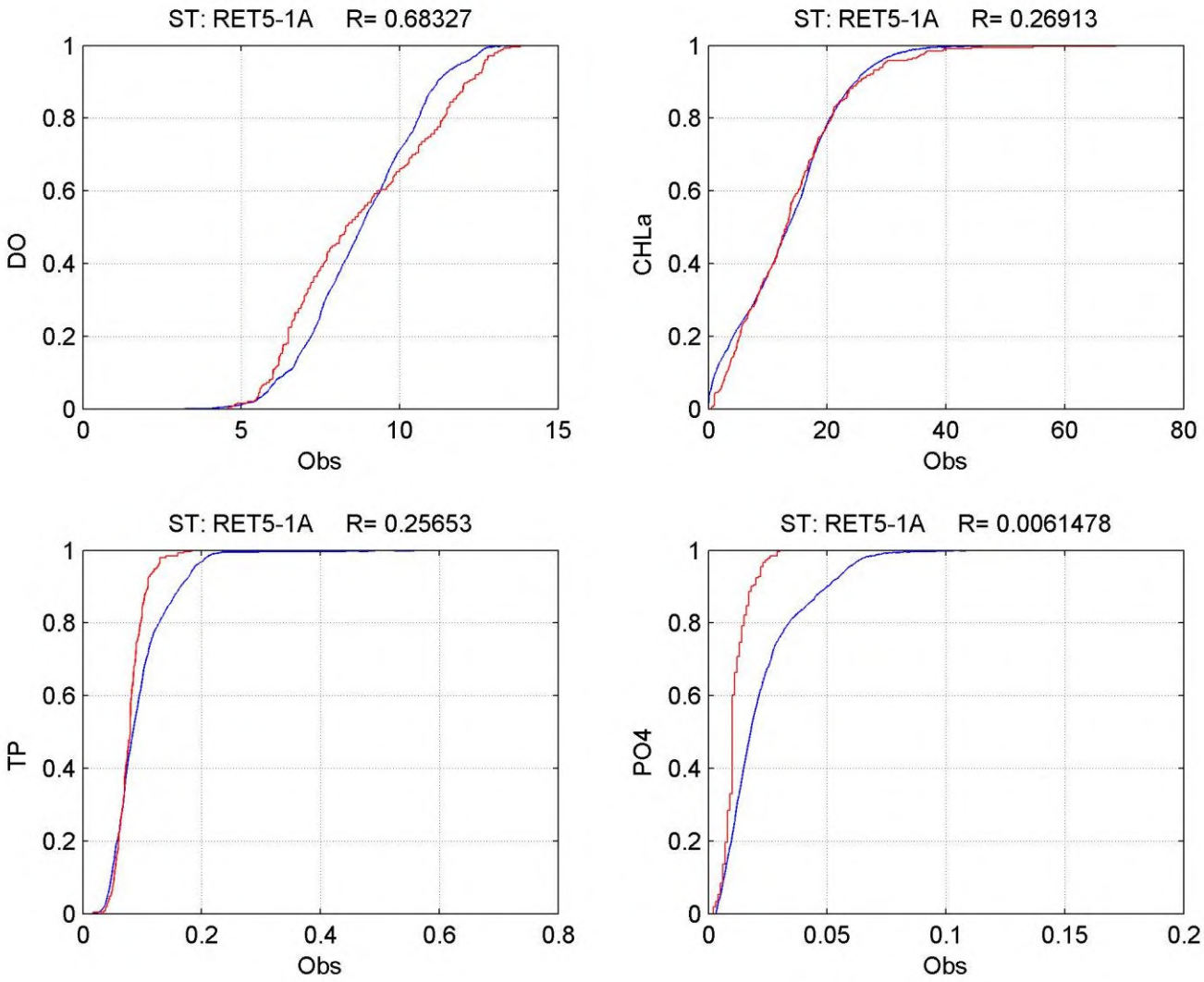
RET5-1A Er= 8.8247 R= 0.33179 SS= -0.4688 WS= 0.61821 ME= -0.13613 AME= 7.4973 RE= 0.4976
CHLa
Year: 1991-1995
RET5-1A Er= 0.14067 R= 0.38877 SS= 0.010194 WS= 0.6179 ME= -0.023419 AME= 0.1389 RE= 0.74055
DIN
Year: 1991-1995
RET5-1A Er= 0.0096983 R= 0.033001 SS= -1.8272 WS= 0.2674 ME= 0.0054516 AME= 0.0097634 RE= 0.8295
PO4
Year: 1991-1995

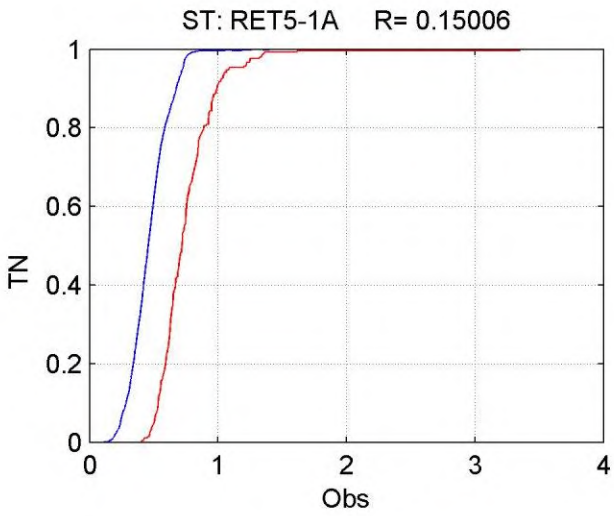

RET5-1A Er= 0.033666 R= 0.26258 SS= -0.044152 WS= 0.42855 ME= -0.013304 AME= 0.037257 RE= 0.6659
NH4
Year: 1991-1995
RET5-1A Er= 0.12097 R= 0.37346 SS= -0.079708 WS= 0.62331 ME= -0.0124 AME= 0.11041 RE= 0.8214
NO23
Year: 1991-1995
RET5-1A Er= 0.84024 R= 0.84726 SS= 0.60267 WS= 0.86385 ME= 0.69152 AME= 1.1713 RE= 0.13626
DO
Year: 1991-1995

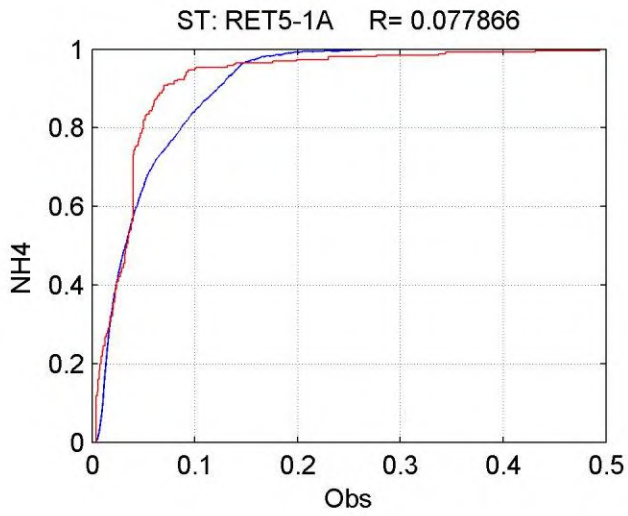

RET5-1A Er= 0.21135 R= 0.17527 SS= -1.7382 WS= 0.46051 ME= -0.28698 AME= 0.32653 RE= 0.37466
TN
Year: 1991-1995
RET5-1A Er= 0.031141 R= 0.23364 SS= -0.29595 WS= 0.49772 ME= -0.014193 AME= 0.037206 RE= 0.35119
TP
Year: 1991-1995
RET5-1A Er= 0.41346 R= 0.10957 SS= -1.7679 WS= 0.31403 ME= -5.4569 AME= 5.4569 RE= 0.84155
TOC
Year: 1991-1995

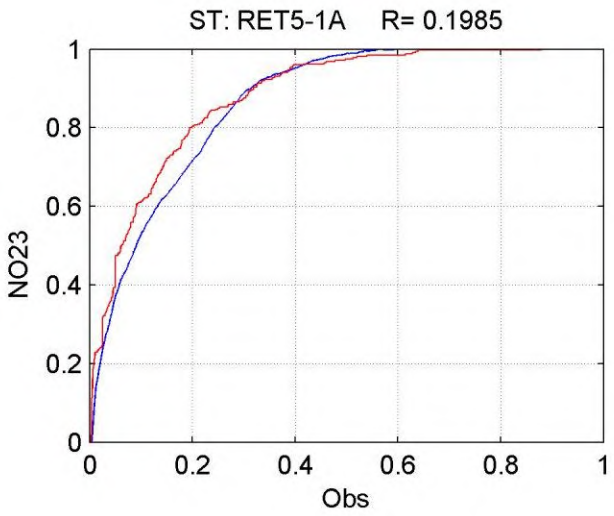

ST: TF5-6 R= 0.82903
DO
Obs
ST: TF5-6 R= 0.54617
CHLa
Obs
ST: TF5-6 R= 0.061998
TP
Obs
ST: TF5-6 R= 0.098134
PO4
Obs

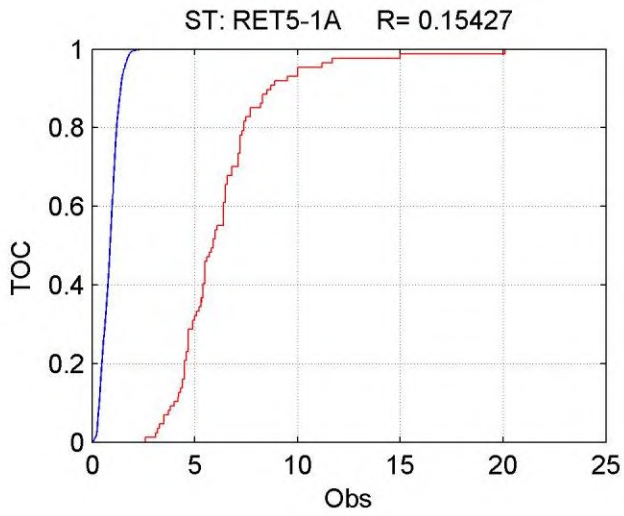

ST: TF5-6 R= 0.31709
TN
Obs
ST: TF5-6 R= 0.55969
NH4
Obs
ST: TF5-6 R= 0.47426
NO23
Obs
ST: TF5-6 R= 0.048685
TOC
Obs


ST: RET5-1A R= 0.68327
DO
Obs
ST: RET5-1A R= 0.26913
CHLa
Obs
ST: RET5-1A R= 0.25653
TP
Obs
ST: RET5-1A R= 0.0061478
PO4
Obs

