Regional Digital Twins of the Ocean: the opportunity for effective integration & real **transformative changes** through fit for purpose multi-platform ocean observing & forecasting, interoperability & open science

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Scientific Excellence with Impact on Society

SOCIB Sistema de Observación y Predicción Costero de las Illes Balears

Take Home Message:

Digital Twins of the Ocean, DTOs -and Regional DTOs in particular- provide ideal symbiotic ecosystems to trigger and contribute to the UN Decade call for transformation in ocean sciences

Ocean Decade: Science, Solutions, People, Transformation

UN Ocean Decade and Digital Twins Opportunity

- **UN Ocean Decade Mission:** 'to catalyse transformative ocean science solutions for sustainable development, connecting people and our ocean'.

- **DTOs** are ideal structures and provide a unique opportunity to lead this transformation, based on state-of-the-art science and responding to society needs.

Scientific Excellence with Impact on Society

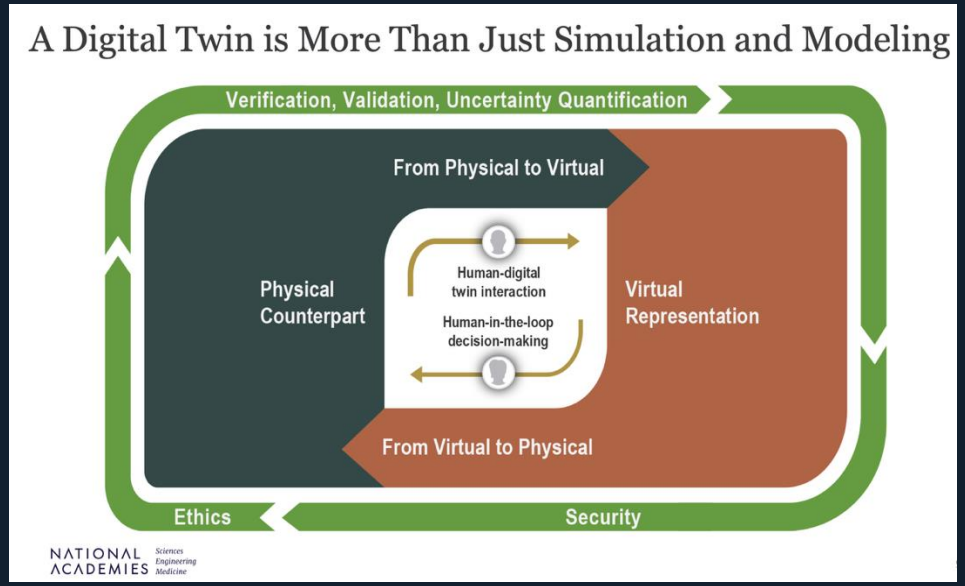
Digital Twins (NAS, 2024)

Definition: A digital twin is a set of virtual information constructs that mimics the structure, context, and behaviour of a natural, engineered, or social system (or system-of-systems), is dynamically updated with data from its physical twin, has a predictive capability, and informs decisions that realize value. The bidirectional interaction between the virtual and the physical is central to the digital twin.

- Refers to "a natural, … system (or system-of-systems)" to describe digital twins of physical systems in the broadest sense possible, including … natural phenomena.
- Introduces "predictive capability" to emphasize that a digital twin must be able to issue predictions beyond the available data to drive decisions that realize value.
- Highlights the bidirectional interaction, which comprises feedback flows of information from the physical system to the virtual representation and from the virtual back to the physical system to enable decision making, either automatic or with humans in the loop.

"Real" Digital Twins are very complex systems

Key Elements of a Digital Twin



Four Key Elements: Observation of the Physical System, Modelling of the Virtual Representation, Bidirectional Interaction, VVUQ.

Digital Twins: great opportunities with important needs...

RECOMMENDATION 1

An Integrated Research Agenda

- Need an integrated research agenda that includes foundational needs as well as domain-specific needs
- Recommend that federal agencies launch crosscutting programs to advance the foundations
- An interagency working group may be helpful to ensure coordination

NATIONAL ACADEMIES Sciences Engineering Medicine

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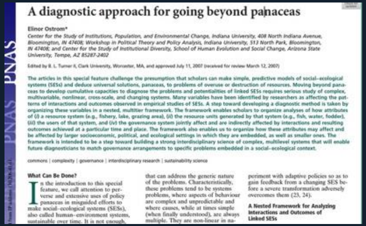
Digital Twins of the Ocean: Opportunity for building Trust, but Organizational Changes are needed

Digital Twins: great expectations,… a word of caution!

