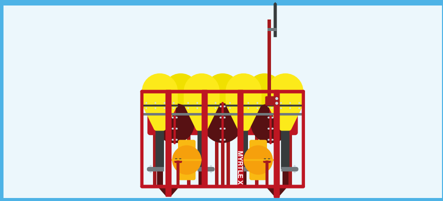
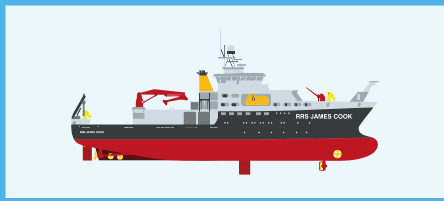
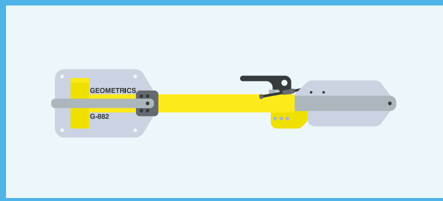
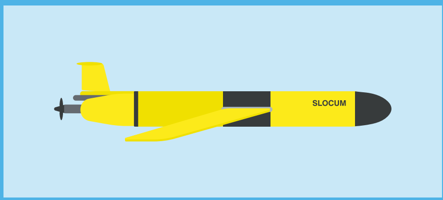
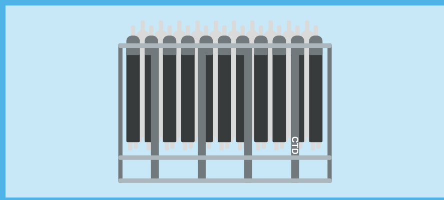
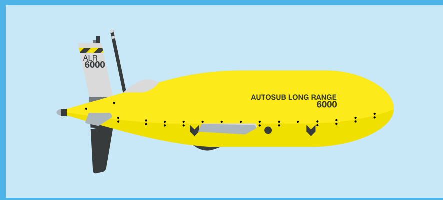


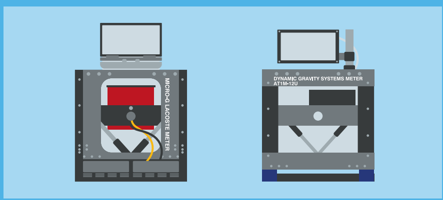


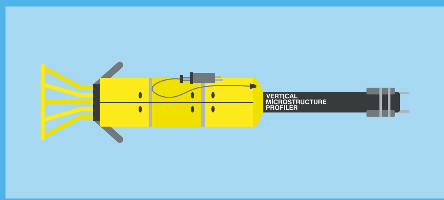


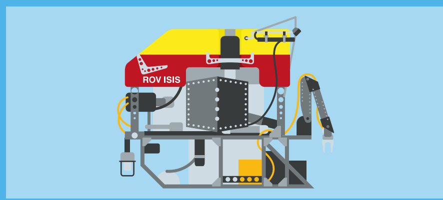






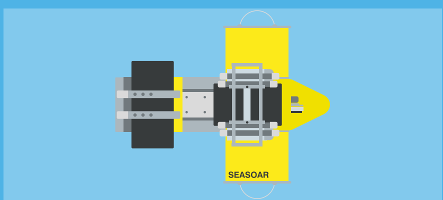


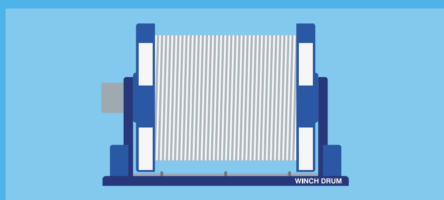


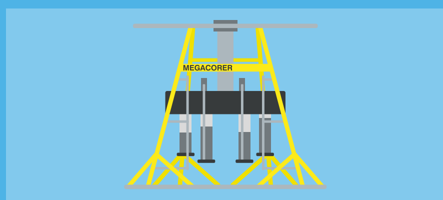


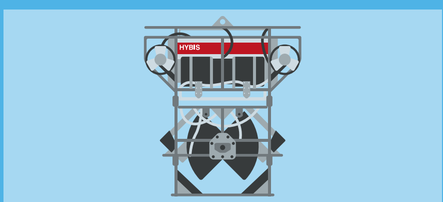
NATIONAL MARINE FACILITIES

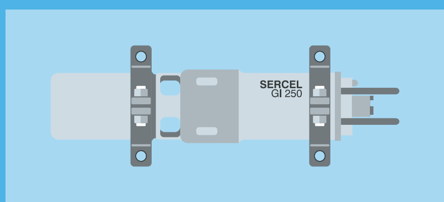
TECHNOLOGY ROADMAP 2020/21

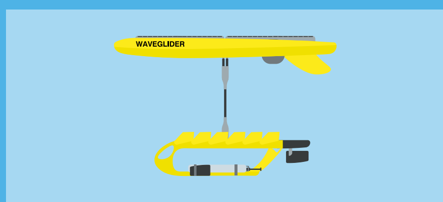


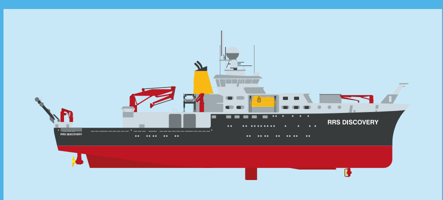


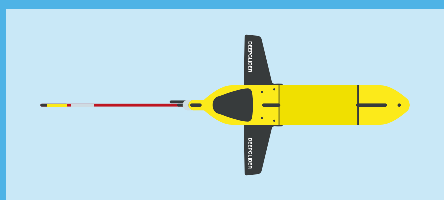


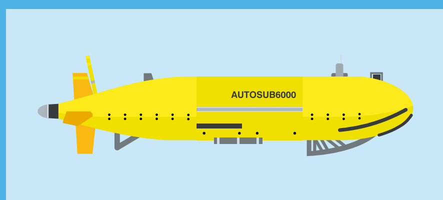












National Oceanography Centre | National Marine Facilities

UKRI Natural Environment Research Council

noc.ac.uk/facilities

EXECUTIVE SUMMARY

The National Marine Facilities (NMF) Technology Roadmap 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 and its constituent parts.

The 2020/21 refresh of the roadmap incorporates new components around deployment planning, data curation and the development of the research ship capabilities. These elements were added to provide a full picture of the support provided to the UK marine science community by NMF and the British Oceanographic Data Centre (BODC).

TABLE OF CONTENTS

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/Sub-surface Survey System
AUV . . . Autonomous Underwater Vehicle
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
LRAUV . . . Long Range Autonomous Underwater Vehicle
MARS . . . Marine Autonomous and Robotic Systems
MEMS . . . Micro-electromechanical Systems
MPUS . . . Modular Payload Underwater Systems
NetCDF . . . Network Common Data Form
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 . . . SOFAR (SOund Fixing And Ranging) spelled backwards
RINGO . . . Readiness of ICOS for Necessities of Integrated Global Observations
ROP . . . Remotely Operated Platform
ROS . . . Robot Operating System
RVDAS . . . Research Vessel Data Acquisition System
SBP . . . Sub Bottom Profiler
SME . . . Ship-time & Marine Equipment Application Form
UDP . . . User Datagram Protocol
UHDAS . . . University of Hawaii Data Acquisition System
USBL . . . Ultra Short Baseline
USV . . . Unmanned Surface Vehicle
WCB . . . Western Core Box
WHOI . . . Woods Hole Oceanographic Institution

1 INTRODUCTION

1.1.1 NATIONAL MARINE FACILITIES

The aim of National Marine Facilities (NMF), part of the National Oceanography Centre (NOC), 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); a collection of over 10,000 instruments and technologies for deployment both from and independently of research vessels.

1.1.2 NMF STRATEGIC GOALS

- To provide the UK Marine Science community with access to the most advanced oceanographic research ship fleet in the world (tonne for tonne) to enable discovery and strategic science.
- To be a world leader in the integrated provision of scientific technology for marine science, with effective deployments, novel capabilities and strong partnerships.
- To train and retain our staff thereby embedding technical excellence and resilience and develop additional capacity.
- To develop strong internal and external partnerships which leverage both our expertise in managing major platforms and observing systems and our strengths in technological development.

1.1.3 HOW NMF ENGAGES WITH THE UK MARINE SCIENCE COMMUNITY

The NMF team works with the UK marine science community, through the National Oceanography Centre Association (NOCA), the Marine Facilities Advisory Board (MFAB) and the Cruise Programme Executive Board (CPEB). These are key channels[1] through which the community can discuss topics and raise, for example, the need for new capabilities for inclusion in the NMEP.

1.1.4 THE NMF TECHNOLOGY ROADMAP

Against a backdrop of tight budgets, rapid technical development, big data and the increasing use of Marine Autonomous Systems (MAS), 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. Working closely with the British Oceanographic Data Centre (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) and the upcoming United Nations Decade of Ocean Science for Sustainable Development.

NMF was commissioned by the NERC in 2018 to operate the RRS *James Cook* and the RRS *Discovery*, the NMEP and the associated planning, logistical, maintenance and repair functions. NMF receives additional capital funding from NERC to replace, refurbish, upgrade and further develop the ship fitted scientific equipment and the 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, the MFAB provides advice to NMF with regards to its strategy for the equipment portfolio it operates and further provides guidance regarding new and emerging requirements.

Within the five year horizon of this Technology 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

[1] In addition, feedback and enquiries are welcome at any time through nmfops@noc.ac.uk

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. In the short term this can be achieved by leveraging the multi-role nature of the UK's research ships, e.g. by mapping the seabed and collecting atmospheric samples at every opportunity whilst fulfilling the primary purpose of the scientific research expedition being delivered. Over the medium term, upgrades to ship hulls and machinery will improve efficiencies alongside the combined operation of multiple, ship-deployed and MAS sensors. Longer term, the next generation of semi-autonomous research ships will utilise novel energy sources, electrical distribution systems and methods of propulsion as well as robotics, MAS, communication systems and advanced manufacturing techniques to meet those targets.

The importance of data management within the NMF Technology Roadmap is highlighted by both goal four of the NOC strategy[2], and the focus on data themes at OceanObs'19 which resulted in the conference statements[3]:

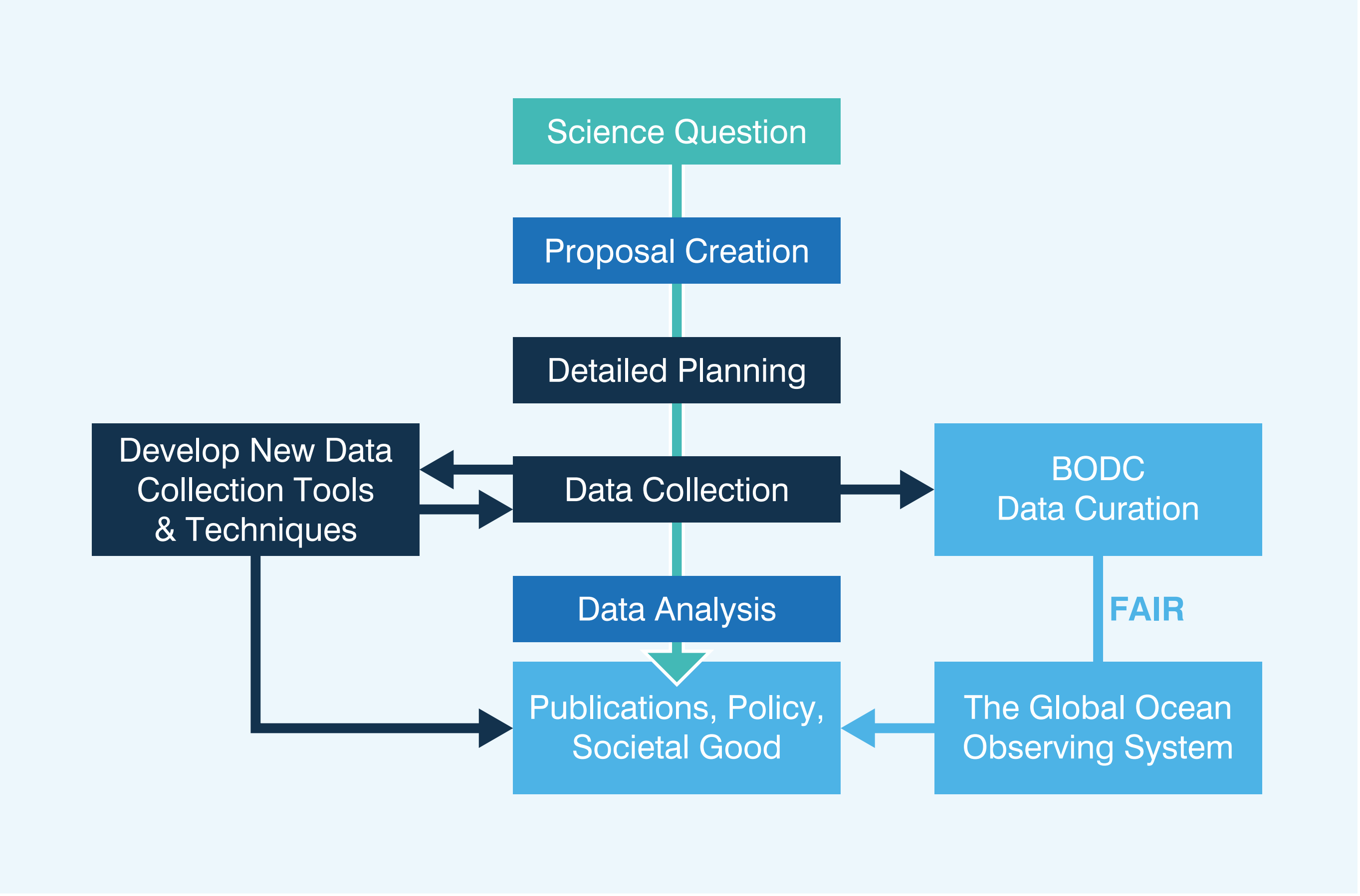
- "Ensure that all elements of the observing system are interoperable, and that data is managed wisely, guided by open data policies and that data are shared in a timely manner"
- "Use best practices, standards, formats, vocabularies, and the highest ethics in the collection and use of ocean data"

