Pulse – A Mooring for Mixed Layer Measurements in the Open Ocean and Extreme Weather

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Abstract *– Measuring the surface mixed layer of the Southern Ocean is technically difficult due to the extreme weather conditions. A novel mooring with a surface expression has recently achieved engineering success in this harsh environment over a 6-month deployment. The mooring was the result of numerous prototypes and utilises a mixed design which includes a taut deep section, a long S-tether, a large mass/damper and bungee cords suspended from a small buoy to decouple surface wave action from the instrument package.*

I. INTRODUCTION

Commonwealth Science and Industry Research Organisation (CSIRO) and University of Tasmania (UTAS) scientists have been studying the properties that control the transfer of CO_2 from the atmosphere to the upper parts of the Southern Ocean and then down through the ocean interior in the form of sinking particles. Measurements using moored sediment traps and ship instrumentation indicated that the processes are complex and vary on daily, weekly, seasonal and interannual timescales. To better understand these processes, it was necessary to make more continuous physical and biological measurements in the surface mixed layer, typically the upper 50m. There are considerable technical challenges to this task. First, the ocean depth in the region of interest is greater than 4000m, with hilly topography. Second, there are currents in the region, which though generally small, are variable in strength and direction and can reach 0.5m/s. Third, and of most concern, the sea-state conditions are amongst the most severe on the globe, at times having wave heights in excess of 15m.

Several options were considered for maintaining the required instrumentation within the surface mixed layer. A conventional taut sub-surface mooring was not possible due to the hilly topography and uncertainty in accurately positioning the anchor, and it being impossible to prevent instrument subduction to below the mixed layer due to the expected variable current. Active moored winches were considered to counter the topography uncertainty and variable current; however, they were discounted due to cost and power requirements. Due to the expected sea-state conditions, we were at first also reluctant to have anything on the surface; however, the only way forward was to suspend the instrument package from a moored buoy. The size and weight of the instrument package, which included a large piece - a McLane RAS500 water sampler with associated CTD and other sensors - necessitated significant decoupling of the package from the surface motion, further complicating the design.

II. PULSE TEST MOORINGS

For reasons associated with the pulsed nature of the biological productivity in the research area, this mooring was called Pulse. The current Pulse mooring is the culmination of several years of test deployments used to gain insights into the engineering challenges of maintaining a large and heavy instrument package in the Southern Ocean's surface mixed layer. Early designs of the surface system were configured around the successful CARIOCA buoy system [1] (Fig 1). This system utilises a small surface buoy with wave decoupling being accomplished through a partly submerged highly buoyant tether and submerged elastic element.

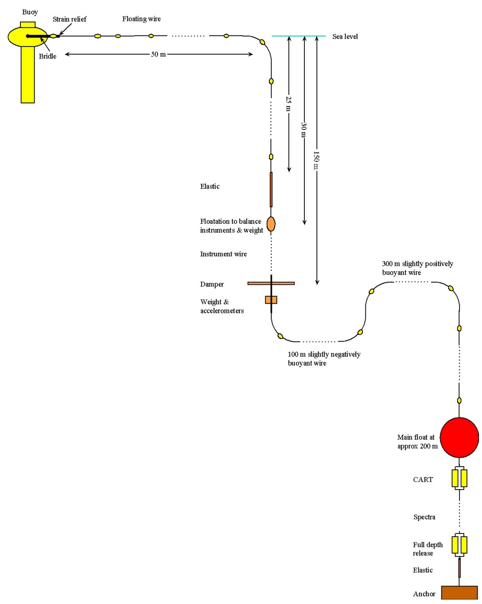

Fig. 1. Early Pulse test system based upon CARIOCA buoy.

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From the onset, the design was separated into two distinct mooring systems; a deep-water conventional taut mooring and the buoy and instrument package. The deep, taut mooring acts as an anchor for the buoy and instrument package enabling the surface system to be based upon technology developed for shallower, wave influenced, waters.

These early systems were instrumented with an Iridium Global Positioning System (GPS) tracker, internal logging 3-axis accelerometer systems and pressure sensors. Despite static mooring design models indicating otherwise, these systems failed due to their inability to handle current resulting in subduction of the buoy – possibly due to higher than expected current at the test site – and no useful test data was recovered.

