



ECOHAM4

User Guide

“Ecosystem Model, Hamburg, Version 4”

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1. Summary

The „Ecosystem Model, Hamburg, Version 4“ (ECOHAM4) simulates the carbon, nitrogen, phosphorus, silicon, oxygen cycle and the carbonate system. The model is implemented for application to the Northwest European Continental Shelf (NECS).

Model Description and Support Specification:

Name:	ECOHAM4
Model type, area:	Northwest European Continental Shelf & Atlantic Margin
system:	Shelf Sea
Authors:	Johannes Pätsch, Wilfried Kühn, Andreas Moll, Hermann Lenhart
Developed at:	Institut für Meereskunde (IfM), Universität Hamburg (ZMAW)
Grid type horizontal:	Arakawa C grid
vertical:	Geopotential (z) surfaces
Model description:	ECOHAM4 is a lower food web functional-type model that was developed within German BMBF- and DFG-funded projects. It is related to NPZD type models, but includes the microbial loop, (partly) variable C:N stoichiometry, and a simple description of benthic biochemical processes.
Model resolution:	NECS configuration: $\Delta\text{lat} = 1/5^\circ$, $\Delta\text{lon} = 1/3^\circ$, 24 vertical layers, time step 1 h
Model input:	Initial data as climatological mean fields for DIC and nutrients; boundary data as climatological mean fields for nutrients, total alkalinity and DIC; forcing data atmosphere N deposition and daily river loads of N, P, C, Si, when available.
Model output:	Monthly means of all state variables in GrADS, selected variables and fluxes in ASCII; daily means of all variables, fluxes and forcing data at selected stations
Post processing:	Matlab, GrADS and ODV tools.
Scientific support:	Institute of Oceanography (Group ‘Theoretical Oceanography’)
Program language:	FORTRAN90
Operating systems:	High Performance Machine (HLRE); Windows
Libraries:	none
Support Level:	Email contact to the developers: johannes.paetsch@zmaw.de , wilfried.kuehn@zmaw.de , andreas.moll@zmaw.de , hermann.lenhart@zmaw.de

It is noteworthy to mention that ECOHAM4 has been implemented into the framework of GOTM. For more information please contact Dr. Frank Janssen or Dr. Larissa Müller, BSH (larissa.mueller@bsh.de).

2. Model description

2.1. State variables

State variables of the model are sub-divided into prognostic and derived state variables which are calculated diagnostically. The model uses constant, but different nutrient/carbon ratios for the main biogenic state variables (e.g. Redfield ratio for the functional units of phytoplankton, different ratios for zooplankton groups and bacteria) and variable ratios for detritus and dissolved organic matter (DOM). The number of state variables is defined within the include file "eco4_par.par" and the names in "eco4_var1.com".

Table 1: Pelagic and benthic variables of the model: Prognostic state variables are opposed to diagnostic state variables, which were derived or arithmetically determined from the prognostic ones.

Number	Name (st_...)	Variable	Unit
(a) Prognostic pelagic state variables			
0	alk	alkalinity	meqv m ⁻³
1	d1c	detritus carbon (slowly sinking)	mmol C m ⁻³
2	d1n	detritus nitrogen (slowly sinking)	mmol N m ⁻³
3	d1p	detritus phosphorus (slowly sinking)	mmol P m ⁻³
4	d2c	detritus carbon (fast sinking)	mmol C m ⁻³
5	d2n	detritus nitrogen (fast sinking)	mmol N m ⁻³
6	d2p	detritus phosphorus (fast sinking)	mmol P m ⁻³
7	d2s	detritus silicate (fast sinking)	mmol Si m ⁻³
8	dsc	detritus calcite (fast sinking)	mmol C m ⁻³
9	doc	labile dissolved organic carbon	mmol C m ⁻³
9	don	labile dissolved organic nitrogen	mmol N m ⁻³
10	dop	labile dissolved organic phosphorus	mmol P m ⁻³
11	bac	bacteria-C	mmol C m ⁻³
12	n4n	ammonium	mmol N m ⁻³
13	n3n	nitrate	mmol N m ⁻³
14	dic	dissolved inorganic carbon	mmol C m ⁻³
15	z1c	zooplankton eggs and non-feeding nauplii	mmol C m ⁻³
16	z2c	zooplankton nauplii biomass	mmol C m ⁻³
17	z3c	zooplankton copepodite 1 biomass	mmol C m ⁻³
18	z4c	zooplankton copepodite 2 biomass	mmol C m ⁻³
19	z5c	zooplankton adults biomass	mmol C m ⁻³
20	z1a	zooplankton egg abundance	Ind m ⁻³
21	z2a	zooplankton nauplii abundance	Ind m ⁻³
22	z3a	zooplankton copepodit I abundance	Ind m ⁻³
23	z4a	zooplankton copepodit II abundance	Ind m ⁻³
24	z5a	zooplankton adults abundance	Ind m ⁻³
25	o2o	dissolved oxygen	mmol O ₂ m ⁻³
26	soc	semi-labile dissolved organic carbon	mmol C m ⁻³
27	x1x	passive tracer	mmol X m ⁻³
28	p1c	diatoms-C	mmol C m ⁻³
29	p2c	flagellates-C	mmol C m ⁻³
30	zec	mesozooplankton-C	mmol C m ⁻³
31	zic	microzooplankton-C	mmol C m ⁻³

32	n1p	phosphate	mmol P m ⁻³
33	n5s	silicate	mmol Si m ⁻³
34	d2s	detritus silicon (fast sinking)	mmol Si m ⁻³
	(sd_...)	(b) Prognostic benthic state variables	
B1	boc (sd_dic)	benthic detritus, organic carbon content	mmol C m ⁻²
B2	bon (sd_din)	benthic detritus, organic nitrogen content	mmol N m ⁻²
B3	bsc (sd_dsc)	benthic detritus, inorganic carbon content (calcite)	mmol C m ⁻²
B4	bop (sd_dip)	benthic detritus, organic phosphorus content	mmol P m ⁻²
B5	bos (sd_dis)	benthic detritus, organic silicon content	mmol Si m ⁻²
	(de_...)	(c) Derived pelagic variables	
	phc	phytoplankton-C	mmol C m ⁻³
	phn	phytoplankton-N	mmol N m ⁻³
	php	phytoplankton-P	mmol P m ⁻³
	zoc	zooplankton-C	mmol C m ⁻³
	zon	zooplankton-N	mmol N m ⁻³
	zop	zooplankton-P	mmol P m ⁻³
	ban	bacteria-N	mmol N m ⁻³
	bap	bacteria-P	mmol P m ⁻³
	psc	phytoplankton carbonate shells	mmol C m ⁻³
	z1n	zooplankton eggs and non-feeding nauplii	mmol N m ⁻³
	z2n	zooplankton nauplii biomass	mmol N m ⁻³
	z3n	zooplankton copepodit 1 biomass	mmol N m ⁻³
	z4n	zooplankton copepodit 2 biomass	mmol N m ⁻³
	z5n	zooplankton adults biomass	mmol N m ⁻³
	p1n	diatoms-N	mmol N m ⁻³
	p1p	diatoms-P	mmol P m ⁻³
	p1s	diatoms-Si	mmol Si m ⁻³
	p2n	flagellates-N	mmol N m ⁻³
	p2p	flagellates-P	mmol P m ⁻³
	zen	mesozooplankton-N	mmol N m ⁻³
	zep	mesozooplankton-P	mmol P m ⁻³
	zin	microzooplankton-N	mmol N m ⁻³
	zip	microzooplankton-P	mmol P m ⁻³
	(ot_...)	(d) Other pelagic variables X	
	o2c	carbon dioxide (CO ₂)	mmol C m ⁻³
	ohc	bicarbonate (X=HCO ₃ ⁻)	mmol X m ⁻³
	o3c	carbonate (X=CO ₃ ⁻)	mmol X m ⁻³
	prot	proton concentration	mmol H ⁺ m ⁻³
	tbor	total boric acid	mmol B m ⁻³
	xbor	borate concentration (B(OH) ₄)	mmol B m ⁻³

DIC, alkalinity and all other species of the carbonate system have volumetric units in the model (mmol m^{-3}) and in the *.prt file. In monthly mean outputs (GrADS) they have the unit $\mu\text{eqv kg}^{-1}$ or $\mu\text{mol kg}^{-1}$, respectively. Alkalinity st_alk is restored from data.

As an overview we present the following model diagrams. The model resolves the nitrogen (Figure 1), carbon (Figure 2), phosphorus (Figure 3), silicon (Figure 4), oxygen (Figure 5) cycles, and has an option for inclusion of structured zooplankton (Figure 7). The state variables (circles) are connected by arrows symbolizing fluxes of matter which are numbered. Numbers are explained in the legend.

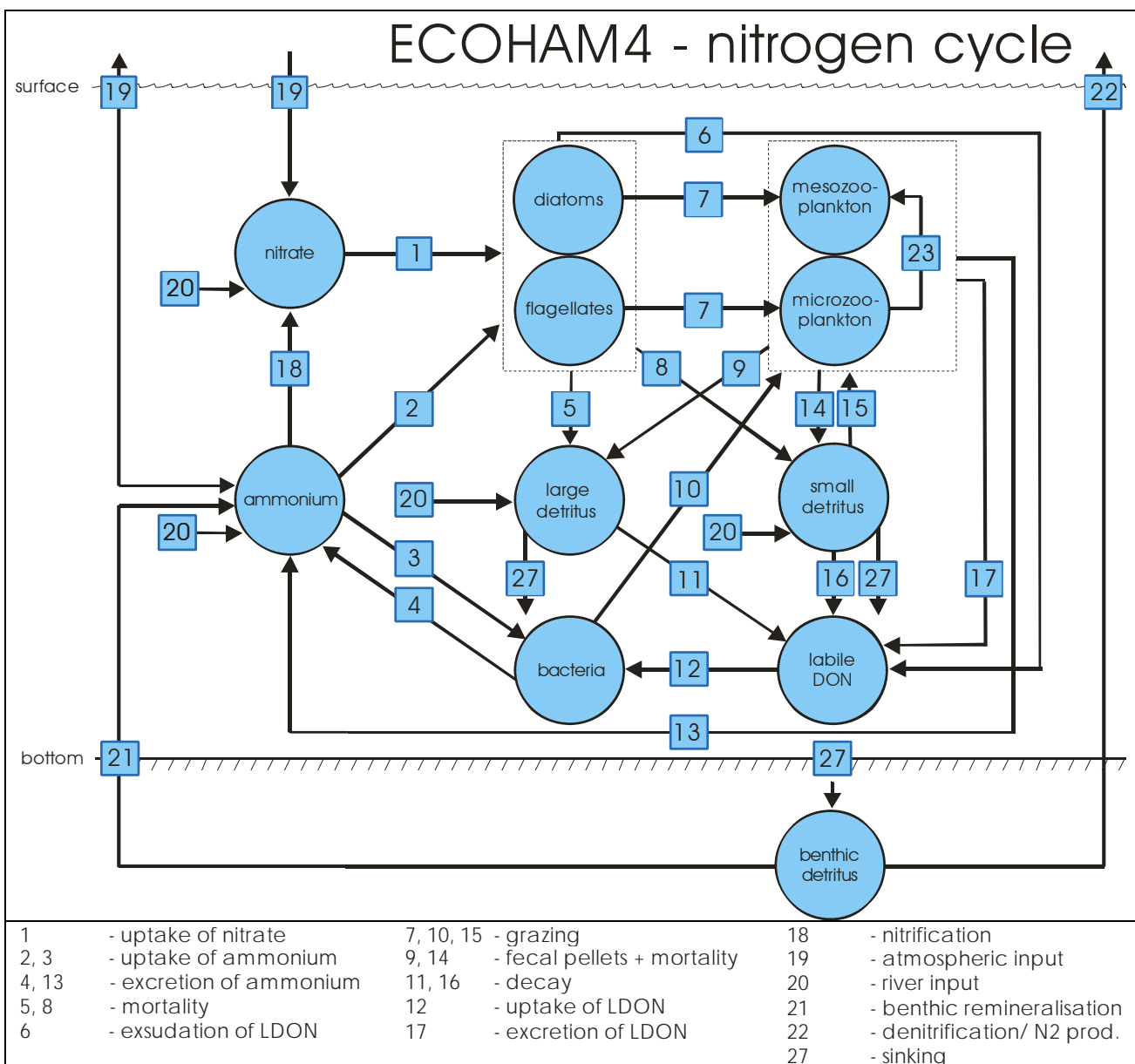


Figure 1: Interaction diagram of ECOHAM4 for the nitrogen cycle.

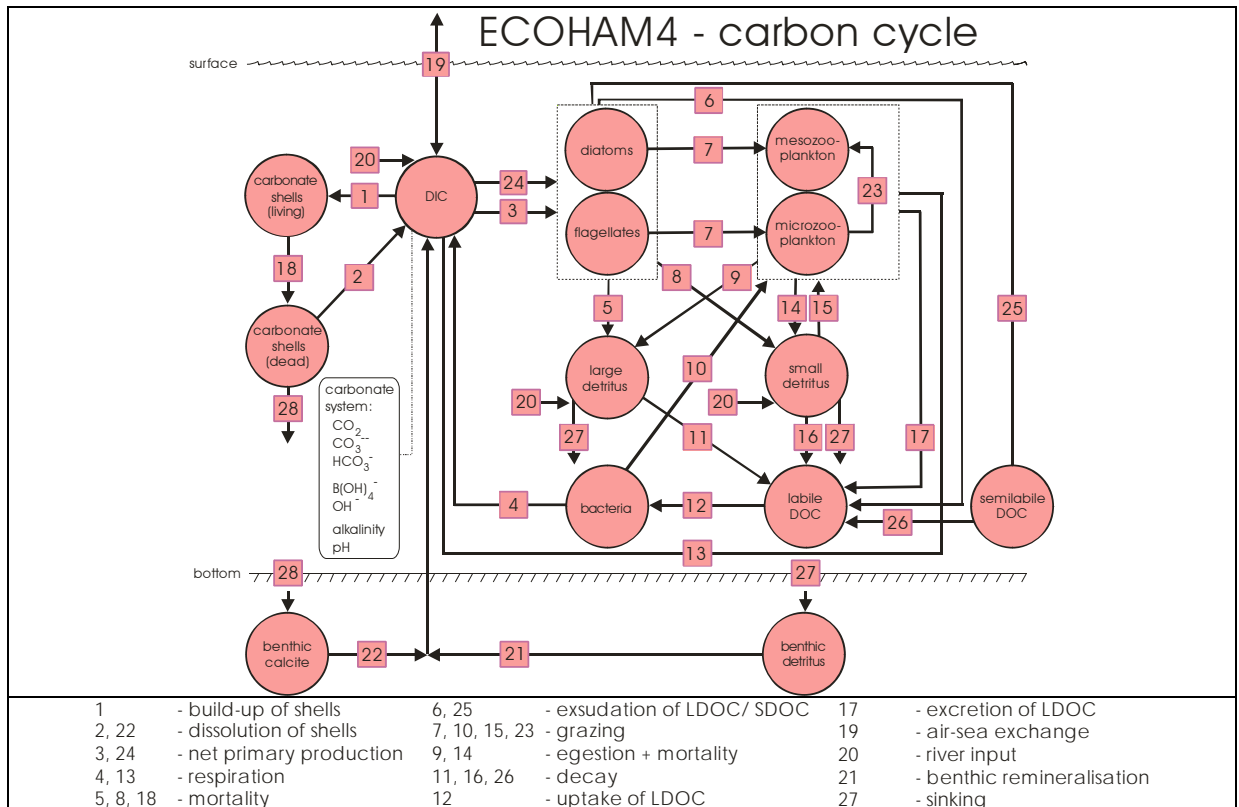


Figure 2: Diagram of the ECOHAM4 carbon cycle.

