SRV *Investigator* Voyage Summary

Voyage #:	IN2016_V05		
Voyage title:	The Great Barrier Reef as a significant source of climatically relevant aerosol particles		
Mobilisation:	Brisbane, 0800 Monday 26 September – 1700 Tuesday 27 September, 2016		
Depart:	Brisbane, 0800 Wednesday 28 September 2016		
Leg 1 Arrive:	Fitzroy Island, Tuesday 11 October, 2016		
Leg 2 Depart:	Fitzroy Island, Tuesday 11 October, 2016		
Leg 2 Arrive:	Magnetic Island, Sunday 16 October, 2016		
Leg 3 Depart:	Magnetic Island, Sunday 16 October, 2016		
Return:	Brisbane, 1700 Monday 24 October, 2016		
Demobilisation:	Brisbane, 0800 Tuesday 25 October – 1700 Wednesday 26 October, 2016		
Voyage Manager:	Lisa Woodward	Contact details:	Lisa.woodward@csiro.au
Chief Scientist:	Professor Zoran Ristovski		
Affiliation:	Queensland University of Technology	Contact details:	z.ristovski@qut.edu.au
Principal Investigators:	A/Prof Graham Jones – Southern Cross University Dr Alain Protat – BOM Dr Robin Beaman – James Cook University (Piggyback Project) Dr Robyn Schofield – University of Melbourne Dr Branka Miljevic – Queensland University of Technology* Dr Hiroshi Tanimoto – NIES Japan* Dr Justin Seymour – University of Technology Sydney* Dr Mike Harvey – NIWA, New Zealand* Dr Melita Keywood – CSIRO O&A* Sarah Lawson – CSIRO O&A*		
Supplementary Project			
Principal Investigator:	Karen Wild-Allen		
Project name:	Biogeochemical and optical properties of the Coral Sea and Queensland shelf		
Affiliation:	CSIRO Oceans & Atmosphere		
Principal Investigators:	Mark Baird – CSIRO Oceans & Atmosphere Lesley Clementson – CSIRO Oceans & Atmosphere* David Blondeau-Patissier – CSIRO Oceans & Atmosphere*		

NB: * indicates participant was not on board during this voyage

Scientific objectives

The Great Barrier Reef as a significant source of climatically relevant aerosol particles

Understanding the role of clouds in the warming and cooling of the planet, and how that role changes in a warming world is one of the biggest uncertainties climate change researchers face. A key feature in this regard is the influence on cloud properties of cloud condensation nuclei (CCN), the very small atmospheric aerosol particles necessary for the nucleation of every single cloud droplet. The anthropogenic contribution to CCN is known to be large in some regions; however, ***the natural processes that regulate CCN over large parts of the globe are less well understood, and particularly in the Great Barrier Reef***. The production of new aerosol particles from biogenic sources (forests, marine biota, etc.) is a frequent phenomenon capable of affecting aerosol concentrations, and therefore CCN, on both regional and global scales. ***The biogenic aerosol particles therefore have a major influence on cloud properties and hence climate and the hydrological cycle***. ***Determining the magnitude and drivers of biogenic aerosol production in different ecosystems is therefore crucial for the future development of climate models.***

The fundamental questions that this study will address are:

1. What is the significance of this ecosystem as a natural source of aerosol particles?
2. How strong is this source at the regional level?
3. What is the mechanism of particle production over the GBR?

Voyage objectives

The MNF has divided this voyage into three separate legs to enable and support all primary and supplementary scientific voyage objectives and to accommodate specialist personnel requirements. Personnel transfer locations have been chosen to align with the proposed voyage track within the Great Barrier Reef Marine Park's designated shipping area.

The main objective of the voyage is to acquire observations that will address four key science questions about the role of atmospheric composition in the GBR region:

1. Do marine aerosols along the north Queensland coast have a significant signature that is coral-derived?
2. How does this aerosol change its physicochemical properties, especially its capacity to act as CCN, as winds carry it from the reefs to the north Queensland rainforests?
3. What is the significance of this ecosystem as a source of aerosol particles and will potential degradation of the reef cause significant variations in particle number being generated over the reef.
4. Should changes in this aerosol, associated with reef degradation, be taken into account when modelling the radiative climate and rainfall?

Supplementary voyage objectives:

1. To collect high resolution biogeochemical observations for validation of the 4km and 1km near real time eReefs models (https://research.csiro.au/ereefs/)
2. To get modellers in the field to better understand methods and issues associated with modern methods of data collection
3. To collect in situ optical data for the NASA CORAL project which is operating a very high resolution airborne hyperspectral sensor along selected transects in the GBR.

Opportunistic voyage objectives

Due to the size of the ship we were unable to approach closer to the reefs. To access the particle composition above and in the vicinity of the reefs we have deployed unmanned aerial vehicles (UAV's). This was the first time that UAV's were launched of the RV Investigator. To use this opportunity an opportunistic voyage objective was added:

1. Deploy the UAV's to measure the emissions from the ship diesel engines and study their dispersion in the marine atmosphere.

Results

To address the first 2 points cloud, aerosol and atmospheric composition data, uncontaminated by ship exhaust, was collected at three dedicated atmospheric measurement stations, where the ship had remained for up to 24 (or more) hours oriented into the wind. In addition, data was continuously sampled during the transient parts of the voyage. Special interest was paid to the transects through the reef that were repeated several times.

The proposed measurement stations included:

- Three stations on the western side of the GBR. These stations enabled us to sample the air masses that have traversed over the reefs and have been enriched by the emissions from the reefs. One of the sites covered the northern part of the reef and 2 of them the southern part of the reef. The 2 southern stations were chosen to be upwind of the land site at Mission Beach. The 2 southern stations enabled us to collect data on the changes in the composition of the atmosphere as the air masses travel from the reefs to the shore (rainforests). This enabled us to capture the process of atmospheric transformation and aging as the air masses traverse from the reefs to the shore.
- One station on the eastern side of the GBR. As the predominant wind direction during the trade wind season is south easterlies this station enabled us to characterise the remote pacific air masses coming towards the GBR. This station was chosen to be south of the most southern part of the reef.
- An optics station in deep water (>200m) east of Heron Island to characterise the sea surface spectral reflectance and in water optical properties including the spectral absorption of optically active constituents in the water. These observations provided the deep water optical reference spectra to compliment inshore fieldwork undertaken at Heron Island in the previous weeks. Optical observations were used to calibrate the NASA very high resolution airborne hyperspectral sensor PRISM that was collecting data along selected transects in the GBR throughout September and October 2016. Given clear skies and good flying conditions every effort was made to overfly the RV *Investigator* and collect synchronised data. The aim of this station was to address the objectives of the supplementary voyage.

On-shore measurement station

In addition to the measurements on board the RV Investigator a measurement station was setup on the shore. From 13 September to 20 October 2016, the AIRBOX mobile air chemistry laboratory was deployed to a semi-rural coastal site at Garners Beach, Queensland (17.82°S, 146.10°E). Sampling commenced on 17 September. The AIRBOX site was approximately 15 m above sea level and 20 m from the waterline, and was surrounded by sparse residential housing and a rainforest reserve. Onsite personnel and an extensive suite of instruments were contributed by University of Melbourne, Queensland University of Technology, University of Wollongong, Southern Cross University, University of Tasmania, CSIRO and ANSTO. These provided a comprehensive data set of atmospheric measurements. Gas phase measurements included concentrations of NOx, ozone, dimethyl sulphide, radon, and other trace gases and isotopes (including CO, CO_2, CH_4 and N_2O). Particle phase instruments investigated aerosol size distributions (from 0.5 – 600nm), volatility, hygroscopicity, optical depth, non-refractory composition, total particle number concentration, and concentrations of trace metals and black carbon. These observations were supported with meteorological measurements by two independent weather stations.

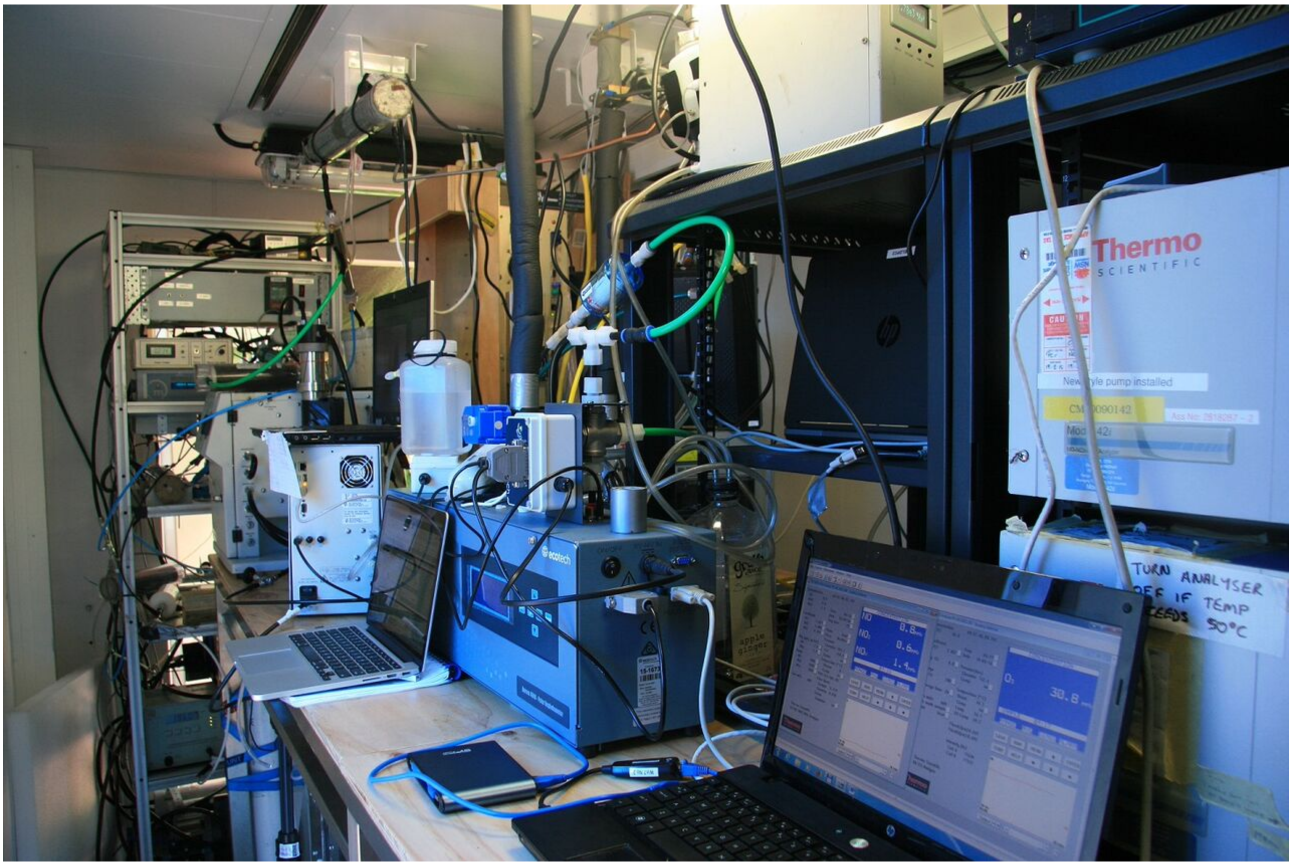


Figure 1 Exterior and interior of the AIR-BOX located at Garners Beach.

Transects:

Several transects through the reef were made through the Palm passage. The aim of these measurements were to collect sufficient data on the changes in the composition of the atmosphere and water (DMS concentration) composition.

CTD Stations

A number of CTD stations were conducted (For details see the supplementary voyage report in Appendix A). We have attempted to conduct 2 CTD casts while in transit and 3 CTD casts while in one of the stations. Measurements of DMSw, DMSO, DMSa, DMSPt, CHL a, plankton, species and accessory pigments, nutrients, NH_4, SST, solar radiation, wind speed and direction, tidal height were taken every 1-2 hours to assess the reef production of DMSw, DMS flux and DMSa and confirm the dominant factors affecting DMSa production to the atmosphere of the GBR.

Detailed Results

Atmospheric Data

A suite of aerosol and gas phase instrumentation was deployed in the aerosol and air chemistry laboratories with the aim of characterising the sources of particles and CCN, focussing on new particle formation over the GBR. This suite of instrumentation complements the permanent atmospheric instrumentation operated by MNF. The following measurements were conducted:

Size dependent aerosol concentrations (PI M. Keywood, PI Z. Ristovski, R. Humphries, L. Cravigan, L. Wang) were continuously measured using CPC's, SMPS's, APS's and a PSM, providing information on the contribution of new particle formation to the aerosol population over the GBR and the background particle concentrations. The measurements covered a very wide range of particle sizes from 1nm to 10,000nm. There were few issues with some of the instruments in the beginning of the voyage but they were quickly resolved. These measurements will enable us to address Objective 1.

Aerosol chemical composition data (PI B. Miljevic, PI P.Selleck, G. Osuagwu). Online data, with the Aerosol Chemical Speciation Monitor (ACSM), and offline data (PM1 filters, TEM samples, trace metal filters) aerosol composition measurements were also taken throughout the voyage and will be used to characterise particle sources and to determine changes in aerosol chemistry due to atmospheric aging. The ACSM worked without any problems for all of the voyage and a number of filter samples were collected that will need to be analysed in the coming months. These measurements will enable us to address Objective 2.

The concentration of precursor gases and molecular clusters (PI B. Miljevic, PI S. Lawson, G. Osuagwu) (with the PTR-MS, CIMS, VOC sequencer) provide information on the mechanisms of new particle formation and secondary aerosol production throughout the voyage. All of the instruments have worked without any major interruption for most of the voyage. Significant amount of data was collected and will be analysed in the coming months. The data, once analysed, will enable us to address Objective 3.

Water uptake (PI M. Keywood, R. Humphries), which is important for aerosol cloud interactions, was continuously measured using the MNF cloud condensation nuclei counter (CCNc).

Additional instruments deployed by the NIWA team (PI M. Harvey, T. Bromley, S. Gray). NIWA has significantly contributed with a number of important instruments. The main 2 instruments used were the ceilometer that measured the inversion layer height and the HiVol sampler. Both instruments were on the level 5 deck. The ceilometer measured continuously during the voyage while the HiVol sampler collected particles on filters with a daily to bi-daily resolution. The data from the ceilometer will be used in all of the calculations on the total fluxes from the reef (Objective 3).

In addition other particle sampling instruments were also provided by NIWA. They were used for supplementary measurements to some of the existing particle counters.

A summary of the atmospheric aerosol and gas instrumentation is shown in *Summary of Measurements and Samples Taken.*

Atmospheric Measurements taken at the supplementary on-shore measurement station

DMSa, DMS Flux and the Sulphur Cycle (PI G. Jones)

Continuous atmospheric DMS measurements (DMS_a, every 20 mins) were made at Garners Beach (Hilton Swan) using an automated gas chromatography system from 28th September -15th October. The analytical configuration consisted of a Varian CP-3800 gas chromatograph (GC) equipped with a pulsed flame photometric detector (PFPD) (Bruker Biosciences, Preston, Victoria, Australia), coupled to an electrically-actuated gas valve and cryogenic sampling system (Swan et al. 2015). This data will be used to compute a seasonal DMS flux from the nearby GBR marine environment, as well as ascertain any tidal influence on the DMSa levels measured. Comparison with DMS flux measurements made on Investigator will also be made.

For the period 28 Sep – 15 Oct DMS_a at Garners Beach average and standard deviation was 1.3 ± 0.6 nmol/m^3 (31 ± 14 ppt) for n = 766 measurements. The range was 0.3 - 4.1 nmol/m^3 (8 - 101 ppt). The minimum value was recorded 10 Oct at 13:40 UTC and the maximum value was recorded 10 Oct at 20:22 UTC.

Additional measurements at Garners Beach included: 1 min avg particle number concentrations (size fraction 0.5-2.5 µm, and >2.5 µm) from 19 Sep to 16 Oct using a Dylos-1700 air quality monitor. A comparison of ^{222}Rn levels measured using a portable radon detector (RAD7) was additionally made with the ANSTO large radon detector in the Air-Box during October.

Seasonal studies of the atmosphere at three stations in Mackay, adjacent to the central GBR commenced in 2016-17, and include the period when RV *Investigator* was off Mackay (John Ivey, PhD). Research objectives are to measure (1) the effect of shipping on the Mackay air shed and the Great Barrier Reef (GBR) as traced by nitrate, sulphate, acid and vanadium (V), air concentrations. (2) Investigate the seasonal variation in the signature of particulate and gaseous sulphur species, from marine primary productivity (i.e. MSA). (3) Compare (1) & (2) using current (J. Ivey) and historical data sets (G.Jones). Equipment includes:

Mt Bassett BoM Station- S.W.A.N.S. 1 sampler (Southern, weather, aerosol, nuclei, sampler); 2x SKC < 2.5um cyclone particle collectors, concurrent quartz and Teflon filters; 1x Dylos > 0.5 < 2.5, >2.5um particle number counter.

Airport Station- GC, Radon and S.W.A.N.S 11; 1x Varian Gas Chromatograph – S gas detector with semi-automated air trapping; 2x SKC < 2.5um cyclone particle collectors, concurrent quartz and Teflon filters; 1x Dylos > 0.5 < 2.5, >2.5um particle number counter;1xAtmospheric Radon detector (RAD7).

Ancillary sampling / analytical equipment-5x SKC solid adsorbent gas sampling tubes (field sampling and complimentary analyses to the GC);1x SKC Sioutas 5 (size) stage particle sampler (field sampling and complimentary analyses to the SKC particle collectors); 1x High pressure liquid chromatograph for Ion Chromatography (analysis of filters for SO4, NO3, and MSA).

This data will enable us to address Objective 1, 3, 4.

Lidar Measurements (PI Alain Protat)

Lidar data was collected continuously during the whole campaign. No problems were experienced and an excellent set of data was collected. This data set will be critical in addressing objective 4 and helping to elucidate the correlation between CCN measured at ground level and at cloud height. An example of lidar measurements of the vertical aerosol profiles are shown in Figure 2.

Figure 2 further illustrates how the lidar measurements will be used to extrapolate the surface aerosol observations aloft. A major challenge of the experiment is to relate the detailed properties of aerosols and their number to subsequent cloud formation aloft. The figure shows a complex vertical distribution of the aerosol layer with distinct layers characterized by enhanced depolarization (yellow colors in the top panel). The comparisons from the bottom panel indicate that there is a good correlation between the aerosol backscatter measured by the lidar near the ground level and the aerosol and CCN concentrations. This opens new avenues to develop lidar algorithms to characterize the aerosol properties aloft. Note that such a high correlation was not always found, which will require further analysis. Signficant further analysis of this data is necessary.

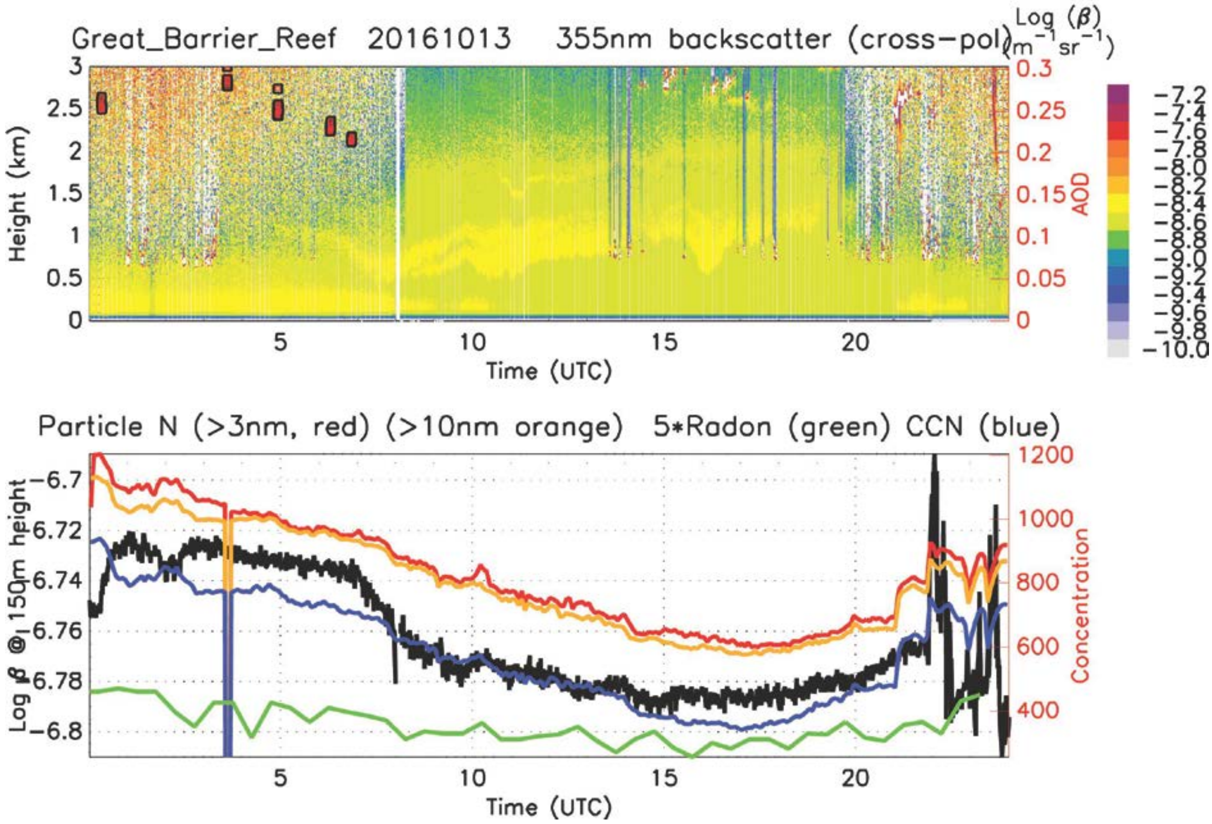


Figure 2 (top panel) Vertical distribution of aerosol backscatter (cross-polarization channel) with the aerosol optical depth overlaid when measured with the NASA Microtops hand-held device (red squares). Enhanced yellow layers indicate higher depolarization, and white spots correspond to cloud (with the signal being extinguished when traversing the clouds). (bottom panel) Time series of lidar backscatter (co-pol channel) at 150m height (black), aerosol concentration for particles of diameter greater than 3 nm (red) or greater than 10nm (orange), cloud condensation nuclei concentration (green), and radon concentration (multiplied by 5, blue).

Deployment of the Helikite (PI Robyn Schoefiled, PI Mike Harvey, S. Fides, C. Vincent T. Bromley, S. Gray, PI Zoran Ristovski)

To address the 2nd objective it was necessary to conduct measurements of the vertical profile of the atmosphere. Vertical profiles of temperature, pressure, relative humidity, wind speed and direction from the surface up to a maximum height of 600m using a helikite – a 9 m^3 helium filled balloon with a kite for stability. In addition vertical profiles of particle concentrations were also conducted on a selected number of flight.

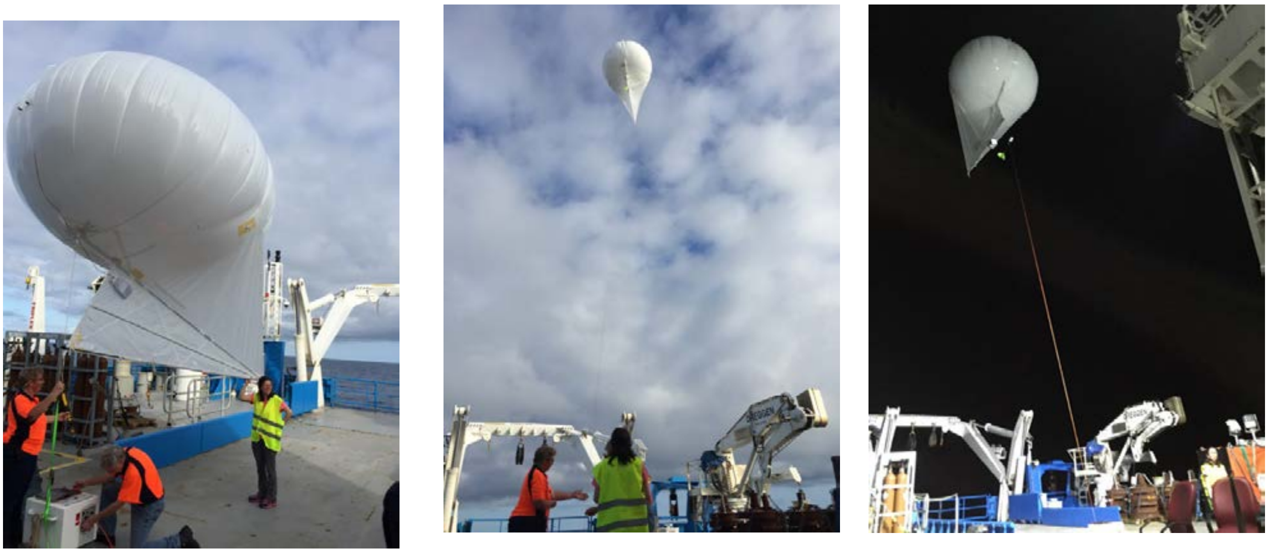


Figure 3 The Helikite during launching from the back deck, while in air and during night flights

Temperature, pressure, and relative humidity observations were made with a windsonde or LOAC. Wind speed and direction were made using an Anasphere. Wind speeds for all flights were required to be always less than 10 Knots. Additional instrumentation measuring aerosol mass and or number density were made using LOAC, MiniDisc and Qtrak instruments to lower altitudes (~200-300m). Observations were made at station 1, 2 and 3. Both daytime and night time observations were conducted. A total of 49 flights were conducted during the voyage.

It is important to mentioned that this was the first time a tethersonde was launched of the RV Investigator.

Deployment of the UAV's (PI Zoran Ristovski, Tommaso Villa)

The deployment of the UAV's from the RV Investigator was another first attempt. The UAV's were successful deployed both from the front and back deck of the ship. The UAV's were provided by the Australian Research Centre for Aerospace Automation (ARCAA), that is part of QUT. The UAV that was carrying the scientific payload was a DJI S800 hexacopter. A separate UAV was used for filming.

The S800 (see Figure 4) weighing 3.7 kg with minimum and maximum take-off weights of 6.7 kg and 8 kg respectively. The UAV uses a 16000 mAh LiPo 6 cell battery, with a hover time of approximately 20 min and no additional payload. The hovering motor power consumption is 800 W with the minimum take-off weight. The motors run in conjunction with 15x5.2 inch props of 13 g each.

Figure 4 DJI S800 hexacopter with the payload concsisting of a Mini Diffusion Size Classifier (DISCmini), to measure the particle concentration, and the Q-trak, to measure the CO_2 concentrations coming from the ship diesel generators.

The telemetry range of the UAV is 2 km. This was adequate to cover the desired sampling distance to the closest reef but the Current Civil Aviation Safety Australia (CASA) regulations restricting the use of small UAV's (< 20 kg) to visual line-of-sight during daylight operation limited the use to a distance of around 500m which was not sufficient to reach the closest reefs. Nevertheless this distance was more than adequate to achieve the opportunistic objective of the voyage to measure ship emissions.

The S800 with the DJI Wookong autopilot, allowed pre-programmed autonomous flights that could track and check the exact location of the UAV during the flight. Information from the autopilot was displayed on a laptop computer via the installed DJI ground station software. A typical flight path used to measure the ship diesel engine plume emission is presented in Figure 5.

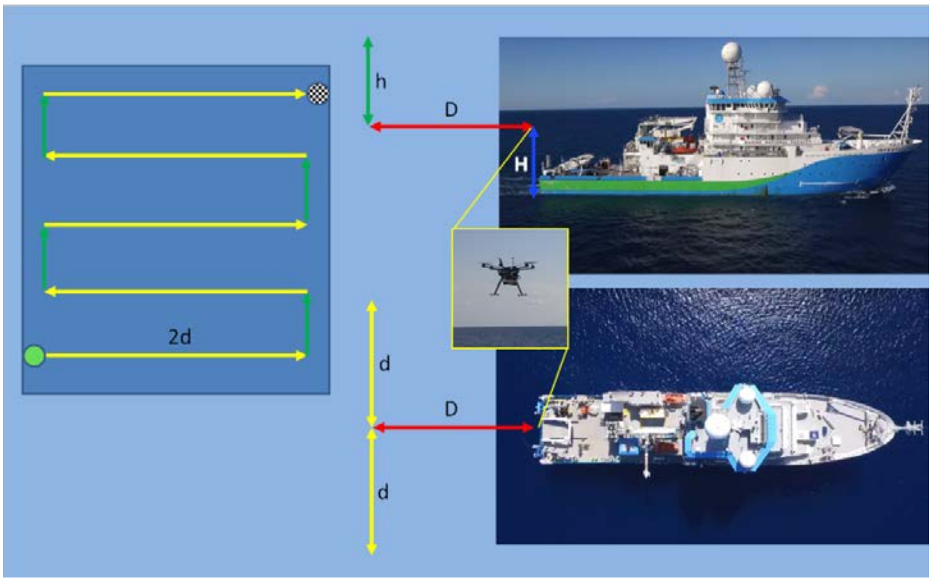


Figure 5 Flight path used to measure the ships diesel engines plume dispersion.

The payload of the S800 consisted of a Mini Diffusion Size Classifier (DISCmini). The DISCmini is a portable monitor used to measure concentration of particles ranging in diameter size from 10-500 nm and a time resolution of up to 1s (1 Hz). A TSI IAQ-calc 7545 model was used as monitor to measure CO_2. It can simultaneously measure and log CO, CO2, temperature and humidity data. The CO_2 sensor is a dual-wavelength NDIR (non-dispersive infrared) with a reading range between 0 to 5,000 ppm and an accuracy of ±3.0% of reading or ± 50 ppm (whichever is greater).

