Aerometric studies in Greater Cincinnati using an integrating nephelometer

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ABSTRACT

Horizontal and vertical scattering profiles are presented for Greater Cincinnati. The ground and upper air profiles were obtained from a nephelometer attached to a station wagon and a Cessna aircraft, respectively. Preliminary results show that under anticyclonic weather the dust dome is well pronounced with scattering coefficients of 8×10^{-4} m^{-1} (304 μg/m^3) on the ground and 5×10^{-4} m^{-1} (190 μg/m^3) at 900 m MSL. The most polluted city areas have about 2–2.5 times higher dust loadings than the outskirts. Under cyclonic weather the scattering profiles are flattened with values below 2×10^{-4} m^{-1} (76 μg/m^3) both for surface and upper air samplings. The vertical profiles seem to indicate that Cincinnati's dust dome does not extend much beyond 1 000–1 500 m above the ground. Horizontal and meridional scattering profiles show that the nephelometer is well suited for monitoring small-scale changes in air pollutant concentrations due to changes in land use. The research has shown that in spite of inaccuracies in the assessment of absolute values, the instrument can provide valuable information on three-dimensional variations of particle concentrations.

1. Description and review of the integrating nephelometer

The instrument consists basically of a xenon flashlamp and a multiplier phototube detector. The effective wavelength of the instrument is 0.5 μm. A fraction of this unpolarized light from the lamp is scattered by aerosols and air molecules and monitored over scattering angles from 8° to 170°. The monitored intensities have empirically been correlated with measured mass concentration giving the following relationship with the 90 % error band:

$$M(\mu g/m^3) = 3.8 \begin{matrix} +3.8 \\ -1.9 \end{matrix} \times 10^5 b\,(m^{-1}) \qquad (1)$$

where b is the intensity of the monitored scattered light (Charlson et al., 1969).

Theoretical calculations using the Mie scattering theory agree with the above relationship within a factor of 2 (Griggs, 1972). Studies have shown that below a relative humidity of 70 % the optical interference of water vapor is minimal. Therefore a heating coil was attached to the air intake hose to heat the incoming air. The integrating nephelometer is discussed to a greater detail elsewhere (Charlson et al., 1967; Ahlquist & Charlson, 1968; Ahlquist & Charlson, 1969; Charlson et al., 1969; Bach & Hagedorn, 1971).

The advantages of the usage of this instrument are quite obvious. Its compact construction, its ruggedness, and its relatively light weight of 5 kg make it particularly useful for mobile sampling on either an automobile or an aircraft. Also, the power requirements for the instrument can be handled by the vehicular electrical systems. Furthermore, warm-up and calibration procedures are simple and not time-consuming. Both zero and gain of the instrument is such that one calibration usually suffices per one hour of operation. For a 1/2 sec time constant setting the instrument provides a practically instantaneous response and thus virtually real time data, which is recorded and extracted easily. Last but not least, this type of instrument is the only one presently available

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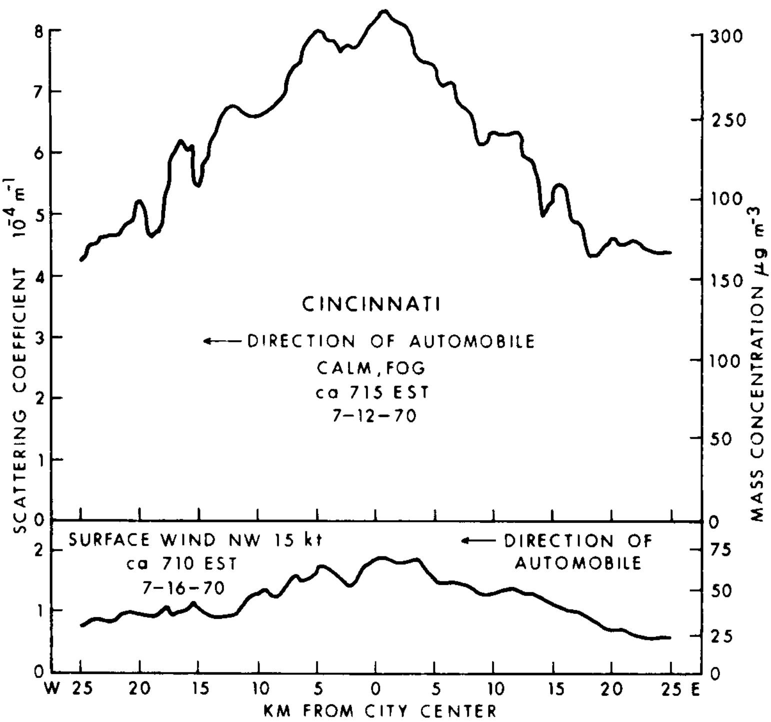

