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*Supplement of*

# Ecosystem carbon transit versus turnover times in response to climate warming and rising atmospheric $CO_2$ concentration

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## Supplement A: Decomposition of the change in ecosystem C transit time

Mean C transit time ($\bar{\tau}_R$) can be expressed as the flux weighted mean age of respired C:

$$\bar{\tau}_R(t) = \sum_{i=1}^{d} a_i\,(t) f_{\mathrm{hr},i}(t) \qquad \text{(S1)}$$

where $a_i$ is C mean age of the $i^{th}$ compartment and the $f_{\mathrm{hr},i}$ is the fraction of respired C from $i^{th}$ compartment.

We define the change of a variable ($\Delta F$) is the difference between the variable at $t$ and the variable at $t_0$:

$$\Delta F(t) = F(t) - F(t_0) \qquad \text{(S2)}$$

The change of mean C transit time can be expressed as:

$$\Delta\bar{\tau}_R(t) = \sum_{i=1}^{d} \Delta\left(a_i(t) f_{\mathrm{hr},i}(t)\right)$$

$$= \sum_{i=1}^{d} \left(a_i(t) f_{\mathrm{hr},i}(t)\right) - \left(a_i(t_0) f_{\mathrm{hr},i}(t_0)\right) \qquad \text{(S3)}$$

For the $i^{\mathrm{th}}$ compartment, the compartment C mean age, $a_i(t)$, and fraction of respired C from this compartment, $f_{\mathrm{hr},i}$, equals to the initial value add the change:

$$a_i(t) = a_i(t_0) + \Delta a_i(t) \qquad \text{(S4)}$$

$$f_{hr,i}(t) = f_{hr,i}(t_0) + \Delta f_{hr,i}(t) \qquad \text{(S5)}$$

Combining equation (S3), (S4), and (S5), the change of mean C transit time is:

$$\Delta\bar{\tau}_R(t) = \sum_{i=1}^{d} \left(\left(a_i(t_0) + \Delta a_i(t)\right)(f_{\mathrm{hr},i}(t_0) + \Delta f_{hr,i}(t))\right) - \left(a_i(t_0) f_{\mathrm{hr},i}(t_0)\right)$$

$$= \sum_{i=1}^{d} a_i(t_0)\Delta f_{hr,i}(t) + \sum_{i=1}^{d} \Delta a_i(t) f_{\mathrm{hr},i}(t_0) + \sum_{i=1}^{d} \Delta a_i(t)\Delta f_{hr,i}(t) \qquad \text{(S6)}$$

When $\Delta a_i(t) \ll a_i(t_0)$ and $\Delta f_{hr,i}(t) \ll f_{hr,i}(t_0)$, the last term $\Delta a_i(t)\Delta f_{hr,i}(t)$, residual, is much smaller in magnitude than first two terms (See Figure 3). $\sum_{i=1}^{d} a_i(t_0)\Delta f_{hr,i}(t)$ and $\sum_{i=1}^{d} \Delta a_i(t) f_{\mathrm{hr},i}(t_0)$ respectively represent change in C transit time due to change in composition of respired C and compartment C age structure.

**Supplement B: Meteorological forcing for CABLE**

CABLE uses the meteorological data sets from National Centers for Environmental Prediction and Climatic Research Unit – (CRU-NCEP) to drive our model in historical period. The meteorological inputs from 1901 to 2100 include temperature, specific humidity, air pressure, downward solar radiation, downward long-wave radiation, rainfall, snowfall, and wind speed. The meteorological variables of CRU-NCEP data from 1901 to 2005 are interpolated from the 6-hourly into hourly (Qian et al., 2006) and re-gridded from $0.5^o$ by $0.5^o$ to $1.875^o$ by $2.5^o$ spatial resolution. From 2006 to 2100, the hourly meteorological variables are generated from Community Earth System Model version 1.0 (CESM) (Li et al., 2016; Hurrell et al., 2013) for Representative Concentration Pathway (RCP) 8.5. All variables from 2006 to 2100 except for wind were adjusted to smooth the transitions in 2006 based on the statistics in historical CRU-NCEP data. (See Figure B1)