An example of a profile of the ships diesel engines plume is shown in Figure 6. Top graphs show particle number concentration profiles while bottom graphs show the CO_2 concentration change. We can see that the particle concentration increase from several hundred to ~ 10^5 particles/cm^3 as the UAV passes through the plume. The CO_2 concentrations are also shown on the bottom graphs.

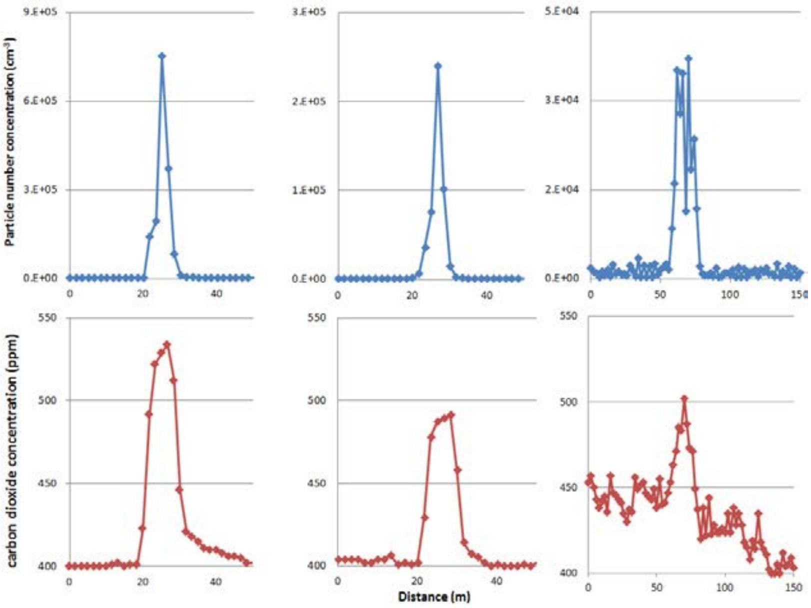


Figure 6 Particle number profiles (top graphs) and CO_2 profiles (bottom graph) collected at 20 m behind the ship and 25 m above the ocean (first 2 columns) and at 100 m behind the ship and 25 m above the ocean (far right graphs).

The measured particle emission factors for the diesel generators used on board the RV Investigator were similar to the emission factors measured from engines used in the land transport industry (trucks) and significantly smaller than the ones measured from ships using high sulphur HVO fuels. First draft analysis of the results shows that the RV Investigator is a very clean ship compared to other ones reported in the literature.

Water Composition Data

Microbial DMS/P cycling – PIs Justin Seymour (not onboard) and Bonnie Laverock, UTS

Under voyage objective 3, seawater samples from CTD stations and underway water were analysed for DMS and DMSP concentrations using a gas chromatograph (GC). In addition, the DMSP lyase assay (DLA) was performed to assess the relative contribution of phytoplankton and bacteria to DMS production, and seawater was filtered and preserved for DNA/RNA extractions and bacterial community analyses.

In addition to sampling performed at CTD stations and underway sampling locations, several different experiments were performed at inner and outer reef sites (Figure 7). At experimental stations, the uptake and production of DMSP by phytoplankton was assessed using incubations with the addition of ^{13}C-labelled DMSP (Fig. 1, “experiments”). Two additional incubation experiments were performed at the same stations, to assess the uptake of DMSP by the bacterial community by stable isotope probing (Fig.1; “SIPs”). Separate incubation experiments used nitrate (NO_3^-) addition to to investigate the influence of nutrient limitation on DMSP production and degradation (Fig. 1, “NO3 exps”). Finally, diel sampling studies were performed at Stations 1 and 3, in order to assess the production of DMS in surface waters over 48 hours (Fig. 1, “diel”).

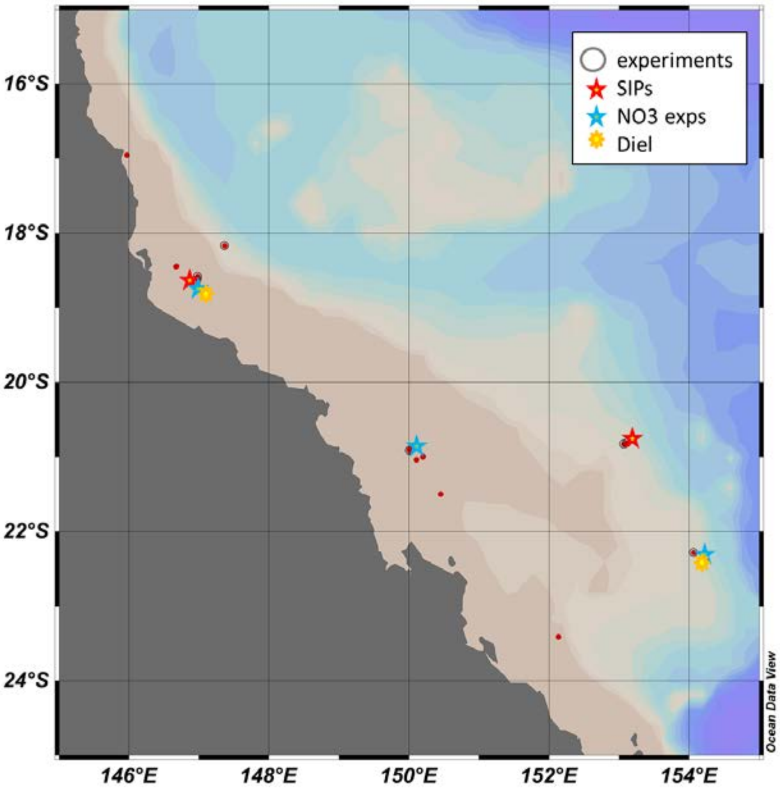


Figure 7 Map showing CTD sampling sites and experimental stations throughout the inner and outer reef.

DMS concentrations were typically within the range of 0.5 to 2 nM in surface seawater (Fig. 2) and throughout the water column; these values are comparable to other oligotrophic and open-ocean environments. Higher concentrations (2-3 nM) were observed at sites to the west of Palm Passage (Bramble Reef and Station 3; Fig. 2).

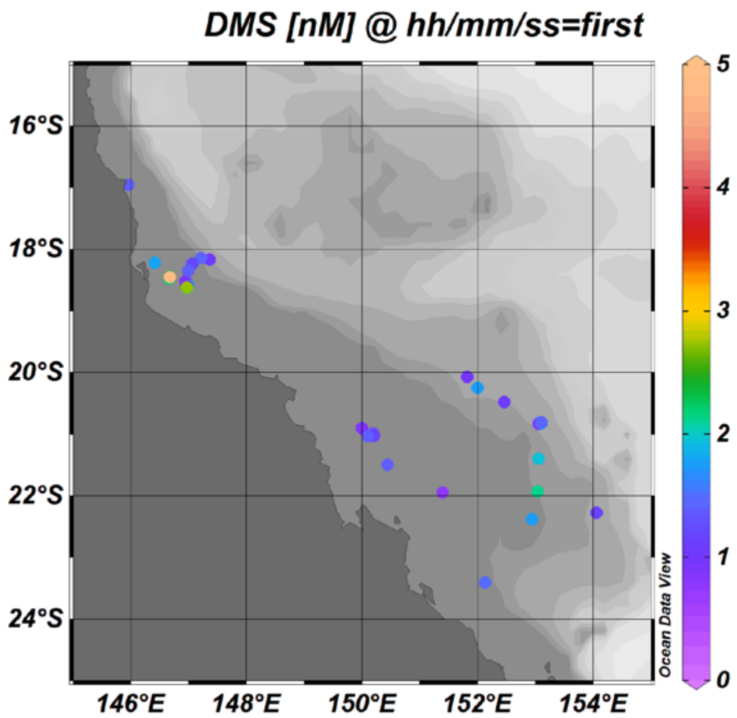


Figure 8 DMS concentration (nM) in surface seawater, collected from CTD locations and underway samples.

Diel studies were conducted at Station 1 and Station 3, to investigate the fluctuation in surface water DMS concentrations and DMSP lyase activity (DLA) over 48 hours. At station 3, two studies were performed; the first during the moon's first quarter (tidal range ~1.2 m) and the second immediately prior to full moon (tidal range ~2.5 m) (Fig. 3). Different diel patterns in DMS and DLA were observed between the two studies, with DLA in particular correlating with wind speed (r = 0.72, study 1; r = 0.63, study 2) (Fig. 3). Further analyses on these samples will reveal the bacterial DLA and the activity of bacterial DMSP degradation genes (*dmdA* and *dddP*).

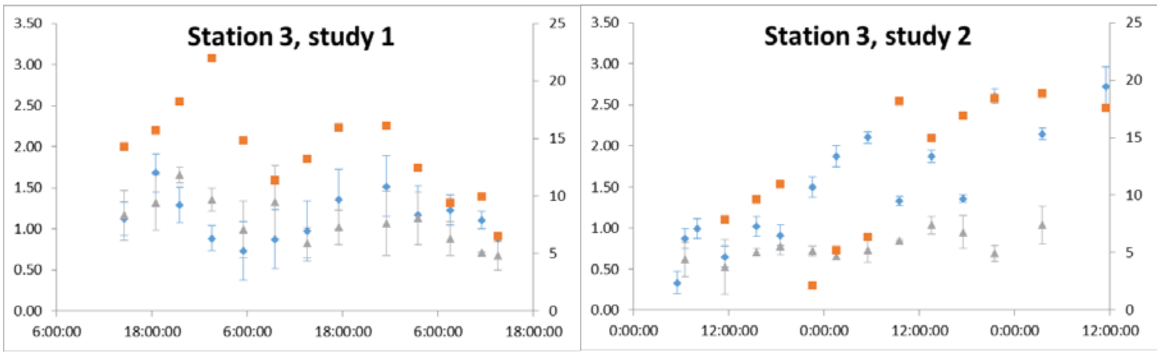


Figure 9 Variation in DMS concentration (nM, left-hand axis, blue diamonds) and phytoplankton DMSP lyase activity (uM min^{-1}, left-hand axis, grey triangles) over 48 hours, during two studies conducted on 7-9 October 2016 (study 1, graph on left) and 13-15 October 2016 (study 2, graph on right). Wind speed (m s^{-1}, orange squares, right-hand axis) is shown.

Preliminary analyses of nutrient addition experiments show that both phytoplankton and bacterial DLA increase over time, following the addition of NO_3^-. This suggests that DMS production by microorganisms in the reef environment may be nutrient limited.

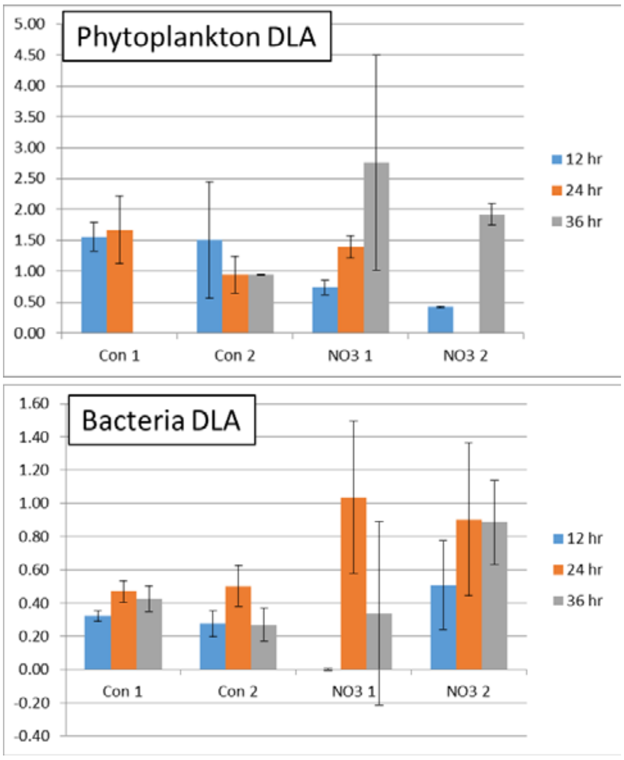


Figure 10 DMSP lyase acitvity (uM min^{-1}) in phytoplankton and bacteria fractions, following the addition of nitrate (NO_3^-). Preliminary data are incomplete.

In summary, although DMS concentrations in both inner and outer reef waters were low (Figure 8), we observed variation on a diel scale, which corresponded well with the more highly resolved DMS data collected by Yuko Omori (University of Tsukuba). This data will enable us to contribute towards calculations of the air-sea flux of DMS over spatial and temporal scales. In addition, our preliminary data indicate that the cleavage of DMSP to DMS (assessed using the DMSP lyase assay, DLA) may be dependent on factors that vary on diel timescales (e.g. solar radiation, wind speed; Figure 9) and, furthermore, is likely to increase with increased nutrient load (Figure 10). Further analyses of preserved filters will allow us to assess the contribution of different bacterial groups to DMSP degradation. Combining these observations with environmental data (e.g. water packet origin data provided by Mark Baird and team, CSIRO) will provide us with a greater understanding of the influence of reef microbial communities in DMS production. Finally, DMSP uptake and production experiments (Figure 7) will be analysed by PhD students Eva Fernandez (University of Technology Sydney) and Erin McParland (University of Southern California), augmenting our understanding of potential DMS production in inner and outer reef waters.

Seawater DMS, DMS Flux, DMSPt studies (PI. G. Jones). DMS flux has been calculated using the wind speed parameterisation method of Liss and Merlivat (1976). Flux values ranged from 0.1-12 μmol m^{-2} d^{-1} (mean 2.9), with fluxes mainly affected by wind speed. These fluxes have been compared to actual DMS fluxes from six coral reefs characteristic of reefs in the GBR (3 inshore fringing reefs; a mid-shelf reef, microatoll, coral cay). Fluxes from the coral reefs are greater than the fluxes from the GBR lagoon and represent a "point source" of DMS to the atmosphere of the GBR. About 200 samples of underway seawater was acidified for DMSPt (= DMSPp + DMSPd) analysis by GC, with most samples collected hourly from station 3 in Hydrographers Passage. These results will be correlated with tidal heights, SST, Chl a, and compared with results obtained from actual coral reefs.

Effect of UV and nitrogen limitation, on production and consumption of DMSP in the water column surrounding GBR, both outside and inside the reef (PI G. Jones (SCU), PI J. Seymour (UTS), B Laverock (UTS), E. McParland (Uni California))

Experiments looking at the effects of UV light and nitrogen limitation on DMSP synthesis have been undertaken (Erin McParland and Bonnie Laverock). All of these experiments were conducted with surface water (5m depth) and therefore the closest community to the air-sea interface which experiences the most extreme light stress. Equipment used was the FIRe fluromoter to collect estimates of phytoplankton photosystem efficiency from the underway system both at station1 and 3, as well as multiple transects inside and outside of the reef.

DMSP synthesis rates were determined with a new technique that involves ^{13}C uptake in conjunction with more traditional DMS(P) analyses (DMS, DMSP total, dissolved, lyase activity plus ancillary data including chlorophyll, fluorometry and flow cytometry). This ^{13}C technique is exciting because it gives us an actual rate of DMSP synthesis, rather than just a snapshot of the DMSP pool at a given time of sample collection. These experiments will provide DMSP synthesis rates as a function of UV and light intensity as well as nitrogen limitation.

Underway measurements of volatile organic compounds in the surface seawater- PI's Hiroshi Tanimoto (National Institute for Environmental Studies, Japan) not onboard and Yuko Omori (University of Tsukuba, Japan)

Dimethyl sulfide (DMS) and other volatile organic compounds (VOCs) are released from coral and coral reef seawater. The Great Barrier Reef (GBR), the largest coral reefs in the world, is thought to be one of the important sources of the atmospheric DMS and other VOCs. DMS is oxidized in the atmosphere to form new particles, such as cloud condensation nuclei, which possibly influence climate over the GBR and rainforest. On IN2016-V05 cruise, we observed the distributions of DMS and other VOCs in the surface seawater to evaluate their sea-to-air flux in GBR.

The concentrations of DMS and other VOCs in the surface seawater were measured by underway measurement system, Equilibrator-Inlet Proton Transfer Reaction Mass spectrometry (EI-PTR-MS). The EI-PTR-MS system comprised a PTR-MS instrument and a bubbling-type equilibrator for equilibration between the liquid and gas phases. Surface seawater was pumped from a seawater intake on the bottom of the ship (approximately 5-m depth), and supplied to the equilibrator. We monitored the concentrations of DMS, propene, acetaldehyde, acetone and isoprene at 1-minute interval during the cruise.

The sea-surface DMS concentration showed spatial and diurnal variations ranging from 0.9 to 2.6 nM around the Southern GBR (Figure 12 and Figure 11). Diurnal cycles of the DMS concentration were observed at St. 1 for 5 days (Figure 12). The DMS concentration increased from 12:00 to 18:00 and decreased during night, which were coincident with diurnal changes in sea-surface temperature (SST). The increase in SST is caused by the flow of coral reef seawater, suggesting that the increase in DMS concentration is also derived from coral reef.

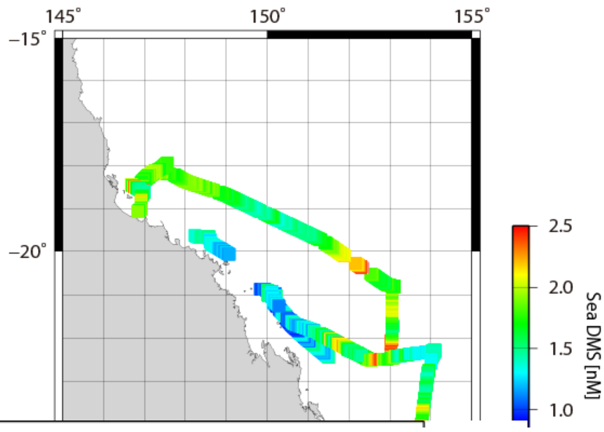


Figure 11 The distribution of DMS concentration in the surface seawater during IN2016-V05 cruise.

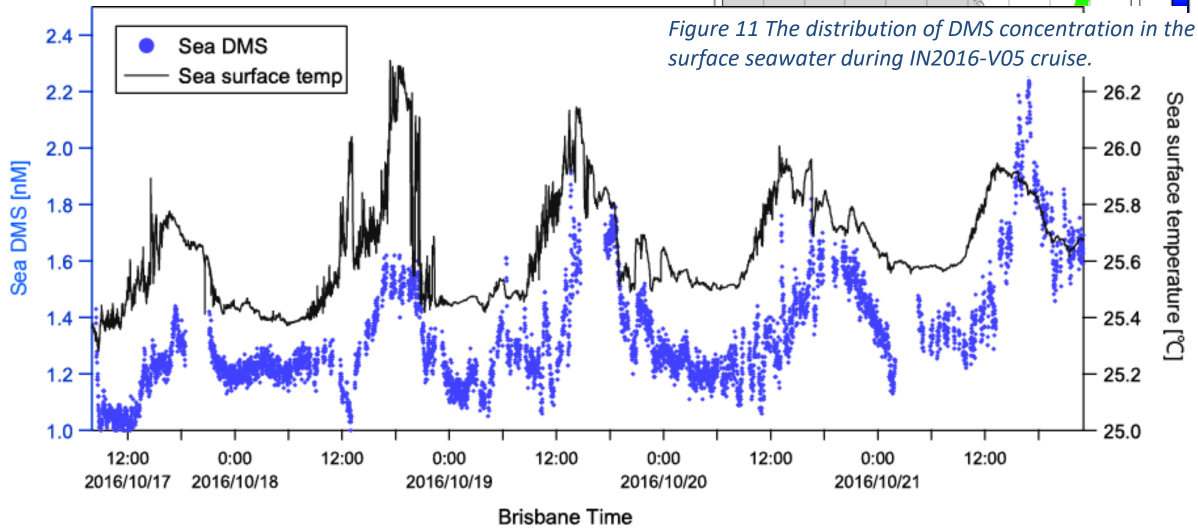


Figure 12 Time series of the DMS concentration and temperature in the surface seawater at St. 1.

Voyage Narrative

Voyage started in Brisbane on the 28th of September. The mobilisation was successful and all of the necessary equipment was loaded on the vessel in time. Most of the atmospheric sampling equipment was ready to collect data from the beginning of the voyage.

Optics Station of Heron Island 29th September

After leaving Brisbane we headed towards the "optics station" of Herron Island. We have arrived at the optics station on the 29th of September and stayed there for several hours. While at the optics station we have conducted a CTD at 3 depths and deployed the Optics cage. The atmospheric equipment was sampling continuously. In the late afternoon we have left for our first atmospheric station.

1st atmospheric station. Inner side of the reef, 30th September to 1st October

Our first atmospheric station was placed in the lower part of the GBR close to the Hydrographers passage. Upon arrival to the station the vessel was oriented in the direction of the wind. This was necessary to avoid contamination from the ships diesel engines. Upon arrival we have had extremely calm conditions with almost no wind. While at the station we have:

1. Deployed the tethersonde (Helikite) for the first time. The deployment was very successful and a number of flights were conducted during going through the night and into the morning. The operation continued for almost full length of this station.
2. 4 CTD's were conducted intertwined with the Optics cage and the deployment of the Hyperpro.

Due to the very calm conditions we have experienced very high humidity. That has caused some problems with condensation in the atmospheric sampling lines as well as significant condensation on the tethersonde.

An important conditions for the atmospheric sampling was that the airmass is not contaminated by the ship exhaust and no under any influences from the continental sources. We can see the contamination through the measurements of particle number concentration as well as the levels of atmospheric radon. These are real time measurements. Upon arrival to the station we have experienced some extremely low particle concentrations that indicated that the airmass has spend significant time over the ocean. These were preferred sampling conditions. Such conditions stayed until the next day (1st October) when the winds started picking up. As the winds increased so did all of the markers that indicate contamination from the continent. Therefore we decided to shorten the stay for 1 day and to proceed to the next station on the 1st October around 10 am.

On route to the second station we have deployed the Triaxus.

2nd atmospheric station. Outside of the reef, 2nd to 4th October

The objective of having the station on the outer side of the reef was to collect data on the atmospheric composition of airmasses that have not passed over the reefs. This would be something similar to a background station. We have arrived at the 2nd station around 2300 on the 2nd October. Upon arrival we have deployed the tethersonde and conducted the CTD's/Optics cage deployment as per agreed schedules. Atmospheric measurements were running uninterrupted. An excellent set uncontaminated data was collect during this station.

We have stayed for around 2 days at this station continuously sampling. On the morning of the 4th October, around 0800, we have left north along the outer side of the reef towards Palm passage.

Transit towards Palm passage.

During transit towards palm passage we have deployed the Triaxus. During transit, unfortunately the winds were mainly south easterlies blowing from the stern of the vessel and bringing exhaust from the ships generators into the atmospheric sampling lines and contaminating the samples.

Palm passage crossing, 6th October

We have arrived at the outer side of the Palm passage on the 6th October. Upon arrival to the Palm passage several crossings were made (towards the West, than back East and than towards the west again). These crossing enabled us to obtain several transects of both the composition of the atmosphere and water.

3rd atmospheric station. Inside of the reef and upwind of the land based station, 7th to 10th October

We have gained 1 more day, as we have spent 1 day less at the 1st Atmospheric station, and decided to spend 3 days, instead of 2 days, at this station. This station was positioned relatively upwind of the land based station and Mission (Garners) Beach. As similar atmospheric composition measurements were done both on the RV Investigator and on the land based station we were able to study the changes in atmospheric composition as the air mass travel from the reefs towards the rainforests (land). The usual monitoring routine was deployed while at this station (CTD's, Optics cast, Hyperpro, Tethersonde – Helikite, etc.)

Transit towards Fitzroy Island and first crew exchange, 10th to 11th October

On the evening of the 10th we have left for Fitzroy Island arriving on the morning of the 11th. The first personnel exchange was done between 1200 and 1400. The ABC filming crew has joined us for the second leg of the voyage.

Return to the 3rd atmospheric station. Inside of the reef and upwind of the land based station, 12th to 4th October

After the exchange we headed back to the 3rd station. The original plan was to have a crossing over the reef through one of the passages in the northern part of the reef (i.e. Flora passage). The plan was changed as we have seen more value in repeating the crossing through Palm passage at a time when the tides would be in a different cycle.

On the morning of the 12th October we have arrived close to the original position of the 3rd station. The new location for the "new" 3rd station was chosen so it is as close as possible to a reef. We have deployed for the first time the UAV's. Transects were flown from the vessel to wards the reef. The aim of these flights were to obtain the change in atmospheric particle concentrations in the vicinity of the reefs. The flights were conducted around low tide as it was expected that the largest emissions from the reefs would be seen around these times.

In the evening of the 12th October we have returned to close to the original position of the 3rd station and continued with the usual monitoring routine.

On the 13th we have done one more crossing of the palm passage but this time it was done during low tide as compared to the crossing on the 6th October. We have returned to the 3rd station in the evening of the 13th. While at the third station in addition to the usual sampling routine we have deployed the UAV's in a number of flights aimed at measuring the emissions from the ships diesel generators.

Transit towards Magnetic Island for personnel exchange from Townsville, 16th October

We have left the 3rd station on the 16th October and sailed towards Magnetic Island for the second and final personnel exchange. The ABC crew, as well as the team responsible for the UAV's has left the vessel at Magnetic Island.

After leaving magnetic Island we headed back towards the 1st station. The aim of returning to the 1st station was to repeat the measurements at roughly the same spot but at different tide conditions. During the second visit both to the 3rd and 1st station the tides were much higher than during the first visit.

Return to the 1st atmospheric station. Inner side of the reef, 18th October to 22nd October

We have returned to roughly the location of the 1st station on the 18th October and have stayed there for 4 days. The usual sampling routine was repeated for most of the time. The winds were slightly higher so there were some problems in deploying the tethersonde-Helikite.

Return to Brisbane via a deep water station 23rd October

It was necessary to collect some deep water samples from depths of more than 400m. As the waters around the reef are relatively shallow we decided to have a deep water CTD station south of the GBR. On the return way to Brisbane we have stopped for several hours in the early morning of the 23rd and conducted CTD's in deep water. As some experiments with the water samples needed 24 hours we needed to collect these samples 24 hours before arrival to Brisbane.

Arrival to Brisbane on the 24th October and demobilisation

On the morning of 24th October reached the pilot station and were picked up by the pilot around 1100 and began our pilotage to Brisbane. As soon as we left the deep water station we have started packing our equipment to be ready to start demobilisation on the day or arrival. We docked at Pinkenba wharf at approximately 1430.

Most of the demobilisation was finished by the end of the day.

Summary

Measurements of the atmospheric composition are strongly dependent on the atmospheric conditions at the place of sampling. Wind conditions (direction and speed) and especially the origin of the air masses can play a significant role in bringing contamination from, not only the ship engines, but also from other contaminations sources (other ships, continental pollution sources, etc.). During this voyage we have had very good conditions for most of the voyage. When the conditions were not optimal for sampling we have taken the advantage of being on a mobile platform and relocated to another place or moved to the next sampling station. Overall we have collected an excellent set of data on atmospheric composition in the GBR area and we have met most of the sampling goals. On board experiments (i.e. biogeochemical assays, DMSP lyase assay, the uptake and production of DMSP by phytoplankton, etc.) were also successful.

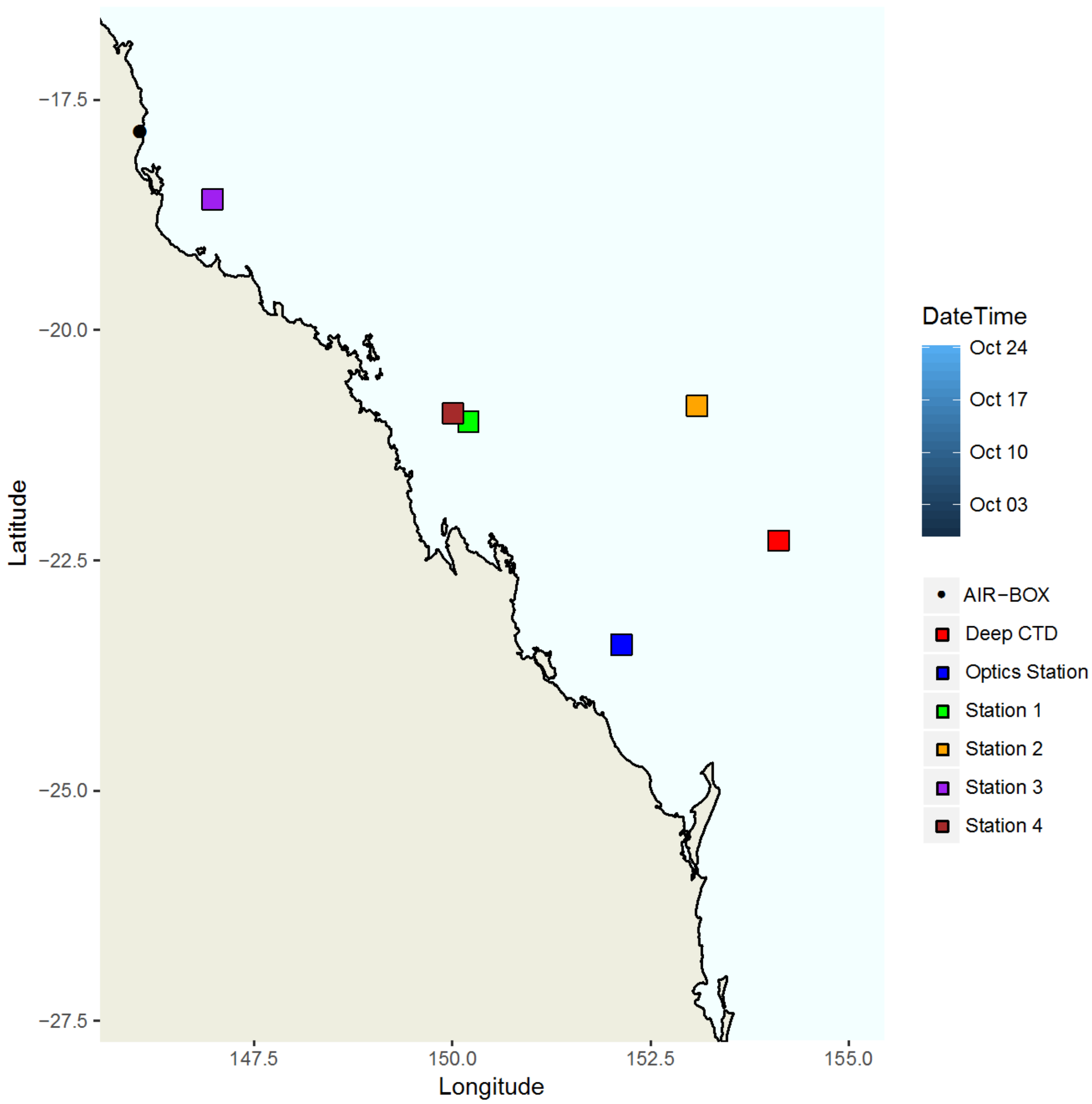
It is worth pointing out that there is a large amount of lab work and especially data processing yet to be completed before we can come up with more definite conclusions.

