THE NERC MARINE CENTRES' STRATEGIC RESEARCH PROGRAMME 2007-2012

Theme 10: Integration of Sustained Observations in the Marine Environment

The marine environment is large in scale, highly dynamic and relatively inaccessible – requiring sustained observations to obtain meaningful information on environmental changes and their causes. This Theme is a NERC Category 1 activity that provides the infrastructure and scientific coordination to support many well-established marine time series and monitoring studies, together with others specifically designed to meet the needs of Oceans 2025. It involves all marine Centres, spans all marine domains and disciplines, and provides essential knowledge on Earth system behaviour and human-driven changes.

Theme 10 comprises fourteen Sustained Observation (SO) activities involving all Oceans 2025 Centres. As follows, with contact names: Marine Biological Association, MBA (*Martin Genner majg@mba.ac.uk*); National Oceanography Centre, Southampton, NOCS (*Denise Smyth-Wright dsw@noc.soton.ac.uk*); Plymouth Marine Laboratory, PML *(Carol Robinson crob@pml.ac.uk*); Proudman Oceanographic Laboratory, POL (*Roger Proctor rp@pol.ac.uk*); Scottish Association for Marine Science, SAMS (*Toby Sherwin tjshe@sams.ac.uk*); Sea Mammal Research Unit, SMRU (*Ailsa Hall* ajh7@st-and.ac.uk); Sir Alister Hardy Foundation for Ocean Science, SAHFOS (*Peter Burkill phb@sahfos.ac.uk*). These SO activities are presented in four groups:

Open ocean	SO 1	Atlantic Meridional Transect (*PML; NOCS)*
	SO 2	Porcupine Abyssal Plain deep ocean observatory *(NOCS)*
	SO 3	The meridional overturning circulation *(NOCS; POL)*
	SO 4	The extended Ellett line *(NOCS; SAMS)*
	SO 5	Argo profiling floats: deployment and coordination *(NOCS)*
	SO 6	Antarctic circumpolar current *(NOCS; POL)*
	SO 7	GLOSS sea level network *(Roger Proctor, POL)*
	SO 9	Climate-quality surface marine observations and products *(NOCS)*
Coastal seas	SO 10	Western Channel observatory *(PML; MBA)*
	SO 11	Irish Sea Liverpool Bay observatory *(POL)*
	SO 12	Tiree Passage time series (SAMS)
	SO 13	Arctic Shelf time series *(SAMS)*
Sea mammals	SO 14	Marine Mammal Survey *(SMRU)*
Plankton	SO 15	Continuous Plankton Recorder *(SAHFOS)*

The text that follows is based on that submitted to NERC. For details on other Themes and National Facilities, see www.oceans2025.org. This information is made public by the Oceans 2025 Directors to facilitate engagement of the wider community in the programme; permission is required for other uses. This text does not include information on resource requirements, and is limited to fully- or partly-funded activities within the Oceans 2025 programme. Since not all the programme is fully-funded, there may be changes to some objectives and deliverables (to be identified in the Implementation Plan).

Theme 10: Integration of Sustained Observations in the Marine Environment

Analysis and interpretation of monitoring and time-series studies

Strategic setting

NERC has a long history of making sustained measurements in the marine environment. Such data collection, collation and stewardship activities are not only critical for NERC to fulfil its mission and charter ('to promote and support high-quality basic, strategic and applied research, *survey, long-term environmental observation* and related postgraduate training…') but also central to NERC's current strategy and science priorities (Earth's life-support systems, climate change and sustainable economies; NERC, 2002), and are also likely to feature strongly in its developing future strategy (www.nerc.ac.uk/consult/strategy07/). NERC marine activities in this area complement UK government policies and programmes on climate change (Defra, 2000) and are strongly aligned with international initiatives, including the Global Earth Observation System of Systems (GEOSS) and the European programme on Global Monitoring for Environment and Security (GMES).

The Sustained Observations (SOs) proposed here span all marine domains from the sea-shore to the global ocean, providing data and knowledge on a wide range of ecosystem properties and processes (from ocean circulation to biodiversity) that are critical to understanding Earth system behaviour and identifying change. They have been developed not merely to provide long-term data sets, but to capture extreme or episodic events, and play a key role in the initialisation and validation of models. Many of these SOs will be integrated into the newly developing UK Marine Monitoring Strategy – evolving from the Defra reports *Safeguarding our Seas* (2002) and *Charting Progress* (2005), thus contributing to the underpinning knowledge for national marine stewardship. They will also contribute to the UK GOOS Strategic Plan (IACMST, 2006) and the Global Marine Assessment.

Theme 10 directly benefits the science Themes 1-7 and contributes to the cross-cutting Themes 8 and 9. It brings together SO activities into coherent clusters, identifying synergies and common methods for the efficient collection, analysis and long-term security of these important resources.

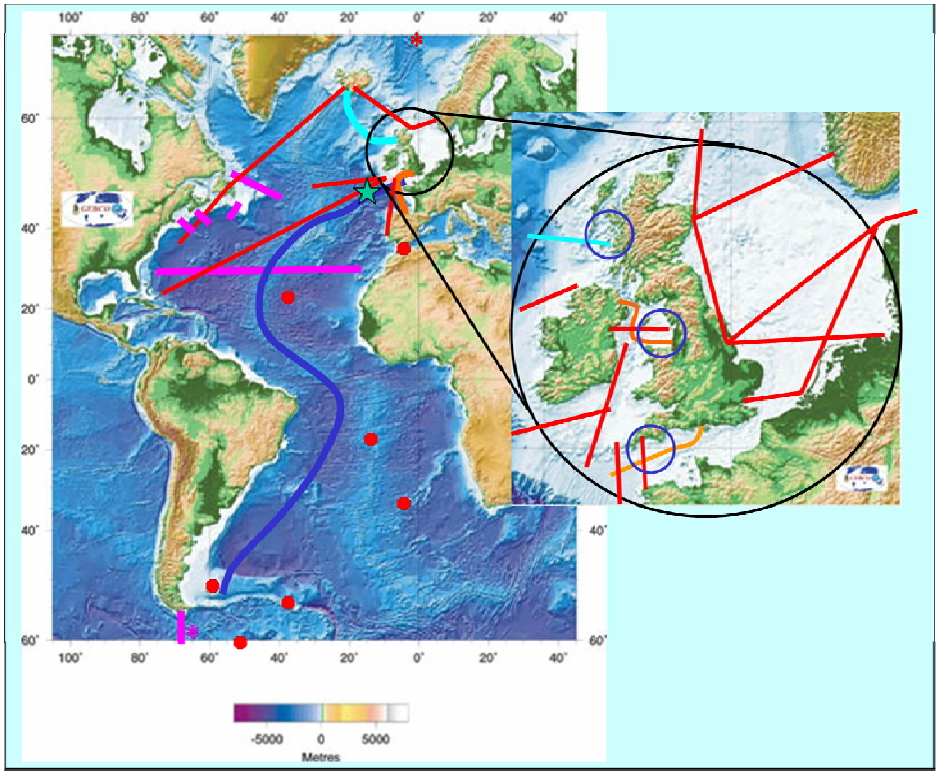

Figure 1. Summary of the spatial coverage of Sustained Observations in Theme 10.

AMT (SO 1)
PAP (SO 2)
MOC, Drake (SO 3, 6)
Ellett Line (SO 4)
UK-GLOSS (SO 7)
Coastal Observatories (SO 10,11)
Arctic series (SO 13)
CPR routes (SO 15)

Plus Argo (SO 5), surface fluxes (SO 9), & marine mammals (SO 14)

Main science aims

The SOs are grouped in four clusters. Those for the open ocean and coastal seas involve multi-disciplinary studies by many Centres, whilst the two biologically-based activities focus on marine mammals (under SMRU, Sea Mammal Research Unit) and plankton (under SAHFOS, Sir Alister Hardy Foundation for Ocean Sciences).

The **open ocean** SOs (SO 1 – 9; listed in box below) have a basin-wide perspective, providing integrated knowledge on the physical, chemical and biological behaviour of both the North and South Atlantic. A shared goal is to reduce uncertainty in the observed components.

SO 1 Atlantic Meridional Transect	SO 6 Antarctic Circumpolar Current
SO 2 Porcupine Abyssal Plain deep ocean observatory	SO 7 UK GLOSS sea level network
SO 3 The Meridional Overturning Circulation	SO 9 Climate-quality surface marine observations and products
SO 4 The Extended Ellett line	
SO 5 Argo profiling floats: deployment and coordination	

The Atlantic Meridional Transect (AMT, SO 1), operational since 1995, aims to understand ocean plankton communities and improve our ability to predict the role of the open ocean in the global carbon cycle. This will be continued by eight further transects over 2007-12. Reducing uncertainty in how ocean ecosystems are structured is also an aim of the Porcupine Abyssal Plain (PAP) ocean observatory (SO 2), involving high frequency measurements of both water column and seafloor processes. Spatial context to SO 2 will be provided by the AMT transects and by a CPR route (SO 15) which pass nearby.

The Meridional Overturning Circulation (MOC; SO 3) is the key component of ocean circulation in the Atlantic responding to climate change. Under the NERC directed programme *Rapid Climate change* (RAPID; www.noc.soton.ac.uk/rapid/rapid.php) two arrays of instruments have been positioned in the ocean to monitor the MOC, one at 26.5^{o}N to capture the southward flow at depth, and the WAVE array across the Canadian-US continental slope, closer to the presumed source variations. SO 3 will continue these measurements to observe the strength and structure of the MOC, working closely with Theme 1 and the proposed RAPID II directed programme. The Ellett Line (begun in 1975 and since 1996 the Extended Ellett Line from Scotland to Iceland) crosses important north Atlantic MOC components and thus provides an additional contribution to understanding the north Atlantic response to climate change. SO 4 will repeat this section annually collecting a wide variety of physical and biogeochemical measurements, and, to enhance the time variable component, make use of Argo floats and gliders. SO 5 leads the UK contribution to the international Argo programme to populate the oceans of the world with autonomous profiling floats – contributing to long-range weather forecasts, as well as informing climate change analyses.

SO 6 continues measurements started in 1993 of the transport of the Antarctic Circumpolar Current (ACC) in the Drake Passage, a strategic choke point for the global ocean circulation which impacts on the North Atlantic and the MOC.

Rising sea levels threaten an increasing percentage of the world's population. The GLOSS network of the Intergovernmental Oceanographic Commission (IOC) for monitoring global sea level will only be fully effective when all ocean regions are adequately equipped with sea level recorders. SO 7 will extend the GLOSS network at Atlantic and Antarctic sites which are the UK's responsibility.

Information on air-sea fluxes, and how they are changing on multi-decadal scales, is critical for monitoring and assessing climate change; improving models; and linking with other major studies (including CASIX, SOLAS and CLIVAR). SO 9 provides the mechanism for integrating the increasing sources of historical and operational environmental data into the coherent datasets essential for understanding climate change.

SO 10 Western Channel Observatory	SO 12 Tiree Passage time series
SO 11 Irish Sea Liverpool Bay Observatory	SO 13 Arctic Shelf time series

The health of our **coastal seas** is vitally important for us all and impacts on our ability to develop sustainable marine economies. Of particular importance is a need to disentangle natural variability from human influence. SOs 10 - 12 continue multidisciplinary observations for the coastal seas of the Western Channel, the Eastern Irish Sea (Liverpool Bay) and the Scottish West Coast. These observatories, in line with the NOOS Strategy (2001), provide real-time physical, chemical and biological measurements and, coupled with real-time modelling systems aim to provide: information on the functioning of shelf seas; useful inputs to marine management; and platforms for process studies conducted in other Themes. The observatories cover a spectrum of conditions with SOs 10 and 12 being 'relatively pristine', making it easier to distinguish between natural and human influences. In contrast, the environment of SO 11 has experienced 150 years of industrial activity and is now in the recovery phase. Biodiversity is a key indicator of climate change and of human impact in marine ecosystems: it is a component of SO 10 via integrated and quantitative time-series of benthos, intertidal organisms, plankton and fish.

The Arctic seas are particularly vulnerable to climate change, and the rapid retreat of the Arctic ice sheet may be one of the most significant indicators of long term climate change. Automatic sensors and data loggers at SO 13 continuously monitor physical and biological changes on an Arctic shelf (Svalbard) at the critical junction between Atlantic and Arctic Oceans.

SO 14 Long-term observations of the dynamics of marine mammal populations

NERC has a statutory duty under the 1970 Conservation of Seals Act to provide advice to the UK government on **marine mammals** (focussed on UK grey and harbour seal populations). SO 14 is primarily designed for this purpose. It will also assist in fulfilling national obligations under the EU Habitats Directive, whilst linking with other Themes in assessing the role of marine mammals in the context of ecosystem interactions and the 'ecosystem approach' to marine resource management.

SO 15 Continuous Plankton Recorder survey (phytoplankton and zooplankton, including fish larvae)

The **Continuous Plankton Recorder** (CPR) has been installed on ships of opportunity since the 1930s and has provided strong evidence for climate change by identifying alterations in the species composition and phenology of shelf and ocean plankton species. SO 15 will assist in the continued deployment of CPR devices on many routes in UK shelf seas and the open Atlantic, providing broadscale and long-term contextual information for other time-series, including SO 10 and SO 11.

National networks

Four SOs (4, 10, 11 and 15) already formally contribute to the Defra-funded **Marine Environmental Change Network** (MECN; www.mba.ac.uk/MECN/partnership.htm). Established in 2002 to coordinate and promote the collection and utilisation of marine time-series and long-term data sets, the goal of the network is to use long-term marine environmental data from around the British Isles and Ireland to separate natural fluctuations from global, regional and local anthropogenic impacts. MECN currently has 17 members with NERC marine Centres well represented. The MECN also provides links to European networks such as MarBEF and terrestrial observation networks such as the Environmental Change Network (ECN). Many of the time series maintained by network partners are multi-decadal in nature, with a range of parameters both physical and biological being measured in coastal and shelf seas. MECN provides a forum for network members undertaking these sustained observations to:

- identify potential areas of collaborative research, to address issues such as the influence of large-scale versus small-scale processes.
- consider quality control issues, to maximise comparability of measurements across the network

- improve the 'fit-for-purpose' of the time series not only for researchers, but also for policy makers and other end-users (i.e. strategic science informing policy).

MECN will therefore play a major role in connecting SOs with other national and European marine monitoring activities, whilst also providing a facility for knowledge transfer between the NERC research community and policy bodies. Note that SOs are also connected to Defra (and IACMST) through the **UK Marine Environmental Data Network**, hosted at the British Oceanographic Data Centre (BODC; NF 1 in Oceans 2025) and to Defra's newly-formed **Marine Data & Information Partnership** (MDIP), as part of Defra's new Marine Monitoring Advisory Strategy (MMAS).

In addition to ensuring closer scientific coherence and integration, Theme 10 will bring together the SOs in a more pragmatic manner by:

- sharing technology wherever possible; e.g. telemetry methodology, data protocols
- ensuring that all data are secured (and available to research users) by transfer to BODC
- giving the SO datasets high visibility by developing a single website, linked to all Centre websites, where information, latest news, latest data and archived data are accessible (with some caveats) to scientists and the general public.

Centres' contributions

The participation of Centres in Theme 10 is as follows:

SO		NOC	PML	POL	SAMS	SMRU	MBA	SAHFOS
1	Atlantic Meridional Transect *to give warning of fundamental change in the functioning of Atlantic-wide ecosystems*	■	■					
2	Porcupine Abyssal Plain observatory *to detect climate change impacts on deep ocean & seafloor ecosystems*	■						
3	The Meridional Overturning Circulation *assessing the role of the Atlantic thermohaline circulation in rapid climate change*	■		■				
4	The Extended Ellett line *quantifying environmental changes off the western seaboard of the UK*	■			■			
5	Argo profiling floats *detecting changes in the circulation and heat content of the global ocean*	■						
6	Antarctic Circumpolar Current *to detect and understand variability in a key component of ocean circulation*	■		■				
7	GLOSS sea level network *construction of the UK component of the global sea level network*			■				
9	Climate-quality surface marine datasets and gridded products from *in situ* and satellite data	■						
10	Western Channel Observatory *combining >100 yr physical and biological timeseries with EO and integrated modelling*		■				■	
11	Irish Sea Liverpool Bay Observatory *integrated time-series studies, EO and modelling to detect ecosystem change*			■				
12	Tiree Passage time series				■			
13	Arctic Shelf time-series: *monitoring cross-shelf water mass transformations in a changing ice environment*				■			
14	Long-term observations of marine mammals *providing advice to the UK government on seal management*					■		
15	Continuous Plankton Recorder survey *the only basin-wide and long-term operational survey of plankton in the world*							■

NOC, National Oceanography Centre, Southampton; PML, Plymouth Marine Laboratory; POL, Proudman Oceanographic Laboratory; SAMS, Scottish Association for Marine Science; SMRU, Sea Mammal Research Unit; MBA, Marine Biological Association; SAHFOS,Sir Alister Hardy Foundation for Ocean Science.

OPEN OCEAN CLUSTER

SO 1 - The Atlantic Meridional Transect

Strategic context

The Atlantic Meridional Transect programme (AMT; www.amt-uk.org) is an open ocean *in situ* observing system that will: i) give early warning of any fundamental change in Atlantic ecosystem functioning; ii) improve forecasts of the ocean's future state and associated socio-economic impacts; and iii) provide a 'contextual' logistical and scientific infrastructure for independently-funded national and international open ocean biogeochemical and ecological research.

AMT addresses key strategic priorities identified by NERC (Science for a Sustainable Future) related to carbon cycling, the diversity of microbial assemblages and the role of microbes in eco-system function. AMT also contributes to three themes in Defra's Science and Innovation Strategy: climate change, conservation, and the marine environment. In particular, AMT provides a means to assess biodiversity trends in relation to environmental change — improving understanding of the structure and functioning of marine ecosystems, the interactions between physical and ecological processes, and the impact of climate change on the ocean.

Overall aims and purpose

The biota of the surface ocean has a profound influence on the global budgets of climatically-active trace constituents in the atmosphere, and hence, climate, while atmospheric deposition of nutrients and changes in weather patterns affect the diversity and activity of marine plankton (Gnanadesikan *et al* 2003; Sarmiento *et al* 2004). To reduce uncertainties in the prediction of the future global environment, an improved knowledge of the interactions between marine and atmospheric biogeochemical cycling is required. AMT (Aiken & Bale, 2000; Aiken *et al* 2000; Robinson *et al* submitted) is a time series of stations along a 13,500 km transect in the Atlantic Ocean (see Figure). The aims of AMT are to quantify the nature and causes of ecological and biogeochemical variability in planktonic ecosystems, and to assess the effects of this variability on biogenic export and on air-sea exchange of radiatively active gases. The programme began in 1995, utilising the passage of the *RRS James Clark Ross* between the UK and the Falkland Islands (50°N to 52°S) southwards in September and northwards in April each year in an extremely cost-effective manner. Eighteen cruises have been completed so far, and the data have contributed to 110 peer reviewed publications and 68 PhD theses. For details see: www.pml.ac.uk/amt/publications/amt_publications.html.

