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THE SEASONAL AND INTERANNUAL VARIABILITY OF TOTAL OZONE AS REVEALED BY THE BUV NIMBUS-4 EXPERIMENT

Ernest Hilsenrath, *Goddard Space Flight Center, Greenbelt, MD*
Barry Schlesinger, *Systems and Applied Sciences, Riverdale, MD*

ABSTRACT

The initial study of the BUV/Nimbus-4 total ozone data is directed toward an analysis of the seasonal and interannual variability for the period April 1970 to April 1972. An objective analysis using a Fourier expansion shows the annual wave dominates at mid and high latitudes where the semiannual wave becomes significant in the tropics. A small interannual difference is detected and is most likely due to changes in the general circulation.

INTRODUCTION

The Nimbus-4 spacecraft was launched April 8, 1970 carrying the Backscattered Ultraviolet (BUV) Spectrometer for measurements of the columnar amount of ozone and the vertical distribution above 30 km. The BUV continued to operate until October 17, 1977 at which time it was turned off due to insufficient spacecraft power. The initial data was processed into ozone values and reported by Krueger (1974) Ghazi (1976) as well as by others. These early analyses used existing instrument calibrations, and orbital and engineering data. In addition, these analyses adjusted the satellite measured total ozone values to Dobson using a linear regression relationship developed from direct comparison of BUV measured values and Dobson values. Because of the recently recognized importance of the data, a task was initiated to reprocess the data and to continue processing the available data until the time the instrument was turned off. Generally, the objectives of the reprocessing activity were to: Establish a primary data base with screened, Earth located, and calibrated data for conversion to radiance values; improve the algorithms for processing the primary data base of radiance values to ozone values; and finally to validate the data and provide a consistent ozone data base. Details on satellite coverage, data quality checks, algorithm improvements, and validation tasks are being compiled and will be published elsewhere.

An extensive analysis of the comparability of BUV with the Dobson network has been conducted by Fleig, et al. (in preparation). This analysis shows from a comparison of nearly 4000 coincident measurements, using 00 code Dobson values and BUV overflight values within 2° of the station, that the average difference changes by about 1 Dobson Unit (∿0.3%) over the two-year period studied here, indicating a high degree of stability in the spaceborne measurement.

The first two years of total ozone data discussed here covers the period April 1970 to April 1972 and contains about 300,000 total ozone values per year. The Nimbus-4 orbital parameters and the BUV instrument description are detailed in the Nimbus-4 User's Guide (1970) and not repeated here. The BUV measurement scheme has been previously described by Mateer et al. (1971) and is briefly summarized below. Total ozone is derived from a measurement of the solar irradiance, Fo, the backscattered radiance, I, at 312.5 nm, 317.5 nm, and 339.8 nm and the effective surface reflectance determined from the photometer. The measured backscattered radiances are compared to those computed from 21 standard profiles sorted into three latitude zones compiled from balloon and rocket data since the radiances are ozone profile dependent. Any total ozone value can then be obtained from the table of precomputed values containing the solar zenith angle dependence, θ, and reflectance by interpolation. A description of the standard profile compilation is given by Hilsenrath (1977).

This discussion of the total ozone is directed toward the interpretation of its seasonal and interannual variability as revealed by the spaceborne experiment over a two-year period. A convenient way of depicting a time varying globally distributed geophysical parameter is in terms of zonal means as a function of time. This analysis is appropriate for total ozone since its variability is dominated season and latitude. A rigorous analysis of the seasonal and interannual variations detected by the BUV is accomplished by a harmonic analysis of the zonal means as a function of time where the first two components represent the significant seasonal waves.

Time Latitude Cross Section

From ten degree wide latitude zones, a time latitude cross section, depicted in figure 1a, is generated from the monthly averaged daily zonal means. Total ozone is shown as contours in 20 Dobson Unit increments for the two year period (regions at high latitudes in winter have no contours). Figure 1b immediately below the cross section sharing the same absiscca is a calculation of the mean global ozone value where this mean value is computed for each month from the sum of the area weights of the zonal means using extrapolation from lower latitudes to include the polar night regions. (Note in proof, the values shown in this figure are not final. Final processing indicate small changes in absolute values, but the seasonal trends are essentially the same.)

The annual seasonal wave is clearly seen in the two hemispheres. There is an ozone high and low at mid to high latitudes in the spring and fall periods respectively in both years. However, there are distinctive differences in the seasonal trends for each hemisphere.

