European
MARINE BOARD
Advancing Seas & Ocean Science

Sustaining *in situ* Ocean Observations in the Age of the Digital Ocean

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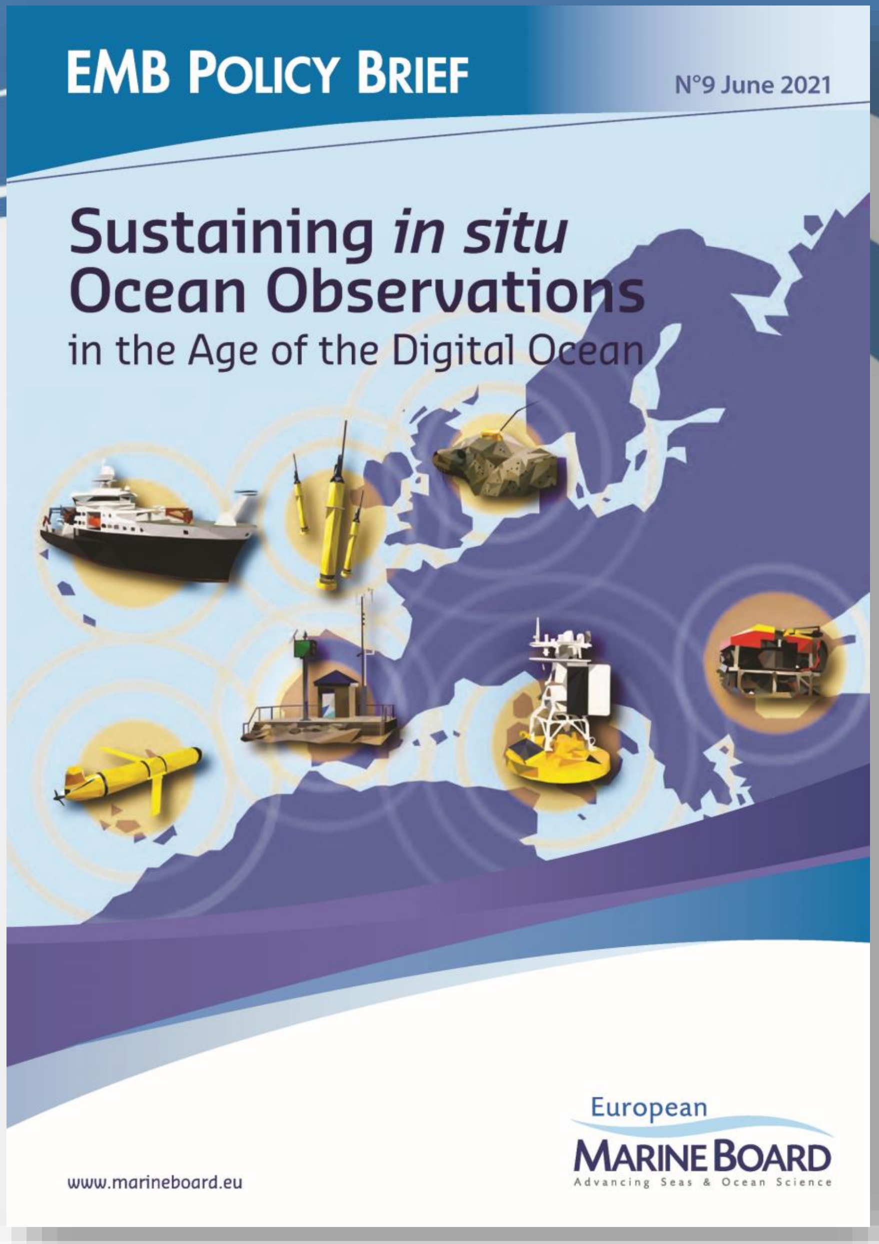

