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ANALYSIS OF ATMOSPHERIC OZONE MEASUREMENTS MADE FROM A B-747 AIRLINER DURING MARCH 1975

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16. Abstract

Measurements of atmospheric ozone in the upper troposphere and lower stratosphere made during March 1975 as part of the NASA Global Atmospheric Sampling Program are reported and analyzed. The interrelationships between the ozone mixing ratio and geographical and meteorological parameters are examined in several case studies. The ozone data correlate well with the difference between the flight altitude and the height of the tropopause, as obtained from National Meteorological Center gridded data. The distribution of ozone mixing ratios with latitude at an altitude of 11 ± 0.5 km shows a poleward increase and large variability at latitudes greater than 30° N in agreement with published mean ozone levels from the North American ozonesonde network.

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ANALYSIS OF ATMOSPHERIC OZONE MEASUREMENTS MADE FROM A B-747 AIRLINER DURING MARCH 1975

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SUMMARY

Atmospheric trace constituents in the upper troposphere and lower stratosphere are now being measured, as part of the NASA Global Atmospheric Sampling Program (GASP), by fully automated air sampling systems operating on four Boeing 747 airliners in routine commercial service. Ozone mixing ratio, static air temperature, and wind speed and direction data obtained during several flights of a GASP-equipped Pan Am airliner in March 1975 are reported and analyzed. The height of the tropopause at each GASP data location for these flights was obtained from National Meteorological Center (NMC) gridded data for the reporting period closest to the flight time. The case studies presented show examples of tropospheric and stratospheric ozone levels, natural variability of stratospheric ozone, and the variation of the ozone mixing ratio with geographical location. Interrelationships between ozone and the meteorological parameters are examined. The ozone data were found to correlate well with the difference between the flight altitude and the height of the (NMC) tropopause. The distribution of ozone mixing ratios with latitude at an altitude of 11 $\pm$0.5 kilometers shows a poleward increase and large variability in ozone for latitudes greater than 30° N. These data are compared with published monthly and seasonal mean values at 11 kilometers obtained from ozone soundings at various latitudes in North America.

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INTRODUCTION

The NASA Global Atmospheric Sampling Program (GASP) is currently obtaining atmospheric trace constituent data in the upper troposphere and lower stratosphere. This report is the beginning of the GASP effort to establish global baseline constituent levels as a prerequisite to long-term monitoring to determine whether emissions from aircraft or other anthropogenic sources are altering the background chemical composition in the upper atmosphere. Two recent climatic impact studies (refs. 1 and 2) have concluded that there is a possibility of both biological and climatological effects if future large fleets of aircraft cruise in the stratosphere. However, there is presently a high degree of uncertainty in assessing environmental effects because of a lack of comprehensive, long-term upper atmospheric data. A primary objective of GASP is to provide needed global data to reduce this uncertainty (ref. 3).

The GASP program began in 1972 with a feasibility study of the concept of using commercial airliners in routine service to obtain atmospheric data. This program has progressed from design and acquisition of hardware (ref. 4) to collecting global data on a daily basis. GASP systems are now operating on four airline aircraft: one United Airlines B-747, two Pan American World Airways B-747's, and one Qantas Airways of Australia B-747. The United airliner is collecting data over the contiguous United States and to Hawaii. Global coverage is provided by the Pan Am and Qantas airliners. Pan Am routes from the United States include around-the-world flights in the Northern Hemisphere, transatlantic flights to Europe, transpacific flights to the Orient, intercontinental flights to Central and South America, and occasionally transpacific flights to Australia. More frequent coverage in the Southern Hemisphere is provided by the Qantas airliner on transcontinental Australian flights and on flights from Australia to the South Pacific and from Australia to Europe. The GASP system design, the measurement instruments, the on-board computer for automatic control and data management, and system maintenance procedures are described in reference 5. Previous independent measurements of constituents to be initially monitored by GASP are reviewed in reference 6.

This report presents an analysis of ozone mixing ratio, static air temperature, and wind speed and direction data obtained at altitudes from 8 to 12 kilometers during several flights of a Pan American World Airways B-747 airliner in March 1975. Although, in the future, GASP constituent monitoring will include ozone, water vapor, carbon monoxide, oxides of nitrogen, particle size and number density, halocarbons, and filter samples, only ozone and related meteorological and flight data are presented and analyzed in this report. The analyses are concentrated on individual case studies to show the interrelationships between ozone and meteorological processes in the atmosphere because this knowledge is of primary importance in explaining the observed distribution and variability of atmospheric ozone. In addition to the case studies, summary analyses of the distribution of ozone with respect to the local tropopause and the distribution of ozone with latitude are presented.

DATA ACQUISITION AND MEASUREMENTS

For each flight, data acquisition begins on ascent through the 6-kilometer-altitude flight level and terminates on descent through this level. A complete GASP sampling cycle is 60 minutes, divided into twelve 5-minute segments. A recording is made at the end of each segment. During alternate segments (at 10-min intervals), air sample data are recorded from all the instruments. During the intervening segments the system is in one of six different calibration modes to allow for checks on instrument operation.

Ozone

The GASP ozone measurement is made by a continuous ultraviolet ozone photometer. The concentration of atmospheric ozone is determined by measuring the difference in intensity of an ultraviolet light beam that alternately passes through the sample gas and through an ozone-free zero gas (generated within the instrument). This instrument and its operation are described in reference 7. The measurement range for this instrument is from 3 to 20 000 ppbv (parts per billion by volume) with a sensitivity of 3 ppbv. Laboratory tests have shown the instrument precision (repeatability) to be ± 1 percent. The instrument is checked in the laboratory (over the range 0 to 1000 ppbv) against an ozone generator that is calibrated by the 1 percent neutral buffered potassium iodide (KI) method (ref. 8). The estimated accuracy of the KI method is 7 percent. Data from flight tests of the ultraviolet ozone photometer and comparisons with flight data from an electrochemical concentration cell ozone meter are given in reference 9.

In-flight monitoring of the ozone instrument includes measurement of the instrument zero by flowing the sample through a charcoal filter external to the instrument, and measurement of the electronic span setting and control frequencies available from the instrument. The instrument is not calibrated in flight with an ozone calibration gas because of the difficulty of generating a precisely known ozone concentration in the flight system. Thus, periodic checks for calibration consistency are performed in the laboratory.

The destruction of ozone in the Teflon sample lines from the inlet probe to the instrument and in the Teflon-coated diaphragm pump that raises the sample pressure to 10 N/cm^2 (1 atm) has been measured under conditions simulating operation in flight. From these data, the ozone mixing ratio at the probe inlet (O_3) can be expressed in terms of the ozone mixing ratio measured by the instrument (O_{3m}) by

$$O_3 = O_{3m} + 2.14 \sqrt{O_{3m}}$$

where O_3 and O_{3m} are in units of parts per billion by volume (ppbv). This relationship has been used in the data reduction to correct the measured values to inlet (ambient) conditions.

Flight Data

In addition to the air sample measurements, aircraft flight data are obtained with each data recording to precisely describe conditions when the data are acquired. Aircraft position, heading, and the computed wind speed and direction are obtained from the inertial navigation system. Altitude, air speed, and static (ambient) air temperature are collected from the central air data computer in the aircraft. Vertical acceleration information (an indication of turbulence) is taken from the aircraft flight recording system. Date and time are provided by a separate GASP clock-calendar unit.

Tropopause Pressure

The National Meteorological Center (NMC) is presently maintaining a library of gridded meteorological data fields that are accessible on various disk and magnetic tape systems (ref. 10). Briefly, the data are interpolated to points on the NMC 65 by 65 grid, a square matrix map transformed from a polar stereographic map of the

Northern Hemisphere. Among these gridded data are tropopause pressures, available on a twice daily basis.

Tropopause pressures are derived as a byproduct of the NMC objective analysis scheme, which determines the height of constant-pressure surfaces above each grid point. Eleven mean layer temperatures are calculated from the vertical separation of the constant-pressure levels above each of the 4225 grid points. They are then fitted with a high-order polynomial curve. The tropopause is defined as the base of the lowest stable layer (pressures $\leq$ 500 hPa (500 mb)) within which the average lapse rate is $\leq$ 2.5 degrees C per kilometer. Because the tropopause has a unique location above each grid point, any subsequent objective contouring over the hemisphere must be continuous in space. From the standpoint of the relationship between the tropopause and trace constituent measurements, the continuous nature of the analyzed fields permits a representative first approximation to the real atmosphere. The analysis technique is particularly suited to tropopause height evaluation in tropical and polar latitudes. But for certain subtropical and midlatitude conditions, smoothed tropopause pressures lack the expected multiple structuring of observed tropopause surfaces (refs. 11 to 13).

