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SYSTEMATIC SIMULATIONS OF AEROSOL OPTICAL PROPERTY RETRIEVAL UNCERTAINTY FOR SCANNING POLARIMETERS

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ABSTRACT. Scanning polarimeters, which utilize multi-angle, multispectral polarimetric observations from aircraft and orbit, represent the next generation of instruments capable of determining aerosol and cloud properties remotely. Retrieval of these properties from observations, however, are not straightforward. Iterative minimization techniques are often used to match radiative transfer simulations to the observations, where the aerosol and cloud parameters of the optimal model match are considered the best estimate of what is physically present in the scene. If the radiative transfer model perturbation sensitivity, expressed as a Jacobian matrix, can be assessed at the solution, then the observation uncertainty can be projected into the domain of the retrieved parameters. These parameter uncertainties provide are an extremely useful means to assess retrieval success. Another aspect of our iterative minimization techniques is the need for a reasonable initial estimate of optical properties. This estimate is provided by matching observations to a Lookup Table (LUT) of pre-computed radiative transfer scenes. This LUT spans a wide range of aerosol and cloud optical properties, and also includes numerical estimates of the Jacobian matrix at each element in the LUT. Using the Jacobians, we can estimate the retrieval uncertainty for all elements of the LUT, and therefore build a table of expected uncertainty. This paper presents how this approach is used in a systematic manner, and how it can be used to test retrieval capability for various combinations of polarized, multi-angle and multispectral observations.

1. Introduction

While the sophistication and accuracy of global climate models have improved greatly recent years, large uncertainties remain. One of the most uncertain elements of climate models are atmospheric aerosols, both through their direct radiative effects and their complex interactions with clouds [1]. Much of this uncertainty is due to the limitations of currently available observations [2, 3]. These orbital instruments are typically capable of creating climatologies of the aerosol total atmospheric column extinction (the aerosol optical depth) and some proxy for particle size distribution. Other aerosol optical properties, such as complex refractive index and a more descriptive measure of size distribution, must be assumed both during observation and in climate models, leading to large overall uncertainty.

One approach to reducing this uncertainty is to observe more scene information, specifically by utilizing the polarized component of radiation scattered by aerosols. Polarization has been used by instruments such as Polarization and Directionality of the Earth's Reflectance (POLDER) [4, 5, 6], the airborne Research Scanning Polarimeter (RSP) [7, 8, 9, 10], and was anticipated for use with the Aerosol Polarimetry Sensor (APS) on the NASA Glory mission [11]. The APS was designed to accurately observe linear polarization at about 250 viewing angles and nine spectral channels (from 410nm to 2250nm). Unfortunately, the Glory satellite failed to reach orbit during its launch in March, 2011. The data processing system created for APS can, however, be used for other purposes. The Lookup Table of pre-computed scenes, including Jacobian sensitivity matrices, can be used to perform comprehensive sensitivity studies of sensor design. Here, we provide an overview for this approach, and show how it will be used to prepare for future missions.

2. Method

The LUT intended for use with the APS instrument includes a variety of aerosol types, and is expressed in terms of two size modes. For each mode, there is a dimension for aerosol optical thickness, complex refractive index, and particle effective radius and variance. At each element in the LUT, the Jacobian matrix, $\mathbf{J}$, is numerically estimated by determining the sensitivity in the forward model, viz.

$$J_{ij}(\mathbf{x}) = \frac{\partial F_i(\mathbf{x})}{\partial x_j} \tag{1}$$

where the partial derivative of forward model, $\mathbf{F}$, for the simulated set of parameters, $\mathbf{x}$, is computed for each observation (i) and each parameter (j). The partial derivative was estimated numerically by perturbing the j^{th} element of $\mathbf{x}$ and recalculating the forward model. Simulated parameter uncertainty is then determined by using the Jacobian to project observation uncertainty into parameter space.

$$\mathbf{C}_x = (\mathbf{J}^T \mathbf{C}_T^{-1} \mathbf{J})^{-1} \tag{2}$$

The square root of the diagonal elements of $\mathbf{C}_x$ are the errors for each parameter in $\mathbf{x}$, provided that the measurement error covariance matrix, $\mathbf{C}_T$, is accurate and the forward model is linear over the perturbation range used to numerically calculate $\mathbf{J}$ [12]. Simulated uncertainties can be determined for a variety of sensor configurations without additional runs of the radiative transfer model. All that is required are appropriate modifications of the measurement error covariance matrix and subsets of the Jacobian matrix.

