Link or sink: a modelling interpretation of the open Baltic biogeochemistry (additional material)

M. Vichi[1], P. Ruardij[2], and J.W. Baretta[3]

[1]National Institute of Geophysics and Volcanology, Bologna, I
[2]Royal Netherlands Institute of Sea Research, Texel, NL
[3]Noctiluca, Wassenaar, NL

Manuscript submitted to

Biogeosciences

October 2004

Additional material: Tables and Color Plates

Description and values of the parameters of ERSEM III used in the presented simulations (cf. Fig. 1 and 2 for the list of state variables).

Symbols refer to the equations detailed in the paper and more in detail in Vichi (2002).

References

Vichi, M.: Predictability studies of coastal marine ecosystem behavior, Ph.D. thesis, University of Oldenburg, Oldenburg, Germany, http://docserver.bis.uni-oldenburg.de/publikationen/dissertation/2002/vicpre02/vicpre02.html, 2002.

Tables

	Preys								
Predators	$P_i^{(1)}$	$P_i^{(2)}$	$P_i^{(3)}$	$P_i^{(4)}$	$Z_i^{(3)}$	$Z_i^{(4)}$	$Z_i^{(5)}$	$Z_i^{(6)}$	B_i
$Z_i^{(3)}$	0	0	0	0	1.0	1.0	0	0	0
$Z_i^{(4)}$	1.0	0.75	0	0	0	1.0	1.0	0	0
$Z_i^{(5)}$	0.1	1.0	0.5	0.1	0	0	1.0	1.0	0.1
$Z_i^{(6)}$	0	0.2	1.0	0	0	0	0	0.2	1.0

Table 1. Pelagic food matrix $\delta_{Z,X}$ (non-dimensional).

	Food Sources											
Consumers	$Y_i^{(1)}$	$Y_i^{(2)}$	$Y_i^{(3)}$	$Y_i^{(4)}$	$Y_i^{(5)}$	$P_i^{(1)}$	$P_i^{(2)}$	$P_i^{(3)}$	$H_i^{(1)}$	$H_i^{(2)}$	$Q_i^{(6)}$	$R_i^{(6)}$
$Y_i^{(1)}$	1.0	0.7	1.0	0	0.5	0	0	0	0	0	0	0
$Y_i^{(2)}$	0	0	0	1.0	0	0	0	0	0	0	0.1	0
$Y_i^{(3)}$	0	0	0	0	0	1.0	1.0	1.0	1.0	0	0.1	1.0
$Y_i^{(4)}$	0	0	0	1.0	0	0	0	0	1.0	1.0	0.3	0
$Y_i^{(5)}$	0	1.0	0	0.5	1.0	0	0	0	0	0	0	0

Table 2. Benthic food matrix $\phi_{Y,X}(\mathrm{d}^{-1})$.

Symbol	$P^{(1)}$	$P^{(2)}$	$P^{(3)}$	$P^{(4)}$	**Description**
r_{0_P}	2.00	2.50	5.00	0.80	Maximum specific growth rate (d^{-1})
Q_{10_P}	2.00	2.00	2.00	2.00	Characteristic Q10 coefficient
h^s_{P1}	1.00	-	-	-	Half saturation value for Si-limitation (mmolSi m^{-3})
b_P	0.05	0.05	0.05	0.05	Basal specific respiration rate (d^{-1})
γ_P	0.10	0.15	0.20	0.20	Activity respiration fraction (-)
α_P	0.05	0.20	0.20	0.05	Excreted fraction of primary production (-)
$h^{p,n,s}_P$	0.10	0.10	0.10	0.10	Nutrient stress threshold (-)
d_{0_P}	0.50	0.50	0.25	0.50	Specific lysis rate (d^{-1})
λ_1	2.5 10^{-3}	5.0 10^{-3}	2.5 10^{-3}	2.5 10^{-3}	Specific affinity for P (mg C^{-1} d^{-1})
λ_3	2.5 10^{-3}	2.5 10^{-3}	0.0	2.5 10^{-3}	Specific affinity for N-NO_3 (mgC^{-1} d^{-1})
λ_4	2.5 10^{-2}	2.5 10^{-2}	2.5 10^{-2}	2.5 10^{-2}	Specific affinity for N-NH_4 (mgC^{-1} d^{-1})
$s^{\max}_{P1}$	0.03	-	-	-	Standard Si:C ratio in diatoms (mmolSi mg C^{-1})
ω^{sink}_{P1}	5.0	0	0	5.0	Minimum sedimentation rate (m d^{-1})
l^{sink}_{P1}	0.70	-	-	0.75	Nutrient stress threshold for sedimentation (-)
Rr^n_c, Rr^p_c	1.26 10^{-2}, 7.86 10^{-4}	1.26 10^{-2}, 7.86 10^{-4}	1.26 10^{-2}, 7.86 10^{-4}	1.26 10^{-2}, 7.86 10^{-4}	Reference nutrient quota (Redfield, mmolN mgC^{-1}, mmolP mgC^{-1})
$n^{\min}_P$, $p^{\min}_P$	$0.5Rr^n_c$, $0.5Rr^p_c$	$0.5Rr^n_c$, $0.5Rr^p_c$	$0.5Rr^n_c$, $0.5Rr^p_c$	$0.5Rr^n_c$, $0.5Rr^p_c$	Minimum nutrient quota (mmolN mgC^{-1}, mmolP mg C^{-1})
$n^{\max}_P$, $p^{\max}_P$	$2Rr^n_c$, $2Rr^p_c$	$2Rr^n_c$, $2Rr^p_c$	$2Rr^n_c$, $2Rr^p_c$	$2Rr^n_c$, $2Rr^p_c$	Maximum nutrient quota (mmolN mgC^{-1}, mmolP mgC^{-1})

Table 3. Values and description of the phytoplankton parameters used in the reference simulation.

