Blue Earth Global Expedition

(BEAGLE – 2003-04)

Leg 5

Cape Town (South Africa) to Fremantle (Australia)

December 9th, 2003 - January 24th, 2004

Bio-Optics Group

Principal Investigator : Dr Shubha Sathyendranath (Canada)

Scientist in charge on board : Pru Bonham (Australia)

POGO Trainees: Dr Margareth Serapio Kyewalyanga (Tanzania)

Benjamin Wigley (South Africa)

(from Cape Town - Port Louis only)

With assistance from:

Cape Town - Port Louis

John Bemiasa (JAMSTEC observer for Madagascar)

Prof Dr Antonio Mubango Hoguane (Mozambique)

Jean Mwicigi (South Africa)

Port Louis - Fremantle

Dr Andrew Forbes (CSIRO Australia)

1. Introduction

The **B**lue **EA**rth **GL**obal **E**xpedition 2003, '**BEAGLE 2003**', is an oceanographic research program developed by Japan Marine Science and Technology Centre (JAMSTEC). The principal objective of this project is to enhance oceanographic research activities in the Southern Hemisphere, in accordance with the Sao Paulo Declaration (POGO, 2000). The detailed objectives are:

1) To detect and quantify temporal changes in the Antarctic Overturn System corresponding to the global ocean and the Southern Ocean warming during this century through high quality and spatially dense observation along the old WHP (World Ocean Circulation Experiment Hydrographic Program 1991-2002) lines.

2.) To estimate the amount of anthropogenic carbon uptake by the Antarctic Ocean.

2. Bio-optical Objectives

The general objectives of the bio-optical project on this expedition are:

- To generate an important database of bio-optical measurements and primary production from the under-sampled Southern Ocean.

To achieve this objective, measurements of radiation (seawater reflectance) are being taken with a variety of radiometers (Simbad, Simbada, Ocean Optics.)

Samples are taken for the analysis of chlorophyll *a* and phaeopigments concentration, and for the determination of absorption properties of particulate (phytoplankton and detritus) and coloured-dissolved-organic-matter (CDOM.)

P&I experiments are also performed for the estimation of primary production parameters.

Samples for the determination of phytoplankton pigment composition by HPLC, as well as for the quantification and identification of picoplankton by flow-cytometry are also being collected.

Results from these analyses are expected to contribute to the validation and calibration, and to assist in the development of regional algorithms, for satellite-derived products (e.g., chlorophyll *a*) by sensors such as SeaWiFS, MODIS, and MERIS.

- To provide a training environment in which trainees could get hands-on experience in collecting phytoplankton related samples and bio-optical data.

- To gain basic knowledge about some of the analysis and processing of bio-optical data.

3. Sampling and Methods

Protocols for the sampling and methods being used for the optical measurements and analysis of biological samples can be consulted in the URL of IOCCG (http://www.ioccg.org/training/pogo_ioccg/protocols/protocols.html).

Most of the samples were taken at the surface, or near surface, of the ocean, except for a second set of samples for chlorophyll analysis which were generally taken at the depth of the fluorescence maximum. Analysis of chlorophyll *a* and phaeopigments concentrations, particulate and CDOM absorption, and P&I incubations were performed on board, while HPLC, flow cytometry and ^{13}C (for the calculations of P&I parameters), as well as a duplicate set of particulate absorption samples, are going to be processed in different laboratories (in Canada, Australia, South Africa and Chile) after the end of the cruise. A preliminary processing of some of the data available was developed onboard during Leg 4, and continued on Leg 5.

4. Features of Leg 5

During leg 5, the main focus was again on chemical and physical oceanography. A total of 146 CTD casts were performed.

For the bio-optical sampling, either one or two stations a day were occupied. Initially, it was intended to sample one station close to noon and another about 4 hours earlier or later. However, on several days, the CTD casts were extremely deep – up to 6300m. Often there was an extensive time delay between casts and it was only possible to sample one station. Additionally there were only two scientists in the Bio-optical team for most of Leg 5, with occasional help from a third scientist, and it was not always feasible to sample two stations a day.

Whenever possible, seawater samples were taken from Niskin bottles at the 5m depth. At several deeper stations, there were not enough Niskin bottles for all the required sampling, and a bucket was used to collect surface water samples. An extra sample for determining the concentration of chlorophyll and phaeopigments was taken from the depth of the fluorescence maximum (indicated by the *in situ* fluorometer attached to the CTD). Again, on the deeper section, it was not always possible to fire a bottle at the chlorophyll maximum, and a sample was taken from the bottle depth closest to the chlorophyll maximum.

