Report to Congress of Findings for 1980 - 1981

Program of Research and Monitoring for Early Detection of Stratospheric Ozone Change

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

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Malcolm Baldrige, Secretary

National Oceanic and Atmospheric Administration
John V. Byrne, Administrator

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Table of Contents

INTRODUCTION

Section 126, on "Ozone Protection," of P.L. 95-95, Clean Air Act Amendments of 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.

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 were intensified when national concern developed about the possible effects of chlorofluorocarbon releases and other pollutants on stratospheric ozone.

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 stratospheric ozone and temperature variations, measures 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 technique.

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, 1980-1981.

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 relationships among ozone, ultraviolet radiation and life may be fragile and that any alteration of the stratospheric ozone abundance should be viewed with concern. Ozone is an important controlling factor in the temperature of the stratosphere, and changes in its concentration may produce significant climatic changes. Monitoring of the vertical distribution of ozone in both the troposphere and stratosphere is essential for the early detection of changes which may affect the value of the total column of ozone.

The immediate impact of the WMO program was to encourage all member nations to upgrade their ozone measuring stations, and to carry out inter-calibrations 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 Dobson spectrophotometers against the world standard operated by the United States is being carried out by NOAA, funded through contributions from the WMO, participating nations, and NOAA.

Continually created by photochemical reactions in the middle stratosphere, ozone is highly reactive gas. It is destroyed by reactions with many other substances, most importantly those of the nitrogen, chlorine, and hydrogen families. The ozone

abundance is vulnerable to human actions which increase the amounts of these substances above the natural equilibrium level in the stratosphere, such as the release of halocarbons, particularly the chlorofluorocarbons CCl_3F and CCl_2F_2, into the atmosphere. To understand the causes of changes in ozone concentrations, stratospheric measurements of relevant trace constituents and processes must be undertaken. 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 features 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, possible 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 allow for an understanding, and removal statistically, of the natural variations to permit the detection of a trend change which exceeds the natural variability.

Ozone monitoring as an early warning system faces a number of significant limitations. For example, due to the time delay between halocarbon release and ozone destruction, the maximum ozone decrease in the stratosphere from release of halocarbons in the atmosphere would occur some 15 years later, even if we assume a scenario in which the release of halocarbons is kept constant at present level. An effective early warning monitoring system must be capable of detecting changes and verifying the causes thereof in time for corrective actions needed to prevent this delayed maximum ozone decrease reaching greater than acceptable levels. The WMO Dobson spectrophotometer network, within the next decade, is not likely to be able to identify a reduction in global total ozone of less than 2 percent. The models predict that such an ozone change will not occur before the year 2000, assuming halocarbon release at the present rate. However, model calculations have shown that the predicted decrease in ozone concentrations at 40 km is about five times as great as is the decrease in total ozone. Monitoring ozone concentrations at this altitude should therefore provide a more sensitive early warning system in the context of an understanding of concurrent changes through the total ozone column.

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. Advantages of the satellite system include global coverage with a single instrument and real-time data acquisition.

SUMMARY OF FINDING'S
1980 - 1981

I. OZONE MONITORING

A. Findings from the Global Ozone Observation Network

Analysis of the World Meteorological Organization's Global Ozone Monitoring Network data through the year 1980 was completed. Figure 1 shows the variation in year-average total ozone from 1958 through 1980 for each hemisphere and the world total, expressed as a percentage deviation from the mean for the period 1958-1977. The vertical bars are confidence limits such that there is about a 95 percent chance that the true value of the annual mean lies within the extent of these bars.

The world total-ozone concentration, observed to be a significant 2.2 percent above the average in 1979, decreased to a non-significant 0.3 percent above average in 1980. All climatic zones, as well as all regions in the north-temperate climatic zone, registered a decrease in total ozone between 1979 and 1980. However, there is little evidence from the ground-based Global Ozone Monitoring Network of a significant trend in total ozone during the 1970's for either hemisphere or for the world.

Photochemical modeling predicts that the largest percentage of ozone depletion from chlorofluorocarbon releases would occur near the 40 km level, and hence anthropogenic effects might first be noted near this level. Crude estimates of the ozone concentration at these heights can be obtained by ground based ozone profile measurements (Umkehr observations) carried out at a limited number of Dobson spectrophometer stations. Figure 2 shows year-average values by this method for north temperate latitudes. (Note change in ordinate scale from Figure 1.) The Umkehr data are presented for stratospheric height-layers 32-48 km, 24-32 km, and 16-24 km. For comparison, ozonesonde data are presented for height layers 24-32 km and 16-24 km based on observations in North America, Europe and until recently, Japan. The volcanic eruptions of Agung and Fuego are shown at the top of Figure 2. The indicated ozone decrease following these eruptions is mostly an artifact in the measurements resulting from the presence of volcanic aerosols in the stratosphere.

In the critical 32-48 km layer the Umkehr year-average value, which in 1979 was a significant 4.3 percent above the average, in 1980 declined to a non-significant 2.9 percent above average. However, there is little evidence from the Umkehr observations of a significant trend in the 32-48 km ozone amount in north temperature latitudes during the 1970's.

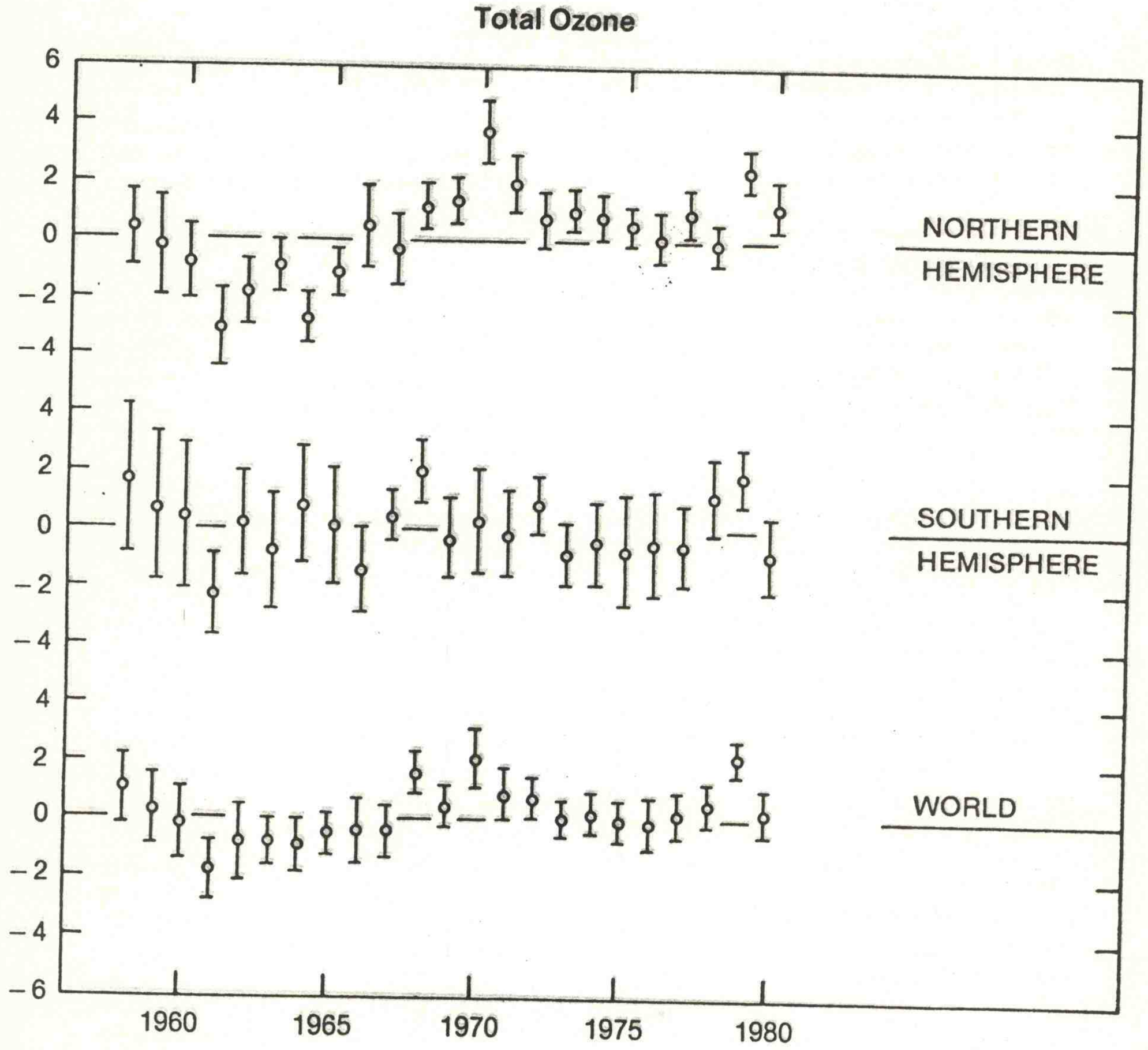

Figure 1. Variation in year-average total ozone for hemispheres and world, expressed as a percentage deviation from the mean.
Vertical bars - there is about a 95 percent chance that the true value of the annual mean lies within the vertical bars.

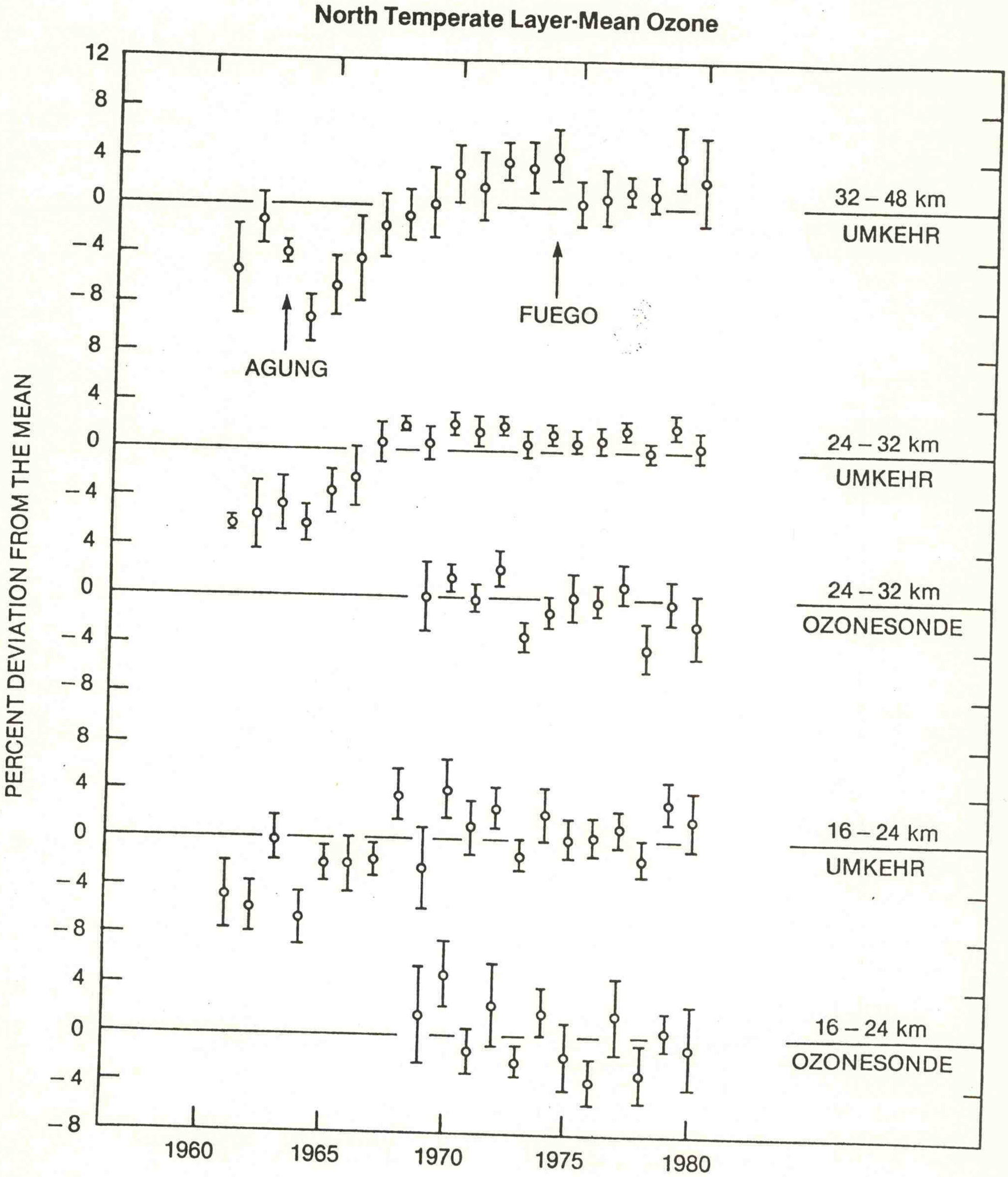

Figure 2. Variation in year-average ozone in stratospheric layers of north temperate latitudes, from Umkehr and ozonesonde measurements.

