MR00K08
Cruise Data Report
Equatorial Pacific, January 2001

R/V Mirai

Prepared for: SeaBASS Bio-optical Archive

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Table 1. List of Symbols and Abbreviations

Symbol	Description	Units
$E(\lambda)$	Instrument measured irradiance	$\mu W\ cm^{-2}\ nm^{-1}$
$E_d(\lambda)$	Downwelling spectral irradiance below the sea-surface	$\mu W\ cm^{-2}\ nm^{-1}$
$E_s(\lambda)$	Downwelling spectral irradiance just above the sea-surface	$\mu W\ cm^{-2}\ nm^{-1}$
$E_{lamp}(\lambda)$	Spectral irradiance of standard lamp at a specified distance	$\mu W\ cm^{-2}\ nm^{-1}$
$F1(\lambda)$	Reduction in Field of View due to differences in refractive index	dimensionless
$F2(\lambda)$	Immersion reflectance changes at window - water interface	dimensionless
$Imm(\lambda)$	Total spectral immersion effects	dimensionless
$L(\lambda)$	Instrument measured radiance	$\mu W\ cm^{-2}\ nm^{-1}\ sr^{-1}$
$L_u(\lambda)$	Upwelling spectral radiance below the sea-surface	$\mu W\ cm^{-2}\ nm^{-1}\ sr^{-1}$
$L_w(\lambda)$	Upwelling spectral radiance just above the sea-surface	$\mu W\ cm^{-2}\ nm^{-1}\ sr^{-1}$
$L_T(\lambda))$	Target Radiance	$\mu W\ cm^{-2}\ nm^{-1}\ sr^{-1}$
$\eta_g(\lambda)$	Relative spectral index of refraction of optical window	dimensionless
$\eta_W(\lambda)$	Relative spectral index of refraction of water	dimensionless
NASA	National Aeronautics and Space Administration (U.S. Space Agency)	
NIST	National Institute of Standards and Technology (U.S. Standards agency)	
ONR	Office of Naval Research	
$\rho(\lambda)$	Spectral reflectance of standard target	dimensionless
R_{rs}	Remote Sensing Reflectance	sr^{-1}

1. Scope

This document summarizes scientific investigations carried out by JAMSTEC and Dalhousie University onboard the R/V Mirai in the equatorial Pacific during January of 2001. It represents work supported by JAMSTEC, Dalhousie University, and the Office of Naval Research, HyCODE project.

2. Referenced Documents

RD 1 Mueller, J.L., and R.W. Austin, 1995: Ocean Optics Protocols for SeaWiFS Validation, Revision 1. NASA Tech. Memo. 104566, Vol. 25, S.B. Hooker, E.R. Firestone, and J.G. Acker, Eds., NASA Goddard Space Flight Center, Greenbelt, Maryland, 67 pp.

RD 2 JAMSTEC, April 2001: MR00-K08 Cruise Report

3. Background and Rationale

Satellite observations of the multi-spectral reflectance of the ocean's surface, as exemplified by the Coastal Zone Color Scanner (CZCS), the Ocean Color and Temperature Sensor (OCTS) and the Sea-Viewing, Wide Field of View Sensor (SeaWiFS), have transformed perceptions of optical variability in the sea.

The objectives of Dalhousie University during this cruise were several and included:

i. Evaluate the net vertical transport of energy associated with penetrating irradiance, for comparison with the net surface heat flux along an equatorial transect.

ii. Carry out a collaborative effort with JAMSTEC in the development and validation of bio–optical algorithms for use with the currently operating SeaWiFS satellite.

iii. To investigate the uptake rates of labeled ^{15}N-nitrate and labeled inorganic ^{13}C-carbon in simulated *in-situ* incubations to determine rates of new and total primary production along equatorial transect 160W to 145E.

iv. To collect shipboard shadow-band data that will be used to develop an algorithm for extracting global and diffuse sky irradiance. For comparison and proper validation of the algorithm the simultaneous sun-photometer data were collected.

4. Participants

Takeshi Kawano / Chief Scientist, JAMSTEC

Geoff MacIntyre M.Sc. / Research Associate, Dalhousie University

Masayuki Fujisaki / Technician, Marine Works Japan Ltd.

Gordana Lazin / Research Associate, Dalhousie University

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5. Mission Summary

Reflectance data were collected on a series of deployments from the R/V Mirai. The Mirai departed Hawaii on January 8, 2001 for a transect along the equator from 160W to 145E, and arrived at Guam on February 1, 2001. A large number of optical, biological, physical and chemical measurements were taken, including profiler and reference optical data.

5.1 Deployment Coordinates

The locations and dates of each station are summarized below.

Table 2. Summary of station locations and dates

Location	Date	Position
Honolulu	Jan 08, 2001	22°00N 158°00W
Stn14	Jan 12, 2001	0°00N 160°00W
Stn13	Jan 14, 2001	0°00N 166°00W
Stn12	Jan 15, 2001	0°00N 170°00W
Stn11	Jan 17, 2001	0°00N 177°00W
Stn10	Jan 19, 2001	0°00N 177°30E
Stn09	Jan 20, 2001	0°00N 175°00E
Stn08	Jan 22, 2001	0°00N 165°00E
Stn07	Jan 23, 2001	0°00N 162°00E
Stn06	Jan 24, 2001	0°00N 160°00E
Stn05	Jan 26, 2001	0°00N 156°00E
Stn04	Jan 27, 2001	0°00N 149°50E
Stn03	Jan 29, 2001	0°00N 145°00E