Radiation measurements (seawater reflectance) were performed about one hour before the rosette sampling, or approximately one hour after the bucket sampling.

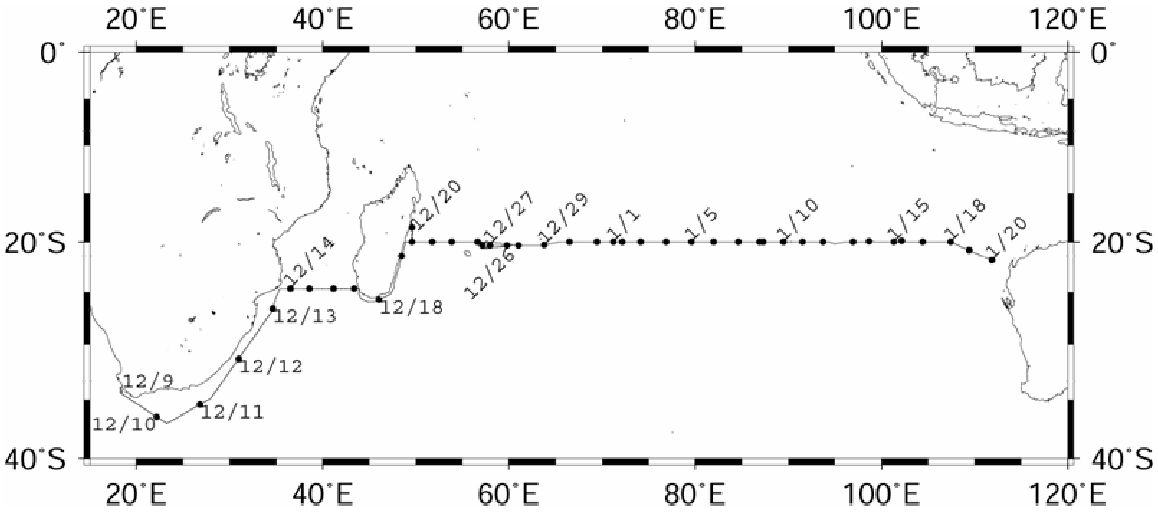


Fig 1. R/V Mirai cruise track, BEAGLE expedition 2003-2004, Leg 5

I. BIOLOGICAL SAMPLING

On Leg 5, 50 complete sets of biological samples were collected, sampling the following parameters. Stored data records are generally divided into week1-7, starting on Mondays.

Photosynthesis v/s Irradiance (PI) Experiments

Each day 1 or 2 experiments were carried out. 42 bottles (and 3 dark bottles) were incubated with ^{13}C in a Larsen box for 3 hours. The contents of 3 bottles, incubated at similar light intensities, were filtered through a single filter and dried at 52°C. Light intensities in the 42 positions in the box were measured daily and recorded. The filters are to be analysed by mass spectrometry at University of Concepcion (Chile.)

Storing: filters were dried and stored in sets of 15 labelled envelopes. Light intensity results are in folder: JAMSTEC/ Leg5/reports&summaries/PIlightleg5

CDOM

Water samples for the determination of coloured-dissolved-organic-matter were filtered through 0.2 μm polycarbonate membrane filters, and immediately scanned in a 10 cm quartz cuvette in a

CARY BIO 50 UV/VIS spectrophotometer. Absorption was measured from 250-750nm with a 50mm pathlength.

Storing: no samples were stored. Results are in folder:
JAMSTEC/CDOM/Leg5/week/dailyfolder ("a" and "b" if two samples were taken in one day.)

Chlorophyll and Phaeopigments concentration

Triplicate water samples from the surface and chlorophyll maximum (or the closest depth) were filtered through 25 mm GF/F glass fibre filters immediately after sampling, extracted in 90:10 acetone, and stored overnight in a freezer. Chlorophyll-*a* and phaeopigments concentrations were measured onboard using a digital Turner Designs 10-AU fluorometer.

Storing: no samples were stored. Results are in folder: JAMSTEC/Leg5/chlorophylls/week/daily files

Phytoplankton Particulate Absorption

Duplicate samples were collected and filtered through 25 mm GF/F glass fibre filters for the determination of particulate absorption. One sample was immediately scanned on board in a CARY BIO 50 UV/VIS spectrophotometer, and the other will be analysed at the Bedford Institute of Oceanography. Ten replicates were read from each particulate sample filter and a blank filter. The sample and blank were then treated with methanol and rescanned.

