CANOPUS
A CANOPY RADIATIVE TRANSFER SCHEME WITH EXPLICIT FAPAR FOR THE INTERACTIVE VEGETATION MODEL ISBA-A-GS: IMPACT ON CARBON FLUXES

Dominique CARRER, Jean-Louis ROUJEAN, Sébastien LAFONT, and Jean-Christophe CALVET

Centre National de Recherches Météorologiques (CNRM) / GAME , Météo-France / Centre National de la Recherche Scientifique (CNRS), Toulouse, France
Contact person: dominique.carrer@meteo.fr, Phone: +33 (0) 5-61-06-84-7; Fax: 33 (0) 5-61-06-98-28

Objectives and Scientific Context

Vegetation attributes impact the Earth's carbon, water and energy budgets by controlling the exchanges between the lower atmosphere and the continental biosphere. One of the most important factors is the distribution of the absorbed fraction of solar radiation within vegetation as it constrains the photosynthesis rate. The ISBA-A-gs interactive vegetation model developed at Meteo-France is particularly well designed to simulate the vegetation fluxes. A new radiation transfer (RT) scheme for the canopy has been designed and implemented in ISBA-A-gs, which adopts a self-shading approach (Carrer et al., 2013). This means that the incoming solar fluxes at the top of the canopy will hit a number of canopy layers prior to reaching the soil background. The photosynthesis model calculates the net assimilation of CO2 of each canopy layer using the absorbed Photosynthetically Active Radiation (PAR) flux of the layer. Integration is carried out to obtain a quantitative estimate of the total net assimilation for the whole canopy layer by summing the contribution of each canopy sub-layer. It is found that the new RT scheme aims at better simulating the Leaf Area Index (LAI) and the Gross Primary Production (GPP), thereby providing better estimates of photosynthesis rate.

CANOPUS RT Model and Photosynthesis Integration

Diffuse fraction

$$Ki = Rg(1,\mu_i) \qquad (1)$$

for $Ki \le 0.22$, $Rbl_{Ki} = 1 - 0.09\,Ki$,

$0.22 < Ki < 0.8$, $Rbl_{Ki} = 0.9511 + (-0.3684 + 4.388 + (-16.64 + 12.34 \times Ki)\,\mu_i)\,\mu_i$

$Ki \ge 0.8$, $Rbl_{Ki} = (1 - \exp(-1))/(1 - (1 - \mu_i)\exp(-1/\mu_i))$

$$Rbl_{veg}(\lambda) = \frac{1 - \exp(-Q_{ext}^{veg}(\lambda)\,L)}{1 - (1 - \alpha_{veg}(\lambda))\exp(-Q_{ext}^{veg}(\lambda)\,L)}$$

$$R = \max\left[1, (Rbl_{Ki} + Rbl_{veg})\right]$$

Clumping Index

$$\Omega_{\mu_i}^{veg,\,ini} = \frac{1}{1 - \alpha_{veg,\,ini}\exp\left(-k_{ext,\,ini}(\mu_i)\,L\right)}$$

$$\Omega_{\mu_i}^{veg,\,ini} = \frac{1 + 0.5 \times \alpha_{veg,\,ini}}{1 + 2\,\alpha_{veg,\,ini}}$$

Completion of Transmittance Function

$$\tau_{\mu_i}^{veg,\,ini}(\lambda,L) = \exp\left(-\alpha_{veg,\,ini}(\lambda)\,\Omega_{\mu_i}^{veg,\,ini}\,k_{ext}^{veg,\,ini}(\mu_i)\,L/R(\mu_i,\lambda)\right)$$

$$\tau_{\mu_i}^{veg,\,real}(\lambda,L) = \exp\left(-\alpha_{veg}^{veg,\,real}\,\Omega_{\mu_i}^{veg,\,real}\,k_{ext}^{veg,\,real}(\mu_i)\,L\right)$$

$$T_i = \prod_{\dots}\left[(1 - Rbl_{veg,\,i})\,\tau_{veg,\,ini}^{veg,\,ini}(\lambda,L) + Rbl_{veg,\,i}\,\tau_{veg,\,real}^{veg,\,real}(\lambda,L)\right]$$

