Optical Depth Instrument Calibrations

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Motivation

Optical depth measurements are taken to gain an understanding of the absorption and scattering of the solar radiation as it passes through the atmosphere. The atmosphere's constituents act to selectively absorb and scatter the incoming solar radiation. The constituents are important in controlling the surface measured radiation because of their time dependent concentration and composition variability. As they interact by either absorbing or scattering incident solar radiation, the constituents both modulate the amount of solar radiation reaching the surface and how much is reflected by the atmosphere. The Beer-Bouger-Lambert Law, which models the change in radiation intensity due to atmospheric absorption, provides the foundation for optical depth measurements. Other transmission/absorption relevant parameters logically follow from these basic measurements. These types of measurements are commonly referred to as sun photometry measurements and the instruments are sun-photometers. Optical depth measurements are central parameters in atmospheric radiative transfer models which are in current use in global climate change research.

Background

The presentation by Peixoto and Oort (1992) is followed closely in section 1.

Section 1

The Beer-Bouger-Lambert absorption law specifically describes how monochromatic radiation intensity changes as it passes through a homogeneous absorbing medium. It assumes a parallel beam and constancy of the absorbing characteristics of the layer.

The basis of the law assumes that the intensity of the radiation transmitted through an arbitrary layer of material having thickness, *ds*, is equal to the "top of the layer" intensity minus the amount absorbed during transmission through the layer. The emergent wavelength specific intensity, $I_{\lambda E}$, is equal to $I_\lambda + dI_\lambda$, where

$$dI_\lambda = -k_{\lambda a} I_\lambda \rho \, ds \qquad (1)$$

with dI_λ being the change in intensity after transmission through the layer. I_λ is the original incoming intensity at a wavelength of λ, $k_{\lambda a}$ is the wavelength specific absorption coefficient and ρ is the medium's density (see figure 1). After rearranging (1),

$$dI_\lambda = -I_\lambda (k_{\lambda a} \rho)\ ds \tag{2}$$

it can be seen that as the product of the absorption coefficient and the density increases the more intensity is subtracted (absorbed) by the layer. The integration of (2) yields the complete Beer-Bouger-Lambert Law. Specifically,

$$I_{\lambda s1} = I_{\lambda 0}\ e^{-\int_0^{s1} k_{\lambda a} \rho\ ds} \tag{3}$$

where 0 and *s*1 are the initial and final levels signifying the thickness or height of the layer. This law assumes the layer is homogeneous ($k_{\lambda a}$ is constant) and that the monochromatic radiation beam is composed only of parallel rays.

Section 2

To directly address the sun photometer problem, the law is extended to include a scattering mechanism. The scattering process acts similar to the absorption process because it also results in diminishing the intensity of radiation as it passes through the layer. As the radiation passes through the layer, a portion of it interacts with the constituents within the layer and scatters in directions different from the incoming parallel rays. This portion is summarized in the scattering coefficient, $k_{\lambda s}$. Combining the scattering coefficient and the absorption coefficient results in the combined extinction coefficient ($k_\lambda = k_{\lambda a} + k_{\lambda s}$). The daily solar zenith angle variation and the resulting path length changes through the atmosphere require a change in variable in (3). The solar zenith angle, *Z,* can be related to the layer thickness, *ds,* by *ds = secZ dz*. We have used the program of Michalsky (1988) for determining Z. With the extinction coefficient and solar zenith angle dependence changes, equation (3) becomes:

$$I_\lambda = I_{\lambda 0}\ e^{-\sec Z \int_0^\infty \rho k_\lambda dz} \tag{4}$$

The integral in (4) is referred to as the total optical thickness or optical depth for wavelength, λ, τ_λ. In application, the path length of interest is that of the distance through the atmosphere and the secZ term is substituted with a path length solution (called airmass) provided by Kasten and Young (1989). Kasten and Young's formula for airmass, m, the relative path length of the direct solar beam radiance through the atmosphere, is,

$$m = \frac{1.0}{[\cos(Z) + 0.50572(96.07995 - Z)^{-1.6364}]}. \tag{5}$$

Making these substitutions results in a standard working equation for optical depths:

$$I_\lambda = I_{\lambda 0} e^{-m\tau} \tag{6}$$

By knowing $I_{\lambda 0}$, the top of the atmosphere output from the sunphotometer for the particular wavelength, λ, the optical depth value may be solved.

The calibration process for optical depth instruments is carried out to determine values of $I_{\lambda 0}$ for each channel of the sunphotometer. This is of value because (6) can be manipulated to solve for time dependent or instantaneous optical depths using the results of the calibrations.

Two normalizations should be considered when using (6) for calibrations. The extraterrestial radiation associated with $I_{\lambda 0}$ measured during the calibration process is effected by the Earth-sun separation distance. Subsequent use of the calibrated instruments at a time of the year which has a different separation distance requires Earth-sun separation distance normalization. Including this term, (6) becomes

$$I_{\lambda} = \left(\frac{R_m}{R}\right)^2 I_{\lambda 0}\, e^{-\tau m}, \tag{7}$$

where R_m is the mean Earth-sun separation distance during calibration and R is the separation distance during subsequent measurements. Since calibration measurements and subsequent measurements may occur at different locations having different altitudes (and consequently densities) a density normalization may be appropriate (Harrison, 1998, Iqbal, 1983). This may be especially important when calibrations are performed at mountaintop locations with subsequent measurements closer to sea level. This concept is diagrammed in figure 2. The paths through the atmosphere are different for the two sites on the figure suggesting a normalization is required. This is accomplished by multiplying m by the standard ρ/ρ_0 term, so the airmass of (7) becomes

$$m_c = \left(\frac{\rho}{\rho_0}\right) m \tag{8}$$

After adding the altitude normalization to (7) and taking the logarithm of the resulting equation, the standardly used linear equation for summarizing the measured sunphotometer calibration data is

$$\ln(I_{\lambda}) = -\tau m_c + \ln\left(\left(\frac{R_m}{R}\right)^2 I_{\lambda o}\right). \tag{9}$$

This summary (9) follows the classical Langley analysis introduced by Volz (1959) over forty years ago. The slope of this linear equation is the total optical depth and the y-intercept term is the channel/wavelength specific extrapolation of the top of the atmosphere (m = 0) sunphotometer output. Figure 3 shows an example the Langley regression for a typical sunphotometer channel. The coefficient of determination for this regression is 1.0 indicating that all of the variation of the independent variable can be explained by the dependent variable. (This value seems improbable from measured data and we interpret it to suggest that roundoff error problems are involved.) The Langley analysis residuals plot for this data (figure(4)) shows the data do not fall exactly on the regression line but fluctuate about it randomly. These plots may be used as a quality assurance tool to help determine if the assumptions for the procedure are met for a particular dataset.

Optical Depth Instrument Calibration Results

Introduction

Classical Langley analyses were performed to characterize/calibrate several instruments which will be used subsequently to determine aerosol optical depths. Various types of instruments were calibrated, there were six separate instruments in all. They included three multi-filter rotating shadowband radiometer (MFRSR) units, two FieldSpec spectral-radiometers, and a Microtops sunphotometer. The spectral-radiometers and the Microtops sunphotometer were pointed to the sun using an Eppley SMT-3 solar tracker device.

The calibration measurements were performed at the Mauna Loa Observatory (MLO, Latitude 19.539 N, Longitude 155.578 W, Altitude 3397 m). MLO has been sited as the optimal location for sunphotometry calibrations because of its extremely stable marine aerosol environment and existing facilities (Dutton et al,1994). Historical radiation data have shown that winter months are characterized with the most stable and clearest skies (Dutton, 1998) so a period in early February was selected for the calibration measurements. The dates that data were acquired ranged from February 7 to February 16, 1998. The MFRSR units, being autonomous, acquired data for the entire period. During the last several days, 2-16 to 2-17, the tracker mounted systems were not operated because the tracker was being fitted with other instruments.

