

CNRS - Universit Pierre et Marie Curie - Universit Versailles-Saint-Quentin
CEA - ORSTOM - Ecole Normale Sup rieur e - Ecole Polytechnique



Institut Pierre Simon Laplace des Sciences de l'Environnement Global

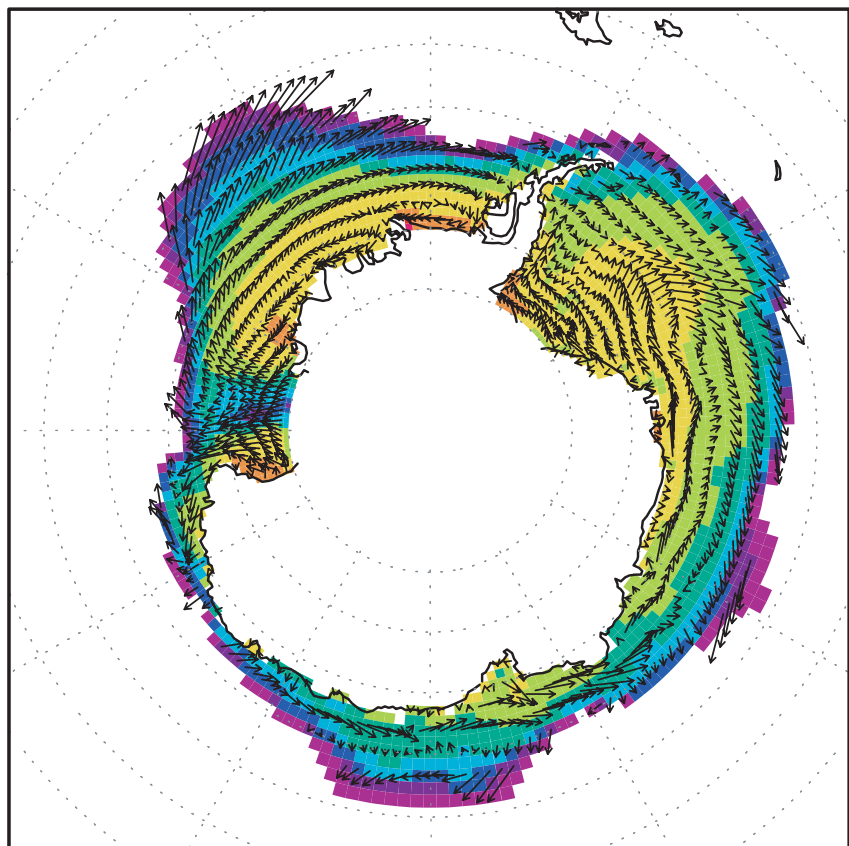
Notes Techniques du Pôle de Modélisation

IGLOO Sea Ice Model Reference Manual

Marie-Ang le Filiberti *, Jean-Louis Dufresne **
and Jean-Yves Grandpeix **

* *Institut Pierre Simon Laplace, Paris, France*

** *Laboratoire de Météorologie Dynamique, Paris, France*



Janvier 2001

IGLOO Sea Ice Model

Version 1

Reference Manual

Marie-Ang le Filiberti *, Jean-Louis Dufresne ** and Jean-Yves Grandpeix **

** Institut Pierre-Simon Laplace, Paris, France*

*** Laboratoire de M t orologie Dynamique, Paris, France*

filiberti@ipsl.jussieu.fr

dufresne@lmd.jussieu.fr

grandpeix@lmd.jussieu.fr

January 2001

CONTENTS

FOREWORD	1
Introduction	2
1. Thermodynamics.....	3
1.A - BASIC EQUATIONS	3
1.B - COUPLING WITH THE OCEAN	7
2. Dynamique	8
3. Coupling with the atmosphere.....	8
4. User's Guide to the IGLOO Sea Ice model.	11
4.A - FLOW CHART OF THE SEA ICE CODE	12
4.B – NAMELIST :.....	15
4.C - ICE ROUTINES DESCRIPTION	17
4.D - LIST OF CPP VARIABLES AVAILABLE FOR SEA -ICE.	22
4.E - PARAMETERS FOR THE ICE SIMULATION.....	22
4.F - DOMAIN AND GRID.....	22
4.G - SEA ICE MODEL CONSTANTS	24
5- How to run the model.....	25
Appendix A- Numerical values and units of the model constants and parameters.....	28
References.....	29

FOREWORD

The authors, CNRS, IPSL and Pierre et Marie university assume no responsibility for errors in, or incorrect use of the IGLOO version 1 Sea Ice Model. It is first a research tool used by researchers and students. The model and this reference have been made available as a service to the climate community.

No guarantees concerning the code, the documentation are intended. We can not certify that the code is free of errors.

Comments and suggestions concerning the code and this reference are welcome.

This version of the IGLOO reference manual is incomplete. This report will be expanded and revised, particularly concerning the dynamics of the ice model.

The IGLOO sea-ice model reference in papers and other publications is as follows°: Filiberti M-A, J-L Dufresne, J-Y Grandpeix, The IGLOO sea ice model (version 1) - reference manual, *Notes techniques du p le de mod lisation*, Institut Pierre-Simon Laplace (IPSL), France, Note n°7, 29 pp.

Introduction

This reference manual presents IGLOO, the sea-ice model which has been developed at IPSL (LODYC and LMD) to study the ice evolution. This model is coupled to the OGCM OPA (Madec et al., 1998) and can also be coupled with an AGCM (Barthelet et al., 1998) using the OASIS2 coupler (Terray et al., 1995). The purpose of this report is to document the governing equations and the physical parametrizations of the sea ice model.

The original idea and the initial one-dimensional version of the model are from Houssais (Houssais, personal communication). This model is very similar to the sea ice model developed by Hibler (1980). Particularly, the model uses a distribution function associated to the different ice types. A realistic representation of the ice distribution including open-water and several ice types (differentiated by thickness) is performed. Different ice types behave in different ways: for example, thin ice grows and decays more rapidly than thick ice. It is thus important to take into account different ice types. Another reason to take the ice thickness distribution into account is the large difference in heat flux between the ocean and the atmosphere over water or over ice of various thicknesses. In Hibler the ice distribution function is only dependent on ice thickness, in IGLOO model it may be dependent on two variables (but for the moment, it only uses the thickness). These variables define axes in a phase space in which the evolution of the distribution function is written.

Properties of sea ice that are strongly dependent on the ice thickness are calculated separately for each ice category: temperature, rate of growth or melting, albedo, heat and salt fluxes, internal reservoir of latent heat content, percentage of each category.

1. Thermodynamics

1.a - basic equations

For an ice type n (with a given fraction w_n) the evolution of thickness h_n (growth or melting) is given by :

$$\frac{\partial h_n}{\partial t} = \left. \frac{\partial h_n}{\partial t} \right|_t + \text{Prec}_s$$

where $\left. \frac{\partial h_n}{\partial t} \right|_t$ is the thermodynamic growth (or melting) and Prec_s the solid part of the precipitation on the area considered.

