WORLD METEOROLOGICAL ORGANIZATION

GLOBAL ATMOSPHERE WATCH

WMO Global Ozone Research and Monitoring Project

No. 22

WMO CONSULTATION ON BREWER OZONE SPECTROPHOTOMETER OPERATION, CALIBRATION AND DATA REPORTING

(Arosa, Switzerland, 2-4 August 1990)

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FOREWORD

The WMO Global Ozone Monitoring and Research Project was established in the mid-1970s' to enable WMO to provide advice to Members and to the United Nations and other appropriate international organizations inter alia on :

(a) the extent to which man-made pollutants, especially CFCs and nitrogen oxides might be responsible of stratospheric ozone reduction;

(b) the possible impact of ozone changes on climate and UV-B reaching the Earth's surface and

(c) the strengthening of the basis for long-term monitoring of the determination of trends.

In direct connection with the latter, since the IGY (1957) WMO has already had in existence the basic total ozone network of stations known as Global Ozone Observing System (GO_3OS) now part of the WMO Global Atmosphere Watch (GAW).

The standardization of measurements, periodic intercomparisons and review of the data quality and preparation of assessments of the state-of-the-ozone layer have always been a priority item in the internationally co-ordinated activities within GO_3OS. These have been successfully executed in collaboration with the International Ozone Commission of IAMAP, the World Dobson Calibration Laboratory operated by the National Oceanic and Atmospheric Administration - Boulder, the National Aeronautics and Space Administration of the U.S.A, the Canadian Atmospheric Environment Service and most importantly with the active participation of numerous scientists from nearly 60 countries. As one of the most recent activities, the Secretary-General of WMO provided the necessary support for the seventh major intercomparison of 18 Dobson ozone spectrophotometers which was conducted in Arosa from 22 July to 10 August 1990.

In addition to the Dobson spectrophotometer, which is the primary instrument used in the ground-based part of GO_3OS, during the last few years the Brewer ozone spectrophotometer started to be used in the GO_3OS. Nearly 50 instruments have been produced, a number of which are now providing data regularly to the WMO World Ozone Data Center operated by the Canadian Atmospheric Environment Service - Toronto. Taking the opportunity of the presence of a number of experts on total ozone research measurements in Arosa, WMO called, in conjunction, a Consultation on Brewer Ozone Spectrophotometer Operation, Calibration and Data Reporting, the report of which is presented in this volume. It is hoped that such joint activities concerning the exchange of information and experience will also continue to be conducted in the future to the benefit of all concerned.

(Dr. Rumen D. Bojkov)
Chief, Environment Division, WMO
Secretary of the Ozone Commission of IAMAP

WMO Consultation on Brewer Ozone Spectrophotometer Operation, Calibration and Data Reporting, August 2-4, 1990, Arosa, Switzerland

Meeting Organized by: R.D. Bojkov, C.S. Zerefos, J. Staehelin, J.B. Kerr, and C.T. McElroy

Report Edited by: R.D. Bojkov, C.T. McElroy, C.S. Zerefos and A.F. Bais

Chairman: J.B. Kerr

1. Opening of the Meeting and Election of a Chairman and Rapporteurs

1.1 Within the framework of the WMO Global Ozone Observing System (GO3OS) and Ozone Project activities, the WMO has organized its seventh intercomparison of Dobson ozone spectrophotometers in Arosa 22 July-10 August, 1990, in which took part 18 individual instruments providing the continuous total ozone data from all parts of Europe. Taking the opportunity of the presence of a number of experts in total ozone research, WMO called also a special Consultation on Brewer Ozone Spectrophotometer Operation, Calibration and Data Reporting. In this WMO Consultation, participants from almost all the European institutions operating Brewer spectrophotometers as well as representatives from AES and SCI-TEC from Canada, shared their experiences on the operation of the Brewer spectrophotometer and presented new developments concerning the improvement of the instrument performance and reliability.

1.2 C.S. Zerefos from the University of Thessaloniki, member of the WMO Executive Council Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry, on behalf of WMO, opened the meeting for users of the Brewer spectrophotometer and other ozone measuring instruments. In his welcoming address to the participants, he emphasized the importance of reliable measurements in the growing field of ozone research and he described the purpose of the meeting which aims at continuing the effort to maintain a high quality of reported ozone data by the WMO Global Ozone Observing System (GO3OS). C.S. Zerefos invited the participants to elect a meeting Chairman and rapporteurs for the sessions of the meeting. J.B. Kerr from AES was elected as Chairman; the names of the rapporteurs are listed in Appendix A. At the start of the meeting an Agenda, which had previously been prepared by the meeting organizers, was reviewed and accepted with minor modifications, and it is reproduced in Appendix B. The scientific part of the meeting opened with session 2 of the Agenda.

1.3 In his opening remarks the Chairman, J.B. Kerr, reminded the participants of the significance of the work being done by those present in order to monitor the stratosphere and understand the impact of changes in ozone on the UV environment on Earth. He noted that the Brewer instrument is becoming an important participant in the WMO Global Ozone Observing System (GO_3OS) and that between 40 and 50 instruments (listed in Appendix C) have been produced, a number of which were starting to provide data regularily. He also announced that Brewer instrument #039 was turned over to the WMO in 1989, to be used mainly as a travelling intercomparison standard to help improve the standard of ozone instrument calibration throughout the world.

2. The Brewer Instrument Calibration

2.1 J.B. Kerr presented a review of the methodology used in the Brewer spectrophotometer to calculate the total ozone amount. The total ozone (Ω) is obtained from the expression:

$$\Omega = \frac{F_o - F}{\alpha m} \qquad (1)$$

where:

F is a linear combination of $\log(I_i)$ terms and I_i is the intensity of light measured at wavelength i.

$\mathbf{F_o}$ is a linear combination of $\log(I_{oi})$ terms and I_{oi} the intensity of light at wavelength i

$\boldsymbol{\alpha}$ is the differential absorption coefficient related to F, and F_o.

m is the path enhancement through the ozone layer

The measured count rates produced by the intensities (I) of light at each observed wavelength are corrected for dead time (non-linearity), dark count (thermal noise), and Rayleigh scattering. The weighting coefficients of the linear combinations are:

$$(0.000, 1.000, -0.500, -2.200, 1.700) \qquad (2)$$

These weighting coefficients are applied correspondingly to the light intensities at the following wavelengths (in nm):

$$(306.3, 310.0, 313.4, 316.7, 319.9) \qquad (3)$$

so that the resulting absorption function is not affected by particle scattering nor by SO_2 absorption. It is useful to recall that the wavelength pairs used in the Dobson ozone spectrophotometer are: A(305.5,325.4), C(311.4,332.4)and D(317.6,339.8).

In equation (1) the components of the parameter (F) are measured and (m) is calculated given the measurement location and time. The parameters Fo and a, must be determined for each instrument using a calibration procedure as described in the following paragraphs.

2.2 For each instrument which is to be calibrated on an absolute scale an extraterrestrial constant (F_o) and a differential absorption coefficient (α) are determined in the following way:

> **F_o**: F values are measured by the instrument over a broad range of zenith angles (e.g. sunrise until noon) and a linear fit of F versus m (where m is airmass) is used to determine the value of F at zero airmass. The data used in this analysis must be taken on clear days, and the ozone value must remain steady through the whole range of m values. The calibration is normally carried out on a mountain top in the tropics (e.g. Mauna Loa), where it is quite likely that these observing conditions will exist.
>
> **α**: the absorption coefficients at each wavelength of the instrument are determined by convolving the measured instrument slit functions with a reference ozone absorption coefficient spectrum (currently Bass and Paur, 1984). The slit functions themselves are determined by scanning a set of reference discharge lines. These normally include a mercury line at 296.1nm, and two cadmium lines at 313.3 nm and 326.1 nm. The line profiles measured define the slit profiles, and the relative positions of the various discharge lines allow the determination of the coefficients of a quadratic relation between the grating adjusting motor step number and wavelength.

2.3 By using the physical calibration it is possible to achieve an agreement in the order of 1% among different, absolutely calibrated, Brewers. To ensure the homogeneity of the Brewer data reported in the GO3OS, most instruments are calibrated against the Brewer Triad (Brewers #008, #015, and #014) in AES, Toronto before being shipped to the observing sites. The travelling and manufacturing standard instruments are regularly calibrated against the Brewer Triad. In this intercomparison procedure the coefficients (F_o) and (α) for the instrument are calculated to give agreement with the Triad to within 1%.

2.4 It is desirable that the calibration of field instruments be maintained through the regular (approximately once per year) intercomparison with the Brewer travelling intercomparison instruments. These include Brewer #017, belonging to AES, and #039 the WMO travelling instrument. Before and after each trip, the travelling instruments are intercompared with the Toronto Triad. If significant changes (e.g. more than 1%) have occured during the trip, the calibrations will have to be redone. This ensures that the calibration is correctly passed from the Triad through the travelling instrument to the field instrument. The obvious benefit accrued through the use of this calibration procedure is that the field instrument is protected from potential accidents which could happen during shipment.

3. Brewer Observations and Data Management

3.1 Ulf Kohler presented some modifications to the Brewer IBM-PC control program. Instead of using solar zenith angles to control the automatic observation schedules, the ability to use time as the control parameter was implemented. Another development added to the program was an automatic test of the light intensity observed by the instrument (the solar intensity). The observed photon count is compared to a μ-dependent value, and direct sun measurements are not made if the light intensity does not exceed this test value. In order to increase the probability of making direct sun measurements on a day with variable cloud, if the intensity test fails two new attempts to make a direct sun are made within a few minutes. It is hoped that this technique will increase the number of direct sun measurements made each month by the Brewer instrument. It should be noted that the above mentioned intensity test values must be determined separately at each particular instrument location.

3.2 Andre Roberge presented a new set of subroutines that prepare daily average files of ozone data and instrument performance on the data disk. Most instrumental test routines, such as the dead time test, the run/stop test, and the micrometer test are included. This will make it much easier to track the performance of the instrument. The summary algorithms also contain some simple calculations and alert the observer if the results of the tests lie outside specified limits.

3.3 Three cases of direct sun and focussed moon comparisons were presented by Ulf Kohler. Normally focussed moon (fm) observations were taken about two to three days on either side of the date of the full moon, and for airmass of less than 2. Two of the data sets were in August of 1986 and March of 1987. These observations showed a large scatter of the individual measurements, but their average is in good agreement with the adjacent daytime direct sun (ds) measurements. The probable explanation for the large scatter were the relatively low altitude of the moon, implying low light intensity, possible tracking error, and the influence of clouds. The third case from the winter of 1990 showed less scatter in the fm data points, but a variation that could be μ dependent. The cause of this has not yet been determined.

3.4 J.B. Kerr showed some statistics for fm observations made at Toronto as well as Resolute and Alert in the Canadian Arctic. The majority of successful observations was expectedly concentrated around the time of the full moon, plus or minus 4 days. Some useful observations were made as much as seven days away from the full moon. The average difference between the nighttime moon observations and daytime ds observations made on adjacent days was found to be less than 1% with a standard deviation of $\pm 5\%$. A more thorough statistical analysis led to the conclusion that most of the 5% variability is due to day-to-day variability in total ozone. It was also found that there is little dependence on the phase of the moon. At Resolute and Alert the fm observations agreed with integrated ECC sonde measurements to within the combined error expectations of $\pm 5\%$.

3.5 The Canadian ozone database under development will have the ability to include all types of Brewer observational and performance test data. The system will be capable of processing and correcting data as well as automating the submition of processed data to the WO_3DC. As one Brewer system can produce as much as 1 megabyte of data per month, a network of 50 stations could produce an enormous amount of data per year. Therefore hardware which provides large storage capacity and rapid retrieval rates is required. Compatibility with other database formats and a general software implementation are needed to meet long term requirements.

4. Total Ozone Intercomparison between various Instruments

Within the framework of the WMO Ozone Project and its Global Ozone Observing System, WMO has been organizing regular ozone instruments' intercomparisons during the past 20 years. In addition the NOAA-Boulder Laboratory is acting as WMO Central Dobson Calibration Laboratory and a large number of instruments have been calibrated there. Also WMO has been facilitating the calibration of individual instruments by experts from the USA and Canada and for the first time arranged for a Brewer to be used as a travelling standard in 1979. These well organized international activities are essential for the quality of the data obtained in the GO_3OS.

4.1 During the last few years, mainly in Europe and North America, intercomparisons have continued to be made to assess the accuracy of the various types of instruments and measuring methods. Especially since the Brewer spectrophotometer is now commercially available, a great interest exists to compare this new instrument offering full automation, versatility and additional capability for measuring SO_2, NO_2 and UV-B with the GO_3OS mainstream and highly accurate Dobson spectrophotometer.

4.2 An intensive investigation carried out in Finland by Esco Kyro has compared total column ozone observations made by the Brewer instrument to those made using other methods (M-83, M-124, SAOZ spectrophotometer, ECC-sonde). From the comparison of 107 Brewer (ds) observations with those made with the M83 instrument, it appears that there is a significant linear relation ($r = 0.96$) between these measurements with a RMS deviation of about 9.3 DU. Similar results but with larger deviations were obtained by comparing the Brewer with the SAOZ instrument ($n = 105$, $r = 0.91$ and RMS deviation = 16.8 DU) and the total ozone calculated from ECC soundings ($n = 46$, $r = 0.88$ and RMS deviation = 31.8 DU). It turns out that the Brewer has the highest reliability and versatility of all instruments compared in Finland, but nevertheless its capability to measure total ozone in polar regions during wintertime, when it is most interesting, is still to be proven.