Symbol	$P^{(1)}$	$P^{(2)}$	$P^{(3)}$	$P^{(4)}$	**Description**
b_P	0.10	0.05	0.10	0.10	Basal specific respiration rate (d^{-1})
γ_P	0.10	0.10	0.20	0.10	Activity respiration fraction (-)
α_P	0.05	0.10	0.10	0.15	Excreted fraction of primary production (-)
λ_1	1.25 10^{-3}	2.5 10^{-3}	2.5 10^{-3}	2.5 10^{-3}	Specific affinity for P (mg C^{-1} d^{-1})
λ_2	1.25 10^{-3}	2.5 10^{-3}	2.5 10^{-3}	2.5 10^{-3}	Specific affinity for N (mgC^{-1} d^{-1})
h_P^n	1.00	0.50	0.10	1.00	Michaelis-Menten constant for NO_3 uptake inhibition (mmolN-NH_4 m^{-3})

Table 4. Values and description of the standard phytoplankton parameters modified in run B3.

Symbol	*B*	**Description**
Q_{10_B}	2.95	Characteristic Q10 coefficient
h_B^o	30.0	Half saturation value for oxygen limitation ($mmolO_2$ m^{-3})
r_{0_B}	8.38	Potential specific growth rate (d^{-1})
b_B	0.01	Basal specific respiration rate (d^{-1})
η_B	0.30	Assimilation efficiency (-)
η_B^o	0.20	Decrease in assimilation efficiency due to anoxia (-)
d_{0_B}	0.00	Specific mortality rate (d^{-1})
ν_B^1	0.50	Specific potential $R^{(1)}$ uptake (d^{-1})
ν_B^6	0.10	Specific potential $R^{(6)}$ uptake (d^{-1})
$n_B^{\max}$, $p_B^{\max}$	1.7 10^{-2}, 1.9 10^{-3}	Optimal nutrient quota (Goldman, mmolN mgC^{-1}, mmolP mgC^{-1})
h_B^n, h_B^p	0.50, 1.00	Half saturation for nutrient uptake (mmolN mgC^{-1}, mmolP mgC^{-1})

Table 5. Parameter values and descriptions for bacterioplankton, B_i.

Symbol	*B*	**Description**
ν_B^1	1.00	Specific potential $R^{(1)}$ uptake (d^{-1})
ν_B^2	0.25	Specific potential $R^{(2)}$ uptake (d^{-1})
λ_1	$5.0\ 10^{-3}$	Specific affinity for P (mg C^{-1} d^{-1})
λ_2	$5.0\ 10^{-2}$	Specific affinity for N (mgC^{-1} d^{-1})
h_B^n	0.05	Michaelis-Menten constant for NO_3 uptake inhibition (mmolN-NH_4 m^{-3})
$n_B^{\min}$, $p_B^{\min}$	$8.5\ \ 10^{-3}$, $9.5\ 10^{-4}$	Minimum nutrient quota (mmolN mgC^{-1}, mmolP mg C^{-1})

Table 6. Values and description of the standard bacterioplankton parameters modified in run B3.

Symbol	$Z^{(5)}$	$Z^{(6)}$	**Description**
Q_{10_Z}	2.00	2.00	Characteristic Q10 coefficient (-)
h_Z^F	30.0	100	Michaelis constant for total food ingestion (mg C m^{-3})
μ_Z	50.0	50.0	Feeding threshold (mg C m^{-3})
r_{0_Z}	2.00	10.0	Potential specific growth rate (d^{-1})
h_Z^o	0.10	0.10	Michaelis constant for oxygen dependence (fraction of O_2 saturation)
b_Z	0.02	0.02	Basal specific respiration rate (d^{-1})
η_Z	0.50	0.30	Assimilation efficency (-)
α_Z	0.50	0.50	Excreted fraction of uptake (-)
ε_Z	0.6	0.8	Partition between dissolved and particulate excretion (-)
$n_Z^{\max}$, $p_Z^{\max}$	$1.26\ \ 10^{-2}$, $7.86\ 10^{-4}$	$1.26\ \ 10^{-2}$, $7.86\ 10^{-4}$	Maximum nutrient quota (mmolN mgC^{-1}, mmolP mgC^{-1})
$\nu_Z^n = \nu_Z^p$	1.00	1.00	Time frequency of the excretion process (d^{-1})
$\zeta_{R1}^n = \zeta_{R1}^p$	0.50	0.50	Preferential recycling for N and P (-)
d_{0_Z}	0.05	0.05	Specific mortality rate (d^{-1})
d_Z^o	0.25	0.25	Oxygen-dependent specific mortality rate (d^{-1})

Table 7. Parameter values and descriptions for microzooplankton and heterotrophic nanoflagellates.