Data periods for the calibrations were confined to morning times associated with airmass values between 2 and 6. These limits have been suggested by Harrison and Michalsky (1994) to reduce the variability in the data due to refraction effects at larger airmasses. Also, diurnal wind effects which make the afternoon range of airmasses unstable are very common at MLO (Ryan, 1997). This factor supported the decision to limit the measurement periods to the morning time.

All calibration data from each instrument was processed using the public domain Langley Analyzer software provided by Lee Harrison’s group from SUNY Albany. The software implements their objective analysis method which rejects data associated with cloud events or atmospheric instability. We have not implemented the density correction term to the airmass calculation in the results that follow.

The entire calibration dataset may be accessed using the internet at http: //sundog.larc.nasa.gov/~Ceres/cal/index.html. Coincident meteorological and radiometric data were acquired courtesy of NOAA’s Climate Monitoring & Diagnostics Laboratory(CMDL). Radiosonde data were obtained from the Hilo, HI city airport. Ozone data were obtained from CMDL and NASA’s Total Ozone Mapping Spectrometer (TOMS) project.

Instruments

Three multi-filter rotating shadowband radiometers (MFRSRs) were calibrated. Yankee Engineering's WinBAND software was used to control the systems and download their data, daily.

Two Fieldspec FR spectral radiometers (unit #s 648 and 660) were operated in sunphotometer mode to accomplish spectral Langley calibrations for each instrument. This was accomplished by using a direct irradiance attachment collimating tube with each instrument. The tube is mounted to the instrument's standard remote cosine receptor (RCR) foreoptic which is used to measure hemispherical irradiance. The tube serves to limit the input to the RCR to allow only the direct beam signal from the sun. By manually monitoring the diopter system associated with a normal incidence phrheliometer, the pointing uncertainty associated with the tracking system was measured to be less than 0.5 degrees. The collimating tube was used with the 2 degree field of view foreoptic. The two FR units were operated using different software systems. One software system collected and output only integer digital counts from the FR system while the other system allowed the conversion to irradiance values. The FR-648 unit was used with the integer count only software and the FR-660 unit was controlled using the standard acquisition software (FR!123.exe) which accomplishes engineering units conversion. An automatic power controller was used to power up the instruments three hours in advance of their use. This was done to allow the instruments to thermally equilibrate so they would exhibit minimal baseline drift.

A single Microtops II portable sunphotometer was attached to the tracker and calibrated. This instrument was set to autoscan once per minute by a controlling portable computer. The sampling optimization parameters associated with the software internal to the photometer were set to allow an integration of all of the collected data. Thirty samples were measured and their mean was stored every minute.

The time was initialized each morning on the controlling system hardware for each instrument. GPS time was acquired using a Garmin GPS 12XL. Data was collected from each instrument, converted to ascii and processed using the LA software. Each instrument except the FR-660 provided raw digital counts (voltage). The FR-660 unit provided irradiances in W/m^2.

Photos 1 and 2 are images of the instruments. Photo 1 shows a single MFRSR unit at MLO. Photo 2 is a picture of the tracker, two spectral radiometer foreoptic collimating tubes and the Microtops sunphotometer implemented at MLO (Mauna Kea in the background).

Environmental Variability

To test the stability of the MLO atmosphere during the period of calibrations, a review of two environmental variables expected to influence the calibrations was performed. Column ozone and precipitable water data are summarized below.

Ozone

Figure 7 shows data from two sources of ozone within the atmospheric column over MLO for the month of February, 1998. The trends observed from these two instruments match based on a comparison polynomial fits of these data. There is an offset between the two fits of approximately seven Dobson units. Both datasets suggest that systematic changes in the ozone above MLO occurred during the calibration period. The percent ozone change (from the minimum to the maximum) observed during the calibration period was 4.4%.

Precipitable Water

Figure 8 shows precipitable water (PW) above MLO for selected days. These were determined from the soundings launched at the Hilo airport approximately 30 miles away. The integrations for the precipitable water calculations were limited to barometric pressures within the range of 700 to 50 millibars. This limit standardized the soundings and shifted the emphasis of the precipitable water measurement to the column above the MLO altitude. The percent precipitable water change (from the minimum to the maximum) observed during the calibration period was 54%.

Summary of MFRSR Calibrations

Langley Analysis Results

Some of the calibration results from the Langley regressions for the three MFRSR instruments are listed in Table 1. These are the basic data for performing the calibrations.

A plot of the data from table 1 (figure 5) shows the total optical depths determined for the three MFRSR units. The figure shows one line per day for each MFRSR unit. The figure illustrates the channel to channel variability for the instruments. The 936 nm channel, a water vapor channel, is observed to have the greatest variability. It is observed that unit 244 produces results that are systematically different on three of the six channels (wavelengths). Optimally the results for each instrument, for each wavelength would randomly vary about some mean value. This would be expected if the nature of the atmosphere did not change during the calibration period. To be shown later,the results obtained from the two spectral-radiometers and the Microtops sunphotometer agreed well with the MFRSR units 378 and 379. Unit 244's performance is suspect.

Figure 6a-c shows the Langley analysis residuals for the three instruments. The DOY designation in the labels of the plots represents the day of the year and the LAMBDA labels convey the instrument's wavelength specific channel. This presentation allows a global perspective of these data. The trend line within each plot is a lowess regression solution for the data. These plots expose several features about the data. We interpret them to suggest that unit 244 is systematically responding differently than the other two units. The systematic trendline curvatures observed in the majority of the unit 244 plots is not dominant in the other two instruments. The plots also suggest that day of the year 46 was, for some reason, an anomaly. This day resulted in systematic trendline curves in the residuals for units 378 and 379 but not in 244.

Based on these observations, calibrations of MFRSR unit 244 will not be performed but the system will be returned to the manufacturer for repair. Additionally, day of the year 46 will be excluded from any further analyses.

Variability of Langley Analysis Results

To understand the variability of the Langley analysis results, the total optical depths data from each MFRFR unit (378 and 379) were pooled. Figure 9* and table 2 summarize these data. Table 2 lists the central tendency and dispersion summary statistics of the total optical depth determinations for all nine days. The water vapor channel at 936 nm shows the greatest variability. Measurements as low as 0.0427 and as high as 0.0705 were observed. The channels at 500 and 615 nm showed the lowest variability. The distributions for these data are shown in figure 10. Both the ordinate and abscissa for each of these histograms float with the data. Based on visual observation, these distributions show that only the 415 approximates a normal distribution. The 500 nm channel appears bimodal and the remaining are skewed. The complexity of these results suggest that the data from some of the channels are heterogeneous.

The variability in the environmental data may explain the variability in the optical depth data either partially or completely. Nonetheless, these results suggest that determining a subset of the data that is homogeneous would be beneficial to complete the calibration procedure.

Determining a Homogeneous Subset

The combination of the observed variability in the environmental variables and the diversity of distribution shapes for the total optical depths for the MFRSR instruments suggests that the atmosphere above MLO was not stable during the calibration measurements. The procedure described below is an approach to identify a subset of the data which represents a more homogeneous set to be used for calibration. In this way, the calibration results will more closely reflect the instruments characteristics as opposed to the instruments plus the varying atmosphere's characteristics.

An approach based on principal components analysis (PCA) was used to reduce the dimensionality of the data with the goal of simplifying the task of identifying a homogeneous subset of data. We opt to define the total optical depth dataset as having a dimension of twelve. This includes six dimensions for each wavelength for the two instruments. Each calibration day produced a set of optical depths that define a single point in this twelve dimension data space. There are nine such points in the calibration data set being summarized (DOY 38-45,47). The goal of the PCA procedure is to help identify the location of these nine points relative to each other so that if appropriate, outliers may be identified.