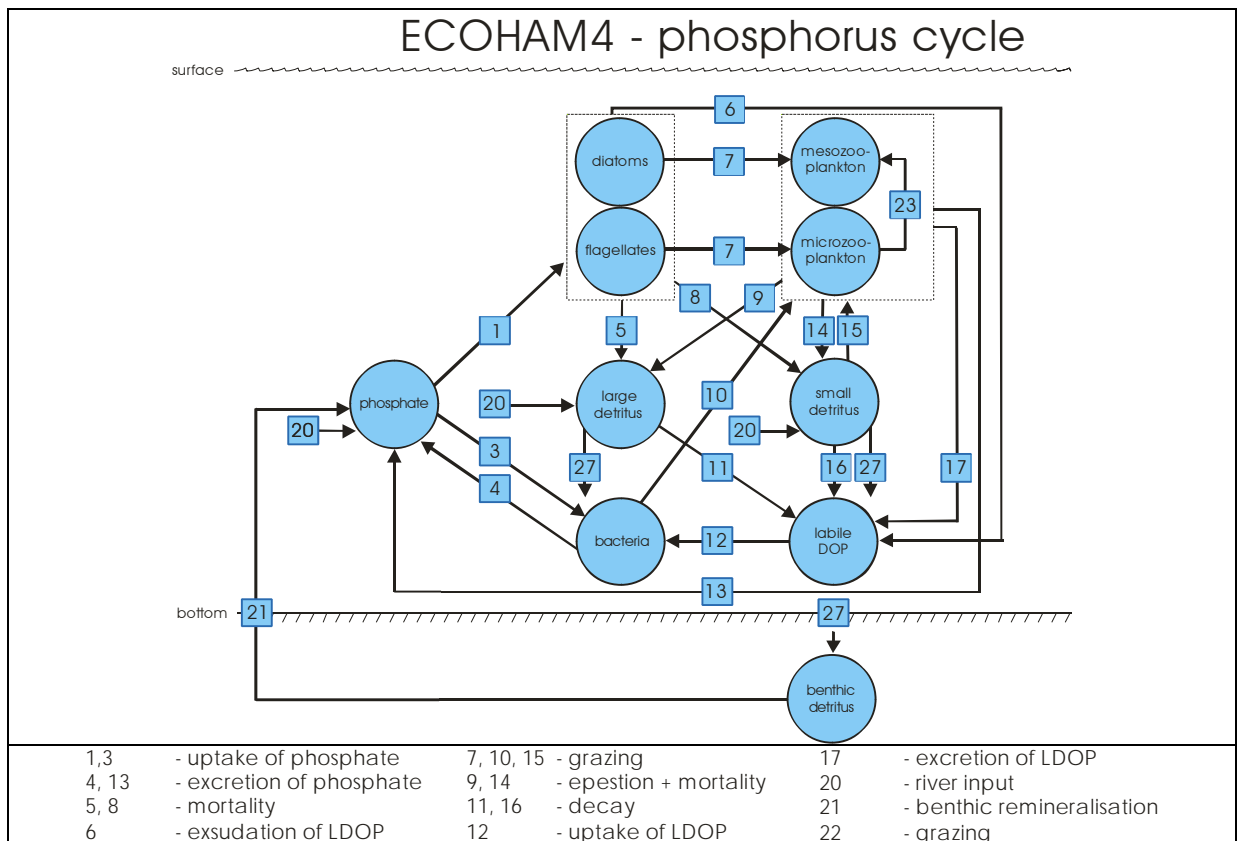


Figure 3: Diagram of the ECOHAM4 phosphorus cycle.

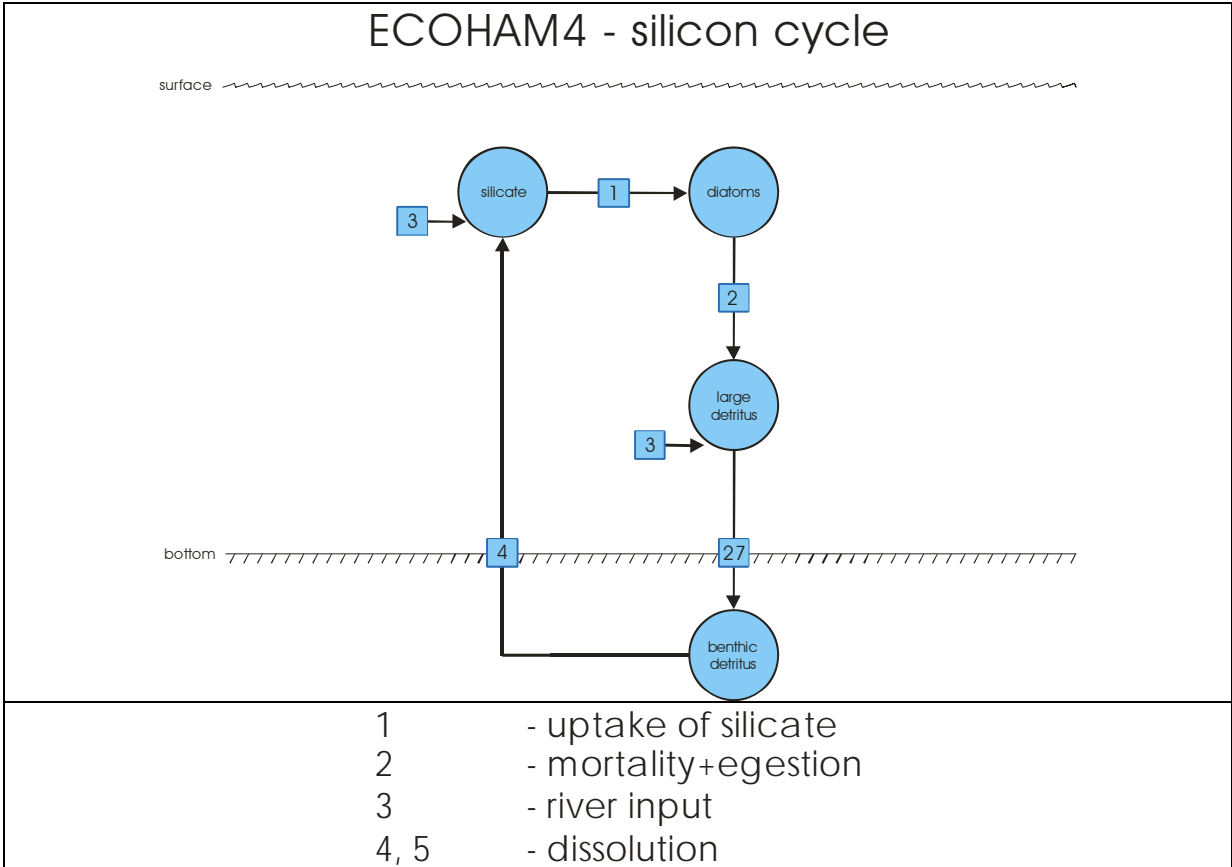


Figure 4: Diagram of the ECOHAM4 silicon cycle.

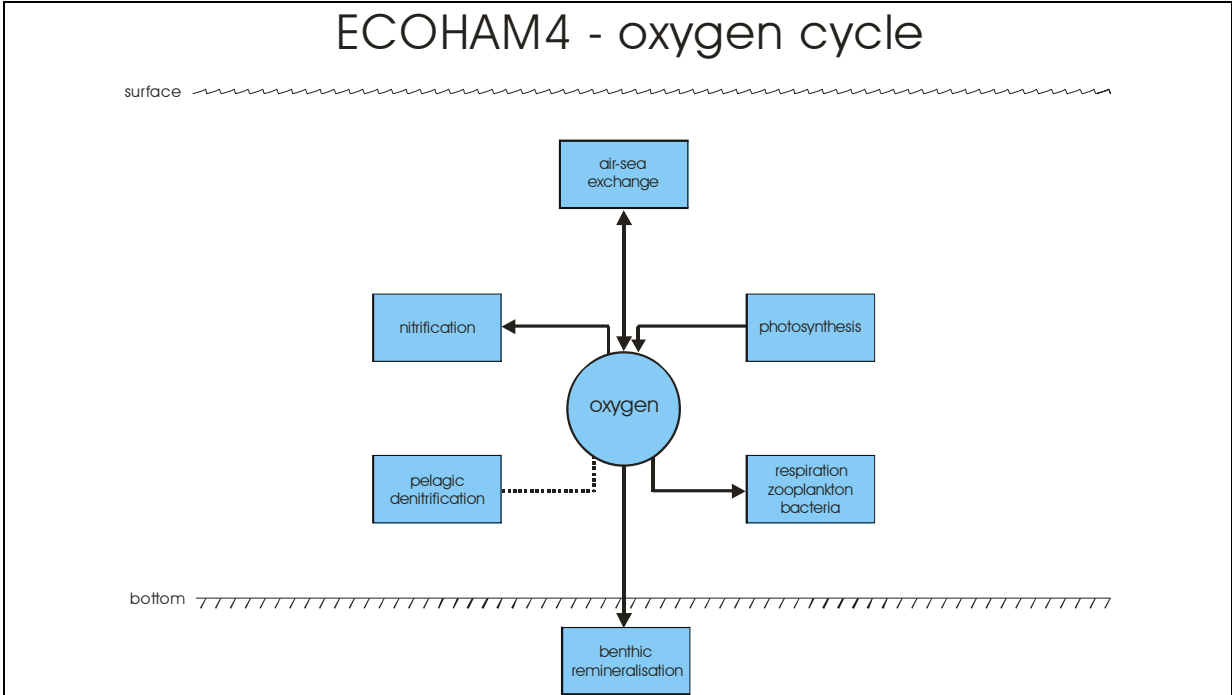


Figure 5: Diagram of the ECOHAM4 oxygen fluxes.

2.2. Mathematical equations and boundary conditions

Table 2: The model equations.

A flux from variable var1 to variable var2 is denoted by the acronym var1_var2. The terms tra(var1) include advection adv(var1) and vertical mixing mix(var1).

state variable	conservation equation
Diatoms-C	$\frac{\partial p1c}{\partial t} = dic_p1c - p1c_zec - p1c_d1c - p1c_d2c - p1c_doc - p1c_soc + tra(p1c)$
Flagellates-C	$\frac{\partial p2c}{\partial t} = dic_p2c - p2c_zic - p2c_d1c - p2c_d2c - p2c_doc - p2c_soc + tra(p2c)$
Diatoms-N*	$\frac{\partial p1n}{\partial t} = n3n_p1n + n4n_p1n - p1n_zen - p1n_d1n - p1n_d2n - p1n_don + tra(p1n)$
Flagellates-N'	$\frac{\partial p2n}{\partial t} = n3n_p2n + n4n_p2n - p2n_zin - p2n_d1n - p2n_d2n - p2n_don + tra(p2n)$
Diatoms-P*	$\frac{\partial p1p}{\partial t} = n1p_p1p - p1p_zep - p1p_d1p - p1p_d2p - p1p_dop + tra(p1p)$
Flagellates-P*	$\frac{\partial p2p}{\partial t} = n1p_p2p - p2p_zip - p2p_d1p - p2p_d2p - p2n_dop + tra(p2p)$
Diatoms-Si*	$\frac{\partial p1s}{\partial t} = n5s_p1s - p1s_d2s + tra(p1s)$
phytoplankton calcite shells	$\frac{\partial psc}{\partial t} = dic_psc - psc_dsc + tra(psc)$
mesozooplankton-C	$\frac{\partial zec}{\partial t} = p1c_zec + d1c_zec + zic_zec - zec_d1c - zec_d2c - zec_doc - zec_dic + tra(zec)$
microzooplankton-C	$\frac{\partial zic}{\partial t} = p2c_zic + bac_zic + d1c_zic - zic_zec - zic_d1c - zic_d2c - zic_doc - zic_dic + tra(zic)$

mesozooplankton-N*	$\frac{\partial zen}{\partial t} = p1n_zen + d1n_zen + zin_zen - zen_d1n - zen_d2n - zen_don - zen_n4n + tra(zen)$
microzooplankton-N*	$\frac{\partial zin}{\partial t} = p2n_zin + ban_zin + d1n_zin - zin_zen - zin_d1n - zin_d2n - zin_don - zin_n4n + tra(zin)$
mesozooplankton-P*	$\frac{\partial zep}{\partial t} = p1p_zep + d1p_zep + zip_zep - zep_d1p - zep_d2p - zep_dop - zep_n1p + tra(zep)$
microzooplankton-P*	$\frac{\partial zip}{\partial t} = p2p_zip + bap_zip + d1p_zip - zip_zep - zip_d1p - zip_d2p - zip_dop - zip_n1p + tra(zip)$
detritus-C, slowly sinking	$\frac{\partial d1c}{\partial t} = p1c_d1c + p2c_d1c + zec_d1c + zic_d1c - d1c_zec - d1c_zic - d1c_doc - snk(d1c, w_{d1}) + tra(d1c)$
detritus-N, slowly sinking	$\frac{\partial d1n}{\partial t} = p1n_d1n + zen_d1n + zin_d1n - d1n_zen - d1n_zin - d1n_don - snk(d1n, w_{d1}) + tra(d1n)$
detritus-P, slowly sinking	$\frac{\partial d1p}{\partial t} = p1p_d1p + zep_d1p + zip_d1p - d1p_zep - d1p_zip - d1p_dop - snk(d1p, w_{d1}) + tra(d1p)$
detritus-C, fast sinking	$\frac{\partial d2c}{\partial t} = p1c_d2c + p2c_d2c + zec_d2c + zic_d2c - d2c_doc - snk(d2c, w_{d2}) + tra(d2c)$
detritus-N, fast sinking	$\frac{\partial d2n}{\partial t} = p1n_d2n + p2n_d2n + zen_d2n + zin_d2n - d2n_don - snk(d2n, w_{d2}) + tra(d2n)$
detritus-P, fast sinking	$\frac{\partial d2p}{\partial t} = p1p_d2p + p2p_d2p + zep_d2p + zip_d2p - d2p_dop - snk(d2p, w_{d2}) + tra(d2p)$
detritus-Si, fast sinking	$\frac{\partial d2s}{\partial t} = p1s_d2s - d2s_n5s - snk(d2s, w_{d2}) + tra(d2s)$
detritus calcite, fast sinking	$\frac{\partial dsc}{\partial t} = psc_dsc - dsc_dic - snk(dsc, w_{d2}) + tra(dsc)$

