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Ozone Measurements from the NOAA-9 and the Nimbus-7 Satellites
Implications of Short and Long Term Variabilities

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Abstract This paper gives an overview of the measurements of total ozone and ozone profiles by the SBUV/2 instrument on the NOAA-9 spacecraft relative to similar measurements from the SBUV and TOMS instruments on Nimbus-7. It is shown that during the three year period from March 14, 1985, to February 28, 1988, when these data sets overlap, there have been significant changes in the calibrations of the three instruments which may be attributed to diffuser plate degradation (for SBUV/TOMS) and to the drift of the NOAA-9 orbit to later equator crossing times (for SBUV/2). These changes in instrument characteristics have affected the absolute values of the trends derived from the three instruments, but their geophysical characteristics and response to short term variations are accurate and correlate well among the three instruments. For example, the total column ozone measured by the three instruments shows excellent agreement with respect to its day to day, seasonal, and latitudinal variabilities. At high latitudes, the day to day fluctuations in total ozone show a strong positive correlation with temperature in the lower stratosphere, as one might expect from the dynamical coupling of the two parameters at these latitudes.

Introduction

The SBUV/2 (Solar Backscatter Ultraviolet) spectrometer on NOAA-9 has been providing global measurements of ozone in the stratosphere on a continuous basis since March 14, 1985. The SBUV/2 ozone data set consisting of total ozone and ozone mixing ratio at pressure levels from 100 to 0.3 mb is currently being archived at the NOAA/NESDIS/NCDC Satellite Data Services Division (Princeton Executive Square, Room 100, Washington DC 20233). This data set, in conjunction with similar data sets obtained from the SBUV and TOMS spectrometers on Nimbus-7 and the BUV spectrometer on Nimbus-4, comprise one of the most comprehensive data sets on stratospheric ozone available, extending over two decades (Hilsenrath and Chandra, 1988). These data sets, if intercalibrated, constitute a valuable resource for monitoring long term changes in the stratosphere and for studying the natural and man made perturbations on time scales varying from a single day to a solar rotation to a solar cycle.

The purpose of this paper is to give an assessment of the SBUV/2 data with respect to their usefulness in studying geophysical and man made perturbations in the stratosphere. This assessment is made by comparing the temporal and spatial characteristics of the SBUV/2 data with those of the TOMS and SBUV data over a three year period (March, 1985 - February, 1988) when these data sets overlap.

Instrument Related Changes in SBUV/2, SBUV, and TOMS

The SBUV/2 instrument on the NOAA-9 satellite and to be flown on a series of future NOAA operational satellites is an improved version of the SBUV instrument flown on Nimbus-7 (Heath et al., 1975). The instrument is a nadir viewing scanning double monochromator designed to measure total ozone and the ozone vertical profile over the pressure (altitude) range 0.7 mb to 30 mb (25 km - 50 km) by accurately measuring the atmospheric albedo, which is defined as the ratio of the radiance backscattered from the terrestrial atmosphere to the extraterrestrial solar irradiance. In its primary mode of operation the monochromator measures the solar UV radiances backscattered by the atmosphere at 12 discrete wavelengths from 255 nm to 340 nm with 1 nm bandpass. Albedos between 255 nm and 306 nm are used in the ozone profile inversion, while albedos between 312 and 340 nm are used to calculate total ozone. TOMS is a variation of the SBUV designed to measure total ozone only. It consists of a single monochromator that very rapidly scans wavelengths from 312 nm to 380 nm while spatially scanning across the orbital track to produce complete global maps of ozone on a daily basis.

The extraterrestrial solar irradiance needed to calculate an albedo is measured daily by deploying a diffuser plate. Since this diffuser plate is the only optical element not common to both the radiance and irradiance measurements, errors in long term calibration for SBUV type instruments are usually traceable to uncorrected changes in the reflecting properties of the diffuser plate. In comparing the SBUV/2 data with data from SBUV and TOMS, one must recognize that there have been changes in the characteristics of each of the three instruments. Comparisons of total ozone measured by SBUV and TOMS with measurements from a network of 36 Dobson stations showed that total ozone measured by the SBUV/TOMS instruments declined relative to the Dobson network by 3 percent between 1979 and 1988 (Heath, 1988; Reinsel et al.,1988). This calibration drift was most likely caused by undercorrection for the degradation of the diffuser plate (Watson, 1988).