B. Model Predicted Ozone Trends

The results of recent model predictions of the total column ozone trend for the decade 1970 to 1980, considering only continuing worldwide emissions of chlorofluorocarbons, is -0.7%. Since the increases during this decade of carbon dioxide and nitrogen oxides tend to increase ozone abundances, the combined effect of increasing chlorofluorocarbons, carbon dioxide and nitrogen oxides on the total column ozone trend for the decade is -0.1%. Uncertainties involved with these predictions are about a factor of 3. The model predicted ozone trend for this decade for the Umkehr layer at 32-48 km is -3.5% for the chlorofluorocarbons only and -2.5% for the combined scenario. Uncertainties in these predictions are about a factor of two.

It is important to recognize that to detect the model calculated ozone trends through monitoring we need to understand the long-term natural variabilities of ozone and the precisions of ozone observations. Long term natural variations of ozone on the same order as the current model predicted chlorofluorocarbon effect may result from changes in solar flux, cosmic rays, stratospheric water vapor, methane, and stratospheric circulations. There is little information on the long term changes of these parameters. Therefore, even if a definitive trend of ozone is observed, one could not rule out at this time the possibility that the trend is due to natural variabilities rather than a result of anthropogenic effects. With regard to the precisions of ozone observations, the uncertainties in the Dobson total column ozone observations during the decade 1970-79 are about 1 to 2% per decade. The uncertainties in Umkehr ozone measurements at 38-42 km altitude are about 10% per decade. These uncertainties are greater than the model calculated ozone trends for the decade.

II. STRATOSPHERIC WATER VAPOR MEASUREMENTS

A balloon-borne, fast-response, self-calibrating instrument for the in-situ measurement of stratospheric water vapor was designed, developed and flown. There have been a total of ten successful flights from Wyoming, Texas and Brazil, the results of which have contributed significantly toward the understanding of tropospheric-stratospheric exchange processes.

Almost all of the flights have found that the stratospheric water vapor concentrations have a minimum just above the tropopause and increase with increasing altitude. Moreover, a comparison of the Wyoming flights with the Brazil flight suggests that stratospheric water vapor increases from the tropics to mid-latitudes. Both of these observed vertical and meridional increases are consistent with a stratospheric source of water vapor, such as the oxidation of methane.

III. STRATOSPHERIC TEMPERATURE MONITORING

Ozone plays an important role in the radiation balance of the earth-atmosphere system, thus influencing global climate. Heat generated in the stratosphere by ozone absorption of solar radiation provides the principal driving force for stratospheric wind systems, and thus controls the climate of the stratosphere.

Monitoring of stratospheric temperature is important also because current and impending stratospheric cooling as a result of long-wave radiation from increasing carbon dioxide will affect the rate at which temperature-dependent chemical changes will occur which are relevant to the ozone balance. Figure 3 (see Air Resources Laboratory, Section I) shows the variation in year-average temperature from rocketsonde data from 1965 through 1979 in the Northern Hemisphere. The rocketsonde data show a large temperature decrease between 1970 and 1976, with only a hint of a warming thereafter. (This cooling is much too large to be associated, in toto, with a carbon dioxide effect.) However, the radiosonde data for the 16-24 km layer (through 1980) show little temperature variation since the warming following the eruption of the Agung volcano. The differences between the rocketsonde and radiosonde derived temperature variations may result from the different altitudes, and do not necessarily point up an inconsistency.

IV. THE ORIGIN OF TROPOSPHERIC OZONE

Collaborative studies between Aeronomy Laboratory and Geophysical Fluid Dynamics Laboratory scientists coupled with direct measurements of NO and NO_2 profiles have indicated that stratospheric ozone is not the sole source of most tropospheric ozone. By using the measured distribution by altitude of NO and NO_2 in combined photochemical and general circulation model calculations, a study demonstrated that recent observational evidence was consistent with the photochemical production of ozone in the upper troposphere, catalyzed by NO and NO_2, the source of which is predominantly the downward transport of reactive nitrogen from the lower stratosphere to the upper troposphere.

This finding suggests that significant ozone production due to subsonic aircraft emissions of reactive nitrogen could occur. This may explain the ozonesonde measured Northern Hemisphere tropospheric ozone increase of about 10% in the decade from 1971-1980. This increase represents about a 1% increase in total column ozone, which would tend to offset somewhat any stratospheric decrease due to halocarbons which may have occurred. This must be investigated in more detail in order to understand the strength of these two opposing effects in the total column ozone determinations.

AERONOMY LABORATORY
Boulder, Co.

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 determining stratospheric chemical composition, in some cases for species occuring 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 atmospheric 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.

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 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. During 1980 and 1981 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.

I. MODEL CALCULATIONS

The Aeronomy Laboratory has continued to play a leading role in the development and use of atmospheric models to predict the behavior of stratospheric ozone. The models themselves have progressed from the relatively simple one-dimensional versions with only vertical transport to more complex two-dimensional

models that included latitudinal transport. Incorporation of photochemistry in existing three-dimensional general circulation models of the Geophysical Fluid Dynamics Laboratory (GFDL) of NOAA is progressing, and will ultimately lead to a fuller undestanding of the influence of ozone changes on global climate. (See Geophysical Fluid Dynamics Laboratory, Section III C).

A. Steady-State Depletion of Total Ozone Abundance Due to Chlorofluoromethane Emissions

Because of the changes during 1980-81 in the reaction rate coefficients of HNO_4 and HNO_3, NOAA's Aeronomy Laboratory 1-D model predicted reduction at steady state of ozone column abundance due to a constant rate of CFM emission at the 1975 rate is now about 7%.[1] For comparison, the previous estimate was 18%.[2] However, the model predicted effects to the ozone column abundance due to stratospheric aircraft and nitrogen fertilizers have increased because of the changes in these reaction rate coefficients.[1]

B. The Origin of Tropospheric Ozone

Collaborative model studies between Aeronomy Laboratory and Geophysical Fluid Dynamics Laboratory Scientists coupled with direct measurements of NO and NO_2 profiles have indicated that stratospheric ozone is not the sole source of most tropospheric ozone. The origin of tropospheric ozone has been a controversial and unresolved question between theories of downward transport of stratospheric ozone and in situ photochemically controlled production by sources and sinks near the surface in the troposphere. By using the measured distribution by altitude of NO and NO_2 in combined photochemical and general-circulation model calculations, a study demonstrated that recent evidence was consistent with the photochemical production of ozone in the upper troposphere catalyzed by NO and NO_2, the source of which is predominantly the downward transport of reactive nitrogen from the lower stratosphere to the upper troposphere. Calculations indicate that photochemical ozone production initiated by reactive nitrogen in this process can produce as much or more ozone than is provided by the direct ozone flux. The added sink of ozone required is found in the lower troposphere by way of a water vapor related ozone destruction path.

This finding suggests that significant ozone production due to subsonic aircraft emissions of reactive nitrogen could occur, which must be investigated in more detail. This may explain the ozonesonde measured Northern Hemisphere tropospheric ozone increase of about 10% in the last decade. This increase represents about 1% increase in total column ozone, which would tend to offset somewhat any stratospheric decrease which may have

occurred. Therefore, it will be important to investigate the altitude distribution of ozone both in the stratosphere and the troposphere in order to understand the relative strengths of these two opposing effects in the total column ozone determinations from ground-based and satellite measurement systems and in appropriate form in model calculations.

C. Effects of Particle Precipitation Events

Two-dimensional studies in collaboration with scientists of the University of Colorado and the National Center for Atmospheric Research have evaluated the effects of particle precipitation events on the mesosphere and stratosphere.[5,6] The effect on odd nitrogen is important in the understanding of the natural variation of stratospheric ozone.

D. Coupled Radiative and Chemical Models

The one-dimensional steady-state and time-dependent models are being used in conjunction with the one-dimensional radiative model of the Geophysical Fluid Dynamics Laboratory of ERL.[7] The coupled models predict that chemical damping of gravity waves is not nearly as important as had previously been thought. This has led to a new approach to the problem, and the results now predict a larger amount of damping, consistent with observation, but basically from radiative effects rather than chemical.

E. Comparison of Theoretical and Measured Values

The one-dimensional combined steady-state and diurnal model has been used to compare theoretical values for the concentrations of NO, NO_2, HNO_3, O_3, and H_2O with those measured in a balloon flight of the University of Denver.[8] Agreement is very good for NO, NO_2, and HNO_3 even though in the lower stratosphere the measured water-vapor concentration is much higher and the measured ozone concentration is lower than a one-dimensional model would predict. This is probably a dynamical problem arising from transport of H_2O and O_3, which are both long-lived in the lower stratosphere.

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II. STRATOSPHERIC WATER VAPOR MEASUREMENTS

Stratospheric water vapor concentrations provide insight into two atmospheric processes. First, water vapor serves as an excellent tracer of tropospheric-stratospheric exchange and transport processes, because the concentrations reflect the temperature of the tropopause through which the water vapor entered the stratosphere. In addition to this tracer role, H_2O concentrations reflect aspects of stratospheric transport and chemical processes.

With the goal of using stratospheric water vapor as a window into these processes, a balloon-borne, fast-response, self-calibrating instrument for the in-situ measurement of stratospheric water vapor was designed, developed, and flown by NOAA scientists. Since 1978, there have been a total of ten successful flights from Wyoming, Texas, and Brazil, the results of which have already contributed significantly toward the understanding of tropospheric-stratospheric exchange processes.

The stratospheric H_2O concentrations over Wyoming have been found to be too low to have entered the stratosphere by crossing the tropopause at this latitude.[5] The concentrations indicate that this water vapor crossed the tropical tropopause into the stratosphere, and was subsequently carried poleward.

Almost all of the flights have found that the stratospheric H_2O concentrations have a minimum just above the tropopause and increase with increasing altitude. Moreover, a comparison of the Wyoming flights with the Brazil flight suggests that stratospheric H_2O increases from the tropics to mid-latitudes. Both of these observed vertical and meridional increases are consistent with a stratospheric source of H_2O, such as the oxidation of methane.

The stratospheric water vapor detector has been redesigned to operate in the daytime. The first application of this new design has been built into an instrument that is carried aboard NASA's U2 aircraft, which flies up to 21 km. This research platform offers serveral hours flight time at many global locations. The first application was in Panama in the late summer of 1980. This mission explored tropical tropospheric-stratospheric exchange processes. The stratospheric water vapor instrument clearly identified significant upwellings into the stratosphere. Their structure and their relation to the air motions in this region are being examined. Several long-distance flights out of Moffett Field, California, have explored the longitudinal and latitudinal variations of stratospheric water vapor.

An international intercomparison of stratospheric and tropospheric water vapor sounding instrumentation was conducted under the leadership of the Federal Aviation Agency at Palestine, Texas in May, 1981 with generally good agreement among a variety of in-situ measuring techniques.

