



## THE NERC MARINE CENTRES' STRATEGIC RESEARCH PROGRAMME 2007-2012

### Theme 8: Technology Development

Technology is fundamental to our ability to make observations. The need is for reliable platforms with instruments that measure the required parameters and appropriate data communications. Whilst there has been tremendous progress over the last two decades, many science goals are elusive because we do not have the tools to make necessary observations and measurements. This Theme targets developments for specific science requirements in Oceans 2025 and also looks to longer-term needs.

Theme 8 comprises three Research Units and nine Work Packages:

#### **Enabling technology for ocean telepresence (National Oceanography Centre, Southampton)**

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- WP 8.1 4D biogeochemical sensors
- WP 8.2 Development of Autosub6000 into an agile deep-diving AUV
- WP 8.3 Towards multi-use of data
- WP 8.4 Towards targeted reliability

#### **Development of instruments, platforms and measurement systems (Proudman Oceanographic Laboratory).**

*POL Theme Leader: John Huthnance [jmh@pol.ac.uk](mailto:jmh@pol.ac.uk)*

- WP 8.5 Measurement systems
- WP 8.6 Telemetry

#### **Towards an optimal observing network (Scottish Association for Marine Science)**

*SAMS Theme Leader: David Meldrum [dtm@sams.ac.uk](mailto:dtm@sams.ac.uk)*

- WP 8.7 Sensor optimisation
- WP 8.8 Water column and seabed platforms
- WP 8.9 Satellite communications and GPS

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## Theme 8: Technology Development

### Strategic setting

Technology and observations are fundamental to ocean science – to provide the basic measurements (e.g. Koblinsky & Smith, 2001) and to serve as the ‘chief source of ideas’ (Stommel, 1989). Fundamental to our ability to make observations is technology, in the guise of instruments and platforms. While there has been tremendous progress over the last two decades in our ability to tackle the problems of sampling the oceans’ space-time continuum, Dickey (2003) postulates that, “Identification, understanding, and prediction of many interdisciplinary oceanographic processes remain as elusive goals of ocean science.” Many of these goals are elusive because we do not have the tools to make necessary observations and measurements.

Developing new tools to serve science is a strength at several of the NERC marine Centres, and through a coordinated approach, as recommended by NERC’s Marine Sector Review, we aim to improve on past performance. Our proposal is for a technology development strategy founded on three pillars:

- i) For the Centres proposing work packages within this Theme – effort will be targeted at well-identified key gaps in capability most relevant to their current and future science needs.
- ii) For all of the Centres in Oceans 2025 – added value will be obtained by developing links, sharing knowledge and facilities, and improving coordination of technology development, test and evaluation coupled with creating new routes and opportunities for knowledge transfer irrespective of the funding mode.
- iii) Improving the connectivity between all NERC Centres with marine technology interests and their partners and collaborators in universities.

Through discussions at the Centres between technologists, scientists and stakeholders we recognised the following four opportunities for improvement:

- For many important chemical and biological measurements, no suitable **sensors** are currently available, or existing sensors are inadequate.
- Existing **platforms** are not always suitable or optimum or affordable for the task in hand.
- Weaknesses in the **communications and information dissemination** chain can mean that the value of the data is not always fully realised.
- On past performance, the systems or methods used are not sufficiently **reliable** or dependable to assure the required data and information return.

### Why now?

For these four topics there are compelling reasons for the work proposed in 2007-12:

- **Sensors** – there is an increasing pull from marine scientists for *in situ* sensors to measure parameters that cannot be adequately measured today, especially for Theme 2 on Marine Biogeochemical Cycles (e.g. Daly *et al.*, 2004). By harnessing recent developments in microfabrication of fluidic devices as the enabling technology we expect significant breakthroughs to emerge over the next seven years (e.g. Mowlem & Statham, 2005).
- **Platforms** – Over the past decade development of several types of autonomous platforms and enabling technologies has opened up the promise of more precise and cost effective measurements within the ocean (e.g. Rudnick & Perry, 2003). Yet there are still substantial gaps in terms of capabilities and reliability, especially for science in the Deep Oceans (Theme 5). With the knowledge and technologies available now and expected over the next five years we are well placed to fill some of the highest priority gaps, in terms of operating depth, more intelligent measurement strategies and long range, long duration reliable operations.
- **Communications and information** – Marine science and technology have the opportunity to embrace rapidly developing infrastructures for communications (e.g. Broadband Global Area Network) and information sharing (e.g. the Semantic Web). In general, scientists have not been keeping up with these paradigm shifts in communications and information technology (see Nature editorial, 1 Dec 2005). Investment in this topic will enable these new technologies to

change radically the impact of the measurements made by the Observatories in Theme 10.

- **Reliability** – a key recommendation from the NERC Autosub Loss Inquiry Board of 2005 was that a risk management and reliability strategy should be introduced. The recommendation has wider applicability than for autonomous vehicles, e.g. to the design, construction and operation of observing systems such as the RAPID monitoring array (Theme 10).

#### **Why us?**

The marine Centre Directors took a strategic decision to bring together the technology development effort in one Theme in order to make it more visible, synergistic and coherent across the Centres – whilst also being explicitly related to the science Themes of Oceans 2025. Staff charged with delivery of Theme 8 have a track record of successfully providing Centre scientists and the NERC marine community with instruments for making field observations and measurements. Individually, they have well-established connections with industry and universities, in the UK and internationally. We now aim to accelerate progress through a more *collective* approach to a coherent set of topics - sustaining innovation in technology across the Centres by designing and proving instruments and platforms for broad applications by marine scientists, not only for Oceans 2025, but also in support of the entire NERC marine community. As such, the Theme directly targets that part of NERC's mission, "to advance knowledge and technology ... to meet the needs of users and beneficiaries" (NERC, 2002), and there has been close involvement in the development of the NERC Technology Management Plan (2006).

#### **Theme-wide science and technology aims**

- i) Provide new sensors and instruments for detailed physical, chemical and biological measurements in the water column, and for sediment dynamics, in order to measure processes hitherto unresolved and hence secure the basis of models for prediction.
- ii) Provide NERC strategic ocean science with distinctive measurement and observation platforms that meet science needs and cannot be sourced from industry, focussing on autonomous underwater vehicles and platforms for deep and long-range, long-endurance operation.
- iii) Develop data and communication pathways and methods to disseminate information from sensors and platforms, enabling more continuous and near-real-time data availability for monitoring and forecasting systems and to provide rigorous tests of models.
- iv) Work towards targeted reliability of observing systems to ensure fitness for purpose.

#### **Centre contributions and coordination**

NOC, POL and SAMS contribute work packages to this Theme, as presented here. The main mechanism for Theme-wide coordination will be Working Groups for each of the four topics. Where other NERC marine Centres have interests in the topic, but not reaching the level of a work package, they may join these Working Groups. Membership will also be open to other parts of NERC and universities, to ensure wide engagement. For example, the British Antarctic Survey has indicated interest in the Communications & Information and Reliability Working Groups.

Coordination will be 'light touch', appropriate to Centres with different managements, ownership and governance. Emphasis will be on knowledge sharing, enabling and harmonisation, on building trust and capability. While there is intentionally no formal leader for Theme 8, NOC will provide a convenor to oversee the coordination measures proposed. The convenor and Working Group chairs will maintain an overview of the Theme and provide periodic reports to the Oceans 2025 Programme Executive Board. Distinct from the Working Groups, workshops focussed on specific issues will also be arranged to further aid coordination.

#### **NOC contribution**

The NOC contribution will cover all four topics. Its established strength is in deep-ocean platforms, most recently with the Autosub autonomous underwater vehicles. The proposed work packages would develop further the latest vehicle Autosub6000 and lead towards a new long range, deep diving AUV. NOC sensor expertise is growing; focussing on *in situ* miniature and micro chemical and biological sensors. There is strong collaboration with international leaders in microsystems at

Southampton and elsewhere. NOC seeks to double the effort on sensor development, as lack of suitable sensors is a key gap for many scientists. The topics of Communication & Information, and Reliability are new to NOC; both will involve modest effort initially. For the former, we will use emerging concepts for the Semantic Web to investigate a whole-life approach to data, from embedding metadata within the sensor to delivery to users and to archives. The proposed NOC work on Reliability emerges from recognising that more can and should be done to understand, and thereby improve, the reliability of instruments and systems used in NERC marine science.

#### ***POL contribution***

POL's contribution will emphasise platforms, sensors and communications. 'Platforms' will take the form of novel instrument configurations to measure: a) microstructure for water-column turbulence, mixing and their effects on water type, nutrient supply and biological production; and b) detailed dynamics of sediments (in currents, waves and turbulence), to include these physics in models of morphology, water quality and (e.g. biogenic) particle transports. Telemetry will enable near-real-time data transmission from remote, long-term deployments: distant coastal 'tide-gauges' for sea level and tsunami; deep-sea pressure, monitoring ocean circulation; sea-bed or mooring-mounted instruments for currents etc. in the ocean interior. Such communication will enable monitoring and forecasting systems, with rigorous tests of models.

#### ***SAMS contribution***

SAMS' contribution will focus on intelligent data handling, communications and autonomous platforms, building on established strengths in these areas and on recent recruitments that will enable new lines of R&D especially 'smart' autonomous instruments. Such packages will make better use of bandwidth and energy by performing intelligent data selection at the point of measurement. Modern 2-way communications allow an organic approach, permitting interaction with the remote package in the development of optimal algorithms. This work benefits directly many of the science themes, at SAMS and elsewhere, complementing sensor and platform work by NOC and POL, and will strengthen existing links with the animal tag team at SMRU. Development of autonomous profilers for measuring turbulence, microstructure and other water column properties will continue. New lander technologies will be explored, with the ultimate goal of building a crawler to allow more spatially representative studies to be made of benthic processes and communities. Finally, new web-based opportunities for sensor networking, real-time data publication and public interaction will be implemented, cooperatively with the other Centres.

