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RADIATION MEASUREMENTS BY BROOKHAVEN NATIONAL
LABORATORY
DURING THE WOODS HOLE OCEANOGRAPHIC INSTITUTION
INTERCOMPARISON STUDY—MAY—JUNE 2000

R. Michael Reynolds, Mary Jane Bartholomew, Mark A. Miller,
Scott Smith and Ray Edwards

1 Dec 2000

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Radiation Measurement (ARM) program in association with national
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Radiation Measurements by Brookhaven National Laboratory during the Woods Hole Oceanographic Institution Intercomparison Study—May–June 2000

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1 Introduction

The WHOI buoy radiometer intercomparison took place during May and June, 2000 at the WHOI facility. The WHOI IMET, JAMSTEC Triton, and NOAA TAO buoy systems were operated from a beach site and the Brookhaven National Laboratory set up two Portable Radiation Package systems (P01 and P02) alongside the WHOI instrumentation on the roof of the Clark Building, about 300 m away (see cover photo). The BNL instruments were named "P01" and "P02" and were identical. Buoy instruments were all leveled to $\pm 1^\circ$ to horizontal.

The purpose of the project was to compare the buoy systems with precision measurements so that any differences in data collection or processing would be evaluated. BNL was pleased to participate so the PRP system could be evaluated as a calibration tool.

The Portable Radiation Package is an integral component of the BNL Shipboard Oceanographic and Atmospheric Radiation (SOAR) system. It is designed to make accurate downwelling radiation measurements, including the three solar irradiance components (direct normal, diffuse and global) at six narrowband channels, aerosol optical depth measurements, and broadband longwave and shortwave irradiance measurements.

Table 1: Participants in the WHOI Intercomparison.

ID	GROUP NAME	SER No.
PMEL600	Pacific Marine Environmental Laboratory Atlas package	600
PMEL601	Pacific Marine Environmental Laboratory Atlas package	601
WHOI 1	Woods Hole Oceanographic Institution IMET system	117
WHOI 2	Woods Hole Oceanographic Institution IMET system	126
JAM	TRITON instrumentation package from JAMSTEC	

2 BNL Portable Radiation Package

The complete radiation package, shown in Fig. 1, is an integration of five primary components: (1) a broadband Precision Spectral Pyranometer (PSP) manufactured by The Eppley Laboratory, Inc.; (2) a broadband Precision Infrared Radiometer (PIR) also manufactured by Eppley Lab.; (3) a preamplifier circuit that multiplies the microvolt signals from the broadband instrument to reduce noise interference; (4) the fast-rotating shadowband radiometer (FRSR); (5) an attitude sensor that measures platform pitch, roll, and azimuth; (6) a small, low-power control data unit (CDU) that performs data collection and operates the system; and (7) an uninterruptable power supply (UPS) that eliminates power surges, minimizes power supply noise, and supports wind or solar power operation for remote operation.

The control data unit (CDU) is custom-made and packaged in a waterproof housing that resides in close proximity to the sensors. The complete data logger package incorporates radio interference and surge protection, operates over a -40 to 65°C temperature range, and is waterproof and immune to shock and vibration. The low-level analog signals from the FRSR head are digitized with a high-speed 12-bit analog-to-digital converter circuit. The CDU communicates with a PC computer in a sheltered area. Compact data packets are transferred to the PC at the end of each sweep.

Portable Radiation Package system components

Figure 1: PRP setup on the BNL test bed.

Eppley Precision Spectral Pyranometer The Precision Spectral Pyranometer comprises a circular multi-junction Eppley thermopile of the plated (copper-constantan) wirewound type. Its receiver is coated with Parson's black lacquer (non-wavelength sensitive absorption). Two concentric hemispheres of Schott optical glass provide filtering of incident radiation and a pass band of from 285 to 2800 nm is achieved. The PSP has been used in shortwave radiation measurements extensively for the past 40 years.

The PSP used on the Portable Radiation Package is packaged in a water tight nylon case. The design here is identical to the nylon case packages used on the NOAA TAO buoy systems. The shading plate is retained.

Eppley Precision Infrared Radiometer The Precision Infrared Radiometer (PIR) is well described in two recent publications [Fairall *et al.*, 1998; Payne and Anderson, 1999] and does not need additional treatment here. The best means of achieving good calibration is by measuring the three output parameters (thermopile, case temperature, and dome temperature) and computing radiation by the modified calibration equation which was developed by Fairall *et al.* [1998].

