

Current meter moorings

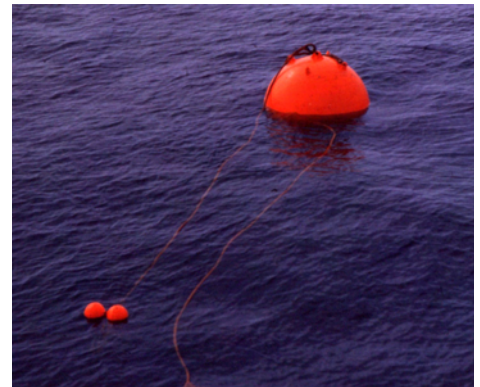
The development of our capabilities from NIO at Wormley in 1965 to the World Ocean Circulation Experiment in the 1990s.

Measurements from moorings are now a central component of our armoury of ocean observing methods. The **RAPID** array of moored instruments has, since 2004, monitored the Atlantic's overturning circulation and is now maintained with 18 months between each cruise to recover and redeploy the moorings and instruments and with small losses of instruments or data.

We weren't always so capable and the journey to the successful present-day has been a long and difficult one. Making progress has required success in several largely independent areas:

- Instruments. Selecting commercially-produced current meters that could deliver good data. This needs sensors to work reliably, successful data encoding and recording, batteries with adequate capacity and the development of robust maintenance and calibration procedures.
- Mooring materials – selecting wires, buoyancy and other components that were strong yet light enough and not subject to significant corrosion.
- Deployment and recovery procedures – needed to be safe, not overly weather dependent and able to be used from a wide variety of ships.
- Acoustic releases - needed to work reliably (their development has been covered on the **Oceans-Wormley** web site)

In this article I give a personal perspective of the first 4 decades of those developments both from an engineering standpoint but also commenting on the contributions that moored current meters made to ocean science. The course of the science and of the mooring technology developments is best, (though not perfectly), captured in cruise reports most of which are available from **BODC**, from the **notebooks of John Swallow** who was the scientist who pioneered the method, from published papers, data and technical reports. The mooring log sheets are held in the NOL archives in Southampton but are not yet easily accessible and have not been used in constructing this narrative.

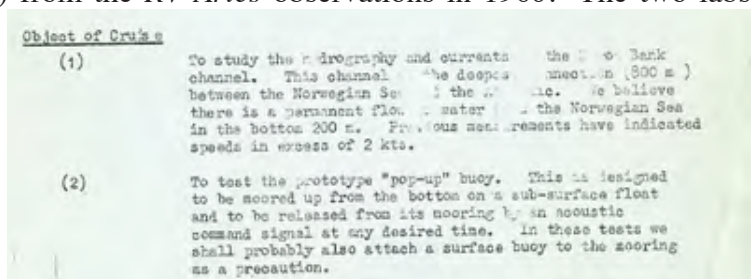


A successful recovery.

The story begins.

In 1955 John Swallow demonstrated that his neutrally buoyant floats could measure deep-sea currents, but the floats moved randomly as they were transported by what we now know is the “weather” of the oceans – variable currents that were much stronger than the average. By the mid 1960s a number of groups had started to develop the techniques needed to collect long records of currents from fixed points. (Eulerian measurements). Among the foremost of these was the Woods Hole Oceanographic Institution (WHOI) in the USA. There was at that time close collaboration between NIO and WHOI, a significant catalyst for which was John Swallow's friendship with Henry Stommel. This had led to the discovery of the undercurrent beneath the Gulf Stream and the oceans' mesoscale variability (“weather”) from the *RV Aries* observations in 1960. The two labs developed their mooring capability in parallel but with NIO very much the junior partner ¹.

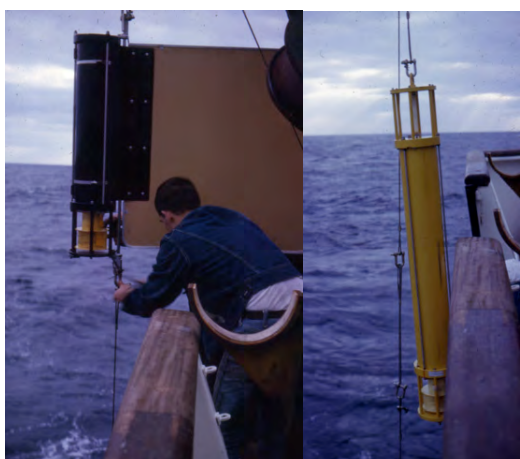
NIO's first efforts focused on the strong deep flows coming out of the Arctic Ocean. In the early summer of 1965 on Discovery Cruise 6 Jim Crease tried to measure the flow through the Faroe Shetland Channel.



Discovery Cruise 6 objectives.

