National Oceanography Centre

NATIONAL MARINE FACILITIES TECHNOLOGY ROADMAP

2023/24

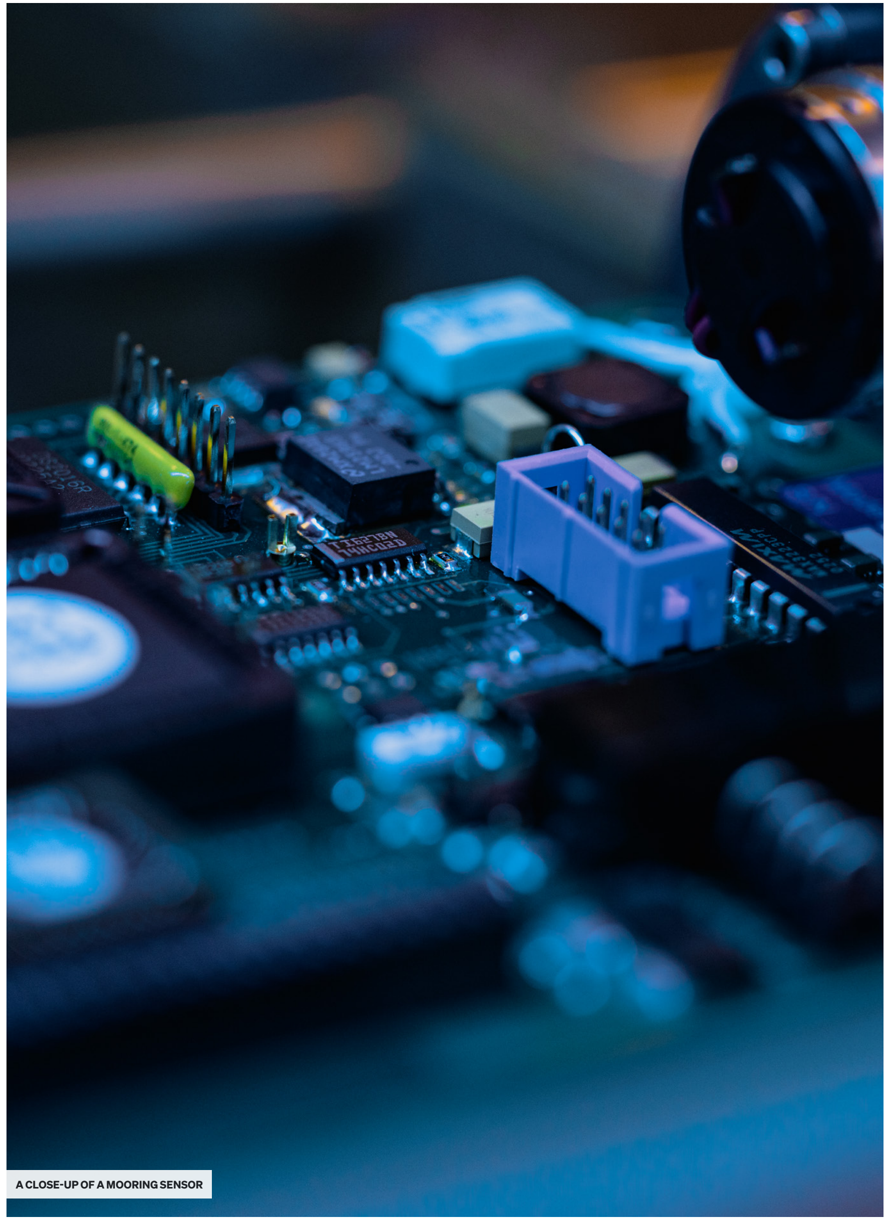
AUTOSUB LONG RANGE (ALR) BEING PREPARED ONBOARD RRS DISCOVERY

EXECUTIVE SUMMARY

The National Marine Facilities (NMF) Technology Roadmap 2023/24 provides information regards how NMF intends developing the National Marine Equipment Pool (NMEP), including ship fitted instrumentation, and associated supporting infrastructure over the coming years. It tries to explain how these capabilities support NERC's commissioning of the National Capability (Large Research Infrastructure), applicable marine science as well as feed into the broader goals of an integrated observing system and how the data gathered can support the Global Ocean Observing Systems (GOOS) and its constituent parts.

The 2023 refresh of the roadmap takes some of the Future Marine Research Infrastructure (FMRI) (formerly Net Zero Oceanographic Capability (NZOC)) report recommendations and starts to consider how they might be implemented over the next 5 years. For this document and on the timescales considered herein, the key recommendations cover the better integration of data flows, further development of autonomous platforms and the scaling up of that capacity and improvements to the research ships so that they deliver more science bang for their carbon buck.

In the background, work continues to assess how we recruit, train and retain sufficient suitably qualified and experienced personnel to develop, maintain and operate the National Marine Equipment Pool (NMEP).


A CLOSE-UP OF A MOORING SENSOR

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INTRODUCTION

NATIONAL MARINE FACILITIES

The aim of National Marine Facilities (NMF), part of the National Oceanography Centre (NOC)[01], is to develop, co-ordinate and provide major platforms, observing systems and technical expertise to support the UK's marine science community. Part of this national capability is the National Marine Equipment Pool (NMEP)[02]; a collection of over 10,000 items available for deployment both from, and independent of, research vessels.

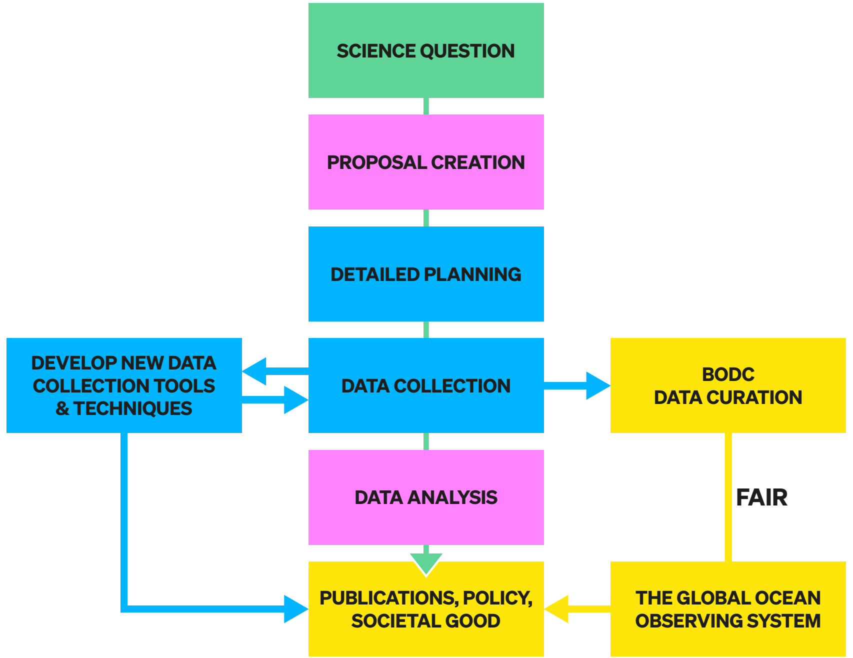
HOW NMF ENGAGES WITH THE UK MARINE SCIENCE COMMUNITY

The NMF team engages formally with the UK marine science community via the Marine Facilities Advisory Board (MFAB)[03]. This is the key forum through which the community can discuss topics and raise, for example, the need for new capabilities for inclusion in the NMEP. In addition, feedback and enquiries are welcome at any time through nmfops@noc.ac.uk.

THE NMF TECHNOLOGY ROADMAP

Against a backdrop of tight budgets, rapid technical development, the increasing use of Marine Autonomous Systems (MAS) and now Future Marine Research Infrastructure (FMRI) (formerly Net Zero Oceanographic Capability (NZOC)), NMF is committed to delivering the best possible support and value for money to the UK science community and to support the UK Marine Science Strategy[04]. Working closely with the BODC, NMF supports GO-SHIP, Argo, RAPID, Ellet and OSNAP programmes which have significant potential impact for international ocean observation activities such as the Global Ocean Observing System (GOOS)[05] and the United Nations Decade of Ocean Science for Sustainable Development[06].

01 https://www.noc.ac.uk
02 https://www.noc.ac.uk/facilities/national-marine-equipment-pool
03 https://www.noc.ac.uk/about-us/our-national-role/advisory-bodies
04 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/183310/mscc-strategy.pdf



NMF was commissioned by the NERC in 2018 to operate the RRS *James Cook* and the RRS *Discovery*[07], the NMEP and the associated infrastructure. NMF receives additional capital funding from NERC to replace, refurbish, upgrade and further develop the ship fitted scientific equipment and NMEP. NMF reviews feedback from multiple stakeholders as well as considering technology developments associated with current capabilities to ensure its strategy for replacement, upgrade and development is evidence based. In addition, MFAB provides advice to NMF with regards to its strategy for the equipment portfolio it operates and provides guidance regarding new and emerging requirements.

05 https://www.goosocean.org/
06 https://en.unesco.org/ocean-decade
07 https://www.noc.ac.uk/facilities/ships

Within the five-year horizon of this roadmap, research vessels will continue to be the primary means of enabling data collection and physical sampling. They will also continue to deploy, recover and service autonomous instruments such as moorings as well as more often deploying and recovering MAS such as floats, gliders and Autonomous Underwater Vehicles (AUVs). However, the growing focus on supporting a sustainable future for our planet will require those assets which have large carbon footprints to maximise their impact per tonne of carbon whilst transitioning to a Net Zero capability. The recent FMRI (formerly Net Zero Oceanographic Capability (NZOC)) report provided recommendations to NERC regards this objective. The importance of data management within the NMF Technology Roadmap is highlighted by both goal four of the NOC strategy[08], and the focus on data themes at OceanObs'19 which resulted in the conference statements[09]:

"Ensure that all elements of the observing system are interoperable, and that data are managed wisely, guided by open data policies and that data are shared in a timely manner".

"Use best practices, standards, formats, vocabularies, and the highest ethics in the collection and use of ocean data".

In recent years, BODC and NMF have worked closely under the Oceanids C2 programme[10] and on the delivery of routine observations from ship-mounted sensor arrays. There is a strong desire to build on these links to address further gaps in capability and integration. Hence, this Technology Roadmap includes a section on data management and practices that will evolve and develop further in future iterations of and as the new NOC Digital Ocean Technology Roadmap forms in coming years.

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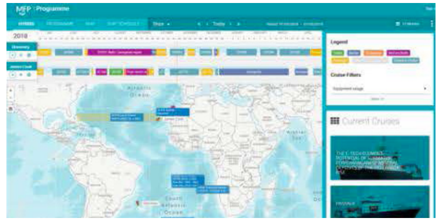
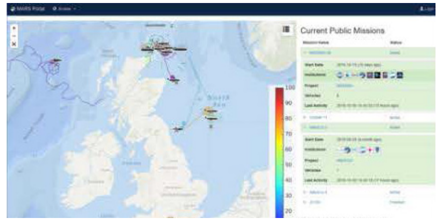
09 file:///M:/BODC_DOC/Temp/NMF Technology Roadmap FY2021.docx#_ftn2
10 https://noc-events.co.uk/sites/conference.noc.ac.uk/files/documents/MATS2019_JBuck.pdf

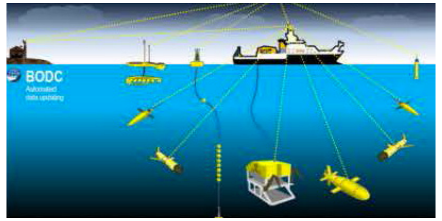


PLANNING



REAL TIME CONTROL

(NEAR) REAL-TIME DATA DISPLAY



DATA ARCHIVE

THE NMF WORKFLOW AND A VISION FOR SCIENCE INTERACTION

A simplified vision of how NMF supports the marine science community is shown in the figure below. The core areas are dark blue with the lower engagement areas shown in progressively lighter blues. NMF's objective is to streamline this workflow so that we can effectively support the UK Marine Science community.

As NMF continues to optimise this workflow it is working towards a vision of four 'screens' that allow scientists and engineers to interact with the planning, data collection and data curation phases. These 'screens', as illustrated below, will be linked to allow data to flow between systems and will act as a hub for information about the research activity. These 'screens' will be underpinned by a set of processes and procedures which will support the data flows and will evolve over time. The intent is to automate and streamline these processes to maximise the benefit to the community. The IODE Ocean Best Practice System (OBPS)[11] has become the repository for documentation and dissemination of processes and procedures used form collection to dissemination of marine data. Alignment to the OBPS would ensure NMF alignment with the marine community.

PLANNING

This 'screen' will capture the planning phase for both ship and autonomous platform deployments. This capability will be built on the existing Marine Facilities Planning

11 https://www.frontiersin.org/articles/10.3389/fmars.2019.00277/full

website. It is envisaged that the planning phase meta-data will flow to the Real Time Control, Real Time Display and Data Archive systems. Data management planning needs to be included throughout the workflow.

REAL TIME CONTROL

Once a system is deployed the real time control system will provide the interface to monitor and control it. This will be built on the existing Command and Control (C2) infrastructure being developed under the Oceanids programme. It is envisaged to encompass the long-range fleet operations, the ROV virtual control room concept, and other deployed but controllable assets such as CTDs and moorings.

(NEAR) REAL-TIME DATA DISPLAY

Closely aligned with the Real Time Control system, will be a more public facing portal that will allow visualization of the science data, but will not provide any control functionality to the deployed system. The degree to which the data will be open to public access will be adjustable, from fully open (all data available on the public portal) to fully restricted (data only available to the science team).

DATA ARCHIVE

The Data Archive 'screen' would allow access to previously collected near real time data and the delayed mode data as per the Findable, Accessible, Interoperable and Reusable (FAIR) data principles. This would be developed based on the BODC infrastructure. When developing FAIR services we need to be conscious that implementations of FAIR vary by community (e.g. oceanography vs. biodiversity) and ensure that we meet the specific implementation requirements of each community.

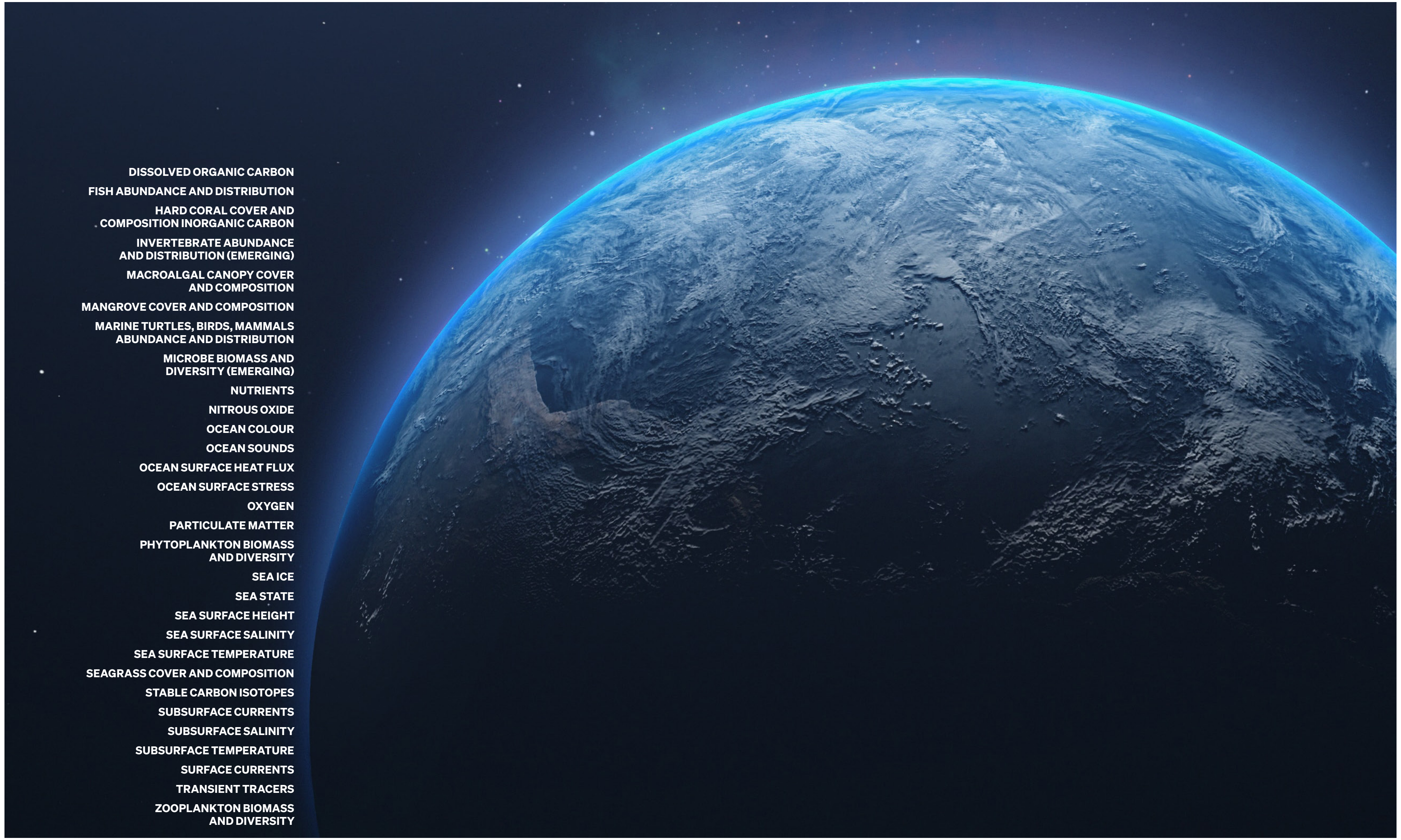
ESSENTIAL OCEAN VARIABLES AND THE GLOBAL OCEAN OBSERVING SYSTEM

NMF and BODC are focused on ensuring that the data that we collect follows the FAIR data principles and can be easily ingested into the Global Ocean Observing System (GOOS). As part of this focus the Technology Roadmap attempts to map the NMEP capabilities to the Essential Ocean Variables (EOVs) as shown below. It is appreciated that although some of these EOV are mature, NMF / NOC also have a much broader capability including less mature and niche parameters not listed as EOVs.

