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Observations of Anthropogenic Cloud Condensation Nuclei

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CCN concentrations and spectral measurements obtained with the DRI instantaneous CCN spectrometer (Hudson, 1989) over the last few years are presented. Recent articles by Wigley (1989), Schwartz (1988), Charleson et al (1987), Coakley et al (1987), and others have pointed out the climatic importance of cloud microphysics. The particles which affect cloud microphysics are cloud condensation nuclei (CCN). The commonly-observed order of magnitude difference in cloud droplet concentrations between maritime and continental air masses (i.e. Squires, 1958) was determined to be caused by systematic differences in the concentrations of CCN between continental and maritime air masses (e.g. Twomey and Wojciechowski, 1969).

Twomey (1977) first pointed out that cloud microphysics also affects the radiative properties of clouds. Thus continental and anthropogenic CCN could affect global temperature. Resolution of this "Twomey effect" requires answers to two questions 1) whether anthropogenic CCN are a significant contribution to atmospheric CCN and 2) whether they are actually affecting cloud microphysics to an extent which is of climatic importance. The reasons for the contrast between continental and maritime CCN concentrations are not understood. Ayers et al. (1982) measured the anthropogenic CN (total particle) production rate for Australia to be 1.4×10^{4} cm^{-2} s^{-1} over the entire continent. Thus even in this most sparsely populated continent the anthropogenic production of CN seemed to completely dominate natural CN production. The issue is far from resolved and the anthropogenic rate is at least a significant fraction of the natural rate.

The work presented here addresses the question of the relative importance of anthropogenic CCN. These observations should shed light on this complex question although further research is being conducted in order to produce more quantitative answers. Accompanying CN measurements made with a TSI 3020 condensation nucleus (CN) counter are also presented.

The first part of fig. 1 shows extremely low CCN concentrations obtained with light onshore winds along the California coast. This figure also shows a typical example of the immediate change to much higher CCN concentrations in urban areas. This seems to indicate that there is direct production of CCN with no intermediate coagulation processes needed in order to explain the existence of the CCN as the air would have spent only a few minutes over land. The higher concentrations shown in the second part of this figure were obtained throughout the city of Santa Cruz on untravelled residential streets as well as main highways. Fig. 2 shows a nearly simultaneous measurement obtained 10 km inland from the coast with only unpopulated and undeveloped land between. These results indicate that natural processes were not causing a change in the CCN concentration as

the air moved in from the coast over a period of about an hour. This again demonstrates the weakness of the natural source of CCN.

Fig. 3 shows one specific particle formation process which was observed on numerous occasions at various locations. The order of magnitude increase in CCN concentration was associated with the passage of a diesel powered vehicle. Fig. 4 shows another example of CCN production from a diesel or fuel oil engine; in this case a plume from a ship offshore from San Diego. This shows that ships indeed are a source of CCN as suggested by Conover (1966) and Coakley et al (1987).

Fig. 5 was obtained under conditions of offshore flow over the southern California area. In the rural areas of California throughout the Owens Valley and on into the Los Angeles basin the concentration of CCN was very low as shown in the early part of this figure. This is a concentration level which is more characteristic of maritime rather than continental air. However these low concentrations were measured over a very wide area and the air must have spent considerable time over the continent in this type of weather situation. As the vehicle moved into the Los Angeles basin through the Cajon pass much higher concentrations were encountered. From that point and to the west and south the CCN concentration was uniformly higher. Consistently high concentrations were detected with the 12 second data collection times which were used. Even though there was a continuous offshore flow of air (Santa Ana condition) the concentration within the basin was continuously maintained at high levels by the production of particles. This result seems to indicate that the concentration of CCN here is dominated by anthropogenic processes.

The aircraft measurement shown in fig. 6 shows an abrupt transition from maritime to continental air over the state of Washington. This order of magnitude change occurs over a horizontal distance of about 30 km at an altitude of about 3,300 m above sea level. This abrupt change which was observed several times is indicative of a rather strong continental source. This is more consistent with the anthropogenic sources which were observed at the surface rather than natural sources which were at best very weak. These higher concentrations were consistently measured over the North American continent except at low altitudes. A weak continental source ought to result in a more gradual transition to higher concentrations over the continent.

Fig. 7 shows an example where the CCN concentration seems to be proportional to the population within an air basin. These measurements were obtained from the vehicle as it was driven on U.S. highway 395 through Reno, Carson City, Minden, Gardenerville, and Topaz Lake on the California border. These measurements were obtained under stagnant weather conditions which held the air stationary for more than a day. This allowed particle concentrations to build up within each air basin. The highest concentrations were obtained in Reno which has the highest population and population density. The concentration showed an abrupt decrease upon entering the Carson City basin which is much less populated. The lowest concentrations are seen

in the least populated Topaz Lake basin. This certainly shows that the CCN concentration in these continental air basins is dominated by local anthropogenic processes.

