Development and validation of a two leaf light use efficiency model based on flux measurements

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Outline

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Light use efficiency model assume that GPP linearly increases with incoming PAR

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<th>APAR 计算</th>
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<td>CASA</td>
<td>$NPP = APAR \times \varepsilon$</td>
<td>$S \times FPAR \times 0.5$</td>
<td>$\min[\frac{SR - SR_{\text{min}}}{SR_{\text{max}} - SR_{\text{min}}} , 0.95]$</td>
<td>$\varepsilon_{\text{max}} f(T) f(\theta)$</td>
<td>Potter et al., 2003, GGC</td>
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<td>C-Flux</td>
<td>$GPP = APAR \times \varepsilon$</td>
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<td>$\varepsilon_{\text{max}} f(T) f(CO_2)$</td>
<td>Veroustraete et al., 2002, RSE</td>
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<td>CFLUX</td>
<td>$GPP = APAR \times \varepsilon$</td>
<td>$PAR \times FPAR$</td>
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<td>$\varepsilon_{\text{max}} f(T_{\text{min}}) f(VPD)$ $f(\theta) f(Age)$</td>
<td>Turner, 2006, Tellus</td>
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<td>GLO-PE M</td>
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<td>$1.08 \times NDVI - 0.08$</td>
<td>$\varepsilon_{\text{max}} f(T_{\text{min}}) f(VPD)$ $f(\theta)$</td>
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<td>BEAM$^c$</td>
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<td>Sasai et al., 2005, JGR</td>
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<td>$GPP = APAR \times \varepsilon$</td>
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<td>MODIS-g GPP 算法</td>
<td>$GPP = APAR \times \varepsilon$</td>
<td>$PAR \times FPAR$</td>
<td>$1 - e^{-LAI}$</td>
<td>$\varepsilon_{\text{max}} f(T_{\text{min}}) f(VPD)$</td>
<td>Zhao et al., 2005, RSE</td>
</tr>
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</table>
Response of photosynthesis to light intensity

Sunlit and Shaded leaves

\[ \text{PSN} \left( \frac{\text{diffuse light}}{\text{shaded leaves}} \right) + \text{PSN} \left( \frac{\text{direct light}}{\text{sunlit leaves}} \right) \neq \text{PSN} \left( \frac{\text{diffuse light} + \text{direct light}}{\text{shaded leaves} + \text{sunlit leaves}} \right) \]
Background

 Contributions of Sunlit and Shaded Leaves to the Total GPP (BEPS, Needleleaf Forests)
Background

- Effect of radiation change on net terrestrial carbon sequestration after Pinatubo volcanic eruption

Harvard Forest

GPP increased by 23% and 8% on clear days in 1992 and 1993, respectively.

Gu et al., Science, 2003
**Background**

- Canopy LUE decreases with sky clearness ChinaFlux sites

Zhang et al., AFM, 2011
Background

- Bias of GPP calculated using the MOD17 algorithm
Two-leaf light use efficiency model

\[ \text{GPP} = \varepsilon_{\text{max, sun}} f(\text{VPD}) g(T_{\text{amin}}) \text{APAR}_{\text{sun}} + \varepsilon_{\text{max, shaded}} f(\text{VPD}) g(T_{\text{amin}}) \text{APAR}_{\text{shaded}} \]

\[ \text{APAR}_{\text{shaded}} = (1 - \alpha) \left[ (\text{PAR}_{\text{dif}} - \text{PAR}_{\text{dif, under}}) / \text{LAI} + C \right] \text{LAI}_{\text{shaded}} \]

\[ \text{APAR}_{\text{sun}} = [(1 - \alpha) \text{PAR}_{\text{dir}} \cos(\beta) / \cos(\theta) + \text{PAR}_{\text{shaded}}] \text{LAI}_{\text{sun}} \]

\[ S_{\text{dif}} = S_g (0.7527 + 3.8453R - 16.316R^2 + 18.962R^3 - 7.0802R^4) \]

\[ \text{LAI}_{\text{sun}} = 2 \cos(\theta)(1 - \exp(-0.5\Omega \text{LAI} / \cos(\theta))) \]

\[ \text{LAI}_{\text{shaded}} = \text{LAI} - \text{LAI}_{\text{sun}} \]

He, Ju et al., 2013, AFM
Validation of the TL-LUE model
Validation of the TL-LUE model

- TL-LUE model outperforms the MOD17 algorithms at half-hour, daily and 8-day time scales

Wu, Ju et al., 2015, Remote Sensing
Validation of the TL-LUE model

- Low sensitivity of the TL-LUE to incoming PAR

Zhou, Ju et al., 2016, JGR-Biogeosciences
Validation of the TL-LUE model

- Slightly higher sensitivity of the TL-LUE to LAI

Zhou, Ju et al., 2016, JGR-Biogeosciences
Validation of the TL-LUE model at regional scale using SIF data

The correlation coefficient between monthly GPP simulated by the TL-LUE model and SIF

Zhan, Zhou, Ju et al., 2017, STE, revised
Validation of the TL-LUE model

- The correlation coefficient between monthly GPP simulated by the TL-LUE model and SIF ($n=3 \times 8=24$)

