An Analysis of the First Two Years of GASP Data

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ABSTRACT

Distributions of mean ozone levels from the first two years of data from the NASA Global Atmospheric Sampling Program (GASP) show spatial and temporal variations in agreement with previous measurements. The standard deviations of these distributions reflect the large natural variability of ozone levels in the altitude range of the GASP measurements. Monthly mean levels of ozone below the tropopause show an annual cycle with a spring maximum which is believed to result from transport from the stratosphere. Correlations of ozone with independent meteorological parameters, and meteorological parameters obtained by the GASP systems show that this transport occurs primarily through cyclogenesis at mid-latitudes. The GASP water vapor data, analyzed with respect to the location of the tropopause, correlates well with the simultaneously obtained ozone and cloud data.

THE OBJECTIVES OF GASP are to obtain atmospheric constituent data in the upper troposphere and lower stratosphere and to document and analyze these data to establish baseline levels and variability of selected constituents, and to assess potential adverse effects from aircraft emissions on the natural atmosphere. Fully automated GASP systems are now operating on a United Airlines B-747, two Pan American World Airways B-747's, a Qantas Airways of Australia B-747, and the NASA CV-990 research aircraft. Data are recorded every five minutes whenever the aircraft are above the 6 km altitude flight level. The GASP system design, the measurement instruments, the on-board computer for automatic control of data acquisition, and system maintenance procedures are described in (1)*. GASP data are available on magnetic computer tape from the National Climatic Center, Asheville, NC (2-8). Analyses of GASP data are reported in (2-12).

MEASUREMENTS

OZONE - Measurements are made using a continuous ultraviolet absorption ozone photometer (13). The range of this instrument is from 3 to 20,000 ppbv, with a sensitivity of 3 ppbv. In-flight monitoring of the ozone instrument includes measurement of the instrument zero and the electronic span setting and control frequencies. Periodic checks for calibration consistency are performed in the laboratory. At the time the data reported herein were obtained, GASP ozone instruments were checked against an ozone generator which was calibrated at 1000 ppbv by the one percent neutral buffered KI method (14).

Prior to measurement of the ozone level, the air sample is pressurized to nominally 1 atm. The ozone readings are corrected for drift of the instrument zero and are corrected to standard atmospheric pressure and to a temperature of 25 degrees C. In addition, the measured values are corrected for the destruction of ozone in the sample lines and in the pump. This relation is determined from ozone-loss tests performed periodically on-board the aircraft under conditions simulating operation in flight (2-8).

WATER VAPOR - Measurements reported herein were obtained with an aluminum oxide dew-frost point hygrometer (15,16). The sensors are calibrated by the manufacturer, with a specified dew-frost point temperature (DFPT) accuracy of $\pm$ 3 deg C for -110 deg C $\leq$ DFPT $\leq$ -60 deg C and $\pm$ 2 deg C for -60 deg C $<$ DFPT $\leq$ +40 deg C.

The sensors are re-calibrated in an environmental chamber at NASA-Lewis prior to installation on the aircraft. Because the sensor output varies with air-sample temperature, calibration is performed at room temperature (+20 deg C), -20 deg C and -40 deg C. Upon removal from the aircraft, sensors are calibrated again at room temperature. Data are used only if the re-calibrations are within the limits specified above.

Laboratory tests on the aluminum oxide hygrometer have shown several serious deficiencies which must be considered in evaluating the flight data:

1) Although the variation of sensor output with equilibrium air sample temperature is accounted for in the data reduction, the sensor has been found to have a transient response to changes in ambient temperature at constant DFPT. This response is dependent on both the magnitude of the temperature change, and the rate of change.

2) The time constant of the aluminum oxide hygrometer in response to a step change in DFPT was found to vary from 8 to 30 minutes

* Numbers in parentheses designate references at end of the paper.

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depending on the equilibrium air-sample temperature and the magnitude and direction of the change in DFPT.

3) The recovery of the sensor from saturated conditions, as are encountered with the passage of the aircraft through clouds, was found to be very slow. This characteristic is apparent in the flight data whenever prolonged saturation is indicated.

CLOUDS - Flight test experience with the light-scattering particle counters included in the GASP systems has indicated that flight through clouds results in a significantly greater count of the largest size particles (D> 3 micrometers) than is obtained in clear air. A simple cloud detector is thus available by observing the counting rate of the largest size particles. This signal is monitored for 256 seconds prior to each data recording. The time during which the cloud rate is greater than a preset level is interpreted as time in clouds. This level was programmed on board the United airliner based on visual observation of a light haze.

DATA PROFILE STATISTICS

Figure 1 shows the distribution of archived GASP data, by month, from March 1975 through December 1976. NMET is the total number of observations, and includes flight and meteorological data. NO3 is the number of ozone observations, and NH2O is the number of water vapor observations reported. Because up to half of the recordings made each flight hour are used for instrument calibration functions, the number of constituent data points is less than NMET. Through September 1976, data were archived from only those flights for which constituent data were available. In response to requests, we began, with the October 1976 data, to report data from all GASP flights.

The distribution of the GASP ozone observations by latitude is shown in figure 2a). This distribution reflects the route structure of the GASP-equipped aircraft. Since this figure is based on all observations reported through December 1976, it includes the effect of the addition of new GASP aircraft; for example, data from the Pan Am B-747SP were available for the first time in April 1976, and the first Qantas data were reported in the third quarter of 1976.

The distribution of the Northern Hemisphere data by geopotential altitude is shown in figure 2b). This distribution does not vary appreciably between the contributing aircraft, except that data above 12 km are mostly from the B-747SP. Since the GASP data are obtained in terms of aircraft pressure-altitude, supplementary data are necessary to effect the transformation to geopotential altitude. This is provided by National Meteorological Center (NMC) gridded data arrays, available for 0000 and 1200 GMT daily, giving the height of standard pressure levels.

ANALYSES

OZONE - GASP data analyses to date have shown spatial and temporal variations which are in agreement with data from ozonesondes. Examples of the variation of the mean ozone levels with latitude and by month are shown in figures 3 and 4 respectively. The GASP data on these figures are for pressure-altitudes from 10.5 to 11.5 km. The shaded areas indicate $\pm$ one standard deviation from the mean, and reflect the large natural variability of ozone in the altitude range of the GASP observations. Measurements from the North American ozonesonde network are shown by the dashed lines (17,18). Although the GASP mean values agree well with these curves, it should be noted that the GASP data are zonal averages, whereas the ozonesonde data are from only the North American sector.