The heat equation balance determine the ice thermodynamic growth or melting :

$$L \left. \frac{\partial h_n}{\partial t} \right|_t = - Q_a + \frac{\partial E_n}{\partial t} + Q_{\text{ocean}} \quad (1)$$

where $E_n = \int_{z_b}^{z_s} \rho_i c T_n dz$ is the ice sensible heat content, Q_a is the total atmospheric heat flux at the surface due to short-wave radiation absorbed within the ice surface, long-wave, sensible and latent heating (Q_a depend on the surface temperature), Q_{ocean} is the heat flux due to advective and diffusive processes within the ocean. L is the volumetric latent heat of fusion of sea-ice (or snow), ρ_i is the ice density, h is the thickness and c is the specific heat capacity, T is the temperature, t the time and z the vertical coordinate of the ice model (z_b for the bottom and z_s for the surface boundary conditions). A downward flux is taken to be positive. The numerical values of the model constants and parameter are listed in annex A.

We use a multi-level model for the prediction of temperature. The number of levels is a parameter but we often use a 'one-level' version as Semtner (1987) shown that one temperature point in the ice slab is sufficient to improve a thermodynamic model compared to a zero layer formulation.

The number of ice and snow levels is a parameter in the model.

In all the simulations, snow is represented by a zero layer formulation (a linear temperature profile is assumed between the air-snow and snow-ice interfaces).

For each ice type, the temperature within the ice is determined by the one-dimensional heat diffusion equation :

$$\rho_i c \frac{\partial T_n}{\partial t} = \kappa_i \frac{\partial^2 T_n}{\partial z^2} \quad (2)$$

where κ_i the thermal conductivity.

At the bottom of the ice slab ($z=z_b$) : $T_n(z=z_b) = T_f$

where T_f is the freezing temperature calculated from ocean surface salinity following Millero (1978).

At the upper ice surface ($z=z_s$):

- when melting occurs : $T^s = T_n(z=z_s) = T_{\text{melt}}$

with T_{melt} is the ice melting temperature.

- when no melting occurs ($T^s < T_{\text{melt}}$) : $Q_a = - Q_{cs}$

where $Q_{cs} = \kappa_i \left. \frac{\partial T}{\partial z} \right|_{z=z_s}$ is the conductive heat flow from below the surface.

After the determination of equilibrium surface temperature and conductive heat flux, the surface is allowed to melt if its surface temperature reaches T_{melt} and bottom accretion or ablation is computed.

Heat storage in brine pockets is also predicted.

Numerically, the ice slab is discretized in M layers and we compute the bottom and top height variation separately.

When the growth/melting of each ice class has been computed, the evolution of each ice fraction of type n w_n in a grid point is given by :

$$\delta w_n = - \sum_l w_{n,l} + \sum_l w_{l,n}$$

where $w_{n,l}$ is the fraction leaving the type n (n varying from 1 to N the number of ice categories) and going to the type l (l varying from 1 to N), and $w_{l,n}$ is the fraction leaving the type l and going to the type n .

If we assumed no ridging :

$w_{l,n} = w_l$ if $h_{\text{min}} < h_l < h_{\text{max}}$ (where h_{min} and h_{max} are the ice type 'n' height limits, and h_l is the height of ice category l before growing or melting) and $w_{l,n} = 0$ otherwise.

The conservation of mass gives :

$$\delta M_n = -\rho \sum_l h_n w_{n,l} + \rho \sum_l h_l w_{l,n}$$

That gives the evolution of height :

$$h_n + \delta h_n = \frac{M_n + \delta M_n}{\rho(w_n + \delta w_n)}$$

For the special case of open-water, the ice formed in open-water is converted in thin ice of h_{min} (generally 0.12m) and we estimate the relative change of open water weight under freezing. For other ice classes, the height under a limit (10^{-10}) is converted in thin ice of h'_{min} (0.01 m).

During the ice distribution between different types, the temperature profile is modified to conserve the sensible heat content. The latent heat reservoir and the snow cover are also transferred from one ice

type to the other to conserve the latent heat energy and the snow mass.

In this study we use a four-level ice thickness distribution : the open-water (the ice height is null), a category of thin ice (height between 0 and 0.5 m), intermediate category (height between 0.5 and 3m) and thick ice (height greater than 3 m).

For the ocean coupling point of view, we assess that the sea-ice is totally included in the first level of the ocean model.

The main attributes of the ice model which are detailed in the following pages are:

- The model takes into account the presence of snow on top of sea-ice, the storage of latent heat, and the transformation of snow into ice due to snow flooding. The snow albedo evolve with the snow age. The albedo is different for melting or freezing ice. A realistic representation of the ice distribution including open-water and several ice types (differentiated by thickness) is performed. The different ice types behave in different ways: for example, thin ice grows and decays more rapidly than thick ice. The existence of a variable fraction of leads in the ice pack is also simulated.

Leads are parametrised to take into account dynamically effects at the closing (exponential) and at the opening through the disappearance of thicker ice classes plus possible prescribed portion of leads.

The penetrating of short-wave radiation and the conversion between sensible heat and latent heat (brine pocket formation and disappearance) are treated via an internal latent heat reservoir which shifts the seasonal cycle of melting/freezing through melting and re-freezing of the brines.

Lateral ice growth in leads:

Since the energy balance determines only the ice volume evolution, we rearranged the weight as only a portion of open water is converted into thin ice of thickness 0.12m.

the equation $L \frac{d(wh)}{dt} = Q$ can be rearranged such that

$\Delta w = \frac{Q \Delta t}{L h}$ where Δw is the ice concentration increment, and h is the height increment.

Lateral ice melt:

The concentration of sea ice is reduced when heat is available to melt the ice, in our case that means when the heat exchange between the ice and the ocean is negative.

Ridging (in routine icpart):

The method developed here is based on Bjork study (1992).

We determine the sum of weight for the ice covered classes: $S_i = \sum w(t)$ and the weight of open-water $S_{ow} = 1 - S_i$.

Following Thorndike et al. (1975) only three parameters are used to control the ridging. Namely, M which states that the ridged ice is M times thicker than

the ice forming ridges, x leads the ice-free area generated by ice deformation and G which is the fraction of ice which is not ridged. The thinnest ($S_i - G$) fraction of the total ice area is active in the ridging process.

The baseline values for M and G are 10 and 0.9 respectively. For x leads the value depend on the hemisphere and on the mean height value.

We have $w_0(t+\delta t) = x$ leads. Where $w_0(t+\delta t)$ is the percentage of open water at the end of ridging; $w_0(t+\delta t) = w_0(t) + \delta w_0$. δw_0 is the increase of open water due to ridging.

