Application Note: GUV "Diffey Dose" Calculations

Temperature-controlled GUV series instruments, when operated by DASWIN software, can deliver a "Diffey Dose." This dose is calculated using the irradiances measured by the GUV at 305, 320 and 340 nm. It is expressed as a UV Index and has taken several forms over the years as our calibration knowledge has progressed and as different definitions of UV Index have been introduced. It is important that GUV users understand these differences and take these differences into account when comparing results from different instruments and when expressing these data in publications.

The "Diffey Dose," also known as the CIE Erythema or "sunburn" dose weighting, describes the capacity for irradiances from wavelengths in the UV to cause sunburn or erythema. Severe erythema exhibits inflammation, blistering and peeling (WHO, 1994). There appears to be a correlation between severe erythema in the young and occurrence of melanoma later in life (WHO, 1994). Figure 1 depicts the Diffey (CIE Erythema) dose along with the location of the GUV channels (305, 320 and 340 nm) and a representative solar irradiance spectrum.

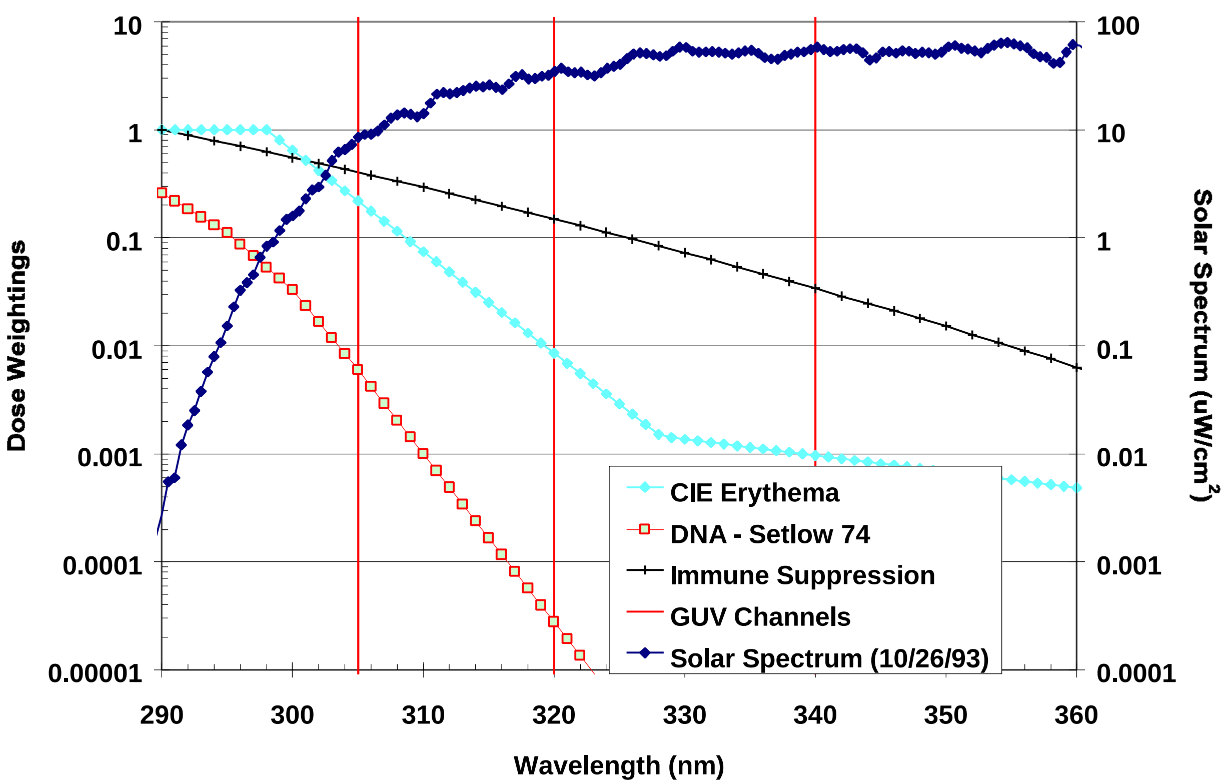

Figure 1. Various UV dose weighting functions plotted with a representative solar spectrum recorded at Palmer Station on October 26, 1993 under severe ozone depletion. The erythema dose studied in this report is that of McKinlay and Diffey (1987) and sanctioned by the CIE.