1. In the Northern Hemisphere the spring maximum occurs nearly simultaneously at mid and high latitudes with the maximum value occurring near the pole with total ozone amounts of about 500 D.U. and a standard deviation of about $\pm$ 50 Dobson Units.

2. In the Southern Hemisphere the spring maximum occurs first in September at 65°S with ozone values substantially lower than those in the Northern Hemisphere spring. The spring maximum values occur about one month later in the polar regions. The asymmetry of the winter buildups in the two hemispheres can be explained by the well known differences in the circulation features in the two hemispheres as described by Newell, et al.(1972), Dütsch (1974) and others. In the Northern Hemisphere, eddy processes associated with the intense winter planetary waves transport ozone poleward from mid latitudes. Whereas in the Southern Hemisphere the circulation is generally more zonal and poleward transport is delayed.

3. In the tropical regions, the total ozone amounts and the seasonal variation are considerably lower than at higher latitudes. The average value is about 250 $\pm$ 10 D.U. The ozone minimum is centered below the equator in April and moves northward as the year progresses. Also note the very rapid decrease in the northern tropics, that appears to coincide with the Southern Hemisphere spring maximum at 65°S in September, occurs in both years.

Global Mean Ozone

A more rigorous description of the total ozone seasonal variations for the two years will be given by the harmonic analysis and is discussed in the next section. However, at this point the seasonal and interannual difference in the global mean ozone amounts, shown in figure 1b, will be briefly discussed. In general, the ozone is shown to decrease when comparing the same months for the two year period. Analysis by Angell and Korshover (1978) as well as others show a comparable decrease over the same period using the Dobson network data. To some extent, however, satellite data suffers from the same uncertainties as those computed from the ground based data because of spatial and temporal coverage biases. BUV makes no observations in the polar night and in some cases coverage was not consistent from one year to the next. The subject of long-term trends in global means as determined from satellite and ground networks is being studied elsewhere (Heath, private communication) and is not pursued here.

The seasonal variation in the global mean, however, is clear from figure 1b. The global mean maximum occurs at the time of the Northern Hemisphere spring maximum (April) where the minimum occurs in December-January, after the Southern Hemisphere spring maximum and prior to the Northern Hemisphere winter buildup. The amplitude of the seasonal trend is about 20 D.U. (the day to day variations in the global means is about 1 D.U.). The seasonal amplitude presented here is about 5 times higher than that reported by Keating (1978) in his analysis of 9 monthly mean global ozone amounts determined from the Nimbus-4 IRIS. In addition, no correlation of the BUV measured mean values could be found with solar activity associated with the 10.7 cm flux as was reported in Keating's analysis of IRIS.

Harmonic Analysis

In order to more objectively characterize the seasonal trends and the year to year differences in the global ozone, a harmonic analysis of the daily zonal mean data was performed. The procedure will be discussed elsewhere (in preparation) but the results are discussed below.

The annual wave or the first harmonic in the Fourier expansion is shown in figure 2a. The amplitude, given in Dobson Units, is the value of the first Fourier coefficient and the percent of the variance contributed by this harmonic is shown in the portion of this figure. Both values are plotted as function of latitude and both years are shown in the single figure to allow for a direct comparison. It should be clear that the data shown in this figure is a representation of information in figure 1a. The important features are:

1. In the Northern Hemisphere the amplitude of the annual wave increases with latitude. In addition, the variance is greater than 90% from subtropical latitudes to the pole. These features are essentially the same for the two years.

2. The amplitude of the annual wave is a minimum in the tropics and is only a few Dobson Units. The variance is nearly zero at the equator at least for the first year and the location of the minimum amplitude shifts about 10° southward in the second year.

3. In the Southern Hemisphere the amplitude of the annual wave is a maximum at mid-latitude and decreases towards the Southern Hemisphere pole. The percent variance of the annual wave is also very small near the pole indicating the south polar region does not undergo a significant seasonal variation in total ozone. At mid-latitudes there is a comparable 10° southward shift in the location of the maximum amplitude. This could be the result of year to year changes in the strength and location of the Hadley cell circulation in the Southern Hemisphere. Interannual changes in the strength of the Hadley cell have been demonstrated by Rosen and Wu (1976) in the Northern Hemisphere.

