Chapter 1

Description of Diat-HadOCC

As shown in Table 1.1 the Diat-HadOCC model has thirteen biogeochemical state variables, representing three dissolved nutrients, two phytoplankton (plus diatom silicate), one zooplankton, three detritus compartments, dissolved oxygen, dissolved inorganic carbon and alkalinity.

All the state variables are advected by the ocean currents and mixed by physical processes such as the isopycnal diffusion, diapycnal diffusion and convective mixing. The biogeochemical processes that affect the biogeochemical state variables are shown below in basic form, with greater detail on the processes given in subsequent paragraphs. In the following equations all flows are body (point) processes except those in [square brackets] which are biogeochemical flows across layer interfaces.

$$
\begin{aligned}
\frac{d\,DIN}{d\,t} &= ph_{resp} + dm_{resp} + ph_{mort} \cdot f_{nmp} + dm_{mort} \cdot f_{nmp} \\
&\quad + grz_{DIN} + zp_{lin} + zp_{mort} \cdot f_{zmrt} + dtn_{remin} \\
&\quad + dtn_{bedrmn} - ph_{PP} - dm_{PP}
\end{aligned}
\tag{1.1}
$$

$$
\frac{d\,Si}{d\,t} = dtsi_{remin} + dtsi_{bedrmn} - dm_{PP} \cdot R^{Dm}_{si2n} \tag{1.2}
$$

$$
\begin{aligned}
\frac{d\,FeT}{d\,t} &= (\, ph_{resp} \cdot R^{Ph}_{c2n} + dm_{resp} \cdot R^{Dm}_{c2n} + ph_{mort} \cdot R^{Ph}_{c2n} \\
&\quad + dm_{mort} \cdot R^{Dm}_{c2n} + grz_{DIC} + grz_{DtC} - dtc_{grz} \\
&\quad + zp_{lin} \cdot R^{Zp}_{c2n} + zp_{mort} \cdot R^{Zp}_{c2n} - ph_{PP} \cdot R^{Ph}_{c2n} \\
&\quad - dm_{PP} \cdot R^{Dm}_{c2n} \,) \cdot R^{eco}_{fe2c} + [\, fe_{dust} \,] - fe_{adsorp}
\end{aligned}
\tag{1.3}
$$

$$
\frac{d\,Ph}{d\,t} = ph_{PP} - ph_{resp} - ph_{mort} - ph_{grz} \tag{1.4}
$$

$$
\frac{d\,Dm}{d\,t} = dm_{PP} - dm_{resp} - dm_{mort} - dm_{grz} - [\, dm_{sink} \,] \tag{1.5}
$$

$$
\frac{d\,DmSi}{d\,t} = dm_{PP} \cdot R^{Dm}_{si2n} - dmsi_{mort} - dmsi_{grz} - [\, dmsi_{sink} \,] \tag{1.6}
$$

Table 1.1: Diat-HadOCC model state variables

Symbol	Description	Units
DIN	dissolved inorganic nitrogen	mmol-N / m^3
Si	silicic acid	mmol-Si / m^3
FeT	total dissolved iron	umol-Fe / m^3
Ph	non-diatom (nd-) phytoplankton	mmol-N / m^3
Dm	diatom phytoplankton	mmol-N / m^3
$DmSi$	diatom silicate	mmol-Si / m^3
Zp	zooplankton	mmol-N / m^3
DtN	detrital nitrogen	mmol-N / m^3
$DtSi$	detrital silicate	mmol-Si / m^3
DtC	detrital carbon	mmol-C / m^3
DIC	dissolved inorganic carbon	mmol-C / m^3
$TAlk$	total alkalinity	meq / m^3
Oxy	dissolved oxygen	mmol-O2 / m^3

$$\frac{d\,Zp}{d\,t} = grz_{Zp} \;-\; zp_{lin} \;-\; zp_{mort} \tag{1.7}$$

$$\begin{aligned}\frac{d\,DtN}{d\,t} &= ph_{mort}\cdot(1-f_{nmp}) \;+\; dm_{mort}\cdot(1-f_{nmp}) \;+\; grz_{DtN} \\ &\quad + zp_{mort}\cdot(1-f_{zmrt}) \;+\; dm_{bedmrt} \;-\; dtn_{grz} \\ &\quad - dtn_{remin} \;-\; [\,dtn_{sink}\,]\end{aligned} \tag{1.8}$$