DOCUMENT STRUCTURE

This Technology Roadmap is updated annually to reflect the ambitions of NMF to meet its remit. The main body of Technology Roadmap details the influences, and short to long term plans and aspirations for each capability. For ease of reference, all current capabilities are listed in the Annex. Each capability is presented sequentially with the following categories:

- **Essential Ocean Variables**. Describes how the capability maps onto the GOOS EOVs.
- **Science Community Drivers.** An overview of the science and operational pulls requiring process and technology developments.
- **Future Capability.** Developments that are planned and have associated funding in place.
- **Aspirations.** Potential future capabilities for which funding will be sought. It covers all ship-fitted equipment, ship deployed equipment, autonomous stationary equipment and MAS operated by NMF. The developments in a lot of areas are carried out alongside the cruise programme, thus it is not always possible to provide timelines for the delivery of the new capability as it will depend on the cruise programme. Where possible timelines for the new capabilities are given.



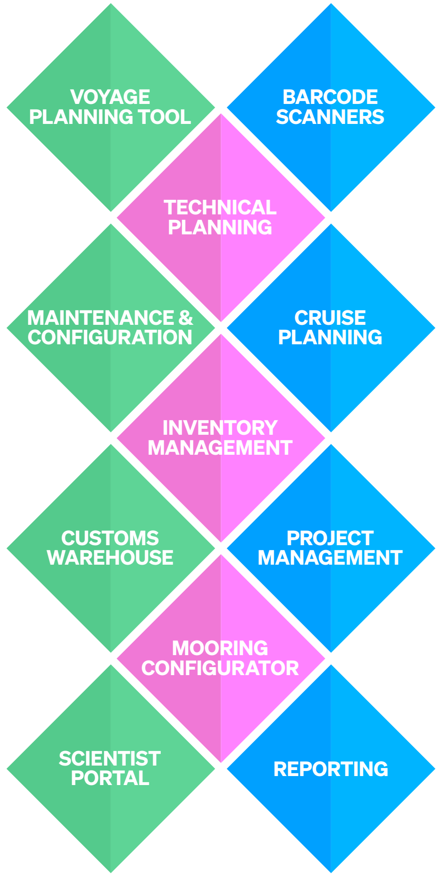
MARINE FACILITIES PLANNING PORTAL (MFP)

SCIENCE COMMUNITY DRIVERS

- **Simplify use.** It is desirable to continue to simplify access to the system and improve the user experience when using the MFP.
- **Increase visibility of equipment capabilities.** At present when requesting equipment, the applicant is presumed to know the capabilities and limitations of the equipment in the NMEP. The visibility of equipment specifications, measurement ranges and limitations, and alternative equipment would provide applicants with the information to request the most appropriate equipment for their objective.
- Extension to Cruise Planning and autonomous platform planning modules to provide ability to generate a draft Data Management Plan (DMP), that can be modified to include non-NMF generated data, held in the MFP and exported to BODC.
- **Q&A.** It is desirable to have a function within the Ship-time and Marine Equipment (SME) application form where questions can be asked to assist equipment selection.

FUTURE CAPABILITY

- **Personnel Capabilities.** The module at present is used to record training and qualification of skills to operate equipment at sea. In the coming months this will be further expanded to include other training that supports NMF operations, such as workshop machinery training for example.



ASPIRATIONS

- The MFP is used as the primary tool for planning and recording NMF activities across all modules. As such, it contains information that can be used to inform improvement initiatives for these activities. At present most of this information can only be extracted manually which is labour intensive and inefficient. The development of a reporting module would allow this information to be accessed quickly and afford more time for improvements to be made.
- Understanding the capacity in terms of availability of personnel is essential in planning activities for a given period. Within the personnel planning module the assigned sea days can be viewed, however this is not combined with allocated maintenance activities in the planned maintenance system, or any planned absences from UNIT4 (NOC business management system). The ability to view all planned activities for an individual and group in one system would give better visibility of spare capacity, and consequently better risk awareness across a group.
- Integration with other systems. To maximise the benefits of the four-screen approach outlined above the MFP should be integrated with the C2 and Data flows to BODC, as noted in sections 3 and 16. Further integration into the NOC finance system will further streamline workflows reducing the operational costs of managing the system.

DATA MANAGEMENT AND PRACTICES

SCIENCE COMMUNITY DRIVERS

- Topic 1 from the MFAB-directed Data Working Group: Easy access to science data on board research vessels.
- Key papers published on FAIR data principles[12] and Ocean Best Practices[13].
- Recommendations from OceanObs'19 and Research Data Alliance for integrated scientific data workflows[14].
- UN's Decade of Ocean Science for Sustainable Development and Sustainable Development Goal #14.
- NERC Digital Environment strategic goal.
- G7 priorities of net-Zero oceanographic capability and development of digital twins.

FUTURE CAPABILITY

- Introduce data management planning and resourcing for autonomous platforms into the MFP process to facilitate integrated end-to-end data management.
- Develop more scalable glider and autonomous platform data processing and delivery.
- Introduce common metadata, standardised data formats, and open source data processing applications to improve access to science data across NERC research vessels.
- Introduce common metadata standards to event logging systems to unambiguously put scientific data into context.
- Some metadata and other information required to process the cruise data is held within the cruise report and must manually extracted by BODC. Where possible NMF will amend how the data is recorded and then used to generate the cruise report, to allow auto-ingestion by BODC.
- Facilitate open data sharing and integration with other sensor networks through enabling Application Programming Interfaces (e.g. National Oceanic and Atmospheric Administration (NOAA) Environmental Research Divisions Data Access Program (ERDDAP)).

ASPIRATIONS

- Develop delayed mode workflows in Oceanids C2 for autonomous platforms.
- Continuous ocean monitoring from fixed sensor arrays on research vessels, delivering near-real time and delayed-mode data to end-users, making efficient and cost-effective use of research vessel time.
- Management systems to ensure archiving, processing and dissemination of high volume data collected from NMF observing platforms, including underwater noise data and the delivery of quality swath bathymetry to Seabed 2030.
- Facilitate open data sharing and integration with other sensor networks through enabling Application Programming Interfaces (e.g. Sensor Web Enablement, SensorThings Application Programming Interface (API).
- Manage data work flows with persistent identifiers for instruments and standardized controlled vocabularies for metadata related to e.g. instruments, platforms, measurements, units.
- Data management plans and integration with BODC's Cruise Inventory to reduce potential duplication of effort.
- Investigate feeding the metadata currently stored in the Cruise report directly to BODC, to allow auto-ingestion of metadata directly post-cruise.
- Enhancing the quality control, assurance and accessibility of near-real time data streams from observing platforms. This is fundamental to ensuring end-user trust in data and any products generated.
- Integrating cutting-edge technologies (e.g. artificial intelligence and machine learning) to support decision- and policy-making from observing platforms.

12 file:///M:/BODC_DOC/Temp/NMF Technology Roadmap FY2021.docx#_ftn1
13 file:///M:/BODC_DOC/Temp/NMF Technology Roadmap FY2021.docx#_ftn2
14 file:///M:/BODC_DOC/Temp/NMF Technology Roadmap FY2021.docx#_edn1

CONTINUOUS UNDERWAY MONITORING

It is the intent of NMF to establish the technologies, processes and funding model to enable the continuous monitoring of key essential ocean variables and projects such as Seabed 2030.

SCIENCE COMMUNITY DRIVERS

- Maximise the data acquired using the ship fitted SURFMET, MBES, EK80 and ADCP systems on passage. This would present the opportunity to contribute to the transit area geospatial picture, which often falls outside of well surveyed shipping lanes.
- Develop the capability for continuous underway monitoring of air chemistry and high frequency measurements for physics, biogeochemistry and biology.

FUTURE CAPABILITY

- Establish processes for cross calibration of underway sensors

ASPIRATIONS

- Establish processes for continuous sensor operation which both comply with dipclear obligations and provide a defined minimum level of data quality, particularly for periods of passage when a technical party is not embarked.
- Automation of data QC, and transmission and ingestion to BODC of all underway data streams.

RRS JAMES COOK

RRS DISCOVERY

RESEARCH VESSELS

SCIENCE COMMUNITY DRIVERS

- Research expeditions by necessity have a high carbon footprint. Alterations and additions to ship fitted equipment to reduce or offset this as technology develops are necessary to meet the carbon reduction targets for 2025 and 2040.
- More reliable, lower latency, higher bandwidth satellite connectivity to support Near Real Time (NRT) data sharing, and enable better remote engagement from science parties and technical support ashore.
- During seismic operations where two of four acoustic sources are towed in line with the propellers, the stability of the acoustic source is affected by the propeller wash from the ships. Modification to the ship infrastructure to move the twin towed beams outboard of the propeller wash could reduce this interaction and improve the stability of the acoustic source.
- Endurance of grey water storage to allow longer periods between discharge where surveys may need to be paused.

FUTURE CAPABILITY

- At the next review of satellite internet provider for the vessels it is intended to transition to a provider with low earth orbit satellite constellation capability. The high bandwidth, low latency connectivity this would provide would give the infrastructure necessary to support the advancement of projects to achieve the FMRI (formerly Net Zero Oceanographic Capability (NZOC)) goals. Remote participation of technical and scientific parties, as well as broader outreach from expeditions will become much more viable with this advancement.
- In 2023 it is planned to conduct a performance trial of Hydrotreated Vegetable Oil (HVO) fuel onboard RRS *James Cook*. The trial will gather data to be used to demonstrate the environmental benefits of using the fuel and as well as highlight any potential issues under controlled conditions. The outcome of the trial will inform any decision to use HVO across all NERC vessels.
- The IT networks onboard both vessels have been redesigned and will undergo complete replacement in the 2023 refit periods. This is required to comply with the latest IMO cyber security requirements and represents a fundamental shift in capability and complexity. It will necessitate a more robust process for network access and integration of third-party equipment than historically required but will not be a barrier to integration.

ASPIRATIONS

- Investigation into the feasibility of hybrid battery installation to reduce fuel use on station and extend the maximum endurance of the ships.

SEISMICS

SCIENCE COMMUNITY DRIVERS

- **Reduce costs.** Long mobilisation periods are required to assemble and commission equipment taking up valuable ship time. Age, complexity and lack of reliability mean that costly sea trials are often required prior to science to provide equipment assurance and staff training. A containerised, ready- assembled system delivered to the ship with minimal set up time and low maintenance overhead will cut mobilisation periods and require less technical support.

AIRGUN DEPLOYMENT DURING SEISMICS OPERATIONS

- **High performance source.** The aged fleet of bolt 1500-LL airguns and associated compressors do not provide the energy or fidelity of signal to make full use of the NMEP modern multi-channel streamer to deliver high resolution 3D images.
- **Reduce wake interference.** The twin propulsion designs of RRS *James Cook* and RRS *Discovery* produces a much greater wake profile than previous research ships. Airguns are fired while being towed through this aerated water seriously affecting source level and consistency. Modifications to the after deck of both ships would allow sources to be towed much wider from the ship's centreline and reduce this problem.
- **Flexibility.** Bolt 1500-LL airguns can only be reconfigured by changing the entire chamber. Chambers are large, unwieldy and expensive and NMF only holds a limited amount of each size therefore limiting the options for reconfiguring array size at sea. The volume of modern Commercial Off The Shelf (COTS) airguns can be reconfigured quickly by the use of an inexpensive plastic insert giving a Principal Investigator an almost unlimited choice of source configurations.

FUTURE CAPABILITY

- A GI airgun beam deployment system has been developed to allow the safe deployment of the GI airgun suite using beams and will be trialled in 2023.
- Additionally, a number of single points of failure and defects identified during JC215 in the data acquisition and firing systems have been addressed, and the systems will be incorporated into a 20ft control container. This will make mobilisation easier, but also allow the system to be set up permanently for training and maintenance, and give visibility of the operations on deck for greater situational awareness. The first trial and use of the containerised systems are planned for 2023.
- Replacement of the Bolt 1500-LL airguns with Sercel G series guns. Stand-alone RVDAS module integration into the containerised topside suite. Trials provisionally planned for summer 2024.

ASPIRATIONS

Due to the funding requirements for seismic capability upgrades, to do so within NMEP capital funding necessitates an incremental approach, with a programme of smaller projects over five years. This is intended to include:

- First stage of the MCSS extension – up to current winch capacity of 3km extension of the MCSS to 3km
- Replacement of the containerised compressors
- Second stage of the MCSS extension - beyond 3km. This will require replacement of the associated winch system
- Procurement of a Passive Acoustic Monitoring (PAM) system
- This may also include the procurement and integration of a navigation system

As well as equipment upgrades, closer collaboration with BAS, OBIC and OFEG partners to share best practice and build understanding and experience with seismic operations.

SAMPLING

SCIENCE COMMUNITY DRIVERS

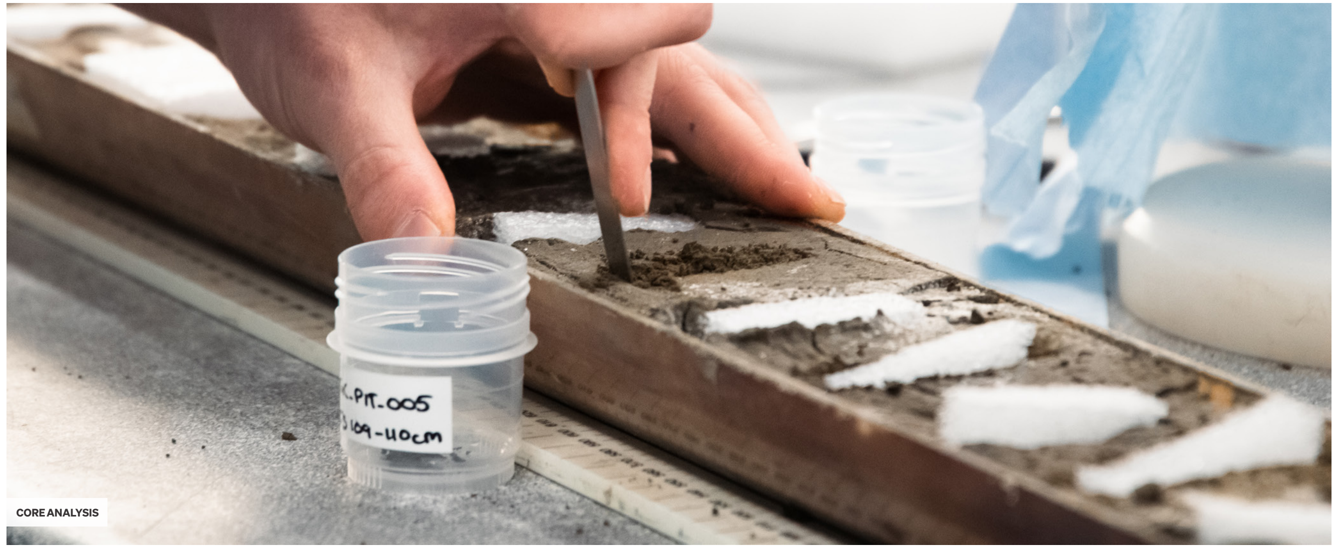
- There is continued demand for trawl capability but with reduced environmental impact and fewer personnel required to meet the FMRI (formerly Net Zero Oceanographic Capability (NZOC)) vision.
- Accuracy of sampling. A lot of time is taken lowering sampling systems with no accurate inspection of the sampling site. Integration of camera systems would be desirable to target sampling to the best possible location.
- Continued need for targeted sampling of geology and biology via remotely operated platforms.
- Availability of Marine Snow Catchers (MSC) to the scientific community, with trace metal free capability.

FUTURE CAPABILITY

- A core splitter is being commissioned to supplement the range of coring capabilities and ensure a safe and consistent core splitting standard for community use.
- A sampling working group with technical and science community representation has been initiated in 2023 to inform development of sampling capabilities.
- After positive review of at the 2019 MFAB capital call, it is intended to bring the marine snow catcher in to the NMEP after the redesign work currently ongoing in the Ocean Technology and Engineering Group (OTEG) to overcome reported safety issues. This model will not be trace metal free.

ASPIRATIONS

- Development of a precision coring system which may potentially involve integration with the ROV. Development to be guided by the newly formed sampling working group.
- Development of a full ocean depth bottom trawl capability that requires fewer personnel to deploy and a reduced environmental impact. Potentially a MOCNESS or RMT capability.
- Recording of sampling metadata through an Event Logger, for direct upload into BODC, to include instrument models and serial numbers.
- Use of BODC vocabularies to accurately label samples taken, along with their units.



CORE ANALYSIS

CROSS PLATFORM DEEP SEA PHOTOGRAPHY

SCIENCE COMMUNITY DRIVERS

- Inclusion of the highest quality camera systems to give maximum resolution of the data collected.
- Taxonomy / Species identification.
- Population Analysis.
- Habitat mapping.

