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Portable Radiation Package (PRP) Instrument Handbook

RM Reynolds

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Acronyms and Abbreviations

A	Ampere
AC	alternating current
ADC	analog-to-digital
AMF	ARM Mobile Facility
ANL	Argonne National Laboratory
AOD	aerosol optical depth
ARM	Atmospheric Radiation Measurement
ASCII	American Standard Code for Information Exchange
BNL	Brookhaven National Laboratory
bps	bits per second
C	Celsius
CDU	Control Data Unit
COG	course over ground
CRC	Cyclic Redundancy Checksum
DAQ	data acquisition
DC	direct current
dia	diameter
DOE	U.S. Department of Energy
EMI	electromagnetic interference
ESRL	Earth System Research Laboratory (NOAA)
FOV	field of view
FRSR	fast-rotating shadowband radiometer
ft	foot
g	gram
GPS	Global Positioning System
Hz	Hertz
IP	Internet Protocol
IT	information technology
LAN	local area network
lwh	length-width-height
mA	milliampere
MFR	multifilter radiometer
MLO	Mauna Loa Observatory (NOAA)
mm	millimeter
mv	millivolt

NASA	National Aeronautics and Space Administration
nm	nanometer
NMEA	National Marine Electronics Association
NOAA	National Oceanic and Atmospheric Administration
PC	personal computer
PIR	precision infrared radiometer
PRP	Portable Radiation Package
PSP	precision spectral pyranometer
PVC	polyvinyl chloride
QA	quality assurance
RAD	radiometer analog-to-digital
RF	radio frequency
RFI	radio frequency interference
RMS	root mean square
R/V	research vessel
aec	second
SGP	Southern Great Plains
SIMBIOS	Sensor Intercomparison for Marine Biological and Interdisciplinary Ocean Studies
SOG	speed over ground
Tbd	to be determined
TCM	tilt compass sensor
TCP	Transmission Control Protocol
UHMW	ultra-high-molecular-weight polyethylene
UPS	uninterruptible power supply
UTC	Coordinated Universal Time
UV	ultraviolet
V	Volts
VDC	Volts direct current
W	Watt
YES	Yankee Environmental Systems

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1.0 General Overview

The Portable Radiation Package (PRP) was developed to provide basic radiation information in locations such as ships at sea where proper exposure is remote and difficult, the platform is in motion, and azimuth alignment is not fixed. Development of the PRP began at Brookhaven National Laboratory (BNL) in the mid-1990s and versions of it were deployed on ships in the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility's Nauru-99 project. The PRP was deployed on ships in support of the National Aeronautics and Space Administration (NASA) Sensor Intercomparison for Marine Biological and Interdisciplinary Ocean Studies (SIMBIOS) program. Over the years the measurements have remained the same while the post-processing data analysis, especially for the FRSR, has evolved.

This document describes the next-generation Portable Radiation Package (PRP2) that was developed for the DOE ARM Facility, under contract no. 9F-31462 from Argonne National Laboratory (ANL). The PRP2 has the same scientific principles that were well validated in prior studies, but has upgraded electronic hardware. The PRP2 approach is completely modular, both in hardware and software. Each sensor input is treated as a separate serial stream into the data collection computer. In this way the operator has complete access to each component of the system for purposes of error checking, calibration, and maintenance. The resulting system is more reliable, easier to install in complex situations, and more amenable to upgrade.

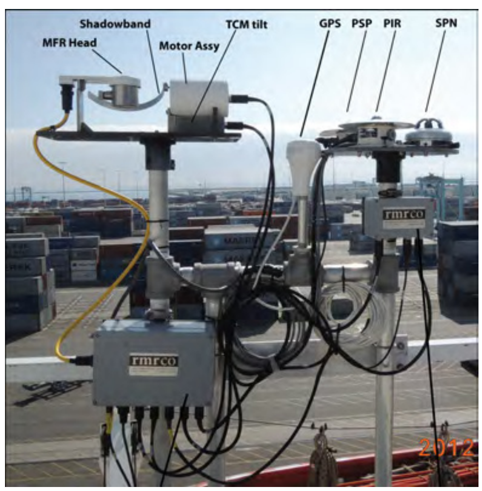

Figure 1. The Portable Radiation Package (PRP) installed on the motor vessel *Horizon Spirit*.

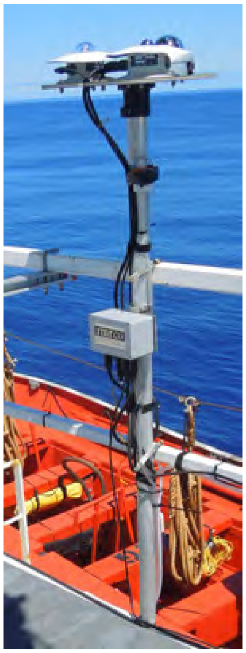

Figure 2. The second radiometer system, RAD2.

Seven independent hardware modules: GPS, TCM, SPN1, RAD1, FRSR, RAD2, and SPN2

Eight separate data streams: GPS, TCM, ADC, SPN1, RAD1, FRSR, RAD2, and SPN2.

1.1 Hardware Modules

Each of the hardware modules here are described in more detail in Sections 7 and B.

- GPS: A global positioning system (GPS) provides latitude, longitude, speed over ground, and course over ground for post-processing calculations.
- TCM: A tilt-compass (TCM) sensor is mounted with the FRSR and measures the pitch and roll of the MFR head.
- SPN1: The SPN sensor (model name SPN-1) measures total and diffuse solar irradiance. It has both an analog and a serial output. SPN1 is located adjacent to the CDU and connects directly to it. Both the analog (see ADC above) and serial outputs are recorded by the data acquisition system.
- RAD1: There are two radiometer analog-to-digital converters (RADs) that convert the microvolt analog signals from PSP and PIR radiometers to physical units. RAD1 is located adjacent to the CDU and connects to it directly.

FRSR: A novel fast-rotating shadowband radiometer (FRSR) operates on the same principle as the MFRSR without the need for precise leveling and azimuthal alignment. Using a standard MFR head, direct beam radiance, diffuse and global irradiance, and aerosol optical depth (AOD) are estimated for six 10 nm shortwave bands (415, 500, 615, 680, 870, and 940 nm).

- RAD2: As a hedge against irradiance errors from shadows, a second RAD and SPN combination was added to the PRP2 system. RAD2 was modified with a small serial server (ICP tiny) so it can be located elsewhere as long as a connection to the system local area network (LAN) is possible.
- SPN2: A second SPN1 sensor was combined with the RAD2. The serial output from the sensor is connected to the serial server in the RAD2.

1.2 Serial Streams

Each of the above sensors has a serial stream that is delivered either to the main serial server hub or the secondary serial server, hub, in the RAD2 enclosure.

- GPS: The 4800 bps NMEA0183 datastream from the GPS module.
- TCM: The output of the TCM, tilt-compass, 9600 bps.
- ADC: An eight-channel, 16-bit, analog-to-digital (ADC) converter is included in the CDU. The two analog voltages from SPN1 are measured. The remaining six analog channels are spare.
- SPN1: The SPN1 has a serial as well as an analog output.
- RAD1: The RAD serial output, 19200 bps RS232.
- FRSR: The FRSR circuit board is located in the CDU enclosure. The MFR head channels, motor control, etc. are controlled by this board and the serial, 38400 bps, output goes to the hub.
- RAD2: The standard RAD serial, 38400 bps, output is connected to the secondary hub.
- SPN2: The second SPN1 serial output is connected to the secondary hub in RAD2.

2.0 Mentor Contact Information

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3.0 Vendor/Developer Contact Information

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MFR head calibration

4.0 Measurements Taken

Table 1. PRP past and current deployments.

ID NAME	LOCATION	START	END	DESCRIPTION
MAG12	NE Pacific	2012-09-22	2013-01-06	*MV Horizon Spirit*, Legs 2-9, Honolulu to Long Beach
BLD13	Boulder, Colorado	2013-05-03	2013-05-03	NOAA Earth System Research Laboratory (ESRL) comparison.
MAG13	NE Pacific	2013-05-26	2012-09-26	*MV Horizon Spirit*. Legs 11-19. RAD2 was deployed for three legs.
SGP14	N. Oklahoma	2014-08-04	2014 tbd	ARM SGP. System burn-in and preparation for next deployment.
MLO14	Hawaii	2014 tbd	2012 tbd	(Planned) NOAA MLO validation and Langley calibrations.
RHB15	NE Pacific	2015 tbd	2015 tbd	(Planned) NOAA *R/V Ron Brown*, Honolulu to Long Beach.

5.0 Links to Definitions and Relevant Information

http://www.arm.gov/data/datastreams/prp

5.1 Data Object Description

https://engineering.arm.gov/tool/dod/showdod.php?Inst=mfrsr&View=user

5.1.1 Manuals and Engineering Information

http://www.rmrco.com/prod/prp2/PRP2.html for online parts list.

5.1.2 Data Plots

Up to this time the PRP2 is not yet a certified ARM instrument and so there is no site for real-time data graphical presentation. PRP data are available as part of the data reports for several field projects. Some are listed above.

5.2 Data Ordering

http://www.arm.gov/data

5.3 Data Plots

http://www.archive.arm.gov/arm/armql.jsp?id=prp

5.4 Data Quality

The following link goes to current data quality health and status results.
http://dq.arm.gov/

The tables and graphs shown contain the techniques used by ARM's data quality analysts, instrument mentors, and site scientists to monitor and diagnose data quality.

5.5 Calibration Data Base

The PRP quality assurance (QA) and calibration records are currently in development.

6.0 Technical Specifications

6.1 System Specifications

As shown by Figure 3, the full PRP 2 system comprises five different components, called "modules." The modules are integrated by a serial server hub, located in the CDU, and Ethernet network. Data collection is provided by a multitasking Linux environment running independent data collection processes for each module.

Table 2. PRP System Specification.

PRP2 part number**	10
Power	10-18 VDC Current = 200mA normal with 3-sec pulses to 2 A when the MFR head heater is on.
Communication	Ethernet connection to the host LAN.
Components	Four main components: FRSR plate, RAD1 (with SPN1). RAD2 (with SPN2), and the Control Data Unit (CDU).
Temperature	Storage: -20 to 80 °C Operating: 5 to 50 °C
Cables	See Figure 3. The complete system is interconnected with nine cables. C3–CDU to RAD1. C4–CDU to MFR head. C5–CDU to TCM tilt sensor. C6–CDU to FRSR motor. C7–CDU to GPS. C8–CDU power input. C9–CDU Ethernet. C10–CDU to SPN1. C13–RAD2 to SPN2 and power. C14–Ethernet RAD2 to host LAN.
Packing	The entire system is packed in three Hardigg Storm cases. The system should be disassembled to individual components that are wrapped carefully to reduce shock damage. See Section 10.1.

** Parts List Online. A complete parts list with photographs, schematics, and manuals to all of the PRP2 is available at http://www.rmrco.com/prod/prp2/PRP2.html. The parts list is checked and updated regularly.

6.2 GPS Technical Specifications

The GPS, the Garman Model GPS17X (or the 16X) is an embedded receiver and an antenna. Internal flash memory allows the GPS to retain critical data through power failures. The receiver is set up for NMEA 0183 GPRMC sentences.

Table 3. GPS specification.

PRP2 part number	10.10 and 10.11
Model	Garman model GPS17X or GPS 16X
Physical	Size: 96.1mm diam. x 49.5mm height Weight: 201 g Case: white molded plastic, waterproof to IEC 60529 IPX7 (immersion in 1 m of water for 30 minutes).
Power	8-33 VDC. 40 mA 12 VDC
Communication	RS232, 4800 bps, 8-n-1 Packed out NMEA 0183
Operating Temperature	20 to 80 °C
Range	Defined by GPRMC specification; see below.
Accuracy/Uncertainty	Typically ± 10 m
Sensitivity	Typically 2 m

An example is:

```
 ID    hhmmss Q  LAT       H      LON     H  SOG  COG    MMddyy VAR   CHK
$GPRMC,235734,A,2454.6144,N,14926.8757,W,017.3,066.8,150613,011.1,E*69
```

The fields are defined by http://www.codepedia.com/1/The+GPRMC+Sentence

6.3 TCM Technical Specifications

The Precision Navigation Inc. TCM2.5 (see http://www.pnicorp.com/products/tcm-legacy is a 3-axis orientation sensing instrument that provides:

- Tilt compensated compass heading. The heading is accurate even when tilted over a 50° tilt range due to precise electronic gimbaling or tilt compensation.
- Precise tilt angles relative to Earth's gravity, known as the pitch and roll angle. Pitch angle is also known as elevation or dive angle. The roll angle is sometimes also called the bank angle.
- Data is output on a standard RS-232 serial interface at 1 Hz with a simple text protocol.

Table 4. TILT-Compass (TCM) specification.

PRP2 Part Number	10.01.03.02
Model	Precision Navigation Inc. model TCM2.5
Physical	Circuit board lwh = 50.8 x 63.5 x 10.7 mm. weight=20 g. Enclosure: lwh = 125 x 80 x57 mm. Mounted on the FRSR plate.
Power	6-18 VDC typ< 20 mA.
Communication	RS232, 0600 bps, 8-n-1 Output format is explained in the TCM manual.
Tilt range	±50°
Sensor tilt accuracy	0.2 °RMS
Operating temperature	-20 to 70 °C
At-sea uncertainty	Typically 1-min mean ±0.2°

The TCM provides the pitch and roll measurements that are used in calculating the solar beam angle relative to the MFR head in the FRSR. They are also used to correct the precision spectral pyranometer (PSP) measurements of shortwave irradiance. At sea, the 1 Hz measurements are a mixture of wave-induced horizontal accelerations and true tilt. However, the horizontal accelerations are sinusoidal and are removed by the 1-min averages. The final data processing focuses on 1-min averages and for this reason the tilts are considered to be accurate.

6.4 RAD1 and RAD2 Technical Specifications

The Radiometer Analog-to-Digital interface (RAD) (see http://www.rmrco.com/prod/rad/) provides a robust, highly accurate conversion from shortwave and longwave radiometers to a calibrated serial string in physical units. The RAD enclosure is mounted near the PSP and precision infrared radiometer (PIR) sensors to avoid electronic noise issues. The overall uncertainty of the RAD (10 sec average) is less than a few tenths Wm^{-2} for either longwave or shortwave irradiance estimates. Thus RAD makes a negligible contribution to the overall measurement uncertainty.

Table 5. RAD specification.

PRP2 part number	10.08
Model	Radiation analog-to-digital (RAD) interface, Model 200
Physical	Enclosure: lwh = 160 x 100 x 81 mm
Power	9-16 VDC. Typ < 10 ma.
Communication	RS232, 19200 bps, 8-n-1 NMEA-like output format is explained in the RAD manual.
Analog inputs	Shortwave: ±8 millivolts Longwave: ±2 millivolts Thermistor: YSI 46006 or equivalent, 0-50°C
Amplifier gain	Shortwave: x 125 Longwave: x 840
Computed irradiance	Accuracy: < 1% Uncertainty: < 1 Wm^{-2}
Temperature	-20 to 70 °C

It is almost impossible to place radiometers on ships so that they are free from shade. Antennas, masts, and other obstacles will shade the radiometers on occasion. For this reason it is essential to make radiation measurements from two locations so at least one radiometer will be fully exposed. RAD1 is the name given to the RAD module that is co-located with the PRP 2. RAD2 (or RA2) is the name given to the RAD module that is located at a second site.

6.5 SPN1 and SPN2 Technical Specifications

The Delta-T SPN1 measures global (total) and diffuse radiation in one instrument without a shadowband mechanism. It uses an array of seven miniature thermopile sensors and a computer-generated shading pattern to measure the direct and diffuse components of the incident solar radiation. The shading pattern and thermopiles are arranged so that at least one thermopile is always fully exposed to the solar beam, and at least one is fully shaded from it, regardless of the position of the sun in the sky. All seven thermopiles receive an equal amount of diffuse light. The computer calculates the global and diffuse horizontal irradiance.

Table 6. SPN1 Sensor specifications.

PRP2 part number	10.08
Model	Delta T Devices Ltd. Model SPN1
Physical	IP67 Enclosure, Size 126 mm dia x 94 mm h. Weight + 786g
Power	Electronics: 5-15 VDC 2 mA Heater: 12-15 VDC up to 1.5A (not connected in PRP2)
Communication	Serial output: RS232, 9600 pbs, 8-n-1 Analog output: 0-2500 milliamps (1 ma + 1 Wm^{-2})
Range	0-2000 Wm^{-2}
Resolution	0.6 Wm^{-2}
Operating Temperature	Operating -20 to 70¨C
Uncertainty	This sensor is currently under evaluation.

Features:

- Output total and diffuse irradiance in Wm^{-2}.
- No routine adjustment or polar alignment.
- No moving parts, shade rings, or motorized tracking.
- Works at any latitude.
- RS232 and analog output.

The module named SPN1 is mounted on the radiometer plate with the PSP and PIR and co-located with the main PRP2 system. The module named SPN2 (or SP2) is mounted with the RAD2 system at the second location

6.6 FRSR Technical Specifications

Table 7. Fast-rotating shadowband radiometer (FRSR) specification.

PRP2 part number	10.01
Model	Remote Measurements & Research Co. FRSR500
Physical	Radiometer plate: 470 x 200 mm, weight + 3.5 kg approx.. Circuit board: lwh = 250 x 100 x 20 mm approx.. weight + 400 g CDU Enclosure: lwh = 280 x 180 x 101 mm
Power	6-18 VDC typ < 20 ma
Communication	RS232, 9600 bps, 8-n-1 Output format is explained in the PRP2 manual.
Operating temperature	0 to 70 °C
Measurement range	0-3500 mv, after FRSR preamp, depending on channel
Accuracy/uncertainty	± 1 mv
Sensitivity	Approx.. 2 mv

The output of the MFR head is amplified by the seven-channel FRSR preamp. The preamp gains are adjusted so in full sunlight the 12-bit ADC for all channels will be nearly full scale. Typically a full-scale reading will be about 3700 mV. The FRSR measures global and sweep voltages in millivolts and these values are recorded. Langley calibrations are performed in millivolts. Lamp calibrations are converted to equivalent millivolts using the end-to-end derived linear fit.