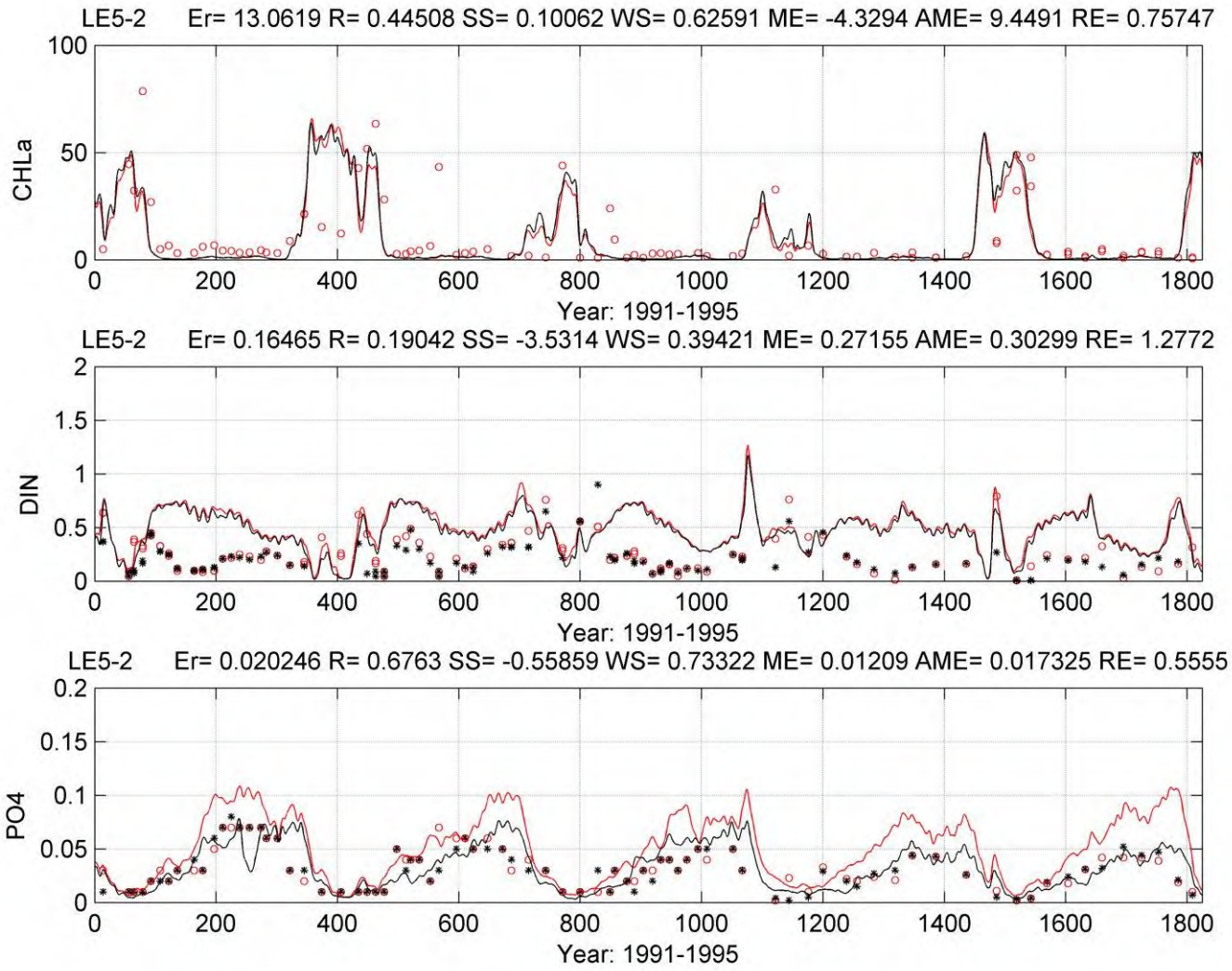

ST: RET5-1A R= 0.15006
TN
Obs
0
0.2
0.4
0.6
0.8
1
0
1
2
3
4

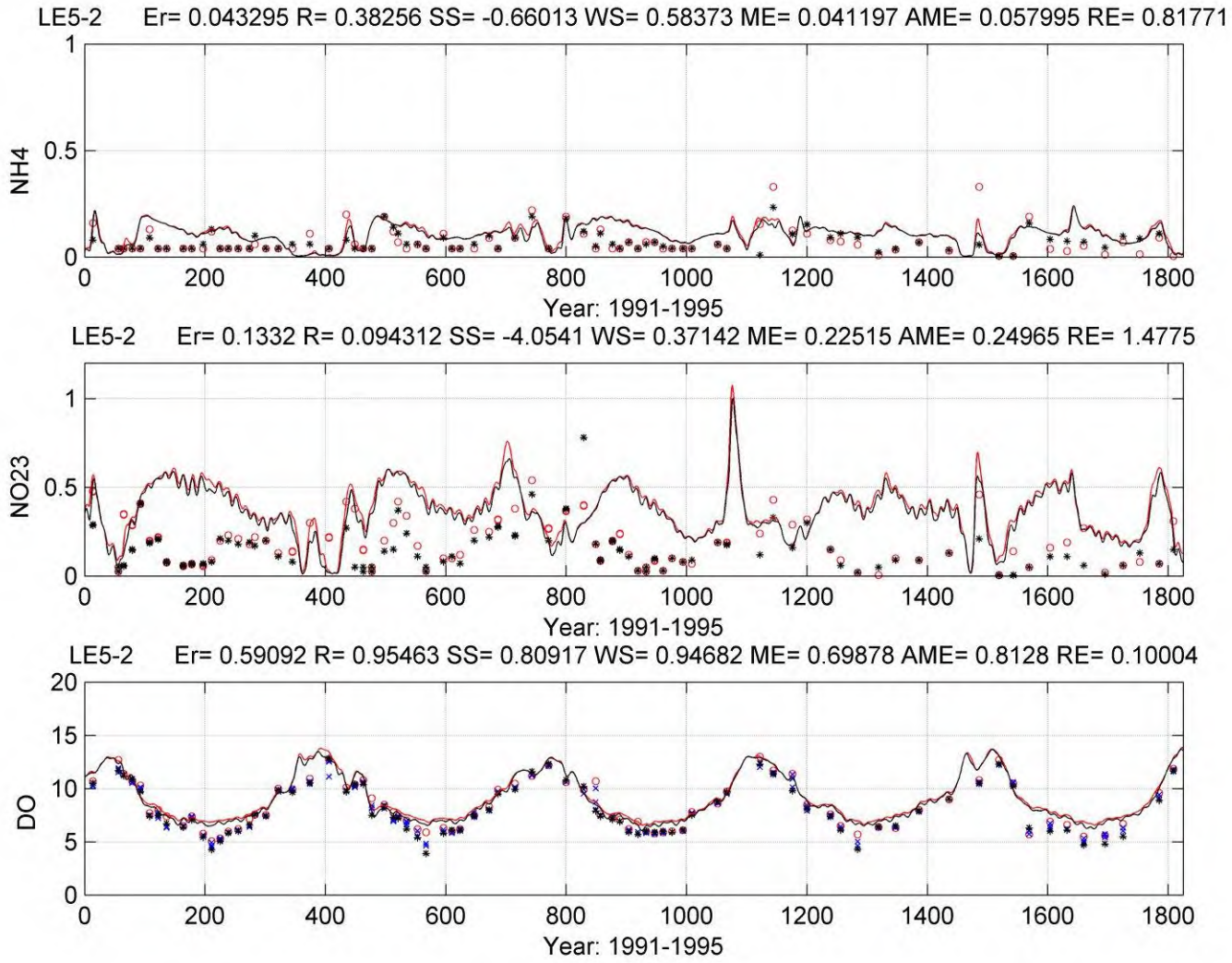

ST: RET5-1A R= 0.077866
NH4
Obs
0
0.2
0.4
0.6
0.8
1
0
0.1
0.2
0.3
0.4
0.5

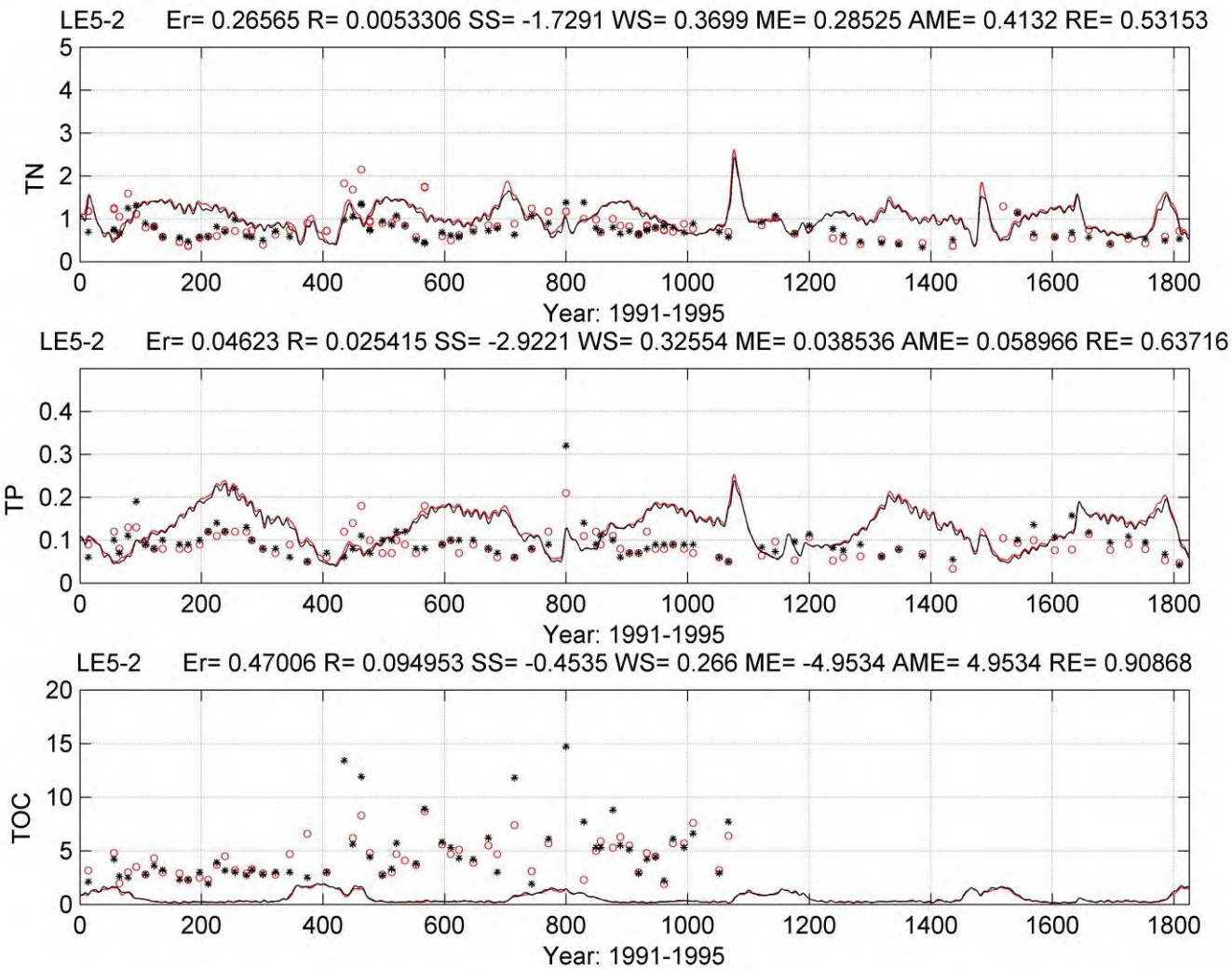

ST: RET5-1A R= 0.1985
NO23
Obs
0
0.2
0.4
0.6
0.8
1
0
0.2
0.4
0.6
0.8
1

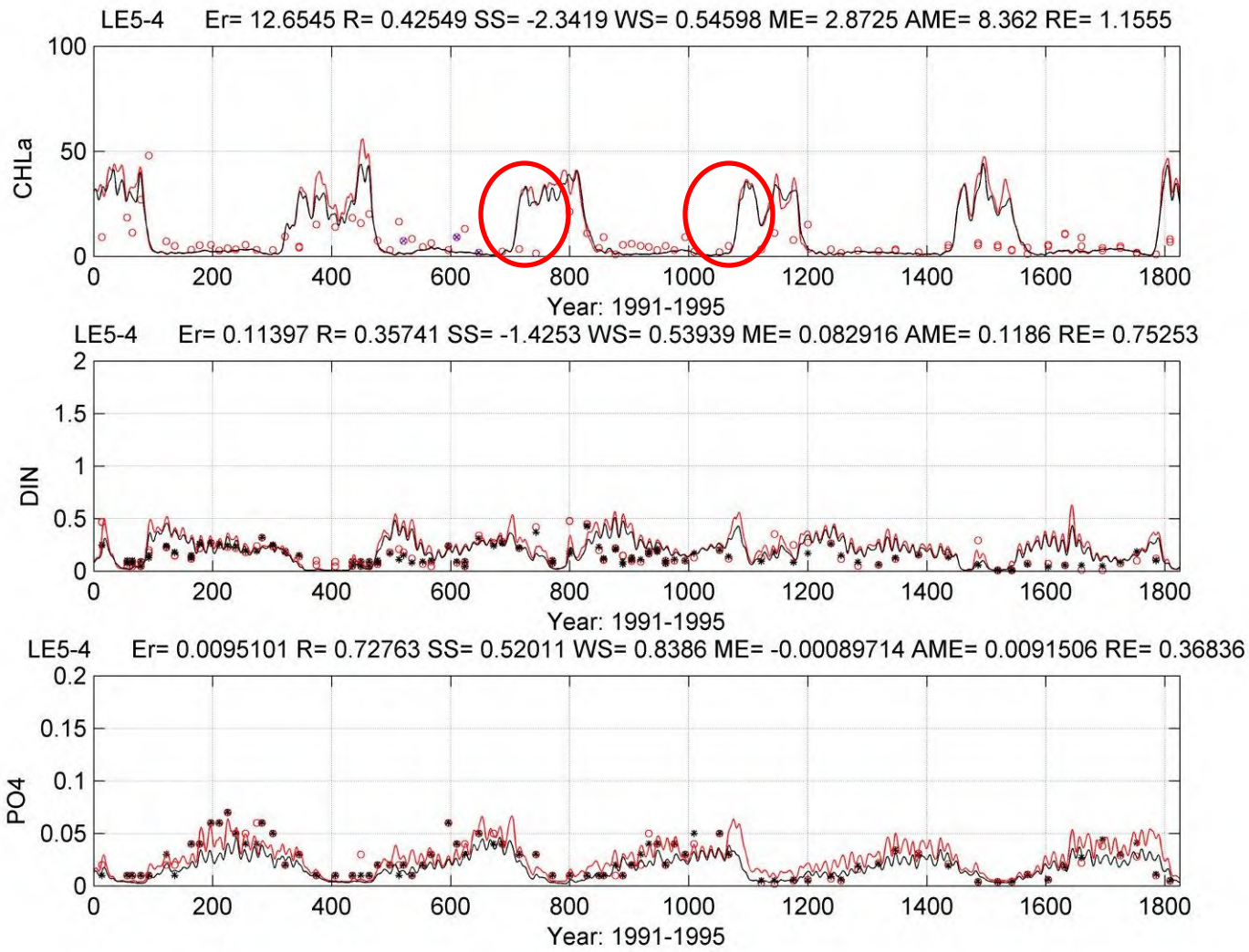

ST: RET5-1A R= 0.15427
TOC
Obs
0
0.2
0.4
0.6
0.8
1
0
5
10
