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Shortwave Array Spectroradiometer–Hemispheric Instrument Handbook

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ARM CLIMATE RESEARCH FACILITY

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Office of Science, Office of Biological and Environmental Research

Acronyms and Abbreviations

AOD	aerosol optical depth
AOS	Aerosol Observing System
ARC	Ames Research Center (NASA)
ARM	Atmospheric Radiation Measurement Climate Research Facility
ARRA	American Recovery and Reinvestment Act
CCD	charge-coupled device
CWV	column water vapor
DOE	U.S. Department of Energy
GSFC	Goddard Space Flight Center (NASA)
IOP	intensive operational period
MFRSR	Multi-Filter Rotating Shadowband Radiometer
NASA	National Aeronautics and Space Administration
NIR	near infrared
NIST	National Institute of Standards and Technology
OMI	Ozone Monitoring Instrument
QC	Quality Control
RH	relative humidity
RSS	Rotating Shadowband Spectroradiometer
SASHe	Shortwave Array Spectroradiometer–Hemispheric
SASZe	Shortwave Array Spectroradiometer–Zenith
SGP	Southern Great Plains ARM megasite
USB	Universal Serial Bus
UT	Universal Time
UTC	Coordinated Universal Time
VAP	Value-Added Product
VIS	visible

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1.0 General Overview

The Shortwave Array Spectroradiometer–Hemispheric (SASHe) provides measurements of direct solar, hemispheric diffuse, and total hemispheric shortwave irradiance over a continuous spectral range from approximately 300 nm to 1700 nm at a rate of about 30 seconds. The SASHe design connects an optical collector located outdoors to a pair of spectrometers and data collections systems located indoors within a climate-controlled building via an umbilical cable of fiber optic and electrical cables. The light collector uses a small Spectralon button as a hemispheric diffuser with a shadowband to distinguish signal from diffuse sky and direct sun.

The SASHe measurements can be used:

- to retrieve aerosol optical depth and angstrom relationship
- for Column Water Vapor
- for ozone and trace gas column amounts
- for thin cloud optical depth, particle size, and cloud water path
- for aerosol column intensive properties
- to retrieve Sub-Cloud Areal Averaged Surface Albedo
- to perform validation/comparison with the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility Southern Great Plains (SGP) site surface remote sensors and future cloud intensive operational period (IOP) campaigns
- to perform multivariate analysis to derive information content in hyper-spectral data sets and to improve cloud retrieval algorithm development
- to compare with radiative transfer models for testing and validating retrieval procedures.

Figure 1. SASHe deployed at SGP.

2.0 Contacts

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3.0 Deployment Locations and History

The SASHe systems were produced with funding from the American Recovery and Reinvestment Act (ARRA) and were delivered to ARM at the end of calendar year 2010. The initial installations were scheduled in 2011 to the ARM SGP site in March and the ARM Mobile Facility (AMF1) field campaign in Nainital, India in June. The system deployed to SGP is dubbed “SASHe #1”. The system deployed to the AMF1 is dubbed SASHe #2. Tables 1 and 2 list deployment dates and repairs for SASHe1 and SASHe2, respectively.

Table 1. Deployment and servicing of SASHe1.

Begin Date	End Date	Serial No.	Location		Description
2011-03-22	2012-07-02	SAS-He1	SGP C1		Initial installation
2011-04-22	2011-05-01	SAS-He1	SGP C1		Azimuth control problem
2011-10-13	2011-11-01	SAS-He1	SGP C1		Band failure
2013-04-18	2013-05-07	SAS-He1	SGP C1		Azimuth drive intermittent
2014-05-29	2014-06-30	SAS-He1	PNNL		Returned for azimuth drive repair
2014-06-31	current	SAS-He1	SGP C1		Redeployed, operational

Table 2. Deployment and servicing of SASHe2.

Begin Date	End Date	Serial No.	Location	Description
2011-06-09	2011-06-10	SAS-He2	PGH	Initial installation
2011-06-11	2011-09-09	SAS-He2	PGH	Azimuth coupler failure, sad
2011-09-11	2012-02-14	SAS-He2	PGH	Monsoon prevents alignment
2012-02-14	2012-04-01	SAS-He2	PGH	Acceptable operation
2012-06-27	2013-03-14	SAS-He2	PVC	Installation for TCAP
2012-11-06	2012-12-06	SAS-He2	PVC	Shadowband failure
2012-12-07	2013-06-21	SAS-He2	PVC	Acceptable operation
2013-12-11	2014-01-13	SAS-He2	MAO	Band misalignment Go-Amazon
2014-09-06	2014-10-16	SAS-He2	MAO	AOS mast shading in AM
2015-06-23	2015-07-08	SAS-He2	MAO	Shutter failure

4.0 Near-Real-Time Data Plots

Near-real-time plots of SASHe diagnostic and sky radiance data generated by the ARM Data Quality Office may be viewed via the Plot Browser. Select the site (SGP, PGH, PVC, MAO) and scroll down the list of datastreams to find xxxsashe (where xxx stands for the relevant site abbreviation above). Figure 1 below shows time-series traces of shortwave irradiance components from the SASHe and collocated MFRSR at wavelengths matching the nominal filter centerlines. These real-time plots have only nominal calibrations applied to both SASHe and Multi-Filter Rotating Shadowband Radiometer (MFRSR) measurements and should only be used to verify similar behavior. Note for example that the SASHe direct components do not track the MFRSR direct components during the early morning. This is an example where the SASHe instrument is shaded by the nearby Aerosol Observing System (AOS) stack as in DQR D141017.3.

5.0 Data Description and Examples

5.1 Data File Contents

The SASHe data files are initially collected as "comma-separated variable" ASCII files of uncalibrated readings. The full content of the raw files is stored and available from the ARM Data Archive. The raw ASCII files are then ingested into ARM netcdf as uncalibrated "a0" level files. These uncalibrated "a0"-level files are subsequently processed in real time to provide nominally calibrated irradiance components in units of W/(m^2 nm) in data files named as follows:

xxxsashevisFN.b1.yyyymmdd.hhmmss.cdf : irradiance components from UV/VIS spectrometer

xxxsashenirFN.b1.yyyymmdd.hhmmss.cdf : irradiance components from SWIR/NIR spectrometer

xxxsashemfrFN.b1.yyyymmdd.hhmmss.cdf: irradiance components matching MFRSR filters

where yyyy ≡ year (i.e., 2006), mm ≡ month, dd ≡ day, hh ≡ hour, mm ≡ minutes, and ss ≡ seconds.

