A one-dimensional multi-layer sea ice biogeochemical process model

[LIM1D v3.20] BETA DOC VERSION

M. Vancoppenolle

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Ouèlcome! LIM1D is a one-dimensional sea ice model with brine and biogeochemical dynamics, conceived for scientific purposes. It is designed to simulate the growth and decay of sea ice and the associated evolution of snow depth, ice thickness, temperature, salinity, and a few biogeochemical tracers at the scale of a few metres, ideally to complete drift station experiments or sea ice tank experiments. It has sufficiently been tested, but not widely, and there are many uncertain parameterizations in there. Hence, it is likely not going to work in all situations at all sites and for all scientific questions. Don't blame us, this is how it is. But! You can contribute to the code by sending us your feedback, questions or suggestions.

In your scientific publications, if you use the model, we kindly ask you to refer to ours:

- *Vancoppenolle et al.* (2010) for ice physics;
- *Vancoppenolle and Tedesco* (2016 (in press) for the ice algal formulations;
- *Moreau et al.* (2014) for gas dynamics;
- *Moreau et al.* (2015) for carbon dynamics.

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2 General Description

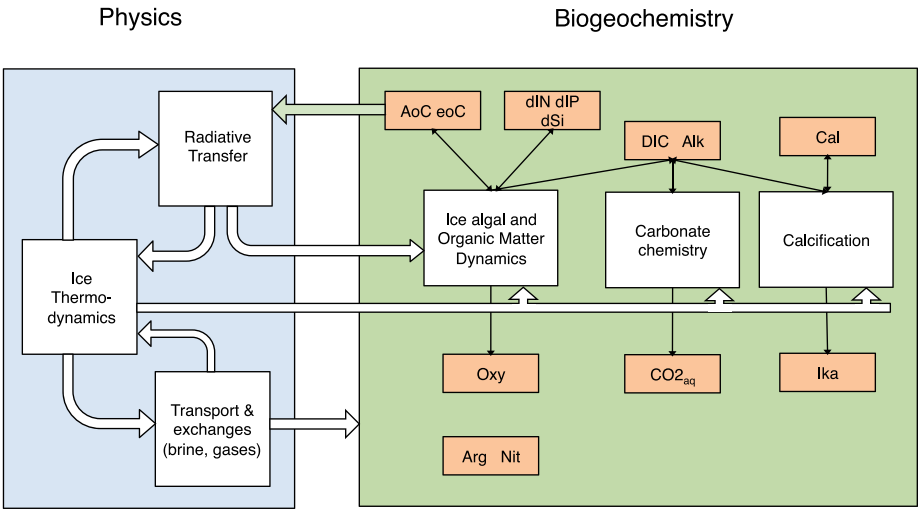

Figure 1: Schematics of LIM1D.

3 Physics

3.1 Thermodynamics

3.2 Halodynamics

$$\frac{\partial}{\partial t}[\phi C_{br}] = -w\frac{\partial C_{br}}{\partial z} + S^{BGC} \tag{1}$$

3.3 Radiative transfer

3.4 Diagnostic brine properties

Brine salinity and density are often required for biogeochemical computations, for which we use the following expressions (see Fig. 2).

Brine salinity at thermal equilibrium depends on temperature only. In thermodynamic computations, we use a linear fit because it simplifies formalism and is precise enough as far as the energetics of the system are concerned (*Notz*, 2005). However, as many biogeochemical processes can be highly sensitive on salinity, in biogeochemical computations, a more precise 3rd-order fit on data from *Assur* (1958) is used to compute brine salinity as a function of Celsius temperature (T_c):

$$S_{br}(T) = -21.4T_c - 0.886T_c^2 - 0.0107T_c^3. \tag{2}$$

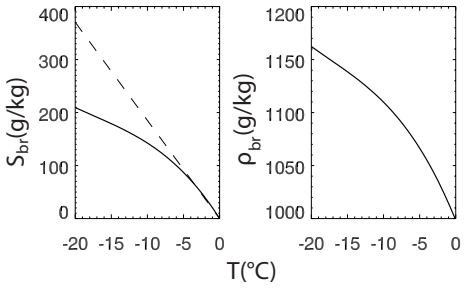

Figure 2: Diagnostic brine properties used in biogeochemical modules as a function of temperature (°C). (left) Brine salinity S_{br} following 3rd-order (solid) and linear (dots) relations; (right) brine density ρ_{br}.

