B-DEOS Plans for establishment of long-term mobile interdisciplinary ocean observatory systems in the N and S Atlantic

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Introduction

Advances in theoretical understanding of the natural systems in the sea and in the Earth below have been closely associated with new data sets made possible by technological advances. Important and unanticipated processes have been revealed as a result of new capabilities in acquiring marine data. The plate tectonic revolution, the discovery of hydrothermal circulation, and many other examples can be attributed to the application of innovative new technology to the study of the sea.

A consortium of research groups and institutions within the United Kingdom is planning a regional system of multidisciplinary ocean observatories to study the linkages between the physical, chemical and biological processes regulating the earth-ocean-atmosphere-biosphere system. Funds have been released for engineering activities leading to the design of the basic mooring and telecommunications/power buoy system, and a UK NERC Thematic Programme is in the planning stage.

The B-DEOS (British - Dynamics of Earth and Ocean Systems) observatory system is designed to allow studies on scales of order 10^{-3}-10^{2} km, as well as to supplement on larger spatial scales the emerging global ocean and seafloor solid earth observatory network. The facility will make it possible to obtain requisite long-term synoptic baseline data, and to monitor natural and man-made changes to this system by:

- Establishing a long-term, permanent and relocatable network of instrumented seafloor platforms, moorings and profiler vehicles, provided with power from the ocean surface and internal power supplies, and maintaining a real- or near-real time bidirectional Internet link to shore.
- Examining the time varying properties of these different environments (solid earth, ocean, atmosphere, biosphere), exploring the links between them and the causes of the variability.
- Developing appropriate methods of acquiring data in real-time, assimilating them into mathematical models of the solid earth, oceans, and air-ocean interface, and promoting interpretation of these data for a truly synoptic understanding of the linked earth-ocean-atmosphere-biosphere system and its components.

Feasibility: Major advances in technology have demonstrated the potential of geophysical and oceanographic sensors mounted on deep water seafloor platforms and moorings for recording and transmitting data to the surface. Major advances have also been made in the oceanographic disciplines over the past decade such that a wide variety of marine properties can now be measured *in situ* over prolonged time periods (eg nutrients, phytoplankton concentration, aqueous geochemistry, ocean currents and temperature). Furthermore developments of subsurface vehicles to carry such sensors are nearly ready for large scale deployment. Satellite telecommunications enable these data to be transmitted from remote areas (inaccessible to shore cables) to land-based data centres in real-time for dissemination via the Internet. These Internet links make it possible for shore-based scientists to modify experimental parameters and instrument operations remotely in response to changing environmental or engineering conditions.

A UK Natural Environment Funding Council supported feasibility study by an academic-industrial partnership (Cardiff University, Kvaerner Oil & Gas Australia Pty Ltd, Southampton Oceanography Centre) has culminated in a design specification for a permanent ocean observatory communications and power supply buoy system. The observatory buoy platform and moorings will be deployable from the largest class of research vessels available to the UK fleet (e.g. RRS James Clark Ross), or international equivalents. The scientific rationale for such an observatory system is summarised below, and the enabling technology of large ocean power/telemetry buoys envisaged for B-DEOS is outlined.

Science planning:

Our efforts are part of a larger international requirement for sustained multi-disciplinary ocean-based observatories. The present proposal falls under the umbrella of DEOS (*Dynamics of Earth and Ocean Systems*), an initiative in advanced planning in the UK and the US (further information about the DEOS observatory programme may be found at www.deos.org). Intersections between B-DEOS and other international ocean observatory efforts such as Euro-GOOS and CLIVAR are also taken into consideration.