The "vis" and "nir" files have identical structure except each also contains spectrometer-specific metadata including model and serial number, pixel wavelength mapping, integration times, and so on. Identical housekeeping measurements are duplicated in each file including shutter position, temperature and relative humidity (RH) of various instrument elements, and computed solar ephemeris quantities.

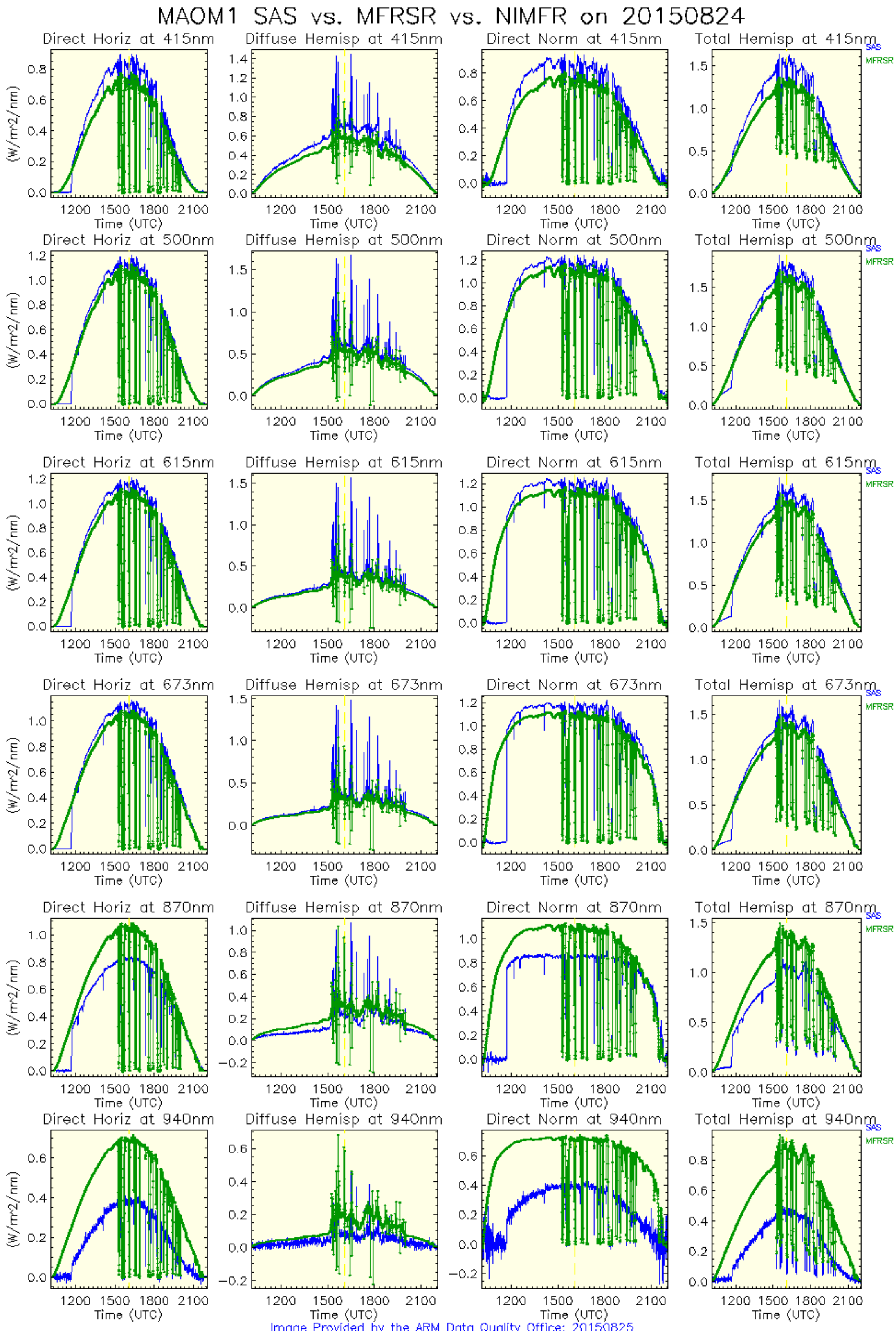

Figure 2. Solar irradiance components from SASHe and MFRSR, MAO.

In addition to the b-level process, the SASHe Aerosol Optical Depth (AOD) Value-Added Product (VAP) produces sashevisaod.c1 and sashenirαod.c1 data files with a 6-week delay to allow for more robust calibrations and for receipt of Ozone Monitoring Instrument (OMI) ozone column amounts from the ARM External Data Center. SASHe AOD c-level data files should always be used in preference to the b-level data whenever the c-level is available because the calibration is more confidently known and more comprehensive QC tests are applied.

5.1.1 Primary Variables

The sashevis.b1 and sashenir.b1 datastreams report the following hyperspectral measurements of irradiance in units of W/(m^2 nm):

- direct_horizontal_zzz: direct solar irradiance incident on a horizontal planar surface
- direct_normal_zzz: direct solar irradiance at normal incidence
- diffuse_hemisp_zzz: diffuse hemispheric irradiance on a horizontal planar surface
- total_hemisp_zz: total solar irradiance = direct horizontal + diffuse hemispheric

Where "zzz" stands for "vis" or "nir" for the corresponding spectrometer file.

The sashemfr.b1 datastream reports analogous quantities for the closest pixel match to the MFRSR nominal filter wavelengths of 415 nm, 500 nm, 615 nm, 673 nm, 870 nm, and 915 nm.

The sashevisaod.c1 and sashenirαod.c1 datastreams (produced by the SASHe AOD VAP) report primary measurements of:

- diffuse_transmittance
- direct_normal transmittance
- aerosol_optical_depth.

The transmittance fields may be converted to irradiance by multiplying by the solar spectrum (included in the aod file) and dividing by the square of the earth-sun distance (also included). The direct normal component may be computed from the direct horizontal by dividing by the cosine of the solar zenith angle (included).