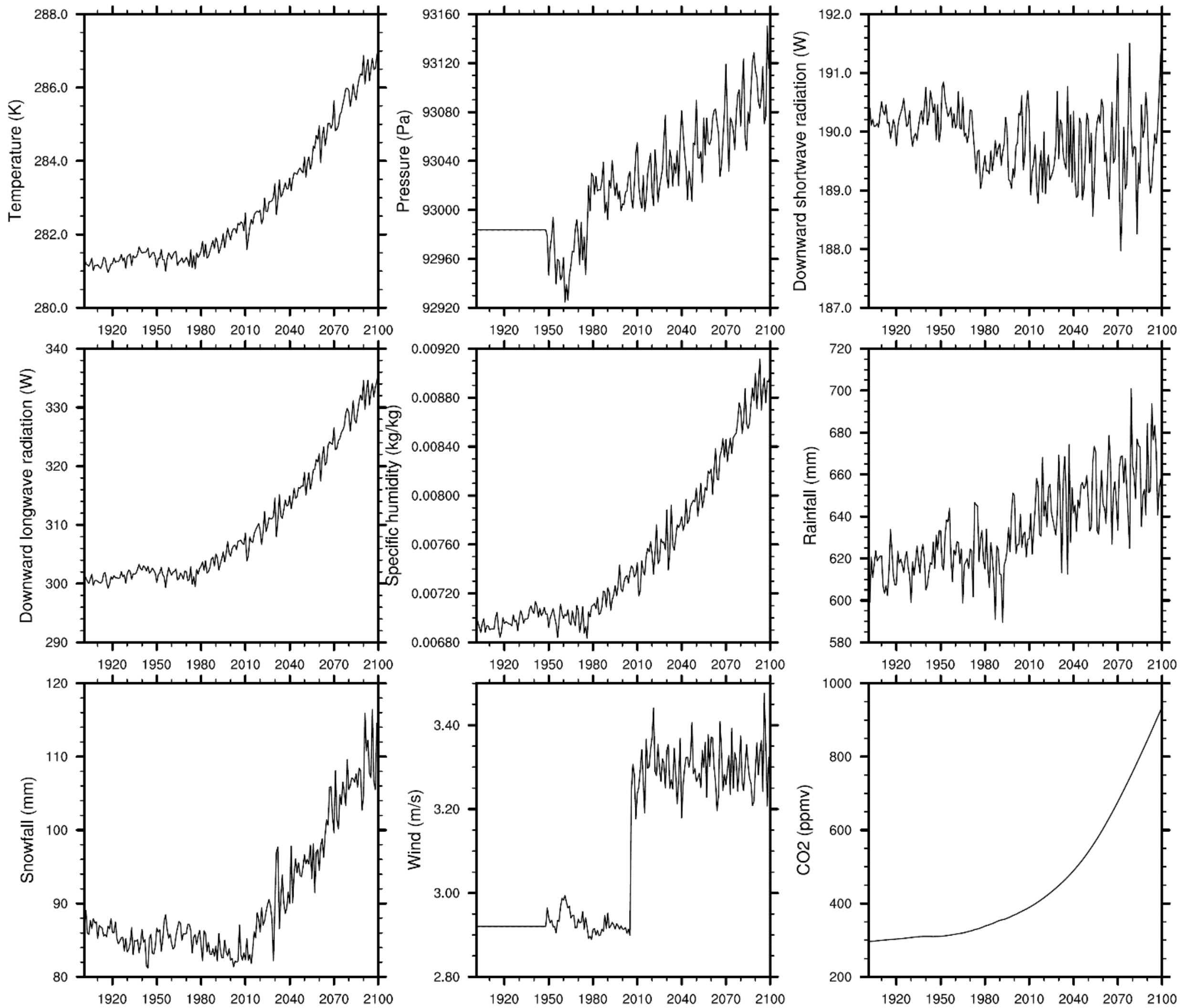


Figure B1. Meteorological forcing and CO2 concentration data used by CABLE from 1901 to 2100. All variables are the annual averaged over global land areas.

## Supplement C: C cycle equations in CABLE

CABLE C cycle model is a linear box model, which includes 3 vegetation C pools: leaf ($C_{leaf}$), wood ($C_{wood}$) and root ($C_{root}$), 3 litter C pools: metabolic litter ($C_{met}$), structural litter ($C_{str}$), and coarse woody debris ($C_{CWD}$), and 3 soil C pools: fast soil ($C_{fast}$), slow soil ($C_{slow}$), and passive soil ($C_{pass}$) (Figure C1). Vegetation C cycle is related to physiology and phenology processes, whereas litter and soil C cycle is related to litter and soil decomposition processes.