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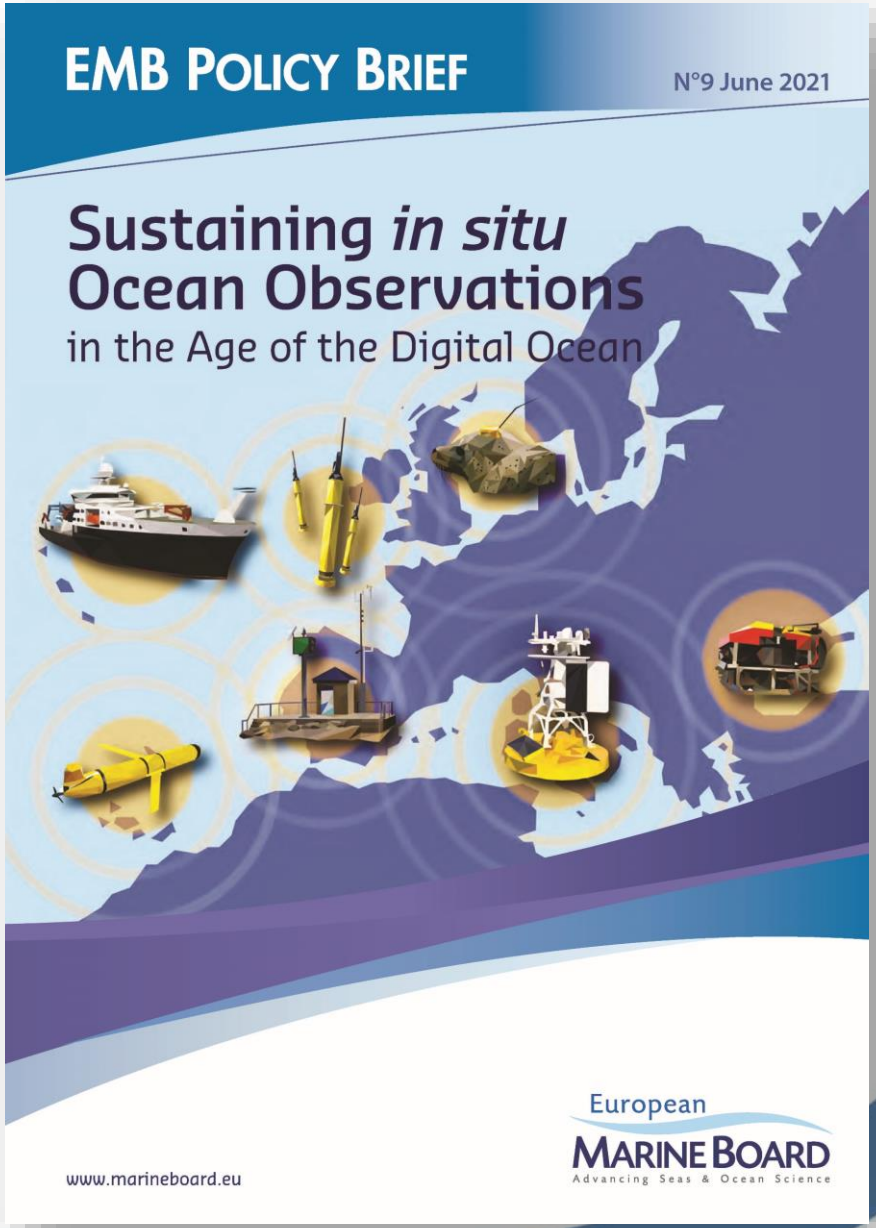


Headline Conclusions

Present ‘sustained’ Ocean observations

- Mostly **national funding**, not well coordinated
- Mandates and funding **mostly within EEZs**
- **Diverse institutions** with **limited coordination**
- Piecemeal, **short-term, insecure** funding

