Spectral invariants in vegetation reflectance modeling

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Vegetation reflectance models rigorously follow the transfer of shortwave radiation in plant canopies. The models differ mainly in the implementation method of the radiation transfer and the approach in quantifying the canopy. In the most simple and already classical approach, the vegetated layer is described as a continuous layer of infinitesimally thin plates – leaves – with predefined orientation. Most detailed models use 3D raytracing and an explicit tree structure model. A compromise in detail and computing speed are the so-called geometric-optical models which describe a vegetation canopy (or, specifically, a forest) as a set of geometric objects, tree crowns.

The foundations of the 'spectral invariants theory' were put forth as a new tool to model the shortwave radiation absorbed or scattered by vegetation nearly two decades ago. According to this theory, the amount of radiation absorbed, reflected or transmitted by a vegetation canopy should, to a great accuracy, depend only on the spectral albedo of canopy elements – leaves – and one or more wavelength-independent parameters quantifying the structure of the canopy. Later, the theory has been extended to the scale smaller than the leaf. The optical properties of a vegetation canopy in the visible and near infrared spectral regions has been demonstrated to largely depend on the absorption spectrum of chlorophyll and a nested set of spectral invariants – an invariant for each structural level (leaf, shoot, tree, canopy). In using abstract canopy levels, spectral invariants are well matched with geometric-optical canopy reflectance models with additional structural levels inside a crown envelope. Other spectral invariants have been introduced to quantify the directionality of canopy scattering. The invariants have their mathematical roots in the eigenvalues of the radiative transfer operator, supporting their application in structurally and optically varying vegetation covers. The spectral invariant – or a set of nested invariants – describing absorption is closely connected to the photon recollision probability. This largely intuitive quantity can be estimated from optical measurements of canopy structure and easily modeled with any modern physically-based canopy radiative transfer model. It has been successfully applied in the simple canopy reflectance model called PARAS and scaling of optical properties between different scales: from needle to the canopy.

We demonstrate some of the applications of the spectral invariants and photon recollision probability in global and local monitoring of vegetation using spectral data. It is especially useful in a boreal forest with distinct levels of clumping, but it is also fully compatible with the two-stream approach in canopy reflectance modelling. The full potential of the theory of spectral invariants, allowing to separate the biochemical and structural components in the spectral reflectance signal of vegetation, is yet to be unleashed.