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PROGRAM OF RESEARCH AND MONITORING FOR EARLY DETECTION OF STRATOSPHERIC OZONE CHANGE

REPORT TO CONGRESS
OF
FINDINGS
FOR
1978 - 1979

AS REQUIRED BY
SECTION 126, OZONE PROTECTION, OF
PUBLIC LAW 95-95, THE CLEAN AIR ACT AMENDMENTS OF 1977

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INTRODUCTION

Section 126, on "Ozone Protection," of P.L. 95-95, the "Clean Air Act Amendments of 1977," which was enacted on August 7, 1977, requires that "The Administrator of the National Oceanic and Atmospheric Administration shall establish a continuing program of research and monitoring of the stratosphere for the purpose of early detection of changes in the stratosphere and climatic effects of such changes. Such Administrator shall on or before January 1, 1978, and biennially thereafter, transmit a report to the Administrator (of EPA) and the Congress on the findings of such research and monitoring." Significant components of the mandated program have been in progress in NOAA for several years and their findings over the 2-year period from January 1978 through December 1979 are reported here.

As part of its assigned mission responsibilities in Upper Atmospheric and Space Research, Global Monitoring of Climate Change, Basic Weather Analysis, and Environmental Modeling, NOAA and its predecessors have conducted modest programs of research and monitoring of the stratosphere for several decades. These programs have been increased since 1977, when national concern developed about the possible effects of chlorofluorocarbon releases and other pollutants on stratospheric ozone. Findings for the period 1978-1979 of the research and monitoring activities of the NOAA centers listed below are presented in the Summary of Findings.

NOAA's stratospheric research and monitoring activities are conducted in six of its centers as follows: The Aeronomy Laboratory, the Air Resources Laboratories, the Geophysical and Fluid Dynamics Laboratory, the Office of Research of the National Environmental Satellite Service, the Climate Analysis Center of the National Weather Service, and the Satellite Data Service Division of the Environmental Data and Information Service's National Climatic Center.

The Aeronomy Laboratory conducts stratospheric composition measurements, laboratory reaction kinetics measurements, model calculations, and atmospheric dynamics measurements.

The Air Resources Laboratories monitors erythemal ultraviolet radiation at the ground, operates the U.S. portion of the World Meteorological Organization Global Ozone Research and Monitoring Network, and is developing an improved stratospheric water vapor monitoring network.

The Geophysical Fluid Dynamics Laboratory conducts mathematical modeling on the dynamical, radiative and chemical processes of the troposphere, stratosphere and mesosphere, with particular attention to the climate effects of atmospheric and oceanic changes in the global environment.

The Office of Research of the National Environmental Satellite Service develops and evaluates NOAA programs for operational satellite measurements of stratospheric properties.

The Climate Analysis Center of the National Weather Service conducts analyses of stratospheric meteorological and ozone data from both ground-based and satellite measurement systems, utilizing data provided by all participating United States agencies.

The Satellite Data Service Division of the Environmental Data and Information Service's National Climatic Center archives the data from the operational satellites, and provides data to users and researchers upon request.

Individual presentations of the stratospheric research and monitoring activities of each of the above centers are incorporated in this report following the Summary of Findings, 1978-1979.

BACKGROUND

The National Oceanic and Atmospheric Administration and its predecessor organizations began systematic measurements of atmospheric ozone in the late 1950's. Total ozone measurements were included in the regular work of the four NOAA baseline stations, beginning in the early 1960's for Mauna Loa, Hawaii and South Pole, and in the mid-70's at Barrow, Alaska and Tutuila, American Samoa.

A network of stations for the specific purpose of monitoring ozone was established in 1963 in Bismarck, ND, Caribou, ME, and Nashville, TN, to which was added Boulder, CO in 1967. Three other stations were started which are no longer operated. In addition, NOAA began in the early 70's the coordination and processing of ozone measurements made by the National Aeronautics and Space Administration at Wallops Island, VA, the Army at White Sands, NM, Florida State University at Tallahassee, FL, and a cooperative station operated by the Peruvian Government at Huancayo, Peru.

The World Meteorological Organization (WMO) established in the mid-70's a Global Ozone Research and Monitoring Program in response to the perceived threat to the earth's ozone layer. Ozone provides the ultraviolet shield which permitted animal and plant life to emerge from the oceans and live on land in open daylight. The concern was voiced that the relationship among ozone, ultraviolet radiation and life may be fragile, and that any alteration of the stratospheric ozone abundance should be viewed with concern.

The immediate impact of the WMO program was to encourage all member nations to upgrade their ozone measuring stations, and to carry out intercalibrations essential to an international monitoring network. International intercomparisons were held at Aspendale, Australia in 1972, Belsk, Poland in 1974 and Boulder, United States in 1977. NOAA maintains the world standard, Dobson ozone spectrophotometer No. 83, at Boulder, CO. A program to upgrade and calibrate against the world standard Dobson spectrophotometers operated by the United States and by other nations has been carried out by NOAA, funded through contributions from the WMO, participating nations, and NOAA.

Continually created by photochemical reactions in the upper stratosphere, ozone is an unstable, highly reactive gas. As it is transported to the mid-and lower-stratosphere, it is destroyed by reactions with many other substances, most importantly those of the nitrogen, chlorine, and hydrogen families. There the ozone abundance is vulnerable to human actions which increase the amounts of these substances above the natural equilibrium level in the stratosphere. To understand the causes of changes in ozone concentrations, stratospheric sampling of these relevant constituents other than ozone must be undertaken in addition to ozone monitoring. NOAA instituted a program of balloon sampling of the stratosphere in 1975 to measure a number of these constituents. This program has been expanded to the Southern Hemisphere in recent years.

Natural variations in ozone include the poleward transport of ozone, resulting in an increase of ozone concentration from equator to pole, seasonal variation of as much as 25 percent in the temperate latitudes, shifts due to changes in solar activity, and local changes due to the passage of weather systems in the lower atmosphere. For these reasons monitoring requires measurement capabilities plus analysis techniques operated over a sufficiently long period of time to permit the removal statistically of the natural variations and detection of trend change which exceeds the natural variability.

Ozone monitoring as an early warning system faces a number of significant limitations. The National Academy of Sciences 1979 study on Stratospheric Ozone Depletion by Halocarbons: Chemistry and Transport states: "There is a time delay between halocarbon release and ozone destruction; the maximum ozone decrease actually occurs some 15 years after all release has stopped. Therefore, to be effective, an early warning system must be capable of detecting changes due to human activity in time to prevent the eventual maximum ozone decrease being greater than acceptable levels... it is unlikely that a Dobson network would within the next decade, be able to identify a reduction in global ozone....of less than 4 to 5 percent. The model predicts that such an ozone change will occur by about 1995....Model calculations have shown that the decrease in ozone concentration....is twice as great at 40 km as is the decrease in total ozone....Monitoring ozone concentrations at this altitude should therefore provide a more sensitive early warning system....At the time of writing, the satellites do not provide a superior system for trend analysis to the Dobson network but should be able to do so in the near future."

NOAA and NASA are now exploring the feasibility of establishing an operational satellite vertical ozone profile monitoring system. The ground-based Dobson ozone network plus rocket and balloon ozonesonde networks will continue to be needed for verification and calibration of the satellite measurements.

SUMMARY OF FINDINGS
1978-1979

The findings from NOAA's stratospheric research and monitoring program are applicable to issues of national concern in three broad areas: measurements from the worldwide ozone monitoring network, other measurements of significant stratospheric parameters and model calculations of stratospheric ozone behavior under continued chlorofluorocarbon release.

STRATOSPHERIC OZONE MONITORING

Findings from the Global Dobson Ozone Network

Under the aegis of the World Meteorological Organization (WMO), participating nations operate a global network of nearly 60 stations, of which NOAA operates the United States network of seven NOAA, one Army, one NASA, and one university station, plus a cooperative station at Huancayo, Peru, for a total of eleven.

Total ozone data from the global Dobson network have been collected and analyzed by the Angell-Korshover method (with variation expressed as a percentage deviation from the mean) for the period from 1958 through 1978 for each hemisphere and for the world.

In 1978 the indicated total-ozone amount in the Northern Hemisphere was below average for the first time in 11 years. The total ozone in the Northern Hemisphere is indicated to have decreased by 1.6 percent between 1977 and 1978. The large interannual variations since 1976 suggest an enhanced quasi-biennial effect. In the Southern Hemisphere the quasi-biennial variation in total ozone continues to be a dominant feature, but the total ozone values have not deviated significantly from the average during the past 10 years. For the world average the total ozone has varied by less than one percent since 1971, with the 1978 value above average by a non-significant 0.2 percent.

Crude estimates of ozone variations by height can be obtained from the small number of Dobson stations which take ozone profile measurements by the Umkehr method. Year-average values have been obtained for the north temperate latitudes only, this being the only climatic ozone with sufficient data for analysis. The data are analyzed for the height-layers 32-46 km and 24-32 km through 1977, the last year data was available.

In the critical 32-46 km layer, where photochemical modeling predicts the largest percentage of ozone decrease due to the effect of chlorofluorocarbons, the 1977 value is still a significant 3.5 percent above

average. Sharp decreases indicated in ozone for this layer following the volcanic eruptions of Agung and Fuego are believed to be errors introduced into the Umkehr method by aerosols of volcanic origin. The Umkehr data for the 24-32 km layer show no significant change in ozone amount since 1969. Ozonesonde data for the 24-32 km layer also suggest no significant overall change in ozone amount since 1969.

Satellite Total Ozone Derivations

An operational satellite system needs to be developed so that measurements from the same instrument can be obtained globally of stratospheric ozone values in the photochemical precursor region of 35-45 km altitude, thus obviating multiple instrument biases.

Currently, the NOAA operational Tiros N spacecraft are equipped with the Tiros Operational Vertical Sounder (TOVS). Subsystems of the TOVS measure atmospheric radiances in the infrared and microwave regions of the spectrum. One infrared channel of TOVS is designed specifically to measure radiation emitted by ozone at 9.6 micrometers. The ozone monitoring capability of TOVS was designed not as a primary data source, but as a correction input to the temperature profiling subsystem. The small influence of ozone on several of the TOVS channels is large enough to require correction and an on-board measurement capability was deemed justifiable for this purpose. However, the accuracy required for these corrections is less than desired for a primary global ozone satellite monitoring system so that the present operational project is considered to be an interim measure.

NOAA and NASA are working closely together to develop and qualify a satellite based system capable of performing operational monitoring of both the vertical profile and the total column value of ozone globally. Such a satellite operational ozone measurement program is planned for implementation in 1984.

STRATOSPHERIC WATER VAPOR MONITORING

New Instrument Development

Because of the influences of stratospheric water vapor on stratospheric ozone, as well as for other climatic reasons, monitoring of stratospheric water vapor is deemed important. With the collaboration of FAA and NASA, NOAA has developed and tested successfully in Wyoming and Brazil a new balloon-borne instrument for measurement of stratospheric water vapor. The instrument contains a hydrogen Lyman-alpha lamp whose short-wavelength ultraviolet radiation dissociates water vapor, and an optical system that measures radiation from the OH fragment.