The local ozone data have been shown in numerous case studies (2,3,5,7,9,10) to correlate well with the difference between the ambient pressure, calculated from the aircraft pressure-altitude, and the tropopause pressure, interpolated from NMC gridded fields. The distribution of the GASP 1975 ozone data as a function of these pressure intervals from the NMC tropopause is shown in figure 5. This profile agrees favorably with the ozone distribution from the 1976 U.S. Standard Atmosphere (19).

From September 1974, through mid-December 1975, the location of the tropopause surface archived by NMC was determined by the Flattery global analysis method (20), which tested the slope of the vertical temperature profile at each NMC grid point upward from the first mandatory pressure level. However, as of December 17, 1975, (1200 GMT), the tropopause pressure surface, archived in the NMC 65X65 arrays, has been formulated using a procedure conceived by Gustafson (21) which scans the potential temperature profile at each grid point downward until a distinct stability transition is found. Zonal mean tropopause pressures for 1975 and 1976 suggest that the current (Gustafson) analysis renders tropopause pressures consistently greater than those derived from the previous (Flattery) method; see (5-8). Because of these differences, the 1976 GASP data are not included in figure 5.

The relationship of ozone to independent meteorological parameters, and meteorological parameters obtained by the GASP systems shows that ozone is a transport dominated species in the altitude range of the GASP measurements. As an example, figure 6 shows the differences in the vertical ozone profile which result when the data are separated based on wind curvature, as determined from the wind field data obtained by the GASP systems (11). The difference between the distributions for cyclonic and anti-cyclonic curvature seems unambiguous from 40 hPa below to 40 hPa above the tropopause, since there is very little overlap in the standard deviations of the two curves. This shows that stratospheric air is injected into the troposphere in large-scale cyclonic systems.

Figure 7 shows contours of constant ozone mixing ratio and potential vorticity for the March 1975 and 1976 data (12). Note the apparent intrusions of stratospheric ozone and potential vorticity below the tropopause near 40 deg N. The monthly mean values of ozone below the tropopause (fig. 8) show an annual cycle. The high springtime levels are most likely a result of transport as shown by figures 6 and 7.

WATER VAPOR - Although the GASP water vapor data available to date are limited by comparison with the ozone data base, they are sufficient to support some preliminary statistical analyses. Only those data points with simultaneous measurements of water vapor and ozone, and with the cloud detector operating, were selected. Also, in recognition of the limitations of the response of the water vapor sensor following saturation, the data set was further restricted by deleting all saturated water vapor readings for which no "time in clouds" was indicated.

The distributions of the water vapor and ozone data with respect to the location of the NMC (Gustafson) tropopause are shown respectively by the solid and long dashed lines in figure 9a). The short dashed curve shows the mean water vapor saturation level calculated from the static air temperature for each observation in each pressure interval. In the troposphere, ozone mixing ratios are low and nearly constant, but the mean measured water vapor mixing ratio decreases rapidly as the tropopause is approached. The mean water vapor saturation level drops rapidly in this region also, since the static air temperature is decreasing. In the stratosphere, ozone levels rise rapidly. Because the air temperature is also rising, the mean saturation water vapor level rises. In contrast to this, the measured water vapor mixing ratios remain low and nearly constant.

The distribution of the mean relative humidity is shown by the solid curve in figure 9b). This is nearly constant in the troposphere, but decreases rapidly above the tropopause. The curve marked 'S' in the figure shows the percent of the water vapor readings which indicated saturation, and for which there was a simultaneous indication of the presence of clouds. The "time in clouds" data are shown by the long dashed curve. Tropospheric values range from 5 to 30 percent, and a drop-off in clouds is apparent above the tropopause, in good agreement with the water vapor data.

CONCLUDING REMARKS

Analyses are presented which show that:

1). Mean ozone levels from GASP observations, shown with respect to month, latitude, and pressure interval from the tropopause, are consistent with previous measurements,

2). The natural variability of ozone is very large in the altitude range of the GASP observations,

3). Tropospheric ozone levels show an annual cycle with a spring maximum, which is believed to result from transport from the stratosphere,

4). Correlations of ozone with potential vorticity and wind curvature show that this transport occurs primarily through cyclogenesis at mid-latitudes, and

5). Water vapor levels decrease rapidly toward the tropopause, and are very low in the stratosphere. Correlations of simultaneously acquired water vapor, ozone, and cloud data are very good.

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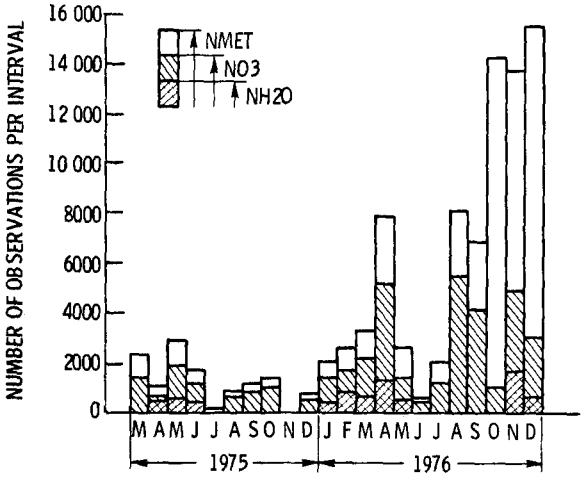


Figure 1. - Distribution of archived GASP data by month; March 1975 - December 1976. NMET = total number of observations; NO3 = number of ozone observations; NH2O = number of water vapor observations.

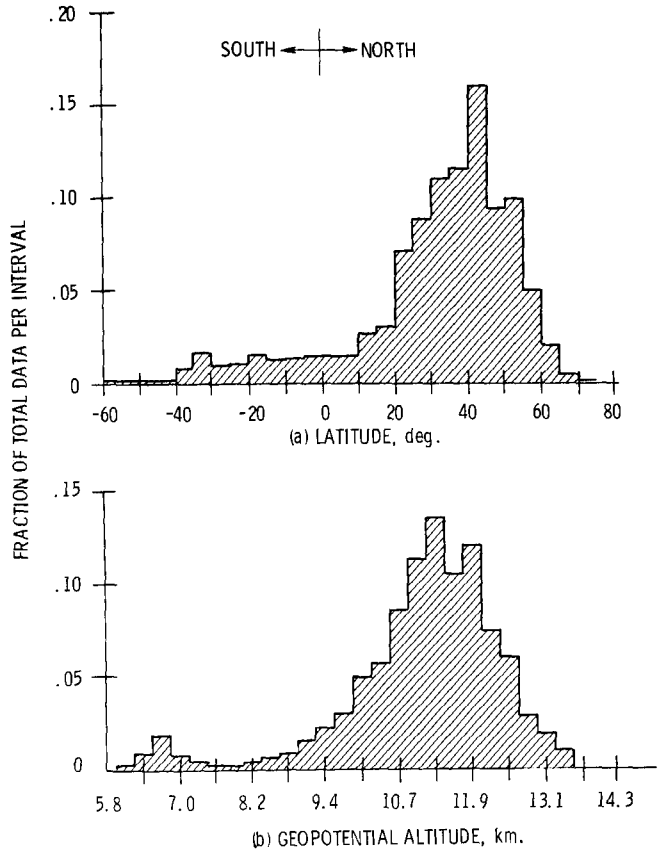


Figure 2. - Distribution of GASP ozone data by latitude and altitude.