Fig. 1. Horizontal scattering profiles under different weather conditions using an automobile in Cincinnati

that provides instantaneous values of suspended particles which is required in mobile sampling.

In using this instrument one should also be aware of the inherent assumptions made in using the relationship between mass concentration and scattered light. [The most critical assumption is that the size frequency distribution of the particles was identical during the calibration and the measurement periods.] Other assumptions, however less critical, are those of identical particle shapes, densities, indices of refraction, and molecular scattering.

The results discussed in this paper are given in terms of the scattering coefficient b and mass concentration M, using equation (1). One has to realize, however, that the absolute values are probably off by a factor of 2, whereas the errors in the relative concentrations are much less, since a rather uniform particle profile and property can be expected throughout the sampled atmosphere.

2. Discussion of results

2.1. *Horizontal scattering profiles on the ground*

In air quality control the assessment of the spatial distribution of air pollutants at breathing levels is very important. For this purpose the nephelometer package was attached to an automobile. The sampling route from the eastern to the western countryside across suburban, downtown and industrial parts of Cincinnati, followed the roads and highways 32–50–264–50 over a distance of about 50 km. Always the outside lane closest to the pedestrian was travelled. Whenever possible a speed of 25–30 mph was kept.

One profile run lasted usually between 1 1/2 hours to 2 hours depending on the traffic conditions. The short time period permitted us to sample under fairly uniform meteorological and traffic conditions.

Fig. 1 shows two of such profiles across Cincinnati. The profile for July 12, 1970 reflects a typical high pollution situation under calm and foggy weather conditions. The smoke pall has engulfed a broad area of metropolitan Cincin-

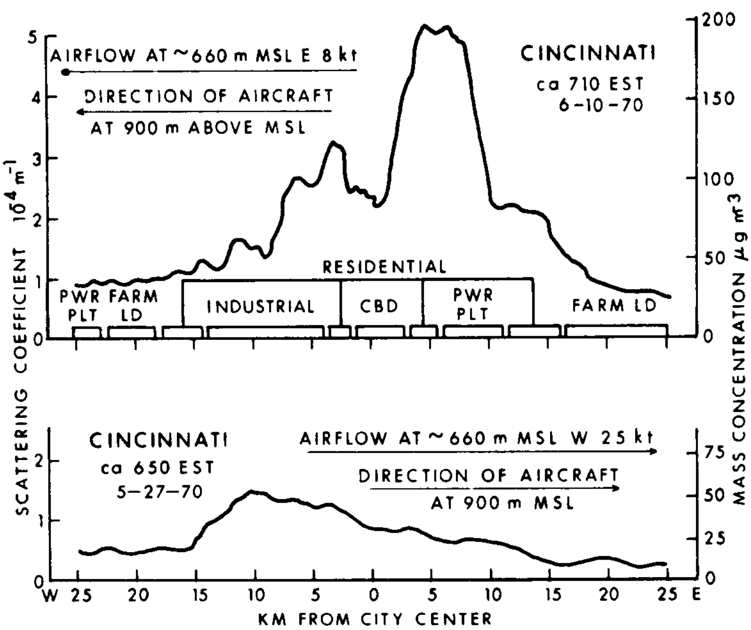

Fig. 2. Horizontal scattering profiles under different weather conditions using an aircraft in Cincinnati.

nati. The sharp peaks and incisions in the graph presumably reflect alternating stretches of roads with heavy and light traffic. It is significant to note that the rural outskirts have only 1/2 of the suspended particulate levels that are measured in the downtown and industrial areas.

The second profile in Fig. 1 was obtained at very nearly the same time but under completely different weather conditions. A strong 15 knot north-west wind reduced the suspended particulate loading at breathing level about four times as compared to the calm situation. Since the profiles were obtained on exactly the same route and at the same time of the day, with presumably similar traffic density, this reduction is in all likelihood due to the greater ventilation.