¹ The story of WHOI's Buoy Group (always pronounced boo-ee) and headed by Bob Heinmiller and with excellent engineering design from Henri Berteau and scientific leadership from Nick Fofonoff and Ferris Webster is nicely documented on the **WHOI web site**.

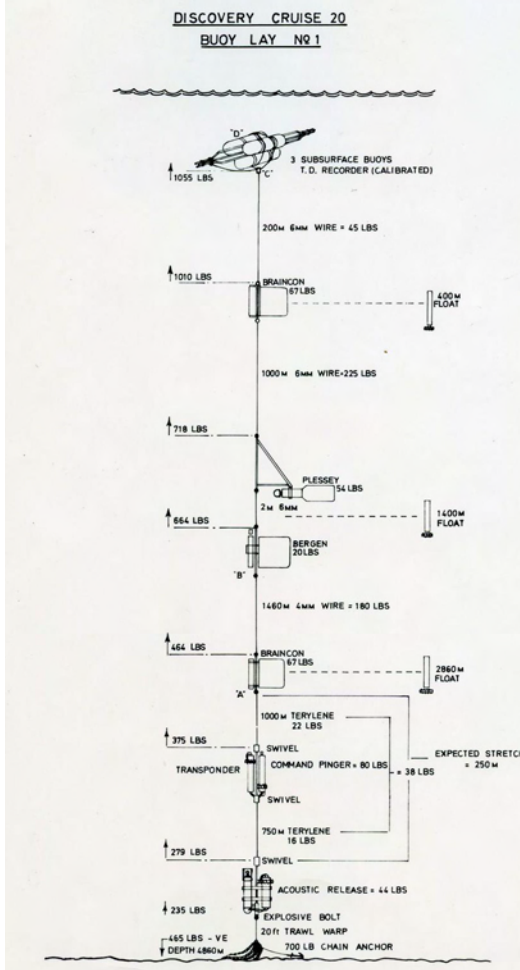
He used Swallow's floats and also moorings with acoustic releases and the recording current meters that had been developed by the Christian Michelsen Institute (CMI) in Bergen, Norway. There is no evidence in the published literature that the moored current meters made a significant contribution!



In spring 1966, on *RRS Discovery* Cruise 10 led by John Swallow south-east of Madeira, moorings and current meters were deployed in much deeper water (2300m, 32°N 15°W). This trials cruise used three current meter designs; [Braincon Model 316](#) (seen left) Geodyne (A-100)² (centre), Plessey (MO-21)³ (right). The

moorings had surface dhan buoys and the acoustic releases were not fitted with their explosive bolts. One mooring was recovered after 4 days but the second was lost on recovery when a shackle jammed in the trawl winch. I was on that cruise as a student helper.

The following year on Cruise 20, 5 moorings were deployed and recovered in the middle of the Bay of Biscay. There was mixed success. Several current meters were damaged (the big fins were torn off the Braincon meters) and several delivered data of poor quality. The Cruise 20 mooring design is shown here. (Courtesy National Oceanographic Library/NOC). The results are in an [NIO Internal report](#).



WHOI had been involved in mooring work [since 1963](#) but were not doing much better. From January to April 1967 John Swallow joined Val Worthington and his WHOI colleagues aboard the Canadian vessel *RV Hudson* to try to recover an array of WHOI moorings measuring the deep flow in the Denmark Strait between Iceland and Greenland using current meters, (the forerunner of the Geodyne instruments) designed by Bill Richardson (Ref 1). It was spectacularly unsuccessful with only 10 out of 30 instruments recovered and usable data provided from only one current meter. So, based on these experiences, the start was not auspicious.

By the time I joined in 1967 NIO had decided to use the commercially-produced Aanderaa RCM4 derived from the CMI instrument. They were small and used magnetic tape (processing film records as in the Geodyne and Braincon current meters was tedious and on at least one occasion led to the processing lab returning only the ends of the record since they thought all the dots and arcs were just dirt!). The Aanderaa instrument could also measured temperature –

