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THE GROWTH OF AEROSOL IN AN URBAN PLUME

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ABSTRACT*

Time changes of aerosol particle size distribution in the range of 0.01 μm diameter, concentration of O_3, NO, NO_2, SO_2, several hydrocarbons, and sulfate were measured in an urban plume. The investigation was conducted in a Lagrangian frame of reference using instrumented aircraft. The air parcel trajectory was identified by the movement of a tetroon launched from the ground to an altitude within the plume. This study was carried out in metropolitan St. Louis, Missouri, U.S.A., during the METROMEX program.

A pronounced change in the aerosol particle size distribution and an increase in the total volume of the aerosol were observed. Gas to particle transformation involving existing nuclei is responsible for the aerosol growth. In this paper the results of the measurement of trace gases and the aerosol particles and their chemical analyses will be presented and discussed.

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*This Abstract has been excepted for presentation in the 12th International Symposium on Atmospheric Pollution, 5-7 May 1976, Paris, France.

The objective of the experiment conducted in St. Louis during the summer of 1975, was to determine physical and chemical changes of pollutant in the city plume. Emphasis was placed on particle growth by coagulation and/or gas to particle transformation. The investigation was carried out in a Lagrangian frame of reference using instrumented DC-3 aircraft. The air parcel trajectory was identified by the movement of a 0.94 m^3 tetroon launched from the ground to an altitude within the plume. Portions of the data will be presented here, details of the results will be reported later.

Size distribution of particles with diameters in the range of 0.01 m to 1.0 m was measured with an airborn Electrical Aerosol Size Analyzer (lie et al, 1974), and those from 0.3 m to about 5 m were obtained with a Royco Optical Sensor Model 220 interfaced with a 16 channel pulse height analyzer and printer. A General Electric Particle Counter was used to measure concentrations of Aitken nuclei. Particles were also collected on IPC filters at the rate of 50 cfm for later chemical analysis. A flame ionization detector was utilized for determining SO_2 concentration. NO, NO_2 and O_3 concentrations were measured with a TECO Model 14D, NO_x Analyzer and a Bendix Ozone Monitor. Temperature due point, and aircraft parameters were also recorded. Most of the parameters were sampled at the rate of five times a second and averaged over the second via a Nova computer and sotred on a seven track magnetic recorder.

The tetroon was launched either from Civic Memorial Airport or Weiss Airport, located at the edge of the city (see Fig. 1), depending on the wind direction. The choice was made to avoid the tetroon from going over the city and interface with commercial aircraft flight. The procedure for deploying the tetroon is that described by Hocker (1975). Before and during each flight, pibal

data were collected to determine wind speed and direction. The tetroon was launched an hour after aircraft take off to allow for instrumentation calibration and stablization.

On August 6, a tetroon was launched at 1615 local time from Weiss Airport to an altitude of 3000 ft MSL. The day was characterized by low overcast stratus and stratacumulus in themorning changing to broken cumulus by about noon. Then broken variable scattered cumulus and swelling cumulus in the afternoon to clear at sunset. The wind was from the northeast at about 17 knots. The temperature inversion at 1647 hours, was located at about 8,000 ft MSL. Although SO_2 data was not collected during this flight, however, a value of 48 to 93 ppb were measured at 3000 ft on August 4 about ten miles upwind of the launch site, and under similar wind conditions.

Figure 2 shows the time changes in the particle volume concentration measured during the flight superimposed on it is the sulfur content of the aerosol. The volume concentrations were calculated from the particle size distribution and the sulfur was obtained from the analysis of the hi-volume filter by X-ray fluorescence technique. It should be noted here that the volume concentration is an average over fifteen minutes of sampling time. The figure shows three distinct features of the aerosol mass concentration profile. The first 60 minutes the sulfur and volume concentrations decreased with time reflecting the domination of plume dilution by diffusion over particle growth. During the second 60 minutes plume diffusion was less significant and theparticle growth was dominating. At the end of this period a new material was entrained to the airparcel resulting in a decreased concentration. At this point the pilot reported smoke from below having reached the sampling level. Apparently this new material has a lower mass concentration but the total number of

particles is higher. The latter conclusion is based on examination of the variation of the total particle number concentration with time (Figure 3). As expected the first two hours was characterized by a continuously decreasing in the particle count as a result of particle growth and plume diffusion. Beyond this point the count started to increase. Although the number concentration was calculated from the measured particle size distribution, similar profile was also observed from the G. E. Aitken Nuclei Counter (Figure 4).

Figure 4 shows the variation of other parameters measured during the flight. The relative humidity value was in the range of 50% to 60% and the temperature fluctuated around 20°C. The change in altitude with time is the sampling altitude but it was very close to the tetroon level. The ozone level slightly increased with time. On the other hand, the ratio of NO/NO_2 decreased and showed no correlation with the ozone. This behavior is typical of the flights we made. The NO and NO_2 levels remained always below about 20 ppb except when a plume was encountered along the tetroon trajectory. In this case a drastic drop in the O_3 level was observed associated with an increase in the NO/NO_2 ratio.