ASPIRATIONS

- A common camera sensor system across multiple platforms, AUV, ROV, Landers with the following characteristics:
    - Decreased training and maintenance overhead.
    - Harmonised / Comparable Photo Data Sets.
    - Fully documented and open instrument design which can be duplicated by other institutions.
    - Lossless RAW data format.
    - Harmonised high-speed flash for capturing fast moving fauna.
    - 6000m full ocean depth rated.
    - Corrosion Resistant for long term deployment.
- Build a larger pool of standardised camera systems, which can be easily mounted on a variety of platforms.
- Develop in house expertise in subsea camera cross calibration.

MOORINGS

MOORINGS

ESSENTIAL OCEAN VARIABLES

- Dissolved organic carbon.
- Inorganic carbon.
- Nutrients.
- Nitrous oxide.
- Ocean colour.
- Ocean surface heat flux.
- Oxygen.
- Particulate Matter.
- Phytoplankton biomass and diversity.
- Sea surface salinity.
- Sea surface temperature.
- Stable carbon isotopes.
- Subsurface currents.
- Subsurface salinity.
- Subsurface temperature.
- Surface currents.
- Transient traces.
- Zooplankton biomass and diversity.

SCIENCE COMMUNITY DRIVERS

- Capability to deploy the next generation of low drift self calibrating bottom pressure landers.
- Improved ability to measure the upper 50m of the water column where ocean / atmosphere interaction is most evident, including in ice covered regions.
- Improved reliability in trawl resistant mounts / landers.
- Better under-ice capability to better observe and understand the seasonally covered ice environment.
- Inclusion and expansion of biogeochemical sensor availability (oxygen, pH, CO_2, nitrate).
- Real-time data telemetry to allow access to environmental conditions to inform up to date key decisions in the NERC science community and our wider stakeholders.
- Wireless communication with autonomous vehicles to enable regular low carbon and low-cost data retrieval.
- The ability to recover moorings weights to better align with the NOC value of environmental responsibility.
- Passive acoustic monitoring.

FUTURE CAPABILITY

- 2x Bathysnap Optical camera moorings capable of 20MP imagery, with a 1 year endurance are under development for inclusion in the NMEP.
- Procurement of 2 x Pinnacle 45kHz ADCPs.

ASPIRATIONS

- Investigate the benefits and feasibility of the development of in situ moored power sources to enable recharging of AUVs and prolong their deployment duration.
- Provide standardised protocols for automated delivery and display of near real-time data, utilising capabilities of ERDDAP.
- Design and implement a standardised workflow for camera systems to allow archive of raw data, with essential metadata, and allow archive and FAIR access to processed products from these systems.
- Investigate methods to extend the duration of long-duration deep water mooring deployments.

CONDUCTIVITY, TEMPERATURE AND DEPTH (CTD) FRAME

CONDUCTIVITY, TEMPERATURE AND DEPTH (CTD) FRAME OPERATIONS

ESSENTIAL OCEAN VARIABLES

- Dissolved organic carbon.
- Inorganic carbon.
- Nutrients.
- Nitrous oxide.
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- Sea surface temperature.
- Stable carbon isotopes.
- Subsurface currents.
- Subsurface salinity.
- Subsurface temperature.
- Surface currents.
- Transient traces.
- Zooplankton biomass and diversity.

SCIENCE COMMUNITY DRIVERS

- A continued ability to collect samples (including trace metal sampling) and deliver 'standard' data streams from sensors (e.g. T.S. fluorescence, O_2 etc.) will likely remain crucial for at least the next decade. The incorporation of state-of-the-art sensors, or the capability to incorporate state of the art sensors above and beyond the current technology will be a key driver of future developments.
- Active Heave Compensation (AHC) systems are beneficial for reducing artefacts in sensor data, especially in large swells and / or with large CTD rosettes, and require further development to be effective over the full depth range (including the top 100m).
- In situ real time measurements of pCO_2 and pH, high resolution nutrient profiling and fuller optical characterisation of both dissolved and particulate constituents are beginning to become feasible, more widely adopted and will likely facilitate new science in fields such as ocean acidification and the physical and biological components of oceanic carbon cycling. All these areas have relevance to a range of NERC Discovery Science and funded National Capability (NC) / strategic programmes.

FUTURE CAPABILITY

- ADCP serial data stream via the SBE9+ for CTD frame deployments.

ASPIRATIONS

- Develop process and equipment for the testing of novel sensors on the CTD frame without reducing the sensor payload to accommodate the new sensor.
- Recording of sampling metadata through an Event Logger, for direct upload into BODC, to include instrument models and serial numbers.

STATIONARY AND TOWED PROFILING BODY SAMPLING

ESSENTIAL OCEAN VARIABLES

- Dissolved organic carbon.
- Inorganic carbon.
- Nutrients.
- Ocean surface heat flux.
- Oxygen.
- Particulate Matter.
- Phytoplankton biomass and diversity.
- Sea surface salinity.
- Stable carbon isotopes.
- Subsurface currents.
- Subsurface salinity.
- Subsurface temperature.
- Surface currents.
- Transient traces.
- Zooplankton biomass and diversity.

SCIENCE COMMUNITY DRIVERS

- There is a continued requirement for profiling of large-scale areas in short time frames that make CTD sampling frame profiling infeasible. The speed and scale of profiling presented with towed undulators is tempered with a lower sensor resolution than possible with CTD sampling frames. Increased resolution of payload sensors and / or an increase in the number of parameters that can be measured would make these survey types more cost effective.

FUTURE CAPABILITY

- Refurbishment and trial of Scanfish in summer 2023 to restore the capability to a Ready to Go state.

ASPIRATIONS

- Refurbishment and trial of SeaSoar to restore the capability to a Ready to Go state.
- Evaluate the feasibility of using synthetic conducting ropes for the towed vehicle fleet (SeaSoar and Scanfish).
- A new triaxis motion reference unit for integration in to SeaSoar to allow higher resolution data acquisition from the vehicle.
- Develop a current meter for use on the VMP 6000.

ISIS ROV

REMOTELY OPERATED PLATFORMS (ROP)

ESSENTIAL OCEAN VARIABLES

The standard GOOS EOV do not easily map onto the ROV's capabilities as it depends on the vehicle sensor fit and the experiments deployed by the ROV. Example GOOS EOVs which can be collected using the vehicle's standard sensors include:

- Hard coral cover and composition.
- Subsurface temperature.
- Subsurface salinity.

It is also worth noting that a large proportion of the ROVs operations do not translate directly into GOOS EOV, but the Deep Ocean Observing Strategy[15] (DOOS), a UN Decade Action, may highlight new EOVs which are more applicable to the deep diving vehicles.

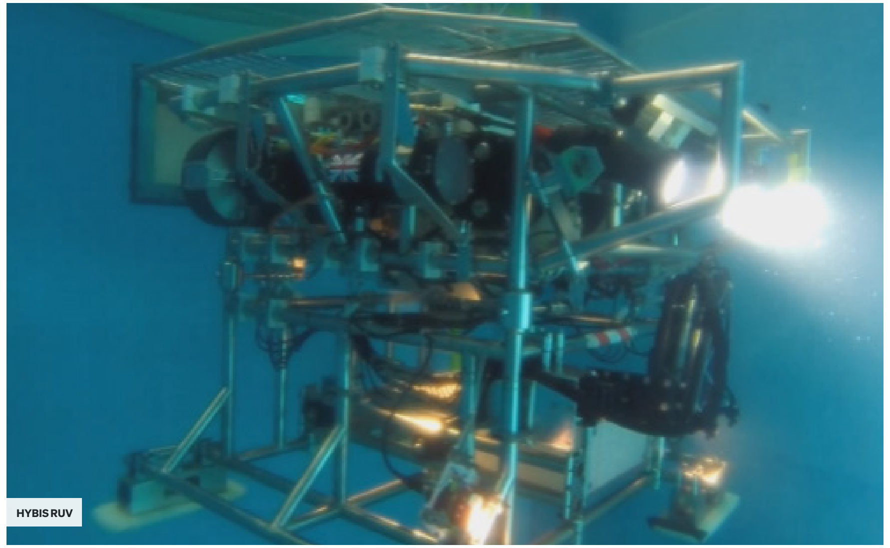
SCIENCE COMMUNITY DRIVERS

- **Increase Operation Audience (science community)** Enhanced scientific interaction. Currently, the number of people who can guide the ROV / HyBIS operations are limited to the people on the cruise. By having the capability live stream video and data feeds from the vessel to institutes, and individuals the number of people who can engage with and potentially guide the vehicle deployments can be increased.
- **Obsolescence management and system upgrades (Isis).** Although Isis has been upgraded significantly over the years not all the systems have been changed. Thus, there is an ongoing need to upgrade systems as they break or become obsolete.
- **Improve the operational reliability of the system (HyBIS).** The existing HyBIS platform, although highly capable, is still immature and has a number of design issues which makes it hard to maintain and operate. These issues need to be addressed to make the system more reliable and operationally effective.

15 deepoceanobserving.org

FUTURE CAPABILITY

- **ROV Control Container Upgrade.** The ROV control containers are now coming to the end of their operational life and will need replacing within the next few years. As part of this replacement, we can upgrade the computing, data recording and video display systems in line with the potential live streaming and virtual control requirement. Additionally, the essential replacement of the Power System (Jetway) will be incorporated into the design. This power system will replace the original unit supplied in 2002, and will incorporate the broader context of power supplies used for the remotely operated platforms.
- **ROV control software upgrades.** The existing ROV software is still based on the early Jason 2 code from the Woods Hole Oceanographic Institution. This code makes interfacing new sensors into the control system difficult. This upgrade will look at modernising the control architecture and will also attempt to reduce the operator load when piloting the ROV.
- **ROV Umbilical Replacement.** The ROV umbilical is now coming to the end of its operational life and will need replacing within the next few years. This replacement will be an opportunity to review the current cable performance and to look at alternative options to facilitate better operational output. Working with other institutes, we can hopefully establish the best route to pursue. As the ROV umbilical is the same specification as the ones used



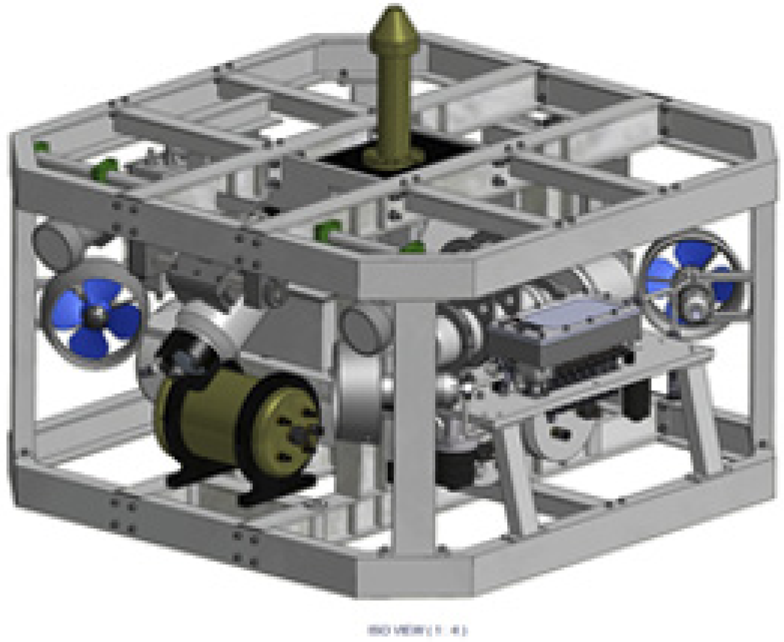
HYBIS RUV

MOJAVE ROV

on both the RRS *James Cook* and the RRS *Discovery* this process will also provide the specification for their umbilical replacements.

- **Launch and Recovery System (LARS) Overhaul and Re-Certification.** The ROV deployment A Frame, Traction Winch, Storage Drum and HPU requires regular maintenance to keep certified and operational. After a significant period of use, the usual routine maintenance is no longer suitable, and the system requires a full strip down, re-paint, re-build and testing at the manufacturers facility. (Dynacon USA). It is anticipated that following the 2023/24 programme that this overhaul could be necessary and will be reviewed at the time.
- **ROV Vibrocorer System.** As an addition to the ROV sampling capabilities the Vibrocorer would be a bolt on system that would fully utilise the vehicles hydraulic and communications systems. As a relatively inexpensive build this unit would increase the ROV capability providing an additional platform that science can request. A prototype and trails have already been carried out, along with most of the design work complete.
- **Modular Payload Underwater Systems (HyBIS) command module upgrade (Phase 1).** The existing HyBIS command module is unreliable, expensive to maintain and has limited upgradeability. To enhance the capability of the system a new command module is being developed. This will include both the physical hardware and the associated control software and will significantly enhance the capability of the system. Due to the complete redesign of the module, the system has been renamed the Modular Platform Underwater System (MPUS).

- **MPUS (HyBIS) recovery payload module.** There are times when equipment is lost at sea, e.g. CTD sampling frames, landers, and AUVs. Generally, it is possible to approximately locate the equipment, but there is usually no capability to recover the items. Under these circumstances either a highly expensive rescue mission is required, or the equipment is written off. A suitably configured MPUS recovery module could be used to recover the lost equipment at minimal cost. Such a module could also be used for the recovery of landers in highly fished areas.
- **Common interface module.** Part of MPUS's flexibility is the ability to integrate different sensor payloads onto a mission specific payload module. Currently this involves considerable input from the ROV team which is costly. To simplify this process a generic payload module is being built with the associated detailed interface document. This will be produced to enable custom payload designs to be created by external users.
- **MPUS Topside Container (Phase 2).** As part of the MPUS vehicle, a new power system is being built into a container to enable easy integration of the High Voltage (HV) requirements onto any vessel. This container will be purpose built to meet all HV safety requirements, whilst allowing all spares, vehicle and modules to be shipped / stored safely in one container. This new power system (Jetway) has been specified to meet the requirements of the ROV system replacement, so that we have commonality across systems.
- **NOC Camera System Integration.** The still camera and flash system being developed for Bathysnap and Autosub 5 will be integrated into the HyBIS / MPUS platforms. This will provide a standard stills camera capability across multiple MARS platforms and will simplify spares and data management.
- **Image / Video Data Management.** We will work with BODC to ensure that the image and video data is made readily accessible to the community and is suitable for ingestion into platforms like Squidle[16], FathomNet[17], etc.



MPUS

ASPIRATIONS

- **Improved camera systems.** The existing camera systems used on the ROV and HyBIS / MPUS use HD sensors. However, camera technology is advancing rapidly and the availability of 4K cameras is increasing. We will continue to monitor the technology changes to assess the optimal time to upgrade the systems.
- **Enable real time image annotation.** The increase in image processing capabilities is enabling automated image classification during the data collection phase. We will look to work with the broader community to provide the computer capability to enable these image processing systems to be deployed on the ROV systems.
- **New MPUS modules.** Create new payload modules and refine the concept of operations for MPUS. There are likely to be other MPUS modules which would significantly benefit the science community, and new modes of operation which can be exploited. The aspiration is to work with the science community to explore and develop these modules and modes of operations as and when resources and science priorities allow.

16 www.squidle.org
17 fathomnet.org/fathomnet/#/

AUTOSUB 5 ONBOARD
RRS DISCOVERY

HIGH POWER MARINE AUTONOMOUS SYSTEMS (MAS)

ESSENTIAL OCEAN VARIABLES

Example EOVs which could be collected by these vehicles depending on sensor fit;

- Hard coral cover and composition.
- Macroalgal canopy cover and composition.
- Ocean surface stress.
- Sea ice.
- Sea surface salinity.
- Sea surface temperature.
- Subsurface currents.
- Subsurface salinity.
- Subsurface temperature.
- Surface currents.
- Oxygen.

SCIENCE COMMUNITY DRIVERS

- **Improved system reliability.** The previous Autosub6000 had significant issues with reliability as identified by the Post-Cruise Assessments (PCAs) these issues are in part associated with the age of the vehicle and the obsolete internal control system. Autosub6000 was replaced by Autosub5 in the 2022/23 programme year.
- **Reduce ship monitoring time.** The time required to monitor Autosub to dive to depth, and to track it back to the surface has been highlighted as an ongoing issue, technologies to alleviate this use of ship time are desirable.
- **Improve the obstacle avoidance system & AUV situational awareness.** The AUV is being tasked more to undertake photographic surveys close to the seabed (DY021,30,34 & JC136) and to perform surveys in extreme terrain (JC125). To make this more robust and to extend the operating envelope, it will be necessary to improve the AUV's obstacle avoidance system and situational awareness.
- **Improved vehicle autonomy & edge compute capability.** The need for higher levels of autonomy will be driven by:
  - The requirement for an improved obstacle avoidance system.
  - A likely increased demand for adaptive mission planning of the AUV.
  - Improved system health monitoring.
  - The need to extract information from large sensors data volume to send back to the surface over a low bandwidth data link for sensor performance monitoring.
- **Replace Autosub3 under ice capability.** The retirement of Autosub3 removed the capability to make high power acoustic sonar measurements under the ice.
- **Water sampling ability.** Following feedback from MFAB on the NMF Technology Roadmap 2019/20, it was highlighted that water sampling for use with AUVs would be desirable.

FUTURE CAPABILITY

- **Continue to develop the next generation on-board control system.** The current AUV fleet (ALR x6, Autosub5, and Autosub Hover One) all utilise a common ROS based control system. This common system allows for share development effort and more in water testing which will Improve the system reliability, make it simpler to integrate new sensors across the fleet. The new systems provides a modern and future-proof system for ongoing development. There will also be new under ice behaviours developed to allow the AUV to operate safely under ice. These behaviours will build on the original Autosub3 work, and couple this to the new Onboard Control System (OCS) and Obstacle Avoidance System (OAS) to further enhance the under-ice capabilities.

