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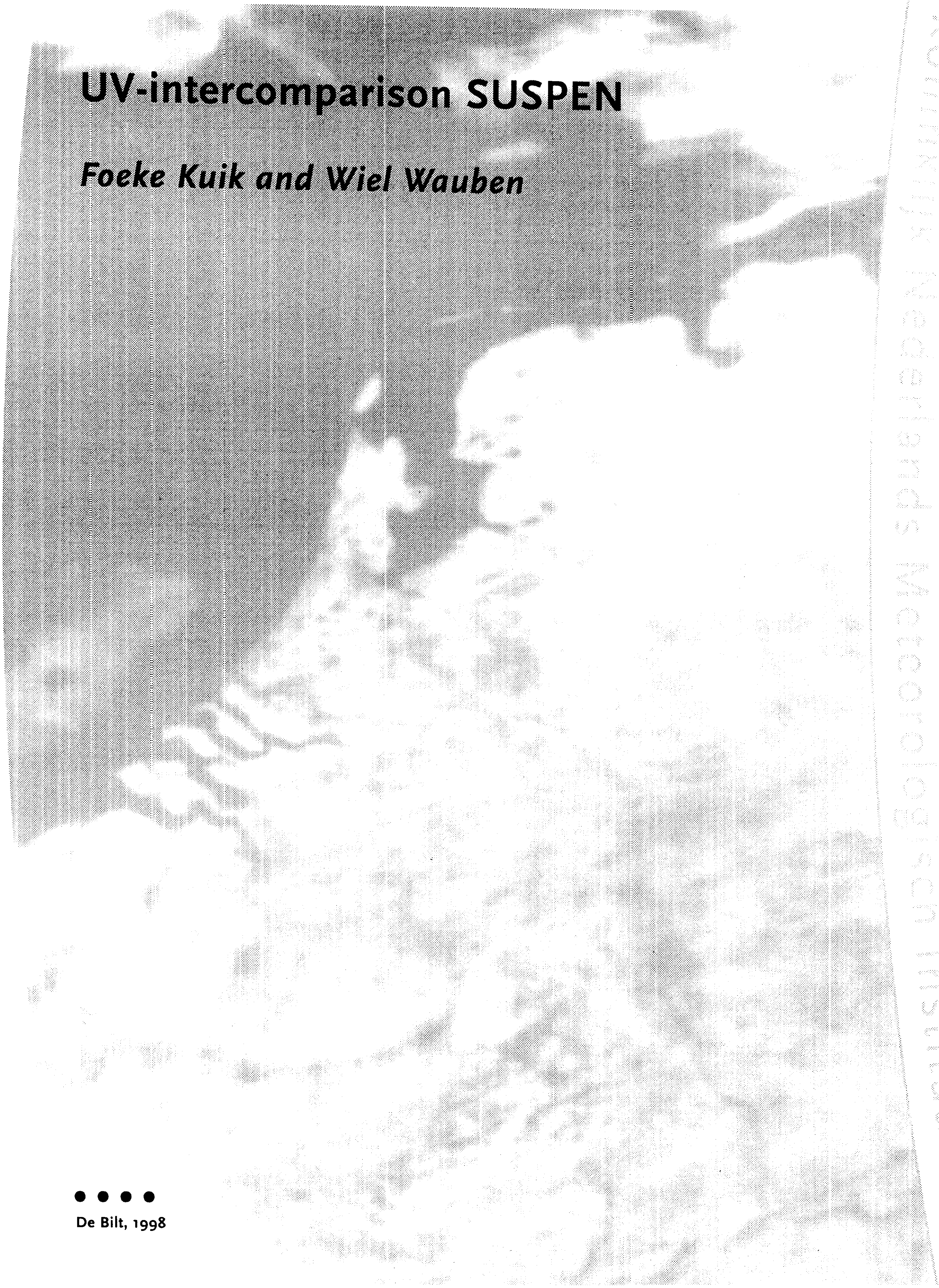
KNMI

UV-intercomparison SUSPEN

Foeke Kuik and Wiel Wauben



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UV Intercomparison SUSPEN

Thessaloniki, July 1 -13, 1997

Foeke Kuik and Wiel Wauben

January 1998

Contents

Summary and Conclusions

In Nea Michaniona, Thessaloniki, Greece, in July 1997 an instrument intercomparison for UV spectrophotometers funded by the EU (SUSPEN) was held. KNMI participated with Brewer #100, and the results of this campaign are discussed in this report. Additionally, in August 1997 Brewer #100 received a new ozone calibration in De Bilt, The Netherlands and various measurements were performed in order to improve the wavelength calibrations for UV scans. This has led to the following.

In general, Brewer #100 has proven to be a good, reliable and stable instrument over the period of 4 years that it is in use at KNMI now. In Thessaloniki it was in 'the reference' on both 'blind days', indicating that it performed well compared to the other instruments.

The ozone calibration has changed by approximately 1% since the installation of Brewer #100 in January 1994. New ETC's are implemented in the Brewer software: 1760/155 and 0.35/1.1707, replacing the old numbers 1754.5/155 and 0.3472/1.1707. The direct sun ozone measurements performed since August 1995 should be reprocessed with the new ETC's because lamp measurements, that are performed frequently to monitor the Brewer calibration, indicate that since that time the calibration has changed.

The Brewer wavelength calibration for UV scans contained several problems. Near the slit change, errors up to ~0.25 nm were found. Based on the analysis of numerous measurements on spectral lamps, 2 important changes has been carried out to improve the wavelength calibration:

- change from slit 1 to slit 5 during a scan at 335 nm in stead of the old 353 nm,
- implement the newly derived dispersion constants for all slits, but most important for slit 1 and 5 (the other slits are not used for UV scans).

The table below shows the new dispersion constants that are implemented for the wavelength calibration now.

Slit	a_0	a_1	a_2
1	2862.90566	0.0743599090	−0.000000663714193
5	3015.04301	0.0693955847	−0.000000552597256

The error s in the wavelength calibrations are now expected to be smaller than 0.03 nm, which is an improvement of roughly a factor 10.

Chapter 1

UV Intercomparison SUSPEN

1.1 Introduction

From July 1, 1997 until July 13, 1997, an international intercomparison for spectral UV instruments was organized by Dr. A. Bais (Aristotle University of Thessaloniki) in Nea Michaniona, near Thessaloniki, Greece. The campaign was funded by the EU and it was named SUSPEN, which is an acronym for *Standardization of Ultraviolet Spectroradiometry in Preparation of a European Network.*

The aim of the project was to achieve and maintain high quality standards in spectral solar ultraviolet measurements performed in Europe, in preparation of the establishment of a European network of UV instruments in the near future. In the previous EU projects several good UV instruments could already be distinguished. One of the objectives of SUSPEN was to enlarge this group of high quality instruments, increase the diversity of the participating instruments and expand the geographical range of the instruments over Europe. To achieve this, several groups were invited to participate, that had not participated in previous EU UV intercomparisons. In addition, groups from New Zealand and the USA were invited. In total 22 groups participated with 19 instruments (see Appendix A for a list of participants).

KNMI was invited to participate in the intercomparison with Brewer #100, an ozone and UV measuring instrument, based on a double monochromator. Two persons from KNMI attended the campaign: Wiel Wauben from the Atmospheric Composition section (AS) and Foeke Kuik from the Instrumental Department (INSA/IO). The instrument was sent to Nea Michaniona by aeroplane, a week before the intercomparison started, and returned a week after the end of the campaign.

In the remaining part of this chapter the procedures and schedule for the intercomparison are discussed, a brief description on a day to day basis of the work that has been done is given, and finally the most important results concerning the KNMI instrument performance from the intercomparison are summarized. The rest of this report discusses the results of the intercomparison in more detail, i.e. irradiance measurements, wavelength calibration measurements (Cd and Hg lamp) and procedures, the measurements of the slit functions with a Cd laser, and a comparison of Brewer #100 ozone measurements with those of two other Brewers.

1.2 The intercomparison

Before the intercomparison started, rules were determined among the participants on 'blindness' of the measurements and the calibrations and the data handling. This meant that the participants were not allowed to discuss calibrations and measurements until the 'blind' part of the campaign had finished. The blind part consisted of almost the entire first week of the campaign, the period in which the instruments arrived, were calibrated in the darkrooms, in which test measurements were performed on the roof, and the 'blind' days with the scheduled measurements. The reason for this blind period was that all instruments had to perform in the best possible manner, in the same way the UV-measurements are performed at the home site. Not being allowed to discuss the above mentioned issues ensured that everyone performed his (or her) measurements independently from the other participants. no persons were allowed on the roof . During the blind days no persons were allowed on the roof in order not to disturb the measurements, except in case of an emergency (and then not during the period in which the UV scans were taken).

1.2.1 Intercomparison site

The intercomparison took place on the roof of the Naval School at Nea Michaniona, approximately 30 km to the south of Thessaloniki. The school is a three story high building located at the coast, with a free horizon (on the roof) in all directions. The roof was about 200 m^2 and had sufficient room to host all 19 instruments. On the story directly below the roof the computer rooms were located where the instrument operators could control their instruments.

1.2.2 Calibration facilities

On the story immediately below the roof, three dark rooms were set up. Two of them were equipped with optical tables and facilities for calibrations with FEL lamps, i.e. for instruments that were calibrated with a horizontal lamp beam. The third dark room was equipped with a setup for DXW lamps, which was used for instruments to be calibrated with vertical lamp beams, such as the Brewer spectrophotometers.

1.2.3 Data acquisition, delivery and analysis

For the actual intercomparison of the whole group of instruments, two blind days were planned. The first UV-scan was scheduled at 3:30 UT (6:30 local time) and the last at 17:30 UT: 29 scans. At every whole and half hour during this period a UV-scan had to be performed from 285 to 365 nm, with a 0.5 nm wavelength step at a 3 seconds interval for each wavelength. The data had to be submitted to the data analysing group before noon the next day.

The data was analysed in several manners:

- all measured spectra were checked for wavelength shifts compared to a reference spectrum,
- all spectra were deconvoluted to eliminate the effect of the individual slit functions; then they were convolved with a triangular slit function again. The comparison of the spectra obtained from the various instruments was performed this way to avoid getting too much noise in the ratios of the spectra,

- from all instruments a group of instruments called 'the reference', was determined. A complicated routine to determine this reference was designed (and previously tested in Ispra, 1995) by B. Gardiner. The routine basically determines the median of all measurements and picks out the instruments that are within certain limits of it. There are some additional requirements for the instruments to get into the reference, e.g. all the scans within a certain period of time must be present. All instruments were compared to the average of the reference instruments.

The slit function from each instrument had to be submitted to the data analysing group before the start of the campaign because it was needed for the data analysis. If available, the cosine response was also requested. It was left to the instrument operators to choose to hand over cosine corrected or uncorrected data.

1.3 Diary

In this section a brief summary is given of the works that has been done during the campaign on a daily basis.

1.3.1 Tuesday, July 1, 1997

Unpacked and brought all equipment to the 2nd story. Set up Brewer #100 in calibration room. Performed calibration with lamp S-833. Three scans were taken. Temperature in darkroom was 40 °C (back home: 20 °C). Brewer installed on the roof, levelled and aligned.

Thessaloniki calibration was found to be 10% lower than the KNMI home calibration. Decided to go into the darkroom again tomorrow to check calibration.