#### ***Contributions from other NERC marine Centres***

- The **Plymouth Marine Laboratory** (PML) will participate in the Sensors and Communications & Information working groups, and help in sharing knowledge and facilities, and developing links, for areas where PML is rapidly acquiring expertise through several UK and EU projects.
- The **Sea Mammal Research Unit** (SMRU) will continue its development of instruments for monitoring the movement and behaviour of marine top predators and their oceanographic environment. These have created a new modality for the collection of ocean data that complements conventional approaches. Such technology crosses all disciplines of ocean science and can both contribute to and utilize developments across all other marine Centres.
- The **Marine Biological Association** (MBA) will participate in the Working Groups on Sensors and Platforms. MBA scientists use technology to answer biological and ecological questions, e.g. to elucidate trophic interactions in the marine environment, in particular, how lower trophic levels can be effectively "imaged" at appropriate scales using sensors aboard AUVs to formulate dynamic maps of subsurface productivity.
- The **Sir Alister Hardy Foundation for Ocean Sciences** (SAHFOS) provides Continuous Plankton Recorders (CPRs) on routine ship-of-opportunity tows as platforms for surface layer, non-plankton, physico-chemical data instrumentation to sea-truth other data acquisition technologies, as well meeting specific research projects. SAHFOS also continues to develop IT software techniques for the interpretation of large scale temporal and geographic data sets.

## Enabling technology for ocean telescience

*Contribution to Theme 8 by the National Oceanography Centre, Southampton*

### Background

The strategic context for the NOC contribution is directed at all four topics of the Theme's framework. This is in keeping with the Centre's position as a national leader in technology for marine science and its commitment to increasing the element of NERC strategic funding directed towards technology in the next 5 years. Our proposal builds on: strong partnerships in micro-system technology for sensors; existing world-class strengths in platform technology; new initiatives in communications and information dissemination; and targeted reliability. These priorities were highlighted at a science and engineering workshop at NOC in July 2005.

Our sensors programme is directed towards the needs of marine scientists and is also strategically aligned with the major initiative in the Life Science Interface at the University of Southampton, bringing the benefits expected from a collaborative Centre. In setting ambitious goals to increase the endurance and depth capabilities of autonomous underwater vehicles (AUVs), our aim is to remain at the forefront of AUV development and use. In proposing a new initiative in communications and information dissemination we seek to bring in new ideas on web-enabled sensor networks and data flow, complementing existing work on data management. A new initiative on reliability is proposed, founded on the development of a risk management process that will then be embedded within technology and observation programmes.

NOC work in Theme 8 is relevant to scientists throughout the NERC marine community. It is aligned with the strategic thinking behind the creation of the National Marine Facilities Division at NOC, in that it targets improved effectiveness of platforms including ships, monitoring and observing systems through directed research, development, test and evaluation.

### Aims and rationale

The NOC contribution to Theme 8 aims to:

- Develop and evaluate novel sensor technologies for biochemical and phytoplankton research.
- Provide NERC strategic ocean science with distinctive measurement and observation platforms that science needs - that cannot be sourced from industry, focussing on autonomous underwater vehicles for deep and long-range operation.
- Initiate a new activity to import emerging ideas on web-enabled sensor networks to enable multiuse of data.
- Develop, document and employ a Risk Management Process tuned to the needs of NERC ocean science and technology.

### WP 8.1 (NOC) 4D biogeochemical sensors

#### Specific objectives

- i) To design, construct and evaluate experimental *in situ* lab-on-chip, micro fluorescence-activated counting systems ( $\mu$ FACS) and evanescent wave sensor devices for biochemical and phytoplankton measurements, first in the laboratory and then in the marine environment.
- ii) To characterise, make robust and then commercialise miniature liquid core waveguide sensor systems for Mn/Fe and ammonia and later for other parameters.

#### Approaches and methodologies

This work package is increased substantially compared to the NOC sensor effort in the 2001-06 core programme. Our focus is on the need of the marine science community for sampling biogeochemical properties in four dimensions (3 spatial dimensions and time). It will coordinate a national programme of development by providing a central hub of research at NOC linked to allied blue skies research at Southampton and elsewhere. It will leverage the latest engineering research and device development from non-marine applications.

Physical sensors are reaching maturity, with numerous commercial systems, whereas very few exist for biogeochemical parameters. These biogeochemical measurements are needed for several of the observatories (in Theme 10), which in turn are used to validate predictive models (Theme 9) of complex biogeochemical processes (Themes 2 – 6) that are often affected by, and feed back into changes in climate (Theme 1). These new biogeochemical measurements will also play an important role in services provided to government and industry.

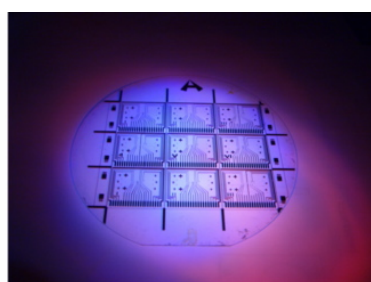
Key biogeochemical processes can vary by two orders of magnitude on hourly and metre scales (Martin *et al.*, 2005) whereas subsurface sampling in all but a few isolated locations occurs on annual and kilometre scales. A technology bottleneck currently prevents accurate measurement of these parameters at appropriate scales. *In situ* sensors have been identified by international consensus (e.g. Gallagher & Whelan, 2003) as offering the most practical and achievable solution to this undersampling. Several organisations are involved in the development of macro *in situ* biogeochemical sensors (Daly *et al.*, 2004) that tend to be large ( $\sim 1\text{m}^3$ ), expensive (£10-100k) one-off devices requiring expert operation. These devices have limited sample density capability. Only oxygen sensors and fluorometers have achieved miniaturisation and robustness for routine use.

We will extend the list of biogeochemical parameters that can be measured routinely from existing platforms, such as Argo floats and gliders, which can (when deployed in sufficient numbers) deliver repeated synoptic measurements in 3D. The new sensors will also help advance chemical and ecosystem oceanography by their inclusion in instruments used for long-term observations. They will be equally suitable for novel vehicles (WP 8.2c) and multiparameter measurements on larger vehicles such as AUVs (see WP 8.2a, b), crawlers (WP 8.8a) and towed vehicles.

WP 8.1 will be closely linked to other parts of Oceans 2025 (through the Sensors working group); the University of Southampton; other UK universities with specialist capabilities; and European partners (e.g. the École Polytechnique Fédérale de Lausanne). In summary, this work package will provide NERC strategic ocean science with the sensors it needs but cannot be bought, or developed with grant funding alone. It will benefit allied scientific and industrial activities outside the marine sector, and will lead to commercialisation of technology developed in the UK.

#### **WP 8.1a Strategic sensor research**

The focus here is on developing novel transduction methods, transferring techniques used outside the marine sector and conceiving innovative approaches to sensing problems. Emphasis will be on lab-based demonstrators. The following technologies and technical approaches are suitable for miniaturised / mass-produced sensors and will receive initial attention.



**Figure 1 Wafer with 9 Cytometers**

*Micro System Technology (MST)*, pioneered for fabrication of electronic microchips and now used extensively in industrial and biomedical applications, shows great potential for biogeochemical sensor creation. MST is inherently flexible – multiple device designs on a single wafer (e.g. Fig 1) allow rapid design and testing iterations; low cost mass production of multiple device designs; and the simultaneous production of families of instruments. On-going NOC collaborative programmes are developing lab-on-chip (LOC) wet chemical analysers (WCA) and cytometers ( $\mu\text{FACS}$ ) for phytoplankton, both the size of a postage stamp. This work package

will support the long-term development of MST and related technologies for marine applications. It will enable pilot studies at the cutting edge of MST sensor research (e.g. *in situ*: genomic devices; cytometry of prochlorococcus and viruses; and multiple analyte chemical analysers).

*Optical Techniques* for chemical sensors that do not require the supply of reagents are attractive as they enable sensor simplicity and longevity. The commercial success of oxygen sensors (using optical indicators based on fluorescence lifetime quenching) illustrates this. In collaboration with the Optoelectronics Research Centre (Southampton), we will investigate the development of optical indicators for additional chemical species, and develop interrogation techniques for miniaturised

platforms. We will also extend existing direct optical techniques, such as UV (Johnson & Coletti, 2002) and evanescent wave spectroscopy (EWAS) (Buerck *et al.*, 2001), Raman (Brewer *et al.*, 2004) and Surface Enhanced Raman Spectroscopy (Murphy *et al.*, 2000) by investigating the use of MST and integrated optics to miniaturise these sensors (through collaboration). We will extend existing programmes for low (open ocean) nutrient level detection with liquid core waveguides (LCW) for WCA systems.

We will develop *electrochemistry tools* suitable for miniaturisation (such as micro-electrodes). We will extend existing activity to include the use of MST to enable cheap rapid fabrication of sensors with reproducible characteristics and evaluation of techniques for a wide range of chemical species. We will also keep a watching brief for emergent technologies in literature and practice (particularly the non-marine sectors) for both miniaturised sensors and macro devices. To avoid over-extending strategic funds, development beyond proof of concept will only be pursued through collaboration, or with grant funding. Technologies currently under review include: mass spectroscopy, chromatography, molecular imprinted polymers, biosensors, and molecular tools.

