Coefficients of an Analytical Aerosol Forcing Equation Determined with a Monte-Carlo Radiation Model

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Aerosol Radiative Forcing Efficiency $\Delta F_{aer}/\tau$

$$\frac{\Delta F_{aer}}{\tau} = -\frac{S_0}{2} T_{atm}^2 (1 - A_{cld}) \left[\bar{\beta}\, \omega (1 - R_{surf})^2 - 2(1-\omega) R_{surf}\right]$$

Aerosol Extensive Properties

ΔF_{aer} is the aerosol forcing
τ is the aerosol layer optical depth (AOD)
$\Delta F_{aer}/\tau$ is the aerosol forcing efficiency

Aerosol Intensive Properties

$\bar{\beta}$ is the average upscatter fraction
ω is the aerosol single scattering albedo (SSA)

Surface Properties

R_{surf} is the surface albedo

Atmospheric Properties

T_{atm} is the transmittance of the atmosphere above the aerosol layer
A_{cld} is the cloud fraction

Solar Properties

S_0 is the solar constant

Average upscatter fraction $\bar{\beta}$ and asymmetry parameter ASY are related for the Henyey-Greenstein (HG) phase function as

$$\bar{\beta} = \frac{1-ASY}{2\times ASY}\left(-1 + \frac{2(1+ASY)}{\pi}\int_0^{\pi/2} (1 - ASY^2 \sin^2\theta)^{-0.5}\, d\theta\right)$$

$$\bar{\beta} = -0.2936\, ASY^3 + 0.2556\, ASY^2 - 0.4489\, ASY + 0.5043$$

Rewrite Aerosol Radiative Forcing Efficiency as linear function of ω

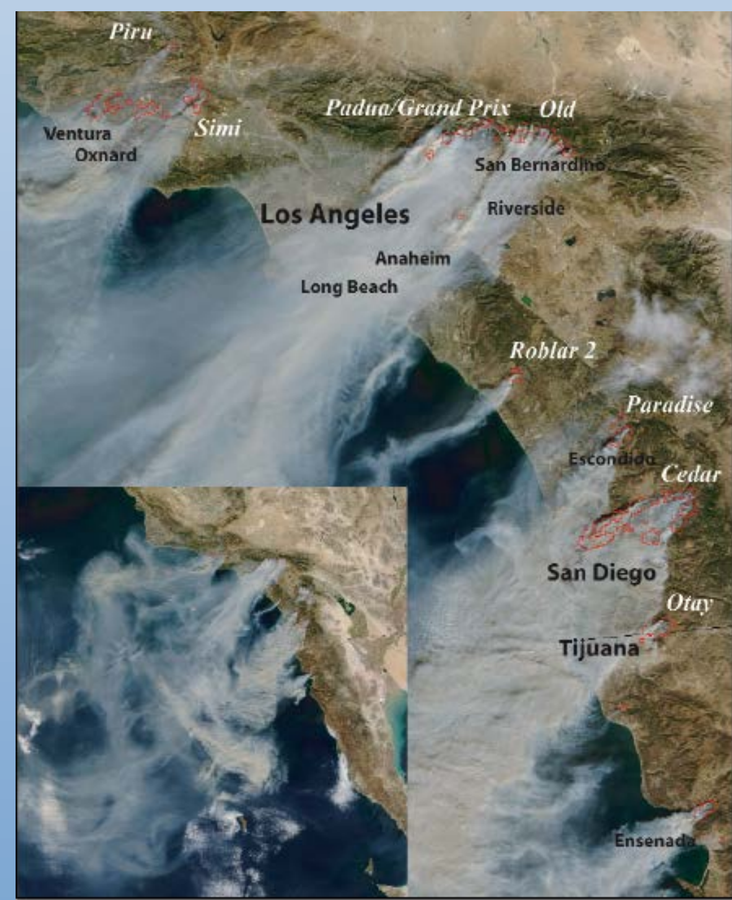
$$\frac{\Delta F_{aer}}{\tau} = \omega\left[\left\{-\frac{S_0}{2} T_{atm}^2 (1 - A_{cld})\right\}\times\left\{2R_{surf} + \bar{\beta}(1 - R_{surf})^2\right\}\right] - 2\left\{-\frac{S_0}{2} T_{atm}^2 (1 - A_{cld})\right\} R_{surf}$$

Temperature of the Earth?