There were a number of first on this voyage:

1. This is the first time that measurements of the atmospheric composition in and around the reefs have been conducted;
2. This is the first dedicated atmospheric voyage of the RV Investigator;
3. This is the first deployment of the RV Investigator in the GBR region;
4. First time a tethersonde-Helikite has been deployed of the RV Investigator;
5. First time UAV’s specialised for sample collection were deployed of the RV Investigator.
6. First time the voyage was divided into several legs with crew exchange.

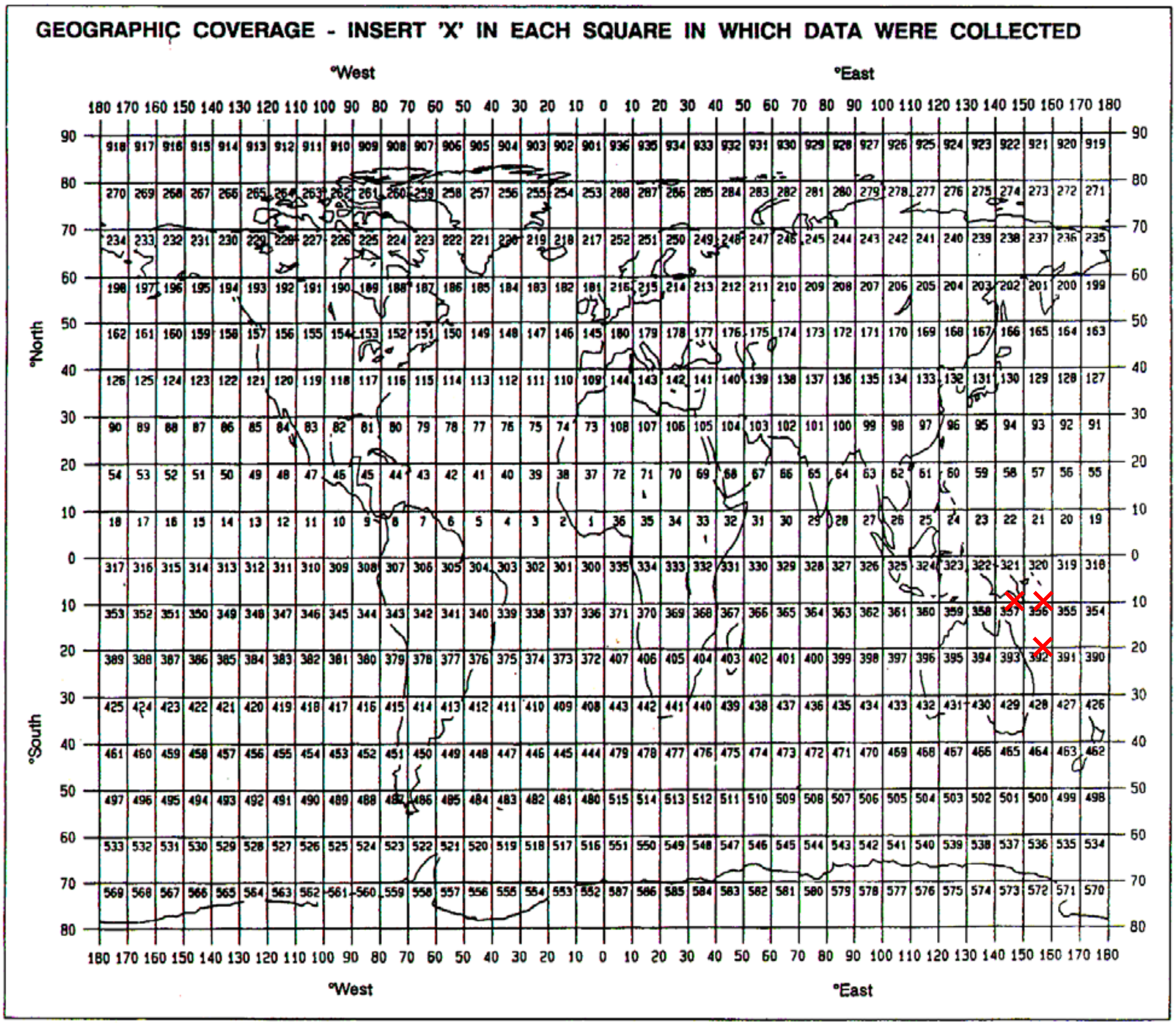
Even with so many “firsts” overall this voyage was very successful and showed that the RV Investigator is an excellent platform for atmospheric measurements. The sciences team, MNF, and ship master, officers and deck crew worked exceptionally well as a team and that was a key to making this voyage successful.

Voyage Track



Marsden Squares

Move a red "x" into squares in which data was collected



Summary of Measurements and samples taken

Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list at Appendix A	DESCRIPTION
1	Alain Protat (BOM)	27	days	M01	**BOM RMAN-511 cloud and aerosol lidar –** The RMAN cloud and aerosol lidar is a vertically-pointing 355 nm lidar, with a Raman N2 channel at 387 nm for calibration. It measures vertical profiles of co-polarization and cross-polarization lidar backscatter. From the two measurements the linear depolarization ratio can be estimated, which provides an indication of the thermodynamic phase of clouds (liquid or ice) and the preferential orientation of ice crystals in ice clouds. The horizontal and temporal resolutions are 15m and 1 minute. The instrument is mounted on a stabilized platform developed in-house by MNF engineers. The lidar worked perfectly during the whole research voyage. The only interruptions to data collection were when the lidar window needed to be cleaned. Calibrated backscatter and depolarization profiles are being produced and should be available in April 2017.
2	Alain Protat (BOM), Jay Mace (Univ. Utah)	27	days	M01	**Unversity of Utah 2-channel Microwave Radiometer (MWR) –** This passive microwave instrument measures brightness temperatures at vertical incidence at two frequencies (23.8 GHz and 31.4 GHz). From these two measurements empirical models and radiative transfer modelling allows for the retrieval if the vertically-intergrated liquid water content (also called liquid water path, LWP) and vertically-integrated water vapour (also called water vapour path, WVP). Data quality is excellent for the whole duration of the research voyage. Calibration of the two microwave channels is ongoing using microwave simulations of the clear air atmosphere. Processed data should be available by April 2017.
3	Melita Keywood (CSIRO)	27	days	M71	**CSIRO 3776 Condensation Particle Counter (CPC) (TSI Inc, USA).** This CPC provides continuous (1 sec sampling) number concentration of aerosols greater than 3 nm. Data will be analysed in conjunction with the MNF 3772 CPC, which measures the number concentration of particles greater than 10 nm. These

Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list at Appendix A	DESCRIPTION
	Zoran Ristovski (QUT)				2 instruments can be used to calculate the 3 to 10 nm particle concentration, a size range that is important for new particle formation. Operated continuously throughout voyage in the aerosol lab.
4	Melita Keywood (CSIRO) Zoran Ristovski (QUT)	27	days	M71	**CSIRO Scanning Mobility Particle Sizer (SMPS) (TSI Inc, USA).** The SMPS continuously (5 min sampling) measures the size dependent number concentration of particles from 14 to 680 nm. Particle size distributions from this instrument will be complemented by measurements from the MNF GRIMM SMPS, which was set to measure from 4 to 430 nm to capture new particle formation events. Operated continuously throughout voyage in the aerosol lab.
5	Zoran Ristovski (QUT) Lin Wang (Fudan University)	21	days	M71	**Fudan University Particle Size Magnifier (PSM) (Airmodus, Finland).** The PSM provides continuous (4 min sampling) size dependent particle concentrations over the size range 1 to 4 nm. This instrument allows the detection of new particle formation in the atmosphere. The PSM is complemented by cpc and smps measurements which can observe newly formed particles concentrations as they grow > 4 nm. Operated from 4/10/2016 to 24/10/2016 in the aerosol lab.
6	Branka Miljevic (QUT) Zoran Ristovski (QUT)	27	days	M71	**QUT Chemical Ionisation Mass Spectrometer (CIMS) (Aerodyne, USA).** Operated with nitrate source. Real time (5 min sampling) measurements of the concentration of selected gas phase constituents and clusters. This instrument provides information on the composition of precursor gases and newly formed particles. Operated continuously throughout voyage in the aerosol lab.
7	Zoran Ristovski (QUT)	24	days	M71	**QUT Nanometre Aerosol Sampler (NAS) (TSI, Inc. USA),** used to collect samples for **Electron Microscopy.** 29 approximately 12 hourly samples were collected from 30/09/16 to 23/10/2016 days in the aerosol lab. These samples will be analysed using electron microscopy at QUT for the morphology and chemical composition of sub-150 nm particles.

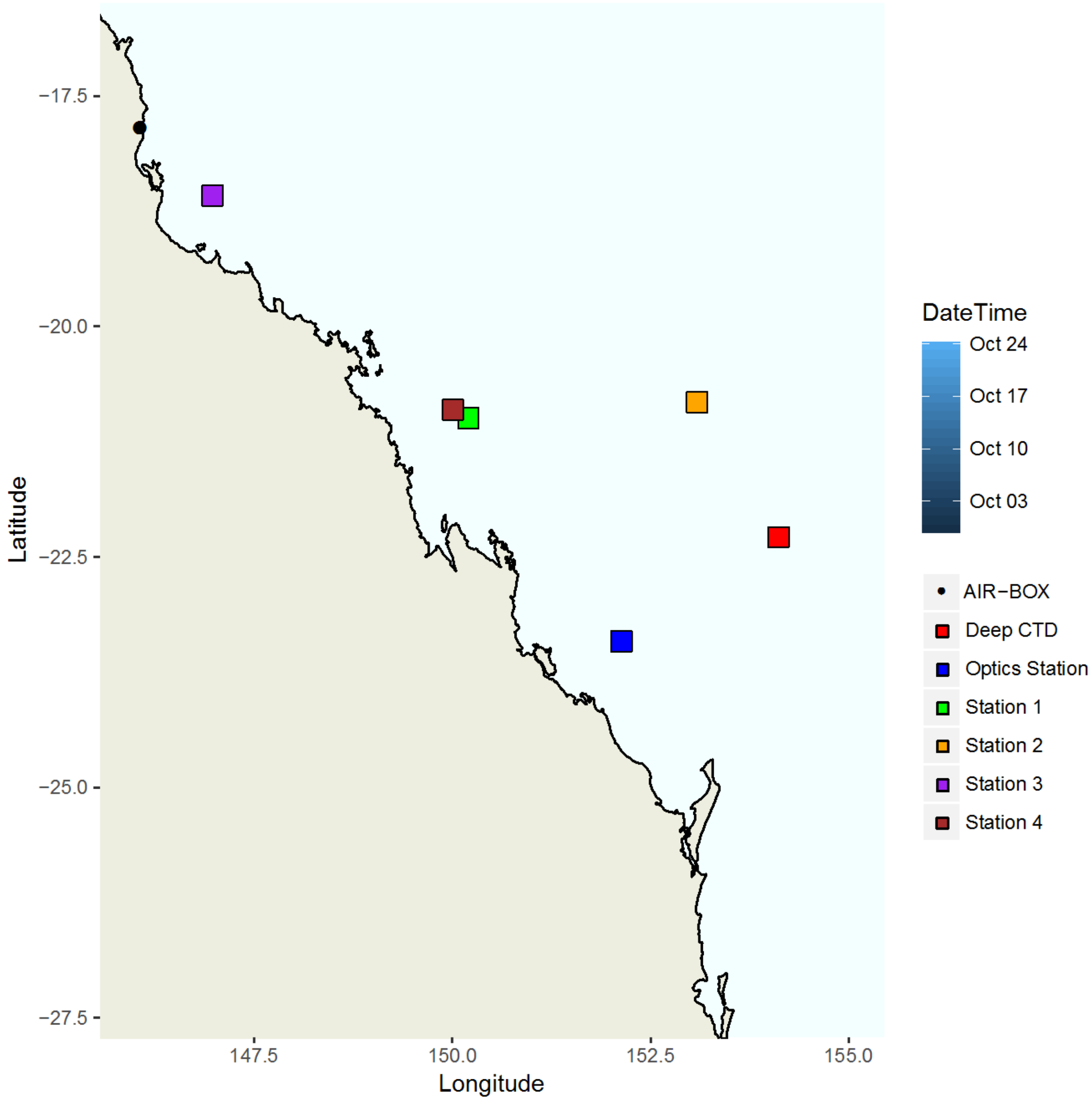
Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list at Appendix A	DESCRIPTION
8	Branka Miljevic (QUT) Zoran Ristovski (QUT)	25	days	M71	**QUT total suspended particulate (TSP) filters** for CIMS analysis. 44 filters sampled for 12 hours were collected from 29/09/16 to 23/10/16 in the aerosol lab. These samples will be analysed using a CIMS and will complement the real time CIMS measurements.
9	Andrew Bowie (UTas)	22	days	M71	**UTas TSP filters for trace metal analysis**. 11 filters, each sampled for 2-3 days, collected between 30/09/16 and 23/10/16 in the aerosol lab. These filters will be analysed for concentrations of trace metals.
10	Melita Keywood (CSIRO)	27	days	M71	**CSIRO Aerosol Chemical Speciation Monitor (ACSM) (Aerodyne, USA).** The ACSM provides real time (10 min sampling) chemical composition of sub 1 µm atmospheric aerosol. Results provide information on sources and atmospheric processing of aerosols. Operated continuously throughout voyage in the air chemistry lab.
11	Melita Keywood (CSIRO)	25	days	M71	**CSIRO PM1 quartz filters.** 25 filters sampled for 24 hours each were collected from 29/09/2016 to 23/10/2016 in the air chemistry lab. These samples will be analysed using ion chromatography and for elemental and organic carbon. These results complement the real time measurements taken using the ACSM.
12	Sarah Lawson (CSIRO)	26	days	M71	**CSIRO Proton Transfer Reaction Mass Spectrometer (PTR-MS).** Real time (15 minute sampling) concentration of volatile gases in the atmosphere, including Dimethyl Sulfide (DMS). Results will be used in conjunction with water based DMS measurements to calculate fluxes of DMS from the ocean to the atmosphere. Operated continuously throughout voyage in the air chemistry lab.
13	Sarah Lawson (CSIRO)	27	days	M71	**CSIRO sequencer for collection of volatile organic compound samples.** 27 cartridges, sampled for 24 hours, were taken from 28/09/16 to 25/10/16 in the air chemistry lab. Samples will be analysed for the concentration of volatile organics. These data will

Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list at Appendix A	DESCRIPTION
					complement real time volatile gas measurements taken using the PTR-MS.
14	Justin Seymour (UTS)	380	Samples	H33	DMS data analysed on board from CTD profiles and underway surface water. Data are stored as chromaograms in the Shimadzu LabSolutions software. Analysis against standard curves performed by Bonnie Laverock and Erin McParland while on board, and stored as Excel files.
15	Justin Seymour (UTS)	380	Samples	H90	Dissolved and total DMSP samples, collected from CTD profiles and underway surface water and preserved using sulfuric acid. Samples will be analysed at UTS and data curated by Bonnie Laverock.
16	Justin Seymour (UTS)	336	Samples	B07	RNA/DNA samples collected from CTD profiles and underway surface water. Filters are preserved at -80 °C and will be processed and analysed at UTS. Sequencing and microbial gene abundance data will be curated by Bonnie Laverock, UTS.
17	Mike Harvey (NIWA)	27	days	M71	**Celiometer** collected continuous data on the inversion layer height. It was operated continuously for 27 days from deck 4.
18	Mike Harvey (NIWA)	20	Samples	M71	**HiVol filter samples.** 20 filters sampled for 24-48 hours were collected from 29/09/16 to 23/10/16 on the deck on level 4. These samples will be analysed for elemental composition at NIWA - NZ.
19	Stephen Archer (AUT – NZ)	27	days	M71	**Biological Aerosol Samples.** Collection of aerosol samples for biological analysis. Data output will be DNA sequences identifying bacterial and eukaryal components of the air masses throughout the voyage. All the analysis will be done at AUT – Auckland.
20	Robyn Schofield	49	Flights	M01, M71	**Helikite vertical atmospheric profiles:** Vertical profiles of temperature, pressure, relative humidity, wind speed and direction from the surface up to a maximum height of 600m using a helikite – a 9 m^3 helium filled balloon with a kite for stability. Temperature, pressure, and relative humidity observations were made with a windsonde or LOAC. Wind speed and direction were made using an

Item No.	PI see page above	NO see above	UNITS see above	DATA TYPE Enter code(s) from list at Appendix A	DESCRIPTION
					Anasphere. Wind speeds for all flights were required to be always less than 10 Knots. Additional instrumentation measuring aerosol mass and or number density were made using LOAC, MiniDisc and Qtrak instruments to lower altitudes (~200-300m). Observations were made at station 1, 2 and 3.

Details of the data collected by the supplementary and piggyback voayges are in Appendix A and B.

Track Chart



−17.5
−20.0
−22.5
−25.0
−27.5
Latitude
147.5
150.0
152.5
155.0
Longitude
DateTime
Oct 24
Oct 17
Oct 10
Oct 03
AIR−BOX
Deep CTD
Optics Station
Station 1
Station 2
Station 3
Station 4

Personnel List

Personnel List – Northbound Leg 1

1.	Lisa Woodward	Voyage Manager	CSIRO MNF
2.	Ian McRobert	SIT Support	CSIRO MNF
3.	William Ponsonby	SIT Support	CSIRO MNF
4.	Nicole Morgan	SIT Support	CSIRO MNF
5.	Matt Boyd	GSM Support	CSIRO MNF
6.	Bernadette Heaney	GSM Support	CSIRO MNF
7.	Kendall Sherrin	Hydrochemistry	CSIRO MNF
8.	Cassie Schwanger	Hydrochemistry	CSIRO MNF
9.	Anoosh Sarraf	DAP Support	CSIRO MNF
10.	Ian Hawkes	DAP Support	CSIRO MNF
11.	Francis Chui	DAP Support	CSIRO MNF
12.	Zoran Ristovski	Chief Scientist	QUT
13.	Luke Cravigan	PhD student	QUT
14.	Chiemeriwo Osuagwu	PhD student	QUT
15.	Erin McParland	PhD student	Uni California (SCU)
16.	Bonnie Laverock	Postdoc	UTS
17.	Eva Fernandez	PhD Student	UTS
18.	Stephen Archer	Researcher	NIWA
19.	Sonya Fiddes	PhD student	Uni Melb
20.	Claire Vincent	Postdoc	Uni Melb
21.	Yuko Omori	Postdoc	Uni of Tsukuba, Japan
22.	Alain Protat	PI	BoM
23.	Karen Wild-Allen	Supplementary PI	CSIRO
24.	Nagur Cherukuru	Supplementary scientist	CSIRO
25.	Mathieu Mongin	Carbon Chemistry & Optics	CSIRO
26.	Farhan Rizwi	Data processing	CSIRO
27.	Charles Kovach	Optics	NOAA
28.	Robin Beaman	CI – Piggy back voyage	JCU
29.	Tony Bromley	Winch Operator	NIWA
30.	Sally Gray	Winch Operator	NIWA

Personnel List – Southbound Leg 2

1.	Lisa Woodward	Voyage Manager	CSIRO MNF
2.	Ian McRobert	SIT Support	CSIRO MNF
3.	William Ponsonby	SIT Support	CSIRO MNF
4.	Matt Boyd	GSM Support	CSIRO MNF
5.	Bernadette Heaney	GSM Support	CSIRO MNF
6.	Kendall Sherrin	Hydrochemistry	CSIRO MNF
7.	Cassie Schwanger	Hydrochemistry	CSIRO MNF
8.	Anoosh Sarraf	DAP Support	CSIRO MNF
9.	Francis Chui	DAP Support	CSIRO MNF
10.	Zoran Ristovski	Chief Scientist	QUT
11.	Luke Cravigan	PhD student	QUT
12	Chiemeriwo Osuagwu	PhD student	QUT
13.	Erin McParland	PhD student	Uni California (SCU)
14.	Bonnie Laverock	Postdoc	UTS
15.	Eva Fernandez	PhD student	UTS
16.	Stephen Archer	Researcher	NIWA
17.	Graham Jones	PI	SCU
18.	Robert Ryan	PhD student	Uni Melb
19.	Robyn Schofield	PI	Uni Melb
20.	Gavin Broadbent	Technician – UAV's	QUT
21.	Tommaso Francesco Villa	PhD student – UAV's	QUT
22.	Dirk Lessner	Technician – UAV's	QUT
23.	Yuko Omori	Postdoc	Uni of Tsukuba, Japan
24.	Alain Protat	PI	BoM
25.	Karen Wild-Allen	Supplementary PI	CSIRO
26.	Janet Anstee	Supplementary PI	CSIRO
27.	Mathieu Mongin	Carbon Chemistry & Optics	CSIRO
28.	Farhan Rizwi	Data processing	CSIRO
29.	Charles Kovach	Optics	NOAA
30.	Tony Bromley	Winch Operator	NIWA
31.	Sally Gray	Winch Operator	NIWA
32.	Kathy McLeish	ABC News	ABC
33.	Timothy Pasmore	QUT Comms	QUT
34.	Dean Caton	ABC News	ABC

Personnel List – Southbound Leg 3

1.	Lisa Woodward	Voyage Manager	CSIRO MNF
2.	Ian McRobert	SIT Support	CSIRO MNF
3.	William Ponsonby	SIT Support	CSIRO MNF
4.	Matt Boyd	GSM Support	CSIRO MNF
5.	Bernadette Heaney	GSM Support	CSIRO MNF
6.	Kendall Sherrin	Hydrochemistry	CSIRO MNF
7.	Cassie Schwanger	Hydrochemistry	CSIRO MNF
8.	Anoosh Sarraf	DAP Support	CSIRO MNF
9.	Francis Chui	DAP Support	CSIRO MNF
10.	Zoran Ristovski	Chief Scientist	QUT
11.	Luke Cravigan	PhD student	QUT
12.	Chiemeriwo Osuagwu	PhD student	QUT
13.	Erin McParland	PhD student	Uni California (SCU)
14.	Bonnie Laverock	Postdoc	UTS
15.	Eva Fernandez	PhD student	UTS
16.	Stephen Archer	Researcher	NIWA
17.	Graham Jones	PI	SCU
18.	Robert Ryan	PhD student	Uni Melb
19.	Robyn Schofield	PI	Uni Melb
20.	Tommaso Francesco Villa	PhD student – UAV's	QUT
21.	Yuko Omori	Postdoc	Uni of Tsukuba, Japan
22.	Alain Protat	PI	BoM
23.	Mark Baird	Supplementary PI	CSIRO
24.	Janet Anstee	Supplementary PI	CSIRO
25.	Emlyn Jones	Carbon Chemistry & Optics	CSIRO
26.	Jenny Skerratt	Data processing	CSIRO
27.	Charles Kovach	Optics	NOAA
28.	Tony Bromley	Winch Operator	NIWA
29.	Sally Gray	Winch Operator	NIWA

Marine Crew

Name	Role
Michael Watson	Master
Roderick Quinn	Chief Mate
Brendan Eakin	Second Mate
James Hokin	Third Mate
Gennadiy Gervasiev	Chief Engineer
Mark Ellicot	First Engineer
Ian McDonald	Second Engineer
Damian Wright	Third Engineer
John Curran	Electrical Engineer
Alan Martin	Chief Caterer
Kyra Lade	Caterer
Rebecca Lee	Chief Cook
Matt Gardiner	Cook
Jonathan Lumb	Chief Integrated Rating
Dean Hingston	Integrated Rating
Christopher Dorling	Integrated Rating
Murray Lord	Integrated Rating
Mathew McNeill	Integrated Rating
Kei Lewis	Integrated Rating
Ryan Drennan	Integrated Rating

Acknowledgements

First of all we would like to thank the MNF for giving us this exceptional opportunity. The support at both see, but also during mobilization, of the MNF and ASP staff was exceptional. Special thanks go to MNF IT and engineering support staff for their dedicated support. We would also like to thank Lisa Woodward for her excellent management of this voyage.

This research was supported under the Australian Research Council's *Discovery Projects* funding scheme (project number DP150101649 awarded to Z. Ristovski, M. Keywood, G. Jones, B. Miljevic, R Schofield), as well as its Linkage Infrastructure and Equipment Fund (project number LE150100048 awarded to P. Rayner, R. Schofield, Z. Ristovski, and 15 others).

Signature

Your name	Zoran Ristovski
Title	Chief Scientist
Signature	
Date:	31/03/2017

Appendix 1 Supplementary Voyage Report

Supplementary Project IN2016_V05: Voyage Report

Biogeochemical and optical properties of the Coral Sea and Queensland Shelf

Lead PI: Karen Wild-Allen – CSIRO Oceans & Atmosphere

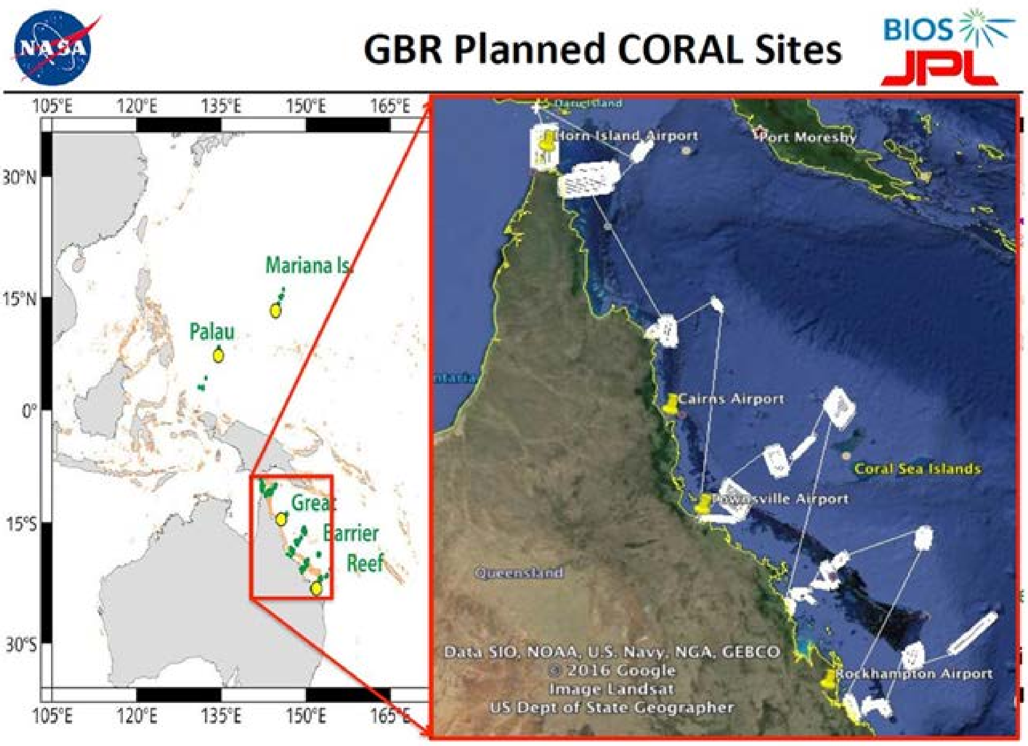
Additional PI's: Mark Baird, Lesley Clementson* – CSIRO Oceans & Atmosphere

Team Members: Mathieu Mongin, Farhan Rizwi, Emlyn Jones, Jenny Skerratt, Nagur Cherukuru, Janet Anstee, David Blondeau-Patissier*

*Lesley & David contributed to the planning and logistics of the project but did not join the vessel.

Objectives

1. To collect high resolution biogeochemical observations for validation of the 4km and 1km near real time eReefs models (https://research.csiro.au/ereefs/)
2. To get modellers in the field to better understand methods and issues associated with modern methods of data collection
3. To collect in situ optical data for the NASA CORAL project which is operating a very high resolution airborne hyperspectral sensor along selected transects in the GBR.



Observing Strategy

The principal platform of deployment was the Triaxus augmented with CTD, optode, transmissometer, fluorometer, optical plankton counter, optical nitrate sensor, and pulsed fluorometer. Four transects are proposed:

1. Southern lagoon to mid shelf (station 2)
2. Mid shelf (station 2) to outer shelf and northwards
3. Outer-shelf north to Palm Passage and across shelf to lagoon
4. Southern lagoon south through Capricorn Eddy.

The CTD and rosette was also deployed to resolve the vertical structure in the water column and collect samples for hydrochemistry and to confirm sensor calibration. Daily casts were achieved at 0530, between 1200-1400, and at time-series stations at 1730 to resolve diel variability.