Elinor Ostrom (1933-2012)
2009 Nobel Prize in Economic Sciences
ICZM: Norway: 2007



A diagnostic approach for going beyond panaceas

Elinor Ostrom*

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Edited by B. L. Turner II, Clark University, Worcester, MA, and approved July 11, 2007 (received for review March 12, 2007)

The articles in this special feature challenge the presumption that scholars can make simple, predictive models of social–ecological systems (SESs) and deduce universal solutions, panaceas, to problems of overuse or destruction of resources. Moving beyond panaceas to develop cumulative capacities to diagnose the problems and potentialities of linked SESs requires serious study of complex, multivariable, nonlinear, cross-scale, and changing systems. Many variables have been identified by researchers as affecting the patterns of interactions and outcomes observed in empirical studies of SESs. A step toward developing a diagnostic method is taken by organizing these variables in a nested, multitier framework. The framework enables scholars to organize analyses of how attributes of (i) a resource system (e.g., fishery, lake, grazing area), (ii) the resource units generated by that system (e.g., fish, water, fodder), (iii) the users of that system, and (iv) the governance system jointly affect and are indirectly affected by interactions and resulting outcomes achieved at a particular time and place. The framework also enables us to organize how these attributes may affect and be affected by larger socioeconomic, political, and ecological settings in which they are embedded, as well as smaller ones. The framework is intended to be a step toward building a strong interdisciplinary science of complex, multilevel systems that will enable future diagnosticians to match governance arrangements to specific problems embedded in a social-ecological context.

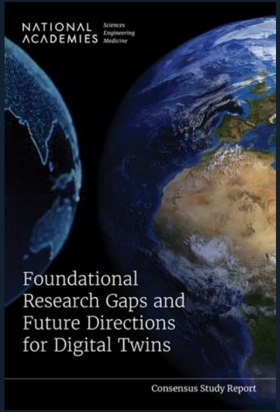
commons | complexity | governance | interdisciplinary research | sustainability science

What Can Be Done?

In the introduction to this special feature, we call attention to perverse and extensive uses of policy panaceas in misguided efforts to make social–ecological systems (SESs), also called human–environment systems, sustainable over time. It is not enough, that can address the generic nature of the problems. Characteristically, these problems tend to be systems problems, where aspects of behaviour are complex and unpredictable and where causes, while at times simple (when finally understood), are always multiple. They are non-linear in na- periment with adaptive policies so as to gain feedback from a changing SES before a severe transformation adversely overcomes them (23, 24).

A Nested Framework for Analyzing Interactions and Outcomes of Linked SESs

Beyond panaceas (2007)…



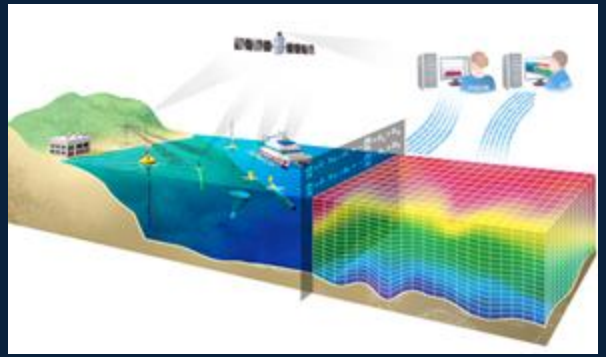
Despite the existence of examples of digital twins providing practical impact and value, the sentiment expressed across multiple committee information-gathering sessions is that **the publicity around digital twins & digital twin solutions currently outweighs the evidence base of success (NAS, 2024)**

“… moving beyond panaceas… requires serious study of complex, multivariable, nonlinear, cross-scale & changing systems”

Science, Real End-Users Focus, Realistic Expectations

Changes and Opportunities that allow now Digital Twins of the ocean,...

