# Marmion Lagoon Measurement Program
# July 2007 to May 2008

WAMSI Node 1 Project 1

Southwest Australian Coastal Biogeochemistry


Graham Symonds and Nick Mortimer



CSIRO Marine and Atmospheric Research Paper 027



www.csiro.au

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Title: Marmion Lagoon measurement program July 2007 to May 2008 :
WAMSI node 1 project 1 Southwest Australian biogeochemistry / Graham Symonds, Nick Mortimer.

ISBN: 9781921605260 (pbk.)
9781921605277 (CD-ROM)

ISSN: 18332331 (pbk)
18332420 (CD-ROM)

Series: CSIRO Marine and Atmospheric Research paper ; 027

Notes: Bibliography.

Subjects: Oceanography--Western Australia--Marmion Lagoon.
Ocean currents--Western Australia--Marmion Lagoon--Measurements.
Ocean waves--Western Australia--Marmion Lagoon--Measurements.
Water quality--Western Australia--Marmion Lagoon--Measurements.

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Dewey Number: 551.4615

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# 1. INTRODUCTION

WAMSI Node 1 Project 1 aims to better characterise the south west Australian marine coastal and shelf ecosystem structure and function, and enhance our shared capacity to understand, predict and assess ecosystem response to anthropogenic and natural pressures. To achieve this aim the following outputs were identified.

*Downscaled hydrodynamic models to explore influences on benthic habitat, and the cross-shore and longshore exchange of water, nutrients and particles between the lagoon and shelf regions*.

*Coupled hydrodynamic and biogeochemical models and a quantitative nutrient budget for coastal waters at shelf and lagoon scales.*

*Improved descriptions and conceptual biogeochemical models for shelf and lagoon waters incorporating seasonal and interannual variability and improved representation of benthic primary production and bentho-pelagic coupling*

*Simple models for assessing and predicting impacts of physical forcing factors, primarily nutrients, on key benthic functional groups/habitats informed by experiments and observations conducted across a range of naturally varying and anthropogenically altered gradients related to nutrient enrichment.*

To achieve the first two outputs at the lagoon scale field and modelling programs were proposed with a focus on the Marmion Marine Park, a box approximately 5km cross-shore and 10km alongshore. The study site was to include the major reef lines in the Marine Park, with the offshore boundary at about the 30m isobath. The purpose of the field work was twofold: first, to provide data to help tune the numerical model and, second, to examine the linkages between the hydrodynamic and biological environments through process-focussed measurements.

A feature of the coastal zone of South West Western Australia is a series of limestone reefs approximately 700 km long and 3-10km offshore (Pattiaratchi et al, 1995) and which occasionally break the surface or are shallow enough for waves to break over them. Currents on the inner shelf (depths < 50m), but offshore of the reefs, are largely wind driven (Pattiaratchi et al, 1995) and Feng et al (2006) report the longshore current at 20m depth is 2.5-3% of the wind speed with a correlation of .87. In the lagoon, shorewards of the reefs, the correlation between wind and current is less and Pattiaratchi et al (1995) report periods during winter months when the current and wind are in opposing directions. Breaking waves have the potential to drive strong currents over the reef crest (Symonds et al, 1995) which may explain some of the differences between winds and currents in the lagoon during periods of high waves. Wave pumping is known to be important on coral reefs (Kraines et al, 1998; Tartinville and Rancher, 2000; Monismith, 2007; Lowe et al, 2009) and Mulligan et al (2008) reported wave-driven circulation in a coastal bay forced by wave breaking on a reef in the middle of the bay. An aim of the Marmion Lagoon Measurement Program was to investigate the importance of wave forcing in the Marmion Lagoon. Fringing coral reefs typically have long stretches of reef O(kms) punctuated by narrow gaps O(100m) while the limestone reefs off the Western Australian coast are more scattered and the gaps between the reefs are often considerably greater than the scale of the individual reefs. In this case the wave-driven flow over the reefs may be confined to the local area around the reefs and have little affect on the broader lagoon-scale flow. However, if the measurements reveal significant wave-driven flows within the lagoon then wave forcing will need to be incorporated into any hydrodynamic model of the lagoon.

This report describes the data obtained during the measurement program which ran between July 2007 to May 2008. Wind and waves measured at Rottnest Island, located 22 km offshore from Fremantle and about 25 km south west of the study site, are shown in Figure 1 for the duration of the measurement program. During the winter months significant wave height (Hs) at Rottnest peak over 6m while in summer Hs is typically less than 3m. At the study site wave heights are reduced by a factor of 2-3 relative to Rottnest due to the combined effects of refraction and bottom friction.

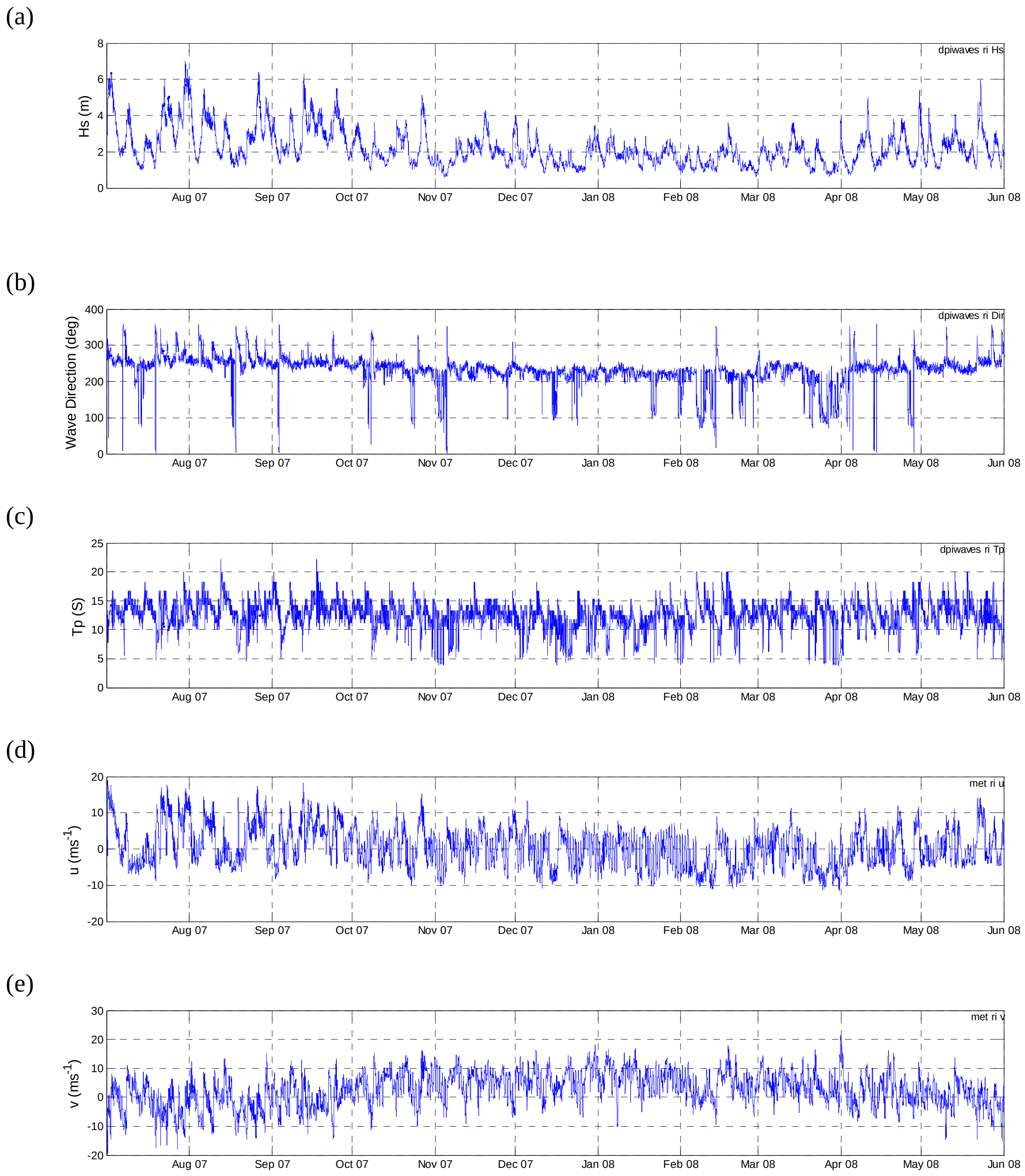



Figure 1 Time series from the Rottnest wave buoy (32$^{o}$ 05'39'S 115$^{o}$24'28'E); (a) significant wave height, (b) direction and (c) peak period. Panels (d) and (e) are the eastward and northward components respectively of wind measured at Rottnest.

## 2. INSTRUMENT ARRAY

An array of instruments as shown in Figure 2 was deployed four times between July2007 and May 2008, recovered after 4-6 weeks each time to download data, clean and check instruments and replace batteries. A summary of the deployment schedule is given in

Table 1 which also includes instrument types and measured parameters at each site. Exact locations, start and stop times and sampling details are given in section 3.

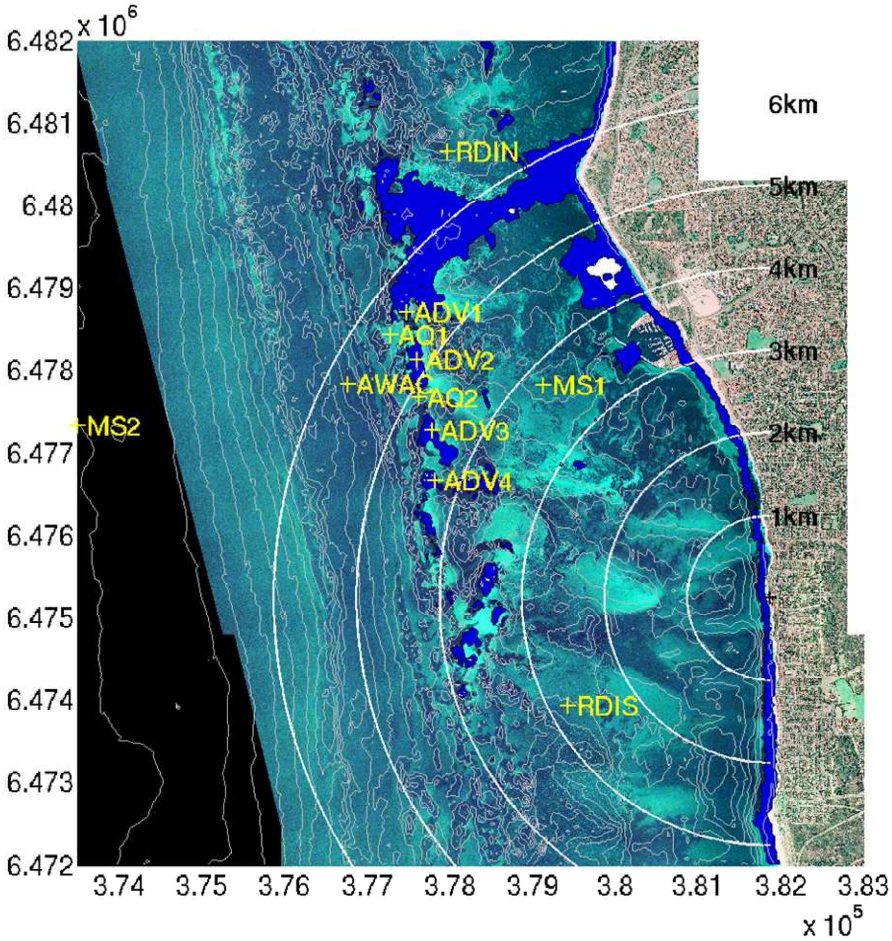



Figure 2 Marmion lagoon showing instrument sites. The filled blue areas denote depths less than 4m. (Aerial photograph courtesy of Oceanica )

A number of instruments were located along the reef line with sites ADV1, ADV2, ADV3 and ADV4 at the back of reefs while AQ1 and AQ2 were in deeper channels between the reefs. The back-reef sites were chosen to measure anticipated onshore flow over the reef crest while the channel sites would capture any offshore return flow. Wave height on the fore reef was measured at the AWAC site while sites RDIN and RDIS were located to measure

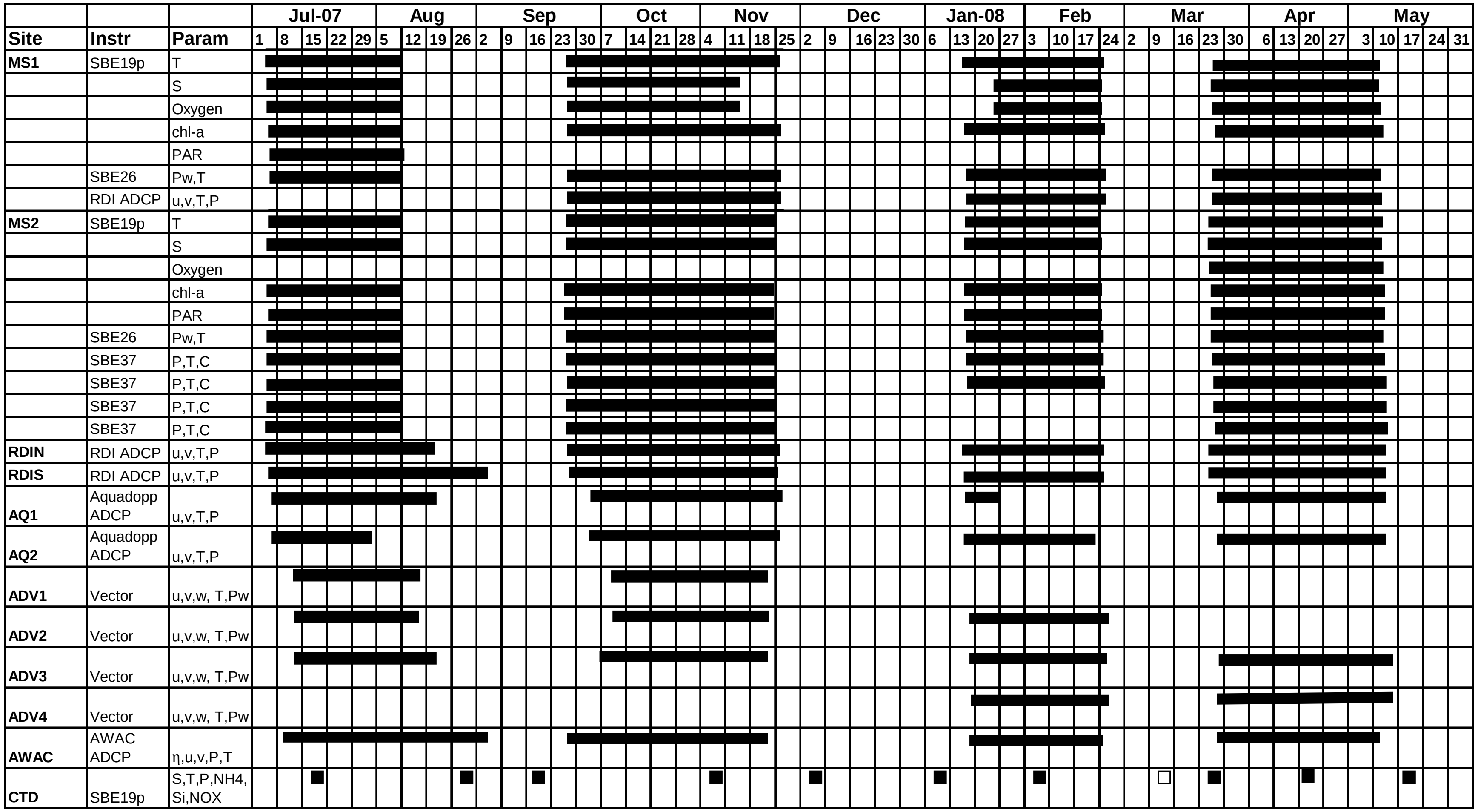



Table 1 Deployment schedule. East (u), North (v) vertical (w) velocity components, mean pressure (P), wave resolving pressure (Pw), sea surface elevation (η), temperature (T), salinity (S), conductivity (C)

inflow/outflow from the lagoon. The two remaining sites, MS1 and MS2 contained a suite of instruments measuring physical and biological parameters listed in Table 1.

In addition to the moorings a CTD survey, including surface and bottom nutrient samples, was completed approximately monthly on a grid of 30 stations over the study area. Nitrate, phosphate, silicate, ammonium and chlorophyll were measured from samples while the CTD recorded temperature, conductivity, fluorescence, light and oxygen.  The approximate times of the CTD surveys are shown in Table 1.

# 3. MOORING DATA

In this section the data are presented by site as defined in Figure 2. Data from the four deployments are presented as single time-series. Where data are missing for a particular deployment some form of instrument failure occurred. The depths in the tables are mean depths as measured by bottom mounted sensors.

## 3.1 AWAC

**Instrument:** Nortek AWAC

Current Profile

- Parameters u, v
- Profile interval 1800s
- Cell size 0.5m

Waves

- Parameters u,v,AST,P,T
- Sample rate 1Hz
- Record length 2048
- Interval 3600s

**Comments**

The AWAC was deployed seawards of the reef line on low relief reef pavement.

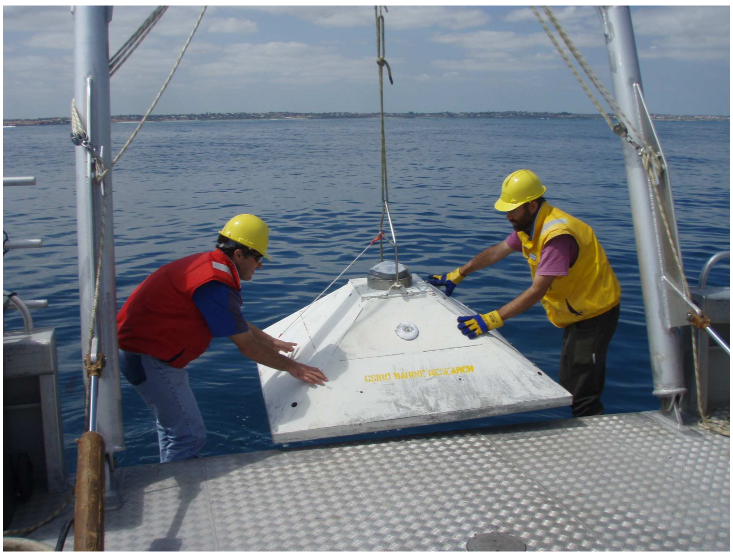


Figure 3 Deployment of the AWAC

| | Deployment | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Latitude | 31.8286S | 31.82868S | 31.82885S | 31.82873S |
| Longitude | 115.6978E | 115.69795E | 115.69822E | 115.69813E |
| Northing (m) | 6477826 | 6477815 | 6477797 | 6477809 |
| Easting (m) | 376769 | 376782 | 376807 | 376799 |
| Depth (m) | 15.8 | 15.0 | 15.4 | 15.3 |
| Start | 11-Jul-2007 19:10:01 | 28-Sep-2007 17:10:01 | 16-Jan-2008 17:10:01 | 27-Mar-2008 17:10:01 |
| Stop | 05-Sep-2007 15:10:01 | 26-Nov-2007 13:10:01 | 25-Feb-2008 13:10:01 | 13-May-2008 15:10:01 |
| AWAC s/n | WPR 0411 | WPR 0411 | WPR 0411 | WPR 0411 |
| OBS s/n | | | | |

Table 2 AWAC deployment details


Figure 4 Time series at AWAC, (a) Significant wave height, (b) wave direction, and (c) wave period.

## 3.2 ADV1

**Instrument:** Nortek Vector and OBS

- Parameters u,v,w,P,T, suspended sediment
- Sample rate 1Hz
- Record length 2048 samples
- Interval 3600s

**Comments**

After losing the Vector velocimeter at site ADV4 in the first deployment it was decided to move the instrument from site ADV1 to ADV4 for deployments 3 and 4 so we only have data at ADV1 for the first two deployments. In deployment 1 all the ADV sites were on sand and all instruments were at least partially buried at the time of recovery. The instruments actually sank into the sand and on subsequent deployments the frames were located on reef, close to the sites used in deployment 1.