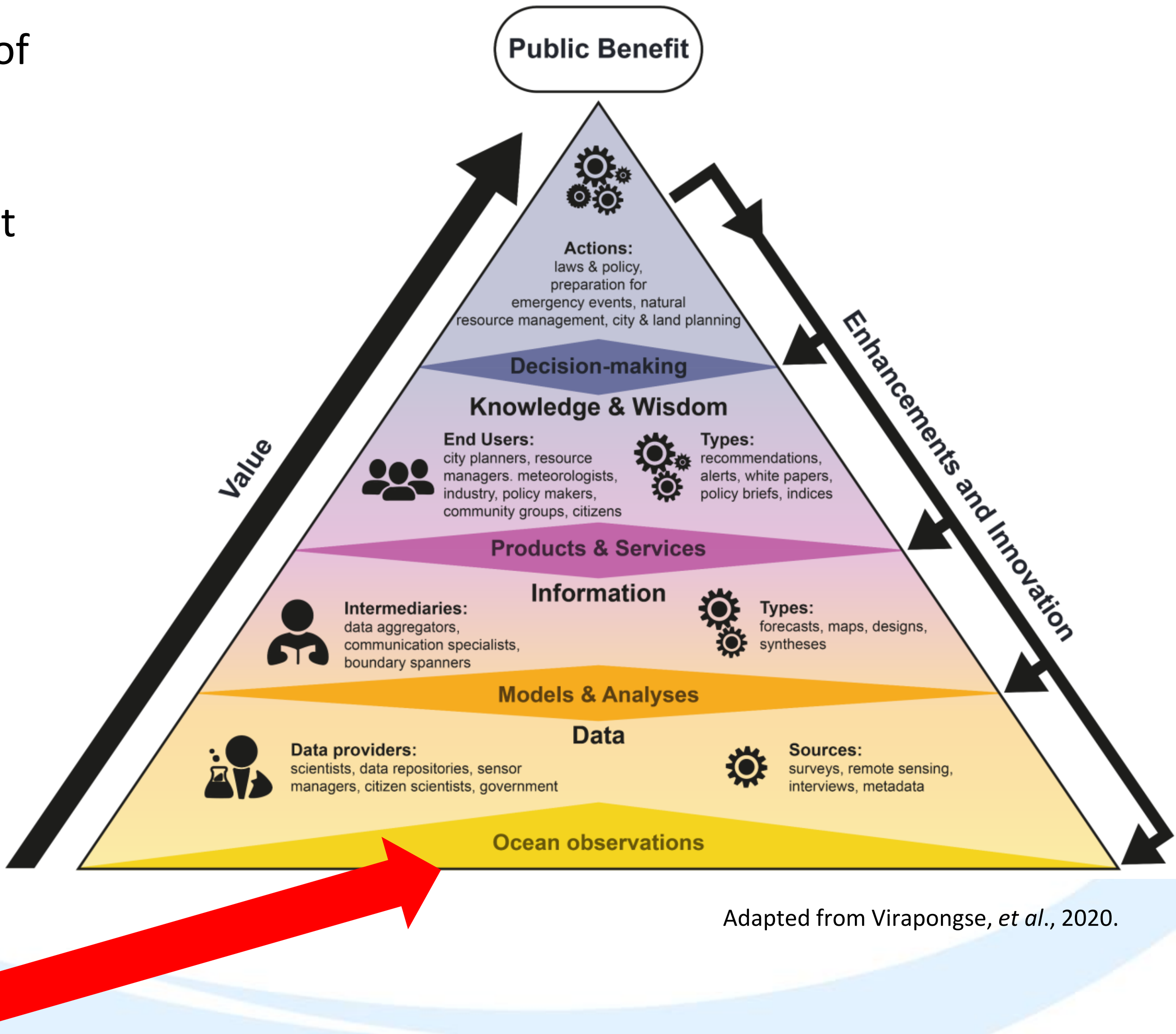
Progress needed

- **Critical global infrastructure** underpinning **value chain**
- **Stable backbone** of core observations
- **Establish economic value and costs of observations**
- **Engage users** in design of integrated observing networks
- Facilitate use of **existing infrastructures** (e.g. commercial)
- **Binding commitments** for durability – e.g. nationally defined contributions
- **‘Big Ocean science’ funding also needs to adapt** (e.g. CERN)

Sustained *in situ* Ocean Observations and the Ocean Information Value Chain

- **In situ:** in water, sea surface/sub-surface, multiple networks of diverse platforms (focus on this major area of concern, complements satellite observations)
- **Sustained:** extended durations (>7 years) or indefinite, repeat with gaps or continuous
- **Ocean observations:** ocean, seas or coastal; environmental/ecological variables
- **Value chain:** steps from sensors to information to benefit - with feedbacks
- **Public Benefit:** Accessible data, Blue Economy, Resources, Ocean Health, Hazards, Advance Science

The Ocean information value chain

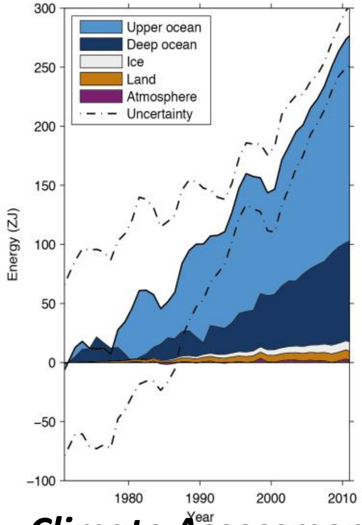


Adapted from Virapongse, *et al.*, 2020.

Systematic, sustained ocean observations

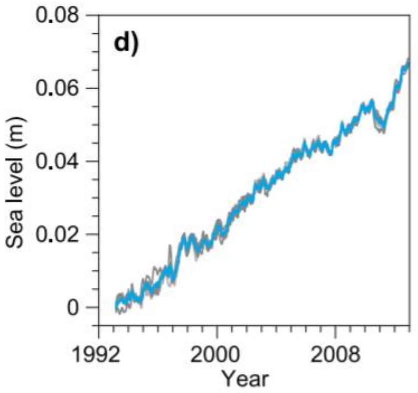
Examples of Benefits of *in situ* Ocean Observations (e.g. GOOS 2030 Strategy)

Climate (change/variability)



