Shortwave Radiation Transfer of Conifer Boreal Forests During BPREAS: Results of Measurement and Modeling

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Abstract The role of Boreal forest biome in climate change has been investigated through the BOREAS experiment. Measurements of solar fluxes in conifer stands show important directional effects in the radiation field. These effects are mainly related to tree sarrangement and crown architecture. A simple model of direct transmittance can explain an important angular signature observed on the results.

Key words Radiation transfer measurements, Directional effects, Modeling

1 INTRODUCTION

The role of boreal forest in determining regional and global climate is critical to understanding both the global carbon cycle and the biophysical feedbacks on the physical climate system and within the environment. Hence, the BOREAS experiment was implemented to improve our understanding of the interactions between the boreal forest biome and the atmosphere and further to clarify their roles in global change. The project gives special emphasis to the governing climatological variables controlling the biome life such like the temperature which is strongly attached with length of growing season and radiation budget.

Radiation appears as a main driver of boreal forest activity with temperature since radiation contributes to warm the inside of the canopy as well to unfreeze understore canopy. Hence, characterizing radiation field inside the forest canopy is central to the understanding of exchanges of energy and mass fluxes but also for describing the complex architecture.

In this paper, initial focus is on presenting solar flux measurements acquired in routine during the summer 1994 at different levels of two major species of the conifer boreal forests. The forest canopy and understory albedos and the vertical profile of transmittance are derived from these measurements, also the fraction f_{APAR} of absorbed PAR. Time series reveal the photosynthetic activity while hourly results are linked to the complex architecture of the forest. It is observed important directional effects on the measurements due to trees arrangement and crown structure. The second focus of this paper is to present first results of an hybrid model of transmittance accounting for radiative transfer within a single tree as a turbid medium and radiation extinction within trees. This approach remains conceptually close to Ni *et al*.[1]

2 DESCRIPTION AND RESULTS OF THE EXPERIMENT

The experiment aimed at measuring solar fluxes over the Old Jack Pine (OJP) and the Black Spruce forests (BS) which are two major species in BOREAS. A plot sized as 15m by 15m was equipped with a permanent set of small hemispherical optical sensors. A sensor is composed of an amorphous silicon detector sensitive in the PAR range (0.4—0.7 μm) and a crystalline silicon detector measuring global shortwave radiation (0.4—1.1 μm). Near infrared signal is then retrieved from difference. Sets of sensors were positioned at ground level, up and under the licken or moss layers, and onto horizontal bars located every 2 meters on a mast. Data were registered every 10mn from sunrise to sunset and from May to September. Transmittances and albedos are derived from these measurements. The retrieved vertical pattern of radiation interception and long-term data sets yield the originality of this experiment.

For OJP, most radiation interception is by the

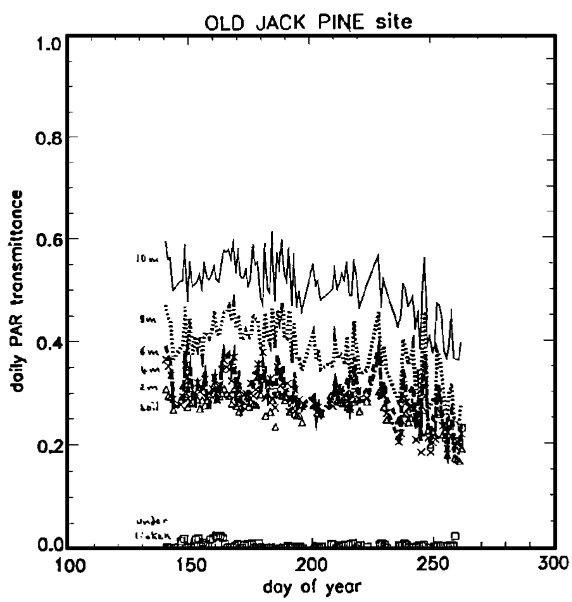

Fig. 1 Seasonal profile of daily PAR transmittance for different levels of OJP stand

crown located on top (Fig. 1) while it is more gradual for BS with absorption by the upper layers earlier in the season (Fig. 2). Unfortunately, the seasonal variability of the sun geometry masks the true interception related to biophysical processes (Fig. 1 and Fig. 2). Note that an important quantity of energy radiation reaches the soil background on OJP stand in comparison to BS.