The results from the Brazil flights have shown that the water vapor concentration reaches the local saturation point near the tropopause. This is an important finding, since the accepted theory suggests that most of the water vapor in the stratosphere arrives through vertical motion in the tropics, and that the tropical tropopause should limit the supply

through a freeze drying mechanism. The data tend to substantiate this argument, but the situation is not completely clear, since the water vapor mixing ratio continues to decrease with increasing height well into the lower stratosphere. This finding, together with the considerable amount of fine structure in the profile of water vapor, is a subject of continuing study, since oxides of hydrogen play a key role in the destruction of ozone.

MONITORING ERYTHEMAL ULTRAVIOLET RADIATION

With funding support from other federal agencies, NOAA has maintained a ground-based network of instruments to measure ultraviolet radiation from the sun over the past six years in collaboration with Temple University Medical School. These instruments measure the approximate wavelength range at which human skin sunburns, which, in turn, is thought to be similar to the wavelength range associated with skin cancer production.

The analysis of the observed change in erythemal ultraviolet radiation intensity with latitude relating to the corresponding change (decreasing equatorward) in stratospheric ozone abundance confirms that in the real world each 1 percent decrease in total ozone produces about a 2 percent increase in erythemal ultraviolet radiation.. The magnification factor is an important element in evaluation of the human and biological effects of a depletion of stratospheric ozone.

STRATOSPHERIC TEMPERATURE MONITORING

Monitoring of stratospheric temperature is important because of the cooling of the stratosphere associated with both a decrease in ozone and an increase in carbon dioxide. The cooling from carbon dioxide may well mask the additional cooling effects on stratospheric temperatures of ozone depletion. Indeed, because the stratospheric cooling should be considerably greater than the tropospheric warming, it is the stratosphere that might provide the earliest warning of a CO_2 effect. Changes, expressed in terms of deviation from the long-term mean in degrees Celsius, are based on radiosonde data.

In the Northern Hemisphere the lower stratosphere was unusually cold during 1977 and 1978, with 1978 the second coldest year of record. In the Southern Hemisphere, there is evidence of a diminution in the cooling apparent since the volcanic eruption of Agung. In the global average, 1977 and 1978 were the second and third coldest years of record, a significant $0.7^{o}C$ and $0.5^{o}C$ below average respectively.

STRATOSPHERIC CONSTITUENT MEASUREMENTS

Balloon Sampling

A balloon sampling program was initiated in NOAA's Aeronomy laboratory in 1975, aimed at measuring the stratospheric concentrations of the chlorofluoromethanes (CFM'S)(F-11 ($CFCl_3$) and F-12 (CF_2Cl_2)) and nitrous oxide (N_2O), the constituents involved in the principal anthropogenic and natural loss mechanisms for stratospheric ozone.

In 1978-79 the program of balloon measurements was extended spatially, with flights from Wyoming, Antarctica, and Brazil. This is the only data base that has provided at least the outline of a global distribution for these stratospheric constitutents. Sampling techniques have been improved to provide an increased height resolution. Measurements have also been extended to include other minor constituents of the stratosphere, including methane (CH_4) and methyl chloroform ($CH_3\ CCl_3$). This has led to a greatly improved understanding of the global distribution of the CFM's and of N_2O, from which the magnitude of the interhemispheric transport can be obtained.

Absorption Spectroscopy

Absorption spectroscopy has been used to study the characteristics of stratospheric NO_2 on a global basis , using ground-based, shipboard, and airborne measurements. A sharp decrease in NO_2 column abundance occurs at high latitudes during the winter in both northern and southern hemispheres. The same technique has been applied to measure the abundance of nitrogen trioxide (NO_3) in the atmosphere, and this important transient species has been detected for the first time . The technique distinguishes between stratospheric and tropospheric NO_3, and interpretation of the measurements has revealed significant discrepancies from theoretical predictions.

MODEL CALCULATIONS OF STRATOSPHERIC OZONE BEHAVIOR UNDER CONTINUED CHLOROFLUOROCARBON RELEASE

1-D Photochemical Models

The NOAA Aeronomy Laboratory's 1-D models to predict the behavior of stratospheric ozone have been continuously updated as new information has become available from direct stratospheric observations or from laboratory measurements of chemical reaction rates. Many of the important chemical reactions that take place in the stratosphere involve transient and highly reactive radical species, and sophisticated techniques are needed to measure the rates of the reactions in the laboratory. One such technique, known as laser magnetic resonance, was developed by NOAA in cooperation with the National Bureau of Standards, and has been used to study reactions involving the HO_2 radical. The temperature dependence of the rate of reaction of HO_2 with chlorine monoxide (ClO) has been measured , and the same technique has been used to measure the rate of the HO_2 reaction with ozone. Insertion of these new reaction rates in the existing NOAA one-dimensional photochemical model has improved the agreement between computed ozone concentrations and observed values, and has led to a new estimate of the reduction of column ozone abundance due to a constant emission at the 1975 rate. The previously calculated reduction of 14% is now increased to 18% . The corresponding ozone column reductions due to supersonic-transport injection of NO_x and to a doubling of the N_2O level (a possible result of vastly increased use of agricultural fertilizers) are negligibly small.

Changes in the stratosphere and the climatic effect of such changes cannot be detected or understood unless the normal state and the physical processes which maintain that normal state are known in detail. The requisite detailed knowledge is not in hand at the end of 1979. Considerable emphasis must be given to a continuing program of research for a number of years to come. The stratospheric research performed at NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) at Princeton for the period 1978-1979 builds on the considerable research base constructed prior to that date.

Improvements to the 40-level General Circulation Model (GCM)

During the past two years, work continued on adding various improvements on the physical processes included in the GFDL 40-level troposphere-stratosphere-mesosphere GCM. This model now possesses the capability to add 3 new dependent variables to allow a self-consistent calculation of ozone. To achieve this, a collaborative effort was undertaken with scientists from the Aeronomy Laboratory. Their chemical model has been converted to the GCM coordinate system and conversion to run efficiently on the GFDL computer has begun. In preparation for this task, a single tracer passive run has been successfully completed in the GCM to test for model accuracy.

Tracer Transport Studies Using GCM Winds

One of GFDL's global 3-D general circulation models has been used to provide self-consistent time-dependent winds for investigating a number of problems dealing with transport of trace constituents.

Analysis has been completed on two preliminary 3-D ozone tracer experiments. The first experiment ("Simple Ozone") introduces a partially simplified ozone photochemistry in the middle stratosphere. The second experiment ("Stratified Tracer") simply prescribes a constant value for the mixing ratio of ozone in the middle stratosphere. In both experiments the ozone is assumed to be inert in the lower stratosphere, while it is removed in the lower troposphere.

Evaluation of the Assessment Capability of the WMO Global Dobson Spectrophotometer Network

Results from the "Simple Ozone" experiment were used to evaluate the capability of the WMO Global Dobson Total Ozone Network to provide meaningful assessments of global means and trends. Since the 1978 report, new analysis has been carried out to evaluate, by collecting statistics on random networks of various sizes, the probable reduction of error to be expected for increases in network size. These results show that the current Dobson network exhibits about the same sampling skill as that of

random networks of similar size. The random network analysis also indicates that network sizes greater than 100 well chosen stations are probably not necessary. Also, an effort to examine a possible effect of "fair weather" sampling bias on total ozone measurements has led to the result that while some systematic error is produced, the effect is smaller than that introduced by spatial and temporal sampling limitations.

Low Resolution Annual Mean Model Experiment

The 40-level GCM low resolution model designated N10 (9° latitude by 10° longitude) has been run for 720 days to a state of near statistical equilibrium. This calculation employs annual mean insolation, prescribed clouds, prescribed ozone below 34km, and a fixed sea surface temperature.

An especially interesting feature of this experiment is the presence of time varying equatorial stratospheric zonal winds on time scales of 2-3 years. The westerly phase appears to be produced by a vertical eddy momentum flux convergence. These results lead to an optimism that this model contains the requisite processes for simulating the quasi-biennial oscillation.

Low Resolution Ozone Reduction Experiment

The dynamical responses throughout the entire stratosphere and the climatic alteration near the earth's surface to a large reduction in ozone amount are not clear at this time. As a means of helping to formulate a longer term research strategy for attacking these problems, a preliminary 40-level GCM low resolution (N10) experiment has been run from day 500 to day 720, assuming a uniform 50% ozone decrease and annual mean insolation.

The zonal mean temperature in this experiment shows a number of features which agree reasonably well with radiatively predicted changes. For example, substantial global mean cooling of about 23^{o} K occurs in the model upper stratosphere and lower mesosphere. Considerably smaller mean cooling is calculated elsewhere, amounting to about 6-8^{o} K from 18-40 km, and ranging from 1-6^{o} from 7-18 km. Although changes were observed in the lower troposphere, further work is needed to assess their physical and statistical significance.

Another important model effect of the 50% reduced ozone is that the stratopause height falls by about 6 km, while the tropical tropopause height rises by 1-2 km.

In the ozone reduction experiment, there were found to be two exceptions to the above rule that the total response is predominantly radiative. The additional effects of a dynamical response was found to be important in the tropical mesosphere and in the vicinity of the tropical tropopause, apparently due to the onset of inertial instability and strongly altered wave activity, respectively, in the two regions. In addition, the temperature near the tropical tropopause was found to be rather sensitive to dynamical

changes because the infrared heating rate there is rather insensitive to temperature. This suggests that the stratospheric water vapor content could change substantially in response to otherwise modest stratospheric climate perturbations.

SYNOPTIC OZONE ANALYSIS

NOAA's Climate Analysis Center has developed a program of ozone analyses and research including stratospheric meteorological analyses.

Daily and monthly mean synoptic maps of total ozone for 1970-71 have been produced during 1979 from the Backscatter Ultraviolet (BUV) ozone measurement system aboard the NASA Nimbus 4 spacecraft.

SATELLITE DATA ARCHIVING

Daily output from both the Tiros-N prototype and NOAA-6 operational spacecraft typically amounts to 7,000 to 8,000 soundings derived from the three Tiros Operational Vehicle Sounder (TOVS) sensors (Microwave Sounding Unit, Stratospheric Sounding Unit, and High Resolution Infrared Radiation Sounder). These data are archived on magnetic tape on a weekly basis (7 days per tape) by the Satellite Data Services Division of the Environmental Data and Information Service's National Climatic Center. Each sounding contains layer mean temperatures, precipitable water amounts, tropopause parameters, cloud cover, measured radiances, and total ozone amounts in Dobson units. The TOVS sounding tapes are available from January 1, 1979.

AERONOMY LABORATORY

There are many individual aspects that must be understood and combined in order to reach a comprehensive understanding of stratospheric behavior. The concentrations of a number of natural and anthropogenic chemical species must be known, including their temporal and spatial variabilities. This leads to a requirement for stratospheric chemical composition determinations, in some cases for species occurring in extremely low concentration. The photochemistry of the atmosphere must be known in order to assess the influence of changes in atmospheric composition on the ozone layer. This requires sophisticated laboratory reaction rate measurements. The motions and transport of atmospheric species influence their atmospheric transport processes. Measurements of atmospheric diffusion, turbulence, temperature, and wind fields are required.