The most important result of these measurements is that the production of CCN by anthropogenic processes is quite apparent but the natural continental source of CCN has still not been measured. If the increased CCN concentrations of continental air are due to anthropogenic processes then this could constitute a significant element of climatic change. Even if this were true for only the continental air and not at all for maritime air then this would constitute a significant climatic change even through the Twomey effect alone. However the continental aerosol may also influence maritime clouds. Prospero and Savoie (1989) show that much of the nitrate aerosol in the mid Pacific is of continental origin while a portion of the sulfate is also of continental origin (Savoie and Prospero, 1989). These results indicate that much of this continental component of CCN is probably of manmade origin. However further research is continuing to quantify this source.

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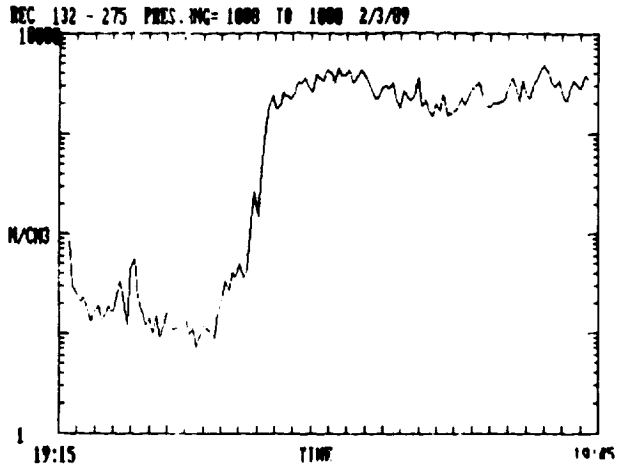

Fig. 1. CCN concentrations obtained while travelling on highway 1 near Santa Cruz, California.

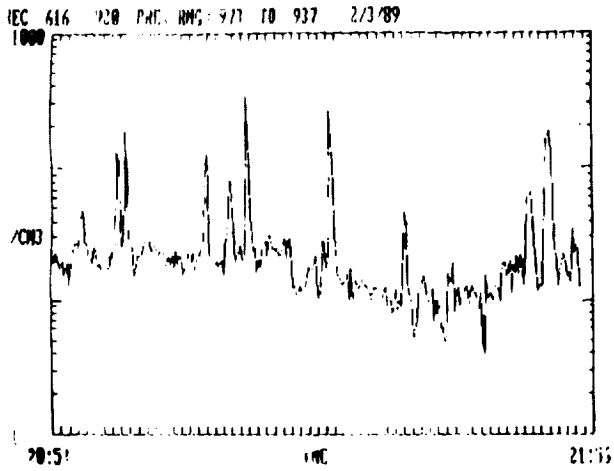

Fig. 2. CCN concentration obtained while driving through the Big Basin Redwood state park 10 miles inland from the coast north of Santa Cruz, California.

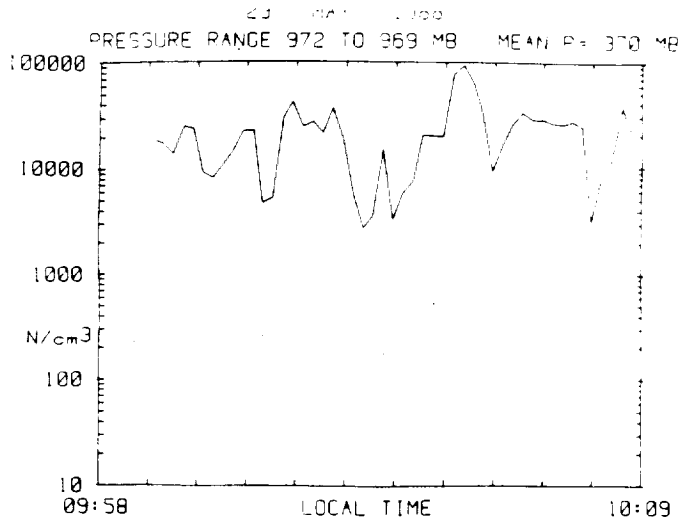

Fig. 3. CN (solid line) and CCN (dotted line) concentration on I-5 in Oregon. A diesel truck was encountered at 10:03.