Symbol	$Z^{(3)}$	$Z^{(4)}$	**Description**
Q_{10_Z}	3.00	3.00	Characteristic Q10 coefficient (-)
v_Z	0.016	0.032	specific search volume (m^3 mg C^{-1})
r_{0_Z}	2.00	2.00	Potential specific growth rate (d^{-1})
b_Z	0.01	0.02	Basal specific respiration rate (d^{-1})
η_Z	0.70	0.85	Assimilation efficency (-)
α_Z	0.50	0.55	Excreted fraction of uptake (-)
d_{0_Z}	0.01	0.02	Specific natural mortality rate (d^{-1})
d_Z^{dns}	0.02	0.02	Specific density-dependent mortality (d^{-1})
β_Z	2	2	Exponent for density dependent mortality (-)
$n_Z^{\max}$, $p_Z^{\max}$	1.26 10^{-2}, 7.86 10^{-4}	1.26 10^{-2}, 7.86 10^{-4}	Maximum nutrient quota (mmolN mgC^{-1}, mmolP mgC^{-1})

Table 8. Parameter values and descriptions for carnivorous and omnivorous mesozooplankton.

Symbol	**Values**	**Description**
Ω_c^o	$\frac{1}{12}$	Unit conversion factor and stoichiometric coefficient ($mmolO_2\ mgC^{-1}$)
Ω_n^o	2.00	Stoichiometric coefficient nitrification reaction ($mmolO_2\ mmolN^{-1}$)
$\widetilde{\Omega}_n^o$	1.25	Stoichiometric coefficient denitrification reaction ($mmolO_2\ mmolN^{-1}$)
Ω_o^r	0.5	Stoichiometric coefficient ($mmolHS^-\ mmolO_2{}^{-1}$)
Ω_n^r	0.625	Stoichiometric coefficient ($mmolHS^-\ mmolN^{-1}$)
Λ_{N4}^{nit}	0.01	Specific nitrification rate (d^{-1})
$Q_{10_{N4}}$	2.37	Q10 factor for nitrification reaction.
$Q_{10_{N3}}$	2.37	Q10 factor for denitrification reaction.
h_{N4}^o, h_{N6}^o	10.0	Half saturation oxygen concentration for chemical processes ($mmolO_2\ m^{-3}$)
Λ_{N3}^{denit}	0.35	Specific denitrification rate (d^{-1})
$\mathcal{M}_o^*$	1.00	Reference anoxic mineralization rate ($mmolO_2\ m^{-3}\ d^{-1}$)
Λ_{N6}^{reox}	0.05	Specific reoxidation rate of reduction equivalents (d^{-1})
$Q_{10_{N5}}$	1.49	Q10 factor for dissolution of biogenic silica
$\Lambda_{R^{(6)}}^s$	0.1	Specific dissolution rate of biogenic silica (d^{-1})
v_{R6}^{sed}	1.5	Settling velocity for detritus ($m\ d^{-1}$)

Table 9. Stoichiometric coefficients and other parameters involving pelagic components.

Symbol	$H^{(1)}$	$H^{(2)}$	**Description**
h_H^m	0.001	0.01	Activity layer thicknesswher mortality rate is halved (m)
$n_H^{\max}$	0.02	0.02	Maximum nutrient quota (mmolN mgC^{-1})
$p_H^{\max}$	0.001	0.001	Maximum nutrient quota (mmolP mgC^{-1})
Q_{10_H}	2	2	Characteristic Q10 coefficient
r_H^{fast},	0.01	0.01	Specific fractional uptake rate of detritus (d^{-1})
r_H^{slow}	0.002	0.002	Specific (slow) uptake rate (d^{-1})
r_{0_H}	8.38	8.38	Specific potential growth rate (d^{-1})
ε_H	0.1	0.1	Fraction of uptake excreted as Q1 (-)
r_H^{Q1}	0.05	0.05	Specific uptakte rate of DOC (d^{-1})
γ_H	0.3	0.6	Fraction of uptake respired (-)
b_H	0.02	0.02	Specific rest respiration (d^{-1})
h_H^n	0.00	0.00	Half saturation constant for nutrient uptake (mmolN m^{-2})
h_H^p	0.00	0.00	Half saturation constant for nutrient uptake (mmolP m^{-2})
ζ_H	2	2	Preference factor for nutrient content in detritus (-)
d_{0_H}	0.05	0.05	Specific mortality rate (d^{-1})

Table 10. Parameter values and descriptions for aerobic and anaerobic bacteria.