5.1.1.1 Definition of Uncertainty

The SASHe measurement is fundamentally a self-referential measurement of atmospheric transmittance obtained by extrapolating the measured irradiance signal at the surface to an idealized "top of atmosphere" value. Irradiance units are reported by multiplying the transmittance by a reference source for top-of-atmosphere solar irradiance after correcting for the earth-sun distance, which varies over the course of the year. Ultimately, the uncertainty in the SASHe measurements is limited by the stability of the instrument response at any given time (mainly statistical), the stability over several weeks (the period over which the calibration is derived), the stability of the atmosphere at a given wavelength (since this constrains our ability to extrapolate surface measurements to top of atmosphere), and the accuracy of the reference source for top-of-atmosphere solar irradiance. Based on examination of time series of top-of-atmosphere calibrations (which necessarily compound uncertainties due to instrument instability and atmospheric effects), the SASHe irradiances or atmospheric transmittances have typical uncertainties on the order of 1% and typically exhibit medium-term variability at less than 1% per day.

When the SASHe irradiances are used to compute optical depths for atmospheric components such as aerosol optical depth or cloud optical depth, only ratios of the irradiances are required so the accuracy of the reference source divides out.

5.1.2 Secondary/Underlying Variables

Solar ephemeris quantities (solar elevation, solar azimuth, air mass) are computed according to the geographic location and time in Coordinated Universal Time (UTC).

5.1.3 Diagnostic Variables

The SASHe systems record a number of housekeeping parameters including the temperature and RH of the collector (near ambient conditions), the data acquisition equipment (located indoors), and the spectrometers (located inside a chilled refrigerator fed with dry air); local atmospheric pressure; and the tilt of the sky collector with respect to level. These are variables that monitor the health of the SASHe.

5.1.4 Data Quality Flags

Data quality flags are generated for almost 20 of the diagnostic variables and secondary variables. The Quality Control (QC) flags follow standard ARM conventions.

The sashe aod files include comprehensive QC for the aerosol optical depth, direct and diffuse transmittances, and atmospheric pressure (required for AOD).

5.1.5 Dimension Variables

The hyperspectral SASHe “vis” and “nir” data files contain time and wavelength dimensions, while the “sashemfr” data files contain only a time dimension.

5.2 Annotated Examples

Figure 3 shows measured direct (top panel) and diffuse (bottom panel) transmittances for April 3, 2015 at SGP when the first half of the day was overcast and the second half clear. Overcast conditions show near-zero direct normal transmittance (sun is blocked by clouds) in conjunction with non-zero diffuse transmittance showing little variation in wavelengths (clouds are spectrally flat). Clear sky shows significant direct normal and diffuse transmittance, both exhibiting pronounced wavelength dependence.

Figure 4 shows the wavelength dependence of diffuse transmittance for overcast conditions at 16:30 UT and clear sky at 21:00 UT for the same day as Figure 3. The clear sky diffuse transmittance (blue line) shows clear wavelength dependence with larger diffuse transmittance at short wavelength and smaller diffuse transmittance at longer wavelengths. The cloudy sky diffuse transmittance (red line) shows less systematic wavelength dependence since clouds appear spectrally flat and more or less gray or white. The shape of the clear sky (blue) diffuse transmittance is dominated by molecular scattering while the wavelength dependence of overcast (red) diffuse transmittance reflects that of the underlying surface. Note, however, the increase in diffuse transmittance above 720 nm due to brighter surface albedo below. This observation is the motivation behind the sub-cloud areal averaged surface albedo VAP currently under development for the MFRSR, but having clear application to the SASHe as well.

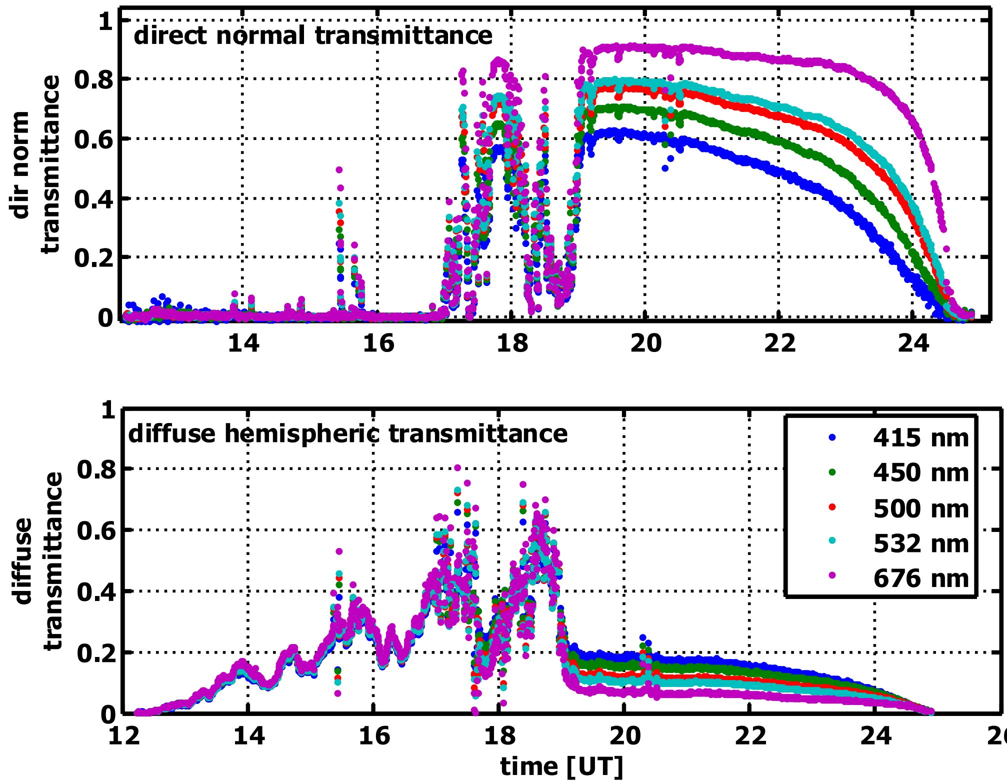

Figure 3. Direct normal (top) and diffuse (bottom) transmittance at SGP, April 3, 2015.