In recent years, BODC and NMF have worked closely under the Oceanids C2 programme, 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 introduces a section on data management and practices that will evolve and develop further in future iterations.

[2] https://noc.ac.uk/files/documents/about/noc-strategy.pdf
[3] http://www.oceanobs19.net/statement/

1.1.5 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' 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.

1.1.6 PLANNING

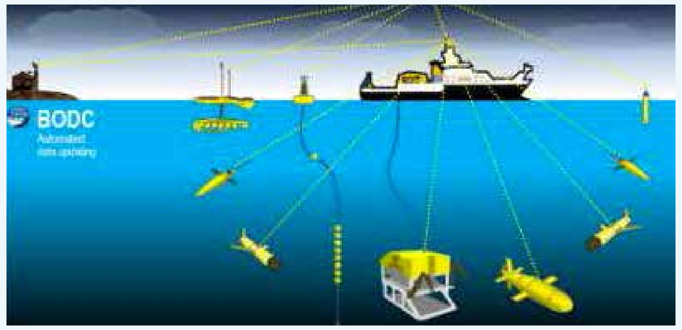
This 'screen' will captured the planning phase for both ship and autonomous platforms. This capability will be built on the existing Marine Facilities Planning website. It is envisaged that the planning phase metadata will flow to the Real Time Control, Real Time Display and Data Archive systems.

1.1.7 REAL TIME CONTROL

Once a system is deployed the real time control system will provide the interface to monitor and control to the platform. 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 Remote Operated Vehicle (ROV) virtual control room concept, and other deployed and controllable assets, such as moorings.

1.1.8 (NEAR) REAL-TIME DATA DISPLAY

Closely aligned with the Real Time Control system, the (Near) Real-Time Data Display will be a 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).



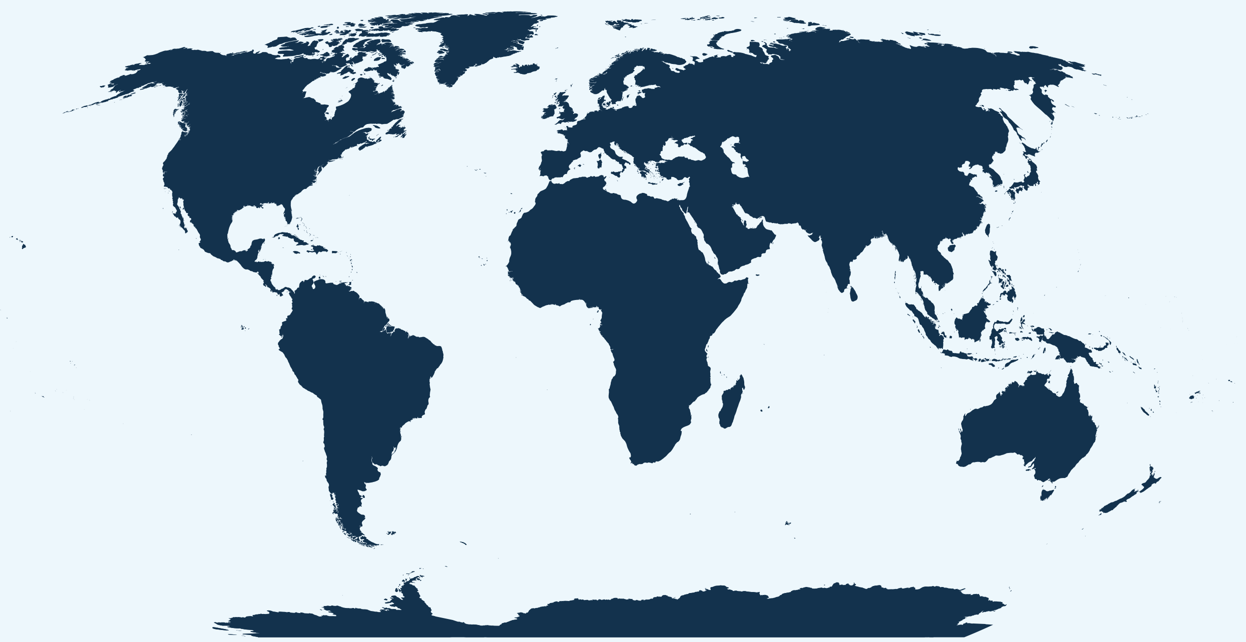
1.1.9 DATA ARCHIVE

The Data Archive 'screen' would allow access to previously collected near real-time data and the delayed mode data as per the FAIR (Findable, Accessible, Interoperable and Reusable) data principles. This would be developed based on the BODC infrastructure.

1.2 ESSENTIAL OCEAN VARIABLES & 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.

DISSOLVED ORGANIC CARBON • FISH ABUNDANCE AND DISTRIBUTION • HARD CORAL COVER AND COMPOSITION • INORGANIC CARBON • INVERTEBRATE ABUNDANCE AND DISTRIBUTION (EMERGING) • MACROALGAL CANOPY COVER AND COMPOSITION • MANGROVE COVER AND COMPOSITION • MARINE TURTLES, BIRDS, MAMMALS ABUNDANCE AND DISTRIBUTION • MICROBE BIOMASS AND DIVERSITY (EMERGING) • NUTRIENTS • NITROUS OXIDE • OCEAN COLOUR • OCEAN SOUNDS • OCEAN SURFACE HEAT FLUX • OCEAN SURFACE STRESS • OXYGEN • PARTICULATE MATTER • PHYTOPLANKTON BIOMASS AND DIVERSITY • SEA ICE • SEA STATE • SEA SURFACE HEIGHT • SEA SURFACE TEMPERATURE • SEAGRASS COVER AND COMPOSITION • STABLE CARBON ISOTOPES • SUBSURFACE CURRENTS • TRANSIENT TRACERS • ZOOPLANKTON BIOMASS



1.3 DOCUMENT STRUCTURE

The NMF Technology Roadmap is updated annually to reflect the ambitions of NMF to meet its remit. The NMF Technology Roadmap is structured to present sequentially each area of capability, categorised as follows:

I. **Essential Ocean Variables**
Describes how the capability maps on the GOOS EOVs.

II. **Current Capability**
A description of the current capability in that area.

III. **Science Community Drivers**
An overview of the science and operational pulls requiring process and technology developments.

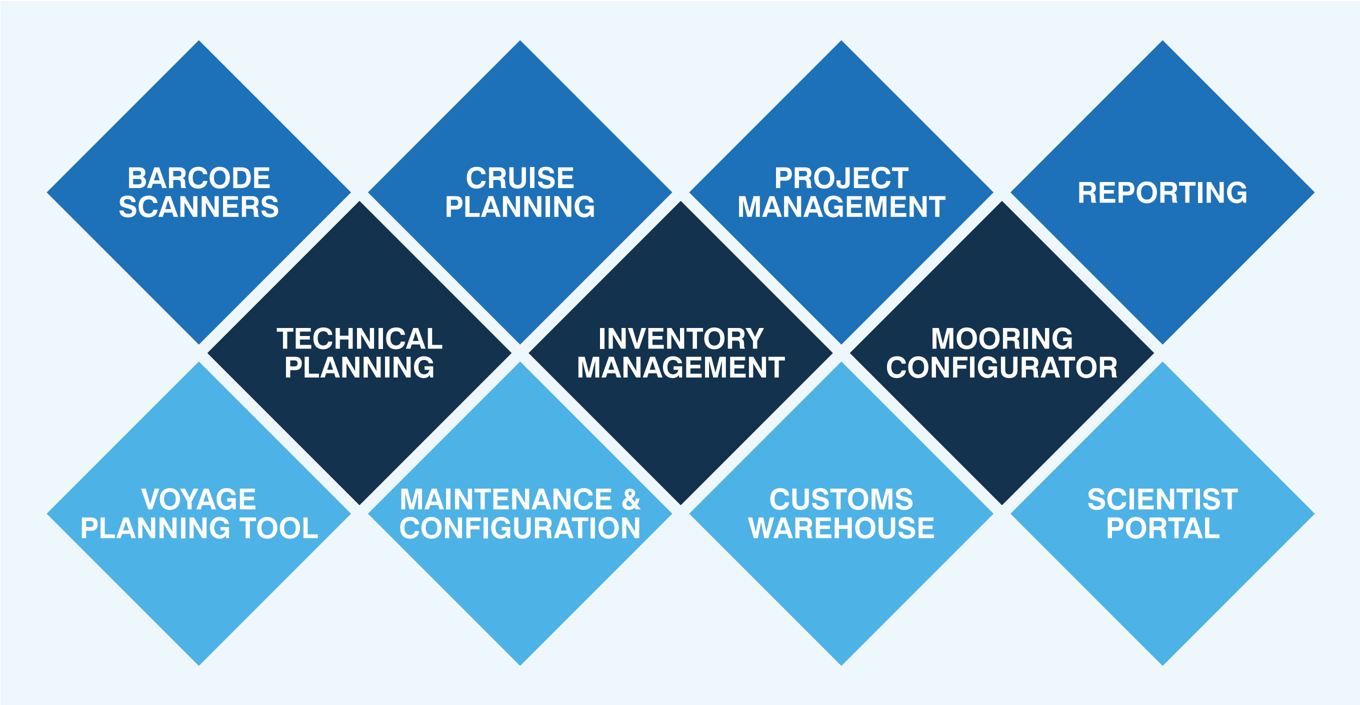
IV. **Future Capability**
Developments that are planned and have associated funding in place.

V. **Aspirations**
Potential future capabilities for which funding will be sought.

VI. **2019/20 Update**
Brief overview of progress developing enhanced capabilities since the previous issue of the NMF Technology Roadmap.

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.

2 MARINE FACILITIES PLANNING PORTAL



2.1 CURRENT CAPABILITY

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

- **Programme 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)**
  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 HM Revenue and Customs (HMRC) customs requirements of the NOC.

- **Personnel Planning Module**
  Used to assign technicians to different expeditions in the programme, whilst highlighting when individuals are nearing or exceeding acceptable days on duty at sea.

- **Programme Construction Module**
  Used in the development of the programme, clearly highlighting constraints for equipment and personnel.

- **Project Management Module**
  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 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.

2.2 SCIENCE COMMUNITY DRIVERS

- **Simplify Use**
  It is desirable to continue to simplify access to the system and improve the user experience when using the Marine Facilities Planning Portal (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.

2.3 FUTURE CAPABILITY

- **Maintenance Improvements**
  Periodic maintenance is recorded for equipment within IMS, but there is not currently the ability to add corrective maintenance or record failure events to give a full work history. Additionally, administration of equipment maintenance must be done on a computer rather than in the mobile application. In 2020, IMS will be upgraded to include corrective maintenance and failure recording, and will be incorporated into the mobile application to provide portable/in-situ access to equipment history, documentation and recording capability.

