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Cloud and Aerosol Remote Sensing: Thinking Outside the Photon State-Space Box

Anthony B. Davis
Jet Propulsion Laboratory - California Institute of Technology

Atmospheric particulates, cloud droplets/crystals and aerosols, are of paramount importance in the climate system, both for their role in the energy budget and the in hydrological cycle. In fact, the complex interactions of (at least partially anthropogenic) aerosols and clouds have been singled out as the most significant sources of uncertainty in predictive climate modeling. This makes them very high-value targets in current and near-future satellite remote sensing missions at NASA and elsewhere.

It has been suggested that polarization is the "last frontier" of space-based remote sensing targeting quantities and properties of atmospheric particulates, either inside or outside of cloud masses. I will show that this statement only makes sense in the current operational framework for processing remote sensing data on a pixel-by-pixel basis—an unnecessarily limited perspective.

Indeed, looking at a single photon detected from a single pixel all we have to work with is its wavelength (photon energy) and direction of propagation (photon wavevector). Upon cumulation of many photons, these attributes lead respectively to multi-spectral and multi-angular retrieval techniques. A closer look at the detected photon population statistics gives access to polarization information, tracing back to the individual photon's third and last quantum property, namely, its spin. We have thus exhausted the possibilities offered by photon state space statistics. But have we exhausted the possibilities offered by remote sensing observations?

The answer is negative, but there is a computational price to access two wide-open frontiers in remote sensing: multi-pixel techniques and time-domain techniques.

The natural physics-based signal prediction model used for pixel-by-pixel radiance (and polarization) processing in the solar through thermal spectrum uses steady-state (vector) radiative transfer theory implemented in plane-parallel slab geometry, a.k.a. 1D (v)RT modeling. So, in spite of the finite—and sometimes tiny—horizontal size of individual pixels, their multiply-scattered signal is assumed to originate from a horizontally infinite and uniform medium. In contrast, EM radiation in nature flows through the Earth's molecular and particulate atmosphere according to the laws of 3D (v)RT, with relevant spatial variability scales ranging potentially from the altitude of the highest cloud tops down to the Kolmogorov dissipation scale. Computationally feasible 3D (v)RT covers only a fraction of this range, and yet is already a challenge for present resources. However, computationally fast—even analytical—approximation techniques are increasingly available. Thus we can contemplate physics-based multi-pixel remote sensing supported by 3D (v)RT, from both space and ground. Several examples will be presented at the conference.

Finally, if we also think beyond spatially distributed steady-state sources (i.e., pulsed lasers) then time-domain and space/time-domain modalities open even more possibilities where classic lidar techniques (single backscatter, with time-of-flight-to-range conversion) are only the starting point. Moreover, the required technology for these advanced concepts is already available. In particular, we'll see that differential oxygen-line/-band absorption spectroscopy in the solar spectrum is a viable surrogate for pulsed laser sources (only without the narrow beam). Ground-based DOE facilities and upcoming NASA missions will soon be exploiting this opportunity.