7.0 Instrument System Functional Diagram

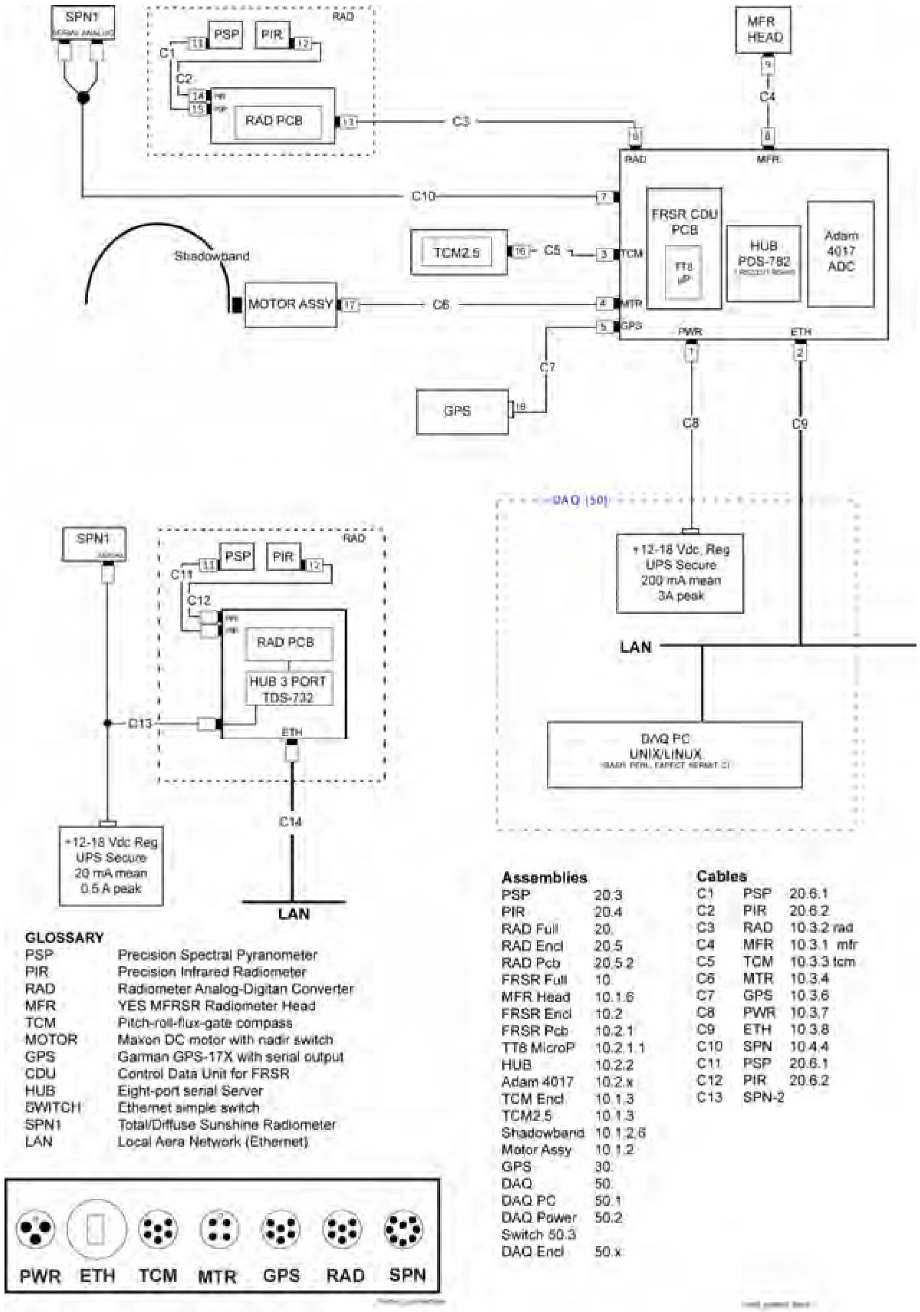

Figure 3. System interconnection.

8.0 Instrument/Measurement Theory

8.1 Basic Concepts

A sun photometer measures the directional solar irradiance in discrete wavelength channels along a vector from the instrument detector to the solar disk. The atmosphere both absorbs and scatters light along this vector, and these effects are treated together through the mass extinction cross section, k_λ (Liou 1980). Because the different scattering and absorbing processes may be assumed to be independent of each other, the total extinction coefficient is a simple sum from all the contributors:

$$k_\lambda = k_A + k_R + k_O + k_N\,, \qquad (1)$$

where the terms on the right represent the mass extinction cross sections, as a function of wavelength, for aerosol scattering, Rayleigh scattering, ozone (O_3) absorption, and nitrogen dioxide (NO_2) absorption.

A parallel beam of radiation, denoted by its irradiance, I_λ, will be reduced in the direction of its propagation by an amount given by

$$dI_\lambda = -k_\lambda \rho I_\lambda \, ds, \qquad (2)$$

where k_λ is defined by (1), ρ is the air density, and ds is the differential path length. If k_λ is constant, the classical Beer-Bouguer-Lambert law results:

$$I_\lambda(s_2) = I_\lambda(s_1) e^{-k_\lambda u}, \qquad (3)$$

Where $u = \int \rho ds$ is called the optical thickness or optical path and integration proceeds along the path the ray takes from s_1 to s_2.

In the atmosphere $k\lambda$ and ρ are not homogeneous and so the full integration of (2) is required. A reasonable approximation is that the atmosphere is horizontally stratified, and this allows integration of (2) along the vertical axis, z, in a coordinate system on the Earth's surface. Then $ds = \sec\theta\, dz$, and

$$I_\lambda(h) = I_{\lambda T} \exp\left(-\int_h^\infty k_\lambda\, \rho \sec\theta\, dz\right), \qquad (4)$$

where $I\lambda(h)$ is the irradiance at the observer at height h above sea level, and $I\lambda T$ is the irradiance at the top of the atmosphere. Integration follows the ray in its refracted path through the atmosphere and, for completeness, must include the curvature of the Earth.

In the case that $k\lambda$ is constant through the air column, as in Rayleigh scattering, it can be moved outside the integral. In the cases when it is non-uniform in the column, as for aerosol, O_3, and NO_2, an effective extinction coefficient can be defined. The resulting effective total extinction coefficient is given by $\tilde{k}\lambda = \tilde{k}_A + k_R + \tilde{k}_O + \tilde{k}_N$ and is defined by

$$\int_h^\infty k_\lambda \, \rho \sec\theta \, dz = \tilde{k}_\lambda \int_h^\infty \rho \sec\theta \, dz = \tau_\lambda \left[\frac{\int \rho \sec\theta \, dz}{\int \rho \, dz} \right] . \tag{5}$$

The terms with tildes are effective mean values that produce the same extinction if uniformly distributed through the atmosphere. The bracketed fraction is defined as the air mass, $m(\theta)$ and is a function of the zenith angle, θ. When the solar beam is normal to the geoid, $m = 1$, the normal atmospheric optical thickness (AOT) is defined as

$$\tau_\lambda = \int_h^\infty k_\lambda \, \rho \, dz = \tilde{k}_\lambda \int_h^\infty \rho \, dz . \tag{6}$$

The resulting formulation for the irradiance becomes

$$I_\lambda(h) = I_{\lambda T} \, e^{-(\tau_A + \tau_R + \tau_O + \tau_N) \, m(\theta)} , \tag{7}$$

which is a working analog to the classical Beer-Bouguer-Lambert equation, (3). Without knowing the vertical and horizontal distribution of the different contributing attenuators, (7) serves as definition of the optical thicknesses which must be derived by observation of the extinction of the solar beam through the atmosphere.

The instantaneous solar irradiance at the top of the atmosphere, I_T, is the solar constant modulated by the Earth-Sun distance, $I_{\lambda T} = I_{\lambda 0}/r^2$, where $I_{\lambda 0}$ is the mean solar irradiance at the top of the atmosphere and r is the ratio of the Earth-sun distance to its mean value (Paltridge and Platt 1977):

$$r = 1 \dot{-} \epsilon \cos\left(a \left[J - 4\right]\right) , \tag{8}$$

where $\in = 0{:}01673$ is the eccentricity of orbit, and J is the day of the year (sometimes referred to as the Julian day). The r^2 correction results in an annual modulation of $I_{\lambda 0}$ of approximately 6%. This is comparable to an uncertainty of about 5% in the measured solar spectrum (see Colina et al. 1996) (Figure 15).

The air mass, $m(\theta)$, is a function of the path of the ray through the atmosphere. When refraction and the Earth curvature are ignored, the simple equation $m = sec\ \theta_T$, where θ_T is the solar zenith angle at the top of the atmosphere, can be used. This approximation is accurate to within 1% when $\theta_T \leq 70$_. Kasten and Young (1989) include both curvature and refraction into a formulation of air mass and use the ISO standard atmosphere for density and index of refraction. They use an index of refraction profile at 700 nm for all wavelengths and then fit the computations to an empirical curve,

$$m(\theta_r) \approx \frac{1}{\cos\theta_r + a \, (b - \theta_r)^{-c}} , \tag{9}$$

where θ_r is the solar zenith angle at the observer, in radians, $a = 0{:}50572$, $b = 96{:}07995$, and $c = 1{:}364$. A pointing sun photometer locates the solar beam and thus automatically measures θ_r but a shadowband instrument must compute it. The ephemeris algorithm by Michalsky (1988; Spencer 1989) is used to determine θ_r and θ_T given the time and geographic position of the observer, and including refraction and curvature.

In (7), the last three normal optical thickness terms can be determined by a combination of measurements and theory. Raleigh scattering is well understood and τ_R can be computed by theoretical formulation. Tables of Rayleigh scattering coefficient, using the relationships from Penndorf (1957), were computed for each channel wavelength and for the atmospheric pressure at the time of the measurement with an empirical equation:

$$\tau_R = \left(\frac{p}{p_0}\right) \left[a_1\lambda^4 + a_2\lambda^2 + a_3 + a_4\lambda^{-2}\right]^{-1} \qquad (10)$$

where (a_1; a_2; a_3; a_4) = (117:2594; –1:3215; 0:00032073; –0:000076842), p is the atmospheric pressure in hPa at the time of the measurement, p_0 = 1013:25 hPa, and λ is the wavelength in μm.

The ozone optical thickness can be computed from measurements of the ozone distribution or inferred from known ozone climatology. The ozone corrections used in this paper are quite small and were provided by NASA (Menghua Wang 1999, personal communication).

8.2 Theory of Shadowband Radiometers

The multi-frequency rotating shadowband radiometer (MFRSR), developed by Harrison et al. (1994) uses independent interference-filter-photodiode detectors and an automated rotating shadowband technique to make spatially resolved measurements at seven wavelength passbands. The MFRSR achieves an accuracy in direct normal spectral irradiance comparable with that of narrow-beam tracking devices. A significant advantage of the shadowband technique is that the global and diffuse irradiance measurements can be used to study overall radiative budgets (Long 1996). Our FRSR makes use of the MFRSR principle and the MFR detector head.

The shadowband radiometer must properly measure the global and diffuse irradiances from which the direct beam irradiance is derived by the subtraction

$$V_H = V_G - V_D\,, \qquad (11)$$

where V_H is the direct-beam irradiance projected onto a horizontal plane, V_G is the global irradiance on the horizontal plane, and V_D is the diffuse irradiance from non-forward scattering. Note in the discussion here we refer to the measured voltages, V, but after calibrations these can be converted directly to the filtered irradiances.

The global irradiance, V_G, is measured when the band is out of the field of view and the sensor is exposed to full sunlight. The irradiance normal to the incident beam is computed by

$$V_N = V_H \sec\theta_r . \qquad (12)$$

A correction for the amount of sky that is blocked by the occulting band is essential for an accurate measurement. An automatic correction for the shadowband is possible through measurement of "edge" irradiance as is done with the land-based MFRSR. The shadow irradiance, V_S, occurs when the sun is completely covered by the shadowband, but a portion of the diffuse irradiance is also blocked. The edge irradiance, V_E, is measured when the band is just to one side of the solar disk and provides a good estimate of the global irradiance minus the portion of sky that is blocked by the shadowband at the time it blocks the solar disk. In practice, V_E is selected from two measurements taken when the shadow is on one side or the other of the diffuser. Generally an average is taken, but in some cases in the early morning or late evening only one of the edges is acceptable. It is easy to show that the fully corrected horizontal beam irradiance is

$$V_H = V_E - V_S . \qquad (13)$$

An advantage of using (13) is that with the fast-rotating technique the edge and shadow measurements are made in a very short time, which reduces noise significantly, especially on partly cloudy days. Also, if the electronics have a constant bias, the bias is removed by the subtraction.

8.3 Accounting for Platform Tilt

Three measurement quantities for each channel are derived from each shadow sweep: the global signal, $V^1{}_G$, the shadow signal, $V^1{}_S$, and the edge value, $V^1{}_E$. The primes indicate the measurement is referenced to the plane of the head, which can be different than a horizontal plane. The two global measurements, V_{G1} and V_{G2}, are combined to produce the best-estimate global voltage, $V^1{}_G$. The shadow voltage, $V^1{}_S$, is the instantaneous minimum for the sweep and the edge value is selected using an objective algorithm that accounts for the fact that the width of the shadow depends on solar zenith and relative azimuth. The objective selection uses one or a mean of both edge measurements to get the best estimate of $V^1{}_E$.

The direct-beam irradiance falling onto the plane of the instrument is given by

$$V'_H = V'_E - V'_S . \qquad (14)$$

This equation automatically corrects for the sky that is blocked by the shadowband and also removes any bias term in the calibration equation, (19). An important point in (14) is that the right-hand quantities are measured in a few tenths of a second, while the shadow crosses the diffuser. In such a short time interval the ship attitude changes insignificantly and interference from moving clouds is minimized.

The diffuse component of the solar signal is computed from

$$V_D = V'_G - V'_H , \qquad (15)$$

and as we have stated previously, V_D is relatively unaffected by small amounts of platform motion.

The exact azimuth and elevation of the solar beam relative to the head must be computed from the following externally-measured variables:

$$\{\alpha_h, \theta_h\} = f(\alpha_S, \phi_P, \phi_R, \alpha_r, \theta_r) \tag{16}$$

where $\{\alpha_h, \theta_h\}$ are the solar azimuth angle and solar zenith angle relative to the plane of the head, is the mean heading of the ship in true coordinates, ϕ_P is the ship mean pitch, and ϕ_R is the corresponding mean roll over the two-minute period. The relative solar azimuth and zenith angles in geographic coordinates, as seen by the observer, are α_r and θ_r. Relationship (16) uses three two-dimensional coordinate transformations in heading, pitch, and roll to shift the solar beam vector from an Earth-based coordinate system to a coordinate system aligned with the FRSR head. The matrix transformation technique is well known and discussed in many textbooks on matrix algebra. Once α_h and θ_h are known, the calibration table can be consulted and an interpolated correction value, $\chi(\alpha_h; \theta_h)$, can be derived.

The direct beam irradiance on a horizontal plane relative to the instrument, $V^1{}_H$, is converted to a direct-beam irradiance into a plane normal to the solar beam using the relationship

$$V_N = \frac{V'_H}{\chi(\alpha_h, \theta_h) \cos\theta_h} . \tag{17}$$

The global and horizontal voltages are re-computed for the Earth frame of reference:

$$\begin{aligned} V_H &= V_N \cos\theta_r \quad \text{, and} \\ V_G &= V_H + V_D . \end{aligned} \tag{18}$$

Given V_N and with V_0 derived from Langley calibration, the optical depth r is derived from equation 25 and aerosol optical depth, r_A from equation 27.

9.0 Setup and Operation of Instrument

9.1 Unpacking, ECCN

1. **Remove the MFR head and FRSR head-motor assembly.** Be careful of the MFR head. Be sure the protective cap is covering the head diffuser. Check the FRSR plate assembly to be sure all screws are tight and no damage has occurred in shipment. Screw the MFR head onto the assembly.
2. **Remove radiometers and plate.** Carefully remove the RAD1 and RAD2 radiometer plates. Be sure radiometer (PSP and PIR) domes are covered with soft cloth or optical wipe. Check all bolts and screws. Install the PSP, PIR, and SPN radiometers. Install the shade plates and be sure the #2 screws are screwed in firmly. NOTE: Double-check all radiometer serial numbers and be sure the correct radiometers are mounted on the correct plates.
3. **Mind the head cable.** The MFR head cable is the thick PVC cable with 18-pin Conexal plugs at each end. One end of this cable is marked with tape. This is the shield-connected end that connects to the

CDU box. The MFR cable is delicate and should be treated with care. Do not flex or twist unnecessarily. Set the MFR cable aside and take care of it.

4. **RAD1 box.** Remove the RAD1 box and set aside. Check that all screws and nuts are tight.
5. **RAD2 box.** Remove the RAD2 box and set aside. Check that all screws and nuts are tight.
6. **Remove the GPS.** The GPS and its mounting pipe should be tight and in good condition. Remove and set aside.
7. **Power supply**. The two power supplies are removed and set aside.
8. **Remove the CDU box.** As before, check for damage and loose hardware.
9. **Check for all cables.** The following cables should be in the shipment.

The system is broken down into three Storm shipping boxes (Hardigg Storm Case MN#iM2370, PRP2 PN#10.12). Each of these is carefully wrapped with padding and packed to minimize shock or damage from transit. Radiometers are wrapped with lintless cloth and with special protection for the domes.

EAR99: Note from the ECCN web page: "If your item falls under the jurisdiction of the U.S. Department of Commerce and is not listed on the CCL, it is designated as EAR99. The majority of commercial products are designated EAR99 and generally will not require a license to be exported or re-exported. However, if you plan to export an EAR99 item to an embargoed or sanctioned country, to a party of concern, or in support of a prohibited end-use, you may be required to obtain a license."