In order to express this dose rate, or the time integrated exposure that a person might receive under certain irradiance conditions, attempts have been made to construct a simple-to-understand "UV Index." To do this, various organizations have contrived simple numeric measures, such as scales of 0 to 10 or 0 to 100 that, in most cases, depart from common physical units. Some scales are based on irradiance measurements and others are based on model projections. Also, some attempt to express differences for clouds and clear conditions while others only consider clear skies. Users wanting more information about UV Index scales are referred to the World Meteorological Organization (e.g. WMO, 1994).

In 1994 the United States Environmental Protection Agency (US EPA) instituted a scale that ranged from approximately 0 to 12 and was scaled in units of hJ/m^2 (or 100 J/m^2). However, this dose definition differs from the "UV Index" promoted by Environment Canada and others, so the US EPA later changed its definition to match that of Canada and the recommendations of the World Meteorological Organization (WMO) and World Health Organization (WHO). The Canadian Index uses the dose rate in weighted W/m^2 and multiplies by 40, producing a unitless scale that typically ranges from 0 to 10. Changing from the original US EPA UV Index to the formulation based on the Canadian Index involves a simple linear scaling of 1.111.

Obtaining a Dose from GUV Data

To estimate the dose weighted irradiance from the GUV, a data set was constructed that contained 5147 high spectral resolution scans recorded in San Diego, California between 12/28/92 and 1/11/94. The measurements were performed by an SUV-100 Scanning Spectroradiometer that is part of the National Science Foundation's Network for monitoring UV Irradiance in Polar Regions. In this data set, which is available on CDROM, only observations where the solar zenith angle was less than 91° were selected. No other selection or filtering process was used beyond the routine data processing and quality control procedures described in the NSF Polar Programs UV Spectroradiometer Network Operations Reports for that period. An SUV measured parameter defined as "dose3" was converted to the "EPA dose" of 1994 by multiplying by 0.36 (3600 seconds per hour x 10^{-4} m^2 per cm^2).

To recast the irradiances reported by the GUV as a "UV Index" or "Diffey Dose," the spectral irradiance recorded by the SUV was integrated at high resolution by the dose definition as defined by the CIE. A database containing the GUV measured irradiances at 305, 320 and 340 nm and the simultaneously recorded SUV integrated dose-weighted irradiances was compiled and examined using multiple linear regression methods. The following equation (Equation 1) was generated to predict the biological dose rate, D_g, from GUV measured irradiances ($E_{305, 320, 340}$). This regression produced an R^2 = 0.99925, indicating excellent agreement (see Figures 2, 3 and 4).

$$D_g = E_{305} a_1 + E_{320} a_2 + E_{340} a_3 \qquad (1)$$

Two sets of coefficients ($a_{1,2,3}$) were issued for the GUV-511, one to calculate the 1994 US EPA Index and one to compute the revised UV Index that corresponds to the Canadian Index. The former coefficients are labeled "1A" and the latter are labeled "1B" in Table 1. Since that time, these coefficients have been revised (see coefficients 2A and 2B in Table 1) to improve linearity. **Biospherical currently recommends that factors 2B be applied to GUV data *unless* retrospective compatibility with the RayBan Network is required.** These factors must be used with the *solar* intercomparison-based calibration factors that are supplied with each GUV. The factors will not yield accurate doses if used with the *lamp-based* factors.