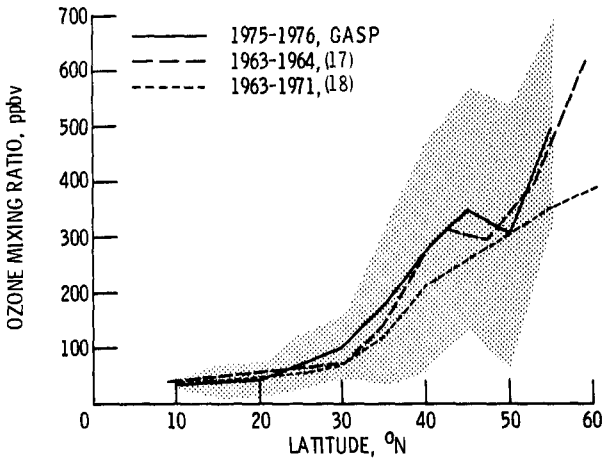


Figure 3. - Latitudinal ozone distribution for March; pressure-altitude 10.5 - 11.5 km.

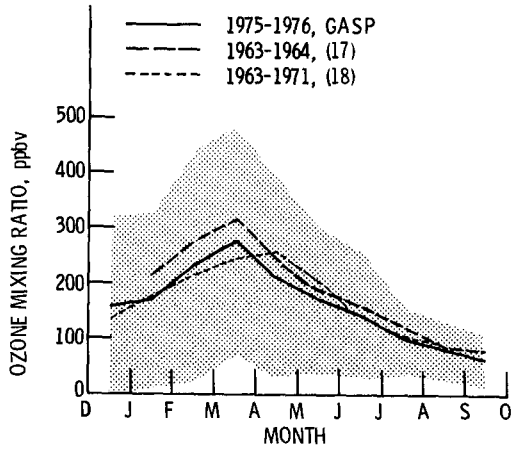


Figure 4. - Bimonthly ozone distribution for 37.5 - 47.5 N latitude; pressure altitude 10.5 - 11.5 km.

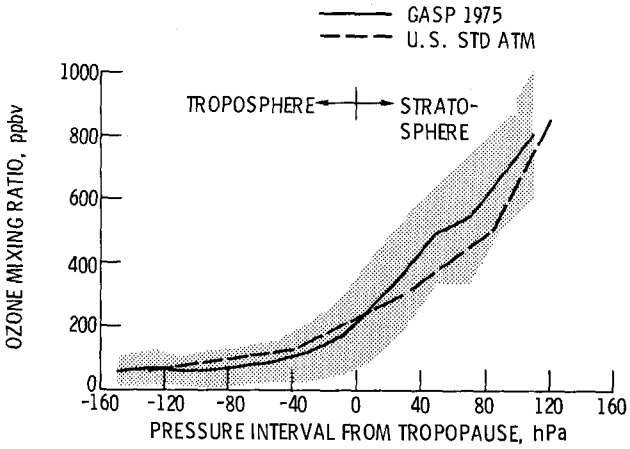


Figure 5. - Distribution of ozone with respect to NMC (Flattery) tropopause.

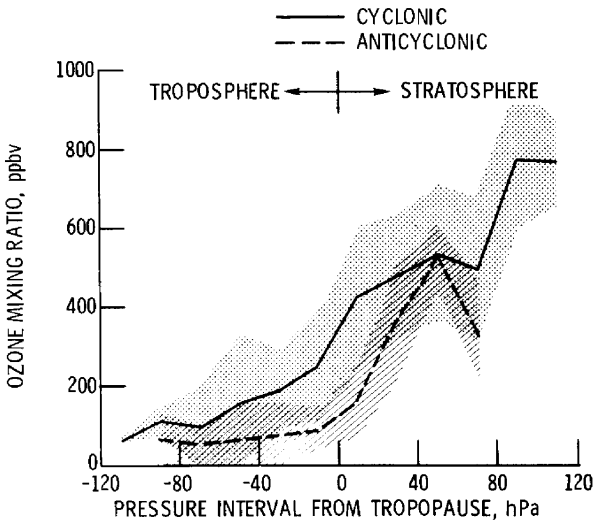


Figure 6. - Effect of wind curvature on ozone distribution with respect to NMC (Flattery) tropopause; spring 1975.

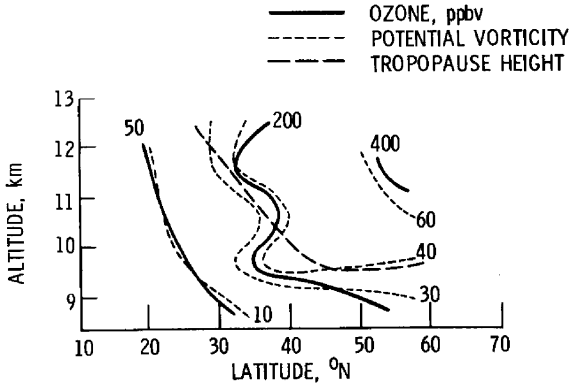


Figure 7. - Correlation of ozone with potential vorticity; March 1975 & 1976.