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III. IN-SITU STRATOSPHERIC COMPOSITION 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 chlorofluorocarbons 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 chlorofluoromethanes 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] The results of 24 flights over the last three years have been summarized recently.[2] This extensive data set has implications for many areas of atmospheric chemistry.

a. The chlorofluorocarbon data set clearly shows steady temporal increases in the ambient tropospheric levels of these chemicals, increases that closely parallel the estimated release rates. These data are being used in models that are aimed at better understanding of the ozone-depletion problem. Furthermore, the clear differences observed between the two hemispheres provide information about interhemispheric transport, since the release of these species is primarily in the northern hemisphere.

b. The N_2O data set demonstrates that there have been some increases in the tropospheric levels of this constituent, these have not been large.

c. Recent balloon flights have employed a larger set of sampling devices. With this finer sampling grid, the monotonic lapse rates of $CFCL_3$, CF_2Cl_2 and N_2O concentrations expected from diffusion and photochemistry alone have been observed occasionally to be perturbed quite markedly. These observations indicate that significant air movements were taking place, causing air masses containing higher mixing ratios of these species to intrude into or over regions where the mixing ratios were lower.

IV. 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.

A major part of the laboratory kinetics program involves developing methods of detecting important atmospheric molecules. A tunable diode laser, originally developed for studying high resolution infrared spectroscopy, was used to analyze whole air samples for their N_2O content.[1] Nitrous oxide, N_2O, is very important in the stratosphere where it is the main source of the nitrogen oxides which are ozone destruction catalysts. The spectroscopic measurement that was made of the N_2O concentration in air settled a major discrepancy amoung several laboratories with extensive N_2O measurement programs. The conclusion of this study was that a significant error existed in the calibration standards used by these laboratories.

Kinetic measurements have been made on the atmospheric reactions of ClO, chlorine monoxide, with nitrogen oxides NO and NO_2 using a laser magnetic resonance system.[2] These reactions act to reduce the ozone destruction by the chlorine species. The temperature and pressure behavior of the reactions were studied as well.

The first measurement of a new reaction path in the reaction of HO_2, the hydroperoxyl radical, with chlorine atoms was made.[3] The reaction of HO_2 with Cl is a major removal process for stratospheric chlorine because inert HCl is formed. This study demonstrated that different products, namely, ClO and OH, hydroxyl radicals, are also produced. This path has a completely different effect on ozone because these products are not inert.

Research has continued on the study of atmospheric ion-molecule reactions. Although no reaction of ions has been found to be significant in stratospheric ozone chemistry, ion chemistry has been shown to be a valuable probe of the composition of the stratosphere. For example, measurements of the ionic composition of the stratosphere when combined with laboratory kinetic data[4] have provided the first data on the amount of sulfuric acid in the stratosphere. Other laboratory studies of ion reactions have allowed predictions of the role of meteoric metals in the stratosphere to be made.[5-8] This subject remains controversial as some scientists have suggested that these metals may act to neutralize the catalytic chlorine species.

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V. 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.[1,2] Substantial changes are associated with stratospheric warming events.[3] 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.[4]

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.

A long series of measurements of the hydroxyl radical, OH, has been obtained at a location near Boulder by the use of spectroscopic techniques.[7] 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 provide the first indication of the temporal variability of stratospheric OH, both with season and solar cycle.

Aeronomy Laboratory scientists have been involved for several years in the planning phases of the Solar Mesosphere Explorer satellite launched October 6, 1981. The stratospheric NO_2 measurement spectrometer on the satellite is an adaptation of an experimental technique pioneered in the Aeronomy Laboratory and previously operated from ship and aircraft platforms and from a number of stationary surface sites. Three Aeronomy Laboratory scientists are members of the satellite team and will be involved in analysis of data now returning from the satellite. In addition to NO_2, SME will measure ozone by three different techniques, water vapor, temperature and solar flux. This coordinated data set should lead to improved understanding of the production and loss processes of stratospheric ozone. The NASA funded satellite is operated by the Laboratory for Atmospheric and Space Physics of the University of Colorado with collaborative support from NOAA and NCAR.

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VI. 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 the dynamics of the stratosphere. The laboratory has developed the technique of using VHF Doppler radars to measure motions of the clear air over a wide range of altitudes and scales of motion.[1] Radars have been constructed and are being operated at Sunset[2] and Platteville, Colorado, and at Poker Flat, Alaska.[3] The latter radar, constructed with the support of the National Science Foundation, is the largest radar in the world dedicated to study of the clear air. Using these facilities, the laboratory is making important contributions to the study of atmospheric dynamics at all scales, including turbulence,[4,5,6,7,8] gravity (buoyancy) waves,[9,10,11] tides,[12] planetary waves, etc. Understanding of motions on these scales will greatly improve our understanding of the ways in which minor atmospheric constituents are transported into and out of the ozone layer.

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AIR RESOURCES LABORATORIES
Silver Spring, MD and Boulder, CO

I. STRATOSPHERIC TEMPERATURE MONITORING

Stratospheric cooling will affect the rate at which temperature-dependent chemical changes will occur which are relevant to the ozone balance. Monitoring of stratospheric temperature is important because of the current or impending cooling of the stratosphere 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.

In the Northern Hemisphere stratosphere temperatures are being monitoring from both rocketsonde and radiosonde data. Figure 3 shows the variation in year-average temperature in the 46-55, 36-45 and 26-35 km layers through 1979, as obtained from rocketsonde data mostly in the western quadrant of the Northern Hemisphere. Shown at the bottom part of Figure 4 is the variation in year-average temperature in the 16-24 km layer through 1980 based on radiosonde observations throughout the Northern Hemisphere. The temperature variations shown by the two sets of data are not in agreement, but since different altitudes are involved, there is not necessarily an inconsistency.

The radiosonde data for the 16-24 km layer show clearly the warming following the eruption of Agung, but little overall temperature variation thereafter. The rocketsonde data, on the other hand, show a large temperature decrease between 1970 and 1976, with only a hint of a warming thereafter. It is noted that the relatively warm temperatures of 1969 and 1978 in the 26-55 km layer were near times of sunspot maxima but it is still too early to say there is a relationship between sunspot number and temperature in middle and upper stratosphere. It is emphasized that the cooling illustrated by rocketsonde data is much too large to be associated, in toto, with a CO_2 effect.

II. OZONE MONITORING

A. Trend Analysis of Data from the Global Ground-Based Ozone Monitoring Network

Because of the possible impact on the earth's ozone shield of chlorofluorocarbons and other anthropogenic emissions, careful analysis of total ozone data (the total amount of ozone in a vertical column above a given point on the earth's surface) is of importance. Total ozone data, as collected by the World Ozone Data Center, Toronto, Canada, are analyzed for the five

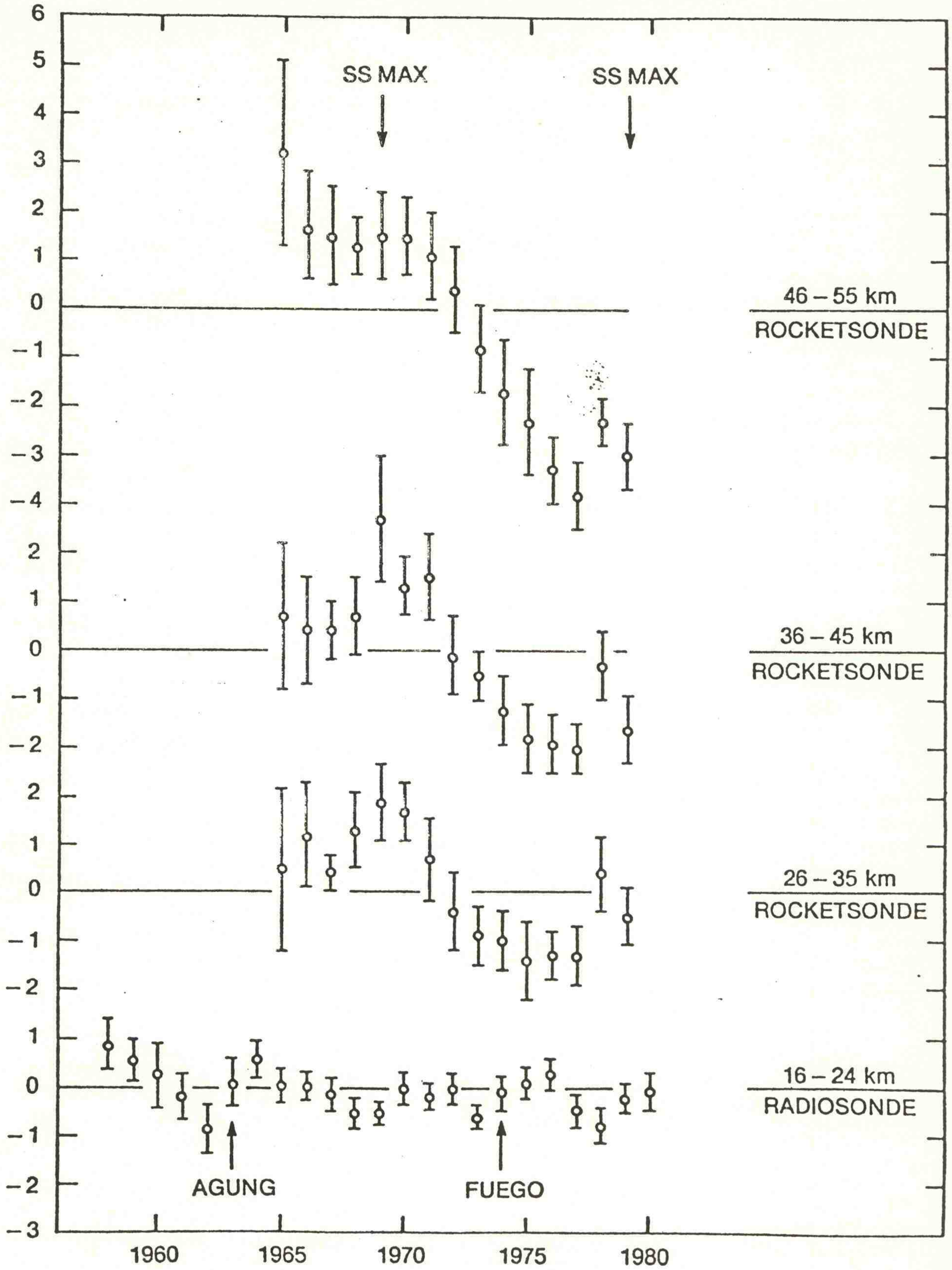

Figure 3. Variation in year-average temperature in stratospheric layers of the Northern Hemisphere, from rocketsonde and radiosonde measurements: Arrows labelled SS MAX indicate year of maximum sunspot activity.

regions in the north temperate climate zone with adequate coverage from instrumented ground sites (North America, Europe, Soviet Union, Japan and India). Total ozone is also analyzed for the other four climate zones, and totals for each hemisphere and the world are calculated from all ground-based data sources. Figure 1 (See Summary of Findings) shows the variation in year average total ozone from 1958 through 1980 for each hemisphere and the world total, expressed as a percentage deviation from the mean. The vertical bars are confidence limits such that there is about a 95 per cent chance that the true value of the mean lies within the extent of these bars.

In the mean for the world, the total ozone amount was observed to be a significant 2.2 percent above average in 1979, and a non-significant 0.3 percent above average in 1980, where the average is based on the years 1958-1977. All regions in the north temperate climatic zone and all four other climate zones, which showed an increase in total ozone between 1978 and 1979, registered a decrease in total ozone between 1979 and 1980. (It is noted that the relatively high total ozone values in 1958, 1970 and 1979 are near times of sunspot maxima, but it is still too early to say there is a relationship.) There is little evidence of a significant trend in total ozone during the 1970's for either hemisphere or for the world.

Photochemical modeling predicts that the largest percentage of ozone depletion from chlorofluorocarbon releases would occur near the 40 km level, and hence anthropogenic effects might first be noted near this level. Crude estimates of the ozone variations at these heights can be obtained by the Umkehr observation method on the Dobson spectrophotometers. Figure 2 (See Summary of Findings) 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, India, and recently, North America). The Umkehr data are presented for stratospheric height-layers 32-48 km, 24-32 km, and 16-24 km. For comparison, ozonesonde data are presented for height layers 24-32 km and 16-24 km based on observations in North America, Europe, and until recently, Japan.

