DOE/ER/61012--4

Final Report
for DOE Grant Award DE-FG08-90ER61012
"Linkage of Anthropogenic Aerosol to Clouds and Climate"

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The work done under this grant concerns differences between clouds and the aerosol particles upon which the cloud droplets condense; the cloud condensation nuclei (CCN). Anthropogenic sources contribute substantially to CCN and this contribution has a substantial effect on clouds.

In July 1991 we participated in ship board measurements in the SEAHUNT project, which found shiptrail clouds. Extremely high CCN concentrations were found under a shiptrail cloud, which occurred in extremely clean air. This cloud feature was also observed by satellite and the results of the episode were accepted for publication in Atmospheric Environment "Ship-produced cloud lines of 13 July 1991" by Hindman, Porch, Hudson, and Durkee. This showed that the shiptrail formed in extremely clean air (concentrations of less than 5 cm^{-3}). Other measurements of ship plumes during SEAHUNT showed that ship smokestacks are prolific sources of CCN. These results indicate that ship trails are indeed a result of the smokestack emissions, which is a substantial anthropogenic source. Low concentrations were found near drizzle indicating that coalescence scavenging is an important mechanism for aerosol removal.

In June, 1992 we participated in aircraft measurements with the ASTEX project in the eastern Atlantic. Here we also found substantial influences of anthropogenic aerosol on clouds through long range transport of polluted air from Europe. A paper that has been accepted for publication ("Microphysical contrasts in Atlantic stratus" by Hudson and Li, Journal of Atmospheric Science) documents the contrasts between clean maritime and polluted maritime clouds. These contrasts were consistent with the CCN measurements that we made near these clouds. The higher CCN concentrations in the polluted air suppressed the cloud supersaturations as predicted. Thus a smaller subset of the CCN actually participate in cloud nucleation when the concentrations are very high. We found that not only were the concentrations higher in polluted air but that the shape of the CCN distribution was also different. Analysis of the droplet spectrum shows that in general the variability in droplet concentration and size distribution is produced by the interaction of the spectrum of updraft velocities with the CCN spectrum. This internal mixing process produces inhomogeneities in the cloud microphysics that

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depend on the shape of the CCN spectrum. The droplet concentrations are higher, the droplets are smaller, and the spectrum is narrower in the polluted clouds. This makes the albedo of these clouds higher and this is an anthropogenic cooling effect on global climate. Our results also show that there are substantially fewer drizzle droplets in the polluted air masses. Thus the CCN also affect precipitation potential of the clouds. Almost no drizzle drops were found in the dirtier air masses. This "pluvial constipation" effect is also an overall atmospheric cooling effect as it tends to prolong clouds, which thus makes for greater global coverage and greater liquid water contents. All of these factors also cool the planet. In fact this process has been suggested as the reason for the observed asymmetric diurnal global warming. Greater nighttime than daytime warming.

Measurements were also made of CCN volatility and size vs. supersaturation in order to better characterize these important particles. Volatility is done by passing the aerosol stream through a tube at various temperature. A temperature of 200° C removes ammonium sulfate the most common aerosol component while 600° C is required to remove NaCl. The size of CCN is obtained by passing the ambient samples through the electrostatic classifier this is the same technique that is used to calibrate the spectrometer with known aerosol material. A paper describing these measurements in various environments was submitted to the Journal of Geophysical Research in August. This article "Volatility and size of cloud condensation nuclei" by Hudson and Da showed significant differences between clean and polluted CCN. The CCN in cleaner air were smaller indicating that they are more likely pure soluble substances whereas the polluted CCN were probably internal mixtures of soluble and insoluble material. Volatility measurements also displayed differences between clean and polluted air masses that are consistent with the size vs. supersaturation differences. These methods can be used to differentiate between the CCN of various sources.

In June, 1994 we participated in another stratus cloud aerosol project off the central California coast. This project was specifically concerned with ship trail clouds. Preliminary results indicated that the CCN from the ships produced the ship trail clouds and that it is not necessary to have very clean air to produce a ship trail. Even in moderately polluted clouds there is an increase in droplet concentration that can be ascribed to the ship emissions. During this project the new CCN spectrometer that had been built with funds from the DOE University Research Program was first operated. It obtained shipboard data for a few days during the project. The use of the two instruments together will make volatility and size vs. supersaturation measurements much better.