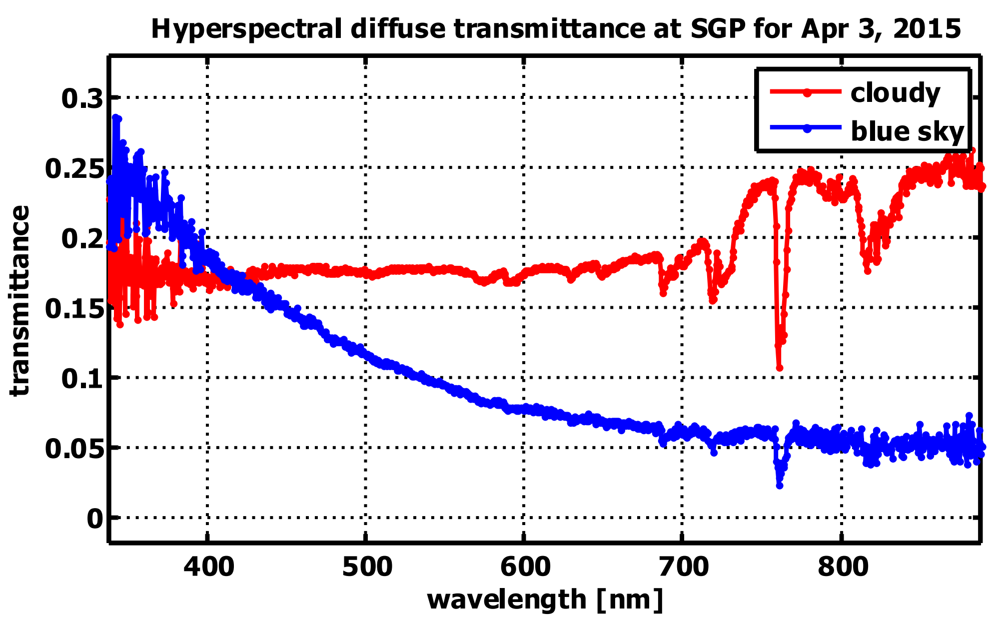

Figure 4. Clear sky (21 UT) and cloudy (16:30 UT) diffuse transmittance spectra exhibit sharply difference wavelength dependence.

5.3 User Notes and Known Problems

5.3.1 Limitations of Langley Analysis

The ARM Program employs on-site Langley calibration of MFRSR and SASHe systems. This approach requires modification for spectral regions where water vapor or other strong absorbers display non-linear curves of growth and thus fail to generate linear Langley regression curves. Even after application of a modified Langley, there will be spectral regions for which it is impossible to apply Langley calibration. An alternative is to augment the Langley calibrations with lamp-derived spectral responsivity measurements. This approach is planned for FY16.

5.3.2 Temperature response of Spectralon

Spectralon is known to exhibit temperature sensitivity for transmittance. Because Langley calibrations are conducted as the sun is rising or setting fairly rapidly, these times also correspond to periods when ambient temperature is changing fairly rapidly. Although the active heating is applied to the SASHe Spectralon button from within the sky collector, it is nonetheless possible for temperature changes to yield instrument artifacts.

5.3.3 Shading by AOS mast at AMF1 MAO

During morning in fall and spring at MAO, the AOS mast casts a shadow over the SASHe. There is no solution for this besides avoiding time periods when the SASHe is shaded and the direct normal is near zero and does not track the direct normal from the MFRSR.

5.4 Frequently Asked Questions

There are no FAQs at present.

6.0 Data Quality

6.1 Data Quality Health and Status

Data Quality for the SASHe will be available from the following web site maintained by DQ Hands: http://dq.arm.gov/

6.2 Value-Added Procedures and Quality Measurement Experiments

The SASHe Langley VAP computes Langley regressions of log (direct normal irradiance) versus airmass to extrapolate top-of-atmospheric calibrations. An example of a good Langley regression for several pixels from the SASHe is shown in Figure 5 below.

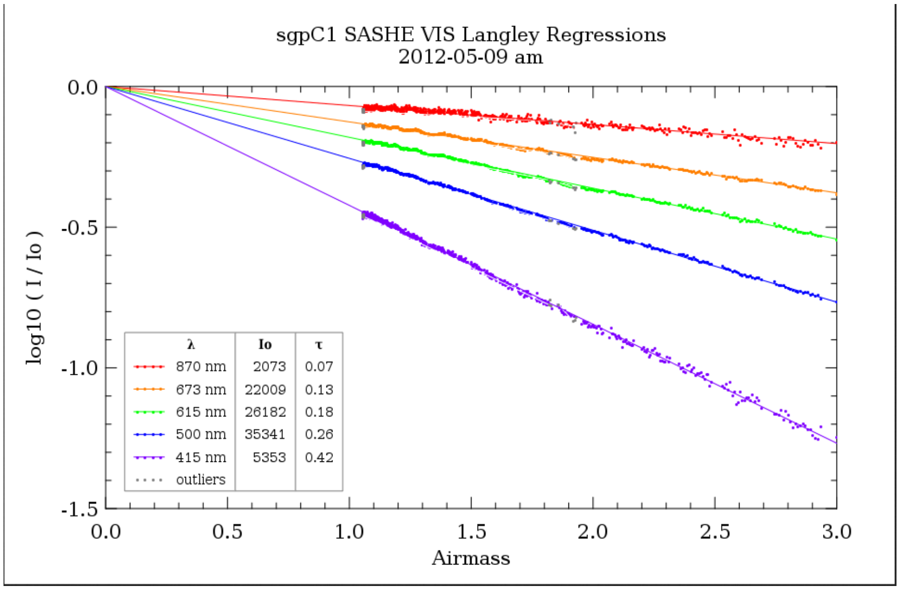

Figure 5. Langley regression for selected SASHe VIS pixels at SGP 2012-05-09.

The SASHe AOD VAP determines robust calibrations from the Langley analysis for those pixel wavelengths free from strong molecular absorbers, and applies these robust calibrations to yield atmospheric transmittance and cloud-screened aerosol optical depths. An automated quick look plot showing cloud-screened AOD measured at PVC on Aug 4, 2012 is shown in Figure 6.

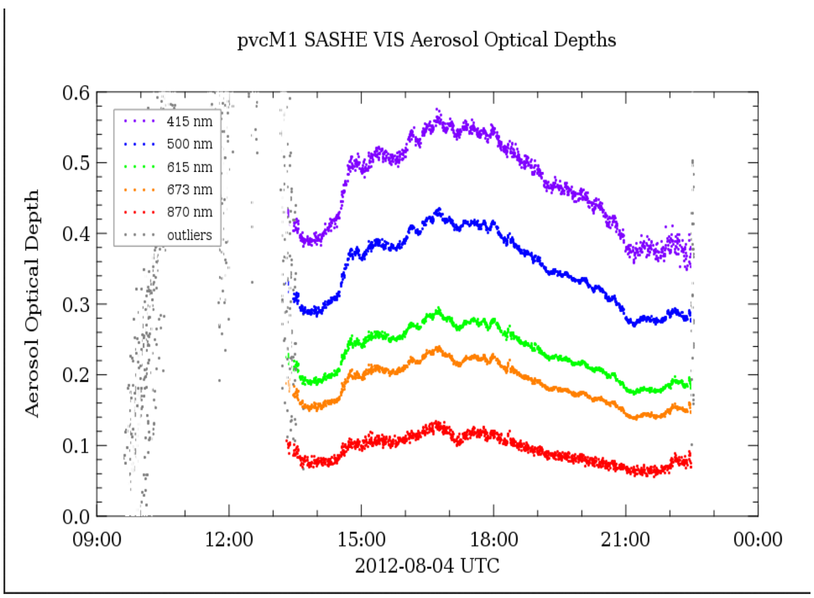

Figure 6. Time series of cloud-screened AOD for selected SASHE VIS pixels.