Climate Assessment

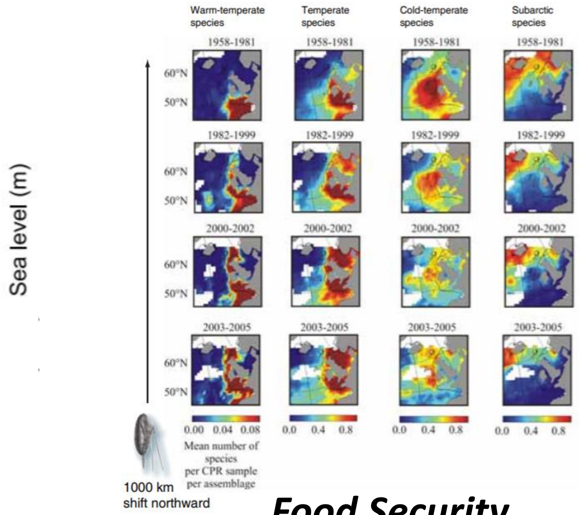
Ocean Heat content



Planning & adaptation

Mean Sea-level rise

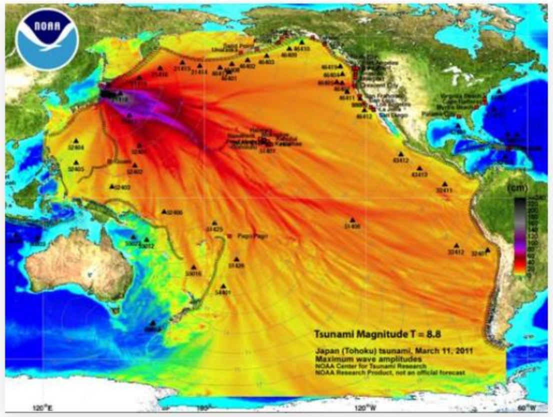
Ocean Health (indicators)



Food Security

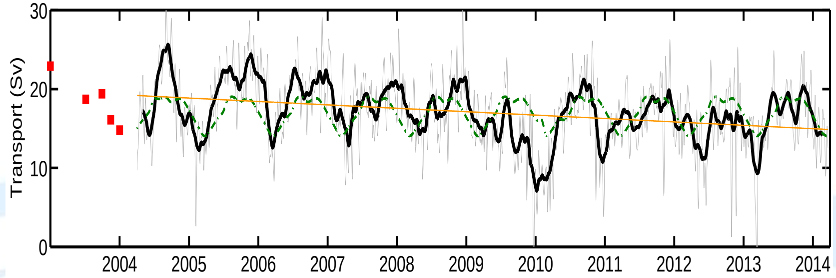
Surface plankton distribution changes

Operational Services



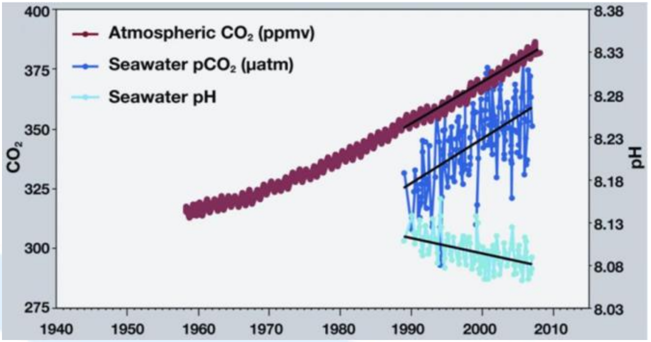
Saving Lives

Tsunami warning



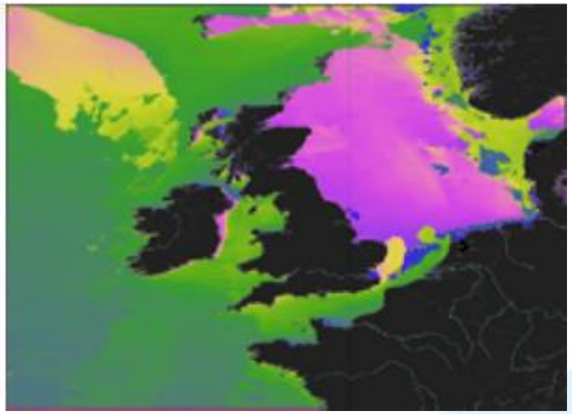
Climate and seasonal weather model prediction/validation

Atlantic overturning circulation



Environmental Health indicators

Ocean acidification



Operational planning

Ocean waves

UN Decade of Ocean Science for Sustainable Development 2021-2030

Ocean observations support all Decade outcomes

- *clean*
- *healthy and resilient*
- *productive*
- *safe*
- *predicted*
- *accessible*
- *inspiring and engaging*