The B-DEOS draft science plan currently calls for establishing in the first instance three observatory locations, employing at each a relocatable 200 km long 1D array of oceanographic sensors bisecting a 50 km on a side 2D array of multidisciplinary sensor platforms. This scenario is based on the staged installation of the first observatory at a high latitude N Atlantic site. After an initial operating period of three years, the bulk of the observatory array will be relocated to the next observatory site. The central node in the array is to be left in place, and modified for very long term operation as part of the global system of permanent geophysical and meteorological stations. The process will be repeated a second time, resulting in establishment of three sites in the N and S Atlantic and Southern Oceans. From an engineering perspective, the instrument array, buoys and moorings have been specified to satisfy the operational and scientific requirements in each of the potential target areas.

Initial observatory site - Reykjanes Ridge:

The location proposed for the first deployment of the UK observatory array is a 200 km long (E-W) by 50 km wide (N-S) area centred on the Reykjanes Ridge – the section of the slow spreading Mid-Atlantic Ridge extending southwards from Iceland to the Charlie-Gibbs transform system. The Reykjanes Ridge represents an area of the North Atlantic at which multi-disciplinary data collected by the observatory array will be able to address fundamental questions relating to biogeochemical fluxes and cycling; to ocean circulation; and to the dynamics of the upper mantle and sea floor spreading. This also serves as a component in the global observatory array.

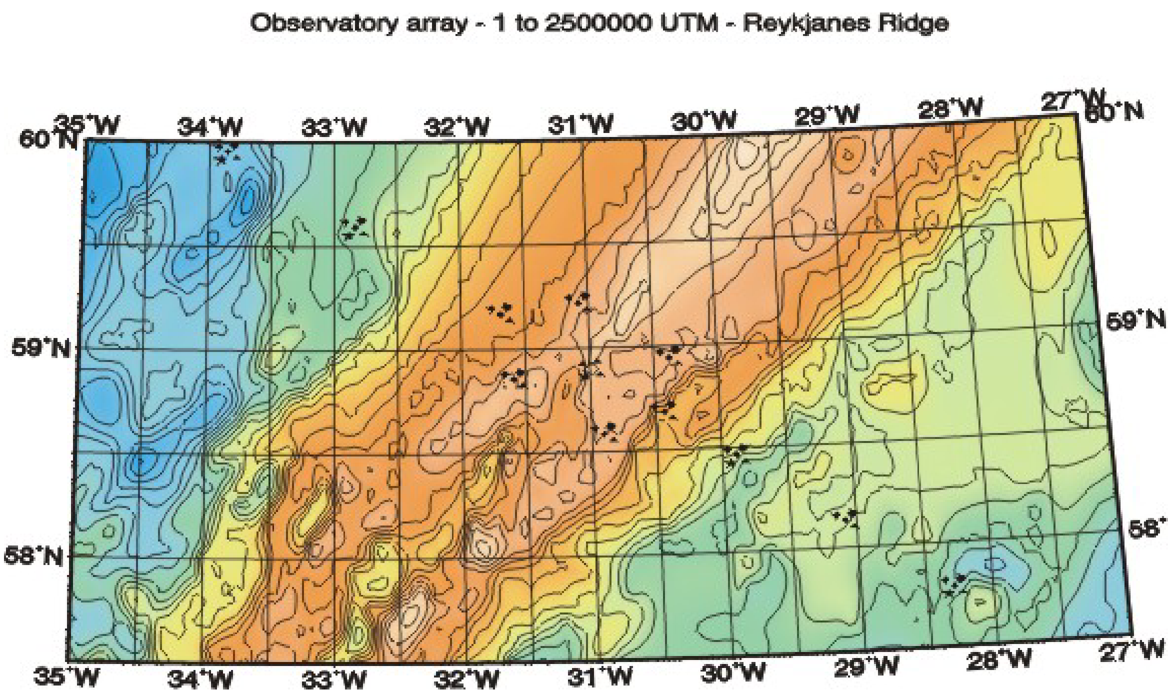

Fig 1. Location of 50 km × 50 km dense observatory instrument array centred on Reykjanes Ridge, with 200 km long 1D instrument transect bisecting the array. This configuration permits study of local, regional and global scale processes. Each point in the array comprises three seafloor landers and a mid-water relay buoy forming a 10 km on a side triangle for high resolution site-specific studies.