labile dissolved organic carbon	$\frac{\partial doc}{\partial t} = p1c_doc + p2c_doc + zec_doc + zic_doc + d1c_doc + d2c_doc - doc_bac + soc_doc + tra(doc)$
semi-labile dissolved organic carbon	$\frac{\partial soc}{\partial t} = p1c_soc + p2c_soc - soc_doc + tra(soc)$
labile dissolved organic nitrogen	$\frac{\partial don}{\partial t} = p1n_don + p2n_don + zen_don + zin_don + d1n_don + d2n_don - don_ban + tra(don)$
labile dissolved organic phosphorus	$\frac{\partial dop}{\partial t} = p1p_dop + p2p_dop + zep_dop + zip_dop + d1p_dop + d2p_dop - dop_bap + tra(dop)$
bacteria-C	$\frac{\partial bac}{\partial t} = doc_bac - bac_zic + bac_dic + tra(bac)$
bacteria-N	$\frac{\partial ban}{\partial t} = don_ban + n4n_ban - ban_zin - ban_n4n + tra(ban)$
bacteria-P	$\frac{\partial bap}{\partial t} = dop_bap - bap_zip - bap_n1p + n1p_bap + tra(bap)$
ammonium	$\frac{\partial n4n}{\partial t} = ban_n4n + zen_n4n + zin_n4n - n4n_p1n - n4n_p2n - n4n_ban - n4n_n3n + bon_n4n + riv_n4n + atm_n4n + tra(n4n)$
nitrate	$\frac{\partial n3n}{\partial t} = n4n_n3n - n3n_nn2 - n3n_p1n - n3n_p2n + riv_n3n + atm_n3n + tra(n3n)$
phosphate	$\frac{\partial n1p}{\partial t} = -n1p_p1p - n1p_p2p + zep_n1p + zip_n1p + bap_n1p - bap_n1p + bop_n1p + riv_n1p + tra(n1p)$
silicate	$\frac{\partial n5s}{\partial t} = -n5s_p1s + d2s_n5s + bos_n5s + riv_n5s + tra(n5s)$
dissolved inorganic carbon	$\frac{\partial dic}{\partial t} = -dic_p1c - dic_d2c - dic_psc + air_o2c + dsc_dic + zec_dic + zic_dic + bac_dic + bsc_dic + boc_dic + riv_dic + tra(dic)$

oxygen	$\frac{\partial o2o}{\partial t} = p1c_o2o + p2c_o2o - o2o_zec - o2o_zic - o2o_bac - o2o_n4n - o2o_sed + air_o2o + tra(o2o)$
benthic organic carbon	$\frac{\partial boc}{\partial t} = dz(k0) \cdot snk(d1c, w_{d1}) \Big _{z=H} + dz(k0) \cdot snk(d2c, w_{d2}) \Big _{z=H} - boc_dic$
benthic organic nitrogen	$\frac{\partial bon}{\partial t} = dz(k0) \cdot snk(d1n, w_{d1}) \Big _{z=H} + dz(k0) \cdot snk(d2n, w_{d2}) \Big _{z=H} - (bon_n4n + bon_n2n)$
benthic organic phosphorus	$\frac{\partial bop}{\partial t} = dz(k0) \cdot snk(d1p, w_{d1}) \Big _{z=H} + dz(k0) \cdot snk(d2p, w_{d2}) \Big _{z=H} - bop_n1p$
benthic opal (organic silicon)	$\frac{\partial bos}{\partial t} = dz(k0) \cdot snk(d2s, w_{d2}) \Big _{z=H} - bos_n5s$
benthic calcite	$\frac{\partial bsc}{\partial t} = dz(k0) \cdot snk(dsc, w_{dsc}) \Big _{z=H} - bsc_dic; \quad k0: \text{pelagic bottom layer}$

2.3. Process parameterisation

Table 2: Process names and parameterisation.

process	parameterization
phytoplankton:	
Redfield carbon fixation by diatoms	$dic_p1c_red = T_{fac1} \cdot p1c \cdot F(I, v_{p1}, p1c) \cdot limd_nps$
effective non-Redfield carbon fixation by diatoms	$dic_p1c = dic_p1c_red + excess \cdot (h_dic_p1c - dic_p1c_red)$
gross carbon fixation by diatoms	$h_dic_p1c = T_{fac1} \cdot p1c \cdot F(I, v_{p1}, p1c)$
Redfield carbon fixation by flagellates	$dic_p2c_red = T_{fac2} \cdot p2c \cdot F(I, v_{p2}, p2c) \cdot limf_np$
effective non-Redfield carbon fixation by flagellates	$dic_p2c = dic_p2c_red + excess \cdot (h_dic_p2c - dic_p2c_red)$
gross carbon fixation by flagellates	$h_dic_p2c = T_{fac2} \cdot p2c \cdot F(I, v_{p2}, p2c)$
nitrate uptake by diatoms	$n3n_p1n = T_{fac1} \cdot p1n \cdot F(I, v_{p1}, p1c) \cdot Q_{11}$
nitrate uptake by flagellates	$n3n_p2n = T_{fac2} \cdot p2n \cdot F(I, v_{p2}, p2c) \cdot Q_{21}$
ammonium uptake by diatoms	$n4n_p1n = T_{fac1} \cdot p1n \cdot F(I, v_{p1}, p1c) \cdot Q_{12}$
ammonium uptake by flagellates	$n4n_p2n = T_{fac2} \cdot p2n \cdot F(I, v_{p2}, p2c) \cdot Q_{22}$
phosphate uptake by diatoms	$n1p_p1p = dic_p1c_red / rpcp$
phosphate uptake by flagellates	$n1p_p2p = dic_p2c_red / rpcp$
silicate uptake by diatoms	$n5s_p1s = dic_p1c_red / rpcs$
exudation of dissolved organic carbon by diatoms	$p1c_doc = \gamma_1 \cdot dic_p1c$
exudation of dissolved organic carbon by flagellates	$p2c_doc = \gamma_2 \cdot dic_p2c$
exudation of dissolved organic nitrogen by diatoms	$p1n_don = p1c_doc / rpcn$
exudation of dissolved organic nitrogen by flagellates	$p2n_don = p2c_doc / rpcn$
exudation of dissolved organic phosphorus by diatoms	$p1p_dop = p1c_doc / rpcp$
exudation of dissolved organic phosphorus by	$p2p_dop = p2c_doc / rpcp$

flagellates	
exudation of "excess" organic carbon by diatoms	$p1c_soc = dic_p1c - dic_p1c_red$
exudation of "excess" organic carbon by flagellates	$p2c_soc = dic_p2c - dic_p2c_red$
mortality of diatoms-C: flux into d1c	$p1c_d1c = T_{fac} \cdot (1 - f_{d2}) \cdot (\mu_{11} \cdot p1c + \mu_6 \cdot p1c \cdot p1c)$
mortality of flagellates-C: flux into d1c	$p2c_d1c = T_{fac} \cdot (1 - f_{d2}) \cdot (\mu_{12} \cdot p2c + \mu_6 \cdot p2c \cdot p2c)$
mortality of diatoms-C: flux into d2c	$p1c_d2c = T_{fac} \cdot f_{d2} \cdot (\mu_{11} \cdot p1c + \mu_6 \cdot p1c \cdot p1c)$
mortality of flagellates-C: flux into d2c	$p2c_d2c = T_{fac} \cdot f_{d2} \cdot (\mu_{12} \cdot p2c + \mu_6 \cdot p2c \cdot p2c)$
mortality of diatoms-N: flux into d1n	$p1n_d1n = p1c_d1c / rpcn$
mortality of flagellates-N: flux into d1n	$p2n_d1n = p2c_d1c / rpcn$
mortality of diatoms-N: flux into d2n	$p1n_d2n = p1c_d2c / rpcn$
mortality of flagellates-N: flux into d2n	$p2n_d2n = p2c_d2c / rpcn$
mortality of diatoms-P: flux into d1p	$p1p_d1p = p1c_d1c / rpcp$
mortality of flagellates-P: flux into d1p	$p2p_d1p = p2c_d1c / rpcp$
mortality of diatoms-P: flux into d2p	$p1p_d2p = p1c_d2c / rpcp$
mortality of flagellates-P: flux into d2p	$p2p_d2p = p2c_d2c / rpcp$
mortality of diatoms-Si: flux into d2s	$p1s_d2s = (p1c_d2c + p1c_d1c) / rpsc + \max(0, dia_adds_loss - dia_ups)$ with: $dia_adds_loss = (p1c_doc + p1c_zec) / rpsc$ $dia_ups = n5s_p1s$
zooplankton:	
grazing of diatoms-C by mesozooplankton	$p1c_zec = G_{11}$
grazing of detritus-N by mesozooplankton	$d1c_zec = G_{13}$
grazing of microzooplankton-N by mesozooplankton	$zic_zec = G_{14}$
grazing of diatoms-N by mesozooplankton	$p1n_zen = G_{11} / rpcn$
grazing of detritus-N by mesozooplankton	$d1n_zen = G_{13} / d1c \cdot d1n$
grazing of microzooplankton-N by mesozooplankton	$zin_zen = G_{14} / rzc n$
grazing of diatoms-P by mesozooplankton	$p1p_zep = G_{11} / rpcp$

grazing of detritus-P by mesozooplankton	$d1p_zep = G_{13}/d1c \cdot d1p$
grazing of microzooplankton-P by mesozooplankton	$zip_zep = G_{14}/rzcp$
grazing of flagellates-C by microzooplankton	$p2c_zic = G_{21}$
grazing of detritus-C by microzooplankton	$d1c_zic = G_{23}$
grazing of bacteria-C by microzooplankton	$bac_zic = G_{24}$
grazing of flagellates-N by microzooplankton	$p2n_zin = G_{21}/rpcn$
grazing of detritus-N by microzooplankton	$d1n_zin = G_{23}/d1c \cdot d1n$
grazing of bacteria-N by microzooplankton	$ban_zin = G_{24}/rbcn$
grazing of flagellates-P by microzooplankton	$p2p_zip = G_{21}/rpcp$
grazing of detritus-P by microzooplankton	$d1p_zip = G_{23}/d1c \cdot d1p$
grazing of bacteria-P by microzooplankton	$bap_zip = G_{24}/rbnp$
calcification	$dic_psc = dic_p2c/q_{cal}$
conversion of shells of living phytoplankton into detritus calcite	$psc_dsc = \frac{p2c_zic + p2c_d1c + p2c_d2c + p2c_doc}{q_{cal}}$
fecal pellets production by mesozooplankton mortality: flux into d1c	$zec_d1c = rzc_n \cdot zen_d1n$
fecal pellets production by microzooplankton mortality: flux into d1c	$zic_d1c = rzc_n \cdot zin_d1n$
fecal pellets production by	$zec_d2c = rzc_n \cdot zen_d2n$

mesozooplankton mortality: flux into d2c	
fecal pellets production by microzooplankton mortality: flux into d2c	$zic_d2c = rzc_n \cdot zin_d2n$
fecal pellets production by mesozooplankton-N: flux into d1n	$zen_d1n = (1 - f_{d2}) \cdot ((1 - \delta - \varepsilon)\mu_2 \frac{zen}{zen + K_6} zen + (1 - \beta)(G_{11} + G_{13} + G_{14}) / rzc_n)$
fecal pellets production by microzooplankton-N: flux into d1n	$zin_d1n = (1 - f_{d2}) \cdot ((1 - \delta - \varepsilon)\mu_2 \frac{zin}{zin + K_6} zin + (1 - \beta)(G_{21} + G_{23} + G_{24}) / rzc_n)$
fecal pellets production by mesozooplankton-N: flux into d2n	$zen_d2n = f_{d2} \cdot ((1 - \delta - \varepsilon)\mu_2 \frac{zen}{zen + K_6} zen + (1 - \beta)(G_{11} + G_{13} + G_{14}) / rzc_n)$
fecal pellets production by microzooplankton-N: flux into d2n	$zin_d2n = f_{d2} \cdot ((1 - \delta - \varepsilon)\mu_2 \frac{zin}{zin + K_6} zin + (1 - \beta)(G_{21} + G_{23} + G_{24}) / rzc_n)$
fecal pellets production by mesozooplankton-P: flux into d1p	$zep_d1p = (1 - f_{d2}) \cdot ((1 - \delta - \varepsilon)\mu_2 \frac{zep}{zep + K_6} zep + (1 - \beta)(G_{11} + G_{13} + G_{14}) / rzc_p)$
fecal pellets production by microzooplankton-P: flux into d1p	$zip_d1p = (1 - f_{d2}) \cdot ((1 - \delta - \varepsilon)\mu_2 \frac{zip}{zip + K_6} zip + (1 - \beta)(G_{21} + G_{23} + G_{24}) / rzc_p)$
fecal pellets production by mesozooplankton-P: flux into d2p	$zep_d2p = f_{d2} \cdot ((1 - \delta - \varepsilon)\mu_2 \frac{zep}{zep + K_6} zep + (1 - \beta)(G_{11} + G_{13} + G_{14}) / rzc_p)$
fecal pellets production by microzooplankton-P: flux into d2p	$zip_d2p = f_{d2} \cdot ((1 - \delta - \varepsilon)\mu_2 \frac{zip}{zip + K_6} zip + (1 - \beta)(G_{21} + G_{23} + G_{24}) / rzc_p)$
respiration (release of dissolved inorganic carbon) by mesozooplankton	$z_{ec_dic} = \begin{cases} f_{_zec} - rzc_p \cdot f_{_zep} + h_{_zec_dic} : & \frac{f_{_zec}}{f_{_zep}} \geq rzc_p \wedge \frac{f_{_zen}}{f_{_zep}} \geq rzn_p \\ f_{_zec} - rz \cdot f_{_zen} + h_{_zec_dic} : & \frac{f_{_zec}}{f_{_zen}} \geq rzc_n \wedge \frac{f_{_zen}}{f_{_zep}} \leq rzn_p \\ h_{_zec_dic} & \text{else} \end{cases}$
respiration (release of dissolved inorganic carbon) by microzooplankton	$z_{ic_dic} = \begin{cases} f_{_zic} - rzc_p \cdot f_{_zip} + h_{_zic_dic} : & \frac{f_{_zic}}{f_{_zip}} \geq rzc_p \wedge \frac{f_{_zin}}{f_{_zip}} \geq rzn_p \\ f_{_zic} - rz \cdot f_{_zin} + h_{_zic_dic} : & \frac{f_{_zic}}{f_{_zin}} \geq rzc_n \wedge \frac{f_{_zin}}{f_{_zip}} \leq rzn_p \end{cases}$