Changes are also occurring in the SBUV/2 spectrometer, but for different reasons than for SBUV/TOMS. For SBUV/2 the changes appear to be associated with the drift of the NOAA-9 orbit. Both Nimbus 7, launched in 1978, and NOAA-9, launched in 1984, are in sun synchronous orbits. But where the equator crossing time for Nimbus-7 is very close to noon and has been stable for more than a decade, the equator crossing time for NOAA-9 was 1420 hours local time at launch and has drifted by about 3 hours over the 5 year period since. By the end of 1987 the time of equatorial crossing was at 1535 hours; and two years later, at the end of 1989, it was 1717 hours. As a result of this change in orbit, the incidence angle of the sun on the diffuser plate has increased with time. While it has not yet been proven, it is likely that error (or change) in the reflective properties of the diffuser plate, its goniometric calibration, has led to the observed apparent *increase* in diffuser plate reflectivity with time. Also, the SBUV/2 measurements of atmospheric radiance at a given latitude are made at continually increasing solar zenith angles which impacts the accuracy of the ozone retrieval algorithm (Klenk et al., 1982).

The "pair justification" technique has recently been developed by the GSFC Ozone Processing Team (McPeters et al., 1989) to stabilize the calibration of backscattered ultraviolet instruments against long term changes in instrument characteristics for the total ozone wavelengths. The total ozone measurement is based on the differential absorption of wavelength pairs, but different pairs have varying sensitivity to calibration change. Time dependent changes in instrument calibration will result in a relative drift between an error sensitive pair and an error insensitive pair. Pair justification uses this relative drift to infer the calibration error itself by requiring that ozone measured by different wavelength pairs be self consistent. The pair justification technique has been used to reprocess the entire TOMS data set. The reprocessed data will be noted as the version 6 (V6) data to distinguish them from the version 5 (V5) data which are currently archived at the National Space Science Data Center (NASA/GSFC, Greenbelt, Md, 20771).

While total ozone from SBUV could be corrected now, the ozone profile data cannot be corrected by pair justification. Other approaches to correct the profile data are currently being explored. Similarly, data from the NOAA-9 SBUV/2 will not be corrected until the physical mechanism for the observed change is better understood.

Comparisons of the SBUV/2, SBUV and TOMS Total Ozone

The data used in this study consist of daily values of total ozone obtained from the SBUV/2, TOMS (versions 5 and 6), and SBUV instruments. The data are zonally averaged in latitude intervals of 10 degrees from 80°S to 80°N and are smoothed with a 5 day running average. Figure 1 shows a comparison of total column ozone measured by different instruments at 50°N . The SBUV and TOMS (V5 and V6) time series start from January 1, 1979 and extend up to February 28, 1988, overlapping with the SBUV/2 time series after March 14, 1985. These plots and similar plots at other latitudes (not shown) suggest that the general characteristics of total ozone measured by the different instruments are remarkably similar both with respect to their seasonal and day to day changes.

Their absolute values and their long term characteristics are, however, different. This is illustrated in Figure 2 which shows the relative changes in TOMS (V5), SBUV and SBUV/2 with respect to TOMS (V6) at the equator. All the time series in Figure 2 are smoothed with a 30 day running average to emphasize their long term characteristics. If one assumes that TOMS (V6) total ozone is independent of instrument drift, an assumption probably good to within ±1%, one may use Figure 2 to estimate the long term changes in the instrument characteristics of TOMS (V5), SBUV, and SBUV/2. For example, the curve labeled TOMS (V5) suggests that the TOMS total ozone measurements degraded by about 4 percent from 1979 to 1988, with most of this degradation occurring after 1983. During the first five years, the TOMS (V5) measurements appear to have been accurate to within 1 percent. The drift in the SBUV instrument was very similar to that for TOMS (V5) since the curve labeled SBUV is almost parallel to the TOMS (V5) curve. This is consistent with the assumption that the cause of the drift is degradation of the shared diffuser plate. However, these curves also indicate that the absolute value of total ozone measured by the SBUV instrument have been about 4 percent less than that measured by TOMS. This constant offset has been recognized since shortly after launch. The difficulty of deriving an absolute wavelength calibration for the multiple-slit TOMS instrument might be the cause of the offset. The difference in time dependence is due to sampling differences between the high density TOMS data set and the low density SBUV data set. The characteristics of the SBUV/2 curve are very different from those of TOMS and SBUV. During the period when both the SBUV and TOMS measurements are drifting downwards, the SBUV/2 curve shows an upward trend of about 3 percent over the three year time interval after 1985. Such an upward trend is difficult to explain in terms of the diffuser plate degradation, since an *increase* in plate reflectivity would be required. The orbital changes for NOAA-9 mentioned earlier coupled with a small goniometric error could produce the observed time dependence.

