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Ecological Research Series

HOUSTON URBAN PLUME STUDY - 1974
Description and Summary of Results

Environmental Sciences Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

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HOUSTON URBAN PLUME STUDY - 1974
Description and Summary of Results

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ABSTRACT

The 1974 Houston Urban Plume Study (HUPS) was undertaken as a preliminary investigation of some of the unresolved features of Houston's air pollution problem. HUPS was intended specifically to gain limited information on the spatial and temporal distribution of air pollutants--particularly, primary and secondary aerosols--in the Houston area as an aid should a later intensive investigation of aerosol character and transport be needed.

Aerial measurements were made of the principal pollutants (SO_2, NO_x, O_3, CO, aerosol) of the Houston area. Wind-field measurements were also made. These data were used to estimate pollutant budgets. Values for SO_2 and NO_x (14 metric tons/hr and 40 metric tons/hr, respectively) were reasonably comparable with values derived from emissions inventories of the Texas Air Control Board (13 and 24 metric tons/hr, respectively). On the basis of the limited sampling period, the industrial area (east of downtown Houston) apparently is the major contributor of primary air pollutants in the Houston area. In the morning hours above the mixed layer, relatively large ozone concentrations (max. 0.2 ppm)--almost certainly of photochemical origin--were found that correlated closely with light scattering aerosol, thus indicating the existence above the mixed layer of strong secondary aerosol sources.

Appendices containing all the data are not included in this report. A complete, unabridged report is available from the National Technical Information Service (NTIS) as EPA-600/3-78-048a, May 1978.

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SECTION 1

INTRODUCTION

The City of Houston is situated on the coastal plains of Texas close to the western section of the Gulf of Mexico. Large land masses extend for great distances in every direction from Houston except toward the southeastern quadrant in which lies the Gulf of Mexico. The proximity of the city to the Gulf leads to a local climate with some maritime characteristics, while, at the same time, the adjacent vast expanse of land gives rise to some continental characteristics. The meteorology is, therefore, subject to such variation depending on the large scale wind pattern prevailing at a given moment.

Typically, in the winter months the climate of the Houston area takes on a continental character owing to penetration of polar air masses. In summertime, the area normally experiences a nearly tropical weather regime with very few frontal passages, high relative humidities, and convective rain showers.

The air pollution potential for the Houston area is low owing to strong thermal mixing and to almost continuous low level winds. The ventilating effect of these winds usually provides good dilution of air pollutants. Long periods of air stagnation are not too common, although frequent periods of short duration (one day or so) do occur. Most commonly, these periods of atmospheric stability are associated with surface-based, radiation-type inversions, although occasionally this low-level stability is caused or reinforced by the advection of cool air from the Gulf of Mexico.

The low air pollution potential for the Houston area is fortunate in view of the area's large pollutant sources. Along the Houston Ship Channel, immediately to the east of the downtown area, lies one of the world's greatest concentration of petrochemical and related process industries. Along the Gulf Coast, centered around Houston some 40% of the nation's basic petrochemicals are produced. In addition, in terms of population the Houston area is one of the fastest growing in the country with a metropolitan population of 1,677,863 in 1970. The city has more single family homes and fewer apartments than other cities of comparable size and boasts a high figure for registered motor vehicles (1,521,245 in 1975 for Harris County).

Along with the low air pollution potential, the area has benefited from the use of natural gas, a clean fuel, as its principal energy source. As this fuel increases in price, becomes depleted, or both, substitution of other fuels will occur and it is possible that this advantage in maintaining air quality may diminish.

In brief, the low air pollution potential for the Houston area is offset by relatively large sources of air pollutants. As a result, Houston usually exceeds (with year to year exceptions) the national standards for carbon monoxide (highest hourly values), total suspended particulate matter (highest daily values), ozone (highest hourly values), and non-methane hydrocarbons (highest values for 6-9 a.m.). In addition, the Houston area is marked by persistent haze conditions caused by light scattering aerosol and the area may act as a source of oxidants and other air pollutants which could produce damage to the peanut, soybean, rice, and other important crops in the coastal region.

Much of what is known of the air pollution problem in the Houston area is based on routine surface monitoring stations operated by the Texas Air Control Board and the City of Houston and on emissions inventories compiled by the Texas Air Control Board. As valuable as such information is, it has left unresolved a number of questions concerning Houston's air pollution - notably, the sources of Houston's oxidant problem and the Houston haze.

The 1974 Houston Urban Plume Study (HUPS) was undertaken by the Atmospheric Aerosol Research Section, Environmental Sciences Research Laboratory, USEPA as a preliminary investigation of some of the unresolved features of Houston's air pollution problem. HUPS was intended specifically to gain limited information on the spatial and temporal distribution of air pollutants - particularly, primary and secondary aerosols - in the Houston area as an aid should a later intensive investigation of aerosol character and transport be needed. The regions studied are indicated in Figure 1.