Following two failures, we abandoned the CARIOCA/floating tether design in favour of a system with higher buoy reserve buoyancy and relying upon a bungee/mass system to gain adequate surface decoupling. The first of the new test systems was deployed in 400m of water (Fig. 2).

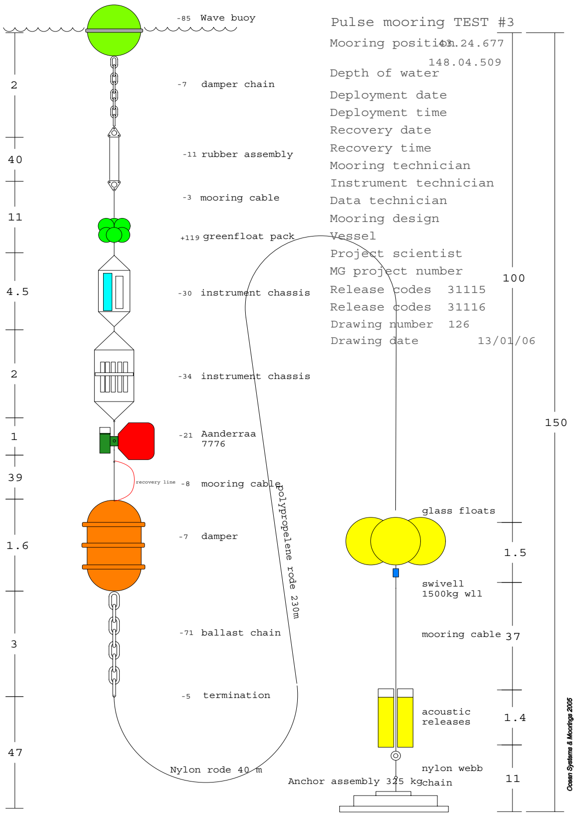

Fig. 2. First bungee test system.

Elastic and mass components were designed to place the resonant frequency of the system well below expected wave frequencies in order to gain significant attenuation of wave motion below the bungee. Attempts to model this system dynamically using WHOI Cable [2] were unsuccessful; however, a simple Matlab application was able to demonstrate that adequate attenuation could be obtained. An example of this analysis is shown in Fig. 3 where the attenuation for a typical Pulse system as a function of wave period and wave height is shown.

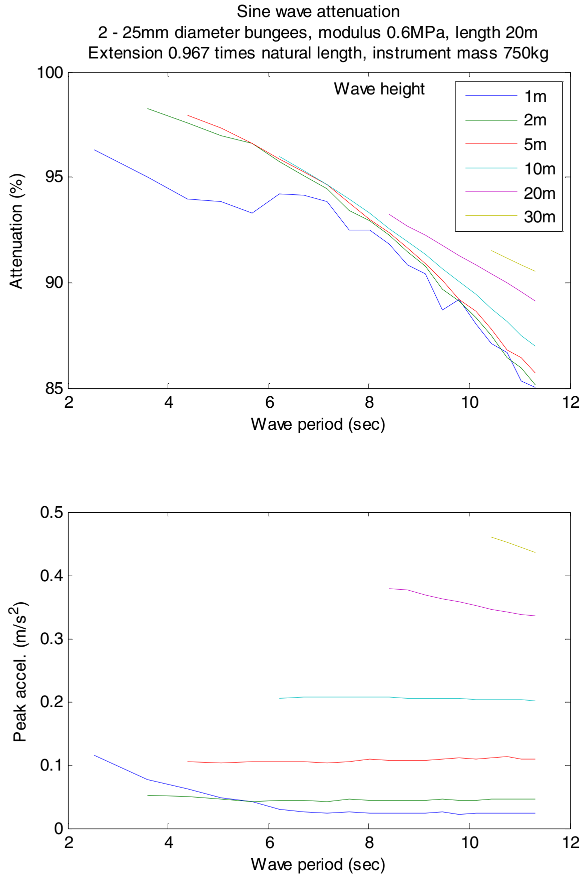

Fig. 3. Attenuation of wave acceleration at the instrument package as a function of wave period and wave height.