Hourly transmittances were firstly averaged from before and after solar noon data in order to improve the space sampling. Results show important directional effects (Fig. 3) which are mainly related to within and between crowns gaps and clumping effects of branches, shoots and needles. All transmittance curves decrease at large sun angles as far sky radiation dominates. Then, a large maximum is observed in the upper layers on OJP stand located just under the

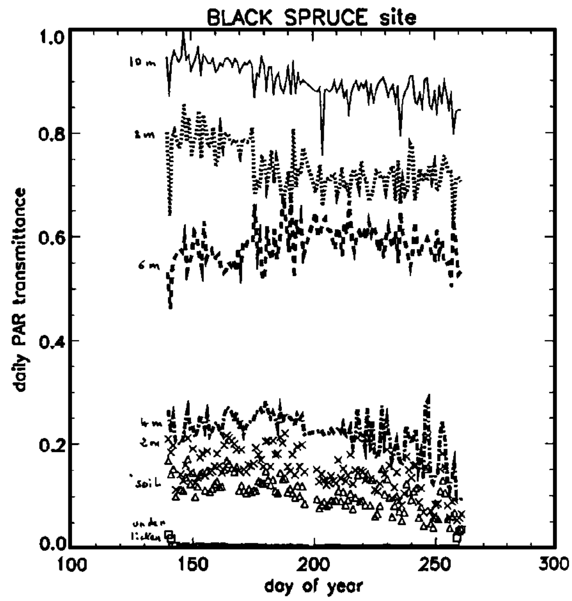

Fig. 2 Seasonal profile of daily PAR transmittance for different levels of BS stand

crown. In the lowest canopy levels, the transmittance goes through a minimum for both conifer stands. It is believed that projection of the crown is responsible for such a feature since it contains most canopy foliage with dominant horizontal branches. Finally, transmittance increases near solar noon due to travel of light between crowns. The light even goes through the liken layer on OJP at noon, while never for the moss layer of BS. This result may be particularly relevant for studying the snowmelting patterns.

3 MODELING THE FOREST TRANSMITTANCE

Modeling has been guided by results of measurements and the work of Larsen *et al*.[2] Basic statement is that a forest canopy is composed of layers having various properties, and that illumination or not of these layers may affect the results. The model presented here assumes the surface is composed of a fraction γ of a turbid medium, for instance the crown surface, and a fraction $(1-\gamma)$ where tree elements (needles, branches) can cast shadows:

$$T(\theta_s) = (T_{geo})^{(1-T_{vol})} \qquad (1)$$

with $T_{geo} = e^{-\frac{h_c}{d_t(1-\gamma F)}\tan(\theta_s)}$ and $T_{vol} = e^{-\frac{LAI}{\gamma}\frac{G(\theta_s)}{\mu_s}}$ where h_c is the canopy height, d_t is the distance between trunks, and F mediates the tree shape.

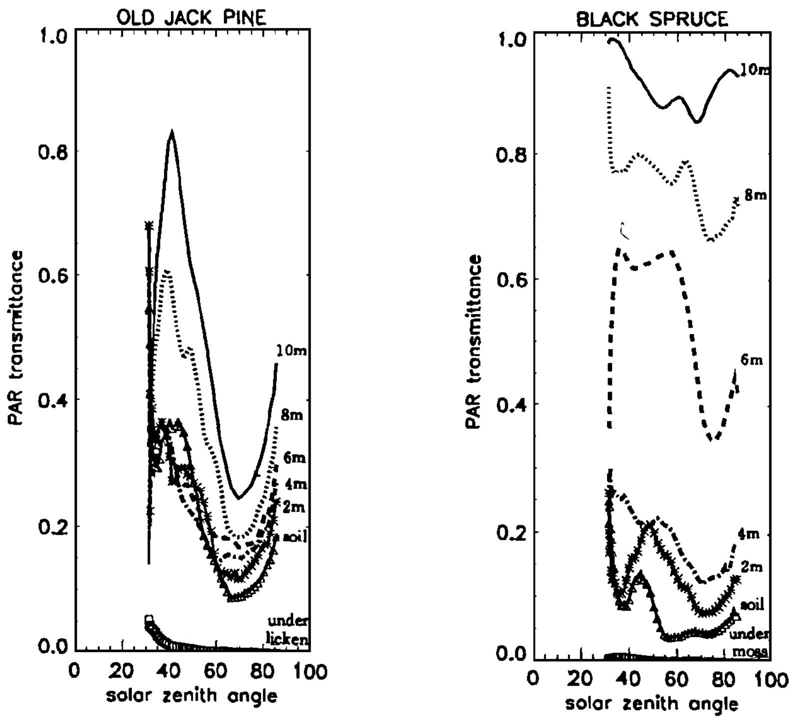

Fig. 3 Diurnal profile of PAR transmittance for different levels of OJP stand (left) and BS stand (right)

