A two-dimensional demonstration of adjoint methods for atmospheric remote sensing

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Improved satellite observations of aerosols near clouds are needed to understand cloud-aerosol interactions. There is mounting evidence that we need to model three-dimensional (3D) effects to retrieve aerosols and clouds together in certain key regions, such as in broken cloud fields and near cloud edges. In previous work, we derived the adjoint method as a computationally efficient path to three-dimensional (3D) retrievals. This talk will show a synthetic retrieval study, in which we use a new two-dimensional (2D) radiative transfer solver (FSDOM) to retrieve cloud extinction and surface albedo from multi-angle reflectance measurements.

We generate multi-angle measurements with noise for several synthetic cloud fields and then retrieve the cloud extinction field as a 2D function of the horizontal and vertical coordinates. Our retrieval algorithm adjusts the cloud extinction field and surface albedo to minimize the measurement misfit function with a gradient-based, quasi-Newton approach. At each step we compute the value of the misfit function and its gradient with two calls to the solver FSDOM. First we solve the forward problem to compute the residual misfit with measurements, and second we solve the adjoint problem to compute the gradient of the misfit function with respect to all unknowns. In this way, the adjoint method allows us to make each adjustment to atmosphere and surface properties with only two radiative transfer calculations, regardless of the number of measurements and unknowns.

Our synthetic retrievals verify that adjoint methods are scalable to retrieval problems with many measurements and unknowns. In cases with moderately thick clouds, we can retrieve the vertically-integrated optical depth as a function of the horizontal coordinate. It is also possible to retrieve the vertical profile, i.e. the full 2D cloud field, for clouds that are separated by clear regions. The retrievals of the vertical profile improve for smaller cloud fractions. This leads to the interesting conclusion that cloud edges actually increase the amount of information that is available for the vertical profile. However, to exploit this information one must retrieve the horizontally heterogeneous cloud properties with a 2D (or 3D) model.

These synthetic retrievals show that adjoint methods can efficiently compute the gradient of the misfit function, and encourage our ongoing efforts to augment the existing 3D radiative transfer code SHDOM with derivative calculations based on the adjoint method.

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