Biophysics review and merge

Working document

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The following is a collection of notes concerning our plan to merge various updates to the biophysics component of CABLE. This is aimed at facilitating a merge of two (six) separate lines of work into a consistent form for possible use within ACCESS-CM2 – these are

- the SLI scheme (already in the trunk)
- the Dekker ground water (GW) hydrology scheme
- the Dekker soil energy balance (Ord parameterisation)

Significant effort has been undertaken already to provide a sensibly merged version of these developments, however these have not been formally advanced to the trunk nor tested within ACCESS. The Dekker advances co-exist in one branch. Additionally there are three incremental advances from Harman

- a suite of bug fixes identified concerning the surface exchange (cls package, u* calculation)
- the REV_CORR package
- the SSEB package

The REV_CORR package includes the earlier bugs; the SSEB package includes both.

Staged implementation: Part 1

The merged SLI/Dekker work is reasonably far advanced. On initial review we have that

- SLI within ACCESS maybe possible – however additional conditions are need to ensure that the correction terms are not evaluated with SLI. This involves ensuring the sensitivity terms (ssnow%dfn_dtg etc.) are initialised to zero (good coding practice anyway) and/or cable_cbm explicitly precludes calculation of the correction terms (canopy%fes_cor etc.)
- Further consideration is needed around SLI's sub-time stepping (if used within ACCESS). Can the algorithm be adapted to prevent overly small sub time steps, hence intense CPU usage and, more problematically, scheduling issues?
- There is a bug on line 1207 of cable_soilsnow_gw – the factor %cls isn't necessary

Once a near finalised code merge is settled it would be sensible to test within ACCESS prior to further effort. This is to ascertain whether there are technical issues (with soilsnow_gw or the Ord parameterisation) for example necessary ancillary information or passing new variables in/out of the UM, through the cable_data module. Once technically implemented any additional changes to SLI/GW/Ord should be minor and not require consideration of the CABLE-UM interface.

Staged implementation: Part 2

The majority of the REV_CORR package (including the entirety of the cls package and other bug fixes) can be directly merged with the SLI/Dekker branch. This includes changes

- cable_cbm
- cable_common
- cable_definetypes (though some of the new variables introduced are not strictly needed so could be commented out)
- cable_iovars
- cable_output
- cable_checks
- cable_radiation* (a separate albedo bug)
- the cable_mpi routines
- cable_soilsnow

A formal difference check/compare is of course necessary. With the assumption that the developers are in agreement in the science – corresponding changes made in soilsnow should be transferred into soilsnow_gw.

The primary difficulty to be faced concerns the merge of cable_canopy. The science behind the REV_CORR changes applies equally to the GW and Ord schemes but the implementation will need to be different. Issues to be faced are:

- the use (or not) of the REV_CORR screen level calculation subroutine (and an extension to the GW and Ord parameterisations)
- the blending of the REV_CORR rhlitt and relitt constructs with the GW/Ord implementation of the Haverd litter resistance and the unsaturated and saturated resistance for water exchange.
- merging of the updates to the within_canopy subroutine
- the extension of the revised sensitivity term formulation to the GW and Ord schemes, including the saturated and unsaturated pathways (applies to both soilsnow_gw and SLI).
- Application of REV_CORR, GW and Ord to sites with a low leaf area density.

For more detail on the last point see the extended notes towards the end. Note that new variables are needed with REV_CORR however these are all internal variables to CABLE that are initialised at each time step (i.e. do not need to be carried through STASH unless needed in output).

Once successfully merged it is recommended that there be a staged testing – single site, global offline – with and without REV_CORR applied. Decisions are needed around which changes are obligatory and which should go in (even if temporarily) on switches. Technical implementation/testing in ACCESS can only go ahead if successful to this point. However, assuming that the implementation of the new variables carries simply into ACCESS, then there are no new ancillary files or STASH variables needed with REV_CORR.

It should be noted that SLI also makes use of sensitivity terms similar to those in soilsnow - as part of the algorithm to time step the soil temperature and soil energy balance. However the changes applied within soilsnow and soilsnow_gw energy balance have not been replicated within SLI.

There are other potential bug fixes in the CABLE ticketing system that could be incorporated into CABLE as part of the testing at this stage (or after part 3)

The codeset to incorporate these changes is provided at /branches/Users/inh599/CMIP6-GM2

Staged implementation: Part 3

The SSEB package proposes a number of changes to the sequencing of the energy balance/soil state evolution calculations. There were three primary motivations for this package

- to apply the soil moisture correction term on the same time step as the soil evaporation correction term
- to enforce physical limits on the corrected soil evaporation (as well as the uncorrected soil evaporation).
- to correct the Penman-Monteith implementation for soil evaporation for snow covered surfaces

The latter two points require changes to the ordering/structure of the cable_canopy and cable_soilsnow code, as well as new code[1]. Consequently SSEB cannot be merged directly with the existing GW and Ord schemes as the necessary equations and code restructure/manipulations are needed.