- **Changes:** in science & technologies, observing, modelling, data, data availability, computing capabilities, AI, international frameworks, society engagement, science-society policy interface, engaging end users from the beginning.
- **Evolution in concepts**: scientific excellence, open science



Blurred distinction

The idea of research excellence is ubiquitous, but what it means depends on the context.

Excellence is everywhere in science. Or that seems to be the plan: to make excellence ubiquitous in research. This month, the University of the West Indies in Kingston, Jamaica, became the latest academic institution to encourage its scientists to excel, setting up a Regional Centre for Research Excellence in the Caribbean.

To be good is no longer enough — excellence, by definition, must go beyond that.

And for those who achieve it — from individual researchers and

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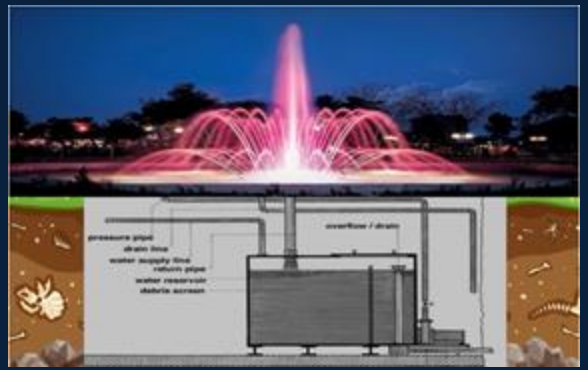
"Some funders are starting to place more importance on the societal impact and relevance of research."

From Observing & Predicting to Impact: The Digital Ocean Opportunity

The Right Time for Transformation: the need for a Common Goal and a Strategy

A common goal: e.g., the sparkly fountain.
"Digital Twins are the visible part of a complex digital data ecosystem"



Terry McConnell – DITTO- 2022

A Strategy is an integrative set of choices that position us to advance towards the goal, and thus succeed. It requires saying no (Roger Martin, 2024).

- It implies trying to create a future that is better than the present, and this is much more difficult than planning. Imagination!
- The output of a Strategy is a Plan, with clear choices (the hard part!). Both are needed.

DTOs because of their Mission-oriented nature have a Common Goal and a Strategy and have therefore the capacities to drive the Transformation called by the Ocean Decade.

DTOs and Ocean Integration: as in music…

Ocean Integration is an essential key element of **Digital Twins of the Ocean!**

Riccardo Muti

"The diversity in the orchestra is to be combined with the need of integration to reach an overall common goal above each one of the elements"

"The harmony on top of the different component"

"From egosystems to ecosystems" Gerd Leonhard & Xavier Ferras

GLOBAL OPTIMISM

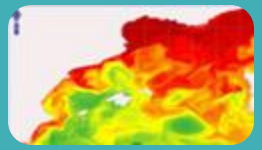
Cristiana Figueres

"Optimism , which actually means courage, hope, trust, solidarity… the belief that we can work together…, injecting optimism into the system"

Digital Twins of the Ocean: The Power of Holistic Integration

The Key Elements of Regional DTOs: SOCIB RI

1 Observing System

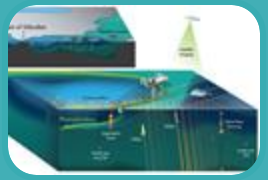


2 Predictive capabilities

3 Ocean Data Lake

SOCIB has:

