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THE FIFTH BIENNIAL WMO CONSULTATION ON BREWER OZONE AND UV SPECTROPHOTOMETER OPERATION, CALIBRATION AND DATA REPORTING

Halkidiki, Greece, September 1998

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

Halkidiki, Greece
September 22-25, 1998

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Chairpersons: **C.T. McElroy and A. Bais**

FOREWORD

There are now over 150 Brewer Ozone Spectrophotometers of different types in the Global O_3 Observing System. While each of these instruments has the potential to make the ozone and ultraviolet radiation measurements crucial to determining the future evolution 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 ultraviolet environment, it is essential that the data collected by individual instruments, including test and inter-comparison results, be archived in the WMO World Ozone and Ultraviolet Radiation Data Centre (WOUDC). Thus, an accurate and detailed retrospective analysis can be uniformly carried out on the data from all stations in the Global Observing System.

The Brewer Workshop meetings are a crucial part of the process of ensuring that all Brewers are properly operated and that instrument calibrations are tightly traceable to international standards.

C.T. McElroy

1998

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Official Opening - The Representative from Aristotle University of Thessaloniki

The meeting was opened by A. Bais of the Aristole University of Thessalonki. He welcomed everyone to the meeting and emphasized the importance of the exchange of scientific and technical knowledge in promoting the Brewer observing system.

I. Opening and Introduction

Introductory Remarks from the IOC and the WMO

C.T.McElroy representing both the International Ozone Commission (IOC) and the Brewer Meeting Chair, opened the meeting

“The Brewer User’s Working Group is supported by the World Meteorological Organization, the International Ozone Commission, and Environment Canada and by the local organizers, in this case the Aristotelian University of Thessaloniki. 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 series took place in 1990 in Arosa, Switzerland in conjunction with an international intercomparison of Dobson and Brewer Spectrophotometers. It is intended that the working group meet every four years in conjunction with the Quadrennial Ozone Symposium and also in the interval between at the same time as another significant event in the ozone community such as an ozone instrument intercomparison. 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 and ultraviolet radiation data and to discuss and promote the enhancement of the Brewer observing system.

There are now more than 150 Brewer Ozone Spectrophotometers of different types in the Global O_3 Observing System. The Brewer network has the capability to provide the very-high-quality data needed to help verify the return of the ozone layer to historical levels. The Brewer Workshop meetings are a crucial part of the process of ensuring that all Brewers are properly operated and that instrument calibrations are tightly traceable to international standards.

It is essential that the information required to properly operate and maintain the Brewers be available to all of those who use them in the global network. The WMO is very interested in supporting the process by sponsoring these workshops and supporting those who need financial help in order to attend them. The informal and open interchange of information between the participants in the workshop is a most important component of the process of successfully operating the global network.

Dr. John M. Miller, the Chief of the Environment Division of the World Meteorological Organization, has passed on his regards and his regret at not being able to attend this year’s meeting. He sent an email which I would like to read you. He writes:

'Greetings from Geneva,

I just wanted to pass on my greetings and best wishes for a successful workshop.

I wanted very much to attend the workshop, but we are so thin here it was just not possible. I am running a new type of workshop in Helsinki next week which I organized (with others of course) and want very much for it to be a success (WMO-EMEP Workshop on Advanced Statistical Methods and Their Application to Air Quality Data Sets).

There is no question that the Brewer system is a critical part of GAW and we need to become more involved in understanding its co-ordination. Also I had hoped that some decision would be made on a new scientific officer, now pending.'

On behalf of the International Ozone Commission I would like to express my appreciation for your attendance here and to underline the great value of the interchange of information which takes place at the Brewer workshops. And I would like to thank again the local organizers, Alkis Bais and his sister Nikki, Christos Zerefos, and their associates, who undertook the many tasks which are a part of any meeting or workshop. I would like, as well, to thank Ed Hare, Tom Grajnar and Jim Kerr of Environment Canada for the assistance they have rendered to the cause. Thank you."

C.T. McElroy

1998

Remarks by the Consultation Chairman

The meeting was opened by T. McElroy, the meeting Chairman, on September 15, 1998 in Halkidiki, Greece who welcomed all participants to the Fifth Biennial Brewer User's Workshop. He re-iterated that the WMO continues to support the workshop series. Training and calibration activities are taking place as part of the workshop for the first time. Six Brewer Spectrophotometers have been installed on the roof for the purposes of inter-comparison and for ensuring that they are operating properly. McElroy was pleased to announce that more participants would be providing talks than at earlier meetings.

With about 150 Brewer Spectrophotometers worldwide, the fastest increase in Brewer Spectrophotometer numbers is for the purpose of UV radiation research. McElroy stressed the importance of ozone and UV radiation science and of publishing papers to further scientific knowledge. Contributions of data from Brewer users to the World Ozone and UV Radiation Centre is also important for the growth of scientific knowledge. This database also facilitates international cooperative scientific assessments, which serve to drive government policy and action.

Ozone and UV radiation science, while not perfect, is based on peer-reviewed publications which result in reliable documents. The scientific method requires that measurements be repeatable and that theory and analysis be duplicated by other researchers. Therefore, scientific assessments should only be done based on publications using publicly archived data analyzed by algorithms which have been verified by the community. The ultimate goal in this regard is a publicly audited data set and calibration record. What is needed is the ability to improve data analysis algorithms and make them globally available to the community.

It is important to keep analysis revisions in step so that only comparable data are compared. Furthermore, a permanent calibration record must be maintained by the database. In order to achieve these goals, all raw data as well as calibration data must be submitted for permanent storage. There must also be an oversight committee which is tasked with certifying data analysis algorithms. Finally, the output from quality control programs must also be made available to the community.

II. Total Ozone Records

Report on the current status of total ozone measurements made using Brewer No.75 and Brewer No. 126 Spectrophotometers – D. Moore

D. Moore of the U.K. Met.. Office reported on the status of the ozone observation program in the United Kingdom. There are the two stations under the supervision of the Met office: Lerwick on the Shetland Islands with Dobsons 35, Brewer 126 and an ozone sonde facility at Camborne in the Southwest of the U.K. with Dobson 41 and Brewer 75. He showed that there have been large variations of the standard lamp test value R5 and R6 and the instrumental high voltage of Brewer 75, which are highly correlated. Additionally, R5 and R6 have also been affected, when temperature drops below 15^{o} C. A new main power supply and EHT voltage multiplier module has reduced the variability of R5 and R6.

The problem of low sun (too large µ-values) at high-latitude stations during winter season could be reduced with focused moon (FM) and focused sun (FZ) observations. Moore, however, showed, that FZ-measurements need to be improved, before they can be used, whereas FM-observations provide acceptable results.

The intercomparison of Dobsons 32 and 35 with Brewer 126 at Lerwick revealed the well-know feature of a µ-depending relative difference, but more pronounced than at Camborne. The enlarged dependence is attributed to a large µ-dependence of Dobson 35.

Total ozone measurements with two Brewers and two Dobson instruments at Arosa, Switzerland, 1996-98 – H. Schill

H. Schill representing the Swiss Meteorological Institute introduced his talk with the historical very-long-term, homogenised total ozone record from Arosa (Switzerland) over a period of more than 70 years. Observations of 5 Dobsons and 3 Brewers have been included to these data. He described their method of quality control, which comprises several steps:

i. **same day**: immediate check by the operator of the total ozone value (Dobson and Brewer) and the condition of the instrument, e.g. of the sun tracking (Brewer);
ii. **day after**: synoptic check of all single measurements, identification and rejection of outliers;
iii. **weekly**: comparison of simultaneous measurements of different instruments;
iv. **monthly:** check of the SL-test-values and possible update of the ETC's;
v. **quarterly/yearly**: comparison of the data of all instruments (1 month- and 12 months-running means);

vi. **long-term calibration**: examination and correction of calibration level with respect to a standard instrument (quadrennial on Dobsons, biennial on Brewers).

Especially the long-term comparison between different instruments, which revealed interesting patterns: the well-known annual course of the relative difference between Dobson and Brewer shows up clearly, but there is a very good agreement between the Brewers #040/#072 and Dobsons Nos. 62/101 without any systematic or periodic variation.

Five years of Ozone measurements at Belgrano station (Antarctica) – L. Ciattaglia

L. Ciattaglia from the National Centre for Research (CNR), Italy emphasised the special conditions, under which ozone observations have to be made in Antarctica (one Italian Brewer since 1992 at Belgrano II-Station, 78^{o} S). Logistics, data transfer, accessibility of station, low temperature and high wind speed, all adversely, affect normal operation. During Antarctic winter (March - beginning of September) no measurements are carried out due to the lack of the direct sun. The instrument is brought inside the laboratory to prevent damage by the extreme weather conditions.

Observations at these types of stations are very valuable for monitoring the state and development of the Antarctic ozone hole. Some data comparison have been presented with other Antarctic stations like Marambio (Argentina) and Halley Bay (U.K.). Finally the opening of a new station was announced: Lampedusa (Italy) in the middle of the Mediterranean Sea, where a Brewer MK III was put into operation in July 1998.

Ozone variations in Eastern Siberia observed by Brewer and SAOZ instruments and ECC ozonesondes, 1992-1998 – V. Dorokhov

V. Dorokhov of the Central Aeronomy Observatory, Russia presented some results obtained with Brewer #045 and other instruments like SAOZ and ECC ozone sondes in Eastern Siberia (Yakutsk, Zhigansk in Russia). Normally total ozone in this region is high (400 - 500 D.U.) at the end of winter/beginning of spring, but in the recent years except 1998 low values, less than 300 D.U., were often observed. ozonesonde-measured profiles verify, that two different processes can produce these ozone minima:

i. chemical ozone depletion inside the polar vortex with obviously reduced ozone in the lower stratosphere at the altitude of the normal ozone maximum.
ii. dynamically induced low total ozone with high tropospause level in subtropical airmasses with their typical ozone profile.

Total ozone observations at these high latitudes can often be done only with zenith sky observations (low sun) or focused moon (polar night).

Fifteen-year Brewer record at Hohenpeissenberg - A valuable supplement to the Dobson data set – U. Köhler

U. Köhler of the German Weather Service, demonstrated that it is possible to combine Dobson and Dobson-normalised Brewer measurements to create a common, total ozone data set using both Hohenpeissenberg (Germany) instruments. The main reason for doing this is to improve the quality of the record by increasing the monthly numbers of observation days because Dobson observations on weekends and holidays were stopped in the mid-eighties, whereas the automated Brewer has a more complete data set. Investigations of the systematic differences between both instruments were done to develop a method to create a Dobson-simulated data set from Brewer measurements. The following causes for the main periodic feature (annual cycle of the relative difference) were found:

i. different temperature dependence of the absorption coefficients of Dobson and Brewer. 10 K difference of the temperature in the ozone layer explains 0.6 % of the amplitude (which is about 3%).
ii. differences in the calculation of μ accounting for 0.3 % in the annual course.
i. A reduction of the amplitude of the annual oscillation can be obtained by corresponding corrections.

Other possible reasons can be airmass dependence caused by different stray light sensitivity (wider angle of view of the Dobson), temperature dependence of the ETC's or an error in the ETC of either instrument.

It was emphasised, that for reliable statistical analyses and determination of trend the data set must be long enough and as complete as possible. Trends derived from shorter data sets are most sensitive to uncertainties (e.g. in monthly means based on few observations).

Update on Brewer Calibration Activities – K. Lamb

K. Lamb of International Ozone Services (IOS) reported on the ozone calibration activities of IOS using travelling standard Brewer #017. He showed that the standard lamp R6 ratio has been stable since March 1997. During 1996 the R6 ratio had increased approximately 6% and so careful adjustment of the ETC was frequently necessary. In March 1997 the instrument was re-calibrated at Mauna Loa (MLO) observatory and the UG11 filter in front of photomultiplier tube was found to be defective and was replaced. New ETC constants and absorption coefficients were established at this time and used until March 1998 when the instrument was calibrated again at MLO.

Prior to this visit the revised micrometer drive mechanism was installed and the Hg wavelength calibration was changed to the 296.7 nm line. Enhanced dispersion testing was completed and the absorption coefficient was adjusted slightly again. The ETC constants for 1998 went down which increases ozone, however the use of proper Rayleigh coefficients reduced the ozone 3 D.U. at standard pressure. The comparison of results using both the 1997 and 1998 constants as compared to #8 (triad instrument) for day 193 in 1997 is shown in Figure 2.1. The difference is minimal at this point and surprising that the change in Rayleigh coefficients was not seen more clearing in 1998.

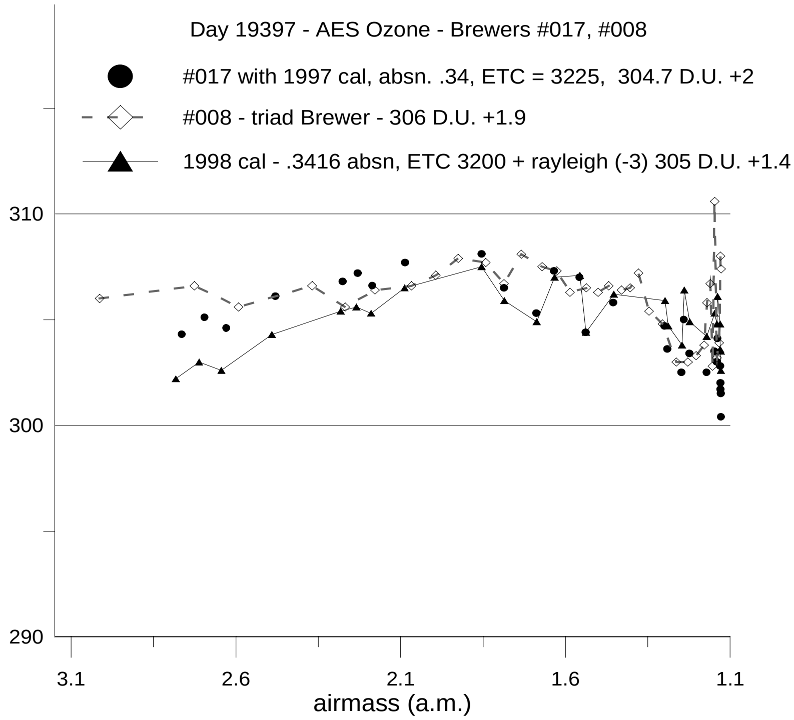


Figure 2.1 The necessary calibration of the traveling standard against the standard triad of Brewers at AES in Toronto emphasizes the importance of regular calibration checks for Brewer instruments.

However, Lamb reported that only 30-40 of the 150 sold Brewers are periodically calibrated. The initial calibration of each Brewer is done against the SCI-TEC Brewer #011, which has been checked against #017 each year.

III Zenith Sky Observations

Zenith-sky Observations at Poprad-Ganovce, Slovakia – M. Chmelik

M. Chmelik of Slovak Hydrometeorological Institute presented the results of the optimization of the zenith sky polynomials developed at the Poprad-Ganovce ozone monitoring station (WOUDC Station No. 331). The Direct Sun (DS) and Zenith Sky (ZS) observation of total ozone performed with the Brewer spectrophotometer #097 for the period 1993-1998 were used for re-calculation of the new coefficients. The DS-ZS pairs were selected to fulfil the following requirements:

(1) that the measurements were taken within 10-minute intervals (or less);
(2) total ozone was stable during the day (< 2 % variability);
(3) the airmass (μ) values were $\mu \leq 4$;
(4) and the measurements taken on the days with clear and partially blue sky condition were preferred – so called good couples.

In the first step, all observations were re-processed by means of updated ETCs based on the regular SL tests. Before the optimization, two polynomials were used for routine operation of the of instrument – the original from SCI-TEC (till June 1997, date of re-calibration) and the updated one since June 1997. The first column of the Table 3.1 shows the annual averages of the daily DS-ZS differences in percents.

Because these differences were too high in several years, it was decided to optimize the polynomials for each particular year by means of the software provided by AES. The results are given in the second column of Table 3.1. But the results were not satisfactory, mainly for 1993-1995 and 1998.

Year	Before ZS opt.	After ZS opt.	Final version
*1993	0.5	-1.0	0.5
1994	0.2	-0.9	0.2
1995	0.3	-0.7	0.3
1996	1.3	-0.9	0.2
1997	2.4	-0.8	-0.5
*1998	0.2	-0.9	0.2

*1993 from 18. August, 1998 till 31. July

Table 3.1. Differences between DS and ZS total ozone at Poprad-Ganovce, annual averages of daily means in percents

To achieve a better agreement between DS and ZS values for the entire period it was decided to keep the original polynomial for 1993-1995 and to develop new coefficients for the period January 1996-June 1997. The polynomial developed after calibration in June 1997 has not been changed, as well. This approach gave the best fit between DS and ZS total ozone (less than 0.5%), see the third column of Table 3.1.

	1993	1994	1995	1996	1997	1998
Filter #2 position 0	-1.4	-2.6	-4.5	3.9	2.1	0.1
Filter #2 position 1	5.1	3.8	4.2	8.1	7.6	6.5
Filter #2 position 2	8.2	4.5	4.9	7.8	9.5	10.1
Filter #2 position 3	9.2	4.2	3.6	7.0	7.9	8.3
Cloudiness ≤ 2	-	-	13.3	9.3	10.0	9.5
Cloudiness <3,5>	-	-	-4.1	5.9	7.0	7.4
Cloudiness ≥ 6	-	-	2.3	4.4	6.3	4.5
Blue Sky in Zenith	-	-	13.9	11.4	14.8	9.7
Cirrus in Zenith	-	-	12.5	10.7	10.1	7.9
Altocummulus in Zenith	-	-	5.8	6.2	7.0	7.5
Thick Cloud in Zenith	-	-	5.3	3.7	6.1	6.5
Weak Sunshine	-	-	6.8	5.0	5.3	4.3
Moderate Sunshine	-	-	5.3	6.3	6.9	3.7
Strong Sunshine	-	-	11.8	8.4	9.0	9.5

Table 3.2. Dependence of the mean differences DS-ZS [D.U.] on sunshine intensity and cloudiness

It is suggested that the main reason, why the results after ZS recalculation have not been improved is a dependence of DS-ZS difference on the cloudiness. This was investigated because of comments found in the b-files, created by operators during ozone measurements available since the January 1995.

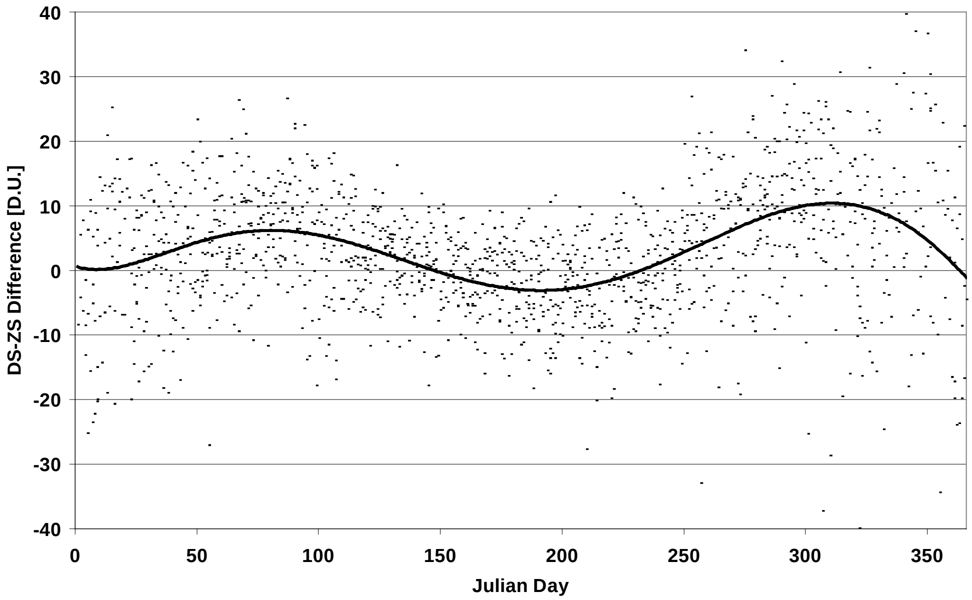


Figure 3.1. Average annual course of DS-ZC differences for B097, 1993-1998

Table 3.2 shows that increased cloudiness results in smaller DS-ZS differences. This can be only explained by a stronger influence of cloudy days in calculation of zenith polynomials than was expected. A dependence of the DS-ZS differences on amount of total atmospheric ozone has been found. The positive deviations prevail for the low (X<300 D.U.) and high (X>400 D.U.) total ozone values and no significant dependence on the relative airmass has occurred. The consequences mentioned above influence the average annual course, which is shown in Figure 3.1. The differences have a tendency to increase near the seasonal maximum and minimum of total ozone.