Storing: The duplicate samples were frozen in liquid nitrogen in a labelled cryogenic vial and then stored in a deep freezer (-80^{o}C). Results of the samples analysed on board are in folder: JAMSTEC/Absorption/Leg5/week/dailyfolder ("a" and "b" if two samples were taken in one day.)

High Performance Liquid Chromatography

Two samples were collected and filtered through 25mm GF/F glass fibre filters for the determination of phytoplankton pigment composition by HPLC. These samples will be analysed in two different laboratories: University of Cape Town (South Africa) and CSIRO Marine Research Hobart (Australia) by Bio-optical specialist Lesley Clementson.

Storing: Both samples were frozen in liquid nitrogen and then stored in two separate labelled aluminium foil envelopes in a deep freezer (-80^{o}C).

Picoplankton

Two samples were collected from surface seawater, fixed with paraformaldehyde, and frozen for later analysis by flow cytometry at Bedford Institute of Oceanography.

Storing: Both samples were frozen in liquid nitrogen and then stored in two separate labelled cryotubes in a deep freezer (-80^{o}C).

II. OPTICAL SAMPLING

SIMBAD

The SIMBAD-03 radiometer had stopped working in the first week of the previous leg (leg 4) It is hoped that the bio-optical specialist on leg 6 may be able to repair it.

Storing: no results for SIMBAD from Leg 5

SIMBADA_21

This instrument is an above-water radiometer and it measures water-leaving radiance and aerosol optical thickness in 11 spectral bands. The bands are centred at 350, 380, 412, 443, 490, 510, 565, 620, 670, 750 and 870 nm. The instrument has an internal GPS antenna that must home in on 3 or more satellites before readings can be taken. The sequence of measurements taken are 1 Dark, 3 Sun, 6 Sea, 3 Sun, and 1 Dark. One set of Simbada measurements was taken while on station, as close to noon as possible. On the days of deeper CTD stations, readings were usually made about 09.30-10.00 as filtering PI samples took preference later, and the ship was often not on station nearer to noon.

On Leg 5, there appear to be some problems with the Simbada_21 functioning after the change to the New Year. The date record is incorrect, and the sun, sea and dark files are all in similar format to the normal “dark” files.Probably the data are retrievable by someone with expertise in the Simbada programming. We continued to collect data until the end of Leg 5.

Storing: The files are in the folder JAMSTEC/Leg5/simbada21/week/dailyfolder.

Hyperspectral radiometer (Ocean Optics)

This instrument measures irradiance from 350 to 1000 nm at 0.5 nm intervals and has a special fibre optic that collects the irradiance from the sky and the sea surface. The downwelling irradiance is measured using a spectralon grey plaque that diffuses the incident irradiance.

One set of Ocean Optics measurements was taken while on station, as close to noon as possible. On the days of deeper CTD stations, readings were usually made about 09.30-10.00 as filtering PI samples took preference later, and the ship was often not on station nearer to noon.

Note: The Ocean Optics reader is designed with an operating temperature of around 20°C. On deck temperatures on Leg 5 were always above 25°C, and above 30°C at the western end of the Leg. To bring the reader down to operating temperature, a double plastic tub was used, with the outer box containing freezer bricks and iced water. The OO reader was placed in an inner, dry plastic box. Trial and error proved that the fastest way to bring the reader down to operating temperature on deck was to cool the boxes for at least 30 minutes and place the reader in the cooler box about 5 minutes before taking it on deck. Usually the OO reader then reached operating temperature in about 5 minutes.

Storing: Files are in folder JAMSTEC/Leg5/OO-processed/week/dailyfolder

Photosynthetically Active Radiation (PAR)

The PAR sensor is mounted outside, above the Atmospheric Observation laboratory. The Licor 1400 data logger connected to the sensor reads measurements every 60 seconds and records hourly average on the hour. Data are downloaded at the end of the leg to be later processed at BIO in Canada.

Storing: Files are in folder JAMSTEC/Leg5/PAR_sensor_data/PAR_Leg5.txt

5. Pogo Trainees Activities

On leg 5, the bio-optical team had two official POGO/IOCCG trainees, Margareth Serapio Kyewalyanga (Tanzania) and Ben Wigley (South Africa). Initially they were both scheduled to participate in Bio-optical sampling from Cape Town to Fremantle, however Ben had to leave the ship in Port Louis for medical reasons.