However, (and this should be explored further), it is likely possible that the approach used to apply the soil moisture correction term on the correct time step can be similarly adopted within soilsnow_gw as it has been within soilsnow, i.e. the concept is carried over if not the code. (The issue is not relevant to SLI given the structural differences in how that soil scheme operates). This change moves the evaluation of the correction terms within soilsnow and cbm earlier in the soilsnow code and then applies this as extra forcing to the soil moisture dynamics. Only these two modules are impacted. Care is required when dealing with moisture limitations and/or snow cover. This will require further discussion between the code developers to determine the details of any implementation.

A similar process of staged testing to part 2 would be needed.

If the full scope of SSEB can be implemented (not proposed at this time) new variables would be needed. These are all internal variables to CABLE that are initialised at each time step (i.e. do not need to be carried through STASH unless needed in output). There are no new ancillary files or STASH variables needed with SSEB (in fact some can be removed).

The remaining two objectives would be left to a later date – based from the new trunk. There is a wider need to consolidate/reorganise the roughness and canopy modules.

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[1] The Penman-Monteith can be, in practice, approximately corrected without the need for the SSEB restructure. However that solution imposes numerical noise within the zetar iteration loop – and is therefore not recommended.

Background to the REV_CORR package and its extension to the GW and Ord models

The REV_CORR package applies two science changes to CABLE (canopy and soilsnow) alongside a number of bug fixes. Firstly, the suite of correction terms to the energy balance is extended to include the net radiation and ground heat flux. This is potentially important as, while the ground heat flux has no impact elsewhere in ACCESS, the net radiation is a direct term within the radiation balance of the atmosphere – i.e. there is a potential feedback within ACCESS that is currently missing.

Secondly, the functional form of the sensitivity terms, and hence correction terms, for the soil sensible and latent fluxes are modified. Currently the flux (e.g. of moisture, E_s) passed to the atmosphere is given by

$$E_s = E_{s0} + \Delta T_s \frac{\mathrm{d}E_{s0}}{\mathrm{d}T_s}$$

where the subscript 0 indicates values at the start of the time step and ΔT_s is the change in soil surface layer temperature over the time step. The second contribution is the 'correction' term and the derivative the sensitivity term. The functional form for E_s (with either the humidity deficit or Penman-Monteith forms) can be written

$$E_s = \gamma \frac{\Delta q}{r_{soil}} = \gamma \frac{[q_s(T_s) - q_a]}{r_{soil}}$$

where γ/r_{soil} includes a set of coefficients (air density, soil wetness, %cls factor), q_s is the water vapour mixing ratio at saturation and temperature T_s, and q_a is the water vapour mixing ratio within the canopy air. The current implementation within CABLE quantifies the sensitivity term as

$$\frac{\mathrm{d}E_{s0}}{\mathrm{d}T_s} = \frac{\mathrm{d}E_{s0}}{\mathrm{d}\Delta q}\frac{\mathrm{d}\Delta q}{\mathrm{d}T_s} = \frac{\mathrm{d}E_{s0}}{\mathrm{d}\Delta q}\frac{\mathrm{d}q_s}{\mathrm{d}T_s}$$

While the numerical detail of the time stepping scheme in SLI is different to that in soilsnow similar sensitivity terms are utilised within SLI. As shown next these should also be revised for compatibility.

However this is strictly incorrect as q_a is not an independent variable and responds to the value of E_s (among other things). More correctly we have that

$$\frac{\mathrm{d}E_{s0}}{\mathrm{d}T_s} = \frac{\partial E_{s0}}{\partial q_s}\frac{\mathrm{d}q_s}{\mathrm{d}T_s} - \frac{\partial E_{s0}}{\partial q_a}\frac{\partial q_a}{\partial T_s}$$

To quantify the second term in the above requires knowledge of the full model for moisture exchange between the soil-vegetation and atmosphere.