A major step towards improved PIR measurements is to calibrate the case and dome thermistors. The YSI #44031 thermistors are specified to have an 0.1°C interchangeability, but in practice, this is not the case. If the published YSI table is used for estimating temperature, then PIR measurement uncertainty of 10 W m^{-2} can be expected [Reynolds *et al.*, 2000; Reynolds, 2000].

Fast Rotating Shadowband Radiometer The FRSR shadowband [Reynolds *et al.*, 2000] 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.

The multi-spectral FRSR head is manufactured by Yankee Environmental Systems, Inc. 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, 670, 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.

The FRSR head is modified to decrease its electrical response time to about one millisecond. The response of the silicone cell detector is well below one millisecond, but the internal preamplifiers in the stock head have integrating low-noise amplifiers which slow the overall response. The head response times are decreased by reducing their low-pass filter capacitors. This is accomplished easily and laboratory tests do not show additional noise in the measurements.

3 Experiment Methods

The two PRP systems were installed on the radiation platform on 15 May, 2000. An initial engineering problem occurred and was repaired immediately, so data from both systems began on 20 May (day 141). Both systems were installed and leveled on the platform, and aligned visually to north.

The serial output from the PRP control data units went to two ports of a PC operating WindowsNT. The software "PCAnywhere" was used over an internet link for full control of both systems from BNL. Using this method, data were downloaded and checked daily and there was no need to return to WHOI until the end of the experiment.

During this time the domes of the radiometers were not cleaned other than by normal rainfall.

4 Data Processing

The data processing procedure for the PRP is shown in Figure 2. The instrument operation software, called "PRPRX," produces a set of ASCII raw data files with extensions of "da0, da1, etc." On a sunny day the "da files" can be 10 MB in size.

A Note on Time Keeping: Both BNL instruments were operated by the same computer and thus maintained identical time bases. The computer was reset each Monday to Friday and the clock was set. Thus the time error for each recorded measurement was probably never more than 5 seconds. All data are recorded in UTC (Greenwich) standard time.

A Note on Averaging: In data averaging (2-minute, hourly, and daily) the recorded time is the time at the start of the averaging period. Two-minute and hourly averages are block averages that begin at the start of the time increment and include all data up to but not including the next increment.

Two-minute and hourly increments begin at 00 UTC and continue through the day. Daily averages of all quantities are computed for the **local standard time**. Shortwave (SW) daily averages are computed from 30-minutes before local sunrise to 30-minutes after sunset, and nighttime values are set to zero. SW daily averages are thus for the full 24-hour period based on local standard time. Longwave (LW) and other daily averages are likewise computed over the local 24-hour day.

4.1 Broadband Data

The broadband and support data are all contained in the “Da0” data files. The files are written for each day. Measurements of the PSP, PIR (thermopile, case and dome thermistors), pitch, roll, compass, and the FRSR head temperature are made two times during the shadowband cycle, and this represents the basic sampling period of approximately 3.4 sec. These are called the “Level 0” or raw data set.

The broadband measurements were analyzed according to the plan shown on the right side of the figure. The da0 files for each day (“Level 0” data) are read using Matlab routines. The recorded millivolts are combined with system calibration data to produce measurements in physical units. The 3.4 sec measurements are averaged into two-minute averaging blocks. The 2-min statistics (mean, standard deviation, minimum, and maximum values) are combined into single time series for the entire measurement period. These files are called “Level 1” data, meaning it has been peripherally cleaned and calibration equations were applied. At this point the case and dome temperatures are computed using the standard YSI tables.

The Level 1 data are then examined by hand using a special hand editing program written at BNL and using Matlab routines. The hand editing is absolutely essential where instrumentation is subject to RF interference, drop out, or other forms of contamination. The WHOI data set had a severe noise problem. Intermittant bursts of noise (Orbcon transmitters?) were picked up in the PSP and PIR thermopile signals. The bursts were quite obvious and were easily removed; they were quite short, no more than a few minutes. Any deleted data points were replaced by interpolation.

4.2 Fast Rotating Shadowband Radiometer Data

The spectral radiometer data from the Portable Radiation Package is processed by a series of Matlab routines that are described in *Reynolds et al.* [2000]. The “shadow value” (S), when the shadowband blocks the solar beam, the “edge value” (E), when the shadowband is just to the side of the solar disc, and the “global value” (G), when the shadowband is below the instrument horizon, are used to compute the solar direct beam irradiance, N , on a plane normal to the beam, the Diffuse irradiance (D), and the corrected global irradiance, G . The normal beam data are used to compute aerosol optical depths (AOD) of the overlying atmosphere.

