Direct Aerosol Forcing: Calculation from Observables and Sensitivities to Inputs
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Abstract
Understanding sources of uncertainty in estimating aerosol direct radiative forcing (DRF), the difference in a given radiative flux component with and without aerosol, is essential to local aerosol radiative closure and to quantifying changes in Earth’s radiation budget over time. We examine the uncertainty of DRF due to uncertainty in the quantities on which it depends: aerosol amount, aerosol optical properties, i.e., single scattering albedo and asymmetry parameter, and atmospheric variables, i.e., solar geometry and surface albedo, and the wavelength dependencies of these quantities.

Objectives:
To determine the uncertainty in forcing as a consequence of uncertainties in the aerosol and surface parameters examined here: optical depth (τ), single scattering albedo (ω), asymmetry parameter (g), and surface albedo (κ).

Approach
We calculate aerosol direct radiative forcing (DRF) based on the radiative forcing efficiency (δi) and a given aerosol optical depth (τ). We then determine the sensitivity (Si) of the DRF to the uncertainty in the property of interest (ci) and its measurement uncertainty (Δci) as used here in an estimate for all measurement techniques.

\[ S_i = \sum \frac{\partial DRF}{\partial c_i} \Delta c_i \]

Last we calculate the total uncertainty in DRF (ΔDRF) due to all properties by summation in quadrature (δF).

\[ \Delta DRF = \sum S_i \Delta c_i \]

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Radiative Transfer Models
Two models, the Santa Barbara DISORT Atmospheric Radiative Transfer (SBDART) and Rapid Radiative Transfer Model (RRTM), were run for each case in a model intercomparison exercise. Both use DISORT within the same spectral range, with 8 streams, a spectral range from 0.25 - 4.0 µm, the Gueymard solar spectrum, and the follow standard atmospheric profile:

\[ \begin{align*}
\text{Case} & \quad \text{Atmosphere} \\
\text{Tropical Western Pacific} & \quad \text{Tropical} \\
\text{Southern Great Plains} & \quad \text{FLD} \\
\text{Southern Great Plains} & \quad \text{Total O3} \\
\text{NSA} & \quad 0.615 \\
\text{US62SGP} & \quad 0.896
\end{align*} \]

Scenario 1: Integrated over the shortwave and averaged over SZA for the Equinox
Direct Radiative Forcing (DRF)

Scenario 2: 550 nm averaged over SZA for the Equinox
Direct Radiative Forcing (DRF)

Scenario 3: Integrated over the shortwave and at 33°, 45°, and 70° SZA for TWP, SGP, and NSA respectively
Direct Radiative Forcing (DRF)

Wavelength Dependence of Aerosol Properties
Wavelength dependence is calculated for each aerosol and surface property in the wavelength range from 0.25 to 4.0 µm. Dependencies are shown for the three base cases:

Surface albedo is parameterized as a constant in two wavelength ranges:

- A: 0 - 8 µm
- B: 8 - 12 µm

Conclusions
Total uncertainties in calculating the aerosol DRF are high, ranging from 0.5 to more than 3 W/m², or from ~20-70% of the calculated value for the base cases. Aerosol optical depth is the strongest driver of changes in aerosol DRF. Sensitivities associated with optical depth are, however, not the highest due to lower measurement uncertainty. Measurement uncertainties are, in general, lower for properties that contribute greater variability to calculated DRF. Overall, the highest sensitivities are for the single scattering albedo due to the combination of a strong contribution to changes in DRF and a higher measurement uncertainty. Efforts focusing on decreasing uncertainty in single scattering albedo may have the greatest potential for reducing uncertainties in calculated aerosol DRF.

Differences in the two models used here are small compared to total uncertainties in calculated DRF but may be on the order of uncertainties for some individual properties.