Development of More Realistic Radiation Schemes for Climate Models and Remote Sensing

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Objective A

To improve the accuracy of the description of canopy radiative transfer while maintaining the simplicity and computational efficiency of radiation schemes in context of climate models (Tian et al. 2006)

Introduction

- Two-stream approximations for canopy radiative transfer have been widely used to obtain canopy reflectance, transmittance and absorptance in climate models.
- Compared with satellite observations such as MODIS, large albedo biases have been identified in climate models over semi-arid and snow-covered vegetated surfaces.
- Two-stream approximations were based on the development made in the field of atmospheric physics. King and Harshvardhan (1986) pointed out that various two-stream approximations for atmosphere models can produce 15~20% relative errors. Similar errors are expected for two-stream approximations for vegetation canopies.

Four-stream isosector scheme

- We adopt the four-stream isosector approximation of Li and Dobbie (1998) for canopy radiative transfer. This scheme approximate the diffuse intensity as isotropic (independent of local zenith angle) in each sector and thus the intensity can be taken out of the integral of the multiple scattering source term and the inherent difficulty of the radiative transfer equation is avoided.
- We solve the complex equations analytically using the software "Mathematica" instead of providing equations. The symbolic solutions derived from the software can be easily applied to canopy radiation modeling given required input parameters.
- For testing, we assume that the G function =0.5 and individual leaves are lambertian scattering elements. i.e., normalized phase function P=1, r=t=0.5ω, where r is leaf reflectance, t is leaf transmittance, and ω is leaf single scattering albedo. r and t are set as 0.05 for the visible band and 0.45 for the near-infrared band.
- The accuracy of our four-stream approximation is examined by comparing the approximate results with the "exact" values computed from a multi-layer canopy radiative transfer (RT) model developed by Myneni et al. (1987).

Conclusions

- The four-stream isosector approximation scheme is an analytical model, and can be easily applied as an efficient approach to improving the parameterization of land surface radiation in climate models.
- The four-stream improves accuracy over the two-stream by a factor of about 3 to 10.

Direct Incident Radiation

- In the visible band, the albedo has a relative error of <10% depending on sun angle for the 2-stream and <6% for the 4-stream in the LAI-μ_0 space. The transmittance for the 4-stream has a relative error mostly less than 2%, even at very low sun positions; the 2-stream has a comparable relative error for high sun positions or low LAI but becomes extremely large at high LAI and μ_0 less than 0.4. The relative error for the absorption is very small for both schemes but the 4-stream still has a better performance.
- In the NIR band, the relative errors of albedo and transmittance are smaller for both the 4- and 2- stream, compared to those in the visible band. The transmittance of the 4-stream gives a relative error less than 2% at all sun angles and the 2-stream has a slightly larger error. The relative error of absorption is larger in the NIR band than that in the visible band, but the 4-stream performs better.

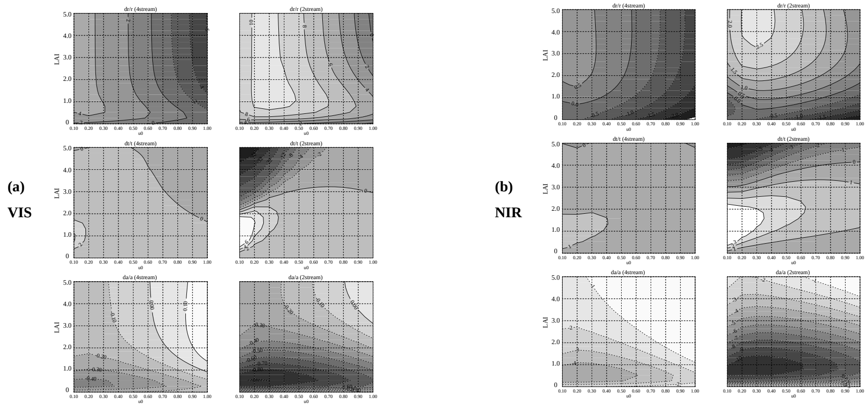

Figure 1. Relative errors of albedo, transmittance and absorptance from the four-stream and two-stream schemes as a function of leaf area index (LAI) and cosine of solar zenith angle (μ_0) in (a) the visible and (b) the NIR band for direct beam radiation under the black soil condition (soil albedo ρ = 0).

Diffuse Incident Radiation

- For the visible band, the albedos of the 2-stream have a low accuracy, with a relative error in the order of 20% (Fig. 2). The relative errors larger than 10% occur for the transmittance with LAI higher than 0.5 and such errors increase almost linearly with LAI. The albedos of the 4-stream have a relative error less than 3%. The transmittance of the 4-stream has a much smaller relative error than that of the 2-stream. For the absorption, the 2-stream generally produces an error of 2-12% while the error of the 4-stream is within 4%.
- The NIR band shows similar features in the relative error as the visible band but with a smaller magnitude.

