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A. Analysis of Satellite Data to Deduce Stratospheric Constituents and UV Spectroscopic Properties of the Atmosphere

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C. Abstract of Research Objectives

The objective of this research is to better understand the stratosphere, its constituents, and its ultraviolet optical properties, through detailed analysis of data from the SBUV instrument on Nimbus 7 and comparison with data from other instruments, including the NOAA 9 SBUV-2, SAGE, SME, and SMM. One clear conclusion to be drawn from the Ozone Trends Panel report is that there are unresolved differences in the ozone profiles measured by different instruments. While the purpose of the proposed work is more to understand the details of the UV radiation field in the stratosphere than it is to assess the accuracy of the SBUV ozone measurement itself, improved understanding of specific problems in the UV will certainly lead to more accurate ozone retrievals. Areas of study include the effect of aerosols on the backscattered albedo, the shape of the ozone profile near the stratopause, the effect of possible polar mesospheric clouds, and the measurability of nitric oxide and sulfur dioxide.

D. Summary of Progress and Results

A paper was completed this year detailing the results of a study of the long term climatology of nitric oxide based on analysis of gamma band fluorescence features in SBUV continuous spectral scan data. The integrated column amount of nitric oxide above an altitude of approximately 45-50 km is inferred from analysis of the strengths of the (10), (01), and (02) nitric oxide gamma bands. Analysis shows that there are about $5-6\times10^{14}\ molecules\ cm^{-2}$ of nitric oxide cumulative above 48 km over a wide range of latitudes, increasing sharply near the winter terminator by about a factor of three to $12-15\times10^{14}\ molecules\ cm^{-2}$. Between 1979 and 1986 column NO near the equator decreased by about a factor of two, from $6.4\times10^{14}\ molecules\ cm^{-2}$ to $3.3\times10^{14}\ molecules\ cm^{-2}$. The time dependence of the decrease correlates well with solar activity, following the decline in solar activity from solar maximum in 1979 to solar minimum in 1985-1986.

In addition work was done to compare measurements made by SBUV with those made by the SBUV-2 instrument on NOAA-9. Because the two satellites are in different orbits, it was necessary to develop a technique to normalize the radiance measurements from each instrument to standard zenith angles so that the measured albedo (radiance to irradiance ratio) could be compared and not just the ozone measurements. This is necessary in order to understand the long term behavior of the calibration of the two instruments, since derived ozone is a very non-linear quantity.

E. Journal Publications

"Intercomparison of NO Column Measurements during MAP/GLOBUS 1985," McKenzie, R.L., W.A. Matthews, Y. Kondo, R. Zander, Ph. Demoulin, P. Fabian, D.G. Murcray, O. Lado-Bordowsky, C. Camy-Peyret, H.K. Roscoe, J.A. Pyle, and R.D. McPeters, J. Atmos. Chem., 7, 353-367, 1988.

"The Climatology of Nitric Oxide in the Upper Stratosphere, Mesosphere, and Thermosphere from 1979 through 1986," McPeters, R.D., J. Geophys. Res., 94, 3461-3472, 1989.

"Long-term Changes in SBUV/TOMS Relative to the World Primary Standard Dobson Instrument," McPeters, R.D. and W.D. Komhyr, in preparation, 1989.

"Pair Justification: a Technique for Achieving One Percent Accuracy in Satellite Ozone Trend Determination ", R. McPeters, J. Herman, R. Hudson, R. Stolarski, C. Wellemeyer, and S. Taylor, paper presented at the 28th Liege International Astrophysical Colloquium on "Our Changing Atmosphere," Liege, Belgium, 26-30 June, 1989.

The Response of Upper Atmospheric O_3 and NO_2 to Solar UV Variations

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Research Objectives

The project makes use of the data from the instruments on the Solar Mesosphere Explorer (SME) satellite for:
(1) Analysis of the data on O_3 and solar UV radiation to determine the response of ozone to short-term variabilities in solar UV, and modeling of this response utilizing existing photochemical models of the mesosphere;
(2) assessing the possibility of utilizing the above data to determine ozone trends in response to solar UV variations during an 11-year solar cycle;
(3) assesing the possibility of utilizing the NO_2 data from SME to determine response to long-term changes in solar UV.