9.1.1 Packing List

Table 8. The complete PRP2 system shipping list. ECCN numbers are required for export licenses from US Customs.

```
2014-12-15 mlo14 breakdown pack list

Box 1 -- 28 kg (61.5 lbs)
------------------------------------
PIR/SN# 35836F3 Cal=3.23 -- RAD2       6A002
SPN1-A925 --  RAD2                     6A002
PSP/SN# 34292F3 -- RAD2                6A002
RAD2 mounting hardware for SPN/PSP/PIR
Collar for SPN/PSP/PIR plate
Plate for SPN/PSP/PIR -- RAD2
RAD2 control box                       4A101

Box 2 -- 30 kg (65.5 lbs)
-------------------------------------
MFR head SN# 00374                     6A002
PIR/SN# 33687F3 -- RAD1 3.63           6A002
SPN1/A349 -- rad1                      6A002
PSP/SN# 33941F3 -- RAD1 8.91           6A002
FRSR, Motor Shadow band brackets
FRSR, Motor Shadow band plate
PIR, PSP, SPN plate -- RAD1
Collar for FRSR, Shadow band plate
4 shields for PSP/PIR
Shadow band arm
RAD1 control box                       4A101
Bag of hardware for SPN/PSP/PIR
Collar RAD1 SPN/PSP/PIR plate
FRSR Shadow band motor                 6A002


Box 3 -- 27.5 kg (60.5 lbs)
-------------------------------------
Miscellaneous test cables
SPN power supply, Radio Shack          3A226
   3amp, 13.8 VDC
MFR head spare, SN# 00370              6A002
PRP mounting hardware
Garmin GPS Antenna                     ZA005
MicroTops, Solar Light Co., SN#003695  6A002
MicroTops, Solar Light Co., SN#01????  6A002
Misc hose clamps
Power supply 16V, 3.3 AMP              3A226
PRP2 CDU box                           4A101
Cables: Cat5 (26') Internet cable, power cable,
  FRSR Shadow band motor cable, RAD1
  control box cable, PSP cable, SPN
  cable, PIR cable, FRSR #00374 cable,
  and TCM cable.
```

9.2 Selecting a Deployment Location

In general any deployment on land at an exposed location can be used. Radiometers should be high and all at about the same level. A location in an open area with little or no shadows from nearby trees or structures is good. Especially, clear horizons in the direction of sunrise and sunset is an important consideration.

Shipboard Locations. It is essential to choose the best, most exposed, location on a ship deployment.

With the new Model 2 PRP2 as designed for the second ARM Mobile Facility (AMF2), the RAD2 system can be deployed independently from the FRSR and in a location away from shadows. In this way the best possible unobstructed sky can be obtained.

The following are considerations for deployment on a ship or other confined place:

- Exposed location. Minimal chance for shadows.
- Minimal RF interference and radar exposure.
- Accessible for occasional service such as dome cleaning.
- The RS232 serial connections to the CDU should be less than 200'.
- Note that if the primary interest for the FRSR is measurements of AOD, r, then it can be located in a location where some solar shading might occur. However, the RAD radiometers should be in the "best" exposed location.

9.3 Install the

Figure 1 shows a reasonably good deployment location on the M/V *Horizon Spirit*.

Table 9. Site installation requirements.

	Site Requirements
RAD mounting pole	1 ½-in. (38 mm) Schedule 40 pipe. Mounted vertically in an exposed location. A minimum of shading is critical.
RSR mounting pole	Same as above. Occasional shade is not as critical as for RAD since the FRSR measures the direct solar beam.
GPS mounting pole	GPS17x—A ¾-in. pipe with standard thread, mounted in an exposed location. GPS16x—a flat surface with reasonable exposure.
PC desk	Desk space in an exposed location. The cable distance from FRSR box to the switch should be 65 m (200 ft.) or less.

Secure power	A power supply capable of supplying 13.8 VDC at the FRSR box (after line voltage drop). An uninterruptible supply is essential.

An installation checklist:

1. Align the FRSR plate so the north direction points to north. On a ship the plate should align to the bow. Align to an accuracy of approximately ±5°.
2. RAD radiometers are at the same height as the head diffuser. As a rule any radiometer should not significantly shade the others down to the horizon.
3. GPS unit is exposed so it has good sky coverage (> 80%).

9.4 Connecting the Cables

9.4.1 The MFR head cable and Conxall connectors

As explained above, the head cable construction is not particularly robust so great care should be exercised in handling it. The cheap Conxall connectors profess to be weatherproof but they are not up to the marine environment.

Figure 4. Connection to the MFR head is delicate and must be made with great care.

Figure 4 shows the head cable connected to the head. Several precautions should be observed:

1. Handle the cable carefully. Avoid twisting or bending the cable unnecessarily. Bend the cable in the same way it was bent in previous deployments.
2. The shield in the cable is connected to only one plug–to avoid ground loops–and the connected end is marked by a wrap of electrical tape. This end of the cable goes to the CDU box.

3. Before deployment it is recommended that the plug backshell is properly sealed with self-sealing tape and a cover of Scotch 88 electrical tape. (The electrical tape protects the sealing tape from UV degradation.) This should be done on both ends.
4. Just before plugging in the cable for the last time before a deployment, rub just a dab of silicone grease into the receptacle female holes.
5. When plugging in the connector, be sure the alignment key is correct, press the plug in slowly, and be sure the retaining ring snaps into place.
6. If you expect bad weather, as a precaution, wrap the connector at the box for a complete seal.

9.4.2 Impulse Underwater Mateable Connectors

The PRP2 uses the oceanographic grade, underwater mateable connectors made by Impulse. The Impulse connectors are the best choice for long-term use in the marine environment, or any other environment for that matter. Impulse connectors are immune to solar degradation and can be connected either under water or in rain.

Cold weather difficulty. The only drawback to Impulse connectors is that it is difficult to remove them in frozen conditions. When the temperature falls below 0°C it is hard to make connections and very difficult to remove them. However, a hot air gun can warm up the connectors so they can be removed.

9.4.3 Network Cables

Lengths less than 100 m.

Install Bulgin Baccaneer weatherproof fittings for CDU and RAD2.

Confirm continuity with a CAT5/RG45 tester.

9.5 Grounding, RFI, and Noise Suppression

Grounding is a black art. The purpose of careful grounding is two-fold. First, the equipment must be protected from damaging electric arcs (lightning) and inadvertent surges or drop out in the local power. Secondly, the electronic amplifiers and converters must be shielded from local electronic or magnetic fields to reduce electronic noise in the measurements. This section will describe basic principles and practices to use and it will give a means of verifying that noise contamination is at a minimum. *But it is essential to know that improper grounding can destroy the data, the instrument, or both.*

9.5.1 Grounding between Components

Each connector into the Control Data Unit is protected from electric discharge with tranzorb shunts. Special circuit boards are fitted over each connector so each pin is shunted directly to case ground. Also, capacitors and ferrite beads protect each line from external radio frequency interference (RFI).

The electronic circuit boards maintain a strict distinction between analog ground, digital ground, and case ground (or earth). Only a single connection occurs between analog and digital ground, and inside each electronic box, only a single connection occurs between the electronic ground and case. All RFI protection circuits are connected to case at a single point.

All external cables are shielded and all maintain a constant connection between the shield and the electronic case grounds. The only exception to this is the FRSR head. Therefore, the FRSR head cable shield is not connected to the case at the head. This prevents ground loops.

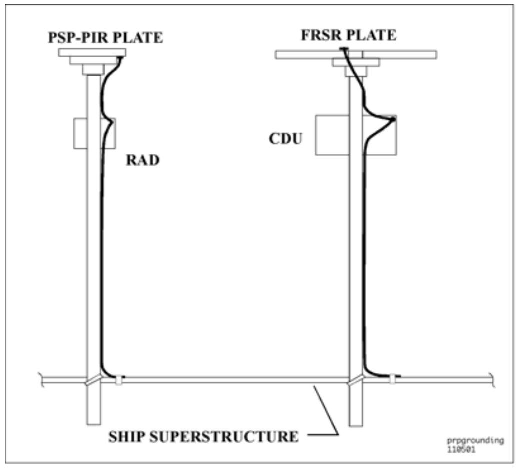

Figure 5. Typical grounding to the ship superstructure.

To be absolutely sure that the case (earth) ground is continuous throughout the entire system, a grounding cable must be connected between the plate, CDU, UPS, and then to the ship superstructure. If necessary, scrape the paint off of the ship superstructure to be sure the earth connection is good.

Use a digital multimeter to measure the resistance between all components. Especially make sure the FRSR head case is common with the ground cable. **The resistance between all components, including the FRSR head and the preamp box, should be less than one ohm.**

9.5.2 How Do I Know the System is Properly Grounded?

The data collection program, PRPRX, displays the one-minute mean and the standard deviation for the Fast Rotating Shadowband Radiometer measurements for each channel. The FRSR data are displayed in millivolts. The global measurements are the mean of the first and last 10 instantaneous analog-to-digital converter readings in each sweep. These represent approximately 14 milliseconds when the shadowband is at each horizon. The displayed data are the mean and standard deviation of the global data points. On a clear day with bright sun, the global means will be on the order of 2000-3000 mv and the standard deviations will be on the order of 5 mv. If there are grounding problems, the standard deviation will be much larger, on the order of 100 mv. When you see this, the grounding must be investigated carefully.

The best figure for noise is to go to the test menu and use the “a¡return¿” command to begin measuring the 12-bit ADC, the FRSR head channels. The display will scroll up the screen. Wait until about 20 measurements are taken, then press the ¡return¿ key. The mean and standard deviation for each channel will be displayed. On a bright, clear day, with the sun overhead the radiation will be very steady and the standard deviations will be on the order of 10-20 mv. If they are much greater, then a better grounding might help reduce them.

9.5.3 Other Grounding Schemes

If the standard grounding scheme, outlined on the previous page, does not yield low noise conditions, some other grounding scheme might be in order. Local conditions might require a different scheme in order to root out ground loops or to properly shield magnetic interference.

Single-point ground to the ship.

This technique was used in one application and resulted in very low noise. (1) Stop the PRP. Turn off the power switch. Remove the power cable from the UPS power in. (2) Use rubber or insulation to isolate the pole from the ship. (3) Remove the ground strap from the ship. At this point, the resistance between the PRP2 and the ship is infinity. (4) Reconnect the power cable. The resistance to the ship now should be ¡ 1 ohm. The power cable shield is grounded through the power supply.

With this technique, there is one and only one ground connection to the ship and this is at the AC power supply.

9.5.4 Grounding and Handling the FRSR Head

1. Be sure the head is always well grounded.
2. Never connect or disconnect the head while the PRP2 is powered.
3. When installing or removing the FRSR head, wear a wrist grounding strap.
4. When removing the head, place it directly into a conductive bag.

9.6 Mentor Preparation of the PC and Software

This section describes how a skilled programmer, preferably the instrument mentor, will prepare the instrument PC and the DAQ software for PRP2 operation.

9.6.1 Network Assignments

Table 10. PRP2 IP numbers. The following table is suitable for a PRP2 using the AMF2 guest module. The IP numbers will vary. These numbers need to be assigned by the IT person in charge. They are programmed into the DAQ software setup file.

Device	Dev IP	Port	Description
PRP2 Hub	198.129.80.48[1]		RS232 or RS485 to Ethernet hub
GPS		10005	External GPS
TCM		10001	Till Compass Sensor
ADC		10001	Adam4017 ADC in the CDU

Device	Dev IP	Port	Description
RAD1		10003	RAD PSP and PIR interface
FRSR		10004	RSR circuit board
SPN1		10004	SPN1 co-located with RAD1
RAD2 Hub	198.129.80.49[1]		RS232 or RS485 to Ethernet hub
RAD2		10001	RAD PRP2 and PIR interface
SPN2		10002	SPN co-located with RAD2
PC or Virtual Machine	198.129.80.47[1]		DAQ computer, PRP2 data collection
Time Server	198.129.80.74[1]		System time server if available

Note (1)—IP numbers are assigned by the project IT engineers.

Currently for AMF2 we use a “virtual machine” (VM), which is a process running on the AMF2 system computer. Generically we will use the term PC to mean whichever computer is being used for the DAQ process.

9.6.2 Check the PC Configuration

The PC must be loaded with all necessary software and configuration files. This section provides a set of commands that will verify that the configuration is correct.

1. Open a terminal session: (1) Turn on the DAQ PC and open a blank terminal window (Unix or Linux).
   OR
   (2)Connect to the system virtual machine (VM) by ssh or an equivalent Windows program.
2. `perl -v` shows perl is loaded.
   ```
   $ perl -v

   This is perl 5, version 12, subversion 4 (v5.12.4)
   Copyright 1987-2010, Larry Wall
   ```
3. `kermit` test if Kermit is loaded.
   The reply is `k>>`.
4. `version` from the `k>>` prompt.
   ```
   k>> C-Kermit 9.0.302 OPEN SOURCE:, 20 Aug 2011...
   ```
5. `quit` to end kermit.
6. `expect -v` Check if Expect is loaded.
   ```
   $ expect version 5.45
   ```
7. Update bashrc if necessary. This needs to be done by a skilled programmer.
   (a) `vi /.bashrc` to open the bashrc in editor.
   (b) Scroll down to position the cursor to the line above "`# PRP2 --`" or the bottom of the bashrc file.
   (c) `dG` delete to the end of the file. This removes all the PRP2 bash content.
   (d) `:r $HOME/swmain/tools/bashrc_prp2.txt` to append the latest PRP2 bashrc.
   (e) Review the complete file and be sure the above commands were correct.
   (f) `:wq` to save and quit vi.
   (g) `bash` will install the bashrc commands. There should be no response. It there is something is wrong.
8. `gtdaq` moves to the DAQ software folder. The prompt will be `~/swmain/apps/PRP2/sw/$` and if this does not occur do not proceed. The bash shell is not running.

9.6.3 Edit the Setup File

The setup file configures the experiment. An example setup file can be found at Appendix A.2. We will assume the current deployment name is "ACAPEX" so we will have a setup file named `su_acapex.txt`.

The setup file is located at `home/swmain/apps/sw/setup/`. You should view and edit the file as described below. Any other text editor can be used; we use vi in the example below. Be sure the IP addresses and hub port numbers (see Table 10) are correct.

1. `gtdaq` moves to the sw folder.
2. `cd setup` move to the setup folder.
3. `ls` Lists the contents of the setup folder.
4. NOTE: if the setup file does not exist it must be created from a previous setup file.
   `cp su_mlo14.txt su_acapex.txt`
   The new setup file will require significant editing.

5. `vi su_acapex.txt` opens the editor. Edit the setup file according to the current deployment.
   - Data entries begin in the first byte with the header, contain a divider ":" followed by the data. Follow the existing setup file.
   - Setup headers are all upper case.
   - Comments are mixed case, have a space in the first position or both. Add as many comments as desired.
6. `:wq` save and quit the editor.
7. `cp su_acapex.txt su.txt` copy the edited setup to the DAQ setup file `su.txt`.
8. Follow the above procedures any time it is necessary to edit the setup. In this way the project setup and the current daq setup are exactly the same.

10.0 Operator Activities

This section is written for general use by trained technicians other than the mentor.

We assume that the instrument is completely installed, cables connected, and it is ready to power up. The PC has been checked; the setup file is edited.

Before doing this section, review the commands and discussion in sections 10.0.5 and 10.0.6.

10.1 Cold Start

1. `gtdaq` moves to the sw folder.

2. `isscreen` to see if a PRP screen is running.

3. IF a screen is running, kill the current data collection. `Stopprp` will kill background screens.

4. PING. If power is on and the ethernet connection to the PRP2 hub is active then a 'ping' command should be successful. Example: `ping 198.129.80.48`.

5. CHECK MODULES Refer to Section 11.0.6 with Table 11 to connect to each module and be sure it is reporting and operating properly. A this point do not open the screen. Work with any terminal window.

   Note: To break any Kermit connection enter "`<control>\`" followed by "`q`". That is first hold down the control key and press '\' then release and press the 'q' key.

   `GPS` to connect to the Garmin GPS.
   Free running, update 1 Hz,

   ```
   $GPRMC,001325,A,4736.1988,N,12217.2811,W,000.1,194.9,200310,018.1,E*6E
   ```

   The fields are UTC time, status, latitude, N/S hemisphere, longitude, E/W hemisphere, speed over ground, course over ground, magnetic variation, and date. Disconnect as described above.

   `TCM` to connect to the TCM tilt sensor.
   Free running, update 1 Hz,

   ```
   $HCHDM,281.3,MP5.5R1.1X-2.64Y21.60Z51.30T31.5*04
   ```

   Fields are Header,compass Magnetic,pitch,roll,XYZ mag field,temperature,checksum. Disconnect as described above.

   `ADC` to connect to the ADC analog-to-digital converter.
   Polled device, enter `#01`,

   ```
   +00.654+00.437+00.347+00.156+00.173+00.080+00.039+00.016
   ```

   Channels 0-7 measured voltage. Disconnect as described above.

   `RAD` to connect to the RAD1 module.
   Free running, 1 Hz,

   ```
   $WIR07,10/03/06,21:02:00, 175, -253.4, 353.69, 19.20, 18.16, 262.54, 17.9, 11.9
   ```

   Fields: Header,UTC date, #samples, pir, longwave, Tcase, Tdome, shortwave, board temp, battery. Disconnect as described above.

`RA2` to connect to the RAD2 module.
Same as RAD. Disconnect as described above.

`SPN` to connect to the SPN1 module.
Polled sensor, enter `R`

```
987.2   23.4   1
```

Fields: Total, diffuse, solar switch. Disconnect as described above.

`SP2` to connect to the SPN2 module.

Same as SPN1. Disconnect as described above.

`RSR` to connect to the FRSR.
THE FRSR sends its data as Bin-Hex packets. The length of the packets depend on whether the FRSR is in a high or low operation mode. Update approx 6 sec.

HIGH-shadow packet:


```
##0357,HC9L0G0n0K2c0T0C0L0P0n0K2c0T0C0L0P000n0n0m0j0g0g0h0g0g0e0d0
d0e0f0g0gg0g0f0i0l0m000J2K2J2E2?2;2?2;29232m1n1n1o112o1021232=2G2J
200c0c0c0‘0^0^0^0^0]0[0Z0Z0Z0[0[0\0[0[0\0_0a0c000T0T0T0R0P0P0P0P0Q
0N0M0N0O0O0O0O0P0O0P0P0Q0S0T000C0C0C0B0A0A0A0A0@0@0@0@00A00A0A00A0B0
C0C000L0L0L0J0I0I0I0I0I0H0H0H0H0I0I0I0I0I0I0J0K0K0000O0P0O0N0L0LL0L
0L0K0K0K0K0L0L0M0M0M0M0N0O0O0O*aX8##
```


HIGH-no shadow packet:


```
##0357,HC9L0G0n0K2c0T0C0L0P0n0K2c0T0C0L0P000n0n0m0j0g0g0h0g0g0e0d0
d0e0f0g0gg0g0f0i0l0m000##
```


LOW packet:


```
##0017,LF9j0D2‘0R0B0J0M0*n5;##
```


These lines should come automatically every six seconds. The lines are decoded and printed by the data acquisition software. Disconnect as described above.

6. <u>Start Data Collection</u>
   If all the above steps are completed successfully, the begin data collection with `StartPrp`.