4.3 Results of long term intercomparisons between Brewer and Dobson instruments at Toronto, Edmonton and Goose Bay were presented by J.B. Kerr. The comparisons showed that the average Dobson total ozone values are between 2% and 3% larger than the Brewer values at all three sites. Most of this difference is attributable to the different ozone absorption coefficient scales used for the Dobson instrument (Vigroux, 1968) and the Brewer instrument (Bass and Paur, 1984). A relative airmass dependence of about 1% over an airmass range between 1 and 3 was observed at all three sites. The cause of this variation is currently not fully understood. A relative seasonal variation of about 1% was observed at all three stations. This variation is most likely due to the different temperature dependence of the ozone absorption coefficients for the Brewer and Dobson instruments combined with the annual temperature variation of ozone. After accounting for the effects of different absorption coefficient scales, SO_2, airmass dependence and annual variation the agreement between the Brewer and Dobson instruments is within $\pm 0.5\%$ (Fig. 4.1).

4.4 The simulated Dobson values of the Brewer (i.e. the calculation is based on the Vigroux's absorption coefficients) are very close to the observed Dobson values of total ozone. This confirms that if a Dobson is replaced by a Brewer there would not be a break in a long term series. Some other comparison results between Dobson and Brewer spectrophotometers in Boulder (A. Diaz) and in Arosa (J. Staehelin, A. Asbridge, H. Schill) were also presented. The discrepancies between the instruments were all less than 1%.

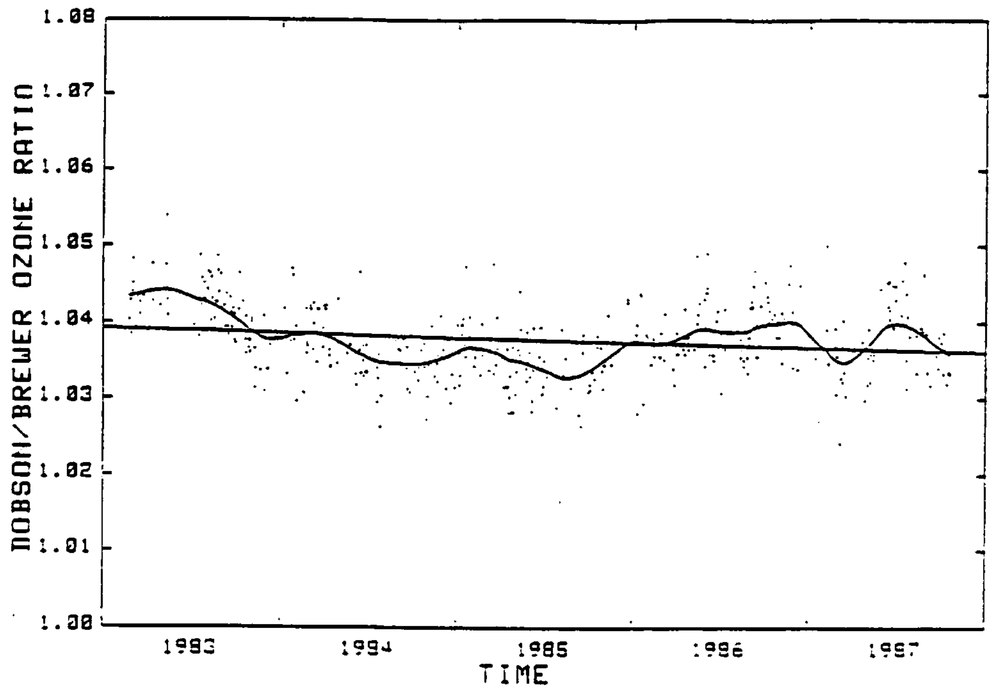


Figure 4.1: *A long term intercomparison between the Brewer and Dobson instruments at Toronto illustrates the good agreement between the two. There is a shift of approximately 3.8% between the two measurement series because the Brewer is calibrated on the Bass and Paur ozone absorption scale, while the Dobson uses the rationalized Vigroux coefficients. Allowing for this difference in calibration scales, the agreement between the two data sets is approximately 0.5%.*

4.5 The differences between the Brewer and the Dobson as determined in Uccle, Belgium were discussed by H. DeBacker and D. DeMuer. The measurements were made for a period of 6 years and they are within $\pm 1.7\%$. The long term trend of the differences is in the order of 0.04% per year (Fig. 4.2a). It is believed that the observed trend in these differences was caused by a slight decrease of the total amount of SO_2, as it can be seen from figure 4.2b where the SO_2 amount as measured by the Brewer has been subtracted from the Dobson values.

4.6 A preliminary comparison of focussed moon observations made at Scott Base in Antarctica (C. Valenti), showed agreement within 10 D.U. between the Brewer and the Dobson spectrophotometers.

4.7 Total ozone measurements made by the Brewer instrument at Table Mountain during the Stratospheric Ozone Intercomparison Campaign (STOIC), July-August, 1989 were presented by J.B. Kerr. Comparison of total ozone measured with the Dobson instrument showed average agreement to within 1% with a standard deviation of 1.2%. Comparison of total ozone measured by TOMS showed an average difference of 3.5% with a standard deviation of 0.7%. The average difference between TOMS and Brewer measurements may be due to the fact that the Brewer measurements were

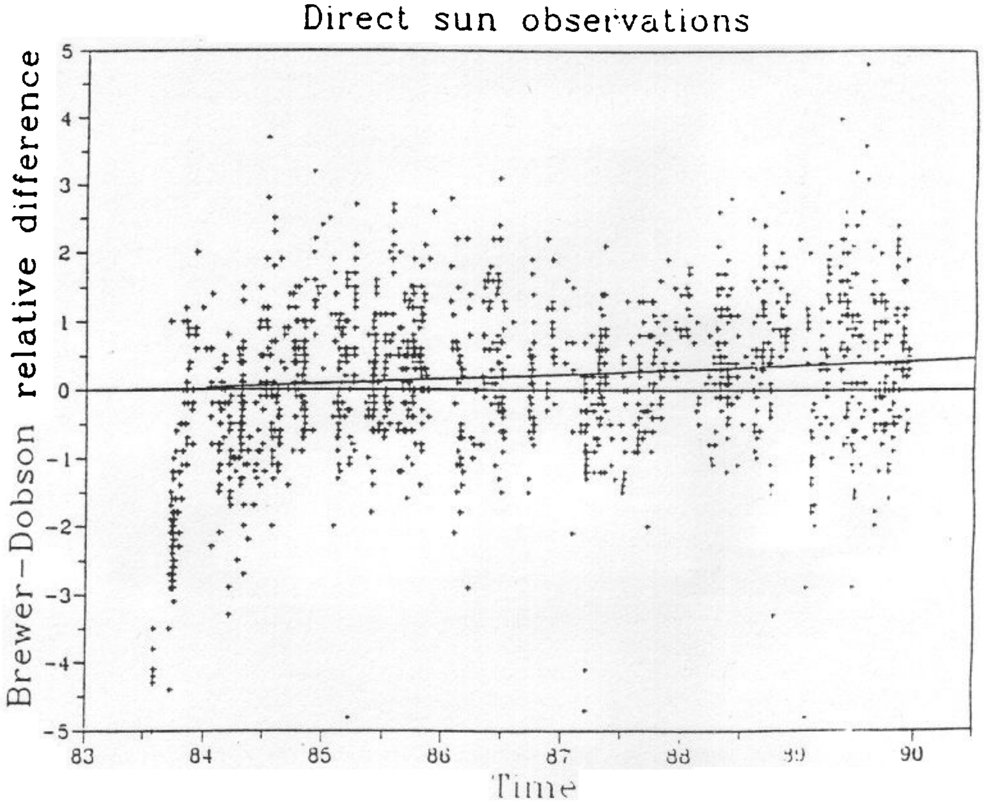


Figure 4.2a: *Brewer-Dobson total ozone differences obtained at Uccle, Belgium for a period of six years.*

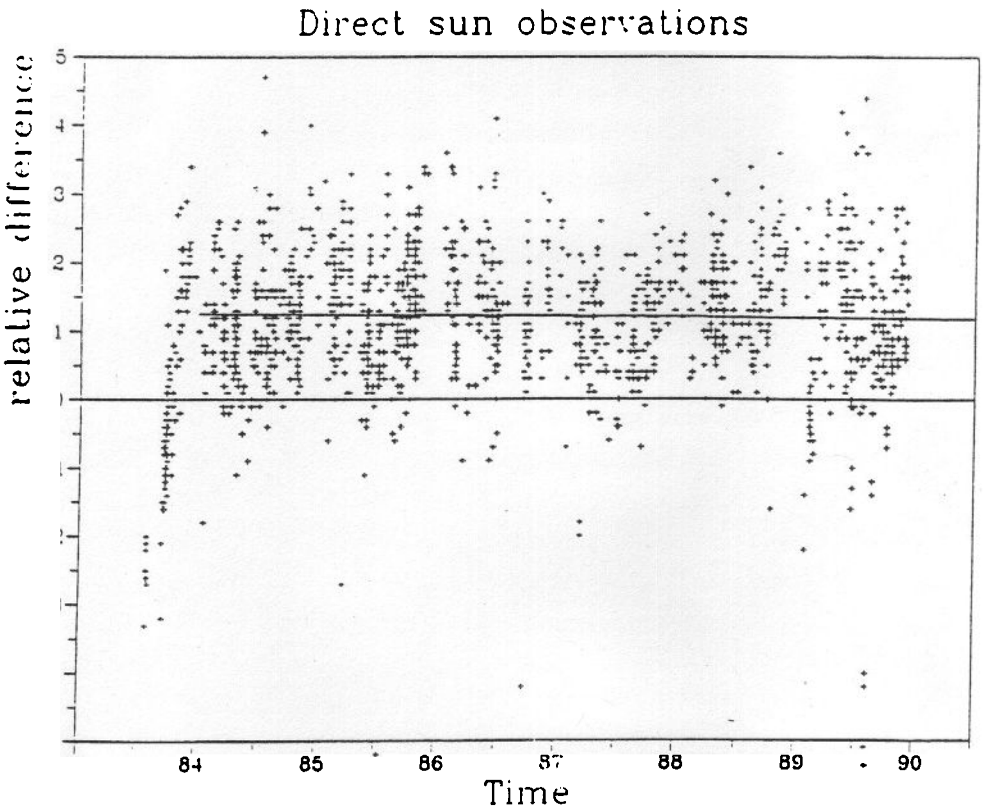


Figure 4.2b: *Brewer-Dobson total ozone differences obtained at Uccle, Belgium for a period of six years. The SO2 values, as measured with the Brewer, have been subtracted from the Dobson measurements*

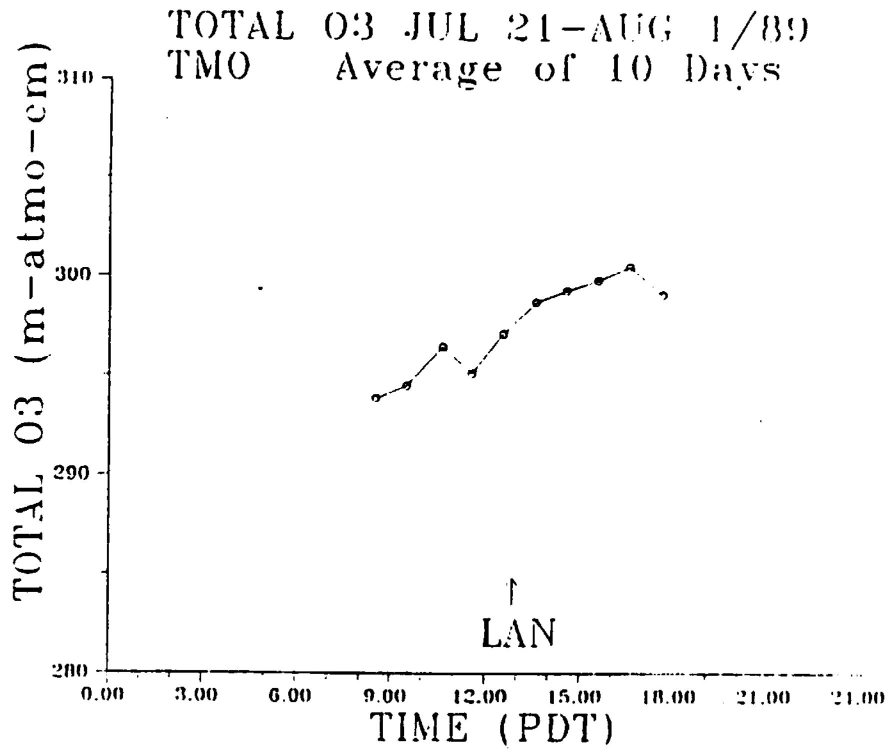


Figure 4.3a: *Variation in the total ozone values throughout the day during the Table Mountain intercomparison.*

