Technical note :
Description of the LOBSTER biogeochemical model implemented in the OPA system

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1 Introduction

The LOBSTER (LODyC Ocean Biogeochemical System for Ecosystem and Resources) model has been developed in LODYC since 1994 (Levy, 1996, Levy et al., 1998, Levy et al., 2001, Memery et al., 2002, Faugeras et al., 2003, Mahadevan et al., 2004, Levy et al., 2004, Kremeur, 2004).

It consists of six prognostic variables expressed in nitrogen units (mmoleN/m3): nitrate (NO3), ammonium (NH4), phytoplankton (P), zooplankton (Z), detritus (D), and semi-labile dissolved organic matter (DOM). Their is an option for three additional variables: Dissolved inorganic carbon (DIC), Alkalinity (ALK) and oxygene (OXY). Their is also a model for light absorption.

LOBSTER describes the biogeochemical source and sink terms of these variables. LOBSTER is implemented in the OPA system (Madec et al., 1998). Tracer transport is achieved by the passive tracer transport module of OPA. Outputs are in netcdf format, and inputs are either analytic or in netcdf format. The model can be run online or offline. This note describes the model equations and their implementation in the OPA system. The reader is referred to the above mentioned references for justification on the model parameterizations.

2 Model equations

Different models are used for the euphotic layer (of constant depth) and below.

2.1 The nitrogen NNPZD-DOM model

The euphotic layer model

Figure 1 shows a schematic representation of the model in the euphotic layer. The model parameters are defined in Table 1.
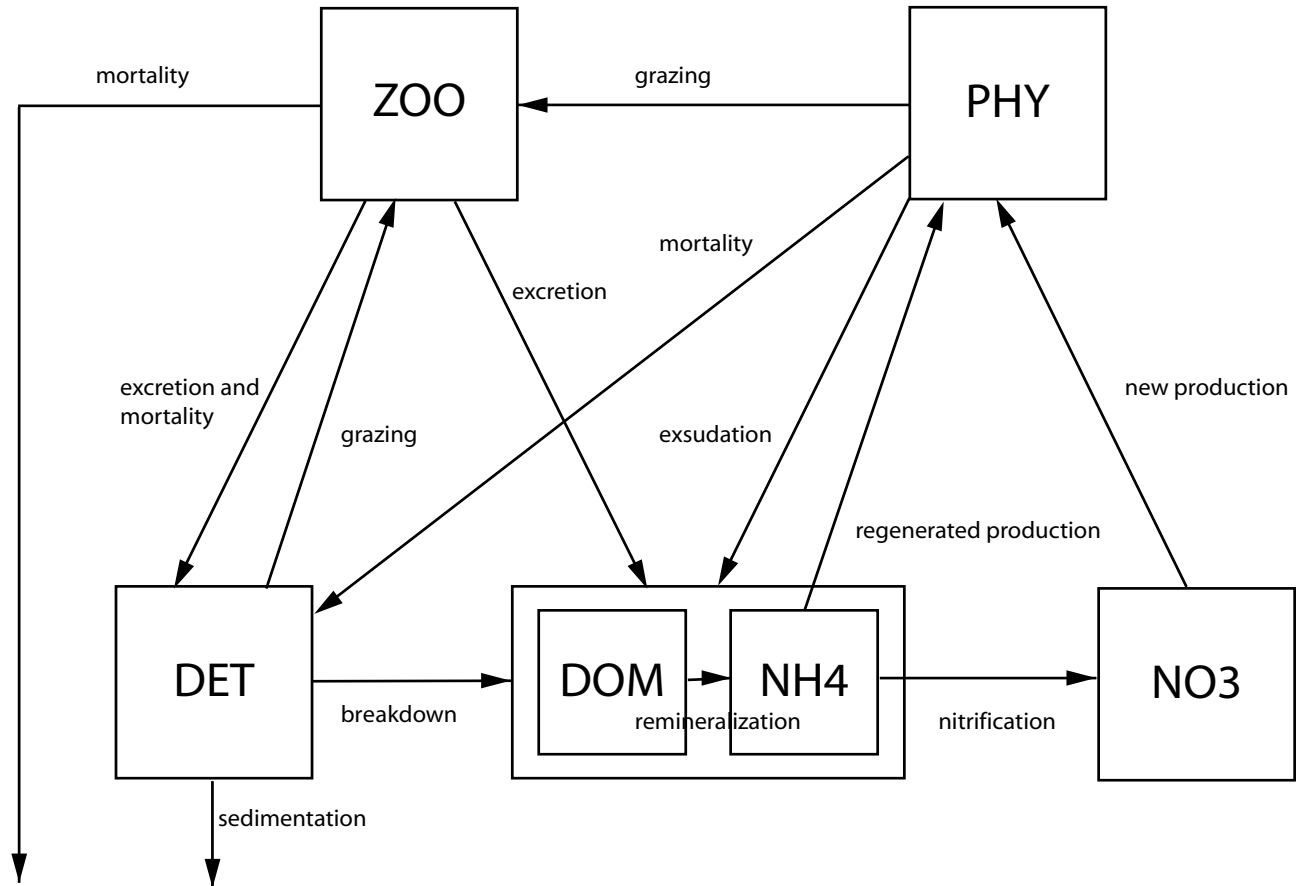

