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Simulation of high-resolution radiance spectrum using the dependent sampling Monte Carlo method

H. Iwabuchi

Center for Atmospheric and Oceanic Studies, Graduate School of Science, Tohoku University, 6-3 Aoba, Aramakiaza, Aoba-ku, Sendai Miyagi 980-8578, Japan (hiroiwa@m.tohoku.ac.jp)

Spectral radiance measurement provides a wealth of information about gases, aerosols, and clouds. Retrieval of an atmospheric quantity from high-resolution radiance spectrum normally requires simulating not only the radiances but also derivatives with respect to the quantity of interest. A radiative transfer model JACOSPAR for spherical shell atmosphere uses the dependent sampling Monte Carlo (MC) method, which allows a simultaneous simulation of spectral radiances at thousands or more wavelengths. The model accounts for radiation sources of solar radiation and thermal emission and the refraction by air density variation. Semi-analytical equations determine a radiance component of single scattering for solar radiation and a direct transmission component of thermal radiation, and multiple scattering components are computed by using the backward-propagating MC algorithm.

The model also employs a sampling method to calculate derivatives of the spectral radiance, for the entire spectrum, with respect to the absorption and scattering coefficients, surface albedo, and atmospheric and surface temperatures. Sampling analytic derivatives of the radiance contribution function for each scattering event of each photon bundle enables to estimate the above derivatives from a single MC simulation. In general, there are quantities to which derivatives cannot be computed by analytical derivatives of the contribution function. An example is the effective particle size of aerosol or cloud particles, which determines the scattering phase function in a complicated way. To estimate derivatives with respect to such a quantity, the dependent sampling method is also useful because it allows deriving solutions for systems with small perturbations in atmospheric and surface properties simultaneously with the original systems and estimating the derivatives by the finite differences.

Numerical tests demonstrated that the model was efficient particularly if the scattering properties were well correlated among different wavelengths, which is usually a valid condition for the solar and infrared spectra. Thus the model enables efficient simulations of hyper-spectral radiances and Jacobian matrices. The dependent sampling results in uncertainties (MC noises) that are correlated among wavelengths. A promising application is remote sensing of gaseous species and aerosols based on the differential optical absorption spectroscopy (DOAS). In the conference, we will show an example of hyperspectral radiances in the ultraviolet-visible region as observed from space and how the mean path length varies by wavelength, altitude, and aerosol amount and type. One more example is angular variation of radiance spectra of twilight sky that depend on ozone amount and aerosol amount, particle type, and vertical distribution.