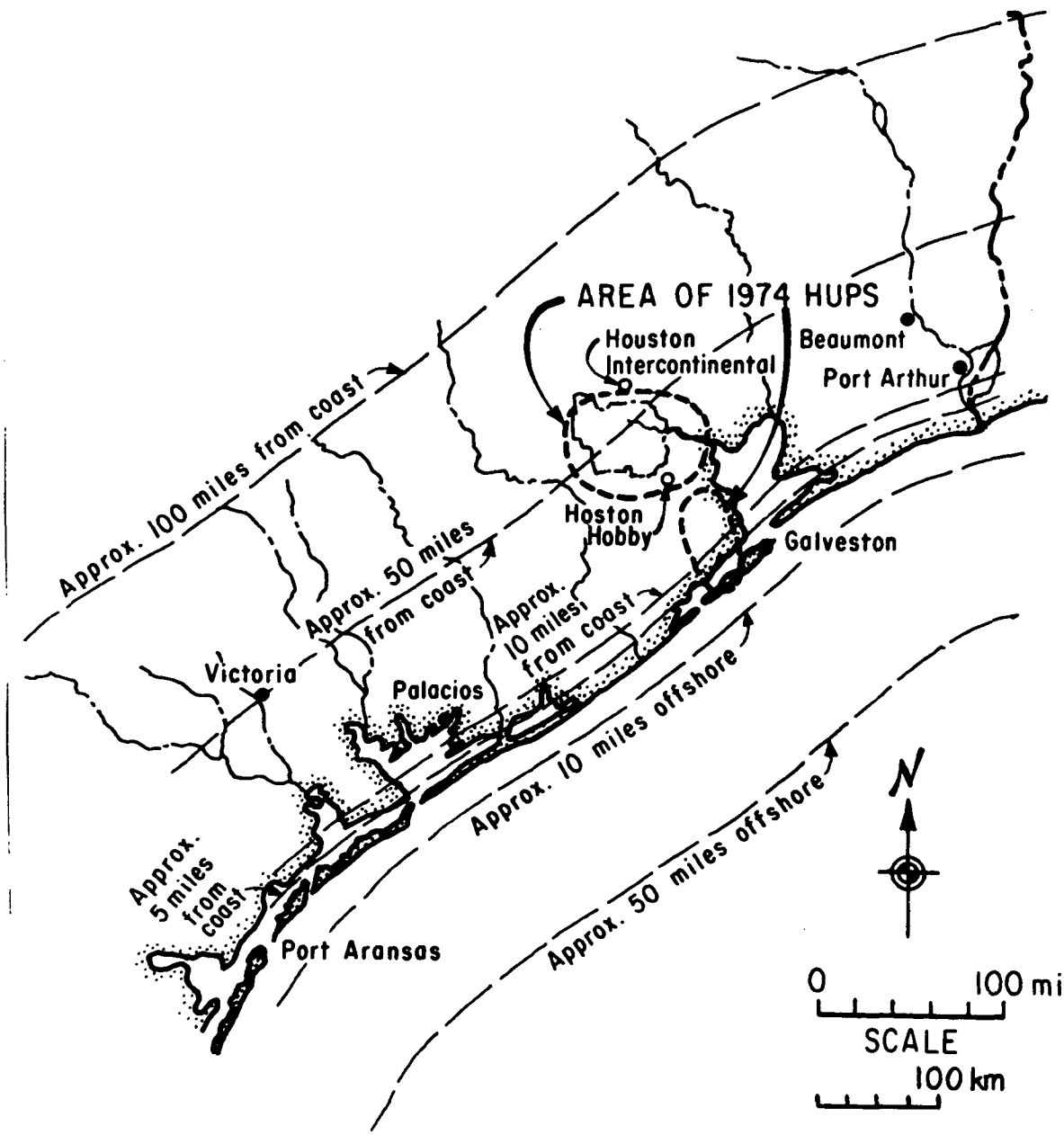

Figure 1. The regions studied by instrumented aircraft and pibal measurements in the 1974 Houston Urban Plume Study.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

The 1974 Houston Urban Plume Study (15-24 July, 1974) had as its objective a preliminary investigation of some of the unresolved features of Houston's air pollution problem. The principal tool in this investigation was an instrumented fixed wing aircraft. The following conclusions derived from the study are based on limited data representing seven days (18-24 July, 1974) of actual operation.

(1) Pollutant budgets for the Houston area for SO_2 and NO_x (14 metric tons/hr and 40 metric tons/hr, respectively) were found to be in reasonable comparison with values derived from emissions inventories of the Texas Air Control Board (13 and 24 metric tons/hr, respectively).

(2) On the basis of the limited sampling period, it appears that the industrial area (east of downtown Houston) is the major contributor of primary air pollutants in the Houston area.

(3) During the period of the study, in the morning hours above the mixed layer, relatively large ozone concentrations (max. 0.2 ppm) - almost certainly of photochemical origin - were found which were correlated closely with light scattering aerosol. This correlation indicated the existence above the mixed layer of strong secondary aerosol sources, possibly associated with the oxidation of SO_2.

This preliminary study has served to indicate more clearly what additional studies are needed to delineate the aerosol character and transport in the Houston area. The most important recommendations are:

(1) Future field studies in the Houston area should be preceded, planned, and carried out adaptively with an adequate air pollution model for the Houston area.

(2) These studies should integrate ground based and aircraft measurements, preferably involving two or more aircraft. At least one helicopter would be desirable to permit sampling below 1000 feet (304.8 m.) owing to frequent low level nighttime inversions in the Houston area.

(3) The studies should be of sufficient duration to permit an adequate sampling of meteorological conditions and diurnal and seasonal variations.

(4) Special attention should be given to characterization of primary sources and background values for the principal air pollutants - particularly for particulate matter.

(5) The test of an adequate delineation of the aerosol transport and character for the Houston area can only be in the form of predictive success of an air pollution model developed previously and adapted extensively from field results.

It is safe to say that studies in the Houston area which proceed without these elements cannot be decisive in resolving the nature of Houston's air pollution problem.

SECTION 3

PROCEDURE

The 1974 Houston Urban Plume Study (HUPS) covered the ten day period 15-24 July. The major elements of the study were a fixed wing aircraft instrumented to measure concentrations of the principal air pollutants and six pilot balloon stations to provide hourly data on wind speed and direction in Houston's atmosphere. These elements were intended to supply information on the spatial and temporal distribution and fluxes of the principal air pollutants.

The following description gives detail on these major elements and list as well auxilary elements of HUPS.