$$\begin{aligned}\frac{d\,DtSi}{d\,t} &= dmsi_{mort} \;+\; grz_{dtsi} \;+\; dmsi_{bedmrt} \;-\; dtsi_{remin} \\ &\quad - [\,dtsi_{sink}\,]\end{aligned} \tag{1.9}$$

$$\begin{aligned}\frac{d\,DtC}{d\,t} &= ph_{mort}\cdot(1-f_{nmp})\cdot R^{Ph}_{c2n} \;+\; dm_{mort}\cdot(1-f_{nmp})\cdot R^{Dm}_{c2n} \\ &\quad + grz_{DtC} \;+\; zp_{mort}\cdot(1-f_{zmrt})\cdot R^{Zp}_{c2n} \\ &\quad + dm_{bedmrt}\cdot R^{Dm}_{c2n} \;-\; dtc_{grz} \;-\; dtc_{remin} \;-\; [\,dtc_{sink}\,]\end{aligned} \tag{1.10}$$

$$\begin{aligned}\frac{d\,DIC}{d\,t} &= ph_{resp}\cdot R^{Ph}_{c2n} \;+\; dm_{resp}\cdot R^{Dm}_{c2n} \;+\; ph_{mort}\cdot f_{nmp}\cdot R^{Ph}_{c2n} \\ &\quad + dm_{mort}\cdot f_{nmp}\cdot R^{Dm}_{c2n} \;+\; grz_{DIC} \;+\; zp_{lin}\cdot R^{Zp}_{c2n} \\ &\quad + zp_{mort}\cdot f_{zmrt}\cdot R^{Zp}_{c2n} \;+\; dtc_{remin} \;+\; dtc_{bedrmn} \\ &\quad + crbnt \;-\; ph_{PP}\cdot R^{Ph}_{c2n} \;-\; dm_{PP}\cdot R^{Dm}_{c2n} \;+\; [\,CO2_{asf}\,]\end{aligned} \tag{1.11}$$

$$\frac{d\,TAlk}{d\,t} = 2\cdot crbnt \;-\; \frac{d\,DIN}{d\,t} \tag{1.12}$$

$$\frac{d\,Oxy}{d\,t} = [\,Oxy_{asf}\,] - \left(\frac{d\,DIC}{d\,t} \;-\; crbnt \;-\; [\,CO2_{asf}\,]\right)\cdot R^{eco}_{o2c} \tag{1.13}$$

The light-limitation of primary production by diatoms and nd-phytoplankton (respectively dm_{PP} and ph_{PP}) is calculated using the production scheme of Anderson (1993). This models the preferential absorption of longer-wavelength light by seawater, so that the spectrum of light available for growth is shifted towards blue deep in the euphotic zone. Note that consequently the light calculated and used in these functions at a given depth will not be the same as that available to the physics (for heating): the physics could easily be made to use the biological light field but does not do so as standard (and will not in the HadGEM3-ES trials). The functions also integrate production over a day, based on the noon surface irradiance and the number of daylight hours. The functions can be represented as:

$$\begin{aligned} dm_{PP} &= Dm \cdot \frac{DIN}{k_{DIN}^{Dm} + DIN} \cdot \frac{Si}{k_{Si}^{Dm} + Si} \\ &\quad \cdot PP(z, sol_{noon}, dlh, chl_{ttl}, P_m^{Dm}, \alpha^{Dm}) \qquad (1.14) \\ ph_{PP} &= Ph \cdot \frac{DIN}{k_{DIN}^{Ph} + DIN} \cdot PP(z, sol_{noon}, dlh, chl_{ttl}, P_m^{Ph}, \alpha^{Ph}) \qquad (1.15) \end{aligned}$$

where k_Y^X are half-saturation constants for uptake of nutrient Y by phytoplankton X, z is the depth of the layers, sol_{noon} is the noon surface solar irradiance, dlh is the number of hours of daylight at that latitude at that time of year, chl_{ttl} is the total (i.e. diatom plus nd-phytoplankton) chlorophyll content in each layer, P_m^X is the assimilation number (maximum growth rate) and α^X is the initial slope of the P-I curve. The calculation is done layer-by-layer, stepping down from the surface; the production at any given depth depends not only on the chlorophyll content in that layer but also in the layers above. Production in layers that are within the mixed layer is calculated for each individual layer and then averaged over the mixed layer.