2.2. *Horizontal Scattering profiles at 900m MSL*

In order to assess particle profiles at higher altitudes above the city the nephelometer was mounted to a Cessna aircraft. The speed of the aircraft was kept constant at about 80 mph. Whereas scattering coefficients obtained from surface profiles are indicative of mostly automobile pollution, samplings conducted at certain heights above the ground may, to a large extent, have been the result of general combustion processes of industrial, commerical or residential origin.

In Fig. 2 again two contrasting scattering profiles are shown for a constant elevation of about 900 m MSL, for early morning conditions, but under different meteorological influences. Two rather well-defined scattering peaks are visible on the upper graph reflecting the industrial area and a localized plume from a large power plant. The scattering coefficient over the industrial area at 900 m MSL is about three times as high than over the farmland; and under the influence of isolated large plumes it can be five times as high. The lower graph in Fig. 2 shows the situation for a strong 25 knot wind from the west at about 660 m MSL as obtained from the Dayton RAOB observations. In the absence of the influence of the power plant smoke plume, the highest scattering value is usually found over the industrial Millcreek Valley. It is also interesting to note that this fairly strong westerly wind did not displace the dust dome to the east. A comparison of the magnitudes of the values in both graphs of Fig. 2 shows that a threefold increase in wind speed is associated with a decrease in the scattering coefficient by approximately a factor of three. Comparing the respective light wind and strong wind graphs in

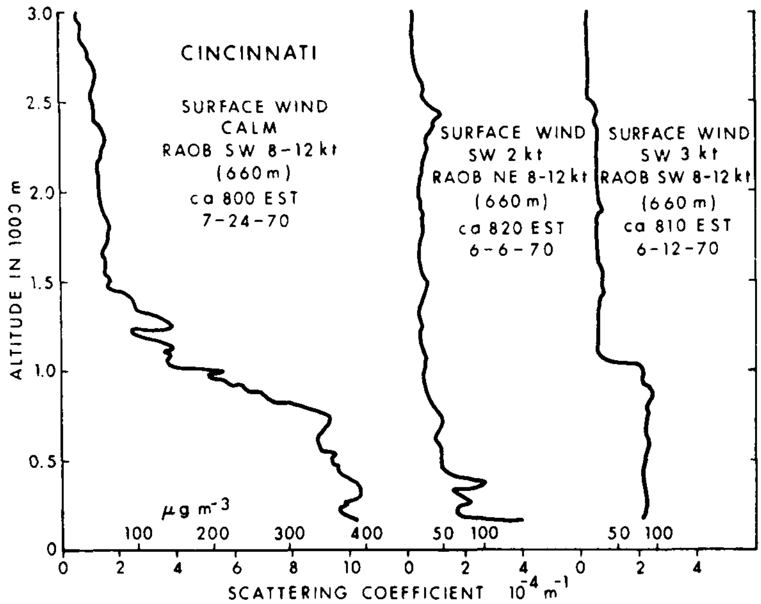

Fig. 3. Vertical scattering profiles under different weather conditions over Cincinnati (Millcreek Valley).

Figs. 1 and 2, it can be seen that under light air motion the surface scattering profile indicates on the average a 100 $\mu g/m^3$ higher dust loading, whereas under strong air circulation the scattering coefficients both on the ground and at 900 m MSL are of almost equal magnitude.

2.3. *Vertical scattering profiles*

The vertical height to which the urban area extends its influence can best be demonstrated by flying vertical profiles. Special permission was obtained from theFAA to fly on three occasions close circle (approximately 300–400 m) loops from about 100 m to 3 000 m above the ground over the lower industrial Millcreek Valley. The results of these morning flights are shown in Fig. 3. The first case shows a calm situation with a very large scattering coefficient. One could estimate from this rugged graph that the dust dome reached to about 1 400 m above the ground. From 1 500 to 3 000 m the dust loading was still fairly high and did not come anywhere close to the air molecule scattering coefficient of 0.23×10^{-4} m^{-1}. As a matter of interest the individual ascent and descent graphs were much more rugged; the graphs plotted here represent the averages of the two runs.

