Implementation of various soil respiration functions in CABLE 2.1

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1. Motivations

Recent studies have identified soil heterotrophic respiration (R_h), the outflow of CO2 from soils that is produced by microbial decomposition of soil organic matter, as a critical source of uncertainty in the assessment of the terrestrial carbon balance (Friedlingstein et al., 2006). However, most of the current state-of-the-art terrestrial biogeochemical module that have been implemented in land surface model, and further in Earth system models (ESM), assume a similar first-order parameterisation of microbial decomposition D_m such as

$$D_m = k \times f_W\left(\theta_s\right) \times f_T\left(T_s\right) \times C_s \tag{1}$$

with with k the reference decay rate that reflects the baseline residence time (Xia et al., 2013). It is scaled by f_T, a function of soil temperature T_s, and by f_W, a function of soil moisture θ_s (usually expressed as a fraction of water saturation; Moyano et al., 2012) and applied to C_s the amount of C in the pool. The product $f_W(\theta_s) \times f_T(T_s)$ is sometimes referred as environmental scalar. Various formulations of f_W (the soil moisture-respiration function, or SMRF) and f_T (the soil temperature-respiration function, or STRF) are used in last generation land models. Although models vary in their network of inter-connected soil carbon pools, R_h is proportional to D_m at the ecosystem scale.

The uncertainty related to choosing a specific combination of a SMRF and a STRF has been recently addressed (e.g. Falloon et al., 2011). Lately, we have performed sensitivity analyses with the CABLE / CASA-CNP model (Exbrayat et al., 2013b). Therefore, we implemented 3 SMRFs and 3 STRFs in the source code by modifying the subroutine casa_xratesoil in the casa_cnp.f90 source file (see Fig 1 and Tables 1 and 2).
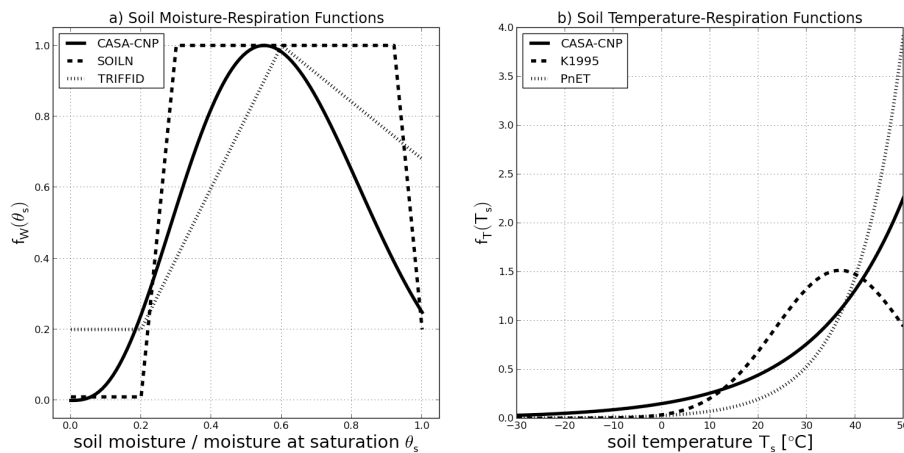

Figure 1. Various f_T and f_W available in the CASA-CNP model code.

These represent a subset of functions that exhibit the main features of variability observed in a larger range of functions (Exbrayat et al., 2013a). We propose to add these different formulations in the official CABLE version in order to ease the setup of further sensitivity analyses in that space. Detailed of equations are included in Tables 1 and 2 in the Appendix.

2. Implementation

First, one must activate the use of these customised functions by setting the following option to true:

cable_user%SRF=.TRUE.

Then, the choice of a soil moisture-respiration function (SMRF) is implemented as a namelist option. The value indicating which SMRF to use are:

casafile%smrf_name = 'CASACNP'
or
casafile%smrf_name = 'SOILN'
or
casafile%smrf_name = 'TRIFFID'

Similarly, the choice of a soil temperature-respiration functions (STRF) is implemented as another namelist option:

casafile%strf_name = 'CASACNP'
or
casafile%strf_name = 'K1995'
or
casafile%strf_name = 'PnET'

This allows user to run CASA-CNP with 9 different formulations of soil physical state controls on decomposition, and hence R_h. Implementing namelist options in this way should also make it trivial for other researchers to implement other formulations if desired. We provide hereafter some global results obtained with these different combinations with the CSIRO Mk3L / CABLE / CASA-CNP coupled system run with prescribed SSTs and nitrogen limitations on NPP.