The grazing function used in the Diat-HadOCC model differs from that used in the HadOCC model in that it uses a switching grazer similar to that used in Fasham et al. (1990; hereafter FDM90). The single zooplankton consumes diatoms, nd-phytoplankton and (organic) detrital particles. As in FDM90 the realised preference $dprf_X$ for each food type depends on that types abundance and on the base preferences $bprf_X$:

$$\begin{aligned} dprf_{denom} &= bprf_{Dm} \cdot R_{b2n}^{Dm} \cdot Dm \; + \; bprf_{Ph} \cdot R_{b2n}^{Ph} \cdot Ph \\ &\quad + bprf_{Dt} \cdot (\, R_{b2n}^{DtN} \cdot DtN \; + \; R_{b2c}^{DtC} \cdot DtC \,) \qquad (1.16) \\ dprf_{Dm} &= \frac{bprf_{Dm} \cdot R_{b2n}^{Dm} \cdot Dm}{dprf_{denom}} \qquad (1.17) \\ dprf_{Ph} &= \frac{bprf_{Ph} \cdot R_{b2n}^{Ph} \cdot Ph}{dprf_{denom}} \qquad (1.18) \end{aligned}$$

$$dprf_{Dt} \;=\; \frac{bprf_{Dt} \cdot (\, R_{b2n}^{DtN} \cdot DtN \;+\; R_{b2c}^{DtC} \cdot DtC \,)}{dprf_{denom}} \tag{1.19}$$

where, if M_N and M_C are the respective atomic weights of nitrogen and carbon (14.01 and 12.01 g Mol^{-1}) and R_{c2n}^{Rdfld} is the Redfield C:N ratio (106 Mol C : 16 Mol N), then the R_{b2Y}^{X} terms convert from nitrogen or carbon units to biomass units that allow the various potential food items to be compared:

$$\begin{aligned}
E &= (M_N + M_C \cdot R_{c2n}^{Rdfld})^{-1} \\
R_{b2n}^{Ph} &= E \cdot (M_N + M_C \cdot R_{c2n}^{Ph}) && (1.20) \\
R_{b2n}^{Dm} &= E \cdot (M_N + M_C \cdot R_{c2n}^{Dm}) && (1.21) \\
R_{b2n}^{Zp} &= E \cdot (M_N + M_C \cdot R_{c2n}^{Zp}) && (1.22) \\
R_{b2n}^{DtN} &= E \cdot M_N && (1.23) \\
R_{b2c}^{DtC} &= E \cdot M_C && (1.24)
\end{aligned}$$

Note that the base preference values supplied (or calculated as a function of iron-limitation) $bprf_X$ are normalised so that they sum up to 1. The available food is:

$$\begin{aligned}
food \;=\; & dprf_{Dm} \cdot R_{b2n}^{Dm} \cdot Dm \;+\; dprf_{Ph} \cdot R_{b2n}^{Ph} \cdot Ph \\
& + dprf_{Dt} \cdot (\, R_{b2n}^{DtN} \cdot DtN \;+\; R_{b2c}^{DtC} \cdot DtC \,) && (1.25)
\end{aligned}$$

and the grazing rates on the various model state variables are:

$$\begin{aligned}
dm_{grz} &= \frac{dprf_{Dm} \cdot Dm \cdot g_{max} \cdot R_{b2n}^{Zp} \cdot Zp}{g_{sat} \;+\; food} && (1.26) \\
dmsi_{grz} &= \frac{dprf_{Dm} \cdot DmSi \cdot g_{max} \cdot R_{b2n}^{Zp} \cdot Zp}{g_{sat} \;+\; food} && (1.27) \\
ph_{grz} &= \frac{dprf_{Ph} \cdot Ph \cdot g_{max} \cdot R_{b2n}^{Zp} \cdot Zp}{g_{sat} \;+\; food} && (1.28) \\
dtn_{grz} &= \frac{dprf_{Dt} \cdot DtN \cdot g_{max} \cdot R_{b2n}^{Zp} \cdot Zp}{g_{sat} \;+\; food} && (1.29) \\
dtc_{grz} &= \frac{dprf_{Dt} \cdot DtC \cdot g_{max} \cdot R_{b2n}^{Zp} \cdot Zp}{g_{sat} \;+\; food} && (1.30)
\end{aligned}$$

