National Marine Facilities

Technology Roadmap

2018/19

National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

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NERC SCIENCE OF THE ENVIRONMENT

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Introduction

Against a back-drop of tight budgets, rapid technical development, big data and the increasing use of Marine Autonomous Systems (MAS) platforms, National Marine Facilities (NMF) are committed to delivering the best possible support and value for money to the UK science community. That means constantly striving to develop equipment and improve processes to deliver more efficient and effective support to NERC's Marine Facilities Programme (MFP). The direction of this progression is necessarily driven by future science needs and relies heavily on the input of the UK science community. This roadmap is updated annually to reflect science priorities communicated via MFAB or other forums and/or advances in technology.

The environmental impact of NMF's activities at sea will be assessed from 2019 onwards with actions taken to mitigate the impact wherever possible.

The Roadmap is structured to present sequentially each area of capability, and within each of these areas to identify and specify: i) current capability, ii) science drivers, iii) planned future capability and iv) aspirations.

Seismics

Current Capability

- Bolt LL configurable airguns
- G guns
- 3Km multichannel streamer
- Big Shot fire control system

The current seismic source arrangements are outdated and optimised for operations on previous classes of research ships. There are limitations with the volume of source that can be deployed and streaming and recovery is slow.

Science 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 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 2-stage firing process.
  - Improved reliability – The system of beam deployed airgun arrays with pneumatic umbilicals 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 repair turn arounds.
  - Reduce wake interference – The twin propulsion designs of RRS *James Cook* and RRS *Discovery* produces a much greater wake profile than previous research ships. Airguns are fired while being towed through this aerated water seriously affecting source level and consistency. Modifications to the after deck of both ships would allow sources to be towed much wider from the ship's centreline and reduce this problem.
  - Flexibility – Bolt LL airguns can only be reconfigured by changing the entire chamber. Chambers are large, unwieldy and expensive and NMF only hold a limited amount of each size therefore limiting the options for reconfiguring array size at sea. GI guns can be reconfigured quickly by the use of a cheap plastic insert giving a PI an almost unlimited choice of source configurations.

Future Capability

A MFAB working group has been set up to consider in more detail what future capability is required to support the geophysics community. This working group aims to present its findings to NERC's Cruise Programme Executive Board in Septemper 2018. It is expected to propose a structured procurement strategy over the next 2/3 years to purchase the following (dependent upon additional funding):

- 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 OFEG 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

Aspirations

A multichannel streamer capability greater than 3000m.

Coring

Current Capability

- NIOZ piston core
- Box core
- Mega core
- Multi core
- Kasten core
- Gravity core

Science 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.

Future Capability

- A wire mounted camera system to view and record sampling sites.

Aspirations

- A 40m piston corer utilising a bespoke handling and deployment system

CTD

Current Capability

The NMEP has both stainless steel and Ti CTD frames and is capable of completely trace metal free sampling (in conjunction with portable MFCTD winches). CTD frames can be fitted with 10 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, and water velocity. They can be deployed to full ocean depth (6000m).

Science Drivers

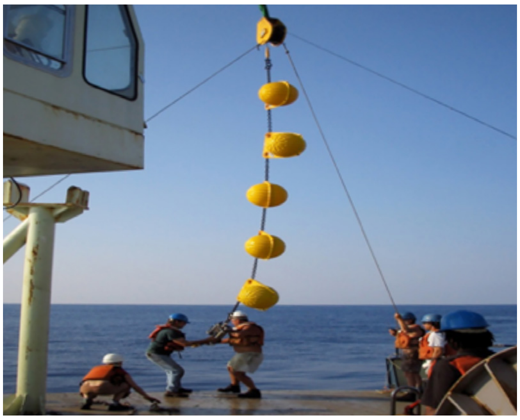
Data from CTDs and the associated sensors are fundamental and contributes to 75% of the biogeochemistry science delivered. The incorporation of state of the art sensors, or the capability to incorporate state of the art sensors above and beyond the current technology is key.

In a world where the acidification of the ocean is increasing and the role of the ocean in modifying atmospheric CO_2 is evermore critical the incorporation of CO_2 and pH sensors is essential. The rapid optical imaging of macroscopic particles and zooplankton in vertical profiles is relevant to NERC programmes investigating carbon export such as NERC COMICS, AMT and WCB.

