UVMFR/MFR/SDR Rotating Shadowband Radiometer

Installation and User Guide

Version 2.34

Multi-filter Rotating Shadowband Radiometer

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YANKEE ENVIRONMENTAL SYSTEMS, INC.

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In This Manual

This manual provides information on setting up a rotating shadowband radiometer instrument, including how to initially align it at the site and maintain it. It covers three primary types of shadowband instruments: SDR-1, MFR-7, and UVMFR as well as single channel variants such as the photopic, quantum energy or Photosynthetically-active Model SDP-1. For simplicity, all of these rotating shadowband radiometers variants are simply referred to as a MFR, but other than number of channels and spectral response the operation is nearly identical. For detailed information on configuring the YESDAS datalogger to collect data from a shadowband instrument, see the *YESDAS Installation and User Guide*.

What this manual covers

This manual covers the following topics:

CHAPTER		DESCRIPTION
1	Overview	Types of shadowband instruments, detailed specifications, and principle of operation
2	Installation	Site requirements and procedure for setting up a shadowband instrument system at the site
3	Interpreting the Data	Information on spectral response and retrieval of total aerosol, optical depth, water vapor, and ozone data
4	Maintenance and Service	Routine maintenance tasks you should perform on the shadowband instrument; troubleshooting information
A	References	Abbreviated list of publications related to the MFRSR
B	Table of Ozone Absorption Coefficients	Coefficients used to calculate ozone optical depth

Related manuals

This manual describes the shadowband instrument only. For detailed information on using YESDAS to log shadowband data, see the *YESDAS Installation and User Guide*. For information on processing the data collected by YESDAS running on a PC under MS-Windows™, see the *YESDAS Manager User Guide*.

Technical support

If you have a question about operating the shadowband instrument and cannot find the answer you need in this manual, contact YES using any of the following methods:

- **Web:** www.yesinc.com (see the *Support* section)
- **Fax:** +1-413-863-0255
- **Sales Phone:** +1-413-863-0200 (9AM-5PM EST Monday through Friday)

Warning: *Please read this manual before using your system*. Because the sensor is active, it should only be left outdoors if continuously powered on and mounted out of the reach of unauthorized personnel. Be sure to connect the standby battery to protect your system against lightening and AC power failures. See the section Important Product Safety and Disclaimer Information on page 4-11.

CHAPTER 1
Overview

Types of shadowband instruments

The Rotating Shadowband Radiometer is a field instrument that measures the global, direct, and diffuse components of solar irradiance at up to seven wavelengths. A microprocessor-controlled shadowband alternately shades and exposes the instrument diffuser, enabling the system to measure all three irradiance components with a single carefully characterized detectors. The YES family of rotating shadowband radiometers consists of these four Models:

- **SDR-1.** Single-Detector Radiometer. This instrument is equipped with one unfiltered broadband thermopile detector channel.
- **SDP-1** Single Detector Photometer. This version contains a detector having either a photopic (human eye), quantum (energy) or Photosynthetically Active Radiation (PAR, 400-700 nm) response.
- **MFR-7.** Multi-filter Radiometer. In addition to the broadband channel of the SDR-1, this instrument has six narrowband channels for aerosol work.

CHANNEL	WAVELENGTH (10 NM EFFECTIVE BANDWIDTH)
1	Broadband thermopile pyranometer
2	415
3	500
4	615
5	673
6	870
7	940

- **UVMFR.** Ultraviolet Multi-filter Radiometer. The UVMFR includes:

CHANNEL	WAVELENGTH (2 NM EFFECTIVE BANDWIDTH)
1	300
2	305.5
3	311.5
4	317.5
5	325
6	332.5
7	368

Applications

The UVMFR is available in configurations of four channels as the UVMFR-4 (for UV-B) or as the UVMFR-7 with seven channels (UV-B + UV-A).

These various configurations make them well suited to many applications:

- The broadband channel together with the rotating shadowband offers a cost-efficient, automated solution for solar resource monitoring applications, such as determining the optimum placement of solar panels. Previously, three instruments were required for solar assessment studies: a normal incidence pyrheliometer (NIP) mounted on a tracker and two separate pyranometers, with one exposed and a second having a fixed shading band or a tracker-drive shading ball. Because the shadowband instrument reports both direct and diffuse (as well as total) irradiance, additional instruments are not required. Aside from not having to track and characterize three separate optical detectors, the elimination of a mechanical tracker significantly improves measurement reliability and overall ease of use.
- The narrowband wavelengths in the MFR-7 are useful in various atmospheric studies. For example, certain wavelengths are affected by aerosols, so by comparing the ratios of data from various channels, you can detect the presence of column aerosols. The 940 nm channel can be used to measure column water vapor; the 415 and 500 nm channels can be used to extract column ozone data.
- The UV wavelengths in a UVMFR can provide the same type of scientific ozone data reported by expensive scanning UV spectroradiometers such as the Dobson or Brewer instruments, but at a much lower cost. Although the UVMFR does not provide the full spectrum recorded by a spectroradiometer, it provides data points of particular interest, including several Dobson pairs.

YESDAS datalogger and host software

The Yankee Environmental Systems Data Acquisition System (YESDAS) controls the system and is core part of each shadowband instrument. This 32-channel data acquisition, and digital control system enables you to precisely control and monitor data collection from a shadowband instrument as well as from several other environmental sensors. In addition to PCMCIA memory expansion modules to store long term data streams at very remote sites, various communications options are available, including telephone modem and direct RS-232 serial cable, which transmits data from YESDAS to a host PC.

Once the raw binary data has been downloaded to your computer, you can use the YESDAS Manager host software to process and analyze the data. The host software includes functions that let you calibrate, plot, and run Langley analysis on the data. See the *YESDAS Manager User Guide* for more details.

Options

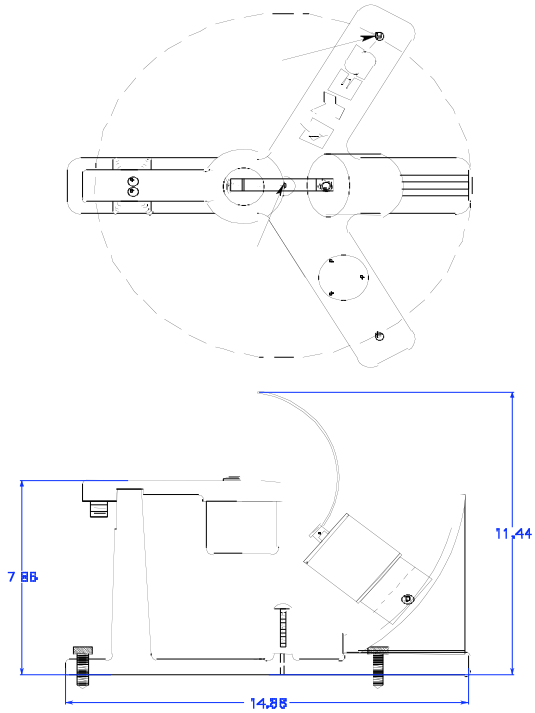
A basic system includes a shadowband instrument, YESDAS, and YESDAS Manager host software. You can optionally order

- A PCMCIA memory expansion card with control board and firmware provides non-volatile data storage and supports higher time resolution measurements (i.e. more accurate Langley optical depth measurements)
- Other radiometers (Model TSP-700, UVA-1 or UVB-1 pyranometers), or met sensors (thermo-hygrometer Model MET-2010 or PTU-2000).

These options are described in the *YESDAS Installation and User Guide*.

Specifications

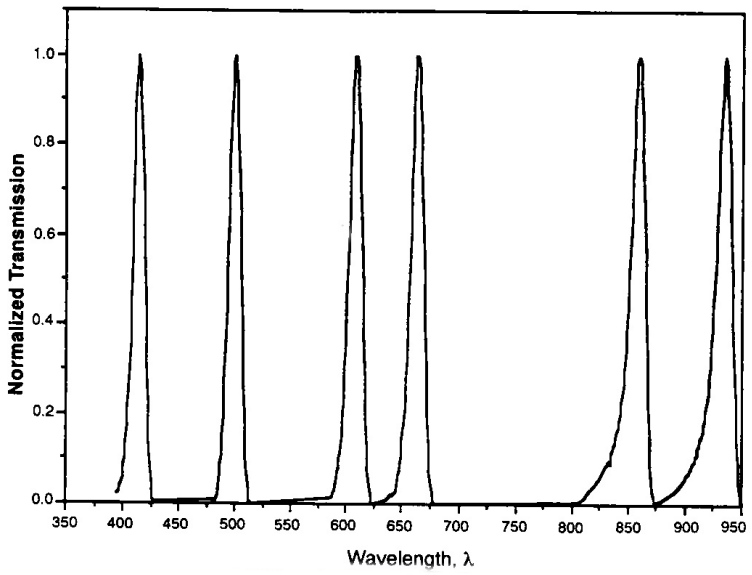
The mechanical detail and operating characteristics for the shadowband instrument are given below.



Dimensions in inches (cm)

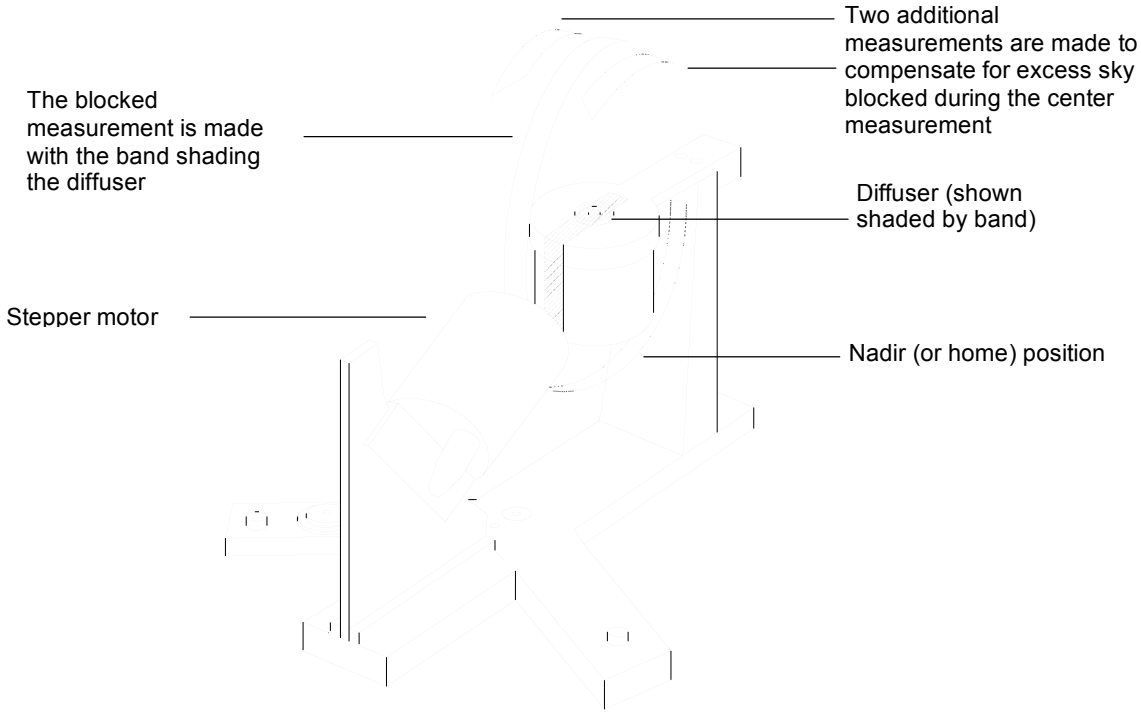
CHARACTERISTIC	DESCRIPTION
Spectral response	The SDR and MFR have one broadband thermopile channel covering 300nm to 2700nm+. The MFR has the following additional wavelengths: 10 nm FWHM centered on 415, 500, 615, 673, 870, and 940 nm* The UVMFR has the following wavelengths: 2 nm FWHM centered on 300, 305.5, 311.5, 317.5, 325, 332.5, and 368 nm*
Cosine response	Better than 5% raw response between 0-80° zenith angle; better than 1% with automatic cosine corrections
Temperature range	-30 °C to +50 °C (All photodiodes, interference filters, and sensitive electronic components are held inside a temperature-controlled enclosure.)
Power requirement	110/250 VAC, 50-60 Hz (50 watts maximum) or 12 Vdc at 1.5 amp 50% duty cycle and 3 amps 50% duty cycle. Requires user-supplied standby lead acid battery.
Weight	11 lb. (4.55 kg)
Packaging	The instrument is designed for continuous outdoor above water use: all fasteners are stainless steel and connectors are potted and weatherproof

*The wavelengths listed are nominal. Each instrument is individually characterized in our Optical Calibration laboratory, and the effective center wavelength and effective bandeaus are included in the calibration file for that instrument. Typical normalized band passes for the six narrowband channels on an MFR-7 are shown below.



Principle of Operation

The physical geometry of the rotating shadowband instrument is shown below. The shadowband is a strip of metal formed into a circular arc and mounted along a celestial meridian, with the instrument's entrance aperture at the center of the arc. The shadowband blocks a strip of sky with a 3.3° umbral angle, sufficient to block the sun. It can be positioned with an accuracy of .4° by a microprocessor-controlled stepper motor. The motor housing is adjusted for the latitude of the instrument and is azimuthally aligned to the North or South pole, depending on the hemisphere.



A microprocessor in YESDAS controls the instrument. At each measurement interval, the instrument computes the solar position using an approximation of the solar ephemeris. The first measurement is made with the band rotated to its nadir position (also called the *home* position) to obtain the global *or total* irradiance. The band is then rotated to make three more measurements. The second measurement (the diffuse-horizontal irradiance) is made with the sun completely blocked; the other two are made with the band rotated 9° to either side of the sun. These side measurements permit the system to correct for the excess sky that is blocked by the shadowband during the sun-blocked measurement.

YESDAS subtracts the corrected diffuse component value from the global irradiance to obtain the direct horizontal component. It then divides the direct horizontal component by the cosine of the solar zenith angle (available from the ephemeris calculation) to compute the direct normal component. This entire sequence completes in less than 15 seconds on an SDR or MFR and can be programmed to occur up to 4 times per minute.(The sequence takes 20 seconds on a UVMFR or high-latitude instrument and can occur up to 3 times per minute.)

Why It's Better Than a Tracker

A rotating shadowband radiometer provides fully automatic measurements of global, diffuse, and direct normal components of broadband solar radiation (irradiance, in Watts/meter^2) using a single detector and only one degree of mechanical freedom. For many decades global/total solar measurements have been made with thermal-type pyranometers (such as the Yankee Model TSP-700) and a two axis mechanical tracker. Two independent pyranometers (one shaded from the sun's direct rays with a disc controlled by the tracker), and a third collimated detector maintained normal to the sun (a *Normal Incidence Pyrheliometer* or NIP).

Historically, these tracker+pyranometers+NIP setups were used to resolve the direct, diffuse and total solar irradiance components in scientific research such as in the Baseline Solar Radiation Network (BSRN). Because the broadband channel in the SDR-1 and MFR-7 produces data that is functionally equivalent to a three instrument, dual axis solar tracker+NIP setup, the question naturally arises as to which method is a better choice for long term unattended measurements of global, diffuse, and direct-normal broadband solar irradiance.

A rotating shadowband radiometer has several advantages over the classic solar tracker with a normal-incidence pyrheliometer (NIP), pyranometer and shaded pyranometer, (or simply *tracker+NIP*):

1 Because a single detector is used to make all three measurements, calibration problems commonly suffered by traditional three detector systems are eliminated. In other words, you only track one absolute calibration in stead of three, and only a single angular and axial dependency, not two. This is a particularly important point, as many of the traditional pyranometers used had widely varying cosine/angular response and axial/azumithal dependencies (although the YES Model TSP-700 largely eliminates these errors).

2 The single-axis rotating shadowband has only one degree of mechanical freedom and resets itself every measurement every 15 seconds. In contrast, a dual axis tracker only resets and realigns itself once per day. This leads to pointing errors and accuracy drift in tracker mechanism. What occurs is the NIP becomes slightly mis-aligned off the disk of the sun. Meanwhile the end data user, who is typically not baby-sitting the tracker at the site, has no way to tell the pointing is inaccurate and assumes the solar irradiance is lower than it actually is. The rotating shadowband technique is thus operationally much more reliable maintaining its lock on the sun vs. a two-axis solar tracker. This solar pointing reliability ultimately results in data that will be statistically more accurate than data taken by traditional tracker setups. Trackers typically periodically encounter random errors due to solar misalignment caused by wind, ice and debris and cable drag from the three instruments.

3 A key issue related to the above is that in addition to being less expensive to buy than a tracker+pyranometers+NIP, a rotating shadowband radiometer is less expensive to maintain. There is no requirement for local human verification of shading, and only a single calibration is required.

A Model SDR-1 is a broadband only version of the MFR-7, which has additional filters for obtaining spectral optical depth data. This thermopile detector covers the full 300-3000 (0.3-3μm) wavelength response. Systems built prior to July 1 2008 had silicon detectors with a more limited spectral response of 0.3-1.1μm.

Getting down to the important question of comparing measurement accuracy between a rotating shadowband radiometer and a three instrument tracker+NIP setup, there are several complex factors to consider and direct intercomparisons are therefore not straightforward. Some of the issues are purely practical. As anyone who has run a tracker at a remote site for any length of time can tell you, maintaining a dual axis tracker aimed precisely on the sun's disc can be a real challenge. You must manually observe the system as there are two degrees of mechanical freedom to worry about. If a cable is dragging or ice binds either of the two angular positioning mechanisms, the detector has no way of knowing that there is a pointing error. The result is the NIP underreports the direct-normal measurement. The colder the climate, the more of a challenge it becomes to keep the tracker properly aligned. In a sense, the normal incident detector on the tracker *can't possibly know* that it is not properly aligned. The misalignment results in improper occultation or shading of the solar disc and lower values (in the case of the direct normal from the NIP) or higher values (in the case of the diffuse from the shaded pyranometer).

In the early 1990s, researchers at the Pacific Northwest National Laboratory within the US Department of Energy became frustrated with maintaining trackers used in renewable energy research. This team developed the rotating shadowband radiometer, which Yankee later licensed for commercial production. In contrast to the tracker+NIP, because the rotating shadowband radiometer re-aligns itself once every 15 seconds and blocks the solar disc using a single degree of mechanical freedom, once aligned, it stays aligned.

Keep in mind that a NIP is a *direct* measurement of the direct normal, whereas the rotating shadowband radiometer calculates the direct normal via a shaded (diffuse horizontal) and unshaded (total/global) measurement and then digitally divides by the cosine of the solar zenith angle. However, while it might appear simpler to make a direct measurement, statistically over time at remote sites one will encounter periods of slight tracker alignment errors on a three instrument tracker setup that are literally impossible to sort out from the data. Add to this the fact that with a tracker setup you must track the absolute response of three different detectors (NIP+shaded pyranometer+unshaded pyranometer) and their angular responses, and you end up with a mathematical analytical mess. The rotating shadowband radiometer's single detector and cosine correction simplifies or eliminates many of these systematic errors.

Tilted Surface Measurements

With titled surfaces, the use of thermal pyranometers mounted at the angle of the surface leads to measurement errors. Inside the glass domed pyranometer, micro gradients build up due to differential solar and biased convective heating, leading to errors. The rotating shadowband system is superior in the sense that it remains horizontal.

Both Tracker+NIP setups and rotating shadowband radiometers can measure direct-normal solar irradiance, that is, the radiation received on a surface normal to the sun's direct-normal rays. This follows industry and scientific convention, as the value can be converted to other arbitrary tilted surfaces. You can convert this value via geometrical conversions to a fixed plane surface (i.e. for a fixed

solar panel array), and such calculations are straightforward. However, you should avoid the temptation of mounting a standard thermopile-type pyranometer on a fixed, tilted surface. Pyranometers are thermal devices and have "micro-climates" inside them. Minute internal convective air flow changes their response such that a pyranometer will not perform the same way mounted tilted as it will mounted on its back and looking at the zenith.

CHAPTER 2
Installation

This chapter explains how to set up a shadowband instrument in the field.

Shadowband Instrument system

The shadowband instrument system is shipped in two boxes. One box contains the shadowband instrument; the other contains the data acquisition system (YESDAS) and support software. Use the packing slip to verify that you have received all components in the system:

- Shadowband instrument. Either an SDR, MFR, or UVMFR instrument (Red caps protect the instrument diffuser and connector during shipment.)
- YESDAS-2 datalogger and control system
- RS-232 null-modem cable for direct connection to PCs or laptops
- Disk containing YESDAS Manager software and calibration files (**.cal/.sol**)
- Manuals for the shadowband radiometer, YESDAS and YESDAS Manager

Installation process

To set up the shadowband system, perform the following tasks:

1 Set up the system indoors and perform the initial checkout procedure.

You might perform this step while field personnel are preparing the site.

2 Install the system at the site:

- **a** Prepare the site (install necessary power and communications equipment) and install YESDAS at the site.
- **b** Mount the shadowband instrument on a platform.
- **c** Align and level the instrument's diffuser.

3 Connect all cables, supply power, and then turn on the system.

4 Initialize the system and begin data collection.

5 Conduct final geographical alignment

6 Send data to factory for factory certification of alignment

This chapter explains how to install and align the shadowband instrument (tasks 2b and 2c). The *YESDAS Installation and User Guide* provides detailed information on the other tasks.

