Calibration Report
Yankee Environmental Systems
Multi Filter Rotating Shadowband Radiometer
(MFRSR) head number 244.

F. M. Denn
Analytical Services & Materials, Inc Hampton, Virginia.
Document date 2005 May 27

Calibration date: 2005 May 01
Next Calibration due: 2007 May 01

An absolute calibration of the Yankee Environmental Systems (YES) (Reference 1) MultiFilter Rotating Shadowband Radiometer, head number 244, was preformed, at Mauna Loa Observatory Hawaii, using the sun as the reference source. These calibration factors, one for each of the six narrow band filters, are applied as scale factors to the 'YES shadowband manager program calibrated output' values, and are dimensionless. Also included in this table are Top Of Atmosphere (TOA) values in W/m^2, normalized to 1 astronomical unit, as determined from the incident spectra and the spectral response of the MFRSR for the six narrow band channels and the broad band channel.

			Normalized to 1 au	
Wavelength, nm	Scale factor	±U95%	TOA, W/m^2	±U95%
Total Si	N/A	49.4	1183	17.8
414.6	1.10	12.6	1.73	8.92
496.7	1.00	7.98	1.96	5.64
613.6	0.985	7.44	1.67	5.26
671.1	0.973	7.04	1.51	4.98
866.6	1.01	6.85	0.956	4.85
936.9	1.11	27.4	0.830	19.4

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 'YES shadowband manager program calibrated output' will provide a more correct estimate of the Top Of Atmosphere (TOA) values. These values were

obtained by located the MFRSR at Mauna Loa Observatory (MLO), Hawaii for several time intervals between March 2002 and June 2005. Langley TOA extrapolations were preformed for morning clear sky morning periods. The YES supplied spectral response function for each filter, and the TOA spectrum as determined by Thuillier et all (Reference 2) were used to obtain an integrated expected TOA irradiance value for each narrow band channel. These integrated and measured irradiances were used to determine, calibration factors, which are applied to the spectral 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 MFRSR level 2 data. The First line in the above table is a broad band silicon detector. Its spectral response was not considered. It is included only for completeness.

METHODOLOGY

Measurements, TOA

The MFRSR was located at Mauna Loa Observatory Hawaii (MLO) during several time intervals between March 2002 and June 2005. Langley TOA extrapolations were performed for morning clear sky periods. Measurements were made every 15 seconds. Four plots of the direct beam irradiance were used to select 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 Figure 1. The Langley regression line is a straight line fit to the natural log of the direct beam component of the solar irradiance as a function of air mass. Air mass is measured in units of atmospheric path length, directly over head is defined as atmospheric path length of 1.0. The regression line is extrapolated to zero air mass. The zero air mass irradiance is the TOA value. For this calibration event, data are used only for air masses between 2.0 and 5.0. The requirement for a clear sky day is that the standard deviation of the residuals about the regression line must be less than or equal to 0.006 for the 613.6nm channel.

The mean and standard deviation of the daily clear sky TOA values, were determined for each channel, for the entire measurement period. The means are taken as the TOA values and are presented in the box at the beginning of the document. The standard deviations will be used in the uncertainty analysis. The distribution of the individual TOA values about their mean was examined and do not strictly fit a normal distribution. The fraction of the measurements which occurred within the bounds of one standard deviation varied from 0.59 to 0.80 while for a normal distribution a fraction of 0.68 would be expected. The individual TOA values, their means, and their standard deviations are displayed for each channel in Figures 2 through 7.