The PCA is a transformation of the original data which reduces the dimensionality by one. The technique partitions the total variance of the original data into the new dimensions so that the first dimension accounts for the largest amount of variation in the original data, the second dimension contains the next highest amount and so forth. The resulting new dimensions (principal component scores) are also uncorrelated to each other (a correlation coefficients summarizing the linear dependence of one component to the next is zero). We performed the PCA on the variance-covariance matrix of the original data since all of the variables had the same units.

PCA Results

Figure 11 shows results of the PCA of the total optical depth data. The component loadings, which convey the relative contributions of the original data dimensions on the components, are plotted (top and right axis, blue). The nine points, each representing data from a specific day, are also plotted (bottom and left axis, black). The first component accounts for 78.6 percent of the original variance and the second component adds 12.9 percent (table 3). These two components combined account for 91.5 percent of the original variance. The loadings plot show that the 936 nm channel variance plays a dominant role in loading the first principal component. These results show that the large variation associated with the water vapor channel dominates the total variance of the entire data set.

The gross character of the precipitable water data is clearly conveyed in this PCA results. DOY 40, 42 and 47 are the only points observed to have positive PCA second component scores. These three days are the only days that the PW was over 0.6 cm. These three days have PW levels much higher than the others, they are deemed outliers, so they will be excluded for calibration summary. These results show a clear association between the environmental data and the total optical depth results. This suggest that some the variability observed in the optical depth data is a result of the influence of environmental factors and is not instrument induced.

Three days are close to each other in this principal component 1 / principal component 2 space. These are the days associated with the symbols 2, 7 and 8 on the plot. The days associated with these symbols are DOY 39, 44 and 45 respectively. The PCA results suggest that these days represent a homogeneous subset. The percentage change in PW for these data is less than 10%. The variability of the ozone data does not seem to correlate with the results of the PCA. Table 4 shows the summary statistics for the total optical depths from the DOY 39, 44 and 45 data. For all wavelengths, the culling procedure reduced the spread of the optical depths. The change was the largest for the 936 nm channels.

Based on these PCA results DOY 39, 44 and 45 represent days when the environmental variables influence on the total optical depth data was similar. These days were used to complete the calibration procedure for the MFRSR instruments. By doing this, the influence of the variability of the atmosphere on the measured precision of the instruments will be reduced.

Calibration Results

The normalized V_o for these days are summarized in tables 5 and 6 for MFRSR instruments 378 and 379 respectively. The highlighted mean values are the calibration coefficients to be used for subsequent measurements. These values are the primary goal endpoint of the calibration procedure.

The spread of these data represent the attained precision associated with the measurements. The accuracy of these results are not summarized here but are understood to be overwhelmingly effected by the linearity of the voltage measurement circuitry within the instruments. These results, based on only three days of data, are not sufficient for performing a statistically oriented uncertainty analysis. What is commonly done in sun photometer calibration summaries is to state the attained precision based on the range of data used for the calibrations. The mean observed range for the pooled MFRSR data is 0.005 optical depth units. Based on the data of table 4, we conclude that the two MFRSR instruments each measure with a precision no better than +/- 0.005 optical depth units for all wavelength channels. This is to say that any single measurement of optical depth bounded by a range formed by using the +/- 0.005 value will bound the mean optical depth of the homogeneous data subset for the appropriate wavelength.

Summary of Spectral-radiometer & Microtops Calibrations

Langley Analysis Results

Some of the calibration results from the Langley regressions for the spectral-radiometers and Microtops sunphotometer instruments are listed in Tables 7-9. These are the basic data for performing the calibrations. Because of several operational situations, data availability for these instruments is not the same as that of the MFRSR units.

A plot of some of the data from these tables (figure 12) shows the total optical depths determined for the three instruments. These data show general good agreement between instruments with the group range of optical depths at each wavelength being less than 0.02 optical depth units. In the case of the 936 nm channel, this range is larger, approaching 0.06 optical depth units.

Figure 13a-c shows the Langley analysis residuals for the three instruments. Again, as in previous figures, the DOY designation in the labels of the plots represents the day of the year and the LAMBDA labels convey the instrument's wavelength specific channel.

The mounting hardware used for securing the Microtops sunphotometer and the FieldSpec 660 system to the tracker did not perform optimally at the beginning of the calibration exercise. As can be seen by the variability of the residual plots for all channels associated with these two instruments (fig 13 b,c) from day 038 and 39, something was happening to induce a higher variability to these data. It was determined that the positioning of the instruments onto a mounting plate designed especially for the tracker effected this noise character. Between DOY 39 and DOY 40, a position change to move the FR660 and Microtops instruments more "inboard", closer to the axes of rotations was performed. The variability of the residuals plots were much reduced after this point and we assume the remaining variability observed after this point is a result of the instrument measurement systems or the atmosphere and not due to tracker mounting. To be clear the tracker was performing properly, it was the mounting of the instruments onto the tracker that caused the problem.

A malfunction of the FieldSpec 660 on DOY 41 resulted in no data collected from this instrument for this day, consequently data from this day will be omitted from the calibration summary. From the review of the column precipitable water, DOY 40, 42, and 47 should be omitted due to their high values. After these omissions, only DOY 38, 39 and 43 remain. These days are summarized below for the three instruments to accomplish the optical depth calibration. The data matrix for this subset had a missing element. For the MICROTOPS on DOY 38, the 870 nm channel data did not pass the LA screening and an optical depth was not determined. To complete the calibration exercise, averaged data from DOY 39 and 43 were inserted into this location.

The inclusion of DOY 38 and 39 data is not optimal (because of the error associated with the mounting problem) but is necessary to obtain a minimum of three days of data. Because of the smaller beginning sample size and these exclusions, no homogeneous subset determination, as was performed for the MFRSR data, can be done.

Calibration Results

Tables 10-12 summarize the optical depth data for the three day period for the three instruments. A review of the data shows that the FieldSpec 648 unit when run in digital counts only mode was superior to the FieldSpec 660 at each wavelength based on a comparison of ranges. The average range of optical depth (across all wavelengths, across calibration days) for the 648 unit was 0.004 versus 0.011 for the 660 unit. The Microtops sunphotometer results produced an average range of 0.009 optical depth units. These numbers are of the same order of magnitude as observed for the MFRSR.

The actual calibration coefficients needed for future instantaneous optical depth calculations from these three instruments are found as the means within tables 11-13.

Overall Observations

To compare the instruments as a function of repeatability/precision or data spread, the range of the measurements were used. Ranges of optical depth for all instruments at common wavelengths were tabulated (Table 16). These data show that all of the instruments measured optical depths to produce a range no greater than 0.011 optical depth units. This represents the worst case (FR660 @ 500 nm). This summary also allows a ranking of the instruments based in attained reproducibility. Based on the averaged ranges across common wavelengths, the most precise instrument was the FieldSpec 648 instrument (range: 0.002), next the MFRSR's (range: 0.005), next the Microtops instrument (range:0.006) and last the FieldSpec 660 unit (range: 0.009).

A comparison of the 500 nm calibration optical depth data for all the instruments is found in figure 14. Each data point used in the calibrations for all instruments are plotted with an interval which was determined from the range of optical depths for the data associated with calibration days. By definition, these intervals will always bound the mean optical depths determined from an individual instrument. Whilst these intervals are not based on a probabilistic approach, they nontheless serve to ain in interpreting the data.

Two means were determined which were based on the results of the calibrations which were grouped as tracker or non tracker mounted instruments.The mean for the MFRSR instruments is slightly higher (statistical difference not determined) than the mean for the instruments mounted to the tracker. It is of interest to note that the MFRSR 500 nm mean is bounded by all of the intervals from both of the MFRSR instruments. This suggests that the two MFRSR are effectively producing the same output after the measurement variability of the instruments are accounted for by using the range intervals. The two instruments which were mounted onto the distal end of the special mounting plate of the tracker show large intervals. The means for the two FieldSpec units and the Microtops device is not bounded by all of the intervals associated with the individual data measurements. The size of the intervals for the FieldSpec FR 648 are closer in size to the MFRSR instruments relative to the MICROTOPS and FR 660 instrument. The average of the MFRSR instruments is not bounded by all of the FR 648 intervals. These results may be indicating that the PCA homogeneity technique is advantageous to use when possible.