In our case before the ridging step we may have sum of weight different to one due to ice advection.

Ridging exists since the area of open water at the beginning ($w_0(t)$) is smaller than x leads.

The number of ice categories participating in the ridging process is j . This value is determined by summing the area of the thick ice categories until the cumulative area sums the closest to G without exceeding it. Let j be the latest class totally ridged $j = j-1$. $G_j = \sum_{i=j}^{j_{pps}} w_i < G$. A fraction ($G_j - G$) of the next category is

added to G_j so that exactly ($S_i - G$) of the thinnest ice is available for ridging every time step.

We determined the fraction concerned by the ridging:

For $i=1, j-1$: $a_i = w_i(t)$ all the class is concerned by the ridging.

For $i=j$ only a portion of the ice class is concerned: $a_i = G - G_{j-1}$

For $i=j+1, n$ $a_i = 0$: the area of the thicker ice categories is not affected by ridging.

The decrease in area of an ice category is given by $\delta w_i = -\alpha a_i(t)$

Due to merging of ice categories a portion $w_i - \alpha a_i(t)$ is given to the ice category corresponding to the height h_i (due to an eventual growth) and a portion $\alpha a_i(t)$ is given to the ice category corresponding to the height Mh_i with the weight $\alpha/M a_i(t)$.

The constraints give:

$$\sum_{i=1}^j a_i(t) = zicov - G \text{ and } \sum_{i=0}^n w_i(t+\delta t) = 1$$

$$w_0(t+\delta t) + \sum_{i=1}^j w_i(t+\delta t) + \sum_{i=j+1}^n w_i(t+\delta t) = 1$$

$$w_0(t+\delta t) + \sum_{i=1}^n w_i(t) + \sum_{i=1}^j -\alpha a_i(t) + \sum_{i=1}^j \alpha/M a_i(t) = 1$$

$$\alpha = \frac{M}{M-1} \frac{1}{(zicov - G)} (w_0(t+\delta t) + \sum_{i=1}^n w_i(t) - 1)$$

We determine the evolution of the weight of each ice category due to melting/growing processes and the evolution due to ridging and we determine the height (for snow and ice), the temperature profile, and the latent heat reservoir after ridging and growing.

1.b - coupling with the ocean

To minimize problems in computing exchanges between the ice and the ocean, the time-step of the ice model, matches the time-step of the oceanic model. For the same reasons the two models use the same grid. The ice model is run on two latitude intervals corresponding to both poles. We assess that the sea-ice is totally included in the first level of the ocean model.

The presence of sea-ice is important for the ocean forcing. First, the sea-ice acts as an obstacle to the atmospheric forcing of the ocean and affecting their heat, salt and momentum exchanges. Second, the sea-ice freezing and melting modify the ocean salinity forcing.

Generally the coupling between ocean and sea-ice is modelled through the exchange of heat and fresh water. The heat exchange between the ice and the ocean is proportional to the difference between the ocean surface temperature and the freezing point temperature. In our case, the surface temperature is fixed to the freezing point temperature and the previous formulation is not applicable.

In our formulation, in absence of ice, we have a flux surface boundary condition in the ocean for the heat vertical diffusion equation to determine the ocean temperature (Neuman boundary condition) :

$$Q_{\text{ocean}} = Q_a.$$

But, in presence of ice, the ocean surface temperature is fixed to the freezing point (Dirichlet boundary condition) and we determine the oceanic heat flux Q_{ocean} with this boundary condition. The presence of ice (or not) is determined by the sea surface temperature. In the ocean model used in this study, the ocean temperature vertical diffusion equation presents an implicit resolution of T . In a time stepping procedure this requires two successive solving [with Neuman and with Dirichlet boundary conditions] of the implicit part of temperature vertical diffusion equation. The oceanic heat flux is used by the ice to determine its growth rate (Equ. 1). This rate is used to determine the water flux to the top of the ocean.

The surface water flux is defined by :

$$Q_{\text{salt}} = S_b \cdot (E-P-R) + (S_b - S_i) \cdot \frac{\partial m_i}{\partial t} + S_b \cdot \frac{\partial m_s}{\partial t} \quad (3)$$

where S_i and S_b are the ice and first level ocean salinity, m_s and m_i are the masses of snow and ice per unit area, $E-P-R$ is the fresh water

budget in open-water area including the evaporation (E), the precipitation (P) and the run-off (R) contribution from rivers. In our case the ice salinity is assumed to be constant ($S_i = 5$ PSU).

We assess that the sea-ice is totally included in the first level of the ocean model.

Any energy absorbed in areas of open water included in ice (leads, polynyas) may be used to melt ice at the bottom or for lateral melting (Maykut and Perovitch, 1987). The way this energy must be distributed between bottom and sides is not well known, different approach have been used in ice modelling. Wu et al. (1997) for example propose a partitioning between the energy flux at the bottom and at the ice sides based on ice thickness and fraction. In the reference version of the ice model all the energy is used for bottom melting. Using lateral melting is also possible.

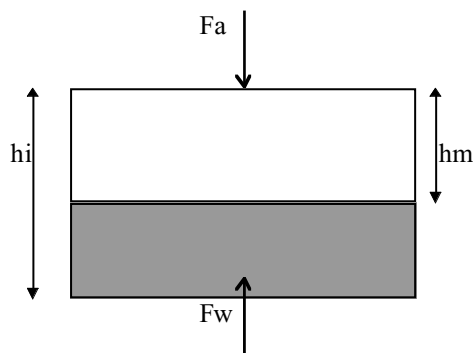


Figure 1

2. Dynamique

not yet available

3. Coupling with the atmosphere

At each coupling time-step the atmosphere provide the following information to the ice-ocean model°:

a- In uncoupled mode bulk formulae are used to determined the ice forcing°: All fluxes are defined as positive downward to be consistent with the oceanic sign convention.

Atmospheric flux parameterizations.

Atmospheric fluxes are computed with various parameterizations : Bulk aerodynamic formulae for the latent and sensible fluxes and the Stefan-Boltzmann radiation law for the long-wave emission.

The present very simplistic atmospheric model does not have different physics for ice and open water (same exchange coefficients, same empirical law for specific humidity) only different surface temperature at the ocean and at the ice surface make different flux estimates for the two surface types.

* *Sensible heat flux* :

$$Q_{sh} = c_a \cdot r_a \cdot c_h \cdot (T_s - T_{atm}) \cdot W$$

where : c_a is the specific heat of air at surface pressure, c_h is the sensible heat transfer coefficient (dimensionless).

c_h is function of the drag coefficient and depend on the roughness (different for ice or ocean) and on the atmospheric stability.

r_a is the air density in kg m^{-3} .

T_s : ocean or ice surface temperature in Kelvin

T_{atm} : air surface temperature in Kelvin (at the first level of the atmospheric model).

