Tables

Table 1 List of model parameters

Parameters	Symbol	Value	Unit	Source
For underwater light dissipation				
Light dissipation coefficient of sea water	α_1	0.04	m^{-1}	(1)
Self shading coefficient by phytoplankton	α_2	0.04	l μmolN^{-1} m^{-1}	(1)
For non-diatom small phytoplankton (PS)				
Initial slope of photosynthesis-irradiance curve	α_{PS}	0.013	W^{-1} m^2 day^{-1}	(5)
Photoinhibition index	β_{PS}	1.4×10^{-15}	W^{-1} m^2 day^{-1}	(5)
Potential maximum light-saturated photosynthetic rate	$P_{S,PS}$	0.4	day^{-1}	(5)
Potential maximum growth rate at 0℃	$V_{0,PS}$	Opt.	day^{-1}	(5)
Potential maximum affinity for NO_3	$A_{0,NO_3,PS}$	Opt.	l μmolN^{-1} s^{-1}	(5)
Temperature coefficient for photosynthetic rate	k_{PS}	0.0693	$℃^{-1}$	(1)
Mortality rate at 0℃	M_{PS0}	0.0585	l μmolN^{-1} day^{-1}	(1)
Temperature coefficient for mortality	k_{MS}	0.0693	$℃^{-1}$	(1)
Respiration rate at 0℃	R_{PS0}	0.03	day^{-1}	(1)
Temperature coefficient for respiration	k_{RS}	0.0519	$℃^{-1}$	(1)
Ratio of extracellular excretion to photosynthesis	γ_S	0.135	(Nodim)	(1)
For diatoms (PL)				
Initial slope of photosynthesis-irradiance curve	α_{PL}	0.045	W^{-1} m^2 day^{-1}	(5)
Photoinhibition index	β_{PL}	1.4×10^{-15}	W^{-1} m^2 day^{-1}	(5)
Potential maximum light-saturated photosynthetic rate	$P_{S,PL}$	1.4	day^{-1}	(5)
Potential maximum growth rate at 0℃	$V_{0,PL}$	Opt.	day^{-1}	(5)
Potential maximum affinity for NO_3	$A_{0,NO_3,PL}$	Opt.	l μmolN^{-1} s^{-1}	(5)
Temperature coefficient for photosynthetic rate	k_{PL}	0.0693	$℃^{-1}$	(1)
Mortality rate at 0℃	M_{PL0}	0.029	l μmolN^{-1} day^{-1}	(1)
Temperature coefficient for mortality	k_{ML}	0.0693	$℃^{-1}$	(1)
Respiration rate at 0℃	R_{PL0}	0.03	day^{-1}	(1)
Temperature coefficient for respiration	k_{RL}	0.0519	$℃^{-1}$	(1)
Ratio of extracellular excretion to photosynthesis	γ_L	0.135	(Nodim)	(1)
For microzooplankton (ZS)				
Maximum rate of grazing PS at 0℃	G_{RmaxS}	0.4	day^{-1}	(1)
Temperature coefficient for grazing	k_{GS}	0.693	$℃^{-1}$	(1)
Ivlev constant	λ_S	1.4	l μmolN^{-1}	(1)
Threshold value for grazing PS	PS^*_{ZS}	0.043	μmolN l^{-1}	(1)
Assimilation efficiency	α_{ZS}	0.7	(Nodim)	(1)
Growth efficiency	β_{ZS}	0.3	(Nodim)	(1)
Mortality rate at 0℃	M_{ZS0}	0.0585	l μmolN^{-1} day^{-1}	(1)
Temperature coefficient for mortality	k_{MZS}		$℃^{-1}$	(1)

Table 1 (continued)