How to Optimize this Process

Resolve the mounting problem before more measurements are taken.

Have simultaneous measurements for all instruments.

Consider getting the number of homogeneous days up to four and extend these results using statistical bootstrapping methods.

Use a multivariate distance metric in the field to help identify when eneough data has been taken.

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Table 1: Basic MFRSR Langley Analysis Results

Data Filename mloYY-DDD-mfrsr###-λλλ.out	$I_{\lambda 0}$	$(R_c/R_m)^2 I_{\lambda 0}$	τ_λ	Standard Deviation of Residuals
mlo98-038-mfrsr244-415.out	15504.41	15084.9	0.21781	0.00211
mlo98-038-mfrsr244-500.out	8813.23	8574.78	0.11322	0.00181
mlo98-038-mfrsr244-615.out	2305.63	2243.25	0.06947	0.00312
mlo98-038-mfrsr244-670.out	2924.63	2845.50	0.03487	0.00288
mlo98-038-mfrsr244-870.out	7805.59	7594.40	0.01091	0.00316
mlo98-038-mfrsr244-936.out	8731.30	8495.07	0.05721	0.00341
mlo98-038-mfrsr378-415.out	13428.92	13065.6	0.21530	0.00129
mlo98-038-mfrsr378-500.out	8619.53	8386.34	0.11104	0.00244
mlo98-038-mfrsr378-615.out	8581.90	8349.73	0.07390	0.00133
mlo98-038-mfrsr378-670.out	4052.48	3942.84	0.04576	0.00273
mlo98-038-mfrsr378-870.out	8919.79	8678.48	0.01509	0.00122
mlo98-038-mfrsr378-936.out	12090.25	11763.1	0.06171	0.00262
mlo98-038-mfrsr379-415.out	11695.01	11378.6	0.21597	0.00182
mlo98-038-mfrsr379-500.out	8303.76	8079.11	0.11206	0.00212
mlo98-038-mfrsr379-615.out	8043.53	7825.93	0.07360	0.00171
mlo98-038-mfrsr379-670.out	4028.48	3919.49	0.04901	0.00241
mlo98-038-mfrsr379-870.out	8641.60	8407.82	0.01468	0.00174
mlo98-038-mfrsr379-936.out	11953.55	11630.1	0.05967	0.00163
mlo98-039-mfrsr244-415.out	15603.96	15187.0	0.22042	0.00224
mlo98-039-mfrsr244-500.out	8865.57	8628.71	0.11597	0.00224
mlo98-039-mfrsr244-615.out	2325.33	2263.21	0.07280	0.00281
mlo98-039-mfrsr244-670.out	2916.66	2838.74	0.03489	0.00197
mlo98-039-mfrsr244-870.out	7931.58	7719.67	0.01523	0.00202
mlo98-039-mfrsr244-936.out	8885.61	8648.22	0.05083	0.00324
mlo98-039-mfrsr378-415.out	13501.38	13140.6	0.21489	0.00116
mlo98-039-mfrsr378-500.out	8676.98	8445.17	0.11242	0.00182

Table 1: Basic MFRSR Langley Analysis Results

Data Filename mloYY-DDD-mfrsr###-λλλ.out	$I_{\lambda 0}$	$(R_c/R_m)^2 I_{\lambda 0}$	τ_λ	Standard Deviation of Residuals
mlo98-039-mfrsr378-615.out	8554.87	8326.32	0.07374	0.00106
mlo98-039-mfrsr378-670.out	4034.39	3926.61	0.04689	0.00262
mlo98-039-mfrsr378-870.out	8963.75	8724.28	0.01505	0.00123
mlo98-039-mfrsr378-936.out	12154.99	11830.2	0.05077	0.00169
mlo98-039-mfrsr379-415.out	11927.16	11608.5	0.21757	0.00177
mlo98-039-mfrsr379-500.out	8354.19	8131.01	0.11181	0.00144
mlo98-039-mfrsr379-615.out	8086.28	7870.25	0.07411	0.00099
mlo98-039-mfrsr379-670.out	4063.14	3954.59	0.05171	0.00200
mlo98-039-mfrsr379-870.out	8729.98	8496.76	0.01489	0.00071
mlo98-039-mfrsr379-936.out	12060.26	11738.0	0.04796	0.00167
mlo98-040-mfrsr244-415.out	15459.56	15051.7	0.21585	0.00307
mlo98-040-mfrsr244-500.out	8764.85	8533.67	0.11140	0.00222
mlo98-040-mfrsr244-615.out	2297.11	2236.52	0.06854	0.00242
mlo98-040-mfrsr244-670.out	2916.01	2839.09	0.03265	0.00309
mlo98-040-mfrsr244-870.out	7725.18	7521.42	0.00763	0.00298
mlo98-040-mfrsr244-936.out	8553.87	8328.25	0.04179	0.00387
mlo98-040-mfrsr378-415.out	13404.37	13050.7	0.21366	0.00160
mlo98-040-mfrsr378-500.out	8629.73	8402.10	0.11260	0.00200
mlo98-040-mfrsr378-615.out	8517.99	8293.31	0.07345	0.00152
mlo98-040-mfrsr378-670.out	3959.58	3855.14	0.04565	0.00260
mlo98-040-mfrsr378-870.out	8861.03	8627.30	0.01403	0.00170
mlo98-040-mfrsr378-936.out	11885.26	11571.7	0.04879	0.00206
mlo98-040-mfrsr379-415.out	11590.11	11284.3	0.21093	0.00164
mlo98-040-mfrsr379-500.out	8275.74	8057.44	0.10979	0.00255
mlo98-040-mfrsr379-615.out	7970.17	7759.93	0.07052	0.00147
mlo98-040-mfrsr379-670.out	3922.85	3819.37	0.04410	0.00246
mlo98-040-mfrsr379-870.out	8524.03	8299.18	0.00927	0.00159
mlo98-040-mfrsr379-936.out	11665.93	11358.2	0.04271	0.00203

Table 1: Basic MFRSR Langley Analysis Results

Data Filename mloYY-DDD-mfrsr###-λλλ.out	$I_{\lambda 0}$	$(R_c/R_m)^2 I_{\lambda 0}$	τ_λ	Standard Deviation of Residuals
mlo98-041-mfrsr244-415.out	15582.77	15177.1	0.21790	0.00185
mlo98-041-mfrsr244-500.out	8853.53	8623.09	0.11372	0.00216
mlo98-041-mfrsr244-615.out	2323.95	2263.46	0.07126	0.00288
mlo98-041-mfrsr244-670.out	2906.96	2831.29	0.03271	0.00297
mlo98-041-mfrsr244-870.out	7915.89	7709.85	0.01226	0.00344
mlo98-041-mfrsr244-936.out	8519.33	8297.59	0.06413	0.00448
mlo98-041-mfrsr378-415.out	13579.06	13225.6	0.21593	0.00166
mlo98-041-mfrsr378-500.out	8695.22	8468.91	0.11384	0.00170
mlo98-041-mfrsr378-615.out	8546.93	8324.47	0.07424	0.00113
mlo98-041-mfrsr378-670.out	3977.03	3873.52	0.04851	0.00293
mlo98-041-mfrsr378-870.out	9001.10	8766.83	0.01665	0.00219
mlo98-041-mfrsr378-936.out	11687.80	11383.5	0.06800	0.00113
mlo98-041-mfrsr379-415.out	12044.36	11730.8	0.21889	0.00350
mlo98-041-mfrsr379-500.out	8402.94	8184.23	0.11270	0.00232
mlo98-041-mfrsr379-615.out	8105.29	7894.34	0.07389	0.00165
mlo98-041-mfrsr379-670.out	3994.41	3890.45	0.04887	0.00244
mlo98-041-mfrsr379-870.out	8767.65	8539.45	0.01515	0.00221
mlo98-041-mfrsr379-936.out	11675.13	11371.2	0.06496	0.00252
mlo98-042-mfrsr244-415.out	15484.93	15087.4	0.21564	0.00278
mlo98-042-mfrsr244-500.out	8789.42	8563.83	0.11149	0.00210
mlo98-042-mfrsr244-615.out	2305.71	2246.53	0.06860	0.00267
mlo98-042-mfrsr244-670.out	2928.22	2853.06	0.03449	0.00186
mlo98-042-mfrsr244-870.out	7802.56	7602.30	0.00902	0.00301
mlo98-042-mfrsr244-936.out	8616.06	8394.92	0.06067	0.00290
mlo98-042-mfrsr378-415.out	13502.62	13156.0	0.21426	0.00123
mlo98-042-mfrsr378-500.out	8641.81	8420.01	0.11228	0.00232
mlo98-042-mfrsr378-615.out	8513.29	8294.78	0.07304	0.00132

