# FMRI DIGITAL INFRASTRUCTURE SCOPING STUDY

This report has been authored by the members of the Future Marine Research Infrastructure (FMRI) Digital Infrastructure Scoping Study (DISS) Working Group:

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**This report – FMRI's Digital Infrastructure Scoping Study – evaluates the current digital infrastructure for marine research, identifies key user requirements, and presents recommendations to guide the development of the future digital infrastructure required to achieve FMRI's aims.**

# METHODOLOGY & APPENDIXES

1) We completed quantitative and qualitative user research (including interviews and workshops) to gather insights on the current state. For more information on the detailed methodology please see the User Research report.

2) Based on the user research feedback, we created the ***How Might We* matrix*** and ***Fig 2. diagram*** in this report. We chose HMWs because they connect the problem space with solution potential, without defining detail which should be decided by FMRI teams at delivery stage(s):

*__What are How Might We's?__ A digital product methodology and process, created specifically for collaborative ideation – created by Sidney Parnes (1967), later pioneered by IDEO, and used widely across the digital industry. Article link

3) We developed user journey mapping (for both Vessels & Autonomous vehicles) based on user research from ocean specialists and users of the digital infrastructure. The HMW's (Step 2) are linked accordingly in the user journey steps.

All the research information gathered has been shared with the FMRI team and incorporated into this document as appropriate.

**All the associated support documents have been published alongside this report:**

- **UX Research report**
- **How Might We Prioritisation Matrix**
- **User Journey 1**
- **User Journey 2**

# SUMMARY AND KEY RECOMMENDATIONS

The current digital infrastructure for marine research in the UK suffers from inconsistencies in the digital foundations across its components, resulting in inefficiencies between the constituent components of the end-to-end system: upstream planning, real-time piloting, data acquisition and transmission, and the downstream data ecosystem.

FMRI is expected to increase the number of autonomous observing platforms (AUVs, gliders, USVs, etc). However, physical infrastructure alone is not enough achieving a step change in our observing capabilities. Efficiently and optimally integrating diverse observing systems will require a novel digital infrastructure.

**Our key recommendations**

1. **A novel digital infrastructure built around two key features; integrated observing capabilities** (within a single national fleet) allowing the remote operation, interoperability and access to data across the shoreside, ships and autonomous vehicles operated within a single fleet, **and a collaborative platform** (across fleets operated by multiple organisations/nodes) enabling collaborative science and coordinated operation across fleets operated by different organisations.

   This novel digital infrastructure would fully support and connect capabilities across the new NERC strategy focusing on the *key themes of green growth and environmental security, while pushing the frontiers of knowledge while moving national capability forward to enable future partnerships and responsible innovation*.

2. **A user-centric approach supported by efficient resourcing and effective governance**
   The optimal exploitation of the recommended digital infrastructure is not only a technology challenge, but a considerable cultural change. Digital infrastructure must be re-designed and developed with the users at the centre, and the efficient maintenance, upgrade and operation of the digital infrastructure for collaboration requires coordinated and multi-disciplinary teams across organisations working in partnership. New roles, training programmes and community building activities will be required.

   Governance capabilities to support a collaborative, federated approach for both the creation and operational phases will be required. However, it is not possible to make specific recommendations on the governance structure for digital at this moment because it will depend on the final shape of the FMRI programme (and how it deals with the fragmented digital governance existing today where different parts of the digital ecosystem have different governance bodies, e.g. NERC EDS, NERC Marine Facilities Planning).

3. **A cybersecure digital infrastructure by design**
   The recommended digital infrastructure is a distributed system that enables high integration within fleet (with a single operator to simplify management and cybersecurity) and collaboration across fleets. The result of FMRI is expected to be a highly distributed system in terms of number of observing devices and users. State-of-the-art cybersecurity will need to be designed

and implemented at the program level, with additional layers of security added as required across specific elements of the new digital infrastructure (e.g. AI co-pilots for autonomous vehicles may require custom security considerations).

# SECTION 1: CURRENT DIGITAL CAPABILITIES. KEY PROBLEMS AND GAPS.

This section describes the current digital infrastructure, identifies key gaps and explores key user requirements for future digital infrastructure.

The current NERC Marine physical infrastructure is composed by two main hubs operated by the National Oceanography (NOC) National Marine Facilities (NMF) and the British Antarctic Survey (BAS). The Scottish Association of Marine Sciences (SAMS) supports and operates some small elements of the NMEP.

- NOC NMF operates two world-class research vessels (RRS James Cook and RRS Discovery) and the National Marine Equipment Pool (NMEP) for the UK community. The NMEP includes thousands of sensors and the biggest robotic fleet in Europe (35 gliders, 4 Autosub Long Range Autonomous Underwater Vehicles (AUVs) with under ice capabilities, one 6000m rated Autosub and the world-class IBIS ROV).
- BAS operates the world-class RRS Sir David Attenborough and six gliders (outside the NMEP).

NOC and BAS also provide downstream digital capabilities to archive and distribute the data generated by the observing systems described above. NOC operates the British Oceanographic Data Centre (BODC) and BAS the Polar Data Centre (PDC).