- **Personnel Capabilities**
  Recording of personnel training is necessary for both individual progression and to assure the technicians embarked on an expedition are suitably qualified and experienced to safely and effectively complete the tasks required at sea. A new personnel capabilities module is in development, which will be used to document the syllabus required to achieve tier 1 and 2 competence in each identified NMF capability, and an individual's progression to achieving this competence. In 2020 this will only be introduced for NMF technicians only but is planned to be extended to mariners once completed.

2.4 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 the NOC business management system; UNIT4. 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.

- Develop the MFP mobile application to simplify using the software in the field, in the workshops, and when away from a computer.

- 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 the section 3, Data Management and Practices, and section 16, Long Range MAS Platforms Command and Control (C2). Further integration into the NOC business management system will further streamline workflows reducing the operational costs of managing the system.

2.5 2019/20 UPDATE

Development of the personnel capabilities module has progressed in 2019, with alpha testing ongoing and due to be completed in 2020.

3 DATA MANAGEMENT AND PRACTICES

3.1 CURRENT CAPABILITY

- Operational Oceanids C2 workflow for near real-time data from gliders and recovered data from Autosub Long Range (ALR) 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 the 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 lifecycle of marine science data from NERC Research Vessels and autonomous platforms.

3.2 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[4] and Ocean Best Practices[5].
- Recommendations from OceanObs'19 and Research Data Alliance for integrated scientific data workflows[6].
- UN Decade of Ocean Science for Sustainable Development and Sustainable Development Goal #14.
- NERC Digital Environment strategic goal.

3.3 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.

3.4 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

[4] https://www.frontiersin.org/articles/10.3389/fmars.2019.00440/full
[5] https://www.frontiersin.org/articles/10.3389/fmars.2019.00277/full
[6] http://www.oceanobs19.net/wp-content/uploads/2019/09/OO19-Conference-Statement_online.pdf

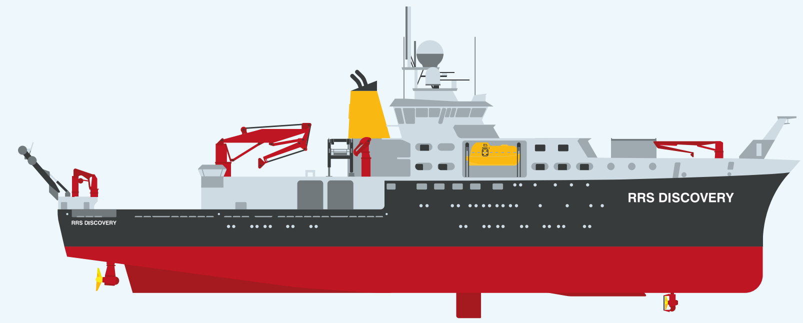
delivery of quality swath bathymetry to GEBCO Seabed 2030.

- Facilitate open data sharing and integration with other sensor networks through enabling Application Programming Interfaces (e.g. National Oceanic and Atmospheric Administration Environmental Research Divisions Data Access Program (ERDDAP), 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.
- Investigate integrating NMF's cruise planning system with BODC's Cruise Inventory to reduce potential duplication of effort.
- Enhancing the quality control and assurance 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.

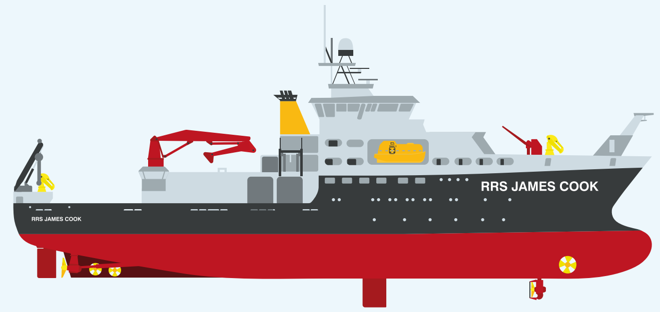
3.5 2019/20 UPDATE

- Oceanids C2 workflow for near real-time data from gliders and recovery data from Autosub Long Range became operational, including delivery of open data via the web.
- Bidding for resource to fund the development of automated near real-time data from research vessel initiated. 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.

4 RESEARCH VESSELS



RRS *DISCOVERY*



RRS *JAMES COOK*

4.1 CURRENT CAPABILITY

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

- Hydroacoustic surveys
- Clean seawater sampling
- Integrated data logging
- CTD surveys

- Deep water coring, towing and trawling
- Adaptable laboratory space
- Seismic surveys
- ROV operations

4.2 SCIENCE COMMUNITY DRIVERS

- During seismic operations where twin acoustic sources are towed, 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.
- 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 highly desirable.

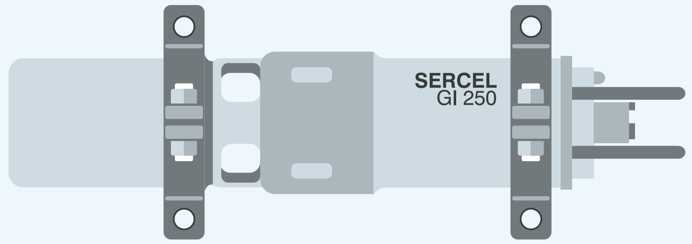
4.3 FUTURE CAPABILITY

Negotiation of long term service agreements with Original Equipment Manufacturer (OEMs) to assure service requirements and reduce costs associated reactive use.

4.4 ASPIRATIONS

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

5 SEISMICS



SERCEL GI 250 AIRGUN

5.1 CURRENT CAPABILITY

- Bolt 1500-LL airguns
- Sercel GI 250 airguns
- 2.4 km multichannel streamer, extended to 3 km where required through hire of remaining 600m length
- Big Shot fire control system
- Avalon RSS-2 array source control 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, providing no advance in capability since the 1980s. There are limitations with the volume of source that can be deployed and streaming and recovery are slow. The multichannel streamer purchased remains up to date and in line with industry use.

5.2 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.

- **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. GI guns deliver a much sharper waveform via a two stage firing process.

- **Improved reliability**
  The system of beam deployed airgun arrays with a pneumatic umbilical is unreliable and can incur failures while firing often resulting in a change of source level while in mid seismic line. Airgun repair then requires a break in science to recover and fix. A J-rail deployment system and buoy mounted gun arrays coupled with the much smaller recoil of GI guns would greatly reduce the mean time between failures and enable faster repairs.

- **Reduce wake interference**
  The twin propulsion designs of the RRS *James Cook* and the 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. GI 250 airguns can be reconfigured quickly by the use of an inexpensive plastic insert giving a Principal Investigator an almost unlimited choice of source configurations.

5.3 FUTURE CAPABILITY

In 2020 a full refurbishment of the Bolt 1500-LL system and compressors is in progress, with trials scheduled in 2020 in preparation for scientific use in 2021. This seeks to not only extend the service life, but to address some of the issues around the stability and reliability of the acoustic source. It also includes the revision of operating procedures to improve the efficiency and safety of equipment handling on deck. Improvements and additions to real time data streaming will also be trialled.

5.4 ASPIRATIONS

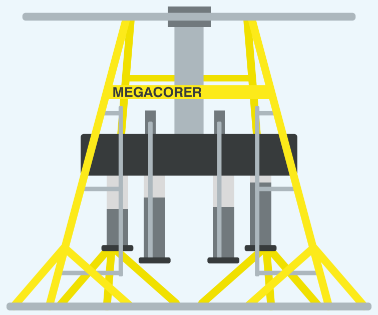
In 2018 the findings of the seismics working group were submitted to the Cruise Programme Executive Board (CPEB) proposing the investment of ~£2M to upgrade the seismic source, handling and towing systems for the Sercel G series guns to provide:

- A versatile, highly configurable seismic airgun source comprising up to 24 individual airguns.
- A source tow depth and geometry control system capable of supporting different scientific applications.
- A versatile and adaptable seismic source deployment system, deployable from Ocean Facilities Exchange Group partner research vessels as well as NERC's fleet, in full or in part

- A full suite of potential field sensing systems, appropriate to fixed and mobile installation on any of the global fleet of scientific research vessels.
- A high resolution, short streamer shallow sub-seabed imaging capability.

An upgrade of this type would allow the retirement of the aging Bolt 1500-LL guns. If this upgrade is completed the extension of the multichannel streamer up to 9,000m would allow the measurement depth to be extended beyond the existing 3,000m limitation.

6 SAMPLING



MEGACORER

6.1 CURRENT CAPABILITY

The NMEP sampling capability is primarily coring, with eight different types of corer with both tubular and box varieties available.

- **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
  - 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

6.2 SCIENCE COMMUNITY DRIVERS

- Enduring requirement for deep sea benthic sampling.
- Accuracy of sampling. A lot of time is taken lowering sampling systems with no accurate inspection of the sampling site.

6.3 ASPIRATIONS

- A 40m piston corer utilising a bespoke handling and deployment system.
- Potential development of a precision coring system deployable using HyBIS platform.
- A wire mounted camera system to view and record sampling sites.

7 MOORINGS

7.1 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

7.2 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 (Conductivity, Temperature and Depth)
- Dissolved oxygen sensors
- Transmissometers
- Backscatter meters

7.3 SCIENCE COMMUNITY DRIVERS

- Capability to deploy the next generation of low drift bottom pressure landers.
- Improved ability to measure the upper 50m of the water column where ocean/atmosphere interaction is most evident.
- Improved reliability in trawl resistant mounts/landers.
- 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.
- The ability to recover moorings weights to better align with the NOC value of environmental responsibility.

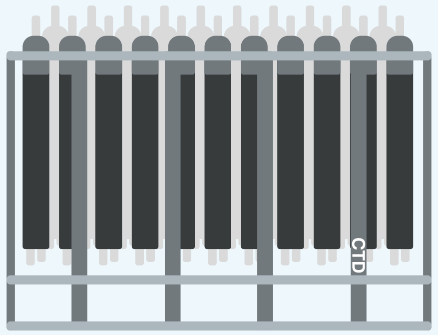
7.4 FUTURE CAPABILITY

A moorings module in the MFP has been developed for the design and costing of bespoke moorings. The module will be tested in 2020 for implementation once proven.

7.5 ASPIRATIONS

- In collaboration with Marine Autonomous Robotics Systems (MARS), investigate the benefits and feasibility of the development of in-situ moored power sources to enable recharging of AUVs and prolong their deployment duration.
- Develop a suitable smoke beacon that will withstand full ocean depth and activate on return to surface, either by pressure or conductivity, to provide a clear locator (better than a flag or strobe in daylight).
- Design syntactic float collars for specific and individual items that would reduce the use of inline glass in moorings for reducing mooring length in certain situations.
- Procure a two-way telemetry system for moorings to allow real-time data transmission and modification of sampling routines during a deployment.

8 CONDUCTIVITY, TEMPERATURE AND DEPTH (CTD)



CTD

8.1 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

8.2 CURRENT CAPABILITY

The NMEP has both stainless steel and titanium CTD systems and is capable of completely trace metal free sampling (in conjunction with portable MFCTD winches). CTD 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, Photosynthetically Active Radiation (PAR) and water velocity. They can be deployed to full ocean depth (6,000m).

8.3 SCIENCE COMMUNITY DRIVERS

- Data derived from bottle samples collected with CTD sampling frames and from the associated sensors are fundamental to all fields of oceanography and likely contribute >75% of the biogeochemistry and physical oceanographic science delivered at sea. 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.

- In-situ real time measurements of pCO2 and pH, high resolution nutrient profiling and fuller optical characterisation of both dissolved and particulate constituents are beginning to become feasible and/or 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 NC/strategic programmes.

8.4 FUTURE CAPABILITY

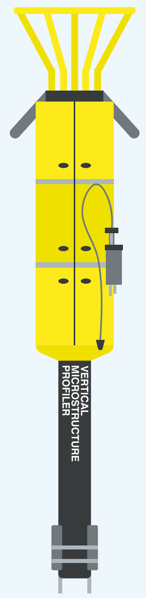
- Full ocean depth carbonate system sensors with rapid response times have been purchased with the intention to trial CTD sampling frame incorporation during the Porcupine Abyssal Plain (PAP) observatory in 2020. If successful they will be included in the NMEP.

- An Underwater Vision Profiler (UVP) is scheduled to be deployed from the RRS *Discovery* in 2020. The benefits of this sensor will be evaluated in during this expedition for the potential inclusion into the NMEP, possibly by incorporation into CTD sampling frames.
- Where possible new CTD sampling frame sensors procured are Ti instruments for trace metal free sampling with a deeper rating (10,500m).