Vegetation Radiative Transfer Modeling

$$\text{If } i \le N \quad dPAR_{soil,\,i} = \left[1 - \alpha_{veg}\right]\left[1 - T_i\right](1 - Rbl)\,\mu_i$$

$$\text{If } i = N \quad dPAR_{soil,\,i} = \left[1 - \alpha_{veg}\right]\left[1 - T_{i-1}\right]\left(1 - Rbl\right)\mu_i + \tau_{veg}\left[1 - \tau_{veg}\right]\left[1 - T_{i-1}\right]\left(1 - Rbl\right)\mu_i + \alpha_{soil}\,\tau_{veg}$$

Sunlit/Shaded Leaves

$$aPAR_{sunlit} = \frac{(1 - \Pi)\cdot LaPAR}{\delta LAI \cdot \mu_{SH}} + \frac{\Pi \cdot LaPAR}{\delta LAI}$$

$$aPAR_{shade} = \frac{\Pi(1 - \mu_{SH})\,LaPAR}{\delta LAI}$$

with $\delta aPAR_i = aPAR_{i,\,i} - aPAR_{i,\,i-1}$; $\delta LAI_i = dc \times LAI$

Leaf Net Assimilation

$$An_{sunlit} = (An + Rd)\left(1 - \exp\left(\frac{-(1-\Pi)\,aPAR_{sunlit}}{An + Rd}\right)\right) - Rd$$

$$An_{shade} = (An + Rd)\left(1 - \exp\left(\frac{-\Pi(1-\mu_{SH})\,aPAR_{shade}}{An + Rd}\right)\right) - Rd$$

$$A_n = \sum_{i=1}^{n}\left[\mu_{SH}\,A_{n,\,sunlit} + (1 - \mu_{SH})\,A_{n,\,shade}\right]\delta_{LAI}$$

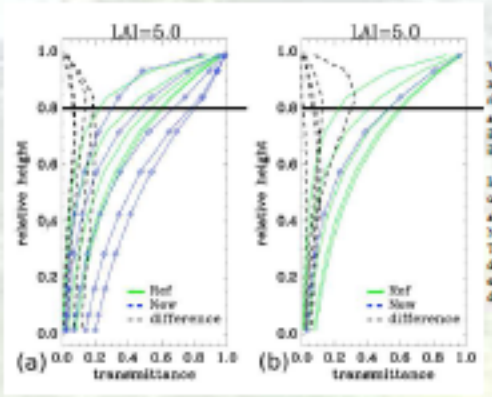
Table 1. Values of the Coefficients Used in the Calculation of the Transmittance Function in the PAR Spectrum[a]

Coefficients of the Transmittance Function		
$A_0^{veg,ini}$	0	$1 - \frac{1}{1.1\,\mu_i}\left[\frac{\alpha_{veg}(\lambda)}{1 - \alpha_{veg}(\lambda)}\right]$ where $\Pi(\lambda)$ is the single-scattering albedo of the leaf of the layer, $1.1\,\mu_i = \mu^*$ = Arbitrary fixed μ to 0.13 in the PAR domain
$A_0^{veg,real}$	0	$1 - \frac{1}{1.1\,\mu_i}\left[\frac{\alpha_{veg}(\lambda)}{1 - \alpha_{veg}(\lambda)}\right]$ where $\Pi(\lambda)$ is the single-scattering albedo of the leaf of the layer, $1.1\,\mu_i = \mu^*$ = Arbitrary fixed μ to 0.13 in the PAR domain
a_{veg} and b_{veg}		0.5 value characterizing spherical distribution of leaves is used.
A_{veg} and k_{veg}		2 cases with $\alpha = 0.5^*$ angle of inclination of the averaged value is used.
τ_{veg} and α_{veg}		$\frac{\alpha_{veg}\cdot\Pi(\lambda)}{\left[1 - \alpha_{veg}\cdot\Pi(\lambda)\right]}$ where values of Π_{leaf} and LAI^{max} fit potentially permit to derive this α coefficient. Values between 1 (crop type) and 4 (forest type) are used.
d_{veg}		$-0.604 \cdot L_{veg} + 3.8$, ratio between height and diameter of the crown with $L_{veg} = 2$.
d_{veg}		$-0.604 \cdot L_{veg} + 3.8$ ratio between height and diameter of the crown with $L_{veg} = 7$.