7.0 Instrument Details

7.1 Detailed Description

The SASHe and the related Shortwave Array Spectroradiometer–Zenith (SASZe) instruments share numerous design elements as listed in Figure 7. The sky collection optics of the SASHe are based on the design of the MFRSR and Rotating Shadowband Spectroradiometer (RSS) spectral shadowband instruments. The light collector (illustrated in Figure 8) uses an 8-mm-diameter Spectralon button as a hemispheric diffuser along with an 8-in.-radius, ½-in.-wide shadowband to separate direct solar irradiance and diffuse sky irradiance. The data acquisition electronics and spectrometers include an in-line, fiber-optic shutter (for automatic dark signal correction) and two Avantes fiber-coupled grating spectroradiometers within a temperature-controlled container. The Avantes Avaspec ULS 2048 charge-coupled device (CCD) spectrometer covers the wavelength range from about 300-1100 nm with a pixel spacing of less than 0.6 nm and a spectral resolution of about 2.4 nm FWHM. The Avantes Avaspec NIR256-1.7 spectrometer covers the wavelength range from about 950 nm to 1700 nm with a pixel spacing of less than 4 nm and a spectral resolution of about 6 nm FWHM.

The optical collector includes active heat control with Minco heating tape. An umbilical containing a fiber optic and electrical cables connects the sky collection optics to rack-mounted data acquisition equipment and fiber-coupled spectrometers located inside a climate-controlled building. The spectrometers themselves are housed within a small refrigerator thermostatically controlled to +/- 1°F and supplied with dry air to keep relative humidity inside the refrigerator well below condensing levels.

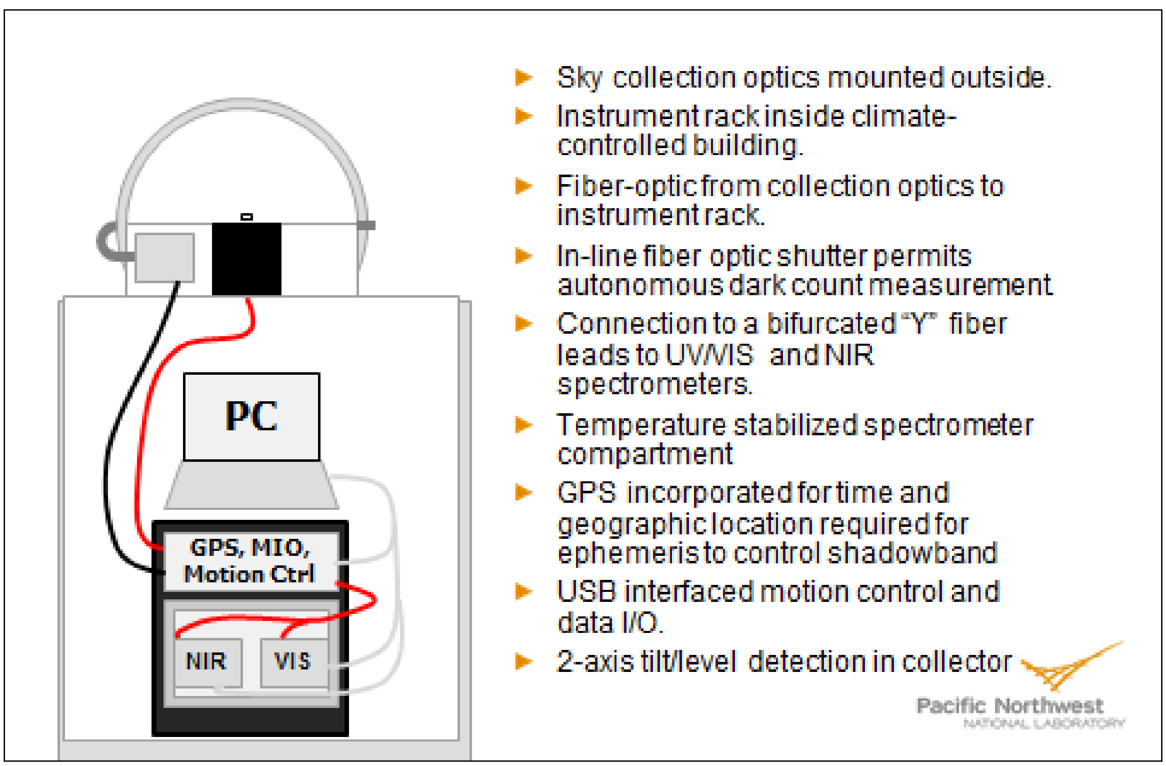

Figure 7. SAS instrument layout concept.

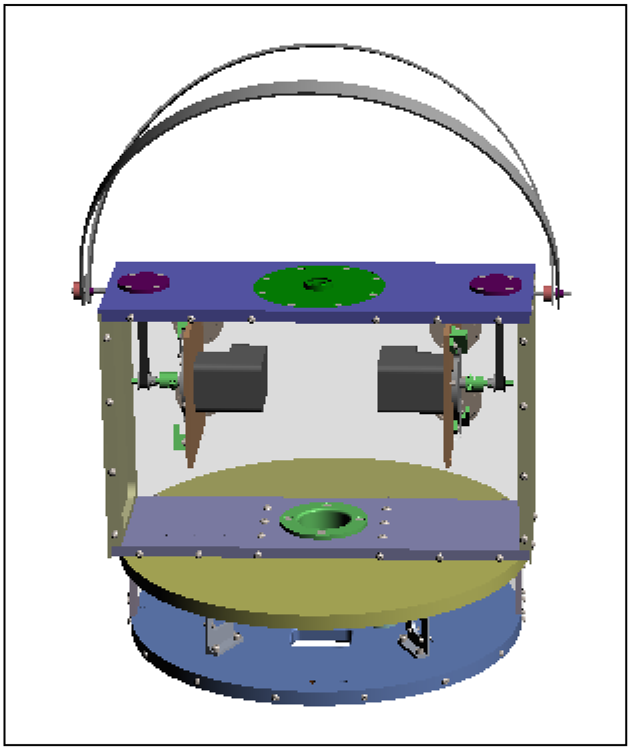

Figure 8. SASHe Sky Collector implementation with two shadowbands.