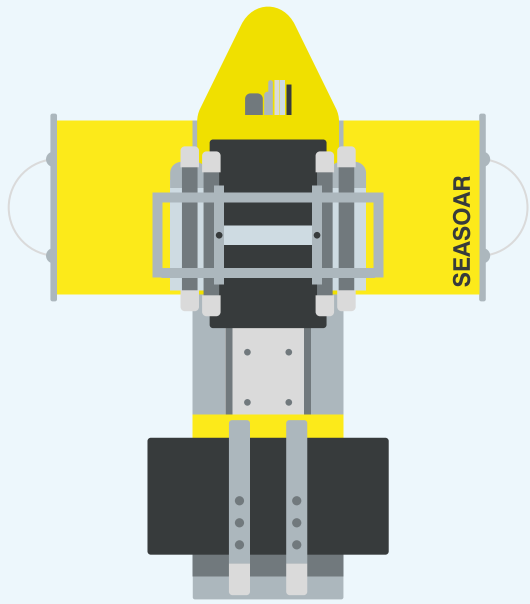
8.5 ASPIRATIONS

Continued use and development of CTD sampling frame swivels to prevent cable torque, improve ship cable life and reducing cost.

9 STATIONARY AND TOWED PROFILING BODY SAMPLING



VERTICAL MICROSTRUCTURE PROFILER (VMP)



SEASOAR

9.1 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

9.2 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.

- **2 x Vertical Microstructure Profiler 6000 (VMP6000)**
  An untethered, autonomous system for the measurement of turbulence microstructure and CTD in a vertical profile of up to 6,000m. 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)**
  A tethered system for the measurement of turbulence microstructure and CTD in a vertical profile of up to 2,000m. As a tethered capability data can be transmitted in real time.

- **2 x ISW Microstructure Profiler (MSS90L)**
  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 VMP 500 when the sample area is less than 500m.

- **SeaSoar**
  A towed vehicle for the measurement of CTD, dissolved oxygen, turbidity, irradiance, bioluminescence, fluoresence and plankton at vessel speeds of up to 12 knots and up to 420m depth. 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)**
  A towed vehicle for the measurement of CTD, chlorophyll concentration and light intensity at speeds of up to 8 knots and up to 300m depth. 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**
  A towed vehicle for the measurement of high quality CTD, dissolved oxygen and bottom depth, at speeds of up to 10 knots in a 200m range at up to 500m. 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.

9.3 SCIENCE COMMUNITY DRIVERS

- There is a continued requirement for profiling of large scale areas in short time frames that make CTD sampling frame profiling unfeasible. The speed and scale of profiling presented with towed vehicles 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.

- Availability of Marine Snow Catchers (MSC) to the scientific community, with trace metal free capability.

9.4 FUTURE CAPABILITY

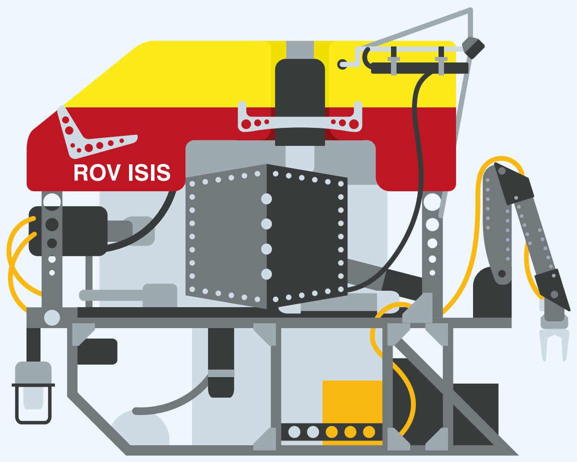
- A new triaxis motion reference unit is in development for integration in to SeaSoar to allow higher resolution data acquisition from the vehicle.

- A third VMP6000 has been purchased for delivery in 2020 to allow greater flexibility and redundancy during 24 hour operations and/or availability in the NMEP.
- After positive review at the 2019 MFAB capital call, it is intended to bring the MSC in to the NMEP in 2020 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.

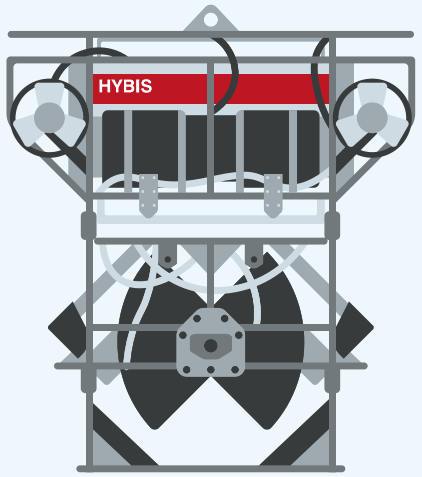
9.5 ASPIRATIONS

- The development of a lower cost deployment option for the towed body with capabilities held.
- Develop a current meter for use on the Vertical Microstructure Profiler 6000.
- Evaluate the feasibility of using synthetic conducting ropes for the towed vehicle fleet (SeaSoar and Scanfish).

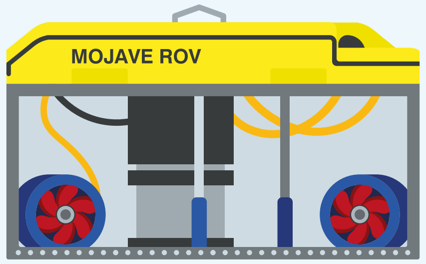
10 REMOTELY OPERATED PLATFORMS (ROP)



ISIS ROV



HYBIS RUV



MOJAVE ROV

10.1 ESSENTIAL OCEAN VARIABLES

The Essential Ocean Variables (EOV) descriptions do not easily map onto the ROV's capabilities as it depends partly on the vehicle sensor fit, but mainly on the experiments deployed by the ROV. The typical EOVs collected using the vehicles standard sensors are:

- 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 EOV that feed into the global ocean observing systems.

10.2 CURRENT CAPABILITY

- ***Isis* Remotely Operated Vehicle (ROV)**
  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 6,000m 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)**
  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 setup 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 Remotely Operated Vehicle (ROV)**
  A small shallow water (300m) rated system. It is equipped with lights, cameras, and a three function manipulator arm.

10.3 SCIENCE COMMUNITY DRIVERS

- **Reduce operating costs (*Isis*)**
  Isis is a large complex deepwater ROV system, and, although highly effective compared to similar systems used by other institutes, it is expensive to run both in terms of consumables and labour. To maximise the utility of the vehicle to the community, these costs should ideally be reduced.
- **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 to create a virtual control room, the number of people who can engage with and potentially guide the vehicle deployments can be increased. A virtual control room would also provide outreach opportunities and could be supported in the operations room within the Innovation Centre at the National Oceanography Centre in Southampton.
- **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.

- **Extend operational capabilities (HyBIS)**
  The current payload modules for HyBIS provide a limited set of options to the community. By developing new payload modules (e.g. precision push cores, mooring weight recovery system) the utility of the platform will increase.

10.4 FUTURE CAPABILITY

- **ROV virtual control room**
  Currently, it is possible to create a virtual control room, but this requires significantly higher bandwidth which is expensive. However, as it is intended to upgrade the ship's data link to 2MB/s this should provide enough bandwidth to create a simple virtual control room. As the ship's uplink (ship to shore) is not utilised to the same level as the downlink, streaming live data from the ROV to shore should be achievable. This work will be done in collaboration with the Scientific Ship Systems group.

- **ROV power supply replacement**
  The ROV (Jetway) power supply unit is the original system acquired for the ROV, and is coming to the end of its life. The replacement unit will be looked at in the broader context of power supplies for the remotely operated platforms supported by the group, and operated from the ship.

- **ROV control software upgrades**
  The existing ROV software is still based on the early Jason 2 code from the Woods Hole Oceanographic Institution (WHOI). 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.

- **Modular Payload Underwater Systems (MPUS) command module upgrade (HyBIS)**
  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 will be 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 Payload Underwater System (MPUS).

- **Active heave compensation (AHC) for MPUS (HyBIS)**
  MPUS is an extremely flexible platform and allows precise control at the seabed; however, as it is directly coupled to the ship it is affected by the ship's motion. Heave compensation on the deep tow winches on the RRS *Discovery* and the RRS *James Cook* would greatly reduce this effect and would make the system more broadly useable.

- **MPUS recovery payload module (HyBIS)**
  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 will be created with the associated detailed interface document. This will be produced to enable custom payload designs to be created by external users.

10.5 ASPIRATIONS

- **More tightly integrate *Isis* into the research vessels**
  The deployment costs of *Isis* and the footprint on the deck can be reduced by more

tightly integrating the vehicle into the NERC research vessels and utilising the vessel's infrastructure. Examples of this closer integration include: deploying *Isis* using the ship's fitted deep tow winch; using the full ship's Ultra-Short BaseLine (USBL) system; and streaming the control van data around the ship.

- **Further enhance the ROV control software**
  Although we intend to upgrade the existing ROV control software as part of the obsolescence management of the vehicle, this upgrade will not focus specifically on reducing and simplifying the piloting load. Using autonomous behaviours has the potential to make piloting easier. This would reduce the training requirements for new pilots and the number of fully trained technicians required for the operations. Background research for these upgrades will be undertaken over the next five years.

- **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.

10.6 2019/20 UPDATE

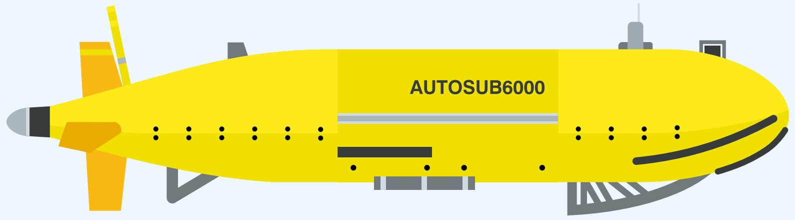
- **MPUS command module upgrade (HyBIS)**
  The MPUS command module upgrade is progressing well. The system has been designed and the majority of the hardware has been purchased. The next phase will be assembly and software development.

- **Heave Compensation**
  The heave compensation was briefly tested on HyBIS as part of the DY094 cruise but proved ineffective. It has since been modified, trialled and used with HyBIS to support DY108 in 2019. The active heave has greatly improved operational capability for both HyBIS

and CTD operations on the RRS *Discovery*. Active heave has since been commissioned on the RRS *James Cook* on the CTD winch with some success, and adding AHC to the deep tow wire is now being investigated

- **Obsolescence management and system upgrades (*Isis*)**
  The ROV *Isis* is currently undergoing 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 is in progress. This is planned to be completed by the end of the Q3 2020.

11 HIGH POWER MARINE AUTONOMOUS SYSTEMS (MAS) PLATFORMS



AUTOSUB6000

L3 HARRIS - C-WORKER 4

11.1 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

11.2 CURRENT CAPABILITY

The high powered Autonomous Underwater Vehicle (AUV) fleet developed by the NOC is becoming routinely used for scientific data collection. The vehicles are particularly well suited to high resolution acoustic surveys and under ice operations. However, they are now being requested to perform photographic surveys very close to the seabed. These photographic surveys are considerably more challenging and significantly increase the risk of loss or damage to the vehicle, and this trend in pushing the operational envelope of the vehicles is expected to continue. Thus, the vehicles will need to continue to be developed.

- **Autosub6000 AUV**
  An established vehicle, which has been continually upgraded since its first deployment in 2007. It is 6,000m depth rated and has rechargeable batteries. This high powered AUV, developed by the NOC, is becoming routinely used for scientific data collection. It is particularly well suited to high resolution deep water acoustic surveys.

- **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 will be equipped with a Sonardyne USBL beacon which will allow the USV to track and communicate with Autosub6000, 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.

11.3 SCIENCE COMMUNITY DRIVERS

- **Improved system reliability**

  The Autosub6000 has 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.

- **Reduce ship monitoring time**

  The time required to monitor Autosub6000 to dive to depth, and to track it back to the surface has been highlighted as an issue by various scientists. Professor Russell Wynn commented on this during the first science cruise of Autosub6000 on the RRS *James Cook* cruise 27 (JC027) and this was reiterated by the PCA for JC132.

- **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**

  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.