METEOROLOGICAL INFORMATION AND DATA

(a) Meteorological forecasting and analysis were provided to HUPS by Dr. Gale F. Hoffnagle, INTERA Environmental Consultants, Ltd., Houston, Texas.

(b) Six single theodolite pilot balloon stations were operated by personnel of the U. S. Air Force, Air Weather Service, 6th Mobile Weather Squadron, Tinker A.F.B. with the assistance of students from Texas A&M University, University of Texas School of Public Health, and North Carolina State University.

The positions of these six pilot balloon (pibal) stations during much of the study (the position of one was shifted occasionally) are indicated on the map, Figure 2.

(c) Important meteorological support was furnished by several agencies. Mr. Ervin Vollbrecht and Mr. William Cope of the National Weather Service, Houston office, made available facilities in collection of rawinsonde data and their forecasting skills. Forecasting assistance was also provided by the Texas Air Control Board, Meteorological Section - particularly Mr. Rollie Schroder. Additional surface wind data were furnished by the Houston Lighting and Power Co. and from a recently installed ambient air quality network made available by Mr. Tim Oujezdaky of the Environmental Protection Agency.

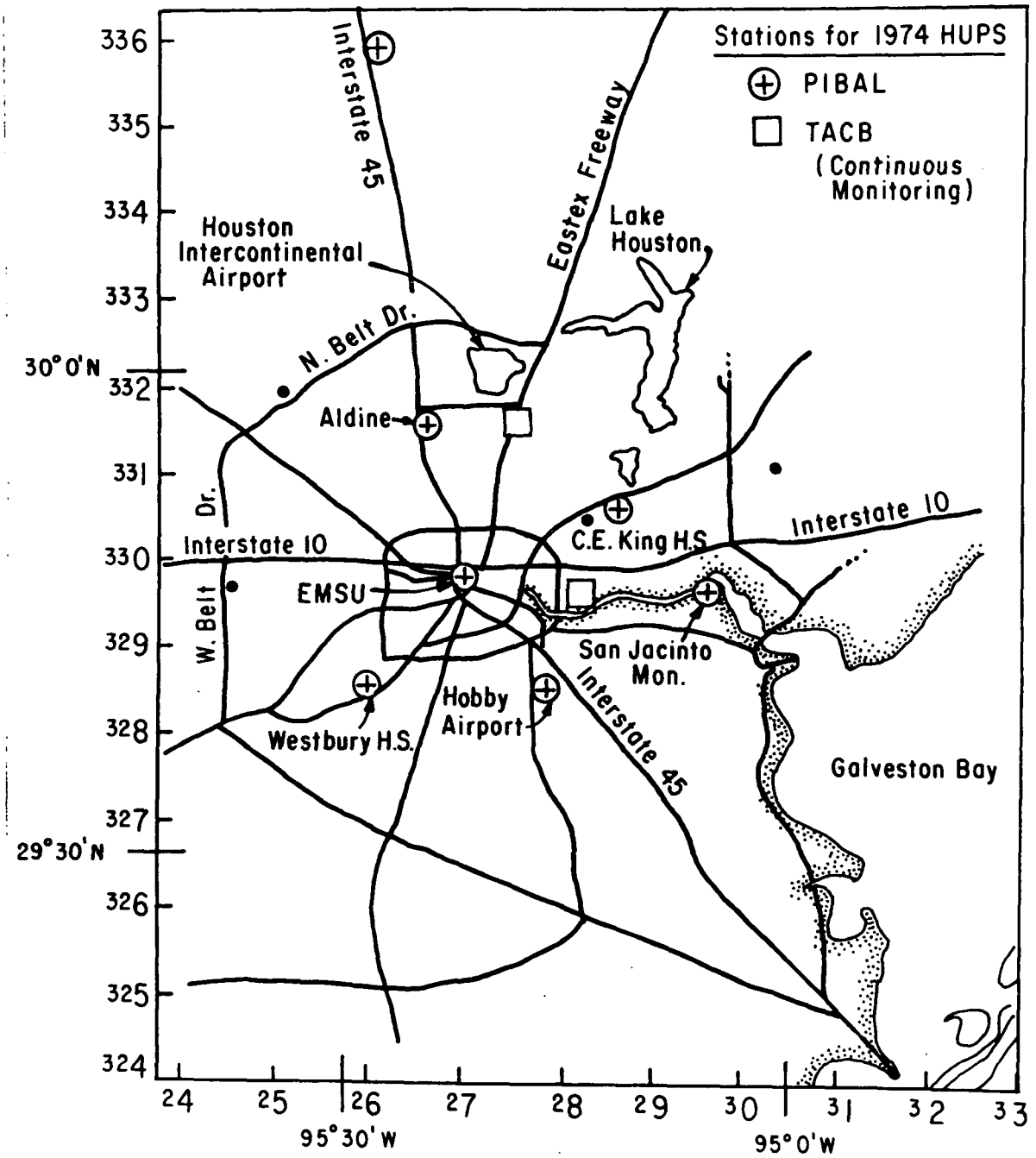

Figure 2. Positions of six pilot balloon stations and TACB monitoring stations during the 1974 Houston Urban Plume Study.

AIRBORNE AIR POLLUTION MEASUREMENTS

(a) The principal air pollutants were measured by means of an instrumented Cessna 206 with Robertson STOL modification and a belly pod. This aircraft operated out of Hobby Airport indicated in Figure 2. The following measurements were obtained by the aircraft.