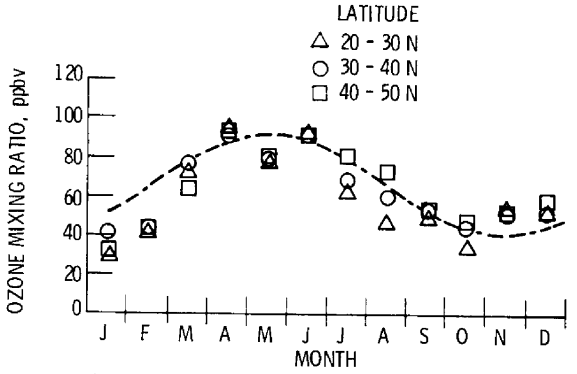
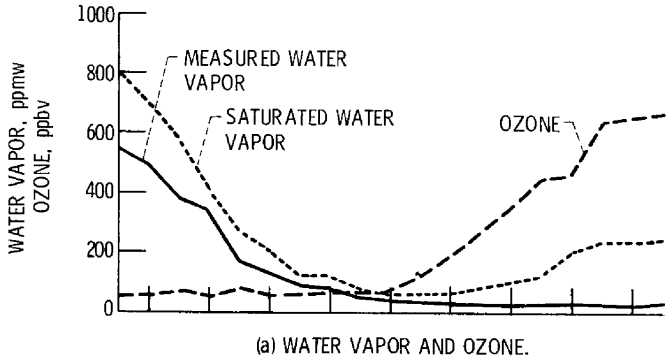
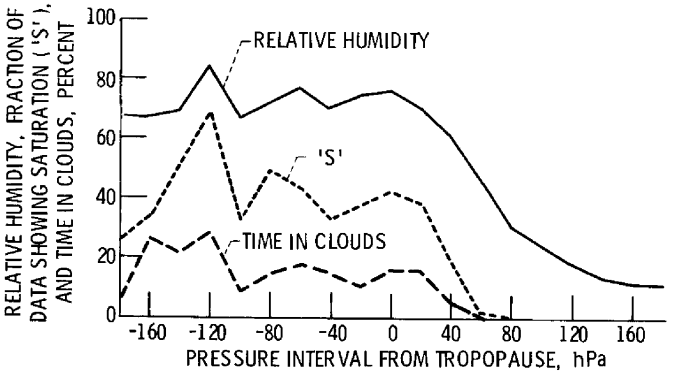


Figure 8. - Monthly mean values of tropospheric ozone.



(a) WATER VAPOR AND OZONE.



(b) HUMIDITY AND CLOUDS.

Figure 9. - Variation of water vapor, ozone, and clouds with respect to NMC (Gustafson) tropopause.

Trends in Atmospheric Particulate Concentrations at a Location in the Northeast United States†

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ABSTRACT

Real-time measurements of total particulate concentrations have been made continuously during the past two years to provide aerometric background information for correlation with meteorological parameters. The measurements were made to determine short and long time variations, frequency distributions, episodical information, effects on solar radiation and spectral analysis to show important time histories in a rural area near the New York City metropolitan region. This study provides useful background data for a much larger program related to emission control practices and trends in air quality in the Northeast United States. Ultimately, these and data from other specific locations will be incorporated in models to describe the transport and transformation of particulate and gaseous concentrations over regional distances.

BACKGROUND

Studies of atmospheric diffusion involving regional scale distances have assumed national prominence since the recent proclamation concerning the probable increase use of coal for future energy utilization.

The Department of Energy (DOE) supports a program called the Multi-State Atmospheric Power Production Pollution Study (MAP3S) to develop guidelines for the most efficient management of pollutant emissions from existing and proposed new sources.

One goal of the MAP3S program is to determine short and long term trends in urban and rural atmospheric background levels of polluting substances in the Northeast United States. For the past two years, real-time measurements of total particulate concentrations have been made continuously at Brookhaven National Laboratory to provide aerometric background information for correlation with meteorological parameters and to compare them with similar results taken in the New York City metropolitan region. The measurements have been used to determine concentration variations, frequency distributions, episodical information, effects on solar radiation and spectral analysis to show the most important time history of the concentration values.

This report will provide some information on all the areas mentioned but will concentrate on three specific ones. The first is a seasonal variation comparison between measurements taken at five locations in the Manhattan area of New York City and those made 100 kilometers east of it. The second area to be discussed will concern particle concentration measurements and their variation during atmospheric stagnation periods. It will highlight the values found during the air mass stagnation time scales. Air mass particle concentrations increase during stagnation periods due to recirculation within the air mass and capping mixing levels. Wind direction, wind speed, temperature, humidity, etc. have little effect on stagnation concentrations. The third area to be reported on involves the effect of total suspended particle concentrations on total incoming solar radiation. Analysis of the two-year measurements shows a near-linear decrease in solar energy received at the earth's surface with increasing particle concentration during the 62 cloudless days analyzed.

CONCENTRATION VARIATION

An Integrating Nephelometer (Model 1550) has been in continuous operation since late 1974 on top of the 125 meter meteorological tower at Brookhaven. Figure 1 shows the general location of the site with a concentration rose superimposed upon it. The rings on the rose represent yearly concentration averages for 1975 in micrograms per cubic meter ($\mu g/m^3$) and the lines represent the wind direction associated with those concentration values. There are slight variations in concentration values except when the wind direction is south to west where prominent values are seen. The reason for the higher values from the west to south is quite evident from the location of high pollution sources in the metropolitan regions of New York City and the transport of source material to the measuring site. The rose for 1976 is similar; however, the concentration values are somewhat higher.

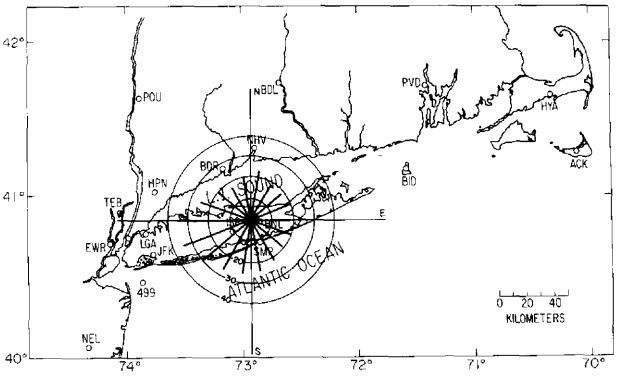

Fig. 1. - Map showing the location of the measuring site and a rose depicting particle concentration in $\mu g/m^3$ as a function of wind direction.

The continuous measurements are recorded on an Esterline-Angus recorder in the main meteorology building so minute-to-minute recordings can be observed and analyzed. Rather sharp changes have been measured over short times during cold frontal passages, rain showers, sea breeze wind shifts and wind direction shifts from most any direction to southwest to west. Figure 2 shows a typical sudden (ten minutes) decrease in concentration values due to an intense rain shower. It is a good illustration of precipitation scavanging. Similar short term (minute) variations have been recorded as well as daily, weekly, and monthly discontinuities.

Hourly mean concentration values have been reduced from the recordings and put on punched cards. Some computations have been made and the data is available on magnetic tape for further studies.