#### **WP 8.1b Practice-based sensor R&D**

Systems demonstrated in the lab will be developed as prototypes and evaluated in the field or simulated environment. Initially, we envisage development of technologies identified by our strategic sensor research (e.g. LOC wet chemical analysers,  $\mu$ FACS for phytoplankton studies and EWAS for *in situ* measurement of methane). In addition, this work package will act as an access point to groups in universities allowing us to select (proactively and reactively) promising technologies corresponding to the needs of the science community.

#### **WP 8.1c Technology and knowledge transfer**

We will seek, and then work with, partners to commercialise proven prototype systems. We envisage early successes including the macro wet chemical analysers for Fe/Mn and ammonia, and the micro-electrode oxygen sensor.

#### **WP 8.1d Science support services**

We will establish and promote a capability for sensor creation for the UK marine community, in response to science pull, based on sensor principles proven in the marine environment, working with industry where appropriate. Examples would be a liquid core waveguide based wet chemical analyser for high-resolution pH measurement (a key requirement for Theme 2) requested by scientists interested in CO<sub>2</sub> and ocean acidification. Essential generic technical effort required across WP 8.1 will include: electronics (for system control, data extraction and logging, power, and platform interface); survivability (resistance to biofouling, corrosion, particles, pressure); and long term performance, (*in situ*) calibration, redundancy, and targeted reliability.

#### **Deliverables**

By the end of year 3: Experimental *in situ* lab-on-chip,  $\mu$ FACS and evanescent wave devices demonstrated in the marine environment. Miniature sensor systems ready for commercialisation to include Mn/Fe liquid core waveguide system, ammonia wet chemical analyzer. Devices produced for direct support of marine science to include: miniature pH (Wet Chemical Analyzer), open ocean nutrients (miniature Liquid Core Waveguide), fast oxygen microelectrode.

## **WP 8.2 (NOC) Autonomous platforms**

### **Specific objectives**

- i) To complete construction of Autosub6000 and test a basic version at sea in late 2007, followed by devising the software and hardware systems needed to make the vehicle agile and highly programmable, and well able to contribute to hypothesis-driven science experiments in water depths to 6000 m in 2010.
- ii) To design, develop, construct and test a prototype long-range, deep-diving AUV ready for long path, long endurance hydrographic applications in 2012.

- iii) To devise a system design for low cost, but effective, air-deployed ocean microbots for large scale synoptic surveys in 2012.

## Approach and methodologies

### **WP 8.2a Development of Autosub6000 into an agile deep-diving AUV**

In 2007/08, we will complete and sea-test the Autosub6000 AUV. Following this, and concurrently with science operations (since there is no substitute for experience gained at sea), we will develop the capabilities of the platform, giving it greater control autonomy, more precise navigation, and a greater ability to carry out controlled experiments in all areas of the oceans. These developments, coupled with availability and integration of appropriate sensors (WP 8.1), are demanded by, and in strong support of several Oceans 2025 topics, particularly in Theme 1 (e.g. overflow and exchanges across sills, abyssal circulation and mixing, Southern Ocean mixing processes), and Theme 5 (e.g. marine census, abyssal circulation and mixing processes, ocean ridge, canyons and seamounts, ocean margins benthic ecosystems, gas hydrate survey).

The Autosub6000 AUV will be developed from a platform for survey and observational science to a tool for directed open-ocean and benthic hypothesis-driven experiments. For detailed 'close in' surveys of benthic biology, geology and geochemistry, we plan to enhance the slow speed manoeuvring and collision avoidance capabilities. A multibeam sonar system will be fitted, providing efficient, high resolution, deep-water bathymetric survey capabilities. The AUV's control and manipulation capabilities will be developed to permit hovering and landing on the seabed. The longterm aim is that it will be able to deliver sensor packages and experiments to the seabed, and collect seabed samples. Following on from other AUV research (e.g. the WHOI ABE AUV's intelligent mapping of buoyant hydrothermal plumes; Yoerger, 2005) we will further develop and field-test intelligent reactive sampling and navigation techniques to map contours and find the maxima of interesting biological or physical signals. These capabilities may also be valuable in the mid water and open ocean regions. Autosub6000 will be able to inject tracers or inoculants (with subsequent mapping of the plumes), and map contours of interesting chemical, biological or physical signals, sampling appropriately. These capabilities may also be used for near-seabed studies, e.g. investigating hydrothermal vents, mud volcanoes and other fluid escape features.

We will further develop the navigation system, to achieve post mission navigation accuracy of better than 1 m over 48 hr missions, without the need for time consuming and expensive deployment of long base line acoustic navigation systems, or continuous navigation updates from the mother ship (which are current state of the art). Prime navigation sensor sources will be *inverted* Ultra Short Base Line (*i*USBL); able to give higher accuracy positioning than the more conventional USBL), Doppler Velocity Logs and Inertial Navigation based around Fibre Optic Gyro systems. Terrain contour matching (using multibeam sonar) based relative navigation will be used to help control navigation error growth in post processing (later in real time). Galileo, the new, more accurate European GPS system (planned to be operational in 2008) will be integrated into the AUV.

Currently the AUV behaviour is heavily prescribed by the mission plan. To make these more challenging experiments possible, we will develop Autosub's real-time reasoning and reactive capabilities. Underpinning all of this, the effectiveness of the platform will be maintained through the adoption of a targeted reliability methodology (WP 8.4).

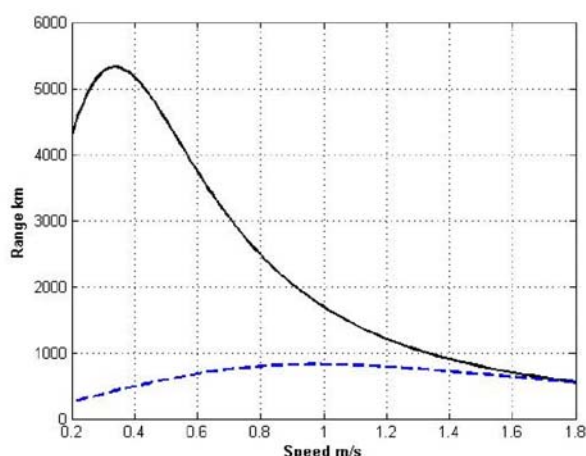
### **WP 8.2b Very long range AUV**

There is a technology gap between present-generation AUVs such as Autosub and undersea gliders. With over 10 yr of experience of AUV design and operations, and with our wide links and collaborations, we are well placed to develop a completely new type of AUV, with range (5000km), depth (6000m), speed, and payload capabilities far in excess of those of present day underwater vehicles. Our preliminary analysis suggests that this involves no high risk technological developments, nor advances in energy sources, and our target would be that this would be completed with a vehicle production cost not significantly higher than that of present day gliders, but with much higher

functionality. The large range makes possible long one way or reciprocal runs, with enough energy remaining for recovery into sheltered areas. Such AUVs would contribute to a very wide range of oceanographic studies, particularly the Sustained Observations of Theme 10. For example:

- *Choke points:* The AUV could execute reciprocal transects across Drake Passage from the Falkland Islands to the Antarctic Peninsula and return. Monitoring the Antarctic Circumpolar Current at Drake Passage is carried out from a ship (RRS *James Clark Ross*) once a year, in early summer, “one of the most important continent-to-continent sections in International CLIVAR planning”.
- *Seasonal transects avoiding aliasing of within-year variations in transport:* There are numerous examples where this technology could contribute, e.g. the extended Ellett line from Scotland across the Rockall trough to Iceland.
- *Ocean basin transects:* e.g. at 24N in the Atlantic the vehicle could continuously monitor the Atlantic meridional overturning, complementing the long term RAPID moored arrays.
- *Station keeping:* It could be used to replace some moorings, particularly those vulnerable to fishing, or destruction by icebergs.

The proposed AUV borrows some ideas from present day marine gliders, but has crucial differences, which will give it much higher performance. Like gliders, it will achieve very long range by going rather slowly (Fig 2), and by carefully controlling and minimising power used by its sensors, command and control systems. Unlike gliders it will use a conventional propulsion system.



**Figure 2.** Solid line: estimated range of proposed long range AUV versus speed, taking into account the extra drag on the vehicle due to uncorrected buoyancy forces. Dashed line (for comparison): the range/ speed characteristics of Autosub3, based on experimental data.

This change will have two main advantages. First, it will about double the efficiency of the gliders’ pumped systems, where efficiency is considered over the entire chain from conversion of stored chemical energy to electrical power to forward speed. Second, the vehicle will be able to sprint (to  $2 \text{ ms}^{-1}$ ).

Its speed for optimum range at  $0.4 \text{ ms}^{-1}$  is about twice as fast as for gliders, hence the AUV’s navigation will be much less affected by ocean currents.

Further it will be able to execute *any* flight envelope (it will not be restricted to saw-tooth profiling as gliders are), and the payload space, volume, and power availability will be considerably less restricted than for gliders. With an operating power of only 1 to 2 W, and using rechargeable lithium ion batteries (developed in the Autosub6000 programme), it will be technically practical, using relatively small photovoltaic arrays, to recharge the batteries when the vehicle surfaces (Jalbert, 2003). This would significantly extend the range and endurance of the vehicle, with deployments ultimately limited only by the system reliability (WP 8.4).