Symbol	$Y^{(1)}$	$Y^{(2)}$	$Y^{(3)}$	$Y^{(4)}$	$Y^{(5)}$	**Description**
$Q10_Y$	2	2	2	2	2	Characteristic Q10 coefficient
r_{0_Y}	0.03	0.11	0.13	0.4	0.08	Potential specific growth rate (d^{-1})
h_Y^F	2000	2000	300.00	2000	2000	Michaelis-Menten constant for food limitation (mgC m^{-2})
μ_Y	50	125	50.0	50	100	Feeding threshold (mg C m^{-3})
α_Y	0.3	0.35	0.25	0.25	0.3	Excreted fraction of uptake (-)
γ_Y	0.25	0.35	0.15	0.45	0.3	Respired fraction of uptake (-)
ξ_Y	0.80	0.80	0.8	0.80	0.80	Selectivity for nutrients (-)
b_Y	0.003	0.003	0.003	0.01	0.003	Basal specific respiration rate (d^{-1})
d_{0_Z}	0	0	0.0025	0.01	0	Specific mortality rate (d^{-1})
D^*	0	0.01	-	0.01	0.01	Threshold depth of oxic layer, limiting uptake (m)
$\alpha_{Y,Q6}$	0	0.8	0.70	0.4	0	Excreted fraction of detritus uptake (-)
$m_Y^{\max}$	0	0.2	0.001	0.03	0	Preferred depth in sediments (m)
$m_Y^{\min}$	0	0	0	0	0	Minimum depth in sediments (m)
$n_H^{\max}$	0.01	0.01	0.01	0.01	0.01	Maximum nutrient quota (mmolN mgC^{-1})
$p_H^{\max}$	7.9 10^{-4}	7.9 10^{-4}	7.9 10^{-4}	7.9 10^{-4}	7.9 10^{-4}	Maximum nutrient quota (mmolP mgC^{-1})
d_w	-	-	3.00	-	-	Concentration factor and available water layer for $Y^{(3)}$ (m)

Table 11. Parameter values and descriptions for benthic organisms.

Symbol	**Value**	**Description**
δ^{tur}	0.02	Depth scale of bioturbation process (m)
τ_0^{tur}	2.0 10^{-6}	Physical part of the turbation factor (m^2 d^{-1})
f_0^{tur}	10.0	Maximum enhancement factor of detritus penetration by bioturbation (-)
$\psi_{Y^{(1)}}^{tur}$	1.00	$Y^{(1)}$ contribution to bioturbation (-)
h^{tur}	10000	Half-saturation biomass density for bioturbation (mg C m^{-2})
$\psi_{Y^{(4)}}^{irr}$	0.10	$Y^{(4)}$contribution to bioirrigation (-)
f_0^{irrr}	10.0	Maximum enhancement factor of diffusion by bioirrigation (-)
h_Y^{irr}	10000	Half-saturation biomass density for bioirrigation (mg C m^{-2})

Table 12. Bioturbation and bioirrigation parameters.

Symbol	Value	Description
p_A	3.00	Adsorption distribution coefficient for ammonium (-)
Q_{10_A}	2.00	Q10 factor for ammonium
D_{0_A}	$1.022\ 10^{-4}$	Constant molecular diffusion at 10^o C for ammonium ($m^2\ d^{-1}$)
k_{0_A}	3.00	Specific nitrification rate (d^{-1})
h_A^o	10	Michaelis-Menten constant for O_2 in pore-waters for nitrification reaction (mmol O_2 m^{-3})
p_N	0	Adsorption distribution coefficient for nitrate (-)
Q_{10_N}	2	Q10 factor for nitrate
D_{0_N}	$0.97\ 10^{-4}$	Constant molecular diffusion at 10^o C for nitrate ($m^2\ d^{-1}$)
d_{0_N}	0.35	Specific denitrification rate (d^{-1})
$\mathcal{M}_o^*$	0.1	Reference anoxic mineralisation (mmol O_2 m^{-3} d^{-1}):
p_S	0	Adsorption distribution coefficient for silicate(-)
Q_{10_S}	2	Q10 factor for silicate
D_{0_S}	$0.207\ 10^{-4}$	Constant molecular diffusion at 10^o C for silicate ($m^2\ d^{-1}$)
s_S	0.08	Specific dissolution rate of biogenic silica (d^{-1})
p_Q	0	Adsorption distribution coefficient for DOM (-)
D_{10_Q}	$0.207\ 10^{-4}$	Constant molecular diffusion at 10^o C for DOM ($m^2\ d^{-1}$)
p_R	0	Adsorption distribution coefficient for reduction equivalents (-)
D_{0_R}	$0.207\ 10^{-4}$	Constant molecular diffusion at 10^o C for reduction equivalents (HS^-, $m^2\ d^{-1}$)
σ_R	0.05	Specific reoxidation rate of reduction equivalents (d^{-1})
p_P^{ae}	400	Adsorption coeff. for phosphates in oxic sediments (-)
p_P^{an}	2	Adsorption coeff. for phosphates in anoxic sediments (-)
D_{0_P}	$0.383\ 10^{-4}$	Constant molecular diffusion at 10^o C for phosphate ($m^2\ d^{-1}$)
θ	1.5	Temperature enhancement of oxygen diffusion (-)
h_{D1}, h_{D2}	0.05	Half-value for the layer shifting (m)
σ	2	Exponent for the damping function in layer shifting (-)
w_{bur}	0.5	Burial velocity ($m\ d^{-1}$)
ϕ	0.4	Sediment porosity (-)

Table 13. Sediment dynamics.

