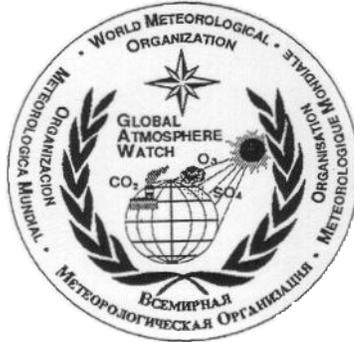


WORLD METEOROLOGICAL ORGANIZATION GLOBAL ATMOSPHERE WATCH



No. 128

The Fourth Biennial WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting

(Rome, Italy, 22-25 September 1996)

Edited by C.T. McElroy and E.W. Hare



WMO TD No. 918

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1. BACKGROUND AND OPENING OF THE MEETING

1.1 Brewer User's Working Group

The Brewer User's Working Group is supported by the World Meteorological Organization, the International Ozone Commission and Environment Canada. The goal of the Working Group is to improve the overall level of performance of the Brewer Ozone Spectrophotometer global measuring system through the informal exchange of information, ideas and scientific results. The first meeting of the Working Group took place in 1990 in Arosa, Switzerland in conjunction with an international inter-comparison of Dobson and Brewer Spectrophotometers. It was intended that the Working Group meet every four years at the time of the Quadrennial Ozone Symposium and also in the interval between in association with other significant events in the ozone community, such as an ozone instrument inter-comparison. The emphasis of the Working Group is particularly focused on the exchange of the scientific and technical knowledge required to properly operate a Brewer ozone station for the collection of high-quality ozone data and to discuss and promote the enhancement of the Brewer observing system.

In this regard, there are now about 150 Brewer Ozone Spectrophotometers of different types in the global observing system. While each of these instruments has the potential to make the ozone and ultraviolet radiation measurements crucial to determining the future evaluation of the UV radiation environment, some are not performing up to expectations. In order to ensure the availability of the highest quality data for the future assessment of the ozone layer and the ultraviolet environment it is essential that the data collected by individual instruments, including test and intercomparison results, be archived in the WMO World Ozone and Ultraviolet Radiation Data Centre so that accurate and detailed retrospective analysis can be uniformly carried out on the data from all stations.

1.2 Opening remarks

The meeting was officially opened by Professor S. Palmieri on September 23, 1996, on the premises of the University of Rome. He welcomed the participants (see Annex A) to the meeting and emphasized the importance of the exchange of scientific and technical knowledge in promoting the Brewer observing system.

Dr. T. McElroy, representing the International Ozone Commission, then spoke saying it was pleasant to see so many of the Working Group members from past meetings able to attend, and hoped that in future, all interested parties would be able to participate. He thanked Professor Palmieri, Dr. Siani and the other members of their group who had worked so hard to provide a well organized and pleasant environment for the Brewer meeting. He expressed certainty that the goal of maintaining the whole Brewer network in proper operational status would be advanced as a result of the informal and formal presentations which would take place over the next few days. Annex B presents the Programme of the meeting.

Dr. J. Kerr, Chairman of the consultation group, also thanked the local organisers for the warm welcome to the University of Rome and for arranging the meeting facilities. He noted that at the Quadrennial Ozone Symposium, held at L'Aquila over the previous two weeks, there were a significant number of scientific papers, both oral and poster, that included results from Brewer spectrophotometers. The instrument had become a mature scientific tool with data records from many sites now longer than ten years. The main purpose of the Brewer Workshops, he said, was to promote communication between the developers, the manufacturers and the users of the Brewer instrument. Over the past 15 years since the Brewer instrument was first used routinely, the instrument and its application have evolved. A large part of this evolution and development had resulted from feedback from the users of the instrument. He emphasized the need to keep the dialogue open between the more mature users and newer users to take full advantage of the potential of the instrument. These Working Groups, of which this is the fourth, were therefore a

very important platform for the promotion of the development and evolution of the Brewer instrument and its applications.

Over the period since the Brewer instrument had been in use, Dr. Kerr continued, there had been several notable scientific contributions which could be attributed to the instrument. The Brewer reference maintained by AES, in Toronto, offered an independent reference for the measurement of atmospheric ozone. Ground-based measurements of SO₂ and UV-B radiation made with the Brewer instrument have been an important reference for satellite measurements of SO₂ and UV-B irradiance. Data measured by the Brewer instrument played an important role in the development of the UV Index programme which is now in operation in many countries.

Dr. Kerr went on to comment that the most important future scientific goal regarding ozone depletion would be the confirmation that the controls put in place by the Montreal Protocol were leading to the long-term recovery of the ozone layer. This would require a significant effort to measure the ozone layer with the accuracy necessary to detect the turn-around in the next ten years or so. The Brewer instrument would undoubtedly play an important role in this process and is well positioned to contribute to the observation of the final outcome. He noted the need to extend these records of ozone and UV-B from the past into the future with the required accuracy and stability and expressed conviction that these Working groups would contribute to achieving this goal.

Dr. J.M. Miller, representing the WMO, provided an overview of the Global Atmosphere Watch programme so that the activities of the Brewer community were put in the context of the larger GAW programme. Dr. Miller stressed the importance of co-operation in the community since the activities must be supported by the individual contributing nations without outside fundraising, but must lead to a co-ordinated data set which can be used for global assessments of the state of the atmosphere.

2. TOTAL OZONE MEASUREMENTS

2.1 A 12-year analysis of the Brewer Triad reference by the Brewer

J. Kerr of the Atmospheric Environment Service, Canada, presented a review of the Brewer triad reference in Toronto. There are two aspects: the ozone and UV-B components in which the standards differ. In the case of ozone, the instrument itself carries the absolute information, whereas, calibrated lamp setups are used for the UV-B information. Secondary standards have been established for the field as well as the travelling standards that are used for inter-comparisons.

Important features of the Brewer triad standard are:

- It was first proposed in Greece in 1984.
- Redundancy is important.
- The need for three instruments is important to validate results in the event one malfunctions.
- Dobson #77 is also available (since 1960) as another validation.
- The triad has been in operation for 12 years.
- The travelling standard is used both in Canada and internationally. This has been designed to minimise the movement of the instruments (both host and remote sites).
- The travelling standard is also used in international comparisons of Dobson instruments.

A diagrammatic illustration of the Brewer Calibration Centre is given in Figure 2.1.1.

Between the years 1984 and 1996 direct sun daily average values for all three instruments were examined with a total of 2227 data points collected and these data show an average standard deviation of 0.82%. The ratio of ozone values measured by Brewer #15 as compared to the triad average value indicates a about a 1-2% variation with a slope of -0.16% per decade (Figure 2.1.2). Table 2.1.1 summarizes the calibration and performance of each instrument over this twelve year period.

The Brewer Calibration Centre also operates a Dobson instrument. Figure 2.1.3 is a comparison of the Brewer triad direct sun daily ozone values with the AD direct sun daily ozone values derived from Dobson #77 over the same twelve year period. The average ratio is 0.9926 with a standard deviation of 0.0182 and a slope of -0.6% per decade. Figure 2.1.3 also indicates when intercomparisons took place. It is hoped that this stability will continue.

A. Bais asked about simultaneous measurement comparisons with the Dobson and whether any changes had occurred since the Mauna Loa campaign. It was suggested that the new results be compared with past records. Some changes are due to the standard lamp, which are also used to adjust for the coefficients. The idea is to compare first to the past, then adjust for the future.

BREWER CALIBRATION CENTER

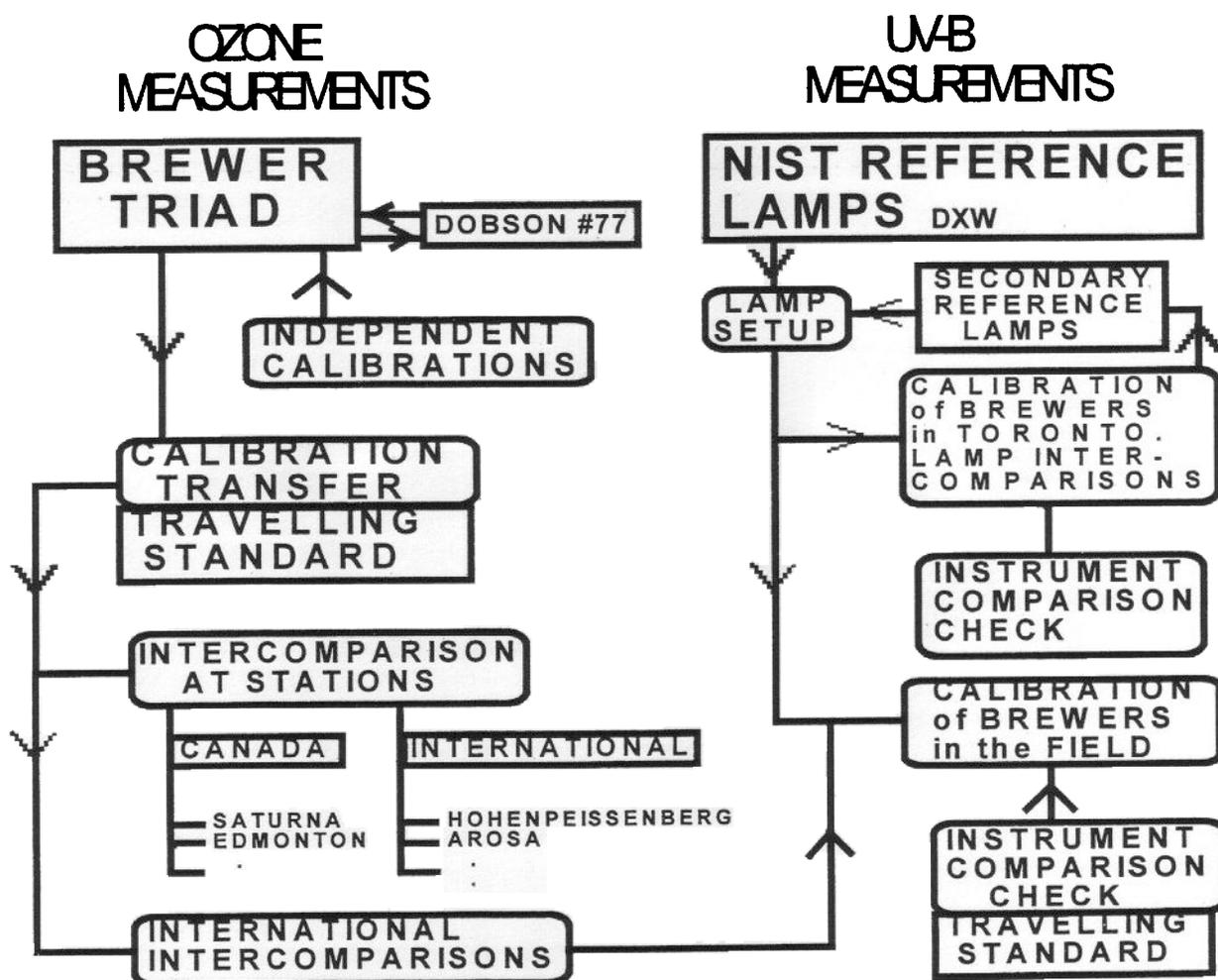


Figure 2.1.1 Brewer Calibration Center

Table 2.1.1 Summary of the calibration and performance of the instruments in the Brewer reference triad. The summary of the performance is based on 2227 daily average values measured over twelve years between 1984 and 1996.

	Instrument#8	Instrument#14	Instrument#15
Calibration at MLO	May 1983 March 1987 February 1992 October 1994	July 1984 November 1991	January 1984 November 1991 October 1994
Mean ratio to triad	1.0032	0.9969	1.0000
Standard Deviation	0.0088	0.0076	0.0078
Slope versus triad	+0.06%/decade	+0.11%/decade	-0.16%/decade

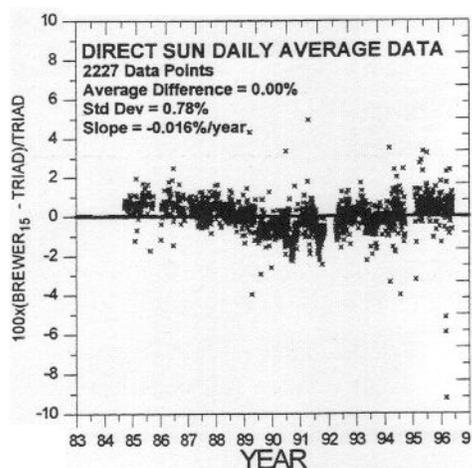


Figure 2.1.2 The ratio between ozone measured by Brewer instrument #15 to the triad ozone value. The average ratio is 1.0000 with a standard deviation of 0.0078. The slope of instrument #15 compared with the triad (dashed line) is -0.00016 per year (-0.16% per decade).