Condensation Nuclei - Environment 1 Condensation Nuclei Counter
B_{scat} - MRI Integrating Nephelometer
Carbon Monoxide - Andros 7000 CO Monitor
Hydrocarbon - TEDLAR Bag samples analyzed with a Loenco gas chromatograph using flame ionization detection
Nitric Oxide-Nitrogen Dioxide - Monitor Labs NO-NO_2 Monitor
Ozone - REM Ozone Monitor
Sulfur Dioxide - Theta Sensor
Particle Size Distribution - Minnesota Aerosol Analyzer System
Particle Filter Samples - membrane and glass fiber filters
Temperature, Relative Humidity, Air Speed, Altitude, Turbulence - A.I.P. Sensors

Data from on-board sensors were acquired by magnetic tape data logger. Calibration of the pollutant gas sensors was provided by the Texas Air Control Board.

(b) It was determined that for purposes of this preliminary study, the aircraft would fly a pattern designed to determine pollutant concentrations at a cross section approximately normal to wind direction. This mode of operation was designed to make possible calculation of pollutant fluxes at the cross section. Flight patterns were to consist of "traverses" and "spirals" in the cross section. A single "traverse" consists of flight in the cross section at a fixed altitude between two specified points on the ground. A single "spiral" consists of a spiral flight path located in a cross section beginning (usually) at maximum altitude and descending to lowest altitude possible around a fixed point on the ground.

GROUND BASED AIR POLLUTION MEASUREMENTS

The principal sources of ground based measurements of air pollutants were the two atmospheric monitoring stations of the Texas Air Control Board (TACB) located in Aldine and Mae Drive as indicated in Figure 2. These stations provide hourly data for the pollutants measured by the aircraft and so are useful for correlation with the aircraft data. A number of gas bubbler samples and high volume particulate sampling stations are in

the Houston area, but these data represent relatively long time averages which are not useful for correlation with the aircraft data.

During the period of the aircraft flights, a seven-channel solar radiometer was operated under the direction of Prof. Richard K. Severs of The University of Texas School of Public Health. Optical depth per channel calculations were performed by NASA-JSC.

SECTION 4

RESULTS

This section presents the data obtained in the 1974 Houston Urban Plume Study (HUPS). First a summary record is presented of the daily activities of the study together with rationale for the measurement program for each day. The section concludes with a presentation of the principal data components: meteorological data, aircraft measurement data, and ground based measurement data.

SUMMARY DATA

Monday, 15 July 1974 - First day of HUPS devoted to installation of pilot balloon crews, checking out instrumentation on MRI aircraft and planning procedures for next day. MRI aircraft had not been fitted with aerosol size distribution measurement system and personnel at University of Minnesota were contacted. Based on meteorological forecast, an urban plume study was set for the next day west of Houston.

Tuesday, 16 July 1974 - MRI aircraft took off at 10:18 a.m. and returned at 12:30 p.m. Plume study to west of Houston attempted. Winds light and variable with visibility aloft (above 300 m.) less than 3 km. Isothermal conditions to 200 m. and near neutral above. Visibility degraded drastically in afternoon to the extent that MRI aircraft could not be operated. A severe air stagnation was announced by local authorities. Data of morning flight lost owing to malfunction of MRI data acquisition system. No plans for aircraft flights for next day owing to prediction of heavy precipitation.

Wednesday, 17 July 1974 - Heavy precipitation in Houston area owing to low in Gulf of Mexico. Day devoted to instrument calibration and maintenance. Afternoon flight tentatively planned for next day.

Thursday, 18 July 1974 - Morning cloudy with only very shallow surface inversion. MRI aircraft took off at 1230 hours CDT for afternoon plume survey. Traverses and spirals flown for cross sections G→I and J→I (see Figure 3). Winds from southeast quadrant. Aircraft data successfully acquired. Morning flight planned for next day.