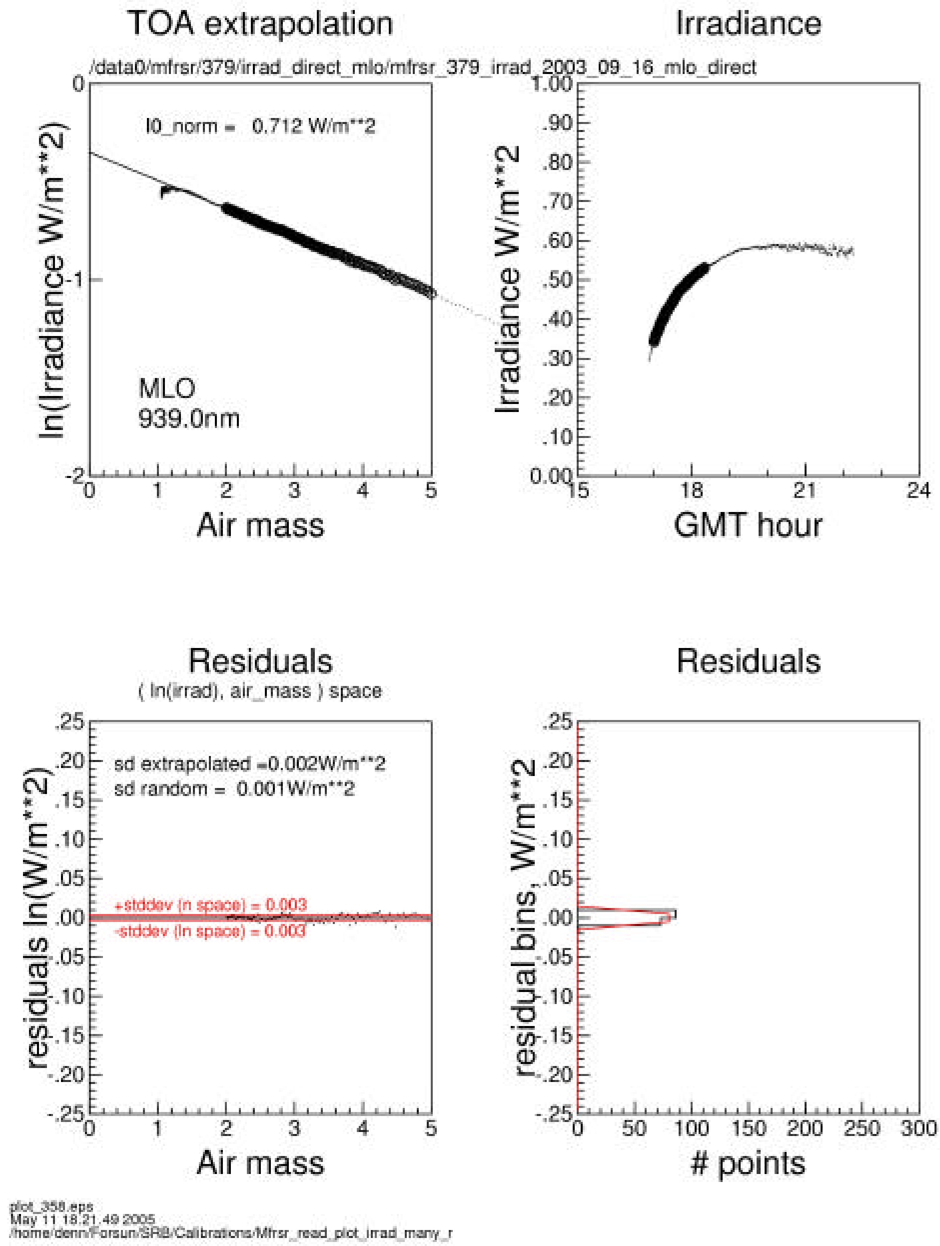

Figure 1. Four direct beam irradiance plots; 1) the Langley regression line (top left); 2) the direct beam irradiance (top right); 3) the residuals about the Langley regression line and (bottom left); 4) the distribution of the deviations of the residuals about the regression line (bottom right). To be considered a clear sky day the standard deviation of the residuals (bottom left) must be less than or equal to 0.006.