In spite of the apparent differences in the long term behavior of the three instruments, there are striking similarities in the latitudinal characteristics of trends inferred from these measurements. Figure 3 compares the linear trends over the three year period from March 1985 to February 1988. These trends are derived using a regression model consisting of linear and seasonal (annual and semiannual) terms. It shows that the three year trends in total ozone inferred from the four data sets are nearly symmetric with respect to the equator. For TOMS (V6) the trend varies from about -3 percent at the equator to about +2 or +3 percent at higher latitudes (40°) in both the hemispheres. The average trend for these latitude bands is only about +0.31 percent. This curve also shows a transition from a negative to a positive trend at about 20°. These trends are largely manifestations of quasi biennial oscillations (QBO) which are extensively discussed in literature (eg., Oltmans and London, 1982; Hilsenrath and Chandra, 1988). Trends derived from such a short data record, only three years, will be particularly influenced by the QBO. The point here is not so much the trend itself as the similarity of the latitude dependence of the trends derived from the four data sets. They differ only by an offset. The SBUV and SBUV/2 data are respectively about 1.5 percent lower and 2.5 percent higher with respect to the TOMS (V6) trends. The trends derived from the TOMS (V5) are almost the same as those from SBUV.

The long term instrument changes have fortunately not affected most of the geophysical characteristics of the SBUV/2 data including the day to day and short term changes. An example of such changes are shown in Figure 4 which compares the daily fluctuations in total ozone inferred from the SBUV and SBUV/2 instruments with those in temperature at 50 mb at 50°S. All the time series in Figure 4 are deseasonalized and detrended using a linear regression model. Figure 4 shows that the day to day fluctuations in total ozone from the SBUV/2 and SBUV measurements are very similar. They both show oscillations with periods ranging from a few days to a few months and strong positive correlation with temperature at 50 mb. A regression analysis of ozone and temperature time series indicates a regression coefficient of 6.4 DU/°K or about a 2 to 3 percent increase in total ozone for a 1°K increase in temperature. These values are in good agreement with the values derived from the spatial variabilities in ozone and temperature during spring months in the southern hemisphere as reported by Newman and Randall (1988) and are indicative of a strong dynamic coupling between ozone and temperature associated with planetary waves at high latitudes (Tung and Yang, 1988).

Comparisons of Ozone Profiles from SBUV/2 and SBUV

In comparing ozone profiles from the SBUV/2 and SBUV instruments, there is no simple way to account for the instrument effects as in case of total ozone. Therefore, a meaningful comparison of the SBUV and SBUV/2 data can only be made by removing linear trends from both the data sets. Figure 5 shows such a comparison for Umkehr layer 8 (about 40 Km) at the equator (±5°). Both the SBUV and SBUV/2 curves in Figure 5 have been detrended, and the SBUV values have been normalized to the March 14, 1985 value of the SBUV/2 to account for the drift in the SBUV data before 1985. In Figure 5, the temporal characteristics of both the SBUV and SBUV/2 curves are almost identical in all their details. The seasonal characteristics of both the curves are predominantly semiannual in nature and are modulated by shorter term fluctuations. These short term fluctuations are manifestations of winter time planetary waves in both the hemispheres. The comparisons at other latitudes and pressures (Umkehr layers) suggest that the temporal and spatial characteristics of the detrended SBUV/2 data are almost identical to those of SBUV over the three year period where the two data sets overlap.

Concluding Remarks

In this paper we have attempted to give an overview of the measurements of total ozone and ozone profiles by SBUV/2 instrument on NOAA-9 by comparing them to similar measurements from the SBUV and TOMS instruments on Nimbus-7. These comparisons clearly suggest that the SBUV/2 data, like that from SBUV, are not presently useful for studying long term trends. However, the detrended data can be very useful for studying a number of geophysical phenomena including short term changes, the QBO, and interannual variabilities.

