ECOHAM5 user guide

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Chapter 1

Introduction

This is a description of the ecosystem model ECOHAM (ECOsystem Model Hamburg) Version 5. The coupled physical-biogeochemical model represents the pelagic and benthic cycles of carbon, nitrogen, phosphorus, silicon and oxygen with the focus of the North Sea. The present ECOHAM Version 5 is revised in major parts for application on new software and hardware platforms in order to provide a parallel version by including MPI communication. In this introduction first a model overview will be provided, followed by a short description of the ECOHAM historic model development with view on applicaitons and finally the major changes of the present version will be highlighted.

1.1 Model Overview

The physical part is based on the hydrodynamic model HAMSOM (Pohlmann, 1996). The biogeochemical part represents the pelagic and benthic cycles of carbon, nitrogen, phosphorus, silicon and oxygen. The state variables included are: the functional phytoplankton-group diatoms and flagellates, micro- and mesozooplankton, slowly and fast sinking detritus, labile and semi-labile dissolved organic matter and bacteria, dissolved inorganic carbon (DIC), alkalinity and oxygen, as well as the nutrients nitrate, ammonium, phosphate and silicate. Additionally, a module for the equilibrium chemistry of inorganic carbon is implemented, so that the model is able to calculate the air-sea flux of CO_2.

For phytoplankton, zooplankton and bacteria fixed, but different C:N:P ratios were prescribed. The C:N:P ratios of detritus and labile DOM can evolve freely. The benthic remineralisation processes are parameterized in a very simple way: the sediment is represented by a horizontal layer (without vertical extension) where the sedimenting material is collected and remineralised, using different remineralisation rates for organic carbon, nitrogen, phosphorus and silicon (opal). The coupled benthic nitrification/denitrification is bound to the oxygen consumption due to carbon remineralisation.

In shallow areas, phytoplankton growth is limited due to self-shading and light attenuation by silt. To include the latter effect, daily silt data from Heath et al. (2002) were interpolated to the grid and prescribed at each grid point. River loads, atmospheric nitrogen deposition and boundary conditions are supplied.

1.2 Model History

1.2.1 Previous model versions: ECOHAM3 & ECOHAM4

The previous ECOHAM3 model was used to calculate nitrogen and carbon budgets in relation to NAO conditions (Pätsch, and Kühn, 2008). This model version was the basis for a case study on oxygen, which was also used within the BSH model framework (Müller, 2008). In an extended version a structured zooplankton module was attached to the existing model version 3 in order to study Pseudocalanus elongatus (Stegert, Moll & Kreus, 2009). The following ECOHAM Version 4 was applied for river nutrient reduction studies with the focus on eutrophication assessment under the OSPAR framework (Lenhart et al,2010). Therefore the nutrient cycles for phosphorus and silicon had to be included in this model version. The latest application covers the CO_2 application with the introduction of Cocolithophores as new phytoplankton group (Lorkowski, Pätsch, Moll & Kühn, 2012).

1.2.2 The present model version: ECOHAM5

Since the new model version was developped in view of a more generic approach to handle different grid resolution for the model domain, the first challenge was to reduce the number of state variables down to 34, but still be able torepresent the pelagic and benthic cycles of carbon, nitrogen, phosphorus, silicon and oxygen. Second the structure of the model code was simplified including an exchange of the internal loops for i- an j-indices. Finally MPI communication statements were included to provide parallel processing of cluster systems.

Chapter 2

Model Description

2.1 ECOHAM state variables

The ecosystem model ECOHAM5 (Ecosystem Model Hamburg) list of pelagic state variables:

Table 2.1: List of ECOHAM5 state variables.

var ID	var code	variable description	unit
pelagic state variables: prognostic			
1	*x1x*	passive tracer	m^{-3}
2	*alk*	alkalinity	meqv m^{-3} ???
3	*dic*	dissolved inorganic carbon (DIC)	mmol C m^{-3}
4	*n3n*	nitrate (NO_3^-)	mmol N m^{-3}
5	*n4n*	ammonium (NH_4^+)	mmol N m^{-3}
6	*n1p*	phosphate (PO_4^{3-})	mmol P m^{-3}
7	*n5s*	silicate (SiO_x)	mmol Si m^{-3}
8	*p1c*	diatom-C	mmol C m^{-3}
9	*p1n*	diatom-N	mmol N m^{-3}
10	*p1p*	diatom-P	mmol C m^{-3}
11	*p1s*	diatom-Si	mmol Si m^{-3}
12	*p2c*	flagellate-C	mmol C m^{-3}
13	*p2n*	flagellate-N	mmol N m^{-3}
14	*p2p*	flagellate-P	mmol P m^{-3}
15	*p3c*	new phyto-C	mmol C m^{-3}
16	*p3n*	new phyto-N	mmol N m^{-3}
17	*p3p*	new phyto-P	mmol C m^{-3}
18	*p3k*	new phyto-K	??????????
19	*z1c*	microzooplankton-C	mmol C m^{-3}
20	*z2c*	mesozooplankton-C	mmol C m^{-3}
21	*bac*	bacteria-C	mmol C m^{-3}
22	*d1c*	detritus-C (slowly sinking)	mmol C m^{-3}
23	*d1n*	detritus-N (slowly sinking)	mmol N m^{-3}
24	*d1p*	detritus-P (slowly sinking)	mmol P m^{-3}
25	*d2c*	detritus-C (fast sinking)	mmol C m^{-3}
26	*d2n*	detritus-N (fast sinking)	mmol N m^{-3}
27	*d2p*	detritus-P (fast sinking)	mmol P m^{-3}
28	*d2s*	detritus-Si (fast sinking)	mmol Si m^{-3}
29	*d2k*	detritus skeleton-$CaCO_3$(fast sinking)	mmol C m^{-3} ???
30	*soc*	semi-lable dissolved organic matter	mmol C m^{-3}

31	*doc*	labile dissolved organic carbon (DOC)	$\mathrm{mmol\,C\,m^{-3}}$
32	*don*	labile dissolved organic nitrogen (DON)	$\mathrm{mmol\,N\,m^{-3}}$
33	*dop*	labile dissolved organic phosphorus (DOP)	$\mathrm{mmol\,P\,m^{-3}}$
34	*o2o*	dissolved oxygen (O_2)	$\mathrm{mmol\,O_2\,m^{-3}}$
pelagic state variables: derived			
1	*ban*	bacteria-N	$\mathrm{mmol\,N\,m^{-3}}$
2	*bap*	bacteria-P	$\mathrm{mmol\,P\,m^{-3}}$
3	*z1n*	microzooplankton-N	$\mathrm{mmol\,N\,m^{-3}}$
4	*z1p*	microzooplankton-P	$\mathrm{mmol\,P\,m^{-3}}$
5	*z2n*	mesozooplankton-N	$\mathrm{mmol\,N\,m^{-3}}$
6	*z2p*	mesozooplankton-P	$\mathrm{mmol\,P\,m^{-3}}$
benthic state variables: prognostic			
1	*sd_poc*	benthic particulate organic matter C	$\mathrm{mmol\,C\,m^{-2}}$
2	*sd_pon*	benthic particulate organic matter N	$\mathrm{mmol\,N\,m^{-2}}$
3	*sd_pop*	benthic particulate organic matter P	$\mathrm{mmol\,P\,m^{-2}}$
4	*sd_pos*	benthic particulate organic matter SiO_x	$\mathrm{mmol\,Si\,m^{-2}}$
5	*sd_pok*	benthic particulate organic matter $CaCO_3$	$\mathrm{mmol\,Si\,m^{-2}}$

2.2 ECOHAM biogeochemical cycles

This section provides schematic illustrations of the carbon, nitrogen, phosphorus, silicon and oxygen cycles.

2.3 Available ECOHAM5 grids

ECOHAM5 can be applied on different grids varying in their spatial resolution and model domain. Table 2.2 shows the main describing parameters of the different model grids currently available for ECOHAM5.

