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OZONE TRENDS ESTIMATED FROM UMKEHR OBSERVATIONS MADE AT EDMONTON, ALBERTA, CANADA

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ABSTRACT

A Brewer Ozone Spectrophotometer has been in service at the Canadian Ozone monitoring station at Stony Plain (53.55° N, 114.10° W), near Edmonton, Alberta, since 1984. During that time, the instrument has been operated in a fully automated mode that includes the collection of morning and evening Umkehr observations. Some 197 Umkehr observations have been analyzed to make an estimate of the temporal trend in ozone amount at high altitude over the station during the last 8 years. This work has shown that at 40 km the trend in the ozone concentration has been observed to be 0.14±0.10 percent per year.

1 INTRODUCTION

Trends in the global ozone amount have been estimated by several independent methods. These have included the estimate of trends in high level ozone using the Dobson Spectrophotometer Umkehr results [DeLuisi and Nimira, 1979], the TOMS data set [Stolarski et al., 1989], and values estimated using the global total ozone data set [Bojkov and Mateer, 1984]. The TOMS data set is nearly independent of the ground-based measurements of ozone in the Version 6.0 form, since the values have been recalculated using an algorithm which suppresses the effects of diffuser degradation [Herman et al., 1991]. The Brewer Umkehr data set offers an additional, independent method for the estimation of ozone trends at high altitude.

The Brewer Ozone Spectrophotometer has been in commercial production for 10 years. During that time a large number of ozone observations have been made at Canadian ozone monitoring sites. A Brewer spectrophotometer has been in service at Toronto since 1982, and at Edmonton since 1984. Umkehr observations [Gotz, 1930; Mateer, 1984; McElroy, 1988] are made automatically as part of the daily Brewer observation schedule. Since 1984 over 500 (see Table 1) Umkehr observations have been attempted at Edmonton (in the first quarter of each year). Many of these were unsuccessful because of the variability in light level which occurs during cloudy weather, but a large number are available for analysis.

The Edmonton data have been chosen to make an ozone trend estimate for several reasons. The Umkehr series from Edmonton is among the longest Brewer data set available, the Edmonton weather conditions are quite good, there is access to good correlative data (ozonesondes), and the Edmonton Dobson data have already been analyzed to determine an ozone trend [Mateer, 1984].

2 DATA COLLECTION

The Umkehr data are collected by turning the Brewer instrument sun director prism toward the zenith and observing the intensity of light scattered vertically downward by the sky at 8 wavelengths in the ultraviolet. The Brewer is designed to make nearly simultaneous measurements at 5 different wavelengths using time multiplexing [Kerr et al., 1980]. Depending on the setting of the spectrometer diffraction grating angle, observations are made at 306.3, 310.1, 313.5, 316.8, 320.1 nm or 316.5, 320.1, 323.2, 326.4 and 329.5 nm. Measurements are made alternately at these two settings during sunrise or sunset. Data from three wavelength pairs are simultaneously fitted in the analysis process.

The Brewer instrument is equipped with a polarizer which is mounted in the foreoptics. Measurements of the strong polarization component of the zenith sky light are made by properly orienting the instrument. The whole spectrometer is rotated in azimuth under computer control to maintain the direction of polarization during the Umkehr period (60 to 90 degrees solar zenith angle).

The data collected each day at the observation site are stored on a floppy disk by the instrument control software. Floppy disks are filled and duplicated at the rate of 1 per week and the copied data are sent to Toronto where they are loaded onto the Brewer data base computer. The results presented here were analyzed after retrieval from the data base.

3 DATA ANALYSIS

The data collected by the Brewer are analyzed using software based on the algorithm of Mateer [1984] (the "short Umkehr method") which uses the technique of Rodgers [1976] to make an optimal estimate of the ozone profile based on both the Umkehr data and a knowledge of ozone climatology based on the analysis of a large ozonesonde data set Mateer et al. [1980].

In the analysis, the data are first preprocessed to produce interpolated intensity values at the Mateer "standard Umkehr angles" (60.0, 65.0, 70.0, 74.0, 77.0, 80.0, 83.0, 85.0, 86.5, 88.0, 89.0, 90.0 degrees solar zenith angle). The processing includes correcting the data for instrument dark count, non-linearity, and interpolating by a least-squares spline algorithm at the standard angles. The data in the longer and shorter wavelength sets are interpolated to the same angles (see Figure 1). The preprocessing stage also includes looking up the appropriate