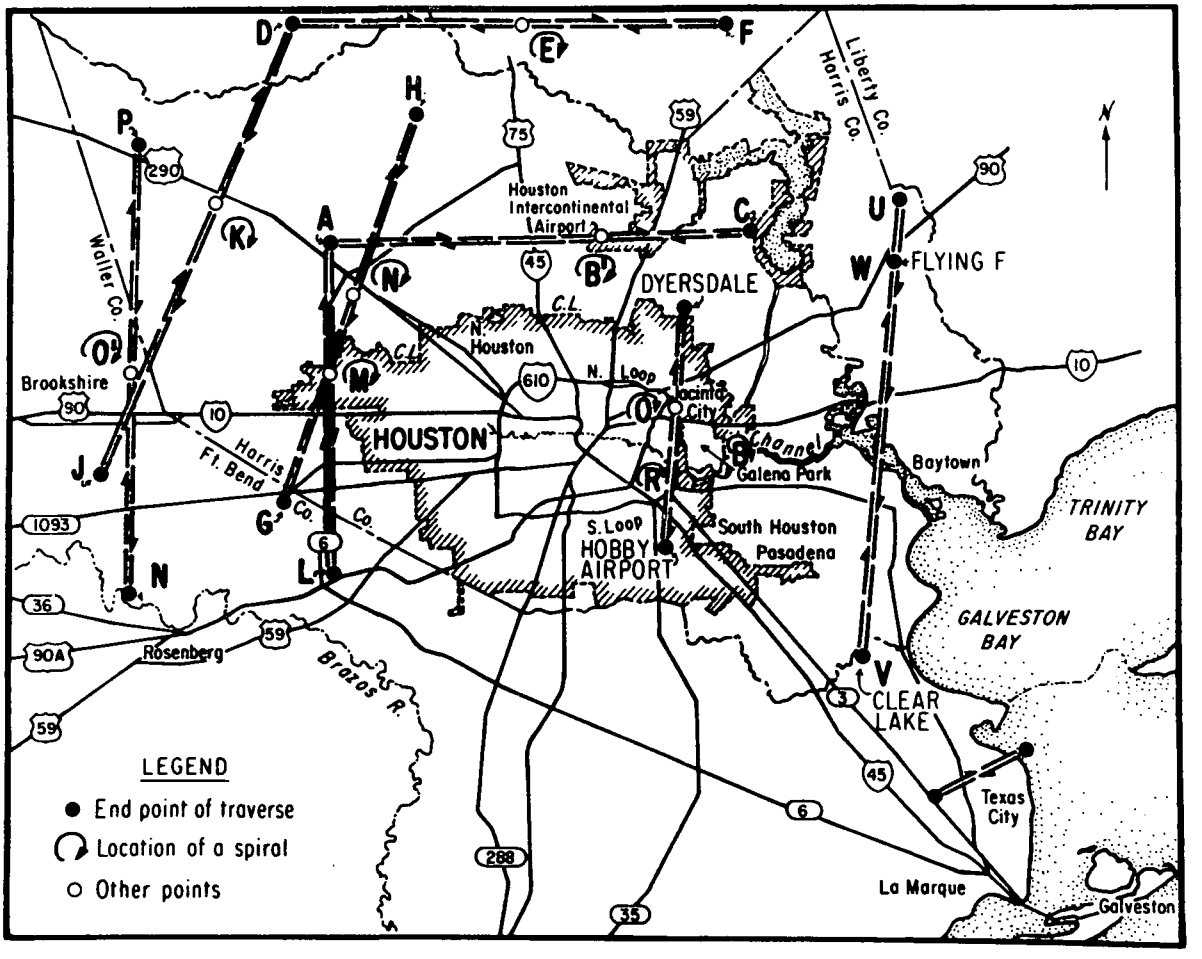

Figure 3. Locations of traverses and spirals of instrumented MRI aircraft during the 1974 Houston Urban Plume Study.

Friday, 19 July 1974 - Winds from southwest to west weakening in afternoon. MRI aircraft took off at 0900 hours CDT. Flew cross section L→A (see Figure 3). Afternoon spent setting up particle size analysis system. Flight planned for next morning.

Saturday, 20 July 1974 - Westerly winds. MRI aircraft took off at 0800 hours CDT. Flew cross section L→A, downwind traverse M→Q, cross section Clear Lake - Flying F→(CL→FF), and cross section Hobby-Dyers (H→D). Particle size analysis system not yet installed. All other data successfully acquired. Aircraft returned to base at 1200 hours CDT. Aircraft took off for afternoon run at 1330 hours CDT. Flew cross sections H→D, CL→FF. Data successfully acquired.

Sunday, 21 July 1974 - Westerly winds. MRI aircraft took off at 0600 hours CDT. Flew cross sections H→D, CL→FF. Aircraft returned to base 0900 hours CDT. Particle size analysis system still not operational. All other data successfully acquired. Particle size analysis system installed Sunday afternoon.

Monday, 22 July 1974 - Westerly winds. MRI aircraft took off at 0700 hours CDT. Flew cross sections H→D, CL→FF. Aircraft returned to base at 1000 hours CDT. Particle size distribution data acquired. All other data successfully acquired. Aircraft took off at 1400 hours CDT. $NO-NO_x$ inoperative due to blown power supply. Aircraft unsuccessfully attempted to fly "wind drift"* pattern over the Houston Ship Channel. Increasing southerly wind component. Several pollutant sensors inoperative and data system inoperative. Only particle size distributions obtained.

Tuesday, 23 July 1974 - Day spent in repair and calibration of instruments.

Wednesday, 24 July 1974 - Westerly winds. Aircraft took off at 0900 hours CDT. Morning spent in obtaining particle filter samples, particle size distributions, and hydrocarbon bag samples over Houston Ship Channel. Aircraft took off for afternoon run at 1500 hours CDT. Flew to Galveston Island and performed spiral over the Gulf of Mexico from 10,000' to 200'. Then flew East to West heading north of Texas City to obtain cross section measurements I-II. Aircraft returned to base at 1730 hours CDT. All data successfully acquired. Final meeting of participants terminating HUPS held in evening.

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*A "wind drift" pattern refers to a mode of flight in which the only component of the velocity of the aircraft in the direction of the wind is that due to the wind.

METEOROLOGICAL DATA

All measured meteorological data for the 1974 Houston Urban Plume Study have been presented in a separate report by Dr. Gale F. Hoffnagle (1). These data will not be reproduced in this report. Data obtained include surface anemometer data, pilot balloon soundings up to approximately 4000 feet altitude, rawinsonde soundings from the National Weather Service, and National Weather Service national weather plots.

From the conclusions of Dr. Hoffnagle's report (1), the following are some of the important features of the meteorological data as they apply to HUPS.

(a) The period of HUPS represents an unusual meteorological situation. A strong and persistent high over Arkansas prevented normal weather systems from penetrating to the Houston area.

(b) This high allowed a mesoscale pattern of consistent and strong westerly to southwesterly flow on each successive morning. The mixing layer was, therefore, well ventilated.

(c) Because of opposing flow for low-level (westerly) and upper-level (easterly) winds, most of the mornings experienced a very calm transition zone between 3000 and 5000 feet. Flows in this zone were weak and variable in direction.

As will be evident in the discussion which follows, the persistent westerly lower-level flows which existed for 19, 20, 21, 22 July were extremely fortunate and made possible day-to-day comparisons of pollutant fluxes and separation of the urban and industrial (Houston Ship Channel) contributions to the air pollutant fluxes. Without this persistence, it would not have been possible to obtain pollutant fluxes at comparable cross sections as was done in this study.

AIRCRAFT MEASUREMENT DATA

Table A-1 in Appendix A summarizes all the traverses and spirals flown by the instrumented MRI aircraft during the 1974 Houston Urban Plume Study (HUPS). The first column in Table A-1 is the identification number (4 or 5 digits) which appears on the computer plots for each pollutant concentration (or other measure). The second column gives date of the run and the third and fourth columns give the times, respectively, for beginning and ending a particular traverse or spiral. The fifth column identifies the beginning and ending surface points for a traverse or, in the case of spirals, the location of the surface point for the spiral. The sixth column gives for a particular

traverse the altitude in feet of the aircraft. The locations of all the surface points are indicated in Figure 3.