- **Improve Autosub6000 navigational accuracy**

  Autosub6000 has experienced problems with high resolution navigation and attitude measurement. These problems have been seen in the camera survey work during DY034, and the sonar surveys in JC044 and JC125. Resolving these issues would significantly enhance the quality of data collected by the AUVs. This improved navigational accuracy has been highlighted as a specific need for surveys of Marine Protected Areas where longitudinal studies need to survey the exact same area repeatedly.

- **Replace Autosub3 under ice capability**

  The retirement of Autosub3 removed the capability to make high power acoustic sonar measurements under the ice. Developments as part of the Oceanids project will provide an enhanced under ice capability from 2021 onwards.

- **Water sampling ability**

  Following feedback from MFAB on the 2019 NMF Technology Roadmap, it was highlighted that water sampling for use with AUVs would be desirable.

11.4 FUTURE CAPABILITY

- **Autosub6000 update program**

  This update programme follows on from the 2018/19 midlife refit. The program involves implementing a number of system improvements identified during the midlife refit, which were outside the deliverable scope of the refit period. The works include further updates to the power system, updating of the logging system to work around component obsolescence, and improvements to the navigation systems to improve integration with the Kongsberg EM2040 Multi-Beam Echo Sounder.

- **Integration with the ships USBL**

  Currently the Autosub6000 tracking and telemetry system utilises a standalone Linkquest USBL fish. To remove the requirement for this fish and to improve interoperability with other

NMEP systems the tracking and telemetry system will be developed so that it can utilise the Sonardyne USBL system fitted to the RRS *James Cook* and RRS *Discovery*.

- **Build Autosub2KUI to replace Autosub3**
  The Oceanids project is funding the development of a fourth generation Autosub2000 which will be built to replace Autosub3. This will integrate the development work described below, and will incorporate a 2,000m rated foam centre section to allow the AUV to carry double the energy of Autosub6000 due to the lower foam density. This will allow the AUV to operate under ice in a similar fashion to Autosub3.

- **Develop a new on-board control system**
  The On-board Control System (OCS) of Autosub6000 is based around Lonworks, a mid-90s distributed computing system. This has served the AUVs well but is now obsolete and is becoming difficult to support. Coupled to this, the internal control and electronics systems have evolved as different requirements arose and are now poorly documented and difficult to maintain. This has also resulted in a diverse range of software tools being required to run the AUV which has produced a complex and error prone system.

  To alleviate these issues a new OCS will be developed. This will improve the system reliability, make it simpler to integrate new sensors, and will provide a modern and future proof system for ongoing development. This development is funded as part of Oceanids and will be integrated into Autosub2KUI. Once fully proven it will be retrofitted to the existing Autosub6000.

  The OCS development will also be integrated into the Autosub Long Range control system upgrade. 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 OCS and Obstacle Avoidance System (OAS) to further enhance the under-ice capabilities.

- **Front seat/back seat architecture**
  MARS aims to adopt 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[7]. For example, an externally written front following algorithm could be added to the back seat to enhance the science utility of the campaign.

- **Upgrade the Obstacle Avoidance and Situational Awareness**
  The current Autosub6000 obstacle avoidance system was developed in 2009 for work in the mid-Cayman rise as part of JC044. The system is optimised for operation in the rugged terrain seen around mid-ocean ridges. The design was constrained by the available deep rated sensor system and the processing power of the Lonworks systems. However, the AUV is now operating in more complex terrain (e.g. Canyons JC125) and close to the seabed for camera surveys (JC136). The current system will be upgraded as part of the Oceanids Autosub2KUI development to provide better situational awareness and will be coupled to the new OCS to enhance the operational envelope of Autosub2KUI. Once fully test the new obstacle avoidance system will be retrofitted to Autosub6000.

- **Monitoring of Autosub6000/Autosub2KUI 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.

[7] 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.

11.5 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.

- **Hover capable AUVs**
  Autosub6000 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.

11.6 2019/20 UPDATE

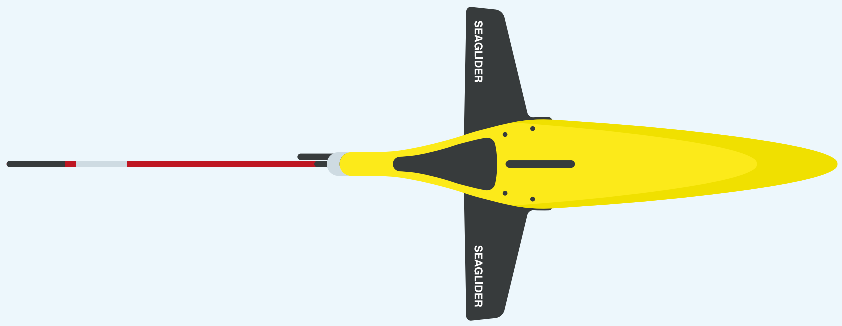
- **Design of Autosub2KUI**
  Development of Autosub2KUI has entered the detailed design phase, initial trials are expected Q1 2021.

- **Innovate UK A2I2 project**
  As part of a collaborative research and development project MARS will be developing a prototype hover capable AUV for trials Q4 2020.

- **Autosub6000 mid life refit**
  Following a number of reliability issues with Autosub6000 the vehicle underwent a much needed mid life refit. Upgrades to the power system, the logger tube, and the workshop and control containers have been undertaken. These developments have improved the performance of the vehicle, and it is expected that full sign off of these upgrades will be completed by the end of 2020.

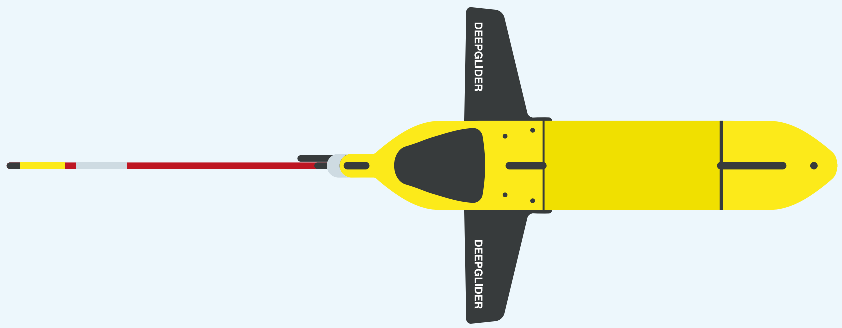
- **C-Worker 4 commissioning**
  Following the purchase of the C-Worker 4 it was trialled as part of the JC166/7 expedition. Unfortunately, a number of issues were identified during this trial which needed to be rectified by the manufacturer. These are being undertaken and it is expected that the NOC will take delivery of the system by the end of 2020.

12 UNDERWATER GLIDER PLATFORMS



SEAGLIDER

SLOCUM GLIDER



DEEPGLIDER

12.1 ESSENTIAL OCEAN VARIABLES

Example EOVs which could 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

12.2 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 & 1,000m)
- 1 x University of Washington Deepglider (4,000m)

12.3 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 sub-surface navigational accuracy of gliders is poor. For many applications this is not an issue, however for long duration sub-surface missions (e.g. under ice) improvements are required.

- **Deeper operations**
  Current gliders are limited to 1,000m depths. This is insufficient for a number of applications, and hence deeper gliders are 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 Acoustic Doppler Current Profilers (ADCPs) can be used to calculate volumes and fluxes where moorings cannot be deployed.

12.4 FUTURE CAPABILITY

- **Deepgliders**
  Procurement of Deepgliders has been problematic with a manufacture unable to fulfill our order due to issues with the 6,000m capable carbon fibre pressure housing. As a consequence, our current Deepglider depth rating has been reduced to 4,000m. We will continue to operate this Deepglider at this reduced depth, which is still practicable for most science requirements; however, we do not have a spare system. We will continue discussions with Deepglider manufacturers with the aim of procuring a reliable system in the coming years.

- **Rechargeable batteries Slocum gliders**
  Gliders currently use single use (primary) cells to maximise the energy for a deployment. However, for shorter or higher power deployments a rechargeable pack is more appropriate. These packs would significantly reduce the deployment costs as no battery purchase is needed. MARS has undertaken an evaluation of the benefits of these rechargeable packs, and has recently purchased a set for evaluation.

- **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. As part of the Oceanids Sensors programme the long range fleet will have a

common sensor interface developed which should simplify the integration of new sensors in the future.

- **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.

12.5 ASPIRATIONS

- **New lower cost primary packs for gliders**
  Current glider packs typically use Electro-chem Lithium Sulfuryl Chloride cells. These cells are highly expensive and the battery packs form a large portion of the battery deployment cost. 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.

- **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.

- **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. Current aspirations include purchasing Slocum G3 gliders and a Deepglider.

- **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.

12.6 2019/20 UPDATE

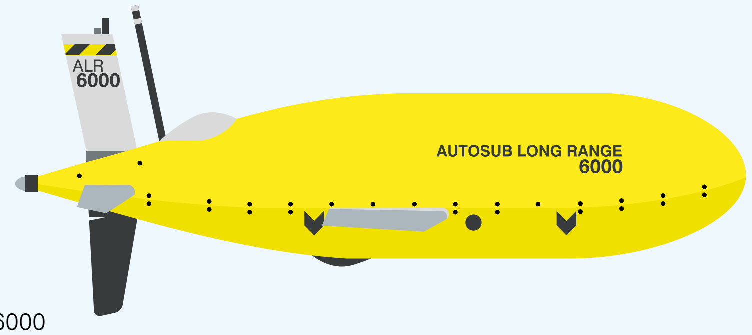
- **Trials of Deepglider**
  The Deepglider is scheduled for its first scientific deployment in 2020.

- **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.

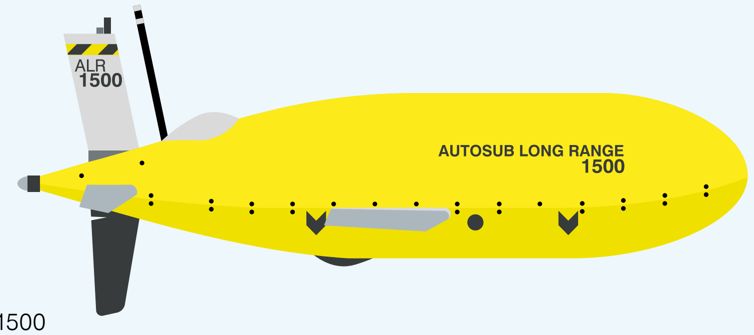
- **Calibration**
  Pumped and non-pumped Slocum CTD sensors are now calibrated in-house significantly reducing the period these sensors are out of service, and saving money Development work for in-house Seaglider CT (Conductivity Temperature) calibrations is in progress.

- **Under ice operations**
  The NOC has started working with partners on the development of glider operations under ice. This work is in its early stages, but will provide a framework to develop this capability from.

13 LONG RANGE AUV PLATFORMS



AUTOSUB LONG RANGE 6000



AUTOSUB LONG RANGE 1500

13.1 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

13.2 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:

- 3x Autosub Long Range 6000 (ALR6000)
  6,000m rated system
- In development: 3x Autosub Long Range 1500 (ALR1500)
  1,500m rated system with three times the energy of the ALR6000 system

13.3 SCIENCE COMMUNITY DRIVERS

- **Increase system energy**
  The current 6,000m rated system does not have the necessary energy for some of the applications currently being proposed. This is because these applications have higher sensor loads, and require increased operational speed.
- **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 2019 NMF Technology Roadmap it was highlighted that water sampling for use with AUVs would be desirable.

13.4 FUTURE CAPABILITY

- **ALR1500**
  To increase the payload power capacity and operational speed of the ALR6000, extra energy is required. To achieve this increase in energy, a shallower rated (1,500m) ALR variant is being developed as part of the Oceanids ALR1500 project. This will use a single central pressure vessel which will be more buoyant than the current 6,000m rated system and hence will allow more batteries to be installed into the vehicle. The ALR1500 vehicle will be developed for under ice operations, but could also be used in other areas such as carbon capture and storage monitoring.

- **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.

- **Rechargeable packs for ALR**
  Currently the ALR (both 6000 and 1500) uses lithium primary packs for their operations. However, for certain higher power shorter duration missions this approach is expensive. A high capacity lithium rechargeable pack would enable the vehicle to undertake shorter duration, higher power missions in a more cost effective fashion. We intend to explore options for the development/purchase of a suitable pack for the ALR.

- **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:
  - Integration of a high precision Attitude Heading Reference System (AHRS) into the ALR.
  - Developing improved navigation techniques as part of the Innovate UK funded P3Nav project.

- **Simulation Environment**
  MARS will develop tools to accurately simulate ALR missions prior to deployment to help identify bugs in the software system.