15
20
25

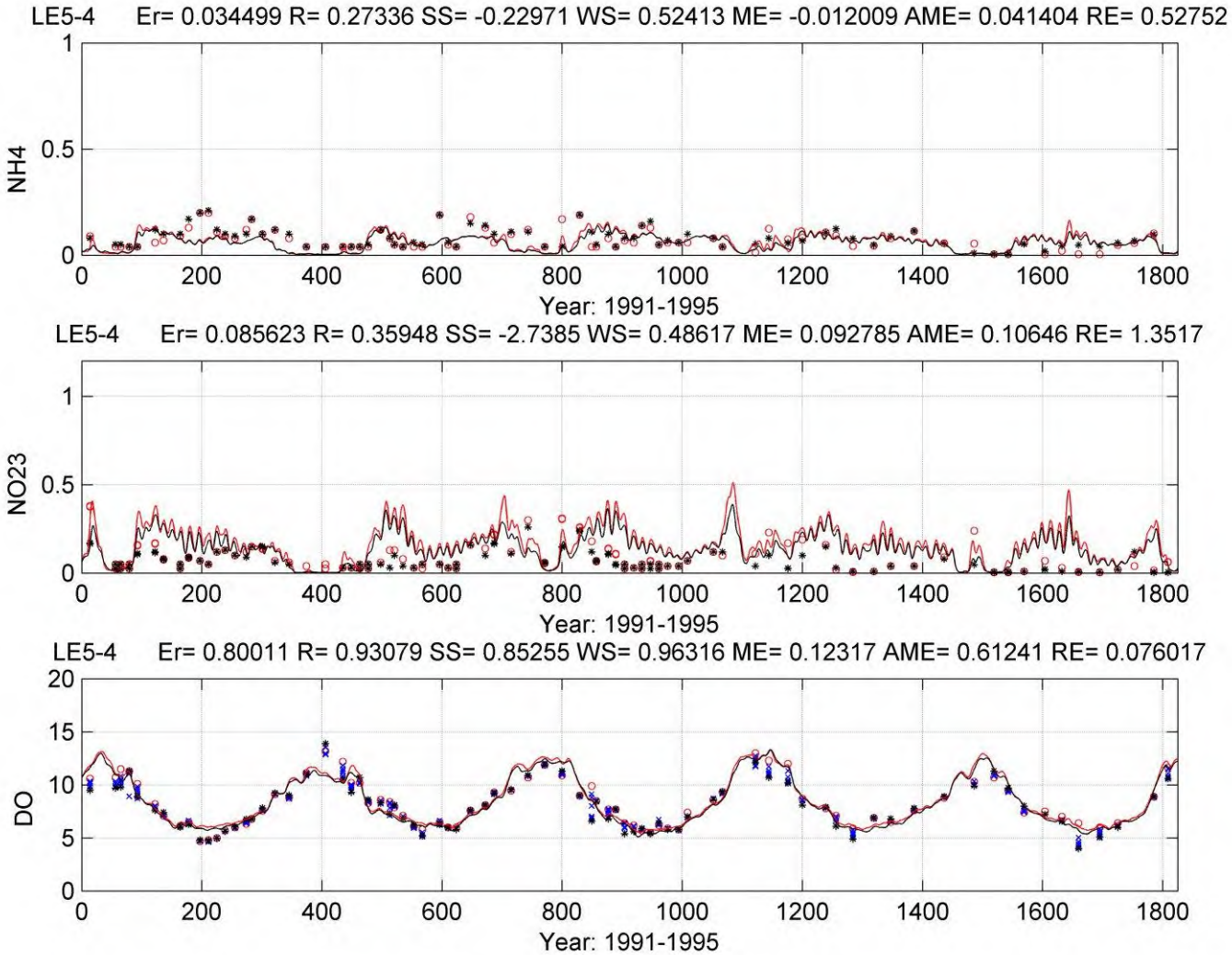
Polyhaline

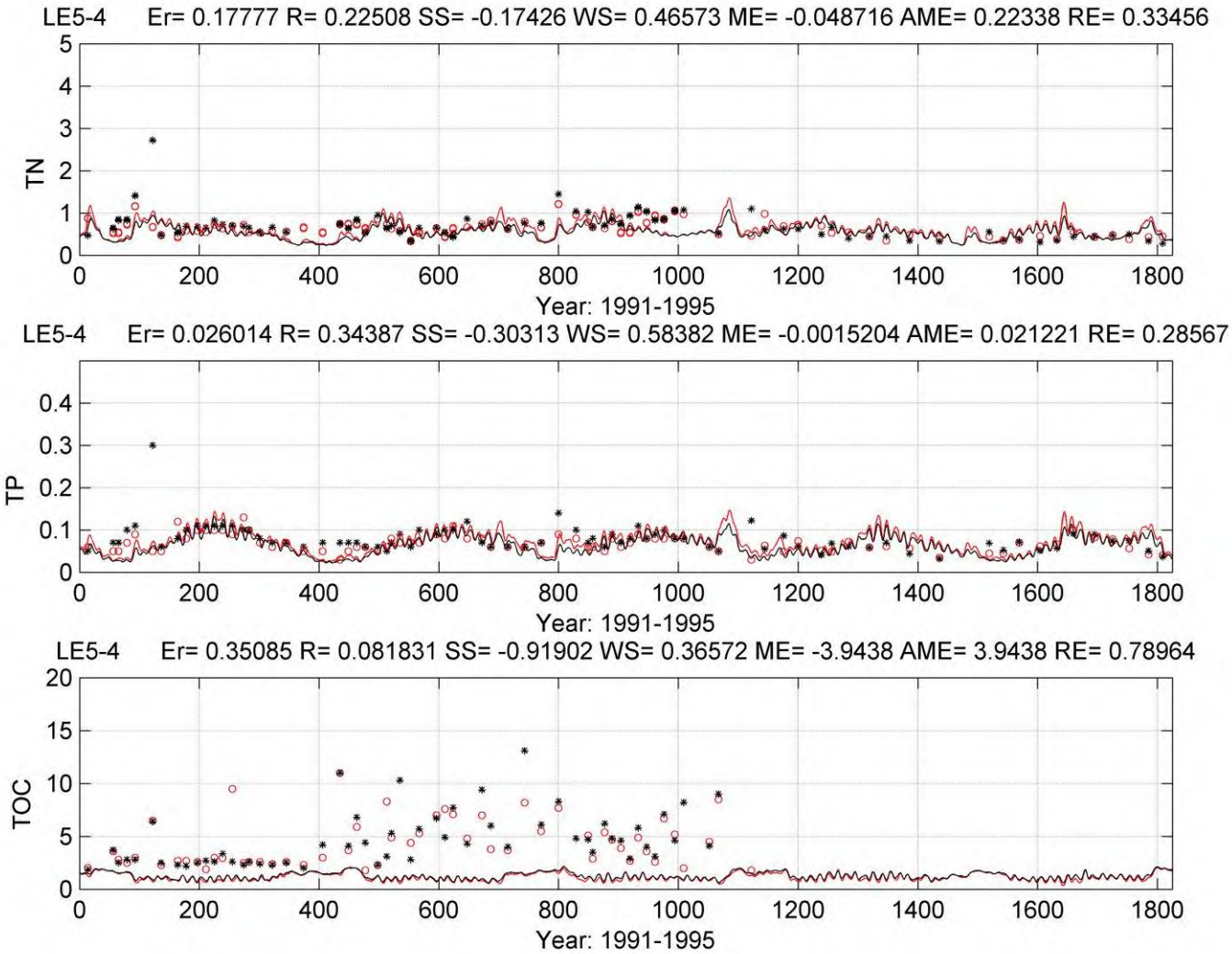

LE5-2 Er= 13.0619 R= 0.44508 SS= 0.10062 WS= 0.62591 ME= -4.3294 AME= 9.4491 RE= 0.75747
CHLa
Year: 1991-1995
LE5-2 Er= 0.16465 R= 0.19042 SS= -3.5314 WS= 0.39421 ME= 0.27155 AME= 0.30299 RE= 1.2772
DIN
Year: 1991-1995
LE5-2 Er= 0.020246 R= 0.6763 SS= -0.55859 WS= 0.73322 ME= 0.01209 AME= 0.017325 RE= 0.5555
PO4
Year: 1991-1995