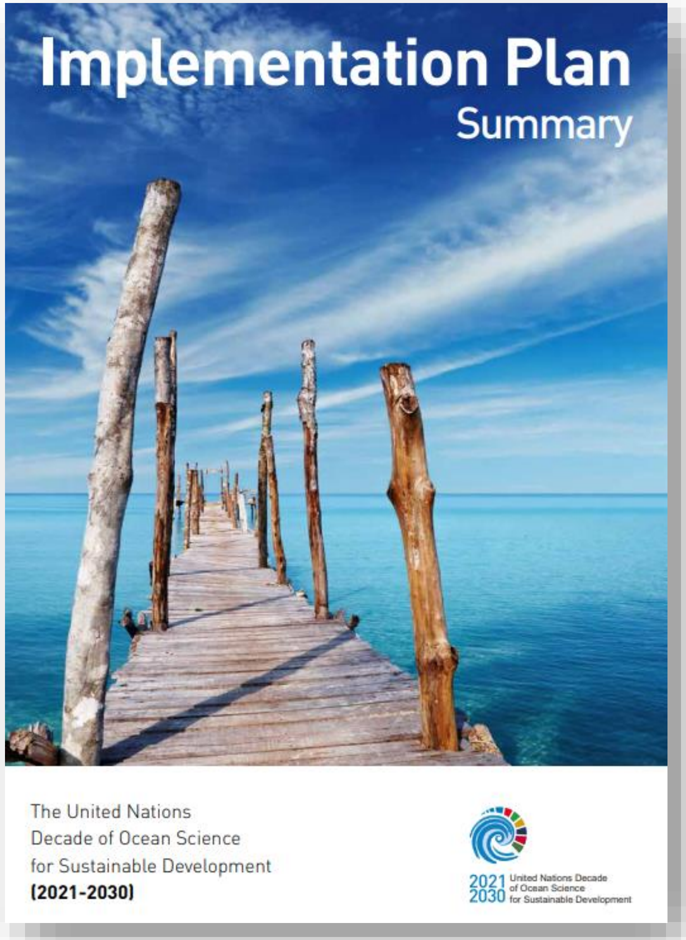
Infrastructural Ocean Decade Challenges

Challenge 6:
Enhance multi-hazard early warning services

Challenge 7:
Ensure a **sustainable ocean observing system**

Challenge 8:
Develop a comprehensive digital representation of the ocean

Recommendation: Strengthen the integrated combined capability of the Ocean observing system, to deliver fit-for-purpose data and information supporting sustainable development.



Quantifying the benefits of in situ Ocean Observations

Economic value hard to quantify - many indirect benefits – but likely high benefit:cost ratio

Examples of some economic analyses
Global Basic Observing Network for Weather (including surface ocean) US $5Bn/year - benefit to cost 25:1

Copernicus Marine Environmental Monitoring Service (in situ and satellite) > 2:1

High ratio estimates - JERICHO-NEXT (Coastal), OECD, UK MEDIN (marine data)

Recommendation: Establish an ongoing process to review the costs and performance of the system and map its economic and environmental benefits.

Funding is driven by mandates for Ocean Observations

Diverse purposes:
differing motivations, mandates, funders

Strongest Mandates
Most secure sustained funding

1. Environment, Health & Resources

- Ocean environmental policy/assessment (e.g. MSFD)
- Public health (e.g. shellfish poisoning)
- Sustainable Blue Economy (e.g. fisheries quotas and management)
- **National law**
- **EU legislation (where applicable)**
- **Mostly EEZ**

Strong Mandates

2. Weather Services

- Operational forecasting
- Safety and Risk (e.g. extreme weather, floods, extreme waves)
- **National Requirements**
- **International weather forecasting**
- **WMO Convention**
- **EEZ and beyond**

Weaker Mandates

3. International Agreements

- Provision of international agreements that imply need to measure or monitor indicators
- **Not in national law**
- **Reasonable Endeavours**
- **Discretionary spending**
- **Inside and <u>outside EEZ</u>**

Science driven
Least secure sustained funding

4. Research & Innovation

- Frascati definition (2015)
- Question-driven basic research – knowledge and understanding of long-term large scale processes of change, variability
- Knowledge and methods to support 1, 2 and 3
- **National Research Priorities**
- **International Research Agreements**
- **Main funder of sub-surface observations outside EEZ (60% of ocean area)**

Governance of Ocean Observations

International coordination/standards

- Global Ocean Observing System (GOOS) and GOOS Regional Alliances (e.g. EuroGOOS)

Ocean Basin scale e.g.

- Atlantic Ocean (AtlantOS), Southern Ocean (SOOS), Indian Ocean (IOGOOS), Tropical Pacific (TPOS2020)
- Connection to GOOS varies could benefit from clear formalized links

National Ocean e.g.

- USA, NOAA's Global Ocean Monitoring and Observing (GOMO)
- USA Integrated Ocean Observing System (US-IOOS)
- Australia, the Integrated Marine Observing System (IMOS)
- Canadian Integrated Ocean Observing System (CIOOS)

Europe e.g.

- EU Research Infrastructures (ERICs) e.g. Euro-Argo, ICOS, EMSO
- The European Ocean Observing System framework as a way to help coordinate this complex landscape (current focus coordinating and supporting funding of in situ Ocean observations)

Organically developed approaches - overly complex system, diverse range of coordination bodies at various levels, duplication, inefficiency, over-coordination, cumulative coordination costs competing with resources to make observations?

Recommendation: Empower and support streamlined, efficient coordination efforts, such as EOOS and GOOS (including National Focal Points) to support Ocean observing activities at pan-European and global scales

Atmosphere and ocean sustained observations comparison

Atmosphere

- **Origin: weather services**
- Quite diverse variables – weather, climate, atmospheric composition, air quality, space-weather
- Core backbone of sustained observations for weather
- Clear focal points (Met Services)
- Operational institutional funding
- **68% funding secure**
- Strong coordination and common standards (operational)
- **Kernel of national and international mandates (**WMO Convention)