13.5 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.

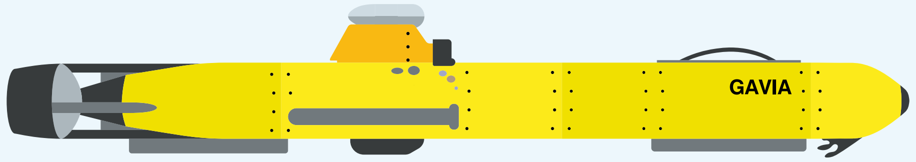
- **General AUV improvements**
  As with the higher power vehicle aspirations we also intend to:
  - — Enhance inter vehicle co-operation.
  - — Enhanced vehicle autonomy.
  - — Develop new concepts of operational and undertake application specific developments.
  - — Develop and curate operational data 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.

13.6 2019/20 UPDATE

- **ALR Operations team**
  Establishment 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.
- **ALR1500 commissioning**
  ALR-4, -5 & -6 have undergone commissioning trials in Loch Ness and at sea.

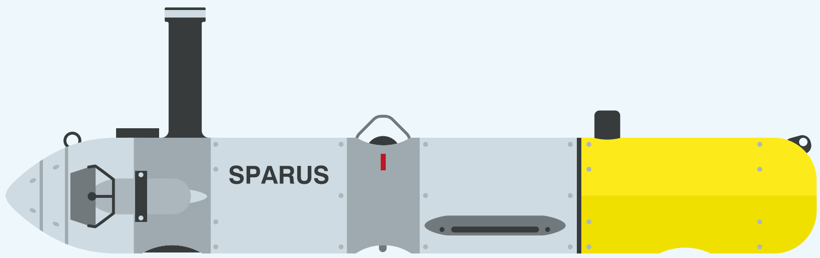
- **ALR1500 long distance proving trial**
  ALR-4 is being prepared to undertake a long distance proving in 2020, and is planning to cover over 2000 km to test endurance and the 4,000m echo sounder used for terrain aided navigation.
- **Sensor Integration**
  Completed a number of successful bespoke integration projects showing the world leading unique nature of the ALR and the NOC development and operations teams:
  - — Rockland Microrider Turbulence probe has been mechanically intergrated into the ALR1500.
  - — The Oceanids sensor program has seen 9 of the 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 is to be deployed on ALR-3 in August 2020.
  - — 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.

14 LOW INFRASTRUCTURE AUV PLATFORMS



GAVIA AUV

ECOSUB AUV



SPARUS2

14.1 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

14.2 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.

14.3 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.

14.4 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.

14.5 ASPIRATIONS

To enhance the NMEP, NMF would like to further develop a low logistics platforms capability (for example ecoSUBs) subject to available funding.

14.6 2019/20 UPDATE

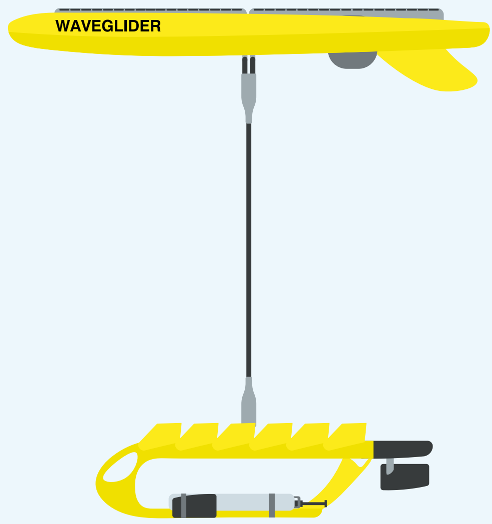
- **Low Cost AUV Technology (LCAT) Project**

  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.

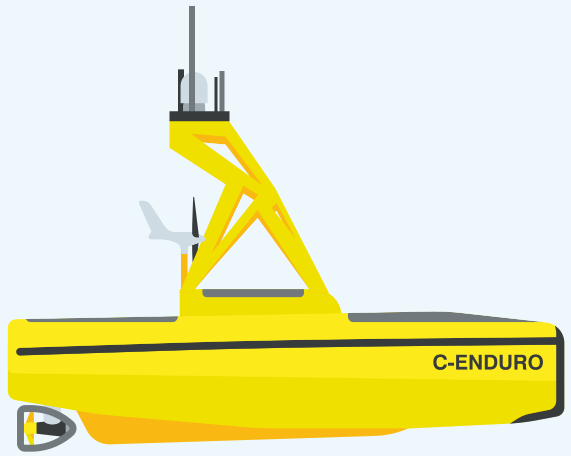
- **Gavia Deployment from the RRS *James Cook***

  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.

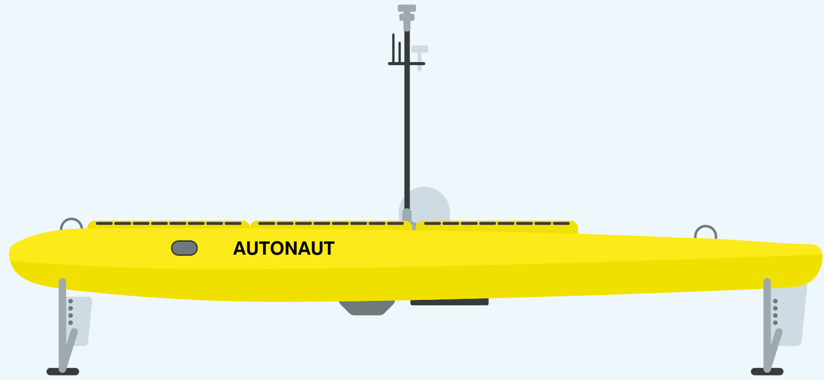
15 LONG RANGE UNMANNED SURFACE VEHICLES



WAVEGLIDER SV3



C-ENDURO



AUTONAUT

15.1 ESSENTIAL OCEAN VARIABLES

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

15.2 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.

15.2.1 PROVEN PLATFORMS

- 2 x Waveglider SV3

15.2.2 EXPERIMENTAL PLATFORMS (NOT RECOMMENDED FOR SCIENCE)

- 1 x AutoNaut
- 1 x C-Enduro

15.3 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 sub-surface 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.

15.4 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 sub-surface 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/Sub-surface 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. The Calibrated pCO2 in Air and Surface Ocean Sensor (CaPASOS) projects will measure the partial pressure of CO_2 in the sea and air from USVs so this exchange can be determined.

15.5 ASPIRATIONS

- **Develop the AutoNaut USV for use in the NMEP**
  The AutoNaut vehicle ‘Gordon’ has proved to be unreliable, and although in principle a

competent platform, is not fit for long term science. There is an aspiration to upgrade the platform to resolve existing reliability issues and to closely integrate the system into the C2 architecture. Once this work is complete the approach could be extended to the large AutoNaut platforms.

- **Review the use of the C-Enduro**
  The user case for the C-Enduro will be evaluated to understand where it adds value in the NMEP. If it cannot be shown to be of benefit to the community, we will look to remove it from the pool.

15.6 2019/20 UPDATE

- **Waveglider sensor integration**
  The Oceanids funded sensors Carbonate Chemistry Autonomous Sensor System (CarCASS), AutoNuts, and CaPASOS are being integrated into the waveglider for trials in 2020.

16 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 BODC. The development efforts for this are funded by the Oceanids C2 project.

16.1 CURRENT CAPABILITY

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

- 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[8]
- MARS piloting portal

16.2 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.

[8] http://mars.noc.ac.uk

- **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.

16.3 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 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.

- **MAS Control Room**
  A bespoke MAS control room will be developed at the NOC for stakeholder engagement around 'over-the-horizon' operations.

16.4 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 On-board 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 calibrations sheets 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**

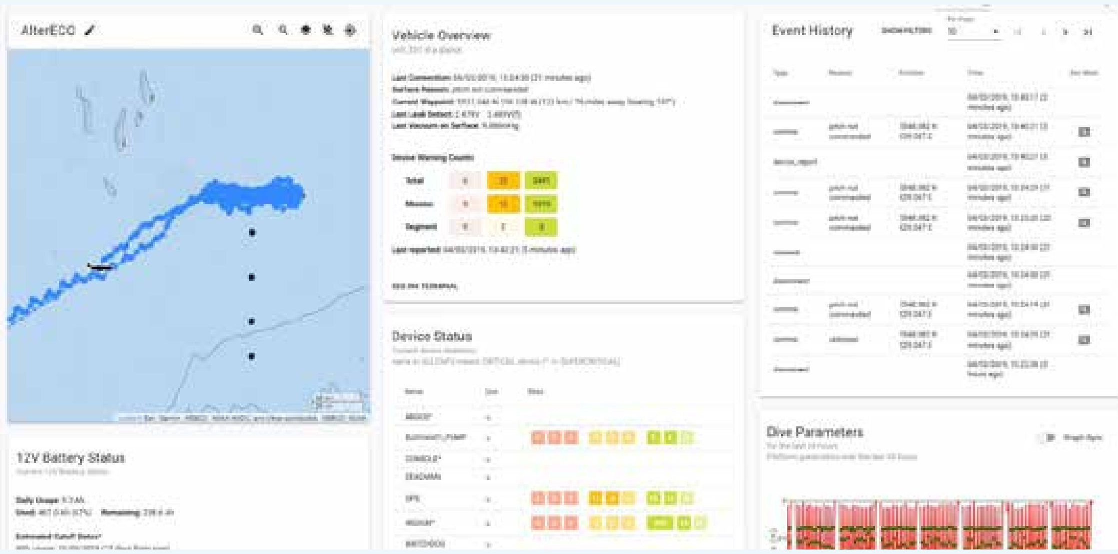
  This app will allow BODC and fleet managers to introduce the metadata required for the assembly of standardize data outputs.

  — **PI App**

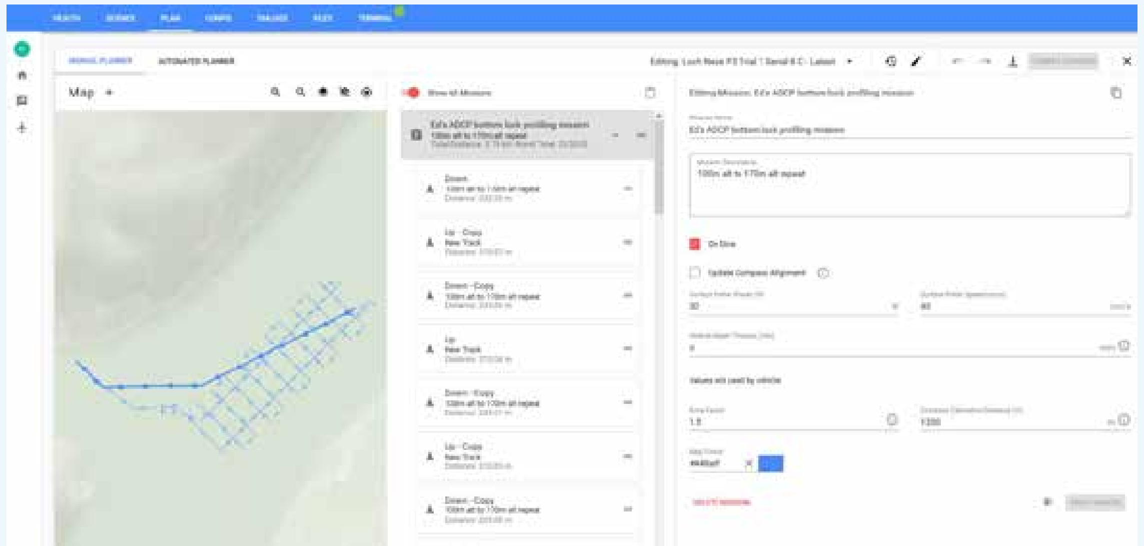
  This app will allow Principal Investigators (PI) and scientists involved in campaigns including autonomous assets, to do mission planning that then will be transmitted to the piloting team. It will also allow the PIs to follow the development of the mission, aggregating under the same system different information (satellite imagery, model information, in-situ sensor data, etc) to allow informed decision making during the deployments.