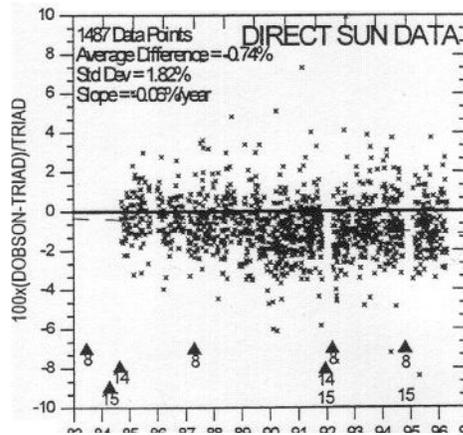


Figure 2.1.3 The ratio of Dobson instrument #77 AD direct sun daily ozone values to the daily triad values over the twelve-year period. The average ratio is 0.9926 with a standard deviation of 0.0182. The slope of the best fit (dashed) line is -0.0006 per year (-0.6% per decade).

2.2 Results of field calibration activities

K. Lamb of International Ozone Services Inc., Canada, presented background information about the newly formed company which focuses on the maintenance and calibration of Brewer instruments. Table 2.2.1 indicates the sites that have recently received calibration visits. The first sites visited are located throughout Europe.

The initial conditions for each instrument were noted and then the first adjustment for the Extraterrestrial Coefficients (ETC's) from standard lamp readings where the typical variance was 1-2%. A weakness was noted in the filters in regions of high humidity. Gears had been troublesome in some instruments.

The UV-B calibrations were observed to have larger errors but about half the systems had <10% change in the response file, although this change can be much higher. It was determined that quartz dome degeneration has lead to some of these problems

A technical note published by International Ozone Services Inc., describes a method to check the proper wavelength number calibration step number using sun scan routine. The reason why the step number needs to be adjusted is a focusing problem of the image in the large mirror following the Hg lamp routine. The technical notes also cover sun scan outputs which should be done at $\mu=2.5$ and 1.5 giving instruction on how to perform this and interpret the results.

A number of issues were discussed at this point, including dome degeneration and its possible causes, and problems within the instruments caused by high humidities.

Table 2.2.1 Site calibration visits

BREWER				O3 results
Location	Date	Inst. #	Initial Condition	SL corrected
Ispra, Italy	Apr.9-11/96	IV - 066	R6 -17% since 95	< 1 %
Sestola	Apr.12-14	IV - 063	R6 -7.7%,-14%	1% to -10%
U. Rome	Apr.15-17	IV - 067	ETC -11units -95	< 1 %
Vigna di Val.A30	Apr. 18-20	II - 024	mic stuck	< 1%
Brindisi	Apr. 22-24	IV - 062	OK -off 2 years	< 2%
Messina	Apr. 25-28	IV - 065	Off bad p.s., gear	< 1 %
Norrkoping	May 31-Ju3	III - 128	OK - 1st good cal	SL stable
Sweden		II - 006	OK	< 0.5%
Oslo, Norway	June 2-4	IV - 042	good - parts repl.	< 1%
Valentia, Ire.	June 5-9	IV - 088	good	< 1%
Yakutsk, Ru.	Aug. 1-6	II - 045	OK, no SL	< 1%
Obninsk, Ru.	Aug.8-10	II - 043	OK, large SL corr.	< 1%
		II - 044	OK, old computer	< 1%
Arosa, Switz.	Aug. 11-18	II - 040	OK	< 1%
		II - 072	OK	~ 1.5%
Sonnblick, Au.	Aug. 19-23	IV - 097	OK SL very stable	< 1%
Hohenp'berg	Aug. 24-28	II - 010	OK with SL corr.	< 1%
Lindenberg	Aug. 28 - 1+B17	IV - 078	OK	< 1 %
Poland inst.	Aug. 28 - 1	II - 064	OK - wl error in uv	< 1 %
Potsdam	Sept. 2-6	III - 118	OK temp. coeff.?	< 1% mu.dep

BREWER		General	H/W	New constants	New Dispersion	New UV resp
Location	UV/DUV	Comments	Comments			
Ispra, Italy	down 10%	2 calcs done	New PM filter, UG11	icf10296	yes	uvr10196
Sestola	down 30%	2 calcs - s/w prob.	FW3 gear 95	icf10496	no	uvr10496
U. Rome	down 5%	FW3 chg. 95	FW3 gear, nd #3	icf10896	no	uvr10796
Vigna di Val.A30	down 30%	csn 136 to 139	Needs pushrod/mic	icf11196	yes	uvr11196
Brindisi	down 55%		Humidity damage?	icf11496	yes	uvr11596
Messina	down 20%	csn 158 to161	P.S., gear, humidity	icf11996	yes	uvr11896
Norrkoping	OK	csn 282 to 287	No changes	icf15196	no	uvr36295
Sweden	down 4%	csn 161, 157, 165	New p.s.,iris,lamp hsg	icf16896	no	uvr15596
Oslo, Norway	down 4%	humidity control	Handle	icf16096	yes	uvr16096
Valentia, Ire.	down 300%	R6 -25 from 89	Motor, gaskets	icf21796	yes	uvr21696
Yakutsk, Ru.	down 20%	csn 138 - 141	Leaking?, TU off 6 steps	icf22296	yes	uvr22296
Obninsk, Ru.	down 20%		Rusty catches	icf22296	yes	uvr22296
	down 10%		Absn. adj to match #17	icf22996	no	uvr22996
Arosa, Switz.	up 2.5%	TU adj. ZE 8 st.	Poor cal in 94	icf22996	no	uvr23096
	OK	chg. dsp for NO2		icf18493	yes	uvr23396
Sonnblick, Au.	up 4%	Pushrod rev./TU8	New p.s., iris, n.d prob	icf-2860	yes	uvr24096
Hohenp'berg	down 9%	temp prob.	Exch. micropr.	icf24496	yes	uvr24396
Lindenberg	OK	csn 158 to 161	New hg,	icf23895	yes +1.8A	uvr24496
Poland inst.	down 10%	csn 284 to 281	OK	icf24796	yes	uvr24996
Potsdam						

2.3 Derivation of total ozone amount under cloudy conditions using the Brewer instrument

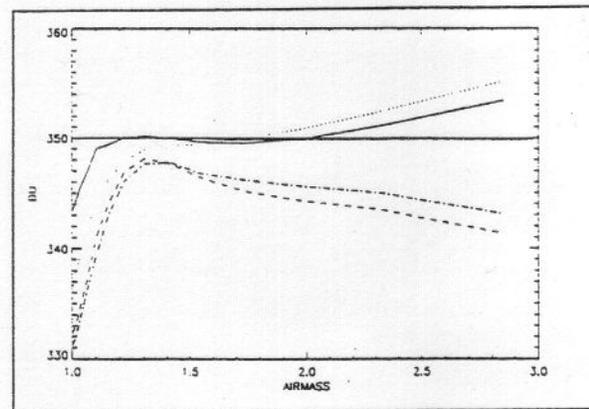
G. Kristiansen of the University of Trömsö presented the results of two sensitivity studies examining the zenith sky (ZS) radiation and global radiation methods. The goal is to develop a more reliable derivation of total ozone column under cloudy conditions and develop a new method for ozone determination using global radiation. A discrete ordinate model has been used with calculations based upon a range of solar zenith angles (between 5 and 80 degrees) and total ozone ranges between 200-500 DU with 50 DU increments. Surface albedo was 0.0 for all calculations. For the sensitivity studies, new model spectra were calculated for various parameters such as albedo, aerosol concentrations, cloud conditions and ozone profiles.

Figures 2.3.1 a-e, illustrates the various responses to changes in these parameters. The ozone amount chosen for these plots was 350 DU. The sensitivity to clouds was found to be small and does not explain the problems encountered during cloudy conditions.

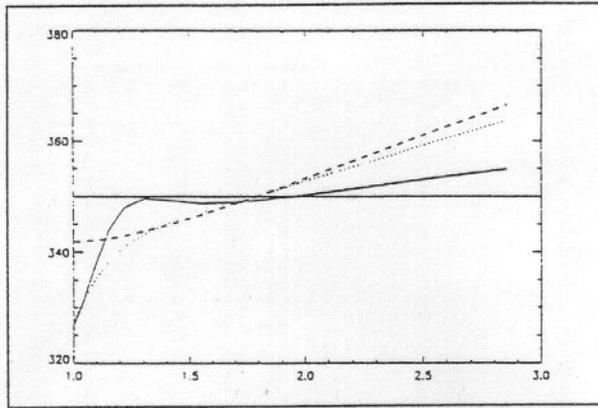
A new method for ozone determination was presented where global radiation measurements by the Brewer were used at the Trömsö site. The global radiation can be measured by the Brewer using the same wavelengths used for the direct sun and zenith sky measurements. A ratio of two or more wavelengths were used whereby the ratio is matched to a model lookup function of that ratio versus ozone abundance. The same radiative transfer model, used in determining the zenith sky sensitivity, was used here to calculate the radiation field. Figure 2.3.2a-d, shows little sensitivity to the four parameters. Daily mean values were within 3% agreement of the DS measurements; thus the global radiation method and DS methods compared well.

In conclusion, it was noted, the ZS method requires no post processing of the data, but it remains sensitive to cloudy conditions and local albedo. The global radiation method has produced ozone values through post processing of data thus far.

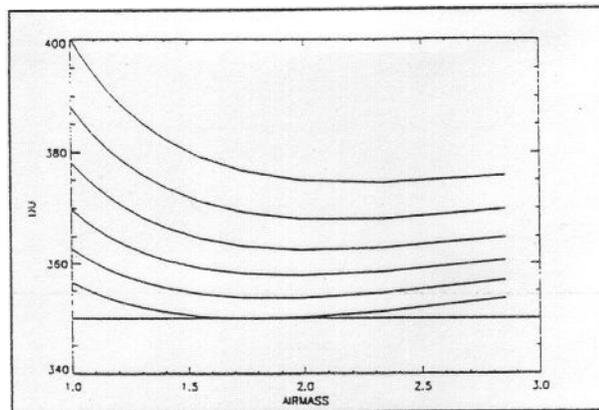
Figure 2.3.1 a-e



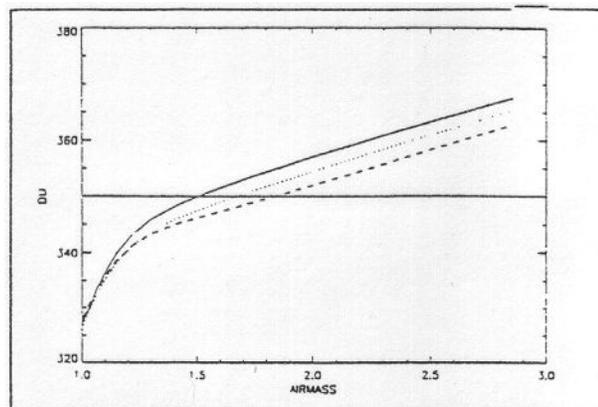
a. Change in ozone prediction for changes in ground albedo. The curves represent albedo values from 0.0 to 1.0.



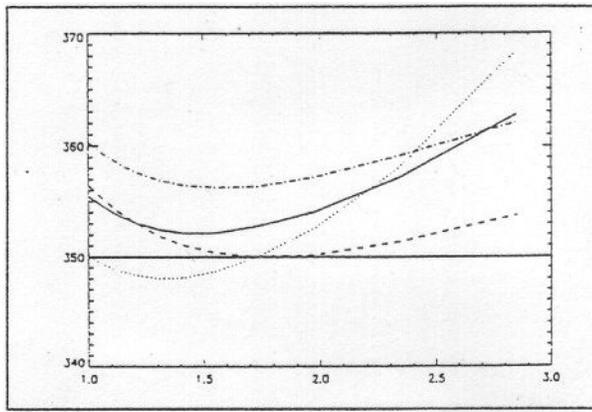
b. Change in ozone prediction for various aerosol conditions.



c. Change in ozone prediction for various cloud optical thicknesses.



d. Change in ozone prediction for cloud optical depth 5.0 at various altitudes.



e. Change in ozone prediction for various ozone profiles.