In the critical 32-48 km layer the short-term Umkehr-indicated decrease in ozone following the volcanic eruptions of Mt. Agung and Fuego is believed to be mostly an instrumental artifact due to errors introduced by stratospheric aerosols of volcanic origin. The magnitude of the ozone increase since the Fuego eruption (presumably due to fallout of the aerosols) implies that there has been little ozone change in this layer since 1970, with the 1979 value a significant 4.3 percent above average and the 1980 value a non-significant 2.9 percent above average, where the average is based on the years 1961-1977. In both 16-24 km and 24-32 km layers the Umkehr data suggest

essentially no change in ozone amount since 1970, whereas the ozonesonde data suggest overall a slight ozone decrease. Thus, we cannot be sure of the actual ozone trend in these two layers during the past decade. Detection of a trend is made difficult by the strong quasi-biennial oscillation of ozone in 16-24 and 24-32 km layers.

B. U.S. Dobson Spectrophotometer Ozone Monitoring

Dobson spectrophotometer total ozone observations have played an important role in recent years in ozone trend analyses. Such observations, in addition, provide "ground truth" data for ozone observations made with satellite borne instrumentation. During 1980 and 1981, the Air Resources Laboratories continued to monitor total ozone at the twelve U.S. Dobson spectrophotometer stations. A list of the station locations, showing the available ozone record, is given in Table 1. Observations at Tallahassee, Florida, which were temporarily discontinued in 1979, were resumed in October, 1981.

Recently, a least squares fit autoregressive trend model has been used to derive ozone trend data for North America for the time interval 1961 through 1980. Data used were provisional monthly mean total ozone values published by the World Ozone Data Centre in Canada. Included were 1980 Canadian and U.S.A. total ozone data submitted for publication but not yet published. Results of the analyses shown in Table 2 and Figure 4 confirm earlier findings that ozone increased over North America during the 1960's but decreased over North America during the 1970's. The decrease for North America is larger than for any other region in the world. The reason for this difference is not known.

In assessing the accuracy of total ozone measurements made with Dobson spectrophotometers, a possible 5% systematic error was investigated. It appears that it is due to use of an erroneous ozone absorption coefficient for the short wavelength of the Dobson instrument A wavelength pair. In related research, the effect of interfering trace gas pollutants on the accuracy of Dobson instrument ozone measurements was studied. Potentially significant interferers were found to be SO_2 and NO_2. Trace gas species having absorption spectra at the Dobson instrument wavelengths but presenting insignificant interference were identified to be N_2O_5, H_2O_2, HNO_3, acetaldehyde, acetone, and acrolein.

Table 1- 1980 U.S. Dobson Ozone Spectrophotometer Station Network

Station	Period of Record	Instrument Number	Agency
Bismarck, N. Dakota	010163-present	33	NOAA/NWS
Caribou, Maine	010163-present	34	NOAA/NWS
Tutuila Is., Samoa	121975-present	42	NOAA/GMCC
Mauna Loa, Hawaii	010264-present	63	NOAA/GMCC
Wallops Is., VA	070167-present	38	NOAA/NASA
Barrow, Alaska	080273-present	76	NOAA/GMCC
Nashville, Tenn.	010163-present	79	NOAA/NWS
Boulder, Colorado	090166-present	82	NOAA/GMCC Hq.
White Sands, N. Mexico	010572-present	86	NOAA/Dept. of Army
Tallahassee, Florida	050273-053179	58	NOAA/Fla. State Univ.
Huancayo, Peru	021464-present	87	NOAA/Huancayo Observatory
Amundsen-Scott, Antarctica	120563-present	80	NOAA/GMCC

Table 2. Running Ten-year Linear Ozone Trends Derived from North America Dobson Spectrophotometer Total Ozone Data

STATION	Periods of Record												
	58-67	59-68	60-69	61-70	62-71	63-72	64-73	65-74	66-75	67-76	68-77	69-78	70-79	71-80
Bismark						1.49 ±2.23	-0.37 ±2.48	-0.91 ±2.47	-2.45 ±2.65	2.46 ±2.62	-2.81 ±2.13	-3.94 ±2.18	-3.7 ±2.12	-3.3 ±2.45
Boulder							-0.07 ±2.04	-1.85 ±2.31	-1.14 ±2.52	-6.48 ±2.99	-5.63 ±2.51	-9.12 ±3.30	-4.49 ±2.55	-1.76 ±2.08
Caribou						0.17 ±3.33	-0.51 ±2.25	-3.88 ±3.86	-3.17 ±3.34	-4.34 ±3.77	-1.34 ±2.98	-3.58 ±2.79	-2.78 ±3.98	-4.27 ±3.88
Churchill								-1.90 ±3.81	-.284 ±3.37	-6.15 ±4.02	-10.77 ±4.24	-7.58 ±3.12	-2.36 ±2.73	-2.02 ±3.85
Edmonton	0.04 ±3.28	5.77 ±3.99	5.70 ±3.67	1.45 ±3.51	-0.34 ±3.35	-1.13 ±3.21	-3.02 ±2.93	-1.24 ±2.58	2.77 ±2.98	-0.61 ±3.07	-1.78 ±3.75	-4.02 ±4.02	-3.41 ±4.25	-3.88 ±3.82
Goose Bay					8.26 ±3.99	8.37 ±4.26	5.73 ±4.29	6.36 ±4.09	3.96 ±2.70	-1.93 ±3.11	-2.61 ±2.56	-1.41 ±1.90	-3.29 ±2.44	-4.29 ±3.05
Nashville						0.94 ±3.21	1.96 ±2.63	1.59 ±2.22	-0.17 ±2.11	-0.68 ±2.23	-1.21 ±3.61	-4.88 ±3.11	-0.61 ±2.79	1.17 ±2.77
Resolute	2.15 ±3.86	3.93 ±4.04	2.21 ±3.91	4.35 ±4.71	0.52 ±4.59	-0.67 ±5.33	-0.37 ±5.11	3.29 ±4.43	1.22 ±3.99	-4.07 ±5.64	-0.46 ±4.33	-2.13 ±5.18	0.88 ±5.32	-1.91 ±3.18
Toronto			4.01 ±3.18	0.11 ±2.93	-0.19 ±2.73	0.16 ±3.03	-2.48 ±2.72	1.24 ±2.76	1.18 ±2.93	0.63 ±2.72	4.00 ±3.81	-0.72 ±3.44	0.24 ±3.11	-0.14 ±2.99
Combined Trends	1.1 ±2.5	4.8 ±2.8	4.0 ±2.1	2.0 ±2.2	2.1 ±1.9	1.3 ±1.4	0.1 ±2.8	0.3 ±1.1	-0.1 ±1.0	-3.1 ±1.2	-2.5 ±1.1	-4.2 ±1.1	-2.2 ±1.1	-2.3 ±1.1

1. Trends are expressed in percent ozone change per decade. Indicated trend uncertainties are 95% confidence level standard errors. (Combined trends have been computed without regard to the statistical homogeniety of the various datra sets, and may require modification.)

2. Above results have been derived from autoregressive model ozone trend analyses.

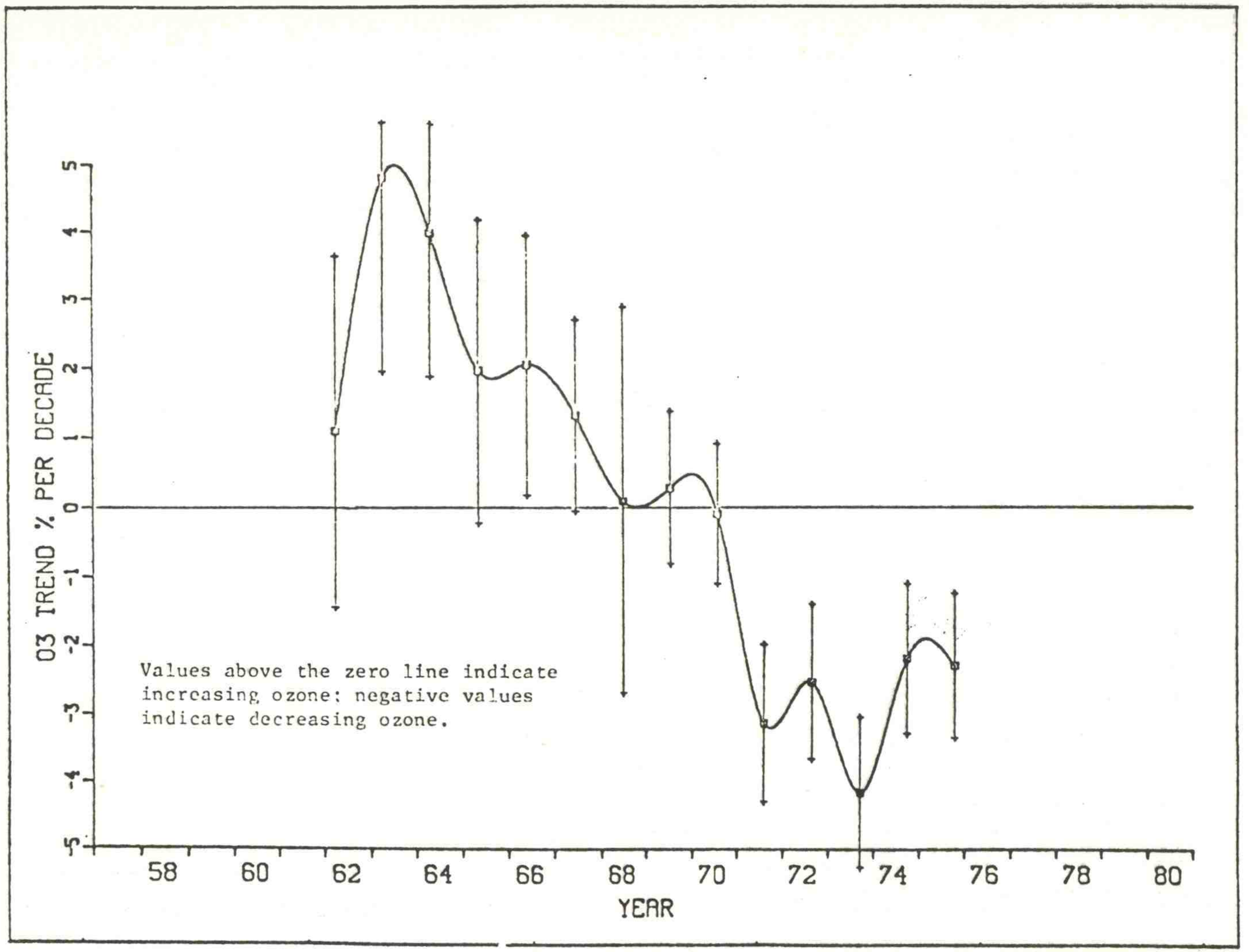

Figure 4. Ozone variations in percent per decade over North America since 1957. The vertical bars represent 95 percent confidence levels (see Table 2).

A program to monitor long-term variations in ozone vertical distribution by the Umkehr method is continuing in Boulder, Colorado. The program goal is ozone trend detection at approximately 40 km altitude (2.8 mb) where photochemical theory predicts that the greatest percent change in ozone will occur due to ozone depletion by chlorofluorocarbons.

Two projects are currently under way to develop improved instrumentation for high altitude ozone vertical distribution measurements. The first entails automation of a Dobson spectrophotometer for Umkehr observations. Use of automatic instruments for such observations would result in an increase in the frequency of such observations, as well as in data that are not observer biased. The second involves adaptation and testing of the electrochemical concentration cell (ECC) balloon ozonesonde for high altitude ozone soundings up to 40 km.

Automation of Dobson spectrophotometer No. 61 is nearing completion. Results of comparison Umkehr data obtained in Boulder on 19 September 1981 with the automated Dobson instrument side by side with the manually operated world standard Dobson spectrophotometer No. 83 are shown in Figure 5.

Adapting the ECC ozonesonde for high altitude soundings has entailed improving the sonde pump efficiency at altitudes above 10 mb, checking instrument performance characteristics such as the sensor background current, and developing a reliable, inexpensive balloon vehicle for reliable height attainment to flight altitudes of 40 km. About 50 percent success has been achieved in obtaining desired flight altitudes using 4000 g rubber balloons. This frequency of success has been, however, deemed insufficient. As a result, tests are currently underway with lightweight (0.23 mil plastic) balloons capable of bearing the sonde flight packages to 40 km altitude. Two flights with plastic balloons have been made to date, both successfully attaining a flight altitude of 40 km.

