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FIRST SOUTHERN HEMISPHERE INTERCOMPARISON OF MEASURED SOLAR UV SPECTRA

R. L. McKenzie[1], M. Kotkamp[1], G. Seckmeyer[2], R. Erb[2], C. R. Roy[3], H. P. Gies[3] and S. J. Toomey[3]

Abstract. Three UV spectroradiometers from the National Institute of Water and Atmospheric Research (NIWA) New Zealand, the Fraunhofer Institute (IFU) Germany, and the Australian Radiation Laboratory (ARL) Australia were intercompared at Lauder NZ on 23 February 1993. Over the spectral range 290-400 nm, the agreement between the IFU and NIWA instruments was better than 5%. At noon on this day, the irradiances measured by all three instruments agreed within ±10%, except at wavelengths shorter than 300 nm, where the ARL instrument gave higher readings. At larger solar zenith angles (SZA) the differences at short wavelengths were more pronounced, and at wavelengths above 300 nm the ARL measurements were systematically lower. The reasons for these differences are discussed. Having established the differences between the sets of instrumentation, spectra of maximum clear sky UV irradiances observed by these groups in New Zealand, Australia, and Europe are compared. The erythemally weighted irradiance observed in Melbourne Australia was the highest (0.35 W m^{-2}). Respective maxima for Lauder NZ and for Neuherberg Germany were 85% and 66% of that in Australia. Differences are larger for DNA-weighted UV.

Introduction

Ozone in the atmosphere is an effective shield that blocks significant amounts of harmful UVB radiation from reaching the Earth's surface. When it became apparent that global ozone levels were decreasing, programmes were initiated to monitor changes in the spectrum of UV reaching the surface, and to study the parameters that influence it.

Instruments to measure the spectrum of solar UV irradiance are complex, and careful procedures must be followed to maintain their calibration so that they remain radiometrically stable over a wide dynamic range, accurately aligned in wavelength, and insensitive to out-of-band radiation [*Kostkowski et al.,. 1980*]. Recent intercalibrations have shown that these requirements are not always achieved, and large instrument-to-instrument differences have been seen [*Gardiner and Kirsch, 1992, 1993; Gardiner et al., 1993*]. Some of these differences are due to variations in angular sensitivity of the instruments. Usually they are designed to have a cosine weighting, but in practise this is difficult to achieve. In addition, the irradiance standards adopted must be traceable to the same standard. Consequently, it has been difficult to compare data from different geographic locations.

In an effort to overcome this limitation, groups from Australia (ARL), Germany (IFU) and New Zealand (NIWA) participated in a measurement intercomparison at Lauder, Central Otago, NZ (45°S, 170°E). Spectral measurements of UV have been made at this site for several years. Ozone data is also available from a Dobson instrument and from weekly balloon soundings. All three groups had previously published results of spectral data in the scientific literature.

Here we report results of intercomparisons made on a single day, 23 February 1993. This day was not perfectly clear, but there were periods with <1/8 cloud cover, which remained close to the horizon and provided stable conditions for the intercomparison. The ozone column amount was 249 DU. An extended intercomparison between the German and New Zealand groups, investigating long term changes over the summer and errors due to departures from the ideal cosine response of the instruments is in preparation.

Instrumentation and Data

The instruments, which have been described previously [*McKenzie et al., 1992; Seckmeyer, 1989; Roy et al., 1989*], and methodologies used by each group are quite distinct.

Table 1. Instrument specifications during the comparison. NEP is the Noise Equivalent Power due to photon statistics.