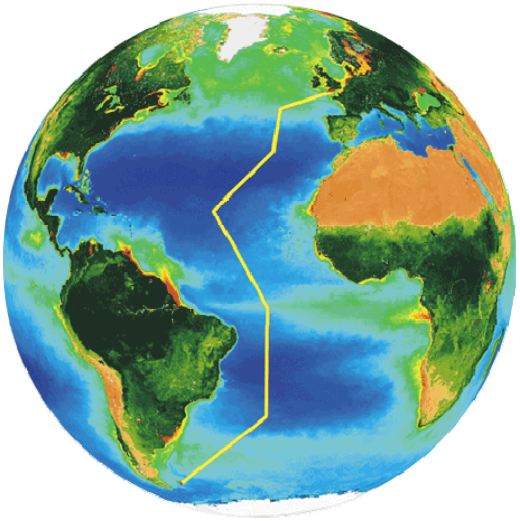

Figure 2. The 'standard' AMT track

This sustained observing system aims to provide basin-scale understanding of the distribution of planktonic communities, their nutrient turnover and biogenic export in the context of hydrographic and biogeochemical provinces. The spatial and interannual variability in the air-sea exchange of climatically important microbiologically mediated gases (e.g. CO_2, O_2, dimethylsulphide) is influenced in part by the composition of the plankton community and the relative magnitude of photosynthesis (P) and respiration (R). The balance between P and R (=net community production NCP) is poorly constrained, with measurements disagreeing on the sign let alone the magnitude (Williams, 1998; Duarte *et al* 2001). Dissolved organic matter (DOM) is an important sink of organic carbon in pelagic ecosystems which can be decomposed in surface waters by both heterotrophic bacteria and short-wave solar radiation. The spatial and temporal extent of this has been well characterised in coastal waters (Bissett *et al* 2005; Smith & Benner 2005) but remains poorly studied in oceanic environments (e.g. Rosenstock *et al* 2005). AMT enables the measure-

ment of P, R, NCP, plankton community structure, nutrient turnover, CO_2, O_2, and DOM photodegradation over large spatial scales and seasonal, interannual and decadal time scales to better define natural variability and long term trends. AMT will be scientifically led and coordinated at PML following the successful management strategy (including stakeholder participation) applied over the past 10 years. The outcome of NERC's 2005 review of AMT is available at www.pml.ac.uk/amt/publications/SMA_review.pdf.

Description of activity

Core measurements

AMT 2007-12 will comprise five transects between the UK and the Falkland Islands collecting core hydrographic, chemical, ecological and optical data. Many of these measurements will be made in underway mode (either via towed instruments or those connected to a non-toxic surface seawater supply onboard) with minimum personnel intervention. However depth profiles of CTD+water samples will also be taken at daily pre-dawn and mid-morning stations to a maximum of 1000m.

The physical environment will be characterised using vessel mounted ADCP and towed undulating profiler (MVP or SeaSoar) data (McDonagh *et al* 2006). Boundaries between upper ocean water masses, edges of eddies and unstable fronts, will be determined by the position of current jets and compared with near real-time satellite images and upper ocean density sections. The depth distribution of inorganic nutrients (nitrate, nitrite, ammonia, phosphate and silicate) will be measured using standard auto-analytical and sensor techniques (Woodward *et al* 1999; Johnson & Coletti, 2002) in order to determine the depth of the nitracline and its impact on plankton production (Maranon *et al* 2000). The distribution of other limiting nutrients (e.g. iron) and their atmospheric deposition pathways would be ideal subjects for SOFI collaboration.

We will deploy a novel suite of optical- and video-based in-line instruments capable of characterising the whole phyto- and zooplanktonic size range from 1µm to 10mm diameter (FlowCam + LiZa). This suite will produce continuous real-time size-distributed biomass data on organisms classified by functional group. Phytoplanton community abundance and composition will be determined from high performance liquid chromatography (HPLC) analysis of pigments (Mantoura & Llewellyn 1983, Barlow *et al* 1997) and the matrix factorisation software CHEMTAX (Mackey *et al* 1996). The UV photoprotecting compounds, mycosporine-like amino acids (MAAs) will be analysed according to Carreto *et al* (2005). Prokaryotic and eukaryotic picoplankton will be quantified and functional groups characterised by flow cytometry (Zubkov *et al* 2000; Tarran *et al* 2006) with larger protists enumerated using a new high speed technique (Zubkov & Burkill 2006).

Phytoplankton photo-physiological parameters and integrated water column primary production (PP) will be determined by ^{14}C uptake photosynthesis-irradiance relationships using the spectral bio-optical model of Tilstone *et al* (2003). The photosynthetic response of phytoplankton will be determined from Fast Repetition Rate Fluorometry (FRRF) and a Satlantic Fluorescence Induction and Relaxation system (FIRe) (Smyth *et al* 2004). Photophysiological properties will be assessed using photoprotective carotenoid measurements and compared to FRRF and FIRe measurements NCP will be derived from underway surface oxygen/argon ratios measured with a recently validated membrane inlet mass spectrometer (MIMS) system (Tortell, 2005; Kaiser *et al* 2005). A newly developed approach to determine P and R from the triple isotopic composition of oxygen (Luz *et al* 1999; Juranek & Quay, 2005) will be used if independent funding is awarded. Additional funding will also be sought to modify the MIMS system to also measure dimethylsulphide (Tortell, 2005). Surface water and atmospheric pCO_2 will be measured using an automated infra-red gas analyser (Cooper *et al* 1998; Watson *et al* 1991) in collaboration with CASIX. The increasing acidification of the ocean gives added value to time series measurements of other carbon species alongside determinations of changes in plankton activity. External funds will be sought to enable the measurement of pH and alkalinity.

To compare export rates of the N and S oligotrophic gyres, sediment traps will be deployed annually in the middle of both gyres. The settling material will be collected in time series collectors to quantify and characterise the exported material (Lampitt *et al* 2001). Additional estimates of basin scale variability in export will be made using HPLC pigment, particularly carotenoid, analysis of particulate material in the twilight zone.

UV and visible Apparent Optical Properties (AOP) will be measured using *in situ* profiling spectral-radiometers (SATLANTIC and TRIOS UV), together with vertical profiles of Inherent Optical Properties (IOP) including total and dissolved spectral absorption and attenuation coefficients (WETLabs ac-9) and spectral backscattering coefficient (WETLabs ECO-VSF1 and HOBILabs Hydroscat-6). The above water UV and visible light fields will be continuously logged using spectral irradiance and UV deck cells. Discrete water samples will be collected to determine the absorption coefficients in the UV and visible of coloured dissolved organic matter (CDOM) (Blondeau-Patissier *et al* 2004; Tilstone *et al* 2004) and particulate, phytoplankton and detrital material (Tassan *et al* 2000). The measurements of AOP, IOP, Chla and PP will be used to: i) validate products from existing (MODIS & MERIS) and future (SENTINEL 3, NPP & NPOESS) satellite sensors (Barnes *et al* 1998; Rast *et al* 1999; Smith *et al* 2005); ii) improve existing ocean colour algorithms; and iii) develop new algorithms, such as the derivation of phytoplankton functional groups from space. AMT data will also enable validation of operational algorithms from national (RSDAS) or international (NASA or ESA) data providers: this research will provide error limits to the data provided by RSDAS to the marine Centres in Oceans 2025 and the wider research and research-user communities.

Additional measurements made on a less frequent basis

As part of Themes 2 and 4 (PML), during the two 2010/11 transects, we will measure rates of key climatically important microbial and photochemical processes such as phytoplankton excretion of ^{14}C-dissolved organic carbon (Moran *et al* 1999) and its subsequent photodegradation, plankton respiration derived from *in vitro* dissolved oxygen flux (Robinson *et al* 2002), concentrations and fluxes of oxidised volatile organic compounds, the distribution of nutrients at nanomolar concentr-ations and the activity of diazotrophic and nitrifying organisms, as well as viral abundance, diversity and activity. As part of Themes 2 and 5 (NOC), during 2007, 2008 and 2010, we will determine prokaryotic and protist phylogenetic composition and quantify their role in the turnover of critical nutrients (Zubkov *et al* 2003, 2004; Zubkov & Sleigh, 2005). The moored sediment traps at the PAP (SO 2) site will be serviced in 2007, 2008 and 2010. In 2008 we will assess the megabenthos of comparable abyssal plain localities at 8 sites using a SHRIMP (Seabed High Resolution IMaging Platform) towed camera platform (Thurston *et al* 1995).

Participation

This sustained, basin-scale data collection will underpin several science questions and modelling activities addressed in Oceans 2025 Themes 2, 4, 5, 6 and 9. Expressions of interest to participate in future AMT cruises have been received from colleagues at the Universities of Plymouth, East Anglia and Warwick, and the Laboratoire d'Oceanographie Villefranche (France), Institute of Microbiology (Czech Republic), Max Planck Institute for Marine Microbiology, Bremen (Germany) and Universities of Washington and San Diego (USA). Samples will continue to be collected for the International Census of Marine Microbes http://icomm.mbl.edu/.

Deliverables

The main deliverable is an unique time series (1995-2011) of spatially extensive and internally consistent observations on the structure and biogeochemical properties of planktonic ecosystems in the Atlantic Ocean that are required to validate models addressing questions related to the global carbon cycle. The current dataset is available via BODC: www.bodc.ac.uk/projects/uk/amt/. Through development of the BODC website, we aim to have the majority of AMT data on open access within 6-12 months of the end of each cruise. In addition we will construct a "basin scale observatory" with web-based data visualisation, and delivery and analysis of *in situ* and earth

observation (EO) data. This will promote knowledge transfer, and enhance visibility and accessibility of AMT data.

Knowledge transfer and public outreach

AMT will provide data to NCOF/Met Office, the ongoing IGBP/SCOR and NERC programmes QUEST, IMBER, SOLAS and CASIX, the NERC service RSDAS and the WMO/IOC/UNESCO/ UNEP/ICSU co-sponsored Global Climate Observing System (GCOS). AMT will provide the 'contextual' infrastructure for UK and international research, continuing a logistical and shared shiptime facility which independently funded colleagues can apply to use, to enable and enhance their science. For example, AMT (2003-2005) provided the infrastructure and scientific environment to complete 11 UK and 16 internationally funded research projects. Applications by national and international colleagues for berths on these cruises exceeded availability by 2:1.

AMT will also continue to make a significant contribution to the training of the next generation of oceanographers – 68 UK and international PhD theses have benefited from AMT to date. The programme maintains and produces a website (www.amt-uk.org) and bi-annual newsletter which provide regular updates of our scientific progress, the website receiving 4000-14000 visits per month. We will extend this outreach through production of a CD and web-based projects for school use, provision of berths to school teachers, and in collaboration with SCOR and POGO, run workshops and enable cruise participation for students from developing countries to learn how to access and utilise the AMT dataset. AMT will maintain contact with other JGOFS and European time series stations (e.g. Hawaii Ocean Time Series and through EurOceans) in order to standardise methodologies and enable intercomparison of data.

Timetable

	2007		2008		2009		2010		2011	
	May	Sep	May	Sep	May	Sep	May	Sep	May	Sep
Core biogeochemical measurements [12 days extra to JCR passage]		■		■		■		■	■	
Service PAP moorings, boat transfer at Azores [further 3 days, SO 2]		■		■				■		
'Added value' surface ocean biogeochemical measurements [Themes 2 & 4 PML]								▒	▒	
'Added value' surface and deep ocean measurements [Themes 2 & 5a NOC]		▒		▒				▒		
Cruise planning meetings Jan & May	•		•		•		•	•		
Annual data workshop			•		•		•			•

Other relevant information

AMT provides the infrastructure for national and international collaboration and would therefore benefit from and enhance University collaborations through SOFI funding via bursaries for berths, sabbaticals for data analysis and co-supervised studentships. Departing from ports in NE England, AMT will sail through Eulerian time series stations SO 10 (WCO) and SO 2 (PAP), providing data on spatial variability surrounding these long term observing sites.

SO 2 - The Porcupine Abyssal Plain (PAP) ocean observatory

Strategic context

The NERC Delivery Plan (2005) gives priority to developing ocean observing systems to detect climate change and its impact on ecosystems. Similar objectives are shared by GOOS and the UN World Summit on Sustainable Development (2002), the latter identifying the need to "establish by 2004 a regular process under the UN for global reporting and assessment of the state of the marine environment….". The only way to fulfil these strategic drivers is to support and develop a variety of long term observing systems. One of the most effective ways to achieve this is by fixed point time-series eulerian observatories equipped with a diverse array of physical, biological and

biogeochemical sensors. The PAP observatory is the only UK open ocean observatory which addresses these issues and internationally is one of only four observatories in the Atlantic.

Overall aims and purpose

The PAP site was chosen as being relatively unaffected by either the continental shelf, the slope or the mid Atlantic ridge. The overall aim is to make observations with sufficient temporal resolution and of sufficient duration to detect environmental change on a variety of time scales and to determine the effects of such changes on ecosystem structure and function. The time scales under consideration range from hours to decades. Studies at the PAP site consider the marine system as an integrated whole, from the physical drivers such as meteorology and ocean physics to upper ocean productivity, particle export from the upper ocean, deep ocean flux and the effects of such processes on the seabed communities and biogeochemistry. This is not achieved elsewhere.

Description of ativity

- Location: 49°N 16.5°W, Water depth 4800m.
- A variety of long term moorings are deployed at the site with sensors which measure a wide range of physical, chemical and biological properties and rates in the top 1000m.
- Data from some of the sensors are transmitted by satellite in real time to NOC.
- Deep ocean downward particle flux (measured since 1989 with gaps).
- Data management at NOC but forwarded to BODC and various other international portals (Coriolis & OceanSITES). Data enter the public domain on the NOC web site immediately after quality control checks which, for real time data is within 4 hr of collection.
- Servicing of moorings is accomplished by research cruises during which there are process studies. These relate directly to the observatory data, depending on them for their interpretation.
- Benthic time lapse camera system (since 1991 with gaps).
- Repeated collection and analysis of benthic fauna during research cruises (since 1989).
- Examination of community structure and biochemistry of benthic fauna in the context of upper ocean processes.
- Data supported by transects carried out by AMT, CAVASSOO and CPR (nearby).

Participation

Main UK users are NOC, Universities of Liverpool and Aberdeen. Upper ocean activity at the site was developed under EU FP5 funding with NOC as the centre responsible for PAP (two other observatories are managed by other partners). Four other European centres are closely involved: Bremen University and IFM-GEOMAR, Germany; ICCM, Canary Islands; and IFREMER, France.

Deliverables

Time series multidisciplinary data from an open ocean location:

- Real time and delayed mode data from the top 1000m of the water column on a range of physical, biological and biogeochemical properties and processes(pCO_2, nitrate, water currents, CTD, particle concentration, phytoplankton concentration).
- Deep water downward particle flux.
- Characteristics, abundance, character and biomass of epibenthic and infauna.

Knowledge Transfer

The data are used directly by EU FP6 programmes MERSEA and CarboOcean and will be a focus for a future ESONET proposal. Also publications in peer-reviewed literature, popular science articles, posters and website content. The principles of public data availability are rigorously adhered to as outlined by the philosophy of OceanSITES.

Other relevant Information

- Site identified as one of the international sites by GCOS, GECC, JCOMM and OceanSITES. In a recent analysis of UK contributions to GCOS it is identified as a “necessary UK commitment”

- Within 18 months the UK Met office will deploy an ODAS observing station at the site to provide contemporaneous meteorological data and a platform for additional atmospheric sensors.
- An FP7 proposal will probably be made to deploy a power and data cable from Ireland to the site so that a wider variety of sensors can be supported with real time data.
- Data from PAP will become a key focus for initialisation, running and validation of biogeochemical models of the North Atlantic.
- The PAP observatory is specifically identified as a requirement for the successful pursuit of Themes 2 and 5 and is closely linked with SO 1 (AMT) from a logistical and scientific perspective.
- PAP is one of three similar observatories in the Northeast Atlantic (the ANIMATE array) with which we are also heavily involved. All data for the array is managed at NOC.

SO 3 - Monitoring the Atlantic Meridional Overturning Circulation

There are two elements to this SO activity, relating to the E-W mooring array in the mid-North Atlantic at 26.5°N (supported by NOC) and the Western Atlantic array between Cape Cod and the Grand Banks (supported by POL). These are initially described separately below, but with combined concluding sections.

SO 3.1 MOC monitoring at 26.5°N

Strategic context

There is a northward transport of heat throughout the Atlantic, reaching a maximum of 1.3PW (25% of the global heat flux) around 25°N. The heat transport is a balance of the northward flux of a warm Gulf Stream plus a warm surface wind driven layer, and a southward flux of thermocline and cold North Atlantic Deep Water. The zonal integral of this circulation defines the meridional overturning circulation (MOC). While parts of the MOC are wind-driven, the basin-scale Atlantic MOC is largely buoyancy-forced. Hence, observing the Atlantic MOC is the fundamental observational requirement to assess the role of the Atlantic thermohaline circulation (THC) in rapid climate change. As a consequence of the MOC northwest Europe enjoys a mild climate for its latitude: annual mean air temperatures over the northern North Atlantic and Western Europe are 5-10°C higher than elsewhere at the same latitude. However, the present strength and structure of the MOC may not continue: climate models suggest that increasing atmospheric greenhouse gas could lead to an abrupt rearrangement of the MOC and climate models and paleoclimate records indicate that the MOC has undergone large and rapid changes in the past 20,000 years.

Analysis of five hydrographic estimates of the MOC at 24.5°N show that the MOC and associated northward heat transport has been constant from 1957 to 1992. However, from 1992 to 2004 there has apparently been a 50% decrease in the southward transport of cold deep water and a corresponding 50% increase in southward thermocline transport, with a consequent decrease in the northward heatflux to 1.0PW (Bryden *et al,* 2005).

Funded by RAPID (NERC programme: Rapid Climate Change) in March 2004 we deployed a pre-operational prototype array to continuously monitor the strength and structure of the Atlantic MOC at 26.5°N. The monitoring array will be recovered and redeployed annually until 2008. Here we propose to continue supporting the RAPID-MOC array, to obtain a total of 10 years of continuous estimates of MOC strength and structure at 26.5°N. From a decade of observations we will better understand if the recent results reflect a real weakening trend in the MOC (as predicted by climate models), of whether it represents a short term oscillation within the natural variability.

Aims and purpose (SO 3.1)

The purpose of the observing system is to measure and understand the current state and variability of the MOC. The results will help assess the risks of rapid climate change from a slow down in the MOC, by providing the necessary data for coupled climate models to predict future climate.

Description of activity (SO 3.1)

Rationale for observing the MOC at 26.5°N

While much of RAPID is focussed on the high latitudes, it is ultimately the ocean heat transport around 25°-35°N that is most relevant for climate. Much of the heat transported northward in the Atlantic is given off to the atmosphere over the Gulf Stream extension (e.g. Isemer & Hasse, 1987), from where it is transported north-eastward toward Europe by the atmosphere. Two characteristics of ocean heat transport mechanisms are crucial: First, the ocean heat transport is mainly accomplished by the MOC (Hall & Bryden, 1982; Ganachaud & Wunsch, 2000). Second, fluctuations in heat transport (and, by implication, transports of other quantities such as freshwater and carbon) are expected to be dominated by fluctuations in the transporting velocity field, and only to a lesser extent by variability in heat (or property) content. For example, Jayne & Marotzke (2001) showed that in a global high-resolution model, heat transport variability equatorward of 40° arose almost exclusively because of velocity fluctuations advecting the mean temperature field. These two characteristics justify this programme's emphasis on the MOC. As one consequence, the basic monitoring of the MOC should occur near the heat transport maximum. 26.5°N has the triple advantage of being close to the heat transport maximum in the Atlantic, of being the latitude of five modern hydrographic occupations, and of offering a long time series of boundary current observations not existing anywhere else (Baringer & Larsen, 2001; see below for the significance of this fact). We take as our starting point that it is not practical to obtain a quasi-continuous estimate of the MOC by constantly manning a hydrographic section, for personnel and financial limitations. This requires a radical re-thinking of how to obtain meridional transport estimates, for which hydrographic lines (top to bottom, coast to coast, ensuring a closed mass balance) have proven to be the most reliable strategy (e.g. Ganachaud & Wunsch, 2000).