The data on atmospheric composition, photochemical reaction kinetics and transport must be incorporated into theoretical models, which serve as the tools for predicting future effects. The whole stratospheric research program in a sense is an effort to refine and sharpen these tools.

During 1978 and 1979 the Aeronomy Laboratory carried out active programs in all of these areas of stratospheric research, the central theme being provided by the problem of stratospheric ozone. The stratospheric ozone layer affects man and his activities in both direct and indirect ways. Ozone absorbs nearly all of the harmful ultraviolet radiation from the Sun that would otherwise irradiate the surface of the Earth and its living organisms, and it also plays a role in the radiation balance of the earth-atmosphere system , thereby helping to determine the parameters of global climate. In addition, the heat generated locally in the stratosphere by absorption of solar radiation provides the principal driving force for stratospheric wind systems, and thus controls the climate of the stratosphere itself. The potential consequences of a change in stratospheric ozone are thus a matter of serious practical concern, and the stratospheric program of the Aeronomy Laboratory is directed toward elucidating the various factors that determine the ozone concentration.

I. STRATOSPHERIC COMPOSITION MEASUREMENTS

In Situ Measurements. The principal natural loss mechanism for stratospheric ozone is through catalytic reaction with nitric oxide (NO), which is in turn produced mainly by reaction of excited oxygen atoms with nitrous oxide (N_2O). The principal anthropogenic loss mechanism for ozone is thought to be through catalytic reaction with chlorine atoms released by sunlight from the chlorofluoromethanes F-11 ($CFCl_3$) and F-12 (CF_2Cl_2), which are used as refrigerants and as spray can propellants. A balloon sampling program was initiated in the Aeronomy Laboratory in 1975, aimed

at measuring the stratospheric concentrations of both the CFMs and N_2O. The challenge was great, since the program called for measurements of concentrations in the range of parts per trillion (10^{-12}). The initial results had a major impact on the field.[1]

In 1978-79 the program of balloon measurements was extended, with flights from Wyoming, Antarctica, and Brazil. This is the only data base that has provided at least the outline of a global distribution for these stratospheric constituents, and the sampling techniques have been improved to provide an increased height resolution. Measurements have also been made of other minor constituents of the stratosphere, including methane (CH_4)[2] and methyl chloroform (CH_3CCl_3). Since the photochemical loss rate for N_2O in the stratosphere is known, the N_2O measurements can be used to determine average vertical transport rates in the atmosphere, and thus calculate the 'eddy-diffusion' coefficient that is required for model calculations. The extensive measurements have led to the accumulation of a substantial amount of information on vertical eddy-diffusion coefficients and their variability.

An instrument for measuring stratospheric water vapor has been developed and flown successfully in Wyoming and Brazil.[3] The instrument contains a hydrogen Lyman-alpha lamp whose short wavelength ultraviolet radiation dissociates water vapor, and an optical system that detects radiation from the OH fragment. The data obtained in Wyoming have confirmed earlier estimates of the stratospheric water-vapor concentration of a few parts per million (ppm), and the results from Brazil have shown that the water-vapor concentration reaches the local saturation point near the tropopause. This is an important point, since the accepted theory suggests that most of the water vapor in the stratosphere arrives through vertical motion in the tropics, and that the tropical tropopause should limit the supply through a 'cold-trapping' mechanism. The data tend to substantiate this argument, but the situation is not clear, since the water-vapor mixing ratio continues to decrease with increasing height well into the lower stratosphere. In all of the flights, a considerable amount of fine structure in the altitude profile of water vapor has been observed. The origin of this structure remains obscure and is a subject of continuing study.

Minimum water-vapor mixing ratios were found to lie 2-3 km. above the tropopause in both mid-latitude (Laramie, Wyoming) and low-latitude (Quixeramobin, Brazil) locations. The minimum values found were respectively 2.6 and 3.6 parts per million by volume. Simultaneous measurements of ozone made on the same flights revealed regions of both correlation and anti-correlation between ozone and water-vapor concentrations. Measurements have been made of the nitrogen oxides NO and NO_2 in the troposphere with a view to understanding the 'clean air' chemistry of these important components of the ozone cycle.

Remote Spectroscopic Measurements. A major development in our knowledge of the distribution of nitrogen oxides in the stratosphere took place in the Aeronomy Laboratory through the use of ground-based spectroscopic measurements. The technique is basically very simple, and involves measurement of the intensity of sunlight or moonlight in a region of the spectrum that is subject to absorption by nitrogen dioxide (NO_2). Comparison with intensities in neighboring regions that are free of absorption then determines the column density of NO_2 in the atmosphere along the line of sight.

This technique has been applied to determine the diurnal, seasonal, and latitudinal variation of stratospheric NO_2 by means of a series of measurements carried out at a fixed location near Boulder, and also in a number of mobile platforms, including jet aircraft (in cooperation with the Air Force Geophysics Laboratory) and a ship (in cooperation with the National Science Foundation). The NO_2 concentration has been found to vary markedly with meteorological conditions, and to show a strong correlation with the large-scale stratospheric circulation pattern.[6] Substantial changes are associated with stratospheric warming events. Automated instruments were installed at a number of stations in collaboration with NOAA's GMCC program, and measurements made at Barrow, Alaska, have confirmed earlier conclusions from aircraft observations concerning the high-latitude behavior of stratospheric NO_2. In winter, NO_2 concentrations within the polar vortex become very low, and the transition between these low values and the more normal midlatitude values occurs very abruptly as the observation point moves to lower latitudes. Measurements made onboard a ship sailing northward up the South American coast have shown clearly that NO_2 behaves in the same way in both Northern and Southern Hemispheres during the local winter.

Recently a similar technique has been applied to measure nitrogen trioxide (NO_3), which is another important member of the family of nitrogen oxides. Concentrations of NO_3 are much smaller than those of NO_2, so that the measurement is considerably more difficult, and the results have shown some unexpected features. For example, NO_3 reaches its maximum stratospheric concentration in the spring, contrary to theoretical expectations. Tropospheric NO_3 concentrations are much lower than expected. There are obviously unexplained anomalies in the behavior of NO_3 that are likely to have important implications for our understanding of the chemistry of nitrogen oxides in the atmosphere.[7]

A long series of measurements of the hydroxyl radical, OH, has been obtained at a location near Boulder by the use of spectroscopic techniques. The OH radical is a species of critical importance to stratospheric chemistry, but relatively few measurements of its concentrations have been made. The observations carried out in Boulder should provide the first indication of the temporal variability of stratospheric OH.

II. LABORATORY KINETICS MEASUREMENTS

The photochemistry of the stratosphere is highly complex, and involves a very large number of chemical reactions. In order to understand and predict the composition of the stratosphere, it is essential that the rates of the important reactions be known, and the only reliable method of deducing reaction rates at present is to measure them in the laboratory. The Aeronomy Laboratory has had a leading position in laboratory reaction-rate measurements for many years, and within the past few years the program has been directed toward measurement of the reactions of importance to stratospheric photochemistry.

In particular, a new technique known as laser magnetic resonance has been developed in cooperation with scientists from the National Bureau of Standards, and has been applied to measuring the rates of reactions involving unstable radicals for which information has been almost completely absent. The first spectacular result was the measurement of the rate of the reaction of NO with the perhydroxyl radical, HO_2, which had a major impact on estimates of the amount of ozone depletion caused by aircraft emissions and by chlorofluorocarbons. More recently study of HO_2 reactions has been extended, and the rate of the reaction with O_3 has been measured, together with a determination of the temperature variation of the HO_2 + NO reaction. The LMR technique has also been used to study reactions involving the ClO radical, which produces the stable compound HOCl through reaction with HO_2. The temperature dependence of the rate of reaction of HO_2 with chlorine monoxide (ClO) has been measured.[4]

Recent studies of thermal energy positive and negative ion reactions with N_2O_5 have led to a new technique for measuring N_2O_5 reactions, using chemical ionization mass spectrometry. The thermal decomposition rate of N_2O_5 has been measured over a wider temperature range (268 to 370 K) than had previously been attained. Its value at low temperature is especially important, since N_2O_5 is a significant reservoir species for odd nitrogen in the stratosphere.

III. MODEL CALCULATIONS

The Aeronomy Laboratory has played a leading role in the development and use of atmospheric models to predict the behavior of stratospheric ozone. Calculations have been made and published concerning the potential effects of stratospheric aircraft, nitrogen fertilizers, and CFM release. These calculations have been continuously updated and improved as new information becomes available from direct stratospheric observations or from laboratory measurements of chemical reaction rates. Active steps are now underway to incorporate realistic atmospheric dynamics and radiative effects in these models. Insertion of the new reaction rates in the existing NOAA 1-D photochemical model has improved the agreement between computed and observed ozone concentrations, and has led to a new estimate of the reduction of ozone column abundance due to a constant rate of CFM emission at the 1975 rate. The previously calculated value of 14 percent is now increased to 18 percent.

IV. ATMOSPHERIC DYNAMICS MEASUREMENTS

The Aeronomy Laboratory's expertise in the field of radar backscatter measurements of ionospheric motions has been applied to the problem of measuring the neutral-air motions associated with winds and waves in the stratosphere. A program of atmospheric measurements is being carried out at Sunset, Colorado, applying techniques developed earlier at the Jicamarca Radio Observatory in Peru. A more extensive development is now underway at Poker Flat, Alaska, with the cooperation of the National Science Foundation. The objective is to construct a dedicated radar facility that will be capable of probing the entire atmosphere from the troposphere to the lower thermosphere, including the entire stratosphere. This MST (mesosphere-stratosphere-troposphere) radar will yield unique data on the atmospheric transport of chemical species, and will greatly improve our understanding of the ways in which minor atmospheric constituents are carried into and out of the ozone layer.

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AIR RESOURCES LABORATORIES

I. Monitoring Erythemal Ultraviolet Radiation at the Ground

With partial financial support by the Department of Transportation, the Department of Health, Education and Welfare, the National Aeronautics and Space Administration, and, most recently, the Environmental Protection Agency, NOAA has maintained a network of instruments to measure ultraviolet radiation from the sun during the past six years in collaboration with the Temple University Medical School. The location of the existing stations in the network appears in Figure 1. The instrument responds to sunlight in approximately the same wavelength range that human skin sunburns which, in turn, is thought to be similar to the wavelength range associated with skin cancer production. In addition, special Dobson spectrophotometers (the instruments used to measure total ozone) were modified to respond to erythemal solar radiation, and were operated at Bismarck, ND, and Tallahassee, FL from 6-73 to 2-75. An analysis of the response of the network sensors with the modified Dobson instruments confirms the dependence of the ratio of their readings upon the elevation of the sun above the horizon.

The observed change in erythemal ultraviolet radiation intensity with latitude relates to the corresponding change in stratospheric ozone content in agreement with theory even though the theory was based on clear sky conditions whereas the observations were taken for all cloud covers. The resulting so-called magnification factor is: a 1 percent decrease in total ozone produces about a 2 percent increase in erythemal ultraviolet radiation. The predicted effects of turbidity (atmospheric dustiness), cloud cover, and ground reflectivity (grass, soil, snow, etc.) in modulating the erythemal ultraviolet radiation have also been demonstrated in the real world. Finally, a climatology of radiation at a number of sites has been obtained and analyzed. The results continue to show surprisingly little year-to-year variability. The amount of ultraviolet radiation increases southward as expected, but the role of cloudiness shows up very markedly, e.g., stations with more clouds at the same latitude have less radiation.