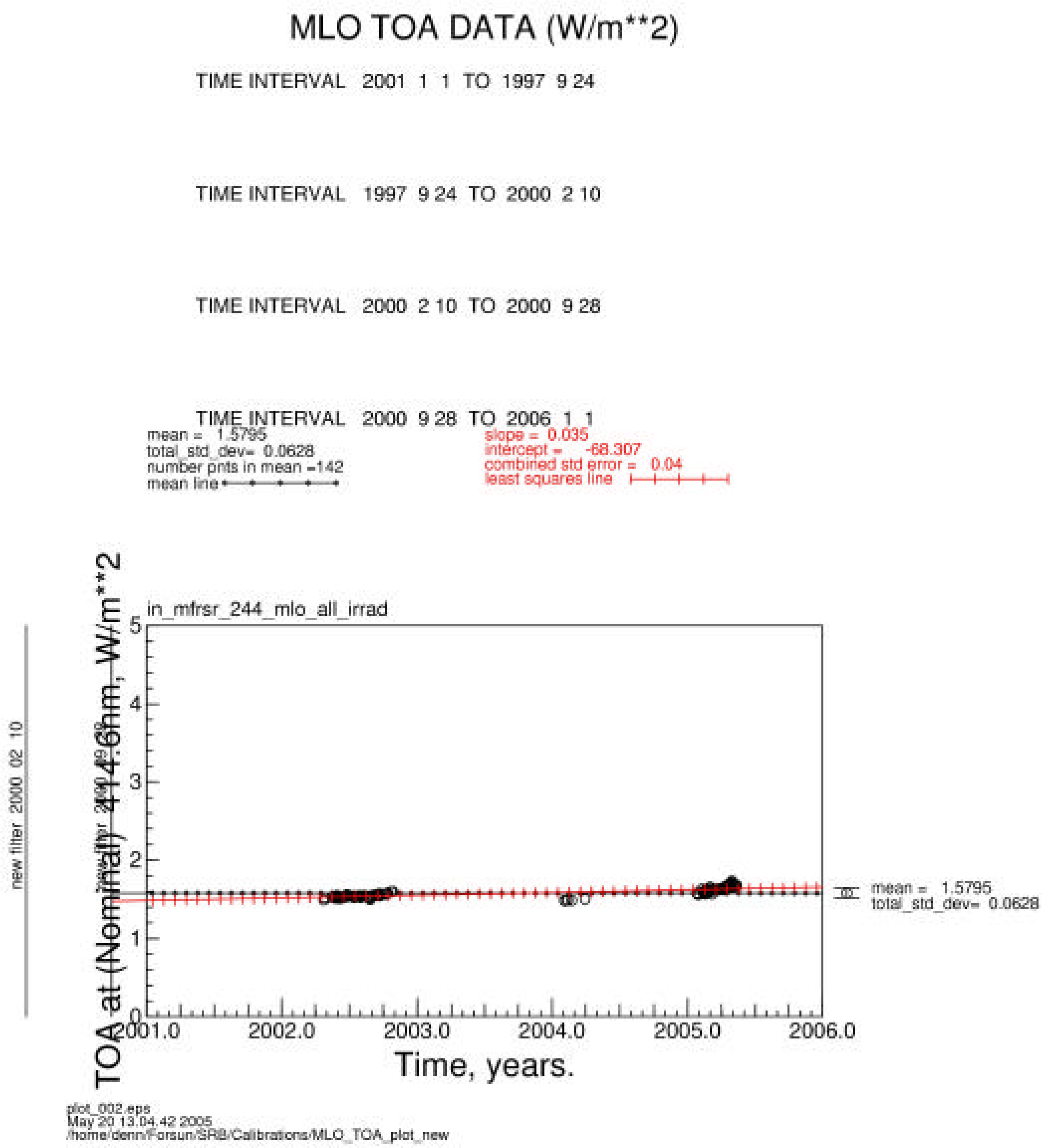

Figure 2. Clear sky TOA values for the 414.6nm filter. The mean is represented by the black line with the dots. The mean is taken as the TOA value. The standard deviation is used as a component in the uncertainty analysis. A linear fit to the data is shown in red and is included only for comparison purposes.

