the Haleakala Observatory on Maui has begun operation. It has an accuracy goal of 2 to 3 cm for each normal point. The Australian station at Orroral Valley near Canberra and the Japanese station at the Dodaira Observatory are nearing completion. A new French station is being established at the Calern Observatory near Grasse, and the West German satellite ranging station at Wettzell will be capable of ranging to the moon also. Measurements in the Soviet Union are expected to continue. A 1974 COSPAR resolution (*16*) referring to LLR recommended "the establishment of a coordinated international program to determine variations in the Earth's rotation. . . ." An initial observing campaign called EROLD (Earth Rotation by Lunar Distance) is scheduled to start in 1977 and to continue for 1 year.

We have demonstrated that lunar laser ranging is capable of accurately determining the earth's rotation. The coverage will be substantially improved when the data obtained during the EROLD campaign are available. Values for both UT1 and polar motion should be obtained. In the future, if one or two Southern Hemisphere sites are added and if all of the observing stations achieve a normal point accuracy of 2 to 3 cm, we expect UT1 and polar motion to be determined with similar accuracy (*17*). Data obtained from lunar ranging and from other new techniques (*18*) thus should give valuable new information on short-period changes in the earth's rotation and on the excitation and damping of the Chandler wobble.

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Cloud Condensation Nuclei on the Atlantic Seaboard of the United States

Abstract. *Concentrations of cloud condensation nuclei measured along the East Coast from Virginia to Long Island ranged from 1000 to 3500 per cubic centimeter as compared to 100 per cubic centimeter in clean maritime air and 300 per cubic centimeter in continental air. The global anthropogenic production rate of cloud condensation nuclei may be comparable to the natural production rate; in some industrial areas cloud condensation nuclei are dominated by anthropogenic sources.*

Cloud condensation nuclei (CCN) are those aerosols in the air which serve as nuclei upon which cloud and fog droplets form. Although CCN form only a small fraction of the total atmospheric aerosol, they are important in determining the stability of clouds and the formation of precipitation (*1*). Some anthropogenic sources of CCN have been identified, for example, paper mills and oil refineries, although not all sources of air pollution are sources of CCN (*2*). However, urban areas in general appear to be CCN sources (*3, 4*). The relative importance of natural and anthropogenic sources of CCN on regional and global scales is still a matter for debate.

We present here the results of measurements of the concentrations of CCN and the optical extinction coefficient b obtained from an aircraft flying just off the Atlantic Coast from Cape Charles, Virginia, to Long Island, New York, on 19 November 1973. During the period of the measurements there was a stable northwesterly airstream over the region; therefore, the sampled air was continental in character and had passed over the heavily industrialized and urban areas of the northeastern states. For most of the time the aircraft flew within a surface haze layer at an altitude of 600 m and at a distance of 10 to 15 km east of the Atlantic Coast. Periodically, however, vertical profile measurements were obtained to the top of the haze layer. At 11:45 E.S.T. the top of the haze layer of Delaware Bay was at an altitude of 1000 m. At 12:45 E.S.T. off Sandy Hook (south of New York City) there were two distinct haze layers with tops at 1000 and 1500 m.

The CCN concentrations were measured with an automatic thermal gradient diffusion chamber (*5*). The value of b, due to both aerosol and gas molecules, was measured with an integrating nephelometer over a broad band of wavelengths centered on 500 nm (*6*). The air intake to the nephelometer was heated in order to evaporate any water on the aerosol; therefore, the measured b value should be that due to the dry aerosol. The visibility range L_v is related to b by $L_v = 3.9/b$ (*7*).

