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# 3D Solar Radiative Transfer in the Earth's Atmosphere/Surface System: Past, Present, and Future Challenges

A.B. Davis
Jet Propulsion Laboratory / California Institute of Technology, PASADENA, United States (anthony.b.davis@jpl.nasa.gov)

I will trace the history, survey the state-of-the-art, and look into the future of 3D radiative transfer (RT) in the Earth's atmosphere/surface system. Focus will be on the solar spectrum, which is dominated by scattering and reflection, and the two main applications that drive the research will be covered, namely, radiative energy budget estimation and remote sensing, both over a wide range of scales and/or sensor resolutions.

Across these broad application areas, one must first assess the 3D spatial variability that violates the standard assumption of horizontal uniformity in 1D RT. Is it at small scales, i.e. sub-pixel or sub-gridcell? Or is it fully resolved in the observations or in the computational grid? Does the variability cover a broad range of scales? How do the variability scales compare with important structural and optical scales, such as the vertical thickness of the medium and the scales that matter for propagation (e.g., inverse of the mean extinction coefficient).

Depending on the outcome of this preliminary analysis as well as the targeted properties of the 3D radiance (or Stokes vector) field, the 3D RT problem at hand falls in one of two broad categories:

* When the variability is resolved and known in all of its specificity, and the desired properties are gridded, then we are faced with an "adjacency" problem in 3D RT; net horizontal radiative fluxes thus need to be modeled explicitly by solving numerically the 3D RT equation (RTE) at some appropriate level of fidelity, accuracy and efficiency. Several approaches are possible, but there are many less computational techniques to choose from than for the 1D RTE.

* When the variability is unresolved, possibly defined only by statistics, and the desired properties are domain-averaged, then we are faced with a problem of "stochastic" RT. In this case, many approaches have been explored, enough to warrant further classification. Does the method rely on one or more solutions of the standard 1D RTE? Are there new parameters that control the modified coefficients to account for spatial variability (a.k.a. homogenization)? Alternatively, is the stochastic RT problem recast completely with a new set of equations to solve?

I will illustrate these two kinds of cloud-related 3D RT endeavor with recent collaborative research that came to fruition only by cross-fertilizing ideas from different disciplines ranging from statistical physics to numerical analysis to inverse problems and computer science.