Figure Captions

Figure 1. Observed and simulated temperature evolution at the surface (a), in the intermediate layer (b, 40m depth) and at the bottom (c). Bottom panel also shows the results of a sensitivity experiments with a relaxation time scale (RTS) to the climatological salinity profile of 720d.

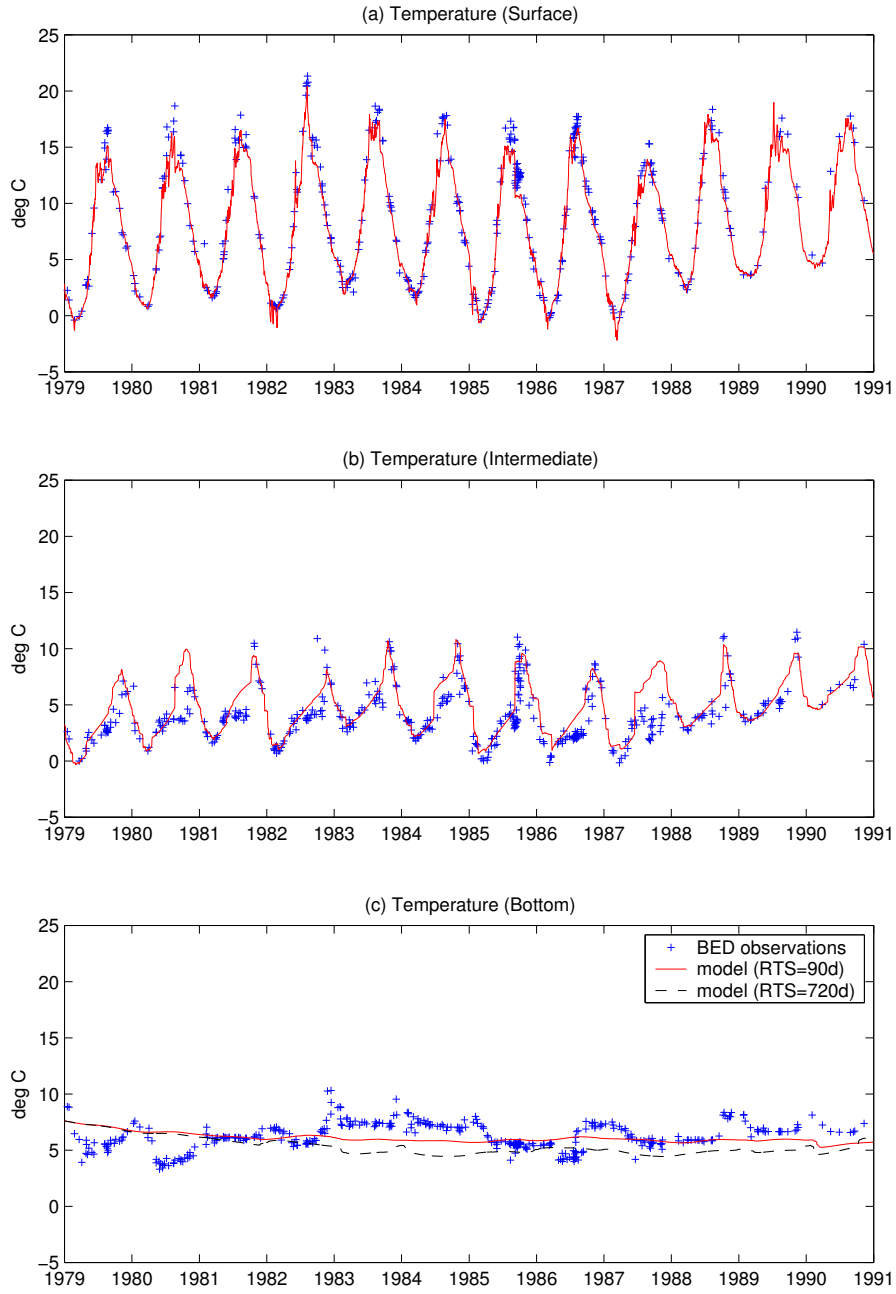
Figure 2. Observed and simulated oxygen saturation at the surface (a) and in the intermediate layer (b). Panel (c) shows the evolution of the dissolved concentration for the simulation with a relaxation time scale for salinity RTS = 90d (continuous line) and RTS = 720d (dashed line). Negative values are indicative of the presence of HS^- ions.

Figure 3. Observed and simulated nitrate concentration at the surface (a) and in the intermediate (b) and bottom (c) layers. The continuous line is the simulation with the relaxation time scale for salinity RTS = 90d and the dashed line has RTS = 720d.

Figure 4. Observed and simulated phosphate concentration at the surface (a) and in the intermediate (b) and bottom (c) layers. The continuous line is the simulation with RTS = 90d and the dashed line has RTS = 720d (only shown for the bottom layer).

Figure 5. Observed and simulated silicate concentration at the surface (a) and in the intermediate (b) and bottom (c) layers.