Progress and Results

We have determined that interference of the El Chichon eruption with NO_2 signal, and drifts in the solar UV and ozone data preclude utilizing the data to investigate (2) and (3). Our work during the second and third years comprised two components: 1) time series analysis of all the available coincident measurements of O_3 and solar UV; 2) modelling the photochemical response of O_3.

The results of our study are as follows:

- There is a high degree of correlation between the changes in Lyman-α and 205 nm radiation measured by the Solar UV spectrometer over the whole 5 years analyzed. However, coincident measurements of O_3 by the UV (UV O_3) and IR (IR O_3) spectrometers do not exhibit the same short-term variability (ie., variations with periods between 5 and 30 days). The lack of correlation between UV O_3 and IR O_3 residuals raises the question of the usefulness of the <u>short-term</u> variations measured by either instrument.
- Analysis of the whole data set yields statistically significant correlations between IR-O_3 and Lyman-α at the altitudes analyzed (50, 60, 68 and 80 km), even after accounting for the decrease in degrees of freedom due to the autocorrelation of the time series. However, the magnitude of the correlation coefficients and time lags at which they peak changes from year to year. The inter-annual changes in the time lag between the IR O_3 and Lyman-α time series cannot be explained in terms of differences in the photochemical response to different spectral components, or as a result of temperature feedback effects induced directly by the solar UV variations.
- The correlation between IR O_3 and Lyman-α is strongest during the summer season for 50, 60 and 68 km. This seasonal behavior would be

expected at 68 km if concentrations of H_2O are larger during the summer than at other times. However, it is unlikely that seasonal changes in water would impact the O_3 below 60 km. The large summer correlation may be due to (concidentally) stronger signals in the solar UV during this season.

- The calculated response of O_3 to changes in the solar UV between days 90 and 270 of 1982 is weaker than the observed short-term variations in the IR O_3 at 60 and 68 km. A weak positive correlation exists between calculations and data at 80 km; no significant correlation is apparent at 68 km, while calculated and measured ozone are weakly anti-correlated at 60 km. Due to the weak response of the model results to the observed solar UV, calculations over a longer period of time (at least two years) would be required in order to improve the statistics.
- Results from both our data analysis and modelling do not unambigously identify a photochemical component in the short-term variability observed in the O_3 measured by SME. A major impediment in the identification of such a response is the lack of coincident temperature measurements, which would allow correcting the O_3 data for dynamically-induced variations.
- We have also investigated the possible impact of meteoritic metals deposited in the upper mesosphere on the chemistry of nitric acid in the Antarctic stratosphere during spring. The publication by M. J. Prather and J. M. Rodriguez suggested that formation of stable metal nitrates on aerosol particles could lead to substantial denitrification in the lower stratosphere.

Publications

Prather, M. J. and J. M. Rodriguez (1988) Antarctic ozone: Meteoritic control of HNO_3. Geophys. Res. Lett., 15, 1-4.

Publications in preparation

Rodriguez, J. M., M. K. W. Ko and N. D. Sze. Statistical and modeling studies of the photochemical response of O_3 to solar UV changes over a solar roation period, as measured by the Solar Mesosphere Explorer (SME).

A. Studies of Middle Atmospheric Radiative and Photochemical Processes using Satellite Data

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C. Research Objectives

(i) Determine the response of middle atmospheric minor species and temperature to short-term solar ultraviolet variations, including latitudinal and seasonal dependences.