10.2 Common DAQ Commands

Table 11. A list of shortcuts and aliases for the DAQ software.

TESTING COMMANDS – use to verify system status	
gtdaq	Change directory to the 'sw' software directory.
isscreen	Check if a screen named "PRP" is operating.
ChkDaq	Checks the times from all modules. Returns 1 if all data are no older than 60 seconds, otherwise returns 0.
DaqChk	A detailed check of the incoming data streams.
StopPrp	Stops data collection, closes the current screen.
SCREEN COMMANDS – use during data collection.	
StartPrp	Opens a new PRP screen and starts all module data collection processes. NOTE: Do NOT use this command if a PRP screen is active. Check with 'isscreen' followed by 'StopPrp' if necessary.
gtscreen	Opens PRP screen process.
KillScreen	Kills the PRP screen process, same as `StopPrp`.
ˆa 1	Inside the PRP screen press <control> and 'a' together then release and press the number of the desired window: ˆa 1=GPS; ˆa 2=TCM; ˆa 3=ADC; ˆa 4=SPN1; ˆa 5=RAD1; ˆa 6=FRSR; ˆa 7=RAD2; ˆa 8=SPN2.

10.3 Direct Serial Connection to a Module

Occasionally one needs to make a direct serial connection with a module. As an example we show the steps for connecting to the RAD1 module.

- `gtscreen` opens the screen into one of the eight windows.
- `ˆa 5` opens the RAD1 window.
- `ˆc` stops data collection.
- `RAD` opens a serial connection to the module.
- Do your business with the module. For RAD or RSR enter 'T' to open the menu.
- To end the connection enter `ˆ\ q`.
- Enter `CR` to begin data collection again.

The procedure for all modules is the same with different program names.

Table 12. Screen and Module syntax.

MODULE	SCREEN	DIRECT	RESTART
GPS	^a1	GPS	GG
TCM	^a2	TCM	GT
ADC	^a3	ADC	GA
SPN1	^a4	SPN	GS
RAD1	^a5	RAD	GR
FRSR	^a6	RSR	GF
RAD2	^a7	RA2	R2
SPN2	^a8	SP2	S2
Detatch	^ad		

The call names are listed in the screen window and thus do not need to be memorized.

10.4 Operation Notes

10.4.1 Switching to RSR between Operate and Standby

There may be times, high winds, excess cold or icing, when the user would like to put the RSR into a standby mode. During standby the shadowband is parked in its nadir position.

1. `gtscreen` opens the PRP screen.
2. `^a6` to go to the FRSR window.
3. Press `H`. The FRSR will go to high mode operation and the shadowband will begin to function.
   or
4. `L` to put the FRSR into low mode. The shadowband will stop rotating.
5. `^ad` to detatch the PRP screen.

11.0 Software

11.1 Data File Contents

Raw data are collected from the modules at the following rates:

Table 13. Raw variables and sample rates.

MODULE	RATE	FILENAME	VARIABLES
gps	1 sec	gps_raw	lat,lon,cog,sog,var
tcm	1 sec	tcm_raw	pitch,roll,fgaz,xmag,ymag,zmag,tpcb,batt
adc	1 sec	adc_raw	total,diffuse
spn1	5 sec	spn_raw	total, diffuse
rad1	1 sec	rad_raw	nsamps,pir,lw,tcase,tdome,sw,tpcb,batt
frsr	6 sec	rsr_raw	mode, thead, shrat, 7 global, 23 sweep bins
rad2	1 sec	ra2_raw	nsamps,pir,lw,tcase,tdome,sw,tpcb,batt
spn2	5 sec	sp2_raw	total, diffuse

Raw data files are accumulated for each day. However, the primary data product for irradiance is a one-minute time series. These files are described below. Details of the raw data files are not provided in this handbook.

11.1.1 Primary Variables

The primary variables are those measurements with scientific relevance such as pitch, and irradiance.

Table 14. PRP2 table of primary variables.

QUANTITY	MODULE	VARIABLE	UNITS	INTERVAL	RESOLUTION	VALID MIN	VALID MAX
RAD1							
Shortwave broadband downwelling hemispheric irradiance	prprad	sw	$W\,m^{-2}$	1 min	0.1	-100	1500
Longwave broadband downwelling hemispheric irradiance	prprad	lw	$W\,m^{-2}$	1 min	0.1	200	800
RAD2							
Shortwave broadband downwelling hemispheric irradiance	prpra2	sw	$W\,m^{-2}$	1 min	0.1	-100	1500
Longwave broadband downwelling hemispheric irradiance	prpra2	lw	$W\,m^{-2}$	1 min	0.1	200	800
FRSR — AFTER POST PROCESSING							
Aerosol optical depth (AOD) 415 nm	aod2	aod	—	6 sec	0.001	0	10
Aerosol optical depth (AOD) 500 nm	aod3	aod	—	6 sec	0.001	0	10
Aerosol optical depth (AOD) 615 nm	aod4	aod	—	6 sec	0.001	0	10
Aerosol optical depth (AOD) 675 nm	aod5	aod	—	6 sec	0.001	0	10
Aerosol optical depth (AOD) 875 nm	aod6	aod	—	6 sec	0.001	0	10
Aerosol optical depth (AOD) 940 nm	aod7	aod	—	6 sec	0.001	0	10

11.1.2 Secondary Variables

Table 15. PRP2 table of secondary variables.

QUANTITY	MODULE	VARIABLE	UNITS	INTERVAL	RESOLUTION	VALID MIN	VALID MAX
RAD1							
Standard deviation of `sw`	prprad	stdsw	$W\,m^{-2}$	1 min	0.1	0	500
Standard deviation of `lw`	prprad	stdlw	$W\,m^{-2}$	1 min	0.1	0	100
PIR thermopile voltage	prprad	pir	$W\,m^{-2}$	1 min	0.1	-300	200
Standard deviation of `pir`	prprad	stdpir	$W\,m^{-2}$	1 min	0.1	0	100
PIR case temperature	prprad	tcase	°C	1 min	0.001	-20	80
PIR dome temperature	prprad	tdome	°C	1 min	0.001	-20	80
RAD2							
Standard deviation of `sw`	prpra2	stdsw	$W\,m^{-2}$	1 min	0.1	0	500
Standard deviation of `lw`	prpra2	stdlw	$W\,m^{-2}$	1 min	0.1	0	100
PIR thermopile voltage	prpra2	pir	$W\,m^{-2}$	1 min	0.1	-300	200
Standard deviation of `pir`	prpra2	stdpir	$W\,m^{-2}$	1 min	0.1	0	100
PIR case temperature	prpra2	tcase	°C	1 min	0.001	-20	80
PIR dome temperature	prpra2	tdome	°C	1 min	0.001	-20	80
TCM							
Pitch (bow up)	tcmprp	pitch	°	1 min	0.1	-20	20
Standard deviation of pitch	tcmprp	pstd	°	1 min	0.1	0	20
Roll (port up)	tcmprp	roll	°	1 min	0.1	-20	20
Standard deviation of roll	tcmprp	rstd	°	1 min	0.1	0	20
Flux-gate compass	tcmprp	fgaz	°M	1 min	0.1	0	360
GPS							
Latitude	gpsprp	lat	°	1 min	0.000001	-90	90
Longitude	gpsprp	lon	°	1 min	0.000001	-180	360
Course over ground	gpsprp	cog	°T	1 min	0.1	0	360
Speed over ground	gpsprp	sog	$m\,s^{-1}$	1 min	0.1	0	30
Magnetic variation	gpsprp	var	°	1 min	0.1	-90	90
SPN1							
Shortwave broadband downwelling hemispheric irradiance	spnprp	total	$W\,m^{-2}$	1 min	0.1	-20	1500
Shortwave broadband downwelling diffuse irradiance	spnprp	diffuse	$W\,m^{-2}$	1 min	0.1	-20	500
SPN2							
Shortwave broadband downwelling hemispheric irradiance	sp2prp	total	$W\,m^{-2}$	1 min	0.1	-20	1500
Shortwave broadband downwelling diffuse irradiance	sp2prp	diffuse	$W\,m^{-2}$	1 min	0.1	-20	500
FRSR							
Shadow ratio	da1avg	shrat	—	6 sec	0.1	0	200
Standard deviation of shadow ratio	da1avg	shratstd	—	1 min	0.1	0	200

11.1.3 Diagnostic Variables

Diagnostic variables are typically variables that do not have a scientific value but instead allow for determination of the proper function of the sensors and system components, e.g., battery voltage, error codes, and standard deviations of the primary variables.

Table 16. PRP2 table of diagnostic variables.

QUANTITY	MODULE	VARIABLE	UNITS	INTERVAL	RESOLUTION	VALID MIN	VALID MAX
RAD1							
Internal temperature	prprad	tpcb	°C	1 min	0.1	-20	80
Power voltage	prprad	batt	volts	1 min	0.1	9.0	16.0
RAD2							
Internal temperature	prpra2	tpcb	°C	1 min	0.1	-20	80
Power voltage	prpra2	batt	volts	1 min	0.1	9.0	16.0
FRSR							
Head temperature	rsrprp_avg_engr	thead	°C	1 min	0.1	38	42

11.2 Data for Different Deployments

Table 17. Measurements taken for each deployment.

NAME	FRSR	TILT	GPS	RAD-1	SPN-1	RAD-2	SPN-2	DESCRIPTION
MAG12	y	y	y	y	y	n	n	Good data.
BLD13	y	y	y	y	n	n	n	Good data.
MAG13	y	y	y	y	y	y	y	Good data.
SGP14	y	y	y	y	y	y	y	Good data.
MLO14	y	y	y	y	y	y	y	Good data.
RHB15	y	y	y	y	y	y	y	Good data.

Note: The RAD2 and SPN2 modules were introduced beginning with MAG13.

11.3 Data Acquisition Folders

11.3.1 Raw Data

During system operation, two sets of real-time data folders are produced: ARM and DATA. Both folders have exactly the same data but formatted in different ways.

The ARM data folder has raw and averaged data stored in text files that are created new each hour. The data files are offloaded by the ARM data system as often as possible. For a ship, this is usually during port times when a network link is available.

In the table here the second column is the sample spacing in seconds.

Table 18. ARM raw data files.

PRP2		The top level folder. Usually located in the $home directory.
FILE	T(sec)	DESCRIPTION
suyyMMddhhmmss.txt		Setup file at the time of START
adc_avg_yyMMddhh.txt	60	Hourly file of 1-min averaged data from the ADC module.
adc_hdr.txt		Describes each field (column) of the data files.
adc_raw_yyMMddhh.txt	1	Hourly file of raw data from the ADC module.
gps_avg_yyMMddhh.txt	60	Hourly file of 1-min averaged data from the GPS module.
gps_hdr.txt		Describes each field (column) of the GPS files.
gps_raw_yyMMddhh.txt	1	Hourly file of raw data from the GPS module.
rad_avg_yyMMddhh.txt	60	Hourly file of 1-min averaged data from the RAD module.
rad_hdr.txt		Describes each field (column) of the RAD files.
rad_raw_yyMMddhh.txt	1	Hourly file of raw data from the RAD module.
rsr_avg_yyMMddhh.txt	60	Hourly file of 1-min averaged data from the FRSR module.
rsr_hdr.txt		Describes the FRSR files.
rsr_raw_yyMMddhh.txt	6≈	Hourly file of raw data from the FRSR module.
spn_avg_yyMMddhh.txt	60	Hourly file of 1-min averaged digital data from the SPN module.
spn_hdr.txt		Describes the SPN files.
spn_raw_yyMMddhh.txt	1	Hourly file of raw data from the SPN module.
tcm_avg_yyMMddhh.txt	60	Hourly file of 1-min averaged data from the TCM module.
tcm_hdr.txt		Describes the TCM files.
tcm_raw_yyMMddhh.txt	1	Hourly file of raw data from the TCM module.
ra2_avg_yyMMddhh.txt	60	Hourly file of 1-min averaged data from the RAD 2 module.
ra2_hdr.txt		Describes each field (column) of the RAD 2 files.
ra2_raw_yyMMddhh.txt	1	Hourly file of raw data from the RAD 2 module.
sp2_avg_yyMMddhh.txt	60	Hourly file of 1-min averaged digital data from the SPN 2 module.
sp2_hdr.txt		Describes the SPN 2 files.
sp2_raw_yyMMddhh.txt	1	Hourly file of raw data from the SPN 2 module.

Above 'yy' is the two-digit year, 'yyyy' is the four digit year, 'MM' is the month, 'dd' is the day, 'hh' is the hour of the day, 'mm' is the minute, 'ss' is the second. All time is UTC. As an example, su121005112345 is the setup file at 5 Oct 2012, 11:23:45 UTC.

SETUP FILE. A setup file is part of the data collection software set. A master setup file, `sw/setup/su.txt`, is maintained with the project. This file has all calibration data, operational parameters, thresholds, Ethernet IP address and port numbers, and anything else that is essential to interpret the data collection software. If any changes are made to the operational equipment or to the runtime parameters, it is recorded in the master setup file. The setup file is text and can be edited with `vi` or other editor.

A run-time setup file is created each time data collection is initiated. At the beginning of data collection, the master file setup file is copies to the data directory with the name `suyyyMMddhhmmss.txt`. This run-time setup file must be collected with the raw data files as it is used in final processing.

11.3.2 Processed Data

The text files in the `DATA` folder are accumulated for a time period. The data collection period might be defined as a cruise, or one leg of a cruise in the case of a ship deployment. In a long-term land deployment, the data collection period may be a week or a month. On a regular basis, the collected data are removed for data post-processing and the folders are cleared.

12.0 Calibration

12.1 Laboratory Calibrations

Laboratory calibration is done in two parts: the electronics and the optical head.

Electronic Calibration: CDU end-to-end electronic gains are carefully calibrated using the data collection software and a precision millivolt reference source in place of each radiometer channel.

The FRSR radiometer head comes fully calibrated in the form of three tables.

Lamp Calibration: First is a precision lamp, direct-normal irradiance gain equation with units of mv/ (Wm^{-2}) for the broadband channel and mv/ $(Wm^{-2}nm^{-1})$ for the narrowband channels. These calibration equations are corrected for the individual bandpass spectral responses for the head.

Bandpass Calibration: The second calibration product is the bandpass spectral response for each narrowband channel. Each of the narrowband filters has a bandwidth of approximately 10 nm, and the calibration provides gain figures at 1 nm spacing.

Zenith angle Calibration: Finally, zenith angle correction is measured on two planes, one on a south-to-north plane and one on a west-to-east plane. The zenith angle corrections are determined by holding the head in a tilting fixture under a collimated beam and tilting the head through 180 degrees in one-degree steps from horizon to horizon in each plane.

The electronic gains are combined with the direct-normal head irradiance gains coefficients to make a single calibration equation relating direct-normal irradiance to the electronic measurement in millivolts.

$$I_h = c_1\, v + c_2\,, \tag{19}$$

where I_h is the irradiance which is computed from the measured voltage v and (c_1, c_2) are the calibration constants. In the case of a parallel beam of radiation, the measured irradiance flux into a plane that is parallel to the head surface is given by

$$I_h = \chi(\alpha_h, \theta_h)\, \cos\theta_h \int_0^\infty I_\lambda\, w_\lambda\, d\lambda \,/ \int_0^\infty w_\lambda\, d\lambda\,, \tag{20}$$

where χ is the cosine correction calibration, α_h and θ_h are the beam azimuth and elevation angle relative to the plane of the head, I_λ is the beam irradiance spectrum in a plane normal to the beam vector, and w_λ is the filter bandpass discussed above.

By combining Eq. (19) with (7), the measured voltage for a solar beam becomes

$$v_N = v_T\, e^{-\tau\, m} - \frac{c_2}{c_1}\,\left(1 - e^{-\tau\, m}\right) \tag{21}$$

and as long as the response is linear and the bias term is negligible (i.e. $|c_2/c_1| \ll 1$), one can use the voltage output to measure τ.

Calibration drift in the multi-frequency head has caused a great deal of consternation to the Sun photometer community. Calibration shift is detectable as a change in V_0 as computed by the Langley method. Calibration shift is erratic and quite variable; it can occur suddenly, over a few weeks, or can degrade slowly over months. The 615 and 680 nm channels are most prone to drift though all narrowband channels are suspect. Researchers suspect that the gain drift is due to a shifting bandpass response.

12.2 Calibration Considerations

Photometric instruments measure light through a bandpass filter and so all wavelength dependency must be integrated over the filter bandpass. Each detector has a different response function, $w_i(\lambda)$, where i is the detector (channel) number. Each detector-filter response is calibrated relative to its maximum value at its center wavelength, λ_i, and $w_i(\lambda_i) \equiv 1$. Its values at other wavelengths are referenced to its response at λ_i. The measured irradiance is related to the actual incident irradiance by the integral

$$I_i = \frac{\int_0^\infty w_i(\lambda)\, I_\lambda \, d\lambda}{\int_0^\infty w_i(\lambda)\, d\lambda}, \tag{22}$$

and all references to irradiance as measured by an instrument imply the above weighted mean based on a known bandpass filter response. The bandwidth of the filter is defined as the width of a top hat unity-response function with the same area as the actual response

$$\Delta\lambda_i = \int_0^\infty w_i(\lambda)\, d\lambda\,. \tag{23}$$

In all discussions after this point, the λ-subscript will be dropped unless it is necessary for clarity. All development refers to monochromatic light and wavelength dependency is implicit. The instrument bandpass and its effect on a spectrum of light is also hereafter implied. The discussion below is applied to all channels in the same fashion, and so unless it is necessary for clarity, the i subscript will be omitted.

Taking the natural log of both sides of (7) results in the classic Langley relationship:

$$\ln(I_N) = -\tau\, m + \ln(I_T)\,, \tag{24}$$

where $\tau = (\tau_A + \tau_R + \tau_O)$, and I_N is the measured irradiance of the solar beam referenced to a plane that is normal to the solar beam and excluding all scattered diffuse light. In the Langley method (Shaw 1983; Harrison and Michalsky 1994a) a plot of m versus $\ln(I_N)$ can be extrapolated to $m = 0$ to derive $\ln(I_T)$. The negative of the slope of the line is τ. The Langley method works whenever the skies are perfectly clear, no cirrus or other layers are present, and if τ is constant over the time duration of the observations. In practice, a Langley plot can be produced from about one hour of clear sky in the early morning just after sunrise or late evening just before sunset when $2 < m < 6$ $(60 < \theta_r < 80°)$. All measurements of I_N are plotted on a log-linear plot and a best estimate straight line is fitted to the data. For sites other than ideal calibration locations, such as the Mauna Loa Observatory described below, a median-fitting algorithm provides the best objective fit to the data. Over the ocean, there are almost always clouds on the horizon. In the tropics these are usually high cumulus clouds or cirrus. As a result, Langley plots from ships are rare gems that must be collected whenever they occur.