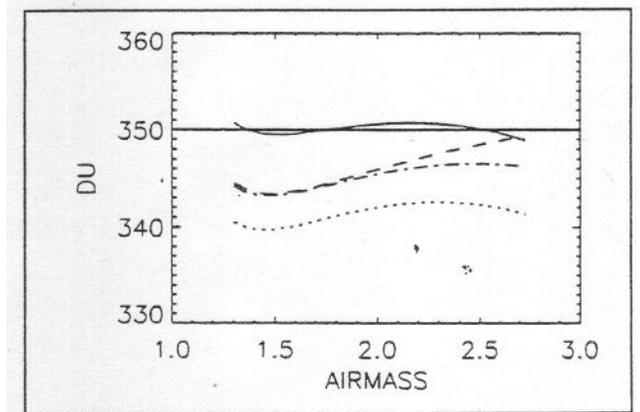
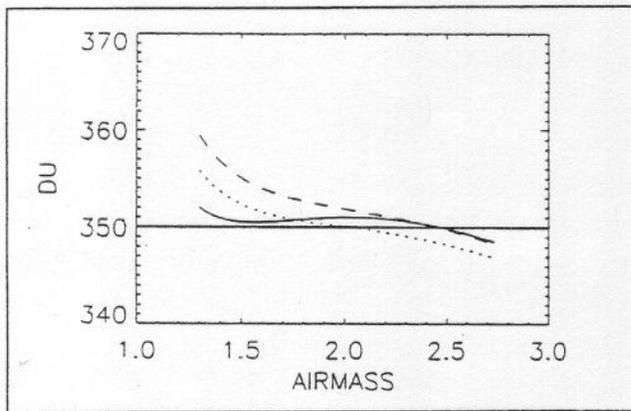
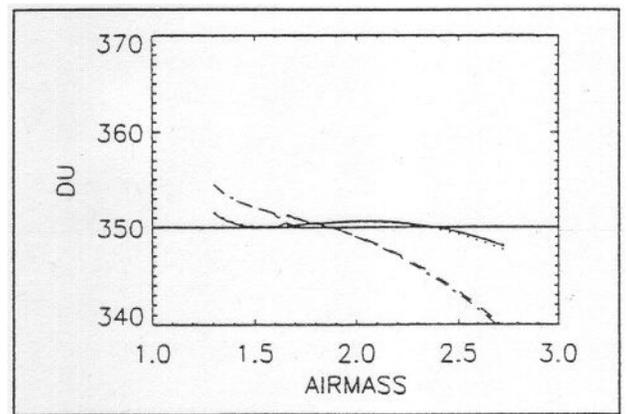
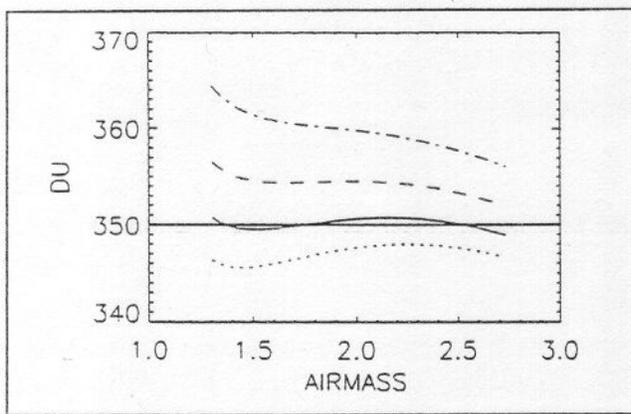


Figure 2.3.2 Results of the sensitivity study of the global ozone measurement method. The first figure shows the effect of albedo, the second the effect of aerosols, the third shows the effect of various cloud optical thickness and the fourth shows the effect of various ozone profiles.

2.4 Calibration problems with Brewer #37

E. Kyrö of the Finnish Meteorological Institute presented results showing calibration problems encountered with Brewer #37 stationed at Sodankylä, Finland. In 1993, Brewer #37 showed good agreement with TOMS data and the travelling standard, Brewer #17. There had been no changes to the coefficients in the first 5 years and ozone values had been compared with the SOAZ instrument. Results of comparisons indicated a 10-15 DU difference between TOMS and Brewer #37. The coefficients were changed in 1995, after the comparison.

Brewer #37 then was compared with Brewer #28 at Norrköping, Sweden in June 1996 and comparison results indicated a 10-15% decrease in values when compared with old coefficients. Brewer #37 was also compared with #107 at Jokioinen in June 1996. The meeting agreed that the errors could be compensated for, but the errors are larger than standard lamp records would indicate. However, #37 data can be re-calculated from 1993 onwards. It was reported that the new coefficients would be adjusted again in Izana this year.

A. Bais asked if the temperature coefficients had been changed or adjusted. It was decided this may be a possibility.

2.5 Calibration problems with Brewer #107

T. Koskela of the Finnish Meteorological Institute presented calibration results from Brewer #107 at Jokioinen, Finland. The standard lamp functions for the period from March to December 1995 and there is good agreement to within $\pm 2\%$ for all curves in the UV-B as illustrated in Figure 2.5.1. In April 1995, the optics were re-aligned, resulting in a much better responsivity.

For total ozone, after the ISPRA lamp ratios were incorporated, deviations in ozone values and ambient temperature changes were observed. The lamp ratios went down again, due in part to the seasonal behaviour, but no other explanation is available at this time. It was observed that moving the instrument indoors caused the R6 values to change. A change of lamp ratios used to adjust ETC values for ozone calculation was noted. The total ozone changed by 2-3 DU. Intercomparisons have produced good results.

J. Kerr suggested examining the temperature coefficients which, if correctly calculated, should eliminate this effect. There is a procedure outlining how to perform this correction by A. Bais, the documentation of which is still in production. T. McElroy suggested that a focusing problem with the early double monochromators may also be a factor and noted that the response to temperature must be examined. In addition, the meeting stated that looking at the external lamp data to examine the ratios is a good method to check on the internal lamp. It was also suggested that the optical alignment be checked after moving the instrument.

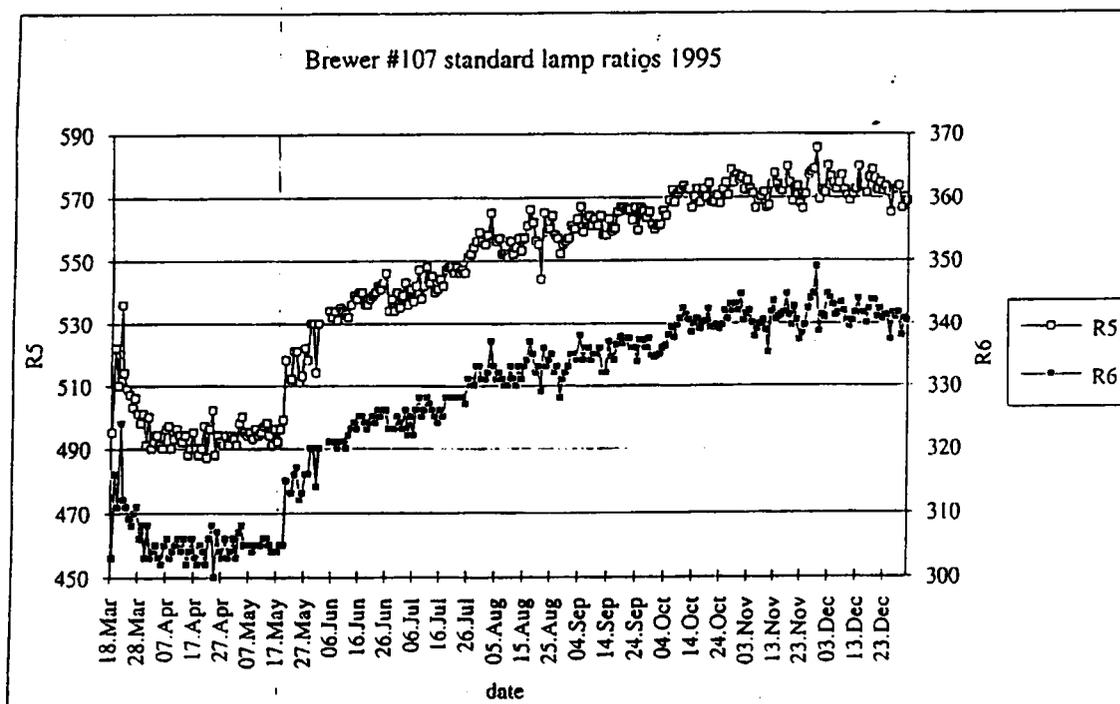


Figure 2.5.1 Standard Lamp ratios for Brewer #107.

2.6 Measurement programme at Valentia Observatory

G. Murphy of the Irish Meteorological Service, reviewed the measurement programme at the Valentia Observatory, Ireland. The observatory performs a suite of surface and upper air measurements which includes Brewer observations made with instrument #83. The maintenance programme includes daily checks of the instrument, and changing the desiccant every two weeks because of the humidity problems with a seaside station.

A direct sun (DS) and zenith sky (ZS) monitoring programme has been established out to $\mu = 4.0$, where cloudy conditions are common. During winter, observations are only up to $\mu = 3.5$. Focused sun (FZ) are reporting lower values than DS during winter. Data processing is done on the following measurements DS, ZS, FZ, SO₂, NO₂, UV-B and Umkehr. New, re-calculated sky charts have been incorporated in the BDMS software to allow stations to insert these values for their own use. Results of the calibration of June 1996 have improved these sky chart values.

The data are now ready for insertion into the BDMS and WOUDC data archive. UV-B measurements are also being done and a forecast centre for reporting UV is being established. The UV index forecast will be done using Brewer ozone and UV data. All data are now being updated and made ready for publication. Ozone data will be submitted to the WOUDC in the future. Comparison of the Valentia Brewer data with the UK Meteorological Service Dobson data at Camborne, England is being arranged. There are no Umkehr profiles as yet, but eventually these data will also be submitted. No UV data will be submitted until an absolute calibration can be performed. The standard lamps have remained within 1% and seem stable.

Some broad-band instruments (based on RB 500 series) have been run along side a Brewer and the data compared. The UV-B response from Brewer #83 was compared to that of the RB instrument. There is about a 15% difference between the data sets as illustrated in Figure 2.6.1.

T. McElroy commented on the FZ measurements indicating that the neutral density filters may be the source of some problems and the need to do the correct lamp correction was stressed.

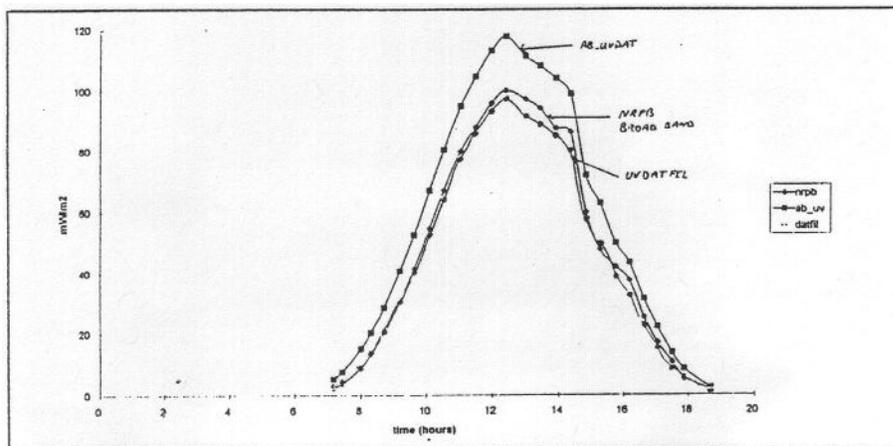


Figure 2.6.1: Comparison of UV-B response of Brewer #83 to RB meter.

2.7 Recent calibrations on Brewers #40 and #72 at LKO Arosa, Switzerland and the consequences on the data

H. Schill of the Swiss Meteorological Institute presented an overview of the measurement programme at the Arosa site which includes total ozone measurements from Brewers #40 and #72 which began operation in 1988 and 1991, respectively. Since 1968 and 1992 Dobson instruments #101 and #62 respectively have been in operation for total column measurements while Dobson #51 is used strictly for Umkehr measurements. Table 2.7.1, indicates the calibration history for Brewers #40 and #72. A 12 month running mean was used to smooth the data and the instrument stability is evident. Results of a comparison between Brewer #72 and Dobson #101 where near simultaneous measurements (within 5 minutes) were made on DS was presented. The data represented the temporal range of August 1992 to July 1996. A shift of 0.5% was observed in the 12 month running mean.

Calibration information from Brewer #40 and Dobson #62 were compared using the 12 month running means. There was no seasonal difference or effects of mu values between the two Dobson instruments; however, the two Brewer instruments were observed to have large variations. After the instruments were refurbished there was better agreement. The two Brewer instruments now compare much better since the June 1996 comparison.

Table 2.7.1 Brewer Calibration History

Brewer #040	
End 1988	Operational
Summer 90	Calibration (Brewer-workshop)
August 92	Doubtful Calibration
August 93	Calibration used as a standard for 1989-96 data-record
Summer 95	(Dobson-Intercomparison) confirmation of 1993 Calibration
August 96	Calibration

Brewer #072	
September 1991	Operational
August 92	Doubtful calibration; instrument remains unstable
April/June 93	Instrument at Sci-Tec, Canada
August 93	Calibration
August 94	Calibration
August 96	Calibration and recalculation of earlier calibrations of 1993/94

DATA COMPARISONS

Under this item, the meeting discussed comparisons of Brewer ozone data with satellite measurements and Brewer ozone and UV measurements at the KNMI.