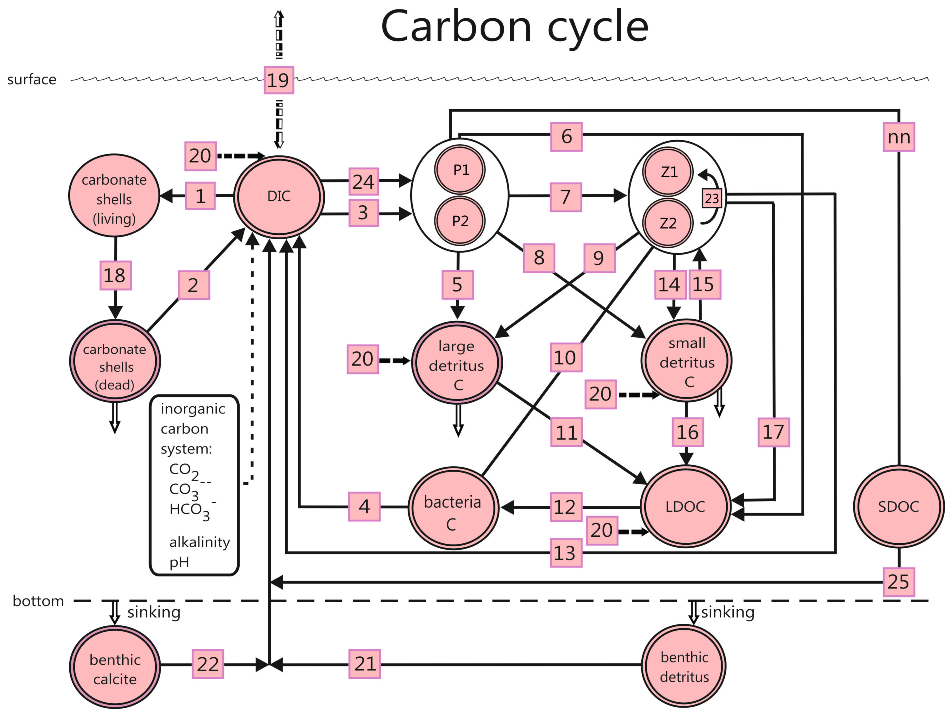


Figure 2.1: ECOHAM5 carbon cycle

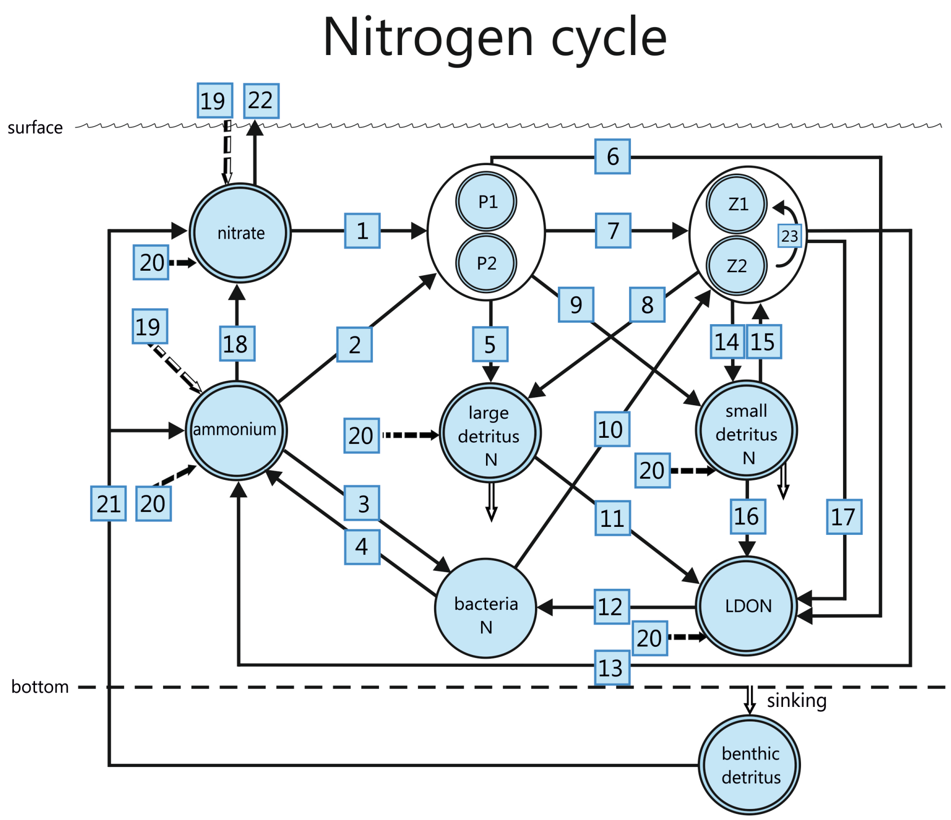


Figure 2.2: ECOHAM5 nitrogen cycle

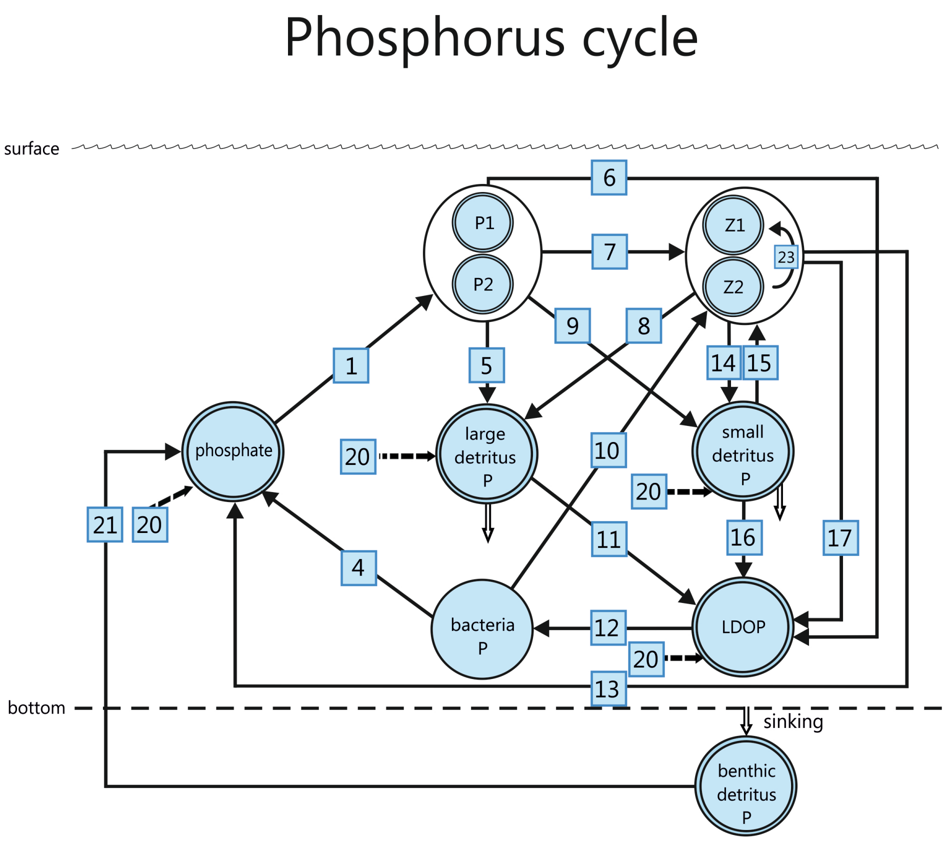


Figure 2.3: ECOHAM5 phosphorus cycle

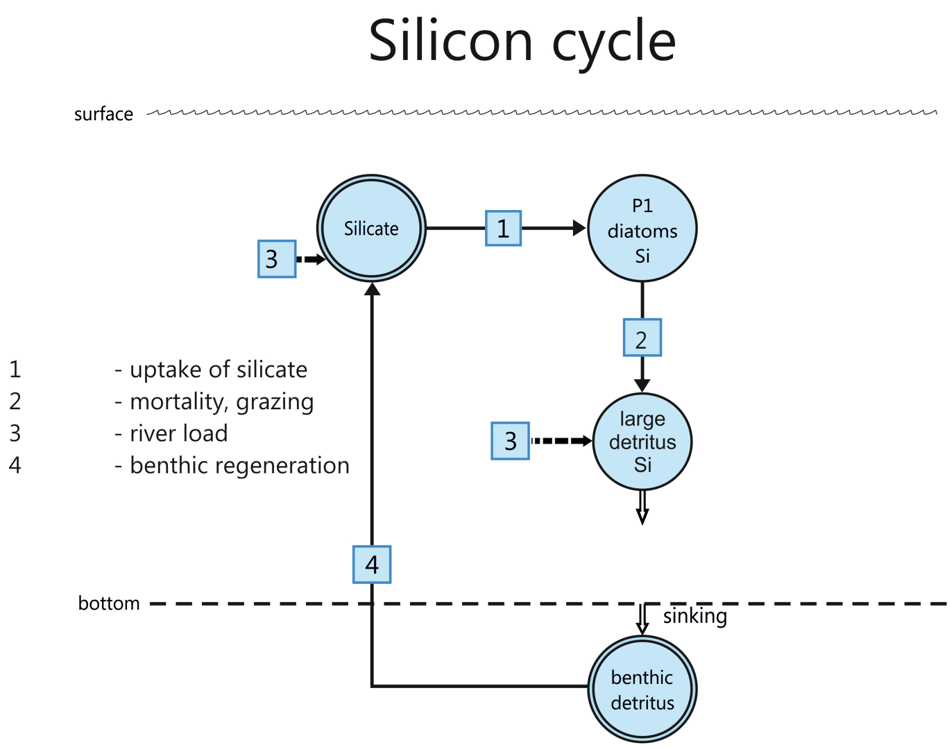


Figure 2.4: ECOHAM5 silicon cycle

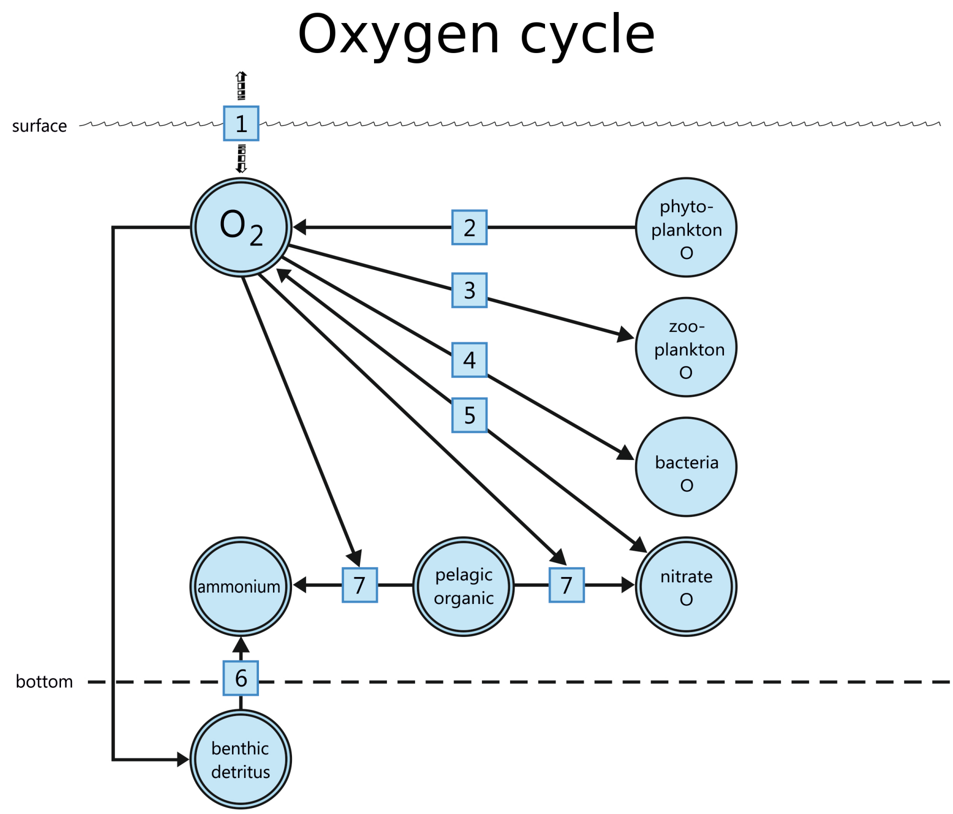


Figure 2.5: ECOHAM5 oxygen cycle

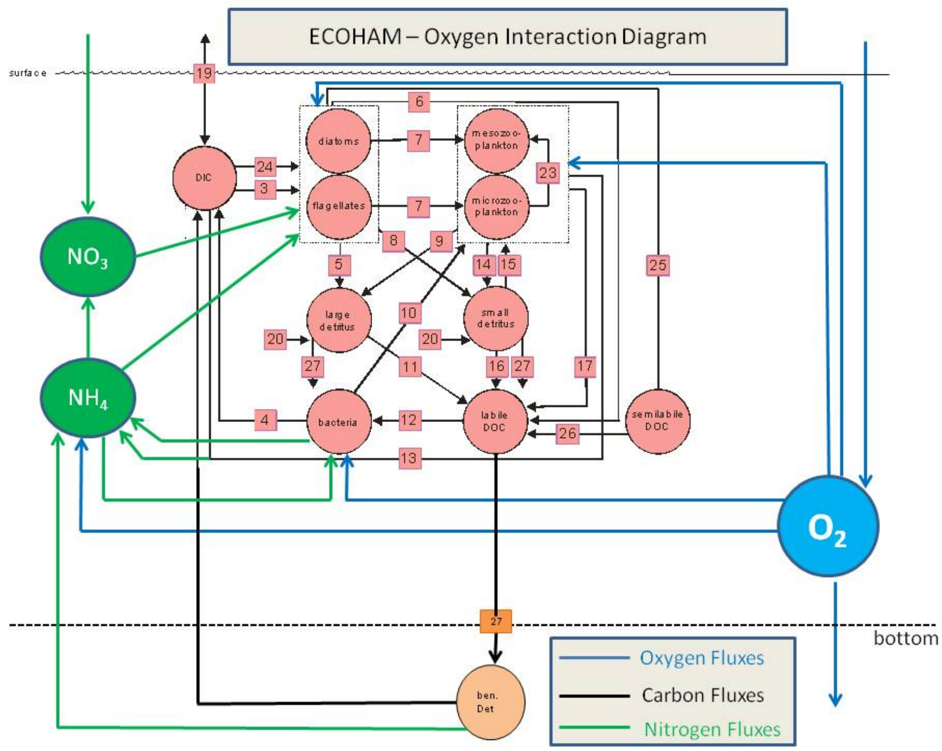


Figure 2.6: ECOHAM5 oxygen interaction

Table 2.2: Currently available grids for ECOHAM5.

grid name	**NWCS20C**	**NWCS20D**	**NS03A**	**NS20C**
domain	NECS	NECS	North Sea	North Sea
n grid points (x, y, z)	88, 82, 24	88, 82, 31	414, 380, 30	39, 33, 21
sourthwesternmost ζ-point	15°5′W, 47°41′N	15°5′W, 47°41′N	4°3′45.12″W, 50°52′14.88″N	3°25′W, 50°53′N
resolution (dx, dy)	1/3°, 1/5°	1/3°, 1/5°	1/24°, 1/40°	1/3°, 1/5°
depth levels (dz)	10, 15, 20, 25, 30 35, 40, 50, 60, 75 100, 150, 200, 300 400, 500, 600, 700 800, 1000, 2000 3000, 4000	10, 15, 20, 25, 30 35, 40, 45, 50, 60 70, 80, 90, 100, 120 140, 160, 180, 200 250, 300, 350, 400 500, 600, 800, 1000 1500, 2000, 3000, 4000	5, 10, 15, 20, 25 30, 35, 40, 45, 50 60, 70, 80, 90, 100 120, 140, 160, 180 200, 250, 300, 350 400, 450, 500, 550 600, 650, 700	5, 10, 15, 20, 25 30, 35, 40, 45, 50 60, 70, 80, 90, 100 110, 120, 130, 140 150, 170
total extent (x)	15°15′W – 14°5′E	15°15′W – 14°5′E	4°5′0.12″W – 13°9′59.88″E	3°15′W – 9°25′E
(y)	47°35′N – 63°59′N	47°35′N – 63°59′N	50°51′29.88″N – 60°21′29.88″N	50°47′N – 57°23′N
n wet points	66552	83558	939379	6159
n wet columns	4455	4455	84390	702

Chapter 3

The model equations

In the following only the variable-specific source and sink terms are listed, i.e. biological processes ($var1\_var2$), air-sea flux (air_var), atmospheric deposition (atm_var), benthic remineralisation (var_brm), and fluxes from the sediment into the pelagic (sed_var). For pelagic biological processes, the term $var1\_var2$ indicates a flux from variable $var1$ to variable $var2$. Besides these fluxes, all pelagic variables experience sedimentation (var_sed, i.e. deposition to the sediment due to sinking) in the case of a sinking velocity $w_{s,var} > 0$. Furthermore, all pelagic variables are affected by river input (riv_var), river dilution (dil_var), restoring (res_var), precipitation (pev_var), and hydrodynamics (hyd_var). The latter involves horizontal and vertical advection (adh_var, adv_var) and mixing (mxh_var, mxv_var). Thus, the general form of the differential equation for the concentration of any *pelagic* state variable *var* writes as:

$$\begin{aligned}\frac{\partial var}{\partial t} &= \mathrm{SOURCES}(var) - \mathrm{SINKS}(var) \\ &\quad - var\_sed + riv\_var - dil\_var + res\_var + pev\_var + hyd\_var.\end{aligned} \tag{3.1}$$

Here, SOURCES and SINKS represent the sums of the source and sink processes listed in the equations in the following tables.

Table 3.1: Model equations for phyto- and zooplankton.

state variable	**conservation equation**
Diatoms-C	$\frac{\partial p1c}{\partial t} = dic\_p1c - p1c\_z1c - p1c\_z2c - p1c\_d1c - p1c\_d2c - p1c\_doc - p1c\_soc$
Diatoms-N	$\frac{\partial p1n}{\partial t} = n3n\_p1n + n4n\_p1n - p1n\_z1n - p1n\_z2n - p1n\_d1n - p1n\_d2n - p1n\_don$
Diatoms-P	$\frac{\partial p1p}{\partial t} = n1p\_p1p - p1p\_z1p - p1p\_z2p - p1p\_d1p - p1p\_d2p - p1p\_dop$
Diatoms-Si	$\frac{\partial p1s}{\partial t} = n5s\_p1s - p1s\_d2s$
Flagellates-C	$\frac{\partial p2c}{\partial t} = dic\_p2c - p2c\_z1c - p2c\_z2c - p2c\_d1c - p2c\_d2c - p2c\_doc - p2c\_soc$
Flagellates-N	$\frac{\partial p2n}{\partial t} = n3n\_p2n + n4n\_p2n - p2n\_z1n - p2n\_z2n - p2n\_d1n - p2n\_d2n - p2n\_don$
Flagellates-P	$\frac{\partial p2p}{\partial t} = n1p\_p2p - p2p\_z1p - p2p\_z2p - p2p\_d1p - p2p\_d2p - p2p\_dop$
Flagellates-$CaCO_3$	$\frac{\partial psk}{\partial t} = dic\_psk - psk\_z1c - psk\_z2c - psk\_d2k$
Coccos-C	$\frac{\partial p3c}{\partial t} = dic\_p3c - p3c\_z1c - p3c\_z2c - p3c\_d1c - p3c\_d2c - p3c\_doc - p3c\_soc$
Coccos-N	$\frac{\partial p3n}{\partial t} = n3n\_p3n + n4n\_p3n - p3n\_z1n - p3n\_z2n - p3n\_d1n - p3n\_d2n - p3n\_don$
Coccos-P	$\frac{\partial p3p}{\partial t} = n1p\_p3p - p3p\_z1p - p3p\_z2p - p3p\_d1p - p3p\_d2p - p3p\_dop$
Coccos-$CaCO_3$	$\frac{\partial p3k}{\partial t} = dic\_p3k - p3k\_z1c - p3k\_z2c - p3k\_d2k$ **(if 3 phytopl. groups, i.e. coccos enabled)**
Microzooplankton-C	$\frac{\partial z1c}{\partial t} = p1c\_z1c + p2c\_z1c + p3c\_z1c + bac\_z1c + d1c\_z1c - z1c\_z2c - z1c\_d1c - z1c\_d2c$ $- z1c\_doc - zic\_dic$
Microzooplankton-N	$\frac{\partial z1n}{\partial t} = p1n\_z1n + p2n\_z1n + p3n\_z1n + ban\_z1n + d1n\_z1n - z1n\_z2n - z1n\_d1n - z1n\_d2n$ $- z1n\_don - z1n\_n4n$
Microzooplankton-P	$\frac{\partial z1p}{\partial t} = p1p\_z1p + p2p\_z1p + p3p\_z1p + bap\_z1p + d1p\_z1p - z1p\_z2p - z1p\_d1p - z1p\_d2p$ $- z1p\_dop - z1p\_n1p$
Mesozooplankton-C	$\frac{\partial z2c}{\partial t} = p1c\_z2c + p2c\_z2c + p3c\_z2c + bac\_z2c + d1c\_z2c + z1c\_z2c - z2c\_d1c - z2c\_d2c$ $- z2c\_doc - z2c\_dic$
Mesozooplankton-N	$\frac{\partial z2n}{\partial t} = p1n\_z2n + p2n\_z2n + p3n\_z2n + ban\_z2n + d1n\_z2n + z1n\_z2n - z2n\_d1n - z2n\_d2n$ $- z2n\_don - z2n\_n4n$
Mesozooplankton-P	$\frac{\partial z2p}{\partial t} = p1p\_z2p + p2p\_z2p + p3p\_z2p + bap\_z2p + d1p\_z2p + z1p\_z2p - z2p\_d1p - z2p\_d2p$ $- z2p\_dop - z2p\_n1p$

Table 3.2: Model equations for detritus, dissolved organic variables and bacteria.

state variable	**conservation equation**
Detritus-C, slowly sinking	$\frac{\partial d1c}{\partial t} = p1c\_d1c + p2c\_d1c + p3c\_d1c + z1c\_d1c + z2c\_d1c - d1c\_z1c - d1c\_z2c - d1c\_doc$
Detritus-N, slowly sinking	$\frac{\partial d1n}{\partial t} = p1n\_d1n + p2n\_d1n + p3n\_d1n + z1n\_d1n + z2n\_d1n - d1n\_z1n - d1n\_z2n - d1n\_don$
Detritus-P, slowly sinking	$\frac{\partial d1p}{\partial t} = p1p\_d1p + p2p\_d1p + p3p\_d1p + z1p\_d1p + z2p\_d1p - d1p\_z1p - d1p\_z2p - d1p\_dop$
Detritus-C, fast sinking	$\frac{\partial d2c}{\partial t} = p1c\_d2c + p2c\_d2c + p3c\_d2c + z1c\_d2c + z2c\_d2c - d2c\_doc$
Detritus-N, fast sinking	$\frac{\partial d2n}{\partial t} = p1n\_d2n + p2n\_d2n + p3n\_d2n + z1n\_d2n + z2n\_d2n - d2n\_don$
Detritus-P, fast sinking	$\frac{\partial d2p}{\partial t} = p1p\_d2p + p2p\_d2p + p3p\_d2p + z1p\_d2p + z2p\_d2p - d2p\_dop$
Detritus-SiO_x, fast sinking	$\frac{\partial d2s}{\partial t} = p1s\_d2s - d2s\_n5s$
Detritus-$CaCO_3$, fast sinking	$\frac{\partial d2k}{\partial t} = p3k\_d2k - d2k\_dic$
Dissolved organic C (DOC)	$\frac{\partial doc}{\partial t} = p1c\_doc + p2c\_doc + p3c\_doc + z1c\_doc + z2c\_doc + d1c\_doc + d2c\_doc$ $- doc\_bac + soc\_doc$
DOC, semi labile (SOC)	$\frac{\partial soc}{\partial t} = p1c\_soc + p2c\_soc + p3c\_soc - soc\_doc$
Dissolved organic N (DON)	$\frac{\partial don}{\partial t} = p1n\_don + p2n\_don + p3n\_don + z1n\_don + z2n\_don + d1n\_don + d2n\_don - don\_ban$
Dissolved organic P (DOP)	$\frac{\partial dop}{\partial t} = p1p\_dop + p2p\_dop + p3p\_dop + z1p\_dop + z2p\_dop + d1p\_dop + d2p\_dop - dop\_bap$
Bacteria-C	$\frac{\partial bac}{\partial t} = doc\_bac - bac\_z1c - bac\_z2c - bac\_dic$
Bacteria-N	$\frac{\partial ban}{\partial t} = don\_ban + n4n\_ban - ban\_z1n - ban\_z2n - ban\_n4n$
Bacteria-P	$\frac{\partial bap}{\partial t} = dop\_bap + n1p\_bap - bap\_z1p - bap\_z2p - bap\_n1p$

Table 3.3: Model equations for dissolved inorganic variables and alkalinity, and benthic variables.