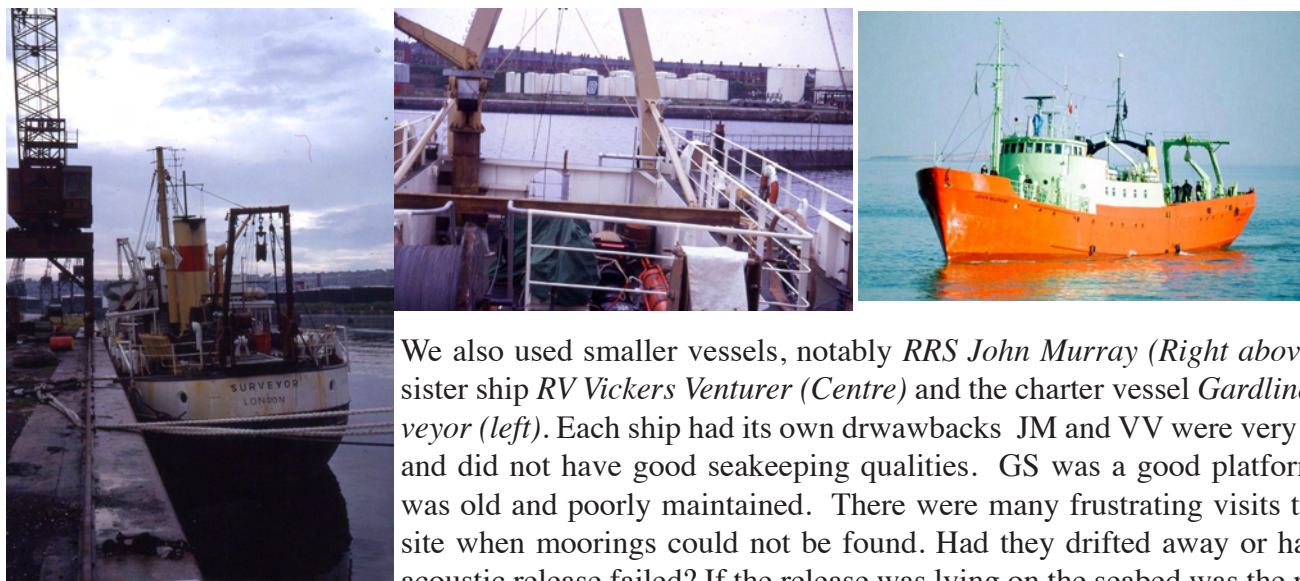
an added scientific bonus and could have a pressure sensor too. After a while such sensors were used routinely on the uppermost instrument of full depth moorings so as to monitor the amount of “knockdown” the mooring experienced when currents were strong. We had a few remaining Braincon instruments but eventually they were all lost.

WHOI had established Site D on the continental slope within a day's sailing of the lab and this was used as a mooring test-bed. We similarly started to use a site on the continental slope in the Northern Bay of Biscay.

² Designed by Bill Richardson in the USA and the instrument of choice at WHOI.

³ This was a fundamental redesign of the current meter developed at the Christian Michelsen Institute in Bergen Norway but using the same 10 bit electromechanical encoder and that had been tested by NIO on the IIOE.

The **Meriadzek Terrace** allowed us to deploy moorings in water between 500 and 2000m and with relatively gentle topography. It was (just) within range of Decca Navigator coverage and was passed by virtually all ships on passage to and from their bases in (first) Plymouth and Barry. Moorings were deployed on an opportunistic basis but we rapidly learned that the area was not noted for its good weather and that it was a favourite location for long-line tuna fishermen from Breton ports.



We also used smaller vessels, notably *RRS John Murray* (Right above), its sister ship *RV Vickers Venturer* (Centre) and the charter vessel *Gardline Surveyor* (left). Each ship had its own drawbacks JM and VV were very noisy and did not have good seakeeping qualities. GS was a good platform but was old and poorly maintained. There were many frustrating visits to that site when moorings could not be found. Had they drifted away or had the acoustic release failed? If the release was lying on the seabed was the rest of

the mooring still there? We spent hours dragging with the trawl warp trying to retrieve lost moorings but with very little success. Without modern day navigation and transponding acoustics we were working “blind”. We did on one occasion however raise a submarine telegraph cable (hopefully disused) to the surface. A flavour of these cruises can be seen in John Swallow’s report of a [John Murray Cruise in October 1969](#).

MEDOC’69 (RRS Discovery Cruise 25) arguably marked the start of the modern era – the ship was now equipped with satellite navigation and a computer. However the mooring work started inauspiciously on the Meriadzek Terrace. The mooring deployed in December was located but the wire failed on recovery. Another mooring in the Bay of Biscay was lost when, on deployment, the buoyancy imploded much shallower than its design depth. The MEDOC moorings, despite atrocious weather, were our first major success; 10 moorings deployed (mooring numbers 28-37⁴) and recovered, 37 instruments deployed, 3 instruments lost, 7 delivering no data.



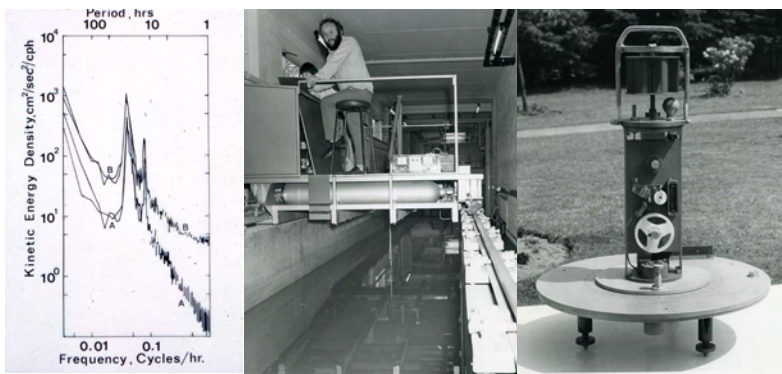
Imploded buoyancy on Cruise 25 with Bob Dickson, MAFF Lowestoft.