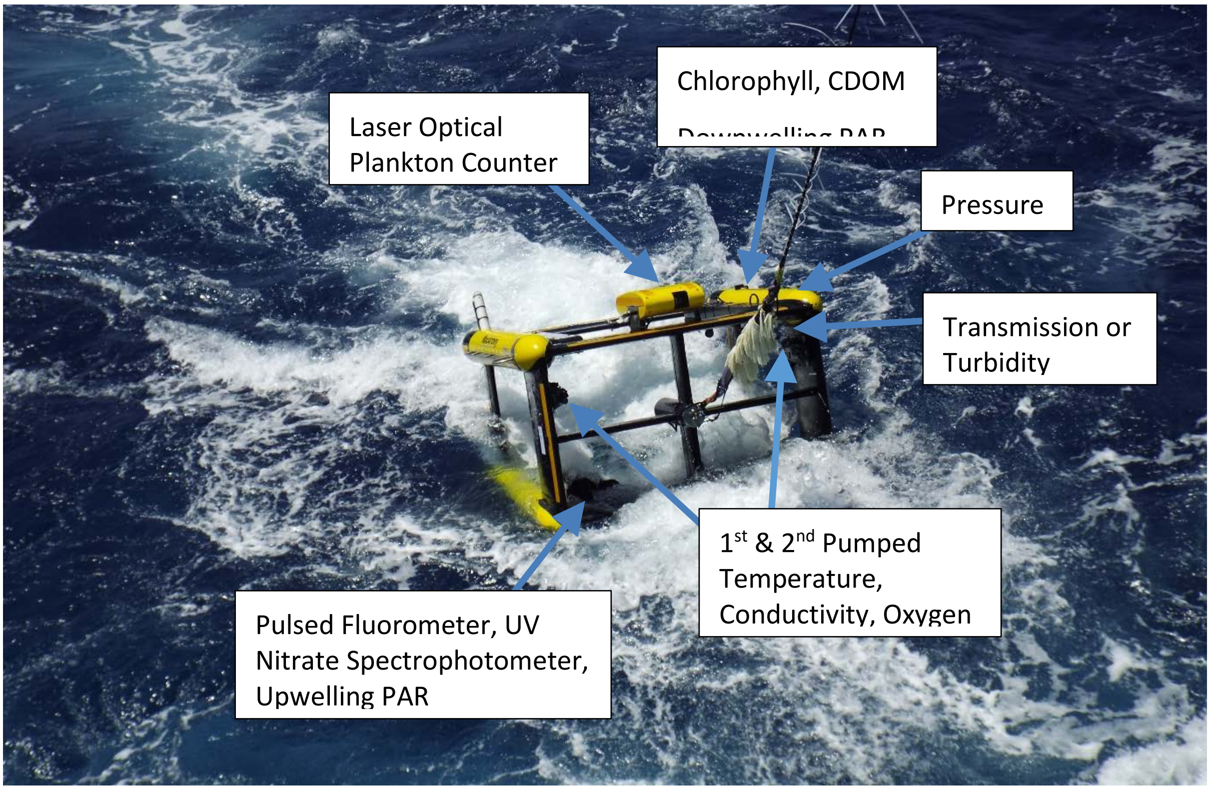
Additional CTD systems augmented with optical sensors were deployed opportunistically between 1000 – 1600, to observe inherent and apparent optical properties (IOP’s & AOP’s), including spectral absorption, scattering and up-and down-welling light. Where possible these profiles were timed to coincide with VIIRS and/or MODIS Aqua ocean colour satellite overpasses; we achieved 1 match-up with the NASA CORAL project PRISM sensor overflying the vessel.

Underway sensors were used to determine surface water characteristics along the cruise track, specifically gradients across inshore, lagoon, shelf and offshore water bodies with respect to carbon chemistry, phytoplankton fluorescence and optically active particles.

A strong motivation for our work was to get modellers into the field to better understand the methods of data collection and issues associated with sample collection, processing, storage and analysis. To this end expert modellers will work alongside experienced observationalists and assist in the deployment of sensors, and collection and processing of samples. Existing capability in the group will be utilised and augmented as team members learn new skills, for example in the deployment and operation of the CTD & Triaxus and the on board data processing and visualisation of these data streams.

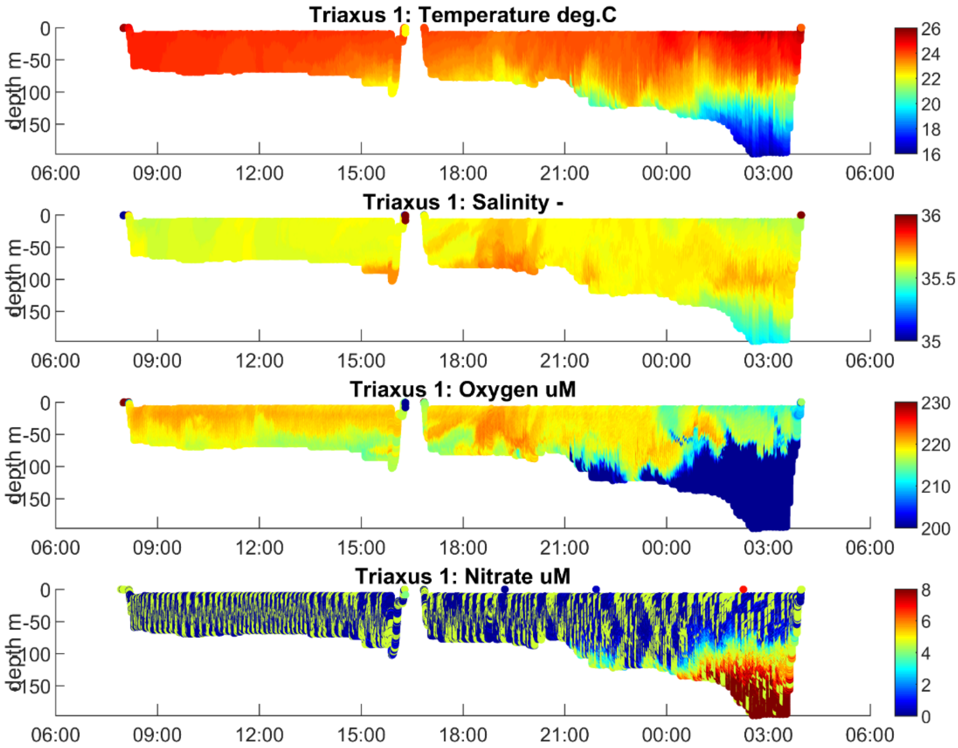
Summary of in water Observations

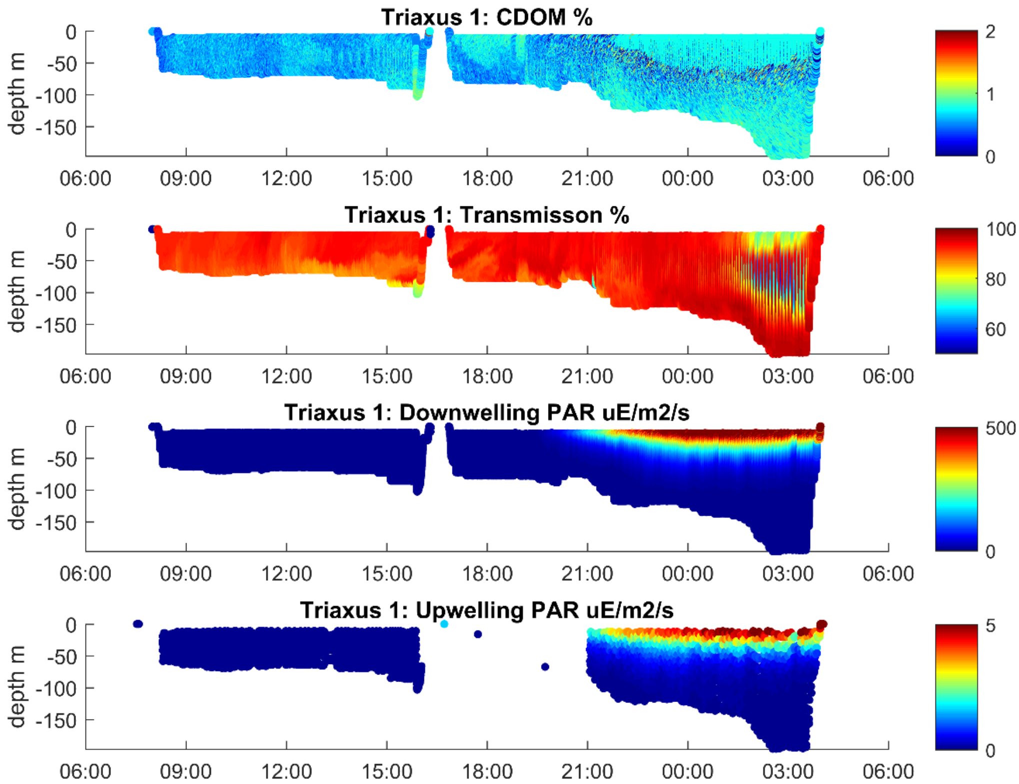
1. **Triaxus**

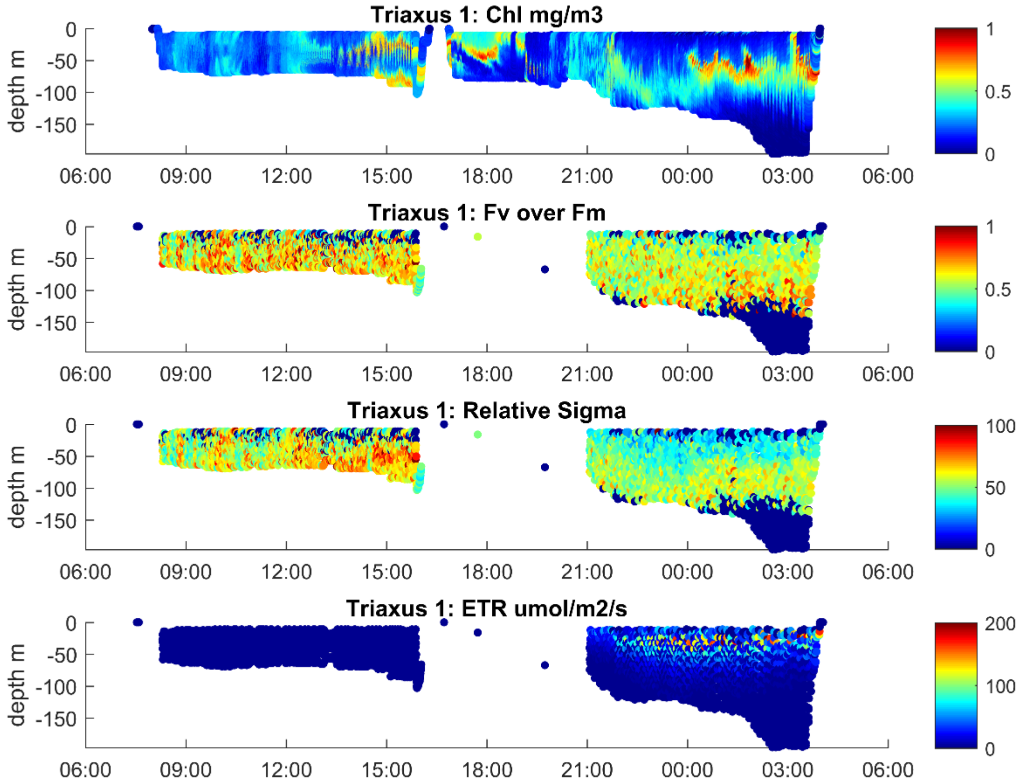


Triaxus undulating towed platform with labelled sensor array.

The first Triaxus deployment towed from 1800 1st September – 1400 2nd September in the Southern GBR from the Lagoon across the shelf. Raw data (SUNA to lab NO3 offset corrected) from the tow is displayed below.

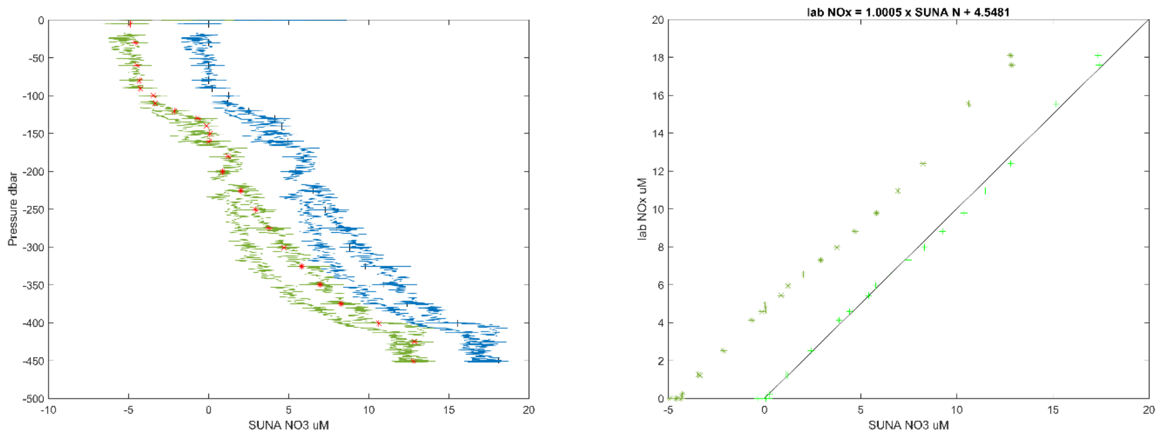

Triaxus 1: Temperature deg.C
Triaxus 1: Salinity -
Triaxus 1: Oxygen uM
Triaxus 1: Nitrate uM
depth m
0
-50
-100
-150
06:00
09:00
12:00
15:00
18:00
21:00
00:00
03:00
06:00
26
24
22
20
18
16
36
35.5
35
230
220
210
200
8
6
4
2
0


Triaxus 1: CDOM %
Triaxus 1: Transmisson %
Triaxus 1: Downwelling PAR uE/m2/s
Triaxus 1: Upwelling PAR uE/m2/s
depth m
0
-50
-100
-150
06:00
09:00
12:00
15:00
18:00
21:00
00:00
03:00
06:00
2
1
0
100
80
60
500
0
5
0



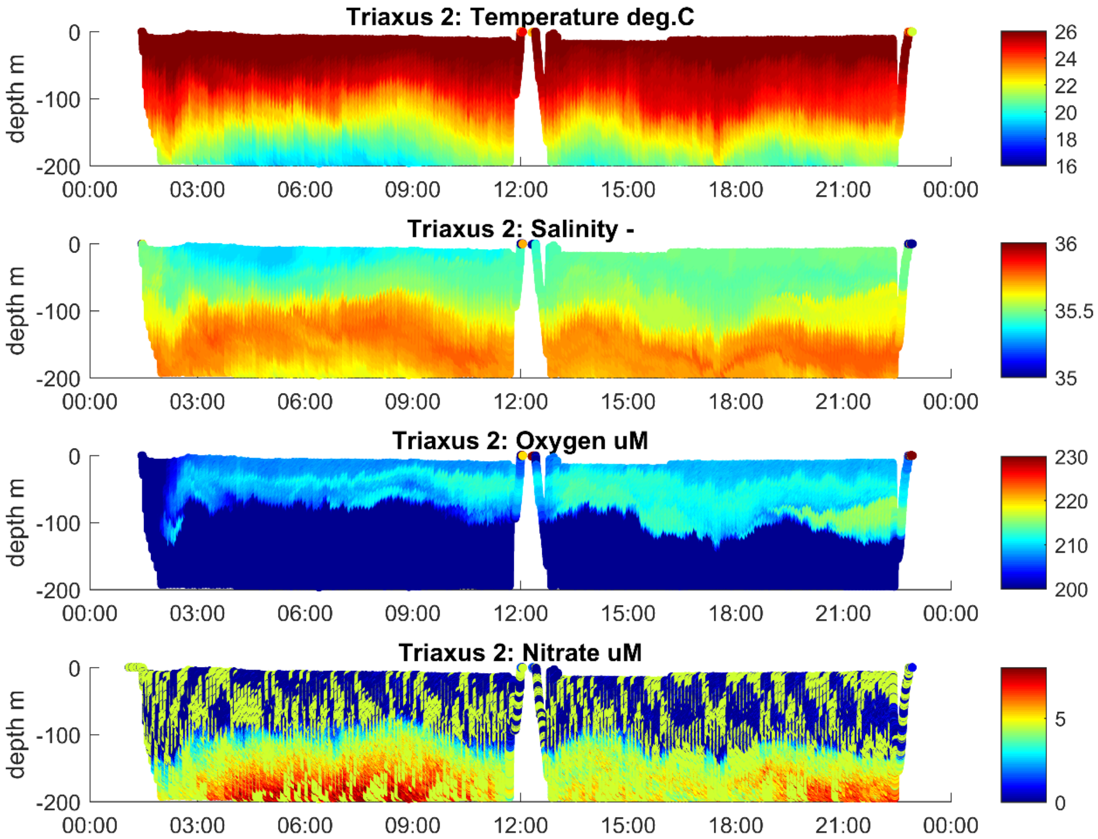
Plots show the evolution of water properties from shallow to deep water and from night to day time [note likely mismatch in chlorophyll and CDOM time/pressure vs CTD and mid tow interruption in FIRe data logging]. On the shelf the water was well mixed to the bottom with near zero nitrate

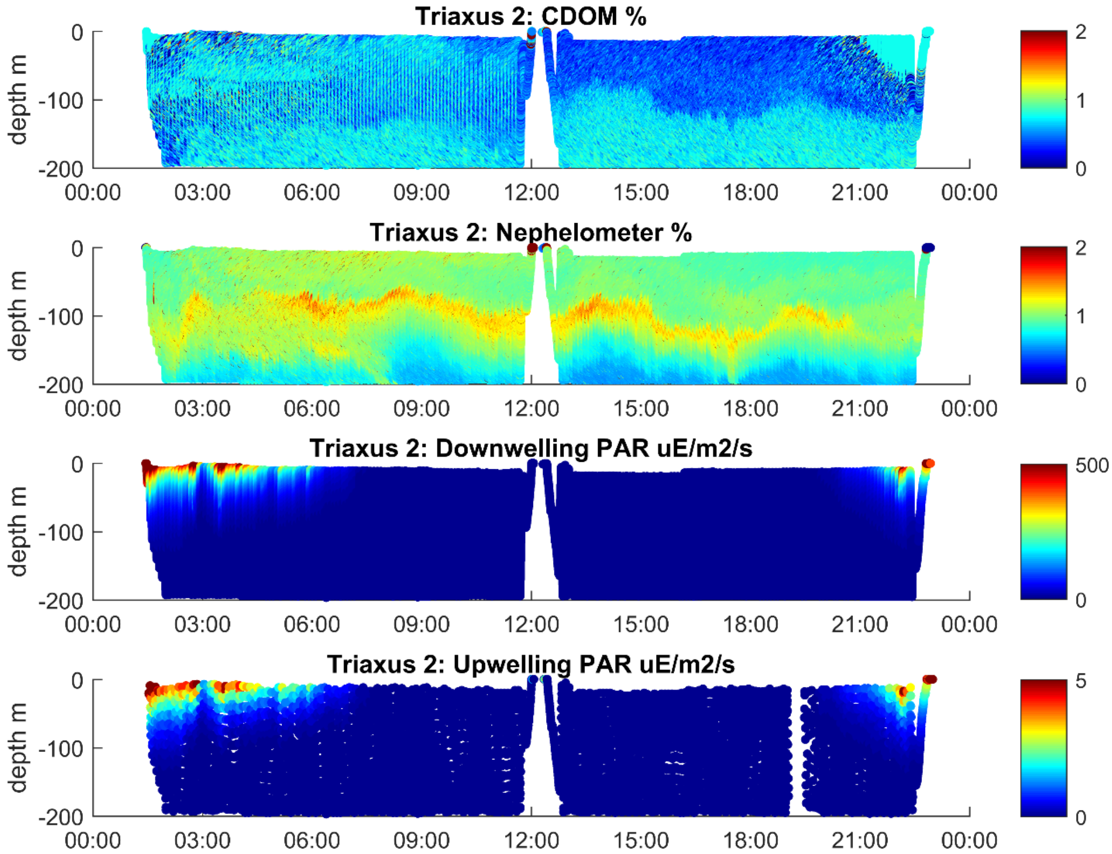
On 3rd October the Triaxus UV nitrate sensor (SUNA) was deployed on the CTD for calibration against hydrochemistry samples. The significant negative offset was effectively removed by post processing linear regression.

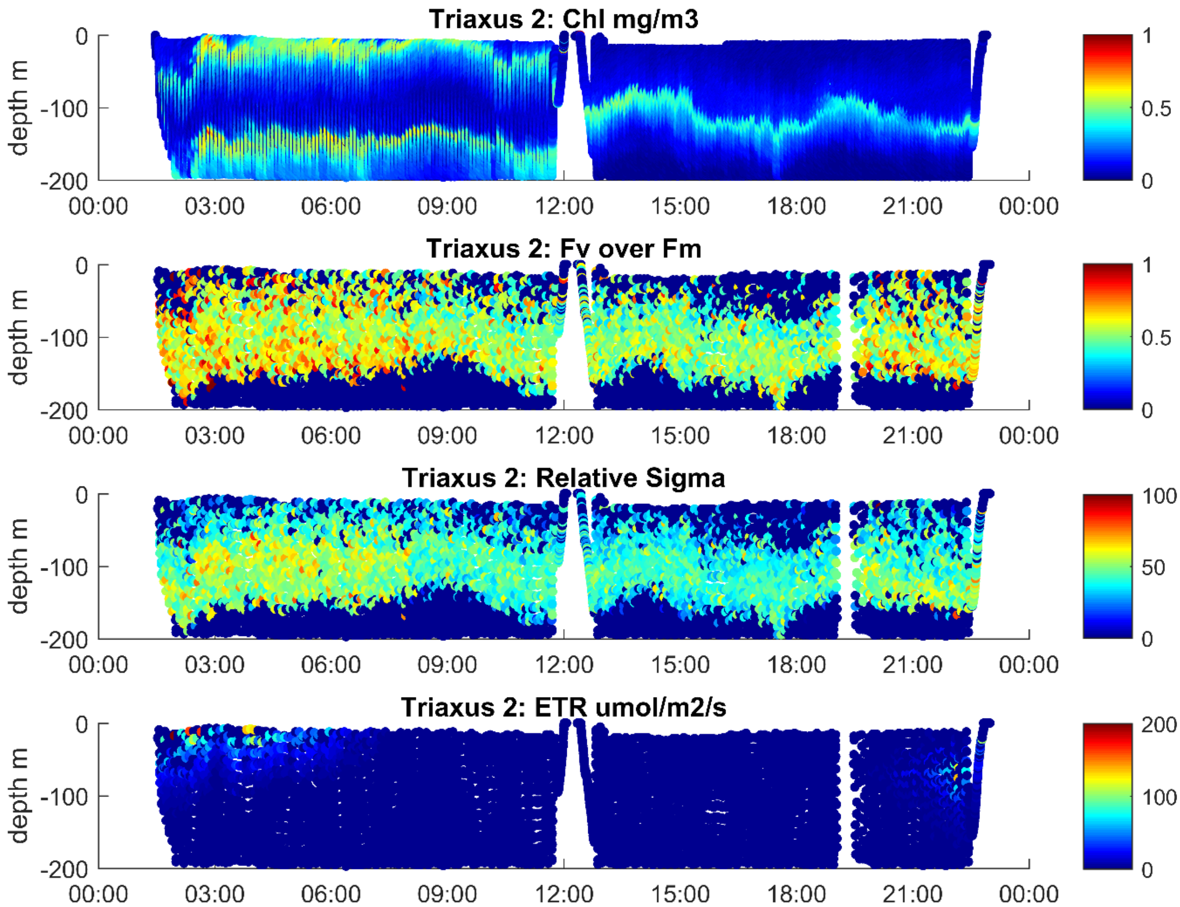


Left figure raw SUNA nitrate (green with red bottle depths on upcast), post processed nitrate (blue with lab nitrate in black). Right figure linear regression (olive green), corrected data (light green) fall on 1:1 line.

The second Triaxus tow commenced at 1130 on 4th October and proceeded northwest along the shelf edge in approximately 300-400m water. The tow finished at 0900 on 5th October due to slow progress against a strong EAC flowing southeast at 2 knots along the edge of the shelf.

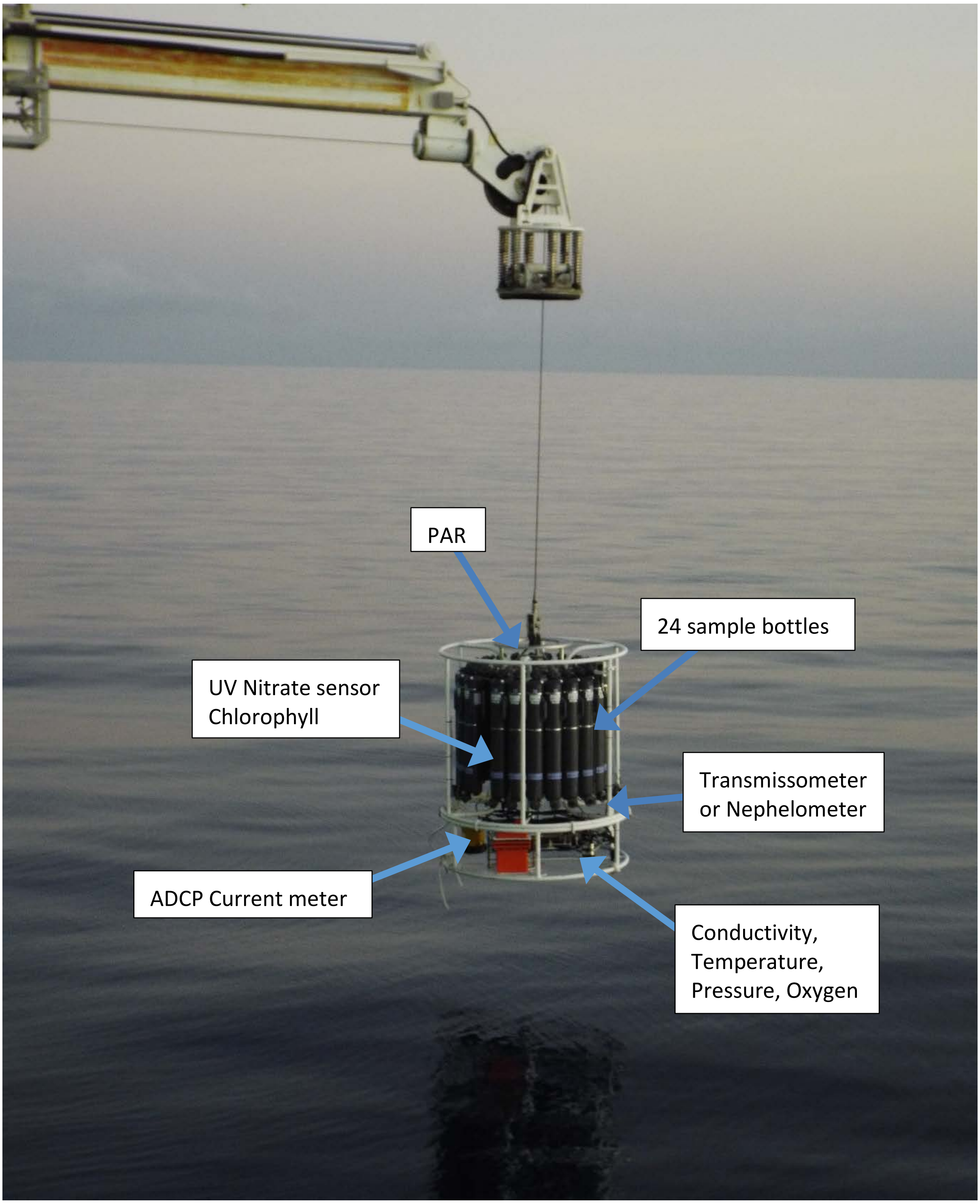

Triaxus 2: Temperature deg.C
depth m
0
-100
-200
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
26
24
22
20
18
16
Triaxus 2: Salinity -
36
35.5
35
Triaxus 2: Oxygen uM
230
220
210
200
Triaxus 2: Nitrate uM
5
0


Triaxus 2: CDOM %
Triaxus 2: Nephelometer %
Triaxus 2: Downwelling PAR uE/m2/s
Triaxus 2: Upwelling PAR uE/m2/s
depth m
0
-100
-200
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
2
1
0
500
5



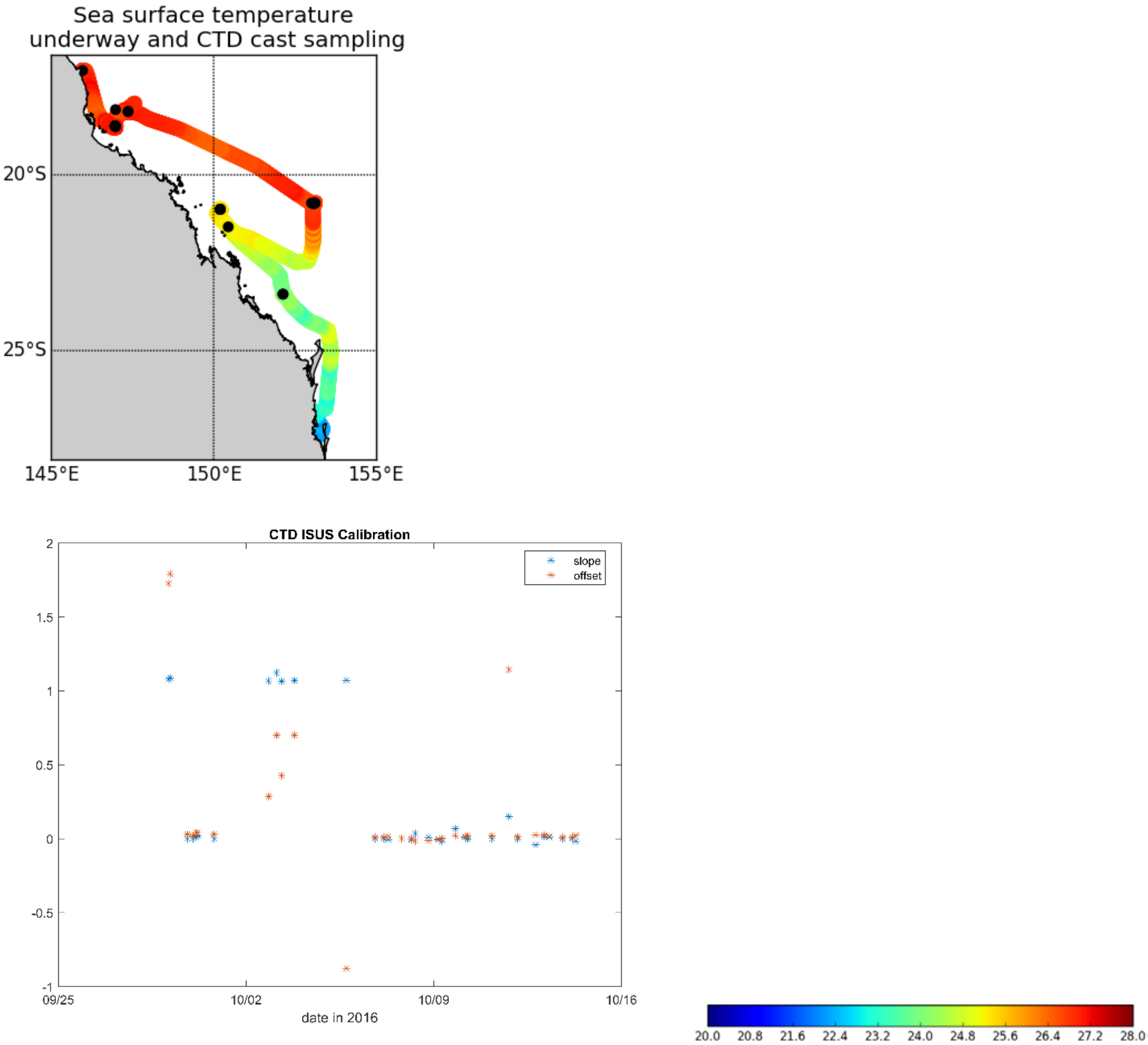
The second Triaxus tow shows the transition from day to night to day. There is a persistent thermocline marking the vertical transition in temperature, salinity, oxygen and nitrate concentration. In the plots of chlorophyll and CDOM the offset between Ecotriplet time/pressure and CTD pressure is clearly shown in the 1st segment of the tow. A more realistic subsurface chlorophyll maximum is observed in the 2nd segment of the tow.