excretion of dissolved organic nitrogen by mesozooplankton	$zen_don = \begin{cases} \frac{f_zen - rzn p \cdot f_zep}{2} + h_zen_don : & \frac{f_zec}{f_zep} \geq rzcp \wedge \frac{f_zen}{f_zep} \geq rzn p \\ \frac{f_zen - f_zec / rz}{2} + h_zen_don : & \frac{f_zec}{f_zen} \leq rzcn \wedge \frac{f_zec}{f_zep} \geq rzcp \end{cases}$
excretion of dissolved organic nitrogen by microzooplankton	$zin_don = \begin{cases} \frac{f_zin - rzn p \cdot f_zip}{2} + h_zin_don : & \frac{f_zic}{f_zip} \geq rzcp \wedge \frac{f_zen}{f_zep} \geq rzn p \\ \frac{f_zin - f_zic / rz}{2} + h_zin_don : & \frac{f_zic}{f_zin} \leq rzcn \wedge \frac{f_zic}{f_zip} \geq rzcp \end{cases}$
excretion of ammonium by mesozooplankton	$zen_n4n = \begin{cases} \frac{f_zen - rzn p \cdot f_zep}{2} + h_zen_n4n : & \frac{f_zec}{f_zep} > rzcp \wedge \frac{f_zen}{f_zep} \geq rzn p \\ \frac{f_zen - f_zec / rz}{2} + h_zen_n4n : & \frac{f_zec}{f_zen} \leq rzcn \wedge \frac{f_zec}{f_zep} \leq rzcp \end{cases}$
excretion of ammonium by microzooplankton	$zin_n4n = \begin{cases} \frac{f_zin - rzn p \cdot f_zip}{2} + h_zin_n4n : & \frac{f_zic}{f_zip} > rzcp \wedge \frac{f_zin}{f_zip} \geq rzn p \\ \frac{f_zin - f_zic / rz}{2} + h_zin_n4n : & \frac{f_zic}{f_zin} \leq rzcn \wedge \frac{f_zic}{f_zip} \leq rzcp \end{cases}$
excretion of phosphate by mesozooplankton	$zep_n1p = \begin{cases} \frac{f_zep - f_zen / rzn p}{2} + h_zep_n1p : & \frac{f_zec}{f_zen} \geq rzcn \wedge \frac{f_zen}{f_zep} \leq rzn p \\ \frac{f_zep - f_zec / rzcp}{2} + h_zep_n1p : & \frac{f_zec}{f_zen} \leq rzcn \wedge \frac{f_zec}{f_zep} \leq rzcp \end{cases}$
excretion of phosphate by microzooplankton	$zip_n1p = \begin{cases} \frac{f_zip - f_zin / rzn p}{2} + h_zip_n1p : & \frac{f_zic}{f_zin} \geq rzcn \wedge \frac{f_zin}{f_zip} \leq rzn p \\ \frac{f_zip - f_zic / rzcp}{2} + h_zip_n1p : & \frac{f_zic}{f_zin} \leq rzcn \wedge \frac{f_zic}{f_zip} \leq rzcp \end{cases}$
excretion of dissolved organic carbon by mesozooplankton	$zec_doc = h_zen_don \cdot rzcn$
excretion of dissolved organic carbon by microzooplankton	$zic_doc = h_zin_don \cdot rzcn$
uncorrected excretion of dissolved organic nitrogen by mesozooplankton	$h_zen_don = \mu_2 \cdot \delta \cdot zen \cdot \frac{zen}{K_6 + zen}$
uncorrected excretion of dissolved organic nitrogen by microzooplankton	$h_zin_don = \mu_2 \cdot \delta \cdot zin \cdot \frac{zin}{K_6 + zin}$
uncorrected respiration by mesozooplankton	$h_zec_dic = h_zen_n4n \cdot rzcn$
uncorrected respiration by microzooplankton	$h_zic_dic = h_zin_n4n \cdot rzcn$
uncorrected excretion of	$h_zen_n4n = \mu_2 \cdot \varepsilon \cdot zen \cdot \frac{zen}{K_6 + zen}$

ammonium by mesozooplankton	
uncorrected excretion of ammonium by microzooplankton	$h_zin_n4n = \mu_2 \cdot \varepsilon \cdot zin \cdot \frac{zin}{K_6 + zin}$
sum of unbalanced carbon fluxes into and out of mesozooplankton	$f_zec = p1c_zec + d1c_zec - zec_d1c - zec_d2c - zec_dic - zec_doc + zic_zec$
sum of unbalanced carbon fluxes into and out of microzooplankton	$f_zic = p2c_zic + bac_zic + d1c_zic - zic_d1c - zic_d2c - h_zic_dic - zic_doc - zic_zec$
sum of unbalanced nitrogen fluxes into and out of mesozooplankton	$f_zen = p1n_zen + d1n_zen - zen_d1n - zen_d2n - h_zen_n4n - h_zen_don + zin_zen$
sum of unbalanced nitrogen fluxes into and out of microzooplankton	$f_zin = p2n_zin + ban_zin + d1n_zin - zin_d1n - zin_d2n - h_zin_n4n - h_zin_don - zin_zen$
sum of unbalanced phosphorus fluxes into and out of mesozooplankton	$f_zep = p1p_zep + d1p_zep - zep_d1p - zep_d2p - h_zep_n1p - h_zep_dop + zip_zep$
sum of unbalanced phosphorus fluxes into and out of microzooplankton	$f_zip = p2p_zip + bap_zip + d1p_zip - zip_d1p - zip_d2p - h_zip_n1p - h_zip_dop - zip_zep$
decay of slowly sinking detritus into dissolved organic carbon	$d1c_doc = \mu_4 \cdot d1c$
decay of slowly sinking detritus into dissolved organic nitrogen	$d1n_don = \mu_4 \cdot d1n$
decay of slowly sinking detritus into dissolved organic phosphorus	$d1p_dop = \mu_4 \cdot d1p$
decay of fast sinking detritus into dissolved organic carbon	$d2c_doc = \mu_5 \cdot d2c$
decay of fast sinking detritus into dissolved organic nitrogen	$d2n_don = \mu_5 \cdot d2n$
decay of fast sinking detritus into	$d2p_dop = \mu_5 \cdot d2p$

dissolved organic phosphorus	
decay of fast sinking detritus into inorganic silicate	$d2s_n5s = \mu_5 \cdot d2s$
dissolution rate of calcite	$dsc_dic = \mu_7 \cdot dsc \cdot \left(1 - \frac{\delta CO_3^{2-}}{\delta CO_3^{2-} + C_0}\right)$ with $C_0 = 100 \mu mol C kg^{-1}$
oversaturation of carbonate and calcium ions	$\delta CO_3^{2-} = \max\left(0, [CO_3^{2-}] - \frac{K_{sp}}{[Ca^{2+}]}\right)$
bacteria:	
uptake of dissolved organic carbon by bacteria	$doc_bac = U_1 \cdot \frac{doc}{don}$
uptake of dissolved organic nitrogen by bacteria	$don_ban = U_1$
uptake of dissolved organic phosphorus by bacteria	$dop_bap = \frac{dop}{xkpb + dop} bap$ if $dop > 10^{-6} mmol P m^{-3}$
uncorrected respiration by bacteria	$h_bac_dic = \mu_3 \cdot bac$
sum of unbalanced carbon fluxes into bacteria-C	$f_bac = doc_bac - bac_zic - \mu_3 \cdot bac$
sum of unbalanced nitrogen fluxes into bacteria-N	$f_ban = don_ban - ban_zin - ban_n4n + n4n_ban$
bacterial respiration	$bac_dic = \begin{cases} h_bac_dic + fdc : & fdc > 0 \wedge n4n < tres_n4n \\ \max(0, h_bac_dic + fdc) : & fdc \leq 0 \end{cases}$ with: $fdc = f_bac - f_ban \cdot rbcn$
uptake of ammonium by bacteria	$n4n_ban = \begin{cases} (r_{do}/rbcn - 1) \cdot U_1' : & fdc > 0 \wedge n4n \geq tres_n4n \\ 0 : & otherwise \end{cases}$
excretion of ammonium	$ban_n4n = \begin{cases} h_ban_n4n - \min(0, h_bac_dic + fdc/rbcn) : & fdc \leq 0 \\ h_ban_n4n : & fdc > 0 \end{cases}$ with: $fdc = f_bac - f_ban \cdot rbcn$
uncorrected excretion of ammonium	$h_ban_n4n = \mu_3 \cdot bac / rbcn$
maximum possible uptake of phosphate by bacteria	$fbpmax = \cdot(n4n_ban / n4n) \cdot n1p$
phosphate required by bacteria	$fbpreq = \cdot(don_ban + n4n_ban - ban_n4n) / rbnp - dop_bap$
phosphate uptake by bacteria	$n1p_bap = \cdot \min(\max(0., fbpreq), fbpmax)$
phosphate release by bacteria	$bap_n1p = \cdot \max(0., -fbpreq)$
further processes:	
decay of semi-labile dissolved organic	$soc_doc = \cdot soc_rate \cdot soc$

carbon	
nitrification	$n4n_n3n = r_n(I, z) \cdot oswitch \cdot n4n$
benthic carbon remineralization	$boc_dic = \frac{brc}{dz(k_0)} \cdot boc$ k_0 : pelagic bottom layer
benthic denitrification	$bon_n2n = bdnf_basic - \max[0, (bdnf_basic - h_bon_n4n)]$
potential benthic denitrification	$bdnf_basic = rbd \cdot o2o_sed$
uncorrected benthic nitrogen remineralization	$h_bon_n4n = \frac{brn}{dz(k_0)} \cdot bon$ k_0 : pelagic bottom layer
benthic nitrogen remineralization	$bon_n4n = \max[0, (h_bon_n4n - bdnf_basic)]$
benthic phosphorus remineralization	$bop_n1p = \frac{brp}{dz(k_0)} \cdot bop$ k_0 : pelagic bottom layer
benthic silicate remineralization	$bos_n5s = \frac{brs}{dz(k_0)} \cdot bos$ k_0 : pelagic bottom layer
benthic calcite dissolution	$bsc_dic = \mu_7 \cdot bsc \cdot \left(I - \frac{\delta CO_3^{2-} _{k_0}}{\delta CO_3^{2-} _{k_0} + C_0} \right)$ k_0 : pelagic bottom layer
oxygen consumption during benthic carbon remineralization	$o2o_sed = uco \cdot boc_dic$
oxygen release during photosynthesis	$phc_o2o = uno \cdot (rpcn \cdot n4n_phn + (rpcn + 2) \cdot n3n_phn) + f_dic_phc - f_dic_red$
oxygen consumption by mesozooplankton	$o2o_zec = uco \cdot zec_dic$
oxygen consumption by microzooplankton	$o2o_zic = uco \cdot zic_dic$
oxygen consumption by bacteria	$o2o_bac = uco \cdot oswitch \cdot bac_dic$
N ₂ production due to denitrification in case of oxygen depletion and nitrate existence	$n3n_nm2 = \frac{1}{2} \cdot (1 - oswitch) \cdot nswitch \cdot \frac{bac_dic}{rbcn}$; ($\neq 0$ for $oswitch=0, nswitch=1$)
anoxic H ₂ S production	$o2o_bac = (1 - oswitch) \cdot (1 - nswitch) \cdot bac_dic$
oxygen consumption by nitrification	$o2o_n4n = 2 \cdot uno \cdot n4n_n3n$
air-sea flux of oxygen	$air_o2o = K_w \cdot K_H \cdot (po_2(air) - po_2(sea)) / dz(1)$ K_w and K_H as defined by Wanninkhof (1992).
air-sea flux of CO ₂	$air_o2c = K_w \cdot K_H \cdot (pco_2(air) - pco_2(sea)) / dz(1)$ K_w and K_H as defined by Wanninkhof (1992).
sinking of matter X	$snk(X, w) = w \cdot \frac{\partial X}{\partial z}$
vertical mixing of matter X	$mix_v(X) = \frac{\partial}{\partial z} \left(A_v \cdot \frac{\partial X}{\partial z} \right)$
horizontal mixing of matter X	$mix_h(X) = \frac{\partial}{\partial x} \left(A_h \cdot \frac{\partial X}{\partial x} \right) + \frac{\partial}{\partial y} \left(A_h \cdot \frac{\partial X}{\partial y} \right)$
advection of matter X (vector upstream)	$adv(X) = u \frac{\partial X}{\partial x} + v \frac{\partial X}{\partial y} + w \frac{\partial X}{\partial z}$
transport of matter X	$tra(X) = adv(X) + mix_v(X) + mix_h(X)$

Table 3: Special functions used for process parametrisations.

name	functions
light-depending growth rate	$F(I, v_p, phc) = v_p \cdot \frac{I_{par}(z)}{I_{opt}} \cdot e^{1 - \frac{I_{par}(z)}{I_{opt}}}$ with z : actual depth
depth-depending PAR	$I_{par}(z) = k_{par} \cdot I_0 \cdot e^{\varepsilon(z)}$ $\varepsilon(z) = (k_w + k_c \cdot phc + k_s \cdot silt) \cdot z$
light limitation of diatoms	$lip1_ir = F(I, v_{p1}, phc)$
light limitation of flagellates	$lip2_ir = F(I, v_{p2}, phc)$
light adaptation	$\frac{\partial I_{opt}}{\partial t} = rupli \cdot (actuallight - I_{opt})$ $rupli = 0.25 d^{-1}$ $actuallight = k_{par} \cdot \bar{I}_0 \cdot e^{\varepsilon(z_a)}$ $z_a : \min(z, z_{max})$ $z_{max} = 4 m$ \bar{I}_0 : daily mean irradiance
nitrate limitation of diatoms	$lip1_3n = \frac{n3n/K_1}{1 + n3n/K_1 + n4n/K_{21}} = Q_{11}$
nitrate limitation of non-diatoms	$lip2_3n = \frac{n3n/K_1}{1 + n3n/K_1 + n4n/K_{22}} = Q_{12}$
ammonium limitation of diatoms	$lip1_4n = \frac{n4n/K_{21}}{1 + n3n/K_1 + n4n/K_{21}} = Q_{21}$
ammonium limitation of flagellates	$lip2_4n = \frac{n4n/K_{22}}{1 + n3n/K_1 + n4n/K_{22}} = Q_{22}$
total nitrogen limitation of diatoms	$lip1_hn = lip1_3n + lip1_4n$
total nitrogen limitation of flagellates	$lip2_hn = lip2_3n + lip2_4n$
phosphate limitation of diatoms	$lip1_1p = \frac{n1p}{K_1 + n1p}$
silicate limitation of diatoms	$lip1_5s = \frac{n5s}{K_1 + n5s}$
Phosphate limitation of flagellates	$lip2_1p = \frac{n1p}{K_1 + n1p}$
mesozooplankton grazing rates for the various food types X1i	$G_{1i} = T_{fac} \cdot g_1 \cdot \frac{p_{1i} \cdot X_{1i}}{K_3 + \sum_j p_{1j} \cdot X_{1j}} \cdot zec$ $X_{11} = p1c, X_{13} = d1c, X_{14} = zic$
microzooplankton grazing rates for the various food types X2i	$G_{2i} = T_{fac} \cdot g_2 \cdot \frac{p_{2i} \cdot X_{2i}}{K_3 + \sum_j p_{2j} \cdot X_{2j}} \cdot zic$ $X_{21} = p2c, X_{23} = d1c, X_{24} = bac$
concentration-dependent grazing preferences	$p_{ki} = \frac{\pi_{ki} \cdot X_{ki}}{\sum_j \pi_{kj} \cdot X_{kj}}$ with $\sum_j \pi_{kj} = 1$ for $k = 1, 2; j = 1, 3, 4$
DON uptake by bacteria	$U_1 = v_b \frac{don}{K_4 + don} \cdot ban$

light-dependent nitrification rate	$r_n(I, z) = \begin{cases} r_0 & : z \geq d_{eu} \\ 0.01 \cdot r_0 \cdot I_{par}(0) / I_{par}(z) & : z < d_{eu} \end{cases}$ with d_{eu} : the depth of the 1% light level
temperature factor	$T_{fac}(T) = 1.5^{\frac{T-T_0}{10}}$ with $T_0 = 10^\circ C$
switch for oxygen availability	$oswitch = \begin{cases} 0: & o2o \leq 0 \\ 1: & o2o > 0 \end{cases}$
switch for nitrate availability	$nswitch = \begin{cases} 0: & n3n \leq 0.1 \\ 1: & n3n > 0.1 \end{cases}$

2.4. Model parameters

In Table 4 all model parameters were listed including full name or description, unit, and value.