COMPARISON

The City of New York Department of Air Resources use high volume air sampler data to compute quarterly values of total suspended particulate matter in several locations throughout the five boroughs. A comparison

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Global Sensing of Gaseous and Aerosol Trace Species Using Automated Instrumentation on 747 Airliners

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ABSTRACT

The Global Atmospheric Sampling Program (GASP) operated by NASA is collecting and analyzing data on gaseous and aerosol trace species in the upper troposphere and lower stratosphere. Measurements are obtained from automated systems installed on four 747 airliners flying global air routes. Since the introduction of this program in 1975, advances have been made in airborne sampling instrumentation. Improved instruments and analysis techniques are providing an expanding data base for trace species including ozone, carbon monoxide, water vapor, condensation nuclei and mass concentrations of sulfates and nitrates. Simultaneous measurements of several trace species obtained frequently can be used to uniquely identify the source of the air mass as being typically tropospheric or stratospheric. A quantitative understanding of the tropospheric-stratospheric exchange processes leads to better knowledge of the atmospheric impact of pollution through the development of improved simulation models of the atmosphere.

AUTOMATED AIR SAMPLING SYSTEMS installed on four 747 airliners were reported at the Third Conference on Environmental Sensing when these systems first became operational in 1975 (1)*. Since that time improved instrumentation has been added. This paper describes this improved instrumentation and presents some in-flight measurements which illustrate the ranges and inter-relationships of the data from these instruments. Brief descriptions of the NASA Global Atmospheric Sampling Program (GASP), and the airborne system in which this instrumentation is used are also included.

Air sample measurements have or will include the concentrations of ozone, carbon monoxide, water vapor, nitric oxide, and chlorofluoromethanes. In addition to these gases, the number density of condensation nuclei and the concentrations of sulfates and nitrates are also measured. During the initial two years of operation, a large data base on atmospheric ozone concentrations at airline cruise altitudes has been obtained. The other air sample measurements have required a more extensive development effort for air borne use. Data bases for these trace species are beginning to evolve.

The GASP effort was initiated to provide baseline information on atmospheric constituents which could be used with other data sets and with computer models to assess the effects of aircraft exhaust emissions on the upper atmosphere. This assessment effort was prompted by studies conducted several years ago (2) (3). The results of a more recent study (4) predict a lesser effect of aircraft emissions on atmospheric ozone. Nevertheless, this latter study does recommend and suggest continued research in certain problem areas, including studies of the dynamics in the region of principal aircraft traffic. It also recommends the simultaneous measurement of the concentrations of the several species critical to ozone destruction. Apart from the ozone problem, simultaneous measurements of several trace species can uniquely identify the source of the air mass as being typically tropospheric or stratospheric. Quantative information on the tropospheric-stratospheric exchange processes when applied to simulation models of the atmosphere provides a better understanding of the impact of pollution on the atmosphere.

*Numbers in parentheses designate references at the end of paper.

PROGRAM DESCRIPTION

The airlines that are presently participating in GASP in this global study are shown in figure 1. This figure shows 747's of United Airlines, Pan Am, Qantas Airways of Australia, and another Pan Am 747-SP (a new long range, higher altitude Special Performance version of the 747). These airlines were chosen to provide coverage of major global air routes, as shown in figure 2. The NASA Convair-990 flying laboratory is also equipped with a GASP system. The CV-990 is used to survey off-airline routes. A recently completed latitude survey mission over the Pacific (5) is one example.

United Airlines flies principally over the United States, coast to coast and to Hawaii. Pan Am flies around the world and to South America. Qantas, based in Sydney, flies frequently to Europe and to the West Coast of the United States.

GASP air constituent measurements and supplemental data are listed in Table I. Ozone, water vapor, nitric oxide and carbon monoxide are measured with in-situ instruments. Chlorofluoromethanes and other trace species can be obtained from laboratory analyses of bottle samples captured in flight. The number density of particles greater than 0.3 micrometer dia. measured with the light-scattering technique, and smaller particles called condensation nuclei measured with the cloud-chamber technique, are also in-situ measurements. Mass concentrations of sulfates and nitrates are determined from laboratory analysis of filter paper samples exposed in flight.

At the time of each air constituent measurement, certain supplemental data are recorded (Table I). Time and position of the aircraft, its altitude, speed, and direction pinpoint each air constituent measurement. Data related to meteorology are also taken. Air temperature, horizontal wind direction and velocity, and an indication of turbulence as measured by the vertical acceleration are recorded. The light-scattering instrument for measuring the larger particle sizes also responds to the presence of clouds in the flight path as determined during flight tests.

Each GASP-equipped aircraft flies about 10 hours per day, for a total of about 8700 km (5400 miles) each day or about 13 million km (8 million miles) per year for the four 747's. A data set is recorded every 5 minutes or about every 72 km (45 miles).

Field service of the GASP equipment and necessary support by the airlines are managed by United Airlines Engineering Group under contract to NASA Lewis. GASP data retrieved by airline personnel from the aircraft are sent to NASA Lewis for processing and finally, are transmitted to the users for detailed analysis.

The data preparation begins with the routine service check of the GASP system on the aircraft and the removal of the data recorded on a tape cassette. The information on the cassette is transcribed onto computer-compatible tape by United Airlines. NASA Lewis then does the data reduction and preliminary analysis. The tropopause pressure fields from the National Meteorological Center and the results of the

bottle samples and filter sample analyses are added to the final data tape as part of the data reduction process. While the final tape is being prepared at NASA Lewis, a report is written describing the availability of the data and some of their selected highlights. As a last step, the prepared tape is sent to the National Climatic Center for archiving and to NASA contractors for detailed analyses. The availability report is mailed to members of the scientific community concerned with the atmosphere.

AIRBORNE SYSTEM DESCRIPTION

Location of the GASP equipment in the 747's is shown in figure 3. The installation is near the nose below the passenger deck. Two air sample inlets mounted in a single strut sample both gases and particulates outside of the aircraft's boundary layer very near the nose. One of the inlets is designed for isokinetic sampling for measuring particle number density. Both inlets are capped when air samples are not being taken.

Air flows from the inlet in a 25.4 mm (1-inch) diameter tube aft to the instruments where pressurization is required for ozone and carbon monoxide measurements. A rack mounted to the airframe holds most of the GASP instruments, as shown in figure 3. The instruments are packaged in standard airline avionics cases. Air is also ducted in a 76 mm (3-inch) diameter tube from the inlet to the other side of the aircraft, where a mechanism is located for exposing the particle filter papers. This mechanism is similar to a slide projector and holds eight filters that are exposed individually at preselected intervals. Two of the four 747's are equipped with the particle filter system.

GASP system control and data management and acquisition are performed by three separate units. Automatic control of all system operations and management of all data are functions of a data managment and control unit. This unit contains a small special-purpose computer preprogrammed to respond to independent aircraft inputs and to operate the instruments. Most of the data are acquired by the second unit which is a conventional airline flight data acquisition unit. Data from the GASP instruments and other parts of the system, as well as from the aircraft systems, flow to this unit. Position and horizontal wind data come from the aircraft's inertial navigation system. All data are recorded on magnetic tape contained in the third unit which is a digital airborne recorder. The tape cassettes from the recorder are replaced about every two weeks.