The large mass (damper) was a tank of water, which could slowly fill and drain. Since we require mass and not necessarily weight, by choosing water, which is only contained when the tank is submerged, the damper is much easier to deploy and retrieve than it would be if the mass was for example steel. It also enabled load on the bungee to be controlled without excessive compensating buoyancy with its implied higher drag. The bungee had a pre-load such that it would never go slack, even in the worst case sea conditions. The length of the S-tether was derived from our static mooring design software, so the buoy would not be subducted in the strongest currents expected. For this test, mock-ups of the instruments planned for the first Pulse deployment were included together with surface and subsurface (below the bungee) 3-axis accelerometer packages, a pressure sensor and current meter. The buoy was a modified 90cm Datawell Waverider buoy fitted with the surface accelerometer package and an Iridium GPS tracker.

The mooring was recovered after 55 days and upon inspection all components were in excellent condition with no sign of wear. An analysis of the accelerometer, pressure and current data indicated that the mooring behaviour was consistent with model predictions. Conclusions reached by analysing this data were similar to those of *Pulse Test 5 (Heavy)* whose results are shown later.

Encouraged by the success of this test deployment, deep water tests were commenced. The first of these failed due to the failure of a shackle or chain and the second due to the implosion of a float shearing the mooring line (Fig. 4).

Fig. 4. Imploded 600mm plastic float.

Inspection of recovered components and analysis of data from the instruments indicated that the basic design principles were sound despite the failures. Two final test deployments were made in order to test the durability and surface attenuation of systems with and without mass below the bungee. We also instigated more formal project management procedures with sign off of designs and deployment dates before commencement of construction. This achieved three results that decreased the risk of project failure. First, it stopped "scope creep" where the design increased in complexity over time, second it stabilised version control, so construction and deployment was not confused by modifications and third it allowed for completion of the build within a known timeframe so testing could be undertaken before deployment.

Pulse Test 5 (Heavy) shown in Fig. 5 was designed to have the same functional form as previous test designs that used bungees.

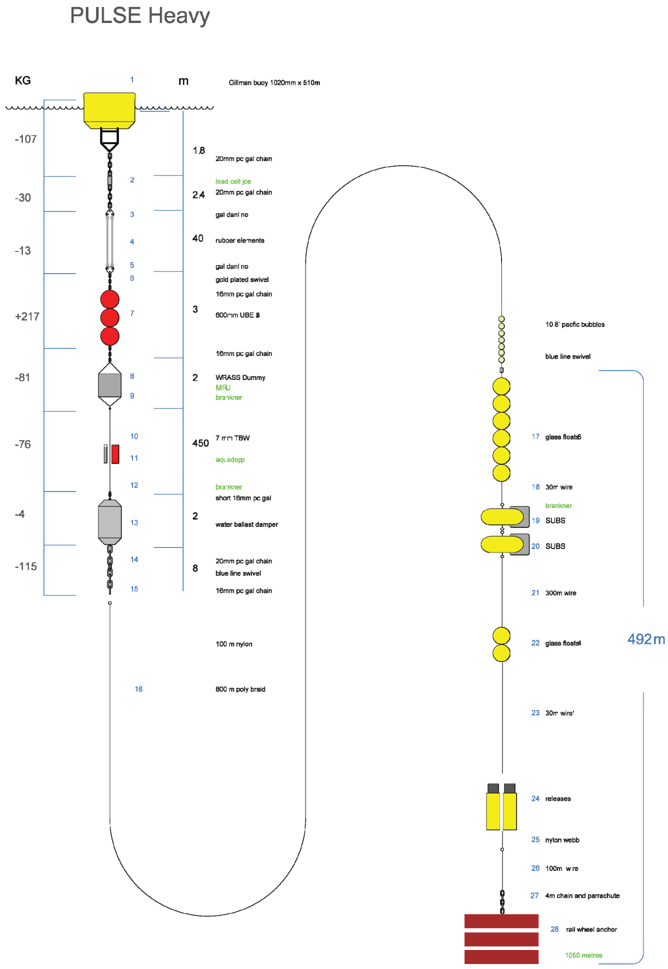

Fig. 5. Test 5 mooring Pulse (Heavy) design.

The significant changes were the replacement of the Datawell 90cm buoy as the surface buoy with a purpose built buoy using a 1m diameter Gilman float with 335kg of buoyancy, and a redesign of the taut subsurface mooring section to cope with the different water depth. The length of the S-tether was determined by modelling with a view to reducing the vertical load on the bungee as the current increases. In simple terms, when vertical, the load on the bungee is proportional to the sine of the angle the tether makes to the horizontal. Hence, increasing the tether length decreases this angle. The tension could be further reduced by placing the top of the taut section above the bottom of the instrument line, but this would increase the chance of tangling. Note that Fig. 5 is misleading in that the design has the top of the taut section below the water mass/damper.