- the facilities
- the knowledge
- the data
- 10 yrs ahead



4 Frontend interactive simulation layer

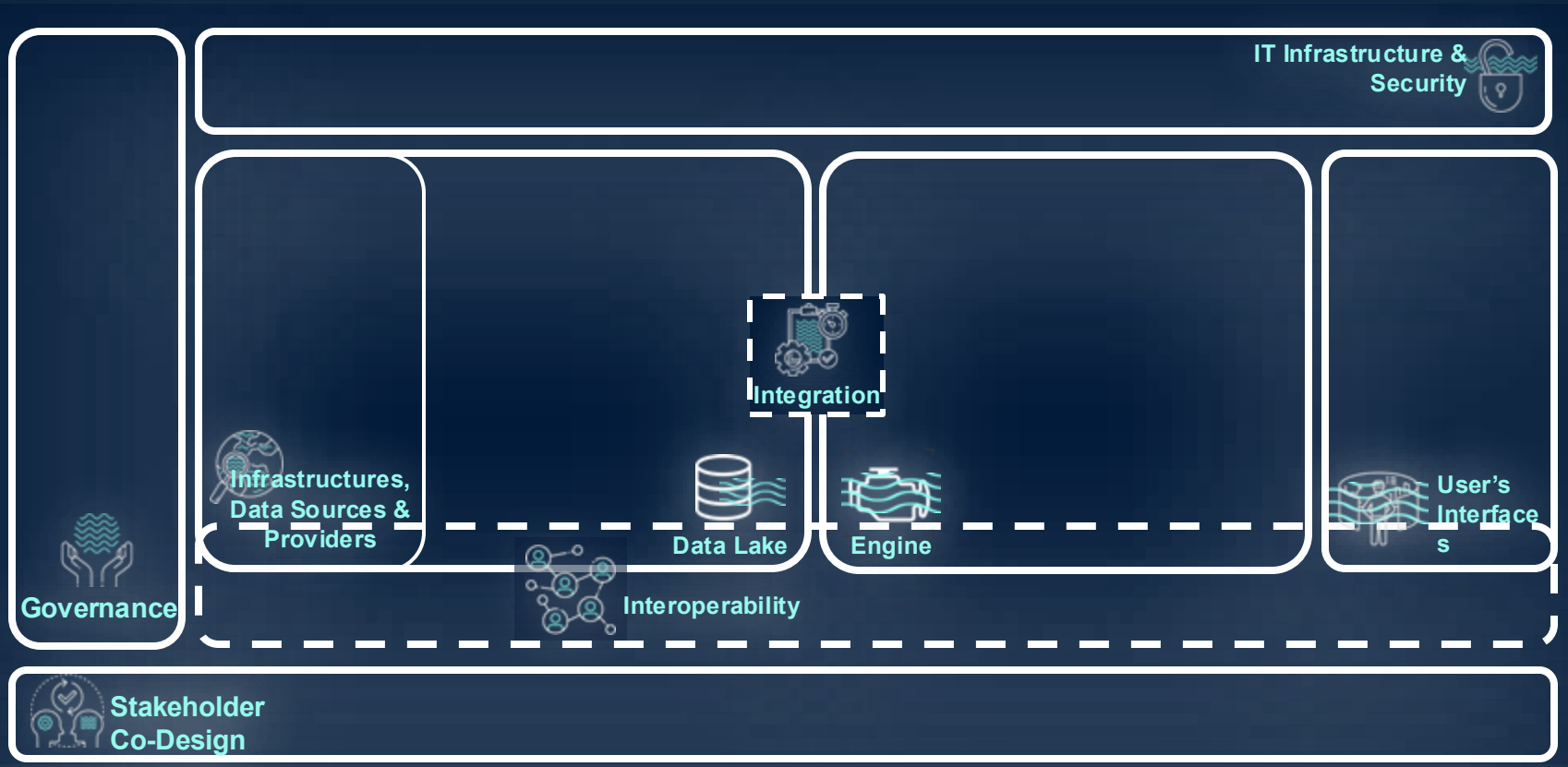
5 Co-design, society engagement & training

SOCIB needs:

+ extra integration effort
+ user needs
+ interoperability (decentralized)
+ scalability & resilience
+ federated system approach