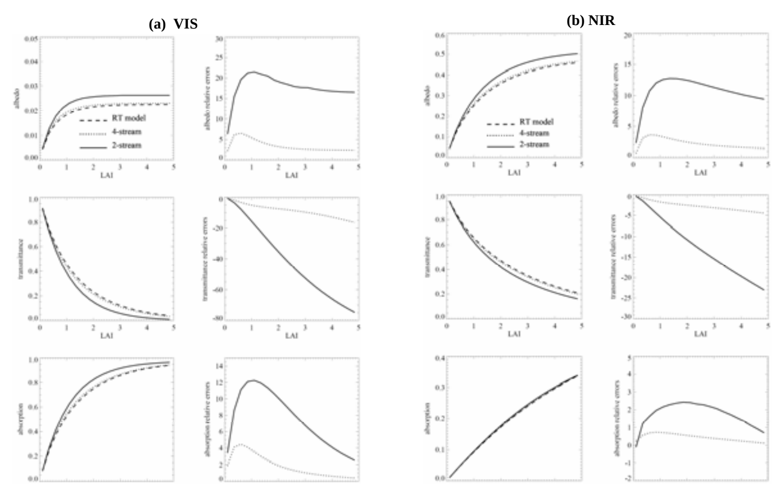

Figure 2. Albedo, transmittance, and absorptance (left panel) and their relative errors (right panel) from the four-stream and two-stream schemes in (a) the visible band and (b) the NIR band for incident diffuse solar radiation under the black soil condition (soil reflectance ρ = 0).

Objective B

To revise the reflection model to begin with a BRF calculation and thus make it also be useable for remote sensing (Tian et al., in preparation).

Methods

Notation: $\Phi(\mu_s, \mu_v)$ the BRF, subscripts ss for the single scattering contribution and ms for the multiscattering, normalized by factoring out single scatter albedo.

$$\Phi(\mu_s, \mu_v) = \omega_u \; \Phi_{ss}(\mu s, \mu v) + \omega^2 \, \Phi_{ms}(\mu_s, \mu_v) \qquad \text{(B1)}$$

ω = single scattering albedo, and its subscript u represents upward direction for asymmetric scattering. It depends on the treatment of leaf shape and orientation and possible depending on sun angle and angle between sun direction and view direction. Leaf orientation effects are neglected in the treatment of the multiscattering. Assume the underlying surface is black, the single scattering term with the effective leaf orientation effect, G, is:

$$\Phi(\mu_s, \mu_v) = 0.5 / (\mu + \mu_s) \, [\, 1. - \exp(-G\,(1/\mu_s + 1/\mu_v))LAI] \qquad \text{(B2)}$$

The multiscattering contribution is evaluated with an eigen-function approach; for small to moderate LAI, a single term is needed. As most of the improvement in the four-stream over two-stream accuracy comes from the integration to get albedo, a single two-stream mode (four-stream would involve an addition mode (or set of modes)) can be used. The multiscattered BRF is written as:

$$\Phi_{ms}(\mu_s, \mu_v) = \; \psi(\mu_s,\tau)\, \psi(\mu_v,\tau) / (\lambda - \omega) \qquad \text{(B3)}$$

with τ = G LAI, and where ψ are derived by integrating either incoming or outgoing radiation attenuated by Beer's law over the resolvent kernel obtained in terms of eigenfunction(s) and λ is the lowest mode eigenvalue (e.g. Huang et al. , 2006) given by $\lambda = k^2 + 4\,\tau^2$ where the k is determined by transcendental equation requiring Beer's law to be satisfied at the boundaries by the eigenfunction. For small τ it simplifies to $2\tau^{1/2}$. The integration is

$$\psi(\mu,\tau) = \int dz \exp(-\tau z/\mu) \cos kz \qquad \text{(B4)}$$

This integration is from 0 to 1, and gives algebraic, trigometric, and exponential terms.

Albedo $\alpha(\mu_s)$ is obtained by a four-stream integration (Tian et al., 2006):

$$\alpha(\mu_s) = \int f(\mu)\, d\mu = 0.5\, [f(0.25) + f(0.75)] \qquad \text{(B5)}$$

where $f(\mu) = 2\,\mu\, \Phi(\mu_s,\mu)$ and Φ is given by B(1)-B(3) . This approach is being validated with the four-stream solutions of Tian et al. (2006).

References

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