A fraction $(1 - f_{ingst})$ of the grazed material is not ingested: of this, a fraction f_{messy} returns immediately to solution as DIN and DIC while the rest becomes detritus. All of the grazed diatom silicate $DmSi$ immediately becomes detrital silicate $DtSi$. Of the organic material that is ingested, a source-dependent fraction (β^X) of the nitrogen and of the carbon is assimilatable while the remainder is egested from the zooplankton gut as detrital nitrogen DtN or carbon DtC. The amount of assimilatable material that is actually assimilated by the zooplankton grz_{Zp} is governed by its C:N ratio compared to that of the zooplankton: as much as possible is assimilated, with the remainder passed out immediately as DIN or DIC.

$$
\begin{aligned}
assim_N &= f_{ingst} \cdot (\, \beta^{Dm} \cdot dm_{grz} \, + \, \beta^{Ph} \cdot ph_{grz} \, + \, \beta^{Dt} \cdot dtn_{grz}) && (1.31) \\
assim_C &= f_{ingst} \cdot (\, \beta^{Dm} \cdot R^{Dm}_{c2n} \cdot dm_{grz} \, + \, \beta^{Ph} \cdot R^{Ph}_{c2n} \cdot ph_{grz} \\
&\quad + \beta^{Dt} \cdot dtn_{grz}) && (1.32) \\
grz_{Zp} &= MIN\left(assim_N, \, \frac{assim_C}{R^{Zp}_{c2n}} \right) && (1.33) \\
grz_{DtN} &= (1 - f_{ingst}) \cdot (1 - f_{messy}) \cdot (\, dm_{grz} \, + \, ph_{grz} \\
&\quad + dtn_{grz} \,) \, + \, f_{ingst} \cdot (\, (1 - \beta^{Dm}) \cdot dm_{grz} \\
&\quad + (1 - \beta^{Ph}) \cdot ph_{grz} \, + \, (1 - \beta^{Dt}) \cdot dtn_{grz} \,) && (1.34) \\
grz_{DtC} &= (1 - f_{ingst}) \cdot (1 - f_{messy}) \cdot (\, R^{Dm}_{c2n} \cdot dm_{grz} \, + \, R^{Ph}_{c2n} \cdot ph_{grz} \\
&\quad + dtc_{grz} \,) \, + \, f_{ingst} \cdot (\, (1 - \beta^{Dm}) \cdot R^{Dm}_{c2n} \cdot dm_{grz} \\
&\quad + (1 - \beta^{Ph}) \cdot R^{Ph}_{c2n} \cdot ph_{grz} \, + \, (1 - \beta^{Dt}) \cdot dtc_{grz} \,) && (1.35) \\
grz_{dtsi} &= dmsi_{grz} && (1.36) \\
grz_{DIN} &= (1 - f_{ingst}) \cdot f_{messy} \cdot (\, dm_{grz} \, + \, ph_{grz} \\
&\quad + dtn_{grz} \,) \, + \, MAX\left(0, \, assim_N \, - \, \frac{assim_C}{R^{Zp}_{c2n}} \right) && (1.37) \\
grz_{DIC} &= (1 - f_{ingst}) \cdot f_{messy} \cdot (\, R^{Dm}_{c2n} \cdot dm_{grz} \, + \, R^{Ph}_{c2n} \cdot ph_{grz} \\
&\quad + dtc_{grz} \,) \, + \, MAX(\, 0, \, assim_C \, - \, assim_N \cdot R^{Zp}_{c2n}) && (1.38)
\end{aligned}
$$

The other loss terms for diatoms, nd-phytoplankton and zooplankton are:

$$
\begin{aligned}
dm_{resp} &= \Pi^{Dm}_{resp} \cdot Dm && (1.39) \\
ph_{resp} &= \Pi^{Ph}_{resp} \cdot Ph && (1.40) \\
dm_{mort} &= \Pi^{Dm}_{mort} \cdot Dm^2 && (1.41) \\
dmsi_{mort} &= \Pi^{Dm}_{mort} \cdot Dm \cdot DmSi && (1.42) \\
ph_{mort} &= \Pi^{Ph}_{mort} \cdot Ph^2 && (Ph > ph_{min})
\end{aligned}
$$

$$
\begin{aligned}
&= 0 \qquad\qquad (Ph < ph_{min}) && (1.43)\\
zp_{lin} &= \Pi^{Zp}_{lin} \cdot Zp && (1.44)\\
zp_{mort} &= \Pi^{Zp}_{mort} \cdot Zp^2 && (1.45)
\end{aligned}
$$