2. CTD Rosette

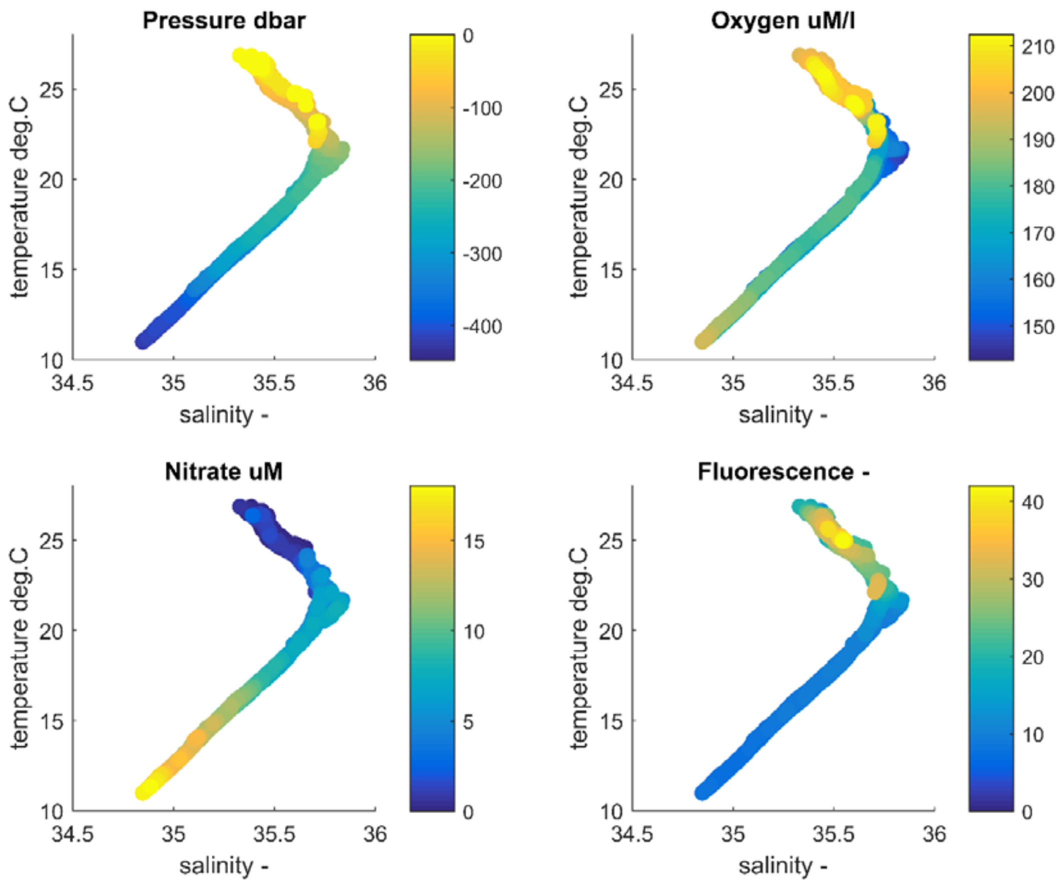


The CTD rosette platform lowers sensors vertically through the water column collecting digital information and, on the up-cast, water samples from selected depths.

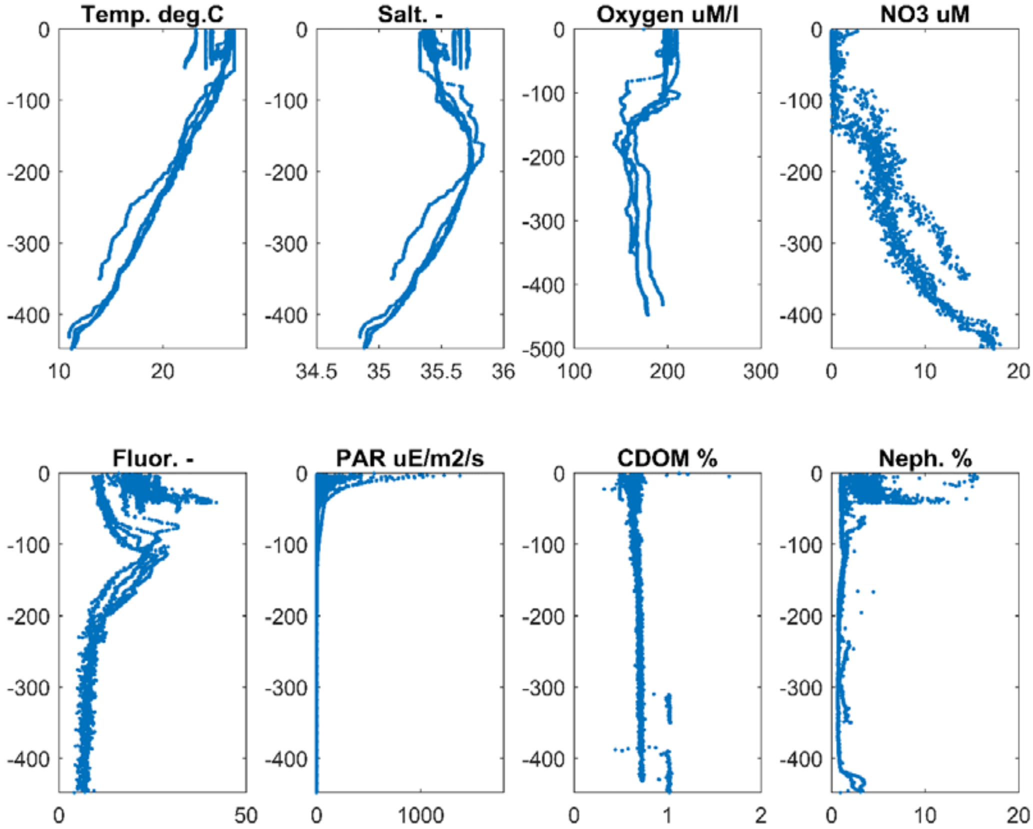
Nitrate hydrochemistry samples were used to calibrate the UV nitrate sensor (ISUS) which demonstrated variable offsets between casts. This variability, and occasional bizzare profile, appeared to be related to warm temperatures in the CTD room; when the unit was stored in the air conditioned lab prior to deployment systematic offsets were much reduced. Shallow water hydrochemistry samples frequently contained zero or near zero nitrate.



CTD station locations (left) and UV nitrate sensor calibration (right).



Summary temperature – salinity plots of all CTD data coloured by pressures, oxygen, nitrate and chlorophyll fluorescence. Shallow waters were characteristically warmer and less saline; there was a peak in salinity (35.8) and minima in oxygen (150uM/l) around 180m; deeper waters were cooler and less saline. Nitrogen was below detection limits in surface waters down to 70m; at greater depths nitrate increased to a maxima of 18 uM at 200m. Photosynthetically active radiation extended to 100m with subsurface chlorophyll maxima observed down to 110m. CDOM and turbidity varied between casts with higher values in surface and bottom waters.

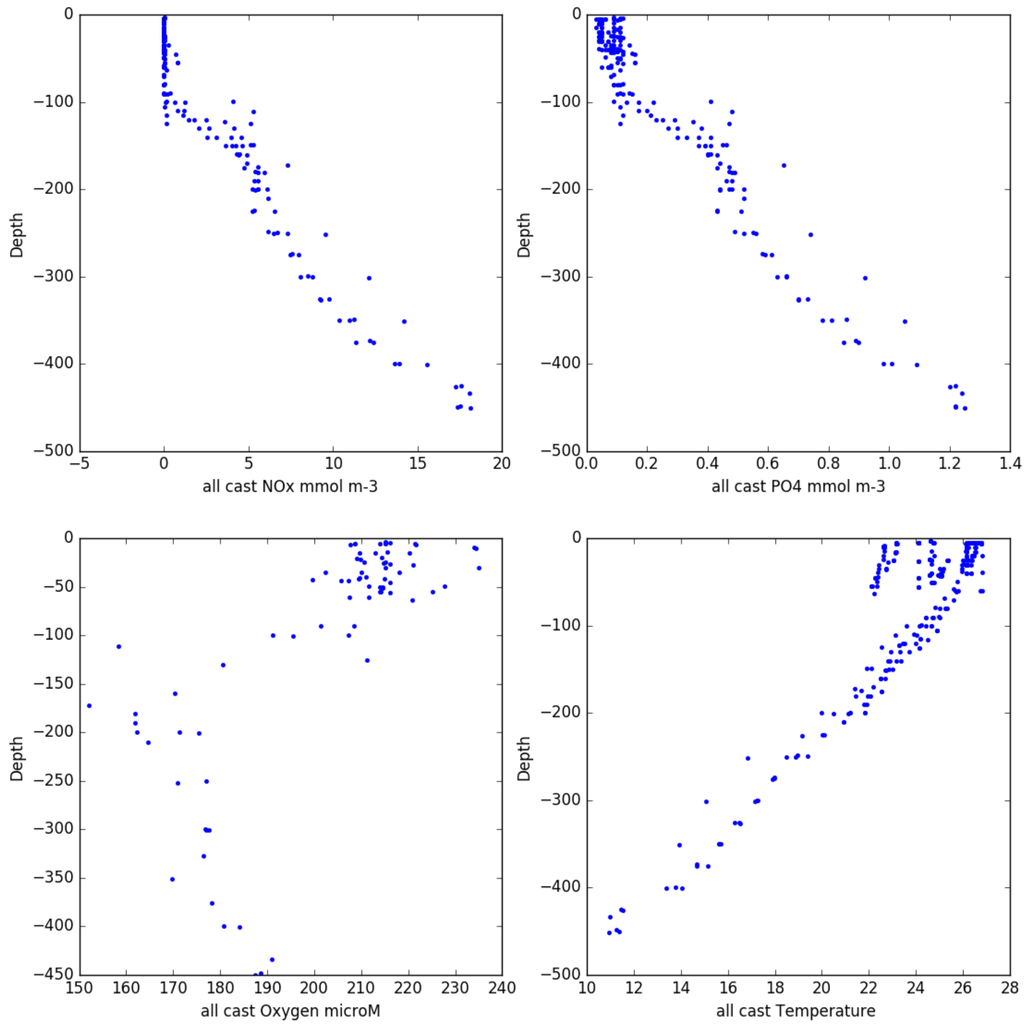


For each CTD cast, water samples were collected from the rosette sample bottles at various depths for hydrochemistry analysis including dissolved oxygen, nutrients (nitrate, nitrite, ammonia, phosphate, silicate) and salinity. Following training from the hydrochemistry team we were able to collect these samples with increasing confidence and accuracy. In addition samples were collected the midday cast for phytoplankton and pigment analysis. Specifically surface and subsurface chlorophyll maximum samples were filtered and preserved for subsequent HPLC pigment and flow cytometry analysis in the Hobart CSIRO Marine laboratory.

CTD samples taken and preserved for subsequent analysis.

CTD Cast	Date, time UTC	latitude	longitude	Hydrochem.	Pigments	Flow Cytometer	Carbon Chemistry
1	2016-09-28T07:17:39Z	-26.0538	153.5148	√			
2	2016-09-29T03:08:14Z	-23.4137	152.1342	√	√	√	
3	2016-09-29T04:28:38Z	-23.4152	152.1295	√			
4	2016-09-29T19:47:28Z	-21.4981	150.45	√			
5	2016-09-30T00:46:32Z	-20.9993	150.2012	√			
6	2016-09-30T03:36:13Z	-20.9934	150.203	√	√	√	
7	2016-09-30T04:48:46Z	-20.9893	150.207	√			
8	2016-09-30T19:44:02Z	-20.9996	150.1993	√			
9	2016-10-02T18:35:25Z	-20.8275	153.0666	√			
11	2016-10-02T20:58:56Z	-20.8276	153.065	√			√
12	2016-10-03T04:25:57Z	-20.8226	153.0887	√	√	√	
13	2016-10-03T09:18:29Z	-20.8162	153.1093	√			

CTD Cast	Date, time UTC	latitude	longitude	Hydrochem.	Pigments	Flow Cytometer	Carbon Chemistry
14	2016-10-03T11:40:23Z	-20.815	153.1118	√			
16	2016-10-03T20:37:53Z	-20.8167	153.1121	√			
17	2016-10-05T19:01:43Z	-18.1663	147.3695	√			
18	2016-10-06T19:44:28Z	-18.5822	146.9737	√			
19	2016-10-07T03:47:38Z	-18.5785	146.9734	√	√	√	
20	2016-10-07T07:46:57Z	-18.5786	146.9732	√			
21	2016-10-07T19:51:55Z	-18.5824	146.9715	√			
22	2016-10-08T04:22:13Z	-18.582	146.9715	√	√	√	
23	2016-10-08T07:56:40Z	-18.5853	146.9711	√			
24	2016-10-08T19:47:37Z	-18.589	146.9723	√			
25	2016-10-09T04:27:40Z	-18.601	146.984	√	√	√	
26	2016-10-09T08:00:08Z	-18.6032	146.9842	√			
27	2016-10-09T19:47:47Z	-18.5854	146.9812	√			
28	2016-10-10T04:24:37Z	-18.5848	146.9834	√	√	√	
29	2016-10-10T06:46:09Z	-18.5956	146.9878	√			
30	2016-10-11T04:30:22Z	-16.9523	145.9706	√	√	√	
31	2016-10-11T19:56:55Z	-18.4478	146.6703	√			
32	2016-10-12T03:45:53Z	-18.4425	146.6809	√	√	√	
33	2016-10-12T19:56:44Z	-18.6268	146.9788	√			
34	2016-10-13T03:27:51Z	-18.6245	146.9792	√	√	√	
35	2016-10-13T08:01:43Z	-18.6244	146.9788	√			
36	2016-10-13T19:51:47Z	-18.6169	146.9771	√			
37	2016-10-14T04:28:20Z	-18.6173	146.9764	√	√	√	
38	2016-10-14T07:50:19Z	-18.62	146.9769	√			



Hydrochemistry water quality profiles from the CTD casts (bottle samples**).**

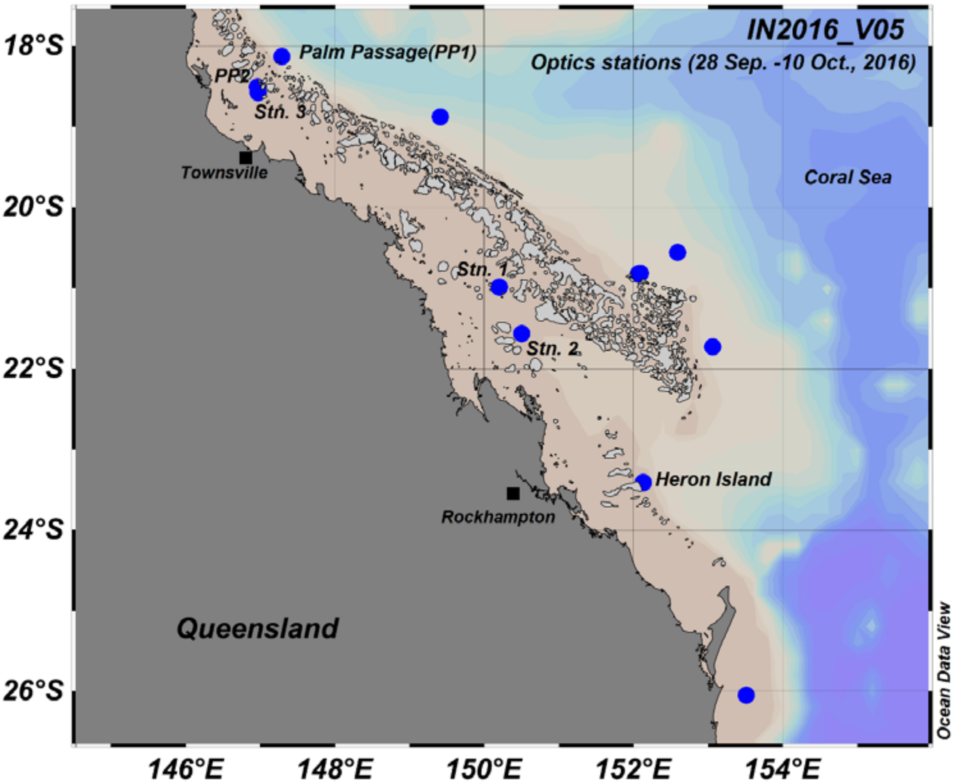
3. CTD with AOP Optics

Rationale:

Bio-optical properties were measured in coastal and oceanic waters around the Great Barrier Reef region to improve

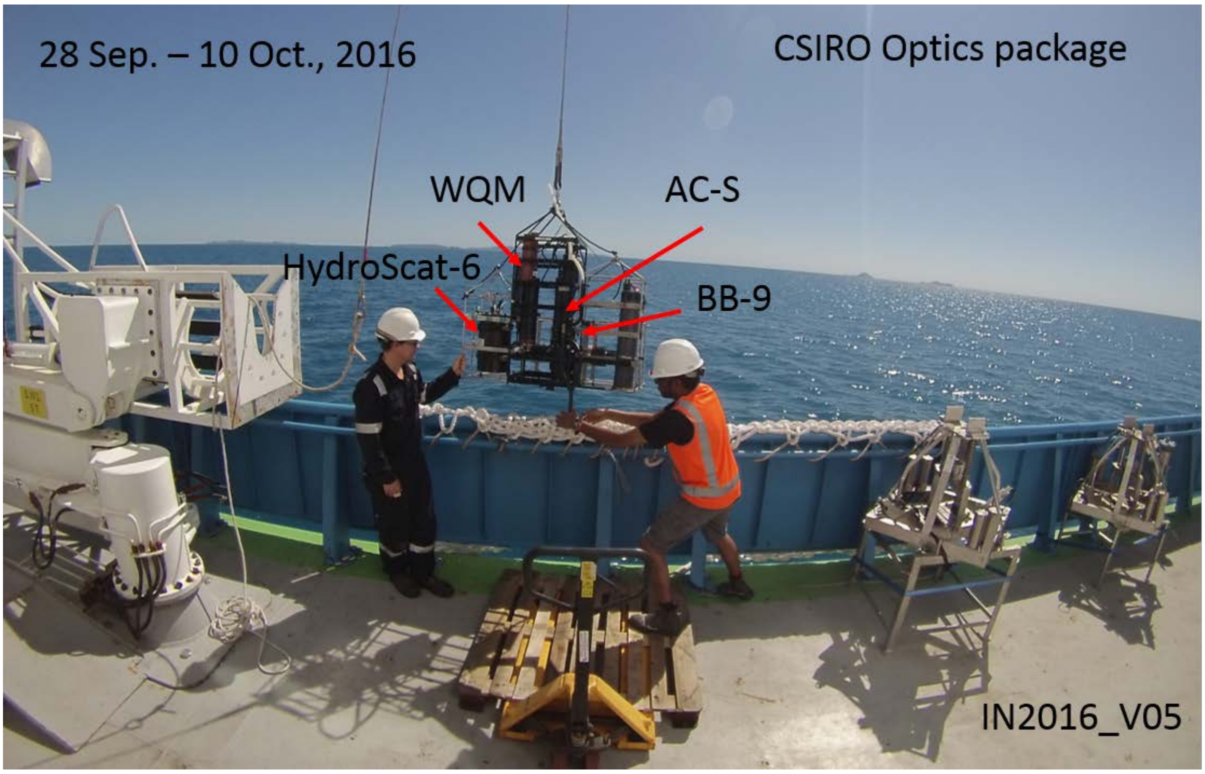
regional optical models used in ecosystem and remote sensing models.

Measurement locations (28 September – 10 October, 2016):



For the first time, in this cruise optical properties of Coral Sea water were measured. Previous studies mainly focussed on the coastal waters of the GBR region. In this voyage both inherent and apparent optical properties of Coral Sea and reef waters were measured. These measurements will fill the existing bio-optical knowledge gap in this region.

Optics instruments used:



IOP kit:
AC-S: light absorption and attenuation (a and c, 1/m)
BB-9 : light backscattering (bb , 1/m)
WQM: temperature, Salinity and depth
HydroScat-6: light backscattering (bb , 1/m)

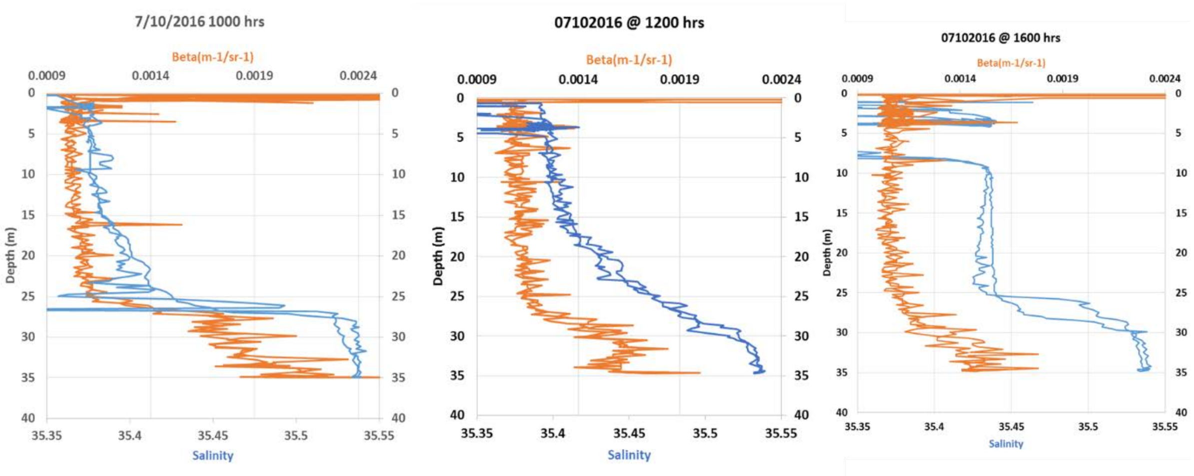
Bio-optical properties measured using the IOP kit will provide information about the variability of inherent optical properties along the water column. Such information could be used to improve optical models used in ecosystem and remote sensing models.

Water sampling:
Table below indicates the locations where water was collected for filtration. Water samples will be analysed for phytoplankton pigments, total suspended sediment concentrations, absorption due to particulate and CDOM absorption, concentrations of dissolved and total organic carbon.

DateUTC	TimeUTC	Lat	lon	sampleID	TSS	HPLC	PABS	CPC	CDOM	DOC	TOC
29092016	0250	-23.41	152.13	CTD02	√	√	√	√	√	√	√
30092016	0330	-20.99	150.2	CTD06	√	√	√	√	√	√	√
01102016	0400	-21.57	150.5	FT01	√	√	√	√	√	√	√
02102016	0400	-21.73	153.06	FT02	√	√	√	√	√	√	√
03102016	0330	-20.82	152.09	CTD12	√	√	√	√	√	√	√
04102016	0100	-20.56	152.59	FT-03	√	√	√	√	√	√	√
05102016	0436	-18.88	149.41	FT-4	√	√	√	√	√	√	√
05102016	2230	-18.51	146.96	PP1	√	√	√	√	√	√	√
06102016	0400	-18.13	147.29	PP2	√	√	√	√	√	√	√
07102016	0330	-18.58	146.97	CTD19	√	√	√	√	√	√	√
08102016	0400	-18.58	146.97	CTD22	√	√	√	√	√	√	√
09102016	0400	-18.58	146.97	CTD25	√	√	√	√	√	√	√

Water samples collected in this voyage were sampled and preserved following ocean optics protocols. Samples will be analysed at a later time in CSIRO Hobart and Adelaide analytical services labs.

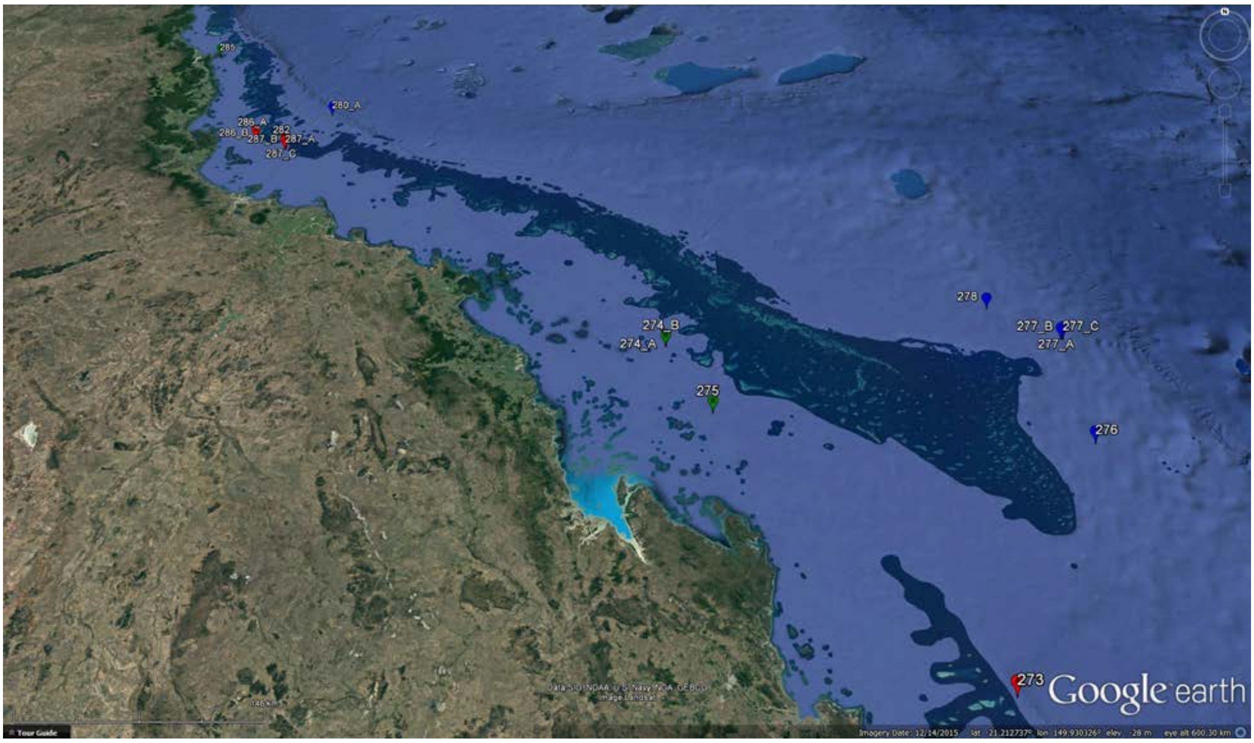
Preliminary results:
Below are some preliminary results from WQM sensor which shows the response of particulate backscattering to changes in the water column structure. Plots were prepared using data collected at station 3 (1000, 1200 and 1600 hours).