Table 1. Dose weighting coefficients for application to GUV data within DASWIN software. The dose rate in units of uW/cm^2 is integrated over 1 hour and converted to the original EPA index by multiplying by 0.36. To convert from 94 US EPA Index to the 96 UV Index (WMO Standard), multiply each coefficient by 1.1111. The original EPA dose had units of hJ/m^2, and the newer index is unitless. ***Biospherical currently recommends that factors 2B be used unless retrospective compatibility with the RayBan Network is required. These factors must be used with the solar intercomparison based calibration factors supplied with your instruments. They will not function correctly if used with the lamp factors.***

GUV Wavelength Channels	305 nm	320 nm	340 nm	Units
Coefficients used in the Bausch and Lomb "RAYBAN UV INDEX"				
1A. Coefficient for the 94 EPA Index	0.8034	0.073105	0.007159	hectaJoules/m^2
1B. Coefficients adjusted for 96 Index	0.8927	0.08123	0.007954	unitless
Alternate coefficients revised for better linearity				
2A. Revised Coefficients (94 EPA Index)	0.8020	0.07365	0.006976	hectaJoules/m^2
2B. Coefficients for 96 UV INDEX	**0.8911**	**0.0818**	**0.007751**	**unitless**
Statistics for the revised 2A coefficients				
Standard errors of the coefficients	0.001792	0.001086	0.000459	
R^2 for the regression	0.9993			

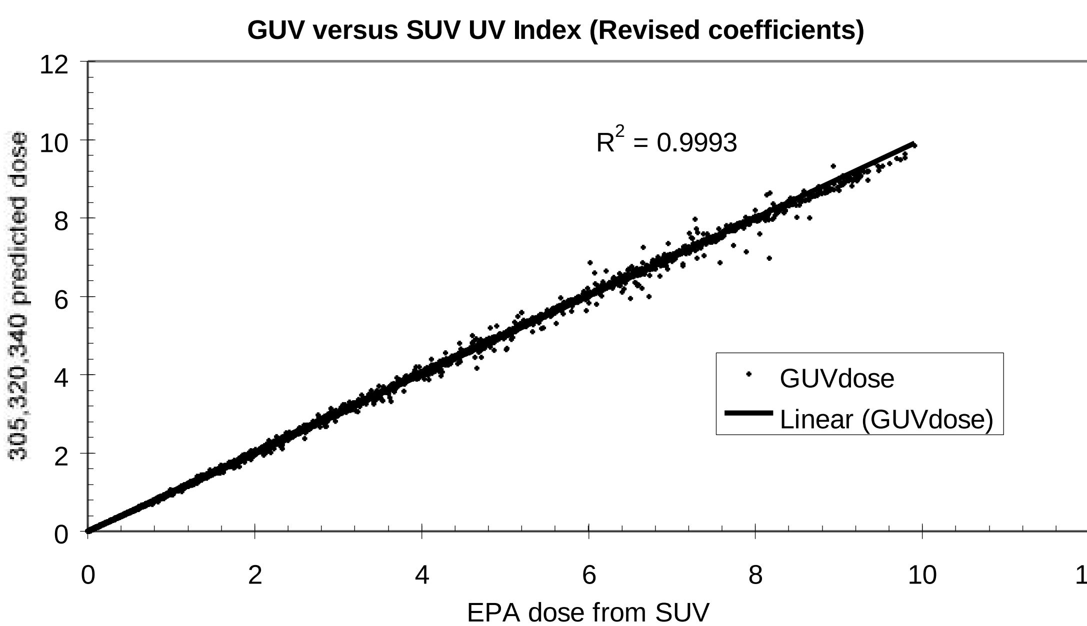

Figure 2. The correlation of the full spectral integrated SUV dose and the "2A" dose (hJ/m^2) calculated from the GUV 305, 320 and 340 nm channels.