Brine density is assumed to linearly depend on brine salinity:

$$\rho_{br} = \rho_0 + B(S_{br} - S_w), \tag{3}$$

where B = 0.81 kg.m^{-3}/(g.kg^{-1}) is derived from *IOC, SCOR and IAPSO* (2010), using seawater at the freezing point and S=34 g/kg. Brine density is used to convert equilibrium constants in mol/kg into mol/m^3: $[./m^3] = \rho_{br}[./kg]$. In practise, following brine salinity, brine density changes solely with temperature.

4 Tracer framework

5 Biogeochemical Processes

5.1 Organic matter synthesis

2 formulations, NP and NPD. Both are Redfieldian. Redfield ratios are .

$$\begin{aligned} S^{AoC} &= syn - rsp - lys \\ S^{DIX} &= r_C^X(-syn + rsp + f^{rem}.lys) \end{aligned} \tag{4}$$

$$\begin{aligned} S^{AoC} &= syn - rsp - lys \\ S^{eoC} &= lys - rem \\ S^{DIX} &= r_C^X(-syn + rsp + rem) \end{aligned} \tag{5}$$

Synthesis
Respiration
Lysis
Remineralization (1 & 2)

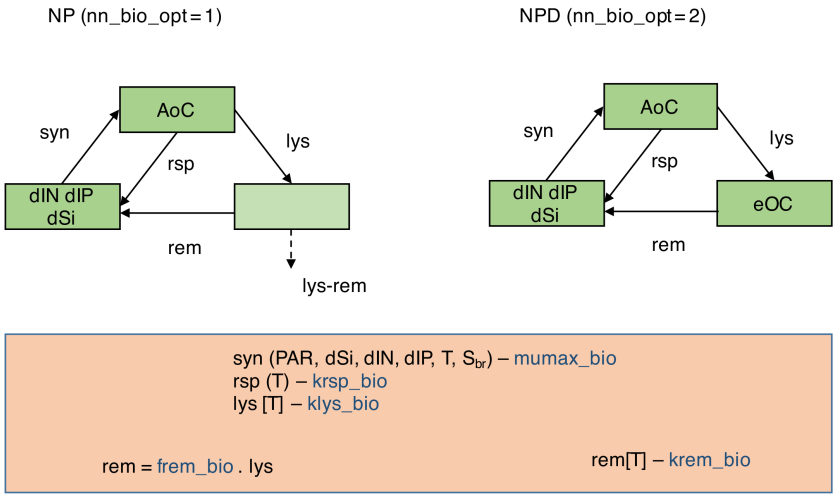

Figure 3: Schematics of model microbial dynamics.

5.2 Calcium carbonate

The second biogeochemical process represented in the model is the precipitation and dissolution of calcium carbonate (Fig. 5.2), occurring at a rate S^{ika}. Calcification of one mole of ikaite affects also DIC (-1 mol), Alk (-2 mol) and Cal (-1 mol).

The rate of calcium carbonate formation or dissolution is (*Moreau et al.*, 2015):

$$S^{ika} = \frac{e}{T^{ika}} \left[CO^{2-}_{3,br} - \frac{K_{sp}(T)}{Ca^{2+}_{br}} \right], \tag{6}$$

which assumes that the rate of calcification varies linearly with the difference between the carbonate concentration (in brine) and the saturation value, with a characteristic time scale $T^{ika} = 100$h, matching the experimental results of *Papadimitriou et al.* (2014). The concentration of carbonate in brine is obtained by equilibration of the carbonate system before calcification (ice_carb_chem).

The ikaite saturation state depends on the solubility product K_{sp} (mmol^2/m^6), which is computed with the fit of *Papadimitriou et al.* (2013), derived from laboratory experiments:

$$K_{sp}(T) = 10^6 \rho^2_{br} 10^{-[a+b/T+c.\ln(T)]}. \tag{7}$$

The experimental data are valid until -9°C. The fitted K_{sp} drastically decreases below -9°C, hence we rather assume K_{sp} to be constant below -9 °C (Fig. 5.2).