Figure 5 shows the changes in the particle number distribution, and the same data is plotted in Figure 6 in turn of volume distribution. It is clear that particles of sizes below about 0.06 μm were growing to sizes up to 0.9 μm. Since the total number of particles decreasing while the total volume was increasing, therefore, the particles were growing by coagulation and chemical condensation. No evidence of homogeneous nucleation of particles can be seen from this data. Similar behavior was also observed by Husar and Whitby (1973) when a large balloon was inflated with Los Angeles ambient

air and exposed to solar radiation.

It is useful to compare this size distribution measurement with those measured a year earlier on August 21, 1975. For this experiment, the tetroon was released to an altitude of 3000 ft MSL, from the Civic Memorial Airport about noon under clear sky with an average wind speed of about 8 knots. Figure 7 shows the size distributions measured. It can be seen taht the particle growth is similar. The two sets of particle size distributions showed the bimodel nature of the distribution. The first mode roughly lies between 0.06 to 0.9 μm, the so called accumulation mode (Whitby 1973). Particles in this range grow by coagulation or condensation. The second mode is above about one micron. Particles of such sizes showed no detectable growth, and as it can be seen from Figure 7, their number decreased with time as a result of plume diffusion. Plume diffusion does seem to dominate the growth of smaller particles as the case of August 6. However, the mass concentration measured on August 21 is much higher than that measured on August 6.

The experiment described above is part of the aerosol and trace gases transformation program aimed at understanding pollutant transformation through field experiment and modeling, with a strong interaction between the experiment and the models. The models are described elsewhere by Hales (1975) and Drake (1976).

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and remarks through out the year, and to F. O. Gladfelder and W. R. Griffith who piloted.