The second profile shows a relatively polluted surface layer under a light NE surface wind and a moderate NE wind of 8–12 kts as measured by RAOB at Dayton. But at about 500 m the dust loading is less than 50 $\mu g/m^3$, continuing to remain low and reaching the molecular scattering coefficient at about 2 700 m. The third proprofile shows for a south-westerly wind and otherwise almost identical weather conditions as in case two quite a different vertical graph. An almost uniform aerosol layer of about 75 $\mu g/m^3$ was extending a thousand meters above the industrial valley. The dust loading decreased drastically beyond a height of 1 000 m to reach the air molecule scattering coefficient at about 2 500 m. These three examples are not sufficient to draw any definite conclusions. Many additional vertical profiles would have to be obtained in order to show whether there is an indication of Cincinnati's dust dome to reach perhaps up to 1 000 m above the ground, and to be no longer discernible beyond 2 500 m above the ground. But nevertheless, they are indicative of the existence of a rather well-developed shallow urban dust dome.

2.4. *Horizontal and meridional scattering profiles as a function of height, time, and weather*

So far profiles have been discussed along one

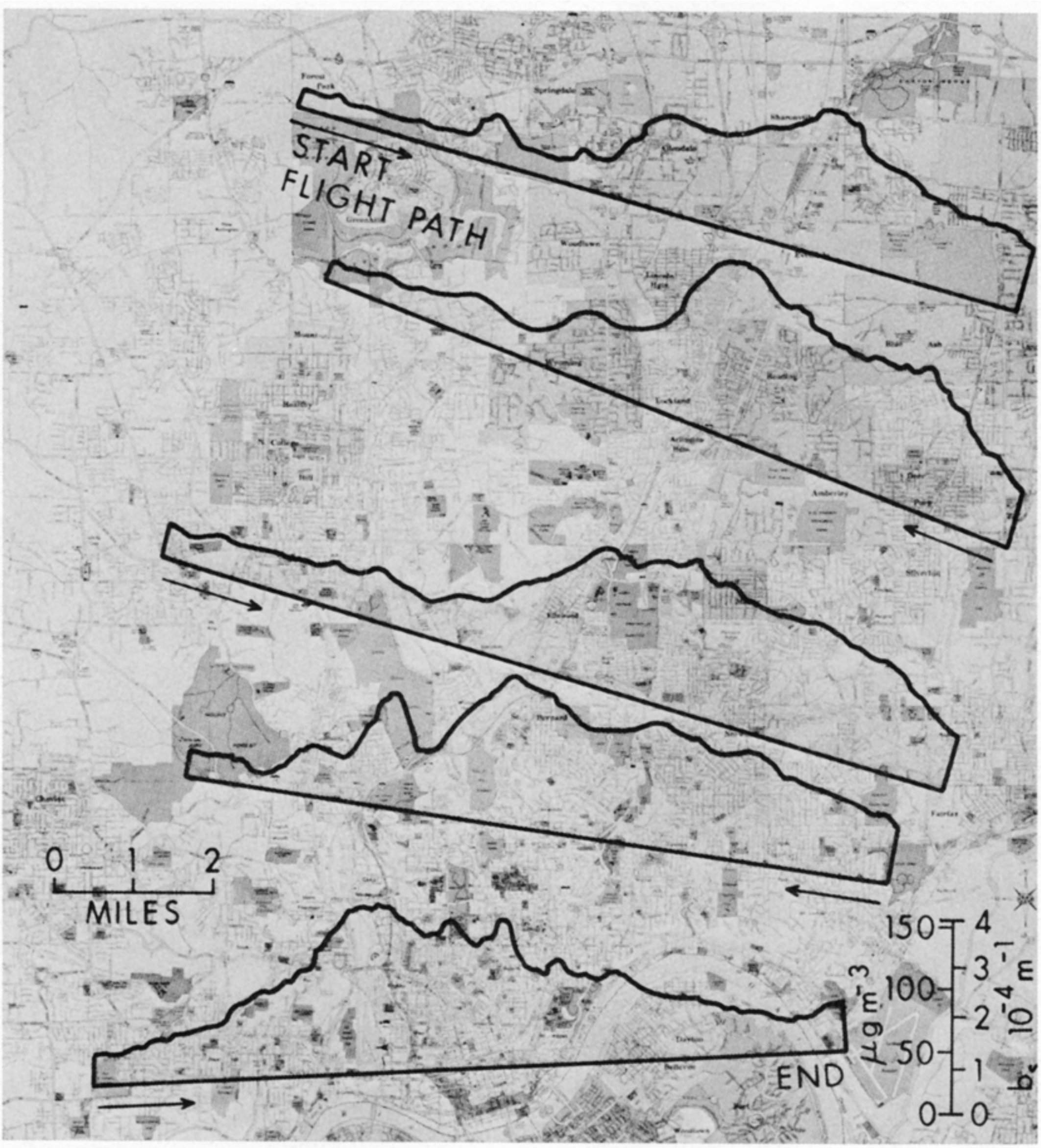

Fig 4a.

specific route across downtown Cincinnati and above the lower industrial Millcreek Valley. In Figs. 4A and B five profiles each are shown at elevations of 660 and 1 000 m reflecting the pollution loading for a variety of different urban functions. A 10-knot wind from the south-west with a visibility of 10 miles produced relatively low scattering coefficients. All 10 profiles reflect very well the influence of differences in land use both at 660 and 1 000 m elevation. The shapes of the profiles at 660 m are remarkably closely resembled by those at 1 000 m with the expected slight reduction in the magnitude of the scattering coefficients at the greater elevations.

In addition to the horizontal profiles three meridional profiles were obtained at different times of a day sampling along the industrialized Millcreek Valley and along the plateau to the east and the west of the valley (Figs. 5A and B). As in Figs. 4A and B the scattering profiles are