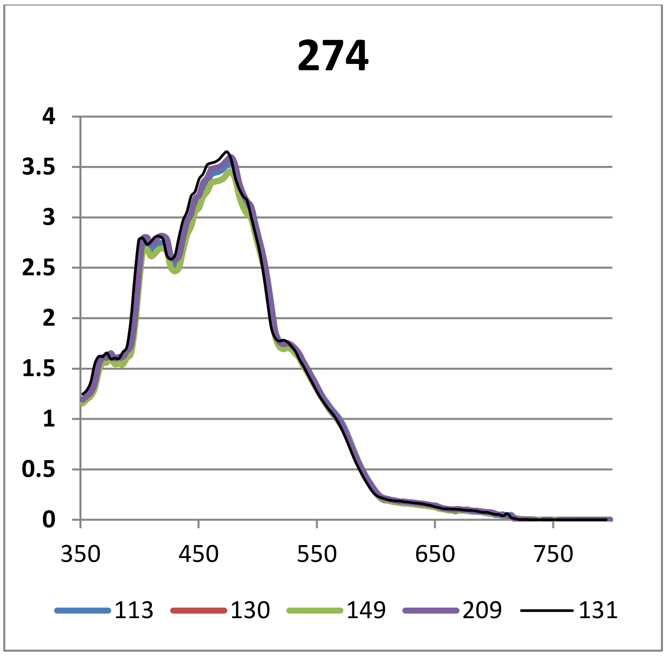


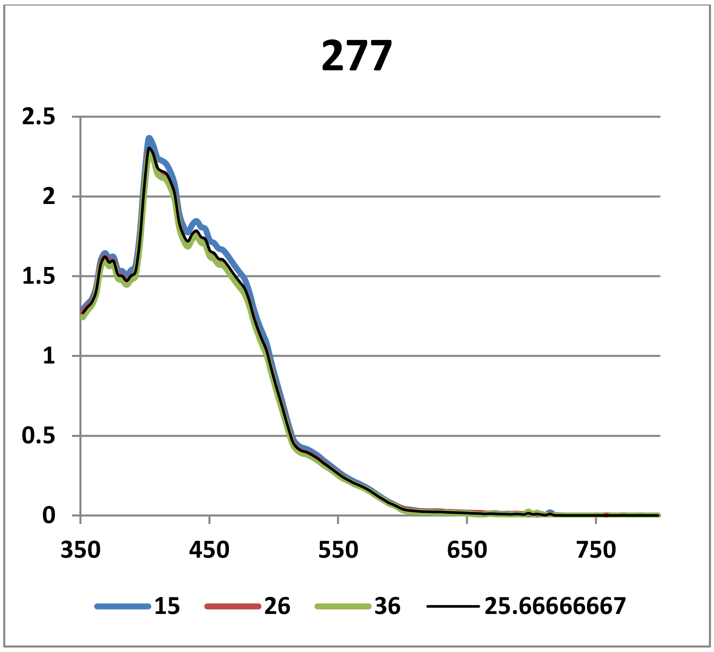
4. CTD with IOP Optics (Hyperpro II)

Charles Kovach from NOAA hand deployed Satlantic Hyperpro II optical profiling CTD that measures up and downwelling spectral radiance from the stern of the vessel coincident with CTD and optical casts. Multiple sets of 3 casts were either completed to 10m or 30m depending on local sea state and current.

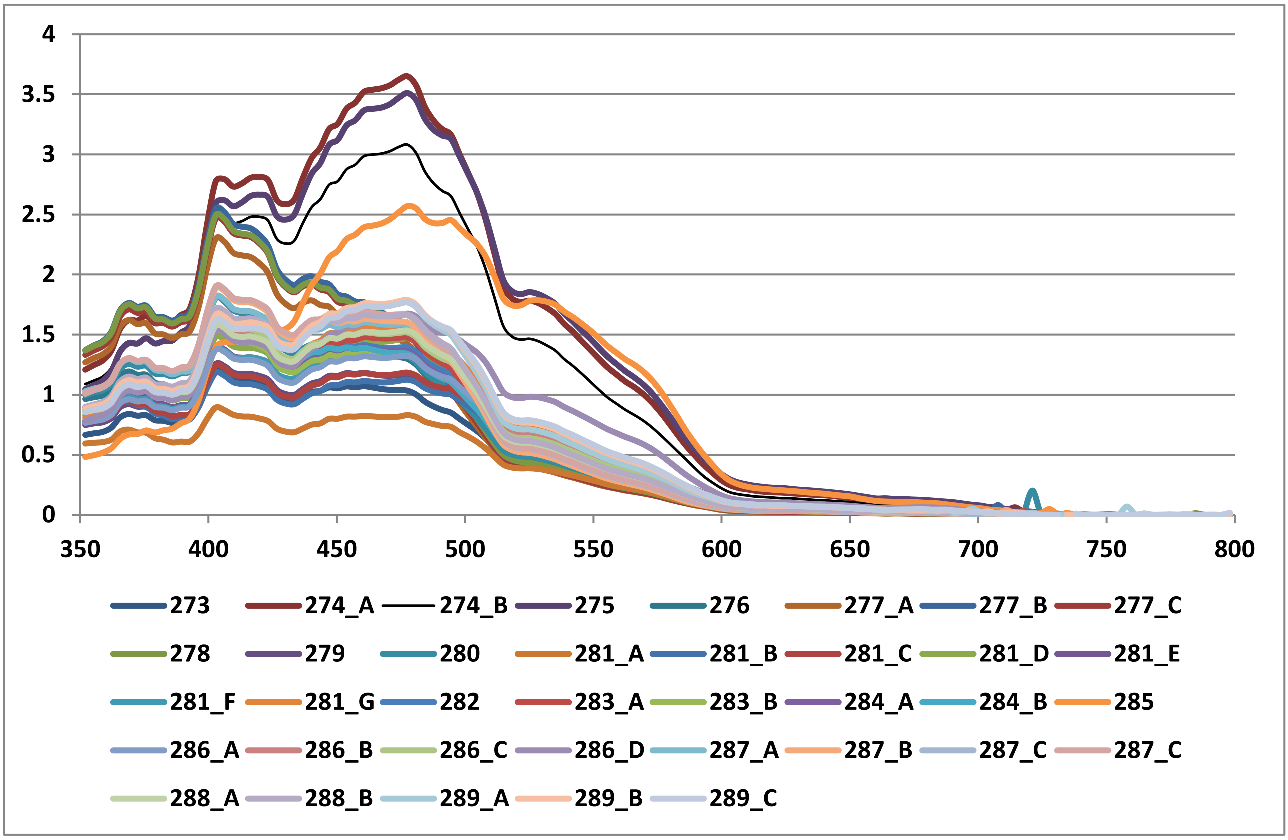
Station positions colour coded by water type (blue = oceanic; green = coastal; red = mixed).


285
280_A
286_A
286_B
282
287_B
287_A
287_C
278
274_B
274_A
277_B
277_C
277_A
275
276
273
Google earth

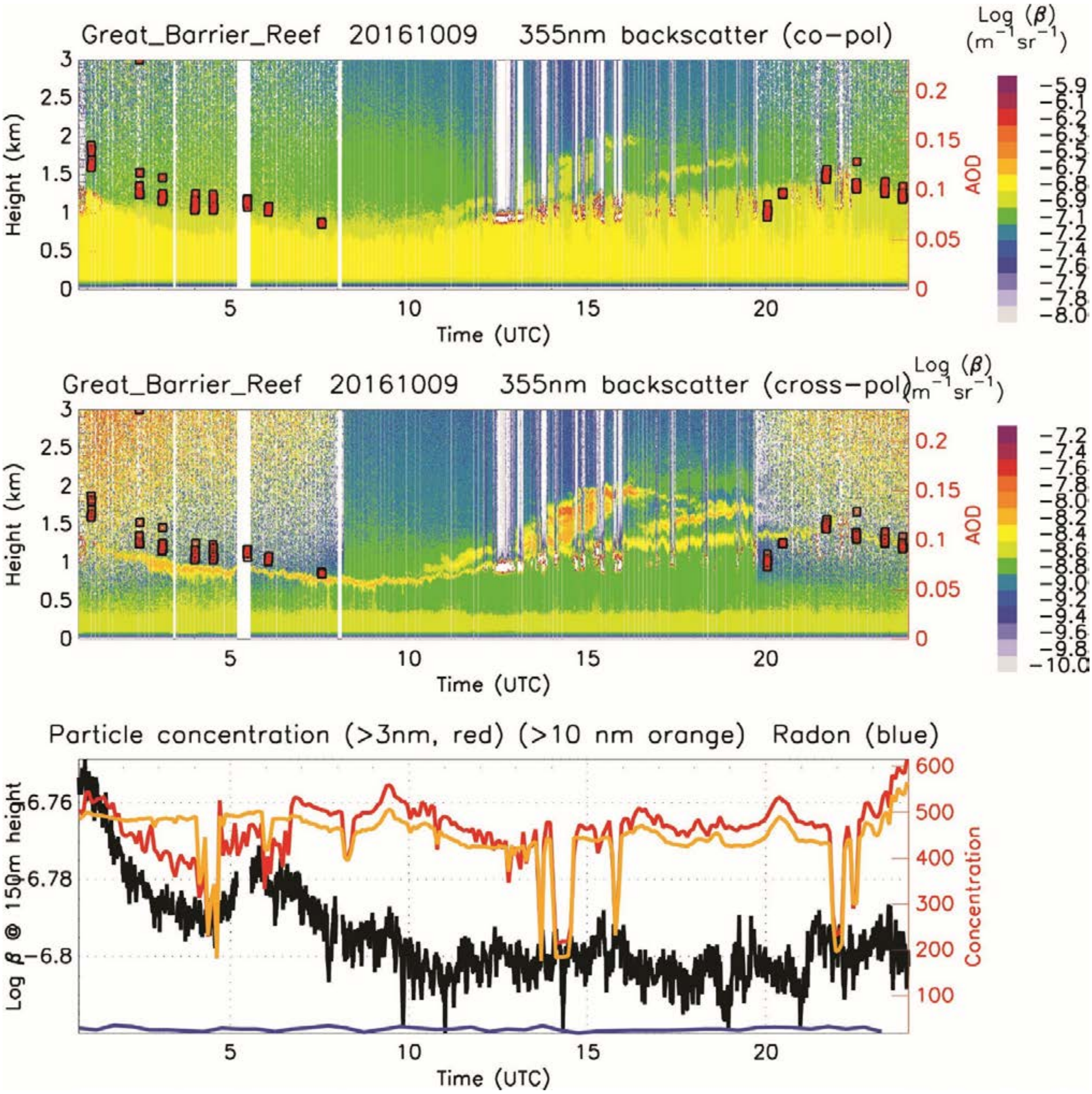

274
4
3.5
3
2.5
2
1.5
1
0.5
0
350
450
550
650
750
113
130
149
209
131



Example spectral water leaving radiance for a coastal site (Station 1, left) and an oceanic site (Station 2, right).

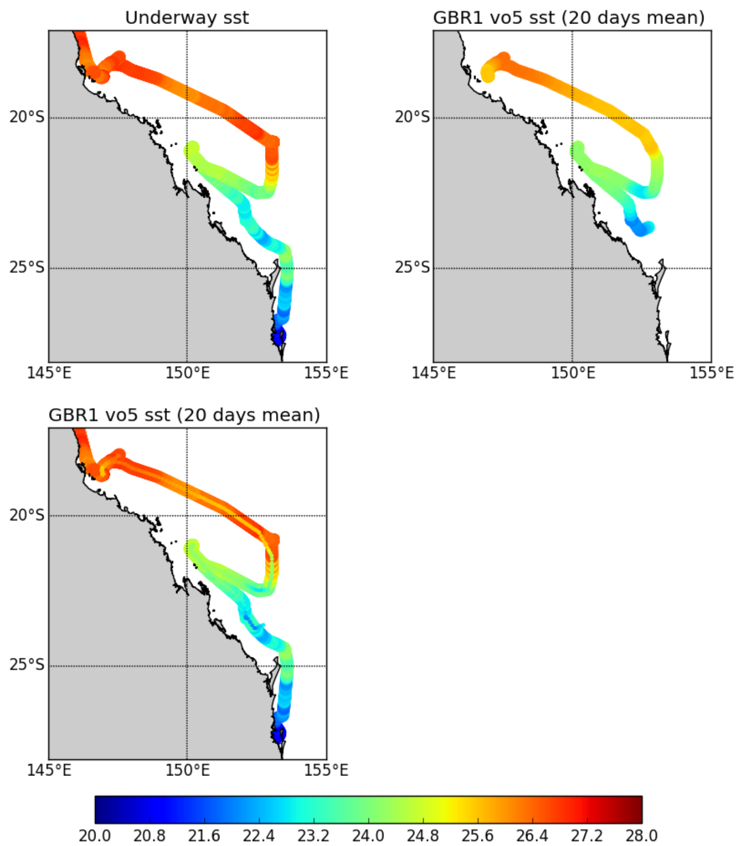


All the spectral water leaving radiance data on the voyage to date. This plot shows the range of water types encountered and cloud conditions at the time of the observation.

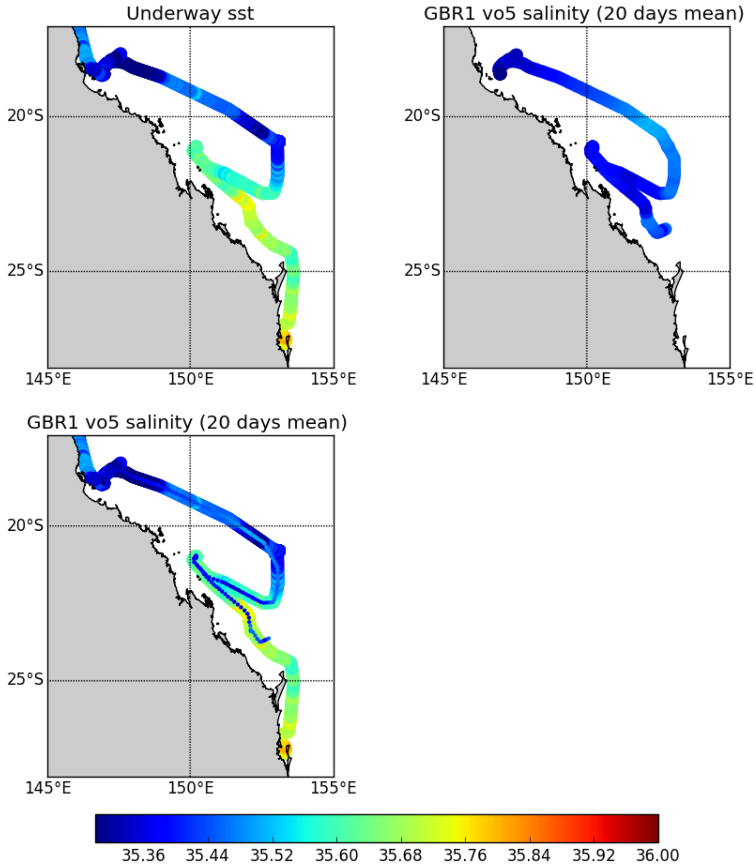


Aerosol optical density as measured with a Microtops hand held sun photometer (red patches) plotted over atmospheric backscatter (from lidar) and particle concentrations as measured on the 9th October 2016. Striping denotes strong atmospheric features and contrasting layers of aerosols.

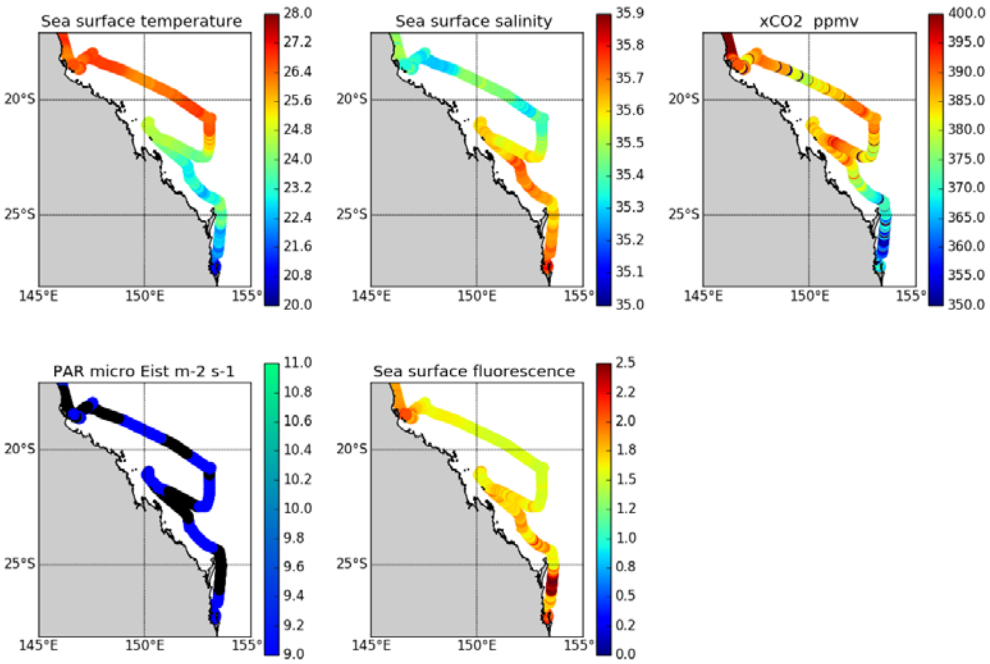
1. Underway



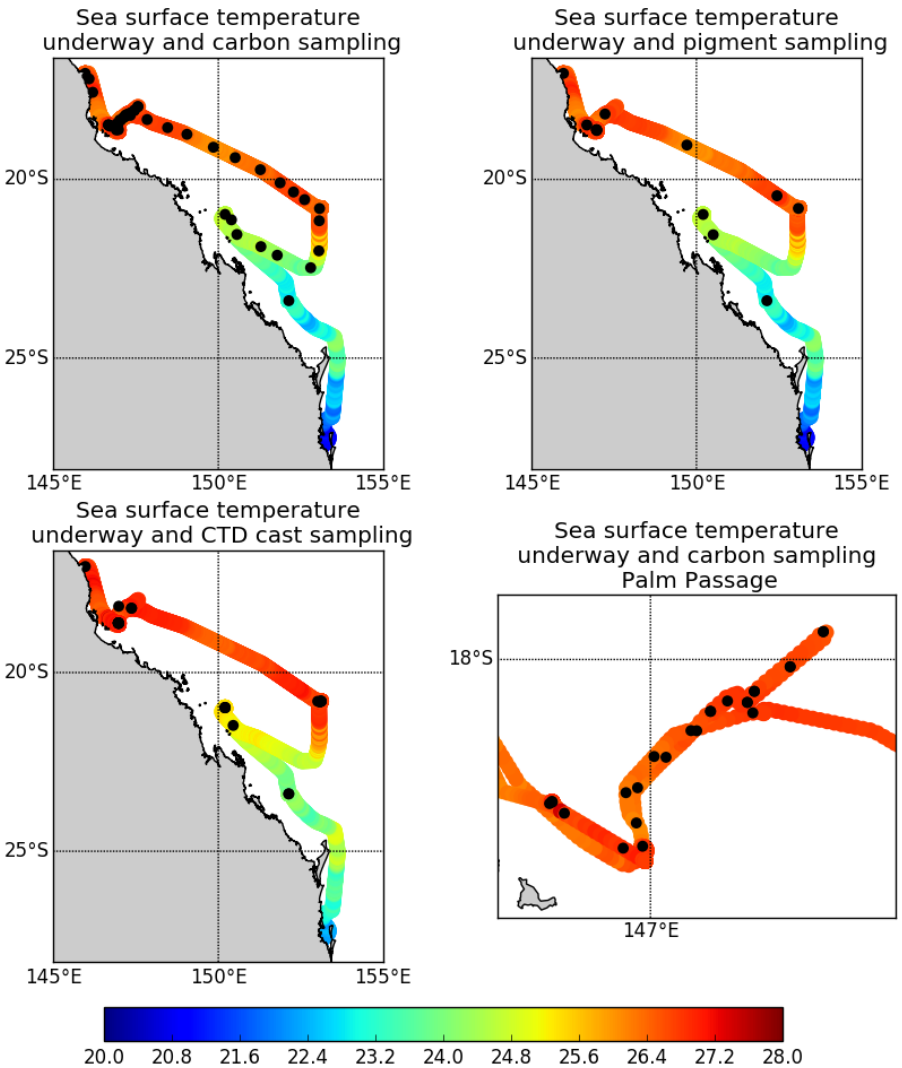
Ship underway temperature (unprocessed, broad line) and simulated surface salinity in the GBR 1km V05 model (using a 20-day average for the model, thin line), generated with script ‘ship_underway_gbr1Vo5.py’.



Ship underway salinity (unprocessed, broad line) and simulated surface salinity in the GBR 1km V05 model (using a 20-day average for the model, thin line) generated with script 'ship_underway_gbr1Vo5.py'.



Ship underway observations (unprocessed), generated with script 'plot_underway_netcdf.py'.



Locations of the different observation stations, underway, carbon bottle sample, pigment sampling and CTD casts ('plot_sampling_location.py').

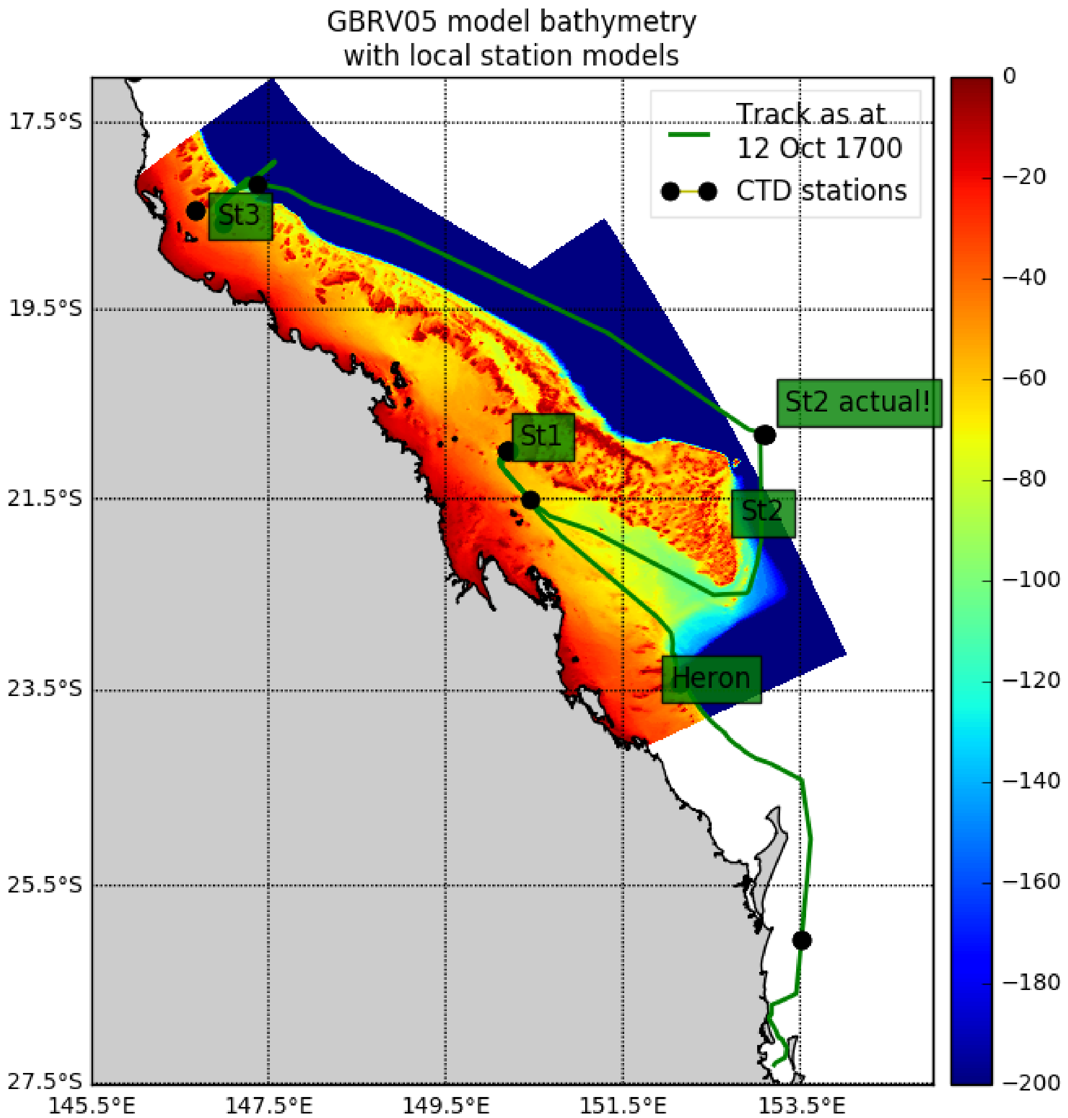
Underway samples taken and preserved for laboratory analysis.

date UTC	time UTC	latitude	longitude	Carbon Chemistry	Pigments	Flow Cytometry
26/09/2016	3:18	-23.4137	152.134	√		
30/09/2016	3:49	-20.9928	150.2036	√		
1/10/2016	1:15	-21.1467	150.5065	√		
1/10/2016	4:16	-21.568	151.5065	√	√	√
1/10/2016	9:20	-20.9021	151.2894	√		
1/10/2016	13:24	-22.144	15.784	√		
1/10/2016	21:07	-22.4935	152.7957	√		
2/10/2016	1:31	-22.021	153.044	√		
2/10/2016	7:40	-21.173	153.055	√		
4/10/2016	0:57	-20.5747	152.6123	√		
4/10/2016	3:00				√	√
4/10/2016	4:49	-20.3584	152.2763	√		
4/10/2016	9:13	-20.097	151.87	√		

date UTC	time UTC	latitude	longitude	Carbon Chemistry	Pigments	Flow Cytometry
4/10/2016	15:20	-19.7232	15.273	√		
4/10/2016	22:02	-19.379	151.51	√		
5/10/2016	2:14	-19.0811	149.85	√		
5/10/2016	3:00				√	√
5/10/2016	6:32	-18.71	149.05	√		
5/10/2016	10:14	-18.519	148.465	√		
5/10/2016	14:41	-18.286	147.845	√		
5/10/2016	19:29	-18.1657	147.334	√		
5/10/2016	20:29	-18.2208	147.1322	√		
5/10/2016	21:56	-18.4132	146.92	√		
5/10/2016	1:26	-18.507	146.954	√		
6/10/2016	0:12	-18.3979	146.958	√		
6/10/2016	1:13	-18.3034	147.0507	√		
6/10/2016	2:16	-18.2213	147.151	√		
6/10/2016	3:22	-18.1289	147.2513	√	√	√
6/10/2016	4:49	-18.1332	147.3161	√		
6/10/2016	5:50	-18.0225	147.456	√		
6/10/2016	6:47	-17.9136	147.564	√		
6/10/2016	8:12	-18.099	147.339	√		
6/10/2016	9:09	-18.161	147.196	√		
6/10/2016	10:36	-18.3011	147.0119	√		
9/10/2016	23:38	-18.579	146.9745	√		
11/10/2016	3:50	-16.9528	145.97	√		
11/10/2016	6:45	-17.1111	146.0849	√		
11/10/2016	9:23	-17.5	146.197	√		
11/10/2016	21:23	-18.447	146.6708	√		
12/10/2016	2:56	-18.442	146.68	√		
12/10/2016	6:10	-18.44	146.678	√		
12/10/2016	6:43	-18.4769	146.7191	√		
12/01/2016	8:23	-18.585	146.911	√		
14/10/2016	4:23	-18.6172	146.976	√		
15/10/2016	3:01	-18.611	146.9817	√		

Summary of Model Runs

During the voyage we ran the local Heron model, RECOM models for Stations 1, 2 and 3 in trike on dino. These fine-scale models were nested in the central GBR 1km model which was run on the servers in Melbourne with daily shore to ship upload of output and forcing files for the local model. All models were fully resolved 3D models with hydrodynamics, sediment, biogeochemistry and optical processing.