Microstrain 3DM-GX1 attitude heading reference systems (referred to as MRUs) were attached to the buoy and the instrument cage mock-up (RAS500 dummy) and the data logged. A subset of the surface data was transmitted to shore via Iridium (See Hughes et al in this volume). The buoy also contained an Iridium/GPS tracker so that the location of the buoy could be determined in near real time. A load cell to measure bungee tension was placed in-line between the buoy and bungee; this was also logged in the buoy and a subset of data sent to shore via Iridium. In order to gain some idea of the local current environment, a current meter was place at a nominal depth of 80m. Pressure sensors were also placed on the instrument cage, the water ballast and the top of the taut mooring section.

Pulse Test 5 (Light), shown in Fig. 6, arose out of concerns that the drag of the large water ballast on *Pulse (Heavy)* was placing undue mechanical stress on the mooring elements. With an understanding that removal of the ballast mass would increase wave induced motion at the instrument cage, it was decided to test whether this motion was acceptable. *Pulse (Light)* used the same buoy, bungee and instrument cage assemblies as *Pulse (Heavy)* with the same instrumentation. Since the weight at the bottom of the instrument line is less, fewer floats were required to support the instrument cage, while keeping the bungee preload at 60kg. The top of the taut subsurface mooring section was also longer in order to compensate for the much shorter instrument line - with a view to decreasing the angle the tether makes to the horizontal as discussed above. There was no current meter on this system since it could reasonably be assumed that the current would be very similar to that at the *Pulse (Heavy)* mooring site which was only 3km away. A pressure sensor was again attached to the top of the taut mooring section.

Both these systems were successfully recovered and the data analysed. In order to determine the effectiveness of the surface decoupling, the MRU data for both systems and for surface and sub-surface units was processed into displacement spectra and an effective significant wave height computed. The effective significant wave height for the deployment duration is shown in Fig. 7 and examples of spectra acquired during a stormy period are shown in Fig. 8. The loss of data midway through the light system deployment was a result of flooding of the tension load cell, which disabled the buoy acquisition system. The effectiveness of the heavy system in decoupling surface wave forcing is clearly evident and is consistent with model predictions. The ability of the heavy system to remove higher frequency forcing when compared to the light system is also evident. Removal of higher frequency forcing, as was the case with *Pulse (Heavy)*, has advantages for mooring survival since this spectral range contributes the

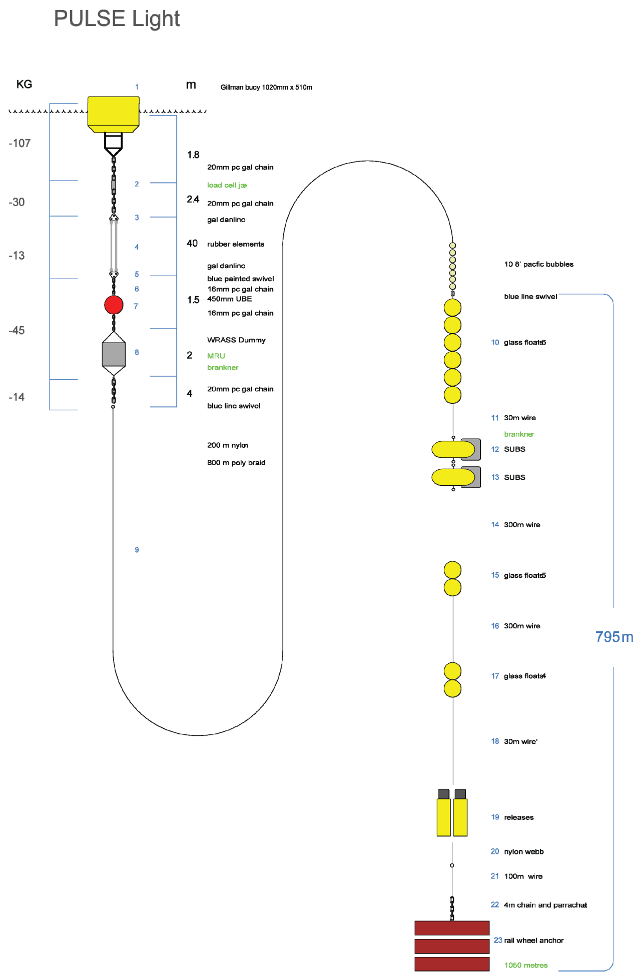

Fig. 6. Test 5 mooring Pulse (Light) design.