In his brief time on Mirai, when he was well enough to work, Ben assisted with general laboratory analysis, some radiation measurements and data processing. His skills in gathering photographic records of activities, and performing data backups, were particularly appreciated. We think Ben enjoyed the CTD sampling watches and was able to relate well to the MWJ and Jamstec scientists. We enjoyed working with Ben and wish him all the best for his future studies.

Margareth already had considerable experience in many of the bio-optical techniques during her PhD studies. Her knowledge was a significant assistance to the program, complementing some of the areas in which I, as a general phytoplankton biologist rather than a Bio-optical specialist, had less experience. The collection of 50 sets of Bio-optics samples on Leg 5 would not have been possible without Margareth's skills, attention to detail, energy and enthusiasm for her work. In particular, Margareth's experience in Fortran programming meant that processing of particulate absorption data could be continued on leg 5.

5.1 Trainees Remarks

Margareth Serapio Kyewalyanga (Tanzania)

This cruise was a very unique opportunity for me! I am happy and proud that I got a golden chance to attend part of the prestigious BEAGLE 2003 Expedition. Working onboard the RV Mirai was an eye-opener to modern oceanographic equipment and facilities. The experience gained will be an asset to me, and my Institute, in our future research plans.

I have learned some new techniques such as determination of downwelling and water-leaving irradiance using modern Instruments (Simbada and Hyperspectral Radiometer); determination of coloured dissolved organic matter, using a spectrophotometer; and how to collect an array of samples from the CTD for water chemistry analysis. In addition, it was refreshing to do again some of the measurement, which I was familiar with (such as PI incubations and particulate absorption).

All the above wouldn't have been possible without the generous sponsorship by POGO, to which I am very grateful. Working with Pru Bonham was a delight; she is full of energy, enthusiasm and teamwork sprit. This made even the hard work seem easy. I would like to thank the JAMSTEC staff for their support and cooperation. The help provided by MWJ technical staff is highly appreciated. Last, but not least, I would like to thank the Captain of RV Mirai, the Officers and Crew Members, who worked so hard to make our day-to-day life on board so smooth!

Ben Wigley

A report was requested from Ben, but it had not arrived by the date of compiling my report. Possibly it has been sent directly to POGO, or to my CSIRO email address. If so, I will forward to Dr Venetia Stuart when I return to Hobart.

6. Data Processing

A series of Fortran routines developed by Dr Vivian Lutz and colleagues during Leg 3 and extended during Leg 4, were used to process the absorption data. Phytoplankton concentrations were again extremely low during Leg 5.

Results can be found in the directory /JAMSTEC/Leg5/data-process.

The program generates four output files with the results of the processing:
SampleID+ABT.txt
SampleID+ABD.txt
SampleID+ABPHY.txt
SampleID+ABSPHY.txt

CDOM data was not corrected on board. It will be processed after the cruise.

Ocean Optics data were processed on board into daily Excel worksheets. Additionally, Microcal Origin software was utilised to produce four preliminary graphs for most files:

- L_m (sea), L_{sky}, L_{spec} radiances
- water-leaving radiance L_W
- downwelling radiance E_D
- and Remote Sensing Reflectance (RRS).

The only preliminary data control was the removal of negative outlier data points in some graphs. A comment worksheet and key to these files has been provided in:
/JAMSTEC/Leg5/OO-processed/OOprocessed-Leg5summary.xls.

Some of the initial files show the sky radiance peaking over 4000. This has been noted. Later in the cruise more experience with the software and determination of integration times largely avoided this. However there were still occasions when the integration time was set appropriately for the conditions, but highly variable solar radiation during the reading caused the readings to run over the limit.

Note: The collecting and processing of Ocean Optics data was made much more difficult by the slow speed and unreliability of the Toshiba laptop computer. Each Excel worksheet is about 6MB in size and the laptop often had difficulty using Excel and Origin software routines, causing it to "hang up" regularly. Also, it is slow to start up and frequently "hung up" when used on deck, or was very slow to react to operator input such as changed integration times. This often made the on-deck procedures more prolonged than necessary.

7. Preliminary Results

This is a preliminary analysis of some of the results obtained on Leg 5. The cruise track is shown in figure 1.

Chlorophyll and phaeopigments: During this leg chlorophyll concentrations were extremely low (Table 1). The exception was the final sample collected on Leg 5, which was collected just off the Australian coast. This sample does not have a matching absorption or CDOM sample and has not been included in the average.