Total weight of the installed system is about 380 kg. All equipment meets FAA certification requirements, and the entire installed system was flight tested during a special flight following which a Supplemental Type Certificate (STC) of airworthiness was issued for the GASP system. Operation is completely automatic, requiring no attention by the flight crews. A more complete description of the operation of the airborne atmospheric sampling system is given in reference 1.

INSTRUMENTATION

The GASP in-situ measuring instruments, their operating principles, and range are listed in Table II. These are basically laboratory instruments with significant range improvements and modifications to operate in a commercial airline environment. Such modifications involve packaging to airline specifications and the ability to withstand a high use factor. Figure 4 illustrates a GASP instrument packaged to airline standards. Two conventional airline avionics cases are used in packaging the carbon monoxide instrument as shown. Other instruments can be contained in only one airline type case. Size and weight of each avionics case are held to a minimum for convenience in handling.

Existing commerical instruments used to measure carbon monoxide, oxides of nitrogen, and condensation nuclei were significantly improved to measure the very low concentrations in the upper atmosphere. Descriptions of these instruments follows.

CARBON MONOXIDE - A modified Non-Dispersive Infrared Absorption analyzer is used to measure CO. In this instrument fluorescence from two isotopes of CO ($C^{12}O^{16}$ and $C^{12}O^{18}$) is used as the source of infrared energy. The two IR radiation spectra are alternately allowed to enter the sample chamber. The $C^{12}O^{16}$ in the air sample (98.9% of all naturally occurring CO is $C^{12}O^{16}$) will absorb this common isotope radiation but not the $C^{12}O^{18}$ radiation. The ratio of these two signals from an IR detector is a measure of the CO concentration in the sample chamber.

The original CO analyzer using the dual isotope fluorescence technique had a full scale range of 20 parts per million (ppm). Modifications to provide the sensitivity needed for GASP included an increase in the optical path length to 10 meters, special reflective optics, and additional electronic gain. These improvements provided a 1 ppm full scale senstivity with a limit of detectability of 0.02 ppm of CO.

In-flight checks on this instrument include a zero reading (sample is passed through a catalytic CO scrubber) and an electronic gain check. These checks are automatically sequenced with atmospheric CO measurements by the on-board GASP programmer.

CONDENSATION NUCLEI - This instrument measures the number concentration of very small airborne particles (nuclei) on which water vapor condenses in a cloud chamber. The attenuation of a light beam by the cloud in the chamber is a measure of the number concentration. The minimum detectable limit for this instrument was extended from 300 nuclei per cc to 30 nuclei per cc. This was achieved by improved sensitivity and a built in pressurization system with a pressure ratio of approximately 4 to 1 to concentrate the sample. A simple air piston consisting of a 3 meter length of 1.1 cm I.D. tubing is used for the gas pressurization system. A low pressure air sample from outside the aircraft is drawn into one end of tube. Pressurized aircraft cabin air filtered free of nuclei is introduced into the other end of the tube behind the low pressure air sample, thus compressing it. The pressurized air sample is drawn from the original inlet end into the cloud chamber of the instrument. With an appropriate sequence of valving this pressurization system can be used for sampling air flow rates of 5 to 50 cc/sec. In-flight checks on this instrument include a zero (using a filtered sample) and a check of the electronic gain.

NITRIC OXIDE - A very high sensitivity chemiluminescent analyzer is used to measure nitric oxide. The very high sensitivity is achieved, in part, by using a high sample flow rate (500 std cc/sec), a special technique for an in-flight zero measurement, and a nitric oxide calibration gas carried with the instrument for a span measurement. The instrument also contains an ozone generator of the silent discharge type. This is a modification of the previously developed high sensitivity instrument which used a bottled ozone mixture instead of an ozone generator (6). The self-contained ozone generator is necessary for the GASP field service frequency of every 2 weeks, since an ozone mixture in a bottle of practicable size would need more frequent replacement. The complete instrument is housed in two airline avionics

cases. Flight tests of the instrument have been completed and installation on the 747 aircraft are scheduled for early 1978.

CONCENTRATIONS OF SULFATES AND NITRATES - These measurements are made by laboratory analysis of filter elements exposed earlier in-flight and returned to NASA. A filter element is automatically inserted into the 76mm diameter air sampling duct for two hours and retracted into a magazine by an actuator assembly developed at NASA. Airflow through the filter during exposure is measured by a venturi unit. Each filter (IPC cellulose fiber) is enclosed in a stainless-steel holder under clean room conditions to minimize contamination. Filter elements are assembled in an eight unit replaceable holder magazine thus allowing several filter exposures between field service periods for the GASP system.

Since generally less than 30 micrograms of any one ionic constituent is collected on an exposed filter element, very sensitive methods of laboratory analysis are required. Ion chromatography is used to meet this requirement. Clean room procedures and filters that are carefully purified prior to exposure are necessary to utilize the high sensitivity of the ion chromatography analysis method. A more detailed description of this method is given in reference 7.

OZONE, WATER VAPOR, AND PARTICLES - Ozone has not presented a measurement problem although much care is needed to provide accurate results. Water vapor was initially measured with an aluminum ozide sensor. Excessive time response to changes in temperature and humidity (particularly from a saturated to an unsaturated condition) limited the amount of valid data obtained with this type sensor. Therefore, this instrument has been replaced with a cooled-mirror frost point hygrometer having a three stage thermoelectric cooler. Flight tests have shown better operating characteristics and a faster time response. Installation of this sensor on all GASP equipped 747 aircraft will be complete by the end of 1977. Aerosol particles greater than 0.3 micrometers in dia. have been measured with a light scattering type sensor. Experience with this instrument has shown a large variability of number density and size distribution. Laboratory calibrations of the instrument have revealed a large uncertainty in the absolute measurement of number density as well as size distribution. An improved instrument is being investigated. Flight test experience with this instrument indicated, however, that flight through a cloud resulted in a particle size distribution that is significantly different from that of a clear air sample, mainly in the total count of the largest size particles. A simple cloud detector is therefore obtained by observing the counting rate of the largest size particles.

TYPICAL FLIGHT MEASUREMENTS

Examples of GASP atmospheric measurements taken simultaneously with in-situ instruments are shown in figures 5 and 6. These data were obtained on the GASP equipped UAL 747 airliner where a data set is normally recorded every five minutes.