A typical mooring frame used at the ADV sites is shown in Figure 5

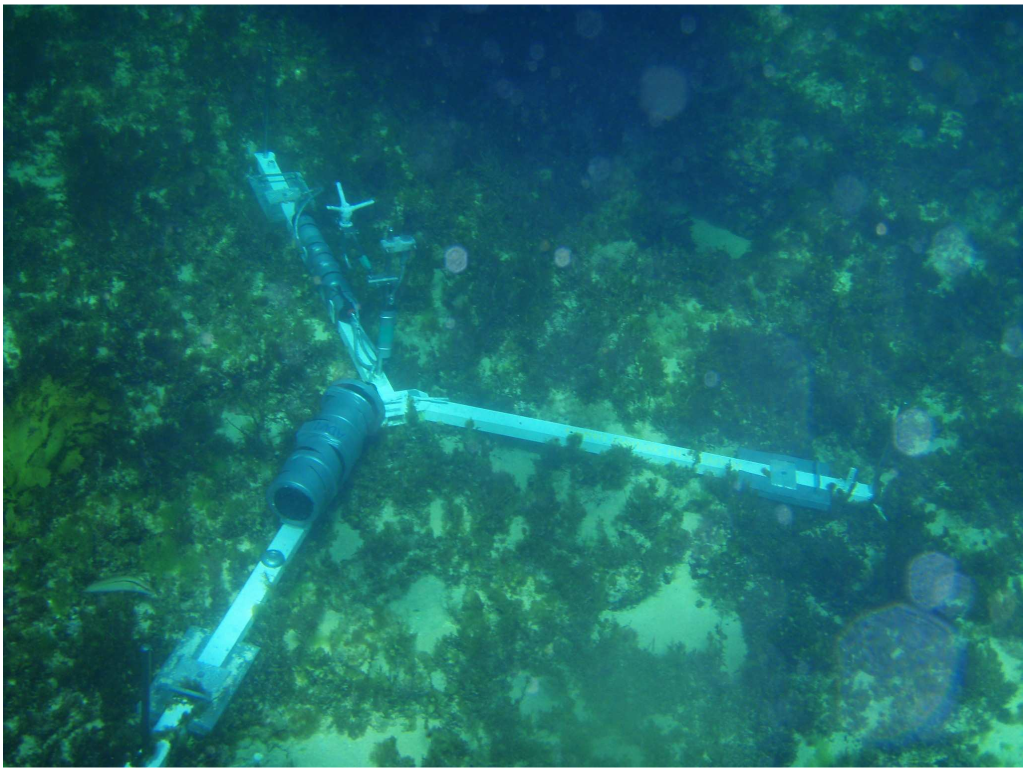
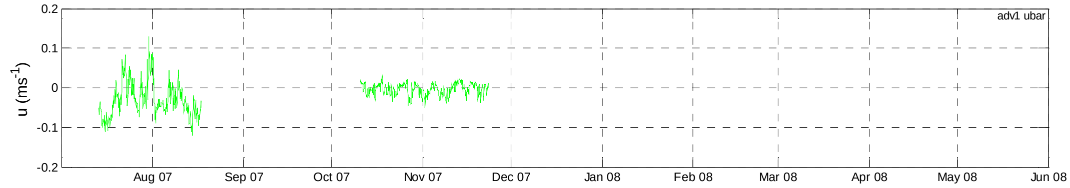


Figure 5 ADV mooring frame

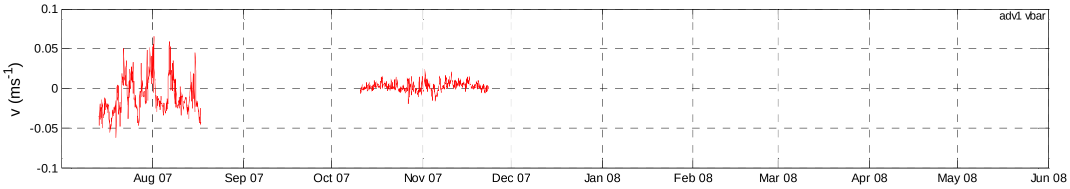
| | Deployment | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Latitude | 31.82077S | 31.82148S | | |
| Longitude | 115.70535E | 115.70583E | | |
| Northing (m) | 6478701 | 6478622 | | |
| Easting (m) | 377471 | 377518 | | |
| Depth (m) | 5.5 | 6.5 | | |
| Start | 13-Jul-2007 17:17:03 | 10-Oct-2007 17:17:03 | | |
| Stop | 17-Aug-2007 13:17:03 | 23-Nov-2007 11:17:03 | | |
| Vector s/n | VEC1672 | VEC1672 | | |

Table 3 ADV1 deployment details

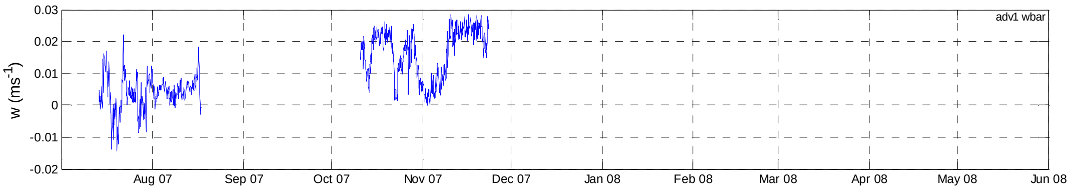
(a)



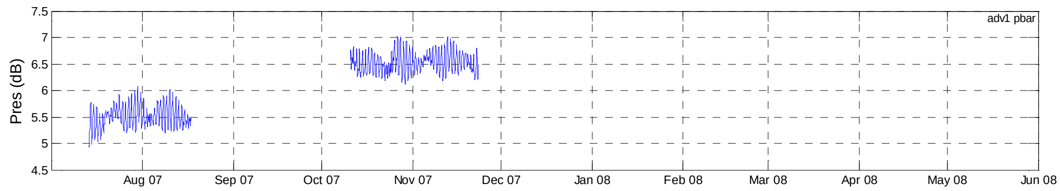

(b)




(c)




(d)




(e)

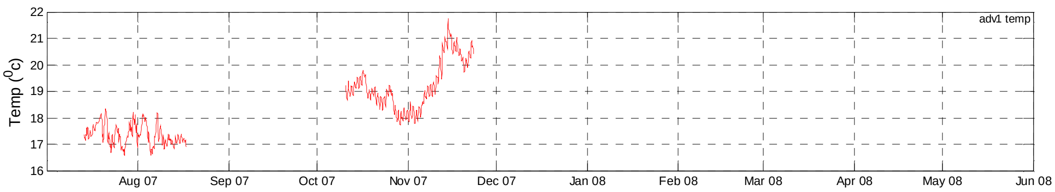



Figure 6 Burst averaged time series from ADV1. (a) eastward, (b) northward, and (c) vertical velocity components, (d) depth and (e) temperature.

## 3.3 ADV2

**Instrument:** Nortek Vector and OBS

- Parameters u,v,w,P,T, suspended sediment
- Sample rate 1Hz
- Record length 2048 samples
- Interval 3600s

| | Deployment | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Latitude | 31.82592S | 31.82778S | 31.82785S | 31.82803S |
| Longitude | 115.70663E | 115.70772E | 115.70778E | 115.70768E |
| Northing (m) | 6478131 | 6477926 | 6477918 | 6477898 |
| Easting (m) | 377600 | 377704 | 377711 | 377702 |
| Depth (m) | 5.6 | 4.4 | 3.8 | 4.1 |
| Start | 13-Jul-2007 17:17:03 | 10-Oct-2007 17:17:03 | 17-Jan-2008 17:17:03 | 28-Mar-2008 17:17:03 |
| Stop | 17-Aug-2007 15:17:03 | 23-Nov-2007 09:17:03 | 27-Feb-2008 07:17:03 | 18-May-2008 09:17:03 |
| Vector s/n | VEC1674 | VEC1674 | VEC1674 | VEC1674 |

Table 4 ADV2 deployment details

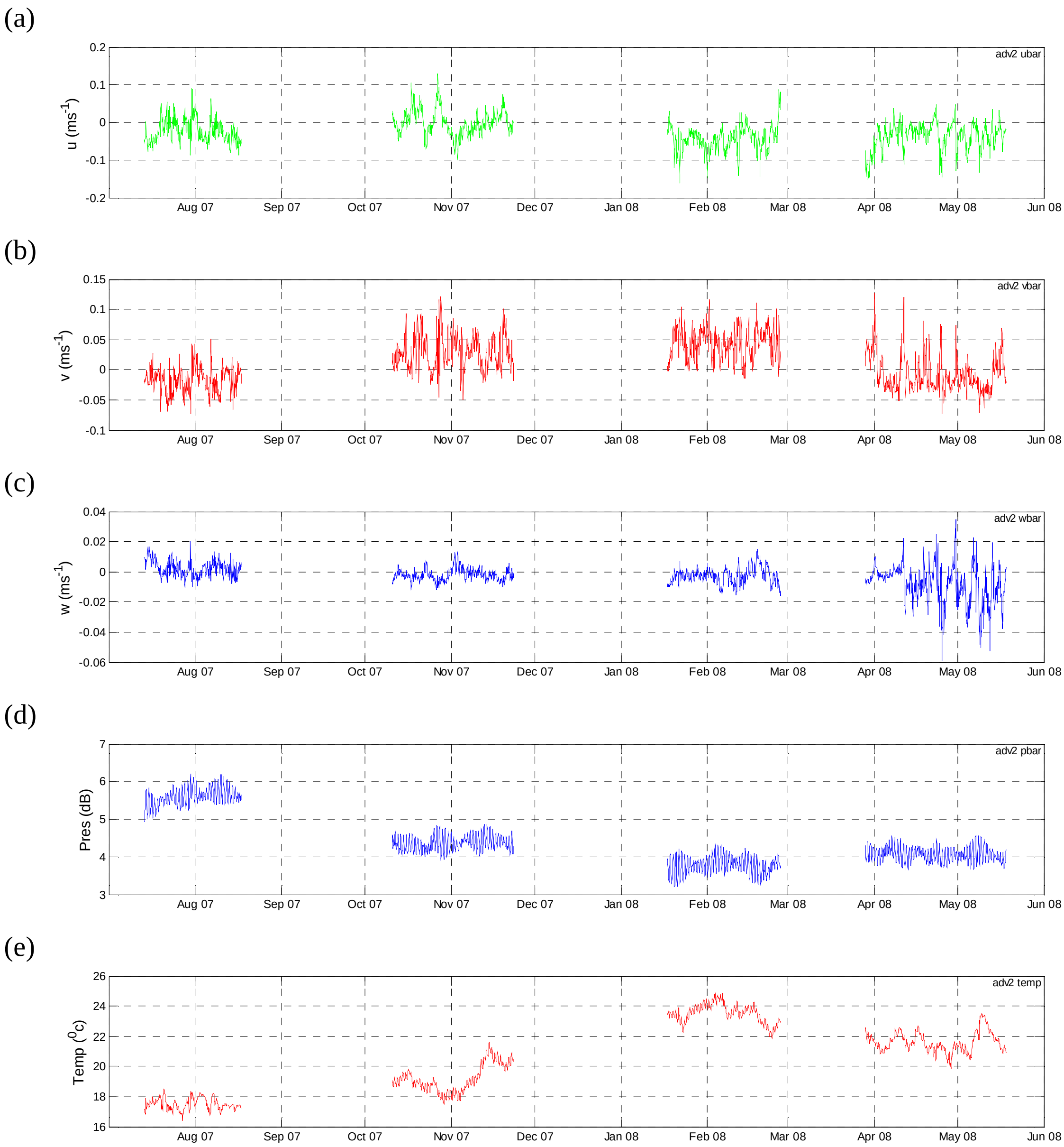



Figure 7 Burst averaged time series from ADV2. (a) eastward, (b) northward, and (c) vertical velocity components, (d) depth and (e) temperature.

## 3.4 ADV3

**Instrument:** Nortek Vector and OBS

- Parameters u,v,w,P,T
- Sample rate 1Hz
- Record length 2048 samples
- Interval 3600s

| | Deployment | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Latitude | 31.83372S | 31.83417S | 31.8341S | 31.83405S |
| Longitude | 115.70853E | 115.70838E | 115.7084E | 115.70853E |
| Northing (m) | 6477269 | 6477219 | 6477226 | 6477232 |
| Easting (m) | 377789 | 377776 | 377778 | 377790 |
| Depth (m) | 5.0 | 3.6 | 3.6 | 3.9 |
| Start | 13-Jul-2007 17:17:03 | 10-Oct-2007 17:17:03 | 17-Jan-2008 17:17:03 | 28-Mar-2008 17:17:03 |
| Stop | 21-Aug-2007 09:17:03 | 23-Nov-2007 15:17:03 | 27-Feb-2008 09:17:03 | 18-May-2008 09:17:03 |
| Vector s/n | VEC1670 | VEC1670 | VEC1670 | VEC1670 |

Table 5 ADV3 deployment details

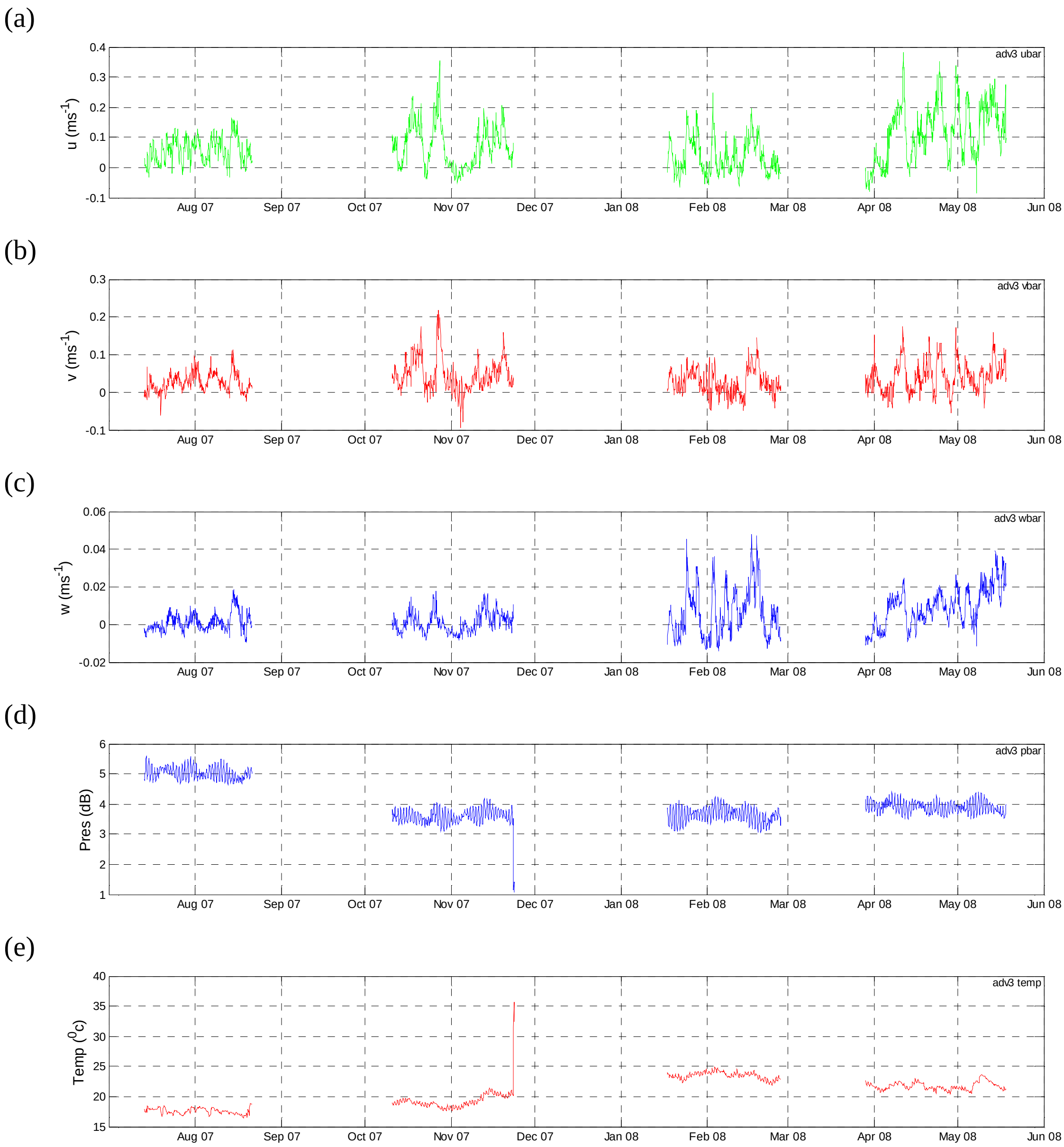



Figure 8 Burst averaged time series from ADV3. (a) eastward, (b) northward, and (c) vertical velocity components, (d) depth and (e) temperature.

## 3.5 ADV4

**Instrument:** Nortek Vector and OBS

- Parameters u,v,w,P,T
- Sample rate 1Hz
- Record length 2048 samples
- Interval 3600s

**Comments:**

The instrument at site ADV4 was completely buried on the first deployment and was eventually located on February 29 and recovered using a suction dredge on March 1. The sensor head was missing and no data were recovered. For deployments 3 and 4 we moved the sensor from site ADV1 to ADV4 to get data from this site for the last two deployments.

| | Deployment | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Latitude | | | 31.83917S | 31.83897S |
| Longitude | | | 115.70863E | 115.70862E |
| Northing (m) | | | 6476665 | 6476687 |
| Easting (m) | | | 377806 | 377805 |
| Depth (m) | | | 3.5 | 3.1 |
| Start | | | 17-Jan-2008 17:17:03 | 28-Mar-2008 17:17:03 |
| Stop | | | 27-Feb-2008 09:17:03 | 18-May-2008 09:17:03 |
| Vector s/n | | | VEC1672 | VEC1672 |

Table 6 ADV4 deployment details

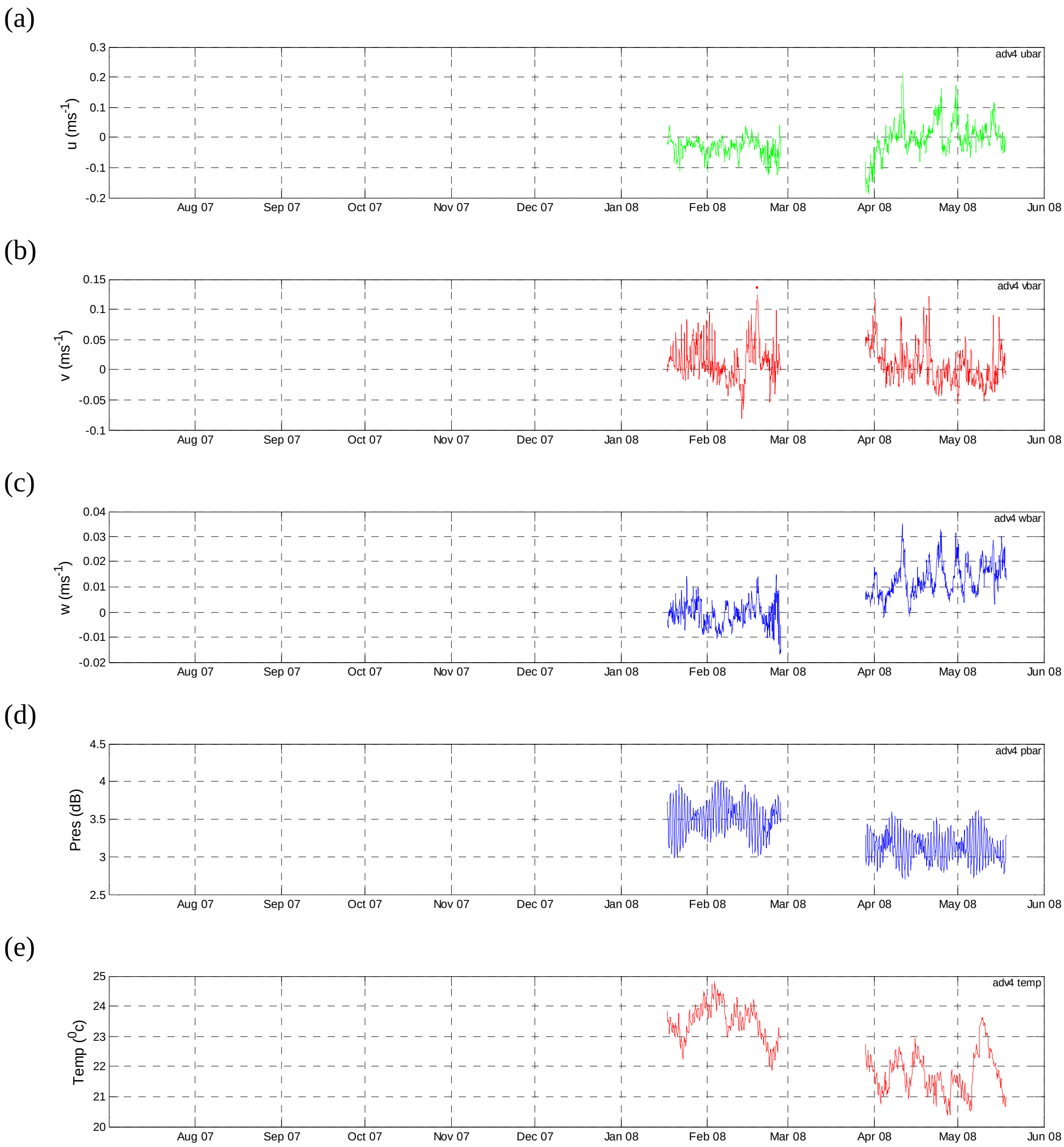



Figure 9 Burst averaged time series from ADV4. (a) eastward, (b) northward, and (c) vertical velocity components, (d) depth and (e) temperature

## 3.6 AQ1

**Instrument:** Nortek Aquadopp (600kHz)

Current Profile

- Parameters u, v,P,T
- Profile interval 3600s
- Cell size 1m
- Averaging interval 1800s

**Comments**

AQ1 was located in the channel between ADV1 and ADV2. In the first deployment it was located on sand, slightly seawards of the mean reef line. In deployments 2, 3 and 4 it was shifted about 300m eastward and located on reef.

| | Deployment | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Latitude | 31.82322S | 31.82317S | 31.82327S | 31.8233S |
| Longitude | 115.70327E | 115.70630E | 115.70627E | 115.70607E |
| Northing (m) | 6478427 | 6478436 | 6478425 | 6478421 |
| Easting (m) | 377277 | 377565 | 377562 | 377543 |
| Depth (m) | 8.1 | 4.3 | 3.8 | 3.7 |
| Start | 06-Jul-2007 11:00:00 | 04-Oct-2007 17:00:00 | 16-Jan-2008 17:00:00 | 27-Mar-2008 17:00:00 |
| Stop | 21-Aug-2007 14:00:00 | 23-Nov-2007 12:00:00 | 26-Jan-2008 06:00:00 | 12-May-2008 11:00:00 |
| Aquadopp s/n | AQD1287 | AQD1287 | AQD1287 | AQD1287 |

Table 7 AQ1 deployment details

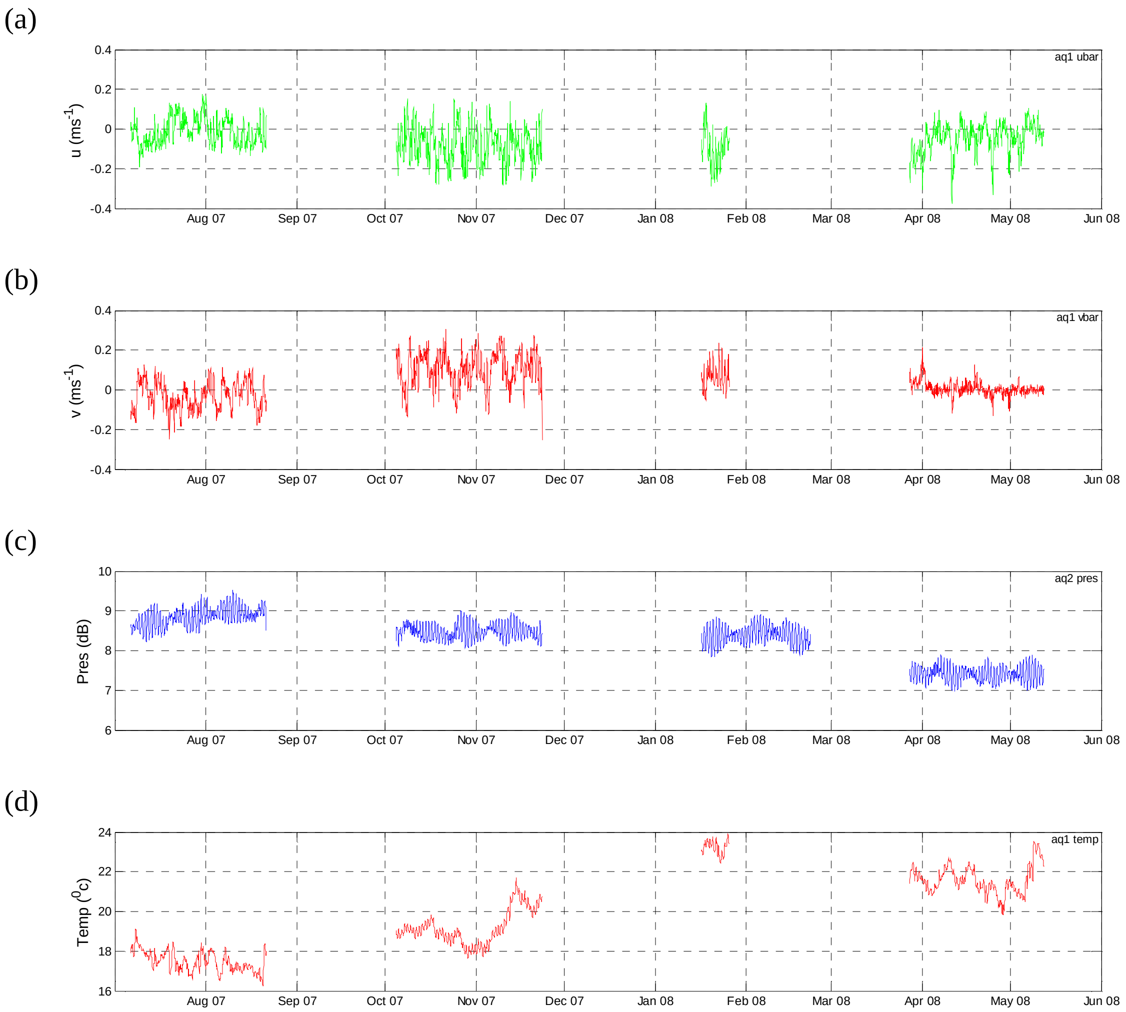



Figure 10 Time series from AQ1. (a) depth-averaged u (eastward) velocity, (b) depth-averaged v (northward) velocity, (c) depth and (d) temperature

## 3.7 AQ2

**Instrument:** Nortek Aquadopp (1MHz)

Current Profile

- Parameters u, v,P,T
- Profile interval 3600s
- Cell size 0.5m
- Averaging interval 600s

**Comments**

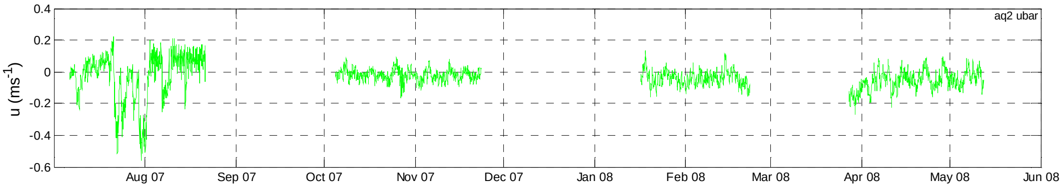
Mooring frame used at AQ2 is shown in Figure 11. These frames also sank into the sand during the first deployment and were subsequently deployed on reef for deployments 2, 3 and 4.