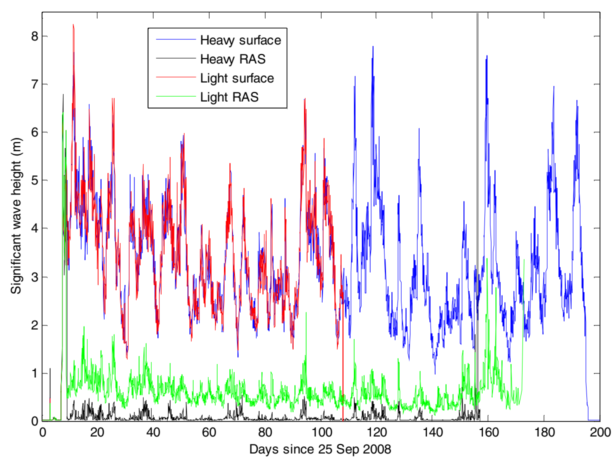

Fig. 7. Significant wave height as measured by the surface MRUs for the light and heavy systems compared with effective wave height at the RAS500 dummy.

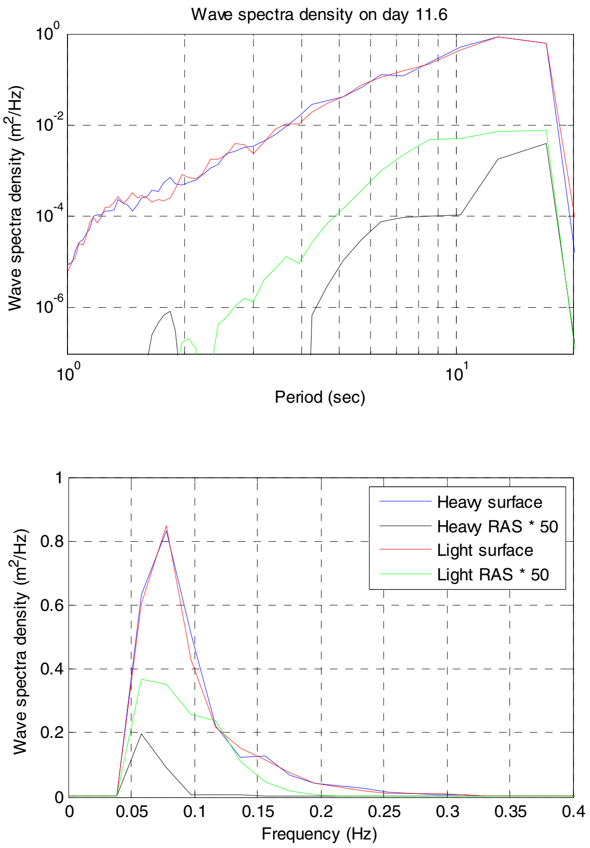

Fig. 8. Displacement spectra for a stormy period during the Test 5 deployment. Note the scaling factor of 50 applied to the sub-surface (RAS500 mockup) data.

most to acceleration and thus loads on the instrument package and fatigue in its couplings.

As an aside, the MRU computed significant wave height data was compared with data derived from a wave model (WAM) [3] – the results shown in Fig. 9 indicate excellent agreement.

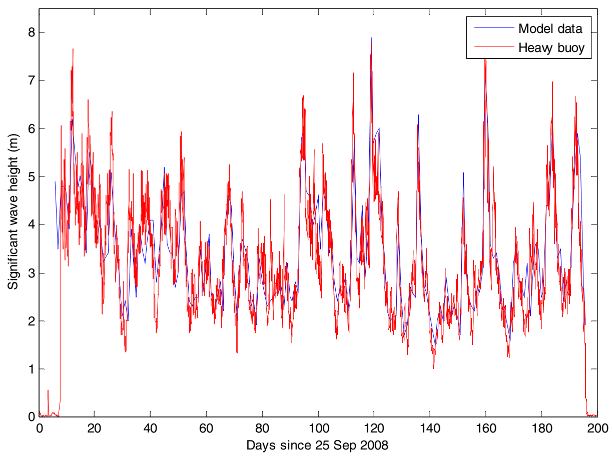

Fig. 9. Model and MRU derived significant wave height.