Basic observational strategy

Our strategy relies on a combination of moored arrays (temperature, salinity, currents, and pressure), hydrographic lines, satellite observations (sea level, winds), the opportunistic use of float data, cable measurements (Florida Strait transport), and modelling to synthesise the observations. The starting point lies in applying geostrophy: Geostrophic mass transport between any two points depends only on the pressure difference between these points; to estimate the MOC thus would require the continuous observation of density at eastern and western boundaries, plus the establishment of a reference level. This idea has been implemented in various ways, though not in a systematic attempt to observe the MOC continuously. *Whitworth III* (1983) monitored Drake Passage transport; Lynch-Stieglitz *et al* (1999) estimated Florida Strait transport during the Last Glacial Maximum; Lynch-Stieglitz (2001) used marginal density information to infer both modern and past integrated circulations; McPhaden & Zhang (2002) found a slowdown of the shallow low-latitude Pacific MOC by using boundary XBT profiles; Curry & McCartney (2001) estimated changes in subpolar gyre strength. Marotzke *et al* (1999) tested endpoint monitoring ideas in their GCM, with some success, while Kanzow (2000) performed array design studies for moorings dedicated to monitoring integrated transports in the western North Atlantic. In part based on Kanzow's findings, Send and co-workers from IfM Kiel deployed moorings at 16°N to observe the deep integrated flow west of the Mid-Atlantic Ridge, as a pilot study to an observing system for the entire MOC (Kanzow *et al* 2005).

The 26.5°N section has the fundamental advantage that the western boundary current flow is confined in the Florida Strait and so can be measured relatively straightforwardly by cable (existing long-term programme by the US, e.g., Larsen (1992); Baringer & Larsen (2001) and regular calibration cruises. This makes the monitoring of the entire MOC equivalent to the task of

monitoring the depth profile at which the flow through the Florida Straits returns southward. Currently, its contribution to the MOC returns southward at depths between 1000m and 4000m (e.g. Roemmich & Wunsch,1985); dramatic shoaling of this return path would be equivalent to a collapse of the MOC (note that there is expected always to be wind-driven flow through the Florida Strait, as shown by the existence of the Kuroshio in the Pacific despite the absence of a deep sinking MOC cell in the North Pacific).

Over the past year, we have performed design studies to test our strategy; in particular, we have successfully tested our proposed antenna in two high-resolution models (Hirschi *et al* 2003, Baehr *et al* 2004). The array was first deployed in Spring 2004 and recovered and then redeployed in Spring 2005 (Cunningham, 2005a; 2005b). To test the monitoring array using an independent method, transoceanic sections are required to obtain MOC estimates at five-year intervals. The SOC James Rennell Division conducted a 26.5°N cruise in 2004 (Cunningham, 2005) and here we propose two further transatlantic cruises, in 2009 and 2014, extending the time-series of high precision physical and chemical measurements at this section to an unprecedented 58 years.

SO 3.2 Western Atlantic Variability Experiment (WAVE)

Strategic context

There is currently high international interest in possible change of the Atlantic thermohaline circulation and its potential importance for northern European climate. This is reflected by the NERC RAPID programme, largely dedicated to the development of a system for monitoring the Meridional Overturning Circulation (MOC). A submission to NERC for a RAPID 2 programme, to ensure continuation of this work, is to be considered in parallel with this strategic science bid. To make best use of the RAPID 2 resources, and to ensure that the NERC Centres are well aligned with these priority activities, it is appropriate that Category 1 strategic funding is also used to support the data-gathering components of the project.

The POL contribution is closely linked to SO 3.1 above, but with a different geographic focus. SO 3.2 will provide support for the Western Atlantic Variability Experiment (WAVE) array, consisting of 6 Bottom Pressure Recorders (BPRs) and 5 temperature/salinity moorings at each of three sections across the US and Canadian continental slope, between Cape Cod and the Grand Banks. The section near to Cape Cod is the WHOI-led Station W section, for which all but the BPRs and some additional T-S sensors are supplied by WHOI with NSF funding. The array was initially deployed in 2004, is to be recovered and re-deployed in 2006 and at 2-year intervals.

Aims and purpose (SO 3.2)

The overall aim is to maintain and service the WAVE monitoring array, to measure changes in the North Atlantic thermohaline circulation along the western boundary of the North Atlantic. This array complements the NOC 26.5ºN meridional section by providing information from north of the Gulf Stream, closer to the presumed source of variations in MOC. The reason for three sections is to test the coherence of the observations between one latitude and another, and to test our understanding of the mechanism by which the MOC adjusts, and hence interpretation of the data. We anticipate being able to rationalise the array once the initial data have been processed and correlations between sites have been determined. This rationalisation will occur as scientific results from the RAPID work dictate, to the extent possible without jeopardising the value of the long time series which are being built up.

Description of activity (SO 3.2)

Two cruises every two years to maintain and redeploy components of the WAVE array

- Cruise 1, in collaboration with WHOI, to recover and redeploy 6 bottom pressure recorders as POL contribution to the Station W section. 2 POL staff on 2 week cruise

- Cruise 2, with UKORS support, to recover and redeploy 12 bottom pressure recorders and 10 moorings representing the other 2 sections of the WAVE array near to Halifax and St. Johns, Canada. 3 POL staff on cruise.
- Initial processing of data recovered from the cruises.

Links to other parts of Oceans 2025

Theme 1: Ocean Circulation, Sea Level and Climate. The two parts of SO 3 will together provide the baseline data for Theme 1 that will underpin:

- hydrographic and air-sea flux observations pole-to-pole in the Atlantic sector, by providing a continuous estimate of the strength and structure of the MOC that will link observations in different seasons and years.
- modelling efforts to understand the processes and mechanisms involved in driving and maintaining the MOC.
- coupled climate modelling efforts to improve predictions, forecasts and consequences of a variable MOC.

In turn, Theme 1 will produce conclusions concerning how to rationalise the array for future deployments.

Theme 8: Technology Development. The RAPID arrays provide one of the leading drivers and test-beds for designing advanced technologies for UK marine scientific research.

Deliverables

- A cost efficient, effective monitoring system for the Atlantic MOC at 26.5°N
- A real time index of MOC strength and variability
- Transatlantic hydrographic sections at 26.5°N in 2009 and 2014 to provide independent estimates of the MOC.
- Time series of ocean bottom pressure, temperature, and salinity, from the North Atlantic Deep Western Boundary Current region, north of the Gulf Stream.

Knowledge Transfer

The primary aims of SO 3 are to deliver calibrated and quality controlled data to Theme 1, to improve predictions of possible changes in the MOC. This time-series will also underpin the modelling effort to be proposed under RAPID 2. Subsequent wider use of the associated analyses is described in detail in Theme 1. This programme has a high public impact; eg the press conference and media coverage following publication of Bryden *et al* 2005. We will continue to exploit opportunities to present this project to the public.

Other relevant information

The small number of staff requested reflects the strong links between this project and work in Theme 1 (by NOC and POL), SO 6 (Drake Passage) and SO 7 (UKGLOSS). There are also links with instrument development work in Theme 8 – and anticipated connections with the NERC RAPID 2 programme. At POL, the same technology staff, and some science staff, are involved in all of these projects, working with both BPRs and tide gauges.

No data have yet been recovered from the initial deployment of the WAVE array, so the proposal currently assumes a continuation of the present mooring gear. However, modelling studies indicate that a boundary section which lies clearly in the subpolar gyre north of the Gulf Stream may also be necessary. The ideal configuration for ongoing monitoring is likely to involve fewer than three sections, but may require a greater depth range to be covered than that occupied by the current moorings. Any flexibility which may come from rationalising the array for deployments in 2008 and 2010 is likely to be retained within RAPID 2, as the major funder of this activity.

SO 4 - The Extended Ellett Line

Strategic context

While anthropogenic climate change is widely expected, its nature and extent remain uncertain. Analysis of numerical models shows that predictability can be improved if the model is constrained in a small number of key locations (Velinga & Wood, 2004). One such location is a hydrographic section in the subpolar gyre, the Extended Ellett Line. Inclusion of such data significantly improves the timely detection of anthropogenic climate change. A weakening in the circulation of the subpolar gyre during the 1990s (Hakkinen & Rhines, 2004) is confirmed partly by data from the Extended Ellett Line time series (Hátun *et al* 2005; Read *et al*, in review). The time series data demonstrate that the increase in heat and salt associated with the decrease in circulation results from a change in the balance of warm water input, with more warm water spreading from the inter-gyre region as the North Atlantic Current diminishes.

Such studies demonstrate the importance of maintaining a monitoring programme in the northeast Atlantic, a region which is anomalously warm for its latitude and one in which climate driven changes will impact directly on UK climate (Theme 1). The usefulness of the Extended Ellett Line has been demonstrated both as a platform on which environmental changes off the western seaboard of the UK can be quantified and from which to observe key biological processes which will be disturbed by climate change (Themes 2, 5).

The Extended Ellett line is a hydrographic section from Scotland to Iceland that has been occupied almost annually for 10 years and in its original form since 1975. The existence and variability of the brackish Scottish coastal current (Ellett & Edwards, 1983) has been demonstrated. Results show variability of up to 1-1.5°C in the relatively warm water flowing through the Rockall Trough (Holliday *et al*, 2000; Holliday, 2003) and on the Scottish Shelf (Inall *et al*, in prep), which moderates European climate. Changes in the transport of warm water along the continental shelf have been shown to impact the ecosystem of the North Sea (Holliday & Reid, 2001; Reid *et al*, 2001). The extension to Iceland captures the other main pathway along which warm saline stratified water from the North Atlantic Current flows towards the Nordic Seas (Bacon, 1997; Read, 2001; Pollard *et al*, 2004; Read *et al*, in review), as well as the pathway for the deep returning flow in the lower branch of the Meridional Overturning Circulation (Hansen & Østerhus, 2000).

Thus the section provides a state and a rate of change indicator on an annual to decadal scale in the North Atlantic of direct relevance to the forecasting objectives of RAPID and EuroGOOS. It provides an important baseline against which water quality objectives can be established to enable the sustainable management of the marine environment, as directed by UK and Scottish Government policy (Theme 6). In addition it provides a platform to investigate processes across the margins of temperate continental shelves (Themes 3 & 5), linking to biogeochemical studies (Theme 2), and with additional SOFI opportunities, e.g investigatinge the role of iron in the Iceland Basin, and processes occurring in the twilight zone (linking to Theme 5).

Overall aims and purpose

We will undertake annual occupations of a hydrographic section plus tracers across the Scottish shelf and the Rockall Trough (the "Ellett Line") and to Iceland (the "Extended Ellett Line"). Temporal coverage will be increased using gliders and floats. In recent years occupations of the line have been expanded to observe critical elements of the upper ocean biological community (Brown *et al*, 2003; Moore *et al,* 2005; Brown *et al*, in review; Johnson *et al*, in review). We will continue this under the Oceans 2025 programme focussing on biotic elements that are particularly susceptible to change (with Theme 2).

Regular and repeated oceanographic sections, such as described here, provide opportunities for acquiring data for SOFI research, research studentships, student projects and other forms of training in a wide range of disciplines and activities beyond those outlined here. Extended Ellett Line cruises will provide valuable formal and informal training for future marine scientists (Category 4 funding).

Description of activity

An annual CTD/hydrography section from Scotland to Iceland, consisting of 48 full depth stations and requiring a minimum of 14 days to complete (including passage and bad weather contingency). Additional days are requested to link with Themes 1, 2, 3, 5 and SOFI science programmes.

Originally the Ellett Line was occupied up to four times a year making it possible to monitor seasonal changes as well as reducing the statistical variability inherent in individual sections. This is no longer viable and we seek to trial alternative measurement technologies. These are Argo floats, deployed on annual cruises, and AUV's, developed specifically to undertake oceanic monitoring. Two Seagliders, proven AUV platforms, will be acquired and deployed from the Scottish coast to undertake continuous monitoring of the section. Along with standard CTD sensors they will be equipped to make dissipation measurements; for which calibration and validation strategies will be developed. The Seagliders will profile the upper 1000m of the water column observing the seasonal signal and relay data in real-time to a shore base. Limits in depth range, sensor availability and power supply mean that these measurements cannot replace ship borne observations.

Much of the eastern component of the outflow from the Nordic Seas is monitored with long term ADCP deployments in the Faroese Channels by FRS Aberdeen and the Faroese Fisheries laboratory. Following EU Framework V MOEN activities, we will continue to monitor the small, erratic, part of the outflow that crosses the Wyville Thomson Ridge with a moored ADCP.

Participation

SO 4 will be implemented by physical, biological and chemical scientists at NOC and SAMS. Observations made on the Extended Ellett Line will underpin work done in Themes 1, 2, 3 and 5, and shiptime will be used to support Theme 8 with *ad hoc* testing of methods and technology. FRS Aberdeen occasionally undertakes Ellett line sections to Rockall and provides ancillary support. The Wyville Thompson Ridge ADCP will be maintained in collaboration with FRS and the University of Hamburg. The Marine Institute in Galway is planning an annual section from Galway to Rockall. Collaboration with HEI's such as the Universities of Southampton, East Anglia and Highlands & Islands and beneficiaries of SOFI will provide training opportunities.

Deliverables

- A time series of the evolution of the hydrography of the northeast Atlantic, together with a more formal understanding of the causes of any changes observed.
- An archived data set available to the international community via BODC.
- A platform for further scientific research

Knowledge Transfer

The Extended Ellett Line is an ICES standard section and data will be incorporated into the ICES annual climate statement. Time series data will be incorporated into numerical models of climate change, improving detection and prediction capabilities of anthropogenic changes. The section will be a key UK contribution to the upcoming Global Marine Assessment. A website describing the data will be maintained (currently at: www.noc.soton.ac.uk/GDD/hydro/nph/ellett/index.php)

A small travel grant will be provided annually to a young scientist to undertake their own fieldwork, or write a diary of their experience for publication on the website.

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SO 5 – Argo profiling float system

Strategic context

A global array of 3,000 profiling floats (Argo) is currently being established to provide significant benefits for seasonal forecasting, climate prediction and operational oceanography. Argo is a major contribution to the Global Ocean Observing System (GOOS) and the Global Climate Observing

System (GCOS), and has been endorsed by the World Meteorological Organization (WMO) and the Intergovernmental Oceanographic Commission (IOC).

The capacity of the ocean to change its heat content dwarfs that of either the atmosphere (much less mass) or the land (much less depth penetration). Around 90% of global warming (heat gained) will occur in the oceans, and the Argo float system is making direct measurements of the change. By providing expertise, NERC has made a fundamental contribution to establishing and developing the national and international Argo programmes to their present status and success. For details on UK involvement in Argo, see www.meto.gov.uk/research/ocean/argo/index.html

Overall aims and purpose

The overall aims are to:

- continue to play a leading role in developing Argo, by appropriate scientific activities.
- ensure that the international and national programmes continue to develop and maintain a data acquisition, calibration and delivery system that facilitates exploitation for NERC's scientific objectives.
- ensure that the UK contribution meets the exacting standards set by the international programme.
- support the deployment of new floats funded under NERC research programmes.

Argo data are exploited in a number of ways, including: direct measurements of changes in ocean properties; calculations of storage of heat and freshwater in the upper ocean on seasonal and longer timescales; providing information on ocean space and time variability to complement data acquired using other measurement strategies; and assimilation into models.

Description of activity

- Participation in the International Argo Steering Team. Leadership and participation in workshops and working groups established by the Steering Team to resolve key issues in the programme. (NOC, BODC)
- Development of new derived products and calibration methods to the point of routine production and adoption by international programme. (NOC)
- Support the deployment of new floats funded by Ocean 2025 Themes and the UK Argo consortium. (BODC, NOC)
- Assemble metadata for UK floats; ensure real-time data delivery; maintain raw data archive. (BODC)
- Scientific calibration of data acquired by UK-funded floats, for delivery to the Global Data Centres. (BODC, NOC)
- Participate in Argo Regional Data Centre activities, meeting the responsibilities agreed for RDCs by the International Steering Team. (BODC)
- Promote and facilitate the use of Argo data by the NERC research community (NOC, BODC).

Participation

This activity will deliver essential data for research in Theme 1. Approximately 10 researchers at NOC are presently involved in research projects using Argo data, funded by core-strategic and NERC research grants, and including graduate students, SOES faculty and NERC divisions. We will underpin the deployment of any new floats purchased in the UK and contributing to Argo, especially those funded under other parts of Oceans 2025 (eg the Extended Ellett Line SO 4).

NOC provides leadership for a UK Argo Users Group, currently of 25-30 members. Argo data are being used in projects and proposals across the NERC-funded HEI community. The UK will contribute 17 papers to the 2nd international Argo Science Workshop in March 2006. The NERC effort is closely coordinated with that at the Met Office and Hydrographic Department. The Met Office (National Centre for Ocean Forecasting) and the ECMWF are the principal users in the UK of the 'real-time' data stream, assimilating Argo data for short-term and seasonal forecasting.

UK efforts are fully integrated in the international programme. We co-lead the development of data products (quality controlled salinity data and float trajectories) and NOC presently hosts the international Argo Director (Gould).

Deliverables

The chief deliverable for Argo from NERC funding under Theme 10 will be the continued existence of a vigorous international programme, delivering data suitable for use in NERC research and by stakeholders. Specific deliverables from this SO activity would be

- Sustained delivery of calibrated UK float data to the Argo Global Data Centres.
- Improved float trajectory algorithms implemented at the Argo Global Data Centres (no trajectory products exist at present); improved salinity calibration methods agreed and adopted. The International Argo Steering Team has tasked NOC to lead workshops on these topics.
- Internationally agreed procedures and regional reference dataset for float salinity calibration in the Southern Ocean (RDC activity).
- A NERC research community familiar with and exploiting Argo data.

Knowledge Transfer

Exploitation of the science results for the benefit of research users is included in Theme 1 (WPs 1.1 -1.3 and 1.8). The expertise of the entire international Argo program is available via published results. Direct contact with stakeholders is maintained via meetings of the UK Argo Expert Group (small committee-type meetings) and the UK Argo Users Group (open meetings for researchers, technologists and stakeholders, with presentations and discussion).

Argo is one of the highest-profile international marine programmes. The simplicity of the float mission concept, our ability to demonstrate a working float, and public awareness of global climate issues makes a powerful and appealing combination. We have taken every opportunity to publicise the UK contribution, ranging from local schools, radio and TV to a slot on BBC's *Tomorrow's World*, working exhibits at the Science Museum and National Maritime Museum, and participation in the Royal Society's Summer Science Exhibition.

Other relevant Information

NERC benefits from significant influence on the international Argo programme through participation of its staff in all the major international Argo initiatives. This ensures that the climate agenda remains high in the programme's decision-making process. If climate-motivated scientists reduce their participation in Argo, the likely consequence would be that the programme is steered towards the real-time forecasting objectives at the expense of ensuring a climate-quality dataset. Note that Defra and MOD presently provide 70% of UK Argo funding. The confirmation of NERC support for Argo infrastructure as a specific component of Oceans 2025 would provide significant encouragement to the co-funding agencies to maintain their commitments:.

SO 6 – Antarctic Circumpolar Current: transport and properties

There are two elements to this SO activity, relating to the hydrographic sections (supported by NOC) and the bottom pressure recorders (supported by POL). These are initially described separately below, but with combined concluding sections.

