

Uncertainty Budget of Version 2 Data from Palmer Station

The total uncertainty of Version 2 data from Palmer Station (PAL) is composed of uncertainties related to (i) radiometric calibration and stability; (ii) cosine and azimuthal error correction; (iii) the finite resolution of the spectroradiometer; (iv) residual wavelength errors after wavelength correction; (v) non-linearity; (vi) stray light; and (vii) photon and electronic noise. All error sources have been discussed in detail by *Bernhard et al.*, [2004] for the instrument located at the South Pole (SPO). Since the SUV-100 radiometers installed at PAL and SPO are virtually identical, we adopted the uncertainties of errors sources (i), (iii), (v), (vi) and (vii) reported by *Bernhard et al.*, [2004] without modification for the instrument at PAL.

Uncertainties related to (iv) were recalculated and are slightly different from those of the SPO instrument. The detection limit or “noise equivalent irradiance” (NEI) was also recalculated. It varied between 0.0002 $\mu\text{W}/(\text{cm}^2 \text{ nm})$ and 0.0007 $\mu\text{W}/(\text{cm}^2 \text{ nm})$ for Volumes 1-8; is 0.0010 $\mu\text{W}/(\text{cm}^2 \text{ nm})$ for Volumes 11-13; and 0.0023 for Volume 9. The poor detection limit during Volume 9 was caused by a ground loop between photomultiplier (PMT) and the power supply of the PMT cooler.

1. Uncertainties caused by cosine and azimuthal errors

Uncertainties related to (ii) are site specific, and were recalculated based on prevailing atmospheric conditions, surface albedo, and SZA at PAL. Uncertainties due to (ii) are somewhat smaller for data of Volumes 1-9 (March 1990 – March 2000) than for data of Volumes 10-13 (March 2000 – May 2004), particularly at long wavelengths. This is due to the fact that azimuthal errors (i.e. variations of system sensitivity with the azimuth position of the Sun), which mostly affected data of earlier years, can be corrected with less uncertainty than cosine errors, which increased after the collector upgrade in March 2000.

1.1. Nomenclature (See *Bernhard et al.* [2004] for further information)

SZA	Solar zenith angle in degrees
λ	Wavelength in nm
f_B	Cosine error
$u_R(f_B)$	Relative uncertainty of cosine error
f_D	Diffuse cosine error, defined as the error in measuring isotropic radiance
$u_R(f_D)$	Relative uncertainty of f_D
R	Ratio of irradiance from the direct solar beam on a horizontal surface to global irradiance
$u_R(f_R)$	Relative uncertainty of R
f_G	Ratio of measured global irradiance affected by the cosine error to true global irradiance
$u_R(f_G)$	Relative uncertainty of f_G
τ	Cloud optical depth at 450 nm
τ_A	Aerosol optical depth at 550 nm

1.2. Calculation of uncertainties caused by cosine and azimuthal errors

The relative uncertainty of the cosine error $u_R(f_B)$ was estimated from variations of the cosine error f_B in different years. For SZAs larger than 70° , the estimate of uncertainty is problematic due to the low frequency of clear sky days used in the parametric determination of the cosine error. At large SZAs, we therefore implemented uncertainties from the instrument installed at McMurdo. For Volumes 1-9, $u_R(f_B)$ was set to <1% for $SZA < 50^\circ$; 1.5% for $SZA = 70^\circ$; 2.0% for $SZA = 75^\circ$; 3.4% for $SZA = 80^\circ$; and 5% for $SZA = 85^\circ$. For Volumes 10-13, $u_R(f_B)$ was set to <1% for $SZA < 50^\circ$; 1.5% for $SZA = 60^\circ$; 2.5% for $SZA = 70^\circ$; 6% for $SZA = 80^\circ$; and 11% for $SZA = 85^\circ$.

The uncertainty $u(R)$ of the direct/global ratio $R(\lambda)$ under clear skies was estimated from the difference of $R(\lambda)$ calculated for aerosol optical depths τ_A of 0.015, 0.025 and 0.035. The choice of this range considers that model estimates of $R(\lambda)$ were based on $\tau_A = 0.025$, whereas measured background aerosol optical depths at the Antarctic coast are in the range of 0.025 ± 0.010 [Shaw, 1982]. Based on these considerations, $u_R(R)$ was calculated to 1.4% at $SZA = 45^\circ$, 2.0% at $SZA = 65^\circ$, 4.1% at $SZA = 80^\circ$, and 8.6% at $SZA = 85^\circ$. These values were also applied to cloudy conditions as the value of the relative uncertainty $u_R(R)$ has little impact on the overall uncertainty $u(f_G)$ when clouds reduce the direct contribution $R(\lambda)$ to near zero.

The uncertainty $u_R(f_D)$, which is mostly caused by the assumption that sky radiance is isotropic, was estimated from model calculations of sky radiance during clear skies for a variety of atmospheric conditions and surface albedo.

