Long-term stability of UV multifilter rotating shadowband radiometers

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ABSTRACT

This is a continuation of work begun by Dave Bigelow and James Slusser in their study of the same name published in 2000 in J. Geophys. Res., 105, 4833-4840. This continuation study began in January 2002, when the entire database for the UV Multifilter Rotating Shadowband Radiometers (UV-MFRSR) was analyzed using the Langley regression technique, as described in "Langley Method of Calibrating UV Filter Radiometers", Slusser et. al., 2000, J. Geophys. Res., 105, 4841-4849. In conjunction with scientists at ASRC, SUNY, Albany (New York), the UVMRP has refined the air mass range versus wavelength that is used in the Langley analysis methodology to conform to the greater optical depths in the UV (290-380 nm) compared with the visible (400-965 nm). A time series of direct Sun voltage intercepts (V_o's) from Langley plots is an indication of stability, which augments the traditional periodic standard lamp calibrations. Overall, 129 cases representing 28 sites and 39 instruments, with 21 sites and 30 instruments having multiple cases, were studied. The results presented herein show the mean annual drift in sensitivity for the seven nominal wavelengths of the UV-MFRSR instrument are: 300nm -1.2%, 305nm -4.8%, 311nm -2.6%, 317nm -3.0%, 325nm -4.8%, 332nm -4.9%, 368nm -3.7%.

Keywords: UV-B, ultraviolet, Langley, radiometer, stability, calibration, Sun

1.INTRODUCTION

The USDA UV-B Monitoring and Research Program (UVMRP) was conceived by the U.S. Department of Agriculture in the early 1990's [Gibson, 1991] to improve our understanding of the potential impact of increased ultraviolet radiation upon the plant and animal components of our agricultural industry, especially following the discovery of an arctic ozone hole. Visible wavelength rotating shadowband radiometers [Harrison et al., 1994], and broadband-type ultraviolet pyranometers, were already in service in several networks, and were incorporated into the nascent USDA Program in 1993. At the same time, developmental work was begun on a rotating shadowband radiometer that would be sensitive in the UV-B spectrum, which is the most damaging component that reaches earth's surface. This ultraviolet multifilter rotating shadowband radiometer, UV-MFRSR, utilizes nominal 2 nm FWHM bandwidth ion-assisted-deposition (IAD) filters to obtain total-horizontal, direct-normal and diffuse-horizontal irradiances at 300, 305, 311, 317, 325, 332 and 368 nominal center wavelengths. The 300 and 305 channels use silicon-carbide photodiodes, and the remaining five channels use gallium-arsenide-phosphide (GAP) photodiodes.

UV filter-based radiometers are a relatively recent development in the field of outdoor UV monitoring, and as such the long-term stability of the filter-photodiode assembly is unknown. Bigelow and Slusser [2000] explored the stability of a smaller dataset of filter radiometers (four instruments at four western sites) by transforming the V_o's into calibrated intensity intercepts (I_o's) by use of prior lamp calibrations. Those lamp calibrations originated from NOAA's Central UV Calibration Facility (CUCF), located in Boulder, Colorado. Future work will resume these comparisons to CUCF lamp calibrations. For this study, we will simply track the stability of the long-term time series of V_o's, in millivolts, using a significantly larger dataset.

As of 31 January 2002, the network consisted of 44 instruments, spread over 30 active climatologic sites, one active research site and 6 as-needed or short-term research sites. As of that date, these instruments had amassed a cumulative 51,083 days, almost 140 years, of service. However, not all of those data sets were usable. For this study, a revised cumulative total of 47,905 days in service, 93.8% of the available data, and 129 usable time series, were used (Table 1), following the selection criteria described below.

