Calibration Report
Yankee Environmental Systems
UltraViolet Multi Filter Radiometer-7
(UVMFR-7) head number 454.

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An absolute calibration of the Yankee Environmental Systems (YES) (Ref. 1) UltraViolet Multi Filter Rotating Shadowband Radiometer was preformed, at Mauna Loa Observatory Hawaii, using the sun as the reference source. These calibration factors, one for each of the seven filters, are applied as scale factors to the 'YES shadowband manager program calibrated output' values, and are dimensionless.

Wavelength, nm	Scale factor	±U95%
300.2	1.11	16.8
305.6	0.94	6.8
311.7	1.04	5.6
317.8	1.11	6.1
325.4	1.09	5.1
332.5	1.26	6.0
368.1	1.05	5.1

Application

$$I_{cal} = I_{meas} * S \pm U95$$

Where: I_{meas} = Irradiance as output by the YESDAS program.
I_{cal} = Calibrated Irradiance
S = Scale factor
U95% = the 95% confidence level

ABSTRACT

Calibration factors, and uncertainties, have been determined which when applied to the 'MFRSR management software calibrated output' will provide a more correct estimate of the Top Of Atmosphere (TOA) values. These values were obtained by locating the UVMFR-7 at Mauna Loa Observatory (MLO), Hawaii

during the months of January 2004 and January 2005. Langley Top TOA extrapolations were preformed for morning clear sky morning periods. Spectral response functions were measured for each of the seven UVMFR-7 channels using a monochromator. The spectral response function for each filter, and the SOlar Radiation and Climate Experiment (SORCE) satellite measured extraterrestrial ultraviolet spectra, were used to obtain an integrated expected TOA irradiance value for each channel. These integrated and measured irradiances were used to determine, absolute calibration factors, which are applied to the spectral ultraviolet flux measurements obtained at the Clouds and the Earths Radiant Energy System (CERES) Ocean Validation Experiment site (COVE). This new data is the available on the web as the UVMFR-7 level 2 data.

METHODOLOGY

Measurements, TOA

The UVMFR-7 was located at Mauna Loa Observatory Hawaii (MLO) during the months of January 2004 and January 2005. Langley TOA extrapolations were performed for morning clear sky periods. A measurement was made every 15 seconds. Four plots of the direct beam normal incident flux were used to select thirty three clear sky periods they are; 1) the Langley regression line; 2) the direct beam irradiance; 3) the deviations of the residuals about the Langley regression line and; 4) the distribution of the deviations about the regression line. An example is presented in Fig. 1. The Langley regression line is a straight line fit to the natural log of the normal incident direct beam component of the solar irradiance as a function of atmospheric path length. The regression line is extrapolated to zero air mass. The zero air mass irradiance is the TOA value. Directly over head is defined as atmospheric path length of 1.0. For this calibration event, data are used only for air masses less than 3.0. The requirement for a clear sky day is that the standard deviation of the residuals about the regression line must be less than 0.006 for the 317.8nm channel.

Ozone is a strong absorber at 300nm therefore the radiant intensity decreases rapidly with increasing air mass. The signals become very small and, measurement accuracy, noise, and discretization become problematic. Therefore only data values greater than 0.00034 (exp(-8.0))W/m^2 are used. This occurs at an air mass of approximately 2.2.

The mean and standard deviation of the thirty three clear sky TOA values were determined for each channel. These means and standard deviations will be used, later in the analysis, as the MFRSR determined TOA values. An example for the 316.8nm case is shown in Fig. 2.