[a] A detailed description of the equations is given in Kucharik et al. [1999].

Evaluation of the Vegetation Transmittance Functions and sensitivity studies

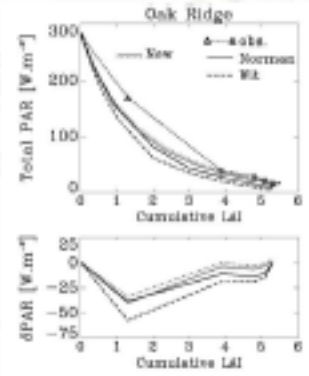
Vertical profile of the transmittance function for a canopy with LAI = 5



Various values of the solar zenith angle are used (from right to left 0°, 20°, 40°, 60°, and 80°) in case of a (a) direct illumination or (b) diffuse illumination.

In blue color: NEW. In green color: REF. In black color: the absolute difference between NEW and REF ("difference"). Transmittance monotonically decreases with the zenith angle except with NEW for the diffuse case.

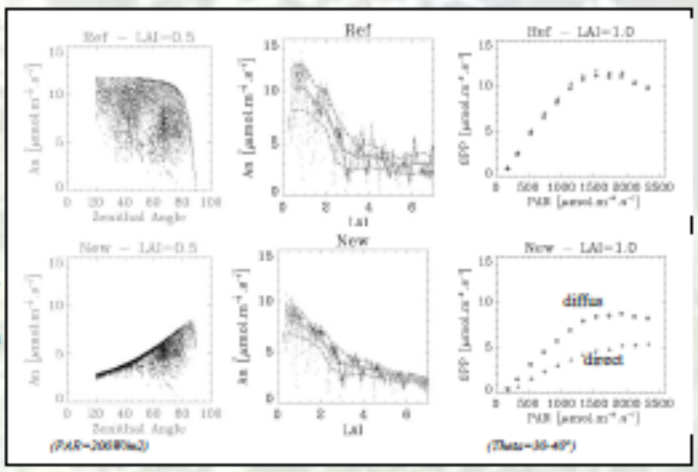
Comparison of calculated and measured mean daily vertical profiles of PAR in Oak Ridge broadleaf forest



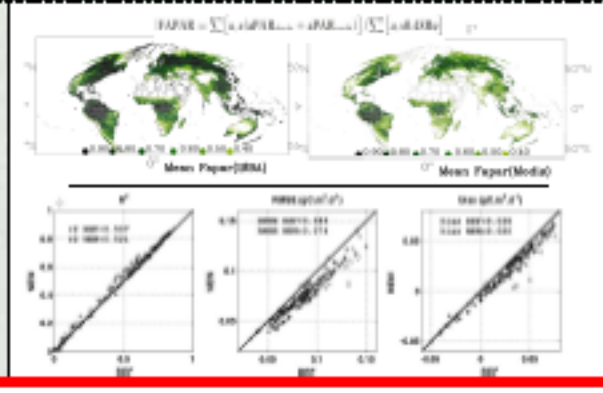
CANOPUS model underestimates values of transmitted PAR in the upper canopy by about 40W m⁻². In the lower canopy, CANOPUS RT model shows a reasonable comparison with in situ measurements, while the two other models both slightly underestimate the measured values by 10–20W m⁻². The seasonal variations of the leaf orientation function, g, along the day is introduced in the plot (dashed line)

