The Multi-Filter Rotating Shadowband Radiometer – A Look Ahead

G. Hodges
Cooperative Institute for Research in Environmental Sciences
University of Colorado
Boulder, Colorado

Introduction

The multi-filter rotating shadowband radiometer (MFRSR) is one of the Atmospheric Radiation Measurement (ARM) Program's original instruments. As atmospheric research has advanced, the ways in which the MFRSR has been used have increased, along with an ever advancing desire from the scientific community for well calibrated measurements. As the ARM Program has matured, however, the upkeep of the MFRSR network and the refinement of its calibration procedures have not kept up as one would hope to accommodate the modern requirements of climate researchers. This has led to the point the MFRSR network is at today, i.e., a network of instruments with significant capability that is instead operating in a mostly suboptimal condition. Several initiatives are under way to bring the MFRSR network in line with modern expectations. Major projects now in progress are the conversion to Campbell Scientific data loggers and the purchase of replacement filter detectors so the numerous broken MFRSR heads can be repaired. A major change in the data reduction method has been proposed and will become operational in the coming months. This new scheme will be used when the Campbell loggers are in place and during the transitional period from the current Harrison style loggers. This reduction method will correctly account for nighttime offsets as well as lead into a proposed method for providing accurate calibrations based on the Langley calibration method.

Problems

Recently, some problems with the way nighttime offsets are being applied in the MFRSR calibration files have come to light. There are several ways in which offsets are incorrectly used. For example, in some cases offsets are applied to the direct data when they should not be. This is because the nighttime offsets cancel out during the direct calculation. In other cases, offsets were not being used with the global and diffuse data when they should have been. There are also cases when logger board offsets are being scaled larger when they should not be. In most cases, the incorrect application of offsets likely cause negligible to small errors. However, there are likely a few cases where the misapplication may have produced significant errors. Now that the offset issues have been fully recognised, steps are being made to ensure offsets are applied correctly and the historical data will be reprocessed. For a description of the correct way nighttime offsets should be applied, see the section on data reduction equations below. Data users should be aware that the misapplication of offsets can result in aerosol optical depth (AOD) errors of not more than 1%.

In general, the calibrated irradiance data from the MFRSR network are of poor quality. (Note that calibration issues do not affect AOD.) Possible exceptions are the Northern Study Area sites and the ARM Mobile Facility (AMF). At these stations, the calibrations are typically no older than one year. The procedure for calibrating a MFRSR up to now has been to perform a standard lamp calibration and then sometimes refine that calibration with Langley plots. The instrument would then be put in the field until it failed, with no subsequent calibrations being performed. This has led to situations where some MFRSRs have not been calibrated for upwards of ten years. Even when an instrument has a new calibration it can only be trusted for a short time, not like the year-long period the broadband instrument calibrations are valid. Because of this, calibrated MFRSR data at this time should not be used for any application that needs more than just a very general estimate.

Calibration issues aside, the biggest problem with the MFRSR network right now is a lack of spare instruments. With a network the size of ARM it is not unusual for an instrument to fail. For many problems spare parts are readily available, but oftentimes what fails is one or more of the filter detectors. Replacement interference filters have historically been difficult to purchase. Unfortunately, when a failure is with a filter detector, it usually means one less MFRSR in the network. Figure 1 shows the sites that currently have an operational MFRSR and those that do not.

An analysis of the past two years of MFRSR Data Quality Reports (DQRs) was recently performed, and of the sixty-four DQRs found, over half (thirty-three) were related to “alignment/shading” issues. Ignoring the weather related DQRs, only twenty result from all other reasons. This is a remarkable number of DQRs related to alignment problems. When a MFRSR is set up correctly on a stable platform, it is not unusual for it to operate years without alignment problems.

Initiatives

Conversion to Campbell Data Loggers (EWO-11425)

In 2003, ECR-00350 was opened, proposing to convert all the current Harrison-style loggers with Campbell Scientific data loggers. This ECR was approved and ARM has been working toward implementing the proposal. A test system is currently running at the Central Facility. A primary benefit is that the Campbell loggers will be less costly to purchase and maintain than the current proprietary loggers. They will also provide programming flexibility, offering the possibility of operating the MFRSRs in innovative ways. For example, one suggestion is to sweep the shadowband continuously rather than making distinct stops, all the while collecting data. Operating the MFRSR in this fashion might also provide a method for ensuring diffuse data are collected when the instrument's diffuser is completely shaded. This might help to mitigate the alignment problems that continue to plague the MFRSR network.

Replacement Filter Detectors (EWO-10875)

Perhaps the biggest issue facing the MFRSR network is an almost total lack of spare instruments. As it stands now, if an instrument fails there is generally not a spare available for replacement. Over time this has had a serious effect on the Southern Great Plains (SGP) MFRSR network. Figure 1 shows what the lack of spare instruments has meant to the SGP network. Failed filter detectors are by far the most common reason an instrument is pulled from service. This is the one replacement part that has been difficult to obtain. Purchasing new interference filters has been an arduous process, but if all goes well it is looking like ARM will soon have enough to repair one hundred MFRSR heads. Currently, prototype filters have been delivered and tested and were found to meet specifications. The order for the full 100 sets was recently placed and delivery is scheduled for May 2006.