UV-B MEASUREMENT

The United States EPA UV-B programme

W. Barnard of the United States Environmental Protection Agency (USEPA) presented a summary of the UV Research Monitoring programme which currently operates 7 sites. Five of these are located in urban areas in Atlanta, Georgia, Washington, D.C., Riverside, California, Research Triangle Park, North Carolina, and Boston, Massachusetts. The other two sites are in Boulder, Colorado and Boleman, Montana. The Brewers at these sites are currently all running under the same schedule measuring the following:

- UV radiation intensities, 286.5-363 nanometers
- Total column ozone
- Optical depths at 320, 340, 360, 480, 510, and 540 nanometers
- Umkehr data to produce stratospheric ozone profiles
- Diffey-weighted UV intensities

Quality assurance for this research monitoring network will be carried out through five different routes to ensure that the data are accurate and comparable to NIST standards. The first of these methods is through a yearly inter-comparison of instruments, where one of the network's Brewer spectrophotometers is compared with similar instruments from the other agencies making UV measurements. The second method is through yearly "blind audits" of the NERL Brewers by the designated CENR auditing facility at NOAA, Boulder. A standard lamp and regulated power supply will be shipped to each of the NERL sites. The operator at each site will have the Brewer scan the lamp and the resulting spectra will be returned to the NOAA laboratory for analysis.

The third method is by instrumental and operator controls within the network (Quality Control). The operational data will be graphed on a weekly basis and checked against running averages to determine if the instrument has suffered wavelength or intensities changes. These can easily be determined from values obtained from internal lamp scans that are programmed into the instrument's daily schedule.

The fourth route will be the use of external lamps that come with the Brewer and are calibrated at the factory against a standard lamp. These are utilized monthly by the site operators and are compared against values programmed into the computer files.

And finally, all of the Brewer spectrophotometers are to be cycled through the University of Georgia's laboratory where they will undergo extensive testing to determine their stray light

characteristics, their slit function, and their response to a horizontally calibrated NIST standard lamp. The five smaller external standard lamps that are utilized by the operators in the field will also be related to the same NIST standard lamp.

Fifteen new Brewers have been ordered and are currently being placed in National Parks across the US.

4.2 Recent analyses of Canadian UV-B data

J. Kerr of Environment Canada gave a presentation which focused on the types of information that could be derived from the following measurements: lamp irradiance calibrations, stray light corrections, and ratioing global spectra from a Brewer to a reference global spectra.

The responsivity calibrations made from a number of standard lamps that had been used over a 3-5 year period were compared to determine their long-term stability. One lamp was very stable with a drift factor of only 0.13 % per year and a standard deviation of about 1.5% from one calibration to another. Other lamps had much larger values. Lamp stability appears to depend on the individual lamp and not just a specific type or brand.

A method for correcting stray light in the single monochromator was presented. The correction uses a measurement of stray light determined from scans of the pure emission line of a 325 nm HeCd laser. Scans of this line show that stray light for a single monochromator is between 10^{-3} and 10^{-4} and for the double it is about 10^{-7} . A method was developed using the stray light characteristics to calculate a stray light spectrum for each measured spectrum. Comparison of spectra corrected for stray light from a single Brewer monochromator with spectra with those made with a double Brewer showed good agreement for a wide range of sun angles throughout the day.

In another analysis of UV data from the World Ozone and Ultraviolet Radiation Database a statistical model was developed which looks at the ratios of intensities at different wavelengths. The intensity of the irradiance at wavelengths between 290 and 325 nm are normalized to the value at 324 nm. The statistical model relates the dependence of the normalized spectra on total ozone and solar zenith angle. This makes it possible to determine total ozone from a measurement of spectral UV-B irradiance with an accuracy of about 3%. It also allows the reconstruction of a UV-B spectrum given the solar zenith angle and the amount of total ozone. Since radiation at 324 nm is negligibly affected by ozone, the measured global irradiance values at 324 nm can be used to study effects of other variables on UV irradiance such as clouds, haze and surface albedo.

The final analysis that was discussed was the concept of ratioing an observed spectra to a standard spectra. Data from Toronto using a single monochromator Brewer #14 were used for the study. The ratioed spectra can be used to quantify ozone absorption, the spectral shift and stretch of the instrument, and the spectral line in-filling of radiance scattered from the sky. After fitting the ratioed spectra to account for these four influences, residuals of the order of 0.1% are seen for spectra made under good observing conditions. It was shown that the record of spectral shift and stretch accurately detected a change in the dispersion constants which were updated in March 1992.

4.3 Characterization of the slit function of the Brewer ozone spectrophotometer

W. Mou of the University of Georgia at Athens, USA presented work that he and co-investigator J. Rives have done with slit function characterization. Two Argon lasers have been used to generate lines at 3157, 3250, 3336, and 3511 Angstroms. Two scans of each laser line were made by each Brewer tested. No Brewer filters were in line for these measurements. Peak

values for most of the laser lines were in the 10 million photon count range. In almost all cases the counts were down to the 10,000 photon range within 5 angstroms of the center frequency of the laser. Beyond that region the stray light was generally less than 1000 photon counts. From their work they concluded that approximately 30-40 percent of the stray light below 296 nanometers came from light in the 300-363 nanometer range. Further tests need to be done at higher wavelengths to determine the stray light contribution from the visible range. The current short wavelength averaging method of subtracting out the stray light background seems to be reasonable.

4.4 Tests on the reliability of the UV-B measurements made by the Brewer MKIV spectrophotometer

F. Cappellani of the Joint Research Center, Italy presented the developments underway to increase the accuracy and reliability of its ground based Brewer UV spectral measurements. The intention is to determine the reliability of the UV data measured during the day by a Brewer Mark IV since 1992. By using instrument intercomparison data taken at the 1995 UV-spectrometer intercomparison campaign held at Ispra on May 1995, they have been able to calibrate and compare the performances of their Brewer and Optronics OL-754 double monochromator. Comparisons between the solar UV-B spectra taken by the Brewer and the calculation of the sun irradiation using a radiative transfer model have also been attempted (for clear sky conditions) in order to have an independent control of the validity of the data measured.

Checks were performed on the Brewer's wavelength stability using an Optronics OL-754. The Optronics instrument was compared at the instrument inter-comparison at Ispra in 1995 and found to vary as much as 10 percent from the reference spectra. Their Brewer was in excellent agreement with NIST lamps and another Brewer belonging to the University in Thessaloniki. Comparisons between their Brewer and the Optronics showed possible stray light and cosine differences between the two.

To further corroborate the accuracy's of both instruments, comparisons were made using radiative transfer codes and comparing the models generated by these codes. Future work will be to utilize UV data calculated from GOME satellite observations to ensure the overall accuracy of the Brewer database.

4.5 Brewer, the Armadillo and UV

V. Fioletov of Environment Canada presented 3-dimensional plots of solar time, wavelength and UV intensity which have been nicknamed "Armadillo" plots. These graphs are generated to look at various anomalies associated with observing at shorter wavelength with Brewer spectrophotometers. These models, derived from a large database of clear-sky UV data, can be used as tools to conduct QA/QC checks on data and to derive ozone values from past measurements of UV radiation. By ratioing the UV intensities at two different wavelengths, one of which was chosen as 324 nm and the other in the strong ozone absorption area of the spectra, it is possible to derive the ozone column amount for the time the measurements were taken. Using a considerable amount of past data an equation was statistically developed to calculate total ozone from the UV spectral data. As was pointed out in the discussion, however, this technique is only accurate under clear-sky conditions and prediction accuracy's decrease with increasing solar zenith angle.

This same equation can be turned around and utilized for instrument comparisons as well if one knows the ozone and sulfur dioxide concentrations. Also introduced during the discussion was data from northern Canadian sites showing the increased UV radiation as a result of snow cover and the seasonal variation of the UV Index. In earlier spring one would expect the UV Index

to have relatively low values because of the high ozone concentrations compared to the same solar zenith angles in the fall when the ozone levels were lower. This was not the case. UV Index levels were higher in the spring. This was caused by the snow still being on the ground and producing a high albedo.

One of the most important parts of the discussion focused on the list of QA/QC flags that were presented at the end. These checks were the results of the development of this statistical model and will prove very useful for those people making long-term UV radiation measurements. This list should be put on a WEB page or ftp server for distribution.

4.6 Synchronisation at intercomparisons

T. Koskela of the Finnish Meteorological Institute gave a presentation on the synchronization of UV instrument measurements at a recent intercomparison. Participants were requested to begin scans on the half hour and run at a scan rate of 0.5 nanometers per second. It was noted that Brewer 107 was not maintaining a smooth scan rate and frequently paused longer at some wavelengths than at others. In tests with this instrument UA scans were performed as well UX scans. It was noted that UX scans done after UA scans seem to run smoother and without pauses. Also noted was the fact that sequential UA scans were not the same. Each had differing scan rates and neither were smooth scans. Questions were raised with the other workshop participants about the reasons for these delays in the UX and UA scans. A possible cause may be extra characters transmitted between the Brewer and its computer in each communication.

5. DATA MANAGEMENT

5.1 WOUDC and BDMS data management systems

E. Hare of Environment Canada presented a report on the status of 2 databases: the World Ozone and Ultraviolet Radiation Data Centre (WOUDC) and the Brewer Data Management System (BDMS).

In the WOUDC, 10% of stations are still using the old "Dobson-style" format. The following points were noted: only Canadian and Japanese stations are submitting UV data; in a sign of the times, 75% of submissions are now electronic; and Brewer data provides approximately 7% of world daily ozone values.

The Brewer Data Management System (BDMS) has grown to 6.5 Gigabytes - predominately from 12 Canadian sites. Currently (1996) the database is growing by approximately 1 Gig per year.

In a review of the geographical distribution of sites, it was noted that South America and Africa are still sparsely represented. Recent developments include:

- The release of a CD-ROM from WOUDC.
- A new archival method is under development.
- A new world wide web page is now operational.

•
Examples of pages at the new WOUDC (<http://www.tor.ec.gc.ca/woudc/>) web site were reviewed by the meeting and there was speculation on its growth as a medium for collecting data from the contributing sites. Brewer users were encouraged to submit their archives of standard Brewer files. Future plans include:

- An inventory database where content is easily defined.
- Separate agency submission accounts with USERNAME/PASSWORD.

- Value-added database output products.

5.2 Flexible self-styling data formats

A. Kylling of Norway reported that two new European databases are facing the problem of data contributions in multiple formats:

- SUVDAMA - Scientific UV DAta MAnagement
- UVRAPPF - UV Radiation in the Arctic; Past, Present, and Future

Requirements for a good database were described:

- easy to write, read, extend, add to, change
- easy to syntax check
- easy to develop interface with data analysis
- easy to document
- must serve its purpose

The FLEXTOR file format with an example of a possible data entry was described. FLEXTOR has 3 operating modes:

1. No checking on symbols; i.e., anything accepted.
2. Only symbols defined in symbol tables are accepted; symbols in any order.
3. Only pre-defined symbols; symbols in pre-defined order.

FLEXTOR and SUVDAMA data storage proposals are available at:

- www.itek.norut.no/~arve
- www.fmi.fi/SUVDAMA

5.3 Automatic remote station control in the Canadian Brewer ozone network

J. Kerr discussed that in Canada many sites do not have scientific personnel on site. This has led to the need for a system in which all sites are connected through telephone links to a central site. There is daily reporting of data to AES for entry into the Brewer Data Management System (BDMS) and subsequent entry into WOUDC. This "real-time" data routinely enters two national programmes: the Ozone Watch programme, and the UV Index programme. Not only data transfer, but also Brewer instrument control is achieved over the telephone link. Using the proprietary software "PCAnywhere", remote monitoring and troubleshooting is possible.

The meeting was informed of the progress towards the establishment of a central (AES) repository of the various versions of the software now in use at the field stations.

6. AEROSOLS AND OTHER TRACE GASES

6.1 The use of Brewer direct sun spectra to determine aerosol optical depth

A. Bais from the University of Thessaloniki, Greece described a method for measuring aerosol optical depth at ultraviolet wavelengths between 295 and 365 nm using the Brewer instrument. The method requires the absolute calibration of direct sun spectral measurements made through the director prism. This was done by comparing direct sun (prism) spectra with global minus diffuse spectra measured through the UV-B diffuser dome of a double Brewer (Mark III) instrument. A shadow disk was made for the Brewer that could be scheduled to block out the direct solar irradiance during the diffuse measurements. From the comparisons, the spectral responsivity of the instrument for the direct sun (prism) measurements and the wavelength dependence of the attenuation of the neutral density filters were determined.

