Reports

On the Global Distribution of Aerosols

Abstract. *Aerosol concentrations were measured during a 54-hour circumnavigation of the earth at altitudes between 238 and 162 millibars and concurrently by a separate flight at lower altitudes over the Pacific Ocean. The aerosol concentrations were found to be symmetrically distributed about the earth. Concurrent meteorological measurements indicate that tropospheric aerosols enter the stratosphere in the vicinity of jet streams and that surface aerosols are carried aloft over the intertropical convergence and Antarctic polar front.*

Surveys of the aerosol concentration in the lower troposphere were first made by J. Aitken, whose work was limited geographically to the British Isles and Europe and vertically by the height of the towers and mountains he used. The first vertical profiles of aerosol concentration were obtained over Europe from a balloon (*1*). Weickmann (*2*) surveyed aerosol concentrations between the surface and the 500-mbar level over North America.

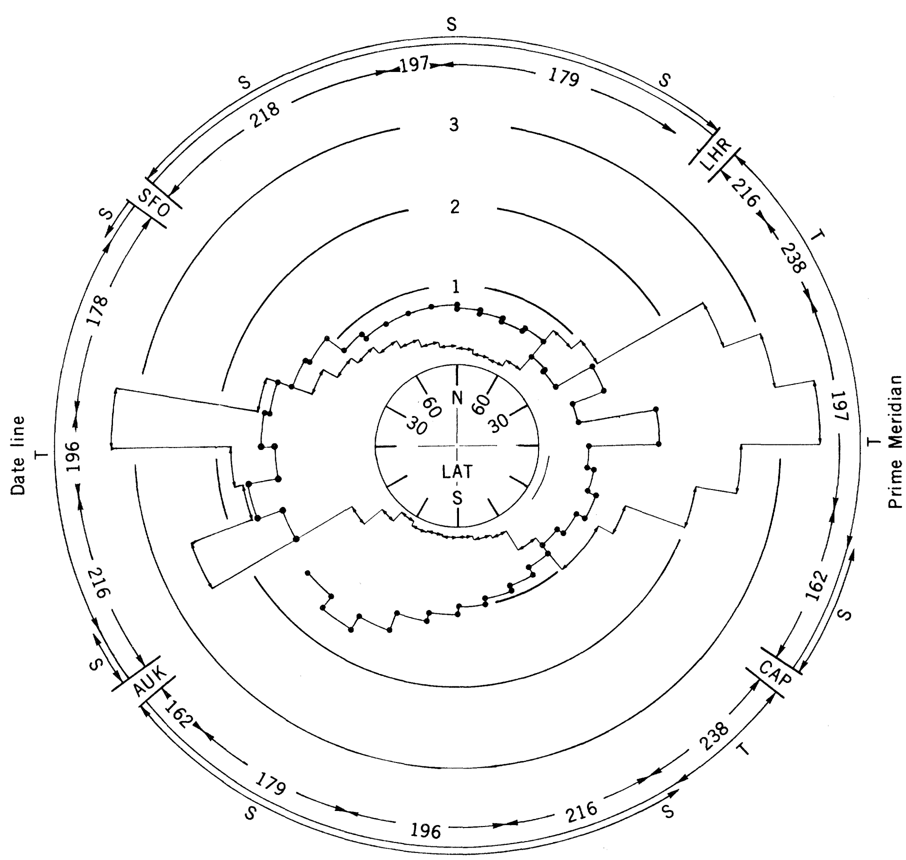
Global surveys of the aerosol concentrations in the air above the seas were begun by R.V. *Carnegie* (*3*) and recently were repeated by R.V. *Oceanographer* (*4*). Additional oceanic surveys have been conducted by several investigators (*5*), whose measurements at islands, ocean stations, and from ships of opportunity have been compiled to show the distribution of aerosol over the seas of the world. Vertical profiles of aerosol concentration are now available for many latitudes (*6*).

An unusual experiment to examine the distribution of aerosol particles at all latitudes during a brief period was recently completed in conjunction with a circumpolar navigation of the earth by Pan Am flight 50 in celebration of that airline's 50th year of operation. A Boeing 747SP was used for this flight and carried instruments to measure aerosol particles, ozone, carbon monoxide, and meteorological parameters as a part of the NASA Global Atmospheric Sampling Program. The U.S. Antarctic Research Program's (USARP) instrumented Navy LC130R (*7*) was proceeding to the Antarctic at the same time. Thus, concurrent measurements could be made at two altitudes over the Pacific between the polar and subtropical fronts.

