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Northern middle-latitude ozone profile features and trends observed by SBUV and Umkehr, 1979–1990

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Abstract. A comparison of Umkehr ozone profile data with the reprocessed solar backscatter ultraviolet (SBUV) ozone profile data in the northern middle-latitude region, 30° to 50°N, is reported. Although significant biases exist between the two types of observations, the long-term variations and least squares linear regression trends agree remarkably well over the comparison period of 1979 to 1990. The ozone trend in the upper stratosphere is of the order of $-0.9\%\ \mathrm{yr}^{-1}$. Near 25 km, little if any trend appears, but a larger negative trend is seen in the lower stratosphere near 15 km. Comparisons show that the average annual ozone cycles in the profiles also agree well. The upper stratospheric ozone results are consistent with photochemical model predictions of ozone depletion near 40 km that are due to the release of anthropogenically produced chlorofluorocarbons. The lower stratospheric ozone trend results are in reasonable agreement with published ozonesonde data trends. It is shown that the ozone trends in the lower stratospheric layers impact significantly on the total ozone trend of the order of $-0.47\%\ \mathrm{yr}^{-1}$. The good agreement now seen between the two types of observations suggests that the combined ground-based and satellite approach could provide a valuable database for long-term monitoring of stratospheric ozone for trends and extraordinary variations.

Introduction

Ever since the scientific community became aware of the chlorofluorocarbon threat to the ozone layer [e.g., *Rowland and Molina*, 1975] observational methods to accurately observe changes in ozone concentrations in the photochemical region near 40 km have received increased attention. Two such methods were the Dobson Umkehr network that started observations at the beginning of the International Geophysical Year (IGY) in July 1957, and the backscatter ultraviolet (BUV) Nimbus 4 satellite experiment that started observations in April 1970. The BUV experiment ran until 1977, which was considered to be a rather commendable record, since satellite lifetimes were quite short during the early 1970s. The BUV was followed by the solar backscatter ultraviolet (SBUV) Nimbus 7 satellite experiment that started observations in November 1978 and produced useful data until June 1990 when large chopper synchronization errors began to degrade the precision of the measurements. The BUV and the SBUV satellites were fundamentally the same, and drifts in the retrieved ozone profiles were detected in both. The cause was attributed to a degradation of the diffuser plate that is used to obtain a solar reference observation [*Fleig et al.*, 1981]. The Dobson network has been active up to the present; however, some stations were voluntarily terminated and others were added as time passed. Also, not all stations made Umkehr observations. The network underwent a rapid increase in size about the beginning of 1962 after the World Meteorological Organization (WMO) urged members countries to start ozone-observing programs. A few stations, including Arosa, Switzerland, and Oxford, England, were operating before the IGY. International data collection and publication by the WMO started with the IGY. Fortunately, a long-term record of total ozone and Umkehr ozone profile data has now been accumulated because of the persistent efforts of the WMO and the member countries. The Umkehr record has been subjected to several analyses for ozone trends in the upper stratosphere above 25 km [e.g., *Reinsel et al.*, 1984; *DeLuisi et al.*, 1989b].

Three major assessments of the status of stratospheric research contain analyses of Umkehr observations; both indicate decreases in stratospheric ozone near the 40-km level and are apparently consistent with photochemical predictions of changes due to fluorocarbon depletion effects [*World Meteorological Organization* (*WMO*) 1985, 1988, 1991].

Early comparisons of Umkehr observations with BUV and SBUV observations by *DeLuisi and Nimira* [1977] and *DeLuisi et al.* [1979] indicated that the Umkehr and SBUV methods of observation revealed annual cycles and ozone concentration magnitudes that agreed reasonably well. A comprehensive comparison of ground-based and satellite measurements was reported by *Bhartia et al.* [1984]. Similar but longer-term data comparisons by *Fleig et al.* [1989]

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Table 1. Layers Used for Umkehr Ozone Profile Retrievals

Layer Number	Layer-Base Pressure, atm	Layer-Base Height, km
1*	$1.00E-1$	0.00
2	$2.50E-1$	10.3
3	$1.25E-1$	14.7
4	$6.25E-2$	19.1
5	$3.12E-2$	23.5
6	$1.56E-2$	28.0
7	$7.81E-3$	32.6
8	$3.91E-3$	37.5
9	$1.95E-3$	42.6

*Layer 1 is a double layer. Read $1.00E-1$ as 1.00×10^{-1}.

revealed a serious drift in the SBUV ozone profile retrievals even after corrections to the diffuser plate reflectance were made to account for the drift. Persistent efforts by NASA scientists [*Taylor et al.*, 1994] to correct the SBUV diffuser plate calibration drift, without having to force a calibration by using data from other sources, have recently produced ozone profile data that are in good agreement with Umkehr measurements made in the same northern midlatitude band.