**The current digital infrastructure for marine research in the UK has four areas** (Figure 1): upstream planning, real-time piloting, data acquisition and transmission, and downstream data ecosystem.

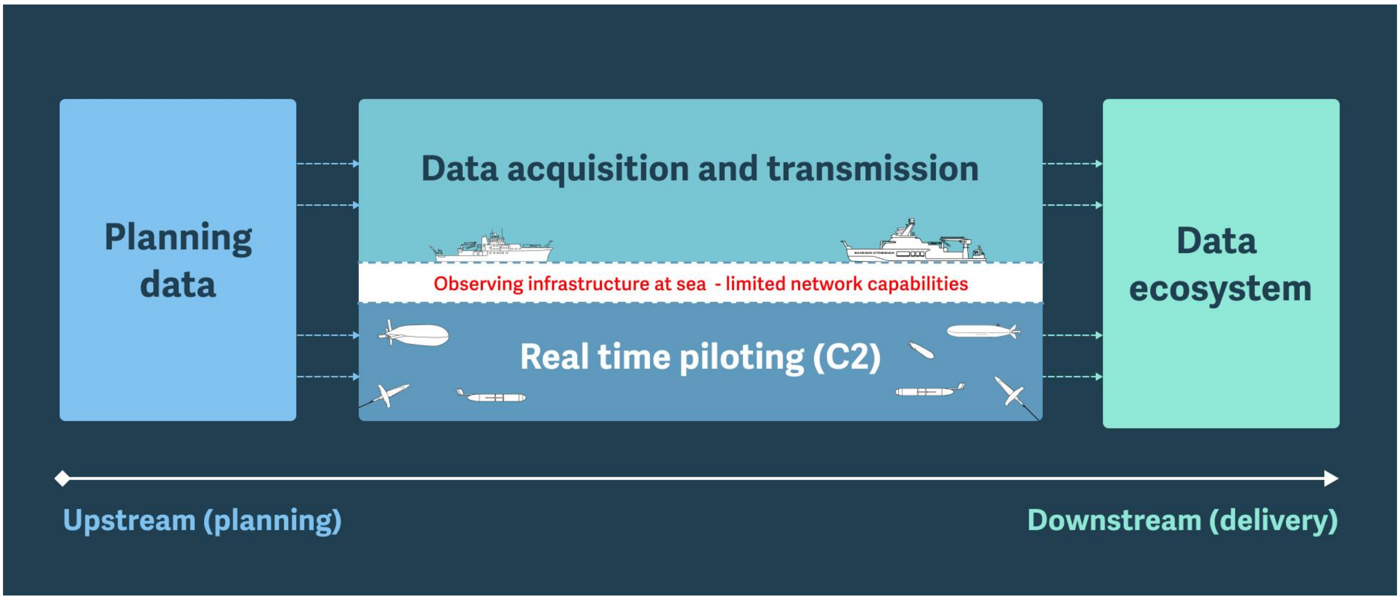


***Figure 1*** *– Schematic showing the four main components of current digital infrastructure for marine research in the UK: Upstream Planning; Real-time Piloting; Data Acquisition and Transmission; Downstream Data Ecosystem.*

1. Planning (upstream) - The NERC planning is mainly done on the Marine Facilities Planning (MFP). The tools and approaches used by MFP are rapidly becoming the standard for science ship operators in the world (users include NOC, GEOMAR, NSF, JAMSTEC and CSIRO). However – the MFP is not suitable for planning of autonomous campaigns (this is all currently done manually, offline).

2. Real-time piloting of observing infrastructure at sea - The piloting ecosystem encompasses the tools utilised to operate autonomous vehicles (AUVs, Gliders, USVs, etc). This is the newest part of the digital ecosystem and significant progress has been made over the last 10 year. While the piloting capabilities are world-leading in the academic context, the level of digital maturity is relatively low; there are no clear standards around interoperability of piloting systems outside of the military domain, this hinders collaboration as integrating those systems into high level planning systems to have a single point to make decisions and then propagated back to the pilots needs to be done ad-hoc for each autonomous platform and their correspondent C2. The general Technology Readiness Level (TRL)[1] of these type of systems remains at level 7.

3. Data acquisition/transmission from observing infrastructure at sea - The ship-based ecosystem includes the ship acquisition systems and data transfer back to shore. While there is a long tradition of operating these types of services at sea, they have remained quite isolated as they were effectively disconnected from the world when at sea. However, that is rapidly changing, with increased bandwidth and decreased latency in satellite communications ships are rapidly becoming effective nodes of the whole ecosystem, able to transmit large quantities of data back to shore in near real time. This brings new opportunities and can accelerate the development of new digital services onboard of ships to leverage new capabilities.

4. Downstream Data Ecosystem - The downstream data ecosystem (which has the biggest digital footprint in terms of data size) provides archiving, curation and delivery of data to marine scientists and broader communities nationally (e.g. NERC EDS, MEDIN) and internationally (e.g. EMODNet, SeaDataNet).

