Response to Reviewers

We would like to thank reviewers for their thoughtful and constructive review. Our responses to reviewers’ comments (italicized) are presented below.

Response for interactive comments #1:

*Authors introduce many variables in Section 2.2, but most of them are not well illustrated. I feel confused about the difference between k-1/2and k-1 in Eq. 12. If the spin-up is driven by monthly climatology, to my understanding, the Jk matrix should depend on a constant matrix of transfer rate among pools and a matrix of pool size for each time step (k) in a specific year. It is vague and confusing that how to calculate the matrix of mean process rate constants (Line 104) for time step k (J(k-1/2)). Section2.2 is the core of this new method, but authors simply list equations and do not explainhow actually they have used it. Additionally, in line 109, Eq. 12 can’t be written as Eq. 15 when using yk=τf(k-1/2), bu tit is valid by using yk=τf(k-1). Authors should carefully check all the equations before submission.*

Response: In this revision, we clarified the definition of half-step Jacobian matrix and the way to compute it. Process rates depend on temperature and the process rate constants are time dependent, Index k-1/2 is introduced due to solving x(k)-x(k-1)= τ\*(g(k-1/2)\*x(k-1)+h(k-1/2)), which, as reviewer noted, would be commonly written as x(k)-x(k-1)= τ \*(g(k-1)\*x(k-1)+h(k-1)) in a purely explicit scheme. However, it can be shown that using process rates at midpoint (k-1/2) is no less accurate than in purely explicit form with (k-1), which is obvious for h(k-1/2). The term h(k-1/2) simply represents the value at the half-time step for function h. For Section 2.2, we revised it to show how each step is being done and how the next step is related to previous time step.

*Line 115, please spell out LU*

Response: LU (Lower and Upper) decomposition refers to a matrix transformation to a Lower or Upper triangular form.

*In line 111, the cyclic boundary condition of this method is x1=x(T+1). As stated in the manuscript, when spin up is made at the monthly time step, T equals to 12 and x1 is the size of carbon pools in January. That means boundary condition is only applied to January carbon pools. This study mainly uses the Harvard Forest site (even though the authors listed seven sites in Table 1) which PFT is deciduous forests. The fluctuation of carbon pool/flux is the largest during the growing seasons. The method is not designed to reach a steady state for all state and flux variables during other months. As this method aims to derive a cyclic steady state, it is supposed to set a threshold or a boundary condition for each month/day or seasonal cycles, as well as for annual carbon balance (NEP)*

Response: Our model simulations are at a monthly step and we assume that, in a steady state, the pool sizes of x in December of the previous year shall equal the values in January of the next year. This treatment allow us reformulate the eq. 15 to eq. 15a to efficiently obtain solutions for x. In addition, we still used the annual NEP to judge if the model has reached a steady state. In this revision, we revised the text to clearly state that our method is not to reach a monthly steady state for pools and fluxes, rather, we still target a steady state for the system at annual time step, in the end of the Section 2.2.

*Authors only present one table (Table 2) that contains the result of the proposed method, and other figures/tables are results from the original spin-up method. I didn’t get the idea why to do this. In the Introduction (Line 42-43), it says that ‘the model will check the stability of the simulated carbon and nitrogen fluxes as well as state variables with specified threshold values’. I didn’t see much of these in Section 2 and 3.Authors list seven sites to apply the new method, but I only see the results at Harvard Forest site, what about the results at other sites?*

Response: In this revision, more details are added to the Result/Discussion sections. We also revise Table 2 to show the site-level results not only using the new method, but also other spin-up methods including a semi-analytical method and the original TEM spin-up method.

To save space for a technical note paper, we intentionally only show the results at one site (Harvard forests) with Figure 2. We state that, similar results are also found for other sites in Table 1. In addition, we used Figure 3 to show regional results in North America to demonstrate the performance of the new method.