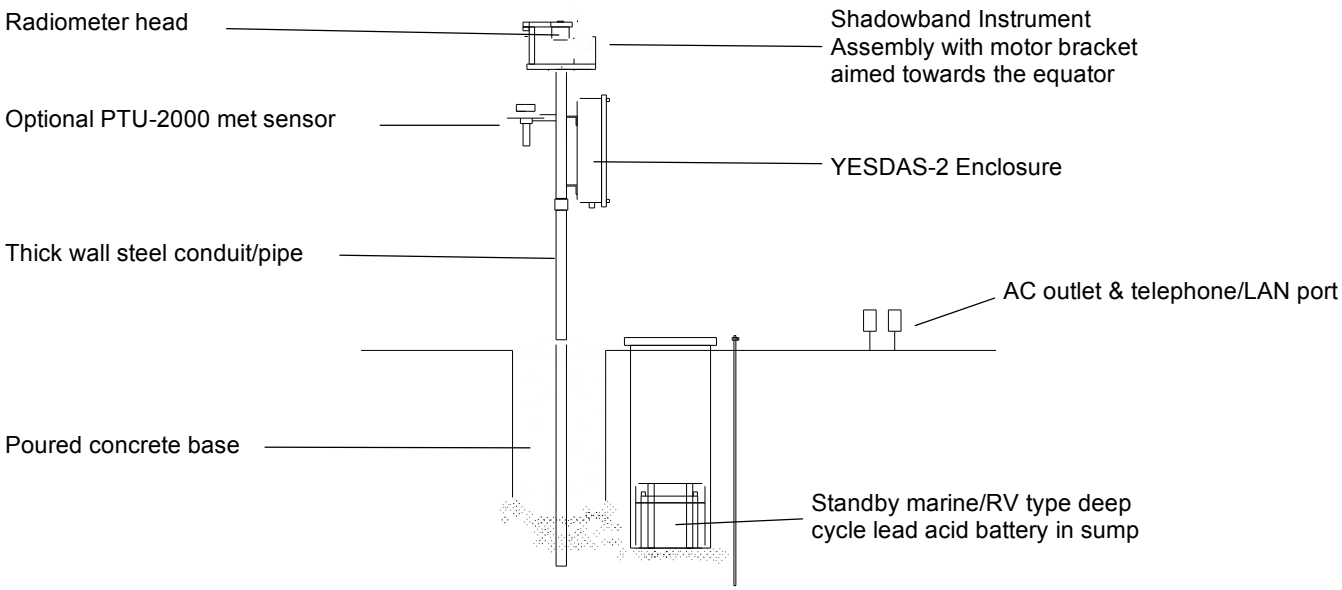
Installing the Shadowband Instrument at the Site

First, you must locate a suitable site for the shadowband instrument system. Ideally, the site should have an unobstructed view of the horizon. An open field or rooftop is always a good choice. In wooded areas, you might want to install the system on an elevated platform.

Once you have decided on a site, ensure that it has the necessary power and ground, communications equipment, and mounting platform. The shadowband instrument is powered from the YESDAS-2 power supply. Refer to the YESDAS manual for information on the power and ground requirements of the system as well as YESDAS communication options. This section explains how to install and align the shadowband instrument at the site.

Mounting post/platform

The instrument should be mounted on a post/platform assembly. A typical field installation is shown below with ground rod and standby battery sump.

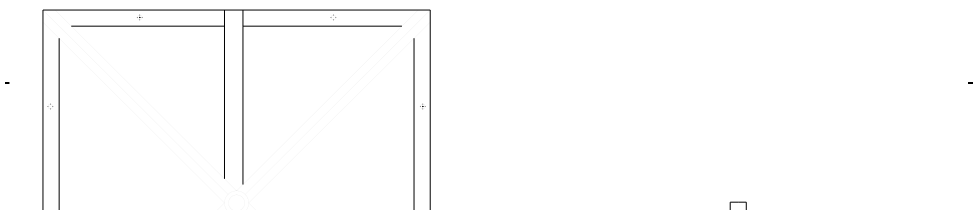


If you decide to use a post mount, ensure that adequate drainage exists as erosion can affect the foundation's stability. Also check the plumb of the mounting platform with a suitable level — it should be roughly within 1° of vertical. You can orient the post/platform or roof-mounting base in any direction; later you will align the instrument motor to *geographical* north/south.

The shadowband instrument assembly must be affixed to the platform, so you should drill a hole through the center of the platform corresponding to the hold-down hole in the instrument base. A #10 (5 mm) through hole should be sufficient. Note that the standby battery is mandatory and protects the system.

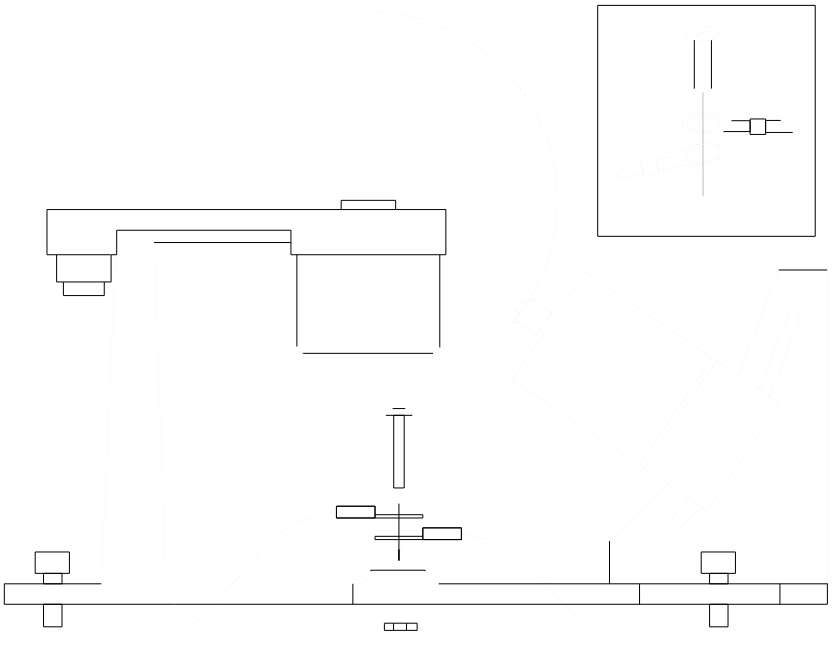
Roof-mounting base

A metal table or freestanding base can also be constructed for installations such as rooftops or atop mountains where digging is not feasible. Top and side views of a typical tripod base are shown below.



The YESDAS-2 enclosure mounts on the post directly below the shadowband instrument (note it is not feasible to lengthen the cables between the enclosure and the radiometer due to the minute analog voltages involved). Attach the YESDAS-2 enclosure to the post before installing the shadowband instrument. This ensures that the post is not disturbed after the instrument has been mounted and leveled. See the YESDAS manual for more information on installing YESDAS. *Leave all cables disconnected for now; you will connect them after all hardware is in place.*

Install YESDAS first



To install the shadowband instrument on the platform:

You should perform this procedure on a sunny day to ensure that the instrument is aligned properly.

Bolt instrument to platform

1. Place the shadowband instrument on the platform on your preinstalled post. Align the hold-down hole in the instrument base over the hole in the platform.
2. Insert a #10-32 x 2”L stainless steel bolt through the hold-down hole. Make the bolt finger tight only, since the instrument alignment and leveling procedures that follow require some freedom of movement of the base. If you’re installing the instrument on the optional rooftop-mounting base, use the supplied hardware and Allen wrench to secure the mounting post in place.

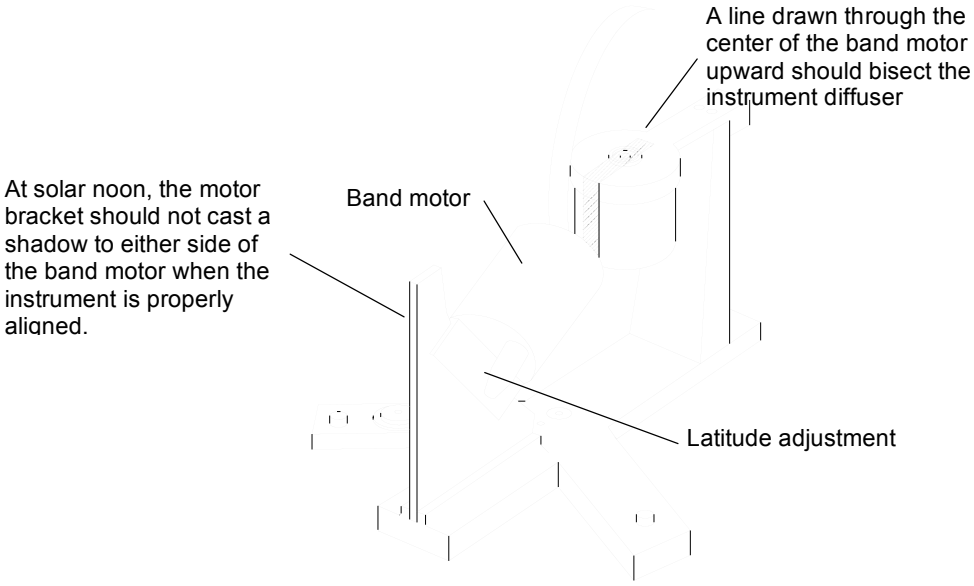
Align the instrument

The shadowband instrument’s motor bracket must be parallel to the local geographical north\south meridian in order to work properly. We recommend that you do this on a clear, sunny day for best results.

4. Obtain the solar noontime for your location using either tabular data or data calculated by the host software. Refer to the host software manuals for information on running the Solar Noon report.
5. If you’re using the table, be aware that the data is reported in coordinated universal time, and you might need to add an offset to convert to your local

time. UTC broadcasts can be picked up at 5.000, 10.000 and 15.000 MHz on the short-wave bands. Solar times can also be calculated using the mean of published local sunrise and sunset times.

6 At solar noon, rotate the shadowband instrument so that the motor bracket faces the same direction as the sun, ensuring that the bracket does not cast a shadow to either side of the band motor. In the Northern Hemisphere, the motor bracket should point south; in the Southern Hemisphere, it should point north.



Level the instrument

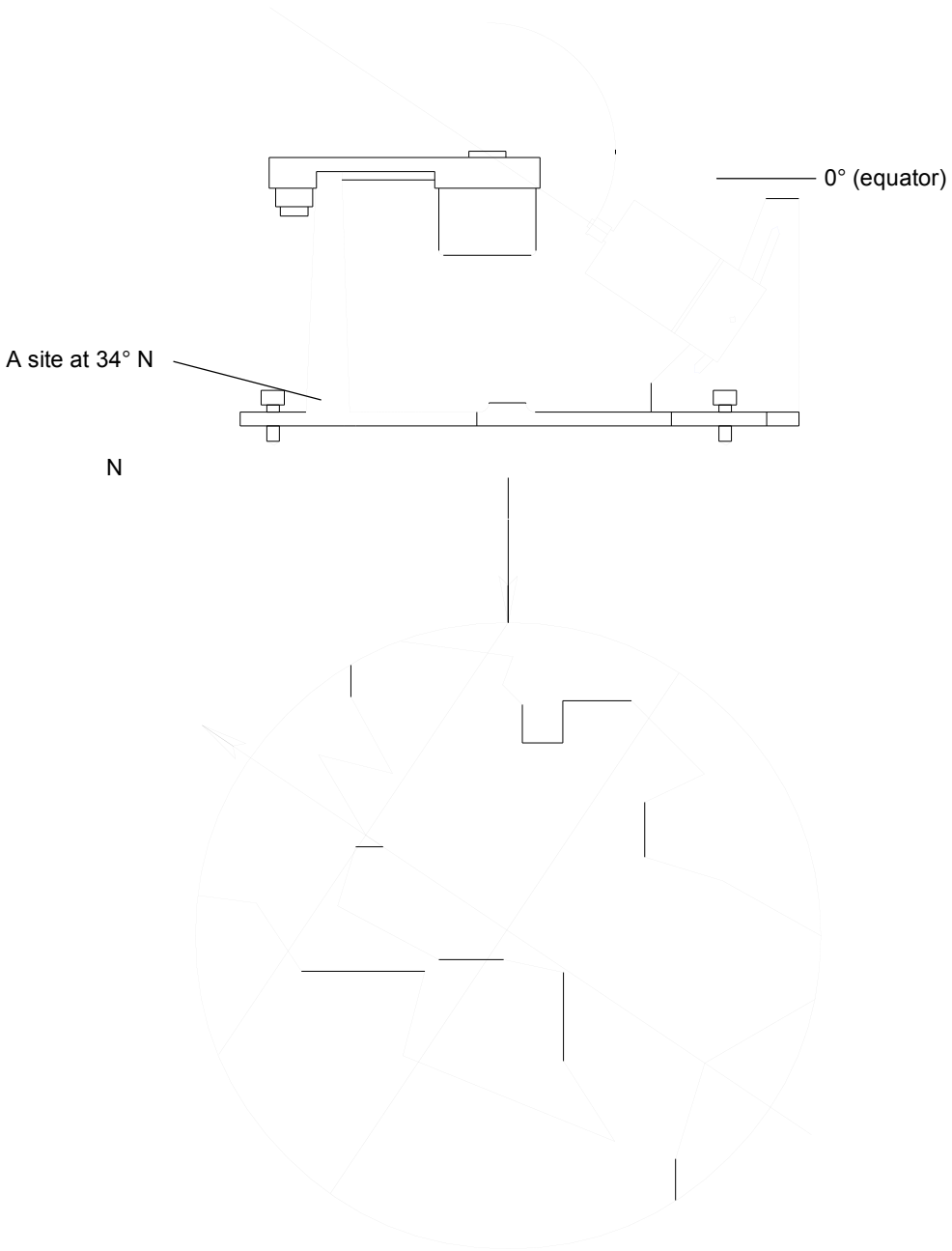
The shadowband instrument base has three leveling screws and a built-in bubble level. Carefully adjust the screws until the bubble is centered in the circle. Next, using a small machinist's level, verify the black ring around the diffuser is level *without touching the diffuser itself*. Once the instrument's diffuser is level, tighten the hold-down bolt to secure the instrument to the platform and re-check.

Check band alignment

We recommend that you check the instrument's shadowband shape every few months to ensure that it is not bent out of alignment.

(If your system has the newer three hole motor bracket, you can skip this section). For proper shadowband operation on a slotted motor bracket, the motor's axis must be mounted parallel to the earth's rotational axis. You set the latitude adjustment to position the motor for your particular site. To do this, loosen the hex screw on the latitude slide and slide the motor to the correct latitude. The angle of the motor can be checked with a machinist's protractor. The latitude adjustment is set correctly when a line drawn through the center of the band motor bisects the instrument diffuser as shown below.

Check latitude adjustment



Although the shadowband does not operate above 75°, you can remove the band and run the instrument as a global radiometer at this latitude. In this case, initialize the channels using the DAYOAUX parameter of the Initialize command instead of the Number command.

Connect ground wire and cables

Proper safety grounding is essential as it reduces measurement noise. The shadowband head and motor cables are pre-wired and run between the instrument and the YESDAS enclosure. A green ground wire is connected the center of the shadowband instrument's base casting. Secure the motor to the motor bracket using the hex socket screw, and push it firmly against the slide while tightening the screw. Next, connect the ground wire together with the YESDAS ground wire to a local ground rod or cold water copper supply pipe.

If you have not already installed the YESDAS enclosure in its permanent location, do this before connecting any cables. Ensure that the AC power switch on the YESDAS chassis is switched off. Then connect the cables from YESDAS to the AC power and the shadowband instrument. If you are plugging into an outdoor receptacle, add a plastic “in use” cover to protect the plug from precipitation. Refer to the *YESDAS Installation and User Guide* for detailed information on grounding the system and connecting cables.

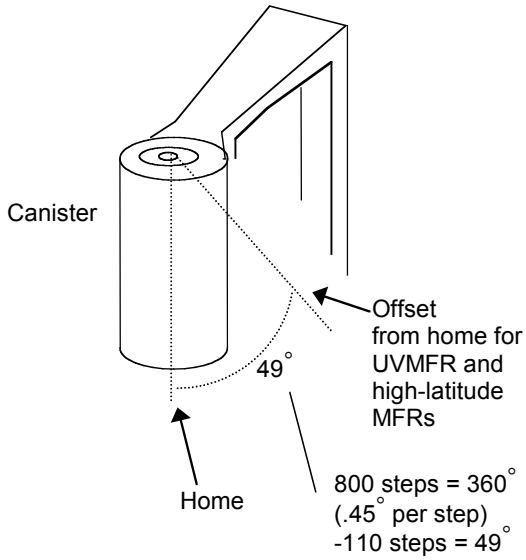
Initialize system

Once all cables are connected, you are ready to initialize the system for data collection. The YESDAS manual provides a sample session to guide you through the steps required to start the shadowband and begin logging data.

If you have a UVMFR or high-latitude MFR, you must also specify a band offset when you configure YESDAS Manager. Use the offset -110 as described below.

Specify a band offset for UVMFRs and high latitude MFRs

If you have a low- or mid-latitude shadowband instrument, you do *not* need to specify a band offset since the band on these instruments rests directly below the canister when the band is stopped. This position is referred to as the *home* position or the *nadir*. For the UVMFR and high-latitude MFR, however, the band rests to one side of the canister, resulting in an offset from the home position. In this case, you must use the band offset parameter of the Locate command to tell YESDAS how many steps to subtract from the usual number required to move the band from home to the sun-blocked position. We recommend using the offset –110, and then physically adjusting the band using the procedure below until the shading is correct.



The -110 offset is determined by calculating the number of steps between the home position and the band offset position.

Note that the band should rest on the east side of the canister in the Northern Hemisphere and on the west side in the Southern Hemisphere.

You should align the instrument and check band shading at solar noon on a *clear* day when alignment errors are easy to detect. You use the Solar Noon utility in the host software to determine solar noon for your location or use the mean of published sunrise and sunset data for your site.

Tools required. To set the band offset, you will need a 0.050" (Xcellite P20 or equivalent) Hex driver or allen wrench.

1 If possible, set the instrument up outside your laboratory first. Then follow the procedures for aligning the instrument and setting the latitude adjustment

described on page 2-4. Adjust the motor bracket latitude to the latitude at the *site*. Be sure that the band is located on the correct side of the instrument canister. In the Northern Hemisphere, the band should rest on the east side; in the Southern Hemisphere, it should rest to the west of the canister.

The purpose of setting up the instrument near the laboratory first is to become familiar with the technique for adjusting the band as well as to come close to the final configuration. Then only small changes if any will be required at the final site.

2 Once shadowband instrument is set up, connect all cables to YESDAS (MFR head cable, motor cable, and null-modem cable for direct serial communication), and then power on the system. Refer to the installation chapter in the YESDAS manual for detailed information on connecting the cables. Always turn off both AC and DC power to YESDAS before connecting and disconnecting cables to avoid damaging system electronics.

3 Initialize the instrument as described in the sample session in the YESDAS manual.

- Specify *UTC time* and not your local time. Be sure the host software is properly time-synchronized to NIST. If the default time is not correct, edit the values in the fields. The band will not block correctly if the time is not accurate. YESDAS synchronizes itself to your PC's time and then calculates an offset to UTC, so ensure its clock is set accurately. Many modern operating systems will keep your PC clock set accurately.
- When you specify the YESDAS location, use the site's latitude and your current longitude. Since the band alignment procedure is performed at solar noon, the results will be close to the configuration required at the final site. For the band offset, use -110 steps:

```
L –110 <lat> <long>
```

If you're using YEStalk, your band offset is recorded in the **site.ini** file in your current site directory. (The current site is displayed in the title bar of the YEStalk main window.) For other terminal programs, make a note of the offset for your records. YESDAS does not display the offset in use when you check the system status.

- Be aware that the maximum sampling rate for a UVMFR (or high-latitude MFR) is *20* seconds; this gives YESDAS time to return the band to the home position after a measurement cycle. The maximum sampling rate is faster for MFR instruments where the band can rotate full circle and is free to drop to the home position at the end of the cycle.
- Be sure to turn on Real-Time Display mode as part of the Initialize command so that you can examine data as you adjust the band.
- Once YESDAS is configured, begin logging data using the G 1 command.

4 Observe the following during a shadowband measurement cycle:

- **Band stopping positions**. The band pauses three times during a measurement cycle. At the second stop, the diffuser-blocked measurement is made—the diffuser should be completely shaded. If it is not, you must physically adjust the band as described below. The two

off-center measurements compensate for the excess sky that is blocked when the diffuser-blocked measurement is made.

- **Band return motion to home position.** Ensure that the band does not strike the canister when it returns to the stopped position. If it does, you must physically adjust the band as described below. The band home position for a UVMFR or high-latitude MFR should be 1 to 2 cm from the canister.
- **Data displayed on the screen.** Examine the real-time data that YESDAS produces each time it samples channels. The format of the data reflects the order in which channels are sampled:

```
spreadsheet date.time  cosine of the zenith angle
ttl_1  ttl_2  ttl_3  ttl_4  ttl_5  ttl_6  ttl_7
dif_1  dif_2  dif_3  dif_4  dif_5  dif_6  dif_7
dir_1  dir_2  dir_3  dir_4  dir_5  dir_6  dir_7
```

If the band is shading properly, the direct-normal component should be greater than zero, assuming it is a clear day. If the direct component is zero, then the band must be adjusted.

Adjusting the band

To adjust the band, you need a 0.050” male hex driver/Allen wrench. This procedure must be performed while YESDAS is running. The procedure assumes you have specified –110 for the band offset in the Locate command and that the instrument is leveled and properly aligned along the North/South meridian. See page 2-4 for more information.

1. First, observe the measurement cycle for the MFR instrument. The second stop is when the diffuser should be completely shaded. In this procedure, you adjust the band so that the band is centered on the diffuser during the blocked measurement.
2. When the band is in the stopped (home) position, carefully insert the Hex driver in the band hub's set screw. Then loosen the set screw ½ turn.

   The band should swing freely on the shaft when the motor runs; otherwise, loosen it a little more.
3. While holding the Hex driver on the set screw with one hand, gently rotate the band with the other hand until the band’s shadow is centered on the diffuser. When you hear the motor run for the second measurement and pause for the diffuser-blocked measurement, tighten the set screw ½ turn, taking care not to overtighten it. Remove the wrench and observe a few measurement cycles. If the band strikes the canister when it returns home, you must increase the gap between the band and canister by loosening the set screw and rotating the band away from the canister. Usually a gap of 2 cm works well. If you increase the gap, repeat the procedure starting with step 1.

Repeat this procedure as necessary. Because you have only a few seconds, it may take a few tries before you get the timing right.