This paper describes the results of a comparison of the newly processed SBUV data with aerosol-corrected Umkehr data for the period 1979 to 1990. Data from five Umkehr stations located in the latitude band 30° to 50°N were used to represent the zonal mean ozone profile to be compared with the zonal SBUV ozone profile for the same latitude band. The comparison revealed a rapid decrease in ozone concentrations within this period and the apparent absence of a recovery that might be expected if the 11-year solar cycle were solely responsible for cyclic changes in stratospheric ozone concentration. On the global scale, latitudinally and seasonally dependent ozone profile trends determined from SBUV data were reported by *Hood et al.* [1993].

Procedure

The SBUV data consist of monthly average ozone profiles, in units of partial pressure, for the latitude range 30° to 50°N. The Umkehr data consist of monthly average ozone profiles obtained from five northern midlatitude stations: Tateno, Japan (36°N); Boulder, Colorado (40°N); Lisbon, Portugal (38°N); Arosa, Switzerland (47°N); and Bielsk, Poland (50°N). SBUV and Umkehr ozone profiles are customarily reported in the standard nine-layer Umkehr format; i.e., the atmospheric pressure of the upper boundary is one-half the lower boundary pressure of a layer, and layer 1 is a double layer. The layers are approximately 5 km thick. A tabulation of pressure and altitude of the Umkehr layer structure is given in Table 1.

The SBUV algorithm for ozone profile retrieval is described by *Bhartia et al.* [1981]. Because the backscattering of ultraviolet radiation by aerosols is weak and because the SBUV observation is from the top of the atmosphere and not through the stratospheric aerosol layer, stratospheric aerosol errors are negligible under most conditions. An effect is seen when extremely high stratospheric aerosol concentrations are present. The effect on the ozone profile is short-lived and confined to the lower stratosphere, as noted after the eruption of El Chichón in 1982 [*Bhartia et al.*, 1983].

The Umkehr algorithm (commonly referred to as the "classical algorithm") for ozone profile retrieval is described by *Mateer and Dütsch* [1964]. Retrieved ozone profiles are affected by stratospheric aerosols [*DeLuisi*, 1969, 1979a]. A correction method for stratospheric aerosol errors to Umkehr ozone profiles using lidar stratospheric aerosol data is described by *DeLuisi et al.* [1989b]. Our calculations of the Umkehr stratospheric aerosol error were recently improved in quality, quantity, and global coverage with the use of stratospheric aerosol data from the Stratospheric Aerosol and Gas Experiment (SAGE I and SAGE II) satellites [*Chu et al.*, 1989]. The results of these calculations were used to correct the Umkehr data that were analyzed for the present investigation. The vertical resolution of the SBUV and Umkehr ozone profiles are comparable. They both face difficulty in precisely resolving changes in layers 1–3 which also are highly correlated with total ozone. *Mateer and DeLuisi* [1992] in their paper describing a new Umkehr retrieval algorithm mentioned that only layers 4–8 should be used for trend analysis. Our purpose in this paper is to determine how well the SBUV and Umkehr profiles match in all nine layers.

The SBUV and Umkehr profiles were deseasonalized by subtracting, for a given month, the average of the same month in all years from the monthly average of the same month in each year. Deseasonalizing was done for each layer and the total ozone. The resulting data set reveals departures from the mean that are easily compared and, furthermore, are related to varying atmospheric (and quite likely solar) phenomena affecting the temporal and spatial stability of ozone. This procedure also removes the bias between the SBUV and Umkehr profiles.

Results

Figure 1 contains plots of deseasonalized Umkehr (solid curve) and SBUV (dashed curve) ozone concentrations in layers 1 to 9, given in terms of percentage departure from the mean versus time in years. The span of years is 1979 through 1990. Deseasonalized total (column) ozone is also shown. Layer numbers are given on the plots. Reasonably good agreement is seen in all layers, with the exception of layer 1, which shows Umkehr measurements varying considerably while the SBUV plot appears to be quite smooth. The salient features of the Umkehr and the SBUV results are qualitatively remarkably similar in all layers and in the total ozone, again with the exception of the Umkehr results in layer 1 (both the SBUV and the Umkehr have a low sensitivity to tropospheric ozone, so the poor agreement is not to be taken seriously) and the first several years of layer 2. One of the most noteworthy features is the minimum in winter of 1984–1985 that is seen in all layers. The variations seen in layers 3–5 match the variations in total ozone; some of the variations in higher layers also match but not so clearly as those of the lower layers. The lower layer results are not unexpected, since it is well known that variations in total ozone correlate highly with variations in the lower stratosphere. The annual cycles in these layers are also in phase with the total ozone annual cycle. Therefore trends in these layers are more likely driven by trends in the total ozone. It is beyond the scope of this paper to attempt explanation for these features.