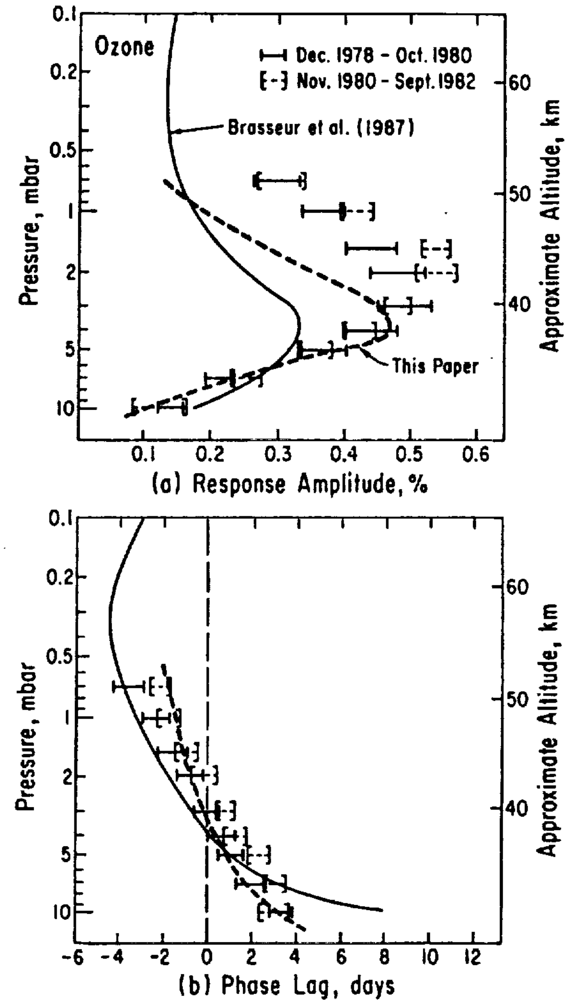
(ii) Interpret the derived responses using models of coupled photochemistry and radiative heating. Examine the consistency of the measured responses with model predictions to evaluate the relative contributions of radiative, photochemical, and dynamical processes to the observed responses.

(iii) Apply results of the short-term analysis to better estimate the effect of long-term (11 year cycle) solar UV induced variations on stratospheric ozone and temperature fields.

D. Summary of Progress

(i) Measurements of upper stratospheric ozone and temperature response amplitudes (defined as the percent change for a 1% change in the solar flux at 205 nm) and phase lags were extended to include dependences on latitude (60°N to 40°S) and season (N. H. summer and winter periods). The analysis was based on approximately 4 years of simultaneous Nimbus 7 SBUV ozone and SAMS temperature data. At levels below 3 mbar, ozone response estimates are generally consistent with direct photochemical forcing via changes in photodissociation rates of chemical species, primarily O_2. At levels above 3 mbar the ozone response characteristics are not consistent with direct photochemical and radiative forcing but exhibit dependences on latitude and season that are similar to those of dynamically driven oscillations. The same is true of the temperature responses at all levels. The dynamically driven oscillations are generated as a result of the interaction of upwardly propagating eddies with the zonal mean flow in the winter hemisphere. Therefore, the measurements may provide indirect evidence that solar ultraviolet variations can significantly modulate the upward propagation of planetary waves in the upper stratosphere. Measurements of the response of mesospheric ozone and temperature fields to short-term changes in solar ultraviolet flux are continuing based on analyses of SME IR ozone data and Nimbus 7 SAMS temperature data. In particular, the negative ozone response near 70 km due to photodissociation of water vapor by solar Lyman α variations has been confirmed.

(ii) The derived upper stratospheric responses to solar UV variations have been compared to the predictions of a one-dimensional radiative photochemical model. This work was done in collaboration with A. R. Douglass using an extension of a perturbation-order photochemical model developed earlier by Douglass and R. Stolarski (GSFC). The figure compares the model-calculated ozone response amplitudes and phase lags to low-latitude response measurements derived previously by Hood and Cantrell [1988]. Also shown for comparison are 27-day response calculations by Brasseur et al. [JGR, v. 92, p. 903, 1987] using a 1-D radiative photochemical code. The current calculated ozone response amplitudes are larger than those estimated by Brasseur et al. because of differences in averaging of the photodissociation rates over solar zenith angle. The calculated amplitudes are within the error bars of the measurements at levels up to about 3 mbar. Above 3 mbar, the data-derived ozone response amplitudes are significantly larger than the model calculations. This is one of several discrepancies that provide evidence for a dynamical component of the coupled ozone and temperature response in the upper stratosphere.



(iii) The same photochemical code used to produce the dashed line model of the figure for the 27-day time scale has been applied in order to calculate the expected long-term variation of ozone mixing ratio at levels between 3 and 10 mbar and at low latitudes during the period of operation of the SBUV instrument. Results show a maximum amplitude of 0.39% at 4.5 mbar ($\sim$ 37 km altitude) for every 1% change in the solar 205 nm flux. At other levels, the calculated change is smaller, ranging from 0.34% at 3 mbar to 0.14% at 10 mbar. Adopting a change in the monthly mean 205 nm flux of $\sim$ 6% between solar maximum in 1980 and solar minimum in 1985 yields a corresponding maximum monthly mean ozone mixing ratio decrease of 2.3% at 4.5 mbar. The net decrease during this interval in total ozone at low latitudes would be less than 1%. However, it is emphasized that this calculation considers only direct photochemical production rate changes; possible solar cycle dynamical effects are not accounted for.