Figure 1: LOBSTER within the euphotic layer

- Nitrates NO3

$$S(NO_3) = -\mu_p L_I L_{NO_3} P + \mu_n NH_4 \quad (1)$$

The first term is new production, the second term is nitrification.

- Ammonium NH4

$$S(NH_4) = \gamma\mu_p L_I(L_{NO_3} + L_{NH_4})P + \alpha_z\mu_z Z + \alpha_d\mu_d D + \mu_{dom}DOM$$
$$+(1 - Rd_{phy}/Rd_{dom})((1 - \alpha_p)\mu_p P + (1 - \alpha_z)\mu_z Z + (1 - \alpha_d)\mu_d D) - \mu_p L_I L_{NH_4}P - \mu_n NH_4 \quad (2)$$

The source terms are phytoplankton exsudation, zooplankton excretion, remineralisation of DET and DOM, and adjustement term (due to the excess of nitrogen received by DOM). Sinks are due to regenerated production and nitrification.

- Phytoplankton P

$$S(P) = (1 - \gamma)\mu_p L_I(L_{NO_3} + L_{NH_4})P - m_p P - G_p \quad (3)$$

Sources are new and regenerated production. Sinks are exsudation, mortality and grazing. Light limitation is :

$$L_I = 1 - e^{-\frac{PAR}{K_{par}}\frac{R_{Chl:N}}{R_{Chl:N}^{ref}}} \quad (4)$$

$$Chl = R_{Chl:N}P \; with \; R_{Chl:N} = \frac{12Redf}{R_{C:Chl}} \quad (5)$$

$$R_{Chl:N} = max(R_{Chl:N}^{min}, R_{Chl:N}^{max} - (R_{Chl:N}^{max} - R_{Chl:N}^{min}))\frac{\overline{PAR}}{PAR_{max}} \quad (6)$$

Light limitation depends on the C:Chl, which depends on $\overline{PAR}$ (Photosynthetic Available Radiation). Instantaneous PAR is used. This choice is consistent with daily forcings but not with forcings resolving the diurnal cycle. In such a case, PAR should represent a daily average.

Nutrient limitation is as in Fasham et al. (1990):

$$L_{NO_3} = \frac{NO_3}{NO_3 + K_{no_3}}e^{-\psi NH_4} \quad (7)$$

$$L_{NH_4} = \frac{NH_4}{NH_4 + K_{nh_4}} \quad (8)$$

- Zooplankton Z

$$S(Z) = a_z(G_p + G_d) - m_z Z^2 - \mu_z Z \quad (9)$$

Zooplankton grazes phytoplankton (Gp) and detritus (Gd). The non-assimilated part of this grazing is lost as detritus. Zooplankton mortality is quadratic. Part of this term (1-f_z) is instanteously exported. The last term corresponds to excretion, in the form of ammonium (α_z), and of DOM (1-α_z). p is the preference for phytoplankton (Fasham, 1990).

$$G_p = g_z \frac{pP}{K_z + pP + (1-p)D} Z \quad (10)$$

$$G_d = g_z \frac{(1-p)D}{K_z + pP + (1-p)D} Z \quad (11)$$

$$p = \frac{\tilde{p}P}{(\tilde{p}P + (1-\tilde{p})D)} \quad (12)$$

- Detritus D

$$S(D) = (1-a_z)(G_p + G_d) + m_p P + f_z m_z Z^2 - G_d - \mu_d D - V_d \partial_z D \quad (13)$$

Detritus are produced by zooplankton fecal pellets and phytoplankton and zooplankton mortality. They are grazed by zooplankton, and remineralised to NH4 or dissociated into DOM. They fall at the speed Vd (sedimentation).

