App. 1. Detailed description of the PhenLAI model.

Initial maximum LAI module

Maximum LAI in a mature stand reaches a more or less steady state that is associated with long-term climate (Grier & Running 1977; Woodward 1987; Stephenson 1990; Luo et al. 1997). In the module, the initial maximum LAI were calculated from the regression equations between maximum LAI and annual mean temperature and moisture indices for major forest types in China that were developed in our previous studies (Table 1). These regressions were based on the field data of maximum LAI from 794 plots with mature or nearly-mature stand ages that were selected from 668 ecological research plots in the Chinese literature before 1996 and 5175 inventory plots collected by Luo (1996). We developed the regressions according to the law of limiting factors (Odum 1971) in a geographical pattern that maximum LAI decreased away from the optimum distribution center of a forest type.

Available soil water module

To be comparable with the calculation of maximum LAI of a mature stand based on long-term climate, the available soil water in a long-term balance state was calculated from the WBM of Vörösmarty et al. (1989). The WBM simulates a long-term water balance that relies on techniques developed by Thornthwaite & Mather (1957). For a site, monthly soil water content as a percentage of total pore space (SWC_i, %) and available soil water (ASW_i, mm), monthly potential evapotranspiration (PET_i, mm) and estimated actual evapotranspiration (EET_i, mm) were obtained by running the WBM with the input data of vegetation type, climate (monthly mean temperature, precipitation and cloudiness), soil texture and elevation. The calculation of net irradiance was based on the input data of latitude and cloudiness. Field capacity and available water capacity of soil for each grid cell were determined as a function of vegetation class, soil texture and rooting depth. In the WBM, the estimates of plant rooting depth were based on the input data of vegetation type and soil texture. A detailed discussion is found in Vörösmarty et al. (1989).

Plant transpiration module

The above calculations of available soil water and potential evapotranspiration were fed into this module. In the module, actual transpiration (AT_i, mm) of plants was related to LAI and soil water content, in which plant transpiration increases as an exponential function of LAI and stomatal conductance, and monthly potential evapotranspiration (PET_i) sets the upper limit of AT_i for each month (McMurtrie & Wolf 1983; Abramopoulos et al. 1988; Kunkel 1990; Saugier & Katerji 1991). This relationship can be expressed as the following (Neilson 1995):

$$AT_i = PET_i(1 - \exp(- k_{at} \cdot CC_i)) \qquad (1)$$

$$CC_i = (lai_i / lai_{max})(SC / SC_{max})$$

Where lai_i and lai_{max} are monthly LAI and maximum LAI for a site, respectively. k_{at} is a constant dependent on forest types: 2.75 for boreal forests, 3.75 for other forests (Neilson 1995). CC_i is monthly canopy conductance (unitless), and SC is forest-type-specific stomatal conductance (mm/s). SC can be expressed as a function of soil water content and potential evapotranspiration (Neilson 1995):

$$SC = (sqr(a^2 \cdot SWP_i^2 - 4b \cdot SWP_i^2 + 4\mathrm{c}) + a \cdot SWP_i) / 2 \qquad (2)$$

$$a = \mathrm{a_s} \cdot PET_i$$

$$b = (SC_{max} / WPP)^2$$

$$c = (SC_{max})^2$$

Where sqr is for calculation of the positive square root. SC_{max} is the maximum stomatal conductance for specific forest types (mm/s): 7.6 for tropical forests, 3.5 for other forests. a_s is a parameter as 0.1. WPP is the wilting point potential (–1.5 MPa). SWP_i is soil water potential (MPa) calculated from the soil water retention curves (Saxton et al. 1986) based on soil texture for a site, as follows:

App. 1, 2, 3, 4. Internet supplement to: Luo, T.; Neilson, R.P.; Tian, H.; Vörösmarty, C.J.; Zhu, H. & Liu, S. 2002. A model for seasonality and distribution of leaf area index of forests and its application to China. *J. Veg. Sci.* 13: 817-830.

$$SWP_i = (A \cdot SWC_i^{\,B}) / 1000 \qquad (3)$$

$$A = 100 \cdot \exp(-4.396 - 0.0715 \cdot PC - 0.000488 \cdot PS^2 - 0.00004285 \cdot PC \cdot PS^2)$$

$$B = -3.140 - 0.00222 \cdot PC^2 - 0.00003484 \cdot PC \cdot PS^2$$

Where PC is percent clay content (%), PS is percent sand content (%).