The main results of the measurements are shown in Fig. 1, where the magnitudes of the CCN concentrations and b are indicated by the lengths of lines drawn perpendicular to the direction of the flight path. At 0.2 percent supersaturation (*8*), the CCN concentrations ranged from 1000 to 3500 cm^{-3} and

b ranged from 6.5×10^{-5} to 14.5×10^{-5} m^{-1} (three to seven times greater than the b value due to the molecular scattering of clean air). These CCN concentrations are very much higher than those measured in clean maritime air masses on the Pacific Coast of Washington State, which are typically less than 100 cm^{-3} (*9*). The CCN concentrations in Fig. 1 are also well above those generally found in continental air remote from large industrial areas. For example, we have found that the average CCN concentration at 0.2 percent supersaturation in the High Plains of the United States during the summer months is about 300 cm^{-3}. Our measurements indicate that the CCN concentrations along the whole northeastern seaboard of the United States are dominated by anthropogenic emissions.

Figure 2 shows the measured CCN concentrations in a vertical cross section between Wallops Island, Virginia, and New York City. This cross section clearly reveals the influence of the New York City–Newark area and, to a lesser extent, Atlantic City (and Philadelphia farther upwind) on the CCN concentrations. If the measurements shown in Fig. 2 are combined with the winds measured by the 1900 E.S.T. coastal rawinsonde stations, the total flow of CCN (active at 0.2 percent supersaturation) through the cross-sectional area of 6×10^{8} m^2 shown in Fig. 2 is 6×10^{18} sec^{-1}. At supersaturations of 0.5 and 1 percent, the corresponding fluxes are about 2×10^{19} and 6×10^{19} sec^{-1}. Analysis of the air-mass trajectory showed that the synoptic flow to the northeastern states during the period of air measurements was from Canada and across the Great Lakes. If we assume that most of the measured CCN originated from the heavily populated and industrialized area extending northwest from the region where our measurements were made across to the Great Lakes, the source area is 3×10^{11} m^2 and the population within this area is 4×10^{7} (about 1 percent of the world's population).