During the three year period for which these data sets overlap, the total ozone measured by the three instruments show excellent agreement with respect to their day to day, seasonal, and latitudinal variabilities. At high latitudes the day to day fluctuations in total ozone show a strong positive correlation with temperature in the lower stratosphere, as one might expect from the dynamical coupling of the two parameters at these latitudes. The linear trends in total ozone inferred from the three instruments show remarkable similarities with respect to their latitudinal characteristics. The trend itself appears to be largely a manifestation of QBO. Relative to TOMS measurements corrected for instrument drift by pair justification, the version 6 data, the SBUV/2 trends appear to be displaced by about 2.5 percent with respect to the corrected TOMS trends at all latitudes between ±50°. In comparison, the uncorrected SBUV and TOMS trends are about 1.5 percent lower in the same latitude region. The TOMS and SBUV trends were affected by the degradation of the common diffuser plates used to measure the extra-terrestrial solar irradiance, while the SBUV/2 instrument appears to have been affected by the drift of the NOAA-9 orbit to higher solar zenith angles (later equator crossing times).

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Figure Captions

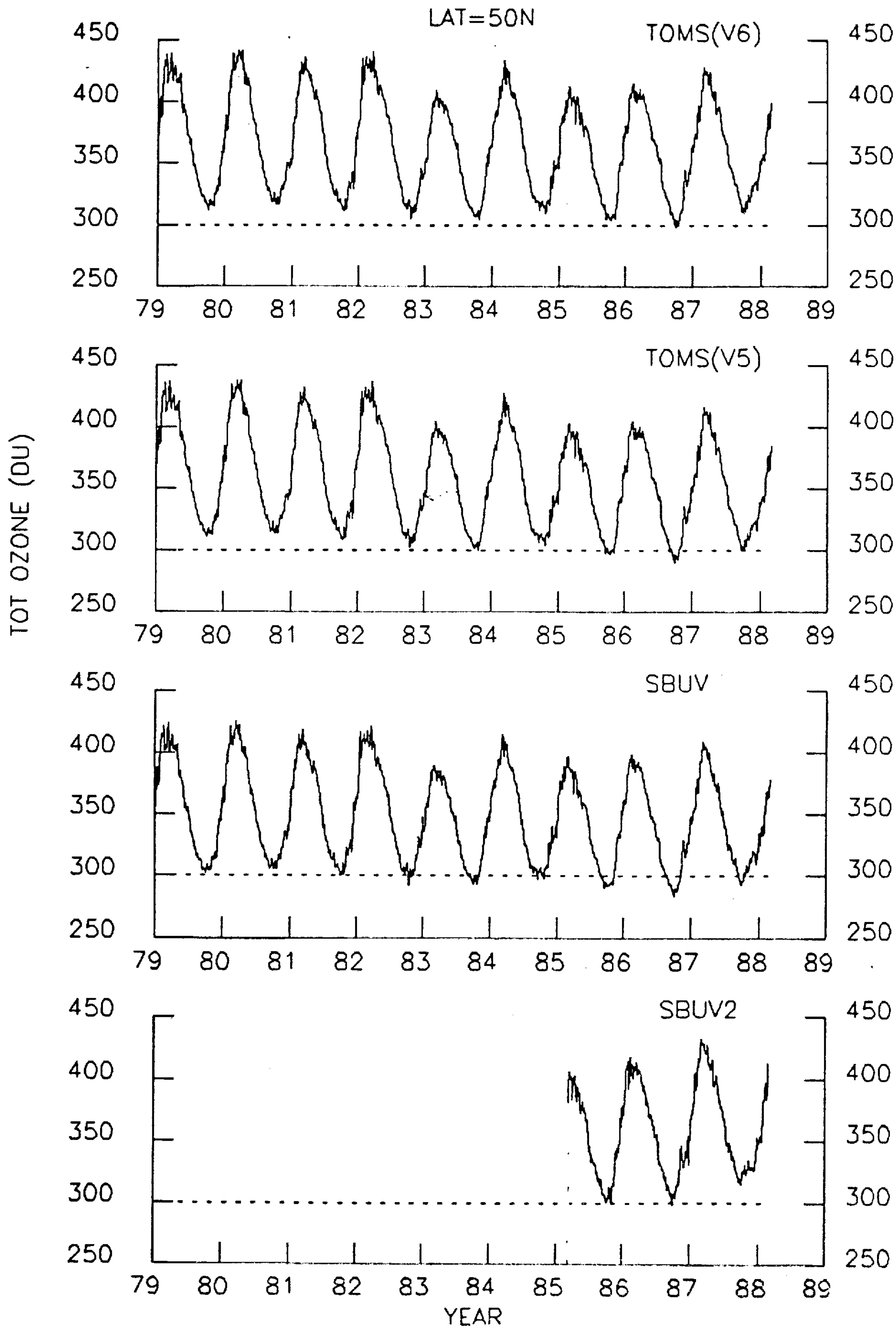
Fig. 1. Time series representing daily values of total ozone at 50°N based on TOMS version 6, TOMS version 5, SBUV, and SBUV/2 measurements. All the curves begin January 1, 1979 and end on February 28 1988, except for the SBUV/2 curve which begins March 14, 1985.