Warning: In no case should the instrument ever be left outdoors in precipitation or 95%+ relative humidity (condensing environment) conditions with the heaters left off. This means that the power cannot fail. The heaters help to keep the internal dry by creating a positive force to expel water vapor. Further, experience has demonstrated that the thermal stabilization the heaters provide are necessary

to obtain high optical depth retrieval accuracy. Evidence of liquid water inside the electronics can void your product warranty.

Standby Battery Installation

Standby Battery is not Optional

You *must* supply a 12 Vdc standby battery and connect it to the DC lead that has an inline fuse in it. The battery is not optional—even if you believe your AC power is clean and very reliable, the standby battery protects the system from power surges and sags that occur periodically and can damage your system. It also prevents the system form stopping and shutting down, much like a UPS. Although a uninterruptible power supply is good to add as additional insurance, most of these systems react too slowly to protect the system from brownouts.

The battery standby battery has a low internal impedance and greatly reduces the effects of nearby lightning strikes by acting as an electrical damper on the DC power supply bus. The use of the standby battery is so vital to maintaining system reliability and keeping both the radiometer and the motor dry inside that failure to connect a standby battery can void your product warranty.

Plugged into AC power, YESDAS will normally keep the battery “float charged” at about 13.4 Vdc. Before you connect the battery terminals, use a digital voltmeter to verify the charge voltage does not exceed about 13.7Vdc. Immediately upon connecting the battery terminals, check the voltage again to verify the fuse is not blown.

Caution: Because batteries under charge generate flammable hydrogen gas, the battery should be located inside a vented plastic box that is corrosion proof, similar to the type used in pleasure boats. In climates where the ambient temperature can drop below freezing, you must locate the battery box in a nearby warm heated location or bury the box in below frost line and vent the box.

The battery float charge voltage setting normally does not need adjustment but can vary based on total system current load to the sensors, the charge state and age of the battery and ambient temperature. If you need to adjust the voltage, the potentiometer is accessible via a hole in the YESDAS chassis beneath the main HDL-1 PCB. Be careful not to exceed about 13.8 Vdc, as this will over charge it, driving off liquid electrolyte within the wet cells and ultimately ruining the battery.

Note the standby battery must be a lead acid type, and the larger the amp-hour capacity, the better. Do not use other rechargeable batteries such as NiCad or Lithium cells. When extending the DC standby battery line, use #16 AWG or heavier wire to handle the 3 Amps of DC current.

Off Grid Operation

Sizing a Solar Powered Installation

If you plan to operate the system off the AC power grid at a remote site, (e.g. connected to a solar panel or wind generator-charged battery), you must provide a solar power charge controller between a suitably-sized solar panel and the DC battery. The solar panels and battery bank must be sized to produce a 24x7 continuously charge rate of 3 Amperes at 12 Vdc (36 Watts). Note that this does not mean you need a 36 Watt solar panel. You need to examine the worst case

local climatology of your site at the time of year you wish to operate. Obviously, the winter months have shorter days and clouds can loiter for months in polar climates. Scale up the size of your panels to accommodate cloudy periods. It is also good engineering practice to oversize the array to accommodate the inevitable loss of efficiency of both the solar cells and battery as they age.

In addition, when operating off the battery you must jumper the +B to +P pin on the four pin power connector “H1” using #18 AWG wire. This connector is located on the HDL-1 PCB, inside the YESDAS enclosure. This provides a path for the battery to power the radiometer internal heaters when it is not plugged into the AC line. Note the system can slightly draw less power for short time if you set *low power* mode, but use this only for temporary measurement campaigns. Because the wind can move the band out of alignment, avoid low power mode for serious measurement work.

In summary, to activate heaters with the AC power off, the +P terminal must be jumpered to +B terminal at connector “H1”. Once you return the system to your permanent site with AC grid power, simply remove the jumper at H1.

Lightning Protection Considerations

Sensitive electronic systems such as the rotating shadowband radiometer require careful attention in order to prevent them from being severely damaged or destroyed. As installations are outdoors and will necessarily be in high areas that are prone to summertime lighting storms such as rooftops, towers, open fields or mountain tops. Cloud-to-ground lighting strikes typically create an electrostatic field wave that propagates for hundreds of meters in all directions along the ground that elevates “ground” to several hundred volts. For several hundred nanoseconds this energy will couple into any power or communication wiring running along or near the ground. To mitigate these risks the following protection steps are strongly recommended at installation time:

Lightning Prevention Precautions

- Independent of whether you select the RS-232 serial interface or 802.3 Ethernet option, deploy fiber optic cable all the way to the instrument’s electronics enclosure. Do not allow any length of metallic cable to exist outdoors between the instrument and the remote location where your network interface is physically located. If you absolutely must use copper wiring, encase it in metallic conduit and install high quality RS-232 lightning suppressors at each end of the line. The reason this electrical isolation is so important is you must eliminate any inductive pickup between wires that might act as antennas. Wiring couples energy from huge ground shift caused by nearby ground strikes and these currents will exceed the maximum input voltage of the interface electronics. Avoid running wires outside in the open.

- Install both whole house metal oxide varistor (MOV) type protector and a Square-D “spark gap” type protector inside the outlet located directly under the instrument. MOVs are sold in various Joule ratings and are made by Intermatic (IG1240RC), Leviton (51120-1), Panamax (gpp8005) as well as GE and Siemens (various models). Install a second pair of identical devices at the service panel feeding the outlet. The MOV will activate and clamp a spike in nanoseconds, while the spark gap will takes over before the maximum number of Joules the MOV can possibly absorb is reached.

- Ground the AC outlet to its own local ground rod located immediately under the instrument. Next, connect the green enclosure ground wire hanging from the enclosure to your building’s lighting protection ground, or a second ground rod located beneath the instrument (however, avoid connecting AC ground to this second ground rod.) The use of two rods provides a low impedance path to ground from the MOV/spark gap combination.

- You want as low an impedance across the power line as possible to clamp any incoming power spikes. When you connect a deep cycle RV/Marine type 12 Vdc car battery to the supplied battery cable, the AC supply keeps the battery float-charged while AC power is on. An online type UPS is also helpful as a protective device in absorbing line transients, however, it is typically too slow to cover up short line drops and these will reset the system.

Following the above guidelines will greatly help your system avoid lightning damage and keep the system running reliably in all kinds of weather.

Final System Alignment

In this section we perform final mechanical alignment and it is critical to follow the steps completely.. After performing initial wiring installation at the site, you next perform several critical steps to verify the alignment will produce radiometric data of sufficient quality, ultimately resulting in a Factory qualification and commissioning. *Do not leave the site thinking the system is aligned without qualifying it!* Precise system mechanical alignment to the earth's axis of rotation is essential to achieving rated specifications and useful, accurate solar data. Even if you believe the system is close to properly aligned, you must verify it. Once final alignment is completed, you will acquire data for several weeks and send data to YES to receive a factory qualification and verification of the alignment.

Factory Commissioning of Site Alignment

A rotating shadowband radiometer has no way of knowing if its band is actually shading its diffuser correctly. You must verify system alignment by directly observing diffuser shading at several times during the day (morning, noon and evening) and by reviewing the data plots remotely. We call this *commissioning the installation*.

Certain symmetrical anomalies in the data can indicate slight misalignment. Diffuse measurements that are not properly fully shaded will result in miscalculation of the direct-normal irradiance. These errors show up in data plots when at times the diffuse exceeds the total/global, which is physically impossible.

Note: There is a subtle optical illusion concerning the band shadow at low sun angles on the diffuser. At lower sun angles, if you place a white business card with an edge east-west bisecting the top of the white diffuser button and look at the band shadow from above, the center of the band shadow should bisect (within 1 mm) the centerline of the top of the diffuser. If you then remove the card, the band shadow will fall on the bottom of the well around the artificial horizon. Observed from above, the shadow will appear to have much more band shadow on the far side of the diffuser and much less shadow on the near side. This illusionary effect is caused by the shape of the well area immediately around the diffuser artificial horizon.

Once securely mounted on a stable platform, and properly aligned, the system should shade properly indefinitely. However, it of course *must* be properly aligned at installation time. Unlike solar trackers, a rotating shadowband system has only one degree of mechanical freedom and this is the beauty of the method: the band resets to zero every measurement assuring proper shadowing in each measurement cycle. As only the instrument head must be removed during calibration (the motor and base remain fixed in place), the alignment is generally preserved during head swaps at calibration time.

To review, the radiometer makes two physical measurements (the *total/global* and *diffuse-horizontal*). These two independent measurements are subsequently used to calculate the *direct-normal*. The firmware makes a diffuse measurement by averaging two side measurements plus a fully-shaded diffuse measurement, to compensate for the error from the portion of the shadowband that is not on the sun's disc that blocks the diffuse. This is the *diffuse-horizontal*. The firmware then subtracts the diffuse horizontal measurement from the total/global measurement to derive the *direct-horizontal*. Finally, it divides the direct-horizontal by the cosine of the current solar zenith angle (SZA) to get the *direct-*

normal. At this point no angular corrections are yet made to the direct normal data; those occur later via the host software and the unique *.sol* Solar information file for your head, as measured at the factory and supplied with your system.

Note: While it may seem counter-intuitive initially, the direct-normal (which is calculated based on solar angle), can sometimes exceed the total/global. However, the diffuse horizontal should never exceed the total/global values. If you observe the diffuse exceeding the total values, this indicates a slight band alignment problem.

Note also that because the direct/diffuse calculations are based on two independent measurements as inputs, there is no way to "post-correct" data taken by a mechanically misaligned system. This underscores the need to properly mechanically align the system at installation time. *Data quality control relies on proper alignment at installation time*.

Visual Observation of Diffuser Shading With the Sun

During conditions where the sun casts a shadow (i.e. clear/hazy), visually verify that the shadowband is fully shading the diffuser on the center stop. Do this at least three times: in the early morning, around solar noon and late in the afternoon. The shadowband may not seem to shade correctly only at a particular time of the day, but properly at other times of the day. If you observe full shading in the morning, noon and afternoon proceed to Reviewing Data for . If you observe a shading problem you must track down the source of the problem before proceeding further, shading can't be "close". Ideally you should also check it seasonally but as a general rule, if the shading is correct over a full day, it should be fine for the year.

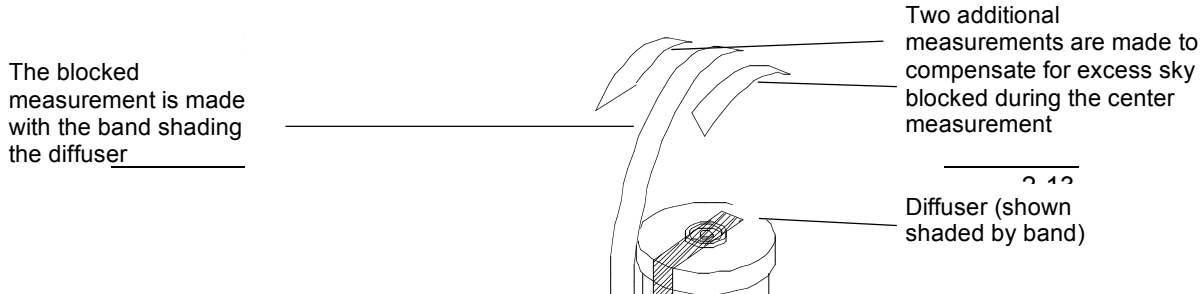
Important: The diffuser must be fully shaded during the center position, *even the vertical sides of the white diffuser*. Conversely, these sides must be fully exposed during the other three stopped positions. Even partial diffuser shading of the sides can cause significant data errors in the diffuse and direct-normal. As the sun nears the horizon, the divisor approaches zero, blowing up the error term. See the sequence of photos below for an example of proper alignment.

Check for patterns in shading: If the band is offset in time or is clamped to the motor shaft in the non-home position, the band motion will appear identical to a constant offset error in time. If a shading error changes from morning to afternoon, suspect north/south alignment, a bent shadowband, or the diffuser not being level. Resist the urge to grab the instrument base and rotate it to correct a shading problem, as this only shifts the shading problem to another time of day.

Verify that the system's motor bracket is geographically north/south aligned (note this is not the same as magnetic north/south) and that on a MFR/SDR the shadowband stops directly below the radiometer head.

Check that the system time is locked to UTC. Set your PC to do this as well.

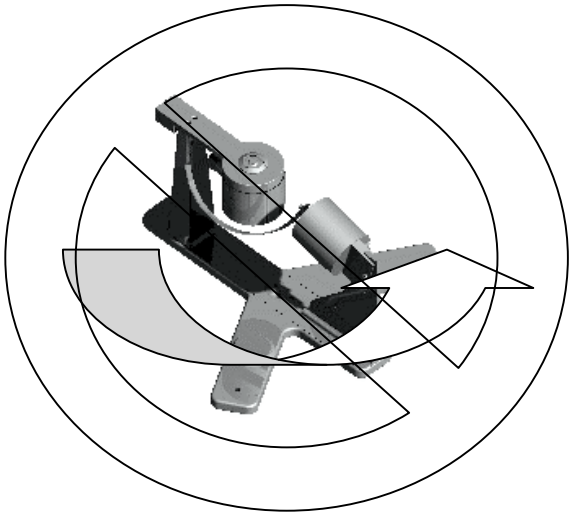
Check the diffuser level with a small machinist's level and the black artificial horizon. Do not assume the base casting level is accurate.



Solving Alignment Problems

In this section we discuss the steps necessary to debug and realign a shadowband system that is not shading properly.

Important: Whenever you observe improper shadowband shading, you may be tempted to simply rotate the casting base about its vertical axis to try to “fix” the shading alignment as shown below. *Do not do this!* While it will shade properly when you turn it, in a few hours it won’t shade properly.



Avoid the temptation to rotate the entire base casting to try to "fix" misalignment! Doing this will only cause misalignment at a different time of the day.

If you observe a shading problem, this checklist of three core areas (time, software and mechanical alignment) will guide you to the culprit:

1. **Timekeeping**: YESDAS-2 system time must be accurate to within a few seconds of UTC/GMT, and YESDAS Manager gets its time from the PC. You must synchronize you PC’s time to UTC, either via RFC868 Internet time servers or via a dialup modem polled connection.

2. **Software Settings**: YESDAS Manager site-specific information must be entered correctly, including band offset, motor bracket type and latitude/longitude in decimal degrees.

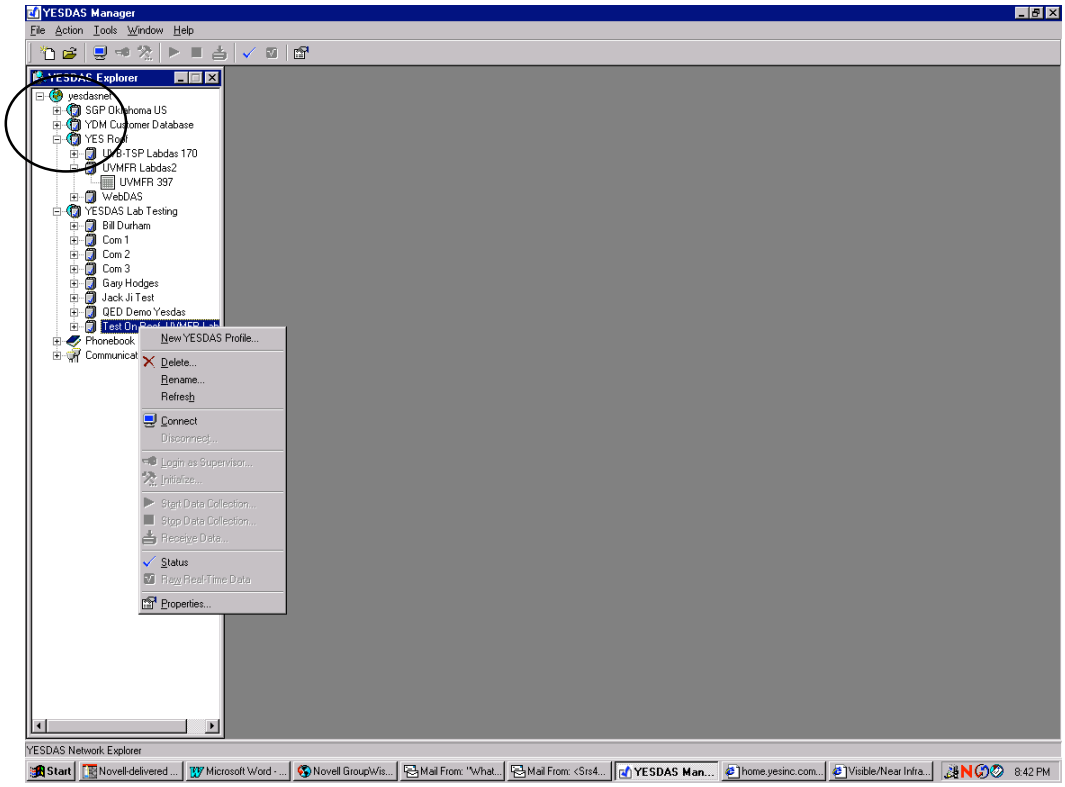
3. **Physical Mechanical Alignment**: Verify that the diffuser is level. Do not rely on the base bubble level. Instead, using a small machinist’s level, verify the artificial horizon surrounding the diffuser is horizontal. Next, the motor shaft angle must be set to current site latitude (or to the next higher hole on three hole brackets). Motor bracket must be vertical, and geographically aligned to north/south (not magnetic). The Motor itself must be secured fully seated against the motor bracket’s curved slide. Shadowband angle on shaft must be set so it is at nadir when in home position. Shadowband is secured to motor shaft such that a small amount of motor shaft is exposed, and the shadowband cannot be bent. Again, the diffuser, not just the base must be checked for precise level, so do not rely on the base level alone. Always verify the artificial horizon surrounding the diffuser is level. Once aligned, the base casting must be secured in place with the center bolt or it will eventually move and become mis-aligned from the wind.

In sections that follow, we discuss each of these areas, which cover the basics of timekeeping, YESDAS Manager software settings and system/motor/shadowband alignment.

Verify YESDAS is synchronized to UTC time

Timekeeping is critical. YESDAS-2 has an embedded control algorithm that calculates solar position in real time to control shading operations. Its crystal-controlled precision time clock keeps accurate time and is kept synchronized to YESDAS Manager, which in turn is synchronized to the PC. You must keep the PC synchronized to Internet time servers via RFC868. An open TCP/IP port (usually port 13) must be setup on your gateway router so support this time service. You must set this synchronization up, especially if you have more than one MFR/YESDAS system co-located for comparison purposes. The time on co-located systems should ideally be kept within one second of each other and NIST time. As YESDAS-2's time is periodically driven and controlled by YESDAS Manager, the PC must keep accurate time. This can be assured by connecting the PC to the Internet via TCP/IP, or by providing a telephone line and modem for the PC to dial directly into NIST using the time synchronization utility supplied with YESDAS Manager. Note YESDAS Manager will not alter your PC time, but to avoid confusion at the file system level it is good practice to synchronize time to a time server via the built in MS-Windows 2000/XP OS level functions.

Note: YESDAS system time, the shadowband angle relative to the motor shaft, and site longitude setting, each affect shading in the same way and are directly analogous to moving the system along a common latitude line. Said another way, solar time can be represented as the angle around the motor shaft.



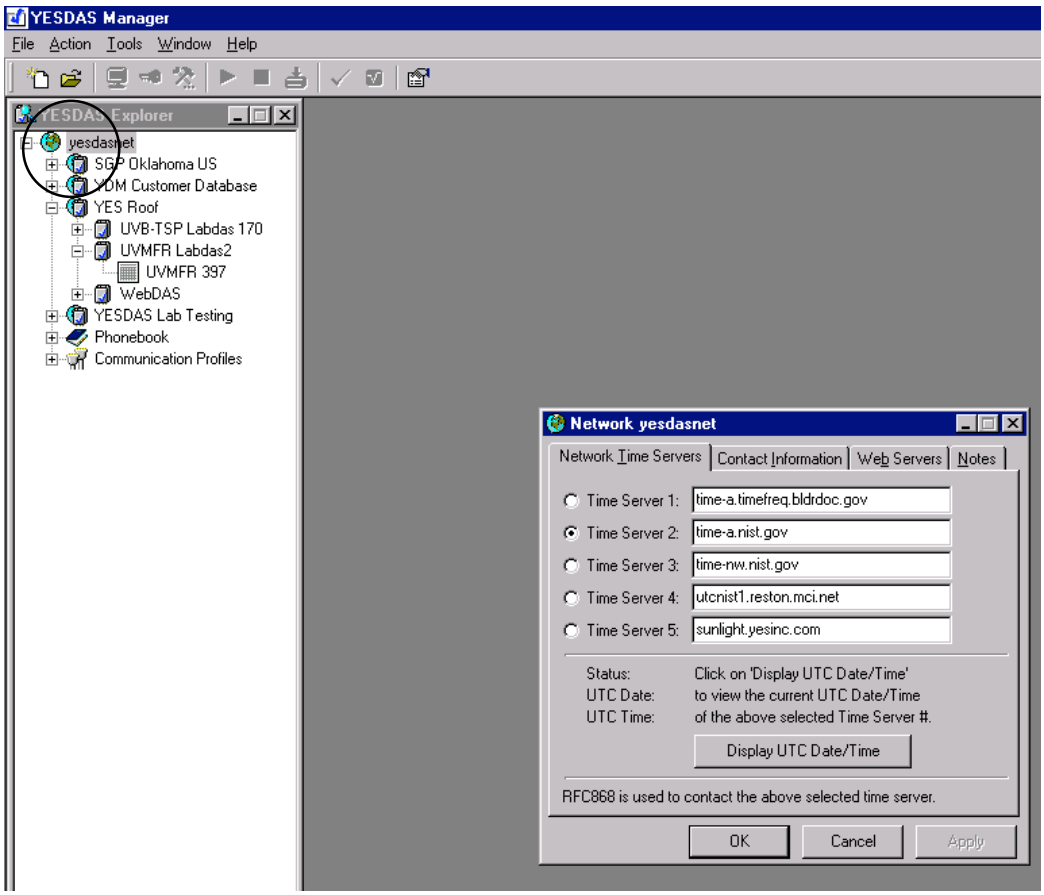
Checking YESDAS-2's time/date while connected to a YESDAS-2 system.