Zenith total O_3 observations (w/ cloud corrections) using a Brewer instrument– H. De Backer

H. De Backer of the Royal Meteorological Institute of Belgium talked about investigation of the accuracy of the zenith polynomials used for calculation of total ozone from the Brewer observations at Uccle, Belgium. DS and ZS measurements performed with the Brewer spectrophotometer #016 at this station for the period August 1983-August 1998 were used for this study.

The zenith polynomials for clear sky were developed based on the assumption that the zenith radiation intensities can be approximated by a polynomial of the second order:

$$F_0 - F = \sum_{i=0}^{2} \sum_{j=0}^{2} a_{i,j}\, \mu^i\, X^j$$

where F represents the weighted function of the logarithms of the incident radiation intensities taken at 306.3 nm (I1), 310.1 nm (I2), 313.5 nm (I3),316.7 nm (I4) and 320.1 nm (I5); F_o represents the same weighted function for the extraterrestrial intensities, $a_{i,j}$ are the regression coefficients, determined from a series of simultaneous observations of F_o-F (from ZS measurements), μ and X are relative optical path length and total ozone values from DS observations, respectively.

$$F = \log_{10}(\frac{I_2}{I_4}) - 0.5\ \log_{10}(\frac{I_3}{I_4}) - 1.7\ \log_{10}(\frac{I_4}{I_5})$$

If we define:

$$A_j = \sum_{i=0}^{2} a_{i,j}\, \mu^i$$

Then the total ozone amount X_{ZB} can be calculated from the equation:

$$X_{ZB} = \frac{-A_1 + \sqrt{A_1^2 - 4\,[A_0 - (F_0 - F)]\, A_2}}{2\, A_2}$$

The simultaneous DS–ZS pairs were selected from the database and taken for calculations as the DS-ZB once, if successive DS measurements existed within 30 minutes. The validation of the ZB polynomial developed in the way described above shows, that the ZB values of total ozone correspond to 0.0+-1.5% with DS.

For observations on cloudy zenith sky the last equation can be applied but a correction depending on the total ozone is required to account for the effect of clouds:

$$X_{ZC} = X_{ZB} + \delta_{ZC}$$

Then δZC is approximated by:

$$\delta_{ZC} = \sum_{i=0}^{2} c_i\, X_{ZB}^i$$

The coefficients, c_i are estimated by a least squares regression analysis on DS and ZS observations when cloudy measurements are treated with Eq. (4). This was done using 3388 simultaneous DS-ZS pairs selected and classified as DS-ZC if there was not an occurrence of successive DS observations within 45 minutes.

The ZC measurements corrected using these cloud corrections correspond to 0.3+-2.0% with DS observations – see Figure 2. Comparison of daily means of DS and ZC total ozone values gave similar results of 0.2+-1.5%. An additional uncertainty (at the 95% level) of ZS observations with respect to DS measurements has been found to be 3-4%.

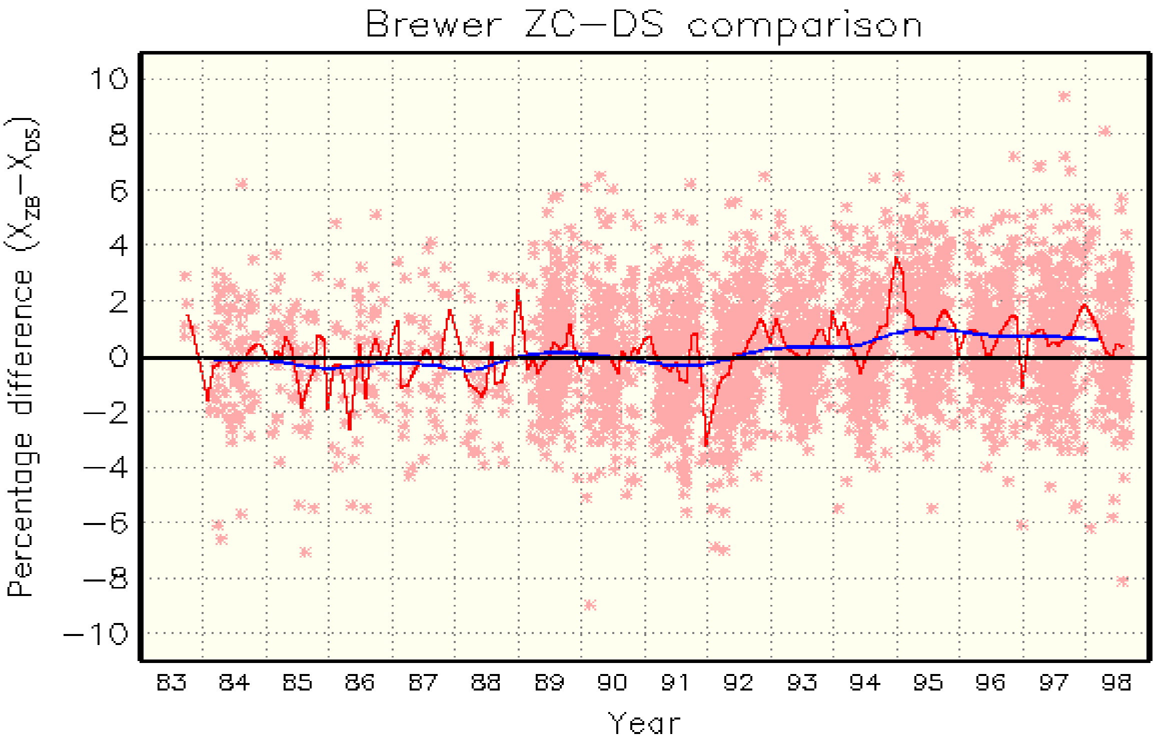


Figure 3.2. Comparison of ZC versus DS total ozone values after cloud correction for Brewer #016 – percentage differences.

IV Station Activities

Total ozone, UVB and Umkehr time series at Izaña – A. R. Marrero

A.R. Marrero from the National Meteorological Institute of Spain at Tenerife began his presentation with a description of the Izaña station, which has a continuous observation program involving ozone and UV measurements. Instruments include two Brewers: a MKII and a MKIV, which began operation in May 1991, as well as a Yankee (YES) broad-band instrument for global UV radiation monitoring. The national network of Spain has a total of five Brewer instruments in operation. Along with the ground-based measurements, vertical soundings using ECC ozonesondes are laucnhed routinely from the nearby city of Santa Cruz. Brewer number 33 is used to normalise the total ozone data calculated from the ozonesonde flight data. Ancillary data collected at the Izaña station includes optical depth and visual observations such as sky conditions.

Daily total ozone values are compared with TOMS and a time series of total ozone from the Izaña station is shown in Figure 4.1, indicating a downward trend. A plot of the SL R6 test for Brewer #33 for years 91-98 was presented along with a comparison of daily average ozone values compared with TOMS Version 7 time series monthly mean data for the years 1991-95. A scatter plot of difference between the Brewer and TOMS data is shown in Figure 4.2.

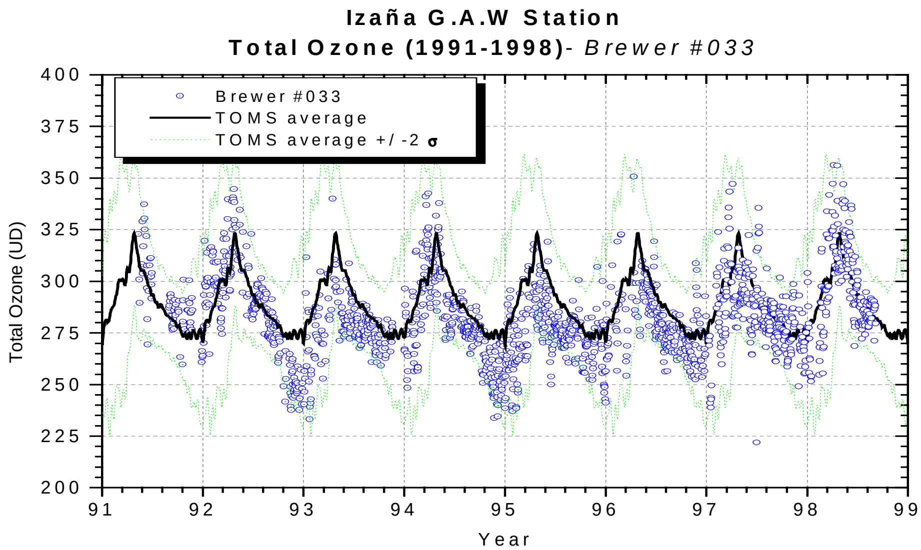


Figure 4.1 Time series plot of Brewer versus TOMS data at the Izaña station.

ECC ozonesonde profiles are routinely compared to Umkehr profiles, derived from Brewer data. And in terms of UV studies, calibration facilities are currently being built at the station, with the intention of having the UV calibrations referenced mainly to different lamp measurements, especially during inter-comparisons. Main references are available for the years 1993, 1995, 1996 and 1997. Lamp tests (using a 50 Watt source) are performed on a weekly basis, when suitable meteorological conditions are available. Comparisons between the 50 Watt lamps and 1000 Watt lamps shows a drift in the 50 Watt output. A temperature dependence is suspected along with noise detected in outdoor calibrations due to the proximity of a nearby TV antenna.

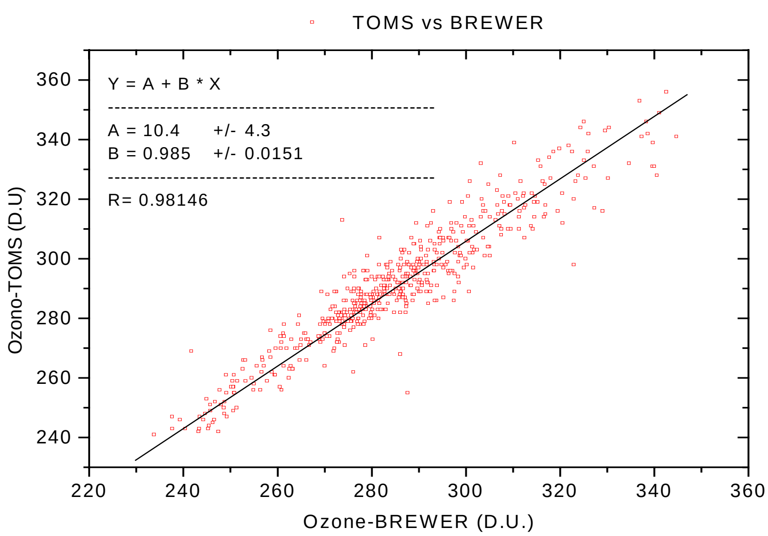


Figure 4.2 A scatter plot of the TOMS versus Brewer monthly mean data for the years 1991-95.

Brewer Measurements at Mauna Loa Observatory – J. Kerr

J. Kerr from Environment Canada posed the question: “Why do Canadians want to operate a station at MLO?” And the answer is to routinely perform Langley plots and so an instrument permanently located at the MLO site can continuously provide data about sky and atmospheric conditions thus yielding a continuous record of extraterrestrial constant information. The operation of the MKIII Brewer #119 at MLO is controlled in Toronto by means of the communication software package, PC Anywhere. ETC values can be derived each day (a procedure which has been done since early 1997) with the only interruption being downtime resulting from a lightning strike. The ozone values are compared to the ETC values along with the SL values. Figures 4.3 and 4.4 show the ETC values from Brewer #009 for the wavelengths 306.3 and 320.0 nm respectively.

A camera mounted on the Brewer, continuously monitors the sky (every 10 minutes), producing a series of sky images. These images indicate the movement of the sun throughout the day (which includes the Umkehr observation) and records the presence of any cloud cover.

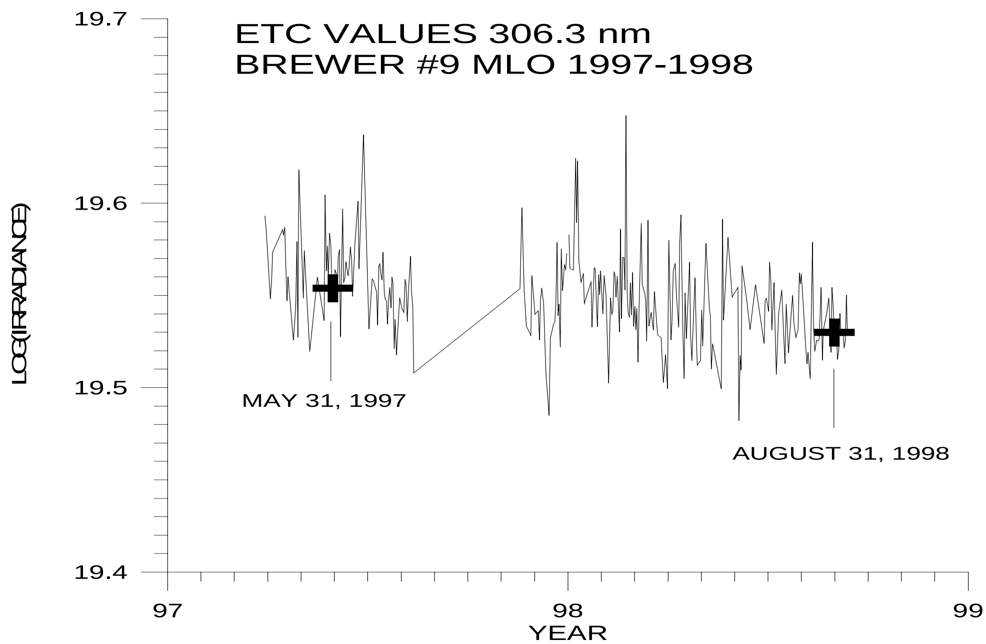


Figure 4.3. Record of ETC values ($\log_e$ of irradiance) for Brewer wavelength #1 (306.3 nm) from March, 1997 to August, 1998. Day-to-day variability is about 1%.

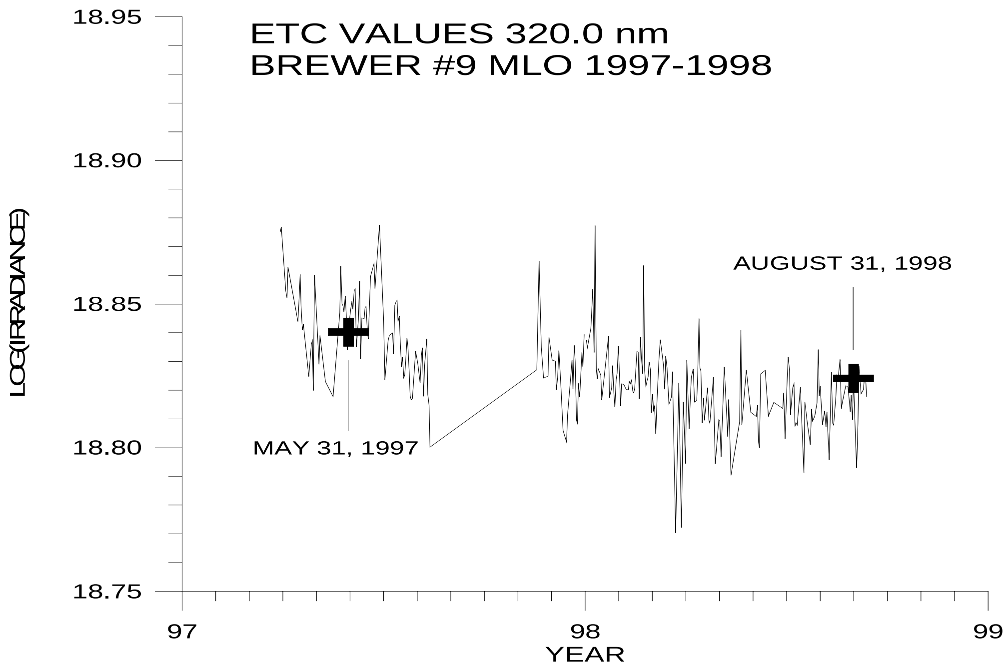


Figure 4.4. Record of ETC values for Brewer wavelength #5 (320.0 nm) from March, 1997 to August, 1998. Day-to-day variability is about 1%.

Figure 4.5 shows the Langley plots generated for Brewer wavelengths 1 and 5 for two separate days: May 31, 1997 and August 31, 1998.

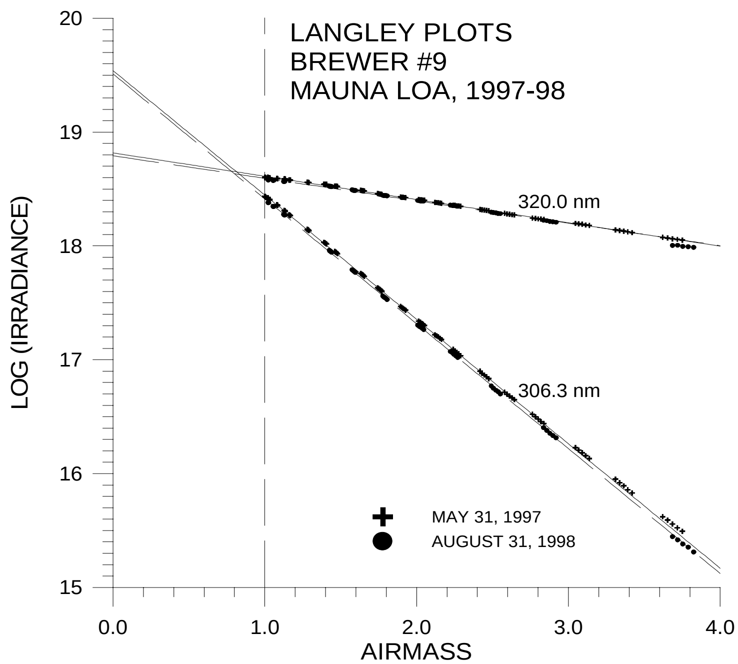


Figure 4.5. Langley plots for Brewer wavelengths #1 and #5 for May 31, 1997 and August 31, 1998.

The proximity of the MLO station to two active volcanoes had caused problems for Brewer #009 in 1998 with respect to SO_2 measurements. All-sky images illustrated the effect of SO_2 emissions where the "milky" or hazy appearance toward the sun indicated the post-volcanic conditions.

V New Instrument Operation & Design Modifications

Revised Grating Micrometer Drive Mechanisms – J. Groebner

J. Groebner from Environment Canada began his presentation with a description of the improved wavelength accuracy of the Brewer spectrophotometer over the spectral range (280-360nm) resulting from a new grating drive mechanism and a new dispersion function derived from the Brewer geometry. With the new mechanism, a series of repeated measurements of the positions of spectral emission lines have yielded standard deviations less than 0.0003 nm (equal to 0.3 pm or 0.04 motor steps) even when a wide wavelength range is traversed between successive measurements. With a thermally compensated version of the new mechanism, wavelength settings change with temperature by 0.4 pm K^{-1} or less. A temperature-induced, fractional spectral stretching of $1.2x10^{-5} K^{-1}$ has been identified.

A comparison between the new and the standard dispersion functions applied to the same spectral line data (for Double Brewer #119) shows a two-fold improvement in the accuracy of the fit. The new function is less prone to wavelength extrapolation error and it can include residual terms arising from periodicity's in the drive mechanism. Spectral line data from ten different Brewers equipped with new or standard drives have been analyzed using the new function. The performance of the new drives, judged from the residuals in the dispersion functions, is comparable to that of the best of these standard drives and much better than the majority. The four new drives give the following RMS residual values: 5.4 pm, .6 pm, .3 pm and 2.4 pm.

VI Data Management and Software Development

Supporting software tools for Brewer data management – K. Vanicek

K. Vanicek from the Czech Republic Hydrometeorological Institute, began his presentation with some basic station information about the Hradec Kralove Solar and Ozone observatory. There is a Brewer MKIV, #098, which has been measuring ozone and UV since 1994 and a Dobson instrument #074 which has been operational since this 1960's. Brewer #098 was re-calibrated by comparison to the traveling standard #017 operated by Ken Lamb (IOS) in 1995 and 1997.