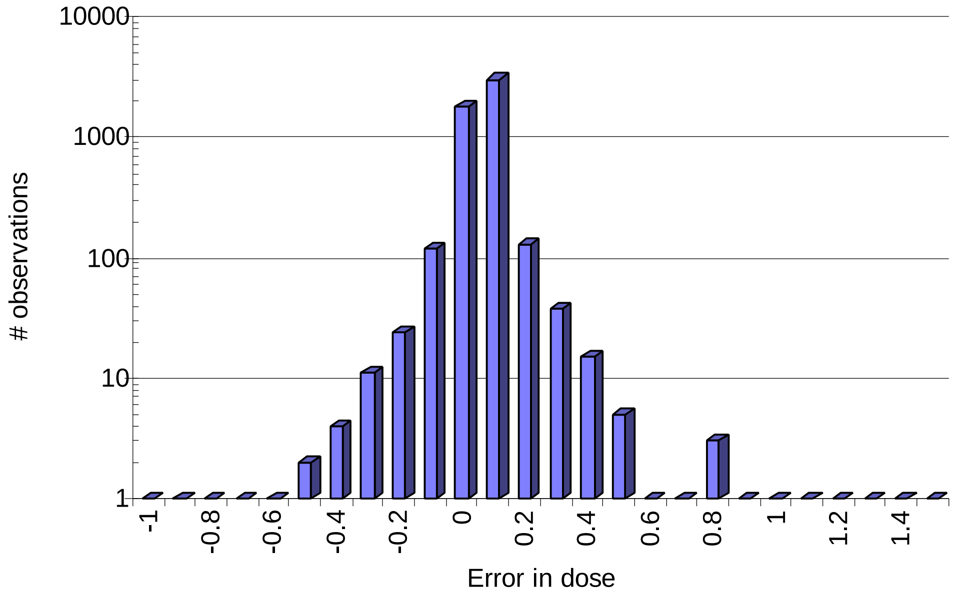

*Figure 3. This figure shows the difference between the UV Index units derived from the full spectral SUV data and those calculated from the GUV 305, 320, and 340nm irradiances ("2A" formulation). Note, this is a **LOG** distribution.*

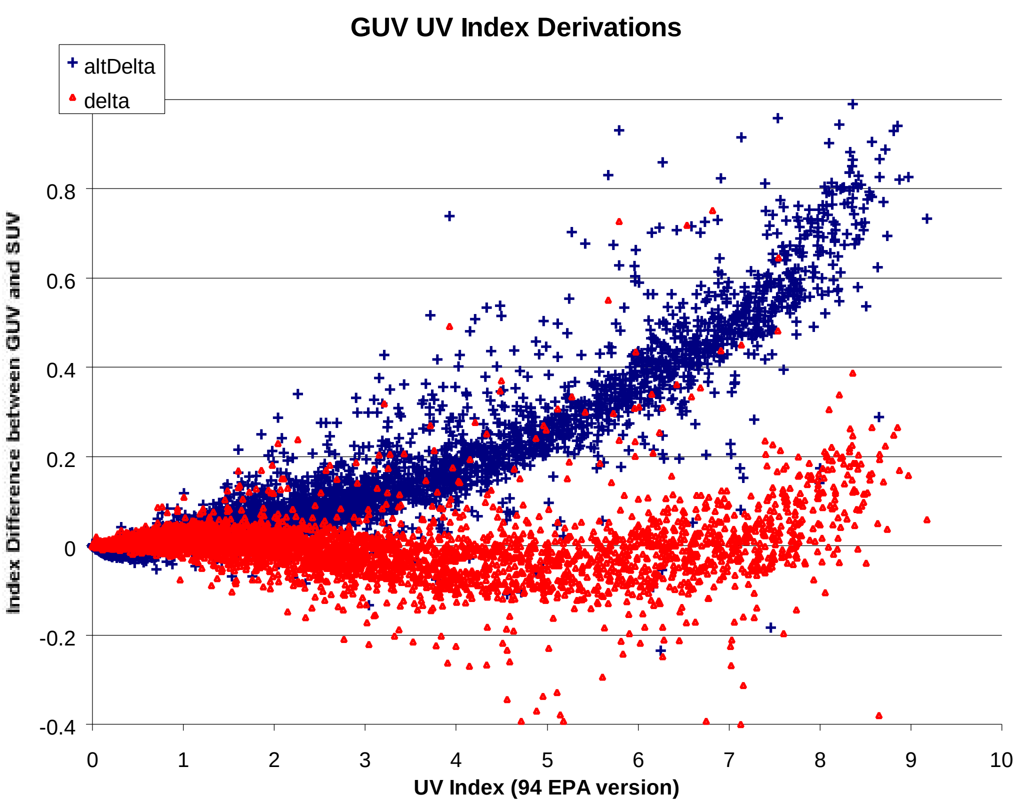

Figure 4. Difference between the UV Index (Original 1994 US EPA Index) units derived from the GUV and those derived using integrated values from the SUV-100 Spectroradiometer. Triangles denote the revised ("2A") coefficients and crosses denote the original ("1A") coefficients.