4.3 The Clear Sky Algorithm

During data processing a “theoretical” clear sky algorithm, written in Matlab language, is used for comparison purposes. The clear sky algorithm we use is modified from a C program used by atmospheric scientists at Pennsylvania State University (Chuck Pavloski, personal communication). The solar flux calculation begins with a computation of the solar azimuth and zenith angle, both top of the atmosphere and refracted, using the algorithm by *Michalsky* [1988] [*Spencer*, 1989].

Given the solar position, a broadband solar flux estimate is computed using methods described by *Iqbal* [1988]. The Iqbal algorithm requires the following parameters other than the solar zenith angle: (a) integrated water vapor in gcm^{-2} , (b) surface pressure in hPa, (c) aerosol optical thickness (AOT) at 380 nm, (d) AOT at 500 nm, and (e) ozone-layer thickness in cm(NTP). For the theoretical curves shown in this study the following default parameter values best fit the measured data:

integrated water vapor = 1 gcm^{-2}

surface pressure = 1013 hPa

AOT(380 nm) = AOT(500 nm) = 0.1

ozone layer thickness = 0

Figure 2: Flow chart of data processing for the spectral information from the Fast Rotating Shadowband Radiometer and the broadband and support data.

5 Results

Broadband radiation measurements of SW and LW (PSP and PIR) were compared between the two BNL units. In all comparisons between SW and LW measurements the BNL Unit P02 is used as the reference. A comparison of the average results are given in the table below.

Table 2: Comparison of SW and LW measurements from different instruments during the time period of 5/20 (141) to 6/29 (181) when all equipment was operating. Values are in W m^{-2} . BNL and PMEL measurements are averaged over two minutes and WHOI are averaged over one minute. The JAMSTEC data are hourly values as these are all that were available.

MSMT	P01	P02	PMEL600	PMEL601	WHOI1	WHOI2	JAMSTEC	MEAN
SW	259	258	254	254	252	251	239*	255
LW	349	349	354	354	353	361*		351

* – excluded from the mean

With the exception of the WHOI-2 LW and the JAMSTEC SW measurements the different instruments all agree to within the 5 W m^{-2} goal for open ocean energy budget measurements. It is interesting to note that the two BNL units compare quite well to each other, but the SW is slightly higher and the LW lower than the other units. The BNL system was on the roof of the WHOI laboratory while the buoy instrumentation was on the beach road nearby. The differences are consistent with a slightly less cloudy and drier atmosphere at the BNL location.

Figure 3: Scatterplots comparing BNL PRP units 01 and 02. Hourly average data points are plotted. The upper panel shows the shortwave (PSP) data and the lower panel shows the longwave (PIR) comparisons.

Figure 4: Bar graph comparing daily SW and LW broadband measurements from PRP 01 and 02.

Table 3: Table of daily averages of broadband data for PRP serial numbers 01 and 02. Theoretical values are derived from the clear sky algorithm that is described in section 4.3.

BROOKHAVEN NATIONAL LABORATORY, ARM OCEAN PROGRAM, DAILY AVERAGES

EXPERIMENT: WHOI RADIOMETER INTERCOMPARISON, MAY AND JUNE 2000

LEVEL 2 RESULTS FROM PORTABLE RADIATION PACKAGES SN 01 AND 02

BROADBAND DATA -- PSP AND PIR ONLY UNITS = W/m²

DAYS COVERED : JD 143 THROUGH 192, YEAR 2000. Program run date: 06-Aug-2000 01:09:33

