# Aerosol and Climate: Some Further Considerations

Abstract. *Approximate numerical radiative calculations show that whether added aerosol causes heating or cooling of the earth-atmosphere system is a function not only of its intrinsic absorption-backscatter characteristics but also of its particular location in the atmosphere with respect to the average cloud as well as of both the cloud reflectivity and the underlying surface reflectivity.*

The climatic effect of changes in atmospheric aerosols, natural or anthropogenic, has been the subject of considerable study and discussion (*1, 2*). The principal questions are: Does added aerosol lead to a net heating or cooling of the earth-atmosphere system? Is this a property of the aerosol alone, or is the effect also dependent on the manner of distribution of the aerosol or upon preexisting atmospheric and surface conditions, or both (*3*)? Very recently Chýlek and Coakley (*4*) have derived an expression indicating that added aerosol may heat or cool the earth-atmosphere system, depending on intrinsic properties of the aerosol characterized by $\omega_a$, the single scattering coefficient, and $\beta_a$, the backscatter coefficient, and upon the preexisting earth-atmosphere albedo, $A$. Relative heating is given by $A - R'$, where $R'$ is the albedo of the earth-atmosphere-aerosol system, and the critical transition point is where $A - R' = 0$, whereupon

$$\frac{1-\omega_a}{\omega_a\beta_a} = \frac{(1-A)^2}{2A} \qquad (1)$$

It is our purpose in this report to point out that conclusions based on the criteria of Eq. 1 may be misleading since its derivation is restricted to the situation or condition in which the added aerosol is distributed as a layer *above* the preexisting earth-atmosphere system. Certainly, with the exception of albedo from volcanic eruptions, aboveground nuclear explosions, or supersonic transport exhausts, most aerosol, natural or anthropogenic, is expected to be distributed at low altitudes (*5*) and below the usual clouds. Although no closed analytic expression apparently exists, we will show by numerical calculations that the critical transition value for $[(1-\omega_a)/\omega_a\beta_a]$ is strongly governed by the particular location of aerosol in the atmosphere with respect to the average cloud and that it is also a function of both the cloud reflectivity and the earth surface reflectivity.

We employ a vertically stratified model earth-atmosphere-aerosol system with a prescribed surface reflectivity, $r_s$. The aerosol and average atmospheric (cloud) transmissivities and reflectivities, $t_a$, $t_c$, $r_a$, and $r_c$, respectively, are computed separately with the use of the modified two-stream Gaussian quadrature approximation of the radiative transfer equation (*6*) with separate specification of $\omega_a$ and $\beta_a$, and $\omega_c$ and $\beta_c$ for aerosol and cloud, respectively. Considering multiple transmission and reflection for the stratified layers and surface, the earth-atmosphere albedo (without aerosol) is given by

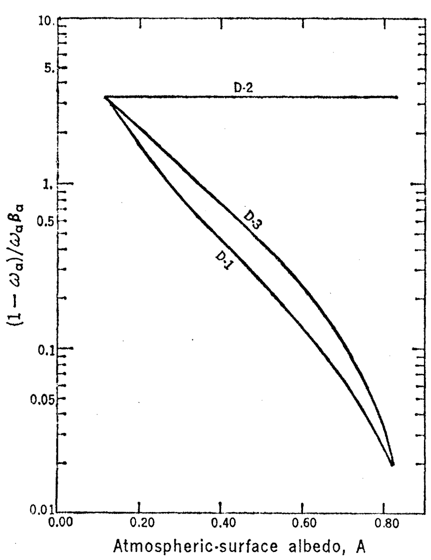
$$A = r_c + \frac{t_c^2 r_s}{1 - r_c r_s} \qquad (2)$$

whereas the albedo of the combined system with aerosol above the cloud is given by

$$\alpha_{ac} = r_a + \frac{t_a^2[r_s t_c^2 + r_c(1 - r_c r_s)]}{(1 - r_c r_s)(1 - r_a r_c) - r_a r_s t_c^2} \qquad (3)$$

and the albedo of the combined system with aerosol between the atmospheric (cloud) layer and surface is identical to Eq. 3 if the subscripts a and c are interchanged. Three distributions of aerosol may now be considered: D-1, aerosol above the cloud, giving albedo $\alpha_{ac}$; D-2, aerosol imposed between the cloud and surface, giving albedo $\alpha_{ca}$; and D-3, aerosol and atmospheric properties well mixed as represented by the arithmetic mean (*7*), the albedo denoted by $\alpha_{\overline{ac}}$.