- **Enhance the Obstacle Avoidance and Situational Awareness.** The original Autosub6000 obstacle avoidance system was limited by the sensors and control systems available in 2009. However, the AUV is now operating in more complex terrain (e.g. Canyons JC125) and close to the seabed for camera surveys (JC136). Thus, an improved OAS is being developed is being developed for Autosub5 utilising a forward looking MBES processed within the OCS to guide control actions. The sensor outputs links into a variety of different behaviours optimised for different environments e.g. under ice.
- **Front seat / back seat architecture.** MARS aims to enhance the OCS software architecture to enable science users to deploy specific algorithms on board the OCS controlled vehicles using the front seat / back seat paradigm[18]. For example, an externally written front following algorithm could be added to the back-seat to enhance the science utility of the campaign.

18 In this case the front seat can be considered the driver of the taxi (or AUV). It is responsible for the safe operation of the vehicle. While the back-seat can be considered the passenger of the taxi who instructs the driver where they would like to go. This separation allows for safe operation of a platform while enabling more complex control behaviours to be added.

- **Improved planning and Command & Control.** The mission planning for the AUVs has traditionally be performed on the ship, but we are now developing a more complex tool chain which allow more detailed permission preparation and risk assessment. This involves the integration of GIS, model data, and vehicle simulation tools into the planning process for mission rehearsal. Alongside this mission planning, we have adapted the MARS web-based command and control infrastructure to operate in a stand-alone fashion from the ship. The "C2 in a box" will continue to be refined for improved control of the Autosub 5, AH1, and ALR platforms.
- **Enhanced integration into the RRS James Cook and RRS Discovery's infrastructure.** The previous AUV fleet was not closely integrated into the vessels infrastructure. This meant extra equipment was needed to mobilise and operate the AUVs from our vessels. Through closer integration with the fabric of the ship we can reduce the equipment taken, and mobilisation time and cost. Example include using the ships USBL as an acoustics communications link, developing systems to use the ships crane for LARS mobilisations, integrating a fixed WiFi systems into the ships.
- **Hover capable AUVs.** Autosub 5 is only capable of conducting photographic survey in flat terrains. A hover capable AUV has the potential to be able to operate in close proximity to canyon walls, seamounts and other rough terrain.
- **Monitoring of Autosub5 and other systems via a USV.** A C-worker 4 unmanned surface vehicle will be used to monitor and track the AUVs using an integrated USBL. This monitoring will significantly reduce the ship time required to track the AUV at the start and end of the mission. It will reduce the navigation error of the vehicle as it won't be subject to the 0.1% of distance travelled error build up associated with dead reckoning as the USV will continually send down USBL position updates. This improvement in navigational accuracy will significantly increase the value of the produced acoustic and photographic datasets. The continual monitoring will also reduce the risk of vehicle loss, and so any deviation from course or collision with the seabed will be seen. The constant communication will also enable the use of more complex adaptive mission planning as the vehicle plan can be continually monitored as the plans evolve and so the risk of poorly adapted plans is reduced.

C-WORKER 4

ASPIRATIONS

- **New sensor integration.** The scientific requirements of an operational AUV continually evolve as research develops. For an operational AUV to remain useful its payload must keep pace with requirements. Continued close collaboration with the scientific user community will lead to improvements in sensors and keep our technology at the leading edge. Current scientific requirements include improved resolution camera systems and the use of 3D imagining.
- **Enhance inter-vehicle co-operation.** As we move towards multi-vehicle missions the systems will need to be developed so that they operate as a co-ordinated fleet. This will tie into the work associated with the long-range fleet command and control but will be local to the existing vehicles.
- **Enhanced vehicle autonomy.** As part of the new OCS development, we will be producing a strong basic control system for the AUV. We intend to utilise this base platform and enhance it by layering on high level autonomy behaviours thereby increasing the utility of the vehicles to the science community. The goal is to build a broad library of behaviours which will support the data collecting. This will be achieved by developing specific, broadly applicable behaviours as part of defined science campaigns. This will allow us to test and prove the behaviours before they are added to the behaviour library.
- **Development and curation of data processing tools.** As part of the NMF support to the science community we intend to create and curate tools to allow rapid processing of data, which can produce operational data products. These operational data products will not be publication quality but enable rapid assessment of the quality of the data gathered, and highlight areas of interest in the data which would require further investigation.
- FAIR aligned observation to data dissemination data management services for high power MAS.
- **Build of Autosub6.**

UNDERWATER GLIDER PLATFORMS

ESSENTIAL OCEAN VARIABLES

Example EOVs which can be collected by these vehicles depending on sensor fit;

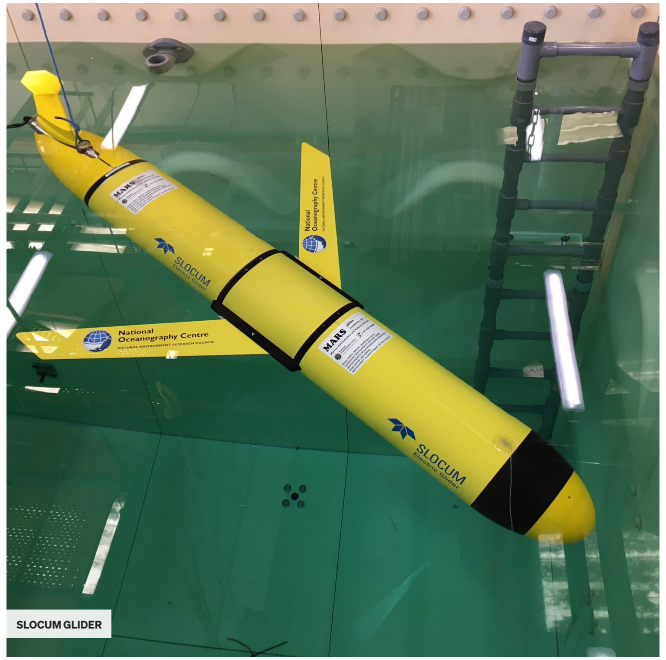
- Nutrients.
- Ocean surface heat flux.
- Ocean surface stress.
- Oxygen.
- Particulate matter.
- Sea ice.
- Sea surface salinity.
- Sea surface temperature.
- Subsurface currents.
- Subsurface salinity.
- Subsurface temperature.
- Surface currents.
- Phytoplankton biomass and diversity.

SCIENCE COMMUNITY DRIVERS

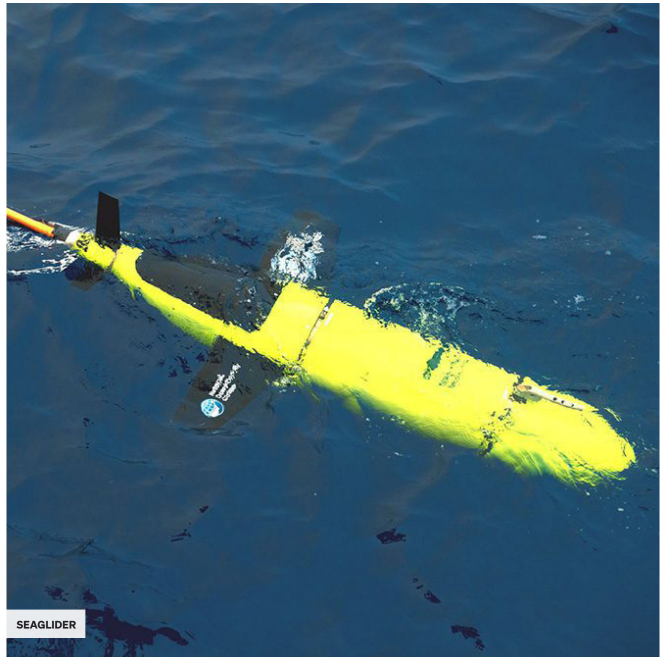
- **Reduction in operational cost.** Reducing these costs will allow a higher utilisation of the fleet and thereby increased science impact.
- **Improve system reliability.** The gliders, although commercial systems, still have reliability issues. Improving process control (e.g through the routine use of helium leak detectors) will enhance reliability and thus science delivery.
- **Under ice capabilities.** Surveying under the Arctic and Antarctic ice shelves is of growing scientific importance. Gliders could in theory collect data from beneath the ice and a long way from the ice front, but there are a number of challenges which need to be overcome before this can be practically achieved.
- **Improve navigational accuracy.** The subsurface navigational accuracy of gliders is poor. For many applications this is not an issue, however for long duration subsurface missions (i.e under ice) improvements are required.
- **Deeper operations.** Current gliders are limited to 1000m depths. This is insufficient for a number of applications, and hence deeper gliders are desirable.
- **Capability extension.** The ability for vehicle hibernation and near surface measurements would be desirable.
- **Instrument calibration.** Pre- and post-deployment calibrations are currently time consuming, potentially removing the vehicle from the fleet for several months at a time. Reducing the calibration time will increase fleet availability.
- **Integration of new science sensors.** As new science sensors mature, the community is keen that these sensors become routinely available on the glider fleet. For example, biogeochemical sensors help address ocean carbonate system questions and high frequency ADCPs can be used to calculate volumes and fluxes where moorings cannot be deployed.

FUTURE CAPABILITY

- **Under Ice Operations.** It is desirable for the glider fleet (both Slocum and Seaglider) to be able to operate under the ice in both the Arctic and Antarctic. Currently these have little if any specialised capabilities to do this. We will endeavour to upgrade the glider software to integrate the ice-avoidance behaviours into the glider fleet software to minimise the danger of operating in ice-covered regions. Finally, RAFOS (Sound, Fixing And Ranging) infrastructure is being purchased as part of the Oceanids Programme to enable navigation under ice using long range acoustic beacons. The technique requires a number of low frequency sound sources at known locations transmitting at known times. The receivers on the vehicle pick up these signals and by knowing the time offset can estimate their position. The sound sources have been purchased and the receiving element will be developed over the next few years.
- **Sensor Integration.** New sensors are continuing to come on stream and will need to be integrated into the long-range fleet. Focus in 2022/23 on integration of biogechemical sensors.
- **Improved system reliability.** Process control will continue to improve, and new checks will be introduced to catch errors early. For example, we now operate a helium leak detector that is being used to find micro leaks before the glider is deployed. We also continue to review failures in the field and have identified issues with certain connectors and will go through a fleet upgrade over time as funding allows. We are investing in our calibration facilities, and have aspirations to broaden the range of sensors that can be calibrated. Doing this in-house takes less time than returning to the manufacturer and thus improve efficiency.
- **New lower cost primary packs for gliders.** Current glider packs typically use Electrochem Lithium Sulfuryl Chloride cells. These cells are very expensive and can form a significant portion of the glider preparation costs. Other cell chemistries are available and we are looking at the potential of developing a lower cost battery pack with similar energy density. If successful, this would significantly reduce the deployment cost for the gliders without impacting the survey range.



SLOCUM GLIDER



SEAGLIDER

ASPIRATIONS

- **Sensor integration.** We will further develop our ability to integrate new sensors into glider systems. This is increasingly required by the scientific community and commercial customers with the integration becoming more complex. We aim to build on our recognised operational expertise, to develop leading mechanical, electronics and software integration expertise within the team. Sensor integration choices should be science community led.
- **Nutrient Slocum Glider.** The NOC OTE group have developed a series of nutrient sensors that can be fitted to a number of long-range platforms. We are currently able to include a suite of nutrient sensors on the Seaglider platform, however having this available just on one platform limits potential scientific operations. We have trailed the use of nutrient sensors on the Slocum glider and we aim to mature this technology to make it available to the scientific community.
- **Glider Fleet Review.** The current glider fleet is aging, and we will approach this challenge by performing extensive maintenance to the Slocum gliders to extend the life of the fleet within our maintenance budgets. We will further review the evolving scientific and commercial requirements and as funding allows purchase new glider platforms to fulfil demand into the coming decade. Enhancing fleet sensing capabilities. To improve sensing capabilities within the glider fleet new sensor payload combinations will be integrated into the fleet as suggested via the UK Glider Community & Everyone's Gliding Observatories (EGO) Workshops.
- **Enhancing fleet sensing capabilities.** To improve sensing capabilities within the glider fleet new sensor payload combinations will be integrated into the fleet as suggested via the UK Glider Community & Everyone's Gliding Observatories (EGO) Workshops.
- **Increase the range of sensors that we can calibrate in-house.** Routinely we return sensors to the manufacturer for calibration however this can remove a glider science bay from the pool for a significant period (6 months). Investing in our calibration facilities, and increasing the range of sensors that can be calibrated will increase efficiency of Glider operations.

AUTOSUB LONG RANGE (ALR) 6000 (FRONT) AND ALR 1500 (BACK)

LONG RANGE AUV PLATFORMS

ESSENTIAL OCEAN VARIABLES

Example EOVs which can be collected by the vehicles depending on sensor fit;

- Hard coral cover and composition.
- Macroalgal canopy cover and composition.
- Ocean surface stress.
- Sea ice.
- Sea surface salinity.
- Sea surface temperature.
- Subsurface currents.
- Subsurface salinity.
- Subsurface temperature.
- Surface currents.
- Oxygen.

SCIENCE COMMUNITY DRIVERS

- **Improved on-board control system.** There is a trend to deploy large mixed fleets of long-range MAS for large area data collections. Thus, the ALR needs to be capable of being integrated into these fleets, as described in the Long Range C2 section.
- **Hibernation.** There are a number of applications which require long-term periodic monitoring. This monitoring could not be accomplished in one ALR mission but the ability to hibernate on the seabed would allow these missions to be undertaken.
- **Water sampling ability.** Following feedback from MFAB on the NMF Technology Roadmap 2019/20 it was highlighted that water sampling for use with AUVs would be desirable.

FUTURE CAPABILITY

- **Improve ALR Control System.** The existing ALR control system has been tailored to a specific deployment programme. Thus, the system needs to be further developed to create a more general system for future deployments. To simplify this development the ALR control scheme will be integrated to the OCS development mentioned for the high power AUVs. This approach will maximise the benefits of the software development efforts with MARS. The ALR OCS variant will also include the front seat / back seat paradigm to allow user defined algorithms to be installed on the ALR vehicles.
- **Under Ice Operations.** It is desirable for the ALRs to be able to operate under the ice in both the Arctic and Antarctic. Currently these have little if any specialised capabilities to do this. Over the next five years we will build detailed under-ice behaviours for the ALR based around the new on-board control system. This will include using terrain-aided navigation techniques to allow Arctic basin crossings. Finally, RAFOS infrastructure is being purchased as part of Oceanids to enable navigation under ice using long range acoustic beacons. The technique requires a number of low frequency sound sources at known locations transmitting at known times. The receivers on the vehicle pick up these signals and by knowing the time offset can estimate their position. The sound sources have been purchased and the receiving element will be developed over the next few years.
- **Improving Navigational Accuracy.** There are a number of areas where improvements in navigational accuracy will be introduced into the long-range AUVs. These developments include the integration of a high precision AHRS into the ALR.
- **Simulation Environment.** MARS will develop tools to accurately simulate ALR missions prior to deployment to help identify bugs in the software system.
- **Mission workshop / control container.** Currently, ALR deployments require a either a shore base or lab space on a vessel to prepare the vehicle before deployment. This restricts where we can operate. A container equipped with all servicing and control systems will allow global operation including remote locations.

ASPIRATIONS

- **ALR hibernation capability.** To allow the ALR6000 to increase its endurance and to perform periodic monitoring of a specific area, techniques will be developed to allow the ALR to hibernate while still maintaining navigational accuracy.
- **General AUV improvements.** As with the higher power vehicle aspirations we also intend to:
  1. Enhance inter vehicle co-operation.
  2. Enhance vehicle autonomy.
  3. Develop new concepts of operation and undertake application- specific developments.
  4. Develop and curate operational data processing tools.
- **ALR docking and recharging.** The ALR capability could be further enhanced by creating the ability to dock with a subsea platform, download the vehicle data and recharge the batteries. This would provide similar capabilities to a field resident AUV, but with the extended range of the ALR would increase the operational usage of the system. This aligns with the ambitions to develop a moored AUV recharging capability outlined previously.

LOW INFRASTRUCTURE AUV PLATFORMS

ESSENTIAL OCEAN VARIABLES

Example EOVs which can be collected by the vehicles depending on sensor fit;

- Hard coral cover and composition.
- Macroalgal canopy cover and composition.
- Ocean surface stress.
- Sea ice.
- Sea surface salinity.
- Sea surface temperature.
- Subsurface currents.
- Subsurface salinity.
- Subsurface temperature.
- Surface currents.
- Oxygen.

SCIENCE COMMUNITY DRIVERS

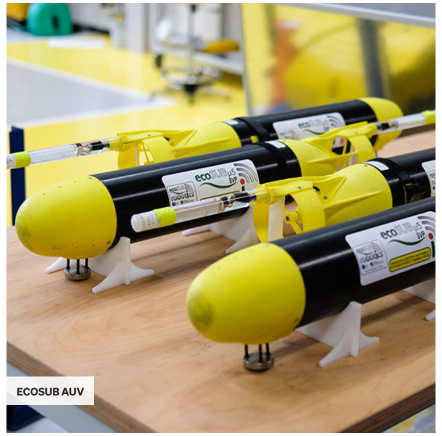
- **Inshore deployments.** The current NMEP fleet is predominately targeted at open ocean operations. Smaller man-portable platforms have a role to play in monitoring of near shore Marine Protected Areas.
- **Low infrastructure vehicles.** Global Challenges Research Fund projects have highlighted a requirement for low cost and low infrastructure vehicles for work with developing nations.
- **Surrogate vehicles for de-risking trials.** The large AUVs in the NMEP are expensive to trial and hence new functionality is often tested in the field on science campaigns. For some developments it is feasible to de-risk these developments through the testing of lower cost surrogate vehicles.