W : surface wind speed (at the first level of the atmospheric model in m s^{-1}).

The air density is approximated by the ideal gas formula :

$$r_a = P_{atm} / (R \cdot T_{atm})$$

with : P_{atm} the surface pressure and R the gas constant of dry air.

The sensible heat transfer coefficient depends on the wind speed and the stability of the atmospheric boundary layer (which is function of $T_s - T_{atm}$).

Note that Q_{sh} is different for every ice thickness (including open water) as is c_d since those quantities depend on the considered surface temperature which is different for every ice thickness.

* *Latent heat flux*

$$Q_{lh} = L_w \cdot Q_e$$

with L_w is the latent heat of vaporization over water or of sublimation over ice or snow and Q_e is the evaporation rate in $\text{kg} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$

$$Q_e = r_a \cdot c_e \cdot (q_s - q_{atm}) \cdot W$$

where q_s and q_{atm} (both dimensionless) are the specific humidities at the ocean (or ice) surface and in the air.

The latent heat transfer coefficient c_e (dimensionless) is taken equal to the sensible heat transfer coefficient c_h .

The specific humidity at the surface is function of the water vapor pressure e and the surface pressure P_{atm} :

$$q_s = m \cdot e / (P_{atm} - (1 - m) \cdot e)$$

where m is the molecular weight of water vapor to that of dry air (dimensionless).

The saturation vapor pressure at the sea surface (in Pa) is given by :

$$e = 611.14 \cdot \exp(a \cdot (T_s - T_0) / (T_s - b))$$

with T_0 corresponds to zero Celsius

$a = 17.269$ for ice cover and $a = 21.875$ over open water

$b = 35.86$ for ice cover and $b = 7.66$ over open water

(we use a linearization in the bulk formulation°:

$$q_s = (rsvip0 + T_s (rsvip1 + T_s (rsvip2 + T_s (rsvip3 + T_s \cdot rsvip4)))) \cdot \mu / P_{atm}$$

Like the sensible heat flux and for the same reason the latent heat flux is different for every ice thickness (including open water).

* *Net outgoing long wave radiation Q_{lr}*

$$Q_{olr} = e \cdot s \cdot T_s^4$$

where e (dimensionless) is the emissivity of water, ice or snow and s is the Stefan-Boltzmann constant.

* *Total non solar heat flux over open water*

$$Q = -(Q_{olr} + Q_{sh} + Q_{lh}) + Q_{dlr}$$

with Q_{dlr} is the incoming long-wave radiation in $W \cdot m^{-2}$

b- In coupled mode°: For the coupling with the atmosphere we use the_OASIS coupler (Terry et al, 1995) and a special treatment for the ice categories (J-L Dufresne and J-Y Grandpeix, 1996)

4. User's Guide to the IGLOO Sea Ice model.

The following user's guide is provided for informational purposes, and is not intended to be complete.

Below, are several sets of notes pertinent to using the IGLOO Sea Ice model. Namely, the conceptual flow chart of the model, a description of the namelist input variables and a description of how the model can be used.

Overview of the sea ice model code.

The purpose of this section is to provide an overview of the IGLOO sea ice model code. It is meant to give the potential user a feel for the structure and flow of the model.

As input variables, two data-sets are necessary for the ice model to successfully start its integration - a data-set that contains the forcing and a data-set that contains the current state of the model in case of restart.

The sea ice model may be integrated under various conditions defined by cpp keys.

Equations discretization

All the fields are discretized on a staggered grid.

In the horizontal plane the ice model is discretized on the ocean grid (the mesh is of the C type following the Arakawa's classification).

4.a - Flow chart of the sea ice code

The basic structure of the IGLOO sea ice model code is illustrated below. There are four basic functions that occur during the integration of the sea ice model: initializing the model (reading the namelist, and a restart dataset); determining the forcing (or exchanging information with the coupler in case of coupling with the atmosphere); advancing the sea ice state variables over one timestep, and saving the model state (history and restart dataset).

The routines are detailed afterwards. This part only describes the flow chart for the thermodynamics version of the IGLOO model.

The code contains two parts:

- The first one is the initialisation phase (with OPA OGCM version 8.1) :

- opa: main routine of the ocean general circulation model

- * initialization of the ocean

- * **iniice**: initialization of the ice

- ◇ **icecst**

- ◇ **icelec**: read namelist input

- ◇ **icectl**

- ◇ **iceini**

- * **icdom**

- * **ocfzpt**

- * **icgrid**

- ◇ **oiaini**

- ◇ **icalbd**

- ◇ **icmean**

- ◇ **iacave**

- The second part is the time stepping. It starts at the end of the initialization phase, as everything is ready to start for the time loop

- step: time step routine (OPA)

- // *Forcing and Data*

- * tau

- flx: routines modified in case of ice model use.

- in case of key_repart*

- ◇ oiacpl

- * cplgrid

- * atmosphere

- atmdat

- atmcli

- atmbk

- coefcd

- * oaecon

- ◇ aicflx
 - * icalbd
 - * icpswr
 - * aicflt
- * diawri => (eventually use of IOIPSL° for the output)°: format: write first output
- * **icedia**°: first output
 - ◇ **icmean**
 - ◇ **icegra**
 - * **ic2gra**
 - ◇ **icebil**

III Ocean physics

TKE, bottom friction, isopycnal slope computation

IIII Tracer trends

ocean°: horizontal advection, horizontal diffusion, bottom boundary layer scheme, vertical advection, surface boundary condition.

Ice°: * **icestp**

- ◇ **icadv**
- ◇ **icdiff**
 - * **aicflt**
 - * **icresv**
- ◇ **iocshf**
- ◇ **traqsr**
- ◇ **temzdf**
- ◇ **oicshf**
- ◇ **icgrow**
 - * **icresv**
- ◇ **iocssf**
- ◇ **iccorr**
 - * **icint**
 - ◆ **icgrid**
 - * **icpart**
 - ◆ **icgrid**
- ◇ **icnext**
- ◇ **salzdf**

IVI Dynamics trends of the ocean

VI Time stepping of prognostic variables

tranxt°: modified in case of ice model use.