II. Upgrading the Global Dobson Spectrophotometer Total Ozone Station Network

Dobson spectrophotometer total ozone observations have played an important role in recent years in ozone trend analyses. Such observations are now used in providing "ground-truth" data for ozone measurements made by satellite-borne instrumentation. The surface network is shown in Figure 2.

Since 1977, NOAA worked with the World Meteorological Organization (WMO) Global Ozone Research and Monitoring Program to intercalibrate regional and primary standard Dobson spectrophotometers, and to modernize and calibrate selected foreign spectrophotometers in order to upgrade significantly the quality of observations obtained by the global total ozone Dobson spectrophotometer station network.

The International Intercomparison of Dobson spectrophotometers, co-sponsored by NOAA and the WMO was held at the NOAA Laboratories in Boulder, CO, during August 1977. Since that time, the secondary standards from the Boulder comparison have been used in subsequent intercomparisons--Arosa, Switzerland and Potsdam, GDR.

During 1978 and 1979, Boulder personnel continued to participate in global ozone monitoring and research to upgrade the quality of the Dobson spectrophotometer throughout the world. Instruments which were reconditioned and calibrated against the world standard #83 housed in NOAA include Mexico City, Mexico; Natal, Brazil; Lenningrad, USSR; Manila, Phillipines; and Boulder, CO, USA.

III. Ozone Monitoring

Because of the possible impact of fluorocarbons and other anthropogenic emissions on the earth's ozone shield, the monitoring of total ozone (the total amount of ozone in a vertical column above the surface) is of importance. Total-ozone data are being monitored for the five data regions in north temperate latitudes with adequate coverage (North America, Europe, Soviet Union, Japan and India), and also for the other climate zones, both hemispheres and the world. Figure 3 shows the variation in year-average total ozone from 1958 through 1978 for hemispheres and world, expressed as a percentage deviation from the mean. The vertical bars are confidence limits such that there is only about a 5 percent chance that the true value of the mean lies outside the vertical extent of these bars.

In 1978 the indicated total ozone amount in the Northern Hemisphere was below average for the first time in 11 years. The total ozone in the Northern Hemisphere is indicated to have decreased by 1.6 percent between 1977 and 1978. The large interannual variations since 1976 suggest an enhanced quasi-biennial effect. In the Southern Hemisphere the quasi-biennial variation in total ozone continues to be a dominant feature, but the total-ozone values have not deviated significantly from average during the past 10 years. In the global average the total ozone has varied by less than one percent since 1971, with the 1978 value above average by a non-significant 0.2 percent.

Photochemical modelling predicts that the largest percentage of ozone depletion from fluorocarbon emissions would occur near the 40 km level and hence any anthropogenic effect should be first noted near the 40 km level. Crude estimates of the ozone variations at these heights can be obtained by the Umkehr method, and Figure 4 shows year-average values obtained by this method for north temperate latitudes, this being the only climatic zone with adequate data (observations in Europe, Japan and India). The data are presented for height-layers 32-46 km and 24-32 km. High-level ozonesonde data are also presented for comparison with the 24-32 km Umkehr data, based on observations in North America, Europe and Japan.

In the critical 32-46 km layer the indicated decrease in ozone following the eruptions of Agung and Fuego is believed to be mostly fictitious and due to errors introduced into the Umkehr method by aerosols of volcanic origin. The magnitude of the ozone increase since Fuego (presumably due to fallout of the volcanic aerosols) implies that there has been little if any actual ozone decrease in this layer since 1970, with the 1977 value still a significant 3.5 percent above average. The Umkehr data for the 24-32 km layer are characterized by great consistency, as shown by the small length of the vertical bars. In this layer, where the aerosol effect on the measurements is apparently small, there has been no significant change in ozone amount since 1969. Ozonesonde data for the 24-32 km layer also suggest no significant overall change in ozone amount since 1969, but with an anomalous alteration in 1972 and 1973.

IV. Temperature Monitoring

Monitoring of stratospheric temperature is important because of the cooling to be associated with an increase in carbon dioxide. Indeed, because the stratospheric cooling should be considerably greater than the tropospheric warming, it is the stratosphere that might provide the earliest warning of a CO_2 effect.

Temperatures in the 16-24 km layer (low stratosphere) are being monitored for the 7 climatic zones, both hemispheres, and the world, based on radiosonde data. Figure 5 shows the variation in year-average temperatures from 1958 through 1978 for hemispheres and world, expressed as a deviation from the mean in degrees Celsius. In the Northern Hemisphere the lower stratosphere was unusually cold during 1977 and 1978, with 1978 the second coldest year of the record. In the Southern Hemisphere, however, there is evidence of a diminution in the cooling apparent since the eruption of Agung. In the global average, 1977 and 1978 were the second and third coldest years of record, a significant 0.7°C and 0.5°C below average, respectively. It is still uncertain to what extent the intermittent cooling in the low stratosphere since 1964 represents a return to "normal" following the low-stratospheric warming due to the Agung eruption.

V. Water Vapor Monitoring

Because of the possible influence of stratospheric water vapor amount on ozone amount, as well as for other climatic reasons, it is also important to monitor stratospheric water vapor. The only long-term record of stratospheric water vapor is that obtained by Mastenbrook at Washington, D.C. The development of a technique for measuring stratospheric water vapor concentration by dissociative fluorescence, and the construction and testing of a new instrument by the Aeronomy Laboratory has provided a basis for transferring the stratospheric water vapor program to Boulder, Colorado and transitioning the instrumentation and monitoring from the Washington site to Boulder. In 1979 training of personnel for this monitoring program was completed and new flight instruments procured.

FIGURE CAPTIONS

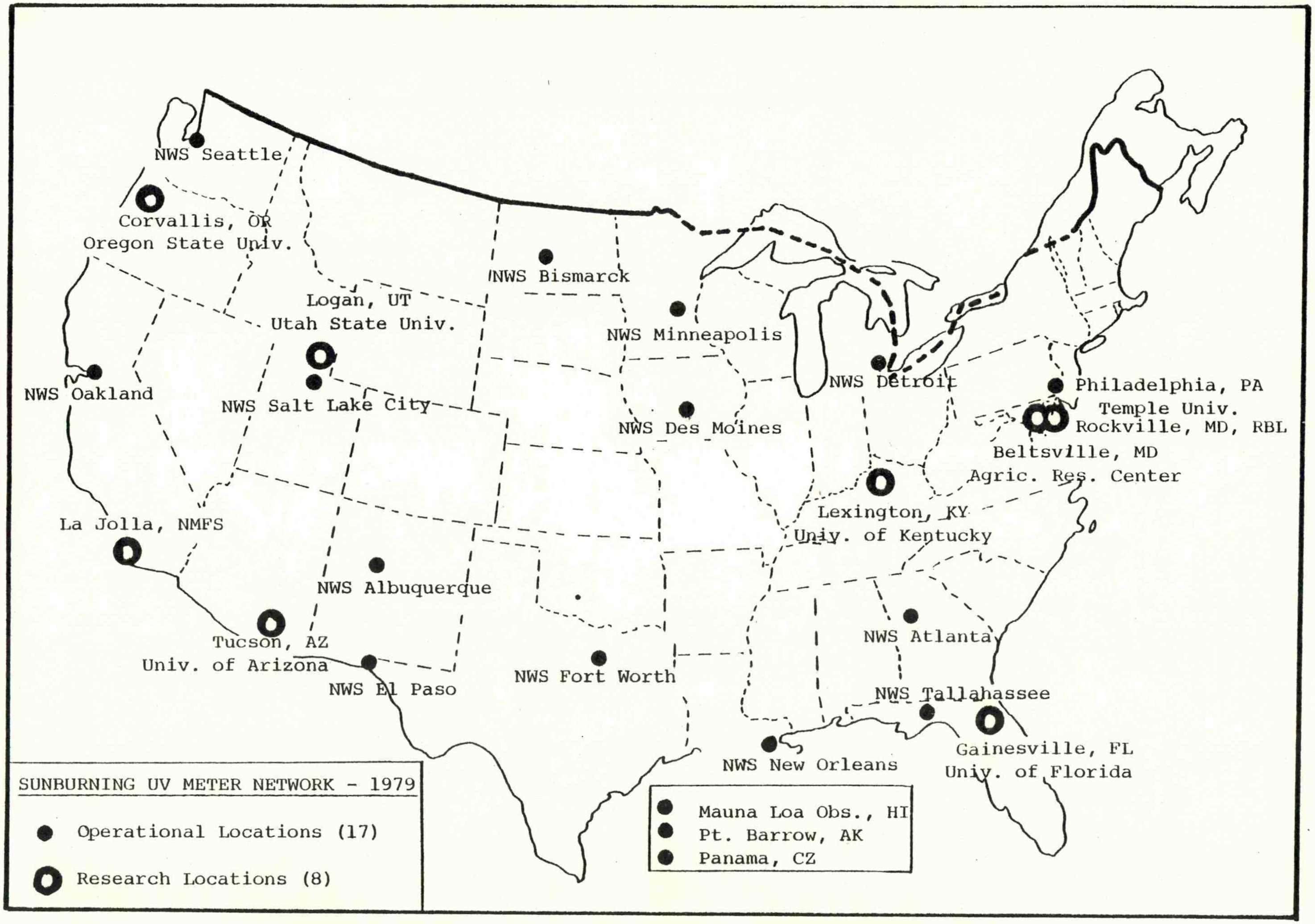
Figure 1. Locations at which erythemal ultraviolet radiation intensity measurements are made in NOAA's Cooperative Sunburning UV Meter Network, 1979. Detroit, Atlanta, New Orleans and Seattle have been in operation beginning October 1977. All others have been in operation beginning in late 1973.

Figure 2. Locations at which Dobson Measurements of Total Ozone Column are made in the U.S.-operated part of the WMO Global Total Ozone Network, 1979.

Figure 3. Variation in year-average total ozone for hemispheres and world, expressed as a percentage deviation from the mean. There is only about a 5 percent chance that the true value of the mean lies outside the vertical bars.