3. Preliminary results

Simulated retrieval uncertainty, as in equation 2, can be computed for the entire LUT, spanning a wide range of aerosol, surface and geometric scenarios. While visualization of such results is challenging, we present a slice of uncertainties for an urban/industrial aerosol at a variety of optical thicknesses in Figure 1. Black lines indicate simulated uncertainty for the full set of observations available to APS (7 polarized reflectance bands and a conservative estimate of roughly 200 viewing angles from $45°$ forward to $45°$ aft of the spacecraft motion). Blue lines indicate the simulated uncertainty at the same viewing angles, but without the shortwave infrared channels. In this case, error increases dramatically for coarse size mode parameters, although it increases for fine size mode parameters

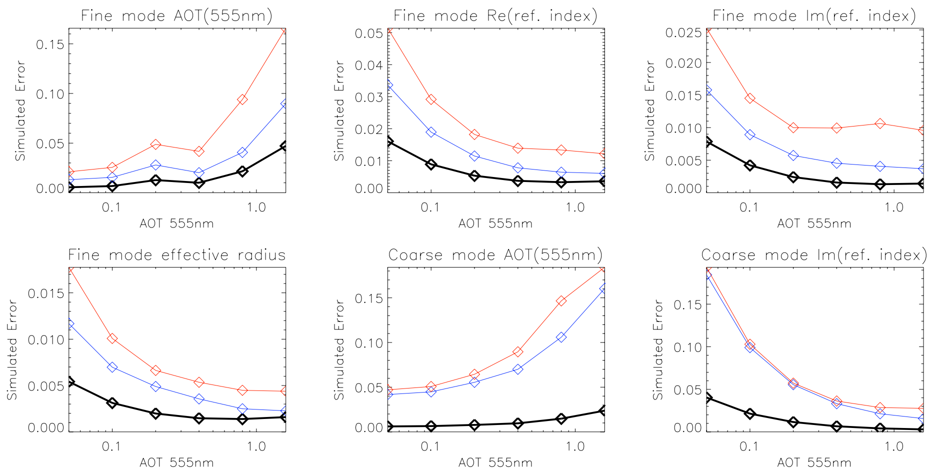

Figure 1. Simulated uncertainty for retrievals of an urban/industrial aerosol (the ”Mexico City” class from [13]) over an ocean with a windspeed of $7m/s$ and Chlorophyll content of $0.1mg/m^3$ at a solar zenith and relative azimuth angle of $45°$. Black lines indicate the simulated uncertainty for observations similar to APS, at wavelengths of 410, 443, 555, 672, 865, 1380, 2250nm. Blue lines are the simulated uncertainties when the short wave infrared bands (1380 and 2250nm) have been excluded, while red lines are the simulated uncertainties when only the 555, 672 and 865nm bands have been used.

as well. Red lines indicate simulated uncertainty after removing the two blue wavelength bands. Simulated uncertainty increases further for fine size mode parameters, but effects on coarse mode aerosols are limited. Parameter uncertainty decreases for most parameters as aerosol quantity increases, the only exceptions are for fine and coarse mode aerosol optical thickness. When expressed as a percent error, however, the latter uncertainties decrease with increasing optical thickness as well.

4. Conclusion

We present a simple, straightforward and computationally inexpensive means to test expected retrieval uncertainty for an entire set of aerosol parameters. While other factors, such as parameter and observation correlation, can affect retrieval success, this is a convenient aid to the design of future sensors.

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