## USER & STAKEHOLDER NEEDS

As part of this report, we have completed research on users and stakeholders' needs (**User and Stakeholder Research Report** and mapping of current user journeys. The key gaps identified by users – and our key insights – are described in **Figure 2** and can be summarised as follows:

- There is a disconnect between the digital infrastructure for research ships and autonomous fleet(s) across the UK, with only partial integrations across different observing platforms. Consequently, we have a siloed view of the observing system which makes transformation towards net-zero difficult and prevents us from having a whole system approach to the environment (for conservation, preservation and economic benefit).

- Field hours don't align to office hours – and this presents additional challenges.

- There is little automatic feedback across digital systems before, during and after operations (e.g. metadata in planning systems needs to be transferred manually to observing systems). This, along with other factors (e.g. funding, skills), make automation and adoption of new technologies (AI), as well as digital transformation, difficult.

[1] https://www.ukri.org/councils/stfc/guidance-for-applicants/check-if-youre-eligible-for-funding/eligibility-of-technology-readiness-levels-trl/

- In addition, because of the very limited funding for improved digital solutions, inefficiencies are often mitigated by increasing the number of human resources dedicated to address specific problems, instead of improving processes and methods for the wider system.

Based on these gaps and insights, we compiled and prioritised a list of **"How Might We"** statements. The HMWs were also grouped into categories, aligned to the four areas of current digital infrastructure for marine research in Fig 1. The categories used are: Data Platforms & Infrastructure, Comms Relays, Fleet Control, Hardware (out of scope) and Non Technical – ie. Governance, People, Training etc.) .

Each of these HMWs statements has been numbered, and these have been mapped to the User Journeys to provide a starting point for defining solutions. The How Might We's also serve as an indicator of the scope of each challenge. We used an indicative range to estimate the level of complexity, based on our estimation of Level of impact and Level of certainty for each HMW:

- Low (1 FTE or below)
- Medium (1-5 FTE)
- High (6+ FTE, large project and/or high complexity)
- Very high (20+, large or long term project and/or high complexity)

Our next step was the creation of a high level Recommended Digital Infrastructure (Section 2). The aim of the Recommended Digital Infrastructure section is to highlight the key digital features and associated human resources that will be required to provide the FMRI program with relevant information of what areas need investment.