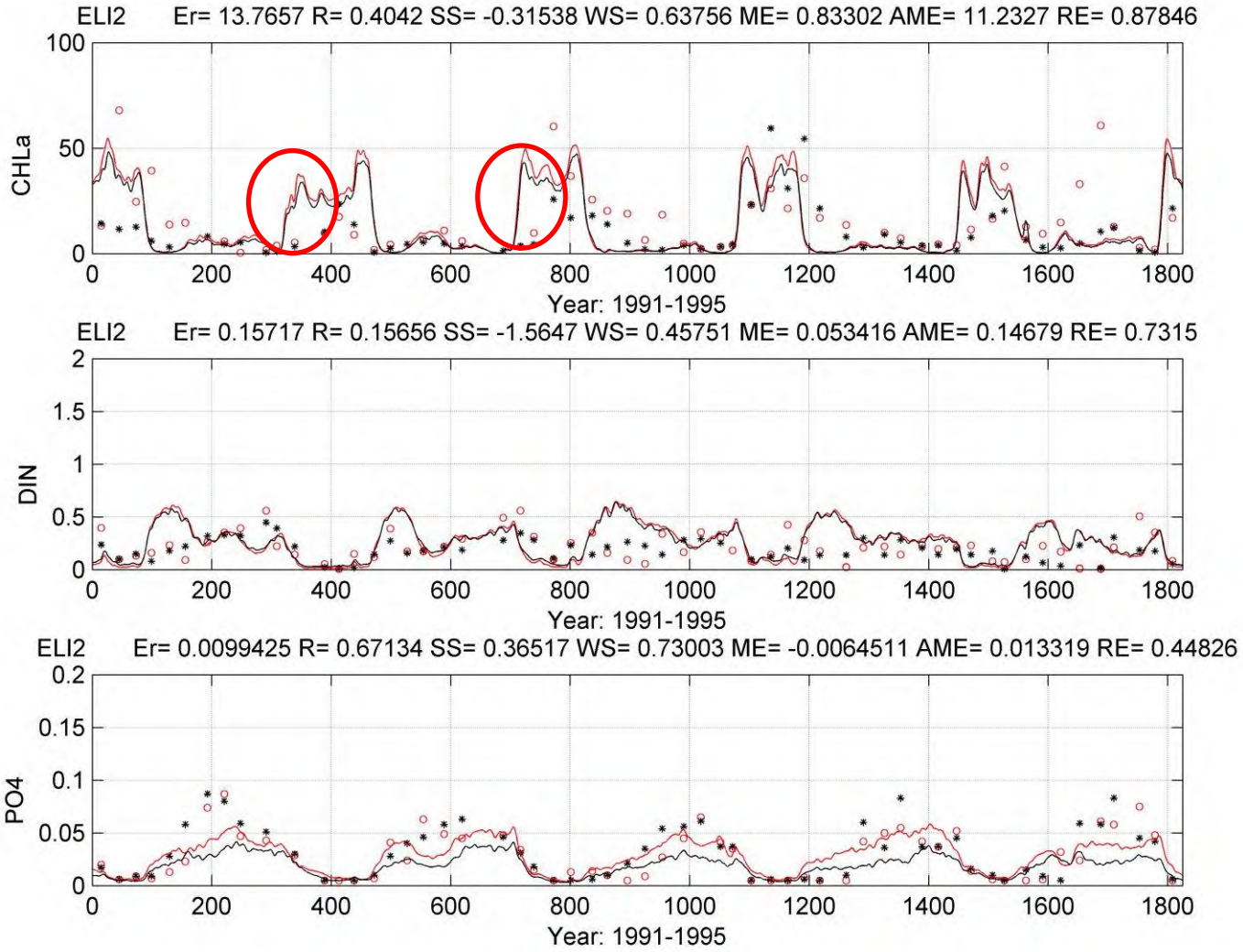

LE5-2 Er= 0.043295 R= 0.38256 SS= -0.66013 WS= 0.58373 ME= 0.041197 AME= 0.057995 RE= 0.81771
NH4
Year: 1991-1995
LE5-2 Er= 0.1332 R= 0.094312 SS= -4.0541 WS= 0.37142 ME= 0.22515 AME= 0.24965 RE= 1.4775
NO23
Year: 1991-1995
LE5-2 Er= 0.59092 R= 0.95463 SS= 0.80917 WS= 0.94682 ME= 0.69878 AME= 0.8128 RE= 0.10004
DO
Year: 1991-1995

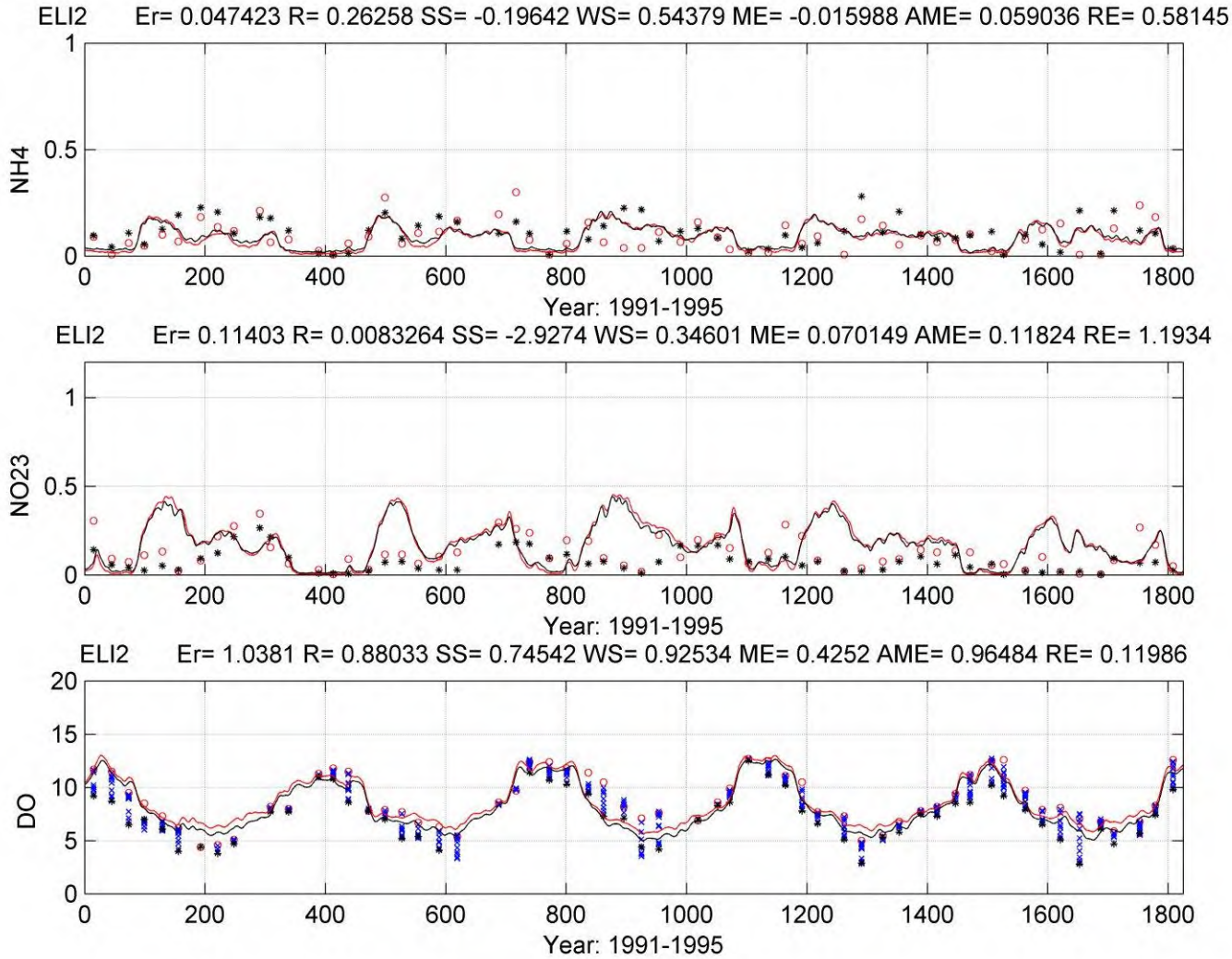

LE5-2 Er= 0.26565 R= 0.0053306 SS= -1.7291 WS= 0.3699 ME= 0.28525 AME= 0.4132 RE= 0.53153
TN
Year: 1991-1995
LE5-2 Er= 0.04623 R= 0.025415 SS= -2.9221 WS= 0.32554 ME= 0.038536 AME= 0.058966 RE= 0.63716
TP
Year: 1991-1995
LE5-2 Er= 0.47006 R= 0.094953 SS= -0.4535 WS= 0.266 ME= -4.9534 AME= 4.9534 RE= 0.90868
TOC
Year: 1991-1995

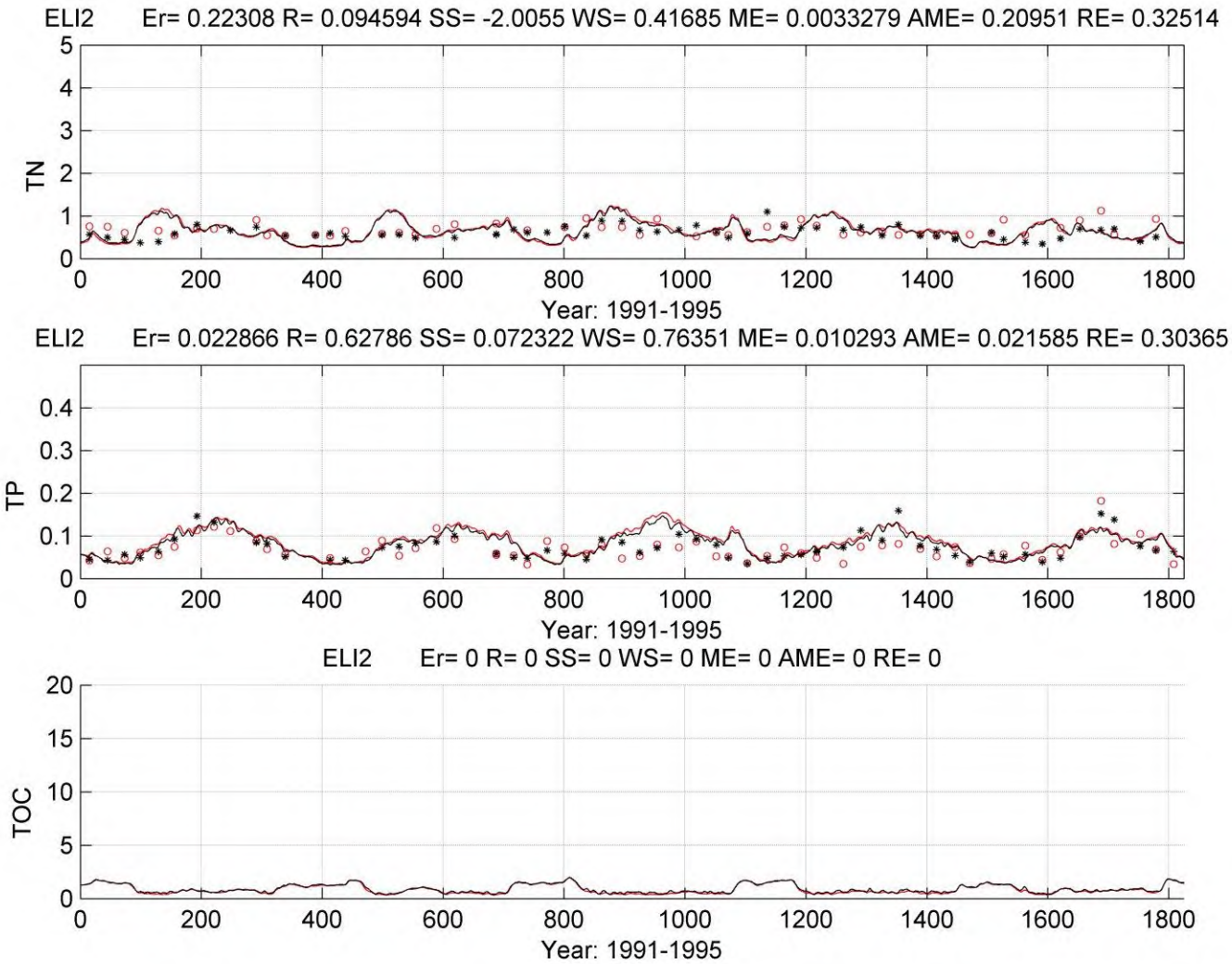

LE5-4 Er= 12.6545 R= 0.42549 SS= -2.3419 WS= 0.54598 ME= 2.8725 AME= 8.362 RE= 1.1555
CHLa
Year: 1991-1995
LE5-4 Er= 0.11397 R= 0.35741 SS= -1.4253 WS= 0.53939 ME= 0.082916 AME= 0.1186 RE= 0.75253
DIN
Year: 1991-1995
LE5-4 Er= 0.0095101 R= 0.72763 SS= 0.52011 WS= 0.8386 ME= -0.00089714 AME= 0.0091506 RE= 0.36836
PO4
Year: 1991-1995