New software tools for managing and analysing the Brewer data have been developed at the Solar and Ozone Observatory. It consists of 4 different subsystems:

Initialization
It is used to uniquely distinguish the measured and processed data. It contains:

- The identification of the measuring station.
- The identification of the instrument (Brewer number)
- Definitions of the data directories where data is stored.
- Ozone, SO_2, NO_2,etc… absorption coefficients.

- The extraterrestrial reference values (ETC's)
- The UV-response files
- Zenith sky coefficients.

Updating.
It makes possible to update and change various parameters that are used to obtain processed data from the measured data (raw data).
- Extraterrestrial constants are updated relative to results from the internal standard lamp. (SL tests)
- UV response calculation from standard lamps.
- Local Zenith sky coefficients.

Listing.
It is possible to extract various data types from the measured data. Criteria are time and dates, type of observations, number of observations, filters, etc…:
- Time frame, start-end
- Type of data
- Type of observation (DS, ZS,…)
- Filters (statistics)
- Output to Display, printer, files

Also it is possible to output individual observations, Daily means and monthly means.

Export data
Various data formats are supported and different export methods are available.
- data to selected directories on the Brewer PC or to a different PC
- Produce WMO monthly reports.
- CREX Messages to WMO/GTS. This allows to have total ozone data available in real time around the whole world.
- Send data to selected ftp servers.
- Produce daily and monthly graphs.

The UV and ozone data management portion of the software is completed and the package has been installed on the Brazilian network of Brewer instruments for testing purposes.

Open questions:

1) What kind of data management software should be included in the standard SCI-TEC controlling software.
2) Is SCI-TEC or WMO willing to assist in these activities.
3) Ask the Brewer Working Group on possible improvements and suggestions.

This package is not yet available and will require further testing before it is released.

Update on the BDMS and WOUDC Data Archives – E. Hare

E. Hare of Environment Canada and the WOUDC reported on the current status of both the Brewer Data Management System (BDMS) and the WOUDC archive. The number of WOUDC stations has been consistently increasing in the last several years with more than 350 registered stations. The BDMS archive contains data from 46 out of a possible 150 Brewer instruments operated worldwide. There are presently 12 different countries that are submitting Level 0 (primary) Brewer data to the BDMS.

The main clients who retrieve data from the WOUDC are: NASA, International Research stations, Trend panels and Universities. E-mail requests can be grouped into different sectors:

42% Education (Main requests from USA, Canada and Europe);
33% Government institutions (Europe, USA) and
23% Commercial (USA, Russia).

In terms of data submission, the WOUDC has introduced a new file format for data submission and retrieval called the “extended Comma Separated Values” or extCSV format. This format is to be used for the submission of Level 1, processed data and that the Brewer B and UV files will continue to be submitted in their original, Level 0 file formats for storage in the BDMS archive. Each data originator/agency are assigned a personal ftp account to submit his/her data. The WOUDC requests that a scientific sponsorship statement or “data passport” accompany the initial data submission. Certain data sets are protected by data protocols signed by each data originator giving the WOUDC instructions on the posting of each set of data such that only selected individuals/institutions can have access to some of the data with permission by the data originators.

SCITEC Update - R. Rösemann

R. Rösemann representing SCI-TEC/Kipp and Zonen Incorporated informed the group that in 1997, SCI-TEC and Kipp&Zonen amalgamated and are now operating as a single company with two component divisions. In terms of maintenance and sales, SCI-TEC will be responsible for USA/Canada and Kipp &Zonen will be responsible for the rest of the world.

In July 1998, the President R. Berman resigned and the company is now under new management. SCI-TEC and Kipp&Zonen are now ISO 9001 certified companies with a product range that includes solar radiation instruments, UV and far infrared instruments. Special design projects are now being undertaken by the Kipp&Zonen component of the company.

VII UV-B Measurement

The Ozone and UV record in Canada – J. Kerr

J. Kerr, representing Environment Canada/AES, presented an update of the Canadian Ozone and UVB monitoring network. AES acts as the calibration center for WMO for the global Brewer network for total ozone and maintains the Brewer Triad, which is used for transferring the calibration to a few travelling standard Brewer spectrophotometers. He described the operation of the calibration center, which comprises three independently calibrated Brewers and Dobson instrument No. 77. In addition, some of the Brewers that operate at AES have participated in inter-comparison campaigns to verify their good calibration status.

Total ozone over Canada is declining with a rate of about 4-5% per decade. This decline is evident when the ozone deviations of the last decade are compared with those of the pre-1989 period. From the analysis of the existing data records it appears that the ozone and UV change with time for clear skies is similar in magnitude to that observed under cloudy conditions. Statistical comparisons between ozone and UV irradiances were shown for different wavelengths (e.g. Figure 7.1). The results in Figure 7.1 illustrate the relationship between UV irradiance and ozone for a zenith angle of about 45^o and at wavelengths of 300 nm and 324 nm. A more complete relationship over all wavelengths between 290 nm and 325 nm and for solar zenith angles between 25^o and 90^o has been quantified with a statistical model reported by Fioletov, et al., GRL, **24**, 2997-3000, 1997. The statistical relationship is used as a quality check on the Canadian data to identify measurement problems. It is also possible to determine total ozone from the UVB spectral irradiance data.

Snow cover has a large effect on surface UV irradiance and this is evident in Resolute (Figure 7.2) where the spring-time UV is higher than the expected for clear skies and is reduced later in the year, when the snow melts. The enhancement of UV due to snow varies between different stations ranging form 8% in Halifax to about 39% in Churchill. The UV data collected at the Canadian stations were used to derive climatologies of UV Index. From the same data set it appears that UV in Toronto is increasing in the period 1989 through 1997.

Finally, Kerr presented to the participants a recently published report of AES entitled “Ozone and UV in Canada”, which is available upon request.

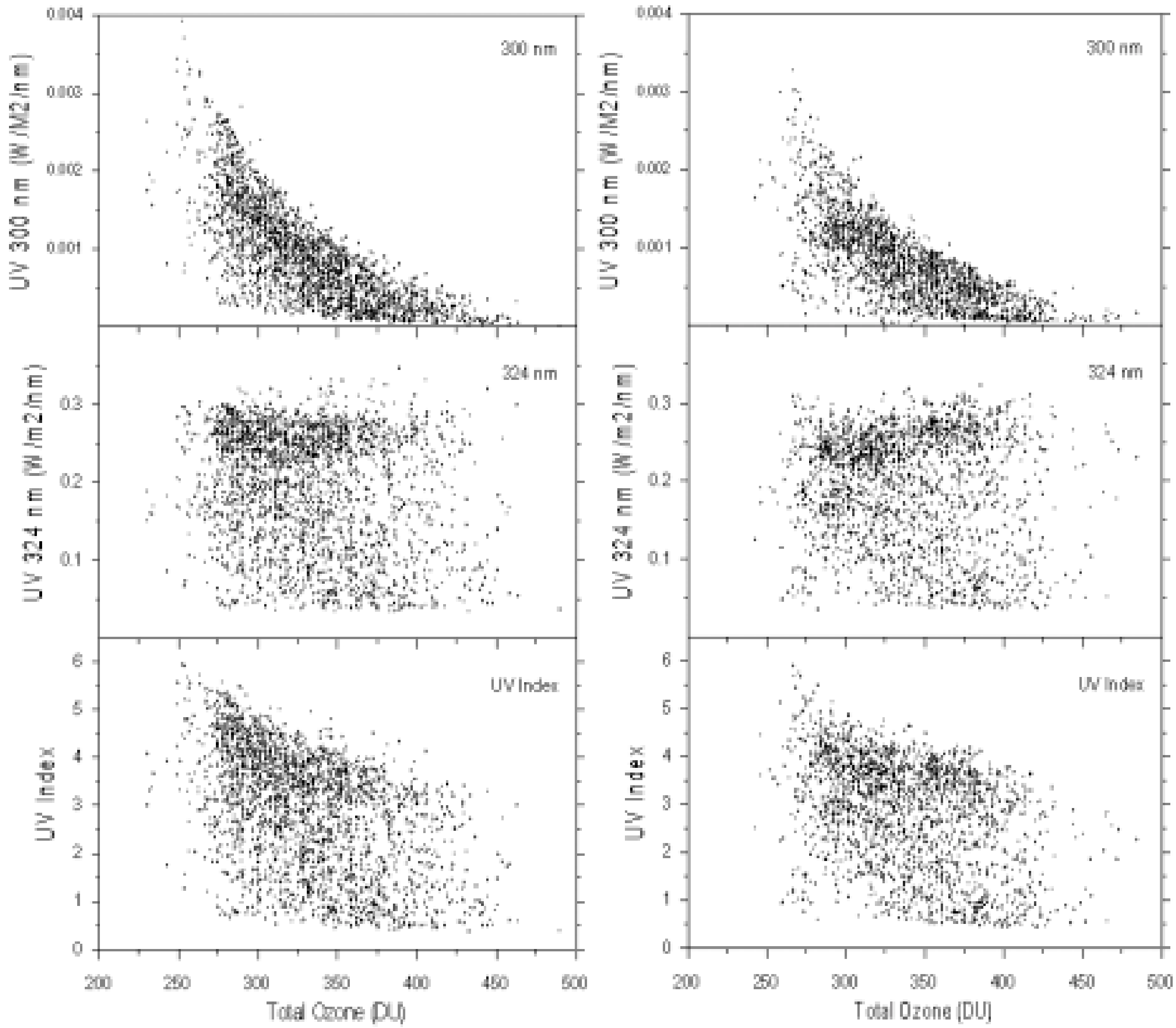


Figure 7.1: Influence of total ozone on irradiance measurements in the UV-B at 300 nm (top), in the UV-A at 324 nm (middle) and the UV Index (bottom) for Toronto (left) and Montreal (right). Measurements are for a solar zenith angle of about 45°. Results from Toronto and Montreal are very much the same.

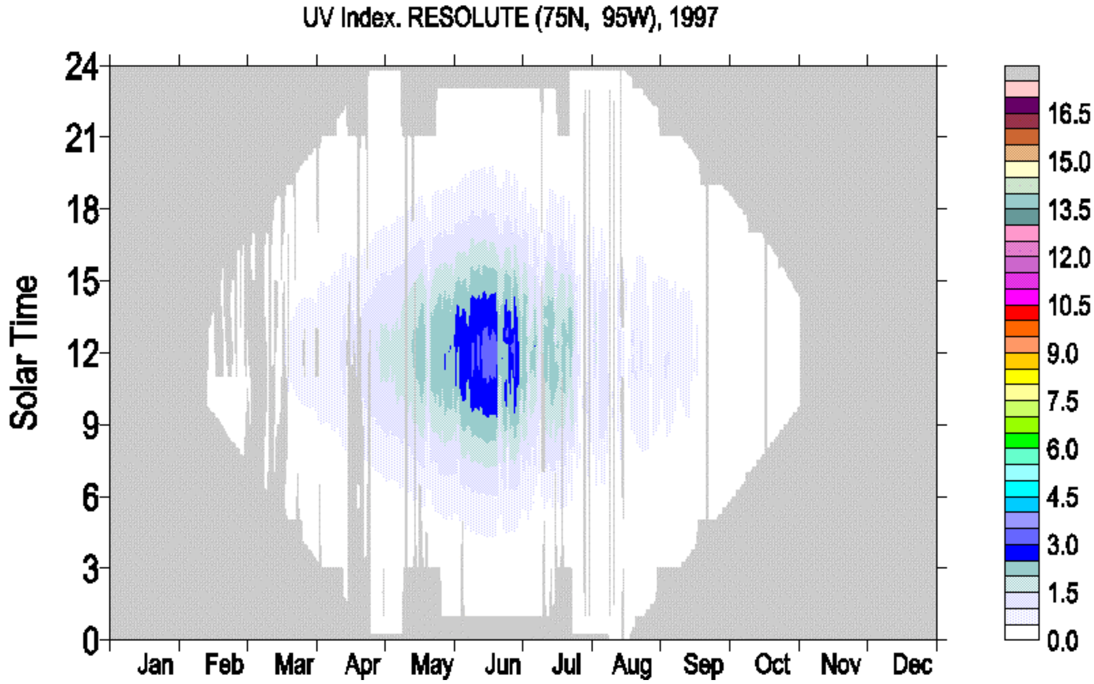


Figure 7.2: Yearly summary of UV Index values for Resolute for 1997. The diagram shows the UV Index value as a function of time of day and time of year. Resolute is in darkness during the winter and continuous sunlight during the summer. The values are higher until mid-June because of the enhancement due to snow on the ground.

Homogenizing The Spectral UV Data Of Brewer #107 – T. Koskela

T. Koskela from the Finnish Meteorological Institute presented the operational status of Brewer #107, which is installed in Jokionnen, Finland. He presented the variation of the UV response of the instrument at different wavelengths during a period of about 2.5 years, which varied by about 10% peak to peak. These results are based on measurements of five 50-Watt and three 1000-Watt lamps (Figure 7.3). Three of the 50-Watt lamps are used every month and two of them once a year.

Brewer #107 took part in the European UV intercomparison at Ispra in 1995 where it was in agreement with Brewers #086 and #107 to within 5%. The UV calibration that was done in Ispra was used a starting point for the calibration of Brewer #107. In addition, Brewer #107 participated in the NOGIC 96 and SUSPEN campaigns, in which its results were close to the comparison reference spectra.

Koskela also presented a comparison of spectral measurements performed by a few different instruments during the NOGIC 96 campaign and showed how the agreement can be improved when the spectra were corrected according to the results derived from lamp spectra measured by these instruments. He mentioned that occasionally some spikes appear in the lamp spectra, which they remove by using the 'spikes' software, with was modified to handle lamp files.

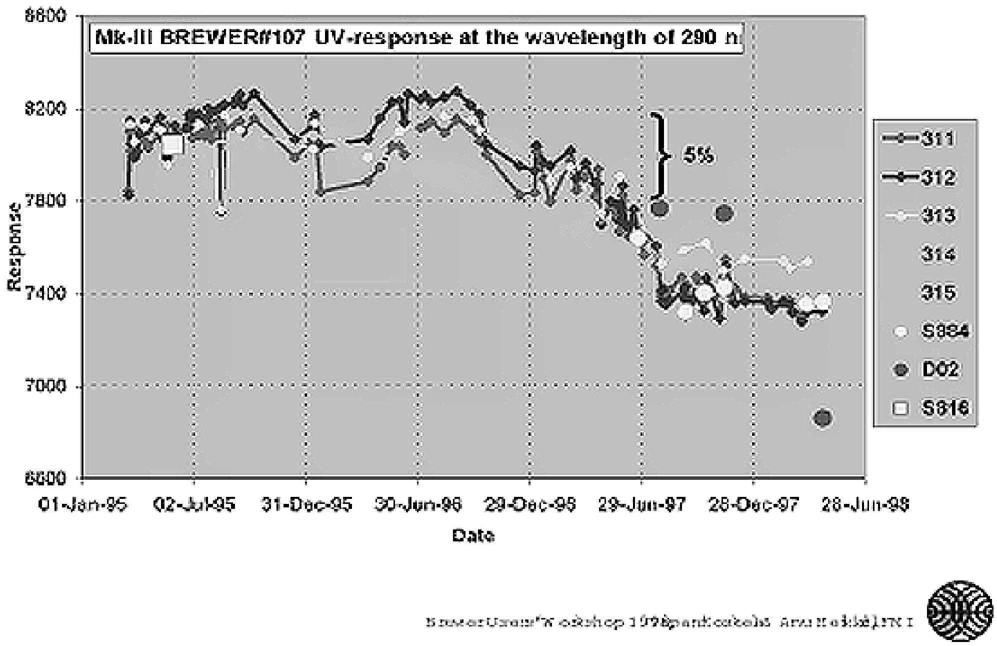


Figure 7.3 A time series of the response for Brewer #107.

Eight years of Brewer UV-B measurements at Sodankyla, Finland - K. Masson,

K. Masson from the Finnish Meteorological Institute presented results from UV-B measurements performed at Sodankyla, Finland. Particularly she talked about the Quality Control of the measurements and the analysis of the 8-year UV-B time series. She presented global UV changes at SZA of 64°±1°during this period, following the methodology described in Zerefos et al. 1995 (GRL). The time series was separated into two parts: one at high albedo conditions (due to snow cover) and the second under low albedo. It appeared that the correlation between ozone and UV-B wavelengths is more significant in the high albedo conditions. The UV time series at 305 nm and 325 nm is shown in Figure 7.4, together with the corresponding ozone series.

It is notable that in springtime, UV has increased, due to the low ozone values occurring at high northern latitudes during the last 8 years. From linear regressions on these time series, it appears that ozone has decreased by 13% during the eight-year period and consequently UV has increased by about 60% at 305 nm and between 3 and 10% at 325 nm.

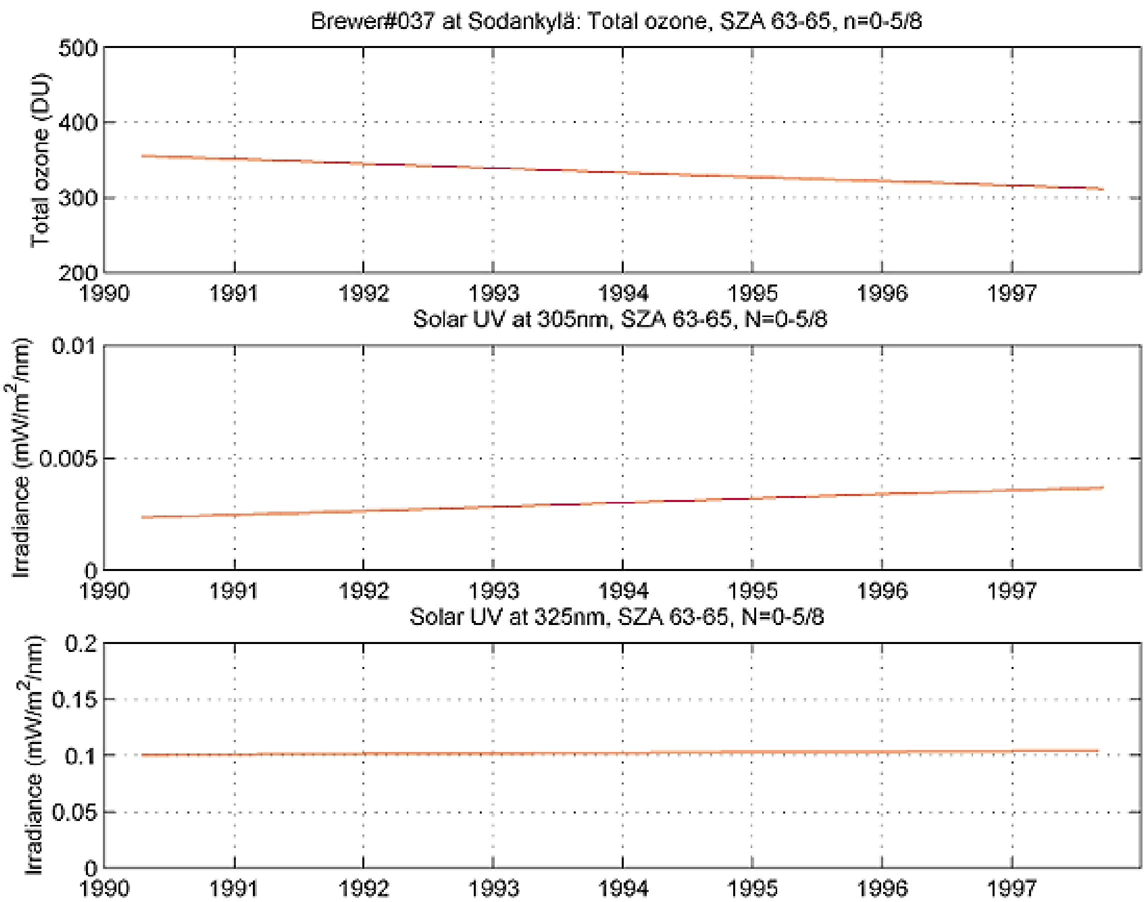


Figure 7.4 The UV time series at 305 nm and 325 nm is shown together with the corresponding ozone series.