SO 6.1 Hydrographic sections in Drake Passage

Strategic context

The Atlantic Meridional Overturning Circulation (MOC), which dominates European climate, is closed to the south by exchange with the Southern Ocean. Thus the Atlantic circulation is linked to the other global ocean basins via the Southern Ocean and in particular by the Antarctic Circumpolar Current (ACC). In order to fully comprehend and eventually predict changes in Atlantic over-

turning, we need to understand variability in the ACC. NERC has completed a hydrographic section from the South American continent to the tip of the Antarctic Peninsula in all but two years since 1993. It is one of the best-observed and most important continent-to-continent sections in international CLIVAR planning. NERC's efforts have established the interannual variability of water properties and transport. It has been suggested that the winds over the Southern Ocean are increasing on decadal timescales. It is critical that the impact of any such changes in forcing on the structure and transport of the ACC be observed. The discrete hydrographic sections proposed here are complementary to the continuous total transport timeseries to be inferred from the POL bottom pressure recorder moorings and coastal tide gauges.

Aims and purpose (SO 6.1)

The aim is to maintain an annual hydrographic section across the ACC at Drake Passage. The standard section includes measurements of the physical properties: temperature, salinity and currents. There is the opportunity to include biogeochemical tracers, especially elements of the carbon system; for example, via SOFI support.

There is need for an annual survey since the differences in transport between the annual sections are significant (~ 10% of the mean). Therefore occasional sections, say every 5 years, could only detect very large changes. Annual sections, in combination with analyses of model output, provide the possibility of extracting a long-term trend from individual measurements of a noisy signal.

Description of activity (SO 6.1)

One hydrographic section per year, which consists of 30 full-depth CTD stations, lowered and shipboard Acoustic Doppler Current Profiler measurements. Operating in 'piggyback' mode makes this a very cost-effective ship-based activity. The ten cruises up to 2004 have required a total of just 40 days of shiptime. We usually embark 6 scientists; an extra two berths would be required to develop a biogeochemistry programme (SOFI opportunity).

The fieldwork is a collaboration between NOC and BAS, presently led by NOC. BAS scientists take part in the cruises, contributing manpower and expertise. The data underpin BAS core programme work on the circulation between Drake Passage and South Georgia, and BAS scientists have previously used them in a variety of scientific studies. Participation by students from UK HEIs (including UEA, Reading, the NOC Graduate School) is welcomed, provides training opportunities, and helps maintain vigorous collaboration between NERC Centres and HEI groups. The data are made freely available and have been used widely by students in the collaborating institutions.

The Southern Ocean is a priority area for UK Argo (SO 5). The sections provide critical measurements for float data calibration, as well as opportunities for deploying floats upstream of the Atlantic sector to maintain the array.

SO 6.2 Bottom Pressure Recorders for Drake Passage ACC

Strategic context

The Drake Passage has been identified by CLIVAR and GLOSS as a strategic choke point for the global ocean circulation. Long term monitoring of bottom pressure, temperature and sea level at this position have been shown to reflect circum-Antarctic flow (Hughes *et al* 1999; 2003; Meredith *et al* 2004). As a by-product of the pressure measurements, temperature time-series have identified processes which may have an important impact on the global ocean circulation, such as annual deep water formation events (Meredith *et al* 2003). In order to obtain sufficiently accurate values for annual mean transport measurement it is necessary to make measurements more frequently than every 10 days (Meredith & Hughes, 2005). Much of the bottom pressure information can also be extracted from tide gauge records on the Antarctic Peninsula (for which support is requested within SO 7 – UK GLOSS), which also have the advantage of accurate datum control between years. SO 6.2 will maintain the key measurements to the north and south of Drake Passage, while adding deployments at different depths in order to assess the need for a continuation of the observations.

This period coincides with the IPY, during which a number of other observation campaigns will take place. Together, these will provide much greater contextual information to assist in interpreting the historical data and planning the appropriate scale of future activities.

Aims and purpose (SO 6.2)

- To maintain the ocean bottom pressure and temperature time series from Drake Passage,
- To adapt the monitoring system to maximize the value of other observational programmes in the region
- To provide better context for interpretation of the existing time series, without jeopardizing the continuity of the time series.

Data from SO 6.2 will be used in POL Theme 1 to assess the need for future BPR deployments in this region. It is known that both BPR data and Antarctic tide gauge data are strongly correlated with transport fluctuations, but a single measurement only appears to explain about 50% of the transport variance. The BPR deployments over this period will be designed to determine how best to combine tide gauge and deep measurements (north and south) to determine total transport, as well as to provide more detail of the spatial patterns associated with the temperature signals measured by the south BPR, which have been associated with a new route of intermediate and deep water formation (Meredith *et al* 2003). The instruments to be used will measure salinity as well as accurate temperatures and pressures, to improve our understanding of this signal.

Description of activity (SO 6.2)

SO 6.2 requires one cruise per year to recover and redeploy Drake Passage lander instruments. These will include two instruments at fixed positions to the north and south of Drake Passage, plus typically two further instruments at different depths to assess the variability of pressure with depth, and the long-term MYRTLE instrument (capable of providing a continuous 5 yr record) at 2500m depth to the south side of Drake Passage. The latter deployment is coordinated with the work of a French group led by Christine Provost in support of the IPY. Flexibility in the positioning of the additional BPR deployments will be used to coordinate to the fullest extent with further IPY observations. A small part of the Drake Passage cruise time will be used to ensure access to Antarctic tide gauges for SO 7.

The POL staff involved in SO 6.2 are also contributing to instrument development work in Theme 8, which feeds into this monitoring programme. This activity complements the NOC hydrographic contribution (SO 6.1) and UK-GLOSS tide gauge observations (SO 7). The data will be used as part of ongoing collaborative work with BAS.

Deliverables

- Continuing time series of ACC volume transport and physical properties at Drake Passage. When the present funding round finishes, we will have a 20 year time-series.
- Datasets to test whether models produce the correct level of interannual variability.
- Time series of ocean bottom pressure, temperature, and salinity, from the Drake Passage region.

Both components of SO 6 contribute to Theme 1 (Climate, ocean circulation and sea level). Thus they provide the observations necessary for study of the thermohaline circulation as it is seen in the Southern Ocean, and data for comparison with sea level measurements at Antarctic tide gauges and by satellite altimetry. Measurements of interannual variability also provide the context for analysis of one-time box, and data for evaluation of variability in models.

Knowledge Transfer

Exploitation of the science results for the benefit of research users will be via Theme 1 (WP 1.2, 1.3). Routes for Knowledge Transfer will include contributions to IPCC assessments and direct contact with stakeholders, such as climate modellers at the Met Office.

Through BAS, media personnel have been on *RRS James Clark Ross* on the cruise leg used for this work. We are pleased to cooperate fully in this activity and have made a number of radio/TV

contributions, adding an oceans and climate dimension to BAS's wider promotion of Antarctic science. High-profile round-the-world sailing events inevitably focus attention on the Southern Ocean, and we contribute to local and national media when opportunities arise.

SO 7 - UK contributions to the GLOSS sea level network (South Atlantic and Antarctic)

Strategic context

The Global Sea Observing System (GLOSS) is coordinated under the auspices of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) of the Intergovernmental Oceanographic Commission (IOC) and World Meteorological Organization (WMO). GLOSS objectives include the provision of sea level data sets for scientific programmes including those of the World Climate Research Programme (WCRP). The UK contributes to GLOSS by providing sea level data from the UK itself, via EA/Defra funding to the National Tidal and Sea Level Facility at POL/BODC, and from British Dependent Territories and Antarctic bases, most of which are in the South Atlantic area. Funding for the latter is the subject of this proposal.

Overall aims and purpose

A general aim is to make a major UK contribution to the construction of the global sea level network (GLOSS) which will be as effective as intended only when all ocean regions are adequately equipped with sea level recorders. Data sets from the network already serve a large number of local practical applications (harbour operations, flood warning, coastal engineering) as well enabling scientific research across a range of space and time scales from the short (tides, surges and tsunami) to the long (seasonal, interannual and secular mean sea level change). However, there remain many gaps in data flow, some of which are the UK's responsibility to fill.

Our more specific aim is to take advantage of the UK-owned sites to provide scientific-quality data sets (some in near-real time) which can be employed in operational oceanography of regional or global importance (e.g. in monitoring of the Antarctic Circumpolar Current or in data assimilation into Mediterranean forecast models) and in oceanographic and climate research (e.g. satellite altimeter calibration, ocean circulation studies, southern hemisphere MSL change). Several studies complement those of other NERC groups (e.g. the Southern Ocean work of NOC and BAS).

A lesser, more practical aim is to provide relevant sea level data sets and products to the British Dependent Territories of the South Atlantic for local applications (e.g. tide tables, wave and surge statistics, engineering extremes etc.), especially in areas of economic importance (notably the Falkland Islands and Gibraltar).

Description of activity

- Maintenance of tide gauges (and in some cases associated GPS receivers and met stations) at Gibraltar, Ascension, St. Helena, Port Stanley, Vernadsky and Rothera. All of these sites have regular access and adequate local infrastructure. They will have redundant sea level instrumentation for data continuity and be able to provide data in near-real time. As far as possible, sites will be equipped with commercially-available hardware adapted by the POL Ocean Engineering & Technology Group for use at each location.
- Installation of gauges (or simple pressure sensors) at Tristan da Cunha, Signy and South Georgia, which provide greater challenges for access and maintenance.
- Delayed-mode quality control of resulting sea level data sets, so enabling the best possible information for long term scientific research (e.g. CLIVAR, GCOS, IPCC).
- Monitoring of technical developments in gauge hardware and telemetry so as to provide the best data sets consistent with GLOSS requirements, and to enable effective technical coordination with other countries.

Knowledge Transfer

The following arrangements will apply to stakeholders and research users

- Scientists in Themes 1 and 3 will have access to a more-globally representative sea level data set than would otherwise have been the case. The data set will have particular relevance to areas of UK scientific interest (e.g. Antarctic coast).
- The wider UK and international sea level science community including participants in altimeter mission science teams, CLIVAR, IPCC etc. will have similar enhanced access, given that all data sets described above will be publicly available.
- The Permanent Service for Mean Sea Level (PSMSL) will receive long term MSL data sets from hitherto data sparse areas.
- The Gibraltar, Falkland Islands and St. Helena Governments will have access to a range of practical sea level information for their coasts.

Deliverables

- Integrations of sea level and/or sub-surface pressure every 15 minutes (at present, likely to be increased to every minute at some locations) at the sites listed above.
- Wave data (approximately 1Hz sampling) at suitable sites.
- Data available in both near-real time mode for operational applications and effective error reporting, and in delayed, fully quality-controlled mode for long term scientific research. Real-time data will be transmitted to the GLOSS Fast Centre at the University of Hawaii (from where it should be accessible by Tsunami Warning Centres). Delayed-mode data will be passed to BODC for full quality-control to international standards.
- Ancillary data sets (air and sea temperature, air pressure etc.) at each site.
- Related necessary geodetic information (levelling data etc.) and metadata.

SO 9 - Climate-quality surface marine observations and products

Strategic context

Datasets essential for the study of marine climate are often collected for non-climate purposes; in some cases considerable effort is required to produce climate-quality versions of the datasets and hence climate-quality gridded products. NOC has unique expertise in the construction of climate datasets from historical and operational data sources, including: development of *in situ* datasets of air-sea exchange (Josey *et al* 1999), detection and correction of bias in marine surface meteorological data (Kent *et a*l 1993; Berry et al 2004; Kent & Kaplan 2006) and the development of new satellite parameters and climatologies (Quartly 2004; Gommenginger *et al* 2003; Woolf *et al* 2003).

Multi-decadal estimates of air-sea exchange are needed for climate modelling work in Theme 1. However, recently available estimates rely on atmospheric reanalyses (Yu & Weller 2006) and show discontinuities as the observing system changes, particularly in the transition to satellite-based systems (Sterl *et al* 2004).

In situ marine meteorological datasets contain well-known variations in sampling density with good data coverage in the main shipping lanes and in the Northern mid-latitudes. Remote sensing can give improved spatial coverage in recent years. Remotely sensed and *in situ* observations can therefore be used together to significantly enhance our characterisation of the surface marine environment over the past 20 years. Remote sensing techniques provide: vital information on salinity, radiation, precipitation and sea surface height which are poorly or sparsely measured *in situ,* and; complementary information on variables measured both remotely and *in situ* such as winds, waves and SST. However, remote sensing techniques are unable to retrieve vital information for flux calculation such as air temperature, humidity or pressure with the required accuracy.

Construction of a 50-year air-sea exchange dataset, independent of both satellite data and the reanalyses, corrected for instrument bias and characterised with uncertainty estimates, will provide a necessary and powerful tool for both basic research and for confronting and understanding the reanalyses themselves.

Overall aims and purpose

SO 9 will generate climate-quality datasets including:

- improved satellite datasets, salinity from SMOS and winds and waves from altimetry
- a 50 year *in situ* surface meteorological and flux gridded product exploiting NOC research on data bias and uncertainty, flux parameterisations and methods for dataset development
- a 20 year surface meteorological and flux gridded product incorporating selected satellite observations to improve spatial coverage.

NOC will take historical and operational data collected by international meteorological programmes and satellite agencies and develop datasets and data products required for ocean circulation and climate research. We will prioritise the datasets which are essential to climate research but do not yet provide climate-quality, unbiased estimates of ocean parameters. NOC will maintain an influential voice in the international programmes overseeing operational data collection in order to ensure the data necessary for our science. As new observing programmes (e.g. GMES and GEOSS) develop, these operational data will increase in importance for research.

Description of activity

NOC will exploit its extensive experience in the development of homogenised climate-quality satellite datasets from different missions and instruments to produce datasets required for ocean climate research and modelling. In 2006, we will have produced a 35-year version of the world-leading NOC Surface Flux Dataset (Josey *et al* 1999). This will be significantly upgraded using state-of-the-art flux parameterisations (developed within Theme 1), improved bias correction, data homogenisation and uncertainty estimates, then extended to give at least a 50 year *in situ*-only record which will be continually updated in near-real time. In well-sampled regions, such as the Extra-Tropical North Atlantic Ocean and Mediterranean Sea, high resolution meteorological and surface flux fields will be developed (Berry & Kent 2006).

In situ surface marine datasets, whilst being able to provide excellent fields in well-sampled regions, have inadequate sampling in other regions. Improved datasets will therefore be developed using both *in situ* observations and satellite retrievals from the mid-1980s onwards. Only satellite datasets meeting required standards will be included (probably SST, wind speed, radiation, precipitation and perhaps humidity). It is noted that a variety of satellite-only flux estimates are already available, and will not be reproduced here.

To achieve our goal of producing the highest-quality, well characterised climate datasets we will be involved in every stage from observing system design to the promotion of our data products. It is vital to participate in the development and management of international programmes overseeing observing system design and operation, and development of standards for data and metadata collection (e.g. JCOMM, ESA, NASA, GCOS). We will engage with international efforts on historical data and metadata discovery, recovery and digitisation (e.g. the JCOMM Expert Team on Marine Climatology). Quality assurance methodologies that can be applied routinely as part of a data management activity will be developed. Bias in a wide variety of data sources must be identified and corrected. For satellites this will include careful sensor cross-calibrations and quantification of drift. For *in situ* this will include quantification of the effects of different instrument types and environmental conditions on the measurements. Uncertainty estimates for individual observations and derived data products will be provided for the first time in many cases. NOC will give feedback to data providers to improve data quality and expect that our improved characterisation of *in situ* and satellite data sources will lead to improvements in atmospheric reanalyses. Our research will determine how to merge non-uniform data to create consistent

climate-quality products and will include, quantification of uncertainty and the use of advanced statistical techniques. New derived products, including gridded datasets, will be produced, validated and then compared with existing products. A capability to routinely update these products in near real time will be developed. The stewardship, maintenance, documentation, dissemination and promotion of datasets and data products will be a priority.

Deliverables

- Vigorous UK participation in international programmes overseeing the collection of data and design of the global marine observing system (e.g. JCOMM, WCRP and GCOS).
- 50 year surface *in situ* meteorological and flux dataset, presented on a monthly mean 1˚ area grid including bias correction, sampling and bias uncertainty estimates and full documentation.
- 20 year combined *in situ* and satellite surface meteorological and flux dataset (as above).
- Higher spatial and temporal (daily or sub-daily) resolution surface meteorological and flux data products where sampling permits and research will benefit.
- Improved measurement method metadata and bias quantification for the *in situ* surface meteorological record.
- Published intercomparisons of *in situ* and remotely sensed SST, winds, waves and precipitation.
- Calibrated, quality assured and documented satellite data and gridded products, incorporating new methods of quality control and estimation of uncertainty, including for sea surface height, waves, winds, salinity and precipitation.
- Near real time availability of data products.

All Oceans 2025 Themes and SOs that require surface data (e.g. meteorological data as a broader-scale context for process studies or repeat measurements) will benefit from this work, particularly Theme 1. There are already many other users of our products and expertise, from the UK and international academic, industrial and government sectors and also international observation programmes.

Knowledge Transfer

Knowledge transfer partnerships already exist with UK industry (Astrium, BAE Systems, SSTL, SOS) and government (Met Office, NCOF) and internationally (NASA, ESA, JCOMM, NOAA, ECMWF). To achieve wide dissemination of *in situ* products, our meteorological products will be served alongside the ICOADS dataset at NCAR. Opportunities for wider outreach will be sought and exploited; e.g. through Oceans4Schools.

Other relevant Information

It is a priority for NOC that the development, production and updating of climate datasets be maintained for the future. Dataset development activities will therefore continue throughout Oceans 2025 and beyond. Significant *in situ* product upgrades will be available after 2 and 4 years. Priorities for dataset production will respond to scientific requirements, both from within Oceans 2025 and for example arising from our expected involvement in CASIX2.

In many cases this work will be done in conjunction with other institutions around the world, for example our altimeter data processing is carried out with TUD and NOAA. Research to improve *in situ* datasets has been carried out in collaboration with the Met Office, NOAA, Environment Canada and WHOI and these collaborations will continue. NOC is the obvious candidate to develop some surface datasets (e.g. fluxes and ocean salinity), for others NOC will use its advocacy within international programmes to encourage others to develop the required datasets. If suitable products already exist they will be used.

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COASTAL CLUSTER

SO 10 - Western Channel Observatory

Strategic context

SO 10 will study, in the context of global climate change, the regional effects of ecosystem variability in the Western English Channel by continuing and building upon long-term time series data sets. There is a long history of *in situ* observation at several stations (by the MBA for over 100 years and PML since the 1980s); these include hydrography, nutrients, phytoplankton, zooplankton, demersal and pelagic fish, and benthic measurements (Hawkins *et al* 2003; Southward *et al*, 2005). This range of observations makes it an exceptional area for investigating long-term change and validating ecosystem models. The weekly zooplankton and phytoplankton time-series, established since 1988 at station L4 (www.pml.ac.uk/L4) is unique in its integrated coverage of lower-trophic level ecosystem dynamics. Ongoing high-frequency observations are also made of *Calanus helgolandicus* reproduction; no other such data-set on interannual variability of secondary production exists. This fact, combined with the extensive information on environmental parameters provides an important opportunity to advance zooplankton seasonal succession modelling, and investigations of inter-annual variability at higher trophic levels.