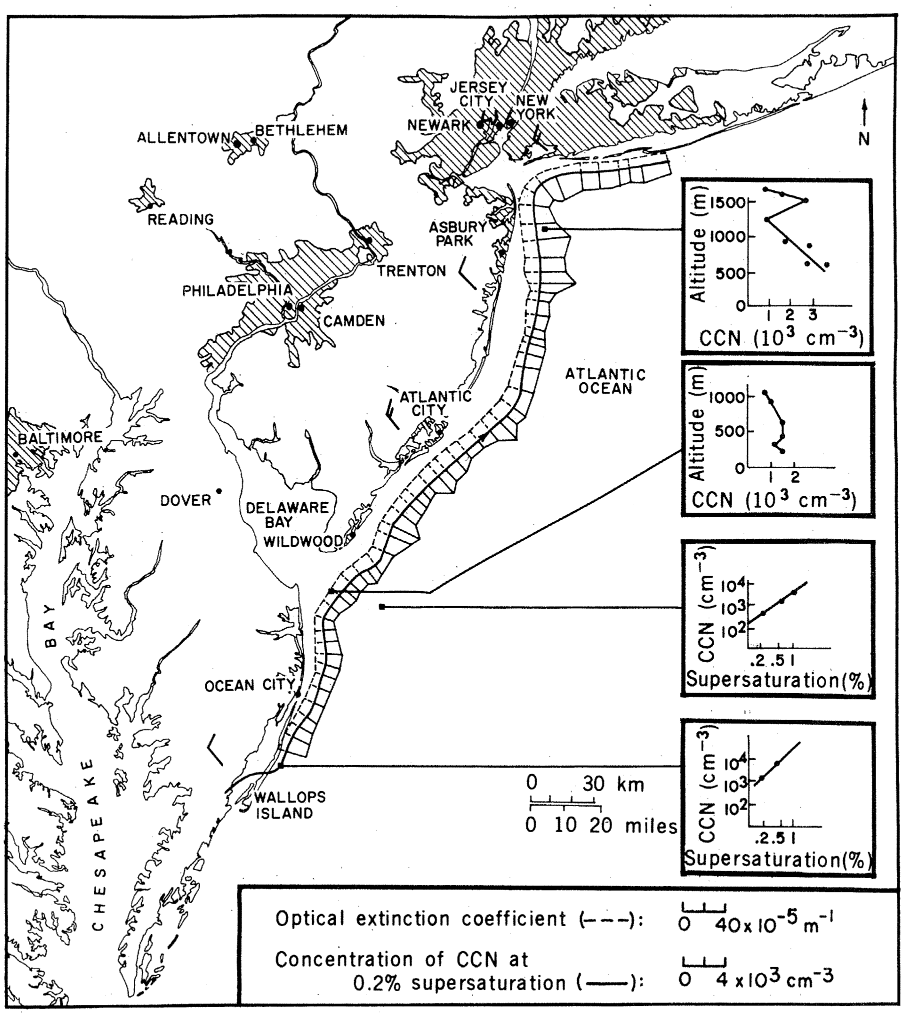

Fig. 1. Measurements of the concentrations of CCN and b are indicated by the magnitudes of the lines (solid and dashed, respectively) drawn normal to the flight path (marked with an arrow). The insets show CCN-supersaturation spectra and CCN concentrations (at 0.2 percent supersaturation) as a function of altitude.

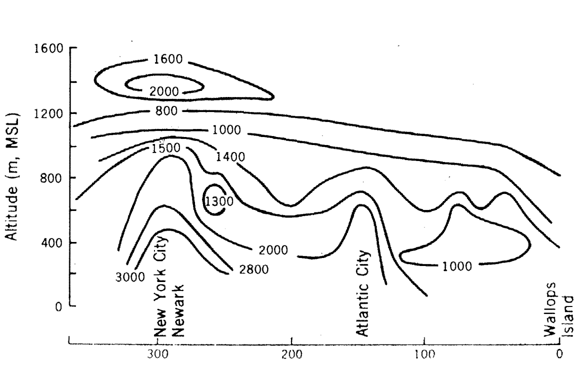

Fig. 2. Vertical cross section just off the Atlantic seaboard from Wallops Island, Virginia, to New York City showing concentrations of CCN (per cubic centimeter) at 0.2 percent supersaturation; mean sea level, *MSL*.

Summarized in Table 1 are estimates of CCN production rates from various point and areal sources, a number of estimates of the worldwide anthropogenic production rate of CCN, and estimates of the global production rate of CCN from natural sources. The following points should be emphasized in connection with these estimates. First, since the principal sources of CCN are not yet known, there is no definitive method for extrapolating results obtained in a restricted area to larger areas. Consequently, several extrapolation techniques (based on population, fuel consumption, steel production, and other factors) are included in Table 1. Second, the CCN source strengths have been estimated from downwind measurements of CCN concentrations on the assumption that the CCN originate at the source itself (for example, at the industrial stack or from the ground). However, there is mounting evidence that CCN can be produced in situ in the atmosphere, probably by gas-to-particle conversion (*9–12*).

Included in Table 1 are three estimates of the global anthropogenic production rate of CCN based on extrapolating (by population) measurements obtained in an industrial region in Australia, measurements in Washington State, and the measurements presented in this report (*13*). These three estimates indicate that the global anthropogenic production rate of CCN is on the order of 10^{20} to 10^{21} sec^{-1}. An estimate of the global produc-

Table 1. Estimates of the strengths of various point, areal, and global sources of CCN.