- Dissolved organic matter DOM

$$S(DOM) = \gamma(1-\mu_p)L_I(L_{NO_3} + L_{NH_4})P + (1-\alpha_z)\mu_z Z + (1-\alpha_d)\mu_d D - \mu_{dom}DOM$$

$$-(1 - Rd_{phy}/Rd_{dom})((1-\alpha_p)\mu_p P + (1-\alpha_z)\mu_z Z + (1-\alpha_d)\mu_d D) \quad (14)$$

The last term is the adjustement flux du to the excess source of nitrogen.

Table 1: Parameters for the euphotic layer model. Values have been set for the northeast Atlantic (Levy et al., 2004).

parameter name	symbol	value	unit	namelist name
Nitrate limitation half-saturation value	K_{no_3}	0.7	$mmole\ m^{-3}$	akno3
Ammonium limitation half-saturation value	K_{nh_4}	0.001	$mmole\ m^{-3}$	aknh4
Inhibition of nitrate uptake by ammonium	ψ	3		psinut
Light limitation half-saturation value	K_{par}	33.	$W\ m^{-2}$	aki
Phytoplankton maximal growth rate	μ_p	$1.21\ 10^{-5}$	s^{-1}	tmumax
Phytoplankton exsudation rate	γ	0.05		rgamma
Phytoplankton mortality rate	m_p	$5.80\ 10^{-7}$	s^{-1}	tmminp
Grazing half-saturation value	K_z	1.	$mmole\ m^{-3}$	aks
Zooplankton maximal grazing rate	g_z	$9.26\ 10^{-6}$	s^{-1}	taus
Assimilated food fraction by zooplankton	a_z	0.7		1-rpnaz,1-rpand
Preference for phytoplankton	$\tilde{p}$	0.5		0.5
Zooplankton excretion rate	μ_z	$5.80\ 10^{-7}$	s^{-1}	tauzn
NH4 fraction of zooplankton excretion	α_z	0.75		fzoolab
Zooplankton mortality rate	m_z	$2.31\ 10^{-6}$	$s^{-1}\ mmole^{-1}\ m^3$	tmminz
Fraction of slow sinking mortality	f_z	1.		fdbod
Nitrification rate	μ_n	$5.80\ 10^{-7}$	s^{-1}	taunn
DOM breakdown rate	μ_{dom}	$3.86\ 10^{-7}$	s^{-1}	taudomn
NH4 fraction of detritus dissolution	α_d	0.2		fdetlab
Detritus sedimentation speed	V_d	$3.47\ 10^{-5}$	$m\ s^{-1}$	vsed
Detritus remineralization rate	μ_d	$5.78\ 10^{-7}$	s^{-1}	taudn
C/N Redfield Ratio for the Phytoplankton	Rd_{phy}	6.56	$molC\ mole\ N^1$	redf
C/N Redfield Ratio for DOM	Rd_{dom}	12	$molC\ mole\ N^1$	reddom
O/N Redfield Ratio	Rd_{oxy}	10.75		refoxy
O/N for nitrification	O/N_{nit}	2		2
Minimum C:Chl ratio	$R_{C:Chl}^{min}$	30.	$mgC/mgChl$	rcchlmin
Maximum C:Chl ratio	$R_{C:Chl}^{max}$	75.	$mgC/mgChl$	rcchlmax
Reference C:Chl ratio	$R_{C:Chl:N}^{ref}$	60.	$mgC/mgChl$	rcchlref
Max PAR for Chl:N ratio	PAR_{max}	5	Wm^{-2}	aparmax
Rain ratio organic carbon vs CaCO3	ρ_{caco3}	0.1		rhocaco3

The model below the euphotic layer

Slow decay to nitrate, detritus sedimentation, and remineralization of zooplankton mortality are considered. Model parameters are in Table 2.