Parameters	Symbol	Value	Unit	Source
For mesozooplankton (ZL)				
Maximum rate of grazing PS at 0℃	$G_{\mathrm{RmaxL,PS}}$	0.1	$\mathrm{day^{-1}}$	(1)
Maximum rate of grazing PL at 0℃	$G_{\mathrm{RmaxL,PL}}$	0.4	$\mathrm{day^{-1}}$	(1)
Maximum predation rate of ZS at 0℃	$G_{\mathrm{RmaxL,ZS}}$	0.4	$\mathrm{day^{-1}}$	(1)
Temperature coefficient for grazing/predation	k_{GL}	0.0693	$\mathrm{℃^{-1}}$	(1)
Ivlev constant	λ_{L}	1.4	$\mathrm{l\ \mu molN^{-1}}$	(1)
Threshold value for grazing PS	$\mathrm{PS}^{*}_{\mathrm{ZL}}$	0.04	$\mathrm{\mu molN\ l^{-1}}$	(1)
Threshold value for grazing PL	$\mathrm{PL}^{*}_{\mathrm{ZL}}$	0.04	$\mathrm{\mu molN\ l^{-1}}$	(1)
Threshold value for predation of ZS	$\mathrm{ZS}^{*}_{\mathrm{ZL}}$	0.04	$\mathrm{\mu molN\ l^{-1}}$	(1)
Assimilation efficiency	α_{ZL}	0.7	(Nodim)	(1)
Growth efficiency	β_{ZL}	0.3	(Nodim)	(1)
Mortality rate at 0℃	M_{ZL0}	0.0585	$\mathrm{l\ \mu molN^{-1}\ day^{-1}}$	(1)
Temperature coefficient for mortality	k_{MZL}	0.0693	$\mathrm{℃^{-1}}$	(1)
For predatory zooplankton (ZP)				
Maximum rate of grazing PL at 0℃	$G_{\mathrm{RmaxP,PL}}$	0.2	$\mathrm{day^{-1}}$	(1)
Maximum predation rate of ZS at 0℃	$G_{\mathrm{RmaxP,ZS}}$	0.2	$\mathrm{day^{-1}}$	(1)
Maximum predation rate of ZL at 0℃	$G_{\mathrm{RmaxP,ZL}}$	0.4	$\mathrm{day^{-1}}$	(2)
Temperature coefficient for grazing/predation	k_{GP}	0.0693	$\mathrm{℃^{-1}}$	(1)
Ivlev constant	λ_{P}	1.4	$\mathrm{l\ \mu molN^{-1}}$	(1)
Threshold value for grazing PL	$\mathrm{PL}^{*}_{\mathrm{ZP}}$	0.04	$\mathrm{\mu molN\ l^{-1}}$	(1)
Threshold value for predation of ZS	$\mathrm{ZS}^{*}_{\mathrm{ZP}}$	0.04	$\mathrm{\mu molN\ l^{-1}}$	(1)
Threshold value for predation of ZL	$\mathrm{ZL}^{*}_{\mathrm{ZP}}$	0.04	$\mathrm{\mu molN\ l^{-1}}$	(1)
Preference coefficient for PL	Ψ_{PL}	4.605	$\mathrm{l\ \mu molN^{-1}}$	(1)
Preference coefficient for ZS	Ψ_{ZS}	3.01	$\mathrm{l\ \mu molN^{-1}}$	(1)
Assimilation efficiency	α_{ZP}	0.7	(Nodim)	(1)
Growth efficiency	β_{ZP}	0.3	(Nodim)	(1)
Mortality rate at at 0℃	M_{ZP0}	0.0585	$\mathrm{l\ \mu molN^{-1}\ day^{-1}}$	(1)
Temperature coefficient for mortality	k_{MZP}	0.0693	$\mathrm{℃^{-1}}$	(1)
For nitrification				
Nitrification rate at at 0℃	V_{Nit0}	0.03	$\mathrm{day^{-1}}$	(1)
Temperature coefficient for nitrification	k_{Nit}	0.0693	$\mathrm{℃^{-1}}$	(1)
For remineralization and decomposition				
$\mathrm{PON_S}$ sinking velocity	$w^{\mathrm{PON_S}}$	3.0	$\mathrm{m\ day^{-1}}$	(3)
$\mathrm{PON_L}$ minimum sinking velocity	$w^{\mathrm{PON_L}}_{\mathrm{min}}$	Opt.	$\mathrm{m\ day^{-1}}$	(5)
$\mathrm{PON_L}$ maximum sinking velocity	$w^{\mathrm{PON_L}}_{\mathrm{max}}$	Opt.	$\mathrm{m\ day^{-1}}$	(5)
Decomposition rate of $\mathrm{PON_S}$ to DON at 0℃	V_{PD0S}	Opt.	$\mathrm{day^{-1}}$	(5)
Temperature coefficient for $\mathrm{PON_S}$ decomposition to DON	k_{PDS}	0.0693	$\mathrm{℃^{-1}}$	(1)
Remineralization rate of $\mathrm{PON_S}$ at 0℃	V_{PA0S}	Opt.	$\mathrm{day^{-1}}$	(5)
Temperature coefficient for $\mathrm{PON_S}$ remineralization	k_{PAS}	0.0693	$\mathrm{℃^{-1}}$	(1)
Decomposition rate of $\mathrm{PON_L}$ to DON at 0℃	V_{PD0L}	Opt.	$\mathrm{day^{-1}}$	(5)
Temperature coefficient for $\mathrm{PON_L}$ decomposition to DON	k_{PDL}	0.0693	$\mathrm{℃^{-1}}$	(1)
Remineralization rate of $\mathrm{PON_L}$ at 0℃	V_{PA0L}	Opt.	$\mathrm{day^{-1}}$	(5)
Temperature coefficient for $\mathrm{PON_L}$ remineralization	k_{PAL}	0.0693	$\mathrm{℃^{-1}}$	(1)
Remineralization rate of DON at 0℃	V_{DA0}	Opt.	$\mathrm{day^{-1}}$	(5)
Temperature coefficient for DON decomposition to $\mathrm{NH_4}$	k_{DA}	0.0693	$\mathrm{℃^{-1}}$	(1)