Table 1: Basic MFRSR Langley Analysis Results

Data Filename mloYY-DDD-mfrsr###-λλλ.out	$I_{\lambda 0}$	$(R_c/R_m)^2 I_{\lambda 0}$	τ_λ	Standard Deviation of Residuals
mlo98-042-mfrsr378-670.out	3919.08	3818.49	0.04605	0.00287
mlo98-042-mfrsr378-870.out	8881.52	8653.56	0.01330	0.00123
mlo98-042-mfrsr378-936.out	11890.06	11584.8	0.06654	0.00299
mlo98-042-mfrsr379-415.out	11703.91	11403.5	0.21231	0.00123
mlo98-042-mfrsr379-500.out	8280.26	8067.73	0.10880	0.00221
mlo98-042-mfrsr379-615.out	7999.17	7793.86	0.07050	0.00121
mlo98-042-mfrsr379-670.out	3899.50	3799.41	0.04455	0.00285
mlo98-042-mfrsr379-870.out	8578.90	8358.70	0.00967	0.00101
mlo98-042-mfrsr379-936.out	11782.79	11480.3	0.06237	0.00271
mlo98-043-mfrsr244-415.out	15624.88	15229.6	0.21800	0.00321
mlo98-043-mfrsr244-500.out	8879.64	8655.02	0.11420	0.00313
mlo98-043-mfrsr244-615.out	2324.79	2265.99	0.07046	0.00503
mlo98-043-mfrsr244-670.out	2922.20	2848.28	0.03328	0.00322
mlo98-043-mfrsr244-870.out	7932.78	7732.11	0.01240	0.00463
mlo98-043-mfrsr244-936.out	8734.10	8513.16	0.05501	0.00328
mlo98-043-mfrsr378-415.out	13662.31	13316.7	0.21590	0.00163
mlo98-043-mfrsr378-500.out	8723.40	8502.73	0.11379	0.00178
mlo98-043-mfrsr378-615.out	8578.18	8361.18	0.07508	0.00151
mlo98-043-mfrsr378-670.out	3920.13	3820.97	0.04738	0.00214
mlo98-043-mfrsr378-870.out	8980.37	8753.20	0.01623	0.00158
mlo98-043-mfrsr378-936.out	11956.63	11654.1	0.05973	0.00143
mlo98-043-mfrsr379-415.out	12030.47	11726.1	0.21627	0.00430
mlo98-043-mfrsr379-500.out	8393.50	8181.17	0.11074	0.00345
mlo98-043-mfrsr379-615.out	8055.22	7851.45	0.07046	0.00220
mlo98-043-mfrsr379-670.out	3932.43	3832.96	0.04510	0.00268
mlo98-043-mfrsr379-870.out	8742.17	8521.03	0.01228	0.00292
mlo98-043-mfrsr379-936.out	11933.75	11631.8	0.05486	0.00285

Table 1: Basic MFRSR Langley Analysis Results

Data Filename mloYY-DDD-mfrsr###-λλλ.out	$I_{\lambda 0}$	$(R_c/R_m)^2 I_{\lambda 0}$	τ_λ	Standard Deviation of Residuals
mlo98-044-mfrsr244-415.out	15643.20	15253.2	0.22023	0.00190
mlo98-044-mfrsr244-500.out	8841.74	8621.36	0.11424	0.00241
mlo98-044-mfrsr244-615.out	2315.95	2258.22	0.06988	0.00264
mlo98-044-mfrsr244-670.out	2909.30	2836.79	0.03239	0.00285
mlo98-044-mfrsr244-870.out	7925.84	7728.29	0.01329	0.00181
mlo98-044-mfrsr244-936.out	8757.36	8539.08	0.04880	0.00229
mlo98-044-mfrsr378-415.out	13614.56	13275.2	0.21636	0.00135
mlo98-044-mfrsr378-500.out	8672.65	8456.47	0.11314	0.00156
mlo98-044-mfrsr378-615.out	8531.87	8319.20	0.07422	0.00152
mlo98-044-mfrsr378-670.out	3877.35	3780.70	0.04689	0.00168
mlo98-044-mfrsr378-870.out	8950.68	8727.57	0.01631	0.00141
mlo98-044-mfrsr378-936.out	12024.90	11725.1	0.05428	0.00187
mlo98-044-mfrsr379-415.out	12004.91	11705.6	0.21839	0.00252
mlo98-044-mfrsr379-500.out	8343.06	8135.09	0.11046	0.00210
mlo98-044-mfrsr379-615.out	8058.09	7857.21	0.07297	0.00155
mlo98-044-mfrsr379-670.out	3909.14	3811.70	0.04753	0.00317
mlo98-044-mfrsr379-870.out	8737.44	8519.63	0.01529	0.00177
mlo98-044-mfrsr379-936.out	11910.72	11613.8	0.04927	0.00149
mlo98-045-mfrsr244-415.out	15504.30	15123.8	0.21412	0.00237
mlo98-045-mfrsr244-500.out	8784.92	8569.37	0.10938	0.00251
mlo98-045-mfrsr244-615.out	2304.26	2247.72	0.06610	0.00287
mlo98-045-mfrsr244-670.out	2891.06	2820.12	0.02790	0.00278
mlo98-045-mfrsr244-870.out	7826.84	7634.80	0.00704	0.00341
mlo98-045-mfrsr244-936.out	8723.39	8509.35	0.04342	0.00313
mlo98-045-mfrsr378-415.out	13584.31	13251.0	0.21331	0.00148
mlo98-045-mfrsr378-500.out	8643.45	8431.37	0.11106	0.00174
mlo98-045-mfrsr378-615.out	8472.33	8264.45	0.07126	0.00119
mlo98-045-mfrsr378-670.out	3827.22	3733.31	0.04409	0.00241