VII Control, diagnostics and outputs

- * **stpctl**°: control step execution.
- * **icewri**°: write the restart for the ice
- * **icedia**°: ice outputs

◇ icmean
◇ icegra
* ic2gra
◇ icebil

* stpcmo°: coupling field°: modified in case of ice model use = if
key_repart used

◇ iacave

4.b – Namelist :

Ice MODEL namelist of options to be modified if necessary

namphy adjustable physical constants for ice

rtf : freezing point of seawater°; *rtf*=-2.

rtr : equilibrium temp. of the reservoir°; *rtr*=-0.1

rlhfib: heat of fusion at the bottom of the ice°; *rlhfib*=2.675e8

rsali : ice salinity°; *rsali*=5.

rch : stanton number (coefficient for sensible heat flux)°; *rch*=1.1e-3

rce : dalton number (coefficient for latent heat flux)°; *rce*=1.75e-3

namsvp°: coefficients of polynomial expression for saturation vapor pressure over ice (for the bulk case°: *key_bulk*)

rsvpi0=610.6675

rsvpi1=49.9993

rsvpi2=1.80147

rsvpi3=0.342165e-01

rsvpi4=0.283682e-03

namalb°: albedo

ralbs : albedo of snow°; *ralbs*=0.75

ralbif: albedo of bare ice°; *ralbif*=0.70

ralbim: albedo of melting ice°; *ralbim*=0.6

ralbw : albedo of seawater°; *ralbw*=0.07

namres°: parameters for penetration of sw radiation into the ice

resmax : max ratio of internal reservoir heat content°; *resmax*=0.3

rpsw01 : fraction of sw penetrating beyond the top 0.1 m of ice°; *rpsw01*=0.17

namlay°: minimum values for a snow or ice temperature layer

rhsmin: minimum allowable value for snow layer thickness°; *rhsmin*=0.05

rhimin: minimum allowable value for ice layer thickness°; *rhimin*=0.1

namopn°: parameterization of open water (o-w) fraction

rhopen : minimum thickness for ice created by freezing in o-w°; *rhopen*=0.12

rleads(n): minimum fraction of o-w during the melting season°for both hemispheres; *rleads*=0.1 and *rleadn*=0.1

namsp°: axis limits in the phase space

rhimax: limit of ice grid (thickness)°; *rhimax*=3.

rtimin: limit of ice grid (temperature)°; *rtimin*=-2.

namspo°: snow precipitation

bprec : boolean for snow precipitation (1 = with°; 0=without)°; *bprec*=1.

namlea°: leads parametrisation

rhlmin(s): maximum height to variable leads fraction both hemispheres°; *rhlmin*=1 and *rhlmis*=0.4

rwlmin(s) : minimum leads fraction°; *rwlmin(s)*=0.02.

rwlman(s): maximum leads fraction°; rwlman(s)=0.15.

namrid ridging parametrization

rgrid : percentage of no ridging ice°; rgrid=0.9

rmh : increase of the thickness of the ridging ice°; rmh=10.

rhopen: minimum thickness for ice created by freezing in open water°;

rhopen=0.12

rhmin: minimum thickness for melting ice°; rhmin=0.01

namdtf°: ice model time step

ricdtf: thermodynamic time step in seconds°; ricdtf=5760.

namice°: limits of the ice covered ocean

nsice : southern latitude of the ice-free ocean°; nsice=35,

nsicel southern latitude of the ice-free ocean°for the low resolution ocean model (key_opal)°; nsicel=11,

nsicea : southern latitude of the ice-free ocean°for the Arctic zoom (key_arctic);°nsicea=0,

nameps°: limits of accuracy

epsice: precision on ice°; epsice=1.e-10,

namopt run options for the ice model

nwrmea : time interval for calculation of diagnostic mean fields°; nwrmea=75

bshu : constant for specific humidity (1= read from file)°; bshu=1.

brhu : use of relative humidity in calculation of specific humidity if non-zero; brhu=0.

bdew : use of dew point temperature in calculation of specific humidity°if non-zero; bdew=0.

bprsl: constant for distinct solid and liquid prec. (1=two distinct fields, solid and liquid; 0=all kinds of precipitation stored in liquid)°; bprsl=1.

namrsi°: restart ice parameter

lrstic boolean term for restart (true or false)°; lrstic =.FALSE.,

nrsidt control of the time step if non-zero (0 or 1)°; nrsidt =1,

namrsc°: restart cpl parameter (key_repart)

lrstcp boolean term for restart (true or false)°; lrstcp =.FALSE.,

nrscdt control of the time step (0 or 1)°; nrscdt =1,

namipr ice print out parameters

niprlv print level°; niprlv =0,

niprst print out frequency°; niprst =5

:

namigr°: ice graphic output parameters

nigrlv graphic output level°; nigrlv =1,

namtst test coupled options

raircp smoothing factor for the energy conservation correction°; raircp =0.,

4.c - ice routines description

1 - iniice°: initialization of the ice. Include different sub-routines.

2 - icecst°: initialize the constants and print the parameters

3 - icelec°: reads ice namelist.

4 - icectl°: control ice parameters

5 - iceini°: ice initialisation.

Method°: 2 cases:

a/ Start from scratch :

- ice thicknesses for the different ice types are defined as mid points of the ice thickness intervals along the thickness axis of the phase space

- snow thicknesses are assumed to be zero

ice temperature profile is derived from linear interpolation between air surface

- temperature (at surface) and freezing point of seawater at bottom.

- weight attached to each ice type apart from open water is determined assuming a uniform distribution of thicknesses between 0 and a maximum value taken as the thickness interval boundary value on the thickness axis being the closest to the maximum nominal value. The nominal value is either fixed arbitrarily or deduced from mean ice thickness data (key_icedta)

- weight attached to open water is either fixed arbitrarily or deduced from ice concentration data (key_icedta)

- latent heat internal reservoir is assumed to be zero

b/ Restart :

all previous variables are initialized from restart file

6 - icdom°: Define equivalence between ice and ocean horizontal grids (adressage indirect) and define geographical areas in which prints out of ice variables are requested.

7 - ocfzpt°: Calculate ocean surface freezing temperature (utilise stafundOPA), calculate related boolean for ice distribution at time step "now" (freezn).

8 - icgrid°: Calculate actual number of snow and ice layers and related booleans after surface and bottom accretion or ablation and precipitation

Calculate vertical grid and masks for a snow covered ice slab

Method°: The maximum number of snow and ice layers is prescribed according to parameters jplays and jplayi respectively

The actual number of snow and ice layers may be forced to zero if the snow or ice thickness drops below a limit value

9 - oiaini°: Initialisation of coupler's variables

10 - icalbd°: Compute surface albedo for each ice type

Under surface freezing°: snow albedo exponentially decreases from the albedo of fresh snow toward the albedo of bare ice with an e-folding time scale of 5 days.

Under surface melting°: snow albedo decreases from its current value prior to melting toward the albedo of melting ice at a rate proportionnal to the relative snow thickness change.

11- icmean°: Compute mean value (from 2 to jpps and normalized) of the statistical distribution of some ice variables.

12 -iacave°: Prepare mean ice variables for the ice => atmosphere coupling
Method°: variables are computed for jpastp types of surfaces :
if jpastp=1 : variable averages include open water contribution
if jpastp=2 : variable averages are computed over open water and ice covered surfaces
variables are time-averaged over the ncpnt time steps preceding the coupling time step.

13 - icedia°: Compute and write ice fields for output. Include different sub-routines.
Vairmer format (key_vairmer) or Netcdf (to be developped). Plus eventually format Grads.