1.3.2 Wednesday, July 2, 1997

Brewer to the darkroom again. Two scans on lamp S-833 at 35 °C. Response curves practically identical to those measured yesterday. Decided to average the 5 response curves obtained today and yesterday to compute the response curve that will be used for the rest of the campaign.

Found out that the Swedish Brewer also suffered from a calibration deviation. Unclear if the Brewers are experiencing so much troubles with travelling by plane or if something is wrong with the darkroom. Alkis Bais tested his Brewer and found satisfactory results. This must mean that travelling by plane does not agree well with 'double Brewers'.

Brewer installed on the roof again.

1.3.3 Thursday, July 3, 1997

Performed various test runs to check the routines we will use for the blind days. Everything seems to work OK, including the analysis programs. Brewer seems stable. The standard lamp ratios (ozone calibration) agree quite well with those measured at home. Ozone calibration seems OK.

1.3.4 Friday, July 4, 1997

First blind day!

Arrived approx. 3:00 UT (6:00 local time). Started with wavelength calibration and 2nd micrometer alignment tests. Everything OK, first scan at 3:30 UT.

In between the UV scans, direct sun ozone measurements are performed, and of course before each scan a wavelength calibration and 2nd micrometer alignment test. All worked well, never missed a scan.

In the 17:00 UT scan a spike was found and corrected. Hardly ever find spikes at home. Seems to be related to the stability of the net power.

1.3.5 Saturday, July 5, 1997

Second blind day.

The same (boring) routine as yesterday. However, The KNMI team is not leaving, as some other groups do after putting the instrument in a measurement schedule. We want to be sure not to miss anything and check the instrument in between scans.

Power break just before the 9:30 UT scan. Brewer starts up again but the initializing routines are not ready in time and this scan is missed. All the other scans are OK. The 10:00 and 17:30 UT scans both show a spike, which are corrected before giving the data to Harry and Brian.

1.3.6 Sunday, July 6, 1997

Roof lamp measurements are performed, but not on the part of the roof where the KNMI Brewer is. The Brewer was put in a schedule to perform ozone measurements and UV-scans (it was agreed amongst the participants to have the instruments doing regular measurements during the periods in which they were waiting to do the roof lamp scans). The lamp measurements take more time than planned and no measurements with Brewer #100 could be made on the lamp this day.

1.3.7 Monday, July 7, 1997

Day off! Joined the excursion to a winery and some very interesting excavations.

1.3.8 Tuesday, July 8, 1997

Meeting with preliminary results. Brewer #100 did OK (2 days in reference), but a shift in the wavelength calibration was found. Checking the constants for the wavelength calibration, we found that the original Sci-Tec constants had been used! We knew that these caused a shift in the wavelength. A newer wavelength calibration should have been used but it is unclear why the file with he old constants still was on the computer.

Decided to take the Brewer into the darkroom immediately after the roof lamp scans are finished and perform measurements for a new wavelength calibration. Unfortunately, due to the hard wind some delay in the lamp measurements and again no measurements with Brewer #100 on the lamp today.

1.3.9 Wednesday, July 9, 1997

Finally did the roof lamp scans around noon. Afterwards took the Brewer down to the darkroom for

- spectral lamp scans (wavelength calibration),

- scans on Cd-laser (slit function).

Tapani Koskela brought his Cd-lamp, which we don't have at home. We decided to do a new wavelength calibration for slit 1 and 5 (both used for the UV-scans) using a combination of Hg and Cd lines. All scans were performed with a wavelength step of 0.01 nm and are very time consuming. Every now and then a power cut (nearby forest fires!) caused the Brewer to start up completely anew with all initializing routines. This caused even more delay.

1.3.10 Thursday, 10 July, 1997

Continued to do scans on the spectral lamps. Finished around noon, and then continued to do scans on the Cd laser (of the German Fraunhofer group) for all 5 slits. The Brewer was put on the floor and the horizontal laserbeam was reflected on the diffuser with an aluminium diffusely reflecting mirror. After some alignment problems all scans were taken successfully (again with 0.01 nm step).

1.3.11 Friday, 11 July, 1997

Finished up the measurements and exchanged data with other groups. Took all the equipment two stories down, packed the instruments and prepared them to fly back.

1.3.12 Saturday, 12 July, 1997

Day off.

1.3.13 Sunday, July 13, 1997

Flew back to The Netherlands.

1.4 The main results for Brewer #100 from the intercomparison

The participation of KNMI with Brewer #100 in the SUSPEN intercomparison has been useful in several ways. It was the second intercomparison where this instrument has been present. To find out how it performs among other spectral UV-instruments still is important as a quality check of the continuous measurements that are performed in De Bilt, The Netherlands. With Brewer #100 in the reference for both blind days the intercomparison was successful.

It was found from the intercomparison of the UV-scans, that Brewer #100 had problems with its wavelength calibration. Various scans on spectral lamps have been performed in Greece and also after returning of the instrument to De Bilt. The procedure to obtain a wavelength calibration for Brewers has been investigated to improve the results. Changes in the UV-scanning routines have been made as a result of this analysis to ensure a better wavelength calibration over the whole measuring range of the Brewer.

It was found at the arrival of the Brewer after the flight from The Netherlands, that the irradiance calibration had changed by approximately 10%. Other Brewers that participated in the intercomparison and that were flown in, suffered the same problem. Brewer operators are confronted with such problems during intercomparisons, which contribute to a better knowledge on the behaviour of the instruments. Sometimes even the causes for such phenomena are found.

The German group brought their Cd laser. It was the first opportunity to make scans for all 5 slits on a Cd laser to determine the Brewer #100 slit functions.

We compared the ozone measurements from Brewer #100 with those obtained with the other Brewers and found good agreement with freshly calibrated instruments. This showed that although Brewer #100 will get a new ozone calibration in August 1997, the measurements are still reliable.

Finally, one of the most interesting things from intercomparisons is that one learns quite a lot by discussing with other people procedures and methods of working. This exchange of information on instrumental operation is extremely valuable and is most efficient during an intercomparison with so many experts present.

Chapter 2

Intercomparison of the blind days

2.1 Introduction

The intercomparison contained a so-called 'blind part'. During this blind part it was for the participants not allowed to discuss instrumental affairs, calibrations, etc., with each other. Neither was it allowed to compare UV-measurements during this period, which, for example, had been performed to test the instrument. This blind period started on July1 and continued officially until the results of the two blind measurement days had been discussed by the data analysis group.

July 1, 2 and 3 were days on which the instruments were unpacked, all kinds of instrumental test were performed and calibrations could be done in the dark rooms. July 4 and 5 were the blind measuring days, with UV-scans scheduled on every half and whole hour, starting at 3:30 UT and ending at 17:30 UT. The preliminary results were made public on July 8, at which time the blind period ended.

The results from the calibrations and the blind days will be discussed now.

2.2 Calibrations

On July 1 and 2, Brewer #100 was in the dark room for irradiance calibrations. The result from a calibration is a so-called response file. This file contains 2 columns. The first column contains wavelengths and the second column the numbers that convert the counts of an uncalibrated UV scan into units of $Wm^{-2}nm^{-1}$.

In Fig. 2.1(b) the response curve (in #counts/($W/m^2/nm$))that was measured in The Netherlands (in December 1996) with calibration lamp S-833, is shown. In the same figure the response curve that was measured in Nea Michaniona with the same calibration lamp is also shown. The Nea Michaniona response curve is the average of 5 individual response curves of which 3 were measured on July 1 and 2 on July 2. The ratios of the individual measurements and the average, varied between $\pm$ 1%. In Fig. 2.1(a) the relative difference between the home response curve and that measured in Nea Michaniona can be seen to vary approximately between 8 to 10.5%. The instrument sensitivity has decreased by this amount coming to Greece.

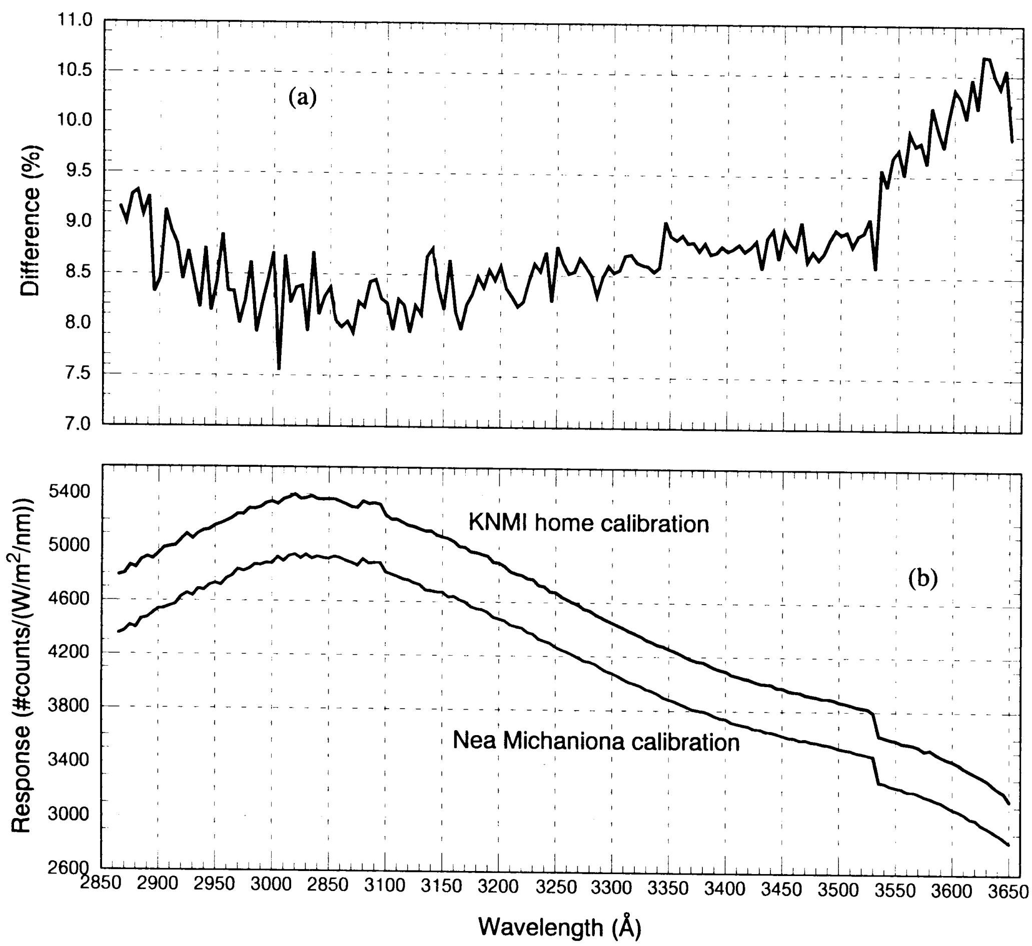

FIGURE 2.1. In (b) the average of 5 individual response curves measurements in Nea Michaniona is shown together with the response curve measured at KNMI in December 1996. Figure (a) shows the difference in percents between the two calibrations.

The calibration history of Brewer #100 starts in 1994 and never displayed differences between consecutive calibrations larger than 1 to 2%. Therefore this large difference found in Nea Michaniona gave cause for some worries.