The 747 was equipped with an automatic condensation nucleus counter. The LC130R, which operated at lower altitudes, was equipped with a sensitive (*8*) photoelectric nucleus counter. Particle losses in the connecting tubing were estimated to be less than 8 percent (*9*). Both particle detectors were calibrated against Pollak-Metnieks (*10*) photelectric nucleus counters constructed by R. Gussman. The number of particles of sufficiently large size to scatter visible light (greater than 0.45 μm in equivalent spherical diameter in this case) were also measured aboard the 747.

Flight 50 departed San Francisco at 9:05 p.m. on 28 October 1977 and followed the 122°W meridian to the North Pole and the 5°E meridian to the vicinity of London, where it landed. It then followed the 3°E meridian to the equator, where it took a slightly more easterly heading to a landing at Cape Town, South Africa. From Cape Town, flight 50 followed 18°E to the South Pole and 173°E from the pole to Auckland, New Zealand. The last leg of the flight followed a great circle passing over the equator at 156°W (that is, directly south of Hawaii) and ended in San Francisco at 2:43 a.m. on 31 October 1977.

The 747 cruised at several altitudes between 238 and 162 mbar. The temperature data obtained during each climb and descent were used to determine the temperature lapse rate and to estimate whether the aircraft was in the upper troposphere or lower stratosphere (Fig.



—Aitken nuclei (100 cm^{-3}) •—• Scattering particles (cm^{-3}) ←214→ Altitude (mbar)

Fig. 1. A polar plot showing the aerosol concentrations measured by Pan Am flight 50 while making a polar circumnavigation of the earth during 28 to 31 October 1977. The flight altitude, in millibars, and the presence of tropospheric (*T*) or stratospheric (*S*) air at the flight altitude are shown on the periphery. Mean values of total aerosol concentration, measured by a condensation nucleus counter and averaged over 10° latitude bands, are shown along with mean values of larger particles found by light-scattering techniques.

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1). Temperature and wind records were used to estimate the latitudes at which the aircraft crossed the tropopause in level flight. An interesting layer of air above the meteorological tropopause was encountered between 57° and 50°S latitude along 172°E. Its lapse rate was nearly adiabatic (tropospheric). Soundings at Campbell Island and Invercargill, New Zealand, indicated the presence of multiple tropopauses in this area.

The concentration of particles large enough to scatter visible light was less than 1 cm^{-3} throughout the northern stratosphere and the Eastern Hemisphere troposphere, except for a small area of greater concentration over tropical Africa. Concentrations increased gradually in the southern stratosphere, reaching a peak value of 1.6 cm^{-3} between 50° and 60°S latitude along the date line. Concentrations greater than 1 cm^{-3} were also found in the upper troposphere over the tropical Pacific. The high values recorded over Africa and the tropical Pacific are in areas of strong convective activity [the intertropical convergence zone (ITCZ)] and within the Hadley cell outflow. The above-average concentrations in the southern stratosphere are above the world's stormiest seas and in the area downwind of this region in the stratosphere poleward of the Antarctic polar front.

The latitudinal variation in total particle (Aitken nuclei) concentration shown in Fig. 1 is different from that of the larger size fraction of the particles. Concentrations of 10 to 40 cm^{-3} were found in the Arctic and northern mid-latitude stratosphere, and concentrations of 10 to 25 cm^{-3} were found in the stratosphere in those latitudes over the Southern Hemisphere. The air of negative lapse rate encountered above the tropopause at 50° to 57°S has an aerosol concentration similar to that of the adjacent air of positive lapse rate. The aerosol concentration decreased with increasing altitude in both polar regions.

Aitken nuclei concentrations measured in the tropical troposphere are extremely interesting because there is a symmetry of high concentrations over both the land and water hemispheres. Higher concentrations were also found over the extratropical front north of New Zealand.

Comparison of the large particle and total particle concentrations shows them to be occasionally out of phase. Large particles constitute 6 to 20 percent of the total in the South Polar stratosophere and up to 5 percent of the total in the North Polar stratosphere. Large particles constitute only 0.1 to 1 percent of the total number in surface maritime air.

The USARP aircraft took off from Christchurch, New Zealand, before midnight on 30 October, flying south and measuring aerosol concentration at several altitudes until reaching 60°S, which Pan Am flight 50 crossed at 9:05 a.m. en route to Auckland. Flight 50 traversed the joint study area and departed it at 30°S at 4:27 p.m. The USARP aircraft again departed Christchurch at 9:00 p.m. but this time flew north. It profiled the atmosphere at altitudes of 500 to 300 mbar until reaching 30°S at 12:30 a.m. on 31 October.

Aitken concentrations measured from the two aircraft are plotted against the latitude and altitude of the observation (Fig. 2). The tropopause, determined from New Zealand Meteorological Service soundings, is plotted as a heavy line, and the base of a second inversion is shown by a dotted line. Wind speeds that exceeded 100 knots are indicated by the letter J.