Simultaneous measurements of ozone, carbon monoxide, condensation nuclei, air temperature, and altitude are plotted against longitude in figure 5 for a flight from Los Angeles to Honolulu. Ozone values under 150 parts per billion by volume (ppbv) shown in figure 5 are indicative of flight in the troposphere. Carbon monoxide concentrations between 100 and 200 ppbv are also characteristic of upper altitude tropospheric air. Condensation nuclei number densities, shown under 300 per cc, are relatively low compared to ground level measurements demonstrating the requirement for the improvements to the minimum detectable limit for this instrument. Somewhat higher values are noted on ascent from 6 km to cruise altitude.

Ozone values over 800 ppb v shown in figure 6 are indicative of flight in the stratosphere. These were encountered during a flight from Seattle to Chicago. Carbon monoxide values are lower than those measured in the troposphere shown in figure 5. Values are in the order of 50 ppb v, which is consistent with previous measurements (8). This demonstrates the need for a low detectable limit and high sensitivity for this instrument also. During descent (figure 6) the rapid decrease in ozone and increase in carbon monoxide indicates that the airliner passed from the stratosphere into the troposphere before the GASP system shut down.

Simultaneous measurements of several trace species as shown in these figures can be used to uniquely determine the source of the air mass, as being typically tropospheric or stratospheric. A quantitative unstanding of the tropospheric-stratospheric exchange processes is required for development of improved simulation models of the atmosphere and thereby a better knowledge of the impact of pollution on the atmosphere.

CONCLUDING REMARKS

Considerable effort has been required to develop airborne environmental instrumentation suitable for automatic unattended operation on commercial airliners. Existing laboratory type environmental measuring techniques were significantly modified to measure the very low concentrations of trace species in the upper atmosphere.

A carbon monoxide analyzer of the dual isotope fluorescence type with an original full scale range of 20 ppm attained a greatly improved sensitivity with a reduced full scale range of 1.0 ppm. With this sensitivity and an improved limit of detectability of 0.02 ppm, values in the order of 0.05 ppm were measured in the stratosphere. Improvements to the condensation nuclei instrument have resulted in a ten fold decrease in the minimum detectable limit for measurement of very small airborne particles. A high sensitivity chemiluminescent nitric oxide analyzer has been acquired, flight tested, and is scheduled for acquiring data on the 747 airliners in early 1978.

Simultaneous measurements of several trace species in flight at cruise altitudes aid in identifying tropospheric or stratospheric air masses, which can lead to quantative information on tropospheric-stratospheric exchange processes.

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TABLE I.

AIR CONSTITUENT MEASUREMENTS

- GASES
  - OZONE
  - WATER VAPOR
  - OXIDES OF NITROGEN
  - CARBON MONOXIDE
  - CHLOROFLUOROMETHANES
- PARTICULATES
  - NO. DENSITY (>0.3 μm DIAM)
  - CONDENSATION NUCLEI
  - MASS CONCENTRATION OF
    - SULFATES
    - NITRATES

SUPPLEMENTAL DATA

- FLIGHT DATA
  - TIME & DATE
  - LATITUDE
  - LONGITUDE
  - ALTITUDE
  - AIR SPEED
  - HEADING
- METEOROLOGICAL DATA
  - OUTSIDE AIR TEMP
  - WIND DIRECTION
  - WIND VELOCITY
  - TURBULENCE (VERTICAL ACCEL)
  - CLOUD ENCOUNTERS

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TABLE II.

GASP MEASURING INSTRUMENTS

OZONE	ULTRAVIOLET ABSORPTION PHOTOMETER RANGE 3 ppb TO 20 ppm
WATER VAPOR	COOLED MIRROR HYGROMETER DEW-FROST POINT RANGE -80^0 TO $+20^0$ C
CARBON MONOXIDE	INFRARED ABSORPTION ANALYZER RANGE 0.02 TO 1 ppm
NITRIC OXIDE	CHEMILUMINESCENT ANALYZER RANGE 0.05 TO 10 ppb
PARTICLES (D > 0.3 μm)	LIGHT SCATTERING SENSOR
CONDENSATION NUCLEI	CLOUD CHAMBER MIN. CONCENTRATION 30/cm^3

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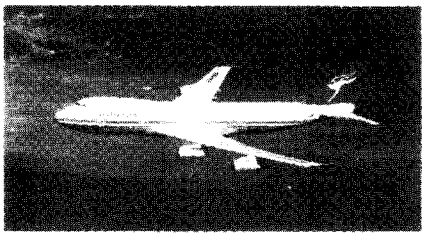
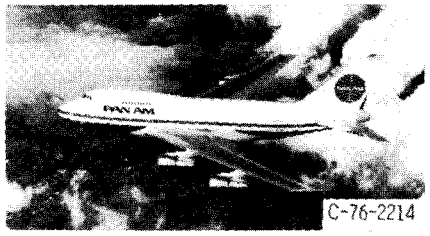
IN SERVICE, DEC 1974

IN SERVICE, MAR 1975



IN SERVICE, NOV 1975



IN SERVICE, MAR 1976

Figure 1. - Airline 747 aircraft participating in NASA global atmospheric sampling program.

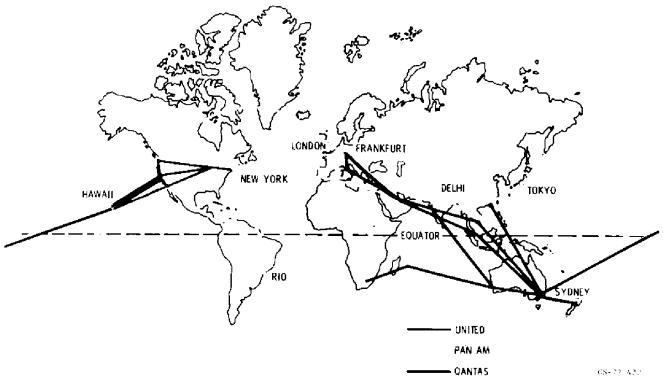
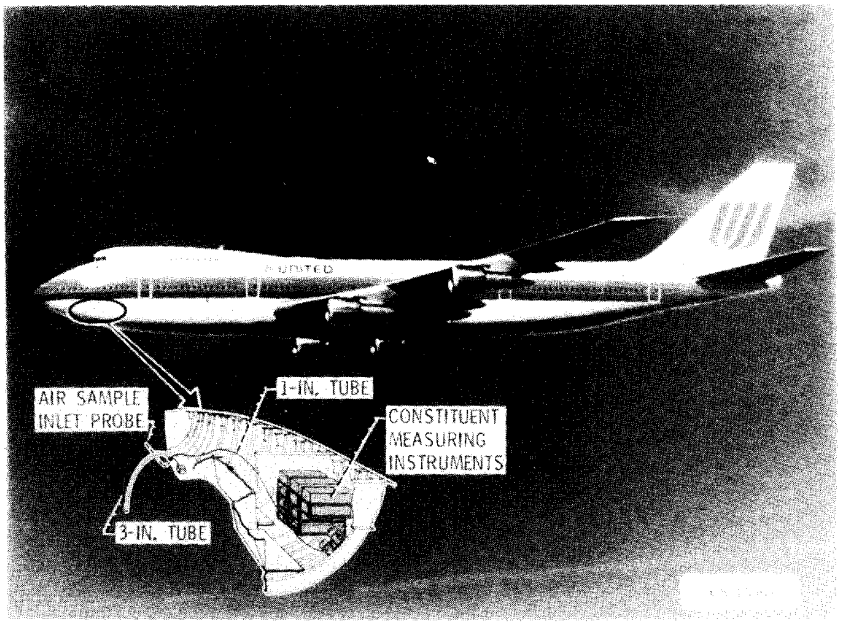


