Nonisotropic Aerosol Scattering Effects on Longwave Irradiance

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PURPOSE/AIM & BACKGROUND

This work investigates the effect of anisotropic aerosol scattering on the surface downwelling longwave irradiance (DLW) in the atmosphere using a Monte Carlo simulation. In the longwave scope of this work, Mie scattering by aerosols and longwave absorption by gases and aerosols are included. Many previous studies have developed a methodology to estimate scattering coefficients, absorption coefficients, asymmetry parameters and phase functions of aerosols using Mie scattering theory by implementation of effective aerosol size distributions and geometric refractive index of different kinds of aerosols. However, the complexity of Mie-type phase functions renders analytical modelling of atmospheric longwave radiation complicated and difficult to implement. Here a Monte Carlo simulation is used to study the effect of anisotropic scattering and to determine the situations when the simplifying assumption of isotropic scattering can be used with satisfactory accuracy. The Monte Carlo simulations allow for the development of a correction factor C for anisotropic aerosol scattering.

METHODOLOGY

A spectrally resolved discrete-ordinates radiative model with 18 plane-parallel atmospheric layers under clear-sky conditions is used to quantify the correction factor C. The boundary of each layer is determined by a constant σ coordinate system. The HITRAN molecular spectral data for five atmospheric gases: water vapor, carbon dioxide, oxygen, methane and nitrous oxide are used to calculate the gases absorption coefficient while the aerosol concentration profiles aerosol size distribution and refractive index at each layer are used to evaluate the aerosol absorption and scattering coefficients.

The Monte Carlo method is a statistical device for studying a stochastic model of a physical process through a large number of simulations. The simulation of longwave radiative transfer between layers can be briefly summarized in the following manner. One first introduces the basic physics of the problem in a probabilistic fashion. A system of coordinates and boundaries are defined, in this case, is the 18 non-uniform atmospheric layer system. The longwave radiation is transferred from one layer to another by a means of emitted photon bundles. The emitted photon bundle is initiated from a random position with a random propagation direction, both of which follow certain probability distribution functions. Then the distance to next collision d_c is simulated and distance to nearest boundary d_b is modeled. If $d_b > d_c$, the photon bundle is either absorbed or scattered at the collision point according to the relative size a random number and the single albedo at that point. If it is scattered, a new anisotropic scattering angle is simulated using Henyey-Greenstein phase function with a pre-defined asymmetry factor g, otherwise, the photon is absorbed in that layer. If $d_c > d_b$, the photon bundle travels to the next layer and the distance to collision is modified accordingly. When all the photon bundles are emitted and tallied, the upward and downward longwave radiative fluxes at various levels in the atmosphere can be calculated by counting the number of bundles surpass that level. Different single albedo ρ and different asymmetry factor g would make the radiative fluxes diverge from isotropic scattering condition. The line-by-line spectral resolved model is simplified by an approximate band model to shorten the Monte Carlo simulation time. Percentage difference of the surface DLW irradiance of anisotropic and isotropic case is then calculated.

RESULTS AND CONCLUSION

Fig. 1 shows the results of Monte Carlo simulation with varying albedos and asymmetry factors. The correction factor C represents the percentage divergence of the surface DLW irradiance with anisotropic scattering from the isotropic case. The divergence increases almost linearly with increasing asymmetry factor g when the albedo ρ is kept constant, while it changes exponentially with changing albedo ρ when g

is held constant as Fig. 2 displays. The relationship between C, g and ρ can be found and the correction factor for any atmospheric conditions can be evaluated with known albedo and aerosol asymmetry factor.

$$C(a) = \frac{\mathrm{DLW}^* - \mathrm{DLW}}{g} = \begin{cases} -5.02e^{0.00335a} + 5.03e^{-0.157a} & \text{for } g \geq 0 \\ -5.27e^{0.00461a} + 5.24e^{-0.147a} & \text{for } g < 0 \end{cases}$$

However, the correction is net-result-based and the parameters in determining the correction factor is only valid for this type of plane-parallel atmospheric system. For other atmospheric systems with different temperature and constituent profiles, the P-1 approximation scaling is more convenient and versatile to use but when aerosol concentration is extraordinarily high, it would underestimate the results. Then this factor can be used to correct the simplified analytical solution obtained by simplifying the aerosol scattering to be isotropic scattering.