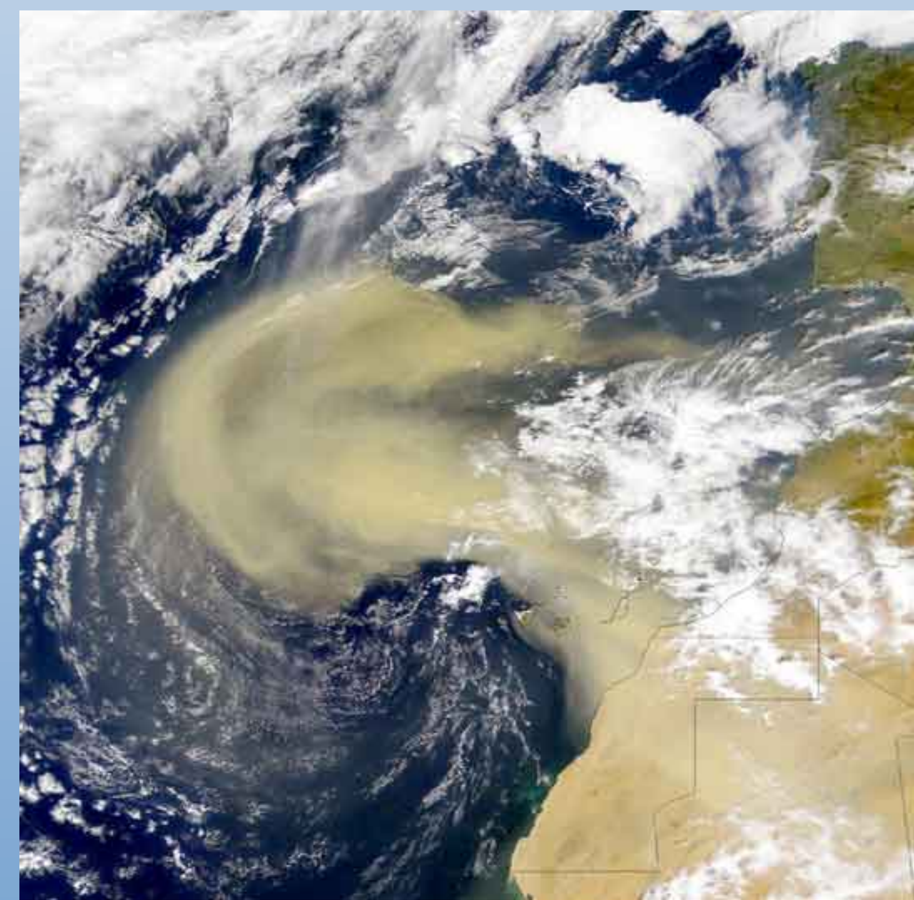
Energy Balance: $E_{in} = E_{out}$ $\quad \frac{(1-\alpha)S}{4} = \varepsilon\sigma T^4$

Resulting Temperature: $T = \sqrt[4]{\frac{(1-\alpha)S}{4\varepsilon\sigma}} = 289\ K$

Aerosols Make the Earth Look Whiter or Darker?



MODIS images of smoke from Southern California wildfires (26 Oct. 2003)



Saharan Dust Plume (February 26, 2000)
Courtesy SeaWiFS/Ocean Color Team

Using the Global MACR (Monte-Carlo Aerosol Cloud Radiation) Model to Test the Analytical Equation