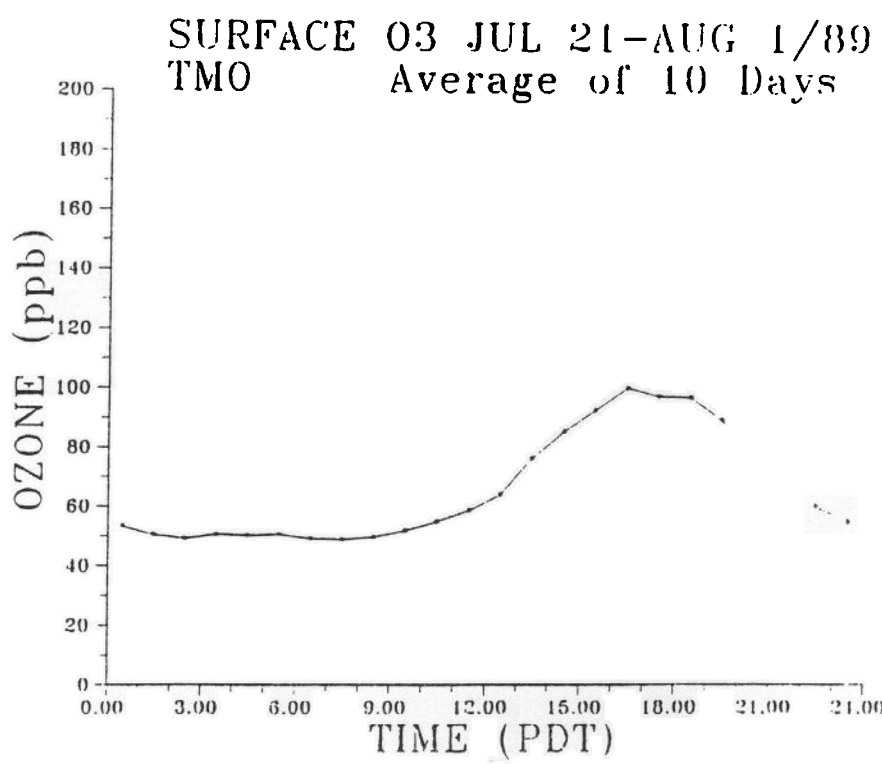


Figure 4.3b: *Surface measurements over the period of the Table Mountain intercomparison were averaged to show the mean surface ozone.*

made at an altitude of 2 km. The TOMS data include a tropospheric contribution, which would not be seen by the Brewer instrument. The average values of total ozone measured over a ten day period at Table Mountain showed a diurnal variation (Fig. 4.3a) with ozone increasing by about 7 DU from early morning to late afternoon. Measurements of surface ozone averaged over the same ten days showed that the cause of this increase is most likely due to a build up of surface ozone during the day (Fig. 4.3b).

4.8 Walter Komhyr has reported preliminary results from the Dobson Intercomparison in Arosa (15 July - 10 August, 1990) which show that a carefully maintained Dobson network may be used for the detection of ozone trends. 13 of 18 compared Dobsons have differences with the standard Dobson No. 65 from Boulder of less than 1% (see Appendix D).

5. Daily Data Exchange within the European Part of the GO3OS.

5.1 This item was devoted to the discussion of a proposal brought forward by C.S. Zerefos and A.F. Bais (University of Thessaloniki) to establish a near real-time total ozone reporting system in Europe, which will also be capable of supporting the European Arctic Stratospheric Ozone Experiment (EASOE) by providing a timely source of maps of the total ozone field over Europe and the Arctic. These data will augment the information available to the scientific community since each of the participating institutions will acquire daily total ozone maps within 24 hours. It was proposed that this collection system would be created and operated by the researchers at the University of Thessaloniki and that it would be funded in part by that Institution.

5.2 The ozone data used to make the maps would include that of any ozone measuring station capable of making regularly an automatic electronic (modem, telex, fax) report of data to the European "near-real-time" WMO Ozone Collection Centre at the University of Thessaloniki.

5.3 Valery Dorokhov of the Central Aerological Observatory of the USSR indicated that the capability of producing ozone field maps based on the extensive Soviet ground-based ozone monitoring system within the Soviet Union already exists, and has been used in the past to track ozone anomalies in the European part of the USSR. He proposed that the available experience in the USSR be shared in making the arrangements proposed by C.S. Zerefos.

5.4 A.F Bais and C.S. Zerefos reported on the technical details of their proposal to automatically collect ozone data, and on the results of a pilot study of an automatic data collection program which is already working within the Greek ozone observing network, comprised of three Brewer instruments installed in northern Greece. The data handling requirements for the system were discussed, as well as a number of alternate strategies which might be used for data communication in the system.

5.5 Some areas of concern relating to the operation of the system and the establishment of a data exchange protocol (e.g. financial support for telecommunications expenses, format of the transmitted data) were elucidated, and remain to be resolved by the participating parties in the future. In particular it was unanimously agreed that the system would be capable of reporting the daily data collected directly to the World Ozone Data Centre in Toronto, consistent with the wishes of the individual data contributors. However, notwithstanding this mechanism for the automatic reporting of data to the WO3DC, it will remain the responsibility of the reporting stations to ensure that their original data are accurately reported in accordance with the established WMO practices in a timely manner with a delay of less than one month, after completing each calendar month. It is not the intention of the proposers, nor of the meeting participants that the daily data reporting system proposed here should in any way replace or supercede the function of the WO3DC. Thus, the proposed system will operate under the WMO GO3OS.

5.6 The dissemination of data outside the proposed system would be carried out only with the prior agreement of the contributing station, and the technical data exchange protocol would include status information relating to this approval process. It is clear that the automatically reported data must be considered provisional, and even if it is provided immediately to the WO3DC, subsequent revision of the data will remain the prerogative of the contributing station.

5.7 Most of the participants indicated strong support for the scientific merit of the proposed "near-real-time" collection system and agreed to participate in preliminary experiments to send data to Greece. Also the Atmospheric Environment Service of Canada has already written a letter of support for the proposal.

5.8 A number of specific recommendations were discussed for future activities to try to realize this goal. They include the following:

a) The pilot collection system currently under evaluation in Greece should continue to be operated in order to learn more about the possible problems associated with its operation. In particular, experiments should be carried out in the collection of data from various countries.

b) A proposal of a formal data protocol should be prepared and circulated among the operators of the stations which are to contribute data in order to permit the testing of the pilot system in an operational manner as soon as possible.

c) The automatic reporting system should have the capability of reporting data on other atmospheric species (e.g. SO_2, NO_2) and parameters such as UV-B, when these are measured.

d) It was recommended that the WMO Secretariat should be asked to transmit a letter officially explaining the proposal, and inviting the participation of all countries with potentially interested station operators in order to address the formal requirements for the exchange of data between different countries.

e) It was agreed that the potential for the use of existing WMO global telecommunications system (WMO-GTS) should be investigated in addition to the proposed use of telephone, telex, fax and electronic mail systems.

f) The proposed system will start initially to operate during the winter of 1991-92, after which the results will be evaluated at a meeting of the participating parties.

6. Umkehr Observations with the Brewer Spectrophotometer

6.1 The first information on the vertical distribution of ozone in the atmosphere was obtained by P.F. Gotz using Umkehr measurements in the early 1930's. However, it was not until a computerized evaluation method was established by Mateer and Dutch in early 1960's and all Umkehr started to be uniformly processed by the WO_3DC, when more systematic data on the ozone vertical distribution become available. There are less than a dozen stations with long term records of Umkehr measurements which allow the estimation of trends of ozone in the upper atmosphere. The classical Dobson Umkehr measurement is usually based on measurements of the C wavelength pair, and since the mid 70's the then developed short Umkehr method uses different wavelength pairs, but it is not commonly applied. Taking Umkehr measurements by using the Dobson spectrophotometer lasts for several hours starting in the morning before sunrise or going on in the evening until after sunset. Therefore the method has to be automated in order to get this useful information in an economical way. In a joint WMO/EPA/NOAA project accomplished in 1979-1980, seven Dobsons were automated and since then they have produced an enormous wealth of information.

6.2 C.T. McElroy presented results showing that the Brewer spectrophotometer can also be used for Umkehr measurements. It utilizes observations of the intensity of zenith sky light at eight wavelengths (306.3, 310.1, 313.5, 316.8, 320.1, 323.2, 326.4 and 329.5 nm) instead of using wavelength intensity ratios as in the Dobson. The approach used to calculate the vertical profiles of ozone in the Brewer Umkehr method is essentially the same as the Dobson short Umkehr. The short Umkehr algorithm is a state-of-the-art inversion method which utilizes first-guess profiles based on a recent climatological analysis of ozone sonde data (C.L. Mateer). This is in contrast to the algorithm used to calculate profiles for the Dobson classical Umkehr which has been in use for nearly 30 years in the processing in the WO3DC of more than 30,000 Umkehr profiles.

6.3 The Umkehr analysis for the Brewer includes the following steps:

a) Select a first guess profile (based on total ozone, latitude, season, and surface pressure).

b) Correct observed N-values for multiple scattering based on the total ozone amount.

c) Do single scattering forward calculation.

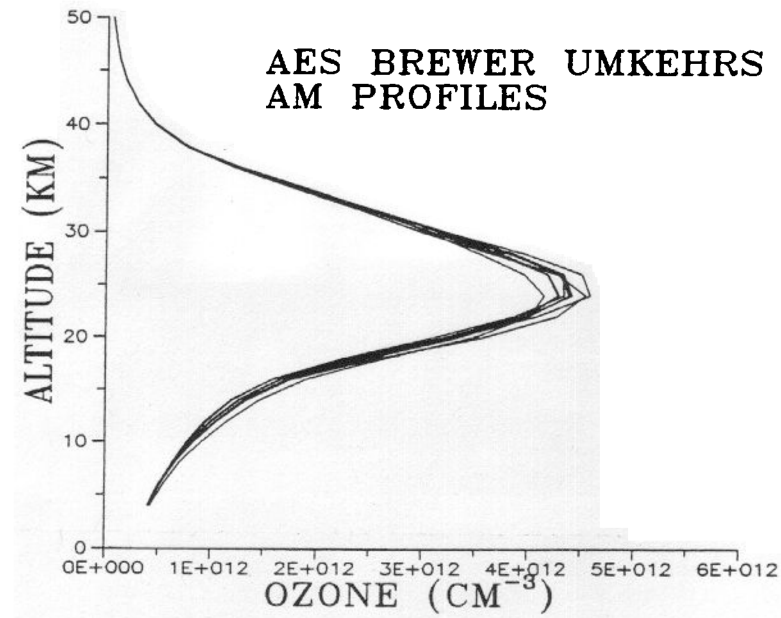
d) Compare to observations.

e) Correct distribution estimate using Rodger's most probable solution method.

f) Judge final results based on fit and convergence.

The solution is fast, requiring only a few iterations. Preliminary software is now available from AES and can be run on an IBM-PC compatible computer, which makes the method attractive for inclusion in the operational Brewer observation schedule. It was considered that operational Brewer Umkehrs would have the potential to provide useful information about stratospheric ozone in an economical way. So far, Umkehr observations are not systematically made by all Brewer spectrophotometers; however, it is desirable that regularly operating instruments have Umkehr observations included in their schedules.

6.4 During the 1989 Stratospheric Ozone Intercomparison Campaign (STOIC) at Table Mountain Observatory in California, the Atmospheric Environment Service of Canada operated a Brewer Ozone Spectrophotometer to make measurements of the total column amount of ozone, and of the vertical distribution of ozone in the atmosphere through the use of Umkehr observations. Umkehr data were collected during STOIC by Brewer instrument #039 operating in the fully automatic mode. In all, 28 opportunities were available to make Umkehr observations during the campaign period, and of these, 21 Umkehrs were successfully inverted to give ozone profiles. Two were lost because the instrument was not operating during the Umkehr observing period, and the others were lost because of unsuitable observing conditions. In the fully automatic mode the instrument makes total ozone measurements on the sun and the moon, and gathers Umkehr data between 60 and 90 degrees of solar zenith angle in both the morning and the evening.



distributions determined from morning Umkehr observations between July 20 and August 2, 1989, during the STOIC campaign, using an automated Brewer spectrophotometer.

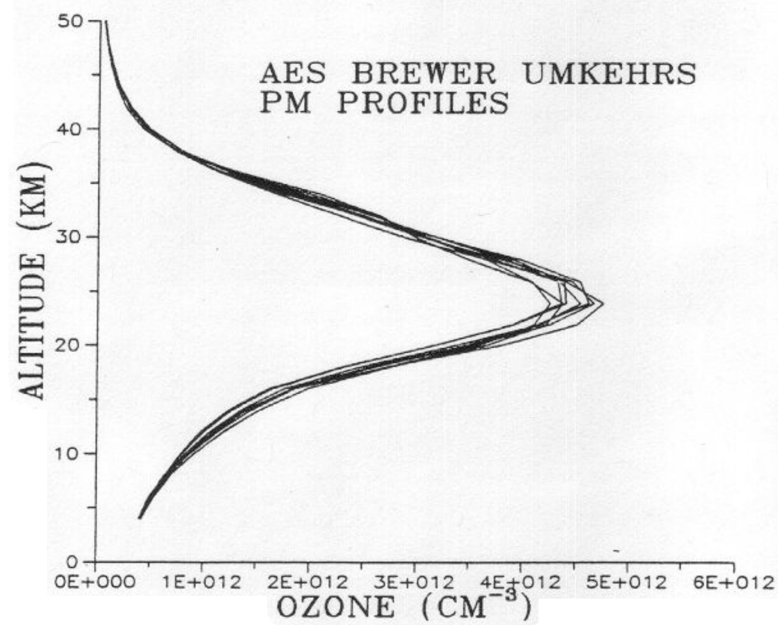


Figure 6.2: *Ozone distributions determined fromevening Umkehr observations between July 20 and August 2, 1989, during the STOIC campaign, using an automated Brewer spectrophotometer.*

6.5 Distributions of ozone derived from morning and evening Umkehrs during the STOIC intercomparison are shown in Figures 6.1 and 6.2 respectively. It can be seen that there is more variability in the evening profiles, and that the variations show up throughout the full altitude range of the profiles. This effect is caused by the fact that the surface ozone at the Table Mountain site increases throughout the day, while the stratospheric component is relatively steady both from day to day, and throughout each day. The variation in the total column caused by the changes in the surface component are reflected into the stratosphere in the process of determining the first guess profile for the inversion algorithm.