A. Assuming you are already either direct-connected (via a serial cable) or dialed into the YESDAS-2 system (via a modem), check the current time by right-clicking on the active YESDAS object, and then select status to see the time/date in GMT/UTC displayed.

B. Compare the status time to the current NIST time, (select Tools -> NIST Time -> TCP/IP). On a MS-Windows workstation, select the **settings | control panel | date/time icon** to see the current system time, or look in the system tray. Note that Windows typically shows your local time based on time zone (not UTC). YESDAS Manager accounts for this local time zone to derive UTC properly, which it then feeds to each YESDAS-2 system.

Important: PC clocks are notorious for their short/long term time instabilities. Some organizations do not by default enable desktop operating systems for LAN time synchronization. Don't assume your PC is synchronized to Internet time. Ideally, YESDAS Manager is installed on a PC that is networked via TCP/IP to the Internet. TCP/IP port 13 is used for RFC868 time services and cannot be blocked on your LAN's firewall. If you cannot get the PC connected to a LAN/gateway or use the provided modem dial-in utility to periodically synchronize the PC's clock to NIST.

C. Click on the *network* object atop the YESDAS Manager browser tree window and select the *Network Time Servers* tab to expose it. Check that at least one time server is selected.



Click on the top YESDAS network object to see PC time vs. NIST Internet time. On the Network Time Servers tab, click on "Display UTC Date/Time" to see if the connection is active.

D. Now, click on **status** on the active profile object to verify the YESDAS-2 time is set correctly.

Note: Synchronizing PC time via modem is an option if your PC cannot be networked to get time via TCP/IP. However, using TCP/IP is by far the most reliable solution. From Tools -> NIST Time, make your choice. If setting up a modem is impossible at your site, you must manually maintain the PC's time precisely, and you should check it at least weekly for drift. See your YESDAS Manager documentation for more information.

Ensure that the date and time displayed in the Date/Time Setting group box are accurate. The Date/Time Setting shows your local PC time and then calculates Greenwich Mean Time (or UTC) based on your Time Zone and Daylight Savings setting in your Windows Control Panel. If the displayed local time is not correct, you can override it on this window.

Important: Be aware that overriding the value on this window does *not* affect your PC clock, it only permits YESDAS Manager to synchronize the time on each YESDAS-2 control system. To change you PC time, you must do this from the Windows Setup -> Control Panel –> Date/Time. As you adjust the time, YESDAS Manager adjusts GMT time to reflect your changes. The Date/Time Setting clock continues counting until you send the Initialization sequence to YESDAS.

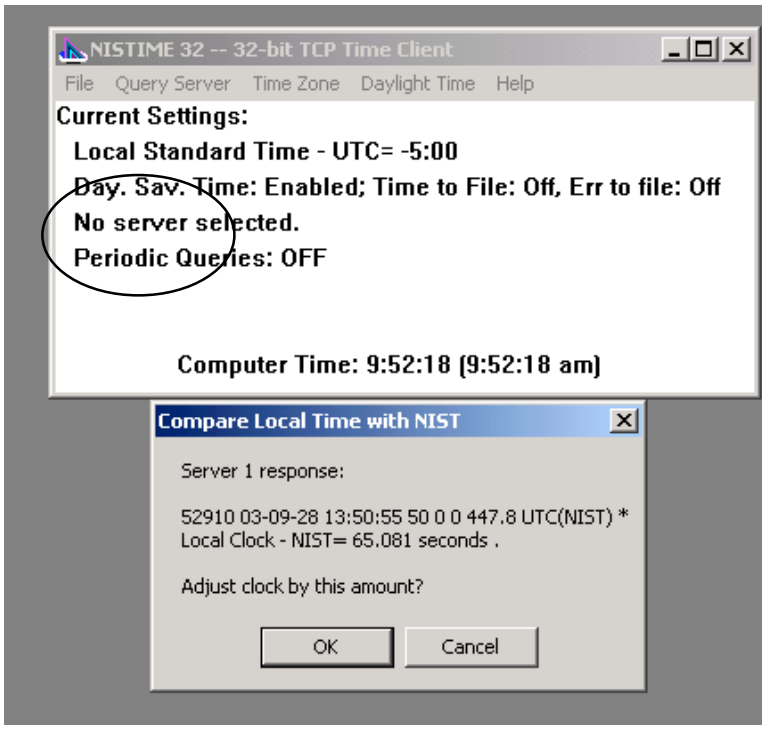
If your PC is currently networked to the Internet via dialup (PPP) or a LAN TCP/IP connection, the *Net Time* button allows you to conveniently synchronize the time displayed in the Date/Time Setting box with a time server on the Internet. This is a convenient and desirable way to keep YESDAS-2 time-synchronized, especially with multiple sites. Note that this feature is only viable if you have an active TCP/IP connection to the Internet and firewalls are not blocking the ports required by the time server. By default, YESDAS Manager is configured for four time servers maintained by U.S. Government agencies that are available to users worldwide via the Internet, so you should not need to adjust these settings. The default time server used in YESDAS Manager is: **time-a.timefreq.bldrdoc.gov** and normally you will not need to change this.

Note: Although the data records are time stamped internally by the YESDAS-2 hardware, Since YESDAS Manager relies on your PC's clock to timestamp individual files it is also important that your PC have an accurate time setting. For example, if you're using a laptop to connect directly via RS-232 to initialize a YESDAS at a field site and you do not have another source for acquiring accurate, network-based UTC time, you should synchronize your laptop's clock before taking it out in the field.

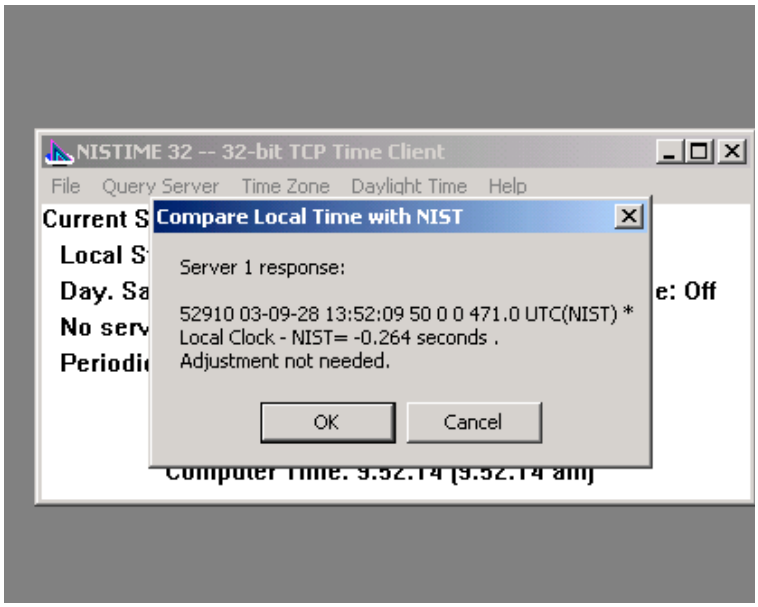
There are many tools available that can automatically synchronize your PC's clock to NIST. For your convenience, the NISTIME32 tools located on the CD-ROM lets you set your PC's clock to NIST's atomic clock, (others are available, see http://www.time.nist.gov for more information on how to use these programs.) Remember, YESDAS Manager's NIST time check only affects YESDAS-2 time relative to the PC's clock - it never alters your PC's internal clock so you need to be sure it is synchronized as well.

If you have a live connection to the Internet, the *Net Time* feature fetches NIST time and updates the time displayed in YESDAS Manager and subsequently used to keep your network of YESDAS-2 hardware time-synchronized. Again, this

only affects YESDAS-2 time; it does not affect your PC's own clock. Due to the technology used in PCs time is likely to be much less stable than the software-trimmed crystal controlled timekeeping system in your YESDAS-2 hardware.



Example live query of NIST time, showing adjustment is needed. Click on OK to correct YESDAS time. Note that this does not actually change your PC's clock, it instead only synchronizes time on the YESDAS hardware.



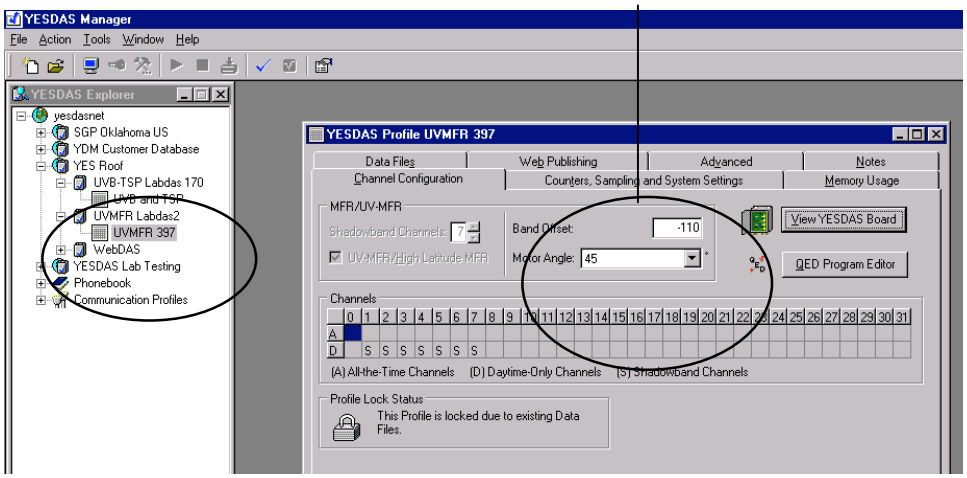
YESDAS Manager is now synchronized to NIST time and ready to keep your network of YESDAS systems time-synchronized to UTC.

Verify Mechanical Configuration Software Settings

We next verify Band Offset, Motor Bracket Type and Latitude/Longitude is Set Correctly In YESDAS Manager.

YESDAS Manager supports MFR-7, SDR-1 and UVMFR-7 systems. The UVMFR-7's deeper head canister requires that its shadowband be mechanically offset from the nadir position. We call this the *band offset*. YESDAS Manager keeps track of this offset and the motor position but you need to indicate which system and bracket setting you have configured, such that the shadowband virtual offset is set correctly in the software for your system hardware configuration. YESDAS Manager needs the correct band offset and motor angle. If these settings do not match the physical configuration, the shadowband will not shade the diffuser properly at all times of the day.

On MFR-7/SDR-1s the band offset is always zero. (With older adjustable slide motor brackets, set the motor angle to your site's latitude.)



Checking for proper band offset. On MFRs this offset must be zero, on UVMFRs it is about -110.

The above UVMFR example shows Motor angle set for a three-hole bracket, where the motor is bolted to the 45° hole.

To look at your own profile setup, use YESDAS Manager's YESDAS Explorer function, browse to your YESDAS system object and right click on the active system profile object and select *properties*. Next, click on the *Channel Configuration* tab to expose it. On MFR-7/SDR-1 systems, the band offset must be zero, indicating the band is parked directly beneath the head at home, at the nadir position. On UVMFR systems the band cannot physically be parked beneath the head and must be physically adjusted to be offset on the motor shaft, the band offset is typically set to –110. Finally, verify that the site latitude/longitude is set correctly by looking at the *site object* properties.

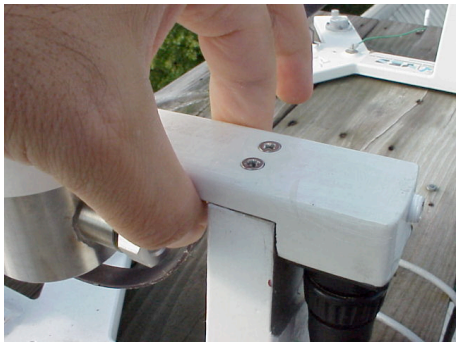
Note: The band offset value does not represent degrees—rather it is the number of *stepper motor steps from nadir*, where a full 360° rotation of the motor shaft is 800 motor steps. Band offset permits remote adjustments of home position.

Verify Mechanical Alignment

We next verify shadowband motor angle, shadowband angle on motor shaft, diffuser level and bracket position relative to geographical north/south.

Note: When properly aligned, the shadowband motor's shaft, if extended to infinity, must protrude through the center of the diffuser. There are two types of motor brackets: adjustable (shipped up until 2000) and three hole. On the adjustable bracket, the motor shaft angle must be set precisely to the site's latitude. If you move the system to a different latitude you must move the motor position. With three hole brackets, installation does not require precise setting of the motor angle and you simply bolt the motor in the next hole higher than the site's latitude, either at 15, 30 or 45°. For example, if the site latitude is 17° use the 30° hole. Note that if the site latitude is above 45°, you will need a 135° long shadowband.

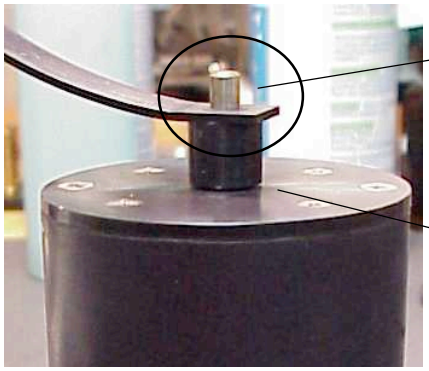
A. Begin by checking that when the shadowband is at home it is parked directly beneath the head (at the *nadir*). While the band is stopped, use your thumb and forefinger to gently feel the end of the band reaching around the neck of the head as shown below:



Checking that band is at nadir position using two fingers to feel the rest position.

If the band does not feel balanced between your fingers, with the system running, loosen the set-screw slightly and wait for the motor to return to the stopped nadir position and quickly retighten it. You may need to take several tries until you get it properly centered at nadir. Do not worry about hurting the motor as it re-homes the band each cycle.

B. Next, verify the shadowband's cylindrical shaft hub is pushed onto the motor such that the motor shaft is exposed as shown below. Avoid pushing it so far that it causes it to bind against the motor housing.

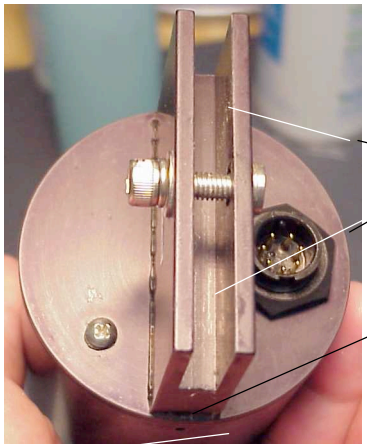


Expose the end of motor shaft as shown, with band hub pushed all the way onto motor.

The small gap here avoids any friction.

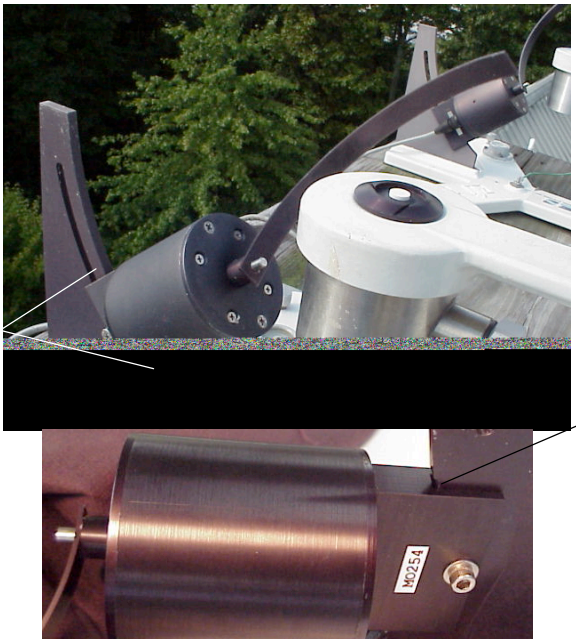
Verify that the band hub exposes the end of the motor shaft, yet there is a small gap to prevent it from rubbing against the motor housing.

C. Grasp the cylindrical motor housing with your hand and try to rock the motor vertically on its slide. It must be firmly seated against the motor slide and there should be no gap on the top or bottom contact points as shown below.



The adjustable motor slide bracket must make direct contact at these two points.

The motor weep drain hole faces down with motor mounted on the bracket. (Older type motor w/connector shown)



Verify no gap exists between the motor slide and the bracket, both above and below the motor.

The motor bracket needs to be firmly pressed against the motor slide at the upper and lower contact point, and the bolt must be tight. The previous figure's top photo shows motor removed from slide bracket exposing the two contact surfaces. On newer three-hole motor brackets, this is not an issue.

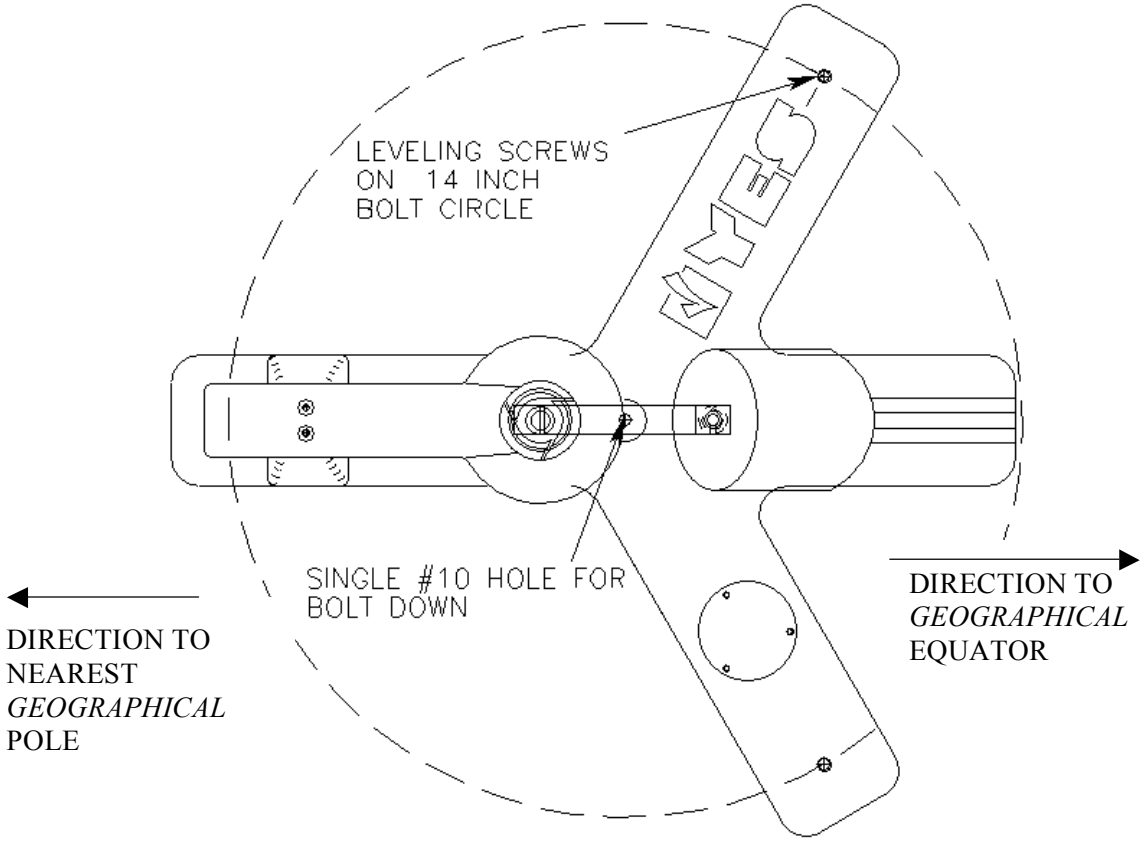
D. Check that the small motor weep drain hole, is underneath the motor and facing downward. The motor cable should be oriented down and away and a small drip loop between the instrument and the electronics enclosure.

E. To set the motor angle with adjustable motor slide brackets, you need a small protractor and piece of rigid cardboard to make a template. Make a triangle by cutting one an angle at the site's geographical latitude. Mark the corner with the angle and use this triangle as a template to precisely set the motor's shaft angle to your site's latitude. Loosen the motor slide bolt and slide the triangle under the motor such that the horizontal side of the right triangle is horizontal against the shadowband base. With your other hand push the motor securely against the adjustable side such that both sides of the motor are in contact and tighten the bolt. Three hole brackets do not need require this adjustment.

F. Using a small machinist's level, verify that the shadowband motor bracket is true to vertical. If it is not, check the two screws that hold it from the casting below and try to adjust it to make it vertical. In rare cases shipping damage can bend this bracket if you suspect this is the problem remove the motor, loosen the two bracket screws and using extreme care, return the bracket to the vertical position and retighten the bracket screws. Again, verify the small motor weep hole is facing downward, under the motor.

G. Using a small machinist's level, carefully verify that the small black artificial horizon surrounding the diffuser is level in both North/South and East/West planes. Loosen the center casting bolt and make adjustments to the three leveling screws until the diffuser is level, then finger-tighten the center hold down bolt. Do not rely on the base casting level alone to perform this check.

Caution: Be especially careful not to let the machinist's level come in mechanical contact with the relatively soft optical diffuser material, as it can cause damage, ruining your cosine calibration and voiding your warranty.