2.METHODOLOGY

This work uses the solar irradiance data accumulated by each instrument during each of its field deployments. The Sun is a free, universally available, and very stable source between 300-400 nm, which allows nearly continual automated field calibrations. For this study, direct Sun voltages were analyzed using the Langley method (Fig. 1). This methodology for obtaining V_o is described by Shaw [1976] and Slusser et al., [2000]. The objective algorithm for determining V_o is described by Harrison et al., [1994], and with only minimal modification is suitable for use in the UV wavelengths. One modification to the algorithm is the relaxation of the 0.006 limit on the allowable residual standard deviation of the variance around the final regression to 0.009. The other adjustment is to the air mass. The range of air masses suitable for Langley regressions is governed by the product of air mass *m* and optical depth τ. The strong absorption due to ozone and increased Rayleigh scattering, proportional to λ^{-4} at the shorter UV wavelengths, causes the attenuation of the direct beam to be much greater in the UV than in the visible wavelengths for the same air mass. Since the current UV-MFRSR detectors are limited to not more than four decades of dynamic range, air mass ranges need to be more restricted to stay within this range. Bigelow and Slusser [2000] used air mass range 1.5 - 3.0 for all seven wavelengths. However, since the publication of that paper, it has been determined by trial-and-error that this could be modified to use air mass range 1.2 - 2.2 for wavelengths 300, 305, 311, 317, and air mass range 1.5 - 3.0 for wavelengths 325, 332, 368.

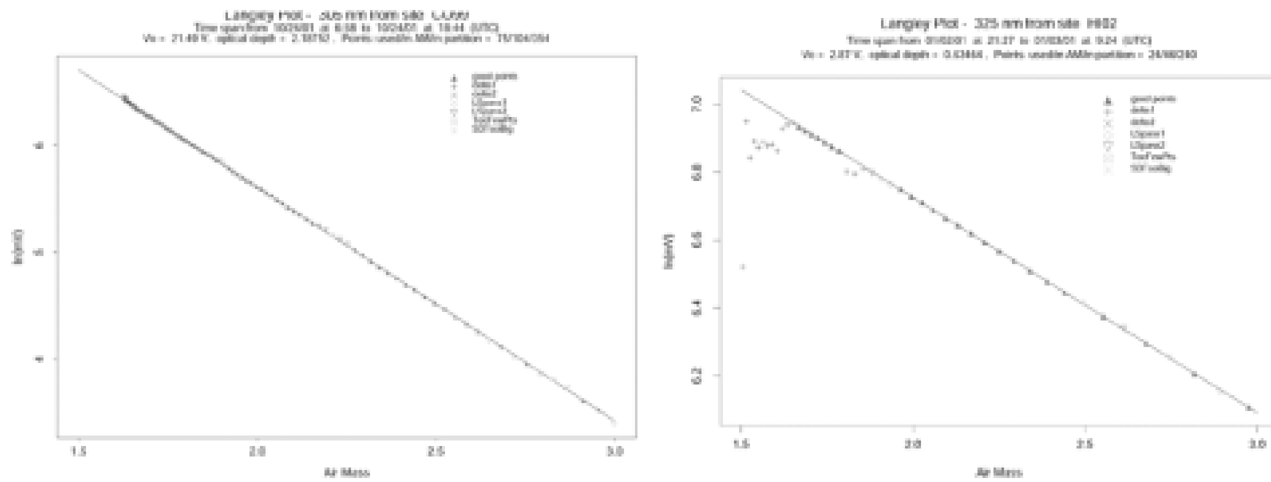

Figure 1: Typical semi-log plots generated from the Langley methodology -- the left shows a sunny morning; the right shows a cloudy morning.

A Perl-script program is used by the Network for routinely determining the V_o's, which are processed by the 5th of each month for the preceding month, and stored in our database. A separate Perl-script program was then run to plot these V_o data for each site for all UV-MFRSR instruments that have been used at that site, which resulted in 176 potentially usable data sets (Table 1). For the drift analysis, data from each V_o graph (Fig. 2) was used where values for number of points was greater than or equal to 20 and number of days in the field was greater than or equal to 90. These were chosen to correlate with the original study, and were further verified based upon visual inspection of the amount of scatter of the V_o points and quality of fit of the regression line in the V_o plots, such that if one more point were added anywhere on the V_o plot, it would radically shift the regression line. In addition, each V_o graph was visually inspected for anomalies, and each anomaly was researched to determine its cause. Anomalies determined to be caused by failure of electronic components were excluded, as were those caused by insufficient data points that had extreme scatter. This gave 129 usable time series, though some wavelengths show fewer cases due to specific problems. Such problems include extremely cloudy days or winter low sun angles which drop the number of usable points for the 300 nm channel below the sigma threshold, and cases where a specific photodiode failed electronically, such that there is no data for that channel, or data for adjacent channels is impacted by electronic noise from the failed photodiode.

The values for the drift and number of data points from these 129 usable Langley analyses were evaluated using the statistics capability of the software packages MS Excel 2002 and OriginPro 7.0, the results of which are shown in Table 3 and Figure 5. Additionally, histograms for each of the seven channels are shown in Figure 4.