Future capability

- The incorporation of full ocean depth CO_2 and PH sensors with rapid response times into CTD frames.
- An Underwater Vision Profiler incorporated into CTD frames by either adapting existing seasoar instrument or purchase of a new one.

Fixed and Towed Body Sampling



Current Capability

Full ocean depth mooring systems capable of 24-month time series observations. Vertical Microstructure Profiler (VMP), Sea Soar and Scanfish delivery systems.

Science Drivers

- There is an ongoing requirement for fixed, low cost, observation systems.
- There is an increasing demand for larger sensor payloads on all platforms.

Future Capability

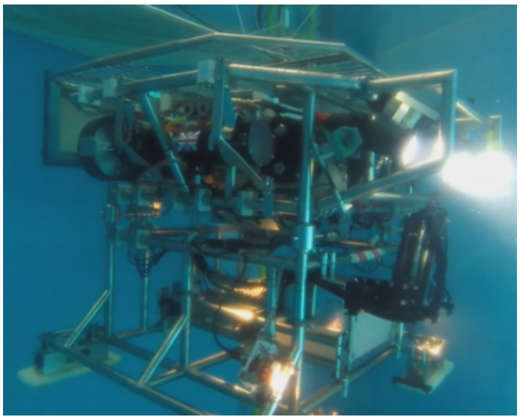
- Develop real time telemetry of data from moored observatories using underwater acoustics and satellite technologies.
- Develop a suitable smoke beacon that will withstand full ocean depth and activate on return to surface, either by pressure or conductivity, to provide a clear locator (better than 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.
- Develop a current meter for use on the freefall VMP.
- Evaluate the feasibility of the use of synthetic conducting ropes for the towed vehicle fleet (Seasoar and Scanfish).

Aspirations

- Develop *in-situ* moored power sources to enable recharging of AUVs and prolong their deployment duration.

Remotely Operated Platforms

Isis ROV



HyBIS ROP

Current Capability

- *Isis* ROV – The *Isis* ROV is a well-established and mature system. Over the years it has gone through a number of upgrades to improve the instrumentation and systems, and this incremental upgrade of the vehicle is likely to continue over the next five years.
- HyBIS ROP – HyBIS is a modular remotely controlled vehicle. It is very similar to a remotely operated vehicle, but without any syntactic foam and so is directly coupled to the ship. The HyBIS system comprises a ship side power and control system, a bottom end command module with cameras and lights, and interchangeable payload modules. This set-up allows each payload module to be precisely located and oriented on the seabed and thus precision seabed sampling is easy to achieve. HyBIS's heavy lift capability also makes it an ideal platform for precision placement and recovery of seabed experiments, thus potentially changing the deployment approach for seabed landers.
- Mojave ROV – The Mojave ROV is a small shallow water (300m) rated system. It is equipped with lights, cameras, and a three function manipulator arm.

Science Drivers

- Reduce operating costs (*Isis*) – *Isis* is a large complex deep water ROV system, and as such it is expensive to run both in terms of consumable costs and labour. To maximise the use of the vehicle these costs need to be reduced.
- Enhanced scientific interaction – The number of people who can guide the ROV / HyBIS is currently limited by the available space on the cruise. By having the capability to create a virtual control room, the number of scientists engaged in guiding the vehicle deployments can be increased. A virtual control room would also provide an excellent platform for out-reach, and could be integrated into the operations room within the Innovation Centre at NOC.
- Obsolescence management and system upgrades (*Isis*) – Although *Isis* has been significantly upgraded 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 it still only a first prototype 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 payload modules for HyBIS provided a limited set of options to the community. By developing new payload modules (e.g. precision push cores) the utility of the platform will increase.

Future Capability

- ROV virtual control room –It is currently possible to create a virtual control room, but requires significantly higher bandwidth which is expensive. However, as the ship is looking to upgrade the data link to 2MB/s by 2019 this should provide enough bandwidth to create a simple virtual control room. As the ship's up-link (ship to shore) is not utilised to the same level as the down-link, 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 starting to come 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 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 flying the ROV.

- HyBIS command module upgrade – 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.

- Heave compensation for HyBIS – HyBIS 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 winch would greatly reduce this effect and would make HyBIS more broadly useable.