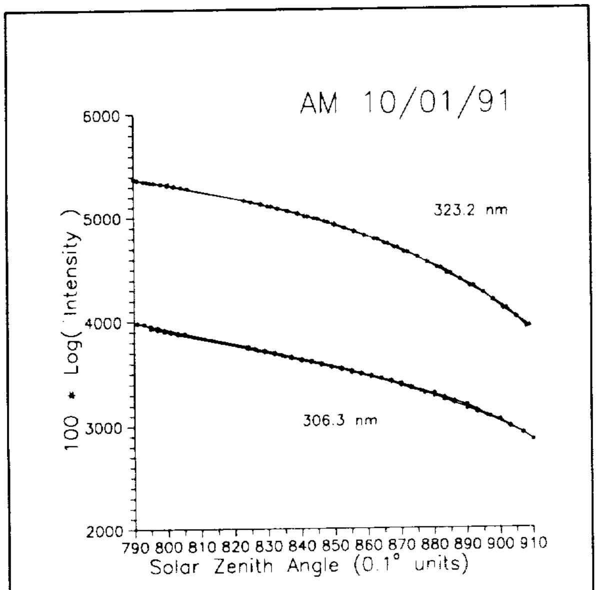

Figure 1 This figure shows the fitted curve and the raw data points output by the preprocessor for the longest and shortest wavelengths observed by the Brewer spectrophotometer.

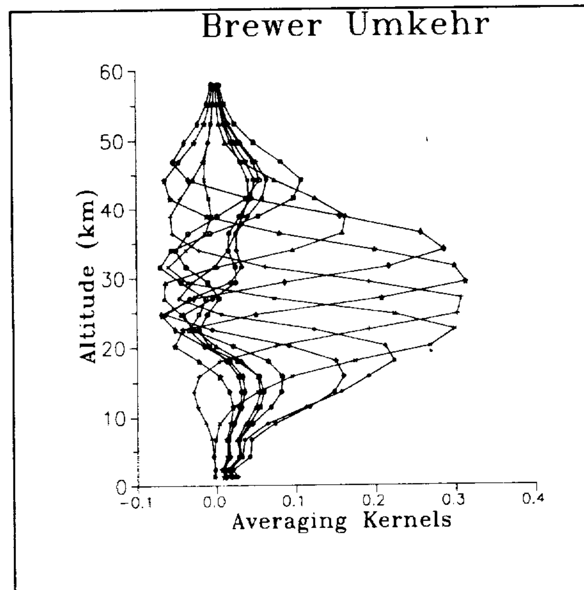

Figure 2 The averaging kernels for the Brewer Umkehr inversion algorithm. Note that the performance of the algorithm is best between 20 and 40 km.

ozone value for each Umkehr curve from the total ozone file for the observing station. All these data are written out in a terse format for further analysis by the Umkehr inversion software. A file is written for each day and instrument, and includes both a morning and evening Umkehr curve.

Quality control is done both at the preprocessing stage and at the Umkehr analysis step. The output from the preprocessor is examined for those days where the spline fitting process does not yield a good estimate of the observed data because of large variations between successive data points. If the RMS error between the observed and the fitted data is excessive the Umkehr is rejected.

If the curves cannot be inverted in 2 or 3 iterations of the inversion algorithm, the results are also rejected. Excessive differences after the second inversion iteration indicates that the observations are not well described by the range of curves represented by the climatology (perhaps due to instrument problems or observing conditions).

4 RESULTS

Table 1 shows the statistics for the success rate for Umkehr observations at Edmonton during the first quarter of each year between 1984 and 1991 inclusive. Of the possible 1444 Umkehrs which could have been observed, 518 were actually logged in the data base. Of these, 327 passed the preprocessing screening step, and 197 actually produced acceptable, inverted profiles. This success rate roughly parallels the "good data" days for Edmonton based on the success rate for total ozone observation attempts.

Table 2 shows the statistical report from the Umkehr analysis program for the data collected in 1991. For each year, all of the data collected in the first quarter were analyzed together to produce a mean profile, and an estimate of the variability of the results for the quarter using the "good" Umkehr curves. Since the same collection criteria were used for all curves, the results for different years should be comparable.

The amount of ozone in each Umkehr layer is recorded as a function of year in Table 3. The averaging kernels [Rodgers, 1990] shown in Figure 2 indicate the height range over which the Umkehr method produces its best results. A profile typical of those inverted from the 1992 Umkehr data is shown in Figure 3. Also included in Figure 3 is the climatological profile which was used in the estimation of the inverted results. The calculated rates of change of ozone based on these data are presented in Table 4. These rates apply to the actual observed ozone amounts and have not been corrected for physical effects such as the solar cycle variation of the solar flux.

