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Interactive comment on "The location of the thermodynamic atmosphere–ice interface in fully-coupled models" *by* A. E. West et al.

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Dear Anton,

Thank you for your review. I will list our response to your comments, and suggested edits, below.

» Coupling through turbulent diffusion in the atmosphere and thermal diffusion in the surface has a few facets: (1) Numerical stability, (2) Conservation, (3) Code modularity, and (4) Accuracy. Numerical accuracy is obviously the highest priority; without stability, there is no solution. Conservation (of energy) is my view also a high priority, because it is a basic physical property of the coupled system. Often (also in the current paper, I think), it is sacrificed to code modularity. Code modularity is obviously

important; without it, code becomes unmanageable. Finally, numerical accuracy is important of course, but given the uncertainty in processes and diffusion coefficients, it may not be the highest priority, although it is good to separate numerical errors from parametrisation errors.

In fact, the system described in Sections 1 and 2 is fully energy-conserving, regardless of which coupling method is used. It is true that the separation of atmospheric and ice thermodynamic processes, and the consequent delay in response of the two systems, results in a less accurate simulation of the surface flux, which passes energy from the atmosphere to the ice, and vice versa. But this does not imply a lack of energy conservation. The amount of energy lost by the atmosphere will be equal to that received by the ice, and vice versa, even though that amount will not in itself by exactly the same as that which would have been passed in reality.

» Although I am quite familiar with atmosphere / surface coupling issues, it took me multiple readings to understand how the two coupling methods work. In fact coupling only becomes an issue due to the combination of long time steps requiring implicit solvers in both atmosphere and sea ice and the technical separation of the atmospheric and sea ice codes. Ideally, one would solve the atmospheric turbulent diffusion and the sea ice diffusion equations simultaneously in a fully implicit and coupled way. Some models follow this route but it is often thought that it requires full integration of the sea ice and atmospheric codes. However, it would be possible to define a proper interface to exchange information between the two models. The information to exchange is a linear relation between temperature and heat flux from both the atmospheric and sea ice models. Such relations can be obtained from the downward elimination sweep of the tridiagonal solver of the atmospheric diffusion problem and the upward elimination sweep of the sea ice problem. In future, I feel that models should aim for this, not only for stability but also for conservation.

Thank you for describing this – it was interesting to hear how an implicit coupling scheme between atmosphere and ice might work. Martin Best explained your idea further. It looks as if it might work well for coupling between the atmosphere and land, but because it requires the exchange of information mid-timestep would not work, in the current framework, for coupling between atmosphere and ice. I have added a brief description of this method to the introduction, with an explanation as to why it was not thought an option for us.

» In addition, the issue of snow on top of ice is not discussed, although it has a big impact on the heat transport into the ice layer. It also has a big impact on the diurnal cycle of temperature (when the sun is above the horizon), which can be seen from ice buoy data.

This was a good point. We have now repeated the experiment with a snow layer, and under two other alternative conditions. The final revised version will describe these experiments in a new subsection, 4.3. Although all variations of the experiment have the effect of increasing the surface flux error of the 'JULES' method relative to that of the 'CICE' method, the 'JULES' errors are still substantially smaller in magnitude.

» 2. The main difficulty with the manuscript is the interpretation of the results. It is concluded that the flux coupling below the surface is best, but what is the reason. In the simple configuration that is tested (sensible heat flux from the atmosphere matches the heat flux into the ice), the diffusion problem from atmosphere to ice is just a continuous diffusion problem in which the diffusion coefficients vary. So why does it matter whether to shift the coupling level by one layer? I can see three possible reasons: (i) There is a jump of diffusion coefficients near the surface that makes one method of coupling better than the other? (ii) Deeper coupling is always better because more fast responding layers are included in the atmospheric problem (where the diurnal forcing is)? (iii) The coupling below the surface avoids the derivative of fluxes with respect to surface temperature (which causes non-conservation; cf. eq. 10), i.e. it is the conservation that improves the accuracy? It would be nice to discuss the possible reasons for the advantage of one coupling method over the other.

The reason is closest to (ii) – the forcing comes from above, not from below (as is mostly the case in reality) and therefore the simulation benefits from a larger proportion of the system being in the atmosphere. An explanation has been added to the discussion section for the final revised version.

» 3. p.9712 l.9 The expression for K_k is not correct; it has a different dimension than in in equation (9). It appears that K_k is scaled with the layer thickness, but not in equation (9).

Yes – equation (9) was written wrongly. The denominator h_k ˆ 2 should just be h_k.

» 4. p.9712 eq. (10) It is commented that equation (10) is an approximation because of the non-linearity of the outgoing long wave radiation. However, if FËĘ*_o is updated after each iteration the equation could be exact? Below eq. (10), the iteration procedure is described. Is it correct that the result is fully implicit in the sense that also the diffusion coefficients correspond to the new time level? At the end of the iteration with full convergence, TËĘm+1 should be the same as TËĘ*, so I do not see a reason that conservation is compromised? Is it because for this way of coupling, the atmosphere does not use the same surface temperature as the ice model? Please explain.

This was probably not written very clearly. In fact equation (10), which is part of the CICE thermodynamic solver, is iterated, along with the rest of the solver, until an accurate energy-conserving solution is achieved. The iteration is carried out for two reasons: (i) because of the nonlinear dependence of outgoing longwave on surface temperature, and (ii) because the specific heat capacity of the ice itself varies with temperature. In fact, conductivities (or diffusion coefficients) are not updated with each iteration, contrary to what was stated in the discussion paper. This is because conductivity carries no direct implications for energy conservation – it only affects how much energy is passed from one layer to the next. This paragraph has been rewritten for the final revised version.

» 5. p. 9713 l.19-22 The solution method for equation (11) is explained here in a single sentence, which is difficult to digest. It is not clear how JULES computes transfer coefficients. Does it need the Richard number as input (i.e. temperature difference and wind) or does it need fluxes? The sentence suggests that it uses temperature first and then fluxes?

JULES actually calculates the surface energy balance over sea ice in exactly the same way as it computes it over land, as described in Best et al (2011). The temperature of the top layer of sea ice is analogous to the temperature of the top soil layer; the conductivity of sea ice plays the same role as the conductivity of the soil. This paragraph has been clarified.

Interactive comment on Geosci. Model Dev. Discuss., 8, 9707, 2015.