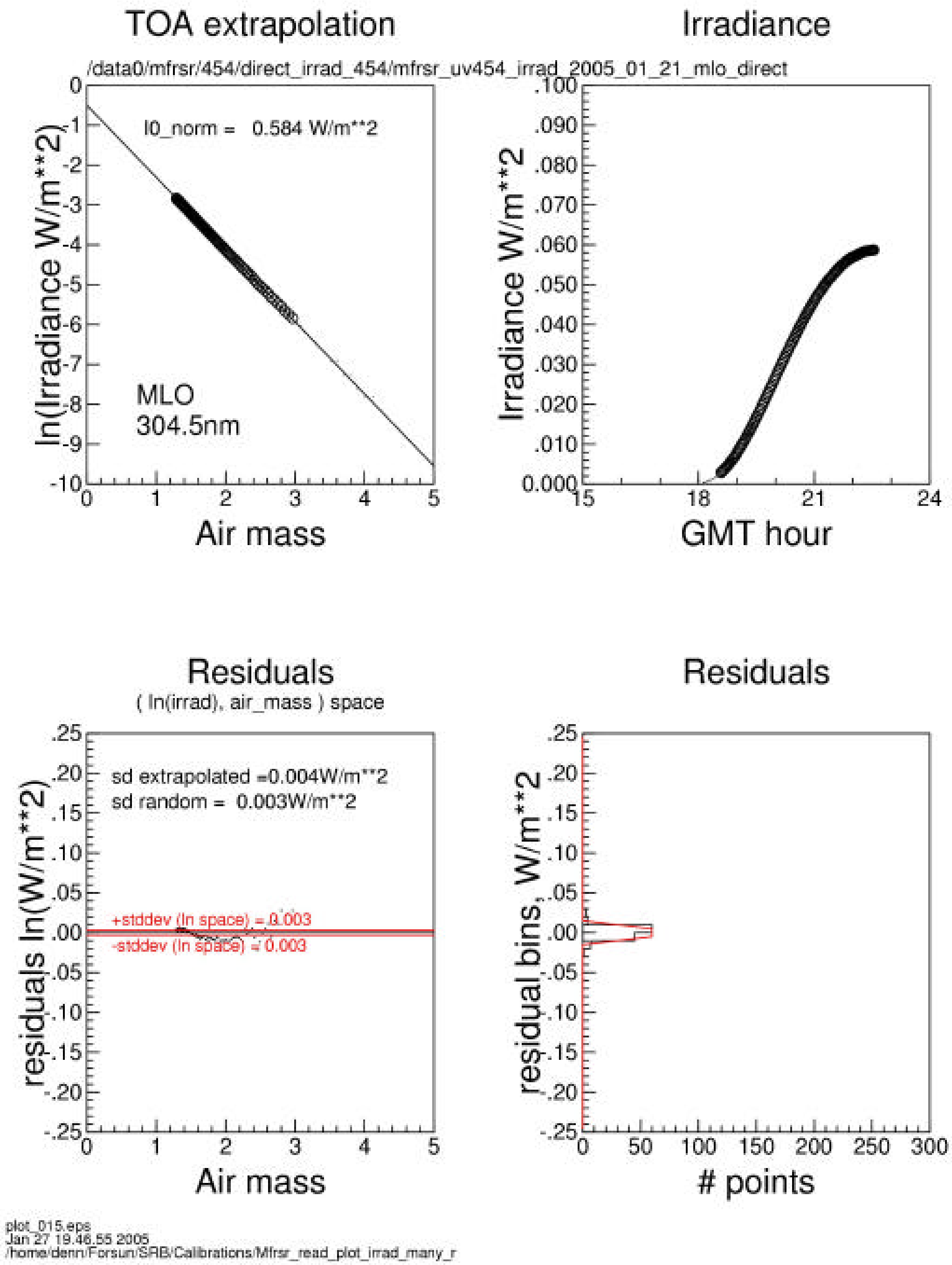

Figure 1. Four direct beam irradiance plots; (top left) the Langley regression line; (top right) the direct beam irradiance; (bottom left) the residuals about the Langley regression line and; (bottom right) the distribution of the deviations about the regression line. To be considered a clear sky day the standard deviation of the residuals (bottom left) must be less than 0.006.