JD	YEAR	MO	DA	----- SW -----		----- LW -----		
				PSP01	PSP02	THEORY	PIR01	PIR02
143	2000	05	22	101.26	95.57	320.23	350.98	368.00
144	2000	05	23	266.93	262.13	321.76	340.15	351.45
145	2000	05	24	145.85	139.50	322.57	361.72	370.49
146	2000	05	25	249.11	248.60	323.33	334.32	342.97
147	2000	05	26	333.21	329.78	324.72	300.71	315.29
148	2000	05	27	300.49	296.20	325.38	303.58	319.63
149	2000	05	28	176.88	170.43	325.99	319.78	334.90
150	2000	05	29	228.88	222.50	326.55	313.15	329.66
151	2000	05	30	300.82	297.07	327.74	298.89	312.49
152	2000	05	31	319.42	316.38	328.19	327.03	342.70
153	2000	06	01	297.76	296.34	328.59	344.97	358.78
154	2000	06	02	303.48	298.23	329.62	364.62	376.31
155	2000	06	03	338.16	335.31	330.60	316.65	325.19
156	2000	06	04	348.43	345.42	330.83	296.65	309.52
157	2000	06	05	280.63	276.03	331.01	329.11	343.37
158	2000	06	06	33.19	28.10	331.83	371.23	381.87
159	2000	06	07	183.87	181.78	331.90	329.93	336.26
160	2000	06	08	278.36	280.19	332.60	316.65	328.86
161	2000	06	09	253.87	250.71	333.25	347.93	361.11
162	2000	06	10	319.84	317.92	333.15	347.28	360.90
163	2000	06	11	260.15	257.75	333.68	356.23	362.80
164	2000	06	12	53.00	46.83	334.16	375.91	375.52
165	2000	06	13	260.33	256.59	334.58	348.06	360.89
166	2000	06	14	213.93	211.01	334.98	355.33	368.44
167	2000	06	15	55.10	51.17	334.56	386.20	401.41
168	2000	06	16	293.41	291.05	334.80	378.64	390.02
169	2000	06	17	309.26	306.73	334.99	379.59	386.60
170	2000	06	18	192.42	187.90	335.12	373.16	385.60
171	2000	06	19	201.13	195.55	335.20	358.36	369.16
172	2000	06	20	335.02	334.22	335.22	328.92	341.10
173	2000	06	21	298.36	296.45	335.17	344.27	356.13
174	2000	06	22	157.27	154.02	334.38	381.31	395.14
175	2000	06	23	321.17	319.55	334.22	346.10	358.98
176	2000	06	24	316.09	312.67	334.70	330.96	344.12
177	2000	06	25	316.36	313.78	334.43	362.09	374.94
178	2000	06	26	206.82	202.76	334.09	409.78	418.86
179	2000	06	27	275.79	272.19	333.71	392.52	399.17
180	2000	06	28	250.70	248.14	333.26	364.93	367.73
181	2000	06	29	116.68	111.93	333.45	369.84	375.50
182	2000	06	30	281.15	278.30	332.89	348.73	358.13
183	2000	07	01	333.61	330.91	332.28	329.80	336.87
184	2000	07	02	333.66	330.02	332.29	337.53	345.50
185	2000	07	03	288.68	284.69	332.25	363.61	373.72
186	2000	07	04	216.94	213.37	331.47	397.22	409.01
187	2000	07	05	325.04	319.03	330.64	348.96	357.99
188	2000	07	06	332.70	329.45	329.75	324.55	334.62
189	2000	07	07	236.93	231.62	329.49	348.88	355.38
190	2000	07	08	313.30	309.48	328.49	314.85	322.19
191	2000	07	09	248.21	245.40	328.81	361.22	370.16

Figure 5: Scatterplots comparing PMEL Units 600 and 601 to BNL PRP 02. Hourly average data points are plotted.

Figure 6: Bar graph comparing PSP daily averages for PMEL Units 600 and 601 to BNL PRP 02.

Figure 7: Scatterplots comparing WHOI Units 1 and 2 to BNL PRP 02. Hourly average data points are plotted.

Figure 8: Scatterplots comparing JAMSTEC and P02 SW data. The upper plot is a scatter plot of hourly averages from JD 155 to 178. Note: the JAMSTEC data was in error by one hour, possibly a daylight savings time error, but when the correction was made the good correlation resulted.

5.1 FRSR

The Fast Rotating Shadowband Radiometer (FRSR), described in section 2 and in detail by *Reynolds et al.* [2000], makes measurements of the diffuse irradiance, D_n

Figure 9: Comparison of G , N , and D at λ_1 for P01 and P02. Axis units are in W m^{-2} . In this and the following plots each panel is a scattergram with P02 data on the ordinate (vertical) and P01 data on the abscissa (horizontal). The two solar components, diffuse (sky) and direct-beam normal irradiances, are separated and their sums are the global values.

Figure 10: Comparison of G , N , and D for Channels 2-7. Axis units are $\text{W m}^{-2} \text{ nm}^{-1}$.