Table 1 (continued)

Parameters	Symbol	Value	Unit	Source
For Opal				
Opal minimum sinking velocity	$w_{\min}^{\mathrm{Opal}}$	Opt.	m day^{-1}	(5)
Opal maximum sinking velocity	$w_{\max}^{\mathrm{Opal}}$	Opt.	m day^{-1}	(5)
Dissolution rate of Opal at 0℃	V_{Opal}	Opt.	day^{-1}	(5)
Temperature coefficient for Opal decomposition	k_{Opal}	0.0693	℃$^{-1}$	(1)
For stoichiometric ratio				
Stoichiometry of carbon to nitrogen	R_{CN}	6.625	molC/molN	(1)
Stoichiometry of iron to nitrogen	R_{FeN}	Opt.	molFe/molN	(5)
PL stoichiometry of silicate to nitrogenous nutrients uptake in iron-replete condition	R_{SiNH}	Opt.	molSi/molN	(5)
PL stoichiometry of silicate to nitrogenous nutrients uptake in iron-deficient condition	R_{SiNL}	Opt.	molSi/molN	(5)
Threshold dissolved iron value for shift in R_{SiNH} to R_{SiNL}	$\mathrm{Fe}_{\mathrm{SiN}}^{*}$	Opt.	nmol l^{-1}	(5)
For aggregation				
Aggregation rates for DON to $\mathrm{PON_S}$ by shear	$\phi_1^{\mathrm{DON}}, \phi_2^{\mathrm{DON}}$	530, 4624	l μmolN^{-1}	(3)
Aggregation rate for DON to $\mathrm{PON_L}$ by shear	ϕ_3^{DON}	69562	l μmolN^{-1}	(3)
Aggregation rates for $\mathrm{PON_S}$ to $\mathrm{PON_L}$ by shear	$\phi_1^{\mathrm{PON_S}}, \phi_2^{\mathrm{PON_S}}$	6228, 69828	l μmolN^{-1}	(3)
Aggregation rates for $\mathrm{PON_S}$ to $\mathrm{PON_L}$ by differential settlement	$\phi_3^{\mathrm{PON_S}}, \phi_4^{\mathrm{PON_S}}$	0, 4.37	l μmolN^{-1} day^{-1}	(3)
For iron				
Iron atomic weight	$A_{w,\mathrm{Fe}}$	55.847	g mol^{-1}	-
Iron content in dust	C_{iron}	3.5	%	(6)
Solubility of iron in dust at the sea surface layer	α	Opt.	%	(5)
Fraction of $\mathrm{Fe_p}$ not removed to sediment	$f_{\mathrm{Fe_p}}$	Opt.	(Nodim)	(5)
Fraction of hard dust	f_{hard}	0.97	(Nodim)	(4)
Dissolution length scale for soft dust	$\delta_{\mathrm{soft\_dust}}$	600	m	(4)
Dissolution length scale for hard dust	$\delta_{\mathrm{hard\_dust}}$	40000	m	(4)
Desorption rate at 30℃	$\lambda_{\mathrm{desorption}}$	Opt.	day^{-1}	(5)
Slope of Arrhenius relation	A_E	4000	K	(4)
Reference temperature for A_E relation	T_{ref}	303.15	K	(5)
Base scavenging coefficient	λ_{scav}	Opt.	cm^2 ng^{-1}	(5)
Total ligand concentration	C_{ligand}	0.6	nmol l^{-1}	(4)
Proportionality constant for scavenging of $\mathrm{Fe_d}$	γ_{high}	Opt.	l nmol^{-1} day^{-1}	(5)
Particulate iron sinking velocity	w_{Fep}	Opt.	m day^{-1}	(5)

Sources noted here are: (1) Yamanaka et al. (2004), (2) Fujii et al. (2007), (3) Aumont and Bopp (2006), (4) Moore and Braucher (2008), (5) This study. "Opt." means that the parameter was optimized in this study, (6) Zhu et al. (1997), and "Nodim" means non-dimensional.