The parameter F, LAI[3], and geometry function G vary vertically within the canopy because most foliage is located in the crown and branches are less horizontal at the top. It is stated that direct radiation reaches an altitude $z_{min}h_c$ where $z_{min} = e^{-\frac{d_t}{h_c}\frac{1}{\tan(\theta_s)}}$. Examples are given in Fig. 4 for ground level transmittance with simple functions of z_{min}: $F = 1 - z_{min}$ and $G(z_{min}, \theta_s) = 0.5[G_n + G_v z_{min}^2 + G_h(1 - z_{min}^2)]$ where $G_n = 0.5$ is for needles, and G_v and G_h stand for vertical and horizontal orientations. The transmittance may be calculated at any altitude z in replacing z_{min} with z, provided $z_{min} < z$ or in accounting for multiple scattering in the layer $[z, z_{min}]$. The model in (1) mimics the minimum of transmittance at low levels but located further from zenith on the measurements (Fig. 3). After validation against in situ measurements, this model will be very useful to detect fine changes in conifer stuctural properties during the active season.

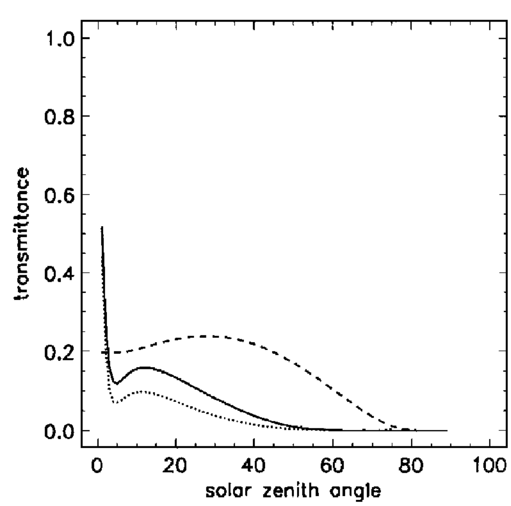

Fig. 4 Simulations of transmittance components T_{geo} (dotted) and T_{vol} (dashed) and total transmittance T (full line) $h_c = 15$ m, $d_t = 5$ m, $\gamma = 0.9$, LAI = 2

4 CONCLUSION AND FUTURE WORK

This paper reported results of radiation transfer measurements collected in boreal conifer stands in the framework of BOREAS. Seasonal and diurnal variations in sun geometry yield important directional effects on the transmittance patterns. The travel of radiation within or between crowns, the arrangement of trees, and the crown architecture are first determining. A model of direct PAR transmittance was presented which reproduces an important observed feature. The inclusion of albedos for tree elements will account for multiple scattering[4]. Other possible improvements on the model are location of the crown and an enhanced description of the vertical pattern of main characteristics. The model will be applied to time series to remove the seasonal variability of insolation in order to get the true evolution of the forests. It will also serve to derive a reflectance model which will be compared with remote sensing observations acquired by the airborne POLDER multiangular instrument.

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AUTHOR

Jean-Louis Roujean was born in November 1963 and received the Ph. D. degree in environmental physics and chemistry sciences (speciality remote sensing) in November 1991 from the Paul Sabatier University, Toulouse, France, while he was working at LERTS. His primary field of interest is the modeling of surface reflectance bidirectional effects for the correction of satellite multitemporal data sets. In 1991, he joined the Centre National de Recherches Météorologiques of Meteo France in Toulouse as a CNES post-doctoral scientist. From 1994, he is with the Centre National de la Recherche Scientifique. His application interests are in the use of remote sensing over land surfaces for meteorology as an investigator of the POLDER project. He also led experiments on shortwave radiation budget inside vegetation canopies during HAPEX-Sahel (1992) and BOREAS (1994). He contributed to 12 publications, 6 as first author, most appeared in remote sensing and geophysical reviews.

BOREAS 中北部针叶林的短波辐射传输测量结果及建模

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摘 要 通过BOREAS实验，我们研究了北部森林植物群落对气候变化所起的作用。对针叶林地带太阳辐射通量的测量表明在辐射场中有重要的方向效应。这些效应主要与树林的分布及树冠结构有关。一个简单的方向传输模型可以解释在观测结果中的一个重要的角度特征。

关键词 辐射传输测量，方向效应，建模