Seasonal LAI module

According to the biological principles described in the text, the seasonality of monthly potential LAI over a year can be modeled as the following formula:

$$initLAI_i = LAI_{min} + (LAI_{max} - LAI_{min})\,(\exp(-k\,(t_i - t_c)^2)) \qquad t_1 < t_i < t_2 \qquad (4)$$

$$initLAI_i = LAI_{min} \qquad t_i \le t_1 \text{ or } t_i \ge t_2$$

In the formula, *exp* is the base of natural logarithm, $initLAI_i$ is initial monthly LAI ($-12 < i < 12$), LAI_{min} is the minimum LAI for a site, LAI_{max} is the maximum LAI for a site, t_c is the month when the maximum LAI and evapotranspiration exist, t_i is i-th month, t_1 is the month of leaf emergence, t_2 is the month of leaf fall, k is equal to $(t_2 - t_1)^{-2}$, $t_2 - t_1$ describes the length of the growing season (months) of the plants.

Determinations of maximum LAI and monthly LAI

In a site with a given long-term climate and specific forest type, the initial maximum LAI ($iLAI_{max}$) is adjusted downwards based on the principle that actual transpiration of plants (AT_{max}) should be less than the available soil water during the month t_c ($ASW_i\,(t_c)$). In seasonal climate conditions with EET_{max}, a monthly LAI (lai_i) approaches its maximum LAI (lai_{max}). Eq. (1) can be expressed as follows:

$$AT_{max} = PET_i\,(t_c) \cdot (1 - exp(-k_{at} \cdot SC / SC_{max})) \qquad (5)$$

Where AT_{max} is the plant transpiration when lai_i equals lai_{max}, $PET_i\,(t_c)$ is the PET during the month with maximum EET (EET_{max}). The initial maximum LAI ($iLAI_{max}$) is adjusted downwards as follows:

If $AT_{max} > ASW_i\,(t_c)$,
$AT_{max} = ASW_i\,(t_c)$ and $lai_{max} = iLAI_{max}$,
$LAI_{max} = lai_i$ calculated from Eq. (1)
Else $LAI_{max} = iLAI_{max}$
Here, $ASW_i\,(t_c)$ is the available soil water during the month t_c.

Once LAI_{max} is defined, monthly initial LAI ($iLAI_i$) can be calculated by Eq. (4). The initial monthly LAI is then adjusted downwards based on monthly soil water availability and plant transpiration:

Set $lai_i = iLAI_i$ and $lai_{max} = LAI_{max}$,
If $AT_i > ASW_i$, then $AT_i = ASW_i$,
$LAI_i = lai_i$ calculated from Eq. (1)
Else $LAI_i = iLAI_i$

In the above calculations, the simulated LAI_{max} is constrained to fall below the maximum water use efficiency (*WUE*) that is the ratio of leaf area duration (*LAD*) to the amount of water transpired (ΣAT_i). The original definition of WUE is the ratio of the amount of carbon assimilated to the amount of water transpired (Eamus 1991). Maximum LAI is the accumulation of leaf growth during the growing season. According to Waring & Schlesinger (1985), gross primary production is related to the leaf area duration that is equal to the product of LAI_{max} and numbers of months in the growing season ($t_2 - t_1$). The ratio of leaf area duration to annual plant transpiration can be considered as a surrogate for the maximum water use efficiency. For forests, *WUE* has been set to 0.25 (Neilson 1995). We have the relations as follows:
If $(LAD / \Sigma AT_i) > WUE$,
$LAI_{max} = (WUE \cdot \Sigma AT_i) / (t_2 - t_1)$

$LAI_i = lai_i$ re-calculated from Eq. (1)

If the winter climate is so extremely cold that potential evapotranspiration approaches zero or is equal to 0, we define LAI_i as LAI_{min}.

Calculation of LAI_{min}

The minimum LAI (LAI_{min}) in deciduous forests was equal to 0. In evergreen forests, the minimum LAI is estimated from the adjusted maximum LAI based on either estimated actual evapotranspiration or leaf life span:

$$LAI_{min} = LAI_{max}(EET\ (t_1) + EET\ (t_2))\ /\ (2 \cdot EET_{max}) \qquad (6)$$

$$LAI_{min} = r \cdot LAI_{max},\ \text{if}\ \ (EET\ (t_1) + EET\ (t_2))\ /\ (2 \cdot EET_{max}) < 0.25 \qquad (7)$$

Here, EET_{max} is a maximum value of estimated monthly actual evapotranspiration, $EET\ (t_1)$ and $EET\ (t_2)$ are the estimated actual evapotranspiration in the months of t_2 and t_1, respectively, and r is the forest-type-specific value of leaf retention fraction from Table 2.