What were we measuring?

By the late 1960s there were many labs worldwide developing and deploying moored current meters and concerns grew around the question Did they all measure the same thing? So, in 1967 SCOR set up Working Group 21 (Continuous Current Measurement), *To design and propose means of carrying out, an intercomparison at sea of the principal current measuring systems now employed for the continuous measuring of current velocity on moored stations*”. John Swallow was its chairman. The first **intercomparison** was at Woods Hole in summer 1967 and the second was in Spring 1970 on the Soviet research vessel *RV Akademik Kurchatov*. I took John Swallow’s place on that cruise, an adventure that is recounted in Chapter in *Of Seas and Ships and Scientists*.

What the Kurchatov intercomparison showed was that current meter performance depended on both mooring and current meter design. Current meters gave anomalously high speeds when deployed on surface moorings due to the “pumping” of the speed sensor by wave motion transmitted down the mooring line.

⁴ Sequential NIO mooring numbers started in 1967 but also included deployments of tide gauges and other devices not necessarily including current meters. They were not used consistently particularly on joint cruises with other labs.



Left. Spectra showing that on a surface mooring (B) both high and low frequency energies were higher than on a co-located surface mooring (A). Centre. Towing tank calibration. Right. Compass calibration of an Aanderaa RCM4. Courtesy National Oceanographic Library/NOC

Another concern that NIO identified was that where tidal currents were strong (and that particularly applied to our usual working area in the NE Atlantic), any deviations of the current meter compasses from a linear response would

result in the rectification of the tidal signal into a spurious mean current component. As a result of this we started to calibrate the compass on each instrument and convert the individual readings to directions using a “look-up table”. The calibrations were done using a sighting compass accurate to 0.1° and a beautifully built, non-magnetic turntable at a site in the NIO grounds free of magnetic anomalies. I explored both of these issues in 1972 when I spent a year working as a postdoc with the WHOI buoy group (Refs 2 and 3).

The speed sensors were also individually calibrated in the towing tank at Wormley. This allowed instruments with high stall speeds to be identified and improved. So, in summary, we put a great deal of effort into the instrument preparation.

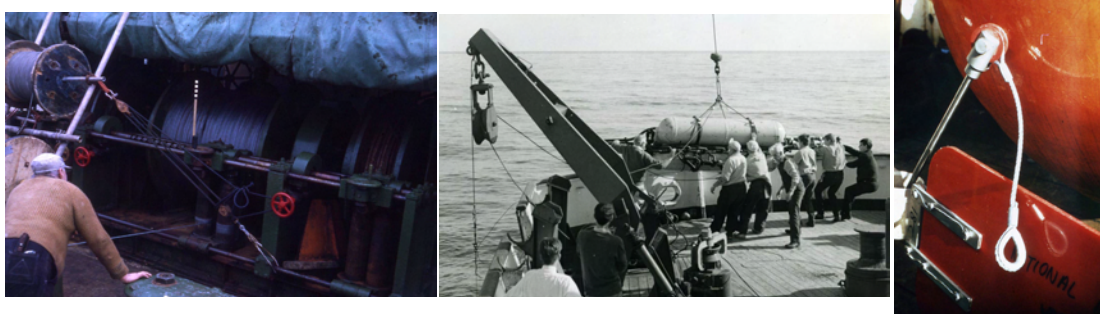
Technological advances

It is hard to reconstruct the exact chronology of the technological and mechanical engineering innovations that led to the improvement of mooring survivability without referring to the mooring log sheets that are held in the archives in Southampton. However the following are significant advances from my recollections and from the cruise reports.

- Ships, “A” frames, wires and winches

At the start of this narrative, even state-of-the-art ships like *Discovery* were totally unsuitable from mooring deployment and recovery. They had small, cluttered working decks, small gantries that preceded the introduction of “A”- frames, and no dedicated mooring winches. Undoubtedly a major advance was the development of the **double-barrelled winch**. Moorings could then be deployed either buoy or anchor first and from virtually any vessel.

In the mid 1970s *Discovery*’s old foredeck hydro winch was removed and replaced with a modest sized mooring “A” frame. The DB winch could then be installed on the foredeck allowing mooring operations to be visible from the bridge. The first use were aboard the chartered *Vickers Venturer* and *Gardline Surveyor* around 1970. The previous technique of winding the mooring on top of the trawl warp on the main winch was hazardous in the extreme.