Winter

Summer

Summer

Autumn

Zan, Zhou, Ju et al., 2017, STE, revised
Validation of the TL-LUE model

- Spatial similarity between monthly GPP simulated by TL-LUE and SIF in different seasons

Zan, Zhou, Ju et al., 2017, STE, revised
Validation of the TL-LUE model

- Spatial similarity between annual GPP simulated by TL-LUE and SIF in different years

Zan, Zhou, Ju et al., 2017, STE, revised
Differences of sunlit and shaded leaves in maximum LUE, LAI, APAR, and GPP for different land cover types

Zhou, Ju et al., 2016, JGR-Biogeosciences
Model Parameterization

- Shaded leaves dominate the maximum LUE of canopy

![Graphs showing correlation between LUE for MOD17 and LUE for shaded leaves or sunlit leaves.](image)

\[ y = 1.70x + 0.06 \quad R^2 = 0.79 \quad p < 0.0001 \]

\[ y = 0.46x + 0.09 \quad R^2 = 0.51 \quad p < 0.0001 \]

Zhou, Ju et al., 2016, JGR-Biogeosciences
Model Parameterization

- Tracking LUE using PRI at Qianyanzhou site

PRI = \frac{(R_{531} - R_{570})}{(R_{531} + R_{570})}

- Dependence of PRI on observational angles

Zhang, Ju et al., 2015, RS; Zhang, Chen, Ju et al., 2017, RSE
Two methods for deriving canopy PRI from observations at different angles

(1) \( \text{PRI}_{\text{obs}} = P_T \text{PRI}_{\text{sun}} + P_S \text{PRI}_{\text{sh}} \)

(2) \( \text{PRI}_b = \frac{1}{N} \sum_{i=1}^{N} \text{PRI}_i \)

\( \text{PRI}_t = \text{PRI}_{\text{sun}} \times \frac{L_{\text{sun}}}{\text{LAI}} + \text{PRI}_{\text{sh}} \times \frac{L_{\text{sh}}}{\text{LAI}} \)

N is the number of observational angles

Zhang, Ju et al., 2015, RS; Zhang, Chen, Ju et al., 2017, RSE
Model Parameterization

- Average diurnal correlation coefficients ($R$) between half-hourly $PRI_b$ and LUE and between half-hourly $PRI_t$ and LUE

Zhang, Ju et al., 2015, RS; Zhang, Chen, Ju et al., 2017, RSE
Model Parameterization

- Relationships of daily mean PRI$_b$ and PRI$_t$ with four bioclimatic factors on 133 non-rainy days over the growing season.

Zhang, Ju et al., 2015, RS; Zhang, Chen, Ju et al., 2017, RSE
Model Parameterization

- Relationships between (a) daily PRIb and LUE, (b) between daily PRIt and LUE, (c) between daily PRIh and LUE, and (d) their variations.

Numbers in parentheses in plot (d) are the sample numbers in each month.
Model Parameterization

◆ Modeling Gross Primary Production for Sunlit and Shaded Canopies Across an Evergreen and a Deciduous Site in Canada

✓ A bidirectional reflectance distribution function (BRDF) was used to model PRI as the linear combination of isotropic, geometric, and volumetric scattering components

\[
PRI(\theta_v, \theta_s, \phi) = K_i + K_g F_g(\theta_v, \theta_s, \phi) + K_v F_v(\theta_v, \theta_s, \phi)
\]

✓ PRI at hotspot as \(PRI_{\text{sunlit}}\)

✓ PRI at darkspot as \(PRI_{\text{shaded}}\)
Model Parameterization

- **Seasonal variations of LUE**

![Graphs showing seasonal variations of LUE](attachment:graphs.png)

Zhou, Hilker, Ju et al., 2017, IEEE TGARS
Model Parameterization

- Seasonal variations of PRI

![Graphs showing seasonal variations of PRI for different datasets and days of year.](Zhou, Hilker, Ju et al., 2017, IEEE TGARS)
Model Parameterization

- Relationships between and at 8-day periods at SOA (a, b and c) and DF-49 (d, e and f), respectively

Zhou, Hilker, Ju et al., 2017, IEEE TGARS
Model Parameterization

- Relationships between and at 16-day periods at SOA (a, b and c) and DF-49 (d, e and f), respectively

Zhou, Hilker, Ju et al., 2017, IEEE TGARS
Model Parameterization

- Tower-based GPP against GPP simulated using 8-day mean LUE (LUE_{sun}, LUE_{shaded}, and LUE) based on observed PRI (PRI_{sun}, PRI_{shaded}, and PRI)
Model Parameterization

- Tower-based GPP against GPP simulated using 16-day mean LUE ($LUE_{sun}$, $LUE_{shaded}$, and $LUE$) based on observed PRI ($PRI_{sun}$, $PRI_{shaded}$, and $PRI$)
Conclusions

- The TL-LUE outperforms the MOD17 algorithm at half-hour, daily, and 8-day temporal scales.
- Optimized model parameters vary significantly with land cover types.
- For a given land cover type, optimized model parameters vary largely across different sites.
- PRI is able to track LUE, useful for improving GPP simulations.


Thanks!