NASA Earth Science Technology Office (ESTO)
Advanced Information Systems Technology (AIST)

ESTO
Earth Science Technology Office
AIST



Earth Systems Digital Twins (ESDT)
Standards for Interoperable Digital Twins

September 18, 2023

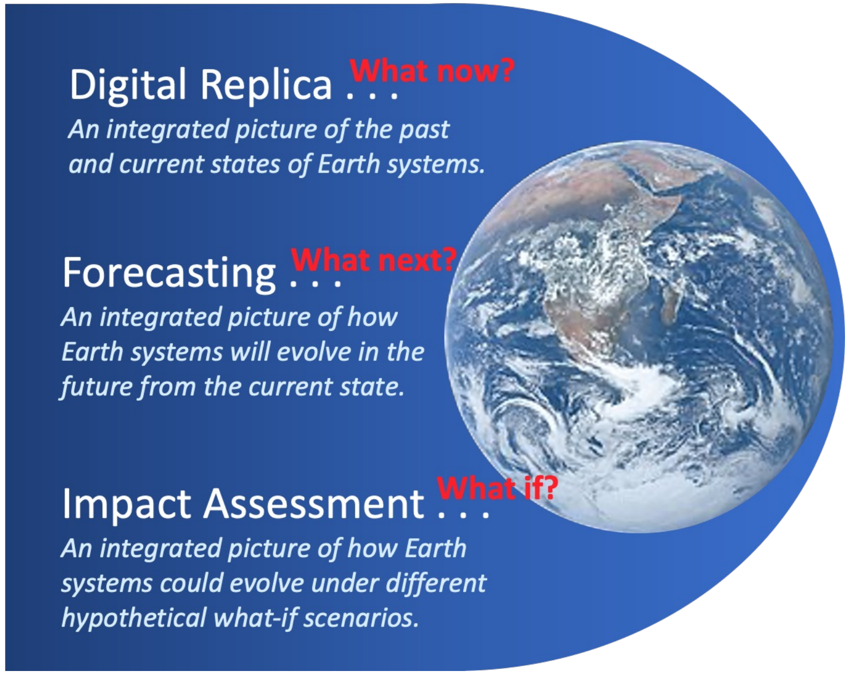
ESTO AIST Earth System Digital Twins (ESDT)
Summary of Activities 2021-2023

ESTO Earth Science Technology Office AIST

NASA

- **Earth Systems Digital Twins (ESDTs) are an emerging capability for understanding, forecasting, and conjecturing the complex interconnections among Earth systems, including anthropomorphic forcings and impacts to humanity.**

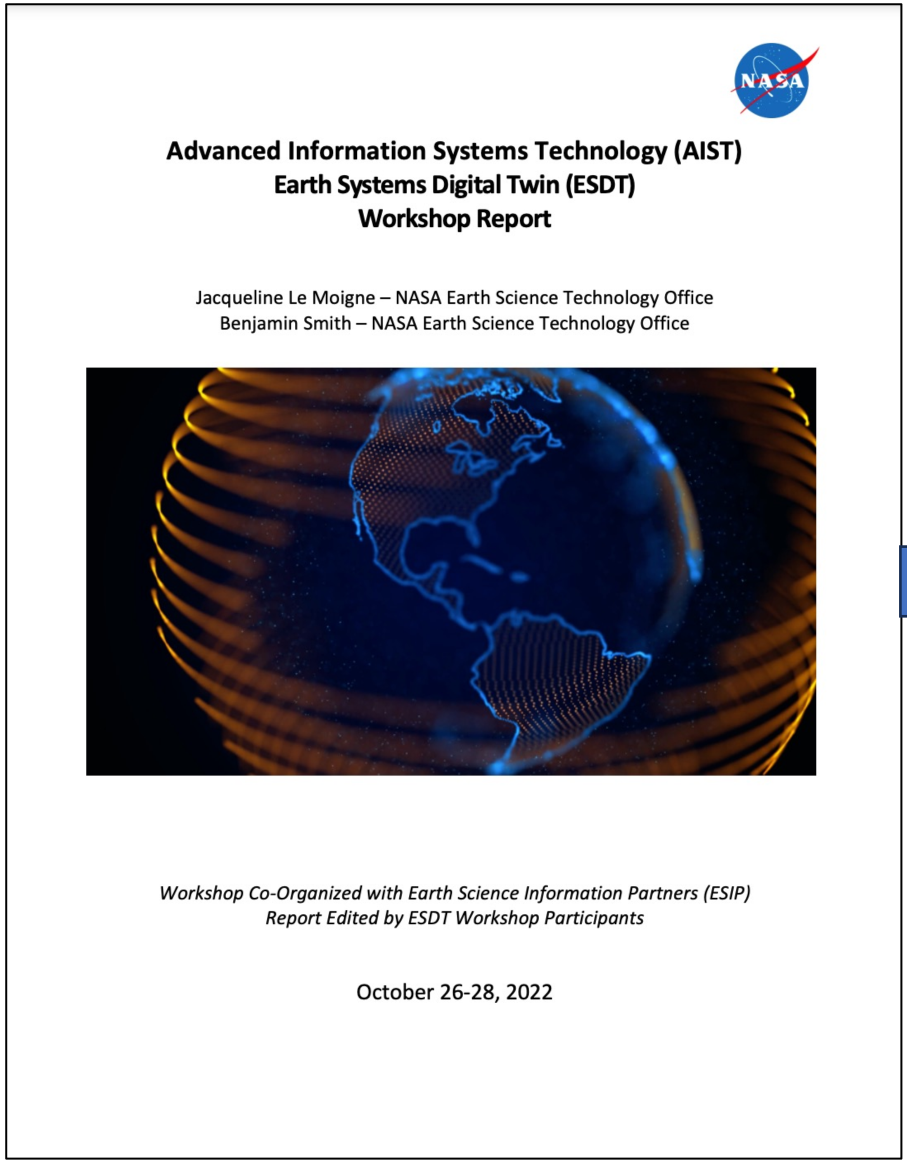
  => "What Now? What Next? What If?
- ESDTs will play a critical role in NASA's new Earth Science to Action initiative.
- AIST-21 Solicitation, first US government Solicitation requesting Digital Twins Technology for Earth Science
- **16 current ESDT technology development projects funded under the Advanced Information Systems Technology (AIST) program** focusing on developing:
  - Underlying analytic capabilities to build Digital Replicas
  - Novel ESDT infrastructure technologies
  - Surrogate modeling and ML emulators
  - Preliminary prototypes including interconnected modeling.
- Workshops and other community meetings to explore science use cases, enabling technologies, frameworks, prototyping, interoperability, and federation:
  - AIST ESDT Workshop: Oct 26-28, 2022. Report: https://go.nasa.gov/3RhezAr
  - Standards for Interoperable Digital Twins Workshop: Sep 18, 2023
  - Currently also developing an ESDT Architecture Framework document.
- Collaboration with ESA, Destination Earth, CNES, and others



Visit the dedicated ESDT webpage at: https://esto.nasa.gov/earth-system-digital-twin/

Standards for Interoperable Digital Twins

AIST



Advanced Information Systems Technology (AIST)
Earth Systems Digital Twin (ESDT)
Workshop Report

Jacqueline Le Moigne – NASA Earth Science Technology Office
Benjamin Smith – NASA Earth Science Technology Office

Workshop Co-Organized with Earth Science Information Partners (ESIP)
Report Edited by ESDT Workshop Participants

October 26-28, 2022

CHALLENGES:

- Local vs. Regional vs. Global vs. Thematic Digital Twins?
- Future "web" of Digital Twins => **How will we federate future ESDT?**

  ➔ **Interoperability/Standards and Protocols at all levels** (Syntactic, semantic, legal and organizational)
- What are the main architecture components of an ESDT?
- How will various data, models, ESDT interoperate?
- How do we trust/validate ESDT (e.g., using historical data, etc.)? How to quantify uncertainty?
- Which computational resources will be required?
- How to visualize a Digital Twin? Which User Interface?
- Which sustainable digital twin governance model should be adopted to address software configuration changes, security and full life cycle management?

September 18, 2023
Standards for Interoperable Digital Twins

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OBJECTIVES:

- Survey Digital Twins standards state-of-the-art in other domains as well as in the Earth Science domain
- Identify specific challenges from Earth Science current developments as well as from other domains' past and current projects
- If possible, categorize and prioritize these challenges => Next Steps

AGENDA:

- Introduction: Objectives of Mini-Workshop
- Experts' Presentations (10 minutes each):
    - Michael Grieves/Digital Twin Institute
    - Siri Jodha Singh Khalsa/IEEE GRSS Standards
    - Trent Tinker/OGC
    - Ryan Berkheimer/NOAA
    - John Stone/NVIDIA
    - Thomas Geenen/ECMWF-DestinE
    - Arne Berre/SINTEF-Iliad DTO and EDITO
- Q&A
- Lessons learned and underlying challenges from participants (e.g., CNES, NOAA EO-DT Projects, etc.)
- Group Discussion and Next Steps

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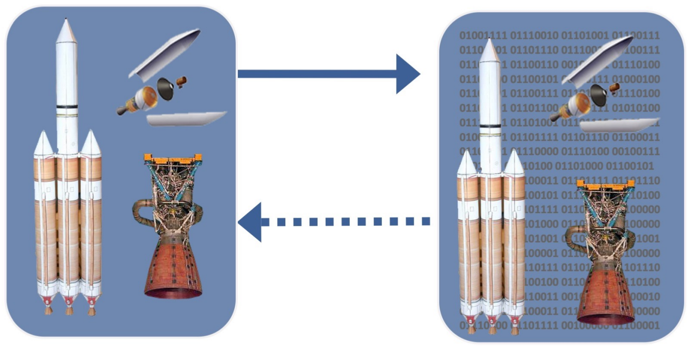


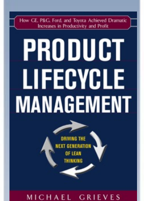
Earth System Digital Twins (ESDT)

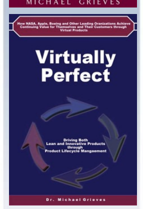
Dr. Michael Grieves
Chief Scientist / Exec Director
Digital Twin Institute/Univ of Central Florida

Sep 18, 2023

Earth System Digital Twin Replication, Prediction, Impact

- Issues of “Boil the Ocean” Multi-Domain System Complexity
- Critical Need for Validation of ESDT Data, Models, Presentation
  - Independent, unbiased audits, reports, ratings – mirror financial world
  - Red team validation of new models
  - Data integrity and consistency
  - Prediction and impact accuracy and reliability
  - Neutral representation (language - extreme, colors - red)
- Digital Twin Interoperability

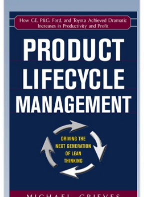


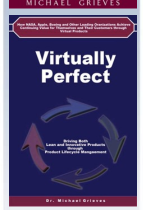


Interoperative Digital Twins Cohesion

- Interoperability requires cohesion for
  - Internally - individual Digital Twins
  - Externally - multiple Digital Twins
- Cohesion enforcement
  - Physical – Material/Forces
  - Virtual – Information inputs/digital processing
- Potential DT Cohesion Solutions
  - Ad hoc programming
  - Standards – Ontologies, Attributes, Method Call Semantics
  - Harmonization
  - Middleware
  - Platforms
  - AI

Selected Publications





- Grieves, M., Product Lifecycle Management: Driving the Next Generation of Lean Thinking. 2006, New York: McGraw-Hill.
- Grieves, M., Virtually Perfect: Driving Innovative and Lean Products through Product Lifecycle Management. 2011, Cocoa Beach, FL: Space Coast Press.
- Grieves, M. Digital Twin: Manufacturing Excellence through Virtual Factory Replication (White Paper). 2014
- Grieves, M. and J. Vickers, Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems, in Trans-Disciplinary Perspectives on System Complexity, F.-J. Kahlen, S. Flumerfelt, and A. Alves, Editors. 2017, Springer: Switzerland. p. 85-114.
- Grieves, M., Virtually Intelligent Product Systems: Digital and Physical Twins, in Complex Systems Engineering: Theory and Practice, S. Flumerfelt, et al., Editors. 2019, American Institute of Aeronautics and Astronautics
- Grieves, M., Intelligent digital twins and the development and management of complex systems. Digital Twin, 2022, 2(8)

https://youtube.com/@digitaltwinDrGrieves

IEEE GRSS Standards Committee

NASA AIST Workshop on Standards for Interoperable Digital Twins

Siri Jodha Singh Khalsa

GRSS Standards Committee Chair

The GRSS is one of 39 IEEE Societies

IEEE Aerospace and Electronic Systems Society (AESS)

IEEE Antennas and Propagation

echnology Soc

Systems Socie

ions Society

IEEE Computational Intelligence

y Society

IEEE Control Systems Society (CSS)

IEEE Dielectrics and Electrical Insulation Society (DEIS)

IEEE Education Society (EdSoc)

IEEE Electromagnetic Compatibility Society (EMC-S)

IEEE Electron Devices Society (EDS)

IEEE Electronics Packaging Society (EPS)

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oscience and Remote Society (GRSS)

ustrial Electronics Society

IEEE Industry Applications Society (IAS)

IEEE Information Theory Society

IEEE Instrumentation and Measurement Society (IMS)

IEEE Intelligent Transportation Systems Society (ITSS)

IEEE Magnetics Society

IEEE Microwave Theory and Technology Society (MTT-S)

Nuclear and Plasma Sciences ty (NPSS)

Oceanic Engineering Society)

Photonics Society

IEEE Power Electronics Society (PELS)

IEEE Power & Energy Society (PES)

IEEE Product Safety Engineering Society (PSES)

IEEE Professional Communication

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IEEE Systems, Man, and Cybernetics Society (SMC)

IEEE Technology and Engineering Management Society (TEMS)

IEEE Ultrasonics, Ferroelectrics, and Frequency Control Society (UFFC)

IEEE Vehicular Technology Society (VTS)

IEEE ComSoc IEEE Communications Society

IEEE Computer Society

IEEE GRSS Geoscience and Remote Sensing Society

IEEE Smart Cities

OES

IEEE

The GRSS Standards for Earth Observation (GSEO) is one of eight GRSS Technical Committees

The GSEO sponsors standards development projects for all types of Earth observing platforms and sensors, and the systems and procedures used to generate and disseminate products and information from those observations.