The initial location of the observatory array has been chosen to allow optimum resolution of the uppermost mantle – between the Moho and 200 km depth – beneath the Reykjanes Ridge. Geophysical observations are used to image the structure of the uppermost mantle, and to determine if the upper mantle structure is consistent with expectations based on models of tectono-magmatic cycles. Such information provides the basis for a new generation of predictive geodynamic models of mantle matrix flow, melt generation and melt extraction that take full account of time variations and their interactions with ridge segmentation.

Geophysical measurements, methodology and array geometry

The geophysical component of the observatory (the central 50 km by 50 km "box" seen in Fig 1) is currently planned to comprise 36 bottom lander sites organised into 12 sub-arrays, all measuring long-period seismic and electromagnetic data (e.g. magnetotelluric <<MT>> data). Each sub-array consists of 3 multi-component instrumentation platforms arranged around a central telemetry mooring (Fig. 1, 2), and each separated from the other platforms by 10 km. Electromagnetic data will be collected by biaxial electric field sensors, and triaxial magnetometers. Seismic data will be collected by triaxial, broadband Güralp seismometers and/or differential pressure gauges. The geometry of the array is optimised to allow adequate spatial coverage for the magnetotelluric sounding, and will allow surface wave phase velocities to be measured at periods from 10 s up to at least 60 s, where the data have the best signal to noise ratio and provide the strongest constraints on the structures of interest.

Ocean physics, air-sea interactions and upper ocean biogeochemistry – the Reykjanes Ridge transect

The 200 km-long E-W oceanographic instrument array, i.e. the Reykjanes Ridge

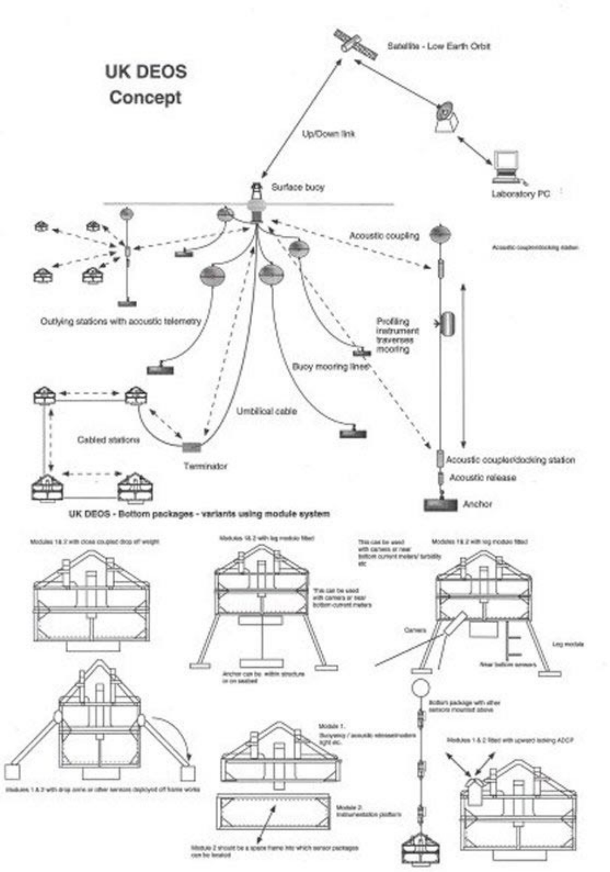

Fig 2. Schematic of central telemetry/meteorological mooring supporting acoustic communications to seafloor instrumentation platforms and to oceanographic mooring.