FUTURE CAPABILITY

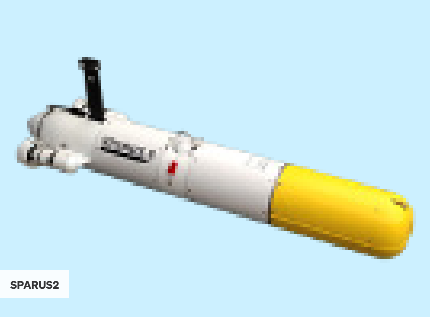
- **Low Cost Platforms.** MARS have been working in partnership with Planet Ocean to develop the ecoSUB range of very low cost AUV platforms.
- **Surrogate vehicles.** A Sparus2 AUV has been purchased by the MARS development group for the testing of collision avoidance behaviours.

ASPIRATIONS

- **To enhance the NMEP.** NMF would like to further develop a low logistics platforms capability (e.g. ecoSUBs) subject to available funding.



ECOSUB AUV



SPARUS2

GAVIA AUV

LONG RANGE UNMANNED SURFACE VEHICLES

ESSENTIAL OCEAN VARIABLES

- Sea state.
- Sea surface height.
- Sea surface salinity.
- Sea surface temperature.

SCIENCE COMMUNITY DRIVERS

- **Acoustic gateway for data harvesting.** Unmanned surface vehicles are an ideal platform to act as an acoustic gateway to harvest data from subsea moorings and landers. For example, this would be very useful for the RAPID Array as it would allow periodic collection of the moorings data between the mooring turn around expeditions.
- **Acoustic gateway and navigational aiding.** Unmanned surface vehicles are also an ideal platform to act as an acoustic gateway and navigational aid to long range subsurface vehicles.
- **Measuring air sea exchange.** Measuring air sea exchange (of for example, CO_2, heat, momentum, etc) is vital to understanding how the oceans and atmosphere interact. USVs provide an ideal platform for directly monitoring these exchanges at the air sea interface. Extension of sensor fits to include other greenhouse gases such as methane would be useful.

FUTURE CAPABILITY

- **Acoustic gateway and navigational aid (USVs).** The USV fleet provides an ideal method of gathering data from fixed sea-bed arrays acoustically, and also providing a navigational aid to subsurface vehicles. To develop these capabilities MARS is part of the North Atlantic Climate System Integrated Study (ACSIS) trial which will be using a waveglider to acoustically harvest data from the RAPID array; and the Innovate UK Autonomous Surface / Subsurface Survey System (ASSS) project which will couple a long-range surface vehicle to the ALR to act as an acoustic gateway and a navigational aid. These techniques will continue to be developed and it is anticipated that these capabilities will be available to the community for routine operations within the next few years.
- **Measuring air sea gas exchange.** Measuring the air / sea gas exchange is vital to understanding how the oceans and atmosphere interact. USVs provide an ideal platform for directly monitoring this gas exchange. MARS will work with the science community to adapt the USVs so that they can provide a platform to measure this gas exchange.

WAVEGLIDER

LONG RANGE MAS PLATFORMS COMMAND AND CONTROL (C2)

Due to the different control infrastructure for each vehicle, there is currently no way to run a large mixed fleet of vehicles in a simple co-ordinated fashion. To maximise the effectiveness of the MARS fleet it is necessary to develop a unified control system to support mixed fleets and to tightly integrate this with automated data ingestion into the British Oceanographic Data Centre (BODC). The development efforts for this are funded by the Oceanids C2 project.

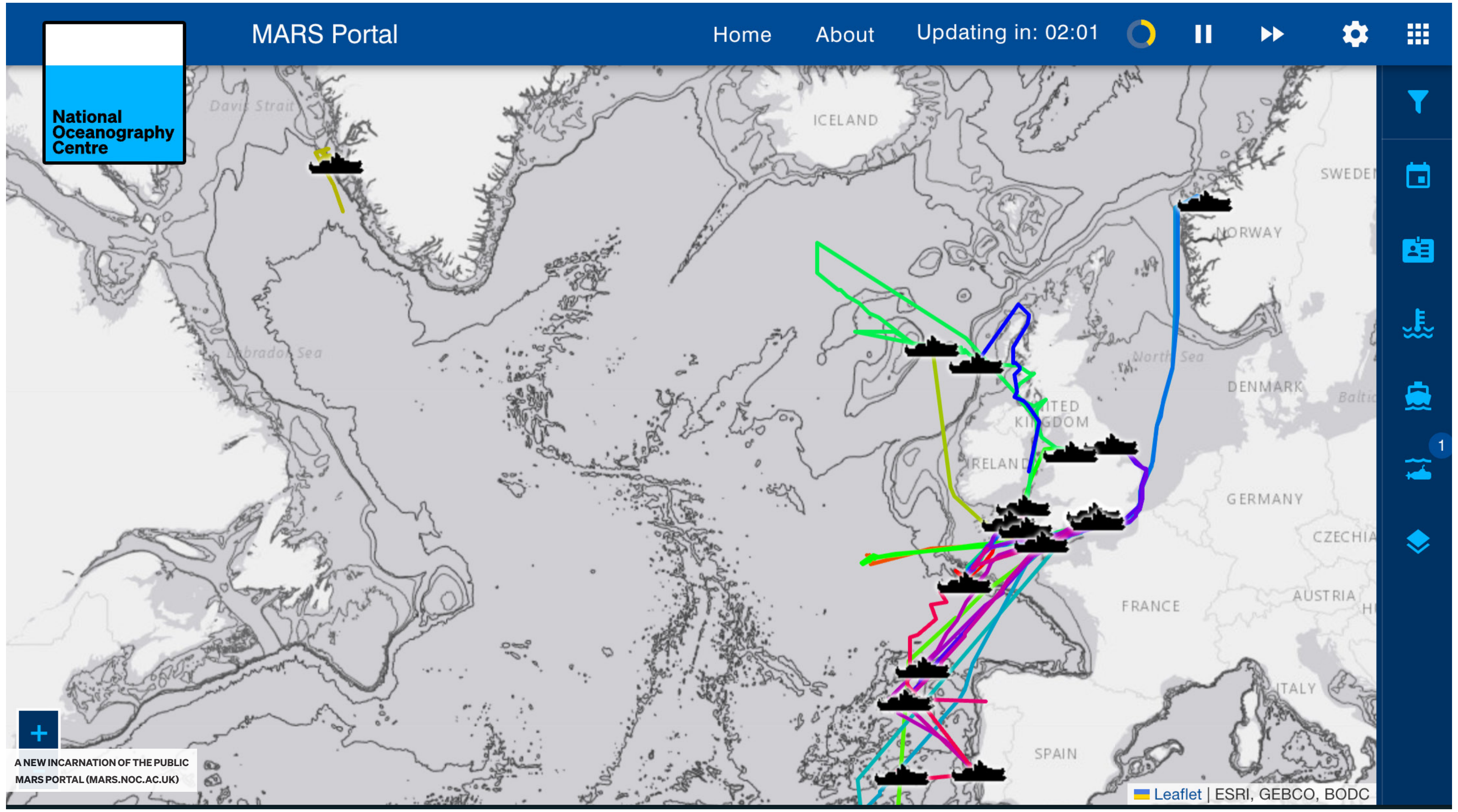
SCIENCE COMMUNITY DRIVERS

- **Simplify the piloting process.** The current piloting system consists of a different user interface for each different platform. This results in significant pilot training costs and makes operating a fleet of diverse vehicles difficult.
- **Semi-automate / Automate vehicle piloting.** To reduce the piloting demand semi-automated piloting should be developed, both to reduce the deployment cost and to optimise the data collection.
- **Reduced data processing overhead.** The overhead in time and money of ingesting the data from the long-range MAS platforms into BODC is considerable and can be significantly reduced through automation.
- **Improved deployment visibility and outreach.** The current deployments for the long-range MAS fleet are not clearly visible to the science community and the wider public. Improving this visibility will assist with outreach and show UK science in action.

FUTURE CAPABILITY

- **Unified control interface.** A unified control interface will be developed to simplify the deployment of mixed fleets of vehicles. This interface will be simple, intuitive, yet powerful enough to allow the pilot to create complex mission plans. The interface will build on the investment that has already taken place in this area and will be integrated into all of the long-range fleet. The development will be undertaken using an agile approach and so iterative upgrades to the system will occur throughout the project duration. The control interface will be available to the wider UK community for piloting and monitoring of the assets.
- **Vehicle Data Processing, Curation & Availability.** The near real time data generated by the vehicle needs to be automatically gathered, processed, QC'd and ingested into BODC or a similar[19] curation facility. This should be done in as close to real time as possible so that it is available for the pilot (human or computer) and can be ingested into forecasting models. The data will be stored in a standard format (e.g. EGO NetCDF) for simplified distribution. The data gathered will also be available via the Piloting Website in real time.
- **Automated piloting infrastructure.** To reduce the piloting load required for mission, an automated piloting infrastructure will be created. This will allow rapid development of automated piloting routines / integration of third-party piloting algorithms for applications using a variety of vehicles.
- **Scientific data fusion.** This part of the C2 development will generate data products from the long-range MAS platforms from the near real time data. These data products can be combined with data from other sources to both validate the data gathered, and to guide the platform to optimise the data collected.
- **Engineering data fusion.** This aspect of the work will develop approaches for automatic fleet health monitoring and mission risk evaluation to better inform human pilots or automated fleet controllers.

19 Data centre accreditation can be via CoreTrustSeal, MEDIN or independently assessed against standard such as ISO e.g., ISO 9001 quality management systems – requirements, ISO 8000 – data quality (multiple parts), or ISO 19650 – Information management using BIM.



A NEW INCARNATION OF THE PUBLIC MARS PORTAL (MARS.NOC.AC.UK)

ASPIRATIONS

- **Extend the C2 infrastructure to other NMF assets.** The development of the website tool provides real time data to the vehicle pilots and will be useable by the wider science community. We intend to investigate using this functionality in other aspects of NMF, specifically the website front end and associated back end ingestion system into BODC. These could be applicable to near real time data from moorings and the NOC research vessels.
- **C2 continued development.** The Oceanids C2 development will significantly enhance the operations of the fleet, but it will not cover all requirements. Thus, we intend to further enhance the command and control as and when new requirements and resources become available.
- **Integration with the OCS.** The ambition is to more tightly integrate the C2 infrastructure with the AUV Onboard Control System, thereby improving the control and autonomy of the long-range fleet.
- **Integrate the MFP with the C2.** This will allow:
  - Automatic configuration of programmed activities on the C2, both in the NMF part of the system and BODC.
  - Automatic ingestion of sensor calibration data in BODC.
  - Automatic reporting of autonomous deployments into the MFP.
- **Development of an ecosystem of Apps.** The C2 design enables the creation of an ecosystem of applications on top of the infrastructure to maximize the utility of the platforms and the data gathered by them. The Piloting App is the most prominent and well known of these apps, but there are a number of them in the pipeline:
  - **Metadata App.** Allowing BODC and fleet managers to introduce the metadata required for the assembly of standardized data outputs.
  - **PI App.** Allowing PIs and scientists involved in campaigns including autonomous assets, to do mission planning that then will be transmitted to the piloting team. It will also allow the PIs to follow the development of the mission, aggregating under the same system different information (e.g. Satellite imagery, model information, in situ sensor data etc) to allow informed decision making during the deployments.

SHIP-FITTED HYDROACOUSTIC SUITE AND HYDROGRAPHY SOFTWARE

ESSENTIAL OCEAN VARIABLES

- Fish abundance and distribution.
- Subsurface currents.
- Surface currents.

SCIENCE COMMUNITY DRIVERS

- **Maintain support for echosounder capabilities by updating old systems.** The EM710 and the EM122 are both approaching end-of-service and will require replacement alongside an upgrade of the Sea-floor Information System (SIS).
- **Investigate performance of Discovery ADCPs.** In 2019 both ships passed each other in the Atlantic allowing a side-by-side comparison of the ADCP performance between the ships. On RRS *Discovery* the depth penetration was about 50% less than expected and the background noise higher.
- **Automate processing of multibeam data to reduce downstream processing effort.** To strengthen our contribution to Seabed2030, we need to put in place automated systems to perform standardised, first-pass processing of multibeam data.
- **Maximise multibeam data collection for Seabed2030.** To strengthen our contribution to Seabed2030, we need the resources to collect multibeam data on all programmed science cruises and passage legs.
- **Maximise capacity for remote operation.** Having a capacity for hydrographers to remotely operate the hydrographic suite would improve operational flexibility.
- **Backscatter data acquisition.** Data optimised for hydrographic survey can compromise the integrity of backscatter data. Efforts should be taken to minimise the impact for future use[20].

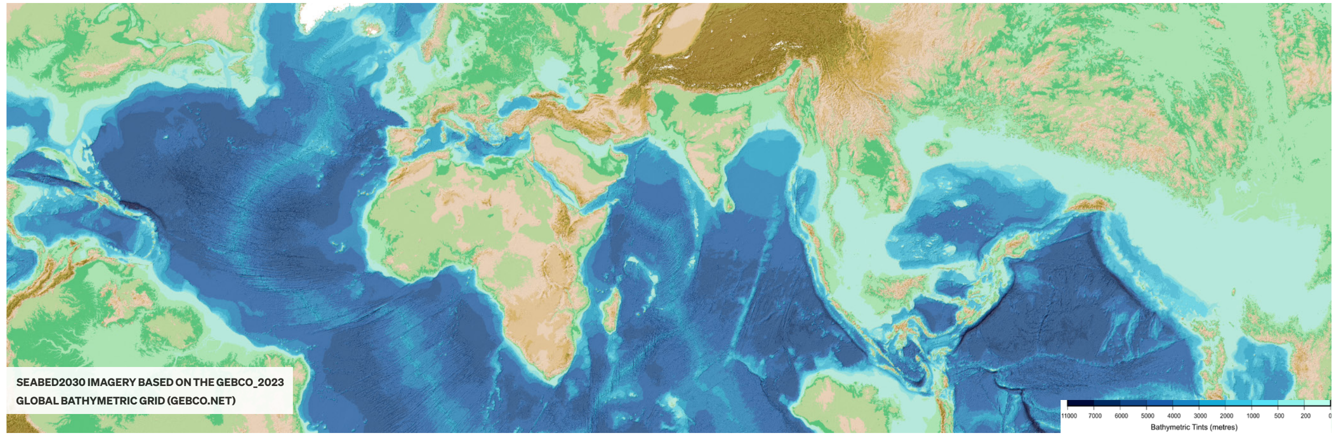
20 Consult International Backscatter Working Group

FUTURE CAPABILITY

- Investigation of automated processing packages for multibeam data and integration in to RVDAS.

ASPIRATIONS

- **Replacement of the EM710 and EM122 multibeam capabilities.** Both are approaching end of OEM supported service life with spares availability expected to diminish between 2025-28.
- Establishment of protocols for continuous operation of multibeam during periods of passage without technical parties embarked.



SEABED2030 IMAGERY BASED ON THE GEBCO_2023 GLOBAL BATHYMETRIC GRID (GEBCO.NET)

OCEAN AND ATMOSPHERE MONITORING

ESSENTIAL OCEAN VARIABLES

- Ocean surface heat flux.
- Ocean surface stress.
- Sea state.
- Sea surface salinity.
- Sea surface temperature.
- Stable carbon isotopes.
- Inorganic carbon.
- Dissolved organic carbon.
- Particulate matter.
- Ocean colour.

SCIENCE COMMUNITY DRIVERS

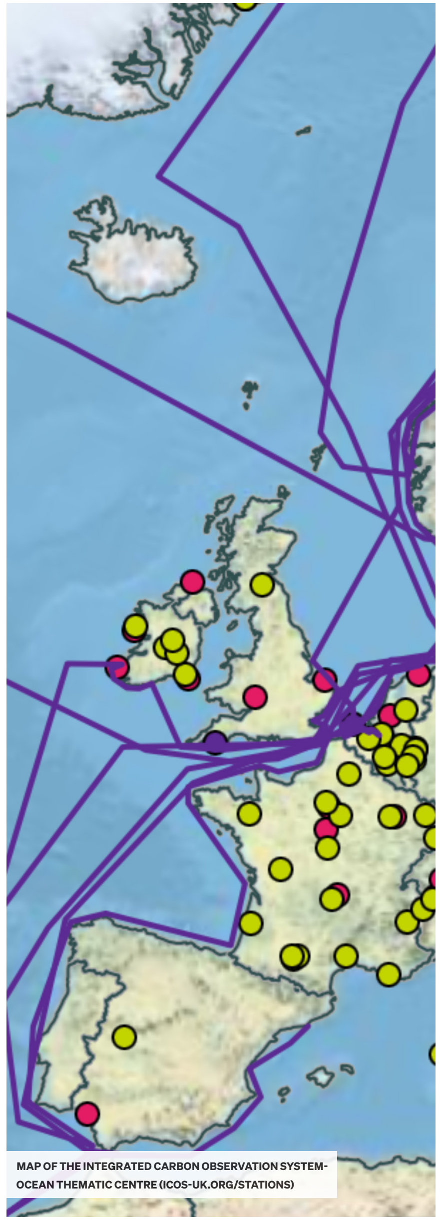
- **Strengthen EOV metadata and data acquisition.** In order to support BODC's drive towards robust, NRT monitoring of Essential Ocean Variables (EOV) upgrades will be developed and implemented to streamline the data acquisition pipeline and the integration of metadata. The aim is to be able to easily scale our ocean and atmosphere monitoring to take on new sensors to collect the full range of EOVs. This work is closely linked to the work being undertaken with our data acquisition systems.
- **Support research into oceanic carbon uptake.** The oceans account for approximately 25% of the net anthropogenic carbon uptake, therefore the consistent acquisition of surface CO_2 levels is essential to monitor and predict future carbon uptake.
- **Support experimental wave measuring approaches.** Novel approaches will give us a third wave height reference to improve confidence of measuring wave height.
- **Develop atmospheric chemistry monitoring capability.** Chemicals and aerosol in the marine atmosphere contribute significantly to Earth's radiative budget, to biogeochemical cycling, and to air quality and thus public health impacts over adjacent land areas. A gap exists for NERC vessels to contribute to continuous monitoring of "bad" chemicals (pollutants) and "good" chemicals (e.g. nutrients) in the atmosphere above the oceans.