Instrument	NIWA New Zealand	IFU Germany	ARL Australia
Entrance optic	PTFE diffuser	Quartz diffuser	Integrating sphere
Cosine corrected	yes	yes	no
Coupling	direct coupled	quartz fibre	liquid light guide
Spectrometer	Jobin Yvon	Bentham	Spex
-model	DH10	M300HR	1680B
Slit width(mm)	.25,.5,.25	1.48 (x3)	0.5,10,0.5
Slit height(mm	)2	20	20
Focal length(mm)	100	300	220
Focal ratio	f/3	f/4.2	f/4
Grating	concave	plane	plane
-type	holographic	holographic	ruled
-ruling(mm^{-1})	1200	2400	1200
-dispersion(nm/mm)	4.0	0.675	1.8
Detector(EMI)	9804QA	9205QB	9635QA
Wvl range(nm)	290-450	285-410	280-400
Sample step(nm)	0.2	0.5(1, λ>320)	1.0
FWHM bandpass(nm)	1.12	0.98	1.0
Scan period(sec)	200	240	540
NEP(μW/m^2/nm)	10	1	10
Temperature stab(°C)	36±2	20.0±0.5	unstabilized
Reference standard	NIST	NPL	NIST/CSIRO

[1] NIWA-Atmosphere, Lauder, New Zealand
[2] IFU, Garmisch-Partenkirchen, Germany
[3] ARL, Yallambie, Australia.

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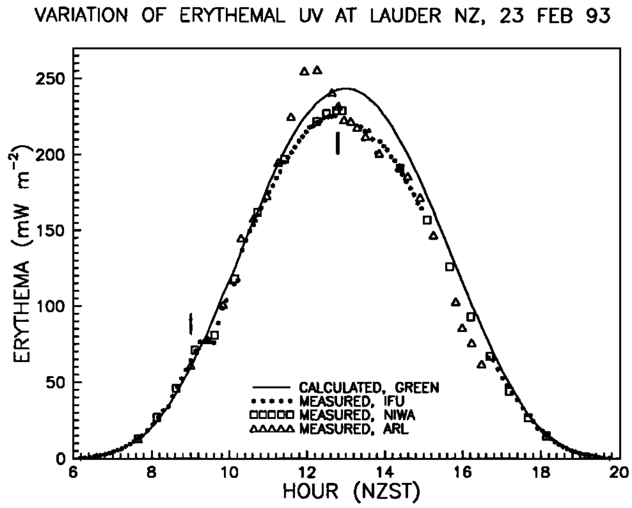

Fig. 1. Time variation of erythemally weighted UV irradiance at Lauder, 23 Feb 1993 measured by the 3 groups and calculated with an adaptation of the Green model.

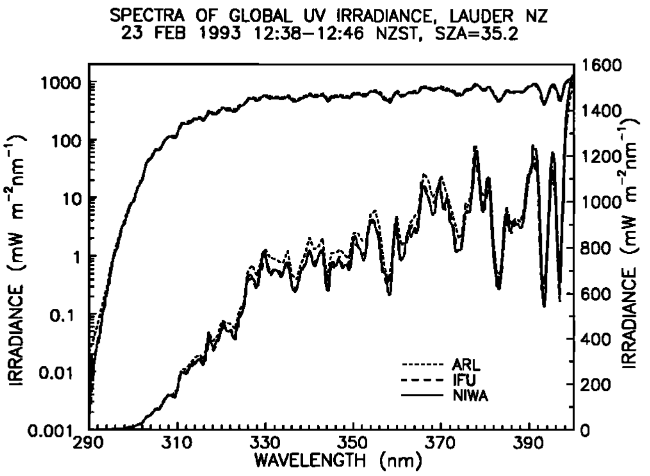

Fig. 2. Solar UV irradiance measured at 12:45 NZST, solar zenith angle 35.2°, by the three instruments. Upper curves refer to the logarithmic scale on the left. Lower curves refer to the linear scale on the right.

Relevant instrument parameters are listed in Table 1. A new quartz fibre was used in the IFU instrument.

The periods of availability of spectral data from each instrument are shown in Figure 1, where the available erythemally-weighted irradiances during the day are plotted. This figure shows that the results from the three instruments generally agree at the 10% level. Three scans made by the ARL instrument between 11:30 and 12:15 showed irradiances that were apparently too large. Later investigations showed that these outliers were caused by departures from a true cosine response for that instrument caused when sunlight entering the sphere was reflected directly from one wall of the sphere to the exit port. Normally several reflections are required.