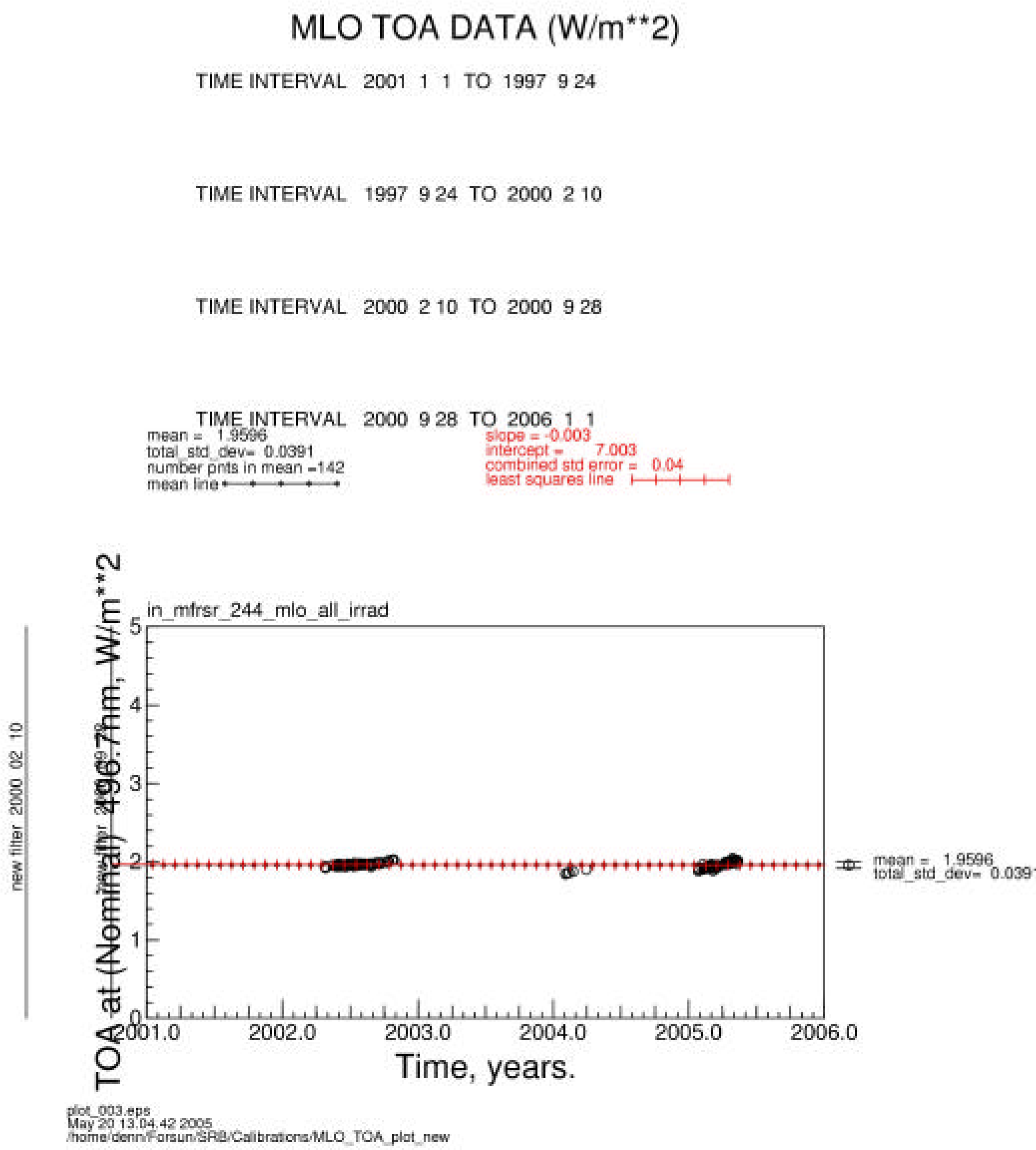

Figure 3. Clear sky TOA values for the 496.7nm filter. The mean is represented by the black line with the dots. The mean is taken as the TOA value. The standard deviation is used as a component in the uncertainty analysis. A linear fit to the data is shown in red and is included only for comparison purposes.