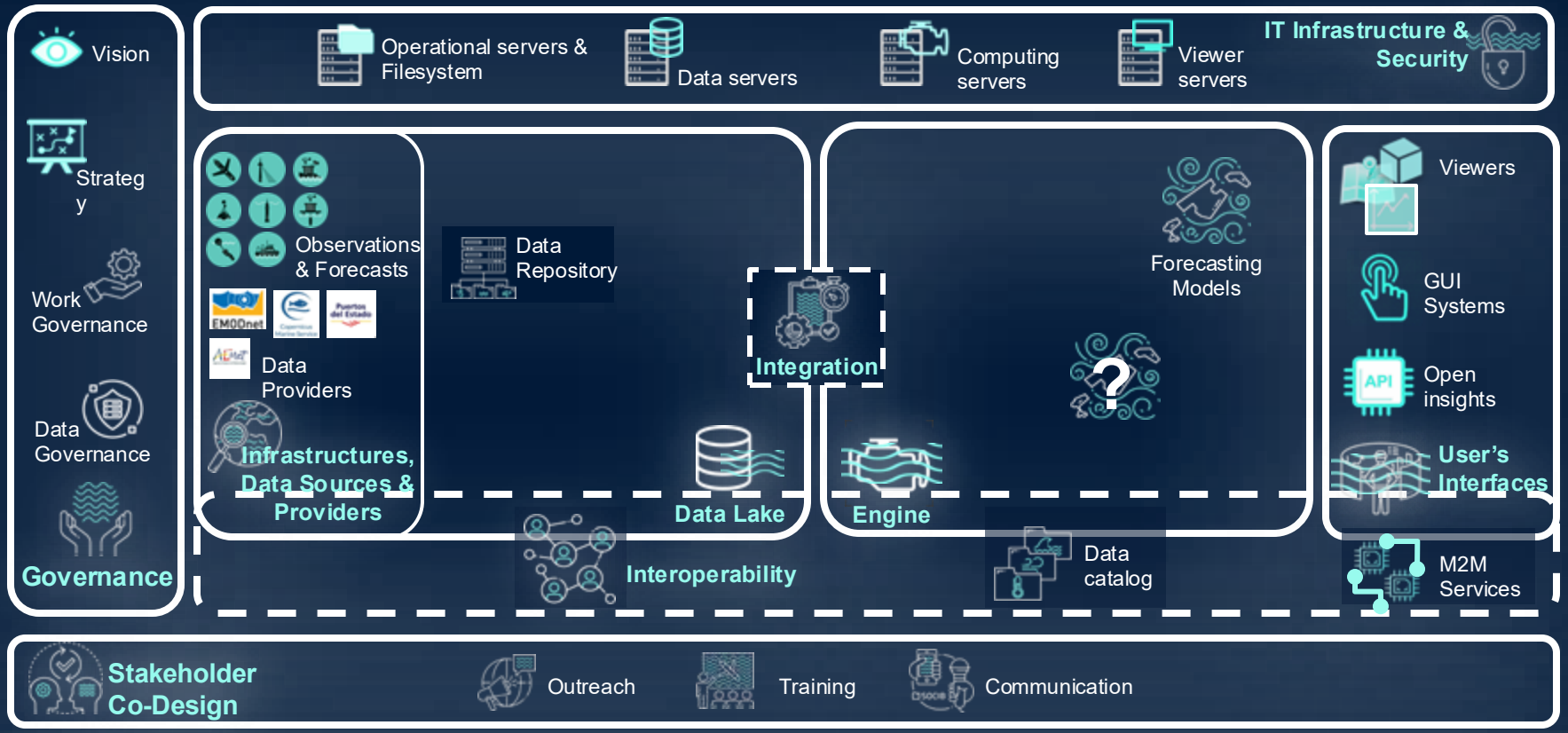
Digital Twins and Research Infrastructures : Catalysts for Transformation