The GSEO has sponsored 6 standards projects

- Characterizing and Calibrating Hyperspectral Imagers (P4001)
- Metadata Model for Synthetic Aperture Radar Data (P4002)
- Describing GNSS Reflectometry Datasets (P4003)
- Calibration Procedures for Microwave Radiometers (P4004)
- Protocol and Scheme for Measuring Soil Spectroscopy (P4005)
- Remote Sensing Frequency Band RFI Impact Assessment (P4006)

IEEE 4003 was Published in 2021

IEEE SA
STANDARDS ASSOCIATION

STANDARDS

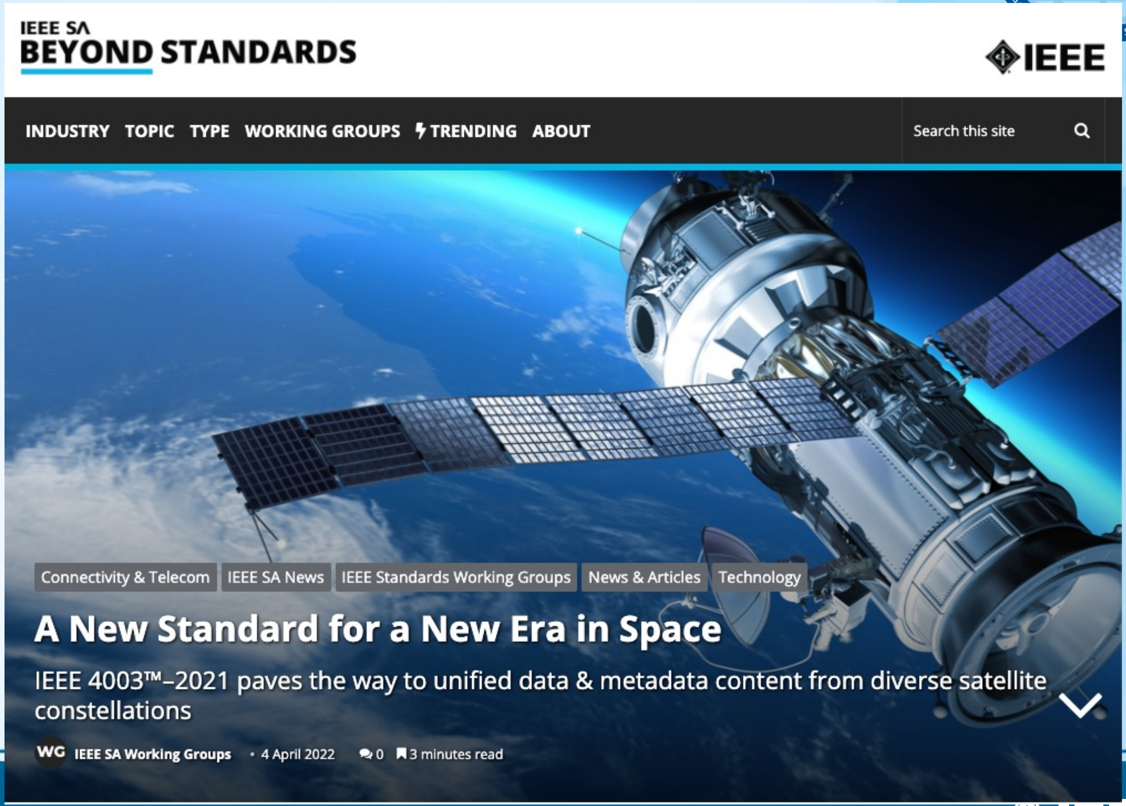
IEEE Standard for Spaceborne Global Navigation Satellite System-Reflectometry (GNSS-R) Data and Metadata Content

IEEE Geoscience and Remote Sensing Society (GRSS)

Developed by the
Standards Committee

IEEE Std 4003™-2021

IEEE



The IEEE Standards Association (IEEE-SA)

IEEE has an active portfolio of nearly 1,300 standards and projects under development.

IEEE is a leading developer of standards in a broad range of technologies that drive the functionality, capabilities, and interoperability of products and services, transforming how people live, work, and communicate.

With collaborative thought leaders in more than 160 countries, IEEE-SA is a leading consensus-building organization that enables the creation and expansion of international markets and helps protect health and public safety.

IEEE Standards Development eTools

myProject: tool to allow you to better manage and keep up to date on projects and topics that you are interested in.

IEEE Attendance Tool: allows Working Groups to setup meetings and record attendance.

Mentor: provides a secure area where Working Groups can manage documents outside of public view.

IEEE SA Open: comprehensive open source development platform that harnesses the power of familiar open source development tools.

iMeet Central: web-based collaboration workspace to share files, continue discussions via available fora, and manage timeline and milestones via calendar.

WordPress: a content management system which can be used to host your Working Group's website.

Webex: Teleconference service offered at no cost to Sponsors and their WGs. Contact your PM for creation.

Listserv: Email list management tool.

IEEE *Xplore*: IEEE store containing IEEE standards, journals, letters, magazines and conference proceedings, and IEEE educational courses.

Standards Dictionary: a database of terms as defined in IEEE standards.

Systems Status Information and Alerts: View status information on service disruptions and planned maintenance for IEEE SA supported tools.

Other Activities of the GRSS Standards Committee

- IEEE P2874 - Spatial Web Protocol
- IEEE P3397 - Standard for SAR Image Quality Metrics
- GSEO is member of OGC/ISO working group to standardize CEOS specifications for Analysis Ready Data
- Working with the IEEE OES, and possibly other IEEE Societies to develop a "Recommended Practice for the Development of Digital Twins of the Earth"

Iliad – Digital Twins of the Ocean

Interoperable, data-intensive, and cost-effective DTOs

Provide a virtual environment representing the ocean

- Capable of running complex, predictive management scenarios
- Integrating sensors, models and digital infrastructures

Aim: Interoperable systems, services and assets

- System-of-Systems approach, interlinked but independent
- Standard interfaces, building blocks, processes needed!

Linked/Aligned with DestinE, EDITO, DITTO, …

56+2 organizations involved

- IEEE WGs would focus on standards and best practices

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IEEE Advancing Technology for Humanity

Thanks for your attention

IEEE GRSS Standards: Sirijodha.Khalsa@ieee.org
IEEE OES Standards and ILIAD: Sigmund.kluckner@ieee.org

Open Geospatial Consortium

OGC Introduction

Standards for Interoperable Digital Twins

Trent Tinker

Sept 18 2023

What is OGC?

A hub for thought leadership, innovation, and standards for all things related to location

Our Vision

Building the future of location with community and technology for the good of society

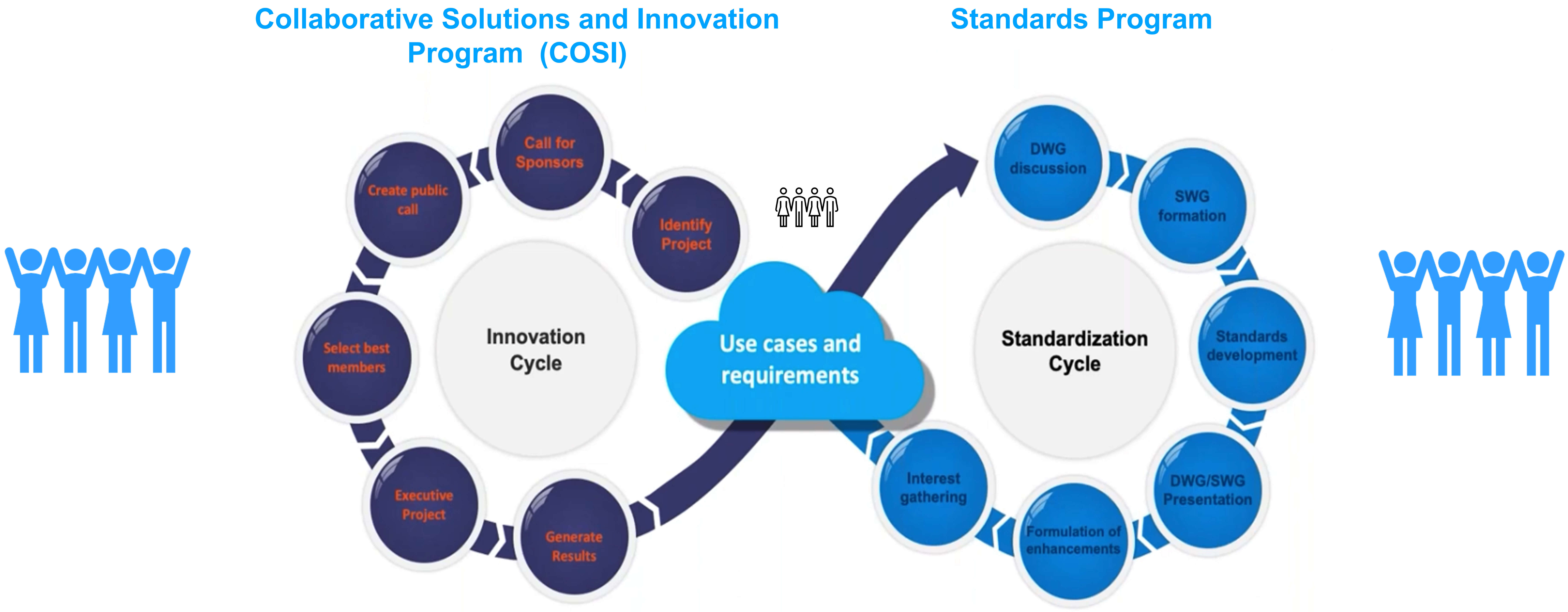
Our Mission

Make location information Findable, Accessible, Interoperable, and Reusable (FAIR)

Our Approach

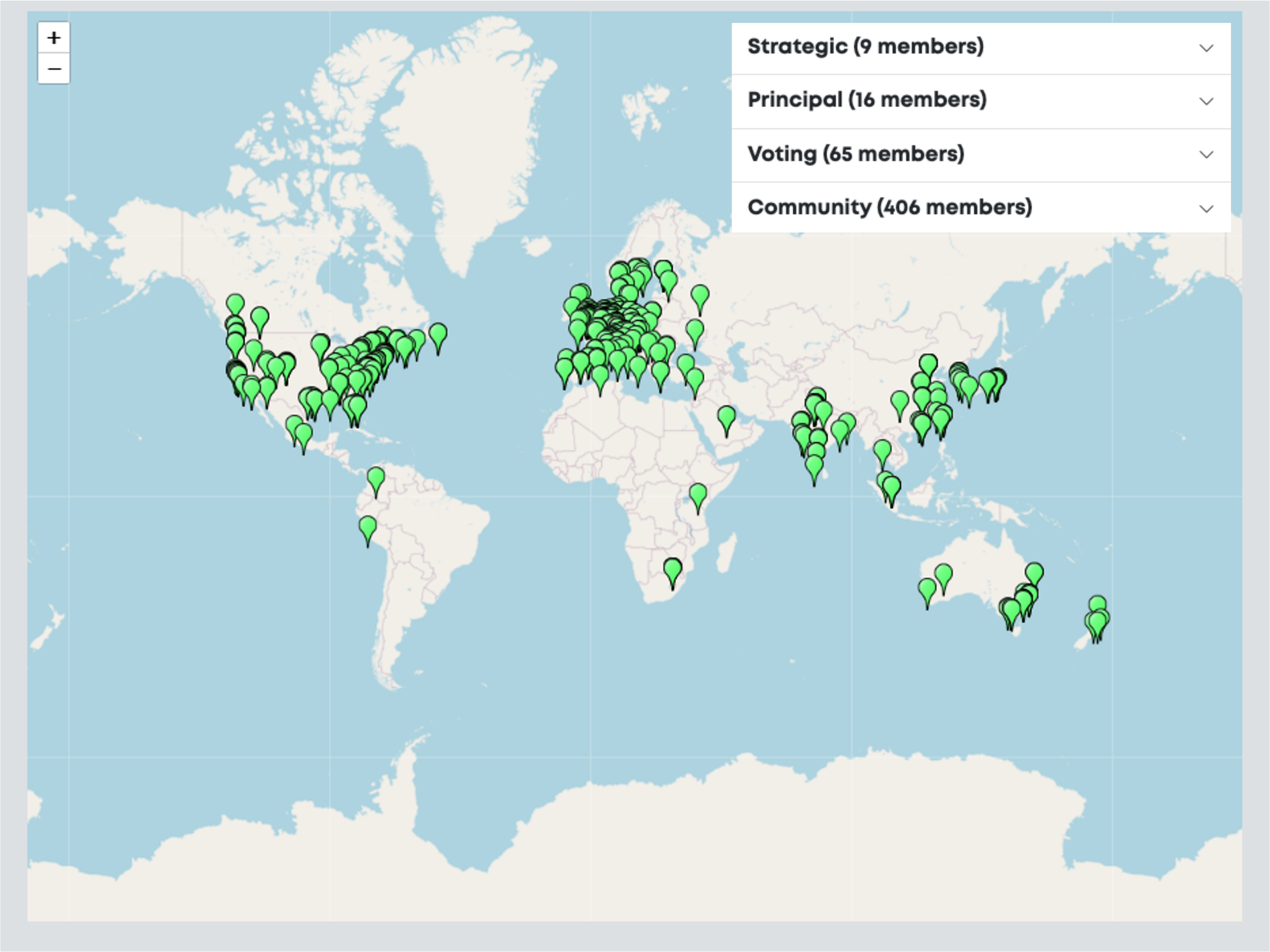
A proven collaborative and agile process combining consensus-based standards, innovation project, and partnership building

Community, Standards and Innovation: A proven process with an agile methodology



Who Are Our Members?