Figure 11: Comparisons of TOA irradiance, adjusted for solar distance, I_0 , from three Langley analyses during the WHOI intercomparison period. The square symbol denotes, from Colina et al. [1996], the best estimate of TOA irradiance from astronomical and satellite measurements and the vertical lines are the uncertainty in these. The Langley estimates are shown by solid circles, and the vertical lines denote the estimated uncertainty in the estimate. To make the graph more readable, each Langley estimate is offset by 5 nm. In the Langley analysis the direct beam irradiance is measured during sunrise or sunset when the solar beam path through the atmosphere is widely varying. A plot of the log of beam irradiance versus the relative path length, by Beer's Law, will be a straight line whose slope is the atmospheric transmittance and whose intersection at zero path length is the TOA irradiance.

Acknowledgements

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References

- Colina, L., R. C. Bohlin, and F. Castelli, The 0.12–2.5 μ m absolute flux distribution of the sun for comparison with solar analog stars, *The Astronomical Journal*, 112, 307–315, 1996.
- Fairall, C. W., P. O. G. Persson, E. F. Bradley, R. E. Payne, and S. A. Anderson, A new look at calibration and use of eppley precision infrared radiometers. part i: Theory and application, *Jour. Atmos. and Oceanic Tech.*, 15, 1229–1242, 1998.
- Harrison, L., J. Michalsky, and J. Berndt, Automated multifilter rotating shadow-band radiometer: an instrument for optical depth and radiation measurements, *Jour. Applied Optics*, 33, 5118–5125, 1994.
- Iqbal, M., *Calculate direct solar irradiance using a parameterization technique*, pp. 196–242, World Scientific, 1988.
- Michalsky, J. J., The Astronomical Almanac's algorithm for approximate solar position (1950–2050), *Solar Energy*, 41, 227–235, 1988.
- Payne, R. E., and S. P. Anderson, A new look at calibration and use of eppley precision infrared radiometers. part ii: Calibration and use of the woods hole oceanographic institution improved meteorology precision infrared radiometer, *Jour. Atmos. and Oceanic Tech.*, 16, 739–751, 1999.
- Reynolds, R. M., Calibrating the precision infrared radiometer (pir) for the shipboard oceanographic and atmospheric radiation (soar) program, *Tech Report SOAR-00-02*, Brookhaven National Laboratory, Upton NY 11973, 2000.
- Reynolds, R. M., M. A. Miller, and M. J. Bartholomew, Design, operation, and calibration of a shipboard fast-rotating shadowband radiometer, *Jour. Atmos. and Oceanic Tech.*, 2000, in press.
- Spencer, J. W., Comments on The Astronomical Almanac's algorithm for approximate solar position (1950–2050), *Solar Energy*, 42, 353, 1989.

A PSP and PIR Time Series Plots

In this section we present Level 2 time series for the entire experiment.

Figure 12: BNL Summary for May 20-21 (JD141-142)

Figure 13: BNL Summary for May 22-28 (JD143-149).

Figure 14: BNL Summary for May 29-June 4 (JD150-156).

Figure 15: BNL Summary for June 5-11 (JD157-163).

Figure 16: BNL Summary for June 12-18 (JD164-170).

Figure 17: BNL Summary for June 19-25 (JD171-177).

Figure 18: BNL Summary for June 26–July 2 (JD178–184).

Figure 19: BNL Summary for July 3-9 (JD185-191).

Figure 20: BNL Summary for June 10-11 (JD192-193).

B AOT Time Series

Figure 21: AOT estimates for 26 May 2000 (JD147).

09-Aug-2000 14:20:07

09-Aug-2000 14:37:36

Figure 22: AOT estimates for 4 June 2000 (JD156).

06-Aug-2000 14:20:16

06-Aug-2000 14:37:45

Figure 23: AOT estimates for 10 June 2000 (JD162).

Figure 24: AOT estimates for 20 June 2000 (JD172).

08-Aug-2000 14:20:33

08-Aug-2000 14:38:04

Figure 25: AOT estimates for 23 June 2000 (JD175).

Figure 26: AOT estimates for 24 June 2000 (JD176).

Figure 27: AOT estimates for 25 June 2000 (JD177).

Figure 28: AOT estimates for 1 July 2000 (JD183).

Figure 29: AOT estimates for 5 July 2000 (JD187).

Figure 30: AOT estimates for 6 July 2000 (JD188).