Table 2 Setting of model parameters for optimization and optimal estimates. Each parameter is represented by a discrete binary string of a certain length. One individual combines all strings of all parameters (one parameter set). The number of possibilities expresses the number of binary digits that describes the number of possible values within the prescribed upper and lower bounds for parameter variations.

Parameter	Lower/Upper bounds	Increment	# of possibilities	Optimal estimates
$V_{0,PS}$	0.1/3.2	0.1	32	0.6 ± 0.3
$A_{0,NO_3,PS}$	1/512	1	512	282± 112
$V_{0,PL}$	0.1/3.2	0.1	32	0.8 ± 0.5
$A_{0,NO_3,PL}$	1/512	1	512	252 ± 115
$w_{min}^{PON_L}$, w_{min}^{Opal}	3/48	3.0	16	6 ± 3
$w_{max}^{PON_L}$, w_{max}^{Opal}	48/198	10.0	16	198 ± 69
V_{PD0S}, V_{PA0S}, V_{PD0L}, V_{PA0L}	0.01/0.32	0.01	32	0.08 ± 0.06
V_{DA0}	0.01/0.32	0.01	32	0.15 ± 0.14
V_{Opal}	0.01/0.32	0.01	32	0.16 ± 0.12
R_{FeN}	$1.0\times10^{-5}/7.3\times10^{-5}$	0.1×10^{-5}	64	$1.7\times10^{-5} \pm 2.6\times10^{-5}$
R_{SiNL}	1.7/4.8	0.1	32	3.6 ± 0.9
R_{SiNH}	1.0/1.7	0.1	8	1.0 ± 0.0
Fe_{SiN}^{*}	0.01/0.63	0.02	32	0.03 ± 0.35
α	1.0/4.5	0.5	8	4.0 ± 1.6
$\lambda_{desorption}$	0.001/0.128	0.001	128	0.003 ± 0.002
λ_{scav}	0.001/0.256	0.001	256	0.185 ± 0.084
γ_{high}	0.0001/0.0256	0.0002	128	0.0044 ± 0.0044
w_{Fep}	0.001/0.128	0.001	128	0.001 ± 0.006
f_{Fe_p}	0.3/1.0	0.1	8	1.0 ± 0.0

Table 3 Normalized parameter sensitivity of annually averaged Fe_d and Fe_p plus Fe_b within the mixed layer for each parameter. This index measures the fractional change in the statistic for a fractional change in the parameter (See text).

Parameter	Parameter range	Standard value	Normalized sensitivity	
			Fe_d in the ML	Fe_p+Fe_b in the ML
$V_{0,PS}$	0.1/3.2	0.6	0.01, -0.15	0.00, 0.01
$A_{0,NO_3,PS}$	1/512	282	-0.01, -0.03	0.00, 0.00
$V_{0,PL}$	0.1/3.2	0.8	-0.64, -0.24	0.02, 0.01
$A_{0,NO_3,PL}$	1/512	252	-0.06,-0.05	0.00, 0.00
$w_{min}^{PON_L}$, w_{min}^{Opal}	3/48	6	-0.24, -0.10	0.01, 0.00
$w_{max}^{PON_L}$, w_{max}^{Opal}	48/198	198	-0.05, -0.02	0.00, 0.00
V_{PD0S}, V_{PA0S}, V_{PD0L}, V_{PA0L}	0.01/0.32	0.08	0.19, 0.30	0.00, -0.01
V_{DA0}	0.01/0.32	0.15	-0.01, 0.00	0.00, 0.00
V_{Opal}	0.01/0.32	0.16	-0.04, 0.00	0.00, 0.00
R_{FeN}	1.0×10^{-5}/7.3×10^{-5}	1.7×10^{-5}	-0.12, -0.14	-0.02, -0.01
R_{SiNL}	1.0/4.1	3.6	0.00, -0.01	0.00, 0.00
R_{SiNH}	1.0/1.7	1.0	0.00, 0.03	0.00, 0.00
Fe_{SiN}^{*}	0.01/0.63	0.03	0.00, 0.00	0.00, 0.00
α	1.0/4.5	4.0	0.10, 0.10	0.02, 0.02
$\lambda_{desorption}$	0.001/0.128	0.003	0.00, 0.00	0.00, 0.00
λ_{scav}	0.001/0.256	0.185	0.01, -0.01	0.00, 0.00
γ_{high}	0.0001/0.0256	0.0044	0.00, 0.00	0.00, 0.00
w_{Fep}	0.001/0.128	0.001	0.00, 0.00	0.00, 0.00
f_{Fe_p}	0.3/1.0	1.0	-0.02	-0.03
C_{ligand}	0.3/1.2	0.6	-0.04,0.02	0.00,0.00