Table 1 summarizes the relative uncertainty $u_R(f_G)$ of global spectral irradiance data for a variety of SZAs, wavelengths and cloud optical depths. The largest uncertainties apply during conditions of variable cloudiness (“ $\tau=?$ ”) when it is not possible to determine whether or not the disk of the Sun is visible. Uncertainties increase with wavelength and are somewhat larger for Volumes 10-13 than for Volumes 1-9.

Uncertainties due to residual azimuthal errors in corrected data were quantified by analyzing the amplitude of periodic diurnal variations in the ratio of measurement and model during clear-sky periods. Unfortunately, clear sky periods lasting more than one day are very rare at Palmer Station. An estimate of the azimuthal error was therefore not possible for all years. Uncertainties typically vary between 1% and 2% and tend to be larger at larger wavelengths. These uncertainties disappear under cloud conditions.

Table 1. Standard Uncertainty (k=1) Caused by the Cosine Error as a Function of SZA, Wavelength λ and Cloud Optical Depth τ .

SZA [deg]	λ [nm]	f_B	f_D	R	$\tau=0$			$\tau=0.2$			$\tau=10.0$		$\tau=?$
					f_G	$u_R(f_G)$	R	f_G	$u_R(f_G)$	R	f_G	$u_R(f_G)$	$u_R(f_G)$
<i>Volume 6 (applicable to Volumes 1-9)</i>													
45	310	0.98	0.972	0.26	0.974	0.5%	0.19	0.973	0.5%	0.00	0.972	0.6%	0.8%
45	400	0.98	0.972	0.58	0.976	0.6%	0.43	0.975	0.5%	0.00	0.972	0.6%	0.9%
45	600	0.98	0.972	0.88	0.979	0.8%	0.65	0.977	0.6%	0.00	0.972	0.6%	1.1%
70	310	0.95	0.972	0.07	0.970	0.6%	0.04	0.971	0.6%	0.00	0.972	0.6%	0.8%
70	400	0.95	0.972	0.39	0.962	0.7%	0.22	0.966	0.6%	0.00	0.972	0.6%	1.0%
70	600	0.95	0.972	0.81	0.951	1.2%	0.47	0.960	0.9%	0.00	0.972	0.6%	1.6%
80	310	0.91	0.972	0.00	0.972	0.6%	0.00	0.972	0.6%	0.00	0.972	0.6%	0.8%
80	400	0.91	0.972	0.17	0.962	0.8%	0.06	0.969	0.7%	0.00	0.972	0.6%	1.1%
80	600	0.91	0.972	0.70	0.931	2.4%	0.25	0.957	1.2%	0.00	0.972	0.6%	2.8%
85	310	0.89	0.972	0.00	0.972	0.6%	0.00	0.972	0.6%	0.00	0.972	0.6%	0.8%
85	400	0.89	0.972	0.03	0.969	0.6%	0.00	0.972	0.6%	0.00	0.972	0.6%	0.9%
85	600	0.89	0.972	0.51	0.929	2.5%	0.07	0.966	1.0%	0.00	0.972	0.6%	2.9%
<i>Volume 11 (applicable to Volumes 10-13)</i>													
45	310	0.98	0.948	0.26	0.956	0.5%	0.19	0.954	0.6%	0.00	0.948	0.6%	0.9%
45	400	0.98	0.948	0.58	0.965	0.6%	0.43	0.961	0.5%	0.00	0.948	0.6%	1.2%
45	600	0.98	0.948	0.88	0.974	0.7%	0.65	0.968	0.6%	0.00	0.948	0.6%	1.7%
70	310	0.87	0.948	0.07	0.942	0.6%	0.04	0.945	0.6%	0.00	0.948	0.6%	0.9%
70	400	0.87	0.948	0.39	0.916	1.1%	0.22	0.930	1.0%	0.00	0.948	0.6%	1.8%
70	600	0.87	0.948	0.81	0.882	2.0%	0.47	0.910	1.6%	0.00	0.948	0.6%	3.4%
80	310	0.76	0.948	0.00	0.947	0.6%	0.00	0.948	0.6%	0.00	0.948	0.6%	0.9%
80	400	0.76	0.948	0.17	0.915	1.2%	0.06	0.937	1.1%	0.00	0.948	0.6%	1.9%
80	600	0.76	0.948	0.70	0.816	4.0%	0.25	0.900	2.4%	0.00	0.948	0.6%	6.1%
85	310	0.68	0.948	0.00	0.948	0.6%	0.00	0.948	0.6%	0.00	0.948	0.6%	0.9%
85	400	0.68	0.948	0.03	0.940	0.9%	0.00	0.947	0.9%	0.00	0.948	0.6%	1.3%
85	600	0.68	0.948	0.51	0.812	5.1%	0.07	0.930	2.2%	0.00	0.948	0.6%	6.8%