Transect (Fig 1), is designed to measure the structure and transport of deep boundary currents on either side of the ridge. Physical oceanographic and upper ocean biogeochemical data will be provided by a set of five vertical sub-arrays, distributed from WNW to ESE across the axis of the Reykjanes Ridge, and extending laterally for 200 km and vertically throughout the entire water column. Each vertical sub-array will be fitted with standard physical oceanography sensors, together with a vertical profiling vehicle which will transit at least once per day through the upper 1000 m of the water column. The vehicle will measure conductivity, temperature and depth (CTD), together with chlorophyll and zooplankton abundance and size distribution.

The surface buoy at the centre of each observatory will be instrumented to measure the fluxes of heat, freshwater and momentum between the atmosphere and ocean.

The transect of time series observatories across the Reykjanes Ridge offers an opportunity to study the boundary between two N. Atlantic biogeochemical provinces, the Atlantic Arctic province (ARCT) to the Northwest and the North Atlantic Drift province (NADR) to the southeast. We seek to characterise the two provinces which lie on either side of the Reykjanes Ridge in terms of their biology and chemistry. This is to be done primarily by a comparison of the oceanographic characteristics at the stations at each end of the cross ridge transect.

As seen in Fig 1, the intention is to deploy five time series moorings across the ridge, each of which supports a profiling vehicle carrying a suite of sensors to characterise the physics, and biology of the upper 1000 m of the water column. Measurements include CTD, chlorophyll and zooplankton abundance and size distribution with the incorporation of nutrient sensors later in the program. Profiles will be made once or twice per day with data being transmitted in real time acoustically to the surface buoy, multiplexed with the other geophysical, oceanographic and meterological data streams, and from there transmitted to the ground station by satellite.

Eventual permanent observatory installation

Since the array is designed to be a relocatable resource, much like a ship we envisage transporting it to new observatory locations over time. However one long-term objective is that the central sub-array on Reykjanes Ridge should be left permanently installed on the ocean floor, connected directly by power and data cables (rather than by acoustic telemetry, which is used during the three year wide area array operations period to relay data between instrument platforms and the central satellite communications buoy) to a long-lived data telemetry surface buoy, to form part of the DEOS global network of seismic and geomagnetic observatories.

At the centre of the array we plan therefore to install a communications mooring, equipped with a large, tethered, surface buoy that will provide the satellite communications link to shore. The buoy will also be fitted with a suite of meteorological sensors, compatible with those installed by the UK Meteorological Office on their other autonomous ocean weather stations.

Future observatory sites - MOMAR, Scotia Sea-Drake Passage

The Mid-Atlantic Ridge southwest of the Azores Archipelago contains four sites of high-temperature hydrothermal venting. These are found along a 200 km section of the ridge crest in varying geological settings and at a range of different depths/pressures. The Lucky Strike vent sites are distributed around a lava lake in the caldera of an axial volcano. The Lucky Strike segment, lying within EU waters, provides a natural laboratory (the InterRidge-designated "MOMAR area) for detailed multidisciplinary investigations in a range of seafloor environments, all within ready reach of the Azores.

The MOMAR area is also of wide interest to researchers into whole water-column processes. This section of the MAR exhibits a complex hydrography which is further affected by the ridge topography, the Mediterranean water tongue and the Azores current and front.

The water column overlying the ridge crest within the MOMAR area is noted for an increased biomass, perhaps linked to local upwelling around the islands as the ridge-crest shoals toward the Azores Archipelago. The intrinsically high biodiversity observed within the mid-water fauna at these latitudes attracts the interest of a wide spectrum of scientists studying biogeochemical cycles.

The Southern Ocean

The Southern Ocean plays a major role in regulating the Earth's climate because it serves as an important conduit for inter-ocean exchange between the Atlantic, Indian and Pacific Oceans via the Antarctic Circumpolar Current (ACC), which flows eastward around the Antarctic continent. A key to understanding the ACC is the Drake Passage - the natural "choke-point" between the southernmost tip of South America and the northernmost tip of the Antarctic Peninsula.