Figure 11 AQ2 mooring and bio-fouling after 6 week deployment

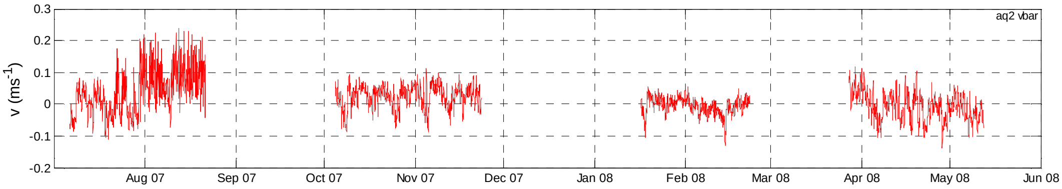
| | Deployment | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Latitude | 31.83010S | 31.83075S | 31.8309S | 31.83088S |
| Longitude | 115.70683E | 115.70648E | 115.70633E | 115.70667E |
| Northing (m) | 6477668 | 6477595 | 6477579 | 6477580 |
| Easting (m) | 377624 | 377592 | 377578 | 377609 |
| Depth (m) | 8.8 | 8.5 | 8.4 | 7.4 |
| Start | 06-Jul-2007 11:00:00 | 04-Oct-2007 17:00:00 | 16-Jan-2008 17:00:00 | 27-Mar-2008 17:00:00 |
| Stop | 21-Aug-2007 13:00:00 | 23-Nov-2007 12:00:00 | 22-Feb-2008 23:00:00 | 12-May-2008 11:00:00 |
| Aquadopp s/n | AQD1287 | AQD1287 | AQD1287 | AQD1287 |

Table 8 AQ2 deployment details

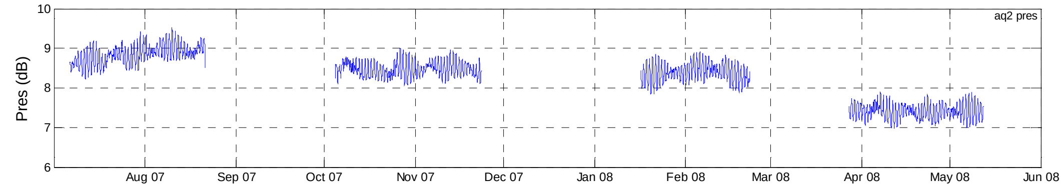
(a)




(b)




(c)




(d)

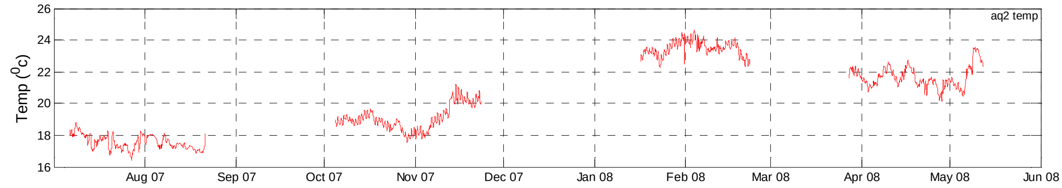



Figure 12 Time series from AQ2. (a) depth-averaged u (eastward) velocity, (b) depth-averaged v (northward) velocity, (c) depth and (d) temperature

## 3.8 RDIN

**Instrument:** RDI Workhorse Sentinel (307.2kHz)

Current Profile

- Parameters u, v,P,T
- Pings per ensemble 600
- Ping rate 0.56s
- Profile interval 3600s
- Cell size 0.5m


Figure 13 RDIN mooring frame with RDI ADCP

| | Deployment | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Latitude | 31.80318S | 31.80447S | 31.80440S | 31.80422S |
| Longitude | 115.71083E | 115.70860E | 115.70853E | 115.70863E |
| Northing (m) | 6480656 | 6480511 | 6480519 | 6480539 |
| Easting (m) | 377967 | 377758 | 377751 | 377760 |
| Depth (m) | 10.6 | 5.7 | 6.6 | 7.6 |
| Start | 06-Jul-2007 08:00:00 | 28-Sep-2007 15:00:00 | 16-Jan-2008 17:00:00 | 26-Mar-2008 17:00:00 |
| Stop | 21-Aug-2007 13:00:00 | 26-Nov-2007 10:59:59 | 26-Feb-2008 07:00:00 | 12-May-2008 08:00:00 |
| RDI s/n | 3713 | 3713 | 3713 | 3713 |

Table 9 RDIN deployment details

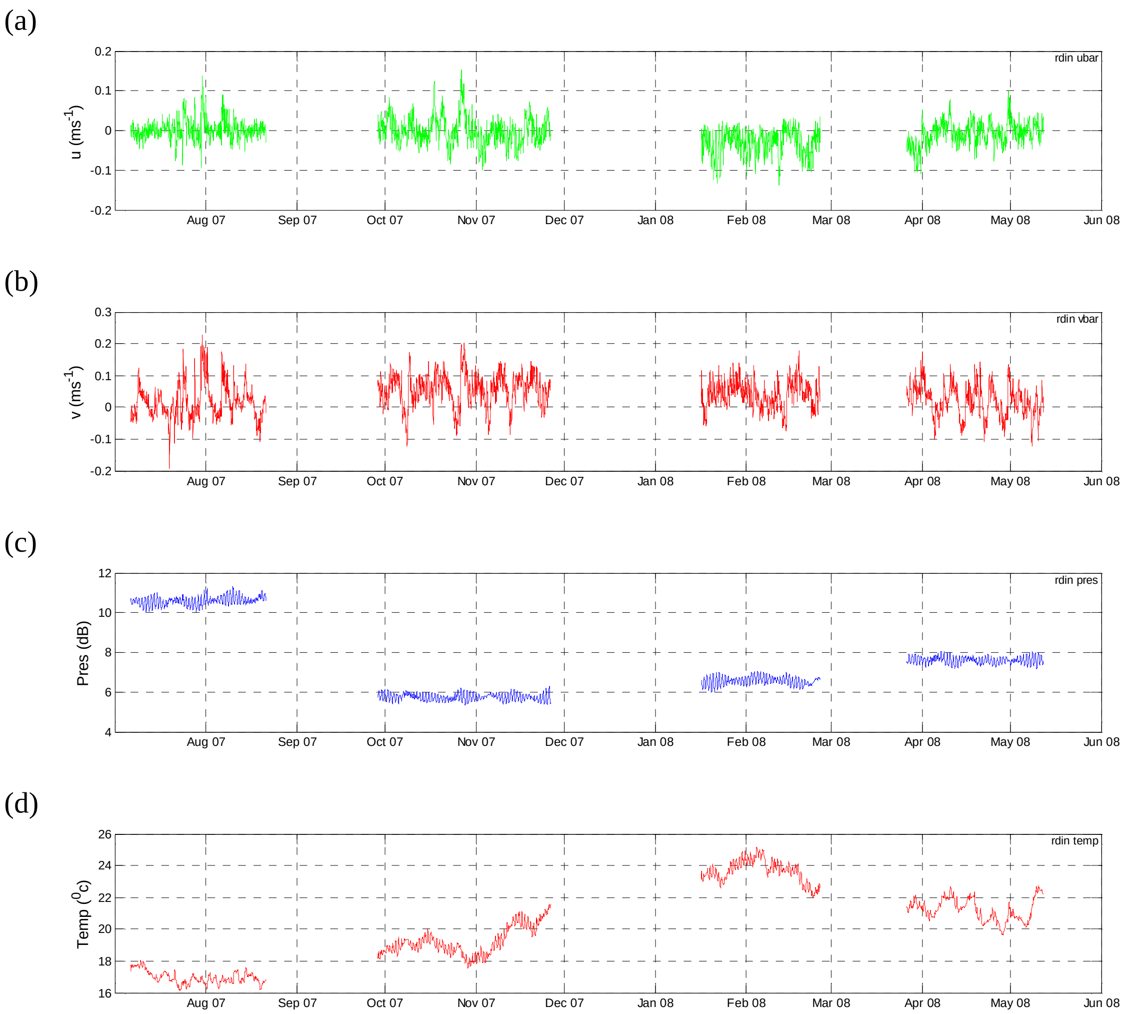



Figure 14 Time series from RDIN. (a) depth-averaged u (eastward) velocity, (b) depth-averaged v (northward) velocity, (c) depth and (d) temperature

## 3.9 RDIS

**Instrument:** RDI Workhorse Sentinel (307.2kHz)

Current Profile

- Parameters u, v,P,T
- Pings per ensemble 600
- Ping rate 0.56s
- Profile interval 3600s
- Cell size 0.5m

| | Deployment | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Latitude | 31.86402S | 31.86705S | 31.86692S | 31.86695S |
| Longitude | 115.72542E | 115.73150E | 115.73128E | 115.73153E |
| Northing (m) | 6473929 | 6473599 | 6473614 | 6473610 |
| Easting (m) | 379427 | 380006 | 379986 | 380009 |
| Depth (m) | 13.2 | 11.0 | 10.5 | 7.6 |
| Start | 06-Jul-2007 08:00:00 | 28-Sep-2007 14:00:00 | 16-Jan-2008 17:00:00 | 26-Mar-2008 17:00:00 |
| Stop | 05-Sep-2007 03:00:00 | 26-Nov-2007 07:59:59 | 26-Feb-2008 07:00:00 | 12-May-2008 08:00:00 |
| RDI s/n | 3712 | 3712 | 3712 | 3712 |

Table 10 RDIS deployment details

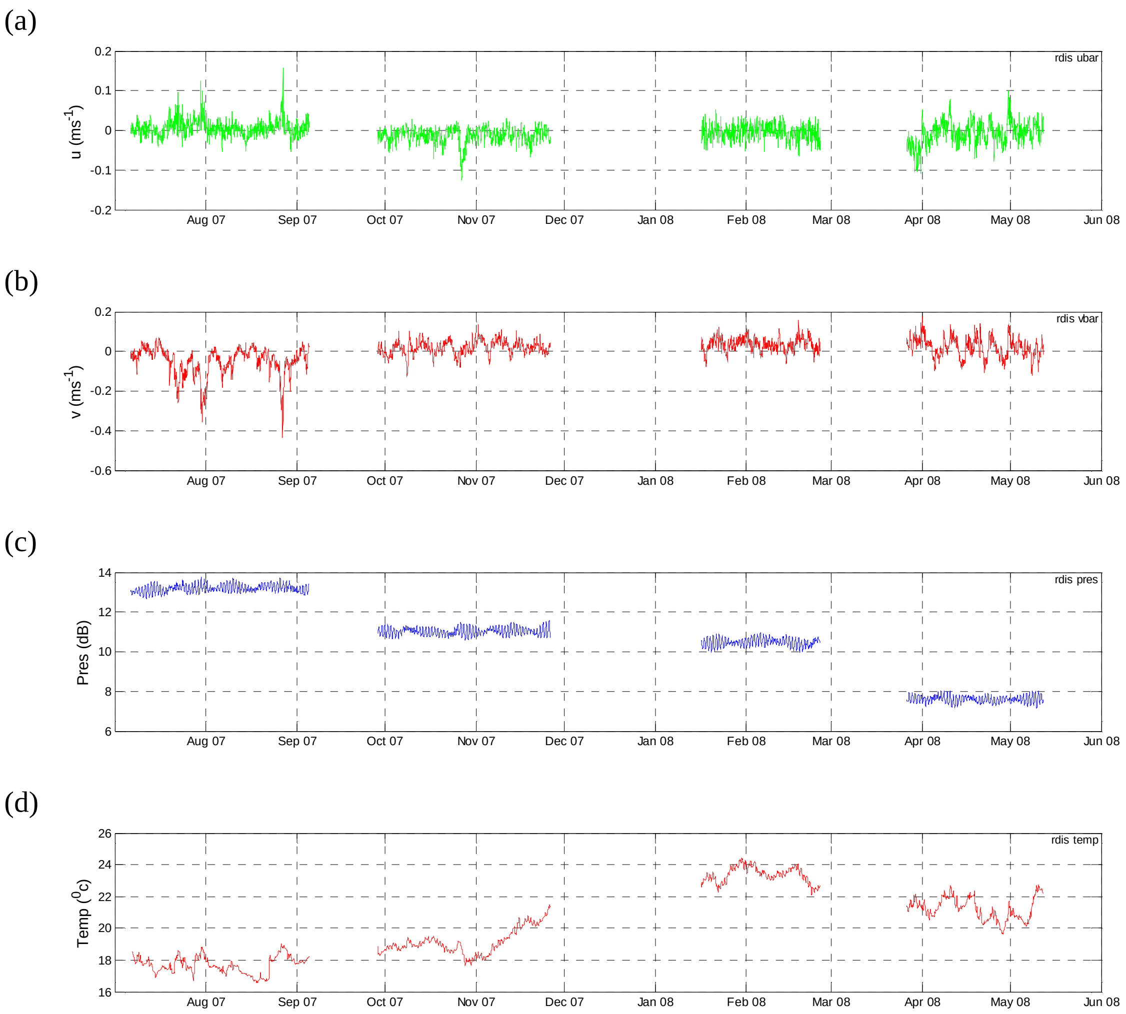



Figure 15 Time series from RDIS. (a) depth-averaged u (eastward) velocity, (b) depth-averaged v (northward) velocity, (c) depth and (d) temperature

## 3.10 MS1

**Instrument:** Seabird SBE19plus

- Parameters T, S, PAR, Fluorescence, Oxygen
- Sampling interval 900s
- Number of measurements per sample 4

**Instrument:** Seabird SBE26

- Tide interval 900s
- Waves every 12 tide samples
- 2400 wave samples/burst at 2 scans/sec

**Instrument:** RDI Workhorse Sentinel (614.4kHz)

- Parameters u,v,P,T
- Pings per ensemble 600
- Ping rate 6s
- Profile interval 3602.5s
- Cell size 0.5m

**Comments**

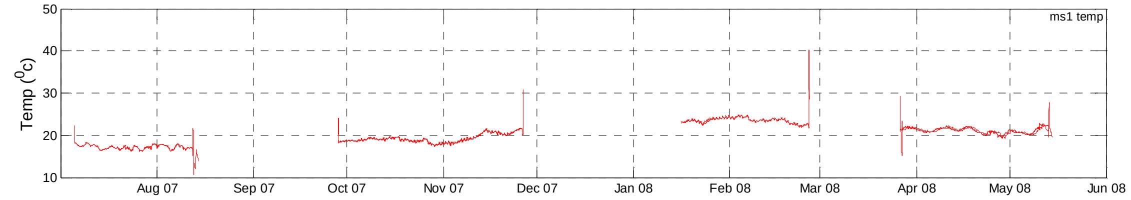
All of the instruments were located on a single bottom-mounted frame (see Figure 16) positioned on seagrass  which prevented the instrument frame from sinking into the sand.

Figure 16 MS1 mooring showing SBE19p (left), SBE26 (middle) and RDI ADCP (right).

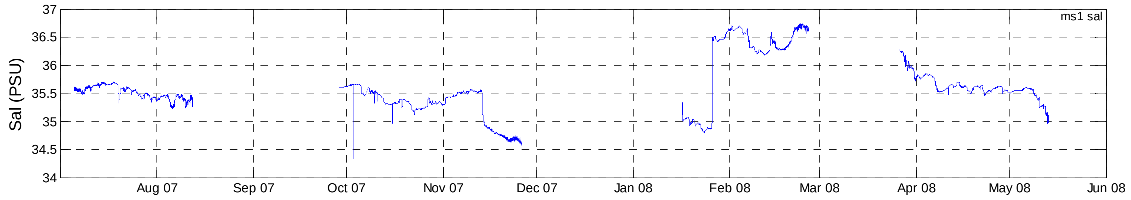
| | Deployment | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Latitude | 31.82893S | 31.82742S | 31.82738S | 31.82742S |
| Longitude | 115.72272E | 115.72308E | 115.72335E | 115.72323E |
| Northing (m) | 6477815 | 6477983 | 6477987 | 6477984 |
| Easting (m) | 379126 | 379159 | 379184 | 379173 |
| Depth (m) | 10.3 | 8.1 | 8.7 | 8.7 |
| Start SBE19 | 05-Jul-2007 14:03:51 | 28-Sep-2007 17:15:01 | 16-Jan-2008 17:15:01 | 26-Mar-2008 17:15:01 |
| Stop SBE19 | 12-Aug-2007 14:18:51 | 26-Nov-2007 10:15:01 | 26-Feb-2008 09:15:01 | 13-May-2008 13:15:01 |
| SBE19plus s/n | 4534 | 4534 | 4534 | 4534 |
| SBE26 s/n | 408 | 408 | 408 | 408 |
| RDI | 2388 | 2388 | 2388 | 2388 |

Table 11 MS1 deployment details

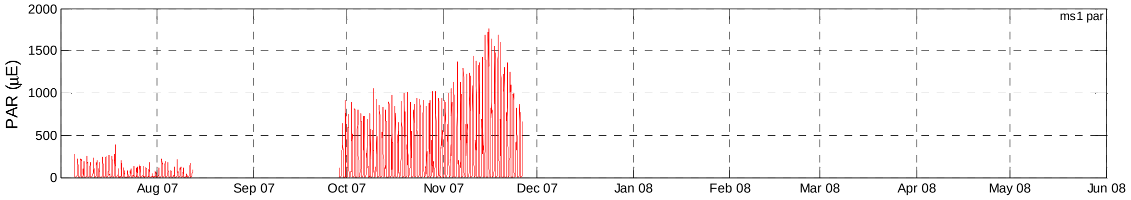
(a)



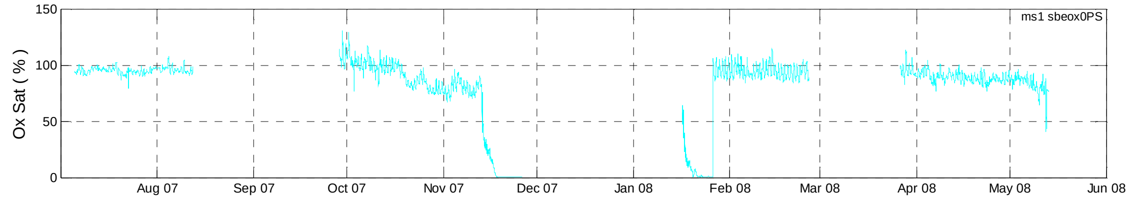

(b)




(c)




(d)




(e)

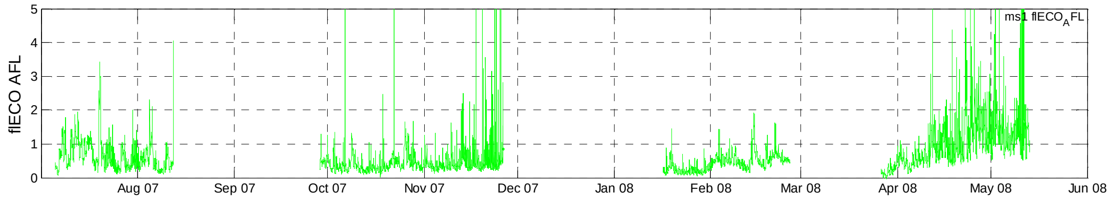



Figure 17 Time-series from SBE19plus at site MS1, (a) temperature, (b) salinity, (c) PAR, (d) oxygen, (e) fluorescence

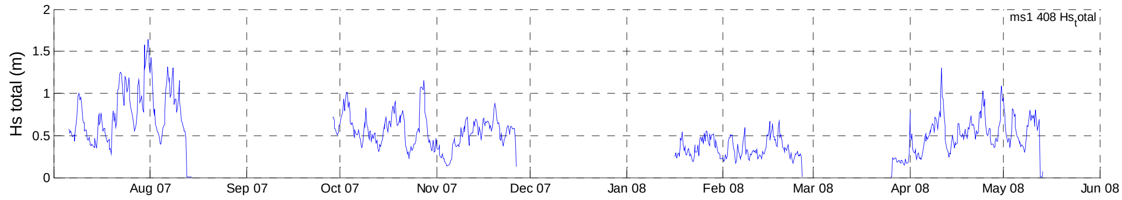



Figure 18 Time-series of significant wave height from SBE26 at site MS1.