- HyBIS recovery payload module – There are times when equipment is lost at sea, e.g. CTD 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 HyBIS recovery module could be used to recover the lost equipment at a minimal cost. Such a module could also be used for the recovery of landers in highly fished area.

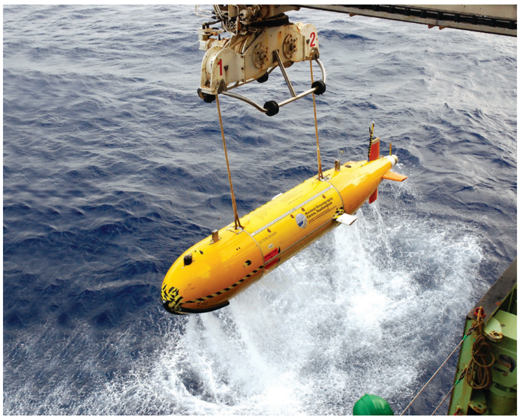
- Common interface module – Part of HyBIS' flexibility is the ability to integrate different sensor payloads onto a mission specific payload module. Currently this involves considerable input from the ROV team which is costly. To simplify this process a generic payload module will be created with the associated detailed interface document. This will be produced to enable custom payload designs to be created by external users.

Aspirations

- 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 reduce the piloting load and thereby 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, but it is yet clear whether these potential benefits can be realised.

- Create New Payload Modules and Refine the Concept of Operations for HyBIS. There are likely to be other HyBIS 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 developed these modules and modes of operations as and when resources and science priorities allow.

High Power MAS Platforms



Autosub6000

C-Worker 4

Current Capability

The high-powered AUV fleet developed by 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 – The Autosub6000 AUV is an established vehicle, which has been continually upgrades since its first deployment in 2007. It is 6000m depth rated and has rechargeable batteries. This high-powered AUV, developed by NOC, is becoming routinely used for scientific data collection. It is particularly well suited to high-resolution deep water acoustic surveys. However, it is now being requested to perform photographic surveys very close to the seabed. These photographic surveys are considerably more challenging and significantly increase the risk to the vehicle, and this trend of pushing the operational envelope of the vehicle is expected to continue. Thus, the vehicle will need to continue to be developed.

- 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) and camera system.

- Retired Autosub3 – The Autosub3 has now been retired from operational use. Development of a 2000m rated, under-ice capable AUV (AS2KUI), part of the Oceanids project, will reintroduce this capability from 2021 onwards.
- NEW C-Worker 4 – MARS has recently purchased a C-Worker 4 Unmanned Surface Vehicle 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 which will be demonstrated in FY1819. 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 will also be used for testing oceanographic sensors, for example project RINGO will utilise the vehicle for testing a pCO_2 sensor

Science Drivers

- Improved system reliability – The Autosub6000 has had significant issues with reliability as identified by the PCAs associated with JC120, JC132, DY021, DY030, & DY034. This is compounded by the internal lonworks control system being obsolete.
- 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. Prof. Wynn commented on this during the first science cruise of Autosub6000 (JC027) and this was reiterated by the PCA for JC132.
- Improve the obstacle avoidance system and 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 higher level 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 AUV range to replace Autosub3 – Autosub3 has significantly more range than Autosub6000. This increased range is invaluable for under ice deployments. To replace Autosub3 we would need to increase the range of Autosub6000.
- Replace Autosub3 – Autosub3 has become antiquated and has been retired, however Autosub3 had significantly more range compared to Autosub6000. This increased range is invaluable for under ice deployments. Developments as part of the Oceanids project will provide an enhanced under ice capability from 2021 onwards.
- Improve navigational accuracy – Autosub6000 has experienced problems with high-resolution navigation and attitude measurement. These problems have been seen in the camera survey work 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.

Future Capability

- Build Autosub2KUI to replace Autosub3 – The Oceanids project is funding the development of second generation Autosub2000 which will be built to replace Autosub3. This will integrate the development work described below, and will incorporate a 2000m rated foam centre section to allow the AUV to carry double the energy of Autosub6000. 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 produce a complex and error prone system. To alleviate these issues a new onboard control system will be developed. This will to 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.
- Upgrade the Obstacle Avoidance and Situational Awareness system – The current Autosub6000 obstacle avoidance system was developed in 2009 for work in the mid-Caymen rise as part of JC044. The system is thus 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 in 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.
- Develop Autosub2KUI under ice capability – As Autosub2KUI will be developed in part to replace Autosub3 it will need to be adapted to operate under ice. As noted above the 2000m central foam will provide the extra energy for this type of operation. There will also be new under ice behaviours developed to allow the AUV to operate safely. These behaviours will build on the original Autosub3 work, and couple this to the new OCS and OAS system to further enhance the under-ice capabilities.
- 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. The monitoring will also reduce the risk of vehicle loss as it will be continually monitored, 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.