Community: 500+ Members



The OGC Standards Program

Standards Architecture Diagram

Drive Standards Development and Adoption

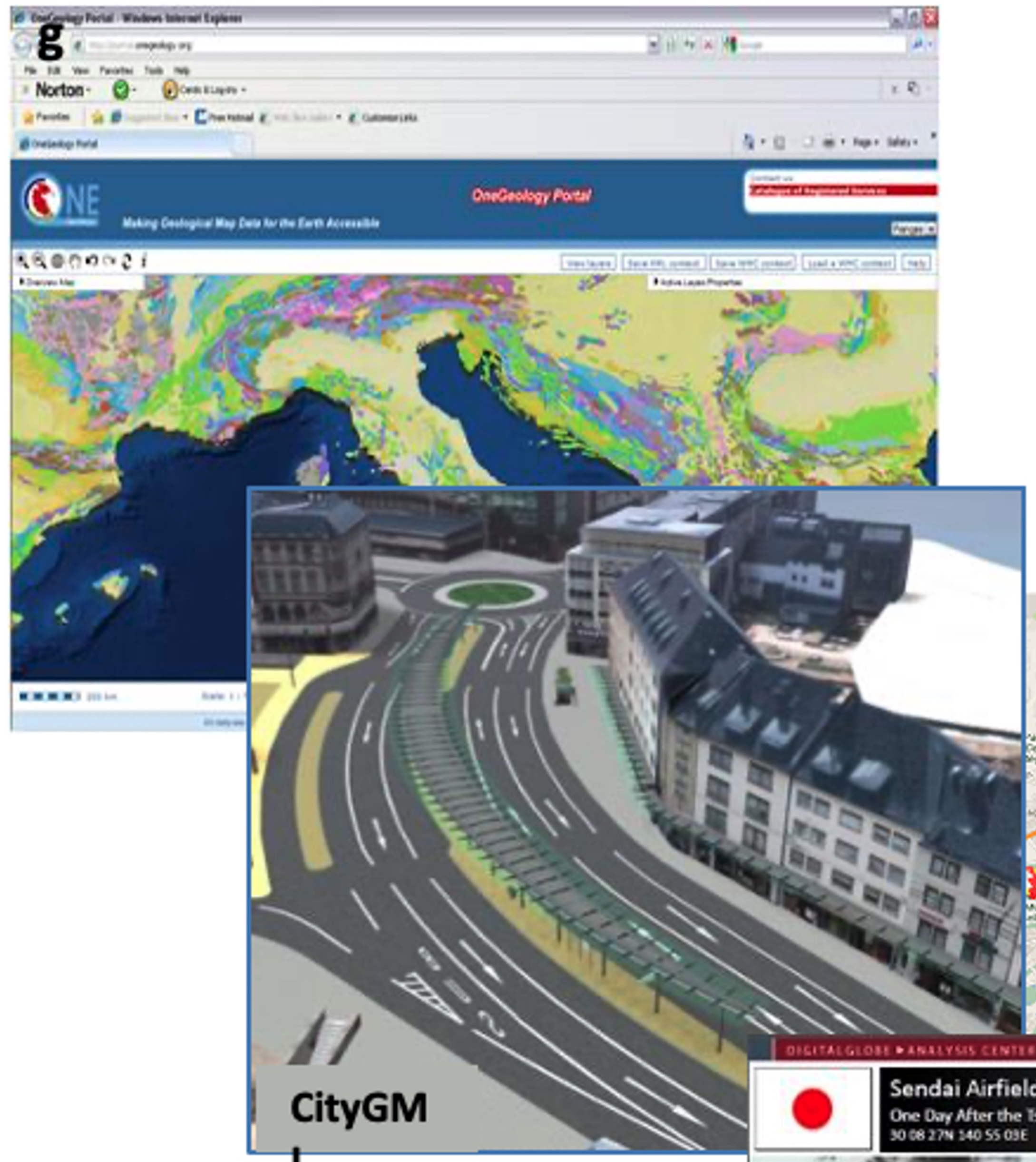
Interactive OGC Standards Online:
https://www.ogc.org/docs/is

Foundational Standards for Earth Systems Digital Twins

Millions of Geospatial Datasets on >200K Servers

OGC Web Services (OWS)
Web Map Service (WMS)
Web Map Tile Service (WMTS)
Web Feature Service (WFS)
Web Coverage Service (WCS)

OneGeology.Or



CityGM
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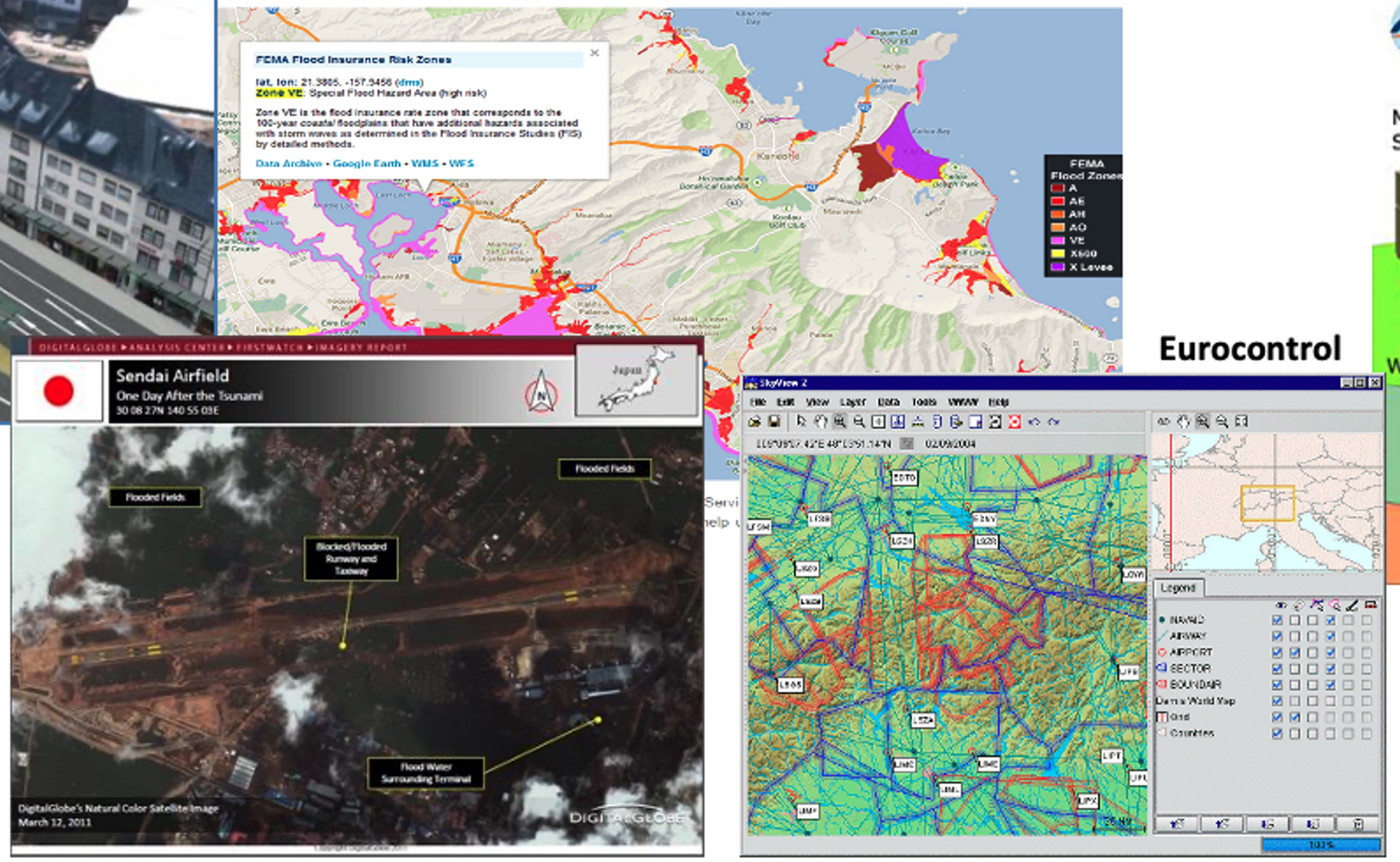
Emergency / Disaster Management