3.DATA

preliminary results --- UV-MFRSR DRIFT --- actual						
after excluding Langley analysis data points as follows:						
-- only outliers beyond 2-sigma during Vo processing						
channel	max	**mean**	*sd*	median	min	N
300	296.7	**-43.6**	*262.9*	-1.8	-1836.2	176
305	4510.8	**10.9**	*412.5*	-3.5	-1643.6	176
311	1789.7	**-8.0**	*256.3*	-2.8	-1643.6	176
317	1424.5	**-81.3**	*1143.4*	-1.8	-14938.7	176
325	1503.6	**-28.8**	*255.2*	-4.0	-1881.0	176
332	404.2	**-30.6**	*212.3*	-3.4	-1643.6	176
368	517.4	**-34.5**	*229.2*	-3.3	-1826.3	176
days	847	**290**	*214*	255	2	176
using all 44 UV-MFRSR instruments in service from 1995 through 31 January 2002						

Table 1: Statistical analysis of raw (not annualized) drift data from initial V_o processing of all irradiance data for each site for all UV-MFRSR instruments that have been used at each site.

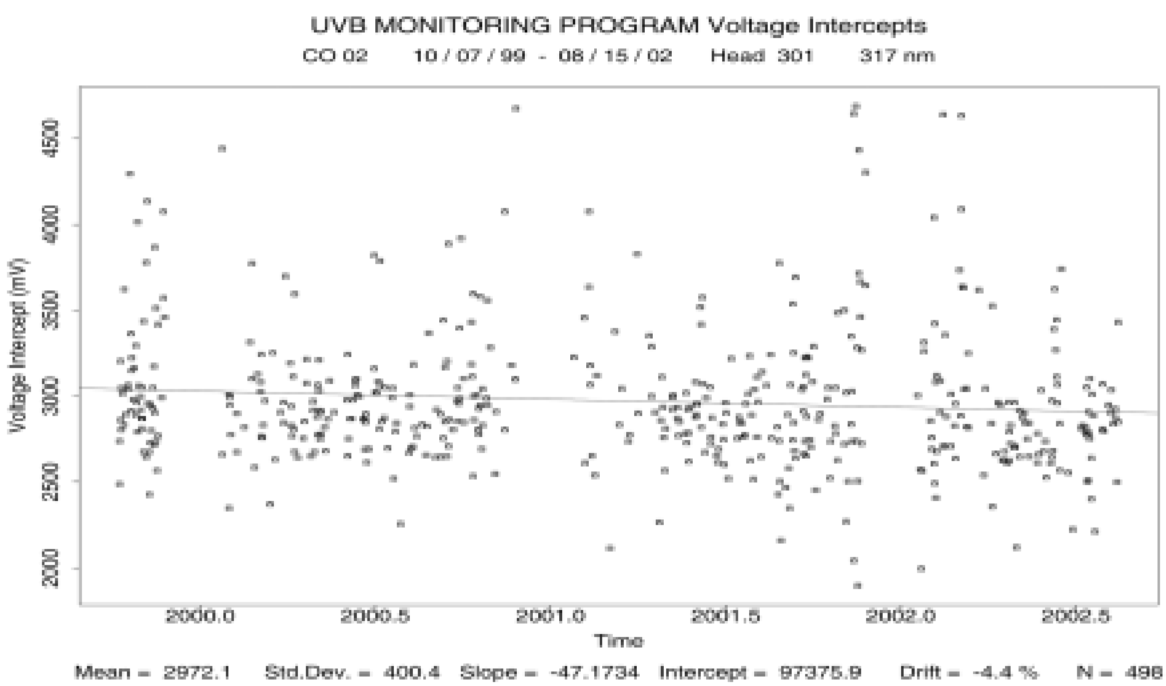

Figure 2: Typical V_o graph, showing irradiance data points (N) that meet the criteria for inclusion in the linear regression, with outliers beyond 2-sigma omitted, and the resultant regression line and raw drift percentage.