Table 3. Inventory of casts[1] – Locations and times

	Station ID	Cast	Date [UTC]	JD [UTC]	Start Time [UTC]	Stop Time [UTC]	Local Time	LAT Deg	LONG Deg	Cast name
	Stn03	B	29-Jan	29	1:45:40	1:48:57	11:45	0.01694S	145.9902E	mr00k08stn03b
	Stn03	C	29-Jan	29	1:51:33	1:54:51	11:51	0.01694S	145.9902E	mr00k08stn03c
	HStn03	A	29-Jan	29	2:02:08	2:10:23	12:01	0.01694S	145.9902E	mr00k08hypstn03a
	Stn04	A	27-Jan	27	1:47:17	1:49:37	11:47	0.00282S	149.8355E	mr00k08stn04a
	Stn04	B	27-Jan	27	1:53:48	1:57:19	11:53	0.00282S	149.8355E	mr00k08stn04b
	HStn04	A	27-Jan	27	2:05:29	2:13:44	12:03	0.00282S	149.8355E	mr00k08hypstn04a
	Stn05	A	26-Jan	26	1:31:17	1:32:19	11:34	0.00055N	155.8640E	mr00k08stn05a
	Stn05	B	26-Jan	26	1:37:54	1:41:09	11:38	0.00055N	155.8640E	mr00k08stn05b
	HStn05	A	26-Jan	26	1:57:16	2:05:46	11:57	0.00055N	155.8640E	mr00k08hypstn05a
	Stn06	A	24-Jan	24	0:37:17	0:40:33	11:37	0.04074N	159.9289E	mr00k08stn06a
	Stn06	B	24-Jan	24	0:42:59	0:43:48	11:43	0.04074N	159.9289E	mr00k08stn06b
	HStn06	A	24-Jan	24	0:51:52	1:00:06	11:51	0.04074N	159.9289E	mr00k08hypstn06a
	Stn07	A	23-Jan	23	0:43:22	0:46:27	11:43	0.00063N	162.0030E	mr00k08stn07a
	Stn07	B	23-Jan	23	0:49:11	0:49:53	11:49	0.00063N	162.0030E	mr00k08stn07b
	Stn07	C	23-Jan	23	0:51:19	0:54:22	11:51	0.00063N	162.0030E	mr00k08stn07c
	HStn07	A	23-Jan	23	1:03:16	1:11:30	12:00	0.00063N	162.0030E	mr00k08hypstn07a
	Stn08	A	22-Jan	22	0:38:33	0:40:19	11:38	0.00123S	165.0000E	mr00k08stn08a
	Stn08	B	22-Jan	22	0:43:17	0:46:20	11:43	0.00123S	165.0000E	mr00k08stn08b
	HStn08	A	22-Jan	22	0:58:10	1:06:24	12:03	0.00123S	165.0000E	mr00k08hypstn08a
	Stn09	A	19-Jan	19	23:43:03	23:46:00	11:43	0.04740N	174.8819E	mr00k08stn09a
REJECTED	Stn09	B	19-Jan	19	-	-	11:49	0.04740N	174.8819E	mr00k08stn09b
	HStn09	A	20-Jan	20	0:02:08	0:10:22	12:03	0.04740N	174.8819E	mr00k08hypstn09a
	Stn10	A	18-Jan	18	23:45:48	23:48:53	11:45	0.00061S	177.4979E	mr00k08stn10a
REJECTED	Stn10	B	18-Jan	18	-	-	11:51	0.00061S	177.4979E	mr00k08stn10b
	Stn10	C	18-Jan	18	23:55:22	23:58:24	11:55	0.00061S	177.4979E	mr00k08stn10c
	HStn10	A	19-Jan	19	0:08:23	0:16:39	12:04	0.00061S	177.4979E	mr00k08hypstn10a
	Stn11	A	16-Jan	16	23:47:06	23:50:03	11:47	0.00153N	176.7685W	mr00k08stn11a
	Stn11	B	16-Jan	16	23:54:09	23:57:24	11:54	0.00153N	176.7685W	mr00k08stn11b
	HStn11	A	17-Jan	17	0:06:26	0:14:42	12:04	0.00153N	176.7685W	mr00k08hypstn11a
	Stn12	A	14-Jan	14	22:36:45	22:39:55	11:36	0.01159N	170.2166W	mr00k08stn12a
	Stn12	B	14-Jan	14	22:43:13	22:46:24	11:43	0.01159N	170.2166W	mr00k08stn12b
	HStn12	A	14-Jan	14	22:57:21	23:05:35	11:57	0.01159N	170.2166W	mr00k08hypstn12a
	Stn13	A	13-Jan	13	22:45:48	22:49:04	11:45	0.00002N	166.3383W	mr00k08stn13a
	Stn13	B	13-Jan	13	22:52:53	22:56:10	11:53	0.00002N	166.3383W	mr00k08stn13b
	HStn13	A	13-Jan	13	23:06:14	23:14:29	12:03	0.00002N	166.3383W	mr00k08hypstn13a
	Stn14	A	11-Jan	11	22:40:33	22:44:01	11:44	0.00495N	160.0055W	mr00k08stn14a
	Stn14	B	11-Jan	11	22:47:17	22:50:40	11:50	0.00495N	160.0055W	mr00k08stn14b
	HStn14	A	11-Jan	11	23:02:49	23:11:05	12:05	0.00495N	160.0055W	mr00k08hypstn14a

[1] "HStn" Station ID's indicate HyperTSRB deployments, while "Stn" refers to SPMR/SMSR casts

Table 4. Inventory of casts – Environmental conditions and processing notes.

Station ID	Cast	SST deg. C	Air temp deg. C	cloud cover	cloud type	Sea cond. [m]	swell [m]	depth [m]	dark correction	Cast and Processing comments (bold comments from data processing)
Stn03	A	30	31	3/10ths	cumulus/haze	small swell	0.5	205	binned	clear, slight high haze, good cast
Stn03	B	30	31	3/10ths	cumulus/haze	small swell	0.5	205	binned	clear, slight high haze, good cast
HStn03	A	30	31	3/10ths	cumulus/haze	small swell	0.5		shutter	
Stn04	A	30	30	3/10ths	cumulus/haze	small swell	1.0	202	binned	**cut off at 150m due to high wispy clouds**
Stn04	B	30	30	3/10ths	cumulus/haze	small swell	1.0	203	binned	clear, slight high haze, good cast
HStn04	A	30	30	3/10ths	cumulus/haze	small swell	1.0		shutter	clouds comprise 20% of cast
Stn05	A	30	30	4/10ths	nimbus	whitecaps	1.5	100	binned	**cut off at 70m due to clouds**
Stn05	B	30	30	4/10ths	nimbus	whitecaps	1.5	200	binned	clear, good cast
HStn05	A	30	30	4/10ths	nimbus	whitecaps	1.5		shutter	clouds comprise 20% of cast
Stn06	A	29	29	5/10ths	cumulus	small swell	0.5	205	binned	clear, good cast
Stn06	B	29	29	5/10ths	cumulus	small swell	0.5	110	binned	**cut off at 55m due to clouds**
HStn06	A	29	29	5/10ths	cumulus	small swell	0.5		shutter	very cloudy; **disabled Prosoft deglitching**
Stn07	A	29	30	5/10ths	cumulus	small swell	1.0	200	binned	cloud at 170m
Stn07	B	29	30	5/10ths	cumulus	small swell	1.0	65	binned	**cut off at 50m due to clouds**
Stn07	C	29	30	5/10ths	cumulus	small swell	1.0	200	binned	clear, good cast
HStn07	A	29	30	5/10ths	cumulus	small swell	1.0		shutter	
Stn08	A	28	29	3/10ths	cumulus	small swell	1.0	120	binned	**PAR plot shows slight cloud below 80m**
Stn08	B	28	29	3/10ths	cumulus	small swell	1.0	200	binned	clear, good cast, cut off at 195m
HStn08	A	28	29	3/10ths	cumulus	small swell	1.0		shutter	clouds comprise 30% of cast
Stn09	A	28	28	3/10ths	cumulus	small swell	1.0	207	binned	clear, good cast, cut off at 200m
Stn09	B	28	28	3/10ths	cumulus	small swell	1.0	206	binned	**rejected due to clouds during first 80m**
HStn09	A	28	28	3/10ths	cumulus	small swell	1.0		shutter	clouds comprise 15% of cast
Stn10	A	28	28	6/10ths	cumulus-cirrus	whitecaps	1.0	206	binned	**PAR plot shows slight cloud in first 25m**
Stn10	B	28	28	6/10ths	cumulus-cirrus	whitecaps	1.0	150	binned	Cloud/variable light, **rejected due to clouds**
Stn10	C	28	28	6/10ths	cumulus-cirrus	whitecaps	1.0	206	binned	clear, good cast
HStn10	A	28	28	6/10ths	cumulus-cirrus	whitecaps	1.0		shutter	
Stn11	A	27	27	3/10ths	cirrus	whitecaps	1.0	205	binned	clear, good cast
Stn11	B	27	27	3/10ths	cirrus	whitecaps	1.0	205	binned	clear, good cast
HStn11	A	27	27	3/10ths	cirrus	whitecaps	1.0		shutter	clouds comprise 20% of cast
Stn12	A	26	26	2/10ths	high cirrus	whitecaps	1.0	205	binned	clear, good cast
Stn12	B	26	26	2/10ths	high cirrus	whitecaps	1.0	205	binned	clear, good cast
HStn12	A	26	26	2/10ths	high cirrus	whitecaps	1.0		shutter	
Stn13	A	26	26	clear	clear	whitecaps	1.0	200	binned	clear, good cast
Stn13	B	26	26	clear	clear	whitecaps	1.0	200	binned	**PAR plot shows slight cloud below 125m**
HStn13	A	26	26	clear	clear	whitecaps	1.0		shutter	
Stn14	A	26	26	clear	clear	whitecaps	1.0	200	binned	clear, good cast
Stn14	B	26	26	clear	clear	whitecaps	1.0	200	binned	clear, good cast
HStn14	A	26	26	clear	clear	whitecaps	1.0		shutter	

The location of data collection events, referenced to the stations above, are shown in Figure 1.