http://oos.soest.hawaii.edu/pacioos/voyager/news/2013/

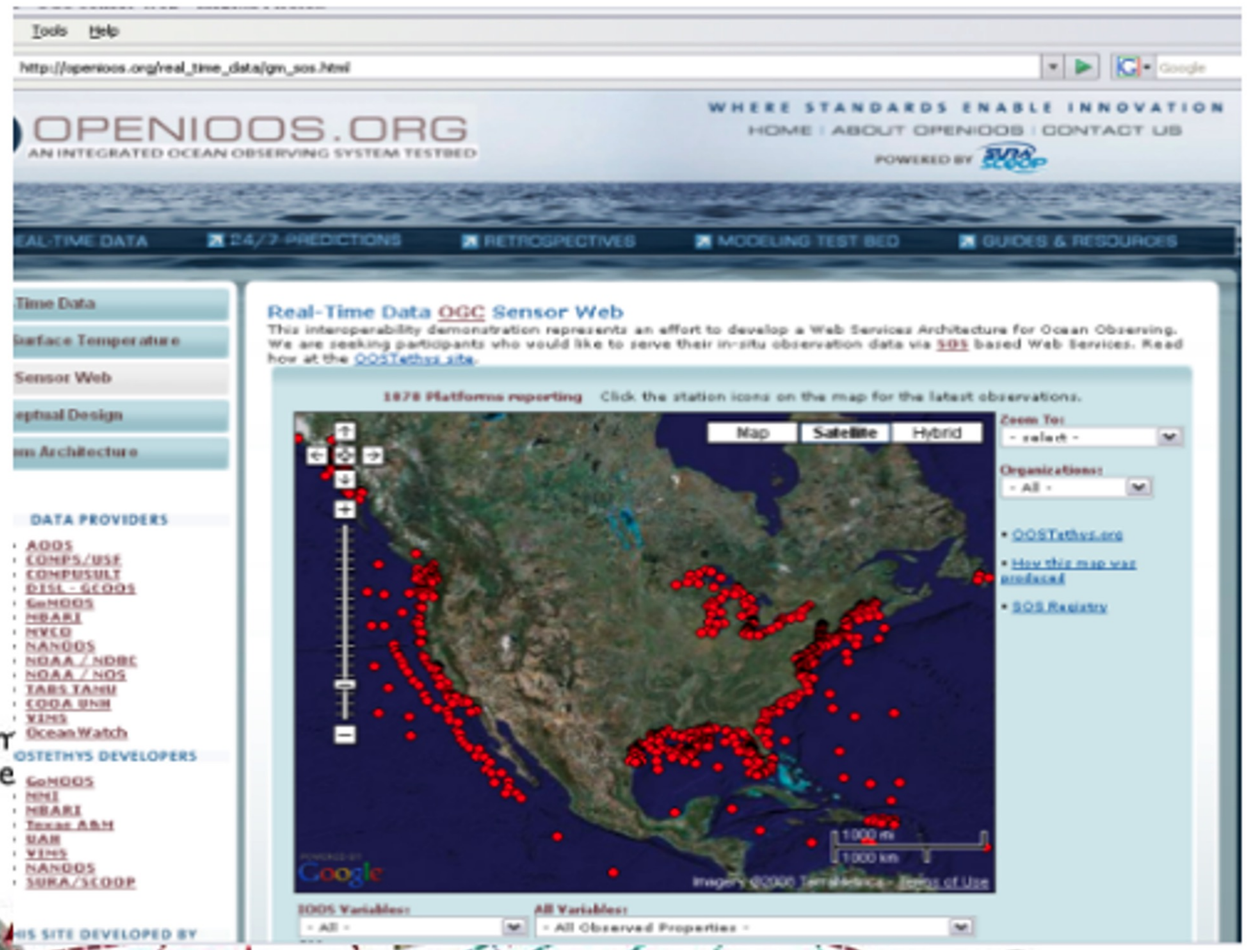


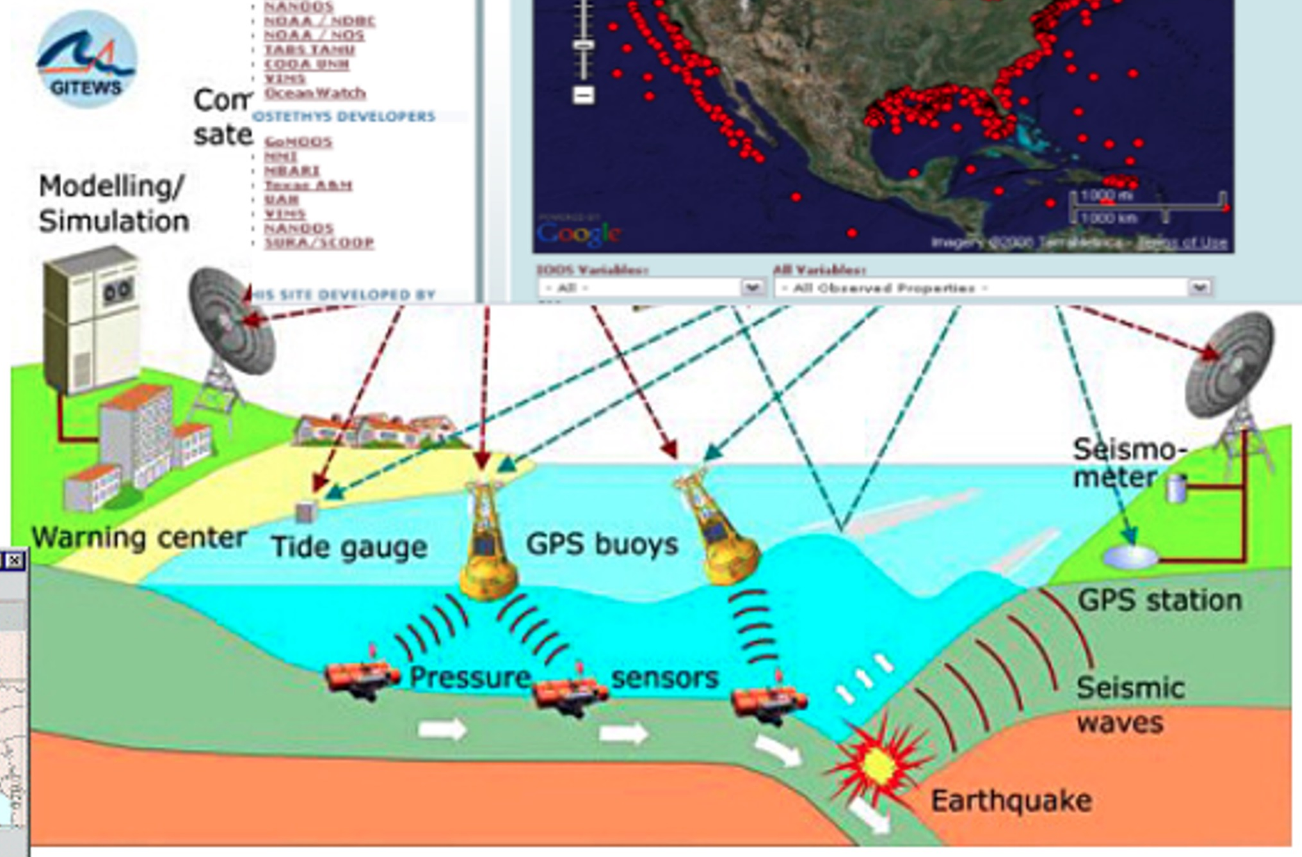
DigitalGlobe

Eurocontrol

Aviation Flight Information / Safety

OpenIOOS.Org





Meteorology, Hydrology, Ocean Monitoring

OGC API Standards

Features

Approved Standard

OGC API - Features - Part 1: Core and Part 2: Coordinate Reference Systems by Reference are both publicly available.

Common

Approved Standard

OGC API - Common specifies those building blocks that are shared by most or all OGC API Standards to ensure consistency across the family.

EDR

Approved Standard

Environmental Data Retrieval (EDR) API provides a family of lightweight interfaces to access Environmental Data resources. Each resource addressed by an EDR API maps to a defined query pattern.

Tiles

Approved Standard

OGC API - Tiles provides extended functionality to other OGC API Standards to deliver vector tiles, map tiles, and other tiled data.

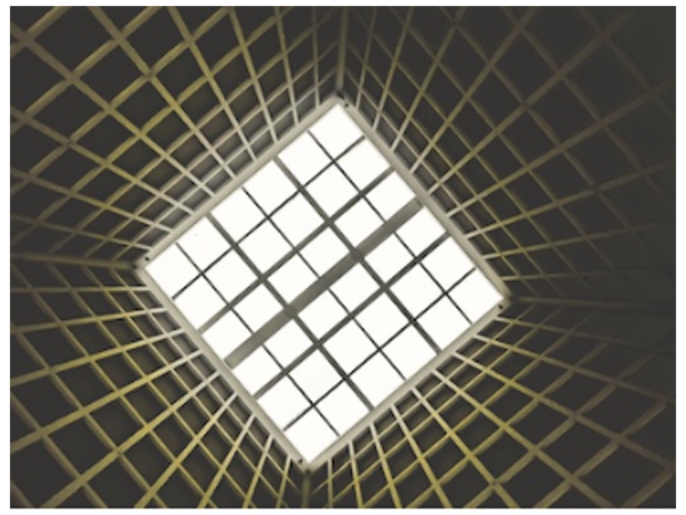
Processes

Approved Standard

OGC API - Processes allows for processing tools to be called and combined from many sources and applied to data in other OGC API resources though a simple API.

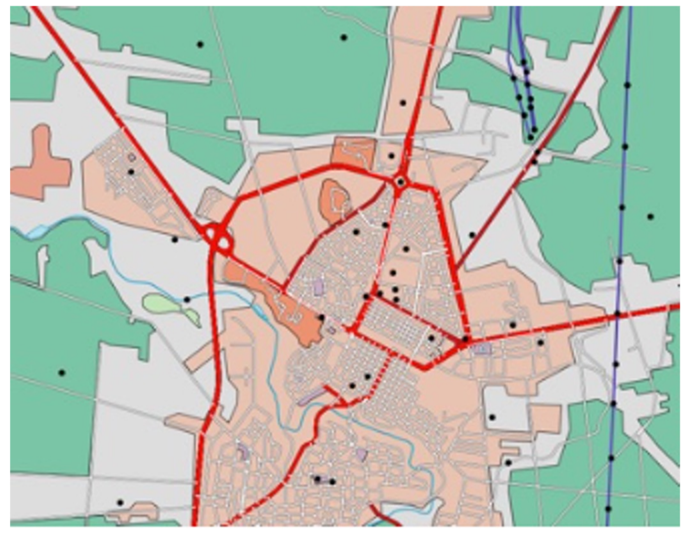
Records

OGC API - Records updates OGC's Catalog Services for the Web by building on the simple access to content in OGC API - Features.



Coverages

OGC API - Coverages allows discovery, visualization and query of complex raster stacks and data cubes.

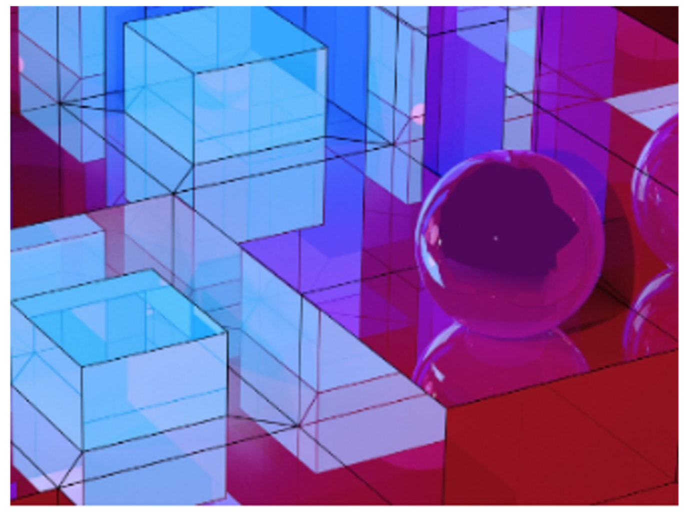


Styles

The OGC API - Styles defines a Web API that enables map servers, clients as well as visual style editors, to manage and fetch styles.

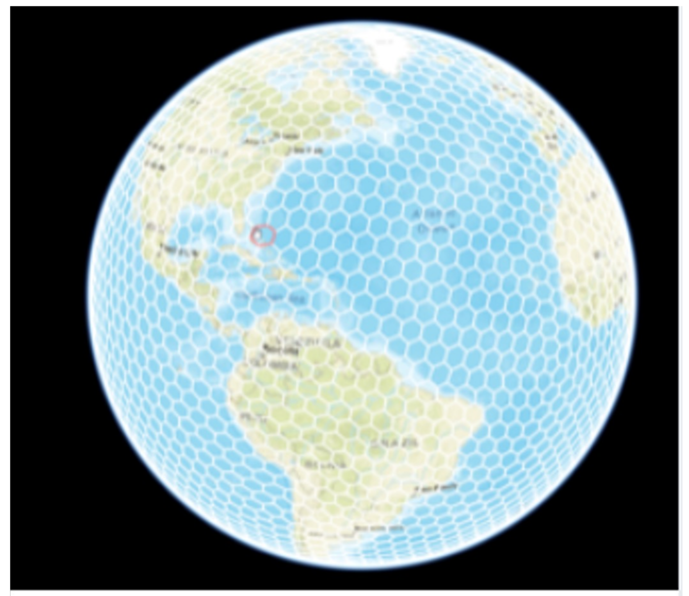
Maps

OGC API - Maps offers a modern approach to the OGC Web Map Service (WMS) standard for provision map and raster content.



3D GeoVolumes

OGC API - 3D GeoVolumes facilitates efficient discovery of and access to 3D content in multiple formats based on a space-centric perspective.



DGGS

Enables applications to organise and access data arranged according to a Discrete Global Grid System (DGGS).

SensorThings

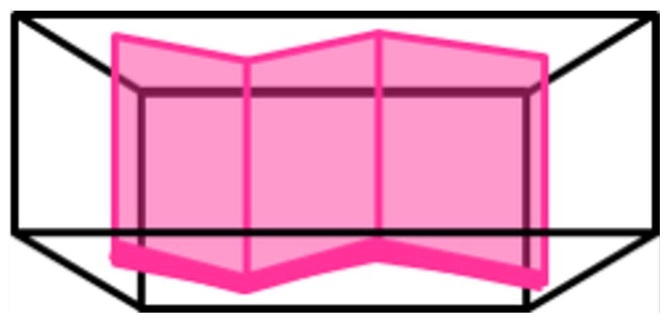
The OGC SensorThings API provides an open, geospatial-enabled and unified way to interconnect Internet of Things (IoT) devices, data, and applications over the Web.

https://ogcapi.ogc.org/

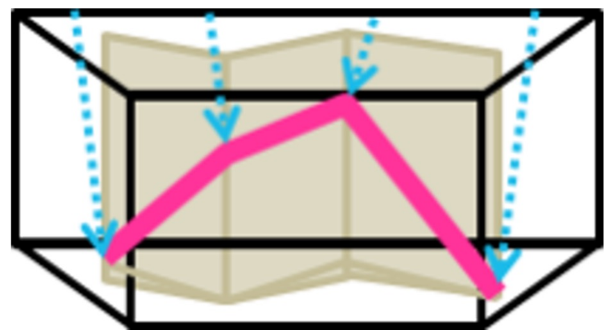
Open Geospatial Consortium

OGC API - EDR

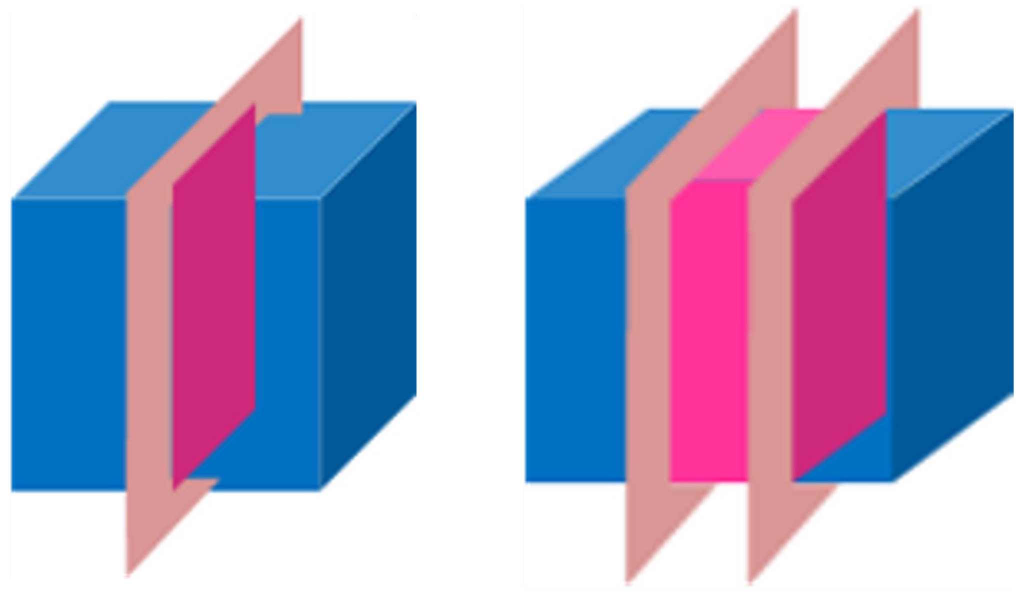
- Provides interfaces to access environmental data resources.
- An EDR collection can contain virtually any data about the natural or built environment that needs to be sampled using a spatio-temporal query pattern.