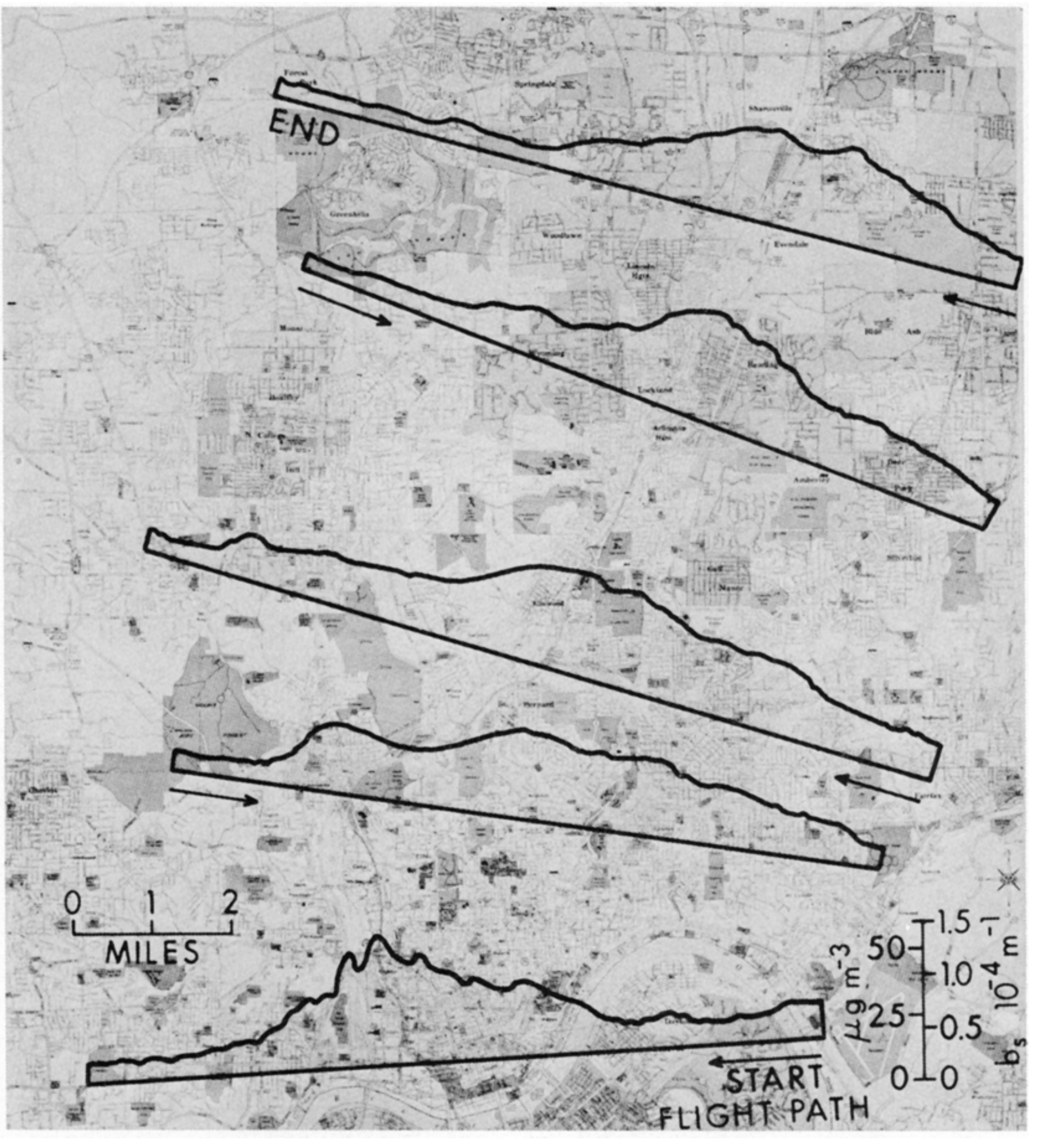

Fig. 4. (A) Horizontal profiles of the scattering coefficient (b_s 10^{-4} m^{-1}) at 660 m MSL over Cincinnati, ca. 900 EST, 5/26/70. (B) Horizontal profiles of the scattering coefficient (b_s 10^{-4} m^{-1}) at 1 000 m MSL over Cincinnati, ca. 1015 EST, 5/26/70.

superimposed on an urban functional map of Cincinnati. The morning flight at an elevation of about 570 m was conducted under a four knot south-easterly wind and a visibility of 12 miles. The suspended particles seem to be most heavily accumulated over the Millcreek Valley where most of them are also emitted. No pollutant accumulation is apparent along the western-most profile, which might have been blown in from the Millcreek Valley under the south-east wind. At noon the wind suddenly veered from the south-east to a westerly direction. It was therefore decided to fly the same meridional transects at the same elevation of 570 m. The