  — **New MARS portal**

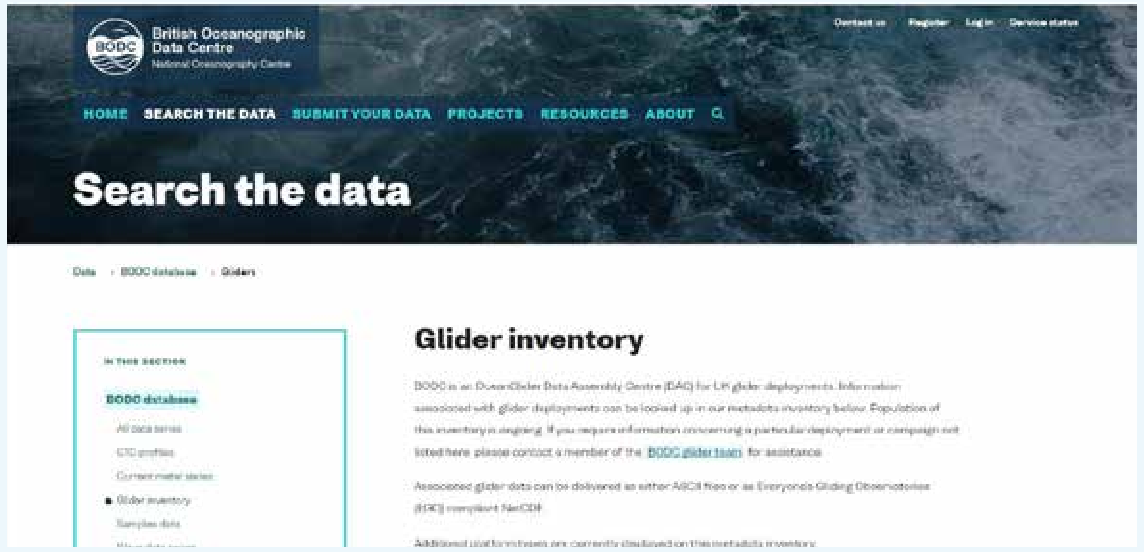
  A new incarnation of the public MARS portal will be developed on top of the C2 infrastructure, leveraging into all the modern technology deployed during Oceanids.



C2 PORTAL VEHICLE OVERVIEW TAB



C2 PORTAL MISSION PLANNING TAB



BODC GLIDER DATA DOWNLOAD PAGE

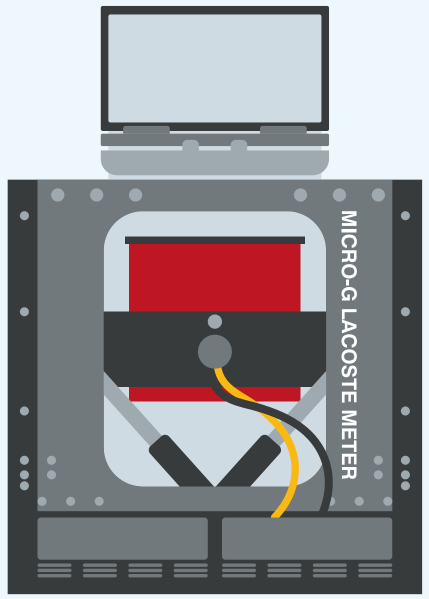
16.5 2019/20 UPDATE

- **Oceanids piloting tools**
  The unified Oceanids web portal has been rolled out to beta testers for piloting of Slocums, Seagliders and ALRs (as shown). Used during several trials in Loch Ness and during on-going glider operations.

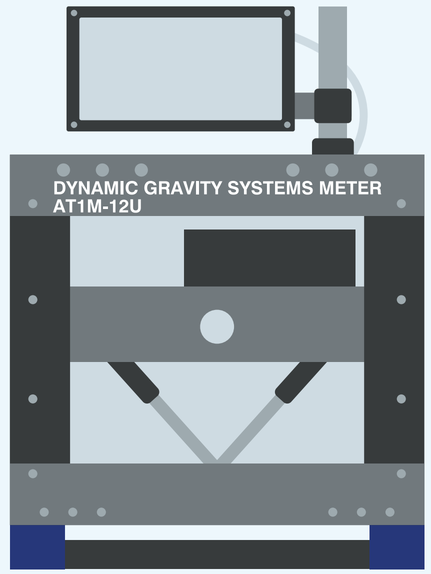
- **Glider near real-time data processing**
  Near real-time data from MARS gliders can now automatically be ingested into BODC and provided in EGO NetCDF format.

- **Ellet Array demonstrator**
  An exercise is planned for 2020, deploying a Slocum glider, a Deepglider and an ALR at the same time an OSNAP Seaglider is in the water. All the platforms will be piloted using the C2, allowing pilots from The Scottish Association for Marine Science (SAMS) and NMF to pilot using the same system.

17 GRAVIMETERS



S084 MICRO-G LACOSTE METER



AT1M-12U DYNAMIC GRAVITY SYSTEMS METER

17.1 CURRENT CAPABILITY

NMF Ship Scientific Systems possesses two L&R-type gravimeters:

- **S084 Micro-G LaCoste meter**

- **AT1M-12U Dynamic Gravity Systems meter**
  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 counterscrew 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.

17.2 SCIENCE COMMUNITY DRIVERS

- **Maintain the reliability and availability of the gravimeters**
  The S084 has many components which are no longer supported or supplied. A review of upgrade options will be undertaken.

- **Compare the performance of AT-series meters with the S-series**
  Two trials have been undertaken, including one study running both the NMF meters with the British Antarctic Survey (BAS) AT-series meter in parallel. The data from this was examined by scientists, technicians and manufacturers. A training session aimed at technicians and scientists is in the pipeline (with BAS) looking at data processing techniques for getting the most out of data recorded by AT-series meters.

- **Provide methods for quality checking gravimeter data and verifying system performance**
  The Ship Scientific Systems group in NMF is, in consultation with members of the marine geophysics community, researching gravity data reduction and methods for correcting common issues with gravity data such as cross-coupling and platform-levelling errors. These are being put together to form a simple package to monitor the gravimeters and provide remedies for faulty datasets, but in common with a National Oceanic and Atmospheric Administration (NOAA) initiative to do something similar, they are not intended to provide a science-ready data product.

- **Investigate addition of vertically-constrained-accelerometer-type gravimeters to NMEP**
  Initial consultation has been undertaken with scientists and Lockheed Martin to look at the feasibility of acquiring a BGM-series meter. Unfortunately, these are no longer manufactured, but some possible avenues are being explored.

17.3 FUTURE CAPABILITY

- S084 upgraded, either to an AT-series meter or with new control modules to replace the obsolete parts.

- Depending on the outcome of the initial investigations on the matter, to purchase a BGM-series meter for the NMEP.

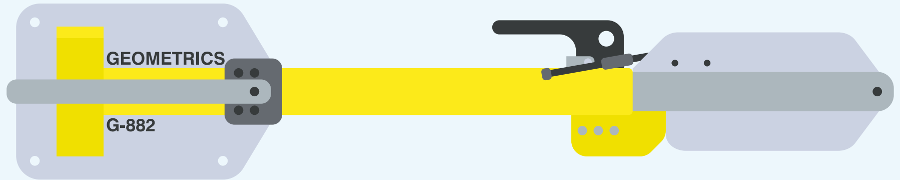
- To provide, on-board, a facility to monitor gravimeter performance and provide functions to correct ‘bad’ data arising from platform or weather issues.

17.4 ASPIRATIONS

To work in partnership with the marine geophysics community to operate and support state-of-the-art marine gravimeters

18 MAGNETOMETERS

SEASPY 2



GEOMETRICS G-882

18.1 CURRENT CAPABILITY

NMF Ship Scientific Systems operates:

- 3 x SeaSPY1 magnetometers (older generation)
- 1 x SeaSPY2 magnetometer (new generation)

18.2 SCIENCE COMMUNITY DRIVERS

- **Upgrade and provide redundancy to maintain reliability and availability**
  The two generations of magnetometer have incompatible component parts. This raises difficulties when magnetometers are required to be mobilised at the same time: changing from one to the other requires spooling a new cable onto the winch drum and faulty parts cannot be swapped out at sea. The newer SeaSPY is lighter, easier to handle on deck, and has better absolute accuracy.

- **Provide methods for quality checking magnetometer data and verifying system performance**

18.3 FUTURE CAPABILITY

- In 2021/22 the aim will be to purchase a new SeaSPY3 (which is compatible with our SeaSPY2 equipment) to give us two consistent mobilisation kits.
- In 2022/23 (or earlier, if possible), the aim will be to replace the two remaining SeaSPY1 magnetometers with SeaSPY3s.

18.4 ASPIRATIONS

Develop or acquire methods to quality check magnetometer data by comparison to a lower resolution reference field.

18.5 2019/20 UPDATE

- Due to other commitments, purchasing another SeaSPY2 was deferred to 2021/22.
- A module was implemented in a trial Techsas system to collect SeaSPY data and thus integrate it with the shipboard data acquisition system. Providing magnetometer data in the NetCDF data products enables our partners in the marine geophysics community to start developing quality checking tools for this dataset.

19 SHIP-FITTED HYDROACOUSTIC SUITE AND HYDROGRAPHY SOFTWARE

19.1 ESSENTIAL OCEAN VARIABLES

- Fish abundance and distribution
- Subsurface currents
- Surface currents

19.2 CURRENT CAPABILITY

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

- Kongsberg EM122 Deep Water Multi-beam
- Kongsberg EM710 Multi-beam
- Kongsberg EA640 Single beam
- Kongsberg SBP120 Sub-bottom profiler
- Kongsberg EK60 Fisheries Echo-sounder
- 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

19.3 SCIENCE COMMUNITY DRIVERS

- **Maintain support for echo-sounder capabilities by updating old systems**
  - — The Kongsberg SBP120 is approaching end of support with obsolescence due in 2021.
  - — The EK60 is no longer supported, so replacement transducers are no longer available.
- **Investigate performance of RRS *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 the RRS *Discovery* the depth penetration was about 50% less than expected and the background noise higher. Some potential causes have been identified and will be tested in the first half of 2020, to allow the inclusion of any rectification work in the 2020 refit if required.
- **Repair the RRS *Discovery's* EK60 system**
  The 18kHz and 38kHz transducers on-board the RRS *Discovery* were found to be faulty in 2019. Replacement transducers are unavailable for the EK60 system, necessitating upgrade of the EK60 to EK80 to restore the full frequency range of the system.
- **Provide a second EK60/80 calibration control box**
  The age of the existing kit has led to spare parts no longer being available.
- **Automate processing of multi-beam data to reduce downstream processing effort**
  To strengthen our contribution to GEBCO Seabed2030, we need to put in place automated systems to perform standardised, first pass processing of multibeam data.
- **Maximise multi-beam data collection for GEBCO Seabed2030**
  To strengthen our contribution to GEBCO Seabed2030, we need the resources to collect multibeam data on all programmed science cruises and passage legs.

19.4 FUTURE CAPABILITY

- **Kongsberg SBP27**
  In 2020/2021, it is planned that the SBP120 will be upgraded to SBP27 on both ships during their respective refits. This will involve the replacement of the topsides amplifier and processing units followed by deep water commissioning in post refit trials. This upgrade will only proceed if there is the opportunity to undertake commissioning.

- **Kongsberg EK80**
  In 2020/21, it is planned that the SIMRAD EK60 on the RRS *Discovery* will be upgraded to EK80 during refit. This will involve the replacement of the topside unit and faulty transducers in 2020, with the remaining transducers replaced in 2021. The EK60 on the RRS *James Cook* will also be replaced from 2021.

- **Automated processing package**
  In 2020/2021, it is planned to begin trialling a process for automatically cleaning multibeam data.

- **EK80 calibration control box**
  In 2020/2021, it is planned to begin trialling a new control box that is being built in-house.

19.5 ASPIRATIONS

- To work with manufacturers to manage the upgrades to obsolescence in our ship-fitted hydroacoustic suite.

- To work in partnership with the scientific community to explore ways we can adapt our capabilities to best meet their needs.

- To work with manufacturers to trial new technologies.

20 OCEAN AND ATMOSPHERE MONITORING

20.1 ESSENTIAL OCEAN VARIABLES

- Ocean surface heat flux
- Sea state
- Sea surface salinity
- Sea surface temperature

20.2 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. A Near Real-Time (NRT) processing system automates the transmission of regular summaries of this data to BODC to support NRT continuous ocean monitoring. Another automated processing system takes recent CTD cast data, summarises this and transmits it to the Met Office for ingestion into forecast models.

20.3 SCIENCE COMMUNITY DRIVERS

- **Strengthen EOV data acquisition**
  In order to support BODC's drive towards robust, NRT monitoring of essential ocean variables 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 essential ocean variables. 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.