14 - icegra°: Ice model output if Grads type used.
At the first time step (nit000), output of the grid-points position and depth and of the mask at t-point.
Each nwrite time step, output of ice model
IF kindic <0, output of fields before the model interruption.
IF kindic =0, time step loop
IF kindic >0, output of fields before the time step loop

15 - ic2gra°: Store ice variables on a direct access output file. Data are coded binary
Each individual data array is stored in a separate record, the length of which varies according to the size of the array
A data sequence of jpsel records constitutes the output of one time step
An initial sequence is first stored which contains the whole information on the geographical grid. this information is to be used for mapping of horizontal distributions of the fields by an adequate software (e.g. ncar)
Information on the different arrays entering a data sequence (array name, number of dimensions and title for plots) is stored on a separate sequential file so that the resulting output file should be readable by the graphic software "grads".

16 - icebil°: Compute and write time and spatial mean value for ice variables.

17 - icestp°: Time stepping of Sea-Ice Model

18 - icadv°: Calculate changes in ice thickness-temperature distribution under advection.

19 - icdiff°: Calculate internal latent heat storage due to penetrating solar radiation within the ice

Calculate change of the vertical temperature profile within the snow-ice slab under vertical diffusion test about occurrence of surface melting

Calculate first estimate of surface ablation rate

Test about disappearance of the snow cover

Calculate conductive heat flux at the bottom of the ice

Advance vertical temperature profile and internal latent heat reservoir to next time step

Solve one dimensional heat diffusion equation along the vertical

The equation is discretized on a fixed number of snow and ice layers with equal thicknesses in each of the medium.

The layer thicknesses vary in time to follow ice thickness changes. only when the thickness of an ice or snow layer falls below a minimum allowable value (rhimin or rhsmin) is the number of layers arbitrarily set to zero

The equation is solved using a backward scheme over a ricdtt time step

20 - aicflt°: Compute total surface heat flux for each ice type category

Compute the atmospheric non solar heat flux for each ice category

First order expansion of the non solar heat flux as a function of surface temperature

If "qaom" is the non solar heat flux calculated by the atmospheric model for a mean surface temperature "tsria", and if "xdqaom" is the derivative of this flux with respect to this surface temperature, then the heat flux qi over an individual ice category with surface temperature ti is given by :

$$q_i(t_i) = q_{aom} + x_{dqaom} \cdot (t_i - t_{sria})$$

Over ice, surface flux includes sw radiation absorbed by the very top layer of the ice

21 - icresv°: Perform correction on heat reservoir or ice thickness in order to maintain the internal latent heat storage below a prescribed upper limit value (a percentage resmax of the ice thickness)

Either store the excess of latent heat which will be further returned to the surface as additional shortwave radiation (routine icdiff)

Or calculate the necessary correction to the ice thickness in the form of an additional ice melting (routine icgrow)

Make sure that the internal latent heat reservoir does not exceed the amount of heat required to melt the existing ice

if kh = 0 : calculate excess of penetrating shortwave radiation

if kh = 1 : calculate correction on ice thickness

22 - iocshf°: Ice-ocean coupling routine : provides ice modified variables as ocean surface forcing

Calculate maximum allowable non solar heat flux at the ocean surface

Calculate total net sw radiation at the ocean surface

Non solar heat flux is kept unchanged over open water and replaced by a maximum allowable value in ice covered grid cells this maximum heat flux allows to test whether the ocean can exit freezing conditions. it should balance the atmospheric forcing on top of the ice after all ice has been melted and the internal reservoir is exhausted

23 - traqsr°: Compute the temperature trend due to the solar radiation penetration and add it to the general temperature trend.

At the bottom, boundary condition for the radiation is no flux : all heat which has not been absorb in the surface layers is absorb in the last ocean model layer.

OPA routine modified if the ice model is used = q is calculated in the ice model and does not contain the solar flux.

24 - temzdf°: Compute and add to the general temperature trend the vertical diffusion and surface forcing trends. the surface boundary condition depends on freezing or not freezing condition.

Diagnose the surface heat flux entering the ocean.

Only used if "key_ice" is activated, else trazdf is called.

The implicit temperature vertical diffusion trend is given by:

$$ta_{ft} = tb + 2 dt ta + 1/bt dk+1(avt bw/e3w^{**2} dk(taft))$$

where taft is the after temperature (backward time scheme)

Surface boundary conditions: depends on freezing condition

* taft > tfreezing: heat flux boundary condition, q (w/m2) = the total surface heat flux, or the non penetrant part of the heat flux ('key_flgqsr' activated).

* taft <=tfreezing: first model level is set to the freezing point. q is update as the ocean-ice heat flux (i.e. the surface flux required to reach the freezing point, taken into account the ocean diffusive and advective contributions to the first layer temperature trend.

Bottom boundary conditions: no flux

Converte taft into the general trend ta :

$$ta = (taft - tb)/(2 dt)$$

Save diffusive and forcing trends (if 'key_diatrdtra' activated)

25 - oicshf°: Ice-ocean coupling routine :

Provides ocean heat flux for ice forcing

Calculate ocean heat flux to the bottom of the ice after redistribution between the different ice types

Calculate growth rate in open water (if freezing, the rate does not include correction for lateral melting)

Estimate fraction of heat used for lateral melting

26 - icgrow°: Calculate change in ice thickness due to thermodynamic growth or melting

Calculate change in snow thickness due to precipitation or melting

Calculate thermodynamic growth rate at the bottom of the ice

Calculate snow accumulation on top of ice

27 - iocssf°: Ice-ocean coupling routine : provides ice modified variables as ocean surface forcing

Calculate fresh water fluxes at the ocean surface for ice covered conditions

Rearrange open water precipitation

Calculate open water and total surface fresh water budgets

Calculate total salt flux at the ocean surface (SI° units; kg/m²/s)

28 - icorr°: Terminate thermodynamic time step by performing various corrections on the thermodynamic variables. Include different sub-routines.

29 - icint°: Interpolate a temperature profile originally defined over vertical layers of different thicknesses (due to surface and bottom accretion or ablation) onto vertical layers of equal thickness (although different for ice and snow)

Conservation of the sensible heat content of the ice and snow must be called before routines "flux" and "ocfzpt" because need to know precipitation and freezing point from current time

30 - icpart°: Calculate ice distribution in the phase space

Define ice types by thickness-temperature coordinates in the phase space

Calculate for each ice type :

- the percentage of grid cell area covered by ice

- the latent heat reservoir capacity

- the thickness of the snow layer

- the vertical temperature profile

external°: icgrid

31 - icnext°: Exchange prognostic variables before next time step

32 - salzdf°: Compute and add to the general salinity trend, the vertical diffusion and surface forcing trends. (see OPA ocean model documentation)

33 - icewri°: write the restart of the ice.