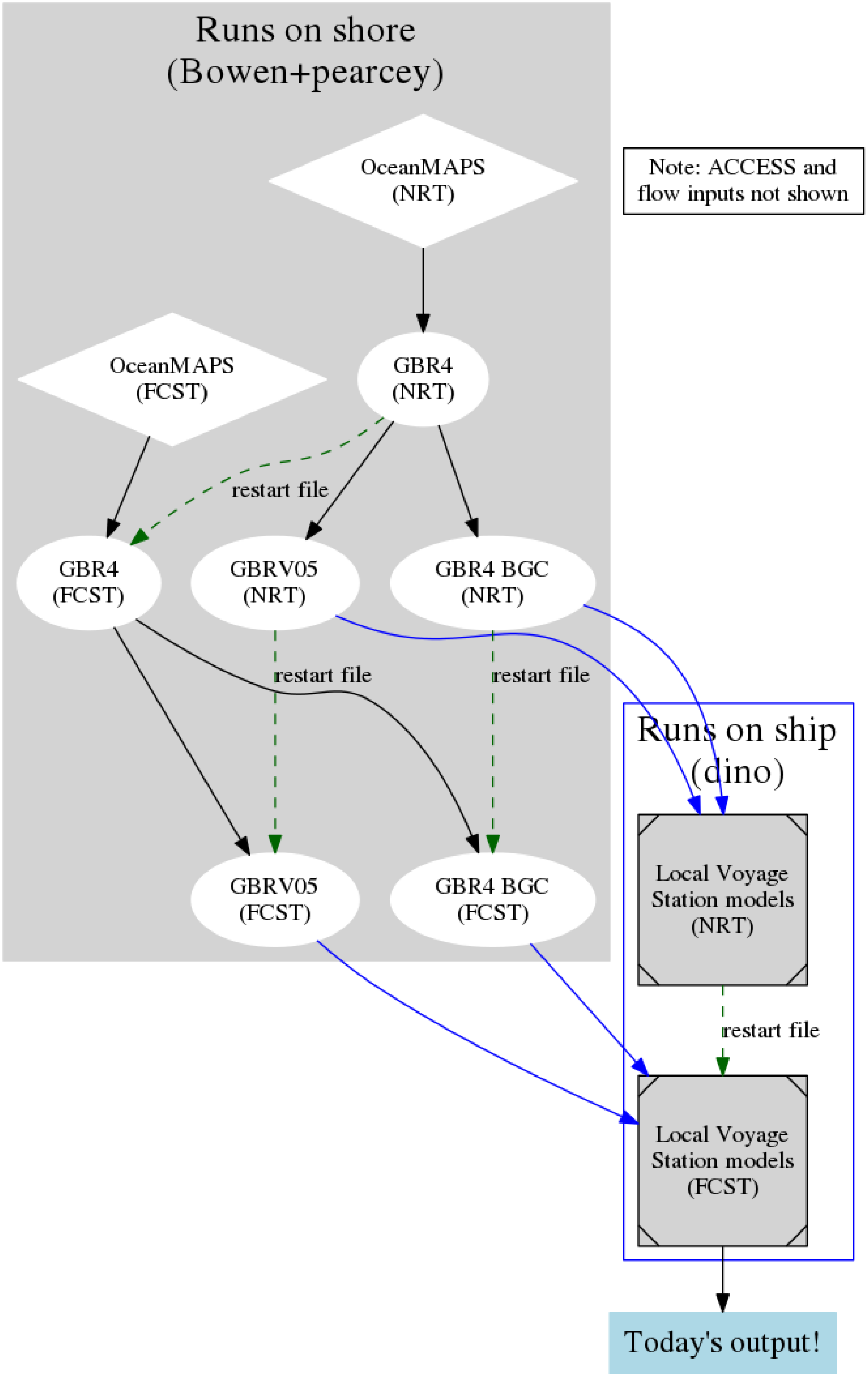


GBRV05 model bathymetry
with local station models
Track as at
12 Oct 1700
CTD stations
St3
St1
St2
St2 actual!
Heron
17.5°S
19.5°S
21.5°S
23.5°S
25.5°S
27.5°S
145.5°E
147.5°E
149.5°E
151.5°E
153.5°E
0
−20
−40
−60
−80
−100
−120
−140
−160
−180
−200

Mechanics of the Modelling infrastructure

This is the overall modelling schematic showing the various dependencies (restart files) and model hierarchy in terms of run-time order

Blue lines indicate file transfers to the ship

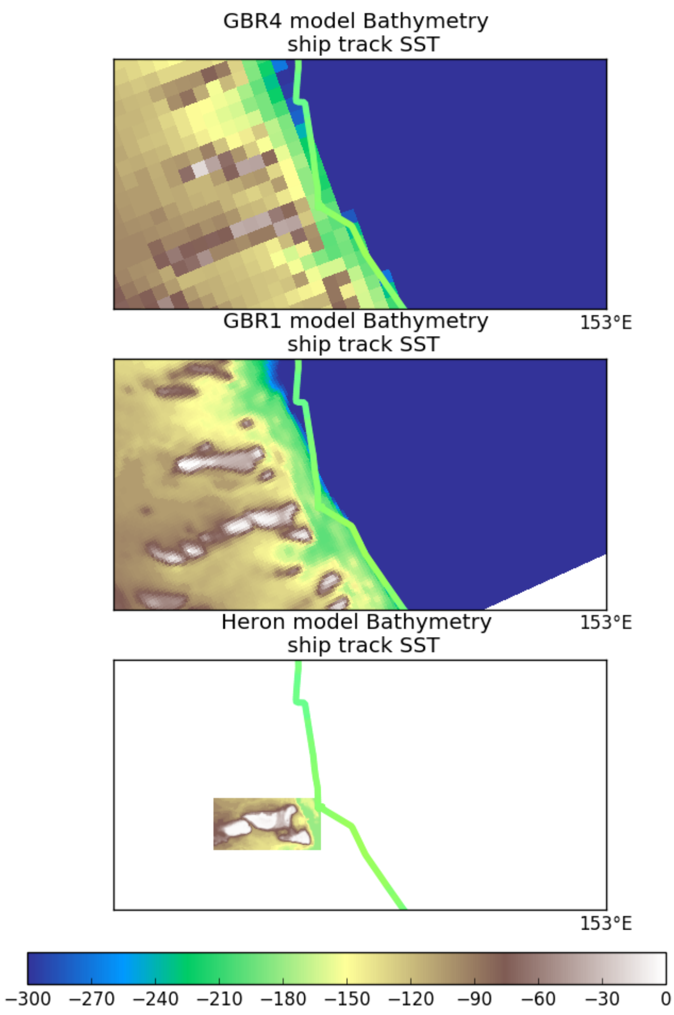


Daily tasks included:

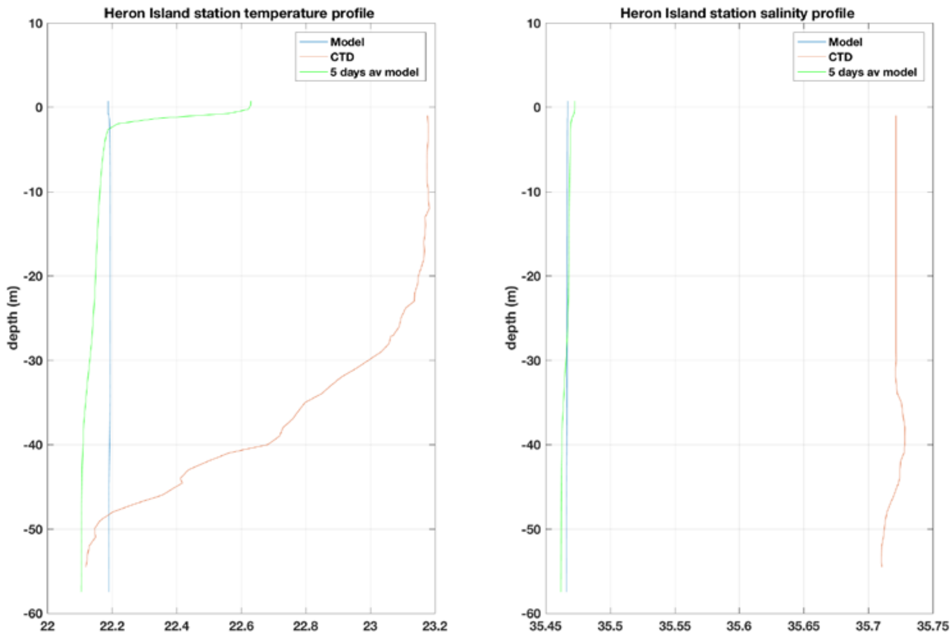
1. Get latest ACCESS file
2. Get latest hydro/bgc for whichever cycle (nrt/fcst) it is, transfer across and concatenate/create links
3. Set off local model(s) in Trike
4. Underway: (see below), round trip for data files and plotting is automated
5. Triaxus/CTD plotting on an as-needed basis

These tasks can be automated but because the plan can change on a daily basis and we don't necessarily need the local models to run after we've left the station, they were done manually. This also saved debug time (and damage control) should things go awry.

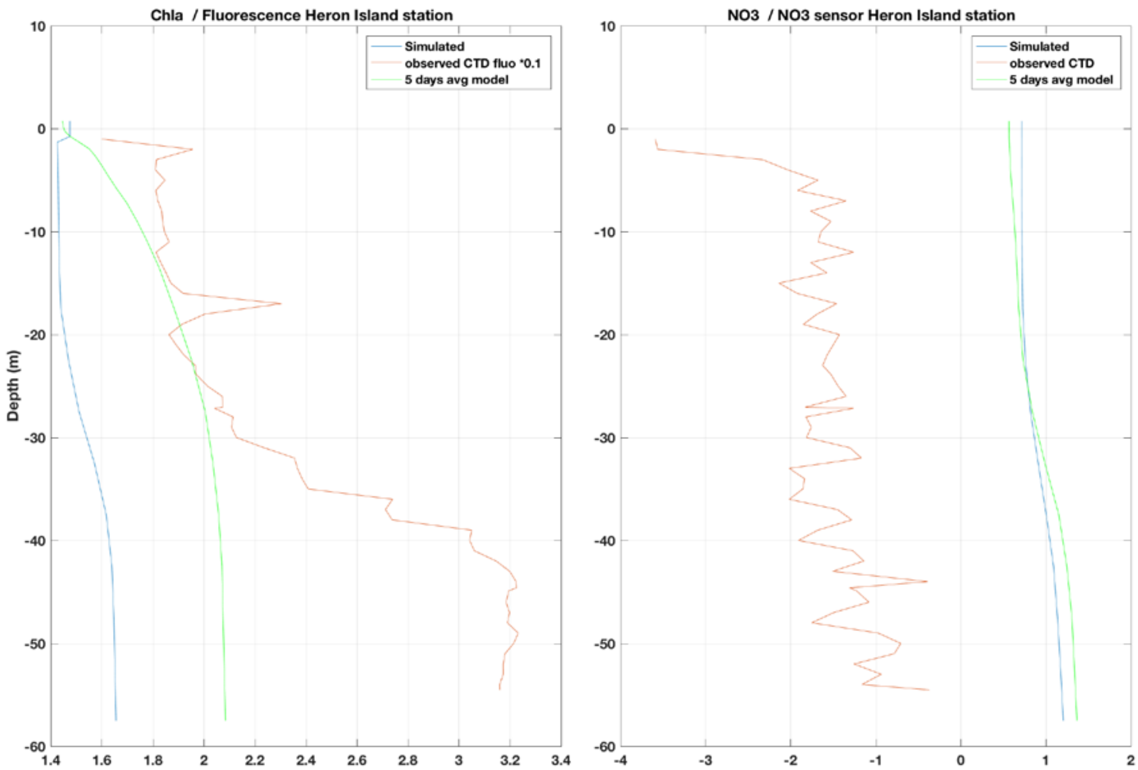
Heron Island Model



Comparison of eReefs GBR4, GBR1 and Heron Island Reefs model bathymetry and IN_2016 _V05 ship track position.

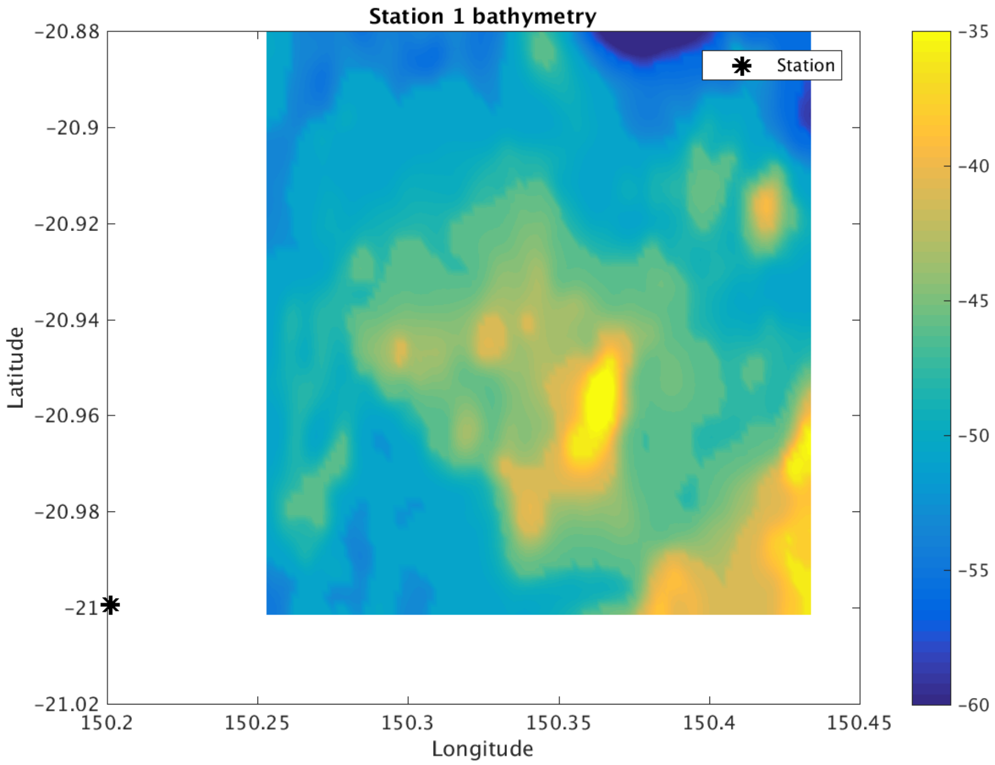


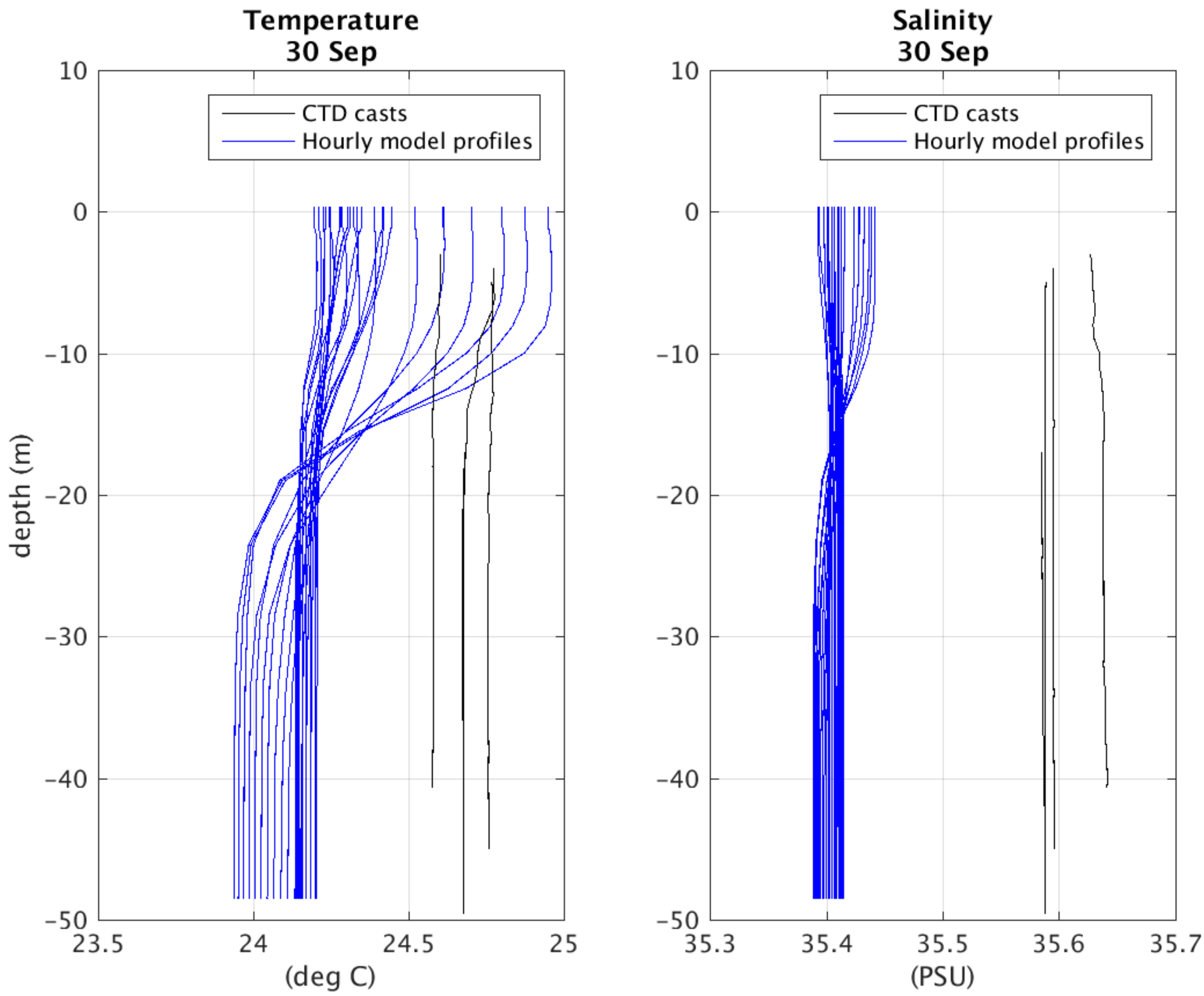
Simulated (blue and green lines) and unprocessed CTD observations (red lines) temperature (left) and salinity (right) profiles, Heron Island station (29th Sept 2016 CTD 2). Green lines show a 5 days average of the simulated profile.



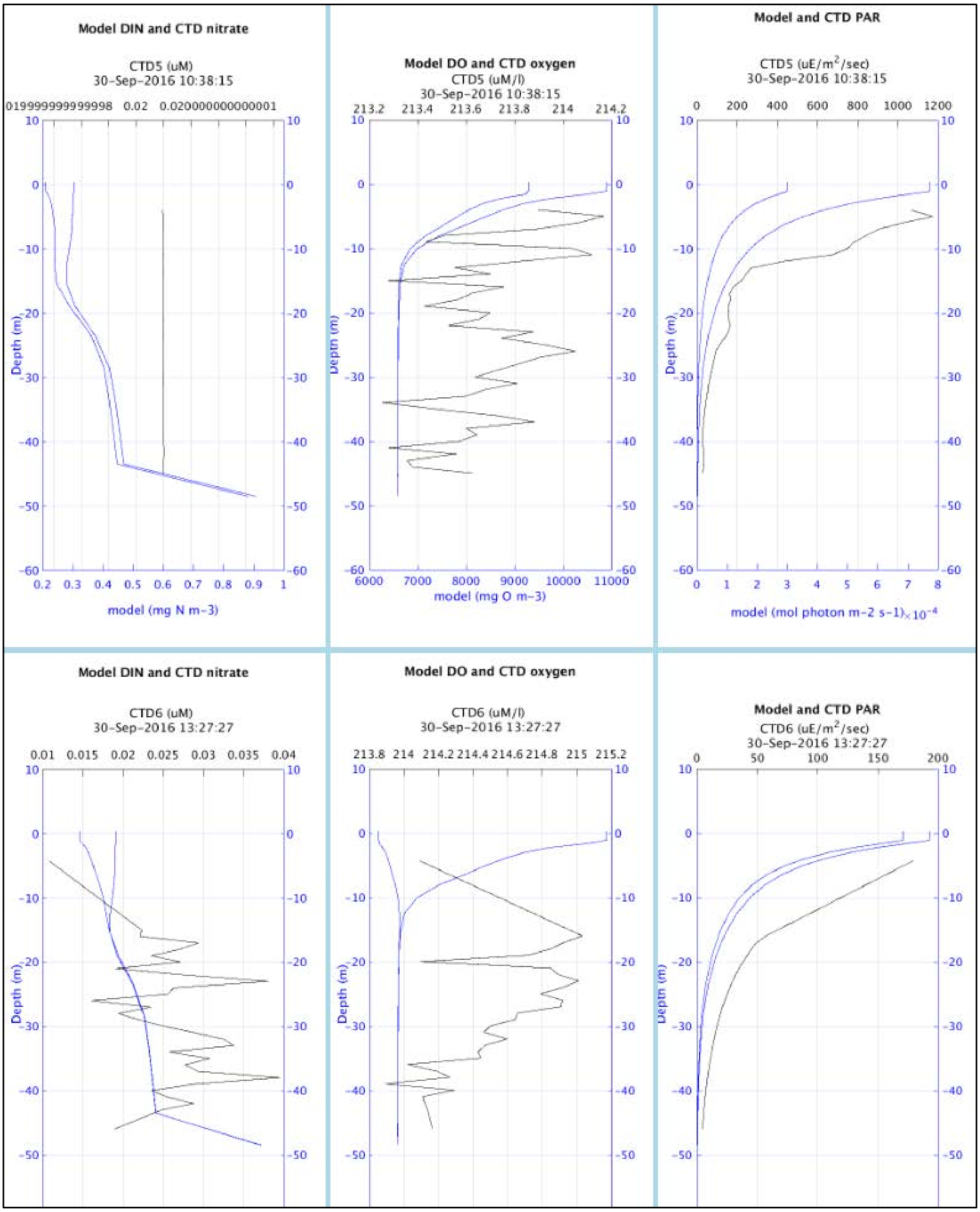
Simulated (blue and green lines) and unprocessed CTD observations (red lines) Chla (mg m-3) unprocessed fluorescence *0.1 (left) and nitrate profile (right mmol m-3), Heron Island station (29th Sept 2016). Green lines show a 5 days' average of the simulated.

Station 1


Station 1 bathymetry
Station
Latitude
Longitude
-20.88
-20.9
-20.92
-20.94
-20.96
-20.98
-21
-21.02
150.2
150.25
150.3
150.35
150.4
150.45
-35
-40
-45
-50
-55
-60



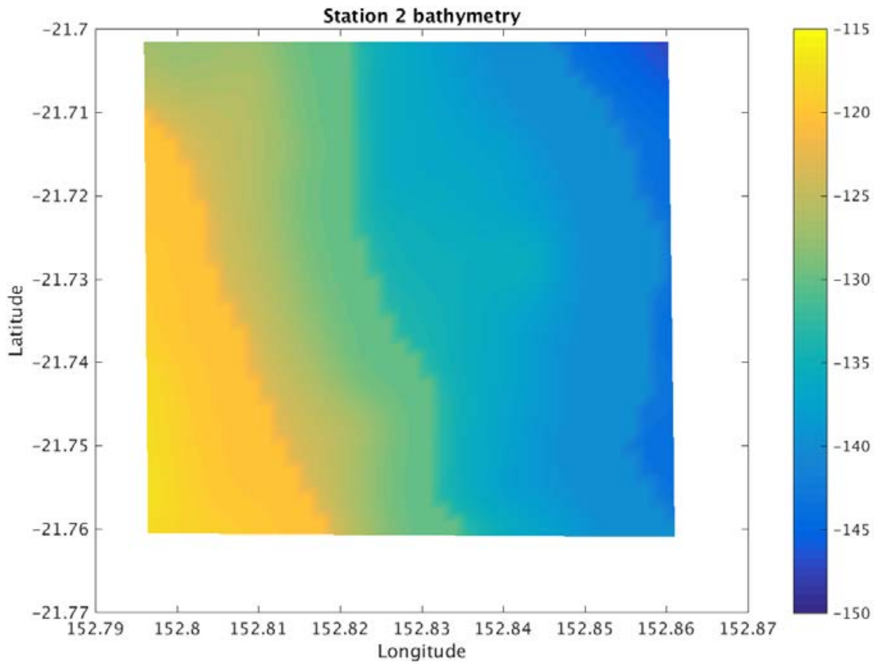
Simulated (blue) and unprocessed CTD observations (black lines) temperature (left) and salinity (right) profiles station 1).

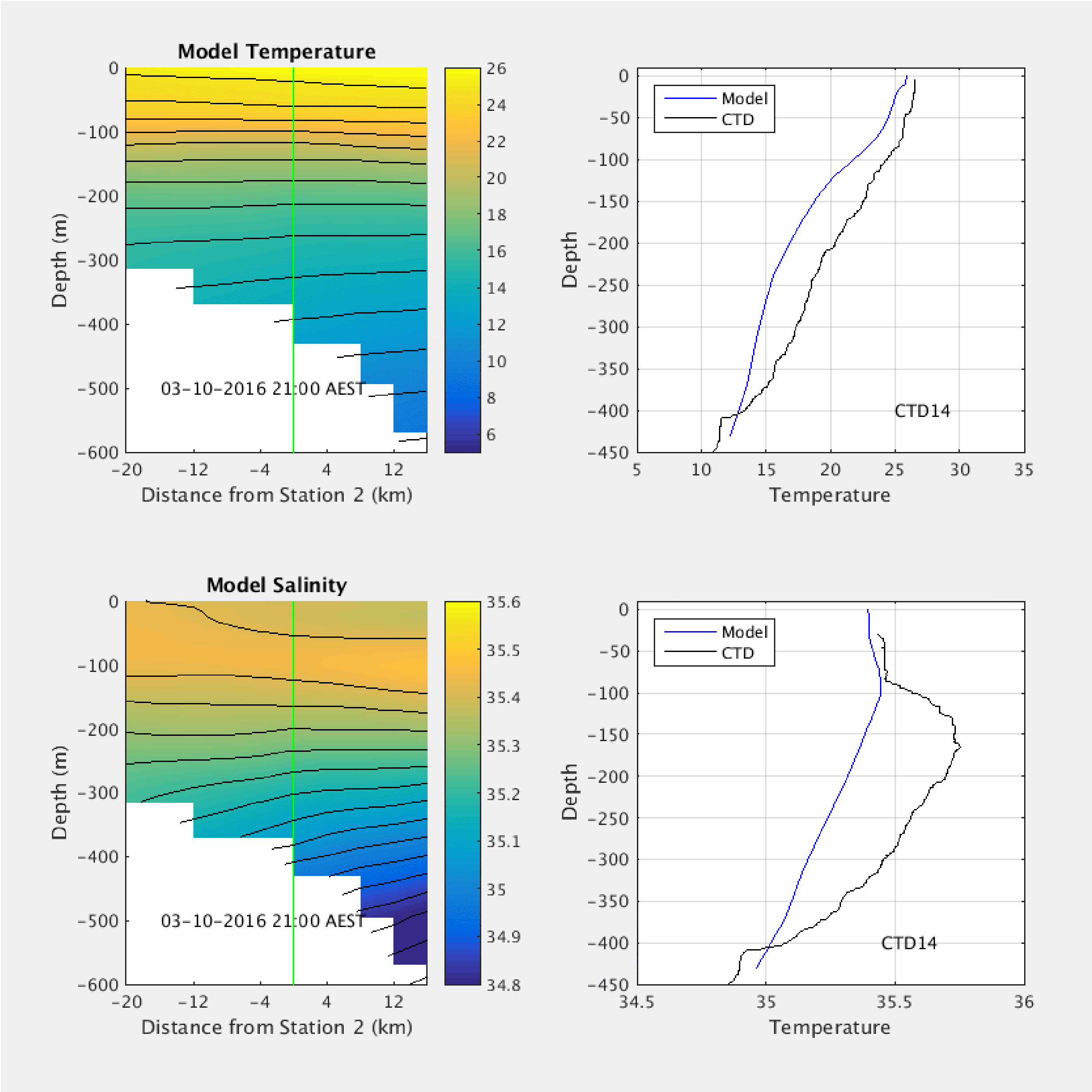


Individual CTD casts (black) bracketed with 3 hourly biogeochemical model output (blue) for nitrate, oxygen and photosynthetically active radiation (note contrasting units for observations and model).

Station 2

Leaving Station 1, we headed south with the Triaxus in tow to round the reef and tuck into Station 2 but the winds were unsuitable for atmospheric observations so we continued into deeper waters. Consequently the actual position of Station 2 was nowhere near the anticipated Station 2 model domain and as the new location wasn't even within the GBR V05 model boundary the best information we had was from GBR4.

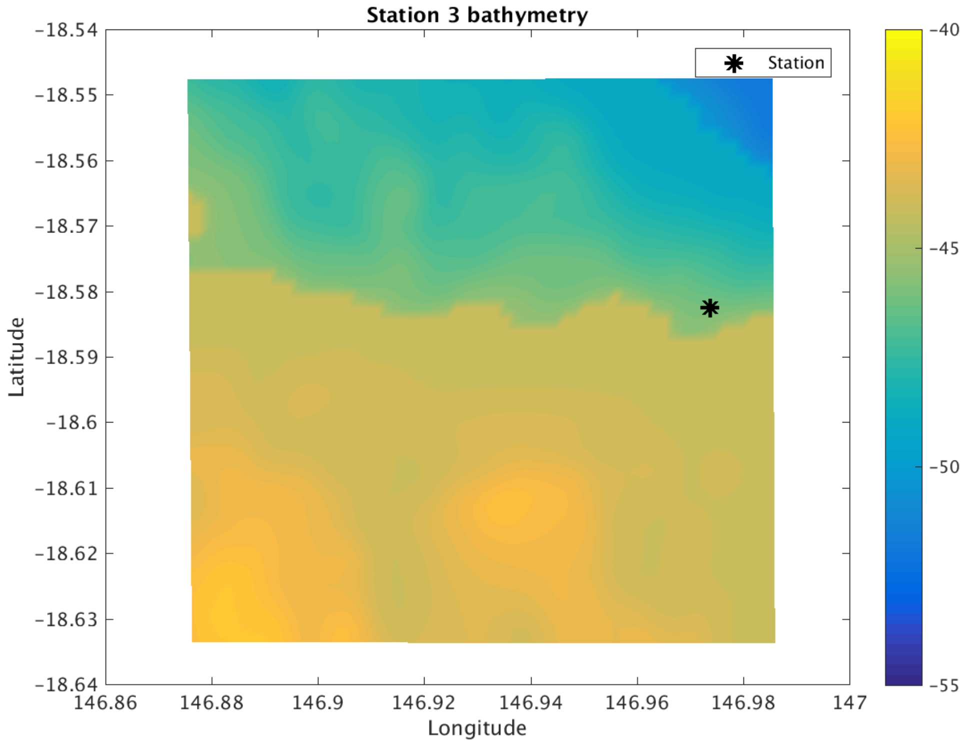


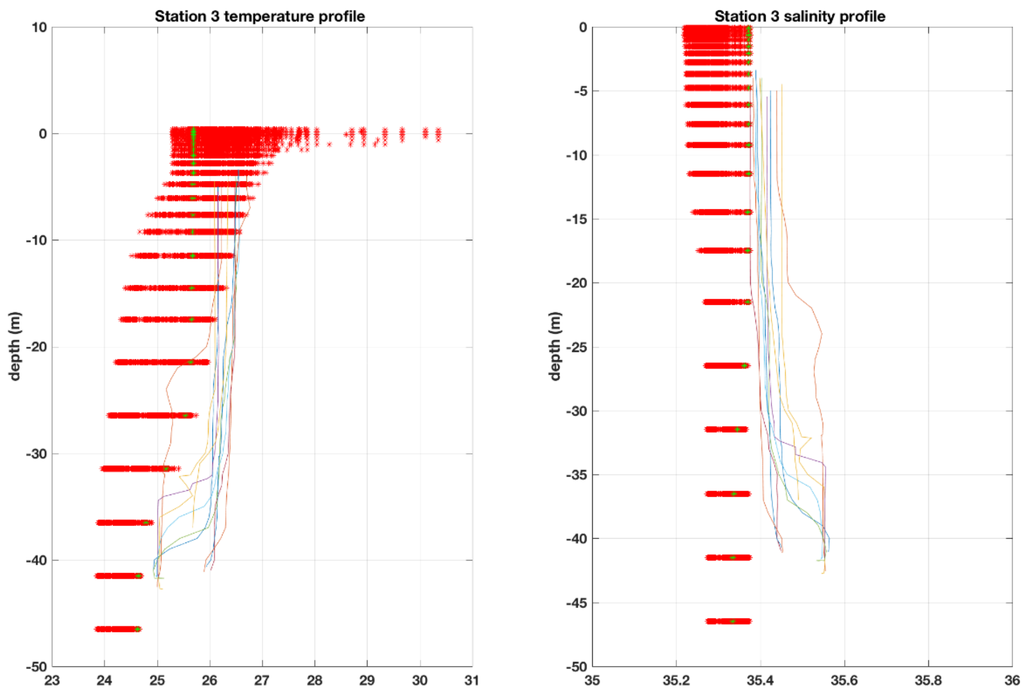


This plot shows CTD casts at Station 2 in the context of the GBR4 section through it. The station was at the 0km mark. The contours on temperature are density whilst salinity has salinity contours plotted.