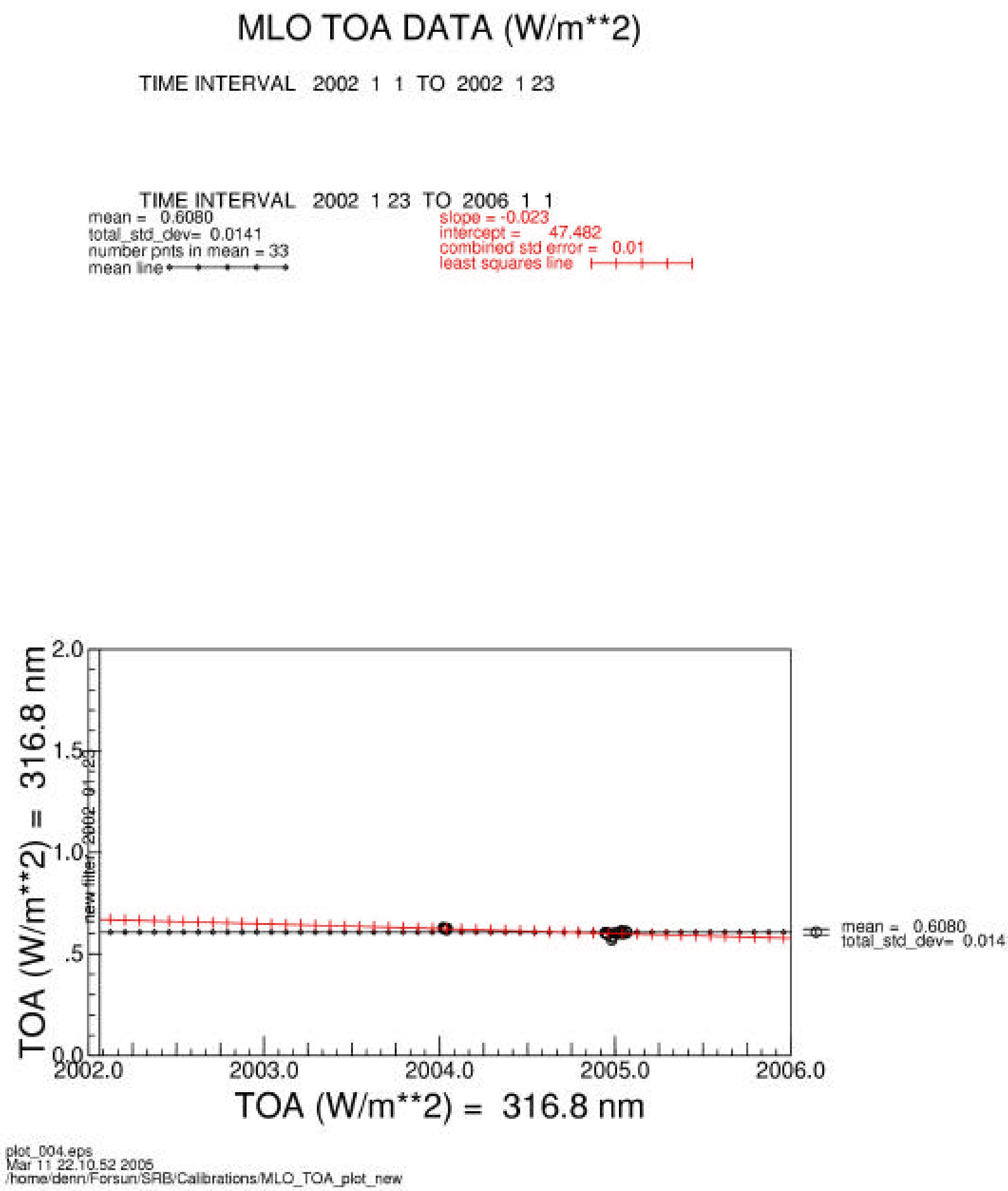

Figure 2. This is a Sample plot of all clear sky TOA values. The mean is represented by the line with the black dots. The mean and associated standard deviation were used in the calibration analysis. A linear fit to the data is shown in red and is included only for comparison purposes.

Spectral Response

A monochromator was used measure the spectral response function of each channel. First the monochromator wavelength registration was determined using a mercury argon spectral calibration lamp. Then the spectral response of each UV-MFRSR channel was measured five times and averaged to obtain a single spectral response function, the five individual spectra showed little variability. At the end of the measurement period the spectral calibration lamp was again used to insure that the monochromator spectral response had not changed.

Five spectral calibration lamp lines were selected which spanned the nominal wave lengths of the UVMFR-7. The offset between the monochromator responses for these lines and their known wavelengths were determined. The mean of the offsets was then determined, and applied as a wavelength correction factor, to the spectral response function for each filter. Each response function was normalized to 1.0 at its respective peak. An equivalent center wavelength was determined by performing a numerical integration of the spectral response and finding the area weighted central value. The normalized spectral response functions, the equivalent center wavelength and, the full width half maximum values are shown are shown in Fig. 3. The Solar Radiation and Climate Experiment (SORCE) (Ref. 2) extraterrestrial ultraviolet data, as measured by the Spectral Irradiance Monitor (SIM) instrument (Ref. 3), is also shown in Fig. 3 (red line). The SORCE data was used later to calculate an expected UVMFR-7 TOA irradiance value.

Expected TOA irradiance values are calculated for each channel. This was done by doing a numerical integration of each spectral response function multiplied by SORCE spectra. Each result is then divided by its respective integrated spectral response function. The integrated and measured UVMFR-7 responses for each channel are presented in Fig. 4. Ratios of these values were calculated and applied to the 'YES MFRSR management software calibrated output values'.