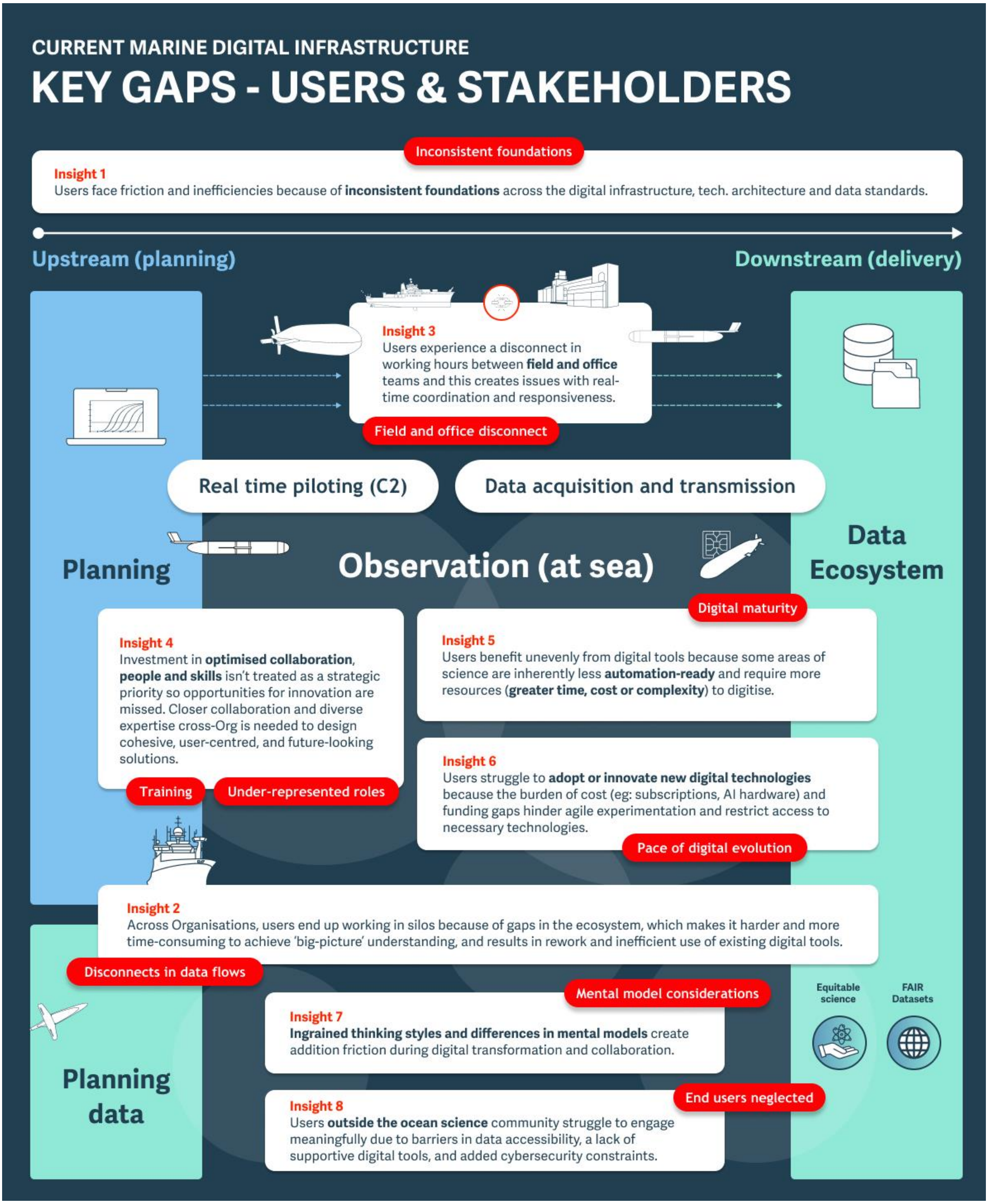


***Figure 2*** *– Infographic describing Key Problems and Gaps for users and stakeholders on current digital infrastructure for marine research in the UK. Additional information is presented in* ***UX Research Report***

## CURRENT IT & TECHNICAL ARCHITECTURE: KEY PROBLEMS AND GAPS

We have analysed the current digital infrastructure from an IT architecture point of view.

Our key findings are presented in **Figure 3**, and can be summarised as follows:

- Existing observing platforms are not fully networked and there is only partial visibility across vessels and autonomous platforms within a particular fleet.
- Planning digital ecosystems are not interoperable and interconnected; for example, NOC and BAS, the Sir David Attenborough plan is in the MFP but the rest of BAS logistics happen outside of it.
- Variable level of maturity in the integration of digital processes across the four components (upstream planning, real-time operations, data acquisition and transmission, downstream data ecosystem) of the digital infrastructure, creating inefficiencies during operations, delaying data delivery and in general not providing enough transparency and observability on both the observing system and data collection and data processing activities.
- Cybersecurity is implemented at local level (e.g. NMEP, downstream datacentres) but not planned and designed as a fully integrated system. This could lead to security disparity between the different components of the full digital ecosystem with not clear security standards to exchange information between them or clear security targets to safeguard data and operations of remote assets.