Langley plot measurements were made at the Izana Observatory (28°N) in July 1995 to determine the absolute extraterrestrial spectrum (ETS) at the Brewer wavelength resolution over the extended Brewer wavelength range (295nm to 365nm). Results of the Langley plots at four wavelengths (300, 310, 330 and 360 nm) are shown for four days in Figure 6.1.1. It is quite clear from these data that observing conditions were very stable over the observation period. The extrapolated values for the complete ETS is shown in Figure 6.1.2. Comparison of the ground-based ETS measurement with the SUSIM satellite ETS shows the Brewer measurement on average about 3% less than the SUSIM values over the wavelength range with wavelength-to-wavelength variability of about $\pm 5\%$.

The absolute ETS was used to take spectral measurements of aerosol optical depth at Thessaloniki. Results of optical depth measurements ranging between 0.1 and 1.0 on different days were shown. There is some wavelength dependence of the optical depth values. It was noted that comparison of Brewer optical depth measurements with those derived from lidar measurements showed good agreement.

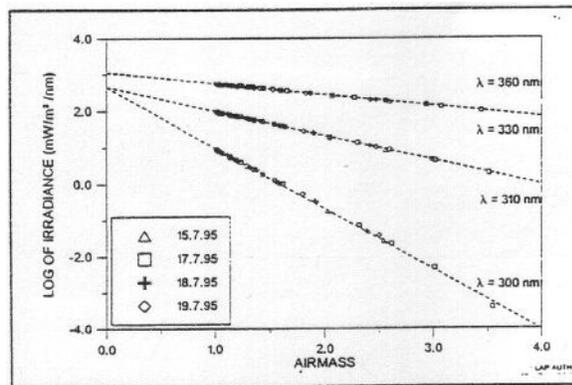


Figure 6.1.1 Langley Plots.

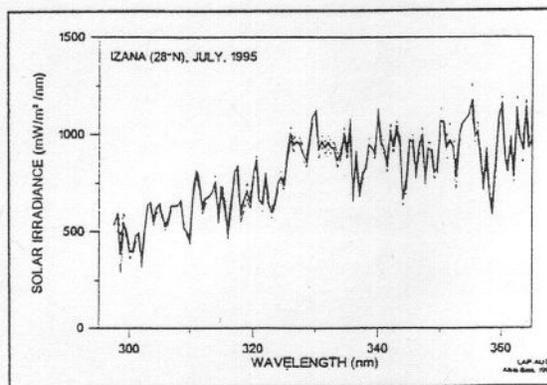


Figure 6.1.2 Extrapolated ET Spectrum.

6.2 Brewer ozone spectrometer aerosol optical depth measurements

D. Henriques from the Meteorological Institute of Portugal was not present to discuss the use of the Brewer instrument for measuring aerosol optical depth at UV-B wavelengths. The Abstract for his presentation, however, is attached as Annex C.

6.3 Satellite measurements of SO₂ and ground-based validation

J. Kerr of the Atmospheric Environment Service (AES) in Canada showed the results of measurements of stratospheric SO₂ from volcanic sources. Both ground-based (Brewer) and Total Ozone Mapping Spectrometer (TOMS) satellite measurements were presented. He indicated that AES and NASA had worked together in the early 1980's to develop the operational algorithm which has since been used to retrieve SO₂ amounts from the TOMS data. The TOMS satellite algorithm is based on the same linear differential technique which is used for the Brewer measurements. SO₂ at high altitude (usually from volcanic eruptions) is detectable by the TOMS satellite, however, SO₂ near the ground (from pollution sources) is not detectable.

The SO₂ values currently being measured by the Brewer instrument are based on absorption coefficient work that was carried out at room temperature at AES around 1980. Results of more recent work by McGee and Burris (1987) from NASA Goddard indicate that the Brewer values for SO₂ at room temperature are too large by about 30%. Furthermore, the McGee and Burris coefficients at cold temperatures (210°K), closer to that of the lower stratosphere, suggest that the derived amount of SO₂ should be reduced to 55% of the Brewer output to account for the effects of colder temperatures on the SO₂ absorption. A summary of the ozone (Bass and Paur, 1985) absorption coefficients and SO₂ absorption coefficients at the Brewer wavelengths is given in Table 6.3.1. The SO₂ absorption coefficients of McGee and Burris at 295°K and 210°K are shown in Figure 6.3.1.

Although there have been several volcanic events detected by TOMS during its operation, there have not been many coincidental ground-based measurements which would be useful for validation. One exception is the September 17, 1992 eruption of Mount Spurr, Alaska which passed over Toronto two days later. Results comparing the Brewer ground-based and TOMS satellite SO₂ measurements as well as the Brewer optical depth measurements during the passage over Toronto are shown in Figures 6.3.2 and 6.3.3.

The NASA Goddard TOMS SO₂ group is very interested in future ground-based validation of volcanic SO₂ events and are co-ordinating an action plan to increase the number of coincident opportunities. The meeting noted that an open letter to Brewer users had been circulated indicating the need for ground-based validating of future volcanic events. A copy of the letter is attached as Annex D.

Table 6.3.1. For the Brewer Instrument N = 5 (i.e. measurements at 5 wavelengths) 5 intensity measurements are weighted and linearly combined by arrays W (for ozone) and W^s (for SO₂)

Brewer #14 Operating Wavelengths

Wavelength, λ_i	W_i	W_i^s
306.316	0.0	0.871
310.063	1.0	-2.917
313.503	-0.5	1.459
316.801	-2.2	2.760
320.017	1.7	-2.173

note: $\sum W_i = 0$; $\sum W_i * \lambda_i = 0$
 $\sum W_i^s = 0$; $\sum W_i^s * \lambda_i = 0$

Wavelength (nm)	O ₃ Absorption (cm ⁻¹)	SO ₂ Absorption Coefficient (cm ⁻¹)		
		Present	McGee and Burris 210K	McGee and Burris 295K
306.316	4.096	11.75	15.87	14.42
310.063	2.314	5.30	4.60	5.29
313.503	1.561	4.90	4.04	4.33
316.801	0.862	2.60	2.30	2.46
320.017	0.677	1.70	1.27	1.43
$\sum W_i * \alpha_i$	0.788	0.02	-0.32	0.15
$\sum W_i^s * \alpha_i$	0.002	5.40	9.89	7.13

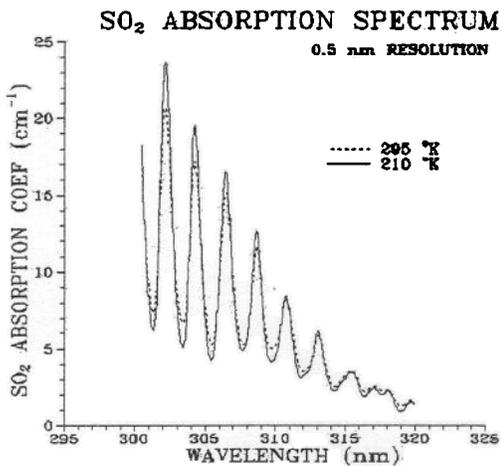


Figure 6.3.1. SO₂ Absorption Spectrum

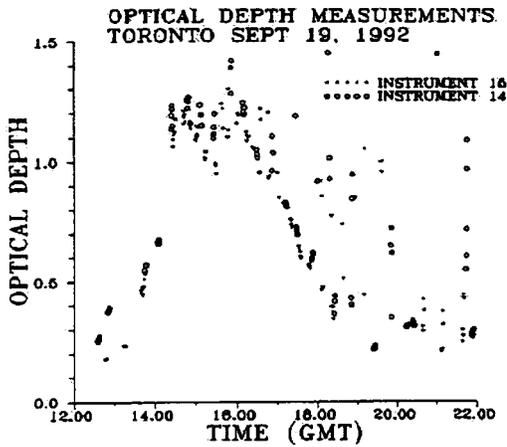


Figure 6.3.2. Optical Depth Measurements

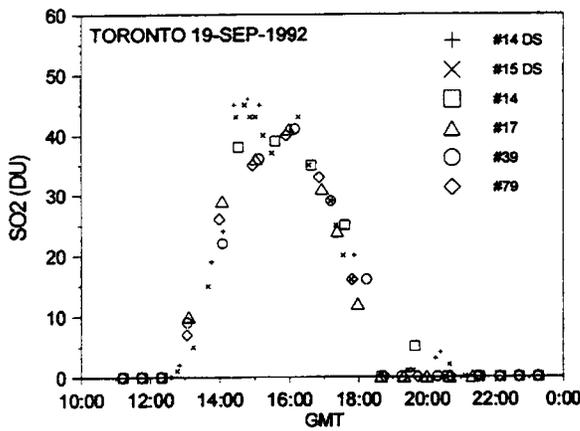


Figure 6.3.3. SO₂ values for September 19/92.

6.4 Brewer #067 in the NO₂ mode

G.R. Casale of University "La Sapienza" in Rome presented results of measurements of NO₂ made in central Rome since 1992 with Brewer MKIV instrument #067. He reported that during the period of operation since 1992 the instrument has been quite stable.

The direct sun measurements of NO₂ show significant day-to-day variability. Variations of the daily average column NO₂ measured by the Brewer instrument are consistent with daily surface concentration measurements. Examples of the comparisons were shown for January and July, 1995.

An analysis of comparisons between column NO₂ values and other variables such as solar radiation, precipitation and ventilation (wind speed and direction) showed that there are complicated relationships. However, some meteorological variables appear to force NO₂ concentrations. For example Figure 6.4.1 shows there is generally less total NO₂ on days when there is more precipitation.

Experience gained from operating the instrument indicated that frequent switching between the ozone and NO₂ modes should be avoided since this may cause wear on filter wheel #3. It was also found that errors result in the determination of stratospheric NO₂ values from the twilight data under heavily polluted situations likely as a result of varying NO₂.

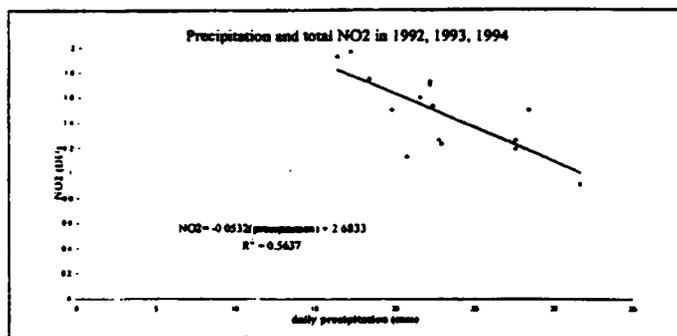


Figure 6.4.1 Precipitation and NO2

7. UMKEHR MEASUREMENTS

7.1 Brewer Umkehr software description and use

T. McElroy reported on the current status of the Brewer Umkehr software and described how to use it. Brewer Umkehr data provide an additional way of obtaining ozone trend information at high altitudes (30 to 50 km) to augment the traditional sources which include SAGE, SBUV and Dobson Umkehr data. These data are urgently needed to confirm the efficacy of the actions taken under the terms of the Montreal Protocol and to track the recovery of the ozone layer over the next 50 years.

The Umkehr measurement technique depends on the process of scattering radiation in the atmosphere. Observations of the zenith sky brightness are made between 60 and 95 degrees solar zenith angle. The variation of the mean scattering height of radiation reaching the instrument as a function of the solar zenith angle, together with the total ozone column amount estimated from direct sun observations is used in a model calculation to deduce the vertical profile of ozone. A useful feature of the Umkehr technique is the relative independence of the retrieved profile on instrumental characteristics providing that an accurate total column ozone measurement is available for the time of the Umkehr observations.

The meeting noted that Brewer Umkehr data can be processed on the IBM-PC using software which can be downloaded from the WOUDC website (www.tor.ec.gc.ca/woudc/), or ftp site ([ftp.tor.ec.gc.ca](ftp://tor.ec.gc.ca)) then access the software from the directory /woudc/software/umkehr. Text files contained in the programme directories explain how to access the Umkehr analysis programmes and how to use them.

The processing procedure is largely automatic once the appropriate programme and data files are collected together into a directory on the computer disk drive. The analysis involves running two different processing programmes which are very similar to the ones used to process Dobson Umkehr data. The algorithm is essentially the Maximum Likelihood method of Mateer and Deluise, adapted to use the data collected at the Brewer Umkehr observation wavelengths. The first step in setting up the programme for use is to enter site- and instrument-dependent data in the setup files for the preprocessor and the Umkehr analysis programme. These data include

such parameters as the instrument ozone absorption coefficients and the site location including the average site surface pressure.