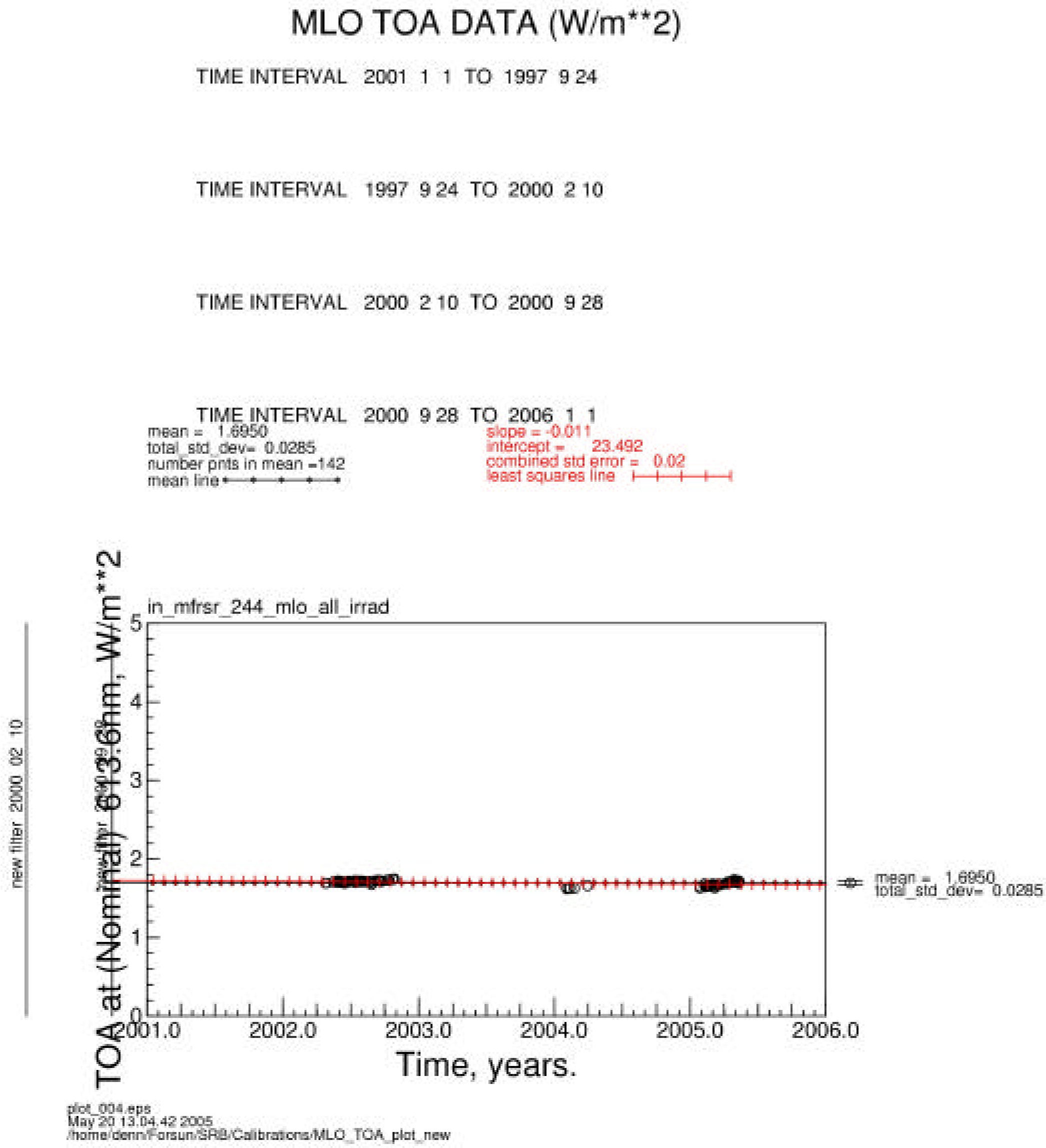

Figure 4. Clear sky TOA values for the 613.6nm filter. The mean is represented by the black line with the dots. The mean is taken as the TOA value. The standard deviation is used as a component in the uncertainty analysis. A linear fit to the data is shown in red and is included only for comparison purposes.