Values calculated with an adaptation of the Green model [*Schippnick and Green, 1982*] are also shown. Generally, this model agrees well with measurements for clear-sky conditions [*Seckmeyer and McKenzie, 1992*]. On this day however, the measured irradiances are generally lower, presumably because of clouds. The total irradiance (300 - 2500 nm) measured at noon with a Kipp and Zonen solarimeter (model CM11) was 870 W m^{-2}, 10% below its typical clear-sky value at this location and SZA.

Periods of elevated, or variable UV irradiances are apparent in the morning. These periods were not considered for closer analysis because of the possibility of intensity changes during the scan. In the erythemally weighted irradiances shown, noise due to changing cloud cover is reduced compared with observations at single wavelength. For example, the noise in the 400 nm irradiance (not shown) is 20% around 10:00 NZST (NZST = GMT + 12). Other periods were discounted because not all instruments were operational (eg calibrations of IFU instrument between 15:00 and 16:30 NZST). A diffuse-sky observation was made with this instrument just after local solar noon. The data selected for closer spectral analysis is marked on the plot.

Comparison of simultaneously measured spectra

Two spectra were selected for closer inspection. These were at midday, and at the largest SZA available.

The "midday" spectra shown in Figure 2 show good agreement in irradiance and in wavelength alignment. The measured irradiances span several decades so, to highlight differences, ratios were considered. Ratios of the data in Figure 2, referenced to the NIWA data (which has the smallest sampling step), are shown in Figure 3. There is noise in the data due to slight differences in spectral resolution, small wavelength alignment errors, and possible non-linearities in the wavelength drives. Wavelength alignment in the NIWA and IFU instruments is by correlation-alignment of observed spectra against a solar reference, with a precision of ±0.01 nm for the NIWA instrument, and ±0.1 nm for the IFU instrument. Non linearities are also corrected, but systematic errors of ±0.1 nm are still possible. No correction for wavelength non linearities is made for the ARL instrument, for which these wavelength uncertainties are less than 0.1 nm.

Noise in the ratios is at the 5% level, but the mean differences between measurement systems is remarkably good. At all wavelengths above 293 nm the mean difference

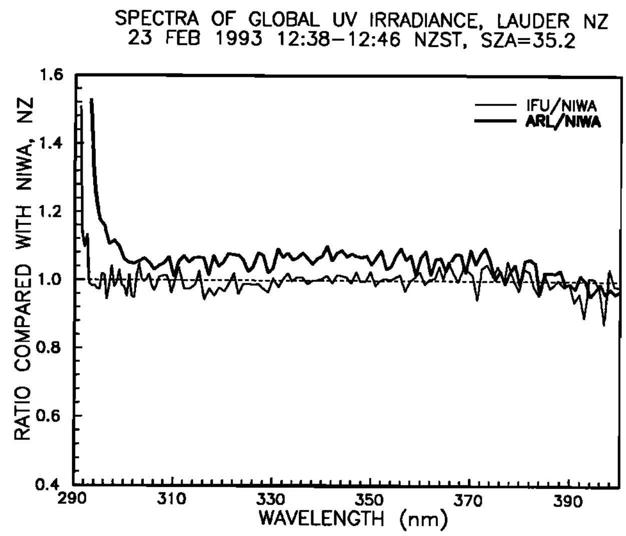

Fig. 3. Ratio of spectra shown in Figure 2, SZA = 35.2°.

between the NIWA and IFU instruments is less than 2%. The ARL instrument readings are approximately 7% higher, except at wavelengths below 302 nm where they increase markedly. This increase may be due to the broader intermediate slit (table 2) for this instrument, which results in line profiles which are higher in the wings. The slit function of each instrument was measured during the campaign using a mercury vapour lamp. The NIWA instrument had the broadest band pass FWHM (full width half maximum). However, the contribution from the wings is also important. On the long wavelength side of the strong Hg 254 nm line, the wing contribution is approximately 10 times greater for the ARL instrument than for IFU instrument. The wing contribution for the NIWA instrument is intermediate.

Other periods when suitable data were available from all three instruments are limited (Figure 1). However, apart from the period noted above, there is similar agreement to that shown in Figure 2 between pairs of instruments over a range of SZA up to 42°.