state variable	**conservation equation**
Ammonium (NH_4^+)	$\frac{\partial n4n}{\partial t} = ban\_n4n + z1n\_n4n + z2n\_n4n - n4n\_n3n - n4n\_p1n - n4n\_p2n - n4n\_p3n - n4n\_ban + sed\_n4n + atm\_n4n$
Nitrate (NO_3^-)	$\frac{\partial n3n}{\partial t} = n4n\_n3n - n3n\_nn2 - n3n\_p1n - n3n\_p2n - n3n\_p3n - n3n\_brm + atm\_n3n$
Phosphate (PO_4^{3-})	$\frac{\partial n1p}{\partial t} = bap\_n1p + z1p\_n1p + z2p\_n1p - n1p\_p1p - n1p\_p2p - n1p\_p3p - n1p\_bap + sed\_n1p$
Silicate (SiO_x)	$\frac{\partial n5s}{\partial t} = d2s\_n5s - n5s\_p1s + sed\_n5s$
Dissolved inorganic C (DIC)	$\frac{\partial dic}{\partial t} = bac\_dic + z1c\_dic + z2c\_dic + d2k\_dic - dic\_p1c - dic\_p2c - dic\_p3c - dic\_psk - dic\_p3k + sed\_dic + sed\_o3c + air\_o2c$
Oxygen (O_2)	$\frac{\partial o2o}{\partial t} = p1c\_o2o + p2c\_o2o - o2o\_z1c - o2o\_z2c - o2o\_bac - o2o\_n4n - o2o\_brm + air\_o2o$
total alkalinity	$\frac{\partial alk}{\partial t} = 2 \cdot (d2k\_dic + psk\_dic - dic\_psk - n4n\_n3n + sed\_o3c) + n3n\_p1n + n3n\_p2n + n3n\_p3n + z1n\_n4n + z2n\_n4n + ban\_n4n - n4n\_p1n - n4n\_p2n - n4n\_p3n - n4n\_ban - atm\_n3n + atm\_n4n + sed\_n4n + n1p\_p1p + n1p\_p2p + n1p\_p3p + n1p\_bap - z1p\_n1p - z2p\_n1p - bap\_n1p - sed\_n1p$
Benthic organic C	$\frac{\partial sd\_poc}{\partial t} = (p1c\_sed + p2c\_sed + p3c\_sed + d1c\_sed + d2c\_sed - sed\_dic) \cdot dz(k0)$
Benthic organic N	$\frac{\partial sd\_pon}{\partial t} = (p1n\_sed + p2n\_sed + p3n\_sed + d1n\_sed + d2n\_sed - sed\_n4n - sed\_nn2) \cdot dz(k0)$
Benthic organic P	$\frac{\partial sd\_pop}{\partial t} = (p1p\_sed + p2p\_sed + p3p\_sed + d1p\_sed + d2p\_sed - sed\_n1p) \cdot dz(k0)$
Benthic opal	$\frac{\partial sd\_pos}{\partial t} = (p1s\_sed + d2s\_sed - sed\_n5s) \cdot dz(k0)$
Benthic $CaCO_3$	$\frac{\partial sd\_pok}{\partial t} = (d2k\_sed + p3k\_sed - sed\_o3c) \cdot dz(k0)$

Chapter 4

Processes and their parameterisation

Table 4.1: Process formulations for phytoplankton.

process description	**process formulation**
effective C fixation, diatoms	$dic\_p1c = dic\_p1c\_red$ $+excess \cdot (h\_dic\_p1c - dic\_p1c\_red)$
Redfield C fixation, diatoms	$dic\_p1c\_red = f_{T,1} \cdot p1c \cdot f_{par}(I, v_{p1}, p1c) \cdot lim\_nps$
gross C fixation, diatoms	$h\_dic\_p1c = f_{T,1} \cdot p1c \cdot f_{par}(I, v_{p1}, p1c) \cdot nut\_lim$
effective C fixation, non-diatoms	$dic\_p2c = dic\_p2c\_red$ $+excess \cdot (h\_dic\_p2c - dic\_p2c\_red)$
Redfield C fixation, non-diatoms	$dic\_p2c\_red = f_{T,2} \cdot p2c \cdot f_{par}(I, v_{p2}, p2c) \cdot limf\_np$
gross C fixation, non-diatoms	$h\_dic\_p2c = f_{T,2} \cdot p2c \cdot f_{par}(I, v_{p2}, p2c) \cdot nut\_lim$
effective C fixation, coccos	$dic\_p3c = dic\_p3c\_red$ $+excess \cdot (h\_dic\_p3c - dic\_p3c\_red) \cdot lim\_calc$
Redfield C fixation, coccos	$dic\_p3c\_red = f_{T,3} \cdot p3c \cdot f_{par}(I, v_{p3}, p3c) \cdot limc\_npc \cdot f_{p3c}$
gross C fixation, coccos	$h\_dic\_p3c = f_{T,3} \cdot p3c \cdot f_{par}(I, v_{p3}, p3c) \cdot nut\_lim \cdot f_{p3k}$
NO_3^- uptake, diatoms	$n3n\_p1n = f_{T,1} \cdot \frac{p1c}{rcn} \cdot f_{par}(I, v_{p1}, p1c) \cdot Q_{11}$
NO_3^- uptake, non-diatoms	$n3n\_p2n = f_{T,2} \cdot \frac{p2c}{rcn2} \cdot f_{par}(I, v_{p2}, p2c) \cdot Q_{21}$
NO_3^- uptake, coccos	$n3n\_p3n = f_{T,3} \cdot \frac{p3c}{rcn3} \cdot v_{p3} \cdot f_{p3c} \cdot Q_{31}$
NH_4^+ uptake, diatoms	$n4n\_p1n = f_{T,1} \cdot \frac{p1c}{rcn} \cdot f_{par}(I, v_{p1}, p1c) \cdot Q_{12}$
NH_4^+ uptake, non-diatoms	$n4n\_p2n = f_{T,2} \cdot \frac{p2c}{rcn2} \cdot f_{par}(I, v_{p2}, p2c) \cdot Q_{22}$
NH_4^+ uptake, coccos	$n3n\_p3n = f_{T,3} \cdot \frac{p3c}{rcn3} \cdot v_{p3} \cdot f_{p3c} \cdot Q_{32}$
PO_4^{3-} uptake, diatoms	$n1p\_p1p = \frac{dic\_p1c\_red}{rcp}$
PO_4^{3-} uptake, non-diatoms	$n1p\_p2p = \frac{dic\_p2c\_red}{rcp2}$
PO_4^{3-} uptake, coccos	$n1p\_p3p = \begin{cases} \frac{dic\_p3c\_red}{rcp3} & \text{for dop\_uptake} = \textbf{.false.} \\ 0 & \text{otherwise} \end{cases}$
DOP uptake, coccos	$dop\_p3p = \begin{cases} \frac{dic\_p3c\_red}{rcp3} & \text{for dop\_uptake} = \textbf{.true.} \\ 0 & \text{otherwise} \end{cases}$
SiO_x uptake, diatoms	$n5s\_p1s = \frac{dic\_p1c\_red}{rcs}$
$CaCO_3$ uptake, non-diatoms	$dic\_psk = \frac{dic\_p2c\_red}{q\_c\_cal}$
$CaCO_3$ uptake, coccos	$dic\_p3k = f_{T,3} \cdot p3c \cdot f_{p3k} \cdot c_{max} \cdot lim\_calc$

Table 4.2: Process formulations for phytoplankton.

process description	**process formulation**
loss of diatoms to d1c	$p1c\_d1c = (1 - frac_{d2}) \cdot M_{p1c}$
loss of non-diatoms to d1c	$p2c\_d1c = (1 - frac_{d2}) \cdot M_{p2c}$
loss of coccos to d1c	$p3c\_d1c = (1 - frac_{d2}) \cdot M_{p3c}$
loss of diatoms to d2c	$p1c\_d2c = frac_{d2} \cdot M_{p1c}$
loss of non-diatoms to d2c	$p2c\_d2c = frac_{d2} \cdot M_{p2c}$
loss of coccos to d2c	$p3c\_d2c = frac_{d2} \cdot M_{p3c}$
loss of diatoms to d1n	$p1n\_d1n = \frac{p1c\_d1c}{rcn}$
loss of non-diatoms to d1n	$p2n\_d1n = \frac{p2c\_d1c}{rcn2}$
loss of coccos to d1n	$p3n\_d1n = \frac{p3c\_d1c}{rcn3}$
loss of diatoms to d2n	$p1n\_d2n = \frac{p1c\_d2c}{rcn}$
loss of non-diatoms to d2n	$p2n\_d2n = \frac{p2c\_d2c}{rcn2}$
loss of coccos to d2n	$p3n\_d2n = \frac{p3c\_d2c}{rcn3}$
loss of diatoms to d1p	$p1p\_d1p = \frac{p1c\_d1c}{rcp}$
loss of non-diatoms to d1p	$p2p\_d1p = \frac{p2c\_d1c}{rcp2}$
loss of coccos to d1p	$p3p\_d1p = \frac{p3c\_d1c}{rcp3}$
loss of diatoms to d2p	$p1p\_d2p = \frac{p1c\_d2c}{rcp}$
loss of non-diatoms to d2p	$p2p\_d2p = \frac{p2c\_d2c}{rcp2}$
loss of coccos to d2p	$p3p\_d2p = \frac{p3c\_d2c}{rcp3}$
loss of diatoms to d2s	$p1s\_d2s = \frac{p1c\_d1c+p1c\_d2c}{rcs} + \max\left(0, \frac{p1c\_doc+p1c\_z2c1}{rcs} - n5s\_p1s\right)$
formation of detritus-$CaCO_3$, non-diatoms	$psk\_d2k = \frac{p2c\_z1c+p2c\_z2c+p2c\_d1c+p2c\_d2c+p2c\_doc}{q\_c\_cal}$
formation of detritus-$CaCO_3$, coccos	$p3k\_d2k = \max(0, M_{p3k})$

Table 4.3: Process formulations for phytoplankton.

process description	**process formulation**
DOC exudation, diatoms	$p1c\_doc = \gamma_1 \cdot dic\_p1c\_red$
DOC exudation, non-diatoms	$p2c\_doc = \gamma_2 \cdot dic\_p2c\_red$
DOC exudation, coccos	$p3c\_doc = \gamma_3 \cdot dic\_p3c\_red$
DON exudation, diatoms	$p1n\_don = \frac{p1c\_doc}{rcn}$
DON exudation, non-diatoms	$p2n\_don = \frac{p2c\_doc}{rcn2}$
DON exudation, coccos	$p3n\_don = \frac{p3c\_doc}{rcn3}$
DOP exudation, diatoms	$p1p\_dop = \frac{p1c\_doc}{rcp}$
DOP exudation, non-diatoms	$p2p\_dop = \frac{p2c\_doc}{rcp2}$
DOP exudation, coccos	$p3p\_dop = \frac{p3c\_doc}{rcp3}$
SOC exudation, diatoms	$p1c\_soc = dic\_p1c - dic\_p1c\_red$
SOC exudation, non-diatoms	$p2c\_soc = dic\_p2c - dic\_p2c\_red$
SOC exudation, coccos	$p3c\_soc = dic\_p3c - dic\_p3c\_red$

Table 4.4: Process formulations for zooplankton.

process description	**process formulation**
microzoopl. grazing on diatoms, C	$p1c\_z1c = G_1(p1n) \cdot \frac{p1c}{p1n}$
mesozoopl. grazing on diatoms, C	$p1c\_z2c = G_2(p1n) \cdot \frac{p1c}{p1n}$
microzoopl. grazing on non-diatoms, C	$p2c\_z1c = G_1(p2n) \cdot \frac{p2c}{p2n}$
mesozoopl. grazing on non-diatoms, C	$p2c\_z2c = G_2(p2n) \cdot \frac{p2c}{p2n}$
microzoopl. grazing on coccos, C	$p3c\_z1c = G_1(p3n) \cdot \frac{p3c}{p3n}$
mesozoopl. grazing on coccos, C	$p3c\_z2c = G_2(p3n) \cdot \frac{p3c}{p3n}$
microzoopl. grazing on detritus, C	$d1c\_z1c = G_1(d1n) \cdot \frac{d1c}{d1n}$
mesozoopl. grazing on detritus, C	$d1c\_z2c = G_2(d1n) \cdot \frac{d1c}{d1n}$
microzoopl. grazing on bacteria, C	$bac\_z1c = G_1(ban) \cdot \frac{bac}{ban}$
mesozoopl. grazing on bacteria, C	$bac\_z2c = G_2(ban) \cdot \frac{bac}{ban}$
mesozoopl. grazing on microzoopl., C	$z1c\_z2c = G_2(z1n) \cdot \frac{z1c}{z1n}$
microzoopl. grazing on diatoms, N	$p1n\_z1n = G_1(p1n)$
mesozoopl. grazing on diatoms, N	$p1n\_z2n = G_2(p1n)$
microzoopl. grazing on non-diatoms, N	$p2n\_z1n = G_1(p2n)$
mesozoopl. grazing on non-diatoms, N	$p2n\_z2n = G_2(p2n)$
microzoopl. grazing on coccos, N	$p3n\_z1n = G_1(p3n)$
mesozoopl. grazing on coccos, N	$p3n\_z2n = G_2(p3n)$
microzoopl. grazing on detritus, N	$d1n\_z1n = G_1(d1n)$
mesozoopl. grazing on detritus, N	$d1n\_z2n = G_2(d1n)$
microzoopl. grazing on bacteria, N	$ban\_z1n = G_1(ban)$
mesozoopl. grazing on bacteria, N	$ban\_z2n = G_2(ban)$
mesozoopl. grazing on microzoopl., N	$z1n\_z2n = G_2(z1n)$
microzoopl. grazing on diatoms, P	$p1p\_z1p = G_1(p1n) \cdot \frac{p1p}{p1n}$
mesozoopl. grazing on diatoms, P	$p1p\_z2p = G_2(p1n) \cdot \frac{p1p}{p1n}$
microzoopl. grazing on non-diatoms, P	$p2p\_z1p = G_1(p2n) \cdot \frac{p2p}{p2n}$
mesozoopl. grazing on non-diatoms, P	$p2p\_z2p = G_2(p2n) \cdot \frac{p2p}{p2n}$
microzoopl. grazing on coccos, P	$p3p\_z1p = G_1(p3n) \cdot \frac{p3p}{p3n}$
mesozoopl. grazing on coccos, P	$p3p\_z2p = G_2(p3n) \cdot \frac{p3p}{p3n}$
microzoopl. grazing on detritus, P	$d1p\_z1p = G_1(d1n) \cdot \frac{d1p}{d1n}$
mesozoopl. grazing on detritus, P	$d1p\_z2p = G_2(d1n) \cdot \frac{d1p}{d1n}$
microzoopl. grazing on bacteria, P	$bap\_z1p = G_1(ban) \cdot \frac{bap}{ban}$
mesozoopl. grazing on bacteria, P	$bap\_z2p = G_2(ban) \cdot \frac{bap}{ban}$
mesozoopl. grazing on microzoopl., P	$z1p\_z2p = G_2(z1n) \cdot \frac{z1p}{z1n}$
microzoopl. grazing on coccos, $CaCO_3$	$p3k\_z1c = p3c\_z1c \cdot \frac{p3c}{p3k}$
mesozoopl. grazing on coccos, $CaCO_3$	$p2k\_z2c = p3c\_z2c \cdot \frac{p3c}{p3k}$

Table 4.5: Process formulations for zooplankton.

process description	**process formulation**
microzooplankton food, C	$F_{z1c} = p1c\_z1c + p2c\_z1c + d1c\_z1c + bac\_z1c$
mesozooplankton food, C	$F_{z2c} = p1c\_z2c + p2c\_z2c + d1c\_z2c + bac\_z2c + z1c\_z2c$
microzooplankton food, N	$F_{z1n} = p1n\_z1n + p2n\_z1n + d1n\_z1n + ban\_z1n$
mesozooplankton food, N	$F_{z2n} = p1n\_z2n + p2n\_z2n + d1n\_z2n + ban\_z2n + z1n\_z2n$
microzooplankton food, P	$F_{z1p} = p1p\_z1p + p2p\_z1p + d1p\_z1p + bap\_z1p$
mesozooplankton food, P	$F_{z2p} = p1p\_z2p + p2p\_z2p + d1p\_z2p + bap\_z2p + z1p\_z2p$
microzoopl. fecal pellets into *d1c*	$z1c\_d1c = [(1 - \delta_{z1n} - \epsilon_{z1n}) \cdot M_{z1n} \cdot rcnz1 + (1 - \beta_1) \cdot F_{z1c}] \cdot (1 - frac_{d2})$
mesozoopl. fecal pellets into *d1c*	$z2c\_d1c = [(1 - \delta_{z2n} - \epsilon_{z2n}) \cdot M_{z2n} \cdot rcnz2 + (1 - \beta_2) \cdot F_{z2c}] \cdot (1 - frac_{d2})$
microzoopl. fecal pellets into *d2c*	$z1c\_d2c = [(1 - \delta_{z1n} - \epsilon_{z1n}) \cdot M_{z1n} \cdot rcnz1 + (1 - \beta_1) \cdot F_{z1c}] \cdot frac_{d2}$
mesozoopl. fecal pellets into *d2c*	$z2c\_d2c = [(1 - \delta_{z2n} - \epsilon_{z2n}) \cdot M_{z2n} \cdot rcnz2 + (1 - \beta_2) \cdot F_{z2c}] \cdot frac_{d2}$
microzoopl. fecal pellets into *d1n*	$z1n\_d1n = [(1 - \delta_{z1n} - \epsilon_{z1n}) \cdot M_{z1n} + (1 - \beta_1) \cdot F_{z1n}] \cdot (1 - frac_{d2})$
mesozoopl. fecal pellets into *d1n*	$z2n\_d1n = [(1 - \delta_{z2n} - \epsilon_{z2n}) \cdot M_{z2n} + (1 - \beta_2) \cdot F_{z2n}] \cdot (1 - frac_{d2})$
microzoopl. fecal pellets into *d2n*	$z1n\_d2n = [(1 - \delta_{z1n} - \epsilon_{z1n}) \cdot M_{z1n} + (1 - \beta_1) \cdot F_{z1n}] \cdot frac_{d2}$
mesozoopl. fecal pellets into *d2n*	$z2n\_d2n = [(1 - \delta_{z2n} - \epsilon_{z2n}) \cdot M_{z2n} + (1 - \beta_2) \cdot F_{z2n}] \cdot frac_{d2}$
microzoopl. fecal pellets into *d1p*	$z1p\_d1p = \left[(1 - \delta_{z1n} - \epsilon_{z1n}) \cdot M_{z1n} \cdot \frac{rcnz1}{rcpz1} + (1 - \beta_1) \cdot F_{z1p}\right] \cdot (1 - frac_{d2})$
mesozoopl. fecal pellets into *d1p*	$z2p\_d1p = \left[(1 - \delta_{z2n} - \epsilon_{z2n}) \cdot M_{z2n} \cdot \frac{rcnz2}{rcpz2} + (1 - \beta_2) \cdot F_{z2p}\right] \cdot (1 - frac_{d2})$
microzoopl. fecal pellets into *d1p*	$z1p\_d2p = \left[(1 - \delta_{z1n} - \epsilon_{z1n}) \cdot M_{z1n} \cdot \frac{rcnz1}{rcpz1} + (1 - \beta_1) \cdot F_{z1p}\right] \cdot frac_{d2}$
mesozoopl. fecal pellets into *d1p*	$z2p\_d2p = \left[(1 - \delta_{z2n} - \epsilon_{z2n}) \cdot M_{z2n} \cdot \frac{rcnz2}{rcpz2} + (1 - \beta_2) \cdot F_{z2p}\right] \cdot frac_{d2}$