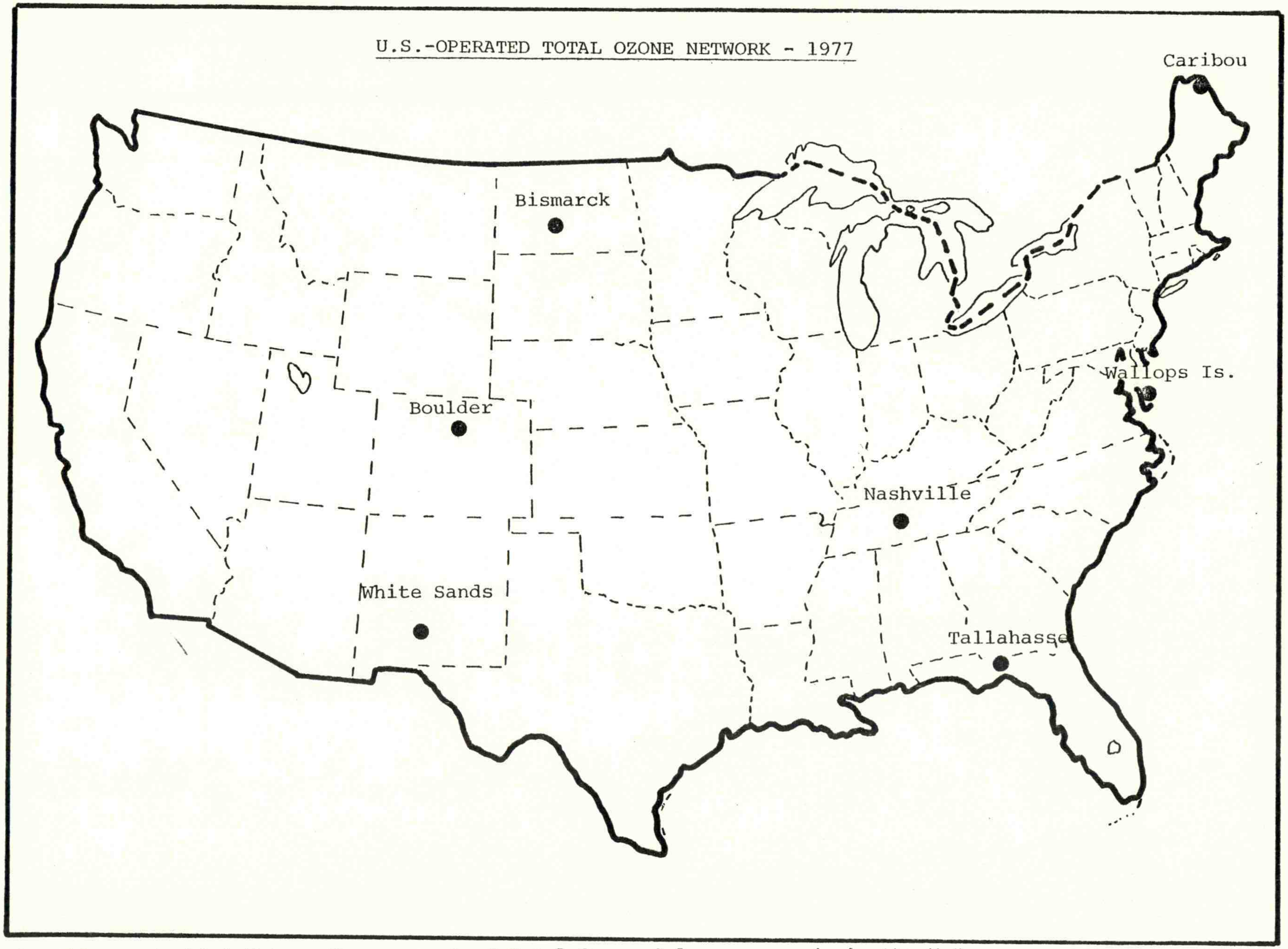
Figure 4. Variation in year-average ozone in 32-46 and 24-32 km layers of north temperate latitudes, as estimated from Umkehr measurements and ozonesondes. The indicated ozone decrease in the 32-46 km layer following the eruptions of Agung and Fuego is believed to be mostly fictitious.

Figure 5. Variation in year-average temperature in the 16-24 km layer (low stratosphere) for hemispheres and world, expressed as a deviation from the mean in degrees Celsius.



Locations at which erythemal ultraviolet radiation intensity measurements are made in NOAA's Cooperative Sunburning UV Meter Network, 1979. Detroit, Atlanta, New Orleans and Seattle have been in operation beginning October 1977. All others have been in operation beginning in late 1973.

Figure 1



Locations at which Dobson Measurements of Total Ozone Column are made in the U.S. operated part of the WMO Global Total Ozone Network, 1979.

Figure 2

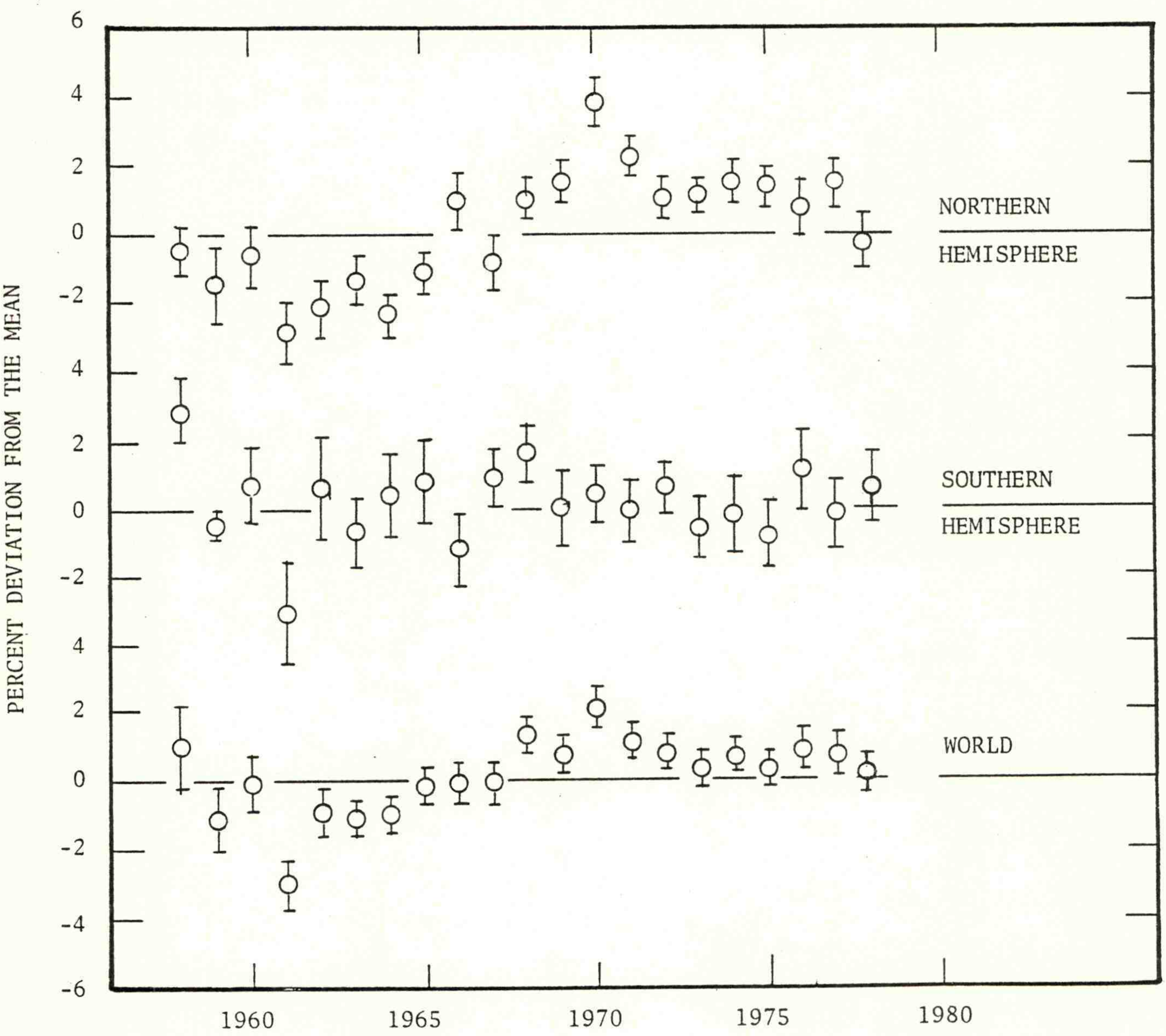


Figure 3

Variation in year-average total ozone for hemispheres and world, expressed as a percentage deviation from the mean. There is only about a 5 percent chance that the true value of the mean lies outside the vertical bars.

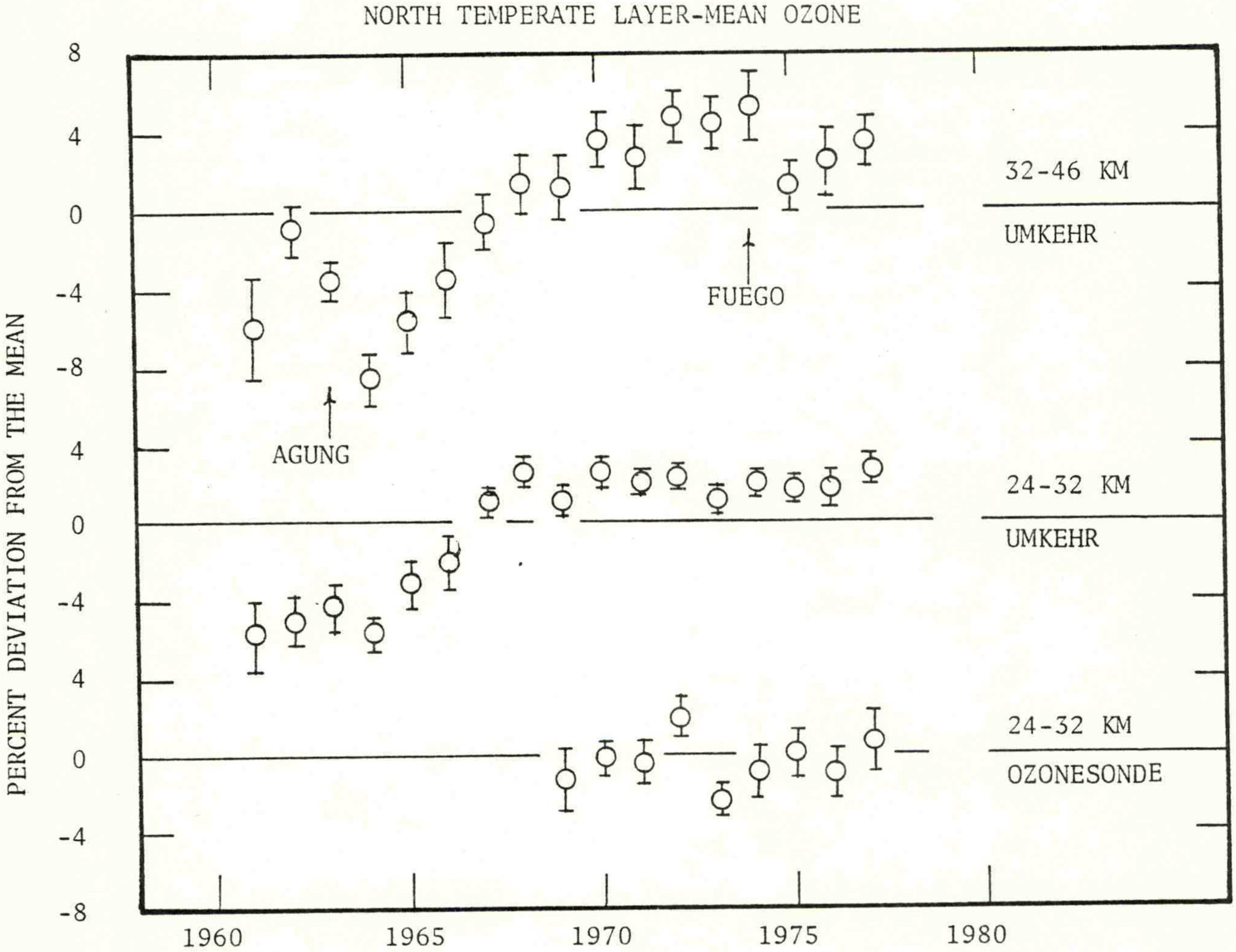


Figure 4

Variation in year-average ozone in 32-46 and 24-32 km layers of north temperate latitudes, as estimated from Umkehr measurements and ozonesondes. The indicated ozone decrease in the 32-46 km layer following the eruptions of Agung and Fuego is believed to be mostly fictitious.