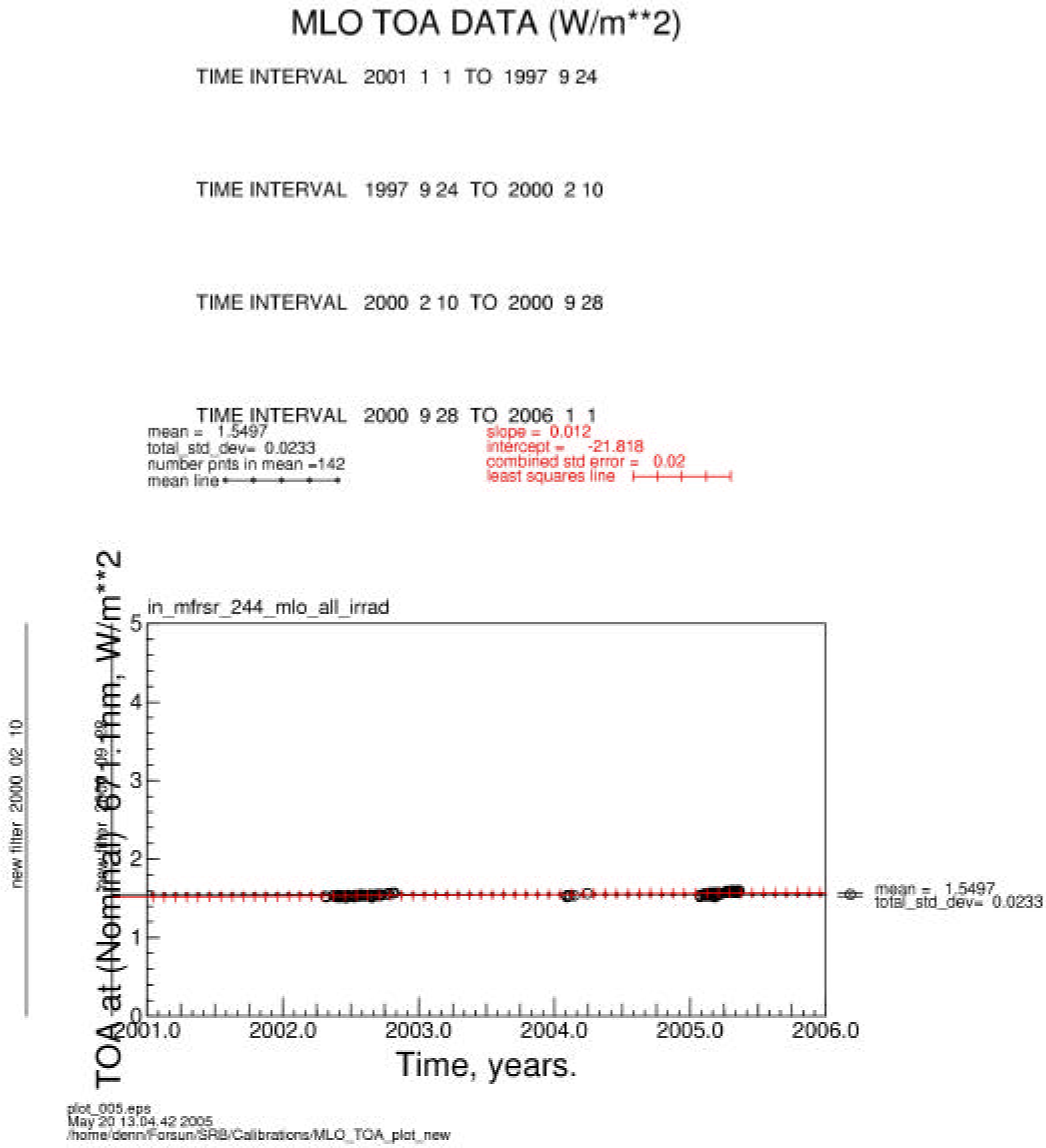

Figure 5. Clear sky TOA values for the 671.1nm filter. The mean is represented by the black line with the dots. The mean is taken as the TOA value. The standard deviation is used as a component in the uncertainty analysis. A linear fit to the data is shown in red and is included only for comparison purposes.

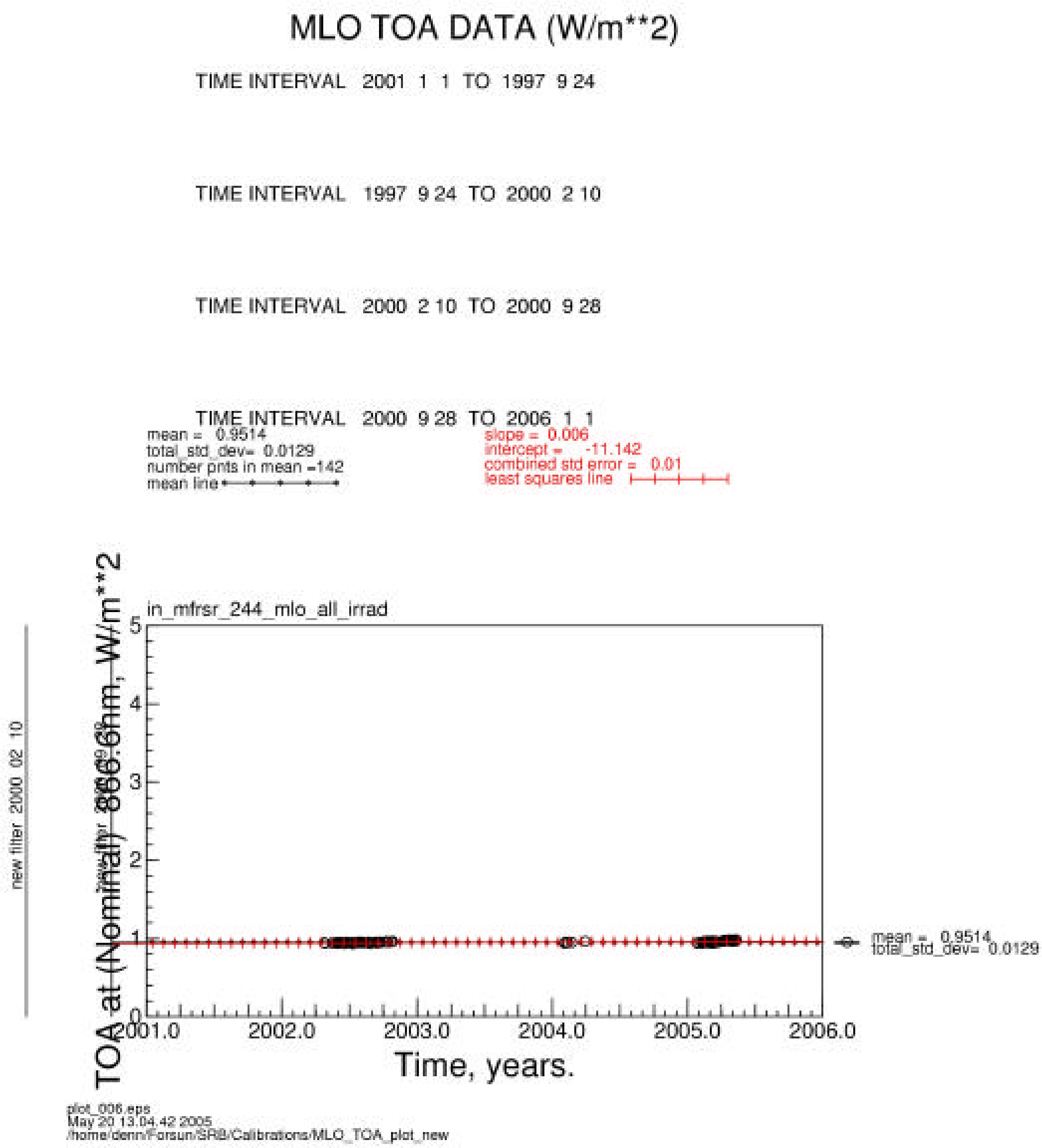

Figure 6. Clear sky TOA values for the 866.6nm filter. The mean is represented by the black line with the dots. The mean is taken as the TOA value. The standard deviation is used as a component in the uncertainty analysis. A linear fit to the data is shown in red and is included only for comparison purposes.