Table 4.6: Process formulations for zooplankton.

process description	**process formulation**
microzoopl., uncorrected C respiration	$h\_z1c\_dic = \epsilon_{z1n} \cdot M_{z1n} \cdot rcnz1$
mesozoopl., uncorrected C respiration	$h\_z2c\_dic = \epsilon_{z2n} \cdot M_{z2n} \cdot rcnz2$
microzoopl., uncorrected NH_4^+ excretion	$h\_z1n\_n4n = \epsilon_{z1n} \cdot M_{z1n}$
mesozoopl., uncorrected NH_4^+ excretion	$h\_z2n\_n4n = \epsilon_{z2n} \cdot M_{z2n}$
microzoopl., uncorrected PO_4^{3-} excretion	$h\_z1p\_n1p = \epsilon_{z1n} \cdot M_{z1n} \cdot \frac{rcnz1}{rcpz1}$
mesozoopl., uncorrected PO_4^{3-} excretion	$h\_z2p\_n1p = \epsilon_{z1n} \cdot M_{z2n} \cdot \frac{rcnz2}{rcpz2}$
microzoopl., uncorrected DON excretion	$h\_z1n\_don = \delta_{z1n} \cdot M_{z1n}$
mesozoopl., uncorrected DON excretion	$h\_z2n\_don = \delta_{z2n} \cdot M_{z2n}$
microzoopl., uncorrected DOP excretion	$h\_z1p\_dop = \delta_{z1n} \cdot M_{z1n} \cdot \frac{rcnz1}{rcpz1}$
mesozoopl., uncorrected DOP excretion	$h\_z2p\_dop = \delta_{z2n} \cdot M_{z2n} \cdot \frac{rcnz2}{rcpz2}$
microzoopl., sum of unbalanced C fluxes	$f\_z1c = F_{z1c} - z1c\_d1c - z1c\_d2c - z1c\_doc - h\_z1c\_dic$
mesozoopl., sum of unbalanced C fluxes	$f\_z2c = F_{z2c} - z2c\_d1c - z2c\_d2c - z1c\_doc - h\_z2c\_dic$
microzoopl., sum of unbalanced N fluxes	$f\_z1n = F_{z1n} - z1n\_d1n - z1n\_d2n - z1n\_don - h\_z1n\_n4n$
mesozoopl., sum of unbalanced N fluxes	$f\_z2n = F_{z2n} - z2n\_d1n - z2n\_d2n - z2n\_don - h\_z2n\_n4n$
microzoopl., sum of unbalanced P fluxes	$f\_z1p = F_{z1p} - z1p\_d1p - z1p\_d2p - z1p\_dop - h\_z1p\_n1p$
mesozoopl., sum of unbalanced P fluxes	$f\_z2p = F_{z2p} - z2p\_d1p - z2p\_d2p - z2p\_dop - h\_z2p\_n1p$

Table 4.7: Process formulations for zooplankton.

process description	**process formulation**
microzoopl., DOC excretion	$z1c\_doc = \delta_{z1n} \cdot M_{z1n} \cdot rcnz1$
mesozoopl., DOC excretion	$z2c\_doc = \delta_{z2n} \cdot M_{z2n} \cdot rcnz2$
microzoopl., DON excretion	$z1n\_don = \begin{cases} h\_z1n\_don + 0.5 \cdot \left(f\_z1n - \frac{1}{rcnz1} \cdot f\_z1c\right) & \text{for } \frac{f\_z1c}{f\_z1n} \leq rcnz1 \wedge \frac{f\_z1c}{f\_z1p} \leq rcpz1 \\ h\_z1n\_don + 0.5 \cdot \left(f\_z1n - \frac{rcpz1}{rcnz1} \cdot f\_z1p\right) & \text{for } \frac{f\_z1c}{f\_z1p} \geq rcpz1 \wedge \frac{f\_z1n}{f\_z1p} \geq \frac{rcpz1}{rcnz1} \\ h\_z1n\_don & \text{otherwise} \end{cases}$
mesozoopl., DON excretion	$z2n\_don = \begin{cases} h\_z2n\_don + 0.5 \cdot \left(f\_z2n - \frac{1}{rcnz2} \cdot f\_z2c\right) & \text{for } \frac{f\_z2c}{f\_z2n} \leq rcnz2 \wedge \frac{f\_z2c}{f\_z2n} \leq rcpz2 \\ h\_z2n\_don + 0.5 \cdot \left(f\_z2n - \frac{rcpz2}{rcnz2} \cdot f\_z2p\right) & \text{for } \frac{f\_z2c}{f\_z2p} \geq rcpz2 \wedge \frac{f\_z2n}{f\_z2n} \geq \frac{rcpz2}{rcnz2} \\ h\_z2n\_don & \text{otherwise} \end{cases}$
microzoopl., DOP excretion	$z1p\_dop = \begin{cases} h\_z1p\_dop + 0.5 \cdot \left(f\_z1p - \frac{1}{rcpz1} \cdot f\_z1c\right) & \text{for } \frac{f\_z1c}{f\_z1n} \leq rcnz1 \wedge \frac{f\_z1c}{f\_z1p} \leq rcpz1 \\ h\_z1p\_dop + 0.5 \cdot \left(f\_z1p - \frac{rcnz1}{rcpz1} \cdot f\_z1n\right) & \text{for } \frac{f\_z1c}{f\_z1n} \geq rcnz1 \wedge \frac{f\_z1n}{f\_z1p} \leq \frac{rcpz1}{rcnz1} \\ h\_z1p\_dop & \text{otherwise} \end{cases}$
mesozoopl., DOP excretion	$z2p\_dop = \begin{cases} h\_z2p\_dop + 0.5 \cdot \left(f\_z2p - \frac{1}{rcpz2} \cdot f\_z2c\right) & \text{for } \frac{f\_z1c}{f\_z1n} \leq rcnz1 \wedge \frac{f\_z1c}{f\_z1p} \leq rcpz2 \\ h\_z2p\_dop + 0.5 \cdot \left(f\_z2p - \frac{rcnz2}{rcpz2} \cdot f\_z2n\right) & \text{for } \frac{f\_z1c}{f\_z1n} \geq rcnz1 \wedge \frac{f\_z1p}{f\_z1p} \leq \frac{rcpz2}{rcnz2} \\ h\_z2p\_dop & \text{otherwise} \end{cases}$

Table 4.8: Process formulations for zooplankton.

process description	**process formulation (D093)**
microzoopl. C respiration	$z1c\_dic = \begin{cases} h\_z1c\_dic + f\_z1c - rcnz1 \cdot f\_z1n & \text{for } \frac{f\_z1c}{f\_z1n} \geq rcnz1 \wedge \frac{f\_z1n}{f\_z1p} \leq \frac{rcpz1}{rcnz1} \\ h\_z1c\_dic + f\_z1c - rcpz1 \cdot f\_z1p & \text{for } \frac{f\_z1c}{f\_z1p} \geq rcpz1 \wedge \frac{f\_z1n}{f\_z1p} \geq \frac{rcpz1}{rcnz1} \\ h\_z1c\_dic & \text{otherwise} \end{cases}$
mesozoopl. C respiration	$z2c\_dic = \begin{cases} h\_z2c\_dic + f\_z2c - rcnz2 \cdot f\_z2n & \text{for } \frac{f\_z2c}{f\_z2n} \geq rcnz2 \wedge \frac{f\_z2n}{f\_z2p} \leq \frac{rcpz2}{rcnz2} \\ h\_z2c\_dic + f\_z2c - rcpz2 \cdot f\_z2p & \text{for } \frac{f\_z2c}{f\_z2p} \geq rcpz2 \wedge \frac{f\_z2n}{f\_z2p} \geq \frac{rcpz2}{rcnz2} \\ h\_z2c\_dic & \text{otherwise} \end{cases}$
microzoopl., NH_4^+ excretion	$z1n\_n4n = \begin{cases} h\_z1n\_n4n + 0.5 \cdot \left(f\_z1n - \frac{1}{rcnz1} \cdot f\_z1c\right) & \text{for } \frac{f\_z1c}{f\_z1n} \leq rcnz1 \wedge \frac{f\_z1c}{f\_z1p} \leq rcpz1 \\ h\_z1n\_n4n + 0.5 \cdot \left(f\_z1n - \frac{rcpz1}{rcnz1} \cdot f\_z1p\right) & \text{for } \frac{f\_z1c}{f\_z1p} \geq rcpz1 \wedge \frac{f\_z1n}{f\_z1p} \geq \frac{rcpz1}{rcnz1} \\ h\_z1n\_n4n & \text{otherwise} \end{cases}$
mesozoopl., NH_4^+ excretion	$z2n\_n4n = \begin{cases} h\_z2n\_n4n + 0.5 \cdot \left(f\_z2n - \frac{1}{rcnz2} \cdot f\_z2c\right) & \text{for } \frac{f\_z2c}{f\_z2n} \leq rcnz2 \wedge \frac{f\_z2c}{f\_z2n} \leq rcpz2 \\ h\_z2n\_n4n + 0.5 \cdot \left(f\_z2n - \frac{rcpz2}{rcnz2} \cdot f\_z2p\right) & \text{for } \frac{f\_z2c}{f\_z2p} \geq rcpz2 \wedge \frac{f\_z2n}{f\_z2n} \geq \frac{rcpz2}{rcnz2} \\ h\_z2n\_n4n & \text{otherwise} \end{cases}$
microzoopl., PO_4^{3-} excretion	$z1p\_n1p = \begin{cases} h\_z1p\_n1p + 0.5 \cdot \left(f\_z1p - \frac{1}{rcpz1} \cdot f\_z1c\right) & \text{for } \frac{f\_z1c}{f\_z1n} \leq rcnz1 \wedge \frac{f\_z1c}{f\_z1p} \leq rcpz1 \\ h\_z1p\_n1p + 0.5 \cdot \left(f\_z1p - \frac{rcnz1}{rcpz1} \cdot f\_z1n\right) & \text{for } \frac{f\_z1c}{f\_z1n} \geq rcnz1 \wedge \frac{f\_z1n}{f\_z1p} \leq \frac{rcpz1}{rcnz1} \\ h\_z1p\_n1p & \text{otherwise} \end{cases}$
mesozoopl., PO_4^{3-} excretion	$z2p\_n1p = \begin{cases} h\_z2p\_n1p + 0.5 \cdot \left(f\_z2p - \frac{1}{rcpz2} \cdot f\_z2c\right) & \text{for } \frac{f\_z1c}{f\_z1n} \leq rcnz1 \wedge \frac{f\_z1c}{f\_z1p} \leq rcpz2 \\ h\_z2p\_n1p + 0.5 \cdot \left(f\_z2p - \frac{rcnz2}{rcpz2} \cdot f\_z2n\right) & \text{for } \frac{f\_z1c}{f\_z1n} \geq rcnz1 \wedge \frac{f\_z1p}{f\_z1p} \leq \frac{rcpz2}{rcnz2} \\ h\_z2p\_n1p & \text{otherwise} \end{cases}$

Table 4.9: Process formulations for detritus.

process description	**process formulation**
decay of slowly sinking detritus into DOC	$d1c\_doc = \mu_{d1n} \cdot f_T \cdot d1c \cdot R_{\mu_{det}}$
decay of fast sinking detritus into DOC	$d2c\_doc = \mu_{d2n} \cdot f_T \cdot d2c \cdot R_{\mu_{det}}$
decay of slowly sinking detritus into DON	$d1n\_don = \mu_{d1n} \cdot f_T \cdot d1n$
decay of fast sinking detritus into DON	$d2n\_don = \mu_{d2n} \cdot f_T \cdot d2n$
decay of slowly sinking detritus into DOP	$d1p\_dop = \mu_{d1n} \cdot f_T \cdot d1p$
decay of fast sinking detritus into DOP	$d2p\_dop = \mu_{d2n} \cdot f_T \cdot d2p$
decay of fast sinking detritus into dissolved SiO_x	$d2s\_n5s = \mu_{d2n} \cdot f_T \cdot d2s \cdot \frac{R_{\mu_{det}}}{10}$
dissolution rate of $CaCO_3$	$d2k\_dic = \begin{cases} \frac{1}{30} \cdot d2k \cdot \left(1 - \frac{\delta CO_3^{2-}}{\delta CO_3^{2-} + 100}\right) & \text{for } \delta CO_3^{2-} < 0 \lor \text{caco3\_diss} = 1 \\ 0 & \text{otherwise} \end{cases}$
oversaturation of $CaCO_3$	$\delta CO_3^{2-} = \max\left(0, [CO_3^{2-}] - \frac{K_{sp}}{[Ca^{2+}]}\right)$

Table 4.10: Process formulations for bacteria.

process description	**process formulation (D093)**
DOC uptake by bacteria	$doc\_bac = v_{ba} \cdot f_T \cdot \frac{don}{K_4+don} \cdot ban \cdot \frac{doc}{don}$
DON uptake by bacteria	$don\_ban = v_{ba} \cdot f_T \cdot \frac{don}{K_4+don} \cdot ban$
DOP uptake by bacteria	$dop\_bap = \begin{cases} \frac{dop}{K_{P,b}+dop} \cdot bap & \text{for } dop > 10^{-6}\ \mathrm{mmol\,P\,m^{-3}} \\ 0 & \text{otherwise} \end{cases}$
max. possible PO_4^{3-} uptake by bacteria	$f\_bap\_max = n4n\_ban \cdot \frac{n1p}{n4n}$
PO_4^{3-} required by bacteria	$f\_bap\_req = (don\_ban + n4n\_ban - ban\_n4n) \cdot \frac{rcnb}{rcpb} - dop\_bap$
	$f\_bap\_diff = \max(0, f\_bap\_req - f\_bap\_max)$
PO_4^{3-} uptake by bacteria	$n1p\_bap = \min(\max(0, fbpreq), fbpmax)$
PO_4^{3-} release by bacteria	$bap\_n1p = \max(0, -fbpreq)$
uncorrected bacteria respiration, C	$h\_bac\_dic = \mu_{ba} \cdot f_T \cdot bac$
sum of unbalanced C fluxes into bacteria	$f\_bac = doc\_bac - bac\_z1c - bac\_z2c - h\_bac\_dic$
sum of unbalanced N fluxes into bacteria	$f\_ban = don\_ban + n4n\_ban - ban\_z1n - ban\_z2n - ban\_n4n$
	$f\_bac\_diff = h\_bac\_dic + f\_bac - f\_ban$
bacterial C respiration	$bac\_dic = \begin{cases} f\_bac\_diff + f\_bap\_diff \cdot rcpb & \text{for } \frac{f\_bac}{f\_ban} > rcnb \wedge n4n \leq tres\_n4n \\ \max(0, f\_bac\_diff) + f\_bap\_diff \cdot rcpb & \text{for } \frac{f\_bac}{f\_ban} \leq rcnb \end{cases}$
NH_4^+ uptake by bacteria	$n4n\_ban = \begin{cases} \left(\frac{1}{rcnb} \cdot \frac{doc}{don} - 1\right) \cdot don\_ban & \text{for } \frac{f\_bac}{f\_ban} > rcnb \wedge n4n > tres\_n4n \\ 0 & \text{otherwise} \end{cases}$
uncorrected NH_4^+ excretion by bacteria	$h\_ban\_n4n = \mu_{ba} \cdot f_T \cdot ban$
NH_4^+ excretion by bacteria	$ban\_n4n = \begin{cases} h\_ban\_n4n + f\_bap\_diff \cdot \frac{rcpb}{rcnb} - \min\left(0, \frac{f\_bac\_diff}{rcnb}\right) & \text{for } \frac{f\_bac}{f\_ban} \leq rcnb \\ h\_ban\_n4n + f\_bap\_diff \cdot \frac{rcpb}{rcnb} & \text{otherwise} \end{cases}$

