Supplementary material

Soil moisture comparison

We adopted soil moisture and temperature data from the GLDAS Noah Land Surface Model L4 monthly 1.0 x 1.0 degree V2.1 (GLDAS_NOAH10_M; Beaudoing and Rodell, 2020; Rodell et al., 2004) dataset and compared them with results from the CLM simulations. GLDAS-2.1 is generated with forcings from a combination of model and observation data including the GPCP V1.3. We used soil temperature and soil moisture in the top 10 centimeters of soil because CLM uses soil properties from the third soil layer (9cm) to determine the start of growing season (Lawrence et al., 2019).

References

Beaudoing, H. and M. Rodell, NASA/GSFC/HSL (2020), GLDAS Noah Land Surface Model L4 monthly 1.0 x 1.0 degree V2.1, Greenbelt, Maryland, USA, Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed: [2021/11/07], 10.5067/LWTYSMP3VM5Z


### Supplementary tables

**Table S1. Summary of differences in land cover type, LAI value, and LAI seasonality between varying geographical locations**

<table>
<thead>
<tr>
<th>Dominant phenology PFT type</th>
<th>Evergreen needleleaf forest across 60°N</th>
<th>Mediterranean</th>
<th>Central Asia (near Kazakhstan)</th>
<th>Southeast China</th>
<th>Southeast US</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean annual LAI range</td>
<td>Around 4 in MODIS and lower than 2 in CLM</td>
<td>Around 2 in MODIS and about 4 in CLM</td>
<td>1-2 in MODIS, 1 in CLM5, and higher than 5 in CLM4.5</td>
<td>3.5 in MODIS, 1.5 in CLM5, and higher than 4 in CLM4.5</td>
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<tr>
<td>Difference in annual LAI range between MODIS and CLM</td>
<td>Lower in CLM</td>
<td>Higher in CLM</td>
<td>Near 0 in CLM4.5 but lower in CLM5.0</td>
<td>Higher in CLM4.5 but lower in CLM5.0</td>
<td></td>
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<tr>
<td>Difference in mean LAI&lt;sub&gt;50%&lt;/sub&gt; DOY between MODIS and CLM</td>
<td>Around 35 days later in CLM</td>
<td>More than 40 days later in CLM</td>
<td>More than 30 days later in CLM</td>
<td>Around 10 days later in CLM4.5 but close in CLM5.0</td>
<td>More than 30 days later in CLM</td>
</tr>
<tr>
<td>Correlation of LAI&lt;sub&gt;50%&lt;/sub&gt; DOYs</td>
<td>Relatively high (~0.6 and significant in North America) in CLM4.5 but low or no correlation in CLM5.0</td>
<td>Low and not significant</td>
<td>Low and not significant</td>
<td>Low and not significant between CLM and MODIS but ~0.5 between CLM5.0 and CLM4.5</td>
<td>Low and not significant</td>
</tr>
</tbody>
</table>
Supplementary figures