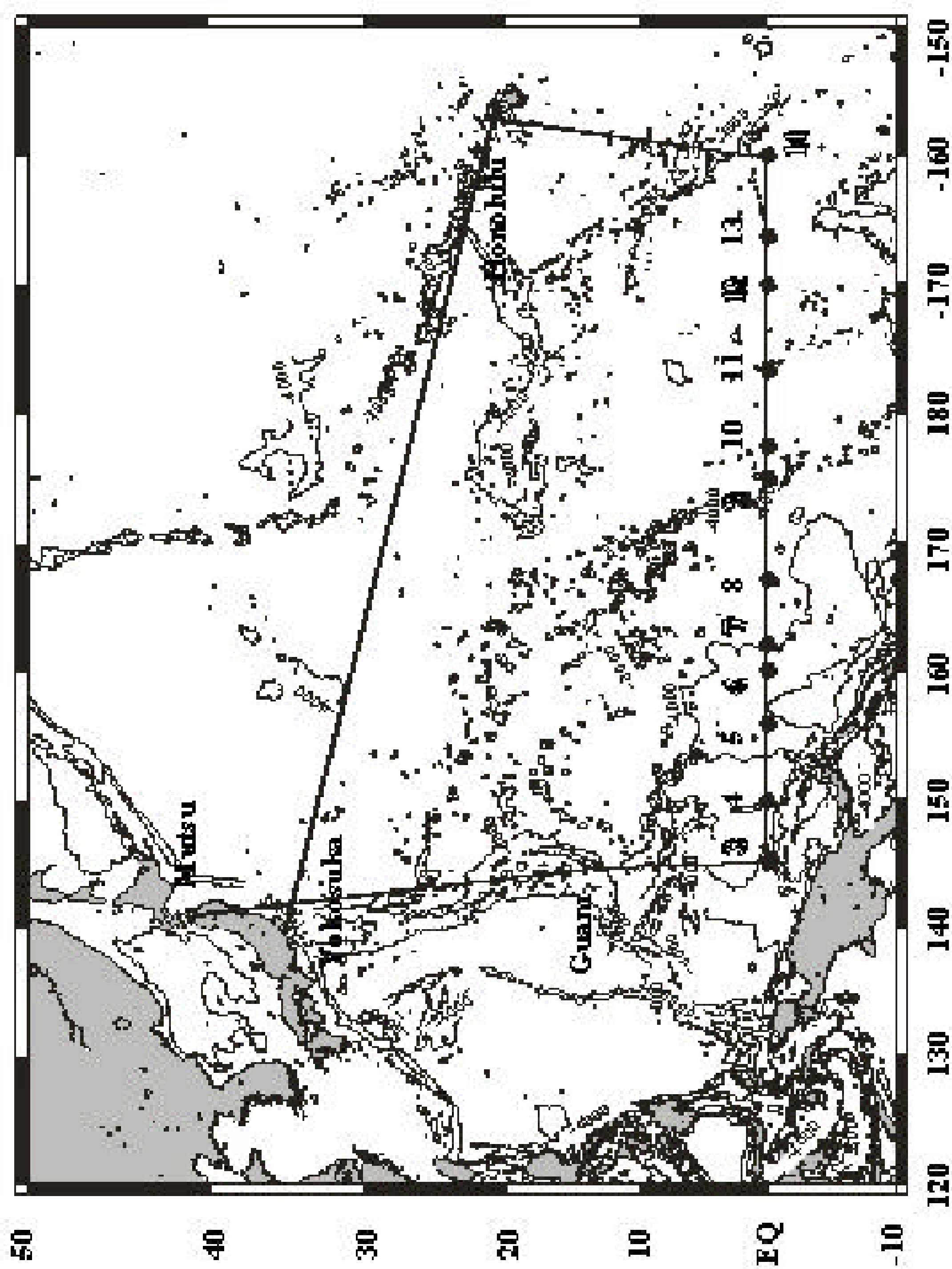

Figure 1. Cruise track for MR00K08

6. Description of Instruments Deployed and Data Collected

6.1 SPMR / SMSR

The primary instrument system deployed was the JAMSTEC SeaWiFS Profiling Multichannel Radiometer (SPMR) and SeaWiFS Multichannel Surface Reference (SMSR). The SPMR is deployed in a freefall mode through the water column while measuring the following physical and optical parameters.

The profiler carries both a 13-channel irradiance sensor (Ed) and a 13 channel radiance sensor (Lu), as well as instrument tilt, fluorometry, conductivity and an external temperature probe. The SMSR or reference sensor has a 13-channel irradiance sensor (Es), tilt meter and an internal temperature sensor. This instrument suite is used for the derivation of the penetration of visible and ultra–violet light in the ocean, and for determination of the vertical distribution of apparent optical properties for comparison with in–situ pigment measurements. It is used to provide normalized water leaving radiance for SeaWiFS calibration and validation and the empirical development of radiative transfer algorithms for the exploration of ocean color satellite data.

The profiler was deployed at least twice per station to a depth of 200m, timed as closely as possible to coincide with a SeaWiFS satellite overpass. Care was taken to attempt to obtain a full cast without clouds fully or partially occluding the sun. The reference was mounted on the compass deck and was never shadowed by any ship structures. The profiler fell at an average rate of $1ms^{-1}$ with tilts of less than 2 degrees.

These measurements provide data for the computation of key quantities required to characterize the underwater light field, such as profiles of reflectance, attenuation coefficients, photosynthetically available radiation (PAR), spectral water-leaving radiance, and remote sensing reflectance. These quantities are linked to the inherent optical properties of the ocean (IOP), and can be used to derive the concentration of sea-water constituents such as dissolved organic matter, suspended sediments, and the local chlorophyll concentration. The water-leaving radiance and remote sensing reflectance obtained from in-water profiles is the most accurate surface truth available for calibration/validation of ocean colour satellites.

Figure 2. Profiler configuration

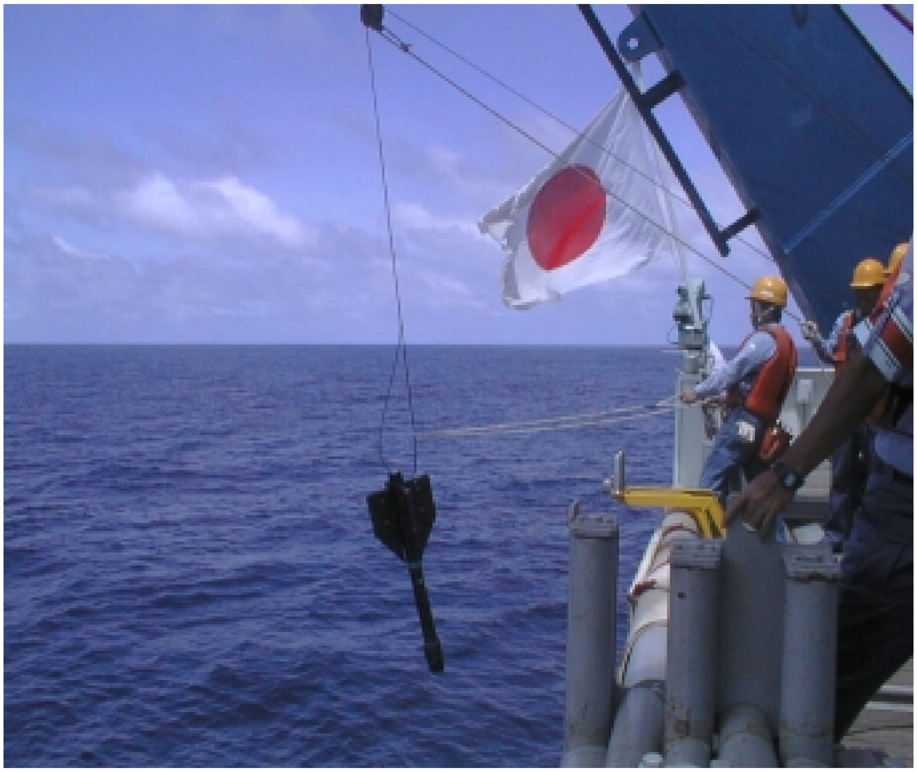

Figure 3. Profiler deployment

Table 5. Center wavelengths of the SPMR/SMSR

SMSR Es	379.5	399.6	412.2	442.8	456.1	490.9	519.0	554.3	564.5	619.5	665.6	683.0	705.9
SPMR Ed	380.0	399.7	412.4	442.9	455.2	489.4	519.8	554.9	565.1	619.3	665.5	682.8	705.2
SPMR Lu	380.3	399.8	412.4	442.8	455.8	489.6	519.3	554.5	564.6	619.2	665.6	682.6	704.5