Most worthy of note is the steep decrease seen in the

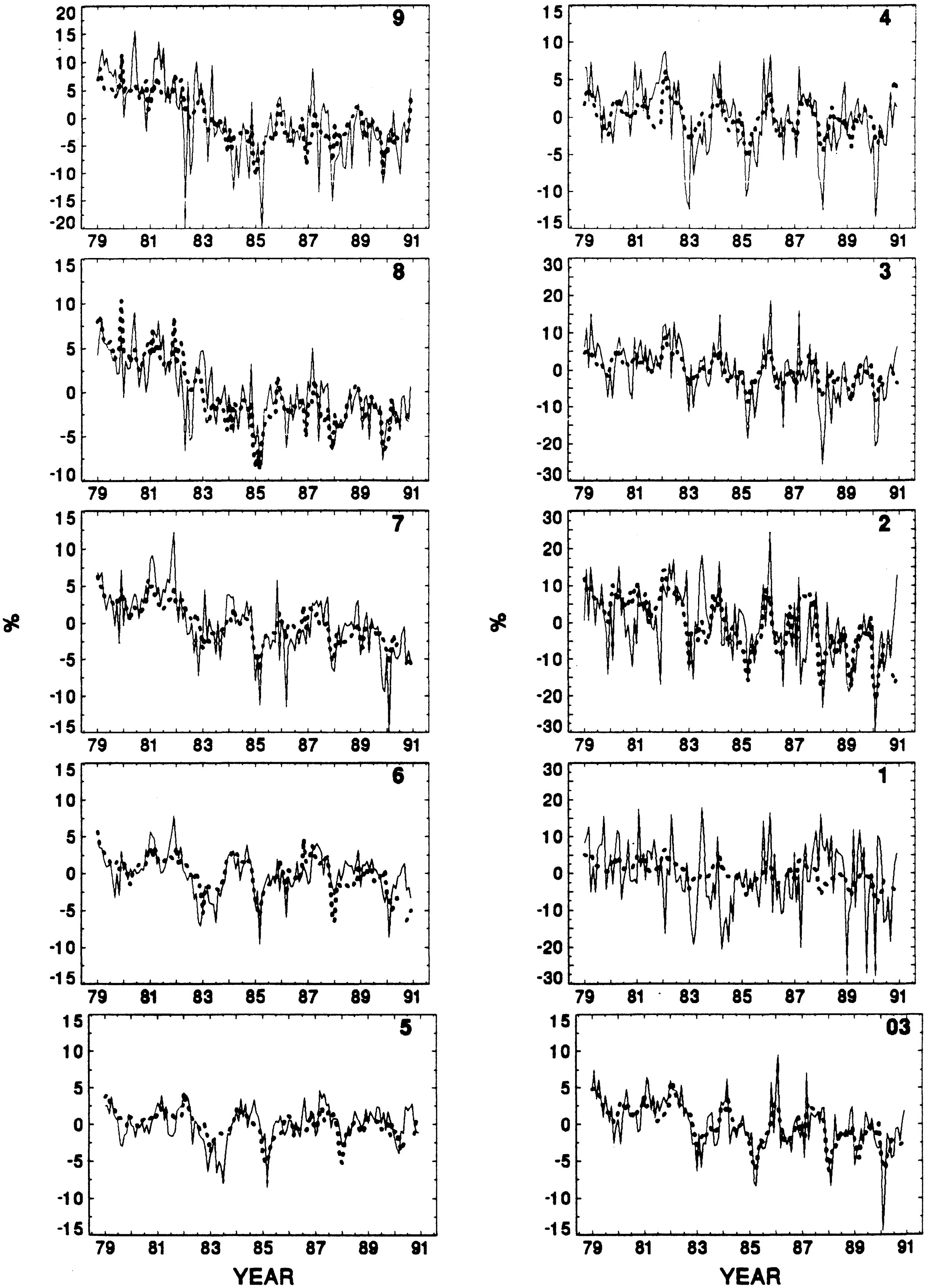

Figure 1. Plots of deseasonalized Umkehr (solid curve) and solar backscatter ultraviolet (SBUV) (dashed curve) monthly average ozone concentration, given as percentage departure from the mean, in Umkehr layers 1 to 9. The deseasonalized total ozone is also shown. The Umkehr plots represent data from five Umkehr stations (see text for details) and the SBUV plots represent data in the latitude region between 30° and 50°N. Abscissa tick marks are at the beginning of the year.