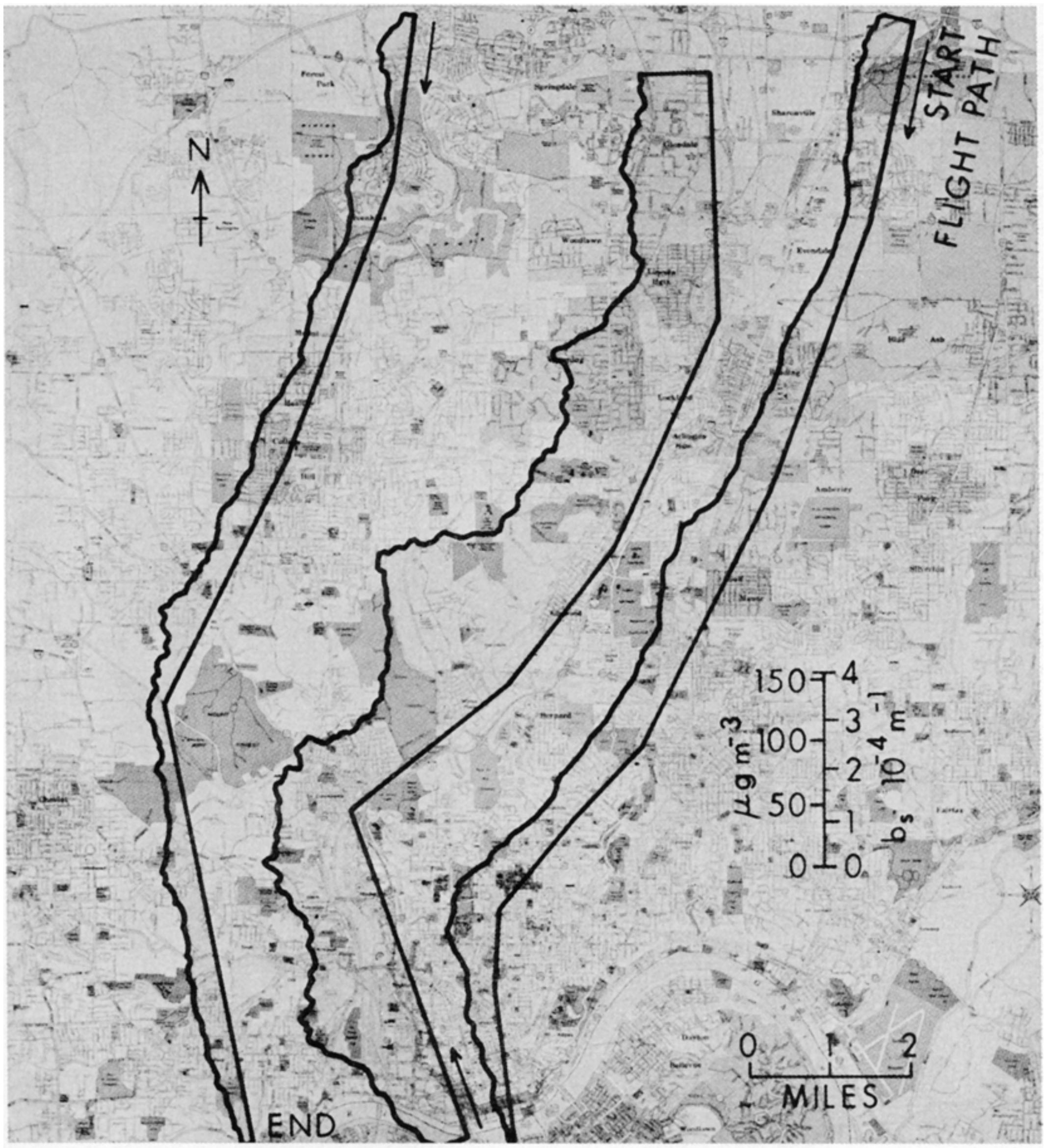

Fig 5 a.

profile shapes in Fig. 5B look almost identical to those in Fig. 5A with a slight reduction in the magnitude of the scattering coefficient. Again the three knot westerly wind was apparently not strong enough to notably displace the pollutants from their original points of emission.

3. Conclusions

Apart from the instantaneous response and thus mobile usage, the nephelometer also measures particles in the respirable size range that is believed to cause adverse health effects. Thus, despite the fact that the relationship between scattering coefficient and mass concentration represents only a factor of 2 in terms of accuracy, the described advantages make the nephelometer a valuable instrument in air quality studies. The results show that valuable information on the three-dimensional variation of aerosol concentration can be obtained.