Response for interactive comments #2:

*First, the section 2.2 is the core of this work, so the equations need more details and a double check. The equations (15) and (15a) are the fundamental equations in this method, but it is unclear how these two equations were derived from (12) and (13), respectively. One major reason for the confusion is that the authors introduced thek-1/2 as a half time step. I encourage the authors to more carefully double check the equations.”*

Response: In this revision, we clarified the definition of half-step Jacobian matrix J and the way to compute it. In our model, process rates depend on temperature and the process rate constants are time dependent. Index k-1/2 is introduced due to solving x(k)-x(k-1)= τ\*(g(k-1/2)\*x(k-1)+h(k-1/2)), which, as reviewer noted, would be commonly written as x(k)-x(k-1)= τ\*(g(k-1)\*x(k-1)+h(k-1)) in a purely explicit scheme. However, it can be shown that using process rates at midpoint (k-1/2) is no less accurate than in purely explicit form with (k-1), which is obvious for h(k-1/2). The term h(k-1/2) simply represents the value at the half-time step for function h. For Section 2.2, we revised it to show how each step is being done and how the next step is related to previous time step.

*Second, even the equations are all corrected, it is the authors’ obligation to illustrate that how this approach could be adopted by other models. As we know, the structure of biogeochemistry in TEM used in this work is much simpler than those in many global land-surface models. For example, there are only two C pools and three N pools (see page 4), this makes the mathematical solution for the steady state much easier than those century-type models. I suggest the authors to add a section to discuss how their approach could be used in other models*

Response: In this revision, we stated that “We consider our method is a general approach to accelerate the spin-up process for process-based biogeochemistry models. As long as the governing equations of the models can be formulated as the form in eq. (9), the algorithm could be adopted accordingly”.

*Third, the authors compared their new approach to the semi-analytical spin-up (SASU) method. The SASU method has shown that using analytical approach can dramatically save the spin-up time. However, many models still use the traditional methods of long-term iteration or some others, such as the accelerated decomposition (please see the technical note for the CLM4.5/5). The reason is that coding the analytical methods into the original model is time consuming. It would be great to see whether this method can save more time than those widely-used simple methods.*

Response: We do consider our approach could be used for process-based models with various structures. To accelerate the spin-up for multiple soil carbon pool models with relatively simple and linear decomposition processes, to implement our method is relatively easy, but will take a great amount of computing time to equilibrate. For models such as CLM, multiple methods have been tested to accelerate their spin-up process, but the direct analytical solution might be time-consuming to achieve. We added some discussion in the end of the Discussion section about this in this revision.

*Forth, as shown in the Table 2, it seems the original TEM model reached the steady state very fast (∼200-500 years). This might be due to the short turnover times in the model (or the B components in the equation 16). Obviously the turnover of soil C is very slow at northern high latitudes. So it is not clear how the method will perform if the parameterizations for the soil module is realistic.*

Response: Relatively quick spin up in TEM is due to the absence of slow soil carbon pool(s) as TEM has only one soil box (pool). Because soil carbon pools and litter pool are aggregated in TEM, the carbon turnover rates are dictated by fast turnover of litter pool, thus equilibration is faster than in CASA (Potter et al., 1993) or CENTURY (Parton et al., 1992) models. Accordingly, the benefit of our cyclo-stationary problem solver is less visible than in the case when it takes 2000 years or more to reach equilibrium. From eq. (17), we could see that our model performs stably for every grid in spite of the turnover rate, as the computation cost for LU decomposition is relatively stable.

Added References:

Potter, C. S., J. T. Randerson, C. B. Field, P. A. Matson, P. M. Vitousek, H. A. Mooney, and S. A. Klooster, 1993, Terrestrial ecosystem production: A process model based on global satellite and surface data, Global Biogeochemical Cycles, 7(4):811-841.

Parton, W.J., B. McKeown, V. Kirchner, and D.S. Ojima. 1992. CENTURY Users Manual. Colorado State University, NREL Publication, Fort Collins, Colorado, USA.