(Oak Ridge measurements from Baldocchi et al. [1985])

Sensitivity to: the solar zenith angle, the LAI, and the diffuse fraction



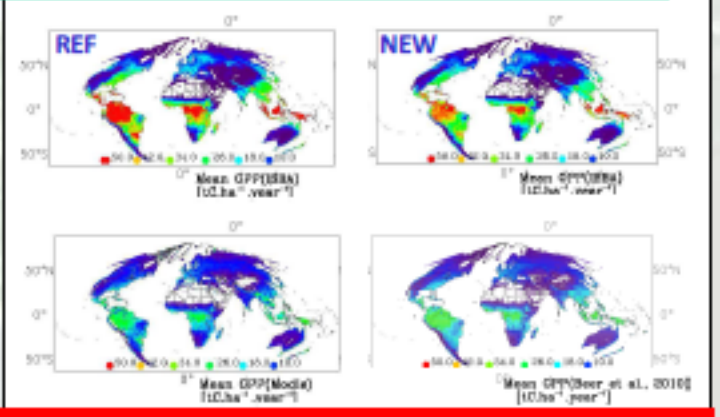
Evaluation and impact on photosynthesis



ISBA-A-gs simulations at global scale are performed is using the atmospheric forcing of Princeton University. Besides, the fraction of absorbed PAR, FAPAR, is foreseen to benchmark SVAT simulations in the near future for the assimilation of satellite derived products. Therefore, it serves here to appraise the reliability of the new RT scheme in analyzing the photosynthesis obtained with Jacobs model [Jacobs, 1994]. Comparison between simulated and MODIS FAPAR reveal higher values about 0.25 with ISBA-A-gs over boreal regions (top left-hand side).

Annual statistical score are shown on the left-hand side (bottom) for a comparison of simulated and observed daily GPP for 36 forested sites (4 years per site). From left to right: correlation, root mean square error, and bias. Each point represents a year for a given station (plus sign, deciduous; asterisk, conifer; open circle tropical).

The terrestrial GPP for 2006 simulated with ISBA presents also a clear overestimation. But this latter is reduced with a new RT scheme by 15% at least compared to the former version of ISBA-A-gs (right-hand side).



Conclusion and Perspectives – New radiative transfer scheme in ISBA-A-gs incorporates the clumping effect for leaves/needles and also diffuse radiation at any level of the canopy. Owing to a discretization of the canopy in 10 layers, the vertical profile of light transmission is sigmoidal-shaped as measured *[see Roujean, 1999a]* and from theory *[Ni et al., 1997]*. Leaf net assimilation of sunlit and shaded leaves aee computed separately. The impact of diffuse radiation aims at fixing a threshold to the productivity. Next step will concern a better calibration of the clumping factor as a function of canopy (mostly stem density and ratio diameter to height of the crown) For the upscaling purpose, gap probabilities between and within plan stands will be handled *[Roujean, 1999b]*. This will serve to enhance the role of soil and vegetation albedos for the sake of coherence with the recent development of a Multiple Energy Budget (MEB) – for soil and vegetation separately - in ISBA-A-gs model.

Beer C, and 23 co-authors, Terrestrial gross carbon dioxide uptake: Global distribution and co-variation with climate*, Science, 329 (5993): 834-838, doi: 10.1126/science.1184984, 2010.

Calvet, J.C., J. Noilhan, J.-L. Roujean, et al., Towards interactive vegetation in meteorological models : including physiology and plant growth in a soil-vegetation-atmosphere transfer scheme, *Agricultural and Forest Meteorology*, 92, 73-95, 1998.

Carrer, D., J.-L. Roujean, S. Lafont, J.-C. Calvet, A. Boone, B. Decharme, C. Delire, and J.-P. Gastellu-Etchegorry (2013), A canopy radiative transfer scheme with explicit FAPAR for the interactive vegetation model ISBA-A-gs: Impact on carbon fluxes, J. Geophys. Res. Biogeosci., 118, doi:10.1002/jgrg.20070.