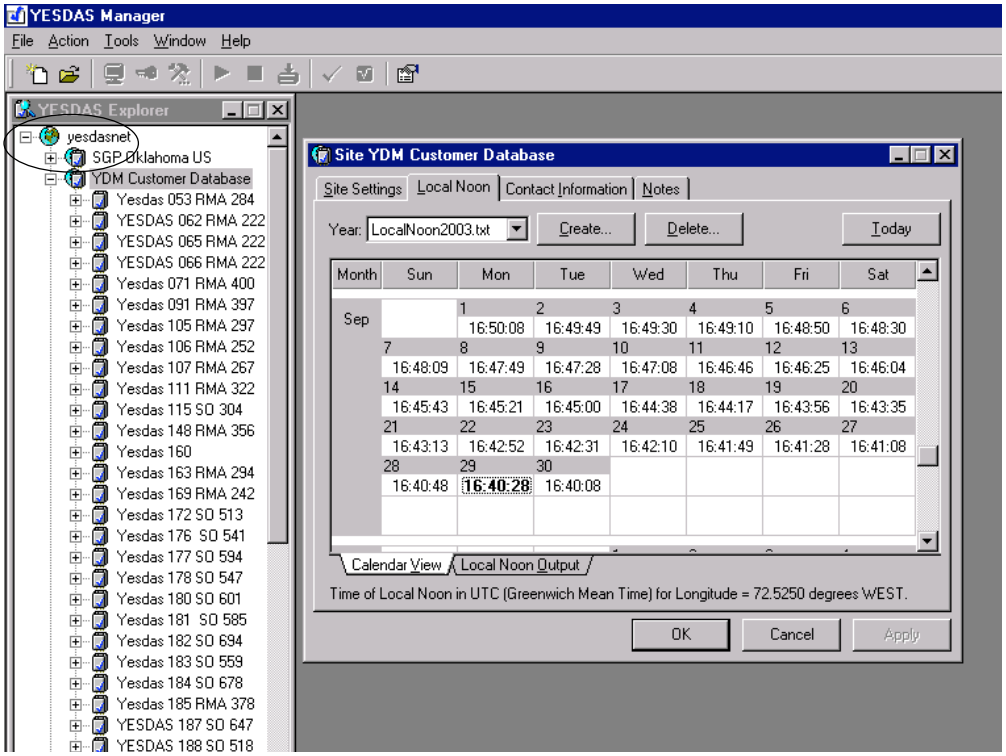
Top view showing three leveling screws and center hold down hole. Do not overtighten center screw as this can warp the base casting in extreme cases. Band is shown in nadir position. At solar noon, no shadow will be seen on either side of motor bracket

Compare the bubble level reading on the base to diffuser level. If they differ, loosen and shim the base level with small pieces of aluminum foil until the two levels agree with each other. The bubble level was set at the factory but the head assembly can move slightly relative to the base in shipment, especially if the head is removed for periodic calibration.

H. Now that you have the diffuser level, check that the motor bracket is north/south. This can be an iterative process and may require patience. You must get the north/south alignment to within a half degree or so and that can be difficult to achieve at some sites.

Note: By north/south we mean *geographical* not *magnetic*. At sites with no metal structures nearby, you can sometimes use a good compass if you know the local magnetic deviation accurately. You need to know north within a quarter of a degree, but compasses cannot achieve this. In steel buildings and near large structures the local magnetic field is warped. Realistically, you need north/south to within plus/minus a quarter degree and a compass won't provide this.

Finally, you will need to verify geographical north south motor on a sunny day around solar noon. At solar noon the shadowband motor bracket should cast no shadow to either side within two minutes of solar noon. Use the built in solar noon calculator in YESDAS Manager to determine when solar noon will occur in UTC.



Right click on your site object to see a solar noon table in UTC time. This is the time at which no shadow should be cast to either side of the motor bracket.

If the day happens to be cloudy and you cannot wait for clearer weather, you have a very difficult situation. One alternative is to use a surveyor's transit to sight visible distant objects and use a geological survey map to pinpoint your location relative to those known objects, which are hopefully on the map. Even if you use this method you must still perform the solar noon verification.

At sites such as small desert islands with no viewable objects you may have no choice but to use the solar noon or stellar methods, such as sighting the North Star Polaris in the early evening. To do this you need to work near sunset and have several hours of clear nighttime weather, and this only works in regions of the northern hemisphere where you can actually observe the star. First, remove the motor from the bracket and mechanically secure a small telescope spotting scope to the bracket. The spotting scope will need an illuminated reticule. Aim the scope at Polaris and then observe the star for several hours, making slight adjustments to minimize the star's wander around the center of the earth's rotation. Once you have it aligned re-attach the motor. While tedious, this is an accurate method of checking geographical north/south alignment in the northern hemisphere.

Important: Once you think you have the system aligned to geographical north/south you still must have someone verify it by visually checking the bracket casts no shadow at solar noon. Within two minutes of solar noon, the shadowband should be vertical during its center block position. If it isn't vertical, the time is off or the shadowband has moved on the motor shaft, or the software has an incorrect band offset setting.

Check the diffuser level one last time with the small machinists level, and secure the base center hold down bolt finger-tight. Avoid over-tightening the hold down screw as you can warp the base casting.

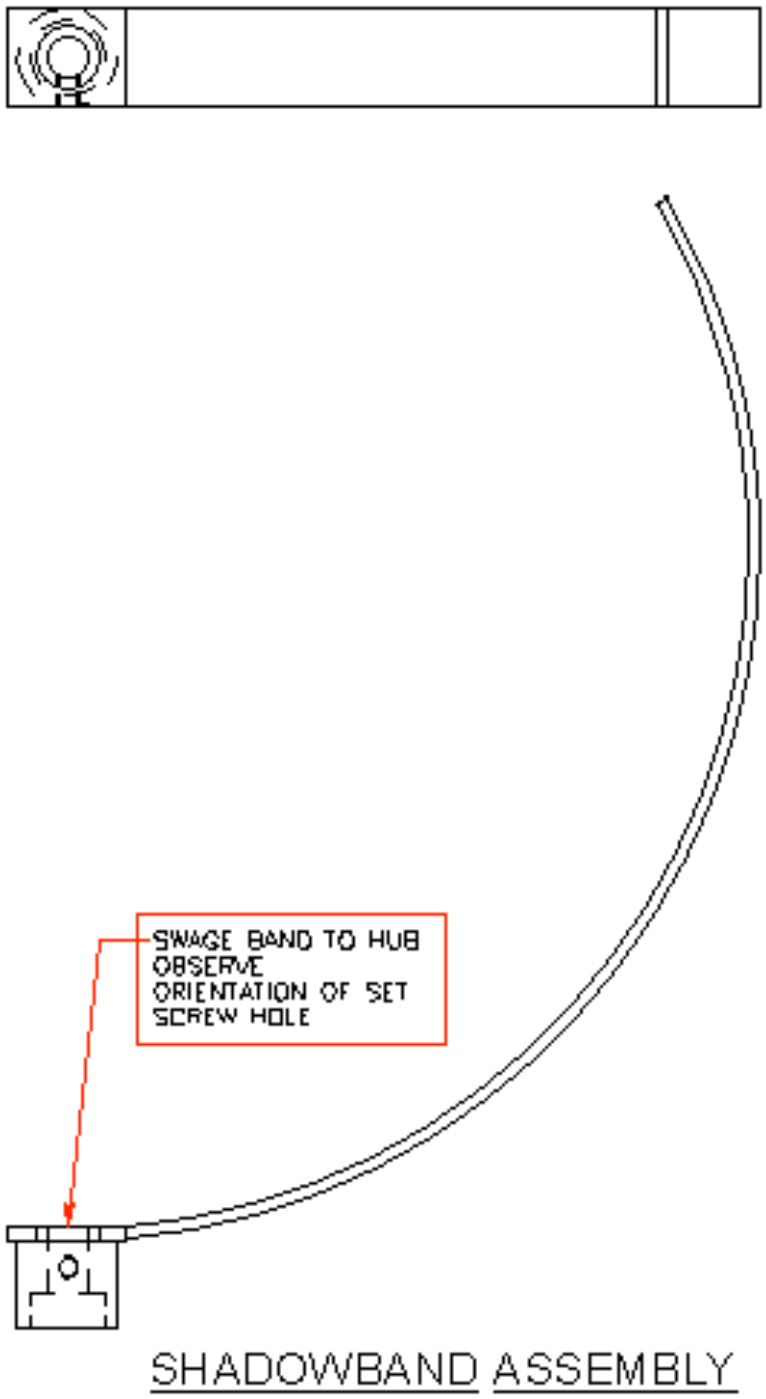
Reviewing Data for Site Commisioning

Once you think you have the system properly aligned, run the system for a while, and collect data from at least a few clear days. This step may take from days to weeks, depending on your site's climatology and the time of year. Browse to http://support.yesinc.com and via email, provide YES technical support your current **.cal/.sol** files and binary **.xmd** data files covering a variety of clear/cloudy sky conditions. These data will be qualified and reviewed by a factory technician for a site commissioning, which validates your system is properly aligned. We will send you feedback on any problems we observe. This step also assures your warranty is registered and that we have end-user contact information such that we can contact you about future system upgrades or any new technology developments.

In summary the following items must be verified:

- The system time, site latitude, and longitude needs to be correct in YESDAS hardware
- The diffuser artificial horizon needs to be level and the motor bracket's geographic North/South alignment verified at solar noon
- The motor latitude adjustment must be correct and the motor fully pushed against the back of its slide. On newer three hole shadowband motor brackets, the motor must be bolted into the hole closest to you site latitude. On older adjustable slide motor brackets, the motor's angle must be the site latitude (not the complement of the angle)
- The shadowband's cylindrical collar should be all the way down on shaft, but not so far as to bind against the motor
- The center stop must fully shade the diffuser, morning, noon and evening; similarly, both side stops should fully expose the diffuser at all times of the day

Shadowband Curvature Test Drawing

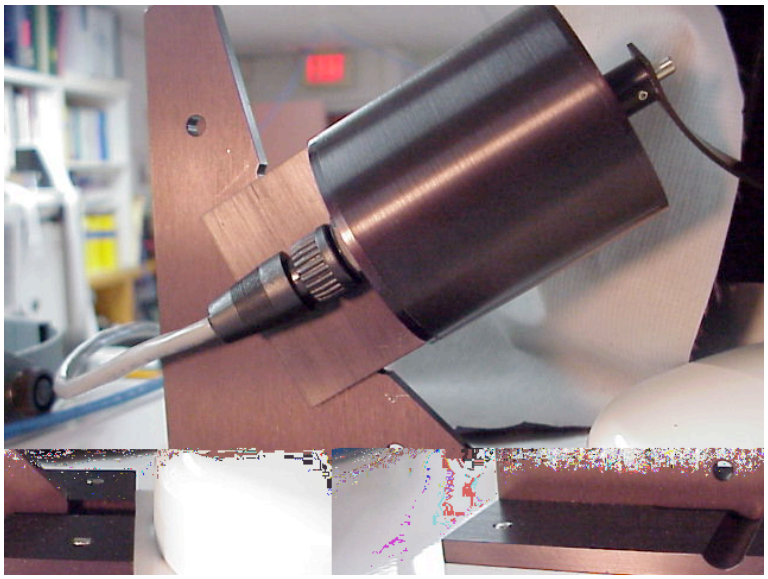


Full scale side view of shadowband. Photocopy and then cut out this page to make a cardboard template you can use to check for a bent shadowband.

Understanding Motor Brackets

Earlier MFR-7/SDR-1 models were equipped with a motor bracket having a slide permitting adjustment of the motor angle shaft to match a site's geographic latitude. Units made after 2000 (and all UVMFR and RSS models) have only three holes in their motor brackets to eliminate the need to make a precise motor angle adjustment, making them simpler to align. Unlike the slotted bracket, three holes are at 15, 30 and 45° and you install the motor into the hole closes to your site latitude. Instrument firmware uses internal mathematical corrections to properly shade the diffuser based on which hole the motor is set to, which is set at initialization time by YESDAS Manager. Check that the motor is installed into the hole closest to your site's latitude. Next, using YESDAS Manager's site profile dialog, indicate the mounting hole angle for the motor.

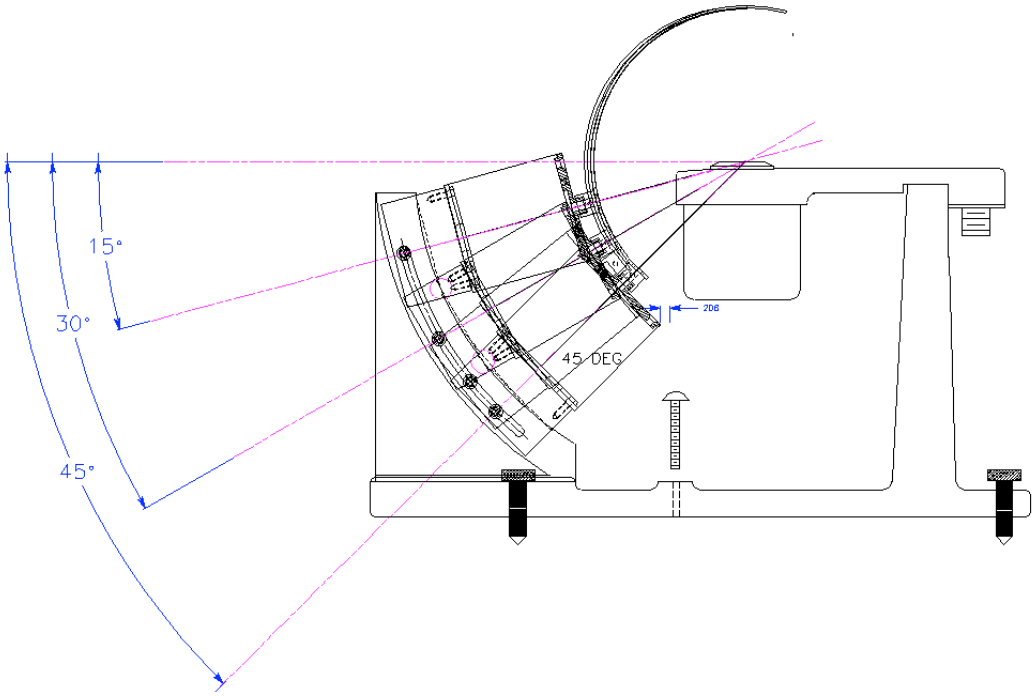
Note that around the summer solstice, at sites located above 45° latitude a slightly longer "135°" shadowband is required to fully block the sun near solar noon; lower latitudes do not need this extra reach. Based on your shipping address, your system should be equipped with the optimum shadowband and motor setting.



Three hole motor bracket. Motor is in the center, 30 degree position.

The three hole brackets eliminated three types of motor brackets used for various latitude ranges. Those brackets supported relocating the instrument outside its original latitude range. The latitude ranges for the older brackets are as follows:

- **Equatorial range.** 0° to ±25°
- **Mid latitudes.** ±15° to ±50°
- **High latitudes.** ±50° to ±75° (A head extender bracket was also required for this range.)



Detail of newer three hole motor bracket angles.

No field site is perfect. As shown here, a tall object in the field-of-view, in this case a utility pole with transformer, will at certain times of the year block the direct normal beam of the sun. Do a quick “site survey” before setting up.

Considerations for ARMS with both MFR-7 and UVMFR-7

If you have the *Atmospheric Radiation Measurement System* consisting of a MFR-7 and UVMFR-7 and they are placed in close physical proximity, you need to avoid having them precisely time-locked together. You can either space them adequately far apart physically or offset the time on one system by a few seconds. The technical issue is that the magnetic ("B") field from the adjacent MFR-7 stepper motor operating/moving its shadowband is detected by the extremely high gain amplifiers within the UVMFR-7 radiometer. One solution is to space the two systems well apart physically, 10 meters or so, as the B field falls off as the eighth power of distance. If you have large field or rooftop, such physical separation is generally feasible.

However, if you need to keep the systems physically adjacent the alternate solution is to offset the YESDAS system time on the MFR-7 by five seconds. By offsetting the time you guarantee the two A/D converters sampling will not overlap. To offset the time, initialize both systems for 20 second sampling (the lowest common denominator of the UVMFR-7 sampling rate.) Next, manually offset the MFR-7 system time back by five seconds. To create this time offset, while you are initializing the system using YESDAS Manager's dialog window, manually override the system time and force the time on the MFR-7 back by five seconds. It is critical that the MFR-7 band is not moving while the UVMFR-7 is making its measurements. Note that because the sky temporally tends to be a slow moving source, there is little issue from a scientific sampling perspective. The USDA's *UV-B Monitoring Program* has standardized on a five second offset. Note that the MFR-7 system has much lower amplification levels, which makes it insensitive to detect the magnetic field created by the UVMFR-7 motor while it is in option. Finally, after you update the system time, observe the two bands to verify their motion is offset in time.

CHAPTER 3
Interpreting the Data

The system collects and stores shadowband instrument data in terms of raw ADC counts, where 1 count = 1 mV. You use the YESDAS Manager host software to process the raw shadowband instrument data. The software produces calibrated output in w/m^2-nm for each wavelength in a shadowband instrument. The host software can also automatically compute optical depth information by way of its Langley analysis function. To derive other data, such as column ozone and water vapor, you must perform additional calculations. This chapter provides background information and equations necessary for these calculations.

Refer to the YESDAS Manager manual for detailed information on processing the raw data.

Multi-filter instrument required for certain data

The type of instrument you are using governs the parameters you can extract from it. This chapter assumes that you are operating a seven-channel MFR-7 rotating shadowband radiometer. While the UVMFR provide optical depth and column ozone information at wavelengths in the UV-A and UV-B regions; however, it cannot provide water vapor information since it does not contain a detector located within a water vapor absorption line. Similarly, the SDR-1single-channel instrument contains only one broadband thermopile channel and cannot provide optical depth, ozone, or water vapor information.

In this chapter

This chapter covers the following topics:

- Considerations for filter selection in multi-filter shadowband instruments
- The angular correction procedure used to improve direct and global irradiance measurements
- Langley analysis of data from clear and stable days to track calibration constants
- Derivation of total columnar aerosol optical depth, ozone, and water vapor

Filter Selection

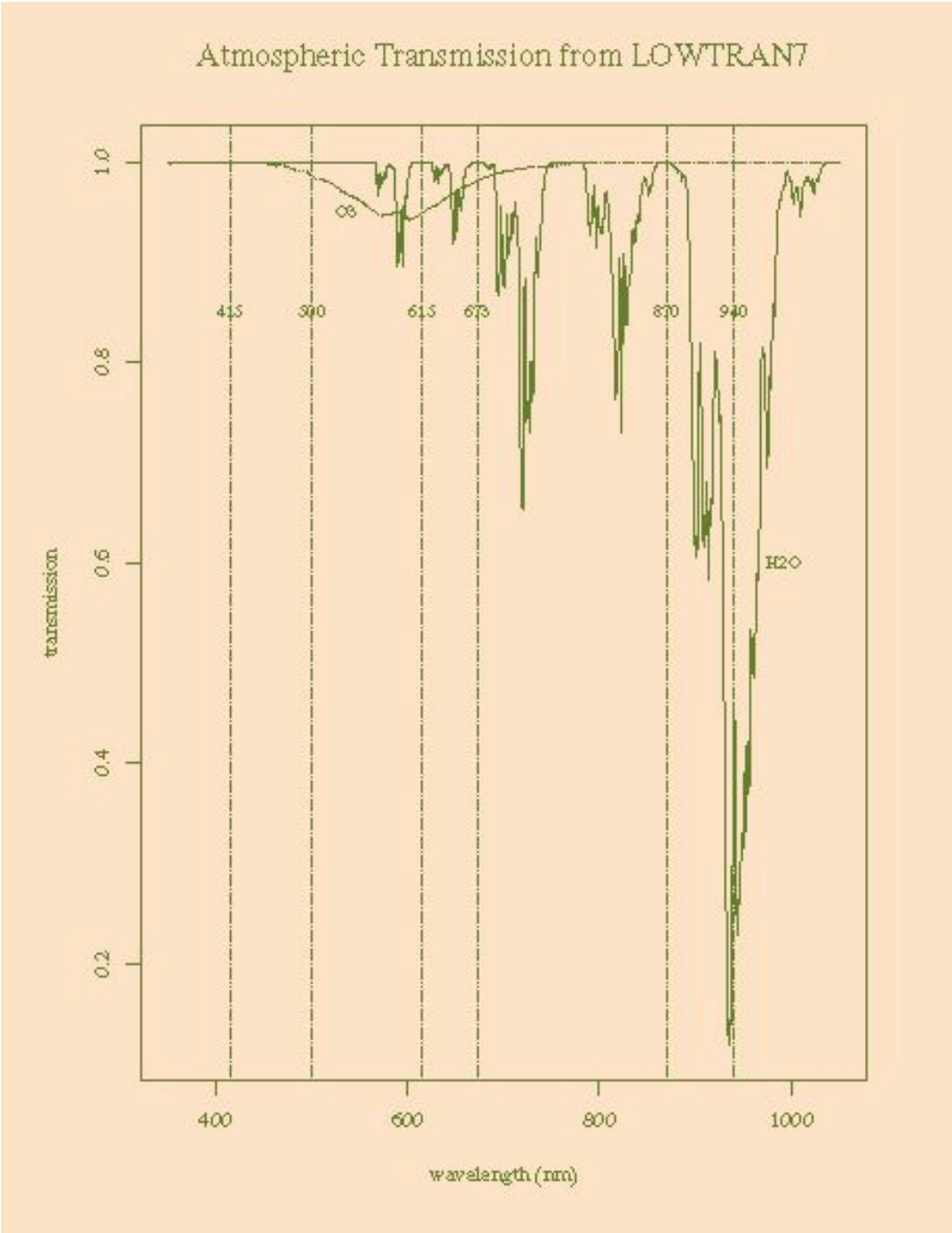
The seven-channel Model MFR-7 visible shadowband instrument *simultaneously* measures horizontal irradiance at six spectral wavelengths near 415, 500, 615, 673, 870, and 940 nm with band passes that are about 10 nm wide at half their maximum transmission. Part of the reason these wavelengths were chosen is based on the science of aerosols and the scattering of optical radiation in the earth's atmosphere. Another reason is for historical purposes and inter-comparison with data from other instruments using WMO-recommended

wavelengths. In addition, a broadband thermopile detector measures radiation between 300 and 3000 nm, providing integrated short-wave irradiance.

Although, in practice, all wavelengths can be used to retrieve the three trace species, certain filtered detectors were specifically selected for their sensitivity to aerosol, ozone, or water vapor measurements:

- 415 and 870 nm are sensitive to aerosols
- 940 nm is sensitive to water vapor (but cannot be used for Langley analysis)
- 500, 615, and 673 nm are sensitive to ozone and aerosols (In the UVMFR, 318 and 325 are sensitive to column ozone and can be compared to 368, which is not.)