When an irradiance calibration for the Brewer #100 is performed in the KNMI dark room, the conditions are always kept the same as much as possible. The Brewer is taken to the dark room one day before the actual calibration. It is installed and switched on in the dark room and some tests are performed. If everything is working properly, it is left to acclimatize for approximately 24 hours before the calibration is performed. The dark room itself is temperature stabilized at 20 °C during the whole period of acclimatizing and calibration. The 24 hours waiting period ensures that all the Brewer components will also have this same temperature.

During the calibration in Nea Michaniona, the temperature reading from the Brewer #100 was 41 to 42 °C, approximately 20 °C higher than at KNMI home calibrations. The second day it was a little lower but still 35 °C. From tests that have been performed at KNMI with Brewer #100 in a climate chamber varying the temperature from −10 to +30 °C, it is known that the calibrations have a temperature dependence of a few percent. However, this cannot explain the ~10% difference that was found in Nea Michaniona.

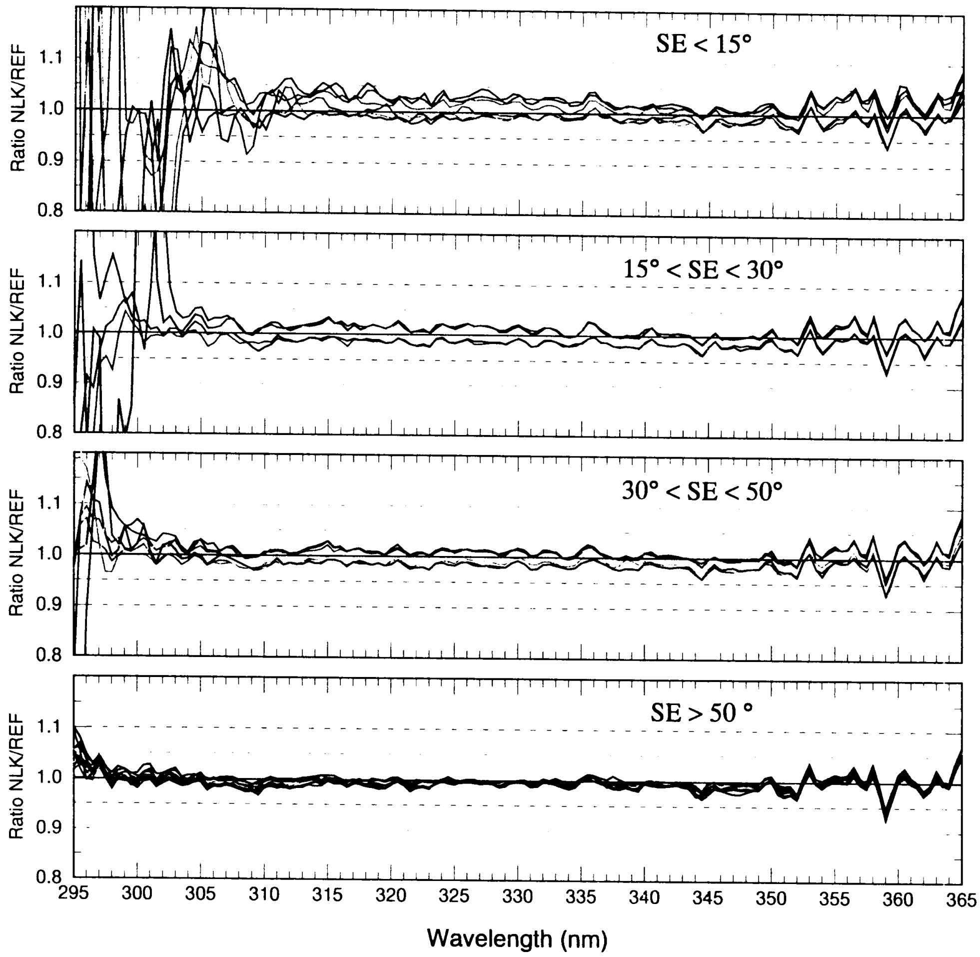

FIGURE 2.2. The ratios of all the UV-scans and the reference for July 4. The 4 graphs are for different ranges of the solar elevations (SE), as indicated in the figures. In total 29 scans are shown.

The equipment in the dark room was supplied by Dr. A. Bais, and it was the same equipment he uses himself for calibrating his Brewer. After the problems with the calibration of the KNMI Brewer, Dr. Bais checked all the equipment in the dark room and everything was found to operate in a correct manner. He also calibrated his Brewer as an additional check and his calibration did not deviate from previous calibrations (within the error margins).

The last possibility that could cause the difference, was that irradiance of lamp S-833 had changed by some 10%. However, in Nea Michaniona it was not possible to check this since only one KNMI 1000W DXW lamp was brought from The Netherlands. Furthermore, there was no visible damage to the lamp and for the time being it was assumed that the lamp had not changed its irradiance output.

It was therefore concluded that the calibration of Brewer #100 really had changed, probably caused by the travelling of the instrument by aeroplane. *During the intercomparison the response curve measured in Nea Michaniona was therefore used to convert the raw UV-scans into calibrated spectral UV-irradiance measurements.*

2.3 Blind day 1, July 4, 1997

2.3.1 Ratio of the spectra and the reference

As was mentioned before, all the instruments were compared to the reference. This procedure shows how the instruments compare to the reference during the whole day, but it is not considered to be an absolute quality mark for the instruments.

In Fig 2.2 the ratios of all 29 UV-scans with the reference are shown for the various ranges of the solar elevation (SE, maximum solar elevation approximately 72.5°). From this figure various things can be concluded.

1. For the low solar elevations the variation around the reference is somewhat larger than for high solar elevations. This probably is caused by the low level of irradiances, resulting in higher levels of uncertainty. This can also be seen at the short wavelengths in the graphs: the wavelength where noise changes into real signal becomes smaller with higher solar elevation.
2. At the short wavelengths up to approximately 355 nm, the ratios show a slight decrease. This indicates that the irradiance calibration of Brewer #100 is also slightly deviating from the reference as a function of wavelength.
3. Above 353 nm there is a sort of discontinuity in the ratios: there is much more structure present than in the wavelength region below 353 nm. This is the location where Brewer #100 changes from slit 1 to slit 5 to scan the last part of the UV spectrum. The wavelength calibrations for both slits are performed independently and therefore the wavelength scale can have this discontinuity feature if the calibration is not correct going from one slit to the next (see Chapter 3).

2.3.2 Diurnal variation

Because the curves in Fig. 2.2 show too much structure to find out if there is a diurnal variation of Brewer #100 compared to the reference, all the spectra, including the reference, have been split up in 10 nm wide intervals for which the irradiances have been integrated. These integrated values for the measured irradiances have been ratioed again with the corresponding values from the reference and plotted as a function of time (UT) in Fig. 2.3.

It can be seen from Fig. 2.3 that the diurnal variation is almost the same for all wavelength intervals. In the morning Brewer #100 produces measurements that are up to 3% higher than the reference and in the evening about 2% lower. A possible reason for this time dependent difference is that the irradiance calibration is temperature dependent. In the top figure the internal Brewer temperature during the measurements is depicted. The calibration was performed at 35-40 °C, and it can be seen from the figure that when the Brewer reaches this internal temperature, the ratio to the reference approaches 1.

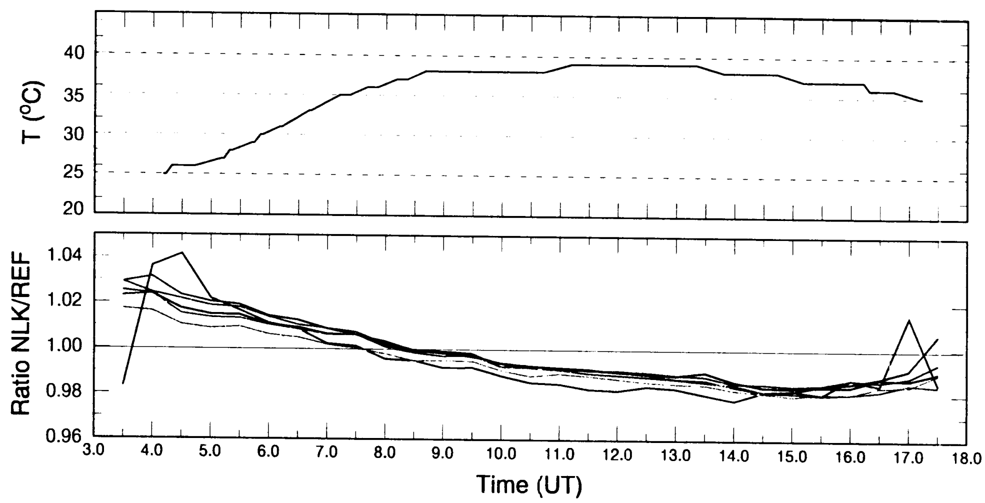

FIGURE 2.3. **The diurnal variation of the 10 nm integrated intervals from 300 to 360 nm, shown as a ratio of the Brewer #100 measurements and the reference. In the top figure the internal Brewer temperature is shown.**

2.3.3 Wavelength shift

The wavelength calibration of all instruments have been checked by deconvoluting the slit functions from the measured spectra and comparing the results with the Kit Peak solar spectrum, which was used as reference. This shift control was performed for a 16 nm running average interval starting at 305 nm up to 365 nm (the last data point in the graph is 365 - 16 = 349 nm). The results of the shift analysis for Brewer #100 is shown in Fig. 2.4. All scans have been analysed and are plotted in this figure for 4 regions of the solar elevation. The shift (in nm) is defined by $\Delta\lambda = \lambda_{\text{Kit Peak}} - \lambda_{\text{Brewer}}$ A positive $\Delta\lambda$ indicates that the Brewer wavelengths are too small, a negative $\Delta\lambda$ that they are too large.

From this figure it can be seen that for low solar elevations there is a small variation in the shifts. For larger solar elevations the shifts are quite stable from one scan to another.

For wavelengths up to approximately 320 nm (interval 320-336 nm) the wavelength shifts for most scans are smaller than 0.01 to 0.02 nm, which is quite good. Then the shifts start to increase up to 0.26 nm in the wavelength region between 320 and 345 nm. Between 345 and 348 the shift decreases and at 349 it has become quite small again. The last few nm show a shift similar to the first part of the spectrum, although in this region the ratio of the Brewer scans and the reference (Fig. 2.2) still show more structure than the rest of the spectrum.

Wavelength shifts up to a few hundredths of a nm are acceptable. The wavelengths of the Brewer #100 spectra are compared with those from the Kit Peak reference spectrum. This is, however, also a measured spectrum with wavelength errors in the order of a few hundredths of a nm. The parts of the Brewer UV spectra between 305 and 336 nm and above 349 nm are good as far as the wavelength calibration is concerned (note that the wavelength numbers in fact represent starting wavelength of the 16 nm averaging interval!). The wavelength calibration between 336 and 349 nm is not satisfactory because shifts up to 0.26 nm are not acceptable.

The reasons for these errors in the wavelength calibration are known and have been corrected. In Nea Michaniona there was the opportunity and the equipment to do measurements for a wavelength calibration. Scans on a Cd and Hg lamp were performed there. Later, in August 1997 the Brewer got a new ozone calibration, at which time the whole instrument was checked thoroughly, including the wavelength calibration. In the next chapter the wavelength calibration and the analysis of the measurements for this new wavelength calibration are discussed in more detail.