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FIGURE CAPTIONS

1 Shows the locations of the tetroon launch sites and the major SO_x point sources emissions in the area.

2 The variation in the aerosol volume concentration and the sulfur content of aerosol measured on August 6, 1975.

3 Concentration of particles larger than 0.01 μm in diameter as a function of time measured on August 6, 1975.

4 Some of theparameters measured during the August 6, 1975, flight and the O_3, NO/NO_2 concentration.

5 Number distribution of particles measured on August 6, 1975.

6 The same as Figure 5 except the data plotted as a value distribution.

7 Volume distributions of particles measured on August 21, 1974.

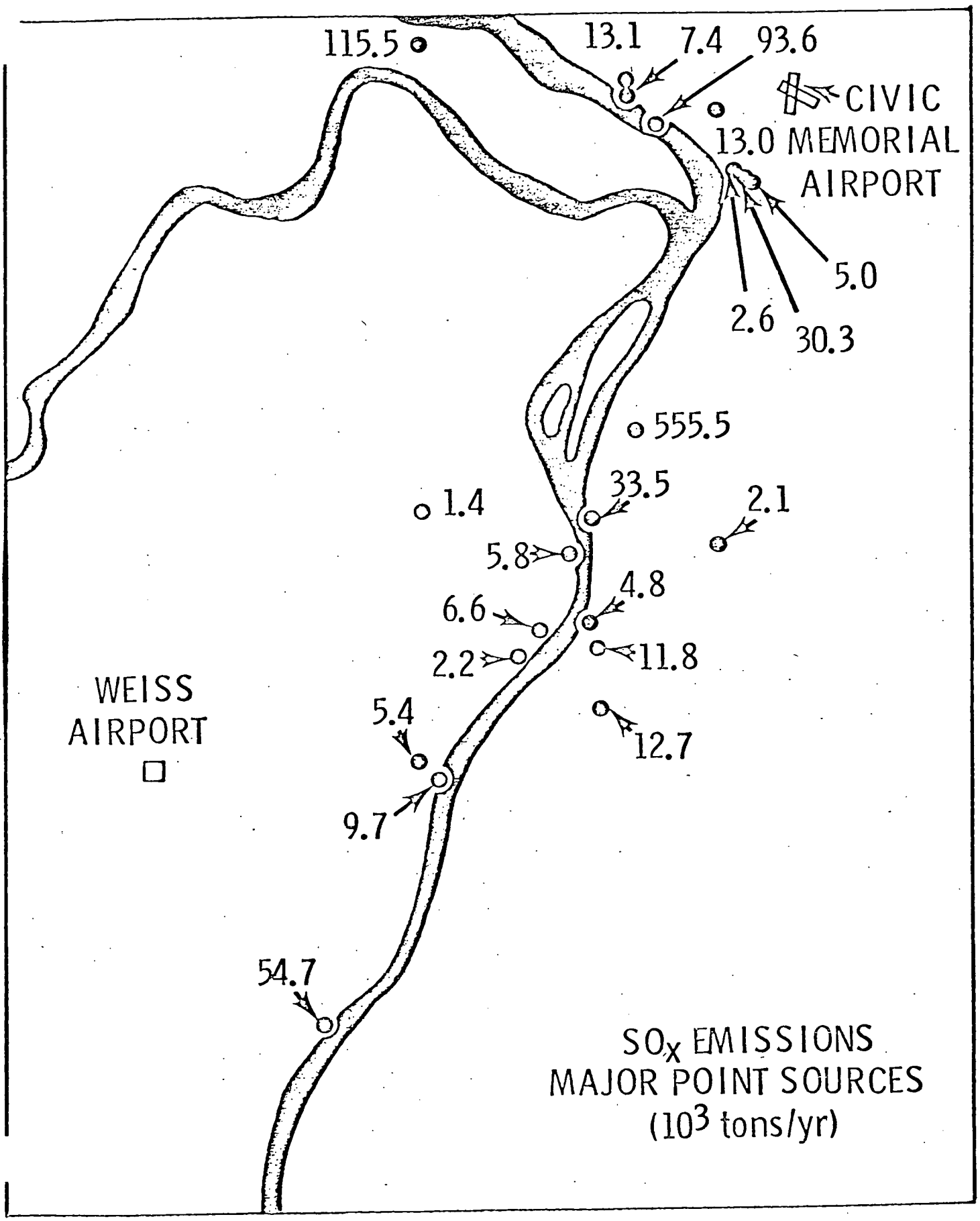
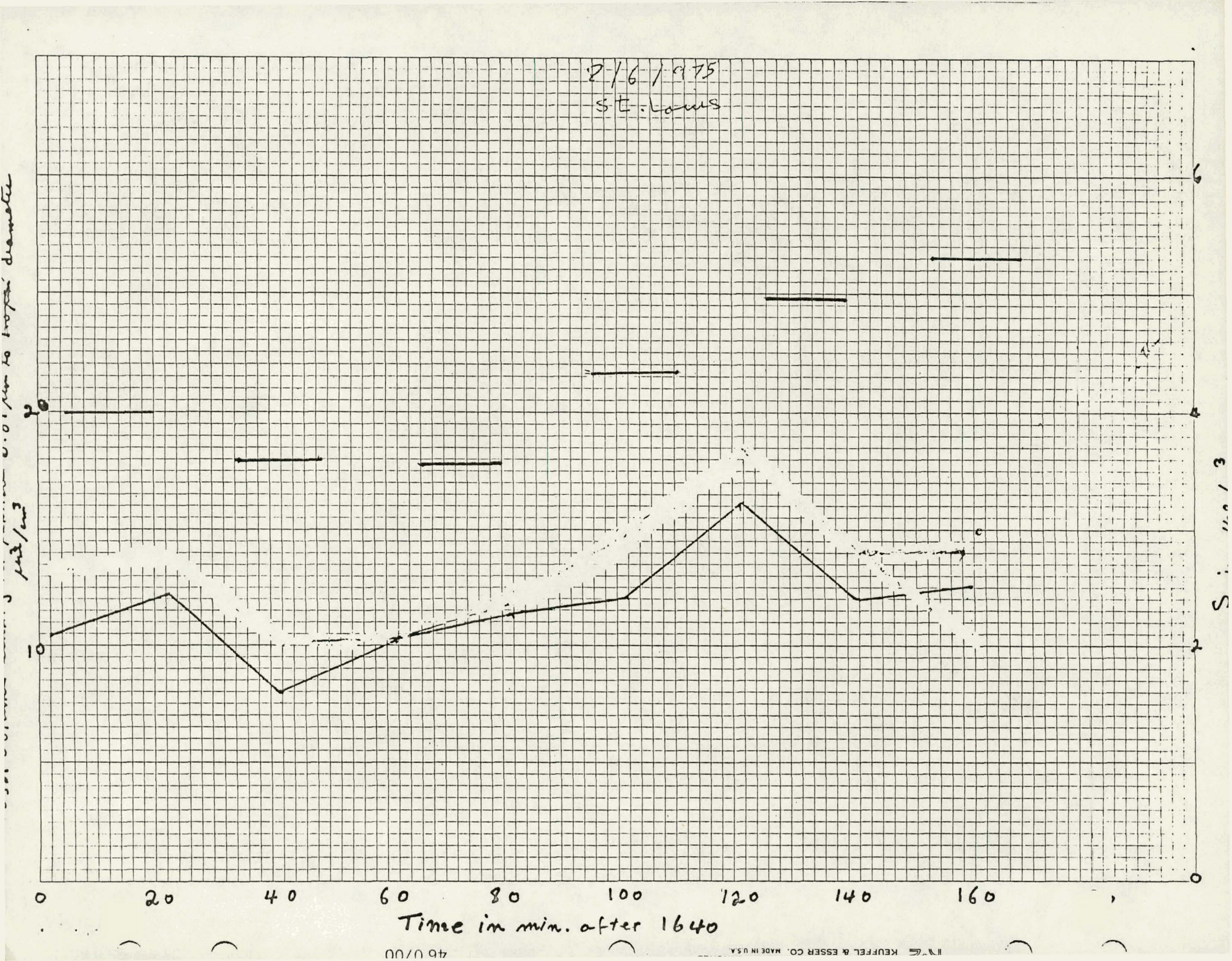
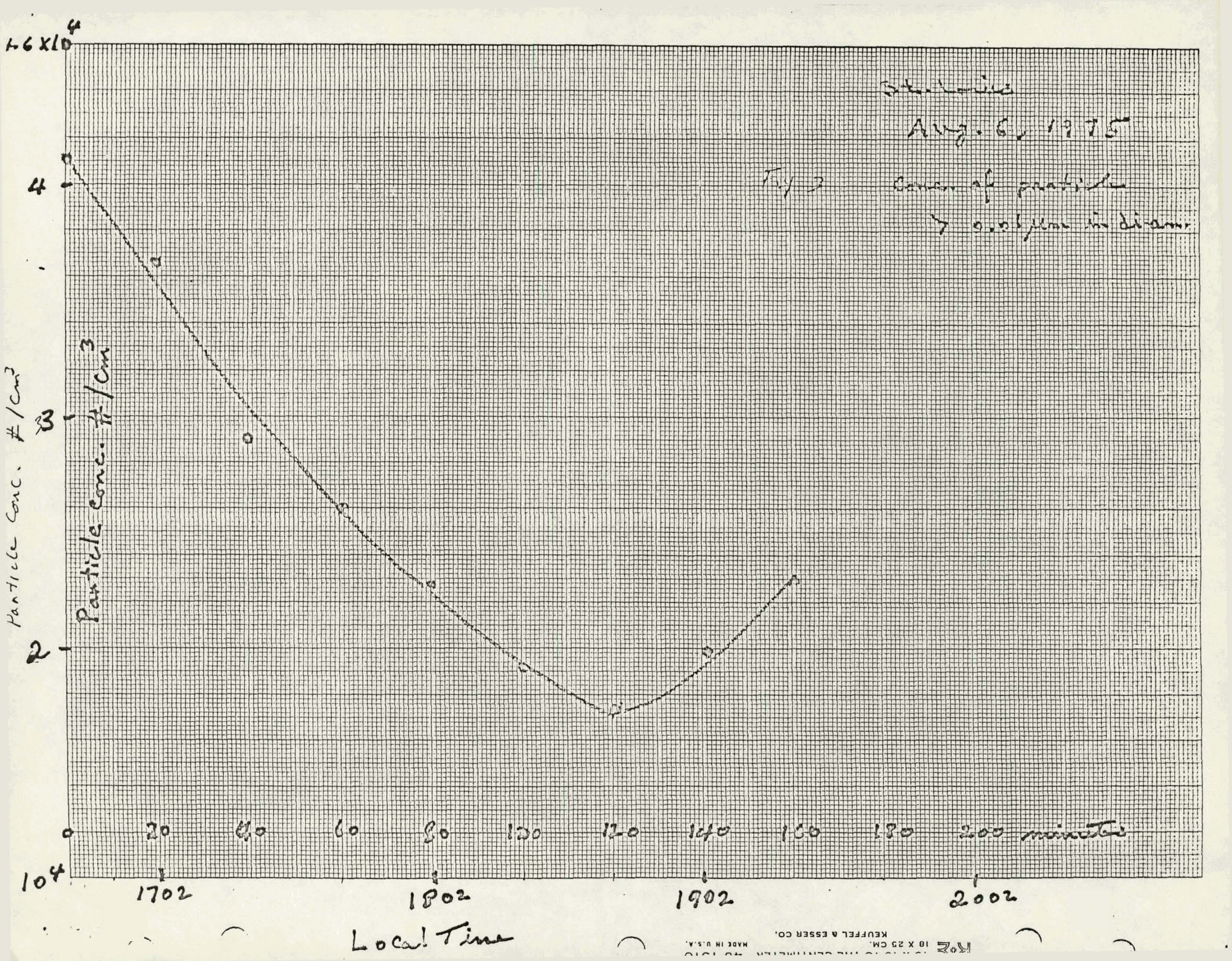
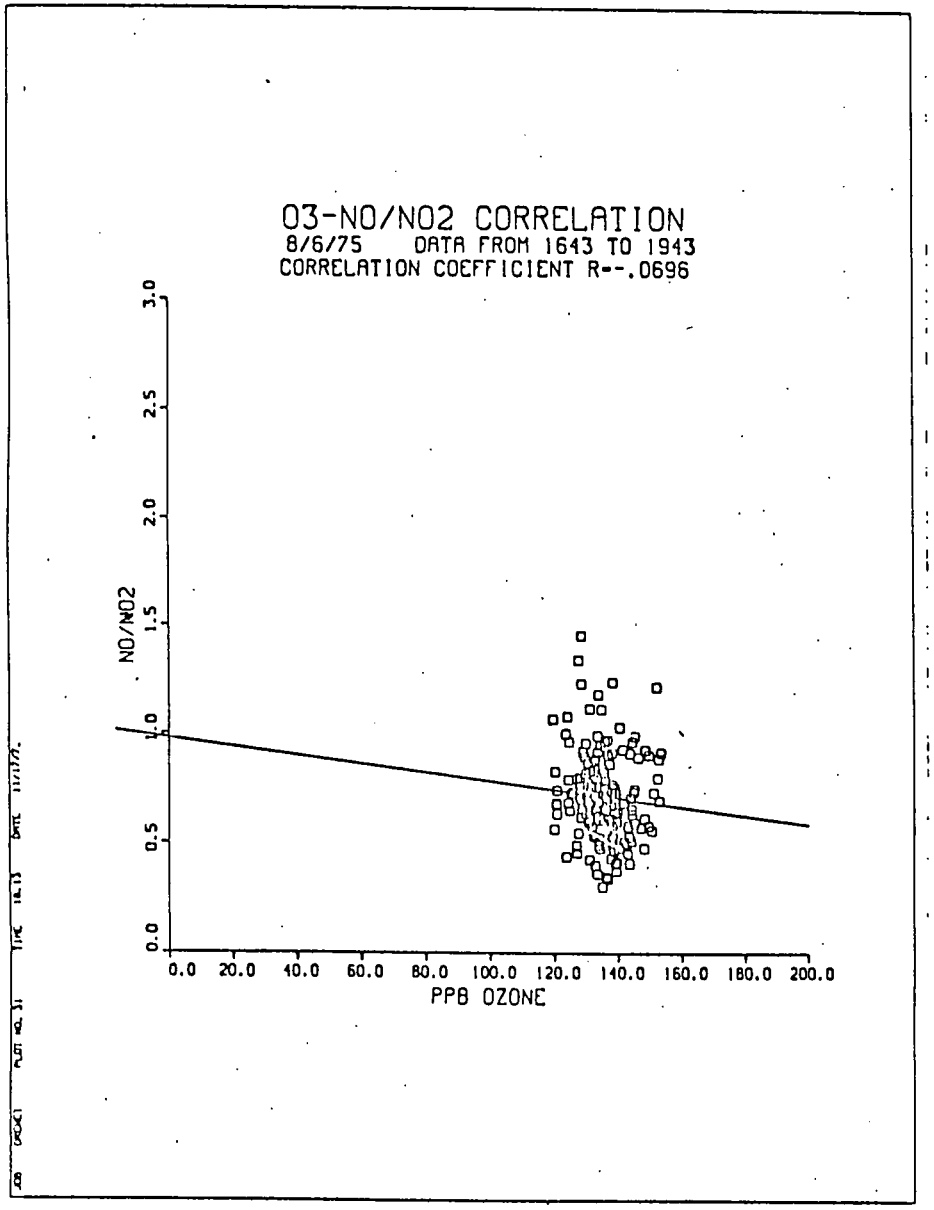
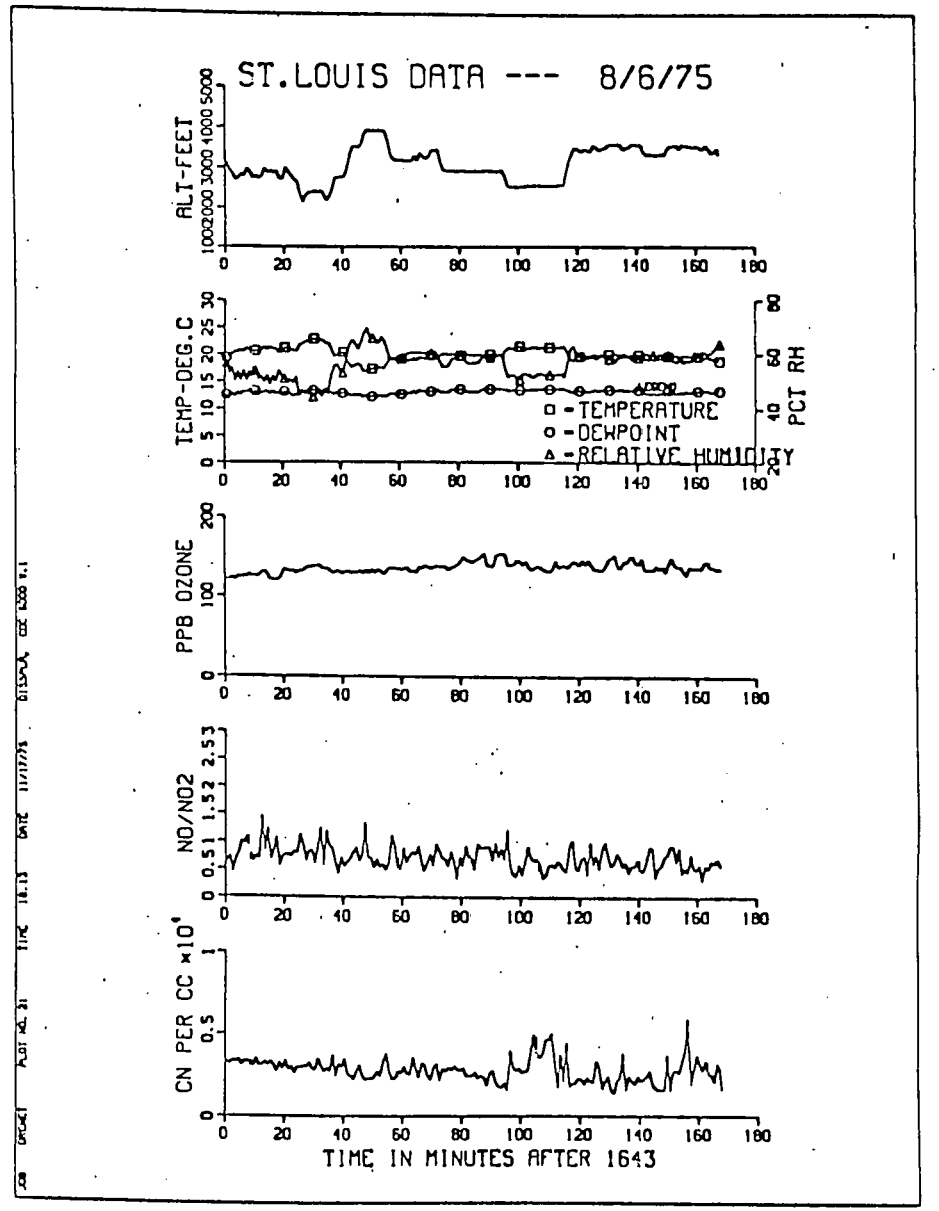