TEMPERATURE, 16-24 KM

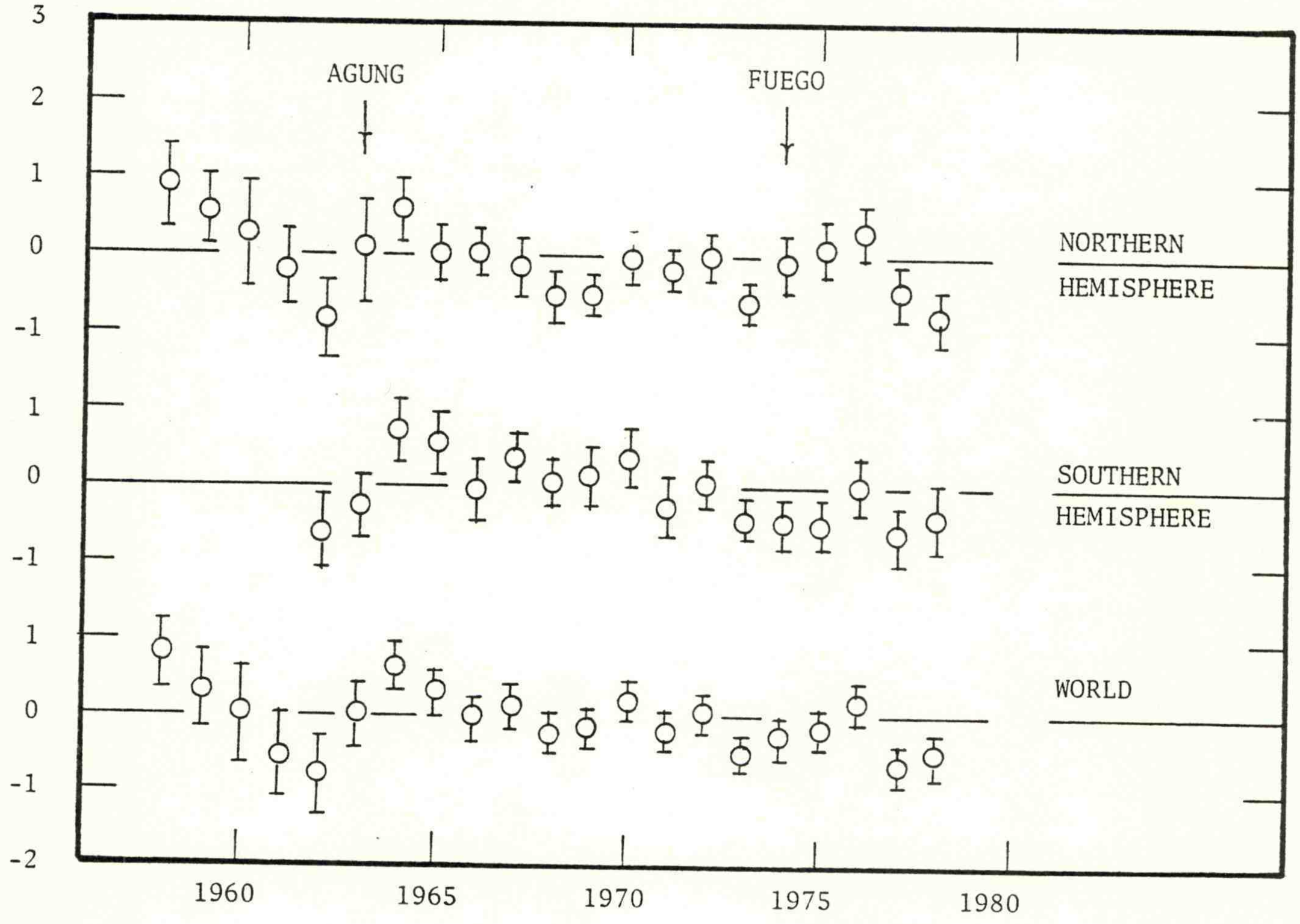


Figure 5

Variation in year-average temperature in the 16-24 km layer (low stratosphere) for hemispheres and world, expressed as a deviation from the mean in degrees Celsius.

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GEOPHYSICAL FLUID DYNAMICS LABORATORY (GFDL)

Changes in the stratosphere and the climatic effect of such changes cannot be detected or understood unless the normal state and the physical processes which maintain that normal state are known in detail. The requisite detailed knowledge is not in hand at the end of 1979 and considerable emphasis must be given to a continuing program of research for a number of years to come.

Basic research conducted to improve the understanding of the general circulation of the atmosphere, including the stratosphere, has been underway at GFDL for over 20 years. The upper atmosphere research effort was accelerated in 1970 when a commitment was made to concentrate specifically on the stratosphere. The summary of stratospheric research performed at GFDL since January 1977 builds on the considerable base constructed prior to that date.

In the previous report, our summary was separated into sections on dynamics, radiation and chemistry. Because of our recent efforts to combine these processes into self-consistent models, such a division no longer seems appropriate. In this report these processes are integrated into discussions on various general circulation model (GCM) experiments.

A. Tracer Transport Studies Using GCM Winds

One of the GFDL's global 3-D general circulation models (GCM) (e.g., Manabe, Hahn and Holloway, 1974; Manabe and Mahlman, 1976) has been used to provide self-consistent, time-dependent winds for investigating a number of problems dealing with transport of trace constituents. Although some of these experiments were completed prior to January 1978, analysis of their results continues.

1. Analysis of Instantaneous Source Experiment

This experiment simulates a tracer released instantaneously into the mid-latitude lower stratosphere and is followed for a period of 4 years. Work on this experiment, somewhat analogous to a nuclear weapons test, has been completed. Previously unreported results are: an improved understanding of the power and the limitations of atmospheric residence time concepts; a better grasp of the mechanisms for interhemispheric transport; and some success in illuminating the relationships between the cross-tropopause tracer fluxes and the mid-latitude and spring peaks in tropospheric radioactive fallout. Complete results on this work are presented in Mahlman and Moxim (1978).[4]

2. Atmospheric N_2O Tracer Experiments

The 3-D experiment simulating the behavior of atmospheric N_2O, assuming a constant lower boundary source, has been completed. A number of features in the simulation have now been observed in the atmosphere. These include: an almost uniform mixing ratio in the troposphere; sharply decreasing stratospheric mixing ratios toward the poles in each hemisphere; and penetration of tropospheric mixing ratios well into the tropical stratosphere.

This experiment generates lower troposphere longitudinal and temporal relative standard deviations ranging from 0.1% to 0.8%. These model results bracket the latest measurements of N_2O relative standard deviations, thus suggesting that previously assumed large sources and sinks of N_2O in the troposphere may not be present. The widely used Junge relationship between relative standard deviation and chemical lifetime for a trace gas is not supported by the results of this experiment. More detailed results are given in Levy, Mahlman and Moxim (1979).[2]

Two new N_2O tracer experiments have been completed which explore the sensitivity of N_2O structure to uncertainties about its tropospheric source. In one experiment the source is removed completely, while the other utilizes a source active only over land areas with rainy climates. Analysis of these experiments is underway.

During the analysis of the initial experiment, new results became available which indicated that the stratospheric N_2O destruction rates used were too high by 40%. A revised experiment is now underway which is evaluating the N_2O sensitivity to this change.

3. Atmospheric Ozone Tracer Experiments

Analysis has been completed on two preliminary 3-D ozone tracer experiments. The first experiment("Stratified Tracer") prescribes the mixing ratio in the middle stratosphere to be a constant value. The second experiment ("Simple Ozone") introduces a partially simplified ozone photochemistry in the middle stratosphere. In both experiments the ozone is assumed to be inert in the lower stratosphere, while it is removed in the lower troposphere.

A comparison of the model structure against available ozone observations shows agreement in a number of important features. The model also has significant deficiencies, particularly in the Southern Hemisphere. A problem of strong current interest is the flux of ozone from the stratosphere to the troposphere. This model predicts a global average flux of 3.7×10^{14} modecules m^{-2} sec^{-1}, with the eddy flux by far the dominant component.

Special attention is directed toward the processes leading to changes in the 10 mb zonal mean mixing ratios. The results show strong interactions between stratospheric transport and chemical change. Also, the effect of constantly changing sun angle combines with temperature dependent chemistry and transport effects to produce complex behavior with significant interhemispheric asymmetries in the chemical source and sink terms.

The early behavior of the initially horizontally uniform "Stratified Tracer" experiment was used to evaluate the transport processes leading to the pronounced poleward-downward slopes of tracer isolines in the lower stratosphere. The analysis shows the zonal mean diabatic circulation to be a systematic, but small contribution to the model's rapid evolution to poleward-downward slopes. Larger contributions are due to eddy processes, particularly vertical removal in low latitudes and horizontal buildup in high latitudes. An independent calculation showed that eddy diabatic processes are quite important for allowing systematic poleward-downward and equatorward-upward flux of air parcels across zonal mean isentropic surfaces.

As an aid to analysis of tracer transports, a Lagrangian "non-transport" theorem is derived for a fluid particle. Utilizing the perspectives gained, some Lagrangian drift type calculations are performed in the model January mean flow. The results show a slow but substantial particle convergence just to the cyclonic shear side of the time mean jet stream axis. This approach provides an alternative explanation to the traditional Eulerian one which shows nearly complete cancellation between eddy and meridional circulation flux convergence. Also, the analysis demonstrated the very important contributions of transient disturbances to the irreversible mixing of heat and tracers into the stratospheric polar vortex. Details are presented in Mahlman, Levy and Moxim (1980).[3]

4. Analysis of Ozone Sampling Networks

Analysis has continued to completion on the use of results from the "Simple Ozone" experiment (described above) to evaluate the capability of the Dobson Total Ozone Network to provide meaningful assessments of global means and trends. Since the previous report, new analysis has been underway to evaluate, by collecting statistics on random networks of various sizes, the probable reduction of error to be expected for increases in network size. These results show that the current Dobson Network exhibits about the same sampling skill as that of random networks of similar size. The random network analysis also indicates that network sizes greater than about 100 well chosen stations are probably not necessary. Also, an effort to examine a possible effect of "fair weather" sampling bias on total ozone measurements has been underway. The results indicate some systematic error is produced, but the effect is smaller than that introduced by spatial and temporal sampling limitations.

5. Total Odd Nitrogen Tracer Experiment

Because of its fundamental role in the self-consistent modeling of ozone, a tracer experiment is now underway for total odd nitrogen (the family of nitrogen compounds that can be readily converted to ozone destroying forms). The stratospheric source for this group is reaction of N_2O with electronically excited atomic oxygen. Its predominant destruction is tropospheric rainout and gas phase transfer into the ocean.