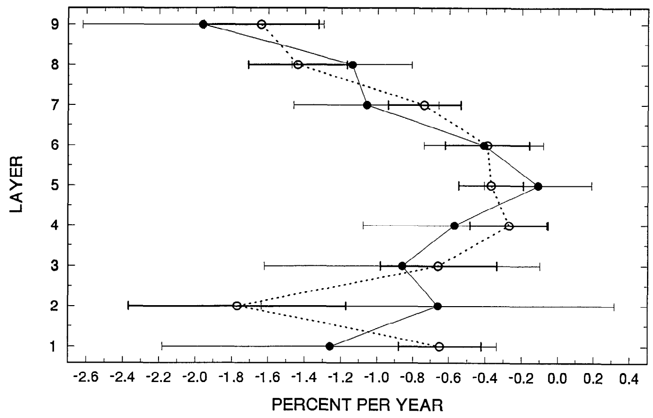

Figure 2. Results of a linear least squares regression fit given as layer number versus trend in percentage per year, to the Umkehr (solid) and SBUV (dashed) data of Figure 1 for the years 1979–1986. The 99% confidence intervals are shown.

ozone concentrations of layers 7, 8, and 9 that occurred in the short period of 1982–1985. The drop happened to occur during a period when the solar cycle was decreasing rapidly [*DeLuisi et al.*, 1989b]. This decrease is responsible for nearly all the linear trend that was determined for the entire record. Note that the plots for the period before and the period after the decrease appear to be rather flat, indicating little or no trend during these periods. The cause for the decrease is not easily explained as being due to solar activity, because the Umkehr record that precedes the period we are examining (going back to 1958) does not clearly reveal decreases of similar magnitude following solar cycle maxima (see, for example, *Reinsel et al.* [1987] and *Angell* [1989]). It could be speculated that stratospheric aerosols from the 1982 eruption of El Chichón might have caused the reduction in ozone by heterogeneous chemical reaction; however, the aerosols would have had to have been transported to 40 km and above and remain for several years, which is unlikely (obviously, gas transport to higher altitudes would not be detected as aerosols). Moreover, the SAGE II satellite measurements of stratospheric aerosols, which began in late 1984, clearly show the decay of El Chichón aerosols near the 20-km maximum, approaching background levels by 1990. The measurements also indicate no significant aerosol enhancements above 40 km. Ozone concentrations near the 20-km level might have been reduced by aerosols from El Chichón shortly after the eruption, but such an effect would be relatively short-lived. In light of these possibilities it is not at all clear what mechanisms, such as dynamical and photochemical, were involved and might have caused the variations seen in the time sequence of Figure 1. *Hood et al.* [1993] noted that the upper stratospheric ozone variation over the last solar cycle appears to have been accompanied by an inphase temperature variation which is most consistent with forcing by solar UV radiation changes. The Umkehr trends reported by *DeLuisi et al.* [1989b] indicated that they were close to the trends predicted by photochemical model calculations that included solar cycle effects. This is shown in the same report.

Layer 9 Umkehr data display somewhat larger short-term deviations than the SBUV data; however, at least some are believed to be real and due to the local variations over a site. Monthly averages of the large amount of ozone profile data obtained by the SBUV will tend to produce smooth results over the 30°–50°N latitude band. Nevertheless, the general agreement is remarkable, especially for those cases when deviations occur for extended periods; note, for example, from 1983 to 1985.

Ozone concentrations in layer 9 and above, retrieved with the Umkehr algorithm, are suspected of being partially dependent on the ozone variations in layer 8 because the available ozone profile information decreases rapidly above layer 8 [*Mateer and DeLuisi*, 1992; *DeLuisi*, 1979b]. The good agreement seen in the comparison of Umkehr and SBUV data for layer 9 is perhaps better than expected. The large trend in this layer is puzzling because the predicted anthropogenic photochemical destruction rate at this altitude is expected to be smaller than that in layer 8 [*WMO*, 1988]. The reliability of these results for layer 9 is open to question, and it is suggested that the reader use caution when interpreting these results.

The two deep minima in 1982 (most obvious in layer 9) are believed to be due to the insufficiency of the lidar data available for that time for calculating aerosol corrections. The lidar data were used because there was a time gap between SAGE I and SAGE II. The spatial distribution of the newly injected stratospheric aerosol from El Chichón was highly nonuniform for several months, and the lidar data taken at sites distant from some Umkehr stations were, at times, unrepresentative of transient aerosol conditions existing over the Umkehr stations. This applies especially to the Tateno station when the aerosol cloud appeared and then quickly subsided, but the higher latitudes had not yet experienced the dense cloud. Monthly averages of aerosol profiles would be susceptible to greater error noise caused by the highly varying aerosol measurements. In the middle layers the magnitude of the aerosol error progressively decreases because the Umkehr is less sensitive to aerosol errors in these layers [*DeLuisi et al.*, 1989b].