Chlorophyll concentration and Particulate Absorption (these paragraphs have been contributed by Dr Margareth Kyewalyanga. I have not reproduced the figures which she has attached to her individual report.)

Although 1.5 litres of seawater were filtered, some of the particulate absorption data lay close to the limit of detection of the spectrophotometer. This caused those spectra to look very noisy. It is expected that duplicate samples, to be ran at the Bedford Institute (Canada) using a more sophisticated spectrophotometer (double beam and with an integrating sphere), may show a better resolution.

Surface chlorophyll concentrations were very low; ranging from 0.016 to 0.142, with an average of 0.037 mg m^{-3} (excluding the final sample collected.). Relatively high values were only observed close to the coast of South Africa and Australia (concentration greater than 0.05 mg m^{-3}). Owing to such low concentrations of chlorophyll-*a*, the resultant absorption spectra of phytoplankton was noisy, despite taking 10 spectra of each for averaging. The shapes, and in most cases the magnitude, of the total particulate absorption and phytoplankton absorption were always similar, suggesting that there was less detrital materials in these waters. Thus, these are case 1 waters, where light absorption by particulate matters is dominated by phytoplankton, albeit of low concentration.

It is also assumed that the waters are dominated by picoplanktonic cells, which easily pass through the GF/F filter. This is further supported by high values of specific absorption coefficient of phytoplankton, which ranged from 0.053-0.294 (average 0.181), with about 50% of the total data being above 0.2 m^2.mg chl-a^{-1}. Hopefully, results from flow cytometry analysis will be able to shed light on the cell size composition in the waters.

In two cases (21st December 03; ID 264371 and 6th January 2004: ID 264396), the water filtered through the Millipore filter (0.2µm) showed some orange-brownish colouration. As a result, although the sample (filtered through GF/F filter) was not coloured, the blanks became coloured because they were rinsed with the 0.2µm filtered sea-water. This completely altered the shapes and magnitude of the spectra (so that the blanks had much higher absorbance than the samples) resulting into complete negative absorption values. We hypothesize that the smaller cells present in the water were probably delicate and burst during filtration, resulting in the observed colouration. This hypothesis could only be proved after analysis of HPLC and Flow Cytometry samples.

8. Acknowledgements

We would like to thank all those responsible at POGO, IOCCG and JAMSTEC, also the Chief and staff at CSIRO Marine Research, for giving us the opportunity of being able to participate in the BEAGLE 2003-04 expedition. We appreciate the support and leadership of the Chief Scientist on Leg 5, Prof. Masao Fukasawa. We particularly acknowledge his support and kindness in allowing Margareth to cease CTD watches so that she could concentrate on sampling, after our Bio-optics team was reduced to two scientists from Port Louis to Fremantle.

We also record our thanks to the chief sampling scientist and the sampling teams for their cooperation and assistance in this matter.

From Cape Town to Port Louis, when one of the trainees, Ben Wigley, was unable to work due to illness for most of the period, we are extremely grateful to the following people who gave us considerable assistance in sampling and processing:

John Bemiasa (JAMSTEC observer), Institut Halieutique Sciences Marines, Madagascar,

Prof Dr Antonio Mubango Hoguane, Universidade Eduardo Mondlane, Mozambique,

and Jean Mwicigi, University of Cape Town, South Africa

After Port Louis, Dr Andrew Forbes (CSIRO Marine Research, Australia) volunteered to assist the Bio-optics group. His support with Fortran programming and data backup, plus on deck assistance with the solar radiation measurements, was invaluable, because it allowed Margareth and myself more time for laboratory analysis.

Special thanks to Principal Investigator Shubha Sathyendranath, and Bio-optical specialists Lesley Clementson, Venetia Stuart and Vivian Lutz for their support during Leg 5. Thanks especially to Vivian for the provision of shorter guides and her excellent training before Leg 5. Eric Madsen and Brian Griffiths (CSIRO Marine Research) have provided a replacement Turner Fluorometer cable for Leg 6.