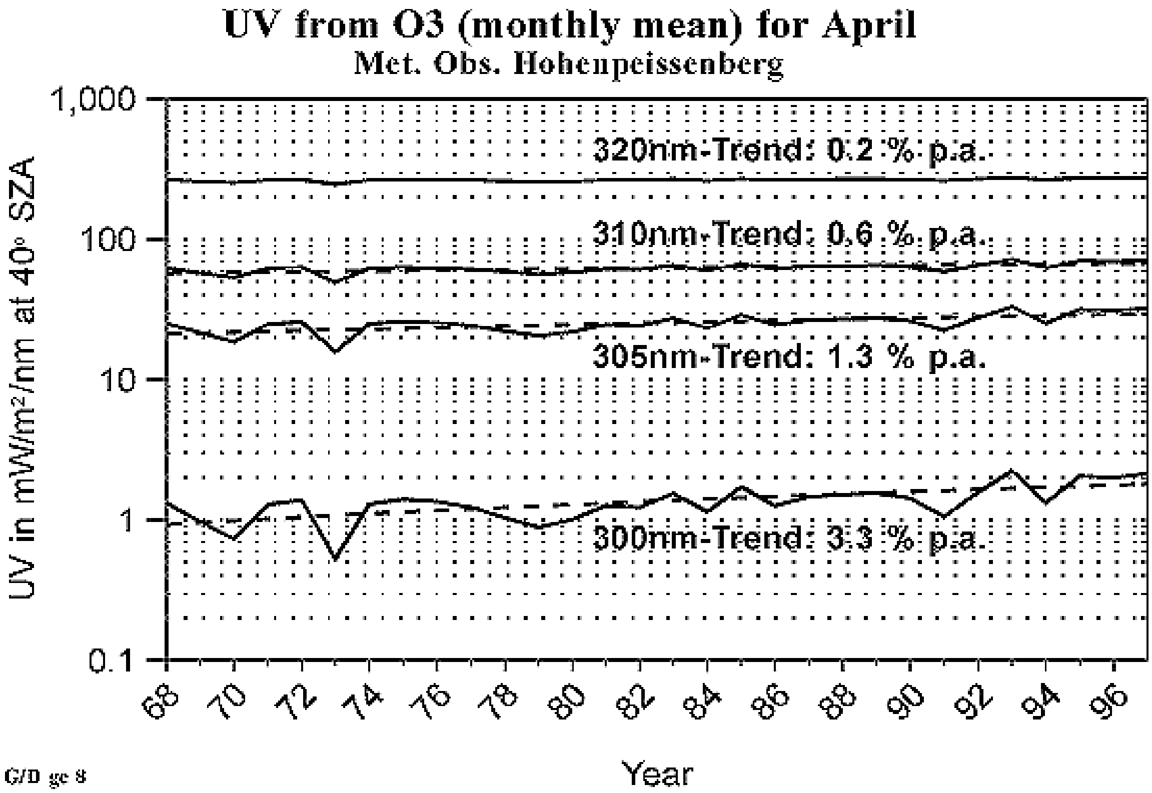
Eight years of regular Brewer UV-observations at Hohenpeissenberg: instrumental and climatological results – U. Köhler

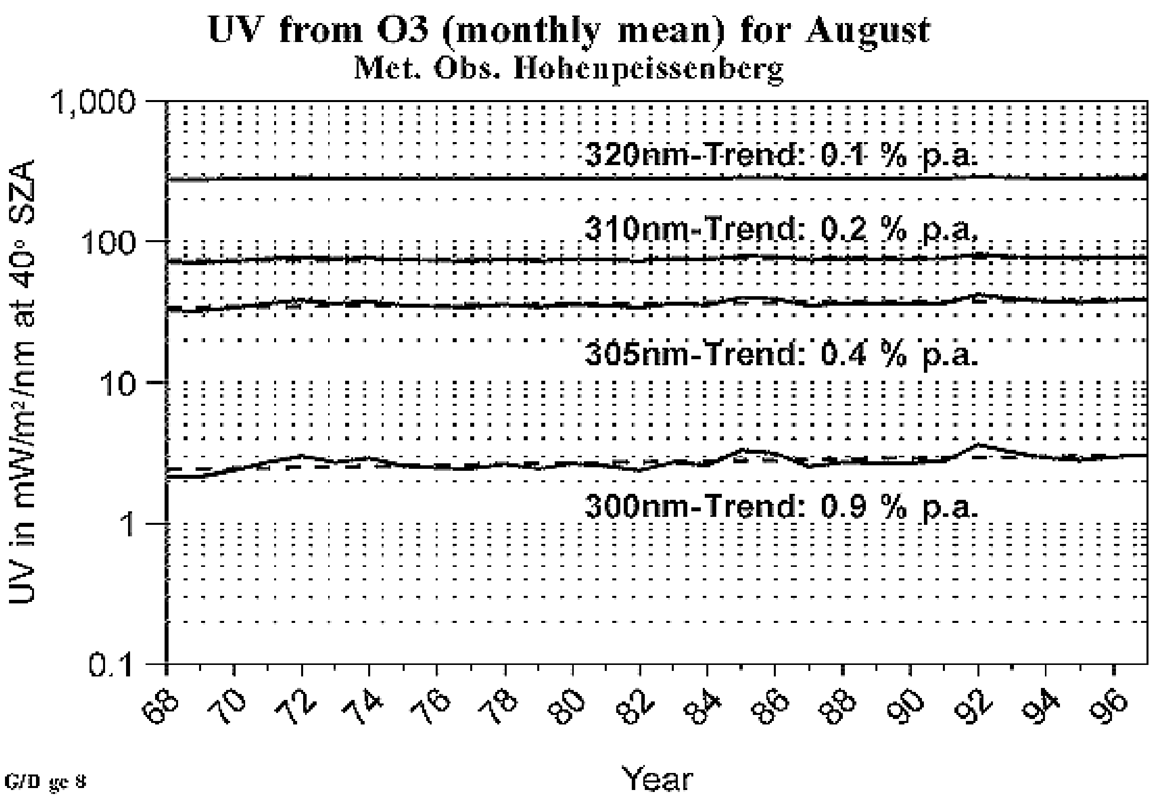
U. Köhler from the Germany Weather Service showed climatological results from eight years of UV measurements at Hohenpeissenberg, Germany, and he described the instrument behavior during this same period. The UV time series consists of half-hour spectra collected since 1991 while in the previous period only sporadic measurements were collected. The instrument calibration was maintained by the use of various types of lamps, including tungsten and spectral lamps. He described that since 1991 they have been using a generalized calibration function for the instrument, and each time a lamp measurement is performed, the residuals from this generalized function are calculated and used to adjust the calibration of the UV spectra.

The cosine response of the instrument was determined in the laboratory and this measurement uncovered a prism misalignment that caused correction values larger than 1 for values at incident angles close to normal. After properly adjusting the prism this effect disappeared.

Their instrument was compared with the Bentham spectroradiometer of the University of Innsbruck, showing good results and its measurements were also compared successfully with calculations of the STAR

Figure 7.5 The calculated UV trend at 300 nm for April and for August at Hohenpeissenberg Observatory.





model of the University of Munich. The application of the usual stray light correction improved significantly the comparison results at shorter UV-B wavelengths.

Köhler then demonstrated the effect of Pinatubo eruption on UV in Germany, by showing a comparison between measured clear-sky values and the expected irradiances calculated with the STAR model. UV in April 1993 was about 30% higher compared to the average of years 1990 and 1994. He also showed the relations between ozone and UV at various wavelengths at constant SZA of 40°. From these data regression lines were derived to describe the ozone-UV relations.

The long-term ozone series at Hohenpeissenberg allows the calculation of trends, which from 1967 to 1997 appear to be –10% for stratospheric ozone and +45% for the ozone in the troposphere. The trend in total ozone is about -0.3% per year. From the ozone trends, the calculated UV trend at 300 nm is about +3.3% per year for April and about +0.9% per year for August, without taking into account the stratospheric noise (Figure 7.5).

Finally, he showed some model estimates of erythemal UV irradiance at various locations, from which it appears that UV levels at Hohenpeissenberg are higher to those at Naples, Italy, mainly due to the altitude difference.

Calibration of Brewer #088 for UVB measurements - G. Murphy

G. Murphy of the Irish Meteorological Office presented the UV calibration facility that was recently installed for the calibration of the Brewer operating at the Meteorological Service in Ireland. The facility uses 1000-Watt standards of spectral irradiance the operation of which is controlled automatically by a computer-based system. The system monitors continuously the lamp current and voltage, the temperature of the shunt and the ambient temperature and uses these data to maintain constant current on the lamp. The whole system is now under testing and Murphy presented some preliminary results about the dependence of the lamp irradiance on the lamp current. These results suggest that a reduction in the current by 0.1% results to a reduction in the UV-B irradiance by 1.5%, which becomes weaker at higher wavelengths. He also showed some preliminary results on the temperature effect on UV measurements.

The response of their Brewer has changed by about 2-5% in the last 3 years in the UV-B region, while the change in the UV-A is insignificant. The future plans include the determination of the slit function of the instrument, the improvement of the wavelength calibration and the determination of the cosine response, as well as the correction of the past data based on the lamp information and their submission to WOUDC.

Cosine correction of global sky measurements using a Brewer Spectrometer - A. Bais,

A. Bais of the Aristotle University of Thessaloniki presented a methodology for correcting the global UV spectral measurements of Brewer MKIII spectrophotometer #086 for the error introduced by its non-ideal cosine response. He presented first the theoretical background of this method and concluded that the determination of the cosine correction factor requires that the cosine response of the instrument is measured in the laboratory and the direct-to-global irradiance ratio is known. In addition, the assumption that the diffuse sky light is isotropic is made. The direct-to-global ratio can be measured by sampling during a global scan and the direct component at a few wavelengths, from which the ratio at any wavelength can be calculated by fitting a suitable polynomial (Figure 7.6).

Depending on wavelength and on the aerosol loading, the cosine correction factors range between 2% and 7%. The uncertainties involved in the calculation of these correction factors were found to be relatively small, ranging from about 0.2% to 2%. The uncertainties at each step are shown in Table 7.1:

Uncertainty in the determination of the cosine response	1.0% - 2.0%
Error due to the asuumption of isotropic diffuse light (Low aerosol)	0.5% – 2.0%
(High Aerosol)	< 0.3%
Uncertainty in the determination of direct to global ratio	< 0.5%

Table 7.1 The uncertainties involved in the calculation of the correction factors.

At the end, Bais showed comparisons of global spectral UV measurements with and without the application of the cosine correction with model calculated spectra and the application of the method to one other Brewer instrument during the SUSPEN campaign, which was held in Nea Michaniona in July 1997. Both comparisons demonstrated the improvement of the measurements and therefore the suitability of the method. This methodology is applicable also to other Brewers, but a suitable neutral density filter must be used for the direct measurements according to the sensitivity of each instrument.

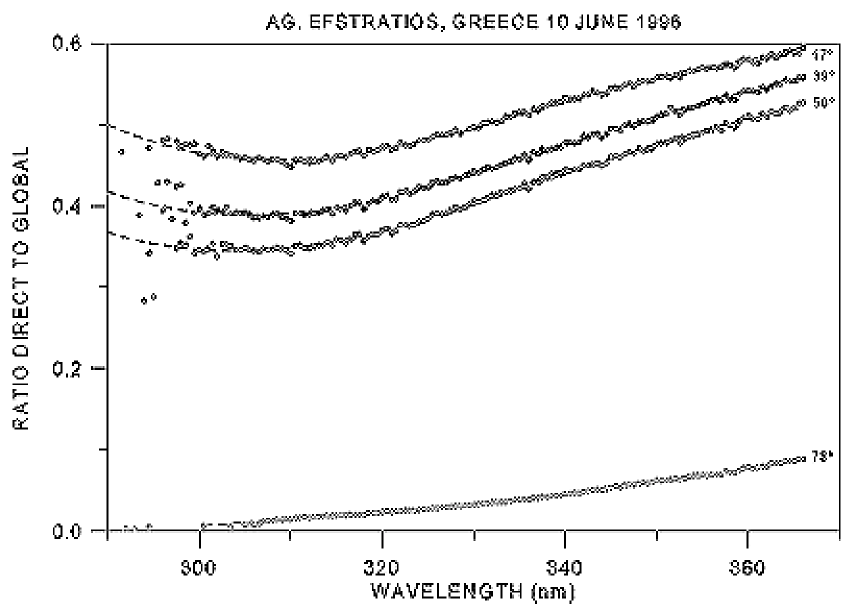


Figure 7.6 The Direct to Global ratios.

Total ozone derived from irradiance measurements with Brewer #042 - A. Dahlback and F. Tønnesen]

A. Dahlback from the University of Oslo, presented a methodology for calculating total ozone from global UV spectra. This method has been implemented as a Brewer routine (GI) and soon will be included in the standard Brewer software. Comparison of GI-derived total ozone with DS measurements (Figure 7.7) reveal a significant zenith angle dependency of about 10%, which however disappears when GI ozone is compared with TOMS total ozone.

Plots of the GI-derived total ozone at Oslo were shown as a function of solar zenith angle, for various ranges of total ozone. It is evident that the method works satisfactorily for zenith angles up to about 80-85 degrees. To exclude the cloud effects on the ozone measurements, a cloud transmission is calculated as the ratio of irradiance measured with the GUV instrument to the irradiance derived from clear-skies model calculations. The GI- derived ozone is acceptable only when the cloud transmission is higher than 0.2. This limit is confirmed by comparisons with TOMS observations (Figure 7.8).

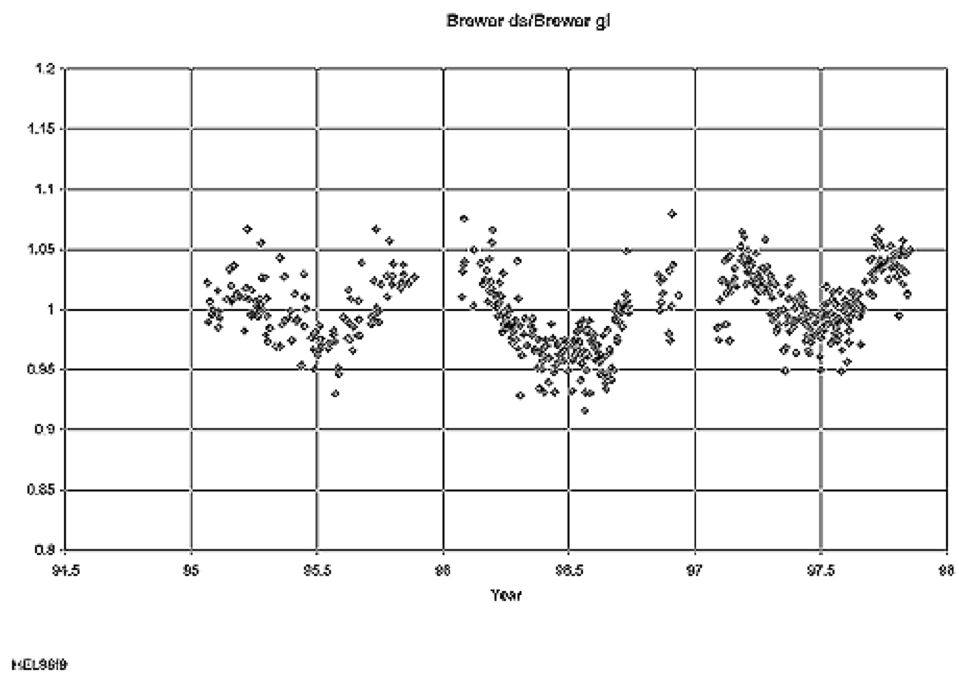


Figure 7.7 Comparison of GI-derived total ozone with ds measurements

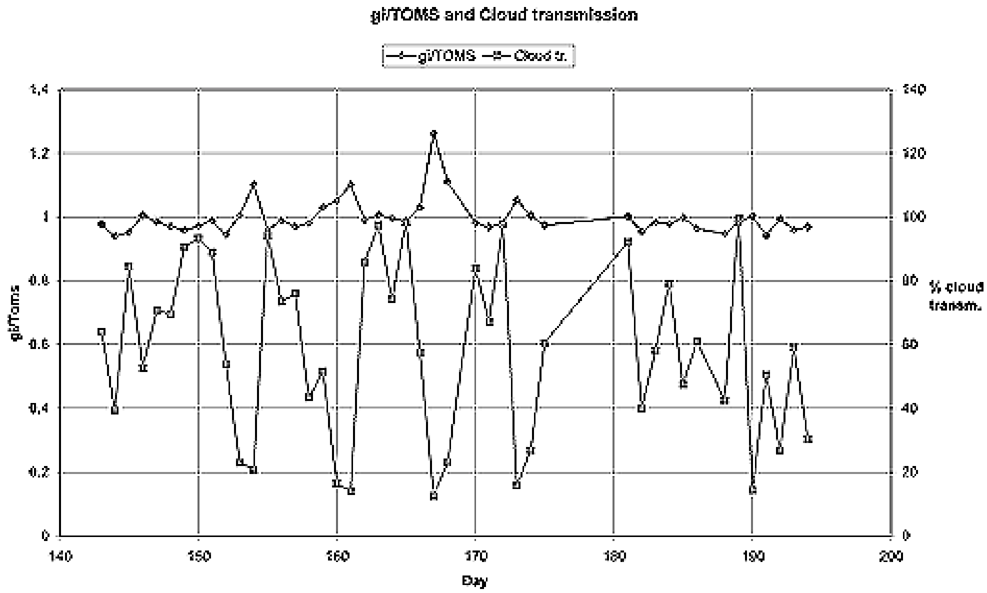


Figure 7.8 Comparison of GI derived ozone with TOMS data.

VIII Aerosol and Other Trace Gases

Use of Brewer Ozone Spectrometer for Aerosol Optical Depth measurements in the UV region - F. Carvalho and D. Henriques

F. Carvalho and D. Henriques from the Portuguese Institute of Meteorology presented a method that was developed for measuring the optical depth of aerosols in the UV from the historical record of direct sun measurements. This analysis would be useful if applied to other data records.

The nature and optical properties of atmospheric aerosol particles was reviewed. The standard method of measuring ozone and SO_2 from the linear combination of direct irradiance measured at the 5 Brewer wavelengths was outlined. The newly developed method for determining aerosol optical depth was described. Aerosols are assumed to absorb equally at all 5 of the Brewer wavelengths. Extraterrestrial constants were determined at the 5 wavelengths by Langley extrapolation. The analysis is done using raw data from the B-files, correcting for dark count and dead time.

Results of aerosol optical depth were given for Lisbon and Funchai showing day-to-day variability.

IX Umkehr Measurement

Comparison of Brewer #025 and Dobson #061 Total Ozone and Umkehr Measurements Made at Boulder Between October 1991 and December 1997 – G. Koenig

G. Koenig from the US Climate Monitoring and Diagnostics Laboratory, NOAA presented Brewer and Dobson activities at the Boulder, USA station. A time series of Dobson #61 and Brewer #025 direct sun total ozone was shown and in general, the Brewer measurements were about 2% higher than those of the Dobson with a standard deviation of about 3%. The differences were similar at all airmass values.

Figure 9.1 shows the comparison of Umkehr measurements averaged over a three-year period (1994-1997) made with the 2 instruments and the average differences. There is reasonably good agreement up to layer 7. Above that the Dobson values are about 15%-20% lower than those of the Brewer. The seasonal averages were also shown and discussed. There were similar differences for all seasons.