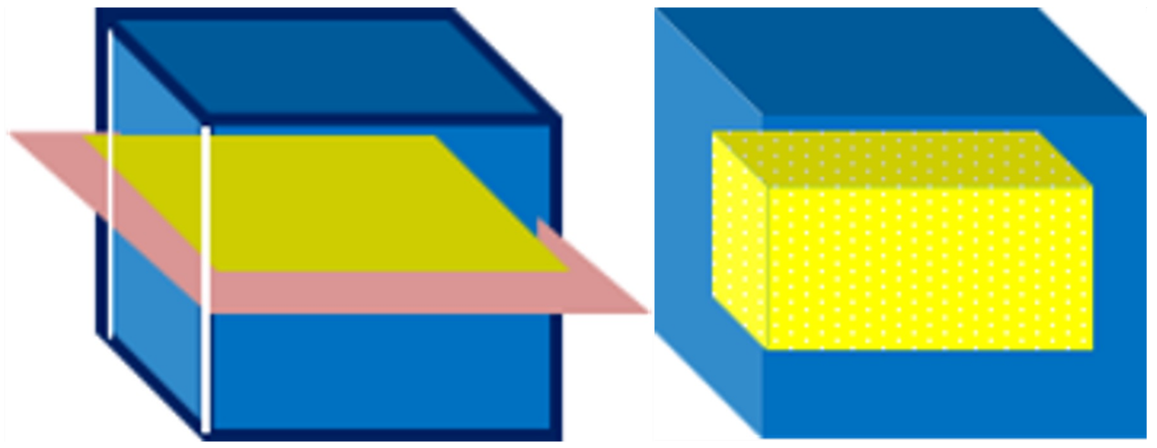
Information from a hydrologic sensor might be found spatially or accessed by ID.



Geospatial gridded data such as a digital elevation model might be accessed along a transect.

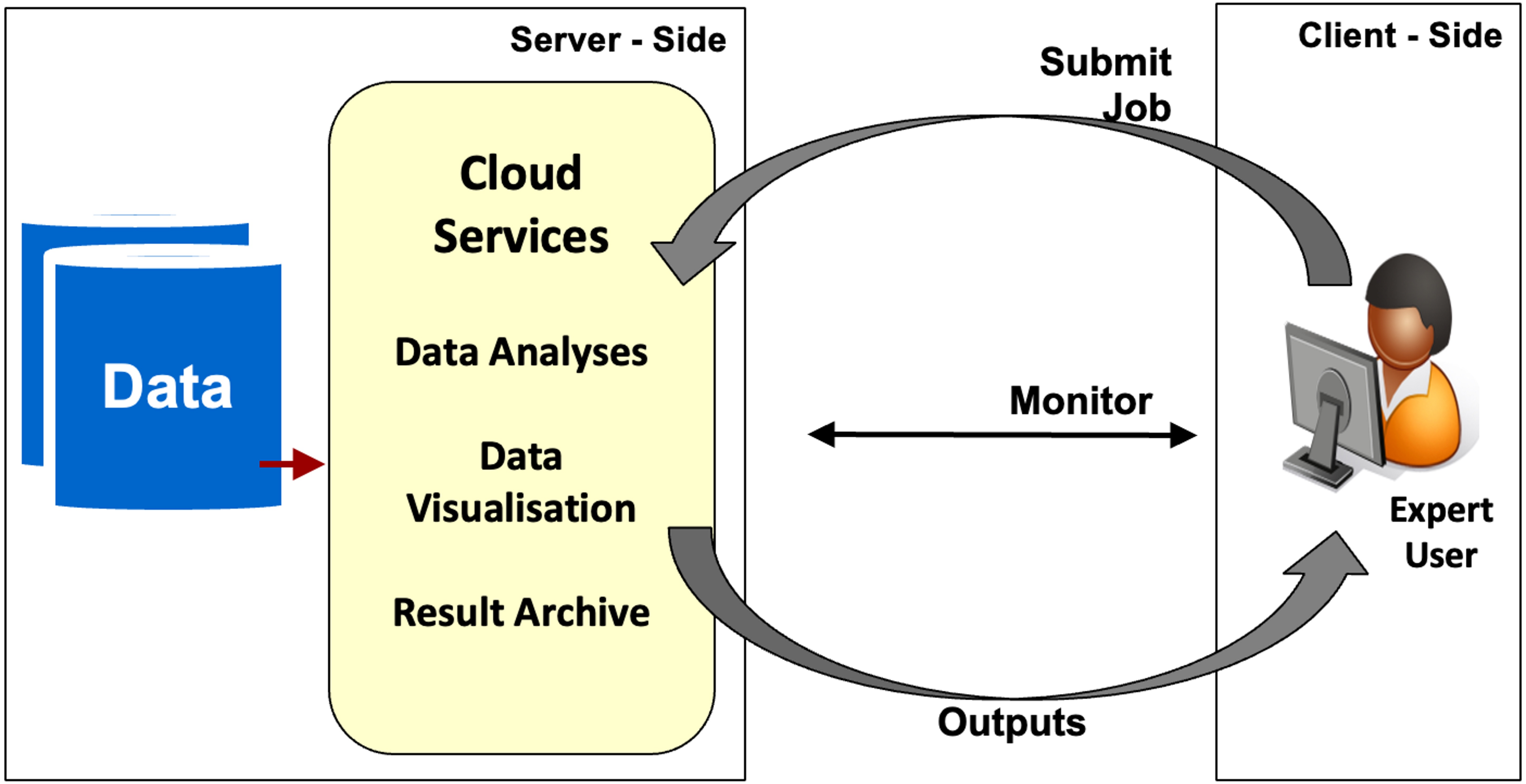


A climate model or weather reanalysis might be accessed at a point or within a bounding rectangle



Weather information from meteorological stations might be queried within a specified polygon.

OGC API - Processes

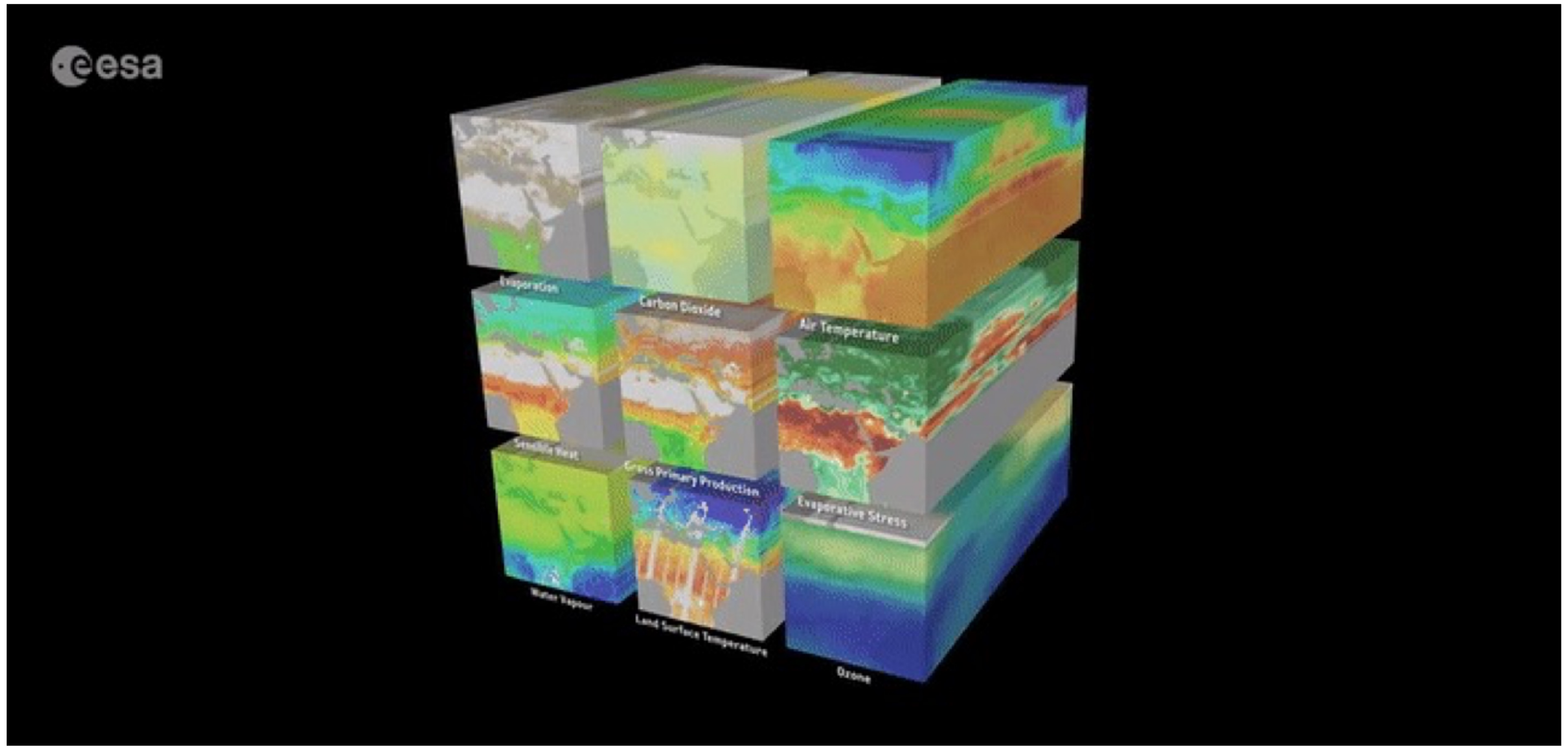


high performance environment

low internet bandwidth

OGC API - Coverages

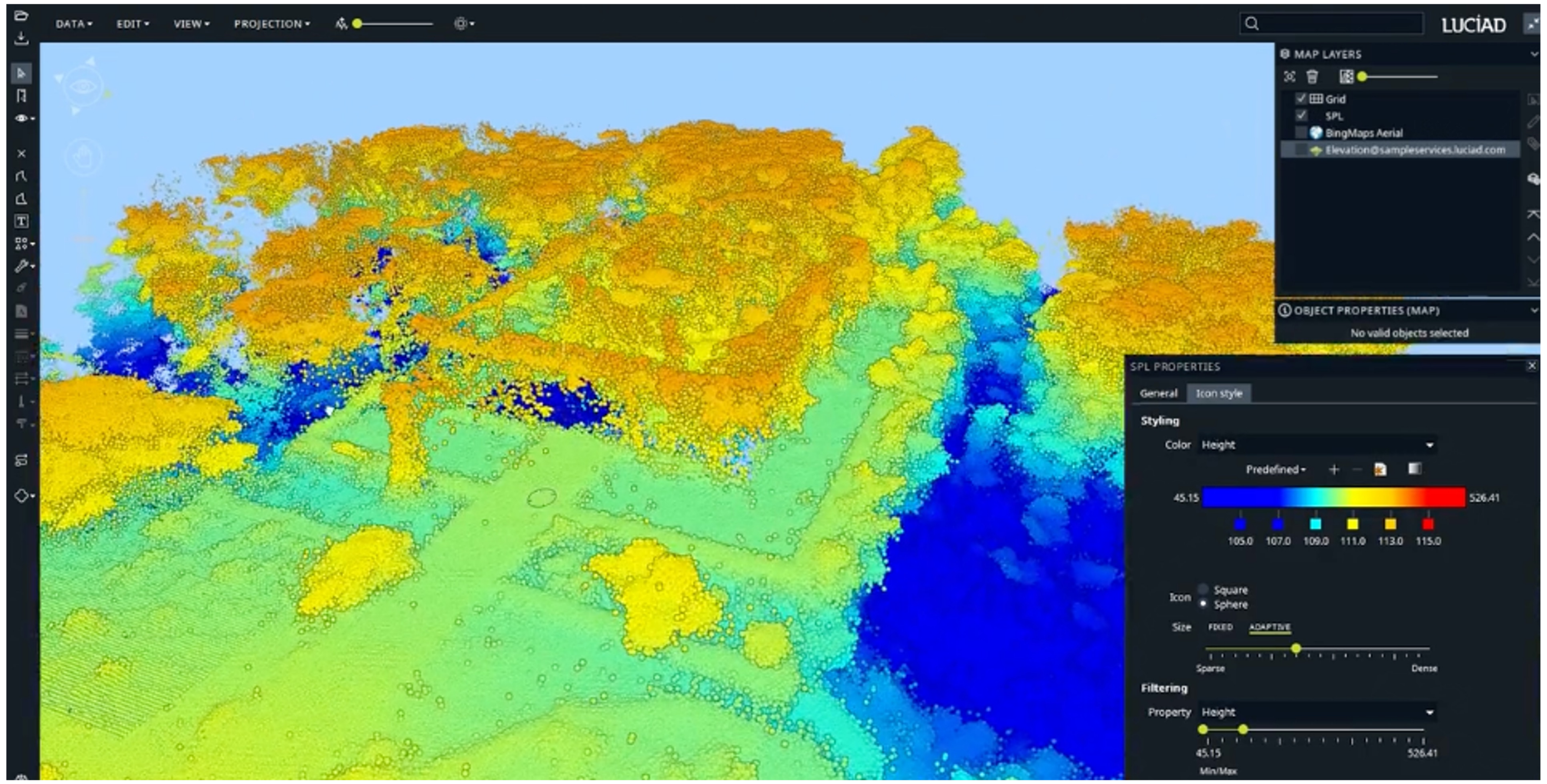
- Gives access to homogeneous collections of values located in space/time (e.g.: coverages).
- Satellite imagery is typically modeled as a gridded coverage.
- Responses in CoverageJSON, netCDF, GeoTIFF, PNG, HTML and other formats.