The Western Channel is an ideal location for sustained observations because it has both ocean-influenced and coastal waters within 30 km of Plymouth, allowing frequent sampling. There are no obvious local/regional confounding effects or impacts (e.g. no obvious eutrophication), therefore it can be used to detect ecosystem responses to climate change, including interactions with large-scale impacts such as fishing. The region straddles biogeographical provinces with both boreal/cold temperate and warm temperate species present (Southward *et al* 2005), giving early warning of change in species composition and distribution elsewhere.

In addition to the measurement of water column properties, PML has recognised expertise in ecosystem modelling (ERSEM) and satellite Earth Observation (EO) science. By integrating quantitative *in situ* measurements made by PML and MBA, modelling studies and EO we are in a strong position to detect changes that may occur in an important and sensitive UK marine environment. Such information is essential both for iterative improvement of predictive capabilities, and for evidence-based policy guidance, regulation and ecosystem based management. SO 10 will provide the context for process orientated studies (Themes 2, 3, 4 and 6) as well as validation data for models in Theme 9.

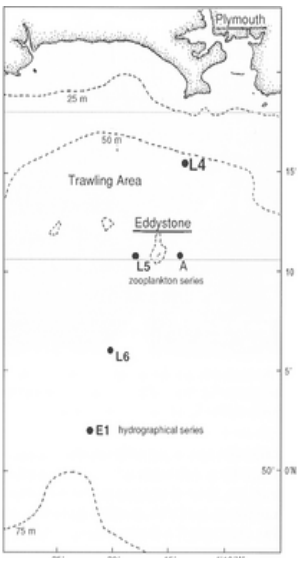

Figure 3. The Western Channel Observatory

Overall aims and purpose

Our purpose is to integrate *in situ* measurements made at stations L4, L5, E1 and adjacent coasts in the western English Channel (see Fig 3) with ecosystem modelling studies and Earth observation; this will be facilitated by web-based GIS technology. Beyond monitoring the ecosystem, the continuation and integration of these long term time-series will allow the following science questions to be addressed at a range of temporal and spatial scales:

What is the current state of the ecosystem? Regular monitoring allows us to assess the state of the ecosystem from the estuary, through the coastal waters to the ocean influenced mid English Channel.

How has the ecosystem changed? Historical and contemporary data collection potentially allows us to discriminate between climate change induced response and natural variability on plankton dynamics and community structure. Such an understanding is the key to predicting ecosystem response to future environmental change. Also, key intertidal

species can be used as cost effective indicators of climate change (Defra, 2005) as fluctuations in their abundance and distribution mirror changes occurring offshore (Southward et al, 2005).

How do the interactions of climate and fishing affect the ecosystem? Long term observations of fish (Sims et al, 2001, 2004; Genner et al, 2004) and benthos enable the relative contribution of bottom-up climate forcing and top-down control by predators on fish, benthic assemblages and the ecosystem (Araujo et al, 2006) to be determined.

Short term forecasts of the state of the ecosystem. The combination of modelling and EO infrastructure along with in-situ data collection for model validation allows us to demonstrate and validate short term forecasts of coastal phytoplankton and nutrient dynamics. This will include operational harmful algal bloom detection using EO data.

SO 10 as a national facility for EO algorithm development, calibration and validation.
A sustained time-series of observations at E1 will provide frequent bio-optical data allowing the validation of different satellite sensors (e.g. MERIS, MODIS, NPP, NPOESS and Sentinel 3) and development of novel EO algorithms for ocean products (Blondeau-Patissier *et al* 2004) and atmospheric correction. In addition the sustained time-series of bio-geochemical and optical measurements are an ideal tool to use for ecosystem model parameterisation and validation.

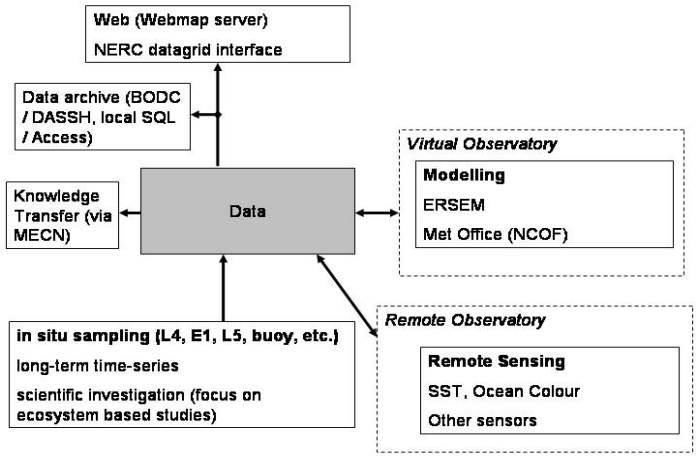

Figure 4. Schematic diagram showing links between components of Western Channel Observatory, SO 10

Description of activity
Fig. 4 shows schematically the various components of SO 10: the *in situ* observations; the remote EO observatory; and the virtual observatory consisting of model data outputs. These components are primarily data generators but feedbacks exist between the data, EO and modelling elements via improvements in parameter-isations. The data will be made available to the wider community via a web GIS and data-based both locally and at the BODC. The time-series will be put into a national context via MECN and an international context via European networks (MarBEF, EurOceans) and the Global Ocean Observing System (GOOS).

In situ sampling: We intend to both maintain the existing time series and expand the range of parameters measured. The *in situ* sampling will be weekly at L4 and fortnightly at E1.

Time-series to be continued will comprise (MBA asterisked; see Southward *et al* 2005 for details):

- *Meteorological station* (since 2003): temperature, humidity, pressure, wind speed and direction, rainfall; PAR, solar irradiance, aerosol loading (Smyth *et al* 2004).
- *Hydrography* (L4 since 2000; *E1 1903-1988, restarted 2002): vertical temperature and salinity profiles.
- *Optics* (L4 since 2000; E1 since 2002): up- and down-welling irradiance (Smyth *et al* 2002); ac-9, VSF and bb6 for inherent optical properties; FRRF and fluorometry, TSM, CDOM, PABS (Tilstone *et al* 2003).
- *Nutrients* (L4, *E1 1924-1987, opportunistically since 2000): nitrate, nitrite, silicate, phosphate and ammonium from stored or frozen samples.
- *Phytoplankton* (L4 since 1988; *E1 1964-1978, restarted 2002): phytoplankton species, abundance and biomass; total and size-fractionated chlorophyll.
- *Pigments* (L4 since 2000, E1 since 2002): HPLC carotenoids and chlorophylls (Llewellyn *et al* 2005).

- *Zooplankton / microzooplankton* (L4 since 1988): zooplankton species abundance (John *et al* 2001); total and size-fractionated particulate POC; mesozooplankton size-fractionated biomass; copepod egg production, particularly *Calanus helgolandicus* (Bonnet *et al* 2005; Irigoien *et al* 2000).
- **Zooplankton / fish Larvae* (E1 1974-1988, restarted 2002; L5 1924-1988, restarted 2002) zooplankton abundance and species including water mass indicator species, fish eggs and larvae (Russell, 1935; 1973; Southward, 1980, Southward *et al* 1995, 2005; Hawkins *et al* 2003).
- **Bottom fish assemblages and phenology* (L4 since 1913, restarted 2001): continue, establish bi-monthly sampling (Genner *et al,* 2004, Sims *et al* 2001, 2004)
- **Benthos* (L4 intermittent since 1899): at L4 and nearby (Holme, 1961, 1966, 1984).
- **SW intertidal time-series* (1950 – 1987; re-started 1997): annual sampling for intertidal indicator species (Southward, 1991; Southward *et al* 2005)

New observations

- *Nutrients* (L4, E1): nutrients (to be analysed within two hours of sampling); nitrate sensor to be deployed for *in situ* measurements.
- In situ *autonomous buoy array* (estuary, Plymouth Sound, L4): depth profiles of temperature, salinity, currents, nutrients and pH, with option of other parameters, to determine flux of materials; data recovery once a month.
- *Flow cytometry*: full range of phytoplankton community structure.
- RV Quest *real-time along track measurements*: along-track telemetered readings of temperature, salinity, attenuation, oxygen, spectral solar irradiance, pH and pCO2 (as part of CASIX).
- *Estuarine sampling*: continuous recording of temperature, salinity, currents and sediment load at a station in the estuary mouth; supported by 6 monthly, axial surveys to quantify the influence of the Tamar estuary on the coastal environment for different seasons and river flow conditions.

Remote observations

Historical data: the entire time series of SST (1982 – present), ocean colour (1978-1986; 1997-current) for the SO 10 region will be reprocessed.
Real-time processing: SST and chlorophyll for the region (and other observatories) will be provided by RSDAS (Shutler *et al* 2005).
HAB now-cast: operational detection of harmful algal blooms will be undertaken based on EO data and HAB detection algorithms (e.g. Miller *et al* in press).
Aircraft: occasional overflights using the new ARSF SPECIM hyperspectral sensor and atmospheric parameter suite.
Validation and algorithm development: the establishment of a National Facility for EO validation and algorithm development at E1.

Virtual observations

Currently we make seven day hindcast simulations of the observatory regions ecosystem using POLCOMS-ERSEM forced by real time met data, and boundary conditions from the UK Met Office shelf seas ecosystem hindcast. This will become a 3 day forecast after the Met Office begins shelf wide ecosystem forecasts (2007). As simulation tools are developed in Theme 9, we will move to forecast using a 1nm regional model (include assimilation of NRT EO data) with a nested 180m coastal/estuarine model. Model forecasts will be evaluated using both *insitu* and EO data.

Underpinning technology

The *in situ*, EO and model data fields will be ingested into a web-based GIS system and served to a wide range of users/scientists/customers. This will initially be set up using SO 10 as an exemplar but could easily be expanded to cover data from the other laboratories leading to a truly integrated UK marine observatory. The interoperability of the technology will allow the addition of further data types and sources at a later date such as SO 8 Ferrybox data. PML already has considerable

expertise in web-based GIS systems. The backlog of MBA historical data in notebooks and in old formats (e.g. Fortran files) will be digitised and made available.

Deliverables

- Operational web-GIS based data delivery system (PML, MBA)
- Web enabled database of all in-situ measurements (PML, MBA)
- Continuous WCO operation (PML, MBA)
- Make backlog of historical data in digital format available to Theme 6 (MBA)
- Web enabled database of all EO data (PML)
- Web enabled delivery of model forecasts (PML)
- Incorporate time series into national and European networks via MECN (MBA), MarBEF (MBA/PML) and EUR-OCEANS (PML).

Separately-funded elements include a pCO_2 system (supported via NERC CASIX); near-real time EO data (from NERC RSDAS); airborne imagery and atmospheric data (from NERC ARSF); and Meteorological Office MRCS data from NCOF.

The work of the observatory will link to other parts of Theme 10 through the CPR routes that cover the Western English Channel (SO 15), and by relevant ship-of-opportunity transects (SO 8). Overall it will form a major part of the Marine Environmental Change Network (MECN).

Timetable 2007 - 12

		Year 1			Year 2		Year 3		Year 4		Year 5	
Activities	Project month	0	6	12	18	24	30	36	42	48	54	60
New measurements												
Nutrients												
In situ autonomous buoy												
Flow cytometry												
RV Quest "live" underway measurements												
Estuarine Measurements												
Remote Sensing												
Near-real time products												
Re-processing of historical AVHRR data				Pr								
Re-processing of historical ocean colour data			Pr									
casi overflights of the coast and estuary												
Modelling												
Setup of initial system for hindcasts and forecasts				Pr								
Model in operational mode												
Integration activities												
Meta data conventions - liaise with other LOs		W	Pr									
Installation of the OGS Web Map Server												
WCO website development			I									
WCO data integrated into UK Observatories												
MECN as NERC/Defra KT mechanism												
Reports												
Annual report												Fr
	Project month	0	6	12	18	24	30	36	42	48	54	60

Key: Operational Axial survey ; Workshop (W); Progress Report (Pr); Final Report (Fr); WCO web page launch (I)

The existing *in situ* measurements will continue throughout the project. Estuarine measurements will be continuous and consolidated with 6- monthly axial surveys shown in the Gantt chart.

Stakeholder relevance

The data from this SO will continue to be an integral part of the MECN to detect and predict environmental change. The SO has relevance to Defra and the Environment Agency (EA) as a long-term monitoring station and in the case of a pollution event or natural disaster, will enable a quantitative assessment of its impact and possible mitigation strategies. The observations have relevance for the UK Meteorological Office; for MRCS model comparisons with *in situ*, EO and model data – and will have wider relevance to the National Centre for Ocean Forecasting (NCOF).

SO 11 - Liverpool Bay Coastal Observatory

Strategic context

Sustained, systematic observations of the ocean and continental shelf seas at appropriate time and space scales allied to numerical models are key to understanding and prediction. In shelf seas these observations address issues as fundamental as '*what is the capacity of shelf seas to absorb change?*' encompassing the impacts of climate change, biological productivity and diversity, sustainable management, pollution and public health, safety at sea and extreme events. Advancing understanding of coastal processes to use and manage these resources better is challenging; important controlling processes occur over a broad range of spatial and temporal scales which cannot be simultaneously studied solely with satellite or ship-based platforms. The stimulus is both scientific curiosity and also the desire to improve the underpinning knowledge required for sound management decisions concerning the quality and sustainability of our coastal seas. The eastern Irish Sea is considered a sensitive region for several reasons: it has a long (150 years) history of industrial contamination, which has been reducing in recent years; it experiences higher than average nutrient loading, a concern for government under the WFD and UWWD because of the potential risk of the onset of *undesirable disturbance* (Anon, 2004) through eutrophication, with the EA adopting the Ribble Estuary (in Liverpool Bay) as its test area; Liverpool Bay is subject to coastal erosion and deposition and the coastal waters interact with the three main estuaries in the region (Dee, Mersey, Ribble); it has a major cluster of renewable energy installations (windfarms) as well as more traditional offshore oil and gas; it has major shipping routes, particularly for Liverpool, and an active marine leisure industry affected by the recently introduced BWD.

Considerable effort has been spent in the last 5 years (2001-06) in setting up an integrated observational and now-cast modelling system in Liverpool Bay (see Fig 5), with the recent POL review (SMA, 2004) stating the observatory was seen as a leader in its field and a unique 'selling' point of the laboratory. Cost benefit analysis (IACMST, 2004) shows that benefits really start to accrue after 10 years. In 2007-12 we will be able to exploit the time series being acquired, the model-data synthesis and the increasingly available quantities of real-time data (e.g. river flows) to provide an integrated assessment and short term forecasts of the coastal ocean state.

Overall aims and purpose

- To continue and enlarge the scope of the existing coastal observatory in Liverpool Bay to routinely monitor the northern Irish Sea
- To develop the synthesis of measurements and models in the coastal ocean to optimize measurement arrays and forecast products. Driving forward shelf seas' operational oceanography with the direct objective of improving the national forecasting capability, expressed through links to the NCOF
- To exploit the long time-series of observations and model outputs to: a) identify the roles of climate and anthropogenic inputs on the coastal ocean's physical and biological functioning (including impacts of nutrient discharges, offshore renewable energy installations and fishing activity) taking into consideration the importance of events versus mean, storms / waves, river discharge / variable salinity stratification / horizontal gradients; b) predict the impacts of climate change scenarios; and c) provide new insights to Irish Sea dynamics for variables either with seasonal cycles and interannual variability, or which show weak or no seasonal cycles.
- To provide and maintain a 'laboratory' within which a variety of observational and model experiments can be undertaken (Themes 3, 6, 8, 9), including capture of extreme events.
- Demonstrate the value of an integrated approach in assessment and forecasting
- Demonstrate the coastal observatory as a tool for marine management strategies through collaboration with EA, Defra, JNCC, EN, DARD, and Local Authorities, providing management information pertinent to policy (e.g. WFD).

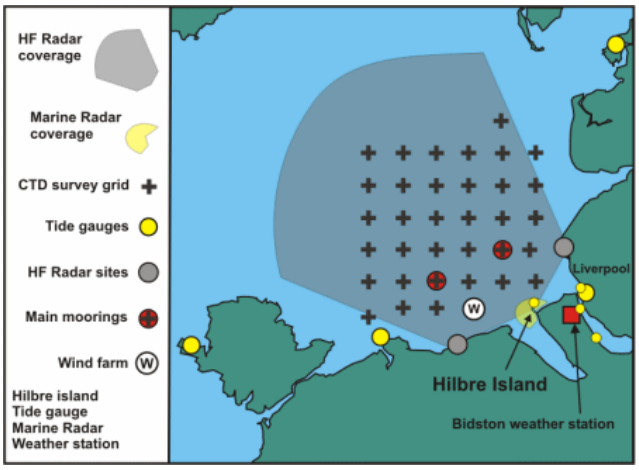

Figure 5: Liverpool Bay Observatory

Description of science

The existing (and ongoing) measurement and modelling activities are fully described in Proctor *et al* (2004) and Lane *et al* (2006). They are summarised in Fig 5 and include:

East Mooring Site: Bottom frame with full suite of physical measurements (high frequency ADCP, conductivity, temperature, turbidity and fluorescence), a Cefas directional wavebuoy, and a Smartbuoy collecting surface properties including salinity, temperature, turbidity, nutrients, irradiance and chlorophyll. All transmit data in real-time via Orbcomm. The Smartbuoy also collects daily water samples.

West Mooring Site: Bottom frame with full suite of physical measurements (high frequency ADCP, conductivity, temperature, turbidity and fluorescence), Smartbuoy.

Spatial survey: Four - six week intervals (determined by biofouling of optical sensors). Spatial surveys comprise of vertical profiles of CTD, SPM, some bed sediment sampling and surface and bed nutrients, phytoplankton, zooplankton.

Ferry: The Birkenhead – Belfast ferry samples near surface (5m depth) temperature, salinity, turbidity, chlorophyll, with data transmitted by Orbcomm. The route is scientifically varied passing through six completely different hydrodynamic regions, which significantly impact on their ecological function.

Tidegauges: Real-time data are obtained from tide gauges operated by MDHC and the UK tide gauge network.

Satellite imagery: Weekly composite satellite data, AVHRR (SST) and ocean colour (Chlorophyll and suspended sediment), are provided by the RSDAS.

HF radar: A phased array HF radar system (a 12-16MHz WERA HF radar) measuring surface currents and waves with maximum range 75km at a resolution of 4km for sea surface currents and for 2-D wave spectra.

Meteorology station: with web camera on Hilbre Island, at the mouth of the Dee.

Operational models complete the integrated system. The Coastal Observatory uses POLCOMS (see Theme 9 and www.pol.ac.uk/home/research/polcoms). Configurations of POLCOMS are routinely transferred to the Met Office (under contract) for national operational forecasting; a nested set of models covering the NE Atlantic Ocean into Liverpool Bay with increasing horizontal resolution [12km Atlantic Margin Model (AMM) linked via open boundary conditions to FOAM; 7km NW European Shelf Medium Resolution Continental Shelf model (MRCS) (7km); 1.8km Irish Sea (IRS)] has been set up. These models are also operational on the POL cluster and a 200m Liverpool Bay (LB) model will be operational mid 2006. Real-time local river discharges will be included through a link-up to the Environment Agency river-flow network. All data are banked with BODC and available on the COBS website (http://cobs.pol.ac.uk).

Under Oceans 2025 future developments of the measurement array include a 3rd mooring site; additional parameter measurements at each mooring site (and on each survey); pCO2 measurements on *RV Prince Madog*; additional ferries instrumented to include nutrients; drifter and glider deployments; *ad hoc* instrumentation deployed by the Liverpool University coastal vessel to capture forecast extreme events. Planned enhancements of the modelling system (from Theme 9) include

fully coupled wave and current model (POLCOMS-WAM) to trial the impact of 2-way wave-current interactions on wave and surge propagation; full implementation of POLCOMS-ERSEM-WAM in the nested model suite from AMM through to LB; development of hydrological forecast models for river discharge and nutrient loading; incorporation of data assimilation to utilize the full suite of measurements.