Source	Location	Strength (CCN/sec)	Supersaturation (%)	Reference	Comments
Large Kraft pulp mill	Washington State	8×10^{16} 4×10^{17}	0.5 1.0	(*14*) (*14*)	Larger values were estimated by Hobbs *et al.* (*2*) for the same Kraft mill, but the differences are thought to be due to recent improved pollution abatement and possible errors due to gas-to-particle conversion in the plume.
Smaller Kraft pulp mills (five mills studied)	Washington State	3×10^{14} to 1.2×10^{15}	1	(*2*)	
Sulfite pulp mills (four mills studied)	Washington State	4×10^{14} to 3×10^{15}	1	(*2*)	
Lumber mills	Washington State	4×10^{14} to 10^{16}	1	(*2*)	Mills were burning wood wastes in open furnaces and power plants.
Aluminum smelter (four sites studied)	Washington State	10^{14} to 5×10^{15}	1	(*2*)	
Aluminum ferro-alloy smelting complex	Washington State	8×10^{16}	1	(*2*)	
Burning of sugar-cane debris	Bundaberg, Queensland, Australia	5×10^{17}	0.5		Estimated from data in (*15*).
Forest fire	Washington State	10^{16}	0.5	(*10*)	About 4 hectares of alder and conifer slash were deliberately set on fire.
City	Denver, Colorado	1.9×10^{16} 3.5×10^{16}	0.5 1	(*3*)	
City	St. Louis, Missouri	5×10^{15} 9×10^{15}	0.5 1	(*16*)	
City	St. Louis, Missouri	10^{16} to 10^{17}	1		Estimated from data in (*17*).
Urban industrial area	Wollongong–Port Kembla, New South Wales, Australia	10^{13} to 10^{14}	0.75	(*18*)	Probably an underestimate (*19*).
Urban industrial area	Wollongong–Port Kembla, New South Wales, Australia	3×10^{16} to 5×10^{16}	0.75	(*19*)	Revised estimate.
Urban industrial area	Eastern seaboard of the United States from Long Island to Cape Charles	6×10^{18} 2×10^{19} 6×10^{19}	0.2 0.5 1	This report	
Anthropogenic	Australia	10^{19}	0.75	(*18*)	
Anthropogenic	United States	5.6×10^{18}	0.5	(*3*)	Extrapolated from the Denver results on the basis of fuel consumption.
Anthropogenic	Northern Hemisphere	2.3×10^{19}	0.5	(*3*)	Extrapolated from the Denver results on the basis of fuel consumption.
Anthropogenic	Global	10^{16}	0.75	(*18*)	Extrapolated from the Wollongong–Port Kembla data on the basis of steel production. Probably an underestimate (*19*).
Anthropogenic	Global	10^{18}	0.75	(*18*)	Extrapolated from the Wollongong–Port Kembla data on the basis of population. Probably an underestimate (*19*).
Anthropogenic	Global	10^{18} to 10^{19}	0.75		Extrapolated, on the basis of steel production, from the revised estimates (*19*) for the Wollongong–Port Kembla area.
Anthropogenic	Global	10^{20} to 10^{21}	0.75		Extrapolated, on the basis of population, from the revised estimates (*19*) for the Wollongong–Port Kembla area.
Anthropogenic	Global	10^{20} to 10^{21}	1		Extrapolated, on the basis of population, from measurements made in Washington State (*2, 14*).
Anthropogenic	Global	2×10^{21} 6×10^{21}	0.5 1		Extrapolated, on the basis of population, from measurements made on the eastern seaboard of the United States from Long Island to Cape Charles presented in this report. Assumes that the primary source of CCN in this area is anthropogenic.
Natural sources	Global	1.4×10^{21}	0.5 to 0.75		Deduced from estimates of natural rates of production over the oceans (*11*) and over the land (*3*).

tion rate of CCN from natural sources, based on a production rate of 5×10^6 m^{-2} sec^{-1} for the land (*3*) and 2×10^6 m^{-2} sec^{-1} for the oceans (*11*), yields a value of about 10^{21} sec^{-1}. On a global scale, the rate of production of CCN from anthropogenic sources may be comparable with that from natural sources. This is not to imply that regions far removed from large anthropogenic sources of CCN are appreciably affected by the CCN from anthropogenic sources, since the average residence time of CCN in the atmosphere is only a few days. On the other hand, the CCN in many industrial or heavily populated areas are no doubt dominated by anthropogenic sources. In view of the profound effects that CCN can have on cloud structure and precipitation processes, greater attention should be paid to the anthropogenic sources of these particles.