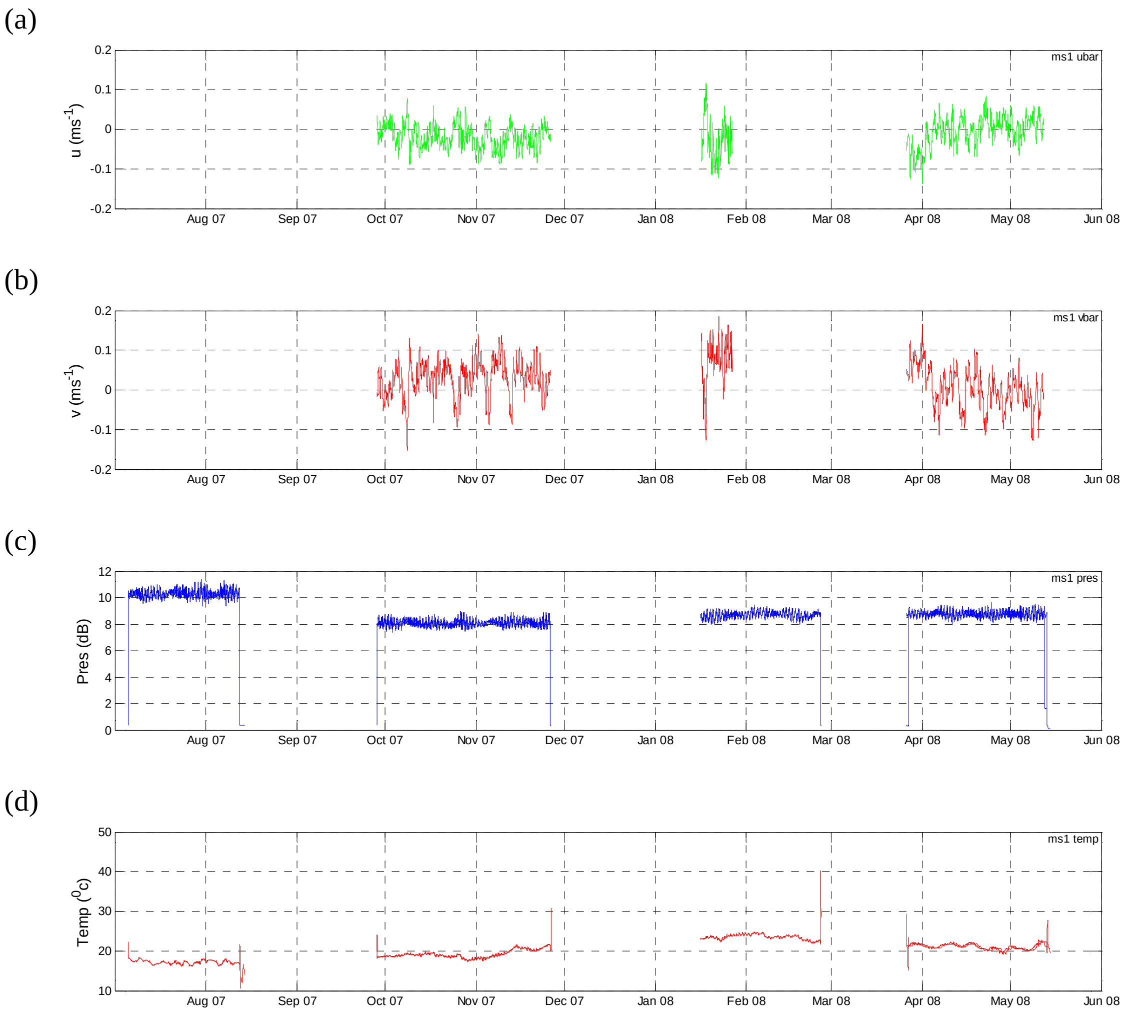



Figure 19 Time-series from rdi adcp at MS1. (a) depth-averaged u (eastward) velocity, (b) depth-averaged v (northward) velocity, (c) depth and (d) temperature

## 3.11 MS2

**Instrument:** Seabird SBE19plus

- Parameters T, S, PAR, Fluorescence, Oxygen
- Sampling interval 900s
- Number of measurements per sample 4

**Instrument:** Seabird SBE26

- Tide interval 900s
- Waves every 12 tide samples
- 2400 wave samples/burst at 2 scans/s

**Instrument:** Seabird SBE37

- Parameters P,T,S
- Sampling interval 900s
- Number of samples in average 100

**Comments**

MS2 consisted of a U-shaped mooring in 25m water depth with the SBE19plus on a subsurface float 15m above the bottom as shown in Figure 20. Below the SBE19plus were four SBE37 temperature, salinity and depth sensors at 5m, 7.5m, 10m and 12.5m above the bottom. The SBE26 was deployed on a second anchor connected to the anchor below the SBE19plus with a ground line.

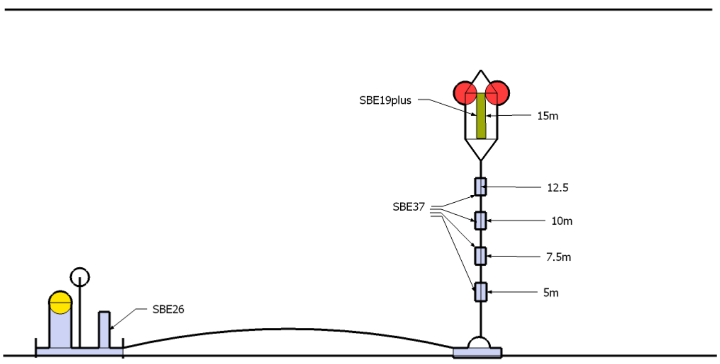



Figure 20 Schematic of mooring at MS2

Figure 21 Deploying MS2 showing acoustic release and SBE26

| | Deployment | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Latitude | 31.83268S | 31.83115S | 31.83170S | 31.83152S |
| Longitude | 115.66323E | 115.66390E | 115.66333E | 115.66288E |
| Northing (m) | 6477331 | 6477502 | 6477441 | 6477460 |
| Easting (m) | 373501 | 373562 | 373509 | 373467 |
| Depth (m) | 26.0 | 25.4 | 25.9 | 25.1 |
| Start SBE19 | 06-Jul-2007 10:26:29 | 28-Sep-2007 17:15:01 | 16-Jan-2008 17:30:19 | 26-Mar-2008 17:15:01 |
| Stop SBE19 | 12-Aug-2007 13:11:29 | 23-Nov-2007 08:15:01 | 25-Feb-2008 13:45:19 | 13-May-2008 13:15:01 |
| SBE19plus s/n | 4536 | 4536 | 4536 | 4536 |
| SBE26 s/n | 409 | 409 | 409 | 409 |
| SBE37 s/n | 3027 | 3027 | 3027 | 3027 |
| SBE37 s/n | 2973 | 2973 | 2973 | 2973 |
| SBE37 s/n | 3028 | 3028 | | 3028 |
| SBE37 s/n | 2972 | 2972 | | 2972 |

Table 12 MS2 deployment details

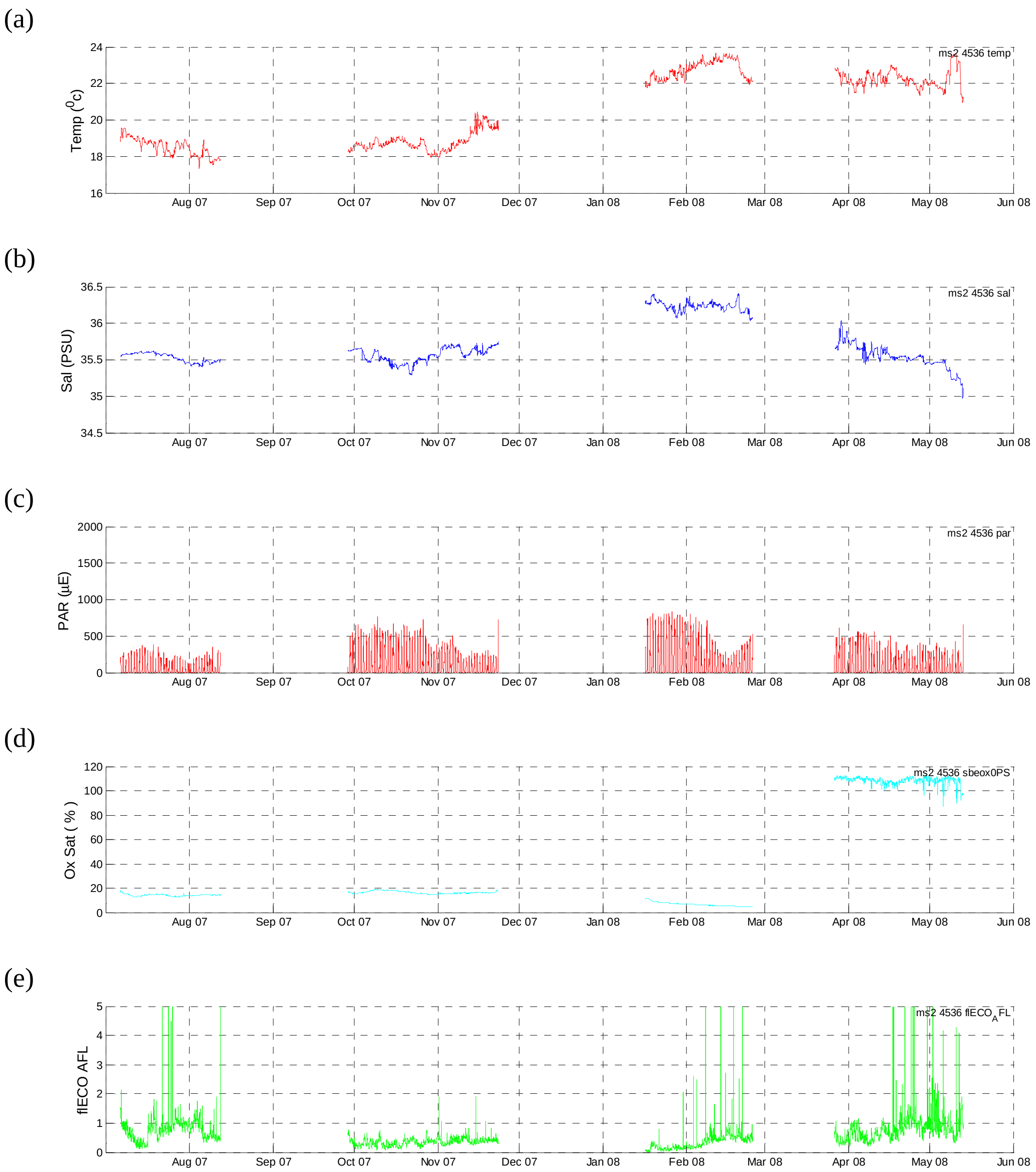
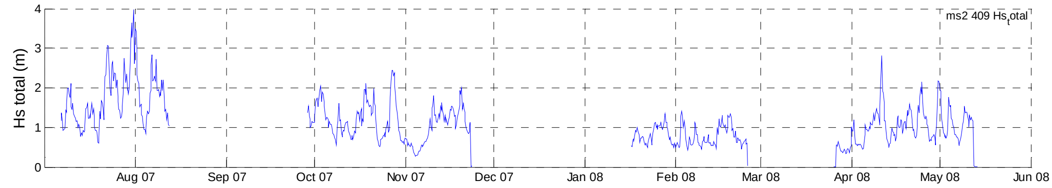



Figure 22 Time-series from SBE19plus at site MS2, (a) temperature, (b) salinity, (c) PAR, (d) oxygen, (e) fluorescence

(a)




(b)

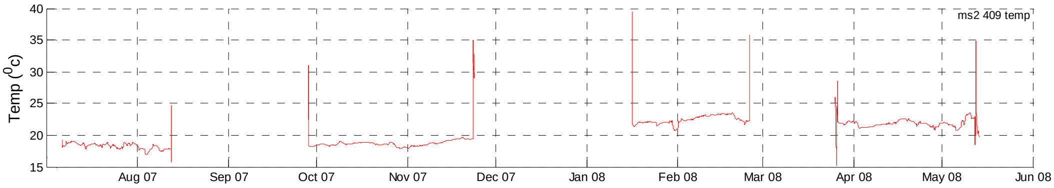
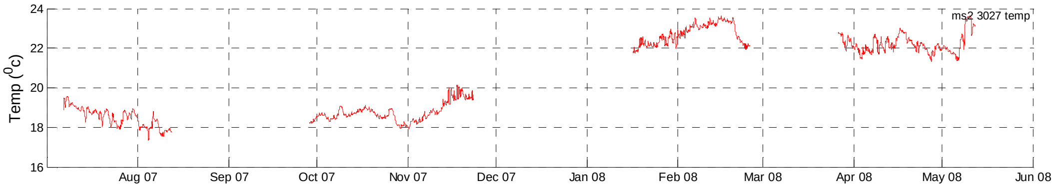
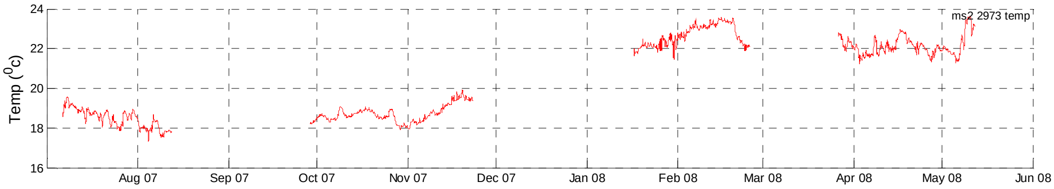



Figure 23 Time-series of (a) significant wave height, and (b) temperature from the SBE26 at site MS2.

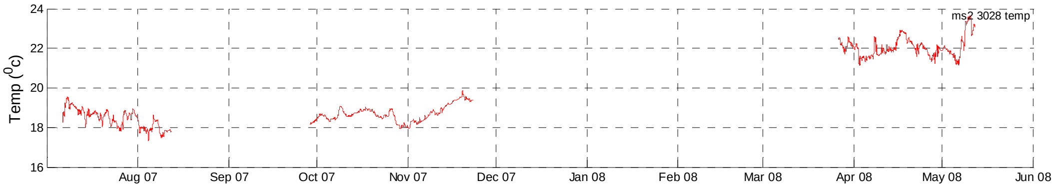
(a)




(b)




(c)




(d)

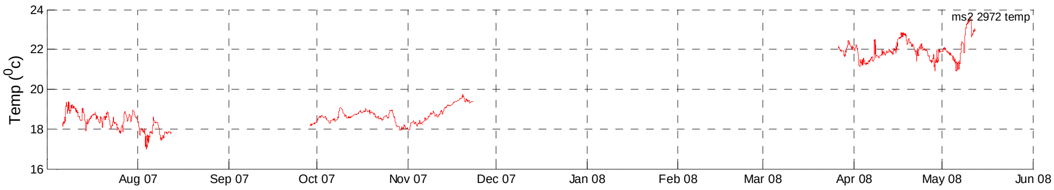



Figure 24 Time-series of temperatures measured by the SBE37's at MS2, with (a) being the shallowest and (d) being the deepest. The sensor depths are plotted in Figure 26.

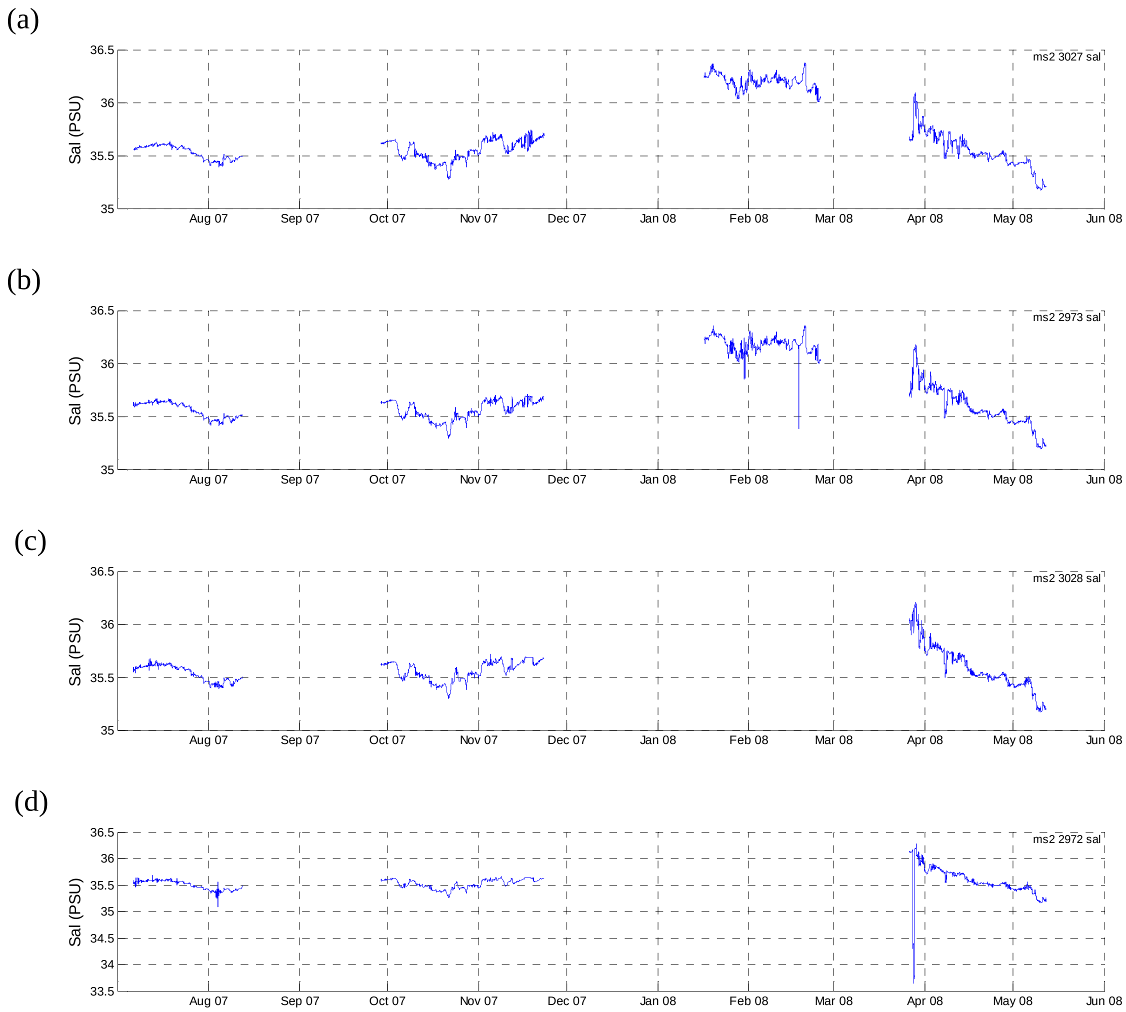



Figure 25 Time-series of salinity measured by the SBE37's at MS2, with (a) being the shallowest and (d) being the deepest. The sensor depths are plotted in Figure 26.

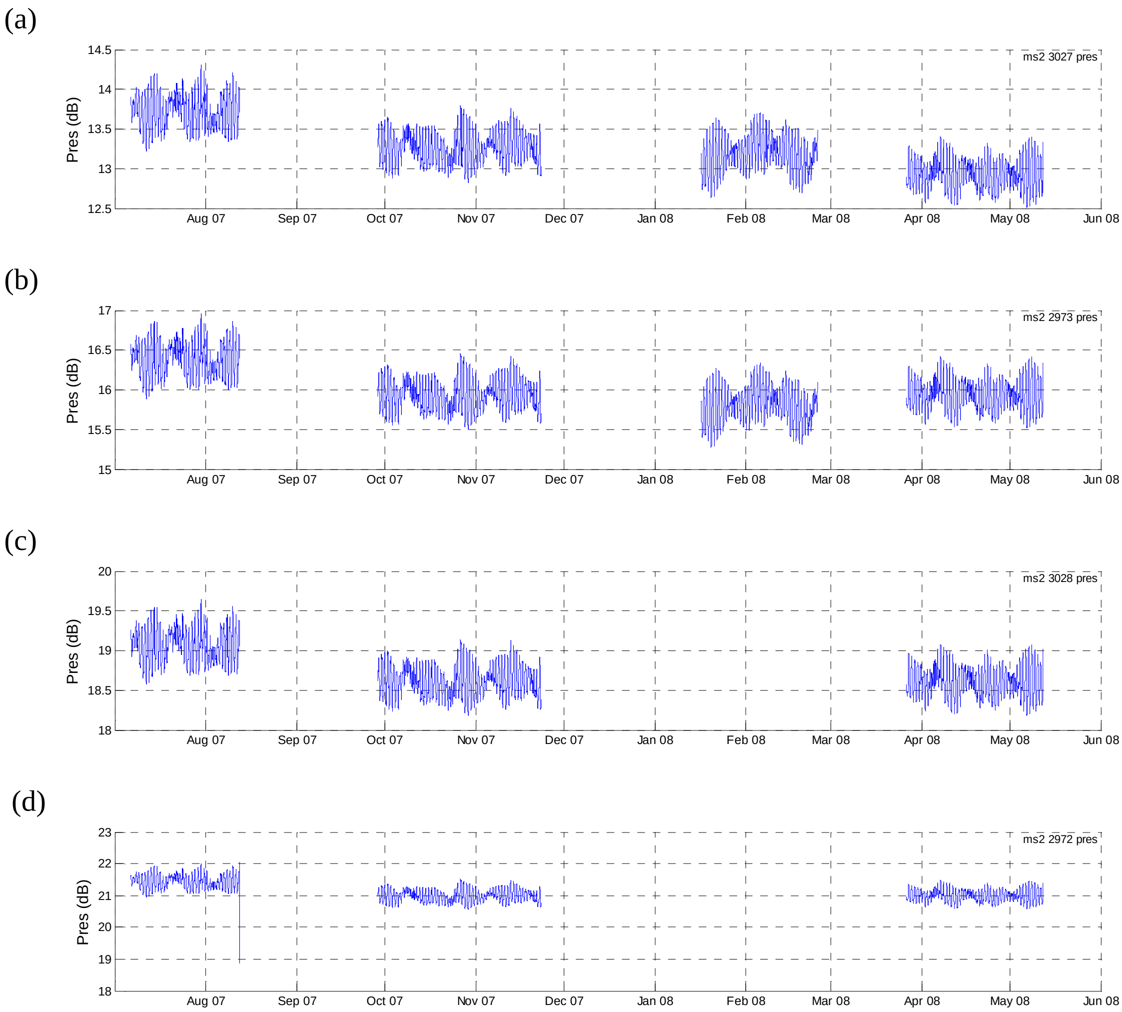



Figure 26 Time-series of depth measured by the SBE37's at MS2, with (a) being the shallowest and (d) being the deepest.

# 4. CTD SURVEYS

During the course of the mooring program a ctd survey of the region was completed at approximately monthly intervals using the RV Linnaeus. In the first 2 surveys a grid of 25 stations was occupied after which a further 5 stations were added to the northern end of the grid (shown on the following figures). Each station was sampled for temperature, salinity, depth, fluorescence, oxygen and PAR. Water samples were collected at the surface and bottom and analysed for phosphate, nitrate, ammonium and silicate. At alternate stations we also filtered surface and bottom samples for chlorophyll a. At MS2 an additional water sample was collected at the depth of the SBE19p.