In addition to the setup files, it is necessary to have a file in standard format (the OZOAVG file as written by the Sci-Tec Brewer control software) so that the preprocessor can determine the total ozone associated with each Umkehr observation. The actual Umkehr data are contained in a separate 'U' file for each observing day. The file names are formatted as Ujjjyy.nnn where the jjj is the Julian local day number, the yy is the two-digit year and nnn represents the instrument serial number. It was noted that different setup files must be used with data from different locations.

The operation of the programmes is coordinated by using a set of batch files which make it easy to process data from individual days or groups of days. The preprocessor generates several output files which can be used for quality control and for input to the Umkehr processing algorithm. The Umkehr processor produces a diagnostic listing file as well as Umkehr layer amounts and number density profile output.

Umkehr observations are made at the standard set of ozone observing wavelengths as well as at three additional wavebands at longer wavelength. The full set of eight Umkehr wavelengths includes 306.3, 310.1, 313.5, 316.8, 320.1, 323.2, 326.4 and 329.5 nm. The preprocessor reduces the observations data from photon counts to corrected count rates per second, and includes a correction for the finite counting speed the photon detection electronics (i.e.: dead time). The intensity at each wavelength, in the form of 100 times the logarithm to the base 10 of corrected counts (the 'N-values'), are fitted as a function of the solar zenith angle using a cubic spline curve in order to interpolate the data to a fixed set of 'standard' Umkehr angles. The values at the standard angles are output to a data file which serves as the input to the Umkehr processing algorithm.

The outputs from the preprocessor include a listing file, which contains information on how well the data were fitted by a smooth curve, as well as the final output records which are independently passed to the Umkehr analysis programme. Background information about the processing run are included so that errors in the input data can be easily detected. A list of the agreement between fitted and observed data is also included. A separate graphical output (Figure 7.1.1) file allows the observed and fitted data to be plotted using a commercial graphing programme so that badly-fitted data can be identified. This is an important step in ensuring that the Umkehr retrieval will provide useful data.

The meeting was informed that inside the Umkehr programme, the data from the preprocessing step are corrected for the multiply-scattered light component and then fitted using a single-scattering, radiative transfer code. The inversion algorithm adjusts the amount of ozone as a function of height to retrieve the vertical ozone profile. The first-guess profile of ozone used in the inversion process is determined from a climatological data set which uses the measured total ozone, the latitude and the day of the year to generate an estimate of the ozone profile for the day to be analyzed. The optimal estimation, or Rodgers', algorithm, is used to retrieve the ozone profile.

The number-density output file is given at a 2-km resolution so that the Umkehr results can be compared to ozone profiles from other sources (e.g.: ozonesondes). In addition, the vertical profile as described by the Umkehr layer amounts and the implied interpolation algorithm used in the Umkehr programme, is output in a concise form for inclusion in the WOUDC database.

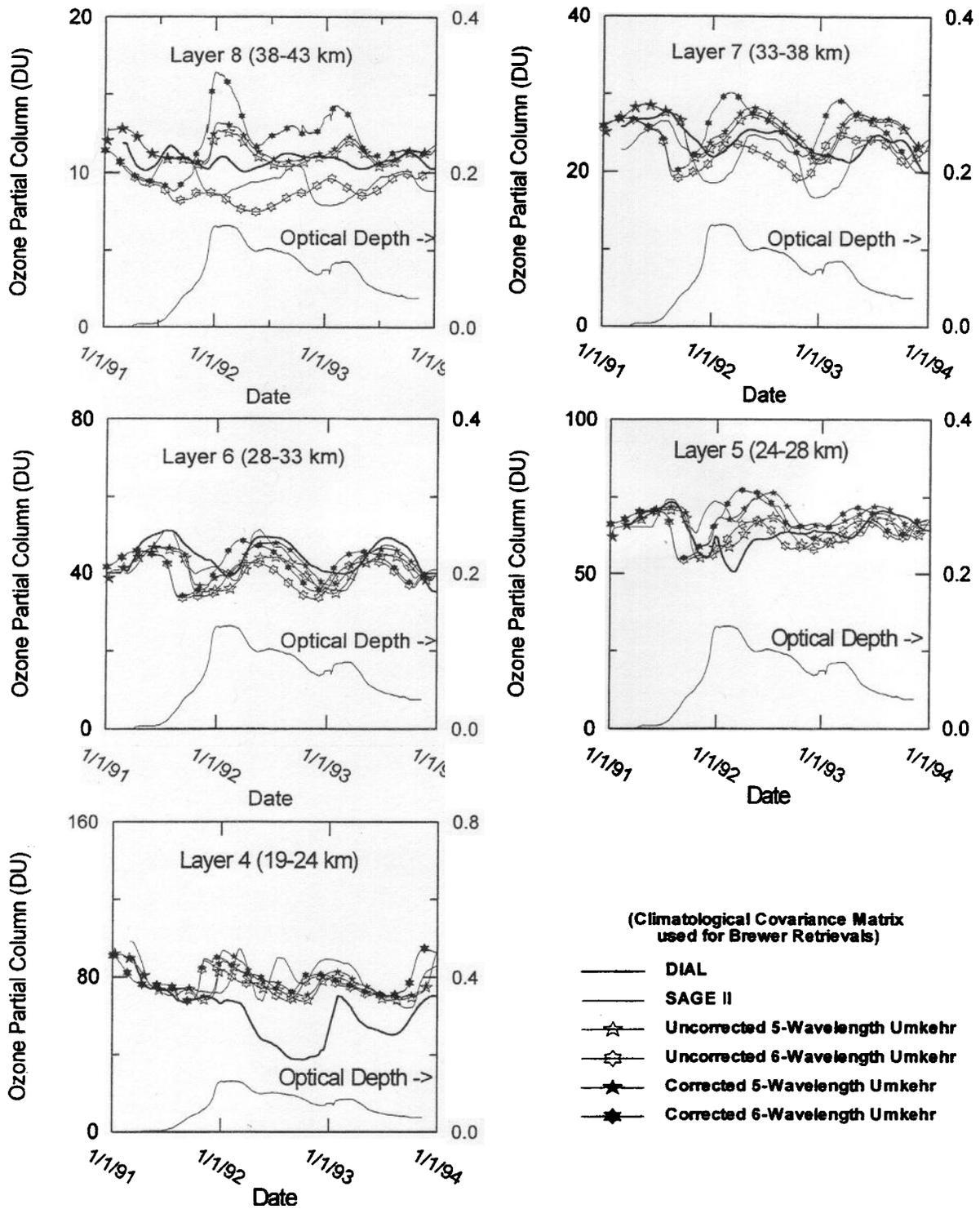


Figure 7.1.1 The time series of ozone partial column amounts in each Umkehr layer is shown as a function of time for four different cases. These include both the 5-wavelength and 6-wavelength retrievals and for both the aerosol-corrected and uncorrected cases. Also shown is a time series of ozone amounts from the Toronto ozone DIAL and from SAGE II.

Figure 7.1.2 shows a profile retrieved from data collected during the Table Mountain ozone intercomparison in 1989. One day from this comparison is included as a test data set in the Umkehr software package to use to verify the correct operation of the Umkehr software when it is installed (day U20389.039).

T. McElroy reported that the Rodgers' algorithm requires a covariance matrix which describes the probable variability expected in the [first guess] ozone profile. This information is used together with the observation covariance matrix in the solution process. Two profile covariance matrices are included. One represents actual climatological variability expected in the atmospheric observations and therefore includes layer-to-layer correlations over a considerable height range. The other is a uniform covariance matrix which has diagonal elements which represent the variability for each layer, and a small positive layer-to-layer covariance which imposes a smoothing constraint on the solutions which result from the inversion process. In general the climatological covariance matrix will provide solutions which, as a set, will correspond most closely to the climatology while the uniform covariance matrix will provide the best information about actual layer trends. Both retrievals are useful, depending on the application of the data.

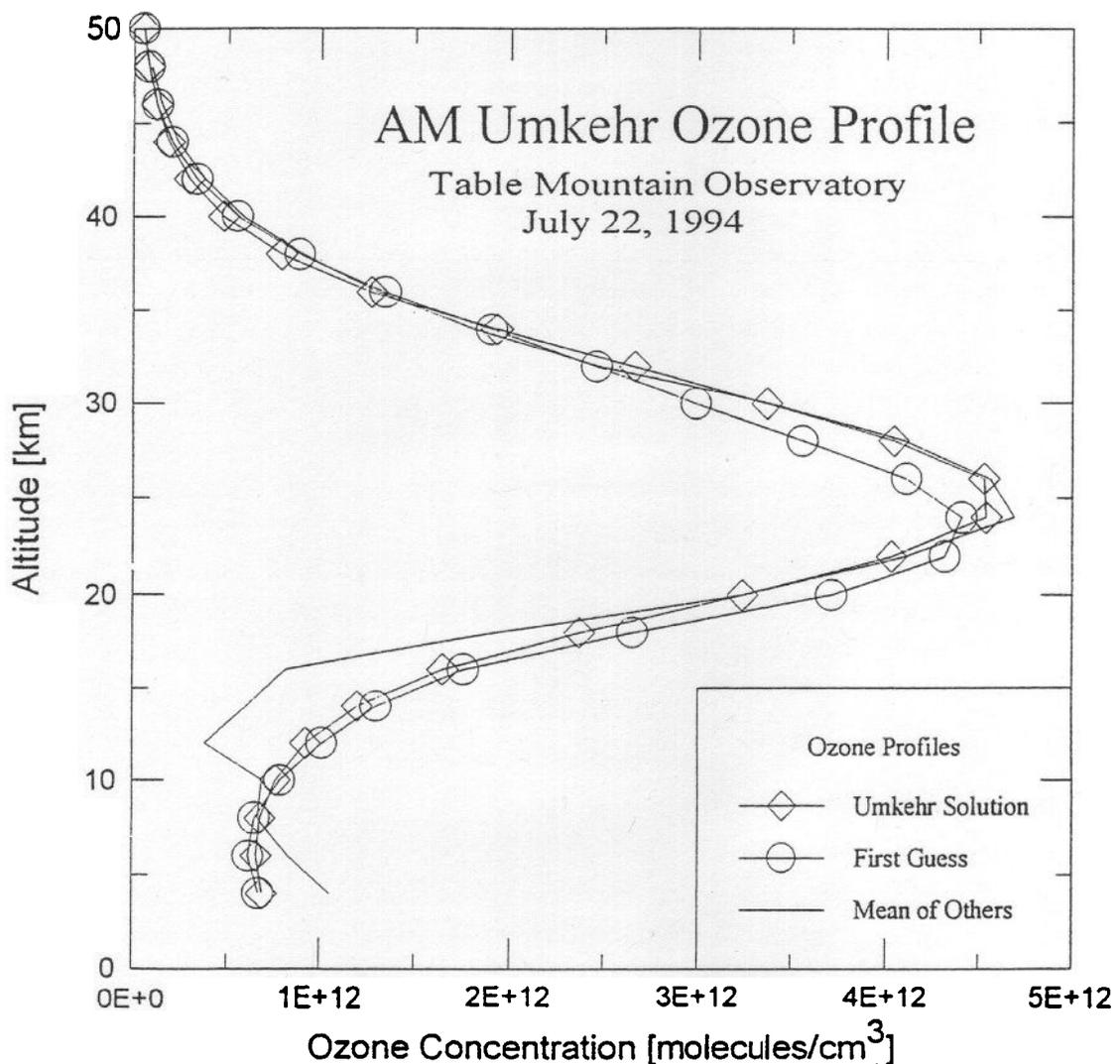


Figure 7.1.2 An ozone Umkehr profile from data collected on July 22, 1989 is compared with the mean profile determined using other methods (see text). The Umkehr first-guess profile is also shown. [After McElroy and Kerr, 1995]

7.2 Brewer Umkehr observations for monitoring high altitude ozone trends

New results were presented to the meeting which suggest that a retrieval algorithm based on the analysis of only the 5 standard ozone-observing wavelengths will provide ozone profile observations which are much less influenced by the presence of volcanic aerosol in the atmosphere. Figure 7.2.1 shows the superior performance of the 5-wavelength algorithm for the period when the upper atmosphere was affected by the aerosol from the Mt. Pinatubo eruption in 1992. In general, the response of the 5-wavelength algorithm is slightly poorer at the highest altitudes. It was noted that both the 5-wavelength and 6-wavelength algorithms are available from the WOUDC ftp site.

7.3 Multiwavelength method for the retrieval of ozone profiles from Umkehr observations

N. Elansky of the Institute of Atmospheric Physics in Moscow reported on a new method for retrieving ozone profiles from Brewer Umkehr observations. The new algorithm is based on the invariant statistical method of the Measuring Computer System Theory (MCST) and allows profiles to be retrieved from Brewer observations directly without the data first being transformed into Dobson ratios. Figure 7.3.1 compares the error resulting from this technique to that of the Mateer and Deluisi (MD) 1992 algorithm currently in use. The error overall and, in the area of 5 to 15km specifically, the error was reduced by a factor of up to 2.5.