Due east of the Drake Passage lies the Sandwich Plate, which extends just 200 km from the medium-fast spreading East Scotia Ridge, in the west, to the South Sandwich Island Arc and trench in the east. The East Scotia Ridge itself exhibits a range in geological characteristics including at least one axial magma chamber beneath the ridge crest and a minimum of two discrete hydrothermal fields, located at opposite ends of the.

Within this area, the possibility exists to provide long-term continuous observations of all the major components of the plate tectonic cycle in real-time with telemetry either from moored arrays or through direct cable connections between the seafloor and land-based relay stations installed on the South Sandwich islands and/or South Georgia, an area of great strategic interest to the UK in which logitistical support is high.

B-DEOS observatory buoy system

An engineering feasibility study has considered competing designs for a stable, long-term buoy system to support sea-surface power generation, transmission of power to the seafloor, and bidirectional telemetry from the above-mentioned instrument array sites to/from the Internet.

Disc buoys have the majority of their volume above or at the waterline resulting in very small heave natural periods (below the wave period) and consequently follow the sea surface resulting in relatively large motions. Spar-type buoys have the ability to modify their natural period and hence 'tune' the response in union with the sea surface. The superior motion characteristics of spar buoys give advantages in terms of satellite communications and reliability, as well as mooring system load.

The B-DEOS spar buoy (Fig 3) is characterised by two sections of different diameters and a conical transition. Differing diameters allow for 'tuning' of the buoy to obtain the most favourable motion response. For SPAR type buoys the natural period is largely dependent on the surface-piercing diameter. Further 'tuning' of the buoy response may be carried out by including a heave-suppression plate around the keel. This allows for additional added mass which ensures the heave natural period of the buoy is in excess of any anticipated wave periods.

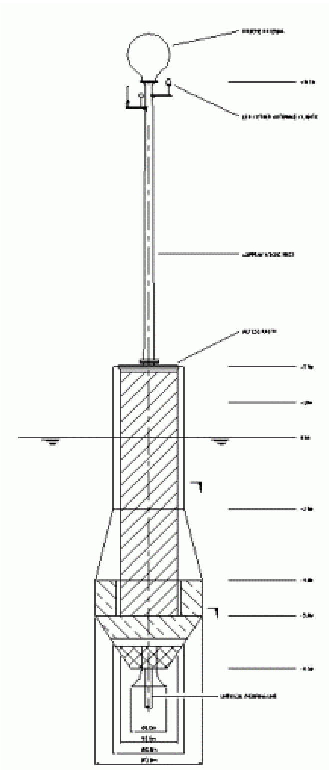

Fig 3. B-DEOS buoy schematic showing two sections of different diameter for tuned response, and INMARSAT antenna dome.

Design service life

The buoy internal and external systems and coatings have a design life of 20 years, with 10 years between major refurbishment (involving recovery of the buoy and subsequent redeployment). The buoy hull structure has been designed for a design life of 2 refurbishment periods (20 years), assuming a scheduled maintenance period of 2 years. This is based around a preventative maintenance program, including refuelling, replacement of consumables such as lubricants, and replacement of relatively low reliability items.

Proposed Locations

To date, four buoy locations have been proposed for the B-DEOS program:

1	58 N 33 W	Reykjanes Ridge
2	37.3 N 32.25 W	MAR axis close to Lucky Strike, 250nm S. of Azores
3	59 S 63 W	Centre of Drake Passage
4	59 S 27 W	Midway between E Scotia rise and S.Sandwich Islands

Operations at water depths of 2500, 4000 and 6000 m have been considered during the design phase.

Operating Condition

Data communications requirements dictate the use of an INMARSAT/B-HSD array for the primary system, necessitating an actively stabilised antenna unit. This places a limitation on the buoy motions to meet the specified design communications uptime of 95% within each monthly period. Wave heights occurring at Reykjanes Ridge are greater than for the other locations for all return periods, and therefore wave height data from this location only has been used for design.

The wave periods chosen in the buoy design specification is generally equivalent to a Beaufort seastate of 6/7 (high/very high). Wave directionality is not a significant design parameter, as the mooring system is not taut, and the buoy will be able to rotate easily inside its watch circle.