Figure 8 shows the SASHe Sky Collector with two shadowbands. Current deployments use one band only. The diffuser is at the center. The fiber-optic cable attaches directly beneath the diffuser.

7.1.1 List of Components

- Custom-machined 8-mm-diameter Spectralon button
- 16-in.-diameter shadowband with ½-in. width
- Low-OH-silica-fiber, 600-um core for transmission from 350-2500 nm
- Avantes FOS-1 inline fiber-optic shutter
- FONT custom fiber-optic Y-splitter: 600 um to two 300-micron arms
- Spectrometers:
  - Avantes Avaspec ULS 2048 CCD Si array
  - Avantes Avaspec NIR256-1.7 linear InGaAs array
- A laptop running the latest Windows operating system (initially WinXP; currently Windows 7)
- NiDAQ for analog/digital conversion and measurement control
- A Universal Serial Bus (USB) interface between the computer and the spectrometers
- M-Drive stepper motor for motion control of azimuth Thorlabs rotary stage
- M-Drive stepper motors for independent control of up to two shadowbands; only one currently used

7.1.2 Specifications

Wavelengths Measured:

2048 channels Si (300-1100 nm)

256 channels for the InGaAs (900-2200 nm)

Instrument Field of View: Hemispheric FOV. Shadowband subtends a full-angle of about 3.6 ° or about 1.8° in scattering angle when centered on the sun.

Sampling Interval: The shadowband cycle takes about 30 seconds to complete. The SASHe does not collect data before sunrise or after sunset.

Integration Time: The integration times for each spectrometer are adjusted by site and over the course of the year to approach the spectrometer dynamic range while avoiding saturation. However, irrespective of the specific integration times used, the data acquisition software averages as many individual spectra as possible within a given 1-second interval.

7.2 Theory of Operation

Photons incident on the collimator at the fore optics of the light collector travel through the large, single-core optical fiber through the in-line shutter to a 50/50 bifurcated Y-fiber that diverts the signal equally to the visible (VIS) and near infrared (NIR) spectrometers. Within each spectrometer, the light is spectrally dispersed by a diffraction grating and focused onto a solid-state linear detector array. The array is then read by an electronic interface that passes the data to the computer via a USB connection. Dark signals are obtained periodically at the same integration time that was used to measure the intensity, by closing the in-line shutter.

By coordinated operation of the spectrometers with the shadowband (described below), it is possible to isolate diffuse hemispheric irradiance from direct solar irradiance, and potentially to obtain detailed information about the intensity and width of the forward scattered lobe.

7.3 Measurement Sequence

The basic SASHe shadowband measurement sequence is illustrated in Figure 9.

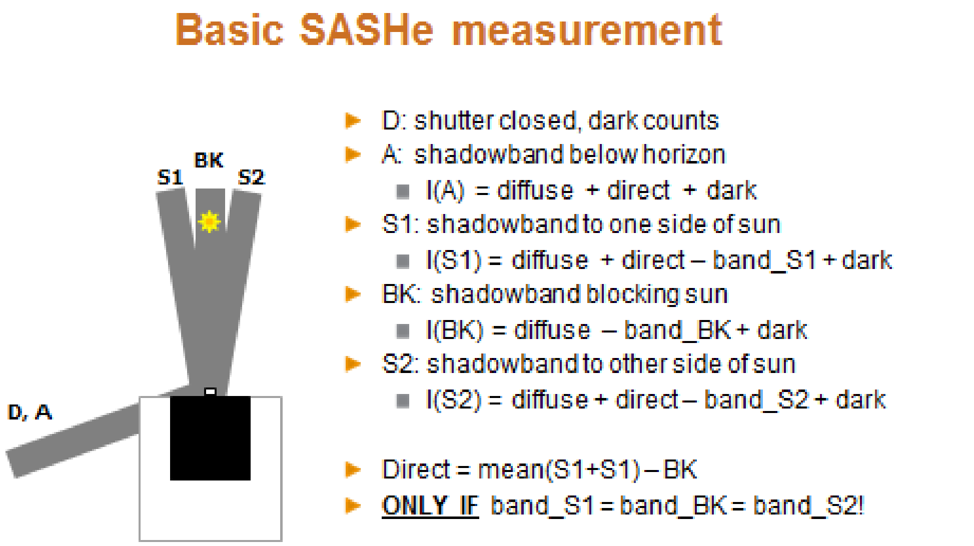

Figure 9. Basic SASHe shadowband sequence.

Step 1: The sequence starts with the shadowband below the horizon and the shutter closed to collect dark signal for 1 second.

Step 2: Then, with the shadowband still below the horizon, the shutter is opened to collect measurement A for 1 second. In this position, with the shutter open, the diffuser is exposed to the diffuse sky PLUS direct beam PLUS dark counts.

Step 3: The shadowband moves to position S1 so that the shadow falls just to one side of the diffuser and collects spectra for 1 second. The signal collected in this band position is the direct beam PLUS the diffuse sky PLUS dark counts MINUS that thin strip of sky covered by the band.

Step 4: The shadowband moves to position BK with direct beam completely blocked and the shadow centered on the diffuser; spectra are collected for 1 second. The signal collected in this position is the diffuse sky PLUS darks MINUS the small strip of sky blocked by the beam.

Step 5: Finally, the shadowband moves to position S1 and collects spectra for 1 second with the shadow just to the opposite side of the diffuser. The signal collected in this position is again the direct PLUS the diffuse sky PLUS dark counts MINUS the strip of sky blocked by the band.

Elementary subtraction of spectra BK from the mean of the side-band positions S1 and S2 yields the raw direct horizontal signal, but only under stable conditions where the sky covered by the band in all three positions—S1, BK, and S2—is equivalent.

7.4 Autonomous Data Processing and Standard Corrections

In conjunction with the shadowband operation, further processing of the raw signals is necessary to obtain proper irradiance components.