The aerosol concentration of about 80 cm^{-3} measured north of Auckland (37°S) is higher than any other stratospheric concentration measured by flight 50 during the circumnavigation. The USARP flight found concentrations exceeding 100 cm^{-3} just above the tropopause, at 270 mbar, near the axis of the strongest winds of that day (from 50° to 55°S). Our interpretation of the aircraft data is that air of recent tropospheric history was encountered just above the tropopause by the USARP flight between 50° and 55°S and 13 hours later by flight 50 between 30° and 35°S. Except for this particle-enriched layer just above the tropopause, aerosol concentrations tended to decrease with increasing altitude, in agreement with accepted knowledge.

On an earlier flight (21 to 22 October), the USARP transpacific plane crossed the ITCZ southbound in the 420- to 500-mbar layer. Aerosol concentrations were typical of those in the trade wind troposphere (that is, similar to the concentrations measured at Mauna Loa) in dry air north of 13°N. Weak turbulence and moist air were encountered at 12°N, and the aircraft was forced to climb slightly and change course several times to avoid cumulus turrets. Air temperature fluctuated, the dew point approached water saturation, and the ozone concentration approached zero between 11° and 4°N. Aerosol concentrations were always

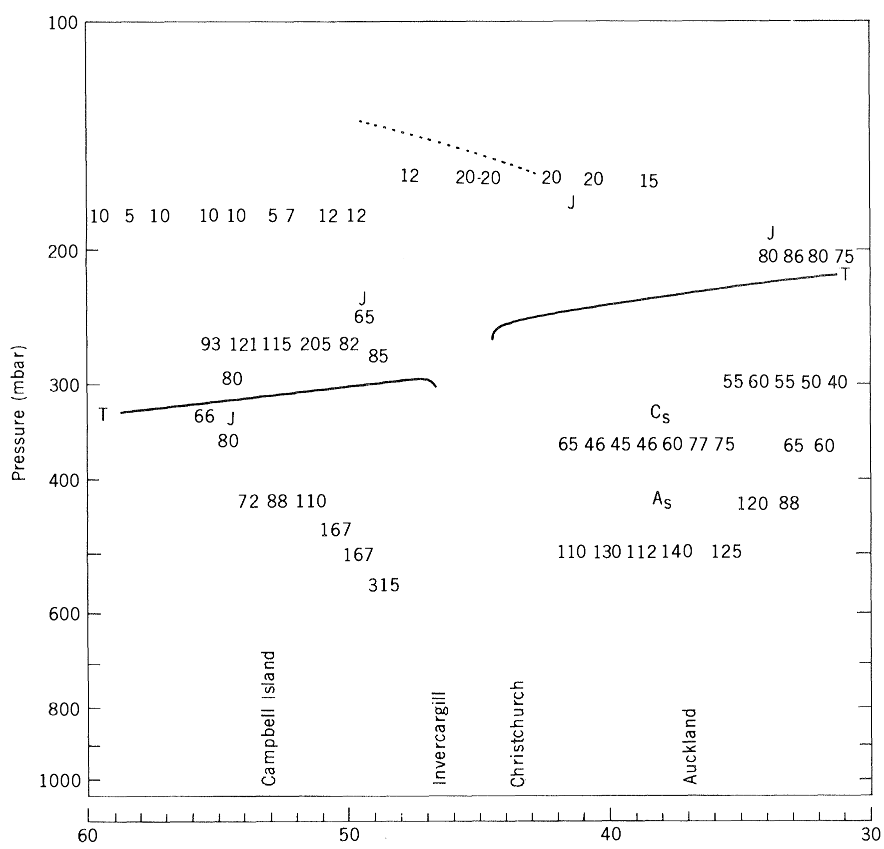

Fig. 2. Aerosol concentrations observed in the vicinity of New Zealand by two aircraft on 30 and 31 October 1977. The USARP plane operated in clear air south of 45°S but encountered cirrostratus (C_s) and altostratus (A_s) as indicated, north of a front. Relatively high aerosol concentrations were found by both aircraft just above the tropopause (T), coinciding with the strongest winds.

greater than 250 cm^{-3} in this area and, during two periods, exceeded 1500 cm^{-3}. Concentrations similar to those measured north of 13°N were found when dry air was reentered at 3°N. On 30 October 1977, flight 50 passed over the ITCZ in the troposphere at 178 mbar and recorded similar increases in aerosol concentration while ozone concentrations again approached zero. Great fluctuations in larger (light-scattering) particles also occurred in this area.