RESULTS AND DISCUSSION

The analyses of data from several Pan Am flights from March 11-30, 1975, are reported in order to evaluate the GASP ozone-mixing-ratio records in terms of their tropospheric and stratospheric behavior. For each flight, GASP data were obtained whenever the aircraft flight altitude was greater than 6 kilometers. Data are reported on a once per 10-minute basis, which permits data points to be resolved at intervals of approximately 150 kilometers along the flightpath.

However, tropopause pressure data are accessible through the NMC tape library on a twice-daily basis only. The tropopause pressure at each GASP data location was obtained by space interpolation from the NMC field for the reporting period closest to the flight time. Thus, all 0000 GMT tropopause pressure fields were assumed to be valid from 1800 to 0600 GMT, and all 1200 GMT fields to be valid from 0600 to 1800 GMT. This simple standardization has thus far proven suitable for data evaluation purposes.

Case Studies

March 11-13, 1975. - The analyses of the tropopause pressures and ozone mixing ratios for a series of flights from San Francisco to Frankfurt, West Germany, via the Far and Middle East are shown in figure 1. As discussed in the previous section, tropopause pressure maps have been used that are time centered (± 6 hr) about 0000 GMT and 1200 GMT. The structure of the tropopause is generally continuous between successive analyses for these dates, although a major isobaric discontinuity appears between the 0000 GMT and 1200 GMT tropopause pressure data on March 13th. This discontinuity is evident over the Middle East.

For individual stratospheric penetrations, particularly over the Pacific Ocean and the Balkans, the agreement among the static (ambient) air temperature, the ozone mixing ratio, and the tropopause height data is good. The ozone peak and the corresponding increase in the static air temperature over the Middle East suggest a brief stratospheric penetration, which is not substantiated by the NMC tropopause height data. This is in the region of the discontinuity in the tropopause pressure fields and may be a consequence of a locally varying or discontinuous tropopause, which the NMC fields would not be expected to model correctly. Although good agreement is observed between the ozone mixing ratio and the static air temperature during each stratospheric penetration, caution must be exercised in the use of the static air temperature as an independent indicator of stratospheric flight since equally warm temperatures can be encountered in the troposphere. A good example is given by the flights at 10.6-kilometer altitude across Southeast Asia and the Indian subcontinent.

The ozone and wind data in figure 1 show that, in the lower stratosphere, ozone maximums are encountered either at or slightly east of each trough. This feature is identified by the shift in the wind direction from the southwest quadrant into the northwest quadrant as the aircraft flies west. Thus, each of the three recorded maximums occur within regions of cyclonic wind flow. The ozone mixing ratios, as well as their abrupt variations at the interface of the upper troposphere and lower stratosphere, are consistent with previous documentation (ref. 14).

March 14, 1975. - This flight from New York to Shannon, Ireland, is characterized by two broad ozone-mixing-ratio maximums separated by approximately 35 degrees of longitude (fig. 2). This is consistent with the longitudinal variation in the static air temperature, which also exhibits relative maximums near 18° and 54° W.

Thus, both records appear to indicate two distinct flight passages into the lower stratosphere, thereby implying an underestimation of the tropopause height between 30° and 45° W. The broad ozone-mixing-ratio maximum (between 50° and 62° W) occurs within a cyclonically curved wind field. The ozone maximum between 15° and 25° W occurs to the east of the inflection point in the streamline curvature and thus within cyclonically curving, northwesterly flow.

March 15, 1975. - The return flight from London, England, to New York shown in figure 3 provides an interesting set of ozone and tropopause data, which may be compared with the flight records of the previous day. It is apparent that the tropopause depression has shifted 15° eastward to approximately 45° W over the preceding 30 hours. The aircraft first encountered stratospheric air at 36° W, as corroborated by each of the three indicators - ozone, temperature, and flight altitude. Inasmuch as the return cruise altitude was nearly 1 kilometer below that of March 14th, the peak ozone mixing ratio near 40° W may be interpreted as having been advected eastward and downward in phase with the tropopause depression. Moreover, this ozone peak, superimposed upon the extensive maximum of the lower stratosphere between 36° W and 71° W, is associated with cyclonic wind flow to the east of a trough.

March 17-19, 1975. - As previously seen during the flights of March 11-13, this series of flights illustrates abrupt ozone increases (decreases) for each apparent entrance into (exit from) the stratosphere (fig. 4). The repeatability of this feature is independent of latitude. The onset of rapid ozone-mixing-ratio increases is particularly evident over Newfoundland ($\sim 60^{\circ}$ W), Germany ($\sim 11^{\circ}$ E), the Middle East ($\sim 40^{\circ}$ E), and the northern Pacific Ocean ($\sim 155^{\circ}$ W). The intersection of the aircraft flight level with the NMC-derived tropopause pressures generally provides an independent means of explaining these high, and often persistent, ozone mixing ratios. However, if the lesser ozone peaks between longitudes 25° to 15° W, 30° to 36° E, and 160° to 165° E are indicative of flight in the lower stratospheric environment, the tropopause analyses have clearly overestimated the base of the stratosphere. With the exception of the flight over Turkey, the corresponding temperature profiles between these longitudes are not convincing evidence of flight in a warmer, stratospheric environment. Note that the major ozone-mixing-ratio maximums are embedded within cyclonic flow and terminate as the curvature of the flow changes to anticyclonic.

March 20-21, 1975. - The flight from Seattle to London, England, in figure 5 depicts the persistence of high ozone mixing ratios (generally >150 ppbv), typical of the lower stratosphere, during 90 percent of the total flight time. In view of a similar persistence of relatively warmer temperatures, even at a cruise altitude of 9 kilometers between 60° W and 8° W, the tropopause analysis east of 60° W longitude is rendered suspect. The temperatures deviate by $\sim$4 degrees C about a mean of nearly -47° C and are clearly suggestive of flight through the lower stratosphere; the values may be compared with those presented for the preceding March flights across the northern Atlantic. Moreover, the recorded ozone mixing ratios over the North American sector agree with the mean levels given in reference 15.

March 21, 1975. - The return from London to New York (fig. 6) began approximately 6 hours after the touchdown of the Seattle-London flight. Because the flight routes differ appreciably, the data are not directly comparable. The meteorological differences are best expressed by comparing the longitudinal temperature and tropopause profiles. Brief aircraft passages through the lower stratosphere in the London-New York flight occur between 18° to 37° W and 55° to 70° W, as evidenced by step increases and decreases in the ozone mixing ratios and temperatures between these longitude bands. The tropopause analysis additionally verifies these locations. As has been repeatedly observed during previous GASP flights, the ozone maximums are associated with cyclonic flow and occur generally to the east of the troughs. The temperature profiles indicate that these two ozone maximums are closely alined with warm advection in the southwesterly wind flow.

March 22, 1975. - The data records during this eastbound flight from New York to London (fig. 7) unveil an analysis problem not seen in the previous transatlantic crossings. Specifically, the brief two- to threefold ozone-mixing-ratio increase for that period of time during which the aircraft descended to and maintained cruise at 9 kilometers is paradoxical in view of the tropopause analysis. Moreover, the static air temperature profile can at best corroborate a vertical temperature lapse rate in a standard atmosphere, that is 6.5 degrees C per 1-kilometer interval. Thus, it appears initially that the temperature increase is due to descent to warmer tropospheric levels.

March 25-27, 1975. - The outstanding feature of the flight records taken during these days (fig. 8) is their remarkable similarity in atmospheric and ozone structure to the data from similar flights during the previous week (cf. fig. 4). One area of interest should be mentioned; the ozone maximum from 30° to 25° W must, by inference from the temperature profile, arise by virtue of a brief passage into and out of the stratosphere. Otherwise, the NMC tropopause pressure analyses appear to have successfully located the stratospheric entrances and exits. Data from 160° W to San Francisco were not obtained because the data recorder failed.

March 29-30, 1975. - These two flight series (figs. 9 and 10) are discussed jointly because the similarity between data records suggests two common features. From Mexico southeastward across Central America to the northern coast of South America, there appears to be little dispersion of ozone mixing ratios about an approximate mean of 30 to 35 ppbv. One may thus reasonably conclude that the troposphere in this region is well mixed at least through those depths covered by aircraft ascent and descent. The second feature of interest is the appearance of a narrow ozone maximum over Baja California; the peak value occurs near 113° W at a flight level of approximately 9 kilometers (314 hPa) on March 29th and at the same longitude the next day at a flight level of 12 kilometers (197 hPa).

Interpretation of Flight Results

The abundance of both ozone and meteorological data during the March flight series renders a few simple statistics and tabulations on a hemispheric basis possible. For each flight series, data summaries (tables I to VII) have been constructed that focus upon the locations of significant ozone, temperature, wind vector, and tropopause variations. The tables highlight those indices that may reasonably explain the causes for such variations; these include first-order indications of flight within the stratosphere and indications of large-scale atmospheric motion. Clearly, agreement within indices tends not only to explain the reasons for the occurrence of various profile features, but also serves as a guide in verifying one indicator against another.