It has been a privilege and a unique experience for us to work on this vessel and participate in this research expedition. We sincerely appreciate the professional collaboration and cooperation received from Prof Masao Fukosawa, Dr Takeshi Kawano, the entire scientific and sampling team from JAMSTEC and Marine Works Japan, as well as Captain Akamine Masaharu, the officers and crew of the *R/V Mirai.*

Table 1. Summary of chlorophyll-*a* and phaeophytin-*a* results from Leg 5

Station ID	Sample ID	Depth(m)	Chl-*a* (mg m^{-3})	phaeo-*a* (mg m^{-3})	Comments
AI04-610N	264362	0	0.097	-0.006	
	264362	45	0.985	0.138	
AI04-602N	264363	0	0.075	-0.012	
	264363	90	0.329	0.337	
AI04-596N	264365	0	0.066	-0.002	
	264365	75	0.585	0.179	
AI04-592N	264366	0	0.071	-0.001	
	264366	60	0.867	0.251	
AI04-591C	264367	0	0.064	0.001	
	264367	55	0.289	0.060	
AI04-586C	264368	0	0.142	0.004	
	264368	65	0.313	0.046	
I03-562N	264369	0	0.092	-0.005	
	264369	60	0.313	0.100	
I03-560N	264370	0	0.040	-0.003	
	264370	95	0.121	0.046	
I03-557N	264371	0	0.037	-0.003	
	264371	120	0.185	0.116	
I03-556N	264372	0	0.033	-0.002	
	264372	100	0.240	0.081	
I03-553N	264373	0	0.035	0.004	
	264373	100	0.267	0.123	
I03-552N	264374	0	0.046	-0.004	
	264374	115	0.209	0.136	
I03-X07C	264375	0	0.039	-0.001	
	264375	110	0.193	0.088	
I03-547N	264376	0	0.030	-0.001	
	264376	100	0.192	0.076	
I03-543C	264377	0	0.028	-0.002	
	264377	100	0.196	0.074	
I03-538C	264379	0	0.039	-0.003	
	264379	115	0.088	0.020	
I03-533C	264381	0	0.037	-0.003	
	264381	110	0.174	0.088	
I03-531C	264382	0	0.029	0.001	
	264382	115	0.149	0.081	
I03-530N	264383	0	0.016	0.002	
	264383	120	0.116	0.093	
I03-526N	264384	0	0.024	0.004	
	264384	110	0.179	0.109	
I03-521C	264385	0	0.031	0.001	
	264385	115	0.136	0.062	
I03-520N	264386	0	0.019	-0.002	
	264386	120	0.134	0.072	
I03-516N	264387	0	0.019	0.000	
	264387	130	0.130	0.062	
I03-515N	264388	0	0.016	0.000	
	264388	130	0.141	0.100	
I03-511C	264389	0	0.018	-0.002	

	264389	125	0.128	0.057	
I03-510N	264390	0	0.016	-0.002	
	264390	125	0.088	0.034	
I03-506N	264391	5	0.016	0.000	
	264391	145	0.129	0.080	
I03-503C	264392	0	0.019	-0.001	
	264392	110	0.142	0.059	
I03-502N	264393	0	0.017	0.000	
	264393	135	0.146	0.105	
I03-X08C	264394	0	0.018	0.001	
	264394	120	0.101	0.042	
I03-498N	264395	5	0.019	0.001	
	264395	140	0.139	0.110	
I03-495C	264396	0	0.027	-0.003	
	264396	100	0.172	0.090	
I03-492N	264398	0	0.030	0.000	
	264398	115	0.139	0.087	
I03-491C	264399	0	0.020	0.002	
	264399	80	0.146	0.010	
I03-487C	264400	5	0.023	0.000	
	264400	130	0.130	0.063	
I03-486N	264401	5	0.021	0.001	
	264401	100	0.108	0.024	
I03-481N	264402	0	0.025	0.003	
	264402	115	0.156	0.090	
I03-480C	264403	0	0.018	0.001	
	264403	145	0.134	0.080	
I03-477C	264404	0	0.021	0.003	
	264404	85	0.137	0.029	
I03-476N	264405	0	0.019	0.001	
	264405	125	0.150	0.108	
I03-473N	264406	0	0.025	0.000	
	264406	110	0.212	0.093	
I03-470C	264407	0	0.029	-0.001	
	264407	115	0.153	0.086	
I03-469N	264408	0	0.025	-0.001	
	264408	100	0.111	0.053	No chl max bottle
I03-467N	264409	0	0.027	-0.003	
	264409	150	0.074	0.041	No chl max bottle
I03-464C	264410	0	0.029	0.004	
	264410	100	0.151	0.101	Chl max not known
I03-461C	264411	0	0.033	0.003	
	264411	100	0.163	0.063	No chl max bottle
I03-458N	264412	0	0.035	0.000	
	264412	85	0.213	0.090	
I03-454N	264413	0	0.052	-0.003	
	264413	90	0.210	0.118	
I03-451C	264414	0	0.067	-0.008	
	264414	75	0.304	0.157	
I03-450N	264415	0	0.057	-0.005	
	264415	85	0.367	0.235	
I03-444N	264416	0	1.538	-0.123	
	264416	45	1.505	-0.049	