Ocean

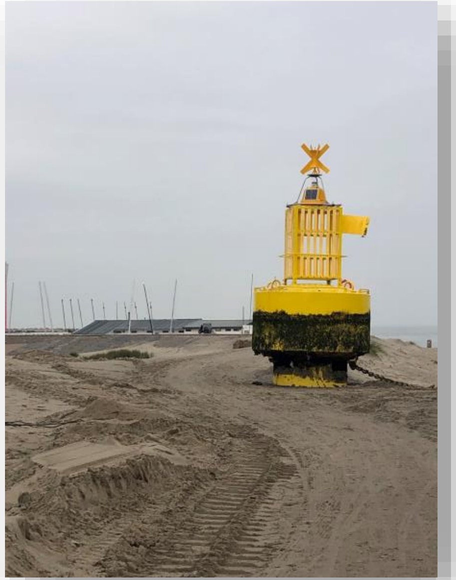
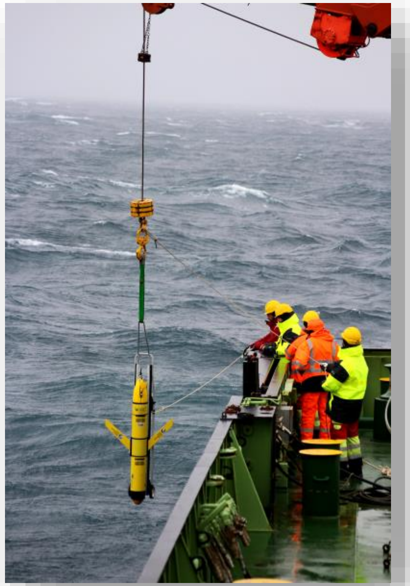
- **Origin: ocean research**
- Very diverse variables, climate, biogeochemistry, ecosystems, seafloor
- No core backbone (except weather and some EEZ obs)
- Diverse delivery organisations
- Research & Innovation project funding
- **28% funding secure**
- Weaker coordination and common standards (research)
- **Little kernel of international mandates outside EEZ**

Funding sustaining Ocean Observations

Technological Innovation and business model

- Rapid technological innovation
- Transformational for assessments, services, science
- Maturity and reliability being achieved
- Can make observations impossible 10-20 years ago
- Can form ocean observing infrastructure

Funding models need to catch up with technological innovations



Existing Funding Models for Ocean Observations

Sustained funding

- Only 28% of the Ocean observing networks have secure funding
- Contrast with 68% of core meteorological networks
- Most funding is and will remain national

Mix of existing funding approaches

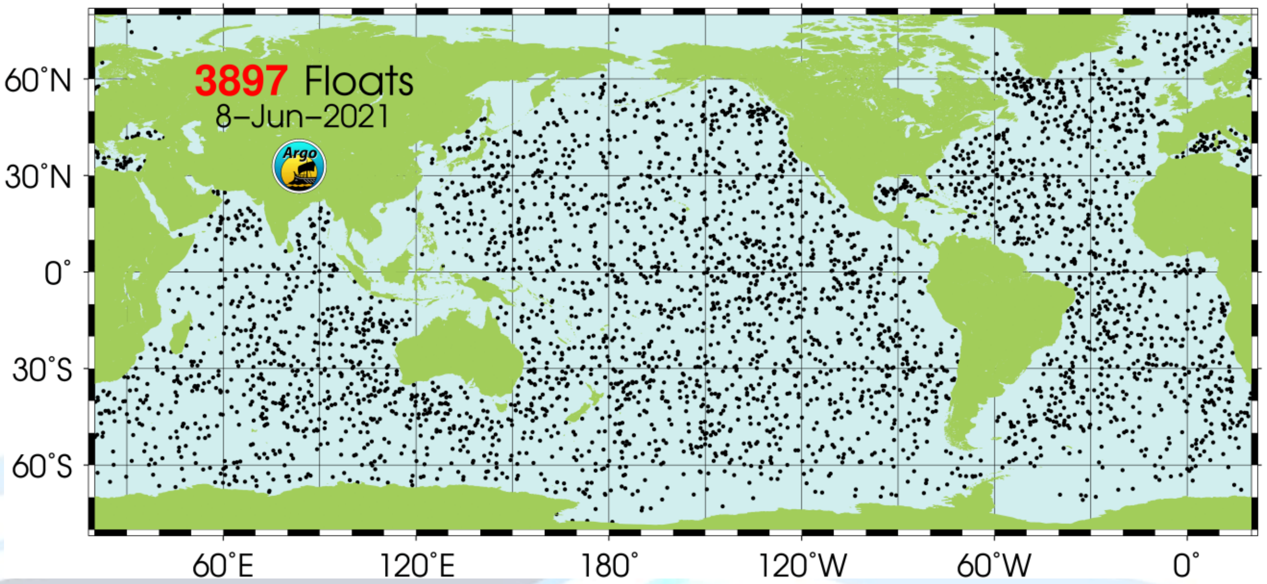
- Project funding
- Long-term institutional funding
- Mandated repeat observations (e.g. Fisheries)
- Capital investments (equipment, “no batteries”)
- Successful transition from research to operational budgets
- Co-funding dual-purpose observing
- In-kind support from opportunistic (commercial) infrastructures

…nevertheless some successes – standard Argo float network

- No legal mandate but network has been grown and been sustained since 2000

How ?