Table 6. Specifications of the SPMR

Spatial Characteristics:		
Field of view	Irradiance	Cosine response
	Radiance	10° in water
Collector area	Irradiance	86.0mm^2
Entrance aperture	Radiance	9.5 mm diameter
Detector type	Irradiance	Custom 17mm^2 and 33mm^2 silicone photodiodes
	Radiance	Custom 13mm^2 and 33mm^2 silicone photodiodes
Spectral Characteristics:		
Number of channels	13	
Spectral bandwidth	10nm	
Bandwidth range	380-705nm	
Filter type	Custom low fluorescence interference	
Electrical specifications:		
Acquisition system	Two 14 channel 24bit DSP A/D system One 8 channel 16bit DSP A/D system	
System frame rate	10 Hz	
Data rate	57.6 kbps	
Data format	Binary	
Data interface	RS-422 / RS-232	
Power	56-80 VDC	
Telemetry	RS485 (RS485 to RS232 converter in deck unit)	
Physical specifications:		
Size	8.9 cm diameter x 122cm long	
Weight	15 kg	
Operating temp. range	-10°C to +60°C	
Depth rating	375m	

6.2 Hyperspectral TSRB

The second instrument deployed was the Dalhousie University Hyperspectral TSRB. This instrument has 80 downwelling irradiance channels and 80 upwelling radiance channels from 380 to 800nm. This buoy type instrument floats at the surface with its irradiance sensor just above the sea surface and its radiance sensor at 0.65m below the surface. The radiometers use high-quality 256-channel spectrographs to obtain hyperspectral data. Light is transferred to the spectrographs using fiber optic bundles. These bundles are connected to two entrance optic devices, one cosine corrected for vector irradiance (HSE), the other a baffled Gershun tube to provide radiance measurements in the standard configuration (HSL). High-speed 18-bit analog-to-digital converters provide data acquisition with a frame rate of 1Hz. Variable and adaptive integration times are used for both the radiance and irradiance spectrometers.

A feature of the Hyperspectral TSRB is the addition of an optical shutter to both the radiance and irradiance spectrometers. This feature allows for dark readings during deployment. Currently, the shutter is configured to activate after every 5th frame. On the 6th frame, the shutter covers the spectrometers' optical openings, and a new measurement is taken. This allows the investigator to obtain real time dark correction. Hyperspectral TSRB deployments were performed immediately after the last profiler cast at every station.

Figure 4. Hyperspectral TSRB deployment

Figure 5. Hyperspectral TSRB and Profiler

Table 7. Specifications of the Hyperspectral TSRB

Optical Specifications:		
Spectral range	400-800nm	
Entrance slit	70 x 2500µm	
Detector type	256 channel Silicon photodiode array	
Pixel size	25 x 2500µm	
Spectral sampling	3.3nm/pixel	
Spectral resolution	10nm (3 pixel slit image)	
Spectral accuracy	0.3nm	
Stray light	$< 1x10^{-3}$	
Field of view	Irradiance	Cosine corrected single collector
	Radiance	8.5° half angle baffled Gershun tube
Electrical specifications:		
Acquisition module	18-bit A/D	
Digital resolution	16 bits	
Frame rate	1 Hz	
Data rate	38.4 kbps	
Data format	Binary	
Data interface	RS-485	
Power	20-60 VDC at 9 Watts.	
Telemetry options	Real time	
Physical specifications:		
Size	3.5" diameter x 48" long buoy (total length)	
Weight	7 kg	
Operating temp. range	-10°C to +40°C	
Absolute maximum spectrometer storage temperature range	-40°C to +60°C	

6.3 Characterization

The instruments are characterized according to the detailed community consensus measurements embodied in SeaWiFS Technical Memorandum, Vol. 25 (RD 3), augmented with advances made by Satlantic in conjunction with NASA and NIST.

Spectral Range

The spectral range is determined by the nature of the spectrometer, the specifications of which are given by the manufacturer. The manufacturer's specifications are cross-checked by viewing a NIST standard source of spectral irradiance, and by viewing lamps with known spectral lines. The spectral range includes the wavebands from 400 to 800nm.

Spectral Resolution

The spectral resolution is determined by the nature of the spectrometer, the specifications of which are given by the manufacturer. The spectral resolution is 10nm.

Spectral Accuracy

The spectral accuracy is determined to within +/- 0.3nm from the calibration sheet provided by the manufacturer.

Field of View

Field of view of the radiance sensor is determined by placing the instrument in a stepper motor controlled rotation table, and performing a rotation about the entrance optics center of rotation in a collimated light beam. The accuracy and precision of the measurement is 0.1 degrees and 0.05 degrees respectively.

Linearity

The linearity of the instrument is determined by placing the instrument on an optical bench, viewing a collimated beam from a 1kW arc source. A series of calibrated neutral density screens are placed in the beam allowing the intensity to be varied by a factor of 1000. The system is linear to less than 1% over the measured range.

Cosine Response

The cosine response of the radiance sensor is determined by placing the instrument in a stepper motor controlled rotation table, and performing a rotation about the entrance optics center of rotation in a collimated light beam. The accuracy and precision of the measurement is 0.1 degrees and 0.05 degrees respectively. The acceptable range of response is within 3% from 0 to 60 degrees, and 10% from 60 to 85 degrees of the perfect cosine response to angle of incidence.

Thermal Response

The thermal response of the dark current is compensated for by using a shutter that measures the dark current every 6 frames. The thermal effects to responsivity are compensated by correction factors if the change in response is greater than 1% from the calibration values. This correction factor is measured by viewing a calibration source while the instrument is thermally stabilized at 5, 10, 15, 25, 30°C (calibrations are done in a thermally controlled room at 20°C±1°C).

Immersion Effects (Radiance)

Due to the difference in indices of refraction between air (where the instrument is characterized and calibrated) and water (where it is operated), a correction factor must be applied to obtain the effective in water radiances. This correction factor is referred to as the immersion factor. There are two effects contributing. First, the reduction in solid angle viewed by the sensors effectively reduces the amount of flux into the sensor. This correction is given by F1:

$$F1(\lambda) = (\eta_W(\lambda))^2$$

where η_W is the index of refraction of water.

To correct for the calibration values in air, the in-water values are multiplied by the effective loss of viewing area in water (F1).

The second effect is due to the change in index of refraction at the glass/air (glass/water) interface. This correction is given by F2:

$$F2(\lambda) = (\eta_w(\lambda) + \eta_g(\lambda))^2 / ((\eta_w(\lambda) \cdot (1 + \eta_g(\lambda))^2)$$

where η_g is the index of refraction of the window.

Since the indices of refraction of water and glass are better matched, there are less reflection losses at the window. The immersion factor thus increases the in-water values to correct for this effect.