Figure 2. - GASP route structure.



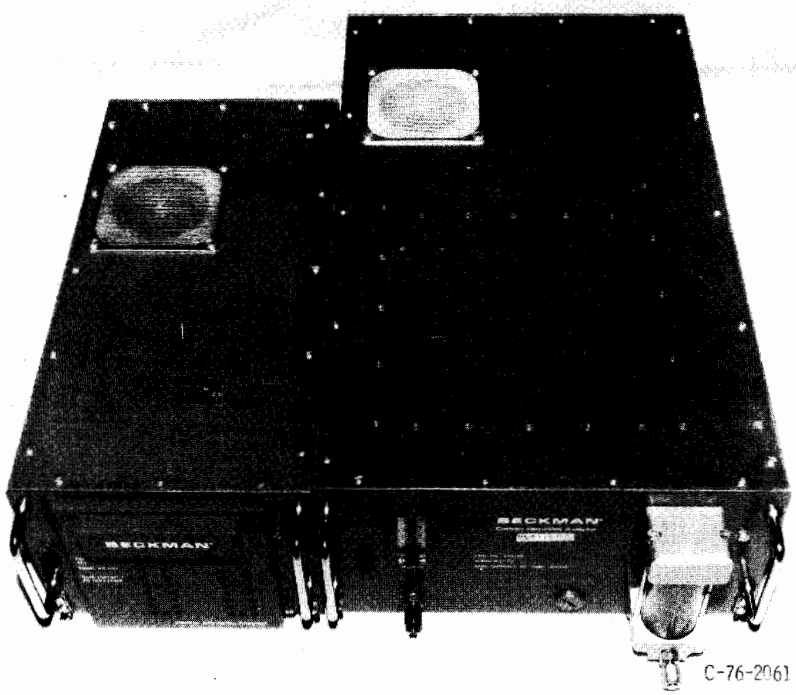


Figure 4. - An airborn GASP instrument (carbon monoxide analyzer) packaged in two avionics cases.

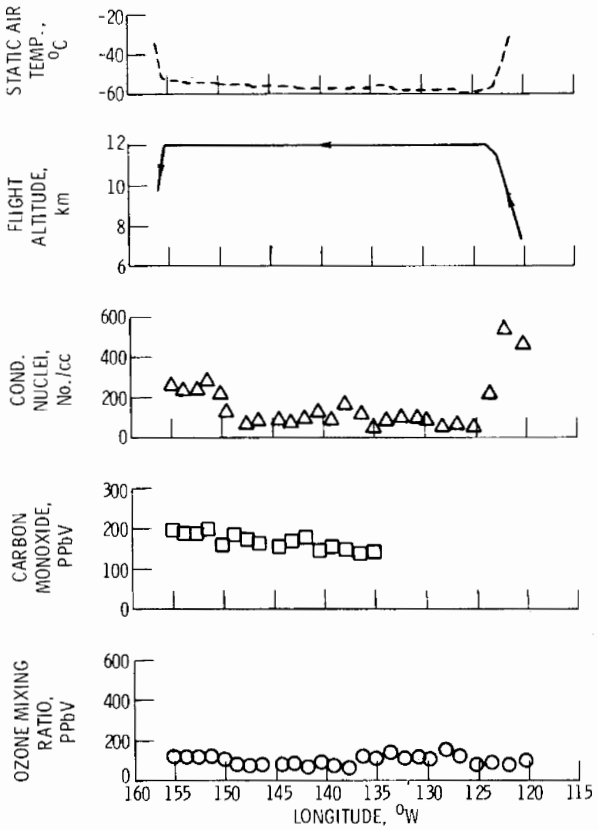


Figure 5. - Simultaneous measurements of ozone, carbon monoxide, condensation nuclei, and air temperature obtained with GASP instruments during a flight from Los Angeles to Honolulu.

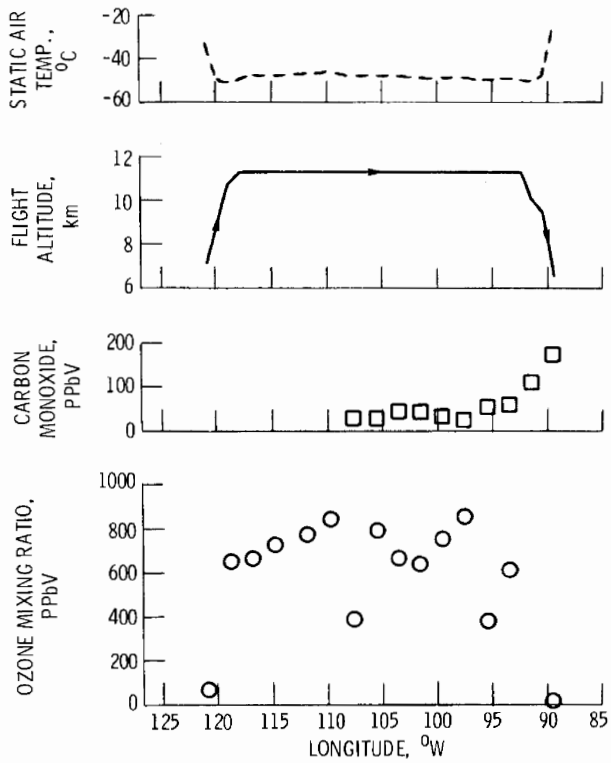


Figure 6. - Simultaneous measurements of ozone, carbon monoxide, and air temperature obtained in the stratosphere with GASP instruments during a flight from Seattle to Chicago.