- Demonstrated benefits for climate (heat content) and seasonal weather prediction; supports work of UNFCC
- Many low cost units, quick to procure – ad hoc opportunities and inclusion in project budgets (all adds up)
- Opportunistic deployment



…successes needs to replicate for BGC and Deep Argo… but may replicate less well for other networks (e.g. larger unit costs and high ship costs)

Infrastructures

Definition of Infrastructure

The basic structure of
an organization or system which
is necessary for its operation,
especially public water, energy,
and systems for communication, [data],
and transport

Ocean Observation networks:
Presently seen too much as a collection of small individual elements mot a whole infrastructure (individual moorings, floats etc)

Some Characteristics

- High capital costs
- High proportion of fixed operating costs
- Long duration lifetime
- Deliver Public goods/benefits (environmental, social, economic)
- Multiple users
- Enables wider economic activity (that can indirectly support cost recovery e.g. taxation)
- Often 'free at point of use' (if public funding)
- Cost to user may not be proportional to use, or full cost of infrastructure
- Capital and operating costs recovered by models like taxation, subscriptions, user levies, tolls
- Public and Private models of operation

Some observing and science infrastructures

Examples (Space, High Energy Physics):

- International Space Station (ISS)
- European Council for Nuclear Research (CERN)
- European Organisation for Exploitation of Meteorological Satellites (EUMETSAT)
- European Space Agency (ESA)

Features

- Binding Conventions/Agreements between Nations (Space Agencies in case of ISS)
- Ministerial-level governance for the core elements
- Clearly defined overall costs
- Defined national contributions (financial, other)

Totality of global and regional ocean observing systems is a data infrastructure.

1. Support as **a public good data infrastructure** (even though made up of multiple networks of smaller elements)

2. Commitments to Ocean observation infrastructure should be **linked to international agreements** relevant to ocean actions e.g. part of binding Nationally-Defined Contributions (NDC) - verification

3. Support sustained observing by **funding models suitable for infrastructure** (not short term projects)
    - Subscription-based models
    - Nationally-Defined Contributions (NDC)

4. Where **infrastructures already exist that could be used for ocean observing** (fixed costs wholly or mainly covered), models to support marginal additional costs of use should be developed e.g.
    - Public funding
    - Incentives for private funding (e.g. tax reliefs, carbon offsetting)

5. Research & Innovation **one of multiple users** of ocean observing infrastructure

Recommendation: Sustained in situ Ocean observations should be supported as a [distributed] infrastructure delivering Ocean data as a public good.

Research & Innovation Funding will remain important

User (big science) and innovator of ocean observing infrastructure

Tension between:

1. **Many R&I funders generally don't like infrastructures**
   - High fixed operating costs for long duration
   - Infrastructure operation favours stability over innovation and agility (inherently conservative)
   - Squeezes financial head-room for new science, limits innovation
   - Concern R&I funding will subsidise other mandates inappropriately
   - Respond to science communities who also don't want infrastructure to limit grant funding opportunities
2. **Ocean Science is changing into truly big science (like Space Science, High Energy Physics)**
   - Questions of basin/global-decadal change variability
   - Technological innovation in ocean observing (continuous, distributed ocean presence – e.g. Argo)
   - Needs backbone of sustained observations as core research methodology
   - Data will increasingly come from share infrastructure not instruments funded from single projects
   - Multiple research projects will use a shared infrastructure – with specific processes and innovations funded by projects
   - **Ocean Science is changing into truly big science (like Space Science, High Energy Physics)**

3. Research funding is well placed to support

- Question driven observations, non-sustained, non-core, process studies, innovations

Research & Innovation may be resistant and most conservative in response to the change that is coming and driven by the very technology innovation R&I has funded ?

Towards an Effective and Efficient Ocean Observing

A whole system – more than its parts:

Design and optimization of Ocean Observing

- Integrated design and co-design with users of the Ocean observation system will help to optimize investments
- Satellite and in situ observations
- Essential Ocean Variables
- Rigorous framework to guide the development of an effective and efficient Ocean observing system e.g. Observing System Simulation Experiments (OSSEs) and Observing System Evaluations (OSEs) can be used (e.g. used in AtlantOS project)
  - ✓ *Deep Argo array would reduce uncertainties in deep temperature and salinity fields by up to 40%*
  - ✓ *Large improvement pCO2 field by optimal design of: Ships of Opportunity, moorings, BGC Argo*
  - ✓ *Globally consistent coastal boundary data (HF radar, moorings, gliders) for coastal predictions*
  - ✓ *Improved El Niño-Southern Oscillation (ENSO) predictions*

- Integration of biological observation is a priority

Recommendation:
Co-design a holistic observing system that integrates all in situ observing capabilities with satellite observations and models

Use of existing infrastructures (public and private)