12.3 Langley Determination Using *V₀*

The voltage output from the MFR head and CDU preamplifiers, V_i, for channel i, is linearly proportional to the filtered incoming irradiance, I_N for that channel, equation 24 can be written

$$\ln(V_N) = -\tau\, m + \ln(V_0)\,, \tag{25}$$

where, for each channel, V_N is the direct-normal measured voltage after correcting for the solar angle to the head normal; τ is the optical depth as above, $m(\theta)$ is the atmospheric mass for the solar zenith angle, θ, and V_0 is the TOA voltage that is determined from an in-field Langley analysis.

Langley plots are constructed as often as possible as a quality assurance tool because they provide an excellent means of detecting calibration changes.

The top-of-the-atmosphere irradiance, I_T, depends on the Sun-Earth separation, but its mean value, $I_0 = I_T\, r^2$, should not change significantly over time. The absolute calibration of the instrument can be compared to the mean reference solar irradiance at the top of the atmosphere, $I_{i\,REF}$, (Colina *et al.*1996) by integrating the reference solar spectrum over the bandpass of the sensor (see Eq. 22) to obtain

$$I_{0\,REF} = \frac{\int_0^\infty w(\lambda)\, I_{REF}(\lambda)\, d\lambda}{\int_0^\infty w(\lambda)\, d\lambda}. \tag{26}$$

In a well-calibrated absolute instrument, $I_0 \approx I_{0\,REF}$. However, as long as the calibration constant, I_0, is constant, as determined from multiple Langley plots, accurate AOT estimates are possible. While many investigators use raw voltages to calibrate their instruments, the extra step of computing I_0 is important since it defines the radiative impact of the aerosol at the surface.

Once V_0 is established for an instrument, (25) is used to estimate aerosol optical thickness for each instantaneous measurement of V_N. After the contributions by Rayleigh scattering and ozone absorption are accounted for, τ_A remains.

$$\tau_A = \tau - \tau_R - \tau_O - \tau_N \tag{27}$$

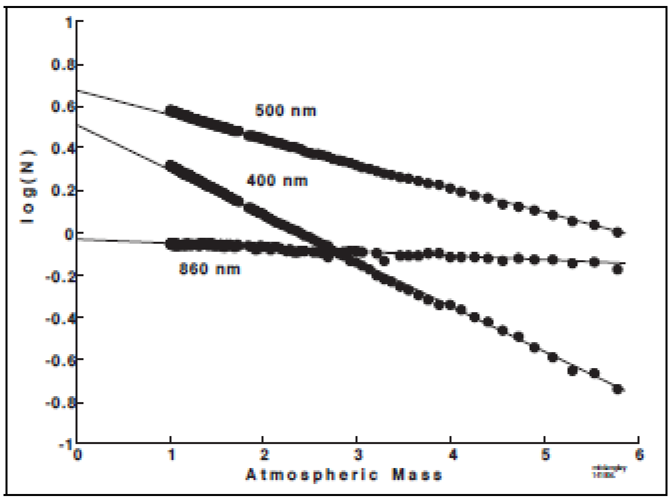

Figure 6. An example of a good Langley plot taken on Mauna Loa (1999, J218). Typically, many days are used to derive a stable V_0 for the seven channels.

13.0 Maintenance

13.1 MFR Head Calibrations

The MFR head is calibrated in exactly the same procedure as used for the MFRSR heads. Calibrations take place at the SGP calibration facility. Three files are produced:

1. Lamp file. Typical name `5E9D_469_std1204_20140805.xls`. Has the response to a calibrated broadband lamp.
2. Angular response. Typical name `MY469.5E9D.20140805163.i`. Gives the relative response of the head to off-normal narrow FOV beam.

3. Specular response. Typical file name: `Vis469_218_2014.1.dat`. Gives the response for each channel to a direct normal fine beam with 0.25 nm steps from 390 to 970 nm.

13.2 Shadowband Motor Assembly

On a regular basis the shadowband motor assembly should be disassembled and given a good preventative maintenance. The main purpose of this procedure is to replace the shaft o-rings and to tighten the shaft set screws if necessary.

The procedure is detailed in Appendix F.

13.3 LokTite, Desiccant, and Anti-seize

As the procedure in section 13.2 makes clear, three things should be in every maintenance toolbox. These are defined in the critical spare parts section, see Table 20.

1. Silicone grease. A good, laboratory-grade, reasonably viscous silicone grease is used on o-rings, to pack connectors, and generally where ever a seal is desired.
2. Blue LokTite. The vibration and accelerations on a ship can cause critical set screws and other fasteners to loosen. Blue LokTite is strong, but can be broken with normal tools and reasonable force. This is a good choice.
3. Anti-seize. A good marine grade anti-seize can be used where fasteners of dissimilar metal, such as stainless bolts into aluminum housings, will corrode and freeze. This is disgusting stuff, but it should be used everywhere, and often.

14.0 Safety

There are no outstanding safety issues associated with the PRP2. No toxic chemicals or radioactive materials are used. Simple professional good practice is sufficient to ensure a safe deployment.

15.0 Citable References

http://www.rmrco.com/docs/pub00 reynolds jtec frsr.pdf —2000: Design, Operation, and Calibration of a Shipboard Fast-Rotating Shadowband Spectral Radiometer, Jtech.

http://www.rmrco.com/docs/pub03 frsr jtech Uncertainty.pdf — 2003: The Accuracy of Marine Shadow-band Sun Photometer Measurements of Aerosol Optical Thickness and A° ngstro¨m Exponent, Jtech.

Appendix A

DAQ System Architecture

This section describes the electronic hardware used in Data Acquisition interface (DAQ). The design is Ethernet TCP/IP based, low power, modular, small, economical, and off the shelf.

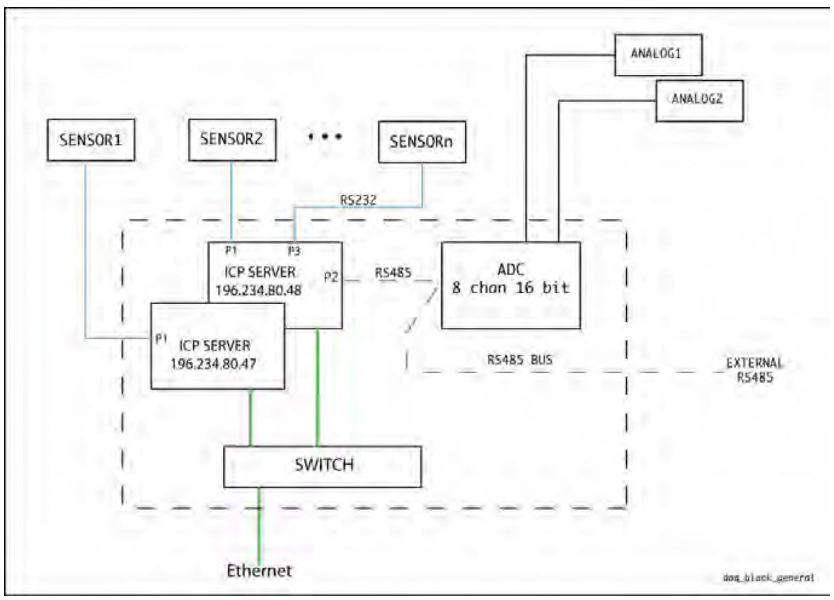

Figure 7. A serial-server-based instrumentation system.

What is the DAQ architecture? Over the past several years the DAQ interface system has been developed and deployed in shipboard applications. The DAQ system provides a completely flexible and expandable interface to analog or serial instrumentation. The key component of the DAQ system is a serial-to-Ethernet hub. Through the hub one has a single point of access to a large number of components. In this way a single program can collect data from any number of sensors, digital or analog. The DAQ software is defined around this hardware paradigm.

What is the serial-to-Ethernet server? The serial server, also called simply the "hub," takes the serial outputs from modern sensors such as GPS, Tilt sensor, FRSR, and RAD and makes them available on a single Ethernet TCP/IP connection. Current DAQ implementations use the ICP PDS-752(D). This device has four serial RS232 and one RS485 connections. If all the four serial ports are occupied one has two options. Either (1) use a network switch to add a second hub or (2) install a different hub model such as the PDS-782(D), which has three additional serial inputs.

How is the RS485 port used? On the ICP hubs, port 2 is dedicated to a RS485 network. RS485 devices are addressable and connected by daisy chain into a multidrop network. Special-purpose modules for analog-to-digital conversion, power relay, and digital I/O can be connected onto the RS485 chain. Thus a single multitasking computer (Unix/Linux) can have complete control of an entire system.

What is the DAQ modular software? For the past several years a script-based software package has been developed for the PRP and other equipment used by RMR Co.

A.1 DAQ Modular Software

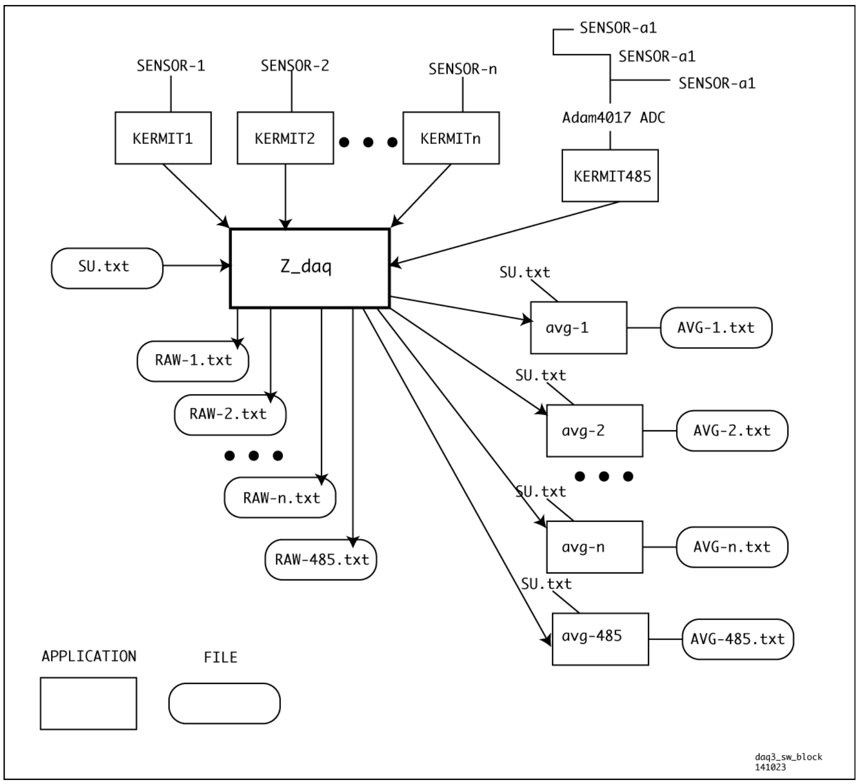

Figure 8, A generic block diagram of the DAQ software.

The core of the software is "`Z_daq`" a program written in the Expect language. Expect is a Unix automation and testing tool, written by Don Libes as an extension to the Tcl scripting language, for interactive applications such as telnet, ftp, passwd, fsck, rlogin, tip, ssh, and others. It uses Unix pseudo-terminals to wrap up sub-processes transparently, allowing the automation of arbitrary applications that are accessed over a terminal."

Serial in/out ports are set up using the "Kermit" software package that was developed at Columbia University. Kermit ports can set up as TCP/IP, ordinary serial, modem, or any of several interface types. The ICP Server has four (or seven) serial RS232 ports and one RS485 port. The RS485 connection can address modules on a 485 network. Other server configurations are available and thus the possible input network is virtually limitless. A setup file, "`su.txt`" defines all the input sensors and any necessary processing parameters.

`Z_daq` keeps track of each input port. When a data string comes in it is appended to file "`RAW-i.txt`" with a time stamp. The raw string is then sent to be processed by the corresponding application "`avg-i`." Statistical averages and any derived variables are written to the text files, "`AVG-i.txt`." Other languages than Perl can be used for the "`AVG-i`"processing programs. Fortran, C, and Python can be included in the DAQ software suite and the "`Z_daq`" Expect program will "spawn" them. A wonderful benefit of this approach is that any of the processing programs can be developed and tested completely off line, then simply introduced via Z_daq. The data files produced by PRP2 are described in Section 11.

A.2 Example Setup File

```
THIS FILE NAME: su.txt
Editdate: 2014 11 19


Data collection PC
#MLO14
PC IP: 192.168.50.230
PC MASK: 255.255.255.0
PC GW: 192.168.50.1
PC DNS1: 72.235.80.4
PC DNS2: 72.235.80.12
TIME SERVER: 72.235.176.150
DOMAIN: mtn.mlo.noaa.gov


   Main serial server
SERIAL HUB URL: 192.168.50.228
SERIAL HUB MASK: 255.255.255.0
SERIAL HUB GW: 192.168.50.1
Secondary hub for RAD2 system with SPN
SERIAL HUB2 URL:  192.168.50.229
SERIAL HUB2 MASK: 255.255.255.0
SERIAL HUB2 GW: 192.168.50.1

RSR 10004, SIMULATE 0
RSR HUB COM NUMBER: 10004
RAD 10003, SIMULATE 0
RAD HUB COM NUMBER: 10003
TCM 10001, SIMULATE 0
TCM HUB COM NUMBER: 10001
ADC 10002, simulate 0
ADC HUB COM NUMBER: 10002
SPN 10006, SIMULATE 0
SPN HUB COM NUMBER: 10006
GPS 10005, SIMULATE -1, FIXED LOCATION 0
GPS HUB COM NUMBER: 10005

RAD2/SPN PACKAGE
RA2 10001, SIMULATE 0
RA2 HUB COM NUMBER: 10001
SP2 10002, SIMULATE 0
SP2 HUB COM NUMBER: 10002


DATA FILES -----SET BY THE START COMMAND
    This file will be set with the START command.
RT OUT PATH: ../data



------- EXPERIMENT SETUP ------------
This section identifies the experiment and the experiment parameters. The instrument location,
and orientation on its platform are identified.
```

```
-------------------------
EXPERIMENT NAME: MLO14
GEOGRAPHIC LOCATION: NOAA MAUNA LOA OBSERVATORY
PLATFORM NAME: MLO SOLAR DECK
LOCATION ON PLATFORM: MIDWAY ON EAST SIDE
HEIGHT ABOVE SEA LEVEL (m): 3397
PRP2 SERIAL NUMBER: 201
PRP SERIAL NUMBER: 001
FRSR SERIAL NUMBER: 1
HEAD SERIAL NUMBER: 374
RAD MODEL NUMBER: RAD-17c
RAD SERIAL NUMBER: 209
RAD PSP SERIAL NUMBER: 33841F3 (8.91)
RAD PIR SERIAL NUMBER: 33687F3 (3.63)
RA2 MODEL NUMBER: RAD-17c
RA2 SERIAL NUMBER: 218
RA2 PSP SERIAL NUMBER: 34292F3 (8.67)
RA2 PIR SERIAL NUMBER: 35836F3 (3.23)
SPN SERIAL NUMBER: A349
SP2 SERIAL NUMBER: A925
TCM SERIAL NUMBER: 17272
GPS MODEL NUMBER: none
GPS SERIAL NUMBER: ???

  Heading source = TCM, COG, FIXED
HEADING SOURCE: FIXED
TCM FIXED PITCH: 0.1;
TCM FIXED ROLL: -0.1
TCM FIXED HEADING: 12

  Location source = GPS, FIXED
  SGP=(36.605,-97.485,12.0), SEATTLE=(47.60329,-122.28797,18.1)  MLO=(19.54, -155.58)
GPS SOURCE = FIXED
GPS FIXED LATITUDE: 19.54
GPS FIXED LONGITUDE: -155.58
GPS FIXED VARIATION: 10

PRP COMMENTS:
  MLO14 calibration/validation exercise.
  Before ACAPEX cruise on Ron Brown
END
RSR COMMENTS:
  140805,10--frsr is running okay but the shadowband has a little wiggle. Needs a look.
END
RAD COMMENTS:
  140804--setup at SGP14
   The rad cdu had suffered a shock and needed repair. The PSP
   channel was not operating so it was returned to Seattle for repair.
END
RA2 COMMENTS:
  140805--setup next to RAD at SGP14.
   We had to opened the box and found the power connector had been jarred loose.
   When plugged back in it worked well.
END
TCM COMMENTS:
 This is a fixed site. The FRSR is aligned to N.
 Head connector pointing to north.
END
```

```
END
GPS COMMENTS
 This is a fixed site and the GPS was not used.
END
ADC COMMENTS
 ADAM 4017 ADC
  Chan0 = spn total volts
  Chan1 = spn diffuse volts
```

```
------- DATA ACQUISITION PROGRAM PARAMETERS -------------------------------
MISSING VALUE: -999

===================
 RSR SETUP
===================
HEAD ZE CAL FILE: setup/374.sol
FRSR CAL FILE: setup/prprx_201_1212.txt
PRP2 INFO FILE: setup/INFO_201_1212.txt

Defines a two-min averaging time for all sweeps.
RSR AVERAGING TIME SECS: 60
The FRSR computer produces 23 bins for the 250 samples
RSR SWEEP BLOCKS: 23
There are seven channels
RSR CHANNELS: 7

RSR DEAD TIME ALARM: 600

## SHUTDOWN CONTROL ##
# v3c -- The hooks are here to be able to use the RAD to switch the RSR on and off.
# The RAD program avgrad.pl output string has either a 0, 1, or -1 in the last field.
# The integers mean 0=below threshold, 1=above threshold, -1=threshold switch disabled.
# The threshold is set up in the su.txt file.
# The program rad_daylight_switch.pl returns the switch value from the last rad_avg_*.txt file.
# The hooks here are disabled. We can send the on/off commands from this program.
The RSR DAQ program will send a 'H' or 'L' to the RSR to put it
into a high or low operation mode. It does this by looking at the
signal from one of the head channels.
0=no action, 1=shutdown control is on.
RSR SHUTDOWN CONTROL: 1
Select channel 0-6, 0=broadband Si
RSR SHUTDOWN CHANNEL: 0
A level of 10 is about first light. 25 is still low light. A level of 100 is bright sun.
RSR SHUTDOWN THRESHOLD: 100
Low temperature. The PRP.ex program reads the averaged data from the
TCM tilt/compass sensor. If the temperature is below the standby
limit below it puts the system into standby until the temperature rises
above the limit. Hysterisis is built in.
LOW TEMPERATURE STANDBY: -5
SHADOW RATIO THRESHOLD
You can set the shadow ratio threshold so only well defined
shadows are processed.
RSR SHADOW RATIO THRESHOLD: 10


===================
  RAD 1 OPERATIONAL PARAMETERS
==================
RAD AVERAGING TIME: 60
RAD DEAD TIME ALARM: 600

SHUTDOWN CONTROL
```

```
If this is '1' if SW is lower than xx W/m^2 a command is sent to
stop the FRSR. Otherwise make it '0';
RAD FRSR SHUTDOWN CONTROL: 0
Send a shutdown command if SW > this amount
RAD FRSR SHUTDOWN THRESHOLD: 130

===================
  RAD 2 OPERATIONAL PARAMETERS
==================
RA2 AVERAGING TIME: 60
RA2 DEAD TIME ALARM: 600

SHUTDOWN CONTROL
If this is '1' if SW is lower than xx W/m^2 a command is sent to
stop the FRSR. Otherwise make it '0';
RA2 FRSR SHUTDOWN CONTROL: 0
Send a shutdown command if SW > this amount
RA2 FRSR SHUTDOWN THRESHOLD: -100

===================
  TCM OPERATIONAL PARAMETERS
==================
TCM AVERAGING TIME: 60

TCM DEAD TIME ALARM: 120


#------- TILT CORRECTION
We do not know the exact orientation of the sensor on the ship.
In port the ship is nearly level. We take a measurement and use the
in-port tilts as correction for all measurements in the future.
# SGP14 corrections -- add to avgtcm.pl v06
TCM PITCH CORRECTION: 8.8
TCM ROLL CORRECTION: 11.4


Heading in deg True
Heading source
'tcm' ==>> use tcm az + variation from gps
'fixed' ==>> stationary site. Fixed.
'??' ==> there can be other sources.
   If source = fixed, enter the correct frsr heading deg T.

===================
  GPS OPERATIONAL PARAMETERS
==================
GPS MIN SAMPLES FOR AVG: 3
GPS AVERAGING TIME: 60
GPS DEAD TIME ALARM: 1800

MINIMUM EXPECTED LATITUDE: 5
MAXIMUM EXPECTED LATITUDE: 60
## make longitude in the range 0-360
## we expect the ship to be in the range [min,max] else missing
MINIMUM EXPECTED LONGITUDE: 60
MAXIMUM EXPECTED LONGITUDE: 300
```

```
--------------------
  AOD PROGRAM OPERATIONAL PARAMETERS
==================
The AOD program takes recent RSR, TCM, and GPS data and
computes the AOD.
Computations are made only when average shadow ratios
exceed this threshold.
```

```
AOD SHADOWRATIO THRESHOLD: 10
Computation update time, secs
AOD COMPUTE TIME SECS: 120
Pull the sweep data from the 23 (0-22) bins.
AOD EDGE INDEX 1: 6
AOD EDGE INDEX 2: 16
AOD SHADOW INDEX: 11

Calibration data must be defined and located.
HEAD ZE CAL FILE: setup/437.sol
HEAD CAL FILE: setup/prprx_201_1003.txt
AOD VERBAL: 0


===================
  ADC OPERATIONAL PARAMETERS
==================
ADAM 4017 COMMAND: #01
ADC AVERAGING TIME: 60
ADC DEAD TIME ALARM: 1800

CHAN0 SPN TOTAL
CHAN0: total
CHAN0 SLOPE: 1000
CHAN0 OFFSET: 0
CHAN1 SPN DIFFUSE
CHAN1: diffuse
CHAN1 SLOPE: 1000
CHAN1 OFFSET: 0
CHAN2 VOLTS
CHAN2: v2
CHAN2 SLOPE: 1
CHAN2 OFFSET: 0
CHAN3 VOLTS
CHAN3: v3
CHAN3 SLOPE: 1
CHAN3 OFFSET: 0
CHAN4 VOLTS
CHAN4: v4
CHAN4 SLOPE: 1
CHAN4 OFFSET: 0
CHAN5 VOLTS
CHAN5: v5
CHAN5 SLOPE: 1
CHAN5 OFFSET: 0
CHAN6 VOLTS
CHAN6: v6
CHAN6 SLOPE: 1
CHAN6 OFFSET: 0
CHAN7 VOLTS
CHAN7: v7
CHAN7 SLOPE: 1
CHAN7 OFFSET: 0
```

```
===================
  SPN OPERATIONAL PARAMETERS
==================
SPN AVERAGING TIME: 60
SPN DEAD TIME ALARM: 1800
CHAN0 SPN = TOTAL
SPN0: total
SPN0 SLOPE: 1
SPN0 OFFSET: 0
CHAN1 SPN = DIFFUSE
SPN1: diffuse


SPN1 SLOPE: 1
SPN1 OFFSET: 0

SP20: total
SP20 SLOPE: 1
SP20 OFFSET: 0
CHAN1 SPN = DIFFUSE
SP21: diffuse
SP21 SLOPE: 1
SP21 OFFSET: 0


===================
  NAV OPERATIONAL PARAMETERS
==================
NAV DEAD TIME ALARM: 600
NAV SSH COMMAND: ssh user@10.0.1.2 'cat ~/NAVSIM/navdat.txt'
  also this: scp  -q user@10.0.1.2:NAVSIM/navdat.txt . ; cat navdat.txt
NAV AVERAGING TIME: 60
NAV COMMENTS:
  SeaNav by ssh
END

END SETUP FILE
```