3. Results

Figure 2 below shows the average R_h for the year 1986. Results for each 9 combinations of a SMRF with a STRF are plotted for runs that use the same restart file in CNP mode (icycle = 3). SMRFs are ordered in rows, and STRFs are ordered in columns. We see for example that the K1995 penalises Rh a lot at high latitudes. Differences appear tiny because we use the same initial pool sizes that also drive the amount of R_h (equation 1). Further, we only integrate the model over one year.
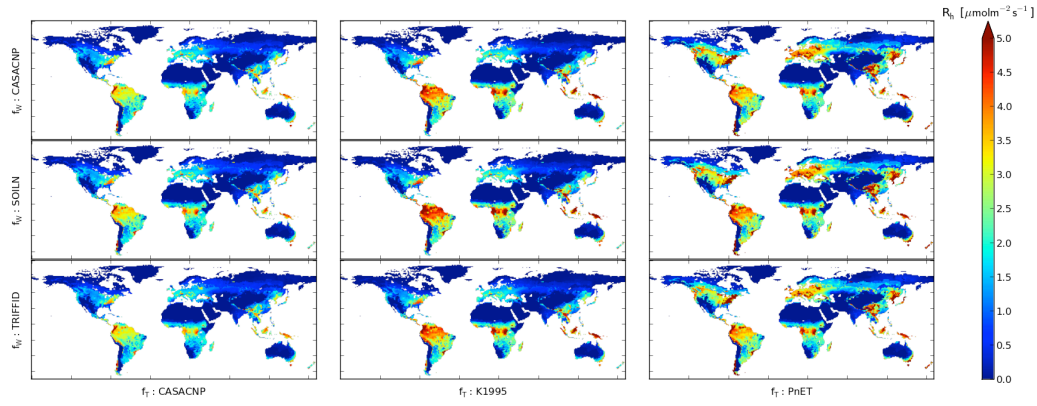
Figure 2. Annual mean R_h flux simulated in 1986 by 9 combinations of a SMRF with a STRF under GSWP forcing, using the same initial conditions.

If we use the same functions over a longer time period (e.g. during model spin-up), we expect these to have a bigger impact on variations in soil carbon pools. We did so in a previous published study (Exbrayat et al., 2013b). Figure 3 below shows pre-industrial steady state soil carbon density achieved after spin-up using each combination of a SMRF (rows) and a STRF (columns). We see that the STRF has a large influence on the latitudinal distribution of soil carbon, while differences introduced by SMRF are more localised to dry or wet regions. Overall, an about five-fold range in equilibrium total soil carbon is generated from these regional differences.
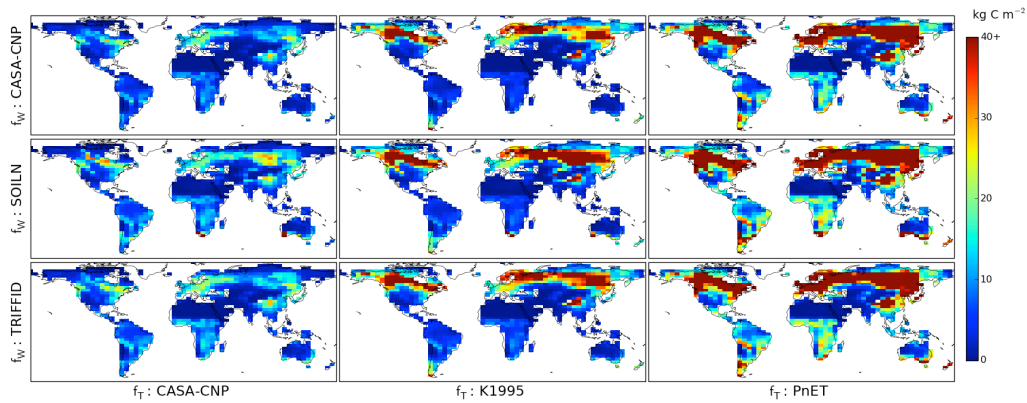

Figure 3. Soil C density at equilibration in 1850 in CN simulations. Each sub-panel corresponds to a single combination of response functions as indicated.