Table 1: Basic MFRSR Langley Analysis Results

Data Filename mloYY-DDD-mfrsr###-λλλ.out	$I_{\lambda 0}$	$(R_c/R_m)^2 I_{\lambda 0}$	τ_λ	Standard Deviation of Residuals
mlo98-045-mfrsr378-870.out	8909.37	8690.77	0.01288	0.00169
mlo98-045-mfrsr378-936.out	11981.03	11687.0	0.04887	0.00145
mlo98-045-mfrsr379-415.out	11899.31	11607.3	0.21721	0.00227
mlo98-045-mfrsr379-500.out	8260.31	8057.63	0.11034	0.00177
mlo98-045-mfrsr379-615.out	7963.59	7768.20	0.07228	0.00147
mlo98-045-mfrsr379-670.out	3855.25	3760.66	0.04826	0.00278
mlo98-045-mfrsr379-870.out	8650.28	8438.03	0.01522	0.00148
mlo98-045-mfrsr379-936.out	11886.02	11594.3	0.05003	0.00168
mlo98-046-mfrsr244-415.out	15697.40	15318.3	0.21971	0.00200
mlo98-046-mfrsr244-500.out	8904.32	8689.32	0.11571	0.00193
mlo98-046-mfrsr244-615.out	2331.88	2275.58	0.07287	0.00167
mlo98-046-mfrsr244-670.out	2946.72	2875.57	0.03609	0.00161
mlo98-046-mfrsr244-870.out	7929.41	7737.95	0.01398	0.00180
mlo98-046-mfrsr244-936.out	8680.14	8470.55	0.05749	0.00177
mlo98-046-mfrsr378-415.out	13814.80	13481.2	0.22039	0.00368
mlo98-046-mfrsr378-500.out	8747.13	8535.93	0.11711	0.00409
mlo98-046-mfrsr378-615.out	8597.37	8389.78	0.07840	0.00275
mlo98-046-mfrsr378-670.out	3874.49	3780.94	0.05366	0.00400
mlo98-046-mfrsr378-870.out	8884.00	8669.49	0.01384	0.00174
mlo98-046-mfrsr378-936.out	11953.45	11664.8	0.06393	0.00325
mlo98-046-mfrsr379-415.out	12031.46	11740.9	0.22367	0.00426
mlo98-046-mfrsr379-500.out	8382.68	8180.28	0.11720	0.00379
mlo98-046-mfrsr379-615.out	8056.40	7861.87	0.07851	0.00458
mlo98-046-mfrsr379-670.out	3850.41	3757.45	0.05147	0.00360
mlo98-046-mfrsr379-870.out	8620.63	8412.48	0.01593	0.00179
mlo98-046-mfrsr379-936.out	11765.05	11480.9	0.06209	0.00241
mlo98-047-mfrsr244-415.out	15492.38	15124.4	0.21386	0.00229

Table 1: Basic MFRSR Langley Analysis Results

Data Filename mloYY-DDD-mfrsr###-λλλ.out	$I_{\lambda 0}$	$(R_c/R_m)^2 I_{\lambda 0}$	τ_λ	Standard Deviation of Residuals
mlo98-047-mfrsr244-500.out	8762.75	8554.67	0.10927	0.00212
mlo98-047-mfrsr244-615.out	2276.15	2222.10	0.06392	0.00458
mlo98-047-mfrsr244-670.out	2890.45	2821.82	0.02888	0.00347
mlo98-047-mfrsr244-870.out	7716.79	7533.54	0.00516	0.00340
mlo98-047-mfrsr244-936.out	8235.89	8040.31	0.06590	0.00481
mlo98-047-mfrsr378-415.out	13467.39	13147.5	0.21001	0.00156
mlo98-047-mfrsr378-500.out	8582.71	8378.90	0.10909	0.00200
mlo98-047-mfrsr378-615.out	8449.94	8249.29	0.07047	0.00153
mlo98-047-mfrsr378-670.out	3748.41	3659.40	0.04293	0.00247
mlo98-047-mfrsr378-870.out	8783.61	8575.02	0.01085	0.00122
mlo98-047-mfrsr378-936.out	11235.28	10968.4	0.07047	0.00363
mlo98-047-mfrsr379-415.out	11664.29	11387.3	0.21158	0.00165
mlo98-047-mfrsr379-500.out	8261.98	8065.78	0.11013	0.00193
mlo98-047-mfrsr379-615.out	7941.46	7752.87	0.07165	0.00166
mlo98-047-mfrsr379-670.out	3800.21	3709.97	0.04787	0.00263
mlo98-047-mfrsr379-870.out	8549.76	8346.73	0.01144	0.00166
mlo98-047-mfrsr379-936.out	11219.96	10953.5	0.06989	0.00376

Table 2: MFRSR Total Optical Depth Distribution Statistics

	Min.	1st Quantile	Median	Mean	3rd Quantile	Max.
415 nm	0.21	0.2134	0.2156	0.2149	0.2164	0.2189
500 nm	0.1088	0.1103	0.1114	0.1114	0.1125	0.1138
615 nm	0.0705	0.07137	0.0732	0.07274	0.0739	0.0751
670 nm	0.0429	0.04525	0.0469	0.04674	0.0482	0.0517
870 nm	0.0093	0.01245	0.0148	0.0138	0.0152	0.0167
936 nm	0.0427	0.04947	0.0573	0.05728	0.06435	0.0705

Table 3: Importance of PCA Components

	Comp.1	Comp.2	Comp.3	Comp.4
Standard deviation	0.01161637	0.00471458	0.00337277	0.00133656
Proportion of Variance	0.78642050	0.12953887	0.06629603	0.01041096
Cumulative Proportion	0.7864	0.9159	0.9822	0.9926

Table 4: Distribution Statistics of MFRSR Total Optical Depth for DOY 39,44 & 45

wavlength, nm	Min.	1stQu.	Median	Mean	3rdQu.	Max.
415	0.2133	0.2153	0.2168	0.2163	0.2175	0.2184
500	0.1103	0.1106	0.1114	0.1115	0.1123	0.1131
615	0.0713	0.0724	0.0733	0.0731	0.0740	0.0742
670	0.0441	0.0469	0.0472	0.0475	0.0481	0.0517
870	0.0129	0.0149	0.0151	0.0149	0.0152	0.0163
936	0.0480	0.0490	0.0496	0.0502	0.0506	0.0543

Table 5: Distribution Statistics for Normalized V_o for MFRSR Unit 378

	Vo415	Vo500	Vo615	Vo670	Vo870	Vo936
Min	13140	8431	8264	3733	8691	11690
1stQu	13200	8438	8292	3757	8708	11710
Median	13250	8445	8319	3781	8724	11730
Mean	13220	8444	8303	3814	8714	11750
3rdQu	13260	8451	8323	3854	8726	11780
Max	13280	8456	8326	3927	8728	11830

Table 6: Distribution Statistics for Normalized V_o for MFRSR Unit 379

	Vo415	Vo500	Vo615	Vo670	Vo870	Vo936
Min	11610	8058	7768	3761	8438	11590
1stQu	11610	8094	7813	3786	8467	11600
Median	11610	8131	7857	3812	8497	11610
Mean	11640	8108	7832	3842	8485	11650
3rdQu	11660	8133	7864	3883	8508	11680
Max	11710	8135	7870	3955	8520	11740

Table 7: Basic FieldSpec Unit 648 Langley Analysis Results

Data Filename mloYY-DDD-mfrsr###-λλλ.out	$I_{\lambda 0}$	$(R_c/R_m)^2 I_{\lambda 0}$	τ_λ	Standard Deviation of Residuals
mlo98-038-fldsp648-380.out	18710.92258	18204.42584	0.30917	0.00255
mlo98-038-fldsp648-400.out	26883.39534	26155.67322	0.25048	0.00255
mlo98-038-fldsp648-415.out	32353.16567	31477.37919	0.21597	0.00272
mlo98-038-fldsp648-500.out	51498.09935	50104.06762	0.11445	0.00246
mlo98-038-fldsp648-673.out	33973.70635	33054.05251	0.04720	0.00237
mlo98-038-fldsp648-870.out	7415.86797	7215.12357	0.02293	0.00363
mlo98-038-fldsp648-936.out	2416.18103	2350.77603	0.09077	0.00719
mlo98-039-fldsp648-380.out	19308.60366	18792.43714	0.30814	0.00197
mlo98-039-fldsp648-400.out	27727.35674	26986.13622	0.24978	0.00205
mlo98-039-fldsp648-415.out	33315.53424	32424.92798	0.21530	0.00194
mlo98-039-fldsp648-500.out	52752.49510	51342.29102	0.11362	0.00225
mlo98-039-fldsp648-673.out	34769.81893	33840.33606	0.04683	0.00275
mlo98-039-fldsp648-870.out	7575.29858	7372.79220	0.02159	0.00375
mlo98-039-fldsp648-936.out	2504.50831	2437.55663	0.07616	0.00637
mlo98-040-fldsp648-380.out	18759.97443	18264.93713	0.30725	0.00206
mlo98-040-fldsp648-400.out	26845.74439	26137.34018	0.24868	0.00215
mlo98-040-fldsp648-415.out	32257.43719	31406.22948	0.21426	0.00191
mlo98-040-fldsp648-500.out	51052.82618	49705.64664	0.11245	0.00204
mlo98-040-fldsp648-673.out	33709.41301	32819.89064	0.04582	0.00196
mlo98-040-fldsp648-870.out	7362.79299	7168.50396	0.02052	0.00303
mlo98-040-fldsp648-936.out	2356.14924	2293.97529	0.07022	0.00616
mlo98-041-fldsp648-400.out	27516.77275	26800.61007	0.25054	0.00239
mlo98-041-fldsp648-380.out	19229.69261	18729.21284	0.30918	0.00253
mlo98-041-fldsp648-415.out	33084.27134	32223.20668	0.21661	0.00248