C. Upgrading the Global Dobson Spectrophotometer Network

The Air Resources Laboratories continued a program begun in 1977 to upgrade, under auspices of the WMO Global Ozone Research and Monitoring Project, the Dobson ozone spectrophotometers operated by other nations. In 1979, the NOAA Dobson Instrument No. 83 at Boulder, CO, was designated by the WMO as the Primary Standard total ozone measuring instrument for the world. In 1980, the WMO designated the Boulder Air Resources Laboratories (GMCC Program) as the World Central Laboratory for Dobson spectrophotometer calibrations.

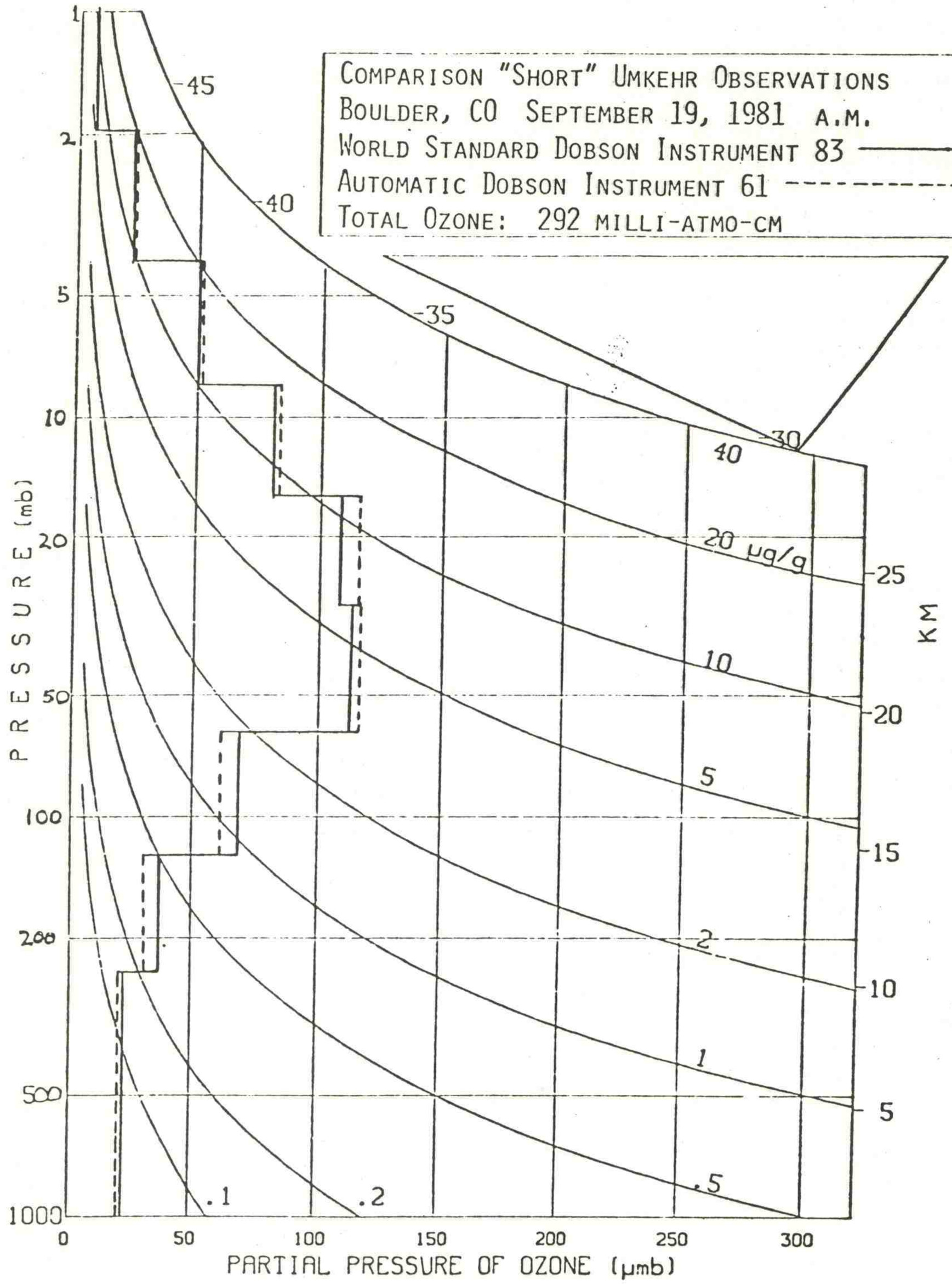

Figure 5. | Umkehr ozone profile obtained with automatic Dobson instrument 61 and manually operated instrument 83.

Foreign Dobson spectrophotometers modernized and calibrated in 1980 and 1981 were Nos. 97 and 99 in Buenos Aires, Argentina; No. 114 in Chachoeira Paulista, Brazil; No. 64 in Potsdam, German Democratic Republic; and No. 41 in Bracknell, United Kingdom. To date 40 instruments (see Figure 6) have been directly calibrated and 40 other instruments have been indirectly calibrated relative to World Standard Dobson Instrument No. 83. This total of 80 instruments represents a substantial fraction of the approximately 110 existing Dobson spectrophotometers, about 73 of which are currently in use for observations.

To standardize Dobson spectrophotometer operating and calibrating procedures throughout the world, an "Operations Handbook - Ozone Observations with a Dobson Spectrophotometer" has been prepared for the World Meteorological Organization. Copies of the handbook are available from the WMO in Geneva, Switzerland, or from the World Dobson Spectrophotometer Calibration Center, Air Resources Laboratories, R329, Boulder, Colorado 80303.

D. Disparities Between Satellite-based and Ground-based Total Ozone Measurements

Ground truth total ozone measurements have been extremely important as a check on satellite total ozone measurements, especially for detecting long term instrument drifts. The Dobson spectrophotometer is the accepted instrument for ground truth measurements. However, there exisits some ambiguity in total ozone measured by the Dobson when different wavelength pairs are used. The wavelengths used on the BUV and SBUV satellite ozone sensors differ from those used by the Dobson. A persistent bias of about 5% has been noted in comparisons between the Dobson and satellite ozone measurements. A close examination of total ozone derived from an ultraviolet transmission spectrum for every 0.2nm in the wavelength range between 298.1 and 319.5nm revealed variations in total ozone amounts on the order of ±5%, yet these variations were consistent with the differences seen between the satellite and Dobson measurements at the several discrete wavelengths used by these instruments. It is suspected that the Dobson might be in error by 5% (too high), and that the cause could be due to the use of incorrect ozone absorption coefficients. However, a satisfactory explanation has not yet been found. This error in absolute value would not affect trend estimates.

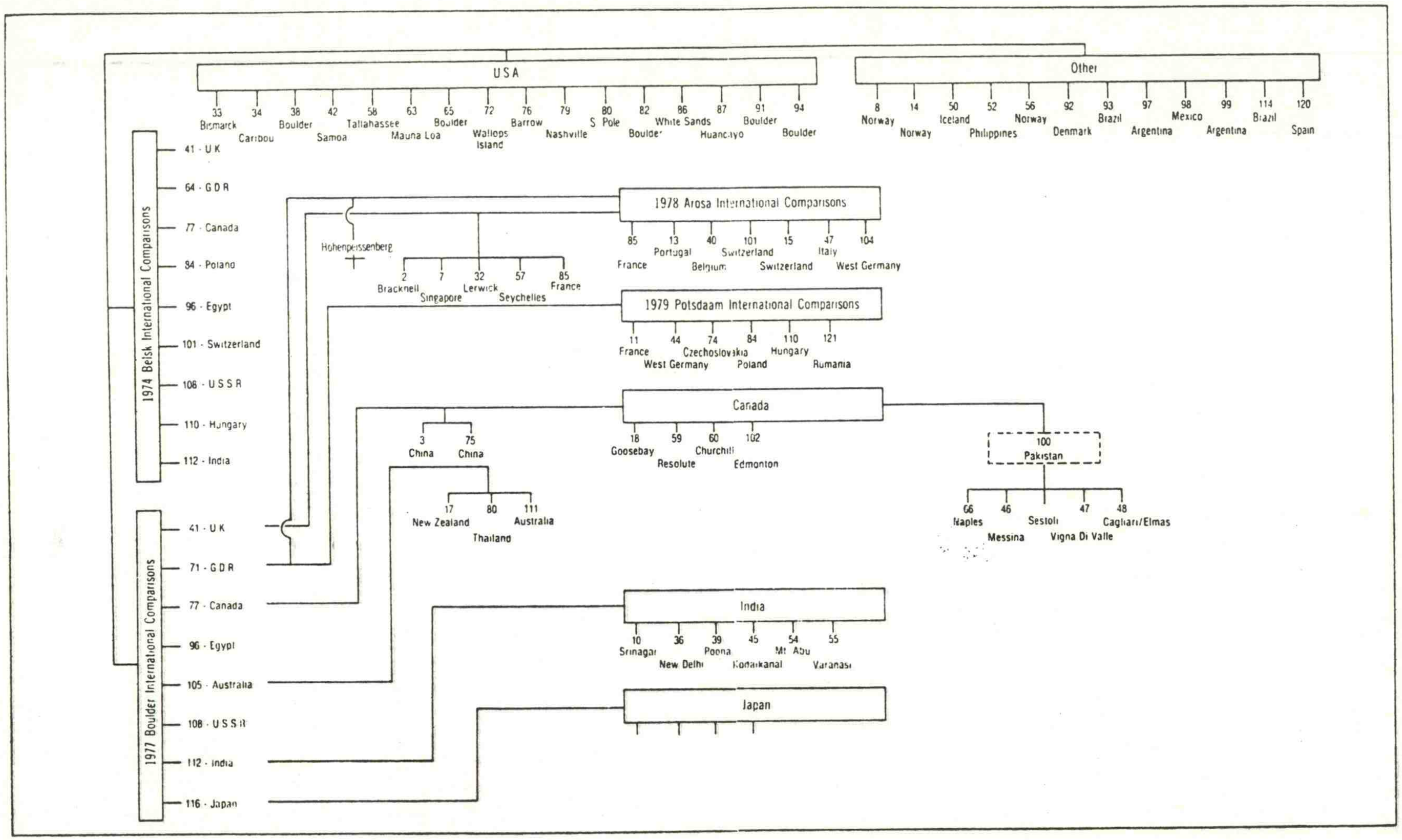

Figure 6. Calibration of global Dobson ozone spectrophotometers relative to World Primary Standard Instrument No. 83 maintained by NOAA.

E. The Short Umkehr Ozone Profile Technique

An improved, more rapid method of acquiring vertical distribution profiles of ozone from the ground-base Dobson spectrophotometer has been developed in a joint Canadian-U.S. effort, designated as the "short Umkehr" method. The short Umkehr method requires zenith sky measurements on the A-, C-and D-wavelength pairs of the Dobson ozone spectrophotometer ranging over the solar zenith angle between 80 and 89 degrees. It has been shown in a theoretical-numerical study that such measurements contain as much information about the ozone profile as do the conventional Umkehr observations taken on the C-wavelength pair over the solar zenith angle between 60 and 90 degrees. The short Umkehr requires about one-third of the observing time needed for the conventional Umkehr.

This reduced observing time gives the short Umkehr at least three distinct advantages over the conventional Umkehr. First, there is less chance that significant changes in the ozone profile will occur during the course of the observation; second, there is a better chance that the zenith sky will remain clear,; and third, it costs less per Umkehr observation in terms of observer time.

A computer program for short Umkehr ozone profile data reduction builds upon the earlier work done on the conventional C-pair evaluation program with the addition of the optimum or maximum likelihood inversion method. This method uses a priori ozone profile information obtained from rocket and balloon ozonesondes. The short Umkehr computer program has been completed and preliminarily tested using ozonesonde observations taken concurrently with short Umkehr observation. It is available for routine reduction of Umkehr measurements submitted to the World Ozone Data Center at Toronto. Comparisons between satellite and Umkehr observations of ozone in the upper stratosphere suggest that the Umkehr may be a reliable ground-based system for validating satellite measurements.