The plots in Figure 2 summarize a basic linear least squares fit trend analysis for the years 1979–1986. The general features of the Umkehr and SBUV trend plots are in good agreement. A significant negative trend in ozone concentration is obvious in the upper and lower levels of the profiles. Weaker trends are noted in layers 4, 5, and 6, with layer 5 being the least. The 99% confidence intervals are shown on the plots. This period was selected because the early SBUV data were showing unexpectedly large trends in the uppermost layers and were being challenged for their credibility. The SBUV trends were approximately twice those revealed by the Umkehr data for the same period. The early SBUV results [e.g., *Reinsel et al.*, 1988] stimulated the formation of the International Ozone Trends Panel, which was organized in 1985 to report on the status of ozone research. One of the panel's objectives was to examine the credibility of the SBUV results. The Umkehr trend results in Figure 2 are essentially the same as the Umkehr results reported by the *WMO* [1988]. Again, these results were in good agreement with photochemical model predictions of ozone concentration changes that accounted for anthropogenic factors and the solar cycle [*WMO*, 1985; *DeLuisi et al.*, 1989b]. The recently improved SBUV data used in the present comparison fortify the validity of the Umkehr trend results given in the Ozone Trends Panel report. This comparison represents the first combined satellite and ground-based observation of stratospheric ozone trends in the upper stratosphere that are in reasonable agreement.

Referring back to the plots in Figure 1, note that they end in 1990, which is approximately the time of the maximum in the sunspot cycle. Also note that plots for the data extending beyond 1986 for layers 7 to 9 (30–50 km) are essentially flat, apparently showing no indication of recovering to the level of the previous solar cycle maximum, which occurred around 1981, near the beginning of the data record presented in Figure 1. It could be argued that the continuous anthropogenic depletion of ozone superimposed on the sunspot cycle tends to mask the maximum, resulting in a steplike downward trend in the continuing ozone record [*Hood et al.*, 1993]. Nevertheless, the length of the data record being examined here is relatively short when considering naturally occurring long-term climatological variations that affect the ozone layer.

Figure 3 shows plots of linear least squares regression trend results for the entire length of the data presented in Figure 1. Compared with Figure 2, the trends in this figure are considerably less in the levels above 25 km (i.e., layers 6–9). At 25 km and below, little change between the two is seen, except for the layer 2 Umkehr trend, which is greater in the longer record. The variations are large in this layer, as seen by the confidence intervals. Table 2 is a numerical summary of the ozone profile trends of Figure 3. Included in the table is the total ozone (that is observed with each Umkehr measurement) trend for the same period; it is of the order of $-0.46\%\ \mathrm{yr}^{-1}$ for the Umkehr, which is in good agreement with $-0.48\%\ \mathrm{yr}^{-1}$ for the SBUV.

Part of the difference between the Umkehr and the SBUV results shown in Table 2 is very likely due to the difference in the SBUV global sampling coverage and the restrictive Umkehr sampling rate as well as the spatial coverage. A comparison of Umkehr and SBUV station over flight ozone profiles could help resolve some of the differences. Another possibility is the inconsistency of the Umkehr and SBUV ozone profile retrieval algorithms [e.g., *DeLuisi et al.*, 1989a]. Here it is worthwhile pointing out that if the trends of layer pairs are combined, i.e., layers 9 and 8, 7, and 6, (essentially reducing the layer resolution), the agreement between SBUV and Umkehr is further improved. The 1964 Umkehr algorithm, which was used as the standard until recently, may suffer from some inadequacies because computing power limited the extent of radiative transfer calculations, and a priori ozone profile information needed for the radiative transfer calculations was limited as well. A new algorithm has been recently developed [*Mateer and DeLuisi*, 1992], and preliminary comparisons of ozone trends determined by both suggest significant differences in layers 3 and 4, where the trends given by the 1964 algorithm were larger than the trends given by the new algorithm. The new algorithm is being subjected to rigorous testing, and one of the tests will include comparisons with the SBUV data. When this task is undertaken, it will be necessary to recalculate stratospheric aerosol corrections for the new algorithm. We mention here that *Mateer and DeLuisi*, [1992] comment that layers 4–8 are useful for trend analysis. Nevertheless, some information is available in layers 2 and 3 because total ozone must be balanced within the complete profile. The same applies with the SBUV. Because the trend estimates in layers 1–3 contain large uncertainties, it is suggested that layers 1–3 be combined for a single trend estimate. In this case, the three-layer trend is $(-0.89 \pm 0.40)\%\ \mathrm{yr}^{-1}$ for the Umkehr and $(-0.79 \pm 0.22)\%\ \mathrm{yr}^{-1}$ for the SBUV.