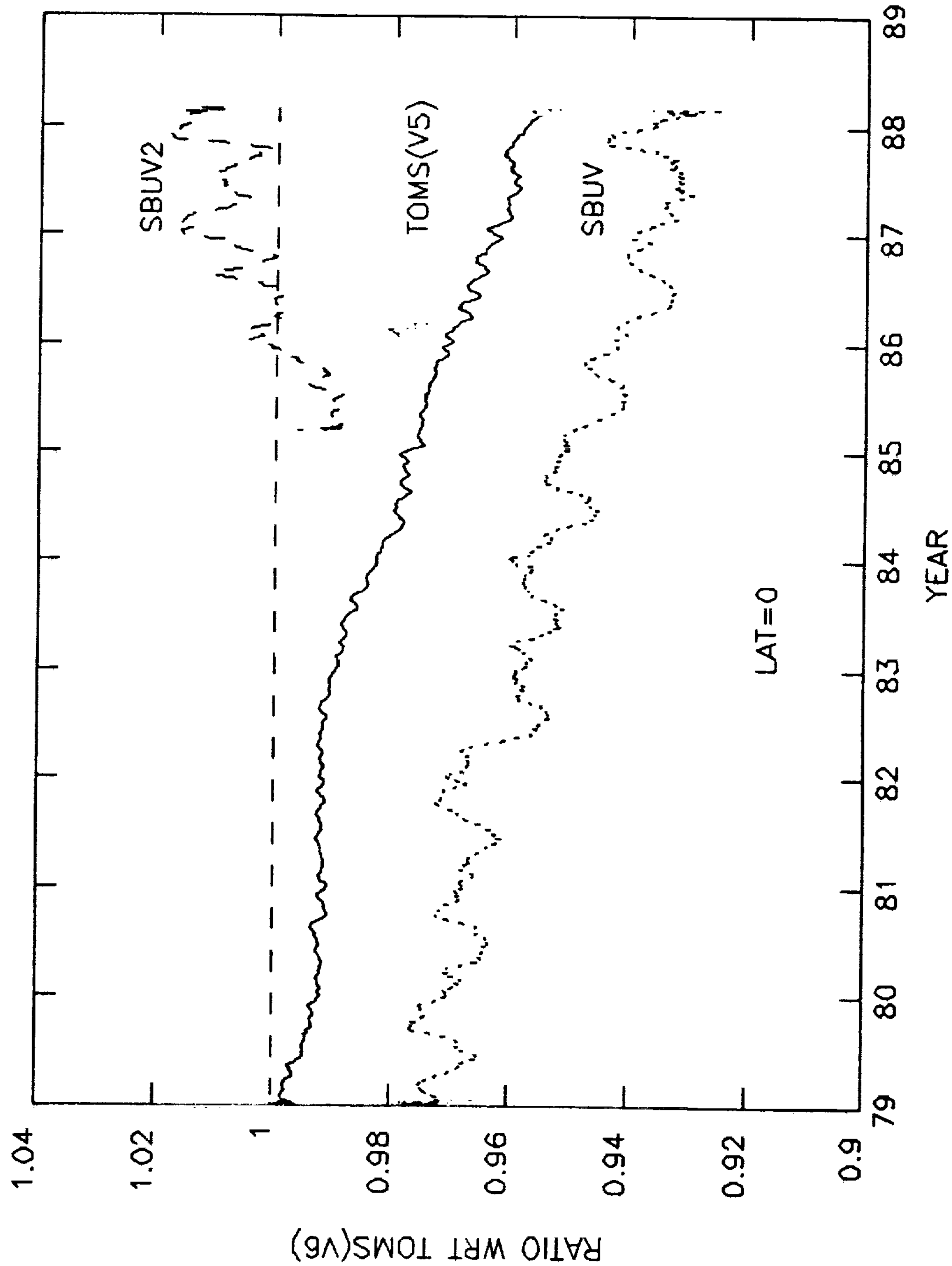
Fig. 2. Long term changes in total ozone at the equator for TOMS (V5), SBUV, and SBUV/2 relative to the TOMS (V6) data which have been corrected for long term instrument change. All the time series are smoothed with a 30 day running average to accentuate their long term trends.