Figures



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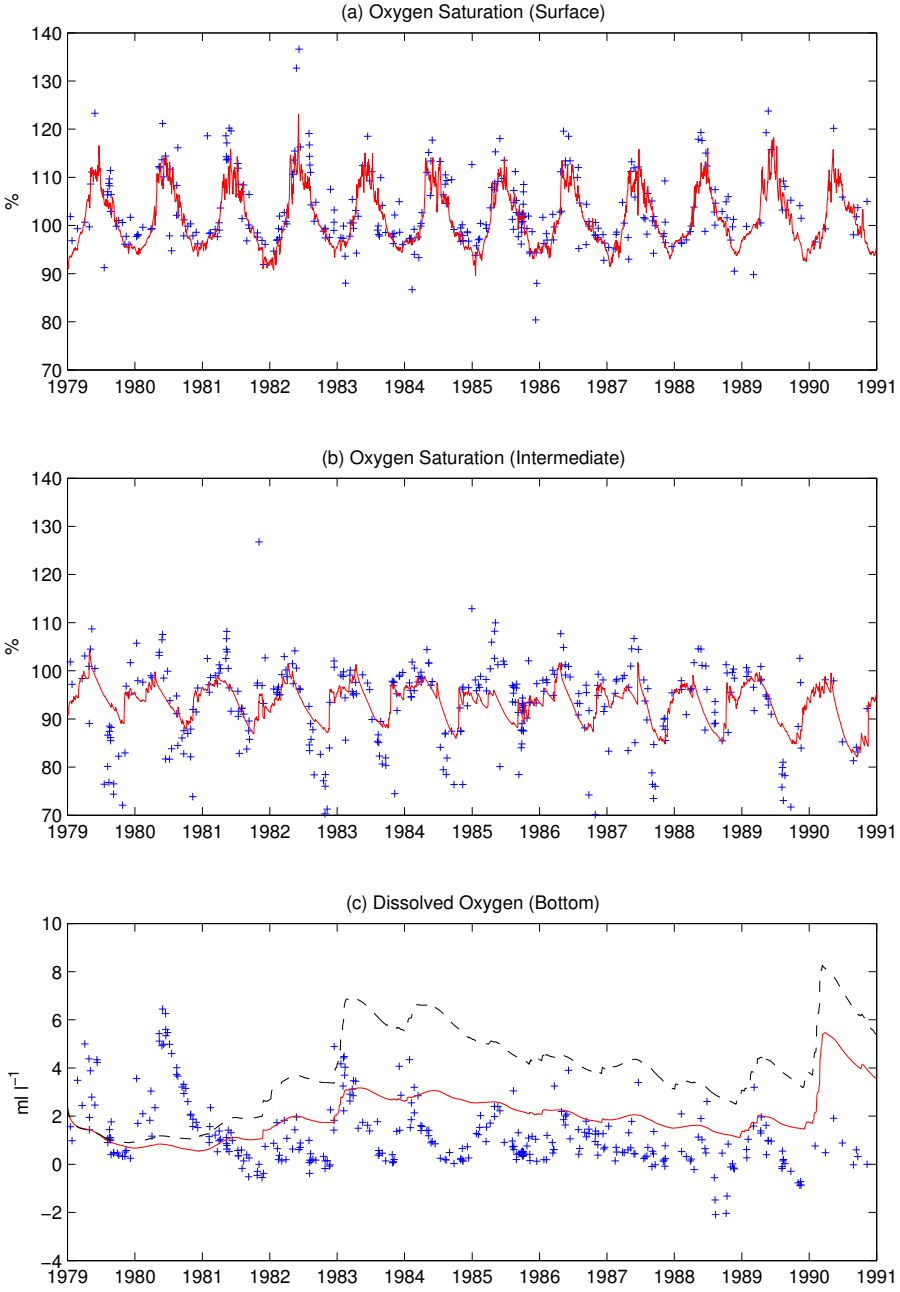