Step 1. Isolate the raw direct solar contribution incident on a horizontal surface.

dir_horz_raw = (S1 + S2)/2 – BK

Step 2. Isolate the raw diffuse hemispheric component from the total hemispheric (measurement A from shadowband sequence above) by subtracting dir_horz_raw and dark signal.

dif_hemisp_raw = total_hemisp –dir_horz_raw – dark

Step 3. Apply "cosine correction" to the raw direct component to account for angular dependence of the diffuser and collection optics to produce the correct direct solar: dir_horz_corr.

dir_horz_corr = dir_horz_raw * cos_corr

Step 4. Apply "diffuse cosine correction" to the raw diffuse hemispheric component.

dif_hemisp_corr = dif_hemisp_raw * dif_cos_corr

Step 5. Compose corrected total hemispheric as the sum of dir_horz_corr and dif_hemisp_corr.

Total_hemisp_corr = dir_horz_corr + dif_hemisp_corr

Step 6. Compute direct normal irradiance from direct horizontal.

dir_norm_corr = dir_horz_corr / cos(sza)

7.5 Expanded SASHe Shadowband Sequence

The expanded SASHe shadowband sequence differs from the basic sequence principally in that it includes a slew measurement where spectra are collected while the band is stepped across the solar disk in small increments and the shadow is scanned across the diffuser. Potentially, this sequence provides more information by scanning the near-sun scattered light. The SASHe system at SGP has operated in this mode for limited periods of time; data exists at the ARM Data Archive, but has not been processed into netcdf. Interested users should contact the mentor for access to this special data set.

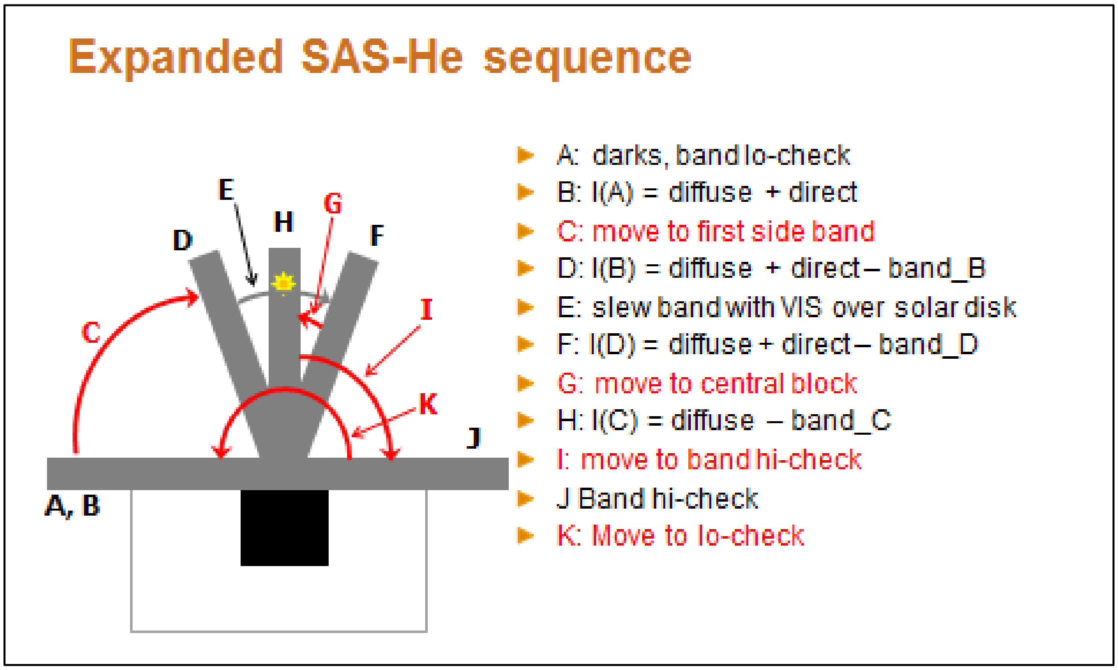

Figure 10. Expanded SASHe shadowband sequence with slew across solar disk (sequence E) to provide information on band alignment and the forward scattered lobe.

7.6 Calibration

7.6.1 Theory

Several aspects of the SASHe require careful characterization and/or calibration.

1. Spectral registration, mapping pixel number to wavelength. The vendor provides a pixel-to-wavelength mapping. We have confirmed the vendor pixel map is accurate to within a pixel using discharge lamps and discrete laser lines.
2. Spectral resolution. In addition to the pixel-to-wavelength mapping, the vendor also provides the spectral resolution for each spectrometer. We have nominally verified these vendor-supplied values based on the observed spectral shape of discrete line sources.
3. Internal stray light within the spectrometers. Figure 11 shows results from a measurement of internal spectrometer stray light determined by scanning a double-slit monochromator positioned in front of a broadband light source over the spectral range of the spectrometer. Except for a few isolated "hot pixels," the stray-light levels are below 0.1 to 0.01% over most of the spectral range.

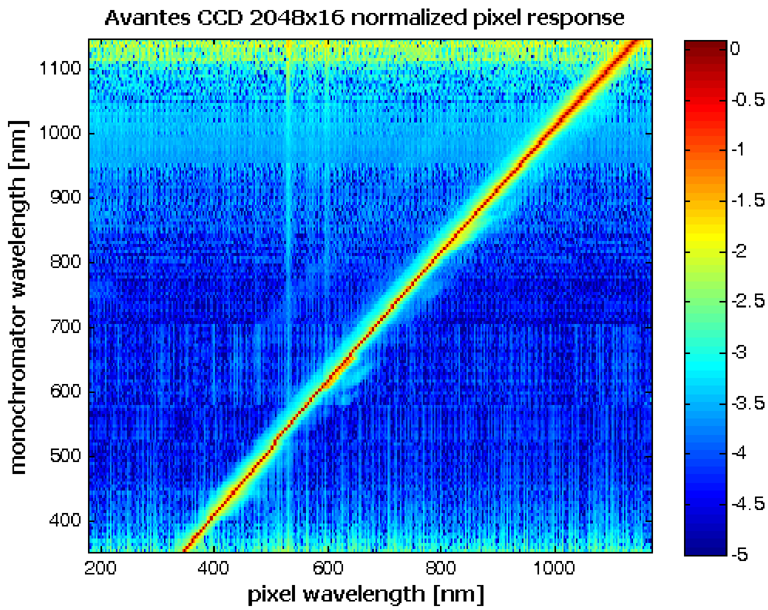

Figure 11. Example of spectrometer internal stray light measurement.

