Bug fix in the evaluation of screen level diagnostics for tall canopies: (Ticket 154)

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Within CABLE the screen level temperature and humidity are purely diagnostic variables – bounded by the values taken at the (prognostic) soil, forcing air and vegetation. The evaluation of the screen level variables involves separate numerical algorithms to the rest of CABLE – although these are scientifically consistent.

The basis of the calculations is that

$$\frac{T_{sc} - T_{air}}{T_s - T_{air}} = \frac{r_x(z_0, z_{sc})}{r_x(z_0, z_{ref})} \tag{1}$$

where $r_x(z_1, z_2)$ represents the resistance between heights z_1 & z_2, z_{sc} is the screen level height, z_{ref} is the reference level and z_0 is the roughness length of the soil surface. Eq (1) is a resistance weighted interpolation between the soil and reference-level temperatures. The functional form of r_x depends on the vegetation characteristics, specifically where z_{sc} sits with respect to *d*, the displacement height. In the case of tall canopies, $z_{sc} \leq d$, the current calculations appear to tie the screen level values extremely closely to the soil temperature, i.e. $r_x(z_0, z_{sc}) \approx r_x(z_0, z_{ref})$. Simple order of magnitude estimates (assuming log-law like turbulence) suggest however that the ratio should take a value between 0.5-0.8.

This mismatch originates from an approximation (and subsequent) error in determining the resistance between the screen level and reference height. For tall canopies the screen level temperature is evaluated from

$$\frac{T_{sc} - T_{air}}{T_s - T_{air}} = \frac{r_x(z_0, z_{sc})}{r_x(z_0, z_{ref})} = \frac{r_x(z_0, z_{sc})}{r_x(z_0, d) + r_x(d, z_{ref})}$$

where $r_x(z_0, d)$ and $r_x(d, z_{ref})$ take values as used within CABLE's energy balance calculations. $r_x(z_0, z_{sc})$ is evaluated using the same functional form as $r_x(z_0, d)$. However $r_x(z_0, d)$ is evaluated via an approximation to an integral and the same approximation can be invalid for $r_x(z_0, z_{sc})$.

In more detail, analytically (CABLE documentation, Eq 14 and 17) $r_x(z_0, d)$ is proportional to

$$r_x(z_0, d) \propto \int_{z_0}^{d} \frac{d}{h_c z \exp\{a(z/h - 1)\}}\, \mathrm{d}z \approx \ln\left(\frac{d}{z_0}\right) \frac{\exp\{a\}}{a} \left[1 - \exp\left\{-a \frac{d}{h_c}\right\}\right]$$

(Terms of $\exp\{-a\, z_0/h_c\}$ are neglected and coefficient *a* depends on other canopy parameters)

The current evaluation of $r_x(z_0, z_{sc})$ is

$$r_x(z_0, z_{sc}) \propto \ln\left(\frac{z_{sc}}{z_0}\right) \frac{\exp\{a\}}{a} \left[1 - \exp\left\{-a \frac{z_{sc}}{h_c}\right\}\right]$$

ie. z_{sc} replaces *d* throughout. However a better approximation is given via

$$r_x(z_0, z_{sc}) \propto \int_{z_0}^{d} \frac{d}{h_c z \exp\{a(z/h - 1)\}}\, \mathrm{d}z - \int_{z_{sc}}^{d} \frac{d}{h_c z \exp\{a(z/h - 1)\}}\, \mathrm{d}z$$

and hence (replacing z_0 by z_{sc} in the 2nd integral)

$$r_x(z_0, z_{sc}) \propto \ln\left(\frac{d}{z_0}\right)\frac{\exp\{a\}}{a}\left[1-\exp\left\{-a\frac{d}{h_c}\right\}\right] - \ln\left(\frac{d}{z_{sc}}\right)\frac{\exp\{a\}}{a}\left[\exp\left\{-a\frac{z_{sc}}{h_c}\right\} - \exp\left\{-a\frac{d}{h_c}\right\}\right]$$

i.e.

$$r_x(z_0, z_{sc}) \propto \ln\left(\frac{z_{sc}}{z_0}\right)\frac{\exp\{a\}}{a}\left[1-\exp\left\{-a\frac{d}{h_c}\right\}\right] + \ln\left(\frac{d}{z_{sc}}\right)\frac{\exp\{a\}}{a}\left[1-\exp\left\{-a\frac{z_{sc}}{h_c}\right\}\right] \quad (2)$$

Implementation (see below) is the simple matter of adjusting the evaluation of variable r_sc to that given by Eq (2) if $z_{sc} \leq d$. The screen level temperature and humidity follow automatically.

The screen level variable evaluation is currently entirely independent of the canopy leaf conditions. This is unphysical. A simple "fix" for this issue has been derived however as this requires would require more substantial modifications to the screen level diagnostics calculations and extensive testing this development has been deferred.

Code changes

In the screen level diagnostics sections (in the main define_canopy subroutine and the new screen_level_SSEB subroutine with the REV_CORR and SSEB pacakges) we have that

```
IF ( rough%disp(j)  > 0.0 ) then
        term1(j) = EXP(2*C%CSW*canopy%rghlai(j)*(1-zscl(j)/rough%hruff(j)))
        term2(j) = EXP(2*C%CSW*canopy%rghlai(j) *                    &
           (1-rough%disp(j)/rough%hruff(j)))
        term5(j) = MAX(2./3.*rough%hruff(j)/rough%disp(j), 1.)
ENDIF
```

and then

```
IF( zscl(j) < rough%disp(j) ) THEN
      r_sc(j) = term5(j) * LOG(zscl(j)/rough%z0soilsn(j)) *           &
           ( EXP(2*C%CSW*canopy%rghlai(j)) - term1(j) ) / term3(j)
```

These second sets of code need to be replaced by

```
IF( zscl(j) < rough%disp(j) ) THEN
      r_sc(j) = term5(j) * LOG(zscl(j)/rough%z0soilsn(j)) *           &
           ( EXP(2*C%CSW*canopy%rghlai(j)) – term2(j) ) / term3(j)
      r_sc(j) = r_sc(j) + term5(j) * LOG(rough%disp(j) /rough%z0soilsn(j) * &
           ( EXP(2*C%CSW*canopy%rghlai(j)) – term1(j) ) / term3(j)
```