B. Models of the Troposphere-Stratosphere-Mesosphere System

1. Model Improvements

During this period, work continued on adding various improvements on the physical processes included in the GFDL-40-level troposphere-stratosphere-mesosphere GCM. The model now possesses the capability to add 3 new dependent variables to allow a self-consistent calculation of ozone. To achieve this, a collaborative effort has begun with scientists from the Aeronomy Laboratory/NOAA. Their chemical model has been converted to the GCM coordinates and conversion to run efficiently on the GFDL computer has begun. In preparation for this task, a single tracer has been run passively in the GCM to test for modeling accuracy.

A static stability-dependent surface flux formulation has been successfully incorporated into the model. A number of improvements to the off-line analysis packages have substantially improved their accuracy. Improved methods for calculating subgrid scale fluxes have been tested.

A new technique for specification of orography at various horizontal resolutions is now being utilized. High resolution (1^o) mountains are spectrally filtered such that almost no forcing is allowed near the computational mode. In addition, a nonlinear smoothing is applied in such a manner as to flatten the oceans without sacrificing peak heights significantly.

Accurate treatment of infrared cooling in the stratosphere requires that the effects of mixed Doppler and Lorentz broadened lines be taken into account. For ozone, the use of the exact line shape in band models is extremely time consuming and impractical for use in GCM's. Two effecient new methods for including this effect have therefore been developed.

Limited distribution of CO_2 transmission tables has begun, and the infrared algorithm developed here is currently in use in several non-GFDL GCM's.

2. Low Resolution Annual Mean Model Experiment

The 40-level GCM low resolution model designated N10 (9° latitude by 10° longitude) has been run for 750 days to a state of near statistical equilibrium. This calculation employs annual mean insolation, prescribed clouds,prescribed ozone below 34km, and a fixed sea surface temperature. The stratospheric zonal-mean structure of this model compares favorable with annual averaged observations in many features. Most notably the previous GCM deficiency of excessively strong zonal winds in the middle stratosphere has disappeared.

An especially interesting feature of this experiment is the presence of time varying equatorial stratospheric zonal winds on time scales of 2-3 years. The westerly phase appears to be produced by a vertical eddy momentum flux convergence. These results lead to an optimism that this model contains the requisite processes for simulating the quasi-biennial oscillation. Some results from this experiment can be seen in Mahlman, Sinclair and Schwarzkopf (1978).[5]

3. Low Resolution Annual Cycle Model Experiment

The 40-level GCM low resolution (N10) model has been run with a seasonal insolation cycle for 1 1/2 years. Its initial field is derived from the annual mean insolation experiment (see 2 above). Analysis of this experiment is just underway. The early results indicate that the middle stratosphere simulation is superior to previous GFDL GCM's in that the cold winter polar bias and the suppressed summertime easterlies are no longer present. A spontaneous major mid-winter sudden stratospheric warming has not yet been attained. The mesosphere simulation is highly deficient because the mid-latitude westerly and easterly jets do not close off properly above the 65 km region. In the tropics, the model appears to have successfully simulated the semi-annual zonal wind oscillation. This may be the first model simulation of that phenomenon.

4. Low Resolution 50° Ozone Reduction Experiment

It is clear that large cooling in the low-latitude upper stratosphere is to be expected in the event of a large reduction in ozone amounts. Considerably less clear, however, are the dynamical responses throughout the entire stratosphere and the climatic alteration near the earth's surface. As a means of helping to formulate a longer term research for attacking these problems, a preliminary 40-level GCM experiment has been run from day 500 to day 720 on the low-resolution (N10) model, assuming a uniform 50% ozone decrease and annual mean insolation.

The zonal mean temperature in this experiment shows a number of features which agree reasonably well with radiatively predicted changes. For example, substantial global mean cooling ($23^{o}K$) occurs in the model upper stratosphere and lower mesosphere. Considerably smaller mean cooling is calculated elsewhere, with values of about $6\text{-}8^{o}K$ from 18-40 km, and ranging from 1^{o} up to $6^{o}K$ from 7-18 km. Although changes are observed in the lower troposphere, further work is required to assess their physical and statistical significance.

Another important model effect of the reduced ozone is that the stratopause height falls by about 6 km, while the tropical tropopause height rises by 1-2 km. In addition, the average meridional temperature contrast in the upper stratosphere is considerably diminished. The reduction in this contrast ranges from about $10^{o}K$ near the stratopause to about $2^{o}K$ in the 20-35 km region. These results also agree with predictions from radiative equilibrium models.

In the lower stratosphere, the cooling acts to increase the magnitude of the reversed meridional temperature contrast by about $4\text{-}5^{o}K$. This arises because less cooling is occurring in high latitudes than above the tropical tropopause, an effect opposite to that predicted by comparison radiative-convective equilibrium calculations. However, a more careful analysis has determined that the radiation-only predictions improve considerably if perturbations are calculated about realistic states, rather than about radiative-convective equilibrium states. This is because temperature change in response to trace constituent perturbations was found to be a strong function of the local temperature itself. This suggests that carefully formulated radiative models can be very useful tools for the study of stratospheric climate sensitivity to perturbations in trace constituents.

In the ozone reduction experiment, there were found to be two exceptions to the above rule that the total response is predominately radiative. The additional effect of a dynamical response was found to be important in the tropical mesosphere and in the vicinity of the tropical tropopause. The explanation of these responses appears to lie in the onset of inertial instability and strongly altered wave activity, respectively, in the two regions. In addition, the temperature near the tropical tropopause was found to be rather sensitive to dynamical changes because the infrared heating rate there is rather insensitive to temperature. This suggests that the stratospheric water vapor content could change substantially in response to otherwise modest stratospheric climate perturbations. More complete results are available in Fels, et al. (1980).[1]

5. Low Resolution Doubled Carbon Dioxide Experiment

In a comparison experiment to the 50% ozone reduction, the 40-level GCM low resolution (N10) annual mean model is run from day 500 to day 720 with a doubled carbon dioxide mixing ratio. In contrast to other climate sensitivity CO_2 experiments, the sea surface temperature is held fixed, thus strongly constraining the tropospheric climate against change. This was done because of the emphasis on the stratospheric response of the experiment.

The strongest effect of increased carbon dioxide is, as expected from radiative considerations, a decrease in temperature of about 10°K near the stratopause. In general, the model changes everywhere agree well with predictions from comparison radiative models calculating perturbations about realistic states (see 4 above).

6. Medium Resolution Annual Mean Model Experiment

A 40-level GCM medium resolution model designated N18 (5° latitude by 6° longitude), with annual mean insolation, has been started by interpolation from day 500 of the low resolution (N10) control experiment (see section 2). The model has been run out to day 900 and has reached a state of statistical equilibrium. A notable exception to this is the zonal wind field in the tropical stratosphere and mesosphere. In this region, long term oscillations in the zonal wind are simulated which are somewhat analogous to the quasi-biennial oscillation. Interestingly, the structure of this oscillation appears to differ somewhat between this and the low resolution (N10) experiment described in section 2.

Although analysis of this experiment is in progress, this experiment does show results which indicate some improvements in simulation capability over that of the low resolution (N10) model (section 2).

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NATIONAL ENVIRONMENTAL SATELLITE SERVICE

Office of Research

The TIROS-N operational spacecraft are equipped with the TIROS Operational Vertical Sounder (TOVS). Subsystems of the TOVS measure atmospheric radiances in the infrared and microwave regions of the spectrum. The first TIROS-N satellite was launched on October 24, 1978, and became operational approximately two months later. One infrared channel of TOVS is designed specifically to measure radiation emitted by ozone at 9.6 micrometers. Other infrared and microwave channels are variously sensitive to the amount of ozone through minor selective absorption or through correlations known to exist between ozone amount and temperature or water vapor structure of the atmosphere as measured by these other channels.

The method of retrieving total ozone amount from the satellite measurements is a regression procedure in which the satellite-measured radiances are related directly to the total ozone amount as measured by surface observing stations located throughout the world. The regression coefficients are derived using radiances which are obtained within a restricted time and space window of ground-based measurements of total ozone with a selected worldwide set of Dobson instruments. This procedure necessarily leads to a delay in making available or archiving the satellite ozone products because of the inherent 2-3 month delay in acquiring the needed Dobson-derived ozone information. The basic measurement procedures, processing and analysis algorithms and mapping routines have been developed and are beginning to be applied to the satellite data.

Since this satellite measurement of ozone is a new operational product and derived for the first time by this technique, special attention is being given to validation. Two methods are being used. First, a computer tape of TIROS-N daily global ozone determinations for January 1979 has been produced. These data are being evaluated as to compatibility and accuracy by the Analysis and Information Branch, Climatic Analysis Center, NWS, by comparing synoptic and statistical analyses of these data with similar data products from the Solar Backscatter Ultraviolet Instrument (SBUV) on Nimbus 7 and with meteorological parameters. Second, the TIROS-N data are being evaluated by a continual comparison of single values obtained at or near observing stations with Dobson instruments with the local ozone values determined by the Dobson technique. This will give statistical evaluation of the satellite data versus ground truth and also provide the basis for a continual updating of the coefficients used in the retrieval system.

When this validation phase reaches a successful level, two events will occur. First, the basic satellite data gathered to date will be used to generate a data record of total ozone amounts for a period of about one year which will be archived on tape. This tape will be available for research in trend analyses. Second, the retrieval coefficients will be inserted into the TOVS retrieval system to enable retrieved ozone amounts to be available as an operational product on a daily basis.

The primary purpose of the TOVS is to obtain vertical temperature profiles for numerical weather forecasting. In routine operations, stratospheric temperatures are determined daily on a global basis, processed on a timely basis for daily forecasting applications, and archived in the NOAA Environmental Data and Information Service.

The ozone monitoring capability of TOVS on TIROS-N was designed not as a primary data source, but as a correction input to the temperature profiling operations. The small influence of ozone on several of the TOVS channels is large enough to require correction and an on-board measurement capability was deemed justifiable for this purpose. However, the accuracy required for these corrections is less than desired for a primary global ozone system so that the present operational product is considered to be an interim measure. A primary monitoring instrument based on the Backscatter Ultraviolet principle--proven in space by NASA from 2 Nimbus and 1 AEM spacecraft--is planned by NOAA and NASA for eventual use on the NOAA satellites beginning about 1984.

NATIONAL WEATHER SERVICE CLIMATE ANALYSIS CENTER
ANALYSIS AND INFORMATION BRANCH

The Analysis and Information Branch has been involved in a multi-faceted program of ozone analysis and research on the following data sets.

A. National Aeronautics and Space Administration (NASA) Backscatter Ultraviolet Ozone Measurement System (BUV-1970)

During 1979, daily and monthly synoptic global maps of total ozone from the NASA BUV-1970 satellite data for the period April 1970 to March 1971 were produced. This program is being extended to the entire 7 years BUV-1970 data set. As the quantity of the data diminishes due to space-craft power limitations, the analyses will be derived on a weekly, bi-weekly or monthly basis. An example of the monthly average synoptic map for each hemisphere for April 1970 is shown in Figures 6 and 7.