F. Aerosol Errors in Umkehr Ozone Profile Measurements

Errors in Umkehr ozone profiles caused by aerosol scattering and absorption are most strongly related to optical depth, and to a much lesser extent to aerosol refractive index, size distribution, and vertical profile in the troposphere. Stratospheric aerosols cause considerably greater error than tropospheric aerosols. Because the aerosol error in ozone profiles is mainly related to aerosol optical depth and in a systematic and linear way, it is feasible to make a correction to the ozone profile if tropospheric and stratospheric optical depth are known. Tropospheric optical depth is commonly obtained by

sunphotometer measurements, but stratospheric aerosol optical depth requires more sophisticated means for its measurement; some possible methods are lidar and satellite (SAGE) measurements or transmission measurements from a remote mountaintop observatory such as Mauna Loa. Finally, the short Umkehr method seems to be less sensitive to atmospheric aerosols, as compared to the standard method by nearly a factor of 2. The reasons are thought to be due to the shorter range of sun angle change needed for the short Umkehr measurement, and curtailment of the measurement at 89° solar zenith angle. Corrections to longterm series of Umkehr observation affected by stratospheric aerosol have been estimated. These corrections show that the sudden decrease in upper stratospheric ozone following the eruptions of Agung and Fuego were likely due to the effect of aerosols on the Dobson spectrophotometer measurements. Corrections are important when stratospheric aerosols are increased by volcanic eruptions.

III. MONITORING ERYTHEMAL ULTRAVIOLET RADIATION AT THE GROUND

With financial support by the Environmental Protection Agency, NOAA has maintained a network of Robertson-Berger meters to measure ultraviolet radiation from the sun during the past eight years in collaboration with the Temple University Medical School. The current stations in the network appear in Table 3. 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.

Climatological maps of ultraviolet radiation (UV) for the contiguous US were prepared and sent to the National Eye Institute, NIH and the Ames Research Center, NASA. The maps were constructed from regression equations which related monthly averages of R-B UV-B radiation to global solar radiation and total ozone. The equations were used to generate climatological UV amounts from the climatological record of solar radiation (1952-1976) and ozone (1958-1978).

TABLE 3
STATIONS REPORTING ERYTHEMAL UV RADIATION
1980-1981

U.S.

Albuquerque, NM
Atlanta, GA
Bismarck, ND
Des Moines, IA
Detroit, MI
El Paso, TX
Ft. Worth, TX
Gainesville, FL
Honeybrook, PA
Houston, TX
La Jolla, CA
Mauna Loa, HI
Minneapolis, MN
New Orleans, LA
Oakland, CA
Philadelphia, PA
(Two Recorders)
Pt. Barrow, AK
Rockville, MD
Salt Lake City, UT
Seattle, WA
Tallahassee, FL
Tucson, AZ

Non-U.S.

Basel, SWIZ
Belsk, POL
Brisbane, AUS
Davos, SWIZ
Hamburg, GER
Hamilton, NZL
Melbourne, AUS
Panama, PAN

The response of the Robertson-Berger sunburn meter is calibrated empirically against the exposure of human skin to solar ultraviolet radiation. The absolute uv energy of a sunburn unit in the human erythema band was not measured until the present investigation. In an in-depth analysis, data from a Robertson-Berger (RB) erythema flux meter were compared with concurrent measurements obtained with an ultraviolet spectroradiometer. It was found that at a solar zenith angle of 30° one sunburn unit (SU) is equivalent to $35 \pm 4 mJ\text{-}cm^{-2}$, and at a solar zenith angle of 69° one SU is equivalent to $20 \pm 2 mJ\text{-}cm^{-2}$ (relative to a wavelength of 297 nm), where the rate of change is nonlinear. The difference is due to the RB-meter's imperfect simulation of the response of human skin to the incident ultraviolet solar spectrum. Moreover, the rate of growth of the deviation with increasing solar zenith angle was found to be 1.2% per degree between solar zenith angles 30° to 50° and 2.3% per degree between solar zenith angles 50° to 70°. These deviations of response with solar zenith angle were found to be consistent with reported RB-meter characteristics. The work now makes it possible to further utilize Robertson-Berger meter measurements in other fields of biological research, and in addition, chemical engineering involved with degradation of materials exposed to solar ultraviolet radiation.

IV. GROUND-BASED MONITORING OF CHLOROFLUOROCARBONS (CCl_3F AND CCl_2F_2) AND NITROUS OXIDE (N_2O)

Chlorofluorocarbons are decomposed in the stratosphere by photolysis, causing catalytic destruction of stratospheric ozone by released chlorine atoms. The major chlorofluorocarbons emissions are CCl_3F and CCl_2F_2 from various human activities. Nitrous oxide (N_2O) also enters into stratospheric photochemical reactions (involving NO_x) that lead to catalytic destruction of ozone. Nitrous oxide is emitted from land by bacterial denitrification of fixed nitrogen, as well as from combustion of fossil fuels for energy and heat.

The Air Resources Laboratories have been monitoring CCl_3F, CCl_2F_2 and N_2O since 1977. Data are obtained at Barrow (BRW), Alaska; Niwot Ridge (NWR), Colorado; Mauna Loa (MLO), Hawaii; American Samoa (SMO), South Pacific; and South Pole (SPO), Antarctica. Results of linear regression trend analyses of the measurement data are shown in Tables 4 and 5.

Note the significant growth rates observed for CCl_3F and CCl_2F_2. Minimum atmospheric lifetimes tentatively calculated for CCl_3F and CCl_2F_2 are 41 and 65 years respectively. N_2O also appears to be increasing at all stations.

Table 4. Summary of CCl_3F and CCl_2F_2 Measurement Results

Trace Gas	Starting Date	Station	No. Obs.	Growth Rate PPTV/Yr	95% S.E. Growth Rate	Mixing Ratio PPTV	95% S.E. Mixing Ratio
	9/7/78	BRW	133	12.10	±0.62	172.9	±0.51
		NWR	130	10.78	±0.72	168.6	±0.65
CCl_3F		MLO	128	12.84	±0.64	163.8	±0.52
	(3 Yr)	SMO	136	12.35	±0.57	155.3	±0.49
		SPO	42	11.17	±2.77	157.0	±2.54
	9/7/78	BRW	112	15.10	±1.39	298.6	±1.09
		NWR	58	18.24	±1.46	295.9	±1.26
CCl_2F_2		MLO	112	18.97	±1.54	295.0	±1.16
		SMO	118	17.48	±0.81	273.1	±0.68
	(3 Yr)	SPO	32	17.93	±1.96	264.7	±1.72

Table 5. Summary of N_2O Measurement Results

Starting Date	Station	No. Obs	Growth Rate PPBV/Yr	95% S.E. Growth Rate	Mixing Ratio PPBV	95% S.E. Mixing Ratio
	BRW	143	0.43	±0.25	301.50	±0.21
	NWR	121	0.90	±0.30	301.78	±0.25
7/1/79	MLO	136	0.88	±0.32	300.66	±0.28
	SMO	144	1.44	±0.36	303.17	±0.29
(3 Yr)	SPO	63	0.44	±0.36	299.44	±0.33
Mean Growth Rate: 0.82 PPBV/Yr				N.H. - S.H. Conc.*: 301.1 - 299.4 = 1.9 PPBV		

*Excluding SMO

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Changes in atmospheric trace constituents and the climatic effect of such changes cannot be detected or understood without a firm knowledge of the processes which maintain and alter the normal state. Although such detailed knowledge is gradually accumulating, a number of important gaps and deficiencies remain at the end of 1981. Further progress requires continued intensive research efforts 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 middle atmosphere research effort was accelerated in 1970 when a commitment was made to concentrate specificially on the stratosphere. The summary of stratospheric research performed at GFDL since January 1980 builds on the considerable base constructed prior to that date.

Listed below are summaries of the 1980-1981 progress in various GFDL research activities related to the atmospheric ozone problem and its potential climatic impact.

I. THREE-DIMENSIONAL MODELING OF TRACE CONSTITUENT BEHAVIOR

A number of problems have been explored since 1979 dealing with the transport and chemistry of trace constituents, using one of the GFDL global 3-D general circulation models (GCM) (e.g., Manabe, Hahn, and Holloway, 1974; Manabe and Mahlman, 1976) to provide self-consistent, time dependent winds.

A. Atmospheric N_2O Experiments

Analysis has continued on a number of 3-D experiments simulating the behavior of atmospheric N_2O. The first experiment assumed the surface emission of N_2O to be horizontally uniform. In the second experiment the surface source is removed completely ("No Source"). In a third experiment the surface source is allowed to emanate only from land areas with rainy climates ("Swamp Source"). Here the global source strength is the same as in the first experiment.

Results from the "No Source" N_2O experiment show indirectly that the lower tropospheric variability is strongly influenced by the local intensity of the surface source, while the downward flux of smaller values of N_2O from the stratosphere plays a lesser role. For the "Swamp Source" experiment, the surface layer concentrations and variabilities are strongly influenced by the locations of the source regions. This result provides a

powerful tool for determination of the source locations and strengths in the actual atmosphere. Details are given in Levy and Mahlman (1980).

Through further analysis, it was determined that, while spatial variability in the boundary layer is strongly dependent on the surface structure, spatial variability in the middle troposphere and above is controlled by large-scale vertical transport. The results of this work also apply to most long-lived trace gases (see Levy, Mahlman, and Moxim, 1981).

In addition, a series of experiments investigating the sensitivity of the stratospheric N_2O distribution to various destruction hypotheses is underway. These experiments have indicated a remaining deficiency in the current state of quantitative modeling of stratospheric N_2O: the use of currently accepted, slower N_2O destruction rates in the model does not produce the best agreement with observations. Faster stratospheric destruction rates are required. Preliminary results from this research are available in Levy, Mahlman, and Moxim (1980b).

B. Reactive Nitrogen in the Troposphere

One of the problems in tropospheric chemistry receiving attention is that of the budget of reactive nitrogen. This quantity is produced by anthropogenic processes at the ground (combustion) and aloft (aircraft) as well by the stratospheric destruction of N_2O. Reactive nitrogen is destroyed primarily through heterogeneous removal in the form of nitric acid.

To explore the possible role of the stratospheric reactive nitrogen source, the results of a previous tracer experiment by Mahlman, Levy, and Moxim (1980) were scaled by using the N_2O fields calculated in the above experiments. The analysis indicates that the stratospheric reactive nitrogen dominates the upper troposphere, and may be significant in regions of the lower troposphere far removed from pollution sources. (Levy, Mahlman, and Moxim (1980a).

A series of model experiments has been started which examine the large-scale spreading and deposition of reactive nitrogen produced by surface combustion (the nitric acid contribution to "acid rain"). These experiments also examine the impact of the U.S. combustion source on the global nitrogen budget. During FY81, a series of short exploratory experiments were run to examine the effects of both rainout removal and surface deposition on the global influence of the U.S. source. Preliminary results indicate that, while combustion nitrogen is distributed throughout the Northern Hemisphere, the stratospheric source still dominates above 500 mb. The relative contributions of the stratospheric source and the combustion source below 500 mb remain uncertain.

C. A Revised Hypothesis for the Origin of Tropospheric Ozone

The results from the above N_2O and reactive nitrogen experiments, combined with recent nitric oxide measurements conducted by members of the Aeronomy Laboratory, have led to a strongly altered view of the behavior of ozone in the troposphere. Tropospheric ozone has previously been thought to be either transport-controlled by flux from the stratosphere or photo-chemically controlled by ozone sources and sinks near the surface. The new view, which arose out of a collaboration with scientists from the Aeronomy Laboratory, seems to explain difficulties with both previous views. Calculations indicate that photochemical ozone production, initiated by reactive nitrogen transported downward from the stratosphere, can produce as much or more ozone than is provided by the direct ozone flux. The added sink of ozone required is found in the lower troposphere by way of a water vapor related destruction path. Details may be found in Liu, et al. (1980).