Example Calculation

Table 2 offers an example calculation of a UV Index, generated from data collected by GUV-511, serial number 9250, at local noon on June 1, 1997, on the rooftop of Biospherical Instruments Inc. in San Diego, California. A sample daily time series of the UV Index is shown in Figure 5. Note that the NOAA/EPA Ultraviolet Index Forecast generated by the National Weather Service's Climate Prediction Center predicted a UV Index of 10 for Los Angeles, CA, at solar noon on the same day (no predictions were issued for San Diego). This correlates well with the GUV-calculated solar noon UV Index of 9.9133 in San Diego. Both Index values correspond to a high or very high exposure level, as defined by the EPA (Table 3).

Table 2. Example calculation of the UV Index using the "2B" coefficients given in Table 1. Irradiances were recorded by GUV-511, serial number 9250 on June 1, 1997, on the rooftop of Biospherical Instruments Inc. in San Diego, CA.

Wavelength (nm)	Irradiance ($\mu W/cm^2$)	Coefficient ($cm^2/\mu W$)	Irradiance x Coefficient
305	7.1850	0.8911	6.4025
320	36.5099	0.0818	2.9865
340	67.6423	0.0078	0.5243
UV Index (i.e., Sum)			**9.9133**

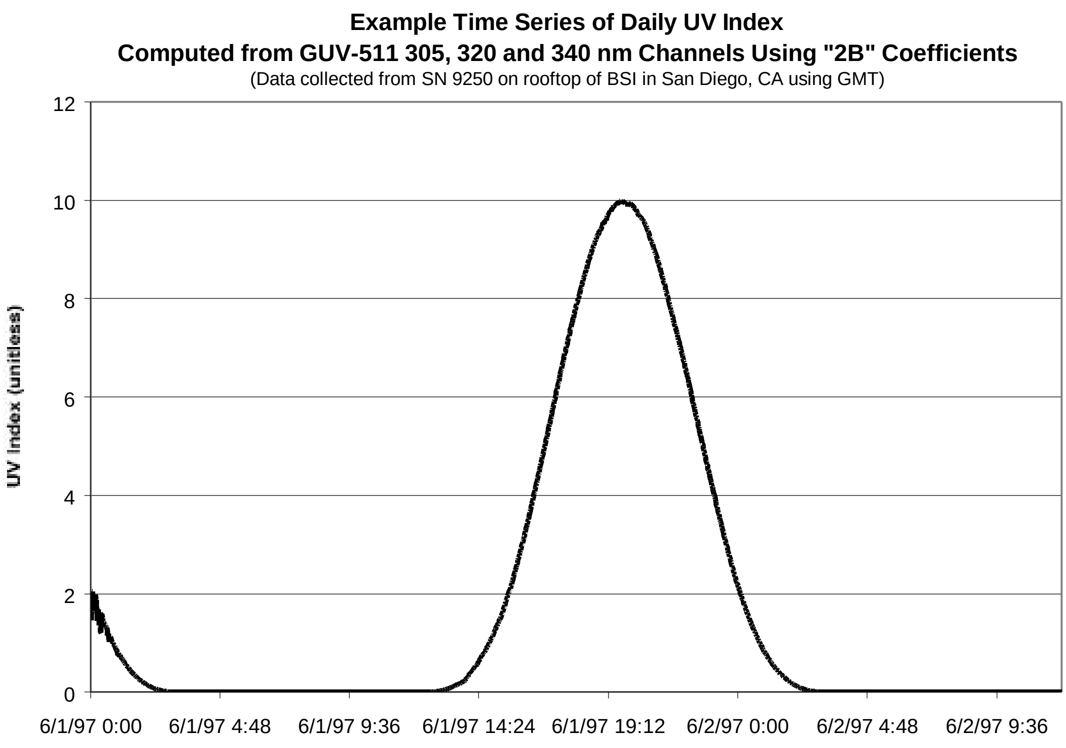

Figure 5. Time series of UV Indexes for GUV-511 serial number 9250 on June 1, 1997.

Table 3. EPA estimations of exposure level versus UV Index (1996 formulation).