Table 4.11: Process formulations for further processes.

process description	**process formulation**
nitrification	$n4n\_n3n = \mathrm{oswtch} \cdot f_T \cdot r_{nit}(I,z) \cdot n4n$
benthic C remineralistaion	$sed\_dic = brc \cdot \frac{sd\_poc}{dz(k0)}, \quad k0:$ pelagic bottom layer index
potential benthic denitrification	$bdnf\_basic = p_{Seitz} \cdot o2o\_brm$
benthic denitrification	$sed\_nn2 = \frac{1}{dz(k0)} \cdot (bdnf\_basic - \max(0, bdnf\_basic - h\_sed\_n4n))$
uncorrected benthic N remineralisation	$h\_sed\_n4n = brn \cdot \frac{sd\_pon}{dz(k0)}$
benthic N remineralisation	$sed\_n4n = \max(0, h\_sed\_n4n - bdnf\_basic)]$
benthic N reduction (anoxic)	$n3n\_brm = 0.5 \cdot (1 - \mathrm{oswtch}) \cdot \mathrm{nswtch} \cdot sed\_n4n$
benthic $CaCO_3$ dissolution	$sed\_o3c = \begin{cases} \frac{1}{30} \cdot sd\_pok \cdot \left(1 - \frac{\delta \mathrm{CO}_3^{2-}\|_{k0}}{\delta \mathrm{CO}_3^{2-}\|_{k0} + 100}\right) & \text{for } \delta \mathrm{CO}_3^{2-}\|_{k0} < 0 \vee \mathrm{caco3\_diss} = 1 \\ 0 & \text{otherwise} \end{cases}$
O_2 consumption by benthic C remin.	$o2o\_brm = [\mathrm{oswtch} + (1 - \mathrm{oswtch}) \cdot (1 - \mathrm{nswtch})] \cdot sed\_dic$
O_2 release by photosynthesis, diatoms	$p1c\_o2o = dic\_p1c$
O_2 release by photosyn., non-diatoms	$p2c\_o2o = dic\_p2c$
O_2 consumption by microzoopl.	$o2o\_z1c = z1c\_dic$
O_2 consumption by mesozoopl.	$o2o\_z2c = z2c\_dic$
O_2 consumption by bacteria/H_2S production	$o2o\_bac = [\mathrm{oswtch} + (1 - \mathrm{oswtch}) \cdot (1 - \mathrm{nswtch})] \cdot bac\_dic$
N_2 production due to denitrifcation	$n3n\_nn2 = 0.5 \cdot (1 - \mathrm{oswtch}) \cdot \mathrm{nswtch} \cdot \frac{bac\_dic}{rcnb}$
O_2 consumption by nitrification	$o2o\_n4n = 2 \cdot n4n\_n3n$
air-sea flux of O_2	$air\_o2o = K_W \cdot K_H \cdot \frac{\mathrm{pO}_2(air) - \mathrm{pO}_2(sea)}{dz(1)}$
air-sea flux of CO_2	$air\_o2c = K_W \cdot K_H \frac{\mathrm{pCO}_2(air) - \mathrm{pCO}_2(sea)}{dz(1)}$
sinking of variable X	$var\_sed = w_{s,X} \cdot \frac{\partial X}{\partial z}$
vertical mixing of variable X	$mxv\_var = \frac{\partial}{\partial z}\left(A_v \cdot \frac{\partial X}{\partial z}\right)$
horizontal mixing of variable X	$mxh\_var = \frac{\partial}{\partial x}\left(A_h \cdot \frac{\partial X}{\partial z}\right) + \frac{\partial}{\partial y}\left(A_h \cdot \frac{\partial X}{\partial y}\right)$
vertical advection of variable X	$adv\_var = w\frac{\partial X}{\partial z}$
horizontal advection of variable X	$adh\_var = u\frac{\partial X}{\partial x} + v\frac{\partial X}{\partial y}$
hydrodynamic fluxes of variable X	$hyd\_var = mxv\_var + mxh\_var + adv\_var + adh\_var$

Chapter 5

Special functions used for process parameterisations

Table 5.1: Formulations for special functions.

function name	**formulation**
depth-depending PAR	$I_{par}(z) = k_{par} \cdot I_0 \cdot \exp(\epsilon(z)) \quad z$: depth $\epsilon(z) = (k_w + k_c \cdot phc + k_s \cdot silt) \cdot z$
light limitation, phytoplankton	$f_{par}(I, v_i, X_i) = \frac{I_{par}(z)}{I_{opt}} \cdot \exp\left(1 - \frac{I_{par}(z)}{I_{opt}}\right)$ with: $X_1 = p1c, v_1 = v_{p1}$ and $X_2 = p2c, v_2 = v_{p2}$
light adaption	$\frac{\partial I_{opt}}{\partial t} = rupli \cdot (actual\_light - I_{opt})$ $rupli = 0.25d^{-1}$ $actual\_light = k_{par} \cdot \bar{I}_0 \cdot \exp(\epsilon(z_a))$ $z_a = \min(z, z_{max}) \quad z_{max} = 4\ m$ $\bar{I}_0$: daily mean irradiance
light-dependent nitrification rate	$r_{nit}(I, z) = \begin{cases} r_0 & \text{for } z \geq d_{eu} \\ 0.01 \cdot r_0 \cdot \frac{I_{par}(0)}{I_{par}(z)} & \text{otherwise} \end{cases}$ d_{eu}: depth of 1% light level
temperature factor, basic	$f_T = const. = 1$
temperature factor, type 1	$f_{T,i}(T) = 1.5^{\frac{T - 10^\circ\mathrm{C}}{10^\circ\mathrm{C}}} \quad$ with $i = 0, ..., 3$
temperature factor, type 2	$f_{T,X_i}(T) = 1.5^{\frac{T - 10^\circ\mathrm{C}}{10^\circ\mathrm{C}}} \quad$ with $X_1 = z1, X_2 = z2$
switch for O_2 variability	$\text{oswitch} = \begin{cases} 0 & \text{for } o2o \leq 0 \\ 1 & \text{otherwise} \end{cases}$
switch for NO_3^- variability	$\text{nswitch} = \begin{cases} 0 & \text{for } n3n \leq 0.1 \\ 1 & \text{otherwise} \end{cases}$

Table 5.2: Formulations for special functions.

function name	**formulation**
NO_3^- limitation, diatoms	$lip1\_n3 = \frac{n3n/K_1}{1+n3n/K_1+n4n/K_{21}} = Q_{11}$
NO_3^- limitation, non-diatoms	$lip2\_n3 = \frac{n3n/K_1}{1+n3n/K_1+n4n/K_{22}} = Q_{12}$
NH_4^+ limitation, diatoms	$lip1\_n4 = \frac{n4n/K_{21}}{1+n3n/K_1+n4n/K_{21}} = Q_{21}$
NH_4^+ limitation, non-diatoms	$lip2\_n4 = \frac{n4n/K_{22}}{1+n3n/K_1+n4n/K_{22}} = Q_{22}$
total N limitation, diatoms	$lip1\_hn = lip1\_3n + lip1\_4n$
total N limitation, non-diatoms	$lip2\_hn = lip2\_3n + lip2\_4n$
PO_4^{3-} limitation, diatoms	$lip1\_1p = \frac{n1p}{K_P+n1p}$
SiO_x limitation, diatoms	$lip1\_5s = \frac{n5s}{K_S+n5s}$
PO_4^{3-} limitation, non-diatoms	$lip2\_1p = \frac{n1p}{K_P+n1p}$
phytoplankton mortality, C, all types	$M_{X_i} = f_T \cdot \mu_{u,Y_i} \cdot X_i + \mu_{q,Y_i} \cdot X_i \cdot X_i$
	with: $X_1 = p1c, Y_1 = p1$; $X_2 = p2c, Y_2 = p2$; $X_3 = p3c, Y_3 = p3$
phytoplankton mortality, $CaCO_3$, coccos	$M_{p3k} = \begin{cases} p3k + dic\_p3k - (p3c + f\_p3c) \cdot \frac{p3k}{p3c}\|_{min} & \text{for } \frac{p3k}{p3c}\|_{new} < \frac{p3k}{p3c}\|_{min} \\ detach\_min \cdot p3k + (p3c\_d1c + p3c\_d2c) \cdot \frac{p3k}{p3c} & \text{otherwise} \end{cases}$
	$f\_p3c = dic\_p3c - p3c\_doc - p3c\_soc - p3c\_d1c - p3c\_d2c$
C:$CaCO_3$ rate at end of time step, coccos	$\frac{p3k}{p3c}\|_{new} = \frac{p3c+f\_p3c}{p3k+dic\_p3k}$

Table 5.3: Formulations for special functions.

function name	**formulation**
microzoopl. grazing rates (Fasham, 1990)	$G_1(X_{1i}) = f_{T,z1} \cdot G_{1,max} \cdot \frac{X_{1i} \cdot \Pi_1(X_{1i})}{K_3 + \sum_j X_{1j} \cdot \Pi_1(X_{1j})} \cdot z1n$
	with: $X_{11} = p1n,\ X_{12} = p2n,\ X_{13} = d1n,\ X_{14} = ban$
mesozoopl. grazing rates (Fasham, 1990)	$G_2(X_{2i}) = f_{T,z2} \cdot G_{2,max} \cdot \frac{X_{2i} \cdot \Pi_2(X_{2i})}{K_3 + \sum_j X_{2j} \cdot \Pi_2(X_{2j})} \cdot z2n$
	with: $X_{21} = p1n,\ X_{22} = p2n,\ X_{23} = d1n,\ X_{24} = ban,\ X_{25} = z1n$
concentration-dependent grazing preferences	$\Pi_{ki} = \frac{\pi_{ki} \cdot X_{ki}}{\sum_j \pi_{kj} \cdot X_{kj}}$ with $\sum \pi_{kj} = 1$
microzoopl. grazing rates (Holling II/III)	$G_1(X_{1i}) = f_{T,z1} \cdot G_{1,max} \cdot \frac{X_{1i}^h \cdot \pi_1(X_{1i})}{K_3 + \sum_j X_{1j}^h \cdot \pi_1(X_{1j})} \cdot z1n,$ with$h = 1, 2$ (type II,III)
	and: $X_{11} = p1n,\ X_{12} = p2n,\ X_{13} = d1n,\ X_{14} = ban$
mesozoopl. grazing rates (Holling II/III)	$G_2(X_{2i}) = f_{T,z2} \cdot G_{2,max} \cdot \frac{X_{2i}^h \cdot \pi_2(X_{2i})}{K_3 + \sum_j X_{2j}^h \cdot \pi_2(X_{2j})} \cdot z2n,$ with$h = 1, 2$ (type II,III)
	and: $X_{21} = p1n,\ X_{22} = p2n,\ X_{23} = d1n,\ X_{24} = ban,\ X_{25} = z1n$
zooplankton mortality, linear, N (D093)	$M_{u,X_i} = pred_1 + f_{T,Y_i} \cdot \frac{\mu_{u,Y_i}}{K_6(X_i) + X_i}$
zooplankton mortality, quadratic, N (D093)	$M_{q,X_i} = pred_1 + f_{T,Y_i} \cdot \mu_{u,X_i} \cdot X_i + \mu_{q,X_i} \cdot X_i \cdot X_i$
	with: $X_1 = z1n, Y_1 = z1$ and $X_2 = z2n, Y_2 = z2$

Chapter 6

Parameters of the biogeochemical model

Note: All rates are valid for 10°C.

Table 6.1: List of parameters used in process formulations.

parameter	**unit**	**value**
assimilation efficiency of microzooplankton		$\beta_1 = 0.75$
assimilation efficiency of mesozooplankton		$\beta_2 = 0.75$
rate of benthic C remineralisation	d^{-1}	$brc = 0.028$
rate of benthic N and PO_4^{3-}remineralisation	d^{-1}	$brn = 0.033$
rate of benthic SiO_xremineralisation	d^{-1}	$brs = 0.013$
DON fraction of losses from microzooplankton		$\delta_{z1n} = 0.4$
DON fraction of losses from mesozooplankton		$\delta_{z2n} = 0.4$
NH_4^+ fraction of losses from microzooplankton		$\epsilon_{z1n} = 0.4$
NH_4^+ fraction of losses from mesozooplankton		$\epsilon_{z2n} = 0.4$
ratio of C breakdown rate to N breakdown rate	mol C/mol N	$R_{\mu_4} = 0.85$
fraction of fast sinking detritus		$frac_{d2} = 0.15$
maximum ingestion rate of microzooplankton	d^{-1}	$G_{1,max} = 0.5$
maximum ingestion rate of mesozooplankton	d^{-1}	$G_{2,max} = 0.4$
exudation fraction of diatoms		$\gamma_1 = 0.05$
exudation fraction of non-diatoms		$\gamma_2 = 0.05$
half-saturation constant of NO_3^- uptake by phytoplankton	$\mathrm{mmol\,N\,m^{-3}}$	$K_1 = 0.5$
half-saturation constant of NH_4^+ uptake by diatoms	$\mathrm{mmol\,N\,m^{-3}}$	$K_{21} = 0.5$
half-saturation constant of NH_4^+ uptake by non-diatoms	$\mathrm{mmol\,N\,m^{-3}}$	$K_{22} = 0.05$
half-saturation constant of PO_4^{3-} uptake by phytoplankton	$\mathrm{mmol\,P\,m^{-3}}$	$K_P = 0.05$
half-saturation constant of SiO_x uptake by diatoms	$\mathrm{mmol\,Si\,m^{-3}}$	$K_S = 0.5$
half-saturation constant of zooplankton ingestion	$\mathrm{mmol\,N\,m^{-3}}$	$K_3 = 1.0$
half-saturation constant of bacteria uptake	$\mathrm{mmol\,N\,m^{-3}}$	$K_4 = 0.1$
half-saturation constant of microzooplankton loss	$\mathrm{mmol\,N\,m^{-3}}$	$K_6(z1n) = 0.2$
half-saturation constant of mesozooplankton loss	$\mathrm{mmol\,N\,m^{-3}}$	$K_6(z1n) = 0.2$

Table 6.2: List of parameters used in process formulations.

parameter	**unit**	**value**
extinction coefficient for phytoplankton	$m^2\,mmol\,C^{-1}$	$k_c = 4.53 \cdot 10^{-3}$
extinction coefficient silt	$m^2\,mg1{-}1$	$k_s = 0.06 \cdot 10^{-3}$
locally varying extinction coefficient for water	m^{-1}	$0.09 \leq k_W \leq 0.1$
conversion factor for PAR		$k_{par} = 0.43$
mortality rate of diatoms, linear	d^{-1}	$\mu_{u,p1} = 0.035$
mortality rate of diatoms, quadratic	$m^3\,mmol\,C^{-1}\,d^{-1}$	$\mu_{q,p1} = 0.01$
mortality rate of non-diatoms, linear	d^{-1}	$\mu_{u,p2} = 0.035$
mortality rate of non-diatoms, quadratic	$m^3\,mmol\,C^{-1}\,d^{-1}$	$\mu_{q,p2} = 0.01$
maximum loss rate of microzooplankton, N, linear	d^{-1}	$\mu_{u,z1n} = 0.2$
maximum loss rate of microzooplankton, N, quadratic	$m^3\,mmol\,N^{-1}\,d^{-1}$	$\mu_{q,z1n} = 0$
maximum loss rate of mesozooplankton, N, linear	d^{-1}	$\mu_{u,z2n} = 0.2$
maximum loss rate of mesozooplankton, N, quadratic	$m^3\,mmol\,N^{-1}\,d^{-1}$	$\mu_{q,z2n} = 0$
excretion rate of bacteria	d^{-1}	$\mu_{ba} = 0.1$
breakdown rate of slowly sinking detritus-N	d^{-1}	$\mu_{d1n} = 0.12$
breakdown rate of fast sinking detritus-N	d^{-1}	$\mu_{d2n} = 0.1$
ratio of detritus breakdown rates C:N	mol C/mol N	$R_{\mu_{det}} = 0.86$
phytoplankton quadratic mortality factor	$m^3\,mmol\,C^{-1}\,d^{-1}$	$\mu_6 = 0.01$
maximum dissolution rate of $CaCO_3$	d^{-1}	$\mu_7 = 0.0333$
grazing preference of microzoopl. for diatoms		$\pi_1(p1n) = 0.0$
grazing preference of microzoopl. for non-diatoms		$\pi_1(p2n) = 0.33$
grazing preference of microzoopl. for coccolithophores		$\pi_1(p3n) = 0.0$
grazing preference of microzoopl. for detritus		$\pi_1(d1n) = 0.34$
grazing preference of microzoopl. for bacteria		$\pi_1(ban) = 0.33$
grazing preference of mesozoopl. for diatoms		$\pi_2(p1n) = 0.33$
grazing preference of mesozoopl. for non-diatoms		$\pi_2(p2n) = 0.0$
grazing preference of mesozoopl. for coccolithophores		$\pi_2(p3n) = 0.0$
grazing preference of mesozoopl. for detritus		$\pi_2(d1n) = 0.34$
grazing preference of mesozoopl. for bacteria		$\pi_2(ban) = 0.0$
grazing preference of mesozoopl. for microzoopl.		$\pi_2(z1n) = 0.33$
ratio of phytoplankton C to $CaCO_3$ shells	mol C/mol $CaCO_3$	$q\_c\_cal = 70$
maximum nitrification rate	d^{-1}	$r_0 = 0.02$
ratio of O_2 consumption by benthic denitrification	d^{-1}	$p_{Seitz} = 0.116$