One implication of this work is that significant ozone production due to subsonic aircraft emissions of reactive nitrogen could occur. Interestingly, analysis by Air Resources Laboratory members of available ozonesonde records (mostly from other countries) indicate an upper tropospheric ozone increase which is not inconsistent with those calculated.

Further research in this area is imperative because of the direct climatic effect of increased tropospheric ozone due to enhancement of the "greenhouse" blocking of tropospheric infrared radiation.

D. Examination of the Classical Theory for Tropospheric Ozone

The above work has led to an intensified interest in the understanding of tropospheric ozone. Because of the difficult and controversial nature of the subject, it was decided that a more basic understanding of the various components of the tropospheric ozone budget is required. Accordingly, an effort was made to examine the classical hypothesis that ozone brought down from the stratosphere is chemically inert and is removed from the atmosphere by contact with the earth's surface. The limits of remaining uncertainty in surface ozone removal have been explored through use in the model of high and low extremes in the surface removal rates. Interestingly, the results show that available observations are well bracketed by these experiments. Whether this means a reduced role for *in situ* ozone chemistry in the troposphere remains to be determined.

E. Review of Stratospheric Trace Constituent Transport

As part of a commitment to the Middle Atmosphere Program (MAP), a comprehensive review has been written for the first time on the problem of transport of trace constituents in the stratosphere. The review covers: the history of various viewpoints, relevant observations, a unified theoretical framework, available methodologies, parameterized transport hypotheses and future research requirements (MAP Study Group 2, 1981).

F. "Maximum Insight" Tracer Experiments

In recent years, there has been a growing interest in Lagrangian-oriented transport analysis methods as possible keys to clarify understanding of transport phenomena. In response to this, an effort is underway to formulate tracer experiments and analyses that seek to maximize physical understanding. For example, insights into some transport problems can be simplified if viewed in isentropic coordinates. To exploit the isentropic coordinate analysis techniques developed in FY81, two simplified tracer experiments have been designed. The first is initialized with the chemically inert tracer mixing ratio set equal to the potential temperature, the second with the tracer prescribed as a constant plus the latitude.

These experiments have revealed, in a very simple way, the essential features responsible for the pronounced downward slope of mixing ratio isolines toward the pole in the stratosphere. In particular, the equilibrium tracer slope appears as a balance between (1) the slope-steepening diabatic circulation, moving mass downward (upward) through the isentropic surfaces in high (low) latitudes, and (2) the direct effect of disturbances propagating into the stratosphere, producing slope-flattening down-gradient mixing along isentropic surfaces.

G. Stratospheric Aircraft Pollution Experiment

An experiment was begun in FY77 in an attempt to simulate the 3-D dispersion of gaseous effluents from an idealized fleet of stratospheric supersonic aircraft. Although the experiment has been run on a low-priority basis only since FY77, it has now been integrated out to equilibrium. Analysis of the results has begun.

II. MODELING OF THE TROPOSPHERE-STRATOSPHERE-MESOSPHERE SYSTEM

For the past 6 years, an effort has been underway to develop a comprehensive, three-dimensional general circulation model (GCM) of the radiative-chemical-dynamical structure of the

atmosphere from the earth's surface to the mesopause. A major goal of this research is to develop an internally consistent capability for simulating ozone and its changes. Activities under this program since 1979 are summarized below.

A. Low Resolution (N10) Annual Cycle Experiment

The low resolution (N10, (9°lat. by 10°long.) GCM has been run out to 3 years. The indication of a semiannual oscillation (SAO) reported previously has been sustained. This SAO appears to be quite realistic in the upper stratosphere. The basic model mechanisms for this SAO are as follows. The westerly phase is generated more or less continuously by momentum deposition from upward and eastward propagating equatorial Kelvin waves, the largest deposition of westerly momentum just below the maximum of the westerly wind. The "maximum entropy" technique used to obtain this result also has revealed the presence of so-called "fast" Kelvin waves near the model equatorial stratopause. The source of these waves has yet to be determined, but such waves have not been identified below 30 km in the model or in observations.

The westerly flow produced by that mechanism is interrupted twice a year by strong cross-equatorial flow producing advection of easterly momentum from the summer hemisphere. The cross-equatorial flow is excited by the unbalanced pressure gradient produced by differential heating between the summer and winter hemisphere. These results are described in Mahlman and Sinclair (1980).

For purposes of evaluating the climatic sensitivity of the stratosphere, it is of interest to know whether the inclusion of the annual cycle is essential. The annual average statistics from this experiment have been compared against the statistics from this annual-mean-insolation experiment of Fels, et al. (1980). The results show the two sets of statistics to be very similar. This suggests that stratospheric climate sensitivity experiments might be run successfully using the simpler annual-mean-insolation models.

B. "Low Diffusion" Medium Resolution (N18) Experiment

Analysis of previous experiments with this model, as well as comparisons with other finite difference and spectral models, led to the inference that low resolution finite difference models were unnecessarily diffusive. As a way of exploring this conjecture, the horizontal non-linear diffusion coefficient has been altered by reducing the multiplicative constant by a factor of three, while increasing the scale selectivity of the horizontal deformation operator. This change was applied to the N18 annual mean control model.

The alteration has had a number of significant effects. The tropospheric subtropical jets are significantly stronger, while the tropical upper tropospheric winds are much less westerly. An easterly acceleration is induced in the tropical middle stratosphere. The most dramatic effect, however, is that the mid-latitude mesospheric jets are reduced in magnitude and become completely closed off near their proper altitude. This behavior is related to an increased mesospheric mechanical dissipation resulting from the decreased horizontal diffusion. In this "low diffusion" experiment, increased wave activity is allowed to leave the troposphere and propagate upwards. The larger wave amplitudes lead to an increased excitation of the model's low Richardson number turbulent dissipation in the mesosphere. The dissipating disturbances force the marked deceleration of the mesospheric zonal flow.

C. Model Analysis Technique Development

Recently, significant effort has been expended to formulate model analysis packages which provide exact and more phenomenologically oriented balance analyses (Andrews, Mahlman, and Sinclair, 1981). Utilization of these packages has led to the diagnosis of a small code error which otherwise would have gone undetected. In addition, the new analysis procedures have produced a clearer identification of the types of aliasing and sampling problems which result from analysis of model data taken at relatively infrequent time intervals.

During FY81, an effort has also been underway to develop a more accurate technique to analyze model transport and wave dynamics in isentropic coordinates. The technique development phase is nearing completion

D. Simpler Models for the Interaction Between Waves and Flows

The effects of tidal motions on the general circulation of the middle atmosphere have been investigated. The heat and momentum fluxes associated with the diurnal tide were computed using separable tidal theory. These fluxes were used in turn to force a simple axisymmetric model of the stratosphere, mesosphere, and lower thermosphere. The results showed that the tide may induce significant mean zonal winds (10-20 m/sec) in the vicinity of the equatorial stratopause. In the lower thermosphere (80-90 km), the diurnal tide forces strong easterlies in the tropics and westerlies in mid-latitudes, in apparent agreement with the observed zonal winds in this region (Hamilton, 1981).

The simple, one-dimensional model of the quasi-biennial oscillation (QBO) of the tropical lower stratosphere originally devised by Holton and Lindzen has been investigated in some detail. It was found that the behavior of this model is very sensitive to the details of the spectrum of waves which are used to force it and to the upper boundary condition employed. In particular it is possible for the mean flow evolution in the model to be dominated by very long period (>10 years) oscillations if waves with phase speeds of 35 m/sec or greater are included.

A two-dimensional quasi-biennial oscillation model has been constructed which allows expansion of the above results. Unlike previous mechanistic models, which have considered only the meridionally averaged equations, the present version allows investigation of the latitudinal structure of the mean flow and of the waves which force the QBO.

A number of integrations have been performed with this model. The results indicate the following conclusions: (1) A vertically propagating Kelvin wave with the observed wavenumber, phase speed and amplitude tends to force a westerly jet which has a much narrower meridional scale than the observed westerly phase of the QBO. This problem can be alleviated by including a rather modest amount of horizontal momentum diffusion in the mean flow equations. (2) When the Rossby-gravity wave is damped with only radiative cooling, the induced easterly accelerations are centered off the equator in a very unrealistic manner. If mechanical dissiption of the wave is included, the accelerations become equatorially centered. However, inclusion of excessive mechanical dissipation (relative to the radiative dissipation) causes the production of an unrealistically narrow easterly jet. (3) With appropriate parameters for the waves and mean flow, a single Kelvin wave and a single Rossby-gravity wave can produce alternating easterly and westerly regimes in the mean flow model.

III. MODELING OF RADIATIVE AND CHEMICAL PROCESSES

A. Computation of Infrared Cooling Rates

An algorithm for computing accurate CO_2 15 micrometer band cooling rates has been completed, including the publication of detailed tranmission function tables (Fels and Schwarzkopf, 1981).

An investigation of the effect of non-Lorentzian shape on the CO_2 15 micrometer bands was begun, with two objectives: a) to assess the sensitivity of transmission functions to such effects; b) to discover the best empirical line shape by comparison with high quality laboratory data.

The comparison of line-by-line and suitable random model results shows that the latter provide a fast way of assessing the effects of altered line shape on transmitivities. It has been found that variation in line profile cutoff between 1 cm and 30 cm alters the total CO_2 absorption by up to 5%.

The availability of excellent laboratory spectra at a large number of pressures and path lengths has made it possible to determine an effective cutoff, (3 cm) which fits the bulk of the data very well. With this value, calculated broad band integrated absorptions agree with the measured values to within 0.5% in most cases.

B. Parameterization of Scale-Dependent Radiative Damping

Radiative transfer is not only important because it drives atmospheric circulations, but also because it plays a central role in the damping of atmospheric temperature disturbances due to infrared thermal emissions. The quantitative description of circulation, temperature, transport, and trace constituent structure in the atmosphere are all strongly affected by such damping processes.

GFDL general circulation models have traditionally incorporated sophisticated radiative transfer computations in which the infrared cooling rate at a given level depends on the temperature not only at that level, but at all others as well. On the other hand, the much simpler linear or mechanistic dynamical models generally use the so-called "Newtonian cooling" approximation. This approach makes radiative transfer calculations trivial by assuming that the cooling rate depends linearly on only the local temperature.

During FY81, a method has been developed which allows the effects of radiative non-locality to be included easily in a wide class of wave-dynamical problems (Fels, 1981). The manner in which a slowly modulated sinusoidal temperature perturbation is affected by radiative damping provides a way to define a scale-dependent generalization of the conventional Newtonian relaxation time.

With the use of the accurate radiative transfer algorithms developed previously (Fels, 1979; Fels and Schwarzkopf, 1981), careful calculations of scale-dependent damping times have been carried out for both the 15 micrometer bands due to CO_2 and the 9.6 micrometer band due to O_3. The results indicate that the effects of non-locality can be of great dynamical importance. For example, a disturbance with a vertical wavelength of 10 km has a purely radiative decay rate which is more than three times as large as that which would be calculated in the local Newtonian cooling approximation.

C. Incorporation of Ozone Chemistry in the Global Circulation Model (GCM)

The collaborative effort with NOAA Aeronomy Laboratory scientists has now reached an advanced stage of development. The chemical code has been properly calculated in the GCM vertical coordinate, including self-consistant temperature and density effects. The photochemically determined, implied shortwave heating rates are now very similar to those determined independently from the GCM short-wave heating algorithm.

The codes now have the capability of calculating both diurnal and diurnally averaged chemical equations. In addition, steady-state or time-marching techniques are optional, depending upon the nature of the problem. This chemical model has been successfully integrated with an off-line version of the GCM radiative transfer code.

D. Radiative-Photochemical Interaction

Although GFDL models have traditionally made use of pre-specified ozone amounts in radiative calculations, the determination of ozone distributions from first principles remains an important long-range goal. A first step in this direction is to gain an understanding of the coupling of photochemistry and radiation in the absence of dynamical processes (i.e., the determination of joint radiative-photochemical equilibrium).

In collaboration with scientists of the Aeronomy Laboratory, a model which combines that group's photochemistry (see Section 3 above) with the GFDL radiation code has been constructed. This model has been used to calculate radiative-photochemical equilibria in the middle atmosphere, as well as to investigate the relaxation of ozone and temperature perturbations toward equilibrium. The results of these perturbation decay experiments suggest that the photochemical enhancement of radiative damping may be less important than scale-dependent radiation (see Section 2 above) in damping middle atmospheric waves.