In the first set of calculations, the results of which are shown in Fig. 1, we set $\omega_c = 0.999$ and $\beta_c = 0.065$ for the atmosphere (cloud) (*8*) and $r_s = 0.12$ [approximately the annual global average as given by Sellers (*2*)]. Then with $\omega_a\beta_a = 0.1$ for the aerosol, we choose values for $(1-\omega_a)/\omega_a\beta_a$ and adjust the optical thickness of the atmospheric cloud to give an $A$ and $\alpha_i$ (i = ac or ca or $\overline{ac}$) such that $A - \alpha_i \rightarrow 0$ within $\pm$ 0.0001. As may be seen, the three aerosol distributions give quite different results. The D-1 curve, representing the distribution of aerosol assumed by Chýlek and Coakley (*4*), is indistinguishable from that generated by Eq. 1. However, the D-2 curve, representing aerosol imposed between atmospheric scatterers and the surface, indicates that the critical value is a constant with the value 3.2. The "well-mixed" distribution, curve D-3, is intermediate between the D-1 and D-2 curves. The curves indicate that at any given preexisting earth-atmosphere al-



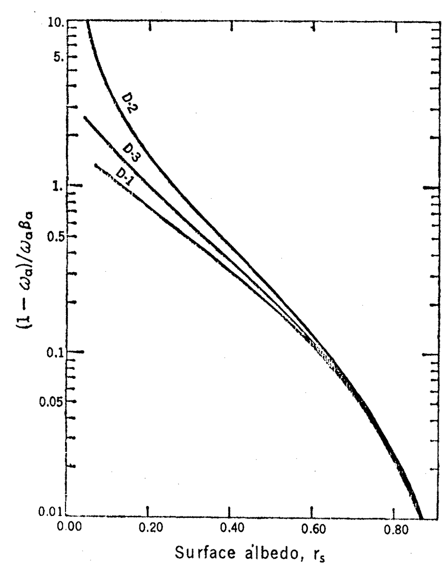




Fig. 1 (left). Values of $(1-\omega_a)/\omega_a\beta_a$ at the transition point of heating-cooling plotted as a function of albedo with three distributions of aerosol; D-1, above the cloud; D-2, between the cloud and the surface; and D-3, "well mixed." the surface reflectivity was fixed at 0.12, and the cloud optical depth varied. Heating would occur above the line in each case. Fig. 2 (right). Values of $(1-\omega_a)/\omega_a\beta_a$ at the transition point of heating-cooling plotted as a function of surface reflectivity with the same distributions of aerosol as in Fig. 1. The cloud optical depth was fixed at 2.0. Heating would occur above the line in each case.

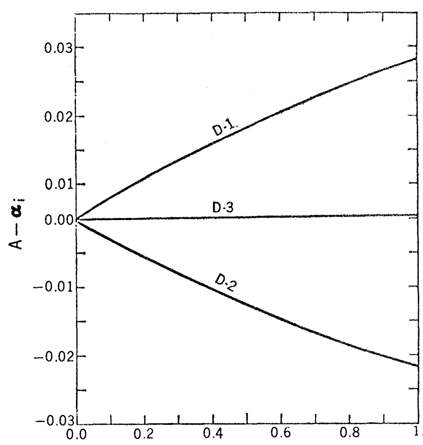



Fig. 3. Relative heating, $A - \alpha_i$, plotted as a function of aerosol optical depth with the same distributions of aerosol as in Fig. 1. The values $\omega_a = 0.9$, $\omega_a\beta_a = 0.1$, $\tau_c = 2.0$, and $r_s = 0.20$ were chosen so that $A - \alpha_{\overline{ac}} \simeq 0$.

bedo, in order for added aerosol to result in heating, the critical absorption-to-backscatter ratio for the aerosol is least when the aerosol is distributed above the cloud. Greater absorption relative to backscatter by the aerosol is necessary if the distribution is either mixed with or below preexisting atmospheric scatterers. In particular, at the annual global average albedo of 0.29, the critical ratio is 0.9 when the aerosol is distributed above the cloud, 1.3 when mixed with the cloud, and 3.2 when between the cloud and the surface.