The second harmonic of the Fourier expansion of the daily zonal means provides information on the semiannual component in the seasonal ozone trend. A semiannual component would be expected because the Sun crosses the equator twice and a photochemical response may be detected in the tropics. On the other hand, a possible correlation may exist with the semiannual oscillation in the temperature and winds detected in the tropics in the upper stratosphere. Though these phenomena are of great interest and there may well be an ozone correlation found in a more detailed analysis that that performed here, it will be shown below the semiannual component detected in the satellite measured total ozone for the two years studied here is the result of the inter-hemispheric influence of the annual wave whose phases are displaced by six months.

Figure 2b depicts the semiannual component in the same format as the previous figure except the ordinate for both the amplitude and the variance are half that of figure 2a. The important features are as follows:

1. In mid-latitude for both years the semiannual wave is small.

2. In the tropics this component becomes significant but less so in the second year. From 0 to 10°S the amplitude of the semi-annual component is comparable to the annual component and the variance is about 40% for the first year. Clearly this feature should be associated with the location and strength of the annual wave in the tropics, and further evidence of this association will be given below.

3. In the Southern Hemisphere the semiannual oscillation becomes important again and the amplitude is comparable to that of the annual wave. However, the significance of this feature should be regarded with some caution since nearly one-half of the values appearing in the highest latitude zone are the result of extrapolation from lower latitudes.

An additional solution to the harmonic analysis is the phase; where for this study represents the time of the maximum ozone value in each of the latitude zones for each harmonic component. Figure 4 shows the time of the maximum ozone value as a function of latitude for both the annual and semiannual waves for each year. The ordinate is given in month as well as day of the year. The significant aspects of the phase are summarized below. It should be noted this result is consistent with what was seen and interpreted from the time latitude cross section, figure 1.

1. In the Northern Hemisphere the time of the maximum of the annual wave occurs nearly simultaneously from mid to high latitudes.

2. In the Southern Hemisphere after going through 6 month phase shift at the equator the spring maximum occurs first at 40°S in September and then spreads poleward and equatorward reaching a maximum value in these regions in November.

3. With regard to the semiannual wave only the time of the first maximum is plotted at latitudes where the variance is greater than 2%. At low latitudes the first peak occurs about April which is coincident with the Northern Hemisphere spring maximum of the annual wave. The second maximum of the semiannual component occurs 6 months later or October which is coincident with the maximum of the annual wave in the Southern Hemisphere subtropics. This result does not exclude a possible response to the solar equatorial crossing but it seems more likely that the semiannual wave detected at low latitudes in the first year is the

influence of the annual waves at higher latitudes in the two hemispheres where the phases are six months apart.

Conclusion

A rigorous analysis of the seasonal and interannual variability of the total ozone measured by the BUV on Nimbus has been initially performed to:

1. Provide information on the relative role of chemistry and transport on the global distribution of ozone.
2. To help recognize transient phenomena in the stratosphere that may be important in Sun/weather relationships.
3. To better understand long-term trends associated with solar cycles, other climate parameters, and man's activities that may effect the environment.

This initial study has shown the BUV data for the period processed between April 1970 and April 1972 has sufficient accuracy and coverage to give a good description of the seasonal variability and reveal some interannual differences in the total ozone. These differences should eventually be correlated with changes in the general circulation. This study provides a starting point for ozone trend investigations from satellite measurements that are important in climate and environmental studies and a basis for studying the anomalous behavior of ozone.

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References

Angell, J. K., J. Korshover, 1978: "Global Ozone Variations: An Update into 1976," Monthly Weather Review, Vol. 106, page 725-737, May 1978.

Dütsch, H. U.: "The Ozone Distribution in the Atmosphere," Canadian Journal Chemistry, Vol. 52, No. 8, p. 1491-1504, 1974.

Ghazi, A., A. Ebel, D. F. Heath: "A Study of Satellite Observations of Ozone and Stratospheric Temperature During 1970-1971," Journal of Geophysical Research, Vol. 81, No. 30, pp. 5365-5376, 1976.

Hilsenrath, E., P. Dunn, C. Mateer, 1977: "Standard Ozone Profiles from Balloon and Rocket Data for Satellite Theoretical Model Input." Contributions Presented at the Joint Assembly CMUA Sessions IAOA/IAMAP, Seattle, Washington, August 1977.

Keating, G. M., 1978: "Relationship Between Monthly Variations of Global Ozone and Solar Activity," Nature, 274.