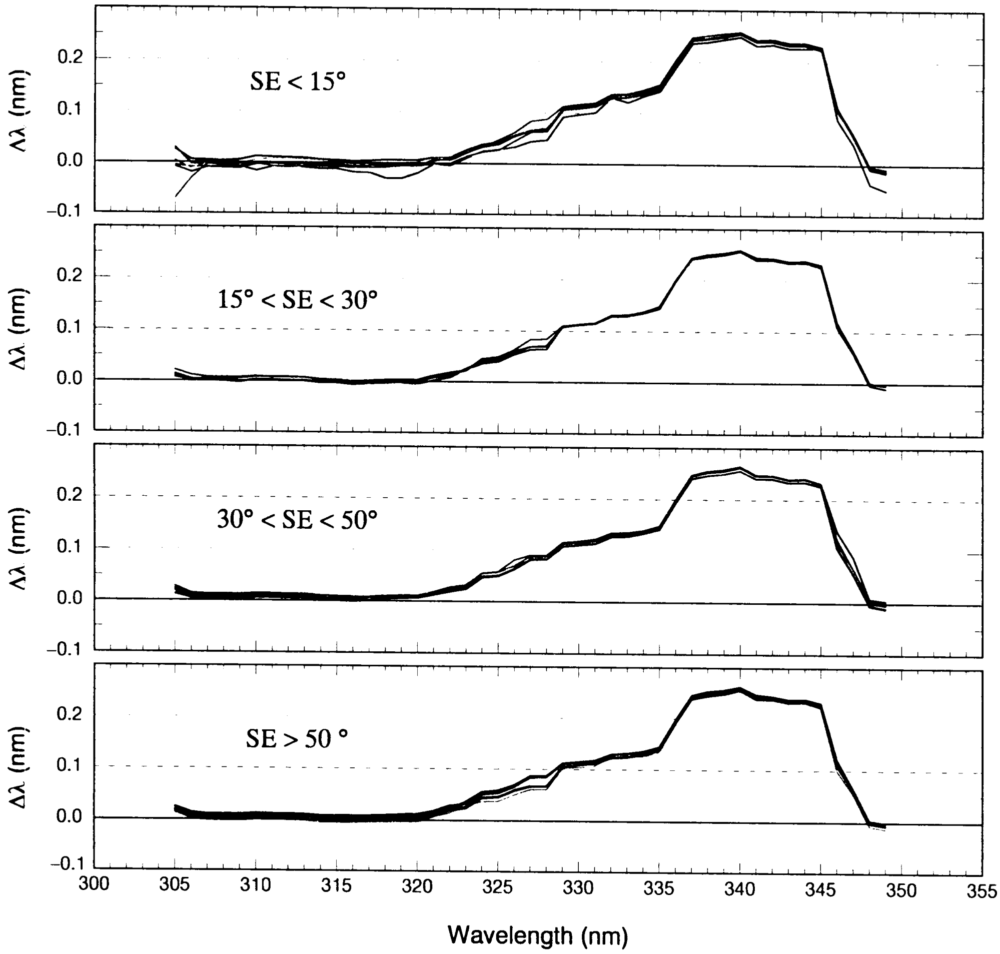

FIGURE 2.4. Wavelength shifts of Brewer #100 compared to the Kit Peak reference spectrum for 4 regions of the solar elevation. $\Delta\lambda = \lambda_{Kit\ Peak} - \lambda_{Brewer}$

2.4 Blind day 2, July 5, 1997

On July 5, the second blind day, the same type of measurements were performed as those of the first blind days. One scan was missed because of a power cut (the 09:30 UT scan). However, almost all instruments missed this scan, except those equipped with a UPS (e.g. the New-Zealand instrument). The Brewer was in the reference again, indicating that it was stable both blind days.

For completeness the same figures that were shown in section 2.3 are also shown here for the second blind day. They do not provide much additional information and are therefore not discussed again.

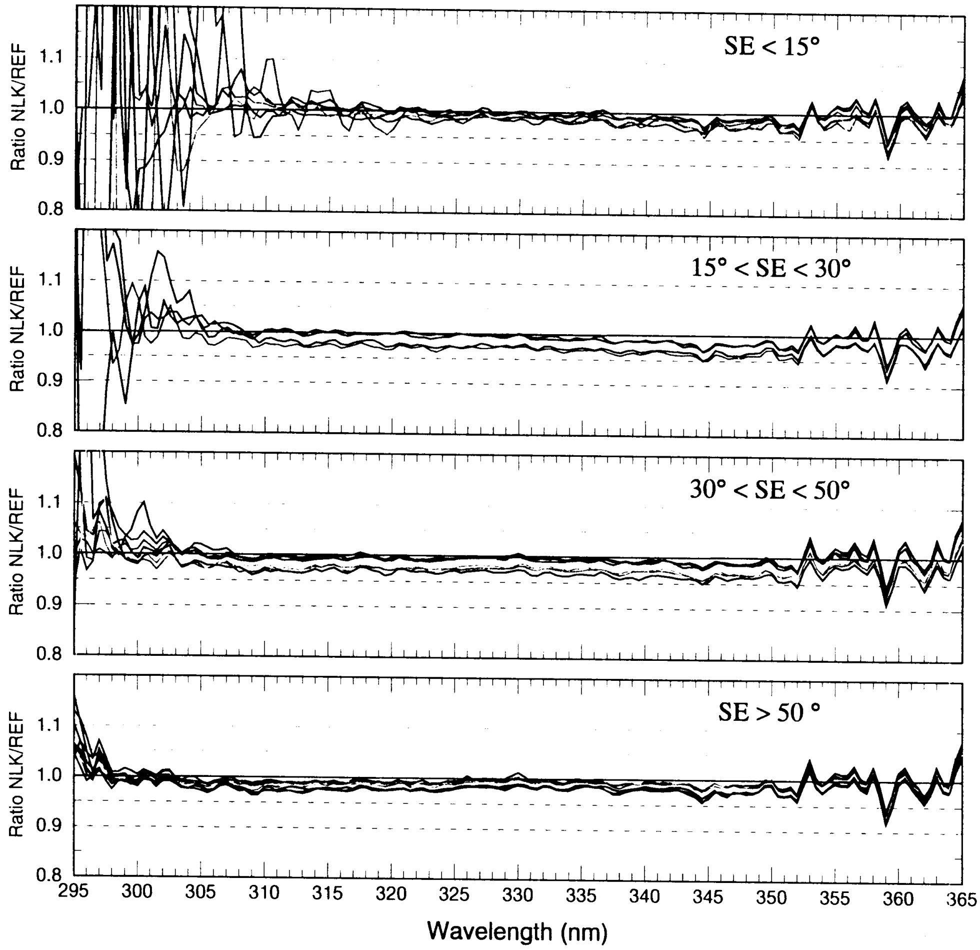

FIGURE 2.5. **The ratios of all the UV-scans and the reference for July 5. The 4 graphs are for different ranges of the solar elevations (SE), as indicated in the figures.**

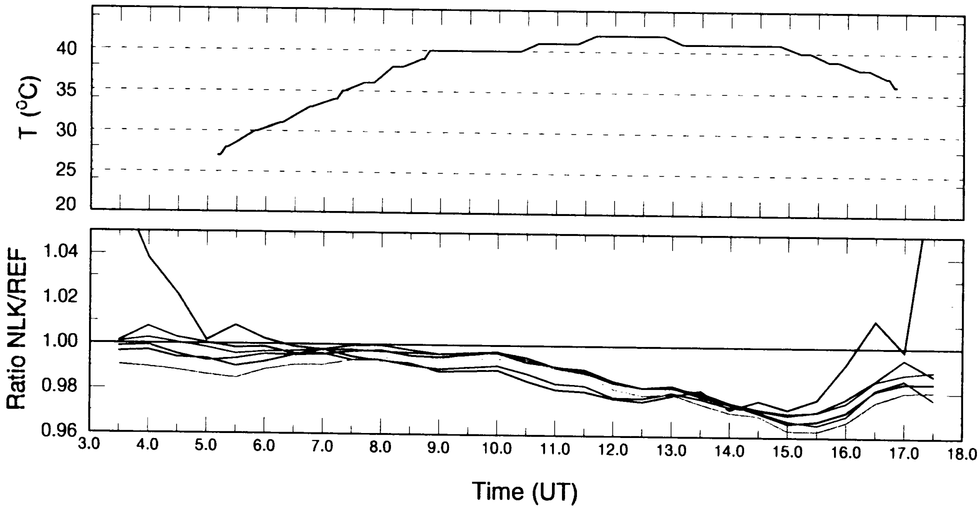

FIGURE 2.6. The diurnal variation of the 10 nm integrated intervals from 300 to 360 nm, shown as a ratio of the Brewer #100 measurements and the reference. In the top figure the internal Brewer temperature is shown.

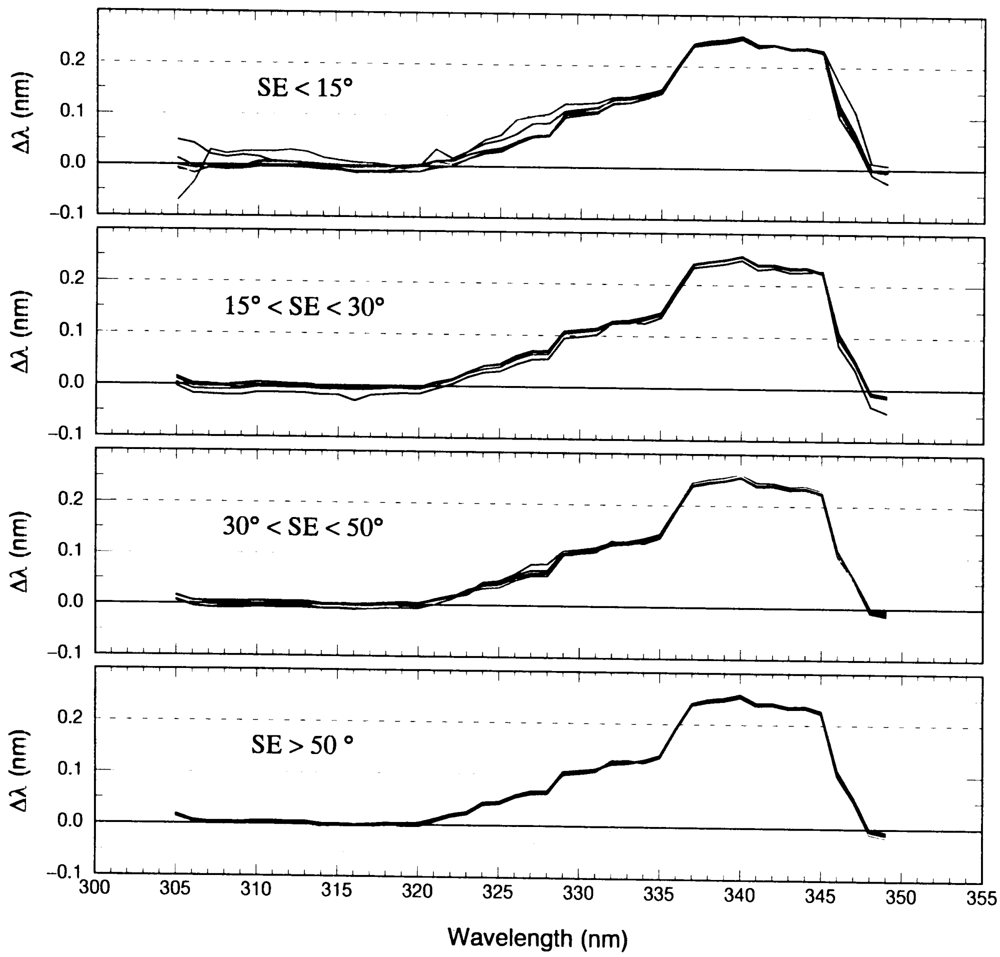

FIGURE 2.7. Wavelength shifts of Brewer #100 compared to the Kit Peak reference spectrum for 4 regions of the solar elevation. $\Delta\lambda = \lambda_{Kit\ Peak} - \lambda_{Brewer}$

2.5 *Concluding remarks*

Several things were learned from the blind intercomparison.