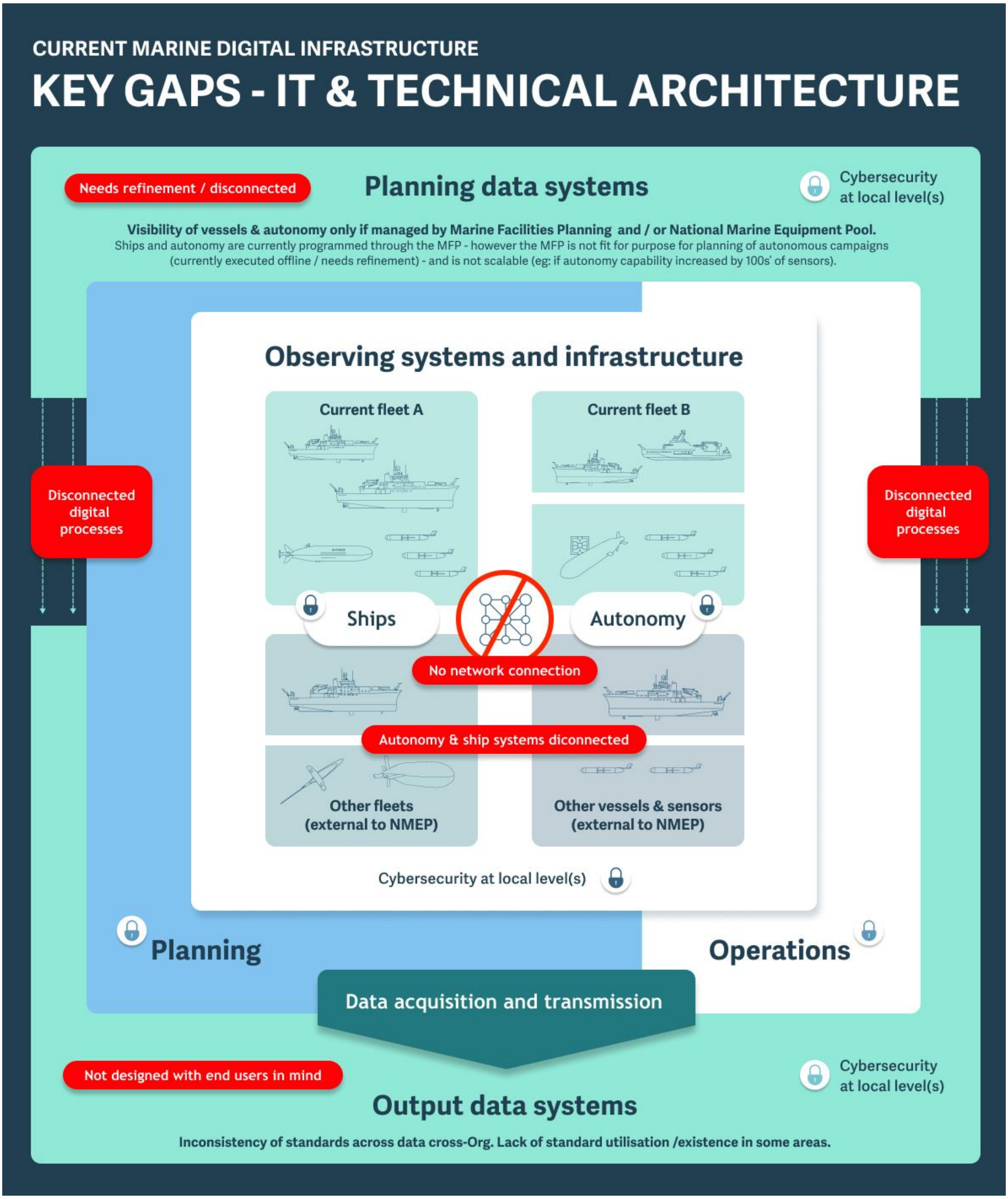


***Figure 3*** *– Infographic describing Key Problems and Gaps in current IT architecture for marine research in the UK.*

# SECTION 2: RECOMMENDED DIGITAL INFRASTRUCTURE

To address current Key Gaps and Problems, we recommend a novel digital infrastructure with two key features:

1. **Networked observing capabilities** enabling coordinated operation across ships and autonomous vehicles (operated by a single organisation within a single fleet single fleet or, via the collaborative platform, across multiple fleets operated by different organisations). This work will develop and improve connections to and from observing capability or “networks” and enable the federation of multiple of these networks under the same system-of-systems or the FMRI System, creating and improving machine to machine interfaces, developing consistent data infrastructures while centrally hosting the core infrastructure. This work will streamline data pipelines and operational activities (like piloting) with the introduction of solid foundational digital capabilities both on premises and in the cloud and leveraging modern AI to automate and optimise day to day problems.

2. **Collaborative platform**, creating the interoperability to enable users to collaborate when operating fleets owned by theirs or different organisations, fostering scientific collaboration and enabling scientific discovery, giving user communities the software tools to interact with the new observing system and share and collaborate on the data. All these while unleashing the power of AI to maximise the quality of the data analysis coping with aggregated information coming from multiple sources and domains.

These can be mapped directly across to the 2023-24 Technology Roadmap workflow and NMF “Four Screens” vision for science interaction (see page 05 in Report) – but also takes into consideration other systems, sensors and processes which are currently external to the NMF.