### **WP 8.2c Aircraft deployed sensors and platforms**

How can we most economically and effectively make ocean measurements on very large 3D scales and within a synoptic time frame? There are clear scientific requirements, particularly in Theme 1 and several Theme 10 activities (e.g. AMT and Drake Passage section). One possible solution is the deployment of a multitude of relatively cheap small sensors packages from a high-flying aircraft. On entering the water, the sensors would sink to depth (obtaining *in situ* calibration from deep water masses), then pop up to the surface where the data would be relayed by satellite. To improve the spatial separation of the array the sensor packages could be configured as GPS-guided gliders

when airborne. In this way a 200 km wide swath of deployed sensors could be achieved with one aircraft track. In principle the whole of the North Atlantic could be covered in a few weeks.

There is an array of possible solutions, variable parameters and degrees of sensor sophistication. Which type of sensor platform is most cost effective: cheap, simple sensor packages (only able to do one profile), ARGO type drifters, underwater gliders or small AUVs? In limited numbers, simple sensor packages such as ARGO floats (Turton, 2002) have already been air-deployed.

WP 8.2c will investigate whether it is possible to radically extend the rate of coverage by using innovative approaches as described. We will focus initially on requirements capture, feasibility and trade off analyses, followed by a preliminary system design. We are very well placed carry out this work package, with in-house expertise, supplemented by established links with university groups on unmanned aerial vehicles, AUVs, and micro-sensor development programs. Links with BAS (who operate Dash-8 aircraft that regularly cross the Drake Passage) will provide expertise on the aircraft issues and will facilitate the future development of test and demonstrator vehicles.

### **Deliverables**

A basic version of Autosub6000 will be tested at sea in late 2007. Staged system developments concurrent with and complementing operational use, delivering agile vehicle capable of intelligent survey and intervention contributing to hypothesis-driven science experiments in water depths to 6000 m in 2010. A prototype of a long-range, deep-diving AUV to be ready for long path or long endurance hydrographic applications in 2012. A system design for low cost, but effective, air-deployed ocean microbots for large scale synoptic surveys in 2012.

## **WP 8.3 (NOC) Towards multi-use of data**

### **Specific objective**

To facilitate and encourage multiuse of data, by using concepts from the Semantic Web to provide web-enabled sensor networks, with embedded metadata and communications capability, from existing data-gathering platforms such as research ships, vessels of opportunity and moored buoys.

### **Approach and methodologies**

Oceanographic data can now have three purposes: i) data gathered in real time is potentially of use for assimilation into ocean models; ii) data can be used for scientific analysis in a more specific context; and iii) data becomes a global public good, accessible by all potential users who would benefit from the information. But efficient use of data for all three purposes is hardly ever achieved. Although high bandwidth communication and e-science tools have the potential to enable sharing of data and facilities in near real time, these techniques are not yet pervasive in our practice or even in our thinking (Rickards, 2005). Communications are being tackled by POL and SAMS in complementary work packages. Here, we tackle the issues of providing interoperable interfaces and metadata encodings within sensors, instruments and observing systems to enable web-connected devices that provide information with multiple purposes. Applications will include data retrieval from observatories as well as from ships, underwater vehicles and platforms. As a new topic area for NOC we will build up a capability over five years, and will work alongside colleagues at the British Oceanographic Data Centre (BODC) and universities already working on related problems.

### **WP 8.3a Multiuse of data through the Semantic Web – enabling the concepts**

We will use ideas from the Semantic Web (Berners-Lee *et al.*, 2001) within a systems approach that considers data and metadata from the sensor to the user. WP 8.3a will complement MarineXML and the work of the ICES/IOC Study Group on the development of marine data exchange systems using XML (Isenor *et al.*, 2004). We recognise that the information chain starts at the sensor with data from its measurement, associated data such as time and position, together with metadata for properties such as instrument type and calibration. Using recently developed concepts and tools, in particular SensorML (Botts, 2002), we envisage embedding within sensors and instruments the ability to create metadata files for communication to data servers and archive centres.

**WP 8.3b Implementing web-connected sensors on research vessels and buoys**

Our first aim would be to provide the interoperable interfaces, metadata encodings and automated processing and dissemination of underway data from RRS *James Cook*, and, in association with BAS, from RRS *James Clark Ross* (building on the existing BAS project to connect instruments in the Antarctic to the web). This would allow for a rich data set, well suited to testing for multi-use, with the benefit of technical support onboard during development. Data could include geo-referenced ocean surface physical properties such as temperature, salinity and density, current profiles, surface chlorophyll with supporting information on incident radiation, surface nutrients and a full set of meteorological data. Geophysical measurements such as from echo sounding, swath bathymetry and sub-bottom profiler could follow. The full benefit of web-connected sensors will come their pervasiveness. As a step towards this goal, we would take the developments made for research vessels and implement onto satellite telemetering surface buoys, as used for the RAPID monitoring array (Theme 10).

**WP 8.3c Towards automatic recalibration**

Embedding metadata within sensors and instruments will enable provenance to be established, with standardised version control. Machine processing and embedded metadata with intelligent software agents could lead to automated recalibration of sensor data streams (e.g. for salinity when drifts in standard seawater occur, as found in the past). The aim will be to automatically cascade corrections down to the relevant calibration data and metadata, and up to products derived from the source data.

**Deliverables**

Generic systems for data acquisition, instrument control, platform control, communications tools, Web-based data access and dissemination tools, installed on *James Cook* and vessels of opportunity in 2009 and 2010. Demonstrations of automatic recalibration in 2010 and 2012.

**WP 8.4 (NOC) Towards targeted reliability****Specific objectives**

- i) To develop a Risk Management Process by early 2008.
- ii) To use the process to inform the RAPID redesign in 2007, with a more complete analysis for the 2011 review.
- iii) To embed risk management within development projects with highest risk, including Autosub6000 and the long-range AUV.

**Approach and methodologies**

Despite a track record of good systems engineering practice, we do not have a formal approach to achieving reliable systems, neither have we sought specific resources for the topic in the past (Strutt *et al.*, 2006). This is a management weakness that appertains to hardware and software designed and constructed by us, to bought equipment and, in a somewhat different vein, to the design, construction and operation of observing systems. The Autosub Loss Inquiry concluded that the present situation is characterised by the term “Revealed Reliability”. That is, there are no reliability goals (that is not to say that engineers do not examine what can go wrong and take preventative measures). Reliability has only been presented as historical data. For example, Griffiths *et al.* (2003) analysed the fault history of Autosub and constructed a statistical model to predict the probability of losing the vehicle when operating under ice. Podder *et al.* (2004) took a similar approach with the MBARI Dorado AUV.

**WP 8.4a Development of a Risk Management Process**

To move towards “Targeted Reliability”, we will develop and document a Risk Management Process (RMP) tuned to the needs and resources of NERC marine technology and science, ensure its adoption at NOC and make it available to the Oceans 2025 community. We envisage the process will combine risk management modules including, risk identification, assessment, tests against risk acceptance criteria, and mitigation strategies informed by the principles of robust design. Key inputs will be numerical statements on acceptable risk and on specification of quality. The RMP

will provide assurance that designs can be achieved and that information will be captured and analysed to show that goals are being met.

Risk assessment will be combined with formal techniques such as Fault Tree Analysis (FTA) in a ‘top-down’ approach, or Fault Mode, Effects and Criticality Analysis in a ‘bottom-up’ approach. These techniques rely on engineers with thorough knowledge of the systems being analysed. With experience of applying FTA and Root Cause Analysis we are well placed to address these goals.

#### **WP 8.4b Applying the Risk Management Process to the RAPID monitoring array**

As a pilot project, these techniques would be applied to the redesign of the RAPID trans-Atlantic observing system in 2007 then for the 2011 review (Theme 10). The RMP would start from the defined maximum allowable uncertainty in, for example, ocean transport and/or from minimum mooring time to failure or the minimum time to failure of critical instruments such as moored profilers. Using historical data we would determine if risks were acceptable or not. If not, we would identify where designs, products or processes need to be improved, or redundancy provided for. Structured data gathering on actual reliability would be instigated to show if targets were being met. We anticipate close contact with manufacturers and suppliers to both gather historical data and to provide feedback on performance.

#### **WP 8.4c Applying the Risk Management Process to AUVs**

We would apply the RMP outlined above, from the outset, to the very long range AUV development (WP 8.2b), in retrospect to the Autosub6000 programme (WP 8.2a), where engineers are already applying lessons learnt from Autosub2 (McPhail, 2005), and to the ongoing operations with Autosub3. Studies of the risks associated with air-deployed microbot vehicles will be of particular importance and will take place in parallel with the early phase of WP 8.2c.

We would promulgate our work to the other centres through the Working Group on Reliability. In this topic, we are aware of opportunities to work with university colleagues on system robustness and reliability, for instance on model-based fault detection and isolation, fault tolerance, formal methods on robustification and adaptive systems that do not rely on automated diagnosis.

#### **Deliverables**

A Targeted Reliability plan to inform the RAPID redesign in 2007, with a more complete analysis for the 2011 review; similar plans for observatories, including PAP and for platforms, including Autosub6000 (in 2008 and an update in 2010) and the long-range AUV (in 2009 and 2010).

#### **Summary research plan for WP 8.1- 8.4**

The research plan is to provide the deliverables identified above as NOC milestones in the Theme-wide Gantt chart in the concluding section. The key dependencies between work packages are also shown there. Expected generic deliverables will include trained people - engineers, at masters and doctoral level; contributions to science and society featuring exciting technology and knowledge transfer successes in sensors and platforms.

## **Development of instruments, platforms and measurement systems** *Contribution to Theme 8 by the Proudman Oceanographic Laboratory*

### **Background**

New and continual measurements give new knowledge of the ocean. POL’s main aims focus on three of the four topics identified in this Theme: sensors and platforms, to measure hitherto unresolved processes, securing the underpinning physics of predictive models, and communications to make data available in near-real-time, long-term, for monitoring and forecasting systems.