In the current CABLE model we have that

$$\frac{q_a - q_{ref}}{r_a} = E_T = E_s + T = \gamma \frac{[q_s(T_s) - q_a]}{r_{soil}} + T$$

where T is the transpiration flux and q_{ref} the independent, reference level water vapour mixing ratio. If we assume that T is independent of T_s then a closed revised form for $\mathrm{d}E_{s0}/\mathrm{d}T_s$ emerges as a function of known resistances etc. This is the functional form applied by REV_CORR for both sensible and latent heat. Care is taken to correctly account for when the canopy leaf density is small enough that there is no distinction between q_a and q_{ref}.

The ground water and Ord parameterisations of soil evaporation alter the functional form of E_s and consequently the same calculations need to be followed through. A generalised model for all parameterisation schemes is

$$\frac{q_a - q_{ref}}{r_a} = E_T = E_s + T = \nu_1 E_{s1} + \nu_2 E_{s2} + T = \nu_1 \frac{r_h q_s(T_s) - q_a}{r_1 + r_3} + \nu_2 \frac{q_s(T_s) - q_a}{r_2 + r_3} + T$$

where r_1, r_2 and r_3 are generalised resistances (which can comprise γ, the conventional soil resistance, the litter resistance and the Ord saturated/unsaturated resistances), r_h is the ground water parameterisation surface relative humidity variable and ν_1, ν_2 are the fractional areas where the flux is controlled by one form over the other.

Rewriting gives

$$\frac{q_a}{\alpha} = \frac{q_a}{r_a} + \nu_1 \frac{q_a}{r_1 + r_3} + \nu_2 \frac{q_a}{r_2 + r_3} = \frac{q_{ref}}{r_a} + \nu_1 \frac{r_h q_s}{r_1 + r_3} + \nu_2 \frac{q_s}{r_2 + r_3} + T = \beta_1 + \beta_2 q_s$$

Now

$$\frac{\mathrm{d}E_s}{\mathrm{d}T_s} = \frac{\nu_1}{r_1 + r_3}\left(r_h \frac{\mathrm{d}q_s}{\mathrm{d}T_s} - \frac{\mathrm{d}q_a}{\mathrm{d}T_s}\right) + \frac{\nu_2}{r_2 + r_3}\left(\frac{\mathrm{d}q_s}{\mathrm{d}T_s} - \frac{\mathrm{d}q_a}{\mathrm{d}T_s}\right); \quad \frac{\mathrm{d}q_a}{\mathrm{d}T_s} = \alpha\beta_2 \frac{\mathrm{d}q_s}{\mathrm{d}T_s}$$

i.e.

$$\frac{\mathrm{d}E_s}{\mathrm{d}T_s} = \left[\frac{\nu_1}{r_1 + r_3}(r_h - \alpha\beta_2) + \frac{\nu_2}{r_2 + r_3}(1 - \alpha\beta_2)\right]\frac{\mathrm{d}q_s}{\mathrm{d}T_s}$$

where

$$\frac{1}{\alpha} = \frac{1}{r_a} + \frac{\nu_1}{r_1 + r_3} + \frac{\nu_2}{r_2 + r_3}; \quad \beta_2 = \frac{r_h \nu_1}{r_1 + r_3} + \frac{\nu_2}{r_2 + r_3}$$

For the current CABLE model $\nu_1 = 0$, $\nu_2 = 1$ and we retrieve (as implemented in REV_CORR)

$$\frac{\mathrm{d}E_s}{\mathrm{d}T_s} = \left[\frac{1}{r_2 + r_3}(1 - \alpha\beta_2)\right]\frac{\mathrm{d}q_s}{\mathrm{d}T_s} = \frac{1}{r_2 + r_3 + r_a}\frac{\mathrm{d}q_s}{\mathrm{d}T_s}$$

(In contrast the current sensitivity term does not include the r_a term). There is a question as to whether the quantitative impact of these changes (r_a is typically much smaller than the soil-atmosphere resistance) justifies the additional computationally expense – especially given the somewhat crude assumption regarding the invariance, to changes in T_s, of the transpiration flux. Also, the question of whether to implement the general model, or for each parameterisation scheme separately, should be considered.

For the GW scheme $\nu_1 = 1$, $\nu_2 = 0$ and we retrieve

$$\frac{\mathrm{d}E_s}{\mathrm{d}T_s} = \left[\frac{1}{r_1 + r_3}(r_h - \alpha\beta_2)\right]\frac{\mathrm{d}q_s}{\mathrm{d}T_s} = \frac{r_h}{r_1 + r_3 + r_a}\frac{\mathrm{d}q_s}{\mathrm{d}T_s}$$

The Ord scheme involves all terms in the generalised model.

The formulation of the sensible heat flux requires similar attention with the GW and Ord schemes, in both soilsnow and SLI.