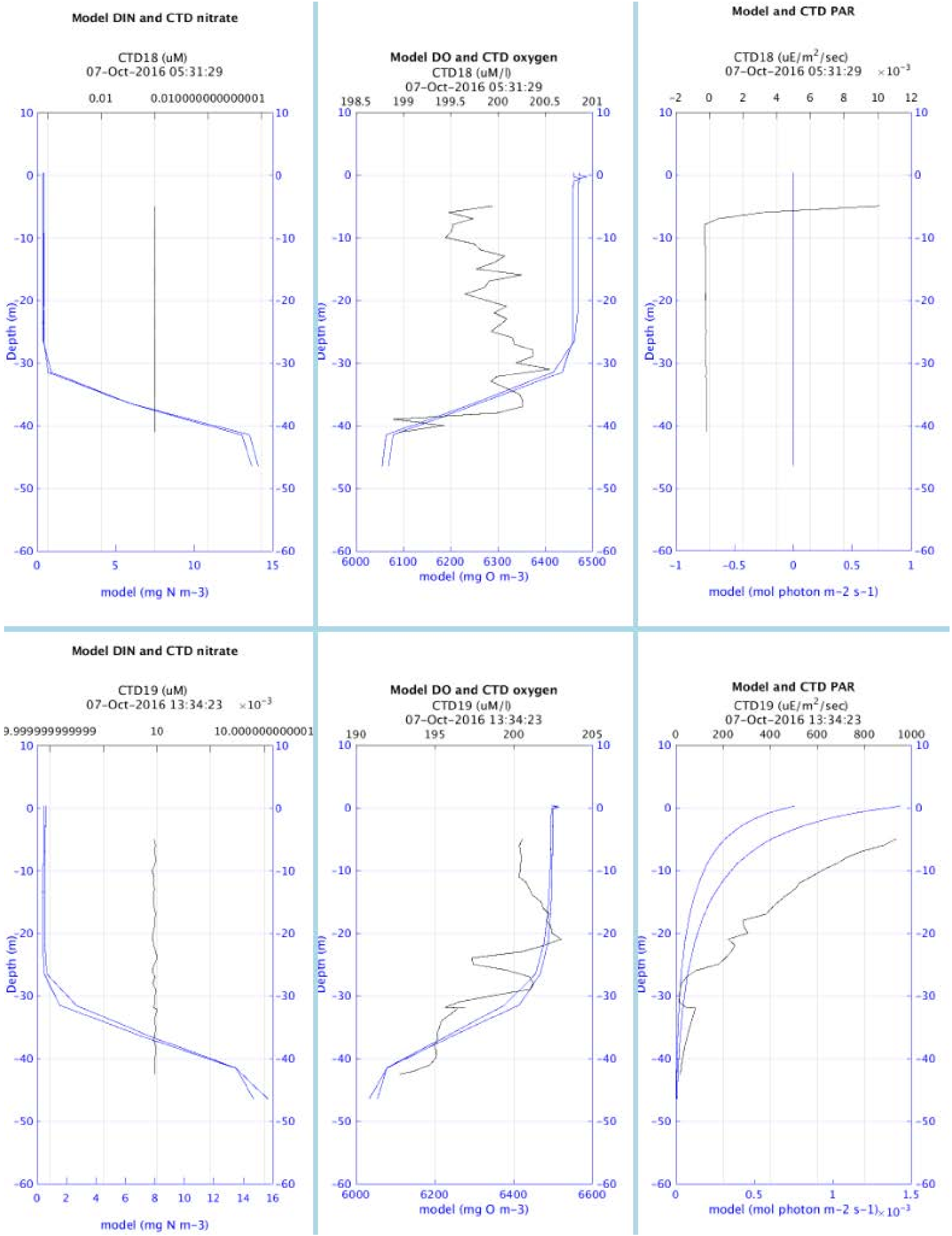
Station 3

Station 3 was located on the inshore southern entrance to Palm Passage.



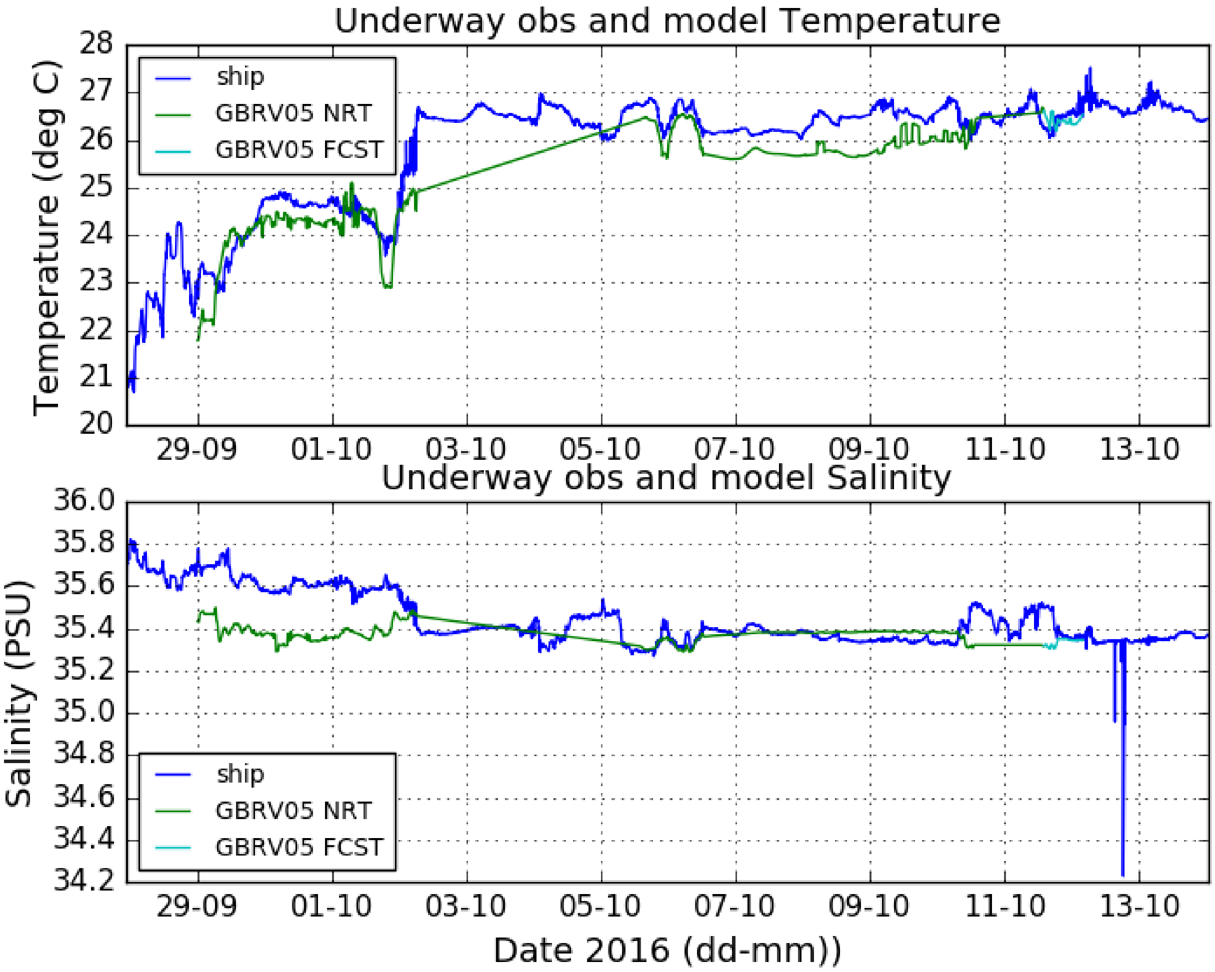


Simulated (red and green dots) and unprocessed CTD observations (multi-coloured lines) temperature (left) and salinity (right) profiles station 1). Green lines show a 5 day average of the simulated profile.



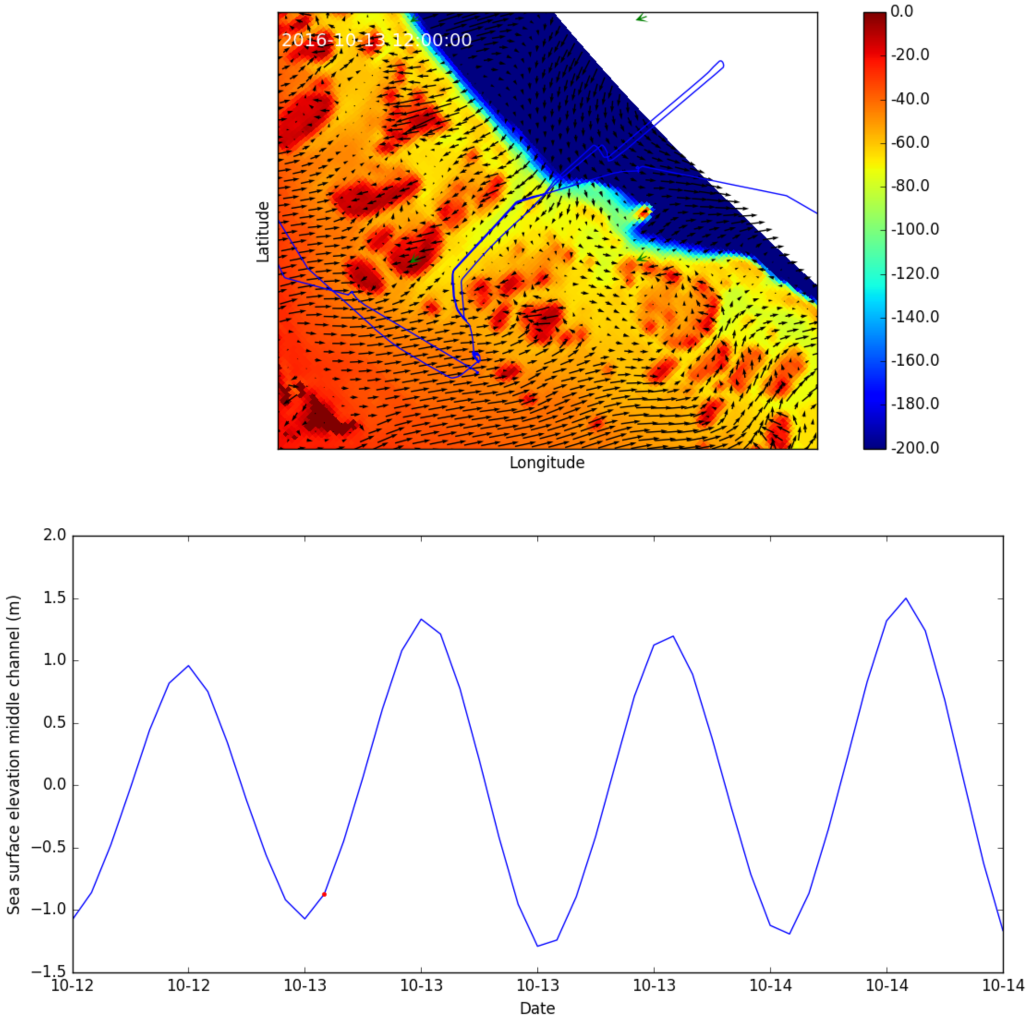
Individual CTD casts (black) bracketed with 3 hourly biogeochemical model output (blue) for nitrate, oxygen and photosynthetically active radiation (note contrasting units for observations and model).

Underway Temperature and Salinity

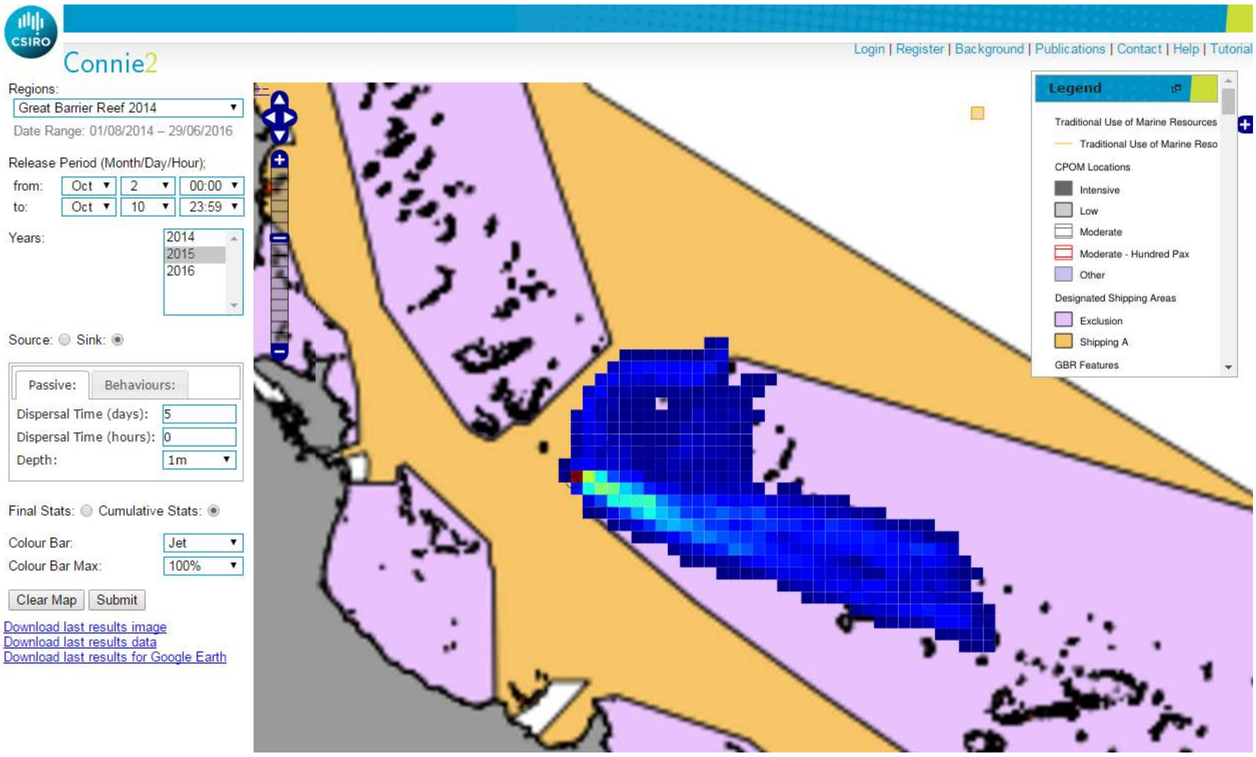


Ocean Current Forecast

An ocean current forecast for the Palm Passage area was run to assist with the planning of voyage activities. The model clearly communicated the evolution of surface currents in the area, forecasting which areas of water were flushed over the reef and when. The model accurately captured increasing wind and a deterioration in the weather. [Note, to achieve this animation the current vectors had to be re-mapped over the curvilinear grid as the visualisation tool Dive did not represent this accurately.]



GBRV05 ocean current forecast for the Palm passage area.



The CONNIE2 model interface was used to show the likely source of water arriving at a particular station. This was of particular interest to members of the science team sampling DMS production in the water column. Whilst near real time model results were not available at the time of the voyage mean conditions from previous years could be displayed.

Personal Reflections

Karen's activities

- Planned voyage, permits, equipment, logistics, boat transfer, daily activities
- attended daily PI meetings, toolbox meetings, safety briefings
- maintained daily communication with NASA; achieved CORAL PRISM overflight of vessel
- communicated science to ABC & QUT reporters
- gave eReefs presentation
- championed 41 CTD & 3 Triaxus deployments
- assisted with sampling the CTD
- calibrated ISUS & SUNA UV nitrate analysers against preliminary hydrochemistry data
- captured Triaxus FIRe data
- preliminary analysis and automated plotting of all CTD and Triaxus variables
- identified all sensor units, optimised sensor configurations, characterised specific sensor platform issues
- assisted Charles, Nagur and Janet with the collection of optical observations
- captured iPhone sea surface colour images
- compiled interim voyage report
- attended to essential project tasks & meetings for other projects

The planning and logistics for the voyage took more time than I anticipated however, once on board we have received helpful support and assistance from the MNF technical staff. The mixed team of modellers and optics specialists have worked well together and we have all shared many science insights. Personally I have enjoyed focussing on science in the field for an extended period. I particularly liked the days when we were isolated from our office email!

Probably the biggest highlight for me from the voyage was looking up and seeing the NASA plane in clear blue sky directly above the Investigator whilst we were deploying the optical sensors. Michelle later described our success as 'a slam dunk for the project'. After all the meetings attended, plans written, updated, re-written, weather reports, clouds, failed VSAT communications, and negotiations with the other PI's on board, we actually achieved our objective!

The multi-disciplinary, international science team on board has been great to work with. We found numerous opportunities to use the models to assist others in interpreting the context of their observations. There is a real and genuine interest to follow up this work with a collaborative project to use the eReefs model to investigate DMS and aerosol hypothesis.

I think the voyage has achieved more that its original objectives and been a great success.

Farhan's activities

- Helped with most of the water sampling from the CTD
- Performed daily filtration along with Mathieu
- Assisted with the daily multiple Hyperpro casts
- Set up computing infrastructure and tools on dino for modelling and as a general server for the CEM team. More info is available at the onboard webpagehttp://150.229.234.70/compute.html
- Remotely kept the regional models (near real-time and forecasts specially set up for the voyage) running on shore (GBR4 hydro/BGC plus the specialised GBRV05)
- Ran scripts daily to extract the necessary boundary data from the regional models for the 4 local models (Heron plus 3 new RECOM setups) and routinely ran the most appropriate model for the location in Trike on dino. More details at http://150.229.234.70/modelm.html
- Plotted up the model vs obs comparisons. See http://150.229.234.70/models.html for more details
- Facilitated Triaxus data processing via Jason Everett
- Plotted model section plots for comparison with the Triaxus data
- Plotted live underway data along with near-real time model data. This is automated and available daily on the front page at http://150.229.234.70/
- Worked with Mathieu on a small scale study of the general circulation around Station 3 to produce short term currents and sea-level forecasts
- Provided IT/modelling/software support to the CEM members onboard

Overall the local models were a lot smoother than the observations which was to be expected due to the differing temporal / spatial scales. Unfortunately there wasn't enough time to develop and understand the models to better be able to ingest the obs into the models for better forecasts. Some things to explore would be the horizontal and vertical grid dimensions, hydrodynanmic parameters, initialisation to real observations fields rather than the coarse resolution regional model and DA, either indirectly via the regional models or directly applied to the local ones. The mechanics of running models on board in Trike worked as well as expected and we always had at least a one-day (usually 2~3) forecast even with limited internet bandwidth. There is much that can be improved but I believe we're past the proof-of-concept stage.

The voyage has been a great educational experience for me and I thoroughly enjoyed it. Seeing how the various ocean data are collected first hand has given me a much better understanding of observational oceanography both the physical and the biological aspects. This was added to by the formal science talks as well as the informal chats throughout the voyage. I now understand a little better the challenges of communicating modelling concepts to non-experts in the field.

It was also great to work with the IT/data processing MNF staff. This sets up well the possibility of future collaboration via the O&A Software Community of Practice as a way to learn from each other. For any future voyages, I would be interested in understanding and assisting with the real-time data delivery of sensor information, especially with QC and workflows.

Mathieu's activities

- CTD sampling
- carbon sampling (underway)
- hyperpro deployment
- near real time and forecast modelling
- water filtration and pigment sampling
- underway and CTD cast data processing
- has a lot of tea break to discuss with other voyage participants

It has been a great experience, while I had previous sea going experience (10 years ago), it was great to keep up to date with the latest technology and experience a new research vessel. I also appreciated being part of a multidisciplinary research voyage where our skills and knowledge of the ocean could be shared with other scientists on board. We also learn a big deal of atmospheric research and managed to create a new collaboration. We now have plan for a phD student which was on the voyage to visit our team to learn how to use the modelling tools we are developing. Our work at forecasting the ocean current around the ship was well received and used by the voyage leader and participants, this prove that our research and work is needed and should be pushed forward. We also had great interactions with the hydrochemists on board the ship, their work is the primary dataset for our models validation.

Appendix 2 Piggyback Voyage Report

Short summary on geophysical operations to 07 Oct 2016

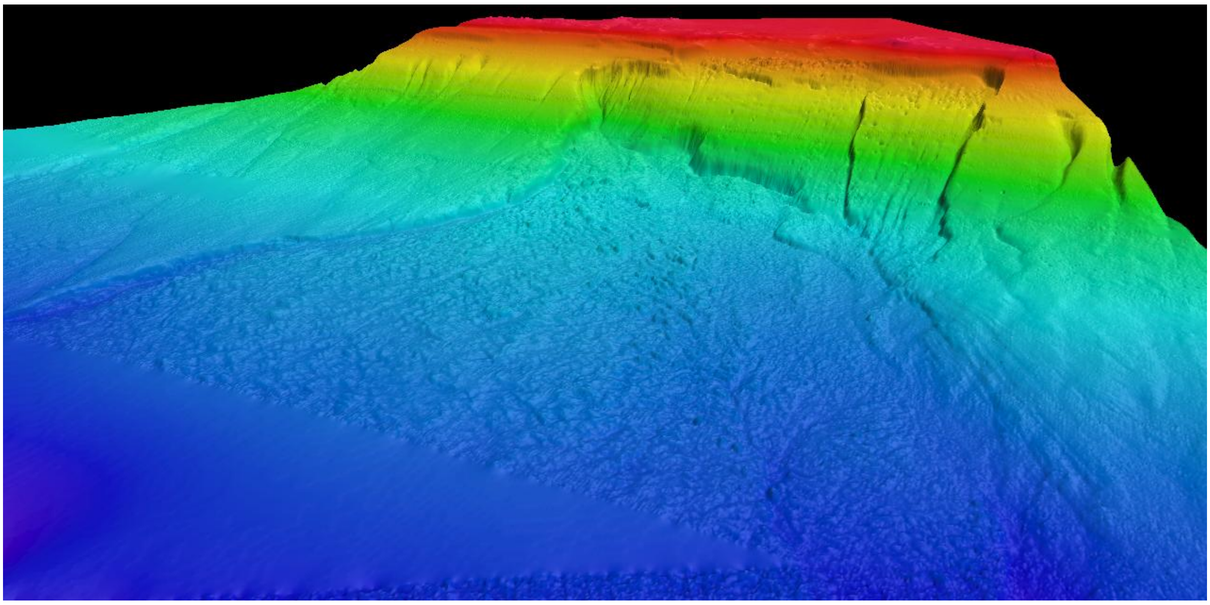
The deep-water EM122 and shallow-water EM710 multibeam swath sounders, and the SBP120 sub-bottom profiler have been operating nearly continuously since we left Brisbane. The only exceptions have been for occasional dropouts, when the ship was stationary or in waters too shallow for the optimal multibeam system. For example, the EM122 multibeam has not been used to log bathymetry data in waters shallower than 300 m. As of 07 Oct, the EM710 has logged 2,296 line km and the EM122 has logged 1,249 line km.

The leg northward of Moreton Bay across the Fraser shelf on 28 Sep revealed large expanses of active dune fields, before dropping over the shelf-break into the upper continental slope opposite Fraser Island. On 29 Sep we transited across the Fraser Canyon and associated gullies to a depth of ~2035 m, the deepest depth surveyed so far. Through the morning, we followed a set of waypoints along the 100 m contour to survey the shelf-break seabed features up to Heron Island.

Heading up the Capricorn Channel and onto the GBR shelf on 30 Sep, found most of the seafloor to be quite flat, with occasional isolated pinnacles or pockmarks. The transit passed over several drowned reef banks with very obvious karst limestone pinnacles around 50 m depth. Approaching Station 1 off Tern Island, the seafloor became less covered in sediment and more karst seafloor was seen as pinnacles showing through depressions in the seafloor.

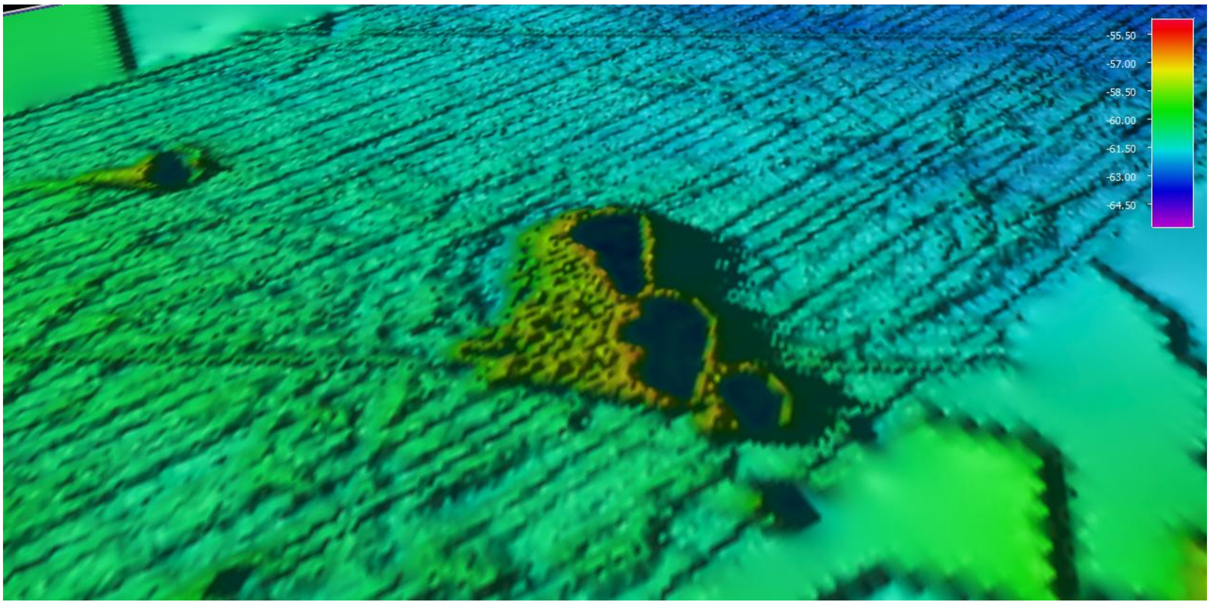
Through 1-2 Oct, the vessel transited on the northern side of the Capricorn Channel, passing over the shelf-edge drowned reef at about 100 m depth along the south-east corner of the Swain Reefs. Then we continued towards Station 2 on the Marion Plateau, completing multibeam operations on arrival at Station 2 in ~450 m of water. Early on 4 Oct, we commenced surveying across the Marion Plateau over a mostly flat seafloor, then on 5 Oct we found an unusual area of low-relief sandwaves.

The vessel passed over the Marion Plateau and into the Townsville Trough early on 6 Oct heading towards the entrance to Palm Passage. We noted the original planned track passing near the Bowl Slide, a 20 km wide undersea landslide in the GBR margin, surveyed by the RV *Southern Surveyor* in 2007 and 2008. The voyage track was altered slightly to pass adjacent to the surveyed area, collecting excellent quality multibeam data to extend the known limits of this remarkable landslide.



The vessel entered Palm Passage in the morning of 06 Oct, and during the day transiting three times on and off the shelf. A highlight was surveying the prominent drowned reefs and fossil coral terraces at the shelf-break around 110 m depth, with each pass through the Palm Passage. On the last pass out, the vessel reached the middle of the Queensland Trough in ~1200 m, before proceeding back onto the shelf and to Station 3 lying north-west of John Brewer Reef.

With the vessel now at Station 3, we are catching up on post-processing and planning. Looking ahead, there is an opportunity during the Leg 3 return to Brisbane, to pass over an unusual dune-like feature recently surveyed by the Navy about 20 km north-east of Holbourne Island. It is about 1 km in size and at a depth 58-60 m lying close to the planned voyage track. A slight change in the planned track will allow a multibeam survey over this feature to help reveal its true geological formation.



In summary, the geophysical operations have been very successful and a great opportunity for me to see the multibeam and sub-bottom profiler equipment in use and the GS&M team in action. The high quality of these datasets reflects the world class surveying equipment onboard the RV *Investigator* and the experience of the GS&M team. I hope my presence onboard and my knowledge of the GBR seafloor has given context to the features being revealed to the benefit of the GS&M team and the larger science team onboard. These new data will be valuable additions to future iterations of the gbr100 grid, now widely used by scientists, marine managers and industry.

Dr Robin Beaman
07 October 2016