A New Data Reduction Scheme (ECR-00571)

A new data reduction scheme was proposed in February 2006 in part to address concerns that have been voiced regarding the poor state of calibrated MFRSR data. As described earlier, in the past there were often fundamental problems with the calibrated data. It was recognised that a complete ground-up reworking of the data reduction process had to be done. To help rectify all prior data reduction problems, the new scheme captures the best estimate of the nighttime offsets and applies those values correctly to the raw data. That is, the offsets are only applied to the global and diffuse data, not the direct. The raw global and direct data are then cosine corrected (as has been done in the past), and the diffuse data will also have cosine corrections based on a Rayleigh sky applied (this is new). The biggest change that a data user will notice is that calibrated data will no longer be produced at the a1 and b1 data levels. To provide the best data possible, the decision was made not to produce calibrated data at these levels. This is in recognition of the fact that calibrations, lamp or Langley, are only valid for a limited time. To continue to produce calibrated data at the a1 or b1 level would be to knowingly provide poor data to the research community, which is precisely what we are trying to get away from. At this time, the ECR has been approved and work is being done to implement the new scheme. Details are in the following data reduction section.

Producing Calibrated Data in a Yet to be Proposed ECR

While calibrated data will no longer be provided in a1 or b1 level data, they will be provided by a value-added product (VAP). This will either be an entirely new VAP or will be incorporated into an existing one. Unlike broadband instruments, e.g., the Eppley PSP, the calibration of a MFRSR changes relatively rapidly with time. To further complicate matters, all the filter detectors drift at different rates. The MFRSR also doesn't lend itself to regular BORCAL style calibrations like are done with the broadband instruments. To bring each MFRSR back to the Central Facility would also mean bringing the data logger in since there are not enough spare loggers to use for this purpose. MFRSRs are also not as straightforward to set up as broadband instruments, and routine BORCAL style calibrations may result in even more alignment problems. With this in mind, the preferred way to calibrate MFRSRs is by performing regular Langley calibrations. The working plan is to provide calibrated data on a month or so delayed basis. The month delay should provide enough clear days to ascertain a stable V_0. Once a stable V0 is found, a calibration value for each channel for the prior month can be calculated and calibrated data will then be available. The 940-nm channel, however, will still have to be calibrated by another method, likely by using a standard lamp. Because of the high variability of water vapor, it is very difficult to get a stable V_0 using the Langley approach. Some trade-offs will have to be made to keep channel 940 nm calibrated. Ideally, each MFRSR could stay in the field indefinitely, but the heads will likely be run under a calibrated lamp on an annual basis to keep the 940-nm calibration reasonably fresh. This will also provide an opportunity to check the Langley calibrations by a second method. Note also that for lamp calibrations only the instrument head needs to be transported to the Central Facility.

Addressing the Alignment Issue (EWO-11474)

At a few of the SGP extended facilities, the single instrument support poles have been replaced with sawhorse style stands because of locally expansive soils. At these sites, instruments were routinely going out of level and alignment as the soil expanded and contracted. It is suspected that this may be happening at other sites, but to a lesser degree. To assess this it was proposed that bubble levels be added to the MFRSR stands that are still of the single post variety. The proposal was approved and EWO-11474 was completed in November 2005. Bubble level readings are now being monitored on a regular basis. Not enough time has elapsed to say if any other sites are suffering from shifting support posts.

Data Reduction Equations

In this section, we discuss the equations that will be used for the new data reduction scheme and when the Campbell loggers are in place. For more details on the new reduction scheme, please see ECR-00571. A brief description of the reworked data levels are provided.

Definitions:

alltime=day and night total horizontal readings (7 values)
blk=sun-blocked measurement *
cordif=cosine corrected diffuse measurement (7 values)
cordirhor=cosine corrected direct horizontal (7 values)
corth=total horizontal calculated using cordirhor and cordif (7 values)
dif=sideband-corrected sun-blocked measurement (7 values)

dirhor=vertical component of the direct on a horizontal surface (7 values)
fsb=first side band *
ssb=second side band *
th=total horizontal (7 values)

* Note that these are not available as output values from the current Harrison style data loggers, but are included here to provide understanding of the measurements. These quantities will be recorded with the Campbell data logging systems.

Equations:

dif=blk + [th -(fsb + ssb)/2]
dirhor=(th + offset) - (dif + offset)=th - dif=
th -blk - [th - (fsb + ssb)/2]=(fsb + ssb)/2 - blk
cordif=dif/(diffuse cosine correction derived from SolarInfo file)
cordirhor=dirhor/(cosine correction from SolarInfo file)
corth=cordif + cordirhor

Offsets are an inherent part of the primary measurements (global, diffuse and the sideband measurements). Since the direct is calculated rather than being a primary measurement, the offsets cancel out. Cosine corrections used in the calculation of corrected-direct-horizontal (cordirhor) are found by running the instrument on a cosine bench. The diffuse cosine corrections are found by modeling a Rayleigh sky with input from the SolarInfo file.

New Data Levels (a0, a1, b1, c1):

a0:Data exactly as they come from the data logger. No processing of any kind is performed.

a1:Data are still in raw units, but have been corrected for bias by accounting for nighttime offsets.

b1:Data are still in raw units, but cosine information has been used to correct the direct and diffuse measurements. The corrected direct and diffuse data are then used to calculate an improved global.

c1:Data are now calibrated and provided in engineering units. c1 level data will be available from a VAP on an approximately month-delayed basis.