$$S(NO_3) = \tau_r\left(NH_4 + P + Z + D + DOM\right) + \partial_z f \quad (15)$$

$$S(NH_4) = -\tau_r NH_4 \quad (16)$$

$$S(P) = -\tau_r P \quad (17)$$

$$S(Z) = -\tau_r Z \quad (18)$$

$$S(D) = -\tau_r D - V_d \partial_z D \quad (19)$$

$$S(DOM) = -\tau_r DOM \quad (20)$$

Remineralization flux f(z) and instantaneous export f(z_{bio}) are defined by :

$$f(z) = f(z_{bio}) \left(\frac{z}{z_{bio}}\right)^{-r} \quad (21)$$

$$f(z_{bio}) = \int_0^{z_{bio}} (1 - f_z) m_z Z^2 dz \quad (22)$$

Condition of no-deposition :

$$f(z_{bottom}) = 0. \quad (23)$$

Table 2: Parameters for the model below the euphotic layer

parameter name	symbol	value	unit	code name
Depth of euphotic layer	z_{bio}	150	m	jpkb
Bottom topography	z_{bottom}	$variable$	m	$tmask$
Remineralization rate at depth	τ_r	$5.80\ 10^{-7}$	s^{-1}	tminr
exponential decay for nitrogen	r	0.858		xhr
exponential decay for carbon and oxygen	rc	0.1		xhrc

2.2   The carbon and oxygen cycles

The carbon and oxygen cycles can be computed with no retroaction on the nitrogen cycle. When this option is activated, three variables are added : Dissoved inorganic carbon (DIC), alklinity (ALK) and oxygen (OXY). Coupling between the nitrogen, carbon and oxygen cycles is done with constant Redfield ratios (O:C:N -175:102:16, except for DOM C:N=12).

The euphotic layer model

- Dissolved inorganic carbon DIC

$$S(DIC) = -\mu_p L_I (L_{NO_3} + L_{NH_4}) Rd_{phy}(1 + \rho_{caco3})\ \mathrm{P} + \alpha_z \mu_z Rd_{phy} Z + \alpha_d \mu_d Rd_{phy} D$$

$$+ \mu_{dom} Rd_{dom} DOM + fluxairmer \quad (24)$$

DIC is produced by the remineralisation of organic matter. DIC is is used for photosynthesis of organic matter, and for the formation of coccolithophore cells (increase of PP by a factor of 1+ ρ_{caco3}. DIC can be lost to the atmosphere by gaz exchange.

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- Alkalinity ALK

$$S(ALK) = \mu_p L_I L_{NO_3} P - 2\rho_{caco3} \, \mu_p L_I (L_{NO_3} + L_{NH_4}) Rd_{phy} P \quad (25)$$

Assimilation of one mole of NO3 increases alkalinity of one mole. The effect of ammonium is neglected. $CaCO_3$ precipitation decreases alkalinity.

- Oxygen OXY

$$S(OXY) = \mu_p L_I (L_{NO_3} + L_{NH_4}) Rd_{oxy} P - (Rd_{oxy} - O/N_{nit})(\alpha_p \mu_p P + \alpha_z \mu_z Z + \alpha_d \mu_d D)$$
$$-(O/N_{nit})\mu_n NH_4 + fluxairmer \quad (26)$$

Oxygen is produced during photosynthesis. It is lost during respiration, remineralisation and nitrification. Oxygene production by photosynthesis follows the redflield ratio (Rd_{oxy}), while nitrification is with a ration (O/N_{nit})=2. Ammonification is done with the ratio (Rd_{oxy} - O/N_{nit}). Oxygene is also exchanged at the surface.

- Gaz exchanges
  Fluxes , in $mol.m^{-2}.\mu atm^{-1}$, are :

$$F = k(S_c,u) \text{sol}(\text{SST},\text{SSS})(P_{gaz}^{atm} - P_{gaz}^{ocean}) \,) \quad (27)$$

P_{gaz}^{atm} and P_{gaz}^{ocean} are CO_2 et O_2 partial pressure in the atmosphere and ocean, respectively (in μatm). $k(S_c,u)$ is the gaz transfert velocity ($m.s^{-1}$), proportional to the Schimdt number S_c and to the wind speed(u). Wanninkhof (1992) parameterisation is used for $k(S_c,u)$ with ν the kinematic viscosity and D the molecular diffusion :

$$k(S_c,u)=0.31u^2(S_c/660)^{-0.5} \ \ \text{avec } S_c= \nu/\text{D}$$

Solubility is computed according to Weiss (1974). $P_{CO_2}^{atm}$ is set to 375 microatm and $P_{O_2}^{atm}$ to 0.20946 atm. $P_{CO_2}{}^{ocean}$ is computed from DIC et de ALK, using the carbonates dissociation constants of Dickson et Millero (1987). $P_{O_2}{}^{ocean}$ is proportionnal to O_2.