All detrital material sinks at a constant speed V_{Dt} at all depths. Diatoms (and its associated silicate) sinks at a constant speed V_{Dm} at all depths. Detrital remineralisation (of DtN and DtC)is depth-dependent, the specific rate varying as the reciprocal of depth but with a maximum value. This functional form gives a depth variation of detritus consistent with the Martin et al (1987) power-law curve. Dissolution of opal does not vary with depth.

$$
\begin{aligned}
dtn_{remin} &= DtN \cdot MIN\left(\Pi^{DtN}_{rmnmx}, \frac{\Pi^{DtN}_{rmndd}}{z}\right) && (1.46)\\
dtc_{remin} &= DtC \cdot MIN\left(\Pi^{DtC}_{rmnmx}, \frac{\Pi^{DtC}_{rmndd}}{z}\right) && (1.47)\\
dtsi_{remin} &= DtSi \cdot \Pi^{DtSi}_{rmn} && (1.48)\\
dt(n,c,si)_{sink} &= V_{Dt} \cdot \frac{d\,Dt(N,C,Si)}{d\,z} && (1.49)\\
d(m,msi)_{sink} &= V_{Dm} \cdot \frac{d\,D(m,mSi)}{d\,z} && (1.50)
\end{aligned}
$$

Since there are no sediments in the Diat-HadOCC model, all detritus that sinks to the sea-floor is instantly remineralised to N, C or Si and spread through the lowest three layers (above the sea-floor). Diatoms (and associated silicate) that sink to the sea-floor instantly die and become DtN, DtC and $DtSi$, as appropriate, in the lowest layer. Therefore, if $btmflx_Y$ is the value of $[Y_{sink}]$ at the sea-floor:

$$
\begin{aligned}
dt(n,c,si)_{bedrmn} &= \frac{btmflx_{Dt(N,C,Si)}}{\Delta_{b3l}} && (\,btm\ 3\ lyrs\,)\\
&= 0 && (\,above\ btm\ 3\ lyrs\,) \qquad (1.51)\\
(dm,dmsi)_{bedmrt} &= \frac{btmflx_{(dm,dmsi)}}{\Delta_{b1l}} && (\,bottom\ lyr\,)\\
&= 0 && (\,other\ lyrs\,) \qquad (1.52)
\end{aligned}
$$

where $btmflx_X$ is the sinking flux of X to the sea-floor and Δ_{bMl} is the combined thickness of the bottom M layers (of course, which layers those are will vary according to the location).

The effect of dissolved iron (FeT) in the Diat-HadOCC model is to vary certain parameter values: the assimilation numbers (maximum growth rates) for diatoms and nd-phytoplankton P_m^{Dm} and P_m^{Ph}, the silicon:nitrogen ration for diatoms R_{si2n}^{Dm}, the zooplankton base preference for feeding on diatoms $bprf_{Dm}$ and the zooplankton mortality Π_{mort}^{Zp}. (Note that, because the base feeding preferences are normalised so that their sum is 1, changing the preference for diatoms will mean the preferences for nd-phytoplankton and for detritus also change.) Each of those parameters has an iron-replete value (the standard) and an iron-deplete value, and the realised value at a given time and location will be:

$$\Pi = \Pi_{replete} + (\,\Pi_{deplete} \; - \; \Pi_{replete}\,) \cdot \frac{1}{1 \; + \; \frac{FeT}{k_{FeT}}} \tag{1.53}$$

where k_{FeT} is similar to a half-saturation constant for iron uptake. In the CMIP5 simulations run using HadGEM2-ES (with the Diat-HadOCC model as the ocean biogeochemical component) only the value of P_m^{Dm} varied.