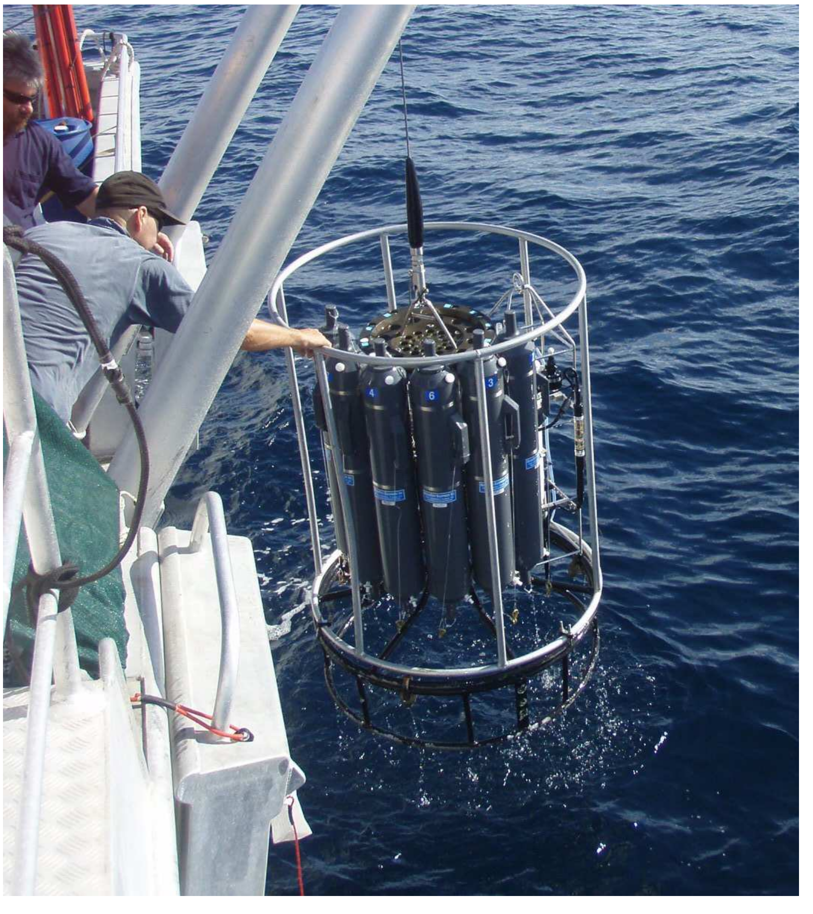


Figure 27 CTD recovery from RV Linnaeus

The following series of plots are of surface temperature, salinity, fluorescence and nutrients for each cruise.

## 4.1 Cruise LH01

**July 18, 2007**

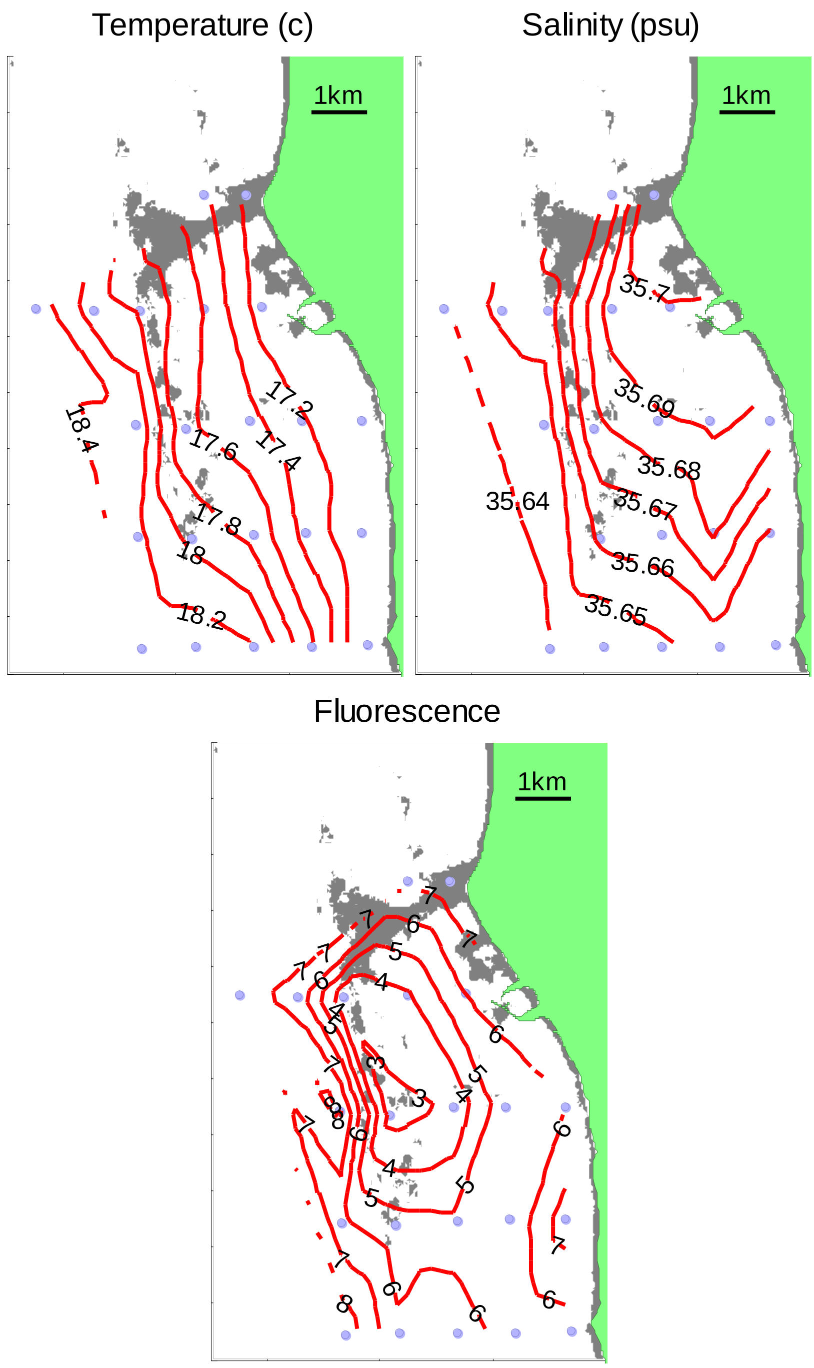



Figure 28 LH01 surface (2m) temperature, salinity and fluorescence.

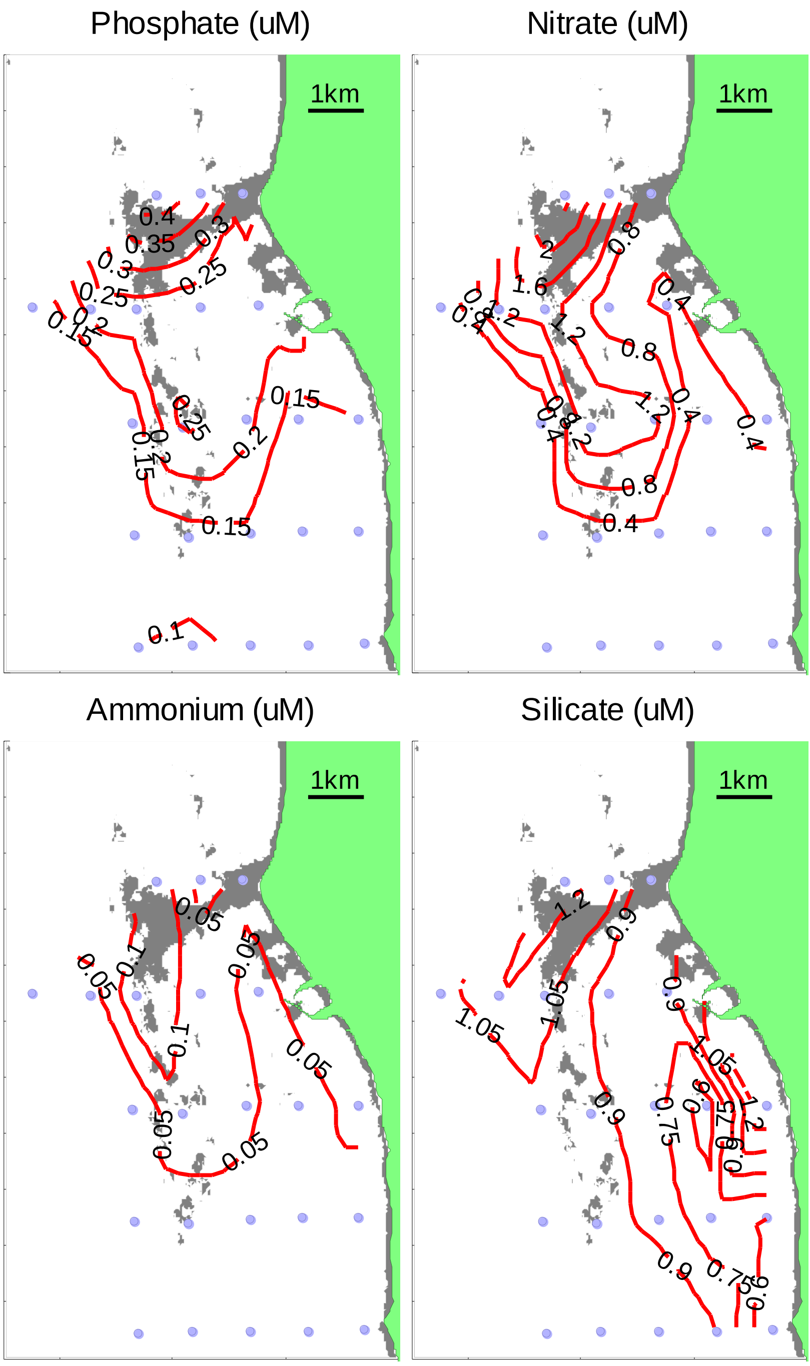



Figure 29 LH01 surface nutrient distributions.

## 4.2 Cruise LI200710

**August 31, 2007**

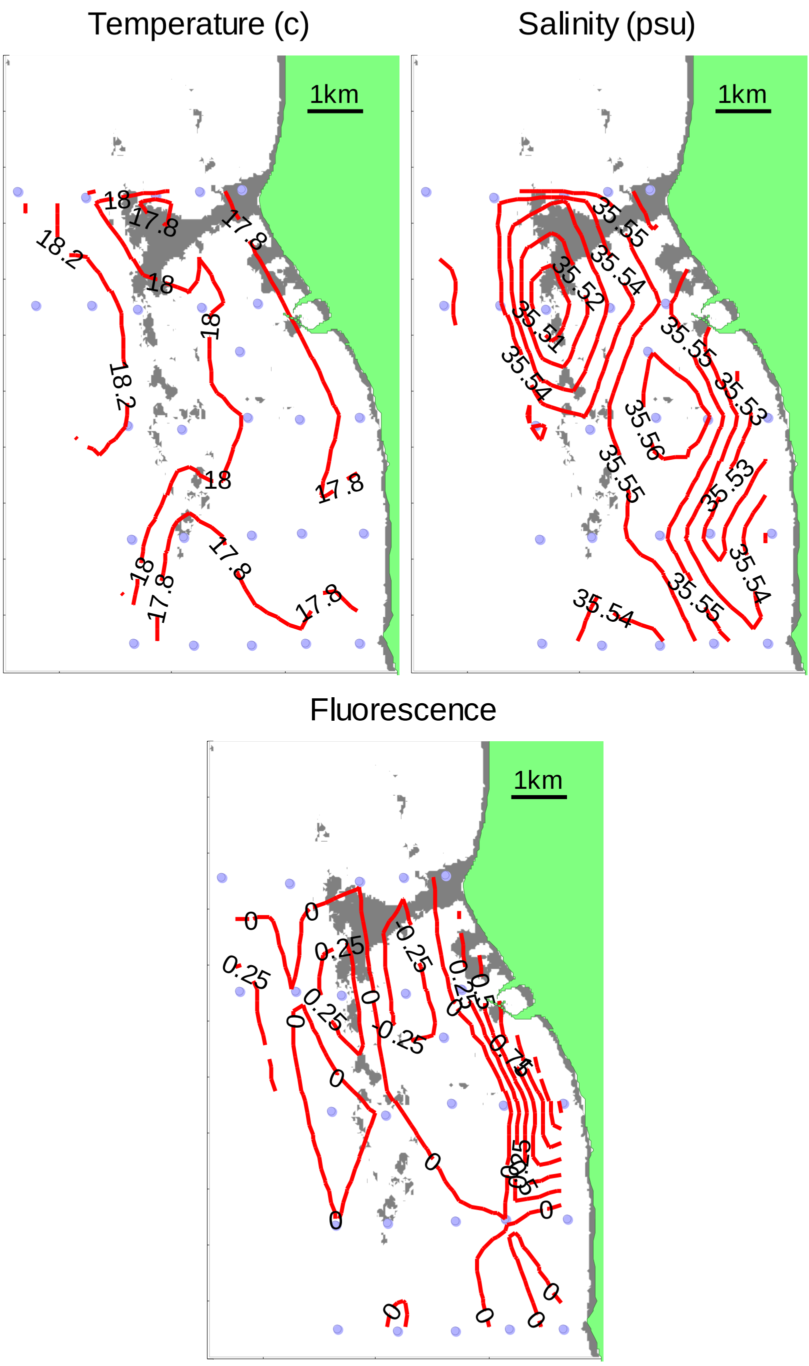



Figure 30 LI200710 surface (2m) temperature, salinity and fluorescence.

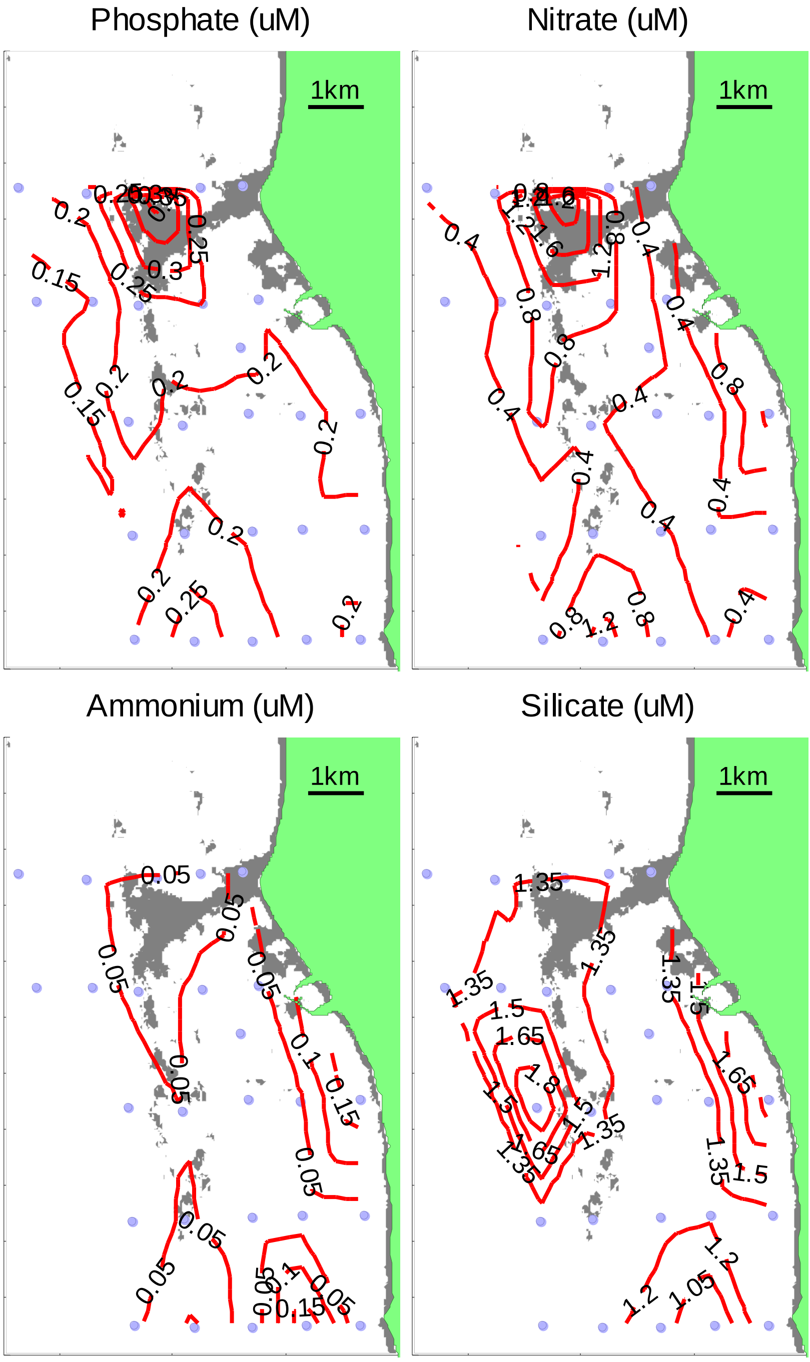



Figure 31  LI200710 surface nutrient distributions.

## 4.3 Cruise LI200712

### September 21, 2007

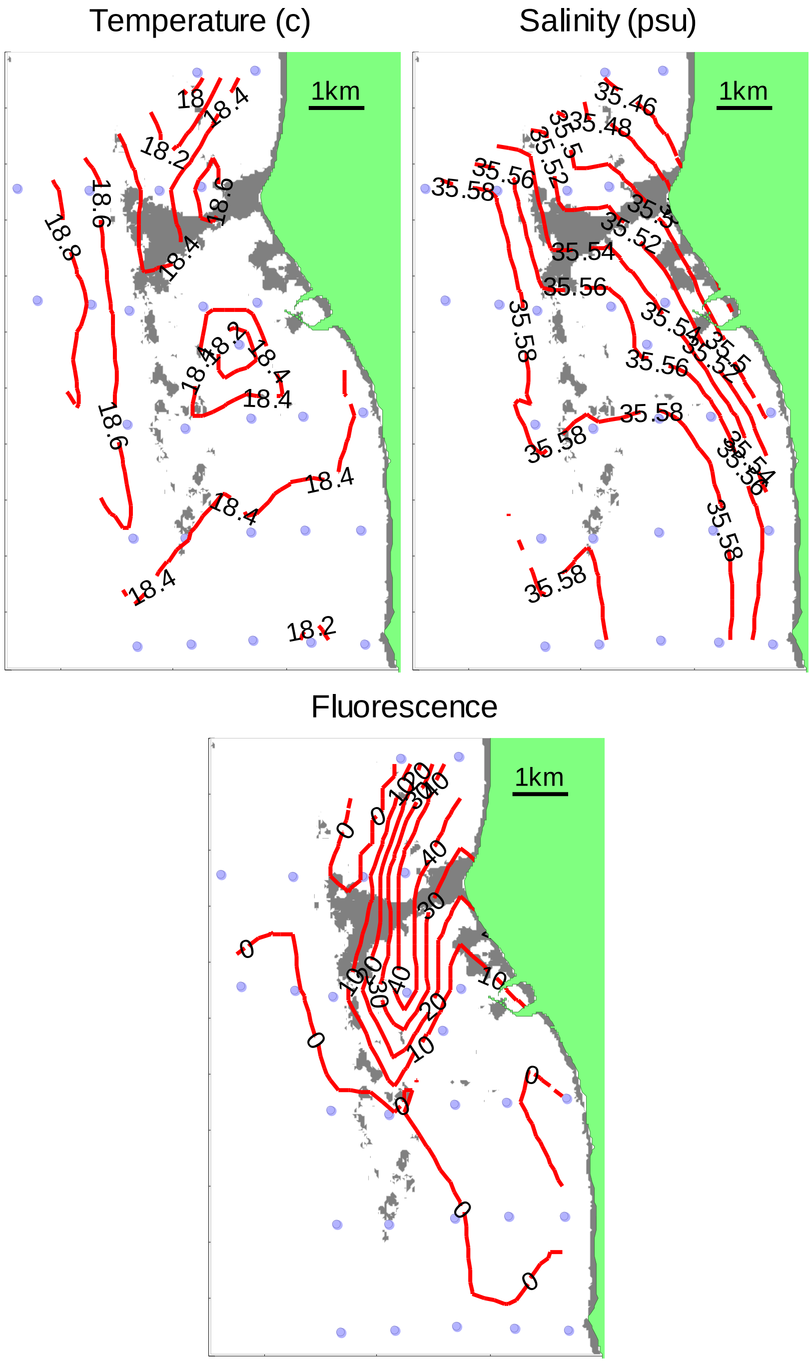



Figure 32 LI200712 surface (2m) temperature, salinity and fluorescence.

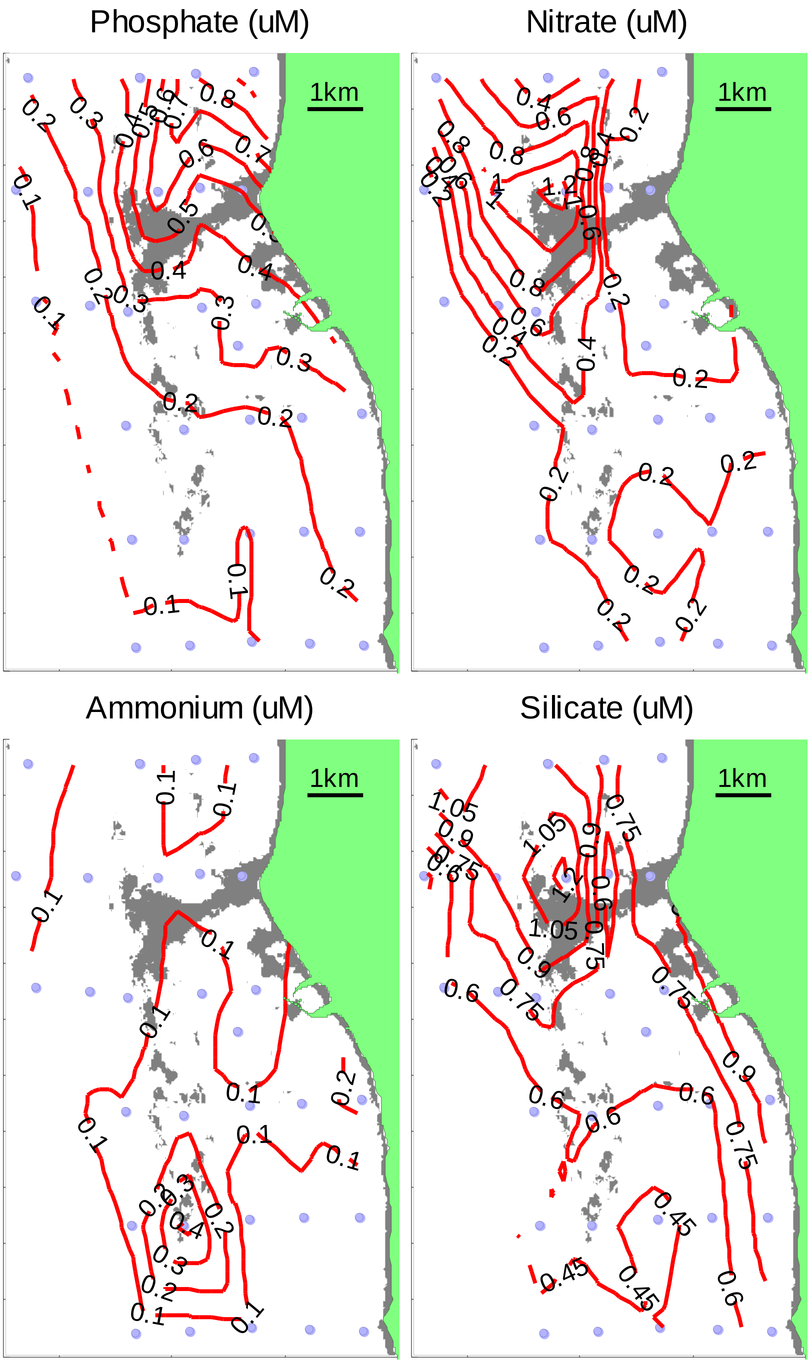



Figure 33 LI200712 surface nutrient distributions.