Table 2. Umkehr and SBUV Linear Trends 1979–1990

Layer	Umkehr LSF %/yr	99% C.L.	SBUV LSF %/yr	99% C.L.
9	−1.07	±0.36	−0.89	±0.21
8	−0.67	±0.18	−0.82	±0.17
7	−0.68	±0.22	−0.56	±0.12
6	−0.16*	±0.17	−0.35	±0.13
5	0.03†	±0.15	−0.20	±0.10
4	−0.39	±0.27	−0.15	±0.13
3	−0.87	±0.43	−0.57	±0.19
2	−1.04	±0.53	−1.53	±0.37
1	−0.46*	±0.57	−0.56	±0.14
O_3	−0.46	±0.19	−0.48	±0.12
1,2,3	−0.89	±0.40	−0.79	±0.22

All slope values except those noted, significant at $\alpha = 0.01$. SBUV, solar backscatter ultraviolet.

*Significant at $\alpha = 0.05$.

†Not significant.

Figure 4 depicts the percentage contribution of the ozone trend in each Umkehr layer to the trend in total ozone for the SBUV and the Umkehr during the period 1979–1990. The agreement between the two types of observations, although rather rough, suggests that the maximum contribution is from the lower layers 2 and 3, i.e., the lower stratosphere,

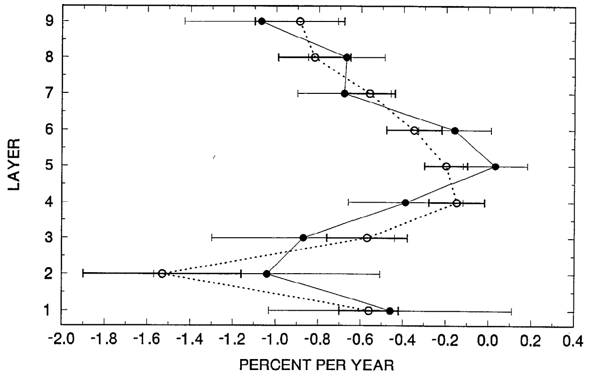

Figure 3. Results of a linear least squares regression fit, given as layer number versus trend in percentage per year to the Umkehr (solid) and SBUV (dashed) data of Figure 1 for the years 1979–1990.

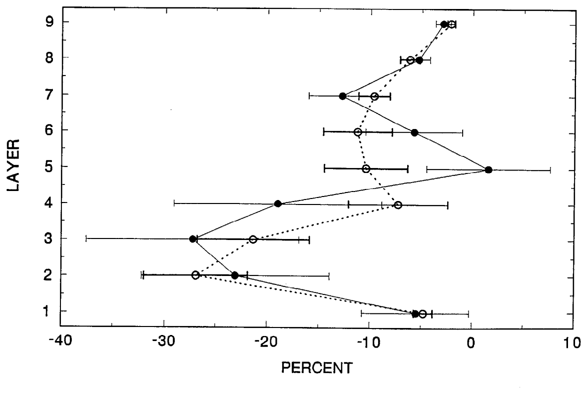

Figure 4. Percentage contribution of ozone trend (abscissa) in each Umkehr layer (ordinate) to the trend in total ozone for the Umkehr (solid) and SBUV (dashed).

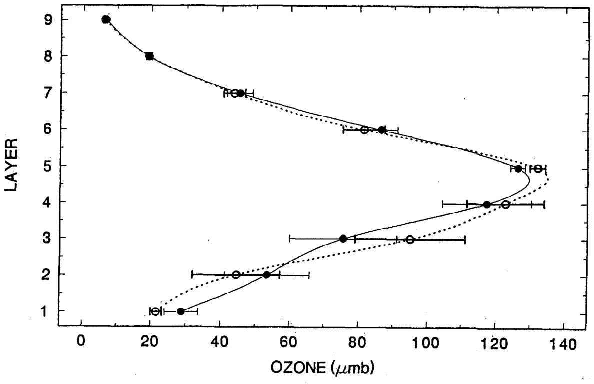

Figure 5. Comparison of mean profiles of Umkehr (solid) with SBUV (dashed), given as layer number versus ozone partial pressure, for the years 1979–1990. The smooth curves are spline fits through the numerical values.

which is consistent with the recent findings in the World Meteorological Organization report. The other altitude region of maximum contribution is in the vicinity of layers 6 and 7. In this region the SBUV changes are not so abrupt as those of the Umkehr. Figures 5 and 6 supply additional information on the SBUV and Umkehr profile comparisons.

Figure 5 compares the mean ozone partial pressure profiles, and Figure 6 shows the percentage bias between the SBUV and the Umkehr, where the Umkehr is the reference. The percentage bias bears some similarities to the analysis that was done by *DeLuisi et al.* [1985] comparing the Umkehr data with the early BUV data. It is believed that at least part of the differences seen in the SBUV and Umkehr comparisons of Figures 4, 5, and 6 are due to the 1964 Umkehr ozone profile retrieval algorithm. Part may also be due to the spatial sampling limitations of the five Umkehr stations.