4.d - List of CPP variables available for sea -ice.

The cpp is used before entering the compilation phase and is controlled by cpp variables defining the chosen options.

key_ice to active the ice model.

key_antarctic to southern hemisphere domain of computation only

key_arctic to northern hemisphere domain of computation only.

key_icedta to include ice data for height and coverage.

For the atmospheric forcing°:

key_bulk bulk formulation over all ocean.

key_repart fluxes calculation depending on surface temperature.

key_newcdrag calculate the drag coefficient taking into account the stability.

4.e - Parameters for the ice simulation

To summarise, when an user wants to set up its own model, he has to°:

- define its grid size (in *parameter.h* for the ocean and *parameter.ice.h* for the ice).

- select the set of cpp variables.

- check the values of namelist variables (*namelist* file for the ocean and *namelist.ice* file for the sea-ice).

Two defaults simulations are available°:

a/ global simulation.

or

b/ limited area simulation = 20x15x19 which may be used in interactive way.

=> modification of *parameter.h*, *parameter.ice.h*, *namelist* (time step=1h) and *domhgr.F*.

Modification of *flx.F* to generate analytic forcing

4.f - Domain and grid

The dimensions are supplied in the *parameter.ice.h* file.

- vertical dimensions

jplays: maximum number of vertical layers used for discretizing the heat diffusion equation in snow

jplayi: maximum number of vertical layers used for discretizing the heat diffusion equation in ice

jpki : maximum number of vertical temperature levels

jplayi=1

jplays=0

jpki=jplayi+jplays+3,

22

jpkim1=jpki-1
jpkim2=jpki-2)

- horizontal dimensions

jpji : number of grid points in the x direction

jjpi : number of grid points in the y direction

jpdist : number of grid points on the ocean grid between nsice (the northernmost limit of the ice in the southern hemisphere) and the southernmost possible limit of sea ice in the northern hemisphere

* For the general case°: global simulation jpdist=65

if key_antarctic jpdist=10°; if key_arctic jpdist=0

* For the low resolution ocean model (key_opal) global simulation jpdist=30

if key_antarctic jpdist=5°; if key_arctic jpdist=0

* For the reduced domain simulation°: jpdist =0

For the general case°: jpji=jpi, jjpi=jjj-jpdist

For the mpp case (key_mpp)°: jpji=jpi, jjpi=jjj

jpi and jjj are the ocean model horizontal dimensions

* For the general case jpi=182, and jjj=149

if key_antarctic jpi=182, jjj=30

if key_arctic jpi=74, jjj=48

* For the low resolution ocean model jpi=92, jjj=76,

if key_antarctic jpi=92, jjj=15

if key_arctic jpi=32, jjj=24, jpk=31

* For the reduced domain simulation°: jpi =20, jjj=15

- dimensions of the phase space

jjpsh : number of selected ice classes along the thickness axis of the phase space

jjpst : number of selected ice class boundaries along the second axis of the phase space

jjpps : total number of ice classes in the phase space

jjpsmx : maximum value reached by jjpps under advection and/or redistribution

jjpsh=4, jjpst=2, jjpps=(jjpsh-1)*(jjpst-1)+1, jjpsmx=2*jjpps)

- print and output file options

jjzprt : maximum number of geographical zones where prints out are requested

jjisel : number of fields in the output file

jjzprt=2, jjisel=27

- atmospheric model

jjpia : number of grid points in the x direction

jjpja : number of grid points in the y direction

jjpastp : number of surface types viewed by the atmosphere

jjpia=jjj, jjpja=jjj, jjpastp=2

4.g - Sea ice model constants

The sea ice model constants are defined in the *icecst.F* file and are communicated to every subroutine by the *common.ice.h* file. See appendix 1 for numerical values.

rsig : stefan's constant
rpgc : universal gas constant
rconds: thermal conductivity of snow
rcondi: thermal conductivity of ice
raucs : volumetric heat capacity of snow
rauci : volumetric heat capacity of ice
raucw : volumetric heat capacity of seawater (t=0c,s=34ppt)
rauw : density of pure water
raus : density of snow
raui : density of ice
riwdr : ratio of ice density over seawater density
rswdr : ratio of snow density over pure water density
rsidr : ratio of snow density over ice density
rlhfw : latent heat of freezing of water
rlhvw : latent heat of vaporization of water
rlhsw : latent heat of sublimation of water
rtmelt: melting point of ice
rems : longwave emissivity of snow
remi : longwave emissivity of ice
remw : longwave emissivity of seawater
rmola : molar mass of air
rmwr : molecular weight ratio (molw/mola)

5- How to run the model.

A reference code is located in a reference directory (like for OPA simulations). Each user has its own directory containing only the routines that he need to change.

During the compilation, these routines will overwrite their counterparts of the reference code in the user s working directory on the computer.

In order to use the code, one must first check that it is suitable for the project (send an e-mail to°: jldufres@lmd.jussieu.fr).

Then he gets the tarfile of the code and makes the same steps as for the OPA GCM simulations (Madec et al., 1998).

The code is stored in its standard reference version in a shared directory. This directory contains the source code for the ice and the ocean, the scripts for building your computing environment. This directory will now be called OPAREF. In the OPAREF directory, you will find a README describing the location of the files in the sub-directories. This README is duplicate here for the purpose of ice simulations.

It is located:

- on the IPSL network:

```
OPAREF=~opalod/LODMODEL ; export OPAREF
```

1) Add the following path (containing some scripts used for the model) to your environment:

```
export PATH=$PATH:$OPAREF/SCRIPTS
```

2) Build your own working directory

```
mkdir WKOPA
```

```
cd WKOPA
```

CAUTION!: your WKOPA directory must contain the OPA or IGLOO source files that you need, i.e. the routines you need to modify, but NOTHING ELSE.

Copy the source files you need to modify in your work directory. For example, if you want to change the grid size defined in the parameter.h and parameter.ice.h files, you need to get these files by typing:

```
(/home/opalod/LODMODEL/SCRIPTS/) geto parameter.h
```

```
(/home/opalod/LODMODEL/SCRIPTS/) geto parameter.ice.h
```

3) Generate your own Makefile in your WKOPA directory by typing:

```
(/home/opalod/LODMODEL/SCRIPTS/)fait_make
```

Answer the questions using the following information:

Typing return keeps the default value indicated in the brackets.