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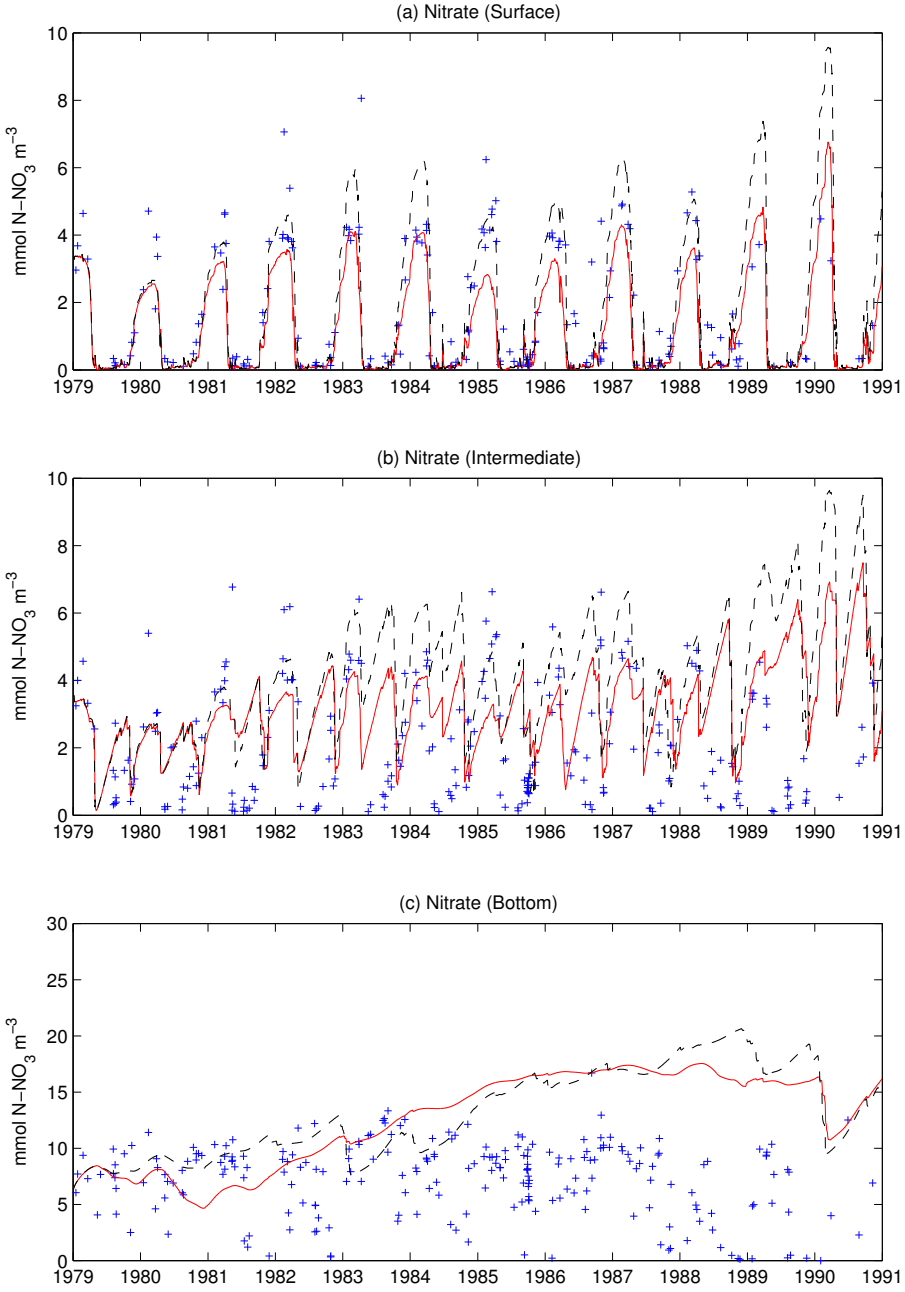

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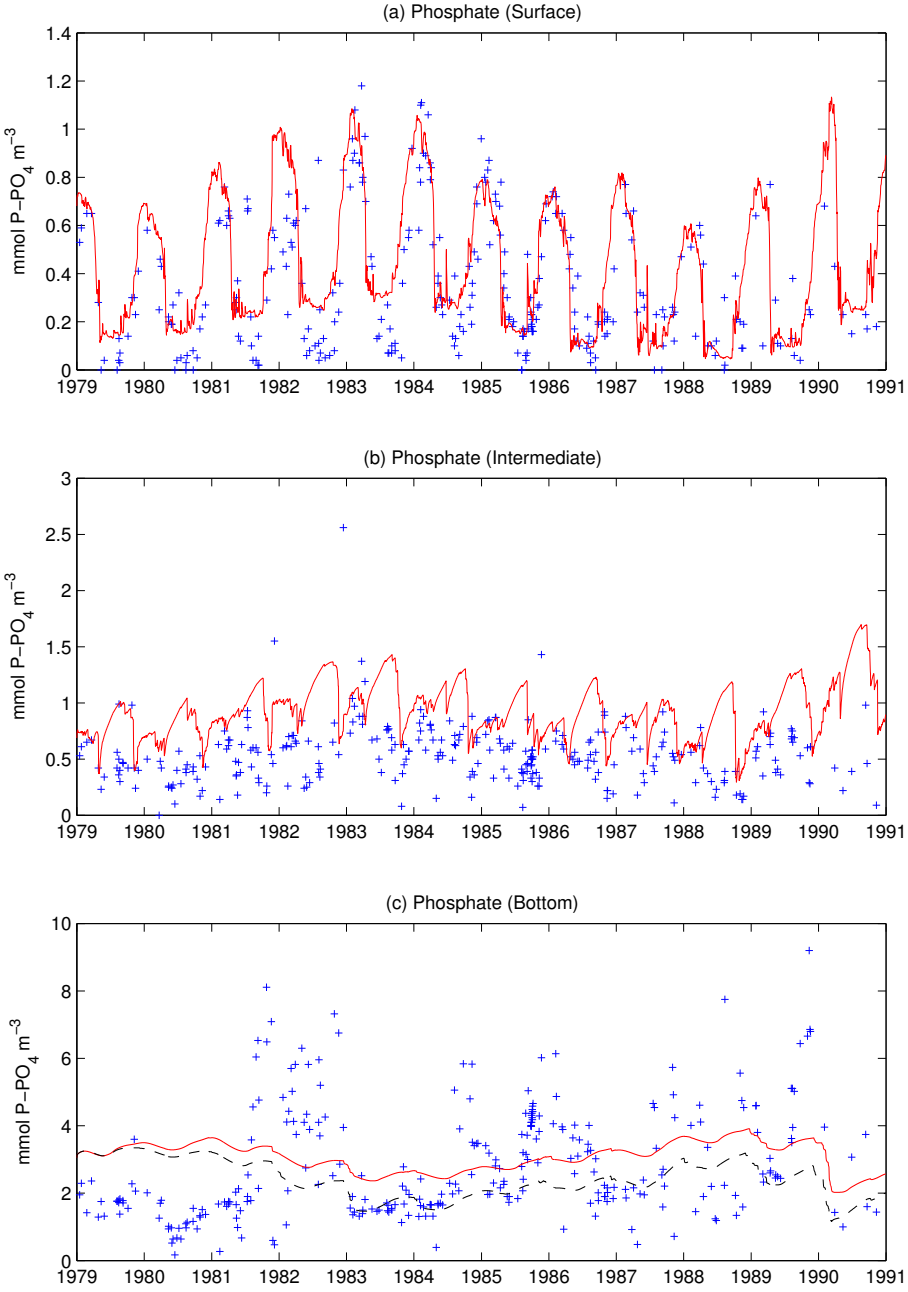