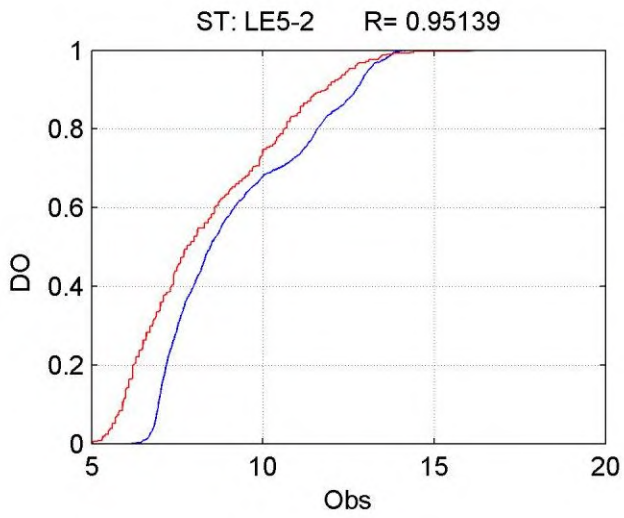

LE5-4 Er= 0.034499 R= 0.27336 SS= -0.22971 WS= 0.52413 ME= -0.012009 AME= 0.041404 RE= 0.52752
NH4
Year: 1991-1995
LE5-4 Er= 0.085623 R= 0.35948 SS= -2.7385 WS= 0.48617 ME= 0.092785 AME= 0.10646 RE= 1.3517
NO23
Year: 1991-1995
LE5-4 Er= 0.80011 R= 0.93079 SS= 0.85255 WS= 0.96316 ME= 0.12317 AME= 0.61241 RE= 0.076017
DO
Year: 1991-1995

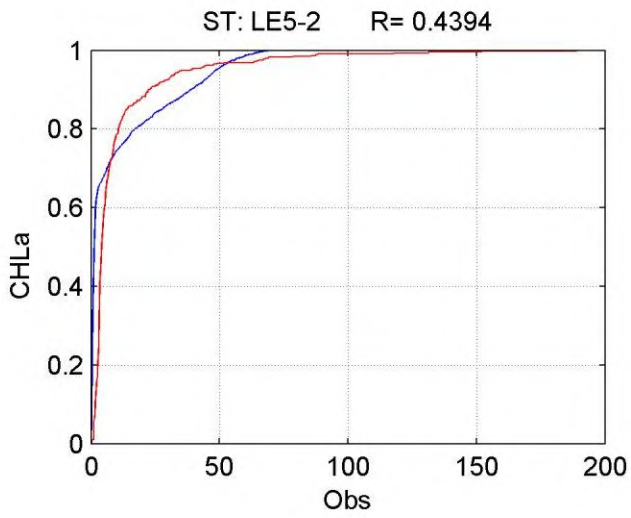

LE5-4 Er= 0.17777 R= 0.22508 SS= -0.17426 WS= 0.46573 ME= -0.048716 AME= 0.22338 RE= 0.33456
TN
Year: 1991-1995
LE5-4 Er= 0.026014 R= 0.34387 SS= -0.30313 WS= 0.58382 ME= -0.0015204 AME= 0.021221 RE= 0.28567
TP
Year: 1991-1995
LE5-4 Er= 0.35085 R= 0.081831 SS= -0.91902 WS= 0.36572 ME= -3.9438 AME= 3.9438 RE= 0.78964
TOC
Year: 1991-1995


ELI2 Er= 13.7657 R= 0.4042 SS= -0.31538 WS= 0.63756 ME= 0.83302 AME= 11.2327 RE= 0.87846
CHLa
Year: 1991-1995
ELI2 Er= 0.15717 R= 0.15656 SS= -1.5647 WS= 0.45751 ME= 0.053416 AME= 0.14679 RE= 0.7315
DIN
Year: 1991-1995
ELI2 Er= 0.0099425 R= 0.67134 SS= 0.36517 WS= 0.73003 ME= -0.0064511 AME= 0.013319 RE= 0.44826
PO4
Year: 1991-1995


ELI2 Er= 0.047423 R= 0.26258 SS= -0.19642 WS= 0.54379 ME= -0.015988 AME= 0.059036 RE= 0.58145
NH4
Year: 1991-1995
ELI2 Er= 0.11403 R= 0.0083264 SS= -2.9274 WS= 0.34601 ME= 0.070149 AME= 0.11824 RE= 1.1934
NO23
Year: 1991-1995
ELI2 Er= 1.0381 R= 0.88033 SS= 0.74542 WS= 0.92534 ME= 0.4252 AME= 0.96484 RE= 0.11986
DO
Year: 1991-1995


ELI2 Er= 0.22308 R= 0.094594 SS= -2.0055 WS= 0.41685 ME= 0.0033279 AME= 0.20951 RE= 0.32514
TN
Year: 1991-1995
ELI2 Er= 0.022866 R= 0.62786 SS= 0.072322 WS= 0.76351 ME= 0.010293 AME= 0.021585 RE= 0.30365
TP
Year: 1991-1995
ELI2 Er= 0 R= 0 SS= 0 WS= 0 ME= 0 AME= 0 RE= 0
TOC
Year: 1991-1995