One feature that reappears on nearly all occasions of ozone maximums in the lower stratosphere is the cyclonic curvature of the wind fields. This is particularly evident during those brief flight encounters with the lower stratosphere associated with cyclogenetic activity through a great depth of the troposphere below. Such cyclonic curvature, often manifested as a distinct wind-shift line along an isobaric surface and above the central portion of the tropopause vortex, is consistent with previous aerological observations (e.g., ref. 16). Furthermore, there are initial indications from the March records that the central longitudes of ozone-mixing-ratio maximums are located east of the troughline and are thus embedded within wind flow with a southerly component. Note from the tables that temperature maximums are often coincident with the peak ozone values. To what extent these data corroborate previous findings (refs. 17 and 18) that the eddy transport of ozone is directed poleward against its mean, lower stratospheric gradient remains to be seen in future GASP flights. In an analysis relating total (vertical column) ozone amounts and meteorological parameters in the lower stratosphere, Ohring and Muench (ref. 19) concluded that "the distribution of vertical velocities in the troughs and ridges is such as to produce ozone maximums ahead of the troughs and ozone minimums ahead of the ridges." The GASP ozone and wind data presented herein are consistent with this finding inasmuch as approximately 75 percent of the changes in total ozone are found in the lower stratosphere (ref. 20).

It is also of interest to present two depictions of the March flights that show the vertical ozone-mixing-ratio profile and the latitudinal distribution at the mean flight altitude. Figure 11 represents a compilation of the three flights around the world (March 11-13, March 17-19, and March 25-27) and expresses the mean ozone mixing ratio as a function of pressure (altitude) above or below the NMC-derived tropopause. Unbiased standard deviations are superimposed upon the histogram as well. The step increase of the ozone mixing ratios beginning at, or near, the tropopause is evident, as is a coincident maximum in the standard deviation values. The ozone gradients in the upper troposphere and lower stratosphere shown by this distribution are consistent with the results of reference 21. The distribution shown in figure 11 is also similar to the height distributions of radioactive materials shortly after their injection into the lower stratosphere (e.g., ref. 22).

A zonal display of GASP ozone data (fig. 12) at an altitude of 11 ± 0.5 kilometers for all flight dates indicates the high degree of variability of the measurements, particularly poleward of 30° N. For comparison, North American mean ozone-mixing-ratio distributions with latitude calculated from data given in reference 15, 23, and 24 are included in figure 12. Mean levels have not been calculated for the GASP data since the result would be biased because of the scarcity of samples at some latitudes and because the GASP data are global whereas the data in references 15, 23, and 24 are for North America.

SUMMARY OF RESULTS

The analysis of ozone-mixing-ratio records and related meteorological data for March 1975 obtained as part of the NASA Global Atmospheric Sampling Program (GASP) permits the following conclusions to be drawn regarding the distribution of ozone in the vicinity of the tropopause:

1. The GASP data records show that atmospheric ozone increases significantly in passing from the upper troposphere to the lower stratosphere. This is in agreement with results published by other investigators over the past three decades. Thus, ozone data provide one first-order indicator of stratospheric flight.

2. For individual flights within the lower stratosphere, ozone maximums were found to be generally associated with large-scale cyclonic motions in the atmosphere, as identified from the aircraft wind speed and direction data.

3. Increases (decreases) in ambient air temperature were generally coincident with ozone increases (decreases) whenever the aircraft flew into (out of) the stratosphere. Also, temperature profiles indicate that temperature maximums coincide with ozone maximums in the lower stratosphere; thus the temperature distributions provide a second indicator of stratospheric flight.

4. Comparison of the flight pressure altitude and the tropopause pressure obtained from the National Meteorological Center (NMC) provides a generally useful, independent indicator of flight within the lower stratosphere.

5. The distribution of ozone above and below the tropopause correlated well with the difference between the pressure altitude of the aircraft and the NMC tropopause pressure. Although the GASP data were obtained from (nominally) horizontal flights at various altitudes, latitudes, and longitudes, the distribution of ozone with respect to the local tropopause is in agreement with vertical distributions in the literature, which were for the most part obtained from vertical soundings.

6. The distribution of ozone with latitude for flights at an altitude of 11 ± 0.5 kilometers shows that atmospheric ozone begins to increase and exhibit greater variability poleward of 30° N latitude. Mean ozone data from the North American ozonesonde network for this altitude and time of year also show this latitudinal increase and are in agreement with the GASP data.

The results presented are the beginning of the GASP effort to establish global baseline ozone levels in the vicinity of the tropopause as a prerequisite to long-term monitoring to ascertain if there are any perturbations occurring that may be attributed to aircraft emissions or other atmospheric pollution.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, May 20, 1975,
197-10.

REFERENCES

1. Grobecker, A. J.; Coroniti, S. C.; and Cannon, R. H., Jr.: Report of Findings: The Effects of Stratospheric Pollution by Aircraft. DOT-TST-75-50, Dept. of Transportation, 1974.
2. Environmental Impact of Stratospheric Flight: Biological and Climatic Effects of Aircraft Emissions in the Stratosphere. National Academy of Sciences, 1975.
3. Rudey, Richard A.; and Holdeman, James D.: Upper Atmosphere Pollution Measurements (GASP). Aeronautical Propulsion. NASA SP-381, 1975, pp. 139-156.
4. Perkins, Porter J.; and Reck, Gregory M.: Atmospheric Constituent Measurements Using Commercial 747 Airliners. NASA TM X-71469, 1973.
5. Perkins, Porter J.; and Gustafsson, Ulf R. C.: An Automated Atmospheric Sampling System Operating on 747 Airliners. Intern. Conf. on Environmental Sensing and Assessment. Vol. 2, Inst. Elec. Electron. Engrs., Inc., pp. 1 26-4 to 10 26-4.
6. Falconer, Phillip; and Miller, John: A Review of Lower Stratospheric - Upper Tropospheric Trace Gas Constituents to be Monitored by the Global Air Sampling Program (GASP). Intern. Conf. on Environmental Sensing and Assessment. Vol. 2, Inst. of Elec. Electron. Engrs., Inc., pp. 1 26-5 to 6 26-5.
7. Bowman, Lloyd D.; and Horak, Richard F.: A Continuous Ultraviolet Absorption Ozone Photometer. Anal. Instrum., vol. 10, 1972, pp. 103-108.

8. Saltzman, Bernard E.; and Gilbert, Nathan: Idometric Microdetermination of Organic Oxidants and Ozone. Anal. Chem., vol. 31, no. 11, 1959, pp. 1914-1920.

9. Reck, Gregory M.; Briehl, Daniel; and Perkins, Porter J.: Flight Test of a Pressurization System Used to Measure Minor Atmospheric Constituents from an Aircraft. NASA TN D-7576, 1974.

10. Gelhard, Robert ; NMC Archives. Office Note 108, U. S. Dept. of Commerce, 1975.

11. Hess, Seymour L.: Some New Mean Meridional Cross Sections Through the Atmosphere. J. Meteorol., vol. 5, 1948, pp. 293-300.

12. Sawyer, J. D.: Day-to-Day Variations in the Tropopause. Geophys. Mem. No. 92 (Great Britain), vol. 11, no. 7, 1954, pp. 1-92.

13. Danielsen, E. F.: The Laminar Structure of the Atmosphere. Arch. Meteorol., Geophys. Bioklimatol., ser. A, vol. 11, no. 3, 1959, pp. 293-332.

14. Bischof, Walter: Ozone Measurements in Jet Airliner Cabin Air. Water, Air, and Soil Pollution, vol. 2, no. 1, Mar. 1973, pp. 2-14.

15. Wilcox, R. W.; Nastrom, G. D.; and Belmont, A. D.: Periodic Analysis of Total Ozone and Its Vertical Distribution. (RR-3, Control Data Corp; NAS2-7807), NASA CR-137737, 1975.

16. Palmen, E., and Newton, C. W.: Atmospheric Circulation Systems: Their Structure and Physical Interpretation. Intern. Geophys. Ser., vol. 13, Academic Press, 1969.

17. Newell, R. E.: Transfer through the Tropopause and within the Stratosphere. Quart. J. Roy. Meteorol. Soc., vol. 89, no. 380, 1963, pp. 167-204.

18. Dobson, G. M. B.: Atmospheric Ozone and the Movement of Air in the Stratosphere. Pure and Appl. Geophys., vol. 106-108, 1973, pp. 1520-1530.

19. Ohring, G.; and Muench, H. S.: Relationships between Ozone and Meteorological Parameters in the Lower Stratosphere. J. Meteorol. vol. 17, no. 2, 1960, pp. 195-206.