The total immersion effect is then:

$$Imm(\lambda) = F1(\lambda) \cdot F2(\lambda)$$

Thus the correction for actual in-water radiance values is:

$$L_{wl}(\lambda) = L\ (\lambda) \cdot Imm(\lambda)$$

6.4 Calibration

Each instrument is calibrated according to the detailed community consensus procedures embodied in SeaWiFS Technical Memorandum, Vol. 25 (RD 3), augmented with advances made by Satlantic in conjunction with NASA and NIST.

Absolute Radiometric Calibration, Radiance

Absolute radiometric radiance calibration is performed with a calibrated 1000W FEL lamp on a 5m optical bar using the 'plaque method'. The lamp is powered by an Optronics 83A current source. The flux from the lamp is normally incident on a 50cm diffuse reflectance target standard at a distance of *D* cm. The instrument views the target at an angle of 45.0° such that the field of view of all the sensors is completely covered by the target. The calibration radiances are determined using:

$$L(\lambda) = (E_{lamp}(\lambda, 50\text{cm}) / \pi) * (50.0 \text{ cm} / D \text{ cm})^2 * \rho(\lambda)$$

where:

$L(\lambda)$ is the calibration radiance

E_{lamp} (λ,50cm) is the lamp standard spectral irradiance at 50cm

$(50.0 \text{ cm} / D \text{ cm})^2$ is the $1/r^2$ distance

$\rho(\lambda)$ is the target standard reflectance

Reflection Target: (Labsphere, calibration traceable to NIST)

Standard Lamp: (Optronics, calibration traceable to NIST)

The demonstrated uncertainty in this method is <3% absolute and <1% relative.

Absolute Radiometric Calibration, Irradiance

Absolute radiometric irradiance calibration is done using a calibrated 1000W FEL on a 5m optical bar using direct radiation from the lamp. The lamp is powered by an Optronics 83A current source. The flux from the lamp is normally incident on the irradiance sensor cosine collector at a distance of 50cm. The calibration irradiances are determined using equation 2:

$$E(\lambda) = E_{\text{lamp}}(\lambda, 50\text{cm}) \cdot (50.0 \text{ cm}/ 50 \text{ cm})^2$$

where:

$E(\lambda)$ is the calibration irradiance

$E(\lambda$, 50 cm) is the lamp calibration at 50 cm

$(50.0 \text{ cm}/50 \text{ cm})^2$ is the lamp $1/R^2$ distance

Standard Lamp: Optronics, traceable to NIST standard

The demonstrated uncertainty in this method is <3% absolute and <1% relative.

6.5 Overview of Data Types

6.5.1 Reflectances and Profiles

The objective of this activity is the collection and collation of a library of reflectance signatures of the ocean, the "Ocean Background".

i. Underwater reference upwelling radiance ($L_u(\lambda)$), at a depth of 0.65 meters

ii. Above water reference downwelling irradiance ($E_s(\lambda)$)

iii. Underwater profiler downwelling irradiance ($E_d(\lambda)$) of the water column

iv. Underwater profiler upwelling radiance ($L_u(\lambda)$) of the water column

A data collection event includes ancillary data taken coincidentally with the radiance and irradiance measurement ("Instrument Measurement Data"). The following observations were recorded:

i. Instrument Measurement Data

ii. Time and location of acquisition

Instrument Measurement Data was acquired and processed as follows:

i. Level 1 data (time series sample data, in digital instrument counts) was acquired from the sensors onboard the platform.

ii. Level 2 data (calibrated physical units, i.e. $\mu W\ cm^{-2}\ nm^{-1}$ for irradiance; $\mu W\ cm^{-2}\ nm^{-1}\ sr^{-1}$ for radiance) was generated using standard instrument software and calibration coefficients derived from a rigorous controlled laboratory absolute radiometric calibration.

iii. Level 3 data (derived and interpolated spectrum, time- and depth-binned for Hyperspectral TSRB and SPMR/SMSR respectively) was generated using standard instrument software.

iv. Level 4 data (computed reflectance spectrum and propagated surface properties) was generated using standard instrument software.

The ocean background reflectance (Level 4) is derived by analysis of the base measurement data. This analysis was performed using Satlantic software. The measurement of spectral upwelling radiance was propagated to, and through the sea-surface using radiative transfer calculations to provide the water-leaving radiances ($L_w(\lambda)$). These values were then normalized by the downwelling spectral irradiance to compute the remote sensing reflectance, $R_{rs}=Lw(\lambda)/E_s(\lambda)$.

6.5.2 Chlorophyll-*a*

At each cruise station, water samples were collected for the measurement of various properties, including chlorophyll-*a*. An estimate of chlorophyll-*a* distributions in the equatorial Pacific was made using fluorometric analysis and HPLC. Results for the HPLC measurements are not available at this time. The remainder of this section paraphrases the fluorometric chlorophyll-*a* measurement methods outlined in the JAMSTEC MIRAI Cruise Report (RD2).

Chlorophyll-*a* measurements were carried out using broadband and narrowband filter fluorometers. Broadband filter fluorometers are commonly used for measuring chlorophyll concentrations, but it is recognized that the acidification technique results in errors when chlorophyll-b is present. The new non-acidification method developed by Welschmeyer (1994) for narrowband filter fluorometers eliminates the effect of acidification error. Narrowband and broadband filter fluorometers are identical, with the exception of their excitation and emission filters and lamp. Though the Welschmeyer method alleviates the need to consider acidification error, an overestimation of chlorophyll-*a* concentration is still introduced, especially when chlorophyll-b is present.

During the cruise, seawater samples were collected at the twelve stations (see Table 2). Samples were collected at 14 depths from 0m to 200m using Niskin bottles, except for the surface water, which was taken by bucket. The samples (0.5L volume) were gently filtered by low vacuum pressure (<20 cmHg) through Nucleopore filters (pore size: 0.4µm; diameter: 47 mm) in the dark room. The sample filters were immediately extracted in the N,N-dimethylformamide (7 ml) and stored at –30 °C until the analysis, which was performed at room temperature.

Traditional acidification and Welschmeyer non-acidification methods were carried out using a Turner design model 10-AU-005 fluorometer. Analytical conditions of the two methods are indicated in Table .

Table 8 Characteristics of Turner fluorometer for chlorophyll-*a* measurements

	Traditional method	**Welschmeyer method**
Excitation filter /nm	5-60 (340-500nm)	436nm
Emission filter /nm	2-64 (>665nm)	680nm
Optical kit	10-037R	10-040R
Lamp	Daylight White F4T5D	Blue F4T5, B2/BP (F4T4, 5B2 equiv.)
Acidification	Yes (1M HCl, 1min.)	No

6.6 Quality Assurance

Several layers of quality assurance were taken during the measurement program. The laboratory calibration provides a first order assurance in that the instrument response is referenced to an internationally traceable reference standard. This calibration took place immediately prior to and after the field program. Deviations greater than 3% in calibration coefficients are flagged for further investigation via controlled laboratory re-calibration checks. No deviations were noted.

During each field deployment, the operator views the spectrum of both upwelling radiance and downwelling irradiance. Visually identifiable departures from “normal” spectra are noted and are flagged for further investigation via controlled laboratory re-calibration checks.

7. Data Reduction/Analysis

The data collection is followed by a defined series of analysis steps, which reduce the collected data to geo-referenced, calibrated, and averaged data products for further statistical analysis. The steps include calibration, time- or depth-binning, and derivation of products, and encompass transitions from Level 1 (raw data) to Level 4 (derived products). The analysis is carried out by the software package ProSoft (Ver. 6.3) developed by Satlantic (copies available on request).

Collected and processed data archiving and organization is based on the level of processing. Data processing was divided into four levels: Level 1, 2, 3 and 4.