- For the first time Brewer #100 participated in an intercomparison where the temperatures varied between 25 to 40 °C. From the patterns of the diurnal variations it can be concluded that due to the temperature dependence of the irradiance calibrations, a 1 to 2% error can occur. In The Netherlands the Brewer is hardly ever exposed to such high temperatures and errors are expected to be smaller there.
- From the previous intercomparison in Ispra (1995) it was known that the wavelength calibration between 334 and 353 nm posed a problem. It was corrected then, but for an unknown reason the same error occurred in the wavelength calibration during this intercomparison again (probably due to switching to another computer with the old software installed). More extensive tests and new calibrations have been performed after the SUSPEN campaign in August 1997, at the same time when a new ozone calibration was performed.

Chapter 3

Wavelength calibration and slit functions of Brewer #100

3.1 Introduction

In Chapter 2 it was shown that for wavelengths interval averaged over 16 nm between 320 and 349 nm, shifts compared to the Kit Peak spectrum were found up to 0.26 nm, whereas differences up to a only few hundredths of a nm are acceptable.

In this Chapter it will be explained how the wavelength calibration of the Brewer is performed, how the new wavelength calibration has been performed, and finally the slit functions for all 5 slits, which have been measured in Greece with a Cd laser, are shown.

3.2 Procedure of the Brewer wavelength calibration

In doing spectral UV-measurements with the Brewer, the gratings in the two monochromators are rotated, driven by stepper motors. In order to determine at which wavelength one is measuring, the relation between the step numbers of the stepper motors and the wavelength of the UV transmitted to the detector must be known. This relation can basically be determined through a simple calibration procedure. Take spectral lamps having lines in the UV region where the Brewer is scanning. Do a scan with the Brewer over these spectral lines, for which the wavelengths are well known. Then determine the step numbers at which the peaks are found and construct a fit to obtain the relation between the step numbers and the measured wavelengths. For the Brewer a second order polynomial is used to describe this relation for each slit seperately

This is basically the procedure that is followed to obtain a wavelength calibration fot a Brewer. There are however, a few things that have to be take into consideration.

First, there exists a fixed linear relation between the step numbers of the first and second stepper motor, that controlls the postion of the grating of the second monochromator. This is convenient, because it means that only the stepper motor of the first micrometer needs to be calibrated. The first micrometer stepper motor is calibrated as described above.

Secondly, the wavelength region that the Brewer can scan starts at 286.5 nm and ends at approximately 365 nm. The fact that it cannot go to larger wavelengths is due to the mechanical construction of the Brewer (a few mechanical adaptions could increase the upper wavelength with 1 or 2 nm, but it is not considered doing this). The UV-scans are performed with the same slit mask that is used for the ozone measurements, since this is the only way to get light into the photomultiplier. Again, because of mechanical limitations, it is not possible to scan the whole UV-region using one slit, but two are needed. During a UV-scan, the Brewer has to change from one slit to another and usually slit 1 and 5 are used. Slit 1 can be used to scan from 286.5 tot 353 nm, and then slit 5 takes over to scan the remaining part up to 365 nm. The wavelength calibration is different for each slit. Therefore the relation between the stepper motor number and wavelength has to be established twice: once for slit 1 and once for slit 5. As many spectral lines as possible have to be scanned with both slits separately.

3.3 Spectral lamps and lines for wavelength calibrations

At the moment there are several spectral lamps available which provide suitable and less suitable lines for wavelength calibrations. The types of lamps are given in Table 3.1 and the suitability of their spectral lines for wavelength calibration is discussed.

TABEL 3.1. Spectral lines generated by various spectral lamps in the UV region where the Brewer performs UV scans. The number(s) in the brackets in the first column indicate(s) the slit that can measure this line. The lines suitable for calibrations are printed fat.

line	λ (nm)	Remarks
Hg (1)	**289.360**	**weak single line suitable for calibrations**
Hg (1)	**296.728**	**strong single line, excellent for calibrations**
Hg (1,5)	302.150	weak line, also other weak lines at 302.347, 302.561, 302.749 nm, don't use for calibrations
Cd (1,5)	**308.082**	**weak line suitable for calibrations, even weaker line at 308.259 nm**
Hg (1,5)	312.567	strong line, lines similar in strength at 313.155 and 313.184, don't use for calibrations
Cd (1,5)	**313.317**	**strong single line, excellent for calibrations**
Cd (1,5)	**326.106**	**reasonably strong line, suitable for calibrations; equally strong line at 325.252 nm**
Hg (1,5)	**334.148**	**weak single line, suitable for calibrations**
Cd (1,5)	**340.365**	**strong single line, excellent for calibrations**
Cd (1,5)	346.620	strong line, but second line at 346.767 nm little less strong, don't use fro calibrations
Cd (1,5)	**349.995**	**weak single line suitable for calibrations**
Ne (1,5)	352.047	reasonably strong line, but 351.519 and 350.122 nm also clearly visible, don't use for calibrations
Cd (5)	361.051	strong line, but also lines at 361.287 and 361.445 nm, not suitable for calibrations
Hg (5)	**365.015**	**very strong line, other much weaker lines at 365.484, 366.288 and 366.328 nm; difficult to use for calibrations**

From the table it can be seen that in total 9 spectral lines can be used for the wavelength calibration, 8 for slit 1 and 7 are available for slit 5.

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3.4 Known problems with the wavelength calibration

In the original setup of the Brewer and its controlling software, slit 1 is used to scan from 286.5 to 353 nm. Then the slit is changed to 5 and the scan is finished at 365 nm. The original (factory) wavelength calibration was performed only using a Hg-lamp with spectral lines that are given in Table 3.1. It can be seen from the table that the last Hg-line suitable for wavelength calibration for slit 1, is located at 334 nm. The fit through the measurements is a second order polynomial. If there is no calibration point at the ends of the interval of the fit, the second order polynomial tends to 'run away'. This is exactly the phenomenon observed in the wavelength shift analysis that was discussed in Chapter 2. In fact, the fit from 334 to 353 nm for slit 1 is an extrapolation that is not reliable.

Slit 5 does not have this problem. Calibrating the wavelength for slit 5 with the 334 and 365 nm Hg lines, produces reasonably reliable wavelengths. However, the number of lines in the region where slit 5 is measuring, is only 1: the 365 nm line. Therefore, better results can be obtained using additional spectral lines from a Cd lamp.

Finally, the relation between step numbers and wavelength is not really a second order polynomial. After constructing a fit from measurements on spectral lines, there will be small deviations between the measured positions of the lines and the position at which they are found using the fit. These differences are in the order of 0.01 nm.

3.5 Wavelength calibration slit 1

Although 8 lines are available for the wavelength calibration of slit 1, only 6 were measured: the 308 and 349 nm Cd lines have been omitted. The lines were scanned with a wavelength step of 0.01 nm, which is a large oversampling. The scans started about 2 nm before and finished about 2 nm after the centre wavelength of the line (the newer version of the Brewer software has a standard routine to scan spectral lines; however, we could not use it in Thessaloniki and wrote our own line scanning routine on site). The step number corresponding to the centre wavelength, was determined by averaging the step numbers corresponding to full width half maximum count rates. The scans were only performed for an increasing wavelength, not in the backward direction. The fit was performed on SUN-workstation using XMGR, which is a plotting software package, also containing various data analysis routines. The results are given in Table 3.2.

TABEL 3.2. The 6 spectral lines used for the wavelength calibration measurements in Thessaloniki for slit 1. The difference between the literature values of the wavelengths and those obtained with this calibration, are shown in the last column. SN is the step number at which the peak was found.

Lamp	λ (nm)	SN	λ_{meas} (nm)	$\Delta\lambda$ (nm)
Hg	289.360	421.5	289.368	0.008
Hg	296.728	1424.0	296.719	–0.009
Cd	313.317	3760.0	313.310	–0.007
Cd	326.105	5639.8	326.114	0.009
Hg	334.148	6858.4	334.154	0.006
Cd	340.367	7820.9	340.359	0.008

In Table 3.3 the original and new constants are given, where the wavelength (in Å) is obtained from $\lambda = a_0 + a_1 x + a_2 x^2$, and x is the step number.

TABEL 3.3. The old and new wavelength calibration constants (dispersion constants).

Constants	a_0	a_1	a_2
old	2860.60700	0.0755480000	–0.000000798240000
new	2862.35402	0.0746045485	–0.000000690528258

The differences in wavelength between th old and new calibration are plotted in Fig. 3.1 as a function of the wavelength computed with the new constants.

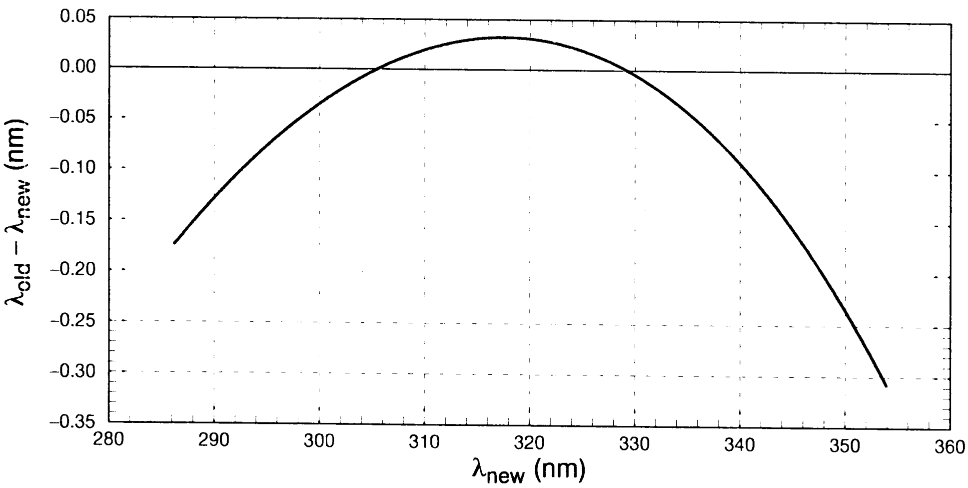

FIGURE 3.1. The difference in wavelength between the old and new calibration as a function of the newly computed wavelengths for slit 1.

It can be seen from this figure that the new calibration produces larger wavelengths below 305 nm and in the region between 330 and 353 nm. From figures 2.4 and 2.7, in which the difference $\lambda_{Kit\ Peak} - \lambda_{Brewer}$ wavelengths was shown, it was concluded that just below 305 nm and above 320 nm, the Brewer wavelengths are too small (positive peak). The new calibration indeed produces wavelengths larger than the old calibration, as can be concluded from the figure. An exact comparison with figures 2.4 and 2.7 is, however, not possible because the wavelength shifts in these figures are averaged over 16 nm intervals and start at 305 nm.