We also perform transient historical simulations using CMIP5 input data of atmospheric CO_2 concentrations. Results in Figure 4 show that functions also introduce large differences in regional soil carbon balance, and net ecosystem accumulation (NEA). Regional differences lead to a global two-fold difference in historical NEA that however falls within the uncertainty of previous estimates (e.g. Canadell et al., 2007).
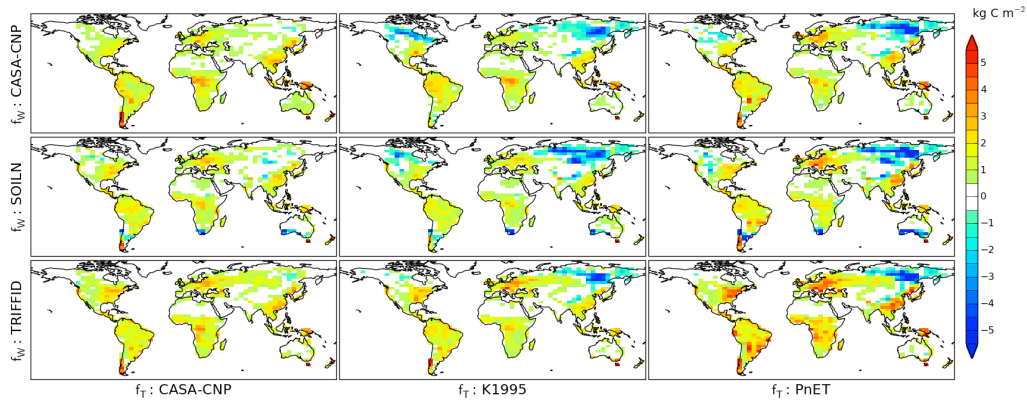
Figure 4. Cumulative NEA (< 0: source, > 0: sink) during historical simulations as represented by the difference in the average land carbon between 1996 - 2005 and 1850 - 1859. Each sub-panel corresponds to a single combination of response functions as indicated.

4. Conclusion

We implemented several formulations of the microbial sensitivity to soil physical states. Results hint that the control of the environmental scalar on both soil equilibrium conditions and its dynamic response to climate change requires more attention.

Results presented here have been published in the open access journal *Biogeosciences* (Exbraya et al., 2013b) and readers should refer to it for more details on the scientific findings.

Appendix

Table 1. Formulations of f_W implemented in the CASA-CNP model (θ_s: soil moisture, θ_{wilt}: moisture at wilting point, θ_{fc}: moisture at field capacity, θ_{opt}: optimum moisture, θ_{lopt}: lower optimal moisture, all expressed relative to moisture at saturation).

Function	Equation
CASA-CNP	$$f_W(\theta_s) = \left(\frac{\theta_s - 1.70}{0.55 - 1.70}\right)^{6.6481} \times \left(\frac{\theta_s + 0.007}{0.55 + 0.007}\right)^{3.22}$$
SOILN	$\theta_{opt} = 0.92$ $\theta_{lopt} = \theta_{wilt} + 0.1$ if $\theta_s > \theta_{opt}$ $\qquad$ $f_W(\theta_s) = 0.2 + 0.8 \cdot \dfrac{(1 - \theta_s)}{(1 - \theta_{opt})}$ if $\theta_{lopt} \leq \theta_s \leq \theta_{opt}$ $f_W(\theta_s) = 1$

if $\theta_{wilt} \leq \theta_s \leq \theta_{lopt}$ $f_W(\theta_s) = \dfrac{\theta_s - \theta_{wilt}}{\theta_{lopt} - \theta_{wilt}}$

if $\theta_s < \theta_{wilt}$ $f_W(\theta_s) = 0$

TRIFFID $\theta_{opt} = 0.5 \cdot (1 + \theta_{wilt})$

if $\theta_s > \theta_{opt}$ $f_W(\theta_s) = 1 - 0.8 \cdot (\theta_s - \theta_{opt})$

if $\theta_{wilt} \leq \theta_s \leq \theta_{opt}$ $f_W(\theta_s) = 0.2 + 0.8 \cdot \dfrac{(\theta_s - \theta_{wilt})}{(\theta_{opt} - \theta_{wilt})}$

if $\theta_s < \theta_{wilt}$ $f_W(\theta_s) = 0.2$

Table 2. Formulations of f_T implemented in the CASA-CNP model (T_s: soil temperature in C).

Function	Equation
CASA-CNP	$f_T(T_s) = 1.72^{(0.1 \cdot (T_s - 35))}$
K1995[1]	$f_T(T_s) = \exp\left(-3.764 + 0.204 \cdot T_s \cdot \left(1 - \dfrac{0.5 \cdot T_s}{36.9}\right)\right) \times 0.66^{-1}$
PnET[1]	$f_T(T_s) = 0.68 \cdot \exp(0.1 \cdot (T_s - 7.1)) \times 12.64^{-1}$

[1]Last terms in the equations are used to scale the original functions to the CASA-CNP model as explained by Exbrayat et al. (2013a)

5. References

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