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APPLICATION OF A COUPLED AEROSOL FORMATION – RADIATIVE TRANSFER MODEL TO CLIMATIC STUDIES OF AEROSOLS

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ABSTRACT

A sophisticated one-dimensional physical-chemical model of the formation and evolution of stratospheric aerosols has been used to predict the size and number concentration of the stratospheric aerosols as functions of time and altitude following: a large volcanic eruption; increased addition of carbonyl sulfide (OCS) or sulfur dioxide (SO_2) to the troposphere; increased supersonic aircraft (SST) flights in the stratosphere; and, large numbers of Space Shuttle (SS) flights through the stratosphere. A radiative-convective one-dimensional climate sensitivity study, using the results of the aerosol formation model, was performed to assess the ground level climatic significance of these perturbations to the stratospheric aerosol layer. Volcanic eruptions and large OCS or SO_2 increases could cause significant climatic changes. Currently projected SS launches and moderate fleets of SST's are unlikely to upset the stratospheric aerosol layer enough to significantly impact climate.

INTRODUCTION

Stratospheric sulfuric acid aerosols normally form an optically thin layer centered near 20 km. Observations of the aerosols show that significant optical depths occur after large explosive volcanic eruptions. Observations as well as theoretical calculations indicate that these enhanced optical depths can lead to significant climatic cooling because the aerosols backscatter solar energy to space (1, 2, 3). Observations of the aerosol optical properties after a volcanic eruption are very limited, severely complicating the difficulties in correctly, theoretically, evaluating the climatic impact of the volcanic aerosols. Hence we developed a 1-D physical-chemical aerosol model to calculate the aerosol optical properties beginning with the aerosol formation from gaseous precursors and considering all the microphysical and large scale processes affecting the aerosol's evolution (4, 5).

In our earlier work we applied the aerosol formation model, together with a 1-D radiative convective calculation of the Earth's vertical temperature profile to theoretically reassess the effects of volcanic aerosols on climate (6). We found that the volcanic aerosols significantly cooled the surface and warmed the stratosphere, in good agreement with observations.

The volcanic aerosols are short-lived ($\sim$2 years) and have significant latitudinal dependence so a proper evaluation of their climatic impact requires at least two-dimensional aerosol and climatic modeling. Such models are under construction. Other perturbation sources to the aerosol layer, such as SST, and SS flights, and increased levels of tropospheric OCS and SO_2 would be long-lived and globally homogeneous due to the continuous nature of the sources. Hence, we have proceeded with 1-D studies of the aerosol enhancement due to these sources.

Aerosol Changes Due to Space Shuttles and SST's

Space Shuttle engines will inject large numbers of small Al_2O_3 particles into the stratosphere. These particles are too small to directly enhance the optical depth of the aerosol layer, but sulfuric acid vapor could condense on these particles and so create larger acid particles which would be optically significant. In order to properly evaluate this possibility, a sophisticated aerosol model, such as the one described here, is a necessity. SST's inject both SO_2 and soot particles into the stratosphere. The SO_2 becomes photochemically converted into H_2SO_4 and directly augments the acid particles, while the soot could serve as nuclei for the growth of new acid aerosols.

Figure 1 illustrates the ambient aerosol size distribution at 20 km, the size distribution if 50 shuttle flights occur every year, and the size distribution that would result if 1 year's supply of Al_2O_3 from the shuttle engine was stored in the stratosphere. Evidently, the small shuttle particles are quickly lost by coagulating with the acid aerosols, few new acid aerosols are formed and the net effect on the aerosol layer is rather small. A similar situation is illustrated in Figure 2 which shows that neither the SO_2 nor the soot from 300 SST's flying 7½ hours per day in the stratosphere has a large effect on the aerosol layer.

The temperature changes due to the aerosol modifications illustrated by Figures 1 and 2 as calculated with the radiative convective model are on the order of 3×10^{-4} °K for 50 SS flights per year and on the order of 3×10^{-3} °K for the fleet of 300 SST's. These changes are undetectably small.

Aerosol Changes Due to Enhanced OCS and SO_2 Emissions

The background stratospheric aerosol layer is apparently maintained by tropospheric SO_2 and OCS diffusing into the stratosphere. Both these sulfur compounds are products of industrial processes and could therefore be significantly enhanced by man. OCS in particular has a relatively long lifetime in the atmosphere, its major source is unknown at present, and quantitative knowledge of its emission rate from industrial processes is not available.