## 4.4 Cruise LI200718

### November 8, 2007

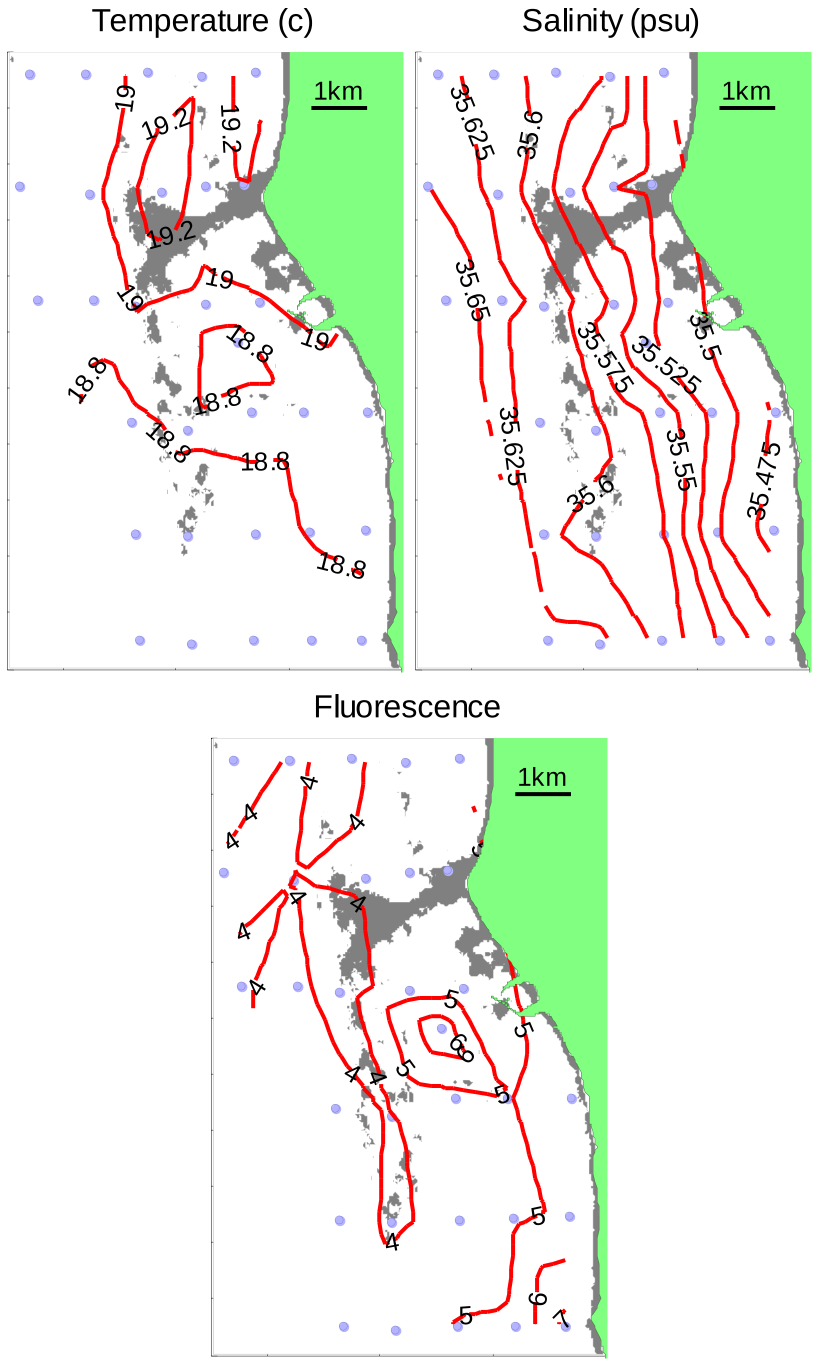



Figure 34 LI200718 surface (2m) temperature, salinity and fluorescence.

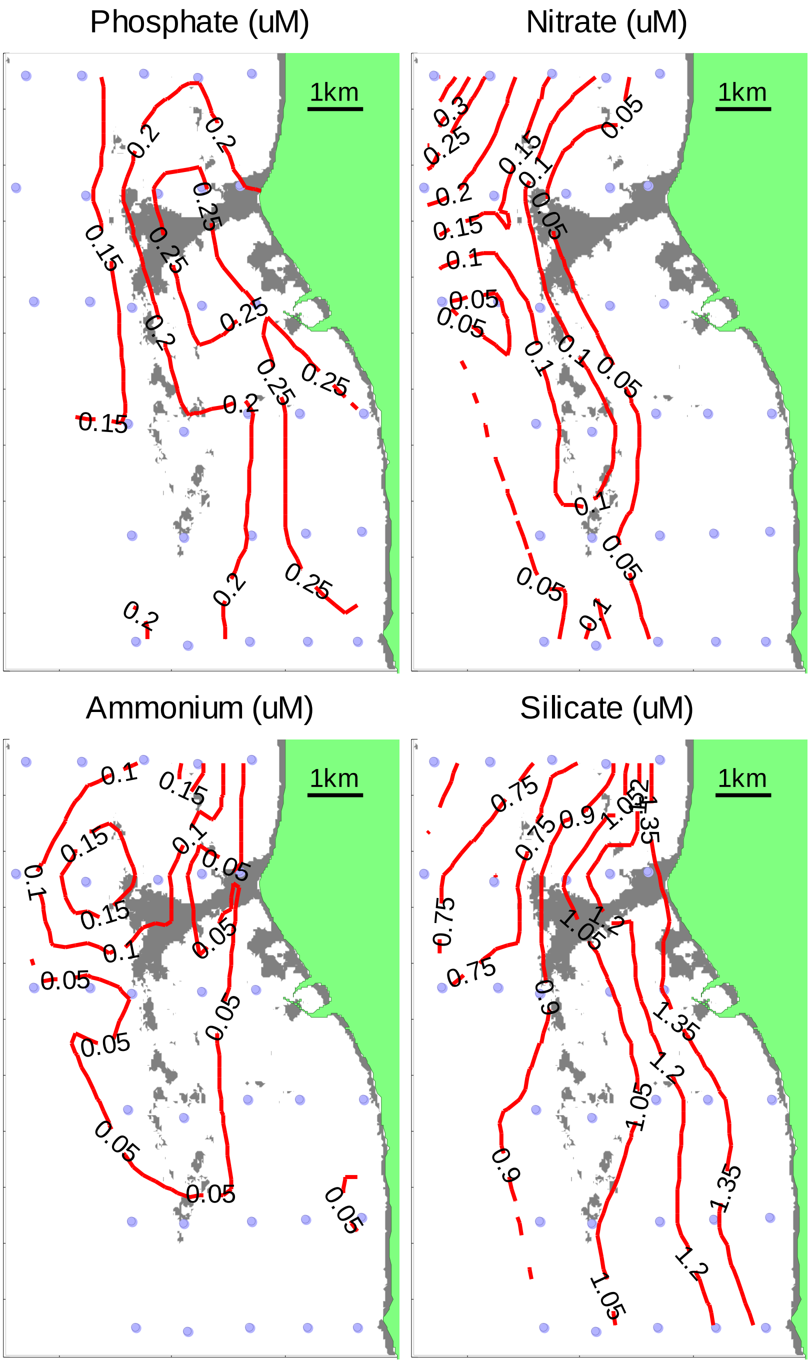



Figure 35 LI200718 surface nutrient distributions.

## 4.5 Cruise LI200724

### December 4, 2007

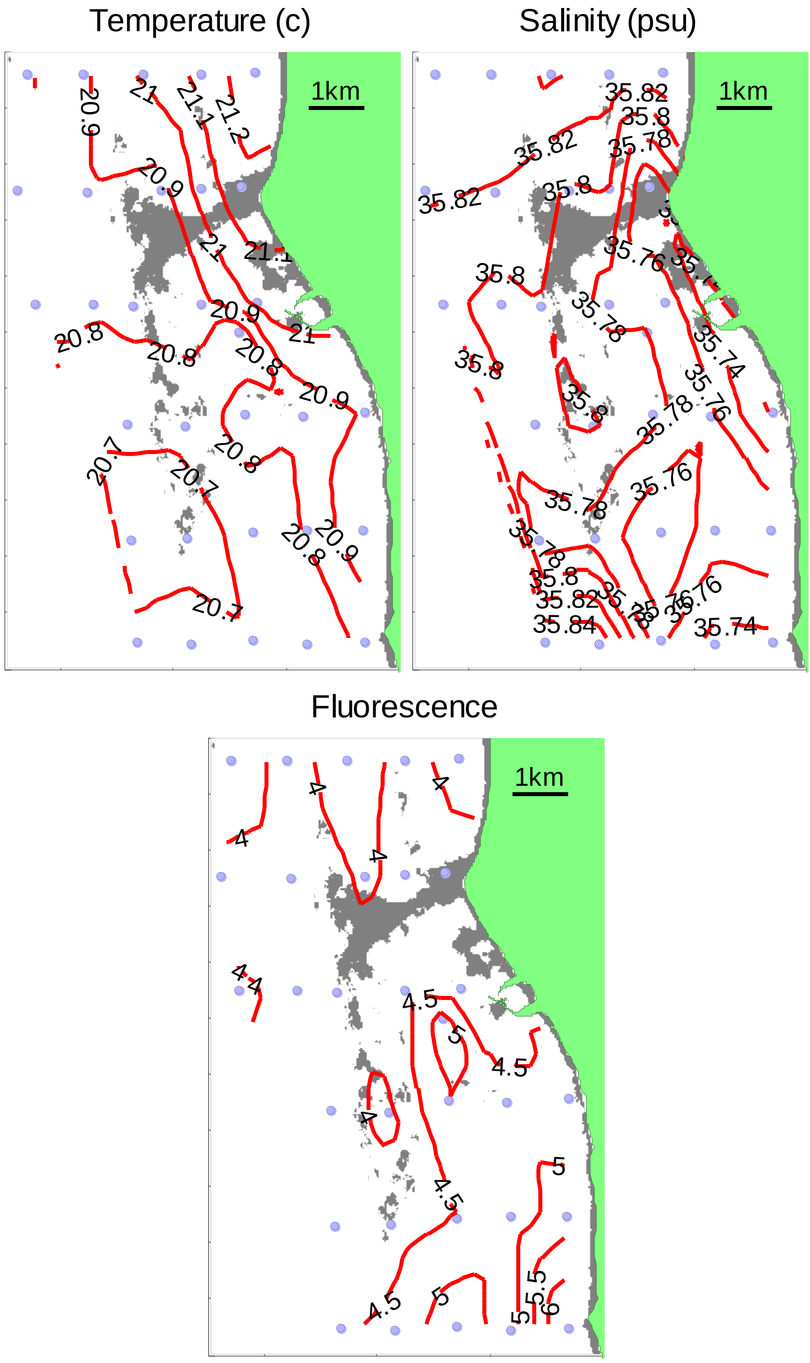



Figure 36 LI200724 surface (2m) temperature, salinity and fluorescence.

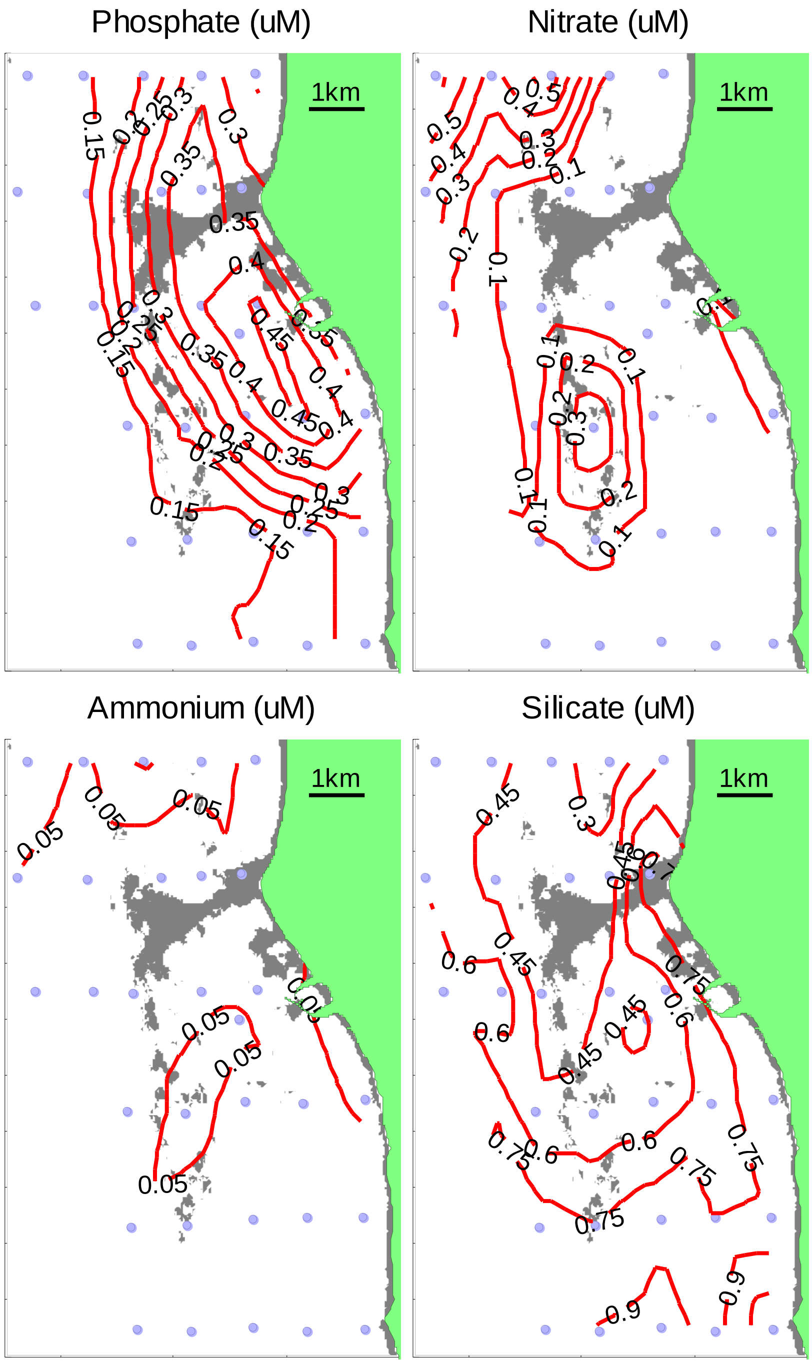



Figure 37 LI200724 surface nutrient distributions.

## 4.6 Cruise LI200801

### January 8, 2008

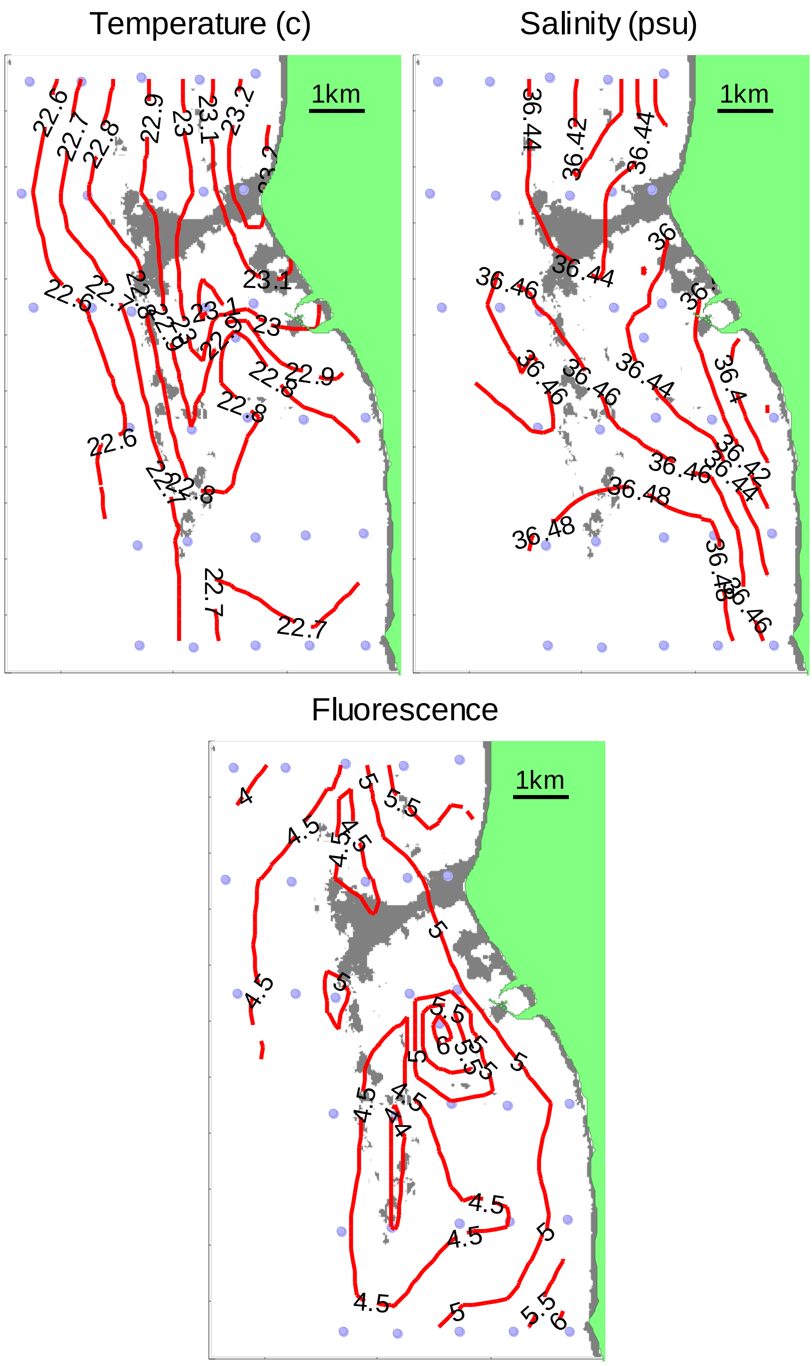



Figure 38 LI200801 surface (2m) temperature, salinity and fluorescence.

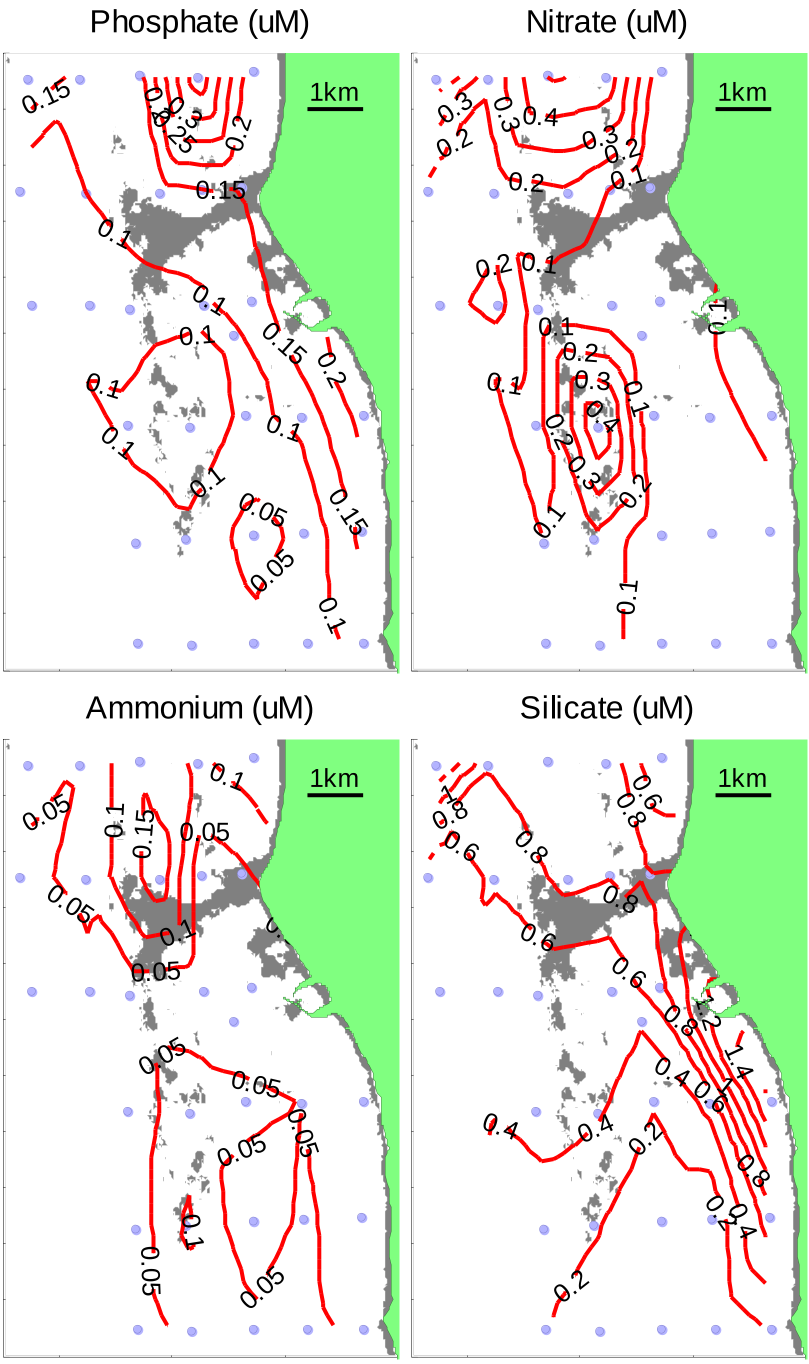



Figure 39 LI200801 surface nutrient distributions.