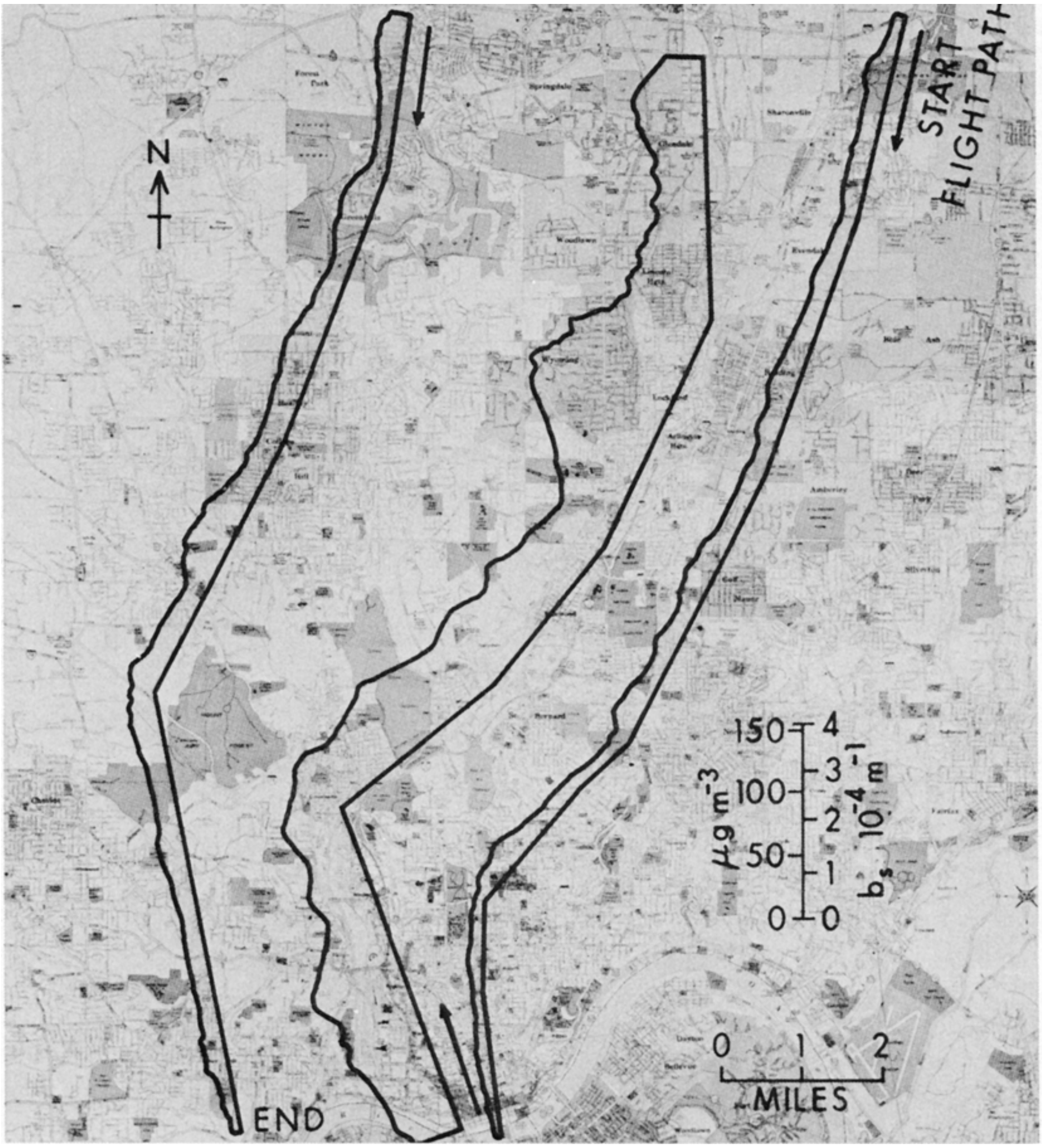

Fig. 5. (A) Meridional scattering profiles over Cincinnati at 570 m MSL, ca. 918 EST, 5/27/70. (B) Meridonal scattering profiles over Cincinnati at 570 m MSL, ca. 1213 EST, 5/27/70.

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АЭРОМЕТРИЧЕСКИЕ ИССЛЕДОВАНИЯ В РАЙОНЕ ЦИНЦИННАТИ С ПОМОЩЬЮ ИНТЕГРИРУЮЩЕГО НЕФЕЛОМЕТРА

Для района Большого Цинциннати представлены горизонтальные и вертикальные профили коэффициента рассеяния. Профили в приземном слое воздуха и в свободной атмосфере были получены с помощью нефелометров, установленных вблизи земли и на самолете типа «Чесна», соответственно. Предварительные результаты показывают, что при антициклонической погоде пылевой купол хорошо выражен с коэффициентами рассеяния, равными $8 \cdot 10^{-4}$ *м*$^{-1}$ (304 *мкг/м*^{3}) у земли и $5 \cdot 10^{-4}$ *м*$^{-1}$ (190 *мкг/м*^{3}) на высоте 900 *м* над уровнем моря. Наиболее загрязненные части города имеют в 2–2,5 раза большие количества пыли, чем пригороды. При циклонической погоне прифили коэффициента рассеяния уплощаются и их величины становятся ниже $2 \cdot 10^{-4}$ *м*$^{-1}$ (76 *мкг/м*^{3}) как для наземных, так и для атмосферных проб. Характер вертикальных профилей указывает, что пылевой купол над Цинциннати не простирается много выше 1 000–1 500 *м* над поверхностью. Горизонтальные и меридиональные профили показывают, что нефелометр хорошо подходит для прослеживания мелкомасштабных изменений концентраций загрязнений воздуха. Данное исследование показывает, что несмотря на неточности в получении абсолютных значений, этот прибор может давать ценную информацию о трехмерных вариациях концентрации частиц в воздухе.