Review of "On the numerical stability of surface-atmosphere coupling in weather and climate models" by Beljaars et al.

It was a pleasure to read this paper and also a surprise to see that this issue has not yet been solved in all land-surface models. This is the typical problem of flux equation discretizations at discontinuities. I have also recently leaned that similar methods are being used for solving diffusion equations on parallel computers when the domain decomposition cuts through the diffusion.

It is not true that an implicit coupling is incompatible with a modular code structure. This has been discussed and solved since Polcher at al. 1998. Most European weather and climate model use a fully implicit coupling and have a modular structure which allows them to run their land-surface scheme off-line or the atmosphere as an aqua-planet without changing the code. Recently ORCHIDEE was coupled to WRF using OASIS while maintaining the implicit solution to the full set of vertical diffusion equations ! With some of the authors we have revisited the issue a few years ago and it is surprising that the fully implicit coupling is still not implemented at ECMWF !

I do not think that introducing an empirical equation is needed to link T_1 to the heat flux at the skin temperature level. During our thesis with Frédréric Hourdin (Hourdin 1992), we proposed to extrapolate the two upper soil temperatures towards the interface and thus provide the surface energy balance equation with a flux and a heat capacity for the infinitesimal layer for which the skin temperature is computed. The benefit of this methodology for complex land surface scheme was documented during the thesis of Jan-Peter Schulz (Schulz et al. 2001).

This has recently been extended to the multi-layer snow scheme without problems (Wang et al. 2013). The referenced paper covers the numerically explicit version of the scheme but this was converted to an implicit scheme coupled to the surface energy balance equation without problems (Will be described in the ORCHIDEE documentation for CMIP6). The same extrapolation then also needs to be done at the bottom of the snow in order to link the heat diffusion in the snow pack with the diffusion in the soil while maintaining a temperature at the contact point between the two media. This allows to solve implicitly the diffusion equations from the top of the atmosphere to the bottom of the soil with clear interfaces and a flexible modular code.

We have also verified that the thermal diffusion equation is numerically stable for very thin upper layers in the soil. This needed to be done when we decided to use a common vertical discretization for the hydrology and thermodynamics (Wang et al 2016). Thus we are quite satisfied with this approach to combine the diffusion equation with an interface temperature. We would agree that the linearity assumption can be criticized on physical grounds.

Indeed, the first few millimetres away from the interface temperature are characterized by very strong gradients and changes in properties which probably break any linearity assumption. Just as a single skin temperature for a complex canopy is dubious. We are currently progressing toward a true 3D energy balance which takes into account the complexity of the vertical structure of the medium which interacts with the atmosphere (Ryder et al. 2015). Even such complex set of equations can be simply solved implicitly and with keeping a maximum of modularity in the code.

I cannot recommend the publication of this paper as it does not take into account sufficiently previous publications on this topic. The references I provide below are only the one I know well as I work everyday with that code. But I know that at Princeton and NCAR some very interesting progress has been made recently on the numerics of the surface processes but I would not know what the most pertinent reference is. Our colleagues at MPI Hamburg have also developed some interesting methods for coupling implicitly multiple surface energy balances to atmospheric columns which are relevant to the discussion proposed.

I do not think either that introducing the empirical equation 8 and its two parameters is justified when the fully implicit solution can be implemented in a modular way and the interface temperature issue solved more elegantly. The linear relation assumed in the Hourdin method is much more tolerable than the scaling relation for α and β !

Jan Polcher

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