Table 6.3: List of parameters used in process formulations.

parameter	unit	value
C:N ratio of diatoms	mol C/mol N	$rcn = 6.625$
C:P ratio of diatoms	mol C/mol P	$rcp = 132.5$
C:Si ratio of diatoms	mol C/mol Si	$rcs = 5.76$
C:N ratio of flagellates	mol C/mol N	$rcn2 = 6.625$
C:P ratio of flagellates	mol C/mol P	$rcp2 = 132.5$
C:N ratio of microzooplankton	mol C/mol N	$rcnz1 = 5.5$
C:P ratio of microzooplankton	mol C/mol P	$rcpz1 = 110$
C:N ratio of mesozooplankton	mol C/mol N	$rcnz2 = 5.5$
C:P ratio of mesozooplankton	mol C/mol P	$rcpz2 = 110$
C:N ratio of bacteria	mol N/mol P	$rcnb = 4$
C:P ratio of bacteria	mol C/mol P	$rcpb = 40$
locally varying silt concentration	$\mathrm{mg\,l^{-1}}$	$0.0 \leq silt \leq 35.7$
decay rate of SOC	$\mathrm{d^{-1}}$	$soc\_rate = 0.00274$
threshold for NH_4^+ uptake by bacteria	$\mathrm{mmol\,N\,m^{-3}}$	$tres\_n4n = 0.001$
maximum uptake rate bacteria	$\mathrm{d^{-1}}$	$v_{ba} = 1.4$
maximum growth rate diatoms	$\mathrm{d^{-1}}$	$v_{p1} = 1.1$
maximum growth rate non-diatoms	$\mathrm{d^{-1}}$	$v_{p2} = 0.9$
maximum growth rate coccolithophores	$\mathrm{d^{-1}}$	$v_{p3} = 0$ (if $p3$ disabled)
sinking velocity of slowly sinking detritus	$\mathrm{m\,d^{-1}}$	$w_{s,d1} = 0.4$
sinking velocity of fast sinking detritus	$\mathrm{m\,d^{-1}}$	$w_{s,d2} = 10.0$
sinking velocity of other state variables	$\mathrm{m\,d^{-1}}$	$w_{s,X} = 0$

Chapter 7

Sinking and mineral ballast

$$\frac{\partial d3c}{\partial t} = z1c\_d3c - d3c\_doc + tra\_d3c \tag{7.1}$$

$$\frac{\partial d3n}{\partial t} = z1n\_d3n - d3n\_don + tra\_d3n \tag{7.2}$$

$$\frac{\partial d3p}{\partial t} = z1p\_d3p - d3p\_dop + tra\_d3p \tag{7.3}$$

$$\frac{\partial d3k}{\partial t} = z1k\_d3k - d3k\_dic + tra\_d3k \tag{7.4}$$

$$faec2\_ratio = \frac{p3k\_z1k}{0.25 \cdot (d1c\_z1c + p2c\_z1c + bac\_z1c + p3c\_z1c)}, \tag{7.5}$$

where $d1c\_z1c$ denotes the grazing on detritus, $p2c\_z1c$ the grazing on flagellates and bac_z1c the grazing on bacteria. This ratio determines, how much material is entering the heavy detritus (with the constraint that it can be at maximum equal to one):

$$z1c\_d3c = faec2\_ratio \cdot 0.25 \cdot (d1c\_z1c + p2c\_z1c + bac\_z1c + p3c\_z1c). \tag{7.6}$$

The rest of the excreted carbon is divided into slowly ($d1c$) and fast ($d2c$) sinking detritus as before. The nitrogen and phosphorus components are calculated by dividing by the respective stoichiometric ratios of zooplankton.

Chapter 8

ECOHAM publications sorted by years

Müller, L.: *Sauerstoffdynamik der Nordsee, Untersuchungen mit einem dreidimensionalen Ökosystemmodell.* Bericht des Bundesamtes für Seeschifffahrt und Hydrographie, 43, 171 pp., 2008. PDF download.

Pätsch, J., Kühn, W.: *Nitrogen and carbon cycling in the North Sea and exchange with the North Atlantic – a model study, Part I. Nitrogen budget and fluxes.* Continental Shelf Research 28, 767–787, 2008. PDF download.

Stegert, C., Moll, A., Kreus, M.: *Validation of the three-dimensional ECOHAM model in the German Bight for 2004 including population dynamics of Pseudocalnus elongatus.* Journal of Sea Research, 62 (1), 1–15, 2009. PDF download.

Lenhart, H.-J., Mills, D.K., Baretta-Bekker, H., van Leeuwen, S.M., van der Molen, J., Baretta, J.W., Blaas, M., Desmit, X., Kühn, W., Lacroix, G., Los, H.J., Menesguen, A., Neves, R., Proctor, R., Ruardij, P., Skogen, M.D., Vanhoutte-Brunier, A., Villars, M.T., Wakelin, S.L.: *Predicting the consequences of nutrient reduction on the eutrophication status of the North Sea.* Journal of Marine Systems, 81 (1–2),148–170, 2010. DOI: 10.1016/j.jmarsys.2009.12.014. PDF download.

Lorkowski, I., Pätsch, J., Moll, A., Kühn, W.: *Interannual variability of carbon fluxes in the North Sea (1970-2006) – Abiotic and biotic drivers of the gas-exchange of* CO_2. Estuarine Coastal and Shelf Science, 100, 38–57, 2012. PDF download.

Pätsch, J., Lorkowski, I.: *Comparison of two techniques to separate physical- and biological-mediated* pCO_2 *in seawater.* Limnology and Oceanography: Methods, 11, 41–52, 2013. DOI: 10.4319/lom.2013.11.41. PDF download.

Chapter 9

ECOHAM setup files

Informationen for ECOHAM setup files. The file `eco_set` and `eco_bio` are nml Files. Also included in this chapter is the makefile for the program run.

The `eco_set.nml` File:

```
 &set_nml
runID            =    'B000'         ! simulation code (:= prefix output filenames)
iy1              =     1997          ! start year
im1              =        1          ! start month
id1              =        1          ! start day
ih1              =        0          ! start hour
iy2              =     1997          ! ending year
im2              =        1          ! ending month
id2              =       10          ! ending day
ih2              =       24          ! ending hour
dt               =     1800.         ! timestep in seconds for the update of hydro data
n_pos_out        =        5          ! number of output-watercolums (prt-files)
n_par2D_out      =        2          ! number of 2D output-strings (var2D_name) to be read
n_par3D_out      =        4          ! number of 3D output-strings (var3D_name) to be read
/

&overhead_nml
isw_dim          =        3          ! isw_dim=1 1D mode, isw_dim=3 3D mode
```

```
isw_sed          =        1          ! with sediment=1, without sediment=0
relrate          =        0.40       ! max rel.rate of change per time step
talk_treat       =        1          ! 0 - diagnostic treatment of alkalinity
!                                    ! 1 - prognostic treatment of alkalinity
CaCo3_diss       =        1          ! 0 - no CaCo3 dissolution above lysocline
!                                    ! 1 - with CaCO3 dissolution also above lysocline
ichain           =        0          ! ichain=0 first set in year
!                =                   ! ichain=1 follow-up sets in year
iwarm            =        1          ! warmstart=1
!                =                   ! cold<=0; cold=-n: n days spinup of hydro
iwarm_out        =        0          ! 0 - write warmstart only at end
!                =                   ! 1 - (re-)write warmstart every day
!                =                   ! 2 - write warmstart each day
iwarm_next       =        1          ! =1 warmstart.dat gets time (iy2,im2,id2)+24h
!                =                   ! =0 warmstart.dat gets time (iy2-1,im2,id2)+24h
warmstart_file   = 'warmstart_NWCS20D.in'
/

&grid_nml
grid_dir         = './Input/'
offset_istart    = 3
offset_iend      = 3
offset_jstart    = 3
offset_jend      = 3
/

&hydro_nml
hydro_dir        = './Input/'
advec            =     .true.        !
dif_hor          =     .true.        !
```

```
dif_ver          =     .true.        !
dyn_hor          =     .false.       !
hev              =       10.0        ! horizontal eddy viscosity  (?? m2/s ??) for biogeo 10
/

&meteo_nml
meteo_dir        = './Input/'
!meteo_suffix     = '.direct'
extw_dat         = './Input/extw.dat'
prec_evap_dat    = 'prec_evap_in.dat'
iwind            =        1          ! 1 - read wind data drom file
!                =                   ! 0 - const. south-westwind 20 m/s
windtimestep     =        6          ! timestep of wind forcing (h)
isol             =        1          ! 1 - read solar radiation from file
!                =                   ! 0 - const. shortwave radiation 100 Wm-2
radsoltimestep   =        2          ! timestep of solar forcing (h)
iairsea          =        1          ! 1 - airsea flux of O2,CO2 and N deposition
!                =                   ! 0 - no air_sea exchange
air_sea_mode     =        1          ! parametrisation of gas air_sea transfer
!                =                   ! 1 - Wanninkhof 1992
!                =                   ! 2 - Wanninkhof & McGillis 1999
!                                    ! 3 - Nightingale et al 2000
meteodilution    =        0          ! 1 - including dilution from prec-evap bilance
!                                    ! 0 - no dilution
atm_n            =      -1.0         ! atmospheric N-deposition (mmol N/m2/d)
!                                    ! -1:atm_n.dat will be read as ann. mean loads (mmol N/m2/d) NOX,NRED
!                                    ! -2:atm_n_mon.dat will be read as clim. monthly loads (mmol N/m2/d) NOX,NRED
extw             =      -1.0         ! extinction coefiecient water (1/m) former 0.04
!                =                   ! <0  => read extinction coeffiecient from file
pafr             =       0.43        ! photosynthetic active fraction of solar radiation
```

```
opt_irr          =       0.0        ! optimal light (w/m**2) only necessary for P-I after Steele
!                                   ! when opt_irr=0 then light adaptation will be performed
r_Iopt           =       0.25       ! relaxation (-time) for adapting Iopt to current light climate
Iopt_min         =      40.         ! -description missing-
Iopt_max         =      70.         ! -description missing-
adepth_max       =       4.         ! -description missing-
/

&silt_nml
silt_dir         = './Input/'
silt_dat         = 'silt.bin'
silt_mode        =       1          ! 0 - const. silt concentration "silt_conc"
!                                   ! 1 - read silt data drom file
!                                   ! 2 - dynamic silt model
silt_conc        =       0.3        ! silt_mode = 0: silt concentration  (g m-3)
!                                   ! silt_mode = 2: silt background concentration  (g m-3)
exts             =       0.06       ! extinction coeffiecient for silt (mg/l):ERSEM=0.04
silt_timestep    =      24          ! timestep of silt forcing (h)
/

&river_nml
river_dir        = './Input/'
river_bin        = 'river.bin'
freshwater_dat   = 'freshwater.dat'
num_riv          =       23         ! 149 old number of rivers loading material   FS:  former 150
!                =                  !  48 newly implemented by HL
!                =                  !  23 setup D093 by IL
riverdischarge   =        1         ! 1 - including river discharges
!                =                  ! 0 - no river input
riverdilution    =        1         ! 1 - including river dilution and freshwater input
```

```
!                =                   ! 0 - no freshwater input
riverdivergence  =     .false.       ! hydro forcing include divergences due to freshwater input
redfield_discharge =      0          ! 1 - derive d1c loads from d1n applying redfield ratio (riv_d1c:=riv_d1n*red)
!                                    ! 0 - keep d1c loads as read from file (NOTE: currently a factor *0.1 is applied addit
/

&restoring_nml
restoring_dir    = './Input/'         ! path to restoring data
restoring_prefix = 'rest'            ! e.g. 'eco4_rest'
restoring_sets   =     12            ! number of restoring sets/entries
/

! water column indeces for 1D output
&pos_out_nml, icol_output = 26 , jcol_output = 48  / ! FLEX
&pos_out_nml, icol_output = 33 , jcol_output = 55  / ! owsf
&pos_out_nml, icol_output = 50 , jcol_output = 71  / ! fsel
&pos_out_nml, icol_output = 58 , jcol_output = 54  / ! AB NERC-NSP
&pos_out_nml, icol_output = 43 , jcol_output = 49  / ! CS NERC-NSP
&pos_out_nml, icol_output = 47 , jcol_output = 67  / ! gg32
&pos_out_nml, icol_output = 49 , jcol_output = 70  / ! HR
&pos_out_nml, icol_output = 38 , jcol_output = 52  / ! CANOBA-38
&pos_out_nml, icol_output = 25 , jcol_output = 45  / ! CANOBA-74
&pos_out_nml, icol_output = 49 , jcol_output = 59  / ! T135
&pos_out_nml, icol_output = 45 , jcol_output = 56  / ! T235
&pos_out_nml, icol_output = 53 , jcol_output = 62  / ! T010
&pos_out_nml, icol_output = 70 , jcol_output = 34  / ! L4
&pos_out_nml, icol_output = 30 , jcol_output = 74  / ! SK06
&pos_out_nml, icol_output = 44 , jcol_output = 61  / ! FI
&pos_out_nml, icol_output = 63 , jcol_output = 55  / ! BCZ330
&pos_out_nml, icol_output = 36 , jcol_output = 40  / ! Stonehaven
```

```
&pos_out_nml, icol_output = 50 , jcol_output = 72  / ! ElbmÃ¼ndung
&pos_out_nml, icol_output = 51 , jcol_output = 71  / ! Weser
&pos_out_nml, icol_output = 52 , jcol_output = 66  / ! Ems
&pos_out_nml, icol_output = 61 , jcol_output = 57  / ! Haringfliet/Meuse
&pos_out_nml, icol_output = 54 , jcol_output = 48  / ! Humber
&pos_out_nml, icol_output = 25 , jcol_output = 62  / ! A_Norwegian rivers into box 23 (N2)
&pos_out_nml, icol_output = 29 , jcol_output = 73  / ! S_Norwegian rivers into box 43 (N10)
&pos_out_nml, icol_output = 48 , jcol_output = 43  / ! Esk of Montrose/Spey
&pos_out_nml, icol_output = 71 , jcol_output = 46  / ! Seine
&pos_out_nml, icol_output = 15 , jcol_output = 40  / !

! list of 2D-variables or keywords (to predifined lists of variables) for output
&var2D_out_nml, var2D_name = 'sedimentvars' /
&var2D_out_nml, var2D_name = 'f_d1c_sed' /
&var2D_out_nml, var2D_name = 'f_sed_dic' /

! list of 3D-variables or keywords (to predifined lists of variables) for output
&var3D_out_nml, var3D_name = 'statevars' /
&var3D_out_nml, var3D_name = 'derivedvars' /
&var3D_out_nml, var3D_name = 'othervars' /
&var3D_out_nml, var3D_name = 'oxygencycle' /
&var3D_out_nml, var3D_name = 'bacteriacycle' /
&var3D_out_nml, var3D_name = 'remineralisation' /
&var3D_out_nml, var3D_name = 'NEP-C' /
&var3D_out_nml, var3D_name = 'N-uptake' /

!-----------------------------------------------------------
! list of keywords available
!-----------------------------------------------------------
!&var3D_out_nml, var3D_name = 'statevars' /
```

```
!&var3D_out_nml, var3D_name = 'derivedvars' /
!&var3D_out_nml, var3D_name = 'othervars' /
!&var3D_out_nml, var3D_name = 'oxygencycle' /
!&var3D_out_nml, var3D_name = 'bacteriacycle' /
!&var3D_out_nml, var3D_name = 'remineralisation' /
!&var3D_out_nml, var3D_name = 'NEP-C' /
!&var3D_out_nml, var3D_name = 'NEP-N' /
!&var3D_out_nml, var3D_name = 'N-uptake' /
!&var3D_out_nml, var3D_name = 'from_to' /
!&var3D_out_nml, var3D_name = 'f_adv' /
!&var3D_out_nml, var3D_name = 'f_adh' /
!&var3D_out_nml, var3D_name = 'f_mxv' /
!&var3D_out_nml, var3D_name = 'f_mxh' /
!&var3D_out_nml, var3D_name = 'f_hyd' /
!&var3D_out_nml, var3D_name = 'f_riv' /
!&var3D_out_nml, var3D_name = 'f_dil' /
!&var3D_out_nml, var3D_name = 'f_pev' /
!&var3D_out_nml, var3D_name = 'f_res' /
```