The model below the euphotic layer

The main process is the remineralization of DIC from organic matter.

$$S(DIC) = \tau_r \, (P + Z + D) \, Rd_{phy} + \tau_r Rd_{dom} DOM + Rd_{phy}\partial_z f + \partial_z f_{CaCO_3} \quad (28)$$

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$$S(ALK) = \tau_r \left(P + Z + D + DOM \right) - \partial_z f + 2\partial_z f_{CaCO_3} \quad (29)$$

$$S(OXY) = -\tau_r \left(P + Z + D + DOM \right) Rd_{oxy} - \tau_r (O/N)_{nit} NH_4 - Rd_{oxy} \partial_z f \quad (30)$$

The remineralization flux $f_{CaCO_3}(z)$ and the export of CaCO$_3$ $f_{CaCO_3}(z_{bio})$ are defined as:

$$f_{CaCO_3}(z) = f_{CaCO_3}\left(z_{bio} \right) \left(\frac{z}{z_{bio}} \right)^{-rc} \quad (31)$$

$$f_{CaCO_3}(z_{bio}) = \int_0^{z_{bio}} \rho_{caco3} \left(\mu_p L_I (L_{NO_3} + L_{NH_4}) Rd_{phy} \text{ P} \right) dz \quad (32)$$

It is assumed that the CaCo3 flux is instantaneously exported to the deep ocean. The bottom condition is:

$$f_{CaCO_3}(z_{bottom}) = 0. \quad (33)$$

2.3 The optical model

Two wavelenght are considered. Model parameters are in Table 3. Q_{sol} is the solar radiation at the sea surface.

$$PAR = PAR_r + PAR_b$$

- Light absorption in red:

$$PAR_r(z) = PAR_r(z - dz) e^{-k_r dz}$$

$$PAR_r(0) = \frac{0.43}{2} Q_{sol}$$

- Light absorption in blue:

$$PAR_b(z) = PAR_b(z - dz) e^{-k_b dz}$$

$$PAR_b(0) = \frac{0.43}{2} Q_{sol}$$

- Absorption coefficient in red:

$$k_r = k_{r0} + \chi_{rp} Pig^{e_r}$$

- Absorption coefficient in blue:

$$k_b = k_{b0} + \chi_{bp} Pig^{e_b}$$

- Absorbing pigments :

$$Pig = \frac{Chl}{r_{pig}}$$

Table 3: Optical parameters

symbol	value	unit	namelist
k_{r0}	0.225	m^{-1}	xkr0
k_{b0}	0.0232	m^{-1}	xkg0
χ_{rp}	0.037	$m^{-1} \left(mgChlm^{-3}\right)^{-e_r}$	xkrp
χ_{bp}	0.074	$m^{-1} \left(mgChlm^{-3}\right)^{-e_b}$	xkrg
e_r	0.629		xlr
e_b	0.674		xlg
r_{pig}	0.7		rpig

3   Code architecture

3.1   cpp keys

The LOBSTER model is activated with the cpp key key-trc-lobster1. The key key-trc-passivetrc is needed to activate the inputs, outputs, initialisation and transport.

An additional key key-trc-carbon activates the carbon and oxygen module. This automatically sets the number of variables (jptra=6 or jptra=9) and the names of the variables. The model requires a specific namelist.bio in which the model parameters are set.

Specific diagnostic (in particular biological trends cumulated in the euphotic layer) have been coded and are activated with the key key-trc-diaadd. All 3D biological trends are saved when the key key-trc-diabio is activated.

3.2   routines

Specific initialisation is needed for the model. trcctl.lobster1.h are some controls, trclsm.lobster1.h reads the namelist.bio for LOBSTER1. These pieces of code are included in the routine trcctl and trclsm when the LOBSTER key is activated.

The routine for LOBSTER are called by trcsms. In order : trcopt (optical model), trcbio.lobster1.h (biological model), trcsed (detritus sedimentation), trcexp (instantaneous export), and when the carbon is activated, trccalexp (instantaneous export of Caco3), p4zche (chemical constants), p4zflx (air sea fluxes).

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