Since the error is reduced to such an extent by using the MCST method, a method for using data taken at only one zenith angle to obtain a profile was also presented. With the 'express' method, two or three profiles might then be obtained in only 10 - 15 minutes. This would be useful in cloudy conditions, during NO₂ episodes and in polar regions where the available zenith angles are limited at certain times of the year. A plot of the error at several zenith angles chosen versus the MD method showed that the higher the zenith angle, the smaller the associated error. It was noted that, while the error for MCST was equal to or lower than that for MD for zenith angles larger than 75° in the troposphere, the error was larger in the 20 to 30km area for all but the 89° zenith angle. With the Brewer it is possible to optimize the time of photon counting and the measurement protocol to eliminate those wavelengths considered less than optimal and redistribute the photon counting among those remaining. A graph of the errors associated with the express MCST, the optimized express MCST and the MD methods at 89° showed an even greater reduction in the error for the optimized MCST method.

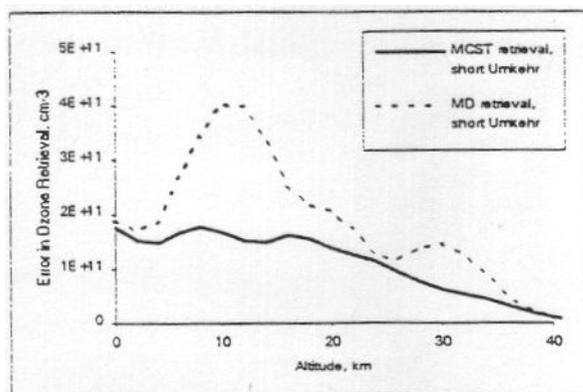


Figure 7.3.1 Comparison of errors.

HIGH LATITUDE MEASUREMENTS

8.1 Ozone measurements made at Belgrano2 and Scott Base in the Antarctic

C. Valenti, from Italy, presented the results of Antarctic ozone measurements which were taken in collaboration with New Zealand and Argentina. Data are requested from stations at -77.85 deg/ -166.67 deg (Scott Base, Brewer #050) and -77.82 deg/ 34.62 deg (Belgrano2, Brewer #035). Sometimes one of the stations is outside the polar vortex, while the other is inside. Both DS- and ZS-measurements are made, as well as FM, which are not published.

The total ozone daily mean record of 1992 shows ozone values down to 150 DU during the southern spring. The total ozone daily mean record of 1993 shows a similar pattern, with ozone values down as low as 120 DU. The greatest differences between the two stations occur due to the relative position with respect to the polar vortex. This is confirmed by TOMS satellite images. Umkehr observations are difficult to make because of the very small range of solar zenith angles.

The total ozone daily mean record of 1994 shows only the results of Scott Base, because Belgrano2 station couldn't be reached because of the ice barrier. Transportation of staff to the station by helicopter was not possible. The total ozone daily mean record of 1995, it was reported, shows Belgrano2 more often within the polar vortex than in earlier years.

The meeting concluded that regular checks with TOMS data are very important to locate the position of the polar vortex. Despite the great importance of ongoing measurements at the two stations after about 6 years of recording, Italian authorities (National Council of Research, CNR) decided to end ozone measurements with Brewer #050 at Scott Base for unknown reasons.

8.2 Focused moon measurements with Brewer #097

M. Chmelik of the Slovak HydroMeteorological Institute presented the results from the Poprad-Ganovce station (706 msl) which is situated in a mountainous region. Brewer MKIV #097 was installed in August 1993 and checked by Ken Lamb in 1995. As the intensity of reflected sunlight from the moon is very low, 40 cycles of photon sampling are needed per measurement, and precise orientation of the instrument is required. The same ETC and absorption coefficients used for the analysis of solar data (DS), are used for analysis of data (FM), sun, are used.

The meeting was informed that data for the period August 1993 to March 1996 have been processed, with a total of 43 successful FM measurements, usually at full moon ± 2 days, sometimes ± 4 days, as shown in Figure 8.2.1. The distribution of the days with FM measurements over the years shows that the best conditions for FM observations are in October, while in the season between April and July the sun is not far enough below the horizon for good FM measurements.

Each measurement campaign lasted 33 hours from 0700 to 1600 of the next day, both including sun and FM measurements, hourly means have been calculated and the missing hourly means have been interpolated by using polynomials; the daily amplitude is about 6 DU, as shown in Figure 8.2.2. This daily variation has been confirmed by the daily course of all total ozone observations made at Poprad-Ganovce, as seen in Figure 8.2.3. Diurnal variations like those seen here are often the result of low-level ozone changes such as those seen by McElroy and Kerr (1995) in the Table Mountain ozone inter-comparison, 5th Edition.

The meeting agreed that the focused moon measurement seems to be a relatively robust method to measure the total atmospheric ozone and is comparable to the direct sun routine. Success of this method is strictly limited by both the phase of the moon and good weather conditions. The daily amplitude of 6 DU derived from the observations seems to be a real daily

background amplitude caused by natural diurnal changes of total ozone, which is not affected by advective changes; the latter are usually more significant.

The meeting noted that the diurnal variation could not be verified at the station of Poprad-Ganovce itself, because the nearest surface ozone measurements are done at distances of 8 km (mountain area, about 200 m higher) and 10 km (in an industrial area).

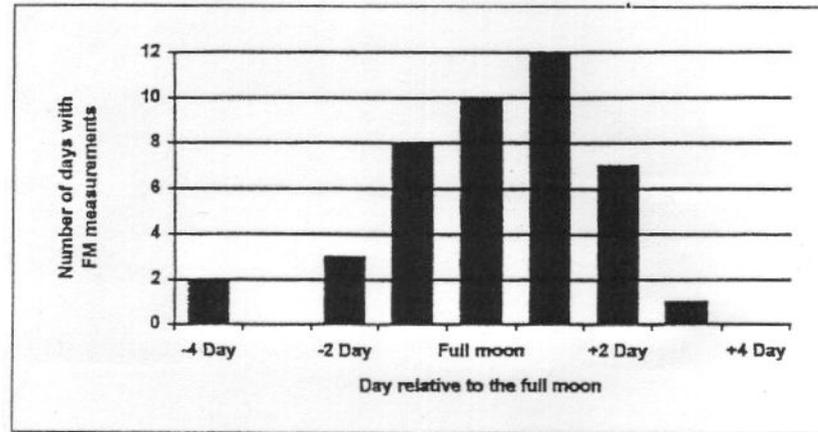


Figure 8.2.1 Distribution of FM measurements as a function of the day relative to the full moon.

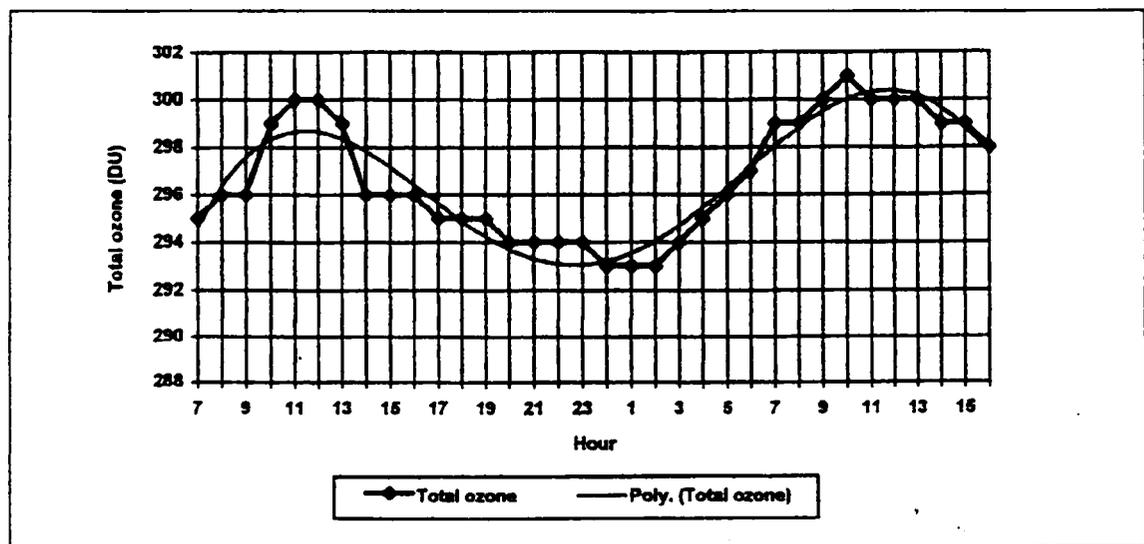


Figure 8.2.2 Daily course of total atmospheric ozone (including FM measurements).

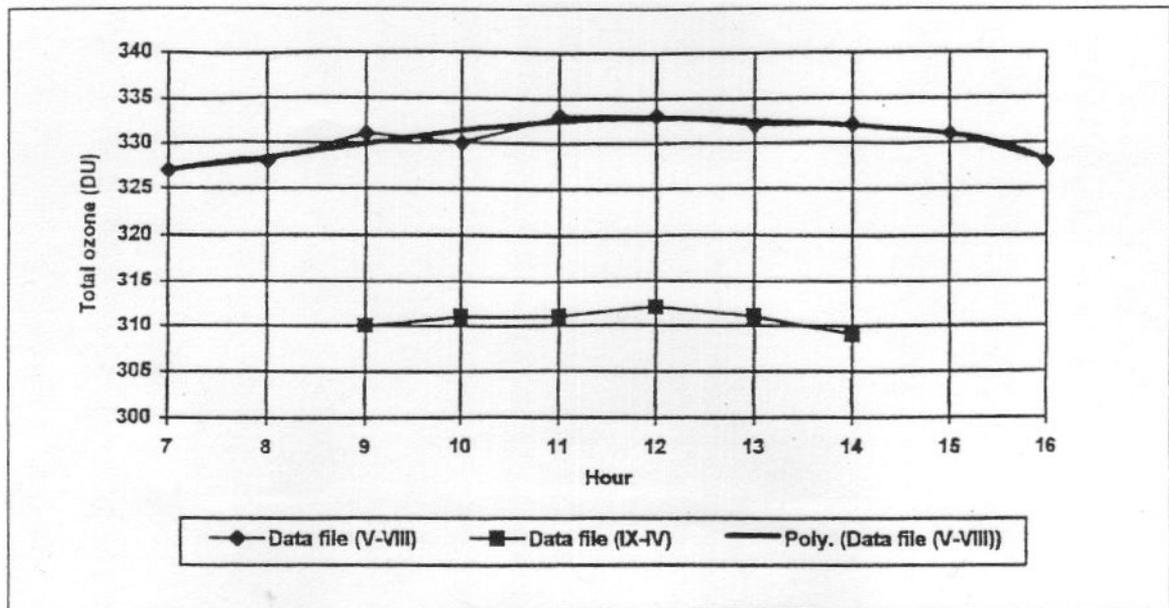


Figure 8.2.3 Part of daily course of total atmospheric ozone determined from the observations at Poprad-Ganovce in the period September 1993-February 1995.

9. NEW DEVELOPMENTS

The meeting, under this programme item discussed new Brewer control software development, design elements of the Brewer double monochromator and scanning performance of the Brewer double monochromator.

10. MEETING RECOMMENDATIONS

As part of the concluding discussions of the Brewer Users' Workshop, a number of recommendations concerning ozone measurements and the operation of Brewer Spectrophotometers under the GAW umbrella were agreed upon by the group members.

1. Recognizing the large effort to have intercomparisons and calibration trips, the working group stresses, as recommended on the report of the previous working group meeting, the need for calibration visits or intercomparisons for all instruments at least every two years.
2. Work to complete the Brewer Users' Handbook and the provision of a written guide to troubleshooting problems with the Brewer should be made available as soon as possible.
3. All types of Brewer raw data and associated calibration information should be submitted to the WOUDC as soon as possible. Data should be sent in within 60 days of being collected.
4. Data should be reprocessed and resubmitted to the data centre or the centre instructed to reprocess the raw data with new calibration information within one year of making observations.
5. It is desirable that all stations monitor the ground-level, tropospheric ozone concentrations.
6. The Brewer Users' Working Group notes, with regret, the decision of the Consiglio Nazionale della Ricerche of Italy to remove Brewer #050 from Scott Base, Antarctica. The Group feels that the closing of this station will produce a significant loss of scientific data.