The irradiance ratios at the largest SZA available are shown in Figure 4. Here the agreement is poorer but, considering the difficulty of the measurements and recent intercomparison results [*Gardiner and Kirsch, 1992, 1993; Gardiner et al., 1993*], the agreement is satisfactory. Larger differences than in the noon comparison are expected. Non-simultaneity becomes important (see Figure 1), and at larger angles, differences in the cosine-weighting of the instruments must also be considered. The ARL instrument has an integrating sphere, whereas the NIWA and IFU instruments have diffusers. For these last two instruments, a correction for departures from the ideal cosine response has been applied. This correction is based on the measured errors in the cosine response. Simple models [*Schippnick and Green, 1982; McKenzie 1991*] are used to deduce the wavelength-dependent proportion of scattered light, which is assumed to be isotropic. The correction is small for noon conditions (+2% for NIWA and +5% for IFU instruments), but increases at larger SZA. At SZA = 60° the corrections in the UVB region are +5% and +8% respectively for the NIWA and IFU instruments. These corrections improve the agreement between these two instruments at noon, but force them to diverge slightly for the SZA = 60° comparison. No correction is applied to the ARL instrument, which gives irradiances 10-15% lower, at wavelengths above 300 nm. Below 300 nm, the ARL values again increase systematically compared with the other instruments. Below 296 nm, the NIWA instrument reads lower than either of the others.

Some of the features in the ratio spectra are common to both observation periods. For example, the minima at 393 nm and 397 nm seen in the ratio IFU/NIWA (maxima in the ARL/NIWA ratio), correspond to the deep Ca doublet (393.6, 396.8 nm) in the solar spectrum, and are probably due to differences in the details of the instrument band passes, or slight alignment errors.

Similar differences are seen between the instruments at larger SZA in the afternoon, indicating that the ARL instrument could be improved by characterizing its cosine response, and applying a correction to the data.

The NIWA and ARL instrument were calibrated using FEL 1000 W lamps referenced to the NIST (USA) standard, whereas the IFU instrument calibration is traceable to the NPL (UK) standard. The good agreement between the NIWA and IFU instruments indicates that there must be good agreement between these calibration standards, and their transfer. This was verified by comparing the outputs of the calibration lamps used by each group, which were found to agree at the 2% level.

Geographic Comparison of Spectra

The results of this intercomparison were applied to comparing UV spectra measured at locations where measurements have been made for extended periods over the summer months by these three groups. In this comparison, the maximum spectrum measured during clear skies at each site was identified. Larger irradiances at each site are occasionally observed during partly cloudy conditions. However, these were avoided in this comparison because intensity changes during such scans can distort the spectra. To take account of calibration differences, the irradiances measured by ARL group have been scaled down by 7%. All

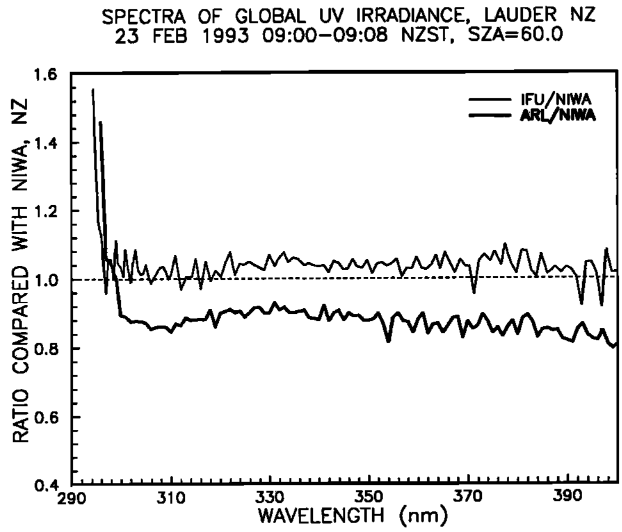

Fig. 4. Ratio of spectra measured at 9:05 NZST, SZA = 60°.

