SUPER_NICE, a super-simple sea ice thermodynamic component for atmosphere-only models

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Here I briefly describe how sea ice thermodynamics could be cheaply represented in atmosphere-only models (like for AMIP simulations). The target is the computation of sea ice surface temperature and albedo, in order to provide a reasonable bottom boundary condition for the computation of surface energy balance. Ice dynamics are neglected, which must be compensated by the use of time-dependent observations of sea ice fraction.
I'm guessing that this approach would largely improve surface temperature and energy balance, with positive impacts on the atmosphere. This is because two major effects would be accounted for: (i) the representation of the snow insulation in winter, which will efficiently isolate the atmosphere from the ocean and cool it, (ii) the seasonal change in surface albedo, that will affect the radiation balance, with global scale impacts, notably on meridional heat transport. Together with this note, I provide an IDL code (sorry not python). I wrote it in a way that avoids obvious pathological cases and that should be easily pluggable into LMDZ.

Want to run the code ? Enter IDL (e.g. on cratos, or ciclad): Type IDL. Then type ".r SUPERN_ICE" and "SUPERN_ICE".

1 Model physics

As the target is to get good temperature and albedo, I decided to keep the physics that are required to get a reasonable estimate of these two fields. The major simplifications of the model are:

- To neglect ice dynamics (complicated and expensive). This is compensated by the use of observed ice concentrations.
- To neglect heat storage in the ice (0-layer approximation), subgrid-scale variations in ice thickness, melt ponds, ...

Doing this, we obtain a model that looks very much like the seminal 0-layer model of *Semtner* (1976). Energy is not conserved, but it is not a problem in an atmosphere-only context.

The model assumes one layer of snow, with a layer of ice below it. We need three state variables, depending on position (lat-lon) and time, namely:

- Ice thickness h_i (m)
- Snow depth h_s (m)
- The snow or ice surface temperature T_{su} (K).

The model equations are:

$$F_{net}(T_{su}) = F_c(T_{su}) - \rho \cdot L \cdot M \quad (1)$$

$$\frac{dh_s}{dt} = P/\rho_s + M - SI \quad (2)$$

$$\frac{dh_i}{dt} = BGM + M + SI \quad (3)$$

where L is latent heat (J/kg).

1.1 Surface energy balance

The surface energy balance (1) gives surface temperature. It represents the energetic balance between the net downwelling atmospheric flux (F_{net}, solar and non-solar) and the conduction flux inside the ice $F_c(T_{su})$. The conduction flux (positive downwards), couples the surface temperature to ice and snow thickness, reading:

$$F_c = K_{eff}(T_{su} - T_b). \quad (4)$$

The use of an effective conductivity factor K_{eff} - weighting snow and ice values according to their respective thicknesses - is there to account for the presence of snow:

$$K_{eff} = \frac{k_i k_s}{k_i h_s + k_s h_i}. \quad (5)$$

If the solution of (1) gives a temperature below zero, the melt rate M is zero. If above zero, the surface temperature is capped to zero and the surface melt rate M is computed as a residual of (1), using either the density of snow (ρ_s) if there is some snow, or that of sea ice otherwise (ρ_i).

1.2 Snow mass balance

The snow mass balance (2) is the difference between precipitation (P), melting (M) and snow-to-ice conversion (SI). The latter represent a dominant process in Antarctica, and was retained in the model to avoid huge piles of snow. The formulation is based on Archimede's principle (see *Fichefet and Morales Maqueda*, 1997, for details). The formulation assumes seawater floods the snow to form ice and zero ice freeboard at the end of the process, giving:

$$SI = \frac{\rho_s h_s - (\rho_w - \rho_i) h_i}{(\rho_s + \rho_w - \rho_i)\Delta t}. \tag{6}$$

1.3 Sea ice mass balance

The sea ice mass balance (3) accounts for basal growth and melt (BGM), surface melt and snow-to-ice conversion. Bottom growth and melt assume that any heat negative or positive imbalance between internal conduction and the oceanic heat flux (F_w, positive upwards) grows or melts ice:

$$\rho_i \cdot L \cdot BGM = -F_c - F_w. \tag{7}$$

In order to correctly position the ice edge, we must add the constraint that ice is only present where satellite concentration is higher than 15%. If not, ice and snow just disappear. Initial ice thickness is 1 cm (maybe we need more) and I suggest a maximum thickness of 6 m, otherwise we may produce huge ice towers where it is f...ing cold (near Greenland for example).

For best performance, I would recommend as well to use the LIM routine albedo.F90 (in the SBC directory of NEMO) that gives a good representation of the dependence of surface albedo on snow and ice thicknesses and surface temperature (*Shine and Henderson-Sellers*, 1985). The routine would be quite easy to plug in I believe. In the IDL code, there is at the moment an ersatz of the original parameterization of *Semtner* (1976), which is reasonable but not as precise.

2 Input and outputs

Inputs

- Snow fall rate (kg/m2/s)
- Downwelling SW or net SW radiation (the latter case can be used if the ice albedo is computed by the atmospheric model, W/m2)
- Net non-solar radiation (W/m2)
- Net non-solar radiation flux sensitivity (W/m2/K)
- Observed ice concentration (dimensionless)

The observed ice concentration is required to identify ice points with ice. Because of the absence of ice dynamics, the model is not able to position the ice edge correctly without an observational constraint. For the rest, everything was conceived and coded to mimic what LMDZ gives to LIM in coupled mode.