- RAW – Level 1 binary data obtained as a result of data acquisition. **(not submitted)**
- REF – Level 2 ASCII data obtained as a result of SMSR and HyperTSRB reference data calibration and some filtration. **(not submitted)**
- PRO – Level 2 ASCII data obtained as a result of SPMR profiler data calibration and some filtration. **(not submitted)**
- BIN – Level 3 ASCII data obtained by depth-binning SPMR/SMSR PRO/REF data and time-binning HyperTSRB REF data. **(submitted)**
- Level 4 files:
    - SPR – ASCII subsurface product for both SPMR/SMSR and HyperTSRB, containing all casts, one per line, obtained from BIN data averaging and data propagation to subsurface level. **(submitted)**
- PNG – Data plots for all casts. **(submitted PNG images within MR00K08-PLOTS.zip)**

7.1 Level 1 to Level 2 Conversion

The first step in the analysis of the data is the conversion from Level 1 to Level 2 calibrated, dark corrected data. Calibration files are used, along with calibration darks for the SMSR, binned darks (from the minimum layer) for the SPMR, and shutter darks for the HyperTSRB, to derive upwelling radiances ($L_u(\lambda)$), and downwelling irradiances ($E_s(\lambda)$), in calibrated physical units ($\mu W\ cm^{-2}\ nm^{-1}\ sr^{-1}$ and $\mu W\ cm^{-2}\ nm^{-1}$ respectively). The steps involved are:

1. Convert raw binary optical (light and dark) and ancillary data into an integer representation in counts.

2. Convert data counts into engineering units in accordance with the calibration equations (see *Satlantic Instrument File Standard V6.0*). The calibration equation for optical data is:

$$L_{DarktDat} = L_{CountsDarkDat} \cdot a \cdot ic \frac{it_1}{it_2}$$

$$L_{LightDat} = L_{CountsLightDat} \cdot a \cdot ic \frac{it_1}{it_2} \qquad (1)$$

   where a is a slope, ic is an immersion coefficient, it_1 is the first integration time and it_2 is the second integration time. a, ic and it_2 are taken from a calibration file, and it_1 is obtained from the same log file as optical data.

3. Check the sequence of frame numbers. Blank the frames that are out of sequence.

4. Deglitch shutter dark data using a first difference filter (optional step for HyperTSRB shutter darks only).

5. Smooth shutter darks using a running boxcar filter (HyperTSRB only).

6. Interpolate shutter darks as a function of measurement time to match the number of dark and light data measurements (HyperTSRB only).

7. Dark correct the light data:

$$L = L_{LightDat} - L_{DarkDat} \qquad (2)$$

8. Correct light data using a derived temperature correction:

$$L = \frac{L}{0.01\left(c_1 \cdot w^3 + c_2 \cdot w^2 + c_3 \cdot w + c_4\right)\left(T - 20\right) + 1} \qquad (3)$$

   where c_1, c_2, c_3 and c_4 are constants, w is wavelength and T is temperature of the radiance or irradiance sensor (here c_1 = 6.79131e-9, c_2 = -1.09902e-5, c_3 = 6.51646e-3, c_4 = -1.31056).

7.2 Level 2 to Level 3 Conversion

The calibrated Level 2 data includes measured radiances, irradiances and ancillary data types. For the HyperTSRB, the nature of the spectrometer is such that the specific center wavelengths do not match precisely. In the Level 3 conversion, there are two options. The radiance and irradiance spectra can be interpolated using a linear interpolator, and the interpolated spectra subsampled at center wavelengths chosen by the operator. Alternatively, optical data can be used at the original wavelengths. For this dataset, the original wavelengths were retained for the hyperspectral instruments. Additionally, the SPMR/SMSR data is depth-binned and the Hyperspectral TSRB data is time-binned to an operator controlled frequency to reduce temporal noise of environmental nature. For this experiment, the binning interval chosen was 1 meter for the profiler and 2 seconds for the Hyperspectral TSRB. The steps of the binning process are:

1. Interpolation of optical data into 1nm wavelength intervals (not performed for this dataset).
2. Natural logarithm transformation of the Level 2 optical data.
3. Data binning. In the case of the Hyperspectral TSRB, only reference data is present and the data is divided into equal 2 seconds subintervals. Data division does not rely on a constant data-recording rate but rather divides the whole time interval into 2 second subintervals. The binning algorithm searches for data recorded within each interval including starting and ending times. Since it is assumed that a starting time and an ending time of the two consecutive subintervals overlap, the number of points within each subinterval could vary from 2 to 3. In the case of the SPMR/SMSR, the optical data consists of both profiler and reference data, and the optical data is instead divided into equal depth layers. The number of data points within each layer could vary (since profiler's falling speed is not constant).
4. Data averaging.
5. Application of exponent to mean log transformed data.

7.3 Level 3 to Level 4 Conversion

The Level 3 data serve as the basis for the production of a number of derived information products. For the Hyperspectral TSRB, two are relevant: the "Surface Products", and the "Remote Sensing Reflectance". For the SPMR/SMSR, the "Diffuse attenuation coefficient" is also relevant. These represent a series of mathematical manipulations of the data in the Level 3 files. The "Surface Products" represent the propagation of both radiance and irradiance to a common depth horizon, which is specified as just below the sea surface. For upwelling radiance taken at some depth below the sea-surface (0.65m in the case of the Hyperspectral TSRB), the radiance just below the surface is estimated by first computing the spectral attenuation coefficient for spectral radiance based on statistical computations using a ratio of blue to green wavebands as input. This attenuation coefficient governs the propagation of radiance to the surface based on an exponential model, and this model is used to determine the upwelling radiance just below the sea-surface. For irradiance, the above-water measurement is used and propagated through the sea-surface using an estimated albedo.

SPMR/SMSR subsurface values are derived from the near-surface data recorded at the start of a cast. For HyperTSRB subsurface values, all the data for a cast are averaged into a single radiance and a single irradiance spectrum. Each set of these spectra is then combined to produce the Level 4 data.

The specific steps used for the HyperTSRB are:

1. For each optical data channel calculate a median value.
2. Calculate diffuse attenuation coefficient K_{ap} for each channel using Austin–Petzold and Morel models.
3. Propagate mean optical data to subsurface z(0_) level.

Remote sensing reflectances are produced by propagating the radiance at a level just below the sea-surface through the surface by use of Fresnel reflectances, giving water-leaving radiances (Lw(λ)). These are then divided by the above-water irradiances on a band by band basis to produce remote sensing reflectances.

7.4 Processing Configurations

7.4.1 SPMR / SMSR

- Pressure Tare performed with Ed sensor just below surface
- Ed – Lu distance (1.14m)
- Es distance to surface (0m)
- Dark correction: calibration file used for SMSR; minimum layer darks used for SPMR
- Number of bins regressed for computing K (NUM_K_BINS) = 11
- 1m binning interval

7.4.2 Hyperspectral TSRB

- Es distance to surface (0m)
- Ls distance to surface (0.65cm)
- Shutter darks used for dark correction
- Binning interval: 2 seconds.

8. Data SUBMISSION

This SeaBASS data submission includes the following:

Table 9. Data Submitted

Data type	Comments
SPMR/SMSR depth-binned data	Level 3 depth-binned data (BIN) files
HyperTSRB time-binned data	Level 3 time averaged data (BIN) files
SPMR/SMSR subsurface data	Level 4 subsurface spectra data (SPR) file
HyperTSRB subsurface data	Level 4 subsurface mean spectra data (SPR) file
Data plots (PNG image files)	Data plots for each station (MR00K08-PLOTS.ZIP)

9. Sample Plots

Sample plots from the westernmost (bluest water) and easternmost station casts are included below. The complete set of plots for all casts is included with the submission in the file MR00K08-PLOTS.zip.