Fig. 3. The latitudinal characteristics of linear trends in total ozone based on the three years (1985-1988) of data from the SBUV/2, TOMS (V6), SBUV, and TOMS (V5) measurements.

Fig. 4. The correlation of daily fluctuations in total ozone from SBUV and SBUV/2 with 50 mb temperature at 50°S. The values shown in this figure are differences of the daily values from the values based on time series consisting of annual, semiannual and linear trends as explained in the text.

Fig. 5. Comparison of SBUV/2 and SBUV time series for Umkehr layer 8 (approximately 40 km) at the equator showing the high correlation of the short term variations. Both the SBUV and SBUV/2 curves have been detrended. The SBUV values have been normalized to those of SBUV/2 on March 14, 1985 to account for possible drift in the SBUV data prior to that date.


LAT=50N
TOMS(V6)
TOMS(V5)
SBUV
SBUV2
TOT OZONE (DU)
YEAR
450
400
350
300
250
79
80
81
82
83
84
85
86
87
88
89


SBUV2
TOMS(V5)
SBUV
LAT=0
RATIO WRT TOMS(V6)
YEAR
1.04
1.02
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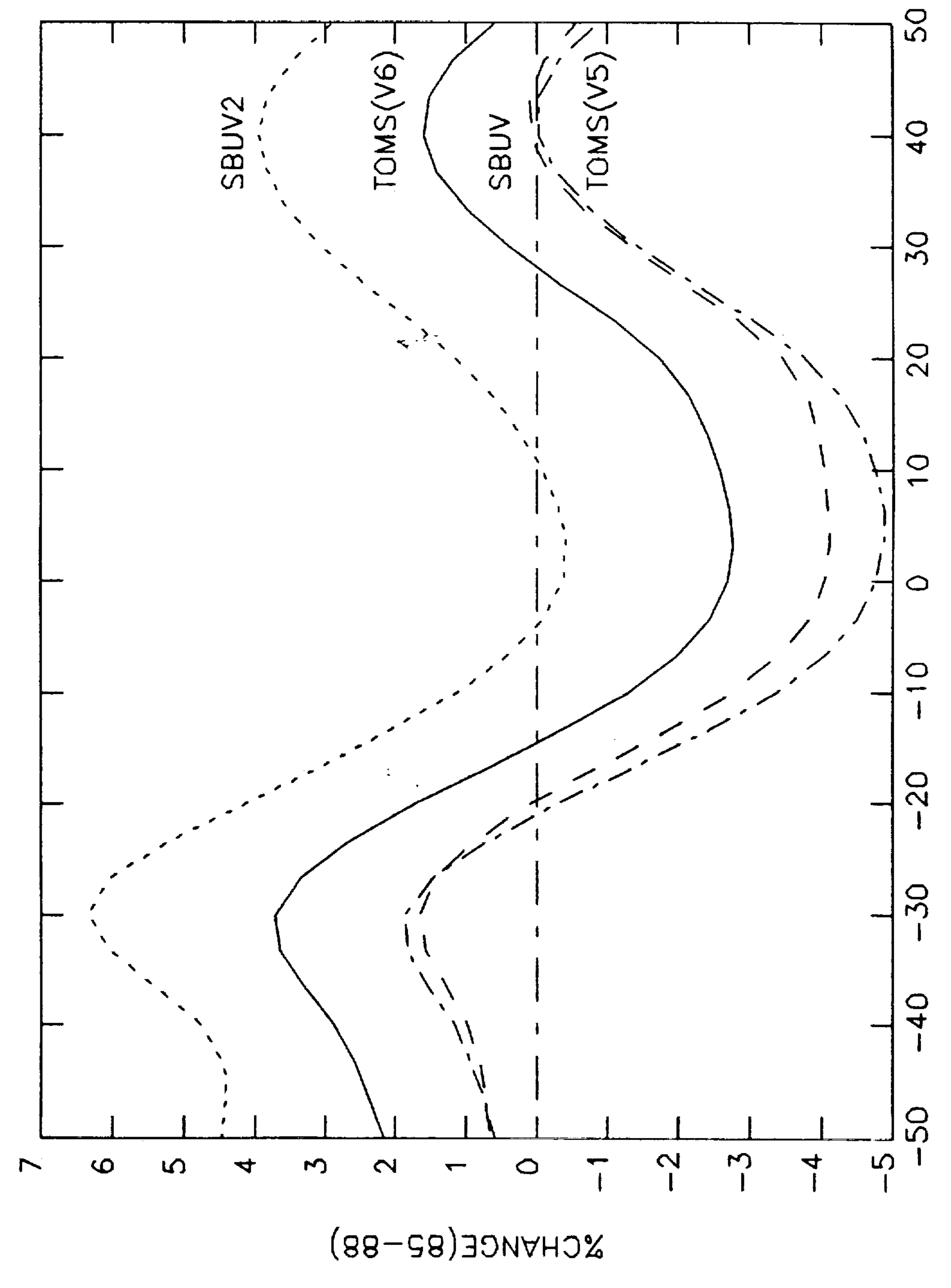
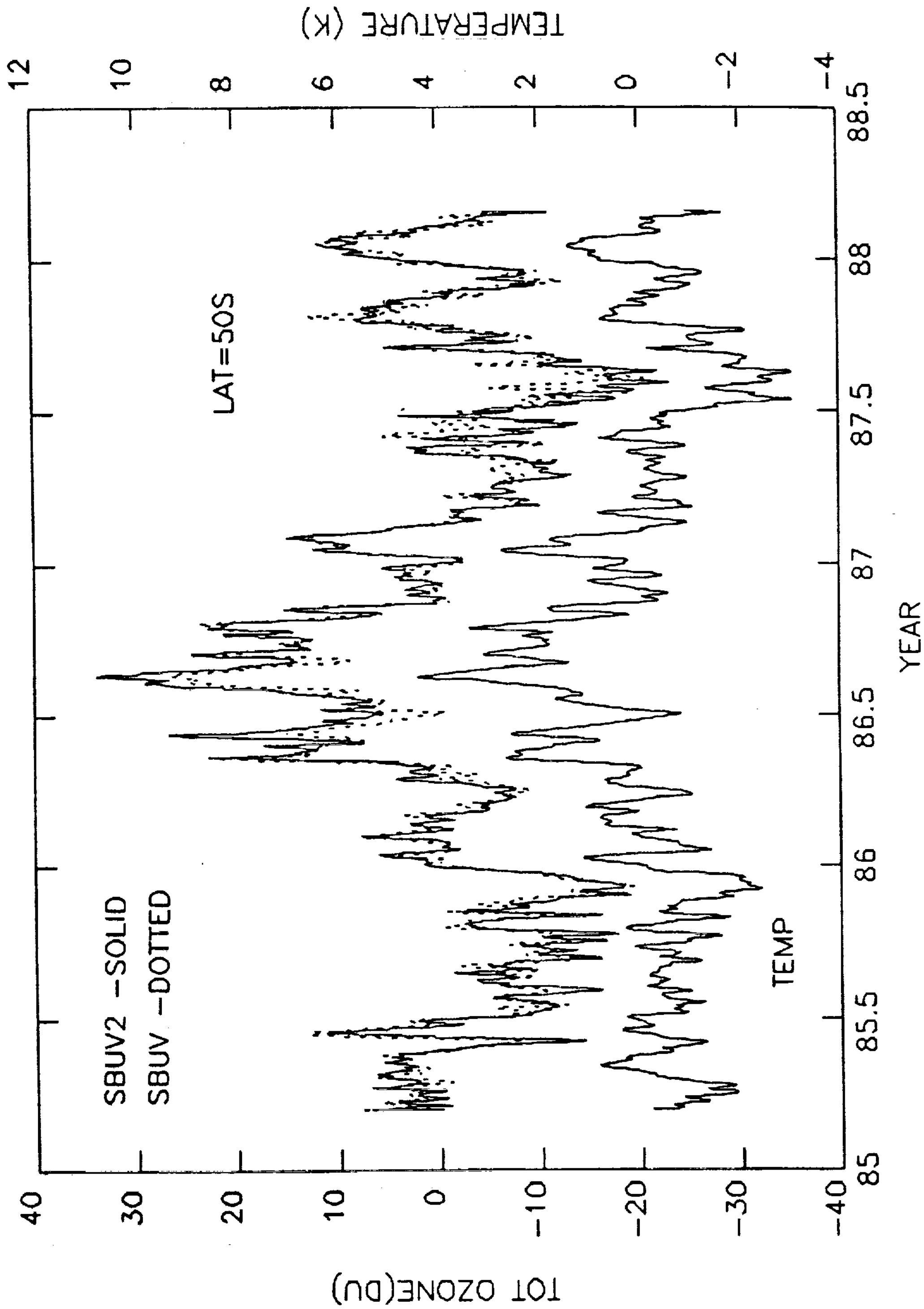
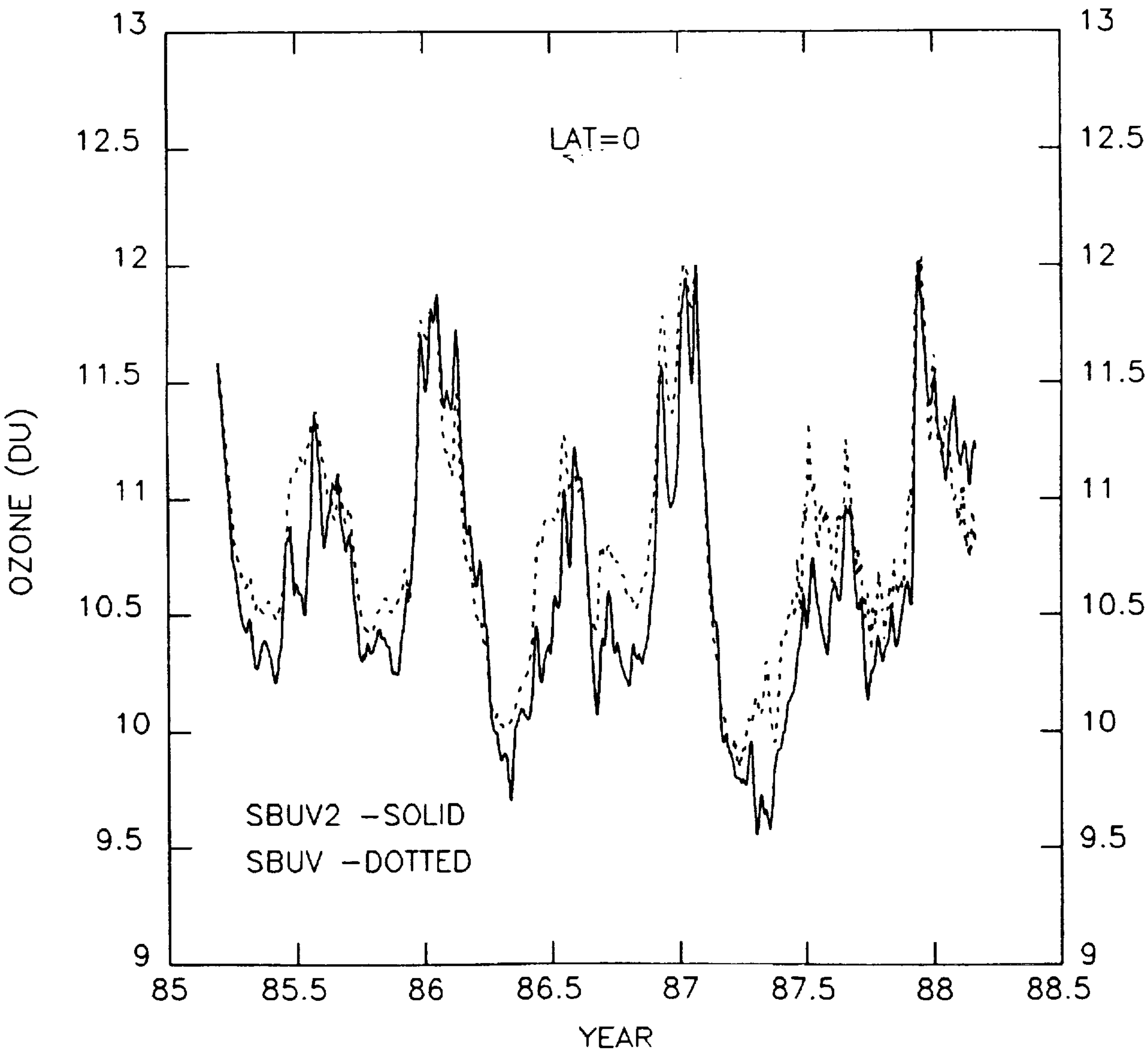
0.94
0.92
0.9
79
80
81
82
83
84
85
86
87
88
89


SBUV2
TOMS(V6)
SBUV
TOMS(V5)
LATITUDE
%CHANGE(85–88)



SBUV2 -SOLID
SBUV -DOTTED
LAT=50S
TEMP
TOT OZONE(DU)
TEMPERATURE (K)
YEAR



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