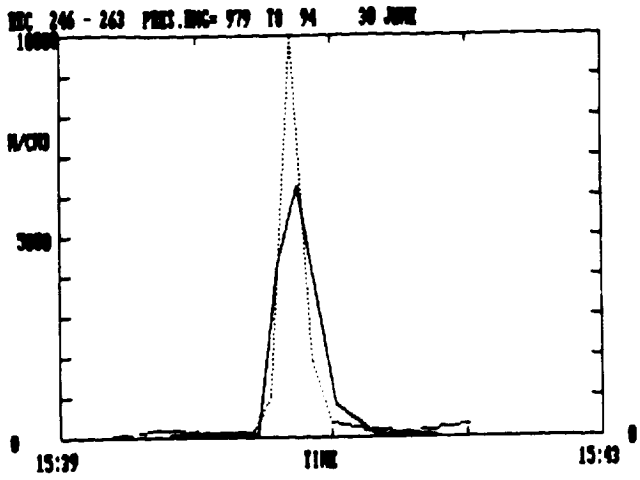

Fig. 4. CN (dotted line) and CCN (solid line) concentrations obtained while flying through a ship plume off the southern California coast.

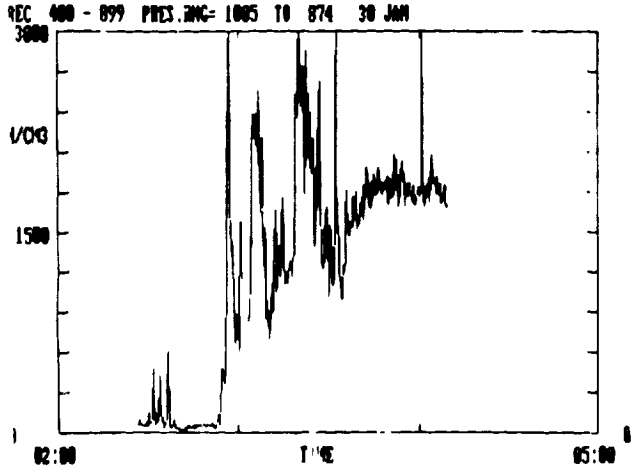

Fig. 5. Surface CCN concentration while driving into the Los Angeles basin. Most of these measurements were obtained while travelling on I-15. Passage through the Cajon Pass into Los Angeles occurred shortly before 0300. The final measurements were obtained in Anaheim, California. These measurements were obtained under Santa Ana wind conditions (offshore flow).

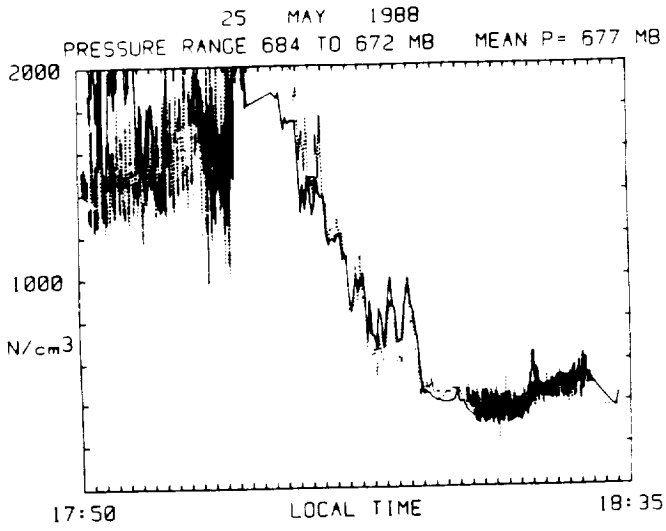

Fig. 6. CN (solid line) and CCN (dotted line) plotted against time during a flight over the state of Washington. This was a flight from Boise, Idaho which shows the transition from continental to maritime aerosol in the flight toward the west.

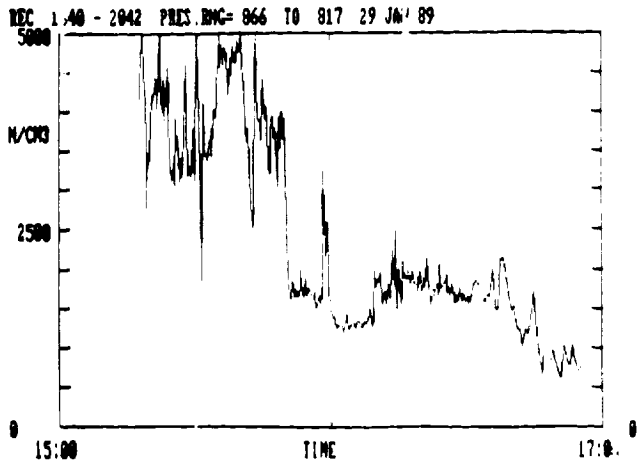

Fig. 7. CCN concentration obtained while travelling on U.S. 395 through western Nevada.