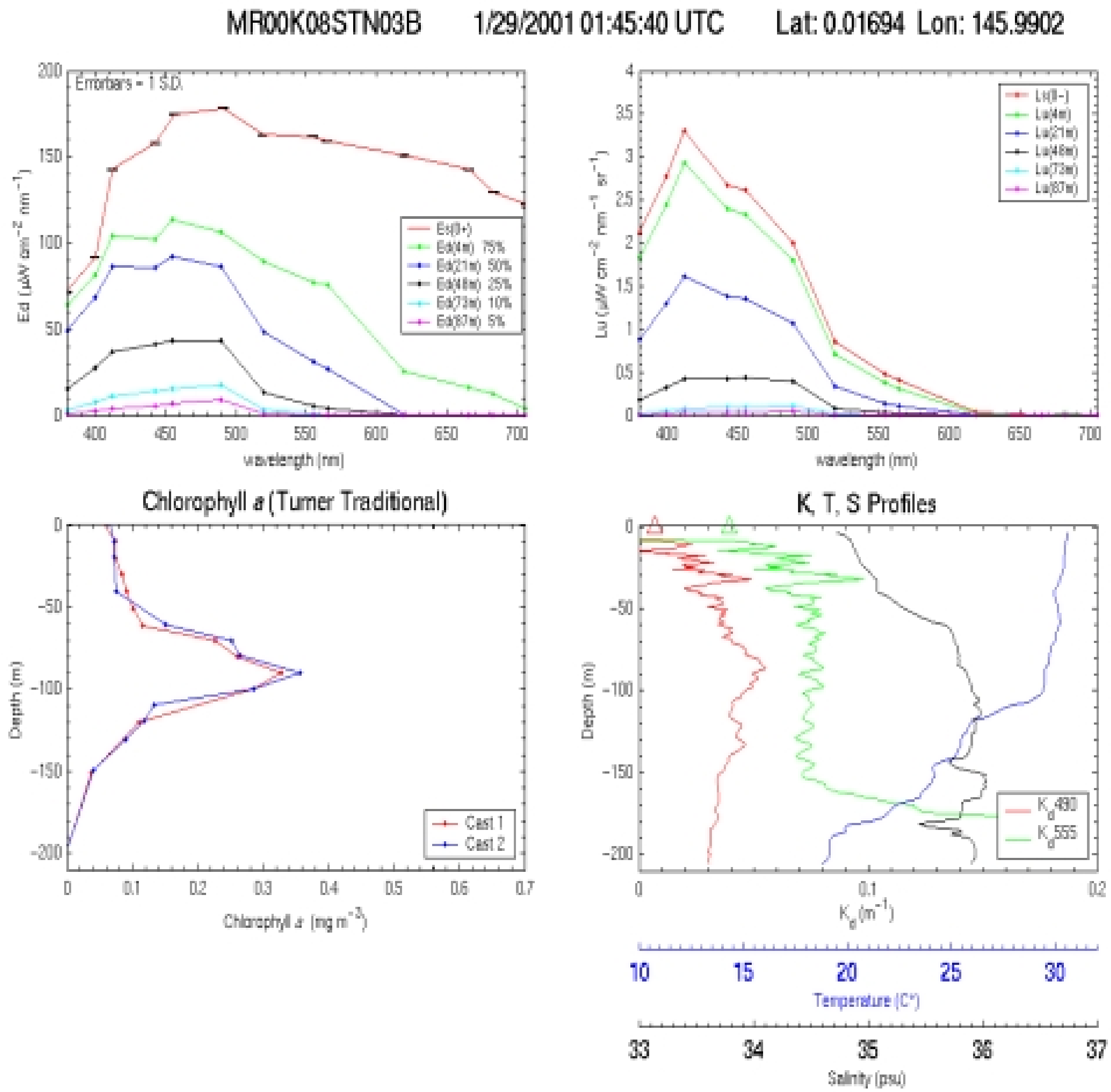

Figure 6. Sample plot 1 for Station MR00K08STN03, Cast B

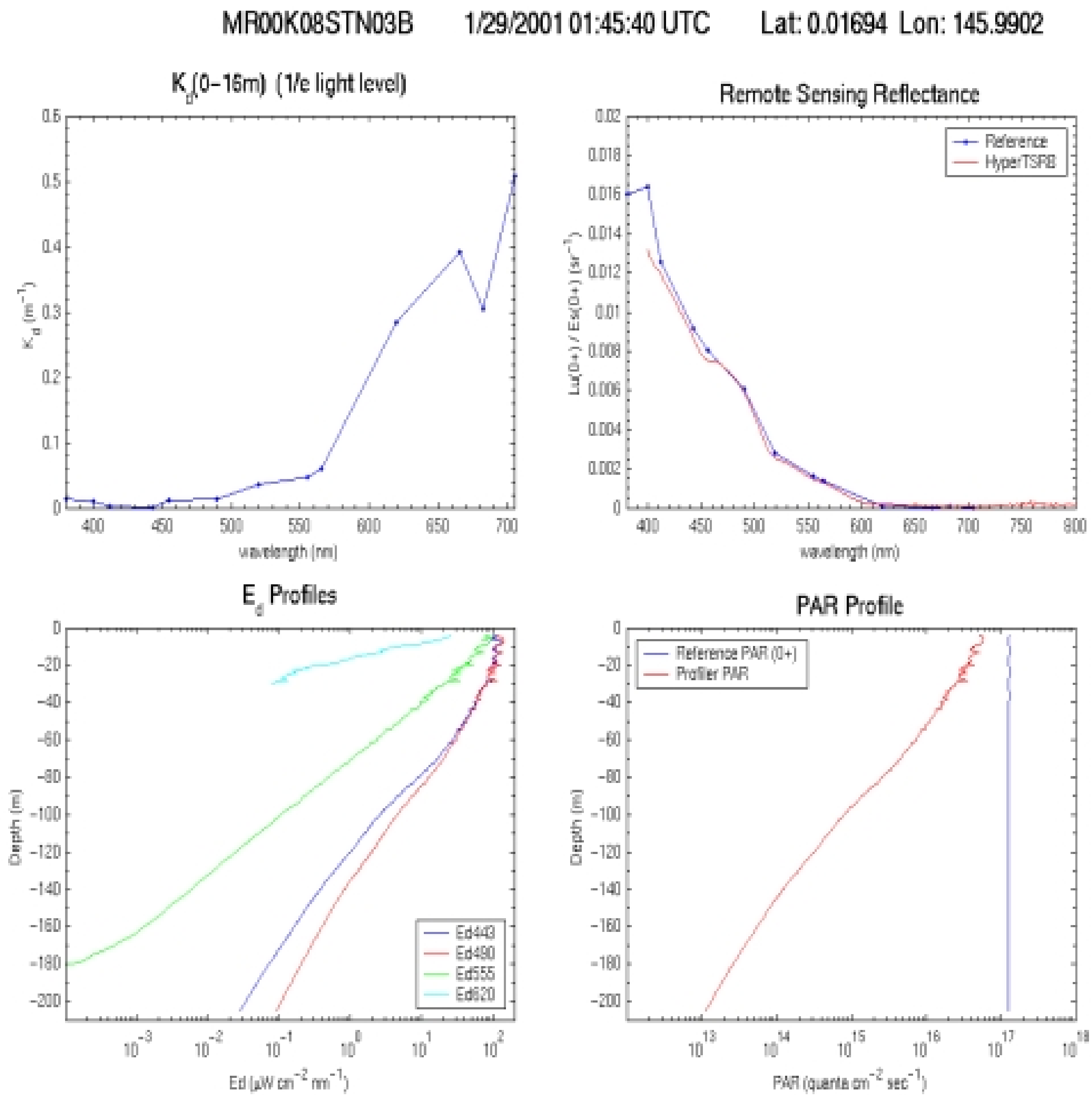

Figure 7. Sample plot 2 for Station MR00K08STN03, Cast B