Specific Objectives

Can we identify how the coastal zone is affected by climatic and anthropogenic factors?
Utilizing the long timeseries of in-situ measurements, inputs to the Irish Sea determined through multi-year model runs (Themes 6 & 9), and the appropriate riverine measurements, we aim to determine which components of the physics and ecosystem response are anthropogenic or climatic in origin and provide an understanding of current and past conditions. This will allow us to conduct scenario testing, with greater certainty, of the response of the system to changed anthropogenic inputs (e.g. reduced nutrient loading) and climate, thereby contributing to the ecosystem approach to marine management.

Can we forecast, to sufficient accuracy for marine management purposes, the physical and ecosystem response in the coastal zone?
This will involve operating POLCOMS-ERSEM-WAM for the Irish Sea (driven by wider area models) to produce forecasts of the coastal seas response to short term (few days) meteorological forcing and river inputs, including river-estuary interaction. For validation, emphasis will be placed on the full integration of measurements and models using appropriate metrics (e.g. those constructed by the EU MERSEA project). Data assimilation will reveal how specific types and frequency of observations reduce the model errors and we will (through Theme 9) explore the impact of several different schemes both in terms of error statistics and computational efficiency. The most beneficial (scientific and economic) design of the system will be optimised following methodology developed in the EU project ODON (eg. OSE, OSSE) in which POL was a partner. An evaluation of the measurement / model system will be carried to determine how well the system performs in meeting end-user requirements.

Does maintaining an observatory enhance our understanding of coastal processes?
We think the answer to this is 'yes' and will aim to demonstrate this added value. Within the infrastructure of continuous monitoring and modelling, detailed process studies can be conducted with effort concentrated on the process under scrutiny. Specific experiments can then be very focussed. For example, studies on the role of gradients (vertical and horizontal) and their spatial variability (e.g. through turbulence probes and gliders), and the effects of storms on benthic fluxes. We will take advantage of the newly acquired Liverpool University Biological Sciences inshore vessel to deploy additional instrumentation to capture extreme events in a way that has not been available until now.

Participation and collaborations (including externally-funded elements)
PML, ecosystem modelling; NOC, ferry measurement practice (SO 8) and nutrient analysis; BGS, sea bed sediments; CEH, catchment-estuary inputs; UK Met Office (NCOF),NWP forcing, boundary conditions from FOAM-HADoCC, robust operational capability, hydrological forecasts; CCLRC Daresbury, model efficiency (grid computing, high performance computing); University of Wales Bangor, ferry measurements; CASIX, $pCO_{2\ and}$ and suspended sediment measurements; EA, real-time river feeds, survey exchange, WFD interaction; Liverpool University, trace metals, nutrient fluxes, benthic fauna; rapid response vessel; DARDNI, western Irish Sea operations; Cefas, wave and biochemical monitoring; DARC: data assimilation; SAHFOS, CPR data (SO 15).

Additional links through the Integrating Coastal Observing Systems project (INCOS; NERC funded via the International Opportunities Fund, 2005-08) and with non-NERC coastal observatories (e.g. Channel Coastal Observatory, andCefas southern North Sea Observatory).

Deliverables

- Continuous measurements (contributing to MECN) and model products

- Validated real time ecosystem model
- Marine system forecasts with error analysis
- An understanding of the importance of events v. mean
- Description of interannual variability
- Understanding of the role of vertical and horizontal gradients
- Evaluation of measurement / model array for meeting end-user requirements
- Optimisation of components for future use.

Schedule 2007-12

1. Continuous measurements and modelling
2. Prince Madog maintenance cruises every 4/6 weeks
3. Measurement system enhancements annually (starting month 15)
4. *Ad hoc* measurements (e.g. for events) using LU boat
5. Modelling system enhancements annually (starting month 9)
6. Standardised data streams starting month 12
7. Observatory website GIS activated and outreach programme started, month 4
8. Observatory website integrated into SO website month 12
9. International Opportunity Fund workshops months 9 and 21

Links with other parts of Oceans 2025

SO 11 will use data from SO 8 (instrumented ships of opportuinity) and SO 15 (CPR) whilst providing underpinning observations for Themes 1, 3 and 6 and technology development in Theme 8. The modelling will link with Themes 3, 6 and 9 and will provide real-time model outputs to the other coastal observatories of Theme 10 (SO 10, Western Channel Observatory; SO 12, Scottish West Coast Marine Amphitheatre).

SOFI opportunities

SO 11 already has strong links to several universities (e.g. Liverpool, Lancaster, Edge Hill and Bangor). Many opportunities exist for additional work through the Oceans 2025 Strategic Ocean Funding Initiative (SOFI); for example, studies of atmospheric and benthic nutrient fluxes; sediment-bound contaminants; river-estuarine interactions; sediment substrate and morphological change; and the socio-economic value of fisheries and other maritime activities.

Knowledge Transfer

SO 11 is critically placed to address pertinent questions of importance to the EA and Defra. The eastern Irish Sea and Liverpool Bay is identified under the WFD as a sensitive area. The EA and Defra (through Cefas) already interact with the present Observatory through the sharing of data and complementary surveys (EA) and moorings (EA, Cefas). The Observatory is a demonstration project for NCOF and is the subject of a cost-benefit study conducted for the IACMST. Outputs from the Observatory have already supported the JNCC Irish Sea Pilot Project and continued involvement is expected. EN, CCW and Airbus have interests through activity in the Dee Estuary and DARD, MI in the wider Irish Sea. The public are the major users of the website (~50% of the 140,000 visitors in 2005). The Observatory has a Steering Committee whose membership is predominantly local stakeholders and policy makers. An education outreach programme will be established to engage the regional schools and colleges.

SO 12 – Tiree Passage time series

(originally proposed as Scottish West Coast Marine Amphitheatre)

The Tiree Passage time series is the longest moored time series of flow and temperature on the NW European continental shelf, having been maintained by SAMS since 1981. The mooring sits on a bank in less than 50 m of water in the narrowest sector of the Passage, a SW-NE orientated strait

between the Isle of Mull to the southeast and the Isles of Coll and Tiree to the northwest, on the western coast of Scotland.

Hourly current and temperature measurements using Aanderaa recording current meters started in June 1981 at the bottom (11 m above the bed) and on November 1987 nearer the surface (22 m above the bed), and ended in September 1997 at both depths. Hourly salinity measurements started in September 1993 at both depths using Aanderaa conductivity sensors. The mooring was re-deployed between June 1999 and February 2000, and in May 2002 until the present with the current meters at 20 m and 45 m. A Seabird Microcat salinity sensor was added at 20 m above bed in August 2002. For further background, see MECN Report 3 (Inall & Griffiths; 2003; online at www.mba.ac.uk/MECN/publications.htm#DCR)

S0 12 will support i) the servicing of the mooring 3-4 times a year, to provide continued observations on flow, temperature and salinity; and ii) the addition of a fluorometer and an improved capability to monitor the current profile through the deployment of an Acoustic Doppler Current Profiler. This information is directly relevant to research in Theme 3 (WP 3.7). Additional studies will be supported by other funding sources.

SO 13 - Arctic Shelf Time Series

Strategic context

Arctic ice cover has reduced significantly over the last 100 years and is predicted to continue to retreat monotonically in response to global warming in the future. During its Northern Seas programme, SAMS began to monitor this retreat with the deployment of a long term mooring in Kongsfjord, Svalbard in April 2002. Although other monitoring stations have been deployed by other nations elsewhere in the Arctic, this mooring is the only long term UK eye on the Arctic Shelf, and the only one near Svalbard, although CoAAT are planning one north of the island. So far the time series has revealed dramatic seasonal water mass transformations and exchanges across the Arctic shelf (Cottier *et al* 2005; Willis *et al* 2006), and provided insights into trigger mechanisms for zooplankton behaviour (Cottier *et al* 2006). In the long run, though, it is vital that monitoring stations such as SAMS Arctic Shelf Time Series are maintained during this period of rapid change in the Arctic, because without them future generations will have no idea of conditions that existed before the sea-ice melted. The time series will directly support SAMS Theme 1 (WP1.6).

Overall aims and purpose

There is no reason why a long term mooring, when in a complex region such as Svalbard, should be located in the same place every year. In particular it is important to monitor different locations in order to a) determine whether there is indeed an ideal single representative location, and b) establish a comprehensive set of baseline data over a sufficiently wide and representative area as quickly as possible. For this reason we will allow the mooring to rotate between three locations in the vicinity Svalbard on an annual basis. When necessary, however, the mooring will be located where it can support other activities or process studies taking place in the region.

Description of activity

A peripatetic mooring will be deployed around Svalbard in order to monitor the physical, sedimentological and biological (Chl a) properties of the Arctic Shelf environment.

- The single point mooring will be deployed in no more than three different locations in ~250m water depth with temperature and salinity at three depths, ADCP, two sediment traps, and two fluorimeters
- It will be serviced 2 times per year, either by SAMS cruises, or by ships of opportunity from other nations.

We have informal agreement with Norwegian partners to participate in their cruises to Svalbard. In 2007 and 2009 it will be serviced during a JCR Theme 1 cruise. SO 13 will primarily be delivered by SAMS, some links with POL (forecast modelling, SO 11)

Deliverables

All data will be archived with BODC. Scientific deliverables, e.g. publications, will be produced in Theme 1

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MARINE MAMMALS

SO 14 - Long-term observations of marine mammal population dynamics

Strategic setting

Marine mammals play a prominent role in UK and European legislation and in international agreements because of their value as indicators of marine environmental health, their potential to exert "top-down" control on the structure of marine food webs, their high public profile (reflected in their amenity and existence value), and the fact that they forage on similar spatial and temporal scales to commercial fisheries.

SO 14 is the contribution made by the Sea Mammal Research Unit (SMRU) to support the NERC strategy through Oceans 2025 and marine management policy in general. SMRU provides advice to the UK government on the management of populations of marine mammal, particularly seals. This allows NERC to discharge its Statutory Duty under the Conservation of Seals Act 1970. NERC's Special Committee on Seals (SCOS) peer-reviews the annual scientific advice provided by SMRU to government (Defra and SEERAD). This advice is drafted in response to questions from government departments that are relevant to specific policy issues and are derived from broad-ranging stakeholder consultation that includes the countryside agencies, particularly SNH and JNCC, and industry including different sectors of the fishing industry. SMRU uses this consultation process as a guide to the principal science requirements of the major stakeholders.

SO 14 contributes to all three of NERC's current science priorities:

- *Earth's life-support systems*: it will help to define the role of marine mammals in the structure and function of marine ecosystems, including the sustainability of marine biodiversity.
- *Climate change*: it will document change by contributing to the long-term observation of the ocean both through changes in marine mammals populations and through the use of animal-borne instruments to measure ocean structure.
- *Sustainable economies:* it will contribute to knowledge of how exploitation of marine bioresources can be sustained and how impacts of marine industries can be minimised.

This proposal also addresses the explicit and implicit requirements for information about marine mammals identified in UK and Scottish Sustainable Development and Biodiversity strategies (Defra, 2002, 2005a; SE/SBF, 2004; SE, 2005) and in a new strategy for Scotland's coast and inshore waters (SCF, 2004). It is also relevant to the jint UK Response to the Review of Marine Nature Conservation (Defra, 2005b); the EU Marine Strategy (CEC, 2002) and the UK Small Cetacean Bycatch Response Strategy (Defra, 2003). Specific examples are:

- Provision of scientific advice directly and indirectly (through the Special Committee on Seals) to SEERAD and Defra.
- Support to the Countryside Agencies for the implementation of the EU Habitats Directive.
- Support, via JNCC, for the OSPAR Convention: three of the current North Sea Ecological Quality Objectives rely on time series supplied by SMRU.
- Provision of marine mammal data for the UK National Marine Monitoring Programme.
- Support for the DTI's Strategic Environmental Assessments of marine areas where industrial developments are planned.
- Membership of the UK delegation to the International Whaling Commission
- Provision of data to the UK Hydrographic Office to support MoD environmental policy.
- Provision of data for ICES multi-species fisheries management models.

In addition to these inputs to government, SMRU has an important near-market role providing advice to marine industry and providing services to the science community, mainly through instrument design and manufacture and software development. SMRU also takes advantage of the iconic status of marine mammals to improve public knowledge about the marine environment.

SMRU's strategic approach

NERC strategic science funding supported 21% of SMRU's overall research in the financial year 2004/5. Whilst this NERC support was mainly for seal research, in the context of the Conservation of Seals Act 1970, SMRU also directs >50% of its research effort on cetaceans. In agreement with NERC, SMRU co-supports its strategic research programme from other sources, including the EU, Defra, SEERAD, MoD, DTI, and from an income stream generated as a result of the development and supply of instrumentation to the rest of the science community. The NERC contribution (as a percentage in brackets) to SMRU's strategic science programme can be summarised as follows:

1. Status of marine mammal populations (including long-term observation)	• Evaluate the status of UK seal populations (90%) • Measure the distribution and abundance of cetaceans over the continental shelf of Europe (0%, but there is a SOFI opportunity for a deep ocean observatory, linking to NOC) • Maintain databases providing access to information about marine mammal distribution and abundance (20%) • Improve the methods used to survey and analyse marine mammal distribution and abundance(50%).
2. Marine mammals as components of marine ecosystems (including long-term observation)	• Determine the diet of grey and harbour seals in the UK (30%) • Determine the energy consumption of marine mammals, and the behavioural and physiological constraints on foraging (30%) • Describe and predict marine mammal movements (30%, a bid will be made under the Joint Grant Scheme with MoDt to co-fund work in this area).
3. Dynamics of marine mammal populations (including long-term observation)	• Measure the vital rates in marine mammals populations and, in particular, how these are likely to change in response to population density (80%) • Measure the response of marine mammals to changes in prey density and the way in which this impacts on population trajectories (0%) • Determine how metapopulation structure affects seal population dynamics (20%) • Determine the effects of disease on marine mammal population dynamics (30%) • Determine the effects of human activities (including physical, chemical and noise pollution) on the survival and reproductive capacity of marine mammals (10%)
4. Social structure and communication	• Determine the role of acoustics in marine mammal communication, foraging and social organisation (0%) • Determine the importance of social structure and genetics in marine mammal population dynamics (20%)
5. Cross-cutting and enabling activities	• Provide the technological basis for observing free-ranging marine mammals and their environment (5%). • Provide and test new analytical tools for dealing with multidimensional environmental data involving hidden processes (5% much done through strong collaborative links with CREEM*)

*CREEM is the Centre of Research into Ecological and Environmental Modelling at the University of St Andrews. It is affiliated with the new National Centre for Statistical Ecology and SMRU has several staff who are members of CREEM.

The proposed NERC-funded part of this programme, presented below, involves seven observational work packages (OWPs). It is placed within Theme 10 of the Oceans 2025 strategy because it is a sustained observation programme designed to provide advice about the management of marine mammal populations.

1. Observation and prediction of population size

OWP 1.1 Population surveys (linked with Themes 4 and 6)

Aims and rational: Regular monitoring of UK seal populations provides the basis for SMRU's long-term observation programme. The remainder of the SMRU research programme, involving

measuring changes in the spatial use of resources, and the impacts of man and disease, is built upon this information. Specific objectives are to:

- maintain the time-series of estimates of grey seal pup production that dates back to 1962
- maintain current efforts to coordinate the abundance estimation of cetaceans in European waters (SCANS and CODA surveys).
- provide an annual update of the estimate of the UK harbour seal population
- develop new methods for surveying seal populations.

Approach and methodologies: For grey seals, we will continue to use the methodology developed in the early 1980s which involves a series of high resolution aerial photographic surveys of the 50 main UK breeding colonies each year. Approximately 40 other colonies, which hold less than 10% of the annual pup production, will be surveyed less frequently. For harbour seals, we will continue the 5-yearly census of the Scottish population using thermal imaging cameras mounted in helicopters. We will also continue the time-series of annual surveys of Special Areas of Conservation (SACs) on the UK east coast. The numbers of seals counted on these surveys will be corrected for the proportion of the population in the water and therefore not counted.

Outcomes

- Annual reports to SCOS - the NERC Special Committee on Seals.
- Provide information about the status of grey and harbour seals in the 16 SACs designated for these species in the UK.
- Provide estimates of the abundance of cetaceans species in UK waters.
- Publish population data annually and deliver to OSPAR and ICES.

OWP 1.2 Population Modelling (linked with Themes 4 and 6)

Aims and rationale: The central aim of this OWP is to make population-level inferences about the factors regulating grey and harbour seal numbers over space and time, using input from OWPs 1.1, 2.1 and 2.2, and to use these inferences to predict the size and distribution of UK seal populations. This WP will also deliver annual estimates of the total UK population of grey seals based upon pup counts. Specific objectives are to:

- Estimate, model and predict grey and harbour seal population size.
- Quantify the influence of the environment in shaping the spatial distribution of grey and harbour seal populations
- Quantify and predict the trophic interactions between grey and harbour seals and their prey by combining population estimates with information on diet and at-sea distribution from OWPs 3.1 and 3.3.

Approach and methodologies: Improving the methodology for extracting accurate estimates of population size from SMRU's long-term monitoring data is an ongoing process. Although population trends can provide a qualitative indication of the health of a population, they are not sufficient to describe how marine mammals interact with their environment. Such interactions result from spatial encounters so it is important to determine how seals are distributed in space (see OWP 3.3) and how this distribution is affected by environmental variables. Accurate models of prey consumption (see OWP 3.2) are necessary if the impact on, and numerical response to, prey populations is to be estimated. Estimating the parameters of these responses is challenging, but the resulting dynamical models will have improved predictive power and can capture indirect community effects.

Outcomes:

- Annual estimates of the UK grey seal population for SCOS.
- Improved models for estimating grey seal numbers from aerial survey counts using state-space techniques and based on biologically realistic models.
- Calibration of existing grey seal time series using independent data from surveys conducted outside the breeding season.

- Information about the age-structure, likely causes of density dependence and vulnerability to environmental influences of the UK grey seal population.
- Adapt stage-structured models, developed by SMRU for other seal species, for use on UK seals.

2. Observing dynamic processes

OWP 2.1 Demographic monitoring (linked with Themes 4 and 6)

Aims and rationale: The population models that will be developed in WP1.2 require reliable information about vital rates (birth, death and maturation rates). Historically, this information was obtained from culled samples of the population. In this WP we will use long-term observation of individual grey seals at two UK colonies to estimate birth and death rates using mark-recapture techniques. These sites also allow us to examine some of the processes that may be involved in the density-dependent regulation of the population and which demographic variables are most sensitive to these factors. Specific objectives are to:

- Measure the demographic rates in grey seals using long-term mark-recapture
- Examine the extrinsic (environmental) factors that affect demographic rates
- Examine the intrinsic (social, genetic and immunological) factors that affect demographic rates.

Approach and methodologies: We will continue the long-term monitoring programmes at our two major study sites, which will be visited annually. The marked population will be maintained and morphometric, condition, dietary and behavioural data will be collected from marked seals. State-space models will be used to assess the relative support for alternative hypotheses about the contributions of intrinsic and extrinsic factors in determining reproductive success and their covariance with survival.

Outcomes:

- Provide environmental predictors of demographic rates that inform the population models of grey seal dynamics (see OWP 1.2).
- Provide data about colony characteristics (environmental variables, temporal and spatial distribution of seals, operational sex ratio, pre-wean pup mortality, lactation duration and time-to-leave) for input to the pup estimation model (see OWP 1.1 and1.2).
- Define the relative and absolute effects of individual characteristics, including condition and genetics, on demographic rates.

