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Atmospheric Measurement Techniques Discussions

Interactive comment on "Statistically optimized inversion algorithm for enhanced retrieval of aerosol properties from spectral multi-angle polarimetric satellite observations" *by* O. Dubovik et al.

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The authors of "Statistically optimized inversion ..." have done a remarkable job in integrative retrieval theory and practice, using POLDER/PARASOL, for aerosols using polarized multi-angle/multi-spectral satellite observations. The idea of using data from multiple pixels surrounding a target pixel is a very promising development that has understandably caught the attention of most of the reviewers. As a statistical ingredient that enhances retrievals grounded in 1D (in this case, vector) radiative transfer (RT) is

not entirely new since MISR's operational aerosol retrieval uses spatial context, as do recent versions of MODIS products for clouds, and likely others.

The question I ask is whether "multi-pixel retrieval" is the proper terminology. I think not, and suggest we talk here about a "multi-scale technique" or a "spatially constrained optimization" or an "adaptive exploitation of pixel context", or any other description that avoids "multi-pixel." The reason for this clarification is not just semantics but touches on the fundamentals of RT and remote sensing science.

To be clear, the forward-modeled and observed quantity in this study is (at least the first 3 components of) the TOA Stokes vector $\mathbf{I}_\lambda(\theta, \phi)$ as predicted by a state-of-the-art 1D RT code with coefficients computed by fully-integrated Mie-Lorentz and non-spherical particle optics codes, and the retrieved properties are input for one or another of these codes. The retrieval methodology presented here is certainly *multi-spectral* because all the λ-indexed values are coupled through the single-scattering computation. It is also *multi-angle* since all the (θ, ϕ)-indexed values are coupled through the multiple-scattering computation. It could also be described as *multi-polarization* since several Stokes vector elements are used and fully coupled in the forward model. However, there is no cross-pixel coupling in this forward modeling framework, so the present retrieval cannot be *multi-pixel* in the same sense of the word.

Forward RT models for TOA radiances $\mathbf{I}_\lambda(x, y, \theta, \phi)$ exist, where (x, y) are horizontal coordinates that can be mapped to different pixels in the scene, typically registered to the ground. However, these are necessarily 3D RT models that can capture cross-pixel radiative interactions. There have been several (although probably not yet "many") published applications of such 3D RT forward models to optical remote sensing data, from both passive and active modalities. In retrospect, these studies should have trademarked the "multi-pixel" terminology as they proactively *exploit* the notorious pixel adjacency effect. By contrast, mainstream atmosphere/surface remote sensing techniques (predicated on 1D RT models) are potentially *contaminated* by these effects.

Finally, there is a fundamental limit in remote sensing that we are now reaching by bringing polarization on line. All the dimensions of photon state space are now being mined! Historically, we started with photon energy/wavelength, hence the multi-spectral approaches of AVHRR, MODIS and kin. From there, we moved to photon momentum/direction, hence the multi-angle (and still multi-spectral) approaches of MISR, ATSR and kin. Now, we have enlisted photon spin as it appears in the statistics of photon populations, hence the polarization-capable methods explored with POLDER/PARASOL, APS/Glory, and future sensors/missions. Is this "The End" of physics-based remote sensing? (I'm recycling here the ominous words used by S. Weinberg, who announced "The End" of physics when the details of the Standard Model for elementary particles will be filled in.)

Not at all! At least two frontiers remain wide open for adventurous remote sensing scientists, particularly when pursuing cloud and/or aerosol properties: space and time. "Space" here means bone fide multi-pixel techniques based on 3D RT forward models. "Time" here means exploitation of time-domain information in lidar and radar signals that is encoded in the multiple-scattering contributions (i.e., beyond the standard radar/lidar equation). Also included as time-domain techniques are passive O_2 A-band studies since the primary information they provide is the pathlength (ct if you will) covered by sunlight as it scattered any number of times in the Earth's atmosphere. At any rate, the required forward RT model will have to be time-dependent.

In summary, we should choose our words as carefully as possible to not confuse the stakeholders of advanced remote sensing RD, and "multi-pixel" will become loaded with multiple meanings if we do not act fast. As a corollary, let us celebrate the complete exploitation of photon state space, and the beginning of a new era in physics-based remote sensing where forward RT modeling goes beyond the steady-state 1D case.

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