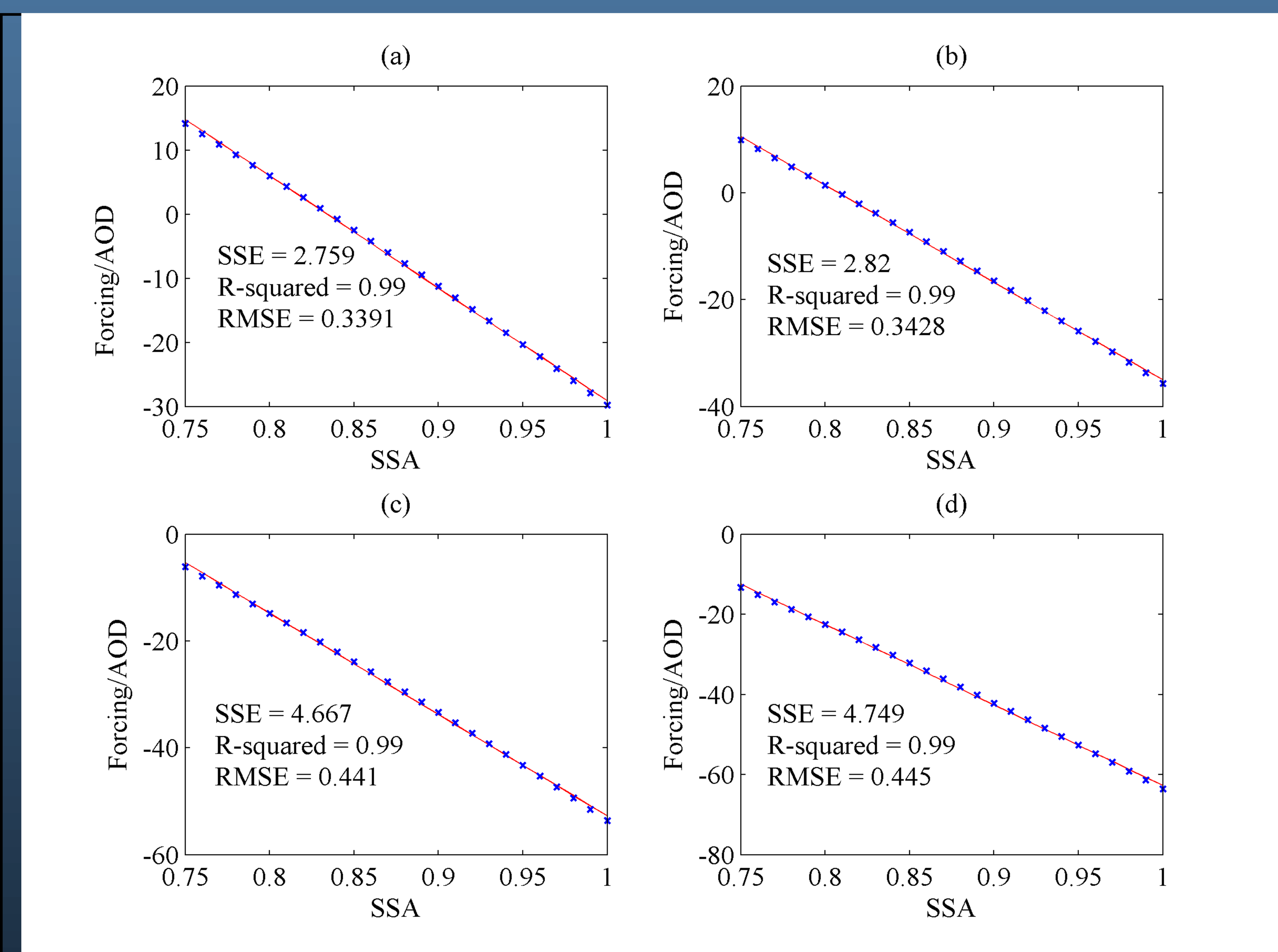
The MACR model incorporated spatio-temporally varying observations for surface albedo, cloud optical depth, water vapor, stratosphere column ozone, etc., but used globally uniform aerosol parameters (i.e., AOD, SSA, and ASY).

Simulation	Specified ASY	Upscatter fraction	$(1-A_{cld})$	T_{atm}	R_{surf}
Cloudy-sky	0.7	0.2146	0.3592	1.03	0.279
Cloudy-sky	0.63	0.2495	0.3592	1.04	0.275
Cloud-free	0.7	0.2146	1	0.735	0.185
Cloud-free	0.63	0.2495	1	0.742	0.183

Table 1. Calculated T_{atm} and R_{surf} for SSA varying simulations from the linear fitting curves.

	Simple semi-observational estimate by Charlson et. al. [10]	Simple semi-observational estimate by Penner et al. [24]	Using the energy budget estimate [23]	Present Study (Linear fit with the MACR model output)		Satellite-based observation as in the MACR model
				with cloud	without cloud	
T_{atm}	0.76	0.79	N/A	1.03	0.74	N/A
R_{surf}	N/A	N/A	0.13	0.28	0.18	0.12

Table 2. Comparison of global average T_{atm} and R_{surf} values.



Results from the MACR model (in blue mark) and from the analytical equation (in red line). (a) Cloudy-sky condition with an ASY of 0.7; (b) cloudy-sky condition with an ASY of 0.63; (c) cloud-free condition with an ASY of 0.7; and (d) cloud-free condition with an ASY of 0.63. The analytical equation results shown in each panel are based on the values of the two parameters (i.e., surface albedo and atmospheric transmittance) in Table 1. These parameter values result from the linear fits of the analytical equation with the MACR model output. The goodness of the linear fit is shown in each panel, where SSE values closer to zero mean a better fit.

Conclusions:

A simple analytical equation is a good way to understand the effects of various parameters on aerosol forcing. Here, we have tested the analytical equation derived by Chylek and Wong (1995). We have found that the equation works well in terms of the functional relationship, but that the global atmospheric transmittance and the surface albedo (two parameters in the equation) need to have unrealistic values, especially for all-sky (i.e., cloudy) aerosol forcing estimation, in order to yield accurate aerosol forcing estimates. The two parameters would need to have more reasonable (still unrealistic for surface reflection) values if the equation is used for estimating clear-sky aerosol forcing. This means that if the user of the equation uses the previously-known (observationally based) parameter values, the estimated forcing would be erroneous, especially for all-sky aerosol forcing.

Acknowledgements

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