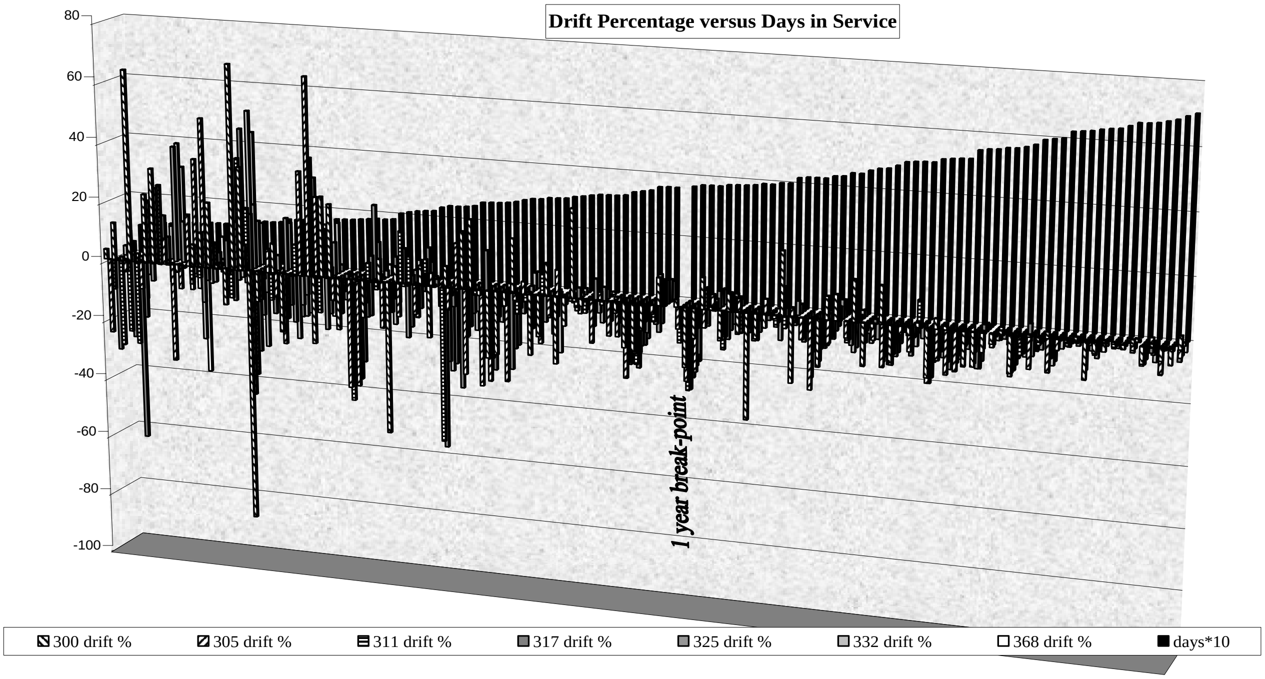

Figure 3: Preliminary data -- x-axis is days in service, z-axis is wavelength (channel), and y-axis is annualized drift percentage -- showing that as days in service (the rearmost row of data) in the field increases, the filter-photodiode-amplifier assembly becomes more stable, i.e. "settles in". Note that the days have been scaled down by a factor of 10 to allow the drift percentage to show as full scale.

instrument serial number	*number of sites*	*days in service*		*instrument serial number*	*number of sites*	*days in service*	
		range	*cumulative*			*range*	*cumulative*
231	4	155 - 651	1483	303	3	93 - 372	830
232	2	273 - 469	742	304	3	204 - 672	1107
270	4	93 - 371	885	305	4	186 - 302	958
271	3	141 - 640	1152	306	4	154 - 311	810
281	3	292 - 516	1167	307	4	152 - 434	1176
282	4	132 - 574	1232	308	2	661 - 714	1375
283	3	168 - 570	1077	386	3	218 - 615	1314
284	4	113 - 515	922	387	3	281 - 447	1031
285	4	242 - 477	1416	388	2	692 - 748	1440
286	4	239 - 628	1599	389	3	166 - 538	1010
287	2	209 - 551	760	390	2	482 - 622	1104
288	3	286 - 808	1552	391	2	91 - 496	587
289	3	103 - 594	1073	392	2	419 - 553	972
290	4	140 - 491	1215	393	3	108 - 382	790
291	3	170 - 601	1219	394	2	520 - 600	1120
292	3	107 - 666	1377	395	4	118 - 580	1278
293	4	133 - 560	1288	396	3	166 - 337	716
294	2	320 - 476	796	397	3	156 - 420	836
295	3	291 - 442	1113	398	2	235 - 755	990
297	4	152 - 513	822	***129 usable data sets***			
299	3	318 - 512	1229				
300	2	704 - 825	1529	*43 total instruments*	*35 total sites*	*91 - 847 total range*	*47905 total*
301	2	680 - 847	1527				
302	3	139 - 574	1286			*days in service*	

Table 2: Serial number of each UV-MFRSR instrument, the number of usable site deployments, the range of days that specific instrument was in use at those sites, and the cumulative number of days of V_o data analyzed for that instrument.