FUTURE CAPABILITY

- Integration of wave height sensor and wave radar to produce a calibrated data product.
- In 2023 to introduce pCO_2 systems on board both vessels with automated processing for ingestion into the Integrated Carbon Observation System-Ocean Thematic Centre (ICOS-OTC) and the Surface Ocean CO_2 Atlas (SOCAT), available either by request or continuous operation when underway.
- Expansion of SURFMET biogeochemical sensors (e.g. pH, dissolved oxygen, backscatter).

ASPIRATIONS

- To work in partnership with BODC and C2 Developers to develop applications which integrate with BODC's data ingestion services.
- To prepare a procedure for the cross-comparison of acquired underway ocean and atmosphere data with deployed instruments (i.e. CTD profiles) and nearby ROV / AUV, moored / fixed stations and other research ships.



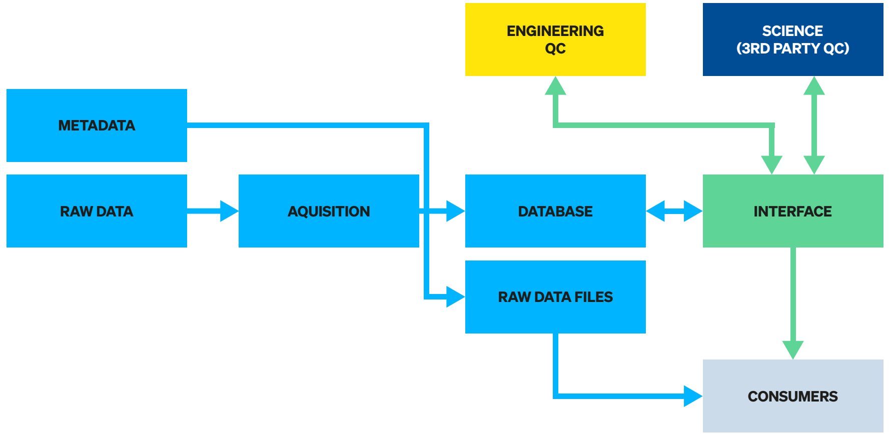
MAP OF THE INTEGRATED CARBON OBSERVATION SYSTEM-OCEAN THEMATIC CENTRE (ICOS-UK.ORG/STATIONS)

SHIP-BASED DATA ACQUISITION SYSTEMS

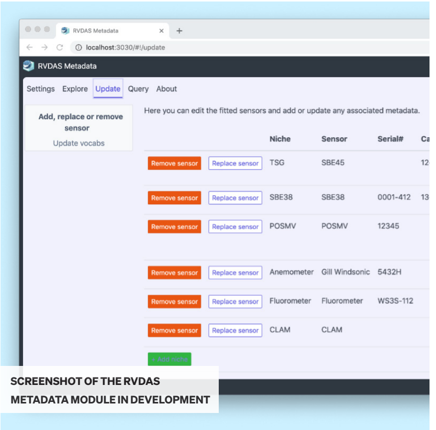
SCIENCE COMMUNITY DRIVERS

Improve rigour of onboard data acquisition and increase accessibility to near-real-time data products for monitoring and onboard scientific work. Developments to our acquisition systems are organised into themes of collection, evaluation, organisation and dissemination:

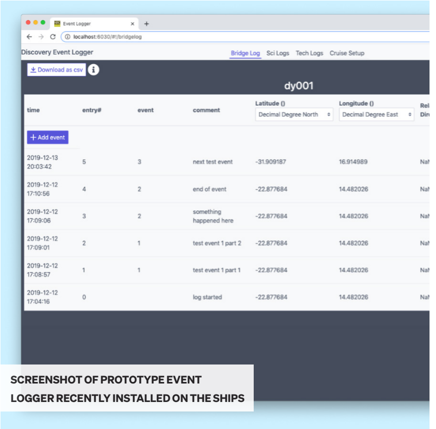
- **Collection.** Developments in this area target data security, sensors, network infrastructure and metadata. The growing requirement to transmit and share near-real-time data to several consumers both on board and ashore requires better integration of metadata. The increasing importance of the data products to a wide range of end-users also requires measures to be taken to ensure the security of data through redundant storage and parallel acquisition networks that eliminate single-point failures.
- **Evaluation.** The growing requirement to transmit and share near-real-time data requires Quality Checking (QC) to be expanded to include automated engineering QC, which processes and flags data which fail basic integrity checks. Furthermore, in working in partnership with the scientific community, it is desirable to integrate specialist QC processes which can evaluate collected data against reference datasets.



- **Organisation.** In order to transmit meaningful data to the wide range of consumers on board and ashore, it becomes necessary to structure the data storage into databases, with the ability to apply metadata at the creation of data products.
- **Dissemination.** Providing access for people and processes to structured FAIR data (including the persistent identification of metadata and data entities) and metadata requires suitable interfaces to be developed to the databases. Such interfaces would enable the development of modular 'post-processors' which would query the database and produce specific data products, such as NRT streams to BODC, onboard data servers or post-processed bespoke data products.
- **Future Capability.** The aim is to build a comprehensive, modular, interface-driven system which enables extensible acquisition and collection of events and other metadata, plug-in QC routines, the storage of structured data and the scalable dissemination of data products to a range of consumers.



SCREENSHOT OF THE RVDAS METADATA MODULE IN DEVELOPMENT



SCREENSHOT OF PROTOTYPE EVENT LOGGER RECENTLY INSTALLED ON THE SHIPS

SCREENSHOT OF DATA MONITORING AND QUERY SYSTEM RECENTLY INSTALLED ON THE SHIPS

In 2023, we hope to:

- Work with BAS to develop better processes for collaboration and version control between our teams.
- Collaborate with BAS in their development of RVDAS components, including the Event Logger, which will eventually use BODC vocabularies, free-form inputs and preconfigured event types to record contextual information during expeditions.
- Release the production version of the metadata module for RVDAS which will enable the configuration, storage and distribution of information associated with the ship's sensors in a useful way.
- Release the production version of the NetCDF module for RVDAS which will extend the types of data product that RVDAS can generate and permit customisation of data outputs.
- Continue to release improvements to the implemented RVDAS raw data acquisition module, data ingestion module, data storage module and data query and visualisation module.
- Connect the shipboard acquisition to the BODC Near-Real-Time ingestion services.

ASPIRATIONS

- Develop interfaces to the related digital twin developments.

CREW ONBOARD RRS DISCOVERY

WINCHES

SHIP FITTED WINCHES
FUTURE CAPABILITY

- A review of cable specifications for future requirements for the deep tow winches.
- A review of the plasma (deep water coring) winch rope specification.

ASPIRATIONS

- Trial the deployment of ISIS from the deep tow winch.
- Subsea package-controlled winch driving, e.g. use an altimeter to drive the winch to keep constant depth. This would be useful for HyBIS / MPUS, and could serve as a safety measure to prevent unintended landing of a package on the seabed, for example in CTD operations.

PORTABLE WINCHES
SCIENCE COMMUNITY DRIVERS

- A review of the portable winches in the NMEP showed a consistent request for line out length and line tension feedback functionality.
- A fleet of primarily general-purpose winches which are more interchangeable and easier to maintain, providing maximum flexibility at sea. A minimum number of bespoke winches that are procured for specific capabilities that can't otherwise be operated from COTS winches.

FUTURE CAPABILITY

- The SeaSoar winch purchased in FY18/19 did not pass Sea Acceptance Trials (SATs) during the NMEP trials in 2019. After rectification work completed by the OEM, SATs are planned for the next available NMEP trials period.
- A second reeler winch is in the final stages of UAT.

ANCILLARY EQUIPMENT AND FACILITIES

CALIBRATION LABORATORY
SCIENCE COMMUNITY DRIVERS

- The integrity of any scientific endeavour is dependent upon the accuracy of measurements. Calibration can be an expensive and time-consuming business. This in-house facility allows us to offer a competitive, fast service to scientists and technical groups.
- Assistance in the testing of sensors in development.
- Establishment of calibration capability for pH, nutrient, and oxygen sensors.

FUTURE CAPABILITY

Develop a glider calibration facility for the full sensor bay including a Seabird 911+.

ASPIRATIONS

- The calibration laboratory is seeking to achieve ISO17025 General requirements for the competence of testing and calibration laboratories. This will provide external assurance of the traceability and uncertainty resolution the NOC calibration facility achieves, which is not currently provided by the leading instrument manufacturers.
- Extend the calibration services offered to include calibration of nutrient sensors.

CONTAINER LABORATORIES
SCIENCE COMMUNITY DRIVERS

The use of container laboratories is crucial to perform analysis under both environmental control and clean chemistry conditions. They provide additional ship laboratory facilities and space, and an effective and efficient approach for undertaking scientific research in challenging environments. The container laboratories reduce the risk of contamination in all the steps related to the processing, analysis and storage of the samples collected from the ship. This is fundamental for trace metal analysis but also for emerging science fields such as microplastics and nano-plastics pollution. Further environmental control conditions are critical to perform multi-stress incubation experiments to simulate future global change scenarios such as ocean warming and ocean acidification.

FUTURE CAPABILITY

As part of the five-year rolling plan NMF have purchased 3 new clean chemistry laboratory containers for use in 2023 to replace the existing fleet of containers as they reach the end of service life. Older clean chemistry laboratories will serve as radionuclide laboratory / general purpose containers as each new laboratory container is received.

CONTAINER LABORATORY

ANNEX

NMEP CURRENT CAPABILITIES AND UPDATES

CURRENT CAPABILITIES

The capabilities available for use by the UK marine science community from the NMEP and NOC operated vessels, and the infrastructure that supports it are detailed in this annex.

Each capability is listed sequentially with the following structure:

- **Current Capability.** A description of the current capability in that area.
- **Update.** Brief overview of progress developing enhanced capabilities since the previous issue of the Technology Roadmap.

MARINE FACILITIES PLANNING PORTAL (MFP)

CURRENT CAPABILITY

The marine facilities planning system provides the backbone of the cruise and autonomous system deployment programme planning activities undertaken by NERC Marine Planning and NOC. It is a world leading system comprising the following modules:

- **Programme Module.** This module provides visibility of the approved programme, including the original Ship-Time & Marine Equipment Application Form (SME), final supply agreement, equipment, technicians and associated documentation for an expedition.
- **Inventory Management System (IMS).** This module is used to plan, record and track the location of all NMEP and non-NMEP equipment within NMF as it moves around the globe in support of the programme; and meets the HMRC customs requirements of NOC. It is also used to plan and record the preventative and corrective maintenance of equipment as required.
- **Personnel Planning Module.** This module is used to assign technicians to different expeditions in the programme, whilst highlighting when individuals are nearing or exceeding acceptable days on duty at sea.
- **Personnel Capabilities Module.** This module gives visibility of the qualifications held by each NMF technician and mariner, and thus provides assurance that all personnel involved in an expedition are suitably qualified and experienced to deliver the objectives of the project safely. It is also used to set training requirements for an individual and chart their progress to completion of qualifications assigned.
- **Programme Construction Module.** This module is used in the development of the programme, clearly highlighting constraints for equipment and personnel.
- **Project Management Module.** This module is used to provide the project framework for each SME, from application, engineering review and funding confirmation, through programme construction, cruise planning and itinerary, equipment preparation and finally post cruise actions and assessment.
- **Scientist Portal.** The portal is the tool used to request ship and / or equipment time by both scientists and technicians. To access this tool an account must be requested at the marine facilities planning website.

UPDATE

- The personnel capabilities module has been completed and populated.
- The MFP mobile application has been updated to allow recording of equipment location and maintenance information in situ, without the need to access a PC, making software use in the field and workshops easier.

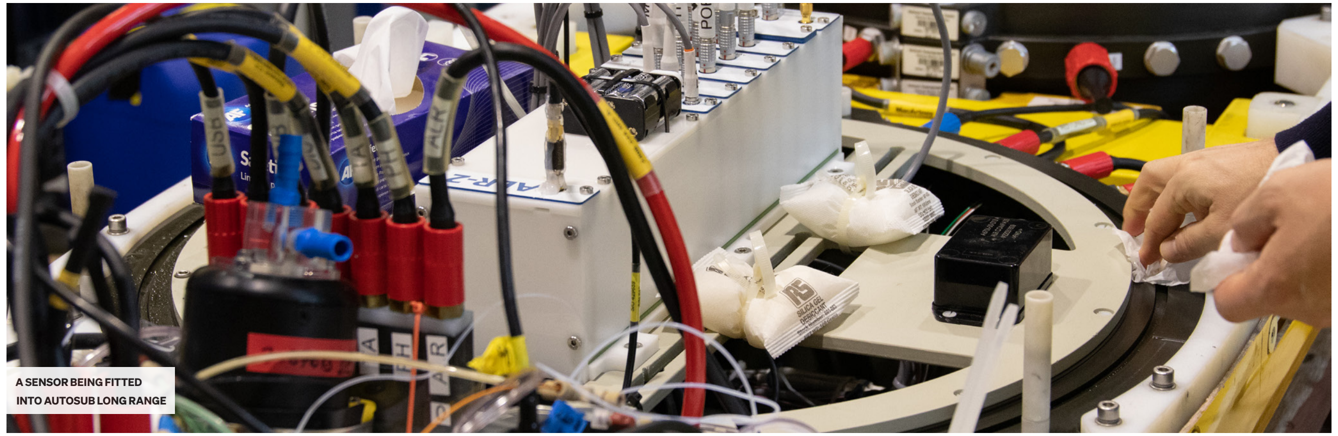
DATA MANAGEMENT AND PRACTICES

CURRENT CAPABILITY

- Operational Oceanids C2 workflow for near-real-time data from gliders and recovered data from Autosub Long Range vehicles.
- Well established manual routes for submission of end of cruise backups of ship system data to BODC.
- Dedicated data processing group (BODC Underway Group), responsible for the delayed-mode and Quality Controlled (QC) delivery of routine underway variables from fixed sensor arrays on NERC research vessels.
- Nippon Foundation – General Bathymetric Chart of the Oceans (GEBCO) Seabed 2030 Global Centre responsible for monitoring global sea-floor mapping activities.
- NERC Vocabulary Server (NVS), a global web service managed by a dedicated team at BODC who is responsible for publishing lists of terms used to standardise marine data and information about data (metadata).
- Manual archive of high volume ROV and geophysical data in NOC.
- The Data Working Group was initiated in 2019 with the purpose of providing expert advice and input to MFAB on topics relating to the full life cycle of marine science data from NERC Research Vessels and autonomous platforms.

UPDATE

- Oceanids C2 workflow for near-real-time data from gliders, including delivery of open data via the web. Current work is focusing on iterating formats and protocols for forwarding data to the UK Met Office and Ocean Gliders.
- Ocean development trailing NRT flow of research vessel data to BODC. This includes data flow standardization across vessels and event logging systems.
- Developed solution and gained approval from the MFAB Data Working group to resolve Topic 1 on the task list of the working group: Easy access science data on board research vessels.
- The GROOM 2 project is defining the scope a glider research infrastructure with European partner will be ahead a potential preparatory phase, a key output of such a network will be the European connection to the glider component GOOS.



A SENSOR BEING FITTED INTO AUTOSUB LONG RANGE

RESEARCH VESSELS

CURRENT CAPABILITY

- NMF operates the two global class research vessels RRS *James Cook* and RRS *Discovery*. Satellite measurements, though increasing in accuracy, remain unable to collect data much below the ocean surface. Therefore, research vessels continue to be the principal platform from which the majority of oceanographic measurements are made, using the capabilities listed in this Technology Roadmap.

SEISMICS

CURRENT CAPABILITY

- Bolt 1500-LL airguns.
- Sercel GI 250 airguns.
- Sercel 428 data acquisition system;
    - Km multichannel streamer, extended to 3 km where required through hire of a further 600m length.
- Big Shot fire control system.
- Avalon RSS-2 array source control system.
- Digicourse streamer levelling system.
- 4 x Hamworthy 2000PSI containerised compressors .

The RRS *James Cook* can accommodate the full deployment of all four compressors and either acoustic source, however the RRS *Discovery* can only accommodate two compressors which in practice limits this to the use of the Sercel GI system only.

The current seismic source arrangements are outdated and optimized for operations on previous classes of research ships. The multichannel streamer purchased remains up to date and in line with industry use.

UPDATE

During JC215 seismic system trials the Bolt 1500-LL airguns, big shot, digicourse and sercel 428 systems were successfully recommissioned after major refurbishment and restored to community use. Sensors deployed at various system points were used to generate a real time seismics acquisition dashboard for the suite performance to inform system adjustments.

The HP air system has been tested at 3000PSI in preparation for replacement of the Bolt 1500-LL airgun suite.

A seismic systems working group has been set up within NMF to co-ordinate work between different engineering groups, with geophysics community representation to help inform development priorities.