For evergreen forests where the estimated actual evapotranspiration in the months of t_2 and t_1 is very low or equal to 0, the minimum LAI has a weak relationship to evapotranspiration. Then, we estimate the minimum LAI using a leaf-retention fraction based on its leaf life span. In general, evergreen conifers have a longer leaf life span than evergreen broadleaved trees. Leaf life span in the coniferous trees varies between 2 and 20 years of age, but within 2 years of age in the conifers such as pines and Chinese-fir growing in the subtropical regions of China (Ewers & Schmid 1981; Luo 1996). The leaf life span in the broadleaved trees varies from 1 to 3 years of age (Wang 1988; Lowman 1992). This implies that evergreen conifers have a larger leaf-retention fraction than evergreen broadleaved forests. In China, the minimum leaf retention rate exists in the north-subtropical evergreen-deciduous broadleaved forest and the tropical monsoon forest (the percentage of evergreenness defined as 50%), in which the evergreen leaf life span is 2 years in average. Then the retention fraction of the whole canopy is estimated as about 25%. Lowman (1992) reported that in Australian rainforest, most of leaves live for 2-3 years, the annual canopy turnover rate (including consumed by herbivores) is from 57% to 63% with an average of 60%. Then the retention fraction in tropical rain forest can be estimated as about 40%. Spanner et al. (1990) reported that in temperate evergreen conifers, there is approximately an annual needle loss of 10% to 30% from most of the coniferous species during the year. Then the retention fraction in temperate evergreen conifers can be estimated as 70% to 90%. Therefore, the threshold leaf-retention fraction for evergreen forests is 0.25.

Determination of growing season length

According to Coutagne’s law of growth (Wang 1960, Lieth 1970), in a given climate, the optimum plant growth rate (g) is related to plant temperature (x) in a logistic function as follows:

$$g = a\ [\exp\ (-\ ((x - c)\ /\ n)^2)] \qquad (8)$$

Where a is the coefficient of development rate ($1/\ a$ = longevity or growth time), c is the temperature for which the most rapid development of the plant is obtained, and n is the coefficient which describes the sensitivity of the plant to temperature.

Integration of this equation yields the total growth time of the plant at any given temperature, x (Lieth 1970). We set g as 1 or 100% for the whole growth during a year. Then, the reciprocal of a value defines the growing season length of a plant while c and n determine the temperature range of plant acclimatization. In the PhenLAI model, the growing season was calculated from the monthly temperature data by the following formula:

$$t_2 - t_1 = 1/a = \sum \left[\exp\left(-\left((x-c)/n \right)^2 \right) \right] \quad x > 0\ ^\circ\mathrm{C} \qquad (9)$$

Here, x was defined as monthly mean temperature(°C) from the input climate data set, c equals 20 °C for the optimum temperature of photosynthesis, 0 °C is for the base temperature of leaf emergence, n equals the temperature range suitable for plant growth between 0 °C and 30 °C (Wang 1960; Anderson 1974).

In Eq. (4), t_c could be defined as the month with EET_{max}, then t_1 and t_2 could be defined as follows:

$$\begin{aligned} t_1 &= t_c - 1 / (2 \cdot a) \\ t_2 &= t_c + 1 / (2 \cdot a) \end{aligned} \qquad (10)$$

App. 2. Description of 13 natural forest sites obtained from our recent study in the Tibetan Alpine Vegetation Transects (TAVT) on the Tibetan Plateau during 1999-2000. The belowground live biomass was harvested by excavating whole root systems in 0.5×0.5 m^2 quadrats with the depth until all root tips had been contained in the sample. The aboveground live biomass was estimated by allometric regressions (App. 3) that were based on harvesting trees and dimensional analysis.