Table 6.1: *Comparison between the mean ozone profiles determined by Brewer-Umkehr observations and by other methods.*

Umkehr Layer	Height [km]	Brewer [DU]	Other [DU]	Npts	Dif.	%
0	2.15					
1	10.29	24.33	24.81	12	-0.47	-1.90
2	14.71	10.06	9.72	12	0.33	3.42
3	19.13	28.19	26.44	12	1.75	6.62
4	23.59	67.42	62.36	13	5.06	8.12
5	28.14	74.82	75.10	39	-0.28	-0.38
6	32.79	51.05	53.66	39	-2.61	-4.86
7	37.65	25.04	27.63	31	-2.60	-9.39
8	42.80	9.58	11.06	31	-1.49	-13.44
9	48.27	3.22	3.57	23	-0.35	-9.82
Total		293.71	294.35		-0.64	-0.22

6.6 In Table 6.1 the morning Umkehr results are compared to the mean of the results of the other profiling instruments which were used during STOIC. The Brewer Umkehr analysis program gives results as partial column amounts in a set of layers with factors of 2 difference in pressure. The lower and upper heights of these layers are listed in the table 6.1. The column labelled 'Other' is the mean of results for each layer reported at various levels by the other participants in the intercomparison and includes values measured by the Jet Propulsion Laboratory Lidar, the NASA/Langley Microwave Instrument, ozonesondes flown by Wallops Island, and the Goddard Space Flight Center Lidar. The number of individual curves averaged for each Umkehr layer is shown under the heading 'Npts'. The data from Table 6.1 are interpolated according to the interpolation scheme used in the Umkehr inversion algorithm to present the comparison results on a density-height plot which is shown in Figure 6.3. Three curves are plotted. These include the first guess profile for a total ozone amount of 300 DU, the mean curve as defined by the other participants in STOIC, and the mean curve

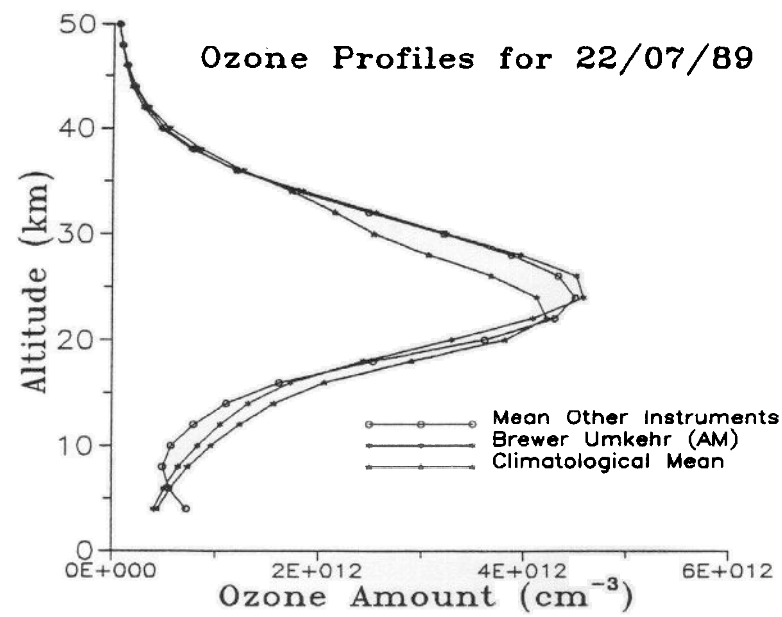


Figure 6.3: *Comparison of the mean Table Mountain Umkehr profiles with the mean curve obtained using the LIDAR, ozonesonde and microwave data. Also incleded is the first quess profile used for the Umkehr calibration. It is labed "midlatitude mean" and is generated by an analytic representation of the global ozone climatology developed by C.L. Mateer.*

for the Umkehr results. It can be seen that there is a systematic difference between the Umkehr results and the mean curve determined by the other STOIC instruments. It would appear that this difference is largely due to the poor agreement between the midlatitude mean curve, used as the first guess, and the TMO mean curve. It is apparent that in the region where the Umkehr is most sensitive (23.59 to 42.80 km, as determined by an examination of the averaging kernels of the inversion operator) that the solution curve has moved significantly toward the TMO mean data curve. In performing this analysis the mean climatological profile used as a first guess was assumed to have a covariance matrix with 0.04 as its diagonal element, and 0.01 as the first off-diagonal elements. The final profiles agree within the expected error limits with the STOIC mean curve.

6.7 The results presented here have demonstrated that the Umkehr method is accurate to approximately 10% in the 20-40 km region of the ozone layer when the analysis of one Umkehr is carried out. The close agreement of profiles taken on different days (Figs. 6.1 and 6.2) during the intercomparison period suggests that there is enough information contained in such a set of observations to considerably improve the final estimate of the mean profile. The curves presented here did not make any allowance of the fact that multiple observations of the atmosphere had been made. In principal a set of N observations should permit the reduction of the absolute uncertainty in the estimate of the mean profile by square-root N. For the case of the

Table Mountain data set this would reduce the error in the region of greatest sensitivity from 10% to about 2%. Observations of the Umkehr effect will continue to provide valuable information about long term trends in ozone amount in the upper atmosphere.

6.8 Luigi Ciattaglia presented some results of Umkehr data collected using the Brewer instrument in Rome and analysed using the new PC-based Umkehr analysis software. Two Umkehr profiles were presented, together with ozone profiles measured using LIDAR at a near-by location. These profiles were observed on successive days in June, 1990. One profile, according to the LIDAR measurement, showed a strong secondary maximum above the main peak of the ozone layer. This maximum, as revealed by the LIDAR profile, was about 10 km above the main peak of the ozone layer, and had a width of about 8 km. In the Umkehr profile this feature was detected as a bulge in the profile at the appropriate altitude. The profile taken on the other day did not show any evidence of a secondary peak in either the LIDAR profile or the Umkehr result. The performance of the Umkehr inversion program in this rather challenging case indicates the good potential which the Umkehr has for providing information about the global distribution and altitude variation of atmospheric ozone.

7. Special Observations (UV-B, NO_2 and SO_2)

UV-B Measurements

7.1 In connection with the ozone decline documented in WMO Ozone Reports #18 and #20 and the growing public concern for the possible increasing of the UV-B reaching the earth, it was noted that the currently existing simple instruments do not provide reliable data. Therefore, the possibility of using the Brewer spectrophotometer for UV-B measurements was of major interest for the meeting attendees. It was suggested that the Brewer instrument was capable of being calibrated to provide accurate measurements of the UV-B part of the spectrum, at wavelengths longer than 290 nm.

7.2 Weine Josefsson presented information of UV-B observations made in Sweden and made a detailed account of his estimates of the absolute and relative errors which occur in the Brewer UV-B measurements. At this early stage of the development of the Brewer UV-B observing technique, he estimated that the expected absolute accuracy of the UV-B measurement is on the order of 20%. This estimate includes the potential calibration and operation errors, such as the lamp stability, the transfer of calibration from the lamps to the instrument, the polarization of light, the cosine and azimuth response, and errors due to temperature and stray light effects. The precision of measurements made by one particular instrument is probably in the order of 10% to 15%. Measurements are conducted using both the Brewer and the Robertson-Berger meter at Swedish observation sites and they appear to agree to within 5%. Current work includes making improvements to the instrument observation and calibration methodology.

7.3 Ulf Kohler presented additional examples of intercomparisons of the Brewer with other UV-B monitoring devices, which show an agreement within 5%. He also presented the calibration method used at Hohenpeissenberg for the UV-B measurements. This method consists of careful lamp measurements in the spectral regions 295-300, 300-305 and 310-315 nm.

7.4 A detailed discussion of the mathematical formulation of the Brewer UV-B calculation developed by D.I. Wardle, was presented by C.T. McElroy. The ultraviolet spectrum is conventionally divided into three regions: the UV-C (100-280 nm), the UV-B (280-320 nm), and the UV-A (320-400 nm). There is no solar radiation reaching the Earth's surface in the UV-C region. The UV-B radiation at the surface is very much dependent on absorption by atmospheric ozone and on meteorological conditions and it is capable of harmful biological effects. The UV-A is not significantly attenuated by ozone. The Brewer Spectrophotometer UV observing routine currently measures the spectral irradiance in the region between 290 and 325 nm. UV flux measurements are made by monitoring the photon count rate from the Brewer while it is observing the light transmitted by a small, horizontal teflon diffuser mounted on the upper surface of the instrument enclosure. This diffusing surface is protected by a quartz dome, and allows the determination of the global UV (sum of diffuse and direct components) radiation.

7.5 In order to make absolute measurements with the Brewer it is necessary to calibrate the response of the instrument in absolute radiation units. This is accomplished using a procedure which involves exposing the teflon diffuser to the radiation emitted by a calibrated 1000 watt quartz-halogen lamp. The lamps used at AES have been calibrated by the United States' National Institute of Science and Technology (NIST). These calibrated lamps are delivered, by NIST, complete with a calibration certificate showing the spectral irradiance falling on a surface 50 cm from the lamp when it is operated at a specified power level. The spectral irradiance is tabulated at a number of selected wavelengths. A third order polynomial in the log of the intensity as a function of wavelength is used (for the Brewer calibration) to calculate the irradiance at 10 selected wavelengths spanning the UV-B observation range, so that the the Brewer UV-B response can be determined at each measured wavelength. Once a number of scans have been made using one or more calibrated lamps, a mean response function is determined using a data analysis program. Using the lamp calibration table, the program calculates the coefficients of the cubic polynomial mentioned earlier, and uses that information for each lamp measured to calculate a response function based on each available calibration scan. At the end, a smooth curve fitted to the individual calibration scans is used to define a response file for the instrument and statistics related to the calculation are printed. The UV-B calibration file for the Brewer instrument consists of 71 numbers which relate the instrument response in counts per second to the spectral irradiance incident on the UV diffuser at wavelengths every 0.5 nm from 290 to 325 nm. A set of standard computer file names have been defined to facilitate the automation of the process of analysing and using the response calibration data.

7.6 Once the response file for a particular instrument exists, the UV-B measuring routine will automatically use it to provide the relationship between observed count rates and absolute radiation levels. As a result, the Brewer operating program can calculate an estimate of the Damaging Ultraviolet (DUV) radiation level in real time. Currently the program uses the erythemal weighting curve (Fig. 7.1) recommended by the American Conference of Governmental Industrial Hygenists, National Insti-

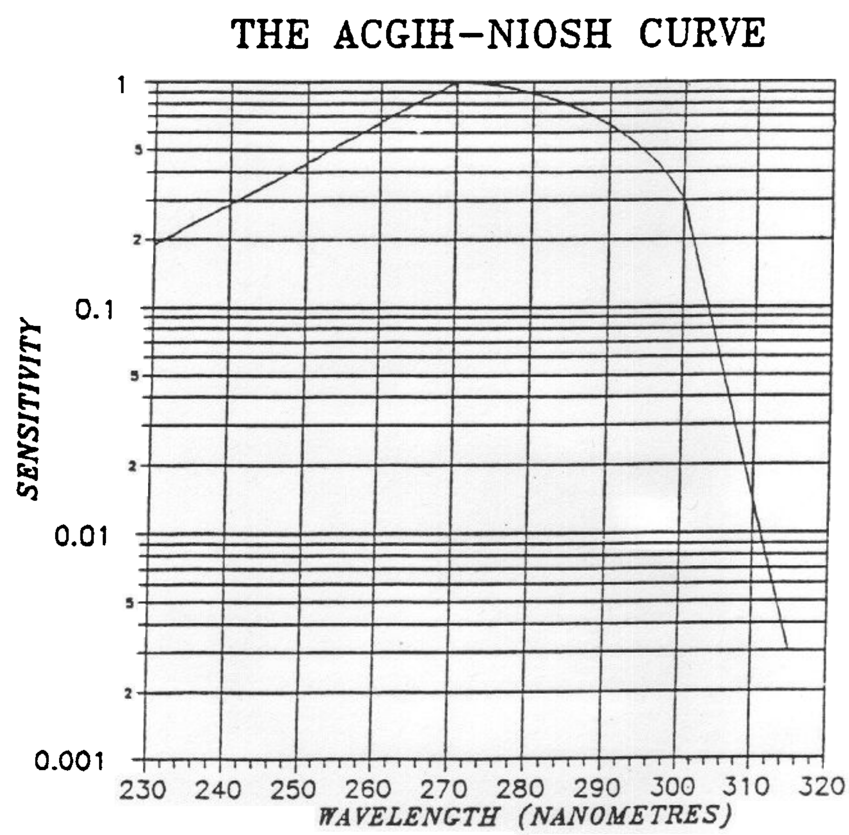


Figure 7.1: *Variation of the erythemal weighting function used by the Brewer control program in the calculation of the damaging ultraviolet radiation (DUV).*

tute for Occupational Safety and Health (ACGIH-NIOSH) because it is conveniently available as an analytic function of wavelength. As other, perhaps better, weighting functions (such as the reference action spectrum recommended by McKinlay and Diffey, 1987) become widely accepted, they can be easily added to the program and the corresponding DUV amounts can also be printed in real time.