E. Journal Publications

1. Hood, L. L. and Douglass, A. R., Stratospheric responses to solar ultraviolet variations: Comparisons with photochemical theory, *J. Geophys. Res.*, *93*, 3905-3911, 1988.

2. Hood, L. L. and Cantrell, S., Stratospheric ozone and temperature responses to short-term solar ultraviolet variations: Reproducibility of low-latitude response measurements, *Ann. Geophys.*, *6*, 525-530, 1988.

3. Hood, L. L., Stratospheric responses to solar ultraviolet variations: Dependences on latitude and season, *J. Geophys. Res.*, submitted for publication, 1989.

THE REDUCTION AND ANALYSIS OF SME UV DATA

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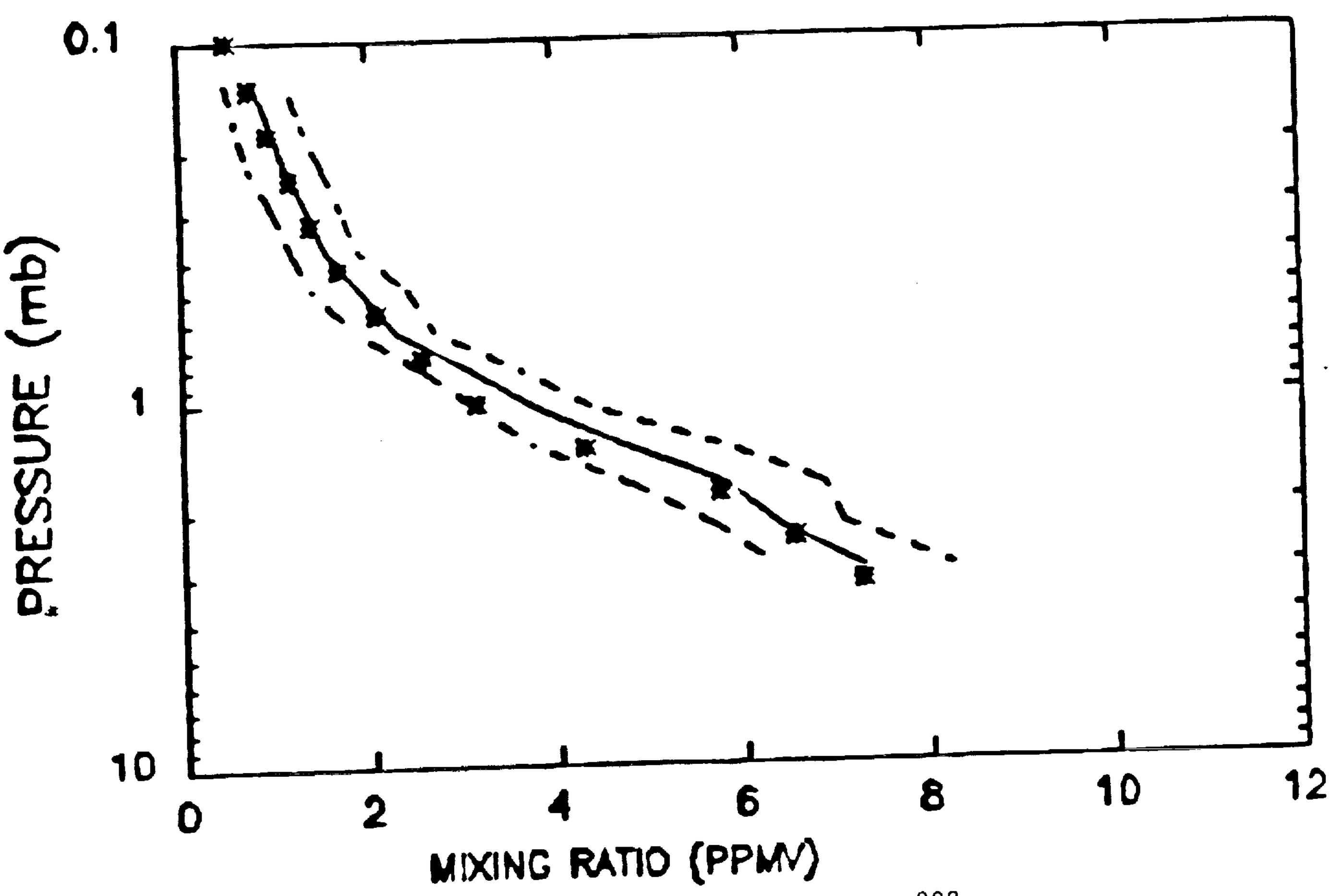
ABSTRACT