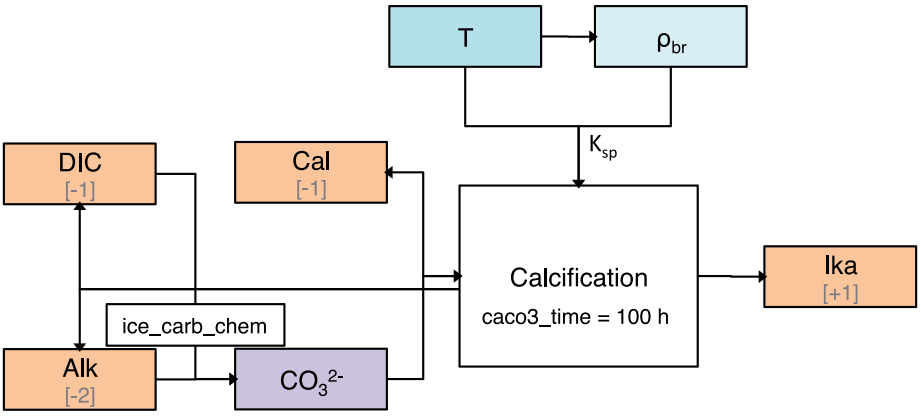

Figure 4: Schematics of model calcification.

5.3 Carbon dynamics

5.4 Oxygen and Argon

6 Technical aspects

6.1 Getting started

LIM1D runs under fortran and produces netcdf files. It works on UNIX, LINUX and MacOSX (tested up to El Capitan), with gfortran (also ifort). So to start with, you have to install the following packages:

- hdf5
- gcc-49
- gfortran
- netcdf
- netcdf-fortran
- blas & lapack

Here are a few links that could help you to install the required libraries:

- BLAS
- LAPACK
- NEMO MacPorts

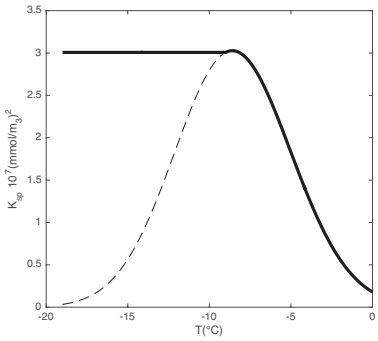

Figure 5: Ikaite solubility product: (dots) from *Papadimitriou et al.* (2013) and (solid) in the model.

6.2 Download the code with SVN

- Ask a login to forge to Martin Vancoppenolle (martin.vancoppenolle_at_locean-ipsl.upmc.fr).
- With this you can login to the svn server at forge.ipsl.jussieu.fr/ipsl/forge/projets/lim1d/svn/
- There are 3 directories on the server (trunk, tags, branches).
- The current tag is 2016/LIM1D_v3.20.
- Download the current tag from your unix/linux/mac terminal using:

```
svn checkout
svn+ssh://user@forge.ipsl.jussieu.fr/ipsl/forge/projets/lim1d/svn/tags/2016/LIM1D_v3.20/
your_dir
```

6.3 Directories

The downloaded LIM1D environment is based on the following directories

DOC GRAPHICS INPUT MAKE README RUN SCRATCH SCRIPTS SOURCES

6.4 Compilation

1. from LIM/MAKE modify directories in config_lim1d.sh

   * choose your LIM directory

   * choose / create your compilation option file xxx.inc [e.g. gfortran_mac.inc, ifort_esker.inc]

2. from LIM/MAKE edit compilation & ncdf options in your compilation option file (xxx.inc)

3. LIM/MAKE execute "./config_lim1d.sh SRC"

4. LIM/MAKE execute "./config_lim1d.sh"

5. LIM/MAKE execute "make"

6. LIM/SCRIPTS update your home directory into "./lim1d_$config.nqs" and execute it

References

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Table 1: List of model biogeochemical tracers.

Long name	Short name	Units	Type	Tag
Dissolved silica	'dSi'	$mmol/m^3$	solute	jn_dsi
Dissolved inorganic nitrogen	'dIN'	$mmol/m^3$	solute	jn_din
Dissolved inorganic phosphorus	'dIP'	$mmol/m^3$	solute	jn_dip
Algal organic carbon	'AoC'	$mmol/m^3$	particulate	jn_aoc
Detrital organic carbon	'eoC'	$mmol/m^3$	particulate	jn_eoc
Dissolved inorganic carbon	'DIC'	$mmol/m^3$	solute	jn_dic
Total Alkalinity	'Alk'	$mmol/m^3$	solute	jn_alk
Aqueous CO_2	'CO2'	$mmol/m^3$	solute	jn_co2
$CaCO_3$ (ikaite)	'Ika'	$mmol/m^3$	particulate	jn_ika
Dissolved calcium	'Cal'	$mmol/m^3$	solute	jn_cal
Argon	'Arg'	$mmol/m^3$	gas	jn_arg
Dioxygen	'Oxy'	$mmol/m^3$	gas	jn_oxy
Dinitrogen	'Nit'	$mmol/m^3$	gas	jn_nit