7.7 A number of investigations have been undertaken to attempt to assess the accuracy of the Brewer in the role of UV-B monitor. These include comparisons of the observations to the results of model calculations, the comparison of calculated DUV to measurements of DUV made using a Robertson-Berger meter, and a study of inferred extraterrestrial spectra from a number of months of observations. Figure 7.2 shows a set of global UV spectra taken at various times during the day. The very

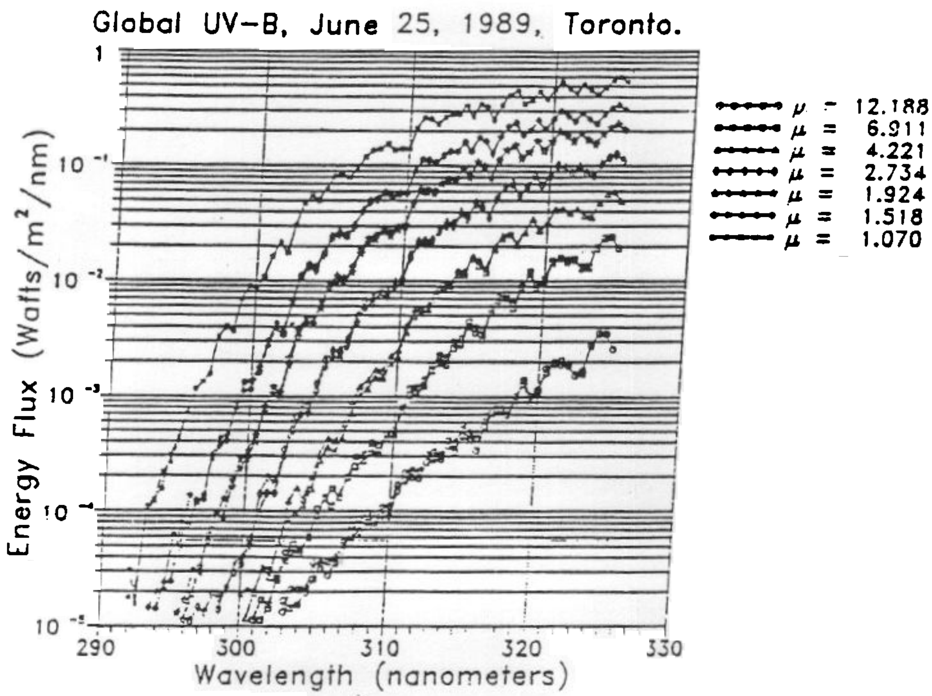


Figure 7.2: *Global UV measurements made on a clear day in Toronto. The very large range of UV irradiance as a function of slant column ozone amount is clearly evident as well as the rapid change in intensity with wavelength. The Brewer is capable of nearly 5 orders of magnitude dynamic range over this spectral interval.*

large change in the UV flux as the solar zenith angle changes is clearly evident. It should be noted that a significant amount of stray light is included in the Brewer measurements at short wavelengths. A correction for stray light is therefore made. The mean number of counts observed on wavelengths between 290 and 292.5 nm is taken as an estimate of the stray light. This amount of light is then subtracted from the observed count values at all other wavelength positions.

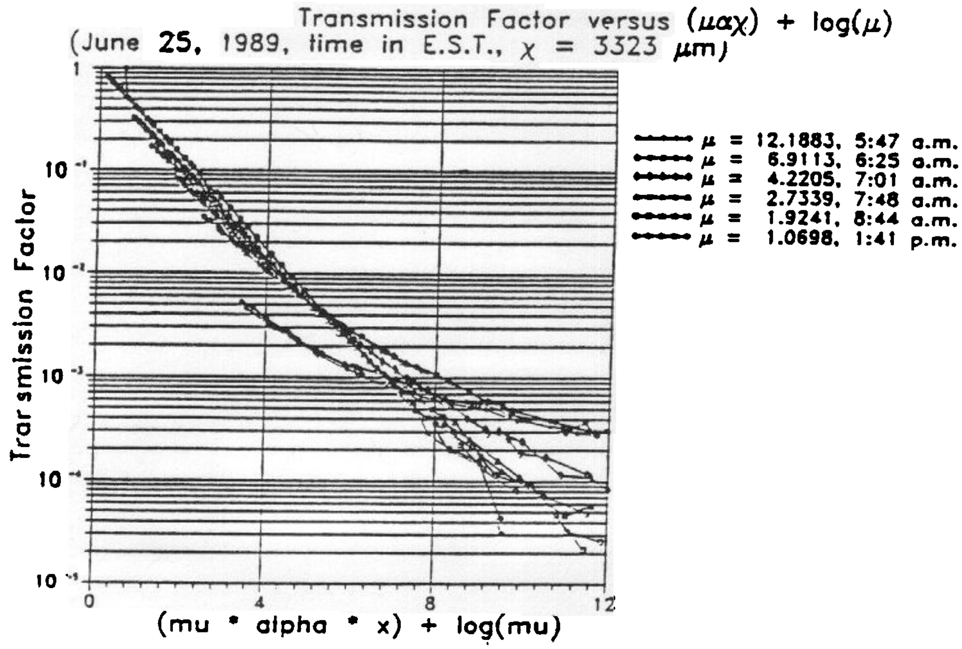


Figure 7.3: *This plot shows the role which the slant column amount of ozone plays in the determination of the global UV-B radiation.*

7.8 It is to be expected that the transmission of the atmosphere in the ultraviolet part of the spectrum, on clear days, will be strongly controlled by ozone absorption, and that, therefore, the UV-B radiation field will be dependent on the amount of ozone as well. Studies of the observed dependence of the atmospheric transmission as a function of wavelength, carried out by D.I. Wardle of AES, have shown that the attenuation of UV-B radiation by the atmosphere has a wavelength and solar zenith angle dependence, which is strongly related to the ozone absorption spectrum. Figure 7.3 shows the atmospheric transmission data derived from the spectra of Figure 7.2. This figure shows an estimate of the atmospheric transmission for global UV radiation as a function of airmass and ozone path for the direct solar beam. While the functional relationship between these variables is not exact, the curves clearly demonstrate that there is a high correlation between the effect of the atmosphere at different wavelengths and that ozone absorption plays an important role in determining the global radiation field.

7.9 In the course of the research which revealed the dependence of the effective atmospheric transmission on ozone amount, a number of estimated extraterrestrial spectra were determined (Fig. 7.4). The day-to-day variation of these inferred spectra has revealed information about the stability of the Brewer in its role as a UV-B monitor. The spectra which contributed to the mean in Figure 7.4 were each normalized at 307.5 nm to remove any effects of absolute intensity variations on the structure of the solar spectrum, and then the mean curve was constructed. From these data, and

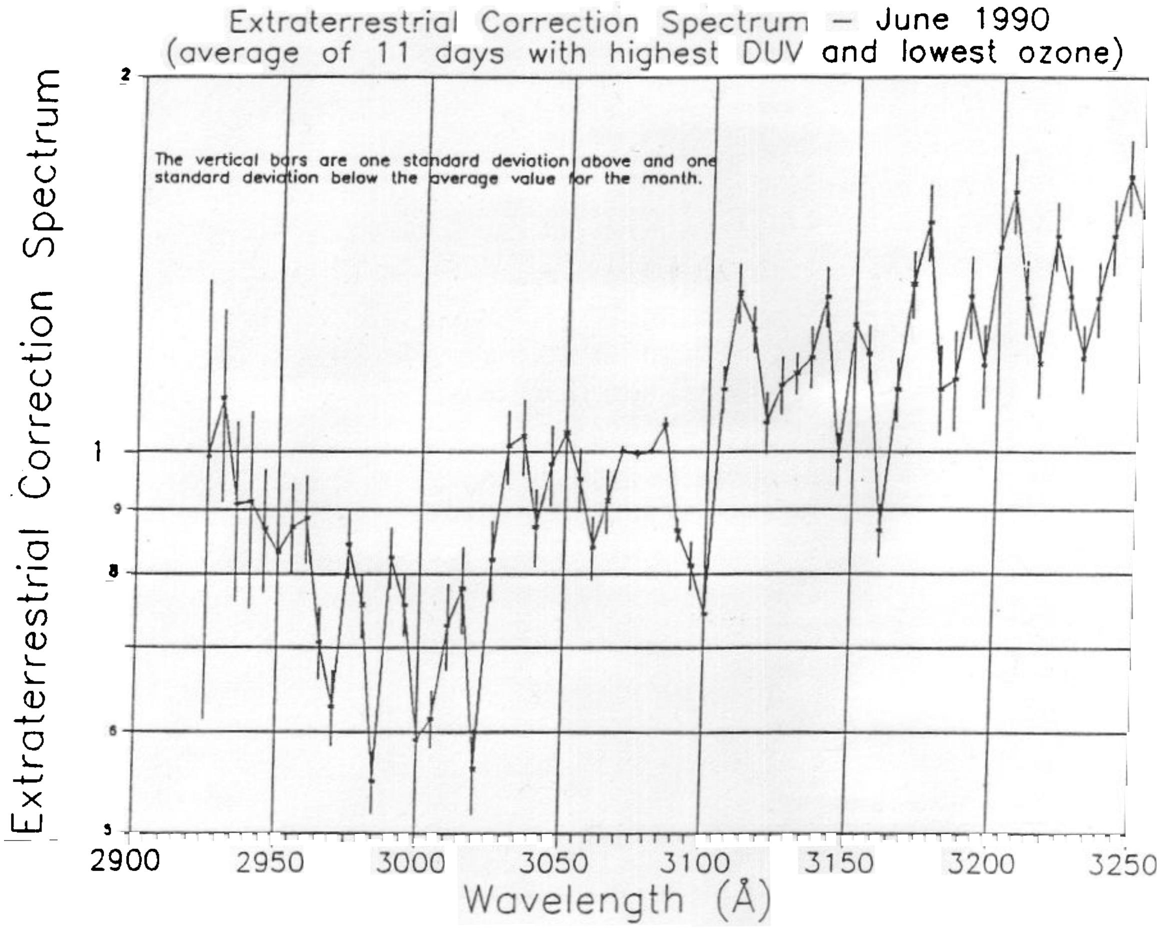


Figure 7.4: *Estimated global UV extraterrestrial spectrum, produced by applying the relations illustrated in figure 7.3 to a number of day's observations of the UV-B spectrum. The sharp Fraunhoffer features in the solar spectrum are evident.*

the use of the Schippnick and Green model, it was determined that the detail in the estimated extraterrestrial spectra (ETS) provides an improved model result for the UV amount. Figure 7.5 compares modelled spectra to observations for a scan made at an airmass of 4.18 and an ozone amount of 309 DU. The results calculated using the Brewer estimates for the extraterrestrial spectra (ETS) are seen to be somewhat better than the curve calculated using the Schippnick and Green ETS.