SOCIB DTOs architecture: major components



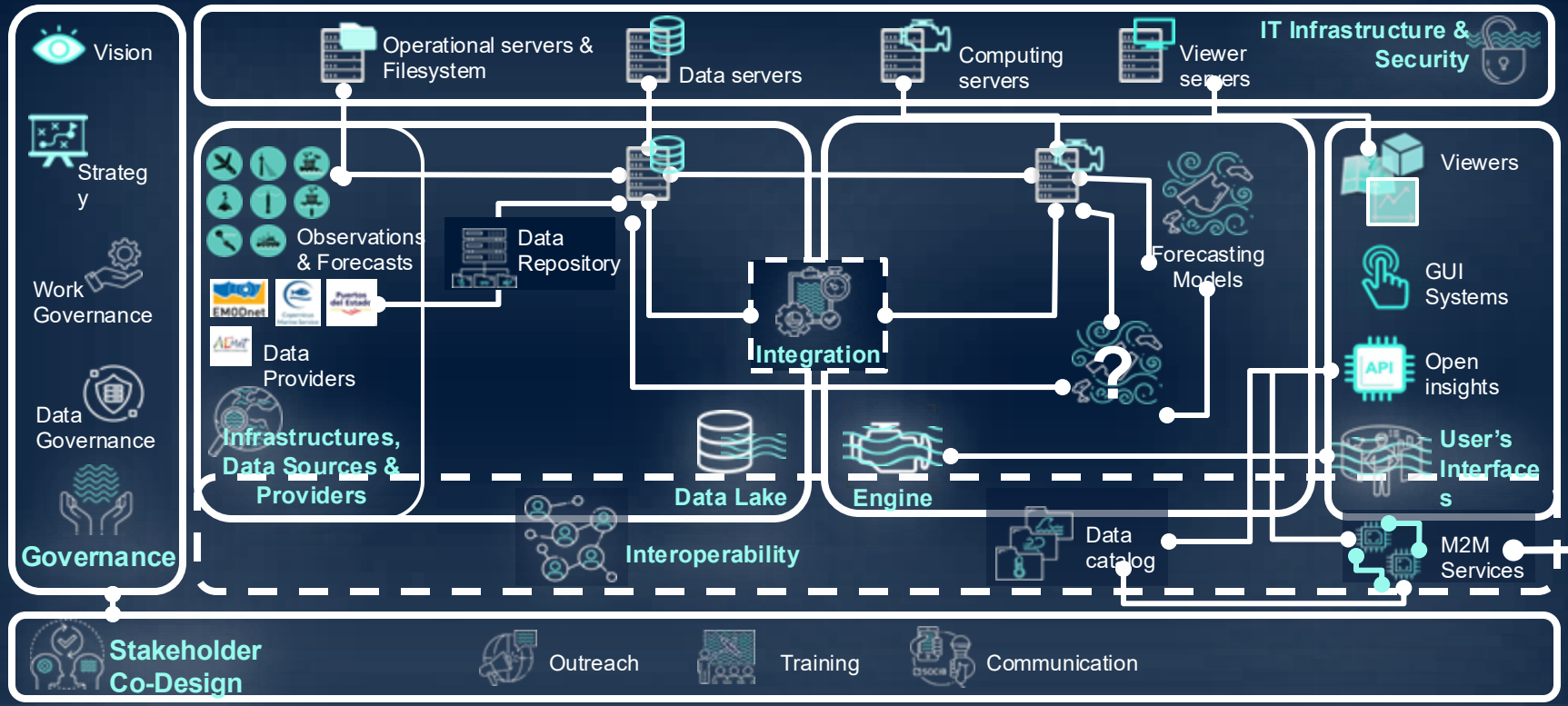
SOCIB added-value: from data acquisition to user-information

SOCIB DTOs architecture: key elements



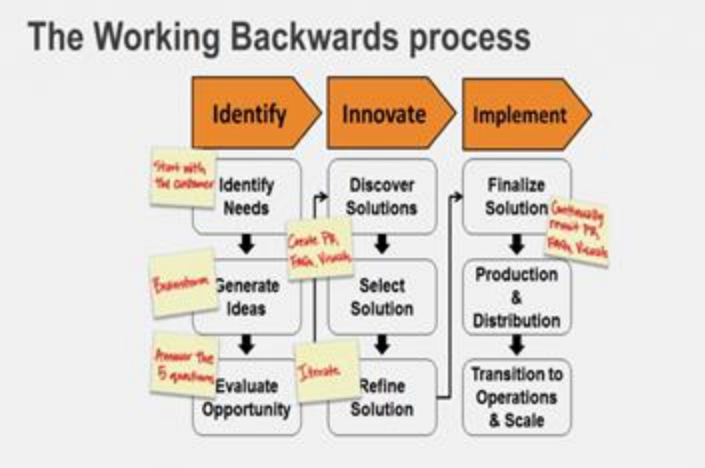
SOCIB added-value: Ocean Data Value Chain

