Revised parts of section 3.2.2

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3.2.2 Multi-layer approach

Radiation interception

The canopy is divided into a number of layers (n, typically 10) of equal leaf area increments $dL_c = L_c/n$. JULES adopts the two-stream approximation of radiation interception from *Sellers* (1985) to calculate surface spectral albedos (*Essery et al.*, 2001) and the absorbed incoming radiation for each canopy layer. The absorbed incident PAR at each layer varies with solar zenith angle, incident direct and diffuse radiation at the top of the canopy, canopy leaf angle distribution and leaf radiation properties in the visible and near-infrared wavebands. JULES explicitly describes absorption and scattering of both direct and diffuse radiation fluxes separately in the visible and near-infrared wavebands at each canopy layer, which leads to the calculation of upward and downward diffuse fluxes of scattered direct beam radiation ($I_{dir} \uparrow_i$, $I_{dir} \downarrow_i$) and scattered diffuse radiation ($I_{dif} \uparrow_i$,$I_{dif} \downarrow_i$) per canopy layer, normalised by the incident direct and diffuse fluxes respectively above the canopy. The normalised fluxes are used to calculate the direct and diffuse fractions of absorbed incident PAR, $FAPAR_{DIR_i}$ and $FAPAR_{DIF_i}$, at each canopy layer i:

$$FAPAR_{DIR_i} = [I_{dir} \uparrow_i - I_{dir} \downarrow_i] \, dL_c \tag{15}$$

$$FAPAR_{DIF_i} = [I_{dif} \uparrow_i - I_{dif} \downarrow_i] \, dL_c \tag{16}$$

A comparison of the vertical profile of absorbed incident PAR calculated with the two-stream approach against the profile estimated with Beer's law showed that the results were similar only when the incident PAR was a direct beam coming from a high sun angle, otherwise the fraction of absorbed PAR at any canopy level is higher when calculated using Beer's law (*Jogireddy et al.*, 2006).

The two-stream approach provides a vertical profile of intercepted radiation within the canopy which allows estimation of photosynthesis and leaf respiration for each leaf area increment within the canopy.

Sunfleck penetration

A further improvement to the estimation of absorbed radiation fluxes within the canopy considers penetration of sunflecks through the canopy, which corresponds to the direct component of the direct beam radiation, i.e. it excludes the scattering component. Such a term is not included in equation 15. Attenuation of I_b, the non-scattered incident beam radiation per unit leaf area at canopy depth L, normalised by the incident direct beam radiation above the canopy, is calculated as (*Dai et al.*, 2004):

$$I_b = (1 - \omega) k_b \exp^{-k_b L} \tag{17}$$

where $(1 - \omega)$, is the non- scattered part of the incident beam (i.e. what is absorbed) and k_b is the canopy beam radiation extinction coefficient.

Following *Dai et al.* (2004) as implemented in *Mercado et al.* (2009), radiation fluxes are split into direct beam radiation, scattered direct beam and diffuse radiation and it is assumed that sunlit leaves absorb all types of radiation, while shaded leaves absorb only diffuse radiation. The fraction of sunlit leaves (f_{sun}), is defined as:

$$f_{sun} = \exp^{-k_b L} \tag{18}$$

For each canopy layer i with leaf area increment within the canopy (dL_c), the fraction of sunlit leaves, fraction of absorbed direct beam radiation (I_{b_i}), fraction of scattered direct beam (I_{bs_i}) and fraction of absorbed diffuse radiation (I_{d_i}) are:

$$f_{sun_i} = \frac{\exp^{-k_b L}(\exp^{-k_b dLc} - 1)}{k_b dL_c} \tag{19}$$

$$I_{b_i} = (1 - \omega) \left(\frac{\exp^{-k_b (L - dL_c)} - \exp^{-k_b L}}{dL_c} \right) \tag{20}$$

$$I_{bs_i} = \omega \left(\frac{\exp^{-k_b (L - dL_c)} - \exp^{-k_b L}}{dL_c} \right) + FAPAR_{DIR_i} \tag{21}$$

$$I_{d_i} = FAPAR_{DIF_i} \tag{22}$$

The fractions of the incident radiation above the canopy which are absorbed by sunlit leaves I_{sun_i} and shaded leaves I_{sh_i} in each leaf area increment within the canopy are calculated as:

$$I_{sh_i} = f_d I_{d_i} + (1 - f_d) I_{bs_i} \tag{23}$$

$$I_{sun_i} = I_{sh_i} + (1 - f_d) I_{b_i} / f_{sun_i} \tag{24}$$

where f_d is the fraction of PAR which is diffuse radiation. I_{sun_i} and I_{sh_i} are used to calculate the radiation absorbed in each canopy layer by sunlit and shaded leaves by multplying by the incident radiation above the canopy, and thus to estimate photosynthesis from sunlit A_{sun_i} and shaded leaves A_{sh_i} for each canopy layer.

References

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