The UK contribution to the Mid-Ocean Dynamics Experiment - MODE[1].

Personal reminiscences from John Gould.

In the early summer of 1973 a large-scale joint experiment between UK and US scientists was mounted in an area SW of Bermuda. It sought to map the oceans' subsurface "weather". While MODE was a predominantly US experiment, the UK contribution was significant and one might say, pivotal. It also marked the start of a modernisation of UK oceanography.

MODE's roots go back to John Swallow's work on *RV Aries* off Bermuda in 1960 when he tried to confirm Henry Stommel's prediction of the slow, poleward interior flow in the deep ocean. Instead, the year-long *Aries* measurements were the first to give direct evidence of an energetic ocean mesoscale (Crease, 1962, Swallow, 1971)[2].

The UK contribution was from scientists at the National Institute of Oceanography[3] led by John Swallow. It involved the deployment of 4 full depth current meter moorings, CTD profiling (143 stations) and the deployment of neutrally buoyant floats at nominal depths of 500, 800, 1500, 3000 and 4000m. These floats were of a radically new design, (Swallow, McCartney and Millard, 1974) and could be tracked from the ship at ranges of up to 70 km. The work was carried out from *RRS Discovery* including preparatory work on the outward voyage (Cruise 52). (John Swallow and several others were at sea for 4 months from 17 Feb to 14 June).

Planning and preparation

Planning for MODE was a long and complicated undertaking involving many formal and informal meetings in cigar smoke-filled rooms in the Woods Hole Oceanographic Institution's Smith Building and at more exotic locations such as Nova University in Ft Lauderdale. I attended many of them since I was at that time a postdoc working in the buoy group at WHOI starting in January 1972 and returning to the UK via Bermuda in January 1973 where a MODE planning meeting was taking place at the Biological Station. Figure 1.

Figure 1. Henry Stommel (left) and Allan Robinson "discussing" MODE at a planning workshop on Bermuda. Nick Fofonoff observes, (far right).

[1] Henry Charnock, NIO Director suggested that MODE stood for Modern Oceanography, Damned Expensive

[2] Both John Swallow and James Crease took part in both MODE and in the Aries experiments, as did Allan Robinson (Harvard).

[3] During the MODE experiment the National Institute of Oceanography, which had been established in 1949, became the Institute of Oceanographic Sciences following its integration with two other UK labs focussed on tidal research and coastal sedimentation.

Technology and innovation

MODE was carried out at a time when technologies we now take for granted were starting to become widely used, (multisamplers, stable CTDs, satellite navigation, shipboard computing), but others, (floats which were not dependent on acoustic tracking, satellite remote sensing) were still but a dream.

My postdoc work had focussed on unravelling the impact of surface wave motion on deep sea current meter measurements. At the same time this was also the focus of SCOR Working Group 21 (Chaired by John Swallow), Gould and Sambuco (1975). This had made clear that we needed to use moorings with subsurface buoyancy and that earlier generations of current meters had significant defects.

For MODE, NIO used moorings with main buoyancy at 200m, Aanderaa current meters at nominal depths of 500, 1500, 3000 and 4000m and backup buoyancy above the acoustic releases. The recovery of some of the moorings provided a lesson in unravelling kilometres of rope.

For the UK contribution we used a CTD that had been built in Woods Hole by Neil Brown and by NIO's Geoff Morrison and first used in September 1972. It proved to be much more stable than previous instruments. It was coupled with 12 bottle multisampler with mercury in glass thermometers. Data were recorded on a dedicated HP 2100A computer. *Discovery* also had an IBM 1800 computer for basic data logging and navigation (a combination of Magnavox transit satellite positions and a 2-component electromagnetic log to interpolate positions between fixes).

Left. John Cherriman and Dick Burt wondering where to start. Below. A MiniMODE float.

The major innovation from NIO were the Minimode floats developed specifically for this experiment. These transponding floats made possible by improved transducers and microelectronics. The ''MiniMODE'' system (Swallow et al., 1974) allowed up to 18 floats to be tracked simultaneously (each identified by its own frequency in the range 5.0 –6.5 KHz). The floats responded to signals transmitted from an interrogator attached to a CTD/water sampler package so that hydrography and float tracking could be conducted simultaneously. This ability to interrogate from a wide range of depths allowed tracking of floats at all depths and the achievement of ranges of up to 70km (almost 2 min signal travel time). Previous Swallow floats had free-running 10KHz sound sources and were tracked from the attendant ship

towing an array of hydrophones. The Minimode floats were recoverable and re-usable whereas earlier ones were expendable.