20. Mateer, C. L.; and Godson, W. L.: The Vertical Distribution of Atmospheric Ozone over Canadian Stations from Umkehr Observations. Quart. J. Roy. Meteorol. Soc., vol. 86, 1960, pp. 512-518.

21. Seiler, W.; and Warneck, P.: Decrease of Carbon Monoxide Mixing Ratio at the Tropopause. J. Geophys. Res., vol. 77, no. 18, June, 1972, pp. 3204-3214.

22. List, Robert J.; and Telegadas, Kosta.: Using Radioactive Tracers to Develop a Model of the Circulation of the Stratosphere. J. Atmospheric Sci., vol. 26, no. 5, pt. 2, 1969, pp. 1128-1136.

23. Hering, Wayne S.; and Borden, Thomas R., Jr.: Mean Distributions of Ozone Density Over North America, 1963-1964. AFCRL-65-913, Air Force Cambridge Research Labs. (AD-629989), 1965.

24. Hering, Wayne S.; and Borden, Thomas R., Jr.: Ozone Observations Over North America, Volume 4. AFCRL-64-30-Vol.-4, Air Force Cambridge Research Labs. (AD-666436), 1967.

TABLE I. - DATA SUMMARY FOR FLIGHTS OF MARCH 11-13, 1975[a]

Approximate determination of-	Northwestern Pacific	Southern Japan	Iraq	Balkans
Longitudinal extent of measured ozone mixing ratios suggestive of flight in a stratospheric environment	145° W - 140° E	138° E - 135° E	50° E - 42° E	20° E - 12° E
Longitudinal extent of temperatures suggestive of a stratospheric environment	146° W - 140° E	Not definable	50° E - 42° E	21° E - 12° E
Longitudes of flight into and out of stratosphere based on NMC tropopause analyses	In, 143° W; out, 139° E	In, 138° E; out, 134° E	No intersection of flight with tropopause	In, 21° E; out, 11° E
Longitudes of ozone peak values	[b]157° W $\pm$ 3°; 164° E $\pm$ 3°	137° E	46° E $\pm$ 2°	12° E
Curvature of in-flight wind vectors	Cyclonic; cyclonic	Not significant	Cyclonic	Cyclonic[c]
Longitudes of temperature peaks	158° W $\pm$ 3°; 165° E $\pm$ 3°; 145° E $\pm$ 3°	Not definable	47° E $\pm$ 2°	13° E $\pm$ 2°

[a]See fig. 1.

[b]Three-unit running mean used to locate ozone peaks.

[c]Inferred from last four wind data points (not shown).

TABLE II. - DATA SUMMARY FOR FLIGHTS OF MARCH 14 AND 15, 1975[a]

Approximate determination of-	March 14, 1975		March 15, 1975
	North Atlantic		
Longitudinal extent of measured ozone mixing ratios suggestive of flight in a stratospheric environment	62° W - 47° W	32° W - 14° W	36° W - 71° W
Longitudinal extent of temperatures suggestive of a stratospheric environment	67° W - 47° W	27° W - 13° W	36° W - 71° W
Longitudes of flight into and out of stratosphere based on NMC tropopause analyses	In, 67° W; out, 42° W	In, 40° W; out, 13° W	In, 36° W; out, 55° W and In, 57° W; out, 71° W
Longitudes of ozone peak values	54° W $\pm$ 2°	18° W $\pm$ 2°	[b]41° W $\pm$ 2°
Curvature of in-flight wind vectors at longitudes of ozone peaks	Cyclonic	Probably cyclonic	Cyclonic
Longitudes of temperature peaks	56° W $\pm$ 2°	15° W $\pm$ 2°	42° W and 68° W $\pm 2^\circ$

[a]See figs. 2 and 3.

[b]Three-unit running mean used to locate ozone peak value.

TABLE III. - DATA SUMMARY FOR FLIGHTS OF MARCH 17-19, 1975[a]

Approximate determination of-	Northern Atlantic	Balkans	Middle East	Northern Pacific	
Longitudinal extent of measured ozone mixing ratios suggestive of flight in a stratospheric environment	60° W - 41° W	12° E - 26° E	32° E - 58° E	158° E - 169° E	153° W - 130° W
Longitudinal extent of temperatures suggestive of a stratospheric environment	63° W - 41° W	Not definable	31° E - 35° E	Not definable	153° W - 128° W
Longitudes of flight into and out of stratosphere based on NMC tropopause analyses	In, 57° W; out, 46° W	In, 12° E; out, 27° E	In, 39° E; out, 56° E	No intersection of flight with tropopause	In, 154° W; out, ?
Longitudes of ozone peak values	[b]53° W $\pm 2^{\circ}$; 43° W $\pm 2^{\circ}$	12° E - 26° E	35° E; 43° E $\pm 2^{\circ}$; 58° E	162° E $\pm 1^{\circ}$	145° W; 137° W
Curvature of in-flight wind vectors at longitudes of ozone peaks	Cyclonic; cyclonic	Not significant	Not significant; cyclonic; not significant	Not significant	Cyclonic; cyclonic
Longitudes of temperature peaks	55° W $\pm 2^{\circ}$; 47° W $\pm 2^{\circ}$	Not definable	31° E - 35° E	Not definable	137° W $\pm 2^{\circ}$

[a]See fig. 4.

[b]Three-unit running mean used to locate ozone peaks.

TABLE IV. - DATA SUMMARY FOR FLIGHTS OF MARCH 20-21, 1975[a]

Approximate determination of-	March 20-21, 1975	March 21, 1975	
	Canada and Northern Atlantic	Northern Atlantic	Nova Scotia
Longitudinal extent of measured ozone mixing ratios suggestive of flight in a stratospheric environment	116° W - 13° W	14° W - 34° W	57° W - 70° W
Longitudinal extent of temperatures suggestive of a stratospheric environment	115° W - ?	26° W - 34° W	55° W - 70° W
Longitudes of flight into and out of stratosphere based on NMC tropopause analyses	In, 117° W; out, 57° W	In, 18° W; out, 37° W	In, 55° W; out, 70° W
Longitudes of ozone peak values	104° W $\pm$ 2°; 73° W $\pm$ 2°: 25° W $\pm$ 2°	22° W $\pm$ 2°	65° W $\pm$ 2°
Curvature of in-flight wind vectors at longitudes of ozone peaks	Not significant; cyclonic; cyclonic	Cyclonic	Cyclonic
Longitudes of temperature peaks	Broad peak between 77° W and 58° W	22° W $\pm$ 2°	69° W $\pm$ 2°

[a]See figs. 5 and 6.

TABLE V. - DATA SUMMARY FOR FLIGHT OF MARCH 22, 1975[a]

Approximate determination of-	Nova Scotia	Ireland
Longitudinal extent of measured ozone mixing ratios suggestive of flight in a stratospheric environment	66° W - 62° W	7° W - 2° W
Longitudinal extent of temperatures suggestive of a stratospheric environment	Uncertain due to aircraft descent	7° W - 2° W
Longitudes of flight into and out of stratosphere based on NMC tropopause analyses	No intersection of flight with tropopause	In, 4° W; out, ?
Longitudes of ozone peak values	65° W $\pm$ 1°	5° W $\pm$ 2°
Curvature of in-flight wind vectors at longitudes of ozone peaks	Cyclonic	Not significant
Longitudes of temperature peaks	--------	Probably near 2° W

[a]See fig. 7.

TABLE VI. - DATA SUMMARY FOR FLIGHTS OF MARCH 25-27, 1975[a]

Approximate determination of-	Northern Atlantic		Balkans	Gulf of Alaska
Longitudinal extent of measured ozone mixing ratios suggestive of flight in a stratospheric environment	60° W - 47° W	30° W - 22° W	15° E - 28° E	178° W - ?
Longitudinal extent of temperatures suggestive of a stratospheric environment	62° W - 47° W	34° W - 20° W	Not definable	177° W - ?
Longitudes of flight into and out of stratosphere based on NMC tropopause analyses	In, 57° W; out, 52° W	No intersection of flight with tropopause	In, 13° E; out, 28° E	In, 179° W; out, 159° W
Longitudes of ozone peak values	50° W $\pm$ 2°	[b]27° W $\pm$ 3°	[b]20° E $\pm$ 3°	[b]165° W $\pm$ 2°
Curvature of in-flight wind vectors at longitudes of ozone peaks	Cyclonic	Cyclonic	Cyclonic	Cyclonic
Longitudes of temperature peaks	54° W $\pm$ 2°	25° W	Not present	165° W $\pm$ 2°

[a]See fig. 8.
[b]Three-unit running mean used to locate ozone peaks.