SOCIB DTOs architecture: integration & interoperability

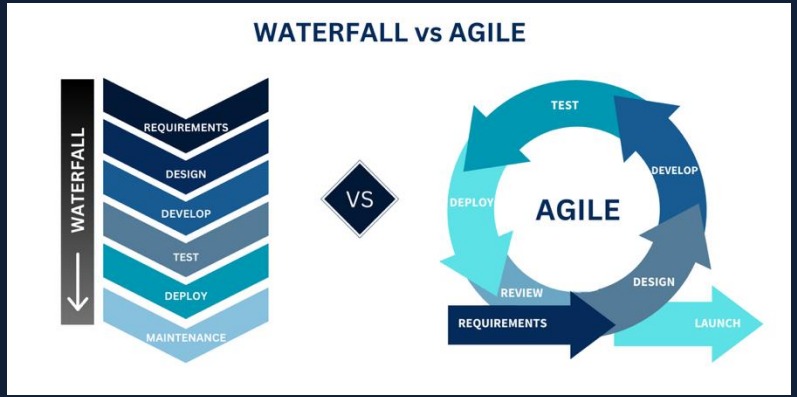


SOCIB added-value: Ocean Data Value Chain and Workflows

SOCIB Organizational Changes: PRFAQ & AGILE



Assuring end users-based applications



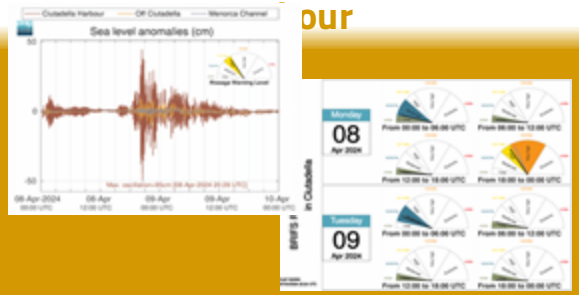
Reduce silos, value to the end-users, iterative people-centred approach