Table 7: Basic FieldSpec Unit 648 Langley Analysis Results

Data Filename mloYY-DDD-mfrsr###-λλλ.out	$I_{\lambda 0}$	$(R_c/R_m)^2 I_{\lambda 0}$	τ_λ	Standard Deviation of Residuals
mlo98-041-fldsp648-500.out	52284.39219	50923.61741	0.11475	0.00236
mlo98-041-fldsp648-673.out	34474.69685	33577.44442	0.04746	0.00224
mlo98-041-fldsp648-870.out	7527.66949	7331.75132	0.02190	0.00310
mlo98-041-fldsp648-936.out	2351.90805	2290.69634	0.09686	0.00644
mlo98-042-fldsp648-380.out	19447.54594	18948.46592	0.30949	0.00272
mlo98-042-fldsp648-400.out	27877.71551	27162.29306	0.25086	0.00270
mlo98-042-fldsp648-415.out	33466.29832	32607.45674	0.21673	0.00259
mlo98-042-fldsp648-500.out	52972.87188	51613.43546	0.11499	0.00260
mlo98-042-fldsp648-673.out	35235.65134	34331.40307	0.04950	0.00265
mlo98-042-fldsp648-870.out	7775.21485	7575.68045	0.02540	0.00357
mlo98-042-fldsp648-936.out	2518.17892	2453.55520	0.10167	0.00586
mlo98-043-fldsp648-380.out	19407.25661	18916.16310	0.30588	0.00109
mlo98-043-fldsp648-400.out	28015.55173	27306.62846	0.24904	0.00091
mlo98-043-fldsp648-415.out	33444.31051	32598.01449	0.21370	0.00079
mlo98-043-fldsp648-500.out	53010.28206	51668.87629	0.11205	0.00061
mlo98-043-fldsp648-673.out	35255.13541	34363.01712	0.04541	0.00059
mlo98-043-fldsp648-870.out	7805.18300	7607.67570	0.02000	0.00119
mlo98-043-fldsp648-936.out	2543.99960	2479.62462	0.08549	0.00259
mlo98-047-fldsp648-380.out	18861.84360	18413.79339	0.30545	0.00352
mlo98-047-fldsp648-400.out	26975.00849	26334.23559	0.24755	0.00316
mlo98-047-fldsp648-415.out	32290.36043	31523.32497	0.21303	0.00324
mlo98-047-fldsp648-500.out	50956.30346	49745.87127	0.11164	0.00307
mlo98-047-fldsp648-673.out	33631.68534	32832.78762	0.04525	0.00230
mlo98-047-fldsp648-870.out	7343.76590	7169.31975	0.02012	0.00302
mlo98-047-fldsp648-936.out	2267.92712	2214.05406	0.10825	0.00624

Table 8: Basic FieldSpec Unit 660 Langley Analysis Results

Data Filename mloYY-DDD-mfrsr###-λλλ.out	$I_{\lambda 0}$	$(R_c/R_m)^2 I_{\lambda 0}$	τ_λ	Standard Deviation of Residuals
mlo98-038-fldsp660-380.out	0.90940	0.88478	0.30177	0.00444
mlo98-038-fldsp660-400.out	1.33076	1.29474	0.24600	0.00378
mlo98-038-fldsp660-415.out	1.55936	1.51715	0.21154	0.00407
mlo98-038-fldsp660-500.out	1.73977	1.69267	0.10629	0.004043
mlo98-038-fldsp660-673.out	1.38533	1.34783	0.04132	0.00291
mlo98-038-fldsp660-870.out	0.88571	0.86173	0.01835	0.00246
mlo98-038-fldsp660-936.out	0.68167	0.66322	0.09740	0.00366
mlo98-039-fldsp660-380.out	0.91606	0.89157	0.30330	0.00447
mlo98-039-fldsp660-400.out	1.33816	1.30239	0.24775	0.00409
mlo98-039-fldsp660-415.out	1.56854	1.52661	0.21400	0.00437
mlo98-039-fldsp660-500.out	1.74617	1.69949	0.10932	0.00448
mlo98-039-fldsp660-673.out	1.38182	1.34488	0.04306	0.00400
mlo98-039-fldsp660-870.out	0.88459	0.86094	0.02024	0.00334
mlo98-039-fldsp660-936.out	0.67538	0.65732	0.07912	0.00819
mlo98-040-fldsp660-380.out	0.98798	0.96191	0.30930	0.00187
mlo98-040-fldsp660-400.out	1.42571	1.38809	0.25333	0.00162
mlo98-040-fldsp660-415.out	1.67992	1.63560	0.22007	0.00142
mlo98-040-fldsp660-500.out	1.86889	1.81958	0.11490	0.00122
mlo98-040-fldsp660-673.out	1.46956	1.43078	0.04871	0.00113
mlo98-040-fldsp660-870.out	0.93413	0.90948	0.02449	0.00228
mlo98-040-fldsp660-936.out	0.69004	0.67184	0.07732	0.00376
mlo98-042-fldsp660-380.out	0.98572	0.96041	0.30772	0.00291
mlo98-042-fldsp660-400.out	1.42137	1.38488	0.25164	0.00238
mlo98-042-fldsp660-415.out	1.67361	1.63065	0.21841	0.00231
mlo98-042-fldsp660-500.out	1.86204	1.81424	0.11365	0.00184
mlo98-042-fldsp660-673.out	1.46471	1.42710	0.04724	0.00233

Table 8: Basic FieldSpec Unit 660 Langley Analysis Results

Data Filename mloYY-DDD-mfrsr###-λλλ.out	$I_{\lambda 0}$	$(R_c/R_m)^2 I_{\lambda 0}$	τ_λ	Standard Deviation of Residuals
mlo98-042-fldsp660-870.out	0.93726	0.91320	0.02404	0.00224
mlo98-042-fldsp660-936.out	0.70338	0.68532	0.10601	0.00352
mlo98-043-fldsp660-380.out	1.00137	0.97604	0.31151	0.00223
mlo98-043-fldsp660-400.out	1.44463	1.40808	0.25540	0.00172
mlo98-043-fldsp660-415.out	1.69733	1.65439	0.22190	0.00178
mlo98-043-fldsp660-500.out	1.88608	1.83837	0.11716	0.00150
mlo98-043-fldsp660-673.out	1.48654	1.44894	0.05008	0.00156
mlo98-043-fldsp660-870.out	0.95221	0.92812	0.02541	0.00160
mlo98-043-fldsp660-936.out	0.71311	0.69507	0.09353	0.00328
mlo98-047-fldsp660-380.out	0.99105	0.96751	0.30899	0.00429
mlo98-047-fldsp660-400.out	1.41449	1.38089	0.25342	0.00283
mlo98-047-fldsp660-415.out	1.66312	1.62362	0.22019	0.00270
mlo98-047-fldsp660-500.out	1.84397	1.80017	0.11607	0.00261
mlo98-047-fldsp660-673.out	1.44181	1.40756	0.04972	0.00246
mlo98-047-fldsp660-870.out	0.91446	0.89274	0.02633	0.00350
mlo98-047-fldsp660-936.out	0.65253	0.63703	0.12073	0.00562