Fig 2. **Preliminary Hyperspectral radiometer (Ocean Optics) results**

Ocean Optics files from a day with heavy overcast, January 17, 2004

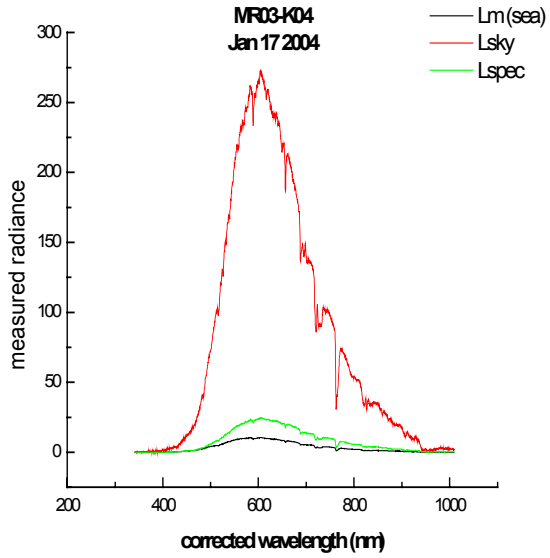


Fig 2a. Measured radiances from sea, sky and spectralon

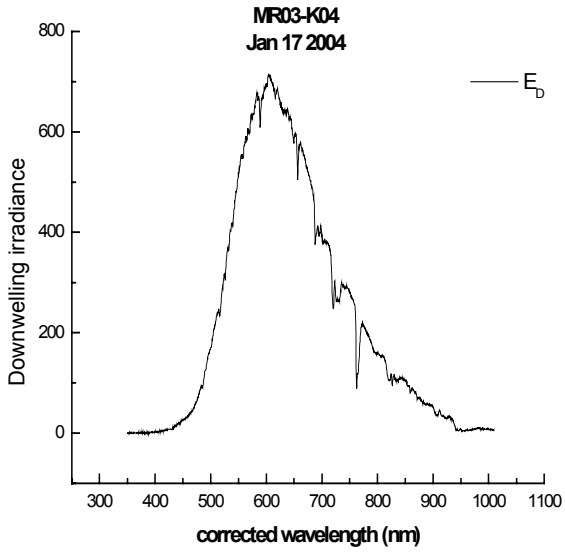
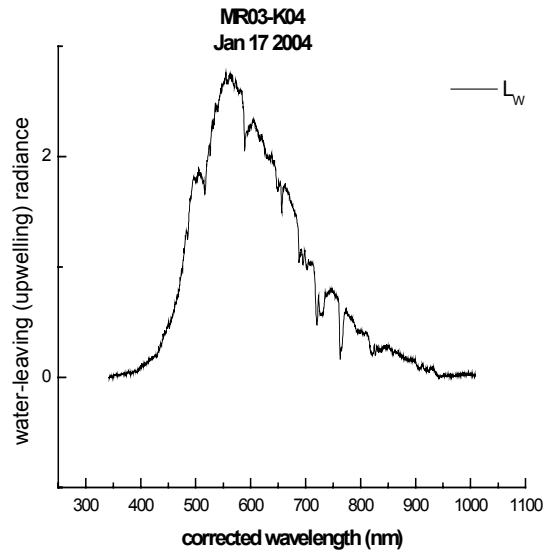