Iron is added to the ocean by dust deposition from the atmosphere (prescribed or passed from the atmospheric sub-model in coupled mode), with a constant proportion (by weight) of the dust being iron which immediately becomes part of the total dissolved iron pool FeT. Iron is taken up by diatoms and nd-phytoplankton during growth in a fixed ratio to the carbon taken up, and moves through the ecosystem in the same ratio, except that any flow of carbon to DtC is associated with a flow of iron back to solution, as there is no iron in organic detritus in the model. All iron that flows through the ecosystem is returned to solution, but there is a final loss term for dissolved iron, namely (implicit) adsorption onto pelagic sinking mineral particles (*not* the models detrital particles) and thence to the (implicit) sediments. Only the fraction of FeT that is not complexed to organic ligands can be adsorbed. The un-complexed (free) iron concentration FeF and the complexed concentration FeL are found by assuming a constant uniform total ligand concentration LgT and a partition function K_{FeL}, and the adsorption flux fe_{adsorp} derived from that:

$$FeT \;=\; FeL \; + \; FeF \tag{1.54}$$

$$LgT \;=\; FeL \; + \; LgF \tag{1.55}$$

$$K_{FeL} \;=\; \frac{FeL}{FeF \cdot LgF} \tag{1.56}$$

$$B \;=\; K_{FeL} \cdot (\,LgT \; - \; FeT\,) \; - \; 1 \tag{1.57}$$

$$\begin{aligned} FeF &= FeT \;-\; LgT \\ &\quad + \frac{1}{2 \cdot K_{FeL}} \cdot \left(B \;+\; \sqrt{B^2 \;-\; 4 \cdot K_{FeL} \cdot LgT} \right) && (1.58) \\ fe_{adsorp} &= \Pi_{ads}^{FeF} \cdot FeF && (1.59) \end{aligned}$$

Solid calcium carbonate is implicitly produced in a constant ratio to organic production by nd-phytoplankton. The total production is summed over the surface layers (those where production is non-zero) and instantly re-dissolved equally through the water column below the (prescribed) lysocline. If the sea-floor is shallower than the lysocline, then the dissolution takes place in the bottom layer (there being no sediments). The depth of the lysocline is always co-incident with a layer interface, and is constant both geographically and in time.

$$\begin{aligned} ccfrmtn &= R_{cc2pp}^{Ph} \cdot ph_{PP} && (1.60) \\ xprt_{cc} &= \sum_{n} (\, ccfrmtn_n \cdot \Delta_n \,) && (1.61) \\ ccdsltn &= \frac{xprt_{cc}}{\Delta_{dsl}} \qquad\qquad (\, valid\ lyrs\ ) \\ &= 0 \qquad\qquad\qquad (\, other\ lyrs\,) && (1.62) \\ crbnt &= ccdsltn \;-\; ccfrmtn && (1.63) \end{aligned}$$

where Δ_n is the thickness of layer n and Δ_{dsl} is the total thickness of the valid layers (where dissolution can occur) in that water column, which is equal to the distance between the lysocline and the sea-floor if the lysocline is shallower than the sea-floor and the thickness of the deepest layer otherwise.

Finally, the calculation of the air-to-sea fluxes of O_2 and CO_2 (respectively $[\,Oxy_{asf}\,]$ and $[\,CO2_{asf}\,]$) follow the methodology of OCMIP.

Table 1.2: Parameter values used in CMIP5 simulations

Param	Value	Units	Description
$P^{Ph}_{m,r}$	1.5	d^{-1}	Max rate of photosynthesis; phyto, Fe-replete
$P^{Ph}_{m,l}$	1.5	d^{-1}	Max rate of photosynthesis; phyto, Fe-limited
$P^{Dm}_{m,r}$	1.85	d^{-1}	Max rate of photosynthesis; diatom, Fe-replete
$P^{Dm}_{m,l}$	1.11	d^{-1}	Max rate of photosynthesis; diatom, Fe-limited
α^{Ph}	0.02	mg C (mg Chl)$^{-1}$ h^{-1} (μEinst m^{-2} s^{-1})$^{-1}$	Initial slope of the psynth-light curve; phyto
α^{Dm}	0.02	mg C (mg Chl)$^{-1}$ h^{-1} (μEinst m^{-2} s^{-1})$^{-1}$	Initial slope of the psynth-light curve; diatom
k^{Ph}_{DIN}	0.1	mMol N m^{-3}	Half-saturation const, N uptake; phyto
k^{Dm}_{DIN}	0.2	mMol N m^{-3}	Half-saturation const, N uptake; diatom
k^{Dm}_{Si}	1.0	mMol Si m^{-3}	Half-saturation const, Si uptake; diatom
R^{Ph}_{c2n}	6.625	mMol C (mMol N)$^{-1}$	Molar C:N ratio, phyto
R^{Dm}_{c2n}	6.625	mMol C (mMol N)$^{-1}$	Molar C:N ratio, diatom
R^{Zp}_{c2n}	5.625	mMol C (mMol N)$^{-1}$	Molar C:N ratio, zoopl
$R^{Dm}_{si2n,r}$	0.606	mMol Si (mMol N)$^{-1}$	Molar Si:N ratio, diatom, Fe-replete
$R^{Dm}_{si2n,l}$	0.606	mMol Si (mMol N)$^{-1}$	Molar Si:N ratio, diatom, Fe-limited
R^{Ph}_{c2chl}	40.0	mg C (mg Chl)$^{-1}$	Carbon to Chlorophyll ratio, phyto
R^{Dm}_{c2chl}	40.0	mg C (mg Chl)$^{-1}$	Carbon to Chlorophyll ratio, diatom
Π^{Ph}_{resp}	0.05	d^{-1}	Phyto respiration, specific rate
Π^{Dm}_{resp}	0.0	d^{-1}	Diatom respiration, specific rate
Π^{Ph}_{mort}	0.05	d^{-1} (mMol N m^{-3})$^{-1}$	Phyto mortality, density-dep rate