Particles large enough to scatter visible light were rather uniformly distributed (1.0 ± 0.5 cm^{-3}) throughout the upper troposphere and lower stratosphere at all latitudes. The concentrations measured tended to be greater than 1 cm^{-3} over the Pacific Ocean and less than 1 cm^{-3} over North America, the Arctic ice fields, Europe, and Africa. This may be evidence that the "ocean hemisphere" (particularly the stormy regions at 50° to 60°S in the Pacific) and the strong convection along the ITCZ may be major sources and transport routes of particles to the layers above them near 200 mbar.

Smaller particles were rather symmetrically distributed around the globe at altitudes between 160 and 250 mbar. A maximum occurred over the ITCZ. Concentrations were nearly equal on the Greenwich and date-line sides of the world. Increased concentrations occurred over the boundaries between tropical and temperate air masses. Comparison of total particle and light-scattering particle data at several latitudes reinforces Junge's conclusion (*6*) that coagulation exceeds sedimentation as a sink mechanism for particles in the higher layers. Where fresh injections are rare and coagulation times long, as over the Arctic and Antarctic, small particles are few.

Generally, aerosol concentrations decrease with increasing latitude, but higher concentrations are sometimes found just above strong inversions in the vicinity of high winds, indicative of a possible transport route for particles from troposphere to stratosphere. The small interhemispheric differences in total aerosol concentration that do occur may be seasonal or even due to chance in a single observation.

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11. We thank the 1977 Transpac crew of LC130 XD9131: E. Oltmans, aircraft commander; K. Smith and S. Adams, pilots; M. Tarkenton, navigator; W. Scarborough, flight engineer; and M. Kehoe, loadmaster. This work was supported in part by NSF grant DPP 7623110 and by the NASA Global Air Sampling Program under contract NSG 3138.

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Earthquakes near Parkfield, California: Comparing the 1934 and 1966 Sequences

Abstract. *Moderate-sized earthquakes (Richter magnitude* M_L *5½) have occurred four times this century (1901, 1922, 1934, and 1966) on the San Andreas fault near Parkfield in central California. In many respects the June 1966 sequence was a remarkably detailed repetition of the June 1934 sequence, suggesting a recurring recognizable pattern of stress and fault zone behavior.*

Rupture of the San Andreas fault during the main shock of the 8 June 1934 earthquake near Parkfield, California, propagated toward the southeast. The main shock occurred at 0447 Greenwich mean time (G.M.T.); 17 minutes 25 seconds earlier, a foreshock of magnitude M_L 5.1 on the Richter scale occurred about 1 km to the northwest of the focus of the main shock. Rupture during the foreshock was toward the northwest. A nearly identical sequence of events occurred at Parkfield on 28 June 1966. The 1934 and 1966 events have been compared to obtain a basis for anticipating the characteristics of future Parkfield earthquakes as well as data needed in modeling fault dynamics. Finding a means for predicting future Parkfield earthquakes is especially significant in

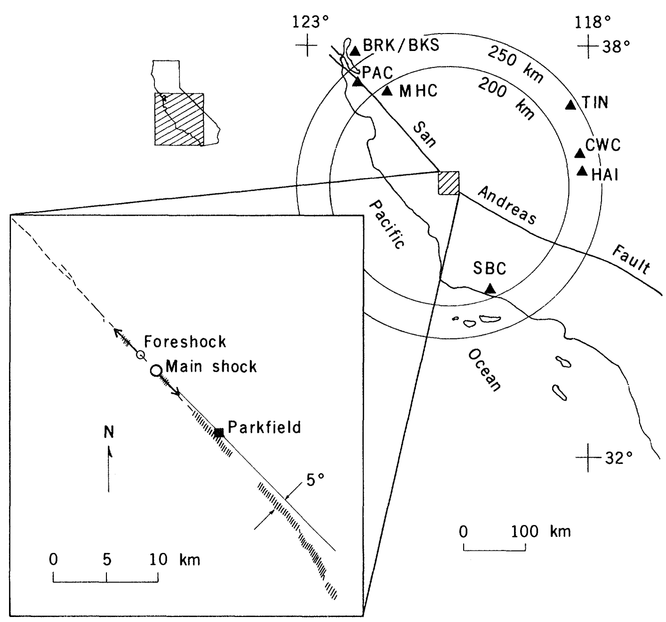

Fig. 1. Location of the Parkfield epicentral region and trace of the San Andreas fault relative to the W-A seismographic stations used (*2*). In the inset, the epicenter locations (open circles) of the 1934 (inferred) and 1966 main shocks and foreshocks together with the direction of rupture expansion for each event (heavy arrows) are shown, as is a 5° change in the strike of the fault trace (*6*). The dashed line represents the mapped trace of the fault, the solid line extends the trend of the fault from the northwest, and sections of the fault where surface displacement during the 1966 sequences was observed (*11*) are indicated by hatching.

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