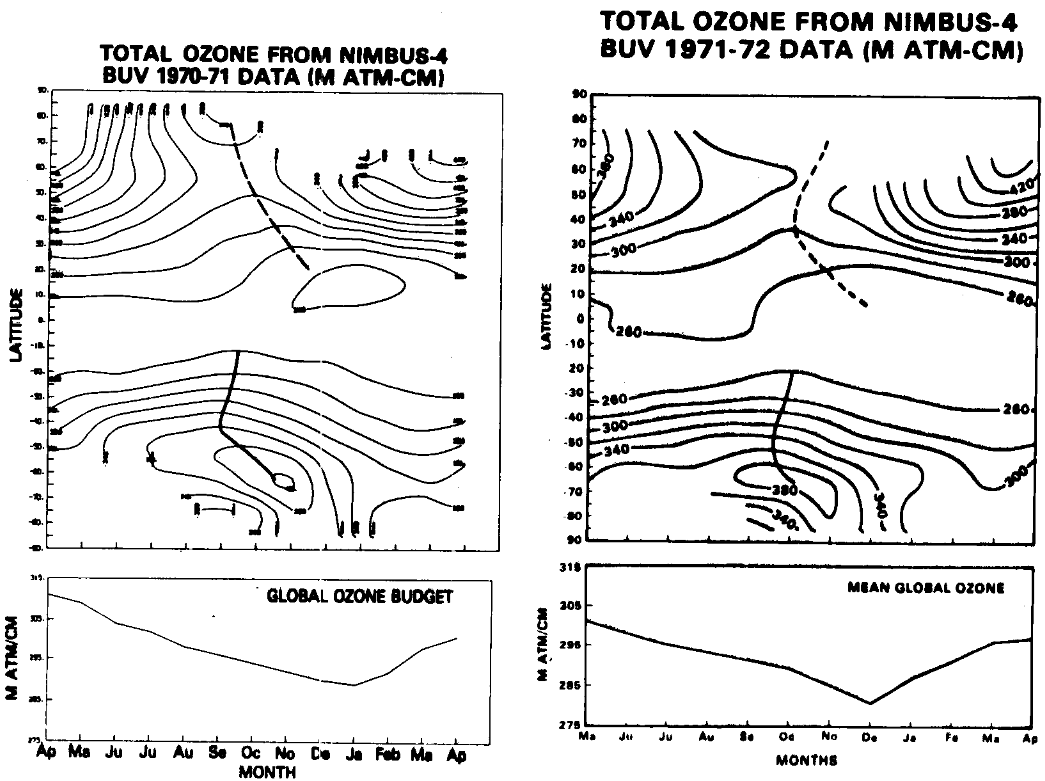
Krueger, A. J., 1974: "Behavior of Atmospheric Ozone Determined from Nimbus Satellite Backscattered Data," Proceedings of the International Conference on the Structure and Composition of the Upper and Lower Atmosphere, Melbourne, Australia, IAMAP, pp. 462-477, and NASA/GSFC X-Document 910-74-101.

Mateer, C. L., D. F. Heath, A. J. Krueger, 1971: "Estimation of Total Ozone from Satellite Measurements of Backscattered Ultraviolet Radiances," Journal of Atmospheric Sciences, 28, pp. 1307-1311.

Newell, R. E., J. U. Kidson, D. G. Vincent, G. J. Baer, 1972: The General Circulation of the Tropical Atmosphere and Interactions with Extratropical Latitudes, MIT Press, Cambridge, MA.

Nimbus Project, 1970: "The Nimbus-4 Users Guide," National Space Sciences Data Center, Greenbelt, MD, 214 pages.