### C1. CABLE vegetation C cycle

Physiology in CABLE include photosynthesis, respiration and allocation processes. The net C input to each pools is allocated from net primary productivity (NPP):

$$NPP = GPP - R_a \tag{C1}$$

GPP is calculated at canopy level from a stomata processes coupled photosynthesis model. Like most other land models, photosynthesis model is based on Farquhar photosynthesis model [*Farquhar et al.*, 1980]. Autotrophic respiration ($R_a$) are estimated from growth respiration $R_g$ and maintenance respiration of leaf ($R_{aleaf}$), wood ($R_{awood}$) and root ($R_{aroot}$) respectively:

$$R_a = R_g + R_{aleaf} + R_{awood} + R_{aroot} \tag{C2}$$

The CABLE C cycle dynamic equations in vegetation pools are:

$$\frac{dC_{leaf}(t)}{dt} = NPP(t)B_{leaf}(t) - K_{leaf}(t)C_{leaf}(t) \tag{C3}$$

$$\frac{dC_{wood}(t)}{dt} = NPP(t)B_{wood}(t) - K_{wood}(t)C_{wood}(t) \tag{C4}$$

$$\frac{dC_{root}(t)}{dt} = NPP(t)B_{root}(t) - K_{root}(t)C_{root}(t) \tag{C5}$$

The allocation fraction $B_i$ to each pool ($i$ refers to leaf, root and wood) changes according to the phenology status, eg. When deciduous plant is in onset status, 80% NPP will be allocated to leaf. When deciduous plant is in offset status, 0% NPP will be allocated to leaf. There is no allometry parameterization in CABLE C allocation processes. The vegetation turnover rate $K_i$ of each pool ($i$ refers to leaf, root and wood) are constant in most of the time, except for being stressed by drought or heat.

Leaf area index (LAI) in CABLE is derived based on leaf C pool size ($C_{leaf}$). LAI is bounded by two specified maximum and minimum values. When LAI exceeds the maximum value, allocation fraction to leaf ($B_{leaf}$) will become 0. When LAI drops below the minimum value, turnover rate of leaf ($K_{leaf}$) will be also set to 0.

In all, in most of the time, these turnover rates and C inputs are mainly dependent on environmental conditions and independent on C pool sizes. Thus, eqn (C3) is considered as linear equations in this study.

**C2. CABLE litter and soil C cycle**

CABLE litter and soil C cycle is also a linear model representing C decay and network transfers. Dynamics equations in litter and soil are:

$$\frac{dC_{met}(t)}{dt} = F_{l\_me}(t) + F_{r\_me}(t) - (A_{me\_fa} + \left(1 - A_{me\_fa}\right))K_{me}(t)C_{met}(t) \tag{C6}$$

$$\frac{dC_{str}(t)}{dt} = F_{l\_st}(t) + F_{r\_st}(t) - (A_{st\_fa} + A_{st\_sl} + \left(1 - A_{st\_fa} - A_{st\_sl}\right))K_{st}(t)C_{st}r(t) \tag{C7}$$

$$\frac{dC_{cwd}(t)}{dt} = F_{w\_cw}(t) - (A_{cw\_fa} + A_{cw\_sl} + \left(1 - A_{cw\_fa} - A_{cw\_sl}\right))K_{cw}(t)C_{cwd}(t) \tag{C8}$$

$$\frac{dC_{fast}(t)}{dt} = F_{me\_fa}(t) + F_{st\_fa}(t) + F_{cw\_fa} - (A_{fa\_sl} + A_{fa\_pa} + \left(1 - A_{fa\_sl} - A_{fa\_pa}\right))K_{fa}(t)C_{fast}(t) \tag{C9}$$

$$\frac{dC_{slow}(t)}{dt} = F_{st\_sl}(t) + F_{cw\_sl}(t) + F_{fa\_sl} - (A_{sl\_pa} + \left(1 - A_{sl\_pa}\right))K_{sl}(t)C_{slow}(t) \tag{C10}$$

$$\frac{dC_{pass}(t)}{dt} = F_{fa\_pa}(t) + F_{sl\_pa}(t) - K_{pa}(t)C_{pass}(t) \tag{C11}$$

where $A_{i\_j}$ represents the proportion of decomposed C transferred from $i^{th}$ pool to $j^{th}$ pool, $F_{i\_j}$ is the amount of decomposed C transferring from $i^{th}$ pool to $j^{th}$ pool, $K_i$ is the turnover rate of the $i^{th}$ pool. The subscript *l*, *w*, *r*, *me*, *st*, *cw*, *fa*, *sl*, and *pa* respectively represent leaf, wood, root, metabolic litter, structural litter, coarse wood debris, fast soil pool, slow soil pool, and passive soil pool. The amount of decomposed C transferring from $i^{th}$ pool to $j^{th}$ pool $F_{i\_j}$ is calculated:

$$F_{l\_me}(t) = A_{l\_me}K_{leaf}(t)C_{leaf}(t) \quad \text{(C12)}$$

$$F_{r\_me}(t) = A_{r\_me}K_{root}(t)C_{root}(t) \quad \text{(C13)}$$

$$F_{l\_st}(t) = A_{l\_st}K_{leaf}(t)C_{leaf}(t) \quad \text{(C14)}$$

$$F_{r\_st}(t) = A_{r\_st}K_{root}(t)C_{root}(t) \quad \text{(C15)}$$

$$F_{w\_cw}(t) = K_{wood}(t)C_{wood}(t) \quad \text{(C16)}$$

$$F_{me\_fa}(t) = A_{me\_fa}K_{me}(t)C_{met}(t) \quad \text{(C17)}$$

$$F_{st\_fa}(t) = A_{st\_fa}K_{st}(t)C_{str}(t) \quad \text{(C18)}$$

$$F_{cw\_fa}(t) = A_{cw\_fa}K_{cw}(t)C_{cwd}(t) \quad \text{(C19)}$$

$$F_{st\_sl}(t) = A_{st\_sl}K_{st}(t)C_{str}(t) \quad \text{(C20)}$$

$$F_{cw\_sl}(t) = A_{cw\_sl}K_{cw}(t)C_{cwd}(t) \quad \text{(C21)}$$

$$F_{fa\_sl}(t) = A_{fa\_sl}K_{fa}(t)C_{fast}(t) \quad \text{(C22)}$$

$$F_{fa\_pa}(t) = A_{fa\_pa}K_{fa}(t)C_{fast}(t) \quad \text{(C23)}$$

$$F_{sl\_pa}(t) = A_{sl\_pa}K_{sl}(t)C_{slow}(t) \quad \text{(C24)}$$

Eqn (C3-24) summarized all equations for CABLE C land cycle model. In addition, Figure C1 shows the network of C transfers from vegetation C uptake to soil C respiration in CABLE.

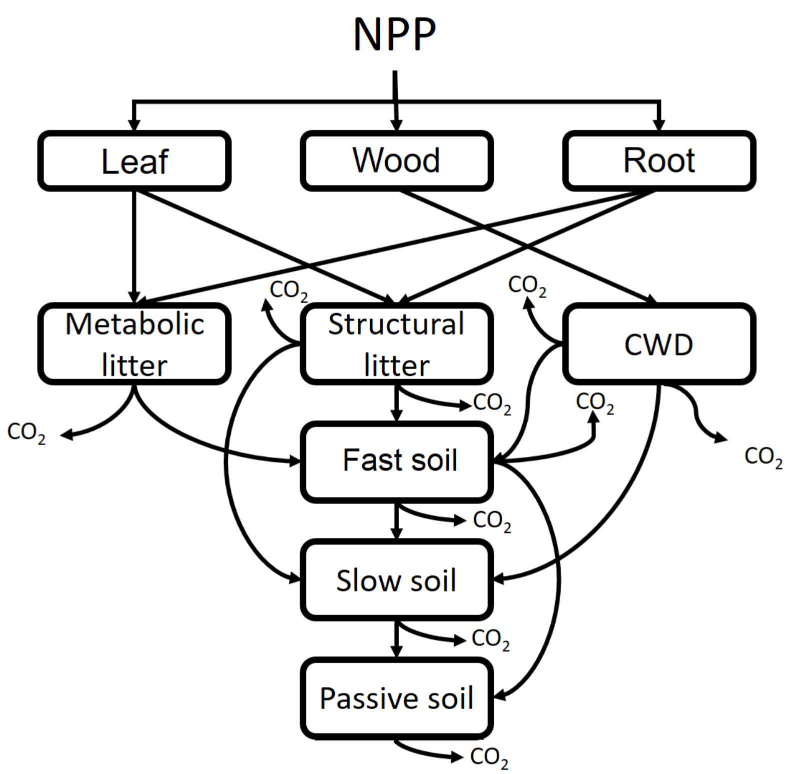


Figure C1 Schematic representation of different pools and flows as represented in CABLE model