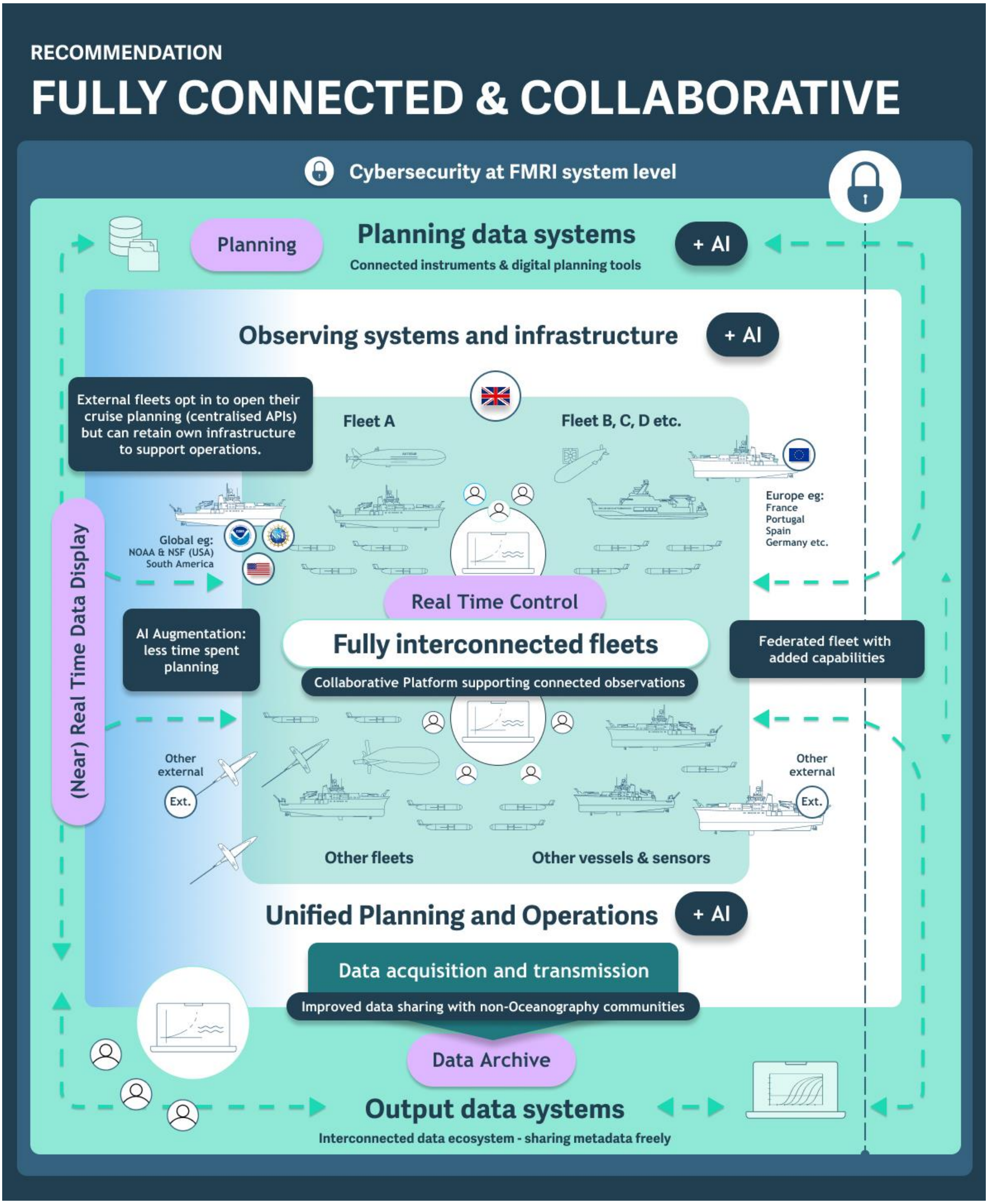


***Figure 4*** – *Infographic describing recommended digital infrastructure for marine research*

## RECOMMENDED DIGITAL INFRASTRUCTURE - IT ARCHITECTURE

An IT architecture view of the recommended digital infrastructure is presented in Figure 5, below.

**The key characteristics are:**

- Consistent architectural design across components (upstream planning, real-time piloting, data acquisition and transmission, and downstream data ecosystem).

- Modular, flexible and interoperable architecture, defining key modules and their interaction at different levels (e.g. store/compute – user dashboards/metadata ingestion). This approach will enabling the iterative development of features (e.g. collaborative platform across fleets) and facilitate the scalability as required by the wider FMRI program based on the demands of the physical observing system (e.g. the system size would be different to cope with 200 autonomous platforms and 2 ships than to 1000 platforms and 5 ships).

- Consistency and sustainability, consolidating and centralising the core infrastructure services with the associated human resources to support them (e.g. central authentication and authorisation services, centralised piloting tools, etc).

- Enabling connectivity by design, allowing dissemination and integration of components across nodes (e.g. multiple AUV data relays sitting in different organisations, ships or anywhere with an internet connection, or different computing facilities providing different capabilities).

- Collaboration-enabling: facilitating the participation of different communities to develop/maintain individual digital modules (e.g. command-and-control module, visualisation dashboard module)

- Innovation-enabling: facilitating the adoption of novel technologies in individual modules (e.g. AI copilots)