TABLE VII. - DATA SUMMARY FOR FLIGHTS OF MARCH 29-30, 1975[a]

Approximate determination of-	March 29-30, 1975	March 30, 1975
	Baja California	
Longitudinal extent of measured ozone mixing ratios suggestive of flight in a stratospheric environment	117° W - 113° W	112° W - 116° W
Longitudinal extent of temperatures suggestive of a stratospheric environment	Not definable	107° W - 115° W
Longitudes of flight into and out of stratosphere based on NMC tropopause analyses	No intersection flight with tropopause	In, 113° W; out, ?
Longitudes of ozone peak values	113° W	113° W
Curvature of in-flight wind vectors at longitudes of ozone peaks	Cyclonic	Cyclonic
Longitudes of temperature peaks	Not definable	113° W

[a]See figs. 9 and 10.

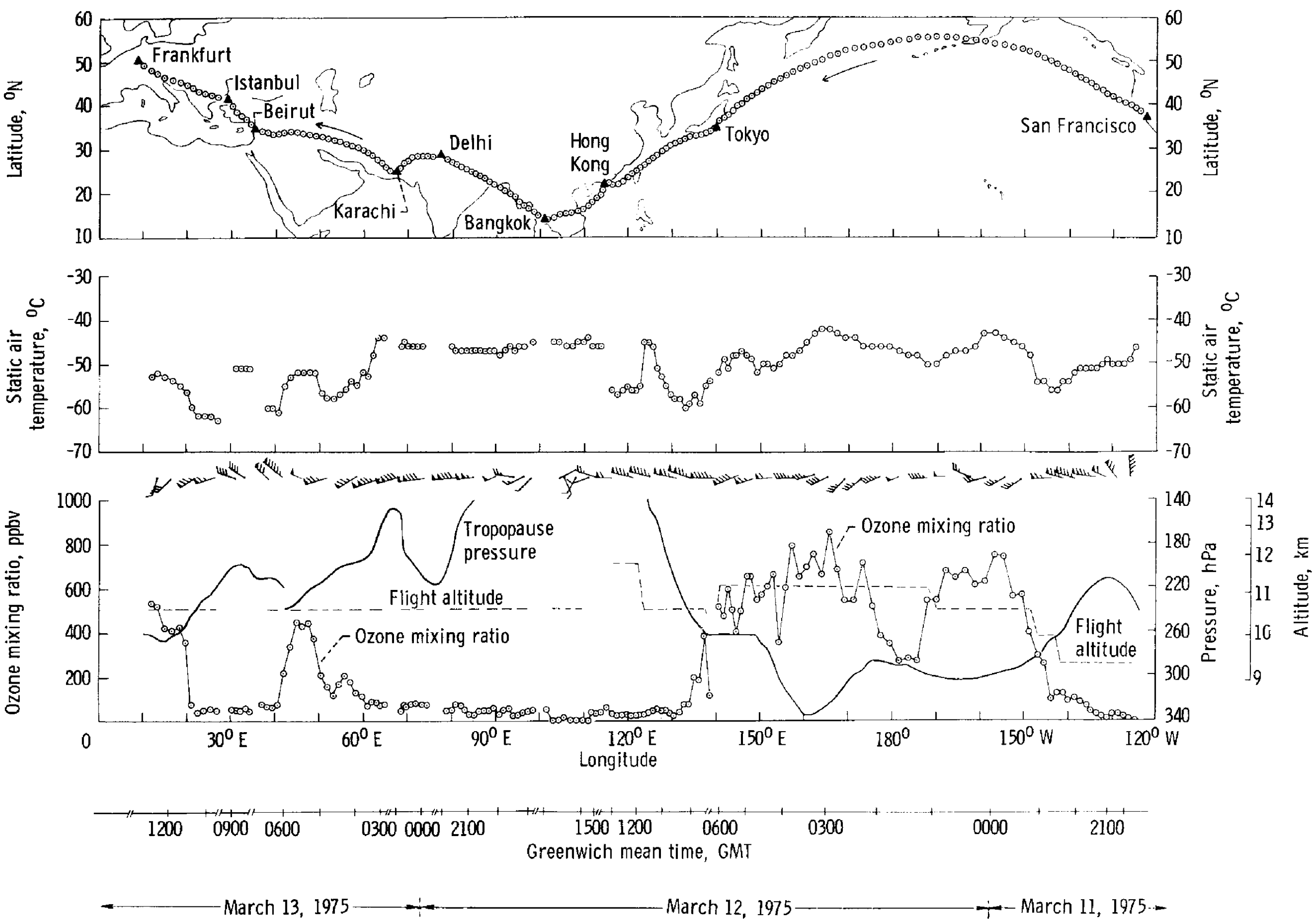

Figure 1. - Flight record of March 11-13, 1975, from San Francisco to Frankfurt, West Germany. Ozone mixing ratios, ambient air temperature, wind data, flight route and altitude are obtained from GASP and aircraft systems. Wind barbs follow standard National Weather Service plotting conventions. Tropopause pressures are obtained from National Meteorological Center data archives and are assumed to be valid for ±6 hours about 0000 GMT and 1200 GMT.

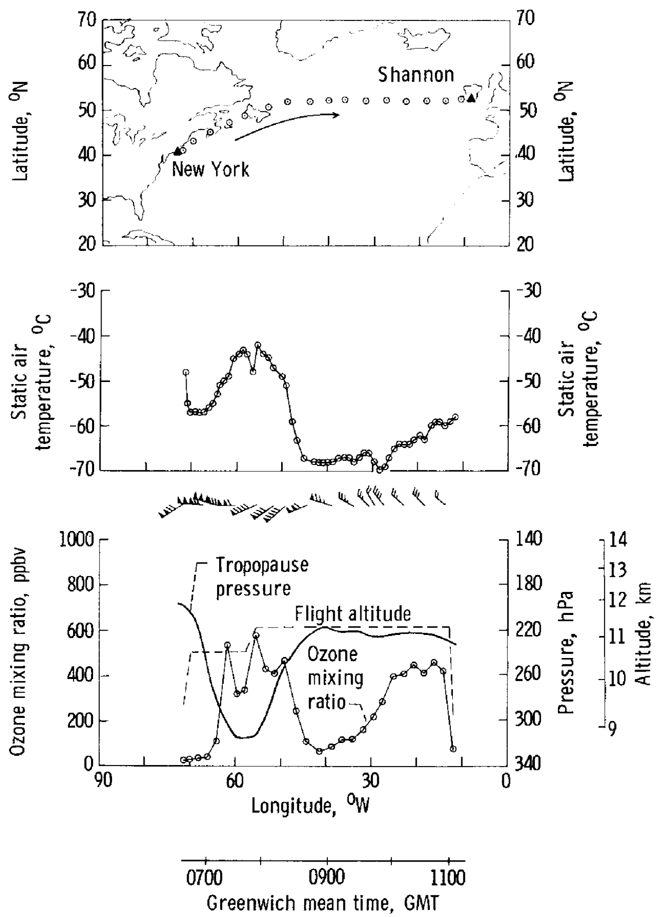

Figure 2. - Flight record of March 14, 1975, from New York to Shannon, Ireland. (See fig. 1 for details of procedure.)

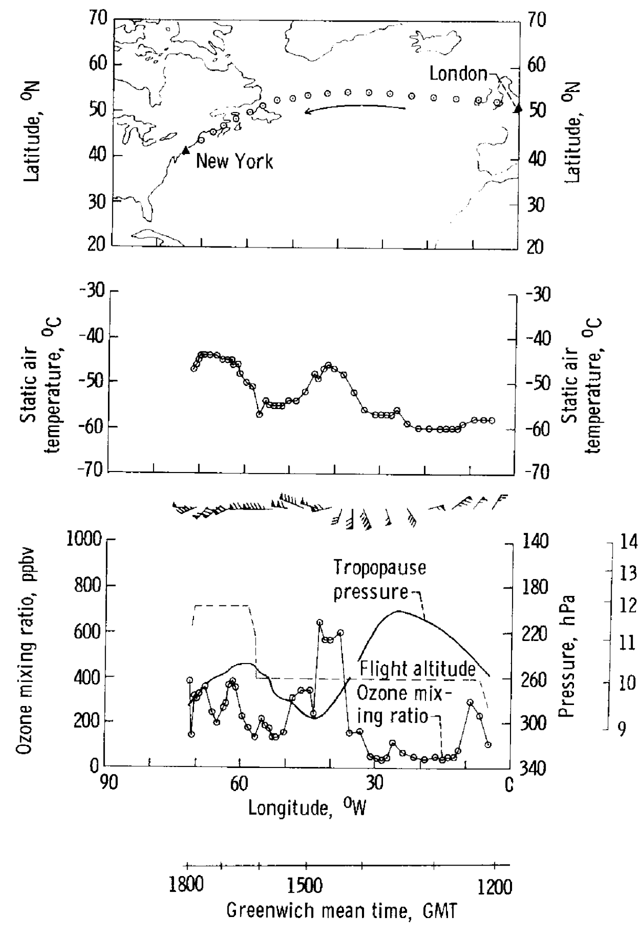

Figure 3. - Flight record of March 15, 1975, from London, England, to New York. (See fig. 1 for details of procedure.)