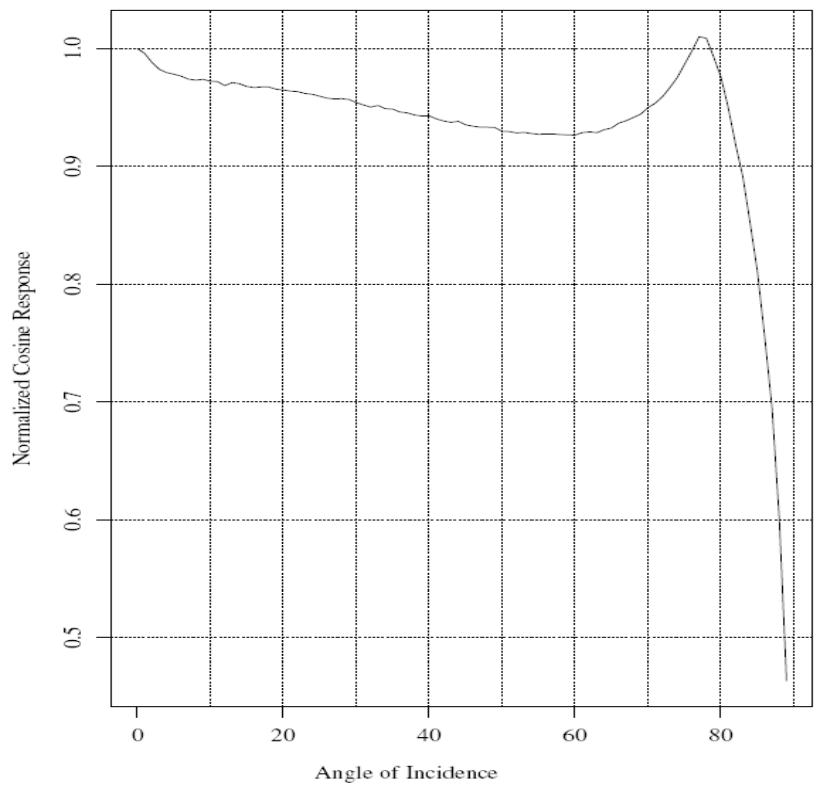
The following figure shows a LOWTRAN7 atmospheric transmission simulation model run output plot of water vapor/continuum transmission and ozone transmission. The model assumed a mid-latitude summer with the sun 45° above the horizon. Aerosol extinction and Rayleigh scattering, which affect all wavelengths, are not shown in the output. Molecular oxygen does not affect the filter wavelengths and, therefore, is also not shown. Filter positions are called out to illustrate the sources of extinction in each filter.



Visible/NIR atmospheric transmission spectrum output from LOWTRAN7

Angular Corrections for Diffuser Instruments

With a diffuser-based radiometer such as the MFR family, considering that the sun is a moving source, any horizontal detector needs to have as close to an ideal angular (cosine) response as possible. Especially as the direct-normal is calculated from the diffuse-horizontal and the total horizontal on these instruments, the diffuser cosine response is critical. A theoretical abstract, the *Lambertian* surface, receives light with a perfect cosine response, that is, the light received is directly proportional to the cosine of the angle of incidence. Although the MFR is among the best radiometers available, as no surface has a perfect response, the host software applies angular corrections to the direct normal data. Periodically, the system's diffuser angular response needs to be re-characterized by the factory. The following figure shows the normalized cosine response of a typical MFR.



Typical MFR normalized cosine (angular) response from zenith-to-horizon.

To normalize the response, the system divides the measured response relative to 0° (zenith) by the cosine of the angle of incidence. Without this normalization, the response would look like the cosine function, which might suggest that angular correction is unnecessary. However, notice that the direct solar radiation incident at 60° is only 93% of that of a perfect Lambertian receiver. This angular

correction is particularly important as the system uses the measured total and diffuse solar measurements to *calculate* the direct solar irradiance. Further, there is no way to cosine correct the diffuse measurement, as we have no way of knowing which direction the photon arrived *from*.

The previous figure shows a typical cosine response taken at a particular azimuth of the receiver but similar responses at other azimuths exist with some variation. For the MFR, the cosine response is measured in the four cardinal directions: north, south, east, and west, and corrections are based on azimuth-angle-weighted corrections at a particular incidence angle.

Calculated direct normal solar radiation is thus corrected throughout the day based on the current solar position. The horizontal component of the corrected direct is added to the diffuse to form an improved estimate of the total horizontal irradiance. Since the spatial distribution of diffuse solar radiation is unknown, angular corrections to the diffuse are not performed.

For detailed information on the angular response measurements of the MFR and other commonly used pyranometers, see Michalsky, Harrison, and Berkheiser (Solar Energy, Vol. 54, pp. 397-402, 1995).

Understanding Langley Analysis

After the data is angle corrected, Langley analysis can be performed. Solar radiation that is not in a molecular water or oxygen band is attenuated according to a relatively simple equation:

$$I = I_o \exp(-\tau m),$$

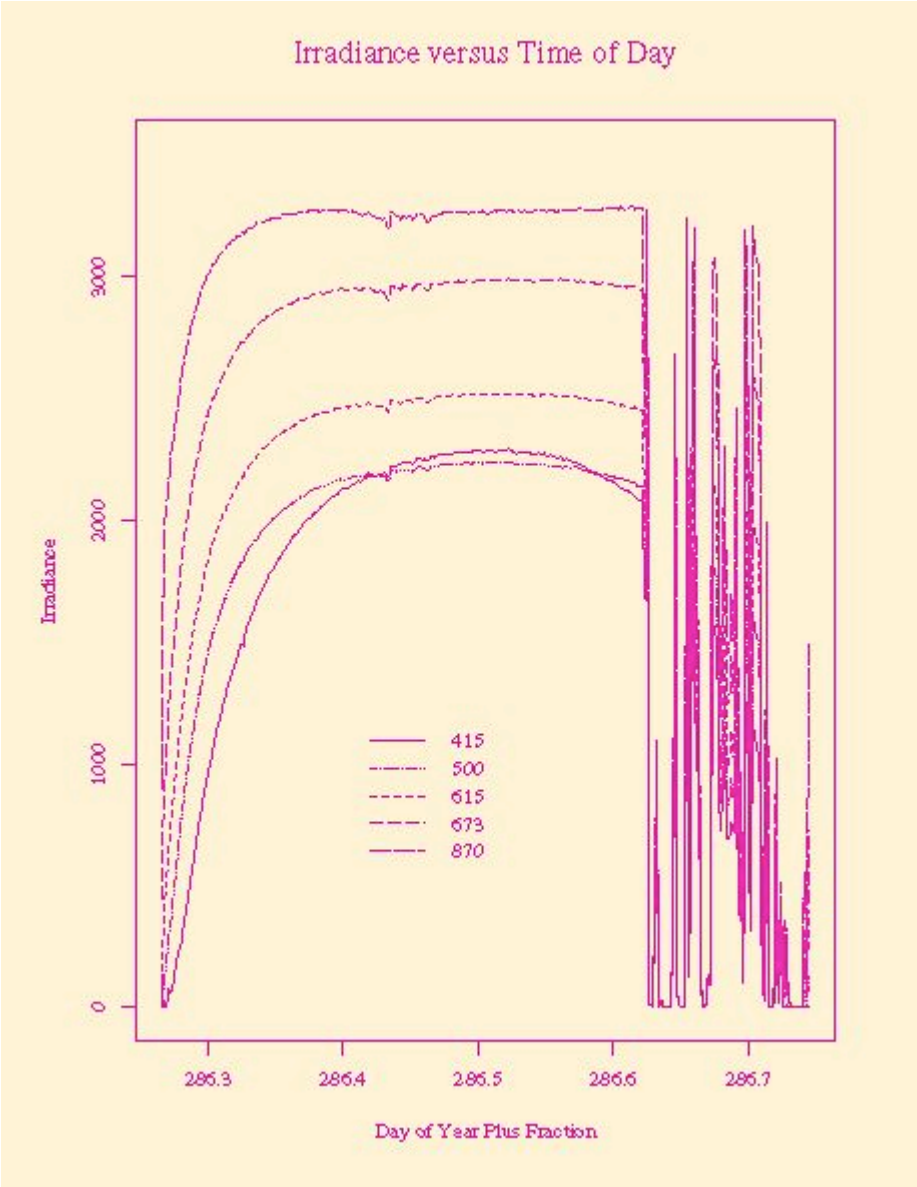
where I is the direct solar at the point of measurement, I_o is the irradiance that would be measured at the top of the atmosphere, τ is the total column optical depth from all sources in the zenith direction, and m is the air mass relative to unit air mass in the zenith direction. One commonly used formula for air mass is

$$\text{air mass} = [\sin(el) + 0.50572(6.07995+el)^{-1.6364}]^{-1},$$

where *el* is the elevation in degrees (Kasten and Young, 1989: Applied Optics, Vol. 28, pp. 4735-4738; also programs for calculating solar position are available on the Internet, search for **asunpos.f**). Taking the natural logarithm of both sides of the equation for irradiance extinction yields

$$\ln(I) = \ln(I_o) - \tau m.$$

Plotting $ln(I)$ versus m on a clear stable day yields a linear plot whose slope is negative and magnitude is the optical depth τ. The intercept is $ln(I_o)$.

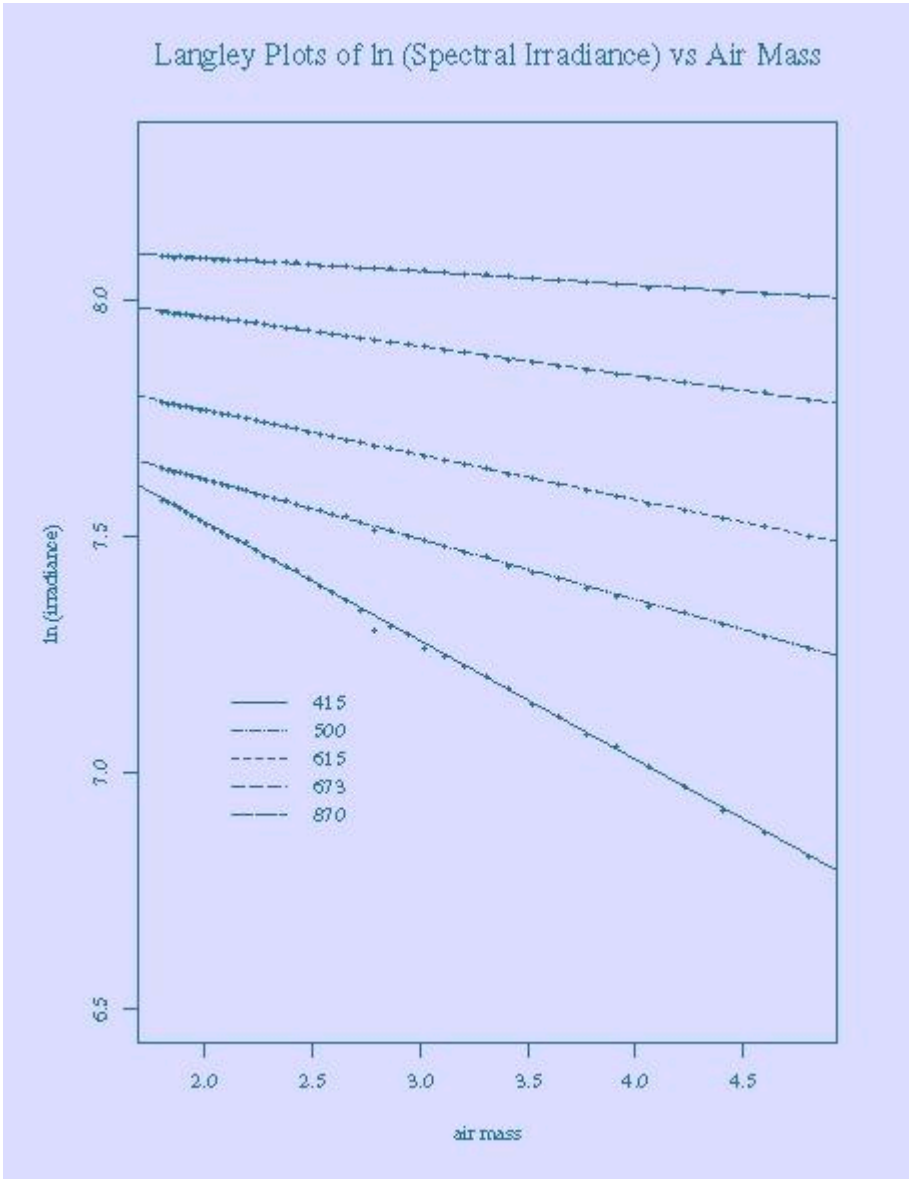


Typical Irradiance versus time of day for several MFR-7 wavelengths.

The figure above shows irradiance versus time for the filters in the MFR that do not contain water or strong oxygen absorption features. The irradiance is in uncalibrated units. Langley analysis only requires a stable and linear detector, whose output is directly proportional to the incident radiation over the entire range of expected irradiance levels. While the morning shown is cloud free and thus a good candidate for Langley analysis, the afternoon is not.

Note that the solar information file dictates to the Langley analysis software precisely which channels are valid to perform Langley the analysis. For example, the broadband channels is far too wide and the 940 nm channel is narrow enough but lies within water vapor absorption lines. Note also that the Langley Report runs the day through the Harrison Objective Algorithm (HOA) and if you do not see any results then you must try a clearer day. If, after many weeks you still do not get any Langley results, this indicates that you may want to move the radiometer to a clearer site.

The figure below shows Langley plots between 1.8 and 4.8 air masses in the morning of a day at Mauna Loa Observatory (a very clear site free of anthropogenic pollutants). A least squares fit to the points produces good linear fits with one slightly discrepant point for both the 415 nm and 500 nm MFR filters. The slope of each line is the optical depth at that wavelength.



Langley plot of ln(spectral irradiance) versus air mass for several wavelengths.

Assuming the channel's spectral response passband is stable, the I_o (at wavelengths outside of strong absorption bands, and corrected for the appropriate solar distance), can be used along with a measured I and calculated m to calculate optical depth at any other time. The challenge is to determine whether the calculated I_o is close to the true value or finding one that is. This is usually done using several clear days and finding some central measure of their values, either a mean or median. Practically, a Langley plot is curve fit to observations, and we extrapolate back to an air mass of zero to get I_o. The important concept here is that from extraterrestrial solar spectral irradiance measurements made over

decades, we know it to be stable to about 0.3%. We can rely on the stability of the extraterrestrial solar irradiance as an absolute calibration reference. That is, if we could physically relocate the exact same radiometer to the top of the atmosphere at the same exact time, we would theoretically measure the same I_o. Since we know the extraterrestrial irradiance we can theoretically tie the instrument's absolute response (that is, the voltage transfer function for each channel) to engineering units. However, as a practical matter this method is more of a check of in-field stability and does not mitigate the need for careful laboratory absolute calibrations of each radiometer channel.

Calculating Total Column Aerosol Optical Depth and Ozone

Once the total column optical depth is determined from either a Langley analysis or a Langley calibrated sun photometer or MFR, the various extinction components — Rayleigh scattering, ozone absorption, water vapor absorption, and aerosol extinction — must be separated:

$$\tau_{total} = \tau_{rayleigh} + \tau_{ozone} + \tau_{h2o} + \tau_{aerosol}.$$

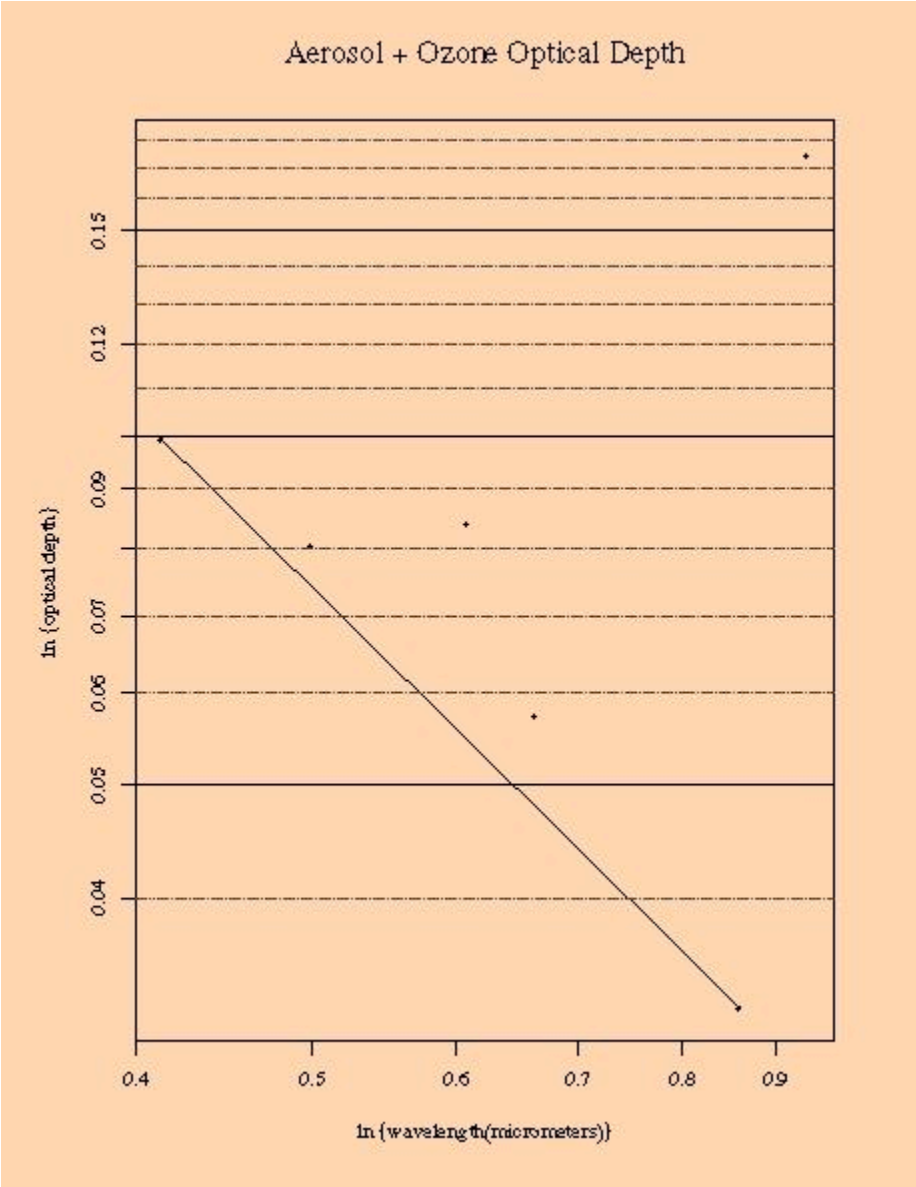
With the exception of the 940-nm filter, the filters are chosen to avoid water vapor absorption. Rayleigh scattering as a function of wavelength is fairly well understood and is removed using

$$\tau_{rayleigh} = 0.008569\lambda^{-4} (1 + 0.0113\lambda^{-2} + 0.00013\lambda^{-4}) P/P_o,$$

where the wavelength λ is in micrometers, and P is the site pressure relative to sea level pressure P_o (Hansen and Travis, 1974: Space Science Reviews, Vol. 16, pp. 527-610). By avoiding water vapor absorption and removing Rayleigh scattering, we are left with aerosol and ozone absorption for the filters 415 through 870 nm.

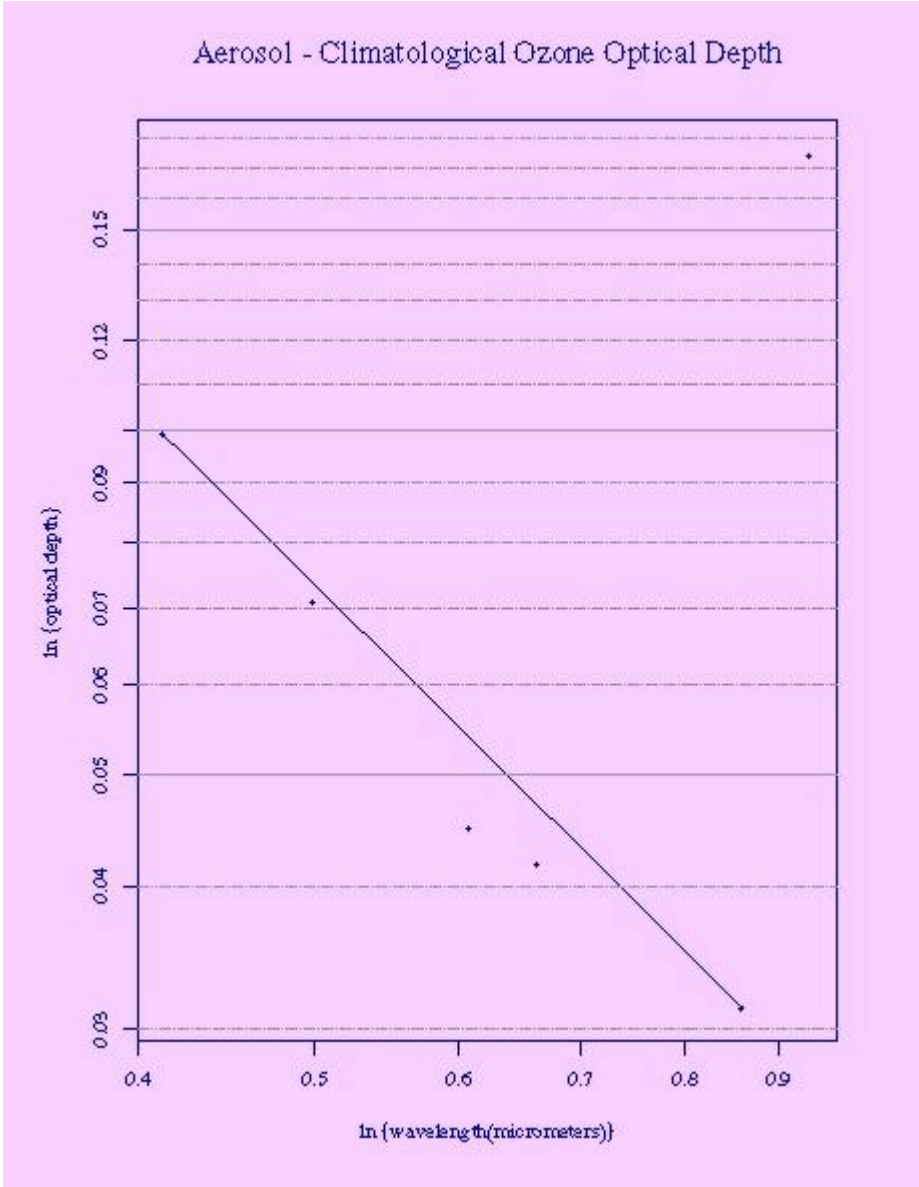
If you have an independent measure of total column ozone over a site, then ozone optical depth can be calculated for the affected filters by multiplying the total column ozone by the Chappuis or Wulf band ozone absorption coefficients listed in Appendix A. The ozone optical depths can be subtracted from the equation, leaving the aerosol extinction optical depths as a function of wavelength.