OGC 3DTiles

- Developed by Cesium

- Adopted as an OGC Community Standard in 2018



An OGC 3D Tiles set visualized using a color map based on its height attribute.

Analysis Ready Data SWG

OGC Forms new Analysis Ready Data Standards Working Group

New OGC Working Group will develop a multi-part Standard for geospatial Analysis Ready Data products that can be integrated & analyzed with minimal effort.

The Open Geospatial Consortium (OGC) is excited to announce the formation of the OGC Analysis Ready Data Standards Working Group (ARD SWG).

The ARD SWG, in partnership with ISO/TC 211, will develop a multi-part Standard for geospatial Analysis Ready Data that builds upon work undertaken in the Committee on Earth Observation Satellites (CEOS) Land Surface Imaging Virtual Constellation (LSI-VC) and Analysis Ready Data (ARD) Oversight Group, OGC Disaster Pilot 2021, and OGC Testbed-16.

The concept of ARD was initially developed by CEOS, which defines ARD as "satellite data that have been processed to a minimum set of requirements and organized into a form that allows immediate analysis with a minimum of additional user effort and interoperability both through time and with other datasets." Adopting the CEOS-ARD definition as a starting point, the OGC ARD SWG will extend the scope of ARD from satellite data to all geospatial data.

A major strength of geospatial and location technologies is their ability to integrate and analyze data from diverse providers concerning many different phenomena so as to better understand or predict what is happening in a given area. However, this

New OGC Working Group will develop a multi-part Standard for geospatial Analysis Ready Data products that can be integrated & analyzed with minimal effort.

3.1 Statement of relationship of planned work to the current OGC standards baseline

There are no existing OGC Standards that completely addresses the above ARD requirements.

The ARD standards are intended to be aligned with some existing OGC Standards, which can partially fulfill ARD capability requirements. Below is a selection which is not meant to be exhaustive.

- WCS: OGC Web Coverage Service can provide on-demand ARD data services for coverage data.
- WFS: OGC Web Feature Service can provide on-demand ARD data services for feature data.
- OGC API – Features can provide on-demand ARD data services for feature data.
- CSW: OGC Catalog Service for Web can provide federated discovery of ARD products from multiple data providers
- GML: GML is a comprehensive encoding of features, geometry, and topology in XML. GML can be used to encode the feature ARD.
- GeoTIFF, NetCDF, and HDF5: These OGC standards are useful for encoding and packing coverage ARD.
- WKT CRS: The Well-Known Text representation of Coordinate Reference Systems offers a standardized way to describe CRSs for reference by any spatial data set fully.
- Observations and Measurements: this standard defines XML schemas for observations, and for features involved in sampling when making observations. These provide document models for the exchange of information describing observation acts and their results, both within and between different scientific and technical communities.
- Several evolving OGC Standards are also relevant: OGC API – Tiles, OGC API – Maps, OGC API – Records, OGC API-EDR, and Cloud Optimized GeoTIFF.
- DGGS Abstract Specification: The goal of DGGS is to enable rapid assembly of spatial data without the difficulties of working with projected coordinate reference systems. DGGSs represent the Earth as hierarchical sequences of equal area tessellations, each with global coverage and with progressively finer spatial resolution.

GeoDataCube SWG

Chapter 1. Purpose of the Standards Working Group

In a very agile approach, this Standards Working Group (SWG) has the goal to facilitate the handling of different GeoDataCubes (GDCs). For this purpose, an Application Programming Interface (API) will be defined that serves the core functionalities of GDCs. GDC users will be able to handle different GDCs according to the same principles, as interoperability between GDCs will be achieved.

The GDC SWG will define a metadata model including provenance and data lineage information to describe all details about a GDC. Furthermore, the SWG will identify formats to be used for data exchange. If existing formats do not meet the requirements, the SWG will extend its work to the development of a GDC exchange format.

The agile process will go through multiple iterations in order to produce standards of growing complexity, starting with the minimum viable solution that is then extended as required. The SWG will first define the basic characteristics of GDCs as well as core requirements for the use of GDCs and the exchange of GDC data. These requirements need to be met by the GDC API, metadata model, and exchange formats.

In the next step, the SWG will decide which existing standards or standards under development should be used or extended to achieve these core requirements. Afterwards, the GDC API, the GDC metadata model, and the data exchange format(s) will be defined and implemented. The goal is to develop a solution that supports a majority of typical GDC application scenarios. The simplicity of the solution will be prioritized over its ability to meet all possible use cases and be compatible with all available standards.

The Open Geospatial Consortium (OGC) is excited to announce the formation of the OGC GeoDataCube SWG.

The GeoDataCube SWG will improve interoperability between existing datacube solutions, simplify the interaction with different datacubes, and facilitate the integration of data from multiple datacube sources. By following a user-centric approach, the SWG will develop solutions that meet the needs of scientists, application developers, and API integrators.

The goal of the OGC GeoDataCube SWG is to create a new API specifically to serve the core functionalities of GeoDataCubes, such as access and processing, and to define exchange format recommendations, profiles, and a metadata model. The SWG also aims to analyze usability of existing Standards and identify use cases.

Similar to other OGC APIs, the GeoDataCube SWG will create this new standard from existing building blocks, such as existing geospatial Standards, outputs from previous OGC Collaborative Solutions & Innovation Initiatives, and other developer resources in a very use-case driven approach, i.e., with a small core and possible extensions. This will allow for interoperability across future OGC Standards.

With regards to existing and emerging OGC standards, the working group may look specifically at:

- OGC API – Environmental Data Retrieval: A family of lightweight interfaces to access Environmental Data resources.
- OGC API – Coverages: Defining a Web API for accessing coverages that are modeled according to the Coverage Implementation Schema.
- OGC Analysis Ready Data SWG products: proposed Standards to describe specific product types that are often implemented as GeoDataCubes.
- OGC API – Processes: Supporting the wrapping of computational tasks into executable processes that can be offered by a server through a Web API.
- Zarr: An OGC Community Standard for the storage of multi-dimensional arrays of data.
- GeoTIFF and Cloud Optimized GeoTIFF: A format used to share geographic image data.
- Hierarchical Data Format (HDF5): A set of formats designed to store and organize large amounts of data.

New SWG will develop datacube interoperability Standards that meet the needs of scientists, application developers, and API integrators.

How to get involved

Member Meetings - 3 Per Year

Registration and Agenda:
https://portal.ogc.org/meet/

COSI Program in Numbers

Sponsor or participate in an Innovation Initiative

Over 90 Participating Organizations

21 Innovation Program Initiatives

$2.1M USD Support for OGC Members


CESIUM
Open Geospatial Consortium
From Oceans to Space
Testbed-19 Kickoff
CESIUM
Open Geospatial Consortium

Domain Working Groups

- Urban Digital Twins
- Energy and Utilities
- Climate Resilience DWG
- Geo for the Metaverse
- Met Ocean DWG
- GeoAI DWG

- Full List: https://www.ogc.org/about-ogc/committees/dwg/

Open Geospatial Consortium

ABOUT MEMBERSHIP STANDARDS & RESOURCES INNOVATION NEWS & EVENTS

Domain Working Groups

Domain Working Groups (DWG or WG) provide a forum for discussion of key interoperability requirements and issues, discussion and review of implementation specifications, and presentations on key technology areas relevant to solving geospatial interoperability issues.

Name space	Project Description	Lead **
3DIM DWG (3DIM DWG)	The OGC 3D Information Management (3DIM) DWG facilitates the definition and development of interface and encoding standards for 3-dimensional content that enable software solutions allowing infrastructure owners, builders, emergency responders, community planners, and the traveling public to better manage and navigate complex	Roensdorf, Carsten (Ordnance Survey) - Group Chair, Biljecki, Filip (National University of Singapore) - Vice Chair, Graham, David (CAE Inc.) - Vice Chair https://lists.ogc.org/mailman/listinfo/3DIM.wg
Agriculture DWG (Agriculture DWG)		
Architecture DWG (Arch DWG)		
Artificial Intelligence		

4.2. Key activities

Key activities for the DWG include the following efforts:

- understand the Standards landscape associated with Urban Digital Twins;
- develop a position paper to describe where Urban Digital Twins fit into the larger OGC domain ecosystem;
- position OGC Standards and Best Practices in the Urban Digital Twins community;
- lead discussion and development of Best Practices associated with Urban Digital Twins;
- explore the use cases surrounding Urban Digital Twins, including those related to Smart Cities, land and energy; and
- work within the OGC context of digital twins in other domains.

Standards Working Groups

3D GeoVolumes SWG (3DGeoVol SWG)
3D Portrayal SWG (3DP SWG)
CDB SWG (CDB SWG)
CityGML SWG (CityGML SWG)
Coverages SWG (CoveragesSWG)
CRS SWG (CRS SWG)
CRS Well Known Text SWG (CRS WKT SWG)
Discrete Global Grid Systems SWG (DGGS SWG)
Environmental Data Retrieval API SWG (EDR-API SWG)
EO Product Metadata and OpenSearch SWG (EO PMOS SWG)
Features and Geometries JSON SWG (FeatGeoJSON SWG)
Features API SWG (FeatAPI SWG)
GeoAPI SWG (GeoAPI SWG)
Geocoding API SWG (GeocodeAPISWG)
GeoPackage SWG (GeoPackage SWG)
GeoPose SWG (GeoPose SWG)
GeoSciML SWG (GeoSciML SWG)
GeoSPARQL SWG (GeoSPARQL SWG)
Geospatial User Feedback SWG (GUFswg)
GeoSynchronization 1.0 SWG (Geosync SWG)
GeoTIFF SWG (GeoTIFF SWG)
GeoXACML SWG (GeoXACML SWG)
GML 3.3 SWG (GML 3.3 SWG)
GMLJP2 SWG (GMLJP2-SWG)
Groundwater SWG (GroundwaterSWG)
HDF SWG (HDF SWG)
Hydrologic Features SWG (HydroFeat SWG)

IndoorGML SWG (IndoorGML SWG)
KML 2.3 SWG (KML SWG)
Land and Infrastructure SWG (LandInfraSWG)
Moving Features SWG (MovFeat SWG)
MUDDI SWG (MUDDI SWG)
NetCDF SWG (NetCDFSWG)
O&M SWG (OM SWG)
OGC API - Common SWG (OGC API-Common)
OGC API - Maps SWG (OGC API - Maps)
OGC API - Processes SWG (OAPIProc SWG)
OGC API - Records SWG (API Records SWG)
OGC API - Styles SWG (Styles API SWG)
OGC API - Tiles SWG (OAPITileSWG)
OWS Common - Security SWG (ComSecuritySWG)
OWS Context SWG (OWScontextSWG)
PipelineML SWG (PipeML SWG)
Points of Interest SWG (PoI SWG)
PubSub SWG (PubSub SWG)
Routing SWG (Routing SWG)
Sensor Model Language (SensorML) 2.0 SWG (SensorML2.0SWG)
SensorThings SWG (SensorThings)
Simple Features SWG (SF SWG)
Styles and Symbology Encoding SWG (Styles SE SWG)
Temporal WKT for Calendars SWG (TemporalWKT)
TimeSeriesML SWG (TimeSeriesML)
Training Data Markup Language for AI SWG (TrainingDML SWG)
WaterML 2.0 SWG (WaterML2.0SWG)

Thank you for your attention!