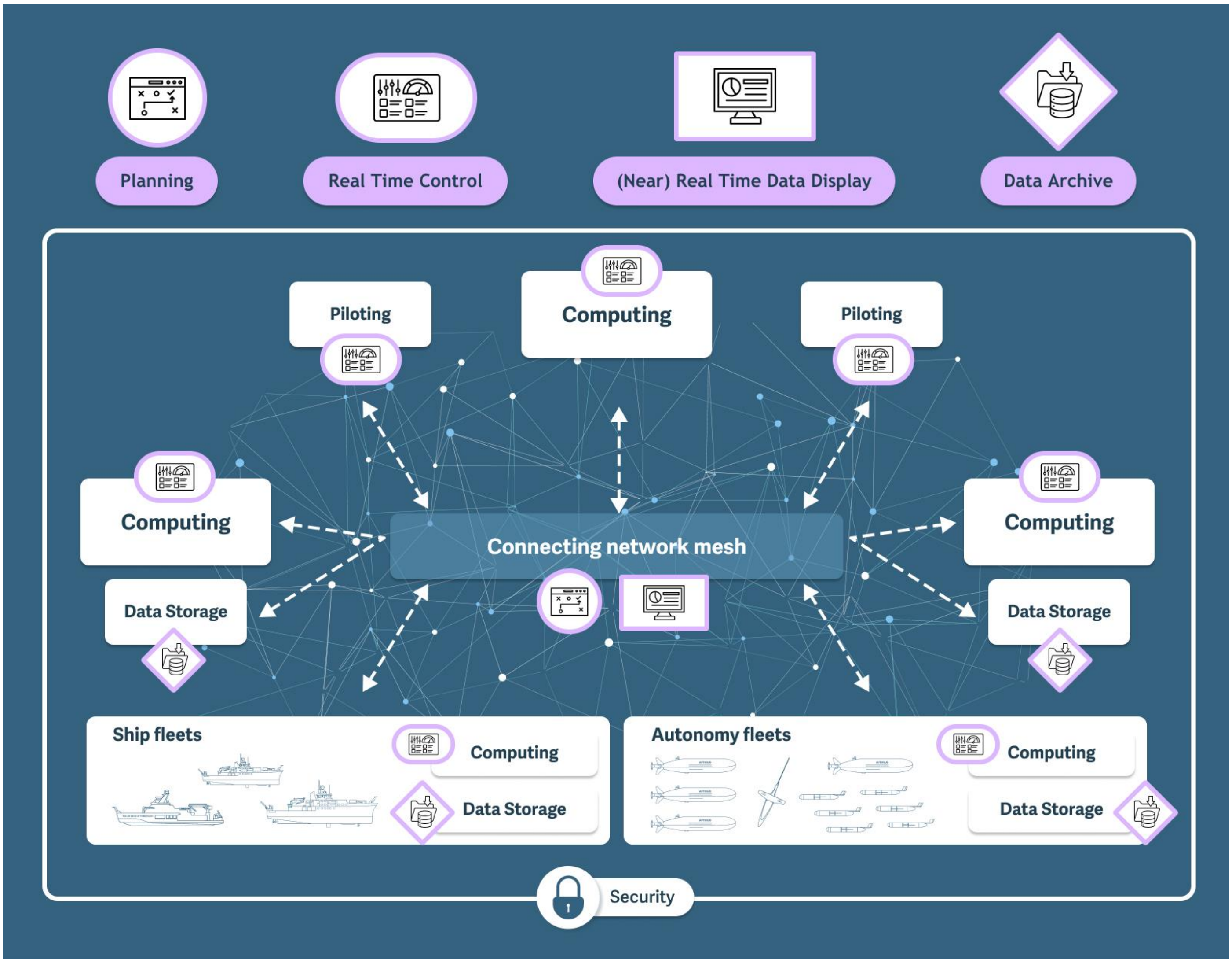


***Figure 5*** *– Diagram of IT architecture of proposed novel digital infrastructure for marine research facilitating federation and integration of components while increasing modularity and shareability.*

**The recommended infrastructure will allow rapid deployment and integration of end-to-end workflows** while increasing computing and reasoning capabilities, maximising the use and utility of the emerging observing system in which autonomous observing platforms will have a larger share.

As shown in Figure 6, the overall architecture of the system allows for a level of abstraction, **enabling components to be interchangeable**. Existing systems will be ported to use this abstracted compute platform, which will allow greater flexibility and more efficient use of resources. The addition of collaborative tools, not linked to any particular sub-system, will enable more effective working in a digitised workplace.

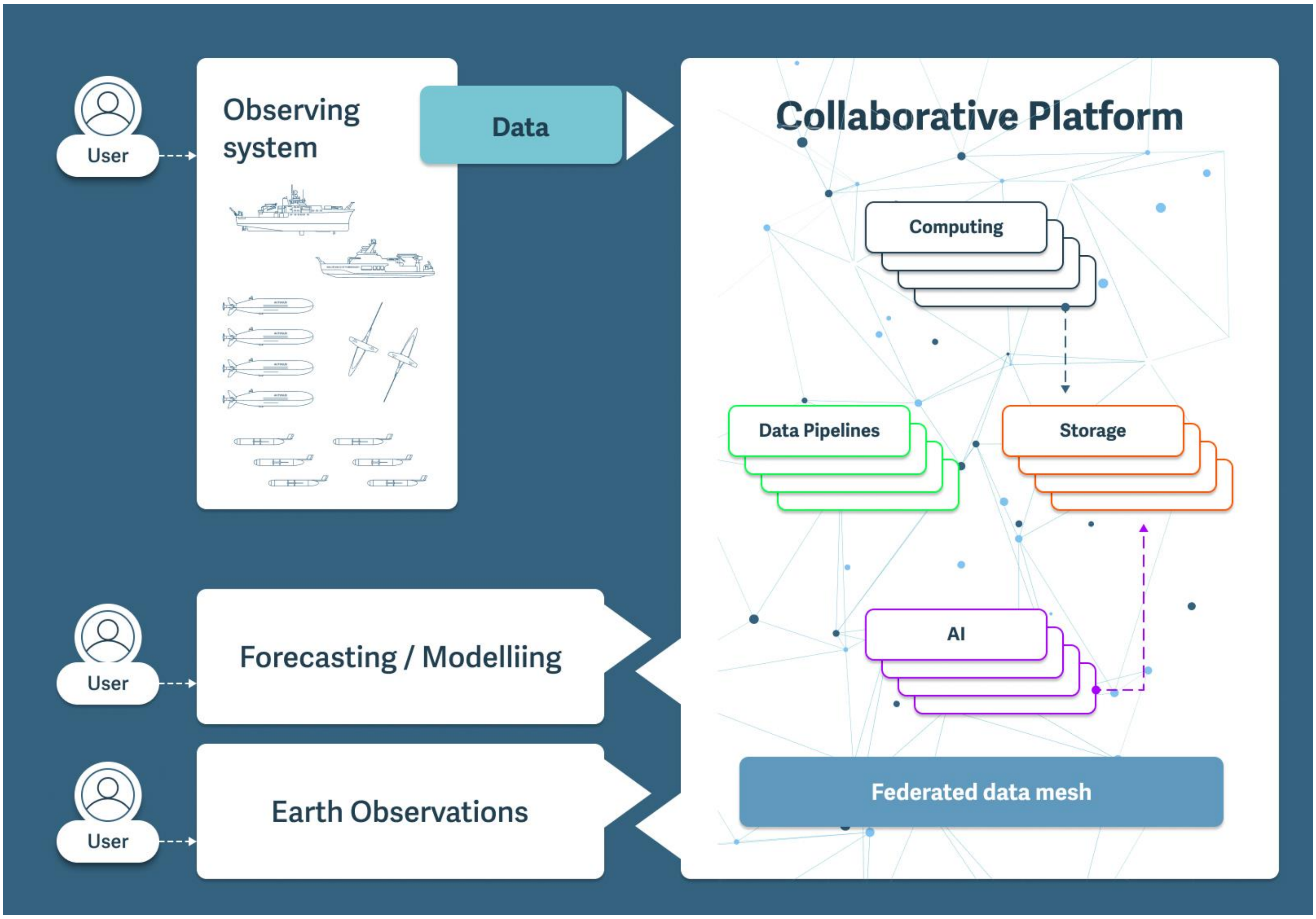


***Figure 6** – Diagram of compute resources facilitating data flow end-to-end*

# RECOMMENDED DIGITAL INFRASTRUCTURE: MODULAR APPROACH

**The recommended digital infrastructure addresses current user needs and technology gaps (summarised in previous sections). It is also aligned with the themes and key goals of NERC's new strategy:**