5 CONCLUSIONS

These results do not show a significant long-term change in ozone concentrations at high altitudes above Edmonton. The SAGE results presented elsewhere in this proceedings have indicateda small, but statistically insignificant trend [McCormick, this issue] which is consistent with the results presented here. However, they demonstrate the quality and quantity of data which are available using the Brewer in its fully automated mode. Based on the success of this analysis, it is recommended that Brewer Umkehr observations from all stations in the global network be analyzed with the current algorithm and published in Ozone Data for the World as soon as possible.

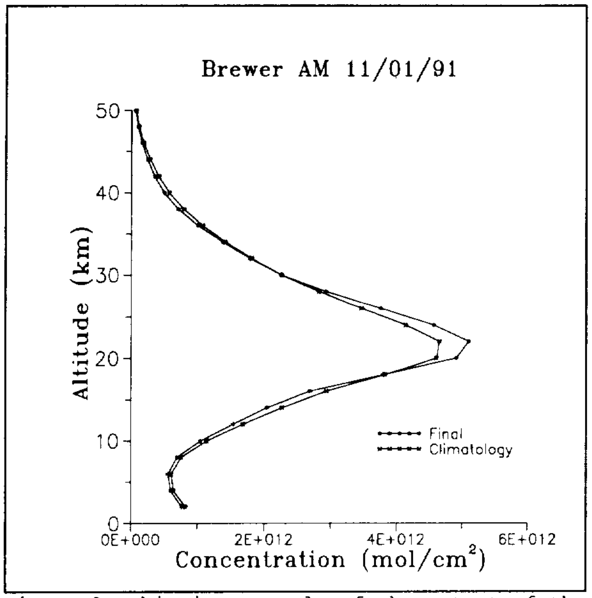

Figure 3 This is a sample of the output of the inversion algorithm presented as an altitude profile of ozone. Both the climatological "first-guess" and the retrieved profile are shown.

YEAR	Chances	Obs	Prepro	Complete	% Obs
1985	180	26	7	6	46.2
1986	180	12	1	1	8.3
1987	180	44	29	22	50.0
1988	182	48	30	19	22.9
1989	180	84	64	35	41.7
1990	180	76	56	40	52.7
1991	180	100	77	41	41.0
1992	182	128	63	33	26.0
Total	1444	518	327	197	38.0

Table 1. Observation statistics for Edmonton Umkehr observations.

Solution Statistics for 41 Profiles
Ozone Obs.=0.3502±0.0438 Sol'n=0.3512±0.043
Avg. Residual = 0.52±0.11 Iterations = 103

Layer	10	9	8	7	6	5	4	3	2	1
AVG	1.5	4.0	11	21	35	63	92	64	34	26
RMS	.1	.3	1	2	4	9	11	13	9	2
% Err	19	17	15	11	11	11	11	13	16	19

Table 2. Statistics for the processing of 1991 Umkehr data from Edmonton.

Layer	1985	1986	1987	1988	1989	1990	1991	1992
10	1.55	1.41	1.54	1.59	1.52	1.50	1.53	1.52
9	4.23	3.49	4.13	4.24	3.97	4.01	3.95	3.99
8	11.5	9.52	11.3	10.6	10.9	11.5	10.5	10.7
7	22.0	19.6	22.3	20.4	22.4	23.5	21.4	21.7
6	35.0	36.3	36.7	34.3	37.2	37.4	35.1	34.9
5	60.5	73.2	67.7	62.4	63.7	64.8	62.6	59.7
4	86.7	98.4	95.1	90.9	88.4	92.9	91.5	88.6
3	70.8	69.0	69.5	66.6	66.4	72.2	64.4	70.1
2	41.9	38.4	40.1	36.7	37.0	41.1	34.1	38.4
1	29.0	27.5	28.1	27.4	27.1	28.1	26.3	27.5
Number	6	1	22	19	35	40	41	33

Table 3. Edmonton ozone amounts (in Dobson Units) in each of the Umkehr layers (see Table 4 for heights).

Layer	Altitude	Trend 1985-92 (%/year)	Trend 1987-92 (%/year)
8	37.7 - 42.8	0.14±0.10	-0.87±0.10
7	32.8 - 37.7	0.69±0.07	0.15±0.10
6	28.1 - 32.8	-0.06±0.05	0.51±0.12
5	23.6 - 28.1	-1.20±0.10	-1.70±0.10
4	19.1 - 23.6	-0.39±0.07	-0.82±0.06
3	14.7 - 19.1	-0.35±0.05	-0.09±0.10

Table 4. Ozone trends estimated using the data in Edmonton Umkehr data.

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