Left. Dick Burt guiding a termination through the trawl winch guide rollers. Centre. Aft deck *Discovery* showing small gantry. (Courtesy National Oceanographic Library/NOC). Right. Swaged Telurit wire termination.

In the early days we used galvanised wires (Brunton’s Kilindo 6mm and 8mm) with swaged (Telurit) terminations made on board. As longer deployments (over 2 months) were attempted we moved to jacketed (plastic covered) wires and eventually to preset wire lengths with factory produced terminations. We started to use non-metal mooring line with some caution. Experience at WHOI had shown that fish-bite was a significant risk in the NW Atlantic but it proved to be less of a problem in our usual working areas. By the late 1970s we were using jacketed Kevlar lines that were lightweight, low drag and low stretch.

- Buoyancy

As mentioned earlier, the 1966/67 moorings used cylindrical aluminium buoyancy units in a frame of scaffolding tubes. These were neither streamlined, nor easy to handle but were supposed to stand well clear of the water to make the moorings easy to see. They rarely worked well and were eventually found to deform significantly shallower than the depth for which they were rated. By the mid 1970s the standard buoyancy unit was changed to a 4ft dia. spun steel sphere. These were robust (though awkward to handle until research vessels started to be fitted with large stern “A” frames) and were still being used into the 1990s.

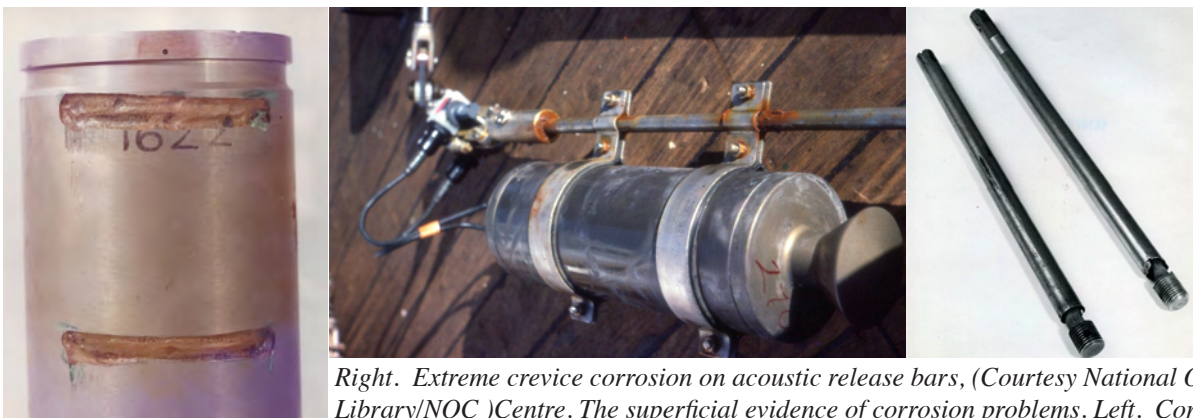


Left. 4' sphere showing the foredeck gantry on Discovery. Centre. A typical tangle of backup buoyancy, current meter and mooring line. Right. Untangling the knitting

The introduction in the 1970s of the computer program “Shape” written by Tim Barber and the inclusion of a pressure sensor on the uppermost instrument allowed us to estimate and measure the amount of “knockdown” due to strong currents and reduce the risk of main buoyancy implosion. Undoubtedly a major advance was the commercial availability from 1969 onwards of Benthos 17” dia. glass spheres. These were low drag, robust and could be made up into multiples of 25kg buoyancy. They were ideal for near-bottom moorings and for incorporating “backup” buoyancy into full depth moorings. However the use of backup buoyancy together with synthetic rope line often resulted in a terrible tangle of spheres, rope and current meters.

- Corrosion

Stainless steel for use in the marine environment had to be an appropriate marine grade (e.g. austenitic 316S16). Throughout this story we encountered occasional rogue batches that were subject to severe crevice corrosion and it was not until titanium became readily available in the 1980s that this potential source of mooring failure was eliminated.



Right. Extreme crevice corrosion on acoustic release bars, (Courtesy National Oceanographic Library/NOC)Centre. The superficial evidence of corrosion problems. Left. Corrosion of an Aanderaa pressure case after less than 1 month in the deep Mediterranean outflow west of Gibraltar.