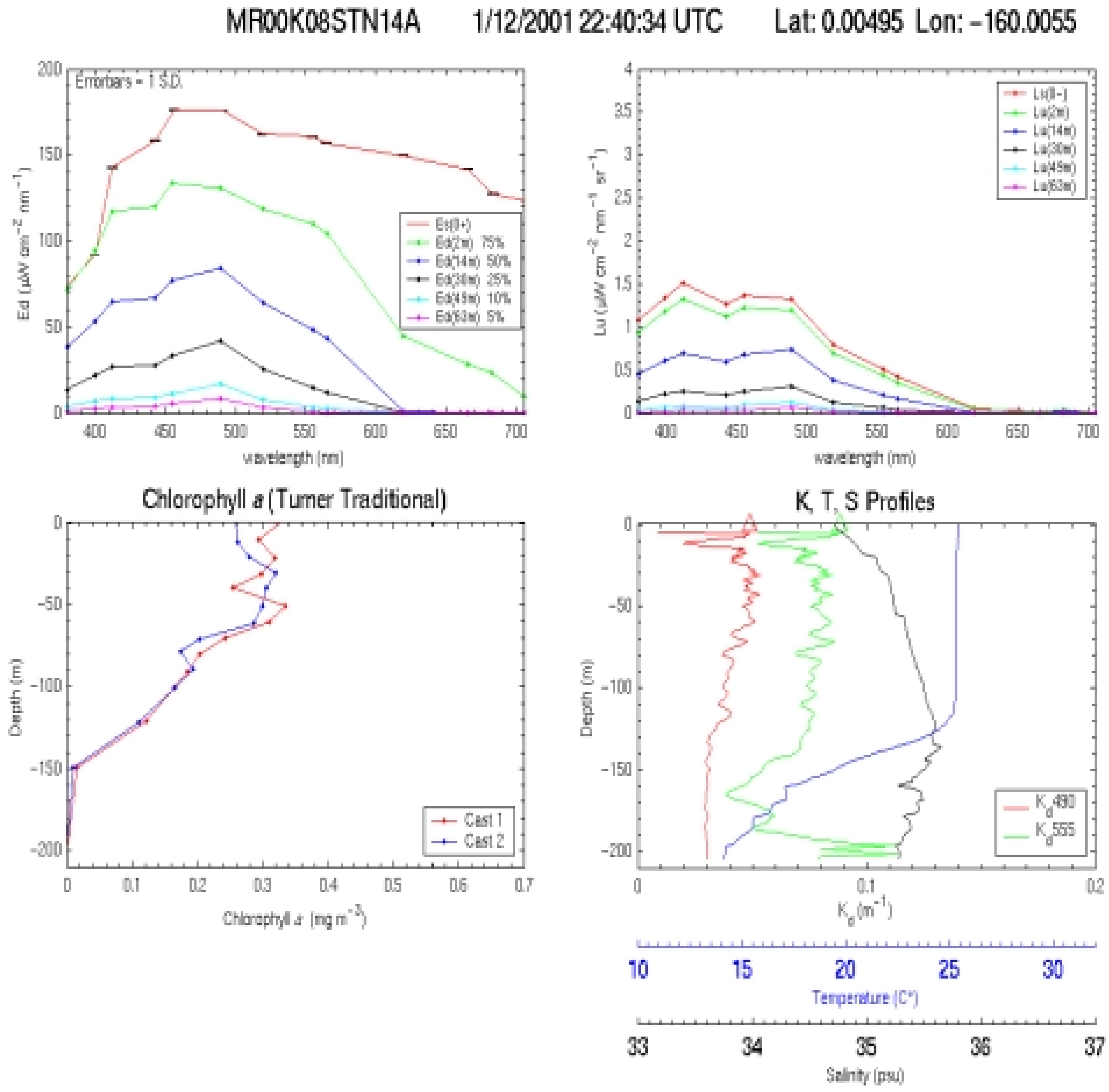

Figure 8. Sample plot 1 for Station MR00K08STN14, Cast A

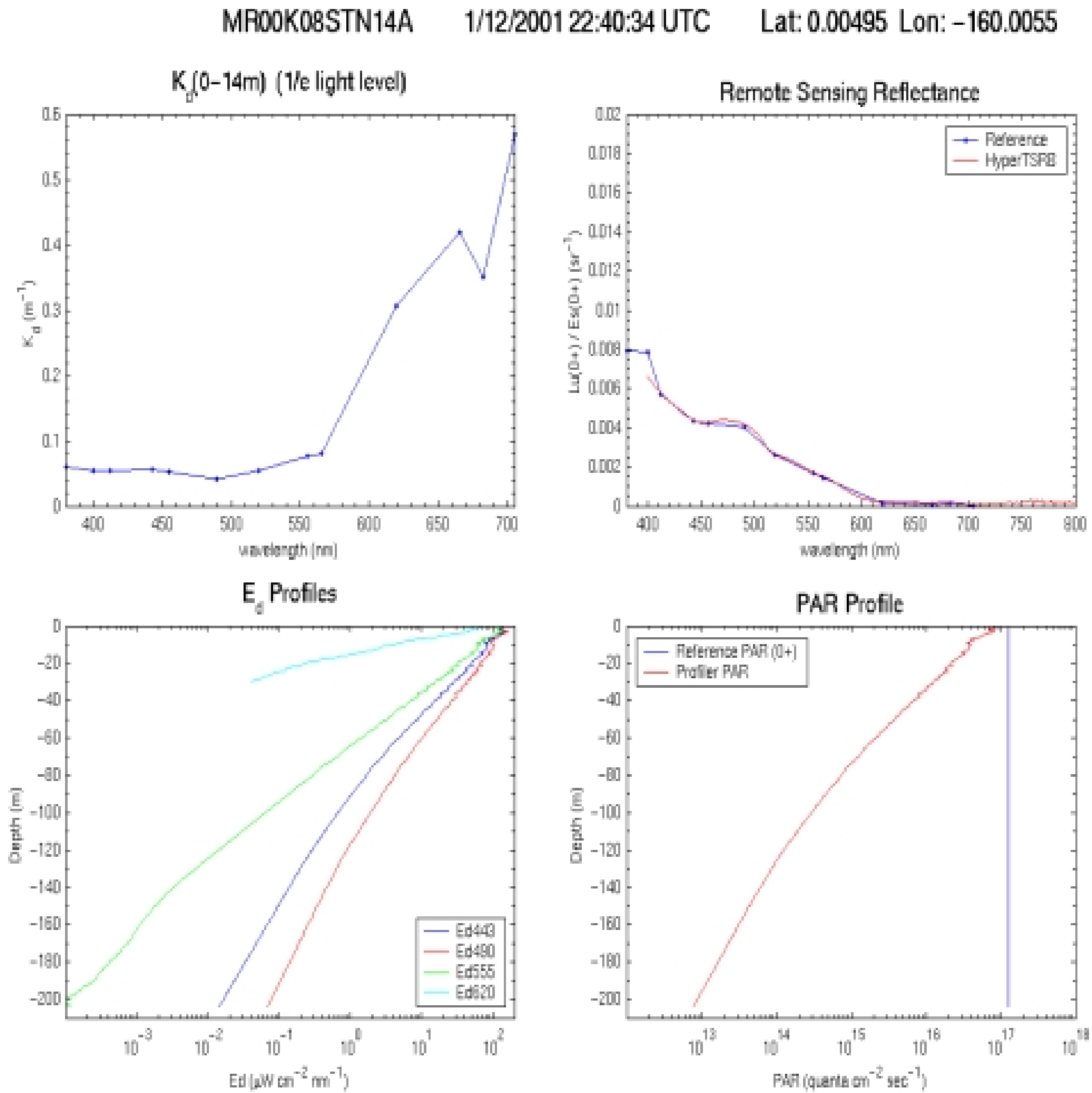

Figure 9. Sample plot 2 for Station MR00K08STN14, Cast A