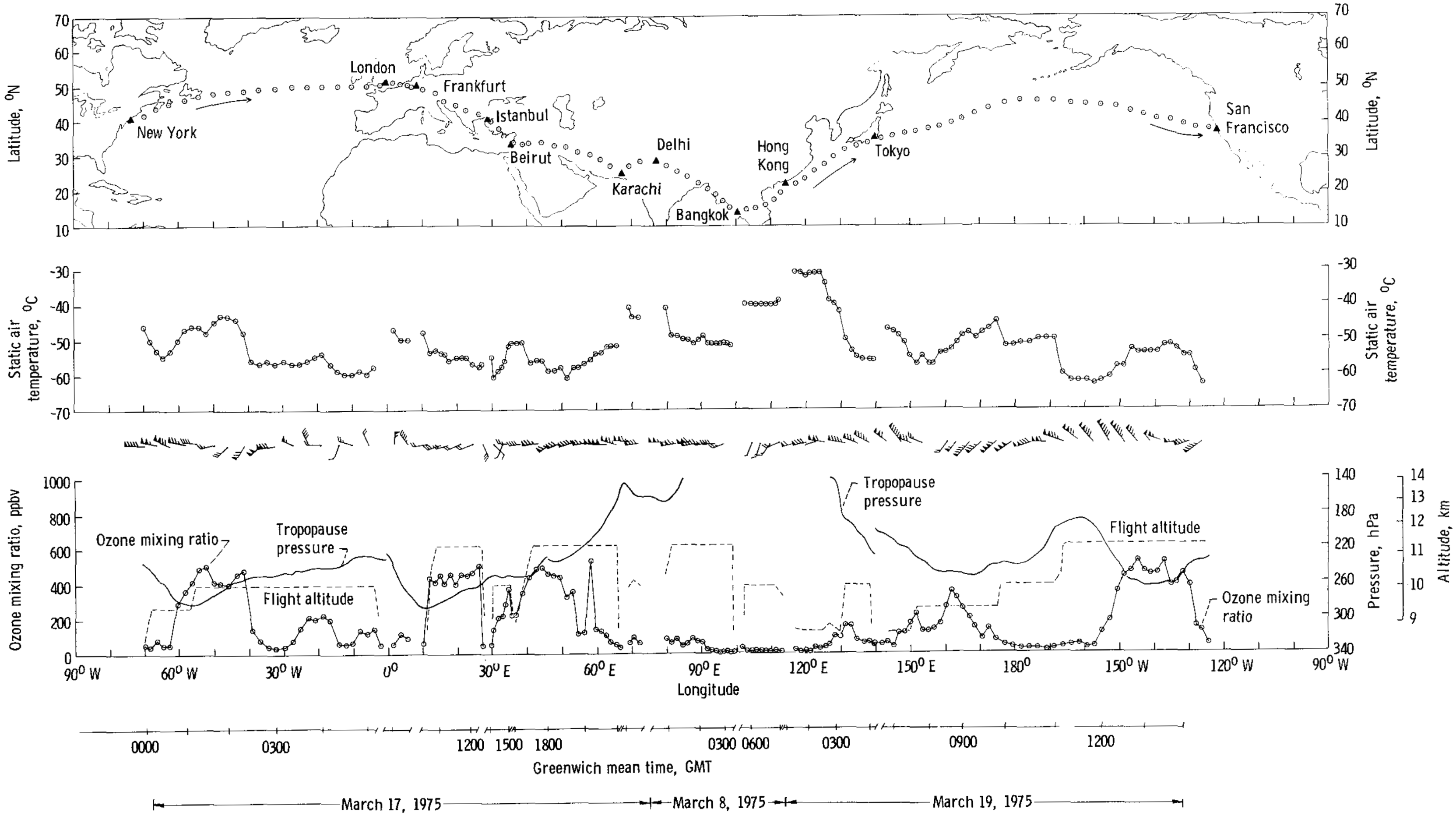

Figure 4. - Flight record of March 17-19, 1975, from New York to San Francisco. (See fig. 1 for details of procedure.)

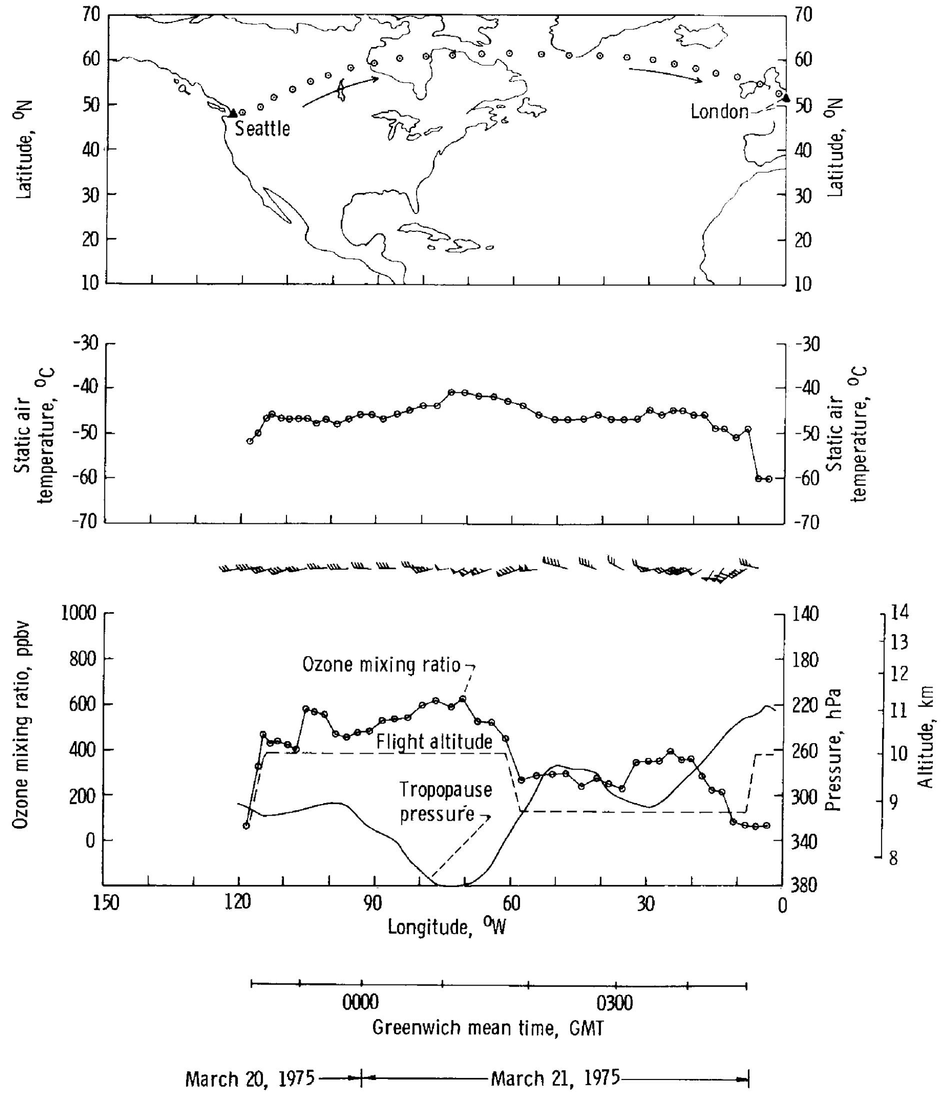

Figure 5. - Flight record of March 20-21, 1975, from Seattle to London, England. (See fig. 1 for details of procedure.)