Innovation

- 120+ Innovation Initiatives
- 380+ Technical reports
- OGC hosted services
- Interoperability enhancement engine

Community

- 500+ International Members
- 120+ Member Meetings
- 60+ Alliance and Liaison partners
- 50+ Standards Working Groups
- 45+ Domain Working Groups

Standards

- 65+ Adopted Standards
- 300+ products with 1000+ certified implementations
- 1,700,000+ Operational Data Sets
  Using OGC Standards

ttinker@ogc.org
or connect via LinkedIn

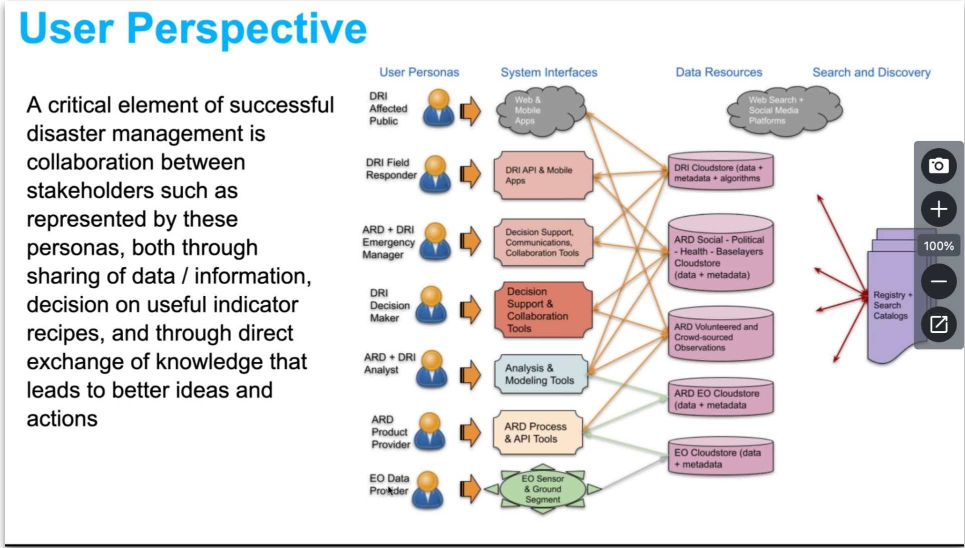
Interop Considerations in Earth Systems Digital Twins

Toward Achieving a Useful Federated Ecosystem

Ryan Berkheimer
Physical Scientist, NOAA NESDIS NCEI
Archive Architect for the NCCF and NCEI

Why Haven’t Spatial Data Infrastructures Been Enough?

- **At every level** of the global spatial data infrastructure, **our system is characterized by data silos**
  - Data **access** is generally difficult
  - **Usage** is generally difficult
  - **Collaboration** is generally difficult
  - **Operationalizing** is generally difficult
  - **Universal Standards management** is nearly impossible - so how can we merge things?
  - ***Useful sustained Interoperabiliy*** *is impossible to achieve under this condition*
- **Data Silos** are **expensive** and **limiting**
  - Resource overhead in duplicating efforts in **feature sets, maintenance, management**, etc.
  - Enormous costs incurred due to resolving conflicts of **definition, provenance, use rights**, etc.
  - **Service offerings** that don’t match data-driven **user preferences**
  - Inability to do holistic comparison of **competitive approaches** and/or **products**
  - Lack of **holistic quality** controls
  - **Reproducibility** crisis leading to trust issues
- **This problem isn’t limited to any particular enterprise**
  - **Data integration** in earth science **is** a **global** issue
  - Enormous value in enabling **connection between organizations** - global **system of systems**
  - **No one organization can solve this problem alone!!! It requires an orchestrated federation of players**

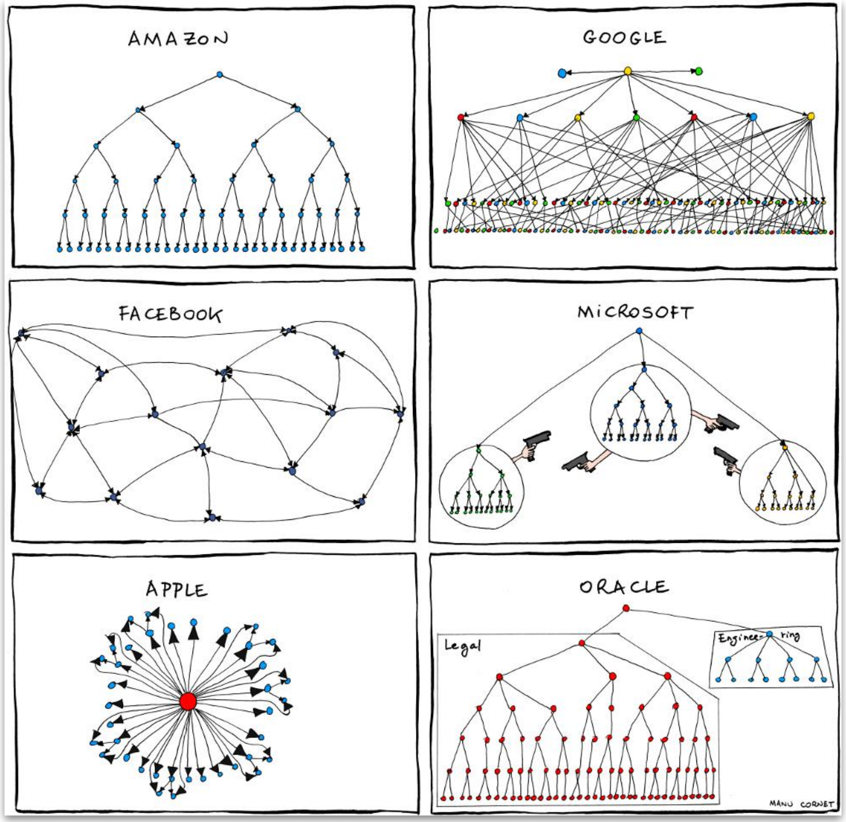


[OGC Disaster Pilot 2023]

We aren’t here quite yet

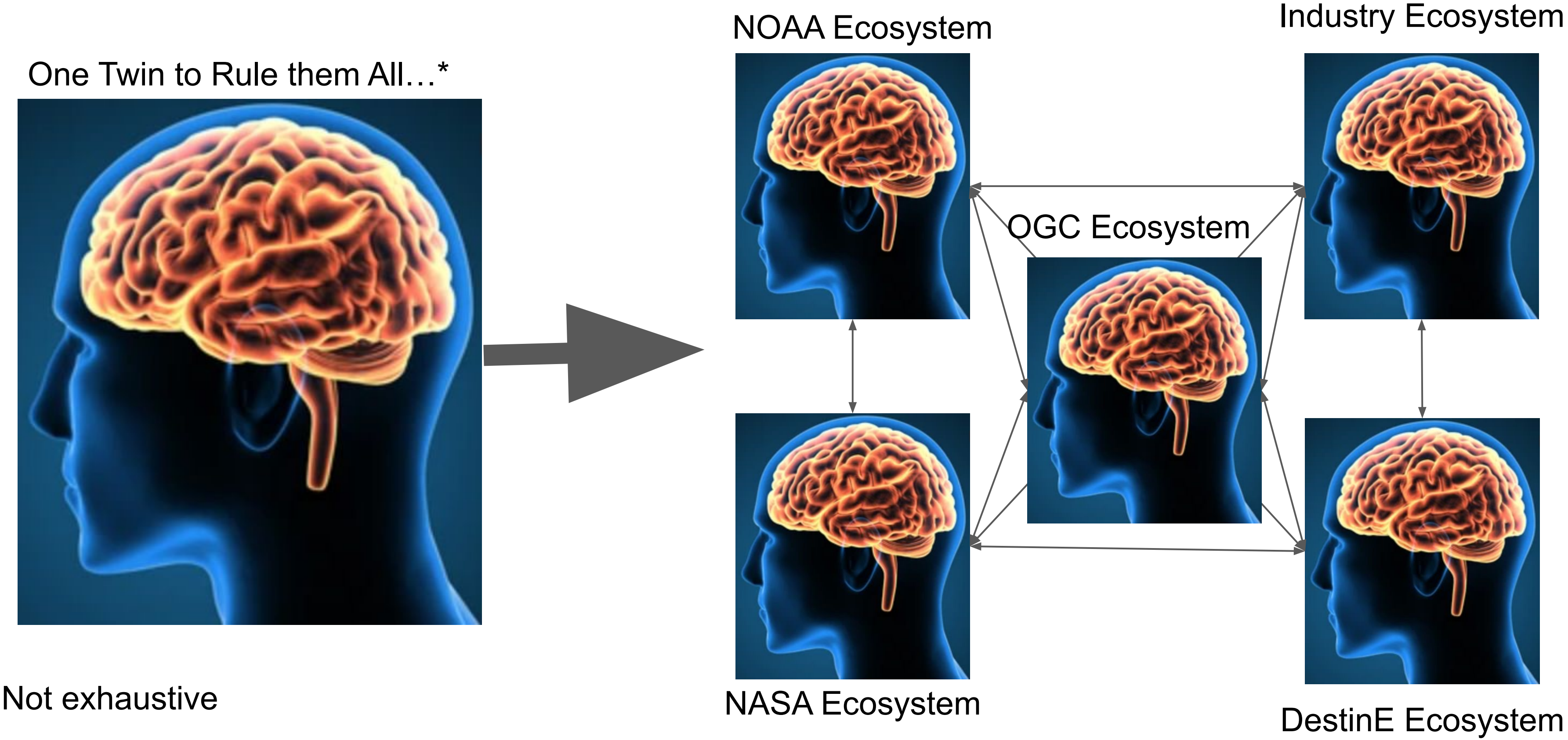
Why is Interoperability Needed? A Communications Problem

- A full resolution earth is an **open system of open systems**
- Lots of humanity spanning effort to **measure, understand, and explain**
- **Decision/feedback loops and optimizations are persona and context dependent**
- **Data is fundamentally interoperable** due to scientific frameworks of understanding
- **But -** most holistic interoperability efforts fail in some way - why?
- **Conway's Law:** any organization that designs a system (defined broadly) will produce a design whose structure is a copy of the organization's communication structure
    - Conway's Law implies hard limits to large efforts in terms of **syntactic, schematic, semantic, and legal interoperability** constraints



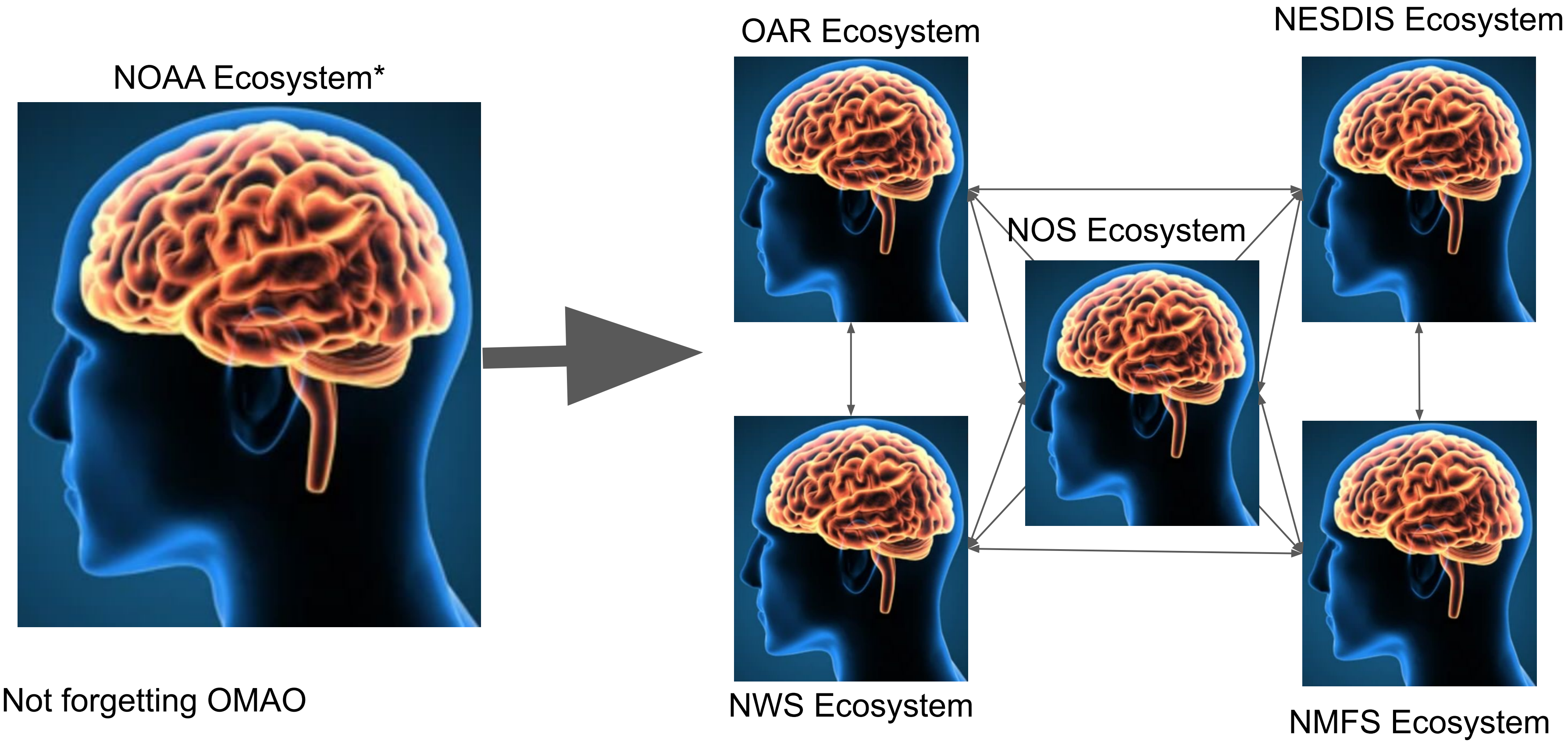
http://scrumbook.org/product-organization-pattern-language/conway-s-law.html