Site No.	Place name	Vegetation type	Longitude (° ' ")	Latitude (° ' ")	Altitude (m)	Root biomass (g DW/m^2)	Aboveground biomass (g DW/m^2)
1	East Mila Mt.	*Betula* deciduous forest	E93 30 00	N30 00 00	3620	1799	3390
2	Nyiyang River Valley	*Quercus* evergreen forest	E94 01 19	N29 45 35	3154	5226	7588
3	Nyiyang River Valley	Mixed forest of *Pinus densata* and *Quercus* evergreen trees	E94 14 32	N29 45 13	3127	2854	4876
4	West Sergyemla Mt.	Alpine fir forest of *Abies georgei* var. *smithii*	E94 33 27	N29 33 32	3780	2140	99598
5	West Sergyemla Mt.	Timberline forest of *Abies georgei* var. *smithii*	E94 35 31	N29 34 52	4073	2063	14178
6	West Sergyemla Mt.	Timberline woodland of *Sabina saltuaria and Rhododendron*	E94 37 22	N29 36 55	4450	2661	11436
7	East Sergyemla Mt.	Alpine fir forest of *Abies georgei* var. *smithii*	E94 42 51	N29 39 04	3800	4898	84142
8	East Gongga Mt.	Evergreen broadleaved forest	E102 03 26	N29 36 16	1900	6745	16520
9	East Gongga Mt.	Evergreen-deciduous broadleaved forest	E102 01 28	N29 35 13	2200	9510	34863
10	East Gongga Mt.	Mixed forest of spruce-fir and deciduous broadleaved trees	E102 01 20	N29 35 10	2850	3563	48161
11	East Gongga Mt.	Alpine fir forest of *Abies fabri*	E101 59 55	N29 34 34	3050	3548	16291
12	East Gongga Mt.	Alpine fir forest of *Abies fabri*	E101 59 55	N29 34 34	3000	2381	36940
13	East Gongga Mt.	Timberline forest of *Abies fabri*	E101 58 05	N29 32 44	3700	698	24223

App. 3. Additional references to the model validation.

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App. 4. Allometric regressions used for estimating aboveground live-biomass of the forest plots in Tibetan Alpine Vegetation Transects on the Tibetan Plateau.