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 camera for the Biocam project.

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 Onboard Control System 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.

New concepts of operational and application specific developments – We will work with the science community and industry to explore and developed new operational concepts for utilising the vehicles, and look at application specific enhancements which will provide utility to the community. This will be done as and when resources and science priorities allow.

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 to 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.

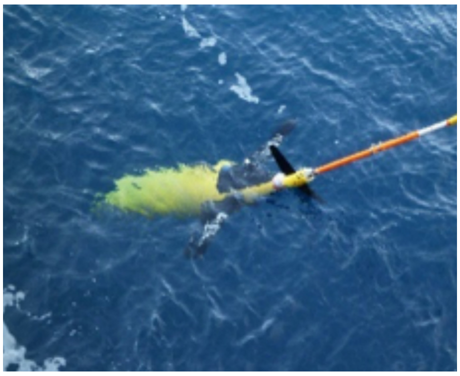
Long Range MAS Platforms

Current Capability

The current vehicles within the 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 the engineering manager responsible for the relevant platform.

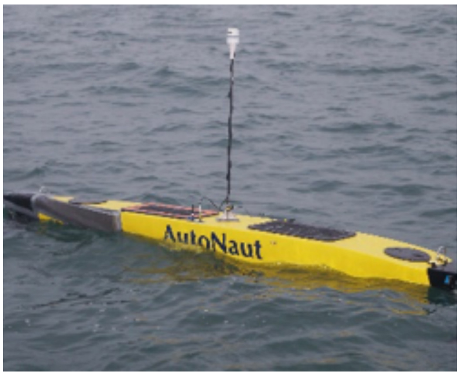
- 10 x Seagliders
- 23 x Slocum gliders (200m & 1000m)
- NEW 1 x University of Washington Deepglider (6000m)
- USVs (2 x Waveglider SV3,1 x Waveglider SV2, 1 x AutoNaut, 1 x C-Enduro)
- 3 x ALR6000


Slocum glider


Seaglider


ALR6000


Waveglider SV3



Autonaut


C-Enduro

Science driver

- **Operational cost reduction** – Reducing these costs will allow a higher utilisation of the fleet and thereby increased science impact.
- **Under ice capabilities** – Surveying under the Arctic and Antarctic ice shelves is of growing scientific importance. Long range MAS platforms can 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 achieved safely.
- **Improve navigational accuracy** – The sub-surface navigational accuracy of long range MAS platforms is poor, and needs to be improved if long duration sub-surface missions are required.
- **Deeper operations (gliders)** – Current gliders are limited to 1000m depths. This is insufficient for a number of applications, and hence deeper gliders are desirable.
- **Instrument calibration (gliders)** – Pre and post deployment calibrations are currently very time consuming. This calibration time removes the vehicle from the fleet for several months at a time.
- **Acoustic gateway and navigational aiding (USVs)** – Unmanned surface vehicles are an ideal platform to act as an acoustic gateway and navigational aid to subsurface assets such as AUVs, gliders and seabed landers.
- **Increase system energy (ALR)** – The current 6000m 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 (ALR)** – 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 large mixed fleets, as described in the Long Range C2 section.

- Hibernation capability (ALR) – 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.

Future Capability

- Deep gliders – Deeper operation of the glider fleet will become available through the purchase of a University of Washington Deepglider. Alongside this purchase NOC is involved in the development of a deep glider as part of the Horizons 2020 BRIDGES project. The H2020 gliders are likely to come on stream within the next four years.

- 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 ACSIS trial which will be using a waveglider to acoustically harvest data from the RAPID array; and the Innovate UK 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.

- Rechargeable batteries Slocum gliders – Glider 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. If successful it is expected that they will be highly in demand and as such more will be purchased.

- ALR1500 – To increase the payload capacity and operational speed of the ALR6000 extra energy is required. To achieve this increase in energy a shallower rated (1500m) 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 6000m 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 would also be applicable to other areas such as carbon capture and storage monitoring.