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SPACE ENVIRONMENT LABORATORY
Boulder, CO.

I. MONITORING SOLAR ULTRAVIOLET RADIATION FROM SATELLITE-AND GROUND-BASED INSTRUMENTS.

The Space Environment Laboratory (SEL) and the Air Resource Laboratories (ARL) began in FY 1980 a program to determine the natural variability of solar ultraviolet radiation, one key driving force in the climate of the earth. The Space Environment Laboratory project is being conducted in cooperation with NASA to monitor solar ultraviolet radiation from satellite-based Solar Backscatter Ultraviolet ozone monitoring instruments (SBUV-2) now being built under a joint NOAA-NASA contract for flights on the operational NOAA (Tiros-N) satellites beginning with a NOAA G launch in 1985. The Air Resources Laboratories conduct ground-based measurements to monitor the longer wave-length solar ultraviolet radiation as well as optical and infrared solar radiation to provide ground - truth for the satellite measurements. ARL is already conducting research to improve understanding of the atmospheric effects of solar UV variability and to improve the precision and accuracy of the measurement systems. Other ARL objectives include: to corroborate satellite measurements of the solar constant (a key factor in both the precision of the Dobson ozone spectrophotomete measurements world-wide and the earth's climate), to determine solar variability as a function of wavelength, and to conduct research to understand the effects of solar UV variability, particularly in the portion of the spectrum involved in sunburning (erythemal) effects.

The objectives of the SEL project are to determine the variability of solar ultraviolet radiation over time scales of months, years and decades; an understanding of why the solar UV flux varies and whether the variations can be predicted; and to determine the atmospheric reactions to solar ultraviolet variations and the extent to which these reactions contribute to climate variations.

During 1980-1981, the SEL project has determined the wavelength dependence of solar-rotation variations (approximately 27 days) of the solar UV flux in collaboration with NASA using Nimbus 7 SBUV data. The Space Environment Laboratory in cooperation with the Cooperative Institute for Research in the Environmental Sciences of the University of Colorado has developed models to explain these variations in terms of solar active region structure and spatial location on the sun. The understanding of these short-term variations is necessary in order to interpret any long-term series of measurements from rocket or shuttle flights as well as the operational

satellites. Also they help to interpret the solar ultraviolet varriations over a solar cycle caused by the build-up of active regions on the sun and the chromospheric network. The long-term varriations (years) recently observed by Nimbus 7 instrumentation are large enough to cause stratospheric changes, but corroborating measurements and further study are necessary to verify that these are real solar variations and not due to instrumentation problems. A program for developing a higher accuracy solar ultraviolet instrument for rocket flight measurements has been initiated. Rocket flight measurements of solar UV radiation are needed to recalibrate the satellite measurements and to permit intercomparison of measurements from satellites (Nimbus 7, Solar Mesosphere Explorer, and NOAA operational Tiros N SBUV-2) launched several year apart.

The Air Resources Laboratories portion of this program included a contract with the Institute for Atmospheric Physics and the Optical Sciences Center of the University of Arizona to conduct studies leading to improvements in the atmospheric corrections for ground-based solar flux measurements and to develop improved instruments and a ground-based solar flux monitoring program. Also the ARL is studying correlations of climate variations in the United States with variations in solar flux to determine the degree of significance of such correlations.

NATIONAL EARTH SATELLITE SERVICE
Suitland, MD

1. THE TIROS OPERATIONAL SATELLITE VERTICAL SOUNDER

Currently, the NOAA operational TIROS-N type spacecraft are equipped with the TIROS Operational Vertical Sounder (TOVS). The TOVS sounders continue to obtain atmospheric radiance data for subsequent inversion and derivation of total ozone amounts globally. The sequence of NOAA satellites and their periods of coverage are:

TIROS-N: April 15, 1979 - January 25, 1981 (demise)
NOAA 6: November 1, 1979 - Present
NOAA 7: August 15, 1981 - Present

The total column 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 designed for this purpose.) However, the accuracy required for these on board corrections is less than desired for a primary global ozone satellite monitoring system. In addition, the present operational capability to derive total ozone data only does not provide ozone profile data necessary for early warning purposes.

II. DEVELOPMENT AND OPERATIONAL IMPLEMENTATION OF THE SATELLITE-BORNE SOLAR BACKSCATTER ULTRAVIOLET (SBUV/2) OZONE MONITORING SYSTEM

The design phase of the SBUV/2 being developed for future NASA research operational use is continuing. A major change from previous instruments of this type will be the ability to command, in space, rotation of the gratings in order to change the wavelengths while in the operating mode. This will enable NOAA to insure a uniform wavelength setting on all of the instruments if any changes were noted to occur during and after launch.

The first SBUV/2 instrument is expected to become operational on the NOAA-G satellite currently scheduled for launch in 1985. (Any schedule of satellite launches is dependent upon unknown budget considerations.) It will be operated in several modes in a planned sequence in order to acquire a variety of data. These are:

1. Earth view mode - the instrument observes the earth in the nadir position and the wavelength sampling is in the discrete mode (ie; a sequence of several pre-selected wavelengths for determinations of total ozone and vertical ozone profiles).

2. Sun view mode - solar flux is measured after reflection off the diffuser for later use in determining the ozone products and for obtaining data on the solar flux itself. The wavelength sampling is both in the discrete mode and the sweep mode (ie. the total wavelength region of the instrument is covered in a continous scan)

3. Wavelength calibration mode - the instrument is directly irradiated by an on-board mercury lamp to periodically check the instrument wavelength settings.

4. Diffuser calibration mode - the instrument is again irradiated by the mercury lamp but reflected off the diffuser. This allows for a continuing history of the relative spectral behavior of the diffuser.

The Preliminary Design Review was held in April 1981. No major flaws were uncovered; however, it was noted that the photomultiplier tube used as the detector exhibited an unexpected hysteresis effect. This is being evaluated by contractor and government scientists.

III. EVALUATION OF THE GLOBAL TOVS TOTAL OZONE DATA

Evaluation and validation of the TIROS-N data is continuing with comparisons between the satellite-derived total ozone amounts and those amounts determined by Dobson spectrophotometers located approximately below at the satellite Nadir at observation time. Comparisons are being made also with the data determined by the R&D NASA SBUV instrument on the Nimbus 7 satellite.

The National Weather Service's Climate Analysis Center initiated daily global total ozone analyses from the operational TOVS data in the spring of 1981, using the ozone values derived by NOAA's National Earth Satellite Service. The analyses are presently archived by the Climate Analysis Center and are being compared against ground-based and NASA research satellite data from Nimbus 7. In addition, the data are being examined for possible utilization in the future by high-altitude aircraft to avoid high in-cabin ozone concentrations detrimental to the passengers and crew.

NATIONAL WEATHER SERVICE CLIMATE ANALYSIS CENTER
Camp Springs, MD

During 1980-1981 the Climate Analysis Center, Analysis and Information Branch (AIB) has focused on two main areas: (1) implementation of an operational stratospheric monitoring program and (2) examination of available data for trend analysis. The elements of each area are discussed below.

I. OPERATIONAL STRATOSPHERIC MONITORING

1. Daily, global meteorological analyses of height and temperature at 70, 50, 30, 10, 5, 2, 1 and 0.4 mb (20-55 km) continue to be constucted once/day, 1200 GMT. While the daily record exists back to late 1978, during the last two years several modifications have been initiated. For example the operational NESS retrievals up to 0.4 mb are utilized rather than derivations of temperatures from a simple regression scheme, as previously done.

2. Daily, global total ozone analyses from the operational TOVS data were initiated in the Spring of 1981 using the ozone values derived by NESS. These analyses are presently archived by CAC and are being compared against ground-based and NASA research satellite data (Nimbus 7). In addition, the data are being examined for possible utilization by high-altitude aircraft in order to avoid high ozone concentrations.

3. A draft version of the Federal Plan for Stratospheric Monitoring has been prepared, by personnel from NOAA, NASA, and FAA, with publication scheduled early in 1982. This plan coordinates the monitoring elements of the several agencies into a cohesive effort to provide the data necessary for precise trend evaluation.

4. The Climate Analysis Center has begun consideration of the data flow and archiving of the complete stratospheric monitoring data base. The basic parameters will include data and synoptic analyses of:

a)meteorological fields - pressure height, temperature and wind from 100 to 0.4 mb (16 to 55 km),

b)total columnar ozone

c)ozone mixing ratio from 30 to 0.4 mb (25 to 55 km), the full range of the data available from the backscattered ultraviolet technique employed on Nimbus 4 and 7 and planned for the Tiros N operational SBUV-2 satellite series beginning in about 1985.

It is anticipated that all operational products will be archived at EDIS, Asheville, North Carolina and at NCAR, Boulder CO.

II. EXAMINATION OF AVAILABLE OZONE DATA FOR TREND DETECTION

1. Monthly average global synoptic analyses of total ozone and ozone mixing ratio at 30, 10, 5, 2, and 1 mb for the period April 1970 - December 1976, from the Nimbus 4 BUV data, have been accomplished. These analyses have been archived at the National Space Science Data Center, Goddard Space Flight Center for public dissemination on magnetic tape or microfilm. An atlas of the ozone charts is in preparation.

2. The monthly average total ozone values from the above Northern Hemisphere analyses have been examined for trends and a paper entitled, "Total Ozone Variations 1970-74 Using Backscattered Ultraviolet (BUV) and Ground-based Observations" is to be published in the Journal of Applied Meteorology.

After consideration of the spatial gaps in the satellite data (utilizing a technique suitable for the Northern Hemisphere) and comparison with concurrent Dobson ground-based observations, no significant trend was found in the Northern Hemisphere BUV data over the years 1970-74.

3. Monthly average ozone mixing ratio from the above data, 30 to 0.4 mb, are currently being examined for trends, in cooperation with Professors George Tiao and Gregory Reinsel of the University of Wisconsin (supported by the Chemical Manufacturers Association), John Frederick of NASA Goddard Space Flight Center, John Deluisi of the Environmental Research Laboratory and Carl Mateer of the Atmospheric Environment Service, Canada.

This multidisciplinary effort was established because there are significantly less upper level data available for comparison against the BUV satellite than is the case for total ozone and significant questions exist as to the effect of solar variations and stratospheric aerosols (e.g. from volcanoes) on the measurements themselves.

Ultimately, the ozone mixing ratio variations will be compared with current theories on ozone depletion and the trend compared with that recently described by Heath based on the limited data samples from the BUV instruments on Nimbus 7 versus Nimbus 4.

4. Satellite ozone profile coverage extends from about 30 to 0.4 mb (25-55 km), since the backscattered

ultraviolet technique is currently bound at the lower level by our ability to consider single versus multiple scattering in the ozone retrieval algorithm. As the ozone concentration maximum, however, is below 30 mb and as there is considerable concern regarding the possible impact of high altitude aircraft on the ozone layer and also the health effect of ozone concentrations in the aircraft cabins, the need exists for complete vertical ozone profile information from the upper troposphere to the stratosphere.

Consequently, a technique is being developed to derive ozone profile information in the lower stratosphere and upper troposphere utilizing the SBUV and possibly the TOVS information. This is, basically, a statistical regression method whereby the average ozone amount in the lower stratosphere - upper troposphere is known from the difference between the total ozone and that integrated from above 30 mb, and the vertical variation within the region is determined via historical regression against available ozone balloon profiles. The preliminary results are very encouraging. We anticipate that a report will be available by summer of 1982. One operational use of such data may be to provide guidance to the aviation industry to aid flight planning in order to avoid high ozone concentrations.

ENVIRONMENTAL DATA AND INFORMATION SERVICE

I. ARCHIVING TOVS SOUNDING DATA

NOAA's National Environmental Satellite Service typically produces 7,000 to 8,000 soundings per day from both NOAA-6 and NOAA-7 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 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, radiances, and total ozone amounts in Dobson units. The TOVS sounding tapes are available from January 1, 1979, and may be ordered from the National Climate Center.