Table 4: Parameters in the biogeochemical model. Note: All rates are valid for 10°C.

parameter	unit	value
assimilation efficiency of (micro/meso)zooplankton		$\beta = 0.75$
remineralization rate of benthic carbon	d^{-1}	$brc = 0.028$
remineralization rate of benthic nitrogen	d^{-1}	$brn = 0.033$
remineralization rate of benthic phosphate	d^{-1}	$brp = 0.033$
remineralisation rate of benthic silicate	d^{-1}	$brs = 0.013$
DON fraction of losses from (micro/meso)zooplankton		$\delta = 0.4$
ammonium fraction of losses from (micro/meso)zooplankton		$\varepsilon = 0.4$
ratio of breakdown rate-C to breakdown rate-N	$mol C / mol N$	$\varphi = 0.85$
fraction of fast sinking detritus		$f_{d2} = 0.15$
maximum ingestion rate of mesozooplankton	d^{-1}	$g_1 = 0.4$
maximum ingestion rate of microzooplankton	d^{-1}	$g_2 = 0.5$
exudation fraction of diatoms/flagellates		$\gamma = 0.05$
half-saturation constant of nitrate uptake by diatoms/flagellates	$mmol N m^{-3}$	$K_1 = 0.5$
half-saturation constant of ammonium uptake by diatoms	$mmol N m^{-3}$	$K_{21} = 0.5$
half-saturation constant of ammonium uptake by flagellates	$mmol N m^{-3}$	$K_{22} = 0.05$
half-saturation constant of phosphate uptake by diatoms/flagellates	$mmol P m^{-3}$	$K_p = 0.05$
half-saturation constant of silicate uptake by diatoms	$mmol Si m^{-3}$	$K_s = 0.5$
half-saturation constant ingestion by (micro/meso)zooplankton	$mmol N m^{-3}$	$K_3 = 1.0$
half-saturation constant uptake by bacteria	$mmol N m^{-3}$	$K_4 = 0.1$
half-saturation constant loss of (micro/meso)zooplankton-N	$mmol N m^{-3}$	$K_6 = 0.2$
extinction coefficient for diatoms/flagellates	$m^2 / mmol C$	$k_e = 4.53 \cdot 10^{-3}$
extinction coefficient silt	m^2 / mg	$k_s = 0.06 \cdot 10^{-3}$

conversion factor for photosynthetically active radiation		$k_{par} = 0.43$
locally varying extinction coefficient of water	m^{-1}	$0.09 \leq k_w \leq 0.1$
phytoplankton linear mortality rate (diatoms/flagellates)	d^{-1}	$\mu_1 = 0.035$
maximum loss rate of (micro/meso)zooplankton	d^{-1}	$\mu_2 = 0.2$
excretion rate of bacteria	d^{-1}	$\mu_3 = 0.1$
breakdown rate of slowly sinking detritus-N	d^{-1}	$\mu_4 = 0.12$
breakdown rate of fast sinking detritus-N	d^{-1}	$\mu_5 = 0.10$
phytoplankton quadratic mortality factor (diatoms/flagellates)	$m^3 \text{ mmol } C^{-1} d^{-1}$	$\mu_6 = 0.01$
maximum dissolution rate of calcite	d^{-1}	$\mu_7 = 0.0333$
grazing preference of mesozooplankton for diatoms		$\pi_{11} = 0.33$
grazing preference of mesozooplankton for detritus		$\pi_{13} = 0.34$
grazing preference of mesozooplankton for microzooplankton		$\pi_{14} = 0.33$
grazing preference of microzooplankton for flagellates		$\pi_{21} = 0.33$
grazing preference of microzooplankton for detritus		$\pi_{23} = 0.34$
grazing preference of microzooplankton for bacteria		$\pi_{24} = 0.33$
ratio of phytoplankton carbon to calcite shells	$\text{mol } C / \text{mol } CaCO_3$	$q_{cal} = 70$
maximum nitrification rate	d^{-1}	$r_0 = 0.02$
C:N ratio of bacteria	$\text{mol } C / \text{mol } N$	$rbcn = 4$
ratio of oxygen consumption to benthic denitrification		$rbd = 0.116$
C:N ratio of dissolved organic matter (variable)	$\text{mol } C / \text{mol } N$	$r_{do} = doc/don$
C:N ratio of (micro/meso) zooplankton	$\text{mol } C / \text{mol } N$	$rzcn = 5.5$
C:P ratio of (micro/meso) zooplankton	$\text{mol } C / \text{mol } P$	$rzcp = 110$
N:P ratio of phytoplankton (diatoms/flagellates) and (micro/meso) zooplankton	$\text{mol } N / \text{mol } P$	$rznp = 20$
N:P ratio of bacteria	$\text{mol } N / \text{mol } P$	$rbnp = 10$
C:P ratio of bacteria	$\text{mol } C / \text{mol } P$	$rbcp = 40$
C:N (Redfield) ratio of phytoplankton (diatoms/flagellates)	$\text{mol } C / \text{mol } N$	$rpcn = 6.625$
C:Si ratio of diatoms	$\text{mol } C / \text{mol } Si$	$rpcs = 5.76$
locally varying silt concentration	mg/l	$0.0 \leq silt \leq 35.7$
decay rate of semi-labile dissolved organic carbon	d^{-1}	$soc_rate = 0.00274$
threshold for ammonium uptake by bacteria	$\text{mmol } N \text{ m}^{-3}$	$tres_n4n = 0.001$
oxygen to carbon ratio	$\text{mol } O / \text{mol } C$	$uco = 1$
oxygen to nitrogen ratio	$\text{mol } O / \text{mol } N$	$uno = 1$
maximum uptake rate of bacteria	d^{-1}	$v_b = 1.4$
maximum growth rate of diatoms	d^{-1}	$v_{p1} = 1.1$
maximum growth rate of flagellates	d^{-1}	$v_{p2} = 0.9$
velocity of slowly sinking detritus	$m \text{ d}^{-1}$	$w_{d1} = 0.4$
velocity of fast sinking detritus	$m \text{ d}^{-1}$	$w_{d2} = 10.0$

2.5. State variables

State variables of the model are sub-divided into prognostic and derived state variables which are calculated diagnostically (indicated by a * in Table 2). The model uses constant, but different nutrient/carbon ratios for the main biogenic state variables (e.g. Redfield ratio for the functional units of phytoplankton, different ratios for zooplankton groups and bacteria) and variable ratios for detritus and dissolved organic matter (DOM). The number of state variables is defined within the include file "eco4_par.par" and the names in "eco4_var1.com".

3. Overview on initial, boundary and forcing data

To run ECOHAM4 several initial, boundary and forcing data-sets are necessary which are summarized in Figure 6. Table 8 summarizes all names of the corresponding data-files.

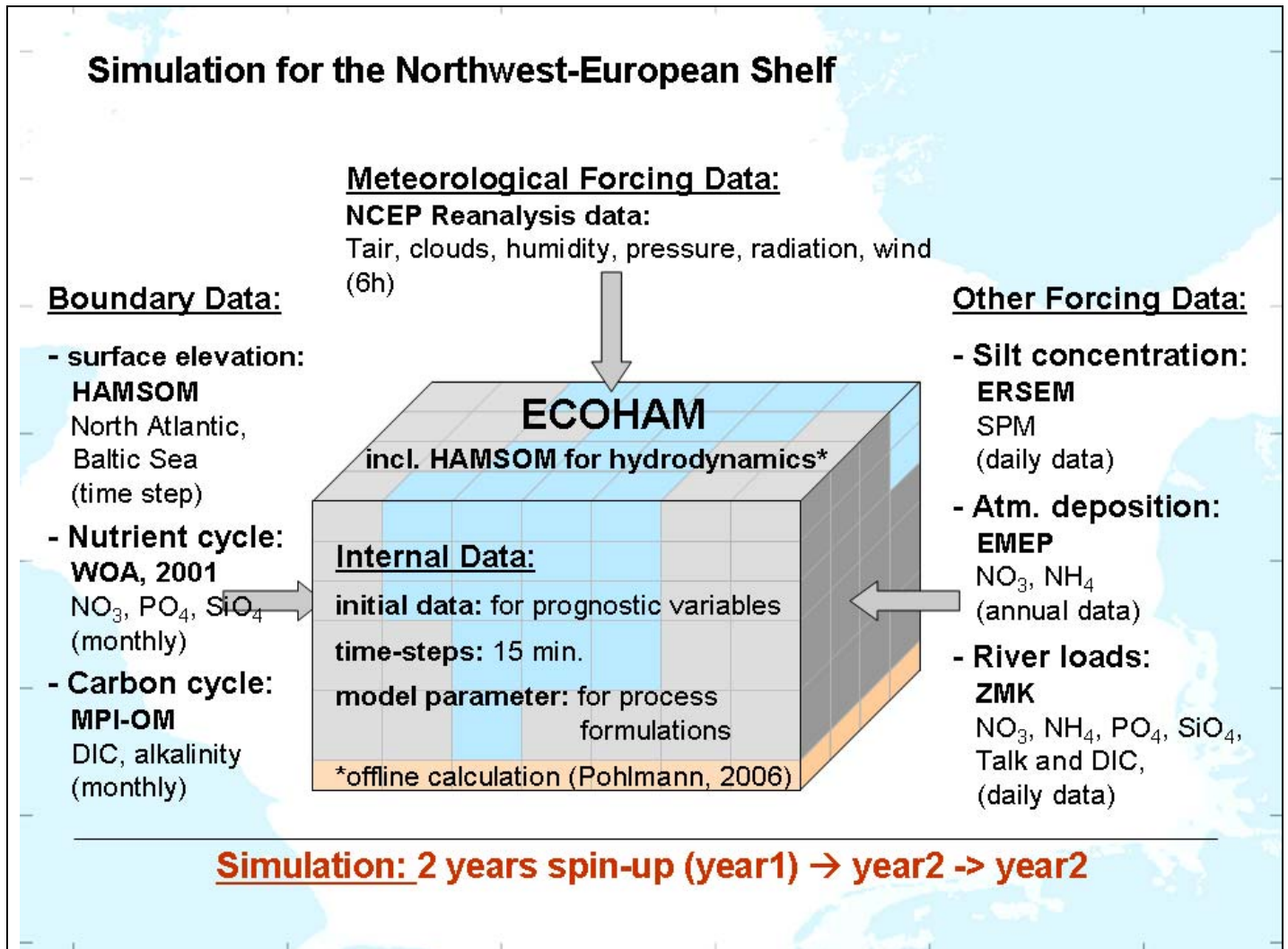


Figure 6: Initial, boundary and forcing data necessary for the ECOHAM4 simulation runs.

4. Control file *eco4_set.dat* and *eco4_set_bio2.dat*

Table 5: The *eco4_set.dat* files.