- Deployment methods

The conditions under which we deployed moorings were very variable – from winter in the north Atlantic to the tropics and from billiard-table flat abyssal plains to mountainous but often unknown topography. We

⁵ Backup buoyancy was inserted above the acoustic release and below the deepest instrument so that the mooring could be recovered if the main buoyancy were lost for any reason. The added buoyancy of course then required heavier anchors.

started by deploying moorings anchor first – a method that did allow the ship to remain in the required position but that meant the entire mooring line was under high tension (typically ~ 1 tonne) throughout and leaving little or no margin for error. Such deployment methods remain essential for positioning moorings in complex topography. The successful move to using buoy-first deployments on *RRS Shackleton* (Cruises 2 and 7/75) made for much safer deployments in areas of flat topography. The two moorings were recovered after 150 days and subsequently the method was used on *Discovery* with the aft section of the bulwark being removed. There is video of these [mooring operations](#) in the NOL archives. Improvements in navigation successively reduced the uncertainty of where the moorings were deployed and, more importantly, helped with the re-location of moorings.

The greatest improvements in the safety and reliability of mooring operations came with modern ship, crane and “A” frame design. *Discovery*, as built in 1962, was designed for observational methods not dissimilar from those used on *HMS Challenger* in the 1870s. *Discovery* was modernised in successive major refits but not until she was lengthened in the early 1990s did she have a large uncluttered aft deck and A frame fitting her for modern day mooring work. Of the other ships we used *RRS Shackleton* (built 1955) was even more cramped. *RRS Challenger* (built 1973) was of a more suitable layout but had limited endurance. The first ship built with mooring work specifically in mind was *RRS Charles Darwin* (1985 onwards). Other aspects of ship design benefitted our work. The introduction of hydraulic ring mains meant that the DB winch did not have to use the extremely noisy air-cooled diesel engine as a power source. Similarly, as articulated hydraulic cranes became commonplace so our ability to handle heavy items safely improved greatly.



These improvements are illustrated above. L to R *RRS Shackleton* mid 1970s, *RRS Challenger* ca 1983, RAPID moorings *RRS James Cook* ca. 2010.

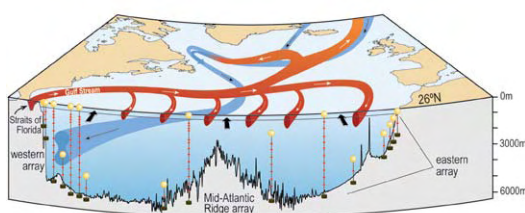
The continuing story

The technological advances have been many and varied with most occurring in the 1970s and 80s. Not all can be described here and a thorough documentation is beyond the scope of this short document. The design of moorings in the 1990s

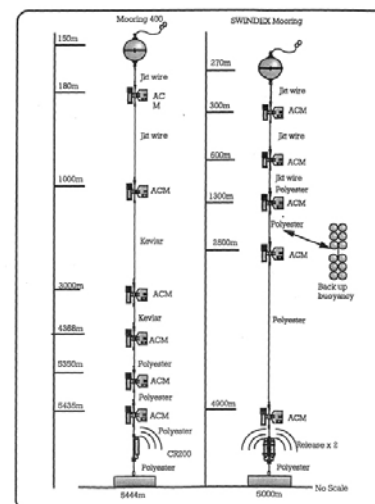
is described in the detailed technical reports of the moorings for the *Left Schematic of the RAPID array between west ADOX* (near bottom moorings) and *Africa and Florida*.

SWINDEX (full depth moorings)

studies in the Southern Ocean (see references in the following section).



Right. Diagram of a SWINDEX mooring and of mooring number 400 deployed in the mid 1980s.



Science as a driver

Innovation in our ability to deploy moored current meters went hand in hand with scientific drivers, with NIO/IOS’s involvement in major projects and with technology developments. MEDOC has already been mentioned but other experiments drove our progress as follows :-