In Figure 11, the horizontal axis is the wavelength reported by the grating spectrometer. The vertical axis is the source wavelength provided by the scanning monochromator. The color scale is log-based 10, so a value of -3 is 0.1% intensity of stray light relative to the peak signal intensity.

4. External stray light (for example, direct sunlight) leaking through the fiber-optic jacketing. By exposing and shading the collector under direct solar exposure, we have confirmed that external stray light is at negligible levels.

5. Spectrometer signal linearity. By varying incident light levels and integration times, we have documented the linearity for each grating spectrometer. The nonlinearity is small, though not negligible. We are evaluating corrections for robustness. These have not yet been incorporated in current processing.

6. Spectrometer temperature sensitivity. The CCD spectrometers show temperature response less than 0.1% per degree. The InGaAs spectrometers show higher temperature sensitivity but this is mostly in thermal background levels that we address through frequent dark measurements. We have also identified that the InGaAs spectrometers show a trough in their temperature response, so we operate our chiller centered on this minimum in temperature sensitivity rather than at the coldest temperatures that would yield the lowest darks.

7. Spectrometer polarization sensitivity. Grating spectrometers and off-axis reflectors have intrinsic sensitivity to linear polarization orientation. We have measured the polarization sensitivity of the optical train end to end, and confirmed sensitivity to 100% polarized light at below 1% as shown in Figure 12 below.

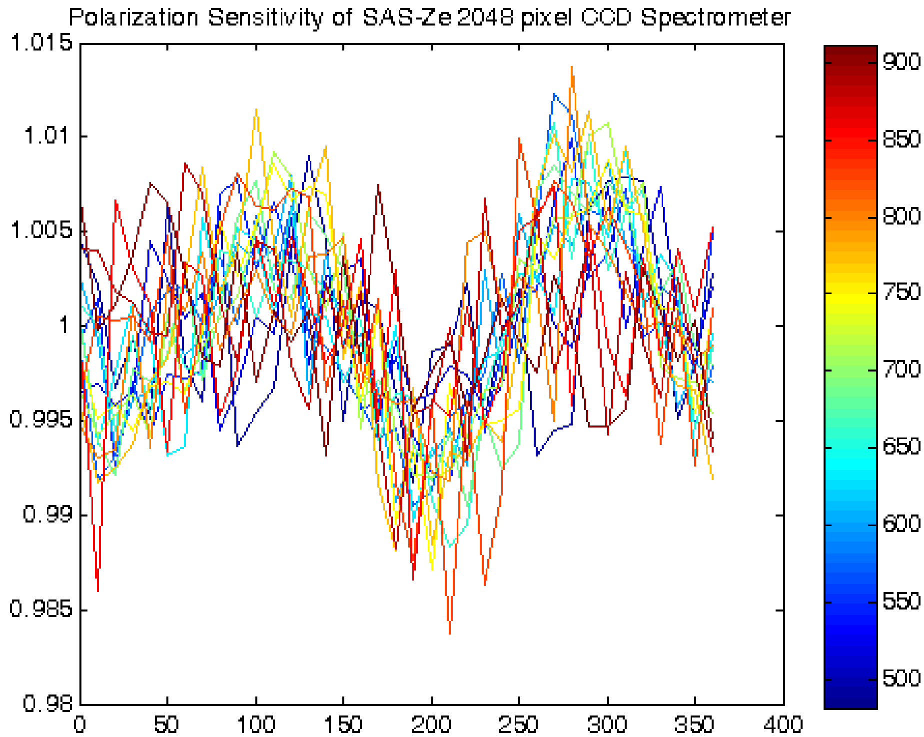

Figure 12. Polarization sensitivity of SASZe collector type "b" to 100% linearly polarized light.

8. Spectrometer spectral responsivity. The SASZe systems receive annual end-to-end radiance calibration by reference against integrating spheres at the National Aeronautics and Space Administration (NASA)'s Ames Research Center or Goddard Space Flight Center (GSFC) that have each been calibrated according to National Institute of Standards and Technology (NIST) standards. The absolute accuracy of the spectral radiance of these reference standards is typically between 1-2% depending on wavelength. The absolute accuracy for the SASZe can certainly be no better than the calibration of the reference spheres. However, in practice, differences between similarly calibrated radiometers have been observed to be as large as 10%. These discrepancies are a topic of current research, but it is evident that the uncertainty in the absolute radiance calibration is not the dominate term.
9. Cosine correction. The angular response of the diffuser is carefully characterized in lab measurements. The derived cosine correction is applied to the direct beam measurements, and a variant of the cosine correction is also applied to the diffuse field.
10. Langley calibration. Extrapolation of Langley regressions of the log (dir_norm) versus airmass to the zero-airmass intercept provides an estimate of top-of-atmosphere "Io" calibration values for spectral elements where strong absorbers do not contribute significantly. However, even in these selected cases, these day-to-day Io values are not statistically robust, mainly due to atmospheric variability during the Langley regression.
11. Lamp calibration with a NIST-traceable broadband light source presents a means of extending calibrations to spectral regions where strong absorbers preclude Langley calibration. This approach has been demonstrated in the literature.

7.7 Operation and Maintenance

7.7.1 Installation and Operation Procedures

Once installed by the mentor, the SASHe system is designed for autonomous operation. When the system is provided with power, the computer will autostart and will automatically begin to collect spectra according to defined schedules. The system requires daily cleaning of optical surfaces. In addition, it requires a supply of desiccant and/or dry air to keep optical surfaces free of condensation. Robust network connection is important, as is a reliable time server, in order to compute accurate solar ephemeris data.

Several documents have been prepared and provided for installation and operation of the SAS-Ze:

- Leveling and alignment of the SAS Instrument.docx
- Adjusting Band Physical Limits.docx
- FlexCouplerReplacement_figures.pptx
- Replacing Band Motor.docx.

7.7.2 Routine and Corrective Maintenance Documentation

Daily, weekly, and monthly preventative maintenance procedures have been developed with on-site support staff. Mostly these procedures entail routine inspection and cleaning of optical surfaces, confirmation of housekeeping measurements falling in nominal ranges, and confirmation of the action of the shutter and appearance of spectra.

7.7.3 Additional Documentation

None available for this instrument.

8.0 Glossary

See the ARM Glossary (http://www.arm.gov/about/glossary.stm)

9.0 Acronyms

See the ARM Acronyms and Abbreviations. (http://www.arm.gov/about/acronyms.stm)

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