prepare	:	0	:prepare=1 Preparation mode only for model installation
	:		:prepare=0 Simulation mode
isw_dim	:	3	:isw_dim=1 1D mode
	:		:isw_dim=3 3D mode
ichain	:	1	:ichain=0 For NEC-job first set in year
	:		:ichain=1 For NEC-job follow-up sets in year
iwarm	:	0	:warmstart=1
	:		:cold<=0; cold=-n: n days spinup of hydro
iwarm_next	:	1	:=1 at simulation end eco5_warm.dat gets
	:		: time (iy2,im2,id2)+24h
	:		:=0 at simulation end eco5_warm.dat gets
	:		: time (iy2-1,im2,id2)+24h
isw_sed	:	1	:with sediment=1, without sediment=0
isw_zoo	:	2	:0 - 1P1Z switch for eco4_set_bio0.dat
	:		:1 - structured zoo, 1P
	:		:2 - 2P2Z
	:		:3 - struct. zoo + 2P2Z
	:		:4 - d15N + 1P1Z
num_riv	:	149	:number of rivers loading material
imass_conserv	:	0	:=1 check mass conservation at icol_out,jcol_out
freshwater	:	0	:switch for both the HAMSOM and the biogeo part
	:		:1 - including freshwater input (River.dat, freshwater.dat)
	:		:0 - no freshwater input
ihyd	:	2	:ihyd=1 => HAMSOM&BIOGEO coupled
	:		:ihyd=2 => BIOGEO offline
	:		:ihyd=3 => HAMSOM only
relrate	:	0.40	:max rel.rate of change per time step
ibarocline	:	1	:HAMSOM parameter (1=barocline, 0=barothrop)
iprognostic	:	1	:HAMSOM parameter (1=prognostic, 0=climateTS)
htmit	:	0.85	:HAMSOM screw:jp former 0.65
	:		:htmit=0:implicite; htmit=1: explicite scheme
hev	:	10.0	:horizontal eddy viscosity (?? m2/s ??)
bounds_out	:	1	: 0 - no output on NEST bounds
	:		: 1 - output on NEST bounds
restore_all	:	1	: 0 - bc mirrored; only the restore_sta vars have fixed bcs
	:		: 1 - for all state vars boundary conditions are prescribed
	:		: restore_sta switched off
restore_n4n	:	1	: 0 - no nitrate restoring, cold start from eco5_rest.n4n
	:		: 1 - daily nitrate restoring; see eco5_rest.n4n
	:		:-1 - no nitrate restoring, cold start with constant value
restore_n3n	:	1	: 0 - no nitrate restoring, cold start from eco5_rest.n3n
	:		: 1 - daily nitrate restoring; see eco5_rest.n3n
	:		:-1 - no nitrate restoring, cold start with constant value
restore_alk	:	1	: 0 - no alkalinity restoring
	:		: 1 - daily alkalinity restoring
	:		:-1 - no alk restoring, cold start with constant value
restore_dic	:	1	: 0 - no DIC restoring
	:		: 1 - daily DIC restoring
	:		:-1 - no DIC restoring, cold start with constant value
restore_nlp	:	1	: 0 - no phosphate restoring, cold start from eco5_rest.nlp
	:		: 1 - daily phosphate restoring; see eco5_rest.nlp
	:		:-1 - no phosphate restoring, cold start with constant value
restore_n5s	:	1	: 0 - no silicate restoring, cold start from eco5_rest.n5s
	:		: 1 - daily silicate restoring; see eco5_rest.n5s
	:		:-1 - no silicate restoring, cold start with constant value
iy1	:	1994	:start year
im1	:	1	:start month
id1	:	1	:start day
ih1	:	0	:start hour
iy2	:	1994	:ending year
im2	:	12	:ending month
id2	:	31	:ending day
ih2	:	23	:ending hour
lat_grid	:	82	:number of North-South grid points
lon_grid	:	88	:number of West-East grid points
kmax_grid	:	12	:number of vertical grid points
delta_lat	:	0.2	:delta lat in degrees
delta_lon	:	0.3333333333	:delta lon in degrees
xlat0	:	47.6833333333	:most southerly zeta point
xlon0	:	-15.0833333333	:most westerly zeta point
istep_output	:	1	:delta t for output (d)
icol_output	:	7	:long. pos. of gridpoint of first output column
jcol_output	:	32	:lati. pos. of gridpoint of first output column
icol_out2	:	55	:long. pos. of gridpoint of second output column
jcol_out2	:	50	:lati. pos. of gridpoint of second output column
icol_out2	:	71	:long. pos. of gridpoint of third output column
jcol_out2	:	33	:lati. pos. of gridpoint of third output column

```

deltat_bio      :      15      :(60 for the coupled case) timestep in minutes
deltat_hyd      :      15      :timestep in minutes for the update of hydro data
windtimestep    :     360      :here in minutes
radsoltimestep  :     120      :here in minutes
climatetimestep:      30      :For T and S in days
iup_chem        :         2      :time interval updating chem. variables
                :                :iup_chem=0: at day end
                :                :iup_chem=1: every bio-time step
                :                :iup_chem=2: every half an hour
dis3_mode       :         3      :dis3_mode=0: no 3d output of state variables
                :                :                =1: 3d output into eco4_res.bin
                :                :                =2: 3d output into eco4.grads
                :                :                =3: 3d output into eco4.grads and cn4_res.bin
mode_p          :         0      :
                :                :mode_p=0      print all data
                :                :mode_p=1      all but no fluxes
                :                :mode_p=2      only state variables
flux_out        : dic_phc      :flux on output No 1
stat_out        : st_n3n      :
io_mean         :         1      :io_mean=1      monthly means of state vars on output
                :                :io_mean=0      15th of each month is time of output
iairsea         :         1      :switch on/off airsea flux of CO2 and N deposition
                :                :air_sea exchange
air_sea_mode    :         1      :parametrisation of gas air_sea transfer
                :                :1 Wanninkhof 1992
                :                :2 Wanninkhof & McGillis 1999
iwind           :         1      :iwind=0 const south-westwind 20 m/s
                :                :iwind=1 read wind data from file
isol            :         1      :isol=0 const shortwave radiation 100 Wm-2
                :                :isol=1 read solar radiation from file
iclim           :         1      :iclim=0 const climate values
                :                :iclim=1 read climateTS from file
jhyd            :        111      :binary triple to switch on/off hydrodynamical processes
                :                :jhyd=000: no adv, no hor_mix, no ver_mix_sink
                :                :jhyd=111:  adv,   hor_mix,   ver_mix_sink
                :                :jhyd=121:  adv,   hor_mix with time varying coeff,
                :                :                ver_mix
cross_sec       :         1      :cross_sec=1 calculate flow across sections
                :                :                =0 do not calculate ..
passive_tracer  :         1      :=0 no passive tracer integration
                :                :=1 state variables and passive tracer xlx are integrated
                :                :=2 only the passive tracer xlx is integrated
machine         :         2      :=1 PC WINDOWS
                :                :=2 DKRZ machine
light_ham       :         1      :treatment of temperature development in HAMDOM
                :                :1-conventional: first layer gets full short wave
                :                :                radiation
                :                :2-dT/dt-dIdZ: possible feedback from biology
light_inhibition:         1      :light_inhibition=0: no light inhibition possible
                :                :light_inhibition=1: light inhibition possible
                :                :this switch only works with light_mode=1

opt_irr         :         0.0      :optimal light (w/m**2) only necessary for P-I (Steele)
                :                :opt_irr=0: light adaptation will be performed
atm_n           :        -1.0      :surface input of N (mmol N/m2/d)
                :                :-1 eco4_atm_n.dat with ann mean loads NOX and NHY
                :                :-2 eco4_atm_n_mon.dat with monthly mean loads NOX and NHY
exts            :         0.06      :extinction coefficient for silt (mg/l):ERSEM=0.04
                :                :0.00 -> no silt data will be read in
extw            :        -1.0      :extinction coefficient water (1/m) former 0.04
                :                :<0 => extw.dat will be read

```

isw_zoo=2 requires eco4_set_bio2.dat (2 groups of phyto- and zooplankton):

```

extp1           :         0.03      :extinction coefficient diatoms (m**2/(mmol N))
extp2           :         0.03      :extinction coefficient flagellates (m**2/(mmol N))
vp1             :         1.1      :PRODUKTIONSRATE diatoms BEI 10 Grad (1/d) (!!!1.1!!)
vp2             :         0.9      :PRODUKTIONSRATE flagell BEI 10 Grad (1/d) (!!!1.1!!)
excess          :         0.5      :>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) (C/N)
xk1             :         0.50      :half saturation constant nitrate (mmol N/m**3)
xk21            :         0.50      :half sat. const. ammonium for diatoms (mmol N/m**3)
xk22            :         0.05      :half sat. const. ammonium flagellates (mmol N/m**3)
xkp             :         0.05      :half saturation constant phosphate (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

```

xmul1	:	0.035	:mortality rate dia (1/d)
xmul2	:	0.035	:mortality rate fla (1/d)
wplc	:	0.0	:sinking velocity diatoms (m/d)
g1_max	:	0.40	:max. ingestion rate of mesozoo (1/d) (!!0.5!!)
g2_max	:	0.40	:max. ingestion rate of microzoo (1/d) (!!0.5!!)
xk31	:	1.00	:half saturation const. mesozoo grazing (mmol N/m**3)
xk32	:	1.00	:half saturation const. microzoo grazing (mmol N/m**3)
p11	:	0.33	:Mesozoo preference Diat grazing
p12	:	0.33	:Mesozoo preference Microzoo grazing
p13	:	0.34	:Mesozoo preference detr. grazing
p14	:	0.00	:Mesozoo preference bacteria grazing
p21	:	0.33	:Microzoo preference Flagell grazing
p23	:	0.33	:Microzoo preference bact. grazing
p24	:	0.34	:Microzoo preference detr. grazing
xmu21	:	0.2	:max loss rate of mesozoo (1/d)
xmu22	:	0.2	:max loss rate of microzoo (1/d)
beta1	:	0.75	:assimilation coeff. of mesozoo
beta2	:	0.75	:assimilation coeff. of microzoo
xk16	:	0.2	:half sat. const. loss of mesozoo (mmol N/m**3)
xk26	:	0.2	:half sat. const. loss of microzoo (mmol N/m**3)
aeps1	:	0.4	:ammonium fraction of mesozoo loss
aeps2	:	0.4	:ammonium fraction of microzoo loss
delta_don1	:	0.4	:LDON fraction of meso loss
delta_don2	:	0.4	:LDON fraction of micro loss
frac_d2x	:	0.15	:fraction of fast sinking detritus d2x
wd1c	:	0.4	:sinking velocity of slow detritus d1c,d1n (m/d)
wd2c	:	10.0	:sinking velocity of fast detritus d2c,d2n,dsc (m/d)
xmu4n	:	0.12	:breakdown of N-DET1 (1/d)
xmu5n	:	0.10	:breakdown of N-DET2 (1/d)
rxmu4c	:	0.85	:ratio of breakdown rates N/C - DET
rb	:	4.0	:C/N of BAC (C/N)
rz	:	5.5	:C/N ratio of ZOO
xk4	:	0.2	:half sat const N-uptake of BAC (mmol N/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)
brc	:	0.028	:benthic remi rate carbon (1/d)
brn	:	0.0333	:benthic remi rate nitrogen (1/d)
brp	:	0.0333	:benthic remi rate phosphorus (1/d)
brs	:	0.013	:benthic remi rate silicon (1/d)
red	:	6.625	:PHYTOPLANKTON redfield ratio (C/N)
rnp	:	20.0	:N:P ratio for phytoplankton cells
rcp	:	132.5	:C:P ratio for phytoplankton cells
rsc	:	5.76	:C:Si ratio in diatom cells
rnpb	:	10.0	:N:P ratio for bacteria
rcpb	:	40.0	:C:P ratio for bacteria
xmq11	:	0.01	:mortality at quadratic loss term diatoms
xmq12	:	0.01	:mortality at quadratic loss term flagellates
xkpb	:	0.02	:halfsat. Const. bacteria uptake of DOP (mmol P/m**3)

5. How to select parameter and operation modus

The model ECOHAM4 comprises the hydrodynamic and biogeochemical marine dynamics. The latter simulates the cycling of carbon, nitrogen, phosphorus, silicon and oxygen. The hydrodynamical part consists of the model HAMSOM (Backhaus, 1985; Pohlmann, 1996; Pohlmann, 2006). The biogeochemical part is published by Lorkowski et al. (2010). Corresponding to these origins the code is separated into the files *eco4.f90* (main), *hamsom.f90*, *biogeo.f90*, *hyd_up.f90* (transport). The model is able to run coupled or offline. The latter mode allows to run HAMSOM and afterwards the biogeochemical module.

The model can be used in 4 different modes:

1. prepare = 1 or 2

prepare=1

Phase 1 of the model-installation: From *eco4_set.dat* the grid dimensions (lat_grid, lon_grid, kmax_grid), and from the file *dep.dat* the topography and the information regarding to the vertical resolution are read (depth of lower edges of levels). The variable `MinmalThickness` is defined within the model (*subroutine set*) its value is 2m by default. The numbering of the different depths in *dep.dat* is oriented from north to south and from west to east (reader friendly). "Land" is defined by 0 (zero). All files containing grid-informations are generated. No simulation will be performed. Table 6 lists the different corresponding files:

Table 6: Grid information files.

IO Dateien	
INPUT	OUTPUT
<i>eco4_set.dat</i>	<i>eco4.prt</i>
<i>dep.dat</i>	<i>eco4_indh.dat</i>
<i>eco4_par.par</i>	<i>nice-map.txt</i>
<i>nsconstant.inc</i>	<i>eco4_neigh_sk.bin</i>
	<i>eco4_neigh_sk.dat</i>
	<i>eco4_neigh.dat</i>
	<i>eco4_neigh.bin</i>
	<i>eco4_par.par</i>
	<i>eco4_par_bak.par</i>
	<i>nsconstant.inc</i>
	<i>nsconstant_bak.inc</i>
	<i>nsconstant_short.inc</i>
	<i>open_bounds_bio_map.txt</i>

prepare=2

Phase 2 of the model-installation: Definition of the open boundaries for the biogeochemical part (in case of `restore_all=0`). No simulation will be performed.

The file *open_bounds_bio_map.txt* will be generated showing the land-sea mask. Here the user should define the open boundaries: "N"-northern-, "S"-southern-, "W"-western-, "E"-eastern- boundary. On these grid points no simulation will be performed but restoring values from the files *eco4_rest.xyz* will be read during the simulation. Usually 3 gridlines nearest grid-end should be restored. Problematic grid points can be switched off by giving "A", "B", "C", ... These cases must be handled by the user in the program (*subroutine ini_open_bounds*). After finishing the execution in this mode some parts of the code are defined new. Therefore the model must be compiled again. Now the grid structure for the biogeochemical part is defined in one 1-D vector. It can be seen for scalars in *eco4_neigh_sk.dat* and for the transport-vectors of the Arakawa-C grid in *eco4_neigh.dat*. All other files are listed in Table 7.

The numbering of the grid cells starts in the south-western corner of the grid with the upper-most grid-cell; the second cell is below the first one, the third below the second one (and so on ..). When all cells of the south-western corner column are numbered the next column neighbouring east of the first column is numbered from the top to the bottom. When all water-columns of the southern first line are numbered the second gridline, north of the first, starts to be numbered (and so on ..).

Table 7: Grid information files and additional files.

IO Dateien	
INPUT	OUTPUT
eco4_set.dat	eco4.prt
dep.dat	eco4_indh.dat
eco4_par.par	nice-map.txt
nsconstant.inc	eco4_neigh_sk.dat
open_bounds_bio_map.txt	eco4_neigh.dat
	eco4_par.par
	eco4_par_bak.par
	nsconstant.inc
	nsconstant_bak.inc
	nsconstant_short.inc
	open_bounds_bio_map.lst

2. prepare = 0 ihyd = 1

Coupled hydrodynamical and biogeochemical simulation.

3. prepare = 0 ihyd = 2

Biogeochemical simulation. The hydrodynamic results were read.

4. prepare = 0 ihyd = 3

Hydrodynamic simulation.

All „prepare=0“-runs are simulations. Table 8 gives the corresponding I/O-files

Table 8: List of I/O files.