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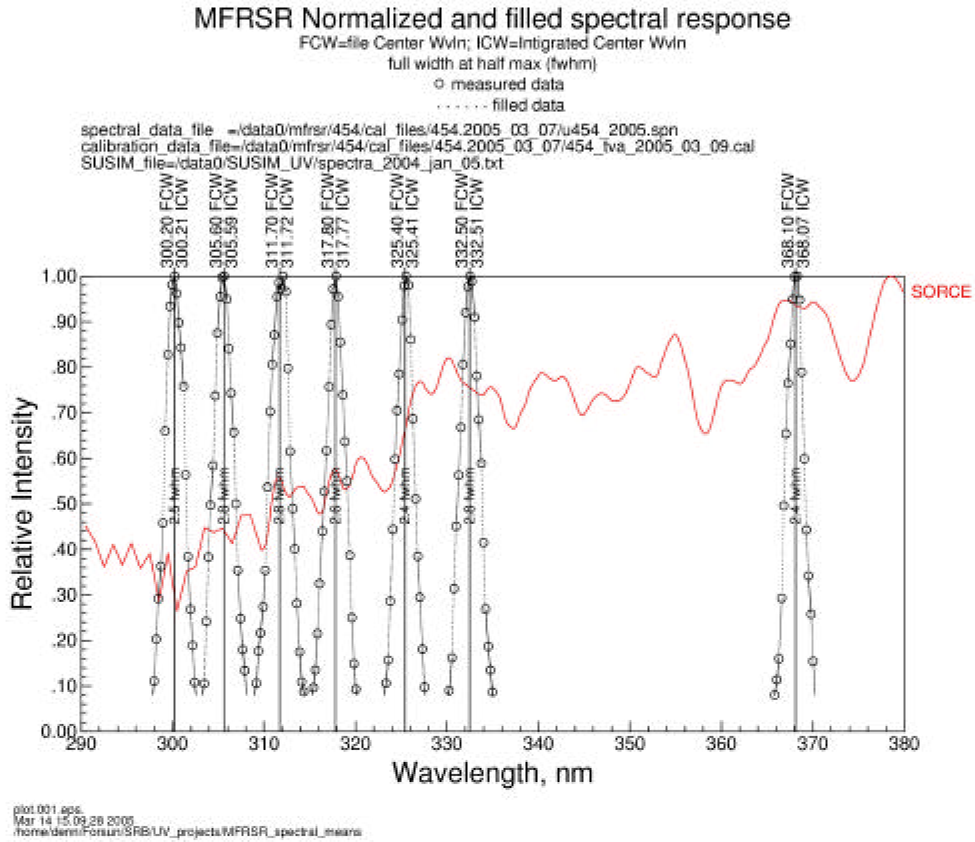

Figure 3. Normalized filter functions for each of the 7 UV-MFRSR channels are presented. Measured (circles) and interpolated (dots) data are displayed. The effective center wavelengths, from two sources for a consistency check, are displayed. Full width half maximum values are also included. The Solar Radiation and Climate Experiment (SORCE) measured extraterrestrial data is also shown (red line).

