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Overview of 3D-TRACE, a NASA Initiative in Three-Dimensional Tomography of the Aerosol-Cloud Environment

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Remote sensing is a key tool for sorting cloud ensembles by dynamical state, aerosol environments by source region, and establishing causal relationships between aerosol amounts, type, and cloud microphysics—the so-called indirect aerosol climate impacts, and one of the main sources of uncertainty in current climate models. Current satellite imagers use data processing approaches that invariably start with cloud detection/masking to isolate aerosol air-masses from clouds, and then rely on one-dimensional (1D) radiative transfer (RT) to interpret the aerosol and cloud measurements in isolation. Not only does this lead to well-documented biases for the estimates of aerosol radiative forcing and cloud optical depths in current missions, but it is fundamentally inadequate for future missions such as EarthCARE where capturing the complex, three-dimensional (3D) interactions between clouds and aerosols is a primary objective. In order to advance the state of the art, the next generation of satellite information processing systems must incorporate technologies that will enable the treatment of the atmosphere as a fully 3D environment, represented more realistically as a continuum. At one end, there is an optically thin background dominated by aerosols and molecular scattering that is strongly stratified and relatively homogeneous in the horizontal. At the other end, there are optically thick embedded elements, clouds and aerosol plumes, which can be more or less uniform and quasi-planar or else highly 3D with boundaries in all directions; in both cases, strong internal variability may be present. To make this paradigm shift possible, we propose to combine the standard models for satellite signal prediction physically grounded in 1D and 3D RT, both scalar and vector, with technologies adapted from biomedical imaging, digital image processing, and computer vision. This will enable us to demonstrate how the 3D distribution of atmospheric constituents, and their associated microphysical properties, can be reconstructed from multi-angle/multi-spectral imaging radiometry and, more and more, polarimetry. Specific technologies of interest are computed tomography (reconstruction from projections), optical tomography (using cross-pixel radiation transport in the diffusion limit), stereoscopy (depth/height retrievals), blind source and scale separation (signal unmixing), and disocclusion (information recovery in the presence of obstructions). Later on, these potentially powerful inverse problem solutions will be fully integrated in a versatile satellite data analysis toolbox. At present, we can report substantial progress at the component level. Specifically, we will focus on the most elementary problems in atmospheric tomography with an emphasis on the vastly under-exploited class of multi-pixel techniques. One basic problem is to infer the outer shape and mean opacity of 3D clouds, along with a bulk measure of cloud particle size. Another is to separate high and low cloud layers based on their characteristically different spatial textures. Yet another is to reconstruct the 3D spatial distribution of aerosol density based on passive imaging. This suite of independent feasibility studies amounts to a compelling proofof- concept for the ambitious 3D-Tomographic Reconstruction of the Aerosol-Cloud Environment (3D-TRACE) project as a whole.