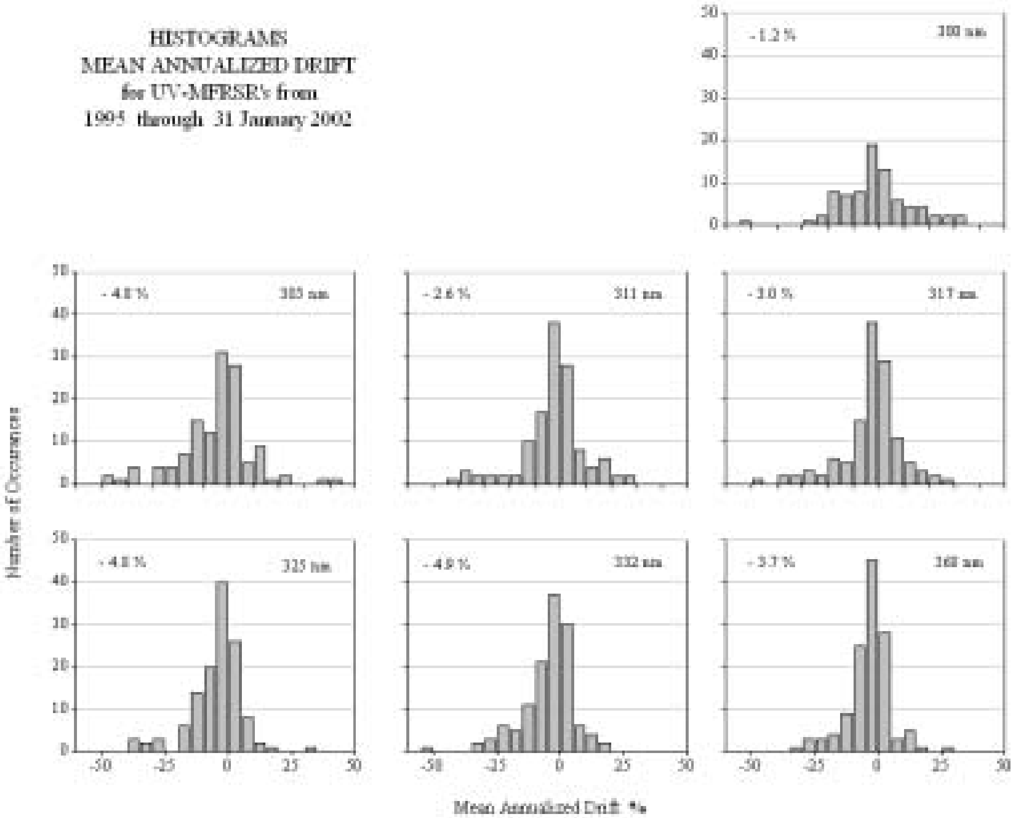

Figure 4: Final results histograms of mean annualized drift for each wavelength (channel).

4.RESULTS

One unanticipated result of this study is the verification of a phenomenon that has been empirically observed over the past few years. Due to the inherently lower irradiance of the UV-B wavelengths, the UV-MFRSR's incorporate additional amplification circuits, which gives rise to a settling-in period for each channel of each instrument. As can be seen in Figure 3, the excursions in the drift values for low service durations are extreme, and tend to dampen with time. The annualized drift statistics presented in Figure 5 and Table 3 are inclusive of all the data shown in Figure 3.

final results --- UV-MFRSR DRIFT --- annualized						
after excluding Langley analysis data points as follows:						
-- outliers beyond 2-sigma during Vo processing AND intercept = -9.0 OR site = HI03 [sun tracker] OR points < 20 OR days < 90 AND heads with known specific problems						
channel	max	**mean**	*sd*	median	min	N
300	33.9	**-1.2**	*13.9*	-1.1	-50.2	79
305	42.2	**-4.8**	*14.3*	-1.7	-48.9	127
311	27.0	**-2.6**	*12.1*	-1.2	-42.3	127
317	26.7	**-3.0**	*11.8*	-1.6	-46.3	125
325	31.7	**-4.8**	*10.3*	-3.1	-39.9	126
332	17.7	**-4.9**	*10.3*	-2.7	-50.8	128
368	25.0	**-3.7**	*8.4*	-2.4	-31.0	128
days	847	**371**	*192*	339	91	129
using 43 of 44 UV-MFRSR instruments in service from 1995 through 31 January 2002						

Table 3: Final results of drift analysis, showing annualized statistical values for each wavelength and days in service.