UVI	EXPOSURE LEVEL
0,1,2	Minimal
3,4	Low
5,6	Moderate
7,8,9	High
10+	Very High

To test the ability of the empirical approach to deriving the UV Index, or erythema dose rate, from three channels of the GUV, we used a second set of SUV data from the NSF Polar UV Monitoring Network. This data set (Table 4) included data from each of the six NSF Network sites and contained a much greater range of observational conditions, including perhaps the worst ozone depletion events recorded on this planet. To simulate the GUV response in each channel, we applied the SUV recorded spectral irradiance to the GUV channel response functions (Figure 6 and Equation 2). This channel response was then "calibrated" by means of linear regression against the SUV's exact measured irradiances at 305, 320 and 340 nm. (Note: This is the same calibration technique employed in our solar intercomparison-based calibrations done routinely at Biospherical for the GUVs.) Next, the calibration coefficients described in Table 1 were applied to the simulated GUV responses to yield the dose weighted irradiance. This dose rate was subsequently compared to that derived by direct integration of the SUV data with the dose function.

Table 4. Summary of high spectral resolution (1nm bandwidth, 0.5nm sample increment) irradiance measurements used to evaluate the GUV dose determinations. These data are from the NSF UV Radiation Monitoring Network 1993 to 1994 Volume 4.0 Data Set, published on CDROM by Biospherical Instruments, Inc..

Site	Start	End	Observations	Selection Method
Barrow	1/28/93	11/15/93	2215	sunrise to noon
San Diego	2/22/93	3/1/94	2744	sunrise to noon
Ushuaia	4/1/94	4/4/94	2560	sunrise to noon
South Pole	2/2/93	1/10/94	1812	even hours
Palmer	3/12/93	3/17/94	2308	sunrise to noon
McMurdo	2/13/93	1/16/94	1894	sunrise to noon
		Total	13533	

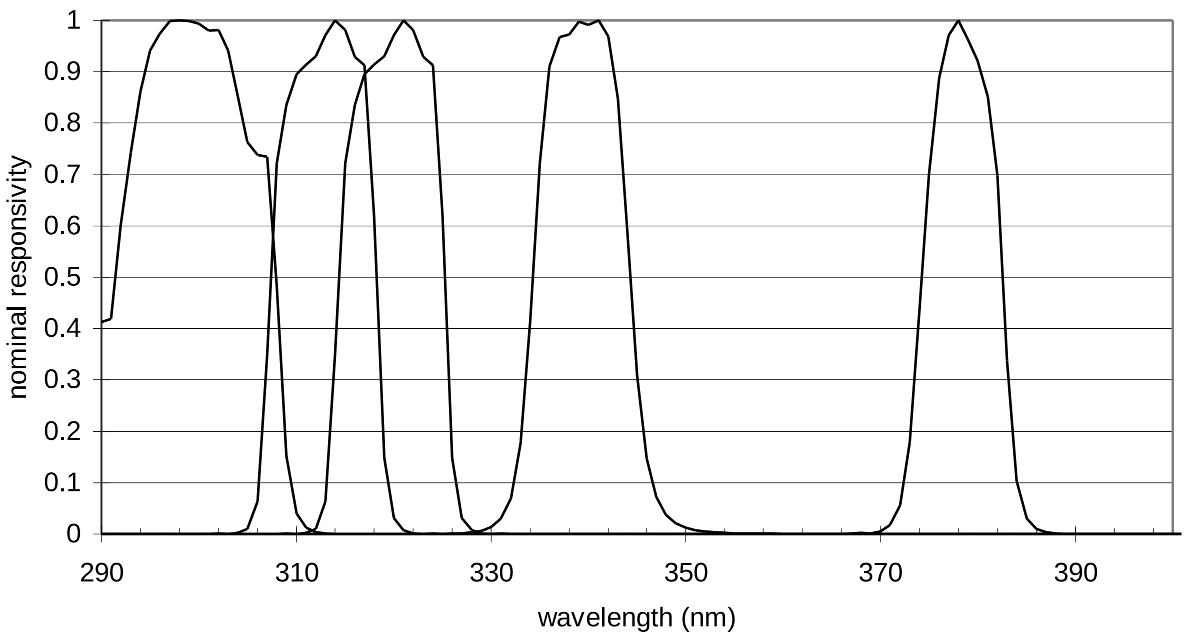

Figure 6. The five channels of the GUV-541. Effective wavelengths are 305, 313, 320, 340 and 380 nm. Plotted with maximum normalized to 1.