IO Dateien	
INPUT	OUTPUT
eco4_set.dat	hydro_time_step_dump.dat
hydro_dump.dat	hydro_dump.dat
hydro_spinup.dat	hydro_spinup.dat
zetam2.dat	bogridinfo.bin
aandera.cfg	u_dmean.asc
	v_dmean.asc
river.dat	z_dmean.asc
climatets.bin	s_dmean.asc
wind.bin	t_dmean.asc
airt.bin	av_dmean.asc
relh.bin	eco4_warm.dat
clou.bin	eco4.prt
eco4_warm.dat	eco4_pco2.dat
	eco4_flux.prt
rad.bin	scratch.dat
wins.bin	eco4_res.bin/.dat
eco4_rest.n3n	eco4_flij.bin./dat
eco4_rest.alk	eco4.grads
eco4_rest.dic	bounds_hydro.dat
eco4_rest.nlp	bounds_biogeo.dat
eco4_rest.n5s	
eco4_rest.xyz	
eco4_riv.bin	
eco4_var1.com	
eco4_flul.com	
silt.bin	
eco4_neigh.dat	
eco4_neigh_sk.dat	
scratch.dat	
PDIndexL21.asc	
eco7_bounds_hydro.dat	
eco7_bounds_hydro.bin	

For all 4 modes the file *eco4_set.dat* contains the switches which organize the simulation. The left column defines the name of the switch, the middle the value, and the right column gives some description or alternative settings. In the following the content of this file is described. Allowed values are in round brackets (); recommended or default values are in acute brackets < >; units are in awkward brackets [].

isw_dim (1,3):

Choice of dimension

isw_dim=1:

Biogeochemical simulation of one water-column. This mode is often used for model-development. Usually the model runs off-line (*ihyd*=2) but is also possible to run ECOHAM in the coupled version (*ihyd*=1). In this case the full hydrodynamical model runs but only the vertical diffusion coefficients and T,S will be used at the water-column defined at *icol_output* and *jcol_output*.

isw_dim=3:

3D-simulation

ichain (0,1)

Only for machine=2 when a job-chain is used (see below)

ichain=0 for the first job within a job-chain

ichain=1 for all jobs after the first job

iwarm (-n,0,1)

Switch to organize the warmstart.

iwarm=1:

The file *eco4_warm.dat* will be read. This defines the initial values for the biogeochemical variables. For the hydrodynamical variables the initialisation is read from *hydro_dump.dat*. Both files are overwritten when ending the simulation successfully.

iwarm=-n

Coldstart: The hydrodynamical model runs n days before the real start in spin-up mode with no surface elevation at the open boundaries. After the spin-up the hydrodynamical status is written into the file *hydro_spinup.dat*.

iwarm=0

Coldstart without spin-up. If the file *hydro_spinup.dat* exists, these data will be read. If the file does not exist the model starts with climatological values for T and S and with vanishing motion-values.

The biogeochemical part starts with prescribed values defined in subroutine *set*. The variables identified by the restore switches (*restore_xyz*) are initialised with interpolated data from the corresponding *eco4_rest.xyz* files.

iwarm_next (0,1)

Switch for the differentiation between spin-up years and real simulation years

iwarm_next=0

At the end of the simulation (*iy2-1,im2,id2*)+24h will be written into the header of *eco4_warm.dat*.

iwarm_next=1

At the end of the simulation (*iy2,im2,id2*)+24h will be written into the header of *eco4_warm.dat*.

isw_sed (0,1) <1>

Switch for the sediment module

isw_sed=0

No sediment module is activated. The sinking material in the lowest level gets lost.

isw_sed=1

Sediment module activated. The sinking material in the lowest level reaches the sediment and can enter this level after remineralisation.

isw_zoo (0,1,2,3,4) <2>

Switch for the model structure of phyto- and zooplankton

isw_zoo=0

1P1Z

isw_zoo=1

Stage resolved zooplankton + 1P1Z

isw_zoo=2

2P2Z

isw_zoo=3

Stage resolved zooplankton + 2P2Z

isw_zoo=4

2P2Z-nest simulation

num_riv (0,n)

Number of rivers used for the biogeochemical part.

num_riv=0

No river input

num_riv=n

There will be n rivers read. The file `eco4_riv.bin` contains all these data and holds daily values. The position (in the grid) of the river inputs are defined in subroutine `riv2pos`.

imass_conservation (0,1) <0>

There is a possibility to check mass preservation during the model run.

ihyd(1,2,3)

Main switch for simulation mode (see above)

isw_bio (0,1) <1>

Switch for biological activities

isw_bio=0

Model-run without biological activities: The sinking velocities must be set to zero.

Recommendation: For a “no-biology run” set all max. Growth rates to epsilon (1.e-4) instead of `isw_bio=0`

isw_bio=1

Biological processes are on.

relrate (eps ...) <0.4>

Limitation of the maximum relative change of a biogeochemical state-variable per time-step. For `relrate=1` the change must not be larger than the value itself. If this limitation is not fulfilled for all state-variables the biogeochemical model performs a time step adaptation.

ibarocline (0,1) <1>

Switch for the hydrodynamical model

ibarocline=0

Barotrop application. For coldstart the climatologic T/S data are not read. In this case the switch `iprognostic` (see below) is not effective.

ibarocline=1

Barocline application. For coldstart climatological values for T/S (*climatets.bin*) are read. In case of `iprognostic=0` these data define always T/S during the run.

iprognostic (0,1) <1>

Switch for the hydrodynamical model

iprognostic=0

Diagnostic mode, T/S is defined climatologically.

iprognostic=1

Prognostic mode. SST is defined by radiation fluxes. Here the files *clou.bin*, *airt.bin*, *relh.bin*, *wins.bin*, *wind.bin* and *rad.bin* are necessary. S will be relaxed in *subroutine boundaryts* to climatological values.

htmit (0..1) <0.65>

Impliciteness of the hydrodynamical model. In *subroutine init* `vtmit=htmit` and `alphats=htmit` are defined.

htmit ≈ 0

Almost explicite, surface elevation quite realistic

htmit ≈ 1

Almost implicite treatment, surface elevation not very realistic, model reacts more patiently.

hev [m2/s] <150>

horizontal eddy viscosity. In *subroutine init* `ad(:)=hev` is defined.

bounds_out (0,1)

switch for output for nest

bounds_out=1

No output for a nest is produced.

bounds_out=0

During the simulation output for a nest within the grid is produced. The simulated values are written fielwide for the start and during the simulation at the borders of the nest. In case of hydrodynamical simulation (`ihyd=1, 3`) these values are written for every timestep into *bounds_hydro.dat*; in case of biogeochemical simulation (`ihyd=1, 2`) the data are written daily into *bounds_biogeo.dat*. The file *PDIndexL21.asc* and hard-wired settings of `xlat0_hi` (and `ff`) in *subroutine set* define the nest.

restore_all (0,1) <1>

Switch for handling of external biogeochemical data for boundaries.

restore_all=0

For most data no restoring values for the boundaries and no initial values are prescribed. All other following switches (`restore_xyz`) are effective.

restore_all=1

For all biogeochemical state variables prescribed values at the open boundaries exist and will be read. All other following switches (*restore_xyz*) are not effective.

restore_n3n (-1,0,1) <0>

Switch for handling of external nitrate data (*eco4_rest.n3n*) for the boundaries and for the coldstart.

restore_n3n=-1

No restoring of nitrate at the boundaries. Coldstart with constant nitrate values (see *subroutine set*).

restore_n3n=0

No restoring of nitrate at the boundaries. Coldstart with external nitrate values (*eco4_rest.n3n*).

restore_n3n=1

Coldstart with external nitrate values (*eco4_rest.n3n*).

Restoring of nitrate concentrations at selected water columns. Such columns can be defined additionally to the open boundary positions. ($i < 4$ or $i > lon - 3$ or $j < 4$ or $j > lat - 3$). All these cells are defined in the header of *eco4_rest.n3n*.

Restoring means a relaxation of simulated values. It can be identified as a sink or a source for the system. These fluxes (it is the difference between simulated and restored value per time) are stored in *f_res_xyz* for each grid cell.

restore_n1p, n5s, alk, n4n und restore_dic (-1,0,1)

See *restore_n3n*

iy1

Beginning year of simulation

im1

Beginning month of simulation

id1

Beginning day of simulation

ih1 <0>

Beginning hour of simulation

iy2

Endyear of simulation

im2

Endmonth of simulation

id2

Endday of simulation

ih2 <23>

Endhour of simulation

lat_grid <82>

Meridionale gridsizes

lon_grid <88>

Zonal gridsizes

kmax_grid <24>
Number of vertical layers

delta_lat <0.2> [°]
Meridionale meshsize

delta_lon <½> [°]
Zonal meshsize

xlat0 <47.683333333> [°]
Meridionale position of the zeta-point (origin of the grid)

xlon0 <-15.083333333> [°]
Zonal position of the zeta-point (origin of the grid)

istep_output (1,2,3,..) <1> [d]
delta t for water column output in *eco4_*.prt*

istep_output=1:
daily values are stored (at the end of a day)

icol_output (1,..,lon)
Defines the zonal position of the first output column

jcol_output (1,..,lat)
Defines the meridional position of the first output column

icol_out2 (1,..,lon)
Defines the zonal position of the following output column

jcol_out2 (1,..,lat)
Defines the meridional position of the following output column

deltat_bio (5,10,20,30,60,120,..) <15> [min]
Maximum time-step for the biogeochemical run. The time-step should be either a divisor or a multiple of 60. In the decoupled mode (*i_{hyd}*=2) this time-step can be larger than in the coupled mode. In the latter mode it makes sense to set *deltat_{bio}*=*deltat_{hyd}*.

deltat_hyd (5,10,20,30,60,120,..) <15> [min]
Time-step for the hydrodynamical simulation; it should be a divisor of 60. If *i_{hyd}*=2 this value is ineffective.

windtimestep (60, 120, 180, 360, 720, 1440) <360> [min]
Time-step of wind forcing. Most meteorological fields have 6-hour intervals. This value is relevant for the input files *wins.bin*, *wind.bin*.

radsoltimestep (60, 120, 180, 360, 720, 1440) <120> [min]
Time-step of the short-wave radiation data, mostly 2-hourly (*rad.bin*). The file *radday.bin* contains daily means necessary to calculate *I_{opt}* (*p_{ii}*).

climatetimestep (1,..) <30> [d]
Time-step of climatological temperature and salinity fields (*climatets.bin*).

iup_chem (0,1,2) <2>

Time-interval for updating the carbonate system

iup_chem=0	at day end
iup_chem=1	every biological time-step
iup_chem=2	every 30 min

dis3_mode (0,1,2,3) <2>

Switch for monthly 3d-output of all state variables. The result file will contain 13 time-steps: First value are the start values at January 1, the twelve following correspond with the months.

dis3_mode=0	no monthly output
dis3_mode=1	monthly output into <i>eco4_res.bin</i> (unformatted, sequential)
dis3_mode=2	monthly output into <i>eco4.grads</i> (IEEE, direct access)
dis3_mode=3	monthly output into <i>eco4_res.bin</i> and <i>eco4.grads</i>

mode_p (0,1,2) <0>

Switch for the structure of the *eco4_xy.prt* result files

mode_p=0	print all data into <i>eco4_xy.prt</i>
mode_p=1	print all but not the fluxes into <i>eco4_xy.prt</i>
mode_p=2	print only state-variables into <i>eco4_xy.prt</i>

flux_out ("flux_name")

The 3d-daily flux "flux_name" will be stored in *eco_flyx.dat*. The key **flux_out** could be repeated line by line 99-fold for corresponding output fluxes. An example of a "flux_name" is *dic_plc*.

stat_out ("stat_name")

The 3d-daily variables "stat_name" will be stored in *eco_stxy.dat*. The key **stat_out** could be repeated line by line 99-fold for corresponding output variables. An example of a "stat_name" is *st_plc* or *lip1_ir*.

io_mean (0,1) <1>

Switch to choose monthly means or a daily value for monthly output.

io_mean=0	monthly means in <i>eco4.grads</i> or <i>eco4_res.bin</i>
io_mean=1	day 15 of each month is stored in <i>eco4.grads</i> or <i>eco4_res.bin</i>

iairsea (0,1) <1>

Switch for the air-sea flux of CO₂, O₂ and N-deposition

iairsea=0	air-sea fluxes switched off
iairsea=1	air-sea fluxes switched on

air_sea_mode (1,2) <1>

Switch to choose different empirical formulas for the gas exchange

air_sea_mode=1	Wanninkhof 1992
air_sea_mode=2	Wanninkhof & McGillis 1999

iwind (0,1)

Modus for wind-treatment

iwind=0	constant windspeed (20 m/s), constant air-pressure (pnull=1013 hPa)
---------	---

iwind=1

Data are read from *wind.bin* and *wins.bin*

isol (0,1) <1>

Switch for shortwave radiation

isol=0: for all modes (*i_{hyd}*=1, 2, 3) constant shortwave radiation (100 W m^{-2}) is assumed.

isol=1: Data are read from *rad.bin* and *radday.bin*.

iclim (0,1)

Switch for climatological data of temperature and salt.

iclim=0: constant values for T and S ($T:=8 \text{ }^\circ\text{C}$, $S:=35 \text{ psu}$) for *i_{hyd}* =1, 2

iclim=1: climatological values from *climatets.bin* are used.

jhyd (000, 001, 010, 011, 100, 101, 110, 111) <111>

3 switches for using different kinds of motion in the biogeochemical tracer-displacement module.

First entry corresponds with the horizontal and vertical advection (0=off, 1=on).

Second entry corresponds with the horizontal diffusion (0=off, 1=on).

Third entry corresponds with the vertical diffusion (0=off, 1=on).

cross_sec (0,1)

Switch for calculating fluxes of material across defined sections

cross_sec=0:

No flux-calculation

cross_sec=1:

Calculation of fluxes of material across defined sections (only for *i_{sw_dim}*=3). The definition of the sections is carried out in *subroutine calculate_section* and the output happens in *subroutine write_section* into the file *flow.dat*. The materials are DIC, TOC, PIC, DIN, TON and water (if *passive_tracer*=1).

passive_tracer (0,1,2)

Switch for passive tracer *st_x1x*.

passive_tracer=0:

No passive tracer but all other state variables are calculated.

passive_tracer=1:

All state-variables and the passive tracer *st_x1x* will be calculated.

passive_tracer=2:

Only the passive tracer *st_x1x* will be calculated.

machine (1,2)

Switch for the choice of the computer

machine=1:

Simulation on Windows PC. All forcing data *real*8*

machine=2:

Simulation on the DKRZ mainframe. All meteorological forcing *real*4*. Job-chains will be performed

light_ham (1,2) <1>

Switch for the treatment of the shortwave radiation in the hydrodynamical model

light_ham=1:

Only the upper layer will be heated. Turbidity (Jerlov), silt and chlorophyll do not affect the temperature dynamics.

ligh_ham=2:

Only in work for the coupled mode (ihyd=1). Now the vertical absorption of light governed by turbidity, silt- and chlorophyll-concentration determine the temperature dynamics.

light_inhibition (0,1,2) <1>

Switch for light-inhibition in the biological module

light_inhibition=0:

no light inhibition: for $I(z) > I_{opt}$ the light limiting factor is "1"

light_inhibition=1:

Light inhibition for $I(z) > I_{opt}$.

light_inhibition=2:

For some special application phyto_convection is parameterised.

opt_irr (0,..,x) [W m-2] <0>

Switch or value for optimal Light intensity for phytoplankton growth.

opt_irr>0.0:

A fixed I_{opt} (opt_irr) – value is used for the P-I function (Steele)

opt_irr=0.0:

A variable I_{opt} ($40 \text{ W m}^{-2} < I_{opt} < 40 \text{ W m}^{-2}$) is used. This value adapts to the light in the upper 4 m of the water column. These values can be changed in *subroutine set*.