3.6 *Wavelength calibration slit 5*

Although 7 lines are available for the wavelength calibration of slit 5, only 6 were measured: the 308 nm line has been omitted. The procedure to determine the position of the peak wavelengths is the same as described in the previous section. The results are given in Table 3.4.

TABEL 3.4. The 5 spectral lines used for the wavelength calibration measurements in Thessaloniki for slit 5. The difference between the literature values of the wavelengths and those obtained with this calibration, are shown in the last column.

Lamp	λ (nm)	SN	λ_{meas} (nm)	$\Delta\lambda$ (nm)
Cd	313.317	1771.6	313.326	0.009
Cd	326.105	3664.7	326.086	–0.019
Hg	334.148	4897.4	334.142	–0.006
Cd	340.367	6874.5	340.386	0.019
Hg	365.015	9938.4	365.012	–0.003

The Hg 365 nm line has been included in this calibration. Because there are multiple spectral Hg-lines around 365 nm, the shape of the line is not symmetrical, as can be seen in Fig. 3.2. The maximum of this curve has been determined by fitting a spline through the curve and looking at the maximum of that. This resulted in a position of the 365 nm at step number 9938.4. Leaving out

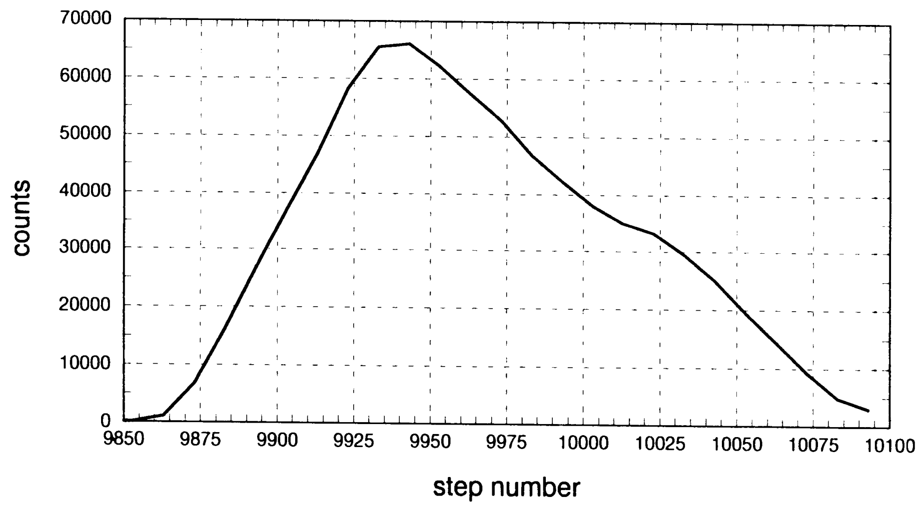

FIGURE 3.2. **The scan of the 365.015 nm line. Due to the asymmetric shape and the presence of multiple lines it is difficult to determine the exact position of the 365.015 nm peak.**

the 365 nm Hg-line in the fitting procedure and afterwards computing the wavelengths from the dispersion constants, resulted in the wavelength of 365.015 nm at step 9991. From Fig. 3.2 it can be seen that this wavelength calibration is running away again. It was therefore decided to use the 365 nm Hg-line, bearing in mind it is not a particularly suitable line for wavelength calibrations.

The wavelength is again obtained from the step number applying the same procedure as for slit 1.

TABEL 3.5. The old and new wavelength calibration constants (dispersion constants).

Constants	a_0	a_1	a_2
old	3008.23000	0.0712438000	-0.000000657229000
new	3009.58545	0.0709702314	-0.000000656011194

The old and new dispersion constants are given in the table below.

The differences in wavelength between the old and new calibrations are plotted in Fig. 3.3 as a function of the wavelength computed with the new constants.

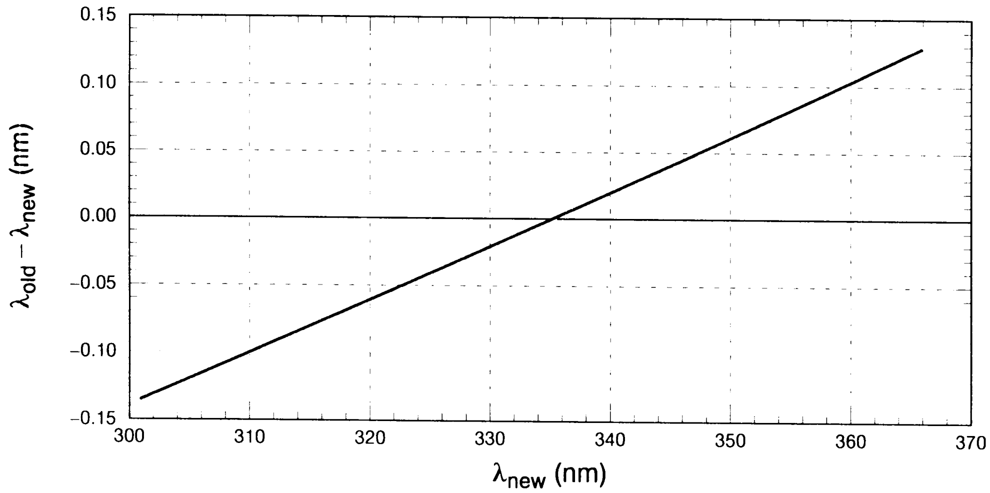

FIGURE 3.3. The difference in wavelength for slit 5 between the old and new calibration as a function of the newly computed wavelengths.

It can be seen from this figure that the new calibration produces larger wavelengths below 335 nm and smaller wavelengths above 335 nm. In figures 2.4 and 2.7 the wavelength shifts are given only up to 349 nm, whereas slit 5 started measuring at 353.5 nm. The 16 nm averaging for the last interval in these figures show that shifts tend to go to negative values, indicating too large wavelengths for the Brewer. The new calibration yields smaller wavelengths than the old one at the same step number (above 335 nm), which is a correction in the right direction.

3.7 Wavelength calibration in The Netherlands, August 1997

During the first week of August 1997, Ken Lamb visited KNMI to perform an ozone calibration on Brewer #100. He also did a series of scans on an Hg and Cd lamp for all slits, using the routine that performs a scan in the forward and backward direction with a increment in step of 10. From both scanning directions the location of the peak was determined, and the final location was taken to be the average of the forward and backward scans. The procedure to determine the location of the peak was the same as described in the previous sections. All measured lines with the corresponding step numbers of the peaks are given in the tables below.

TABEL 3.6. The step numbers at which the peaks of the spectral lines are found for slit 0. The last column contains the difference $\lambda_{literature} - \lambda_{meas}$ in nm.

Lamp	λ (nm)	slit 0			λ_{meas} (nm)	$\Delta\lambda$ (nm)
		forward	backward	average		
Hg	289.3600	853.599	853.729	853.664	289.370	0.0100
Hg	296.7280	1856.19	1856.26	1856.220	296.716	–0.0120
Cd	308.0822	3445.045	3445.02	3445.033	308.078	–0.0042
Cd	313.3167	4193.870	4193.465	4193.668	313.314	–0.0027
Cd	326.1055	6073.225	6073.580	6073.403	326.126	0.0205
Hg	334.1480	7285.905	7285.985	7285.945	334.137	–0.0110
Cd	340.3652	8249.775	8249.905	8249.840	340.364	–0.0012

TABEL 3.7. The step numbers at which the peaks of the spectral lines are found for slit 1. The last column contains the difference $\lambda_{literature} - \lambda_{meas}$ in nm.

Lamp	λ (nm)	slit 1			λ_{meas} (nm)	$\Delta\lambda$ (nm)
		forward	backward	average		
Hg	289.3600	416.477	416.325	416.325	289.375	0.015
Hg	296.7280	1420.69	1420.37	1420.53	296.720	–0.0080
Cd	308.0822	3010.055	3010.235	3010.145	308.073	–0.0092
Cd	313.3167	3758.6	3758.46	3758.53	313.301	–0.0157
Cd	326.1055	5639.625	5639.205	5639.415	326.114	0.0085
Hg	334.1480	6855.92	6856.035	6855.978	334.152	0.0040
Cd	340.3652	7821.255	7821.42	7821.338	340.390	0.0248
Cd	349.9952	9344.305	9343.295	9343.800	349.976	–0.0192

TABEL 3.8. The step numbers at which the peaks of the spectral lines are found for slit 2. The last column contains the difference $\lambda_{literature} - \lambda_{meas}$ in nm.

Lamp	λ (nm)	slit 2			λ_{meas} (nm)	$\Delta\lambda$ (nm)
		forward	backward	average		
Hg	296.7280	884.620	884.217	884.419	296.734	0.0060
Cd	308.0822	2475.175	2475.37	2475.273	308.083	0.0008
Cd	313.3167	3223.415	3223.44	3223.428	313.302	–0.0147
Cd	326.1055	5106.98	5107.21	5107.095	326.107	0.0015
Hg	334.1480	6326.91	6327.35	6327.130	334.146	–0.0020
Cd	340.3652	7295.9	7295.83	7295.865	340.385	0.0198
Cd	349.9952	8825.565	8826.795	8826.18	349.984	–0.0112

TABEL 3.9. The step numbers at which the peaks of the spectral lines are found for slit 3. The last column contains the difference $\lambda_{literature} - \lambda_{meas}$ in nm.

Lamp	λ (nm)	slit 3			λ_{meas} (nm)	Δλ (nm)
		forward	backward	average		
Hg	296.7280	387.266	386.947	387.106	296.733	0.0050
Cd	308.0822	1978.14	1978.295	1978.218	308.081	–0.0012
Cd	313.3167	2727.805	2728.535	2728.17	313.308	–0.0087
Cd	326.1055	4614.245	4614.585	4614.415	326.108	0.0025
Hg	334.1480	5836.505	5836.74	5836.623	334.138	–0.0100
Cd	340.3652	6810.41	6810.69	6810.55	340.388	0.0228
Cd	349.9952	8347.965	8347.705	8347.835	349.985	–0.0102

TABEL 3.10. The step numbers at which the peaks of the spectral lines are found for slit 4. The last column contains the difference $\lambda_{literature} - \lambda_{meas}$ in nm.

Lamp	λ (nm)	slit 4			λ_{meas} (nm)	Δλ (nm)
		forward	backward	average		
Cd	308.0822	1497.135	1496.73	1496.933	308.086	0.0038
Cd	313.3167	2248.5	2248.125	2248.313	313.315	–0.0017
Cd	326.1055	4136.185	4136.42	4136.303	326.102	0.0015
Hg	334.1480	5362.135	5362.295	5362.215	334.135	–0.0130
Cd	340.3652	6339.36	6339.955	6339.658	340.388	0.0228
Cd	349.9952	7883.98	7882.945	7883.463	349.988	–0.0072

TABEL 3.11. The step numbers at which the peaks of the spectral lines are found for slit 5. The last column contains the difference $\lambda_{literature} - \lambda_{meas}$ in nm.