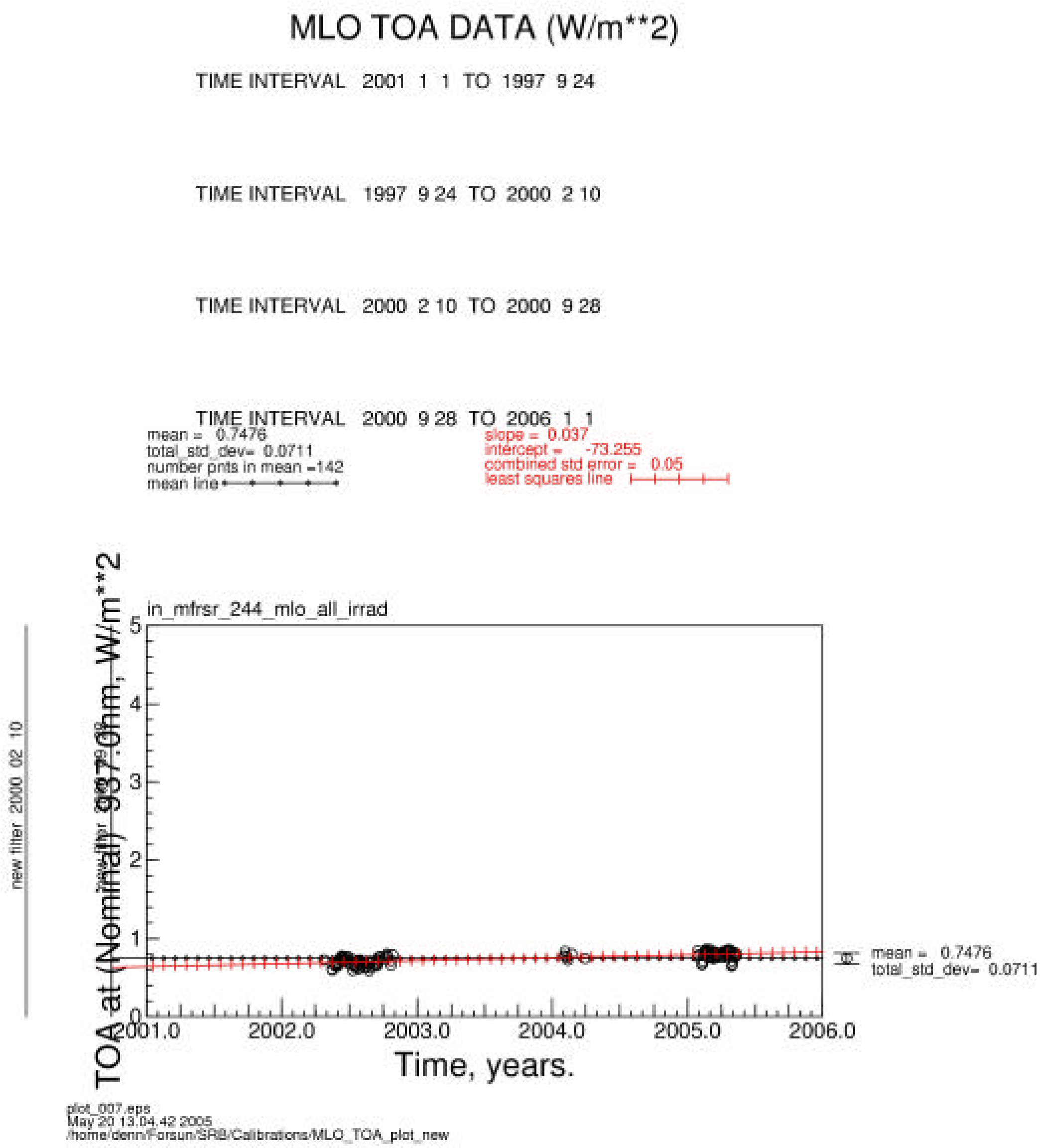

Figure 7. Clear sky TOA values for the 937.0nm filter. The mean is represented by the black line with the dots. The mean is taken as the TOA value. The standard deviation is used as a component in the uncertainty analysis. A linear fit to the data is shown in red and is included only for comparison purposes.