## Cruise LI200811

### February 6, 2008

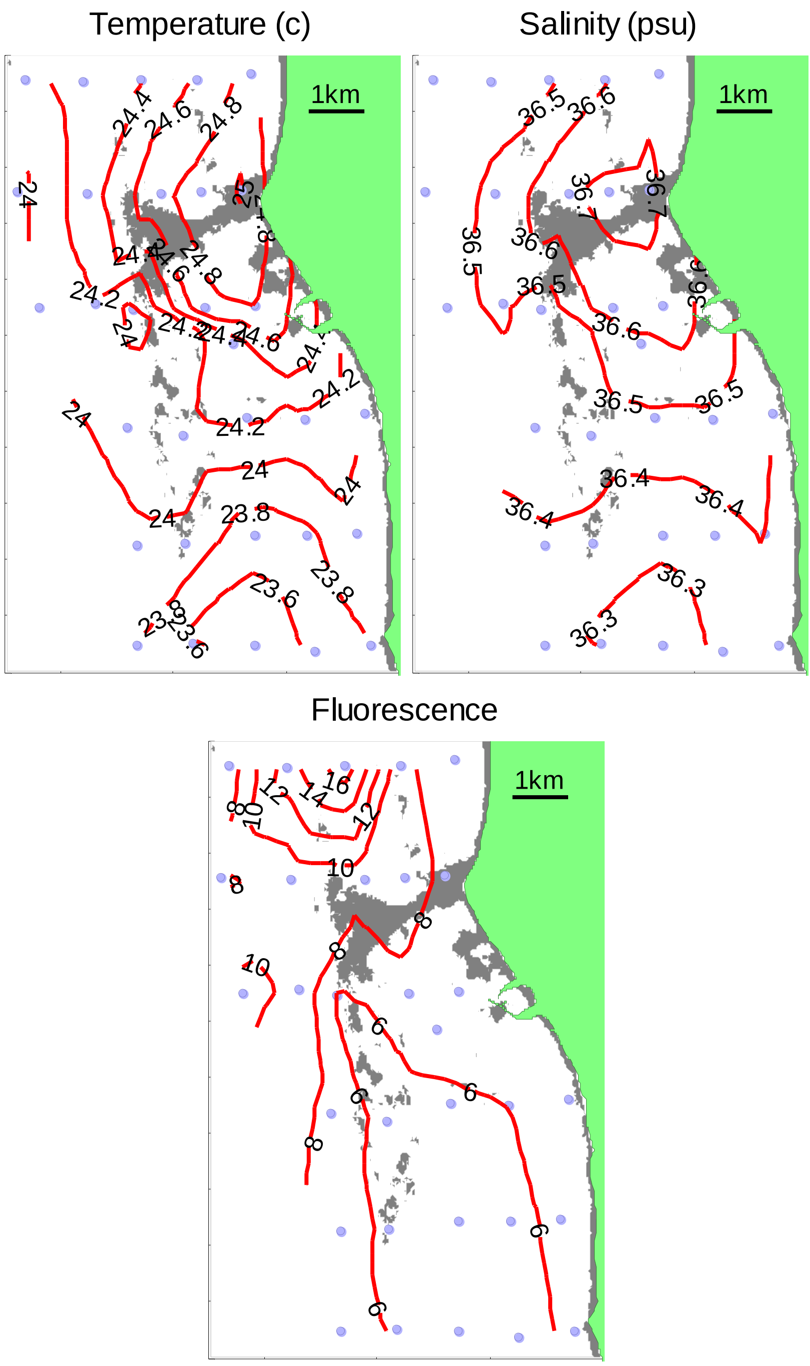



Figure 40 LI200811 surface (2m) temperature, salinity and fluorescence.

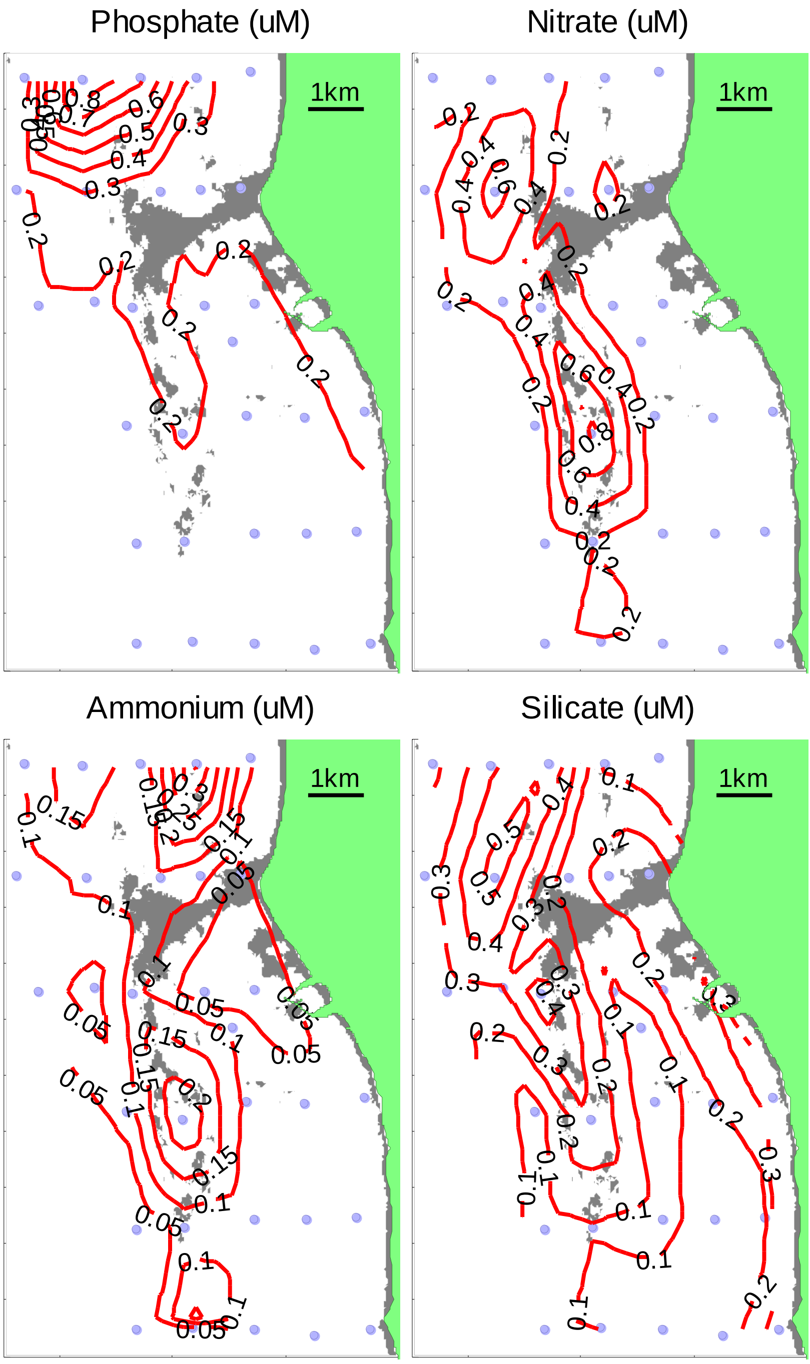



Figure 41 LI200811 surface nutrient distributions.

## Cruise LI200830

### March 11, 2008

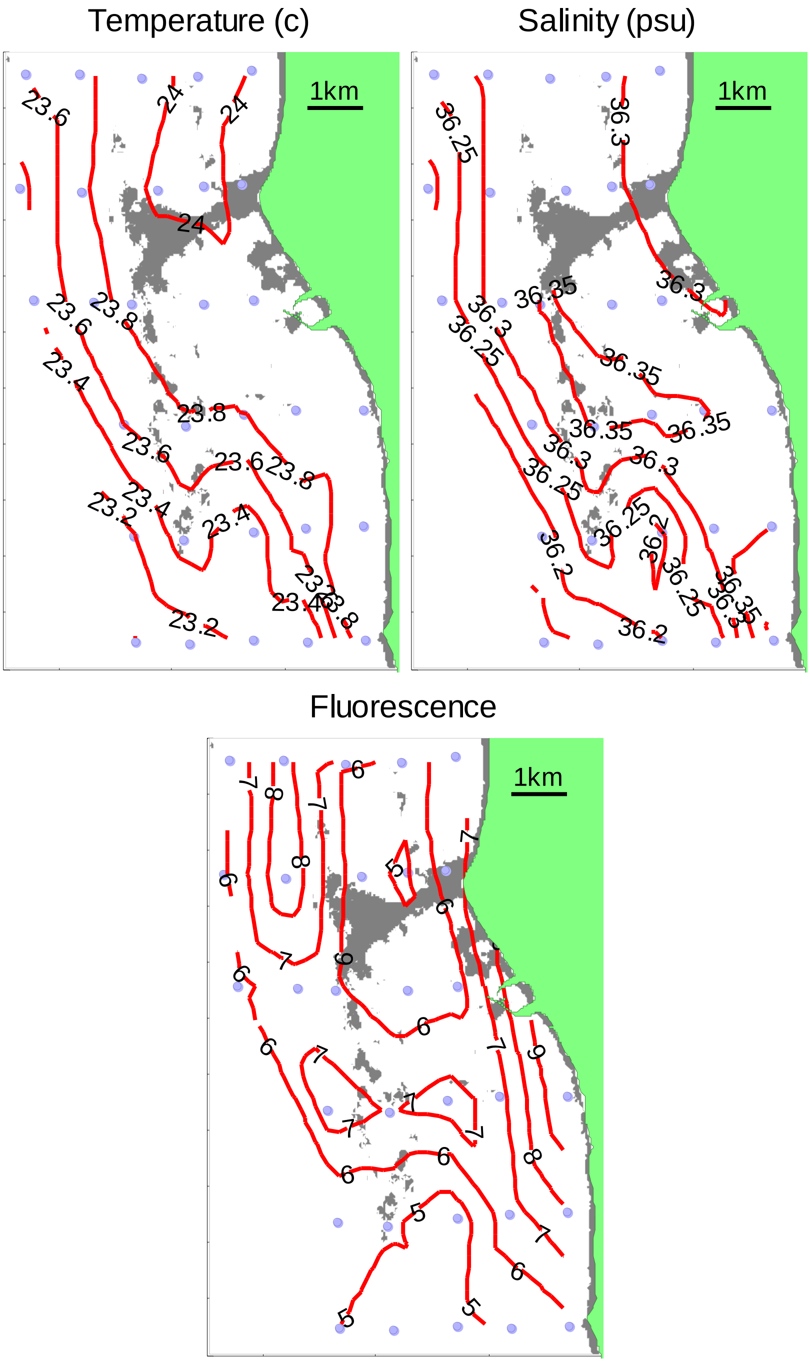



Figure 42  LI200830 surface (2m) temperature, salinity and fluorescence.

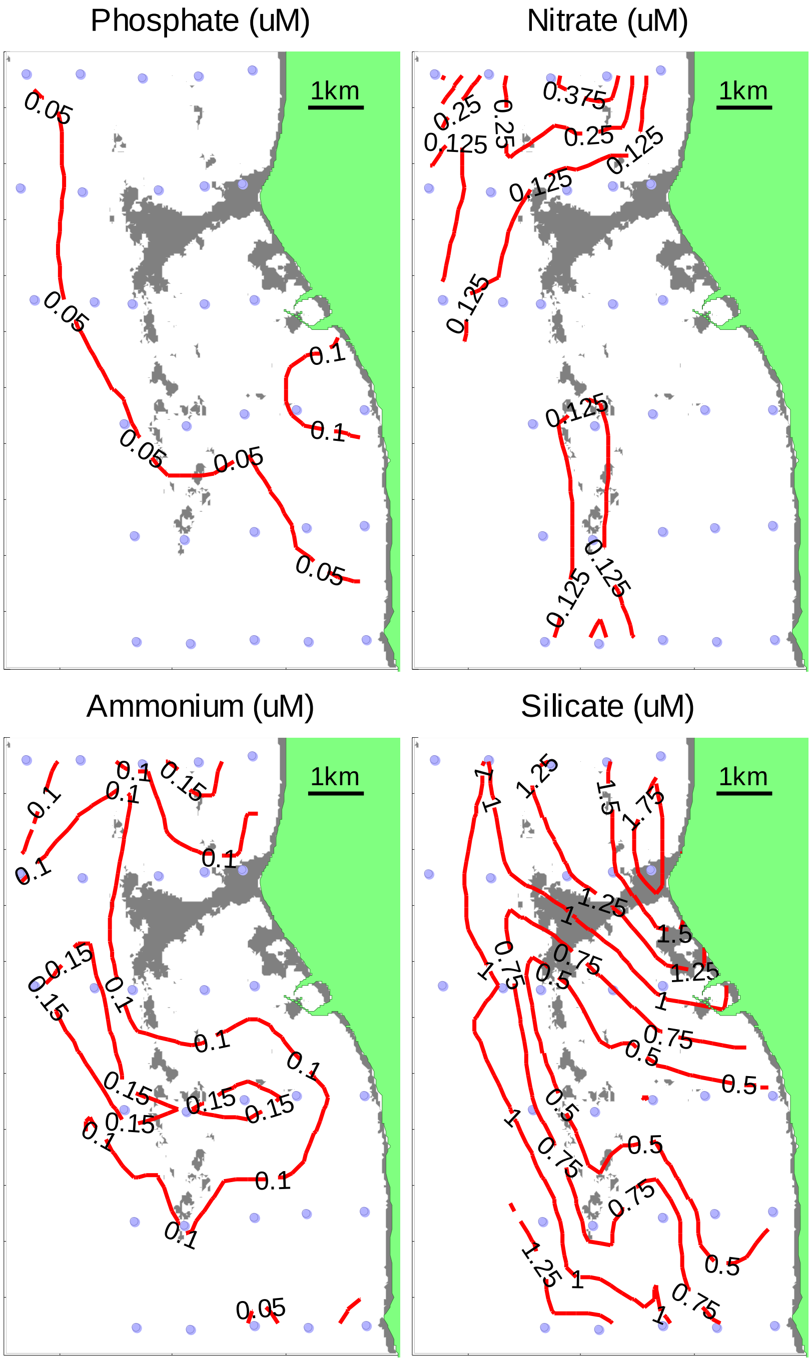



Figure 43 LI200830 surface nutrient distributions.

## 4.7 Cruise LI200836

### March 25, 2008

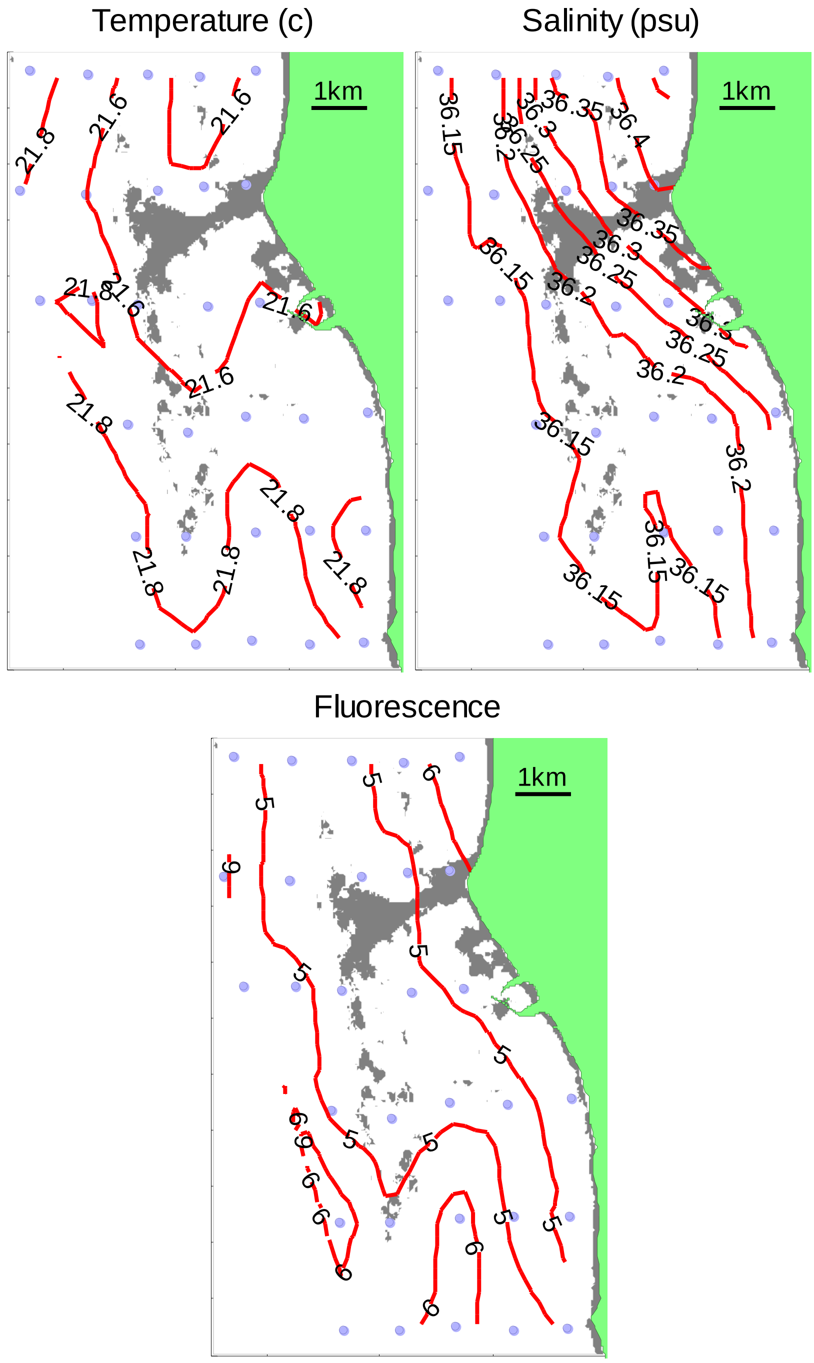



Figure 44 LI200836 surface (2m) temperature, salinity and fluorescence.

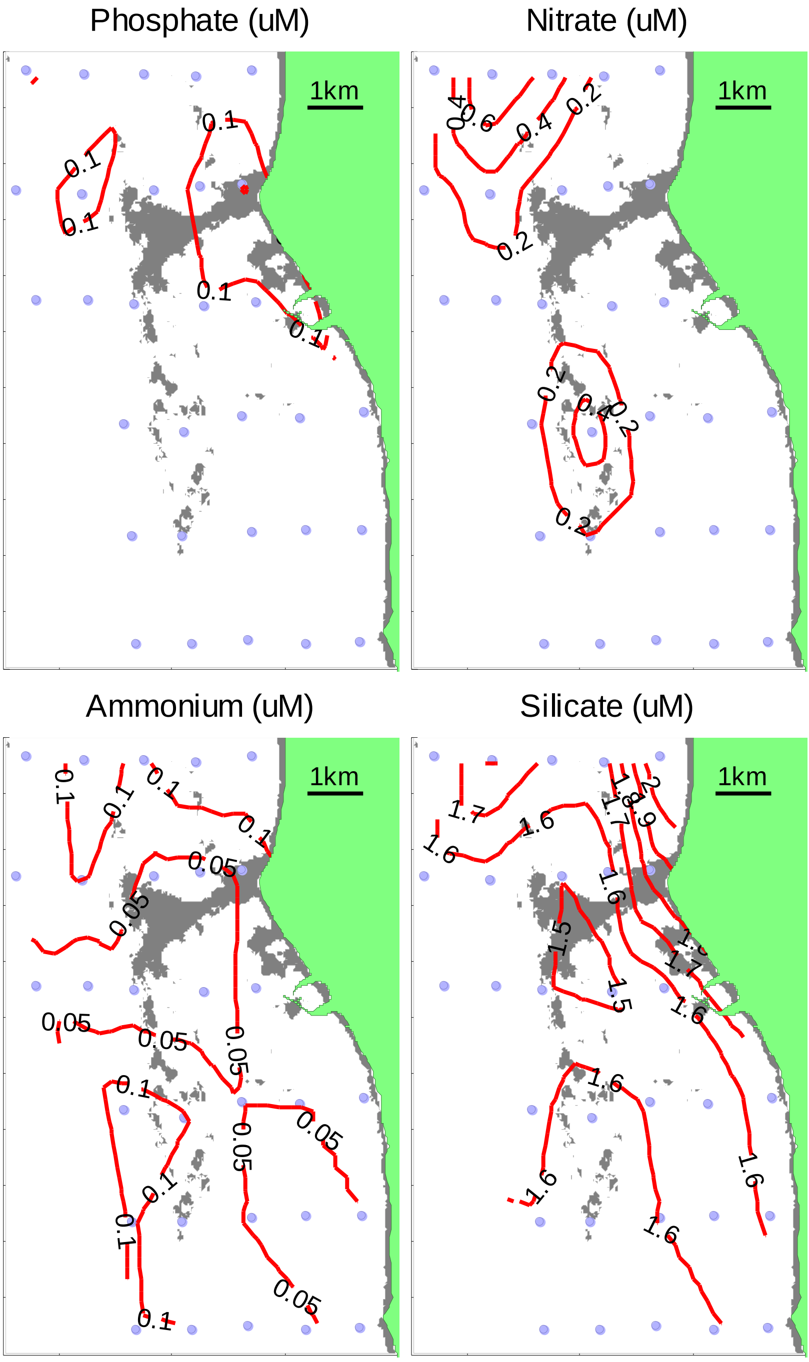



Figure 45 LI200836 surface nutrient distributions.

## 4.8 Cruise LI200845

### April 22, 2008

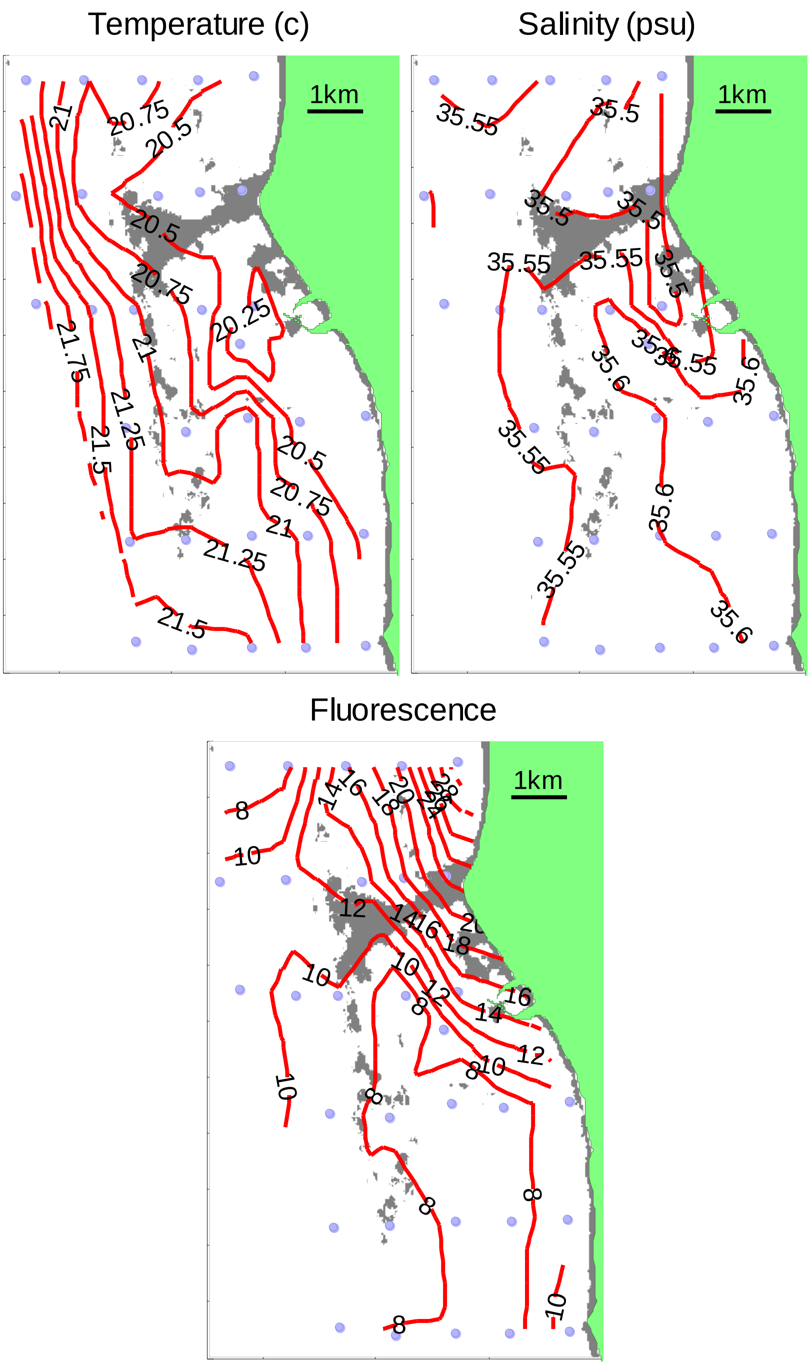



Figure 46 LI200845 surface (2m) temperature, salinity and fluorescence.