Lamp	λ (nm)	slit 5			λ_{meas} (nm)	Δλ (nm)
		forward	backward	average		
Cd	308.0822	1021.417	1021.129	1021.273	308.105	0.0228
Cd	313.3167	1772.99	1772.85	1772.85	313.308	–0.0087
Cd	326.1055	3665.225	3665.68	3665.453	326.079	–0.0265
Hg	334.1480	4894.485	4895.12	4894.803	334.118	–0.0300
Cd	340.3652	5874.545	5874.855	5874.7	340.382	0.0168
Cd	349.9952	7426.76	7426.935	7426.848	350.042	0.0468
Hg	365.0150	9938.81	9938.22	9938.515	364.994	–0.0210

From these measurements again the dispersion constants have been derived. The are given in the following table.

TABEL 3.12. The dispersion constants for all 6 slits derived from Ken Lamb's measurements performed in August 1997 in De Bilt, The Netherlands.

Slit	a_0	a_1	a_2
0	2830.08618	0.07509798	−0.000000675733903
1	2862.90566	0.0743599090	−0.000000663714193
2	2902.77435	0.0736030184	−0.000000674795891
3	2939.18682	0.0729664329	−0.000000695230698
4	2974.29317	0.0722457942	−0.000000707389740
5	3009.13376	0.0710968067	−0.000000666069934

The calibration for slit 1 looks good: the largest differences between the measured wavelengths and the literature values are approximately ±0.02 nm.

However, the differences for slit 5 are slightly larger: up to approximately 0.05 nm. These differences can be made smaller. Slit 5 is used for UV-wavelengths larger than 353.5 nm. Therefore, the calibration for the region 330 nm to 366 nm is more important than the part between 308 and 330. Disregarding the spectral lines at 303, 313 and 326 nm provides a calibration closer to the spectral lines for wavelengths above 330 nm. The results now become

TABEL 3.13. The step numbers at which the peaks of the spectral lines are found for slit 5. The last column contains the difference $\lambda_{literature} - \lambda_{meas}$ in nm.

Lamp	λ (nm)	slit 5			λ_{meas} (nm)	$\Delta\lambda$ (nm)
		forward	backward	average		
Hg	334.1480	4894.485	4895.12	4894.803	334.148	0.0000
Cd	340.3652	5874.545	5874.855	5874.7	340.365	−0.0002
Cd	349.9952	7426.76	7426.935	7426.848	349.995	−0.0002
Hg	365.0150	9938.81	9938.22	9938.515	365.015	0.0000

The new dispersion constants are

TABEL 3.14. Dispersion constants for slit 5 without the 308, 313 and 326 nm spectral lines included in the calibration.

a_0	a_1	a_2
3015.04301	0.0693955847	−0.000000552597256

3.8 *Check of the wavelength calibrations vs. ozone wavelengths*

The Brewer measures ozone using slit 1 to 5, with the stepper motor set at step number 2751. In the data analysis procedure in the Brewer software, wavelengths are given that correspond to these slits. In the Table 3.15 the values used in the Brewer software are given, together with the values that follow from the dispersion constants in Table 3.12.

TABEL 3.15. The wavelengths that are used for the ozone measurements as implemented in the Brewer software and according to the wavelength calibrations in Table 3.12.

	slit 1	slit 2	slit 3	slit 4	slit 5
software	306.240	310.025	313.474	316.770	319.994
measured	306.245	310.015	313.466	316.769	319.968
difference	0.005	–0.010	–0.008	–0.001	–0.026

All measured wavelengths agree within ±0.026 nm of the software implemented wavelengths.

3.9 *Recommendations*

The wavelength calibrations discussed above are only relevant for the spectral UV-scans (the wavelength calibration for the ozone measurements is independent of that for the spectral UV-measurements). The calibration for slit 1 produces reliable wavelengths over the entire scanning interval from 286.5 to 353.5 nm.

However, slit 5 is more difficult to determine a wavelength calibration for, as was shown here. To perform UV-scans with the best possible wavelength calibration, it is recommended to

- in the UV-scan-routine change from slit 1 to slit 5 around 335 nm,
- use a wavelength calibration for slit 5 without using the 308, 313 and 326 nm spectral lines.

The dispersion constants to be used for Brewer #100 are

TABEL 3.16. The newly recommended dispersion constants for slit 1 and 5.

Slit	a_0	a_1	a_2
1	2862.90566	0.0743599090	–0.000000663714193
5	3015.04301	0.0693955847	–0.000000552597256

In Fig. 3.4 the differences in wavelength are shown between the August 1997 calibration (dispersion constants from Table 3.16) and the original calibration (Tables 3.3/3.5), and the August 1997 calibration with the Thessaloniki calibration (Tables 3.3/3.5).

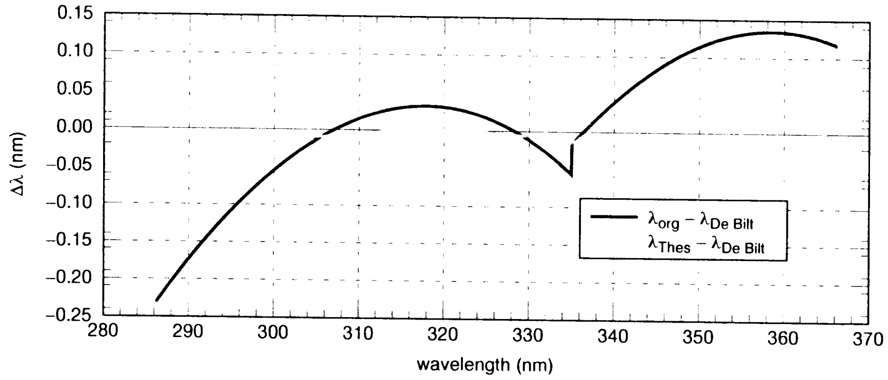

FIGURE 3.4. The wavelength differences between the original calibration and august 1997 calibration (De Bilt), and between the Thessaloniki calibration and the August 1997 calibration (De Bilt).

It can be seen that the original calibration deviates from the August calibration between −0.23 and +0.14 nm. The last 2 calibrations, Thessaloniki and August 1997 (De Bilt), show only small differences. At 349 nm a Cd lines was included in the August 1997 calibration and this calibration can be expected to be better at this wavelength than the Thessaloniki calibration.

3.10 Slit functions

On July 10, 1997, a series of scans have been made on the Cd laser the German group had brought to the campaign. Slit 1 to 5 have been measured using a step increment of 1, corresponding to approximately a 0.007 nm wavelength step. Since only the original Sci-Tec wavelength calibration for slit 2 to 4 were available in Thessaloniki, it was decided to first perform a wavelength calibration for all slits when the Brewer returned to The Netherlands. In the beginning of August Ken lamb visited KNMI to perform a new ozone calibration on Brewer #100. He also installed the new version of the Brewer software, including the routines to perform scans for the wavelength calibrations. The dispersion constants that were the result of this calibration (see section 3.5-3.7) have been used to compute the wavelengths for the scans on the Cd laser for each slit. Note that for slit 5 the calibration with the complete set of available spectral lines was used. The laser line is located around 325 nm and the best wavelength calibration for slit 5 in this region is obtained by also using the spectral lines available in this region for the calibration.

The raw counts from the measurements were dead time corrected, using the same procedure the sky UV scans are processed (deriving the slith widths from the uncorrected measurements produce widths approximately 0.15 nm larger than the corrected scans).

From Fig. 3.5 it can be seen that the wavelength calibrations for all 5 slits are consistent: the location of the maximum intensity is the same for all slits and the shapes of the curves hardly differ. Also the measured intensities are approximately the same for all slits (nornmalized to 1 in the figure). The reason that the shape of the laser line is slightly different for the 5 slits, can be caused

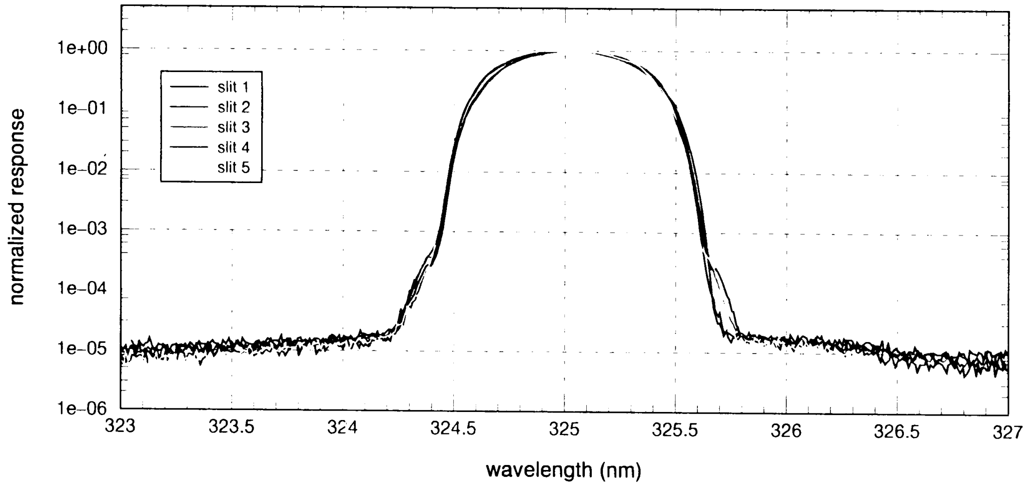

FIGURE 3.5. Slit functions for slits 1 to 5, normalized to the maximum number of counts. The wavelength scale is based on calibrations that were performed in August 1997 in De Bilt, The Netherlands. The measurements on the Cd laser were performed on July 10, 1997, in Thessaloniki.

by physical differences between the 5 slits or by the inaccuracy of the measurements. Repeating the measurements several times is needed to distinguish between the 2 effects. However, KNMI does not have a Cd laser so at the moment no further scans on a Cd laser are possible.

3.10.1 Slit width

From the measurements on the Cd laser the width of the slits has been determined by taking the the FWHM. The results ar given in Table 3.16.

It was noted that these numbers are larger than the previously assumed values for the FWHM, which were based on scans on spectral lines of a Hg lamp. To check these numbers, a closer look was taken at the measurements on the 326 nm Cd lines. In Thessaloniki measurements were performed on this line also with 0.01 nm increment in the wavelength. Ken Lamb scanned the same line in August 1997 at KNMI, but now with a increment of 10 steps, i.e. approximately 0.07 nm. In Fig. 3.6 both scans are plotted. The FWHM derived from these measurements are 0.535 for-both the Thessaloniki the De Bilt scans. The number for all 5 slits are given in Table 3.16.