7. It is recommended that Sci-Tec Instruments, Limited, the manufacturer of the Brewer Ozone Spectrophotometer, maintain an internet site for the distribution of both Sci-Tec-supported and user-contributed Brewer software.
8. The next meeting should be held in two years time, possibly in conjunction with the next Dobson intercomparison in 1998 at Arosa or in connection with a Brewer instrument intercomparison.

11. ACKNOWLEDGEMENTS

The authors would like to acknowledge the efforts of Drs. S. Palmieri and A.M. Siani and their staff at the University of Rome in providing excellent facilities for the workshop and the fine reception at the Italian Airforce Officers Club. Also, thanks to Dr. Georgio Fiocco for the tour of his laboratory facilities. Ms K. Parkhill provided assistance in the preparation of this report.

The Meeting adjourned on 25 September 1996.

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Annex A

LIST OF PARTICIPANTS

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Annex B

MEETING PROGRAMME

Monday September 23, 1996

0900 - 0930 Registration

0930 - 0945 Opening

Session 1 Opening and Introduction

0945 - 0955 Introductory Remarks by the Chairman of the Scientific Organising Committee.
[C.T. McElroy, IOC]

0955 - 1005 Remarks by the Consultation Chairman.
[J.B. Kerr, Canada]

1005 - 1020 Global Atmosphere Watch and the Brewer Network.
[J.M. Miller, WMO]

Session 2 Total Ozone Measurement

[E.W. Hare, Rapporteur]

1050 - 1105 A 12-year Analysis of the Brewer Triad Reference by the Brewer
[J.B. Kerr, Canada]

1105 - 1120 Results of Field Calibration Activities.
[K. Lamb, Canada]

1020 - 1050 *Coffee Break*

1120 - 1130 Derivation of Total Ozone Amount under Cloudy Conditions using the Brewer
Instrument.
[G. Kristiansen and A Kylling, Norway]

1130 - 1145 Calibration Problems with Brewer #037.
[E. Kyro, Finland]

1145 - 1200 More on Calibration Problems with Brewer #107.
[T. Koskela, Finland]

1200 - 1230 Measurement Programme at Valentia Observatory
[G. Murphy, Ireland]

1230 - 1430 *LUNCH BREAK*

1430 - 1445 Recent Calibrations on Brewers #040 and #072 at LKO Arosa, Switzerland, and
Their Consequences on the Data Records.
[H. Schill, Switzerland]

Session 3 Data Comparisons

[D.I. Wardle, Rapporteur]

- 1445 - 1515 Comparison of Brewer Ozone Data with Satellite Measurements.
[V. Fioletov, Canada]
- 1515 - 1545 Brewer Ozone and UV Measurements at the KNMI
[W. Wauben, The Netherlands]
- 1545 - 1615 *Coffee Break*

Session 4 UV-B Measurement

[W. Barnard, Rapporteur]

- 1615 - 1645 The United States EPA UV-B Programme.
[W. Barnard, USA]
- GAW UV-B Activities and Organisation.
[D.I. Wardle]
- 1645 - 1715 Recent UV-B Analyses of Canadian Data.
[J.B. Kerr, Canada]

Tuesday September 24, 1996

- 0930 - 0945 Sensitivity Study of the Brewer Direct Sun Ozone Retrieval Algorithm using
Numerical Simulations.
[W. Wauben, The Netherlands]

Session 4 UV-B Measurement - continued

- 0945 - 1005 Characterization of the Slit Function of the Brewer Ozone Spectrophotometer.
[J. Rives and W. Mou, USA]
- 1005 - 1025 Tests on the Reliability of the UV-B Measurements made by the Brewer MKIV
Spectrophotometer.
[F. Cappellani and C. Koechler, Italy]
- 1025 - 1055 Brewer and the Armadillo.
[V. Fioletov, Canada]
- 1055 - 1105 Synchronization at Intercomparisons.
[T. Koskela, Finland]
- 1105 - 1130 *Coffee Break*

Session 5 Data Management

[D. Turnbull, Rapporteur]

- 1130 - 1155 WOUDC and BDMS Data Management Systems.
[E. Hare, Canada]
- 1155 - 1215 Flexible Self-describing Data Formats.
[A. Kylling, Norway]
- 1215 - 1225 Automatic Remote Station Control in the Canadian Brewer Ozone Network.
[J.B. Kerr, Canada]

Session 6 Aerosols and Other Trace Gasses

[J.B. Kerr, Rapporteur]

- 1225 - 1240 The Use of Brewer Direct Sun Spectra to Determine Aerosol Optical Depth.
[A. Bais, Greece]
- 1240 - 1430 *LUNCH BREAK*
- 1430 - 1445 Brewer Ozone Spectrophotometer Aerosol Optical Depth Measurements.
[D.V. Henriques, Portugal]
- 1445 - 1500 Satellite Measurements of SO₂ and Ground-based Validation.
[J.B. Kerr, Canada]
- 1500 - 1515 Brewer #067 in the NO₂ Mode.
[G. Casale et al., Italy]

Session 7 Umkehr Measurements

[G. Koenig, Rapporteur]

- 1515 - 1530 Brewer Umkehr Software Description and Use.
[C.T. McElroy, Canada]
- 1530 - 1545 Brewer Umkehr Observations for Monitoring Ozone Trends.
[C.T. McElroy and J. Hahn, Canada]
- 1545 - 1600 Multiwavelength Method for Retrieval of Ozone Profiles from Umkehr Observations.
[N. Elansky, Russia]
- 1600 - 1630 *Coffee Break*

Session 8 High Latitude Measurements

[H. Schill, Rapporteur]

- 1630 - 1645 Ozone Measurements Made at Belgrano2 and Scott Base in the Antarctic.
[L. Ciataglia, C. Valenti, Italy]
- 1645 - 1700 Focused Moon Measurements with Brewer #097
[M. Chmelik, Slovakia]
- 1700 - Discussion

Wednesday September 25, 1996

Session 9 New Developments

[T. Svenøe, Rapporteur]

- 0930 - 1015 New Brewer Control Software Development.
[D. Turnbull, Canada]
- 1015 - 1030 Design Elements of the Brewer Double Monochromator.
[D.I. Wardle and C.T. McElroy, Canada]
- 1030 - 1100 *Coffee Break*
- 1100 - 1120 Scanning Performance of the Brewer Double Monochromator.
[D.I. Wardle and C.T. McElroy, Canada]
- 1120 - Discussion

Session 10 Closing Activities

Preparation of Meeting Recommendations and Closing of the Meeting.
[Users' handbook etc.]

Visits to the University of Rome Physics Department and Brewer #067

Annex C

Use of the Brewer Ozone Spectrophotometer for Aerosol Optical Depth Measurements in the Ultraviolet-B Region

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ABSTRACT: The Brewer ozone spectrophotometer has been mainly used for automated measurements of total ozone, SO₂ and global UV-B radiation. However, the power of this scientific instrument allows the possibility of other types of measurements in the UV-B region of the solar spectra, such as, for example, aerosol optical depth. This work shows a very simple method to retrieve the aerosol optical depth using direct sun Brewer measurements at the five operational wavelengths (306.3, 310.0, 313.5, 316.8 and 320.0 nm). The direct sun measurements are corrected with respect to the instrumental factors (dark count, dead time, temperature dependence and neutral density filter attenuation) and then with respect to the Rayleigh scattering. These radiances are also corrected for total ozone, and SO₂ absorption using the recorded results. The spectral extraterrestrial constants are obtained from a selection of the best daily Langley plots, adjusted with the calibration data (O₃ and SO₂ ETCs) and corrected for the sun-earth distance. For this method, it is assumed that the aerosol optical depth is approximately constant over the operational wavelength range and therefore only one "average" aerosol optical depth value is derived for each direct sun observation. Some interesting results obtained at Lisbon and Funchal (Madeira Is.) ozone stations during the 2nd half of 1991 show some common features, probably related with synoptic and larger scale motions.

ENVIRONMENTAL POLLUTION MONITORING AND RESEARCH PROGRAMME REPORT SERIES

1. Final Report of the Expert Meeting on the Operation of Integrated Monitoring Programmes, Geneva, 2-5 September 1980
2. Report of the Third Session of the GESAMP Working Group on the Interchange of Pollutants Between the Atmosphere and the Oceans (INTERPOLL-III), Miami, USA, 27-31 October 1980
3. Report of the Expert Meeting on the Assessment of the Meteorological Aspects of the First Phase of EMEP, Shinfield Park, U.K., 30 March - 2 April 1981
4. Summary Report on the Status of the WMO Background Air Pollution Monitoring Network as at April 1981
5. Report of the WMO/UNEP/ICSU Meeting on Instruments, Standardization and Measurements Techniques for Atmospheric CO₂, Geneva, 8-11; September 1981
6. Report of the Meeting of Experts on BAPMoN Station Operation, Geneva, 23-26 November, 1981
7. Fourth Analysis on Reference Precipitation Samples by the Participating World Meteorological Organization Laboratories by Robert L. Lampe and John C. Puzak, December 1981*
8. Review of the Chemical Composition of Precipitation as Measured by the WMO BAPMoN by Prof. Dr. Hans-Walter Georgii, February 1982
9. An Assessment of BAPMoN Data Currently Available on the Concentration of CO₂ in the Atmosphere by M.R. Manning, February 1982
10. Report of the Meeting of Experts on Meteorological Aspects of Long-range Transport of Pollutants, Toronto, Canada, 30 November - 4 December 1981
11. Summary Report on the Status of the WMO Background Air Pollution Monitoring Network as at May 1982
12. Report on the Mount Kenya Baseline Station Feasibility Study edited by Dr. Russell C. Schnell
13. Report of the Executive Committee Panel of Experts on Environmental Pollution, Fourth Session, Geneva, 27 September - 1 October 1982
14. Effects of Sulphur Compounds and Other Pollutants on Visibility by Dr. R.F. Pueschel, April 1983
15. Provisional Daily Atmospheric Carbon Dioxide Concentrations as Measured at BAPMoN Sites for the Year 1981, May 1983
16. Report of the Expert Meeting on Quality Assurance in BAPMoN, Research Triangle Park, North Carolina, USA, 17-21 January 1983
17. General Consideration and Examples of Data Evaluation and Quality Assurance Procedures Applicable to BAPMoN Precipitation Chemistry Observations by Dr. Charles Hakkarinen, July 1983

18. Summary Report on the Status of the WMO Background Air Pollution Monitoring Network as at May 1983
19. Forecasting of Air Pollution with Emphasis on Research in the USSR by M.E. Berlyand, August 1983
20. Extended Abstracts of Papers to be Presented at the WMO Technical Conference on Observation and Measurement of Atmospheric Contaminants (TECOMAC), Vienna, 17-21 October 1983
21. Fifth Analysis on Reference Precipitation Samples by the Participating World Meteorological Organization Laboratories by Robert L. Lampe and William J. Mitchell, November 1983
22. Report of the Fifth Session of the WMO Executive Council Panel of Experts on Environmental Pollution, Garmisch-Partenkirchen, Federal Republic of Germany, 30 April - 4 May 1984
23. Provisional Daily Atmospheric Carbon Dioxide Concentrations as Measured at BAPMoN Sites for the Year 1982. November 1984
24. Final Report of the Expert Meeting on the Assessment of the Meteorological Aspects of the Second Phase of EMEP, Friedrichshafen, Federal Republic of Germany, 7-10 December 1983. October 1984
25. Summary Report on the Status of the WMO Background Air Pollution Monitoring Network as at May 1984. November 1984
26. Sulphur and Nitrogen in Precipitation: An Attempt to Use BAPMoN and Other Data to Show Regional and Global Distribution by Dr. C.C. Wallén. April 1986
27. Report on a Study of the Transport of Sahelian Particulate Matter Using Sunphotometer Observations by Dr. Guillaume A. d'Almeida. July 1985
28. Report of the Meeting of Experts on the Eastern Atlantic and Mediterranean Transport Experiment ("EAMTEX"), Madrid and Salamanca, Spain, 6-8 November 1984
29. Recommendations on Sunphotometer Measurements in BAPMoN Based on the Experience of a Dust Transport Study in Africa by Dr. Guillaume A. d'Almeida. September 1985
30. Report of the Ad-hoc Consultation on Quality Assurance Procedures for Inclusion in the BAPMoN Manual, Geneva, 29-31 May 1985
31. Implications of Visibility Reduction by Man-Made Aerosols (Annex to No. 14) by R.M. Hoff and L.A. Barrie. October 1985
32. Manual for BAPMoN Station Operators by E. Meszaros and D.M. Whelpdale. October 1985
33. Man and the Composition of the Atmosphere: BAPMoN - An international programme of national needs, responsibility and benefits by R.F. Pueschel. 1986
34. Practical Guide for Estimating Atmospheric Pollution Potential by Dr. L.E. Niemeyer. August 1986
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