ST: LE5-2 R= 0.95139
DO
Obs
0
0.2
0.4
0.6
0.8
1
5
10
15
20


ST: LE5-2 R= 0.4394
CHLa
Obs
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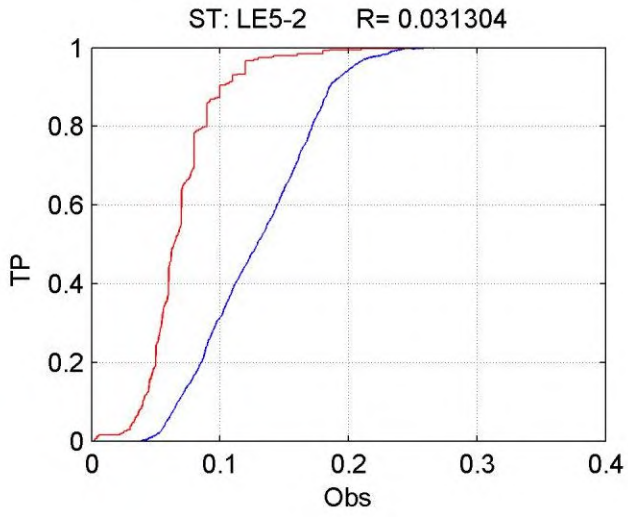
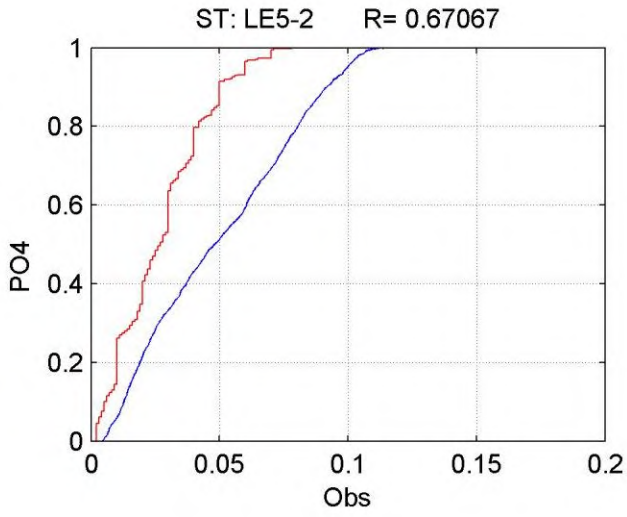
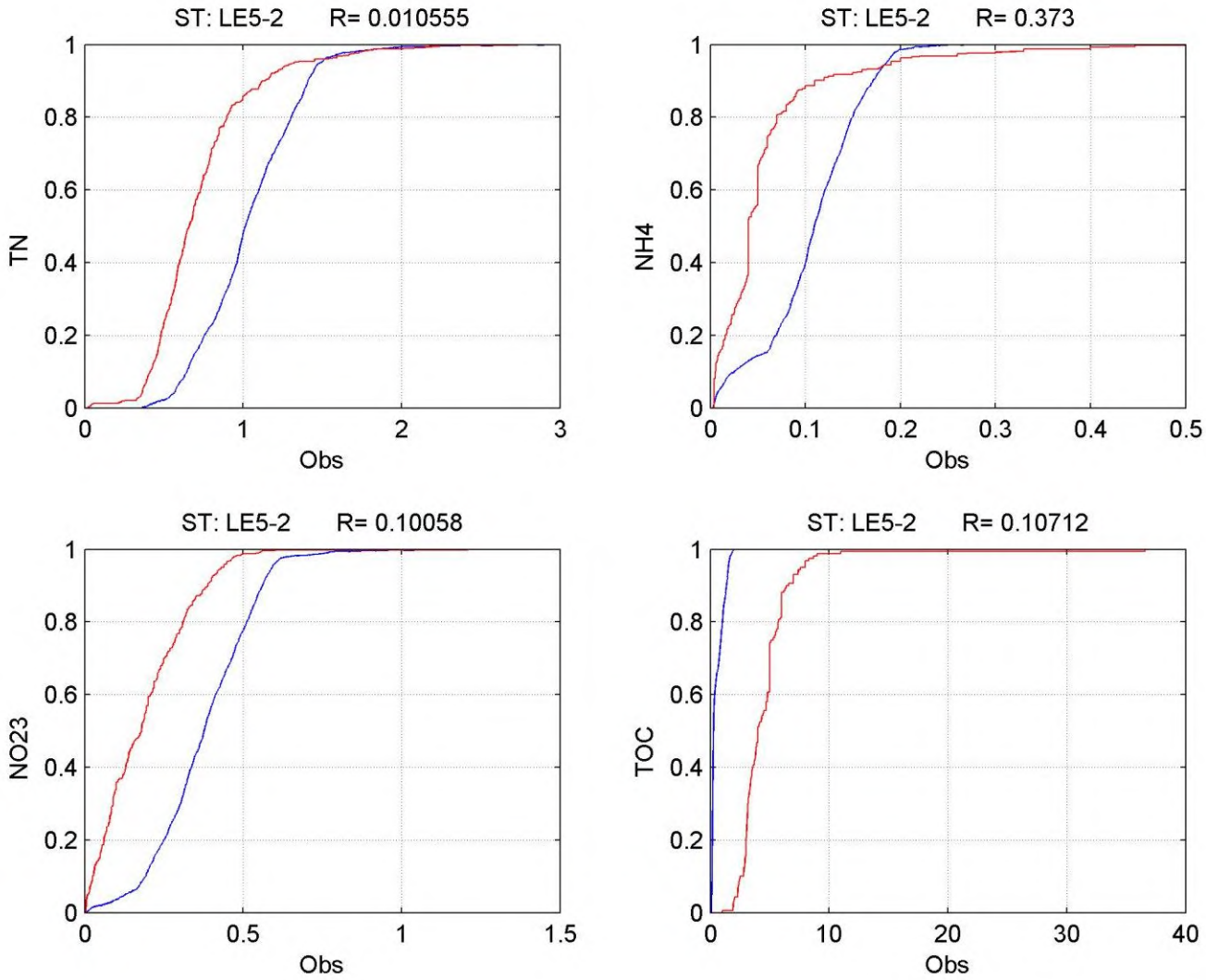
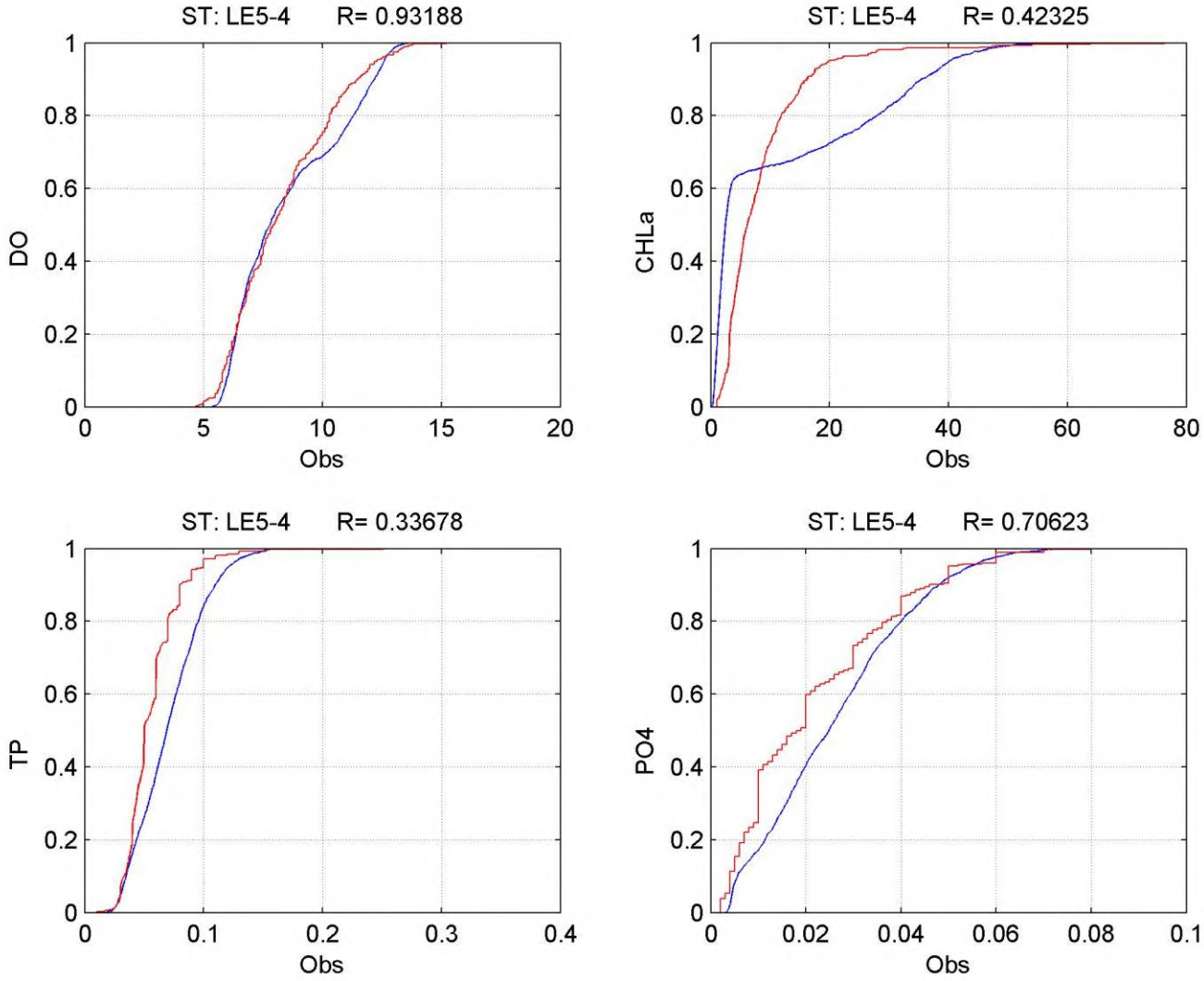
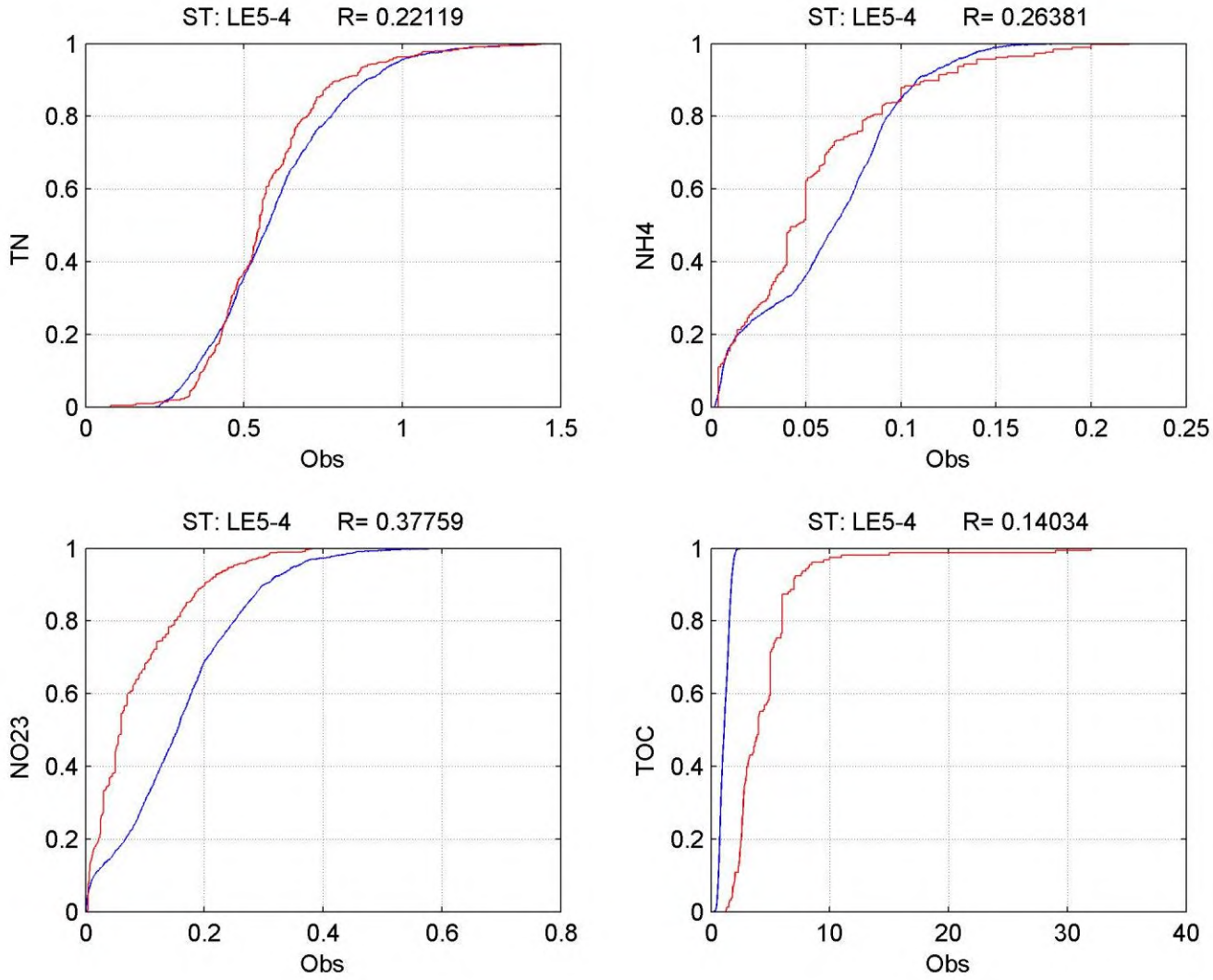
0.2
0.4
0.6
0.8
1
0
50
100
150
200

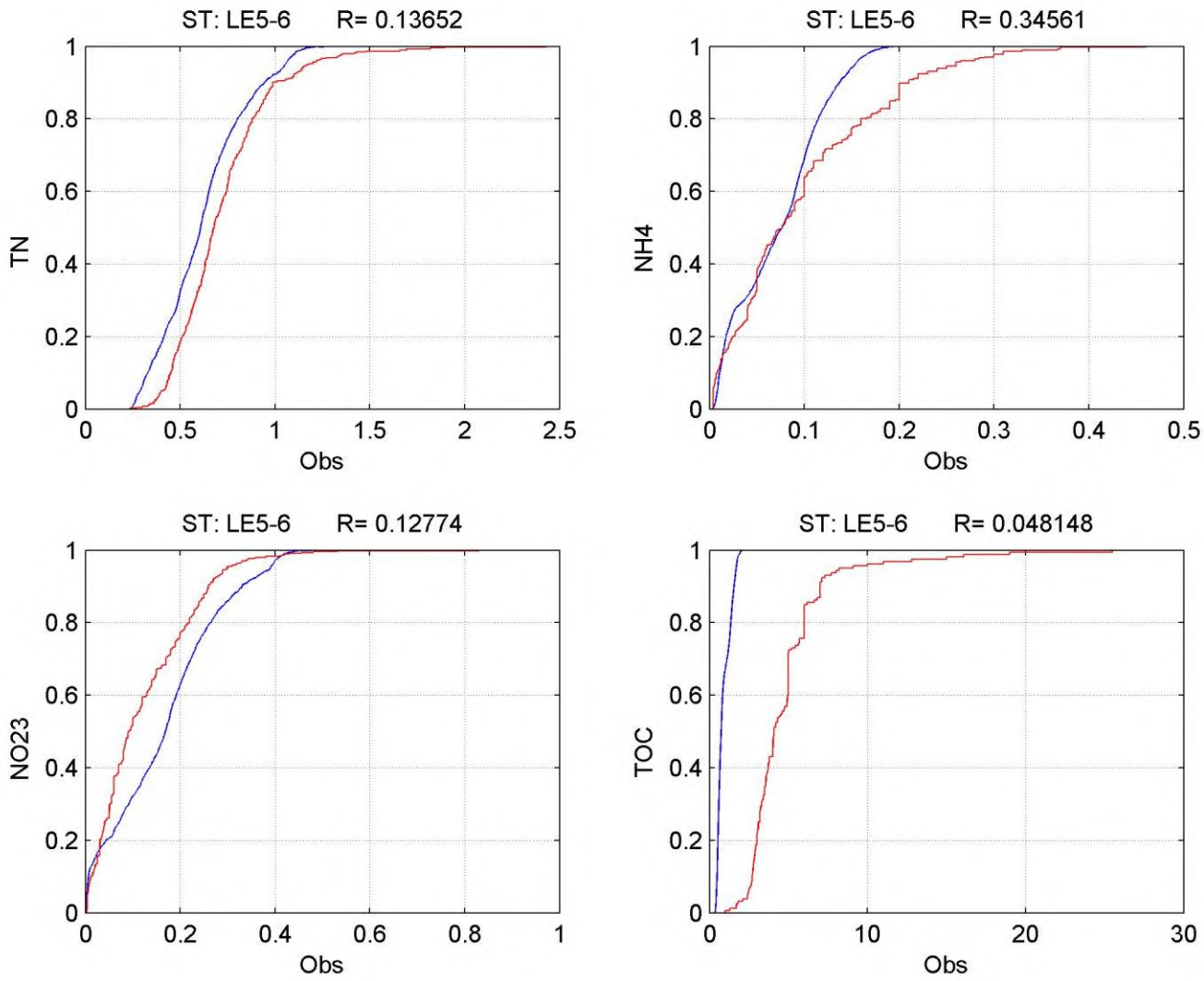

ST: LE5-2 R= 0.031304
TP
Obs
0
0.2
0.4
0.6
0.8
1
0
0.1
0.2
0.3
0.4


ST: LE5-2 R= 0.67067
PO4
Obs
0
0.2
0.4
0.6
0.8
1
0
0.05
0.1
0.15
0.2


ST: LE5-2 R= 0.010555
TN
Obs
ST: LE5-2 R= 0.373
NH4
Obs
ST: LE5-2 R= 0.10058
NO23
Obs
ST: LE5-2 R= 0.10712
TOC
Obs


ST: LE5-4 R= 0.93188
DO
Obs
ST: LE5-4 R= 0.42325
CHLa
Obs
ST: LE5-4 R= 0.33678
TP
Obs
ST: LE5-4 R= 0.70623
PO4
Obs