Appendix B

PRP2 Hardware

B.1 FRSR Plate

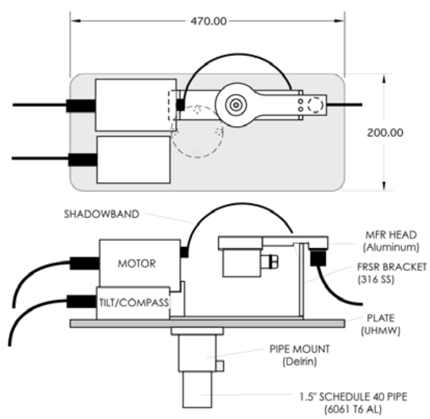

Figure 9. The FRSR radiometer plate assembly. The TCM tilt sensor is mounted on the plate. The MFR head is a standard ARM MFRSR head and is calibrated and maintained with other MFRSR equipment. The motor is a continuous-running DC motor. A magnetic nadir switch indicates when the shadowband is at the bottom (nadir).

B.2 Control Data Unit (CDU)

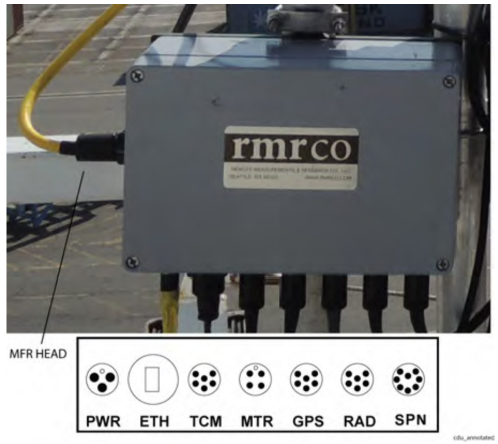

Figure 10. The Control Data Unit (CDU) contains the FRSR electronics control circuit board, the main serial server hub, the 16-bit ADC, and power distributor.

B.3 GPS

Figure 11. The Global Positioning System (GPS) receiver is a Garman Model GPS17X. The all-in-one unit is programmed to operate at 1-Hz NMEA0183. The NMEAOI83 record includes UTC, position, SOG, COG, and magnetic variation.

B.4 Tilt Compass (TCM)

Figure 12. The TCM is the Precision Navigation Inc. Model 2.5. The serial output format includes pitch, roll, flux-gate compass, board temperature, and three components of earth magnetic field. The TCM sensor is located on the FRSR plate and the tilts are used to determine the tilt of the MFR head.

B.5 RAD

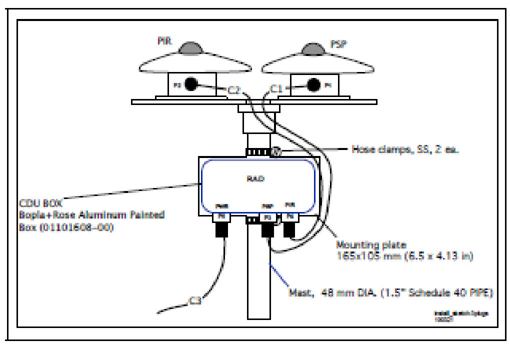

Figure 13. The Radiation Analog-to-Digital (RAD) interface accepts the analog thermopile voltages from the PSP and PIR radiometers and the PIR thermistors and computes the final shortwave and longwave irradiances. The module RAD1 is located with the FRSR CDU and RAD2 is a satellite system.

B.6 SPN

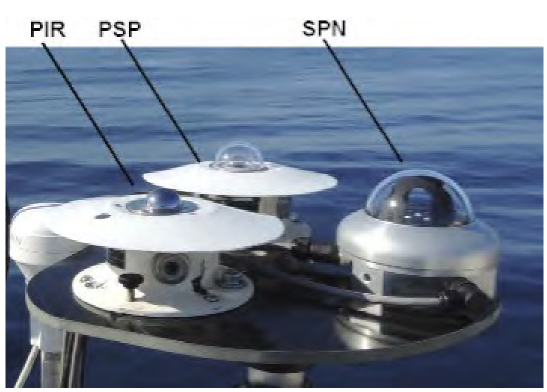

Figure 14. The SPN is located next to the PSP and PIR in combination with the RAD.

B.7 FRSR

The multi-spectral FRSR head is manufactured by Yankee Environmental Systems, Inc. (YES). It is a modified version of the commercially available, multi-frequency, rotating shadowband radiometer (MFRSR) spectral radiometer head and has seven detectors (channels): a broadband channel and six, ten-nm-wide bandpass-filtered channels at 415, 500, 610, 680, 870, and 940 nm. The head construction, adeptly described by Harrison et al.(1994), is environmentally sound, robust, and suitable for use in a marine environment. Figure 15 shows the Colina et al. (1996) reference solar spectrum at the top of the atmosphere and a typical spectrum for the Earth's surface. Superimposed on the graph are the FRSR pass bands, the silicon cell photodiode (called broadband here), and the six narrowband spectral channels. Passbands on the SeaWiFS satellite are shown for comparison.

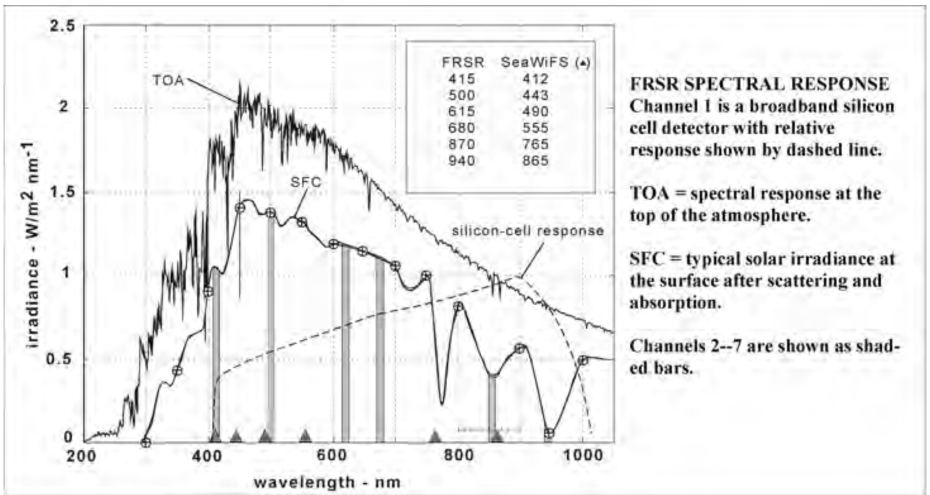

Figure 15. MFR head passbands.

B.7.1 Sweep Operations

The installation location of the instrument on a ship must be carefully selected. Ideally, the FRSR should be mounted in an exposed location as high as possible and free of nuisance shadows from other objects. This is often difficult. Radiative flux measurements on a ship always need to consider errors from the ubiquitous masts and antennas. A ship's communication antennas have highest vertical priority as do the running lights, and one must be careful of radar beams, which can cause severe electronic noise.

Several external observations are necessary for data analysis. Accurate time, latitude, and longitude are needed to compute solar zenith and azimuth angles. To correct the sensor's cosine response, one also needs the ship's pitch, roll, and heading so the exact angle between the normal of the head and the solar beam can be derived. A pitch-roll-compass sensor is read twice during each cycle of the shadowband. A GPS receiver provides time, position, and magnetic variation each second.

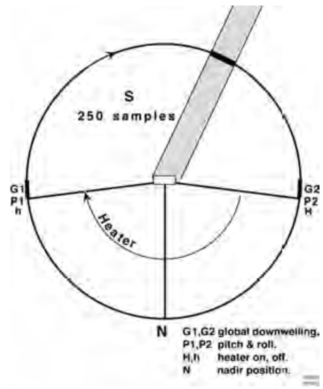

Figure 16. FRSR Sweep Operations. The CDU performs several functions as the shadowband completes each cycle. A nadir switch (N) is used for timing. When the shadowband is at each horizon, the tilt sensor is read for pitch and roll (T1 and T2). During the lower half of a revolution, the heater is operated as necessary to maintain a head temperature of 10 ±0.2°C (H and h). During the sweep, when the shadowband crosses the upper hemisphere, 250 measurements are made for each channel. The first and last 10 samples for each channel of each sweep are averaged and we refer to these measurements as the global measurements, v_{G1} and v_{G2}.

The head is well insulated (thermal time constant ≈ 15 min.), and has a 25 W heater circuit. Thus, the heating current is applied only when the head temperature falls below 40°C, which reduces system power requirements. In cruises thus far, the head easily maintained 40 ± 0.2°C with the above scheme.

B.7.2 Shadow Ratio

The FRSR shadowband (Figure 17) rotates continuously and moves across the upper hemisphere in 3.4 sec. The hemispherical shape of the shadowband ensures that the sensor will see a shadow, regardless of its azimuth heading and at all but minimal solar elevations. Typically, the shadow moves across the face of the Sun in a few tenths of a second and the head is in full shadow for about one tenth of a second.

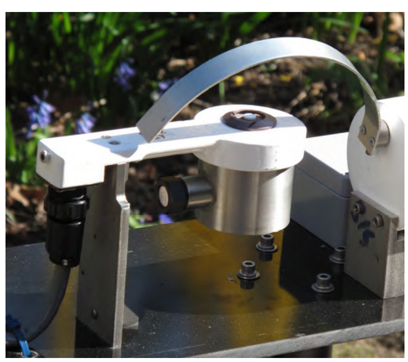

Figure 17. The shadowband in sunlight with the shadow just crossing the MFR head diffuser.

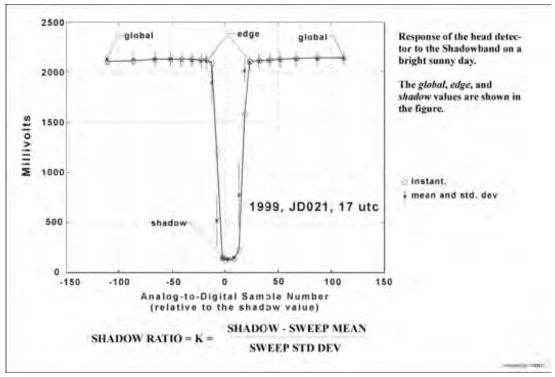

Figure 18. When the shadowband creates a shadow over the diffuser, the detector signals show a dip in the solar signal.

At the end of each sweep of the shadowband, the channel-1 voltage measurements are examined and a decision made whether a viable shadow was present. See Figure 18. The shadow ratio is a sensitive measure of the intensity of the direct solar beam and is computed by the equation

$$\epsilon = \frac{v_{av} - v_{min}}{\sigma_v}, \tag{28}$$

where v_{av} is the mean signal voltage for the entire sweep, v_{min} is the minimum signal voltage, and σ_v is the standard deviation for the sweep. (Measurements ± 0.3 sec from the minimum value are excluded from the computation of mean and standard deviation.) It has been found that a criterion of $\epsilon \geq 2.3$ captures almost all true shadow cases and seldom permits a false positive. On sunny days the shadow ratio can exceed a value of 80.

B.7.3 Sweep Block Averaging

Any sweep with $\epsilon \geq 2.3$ is block averaged and stored in a compressed binary packet. Block averaging of the sweep retains all of its significant characteristics but significantly reduces data storage requirements. Block averaging begins at the minimum index value, i_{min}, and moves left and right through the sweep array with increasing block sizes. Twenty-three contiguous block averages, b_{ij}, where i is the channel number 1–7, and j is the bin number, are computed according to Table 18 below. The shadow index, i_{min}, depends on the

solar azimuth and zenith angles, the ship heading, and the pitch and roll, and thus can occur anywhere in the 250-point sweep array. In the block averaging process some bins fall outside the sweep and are given a “missing” value.

Table 19. Table of sweep block averaging bins, b_{ij}, $i = 1$,23, $j = 1 \ldots 6$. The 23 bins and the number of points in each bin are shown. Bin 12 is the minimum (shadow) point.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
30	20	20	10	10	10	5	5	5	5	5	1	5	5	5	5	5	10	10	10	20	20	30
											↑											

B.7.4 Compressed Sweep Packets

A compressed binary packet with global and sweep data for all detectors is transmitted as a 38400 bps RS232 serial stream to the base computer. The binary packet has start and end character strings and a Cyclic Redundancy Checksum (CRC) for error-free transmission.

The packet must be transmitted just before the nadir (N). Once the packet is transmitted, the shadowband cycle begins again.

There are three different packets possible.

1. **High Shadow Mode.** For a clear-sky period, the binary packet has about 2500 characters.
2. **High, No Shadow Mode.** If no shadows are detected it transmits only global information from all the radiometers and will be about 400 characters.
3. **Low Mode.** When the solar flux falls below approximately 5 Wm^{-2}, the PRP goes into night time operation. The shadowband is parked at its protected nadir position and the head temperature is maintained at its set point.