Study area	Tree species	Allometric regressions of individual tree biomass[#]			
		Stem	Branch	Leaf	Authors
Gongga Mts	*Picea brachytyla*	$W=0.0139(D^2H)^{1.0075}$ $r^2=0.9986^{**}$, n=13	$W=0.0014(D^2H)^{1.0503}$ $r^2=0.9118^{**}$, n=13	If DBH<40cm: $W=0.0003(D^2H)^{1.2032}$ $r^2=0.9341^{**}$, n=11 $W=0.0014D^{2.9302}$ $r^2=0.9419^{**}$, n=11 if DBH>40cm: $W=11.506\ln(D^2H)-74.733$, $r^2=0.7539^{**}$, n=13 $W=29.541\ln(D)-63.15$ $r^2=0.7574^{**}$, n=13	This study
WesternSichuan	*Abies fabri*	$W=0.0405D^{2.5680}$ $r^2=0.9890^{**}$, n=13	$W=0.0037D^{2.7386}$ $r^2=0.9450^{**}$, n=13		
Gongga Mts WesternSichuan	Broadleaved trees in alpine spruce-fir forests	$W=0.0097D^2H+5.8252$ $r^2=0.9914^{**}$, n=15	$W=0.0051D^2H+3.508$ $r^2=0.9825^{**}$, n=15	$W=0.0004D^2H+0.7563$ $r^2=0.9333^{**}$, n=15	This study
Nyiyang River Valley, Southeast Tibet	*Quercus* evergreen trees	$W=1.917\exp(0.0034D^2H)$ $r^2=0.9841^{**}$, n=6 $W=0.1216D^{2.0736}$ $r^2=0.9059^{*}$, n=6	Perennial branch: $W=0.5414\exp(0.0046D^2H)$ $r^2=0.9781^{**}$, n=6 $W=0.0133D^{2.7973}$ $r^2=0.8881^{*}$, n=6 Current branch: $W=0.0909\exp(0.0037D^2H)$ $r^2=0.9692^{**}$, n=6 $W=0.004D^{2.3283}$ $r^2=0.9189^{*}$, n=6	One year's leaf: $W=0.2992\exp(0.0037D^2H)$ $r^2=0.9692^{**}$, n=6 $W=0.0132D^{2.3283}$ $r^2=0.9189^{*}$, n=6 Current leaf: $W=0.224\exp(0.0037D^2H)$ $r^2=0.9692^{**}$, n=6 $W=0.0099D^{2.3283}$ $r^2=0.9189^{*}$, n=6	This study
East MilaMts Southeast Tibet	*Betula* deciduous trees	$W=0.0347(D^2H)^{0.8714}$ $r^2=0.9811^{**}$, n=6 $W=0.0793D^{2.2094}$ $r^2=0.9803^{**}$, n=6	$W=0.0061(D^2H)^{0.9925}$ $r^2=0.9224^{*}$, n=6 $W=0.0157D^{2.5191}$ $r^2=0.9258^{*}$, n=6	$W=0.0189(D^2H)^{0.6693}$ $r^2=0.9598^{**}$, n=6 $W=0.0356D^{1.6978}$ $r^2=0.9608^{**}$, n=6	This study
Bomi, Southeast Tibet	*Pinus densata*	$W=0.0628D^{2.49921}$ $r^2=0.9914^{**}$, n=13 $W=0.0211(D^2H)^{0.96231}$ $r^2=0.9998^{**}$, n=13	$W=-25.9827+2.2091D$ $r^2=0.7670^{**}$, n=13 $W=0.2491(D^2H)^{0.50695}$ $r^2=0.7215^{**}$, n=13	$W=-15.2597+1.2974D$ $r^2=0.7669^{**}$, n=13 $W=0.1463(D^2H)^{0.50694}$ $r^2=0.7215^{**}$, n=13	Luo et al. (1999)
Bomi,Chayu Southeast Tibet	*Picea* sp.	$W=0.0650D^{2.51019}$ $r^2=0.9744^{**}$, n=27 $W=0.0449(D^2H)^{0.90167}$ $r^2=0.9996^{**}$, n=27	$W=-66.45+72.06\lg(D)$ $r^2=0.7085^{**}$, n=27	$W=-36.92+40.03\lg(D)$ $r^2=0.7085^{**}$, n=27	Luo et al. (1999)
Bomi,Chayu Southeast Tibet	*Abies* sp.	$W=0.1587D^{2.38949}$ $r^2=0.9537^{**}$, n=8 $W=0.0393(D^2H)^{0.93490}$	$W=9.8858+0.0160D^2$ $r^2=0.7356^{*}$, n=8 $r^2=0.9974^{**}$, n=8	$W=6.059+0.0098D^2$ $r^2=0.7344^{*}$, n=8	Luo et al. (1999)
Ailao Mt., Yunnan	*Machilusviridis*	$W=0.0283(D^2H)^{0.9560}$ $r^2=0.9855^{**}$, n=13	$W=0.0285(D^2H)^{0.6756}$ $r^2=0.9333^{**}$, n=13	$W=0.0601(D^2H)^{0.4320}$ $r^2=0.7564^{**}$, n=13	Qiu & Xie(1998)
Ailao Mt., Yunnan	*Lithocarpus xylocarpus*	$W=0.0347(D^2H)^{0.9470}$ $r^2=0.9944^{**}$, n=12	$W=0.0084(D^2H)^{0.9112}$ $r^2=0.9197^{**}$, n=12	$W=0.0072(D^2H)^{0.6893}$ $r^2=0.8606^{**}$, n=12	Qiu & Xie(1998)
Ailao Mt., Yunnan	*Castanopsis wattii*	$W=0.0177(D^2H)^{1.0168}$ $r^2=0.9962^{**}$, n=12	$W=0.0364(D^2H)^{0.6530}$ $r^2=0.9686^{**}$, n=12	$W=0.1533(D^2H)^{0.2948}$ $r^2=0.7616^{**}$, n=12	Qiu & Xie(1998)
Qilian Mt, Gansu	*Sabina przewalskii*	$W=0.2738(D^2H)^{0.6912}$ $r^2=0.9212^{**}$, n=13	$W=0.0061(D^2H)^{0.9455}$ $r^2=0.7213^{**}$, n=13	$W=0.0042(D^2H)^{0.8986}$ $r^2=0.7529^{**}$, n=13	Wang et al. (1998)

Variables (unit): *W* dry matter weight (kg), *D* diameter at breast height (cm), *H* tree height (m), *n* sampled trees, *r* correlation coefficient.
* Significance level at $p < 0.01$; ** Significance level at $p < 0.001$.

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