7.10 Figure 7.6 shows some very preliminary results comparing measurements made using a Robertson-Berger meter with data from the Brewer UV-B instrument in Toronto. The reciprocal of the Robertson-Berger scale of "Sundex" (which is a measure of sunburning time for a particular skin type) is seen to be related to the DUV number as determined by the Brewer instrument. The Brewer results were scaled so the first few days' comparison agreed reasonably well. The results must be regarded with some skepticism, since the two instruments are located at widely separated locations and the observations were not taken simultaneously. In addition,

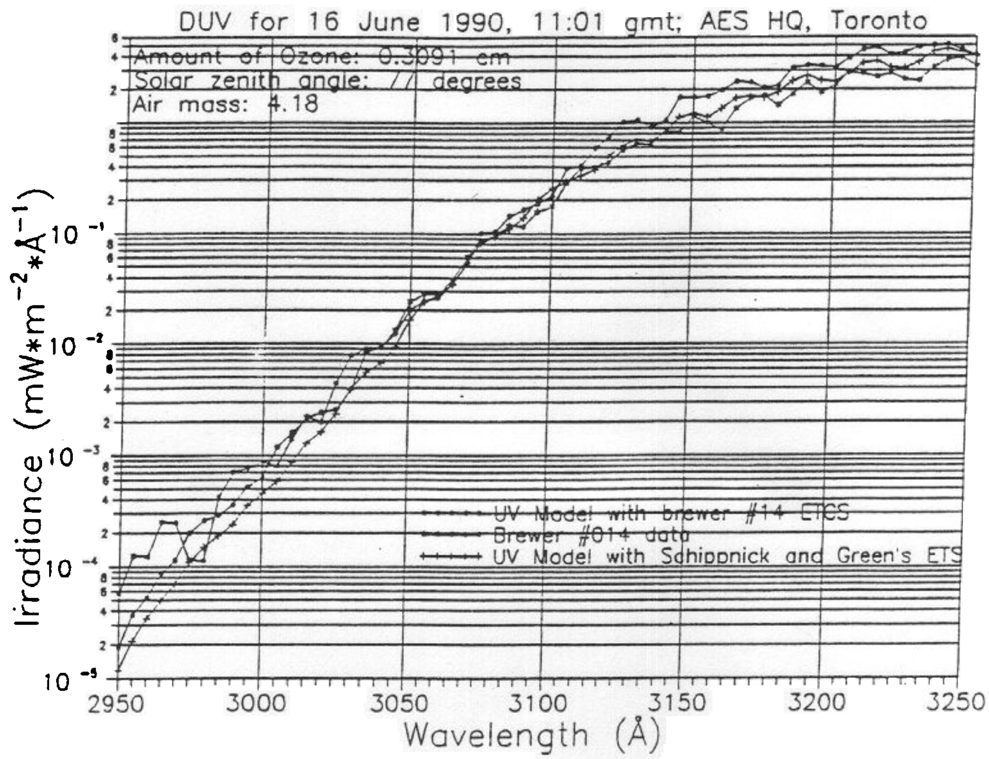


Figure 7.5: *A comparison of observed and calculated global UV-B spectra. The calculations were done using the semi-empirical model of Schippnick and Green, both with their recommended extraterrestrial spectrum and with the one presented in figure 7.4.*

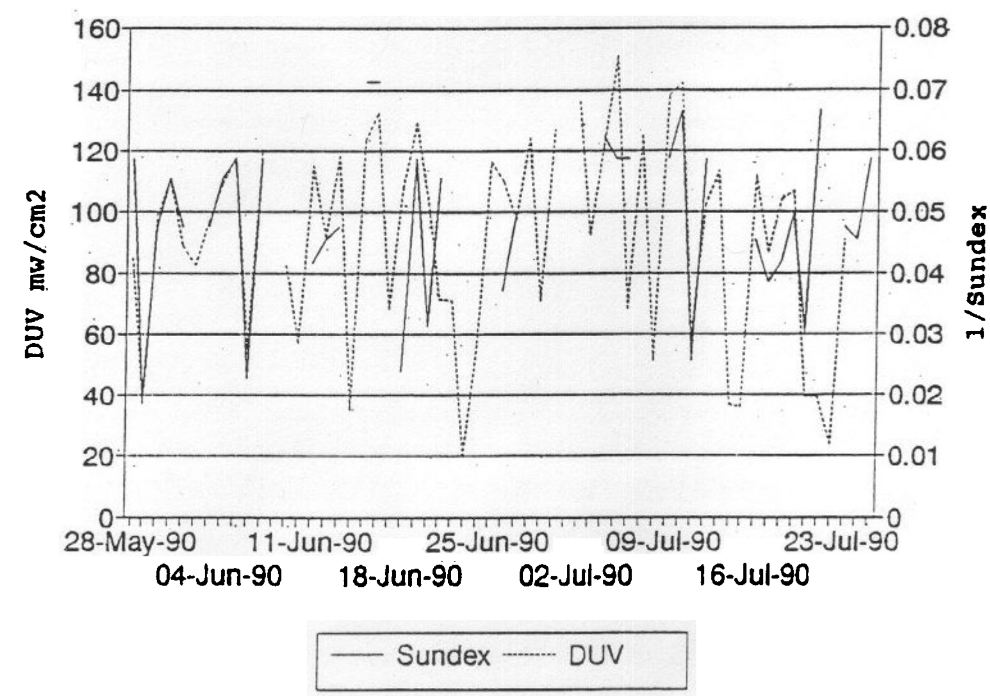


Figure 7.6: *Preliminary results of a comparison of Robertson-Berger meter measurements with DUV as calculated using Brewer observations. The instruments were not co-located.*

it should be noted that the new Robertson-Berger meter is calibrated to yield results consistent with the McKinlay-Diffey recommended reference action spectrum, while the Brewer DUV numbers are calculated using the ACGIH-NIOSH action spectrum. Nonetheless, it can be seen that there is some correlation between the two measurement sets. Further work using coincident measurements will soon be undertaken.

7.11 It was the feeling transmitted by the presentation of C.T. McElroy that the Brewer instrument could provide useful information in the UV-B region of the solar spectrum and Brewer instruments should be programed to collect this data at all observing sites.

7.12 Ken Lamb of Sci-Tec discussed the value and use of a portable, external lamp assembly to monitor the stability of the UV-B measurements and to provide an initial estimate of the absolute calibration of the Brewer as delivered by the manufacturer. This device comprises a stabilized power supply, a digital volt-meter and a set of five 50 Watt halogen-lamps which are being calibrated against the secondary standard lamps of the AES in Toronto. It is recommended that two of these lamps be used on a regular basis, while the third is used at longer time intervals in order to monitor the stability of the other two lamps. The last two lamps are kept as spares. A.F. Bais recently developed some new software routines to help monitor the lamp performance and to determine the instrument's temperature dependence.

7.13 Uwe Feister showed comparisons between two Brewer instruments UV-B results and some model calculations of UV-B. The spectra obtained by the different instruments were in good agreement, but differences in the absolute calibration were evident.

7.14 While the presentations in this session indicated that more accurate calibrations and clearly defined measurement procedures are required for the Brewer so that it can provide better quality UV-B data, the Brewer instrument has a large potential for global UV-B monitoring, which should be explored and implemented at most of the stations. C.S. Zerefos announced that the Laboratory of Atmospheric Physics in Thessaloniki is participating in a research program financed by the European Communities, to improve the Brewer UV-B measurements and to perform intercomparisons with other UV-B instruments in order to establish or develop a standard UV-B monitoring instrument.

NO_2 Measurements

7.15 Since the early 1970's, several groups have made measurements of the NO_2 column by using its absorption in the wavelength region 430 to 460 nm in direct sunlight. With the Brewer instrument 5 wavelengths are used. The light intensity of each is measured and gives the value of a function F. The wavelengths are selected so large differential absorption is achieved. In F the effects of ozone, Rayleigh and Mie scattering are eliminated. One gets the expression:

$$F = F_0 - \Delta a\, m\, X \tag{4}$$

where Δa express the combination of the differences in absorption units. X is the thickness of the NO_2 layer and m is the slant path length through the NO_2 layer. F_0 is the extraterrestrial value as it would be measured by the instrument outside the atmosphere and it is determined by linear extrapolation. This has been experimented with the NO_2 Brewer instrument in Toronto. A large number of observations have been made in Toronto and the NO_2 total column amount has been calculated (Fig. 7.7). The results give a characteristic diurnal variation of the NO_2 amount, i.e. an

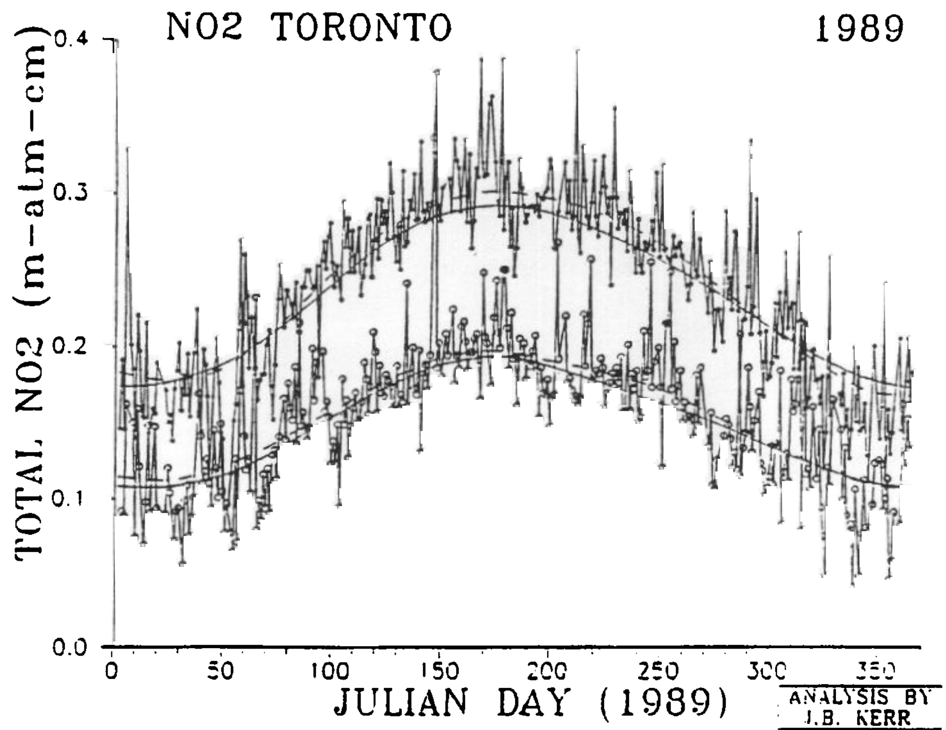


Figure 7.7: *The variation of the stratospheric NO_2 column over Toronto throughout 1989. The upper curve shows the results from sunrise measurements and the lower curve from sunset measurements.*

increase in the NO_2 amount in the morning with a maximum at noon and a decrease in the afternoon. Regular observations made in Toronto from 1985 show a large scatter, but it seems reasonable to determine an increase in NO_2 of 3% per year. It should be notted that these measurements of the total column amount are dominated by tropospheric NO_2.

7.16 One can also measure the absorption in light scattered from zenith. When the sun is low the mean scattering level is in the stratosphere and the absorption of the scattered light reaching the instrument will be caused mostly by the NO_2 in the stratosphere. Both the stratospheric column amount of NO_2 and its vertical distribution have been determined by relating the observations to model calculations of the changes in absorption by NO_2 as a function of solar angle at twilight in different heights in the stratosphere. Results of such determinations were shown.

<u>SO_2 Measurements</u>

7.17 C.S. Zerefos described the results from a long series of co- located near local noon columnar SO_2 amounts (in m-atm-cm) and the nearest ground-level SO_2 measurements (in mgr m^{-3}) obtained with the Brewer #005 spectrophotometer and a commercial fluorescent SO_2 analyser. These measurements cover the period from Oct. 1984 through Oct. 1988 and they were obtained on the roof of the four storey Physics building at the University of Thessaloniki, Greece (40.5 N, 22.9 E). These time

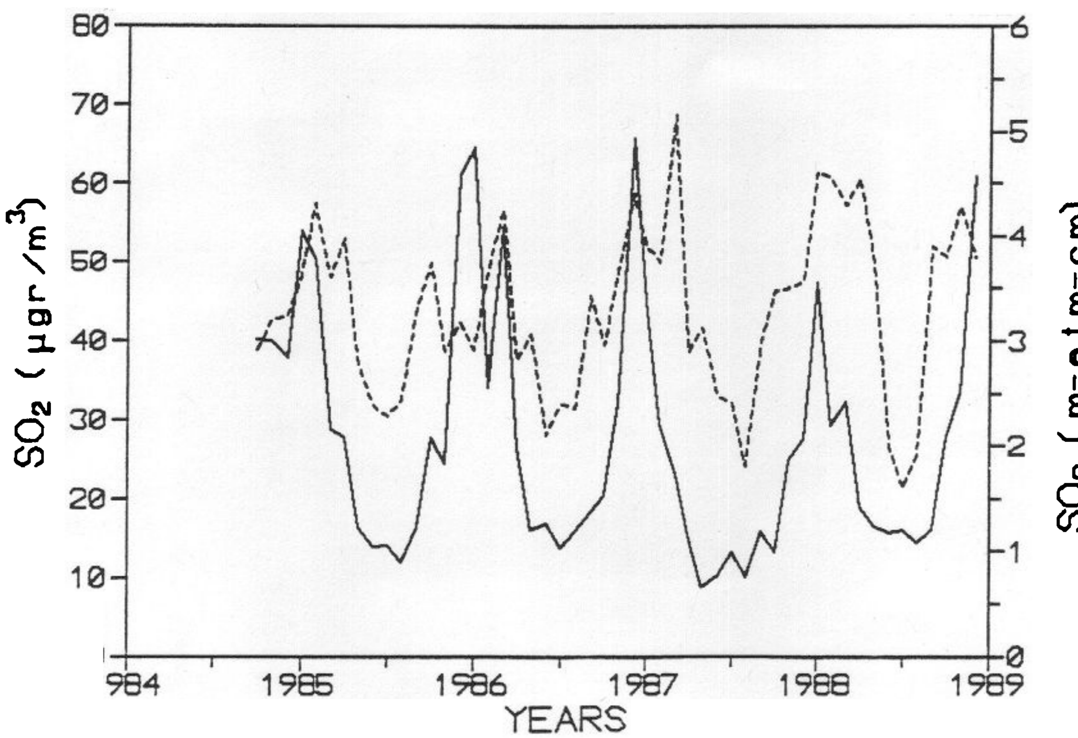


Figure 7.8: *Monthly mean time series of co-located columnar SO_2 amounts (scaled to the right, dashed line) obtained with the Brewer #005, compared to gound-level SO_2 concentrations (scaled to the left, solid line) at Thessaloniki, Greece.*

series are displayed in figure 7.8, both showing a marked annual variation with maximum in the winter, caused by the annual variation of the emissions. The correlation coefficient between the columnar and the ground-level SO_2 mean monthly values is significant at the 99% confidence level ($r = 0.493$). This means that 25% of the total variance of columnar SO_2 amounts is explained by the variance of sources discharging in the mixing layer. It should be noted here that although the correlation between ground-level and columnar SO_2 is high and significant, there is still a large proportion of unexplained variance. This is because ground-level concentrations are determined not only from sources and local local ventilation but also by the height of the mixing layer, which has a pronounced annual variation. On the other hand the total SO_2 column is not influenced by the annual variation of the mixing height and it is more representative of the overall emissions and continuity in a larger area.

