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From vegetation BRDF to BPDF: Vector remote sensing basic model and its application on vegetation chlorophyll retrieval

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High-accuracy remote sensing retrieval of vegetation ecological parameters can help to understand and accurately predict near-surface climate change. Light is essentially transverse electromagnetic vector wave. Scalar-based remote sensing, taking bidirectional reflection distribution function (BRDF) as its basic model and neglecting the polarization characteristics, regards the reflected radiation as overall intensity, whereas vector remote sensing, considering polarization characteristics of light, distinguishes the vegetation reflected radiation as its specular and interior partition, and helps to achieve more detailed and accurate retrieval of vegetation parameters. As the fundamental model of vector vegetation remote sensing, bidirectional polarization distribution function (BPDF) model is of great significance.

This study aims to use mechanism of interaction between photons and vegetation elements to develop a vegetation polarization BPDF model and achieve more reliable retrieval of key ecological parameters. We first derive more accurate description of photon-canopy interaction by accounting for variation of leaf scattering with dry matter content, so that photon directional escape probability (DEP) can be more accurately obtained via spectral invariant model from remote sensing data. Based on the first-order DEP, we propose a vegetation BPDF physical model named DEP-P. The analytical expression and general expression of the DEP-P model are derived based on the principle of the first-order photon-canopy interaction. The forward modeling of vegetation polarized reflectance of the model is directly validated through the three-dimensional vegetation and actual forest scenes, and the root mean square error is within 0.001. The model is also indirectly validated using multi-scale multi-angle polarization data. Based on the inversion mode of DEP-P model, remote sensing retrieval of leaf chlorophyll based on polarization observation is realized for the first time. The root mean square error of chlorophyll retrieval in the actual forest scene reaches only 4.8 $\mu g/cm^2$, which coincides with the leaf clamp method. Using airborne and spaceborne polarization data, DEP-P chlorophyll retrieval algorithm is cross-validated compared with other algorithms and existing products. The DEP-P chlorophyll retrieval is mechanism-based non-parameter method so the algorithm is simpler and more generalizable compared with existing methods. This study preliminarily proves that the capability of BPDF model to accurately retrieve vegetation parameters.

Keywords: Vegetation, BRDF, BPDF, Vector remote sensing, Polarization, Ecological parameters