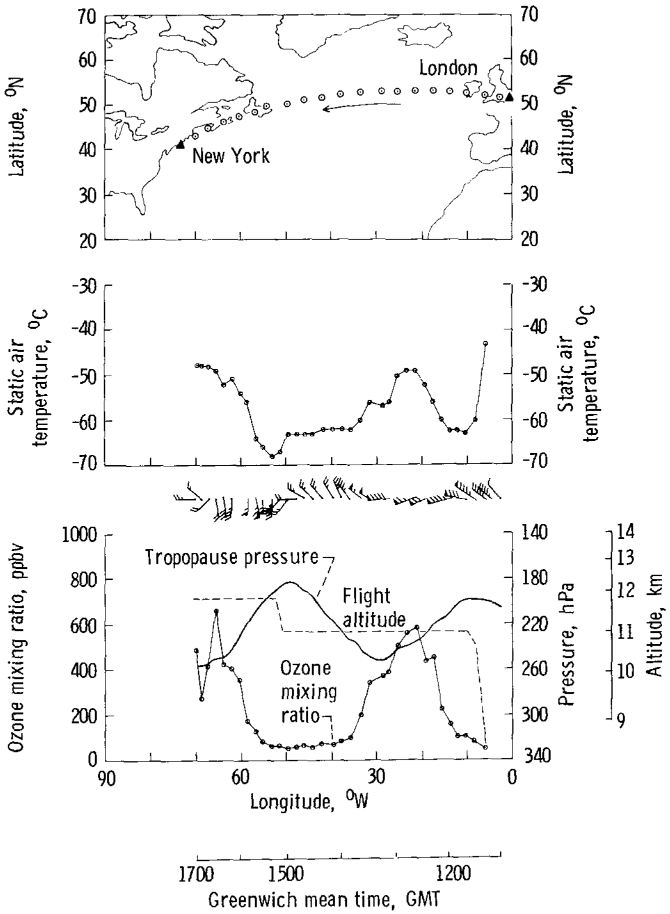

Figure 6. - Flight record of March 21, 1975, from London, England, to New York. (See fig. 1 for details of procedure.)

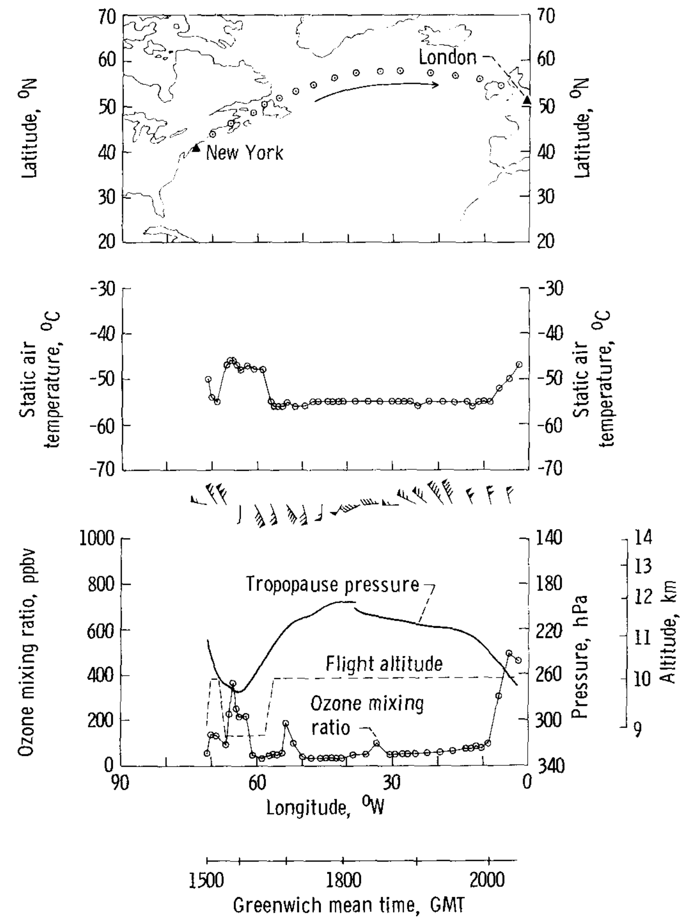

Figure 7. - Flight record of March 22, 1975, from New York to London, England. (See fig. 1 for details of procedure.)

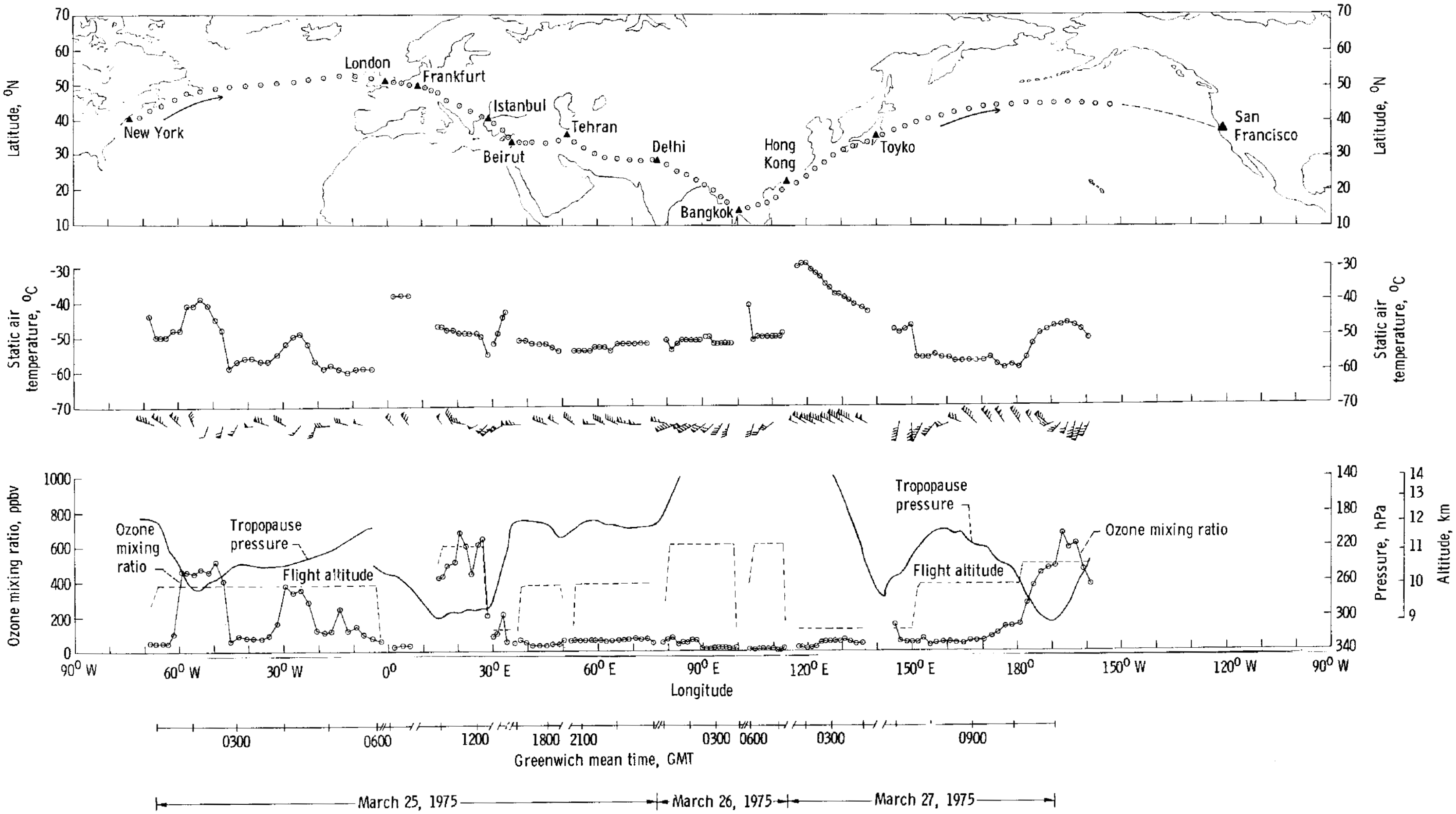

Figure 8. - Flight record of March 25-27, 1975, from New York to San Francisco. (See fig. 1 for details of procedure.)

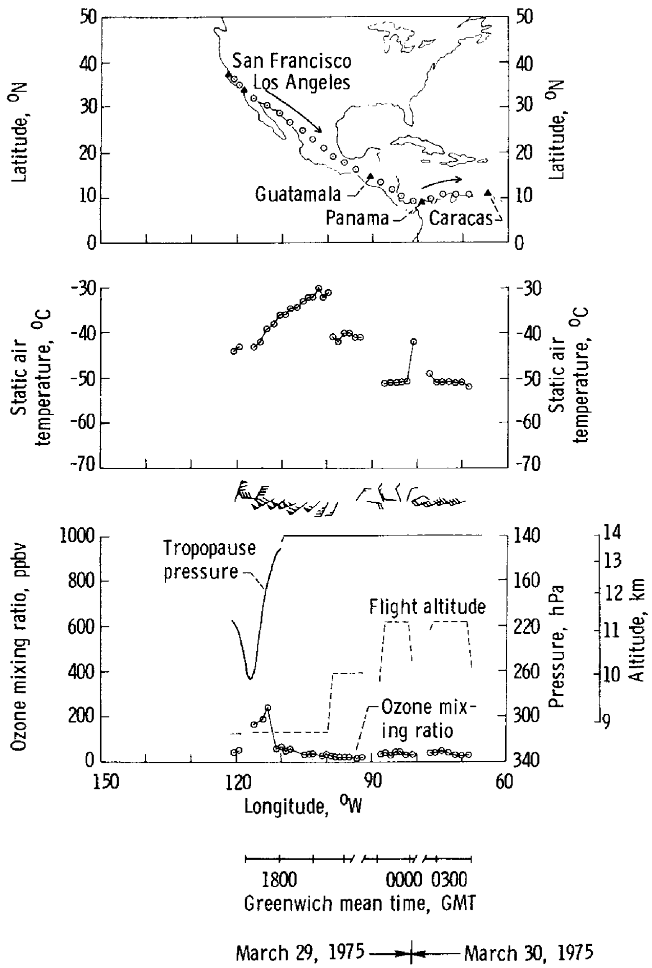

Figure 9. - Flight record of March 29-30, 1975, from San Francisco to Caracas, Venezuela. (See fig. 1 for details of procedure.)