Existing Infrastructures - capital and operating costs already paid for

- Commercial Ships
- Naval vessels
- Research Ships
- Citizen-owned vessels – yachts
- Offshore structures

Potential uses

- Underway measurements including: meteorology, SST, SSS, pCO2, plankton, seabed mapping
- Note compliance with UNCLOS

Marginal cost of use

- Sensing instruments capital,
- Installation, servicing, calibration,
- data analysis, data management, programme administration
- Small compared to infrastructure cost ($M 10's-100s)
- But can be a significant barrier to their use by institutions ($10-100s k)

Recommendation:
Establish partnerships with a private sector and civil society to enable the inclusion of wider Ocean observations, and establish incentives to share those observations with a wide user base, and support the marginal costs of using existing public and privately-owned infrastructures as Ocean observing platforms

The Age of the Digital Ocean

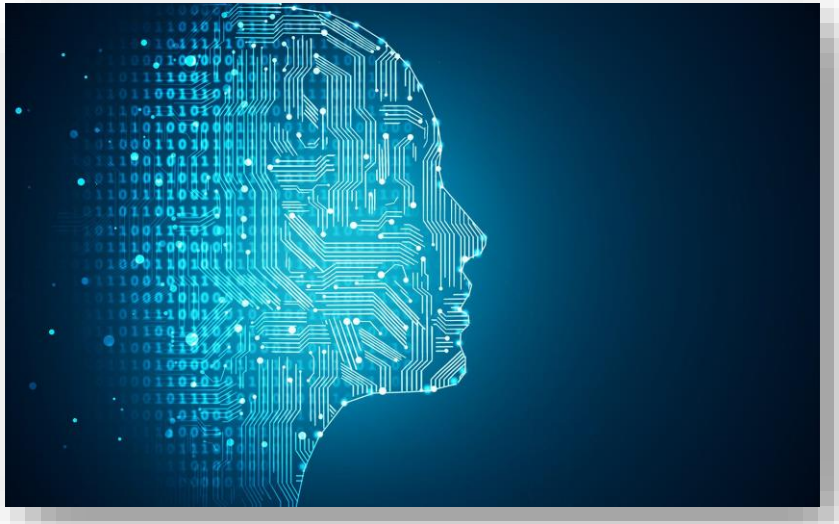
- **Digital Ocean Twins** is motivation for a robust Ocean data and information infrastructure.

- Without sufficient [subsurface] Ocean observations we risk a subsurface **digital void**

- Many decisions will be made based on sensors as part of the **'Internet of Things'** (IoT) generating **Big Data -** need to be 'Things' in the ocean

- **Human view** – 'ocean is out of sight and out of mind'
- **Machine learning bias** –heavy surface bias of most ocean observations e.g. satellites

Machine taught view ? - 'ocean is out of sight and out of artificially intelligent mind'



Let's teach machines about the sub-surface ocean and its wonders using the 'Ocean Internet of Things'

Physics, Biogeochemistry, Geology, Ecology

Recommendations

- Recommendation 1: **Recognize sustained in situ observation as a large-scale, essential, and enabling infrastructure generating global public-good data that create information and knowledge-based services**, and advance its implementation with appropriate financing models to deliver systematic and long-term monitoring. A possible endpoint could be an international entity with a subscription-based or a binding Nationally- Defined Contributions model, with a backbone/core Ocean observing capability, overarching governance and institutional arrangements, and roles and functions for nations and the EU;
- Recommendation 2: **Empower and support streamlined, efficient coordination efforts such as EOOS and GOOS** (including National Focal Points) to support Ocean observing activities at pan-European and global scales, thereby improving the overall efficiency of national and European investments in a shared in situ Ocean observation infrastructure;
- Recommendation 3: **Strengthen the integrated combined capability of the Ocean observing system to deliver fit-for-purpose data and information** supporting sustainable development, the 'Green Deal' and sustainable blue economy through connecting its funders, implementers and users;
- Recommendation 4: **Establish an ongoing process to review the costs and performance of the system and map its economic and environmental benefits**. At present, the collective benefits of sustained Ocean observations are often indirect and not always measurable, leading to poor and incomplete cost-benefit analyses. A continuous census of the results and products obtained from in situ Ocean observations with European, national and regional funding, would benefit management applications and prove useful to users such as industry, civil society, research and forecasting systems;
- Recommendation 5: **Establish partnerships with the private sector and civil society** (e.g. shipping, exploration and commercial industries; philanthropic and other foundations, divers, boaters, citizen science) to enable the inclusion of wider Ocean observations and establish incentives to share those observations with a wide user base and support the marginal costs of using existing public and privately-owned infrastructures as Ocean observing platforms;
- Recommendation 6: **Co-design a holistic observing system that integrates all in situ observing capabilities with satellite observations and models.** This will require well functioning Ocean observation simulation capability (akin to a Digital Twin Ocean) that covers the value chain from data collection to applications and services and includes the cost and benefits of observations.

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Questions and Discussion

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