8. Future developments of the Brewer Spectrophotometer

8.1 C.T. McElroy presented results of work which has been done by D.I. Wardle at AES to investigate the effects of stray light within the Brewer instrument. For light at wavelengths where there is large ozone absorption the signal is reduced, and stray light scattered from other wavelengths with less ozone absorption can be significant. In order to quantify this effect, an independent measurement of ozone was developed using a different weighting for the logs of the light intensities with a larger effective ozone absorption coefficient. Comparison of the two types of ozone measurement indicated good agreement when less than 1.2 cm of ozone is in the optical path and systematic differences increasing with larger ozone absorption. The differences were attributed to scattered light within the instrument and were simulated reasonably well by a stray light model. A seasonal difference between the two ozone measurements was also observed and is thought to be due to the different temperature dependence of the two sets of ozone absorption coefficients. This effect is also seen when Dobson and Brewer measurements are compared.

8.2 A double monochromator Brewer instrument has been constructed by AES and is undergoing tests. Stray light in the double instrument is several orders of magnitude less than that in a conventional single Brewer instrument. The purposes of this instrument are to investigate the effects of scattered light on ozone and UV-B measurements and to make accurate light flux measurements at wavelengths down to 290 nm. This double instrument was made by linking two modified single Brewer optical frames together. It should be recognized that in the long run the stability of a single Brewer instrument with a scattered light correction may be better than that of a double monochromator.

8.3 R. Lowe and C. Goulgkidas of the University of Western Ontario, in cooperation with the Canadian Atmospheric Environment Service, have undertaken a study of the application of the Brewer Ozone Spectrophotometer to the measurement of the second Umkehr effect. Conventional observations of the Umkehr effect are made between 60 and 90 degrees of solar zenith angle. Over this range the apparent amount of ozone absorption, measured using an intensity ratio, first increases and then decreases. This is the region of the curve which is analysed in the conventional Umkehr method to give vertical profiles of ozone. This change in absorption occurs because the mean scattering height in the atmosphere for light of different wavelengths varies differently with solar zenith angle. Because different wavelengths have different mean scattering heights, the measurements have a sensitivity to the vertical profile of ozone. This behaviour occurs because of the combined effect of the wavelength variation of the ozone absorption coefficient and of the Rayleigh scattering cross section. If observations are made beyond a zenith angle of 90 degrees it is found that the apparent ozone absorption again increases at zenith angles greater than about 95 degrees. This later increase in absorption is essentially brought about because the shadow of the Earth sweeps up through the atmosphere from the surface after 90 degrees solar zenith angle, and causes the mean scattering height to move upward as well. At the same time the path of light through the ozone layer travelling toward the scattering point increases with solar angle, and hence the apparent absorption increases.

8.4 Second Umkehr data taken with a predecessor of the Brewer have been analysed before (P.A. Davis, 1972) to yield information about the vertical distribution of ozone at high altitude (40 to 60 km region). The purpose of the current work is to evaluate the usefulness of the operational Brewer instrument for the collection of second Umkehr data, and the evaluation of its application to the study of the upper level ozone concentration. In the research being conducted now, the Brewer is programed to make measurements of the zenith sky at the standard Umkehr wavelengths (8 of them) and to make observations using both components of polarization. These components are the ones parallel to the solar azimuth direction and to its perpendicular.

8.5 A Brewer spectrophotometer to be put in the Space Shuttle is currently under construction (Fig. 8.1). This instrument uses basically the same measurement principle as the TOMS instrument; the ozone concentration is determined by measuring the intensity of several bands in the absorption spectrum of ozone, using backscattered UV from the earth's atmosphere. The Brewer instrument will be used to compare ground and space-based Brewer ozone measurement results.

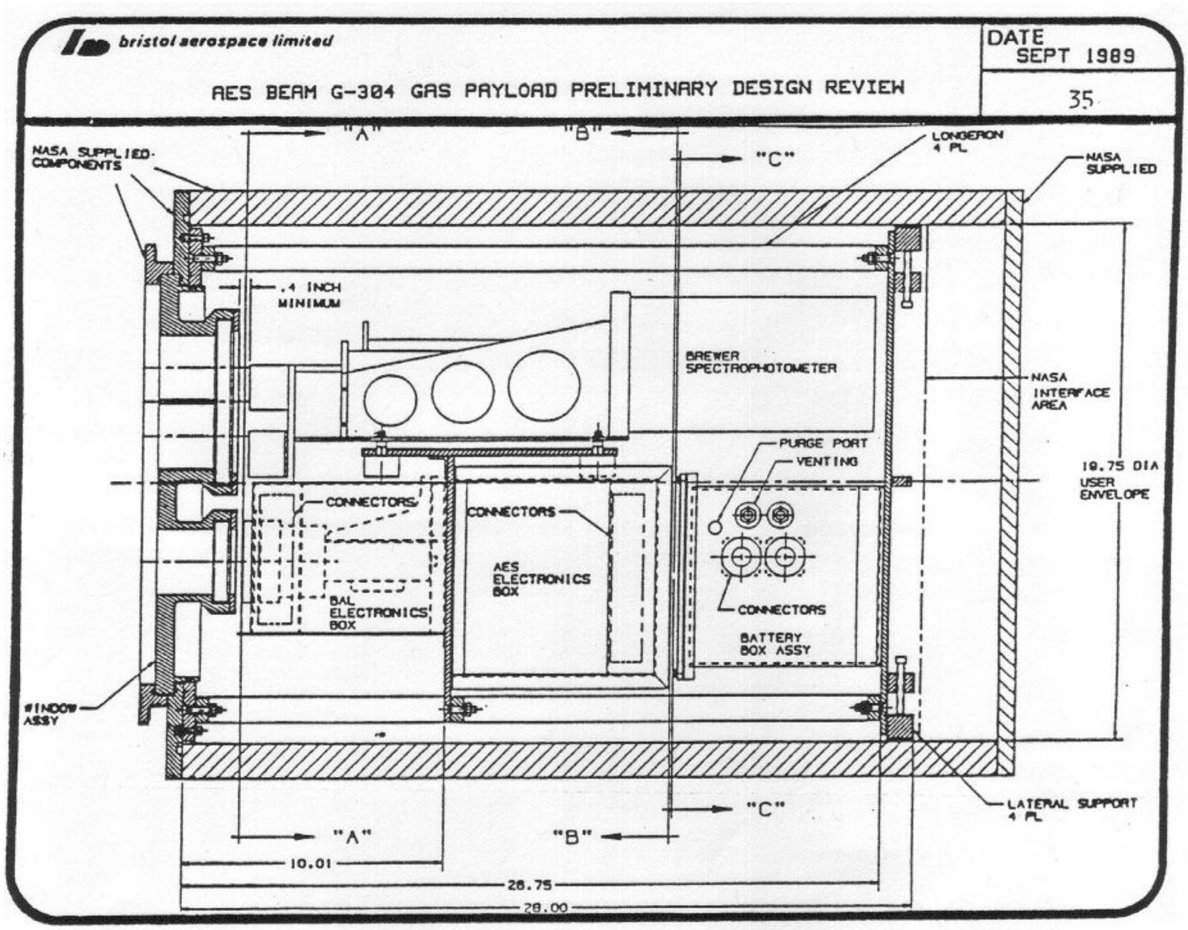


Figure 8.1: *General layout of the Brewer instrument, which is prepared to fly on-board the United States's Space Shuttle.*

8.6 In the future the Brewer instrument could be used as a basis for the following developments:

a) a small hand-held spectrophotometer for use on the space shuttle.

b) long path observations of minor constituents (such as SO_2, NO_2) near the ground.

c) an array spectrometer; it would however not be possible to use the detector array for measurements in the UV, because of a lack of sensitivity.

d) the measurement of UV-B may turn out to be the most important.

9. Closing Remarks and Recommendations

9.1 In the closing part of the meeting the rapporteurs summaries were read and discussed in detail by all of the meeting attendees. Reports were clarified and errors corrected, and considerable discussion took place concerning several session reports, in particular on item 5. As a result of this discussion process a number of statements and recommendations were agreed on, and have been included in this report. The meeting authorized R.D. Bojkov, C.T. McElroy, C.S. Zerefos and A.F. Bais to edit the final report and arrange to be published in the WMO Ozone Project Report series.

9.2 It was recommended that the WMO be asked jointly with the Ozone Commission of IAMAP to quickly adopt a consistent set of Dobson ozone absorption coefficients so that both Brewer and Dobson data may be consistently reported on an absolute scale in the WO3DC publications. Brewer data are now being reported twice in two different formats by WO3DC according to instructions that have already been published.

9.3 It is suggested that arrangements be made within the GO3OS, so that periodic calibration visits to Brewer stations using one of the travelling intercomparison instruments can be conducted at least every two years and that the intercomparison instruments themselves should return frequently to Toronto to maintain the accuracy of their calibration through intercomparison with the Toronto Triad of Brewer instruments.

9.4 It was recommended that all stations with Brewer instruments implement and report focussed moon observations.

9.5 It was recommended that, in future, new Brewer ozone reporting stations not report zenith sky ozone results for the first two years of operation so that adequate time is given to the stations' operators to determine and verify an accurate relationship between the direct sun total ozone measurements and the zenith sky observations ("sky chart").

9.6 It was recommended that guide-lines concerning the use of zenith sky data be prepared by the Toronto experts and published by the WMO.

9.7 It is desirable that further study of the usefulness of zenith sky, Umkehr data, and focussed moon observations in the polar and sub-polar regions be undertaken.

9.8 It was recommended that more Brewer Umkehr observations be made.

9.9 All Brewer instrument operators should be encouraged under carefull scientific supervision to collect UV-B data using the Brewer. There is an urgent need for international intercomparison activities to improve the accuracy of UV-B measurements. In the absence of badly needed guide-lines for the monitoring of UV-B radiation it is recommended that measurements of UV-B be made approximately once per hour, and as a minimum, that daily observations be made near local noon. It has been recognized that the Brewer instrument has a strong potential for use in research toward the understanding of the global radiation field in the UV spectral region.

9.10 It should be noted that the Brewer instrument DUV value is currently calculated using the ACGIH-NIOSH erythemal weighting curve (action spectrum), which may be a poor choice for some applications (Fig. 7.1). An improved action spectrum should be identified and adopted as soon as possible. It is possible that the Brewer should be made to calculate DUV values using several different action spectra.

9.11 There is a need to have regular meetings of Brewer instrument users within the WMO GO3OS, such as this one, to improve and expand the capabilities of the Brewer instruments used in the WMO/GO3OS. It is recommended to the WMO Secretariat to endeavour to organize a meeting every two years, timed to coincide with the Quadrennial Ozone Symposium, and with a major instrument intercomparison in the alternate 2 year intervals.

9.12 Concerning the European near-real-time data collection proposal, all attendees have agreed on the importance of this joint venture and have agreed to attempt to establish the communications links required. The WMO Secretariat should determine a trail period and the group at the University of Thessaloniki in collaboration with the other European ozone stations and the AES, should start operating the data exchange system in order to examine its performance and detrmine any possible modifications and improvements, which may be needed.

9.13 The WMO Consultation was closed on Saturday the 4th of August, with the adoption of the outlines of this report by the participants.