RVDAS'S PLOTTING MODULE (GRAFANA), SHOWING THE SEISMICS ACQUISITION DASHBOARD

SAMPLING

CURRENT CAPABILITY

The NMEP sampling capability consists of coring, with eight different types of corer with both tubular and box varieties available, trawling and dredging;

TUBULAR CORERS

- **Gravity Corer**
  (Sample tubes 63.5mm OD, 1 to 4m depth).
- **Kasten Corer**
  (Sample 150mm square, up to 5m depth).
- **Piston Corer**
  (Sample tubes 90mm or 110mm OD, up to 25m depth).
- **Multi Corer**
  (Up to 12 sample tubes 56mm OD, 0.6m depth) retired from IMS.
- **Mega Corer**
  (Up to 12 sample tubes 100mm OD, 0.6m depth).

BOX CORERS

- **SMBA Corer**
  (Sample 600mm square, 0.45m depth).
- **NIOZ (haja) Corer**
  (sample 500mm square, 0.5m depth) .
- **Day Grab**
  (10kg surface sample).

TRAWLING AND DREDGING

- **Aggaziz Trawl.** Full ocean depth trawler (2.5m wide x 4m long tapered fishing net).
- **OTSB Trawl.** Full ocean depth bottom trawler (14m wide x 25m long tapered net).
- **Rock Dredge.** Full ocean depth dredge (1m wide x 0.5m height x 1.5m long steel net).

MOORINGS

CURRENT CAPABILITY

Bespoke full ocean depth mooring systems capable of up to 24-month time series observations, utilising a wide range of NMEP and user supplied sensors and sampling devices, are designed according to the specific science requirements of the study. The following sensor types are available from the NMEP:

- ADCPs 75kHZ – 1200kHz.
- Fluorimeters.
- PAR sensors.
- CTDs.
- Dissolved oxygen sensors.
- Transmissometers.
- Backscatter meters.

CONDUCTIVITY, TEMPERATURE AND DEPTH (CTD) FRAME OPERATIONS

CURRENT CAPABILITY

The NMEP has both stainless steel and Titanium CTD sampling frames and is capable of completely trace metal free sampling when deployed using portable MFCTD winches. CTD sampling frames can be fitted with 10 (Titanium CTD sampling frame only) and 20 litre sample bottles (24 of each). The frame can carry sensors to measure conductivity, temperature, pressure, turbidity (transmissometer and back scatter), oxygen, chlorophyll, PAR and water velocity. They can be deployed to full ocean depth (6000m).

UPDATE

Full ocean depth carbonate system sensors with rapid response times have been purchased and successfully trialled during CTD frame deployments.

A CTD BEING LOWERED INTO THE OCEAN

STATIONARY AND TOWED PROFILING BODY SAMPLING

CURRENT CAPABILITY

- **15 x Stand Alone Pump System (SAPS).** The SAPS were reintroduced in to the NMEP after the NMEP trials in 2019, after removal to allow redesign work to combat increasing reliability issues and robustness. This includes redesigned more efficient impeller and pump heads with more efficient programming timer control.
- **3 x Vertical Microstructure Profiler 6000 (VMP6000).** This is an untethered, autonomous system for the measurement of turbulence microstructure and CTD in a vertical profile of up to 6000m. As a battery powered untethered capability data is recorded and downloaded and batteries recharged on recovery. This necessitates at least two profilers to be allocated to maintain 24-hour operations.
- **2 x Vertical Microstructure Profiler 2000 (VMP2000).** This is a tethered system for the measurement of turbulence microstructure and CTD in a vertical profile of up to 2000m. As a tethered capability data can be transmitted in real time.
- **2 x ISW Microstructure Profiler (MSS90L).** This is a tethered system for the measurement of turbulence microstructure and CTD in a vertical profile of up to 500m. Smaller, lighter and easier to deploy, this presents a lower cost option to the VMP2000 when the sample area is less than 500m.
- **SeaSoar.** SeaSoar is a towed vehicle with a sinusoidal or level survey profile, fitted with a full biogeochemical instrument suite. Instrument locations on the vehicle have been optimised, and redundancy of primary instruments built in. The high tow speed (9 knots ideal) allows mesoscale surveys and the ability to track moving features such as eddies that cannot be surveyed using other means. The data quality on both the up and down casts are equally good. Best used for long deployments and can continue high quality survey in poor weather conditions. As a tethered capability data can be transmitted in real time. This capability is not "ready to go", and intentionally mothballed to prioritise funding for equipment currently scheduled in the marine facilities programme. It remains however, available for use with an increased notice period.
- **Moving Vessel Profiler (MVP 300-1700).** The MVP is a towed platform with a sawtooth survey profile for the measurement of CTD, chlorophyll concentration and light intensity from 0.5 to 10 knots and 300-1700m depth (sensor payload dependant). It is quick to deploy and recover, frequently used to profile between CTD stations as it does not need to be fully recovered for breaks in survey lines. When towed at low survey speeds it provides very high horizontal spatial resolution. It also has a small footprint to maximise deck space. As a tethered capability data can be transmitted in real time. This capability is not "ready to go", and intentionally mothballed to prioritise funding for equipment currently scheduled in the marine facilities programme. It remains however, available for use with an increased notice period.
- **EIVA Scanfish III Rocio.** Scanfish is a towed vehicle with a sinusoidal or level survey profile for the measurement of high quality CTD, dissolved oxygen and bottom depth, with an ideal survey speed of 6 knots and range of surface to 150m depth. Highest quality instrument suite of all the towed undulator capabilities, with most instruments identical to and interchangeable with the CTD frame. As a tethered capability data can be transmitted in real time. This capability is not "ready to go", and intentionally mothballed to prioritise funding for equipment currently scheduled in the marine facilities programme. It remains however, available for use with an increased notice period.


ISIS ROV BEING DEPLOYED OFF RRS JAMES COOK

REMOTELY OPERATED PLATFORMS

CURRENT CAPABILITY

- **Isis Remotely Operated Vehicle (ROV).** The Isis ROV is a mature world class deep water ROV system. It is Europe's deepest diving science ROV and is arguably the most capable of the five 6000m rated science ROVs in Europe. Since delivery in 2003 it has gone through a series of upgrades to improve the instrumentation and sub-systems to maintain its world class capabilities. The incremental upgrades to this vehicle are likely to continue over the next five years.
- **HyBIS Robotic Underwater Vehicle (RUV).** HyBIS is a modular remotely operated platform. It is very similar to a remotely operated vehicle, but lacks syntactic foam and so is directly coupled to the ship. The HyBIS system comprises a ship side power and control system, a bottom end command module with cameras and lights, and interchangeable payload modules. This set-up allows each payload module to be precisely located and oriented on the seabed and thus video guided seabed sampling is possible to achieve. HyBIS's heavy lift capability also makes it an ideal platform for video guided placement and recovery of seabed experiments, thus potentially changing the deployment approach for seabed landers.
- **Mojave ROV.** The Mojave ROV is a small shallow water (300m) rated system. It is equipped with lights, cameras, and a three-function manipulator arm.

UPDATE

- **MPUS Command Module Build (HyBIS Replacement).** The MPUS command module build is progressing well. The system has been designed and the majority of the hardware has been purchased.
- **Heave Compensation.** The active heave system for both the RRS *Discovery* and RRS *James Cook* Deep Tow winches have now been fully commissioned and trialled greatly improving operational capability for both HyBIS and CTD operations on the vessels.
- **Obsolescence management and system upgrades (Isis).** The Isis ROV has undergone a significant upgrade of the fibre optic telemetry system. With spares now unavailable and the existing systems showing signs of wear, a move to a new platform was essential.
- **ROV Control Container Upgrade.** The container upgrade is currently in the early stages of thought/design. The power system (Jetway) has been specified as part of the MPUS phase 2 build and will be procured after the MPUS system is up and running.

HIGH POWERED MARINE AUTONOMOUS SYSTEMS (MAS)

CURRENT CAPABILITY

- **Autosub 5.** AUV is a newly commissioned vehicle. It is 6000m depth rated and has rechargeable batteries. This high-powered AUV, developed by NOC, it has been designed to take over the routine scientific data collection previously conducted by Autosub6000. It is particularly well suited to high-resolution deep water acoustic surveys. It is fitted with the highly successful AESA camera system, and also offers reserve payload capacity for user supplied equipment.
- **C-Worker 4.** MARS purchased a C-Worker 4 Unmanned Surface Vehicle in 2018 for use as part of the fleet. Although not a high power AUV it has been purchased to support the high power AUV work. It has a modular payload bay and so will fulfil a number of roles. These include:
    - **Tracking and communications with subsurface assets.** The C-Worker is equipped with a Sonardyne USBL beacon which will allow the USV to track and communicate with Autosub 5, ALR6000, and seabed landers. This tracking should significantly improve the AUV navigational accuracy, and reduce the ship monitoring time.
    - **Shallow bathymetry surveys.** The modular payload allows an EM2040 multibeam system to be fitted for high resolution bathymetric surveys.
    - **Sensor testing.** The C-Worker can also be used for testing oceanographic sensors, e.g. the sensors being developed as part of the Oceanids programme.

UPDATE

- **Commissioning of Autosub 5.** Autosub 5 was commissioned into the NMEP in Q2 2022 and proceeded to be used highly successfully for commissioned science on JC237 in Q3 2022.
- **C-Worker 4 commissioning.** Following the purchase of the C-Worker 4 it was trialled as part of the JC166/7 expedition. Unfortunately, a number of issues were identified during this trial which needed to be rectified by the manufacturer. Re-delivery of the system was taken in Q2 2022, further trials are required before commissioning into NMEP.

UNDER WATER GLIDER PLATFORMS

CURRENT CAPABILITY

The underwater gliders within the MARS long-range fleet are listed below. However, these vehicles can be equipped with a variety of different sensors, and ancillary systems which will enhance their basic capabilities. For a full understanding of these capabilities it is necessary to speak to the engineering manager responsible for the relevant platform:

- 10 x Seagliders.
- 20 x Slocum gliders (200m & 1000m).
- 1 x University of Washington Deepglider (4000m).

UPDATE

- **Helium leak detector.** The helium leak detector is now routinely used and has successfully identified failed components before they have been deployed in the field.
- **Under ice operations.** NOC has started working with partners on the development of glider operations under ice. Significant steps forward have been made and this work will continue.
- **Commercial Operations.** The Glider team delivered commercial glider operations.

AUTOSUB 5 ONBOARD RRS DISCOVERY

LONG RANGE AUV PLATFORMS

CURRENT CAPABILITY

The long range AUVs under development for the MARS long-range fleet are listed below. These vehicles can be equipped with a variety of different sensors, and ancillary systems which will enhance their basic capabilities. These novel vehicles are not yet fully supported in the NMEP but may be accessed by the science community through collaboration with the MARS Development Group:

- 3 x Autosub Long Range 6000 (ALR6000). A 6000m rated system.
- In development : 3 x Autosub Long Range 1500 (ALR1500). A 1500m rated system with three times the energy of the ALR6000 system.

UPDATE

- **ALR Operations team.** Continued development of the ALR Operations team to help migrate the ALR systems into the NMEP and lead operations into the future.
- **Commercial operations.** First successful commercial contract undertaken, with a second planned for the summer.
- **ALR-1500 commissioning.** ALR-4, -5 & -6 have undergone commissioning trials in Loch Ness and at sea.
- **ALR 1500 long distance proving trial.** ALR-4 successfully undertook a long distance proving trial covering over 2000km testing the endurance and the 4000m echo sounder used for terrain aided navigation.
- **Sensor Integration.** Completed a number of successful bespoke integration projects showing the world leading unique nature of the ALR and NOC development and operations teams.
- Rockland Microrider Turbulence probe has been mechanically integrated into the ALR-1500.
- The Oceanids sensor program has seen 9 of NOCs Lab-On-Chip sensors deployed on ALR-2 in Loch Ness. Data could be reviewed over C2 whilst the ALR was deployed.
- Deep rated BioCam deployed on ALR-3.
- Collaboration with scientists, using ALR 2 in August 2020 to provide useful science from trials developments.
- **Enhancements to the C2 and OCS.** With the increasing use of the ALR platforms operationally the C2/OCS interface continues to improve usability.

LOW INFRASTRUCTURE AUV PLATFORMS

CURRENT CAPABILITY

- **Gavia AUV.** The Gavia AUV Freya is a small, lightweight system which can be operated from a small boat. It has a 500m depth rating and is equipped with a GeoSwath+ sonar (bathymetry and sidescan), camera system and in 2019 was upgraded with the addition of a sub-bottom profiler and a science bay with a seabird GPCTD and an Aanderaa Oxygen Optode.

UPDATE

- **Low Cost AUV Technology (LCAT) Project.** A fleet of 10 ecoSUBs were deployed in Plymouth in July 2019 as part of the Innovate UK funded LCAT project. This was used to demonstrate collaborative operation and localization of a fleet of vehicles which communicated using a low-cost acoustic modem. The goal was to create a Long Baseline (LBL) net to improve the navigational accuracy and co-ordination of these low-cost assets.
- **Gavia Deployment from the RRS *James Cook*.** The Gavia was updated with a new Sub-Bottom Profiler module, an extra battery pack and a new science bay with CTD and dissolved oxygen sensor for the JC180 cruise. During this cruise the Gavia performed well and the operational procedures for deployment from the RRS *James Cook* were refined. The Gavia can now be readily deployed from the larger research vessels.

LONG RANGE UNMANNED SURFACE VEHICLES

CURRENT CAPABILITY

The long-range unmanned surface vehicles currently available in the MARS are listed below. They are split into proven platforms, which have demonstrated their ability to reliably deliver scientific data, and experimental platforms which show promise, but are still immature. All of these vehicles can be equipped with a variety of different sensors and ancillary systems which will enhance their basic capabilities.

For a full understanding of these capabilities it is necessary to speak to the Engineering Manager responsible for the relevant platform.

PROVEN PLATFORMS

- 2 x Waveglider SV3.

LONG RANGE MAS PLATFORMS COMMAND AND CONTROL (C2)

CURRENT CAPABILITY

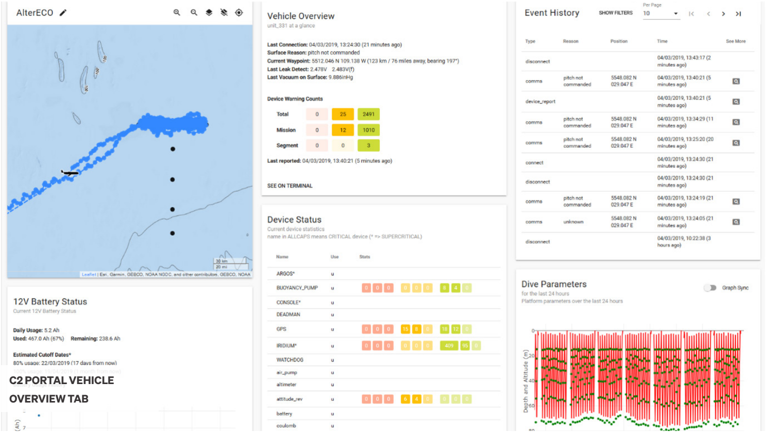
The current command and control system for the long-range fleet consists of the following components:

- ALR control interface (integrated into the unified C2 infrastructure).
- Slocum control interface (integrated into the unified C2 infrastructure).
- Seaglider control interface (integrated into the unified C2 infrastructure).
- Waveglider control interface.
- MARS portal[21].
- MARS piloting portal.

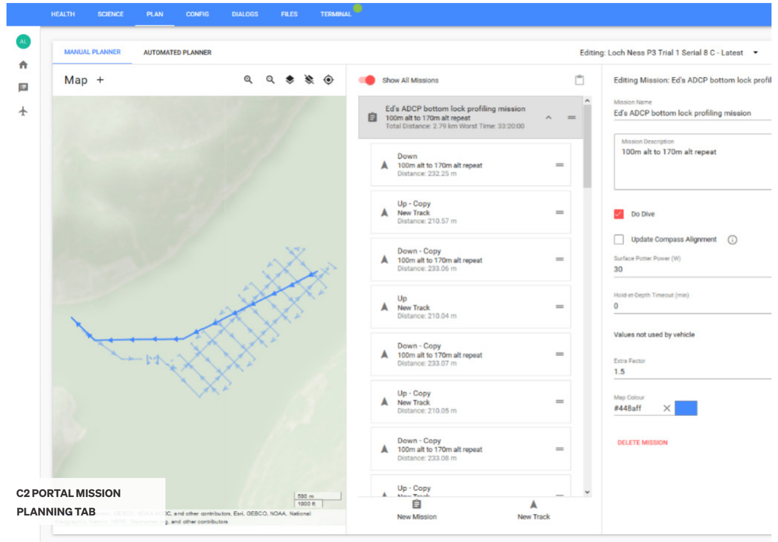
UPDATE

- **Oceanids piloting tools.** The unified Oceanids web portal has been rolled out to beta testers for piloting of Slocums, Seagliders and ALRs. Used during several trials in Loch Ness and during on-going glider operations.
- **Glider near real-time data processing.** Near real-time data from MARS gliders can now automatically be ingested into BODC, provided in EGO NetCDF format.