115.5
13.1
7.4
93.6
CIVIC
13.0 MEMORIAL
AIRPORT
5.0
2.6
30.3
555.5
1.4
33.5
2.1
5.8
4.8
6.6
11.8
2.2
WEISS
AIRPORT
5.4
12.7
9.7
54.7
SOx EMISSIONS
MAJOR POINT SOURCES
(10³ tons/yr)

Fig. 1


2/6/1975
St. Louis
Time in min. after 1640
0
20
40
60
80
100
120
140
160
0
2
4
6


4.6 x 10^4
4
3
2
0
10^4
Particle conc. #/cm^3
Particle Conc. #/cm^3
Stratocu
Aug. 6, 1975
Typ 2
Conc of particles
> 0.3 μm in diam
20
40
60
80
100
120
140
160
180
200 minutes
1702
1802
1902
2002
Local Time
KEUFFEL & ESSER CO.
MADE IN U.S.A.


O3-NO/NO2 CORRELATION
8/6/75 DATA FROM 1643 TO 1943
CORRELATION COEFFICIENT R=-.0696
NO/NO2
PPB OZONE


ST.LOUIS DATA --- 8/6/75
ALT-FEET
TEMP-DEG.C
PCT RH
□ -TEMPERATURE
○ -DEWPOINT
△ -RELATIVE HUMIDITY
PPB OZONE
NO/NO2
CN PER CC x10⁴
TIME IN MINUTES AFTER 1643