Spectrally based TOA values

Expected TOA irradiance values are calculated for each channel. This was done by doing a numerical integration of each spectral response function, as supplied by YES, multiplied by the Thuillier spectrum. Each result is then divided by its respective integrated spectral response function. The integrated and measured MFRSR responses for each channel are presented in Fig. 8. Ratios of these values were calculated for application to the 'YES MFRSR management software calibrated output values'.

.

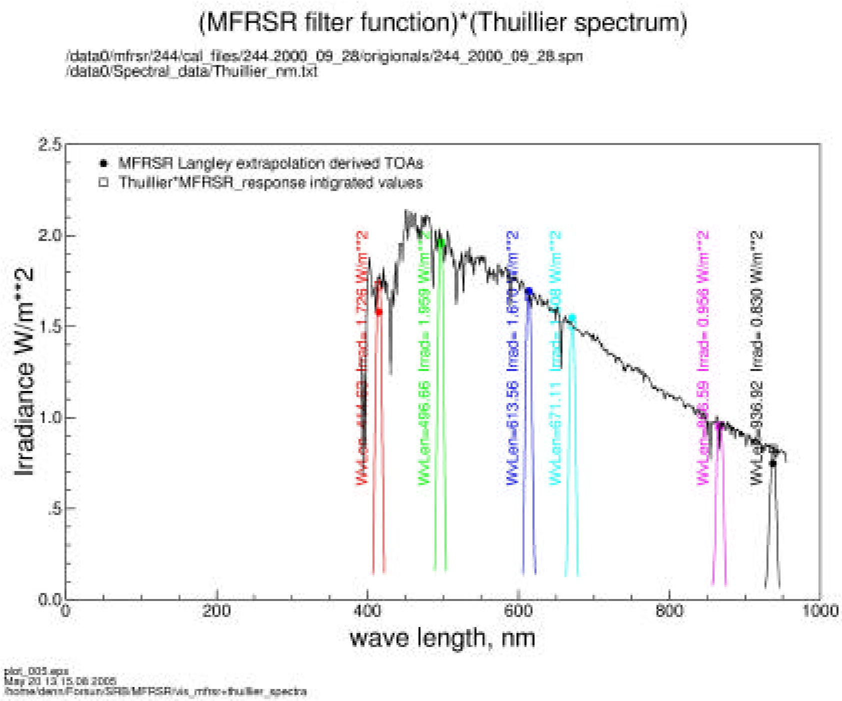

Figure 8. Measured and integrated TOA irradiance values for each narrow band MFRSR channel are presented. Ratios of these values were calculated for application to the 'YES MFRSR management software calibrated output values'.

Uncertainty Analysis

The standard deviation of the Langley TOA extrapolations was determined for each channel. The means of the standard deviations of the residuals about the regression lines were also determined. The published uncertainty of the Thuillier spectral data is 1.1% to 0.6% in the spectral range 2500nm to 900nm, The published uncertainty of the Spectral Irradiance Monitor instrument is 2% Reference 3, the 2% value will be used here. The 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 determined. This combined standard deviation is then multiplied by 2.0 to obtain the U95 uncertainty which is then converted to a percent of measurement. A measured value is expected to be within the U95 uncertainty of the true value 95% of the time. The uncertainty for an individual measurement is taken to be the square root of 2 (1.414) times the TOA uncertainty. This is because the uncertainty of the measurement with respect to the TOA value is equal to the uncertainty of the TOA value. The root sum square technique is again applied which results in an increase in the uncertainty by a factor of 1.414.

SUMMARY

Calibration factors, and uncertainties, have been determined which when applied to the 'YES shadowband manager program calibrated output' will provide a more correct estimate of the Top Of Atmosphere (TOA) values. These values were obtained by located the MFRSR at Mauna Loa Observatory (MLO), Hawaii for several time intervals between March 2002 and June 2005. Langley TOA extrapolations were preformed for morning clear sky morning periods. The YES supplied spectral response function for each filter, and the TOA spectrum as determined by Thuillier et all (Reference 2) were used to obtain an integrated expected TOA irradiance value for each narrow band channel. These integrated and measured irradiances were used to determine, calibration factors, which are applied to the spectral 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 MFRSR level 2 data. The First line in the above table is a broad band silicon detector. Its spectral response was not considered. It is included only for completeness.

REFERENCES

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

Reference 2. G. Thuillier, M. Herse, D. Labs, T. Foujols, W. Peetermans, D. Gillotay, P. C. Simon, and H. Mandel. Solar Physiscs 214: 1-22, 2003.

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