APPENDIX A

List of Rapporteurs

Session	Name of Rapporteur
1.	
2.	E. Kyro
3.	W. Josefsson
4.	U. Kohler
5.	V. Dorokhov & C.T. McElroy
6.	J. Staehelin
7a.	A. Roberge
7b.	S. Larsen
8.	D. DeMuer & H. DeBacker
9.	C.T McElroy & C.S. Zerefos

APPENDIX B

MEETING AGENDA

Thursday, August 2, 1990 Chairman: J.B. Kerr, AES

08:45 1. OPENING OF THE MEETING AND ELECTION OF CHAIRMAN AND RAPPORTEURS [C.S. Zerefos]

09:15 2. BREWER INSTRUMENT CALIBRATION

i) Absolute Calibration of the Toronto Triad and the use of Travelling Standards [J.B. Kerr]

ii) Implementation of the Brewer calibration methodology [K. Lamb]

10:15-10:45 Coffee Break

10:45 3. BREWER OBSERVATIONS AND DATA MANAGEMENT

i) Modification of original Brewer control program for automated data checking [U. Kohler]

ii) Modification of subroutines to record daily statistical data on instrument performance [A. Roberge]

iii) Overview of Canadian Brewer ozone database under development [J.B. Kerr]

iv) Comparison of focused moon and direct sun observations [U. Kohler]

v) Arctic moon observations [J.B. Kerr/V. Dorokhov]

12:15-13:45 Lunch Break

13:45 4. TOTAL OZONE INTERCOMPARISONS BETWEEN VARIOUS INSTRUMENTS

i) How the results of a few different total ozone measurement techniques compare [E. Kyro]

ii) Brewer/TOMS/Dobson [J.B. Kerr]

iii) Brewer #040 at LKO Arosa: comparison with Dobson measurements and Brewer #39 (WMO standard instrument) [J. Staehelin, A. Asbridge and H. Schill]

iv) Intercomparison of Dobson and Brewer instruments in Uccle from 1984-1989 [H. DeBacker/D. DeMuer]

v) Antarctic Dobson/Brewer Intercomparison [C. Valenti]

vi) Dobson/Brewer in Boulder [A. Diaz]

vii) Dobson Results - Arosa 1990 [W. Komhyr]

15:15-15:45 Coffee Break

15:45 5. DAILY DATA EXCHANGE WITHIN THE EUROPEAN PART OF THE GLOBAL OZONE OBSERVING SYSTEM [C. Zerefos/A.F. Bais]

i) Need for real-time ozone data and participation of Brewer, Dobson and M-124 stations in the European Arctic Ozone campaign, 1991/92 [V, Dorokhov]

ii) Presentation of the pilot study for real-time data exchange with Brewers in Greece and possible future structure

iii) Operational cost and financial support

iv) Discussion of the protocol for data distribution to the institutions, and on the data validity

v) Arrangements for timely deposition of collected data to the WMO World Ozone Data Centre

vi) Collaboration with WMO, AES, and other organizations

vii) Preparations for the next meeting of European ozone station operators

Friday, August 3, 1990

08:45 6. UMKEHR OBSERVATIONS WITH THE BREWER [C.T. McElroy]

i) Analysis technique

ii) Routine operation and analysis of Umkehr data

iii) 1989 Table Mountain intercomparison results

iv) Umkehr Measurements in Rome [L. Ciattaglia]

10:15-10:45 Coffee Break

10:45 7. SPECIAL OBSERVATIONS: A

i) UV-B Observations [W. Josefsson]

i) UV-B Observations [U. Kohler]

iii) UV-B observations and calibration [C.T. McElroy]

iv) UV-B observations and calibration [K. Lamb]

v) UV-B Observations [U. Feister]

12:15-13:45 Lunch Break

13:45 7. SPECIAL OBSERVATIONS: B

i) Brewer SO2 observations [Ch.S. Zerefos]

ii) Brewer NO2 observations [J.B. Kerr]

iii) New Swiss Radiosonde [B. Hoegger]

15:15-15:45 Coffee Break

15:45 8. FUTURE DEVELOPMENTS OF BREWER INSTRUMENT [C.T. McElroy]

i) Correction for scattered light

ii) Double monochromator Brewer

iii) Second Umkehr effect

iv) Brewer Earth Atmosphere Measurements (BEAM) experiment on space shuttle

Saturday, August 4, 1990

09:30 9. ADOPTION OF OUTLINES OF THE REPORT AND CLOSING OF THE MEETING [Ch.S. Zerefos]

APPENDIX C

List of Brewer Instruments

BREWER LOCATIONS (Nov./90) SCI-TEC Instruments Inc.

S/N	Country	Location	Lat.	Long.	Contact	Remarks
005	Greece	Saloniki	40.52	- 22.97	C. Zerefos	82 O3/SO2/UVB MKII
006	Sweden	Norrkoping	58.61	- 16.12	W. Joselson	82 O3/SO2/UVB MKII
007	Canada	Toronto			T. McElroy	82 Aircraft WB57-F
008	Canada	Toronto	43.78	79.47	J. Kerr, Triad	82 O3/SO2 MKII
009	Canada	Toronto			R. Olafson	82 Aircraft CV990
010	Germany	Hohenp'bg	47.80	- 11.02	U. Kohler	82 O3/SO2/UVB MKII
011	Canada	Saskatoon	52.11	106.71	Ken Lamb	87 O3/SO2/UVB MKII
012	Canada	Alert	82.50	62.30	J. Bellefluer	83 O3/SO2 MKII
013	Canada	Stony Plain	53.55	114.10	J. Bellefleur	83 O3/SO2/UVB MKII
014	Canada	Toronto	43.78	79.47	J. Kerr, Triad	83 O3/SO2/UVB MKII
015	Canada	Toronto	43.78	79.47	J. Kerr, Triad	83 O3/SO2 MKII
016	Belgium	Brussels	50.80	- 4.35	D. DeMuer	83 O3/SO2/UVB MKII
017	Canada	Toronto	Traveling Std		D. Wardle	84 O3/SO2/UVB MKII
018	Canada	Goose Bay	53.32	60.30	J. Bellefleur	84 O3/SO2/UVB MKII
019	Canada	Grandora	52.14	107.06	J. Bellefleur	84 O3/SO2/UVB MKII
020	Canada	London	U. W. Ont.		B. Lowe	85 O3/SO2/UVB MKII
021	Canada	Toronto	43.78	79.47	T. McElroy	85 O3/SO2/UVB Dual
022	Canada	Toronto	43.78	79.47	J. Kerr	85 NO2 Standard
023	Taiwan	Taipei	25.03	-121.50	Fu-Lai Chen	85 O3/SO2/UVB MKII
024	Italy	Vigna'Valle	42.08	- 12.22	C. Tasso	85 O3/SO2/UVB MKII
025	USA	Boulder	40.01	105.15	B.Evans	86 O3/SO2/UVB MKII
026	Canada	Churchill	58.75	94.07	J. Bellefleur	85 O3/SO2 MKII
027	Canada	Winnipeg			R. Olafson	85 Shuttle Backup
028	Canada	Toronto			R. Olafson	86 Shuttle
029	Canada	Toronto			J. Kerr	86 CLO3 Evaluation
030	Germany	Potsdam	52.36	- 13.05	U. Feister	87 O3/SO2/UVB MKII
031	Canada	Resolute	74.72	94.98	J. Bellefleur	86 O3/SO2 MKII
032	Canada	Alert	82.50	62.30	J. Kerr	87 NO2 only
033	Spain	Madrid	40.45	3.72	J. Cisneros	87 O3/SO2/UVB MKII
034	Japan	Syowa	-69.0	- 39.58	K. Matsubara	87 O3/SO2/UVB MKII
035	Italy	Scott Base	-74.7	-164.10	C. Valenti	87 O3/SO2/UVB MKII
036	Greece	Saloniki	40.5	- 22.50	F.Vosniakos	88 O3/SO2/NO2 MKIV
037	Finland	Sodankyla	67.4	- 26.60	Esko Kyro	88 O3/SO2/UVB MKII
038	Canada	Calgary			T. McElroy	88 CCD test
039	WMO	Toronto	Traveling Std.		A. Asbridge	88 O3/SO2/UVB MKII
040	Switzerland	Arosa	46.78	- 9.67	B. Hoegger	88 O3/SO2/UVB MKII
041	Greece	Kozani	40.27	- 21.77	N. Stamnous	88 O3/SO2/NO2 MKIV
042	Norway	Oslo	59.91	- 10.72	S. Larsen	90 O3/SO2/UVB/NO2 MKIV
043	USSR	Kislovodsk	43.73	- 42.66	N. Elansky	88 O3/SO2/UVB MKII
044	USSR	Obninsk	55.50	- 36.20	A. Ishov	88 O3/SO2/UVB MKII
045	USSR	Moscow	55.75	- 37.57	V. Dorokhov	88 O3/SO2/UVB MKII
046	Canada	Saskatoon	52.11	106.71	R. Adle	88 O3/SO2/UVB MKII
047	Portugal	Lisbon	38.77	9.13	M. Figueira	88 O3/SO2/UVB MKII
048	Portugal	Madeira Is.	32.64	6.89	M. Figueira	88 O3/SO2/UVB MKII
049	USSR	Heiss Is.	80.62	- 58.10	V. Dorokhov	89 O3/SO2/NO2/UVB MKIV
050	Italy	Rome	41.92	- 12.62	L. Ciattaglia	89 O3/SO2/UVB/NO2 MKIV
051	Morocco	Casablanca	33.57	7.67	B. Louaked	89 O3/SO2/UVB MKII
052	Japan	Tateno	36.05	-140.10	T. Ito	89 O3/SO2/UVB MKII
053	Denmark	Copenhagen	55.72	- 12.57	T. Jorgensen	90 O3/SO2/UVB MKII
054	China	Beijing	39.95	-116.32	Qing-yu Xue	90 O3/SO2/UVB MKII
055	Canada	Victoria	48	122	J. Kerr	90 O3/SO2/UVB MKII
056	Brazil	Cuiaba	-16.2	35.0	W. Kirchhoff	90 O3/SO2/UVB MKII
057	Japan	Tskuba	36.05	-140.10	H. Inoue	90 O3/SO2/UVB MKII
058	Japan	Sapporo	43.05	-141.30	T. Ito	90 O3/SO2/UVB MKII
059	Japan	Kagoshima	31.60	-130.60	T. Ito	90 O3/SO2/UVB MKII
060	Japan	Okinawa	26.20	-127.67	T. Ito	90 O3/SO2/UVB MKII
061	Italy	Rome				90 O3/SO2/UVB/NO2 MKIV
062	Italy	Rome				90 O3/SO2/UVB/NO2 MKIV
063	Taiwan	Jhyrehtan			Fu-Lai Chen	90 O3/SO2/UVB/NO2 MKIV

APPENDIX D

Preliminary results of Dobson Intercomparison (22/7-10/8-90)

Inst. No	Country-Location	Last Intercomparison	Initial Delta Xad (%)	Final Delta Xad (%)
13	Portugal-Lisbon	1987	0.28	-0.16
14	Norway-Tromso	1977	-0.99	-0.19
15	Switzerland-Arosa	– –	-4.96	0.82
40	Belgium-Uccle	1986	-0.60	-0.15
41	United Kingdom	1985	-0.59	0.15
50	Iceland-Reykjavic	1977	-0.16	0.05
64	GDR-Potsdam	1977	0.22	-0.09
74	Czech.-Hradek Kralove	1986	-0.66	-0.07
84	Poland-Belsk	1986	0.35	-0.05
92	Denmark-Greenland	1986	-0.50	-0.05
101	Switzerland-Arosa	1986	0.37	0.09
104	FRG-Hohenpeinsemberg	1986	-2.40	-0.04
107	USSR-Moskow	1988	-0.95	
110	Hungary-Budapest	1988	0.93	-0.24
118	Greece-Athens	Never *	-2.27	0.03
120	Spain	1989	-1.92	
121	Rumania-Bucharest	1988	-0.06	0.04
65	USA-standard	1990	0	0

* Has never been used or calibrated before this intercomparison.

APPENDIX E

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WMO GLOBAL OZONE RESEARCH AND MONITORING PROJECT

Report No.	Title	Status
No. 1	Atmospheric Ozone (UNEP Meeting of Experts on the Ozone Layer)	Not available
No. 2	Report of the Meeting of Experts on Ozone Modelling and Stratospheric/ Tropospheric Exchange Processes	
No. 3	Report of the Meeting of Experts on UV-B Monitoring and Research	Not available
No. 4	Report of the Meeting of Experts on Measurements of Rare Species Relevant to the Ozone Budget	Not available
No. 5	Report of the Meeting of Experts on Stratospheric Circulation Analysis and Ozone	
No. 6	Operations Handbook - Ozone Observations with a Dobson Spectrophotometer (W.D. Komhyr)	Not available
No. 7	Report of the WMO Meeting of Experts on 2-D Ozone Models	Not available
No. 8	Report of the WMO Meeting of Experts on Rare Atmospheric Constituents of Importance to the Ozone Layer, Washington, D.C.	Not available
No. 9	Report of the Meeting of Experts on Assessment of Performance Characteristics of Various Ozone Observing Systems	Not available
No. 10	Contribution of Ozone and Other Minor Gases to Atmospheric Radiation Regime and their Possible Effect on Global Climate Change (E.L. Aleksandrov, I.L. Karol, A. Ch. Khrgian, L.R. Rakipova, Yu. S. Sedunov)	Not available
No. 11	The Stratosphere 1981 Theory and Measurements (A Meeting of Experts on the State of the Stratosphere, Hampton, Virginia, 18-22 May 1981)	
No. 12	Report of the Meeting of Experts on Sources of Errors in Detection of Ozone Trends	

(RDP 359)

Report No.	Title	Status
No. 13	Review of the Dobson Spectrophotometer and its Accuracy (Reid E. Basher)	
No. 14	Report of the Meeting of Experts on Potential Climatic Effects of Ozone and Other Minor Trace Gases	
No. 15	Report of the Meeting of Experts on Tropospheric Ozone, its Changes and Possible Radiative Effects	
No. 16	Atmospheric Ozone 1985 Assessment of our Understanding of the Processes Controlling its Present Distribution and Change (3 volumes)	Not available
No. 17	Measurement of Atmospheric Ozone Profiles Using the Brewer/Mast Sonde - Preparation, Procedure, Evaluation	Not available
No. 18	WMO/NASA Ozone Trends Panel Report-1988 (2 volumes)	
No. 19	Summary Results from Dobson Intercomparisons (Reid E. Basher)	In preparation
No. 20	Scientific Assessment of Stratospheric Ozone: 1989 (2 volumes)	
No. 21	Report of the Preparatory Meeting of the Ozone Research Managers of the Parties to the Vienna Convention for the Protection of the Ozone Layer (Geneva, 7-9 February 1990)	