$$R_n = \int_{g=280}^{600} R_n(l)E(l)d\,l \qquad (2)$$

The results of this comparison of SUV and GUV predicted indexes can be seen in Figure 7, which displays the error in index prediction using the "1B" coefficients of Table 1. There is little difference between these predictions, and the errors in most cases are less than 0.1 index unit. However, there is a tendency for the GUV index measurement to be high by 0.05 units in the middle to high index values. This is due to a tendency of the GUV to be high in estimating 305 nm irradiance at high irradiance levels. We are currently investigating improved data handling techniques that promise to further improve this performance, however, we consider the performance documented here to be excellent.

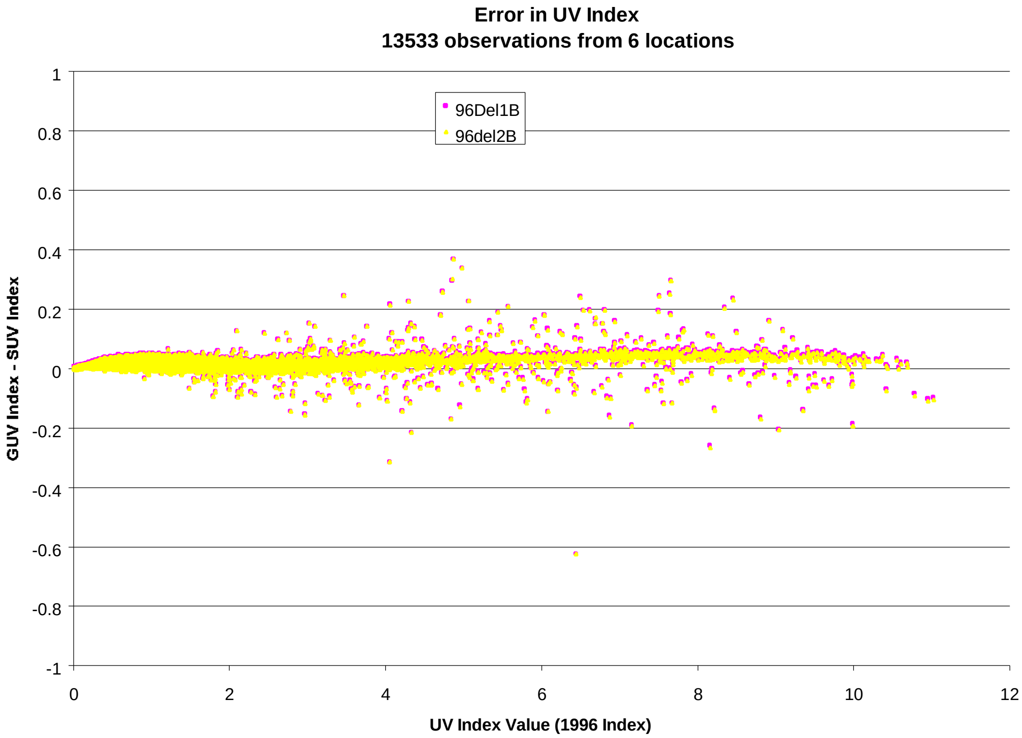

Figure 7. Error in UV Index prediction between the SUV integrated dose and the simulated GUV dose. Note that the errors in most cases are less than 0.1 index unit.

References:

Booth, C.R., T.B. Lucas, J.H. Morrow, C.S. Weiler, and P.A. Penhale. 1994. The United States National Science Foundation's polar network for Monitoring Ultraviolet Radiation. *Antarctic Research Series*, edited by C.S. Weiler and P.A. Penhale, 62, 17-37.

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World Meteorological Organization. 1994. Report of the WMO Meeting of experts on UV-B measurements, data quality and standardization of UV indices. Les Diablerets, Switzerland, 1994. WMO publication 95.