Figure 3 illustrates the effects on the aerosol layer of removing SO_2 and OCS and of increasing SO_2 by a factor of 10 and OCS by factors of 5 and 10. Obviously, OCS provides most of the sulfate to the ambient layer, though SO_2 is significant at lower altitudes. Enhanced OCS or SO_2 significantly perturbs the aerosol layer, and may increase the aerosol mass by a factor of 2-4.

Using the 1-D radiative convective model we find that the Earth's surface temperature might decrease by a slightly more than $0.1^{o}C$ due to a tenfold enhancement of OCS. Within the aerosol layer the stratospheric temperature increased by about $0.1^{o}C$ due to an increase of OCS by a factor of 10. We have not yet completed the radiative calculations for an SO_2 enhancement by 10, but based on the aerosol model results, they should be comparable to those due to the OCS enhancement by a factor of 10. Wang et al's (7) results suggest that a tenfold increase in SO_2 might increase the temperature by about $0.1^{o}C$ due to an increased greenhouse effect. However, the SO_2 concentration drops sharply with altitude so a tenfold increase in the stratosphere could result without a corresponding increase in net tropospheric SO_2 by altering the upper tropospheric SO_2 sinks. Hence the net climatic impact of increased SO_2 depends on the circumstances of its alteration. No greenhouse calculations have been reported for OCS. However, OCS does have an absorption feature near 850 cm^{-1} so its greenhouse effect could be significant compared with the aerosol impact.

Temperature changes on the order of $0.1^{o}C$ are marginally significant climatic changes. So little is known about OCS that a factor of 10 increase in its abundance cannot be ruled out. Further information on the source of OCS, and on its greenhouse effect is important to obtain.

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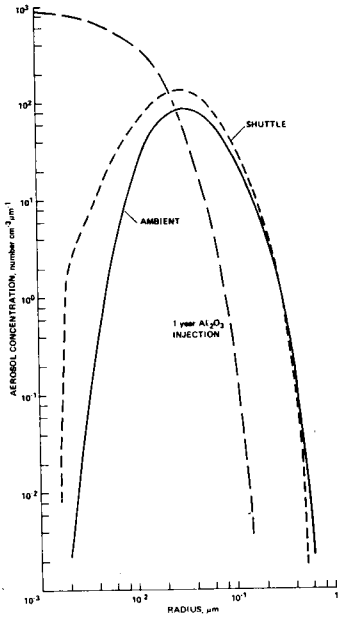

Fig. 1: Aerosol size distribution at 20 km under ambient and Space Shuttle perturbed conditions, as well as 1 year's Space Shuttle debris.

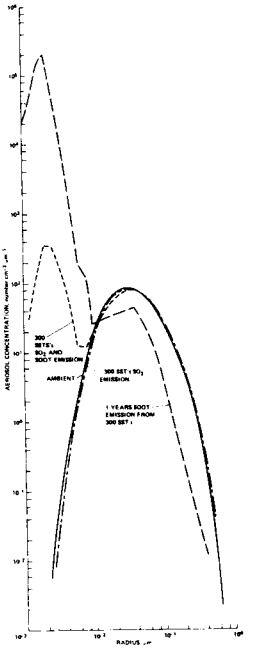

Fig. 2: Aerosol size distribution at 20 km under ambient and SST perturbed conditions as well as 1 year's SST soot emissions.

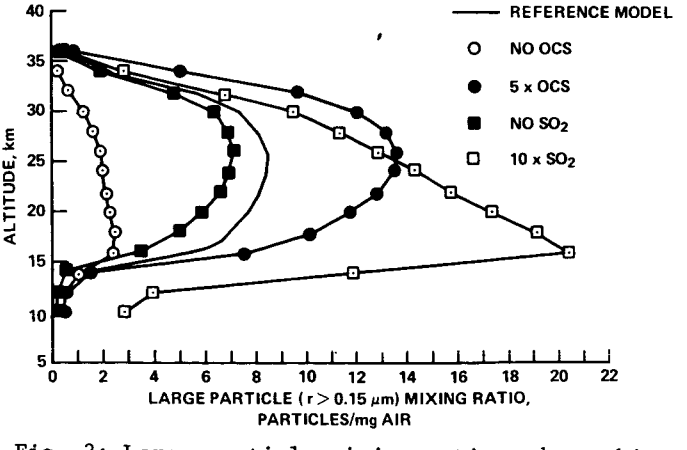

Fig. 3: Large particle mixing ratio under ambient conditions, and for altered ground level abundances of SO_2 and OCS.