### **Aims and rationale**

*Turbulence in the water column* is a control on many processes studied in Themes 1, 2 and

especially 3: air-sea momentum transfers (modulated by Langmuir circulations); vertical fluxes of nutrients; patchiness in relation to shelf topography; mixing where internal waves are energetic (e.g. shelf edge, canyons); algal functional groups; phytoplankton photo-physiology and their mixing through light and nutrient gradients; SPM aggregation (also influenced by algae).

*Sediment dynamics* (Theme 3) control morphology, water quality and (biogenic) particle transports; modelling entails parameterising small-scale processes of (non-cohesive and cohesive) sediment transport. In turn, we need: simultaneous co-located profiles of near-bed turbulence and intra-wave flow, suspended particle concentration and size (flocculation related to turbulence); to resolve the wave boundary layer and variation of suspended sediments over a rippled bed; to distinguish suspended load, sheet flow and bed-load; long duration to include storms.

Themes 1, 3 and 10 will use *remote instrument control and continual data supply* (to near-real-time Web display) from: coastal gauges for sea level, tsunami; deep-sea pressure for ocean circulation; sea-bed or moored instruments for currents etc. in the ocean interior and the POL Coastal Observatory. Large data volumes can easily be handled via broadband. Duration of the deep-ocean POL lander MYRTLE can be increased to ten years use BGAN retrieval. Broadband systems will deliver fast sampling in near-real-time, allowing monitoring of short-period events, e.g. tsunami, interrogation for assimilation in forecast models, rigorous tests of models (Theme 9), better reliability by fault diagnosis and rectification, remote-controlled sampling and less use of ships.

## WP 8.5 (POL) Measurement systems

### Specific objectives

To design, construct and deliver to the science community, measurement systems for in water microstructure, to estimate turbulence and mixing in the water column, and for the detailed dynamics of particles in currents, waves and turbulence.

### Approach and methods

#### WP 8.5a In-water microstructure

*Air-sea momentum transfer* measurements from ships would be enhanced by a microstructure probe on a “stinger” ~ 1m below the sea surface on the bow. Successful precedents are: i) a short pitot tube and pressure gauge on the front of a catamaran sponson (Thwaites *et al.*, 2000) and ii) microstructure and pressure sensors on a bow-mounted frame (e.g. Soloviev & Lukas, 2003; custom-made; they discuss flow distortion, analysis separating waves and turbulence, allowance for varying sensor depth in waves with ship pitching). The “stinger” will be designed to be removable (bolted to a permanent fixing) yet robust.

*Microstructure* can be profiled vertically by a commercially available free-fall instrument. To sample complementary horizontal patchiness, we propose to mount microstructure sensors, with fluorometry to support dye-release experiments, on a small AUV and a glider. Microstructure has been measured from a large AUV (e.g. Autosub). However, a small AUV or glider is easier to deploy; POL has recovered a glider from a RIB, but a (propelled) AUV might be necessary for speed in the water. Small AUVs, gliders and sensors exist (e.g.  $\mu$ ASTP, or MSS as on the POL and SAMS-developed HOMER). The development would become a UKORS package. Microstructure measurements give scope for novel analysis development (e.g. by UWB), a SOFI opportunity.

For *horizontal resolution of thermocline and chlorophyll structures*, in conjunction with vertical profiling, we propose to develop a towed temperature-fluorometer chain. This would improve on present ~ 1 km horizontal resolution (from Scanfish, Seasoar etc.) and resolve the vertical to ~1m. Interpretation of the temperature and chlorophyll fields will be helped by currents from shipboard ADCP data at similar resolution. A 1980s towed thermistor chain (now lost) used a depressor; a compact fluorometer to include in a line is now available. We aim for synchronization; an ADCP on the depressor; integration of sensors, towing and data line in a robust easily-paid-out “chain”.

*Thermal and density structures, and internal waves*, are imaged extensively (10s-100s km) and in

detail (10-50m) in 2-D seismic sections of the water column (Holbrook *et al.* 2003; Holbrook & Fer, 2005). The promise of seismics will be tested in the Geophysical Oceanography project (GO, 2006-09, 50% EU-funded), comparing inferred waves and mixing in contemporary seismic and *in situ* measurements (in the Gulf of Cadiz; Mediterranean Water descends the slope and mixes).

#### **WP 8.5b Particle dynamics**

*Simultaneous, co-located profiles* of near-bed flow and turbulence are measured by the present POL 3-axis coherent Doppler (CDVP) (Betteridge *et al.*, 2005). However, averaged data (initially sampled at ~ 500Hz) are noisy above 2 Hz, limiting intra-wave temporal resolution; the spatial resolution, 0.04 m, is useful but not sufficient in the wave boundary layer. We will further develop the CDVP, for good signal / noise ratios up to resolutions 8 Hz and 0.01m, and for autonomy in the sea. To measure profiles of suspended particle size and concentration, we will add another acoustic transducer at a different frequency. Testing will be in the EU-FP6 project Hydralab III.

Three estimates of *particle size* are given by POL's 3-frequency ABS (acoustic backscatter system; Thorne & Hardcastle, 1997). However, inversion for mean particle size and concentration requires *a priori* knowledge of the relative size distribution in suspension. (LISST optics give size distribution, but do not profile and cannot be placed very close to the bed). We propose a 6-frequency ABS, for 15 particle-size estimates and some evidence of size distribution. To profile the wave boundary layer and near-bed transport, we will also aim for finer resolution ~ 0.0025 m. For particle size and shape (especially small, cohesives), we will also develop multi-frequency optical backscatter (OBS). OBS will enable estimates of settling velocity and flocculation (via its fractal effect on OBS; Nikora *et al.*, 2004). We will also use photography/video through collaboration with a university group such as Plymouth or Bangor.

Waves over a *rippled bed* generate vortices, which may be a prime cause of sediment suspension. Process studies in Theme 3 need a transducer array or multi-beam system, to image suspension over the length of a ripple. The development could be carried out solely by POL, or if cost-effective with Marine Electronics (as for POL's ripple profiler).

*Bed-load* is poorly measured despite normally being dominant in sand transport when the bed is flat, as often under large waves in shallow water. Outside the swash zone, we aim to use acoustics. Building on POL experience, we propose a 5-10 MHz 1-axis acoustic Doppler system, wavelength 0.3-0.15 mm, with spatial resolution O(1 mm). This should estimate bed-load flux directly from the Doppler shift (for velocity) and signal amplitude (for concentration). Although at the limits of the acoustics, medical applications suggest feasibility.

To *span storms and periods between*, we need long-term continuous measurements by ADV, ADCP, ripple-profiler etc. To install such instruments in inter-tidal areas, POL will develop a modular framework, cabled power and data transmission. The system may be used in the Dee or adjacent Coastal Observatory (with Web display), a representative area for mobile sediments; cable laying by boat from Hilbre Island may be feasible along a protected, short route with permissions.

#### **Deliverables**

For in-water microstructure, a microstructure stinger will be mounted on a vessel bow (2007-09), microstructure measurements will be made from a propelled AUV (2008-10) and from a glider (2010-11), and a towed thermistor-fluorometer chain constructed (2007-09). For particle dynamics, a 3-axis coherent Doppler (CDVP) will be built (2007) followed by a finer-resolution version (2007-10); also a 6-frequency ABS (2007-08), an imaging array over a ripple length (2008-10) and HF acoustic Doppler for bedload flux (2010-11).

### **WP 8.6 (POL) Telemetry**

#### **Specific objective**

To design, construct and implement systems for data telemetry from remote locations: coasts, deep-sea (bed and moorings).

## Approach and methods

POL will develop new BGAN (Broadband Global Area Network; Inmarsat) based telemetry systems and build on current developments using Broadband, Orbcomm, Iridium and Meteosat / GOES-based satellite systems. Broadband technology enables continuous data transfer over the Internet, even from remote locations (e.g. Antarctic, South Atlantic islands). For a dispersed sensor network, it enables high-speed two-way communications, continuous availability and removal of timing errors using Internet time servers.

BGAN allows operation in remote locations, independent of local infrastructure and benefiting applications such as tsunami monitoring. Terminal units are available commercially, but need development for marine applications. BGAN will provide seamless worldwide coverage; by mid 2006, all non-polar regions except the Pacific. BGAN will offer:

- standard IP service up to 492 kbit/s for email, file transfer and Internet
- streaming IP service for time-critical data-exchange (e.g. video streams) at 256 kbit/s
- compact, low power terminals.

### ***POL application of telemetry development***

POL uses Orbcomm telemetry extensively in high profile projects, e.g. the Coastal Observatory (Liverpool Bay with Web display: <http://cobs.pol.ac.uk/>) and four remote sea level stations in the South Atlantic and Mozambique. Large data volumes from Coastal-Observatory HF and X-Band radars can easily be handled *via* land-based or satellite broadband; faster data rates will also benefit telemetry from ferries and from ADCPs *via* surface buoys (lower power use also helps). The deep-ocean long-term POL lander MYRTLE (Multi Year Return Tidal Level Equipment) has four years duration using Orbcomm data capsules released to the surface annually. We plan ten years duration using BGAN to retrieve the larger data sets. For shorter-term deployments, e.g. in remote ocean areas, the low-cost POL Microlander sensor platform will be developed to use satellite telemetry.

Broadband, BGAN and Iridium fast (e.g. 1-min. to 1-sec.) near-real-time sampling will allow:

- monitoring of short-period events, e.g. tsunami, seiche
- multi-variable recording (including meteorology, near-surface fresh water)
- interrogation for assimilation in forecast models
- better reliability by fault diagnosis *via* two-way telemetry
- sampling intervals that can be altered remotely
- reduction in ship-time for offshore deployments and recoveries.