**Figure S1.** Annual cycle of LAI of different PFTs from CLM5.0 (GSWP3) simulation at one grid point (28.74°N, 81.25°W) in 2009. The PFTs that coexist in this grid cell are needleleaf evergreen temperate tree (phenology routine: evergreen); broadleaf evergreen tropical tree (evergreen); broadleaf evergreen temperate tree (evergreen); broadleaf deciduous tropical tree (stress deciduous); broadleaf deciduous temperate tree (seasonal deciduous); broadleaf deciduous temperate shrub (stress deciduous); C3 non-arctic grass (stress deciduous); c4 grass (stress deciduous); C3 crop: generic crop that is treated as C3 grass (stress deciduous).
Figure S2. Comparison of mean spring (April, May, and June) LAI values derived from MODIS, CLM5.0, and CLM4.5 averaged between 2003-2014 for different phenology plant functional types. For each box plot, center line denotes the median mean LAI value, box limits show the upper and lower quartiles (25\% and 75\%), and whiskers indicate the 5th and 95th percentiles. Left column: mean spring LAI for non-tropical evergreen PFTs. Middle column: mean spring LAI for non-tropical stress deciduous PFTs. Right column: mean spring LAI for seasonal deciduous PFTs.
Figure S3. Comparison of mean annual range of LAI (annual maximum minus annual minimum) derived from MODIS, CLM5.0, and CLM4.5 averaged between 2003-2014 for different phenology plant functional types. For each box plot, center line denotes the median LAI mean annual range, box limits show the upper and lower quartiles (25% and 75%), and whiskers indicate the 5th and 95th percentiles. Left column: LAI mean annual range for non-tropical evergreen PFTs. Middle column: LAI mean annual range for non-tropical stress deciduous PFTs. Right column: LAI mean annual range for seasonal deciduous PFTs.
**Figure S4.** Mean DOY when LAI crosses 50% threshold of annual dynamical range averaged between 2003-2014.
**Figure S5.** Comparison of LAI 50% threshold DOYs derived from MODIS, CLM5.0, and CLM4.5 averaged between 2003-2014 for different phenology plant functional types. For each box plot, center line denotes the median DOY, box limits show the upper and lower quartiles (25% and 75%), and whiskers indicate the 5th and 95th percentiles. Left column: LAI 50% threshold DOYs for non-tropical evergreen PFTs. Middle column: LAI 50% threshold DOYs for non-tropical stress deciduous PFTs. Right column: LAI 50% threshold DOYs for seasonal deciduous PFTs.
Figure S6. Maps showing difference in mean 10cm soil temperature. (a) Ratio of mean 10cm soil temperature difference between CLM4.5 GSWP3 and NOAH (compared to NOAH). (b) Ratio of mean 10cm soil temperature difference between CLM5.0 GSWP3 and NOAH (compared to NOAH). (c) Ratio of mean 10cm soil temperature difference between CLM4.5 CRUNCEP and CLM5.0 GSWP3 (compared to CLM5.0 GSWP3). (d) Ratio of mean 10cm soil temperature difference between CLM4.5 GSWP3 and CLM5.0 GSWP3 (compared to CLM5.0 GSWP3).
Figure S7. Maps showing the difference in mean 10cm soil moisture. (a) Ratio of mean 10cm soil moisture difference between CLM4.5 GSWP3 and NOAH (compared to NOAH). (b) Ratio of mean 10cm soil moisture difference between CLM5.0 GSWP3 and NOAH (compared to NOAH). (c) Ratio of mean 10cm soil moisture difference between CLM4.5 CRUNCEP and CLM5.0 GSWP3 (compared to CLM5.0 GSWP3). (d) Ratio of mean 10cm soil moisture difference between CLM4.5 GSWP3 and CLM5.0 GSWP3 (compared to CLM5.0 GSWP3).
Figure S8. Maps showing correlations of mean 10cm soil temperature between different datasets. (a) Correlation of mean 10cm soil temperature between CLM4.5 GSWP3 and NOAH. (b) Correlation of mean 10cm soil temperature between CLM5.0 GSWP3 and NOAH. (c) Correlation of mean 10cm soil temperature between CLM4.5 CRUNCEP and CLM5.0 GSWP3. (d) Correlation of mean 10cm soil temperature between CLM4.5 GSWP3 and CLM5.0 GSWP3. Black crosses denote grid points exhibiting significant correlation after adjustment for false positive.
Figure S9. Maps showing correlations of mean 10cm soil moisture between different datasets. (a) Correlation of mean 10cm soil moisture between CLM4.5 GSWP3 and NOAH. (b) Correlation of mean 10cm soil moisture between CLM5.0 GSWP3 and NOAH. (c) Correlation of mean 10cm soil moisture between CLM4.5 CRUNCEP and CLM5.0 GSWP3. (d) Correlation of mean 10cm soil moisture between CLM4.5 GSWP3 and CLM5.0 GSWP3. Black crosses denote grid points exhibiting significant correlation after adjustment for false positive.
Figure S10. Difference in peak growing season length as indicated by LAI 75% threshold averaged between 2003-2014.
Figure S11. Comparison of peak growing season length derived from MODIS, CLM5.0, and CLM4.5 averaged between 2003-2014 for different phenology plant functional types. For each box plot, center line denotes the median peak growing season length, box limits show the upper and lower quartiles (25% and 75%), and whiskers indicate the 5th and 95th percentiles. Left column: peak growing season length for non-tropical evergreen PFTs. Middle column: peak growing season length for non-tropical stress deciduous PFTs. Right column: peak growing season length for seasonal deciduous PFTs.
Figure S12. LAI time series at three illustrative grid points. (a) LAI seasonal cycles at a needleleaf evergreen boreal tree dominated grid cell (CLM phenology: evergreen). (b) LAI seasonal cycles at a broadleaf deciduous temperate tree dominated grid cell (CLM phenology: seasonal deciduous). (c) LAI seasonal cycles at a grassland dominated grid cell (CLM phenology: stress deciduous). Original 8-day composite of MODIS LAI is represented with black dots and the fitted smoothing spline is plotted using black lines. LAIs from CLM5.0 with GSWP3 forcing are colored red while CLM5.0 with CRUNCEP forcing is in magenta. LAIs from CLM4.5 with CRUNCEP forcing are colored blue.