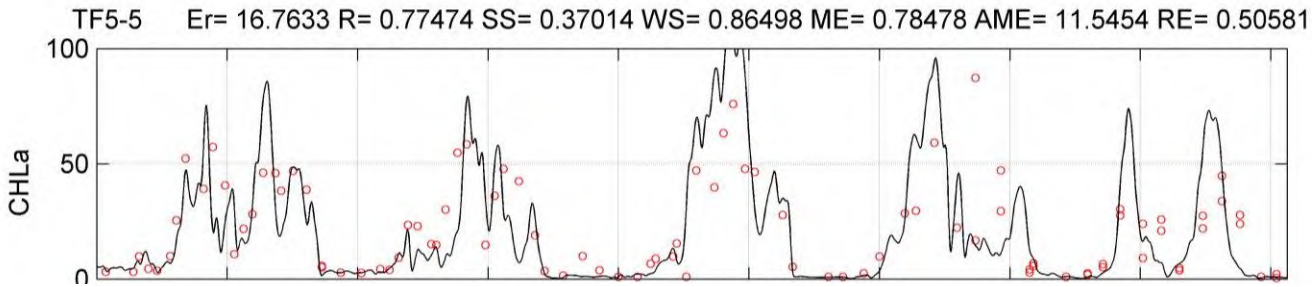

ST: LE5-4 R= 0.22119
TN
Obs
ST: LE5-4 R= 0.26381
NH4
Obs
ST: LE5-4 R= 0.37759
NO23
Obs
ST: LE5-4 R= 0.14034
TOC
Obs


ST: LE5-6 R= 0.13652
TN
Obs
ST: LE5-6 R= 0.34561
NH4
Obs
ST: LE5-6 R= 0.12774
NO23
Obs
ST: LE5-6 R= 0.048148
TOC
Obs

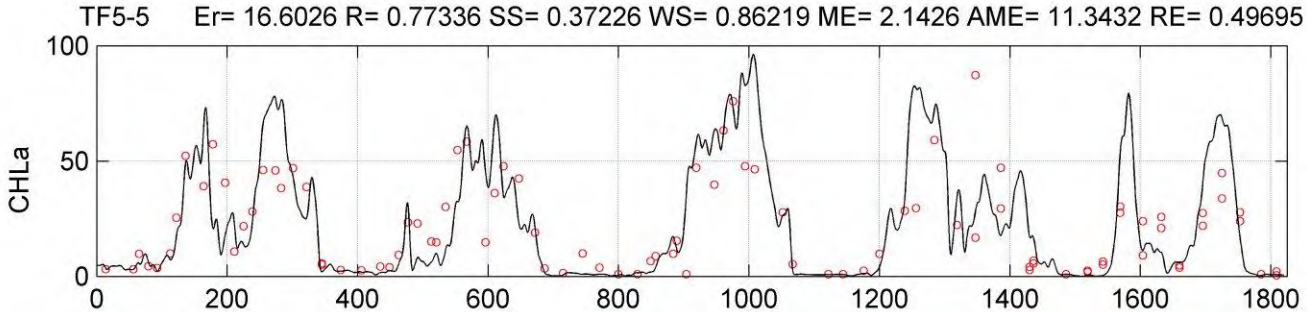
Discussion

- Selection of algal species
- Primary production
- Seasonal change of C:Chl-a ratio
- Stratification, DO, and transport scheme