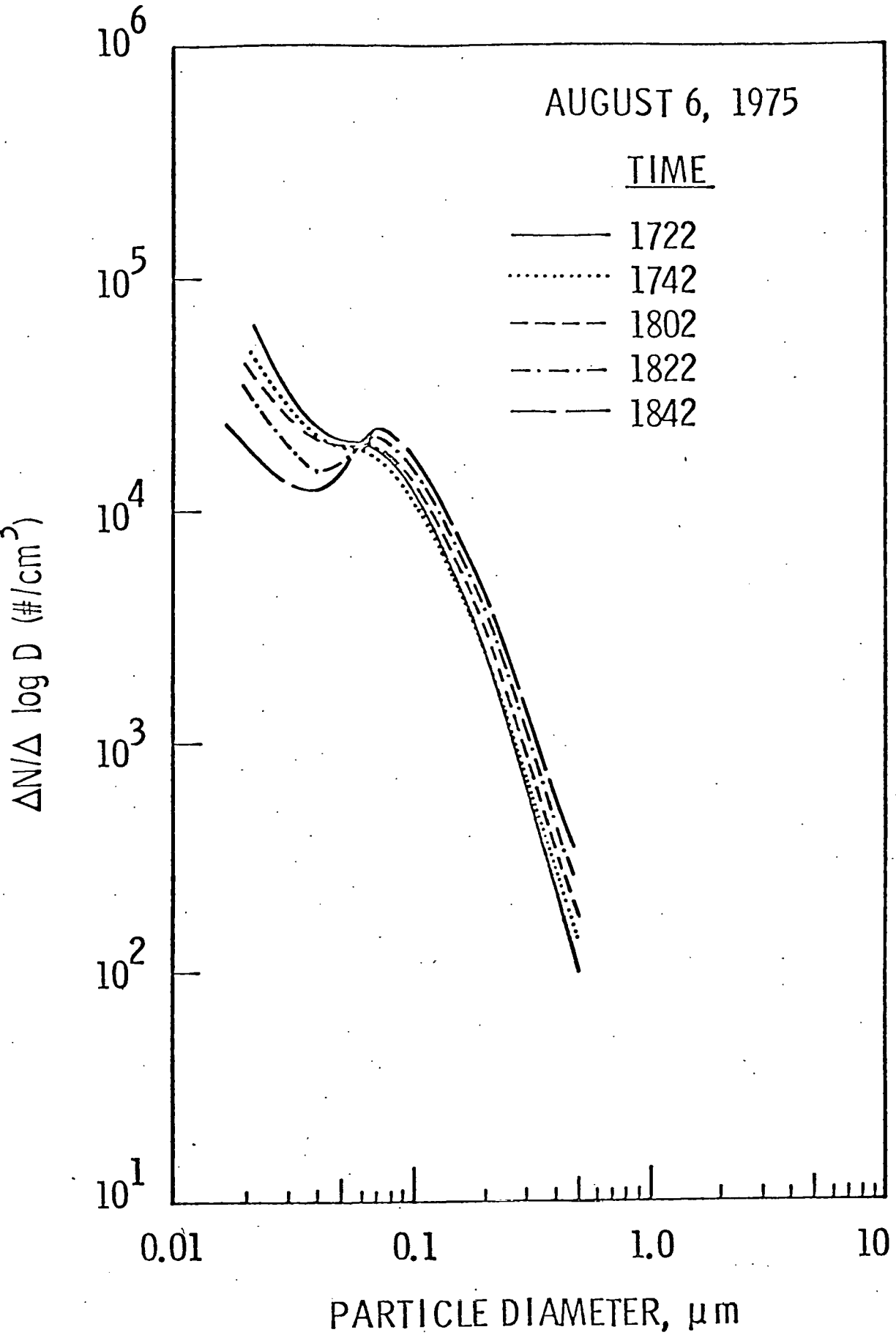

AUGUST 6, 1975
TIME
1722
1742
1802
1822
1842
10^6
10^5
10^4
10^3
10^2
10^1
$\Delta N/\Delta \log D$ (#/cm^3)
0.01
0.1
1.0
10
PARTICLE DIAMETER, μm