One of the requirements of the Pulse mooring is that the instrument package remains within the surface mixed layer for the duration of the deployment. To explore this, the pressure sensor on the instrument package was compared with current and the results presented in Fig. 10. Clearly current had less of an affect on the light system, however, the 15dbar subduction observed in the heavy system was considered acceptable. The significant deepening at the beginning of the deployment seen in both systems is due to the bungee not returning to its initial state after significant stretching. As a consequence all bungees are now pre-stretched before deployment.

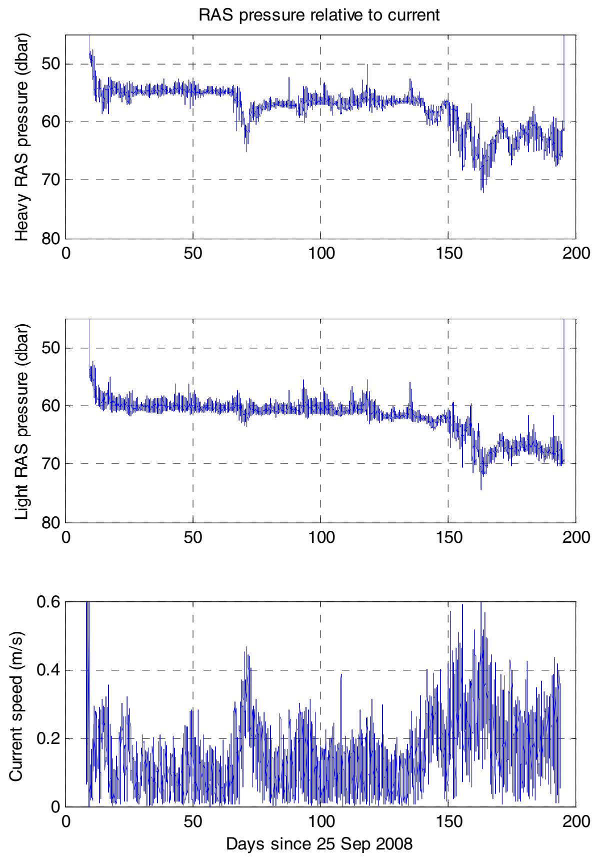

Figure 10. Pressure at the RAS500 mock-up (instrument package) compared with current for the Pulse Test 5 systems.

III. The Pulse Mooring

The current Pulse mooring design, which evolved from the various test deployments and numerical modelling, is very similar to *Pulse (Heavy)* shown above. The heavy system was chosen in preference to the light system due to its superior surface decoupling (Fig 7 & 8). It utilises the same Gilman buoy suspending the instrument package 30m below the surface via three 15m, 2.5cm Buoytec solid rubber bungees deployed in parallel. This is a stiffer system than that used in the test deployments in order to minimise the chances that the instrument package will be pulled below the mixed layer in strong currents. The decrease in surface decoupling resulting from this stiffer system was considered acceptable. Between the instrument package and bungee there is a floatation package designed so that the weight on the bungee extends it by 10m beyond its unloaded length. Suspended 450m below the instrument package is the large mass (750kg), low weight (14kg) water mass/damper. This brings the resonant frequency of the bungee/mass system well below the frequency of the longest waves expected effectively decoupling the instrument package from the surface forcing. The 1.2km S-tether is made from nylon and polypropylene ropes.

The instrument housing (Fig. 11) contains a RAS-500 water sampler, CTD and sensors to measure PAR, oxygen, total dissolved gases, phytoplankton fluorescence and particle backscatter. The complete instrument package measures approximately 1m on all sides and weighs 72kg in water. The surface buoy transmits its GPS location and also acceleration statistics from a motion reference unit via Iridium telemetry. For this deployment and planned future deployments the GPS and motion reference data are provided in near real-time to the Internet via the IMOS Ocean portal. It is planned to transmit wave data rather than acceleration statistics in future deployments.

The fully instrumented Pulse mooring was first deployed 22nd September 2009 and recovered 18th March 2010. Upon recovery, the complete system was in excellent condition with little sign of wear, though results from fatigue testing are as yet unavailable, but they will be considered and the mooring will be serviced and prepared for another rotation into the Southern Ocean in September 2010.

Fig. 11. Tom Trull and Dave Cherry make final preparations to the Pulse instrument package.

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