If ozone estimates are not available, the following figure shows a plot of the natural log of aerosol plus ozone optical depth as a function of the natural log of the wavelength. The 940-nm optical depth is in the upper right hand corner and is clearly contaminated by water vapor absorption. The two ozone free filters are connected by a straight line. Calculations for typical aerosol size distributions and actual aerosol data indicate that, on a log-log plot, we should expect slight curvature at most and often a nearly straight line. In the ozone filters, the optical depths are too high, and they appear too high in proportion to their absorption coefficients.



Typical aerosol and ozone optical depths.

The next figure shows a similar plot, except climatological ozone is multiplied by the ozone absorption coefficient at each wavelength and subtracted. The data appears slightly low in these three filters suggesting that too large an ozone optical depth was subtracted because the climatological ozone exceeded actual ozone for that morning.

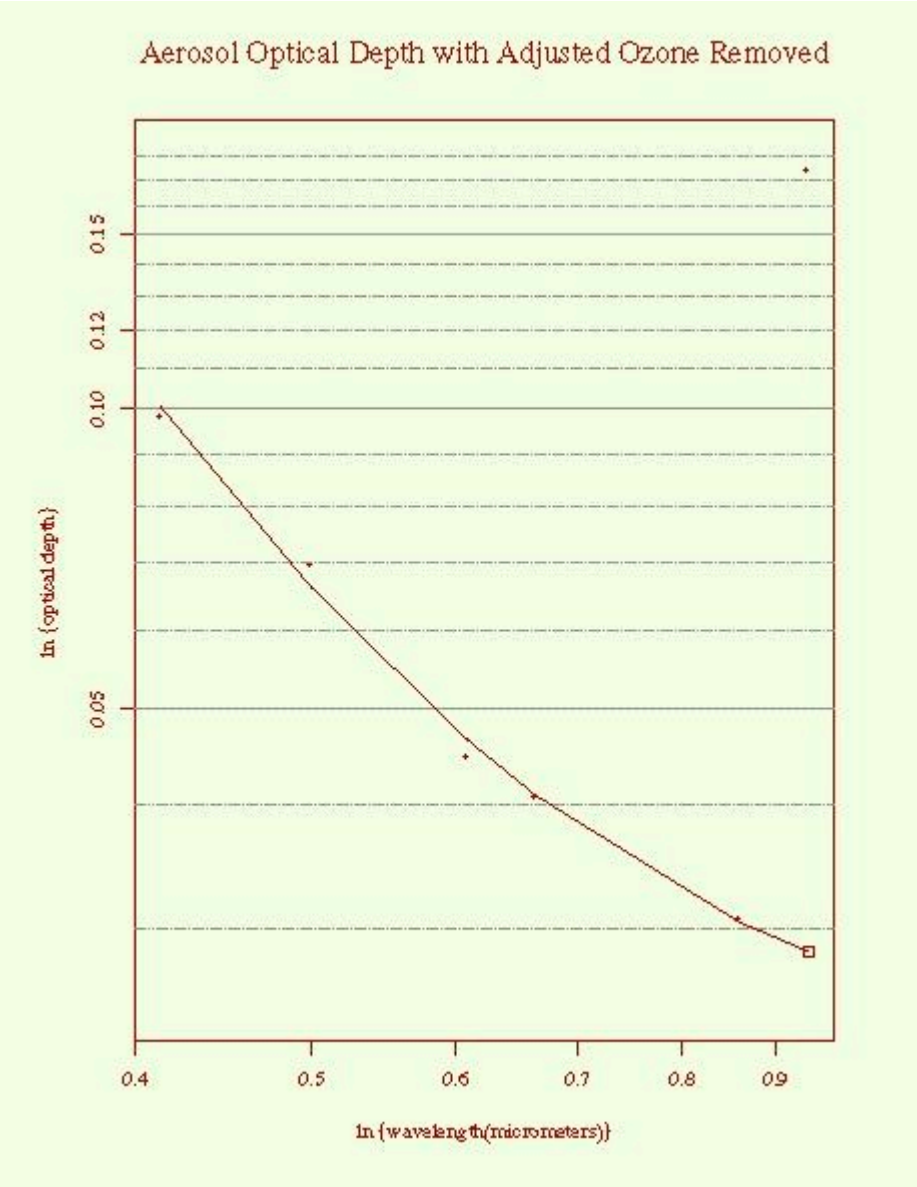


Aerosol - climatological ozone optical depth

The technique for estimating ozone is based on the work of King and Byrne (*Journal of the Atmospheric Sciences*, Vol. 33, pp. 2242-2251, 1976). First, climatological ozone is removed and then a least-squares fit of a quadratic function is performed on the data:

$$\ln(\tau) = a + b \ln(\lambda) + c [\ln(\lambda)]^2$$

Ozone optical depth is then adjusted until the fitting procedure produces a minimum root-mean-square error. The ozone at this point is the estimate of true ozone. The following figure shows the result of this procedure applied to the same data set.



Aerosol optical depth with adjusted ozone removed

Calculating Total Column Water Vapor from 940nm

Reagan, Thome, Herman, and Gall (*Proceedings, International Geoscience and Remote Sensing Symposium*, '87 Symposium, Ann Arbor, Michigan, IEEE, pp. 63-67, 1987) introduced the modified-Langley technique for deriving water vapor. Bruegge, Conel, Green, Margolis, Holm, and Toon (Journal of Geophysical Research, Vol. 97, pp. 18,759-18,768, 1992) presented a more accessible procedure using this method. Michalsky, Liljegren, and Harrison (Journal of Geophysical Research in press) contains the actual details of the procedure that is followed in outline form here.

The modified Langley equation is

$$\ln (I) + \tau_{scat}\, m = \ln(I_o) - k(um)^b,$$

where τ_{scat} is the aerosol plus Rayleigh scattering optical depth at 940 nm, u is the total column water vapor in the zenith direction, and k and b are constants that depend on the exact filter profile of the 940-nm filter. The transmission t_{water} through the filter is modeled as

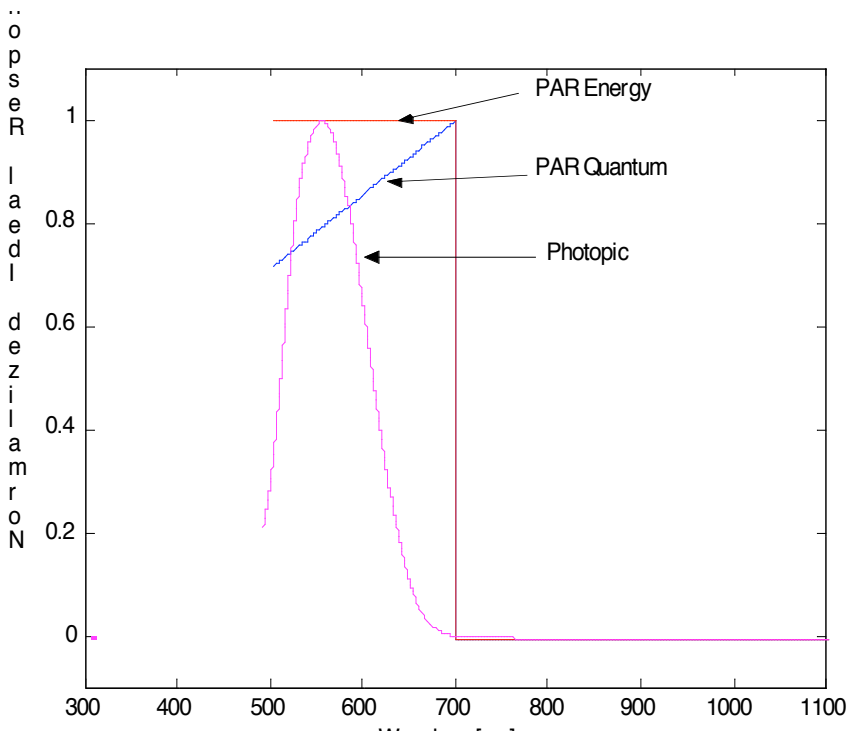
$$t_{water} = \exp(-ku^b).$$

MODTRAN2 is used to calculate transmission through a filter for several values of water vapor and a least squares fit of this function to those data provides the constants k and b. The aerosol component of the τ_{scat} is obtained by extrapolating the function in Figure 7 to 940 nm. Plotting the left-hand side of the modified Langley equation versus m^b and fitting with a linear least squares fit allows one to so obtain the slope $-ku^b$ and intercept $ln(I_o)$.

A single fit of the modified Langley equation is not sufficient for a calibration of I_o since water vapor is much less stable than aerosol, so several retrievals of I_o are used to find a median that is used subsequently to calculate u. This is considered more stable since the slope determined from a single Langley regression is subject to the considerable variation because of ever present water vapor changes.

Quantum, PAR and Photopic Spectral Responses and Calibration

Three other specialized spectral responses are available on the Model SDP-1 single detector photometer instrument, including the human eye (*photopic*), *Photosynthetically Active Radiation* (PAR 400-700 nm), and *quantum/energy*-weighted PAR. The theoretical response of each model appears below.

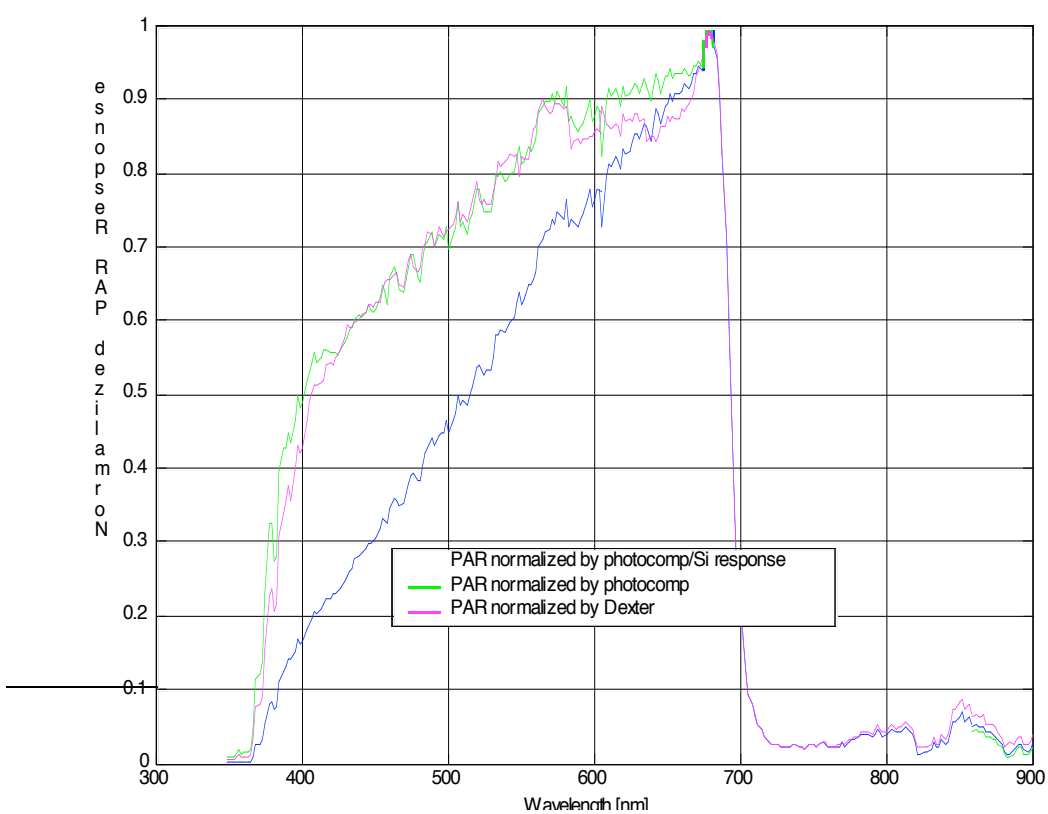


Theoretical PAR, photopic and quantum spectral responses.

In order to calculate the desired quantity $M_{solarpar}$ we can use:

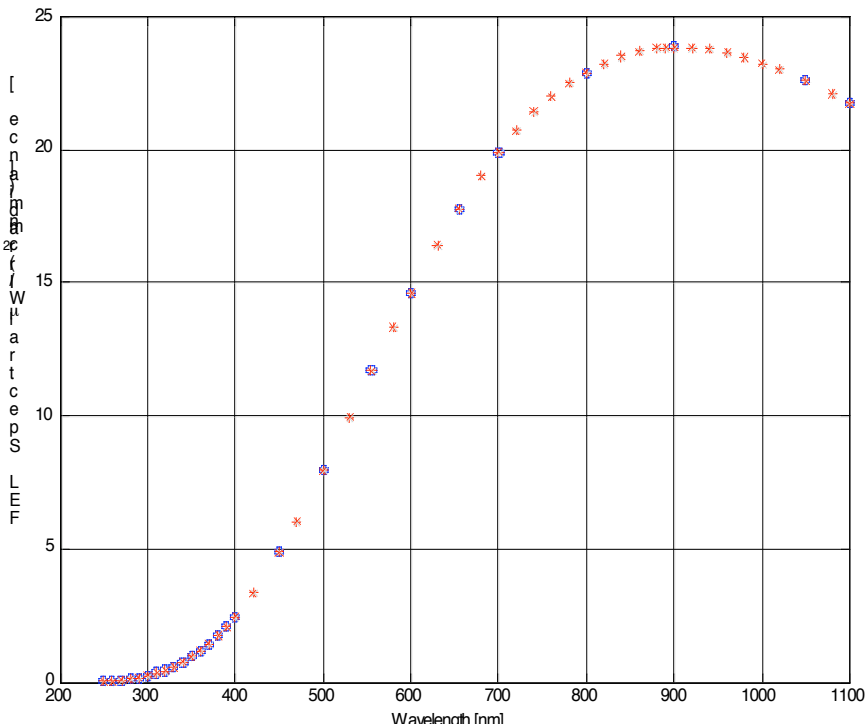
$$M_{solarpar} = \int_{400}^{700} I_{solar}(\lambda)\, d\lambda$$

However, in practice, any instrument will have an imperfect PAR spectral response, $R(\lambda)$ as shown in the following figure.

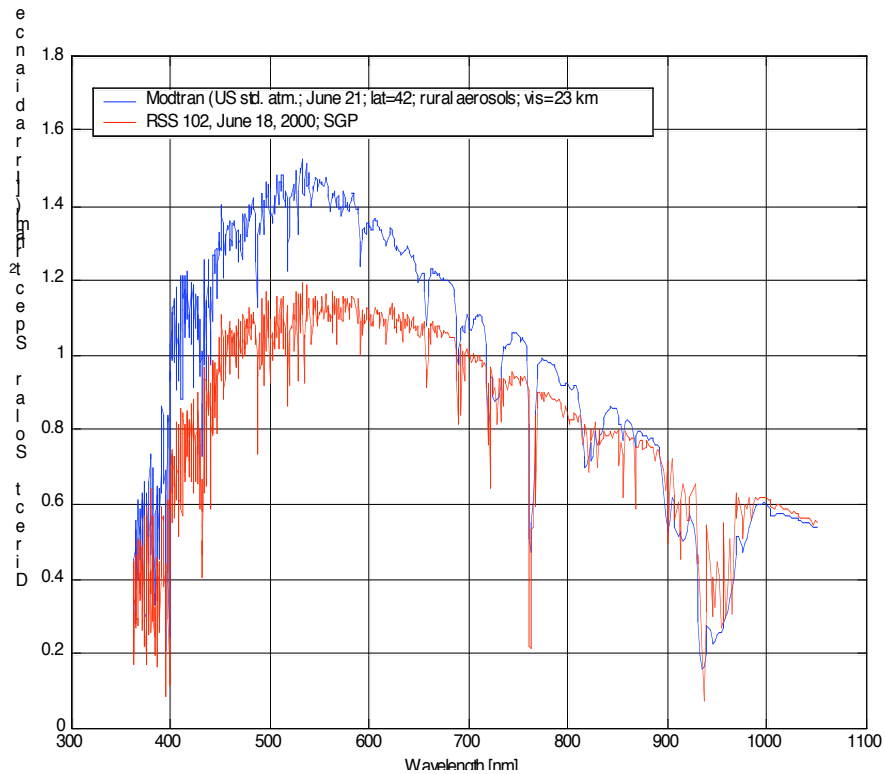


In the figures that follow, note the difference between the output of a irradiance standard “FEL” lamp operating at about 3000°K, vs. the sun, whose photosphere reaches about 6000°K. If we mathematically convolve these spectra against themselves, we obtain slightly different results. For many practical reasons, photometers having arbitrary spectral responses are calibrated by using standard sources, usually lamps.

Under ideal conditions this might not amount to a significant difference, but usually one adjusts calibration coefficient for conditions that judged to be as close as possible to the average (or most important) conditions of interest.



Spectral Irradiance of a typical NIST-traceable standard “FEL” lamp used for absolute calibration of MFR channels.



Typical spectral Irradiance curves; Red is modeled US standard atmosphere, rural aerosols, vis=23 km, solar noon on summer solstice (direct beam normal to sun). Blue is a Model RSS-1024 direct beam spectrum (horizontal surface).

In the calibration lab, one obtains a coefficient K_{fel} from the FEL lamp by dividing the measured output of the instrument under test by the total irradiance integrated in the spectral band of interest (e.g. the PAR band):

$$K_{fel} = \frac{V_{fel}}{\int_{400}^{700} I_{fel}(\lambda)\, d\lambda}$$

As the actual response of the PAR channel is different from the denominator above, we actually have something that looks like:

$$V_{fel} = K_{fel} \int_{400}^{700} I_{fel}(\lambda)\, d\lambda = K^* \int_{400}^{700} R(\lambda)\, I_{fel}(\lambda)\, d\lambda$$

The introduced coefficient K^* is the actual conversion to volts from power that is absorbed by the detector. Solving for K^* we get:

$$K^* = K_{fel} \frac{\int_{400}^{700} I_{fel}(\lambda)\, d\lambda}{\int_{400}^{700} R(\lambda)\, I_{fel}(\lambda)\, d\lambda}$$

In a solar spectrum we have:

$$V_{solar} = K_{solar} \int_{400}^{700} I_{solar}(\lambda)\, d\lambda = K^{*} \int_{400}^{700} R(\lambda)\, I_{solar}(\lambda)\, d\lambda$$

where K_{solar} is the coefficient that, applied to the output voltage, "gives the right answer", *i.e.* $M_{solaepar}$ (for that spectrum). K_{solar} is <u>not</u> the same as K_{fel} , but K^{*} <u>is</u> the same. We can use K^{*} found in the FEL calibration and the selected solar spectrum to find the new K_{solar}:

$$K_{solar} = K_{fel} \frac{\int_{400}^{700} I_{fel}(\lambda)\, d\lambda \quad \int_{400}^{700} R(\lambda)\, I_{solar}(\lambda)\, d\lambda}{\int_{400}^{700} I_{solar}(\lambda)\, d\lambda \quad \int_{400}^{700} R(\lambda)\, I_{fel}(\lambda)\, d\lambda}$$

The user then measures the voltage (via the ADC in the system) and applies the sensitivity coefficient to obtain the solar irradiance in the PAR band:

$$M_{solarpar} = \int_{400}^{700} I_{solar}(\lambda)\, d\lambda = \frac{V}{K_{solar}}$$

Typical PAR Calculations

By using the measured spectra shown above, we can determine the following values:

$\int I_{fel}(\lambda)\, d\lambda = 29.2$ W/m^2

$\int R(\lambda)\, I_{fel}(\lambda)\, d\lambda = 23.84$ W/m^2

$\int I_{solar}(\lambda)\, d\lambda = 310.4$ W/m^2

$\int R(\lambda)\, I_{solar}(\lambda)\, d\lambda = 244.1$ W/m^2

$\int I_{RSS}(\lambda)\, d\lambda = 390.4$ W/m^2

$\int R(\lambda)\, I_{RSS}(\lambda)\, d\lambda = 305.7$W/m^2

$K_{fel} = 1.6050$ mV/(W/m^2)

$K_{solar} = 1.5458$ mV/(W/m^2)

$K_{RSS} = 1.5394$ mV/(W/m^2)

$K_{fel} / K_{solar} = 0.96311$

$K_{fel} / K_{RSS} = 0.95914$

$K_{solar} / K_{RSS} = 1.0041$

CHAPTER 4
Maintenance and Service

The shadowband instrument is designed for long-term unattended use in the field. Only a few maintenance procedures are required to keep the instrument in good working order:

- Clean the diffuser about once a week
- Check band alignment once a month or so

  You can see band alignment problems in the data; see the discussion below for more information.
- Check the instrument diffuser is level once a month
- Check the battery electrolyte levels in the standby battery once a month
- Check YESDAS time and date once or twice a week

  Clock drifts can affect the position of the shadowband during blocked measurements and result in incorrect readings.
- Check cables for animal or wind wear periodically
- Recalibrate the instrument once a year

These tasks are described below. This chapter also provides troubleshooting and service information for the shadowband instrument.

Gently clean the diffuser

To ensure that your measurements are accurate, you should clean the instrument diffuser every week or so. The cleaning frequency may vary with the season or location. For example in the late spring, more frequent cleanings might be required to remove pollen. If the site is near the ocean where bird landings are common, you might also need to check the instrument more often.