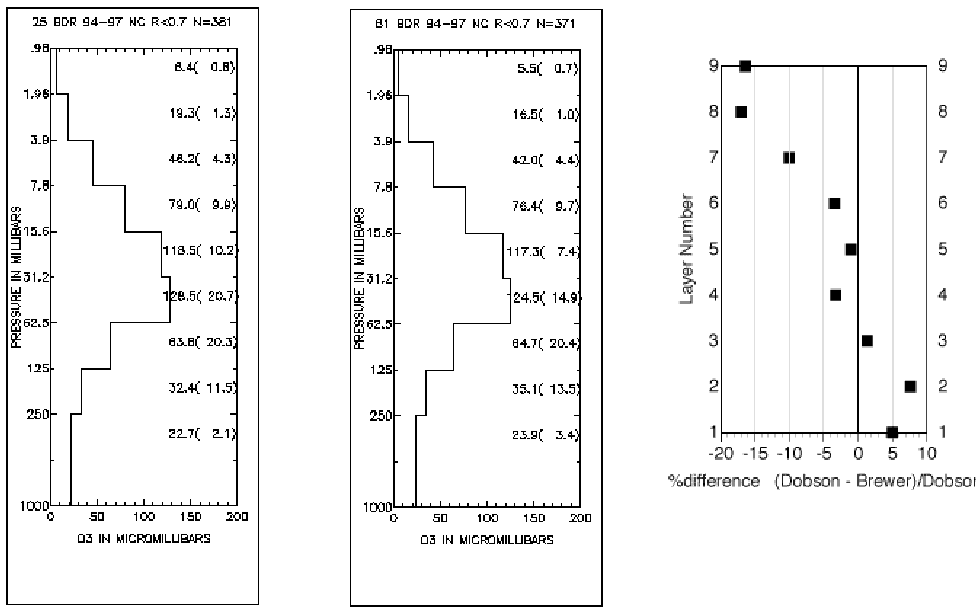


Figure 9.1. Umkehr profiles made by Brewer instrument #25 (left) and Dobson instrument #61 (middle) averaged between 1994 and 1997. The differences (in percent) are shown at the right.

New Developments in the Brewer Umkehr Algorithm – T. McElroy

A number of changes have been made to the Brewer Umkehr software in the last few years. These include a change to the preprocessor to address a problem with getting the dates right near the dateline, and a number of small changes to the Umkehr processing program. The Umkehr processing program was altered to allow the direct entry of a noise estimate for each wavelength measured. This allows the inclusion of a more realistic noise estimate for each wavelength to be made and included in the UMKSETUP.nnn file (where nnn is the instrument number). In the program, the estimate for each ratio of the three used in the analysis at this time is constructed as the root-sum-square of the noise level for each of the two wavelengths considered. The setup file must have 8 numbers in it corresponding to the four shortest and four longest wavelengths measured. If the noise level is reduced very much from 1% on the individual wavelengths (the real noise level is about 0.4 to 0.15 depending on the wavelength as compared to 1.0 for the 'standard' case), the agreement with other measurements (e.g.: the Table Mountain set) gets poorer. This is probably due to a remaining small error in the forward model or retrieval code.

A small problem in the interpolator used to fill the fine optical calculation grid was discovered. This, along with a change to a linear interpolator in setting up the pressure-height profile results in small (<1%) changes to a few layers. In addition, the program has been set up to make the ozone absorption coefficients temperature dependent as a function of height. This is done using the pressure-height profile included (input file in the setup file; normally the file STDTABS.DAT) as input data and estimating the scale height between layers to get the temperature. The file can be changed to use another pressure-height profile if it is desired. The file should be in the same format as the first part of STDTABS.DAT. The 81 at the beginning, describes how many ordered pairs are to follow. The ozone tables, which follow, are not used in the current version of the program since an analytic climatolgy has been included in the program for some time. These points are probably not needed in the pressure-height file.

The Umkehr program has also been changed somewhat to allow the scaling of the scattered light corrections. It is recommended that this constant be left at 1.0 as in the example. The scattered light corrections are already scaled by pressure squared inside the program to account approximately for the altitude differences at different stations. The value of this constant is also included in the output file.
Figure 9.2 shows the results of the algorithm.

Sample Preprocessor Setup File

1) ozoavg89.039
2) 0999 TMO 34.383 117.683
3) 80.0 89.0

Meaning of the line contents. (The lines are not numbered in the file.)
1) Name of daily ozone file for the year
2) Station number, header code, latitude and longitude of observing station
3) Range of Umkehr angles considered valid

Sample Umkehr setup file (note line numbers not included - see file on web site)

1) SXuni4m.DAT
2) stdtabs.DAT
3) O3TABLE.DAT
4) CQMS.DAT
5) 4.1099 2.3155 1.5600 0.8637
6) 0.6760 0.3187 0.1490 0.0776 .. ozone coefficients for #039 STN TMO
7) 3 6 11 12 1 1.0 783.0
8) 999 1 34.838 0
9) 0 ... debug file
10) 0.00 ... low level ozone offset
11) 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 .. inst. error short to long wavelength
12) 1.00 0.0 /* multiple scattering scale factor, angle dependent noise slope */

The lines are used for the following:

1. The name of the covariance matrix for the solution. Two choices included are 1. XCLIMAT.DAT and SXUNI4M.DAT

2. The pressure height table to be used. See the example for the format.

3. O3TABLE.DAT is a set of coefficients which are used by the climatology algorithm to generate vertical profiles of ozone at every location on earth as a function of the date and total ozone value.

4. CQMS.DAT contains the correction for multiple scattering used to analyze the data. They are calculated for zero albedo and for 1 atmosphere pressure. The values are scaled by pressure squared according to the station pressure included in the setup file, UMKSETUP.###.

5./6. Lines 5 and 6 are the ozone coefficients at -44 degrees C for the instrument whose data are being analyzed. There are 8 coefficients for the 8 wavelengths input from the preprocessor. Only six are currently used: the three shortest and three longest. These values should be changed to those appropriate for the data to be analyzed and the file renamed with the appropriate suffix (instrument number).

7. This line has 7 parameters:

   1 Minimum starting zenith angle
   2 Maximum starting zenith angle
   3 Minimum ending zenith angle
   4 Maximum ending zenith angle
   5 Output control flag.
   6 Ozone scaling factor (used with Dobson data)
   7 Surface pressure of the station

8. This line has 4 parameters:

   1 Station identifying number (3 digits)
   2 Parameter no longer used
   3 Latitude of station - used for first guess
   4 Output control flag

9. Output control flag - see listing.

10. Low level ozone offset value - leave at zero.

11. Noise vector - 8 elements.

12. Additional scale factor for the multiple scattering corrections.
    Leave set to 1.0.

13. The addition of a 13th line causes the data to be analyzed using a zenith sky extraterrestrial value - see listing. This line must be empty and there can be no other information in the file for the program to work properly.

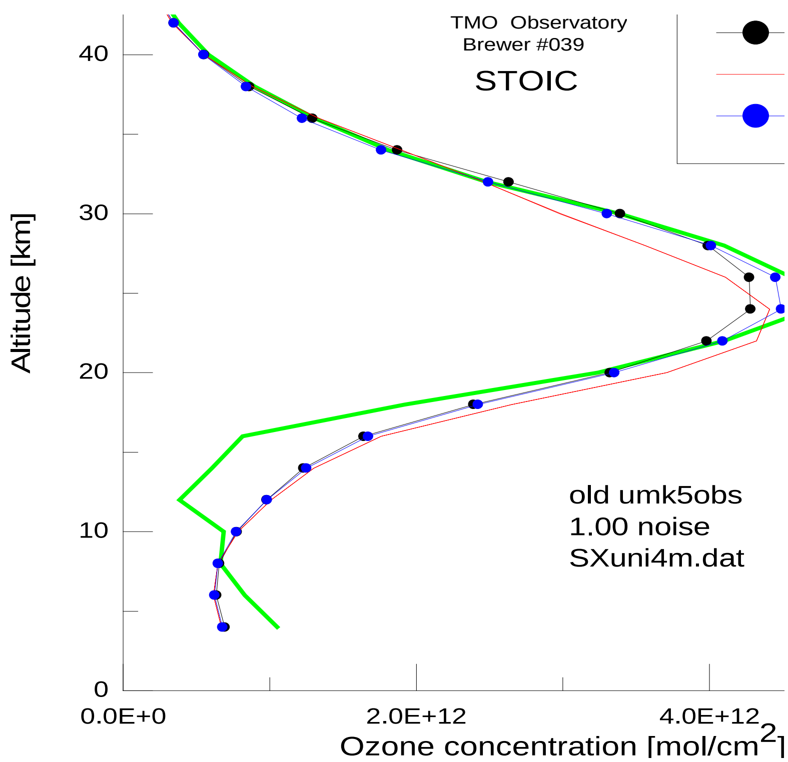


Figure 9.2: Results of the new Umkehr algorithm applied to Table Mountain data.

X Network and Monitoring Programs

The Canadian Brewer Network - Tom Grajnar

T. Grajnar from Environment Canada presented activities of the Canadian Brewer Spectrometer Network (CBSN) which operates Brewer spectrometers at 13 stations across Canada, 2 Brewer spectrometers at the Mauna Loa Observatory in Hawaii, and one Dobson spectrometer at the Atmospheric Environment Service Headquarters in Toronto, Canada. The primary objective of the CBSN is to provide a high quality ozone and UV data stream while minimizing operational downtime. This objective is being pursued through staff training, near-real time diagnostic checks, routine calibration and maintenance and continuous system improvement.

The CBSN is administered by the Network Manager who is supported by one student and occasional contracted help. The Network Manager also relies on station operators to provide routine instrument maintenance as well as some types of repair work. Approximately one-half of the station operators are full-time Government employees while the remainder are individuals or contractors who have been contracted to provide support. Training of staff occurs during station visits, through ongoing communication as well as the occasional training of new staff at AES Headquarters.

Network spectrometers are typically controlled by 486-series computers with Microsoft DOS 5.0 operating systems. A few spectrometers are controlled by Pentium computers running Microsoft Windows NT 4.0 and one spectrometer is controlled by a 486 computer running Microsoft Windows 95. All of these hardware and software configurations have been found to be quite reliable for long-term spectrometer operation. PCAnywhere software is used to allow centralized access to any spectrometer in the Network as well as to facilitate the automated daily download of all spectrometer data files at all stations to a central computer server. Ozone and UV data bulletins are automatically issued by each Network spectrometer at a rate of two to three times per hour during daylight hours. Daily data downloads facilitate the daily checking of instrument diagnostic parameters to ensure proper spectrometer operation.

Brewer stations are visited every two years for the purpose of spectrometer calibration, maintenance, repair and operator training. Calibrations routinely performed during station visits include dispersion, UV and ozone. Approximately eighty checks and maintenance items are addressed during each visit. Operator training and is provided as needed.

Improvements to computer hardware, software, communications and instrument calibrations are being pursued and implemented on an ongoing basis in order to continually improve data quality and to minimize operational downtime.

Brewer performance as assessed by satellite intercomparison – J. Kerr

J. Kerr from Environment Canada presented a study involving several Brewer instruments that have been in operation for enough years to carry out a meaningful assessment of their performance as a network, by using comparisons with satellite data. This was carried out by V. Fioletov at AES who compared satellite total ozone data with measurements made at 29 Brewer sites, 86 Dobson sites and 48 M-85 sites. It was found that the coincidence of the comparison, both in time and space, is important. Data for Toronto indicates the best agreement (minimum standard deviations of the differences) occurs when ground based measurements made within one or two hours of the satellite overpass. The best agreement is about 2% at coincidence and becomes worse (about 4%) if measurements are made 12 hours apart. Figure 10.1 shows how the agreement depends on spatial separation. For small differences (<20 km) the standard deviation is also about 2% and becomes worse (about 5%) for separations of 500 km.

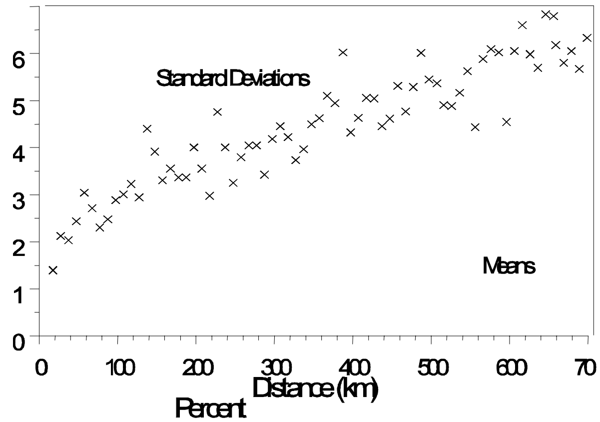


Figure 10.1: The means and standard deviations of the differences between ground-based daily total ozone values and solar beckscattered ultraviolet (SBUV) overpasses as a function of distance between station and overpass point. Data from 17 midlatitude stations for the period 1978-1990 were used

Figure 10.2 summarizes the agreement between satellite and ground-based measurements for all three types of instruments. Histograms of the mean bias for the different instrument types is shown for both direct sun and zenith sky measurements. The overall network agreement with satellite and Brewer is 0.2% with a standard deviation of 2.2%.

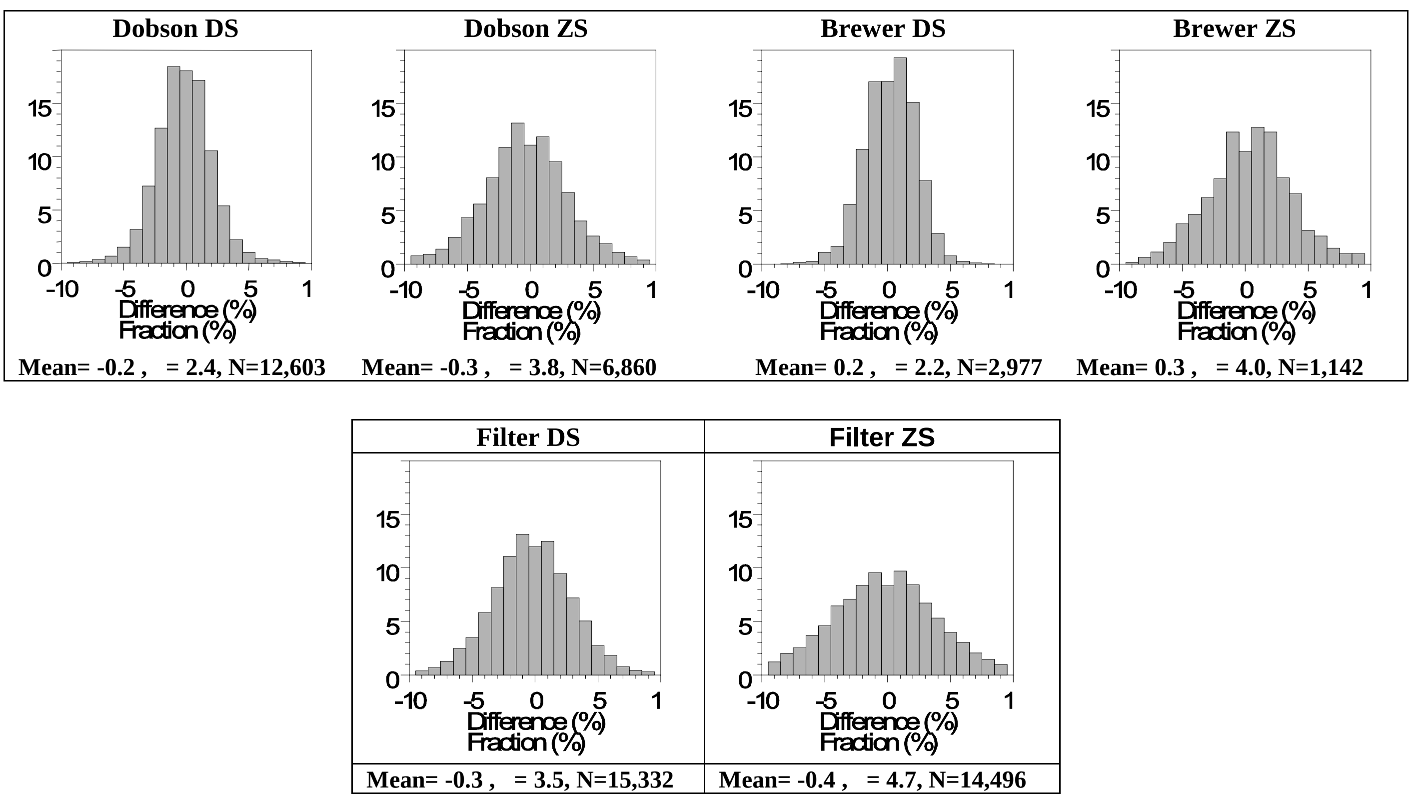


Figure 10.2: Histograms of the differences between TOMS overpasses and daily mean total ozone from (top-left) Dobson, (top-right)Brewer, and (bottom) filter ozonometer direct sun (DS) and zenith sky (ZS) observations. Mean difference (M) with TOMS, standard deviation (σ), and total number of pairs of observations (N) are shown in the legend.

The Performance of Brewer Spectrophotometers in China – X.D. Zheng

X.D. Zheng from the Chinese Academy of Meteorological Sciences began the presentation with a summary of the four Brewer instruments in operation in China, which are: #054, #074, #076 and #077. Table 10.1 provides the details about the location of these instruments.

Serial No.	Type	Location	Period of working	Measurements
#054	MKII	Gonghe (34.27°N,100.0°E)	Sep.91-Aug.,1993	O_3,SO_2,UVB
#054	MKII	Mt. Wa Liguan (34.30°N,100.97°E)*	Aug.,93--present	same as above
#074	MKIV	Zhongshan (69.37°S,76.38°E)	March,93--present	O_3,SO_2,NO_2,UVB
#076	MKII	Long Fengshan (44.73°N,126.60°E)	Aug.,93--present	O_3,SO_2
#077	MKII	Lin'an (30.30°N,119.73°E)	Aug.,93--present	O_3,SO_2

*WMO /GAW baseline station

Table 10.1: Operational status of four Brewer ozone spectrophotometers in China

SL tests from Brewer #076 became abnormal in the summer season of 1996, during the rainy season, i.e. a decrease in the observed column ozone from normal levels. By the spring of 1997, the R5 and R6 values increased ,and this status lasted about two months, correspondingly, the observed ozone amount is larger than the real data. In the summer of 1997, the R5 and R6 increased again and the observed ozone data became much larger than normal. In January 1998, a new GU11 UV filter was used and the SL tests were more stable. Abnormal SL tests often occur during the rainy season where the values of R5 and R6 increased during the summer of 1997 and spring of 1998. During this period, rain was observed for a long period of time at the Lin'an station.

Brewer #074 located at Zhongshan station, Antarctica also measured a slightly decreasing trend for the R5 and R6 values and the SL results may be considered stable, at least for the last 5 years as seen in Figure 10.3. The dead time of the PMT has been stable except that there were some sparse abnormal records at low position during the period from July 1994, to the April 1995. The High Voltage on the PMT and the intensity of the HG lamp have some obvious variation that are perhaps caused by the seasonal changes in the ambient temperatures or very weak intensities observed from the HG lamp output from January to April., 1995.