In Appendix A are assembled, according to the code in Table A-1, computer plots of all the real time data acquired by the instrumented MRI aircraft during HUPS. The information in Table A-1 is reproduced for each plot sequence which comprises the data for b_{scat}, condensation nuclei concentration, CO, O_3, NO, NO_x, SO_2, temperature, and relative humidity.

Airborne Hydrocarbon Bag Samples

In Appendix B are found the data for ambient hydrocarbon concentrations. Hydrocarbon samples were collected in Tedlar bags, the usual procedure being to fill a bag during a given traverse or spiral. Subsequently, the bag samples were analyzed by means of a Loenco gas chromatograph.

Airborne Particulate Filter Data

Two types of particulate filter samples were collected in the air: glass fiber filter samples for subsequent sulfate analysis and membrane filters for subsequent microscopic examination.

The glass fiber filter samples were obtained in the usual manner when sampling for particulate sulfate - namely, two filters, suitably treated to reduce their effect in oxidizing gaseous SO_2, are employed in series. The first filter is designed to collect particulate sulfate; the second filter similarly treated serves as a reference for the extent of conversion of SO_2 to sulfate on the first filter. Unfortunately, ambient conditions were such that in all samples, sulfate on the first filter was found to be only 7-35% higher than the second, backup, filter. Thus, the reliability of the data are questionable. These data are, therefore, omitted from this report.

Aerosol samples were collected on 0.8 μm Millipore filters on 19, 20, 21 July 1974, using the MRI aircraft sampling systems. The prevailing westerly winds were the same on all the sampling days and during all sampling runs. These samples were analyzed by optical and electron microscopy by Drs. R. Draftz and J. Graf of I.I.T.R.I. The results of their investigation are discussed in the next section and are presented in Appendix C.

Airborne Particle Size Distribution Measurements

Particle size distributions were determined using the airborne particle size analysis system which consists of a Royco optical particle counter and a TSI Aerosol Mobility Analyzer.

Calibration values for converting the field readings to particle size distributions were provided by Dr. Bruce Cantrell of the University of Minnesota. It must be pointed out that the measurement of the particle size distribution by this system is not in real time; a bag is filled over some period of time, typically of the order of a minute and the bag sample requires of the order of two minutes to be run by the system. The measurements are, therefore, averages over some unspecified volume and are subject to inaccuracies owing to those introduced by bag sampling and to those inherent in the system itself. The errors introduced thereby, will generally serve to give values for particle concentrations which are lower than the ambient values. The data for particle size distribution are presented in Appendix D as plots of particle volume density, dV/dlogD, in units of $\mu m^3/cc$ as a function of particle diameter in μm. The signals from particle size analysis system were fed into the MRI data logging system. In some cases, flags were missing so that some measurements corresponded to samples collected at locations not precisely known. An index at the front of Appendix D is given for all the subsequent figures.

SECTION 5

DISCUSSION

During the period of HUPS a strong and persistent high over Arkansas allowed a mesoscale pattern of consistent and strong westerly to southwesterly flow on each successive morning extending up to approximately 1300 meters. These persistent lower level flows which existed for 19-22 July 1974 made possible day-to-day comparisons of pollutant fluxes and the separation of the urban and industrial (Houston Ship Channel) contributions to the air pollution fluxes.

Also an important qualitative observation was derived from the real time aircraft data. This was the occurrence above 300 meters altitude during the morning hours of closely correlated layers of light scattering aerosol and ozone approximately 500 meters thick. Maximum ozone concentration in these layers was of the order of 0.2 ppm. These layers appeared to exist on each morning during HUPS and apparently extended over the entire Houston area.

POLLUTANT BUDGETS FOR HOUSTON AREA

In addition to information on the evolution of the Houston haze aerosol, the principal result of HUPS is the calculation of pollutant budgets for the Houston area from the aircraft data. These calculations were performed for three cross sections which were approximately perpendicular to the lower westerly flows during the period 19-22 July 1974. Starting from west of downtown Houston these cross sections were as follows (please refer to Figure 3): (a) L→A, a plane perpendicular to the surface extending from Sugar Land on the south to a point immediately west of the Flying Acres Ranch on the north up to an altitude of approximately 1200 meters. (b) H→D, a plane perpendicular to the surface extending from Hobby Airport on the south to Dyersdale on the north up to an altitude of approximately 1200 meters. (c) CL→FF, a plane perpendicular to the surface extending from Clear Lake on the south up to Flying F Ranch on the north (a distance of 47 km) up to an altitude of approximately 1200 meters. Pollutant fluxes were calculated in each of these cross sections.

These fluxes are shown in metric tons/hr-km^2 in Figure 4 in a pictorial fashion. The westerly winds are indicated as being perpendicular to the three cross sections; actually, the winds deviated from a direction of 270°. The wind velocity component normal to the cross sections was always employed in the flux calculations. Pibal data for the study period are given in Ref. (1) In Tables I-47 of Ref. (1), the last row entry of CONROE for Pibal launch site should read San Jacinto Monument.

These pollutant fluxes were used to estimate pollutant budgets for the areas between cross sections L→A to H→D and H→D to CL→FF. It was determined from the aircraft measurements that the plane CL→FF included the pollutant plumes of Houston and the industrial area along the Houston Ship Channel. Total pollutant transport rates for the Houston area are presented in Table 1. Also budget values for the Houston area were calculated by subtracting the background values for L→A from the CL→FF values. These values for SO_2 (14 metric tons/hr) and NO_x (40 metric tons/hr) are found to compare reasonably well with the values derived from emissions inventories of the Texas Air Control Board for 1974 (13 and 24 metric tons/hr, respectively).