Sadly, no audio recordings survive of the sounds made by the MiniMODE floats – a seemingly random sequence of differing notes against a background of underwater noise. If the system had a weakness it lay in the complex switching system contained in the multisampler/ CTD/interrogator package and its underwater connections.

A detailed description of the technology used on the MODE cruise can be found in the cruise report (Swallow, 1973).

Cruise recollections

For all of those taking part it was a long cruise but Bermuda was a pleasant, exotic and novel port call for most of the officers, crew and scientists. We used St George's as a base (as had *Aries* 13 years before) with the ship berthed alongside the yacht club. There were several minor casualties due to the incompatible combination of rum and mopeds. Many of the catering staff had just joined *Discovery* from Cunard and so the food was good and continued the rather traditional silver service catering using china bearing the ship's logo. Some members of the crew provided impromptu entertainment in the local night clubs that eclipsed that provided by the professional performers.

Water was in very short supply in Bermuda and during the mid-cruise port call *Discovery* relocated from St George's (where water came slowly from a small tanker truck) to Hamilton where supplies were better. When there, it was clear how small our ship was compared with even a modest-sized cruise liner (Figure 2). Our final departure from St George's was marked by a big fire in the nearby yacht club the night before we sailed!

Figure 2. Discovery in Hamilton, Bermuda.

Analysis, publications

The experiment produced a unique data set that attracted a great deal of interest and there were as many workshops and meetings to help with the interpretation as there had been for the planning. It also drew in several people who had not been involved in the observational phase.

Figure 3. Al fresco lunch, MODE analysis workshop, Nova University, Fort Lauderdale, 1974. Names (L to R, seated unless stated otherwise). Peter Rhines, Nelson Hogg (standing), Tom Sanford (1940-2020), ?? standing, Ants Leetmaa (-2017,standing) ,??, Tony Sturges (-2022, standing), Jim Baker, Nick Fofonoff (1929-2003, standing), Ferris Webster, Rich Scarlett, Carl Wunsch, Gerold Siedler, Bill Holland (standing), Henry Stommel (1920-1992,standing), ?? (standing).

At one such analysis workshop in Bermuda I learned an important lesson – Always stay in the room when tasks are being allocated – I left the room and thereby became an editor of the MODE Atlas. MODE resulted in many publications of all types including a full-length movie and perhaps the least formal being the MODE play written by the late Bill Richardson[4] with its depictions of the dramatis personae. One that rang particularly true was the line "Enter Crease and Swallow, muttering". The experimental results were summarised in a synthesis paper. (The MODE Group, 1978)

Legacy

MODE was not the first experiment to explore the ocean mesoscale in a systematic manner. In 1970, Soviet scientists had mounted their POLYGON experiment in the eastern Atlantic tradewind zone. I, and WHOI's Bob Heinmiller[5], had taken part in POLYGON as part of the SCOR WG 21 intercomparison of current meters (Gould and Zenk, 2020). Arguably MODE came at a turning point in physical oceanography. In the following years, encouraged by PolyMODE the exploration of the ocean mesoscale expanded into the eastern North Atlantic. In 1978, SeaSat, the first satellite dedicated to ocean science, was launched and it's brief 100-day life gave a glimpse of the possibility of observing the ocean systematically on a global scale.

That possibility came to fruition with the World Ocean Circulation Experiment (WOCE), the planning of which involved several of the prime movers from MODE (Francis Bretherton (Chair), Jim Crease and Carl Wunsch were among the first members of the WOCE SSG in 1982) Figure 4.

[4] Bill Richardson was professor of physical Oceanography at NOVA University. Sadly, he was lost at sea 2 years after MODE.

[5] We were the only two people to take part in the fieldwork of both POLYGON-70 and MODE.

Figure 4 L-R Carl Wunsch, Francis Bretherton and Jim Crease at WOCE SSG11 in 1984.

So, the MODE corporate memory carried over into WOCE. Many of the *in situ* observing components of MODE were the continued into WOCE – CTD stations, deep-sea pressure gauges, current meter moorings and neutrally buoyant floats though these were now largely freed from the constraints of acoustic tracking. So, MODE made the crucial quantum leap that took us out of the observing systems available up to the 1960s and into the world we know today.

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