Another aspect of the program is to monitor UV. In order to assess the quality of UV-B measurements, an inter-comparison of a Yankee (YES) DAS UV-B band pyranometer and Brewer #054 ozone spectrophotometer was undertaken at the Mt. Waliguan Station. The difference between the model calculation and the measurements by the Pyranameter are small, since the Model calculation assumes the aerosol depth to be zero for clear sky conditions. The Brewer values were smaller than both the

Pyranometer's observation and the model calculation. Reasons perhaps come from both of the different wavelength band and the system errors: because the band of the Pyranometer is from 280--330nm,

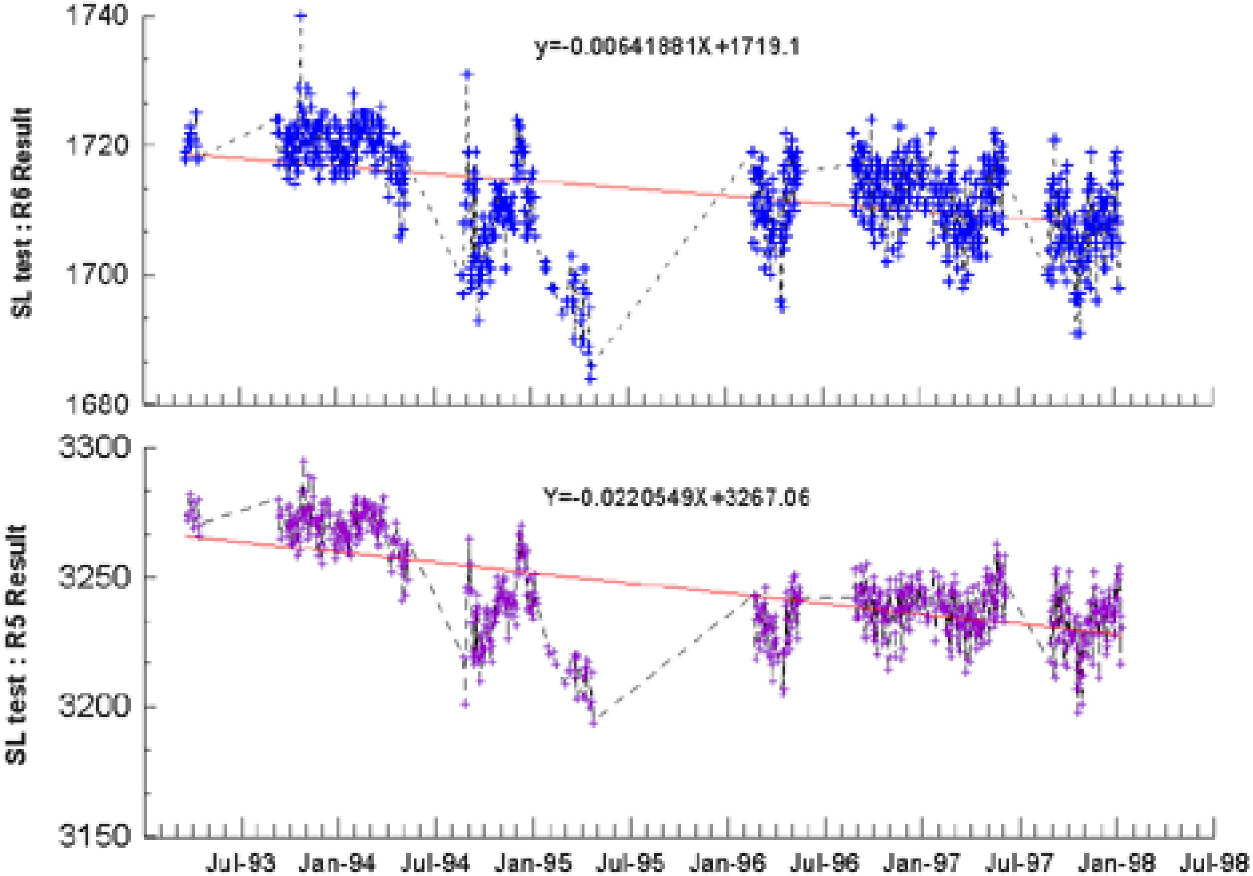


Figure 10.3: Brewer #074 located at Zhongshan station, Antarctica also measured a slightly decreasing trend for the R5 and R6 values and the SL results may be considered stable, at least for the last 5 years

while the Brewer's wavelength region is only 290--325nm. Key conditions for the UV-B intercomparison are the simultaneous measurements and the least variations of the solar zenith angle's variations, therefore, we choose the data set taken at or near local noontime. The data of Pyranometer is averaged data set in 8 minutes because of the one Brewer scan UVB measurements need about 8 minutes.

XI   New Developments

New Measurement Methods – J. Kerr

J. Kerr from Environment Canada presented a new method for measuring ozone, UV-B radiation and other variables such as SO_2, aerosol optical depth and ozone temperature was presented. The method is a combination of the standard 5-wavelength rapid scan technique using the chopping mask (direct sun, zenith sky measurements) and the slower scan made by rotating the grating (UV-B measurements). The standard 5 Brewer wavelengths lie between 306.3 and 320.0 nm with fairly uniform spacing of about 3.4nm. The new method fills in the spaces between the standard wavelengths by positioning the grating at 8 additional settings spaced about 0.5 nm apart. This new type of measurement ("grouped" scan) yields spectra with 45 elements (9 grating positions times 5 slits) for wavelengths between 306.3 and 324.0 nm made at the Brewer resolution of about 0.56 nm. A grouped scan measurement is made by sampling from grating position 1 (standard setting) to position 9 (+4.0 nm) and back and (logarithmically) averaging the respective elements from the forward and reverse directions. The measurement takes less than 3 minutes if 8 samples per wavelength (4 cycles of the shutter motor) are made at each grating position.

In general, atmospheric absorbers are quantified by fitting (using least squares) an observed absorption spectrum (log of extraterrestrial spectrum minus log of ground-based spectrum) with the known absorption spectra (at the appropriate wavelength resolution) of atmospheric constituents. Ozone absorption cross-sections measured by Bass and Paur (those presently used for the standard Brewer ozone algorithm) measured at several temperatures may be used to determine the temperature dependence of ozone absorption. In addition to absorbers, the optical depth of neutral and near neutral attenuators (such as clouds and aerosols) may be measured.

The grouped measurement method has the capability of quantifying and reducing the effects of varying conditions (changes in clouds or haze) that may occur during the course of the scan. For the analysis of the scan data it is assumed that variations in clouds or haze affects all 5 wavelengths in a particular group by the same amount. Thus 9 constant offsets are determined for each scan. The mean of the 9 offsets is a measure of the optical depth and the standard deviation is a measure of the variability during the course of the measurement. Measurements made under stable observing conditions result in a standard deviation of about 0.1%, a value comparable to the photon counting accuracy.

These group scan measurements have been made with Brewer #14 at Toronto since late 1996. In addition extraterrestrial measurements were made at Mauna Loa Observatory in March-April, 1997. Figure 10.4 shows the extraterrestrial solar spectrum measured at the 45 wavelengths compared with satellite data. Absolute irradiance values were determined by transferring the normal UV-B calibration on the Teflon diffuser to the direct sun port. An example of preliminary results showing the variation of ozone temperature at Toronto for nearly two years is shown in Figure 10.5. The annual variation from winter to summer is quite reasonable.

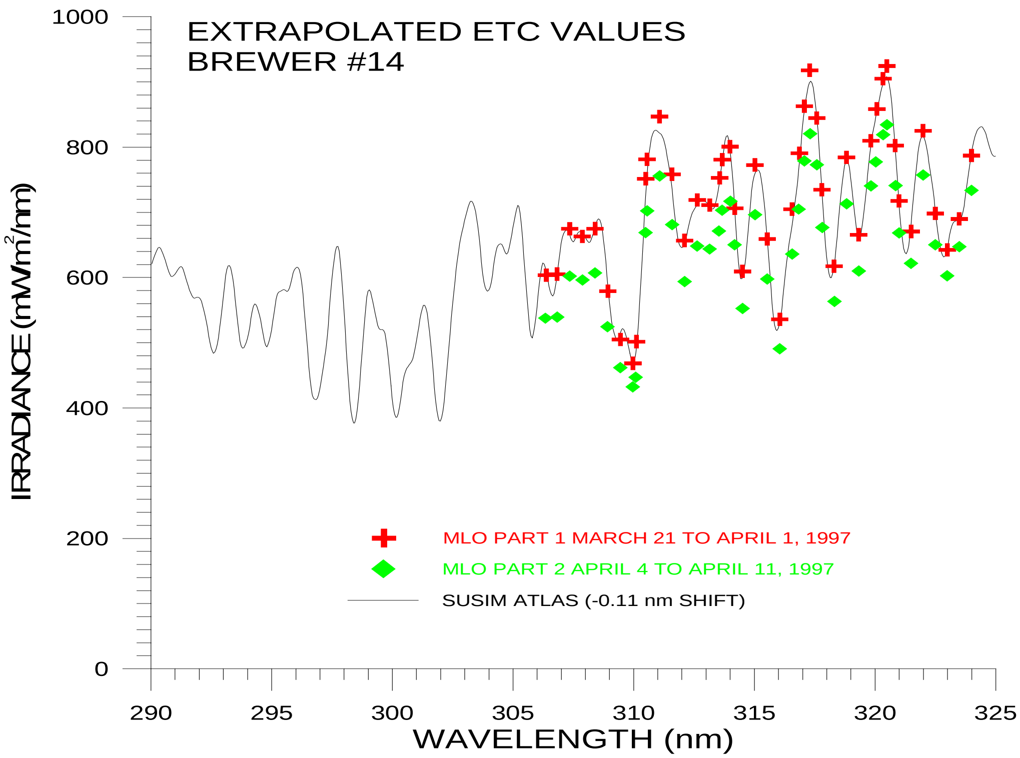


Figure 10.4: Extraterrestrial irradiance values at 45 wavelengths determined from Langley plots of direct sun scans made at Mauna Loa Observatory in March-April, 1997.

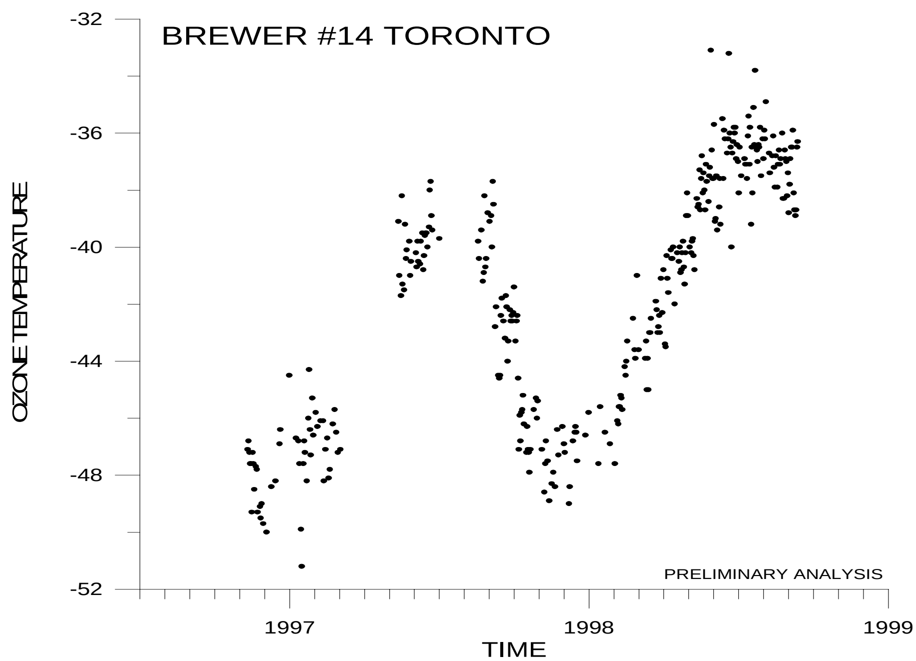


Figure 10.5: The observed record of ozone temperatures at Toronto, for nearly 2 years, between 1996 and 1998. Note the variation from winter to summer.

XII Poster Sessions

Two Poster Sessions were held as part of the afternoon program. This was the first time the Brewer Workshop held such a session and the consensus by those members who participated, was that a Poster Session was a value added component of the workshop. An informal meeting, chaired by E. Hare, was held during Day 2 of the Poster Session. The meeting involved an open discussion about data submission and data protocol issues with regards to file submission to both the BDMS and the WOUDC.

Poster Sessions - Abstracts

Ozone and UV-B trends at Ispra from 1993 to 1997

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An analysis of the ozone trend at Ispra (Italy) has been performed to ascertain if, even in a short time period of five years (1993-1997), a decline of the monthly mean values of the total ozone column could be put in evidence. A linear fit of the data displays a decrease of 0.21% per year with a mean value equal to 319.2 D.U.. A linear regression of the surface monthly mean ozone values have been also performed showing a decreasing trend that could contribute, even if for a very small amount, to the decline of the total ozone values. Ispra monthly mean total ozone data have been compared with those of three stations located within 2 degrees latitude and 3 degrees longitude from Ispra (Haute Provence, Hohenpeissenberg and Arosa). A linear fit of the data shows some discrepancies in the ozone trends attributable to the limited length of the observational period.

An analysis has been performed to verify if the trend of the monthly mean values of ozone at Ispra is in agreement with the trend of the solar UV measurements at a wavelength (305 nm) where the ozone absorption is still remarkable. The results, taken at a fixed solar zenith angle of 68°, show that the linear fit of the monthly mean values of UV is anticorrelated with the behaviour of the ozone column.

Five Years Of Total Ozone Measurements At Belgrano2 Antarctic Station[i].

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Marisa Moriconi and Claudio Rafanelli

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The survey of stratospheric Ozone in Antarctica by PNRA (National Research Program in Antarctica) of Italy had a start in 1988-1989 at New Zealand Scott base (discontinued in1996), then on January 1992 a second Brewer was installed in the antarctic Argentine base Belgrano 2 (77° 52' S, 34° 38' W) in the southermost tip of the Weddel sea. The station, managed by the Argentine Antarctic Program, is situated on the nunatak Bertraub at about 10 nautical miles from the coast at an elevation of 255 metres from sea level. The operator, who is in charge of the Brewer program, usually has previous training on an identical instrument which is in operation at the Ushuaia (Tierra del Fuego) station.

The climatic conditions of the site are rather severe, with temperatures during the winter that stay below –20°C for long periods of time. Winds also affect the instrument and it's use, in particular, frequent catabatic episodes due to the presence of the Antarctic plateau, south of the site. Finally, the lack of direct sunlight during the period of March to September is a limitation. During that time interval it is preferred to bring the instrument inside the laboratory because the amount of effort to obtain few Zenith Sky or Moon measurements does not compensate for the risk due to the adverse climatic conditions.

The behaviour of total ozone and some statistics for the years 1992 to 1997, with the exception of 1994 (when the ship could not get to the station) will be presented together with some comparison with complementary data taken at the Marambio (Argentine Meteorological Service) and Halley Bay (UK British Antarctic Survey) stations, where two Dobson are in service. Finally some Brewer-Umkehr profiles of Belgrano station will be shown providing evidence of the Ozone Hole phenomenon.

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O_3 And UV-B Irradiance Measurements By Brewer #067 At Rome Station

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Total ozone and UV-B irradiance observations have been made routinely since 1992 at the University of Rome using Brewer #067. Ground-based direct sun total ozone measurements from January 1992 up to April 1998 (Figure 1) have been analyzed to investigate their temporal characteristics. As a climatological frame of reference, the long Dobson ozone time series (1957-1986) of Vigna di Valle (VV), which is 50 Km away, is used. UV-B measurements went through a re-processing and re-analysis in order to guarantee the data quality. In Figure 2, the UV-B irradiance observations, together with a transfer radiative model (System for Transfer of Atmospheric Radiation STAR code) values, are shown. A monthly comparison between Brewer, Dobson and TOMS satellite data is presented in order to investigate the Rome and Vigna di Valle measurements discrepancies.

The temporal behaviour of SL ratio, used as an indicator of internal stability, are plotted in Figure 3. Table 1 reports the history of the instrument. The performance has been checked by means of the calibration with the travelling standard one (#017) almost every year. About the 80% of direct sun measurements are of good quality for each year.

Monthly ozone comparisons between Rome and Vigna di Valle stations, Vigna di Valle and Arosa stations are shown in Figures 4 and 5; moreover data from Nimbus 7 (January 1992 to April 1993) and Earth Probe (August 1996 to April 1998) TOMS instrument are used to assess the performance of the considered ground-based measurements (Figure 6). Rome and Vigna di Valle sites show an increasing trend in the monthly mean differences (from -2.9% in 1992 up to 6.6% in 1996). The comparison between Vigna di Valle and Arosa, a high altitude station, show a systematic difference until 1993. During the summer of 1993, the Vigna di Valle series oversteps the Arosa record. Brewer -TOMS differences data present an agreement <1%, while for Dobson -TOMS data is about 1.6% considering all years.

The behaviour of Rome Brewer station (#067) is presented. Results of the comparison with Vigna di Valle Dobson and some TOMS data on a monthly basis are also discussed. The performance of Brewer #067 appears quite regular and stable mainly after February 1996.

XIII Special Inter-comparison Summary and Report

Results of the intercomparison of Brewer spectrophotometers

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Introduction

In the last few years the enhancement of solar ultraviolet radiation reaching the Earth's surface, expected due to ozone depletion, is evident in many locations (WMO/UNEP, 1998). This observation has increased the scientific interest worldwide because of the biological, ecological and chemical impacts of UV radiation.

The effects of UV radiation depend strongly on wavelength and its importance for specific damages is described by the corresponding spectral sensitivity functions (action spectra). The most crucial wavelengths for living organisms are the shorter ones because the photons energy is inversely proportional to the wavelength.

The need for accurate assessment of the effects and for the quantification of the relations of UV with other atmospheric parameters imposed the necessity of performing accurate ground-based spectral measurements. Due to the weakness of ultraviolet radiation at the Earth's surface, especially at the low wavelengths, reliable monitoring of spectral UV irradiance requires high-grade spectroradiometers (Seckmeyer et al., 2000). Intercomparison campaigns with the participation of independent spectroradiometers led to set standards for their technical specifications, calibration and operation procedures (Gardiner and Kirsch, 1995). Although the quality of these instruments is constantly improving, in many cases the reliability of UV measurements is still doubtful due to insufficient quality control at the monitoring stations. The simultaneous intercomparison of measurements conducted by a series of spectroradiometers remains the best way of assessing, improving and assuring the quality of spectral UV measurements.

In this context, a small intercomparison campaign was organized in Porto Karras, Halkidiki, Greece, in the framework of the 5th Biennial Workshop of Brewer Users (13 -21 September 1998). Six Brewer spectroradiometers of independent organizations took part and this study presents the results of their performance.

Site and time

The intercomparison took place from 14th to 18th of September 1998 (days of year from 257 to 261). The instruments were arranged on the flat roof of a four stories hotel, where the Brewer Workshop was taking place. The hotel was located at latitude 40.10°N, longitude 23.74°E and at the sea level. The horizon of the site did not present any serious obstacles, except during sunrise, when the Sun was obscured by nearby hills. However, the effect of the shadow was the same on all instruments while throughout the rest of the day the instruments had a clear view of the Sun and sky.

The weather conditions during the period of the campaign were marginally good for an intercomparison, with partly cloudy intervals but with no rain. Figure 1 shows the diurnal course of the erythemal irradiance during each day of the campaign, as measured by a broadband detector located on the same roof. It can be seen from this figure, that days 257, 258 and 261 had clear sky in the morning with clouds to be observed near local noon and throughout the rest of the day. Days 259 and 260 were quite sunny with few exceptions especially on day 260, while there is no much information about day 256.

Instruments

Three types of Brewer spectrophotometers participated to the intercomparison campaign: models MK III, MK III and MK IV. Brewers MK II and MK IV are single monochromators while Brewer MK III is a double monochromator. The main difference between a single and a double spectroradiometer is that the second consists of two single monochromators in tandem, resulting in effective reduction of stray light (Bais et al., 1996). Since the participated instruments were all Brewer spectroradiometers, they present many similarities to their principle of operation, technical characteristics and calibration methods. All models provide total ozone and columnar SO_2 measurements, besides the spectral scans, while model Mk IV is also capable of measuring columnar NO_2.

The single monochromators Mk II and Mk IV operate in the spectral range from 290nm to 325nm, which may be extended up to 335nm by changing the operational slit. The double monochromators (Mk III) were especially designed for spectral UV measurements, presenting higher quality and performance compared to the conventional models. Their operational wavelength range is wider, from 287.5nm to 363nm (366nm in #086). All models scan the ultraviolet region in steps of 0.5nm. Due to the extended wavelength range, the duration of a scan with the double monochromator is about 4 minutes longer than with the single one.

A list of the instruments that took part in the campaign and some of their technical characteristics are given in Table 1, together with the organizations responsible for their regular operation.

Instrument ID	Model	Responsible Institute	FWHM (nm)	Spectral range (nm)
017	Mk II	Ozone Services Inc., CA	0.61	290-325
025	Mk II	National Oceanic and Atmospheric Administration, U.S.	0.62	290-325
041	Mk IV	Technological Institute of Kozani, GR	not measured	287.5-325
086	Mk III	Aristotle University of Thessaloniki, LAP, GR	0.55	287-366
145	Mk III	Spanish Meteorological Service, ES	0.62	287.5-363
150	Mk III	Atmospheric Environment Service, CA	0.62	290-363

Table 1. List of Instruments that took part in the campaign.