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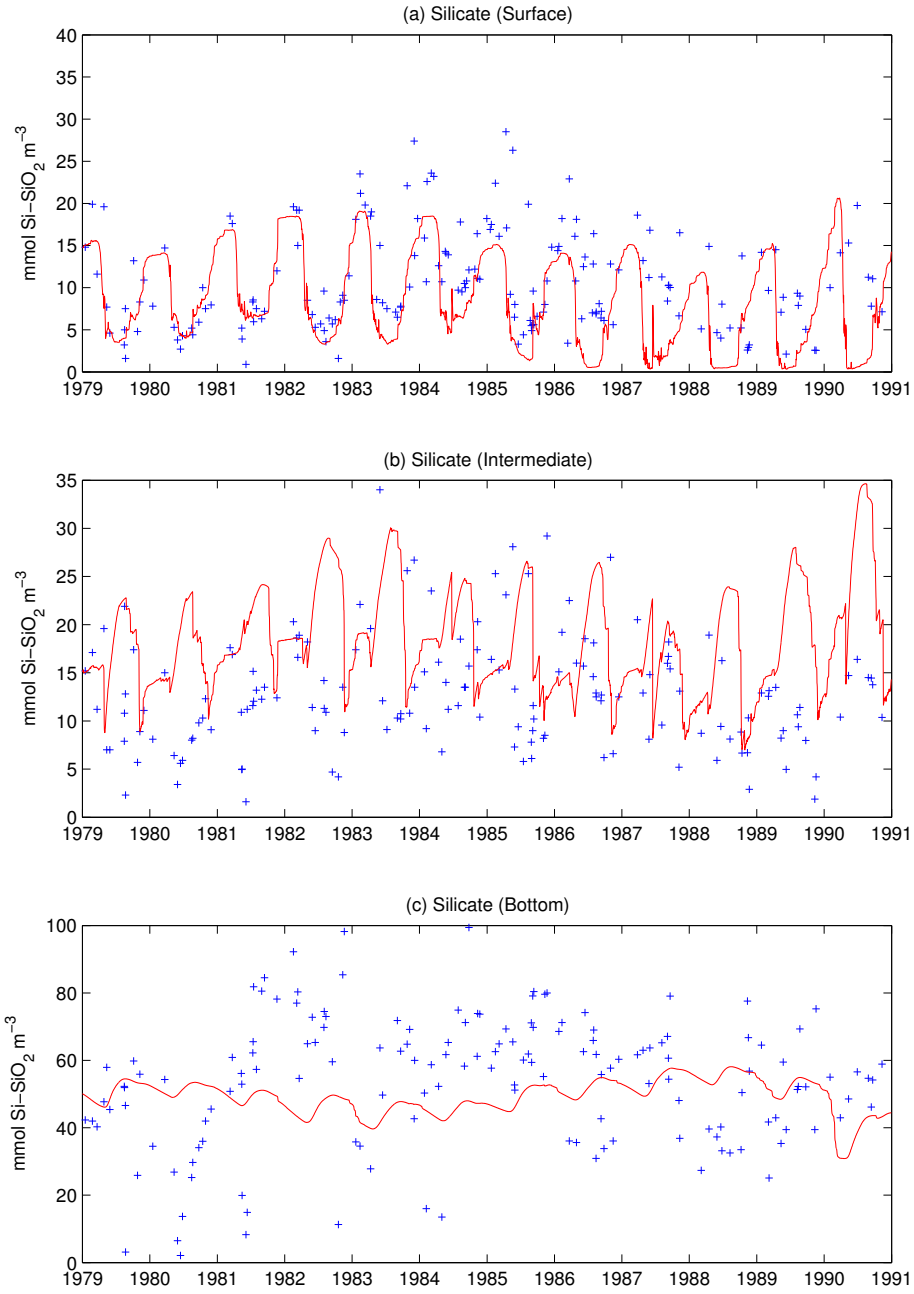

Figure 5. Observed and simulated silicate concentration at the surface (a) and in the intermediate (b) and bottom (c) layers.