Suspended particulate matter fluxes and budgets were estimated using an empirical correlation (2) between light scattering coefficient b_{scat} and particle mass concentration:

$$\text{Particulate mass concentration } (\mu g/m^3) = 38\ b_{scat}\ (10^{-4}m^{-1}).$$

It is not possible to assess the accuracy of this correlation for the conditions of HUPS.

The flux and budget values for CO appear to be unreasonable. Examination of the CO data for aircraft measurements in the spiral mode indicate that the CO sensor was probably malfunctioning during all the aircraft measurements; the reason for this malfunction is unknown.

ADDITIONAL OBSERVATIONS

A number of important qualitative observations were derived from the real time aircraft data.

One of these was the occurrence above 300 meters altitude during the morning hours of closely correlated layers of light scattering aerosol and ozone. These layers were approximately 500 m. thick and were found over the entire region of the HUPS study. Maximum ozone concentration in these layers was of the order of 0.2 ppm.

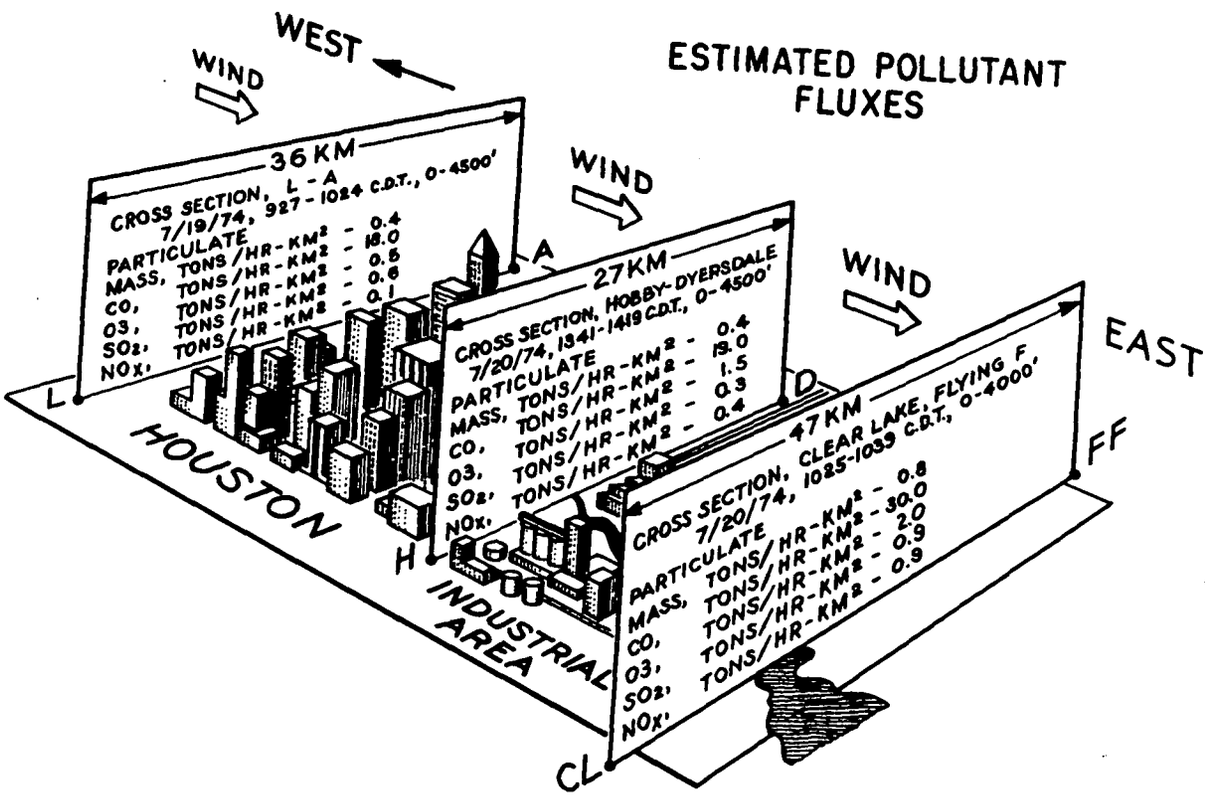

Figure 4. Fluxes of pollutants in metric tons/hr-km^2 calculated from aircraft data of July 19 and 20, 1974 during the 1974 Houston Urban Plume Study. 1 foot = 0.3048 meters.

TABLE 1. POLLUTANT TRANSPORT THROUGH CROSS SECTIONS FOR HOUSTON AREA CALCULATED FROM AIRCRAFT DATA, 1974 HOUSTON URBAN PLUME STUDY, METRIC TONS/HR

Cross Section	Suspended Particulate Matter*	CO	SO_2	O_3	NO_x
L A	22	950	32	26	5
Area: (5.5 km south of Sugar Land to 5.5 km north of Flying Acres Ranch X 1200 meters altitude) Date and Time: 7/19/74, 0927-1024 CDT					
H D	21	960	22	54	15
Area: (10 km south of Hobby Airport to 10 km north of Dyersdale X 1200 meters altitude) Date and Time: 7/20/74, 1341-1419 CDT					
CL FF	42	1500	46	88	45
Area: (Clear Lake to Flying F Ranch X 1200 meters altitude) Date and Time: 7/20/74, 1025-1039 CDT					

*Calculated from light scattering coefficient.

The relatively large ozone concentrations observed most probably are the result of photochemical reactions; no primary ozone sources of sufficient magnitude to account for these concentrations are known.