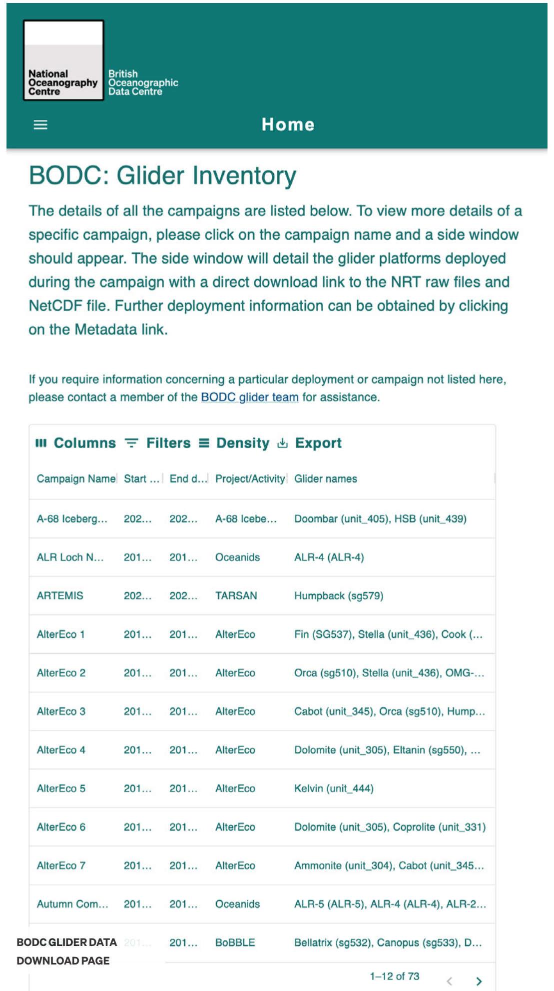
21 mars.noc.ac.uk



C2 PORTAL VEHICLE OVERVIEW TAB



C2 PORTAL MISSION PLANNING TAB



BODC GLIDER DATA DOWNLOAD PAGE

GRAVIMETERS

CURRENT CAPABILITY

- NMF Ship Scientific Systems possesses two L&R-type gravimeters: the S084 Micro-G Lacoste meter and the AT1M-12U Dynamic Gravity Systems meter.
- The AT1M-12U is an upgrade of an old S-series meter which has been modified so the beam is controlled with a full-force feedback system which locks it at the reading line of the sensor, obviating the need for a counter screw or spring tension motor. It is also equipped with an improved platform stability system that aims to give improved performance in turns and rougher weather.

MAGNETOMETERS

CURRENT CAPABILITY

- NMF Ship Scientific Systems operates one complete SeaSpy1 system with spares and one complete SeaSpy2 system with spares.

RRS DISCOVERY

SHIP-FITTED HYDROACOUSTIC SUITE AND HYDROGRAPHY SOFTWARE

CURRENT CAPABILITY

NMF Ship Scientific Systems operates on each ship, a hydroacoustic suite consisting of:

- Kongsberg EM122 Deep Water Multibeam.
- Kongsberg EM710 Multibeam.
- Kongsberg EA640 Single beam.
- Kongsberg SBP27 Sub-bottom profiler.
- Kongsberg EK80 Fisheries Echosounder.
- Kongsberg SIS.
- Teledyne CARIS.
- Teledyne RDI OS75 Acoustic Doppler Current Profiler.
- Teledyne RDI OS150 Acoustic Doppler Profiler.
- UHDAS+CODAS ADCP software.
- VMDAS ADCP software.
- Sonardyne Ranger2 USBL Underwater Positioning System.

UPDATE

- **Upgraded the SBP120 to SBP27 on both ships**. The build and test of new EK80 calibration box has been completed, with the EK60 updated to EK80 on both ships.

OCEAN AND ATMOSPHERE MONITORING

CURRENT CAPABILITY

- NMF Ship Scientific Systems supports and operates ocean and atmosphere monitoring stations on each ship. These measure wave height and direction, wind speed, wind direction, air temperature, humidity, solar irradiance, air pressure, salinity, conductivity, water temperature, flow rate, water fluorescence and transmittance through water.
- Another automated processing system takes recent CTD cast data, summarises this and transmits it to the Met Office for ingestion into forecast models.

UPDATE

- Downward pointing wave height sensor fitted to both vessels, providing a reference dataset for the wave radar. SST probe installed in the drop-keel, for direct monitoring of the SST surrounding the vessel.

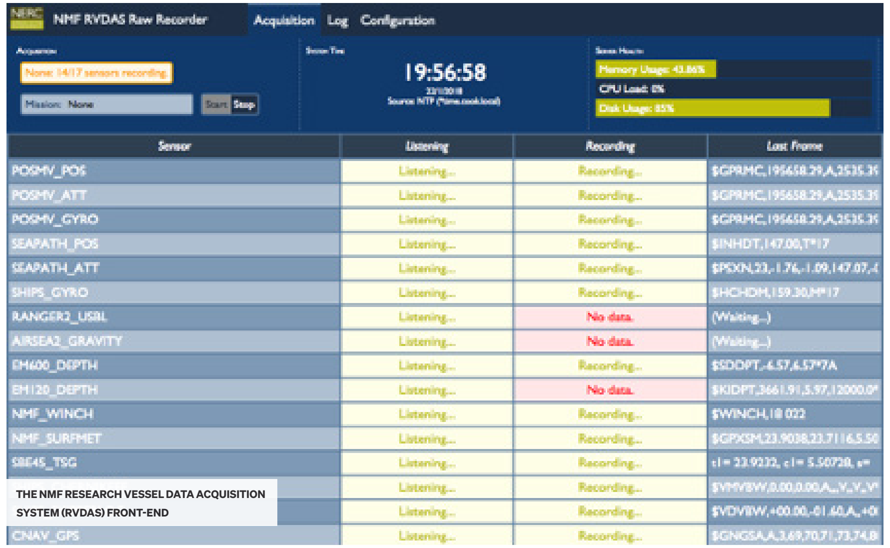
SHIP-BASED DATA ACQUISITION SYSTEMS

CURRENT CAPABILITY

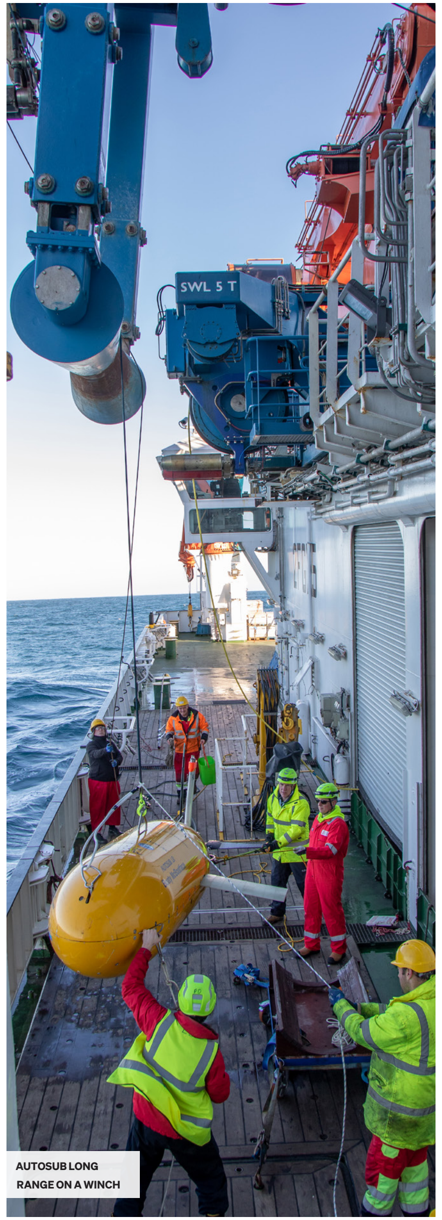
- NMF Ship Scientific Systems supports an acquisition network which collects serial and User Datagram Protocol (UDP) messages from our suite of sensors for acquisition by TECHnical Sensor Acquisition System (TECHSAS) and NMF Research Vessel Data Acquisition System (RVDAS). Position, altitude, heading, ocean and atmosphere, depth, gravity, wave radar and USBL fixes are collected by our acquisition systems.

UPDATE

- Prototype of the metadata management module has been released to the NMF and BAS ships. NetCDF data product module has been tested on the RRS *Discovery* and released to the RRS *James Cook*. Enhanced the ingestion module to acquire data streams from the seismics topsides.



THE NMF RESEARCH VESSEL DATA ACQUISITION SYSTEM (RVDAS) FRONT-END



AUTOSUB LONG RANGE ON A WINCH

WINCHES

Winches are consistently used across the full range of scientific expeditions and disciplines for the deployment and recovery of NMEP equipment and are a critical requirement for scientific delivery. To support the different requirements of NMEP and user supplied equipment, NMF has a range of portable winches as well as a suite of ship fitted winches on board both ships.

SHIP-FITTED WINCHES

CURRENT CAPABILITY

- Both ships have fitted as standard the winches listed in the table below.

UPDATE

- Active heave compensation for the deep tow winch was installed onboard RRS James Cook.

PORTABLE WINCHES

CURRENT CAPABILITY

The NMEP includes a range of portable winches including:

- 1 – 5Te general purpose winches.
- Moorings deployment winches.
- Metal free portable winches (electrical and electro-optic).
- Towed vehicle and seismic operations specific winches.

UPDATE

- Two counting sheaves have been purchased to bring the option of line out length read out capability for all winches in the NMEP.
- A second reeler winch has been purchased to allow more flexibility when planning cable installations and removals.

Winch	Maximum Operating Load	Nominal Length	Uses	Active Heave Compensation
CTD	3.36Te	8000m	CTD	JC and DY
Deep Tow	7.62Te	10000m	SVP	JC and DY
Trawl	5.20Te	15000m	HyBIS/MPUS	NA
GP (Core)	7.42Te	7000m	Secondary CTD	NA
Plasma (Deep Water Core)	30Te	8000m	Trawling / Dredging	NA

ANCILLARY EQUIPMENT AND FACILITIES

CALIBRATION LABORATORY

CURRENT CAPABILITY

NMF currently has a bespoke ocean instrument calibration facility, traceable to National Standards, open to internal and external customers and capable of high-quality temperature, conductivity, salinity, and pressure calibrations. NMF seeks to maximise the use of the Calibration Laboratory by NOC teams and reduce the volume of equipment calibration subcontracted outside of NMF within the resource capacity of the facility.

UPDATE

- The facility achieved full ISO9001 accreditation in April 2022.
- A further 300L bath has been procured, increasing the capacity of the facility to support the requirements of the Glider Servicing Centre. This model of fluid bath is of fibreglass construction, chosen specifically to address issues of corrosion of Slocum glider science bays during calibration due to stainless steel fluid baths, without the need for separate sacrificial anodes.
- The NOC calibration laboratory is a one of the 16 participating facilities in the Metrology for Integrated Marine Management and Knowledge-transfer Network (MINKE), providing transnational access to metrological validation facilities.

CONTAINER LABORATORIES

CURRENT CAPABILITY

Container laboratories are used to supplement the laboratories on board both vessels. The NMEP currently holds the following container laboratories:

- 3 x Clean chemistry laboratory containers.
- 2 x Radionuclide laboratory containers.
- 2 x Refrigerated containers.

ACRONYMS

ACSIS
North Atlantic Climate System Integrated Study

ADCP
Acoustic Doppler Current Profiler

AHRS
Attitude-Heading Reference System

ALR
Autosub Long Range

AMT
Atlantic Meridional Transect

ASSS
Autonomous Surface / Subsurface Survey System

AUV
Autonomous Underwater Vehicle

BAS
British Antarctic Survey

BODC
British Oceanographic Data Centre

CAPASOS
Calibrated pCO2 in Air and Surface Ocean Sensor

CARCASS
Carbonate Chemistry Autonomous Sensor System

CODAS
Common Ocean Data Access System

COTS
Commercial Off The Shelf

CTD
Conductivity, Temperature and Depth

DVL
Doppler Velocity Log

EGO
Everyone's Gliding Observatories

EOV
Essential Ocean Variable

ERDDAP
Environmental Research Divisions Data Access Program

FAIR
Findable, Accessible, Interoperable and Reusable

FAT
Factory Acceptance Testing

GEBCO
General Bathymetric Chart of the Oceans

HAT
Harbour Acceptance Testing

HYBIS
Hydraulic Benthic Interactive Sampler

ICOS
Integrated Carbon Observation System

IMS
Inventory Management System

INS
Inertial Navigation System

LBL
Long Baseline

MARS
Marine Autonomous and Robotic Systems

MAS
Marine Autonomous Systems

MEMS
Micro-electromechanical Systems

MPUS
Modular Payload Underwater System

NERC
Natural Environment Research Council

NETCDF
Network Common Data Form

NMEP
National Marine Equipment Pool

NMF
National Marine Facilities

NOC
National Oceanography Centre

NRT
Near-Real-Time

OAS
Obstacle Avoidance System

OCS
On-board Control System

OEM
Original Equipment Manufacturer

OS
Ocean Surveyor

OTEG
Ocean Technology and Engineering Group

PCA
Post-Cruise Assessment

RAFOS
RAFOS is the word SOFAR spelled backwards

SOFAR
SOund Fixing And Ranging

RINGO
Readiness of ICOS for Necessities of Integrated Global Observations

ROP
Remotely Operated Platform

ROS
Robot Operating System

ROV
Remotely Operated Vehicle

RVDAS
Research Vessel Data Acquisition System

SBP
Sub Bottom Profiler

SME
Ship-time & Marine Equipment Application Form

SURFMET
Surface Water and Meteorological Monitoring System

UDP
User Datagram Protocol

UHDAS
University of Hawaii Data Acquisition System

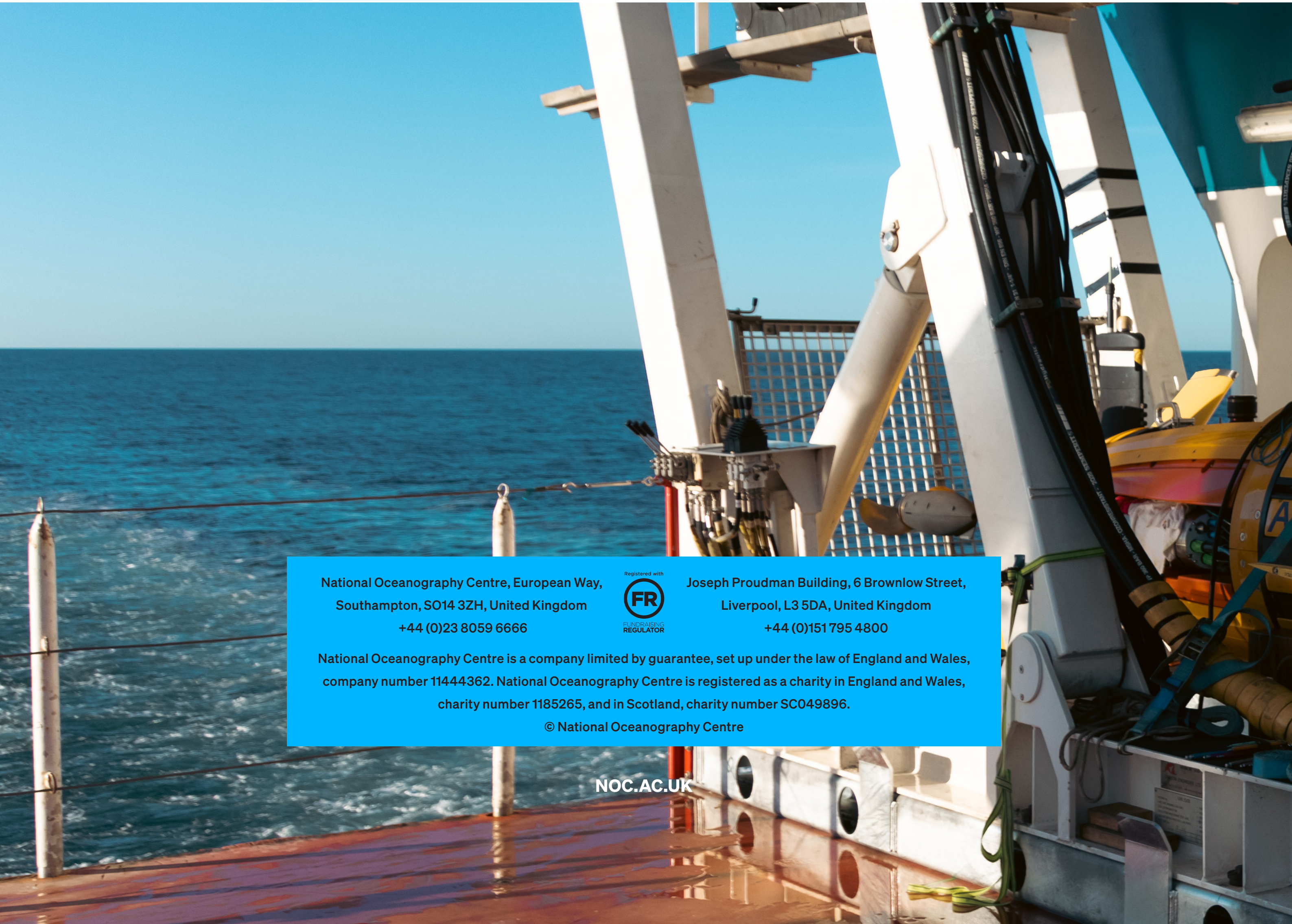
USBL
Ultra-Short Base Line

USV
Unmanned Surface Vehicle

LRAUV
Long Range Autonomous Underwater Vehicle

WCB
Western Core Box

WHOI
Woods Hole Oceanographic Institution



National Oceanography Centre, European Way,
Southampton, SO14 3ZH, United Kingdom
+44 (0)23 8059 6666

Joseph Proudman Building, 6 Brownlow Street,
Liverpool, L3 5DA, United Kingdom
+44 (0)151 795 4800

NOC.AC.UK