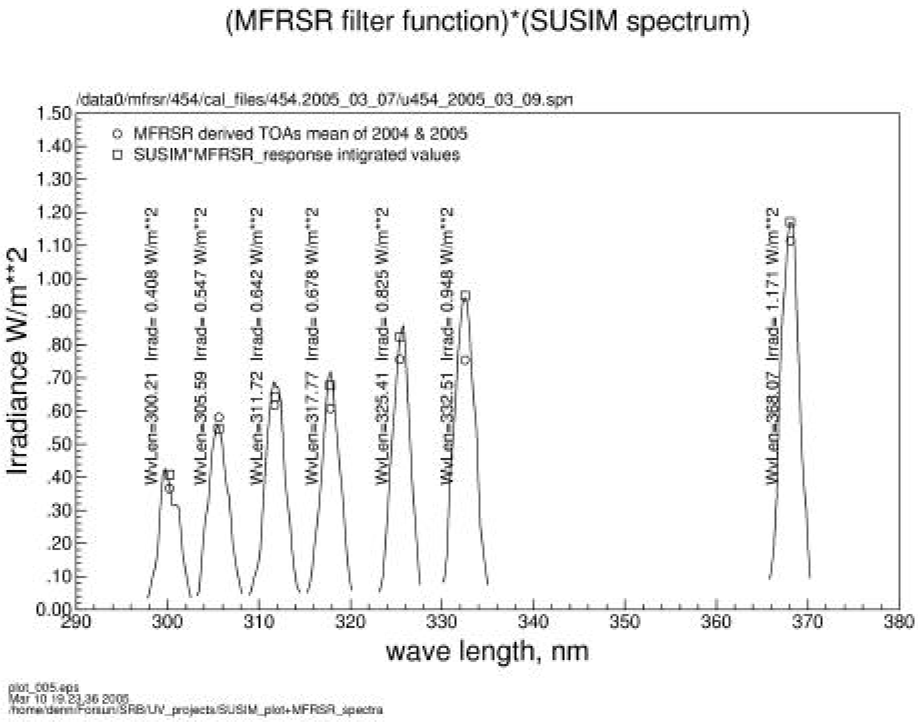

Figure 4. Measured and integrated TOA irradiance values for each UV-MFRSR channel are presented. Ratios of these values were calculated for application to the 'YES MFRSR management software calibrated output values'.

Uncertainty Analysis

The standard deviation of the thirty three Langley TOA extrapolations was determined for each channel. The standard deviation of the residuals about the regression line was also determined; it is generally much smaller than the standard deviation of the TOA measurements. The published uncertainty of the SIM instrument is 2% (Ref. 3). The two standard deviations were combined using the root sum square method. In the root sum square method each component is squared, the sum of the squares is determined, and the square root of the sum is calculated, this square root is the combined standard deviation. The combined standard deviation is then converted to a percent of the TOA measurement. This percent combined standard deviation is then combined with the SIM uncertainty by again using the root sum square method, to get the total standard deviation. This total standard deviation it then multiplied by 2.0 to obtain the U95 uncertainty as a percent of measurement. A measured value is expected to be within the U95 uncertainty of the true value 95% of the time.

Verification

As a final step the ratios were applied to the MLO obtained clear sky direct beam irradiance data, and new TOA values were determined. These new TOA values were then compared SIM derived expected values and are presented in tabular from below.

Wave length nm	SIM derived TOA W/m^2	Corrected UVMFR-7 TOA W/m^2	difference W/m^2
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300.2	0.408	0.404	0.004
305.6	0.547	0.547	0.000
311.8	0.642	0.641	0.001
317.8	0.678	0.677	0.001
325.4	0.825	0.824	0.001
332.5	0.948	0.947	0.001
368.1	1.171	1.169	0.002

The SIM derived TOA values are greater than the UVMFR-7 values for 6 of the 7 channels. In the worst case the difference is 1% but is typically closer to 0.2%. The reason for the SIM always being greater than the UVMFR-7 was not investigated.

SUMMARY

Calibration factors, and uncertainties, have been determined which when applied to the 'MFRSR management software calibrated output' will provide a more correct estimate of the Top Of Atmosphere (TOA) values. These values were obtained by locating the UVMFR-7 at Mauna Loa Observatory (MLO), Hawaii during the months of January 2004 and January 2005. Langley Top TOA extrapolations were preformed for morning clear sky morning periods. Spectral response functions were measured for each of the seven UVMFR-7 channels using a monochromator. The spectral response function for each filter, and the SOlar Radiation and Climate Experiment (SORCE) satellite measured extraterrestrial ultraviolet spectra, were used to obtain an integrated expected TOA irradiance value for each channel. These integrated and measured irradiances were used to determine, absolute calibration factors, which are applied to the spectral ultraviolet flux measurements obtained at the Clouds and the Earths Radiant Energy System (CERES) Ocean Validation Experiment site (COVE). This new data is the available on the web as the UVMFR-7 level 2 data.

REFERENCES

Reference 1. Yankee Environmental Systems, Inc. Airport Industrial Park, 101 Industrial Blvd. Turners Falls, MA 01376 USA

Reference 2. The Solar Radiation and Climate Experiment (SORCE) is a NASA-sponsored satellite mission that will provide state-of-the-art measurements of incoming x-ray, ultraviolet, visible, near-infrared, and total solar radiation. (This reference was obtained from the SORCE web site.)

Reference 3. Absolute accuracy is presently not better than approximately ±2%, pending forthcoming in-flight calibrations for the Spectral Irradiance Monitor (SIM) instrument. (This reference was obtained from the SORCE web site.)