The `eco_bio` **File:**

```
&bio_nml
!------------------- switches -------------------------------------------
extp_feedback   =       0          ! 0 - light extinction based on biomass and constant Chla:C ratio
!               =                  ! 1 - light extinction based on dynamic Chla (e.g. Cloern et al. 1995)
!------------------- phytoplankton -------------------------------------------
extp            =       0.03       ! extinction coefficient for PAR due to Chla (m**2/(mg Chl))
extp1           =       0.03       ! extinction coefficient diatoms  (m**2/(mmol N)     (obsolete! only used with flag "D0
extp2           =       0.03       ! extinction coefficient flagellates  (m**2/(mmol N) (obsolete! only used with flag "D0
extp3           =       0.00       ! extinction coefficient coccos  (m**2/(mmol N)      (obsolete! only used with flag "D0
vp1             =       1.1        ! PRODUKTIONSRATE diatoms BEI 10 Grad (1/d) (!!1.1!!)
vp2             =       0.9        ! PRODUKTIONSRATE flagell BEI 10 Grad (1/d) (!!1.1!!)
vp3             =       0.000      ! PRODUKTIONSRATE coccos BEI 10 Grad (1/d)
xk1             =       0.500      ! half saturation constant nitrate   (mmol N/m**3)
xk13            =       0.250      ! half saturation constant nitrate for coccos (mmol N/m**3)
xk21            =       0.50       ! half saturation constant ammonium for diatoms     (mmol N/m**3)
xk22            =       0.05       ! half saturation constant ammonium for flagellates (mmol N/m**3)
xk23            =       0.25       ! half saturation constant ammonium for coccos (mmol N/m**3)
xkp             =       0.05       ! half saturation constant phosphate (mmol P/m**3)
xkp3            =       0.05       ! half saturation constant phosphate for coccos (mmol P/m**3)
xks             =       0.50       ! half saturation constant silicate  (mmol Si/m**3)
gam1            =       0.05       ! exudation fraction diatoms
gam2            =       0.05       ! exudation fraction flagellates
gam3            =       0.000      ! exudation fraction coccos (noch gleich zu flagellates)
xmu11           =       0.035      ! mortality rate dia (1/d)
xmu12           =       0.035      ! mortality rate fla (1/d)
xmu13           =       0.000      ! mortality rate coccos (noch gleich zu fla) (1/d)
xmq11           =       0.01       ! mortality at quadratic loss term diatoms
xmq12           =       0.01       ! mortality at quadratic loss term flagellates
xmq13           =       0.000      ! mortality at quadratic loss term coccos (noch gleich zu fla)
```

```
wp1c            =       0.0         ! sinking velocity diatoms (m/d)
wp2c            =       0.0         ! sinking velocity flagellates (m/d)
wp3c            =       0.0         ! sinking velocity coccos (m/d)
excess          =       0.50        ! >0: excess carbon assimilation via primary production
!               =                   ! =1: maximum excess production
!               =                   ! =0: no excess carbon assimilation
soc_rate        =       0.00274     ! remi rate SOC (1/d)
q_c_cal         =      70.0         ! ratio c(soft tissue)/c(skeleton) (mol org C (mol calcite C)^-1)
c_max           =       0.02        ! maximum calcification rate (mol calcite C (mol org C)^-1 d^-1)
rccalc_min      =      40.0         ! ratio of organic carbon to calcite carbon in coccolithophores
xkc_ir          =      22.0         ! half saturation for light in cocco primary production (Wm^-2)
xkk_ir          =       8.5         ! half saturation for light in cocco calcification (Wm^-2)
xkk             =       0.4         ! half saturation for dependence on omega (Gehlen et al 2007)
detach_min      =       0.0         ! minimum detachment rate of coccospheres (~10% Tyrell&Taylor)
!-------------------- zooplankton ---------------------------------------------
g1_max          =       0.50        ! max. ingestion rate of microzoo  (1/d) (!!0.5!!)
g2_max          =       0.40        ! max. ingestion rate of mesozoo (1/d) (!!0.5!!)
xk31            =       1.00        ! half saturation const. microzoo  grazing (mmol N/m**3)
xk32            =       1.00        ! half saturation const. mesozoo grazing (mmol N/m**3)
p1_p1n          =       0.00        ! Microzoo preferency diatoms  grazing
p1_p2n          =       0.33        ! Microzoo preferency flagell  grazing
p1_p3n          =       0.00        ! Microzoo preferency coccos grazing
p1_d1n          =       0.34        ! Microzoo preferency detritus grazing
p1_ban          =       0.33        ! Microzoo preferency bacteria grazing
p2_p1n          =       0.33        ! Mesozoo  preferency diatoms  grazing
p2_p2n          =       0.00        ! Mesozoo  preferency flagell  grazing
p2_p3n          =       0.00        ! Mesozoo  preferency coccos grazing
p2_d1n          =       0.34        ! Mesozoo  preferency detritus grazing
p2_ban          =       0.00        ! Mesozoo  preferency bacteria grazing
p2_z1n          =       0.33        ! Mesozoo  preferency microzoo grazing
```

```
xmu21           =       0.2       ! loss rate (fasham_loss) or mortality rate at linear loss term of microzoo  (1/d)
xmu22           =       0.2       ! loss rate (fasham_loss) or mortality rate at linear loss term of mesozoo (1/d)
xmq21           =       0.0       ! mortality at quadratic loss term of microzoo  (1/d)
xmq22           =       0.0       ! mortality at quadratic loss term of mesozoo (1/d)
xmu6            =       0.01      ! min (maintenance) loss rate of micro/mesozoo (1/d)
xmu6c           =       0.00      ! respiration rate reflecting energy required for feeding-activities & biosynthesis
beta1           =       0.75      ! assimilation coeff. of microzoo
beta2           =       0.75      ! assimilation coeff. of mesozoo
xk16            =       0.2       ! half sat. const. loss of microzoo  (mmol N/m**3)
xk26            =       0.2       ! half sat. const. loss of mesozoo (mmol N/m**3)
aeps1           =       0.4       ! ammonium fraction of microzoo loss (depreciated, only used for D093 compatibility)
aeps2           =       0.4       ! ammonium fraction of mesozoo loss (depreciated, only used for D093 compatibility)
delta_don1      =       0.4       ! LDON fraction of microzoo loss (depreciated, only used for D093 compatibility)
delta_don2      =       0.4       ! LDON fraction of mesozoo loss (depreciated, only used for D093 compatibility)
frac_dic        =       0.5       ! fraction of dic with respect to the dissolved fraction of losses
frac_n4n        =       0.5       ! fraction of n4n with respect to the dissolved fraction of losses
frac_n1p        =       0.5       ! fraction of n1p with respect to the dissolved fraction of losses
frac_det        =       0.33      ! fraction of mortality(predation) going to detritus
frac_d2x        =       0.15      ! fraction of fast sinking detritus d2x
!------------------- detritus ---------------------------------------------
wd1c            =       0.4       ! sinking velocity of slow detritus d1c,d1n (m/d)      (0.4)
wd2c            =      10.0       ! sinking velocity of fast detritus d2c,d2n,dsc (m/d) (10.0)
xmu4n           =       0.12      ! breakdown of N-DET1 (1/d) (0.12)
xmu5n           =       0.10      ! breakdown of N-DET2 (1/d) (0.10)
rxmu4c          =       0.85      ! ratio of breakdown rates N/C - DET
!------------------- bacteria ---------------------------------------------
xk4             =       0.2       ! half sat const N-uptake of BAC (mmol N/m**3)
xkpb            =       0.02      ! halfsaturation constant for bacteria uptake of DOP (mmol P/m**3)
eta             =       0.6       ! ratio n4n/don uptake by BAC
vb              =       0.5       ! max uptake rate of BAC at 10 deg (1/d) (!!1.4!!)
```

```
xmu3           =      0.1       ! excretion rate of BAC (1/d)
xknit          =      0.02      ! nitrification rate (1/d)
!------------------- molar stoichiometry-----------------------------------
red            =      6.625     ! PHYTOPLANKTON redfield ratio (C/N)
rcn            =      6.625     ! C:N  ratio for diatoms
rcp            =    132.5       ! C:P  ratio for diatoms
rcs            =      5.76      ! C:Si ratio for diatoms
rcn2           =      6.625     ! C:N  ratio for flaggelates
rcp2           =    132.5       ! C:P  ratio for flaggelates
rcn3           =      6.625     ! C:N  ratio for coccos
rcp3           =    212.0       ! C:P  ratio for coccos
rcnb           =      4.0       ! C:N  ratio for bacteria
rcpb           =     40.0       ! C:P  ratio for bacteria
rcnz1          =      5.5       ! C:N  ratio for micro-zooplankton
rcpz1          =    110.0       ! C:P  ratio for micro-zooplankton
rcnz2          =      5.5       ! C:N  ratio for meso-zooplankton
rcpz2          =    110.0       ! C:P  ratio for meso-zooplankton
chl_p1c        =     0.24       ! Chl:C ratio for diatoms (g Chl/(mol C)) [0.24 := 12 g Chl / (50 gC)]
chl_p2c        =     0.24       ! Chl:C ratio for flaggelates (g Chl/(mol C))
chl_p3c        =     0.24       ! Chl:C ratio for coccos (g Chl/(mol C))
/

&sediment_nml
brc            =      0.028     ! benthic remi rate carbon     (1/d)  (0.028)
brn            =      0.0333    ! benthic remi rate nitrogen   (1/d)  (0.0333)
brp            =      0.0333    ! benthic remi rate phosphorus (1/d)  (0.0333)
brs            =      0.0130    ! benthic remi rate silicon    (1/d)  (0.0130)
/
```

The `makefile`:

```
#################################################
#     makefile for ECOHAM-model (version 5):    #
#################################################
#
# set name for executable
#------------------------------------------------------------------------
ifndef $(EXECUTABLE)
EXECUTABLE = ecoham
endif
#
# set default compiler
#------------------------------------------------------------------------
ifndef $(FORTRAN_COMPILER)
  HOSTNAME=$(findstring blizzard,$(HOST))
  ifeq ($(HOSTNAME),blizzard)
    FORTRAN_COMPILER=xlf
  else  # set gfortran as default compiler on any other machines
    FORTRAN_COMPILER=gfortran
  endif
endif
#
# include compiler specific parts into the makefile
#------------------------------------------------------------------------
ifndef MK_CONFIG_FILE
  ifdef FORTRAN_COMPILER
    MAKE_INCLUDE=${PWD}/make-config/$(FORTRAN_COMPILER).config
  endif
else
  MAKE_INCLUDE=${PWD}/make-config/$(MK_CONFIG_FILE)
```

```
endif

ifeq ($(wildcard $(MAKE_INCLUDE)),)
  include ${PWD}/make-config/dummy.config
else
  $(info ### make include : $(MAKE_INCLUDE))
  include $(MAKE_INCLUDE)
endif
#
# choose grid for compile dependencies
#-------------------------------------------------------------------------
ifndef ECOHAM_GRID
  include ${PWD}/make-config/dummy.grid
endif
$(info ### ECOHAM grid  : $(ECOHAM_GRID))
#
#
#-------------------------------------------------------------------------
# preprocessor defines for program control
#-------------------------------------------------------------------------
   # DEFINES   += -DNCEP -DCalcAv_ECO
   DEFINES   += -DNETCDF#
   # DEFINES   += -DdebugMK#
#    DEFINES   += -Ddebug_zoo# # investigate unbalanced zooplankton fluxes
   DEFINES   += -Dmodule_restoring#
   DEFINES   += -Dmodule_rivers#
   DEFINES   += -Dmodule_meteo#
   DEFINES   += -Dmodule_chemie#
   DEFINES   += -Dmodule_sediment#
   DEFINES   += -Dmodule_silt#
```

```
   DEFINES   += -Dmodule_biogeo#
#    DEFINES   += -Dold_discharge#   # discharge of tracers not included in river forcing defined as ZERO
#    DEFINES   += -Dexclude_restoring_cells_hydro#
#    DEFINES   += -Dexclude_restoring_cells_meteo#
   DEFINES   += -Dexclude_restoring_cells_chemie#
#    DEFINES   += -Dexclude_restoring_cells_biogeo#
#    DEFINES   += -Dadvection_acceleration
#    DEFINES   += -Deco9#
   DEFINES   += -Dd093#            # compile code according to run D093
#! for a real D093 setup, following flags are required:
   DEFINES   += -Dold_bac#         # bacteria according to run D093
   DEFINES   += -Dfasham_grazing#          # grazing is formulated based on fasham (according to run D093)
   DEFINES   += -Dfasham_losses#           # loss-terms (metabolism+mortality) are formulated based on Fasham (according to
#    DEFINES   += -Dfasham_losses_revised#   # apply revision (markus version 2010) on fasham formulations
   DEFINES   += -Dold_feces_stoichiometry#   # feces have C:N:P from zooplankton (according to run D093)
#    DEFINES   += -Dvariable_phytoplankton_stoichiometry#  # use real C:N:P-ratios from statevariables instead of values fr
#    DEFINES   += -Dquadratic_mortality#     # use linear + quadratic mortality closure instead of Fasham formulation
#    DEFINES   += -Dexplicit_predation#      # apply external predation pressure
#
#-------------------------------------------------------------------------
#     adjust to IBM compiler syntax
#     ------------------------------------
ifeq ($(IBM_compiler),TRUE)
   DEFINES:=-WF,"$(DEFINES)"
endif
#$(info $(DEFINES))
#-------------------------------------------------------------------------
#
###############################################
# SPECIFY COMPILATION OBJECTS                #
```

```
##############################################
OBJS_GRID =  \
        grid_$(ECOHAM_GRID).o  \
        riv2pos_$(ECOHAM_GRID).o

OBJS =  \
        eco_par.o        \
        eco_common.o     \
        eco_var.o        \
        eco_flux.o       \
        utils.o          \
        eco_restoring.o  \
        hydro.o          \
        eco_rivers.o     \
        eco_chemie.o     \
        eco_meteo.o      \
        eco_silt.o       \
        eco_sediment.o   \
        eco_boundaries.o \
        eco_biogeo.o     \
        eco_ncdfout.o    \
        eco_output_1D.o  \
        eco_output_3D.o  \
        eco_output.o     \
        eco_init.o       \
        eco_main.o       \
        ecoham5.o


##############################################
```

```
# BASIC COMPILE INSTRUCTIONS AND DEPENDENCIES #
###############################################
.SUFFIXES:
.SUFFIXES: .f90 .o

%.o : %.f90
$(FC) $(FFLAGS) $(DEFINES) $(INCDIRS) $(LIBDIRS) $(EXTRA_LIBS) -c $<
# $(FC) $(FFLAGS) $(DF)  $<

$(EXECUTABLE):   $(OBJS_GRID) $(OBJS)
@echo "===== linking"
$(FC) -o $@ $(LDFLAGS) $(INCDIRS) $(OBJS_GRID) $(OBJS) $(LIBDIRS) $(EXTRA_LIBS)

clean:
rm -f $(EXECUTABLE) *~ *.o i.* *.mod *.lst

# dependencies
#--------------
eco_common.o:               eco_par.o grid_$(ECOHAM_GRID).o
riv2pos_$(ECOHAM_GRID).o:  grid_$(ECOHAM_GRID).o
ecoham5.o:                  eco_main.o
eco_main.o:                 eco_output.o eco_ncdfout.o eco_boundaries.o
eco_init.o:                 eco_output.o
eco_ncdfout.o:              eco_var.o
hydro.o:                    utils.o
eco_boundaries.o:           eco_rivers.o eco_restoring.o eco_meteo.o eco_silt.o
eco_output_1D.o:            utils.o hydro.o eco_sediment.o
eco_output.o:               eco_output_1D.o eco_meteo.o eco_silt.o
utils.o:                    eco_flux.o
eco_meteo.o:                utils.o eco_flux.o eco_chemie.o
```

```
eco_chemie.o:             hydro.o
eco_rivers.o:             utils.o hydro.o
eco_sediment.o:           eco_var.o
eco_flux.o:               eco_var.o
eco_restoring.o:          eco_flux.o
eco_sediment.o:           eco_flux.o eco_chemie.o
eco_biogeo.o:             eco_var.o hydro.o eco_meteo.o eco_chemie.o
eco_silt.o:               eco_meteo.o eco_var.o hydro.o
```

Chapter 10

Description of Model Setup and Testcases

In this chapter the structure of the ECOHAM5 model in terms of files and directories is described. Furthermore a testcase is presented with basic information on how to start a model simulaton and the structure of the related output files.

10.1 ECOHAM file structure

Beginning with the starting directory:

```
ECOHAM5_reference
```

we have the following subdirectories:

```
ECOHAM5-git  EM  scratch
```

which contain the following parts of the model:

1. **ECOHAM-git** contains the local clone of the actual ECOHAM version from the GIT repository. This is also the directory to start the job and contains the source code.

2. **EM** contains the inforamtion of the ECOHAM setup including HAMSOM

3. **scratch** is the working directory when running ECOHAM

Now look what model content is placed into these different directories.

10.1.1 ECOHAM-git

As mentioned above, `ECOHAM5-git` contains the local clone of the actual ECOHAM version. It is basically a copy of a certain content from the version control system and can easily be updated by GIT commands from the repository.