- ALR hibernation capability – To allow the ALR6000 to increase its endurance and to perform period monitoring of a specific area, techniques will be developed to allow the ALR to hibernate while still maintaining navigational accuracy. This capability will be developed over the next few years.

- Improve ALR Control System – The existing ALR control system has been tailored to specific deployment programme. Thus, the system needs to be further developed to create a more general system for future deployments as mentioned above. 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.

- Under Ice Operations – It is desirable for the ALR & 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. Over the next five year 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. We will also 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 infrastructure is being purchased as part of Oceanids to enable navigation under ice using long range acoustic beacons. The technique requires a number of low frequency sound sources at known locations transmitting at known times. The receivers on the vehicle pick up these signals and by knowing the time offset can estimate their position. The sound sources have been purchased and the receiving element will be developed over the next few years.

- Improving Navigational Accuracy – There are a number of areas where improvements in navigational accuracy will be introduced into the long-range fleet. These developments include:
    - Investigating and upgrade on-board compass modules on the glider fleet
    - Integration of a high precision AHRS into ALR
    - Developing improved navigation techniques as part of the Innovate UK funded P3Nav project.
- 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 simply the integration of new sensors in the future.
- 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. Currently the RINGO and CaPASOS projects will measure pCO_2 from USVs
- Development of the AutoNaut USV – The AutoNaut vehicle Gordon has been recently upgraded following damage sustained during a deployment. These upgrades will be tested, and the vehicle will continue to be developed within NOC in collaboration with AutoNaut.

Aspirations

- New lower cost primary packs for gliders. Current glider packs typically use Electrochem 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.
- 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 be operated for 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.

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.

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 is funded by the Oceanids C2 project.

Current Capability

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

- ALR control interface
- Slocum control interface
- Seaglider control interface
- Waveglider control interface
- Autonaut control interface
- C-Enduro control interface
- MARS piloting portal (http://mars.noc.ac.uk)

Science Drivers

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

Future Capability

- **Unified Control Interface** – A unified control interface will be developed to simplify the deployment of mixed fleets of vehicles. This interface will be simple, intuitive, yet powerful enough to allow the pilot to create complex mission plans. The interface will build on the investment that has already taken place in this area, and will be integrated into all of the long-range fleet. The development will be undertaken using an agile approach and so iterative upgrades to the system will occur throughout the project duration. The control interface will be available to the wider UK community for piloting and monitoring of the assets.

- Vehicle Data Processing, Curation and Availability – The 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 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 (eg 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, and 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 also to guide the platform to optimise the data collected.
- Engineering data fusion – This aspect of the work will develop approaches for automatic fleet heath monitoring and mission risk evaluation to better inform human pilots or automated fleet controllers

Aspirations

The development of the website tool will provide real time data to the vehicle pilots and the 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. This would be applicable to the moorings team and also the near real time data from the ship.

The Oceanids C2 development will significantly enhance the operations of the fleet, but it will not cover every requirement. Thus, we intend to further enhance the command and control as and when new requirements and resources become available.

Gravity Meter

Current Capability

S-040, S-84 gravity meters

Science Driver

Feedback from scientists suggest that the data from NMEP gravity meters is not sufficient for science needs.

Future Capability

The performance of the upgraded S-040 will be evaluated alongside that of the S-84 by NMF SSS group and a geophysical user group to determine whether a stepped improvement has been realised and the quality of data is sufficient for science needs. This information will be used to inform the decision whether to upgrade the S-84 or to incur the much greater capital cost of purchasing a new Gravity meter.

Acquisition systems

Current Capability

Ifremer TECHSAS acquisition system

Science Drivers

The two ships will receive an upgraded Ifremer TECHSAS acquisition system during 2018. A lab version will be installed ashore in March to allow it to be trialled and prepared for implementation on the ships later in the year. At the same time, an internal review of our approach to acquisition conducted between 2016-2017 made a number of recommendations towards the design of a parallel system, built in-house and with liaison with the scientific community, to deliver improvements over our current system, including:

- Redundancy: There is a single point in the current system through which all data acquisition currently passes. If this component fails, it will take down the acquisition of many important streams until it is repaired or replaced. Point-of-entry acquisition which retains data locally if the acquisition network goes down could solve this issue.
- Timing: The design of the system introduces uncertainty over the timing of acquisition events. Implementing a system which time-stamps signals at the point-of-entry to the acquisition network can reduce this uncertainty.
- Retention of raw data: Until a recent stopgap measure was built in-house, the current system did not retain any raw data, making it difficult for scientists to isolate the effect of TECHSAS's post-processing from real physical phenomena.
- Quality checking: Other than visual inspection of signals via the display system, there is no formal process or automated program for quality-checking data. This can be developed and implemented independently of any acquisition system.