Figure 7 is an illustration of the average annual cycles of Umkehr and SBUV ozone profiles, i.e., the average of all monthly averaged data for the years 1979–1990. The biases shown in Figure 6 have been removed. The entire set of Umkehr and SBUV data were used to produce these plots. The biases, which are quantified in Figure 6, are largely due to the a priori statistics of the Umkehr and SBUV algorithms. With the exceptions of layers 5 and 1, the annual cycles track each other fairly well. Layers 1, 2, and 3 of the SBUV data are identical in phase. Also, the SBUV total ozone cycle closely follows the SBUV cycles in layers 1, 2, and 3, suggesting that the total ozone might be artificially dominating the SBUV retrievals in these layers. On the other hand, for the Umkehr data the total ozone cycle best follows the cycle in layer 4. Some resemblance is seen between the layer 5 SBUV cycle and the layer 4 Umkehr cycle, again suggesting possible profile retrieval algorithm artifacts.

Although trends below layer 4 are shown in Figures 2 and 3, they are not in serious disagreement with trends observed by ozonesondes in this region where a maximum negative trend at 15 km was noted by *Tiao et al.* [1986]. The degree to which the Umkehr and SBUV have the ability to vertically resolve the true features of trends in the lower stratosphere is less than for layers 4–8. This is a subject currently under study.

Summary

The comparison of 1979–1990 aerosol-corrected Umkehr data from five stations in the northern hemisphere with SBUV data averaged between 30° and 50°N shows very good agreement. Least squares trend analyses done on both sets of data are also in good agreement, although the record is rather short. The trend analyses indicate significantly large trends in the upper stratosphere, of the order of $-0.9\%\ \mathrm{yr}^{-1}$ at 45 km, and in the lower stratosphere, of the order of $-0.7\%\ \mathrm{yr}^{-1}$. No significant trend appears in the middle stratosphere in the vicinity of the ozone maximum near 25 km. The Umkehr result for layer 9 (45 km) is believed to be strongly dependent on the result for layer 8. The upper stratospheric trend results appear to be in agreement with current chlorofluorocarbon photochemical depletion theory; the trend results below the maximum might be due to heterogeneous chemistry involving anthropogenic chlorine and lower stratospheric aerosols [e.g. *Hoffman and Soloman*, 1989].

The ozone concentration in the upper stratosphere initially appears to follow the solar cycle, reaching a minimum in 1985, but does not recover to the early 1980 value as the solar cycle tended toward a maximum in 1990. A steep decrease occurring in the ozone concentrations of layers 7, 8, and 9 during the years 1981–1985 seems to account for most of the ozone decrease seen in the record. The cause could be due to anthropogenic depletion superimposed on an 11-year solar cycle.

An analysis of the contributions of the trends in each layer to the trend in total ozone indicates that the largest contributions are in the lower stratosphere. There is some disagreement between the SBUV and the Umkehr data as to whether the maximum contribution is by layer 2 or 3. Both methods have difficulty in resolving trends in layers 1–3. A new Umkehr algorithm now in use may shed some light on this [*Mateer and DeLuisi*, 1992].

Efforts to improve the SBUV and Umkehr methods are continuing and it is expected that these efforts will improve the agreement between the two methods. Comparisons like the one presented in the current work are extremely helpful. It is important to note that the SAGE II stratospheric aerosol and ozone profile data aided greatly in the calculations of the stratospheric aerosol corrections for the Umkehr. Lidar data, when available, are used in the absence of SAGE data.

The Umkehr data record goes back to 1958, which is by far the longest historical record of ozone profile observations. It makes sense to investigate this record with great care to determine whether and to what extent the interesting fea-

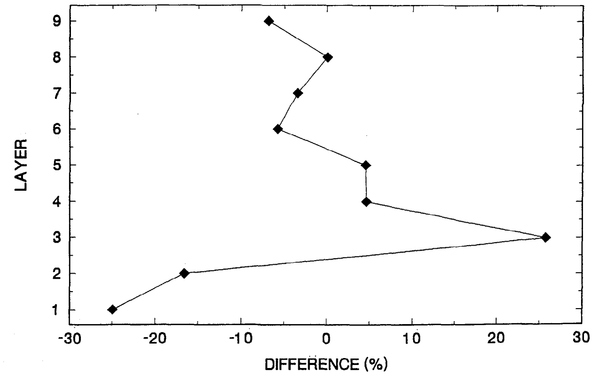

Figure 6. Umkehr layer number versus percentage bias between Umkehr and SBUV mean profiles of Figure 5. The Umkehr is the reference.