2. Combined uncertainty

The combined uncertainty of Version 2 PAL data is presented in Table 2. Expanded relative uncertainties (coverage factor k=2, equal to uncertainties at the 2 σ -level) vary between 4.6% and 13%. Expanded uncertainties for spectral irradiance at 310 nm range between 6.2% and 6.4% and are dominated by uncertainties related to calibration, stability, and wavelength errors. At larger wavelengths, the greatest uncertainty arises from the insufficient knowledge of the contribution of direct irradiance to global irradiance. This is a problem particularly during periods of varying cloudiness when it is difficult to determine whether the cosine correction factor for clear or overcast sky should be applied. The uncertainty budget presented in Table 2 therefore distinguishes between the cases of “clear-sky”, “overcast” and “unknown sky condition”. Expanded uncertainties for spectral irradiance at 600 nm range between 4.6% for overcast conditions and 13.0% for periods with variable cloudiness and large SZA. Expanded uncertainties for erythemal irradiance (i.e. spectral irradiance weighted with the CIE action spectrum for sunburn [McKinlay and Diffey, 1987]) and DNA-damaging irradiance (action spectrum by Setlow [1974]) vary between 5.6% and 6.4%, and are only slightly influenced by sky condition.

Table 2. Uncertainty Budget of Version 2 Data Palmer Station.

Error source	Relative Standard Uncertainty in %									
	SZA=45°					SZA=80°				
	310 nm	400 nm	600 nm	Ery ^a	DNA ^a	310 nm	400 nm	600 nm	Ery ^a	DNA ^a
Calibration, stability	2.7	2.1	2.1	2.7	2.7	2.7	2.1	2.1	2.7	2.7
Spectral Resolution	0.8	0.0	0.0	0.3	0.9	0.8	0.0	0.0	0.3	0.9
λ- shift in UV-B	0.9	0.0	0.0	0.4	0.9	0.9	0.0	0.0	0.4	0.9
λ- shift + Fraunh. lines	0.4	0.3	0.1	0.0	0.0	0.4	0.3	0.1	0.0	0.0
Azimuthal error	1.2	2.0	2.0	1.2	1.2	1.2	2.0	2.0	1.2	1.2
Non-linearity	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Stray light	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Noise	0.7	0.4	0.4	0.1	0.3	0.7	0.4	0.4	0.1	0.3
<i>Additional uncertainties for clear-sky conditions, Volumes 1-9</i>										
Cosine error	0.5	0.6	0.8	0.5	0.5	0.6	0.8	2.4	0.6	0.6
Combined uncertainty	3.1	2.3	2.3	2.8	3.1	3.2	2.4	3.3	2.9	3.1
Expanded uncertainty (k=2)	6.2	4.6	4.6	5.6	6.2	6.4	4.8	6.6	5.8	6.2
<i>Additional uncertainties for clear-sky conditions, Volumes 10-13</i>										
Cosine error	0.5	0.6	0.7	0.5	0.5	0.6	1.2	4.0	0.6	0.6
Combined uncertainty	3.1	2.3	2.3	2.8	3.1	3.2	2.5	4.6	2.9	3.1
Expanded uncertainty (k=2)	6.2	4.6	4.6	5.6	6.2	6.4	5.0	9.2	5.8	6.2
<i>Additional uncertainties for overcast conditions, Volumes 1-13</i>										
Cosine error	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Combined uncertainty	3.2	2.3	2.3	2.9	3.1	3.2	2.3	2.3	2.9	3.1
Expanded uncertainty (k=2)	6.4	4.6	4.6	5.8	6.2	6.4	4.6	4.6	5.8	6.2
<i>Additional uncertainties if sky condition is unknown, Volumes 1-9</i>										
Cosine error	0.8	0.9	1.1	0.8	0.8	0.8	1.1	2.8	0.8	0.8
Combined uncertainty	3.2	2.4	2.5	2.9	3.1	3.2	2.5	3.6	2.9	3.1
Expanded uncertainty (k=2)	6.4	4.8	5.0	5.8	6.2	6.4	5.0	7.2	5.8	6.2
<i>Additional uncertainties if sky condition is unknown, Volumes 10-13</i>										
Cosine error	0.9	1.2	1.7	0.9	0.9	0.9	1.9	6.1	0.9	0.9
Combined uncertainty	3.2	2.5	2.8	2.9	3.2	3.2	2.9	6.5	2.9	3.2
Expanded uncertainty (k=2)	6.4	5.0	5.6	5.8	6.4	6.4	5.8	13.0	5.8	6.4

^aEry, erythemal irradiance; DNA, DNA damaging irradiance. On the basis of individual uncertainties, a combined uncertainty was calculated and multiplied with a coverage factor of 2 in accordance with ISO [1993] guidelines. These final uncertainties are the quintessence of the uncertainty budget and are therefore printed in boldface.

References

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