TABEL 3.17. The slits FWHM derived from measurements on the Cd laser and from the 326 nm spectral line fron a Cd lamp.

slit	FWHM Cd laser (nm)	FWHM Cd 326 nm spectral lamp
1	0.637	0.535
2	0.620	0.531
3	0.658	0.554
4	0.682	0.545
5	0.697	0.542

It was postulated that because of the high intensity of the Cd laser, the photomultiplier was starting to get saturated, which caused the lines to look wider than the realy are. The number of raw

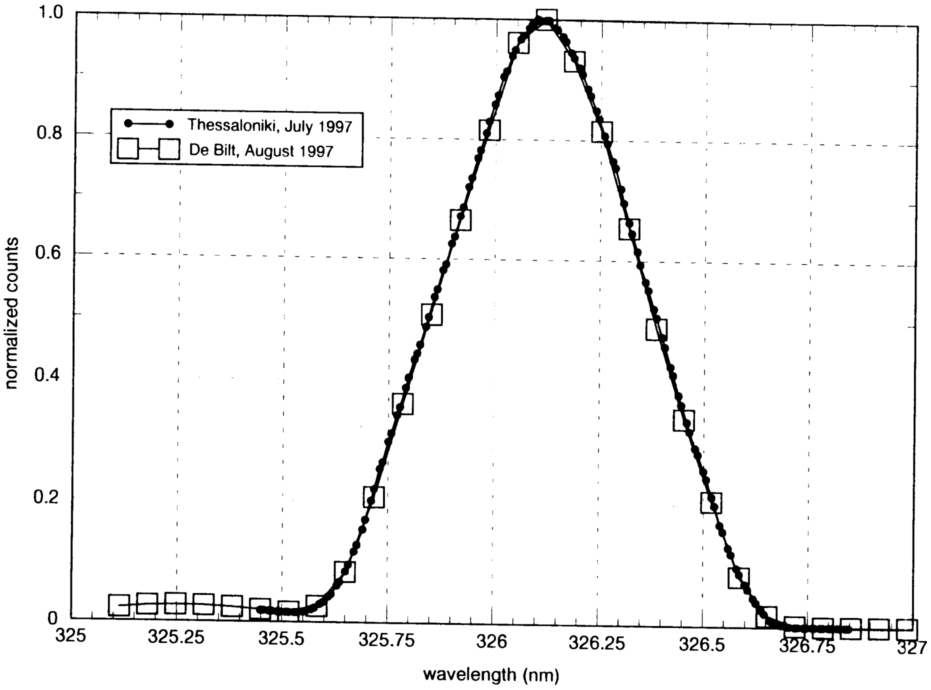

FIGURE 3.6. The Cd 326 nm line scanned through slit 1 in Thessaloniki with a 0.01 nm step and in De Bilt approximately with a 0.1 step.

counts at the center wavelength for the scans in Fig. 3.5 was approximately 450000 for all slits. In Thessaloniki also a scan with a maximum number of counts of approximately 250000 was performed on the Cd laser, with a step increment of 15 (~0.1 nm). Analysing this scan the same manner as the scans in Fig. 3.5 produced a FWHM of 0.559 nm. This is closer to the value obtained from the measurements on the Cd lamp than those derived from the other scans on the laser.

3.11 Concluding remarks

The measurements in Thessaloniki have shown to be very valuable for Brewer #100.

The wavelength calibration was found to contain errors up to 0.25 nm. A new calibration was performed in Thessaloniki and in August again in The Netherlands. Both new calibrations improve the measured wavelengths considerably with respect to the original calibration, and the new calibrations differ only slightly relative to each other. It was furthermore decided to change from slit 1 to 5 at 335 nm so that a good wavelength calibration is guaranteed for the entire scanning region.

The slit functions have been measured using a Cd laser. The results differ if the intensity of the laser is varied. Deriving the slit functions from simple spectral lamps produces the narrowest FWHM, which are close to those measured with a 'low intensity' laser signal. As of yet, no satisfactory explanation has been found for the observed phenomena.

Chapter 4

Ozone measurements during the SUSPEN campaign

4.1 Introduction

During the intercomparison the KNMI, SMHI and FMI Brewers, #100, #128 and #107, respectively, have been measuring the total ozone column. In this Chapter the results of the 3 Brewers are compared and discussed.

4.2 Ozone measurements with Brewers #100, #107 and #128

In between the UV scans the 3 Brewers have performed ozone measurements. Brewers #107 and #128 are 'younger' then Brewer #100, which was last calibrated for ozone measurements in August 1994. In August 1997 Ken Lamb visited KNMI and performed a new calibration. The result of this calibration will be discussed at the end of this Chapter.

In Fig. 4.1 the ozone measurements are shown for the 2 blind days. In the graph only direct sun measurements are depicted. Each point in the graph is the average of 6 direct sun measurements that are taken immediately after each other. The error bars are the standard deviation of the averages.

On both days the measurements performed with Brewer #100 at low solar elevations, are approximately 1% higher than those of the other Brewers. At high solar elevations the 3 instruments show good agreement, although on July 4 between 11 and 12:00 UT, Brewer #100 again produces ozone columns a few DU lower than the other 2 instruments. However, in this period the standard deviations of the measurements are also relatively large in the Brewer #100 measurements, indicating some instability in the measurements.

From the figure it can be seen that the Brewer #128 measurements at low solar elevation deviate from the other two instruments. The time period both in the morning and evening where this feature is observed, correspond to air mass factors larger than approximately 2. Brewer #100 and #107 still can produce good ozone measurements for air mass factors up to 3.5. Probably the sensitivity of Brewer #128 in the range of the ozone wavelength is lower than that of Brewers #100 and #107.

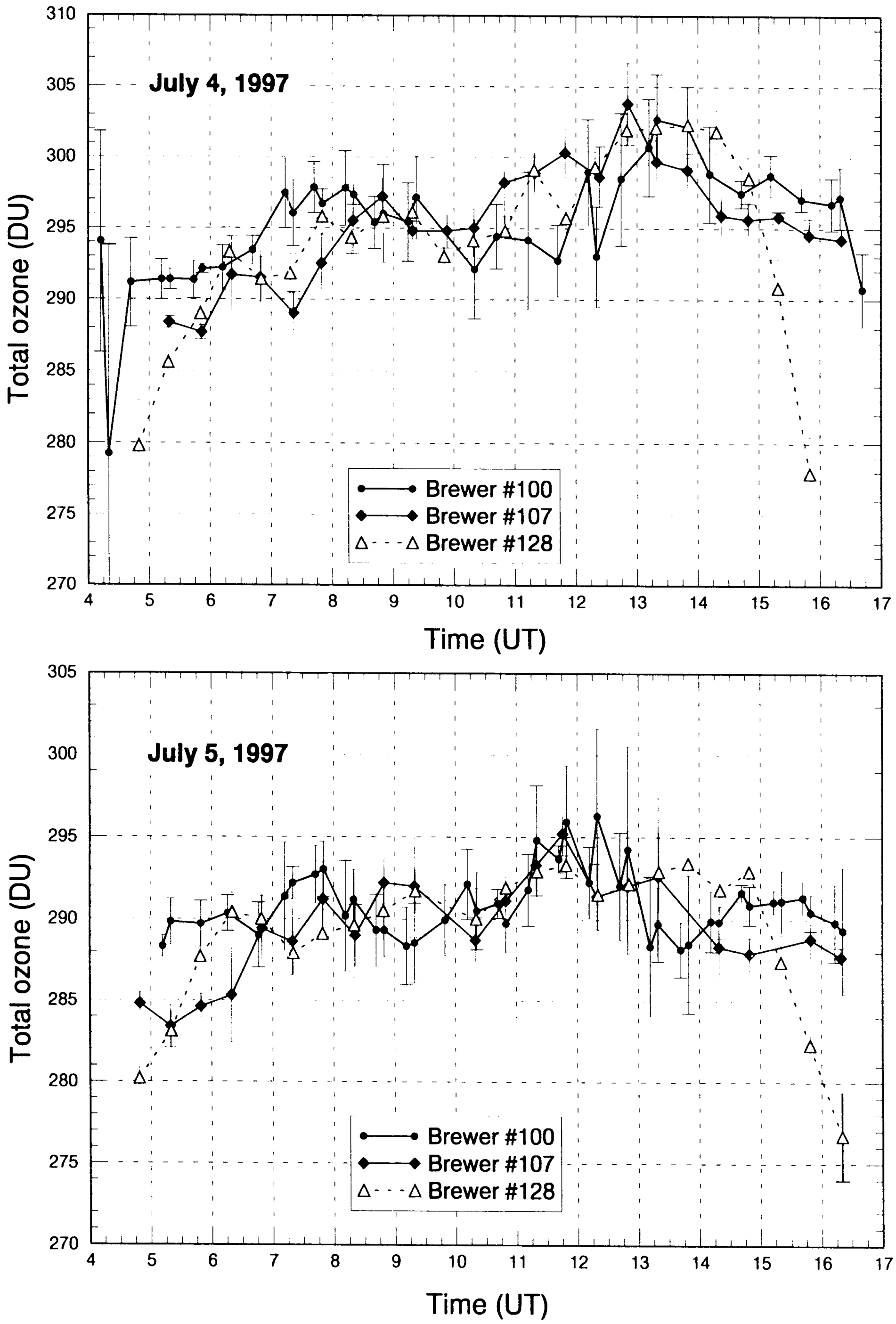

FIGURE 4.1. Ozone measurements of the 3 'double' Brewers for the 2 blind days.

4.3 Calibration Brewer #100

The ETC (extra-terrestrial) constants for Brewer #100 derived in the 1994 calibration are 1754.5/155 and the absorption coefficients 0.3472/1.1707. The lamp ratios R6 and R5, which in principle should be instrument constants, had the values 490/700 when the Brewer was first installed in De Bilt, in January 1994. In August 1995, one week after the EU intercomparison in Ispra, these number changed to 520/770. This was an indication that the ozone calibration could have changed in the order of 1%. However, at that time it was not possible to calibrate Brewer #100, and it has been measuring with the same ETC's until August 1997.

From August 5 to 8, 1997, Ken Lamb brought travelling standard Brewer #017 to Brewer #100 at KNMI in De Bilt. The weather was near perfect for three days during this period and approximately 175 direct sun measurements were taken for calibration purposes. From these measurements Langley plots have been made from which new ETC's have been derived. The numbers for the 3 days have been averaged, resulting in 1760/155 and 0.35/1.1707. This change in ETC's is consistent with the change in the raitos R5/R6, that occured in August 1995.

In Lamb's calibration report[1] the ozone measurements for the 3 days are processed with both old and new ETC's. The result is that for air mass factors larger than approximately 1.5 (solar elevations < 40°) the ozone readings become approximately 1% lower with the new ETC's than with the old ones. For air mass factors < 1.5, the difference between the ozone columns derived with the old and new calibration in general differ less then 1%.

For the ozone measurements in Thessaloniki air mass factors > 1.5 correspond to the period before approximately 6:00 UT and after 14:00 UT. Looking at Fig. 4.1, it can be observed that during these periods Brewer #100 produces higher values for total ozone than #107 and #128. The Finnish instruments in these periods produced measurements that were more accurate than those obtained with Brewer #100, although the difference is only in the order of 1%. Brewer #128 experiences problems with its sensitivity for these air mass factors, which causes the measurements to be unreliable there altogether.

4.4 Conclusions

New ETC's are implemented in the Brewer software: 1760/155 and 0.35/1.1707, replacing the old 1754.5/155 and 0.3472/1.1707.

The measured ozone columns will be approximately 1% lower for air mass factors > 1.5 compared to the old calibrations. For smaller air mass factor the differences will be smaller.

The ozone measurements that have been performed since the change in the lamp ratios R6/R5, i.e. since August 1995, should be reprocessed with the new ETC's.

In general, Brewer #100 has been a stable instrument concerning the ozone measurements over the last 4 years. A change in calibration of 1% may be considered as a good performance. Watching the lamp ratios R6/R5 closely, provides continues information on the stability of the calibration. Continuing this procedure in the future, KNMI will be provide with good ozone measurements during the next coming years.

1. *Calibration Report: Brewer #100 - De Bilt, Netherlands Aug. 5-8, 1997*, Ken Lamb, Januari 1998.

Appendix A: List of Participants

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