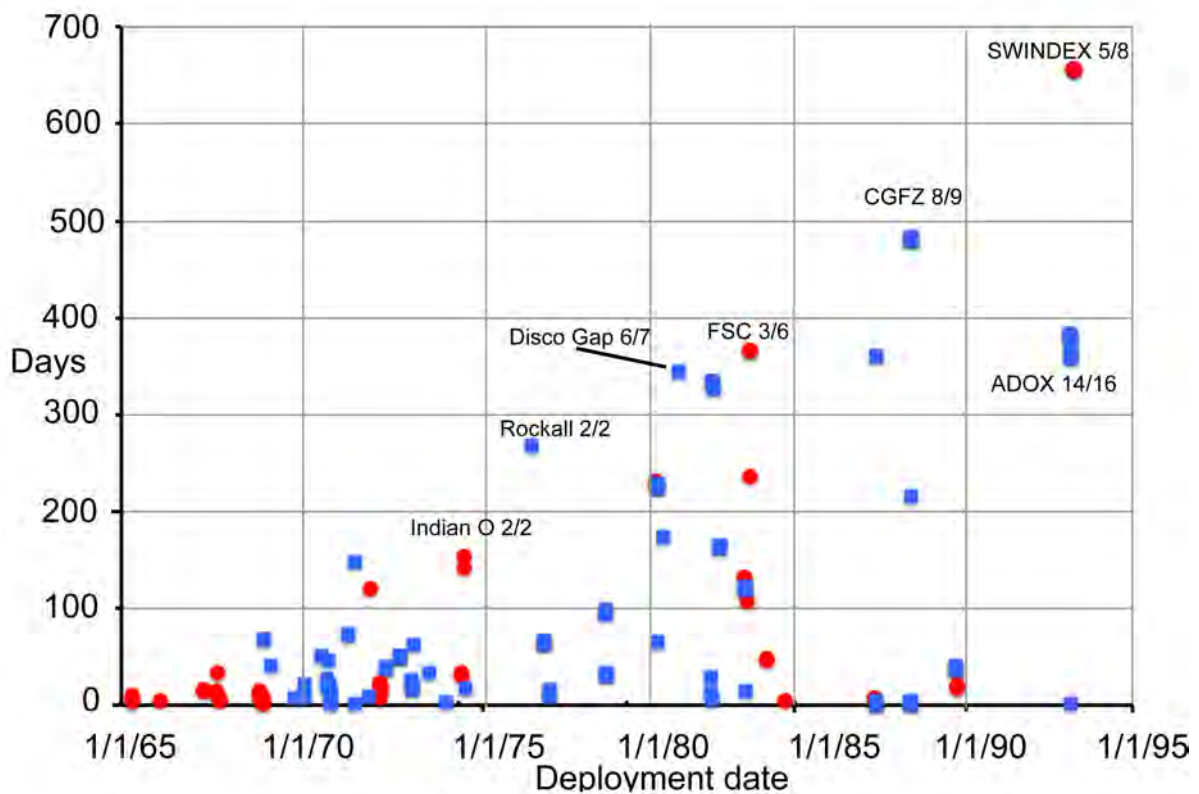
- Internal wave spectra
Records that we collected in the late 1960s were typically 30 days long with a measurement every 10 minutes. Because they had temperature measurements they were ideal for studying internal waves and were used by Walter Munk and Chris Garrett (Ref 4) to validate their universal internal wave spectrum.
- The MEDOC experiments in the western Mediterranean in winters of 1969 and 70 arranged jointly with Woods Hole and French scientists used moorings to reveal the form and vertical structure of chimneys in which deep water was being formed (Ref 5)
- Studies of Mediterranean outflow and Mediterranean water variability
The measurement of the Mediterranean water outflow by Steve Thorpe (Ref 6) revealed remarkably rapid corrosion of the current meter pressure cases – never adequately explained.
- Slope currents around NE Atlantic
The accumulation of measurements on the Meriadzek Terrace in the 1970s and later elsewhere on the NW European continental slope confirmed the existence and characteristics of the poleward slope current. (Refs 7 and 8)
- Mid Ocean Dynamics Experiment (MODE) off Bermuda 1973
The continuation of John Swallow and Henry Stommel’s exploration of the ocean mesoscale continued with MODE. Though SOFAR floats were undoubtedly the major contributor there was a large array of moorings of which NIO (which became IOS during the experiment) contributed 5 using the then new Vector Averaging Current meters (VACMs). (Ref 9)
- Abyssal flows.
In 1975 moorings and floats were used to study the flow and stratification around a small hill on the Iberian Abyssal Plain. Though the experiment was a success (Ref 10) it revealed that at high pressures the nickel-plated Anderaa pressure cases became magnetised and affected the compasses.(Ref 11)
- Indian Ocean
In 1975 RRS Shackleton was in the Indian Ocean and the opportunity was taken to deploy two moorings on the equator from March to August. This required a degree of innovation, deploying the moorings “buoy first” with the vessel going astern! Both were recovered successfully – the longest IOS deployment to date . (Ref 12).
- North East Atlantic Dynamics Study, (NEADS) 1976-78
Following on from MODE, there was a joint USA-USSR study (PolyMODE) to explore the geographical variability of mesoscale variability. One component was long deployments of current meter moorings throughout the North Atlantic. A European component the North East Atlantic Dynamics Study (NEADS) contributed to PolyMODE and was also a component of the study of radioactive waste disposal. Amongst other discoveries it revealed a seasonal signal in mesoscale variability that penetrated to the ocean floor. (Ref 13). IfM Kiel (now Geomar) have maintained one NEADS site near Madeira (Kiel 276) to the present day.
- Joint Air-Sea Interaction Experiment JASIN 1978,
This experiment that coincided with the launch of SeaSat used moorings with surface buoys measuring upper ocean structure and meteorology together with subsurface moorings to determine the mean circulation and variability of the Rockall Trough. The subsurface moorings were extended to provide current climatologies for offshore oil exploration west of the UK. (Ref 14). This started a close collaboration in mooring work between IOS and the Dunstaffnage Lab (now SAMS)
- Continental Slope Experiment CONSLEX (western European continental slope (1982/3)
Following on from the Rockall measurements a consortium of oil companies funded IOS to measure currents on the NW Shetland continental slope. Scientifically these measurements were a contribution to the North Atlantic Norwegian Sea Exchange (NANSEN) project. (Ref 15).
- Studies of near bottom flows in the N Atlantic.....
These started in the late 1970s with a study of flows around a small abyssal hill (Ref 16) and continued through the 1980s (driven by the radioactive waste work) and into the 1990s as part of the World Ocean Circulation Experiment (WOCE), IOS studied the flow of near bottom water masses through choke points (Discovery Gap (Ref 17) , Charlie Gibbs Fracture Zone (Ref 18)) and south of Iceland. (Ref 19).