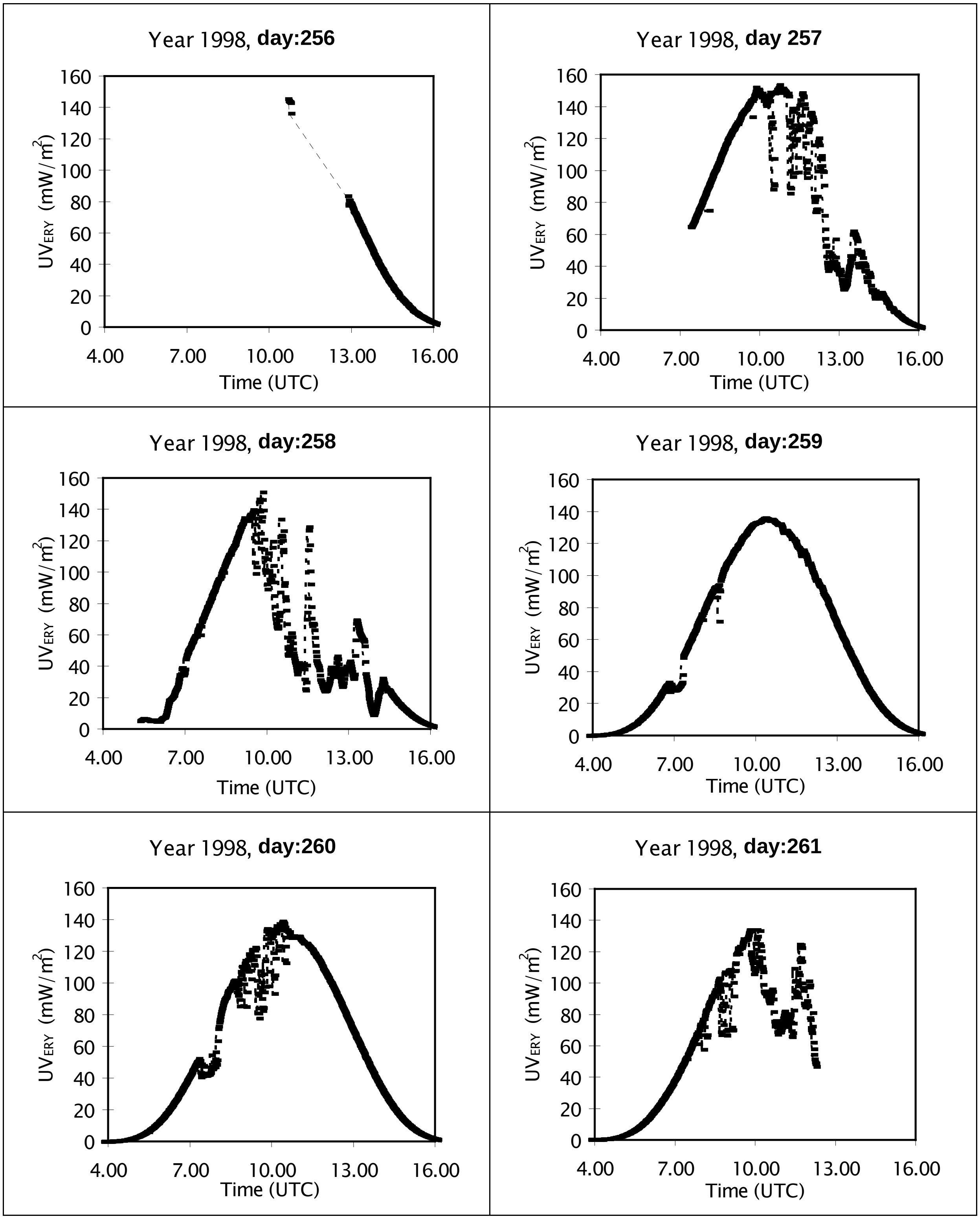

Figure 1: Diurnal variation of erythemal irradiance during the days of the intercomparison.

Wavelength alignment is achieved at all models by scanning an internal Hg lamp and positioning the micrometer at the wavelength of maximum intensity. Due to the absence of a dark room at the campaign site, absolute calibration of the spectral measurements with the use of standard 1000 W lamps was unachievable. The absolute calibration of each spectroradiometer was carried out at its home-site and it was verified at the intercomparison with the use of transportable units of 50 W lamps.

Most instruments were operated for a period of 4 days from day of year 257 to 261 (14/9/98 - 18/9/98), with the exception of Brewer #041 for which due to technical problems only during day 261. Due to its short operation this instrument could not be compared with the other spectroradiometers.

Operational errors

The quality of the data provided by a spectroradiometer may be affected by many sources of errors, most of which are well known and properly characterized. Through international cooperation and coordination it has been possible to develop procedures and tools for reducing the influence of errors on the UV measurements (Webb et al., 1998).

Slit function

Ideally, a spectroradiometer should measure precisely the monochromatic radiation at each individual wavelength. In reality though, spectroradiometers allow radiation belonging to a narrow band of neighboring wavelengths to reach the detector. Each instrument has a characteristic slit function, which provides the possibility of photons at a particular wavelength to get through the exit slit, relative to those of the measured wavelength (Gardiner and Kirsch, 1995). The slit function is unique for each instrument depending on the constructional details and its size is measured as the width at the half of its maximum value (FWHM). It can be determined in the laboratory using a monochromatic source of radiation at well-known wavelengths. In this intercomparison, the FWHM of each instrument was estimated by scanning the 296.7 nm line of a mercury lamp at fine steps. The intensities at the measured wavelength range were normalized with the observed intensity at the nominal wavelength while the nominal wavelength was set as zero. The derived slit functions of the instruments are illustrated in Figure 2, and the measured FWHM are shown also in Table 1.

Wavelength shift

Inadequate mechanical positioning of the optical components or uncertainties of the wavelength calibration procedures may cause improper wavelength alignment (Gröbner et al., 1998). The wavelength shift error is more significant in the UVB region because of the marked wavelength structure and the weak intensities demonstrating variations of several orders of magnitude. This type of error is determined by scanning either a mercury lamp or by making use of the Fraunhofer lines of the solar spectrum.

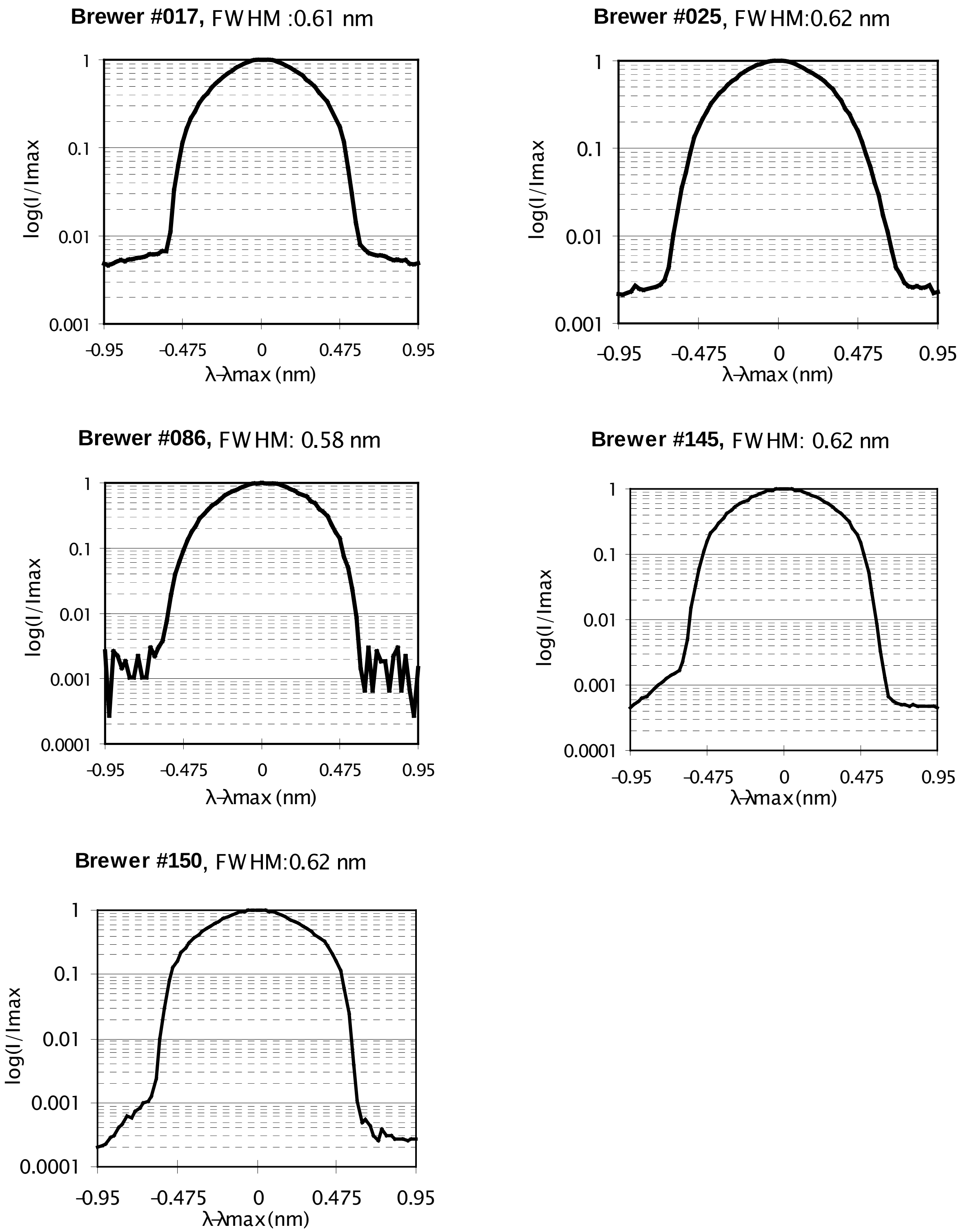

Figure 2: The slit functions of the instruments participated in the intercomparison.

For analyzing the performance of the spectral scans of a spectroradiometer, ratios of simultaneous measurements with a reference instrument are usually formed. The different slit functions and wavelength shifts presented by the individual instruments introduce great fluctuations in the ratios resulting in veiled assessment. To minimize the amplitude of fluctuations, the comparison of spectral scans should utilize measurements corrected for both factors. The whole procedure consists of many complex steps but it becomes a routine with the use of the algorithm SHICrivm (Slaper et al., 1995). According to this algorithm first the under examination scan is corrected for the effect of the slit function (deconvolution) and then it is convoluted to obtain a spectrum corresponding to a virtual triangular slit function with a FWHM of 1 nm.

Through this procedure, the wavelength shift of each scan can be accurately determined and the spectral measurements could be corrected for it. Figure 3 shows the upper and the lower limit of wavelength shifts for each spectroradiometer, as estimated of all available spectral measurements during the intercomparison.

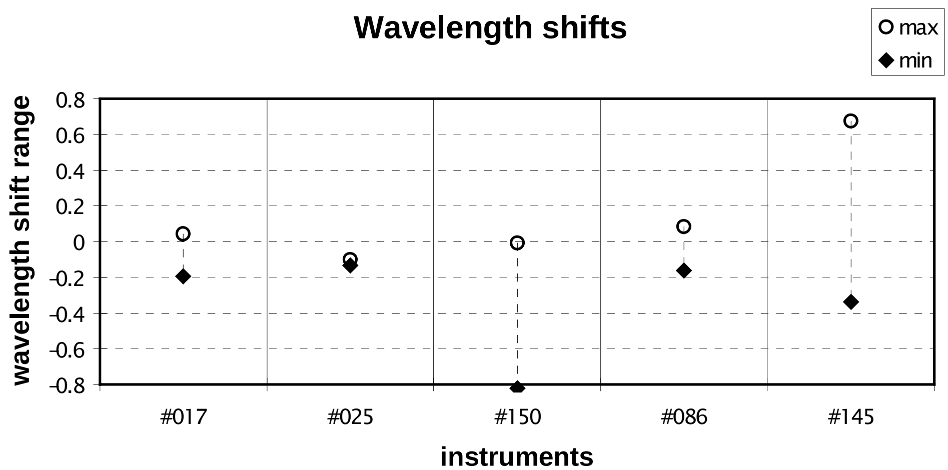

Figure 3: The wavelength shift range of each instrument during the intercomparison. The estimates of this graph came out of the algorithm SHICrivm.

The reference instrument

As it has been mentioned, the results from different instruments are best described by examining the ratios of their spectral scans. The presence of more than two or three instruments makes the comparison confusing and a reference instrument or a group of them to which all the rest can be compared, should be chosen. In the reported intercomparison there was no absolute standard of comparison and due to the limitted number of the participated instruments, one of the spectroradiometers was chosen as the reference. The reference instrument used was the monochromator numbered as #086 and the reasons for its choice are following:

- It was one of the instruments with the ability to measure solar irradiance at the widest range of wavelengths.
- It is a double monochromator and therefore, its spectral measurements do not suffer from the stray light effect.

- It could provide spectral measurements corrected for the cosine error.
- It took part in a large number of similar campaigns in the past with satisfactory performance and results.
- It was proved to be a reliable instrument in the past and it presented stable behavior during the campaign.
- It had been recently calibrated at LAP and its transportation to the campaign site (~100 km away) was done by road, in contrast to the other instruments that were shipped by plane from different countries.

Data analysis

To assess the results of the intercomparison, ratios of spectra recorded by each instrument with Brewer #086 were formed. The absolute magnitude of these ratios reflects the differences in the absolute calibration of the instruments, while the spectral structure of the ratio reflects their differences in their slit function, and wavelength alignment. As all instruments were Brewer spectrophotometers, it is expected to have similar constructional characteristics, so that much of the structure in the ratios in eliminated.

An external factor that may affect the ratios is the asynchronous sampling, which becomes more important in partly cloudy skies. In the campaign particular emphasis was given to obtain almost simultaneous spectral measurements, although most of the instruments were incapable, due to software limitations, to perform synchronized scans. Due to this problem in association with the unfavorable weather conditions during the campaign (see Figure 1), and the discontinuous operation of a few instruments, due to hardware problems, it was extremely difficult to find in the campaign dataset simultaneous undistorted scans for all instruments.

The software used by the reference instrument to take spectral measurements was modified in order to measure the direct irradiance at individual wavelengths during the scans. Based on the instrument's angular response determined in the laboratory and the direct irradiances spectral coefficients for correcting global irradiance spectra were obtained to reduce the effect of the cosine error (Bais et al., 1998). In the following analysis cosine-corrected spectra were used for Brewer #086. For improving the spectral measurements of the single monochromators the stray-light effect was considered by applying the usual for the Brewer instruments correction, i.e. by subtracting from the irradiance measured at each wavelength the average irradiance recorded at wavelengths below 292 nm.

Figure 4 demonstrates the comparison of the participated instruments with the reference for three cases of almost simultaneous scans. The spectral measurements were taken on days 257, 258 and 260 and at solar zenith angles 41°, 69° and 45° respectively. Each ratio to the reference at the three observation times was derived from the original spectral data (left panels of Figure 4) and the standardized (corrected for the slit function and wavelength shift) spectral data (right panels of Figure 4). Despite the small differences between the slit functions of the reference and the individual instruments, it can be seen from the left panels of Figure 4 that the use of the raw data for calculating the ratios introduces noisy fluctuations. These fluctuations demonstrate an almost repeatable pattern for each instrument at all examined cases, which is a result of the combination of the instrumental slit function with the Fraunhofer structure of the solar spectrum. The existence of fluctuations result in poor comparability, especially when the slit functions of the instruments present important dissimilarities. As it is obvious from the right panels of Figure 4, the derived from the algorithm SHICrivm standardized spectra with a slit function of 1nm FWHM, provide ratios in which great part of the noise has been eliminated. Even though the levels of the differences in the absolute calibration remain the same in both cases (original and standardized), the latter ratios make available a more detailed comparison providing precise information about the instruments' performance.

The first evidence of this comparison is that the absolute calibration of the instruments differs from the reference by a few percent. However, the levels of the ratio of each examined instrument remain almost stable at the three observation times suggesting a consistent behavior. The best agreement with the reference instrument's absolute calibration is achieved with the Brewers #017 and #150, which present percentage mean difference of about -1% and +0.9% respectively. Brewer #025 underestimates the solar irradiance by about -7% while Brewer #145 overestimates it by about 9%. The percentage differences were estimated for wavelengths longer than 300 nm for days 257 and 260 and longer than 305 nm for day 258. The deviations observed for the same instruments between different cases, are mostly due to differences in solar zenith angle caused by lack of synchronization of the spectral measurements. This is apparent in the ratio of Brewer #025 on day 257, which started scanning three minutes earlier of #086. Ratios present the highest variations from the mean at the shortest wavelengths confirming for all instruments the difficulty of measuring low intensities with high accuracy. This is more evident from the ratios of the single monochromators, where stray light introduces variations of up to 40%. Ratios are wavelength dependent also at longer wavelengths but, in general, the standard deviation of the mean value is quite small (±1-2%). Each instrument's absolute calibration shows different dependency on the wavelength i.e. Brewer #145 presents a slightly negative slope with the increase of wavelength while Brewer #150 shows alternative ranges of wavelengths with negative and positive deviations from the mean. It is noted that all these results are relative to Brewer #086, which although is considered a reference for comparison purposes, it cannot be proven that its measurements are absolutely correct.

In order to assess the instruments' performance at various solar zenith angles, almost simultaneous spectral measurements taken under clear sky conditions, were used. The ratios of the scans were classified at intervals of 10° for solar zenith angles from 35° to 75° and at an interval of 15° from 75° to 90°. As it has been already been mentioned, the spectral measurements of the reference instrument are corrected for its angular response. The mean spectral ratios of the examined spectroradiometers for the various categories of zenith angles are presented in the left panels of Figure 5. It is clear from these figures that the levels of the spectral ratios are discrete at the various zenith angles and this is more evident in the ratios of Brewers #025 and #145. The ranges of mean ratios as calculated for wavelengths longer than 300 nm, are 0.98–0.99, 0.90-0.94, 1.03-1.10 and 0.99-1.01 for the Brewers #017, #025, #145 and #150 respectively. Brewer #017 presents the most stable behavior at the various zenith angles, but it should be noticed that there is no information about this instrument for the last category (75° to 90°). As one can see from the figures referring to the other instruments, the lowest ratios are observed at this category. Moreover, the highest ratios are persistently observed at solar zenith angles from 55° to 65° and this might be attributed to the combination of the errors introduced by angular response and instrumental temperature.

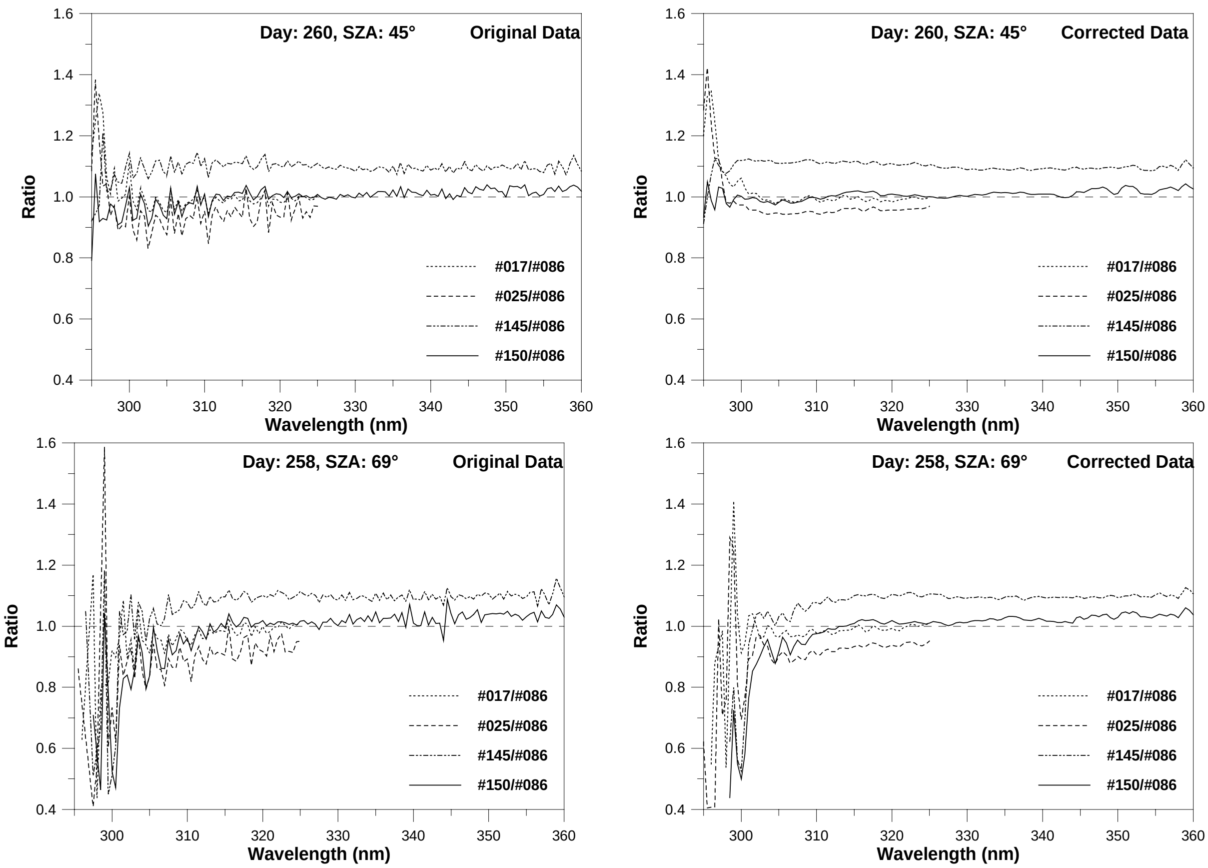

Figure 4: Ratios of spectra from four Brewers against those of Brewer #086, recorded almost simultaneously at three days of the campaign (left column). The right panels show the same ratios as they were derived after the spectral measurements were passed through the Schicrivm algorithm.