- **Improve effectiveness of wave-radar data acquisition**
  Without a reference dataset, the ship-fitted wave radar cannot give meaningful wave-height data, which reduces the usefulness of this dataset.

20.4 FUTURE CAPABILITY

- **Provide a reference dataset for the wave-radar**
  In 2020, the intention is to install bow-mounted wave-height sensors to provide a reference dataset for the wave-radar.

- **Improved ocean and atmosphere data acquisition suite**
  The aim is to develop and implement a System Control And Data Acquisition (SCADA) standalone ocean and atmosphere monitoring station, with an integrated database and configuration interface leveraging the latest web based technologies, such as Influx, NodeRED and Python. This will interface with the ship's data acquisition system, metadata manager and NRT transmission modules to provide an extensible, robust pipeline for the measurement of essential ocean variables.

20.5 ASPIRATIONS

- To work in partnership with BODC and C2 Developers to develop applications which integrate with BODC's data ingestion services.

- To introduce pCO2 systems on-board both vessels with automated processing for ingestion in to 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. Recommissioning of the existing Plymouth Marine Laboratory (PML) Dartcom systems under review for cost and time efficient introduction of this capability, with a view to upgrade both systems in future.

21 SHIP BASED DATA ACQUISITION SYSTEMS

21.1 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, attitude, heading, ocean and atmosphere, depth, gravity, wave radar and USBL fixes are collected by our acquisition systems.

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

21.2 SCIENCE COMMUNITY DRIVERS

- **Improve rigour of on-board data acquisition and increase accessibility to near real-time data products for monitoring and on-board 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 a number of 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.

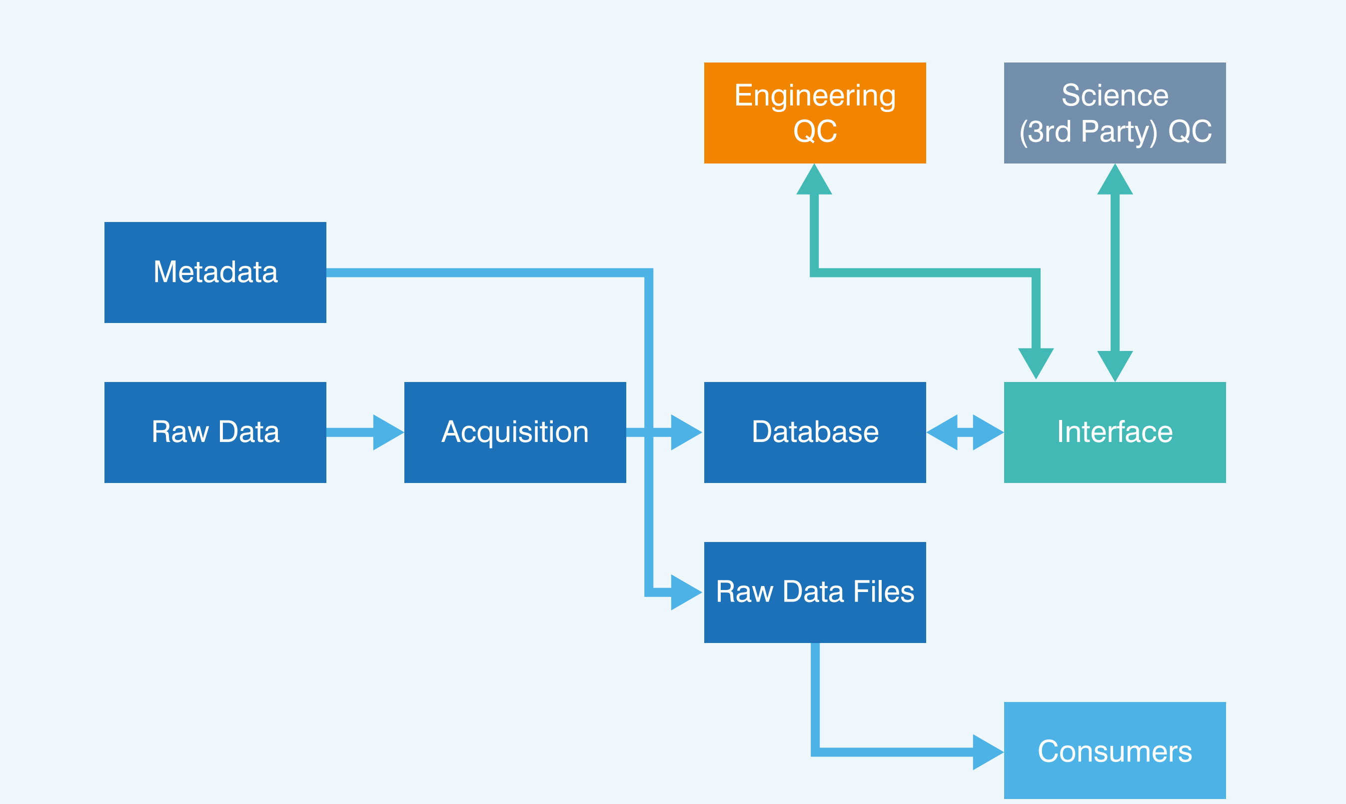
— **Evaluation**
The growing requirement to transmit and share near real-time data requires quality checking (QC) to be expanded to include automated engineering QC, which processes and flags data which fail basic integrity checks. Furthermore, in working in partnership with the scientific community, 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 data 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 near real-time streams to BODC, on-board data servers or post-processed bespoke data products.

21.3 FUTURE CAPABILITY

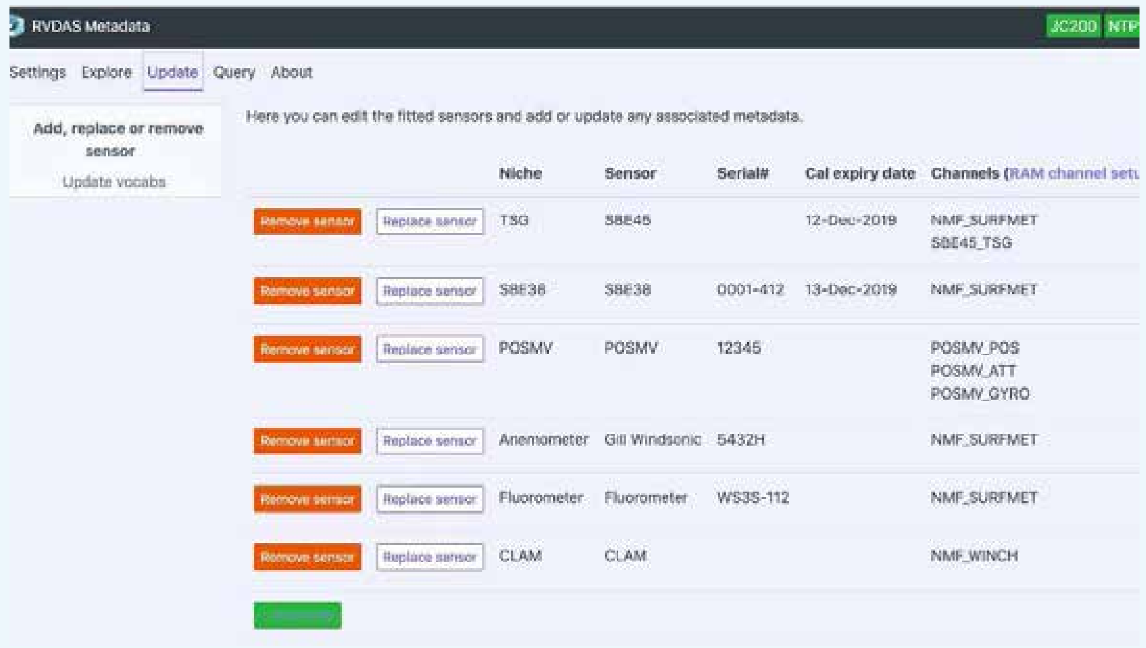
The aim is to build a comprehensive, modular, interface driven system which enables extensible acquisition and collection of events and other metadata, plugin QC routines, the storage of structured data and the scalable dissemination of data products to a range of consumers.



CONCEPT OF A MODULAR ACQUISITION SYSTEM WITH A UNIFIED INTERFACE TO CONSUMERS

In 2020-2021, we hope to:

- Continue to work with BAS in their development of an Event Logger, which will eventually use BODC vocabularies, free form inputs and preconfigured event types to record contextual information during expeditions.
- Release a 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 a NetCDF module for RVDAS which will extend the types of data product that RVDAS can generate and permit customisation of data outputs.



RVDAS METADATA MODULE IN DEVELOPMENT

PROTOTYPE EVENT LOGGER RECENTLY INSTALLED ON THE SHIPS

DATA MONITORING AND QUERY SYSTEM RECENTLY INSTALLED ON THE SHIPS.

- Continue to release improvements to the implemented RVDAS raw data acquisition module, data ingestion module, data storage module and data query and visualisation module.

21.4 ASPIRATIONS

- To work with BODC and BAS to align our developments to the needs of our data centres and scientific stakeholders
- To work with BODC to develop applications which integrate into BODC's data ingestion services.
- To work with MARS to enable access to snapshots of ship data on the NOC/MARS portal.

22 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.

22.1 SHIP FITTED WINCHES

22.1.1 CURRENT CAPABILITY

Both ships have as standard the following winches fitted:

WINCH	MAXIMUM OPERATING LOAD	NOMINAL LENGTH	USES	ACTIVE HEAVE COMPENSATION
CTD	3.36Te	8,000m	CTD SVP	RRS *James Cook* RRS *Discovery*
DEEP TOW	7.62Te	10,000m	HyBIS/MPUS Secondary CTD	RRS *Discovery*
TRAWL	5.20Te	15,000m	Trawling Dredging	N/A
GP (CORE)	7.42Te	7,000m	Coring	N/A
PLASMA (DEEP WATER CORE)	30.0Te	8,000m	Deep Water Coring	N/A

22.1.2 FUTURE CAPABILITY

- The installation of active heave compensation for the deep tow winch on-board the RRS *James Cook* in the 2021 refit period.
- A review of cable specifications for future requirements for the CTD and deep tow winches.
- A review of the plasma (deep water coring) winch rope specification, in conjunction with continued commissioning work on-board both vessels during the 2020 refit periods to improve identified scrolling issues.

22.1.3 ASPIRATIONS

Trial the deployment of *Isis* from the deep tow winch.

22.1.4 2019/20 UPDATE

Winch trials took place on-board both vessels during the post refit trials periods. The active heave compensation systems were fully set to work and successfully trialled at >4km depth. Based on the trial results all active heave compensation systems are available for use.

22.2 PORTABLE WINCHES

22.2.1 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

22.2.2 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 Commercial Off The Shelf (COTS) winches.

22.2.3 FUTURE CAPABILITY

- Counting sheave to be purchased in 2020 to provide potential for line out length read out capability for all winches in the NMEP.
- 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 again for the 2020 NMEP trials.
- Only the Romica 5T GP winch has line out length and line tension feedback capability in the current fleet, therefore this winch is in high demand. A second smaller winch with the same functionality has been ordered and due for delivery 2020, for SATs during DY121.

22.2.4 ASPIRATIONS

As the fleet of winches reach end of service life, they will be replaced by winches with line out length and line tension feedback functionality. Where possible suppliers will be standardised for component and technology similarity.

23 ANCILLARY EQUIPMENT AND FACILITIES

23.1 CALIBRATION LABORATORY

23.1.1 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 the NOC teams, and reduce the volume of equipment calibration subcontracted outside of NMF within the resource capacity of the facility.

23.1.2 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.

23.1.3 FUTURE CAPABILITY

- Develop a glider calibration facility for the full sensor bay including a Seabird 911+.
- We aim to achieve full ISO9001 accreditation in 2020.

23.1.4 ASPIRATIONS

- Extend the calibration services offered to include calibration of nutrient sensors.

23.2 CONTAINER LABORATORIES

DATA MONITORING AND QUERY SYSTEM RECENTLY INSTALLED ON THE SHIPS.

23.2.1 CURRENT CAPABILITY

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

- 3 x Ultraclean/Clean chemistry laboratory containers
- 2 x Radionuclide laboratory containers
- 1 x Constant temperature laboratory container
- 2 x Refrigerated containers

23.2.2 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 nanoplastics pollution. Further environmental control conditions are critical to perform multi-stress incubation experiments in order to simulate future global change scenarios such as ocean warming and ocean acidification.

23.2.3 FUTURE CAPABILITY

As part of the five-year rolling plan NMF will purchase one new clean chemistry laboratory container every year 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.

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