The packets begin and end with ##. The beginning of the packet has the number of characters transmitted (357, 35, and 17 for the three modes followed by ASCII 'H' or 'L'. The checksum is computed between the double hash marks. The checksum is converted to three ASCII characters and is posted at the end of the packet after an asterisk.

B.7.5 Packet Checksum Algorithm

```
HIGH SWEEP SHADOW:
18 2014 09 25 19 09 03 ##0357,HN9M1b0\7b<A6_4i2E3h1j71=L6g4o2J3m1_7'7Z7Q7I7A797o636j4_4'4n4C60797?
7H7T7[7b7h700f<f<Y<F<6<e;W;I;@:N8=8;8J8::@;L;T;d;<<L<]<m<00D6D6?666o5g5'5Y5
k4n3f3f30445Y5_5c5k556<6C6K600'4a4]4W4R4L4H4B4Z3l2g2h213g3C4H4K4Q4X4]4b4f400k2k2h2e2b2_2\2X2?
2c1_1_1g1I2Z2\2^2b2f2i2l2n200F3F3C3@3=3936313X2;26272>2a2337393=3B3D3G3I300i1j1j1i1g1d1b1_101:
15161:101^1a1c1f1i1k1l1m100*GN;##

HIGH NO SHADOW MODE:
199 2014 09 25 19 27 05 ##0035,HN9W0b0X5P9T4K372O2G1S5G9O4H342M2F1*_O1##
```

```
LOW MODE:
2936 2014 09 26 00 01 30 ##0017,LL9C0W0A0;080;050*TB4##

sub CheckSum
# Call:  $s = CheckSum($str);
#  Routine to compute checksum based on a shifting summation of all
#  bytes.  Routine provided by L. Hatfield of Battelle, 9404.
#  See Reynolds notes, pp 1207-1208. 940505
#  Modified for binary blocks of size N. 990108
{
my $packet=shift();
my $N = length($packet);
my $nbyte=0; my $sum=0;
my $chr;

while($nbyte < $N){
if($sum & 01){ $sum = ($sum>>1)+0x8000 }
else{ $sum = $sum >> 1 }
$chr=ord(substr($packet,$nbyte,1));
$nbyte++;
$sum += $chr;
$sum &= 0xFFFF;
}
my $b1=$sum;
my $c1 = $b1 % 64 + 48;   # msb
my $b2 = $b1 / 64;
my $c2 = $b2 % 64 + 48;
my $b3 = $b2 / 64;
my $c3 = $b3 % 64 + 48; # lsb
my $c=sprintf("%c%c%c",$c1,$c2,$c3);
return $c;
}
```

B.8 DAQ PC

The DAQ software has been run on the following systems: (1) Virtual PC running Linux (Centos); (2) PC running Linux (Umbuntu); (3) Mac OS X (Unix).

B.8.1 Required Software

BASH	The default version of Unix/Linux will be `bash`.
VI	The VIM or VI bash editor.
KERMIT	A powerful serial interface program.
PERL	Standard PERL software available in most Unix/Linux installation.

PERL, HiResTime module	A special package for matrix manipulations.
EXPECT (TCL)	A Unix automation and testing tool, written by Don Libes as an extension to the TCL scripting language. Enter `expect -v` for the version number. Version 5 or greater is recommended.

B.8.2 Director Tree

```
/home
  /prp2
     /data
        (all data files are located here)
     /setup
        (the setup file with all operational parameters are in this directory)
        setupfile.txt -- example setup file name
```

B.8.3 Settings in 'bashrc'

The text file at `$HOME/.bashrc` has many aliases and functions that are used by the software system. This file should be installed.

B.8.4 Kermit Startup File '.kermrc'

The text file at `$HOME/.kermrc` forces a kermit prompt of >>. This file should be installed.

B.8.5 Cron Job for Reset

A special cron job can be run each hour or sooner. The procedure checks the last raw data record for all modules and assures no records are older than one minute. If any of the modules fail, a restart procedure kills current data collection and restarts.

`crontab -e` opens the cron table with the vi editor.

Enter the following lines:

```
# PRP2 Reboot Procedure
20 * * * * /home/oper/swmain/apps/PRP2/sw/UpdateDaq
```

The check will occur every hour at 20 minutes.

Appendix C

System Takedown and Packing

C.1 Preparation

For system takedown and packing, follow these steps.

1. Takedown—remove all cables and modules and return to the workshop.
2. Breakdown–take the system to parts for maintenance and packing.
3. Maintenance—go over all parts, inspect for damage, repair and preventative maintenance.
4. Packing—Properly pack all items into packing crates for long-distance shipping.

Be sure to use sufficient packing foam or other padded materials. Note: The complete PRP2 with the RAD2 module is more than the original PRP2 was when it was shipped.

C.2 Takedown

1. PARK THE FRSR. The shadowband needs to be parked at it's nadir (bottom) position.
   (1) `gtscreen` opens the screen into one of the eight windows.
   (2) `^a 6` opens the FRSR window.
   (3) `L` puts the FRSR in Low Mode.
   Wait for the shadowband to park. The mentor can do this prior to beginning the takedown.
   An alternative to the above method is simply to pull out the CDU power plug (#1) at the instant the shadowband is at the nadir position.
2. POWER OFF. Unplug the main power supply. Note the UTC time.
3. SERIAL NUMBERS. Just for completeness, record the serial numbers of all the sensors.
   RAD1: PSP, PIR, SPN.
   RAD2: PSP, PIR, SPN,
   FRSR: MFR Head.
   Record the numbers and email to the PRP2 mentor.
4. PACK CABLES. Remove all the cables. Put cables for each module (RAD1, RAD2, FRSR/CDU) into individual plastic bags. Pack the power supply, serial switch and ethernet cables into a separate plastic bag with adequate foam insulation.
5. REMOVE THE SHADOWBAND. Note if the shadowband is loose or tight on the shaft. Use a 3/32 allen wrench to loosen the shadowband set screw. Carefully slide the shadowband off the shaft.
6. REMOVE RADIOMETERS. Carefully remove all radiometers. Remove the sun plates from the PSP & PIRs.
   (1) RAD2: PSP, PIR, SPN.
   (2) RAD1: PSP, PIR, SPN.
   (3) FRSR: MFR head
   Note: Be very careful with all screws, washers, and nuts. Screw back or place in a special pill jar.

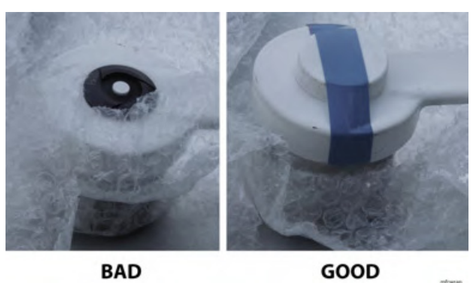

Figure 19. Pack MFR head. Be sure to cover the diffuser button. A cap from a Clorox bottle works well.

7. RETURN TO THE SHOP. Unscrew the frame, RAD2 post, and all mounting hardware. Carefully bring all radiometers, enclosures, and other hardware back to the shop. Keep all hose clamps with the hardware.
8. GPS. Pack the GPS, mounting hardware and cable into a plastic bag and wrap in bubble foam.

Appendix D

Maintenance Checklists

D.1 Pre-Deployment Service Checklist

Extract this page and fill in the blanks for a good daily check list record. Or create a spread sheet with these items for an online record of the daily service.

Date: ______________ Technician: ______________

1. ___ **Shadowband motor service.** Only one preventative maintenance task is needed before shipping. That is to go through the shadowband motor assembly and be sure it is tight and weather protected. Refer HERE for “PRP Shadowband Service.” Follow this procedure to ensure solid FRSR service.
2. ___ **Set IP numbers.** Refer to table 9 (HERE). Each of the components listed must be set to the assigned IP numbers.

D.2 Installation Checklist

Extract this page and fill in the blanks for a good daily checklist record. Or create a spreadsheet with these items for an online record of the daily service.

Refer to Section 10.

Date: _______________ Technician: _______________

1. ___ **Check all parts.** Review section 10.1 (and be sure all parts are unpacked and ready to install.
2. ___ **Check all parts.** Review table 8 (HERE) and be sure all parts are on hand.
3. ___ **Deployment location.** Review table 10.2 (HERE) and select a location.
4. ___ **Install equipment.** Review table 10.3 (HERE) installneeds
5. ___ **Connect MFR cable.** Review table 10.4.1 (HERE) and carefully make the connections for the MFR cable.
6. ___ **Connect CDU cables.** Review table 10.4.2 (HERE) and carefully make all CDU connections From RAD1, TCM, SPN1, and ADC.
7. ___ **Check grounding.** Review table 10.5.1 (HERE) and ensure the system is grounded with at least a single-point ground..
8. ___ **Ethernet connection.** Make the ethernet connection from the CDU to the assigned system LAN.
9. ___ **Power connection.** Connect the power cable to 13–18 VDC, 2A power source. Note the shadowband will begin to rotate when power is applied.
10. ___ **Install RAD2** Install RAD2 in its designated location. Connect the ethernet cable to the assigned LAN router. Connect 13-16 VDC, 0.5A power source. Turn on the power.
11. ___ **Confirm LAN connections.** Use the `ping` command to confirm connections to all components. For this example we use the IP numbers from table 9.

    ping 198.129.80.48 CDU serial server

    ping 198.129.80.49 RAD2 server

12. ___ **Cold start.** Review section 11.0.4 (HERE) and cold start the system.
13. ___ **Daily check.** End the cold start by performing a daily check as outlined in section D.3.

D.3 Daily Service Checklist

Extract this page and fill in the blanks for a good daily checklist record. Or create a spreadsheet with these items for an online record of the daily service.

Note: `^a = < control >a`. Hold down ‘control’ key and ‘a’ at the same time, then release.

Date,Time: ____________________ Technician: _______________

1. ___ **Shadowband High Mode Operation.** During daylight, observe the shadowband rotation. Rotation rate should be on order 6.2 sec. Motion should be smooth; no jerks or sudden drops. These indicate the set screw is slipping.
2. ___ **Hose off everything.** Use a hose with fresh water to wash down the system. Salt deposits will build up and corrode the parts. (Not necessary every day, but at a minimum every four days when at sea.)
3. ___ **Clean radiometer domes.** Use distilled water and lintless cloth or tissue to wipe off any deposit from the PSP, PIR, SPN, and the MFR head.
4. ___ **Shadowband Low mode alignment.** When the shadowband is parked, at night or when in test mode, the shadowband should be at its nadir (bottom) position. When the technician is around the FRSR at night, note the shadowband is at nadir.
5. ___ **Quick terminal check.** Open a terminal window connected to the PRP2 VM. Enter `gtdaq` to go to sw folder: `~/swmain/apps/PRP2/sw/$`.
6. ___ **Quick check programs.** Enter `search_ps` to check all running programs. If a ‘1’ is returned, all is well. A ‘0’ means something is wrong and one of the data acquisition programs has failed.

```
~/swmain/apps/PRP2/sw/$ search_ps
1~/swmain/apps/PRP2/sw/$
```

7. ___ **Check data are current.** Enter `DaqUpdate` to check the most recent records in each data folder. If any data is older that 60 seconds from the current time the word `FAIL` will appear. In the example below all modules are operating properly.

```
~/swmain/apps/PRP2/sw/$ DaqUpdate
NOW = 1420507916
nav     1420507860     57    OK
gps     1420507918     0     OK
tcm     1420507918     1     OK
rad     1420507926     -6    OK
spn     1420507921     1     OK
ra2     1420507928     -4    OK
sp2     1420507925     0     OK
good = 1
~/swmain/apps/PRP2/sw/$
```

8. ___ **End of Daily Check**

D.3.1 Monitor Raw Data

The raw data can be monitored with the commands here. All commands in this section open a window that updates each time a new raw record is received. End the process with `<control>-c`.

1. ___ **NAV raw data** `navraw`.

```
~/swmain/apps/PRP2/sw/$ navraw
hd,yyyyMMdd,hhmmss,lat,lon, sog, cog, pitch, roll, hdg*cc
$WINAV,20150106,014749, 21.36731,-157.96458,  0.00,233.2, -0.10,  0.46, 233.25*5B
$WINAV,20150106,014751, 21.36731,-157.96458,  0.00,304.8, -0.10,  0.48, 233.25*53
$WINAV,20150106,014753, 21.36731,-157.96458,  0.00,323.2, -0.10,  0.46, 233.24*51
....
```

2. ___ **GPS raw data** `gpsraw`.

```
~/swmain/apps/PRP2/sw/$ gpsraw
nrec yyyy MM dd hh mm ss lat lon sog cog var
76517 2015 01 06 01 58 20 21.367477 -157.964575 0.0 0 9.7
76518 2015 01 06 01 58 21 21.367477 -157.964577 0.0 0 9.7
76519 2015 01 06 01 58 22 21.367473 -157.964575 0.0 0 9.7
....
```

3. ___ **TCM raw data** `tcmraw`.

```
~/swmain/apps/PRP2/sw/$ tcmraw
nrec yyyy MM dd hh mm ss comp pitch roll Xmag Ymag Zmag Ttcm
76596 2015 01 06 01 59 37 260.6 -9.0 -13.2 -0.02 30.76 54.61 27.0
76597 2015 01 06 01 59 38 260.6 -9.0 -13.2 -0.01 30.77 54.61 27.0
76598 2015 01 06 01 59 39 260.6 -9.0 -13.2 -0.01 30.80 54.61 27.0
76599 2015 01 06 01 59 40 260.6 -9.0 -13.2 -0.01 30.77 54.61 27.0
....
```

4. ___ **SPN raw data** `spnraw`.

```
~/swmain/apps/PRP2/sw/$ spnraw
nrec yyyy MM dd hh mm ss total  diffuse sun
76706 2015 01 06 02 01 28 SPNRAW   397.9,   99.4,1
76707 2015 01 06 02 01 29 SPNRAW   397.4,   99.4,1
76708 2015 01 06 02 01 30 SPNRAW   397.5,  100.7,1
76709 2015 01 06 02 01 31 SPNRAW   397.5,  100.7,1
....
```

5. ___ **RAD raw data** `radraw`.

```
~/swmain/apps/PRP2/sw/$ radraw
nrecs yyyy MM dd hh mm ss $WIR07,yy/MM/dd,hh:mm:ss,npts,pir,lw,tcase,tdome,sw,trad,batt
76770 2015 01 06 02 02 33 $WIR02,15/01/06,01:32:19,  12, -271.8, 360.79, 26.26, 26.51, 364.21, 34.7, 10.7
76771 2015 01 06 02 02 34 $WIR02,15/01/06,01:32:20,  12, -272.1, 360.80, 26.27, 26.51, 364.52, 34.7, 10.7
76772 2015 01 06 02 02 35 $WIR02,15/01/06,01:32:21,  12, -271.1, 361.02, 26.26, 26.51, 364.29, 34.8, 10.7
76773 2015 01 06 02 02 36 $WIR02,15/01/06,01:32:22,  13, -272.1, 360.79, 26.27, 26.51, 364.05, 34.8, 10.7
....
```

6. ___ **FRSR raw data** `rsrraw`.

```
~/swmain/apps/PRP2/sw/$ rsrraw
....
```

7. ___ **RA2 raw data** `ra2raw`.

```
~/swmain/apps/PRP2/sw/$ ra2raw
nrecs yyyy MM dd hh mm ss $WIR07,yy/MM/dd,hh:mm:ss,npts,pir,lw,tcase,tdome,sw,trad,batt
76840 2015 01 06 02 03 44 $WIR09,15/01/06,02:05:28,  12, -221.7, 363.88, 25.15, 25.24, 385.00, 31.5, 12.3
76841 2015 01 06 02 03 45 $WIR09,15/01/06,02:05:29,  13, -220.4, 364.21, 25.14, 25.24, 385.25, 31.5, 12.3
76842 2015 01 06 02 03 46 $WIR09,15/01/06,02:05:30,  12, -221.3, 363.41, 25.13, 25.24, 385.07, 31.5, 12.3
76843 2015 01 06 02 03 47 $WIR09,15/01/06,02:05:31,  12, -220.9, 364.11, 25.15, 25.24, 385.15, 31.5, 12.3
....
```

8. ___ **SP2 raw data** `sp2raw`.

```
~/swmain/apps/PRP2/sw/$ sp2raw
nrec yyyy MM dd hh mm ss total  diffuse sun
76897 2015 01 06 02 05 04 SP2RAW   412.6,   107.6,1
76898 2015 01 06 02 05 05 SP2RAW   413.4,   109.0,1
76899 2015 01 06 02 05 06 SP2RAW   412.6,   107.6,1
76900 2015 01 06 02 05 07 SP2RAW   413.4,   109.0,1
....
```

navg yyyy MM dd hh mm ss lat lon sog cog pitch pstd roll rstd hdg 1 2015 01 05 04 43 00 21.36732 -157.96459 0.00 359.6 -0.1 0.0 0.4 0.0 232.6 2 2015 01 05 04 44 00 21.36732 -157.96459 0.00 329.5 -0.1 0.0 0.4 0.0 232.6 3 2015 01 05 04 45 00 21.36732 -157.96459 0.00 358.5 -0.1 0.0 0.4 0.0 232.6 4 2015 01 05 04 46 00 21.36732 -157.96459 0.00 24.0 -0.1 0.0 0.4 0.0 232.6

D.3.2 Review AVG Data

The 1-min-averaged files are written to the average files. The commands here open the most current average
files with the Unix “less” program. Here are a basic set of less commands:
`<space>` jumps down one screen.
G jumps to the last (most recent) records.
g jump to the top.
`/2015 01 02 12 14` jumps to the date string “`2015 01 02 12 14`”.
q quits the program.

