Supplement of

The Yale Interactive terrestrial Biosphere model: description, evaluation and implementation into NASA GISS ModelE2

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Supporting information

Spin-up process for YIBs-offline

We use the off-line YIBs model to obtain the initial conditions for tree height and soil pools. Vegetation carbon reaches equilibrium in a timescale of 10s years. In the model, we set a uniform initial height $H_0$ for each PFT (Table 1). We then run the model for 60 years with fixed CO$_2$ concentrations and meteorological forcing at the year 1980. By the end of the spin-up run, the year-to-year variations of global average tree height, LAI, GPP, and NPP are all within ±0.05%. Soil carbon pools evolve much more slowly and reach equilibrium on timescales of 100s years (Clark et al., 2011). In the model, we use the global soil carbon content at the top 30 centimeters developed by Batjes (2009) as the initial condition. Studies investigating terrestrial carbon fluxes usually initialize models from the preindustrial period when human perturbations are negligible and soil carbon pools are considered to be at an equilibrium state (Huntzinger et al., 2013; Sitch et al., 2015). We do not initialize our model in the same way due to the availability of hourly meteorological forcing, which starts only from 1980. In a sensitivity test, Wutzler and Reichstein (2007) applied a transient correction to the soil carbon pool so that the simulated stocks match observations. We followed a similar strategy by spinning up the model with fixed CO$_2$ and meteorology at the year 1980 for ~80 years until the transient NEE is equal to -2 Pg C a$^{-1}$, a value supported by observations and multi-model ensembles (Piao et al., 2013). The simulated carbon pools are then used as initial conditions for off-line simulations for the 1980-2011 period.
Figure S1. Average correlation coefficients between monthly GPP and drought-dependent phenology $f_D$ at (a) shrub and (b) grass sites derived with different water stress thresholds ($\beta_{\text{min}}$ and $\beta_{\text{max}}$). The results are based on 14 warm sites, 8 for shrub and 6 for grass, with annual soil temperature $> 12 \, ^\circ\text{C}$ as shown in Fig. 2.
Figure S2. Comparison of simulated (solid lines) and observed (blue points) monthly gross primary productivity (GPP) at 145 sites from FLUXNET and NACP network. Both simulations and observations are averaged over the period when measurements are available (Table S1). Error bars represent one standard deviation of observations while shadings represent that of simulations. The relative bias and correlation coefficient are shown on each panel. The land types include evergreen needleleaf forest (ENF), evergreen broadleaf forest (EBF), deciduous broadleaf forest (DBF), shrublands (SHR), grasslands (GRA), and croplands (CRO). Units of GPP: g C m$^{-2}$ day$^{-1}$.
Figure S2. Continued.
Figure S2. Continued. Dashed lines in some shrub and grass sites represent simulations with cold phenology alone.
Figure S2. Continued. Dashed lines in some grass sites represent simulations with cold phenology alone.
Figure S3. Histogram of changes in (a) correlation coefficients ($R$) and (b) root mean square error (RMSE) between the observed and simulated GPP after the inclusion of drought phenology at 14 warm sites (annual soil temperature $> 12$ °C). Each bar represents the number of sites where $\Delta R$ or $\Delta$RMSE of simulations fall between the specific ranges as defined by the x-axis intervals. The minimum and maximum of $\Delta R$ or $\Delta$RMSE are indicated as the two ends of x-axis in the plots. The distribution of x-axis is asymmetric. Detailed comparisons at these sites are presented in Fig. S2. Units of RMSE: g C m$^{-2}$ day$^{-1}$. 
Figure S4. Comparison of simulated (solid lines) and observed (blue points) monthly net ecosystem exchange (NEE) at 145 sites from FLUXNET and NACP network. Both simulations and observations are averaged over the period when measurements are available (Table S1). Error bars represent one standard deviation of observations while shadings represent that of simulations. The relative bias and correlation coefficient are shown on each panel. The land types include evergreen needleleaf forest (ENF), evergreen broadleaf forest (EBF), deciduous broadleaf forest (DBF), shrublands (SHR), grasslands (GRA), and croplands (CRO). Units of NEE: g C m\(^{-2}\) day\(^{-1}\).
Figure S4. Continued.
Figure S4. Continued. Dashed lines in some shrub and grass sites represent simulations with cold phenology alone.
Figure S4. Continued. Dashed lines in some grass sites represent simulations with cold phenology alone.
Figure S5. Simulated (a) annual and (b) June-August mean surface ozone concentrations with ModelE2.
Figure S6. Simulated (left) leaf area index (LAI) with ModelE2-YIBs and (right) its differences relative to simulations with offline YIBs driven by WFDEI reanalysis for period 1996-2005. Each row represents results averaged for a specific month. Units: m$^2$ m$^{-2}$. 
Figure S7. Simulated (left) GPP with ModelE2-YIBs and (right) its differences relative to simulations with offline YIBs driven by WFDEI reanalysis for period 1996-2005. Each row represents results averaged for a specific month. Units: g m$^2$ day$^{-1}$. 
Figure S8. Simulated (left) net primary productivity (NPP) with ModelE2-YIBs and (right) its differences relative to simulations with offline YIBs driven by WFDEI reanalysis for period 1996-2005. Each row represents results averaged for a specific month. Units: g m$^{-2}$ day$^{-1}$. 
Figure S9. Differences of surface air temperature between ModelE2-YIBs and WFDEI for period 1996-2005. Each panel represents results averaged for a specific month. Units: °C.
Figure S10. Differences of total Photosynthetically active radiation (PAR) between ModelE2-YIBs and WFDEI for period 1996-2005. Each panel represents results averaged for a specific month. Units: W m\(^{-2}\).
Figure S11. Differences of canopy humidity between ModelE2-YIBs and WFDEI for period 1996-2005. Each panel represents results averaged for a specific month. Units: g kg^{-1}. 
Figure S12. Differences of soil wetness at the 5th soil layer (~1.5 m) between ModelE2-Y1Bs and WFDEI for period 1996-2005. Each panel represents results averaged for a specific month. Units: fraction.
Table S1. Descriptions of 145 flux tower sites from NACP and FLUXNET.a.

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a The NACP site information is adopted from Schaefer et al. (2012), except that the operational time span listed here is only for the period when measurements of GPP are available. Most of NACP sites are also part of the FLUXNET network.

b PFT names are: evergreen needleleaf forest (ENF), deciduous broadleaf forest (DBF), shrublands (SHR), grasslands (GRA), and croplands (CRO). Some site biome definitions are attributed to the closet model PFT. For example, closed shrublands, permanent wetlands, and woody savannas are attributed to shrublands. Mixed forests are attributed to ENF.
References