### **Deliverables**

Techniques for broadband data transmission from land-based sites will be established, and 2-way (telephone) links with land-based sites for fault diagnosis and adaptive sampling (2007). Orbcomm telemetry from buoys, and sub-surface *via* Link-Quest acoustic modem will be set up (2008), and broadband transmission of data from Radars (HF radar - 2007; X-band radar – 2008). BGAN data telemetry from MYRTLE will be set up (probably *via* surface telemetry buoy or cable: 2009-11).

### **Summary of research plan for WP 8.5 - 8.6**

The deliverables identified above are milestones of the POL entries in the Theme-wide Gantt chart. WP 8.5 and WP 8.6 will run in parallel; each has its own progressive sequence of developments.

## **Towards an optimal observing network**

*Contribution to Theme 8 by the Scottish Association for Marine Science*

### **Background**

To retain a competitive edge in marine science, SAMS needs to develop new tools and technologies in parallel with new scientific ideas. Modelling tools allow us to make predictions by which our

ideas and hypotheses can be tested through experiment: observational tools allow us both to conduct these experiments and to discover the new phenomena and processes which will drive forward the next wave of scientific endeavour. The overall aim is to develop our understanding of the natural world, to benefit society and to satisfy our scientific curiosity. In particular we recognise the importance of:

- The move away from ship-based unrepresentative snapshot measurements towards long duration smart autonomous platforms in direct communication with the laboratory;
- The need to test understanding of basic processes by building high skill content models with predictive capability.

SAMS already participates in major international efforts such as the Argo float programme and the Data Buoy Co-operation Panel, both of which are actively engaged in deploying autonomous instruments throughout the world's oceans. Similarly, we work closely with many international partners in adapting and harnessing satellite technology for oceanographic applications. The technology development group is now also being strengthened through a number of new appointments, including the recent recruitment of a senior engineer with a major academic and practical track record in robotics, intelligent sensor systems, acoustic imaging and image processing. This will position the group well in tackling the technology issues of the next decade.

### **Aims and rationale**

The aims and rationale of the SAMS contribution are as follows:

- Sensor optimisation, to allow the best possible description of the environment and its changes
- Smart data processing (adaptive sampling, compression, image processing), to maximise the return of useful data when resources are scarce
- Development of platforms (landers and crawlers, gliders, profilers, actuators and manipulators), to replace expensive and unreliable ships and people, and extend our observational frontiers
- Extended use of satellite and other communications and positioning techniques (RF and satellite, acoustic, optical, GPS), to bring observations to the scientist in real time, and permit remote control of platforms
- Implementation of monitoring networks (instrumentation and modelling of a semi-open basin, self-configuring network architectures, optimal deployment strategies for free-drifting instruments), to observe critical ocean areas and inform ocean, atmosphere and climate models
- Wider data publication and outreach (web publication, public interaction), to tell our story to other scientists and to the public

## **WP 8.7 (SAMS) Sensor optimisation and smart data processing**

### **Specific objectives**

- To tackle the problems of how best to characterise the environment in terms of the observables measured, and how to cope with the problems of sensor stability during long deployments.
- To develop smart *in-situ* data processing techniques to make best use of the available energy budget in autonomous platforms.

### **Approach and methodologies**

#### **WP 8.7a Sensor optimisation**

This will involve close interaction with the data users and modellers to specify the key variables for the future, and the required precision and measurement density in space and time. The solution not involves traditional engineering skills, but also requires the development of new classes of sensor (e.g. Molecularly Imprinted Polymer Sensors, the subject of a recent collaboration between SAMS and the Robert Gordon University), and the use of modern statistical and computational techniques to generate best estimates of the measurand in the presence of noise and drift. This work will especially benefit Themes 1, 5 and 10 (turbulence measurement, moving observatories, SOs), and complements work at NOC.

**WP 8.7b Smart data processing**

Given our overall aim to develop a new generation of long duration smart autonomous platforms in real-time contact with the laboratory, a fundamental problem is how to make best use of the available energy budget, and indeed how to replenish it if possible. We believe that the traditional linear approach to data processing and telemetry is no longer energy efficient, and that modern processors (e.g. compact geometry FPGAs and low power microprocessors), coupled with event-driven sampling, rule-based data selection, adaptive algorithms and data compression, will lead to important energy efficiencies and improved data quality. SAMS, in collaboration with DSTL, has already demonstrated the value of adaptive data sampling in characterising water column properties from small free-drifting platforms, and we are well placed through new recruitments to develop this philosophy further (e.g. to improve the utility of data collected by Argo floats; Theme 10, SO 5). A further goal concerns the transmission of video imagery from seabed landers and crawlers via acoustic links. This imagery is required both for scientific purposes (e.g. the examination of benthic colonies such as coral mounds) and for engineering diagnostics. While much image compression software is readily available (e.g. JPEG, MPEG-4), none is optimal for the generally slow-changing image content of sub-sea imagery: new approaches (e.g. using bespoke embedded processors) may yield significant advances in this area and be of benefit to development work at NOC and POL.

**Deliverables**

The design of an optimal sensor network for a pilot area, implementation of a network and data conditioning and management procedures; the development of adaptive sampling techniques for autonomous vehicles, specifically profilers and gliders; the demonstration of real-time video from autonomous sea-bed packages.

**WP 8.8 (SAMS) Water column and seabed platforms****Specific objectives**

- i) To further develop the reliability and range of the Homer and Simop profilers to allow profiling to full ocean depth.
- ii) To equip the profilers and landers with new sensors as they become available.
- iii) To develop a robotic crawler capable of exploring the sea floor.

**Approach and methodologies**

SAMS plans to build on its established record in benthic landers and profilers (the seabed-resident Homer and its inverted ice-tethered counterpart Simop) to equip NERC scientists with a new range of tools for studies of the water column and seabed and the communities that inhabit them. Platforms will be equipped with new sensors and processors as they come on line (this complements work at NOC), and the video links described above will accelerate the engineering development and validation process. Given the emergence of new robotic techniques for navigation, decision-making and manipulation, some of which are particularly suited to the subsea environment (e.g. electrostrictive actuators), and our new capabilities in this area, we plan to take the lead in the UK development of crawlers for scientific use (Themes 1, 3 and 10).

**Deliverables**

The demonstration of reliable long profile capability from Homer and Simop, the demonstration of a prototype robotic benthic crawler.

**WP 8.9 (SAMS) Satellite communications, GPS and monitoring networks****Specific objectives**

- i) To develop long duration Iridium equipped drifters for ocean and polar science.
- ii) To develop optimal strategies for the deployment and re-seeding of networks of free-drifting platforms.
- iii) To develop self-configuring sensor networks that reduce reliance on underwater connectors.

- iv) With SMRU, to develop the next generation of sea mammal tags.
- v) To develop and extend the SAMS local observing network to the Sea of the Hebrides.
- vi) To open public access to our observations and experiments using web-based tools.

### **Approach and methodologies**

#### ***WP 8.9a Satellite communications and GPS***

As an internationally-recognised centre of excellence in the use of satellite communications for scientific purposes, we plan to further exploit this technology and the new strategies it enables for on-line interaction, diagnostics, reprogramming and control to further extend the application of space science philosophies and methodologies to the management of arrays of autonomous platforms. This work is complementary to initiatives elsewhere, notably NOC, POL and SMRU. Satellite communications are not always necessary or feasible, however, and we plan to continue our efforts in the fields of GSM and acoustic communications. We also plan to further develop connector-less subsea communications techniques. As is well known, connector problems have bedevilled many subsea technology developments: efforts to reduce the number of connectors and pins therein generally pay substantial dividends. To this end we will continue our work on IR data transmission and bus architectures, the use of self-configuring sensor networks based on a 2-wire power and data bus, and will collaborate with a Scottish company researching novel wireless electromagnetic techniques for subsea use (relevant to Theme 10, SO 5 and SO 12). We will also build on our skills in adapting low power GPS receivers for scientific use to work with SMRU in creating a new generation of GPS-based data tags for sea mammal and oceanographic research.

#### ***WP 8.9b Monitoring networks***

Significant advances have been made in the creation of high skill-content models for the modelling of the hydrographic and biological properties of ocean basins (e.g. POLCOMS, ERSEM). These modelling efforts need to be supported by observational programmes (e.g. the Liverpool Bay Coastal Observatory), both to inform the models and to validate their output. In the Scottish context, we are well placed to develop a combined modelling and observational programme to study a semi-open ocean basin, the Sea of the Hebrides. This basin is amenable to this approach, through the existence of a considerable infrastructure (Northern Lighthouse Board and UHI sites) for the support of an observational network. This work is especially timely in view of the increasing UK-wide awareness of the need for a marine monitoring programme and associated policy requirements (Themes 6 and 10). In the global context, large deployments of drifters and Argo floats have gone a long way towards the routine measurement of upper ocean properties in support of climate observation, understanding and modelling. Nonetheless, there is wide recognition that the time is right for the development of optimal deployment and reseedling strategies that maximise the usefulness of these observations and their value for money. Recently available ocean current climatologies, themselves derived from many years of drifter programmes, coupled with new insights into the existence of critical regions for ocean observation, make possible valuable research into the design of optimal strategies. This is an area that SAMS intends to pursue (Themes 1 & 10).