Fig. 5

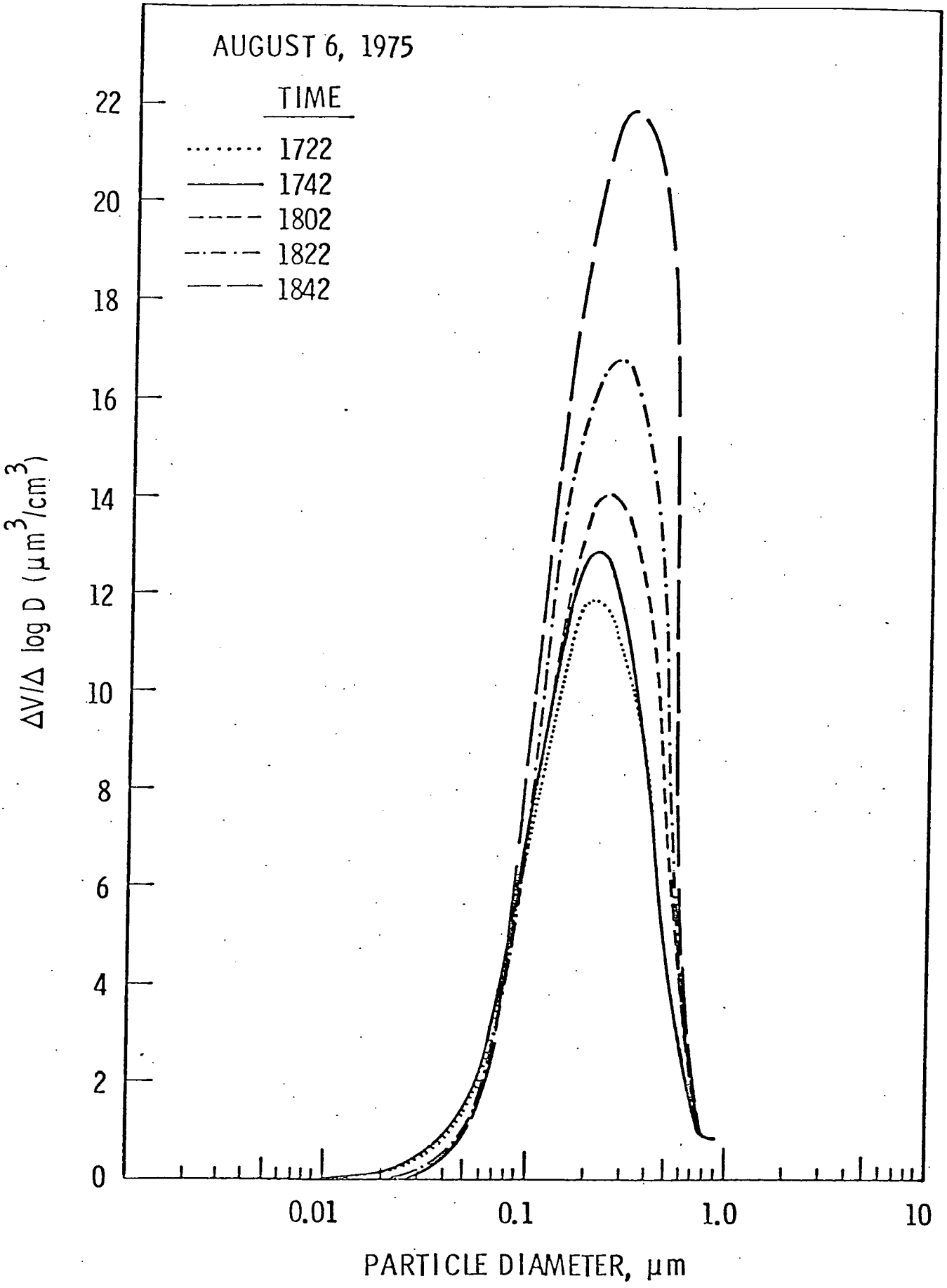

AUGUST 6, 1975
TIME
1722
1742
1802
1822
1842
22
20
18
16
14
12
10
8
6
4
2
0
ΔV/Δ log D (μm³/cm³)
0.01
0.1
1.0
10
PARTICLE DIAMETER, μm

Fig. 6

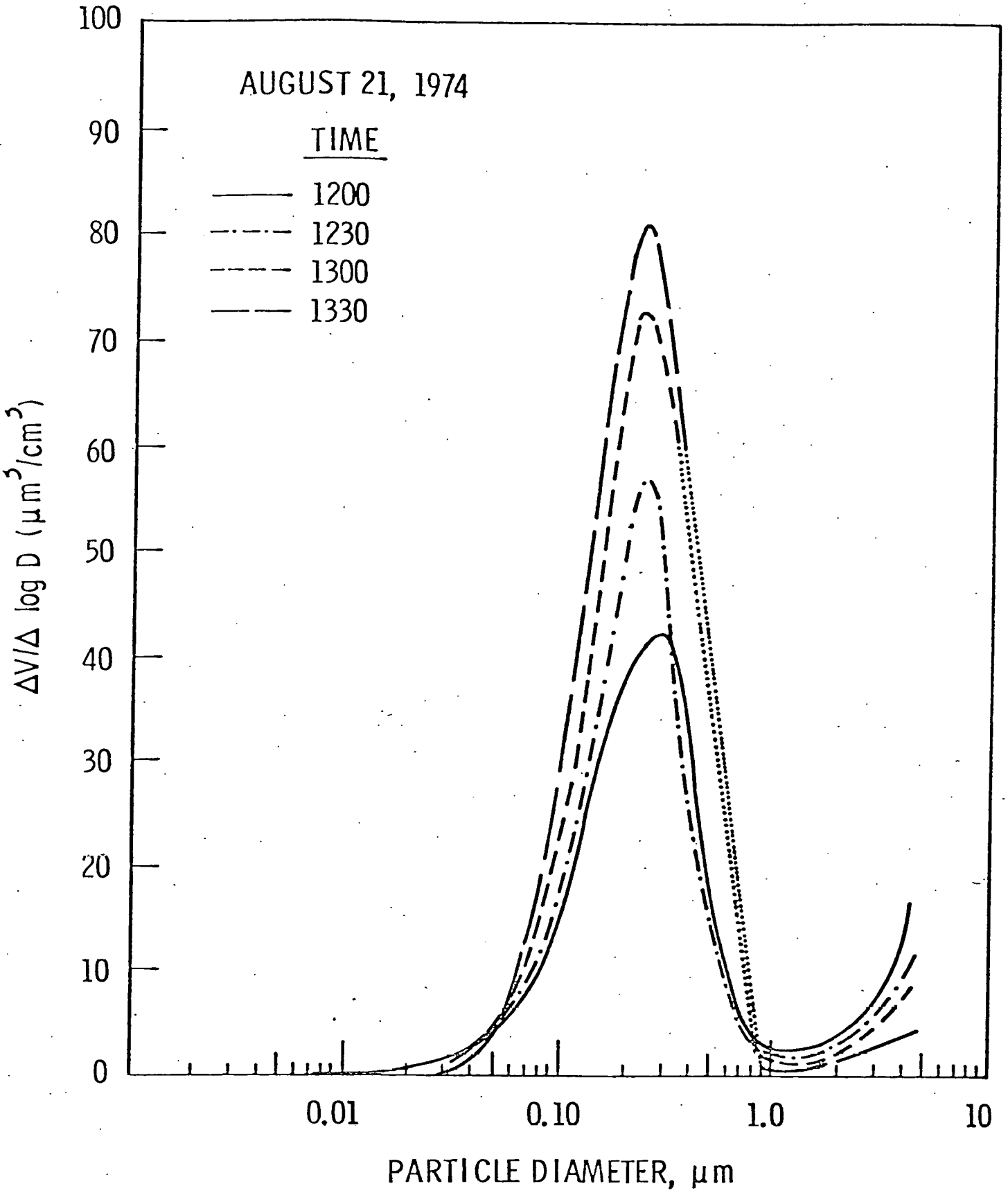

AUGUST 21, 1974
TIME
1200
1230
1300
1330
100
90
80
70
60
50
40
30
20
10
0
ΔV/Δ log D (μm³/cm³)
0.01
0.10
1.0
10
PARTICLE DIAMETER, μm

Fig. 7