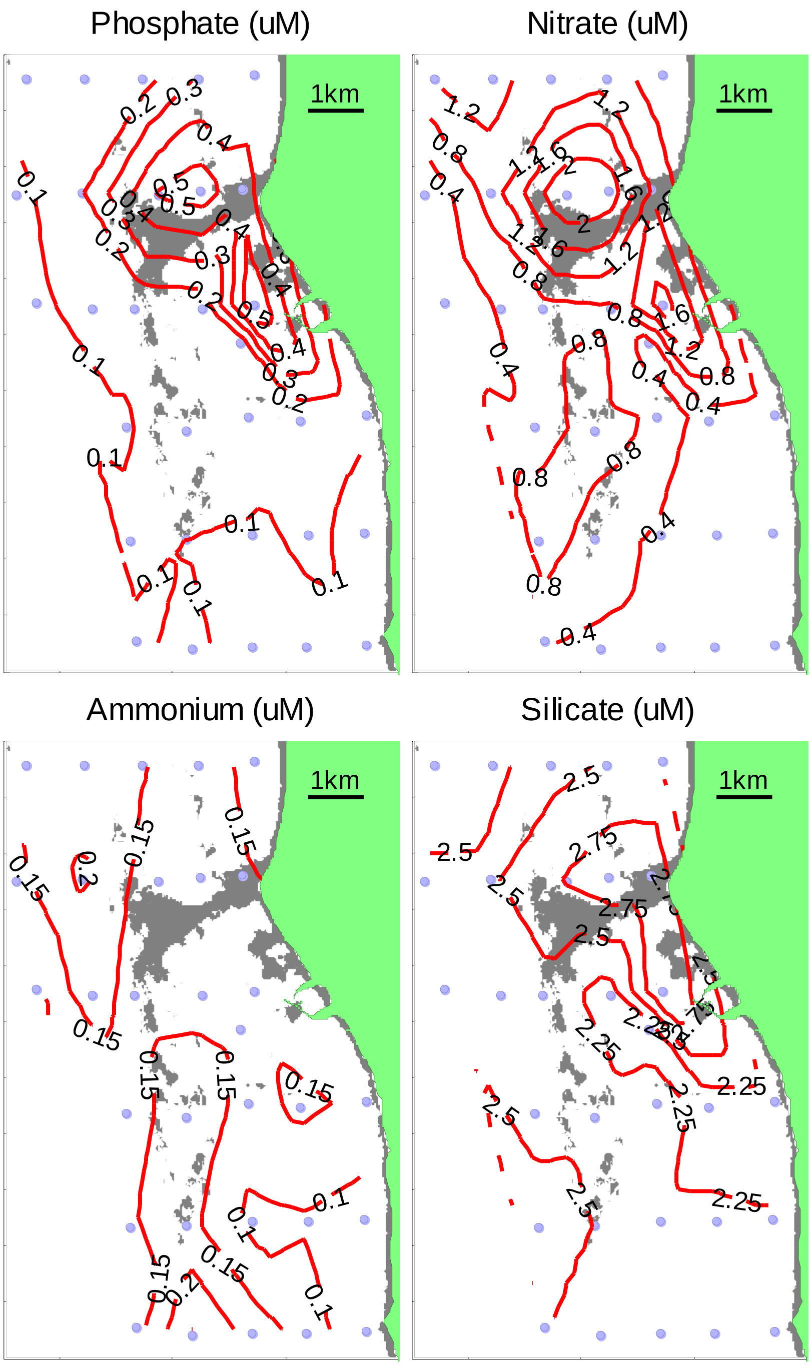



Figure 47 LI200845 surface nutrient distributions.

## 4.9 Cruise LI200852

### May 21, 2008

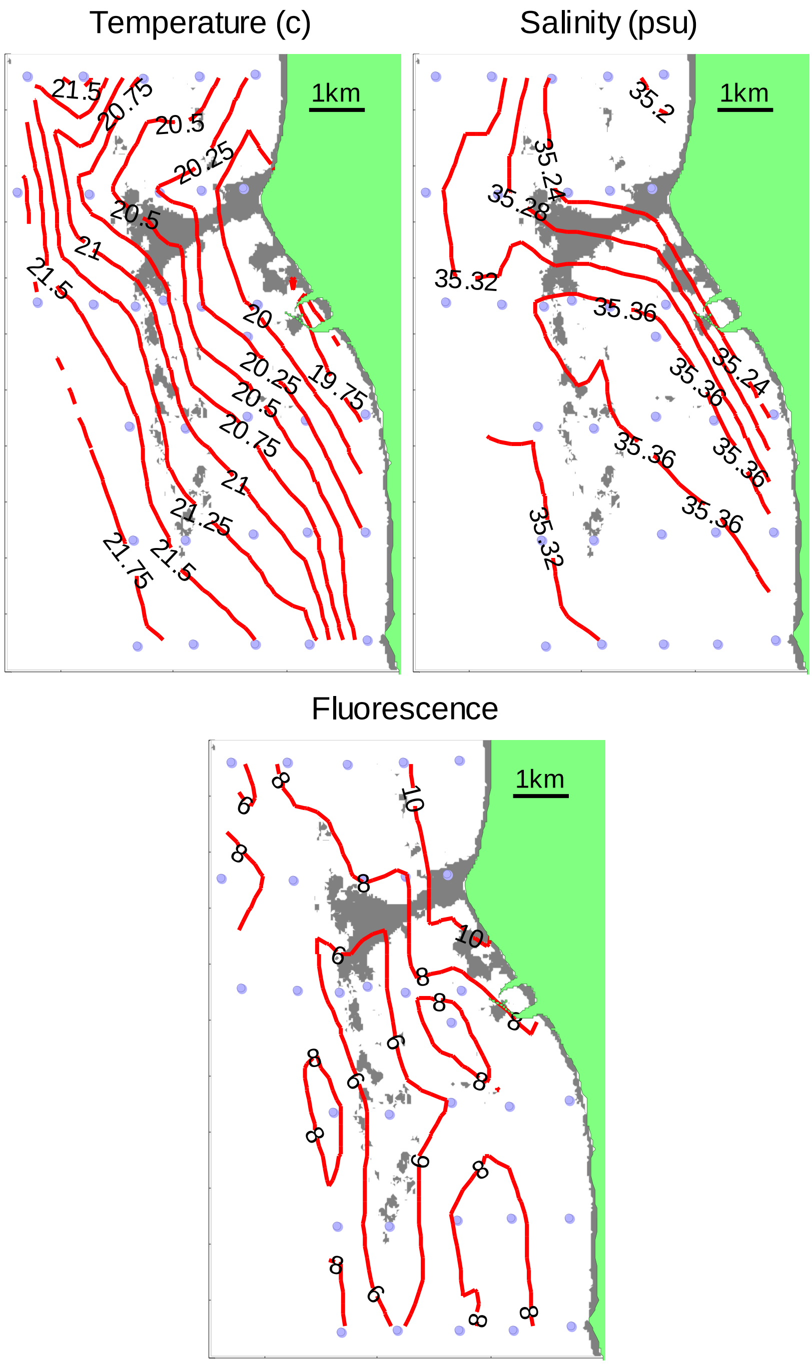



Figure 48 LI200852 surface (2m) temperature, salinity and fluorescence.

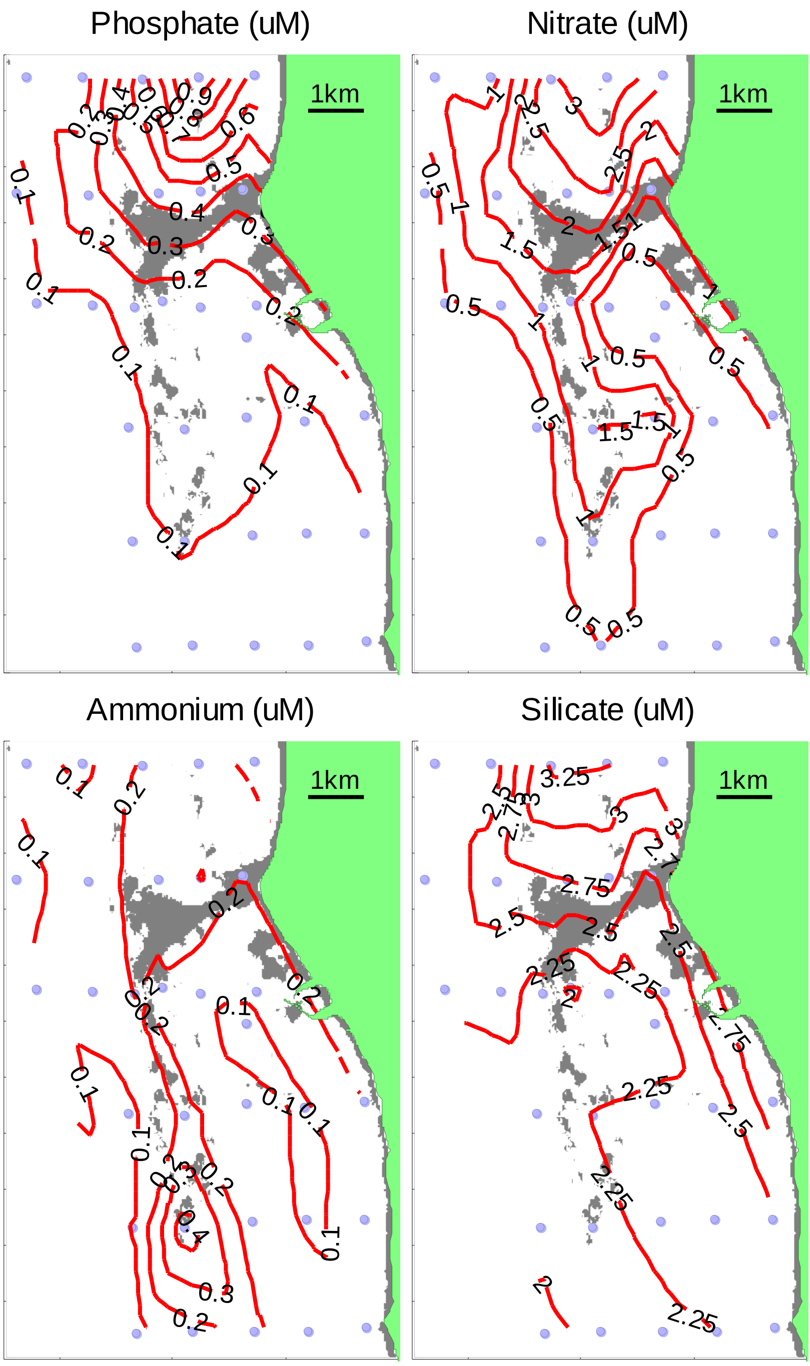



Figure 49 LI200852 surface nutrient distributions.

# 5. PRELIMINARY RESULTS

Wave forcing of mean flows will only be important when the waves are big enough to break over the reefs. A measure of how often waves break on the reefs can be obtained by comparing the wave heights on the fore-reef (at the AWAC site) with the wave heights at the back of the reefs, calculated from the bottom pressure records at the ADV sites. If the waves are too small to break on the reefs the back-reef wave height will increase linearly with the offshore wave height. As the offshore wave height continues to increase the waves will begin to break on the reef and the back-reef wave height will diverge from the linear relationship, approaching a maximum height determined by the depth over the reef. Plots of the back reef versus forereef wave height are shown in Figure 50 where it can be seen that the onset of breaking varies between the reefs but occurs when the offshore root mean square wave height is 1-2m, and a little less at site ADV3.

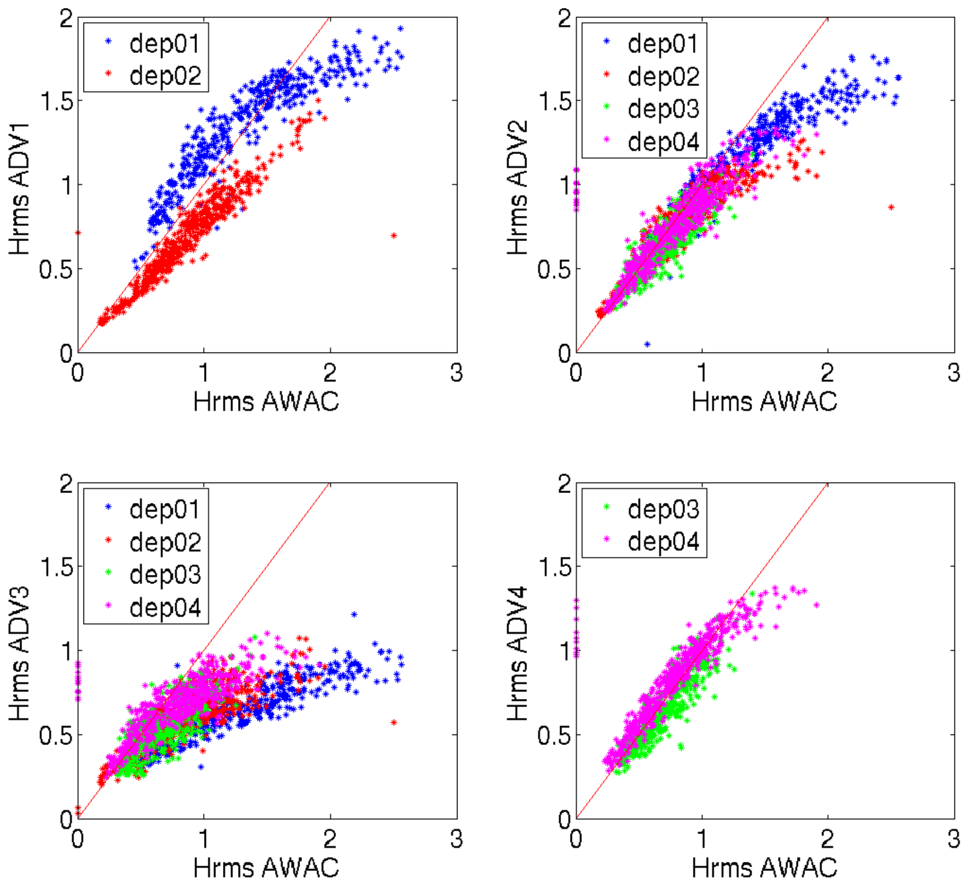



Figure 50 Scatter plots of root-mean-square wave height measured offshore by the AWAC against the root-mean-square wave height at the ADV sites.

If the root-mean-square wave height offshore is less than 1m the waves do not break and we would not expect to see any correlation between mean flows in the lagoon and the offshore wave height. However, as the root-mean-square wave height offshore increases the waves begin to break and we might expect to see a correlation between mean flows and offshore wave height. Scatter plots of the mean eastward and northward currents at the two lagoon sites, RDIN and RDIS are plotted against the root mean square wave height offshore in Figure 51 . The eastward and northward current components are the means calculated for each hourly wave burst of 2048 samples measured at 1Hz.

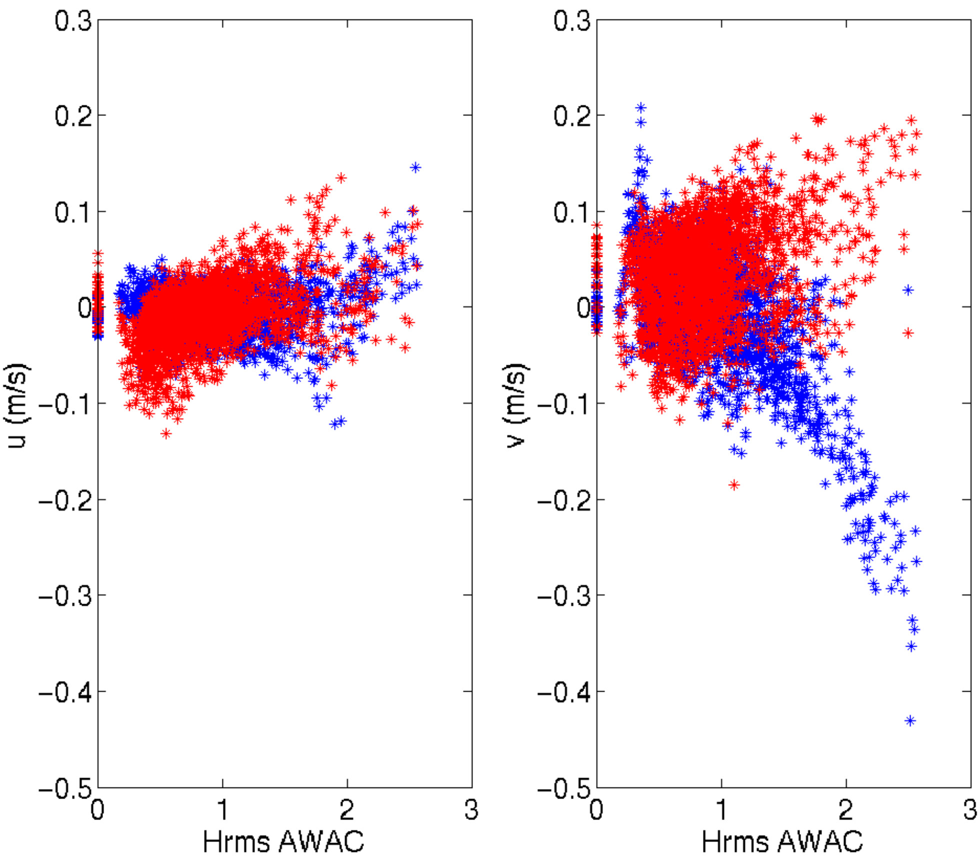



Figure 51 Mean eastward (left panel) and northward (right panel) currents at RDIN (red) and RDIS (blue).

There is little correlation between the eastward currents shown in the left hand panel of Figure 51 and the offshore wave height. However, when the offshore wave height exceeds about 1.5m the mean flow at RDIS is towards the south and increases with increasing wave height shown in blue in the right hand panel of Figure 51. At RDIN there is weak northward flow associated with wave heights greater than 1.5m shown in red in the right panel of Figure 51.

The eastward velocity at the ADV sites is also correlated with the larger offshore waves as shown in Figure 52 though there is more scatter. At ADV1 the correlation appears only during the larger wave events in deployment 1. At ADV3 good correlation is seen for deployments 2, 3 and 4, even with relatively low waves which is consistent with the earlier onset of breaking observed at this site and shown in Figure 50. The low correlation in deployment 1 at ADV3 may be due to the sensor being buried. In general, when the wave height exceeds 1-1.5m the eastward velocity at the ADV sites is positive, into the lagoon.

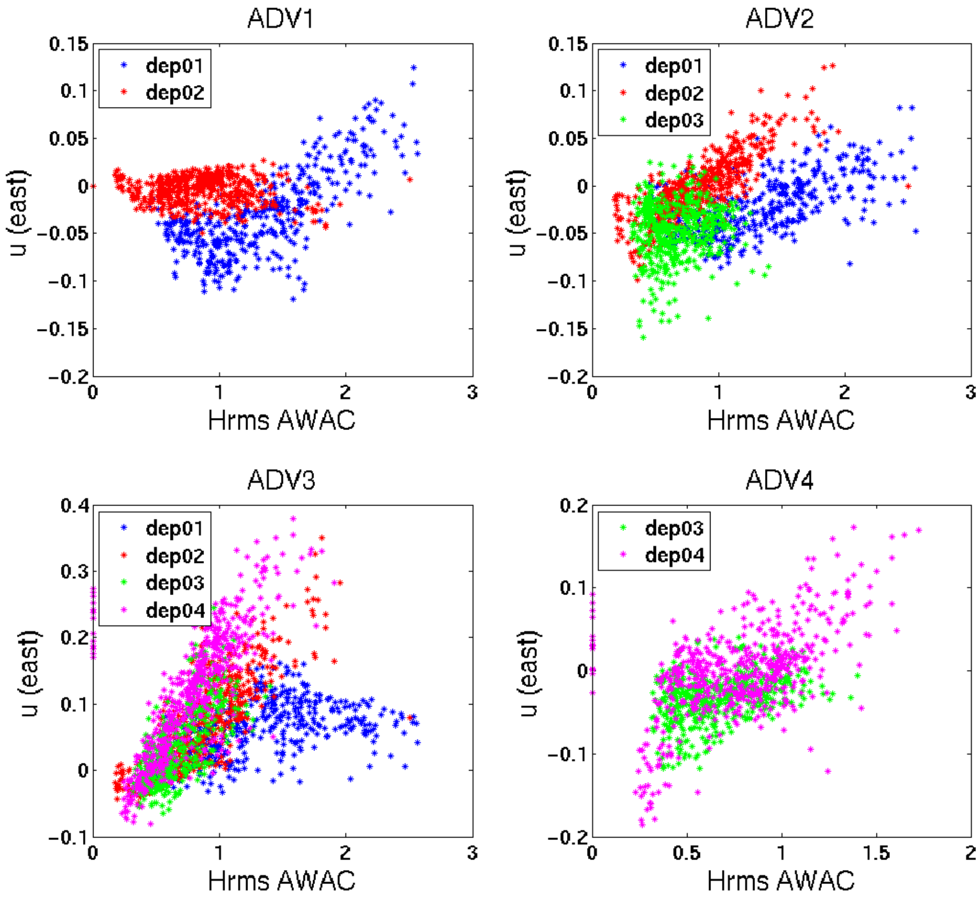



Figure 52 Scatter plots of the root-mean-square offshore wave height with eastward currents at the ADV sites.

These results suggest that wave forcing is important in Marmion lagoon, at least when the waves are big enough to consistently break on the offshore reefs. The strongest currents at all sites show some correlation with waves, which may dominate over wind forcing, contrary to conclusions in previous reports. However, previously reported current measurements tended to be either outside the main reef line or in regions where the reefs are too deep to cause significant breaking.

## 6. ACKOWLEDGEMENTS

All the mooring deployments and recoveries, and the CTD surveys were done using CMAR's RV Linnaeus skippered by Stelios Kondylas who also provided invaluable support with all operations on board. Divers were required to deploy and recover the mooring frames at the ADV sites and to recover the moorings at the other sites except for MS2 which was recovered using an acoustic release. Martin Lourey, James McLaughlin, Ryan Downie, Andrew Limbourne and Stelios Kondylas provided diving support. Jim Greenwood, Jim Gunson, Ryan Crossing, Martin Lourey and James McLaughlin assisted on the CTD surveys and Neale Johnson and Peter Hughes analysed the nutrient samples. Additional field support was also provided through CMAR in Cleveland with Ted Wassenberg, Ian McLeod and Clinton Dell travelling to Perth for some of the field operations including the search and recovery of the buried current meter at site ADV4.

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Email: enquiries@csiro.au
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