OWP 2.2 Factors affecting survival in seal populations (linked with Theme 6)

Aims and rationale: Infectious diseases are probably the main cause of death of seals in UK waters. Marine mammals tend to bioconcentrate lipophillic persistent organic pollutants because they are top predators with large lipid stores. These pollutants are often endocrine disrupters with immunosuppressive effects. Possible synergies with pathogen exposure increase the risk of adverse effects, particularly in naive animals. As part of our effort to predict the trajectories of marine mammal populations (OWP 1.2), we aim to address two major questions

- How do extrinsic factors, such as disease and pollution, affect seal population dynamics?
- Does temporal and spatial population structure affect the population consequences of environmental perturbations, such as disease outbreaks or pollutant exposure?

Approach: Within the context of monitoring populations we will investigate the effect of contaminants and pathogens on UK seals. This will use both in vitro and in vivo approaches, studying wild populations and animals held in SMRU's captive facility.

Outcomes:

- Determine the toxico-kinetics of contaminants in seals using *in vitro* and *in vivo* approaches.
- Evaluate relationships between contaminants and prey type and quality.
- Use physiologically based pharmacokinetic models to assess the risk posed by contaminants.
- Use information from OWPs 1.2 and 3.3 to predict the likely impact of future epidemics and exposure to emerging pathogens, e.g. toxoplasmosis and leptospirosis, on UK seals

- Assist in the revision of the UK contingency plan for future marine mammal mass mortalities.

3. Impact on bioresources (interactions with environment)

OWP 3.1 Observation of seal diet (linked with Themes 4 and 6)

Aims and rationale: Descriptions of seal diet and feeding behaviour are required to model the trophic interaction between UK seals and their prey (OWP1.2). This OWP will document spatial and temporal variations in the diet of UK seals in response to changes in the prey base. Specific objectives are to

- Provide range-wide estimates of the diet of UK grey seals
- Improve current knowledge of harbour seal diet
- Develop a system for monitoring diet at reference sites
- Link diet data into habitat preference models
- Use the data from long-term monitoring of individuals (see OWP 2.1) to assess interannual variability in diet.

Approach and methodologies: Seal feeding is rarely observed, so we use combinations of indirect techniques to assess diet. Analysis of prey remains in faecal samples continues to be our main tool for observing diet. However, it has inherent biases and cannot usually be related to specific individuals. Fatty acids (FA) pass relatively unchanged up the food chain and many of the 60+ FAs in seal blubber are derived totally from the diet. In tandem with faecal sample analysis we will continue to develop quantitative fatty acid signature analysis (QFASA) to provide quantitative descriptions of diet. We will use seals fed known diets in the captive facility at SMRU to calibrate the QFASA method.

Outcomes:

- Comprehensive assessment of diet in grey seals including variability in space and time
- Improved assessment of diet in harbour seals
- Provision of diet data to OWPs 1.2 and 3.2, ICES and OSPAR
- A library of fatty acid profiles for seal prey species from Scottish coastal waters.

OWP 3.2 Observing prey consumption (linked with Themes 4 and 6)

Aims and rationale: This OWP aims to quantify two relationships that are essential for understanding the trophic interactions between marine mammals and their prey (OWP1.2). In order to relate estimates of diet (OWP 3.1) to total prey consumption we require appropriately structured, accurate estimates of field metabolic rates (FMR). And we need to understand the way in which predators respond to changes in local or regional prey abundance (their functional response). Specific objectives are to

- Improve current estimates of FMR
- Determine how prey preference varies with prey accessibility, abundance and energy value.

Approach and methodologies: Studies of geographical and individual differences in diet composition (see OWP 3.1) and distribution (see OWP3.3) will be combined with estimates of total energy requirements under a range of environmental conditions from laboratory-based studies using respirometry and isotope dilution methods. We will investigate the way in which prey preferences vary with prey accessibility, abundance and energy value in controlled situations using the captive facility at SMRU.

Outcomes:

- Provide geographically and temporally structured estimates of the energy requirements of UK grey and harbour seal populations.
- Provide descriptions of single- and multi-species functional response
- Report results annually to SCOS and ICES.

OWP 3.3 Observing at-sea distribution (linked with Themes 6 and 8)

Aims and rationale: A knowledge of at-sea distribution is necessary to understand the way in which marine mammals interact with their environment and with human activities, such as pollution and fishing. This OWP will provide the information required to convert estimates of diet and prey preference from OWPs 3.1 and 3.2 to spatially-structured estimates of prey consumption, and to assess the vulnerability of seal populations to pollutants and pathogens (OWP 2.2). Specific objectives are to:

- Continue to develop data collection technology (SMRU already supplies a large proportion of the world market with this technology)
- Estimate the spatial distribution of grey and harbour seals while they are at sea
- Estimate the spatial distribution and abundance of cetaceans in UK waters
- Develop new approaches for the visualisation and analysis of multi-dimensional data from telemetry devices.

Approach and methodologies: We will build upon the engineering/biological expertise within SMRU to increase the efficiency and functionality of existing telemetry tags to measure physiological and environmental variables. We will continue to build our databases on UK seal distribution at sea by deploying additional tags.

Outcomes:

- Development of new instruments including additional sensors and the use of mobile phone technology to relay data ashore.
- Estimate habitat usage and preference, including provision of distribution maps (link with OWP 1.2 and 3.1).
- Delivery of data about critical habitat for marine mammals for use in marine spatial planning.
- Delivery of data about the distribution of cetaceans
- Report results annually to SCOS and ICES.

Knowledge transfer

The SCOS process is an integral part of SMRU's activities and this helps to link SMRU science and policy. It also serves to improve the alignment of SMRU's research outputs with stakeholders' needs. Several current research projects involve the direct application of SMRU science outputs to meet society's needs:

- Sponsorship from a range of trusts, the Scottish Executive and SNH has led to a research to support a groundbreaking management plan for seals and salmon fisheries in the Moray Firth
- SMRU, in collaboration with BAE Systems and CREEM, is supplying an environmental risk management capability to the Royal Navy.
- SMRU is supplying marine mammal monitoring for marine tidal turbine developments.

Data management

SMRU's data centre is BODC. All data will be streamed into BODC.

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PLANKTON

SO 15 - Continuous Plankton Recorder Survey

Strategic context

The Continuous Plankton Recorder (CPR) survey, now managed by the Sir Alister Hardy Foundation for Ocean Sciences (SAHFOS) celebrated its 75th anniversary in June 2006 as the only basin-wide and long-term operational survey of plankton in the world. There has been an increasing recognition of the value of this multidecadal time series as a 'barometer' against which to assess environmental change.

The time-series available from the CPR are especially valuable, as there are few long data sets of marine biological information available in the world. There is a growing awareness that the quality of marine ecosystems is subject to a wide range of human impacts from pollution, eutrophication, loss of biodiversity to over fishing. Evaluating and quantifying the scale and effects of such issues is becoming increasingly important as an ecosystem approach is applied to environmental management. Superimposed on the above issues are the potential effects of climate change and acidification on oceanic ecosystems. Modelling studies indicate that such effects are likely to be more pronounced in the North Atlantic and that this region plays a key role in the climate of the world (e.g. solubility and biological pumps).

More than 200,000 samples have been analysed into ~500 different taxa of zoo- and phytoplankton over the more than 5 million miles that have now been towed since 1931. New breakthroughs have demonstrated the potential to apply molecular analysis and calibrate remote sensing products with CPR data. Products from the survey are also being used to construct and validate a new generation of ecosystem, fishery and climate models.

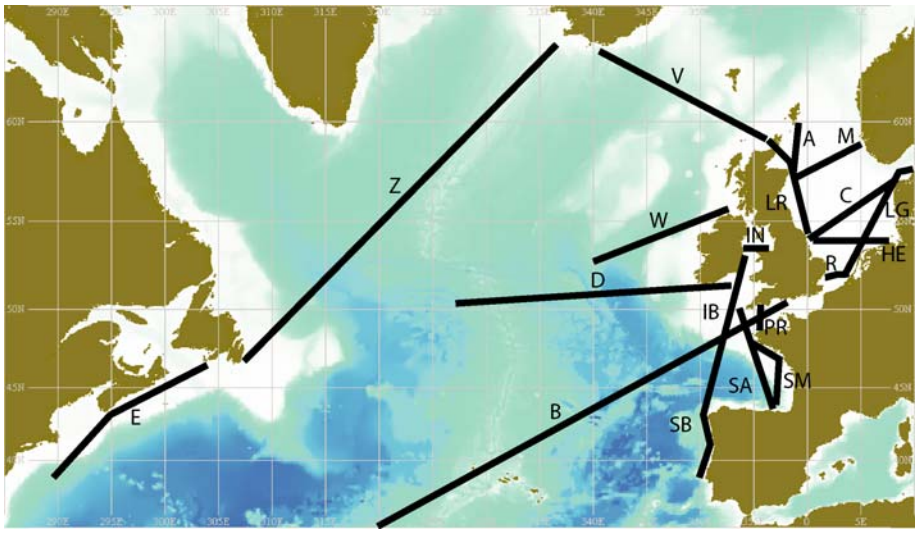

Figure 6.

Standard CPR tow routes sampled during 2004

SAHFOS holds a unique global expertise in taxonomy and other survey skills and is an active promoter of oceanographic education with sophisticated expertise in Knowledge Transfer. As the largest plankton monitoring programme in the world the Survey provides a long-term baseline of the near-surface distribution, abundance and diversity of phyto- and zooplankton, together with opportunities for research on pelagic ecosystems at temporal and spatial scales that would otherwise be impossible.

Overall aims and purpose

As a long-term monitoring programme the main objective of the CPR survey is to maintain the spatial and temporal integrity of the core North Atlantic survey by ensuring an adequate sampling coverage and adding further years to the time series. The current route coverage is shown in Figure 6 and is believed to be the minimum that is needed to assess variability in the North Atlantic, as key

areas are under-sampled. Since 1997 a separate survey has been implemented in the North Pacific and operated by SAHFOS from Plymouth opening up many new opportunities for research, including inter-ocean comparisons. Most of the funding for the North Atlantic survey is used to support the operational programme (20.4 FTE). Research is also carried out on the results by a small team (2.5 FTE). Other objectives under a research heading include: the development of an improved understanding of mechanisms behind observed decadal and shorter period spatial and temporal variability and the interpretation of hydrobiological variability and biodiversity within the context of global and climate change in marine ecosystems. Central to the aims of SAHFOS is the promotion of the CPR approach within international programmes such as the GOOS, GLOBEC and LME initiatives. The SAHFOS partnership in Oceans 2025 will help to reinforce the research links already in place with NERC marine Centres and increase the application of CPR data to a new range of research themes.

Description of activity

Each month the CPR survey uses voluntary ships of opportunity to tow machines at ~10m that sample the plankton on a band of silk along their standard routes of passage. A total of 267 ships have participated in the survey since 1931. Four operational phases are involved in the survey, in sequence: logistics, workshop maintenance, plankton analysis and archiving of data and samples. Throughout the sequence strict quality control procedures are maintained. Liaising with the ships and their operators and the management of the transfer and recovery of CPRs from these ships as well as the manufacture and fitting of specialised tow davits is a major logistical exercise. Workshop maintenance of the CPRs has become more onerous because of the ageing CPR fleet (50 machines, most over 30 years old and one still in use that was built in 1938) and due to damage when the machines are deployed or recovered as many ships now travel faster. On the 26 March 2004 a total tow mileage of 5 million nautical miles was passed – a truly astounding achievement.

The filtering silk that has sampled the plankton is divided into 10cm sections representing 18 km (10 nautical miles) of tow for analysis under a microscope. Typically, alternate 10 nautical mile samples are analysed to a standard procedure under a microscope. More than 500 different taxonomic categories of zoo- and phytoplankton are identified and enumerated, half to the level of species. Despite the relatively large size of the mesh aperture, many phytoplankton cells are retained and colour the silk, an attribute that is used to provide a coarse visual estimate of chlorophyll *a* that has recently been calibrated with satellite measures of chlorophyll from SeaWiFS (Raitsos *et al* 2005). At the present time the Survey has the equivalent of 12 FTE highly experienced plankton analysts. Many of the analysts have specialist expertise in specific plankton groups (e.g. decapods, fish larvae) outside the general skills used in CPR analysis. The size of this reservoir of taxonomic skills in plankton identification is unique in the world at a time when taxonomic skills are in major decline and yet recognised as fundamental to the future development of marine science. It is now realised that information at the species and functional group level is crucial to understanding marine processes. SAHFOS is widely recognised internationally as a centre of taxonomic expertise.

Data produced by the survey (currently from January 1946) is housed in the SAHFOS database, a unique resource, made up of the results of close to 200,000 samples and comprising > 2.3 million positive plankton records. The database and the associated GOOS compliant open access data policy are central to the success of the survey. Data requests from a wide range of countries have increased dramatically with 40 data requests in 2004 rising to over 60 in 2005. In addition there have been ~100 downloads of the gridded plankton database for the North Sea WinCPR since it was launched in March 2005. There has been a similar increase in the use of the archive of formalin preserved sample for genetic, biochemical, radioisotope and plastic particle research. The data is increasingly being used by ecosystem fishery and climate change modellers and for calibration and interpretation of multispectral satellite products. Other applications include the assessment of eutrophication and as classification tools for water quality, through the development of indicators.

CPRs could obtain considerable additional information if they were all equipped with instrumentation packages. However, the high cost of the necessary instruments as well as the considerable additional personnel requirements for calibration, maintenance and data processing has so far made the routine application of such methodologies impracticable. However, much additional information has been obtained from Aquapacks, Minipacks and temperature loggers for a number of standard CPR routes in the North Atlantic. Additional instruments will be added to the current pool as resources become available. Results from the temperature loggers are placed on the SAHFOS web site as soon as the CPRs are returned to the laboratory - in semi-real time.

Participation

Apart from contributing to Oceans 2025 as a long-term observation system, the CPR survey is considered essential in answering many of the themed scientific goals of Oceans 2025 by providing a macro-scale perspective on the marine ecosystems of the North Atlantic. As such, the CPR survey, in some capacity, has links (or scope for links) with almost of the Themes 1 - 9 as well as connections with other sustained observing activities, in particular SO 1, SO 3, SO 8, SO 10 and SO 11. CPR data is considered fundamental in monitoring large-scale marine ecosystem changes including climate change impacts, regime shifts, fishery recruitment variability, eutrophication and biodiversity as well as contributing to integrated assessments of regional-scale marine ecosystems. In addition SAHFOS is working closely with a number of NERC laboratories for example CEH examining relationships between plankton, fish larvae and sea birds and is providing data for use in the development and validation of ecosystem models with PML and POL.

In addition to NERC linkages, SAHFOS also meets a wide range of other government requirements. Results from the survey are used by Defra to support policy under the headings fisheries, environmental assessment and quality, biodiversity as well as the production of indicators. Work from SAHFOS made a major contribution to the Defra report ‘Charting Progress: An integrated assessment of the state of UK seas’ and has been used by Defra to support OSPAR Quality Status Reports. In a fisheries context the data is being used by Cefas in the development of new modelling approaches to Fisheries Assessment as part of the ICES REGNS working group. Data from the survey has also been used by the environment agencies and SEPA is assessing the possibility of using towed CPRs in shallow water to sample for the Water Framework Directive. Products from the survey are regularly used by DTI for Strategic Environmental Assessments of oil exploitation areas. The data is now been extensively used by the Hadley Centre in Climate Change models and is expected to be a key data source for future modelling within the new National Centre for Ocean Forecasting. On the conservation front the data is increasingly being used by the conservation agencies in the development of their marine programmes. The CPR programme is an integral part of the National Marine Monitoring Programme and contributes to the work of the IACMST GOOS Action Group.

Internationally, the survey is part of the Initial Observing System of the Global Ocean Observing System (GOOS). Development and training for the establishment of new surveys is an important part of the work of the Foundation. Pilot tows have been completed for a new survey around southern Africa as part of the Benguela Current Large Marine Ecosystem (BCLME) study and preparations are in hand with UNIDO to start a second phase of a survey in the Gulf of Guinea. Data from the survey is used by all the funding nations in the development of advice and policy. As one example, the Canadian Department of Fisheries and Oceans (DFO) uses data from the CPR survey in the western Atlantic to contribute towards assessments of the marine environment and fish stocks on the Nova Scotian shelf as part of the Canadian Atlantic Zone Monitoring Programme.

Deliverables

As an operational programme all the deliverables will be repeated on a rolling annual cycle:

- Completion of the analysis of CPR samples and the processing of instrumentation results by October of the year following the collection of the samples.

- Incorporation of results for the previous year into the main CPR database, after quality control checks by December of the year following the collection of the samples.
- Ensuring that data requests, especially from the NERC 2025 partners, are processed rapidly and efficiently.
- Annual publication of an 'Ecological Status Report' on the status of the seas around the United Kingdom with specific reference to the results from the CPR.
- Publication of an Annual Report, summarising research outputs and logistics in the previous year.

Knowledge Transfer and Science & Society

A primary mandate of SAHFOS as a charity is to promote and advance education and knowledge about the marine environment for the public benefit by disseminating information derived from the study of plankton populations in the oceans and coastal seas. The NERC SMA noted "The high profile of SAHFOS's KT work" and the additional burden this provides "for the organisation in servicing the demand for knowledge products". A highly successful educational programme has been developed for four different age groups in schools and university undergraduates starting with '*Bertie Basking Shark and his plankton pals*'. A wide variety of resources for pupils and teachers can be downloaded from the web. Regular visits and workships are held in schools and lectures given on the work of the survey at a number of universities within the UK and internationally. Published articles have also been produced for a school readership and the Director presented the Vetlefsen lecture at the University of Rhode Island in 2004 for example. SAHFOS has played an active role in the Global Ocean Ecosystem Dynamics (GLOBEC) programme and has a regular page in the GLOBEC newsletter. As indicated earlier the Foundation also has a strong record in the supervision and training of PhD students, 5 currently (with a further new student from Ireland due to start soon) from and affiliated to universities in a number of countries.

Two web-based products have been produced to further improve accessibility to information on the marine environment to a wide range of users. The software from at least one of these applications has development possibilities. The first product is a web-based gridded plankton browser for the North Sea, WinCPR that can be downloaded for free from the SAHFOS web. It contains information, with a range of plotting options on >100 phyto and zooplankton taxa on a grid of 172 pixels covering the whole of the North Sea. For example, the browser contains a total of 67,200 distribution maps of monthly plankton abundance (12 months x 50 years x 112 taxa) for the period 1948 to 1997. Work is underway with NERC funding to develop a North Atlantic version of WinCPR that will also include physicochemical measurements to the same grid. The second product is a 'Pilot Marine Climate Change Encyclopaedia'. A CD version was produced in 2005 and the launch of the web version is planned for the end of February.

Timetable

The collection of CPR data is ongoing, and will continue to be so. The timetable for this project is linked into the annual cycle of the deliverables, but will be adjusted as necessary to meet the requirements of participants in Oceans 2025.

Other relevant information

Over the last 3 years SAHFOS has averaged 35 publications pa. Titles and abstracts are online at http://192.171.163.165/bibliography.htm. An indication of the relevance and usefulness of the Survey to current scientific problems is reflected in the steady output of papers in *Nature* and *Science* from SAHFOS staff and students, or those that have used CPR data, Such high profile papers have recently included: analyses of trophic cascades (Frank *et al* 2005); modelling ocean ecosystems (DeYoung *et al* 2004); climate impact on plankton (Richardson & Schoeman 2004); climate change & trophic mismatch (Edwards & Richardson 2004); increasing marine plastics (Thompson *et al* 2004); cod and climate change (Beaugrand *et al* 2003*);* biogeography and climate (Beaugrand *et al* 2002); and ecosystem modelling (Taylor *et al* 2002).