atm_n (0,..,x) [mmol N m-2 d-1] <-1>

Switch or value for atmospheric deposition of nitrogen

atm_n=-1:

The file *eco4_atm_n.dat* will be read. It contains the regional resolved annual means of NO_x and NH_y . NO_x goes into the NO_3^- , and NH_y goes into the NH_4 -pool of the upper layer, respectively.

atm_n=-2:

The file *eco4_atm_n_mon.dat* will be read. It contains the regional resolved monthly means of NO_x and NH_y . NO_x goes into the NO_3^- , and NH_y goes into the NH_4 -pool of the upper layer, respectively.

atm_n = 0

No input by atmospheric N-deposition.

atm_n > 0

Input of *atm_n* ($\text{mmol N m}^{-2} \text{ d}^{-1}$) atmospheric N, half into the NO_3^- , and half into the NH_4 -pool of the upper layer.

exts (0,..,x) <0.06>

Switch or value for silt

exts=0: Silt-data will not be read.

exts>0.0

Daily values of silt concentration (mg/l) will be read (*silt.bin*), *exts* is the extinction coefficient, which is multiplied by the daily data in the model.

extw (0,..,x) [m⁻¹] <-1>

Water extinction due to dissolved material (Gelbstoffe). This value is part of the formula to determine underwater-light, defining the temperature dynamics (*ihyd=1*, *light_ham=2*), phytoplankton growth and nitrification.

extw>0.0

The fixed value *extw* is used (depending on the Jerlov Type).

extw<0.0

Time and space varying extinction-coefficients are read (*extw.dat*)

In case of *isw_zoo = 2* (2P2Z) the file *eco4_set_bio2.dat* will be read. It holds the more biological settings.

extp1 (0,..,x) [m²/(mmol N)] <0.03>

Extinction-coefficient for Diatoms-N.

extp2 (0,..,x) [m²/(mmol N)] <0.03>

Extinction-coefficient for Flagellates-N.

vp1 [d⁻¹] <1.1>

maximum growth rate Diatoms (10°C)

vp2 [d⁻¹] <0.9>

maximum growth rate Flagellates (10°C)

excess (0..1) <0.5>

Excess-assimilation of carbon by phytoplankton

excess=0:

The ratio of DIC/DIN-uptake is the Redfield ratio

excess=1:

Full excess-assimilation. The carbon-assimilation is no more nutrient limited.

0<excess<1:

Reduced excess-assimilation.

It is: $dic_phc = (full\ excess\ assimilation - Redfield\ assimilation) \cdot excess$

soc_rate (0,..,x) [d⁻¹] <0.0074>

Remineralisation-rate for semi-labile DOC

xk1 [(mmol N/m³)] <0.5>

Half-saturation constant nitrate for diatoms and flagellates

xk21 [(mmol N/m³)] <0.5>

Half-saturation constant ammonium for diatoms

xk22 [(mmol N/m³)] <0.05>

Half-saturation constant ammonium for flagellates

xkp [(mmol P/m³)] <0.05>

Half-saturation constant phosphate for diatoms and flagellates

xks [(mmol Si/m³)] <0.5>

Half-saturation constant silicate for diatoms

gam1 <0.05>

Exudation-factor for diatoms

gam2 <0.05>

Exudation-factor for flagellates

xmu11 [d⁻¹] <0.035>

Mortality-rate for diatoms

xmu12 [d⁻¹] <0.035>

Mortality-rate for flagellates

wp1c [m d⁻¹] <0.0>

Sinking-rate for diatoms

g1_max [d⁻¹] <0.4>

Ingestion-rate mesozooplankton

g2_max [d⁻¹] <0.5>

Ingestion-rate microzooplankton

xk31 [(mmol N/m³)] <1.0>

Half-saturation constant mesozooplankton-N grazing

xk32 [(mmol N/m³)] <1.0>

Half-saturation constant microzooplankton-N grazing

p11 <0.33>

Mesozooplankton preference factor for diatoms

p12 <0.33>

Mesozooplankton preference factor for microzooplankton

p13 <0.34>

Mesozooplankton preference factor for detritus

p14 <0.00>

Mesozooplankton preference factor for bacteria

p21 <0.33>

Microzooplankton preference factor for flagellates

p23 <0.33>

Microzooplankton preference factor for bacteria

p24 <0.34>

Microzooplankton preference factor for detritus

xmu21 [d⁻¹] <0.2>

Maximum loss-rate mesozooplankton

xmu22 [d⁻¹] <0.2>

Maximum loss-rate microzooplankton

beta1 [] (0..1) <0.75>

Assimilation-coefficient mesozooplankton

beta2 [] (0..1) <0.75>

Assimilation-coefficient microzooplankton

xk16 [mmol N/m³] <0.2>

Half-saturation constant loss mesozooplankton

xk26 [mmol N/m³] <0.2>

Half-saturation constant loss microzooplankton

aeps1 <0.4>

Ammonium Fraction of mesozooplankton loss

aeps2 <0.4>

Ammonium Fraction of microzooplankton loss

delta_don1 <0.4>

DON Fraction of mesozooplankton loss

delta_don2 <0.4>

DON Fraction of mesozooplankton loss

frac_d2x (0,..,1) <0.15>

Fraction of fast sinking detritus

wd1c <0.4> [m/d]

Sinking velocity of slowly sinking detritus

wd2c <10> [m/d]

Sinking velocity of fast sinking detritus

xmu4n <0.12> [1/d]

breakdown-rate of slowly sinking detritus-N

xmu5n <0.10> [1/d]

breakdown-rate of fast sinking detritus-N

rxmu4c <0.85>
ratio of brakedown-rates N/C-Detritus

rb <4>
C/N-ratio bacteria

rz <5.5>
C/N-ratio zooplankton

xk4 [mmol N/m³] <0.2>
Half-saturation constant uptake bacteria

eta <0.6>
Ratio ammonium/DON uptake by bacteria

vb <0.5> [1/d]
Maximum growth-rate of bacteria

xmu3 <0.1> [1/d]
Excretion-rate of bacteria

xknit <0.02> [1/d]
Nitrification-rate

brc (0,..,x) [d⁻¹] <0.0281>
Benthic remineralisation rate of POC

brn (0,..,x) [d⁻¹] <0.0333>
Benthic remineralisation rate of PON

brp (0,..,x) [d⁻¹] <0.0333>
Benthic remineralisation rate of particulate organic phosphorus

brs (0,..,x) [d⁻¹] <0.0333>
Benthic remineralisation rate of Opal

6. Different ECOHAM applications

ECOHAM has been developed within the ecological modelling group at the Institute of Oceanography, University of Hamburg over several years. Different applications and publications have required different model-setups.

Table 9: Reference data of the grid structure for different ECOHAM versions.

	ECOHAM1	ECOHAM2	ECOHAM3	ECOHAM4	ECOHAM4 N-Isotope
internal name	ecoham	cn3/hcn3	hcn4	eco4	eco7p
area	North Sea	North Sea/North Atlantic	NECS	NECS	Southern North Sea
Grid points					
x	58	58	88	88	39
y	65	65	82	82	33
z	19	19	24	24	21
1 st ζ point (1,1)	-5.0833 61.7833	-5.0833 48.8833	-15.083333333 47.683333333	-15.083333333 47.683333333	-3.3958 50.8708
Resolution					
d ϕ	0.333333 (20')	0.333333 (20')	0.333333 (20')	0.333333 (20')	0.333333 (20')
d λ	0.200000 (12')	0.200000 (12')	0.200000 (12')	0.200000 (12')	0.200000 (12')
dz	5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 75, 100, 150, 200, 250,350, 600,1000	5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 75, 100, 150, 200, 250,350, 600,1000	10, 15, 20, 25, 30, 35, 40, 45, 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, 75, 100, 150, 200, 300, 400, 500, 600, 700, 800, 1000, 2000, 3000, 4000	5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90,100, 110, 120, 130, 140, 150, 170
total extent lon	-5.25 to 14.0833	-5.25 to 14.0833	-15.25 to 14. 0833	-15.25 to 14. 0833	-3.4166 to 9.250
Lat	48.7833 to 61.7833	48.7833 to 61.7833	47.5833 to 63.9833	47.5833 to 63.9833	50.8888 to 57.2888
wet points	15949	15949	66839	66839	6143
wet columns	1431	1431	4455	4455	702
User Guide	(Moll, 1997)	(Moll et al., 2003)	- none -	(Pätsch et al., 2009)	- none-
Applications:	(Moll, 1998) (Luff and Moll, 2004) (Skogen and Moll, 2005) (Reiss et al., 2010)	(Kühn and Radach, 1997) (Pätsch et al., 2002) (Moll et al., 2003) (Moll and Stegert, 2007)	(Pätsch and Kühn, 2008) (Kühn et al., 2010) (Stegert et al., 2009) (Tiedje et al., 2010)	(Lorkowski et al., 2010) (Lindemann et al., in preperation)	(Pätsch et al., 2010)

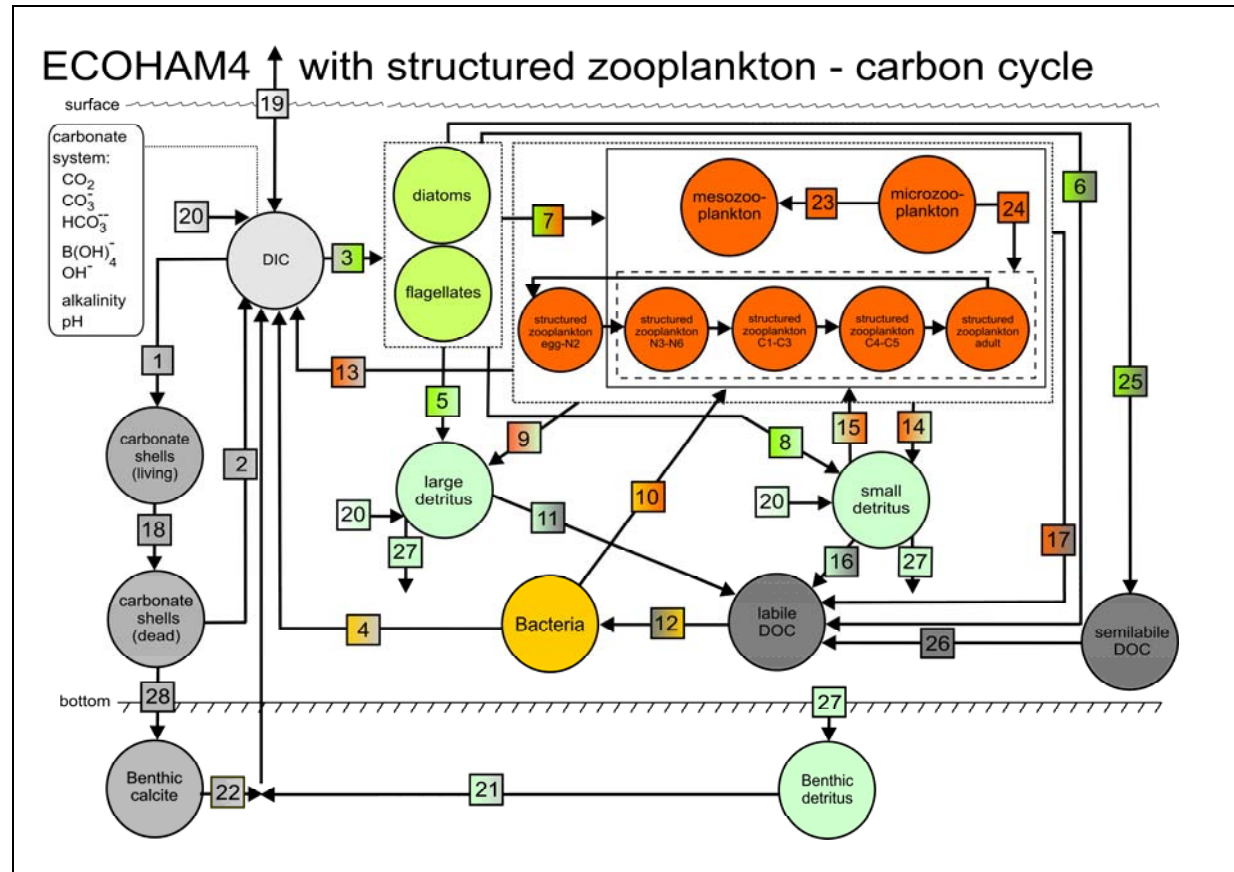


Figure 7: Diagram of the carbon cycle with structured zooplankton (for `isw_zoo=3`), which is under development (Lindemann et al., in preparation).

7. Station and grid data for several North Sea positions

Several well known station data from the North Sea or the Northwest European Continental Shelf (NECS) are allocated to specific grid points ordered chronologically during our work. The tabulated information consists of station name with citation and geographical information converted to the grid of ECOHAM4, with the index in x-direction, index in y-direction, the number of layers, and longitude, latitude and depth of the model grid cell. The positions are indicated in red in the table next page.

Station Name (Citation)	X_index	Y_index	Layers	Longitude	Latitude	Depth	Pos.
FLEX 1976 (Kühn et al., 1997)	48	57	13	0.5833	58.8833	135	A
OWS Famita (Moll, 1998)	55	50	11	2.9167	57.4833	65	B
FS Elbe1 (Moll, 1998)	71	33	3	8.25	54.0833	20	C
AB NERC-NSP (Blackford et al., 2004)	54	26	7	2.5833	54.0833	39	D
CS NERC-NSP (Blackford et al., 2004)	49	40	10	0.9166	55.4833	66	E
GG#32 GLOBEC-Germany (Stegert et al., 2009)	67	36	7	6.9166	54.6833	38	F
HR Helgoland Reede (Greve et al., 2004)	70	34	3	7.9166	54.2833	20	G
CANOBA 38 (Thomas, 2002)	52	43		1.9166	56.0833	86	H
CANOBA 74 (Thomas, 2002)	45	58		-0.4166	59.0833	150	I
T010 (TERSCHELLING) (Blaas et al., 2007)	61	29		5.06°	53.27°	20	J
T100	60	33		4.51°	54.14°	47	K
T135	59	34		4.13°	54.36°	51	L
T175	58	36		3.77°	54.72°	46	M
T235	56	38		3.32°	55.15°	27	N
L4 English Channel (Southward, 2004)	34	13	10	-4.0833°	50.2500°	70	O
TH06 (Skagerrak Torungen-Hirtshals) (Dahl and Danielssen, 1992)	74	53	18	9.1833°	58.1333°	600	P
Fair Isle Strait (Turrell et al., 1996)	39	61		-2.4166	59.6833	75	Q
BCZ 330 (Lancelot et al., 2007)	55	20		2.8083°	51.4417°	16	R
Stonehaven (Valdes et al., 2006)	40	47		-2.0833°	56.8833°	67	S
Norwegian Trench (Utsira) (Hjollo et al., 2009)	61	59				230	T
Norwegian Trench (NT)	58	77				701	U

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