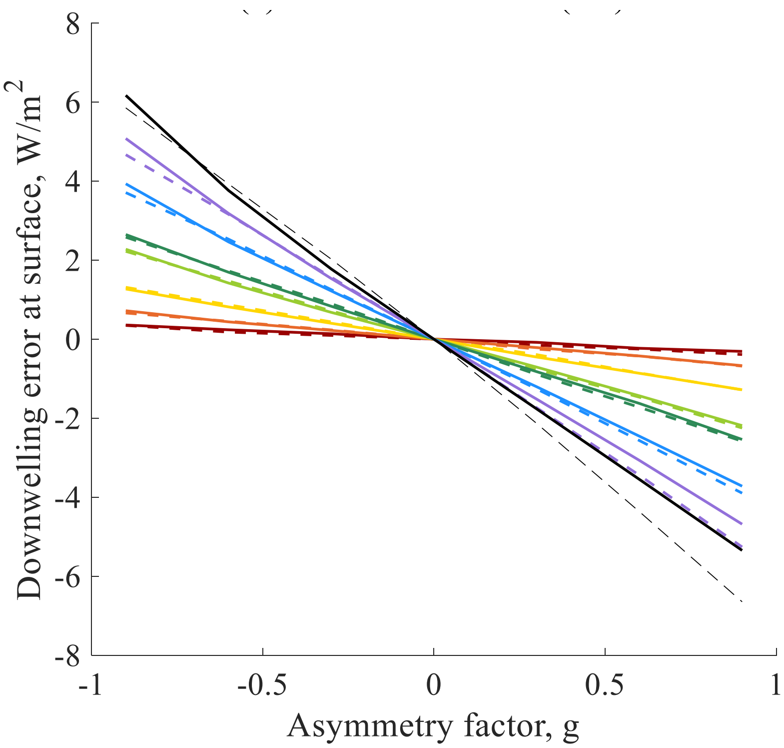

Figure 1. Correction factor for anisotropic scattering with varying asymmetry factor and albedo

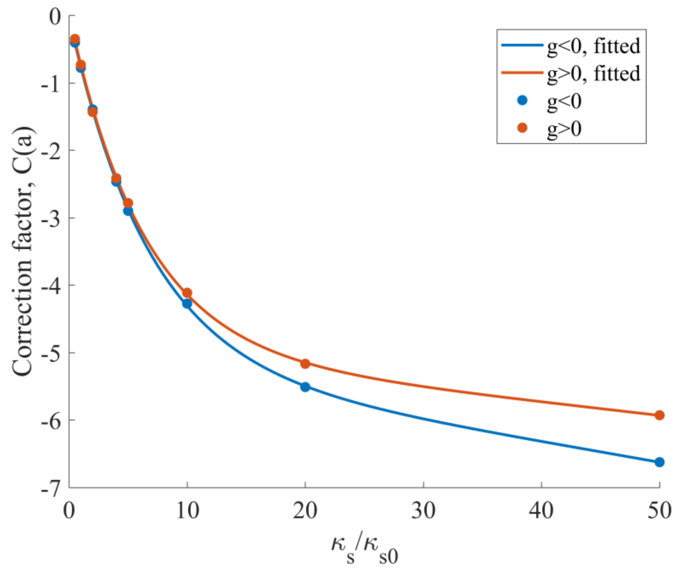

Figure 2. Corrector factor C(a) that relates the surface downwelling longwave radiation error due to anisotropic scattering to asymmetry factor. This relationship differs slightly for forward and backward scattering situations and this difference becomes large when aerosol concentration is high.

Keywords**:** Monte Carlo Simulation, Mie scattering, atmospheric longwave radiation models