Fig 2b. Downwelling radiance measured with spectralon



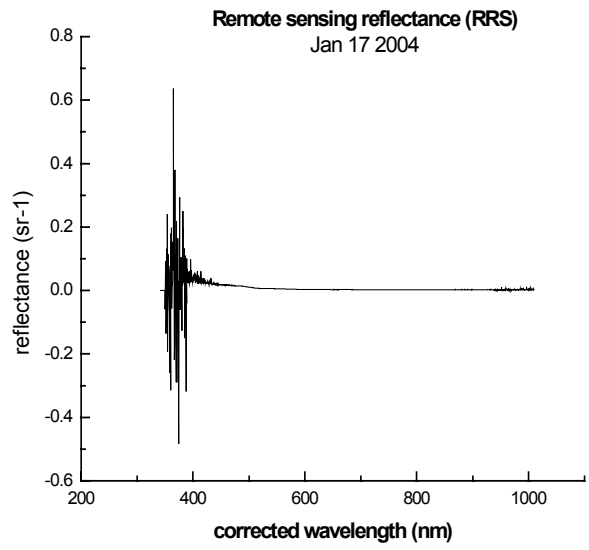
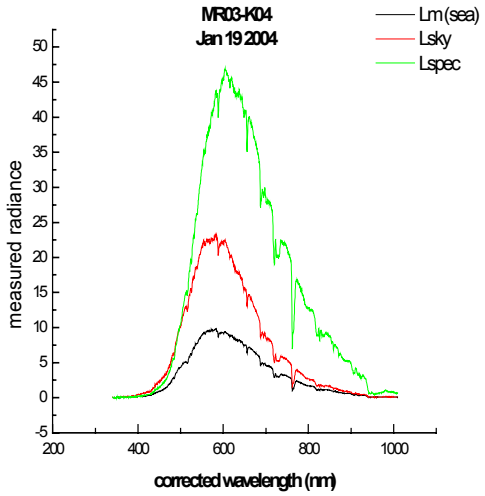


Fig 2c. Water leaving radiance L_W

Fig 2d. Remote sensing reflectance RRS

Fig 3. **Preliminary Hyperspectral radiometer (Ocean Optics) results**

Ocean Optics files from a sunny day, January 19, 2004



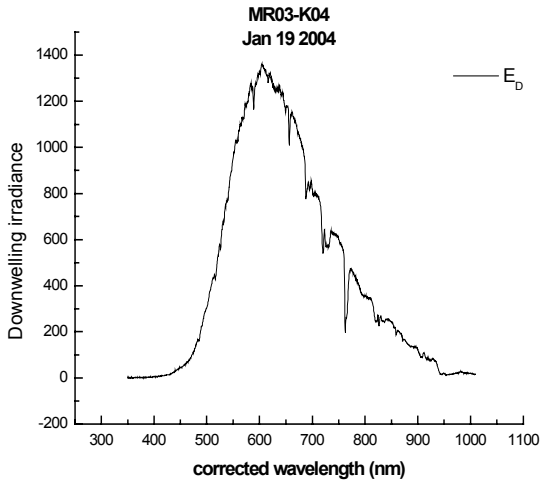
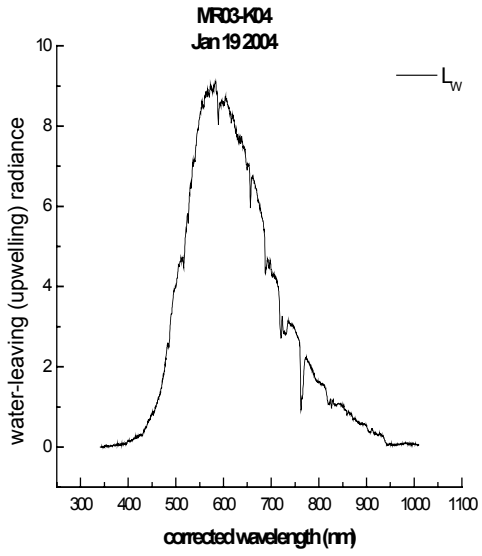


Fig 3a. Measured radiances from sea, sky and spectralon

Fig 3b. Downwelling radiance measured with spectralon



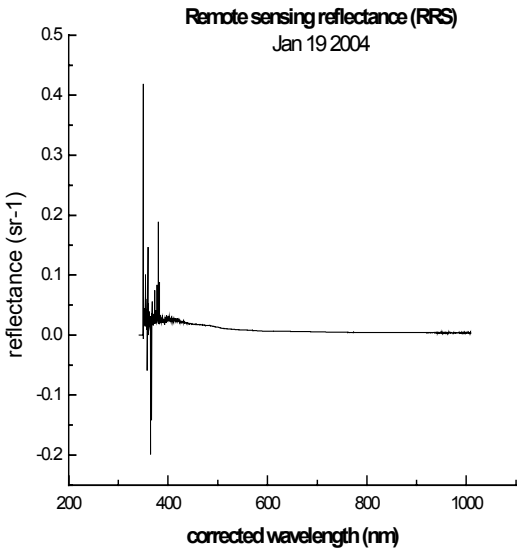


Fig 3c. Water leaving radiance L_W

Fig 3d. Remote sensing reflectance RRS