Future Capability

In the short term, the organisation of an Acquisition System group between Scientific Ship Systems and interested scientists to prepare an initial approach to and specification for the system and quality checking processes. In the medium to long term, a system developed in stages to deliver incremental improvements to our acquisition capability.

Magnetometers

Current Capability

Scientific Ship Systems currently operate three old SeaSpy1 magnetometers and one new SeaSpy2 magnetometer.

Science Drivers

Magnetometers are deployed in pairs to provide redundancy, and occasionally there is the requirement to have both pairs deployed on different ships.

The SeaSpy1 tow cable is incompatible with SeaSpy2 magnetometers, which incurs a long and complicated changeover if a magnetometer needs to be replaced during a science cruise.

It would be preferable to have one complete SeaSpy1 system and one complete SeaSpy2 system so only one cable type needs to be provided with each deployment.

Future Capability

One new SeaSpy2 magnetometer to be able to provide two complete and consistent magnetometer deployment kits.

Surface and meteorology

Current Capability

Wave recording – The supplier and supporter of our wave radar system (OceanWaves WaMoS) has been taken over by another company who have discontinued support and upgrades for the system in its current form. Given that any upgrade will now incur significant costs, the nature and capability of wave recording devices should be reviewed with the scientific community to agree a way forward.

Dartcom weather satellite receiver – The Orbit antenna on the RRS *James Cook* which tracks weather satellites has reached its operational end-of-life. There will be a substantial cost to replace this system, so it is necessary for the scientific community to review whether this capability should be continued.

Science Drivers

The on-going development of theory, practice and standards makes it necessary for the scientific community to review the ships' surface water and meteorological monitoring provision and identify improvements and developments that could be made to meet current requirements.

Future Capability

An upgrade of the surface and meteorology monitoring provision to meet the requirements of the scientific community.

Winches

Current Capability

The NMEP includes a comprehensive suite of deck winches including: 1 tonne – 5 tonne rated general purpose winches, 5 tonne rated North Sea winches and a 10 tonne GPC winch as well as winches specific to mooring deployment, VMP/seasoar/scanfish platforms and seismic operations.

In addition, the NMEP has two metal free portable winches, one electrical and one electro-optic (nb both these winches require some redesign and repair and hence will be withdrawn from use until they can be fixed and successfully trialed later on in 2018).

Science Drivers

Reliable winches that can be operated in all conditions by NMF technicians or, were appropriate, NMF mariners. There will always be a trade-off between the use of general purpose winches which are easier to maintain and operate and bespoke winches which can be more complicated to operate and more expensive to maintain.

Future Capability

An analysis of winch usage from 2015 onwards will be undertaken by NMF in 2018. This will inform a review of the winches held within the NMEP.

Ancillary Equipment and facilities

Cal Lab

Current Capability

NMF currently has a bespoke ocean instrument calibration facility open to internal and external customers capable of high quality temperature, conductivity, salinity and pressure calibrations.

Science 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. We work closely with OTEG to test their development sensors.

Future Capability

- Develop a glider calibration facility for the full sensor bay including a Seabird 911+.
- Design and build a temperature calibration bath.
- The NMF Calibration Lab is fully traceable to National Standards. In addition, we aim to achieve full ISO9001 accreditation in 2018.

Aspirations

Undertake a review of NMF sensors to determine if this facility should be expanded.

Container Laboratories

Current Capability

The current fleet of container laboratories includes radionuclide, clean chemistry, constant temperature and general purpose containers.

Science Drivers

These container laboratories will continue to supplement the laboratory facilities onboard the RRS *James Cook* and RRS *Discovery* as well as other ships.

Future Capability

As part of the 5-year rolling plan NMF will purchase one new ‘clean chemistry’ lab and one new radionuclide lab over the next 2 years.