- and in the Southern Ocean

My final involvement with moorings was on Discovery Cruise 201 in 1993 when in a joint contribution (ADOX) to WOCE between IOS and MAFF (CEFAS) moorings were deployed for a year to measure bottom currents in the Crozet-Kerguelen area (Ref 20). At the same time Raymond Pollard deployed moorings around the Crozet plateau for 2 years to study the circulation of the SW Indian Ocean. (Refs 21,22)

Measuring progress

In an effort to quantify the progress we made I have compiled a spreadsheet of information from cruise reports documenting the deployment and successful (or not) recovery of current meter moorings. The records are certainly not complete but moorings deployed in most major experiments between 1965 and 1995 have been studied. As has been alluded to in the previous sections, improvements in mooring technology went hand in hand with the drive by scientists to deploy ever increasing numbers of moorings from longer periods. The following figure charts the successes and differentiates between full depth moorings (covering all or the greater part of the water column) and near bottom moorings (covering only the lowest few hundred metres of the abyssal ocean)



Duration of mooring deployments (Blue, near bottom, Red, full depth or surface). The numbers e.g. 6/7 denote number of moorings recovered and number deployed

People –the key to success

Finally credit needs to be given to the NIO/IOS “mooring team”. This team was never quite as clearly defined as the WHOI buoy group but without its dedication none of this story would have been possible.

Among those people were

- Dennis Gaunt: engineering design including the double barrelled winch
- John Cherriman, Ian Waddington and Keith Goy: responsible for putting moorings together and for instrument preparation
- Bob (Ace) Wallace, Dave Grohmann, Rob Bonnor and many others: engineering support and winch driving.
- Mac Harris, Greg Phillips, Eric Darlington, Mike Sawkins : mooring acoustics.

- Ships officers and crew : on *Discovery* in the early days Dick Burt (netman) and Harry Moreton (bosun) were essential and often worked in conditions that we would now consider unsafe. On each cruise the bosuns and deck crew (too many too name) all gave us unstinting support

Postscript - The start of a day of moorings

As the chief scientist on many mooring cruises I have vivid memories of successes and failures. There is however a sequence of events at the start of a day of mooring operations that is a lasting one and that will be recognised by others who have been in a similar situation at the start of a day oceanographic activities.

A wakeup call on the cabin telephone or a knock on the cabin door. It is before dawn.

You are instantly awake, your senses alert to the ship's motion. Are we under way or hove-to? How rough does it feel?

You have quick, shower (maybe), get dressed and go to the main laboratory for a cup of tea and a chat to the science watchkeepers to find what has happened over night.

Then up to the bridge to talk to the mate who is in command for the 0400-0800 watch. It is still dark outside. Are we in position for the first mooring and if not when will we be there?

If the weather is likely to be fit for mooring work (that was often a matter of tense discussion between the chief scientist officer of the watch) and we are close to the position we call out the the team to make contact with the mooring's acoustic release. If successful then its time to alert the rest of the mooring team and the deck crew.

Then everyone concerned has an early breakfast

When everyone is ready, position the ship downwind of the mooring position. Send the release signal.

Wait for confirmation that the mooring has separated from its anchor. All hands keeping a sharp eye for the buoyancy at the surface. There it is! Manoeuvre the ship into position. Crew throw the grappling iron.

Connect the mooring to the recovery winch and start the recovery. We are already 3 hours into what will be a very long day.

Sometimes you have to wait.



In 2008 via a roundabout route we learned that in the process of clearing debris from an oil drilling site in on the west Shetland slope some mooring equipment had been found. We were sent photographs and it looked familiar. The equipment, a single Aanderaa current meter, an acoustic release and a sort length of wire were returned to Southampton. We identified its as the bottom part of mooring 317, deployed in March 1982 (over 25 years earlier!). Amazingly the instruments had not leaked and the data (almost a complete year's worth) were readable. How many more years of data are still lying on the seabed?

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August , 2017**