#### ***WP 8.9c Data dissemination and outreach***

Ocean science is no longer the exclusive preserve of the professional ocean scientist, and recent years have seen a huge expansion in the use of the internet both for the publication of ocean data and products (both real-time and delayed mode), and as part of an important outreach to the general public. At SAMS we have pioneered the use of the internet for the real-time publication of observations from the polar regions, relayed via the Iridium satellite communication system, and we intend to build on this strength to include internet publication of deep-ocean data and imagery, and to allow public interaction with underway experiments.

### **Deliverables**

The implementation of long-duration Iridium equipped drifters for ocean and polar research, the demonstration of self-configuring sensor networks using IR communications and 2-wire bus architectures, the development of prototype low-power GPS + ocean sensor sea mammal tags (with

SMRU), the installation of a pilot network in Sea of the Hebrides (complementary to SO 12), the development of optimal deployment and reseeded strategies for surface drifters, the implementation of real-time web publication of observatory data and imagery, the development of a pilot site for public interaction with observatory and other data collection activities.

### Summary research plan for WP 8.7– 8.9

The plan is summarised in the Theme-wide Gantt chart (concluding section), with major deliverables identified as milestones. Alongside milestone events, ongoing deliverables will include capacity building for UK marine science, education, outreach and knowledge transfer.

## Theme 8 Synthesis and Concluding Material

### Oceans 2025 synergies and wider links

Prime examples are summarised below of pull from science Themes in Oceans 2025 alongside the capability developed through Theme 8.

Science Theme	Science pull	Capability developed	Delivered by WPs
1	Requirement for real time data transmission for analysis, assimilation and display	Satellite BGAN links, web-enabled sensors	8.9, 8.7, 8.6, 8.3
2	Biogeochemical measurements	$\mu$ FACS cytometers, miniature wet chemical analysers for nutrients and pH, miniature liquid core waveguide nutrient sensors	8.1
3	Turbulence measurements on platforms and autonomous vehicles, measurements for sediment dynamics studies.	In-water microstructure probes, towed temperature/fluorescence chains, coherent acoustic Doppler instrument and ABS.	8.5
5	Bathymetry and multidisciplinary measurements in the deep oceans around complex terrain	Autosub6000 autonomous vehicle	8.2
	Biogeochemical studies in the twilight zone	Autosub6000 with suitable sensors	8.2, 8.1
10	Biogeochemical measurements on moorings, fixed and moving observatories	$\mu$ Facs cytometers, miniature wet chemical analysers for nutrients and pH, optical and electrochemical sensors	8.1
	Requirement for real time data transmission for analysis, assimilation and display	Satellite BGAN links, web-enabled sensors	8.6, 8.7, 8.9, 8.3
	Need for reliable instruments and systems for long-term moorings and observatories.	Risk management process developed and Targetted Reliability introduced	8.4
	Repeat hydrography of physical and subsequently biochemical parameters	Long range AUV and suitable long-endurance biogeochemical sensors	8.2, 8.1
	Continuous monitoring of a relatively pristine coastal environment	Water column profilers, landers and crawlers	8.8

This theme has its strongest links to the Sustained Observations (SOs) in Theme 10 as they provide the bridges between technology and science. These serve two purposes. First, SOs such as the RAPID long term mooring array (SO 3) and the Liverpool Bay Coastal Observatory (SO 11) are direct drivers of technology, for example, for improved platforms with better reliability and data communications. Second, SOs can provide highly relevant and cost-effective test platforms for new technology (e.g. as with the Bermuda Testbed Mooring; Dickey *et al.* 1997). We would expect to use regularly serviced near-shore SOs for early-stage trials of new sensors, followed as necessary by deep-ocean deployments. The concept of being able to use or re-use data for purposes they were not initially intended, which will be facilitated through work envisaged in this Theme, are fundamental to the work on flux climatologies in Theme 10 (SO 9).

Links with science Themes include POL's contribution in respect of the water column and sediments (directly targeted towards Theme 3), while the proposed work on telemetry and data dissemination will advance Theme 1 and observatories within Theme 10, with a follow-on to testing model development (Theme 9). NOC's contributions in sensor and platform development is directed towards advancing the science in Themes 1, 2, 5 and 10 in particular, but is also relevant to

Themes 3, 4, 6 and 7. The links with national facilities include those to BODC for multi-use and archiving of data and to UKORS and National Marine Facilities Division at NOC to transition equipment developed into operational use.

Collaboration with international colleagues will continue, aided in the key areas of autonomous vehicles and observatories by current NERC International Opportunities Fund grants to NOC for Cooperative Autosub Science in Extreme Environments and to POL on facilitating good practice worldwide in coastal observing systems.

A coordinated approach to technology development across the centres will bring added value. Initially, we propose:

- A cross-centres mentoring programme for technologists, helping professional and career development, for example, preparing cases for corporate membership of engineering institutions, helping build relationships between individuals across Centres.
- Fostering opportunities for staff exchanges among Centres and between Centres and industry.
- Workshops targeted at timely issues, such as: making knowledge transfer to industry work; managing engineering intellectual property; cross-over opportunities from devices on marine mammals and autonomous underwater vehicles.
- A clearing-house and electronic forum to improve cross-cutting activity, ideas and techniques and to allow ideas imported from blue skies research to be applied in prototypes of new equipment to meet science needs. It is important to recognise this end of the R&D spectrum, and the opportunities (missed by many in the NERC community so far) to work with programmes such as RCUK's Basic Technology.

#### **Theme-wide stakeholder relevance and knowledge transfer activities**

All the Centres in Theme 8 have obtained, and will continue to obtain, private and public sector funding for research that meets specific research-user needs. Such commissioned research is not presented here; nevertheless, it is the direct consequence of NERC strategic funding. Oceans 2025 will provide the underpinning capabilities, expertise and facilities to continue meeting user needs in future, whilst itself delivering data, information and understanding directed at national needs. The main stakeholders in this Theme are:

- *Marine and other businesses* need new products, but they may not have the capacity to test out early-stage ideas. Our annual Ocean Technology Marketplace (with the Association of Marine Scientific Industries) will provide industry with regular contact with researchers, and provide insights into the emerging needs of industry.
- *Central government and the devolved administrations.* All of the work packages are relevant to the Ministry of Defence and the Defence Science and Technology Laboratory (DSTL) in risk reduction and technology assessment concerned with underwater vehicle and sensor technology. We engage in their 'Towers of Excellence' process to create project teams with industry allied to the work described here. The improved chemical and biological sensor technologies and communications to be developed here will be highly appropriate to the Defra and Environment Agency remits to monitor coastal seas. The technologies to be developed may become relevant to the Cabinet Office and Home Office's remits on security.
- *Regional Development Agencies.* By engaging with RDAs, e.g. through clusters and enterprise hubs, with their business champions and facilitators, we become relevant to local marine and knowledge businesses, helping those businesses to grow and enter new markets with new technologies.
- *National and regional marine resource managers.* In 2006 NOC aims to lead the formation of a pan-European analogue to the successful Alliance of Coastal Technologies in North America, to bring together research institutions, national and regional resource managers, and the private sector interested in developing and applying sensor and platform technologies.
- *UK marine scientists* in order to maintain national capability in advanced technology for marine science individual scientists and groups such as the National Centre for Ocean Forecasting have

driven the Theme's formation and scope, and will provide oversight and direction throughout its life. We will arrange a biennial Sandpit\* involving technologists and scientists across the Oceans 2025 community (including stakeholders and universities), on topics for engineering R&D for ocean science. [\* residential interactive workshop involving 20-30 participants, a facilitator and stakeholders to encourage lateral thinking and new approaches].

### **Knowledge transfer strategy**

This Theme has a strategy for knowledge transfer founded on dialogue with those that would benefit from our know-how. We propose to focus our knowledge transfer efforts in three key areas:

#### ***Industry***

Our aim is to contribute to wealth creation through knowledge transfer to industry. The main mechanisms we will use for turning technology innovation into commercial success will be: a) licensing of intellectual property<sup>1</sup>, especially sensor technology and the know-how behind the new generation of autonomous underwater vehicles; and b) partnering with creative companies on commissioned research contracts where our know-how adds value for the customer, e.g. with Qinetiq via its partnership with the University of Southampton. To facilitate this interaction, we will hold annual Ocean Technology Marketplaces as joint events between this theme and the Association of Marine Scientific Industries. They would expose industry to the technology available in the NERC marine community – and the science community to the opportunities and benefits of working with industry. The Marketplace and our regular participation in the Marine Measurement Forum would highlight several routes for technology development and exploitation, including:

- Exposure to, and opportunities for industry to support and be involved in, proposals for developments that would be expected to lead to commercially exploitable products.
- Opportunities for companies to sponsor Industrial CASE studentships.
- Tapping the benefits of Knowledge Transfer Partnerships.
- Facilitating exposure and discussions leading to licensing or spin-out of technology.
- Increased contact with companies will enable transfer of best practice from industry to research, promote effective outsourcing, help improve efficiency and lower costs.
- SAMS will continue with its existing knowledge transfer practices, whereby suitable technology (e.g. novel sensors and platforms) is taken to pre-market stage using support from NERC SBRI and LEC initiatives.

#### ***Public sector agencies***

To provide relevant and timely advice to government on marine environmental technologies we aim to work with the Inter-Agency Committee on Marine Science and Technology (IACMST), whose members include central government departments, the devolved assemblies and agencies. We propose the formation of a joint working group between IACMST and this Theme whose remit would be to plan a series of events focusing on the UK requirements for new marine technologies to meet government needs. For example, workshops on sensor technology for cost-effective intelligent sampling of the marine environment tuned to the needs of marine monitoring and future UK and EU legislation.