Transformative Internal Organizational Changes

SOCIB DTO Prototypes in the Balearic Sea

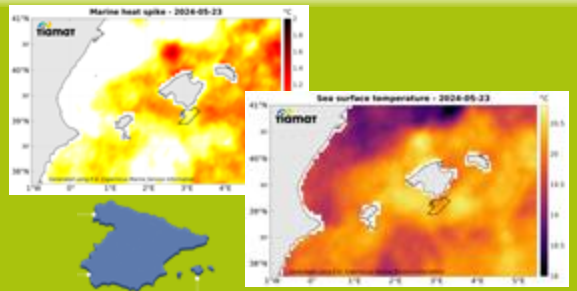
1 Meteotsunami Early Warning System

Prediction of extreme sea level oscillations in Ciutadella



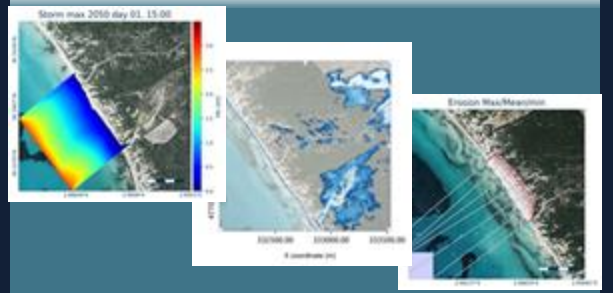
2 Marine Protected Areas Monitoring

Monitoring climate change impact in Cabrera National Park



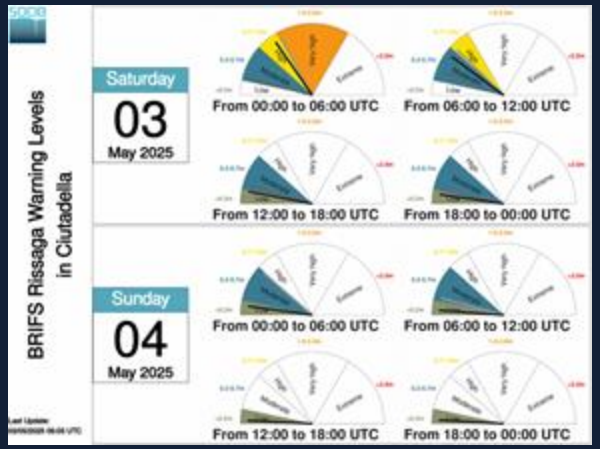
3 Climate Change Adaptation Planning

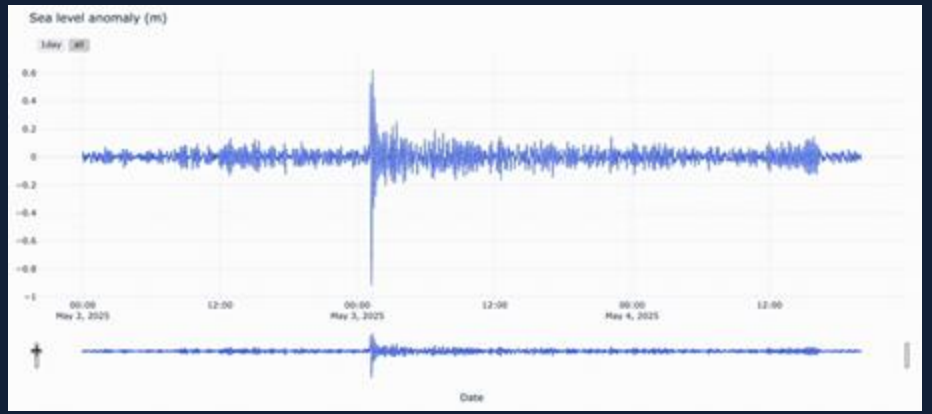
'What-ifs' scenarios of coastal flooding and erosion

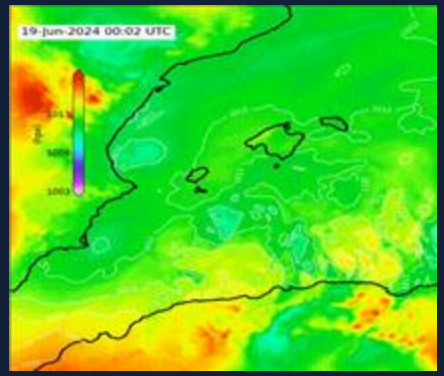


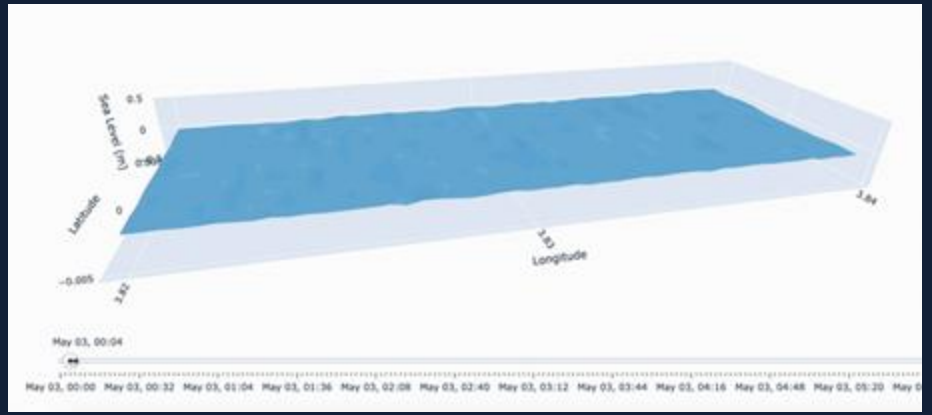
SOCIB DTO Prototypes & Calypso Science DTO: well-aligned with EU Digital Twin Ocean EDITO & DITTO, and contributing to CoastPredict

SOCIB DTO Prototype for Meteotsunamis Early Warning









SOCIB 2030: DTO Prototypes Implementation Phases

2023

Launching of the SOCIB 2030 initiative

2024

Finalization of the Co-design, Implementation, and Management Plan of different DTs prototypes in the Balearic Sea

2026

Launching of the first two prototypes in the Balearic Sea: climate change adaptation and marine protected areas

2030

Development of SOCIB 2030: Completion of the first two DTs, validation, test and training and launching of the third prototype

2033

Integration of Digital Twin prototypes with the European DTO

PAST | PRESENT | FUTURE

2023-2026 | 2027-2030 | 2031-2033

INITIATING | PLANNING | EXECUTING | CLOSING

In Summary: DTOs, Opportunities for Transformation

1) Key elements needed for the transformative ocean science solutions.

2) Lead to symbiotic ecosystems that foster scientific excellence with tangible societal impacts.

3) Contribute to build Trust, effective synchronization & alignment of all components.

BUILDING TRUST

BUT

For Real and Effective Transformation, … we need…

Reach People Emotionally

"After almost 100 years on the planet, I now understand the most important place on Earth is not on land, but at sea,"
David Attenborough – May 2025

TRUST and EMOTIONS

Thank you very much
for your attention!

MERCI!!!!