ph_{min}	0.01	mMol N m^{-3}	Phyto conc below which phyto mortality is zero
Π^{Dm}_{mort}	0.04	d^{-1} (mMol N m^{-3})$^{-1}$	Diatom mortality, density-dep rate
Π^{Zp}_{lin}	0.05	d^{-1}	Zooplankton losses, specific rate
Π^{Zp}_{mort}	0.3	d^{-1} (mMol N m^{-3})$^{-1}$	Zoopl. mortality, density-dep
F_{nmp}	0.01	(none)	Fraction of mortality to dissolved nutrient
F_{zmort}	0.67	(none)	Fraction of zoopl mortality to dissolved nutrient
g_{max}	0.8	d^{-1}	Max specific rate of zooplankton grazing
g_{sat}	0.5	nMol N m^{-3}	Half-saturation const for zoopl grazing
$bprf_{Ph}$	0.45	(none)	Zoopl base feeding preference for phyto
$bprf_{Dm,r}$	0.45	(none)	Zoopl base feeding preference for diatom, Fe-replete conditions
$bprf_{Dm,l}$	0.45	(none)	Zoopl base feeding preference for diatom, Fe-limited conditions
$bprf_{Dt}$	0.10	(none)	Zoopl base feeding preference for detritus
F_{ingst}	0.77	(none)	Fraction of food that is ingested
F_{messy}	0.1	(none)	Fraction of non-ingested food to dissolved nutrient/carbon
β^{Ph}	0.9	(none)	Fraction of ingested phyto that can be assimilated
β^{Dm}	0.9	(none)	Fraction of ingested diatom that can be assimilated
β^{Dt}	0.7	(none)	Fraction of ingested detritus that can be assimilated
V_{Dt}	10.0	m d^{-1}	Sinking speed, detritus
Π^{DtC}_{rmndd}	8.58	m d^{-1}	Detrital remineralisation rate factor, carbon
Π^{DtC}_{rmnmx}	0.125	d^{-1}	Maximum detrital remineralisation rate, carbon

Π^{DtN}_{rmndd}	8.58	m d^{-1}	Detrital remineralisation rate factor, nitrogen
Π^{DtN}_{rmnmx}	0.125	d^{-1}	Maximum detrital remineralisation rate, nitrogen
Π^{DtSi}_{rmn}	0.05	d^{-1}	Detrital silicate (opal) remin/dissolution rate
V_{Dm}	1.0	m d^{-1}	Diatom sinking speed
R^{eco}_{fe2c}	0.025	μMol Fe (mMol C)$^{-1}$	Molar Fe:C ratio for ecosystem
k_{FeT}	0.2	μMol Fe m^{-3}	Half-saturation factor for Fe-limitation
LgT	1.0	μMol m^{-3}	Total ligand concentration
K_{FeL}	200.0	(μMol m^{-3})$^{-1}$	Fe-ligand partition function
Π^{FeF}_{ads}	5.0×10^{-5}	d^{-1}	Adsorption rate of iron onto particles
R^{eco}_{o2c}	1.302	mMol O_2 (mMol C)$^{-1}$	Molar O_2:C ratio for ecosystem
R^{Ph}_{cc2pp}	0.0195	mMol $CaCO_3$ (mMol C)$^{-1}$	Molar ratio of carbonate formation to organic production, phyto
Z_{lys}	2113.0	m	Depth of lysocline