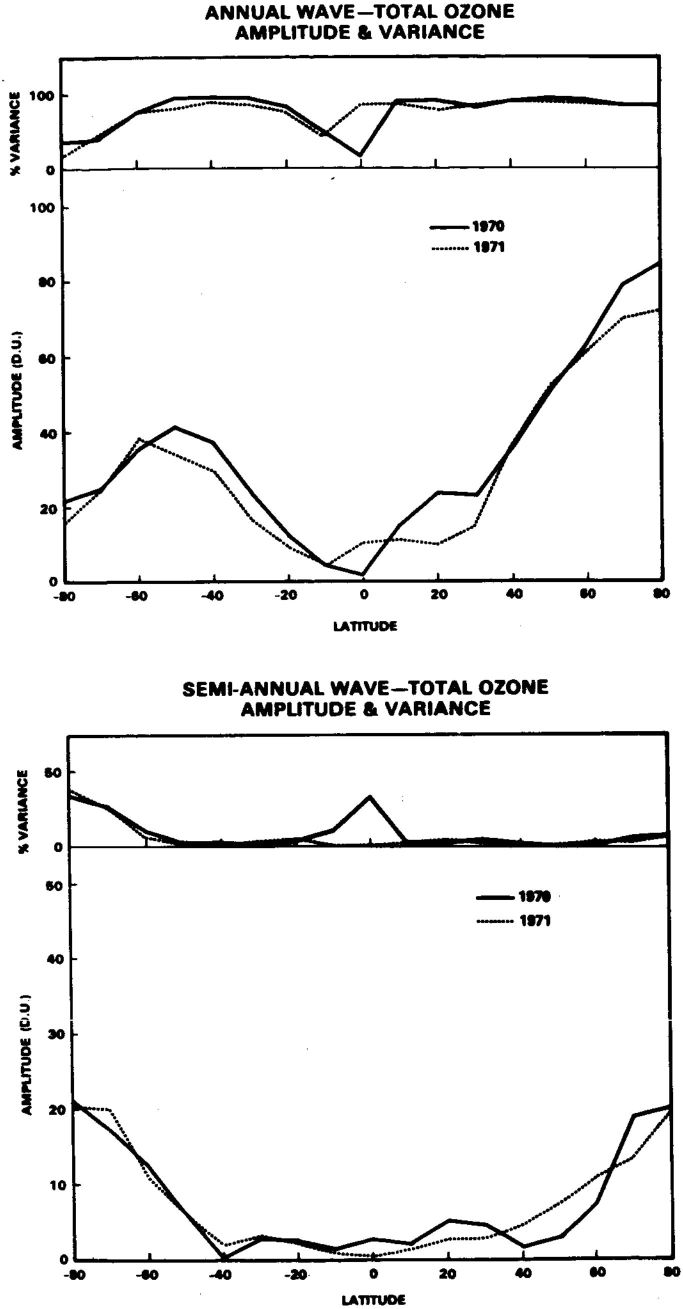
Rosen, R. D. and M. Wu, 1976: "Observational Study of the Interannual Variability in Certain Features of the General Circulation," Journal of Geophysical Research, 81, pp. 6383-6389.



(a)

(b)

Figure 1a. Time latitude cross section for April 1970-April 1972.
2b. Global mean ozone calculated from area weights of zonal means.



(a)

(b)

Figure 2. Solution to harmonic analysis. Annual (a) and semi-annual (b) wave correspond to first and second coefficient respectively.

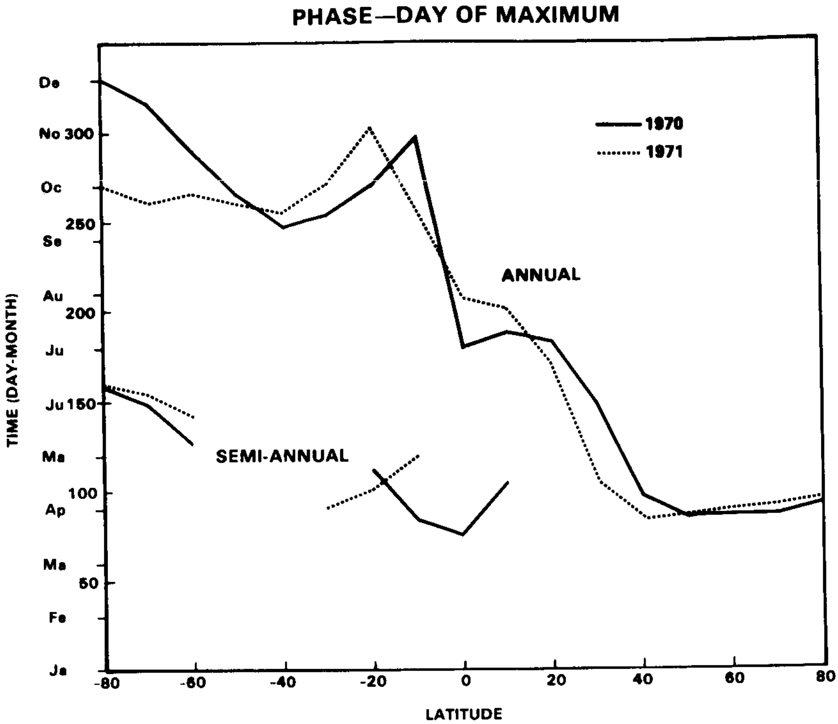


Figure 3. Phase of harmonics corresponding to day of maximum total ozone value. For semiannual wave, day of first maximum is indicated.