Outputs.

The two interesting fields to be sent to the atmosphere are:

- Surface temperature (K)
- Sea ice albedo!

3 Tuning the model

Tuning the model can be achieved easily (careful, the model is super-sensitive).

- The oceanic heat flux should depend on the hemisphere (2 W/m^2 or so for the Arctic and 20 for the Antarctic.
- The parameter gam_SM tunes the intensity of heat conduction. Increasing it should grow ice more efficiently
- The parameter bet_SM tunes the energy partitioning to account for the absence of brine inclusions. Increasing it increases the albedo and reduces summer melt.

4 Two quick examples

To illustrate how the model works, I used a very standard Central Arctic heat forcing (*Semtner*, 1976). And I imposed two ice concentration seasonal cycles. One with 1 all the time (perennial ice), and the other one with a seasonal evolution typical of the seasonal ice zone. The dynamical coupling between ice and snow thicknesses and surface temperature is obvious.

References

Fichefet, T., and M. A. Morales Maqueda (1997), Sensitivity of a global sea ice model to the treatment of ice thermodynamics and dynamics, *Journal of Geophysical Research*, *102*, 12,609–12,646.

Semtner, A. J. (1976), A model for the thermodynamic growth of sea ice in numerical investigations of climate, *Journal of Physical Oceanography*, *6*, 379–389.

Shine, K. P., and A. Henderson-Sellers (1985), The sensitivity of a thermodynamic sea ice model to changes in surface albedo parameterization, *Journal of Geophysical Research*, *90*, 2243–2250.

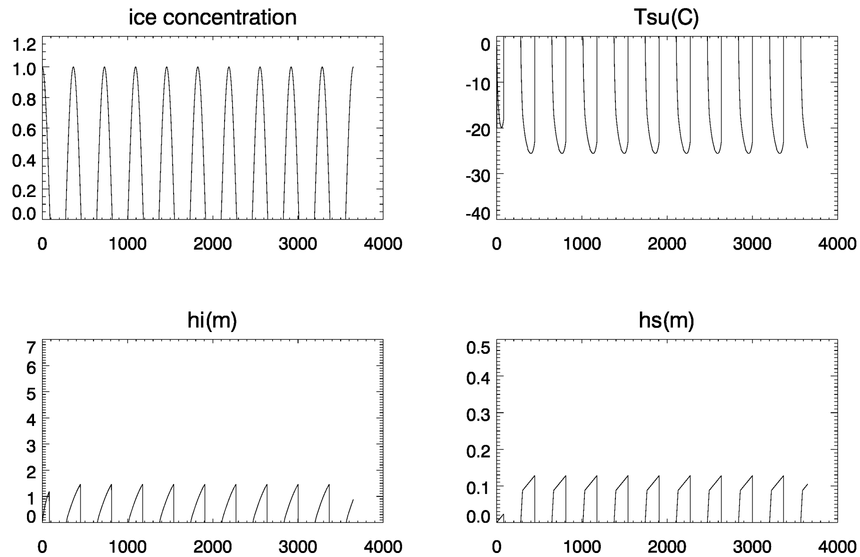

Figure 1: A run where imposed ice concentration follows a typical seasonal ice pattern.

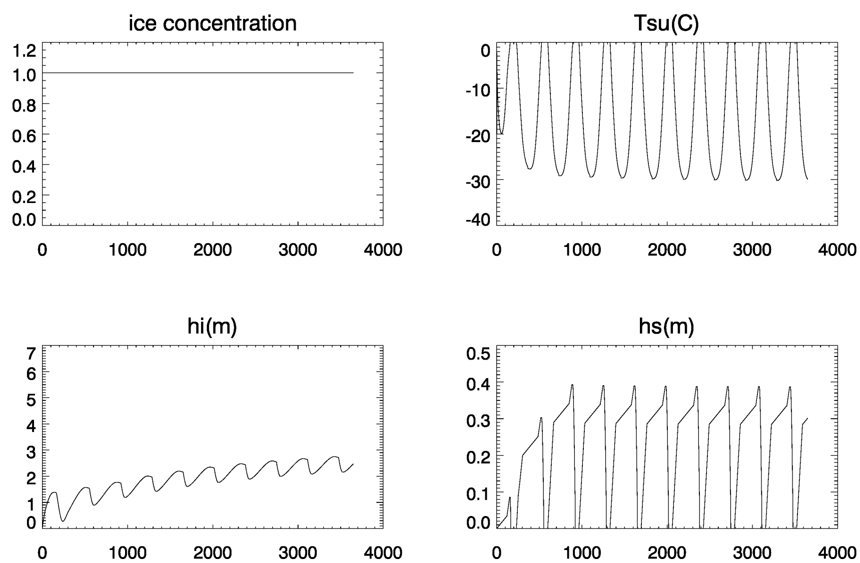

Figure 2: A run where concentration is one all the time (perennial ice).