The concentration ratios $(NO)(O_3)/(NO_2)$ exceed the steady state value of 0.0209 ppm expected in the presence of only sunlight, O_3, NO, NO_2, and air . In fact, values of this ratio ranged from around 0.04 ppm to 0.15 ppm in the ozone layers. This suggests the presence of hydrocarbons and the absence of any primary source input of NO into these layers during the course of the reactions leading to formation of O_3.

In addition, the close correlation of b_{scat} and O_3 concentrations indicates the existence of secondary aerosol sources in these layers. A possible secondary aerosol source would be that arising from the accelerated oxidation of SO_2 which occurs in the presence of photochemical reactions and involves O_3 and olefinic hydrocarbons. Unfortunately the analysis of particulate filter samples for sulfate was not successful so that there is no direct confirmation of this hypothesis.

Analysis of aerosol samples collected on 0.8 μm Millipore filters by Drs. Draftz and Graf of I.I.T.R.I. showed that feldspars and clay minerals were the predominant types of particles on all the samples. According to Drs. Draftz and Graf, little or no urban (auto exhaust, combustion products) aerosol particles were found in the samples, even in the downwind samples. Samples downwind of maximum industrial activity in the ship channel area were believed to contain very few particles indicative of primary sources of fine particles. In fact, the mineral particle concentrations appeared slightly greater in these samples than in those collected at the west side of Houston.

A few samples contained several clusters of fluffy, carbonaceous deposits. These have not been identified but are not believed to be oil soot, auto emissions, or from coal burning.

The extensive industrial activity in the Houston area and the absence of significant quantities of combustion derived particles suggests possible malfunction of the filter sampling system on the MRI aircraft or sample loss in the process of microscopic analysis. There is ample photographic evidence and evidence from b_{scat} and condensation nuclei counts from the instruments aboard the aircraft showing substantial quantities of fine particles associated with combustion processes. For completeness, the report of the microscopical analyses of the filter samples by Drs. Draftz and Graf of I.I.T.R.I. are given in Appendix C.

Particle size distributions were obtained from data supplied by a system consisting of a TSI Model 3030 electrical aerosol size analyzer and a Royco Optical Particle Counter. The calibrations for converting the raw data were furnished by Dr. B. Cantrell of the University of Minnesota. In a number of cases it is observed that there is a substantial mismatch between the T.S.I. analyzer and the Royco counter in the region of particle size overlap. In addition to these occurrences, there are also questions concerning the biasing and sample loss attributable to the sampling procedure. Added to the suspected difficulties cited for the filter samples, the operation of the airborne aerosol size analysis system required filling a plastic bag with sample which was then retained in the bag for the 2-3 minutes required for acquisition of the data. No satisfactory assessment can be given of the possible inaccuracies introduced through these deficiencies. At best the data may be viewed as providing a qualitative measure of the particle concentration.

Included in the particle size distribution data given in Appendix D is an interesting set of measurements taken during spirals over Hobby Airport. These data represent particle size distributions from ground level to approximately 3000 m. They correlated qualitatively with the seven-channel solar radiometer measurements to be discussed in a separate report.

Unfortunately no filter or bag samples were obtained in the ozone and particulate-rich layers observed in the morning above 300 m. This is one of many instances in which immediate access to data would have been invaluable. In the HUPS study, the aircraft data were not available for study until six to twelve months after the completion of HUPS.

SECTION 6

SUMMARY AND CONCLUSIONS

The 1974 Houston Urban Plume Study was intended specifically to gain limited information on the spatial and temporal distribution of air pollutants - particularly primary and secondary sources of aerosols - in the Houston area as an aid should a later intensive investigation of aerosol character and transport be needed. To this extent the study was successful.

The principal results and conclusions of the study were:

(1) Pollutant budgets were established for the urban and industrial (east of downtown Houston) areas of the Houston area. The budget values for SO_2 and NO_x found by aircraft measurement (14 metric tons/hr and 40 metric tons/hr, respectively) compared reasonably well with values derived from emissions inventories of the Texas Air Control Board (13 and 24 metric tons/hr, respectively).

(2) On the basis of the limited sampling period, it appears that the industrial area (east of downtown Houston) is the major contribution of primary air pollutants in the Houston area (please see Table 1).

(3) During the period of the study, in the morning hours above the mixed layer, relatively large ozone concentrations - almost certainly of photochemical origin - were found which were correlated closely with light scattering aerosol. This correlation indicated the existence above the mixed layer of strong secondary aerosol sources, possibly associated with the oxidation of SO_2.

Additional work as outlined in the recommendations of Section 2 of this report will be needed to gain an understanding of aerosol character and transport in the Houston area.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

The 1974 Houston Urban Plume Study (HUPS) was undertaken as a preliminary investigation of some of the unresolved features of Houston's air pollution problem. HUPS was intended specifically to gain limited information on the spatial and temporal distribution of air pollutants--particularly, primary and secondary aerosols--in the Houston area as an aid should a later intensive investigation of aerosol character and transport be needed.

Aerial measurements were made of the principal pollutants (SO_2, NO_x, O_3, CO, aerosol) of the Houston area. Wind-field measurements were also made. These data were used to estimate pollutant budgets. Values for SO_2 and NO_x (14 metric tons/hr and 40 metric tons/hr, respectively) were reasonably comparable with values derived from emissions inventories of the Texas Air Control Board (13 and 24 metric tons/hr, respectively). On the basis of the limited sampling period, the industrial area (east of downtown Houston) apparently is the major contributor of primary air pollutants in the Houston area. In the morning hours above the mixed layer, relatively large ozone concentrations (max. 0.2 ppm)--almost certainly of photochemical--origin were found that correlated closely with light scattering aerosol, thus indicating the existence above the mixed layer of strong secondary aerosol sources.

17. KEY WORDS AND DOCUMENT ANALYSIS

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