| Theme | Key Goals |
|---|---|
| A. Green Growth | Net zero transition, effective environmental management and restoration, whole system approach to maximise value of environment to the economy |
| B. Environmental Security | Improved accuracy of sensing and predictive observations to near real-time to predict change, integrate geopolitical risks, system resilience |
| C. Responsible Innovation | Technology integration, data usability, policy insight |
| D. Frontiers of Knowledge | Interdisciplinary science, skills development, agile funding |
| E. National Capability | Future-fit infrastructure, innovation support, sustainable operation |
| F. Partnerships | International leadership, co-designed programmes, business engagement |

## Our recommendations relate to NERC strategy themes & goals as follows:

| | **Novel Capabilities in<br>Recommended Digital Infrastructure** |
|---|---|
| **Planning** | • MFP ecosystem expansion<br>  ○ Fully modular development ecosystem.<br>  ○ Automatic metadata harvesting for the automation of downstream activities (data management and piloting).<br>• Enhanced AI planning optimisation.<br>• Enhanced Carbon accounting for fleet |
| | Addressing the following user needs - Insights 1, 2, 5 (see Figure 2 & Research Report)<br><br>***Supports NERC Strategy Themes: A, C, D & E:***<br>• whole systems approach<br>• improved accuracy to predict change<br>• data usability<br>• skills development, agile funding<br>• future-fit infrastructure, sustainable operation |
| **Real-time piloting and Data acquisition (Vessels)** | • Open-source Ship-based digital backbone with the following features<br>  ○ Metadata capturing tools within the ship ecosystem.<br>  ○ Synchronisation with shoreside systems.<br>  ○ Standardised sensor/device integration toolkit once integrated will leverage the metadata capturing and shoreside synchronisation.<br>  ○ Real time user collaboration with distributed teams, enabling remote science.<br>• State-of-the art cybersecurity. |
| | Addressing the following user needs - Insights 1, 2, 3, 6, 7 (see Figure 2 & Research Report)<br><br>***Supports NERC Strategy Themes: B, C, D, F:***<br>• environmental security<br>• technology integration |

| | |
|---|---|
| | • interdisciplinary science<br>• co-designed programmes |
| **Real-time piloting and Data acquisition (Autonomy)** | • AI ready open infrastructure (shoreside and edge), facilitating work with academia and industry to develop novel AI systems to automate and co-pilot.<br>• State-of-the art cybersecurity<br>• Federated open-source Command-and-Control enabling international cooperation. |
| | Addressing the following user needs - Insight 3, 6 (see Figure 2 & Research Report)<br><br>***Supports NERC Strategy Themes: B, E, F:***<br>• environmental security<br>• national (+) capability<br>• international leadership & business engagement |
| **Downstream Data Ecosystem** | • Fully open-source data ingestion pipeline architecture integrated with NERC's Environmental Data Services (EDS), enabling optimal cross-data search, cross-dataset analysis.<br>• Integration of novel data sources (e.g. images, video)<br>• Contextual metadata annotations, near-real-time DOIs and modular QC (AI augmented)<br><br>NOTE: the recommended digital infrastructure includes the procurement of adequate and scalable cloud solutions to cope with increased data volumes from autonomy fleet. |
| | Addressing the following user needs - Insights 1, 2, 3, 8 (see Figure 2)<br><br>***Supports NERC Strategy Themes: A, C, E:***<br>• green growth / whole system approach<br>• data usability<br>• national capability: sustainable operation |
| **System-wide capabilities** | • Full cloud resilient implementation, including cybersecurity.<br>• Dedicated development of digital infrastructure (and tools) involving multi-disciplinary squads (Researchers/Scientists, Product Owners, UX/UI Designers, Technical Architects, and Developers) and user-centric design.<br>• Usability testing & assessment of operations-based metrics in place for ongoing optimisation and measurement (value-driven outcomes).<br>• The proposed digital infrastructure enables the pursuit of different business models.<br><br>Service design mapping of end-to-end ecosystem will reveal any other disconnects and create a backlog for ongoing optimisation. Please see the **User and Stakeholder Research report** and **"How Might We"** guides for more detail on how these will address user needs.<br><br>***Supports across all NERC Strategy Themes, with focus on C, D, E & F:***<br>• Technology integration<br>• Interdisciplinary science, skills development, agile funding<br>• Future-fit infrastructure, innovation support, sustainable operation<br>• International leadership, business engagement |

THE END