B. NOAA Tiros N High Resolution Infrared Radiation Sounder (HIRS-2) Total Ozone Determinations

At this point we have developed the analysis technique to be utilized on the HIRS-2 ozone data from test data and have provided NESS with correlative Dobson data to update their regression coefficients. Data for January 1979 will be analyzed and compared with that from other instruments such as the NASA Nimbus 7 Solar Backscatter Ultraviolet Ozone Measuring System (SBUV-1978) and Total Ozone Mapping System (TOMS) and the Department of Defense Meteorological Satellite Ozone channel at 9.8 micrometers.

C. SBUV/TOMS

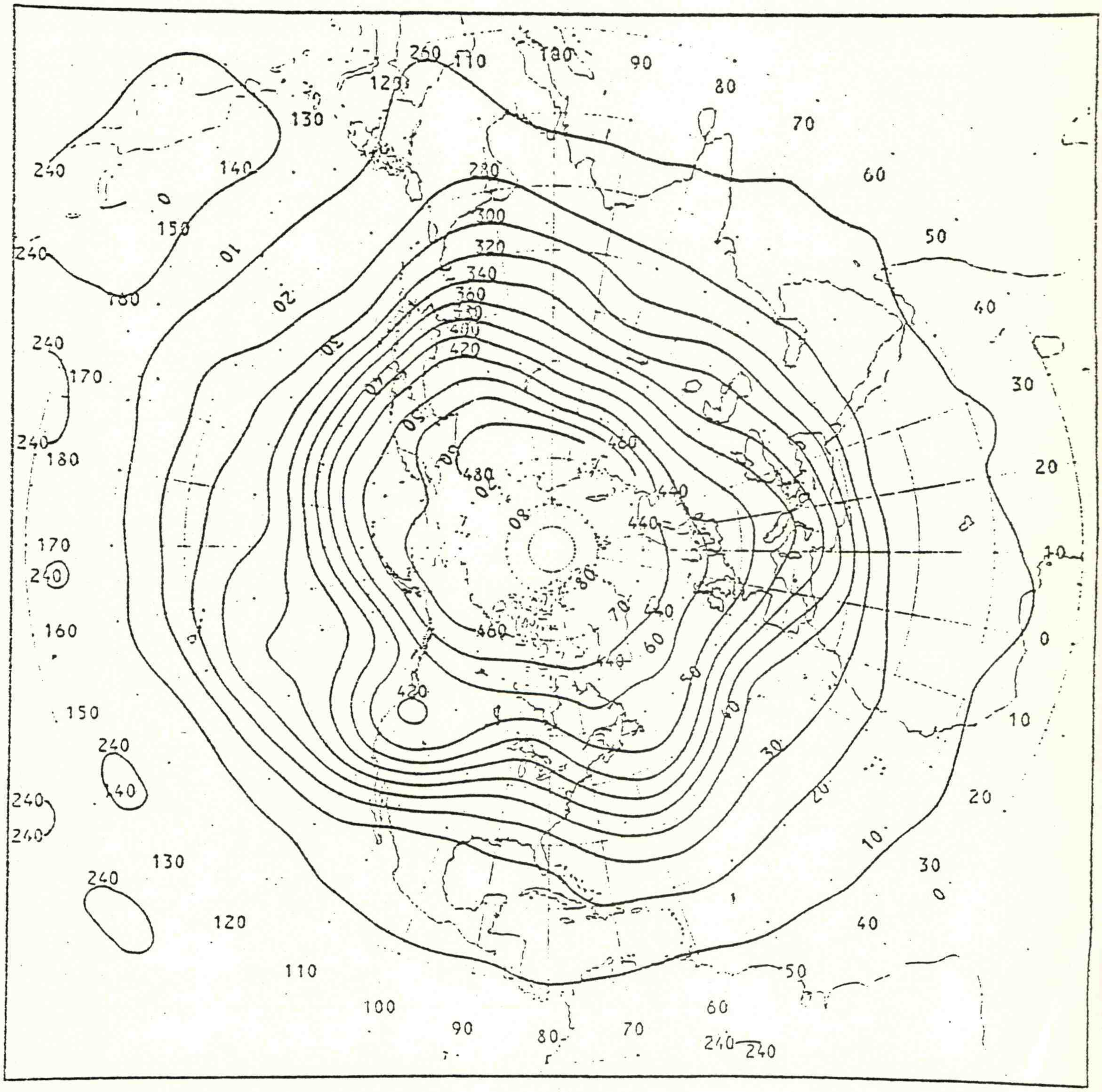
NOAA is a member of the NASA SBUV/TOMS Nimbus Experiment Team (Nimbus 7) and is currently active in evaluating and verifying the results from this experiment for NASA.

D. Meteorological Parameters

Effective October 1978, the Branch has initiated daily, global analyses of height and temperature at the stratospheric pressure levels of 70-, 50-, 30-, 10-, 5-, 2-, 1-, and 0.4- mb. These data are being merged with the ozone data from SBUV-1978 to aid in the evaluation of the satellite ozone determinations as well as to study the ozone dynamics and transports in the stratosphere.

E. Other Related Activities

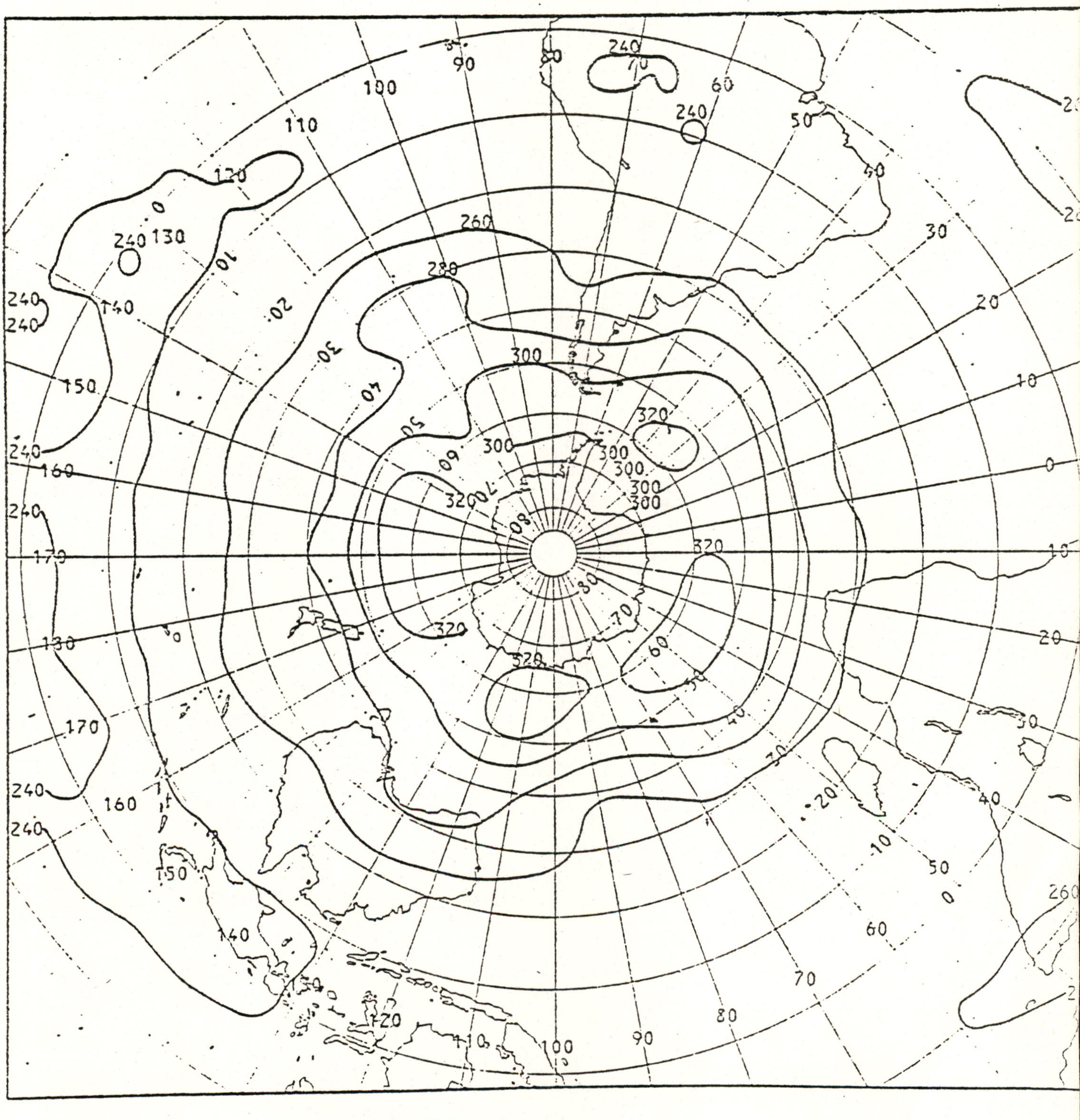
Members of the Branch have been active on several committees and working groups of importance to the stratospheric monitoring project. Among these are the Interagency Working Group to draft the National Plan for Ozone Monitoring and Early Detection of Stratospheric Change and the Interagency Committee for Stratospheric Ozone Protection.



N.H. APRIL, 1970. MEAN MONTHLY TOTAL OZONE (DOBSON UNITS)

Mean Monthly Total Ozone in Dobson Units for the Northern Hemisphere, April, 1970.

Figure 6



Mean Monthly Total Ozone in Dobson Units for the Southern Hemisphere, April, 1970.

Figure 7

ENVIRONMENTAL DATA AND INFORMATION SERVICE

NOAA's National Environmental Satellite Service typically produces 7,000 to 8,000 soundings per day from both TIROS-N and NOAA-6 satellites. These soundings are derived from the three TIROS Operational Vertical Sounder (TOVS) sensors (Microwave Sounding Unit, Stratospheric Sounding Unit, and High Resolution Infrared Radiation Sounder) and are archived on magnetic tape on a weekly basis (7 days per tape) by the Satellite Data Service Division of the Environmental Data and Information Service's National Climatic Center. Each sounding contains layer mean temperatures, precipitable water amounts, tropopause parameters, cloud cover, radiances, and total ozone amounts in Dobson units. The TOVS sounding tapes are available from January 1, 1979.

Atmospheric trace constituents data measured by NASA's Global Atmospheric Sampling Program (GASP) are available on magnetic tape from the National Climatic Center. Automated air sampling systems, onboard several commercial B-747 aircraft in routine airline service, acquire the data in the upper troposphere and lower stratosphere. These magnetic tapes are described in NASA Technical Memorandum 79058, "NASA Global Atmospheric Sampling Program (GASP) Data Report for Tape VL0009," December 1978, which was prepared by Lewis Research Center, Cleveland, Ohio.

The World Data Center-A (WDC-A) for Meteorology, collocated with the National Climatic Center, archives ozone data deposited with it and is cognizant of ozone data filed elsewhere, such as the World Ozone Data Center at Toronto, Canada. Data filed in WDC-A, such as satellite data from the Defense Meteorological Satellite, cover the period through December 1978. Assistance is given to scientists who need data held by other organizations.