To investigate the consistency of the ratios at the measured spectral range, the mean ratios at each solar zenith angle category were calculated for the ranges 300-310 nm (low intensities), 310-325 nm (moderate intensities) and 325-360 nm (high intensities). The corresponding results are shown on the right panels of Figure 5 where the bars represent the standard deviation of the mean ratio at each category. In this figure as reference solar zenith angle is used the central one of the class. The differences in the ratios at the examined spectral ranges are less for the Brewer #017 while the highest variation is observed in the ratios of the Brewer #150, confirming the spectral dependency of its absolute calibration. In all cases, the mean ratios for the wavelength range 300-310 nm show large deviations, which increase with increasing solar zenith angle. Except from Brewer #017, the ratios at this range are lower, presenting the lowest value at 70° SZA (65°-75°). The fact that the irradiances of the shortest wavelengths demonstrate the largest underestimation at 70° could result from the proportion of the two components (direct and diffuse) of global irradiance in combination with the instrumental cosine response at these angles. The variations of the ratios for the spectral ranges of longer wavelengths demonstrate less dependency on solar zenith angle and the standard deviations of the mean ratios are quite small especially for the spectral range 325-360 nm. It is also noticeable that the performance of the Brewer #017 for both spectral ranges is almost stable and the standard deviations at wavelengths from 310 to 325 nm are comparable with the ones of double monochromators for the range 325-360 nm. The estimated maximum and minimum percentage differences in the absolute calibration between the examined instruments and the reference at the three (two) spectral bands are shown in Table 2.

Instrument ID	Difference from #086 (%)		
	300–310 nm	**310-325 nm**	**325–360 nm**
017	-2 – 1	-2 – -1	–
025	-13 – -6	-9 – -5	–
145	0 – 10	4 – 10	4 – 10
150	-11 – -1	-2 – 1	0 – 3

Table 2. Ranges of differences from the reference at different wavelength bands

The diurnal behavior of the instruments was examined by using all available -during the campaign- ratios to the reference at wavelengths 305nm, 325nm and 350nm, which were selected according to the spectral absorption of ozone; i.e. strong at 305nm, weak at 325nm and negligible at 350nm. The diurnal variation of the irradiance at these wavelengths is shown on the upper panels of Figure 6, in which measurements taken under cloudy conditions are included as well. The irradiance at 325nm is about ten times that at 305nm, while the irradiance at 350nm is about fifteen times larger. The ratios corresponding to each wavelength are presented at the lower panels of Figure 6. The largest deviations of the ratios at all wavelengths are observed in early morning and late evening hours when the largest solar zenith angles occur. This could be attributed not only to the measurements' cosine error but also to small differences in the timing between the scans. For each instrument, the mean ratio over the time period covering the solar zenith angles from -75° to 75° are presented as straight lines. The dispersion of the ratios about the means is quite high for all instruments at 305nm and the statistical analysis showed that the standard deviations from the mean value could be up to four times larger compared with those at 325nm and 350nm. The results of the comparison of the diurnal variations give also evidence of the difficulty to measure the shortest wavelengths, which are the most important for the biological effects of UV.

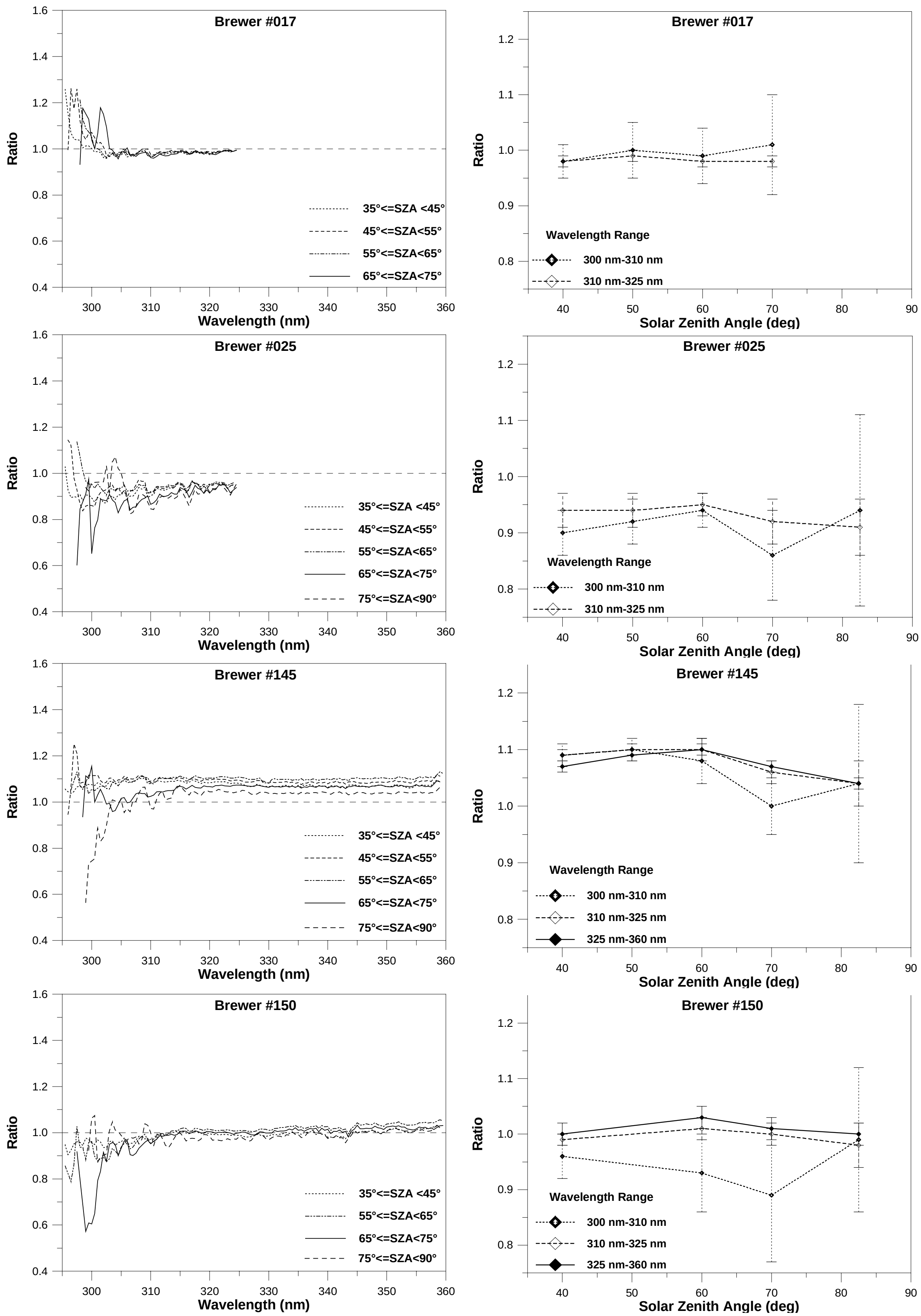

Figure 5: Spectral ratios of four Brewers against Brewer #086 averaged over four solar zenith angle categories (left column). Averaged ratios over three wavelength bands as a function of solar zenith angle (right column).

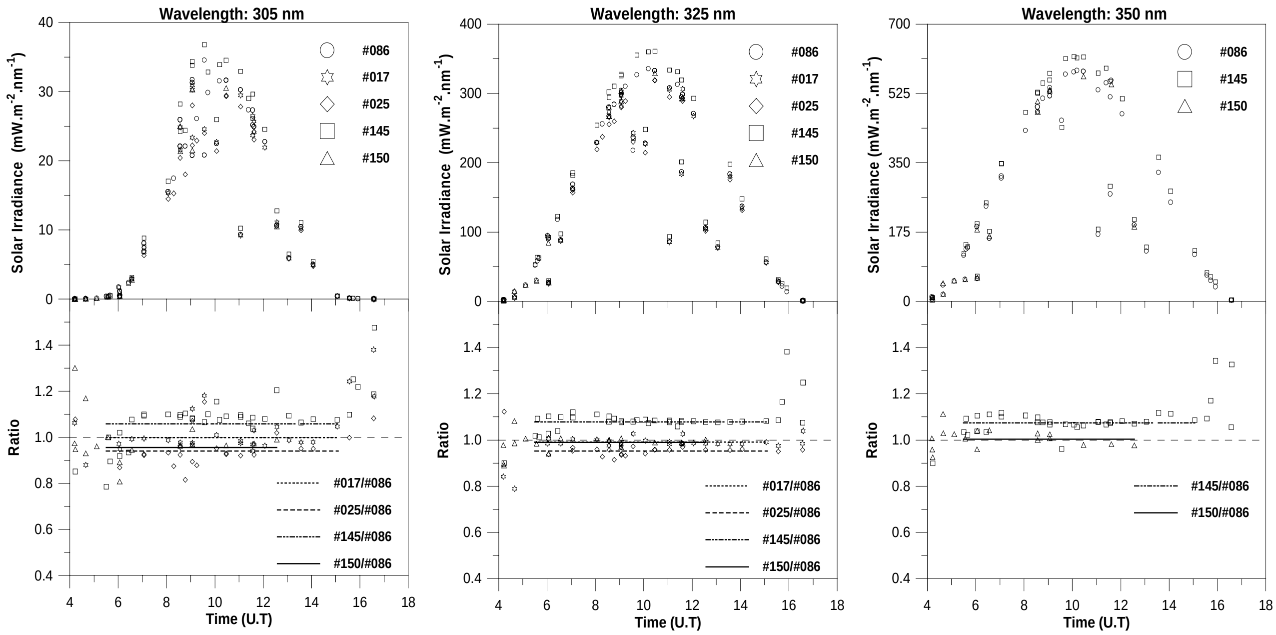

Figure 6: Diurnal variation of the irradiance measured by all the participated instruments at 305nm, 325nm and 350 nm (upper panels). The lower panels show the ratios of the irradiances measured by four Brewers against those measured by Brewer #086.

Discussion – Conclusions

The intercomparison held at Halkidiki, Greece in September 1998 served two goals: The training of new Brewer operators and the improvement of the old ones and the assessment and the upgrading of the participated instruments' performance. The first scope was considered as major since many sources of errors of the spectral measurements originated with the operational procedures. The operation of six Brewer spectroradiometers during the intercomparison was a demonstration of the instrument's control, the possible problems arisen from instrument's hardware or software and the eventual solutions and finally, the requirements of reliable spectral measurements. The priority given in the first task and the requisite of upgrading the performances during the intercomparison, resulted in the existence of time intervals in which one or more participated instrument's operation was interrupted and consequently, in limit number of simultaneous scans of all spectroradiometers.

The scans of the 50 W lamps proved that the spectral response of each instrument remained stable after the transportation and consequently, the absolute irradiances provided by the operators were based on the response calibration carried out at home site. From the very first steps of the measurements analysis, it was realized the requirement of uniform data, even though the technical characteristics of the spectroradiometers were quite similar. For this reason, the convolution for the individual slit function and corrections of the estimated wavelength shifts were applied on the spectral measurements of each instrument. The three approaches of comparison demonstrated, more or less, similar information about the performance of the instruments. The lower and the upper limits observed at the levels of the ratios, denoted that the difference in the irradiance measured side-by-side and at the same time could be more than 15% for moderate irradiances. The estimated differences and their wavelength dependency introduce the necessity for proper calibration procedures including the validation of the standard lamps. The large deviations of the ratios at the shortest wavelengths confirm once more the difficulty of monitoring accurately low intensities. Even part of the stray light on single monochromators was subtracted its effect is still evident at the shortest wavelength resulting in large overestimations. The most of the effort spending on achieving reliable spectral measurements should be focused at the low part of UV-B region. Finally, the dependency of the individual instruments' performance on the solar zenith angle should be encountered as an additional problem to be resolved.

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XIV Closing Activities

Preparation of meeting recommendations and review of draft report.

XV Meeting recommendations

The members of the 5th biennial Brewer Users' Meeting Recommend:

1. The Brewer workshop participants endorse the formation of a Brewer steering committee which will carry out tasks that will facilitate the operation of and improve the performance of the Brewer global ozone network. This committee should be chaired by a person who is appointed by the WMO Scientific Advisory Group for ozone measurement and who reports directly to the WMO SAG for ozone measurement and the WMO SAG for UV measurements. The tasks and responsibilities of the Brewer steering committee will include the following:
    - certify software for network operation
    - specify the requirements for calibration and maintenance for the global network
    - reference manuals
    - new developments
    - relationship to other total ozone monitoring systems
    - network operations including operating schedules
    - organizing meetings and training activities
    - promote communications with data centres
    - maintain contact with the Brewer manufacturer and service contractors
2. That the appropriate action be taken to hold the next Brewer workshop in conjunction with the QOS in Japan.
3. WMO should encourage as many Brewer operators as possible to submit 'raw' data (B-files and other required information) to the WOUDC.
4. To encourage the deposition of 'raw' data into the WOUDC, steps should be taken toward the establishment of a data exchange and security protocol for the inclusion of 'raw' data in the database.
5. After its formation, the Brewer steering committee should move quickly to resolve the issue of what Rayleigh scattering coefficients should be used to evaluate Brewer data. Brewer operators should be encouraged not to make this change until it can be done in a uniform manner.
6. WMO should recommend that the global UV-B total ozone routine (gi.rtn) and the collection of direct solar scan data be included in operational schedules throughout the network. The new data should be stored in the B-files.
7. The Brewer workshop members wish to express their disappointment at the closing of the scientific component of the Potsdam Observatory.
8. The Brewer workshop members expressed concern that the number of calibration and maintenance events conducted per year within the Brewer network has not increased sufficiently in response to past recommendations.
9. WMO should encourage all Brewer operators to collect and submit Umkehr data to the WOUDC for processing and analysis.
10. Brewer observations should be supplemented by pyranometer measurements performed using WMO-recommended devices.
11. The Brewer workshop participants endorsed the activities of the WMO UV steering committee in developing international UV calibration facilities.

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XVII Meeting Programme:

Tuesday, September 15, 1998

1900-2000 Registration, Election of Rapporteurs and Review of Agenda

2000- Informal Ice-breaker

Wednesday, September 16, 1998

0830-0900 Opening by a Representative from Aristotle University of Thessaloniki
[C. Zerefos]

Session I Opening and Introduction
Rapporteur [T. Grajnar]

0900-0910 Introductory remarks by the Chairman of the Scientific Organizing Committee.
[C. Thomas McElroy, *IOC]*

0910-0930 Remarks by the Consultation Chairman.
[C. Thomas McElroy, *Canada*]

Session II Total Ozone Records
Rapporteurs [H. De Backer and U. Koehler]

0930-0945 Report on the current status of total ozone measurements made using Brewer No.75 and Brewer No. 126 Spectrophotometers.
[Dave Moore, *UK*]

0945-1000 Total ozone measurements with 2 Brewers and 2 Dobsons at Arosa 1996-98
[Herbert Schill, *Switzerland*]

1000-1015 Five years of Ozone measurements at Belgrano station (Antarctica)
[Luigi Ciattaglia, *Italy*]

1015-1030 Ozone Variations In Eastern Siberia Observed by Brewer, SAOZ and ECC Ozonesondes In 1992-1998.
[Valery Dorokhov, *Russia*]

1030-1100 *Coffee Break*

1100-1115 Fifteen-year Brewer record at Hohenpeissenberg - A valuable supplement to the Dobson data

set.
[Ulf Koehler, *Germany*]

1115-1130 Update on Brewer Calibration Activities
[Ken Lamb, *Canada*]

Session III Zenith Sky Observations

Rapporteur [K. Vanicek]

1130-1145 Zenith-sky Observations at Poprad-Ganovce
[Miroslav Chmelik, *Slovakia*]

1145-1200 Zenith Total ozone observations with a Brewer instrument including cloud corrections
[Hugo De Backer, *Belgium*]

Session IV Station Activities

Rapporteur [E. Hare]

1200-1215 Total ozone, UVB and Umkehr time series at Izaña
[Alberto Redondas Marrero, *Spain*]

1215-1230 Brewer Measurements at Mauna Loa Observatory.
[Jim Kerr, *Canada*]

1245 - 1700 *Afternoon Break*

Poster Session I

1700-1900 *Posters*

1900-2100 Poolside Social Gathering
[Society of Opticians and Optometrists of Northern Greece]

Thursday, September 17, 1998

Session V New Instrument Operation and Design Modifications
Rapporteur [J. Groebner]

0830-0850 Revised Grating Micrometer Drive Mechanisms
[Julian Groebner and Ken Lamb, *Canada*]

Session VI Data Management and Software Development
Rapporteur [J. Groebner]

0850-0905 Supporting software tools for Brewer data management.
[Karel Vanicek, *Czech Republic*]

0905-0920 Update on the BDMS and WOUDC Data Archives
[Ed Hare, *Canada*]

0920-0935 SCITEC Update
[R. Rösemann, *The Netherlands*]

Session VII UV-B Measurement
Rapporteur [A. Bais]

0935-0950 The Ozone and UV record in Canada
[Jim Kerr, *Canada*]

0950-1005 Homogenizing The Spectral UV Data Of Brewer #107.
[Tapani Koskela, *Finland]*

1005-1020 Eight years of Brewer UV-B measurements at Sodankyla, Finland.
[Kaisa Masson, *Finland*]

1020-1035 Eight years of regular Brewer UV-observations at Hohenpeissenberg: instrumental and climatological results.
[Ulf Koehler, *Germany*]

1035-1105 *Coffee Break*

1105-1120 Calibration of Brewer #088 for UVB measurements.
[Gerry Murphy, *Ireland*]

1120-1135 Cosine correction of global sky measurements using a Brewer Spectrometer.
[Alkis Bais, *Greece*]

1135-1150 Total ozone derived from irradiance measurements with Brewer #042
[A. Dahlback and F. Tønnesen]

Session VIII Aerosol and Other Trace Gases
Rapporteur [J. Kerr]

1150-1205 Use of Brewer Ozone Spectrometer for Aerosol Optical Depth measurements in the UV region
[Fernanda Carvalho and Diamantino Henriques, *Portugal*]

Session IX Umkehr Measurement
Rapporteur [J. Kerr]

1205-1220 A Comparison of Brewer #025 and Dobson #061 Total Ozone and Umkehr Measurements Made at Boulder Between October 1991 and December 1997.
[Gloria Koenig, *USA*]

1220-1235 New Developments in the Brewer Umkehr Algorithm
[Tom McElroy, *Canada*]

1235-1700 *Afternoon break*

Poster Session II

1700-1900 *Posters* and a meeting with Ed Hare concerning the WOUDC.

Friday, September 18, 1998

Session X   Network and Monitoring Programs

Rapporteur [T. McElroy]

0830-0845   The Canadian Brewer Network.
[Tom Grajnar, *Canada*]

0845-0900   Brewer performance as assessed by satellite intercomparison.
[Jim Kerr]

0900-0915   The Performance of Brewer Spectrophotometers in China
[Zheng Xiangdong, *China*]

Session XI   New Developments

Rapporteur [G. Koenig]

0915-0930   New Measurement Methods
[Jim Kerr, *Canada*]

0930-0945   Chappuis Band Ozone Measurements using a Photo-diode Array Spectrometer
[Tom McElroy, *Canada*]

Session XI   Closing Activities

Preparation of meeting recommendations and review of draft report

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[i] Fifth WMO Meeting on Brewer operation , calibration and data reporting.Halkidiki, Greece,16-18 Sept. 1998