This is also the directory to start the job and contains the source code, with the following structure of subdirectories:

```
CompileJob-linuxPC.sh extras  input  script  src  wrk
```

the following parts of the model are placed in these sub-directories :

src covers the complete Fortran code of the model.

script one can find the follwoing information:

```
link_input_files.ifmlinux34.sh
old
RunJob-ifmlinux34.sh
RunJob-mistral.sh
uli
link_input_files.template.sh
RunJob-blizzard.sh
RunJob-linuxPC.sh
RunJob-serial.sh
```

wrk has the following structure:

```
eco_bio.nml
eco_set.nml
link_input_files.sh
nice-map_eco4jki.txt
run_eco.sh
warmstart_NWCS20D.in
```

with `eco_set.nml` the file for the setup of the model configuration

and `eco_bio.nml` the list of the biological rates

`link_input_files.sh`

`warmstart_NWCS20D.in`

input this subdirecotry contains the following files:

```
eco_bio.nml
eco_set.template.nml
host.list
warmstart_NWCS20D_D093.in
warmstart_NWCS20D.in
```

the file `eco_set.template.nml` is used for ????

extras holds additional information:

```
Grid_Names.txt  make_forcing  postprocess.sh  st_var_info_ECOHAM4_to_ECOHAM5.txt  t
```

10.1.2 EM

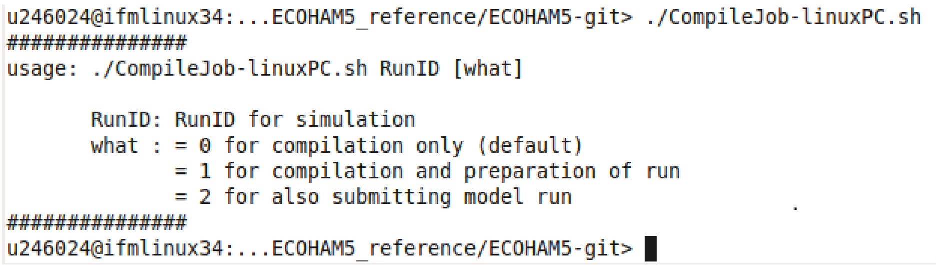
is the basic directory for ECOHAM including HAMSOM, with subdirectories:

forcing

ECOHAM

in these different direcories are the final forcing files or the links to the pool of forcing, e.g. from HAMSOM simulation.

```
airsea  extw  hydro  meteo  restoring  river  silt
```



```
u246024@ifmlinux34:...ECOHAM5_reference/ECOHAM5-git> ./CompileJob-linuxPC.sh
###############
usage: ./CompileJob-linuxPC.sh RunID [what]

       RunID: RunID for simulation
       what : = 0 for compilation only (default)
              = 1 for compilation and preparation of run
              = 2 for also submitting model run
###############
u246024@ifmlinux34:...ECOHAM5_reference/ECOHAM5-git>
```

Figure 10.1: ECOHAM5 start option

10.2 Start ECOHAM simulation

go into directory

`ECOHAM5-git/`

start the model with the relevalt shell, here CompileJob-linuxPC.sh without any further information

`./CompileJob-linuxPC.sh`

results in the request:

- a) to provide a RUNID, that could be for example "Test001"
- b) to select what the model should do, we choose 1 "for compilation and prepare run"

so after the input the following compilation starts:
and ends with the following notice:
BILD: Option1-Compilaten-End.png
The directory `/ECOHAM5_reference/scratch` now a new sub-directory `ECOHAM.Test001` is created, which contains the runscript `RunJob.Test001` and a number of further sub-direcotys:

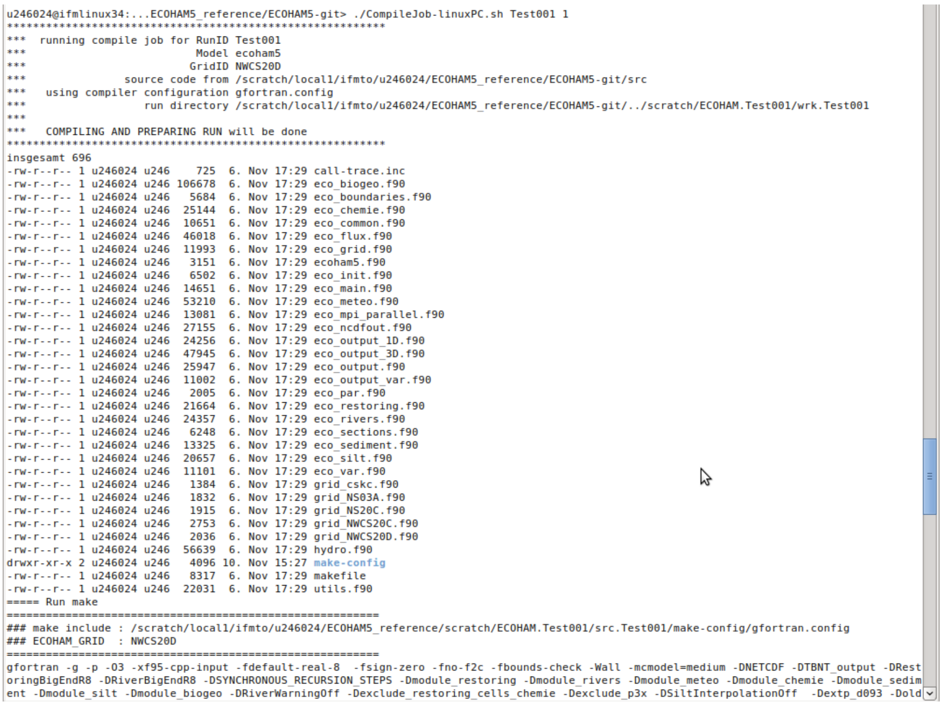
`input.Test001  list.Test001  objects.Test001  RunJob.Test001  script.Test001  src.T`

the **wrk** directory contains all the simulation output, the log-file and the warmstart file, to be used for a simulation for the following year.

The `eco_logfile.dat` covers the control sequences as printed out by the model during the simulation.

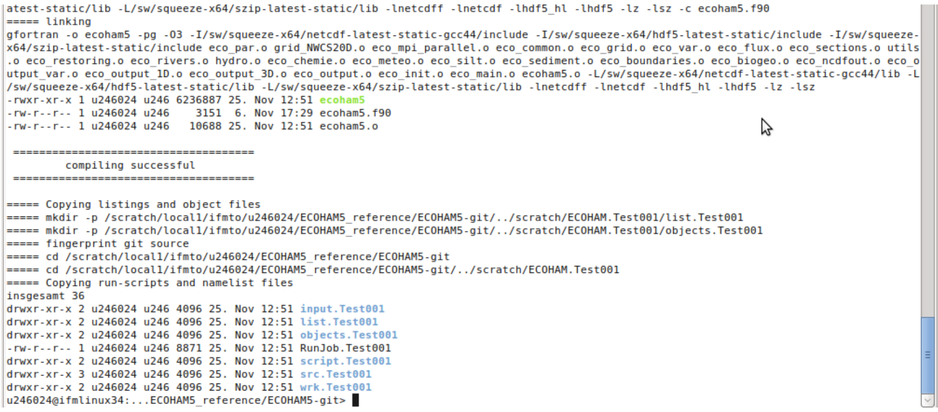
`*.prt` files contain the information for the 1-D watersolum budget files as declared in the `eco_set.nml` model setup.

Accoringly the `*.nc` file contails all information from 2D or 3D state varieble or fluxes as declared it the model setup. For further information, a copy of the `eco_set.nml` and the `eco_bio.nml` files are also stored in this directory.



```
u246024@ifmlinux34:...ECOHAM5_reference/ECOHAM5-git> ./CompileJob-linuxPC.sh Test001 1
**********************************************************
***  running compile job for RunID Test001
***                           Model ecoham5
***                          GridID NWCS20D
***                source code from /scratch/local1/ifmto/u246024/ECOHAM5_reference/ECOHAM5-git/src
***   using compiler configuration gfortran.config
***                   run directory /scratch/local1/ifmto/u246024/ECOHAM5_reference/ECOHAM5-git/../scratch/ECOHAM.Test001/wrk.Test001
***
***   COMPILING AND PREPARING RUN will be done
**********************************************************
insgesamt 696
-rw-r--r-- 1 u246024 u246    725  6. Nov 17:29 call-trace.inc
-rw-r--r-- 1 u246024 u246 106678  6. Nov 17:29 eco_biogeo.f90
-rw-r--r-- 1 u246024 u246   5684  6. Nov 17:29 eco_boundaries.f90
-rw-r--r-- 1 u246024 u246  25144  6. Nov 17:29 eco_chemie.f90
-rw-r--r-- 1 u246024 u246  10651  6. Nov 17:29 eco_common.f90
-rw-r--r-- 1 u246024 u246  46018  6. Nov 17:29 eco_flux.f90
-rw-r--r-- 1 u246024 u246  11993  6. Nov 17:29 eco_grid.f90
-rw-r--r-- 1 u246024 u246   3151  6. Nov 17:29 ecoham5.f90
-rw-r--r-- 1 u246024 u246   6502  6. Nov 17:29 eco_init.f90
-rw-r--r-- 1 u246024 u246  14651  6. Nov 17:29 eco_main.f90
-rw-r--r-- 1 u246024 u246  53210  6. Nov 17:29 eco_meteo.f90
-rw-r--r-- 1 u246024 u246  13081  6. Nov 17:29 eco_mpi_parallel.f90
-rw-r--r-- 1 u246024 u246  27155  6. Nov 17:29 eco_ncdfout.f90
-rw-r--r-- 1 u246024 u246  24256  6. Nov 17:29 eco_output_1D.f90
-rw-r--r-- 1 u246024 u246  47945  6. Nov 17:29 eco_output_3D.f90
-rw-r--r-- 1 u246024 u246  25947  6. Nov 17:29 eco_output.f90
-rw-r--r-- 1 u246024 u246  11002  6. Nov 17:29 eco_output_var.f90
-rw-r--r-- 1 u246024 u246   2005  6. Nov 17:29 eco_par.f90
-rw-r--r-- 1 u246024 u246  21664  6. Nov 17:29 eco_restoring.f90
-rw-r--r-- 1 u246024 u246  24357  6. Nov 17:29 eco_rivers.f90
-rw-r--r-- 1 u246024 u246   6248  6. Nov 17:29 eco_sections.f90
-rw-r--r-- 1 u246024 u246  13325  6. Nov 17:29 eco_sediment.f90
-rw-r--r-- 1 u246024 u246  20657  6. Nov 17:29 eco_silt.f90
-rw-r--r-- 1 u246024 u246  11101  6. Nov 17:29 eco_var.f90
-rw-r--r-- 1 u246024 u246   1384  6. Nov 17:29 grid_cskc.f90
-rw-r--r-- 1 u246024 u246   1832  6. Nov 17:29 grid_NS03A.f90
-rw-r--r-- 1 u246024 u246   1915  6. Nov 17:29 grid_NS20C.f90
-rw-r--r-- 1 u246024 u246   2753  6. Nov 17:29 grid_NWCS20C.f90
-rw-r--r-- 1 u246024 u246   2036  6. Nov 17:29 grid_NWCS20D.f90
-rw-r--r-- 1 u246024 u246  56639  6. Nov 17:29 hydro.f90
drwxr-xr-x 2 u246024 u246   4096 10. Nov 15:27 make-config
-rw-r--r-- 1 u246024 u246   8317  6. Nov 17:29 makefile
-rw-r--r-- 1 u246024 u246  22031  6. Nov 17:29 utils.f90
===== Run make
==========================================================
### make include : /scratch/local1/ifmto/u246024/ECOHAM5_reference/scratch/ECOHAM.Test001/src.Test001/make-config/gfortran.config
### ECOHAM_GRID  : NWCS20D
==========================================================
gfortran -g -p -O3 -xf95-cpp-input -fdefault-real-8  -fsign-zero -fno-f2c -fbounds-check -Wall -mcmodel=medium -DNETCDF -DTBNT_output -DRest
oringBigEndR8 -DRiverBigEndR8 -DSYNCHRONOUS_RECURSION_STEPS -Dmodule_restoring -Dmodule_rivers -Dmodule_meteo -Dmodule_chemie -Dmodule_sedim
ent -Dmodule_silt -Dmodule_biogeo -DRiverWarningOff -Dexclude_restoring_cells_chemie -Dexclude_p3x -DSiltInterpolationOff  -Dextp_d093 -Dold
```

Figure 10.2: ECOHAM5 start of compilation



```
atest-static/lib -L/sw/squeeze-x64/szip-latest-static/lib -lnetcdff -lnetcdf -lhdf5_hl -lhdf5 -lz -lsz -c ecoham5.f90
===== linking
gfortran -o ecoham5 -pg -O3 -I/sw/squeeze-x64/netcdf-latest-static-gcc44/include -I/sw/squeeze-x64/hdf5-latest-static/include -I/sw/squeeze-
x64/szip-latest-static/include eco_par.o grid_NWCS20D.o eco_mpi_parallel.o eco_common.o eco_grid.o eco_var.o eco_flux.o eco_sections.o utils
.o eco_restoring.o eco_rivers.o hydro.o eco_chemie.o eco_meteo.o eco_silt.o eco_sediment.o eco_boundaries.o eco_biogeo.o eco_ncdfout.o eco_o
utput_var.o eco_output_1D.o eco_output_3D.o eco_output.o eco_init.o eco_main.o ecoham5.o -L/sw/squeeze-x64/netcdf-latest-static-gcc44/lib -L
/sw/squeeze-x64/hdf5-latest-static/lib -L/sw/squeeze-x64/szip-latest-static/lib -lnetcdff -lnetcdf -lhdf5_hl -lhdf5 -lz -lsz
-rwxr-xr-x 1 u246024 u246 6236887 25. Nov 12:51 ecoham5
-rw-r--r-- 1 u246024 u246    3151  6. Nov 17:29 ecoham5.f90
-rw-r--r-- 1 u246024 u246   10688 25. Nov 12:51 ecoham5.o

 =====================================
        compiling successful
 =====================================

===== Copying listings and object files
===== mkdir -p /scratch/local1/ifmto/u246024/ECOHAM5_reference/ECOHAM5-git/../scratch/ECOHAM.Test001/list.Test001
===== mkdir -p /scratch/local1/ifmto/u246024/ECOHAM5_reference/ECOHAM5-git/../scratch/ECOHAM.Test001/objects.Test001
===== fingerprint git source
===== cd /scratch/local1/ifmto/u246024/ECOHAM5_reference/ECOHAM5-git
===== cd /scratch/local1/ifmto/u246024/ECOHAM5_reference/ECOHAM5-git/../scratch/ECOHAM.Test001
===== Copying run-scripts and namelist files
insgesamt 36
drwxr-xr-x 2 u246024 u246 4096 25. Nov 12:51 input.Test001
drwxr-xr-x 2 u246024 u246 4096 25. Nov 12:51 list.Test001
drwxr-xr-x 2 u246024 u246 4096 25. Nov 12:51 objects.Test001
-rw-r--r-- 1 u246024 u246 8871 25. Nov 12:51 RunJob.Test001
drwxr-xr-x 2 u246024 u246 4096 25. Nov 12:51 script.Test001
drwxr-xr-x 3 u246024 u246 4096 25. Nov 12:51 src.Test001
drwxr-xr-x 2 u246024 u246 4096 25. Nov 12:51 wrk.Test001
u246024@ifmlinux34:...ECOHAM5_reference/ECOHAM5-git>
```

Figure 10.3: ECOHAM5 end of compilation

The file warmstart.in comprises all information that is needed to start a simulation in a warmstart mode for the following year.

`gmon.out` ?????????

Finally the `input` directory contains all the links to the dorcing data that are used as model input for the model run.

Appendix A: Changes in variable names from ECOHAM4 to ECOHAM5

Table I.1: New (ECOHAM5) and old (ECOHAM4 and predecessors) state variable indices and codes.

new index	new variable code		old variable code & index
1	*x1x*	=	25
2	*alk*	=	0
3	*dic*	=	13
4	*n3n*	=	12
5	*n4n*	=	11
6	*n1p*	=	31
7	*n5s*	=	32
8	*p1c*	=	27
9	*p1n*	=	34
10	*p1p*	=	36
11	*p1s*	=	35
12	*p2c*	=	28
13	*p2n*	=	37
14	*p2p*	=	38
15	*p3c*	⇒	new, derivable from *p1c*
16	*p3n*	⇒	new, derivable from *p1n*
17	*p3p*	⇒	new, derivable from *p1p*
18	*p3k*	⇒	new, derivable from *p3c*/*q_c_cal*
19	*z1c*	=	*zic* (30)
20	*z2c*	=	*zec* (29)
21	*bac*	=	10
22	*d1c*	=	3
23	*d1n*	=	4
24	*d1p*	=	39
25	*d2c*	=	5
26	*d2n*	=	6
27	*d2p*	=	40
28	*d2s*	=	33
29	*d2k*	=	*dsc* (7)
30	*soc*	=	26
31	*doc*	=	8
32	*don*	=	9
33	*dop*	=	41
34	*o2o*	=	24