Since 1997 a separate survey, operated by SAHFOS from Plymouth, has been implemented in the North Pacific with transects between Canada and Japan via the Aleutians and from Alaska to California or Washington. The operation of this survey is funded and managed independently of the North Atlantic monitoring programme, although the data is housed in the SAHFOS database. The initiation of this second survey, that uses exactly the same methodologies, has opened up many new opportunities for research, including inter-ocean comparisons.

Investment/capital equipment

Support for capital items has proved particularly problematic in the past, for example only one new CPR has been purchased in 30 years out of a current fleet of 50. One of these machines was built in 1938 and is still in use.

Plankton recorders. The Core monitoring programme is central to the whole work of SAHFOS, but its products would not be available without appropriate capital tools. Although only 3 machines have been lost in the last decade, under-funding of equipment renewal has prevented any replacement of the ageing CPR fleet. The survey has a fleet of 50 operational CPRs, some from the 1930s, and is now operating at full stretch using all available machines in operational deployment, and sustaining an increasing maintenance load. The first new purpose built, and CAD designed, CPR has been purchased in 2005 in part funded by IFREMER.

Microscopes. The microscope suite is largely 50 years old. Four have recently been replaced with new specially designed and ergonomic microscopes, but another four are required to ensure the future health and safety of staff. Samples are handled in formalin but the ventilation arrangements in the workshop are barely satisfactory, and with the need to minimise exposure to the lowest possible level, it behoves employers to use the best technology for formalin extraction both there and in the laboratory.

The Foundation needs to:

- initiate a progressive upgrade and replacement of the CPR fleet
- improve workshop ventilation, lighting and tools
- continue the replacement of microscopes
- upgrade formalin extraction arrangements.

Costs were provided in the Oceans 2025 proposal submitted to NERC.

References for SO 15

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Theme 10 Synthesis and Concluding Material

Oceans 2025 synergies and links

As indicated in the preceding pages and the Theme-specific proposals, all SOs are closely tied to the science Themes of *Oceans 2025*, some of them supporting many Themes. The matrix below shows the main synergies of SOs with Themes, with other SOs (identified under Theme 10) and with National Facilities #1 (British Oceanographic Data Centre) and #2 (Permanent Service for Mean Sea Level).

Theme	S0 1	S0 2	S0 3	S0 4	S0 5	S0 6	S0 7	S0 9	S0 10	S0 11	S0 12	S0 13	S0 14	S0 15
1														
2														
3														
4														
5														
6														
8														
9														
10	S0 2 S013 S015	S0 1	S0 6 S0 7 S0 15	S0 5	S0 4	S0 3	S0 3		S0 1 S011 S015	S0 8 S010 S015	S0 4 S0 10	S0 3 S0 4		S0 1 S0 3 S010 S011
BODC														
PSMSL														

Many of the SOs make efficient use of ships. For example, SOs 1, 3, 4, 5 'piggyback' on the BAS passage-leg cruises of the *James Clark Ross* to the Antarctic; SO 3 conducts some of its work aboard Canadian ships; and SOs 11, 13, 15 deploy instruments aboard ships of opportunity.

Note that SOs 3, 4, 10, 11, 14 introduce new technology through a link to Theme 8, and that all SOs provide their data to BODC (NF1).

Science collaborations

The SOs have wide collaborative links with national and international universities, through participation in national and international programmes, and with national and international institutes and government (and non-government) organisations. This is shown by the very wide range of programmes the SOs contribute to – from global (eg. GCOS, JCOMM), through regional (eg. EuroGoos/NOOS, EurOceans, MarBEF) to national (MECN, MARG).

Main links and collaborations between Theme 10 and outside Oceans 2025 are as follows:

UK universities	Aberdeen, Bangor, Cambridge, East Anglia, Edge Hill, Hull, Lancaster, Leicester, Liverpool, Newcastle, Plymouth, Reading, Southampton, Warwick
Other UK groups	BAS, CCW, DARDNI, Defra/Cefas, EA, EN/NE, JNCC, Met Office, NCOF, RSDAS, SEERAD/FRS, SEPA, SNH
Overseas universities	Bergen, Bremen, Kiel (IFM-GEOMAR,Germany), Tech Univ Delft (Netherlands), ICCM (Spain), Hawaii, San Diego, Washington (USA), Univ Centre on Svalbard,
Other overseas research groups and organisations	Canadian Dept of Fisheries, ICES, ICOADS, ICSU, IFREMER (France), IOC, Inst Microbiol (Czech Republic), Irish Marine Institute, FAGS, GECC, Lab d'Oceanographique Villefranche, NASA, NOAA, Norwegian Polar Inst, Environment Canada, WHOI, WMO
UK programmes	CASIX, DASSH, MarLIN, MarQuest, MECN, RAPID (RAPID 2), UK GOOS, UK SOLAS
International programmes	ANIMATE, Argo, ASOF, CarboOcean, CAVASOO, CLIVAR, Diversitas, EurOceans, GCOS, GEOSS, GODAE (through GHRSST-PP), GOOS, GLOSS, IGBP, IMBER, IPCC, MarBEF,MERSEA, MarClim, NOOS, SCOR, SOLAS, WCRP

Theme-wide stakeholder relevance and Knowledge Transfer activities

Examples of stakeholder links for the ocean cluster of SOs include:

- Ocean measurements contribute to international programmes such as the Global Climate

Observing System, GCOS (co-sponsored by WMO, IOC, Unesco, UNEP and ICSU); projects under IGBP and SCOR (e.g. SOLAS and IMBER); also GECC, JCOMM and Argo

- Global sea level data makes a major contribution to IPCC assessments
- North Atlantic hydrography contributes to the ICES annual climate statement
- Data are used directly by European projects MERSEA, CarbOcean, ANIMATE
- Ocean measurements contribute to national programmes such as RAPID-2, QUEST, UK SOLAS and CASIX
- The data will be used by the Met Office / Hadley Centre and NCOF for climate studies; by Defra for environmental statistics and marine status reports (e.g.*Charting Progress*), and also a key UK contribution to the Global Marine Assessment.

Examples of stakeholder links for the coastal cluster of SOs include:

- Many of the climatological datasets, once integrated, will be directly relevant to the UK Meteorological Office/Hadley Centre and the National Centre for Ocean Forecasting (for comparisons with *in situ*, EO and model data); also Intergovernmental Oceanographic Commission (IOC) for climate change research and coastal impact studies.
- As an operational system, underpinned by web-based technology, the SOs will have direct relevance to the Inter-Agency Committee on Marine Science and Technology (IACMST). They will be an integral part of the MECN, to detect and predict environmental change and regional seas status reporting, and deliver information to policy end users.
- High relevance to Defra/Cefas, SEERAD/FRS, DARDNI and the EA; for example, during pollution events enabling a quantitative assessment of its impact and possible mitigation strategies; identification of undesirable disturbance, relevant to aggregate extraction/dredging, flood warning systems, tsunami threat and instrumental warning systems, coastal defence and managed retreat; UK Marine Monitoring Strategy in context of EU Water Framework Directive, EU Habitats Directive and EU Marine Strategy.
- The observations will also have interest for English Nature (EN/NE), Countryside Commission for Wales (CCW), Scottish Natural Heritage (SNH) and the Joint Nature Conservation Committee (JNCC) in the context of environmental stewardship
- In Scotland, many of the datasets have relevance to the Scottish Coastal Forum, Hebridean Whale and Dolphin Trust, Scottish Quality Salmon, Scottish Tourist Board, and Fisheries Research Services (FRS).
- The biological observations gathered will have direct relevance to the National Biodiversity Network (NBN) and Census of Marine Life, will be distributed via the NBN gateway.
- UK Local Authorities (flood risks, water quality, coastal erosion).
- UK contribution to the Arctic observational capacity during International Polar Year.

Stakeholder links for SO 14 and SO 15 are summarised in those sections of this proposal

Strategic Ocean Funding Initiative (SOFI)

The SOs provide many opportunities for collaborative activities and research studentships, several of which are identified in the sectional text (and providing links to the science Themes). As an example of their track record in this area, SO 1 (AMT) has to date resulted in 68 PhD degrees.

Schedule 2007-12

The Table below summarises main activities and consolidated fieldwork

SO	Activity	Consolidated fieldwork
1	*James Clark Ross* cruise programme	8 cruises (16 days /year) of the passage leg of JCR (UK to Falkland Islands)
2	annual cruise; continuous measurement	20 days /year

3	cruise programme; continuous measurement	40 days 2009
4	annual cruise	18 days /year
5	continuous measurement, processing and analysis	Not applicable
6	JCR cruise programme; continuous measurement	4 days / year on JCR
7	JCR cruise programme; continuous measurement; installation of new gauges	1-2 days /year on JCR
9	continuous processing and analysis	Not applicable
10	weekly / bi-weekly cruises; continuous measurement; bi-annual benthic survey	30 days /year on *RV Quest*
11	monthly (summer) / six-weekly (winter) cruises/surveys; continuous measurement; continuous model outputs	30 days/year RV *Prince Madog*; 10 days Liverpool Univ vessel
13	continuous measurement	JCR in 2007 and 2009, SOO in other years
14	annual surveys; some continuous monitoring	Not applicable
15	SOO; continuous measurement	SOO; continuous measurement

Summary of SO deliverables

SO 1 Timeseries of spatially extensive and internally consistent observations on the structure and biogeochemical properties of planktonic species in the Atlantic Ocean

SO 2 Real-time timeseries from the top 1000m of the water column; deep water downward particle flux; characteristics of epibenthic and infauna

SO 3 Cost effective monitoring system for the MOC; real-time index of the MOC

SO 4 Annual survey data; description of the evolution of the hydrographic field of the north east Atlantic over the last 35 years

SO 5 Calibrated UK float data to the Argo Data Centres; improved float trajectory algorithms

SO 6 Timeseries of ACC volume, heat and salt transport and physical properties at the Drake Passage

SO 7 Real-time timeseries of sea level at GLOSS sites; wave data, atmospheric and geodetic data at selected sites

SO 9 Climate-quality surface marine datasets and gridded data products from *in situ* and satellite data

SO 10 Operational western channel observatory; reprocessed archive of EO data; operational ecosystem model

SO 11 Operational eastern Irish Sea observatory; continuous measurements and model products; system forecasts with error analyses; component optimisation

SO 13 Timeseries of physical, biological and geochemical data

SO 14 Size and status of harbour and grey seal populations; impact on marine bio-resources; assessment of value for marine spatial planning

SO 15 Timeseries of planktonic species along ship tracks in shelf seas and ocean; analysis of species composition; monitoring of invasive species; monitoring of climate change.

In addition, Theme 10 will deliver:

- efficiencies and advances through shared technology
- all data securely transferred to BODC via technology such as web-enabled GIS
- a single website, linked to all Centre websites, from which information, latest news, latest data and archived data are accessible (with some caveats) to scientists and the general public
- where appropriate, integrations of the different SO datasets to provide enhanced analysis value to the other Themes
- an integrated coastal observatory network for UK coastal waters, incorporating non-NERC observatories and drawing on the NERC-funded International Opportunities ICOS project (run by POL) to facilitate good practice worldwide.

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Acronyms for all sections of this document

ac9 Instrument to measure absorption (a) and attenuation (c) at nine wavelengths
ACC Antarctic Circumpolar Current
ADCP Acoustic Doppler Current Profiler
ANIMATE Atlantic Network of Interdisciplinary Moorings and Time-series for Europe
AOP Apparent Optical Properties
ARSF (NERC) Airborne Research and Survey Facility
AUV autonomous underwater vehicle
AVHRR Airborne Very High Resolution Radiometer
BAS British Antarctic Survey
bb6 Instrument to measure backscatter (bb) at six wave-lengths
BODC British Oceanographic Data Centre
BPR Bottom Pressure Recorder
BWD Bathing Water Directive
CAD Computer aided design
CarboOcean Marine carbon sources and sinks assessment (EU)
CASIX Centre for Air Sea Interactions and Fluxes
CAVASOO Carbon variability studies by ships of opportunity (EU)
CCLRC Council for the Central Laboratory of the Research Councils
CCW Countryside Commission for Wales
CDOM Coloured dissolved organic matter
Cefas Centre of Environmental, Fisheries and Aquaculture Sciences
CEH Centre for Ecology and Hydrology
CLIVAR Climate Variability Experiment
CODA Cetacean Offshore Distribution and Abundance
CPR Continuous Plankton Recorder
CREEM Centre for Research into Ecological and Environmental Modelling, University of St Andrews.
CTD Conductivity, Temperature and Depth
DARC Data Assimilation Research Centre
DARDNI Department of Agriculture and Rural Development in N Ireland
DASSH Data Archive for Seabed Species and Habitata
Defra Department of Environment, Food & Rural Affairs
DMS Dimethylsulphide
DFO Canadian Department of Fisheries
DOM Dissolved organic Matter
DTI Department of Trade & Industry
EA Environment Agency
ECN Environmental Change Network
EN/NE English Nature (changing to Natural England)
EO Earth Observation (satellite remote sensing)
ERSEM European Regional Seas Ecosystem Model
ECMWF European Centre for Medium range Weather Forecasts
ESA European Space Agency
ESRL NOAA Earth System Research Laboratory
EU European Union
EurOceans EU network for Ocean Ecosystems Analysis
EuroGOOS European GOOS
FEC Full Economic Cost
FlowCam Flow cytometer + imaging camera
FMR Field metabolic rate
FOAM-HADoCC Forecast Ocean Assimilation Model – Hadley Centre Ocean Carbon Cycle
FRRF Fast Repetition Rate Fluorometer
FTE Full Time Equivalent
FRS Fisheries Research Services
GCOS Global Climate Observing System
GECC Global Environment Change Committee
GEOSS Global Earth Observation System of Systems
GIS Geographical Information Systems
GLOBEC Global Ocean Ecosystem Dynamics
GLOSS Global Sea Level Observing System
GMES Global Monitoring for Environment and Security
GODAE Global Ocean Data Assimilation Experiment
GOOS Global Ocean Observing system
GPS Global Positioning System
GHRSTT-PP Global High Resolution Sea Surface Temperature – Pilot Project
HEFC Higher Education Funding Council
HEI Higher Education Institute (= UK University)
HF High Frequency
HPLC High Precision Liquid Chromatography
IACMST Inter-Agency Committee for Marine Science and Technology
ICES International Council for the Exploration of the Seas
ICOADS International Comprehensive Ocean-Atmosphere Dataset
ICSU International Council for Science
IDP International Drilling Program
IFREMER French Research Institute for Exploitation of the Sea
IGBP International Geosphere Biosphere Programme
IMBER Integrated Marine Biogeochemical Ecosystem Research
IOC Intergovernmental Oceanographic Commission
IPCC Intergovernmental Panel on Climate Change
IPY International Polar Year
JCOMM Joint Technical Commission for Oceanography and Marine Meteorology (of WMO and IOC)
JCR RRS *James Clark Ross*
JGOFS Joint Global Ocean Flux Study
JNCC Joint Nature Conservancy Committee
KT Knowledge Transfer
LiZa Optical plankton counter
LME Large Marine Ecosystem initiatives
MarBEF Marine Biodiversity and Ecosystem Functioning 9EU network0
MarClim Marine Biodiversity and Climate Change programme
MARG UK Defra Marine Assessment and Reporting Group
MDHC Mersey Dock and Harbour Company
MECN Marine Environmental Change Network
MERIS Medium Resolution Imaging Spectrometer
MERSEA Marine Environment and Regional Security for the European Area
MI Marine Institute, Ireland
MIMS Membrane inlet mass spectrometer
MOC Meridional Overturning Circulation
MOD Ministry of Defence
MODIS Moderate Resolution Imaging Spectrometer
MOEN Meridional overturning exchange with the Nordic Seas

MRCS Medium Resolution Continental Shelf Model (UK Met Office)
MYRTLE Multi-Year Return Tidal Level Equipment (POL's long period BPR)
NASA National Aeronautics and Space Administration
NBN National Biodiversity Network
NCAR National Center for Atmospheric Research
NCOF National Centre for Ocean Forecasting
NERC Natural Environment Research Council
NOAA National Oceanic and Atmospheric Administration
NOC National Oceanography Centre, Southampton
NOG Northern Oligotrophic Gyre
NPP NPOESS Preparatory Program
NPOESS National Polar-orbiting Operational Environmental Satellite System
NRT Near Real Time
NSF National Science Foundation
ODAS Offshore Data Acquisition System
ODON Optimal Design of Observing Networks
OSE Observing System Experiments
OSSE Observing System Simulation Experiments
OSPAR Olso-Paris Convention
PABS Particulate Absorption
PAP Porcupine Abbysal Plain
PAR Photosynthetically Available Radiation
PML Plymouth Marine Laboratory
POC Particulate Organic Carbon
POGO Partnership for Observation of the Global Oceans
POL Proudman Oceanographic Laboratory
POLCOMS POL Coastal Ocean Modelling System
POM Particulate organic matter
PP Primary production
PSMSL Permanent Service for Mean Sea Level
QFASA quantitative fatty acid signature analysis
QUEST Quantifying and Understanding the Earth System
RAPID NERC directed programme on Rapid Climate Change
REGNS Regional Ecosystem Study Group for the North Sea
RSDAS Remote Sensing Data Analysis Service
SACS Special Areas of Conservation
SAHFOS Sir Alister Hardy Foundation for Ocean Science
SAMS Scottish Association for Marine Science
SCANS Small cetacean abundance in the North Sea
SCOR Scientific Council for Oceanographic Research
SCOS Special Committee on Seals
SEERAD Scottish Executive Environment & Rural Affairs Department
SEPA Scottish Environmental Protection Agency
SENTINEL 3 The ESA mission to support marine aspects of GMES
SHRIMP Seabed High Resolution IMaging Platform
SMRU Sea Mammal Research Unit
SOES School of Ocean and Earth Sciences
SOFI Strategic Ocean Funding Initiative
SOG Southern Oligotrophic Gyre
SOLAS Surface Ocean Lower Atmosphere Study
SMOS Soil Moisture and Salinity
SMRU Sea Mammal Research Unit
SNH Scottish Natural Heritage
SOC Southampton Oceanography Centre
SOO Ships of Opportunity
SOS Satellite Observing Systems Ltd
SPCT Swire Pacific Charitable Trust
SPM Suspended Particulate Matter
SST Sea Surface Temperature
SSTL Surrey Satellite technology Ltd
THC Thermohaline Circulation
TSM Total Suspended Matter
TUD Technische Universteit Delft
UEA University of East Anglia
UHI Millennium Institute of the Highlands and Islands
UKORS UK Ocean Research Services
UKMMS UK Marine Monitoring Strategy
UNIDO United Nations Industrial Development Organization
UNEP United Nations Environment Programme
Unesco United Nations Educational, Scientific and Cultural Organization
UWWD Urban Waste Water Directive
VM-ADCP Vessel mounted ADCP
VSF Instrument to measure the Volume Scattering Function
WAM Wave Model
WAVE Western Atlantic Variability Experiment
WCRP World Climate Research Programme
WFD Water Framework Directive
WHOI Woods Hole Oceanographic Institution
WinCPR PC Windows based CPR data viewer
WMO World Meteorological Organisation