Nom du repertoire contenant les scripts pour OPA8 de reference

```
(/home/opalod/LODMODEL/SCRIPTS)? -> directory containing scripts
```

/home/opalod/LODMODEL/SCRIPTS

Nom du repertoire contenant les sources OPA8 de reference
(/home/opalod/LODMODEL/SRC_OPA)? -> directory containing the OPA
reference source files

/home/opalod/LODMODEL/SRC_ORCA for the global ocean model

**/home/opalod/LODMODEL/SRC_OFFLINE_ORCA for a restricted domain
ocean model.**

Souhaitez-vous incorporer le modele de glace : o pour Oui, n pour Non (n) ?
E include ice model yes (o) or no (n)

o

Nom du repertoire contenant les sources du mod le de glace de reference
(/home/opalod/LODMODEL/SRC_ICE)? -> directory containing the IGLOO
reference source files

/home/opalod/LODMODEL/SRC_IGLOO for the global sea-ice model

**/home/opalod/LODMODEL/SRC_OFFLINE_IGLOO for a restricted domain
model.**

Souhaitez-vous incorporer le modele traceur : o pour Oui, n pour Non (n) ?
E include tracer model yes (o) or no (n)

n

Machine de calcul (atlas.idris.fr) ? -> name of the computer where the model
runs

atlas (for example)

Login sur la machine de calcul atlas.idris.fr () ?

E login name on this computer

reee692 (for example)

Repertoire sur atlas.idris.fr contenant les sources (WKOPA) ?

E directory on this computer where the source files
are stored (should be permanent)

WKOPA (to be created in the home directory)

Etes vous satisfait : o pour Oui, n pour Non (o) ?

E confirm your choices and start generating the local
Makefile yes (o) or no (n)

o

CAUTION!: This "fait_make" step will have to be re-done as soon as you ADD
A NEW FILE in the WKOPA on your local network (modifying an existing file
does not imply to do the "fait_make" again).

In order to have this work, before running make, you must, once for all:

- create the directory WKOPA (or the name you have chosen) on the remote
computer (atlas.idris.fr by default)

- check your access to all the remote commands by filling the .rhosts files on
the remote and local computers.

4) On your local network, in WKOPA, run the makefile by typing:

make

This step copies all the source files (the ORCA and IGLOO references and your own modifications) in the directory (default WKOPA) of the remote login, on the remote computer.

5) You must now log on the remote computer with the remote login. Then type:

cd WKOPA (or the name you have chosen)

fait_make_remote

This step builds the Makefile on the remote computer in the WKOPA directory. This Makefile will build the executable, taking in account your choices for the cpp key_words, the compiler and loader options, and the location of the listings and executables.

Answer the questions using the following indications:

Options pour cpp: the suggested default value runs the ocean model with no input data, and analytic wind forcing. To use the ice model with an analytic forcing you must use the following keys°: -Dkey_fixqsr -Dkey_zdftke -Dkey_ice -Dkey_repart -Dkey_newcdrag

6) Create the executable on the computer by typing:

make

7) On the remote computer, in WKOPA, you will find an example job_ice for an ORCA°/IGLOO standard forced run.

Copy the script in a file called job (for example), adapt it for your own purpose and submit your job (qsub job on cray for example).

Appendix A- Numerical values and units of the model constants and parameters.

Symbol	Definition	Value
ϵ_i	long-wave emissivity of sea ice	0.97
ϵ_s	long-wave emissivity of snow	0.99
ϵ_w	long-wave emissivity of sea water	0.97
C_{pi}	specific heat of sea ice	2033.5 J kg ⁻¹ K ⁻¹
C_{ps}	specific heat of snow	2090 J kg ⁻¹ K ⁻¹
C_{pw}	specific heat of sea water	4002 J kg ⁻¹ K ⁻¹
C_a	specific heat of air at the surface	1004 J kg ⁻¹ K ⁻¹
κ_i	thermal conductivity of ice	2.034 W m ⁻¹ K ⁻¹
κ_s	thermal conductivity of snow	0.3097 W m ⁻¹ K ⁻¹
T_{melt}	melting point of sea ice	273.15 K
S_i	sea ice salinity	5 psu
α_{if}	albedo of bare ice	0.7
α_{im}	albedo of melting ice	0.6
α_s	albedo of snow	0.75
α_w	albedo of sea water	0.07
ρ_i	density of sea ice	925 kg m ⁻³
ρ_s	density of snow	330 kg m ⁻³
ρ_w	density of pure water	1000 kg m ⁻³
L_{fw}	latent heat of freezing of water	3.325 x 10 ⁵ J kg ⁻¹
L_{vw}	latent heat of vaporization of water	2.5 x 10 ⁶ J kg ⁻¹
L_{sw}	latent heat of sublimation of water	2.834 x 10 ⁶ J kg ⁻¹
R	universal gas constant of dry air	2.87 10 ² Pa K ⁻¹ m ³
T_0	zero Celsius	273.15 K
h_{min}	minimum thickness of newly formed ice	0.12m
μ	molecular weight ratio	0.622
σ	Stefan-Boltzman constant	5.67e-8 W m ⁻² K ⁻⁴

References

Barthelet, P., S. Bony, P. Braconnot, A. Braun, D. Cariolle, E. Cohen-Solal, J.-L. Dufresne, P. Delecluse, M. Diquet, L. Fairhead, M.-A. Filiberti, M. Forichon, J.-Y. Grandpeix, E. Guilyardi, M.-N. Houssais, M. Imbard, H. Le Treut, C. Levy, Z. X. Li, G. Madec, P. Marquet, O. Marti, S. Planton, L. Terray, O. Thual, and S. Valcke, 1998: Simulations couplées globales des changements climatiques associées à une augmentation de la teneur atmosphérique en CO₂. *Compte-rendu l'Académie des Sciences, Paris*, **326**, 677-684.

J-L Dufresne and J-Y Grandpeix, 1996: Raccordement des Modèles Thermodynamiques de Glace, d'Océan et d'Atmosphère. Laboratoire de Métrologie Dynamique, Note Interne 205, juin 1996. In french.

Hibler, W.D., III, 1980: Modeling a variable thickness sea ice cover. *Mon. Wea. Rev.*, **108**, 1943-1973.

Madec, G., P. Delecluse, M. Imbard, C. Levy, 1998: OPA 8.1, ocean general circulation model reference manual, *Notes du pôle de modélisation*, Institut Pierre-Simon Laplace (IPSL), France, Note n°11, 91 pp.

Millero, F.J., 1978: Freezing point of seawater, in *Eighth Report of the joint panel on oceanographic tables and standards*, *Unesco tech. papers in the marine science*, **28**, annex 6, pp29-35, UNESCO, Paris.

Terray L., E. Sevault, E. Guilyardi, O. Thual, 1995: The OASIS coupler User Guide Version 2.0, CERFACS technical report TR/CMGC/95-46.

Schramm J. L., M.M. Holland, J. A. Curry and E. E Ebert, 1997: Modeling the thermodynamics of a sea ice thickness distribution. Part 1- Sensitivity to ice thickness resolution. , *J. Geophys. Res.*, **102**, 23079-23092.

Semtner A. J., Jr., 1987: A numerical study of sea ice and ocean circulation in the Arctic. *J. Phys. Oceanogr.*, **17**, 1077-1099.