A cleaning solution can be prepared using distilled H_20 and up to 50% *pure* ethanol under cold conditions. Do *not* use methanol, which attacks aluminum, or *denatured* ethanol whose usual denaturant is methanol. Optionally add one drop of Ivory dish washing soap per liter. This is a source of sodium lauryl sulfate and can help in greasy or sooty environments.

To clean the diffuser:

1 Use a lab squirt bottle to hydraulically flush the diffuser and area inside the blocking ring. Let this drain away on its own. Be sure to squirt the jet at an angle to wash deposits from the surface. Do not hold the nozzle of the bottle close to the surface at a normal orientation. The center of the face of the diffuser is a relatively thin plastic membrane and must not be dimpled.

2 Check that the fluid drains away from the blocking ring.

If the diffuser is visually soiled after normal cleaning, then more aggressive steps must be taken with care as described below. In general, however, contamination that resists cleaning with the wash bottle method are probably caused by a factor other than atmospheric deposition. Try to eliminate the source.

Caution: The diffuser is quite fragile. *Avoid applying excessive mechanical force on the fragile diffuser during cleaning*. The diffuser is not solid, the top is a thin membrane, so be very gentle when pressing on it. Applying too much abrasion can permanently damage the shape of the top of the diffuser, which would permanently alter the radiometer's fundamental angular/cosine response and deviate form the .sol angular correction values. This would require factory repair and calibration, and any mechanical damage to the diffuser will void your warranty. Of course, avoid using sharp objects to try to scrape it, it is made our of a mechanically-soft plastic. For this reason, only allow properly trained personnel to clean the diffuser and stress that it is essential to apply near zero force to the top of the diffuser.

For more rigorous cleaning, purchase standard laboratory or computer grade cotton swabs. Be sure that they do *not* contain a skin lubricant. Prepare the cotton swabs as follows:

1 Soak the swab end for at least one hour in a Normal Sodium Hydroxide solution in distilled water.

2 Remove from the solution and rinse with distilled water.

3 Soak the swab in excess distilled water overnight to eliminate sodium hydroxide residue, which will attack aluminum. Then dry and package the swab.

   The treatment with NaOH improves the wicking ability of the cotton, and removes residual oils. (You can test this method on a piece of cotton shoelace; you will see a dramatic improvement in its ability to wick up water.)

4 The treated swabs can be used *delicately* with excess cleaning solution for stubborn soil. As mentioned earlier, take care not to damage the diffuser membrane.

If the above procedure does not clean the diffuser, it should be returned to YES for service. More aggressive cleaning procedures will generally require disassembly and subsequent recalibration.

Ice on the diffuser

The instrument's internal heater makes the occurrence of icing very rare. If AC power fails, however, the instrument can be covered by the same rime ice that brought down the power line. If that occurs, do not attempt to mechanically remove ice because the optical surface of the diffuser can be damaged easily. If the instrument's heater and a generous squirt of the EtOH solution does not remove it, let the system sit and run a while. The instrument's heater will eventually take care of it. It is better to loose a little data than damage the instrument diffuser. To speed up deicing, relocate the radiometer inside to a warmer area to melt it.

Caution: Be sure to disconnect both AC power and the standby battery line before removing the head cable! The risk of icing underscores the need to provide a solid standby battery and maintain it.

Check band alignment

Normally, the band needs no adjustment once it is set up properly. However, if the instrument has suffered an animal attack or severe ice storm, the band might be slightly bent. By looking at plots of the retrieved data (or the output of Real-Time Display mode), you might remotely diagnose a band alignment problem. For example, if on a partly sunny day, you have diffuse data only (i.e., no direct data and the total reading is equal to the diffuse), then the band is not properly blocking the direct beam.

Be aware that incorrect data does not necessarily mean that the shadowband is bent. The most common cause of alignment errors is failure to properly set the UTC time, date, and location of YESDAS. If you have verified that these parameters are set properly using the Status command, then you should stop the system and check the band. The band should rest in the nadir position when stopped (unless the system is a UVMFR or has a high-latitude bracket, in which case it is offset to the side). Use the procedure on page 2-4 to check the band alignment.

Check level

Periodically check the bubble level to verify that the mounting platform or instrument has not shifted from the horizontal position. Errors in leveling will seriously impair the quality of measurements made in the visible region.

Check YESDAS time and date

Although the time keeping on YESDAS is highly precise, it is a good idea to periodically check the time for slight drifts, about once per month. You might be able to detect significant shifts in timekeeping by examining day plots. See the discussion earlier on checking band alignment for more information.

Most versions of MS-Windows can automatically synchronize to NIST time if a connection to the Internet is available. However, timekeeping on most workstations (especially PCs) is less stable than YESDAS's clock, so you might want to use a more reliable method to set the YESDAS system to UTC, such as listening to short-wave broadcasts.

Check cables

Ensure that the connectors and insulation on all cables is intact and not split. System operation as well as your data can be affected by water leaking into a broken cable. In most cases, you can repair broken cables. However, if the multiconductor shadowband cable needs repair, we recommend that you order a new one from YES.

Recalibrate

Like most instruments, the shadowband instrument should be periodically recalibrated. The frequency of these recalibrations is a function of how long the instrument has run in the field, how important the precision and reliability of the measurement is to your work, and your operating budget. In general, we recommend recalibrating the shadowband instrument once a year, and recalibrating YESDAS once every five years.

Each shadowband instrument detector undergoes three types of calibrations: angular, spectral and absolute. These calibrations are performed at YES in dedicated, NIST-traceable optical calibration facilities. Because extensive equipment and expertise is required to calibrate the instrument, we recommend that you return the instrument head to YES for recalibration (see page 4-5 for

information on detaching the instrument head). However, you can check the absolute global response of the instrument's broadband channel in your own laboratory, if you want.

The broadband channel can be verified against a WMO secondary standard global visible pyranometer. The calibrated pyranometer should be wired to channel 12, 13, 14, or 15 of YESDAS and co-located with the shadowband instrument head. By comparing the cosine-corrected shadowband instrument global data column with the pyranometer data column, it is possible to calculate a new calibration factor for the broadband thermopile channel.

Removing the Instrument Head or Replacing a Motor

When it is time to recalibrate your shadowband instrument, you need only return the instrument *head* to YES; you do not need to ship the entire instrument. If you have a spare head, you can rotate it in while the first is undergoing calibration. This strategy minimizes gaps in your data.

There are no user-serviceable parts inside the sealed head or motors. Do not attempt to open them as special fixtures are required for proper re-assembly.

Caution: NEVER disconnect the head from the YESDAS-2 until both the AC power is switched off AND the 12 Vdc standby battery is disconnected. Particularly when operating in *campaign mode* (i.e. portable operation), it is critical that you do not ever “hot swap” the head while AC power is on or the battery is still powering the system. The electronics measure picoampres to femptoampere precision. While not dangerous, by unplugging the head when it is on (*hot swapping*) you can permanently damage the electronics in the head.

You will need a #4 Phillips screwdriver for the following procedure.

To remove the instrument head:

1 Retrieve any data from YESDAS. You must shut down the system in order to work on the instrument and any data will be lost when you restart YESDAS.

2 Turn off the red AC power switch on the YESDAS chassis and unplug the system. Also, disconnect the backup battery by detaching the +12 volt lead or opening the in-line fuse.

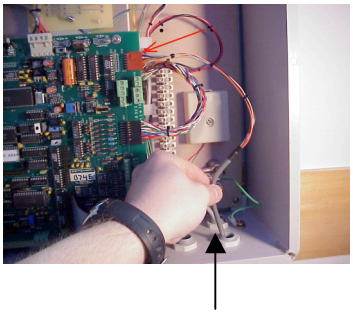
3 Disconnect the cable from the band motor by turning the lock ring a 1/4 turn and then unplugging the connector.

4 Using the Phillips screwdriver, remove the two #6-32 flat head screws that hold the head to the base. Be sure to thread the screws back into their original holes so they don't get lost.

5 Insert the instrument head in a sealed static shielded bag and then wrap it in bubble wrap to protect it during shipment. Be sure to insure the head for its full replacement cost and prepay the shipping. Also, include the purchase order with the shipment to ensure timely processing.

Replacing a Motor

Earlier MFR systems contained a connector on the rear of the motor, while newer designs have a hard wired connection, to eliminate connector failures. This section discusses how to change over a motor with the newer style cable.

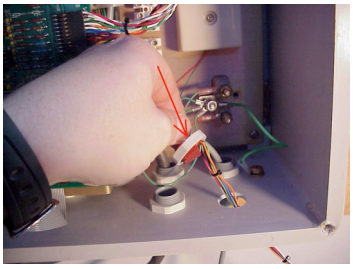


1 Remove the old motor cable by unplugging the motor cable connector from the HDL board.

2 Loosen the nut securing your motor cable in the strain relief, such that the motor cable can move freely.

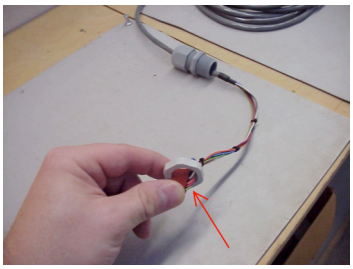
3 Unscrew the mounting jam that secures the strain relief to the enclosure box.

4 Carefully splay the connector wires that exit the rear of the orange/red connector 90° so that the mounting nut can be slipped off over the connector. Remove the strain relief, and motor cables completely from the enclosure.



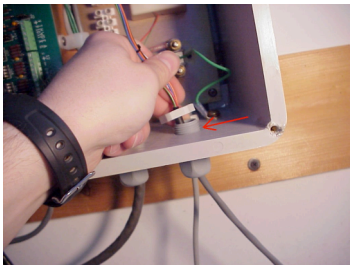
5 Take your new Motor cable and unscrew the mounting nut from the strain relief. Carefully bend the connector wires 90° and slip the mounting nut over the connector, slip the motor cable through the through the hole in the enclosure.

6 Now slip the mounting nut back over the motor cable connector, and straighten the motor cable connectors wires back out, and slide the strain relief up the motor cable and into location in the enclosure hole. Tighten the mounting nut on the strain relief.

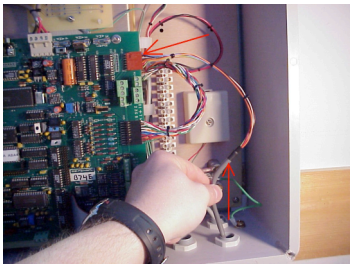


7 Pull the motor cable up through the strain relief and plug the connector into the HDL-1 board.

8 Pull the motor cable up through the strain relief about 3 cm to prevent stress on the motor cable and then tighten the nut to secure the motor cable in the strain relief. Make sure that the nut creates a tight seal to prevent moisture from coming into the enclosure. This is done by moving the motor cable up and down slightly and tightening the nut at the same time.



9 Finally, once the motor cable's movement becomes slightly restricted, tighten the nut one full turn. This should be enough tension to properly seal the motor cable in the strain relief to prevent moisture from coming in.



Note: Earlier MFR motors had a seven pin round connector at the back of motor, which tended to corrode and fail after about five years. Newer motors have a fixed connection at the motor and you insert the cable as described here.

Troubleshooting

The rugged design of the shadowband instrument helps to minimize most hardware problems. Problems that you may encounter typically involve installation and alignment issues rather than actual instrument failure. If you notice inconsistencies in your shadowband data, most likely the band is not shading the diffuser correctly. You should check all installation parameters carefully. This section helps you troubleshoot problems related to shadowband instrument operation. For information on troubleshooting YESDAS problems (errors communicating with the system, for example), see the *YESDAS Installation and User Guide*.

Band is Not Moving or Shading Properly

If YESDAS seems to work — you can log in and sample channels — but the shadowband is not moving, or it is moving randomly, check the motor cable and system power, starting at the voltage on the standby battery terminals. Change your DVM to ohms, and test the continuity of each lead end to end in the battery cable the motor cable and the head cable.

Caution: Be sure the AC power is turned off and the standby battery is disconnected when unplugging the head cable (do not *hot swap* the head cable). Remember that even with the AC unplugged, assuming the standby battery is charged it is still powering the system.

Next, check for broken or corroded pins wires at the back of the motor cable connector (H13), the current through the motor cable can drive corrosion. If the cable and connector check out, and the voltages from the radiometer appear normal, and you suspect a lighting hit, try replacing the stepper motor driver IC, U23. There is often a spare, unused driver IC part socketed adjacent to U23 you can try. See the *YESDAS Installation and User Guide* for information on servicing the YESDAS PCB.

Note: By comparing plots of shadowband data with empirical data (notes of sky conditions for the day, for example), you can often detect band-shading problems remotely. For example, if no direct normal data was collected on a day that you know the site had a clear cloudless day on, the band was off (that is the measured diffuse was identical to the unshaded total/global). In this case you must have a gross misalignment and the band should be checked. Assuming you had initially aligned it properly, begin by asking yourself what changed at the site?

Band Not Shading Properly

Several factors affect the position of the band during blocked measurements. If one or more of them is set incorrectly, your band will not shade the direct beam properly.

- **System location.** Run the Status command and check the latitude and longitude parameters in the status message. Latitude appears first followed by longitude.
- **System time.** The status message also shows the time. Be sure that the YESDAS clock is set to *UTC time* and not your local time.

- **Instrument leveling and alignment.** See Chapter 2, Installation, for detailed information on setting up the instrument. The instrument should be within 2° of vertical and, at solar noon, the motor bracket should not cast a shadow to either side of the shadowband motor.
- **Shape of the band.** Ensure that the band is not bent. See page 2-4 for more information on checking the band. Vandals or large hail may have bent the band out o its normal shape. Make a template out of the pattern in Shadowband Curvature Test Drawing on page 2-26.
- **Latitude adjustment.** This adjustment was preset for your location during manufacture. You normally should not need to adjust this setting, but on motor brackets with an open slide you may have a loose motor, or the motor may not be pushed all the way back against the slide. Note you may need to replace the motor bracket if you move the instrument out of the latitude range supported by the bracket (i.e. moving form the equator towards the poles). You can order a new bracket from YES or a new PROM and a three hole bracket which supports a much wider latitude range.
- **Band offset for high-latitude and UVMFR instruments**. The bracket on high-latitude shadowband instruments and the canister on UVMFRs do not allow the band to rest at the nadir, directly below the canister. Instead, the band is offset from the nadir, effectively changing the home position of the band. When you configure YESDAS, you must specify this offset so that YESDAS can determine the correct number of steps required to make a blocked measurement. Otherwise, YESDAS assumes the home position is vertically down and ignores the offset when moving the band.

  You specify the offset in the Locate command. We supply an offset based on the distance the band is set from the canister during manufacture. If you change the band position (not recommended) or the band becomes loose, the supplied offset will no longer work. In addition, the band on a UVMFR might strike the canister during a measurement cycle (see below).

  See page 2-6 for information on adjusting the band on UVMFR and high-latitude shadowband instruments.

Shadowband Strikes UVMFR Canister

Because the canister on a UVMFR is deeper than canisters on SDR and MFR instruments, the home position of the band on a UVMFR must be mechanically offset from the canister, rather than parking directly below it at the nadir rest position. Although the band is properly adjusted during manufacture, it may become loose during shipment. If the band strikes the canister during a measurement cycle, it must be manually readjusted and retighten as described on the next page.

Note: The offset factor that you specify in the Locate command does *not* affect the physical distance that the band is located from the canister. The only way to prevent the band from striking the canister is to manually change the home position of the band. Once you adjust the band, you use the offset factor to tell YESDAS the number of steps the band is offset from the canister. This way YESDAS can factor this offset into its calculations when it moves the band from the home position to the appropriate position for a blocked measurement. If you do not specify an offset factor, YESDAS assumes the home position is at the nadir, regardless of its actual position.

Before you begin

For this procedure, you will need the following tools:

- 0.050" (Xcellite P20 or equivalent) Hex driver
- 2-cm thick block of wood (or similar device) to space the band off the canister

During this procedure, you will loosen and retighten the band. The small set screw that holds the band to the motor has a soft brass tip designed to bite into the motor's shaft without causing excessive torque. Take care not to overtighten this screw.

Note that since there is little time between the steps in this procedure, you should read the entire procedure first to become familiar with the sequence of steps.

To adjust the home position of the shadowband:

1. Initialize YESDAS with the default offset and enable the shadowband.
2. Carefully insert an Hex driver in the band hub's set screw. Take care not to prevent full motion of the band. When the band stops at the current home position, loosen the setscrew ½ turn.

   Note: The band should now swing freely on the shaft when the motor runs. Otherwise, loosen it a bit more.

3. Using a spacer block (i.e. a block of wood), offset the shadowband about one cm from the canister. Verify a 2 mm space exists between the band hub and motor face plate to prevent any friction during band motion.
4. Listen for the band motor to reach the end of a cycle and shut off at the home position. Then tighten the screw, taking care not to overtighten it.
5. Remove the wrench and spacer block and observe the band motion. If it still strikes the canister, repeat the above procedure.
6. If the band is not shading the diffuser properly during blocked measurements, you may need to adjust the offset parameter of the Locate command. For more information, see the YESDAS manual.

   Important: The band will not shade properly if the instrument is not aligned along the North/South meridian. See page 2-4 for more information.

7 Make a note of the new offset in case you must reset or reinitialize the system in the future.

Shadowband Head ID is Set to Zero

The **.cal and .sol** files are each time and date-tagged with spreadsheet time/dates to prevent the misapplication of optical characterization data to old data from a different epoch. Similarly, both files have a serial number for the YESDAS-2 and head to prevent misapplication of calibration data from the wrong site or instrument head. The head ID is read once at power on. In order to detect a head is hot-swapped (that is, connected after the power is applied), the head ID is set to zero. After that point if you take data the cal/sol fiel will not allow you to process it. In some cases hot-swapping the head can actually blow the solid state ID. Either way, the acquired solar data are generally unaffected and this is only a quality control mechanism.

If you receive errors when attempting to process a data file from a shadowband instrument system, check the shadowband head ID in the YESDAS status message. If the value is $0000, the head ID is blown. This can occur if the head is disconnected and connected while AC power is applied or if static discharge is present. Try disconnecting the standby battery and removing AC power to reset the system, and then reinitializing using YESDAS Manager to see if this clears the problem.

Shadowband head ID

```
$0915 $0000 7Y [7] -33.2700 70.4000
15:03:12 05-09-1995 34827.62517 (0)
$A1 $0 $0 $000000
   15   60
    0    0
```

Now, as the head ID in the data file no longer matches the ID in the **.cal** and **.sol** files, the host software reports an error when you attempt to process the data. You must edit the header of the **.cal** and **.sol** files and change the head ID. Create a new site profile for this special case (be sure to substitute your own binary head ID for the $1011 shown in this example).

```
MULTIFILTER32 7 21 $9231 $1011 33000 STANDARD
```

Change the head ID in the **.cal** file to 0.

Important Product Safety and Disclaimer Information

Important: READ THIS PAGE BEFORE USING THE SYSTEM!

Be careful with AC

Because the system operates from high voltage AC power, there is always the potential for injury if you physically touch it and there is a ground failure or if it is setup improperly. Take the same precautions that you would while working near any electrical equipment outdoors in potentially wet conditions. The sensor must be mounted such that it is out of reach or anyone standing under it. If you cannot do this, install it inside a secure fence line such that children and unauthorized personnel are denied physical access to it *at all times*.

Caution: Fences create shadows. If you do fence in the site, be sure the fence is far enough away so that it does not block direct-normal radiation from reaching the diffuser. *Installation factors are not within the control of the manufacturer and it is therefore your responsibility to install and use the system properly.*

Lethal voltages present inside enclosure

There are lethal voltages inside the electronics enclosure, therefore no work should be performed on it while it is connected to AC line power - always disconnect AC line power before servicing the system. Only operators familiar with the detailed operation of the system should be allowed to maintain it, and all servicing is to be performed by qualified, technically-trained personnel only.

Danger: Use extreme care when working on the system where the ground is wet, you can be killed! Always disconnect AC power first before opening the enclosure or touching the system, and wear gloves and rubber soled shoes.

Advisory use only

This equipment is not designed or intended for hazardous or otherwise life-critical applications. The complex and random physics of environmental measurements depend on complex behavior of the atmosphere and is difficult to control. Yankee Environmental Systems, Inc. (YES) provides this equipment *as-is* and makes *no warranty as to the suitability of purpose of the product or the data it produces*. Data provided by the system are for “advisory” use only. While best practices have been employed in the design and manufacture of the system, malfunctions can and will occur, requiring periodic user-maintenance and intervention.

Disclaimer

You agree to use the product and the data it provides *at your own risk*. YES, its agents, distributors, assigns, shareholders or employees are not responsible for any damages whatsoever, resulting from either proper or improper use of this product, or application of data it provides. Further, YES, its agents, distributors, shareholders or employees are not responsible for any injury or injuries that may result from improper installation, malfunction, system design elements, improper or normal operation, or as a result of real or perceived negligence on the part of anyone. By using the instrument, you agree to these terms herein included in this User Manual as provided with the system at time of purchase. If you have any questions about this policy or on using the equipment in your application, contact technical support before proceeding with installation or use via any of the methods listed in *In This Manual* located just after the table of contents.

Product Warranty

Warranty Terms

The YES standard product warranty applies only to defects in manufactured parts as described by its general product warranty located at www.yesinc.com.

Documentation Feedback

While we strive to provide the highest level of technical accuracy in this document, we welcome any comments you have on this user guide, both positive and negative. Please do not hesitate to contact us via any of the methods listed in the section *In this Manual* located just after the table of contents.

Also, be sure to check our corporate web site for the latest technical information—look in the *support* section, under the data sheets and in the *frequently asked questions* link. In addition to providing the latest development news, the YES web site www.yesinc.com offers downloadable software updates to licensed customers, and in some cases tutorials on topics too changeable or complex to be covered in a printed manual (such as videos demonstrating complicated service procedures). You can also submit feedback and questions directly to the YES engineering team via the on line support site.

APPENDIX A
References

The MFR is at the center of a large variety of research efforts. Below is a summary as of this writing of published work on the instrument. If you are interested in learning more about the algorithms and history of development please consult these published documents.

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