Table 9: Basic MICROTOPS Langley Analysis Results

Data Filename mloYY-DDD-mfrsr###-λλλ.out	$I_{\lambda 0}$	$(R_c/R_m)^2 I_{\lambda 0}$	τ_λ	Standard Deviation of Residuals
mlo98-038-microtop-380.out	1748.09654	1700.79128	0.29741	0.00555
mlo98-038-microtop-500.out	822.83899	800.57214	0.10078	0.00518
mlo98-038-microtop-675.out	1038.53009	1010.42641	0.03388	0.00479
mlo98-038-microtop-936.out	1300.85753	1265.65501	0.06237	0.00404
mlo98-039-microtop-380.out	2135.47270	2078.40443	0.30882	0.00182
mlo98-039-microtop-500.out	971.02280	945.07324	0.11018	0.00271
mlo98-039-microtop-675.out	1131.80559	1101.55927	0.04134	0.00556
mlo98-039-microtop-870.out	780.98640	760.11536	0.01393	0.00422
mlo98-039-microtop-936.out	1492.95564	1453.05797	0.05683	0.00455
mlo98-040-microtop-380.out	2170.49797	2113.24167	0.31339	0.00115
mlo98-040-microtop-500.out	1018.69976	991.82714	0.11112	0.00048
mlo98-040-microtop-675.out	1241.63642	1208.88287	0.04128	0.00089
mlo98-040-microtop-870.out	845.39700	823.09599	0.01465	0.00041
mlo98-040-microtop-936.out	1542.62295	1501.92957	0.05644	0.00170
mlo98-041-microtop-380.out	2118.03540	2062.90746	0.30973	0.00133
mlo98-041-microtop-500.out	1003.98702	977.85539	0.11020	0.00095
mlo98-041-microtop-675.out	1235.31135	1203.15884	0.04159	0.00158
mlo98-041-microtop-870.out	845.14775	823.15036	0.01665	0.00079
mlo98-041-microtop-936.out	1498.16378	1459.16977	0.07950	0.00412
mlo98-042-microtop-380.out	2123.77995	2069.27626	0.31121	0.00143
mlo98-042-microtop-500.out	1009.96959	984.05020	0.11106	0.00079
mlo98-042-microtop-675.out	1240.18100	1208.35357	0.04114	0.00064
mlo98-042-microtop-870.out	847.01159	825.27428	0.01609	0.00036

Table 9: Basic MICROTOPS Langley Analysis Results

Data Filename mloYY-DDD-mfrsr###-λλλ.out	$I_{\lambda 0}$	$(R_c/R_m)^2 I_{\lambda 0}$	τ_λ	Standard Deviation of Residuals
mlo98-042-microtop-936.out	1536.81716	1497.37700	0.07970	0.00297
mlo98-043-microtop-380.out	2139.98857	2085.85180	0.30887	0.00218
mlo98-043-microtop-500.out	1003.79461	978.40093	0.10954	0.00129
mlo98-043-microtop-675.out	1213.53050	1182.83098	0.04106	0.00305
mlo98-043-microtop-870.out	835.65875	814.51851	0.01564	0.00168
mlo98-043-microtop-936.out	1545.43703	1506.34104	0.07070	0.00154
mlo98-047-microtop-380.out	1883.64684	1838.90721	0.31046	0.00150
mlo98-047-microtop-500.out	808.67217	789.46492	0.10721	0.00171
mlo98-047-microtop-675.out	928.17937	906.13363	0.03968	0.00292
mlo98-047-microtop-870.out	638.06769	622.91257	0.01237	0.00225
mlo98-047-microtop-936.out	1138.29899	1111.26257	0.08585	0.00423

Table 10: Distribution Statistics for Optical Depth for FieldSpec Unit 648

	tau380	tau400	tau415	tau500	tau673	tau870	tau936
Min.	0.3059	0.2490	0.2137	0.1120	0.04541	0.02000	0.07616
1stQu.	0.3070	0.2494	0.2145	0.1128	0.04612	0.02080	0.08083
Median	0.3081	0.2498	0.2153	0.1136	0.04683	0.02159	0.08549
Mean	0.3077	0.2498	0.2150	0.1134	0.04648	0.02151	0.08414
3rdQu.	0.3087	0.2501	0.2156	0.1140	0.04702	0.02226	0.08813
Max.	0.3092	0.2505	0.2160	0.1144	0.04720	0.02293	0.09077

Table 11: Distribution Statistics for Optical Depth for FieldSpec Unit 660

	tau380	tau400	tau415	tau500	tau673	tau870	tau936
Min.	0.3018	0.2460	0.2115	0.1063	0.04132	0.01835	0.07912
1stQu.	0.3025	0.2469	0.2128	0.1078	0.04219	0.01929	0.08632
Median	0.3033	0.2477	0.2140	0.1093	0.04306	0.02024	0.09353
Mean	0.3055	0.2497	0.2158	0.1109	0.04482	0.02133	0.09002
3rdQu.	0.3074	0.2516	0.2179	0.1132	0.04657	0.02282	0.09546
Max.	0.3115	0.2554	0.2219	0.1172	0.05008	0.02541	0.09740

Table 12: Distribution Statistics for Optical Depth for MICROTOPS II

	tau380	tau500	tau675	tau870	tau936
Min.	0.2974	0.1008	0.03388	0.01393	0.05683
1stQu.	0.3031	0.1052	0.03747	0.01436	0.05960
Median	0.3088	0.1095	0.04106	0.01479	0.06237
Mean	0.3050	0.1068	0.03876	0.01479	0.06330

Table 12: Distribution Statistics for Optical Depth for MICROTOPS II

	tau380	tau500	tau675	tau870	tau936
3rdQu.	0.3088	0.1099	0.04120	0.01521	0.06653
Max.	0.3089	0.1102	0.04134	0.01564	0.07070

Table 13: Distribution Statistics for V_o for FieldSpec Unit 648

	V_o 380	V_o 400	V_o 415	V_o 500	V_o 673	V_o 870	V_o 936
Min.	18200	26160	31480	50100	33050	7215	2350
1stQu.	18500	26570	31950	50720	33450	7294	2394
Median	18790	26990	32420	51340	33840	7372	2437
Mean	18640	26820	32170	51040	33750	7398	2422
3rdQu.	18850	27150	32510	51500	34100	7490	2458
Max.	18920	27310	32600	51670	34360	7607	2479

Table 14: Distribution Statistics for V_o for FieldSpec Unit 660

	V_o 380	V_o 400	V_o 415	V_o 500	V_o 673	V_o 870	V_o 936
Min.	0.8848	1.295	1.517	1.693	1.345	0.8609	0.6573
1stQu.	0.8882	1.299	1.522	1.696	1.346	0.8613	0.6603
Median	0.8916	1.302	1.527	1.699	1.348	0.8617	0.6632
Mean	0.9175	1.335	1.566	1.744	1.381	0.8836	0.6719
3rdQu.	0.9338	1.355	1.591	1.769	1.398	0.8949	0.6791
Max.	0.9760	1.408	1.654	1.838	1.449	0.9281	0.6951

Table 15: Distribution Statistics for V_o for MICROTOPS II

	V_o 380	V_o 500	V_o 675	V_o 870	V_o 936
Min.	1700	800	1010	760	1265
1stQu.	1889	872	1056	773	1359
Median	2078	945	1101	787	1453
Mean	1954	907	1098	787	1408
3rdQu.	2082	961	1142	800	1480
Max.	2085	978	1182	814	1506

Table 16: Ranges of Optical Depth for Common Wavelengths on Calibration Days

Instrument/Wavelength	500nm	673nm	870nm	Average
FieldSpec FR 648	0.002	0.002	0.003	0.0023
FieldSpec FR 660	0.011	0.009	0.007	0.0090
MICROTOPS II	0.009	0.007	0.002	0.0060
MFRSRs (pooled)	0.003	0.008	0.003	0.0046