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Light Flashes Observed on Skylab 4: The Role of Nuclear Stars

Abstract. *The astronauts on Skylab 4 observed bursts of intense visual light flash activity when their spacecraft passed through the South Atlantic Anomaly. Flash rates as high as 20 per minute have in the past been considered unexpectedly high. When the effect of nuclear interactions in and near the retina is included, the apparent anomaly is removed.*

The astronauts on Skylab 4, Dr. Edward Gibson and Lt. Col. William Pogue, reported observing occasional 5- to 10-minute bursts of intense visual light flash activity when their spacecraft passed through that portion of the earth's inner trapped radiation belt known as the South Atlantic Anomaly (SAA). Two experimental sessions were carried out on board Skylab 4 under the direction of Pinsky *et al.* (*1*), who compared the flash rates with the measured flux of particles of Z (atomic number) ≥ 1 that would pass through the astronaut's eyes. The flash rates were found to be anomalously high, which led Pinsky *et al.* to postulate the existence of a previously unobserved inner belt flux of multiply charged nuclei.

Because of the important magnetospheric implications, we explored alternative explanations for the anomalous flash rates that would be consistent with the accepted SAA flux values (*2*) and the limited laboratory data on particle-induced visual sensations in human subjects (*3, 4*). We show here that, when one includes the effects of nuclear interactions in and near the retina which result in star formation (the emission of slow protons and alpha particles from the nucleus in an evaporation-like process), the apparent anomaly is removed.

On the basis of calculations fitting the flash rates observed on Skylab 4 outside the SAA and on Apollo flights in deep space, Pinsky *et al.* (*1*) expressed their threshold requirements for flashes as lower limits on two parameters: the linear energy transfer (LET) must be at least 37 kev/μm, and the path length of the particle's trajectory through the sensitive layer of the retina must exceed 40 μm. Such a particle would deposit a total of 1.5 Mev in the sensitive layer. Because the dark-adapted retina can integrate signals over distances as great as 300 μm, it is possible that particles with LET values below 37 kev/μm might by having path lengths greater than 40 μm still deposit more than 1.5 Mev in the sensitive layer and not be included in calculations of flash rates. This distinction, although possibly not significant outside the SAA, is important inside it. As a result, we express the threshold here in terms of a minimum deposition of energy within a region of the sensitive layer 300 μm in diameter. It is also possible that two particles might traverse the retina near enough to one another for their combined contributions to sum to more than 1.5 Mev although the individual particles do not exceed threshold. The visual effect might still appear as a flash or short streak.

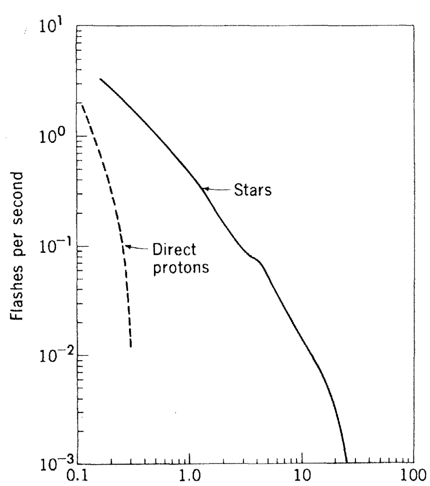

Fig. 1. Predicted flash rate as a function of the retina threshold sensitivity for a retinal area with a diameter of 300 μm.

Unfortunately, there are, as far as we know, no light flash data for accelerated protons. Furthermore, there is no certainty that the concept of threshold, which holds for the detection of Cerenkov flashes (*4*), is valid for nonrelativistic particles; experiments with alpha particles indicate that particles with LET values above 10 kev/μm are detected with roughly 40 percent efficiency at exposure rates of 10 per second but with less than 5 percent efficiency at very low exposure rates (*3*). Detection efficiencies probably vary for different regions of the retina. However, in examining the evidence for anomalous flash rates and comparing our results with those of Pinsky *et al.* (*1*), we assume that threshold is a valid concept and that the retina is uniformly sensitive.

The physical model used in our calculations of star production is as follows. Protons that have a typical SAA energy spectrum (*2*) impinge upon the eye, which is considered to be a sphere 2 cm in diameter with two-thirds of its area surrounded by a sensitive layer of the retina 30 μm thick.

Following Pinsky *et al.* (*1*), we ignore