#### ***Society at large***

Our aim is to capitalize on the popularity of ocean exploration and technology with the public. We will build on our existing culture of dialogue with the public, centred on creating exhibits at national museums and science centres with high visitor numbers. Imaginative displays of actual equipment, complemented with models and interactive computer graphics (which have included 'design your own autonomous underwater vehicle') have proven popular. We aim to provide

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<sup>1</sup> The Autosub licence to Subsea7 remains NERC's largest licence agreement to date.

exhibits at the Science Museum<sup>2</sup> and the National Maritime Museum, and to enter new partnerships with the National Marine Aquarium, the new InterACTION gallery at Portsmouth Historic Dockyard and the London Aquarium. The envisaged Web display of continuous measurements is very effective in stimulating user access to data and science, as shown already in the Liverpool Bay Coastal Observatory. POL and the NERC e-science teams are already working together to promote development and awareness of distributed sensor networks using broadband technology and to provide greater access.

### **Strategic Ocean Funding Initiative (SOFI)**

Up to 10% of the available research funding for Oceans 2025 will be made available to UK universities and other academic institutions eligible to receive NERC support. Such funding will be awarded for research that is complementary to the Oceans 2025 science Themes, in defined topic areas in a series of funding calls (first call to be announced in 2007). For Theme 8, the following SOFI opportunities have been identified:

- Collaboration and access to microfabrication and design facilities.
- Specialised analysis of microstructure profiler data.
- Development and testing of collision avoidance and manoeuvring algorithms using hardware-in-the-loop simulations for advanced autonomous vehicles that bridge software simulation and at-sea testing.
- Development of automatic fault detection and intervention strategies to enhance reliability.

### **Consolidated fieldwork**

Our aim is to develop (during 2006) a plan and a structure to facilitate coordinated fieldwork for technology development. Between NOC, POL and SAMS we anticipate that the coordinated approach would include:

- Open ocean dedicated engineering trials cruises, annually (if called for), which would be led by NOC but with a call for participation by the other Centres (this has already begun, with approval for a trials cruise in 2007 that will involve three Centres).
- Coastal dedicated ship-based and moored trials on shorter timescales than deep-ocean cruises using the RV *Calanus* (SAMS) on a repayment basis.
- Opportunistic trial deployments in shallow water tied in to the regular ship schedule for servicing the Liverpool Bay Observatory. We also envisage equipment under development being moored for extensive periods at the Observatory, benefiting from the measurements being made by all of the other installed equipment.

Information on coordinated trials opportunities will be available to the community via the web.

### **Summary of theme-wide outcomes**

Deliverables planned for the early and mid stage of Oceans 2025, include, by topic:

- *Sensors* – a 3-axis coherent Doppler velocity profiler in 2007; dissolved iron/manganese and ammonia sensors licensed to industry and a 6-frequency ABS field-tested in 2007/8; microstructure stinger on vessel bow and towed thermistor-fluorometer chain trialled in 2007/9.
- *Platforms* – sea trials of Autosub6000 in late 2007 and fully operational in 2010.
- *Communications and Information* – the technique of BGAN telemetry to be proven from land-based sites and two-way links for fault diagnosis in 2007; BGAN connection of radars in 2007/8; web-publication of data, an optimal drifter seeding strategy and extended Iridium drifters, Homer and Simop in 2008, and in 2009, to be testing web-connected instruments and sensors on board the RRS *James Cook*.
- *Reliability* - a Targeted Reliability plan to inform the RAPID redesign in 2007, a Risk Management Process by early 2008 and a reliability analysis of Autosub6000 in mid 2008.

<sup>2</sup> Our Autosub exhibit at the Wellcome Gallery of the Science Museum was listed as an example of NERC outreach in the Government's response to the House of Lords Select Committee on Science and Technology's third report on Science and Society.

**Schedule 2007 – 2012**

NOC	2007	2008	2009	2010	2011	2012
<b>WP8.1a Sensor research</b>						
Extended range $\mu$ FACS	▲	▲	●			
Genomic $\mu$ FACS	▼			●		
Multianalyte LOC					●	
<b>WP8.1b Practice-based sensor R&amp;D</b>						
LOC sea trials				●		
EWAS field trials	▼	▼	▼	●	▼	
<b>WP8.1c Knowledge transfer</b>						
<b>WP8.1d Science support</b>						
Micro pH sensor trials				●		
Micro logger/controller			●			
<b>WP8.2a Autosub6000</b>						
First sea trial		▲	●			
Science missions start				●		
<b>WP8.2b Very long range AUV</b>						
First sea trials				▲		
Science missions start					●	●
<b>WP8.2c Air deployable platforms</b>						
<b>WP8.3a Multiuse data - enabling</b>						
<b>WP8.3b Implementing web-connect</b>						
Web-connect vessels			●	●		
<b>WP8.3c Towards auto recalibration</b>						
Auto recalibration demo					●	●
<b>WP8.4a Develop Risk Process</b>						
Risk Process complete		●				
<b>WP8.4b Application to RAPID array</b>						
First risk study report	●					
Second risk study report	▼			●		
<b>WP8.4c Application to AUVs</b>						
Autosub6000 reports			●		●	
VLR AUV reports				●		●
<b>POL</b>						
<b>WP8.5a In-water microstructure</b>						
Stinger fabrication, trial			●	●		
AUV/Glider microstructure				●	●	●
Towed chain built/trials			●	●		
<b>WP8.5b Particle dynamics</b>						
CDVP built/trials	●	●		●	●	
6-freq. ABS built, trial			●	●		
Intra-ripple; bed-load					●	●
<b>WP8.6 Telemetry</b>						
Land broadband, 2way	●					
From buoys, radars		●				
Myrtle BGAN trial				●	●	
<b>SAMS</b>						
<b>WP8.7a Sensor optimisation</b>						
Design pilot optimal network			●			
<b>WP8.7b Smart data processing</b>						
Adaptive sampling				●		
Video from seabed units					●	
<b>WP8.8 Platforms</b>						
Extended Homer & Simop		●		●		
Prototype benthic crawler						●
<b>WP8.9a Communication techniques</b>						
Extended Iridium drifters		●				
Self-configuring sensor net IR				●		
Self-configuring sensor net 2-wire					●	
Sea mammal GPS sense tag			▼	●		●
<b>WP8.9b Monitoring networks</b>						
Sea of Hebrides pilot net				●		
Drifter seeding strategy			●			
<b>WP8.9c Data dissemination/outreach</b>						
Web publication of data			●		●	
Pilot public interaction			●		●	

Black lines show periods of major activity, grey lines show background activity, e.g. collecting data  
 The filled circles are major milestones for the work packages. Arrows show key connections between work packages.

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## Acronyms

ABE	Autonomous Benthic Explorer (an AUV from WHOI)	LEC	Local Enterprise Company
ABS	Acoustic Backscatter Sensor	LISST	Instrument - Laser diffraction particle size analysers
ADCP	Acoustic Doppler Current Profiler	LOC	Lab on Chip
ADV	Acoustic Doppler Velocimeter	MBARI	Monterey Bay Aquarium Research Institute
ARGO	Global system of drifting neutrally buoyant sub-surface floats	MSS	Micro scale water stratification measurement system
ASTP	Instrument name – a small microstructure sensor	MST	Micro Systems Technology
AUV	Autonomous Underwater Vehicle	MYRTLE	Multi Year Return Tidal Equipment
BAS	British Antarctic Survey	NERC	Natural Environment Research Council
BGAN	Broadband Global Area Network	NOAA	National Oceanic and Atmospheric Administration
BODC	British Oceanographic Data Centre	NOC	National Oceanography Centre, Southampton
CASE	Cooperative Awards in Science and Engineering	OBS	Optical Backscatter Sensor
CDVP	Coherent Doppler Velocity Profiler	POL	Proudman Oceanographic Laboratory
Defra	Department for Environment Food and Rural Affairs	POLCOMS	Proudman Oceanographic Laboratory Ocean Modelling System
DSTL	Defence Science and Technology Laboratory	R&D	Research and development
EMEC	European Marine Energy Centre	RAPID	NERC directed programme on rapid climate change
ERSEM	European Regional Seas Ecosystem Model	RMP	Risk Management Process
EWAS	Evanescence Wave Spectroscopy	RSU	Research Ship Unit (NERC)
FACS	Micro Fluorescence-Activated Cell Sorter	SAMS	Scottish Association for Marine Science
FPGA	Field Programmable Gate Array	SBRI	Small Business Research Initiative
FTA	Fault Tree Analysis	SIMOP	Sea Ice Mounted Oceanographic Profiler
FTE	Full Time Equivalent (person years)	SMRU	Sea Mammal Research Unit
GPS	Global Positioning System	SO	Sustained Observations
GSM	Global System for Mobile communications	SOFI	Strategic Ocean Funding Initiative (Oceans 2025)
HF	High Frequency (Radio waves between 3–30MHz)	SPM	Suspended Particulate Material
HOMER	Homing Environmental Monitor	UCL	University College London
IACMST	Inter-Agency Committee on Marine Science & Technology	UHI	Highlands and Islands Millennium Institute
IOC	Intergovernmental Oceanographic Commission	UKORS	UK Ocean Research Services (NERC)
IR	Infra Red	UWB	University of Wales Bangor
iUSBL	Inverted Ultra-Short Base Line (for acoustic navigation)	WCA	Wet Chemical Analyzer
JCOMM	Joint WMO/IOC Commission for Oceanography and Marine Meteorology	WHOI	Woods Hole Oceanographic Institution
LCW	Liquid Core Waveguide	WMO	World Meteorological Organisation
		XML	Extensible Markup Language