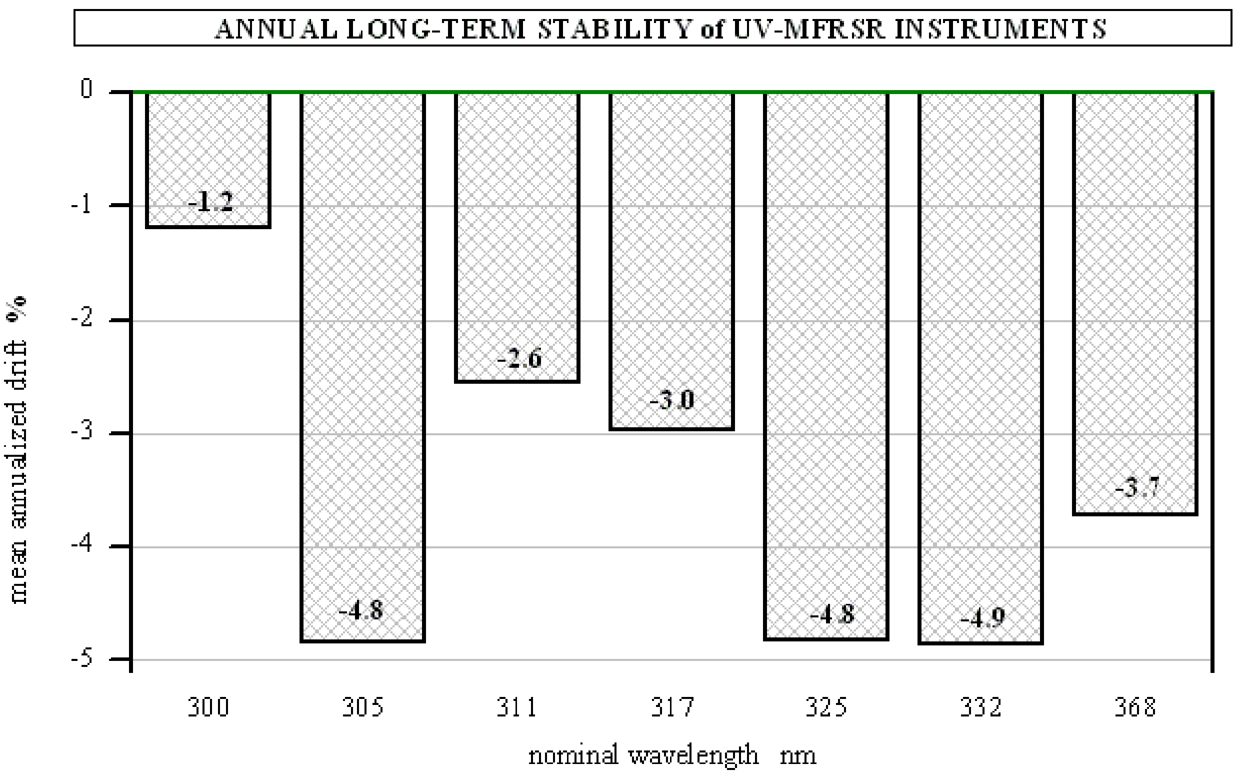

Figure 5: Graphical representation of annualized drift values from Table 3.

5.CONCLUSIONS

One goal of the USDA UV-B Monitoring and Research Program is to provide data to the user community that is as accurate as possible, within 5% of what is perceived by that user community as valid. To that end, this paper shows that the filter-photodiode assembly in use is stable to better than that standard. The mean annual drift in sensitivity for the seven nominal wavelengths of the UV-MFRSR instrument are: 300nm -0.9%, 305nm -3.5%, 311nm -3.5%, 317nm -4.3%, 325nm -3.8%, 332nm -3.7%, 368nm -3.5%. Future work on this analysis will continue the comparisons to CUCF lamp calibrations that was also addressed by Bigelow and Slusser in their earlier study.

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