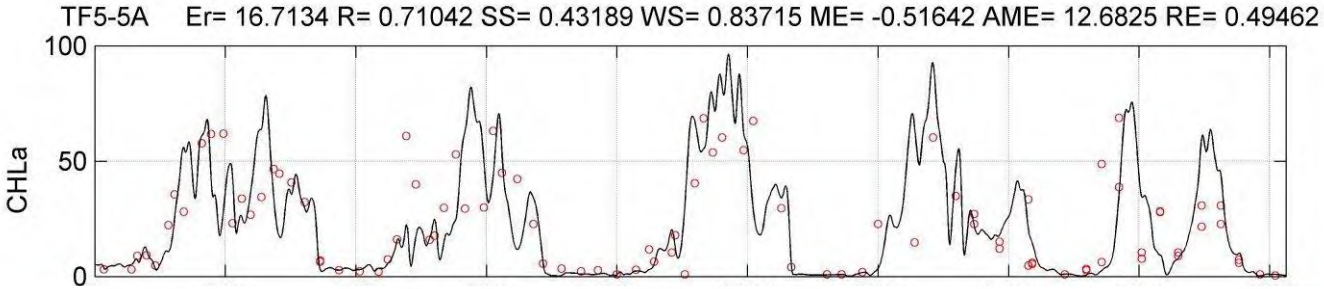
3 species



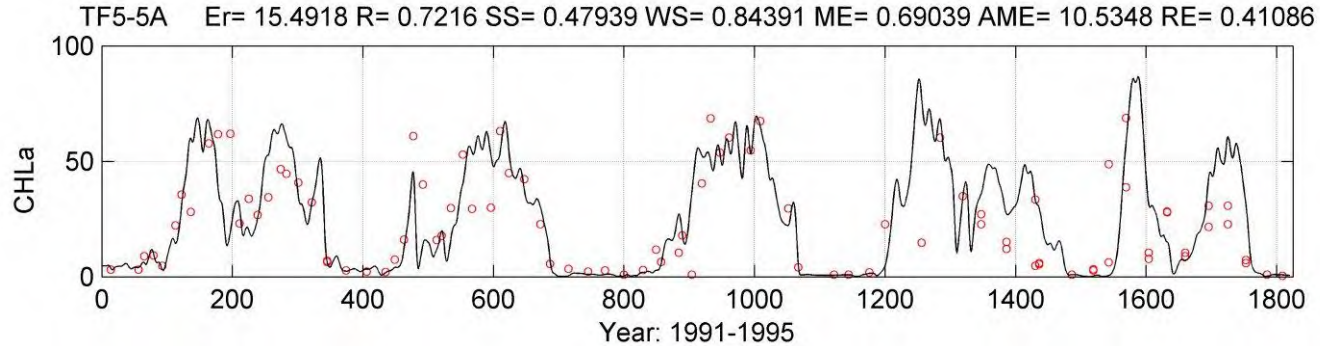
2 species

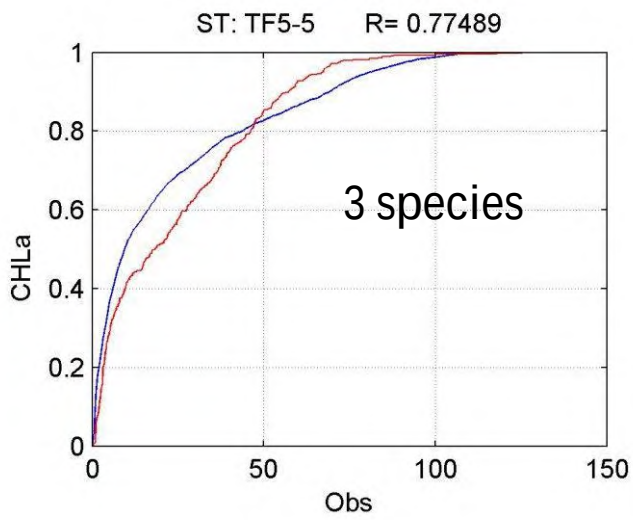


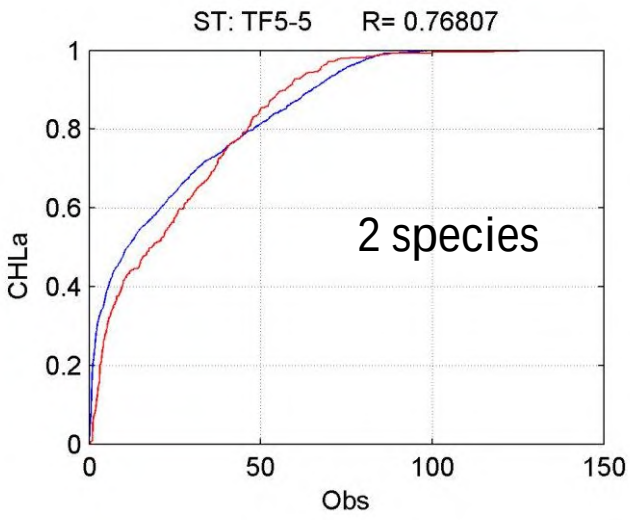
3 species

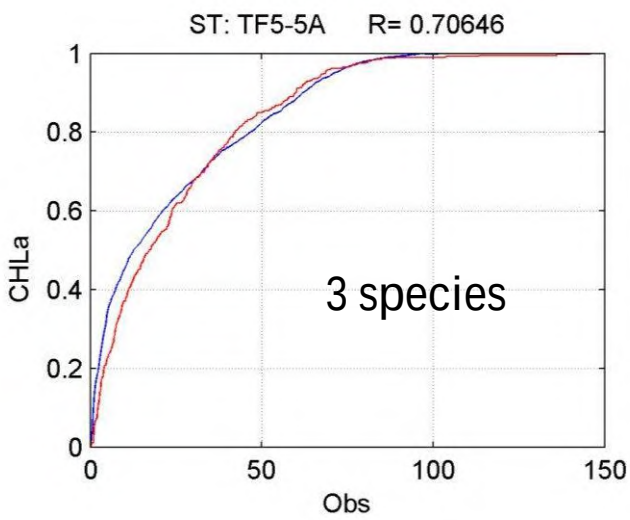


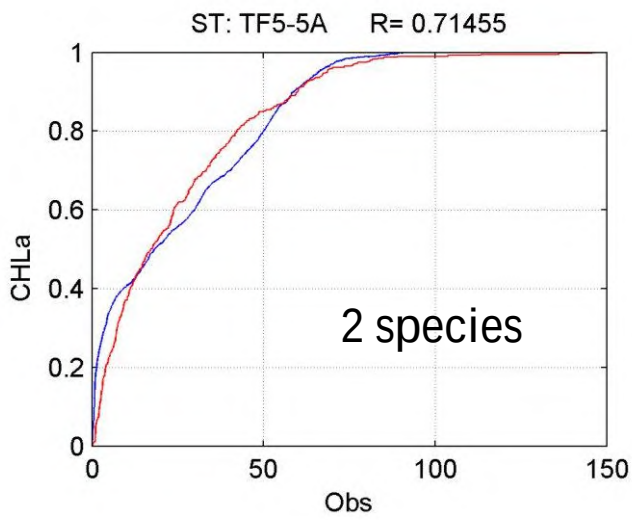
2 species



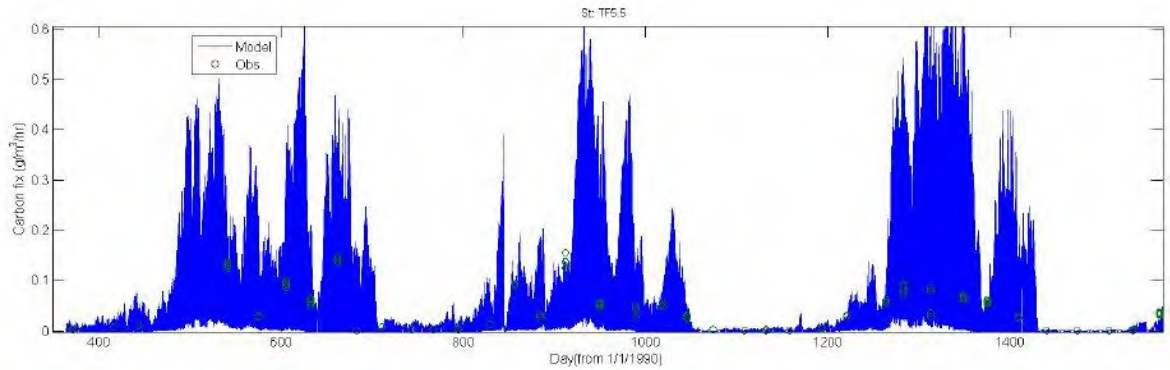

ST: TF5-5 R= 0.77489
3 species
CHLa
Obs
0
0.2
0.4
0.6
0.8
1
0
50
100
150

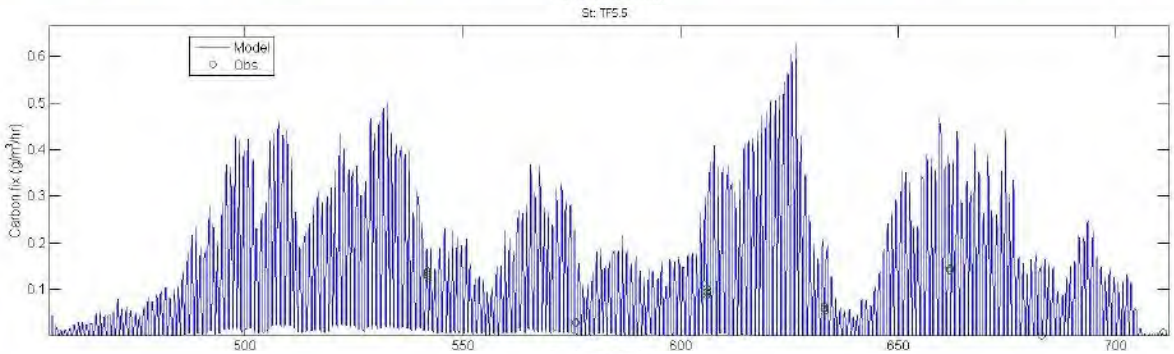

ST: TF5-5 R= 0.76807
2 species
CHLa
Obs
0
0.2
0.4
0.6
0.8
1
0
50
100
150

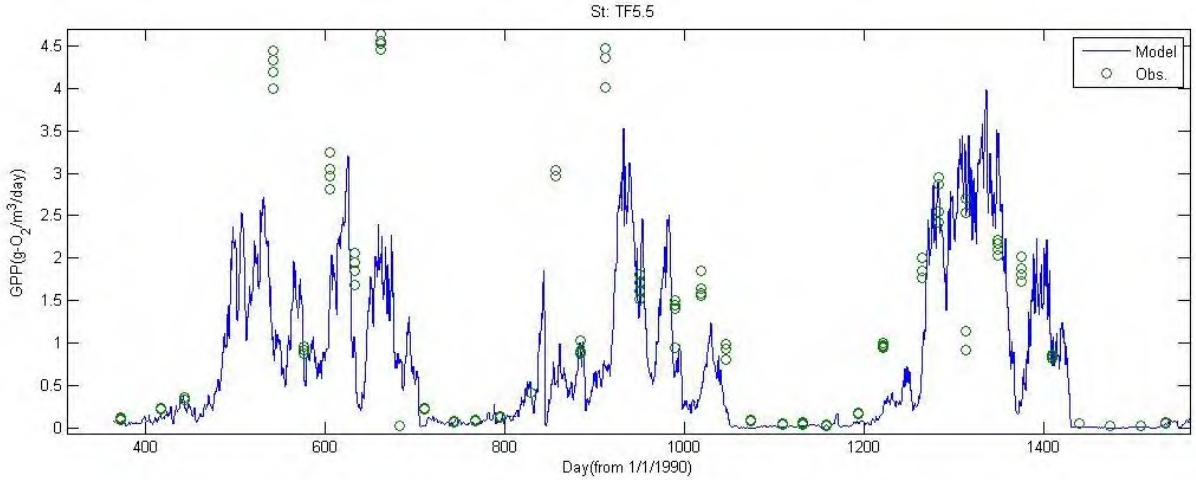

ST: TF5-5A R= 0.70646
3 species
CHLa
Obs
0
0.2
0.4
0.6
0.8
1
0
50
100
150


ST: TF5-5A R= 0.71455
2 species
CHLa
Obs
0
0.2
0.4
0.6
0.8
1
0
50
100
150

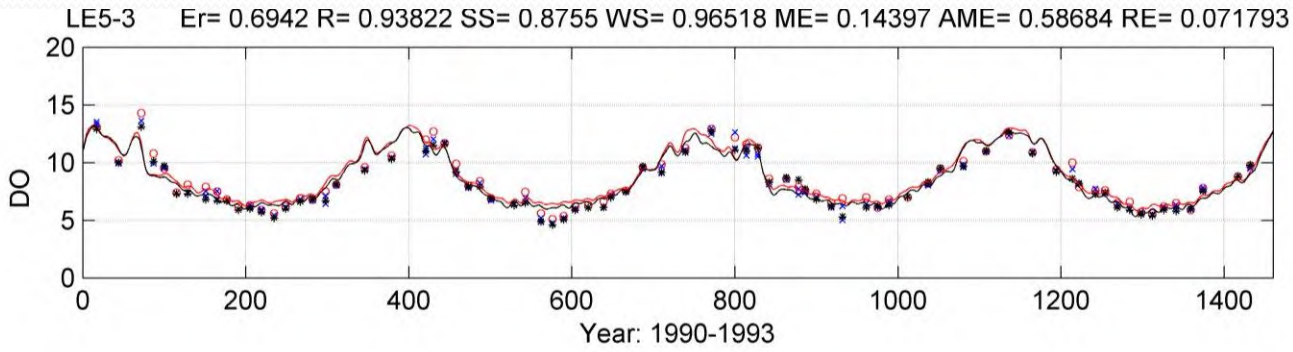
- How to evaluate primary production

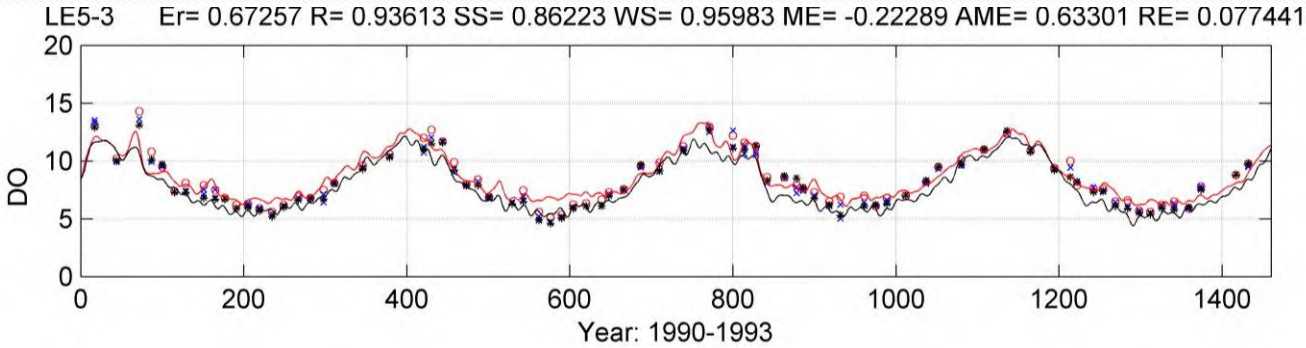


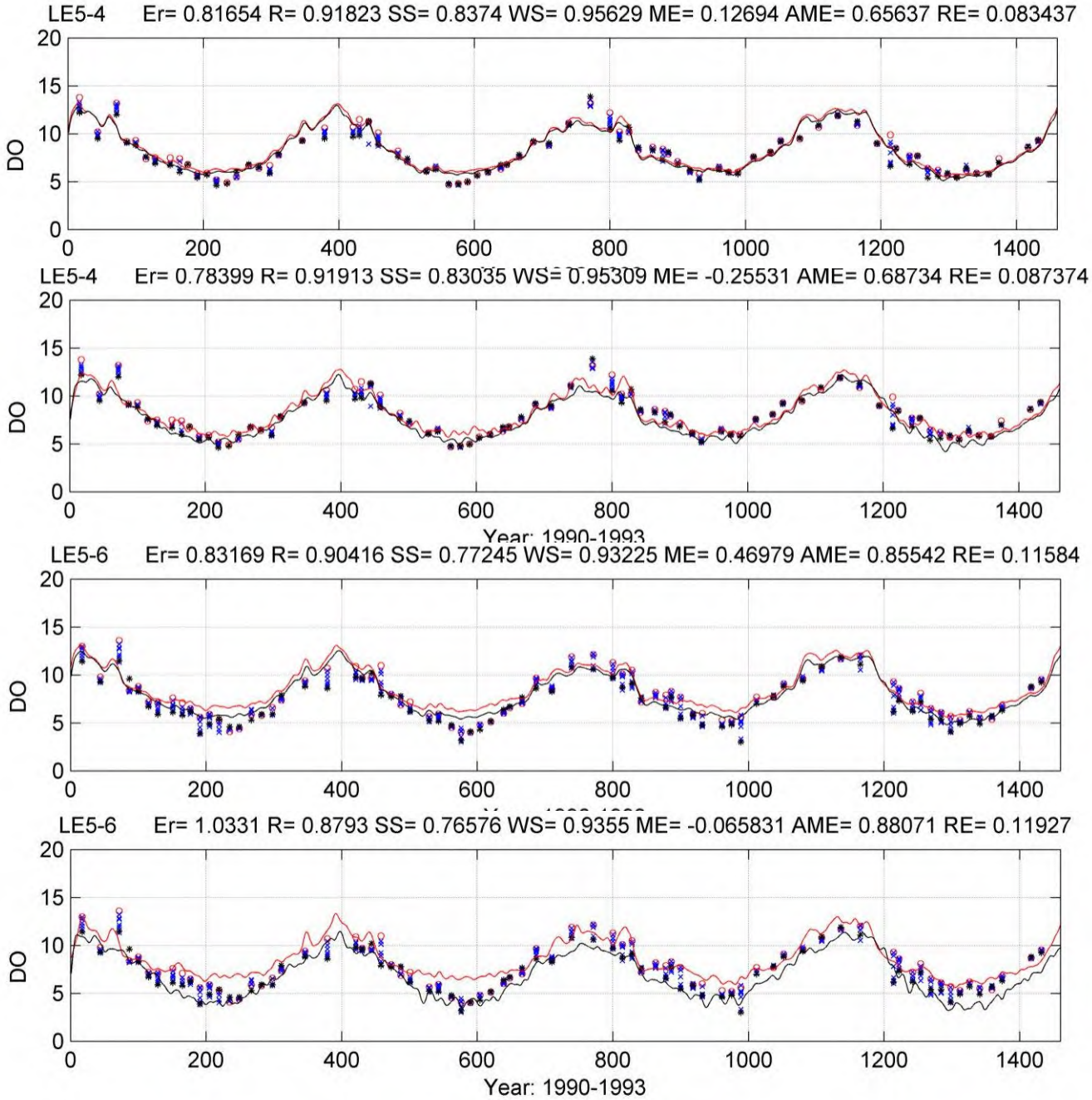




Impact of Stratification on DO






LE5-4 Er= 0.81654 R= 0.91823 SS= 0.8374 WS= 0.95629 ME= 0.12694 AME= 0.65637 RE= 0.083437
LE5-4 Er= 0.78399 R= 0.91913 SS= 0.83035 WS= 0.95309 ME= -0.25531 AME= 0.68734 RE= 0.087374
LE5-6 Er= 0.83169 R= 0.90416 SS= 0.77245 WS= 0.93225 ME= 0.46979 AME= 0.85542 RE= 0.11584
LE5-6 Er= 1.0331 R= 0.8793 SS= 0.76576 WS= 0.9355 ME= -0.065831 AME= 0.88071 RE= 0.11927
DO
0
5
10
15
20
0
200
400
600
800
1000
1200
1400
Year: 1990-1993

Future Work

- Revise light function
- Evaluate primary production results
- Continue work on downstream model calibration
- Assess model skill of sediment model
- Conduct model simulation for the period from 2007-2013