Instruments on the Solar Mesosphere Explorer (SME) have measured ozone in the Earth's atmosphere for five years from 1982 through 1986. These measurements have been analysed and have contributed to our understanding of the chemistry of ozone at and above the stratopause. The Ultraviolet Spectrometer (UVS) on SME has measured atmospheric Rayleigh scattering at a variety of wavelengths during the operation of SME. Ozone densities have been derived only from the wavelengths which provide ozone densities above 1.0 mbar. Additional wavelengths measured will allow the ozone mixing ratios to be determined down to near 40km or about 3 mbar. We are in the process of analyzing these longer wavelength data to obtain ozone densities in the 3.0 to 1.0 mbar region.

In the first 6 months of the grant period, radiance data at the additional four wavelengths have been reduced and placed in the radiance data base. This work is in preparation for the actual inversion to ozone mixing ratios which will begin shortly. This effort will result in an ozone data base which will overlap SBUV and SAGE II measurements and will be compared to these data and to models. A sample inversion of SME UVS data from the six wavelengths is shown in the figure as the asterisks.



DAY 135 OF 1983, LAT= 40

THE DETECTION AND INTERPRETATION OF LONG-TERM ATMOSPHERIC CHANGE: TASKS IN ASSOCIATION WITH THE SHUTTLE SOLAR BACKSCATTER ULTRAVIOLET RADIOMETER

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RESEARCH OBJECTIVES:

This effort is performed in conjunction with the Shuttle Solar Backscatter Ultraviolet (SSBUV) radiometer project at Goddard Space Flight Center. The role of SSBUV is to perform in-orbit calibration updates of operational SBUV/2 ozone monitors carried on NOAA satellites. The objectives of work performed at the University of Chicago are: (a) to define the variables that influence the utility of SSBUV as a calibration standard and (b) to estimate the accuracy with which geophysical trends can be derived from a combined SSBUV-SBUV/2 data set which spans one full decade.

PROGRESS AND RESULTS (1988-89):

We have completed a detailed analysis of the trend detection capability of the SBUV/2 system when SSBUV provides the calibration standard. The quantity to be measured is the ratio of backscattered radiance which emerges from the atmosphere in the vertical to the incoming solar irradiance at 12 wavelengths between 250 and 340 nm. We refer to this as the "backscatter ratio" We have used measured backscatter ratios from the Nimbus 7 SBUV instrument to generate synthetic data bases from SBUV/2 and SSBUV for the time period 1989 through 1999. We impose drifts, presumed to be of instrumental origin, on the SBUV/2 data set, which will be obtained by two to four separate instruments over the decade. In addition we impose a known geophysical trend on the entire data set. The objective is to determine the accuracy with which this geophysical trend can be estimated using SSBUV as a calibration standard.

The SSBUV data set, based on 14 simulated flights over the decade, is then used to remove the drift from each SBUV/2 instrument. The most important factor here is the repeatability of the SSBUV calibration from one Shuttle flight to the next. When this repeatability is in the range plus or minus 1%, we find that the geophysical trend in backscatter ratio can be recovered to an accuracy of plus or minus 0.9% per decade (two sigma limits).

Reflection from clouds poses a unique problem for the intercomparison of SSBUV and SBUV/2 measurements. The observations to be compared can be separated by as much as one hour, so that changes in cloudiness can hinder attempts to use SSBUV as a calibration standard. We have developed a radiative transfer model that allows a detailed examination of this issue. The results indicate that comparisons between SSBUV and SBUV/2 should not be done at wavelengths longer than 295 nm.

JOURNAL PUBLICATIONS (1988-89):

Frederick, J. E., X. Niu, and E. Hilsenrath, The detection and interpretation of long-term changes in ozone from space, Advances in Space Research 1988, in press, 1989.

Frederick, J. E., X. Niu, and E. Hilsenrath, An approach to the detection of long-term trends in upper stratospheric ozone from space, J. Appl. Meteor., submitted, 1989.