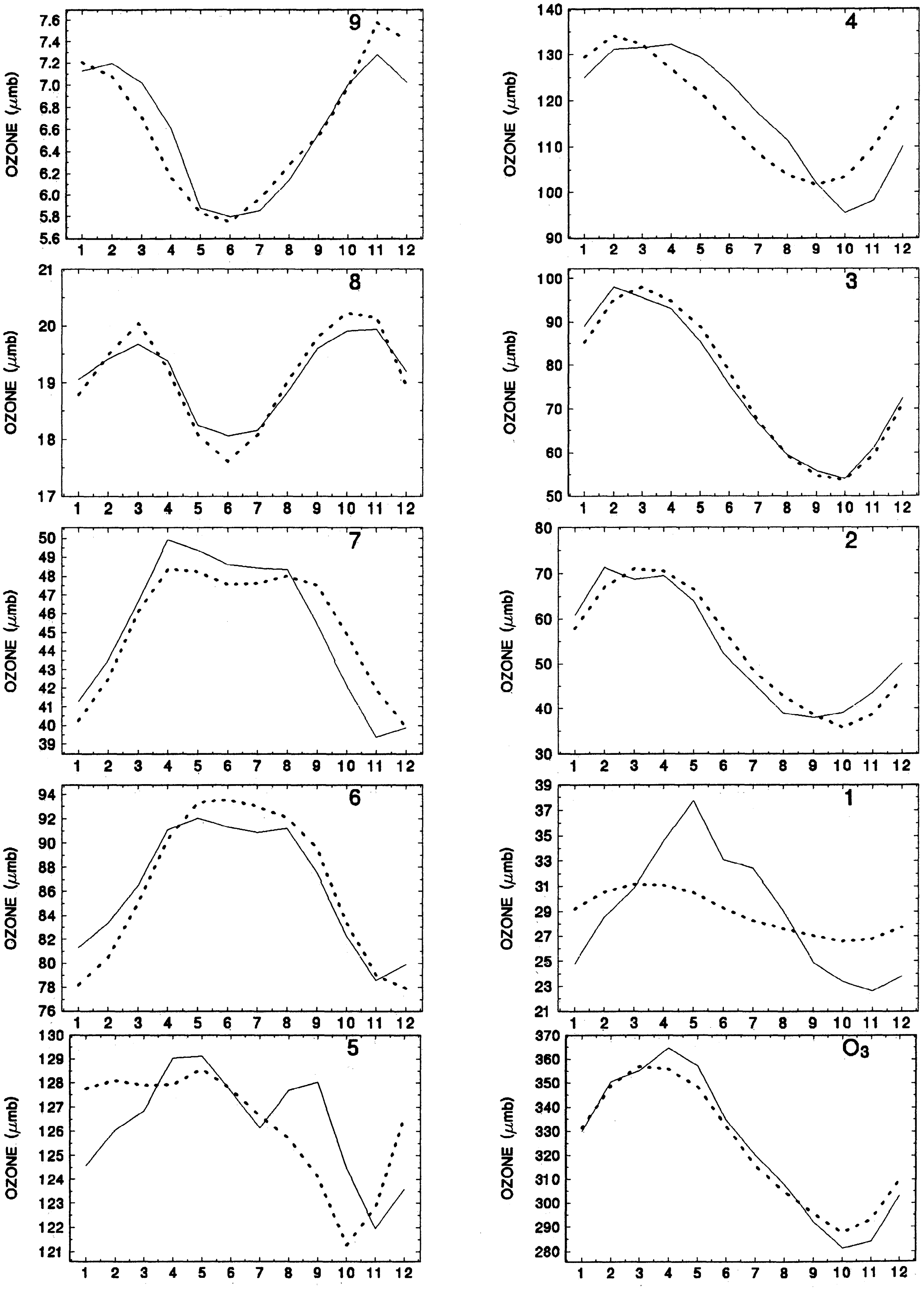

Figure 7. Comparison of Umkehr (solid) with SBUV (dashed) annual ozone cycles in the nine Umkehr layers. Plots are ozone partial pressure versus month, and total ozone is also shown. The biases shown in Figure 6 have been removed. The cycles were determined by averaging the monthly data for the years 1979–1990.

tures seen in the 1979–1990 SBUV and Umkehr profile records were extraordinary departures from the "normal climatology" of stratospheric ozone behavior. Some form of corrections for volcanic stratospheric aerosols will be required.

The new Umkehr algorithm, which already appears to be an improvement over the older algorithm, should be thoroughly tested. Recalculation of stratospheric aerosol corrections compatible with the new algorithm is required, and comparisons with the SBUV and other vertical ozone profilers should be done to quantify the degree of improvement. Also, an effort is under way to reprocess various Dobson network total ozone observations that have been determined to be flawed, which has some effect on the retrieved ozone profiles. The entire effort to improve the Umkehr profile retrieval algorithm, recalculate stratospheric aerosol errors, and reprocess the total ozone data is indeed ambitious. The work should be followed by a thorough and complete analysis of the data using the procedures that have been employed in the past number of investigations.

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