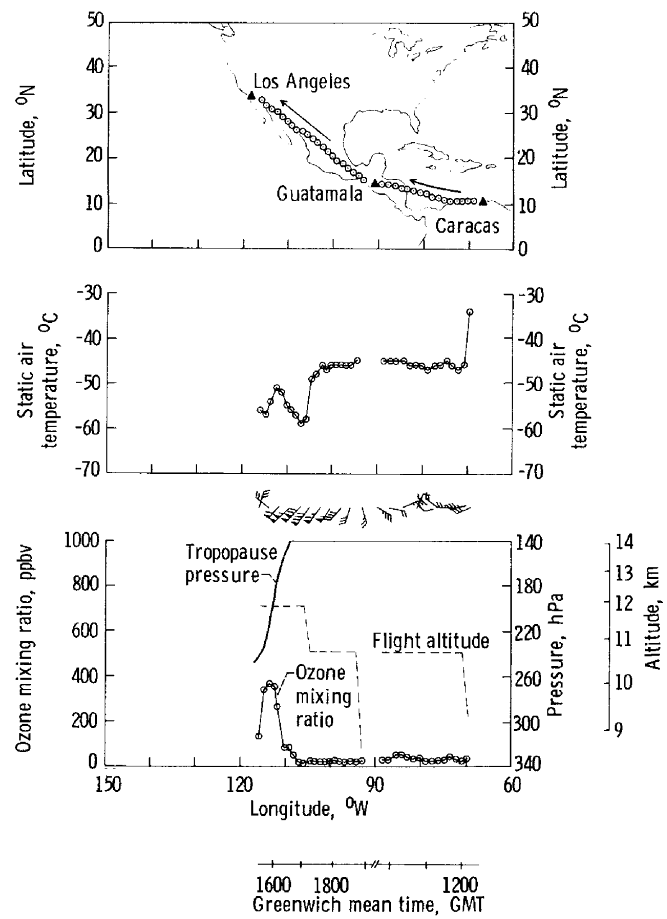

Figure 10. - Flight record of March 30, 1975, from Caracas, Venezuela, to Los Angeles. (See fig. 1 for details of procedure.)

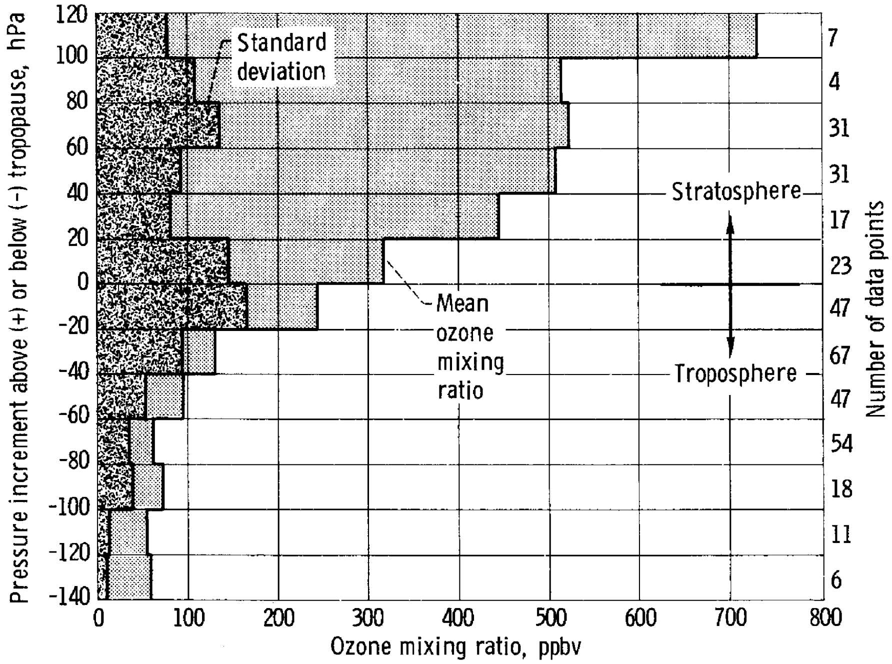

Figure 11. - Vertical ozone distribution in terms of difference between NMC tropopause pressure and aircraft pressure altitude.

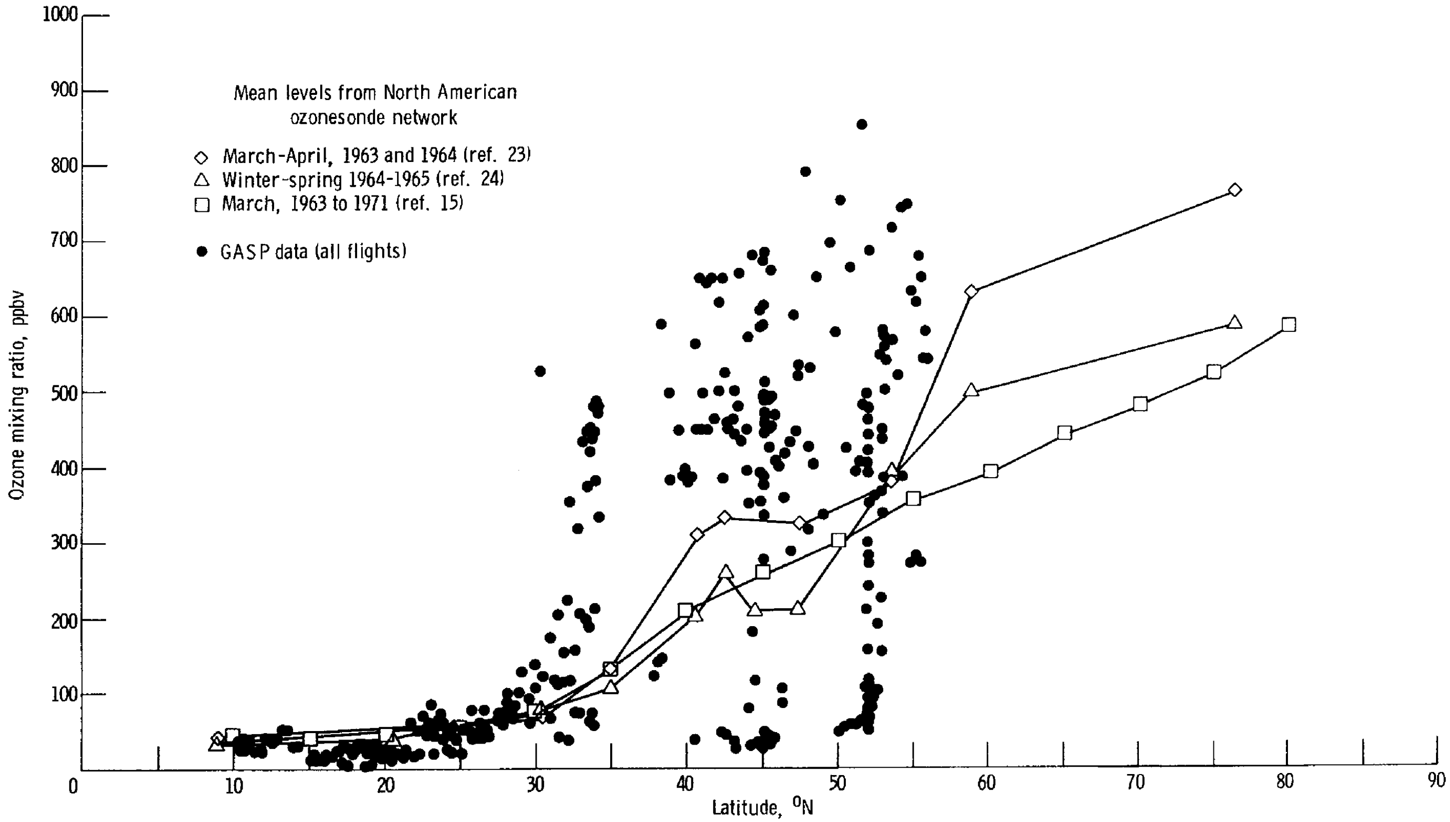

Figure 12. - Variation of ozone with latitude at altitude of 11±0.5 kilometers.