In a second set of calculations, the results of which are plotted in Fig. 2, we set the atmospheric optical depth, $\tau_c$, at 2.0 (a value which, together with $r_s = 0.12$, gives the global average albedo of 0.29) and vary the surface reflectivity. In this case also the distribution D-3 gives critical ratios that are intermediate between the D-1 and D-2 distributions, with the lowest values of absorption relative to backscatter required for heating to occur when the aerosol is distributed above the cloud. Convergence of the critical ratio occurs at high surface reflectivities.

Equation 1, applicable to the D-1 distribution, indicates that the critical point of transition from heating to cooling resulting from added aerosol is independent of its optical depth. Our calculations for the other distributions indicate that this is also true within the limits of error of the convergence criteria in the range of aerosol optical depth investigated, 0.1 to 2.0.

Finally, to further illustrate the effect of aerosol distribution on heating, we choose a set of values for $\omega_a$, $\beta_a$, $r_s$, and $\tau_c$ such that $A - \alpha_{\overline{ac}} \simeq 0$. We then plot $A - \alpha_i$ as a function of the aerosol optical depth, $\tau_a$, in Fig. 3 from which it is clear that the aerosol leads to net heating when distributed above the preexisting atmospheric scatterers but to net cooling when distributed below them.

As with the calculations of Chýlek and Coakley (*4*), the validity of the results reported here are limited by the approximations inherent in the radiative calculations. In particular, it is limited to the global average situation since solar zenith angle dependency has not been taken into account. Also in our calculations we have assumed a diffuse thin atmospheric cloud rather than a system composed partially of thick cloud and partially clear atmosphere. These limitations do not detract from the general conclusion that the effect of added aerosol on radiative balance is dependent not only on its intrinsic optical properties but also on its distribution within the atmospheric system and the preexisting atmospheric and surface reflectivities.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**References and Notes**


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## Environmental and Evolutionary Stability in Bivalve Mollusks


Abstract. *There is no relationship between environmental stability* [*as indicated by infaunal (stable) versus epifaunal (unstable) habits*] *and the generic duration of extinct marine bivalve mollusks when the effects of cosmopolitanism (which is associated with long generic durations) and other paleontological "noise" are excluded. This is contrary to the "depauperate gene pool" hypothesis of extinctions.*


The nature is the relationship between environmental stability and evolutionary stability has been the object of much recent concern (*1–3*). Does an unstable environment produce frequent extinctions and rapid taxonomic change? Or does it provide continuous selection for genetic diversity so that taxa are better able to survive eventual major changes of the environment? The latter is predicted by the "depauperate gene pool" hypothesis of extinctions (*4*).

Neontologic evidence is contradictory (*1*) and cannot provide the necessary time perspective. Paleontology does, but the definition and recognition of unstable ancient environments is a fundamental problem. Bretsky (*5*) assumed that benthic environments became more stable as water depth (approximated by distance from the ancient shore) increased. From an inferred evolutionary sequence of communities, he concluded that environmental instability favored evolutionary and taxonomic stability, but this result has been questioned (*1, 6*).

I consider here an alternative measure of environmental stability: infaunal versus epifaunal habit. Epifaunal organisms live on the surface of the substratum and are subject to the full range of environmental fluctuations. Infaunal animals live within the sediment and are insulated from short-term changes of the environment (*7*). Although genetic variability is not in general related to environmental stability (*1*), reduced genetic variability is indicated in the relatively uniform "underground" environments occupied by fossorial rodents and infaunal bivalve mollusks (*3, 8*). If infauna are