Heave and pitch are driven by a combination of wave forcing and dynamics. The wave forcing has two components: pressure driven and inertia driven.

The dynamic behaviour is characterised by a sharp resonant peak at the heave natural period. If the forcing cancellation and heave natural period coincide, heave motion is minimised over the operating range. This cancellation period can be manipulated by changing the geometric properties of the buoy; specifically the relative diameters of the cylinders and the cone angles. Heave motion can also be reduced by increasing vertical damping, over the frequency range where the dynamic component is large.

Servicing

The intent is that the buoy will be accessible for servicing and retrieval at least 3 months during the year. Servicing of the buoy will be carried out by either retrieving the buoy onto the deck of a vessel (either a research vessel or a supply boat) for repairs or maintenance or using standard connections for replenishment. The design of the payload package of the buoy is to allow simple removal and replacement of all major components in package form, with all connections between package systems and buoy hull systems to be made at a single location where possible. Servicing of seafloor packages will be possible by ROV, including the new UK national deep submergence facility currently being established.

Payload Requirements

The payload requirements are:

- Electronics Package
  - Buoy Control CPU
  - Telemetry CPU / Communications control hardware
  - Distribution panels
- Battery Package - Batteries for 1000W continuous use
- Generator Package - 1.5 kW generator for recharging the batteries
- Fuel Bladders - 6000 litres of fuel in independent bladders

Mechanical/Buoy Systems

In addition to the equipment included in the payload package, there will be various equipment installed on the buoy hull structure to enable it to function. This shall include the following.

- Inmarsat radome antenna array (approx. 1m diameter), other antennae as required
- Piping systems (fuel, exhaust, ballast, etc.)
- Bilge pump
- Hazard detection
- Navigation Aids, including lights
- Compartment access ways and seals
- Interface connectors
- MetOcean equipment

Power Generation and Supply

One of the major requirements of the buoy is to generate power for both subsea instrumentation and for buoy systems. Given the limitations of the buoy in terms of size, weight, and reliability requirements, the base case is diesel power generation. However, it is important that alternate means of power generation are investigated, as significant improvements in reliability and fuel efficiency may be possible. Possibilities may include fuel cells, wind or wave power generation, or other emerging technologies.

Power requirements are initially defined as: 1.0 kW for the buoy system, with 0.5 kW delivered to a subsea junction box for provision of subsea instrumentation packages. Power losses along the umbilical/mooring line can be significant (as much as 50%). The power supply methodology is DC current, 110V to maximise supply efficiency. Based on these requirements, the power generation capacity required at the buoy is estimated to be 2.0 kW.

Satellite Data Transmission

The satellite telemetry requirements of the scientific payload are planned to lie within the capabilities of a 64 kbps communications link (additional effective bandwidth may be obtained through the use of data compression techniques). The most cost-effective system to achieve this bandwidth is INMARSAT/B-HSD (high speed data) which can provide either 56 or 64kbps of bandwidth. There are a number of competing satellite systems proposed for installation over the next decade, which would also be capable of providing this bandwidth in a cost-effective manner. However, recent experience has shown that at least some of these proposed systems will be abandoned before installation. B-DEOS have therefore implemented a conservative design, under the assumption that non-INMARSAT options will have less stringent antenna stability requirements, and therefore all alternatives may be accommodated safely within the operating margins for INMARSAT/B-HSD.

Based on the use of INMARSAT/B-HSD a gyroscopically stabilised antenna is required to maintain the pointing accuracy needed by the INMARSAT system. However, the more that these motions can be reduced through the design of the buoy, the less complexity and power is required by the stabilising system and the greater the reliability.

Other backup systems are to be provided, including an emergency beacon, GPS positional data collection, and lower bandwidth data transmission via LEO satellite (omnidirectional antenna) in the case of a failure of the INMARSAT system.