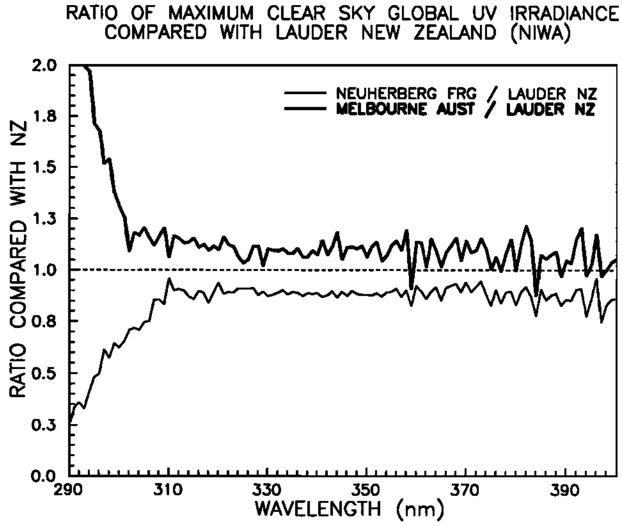

Fig. 5. Ratios of maximum clear-sky spectra measured at Melbourne Australia (ARL) and Neuherberg Germany (IFU) compared with Lauder New Zealand (NIWA). The ARL data has been reduced by 7%.

Table 2. Geographical comparison of maximum clear sky UV irradiance (W m^{-2}). Normalization at 300 nm for DNA-weighted and 297 nm for erythemally-weighted values.

Location	Neuherberg Germany	Lauder NZ	Melbourne Australia
Date	13-Jul-90	28-Dec-92	29-Jan-93
SZA (°)	26.3	21.8	19.8
Ozone (DU)	310	278	259
UVA (315-400nm)	56.0	64.1	69.4
UVB (280-315nm)	1.75	2.12	2.63
UV Eryth Weighted	0.232	0.298	0.350
UV DNA Weighted	0.130	0.191	0.242

the data presented was obtained at small SZA, so differences in cosine responses between the instruments are unimportant. The differences, shown in Figure 5, are larger than the intercalibration uncertainties, and are due to differences in sun-earth separation, SZA, ozone, and aerosols. Differences between the three spectra are largest at short wavelengths where ozone absorption, and scattering losses are largest. At wavelengths greater than 340 nm ozone absorption is negligible. Scattering losses by air and aerosols reduce with increasing wavelength.

The quantitative differences in UV depend critically on the weighting function that is applied to the spectra. For example, comparisons between erythemally-weighted [*CIE, 1987*] and DNA-weighted [*Caldwell, 1986*] irradiances are shown in Table 2.

The maximum clear-sky erythemally weighted UV irradiance measured in Melbourne Australia is 17% greater than at Lauder New Zealand, and is 50% greater than in Europe. The Lauder measurement is 28% greater than in Germany and is consistent with that previously noted [*Seckmeyer and McKenzie, 1992*].

It should be noted that the values in Table 2 do not represent absolute maxima for the three countries. Irradiances 20% greater than those listed at each site have been observed during partly cloudy conditions at Lauder. Further, the three observing sites are all in the South of the countries concerned. In Northern New Zealand and Australia higher UV levels would be expected, whereas in Northern Germany the UV levels would be lower.

Conclusions

Solar UV spectral irradiances measured by three groups using widely different instruments have been compared. Differences larger than 10% were observed at large SZA, but for observations at smaller SZA (less than 42°), agreement was better than 10%.

The close agreement shows that differences in UV spectra previously observed by these instruments at different sites are real, rather than due to instrument differences.

Maximum clear-sky spectra measured in Australia, New Zealand, and Europe were compared. Irradiances measured in Australia were the greatest, while those measured in Germany were the lowest.

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R. L. McKenzie and M. Kotkamp, National Institute of Water & Atmospheric Research, Lauder, Central Otago, NZ.
G. Seckmeyer and R. Erb, Fraunhofer Institut fur Atmopsharische Unweltforschung , 81 Garmisch-Partenkirchen, Germany.
C. R. Roy, H. P. Gies and S. J. Toomey, Australian Radiation Laboratory, Yallambie, Victoria 3085, Australia.

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