1. ___ **NAV avgerage data** `navavg`.

```
navg yyyy MM dd hh mm ss lat lon sog cog pitch pstd roll rstd hdg
1 2015 01 05 04 43 00  21.36732  -157.96459  0.00 359.6  -0.1 0.0  0.4 0.0  232.6
2 2015 01 05 04 44 00  21.36732  -157.96459  0.00 329.5  -0.1 0.0  0.4 0.0  232.6
3 2015 01 05 04 45 00  21.36732  -157.96459  0.00 358.5  -0.1 0.0  0.4 0.0  232.6
4 2015 01 05 04 46 00  21.36732  -157.96459  0.00 24.0  -0.1 0.0  0.4 0.0  232.6
....
```

2. ___ **GPS avgerage data** `gpsavg`.

```
navg yyyy MM dd hh mm ss lat lon sog cog var
1 2015 01 05 04 43 00  21.36747  -157.96450   0.00    0.0   9.7
2 2015 01 05 04 44 00  21.36749  -157.96452   0.00    0.0   9.7
3 2015 01 05 04 45 00  21.36749  -157.96455   0.00    0.0   9.7
4 2015 01 05 04 46 00  21.36749  -157.96454   0.00    0.0   9.7
....
```

3. ___ **TCM avgerage data** `tcmavg`.

```
nsamp yyyy MM dd hh mm ss fgaz pitch pstd roll rstd xmag ymag zmag ttcm
1 2015 01 05 04 43 00 260.4 -0.2 0.0 -1.7 0.1 -0.419 31.968 55.012 21.0
2 2015 01 05 04 44 00 260.3 -0.2 0.1 -1.7 0.1 -0.423 31.973 55.016 21.0
3 2015 01 05 04 45 00 260.3 -0.1 0.1 -1.7 0.1 -0.437 31.977 55.016 21.0
....
```

4. ___ **SPN avgerage data** `spnavg`.

```
nrec yyyy MM dd hh mm ss total stdtotal diffuse stddiffuse last_sun
1 2015 01 05 04 43 00  0.9 0.5 0.0 0.2 0
2 2015 01 05 04 44 00  0.8 0.5 0.1 0.3 0
3 2015 01 05 04 45 00  1.1 0.5 0.2 0.5 0
4 2015 01 05 04 46 00  1.0 0.6 0.2 0.4 0
....
```

5. ___ **RAD avgerage data** `radavg`.

```
navg yyyy MM dd hh mm ss     sw stdsw   lw stdlw     pir stdpir    tcase  tdome   tpcb  batt rsroff
0 2015 01 05 04 43 00   1.1 0.2   388.7 0.3   -116.8 0.9   21.030 20.929   26.826 10.7 -1
1 2015 01 05 04 44 00   1.1 0.2   389.7 0.4   -114.7 0.9   21.029 20.917   26.865 10.7 -1
2 2015 01 05 04 45 00   1.1 0.2   389.9 0.2   -113.8 0.6   21.016 20.903   26.877 10.7 -1
3 2015 01 05 04 46 00   1.2 0.2   389.2 0.3   -114.9 0.7   21.007 20.903   26.897 10.8 -1
4 2015 01 05 04 47 00   1.2 0.2   388.7 0.3   -116.5 0.7   21.002 20.900   26.900 10.7 -1
....
```

6. ___ **FRSR avgerage data** `rsravg`.

```
....
```

7. ___ **RA2 avgerage data** `ra2avg`.

```
navg yyyy MM dd hh mm ss    sw stdsw   lw stdlw     pir stdpir    tcase  tdome   tpcb  batt rsroff
0 2015 01 05 04 43 00   -0.0 0.1   390.9 0.4   -103.9 1.0   21.350 21.196   25.100 12.3 -1
1 2015 01 05 04 44 00   0.1 0.1   391.7 0.6   -101.6 1.2   21.342 21.190   25.100 12.3 -1
2 2015 01 05 04 45 00   0.3 0.1   391.8 0.5   -100.5 1.0   21.332 21.191   25.100 12.3 -1
3 2015 01 05 04 46 00   0.9 0.3   391.1 0.4   -102.5 0.9   21.333 21.189   25.100 12.3 -1
4 2015 01 05 04 47 00   1.1 0.3   390.2 0.6   -105.8 1.1   21.332 21.173   25.100 12.3 -1
....
```

8. ___ **SPN2 avgerage data** `sp2avg`.

```
nrec yyyy MM dd hh mm ss total stdtotal diffuse stddiffuse last_sun
1 2015 01 05 04 43 00  0.8 0.5 0.2 0.4 0
2 2015 01 05 04 44 00  0.7 0.3 0.0 0.2 0
3 2015 01 05 04 45 00  0.7 0.3 0.0 0.2 0
4 2015 01 05 04 46 00  0.6 0.2 0.0 0.0 0
....
```

D.3.3 Stopping and Starting Data Collection

If the tests above indicate one or more of the data collection modules has failed, the first step is to reboot the data collection.

1. ___ **Stop data collection.** `Stopprp`
2. ___ **Re-start data collection.** `Startprp`

D.3.4 Entering the Background Screen

1. ___ **Terminal check.** If all is well, the full terminal check will take 30 sec or less. Open a terminal window and connect to the PRP. Enter `gtscreen` to open the PRP background screen. Enter `^a 1` to go to the GPS window. Confirm GPS is updating.

2. ___ **TCM Check** Enter `^a 2` to go to the TCM window. Confirm tilt, pitch and roll records are updating.

3. ___ **ADC Check** Enter `^a 3` to go to the ADC window. Confirm SPN1 total and diffuse data are coming in properly.

4. ___ **SPN1 Check** Enter `^a 4` to go to the SPN1 window. Confirm records are updating and that total and diffuse data are identical to the ADC values.

5. ___ **RAD1 Check** Enter `^a 5` to go to the RAD1 window. Confirm records are updating. SW data should be very near SPN Total. LW data is in the range of 300–500 W m^{-2}. Tcase and Tdome are within 1°C of each other.

6. ___ **FRSR Check** Enter `^a 6` to go to the RSR window. Head temperature is 40 ± 1 C. Shadow ratios are reasonable for current conditions.

7. ___ **RAD2 Check** Enter `^a 6` to go to the RAD2 window. Confirm records are updating. SW data should be very near SPN Total. LW data is in the range of 300–500 W m^{-2}. Tcase and Tdome are within 1°C of each other.

8. ___ **SPN2 Check** Enter `^a 7` to go to the SPN2 window. Confirm records are updating and that total and diffuse data are identical to the ADC and SPN1 values.

9. ___ **Close screen.** Enter `^a d` to detatch the screen session.

D.4 Long-Term Service Checklist

Extract this page and fill in the blanks for a good daily check list record. Or create a spread sheet with these items for an online record of the daily service.

Date,Time: ____________________ Technician: ______________

1. ___ **Receive Shipment.** Coordinate with the shipper. Store the boxes in a protected place until it is time to open.
2. ___ **Report Delivery.** Email the agent that the goods are received.
3. ___ **Inspection.** Open boxes and inspect everything. Photograph the open boxes. Review the shipping list and confirm everything is there.
4. ___ **Inspect radiometers.** Examine the PSP and PIR condition. Photograph. Arrange for calibration.
5. ___ **MFR head.** Examine the MFR head condition. Test that all channels are operating. (See the MFR head incoming test procedure HERE??.)
6. ___ **Head calibration.** Contact ARM to arrange for the heads to be calibrated.
7. ___ **Full inspection.** Examine the condition of the other hardware. Do we need to powdercoat or touch up any pieces? Photograph any damage.
8. ___ **CDU operation.** Set up CDU for operation. Confirm it is operational.
9. ___ **Needed tasks.** Prepare a list of needed work and send to "Operations" for approval and schedule.
10. ___ **Radiometer calibrations.** Package and ship the radiometers to calibration.
11. ___ **CDU preamp calibration.** Perform the CDU calibration with Volt-a-vider. See calibration spread sheet.??
12. ___ **RAD calibration.** Perform the RAD1 calibration with Volt-a-vider. Repeat for RAD2. See calibration spread sheet.??
13. ___ **System burn-in** Collect all parts and assemble the complete PRP. Start operation. Set up for outside operation and run for one week.
14. ___ **Burn-in QA** Inspect the data and verify the system is operating properly.
15. ___ **Pack & ship.** Pack everything into the boxes. Make an outgoing packing sheet. Photo the boxes before closing. Call shipper and return the good to operation.

Appendix E

Procedure: Calibrate FRSR Preamp

Equipment needed:

- Volt-a-vider or other voltage reference.
- CDU MFR test cable
- Laptop with 38400 bps, 8N1 terminal connection.
- CDU test power cable.
- CDU test Ethernet cable.
- Reference resistors (5.06K, 10K, 15K).
- Cal test spreadsheet.

Steps:

1. Connect to the CDU to the terminal and confirm operation.
2. Fill in the calibration sheet hardcopy with pencil.
3. Connect the MFR test cable to the MFR input plug.
4. Set the Volt-a-vider to 0 mv. Connect to channel 1.
5. Go through all voltage settings on all channels and fill in the mean and standard deviation for each setting. Be sure all the other channels are grounded at the test plug.
6. Repeat for channels 2–7.
7. Copy the cal spreadsheet as "dlxxx_yyMM.numbers" where xxx is the data logger SN, yy is the year and MM is the month of this calibration.
8. Fill in the spreadsheet with the numbers from the calibration.
9. Run the calibration MATLAB software. This is done by the mentor or trained data person.

Appendix F

Procedure: Shadowband Motor Service

Remove the Shadowband.

1. Use a 3/32” Allen wrench to loosen the shadowband set screw.
2. Carefully slide the shadowband off of the shaft.

Remove the end cap.

Figure 20. Unplug the motor cable and unscrew the four screws using a 3/32” Allen wrench.

Figure 21. Carefully remove the endcap. Unplug the in line connector to free the endcap.

Remove the Shaft Assembly.

1. Use a flashlight if necessary to see the two screws that hold the shaft assembly in the motor housing.
2. Use the long 9/64” Allen wrench to remove the two cap head socket screws.
3. Push in the shadowband shaft to free the assembly.

Align the Motor Shaft.

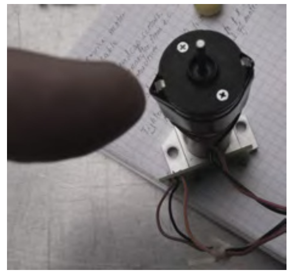

Figure 22. Connect about 5 VDC to the terminals of the motor. A voltage of 5-12 V can be used, but the motor turns more slowly with smaller voltage and thus us easier to align.

Figure 23. Align the motor shaft so the flat surface is pointing toward the access hole.

Secure the Shadowband Shaft.

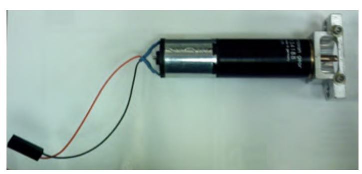

Figure 24. Motor assembly.

Figure 25. Shadowband shaft assembly. The set screw is at the top left and nadir magnet is on the right. The o-rings should be smooth and in good condition.

1. Remove the shadowband shaft from the motor. If needed, use the 0.05” Allen wrench to loosen the set screw.
2. Examine the shaft assembly. Check that the magnet is good. Examine the o-rings and replace if necessary.

3. Remove the set screw and add a dot of blue LokTite to the hole. Replace the set screw. The curing time for LokTite is 24 hours.

Re-assemble the Motor.

Figure 26. Blue LokTite is very strong but the set can be broken with ordinary tools. It is best for all set screws.

Figure 27. Anti-seize is messy but is essential for exposed hardware, especially for dissimilar metals such as for stainless bolts in aluminum.

1. Fit the shadowband shaft onto the motor shaft with the set screw pointing to the access hole. Tighten the set screw securely.
2. Use silicone grease such as “Chemplex 710” from McMaster-Carr, on the shaft o-rings.
3. Insert the shaft assembly into the housing and screw in the #8 cap screws using the 9/64” Allen wrench.
4. Grease the endcap o-rings.
5. Connect the internal connector and insert the endcap. Note: rotate the endcap so it fits over the motor. There is a cutout on the inside wall of the endcap for the motor.
6. Screw in the four endcap screws. Note: use a drop of anti-seize on each screw.

END OF PROCEDURE

Appendix G

Procedure: MFR Head Temperature

A reliability weakness in the FRSR relates to the head temperature thermistor circuit. If the measured head temperature falls outside of a narrow range (37-43°C), data processing stops. Head calibrations are valid for temperatures around 40°C and thus measurements are marked missing when the temperature falls outside of this range.

Also, the heater circuit is not actuated when the thermistor circuit is open.

If the thermistor circuit shows an open condition:

- Check the voltage at TP22 (right edge of the board.). An open circuit will make this zero volts.
- Check the cable continuity. Open the plug backshells and look for bad solder connections. The thermistor connects to pin 1 and its excitation pin is 12.
- Connect 10K ohms between pins 1 and 12 at the receptacle at the PRP box. Use the FRSR menu to see the measured temperature. The measured temperature should be 25°C.

Appendix H

RAD Maintenance Notes

The RAD system is aimed at simplifying the difficult task of making measurements of shortwave and longwave radiation fluxes from a remote measurement site. The system was designed for ship deployments and to withstand corrosive atmospheres, severe wind and precipitation, and extreme heat. A general manual of the RAD is provided online at http://rmrco.com/prod/rad/rad manual v9.pdf .

This document is a brief overview of the maintenance required to properly maintain the RAD system in good working order so the radiation measurements will be as accurate as possible and the system will suffer minimal degradation from environmental stresses.

H.1 Isolating Dissimilar Metals

The output of the radiometers is often only a few tenths of a millivolt and the RAD input preamplifiers are typically 120 and 820 for the PSP and PIR respectively. Thus they are particularly sensitive to electromagnetic interference (EMI) which can be extreme in typical shipboard, mast-top installations. Thus the RAD is made to reside as close as possible to the radiometers and uses shielded cables for all connections. The RAD enclosure is an aluminum diecast box and the electronic circuit connects to case ground by a single-point ground.

Dissimilar metal corrosion. The RAD box is a powder-coated diecast 6061-T6 aluminum. Unfortunately, the box and backplate hardware are 316 stainless steel, which is very well suited for marine use, but great care must be taken to avoid corrosion. *It is not unusual for the lid screws to become so corroded that they cannot be removed and the lid has to be cut off.*

Non-metallic (UHMW plastic) plate is used for the box backplate and the radiometer plate. The backplate has tabs and holes for convenient mounting using hose clamps.

Rules

- Use nylon washers and insulators to insulate all hardware from the RAD box.
- Use nylon washers and insulators to separate the stainless bolts from the brass radiometer cases.
- Use anti-seize compound on all fasteners. Be sure to use lock washers or locking nuts.
- In the box, use sealing compound in the backplate mounting screw holes (Figure 28).
- Use silicone grease for the lid o-ring.

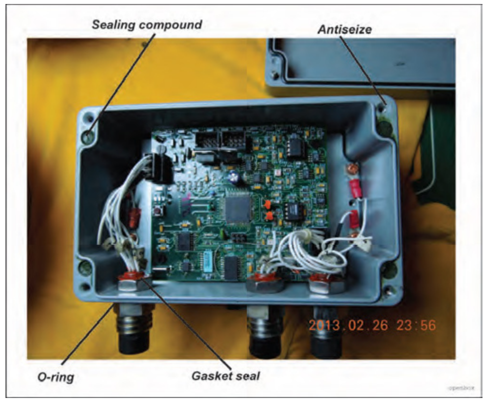

Figure 28. A new RAD enclosure ready for shipping. The backplate hardware is dipped in anti-seize and the holes for backplate hardware are sealed with sealing compound (also known as monkeysh*t). In the picture here the "o-ring" reference points to the o-ring under the three Impulse connectors. The lid has a soft o-ring that sits in a grove and seals against the raised ridge around the top. The lid o-ring should be greased with silicone grease before the lid is finally installed.

H.2 Installation and Grounding

Installation is covered in the manual. The only note here is to be sure the ground strap has a good contact with the ship. It may be necessary to scrape a bit of paint off of a railing or stanchion in order to get good contact.

The ground connection is prone to corrosion. Once it is made, the connection can be painted to help reduce the rate of corrosion. The grounding joint should be checked, visually and with an ohmmeter, on a regular basis (typically six months).

H.3 Radiometer Inspection and Cleaning

The radiometers need to be inspected on a regular basis.

Rules

- Corrosion. Watch for excessive corrosion. The Amphenol connectors used for the radiometers are not particularly suited for marine use (Figure 30).
- Rinse with fresh water. Use a small flask of fresh water to rinse off the radiometers and clean the domes. A regular rinse does wonders to reduce corrosion.
- Clean the domes. Dirt can be removed first by rinsing as above then by using a combination of wet then dry lintless optical wipes. Ordinary Kleenex such as Bounty has been recommended by some opticians as suitable. But avoid paper towels, which usually have an abrasive mixed in with the paper. Figure 29.
- The time between inspections depends on the environment. Tropical conditions with regular rainfall might not need cleaning more than once each few weeks. In situations where the ship exhaust

sometimes covers the installation, or dry dusty conditions prevail, actual conditions will dictate more regular cleaning.

Figure 29. An accumulation of dust on a PSP from the Saharan desert. The radiometer was on a ship operating in the Caribbean Sea and the deposit came across the Atlantic Ocean.

Figure 30. The PIR in this image was left unattended for several months on a tropical island in the Indian Ocean.

Figure 31. This enclosure has suffered severe water damage from a small nick in the connector o-ring. When the connector holes are drilled, the powder coat is broken. Normally, the receptacle o-ring prevents water getting into the break. After two years on a NOAA ship, salt water penetrated under the damaged o-ring and under the powder coat finish. Extra care is taken to assure the o-rings are perfect and a sealant is used to further protect the box.

Appendix I

PRP2 Critical Spare Parts

Table 20. Critical spare parts for PRP2 operations.

ITEM	MODULE	DESCRIPTION	PART#[(a)]	TECH LVL[(b)]	SOURCE
1	FRSR	Calibrated MFR head	10.01.06.01	1	ARM
2	FRSR	Cable	10.03.01	1	RMR Co.
3	FRSR	Shadowband	10.01.02.06.01	1	RMR Co.
4	CDU	Ethernetplugs	10.03.08	1	Newark# 25H6701
5	CDU	Onset TT8	10.02.01.01	2	ANL cache
6	—	Hose clamps	—	1	McMaster
7	RAD	Preamp INA118	10.03.34	2	DK# INA118P-ND
8	RAD	Preamp LTC1050A	10.03.34	3	DK# LTC1050CS8#PBF-ND
9	—	Silicone grease	04.30.14	1	McMaster# 1418K31
10	—	LokTite Blue	04.30.16	1	McMaster# 1810A3
11	—	Antisieze, marine grade	04.30.17	1	McMaster# 10045K23
12	RAD	#2 screws for shade plates		6	ARM

(a) Part numbers from RMR Co. archive. Contact the mentor for more detail.

(b) Technician levels are borrowed from
http://academicaffairs.ucsd.edu/_files/staffhr/classification/concepts-electech.pdf,
(1) Trainee/Novice (2) ET (3) Senior ET (4) Principal ET top

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Office of Science