A Federated Viewpoint of Digital Twins



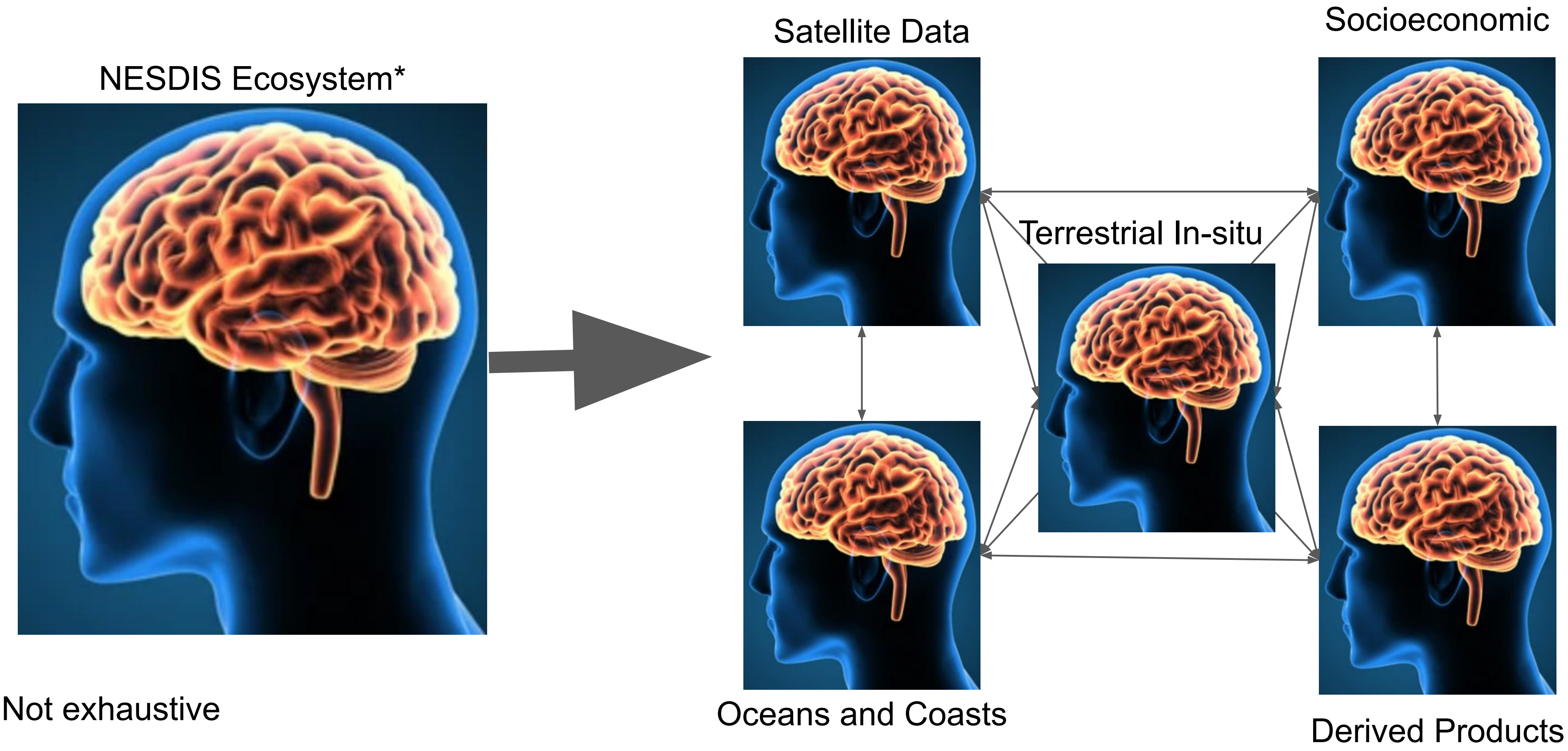
* Not exhaustive

A Federated Viewpoint of Digital Twins



* Not forgetting OMAO

A Federated Viewpoint of Digital Twins



* Not exhaustive

Model Axioms

- **Axiom A** - The Earth system is an ecosystem of open systems characterized by unstable groups of agents (users).
- **Axiom B** - Users may greatly improve their own decision-making (process) confidence, capacity, and capability due to improved model capability via shared representation.
- **Axiom C** - Achieving a shared representation of users is limited by the communication interfaces they share.
- **Axiom D** - Issues with communication interfaces may be defined and addressed in terms of GEO-classified interoperability.

Requirements

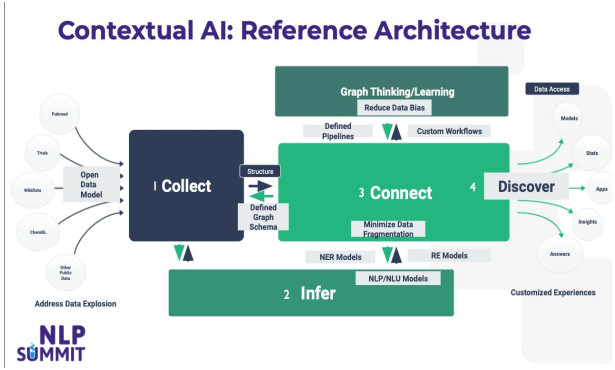
Digital Twin - A virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning and reasoning to help decision-making.

Capabilities

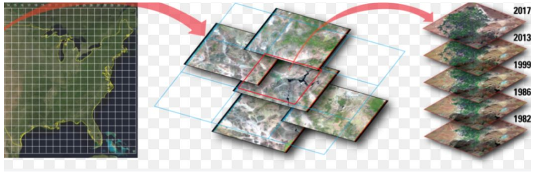
- **Operations optimization** via simulation and monitoring
- **Predictive maintenance** recommendations based on holistic or targeted analysis of system properties
- **Anomaly detection** based on historical trend reliant models
- Fault isolation via reasoned **root cause analysis**

Major Considerations for Digital Twin Federation (Interop) Architecture

- **Agree** on the fact that **Knowledge Sharing is a federated problem**
    - Organizational specializations
    - Domain characteristics
    - Continuous innovations and reconfigurations
    - Competing priorities
    - Nearly infinite user concerns and use cases
- **Consider intra-twin interoperability** concerns, e.g.
    - How do we ensure **reproducibility**? (not science without it!)
    - How how do we **automatically combine** different timescales, units, etc.?
    - How do we **capture provenance** in a FAIR way?
    - How do we **associate uncertainty** with prediction and data?
    - How do we guarantee **performance and scale**?
- **Consider inter-twin interoperability** concerns, e.g.
    - How do we **capture decisions** (non-spatial-data) and associate with lineage and provenance?
    - How do we **avoid limiting** ourselves to a particular **catalog** viewpoint?
    - How do we support **pre-flight cost** simulation, aka **process shopping,** for a given describe plan?
    - How do we **enable inference** that helps us look for unknown connections?
    - How do we **manage legal interoperability** issues, **CARE** issues?
        - *Access rights to processes?*
        - *Bad actors?*

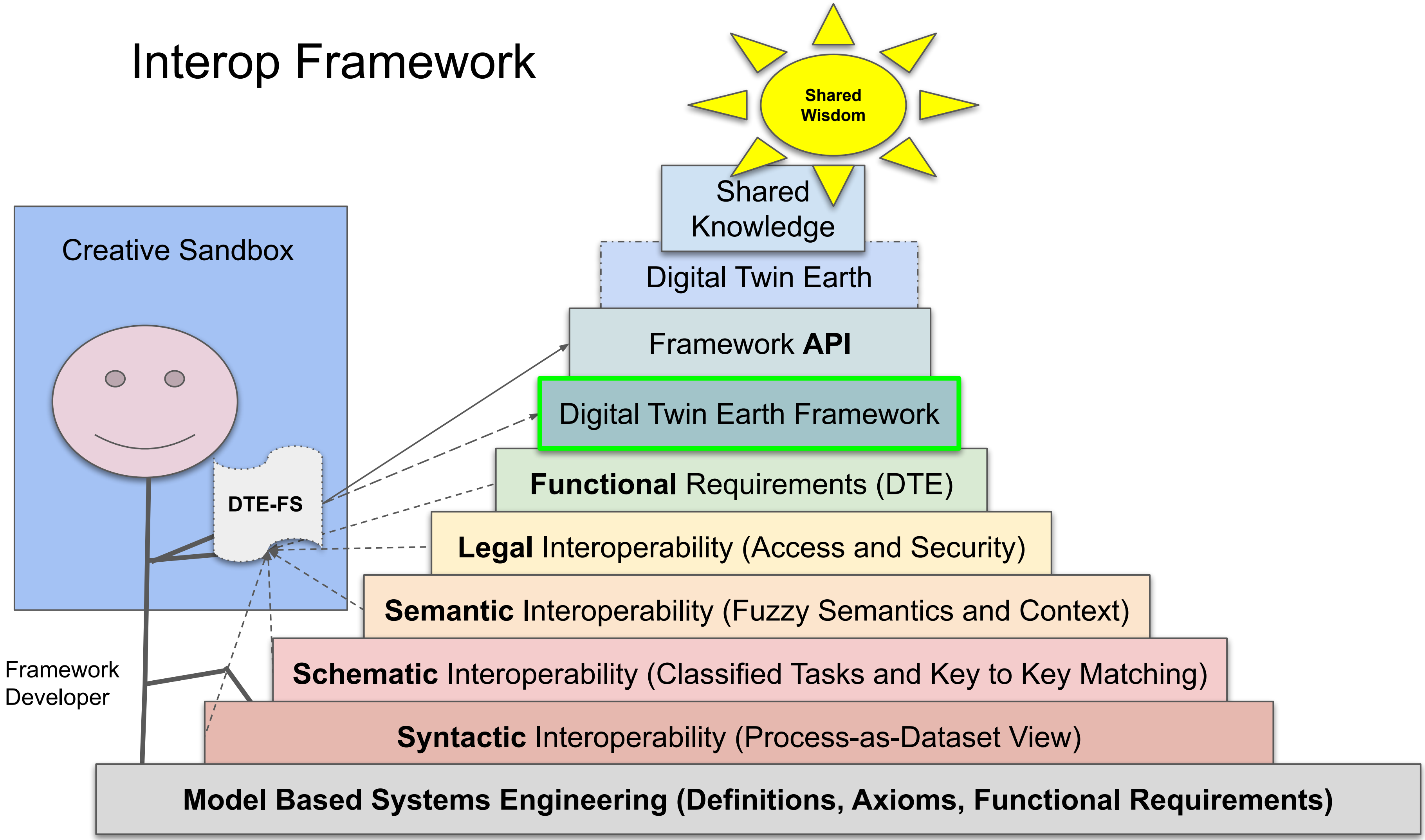


NLP Summit 2022

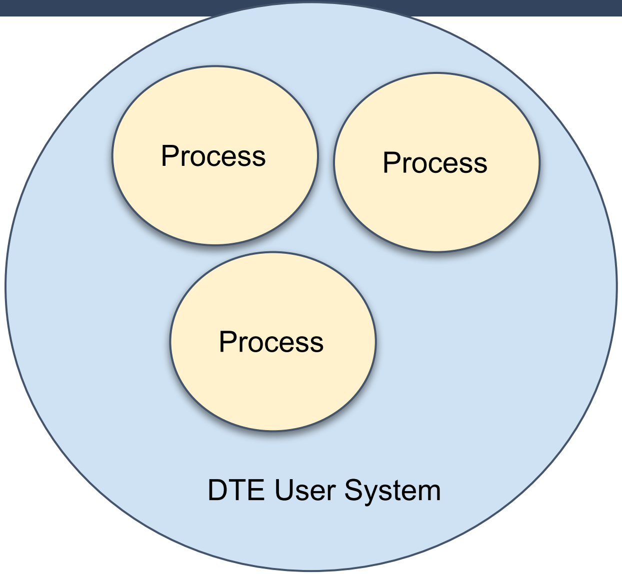


Deconstructing Analysis-Ready Data

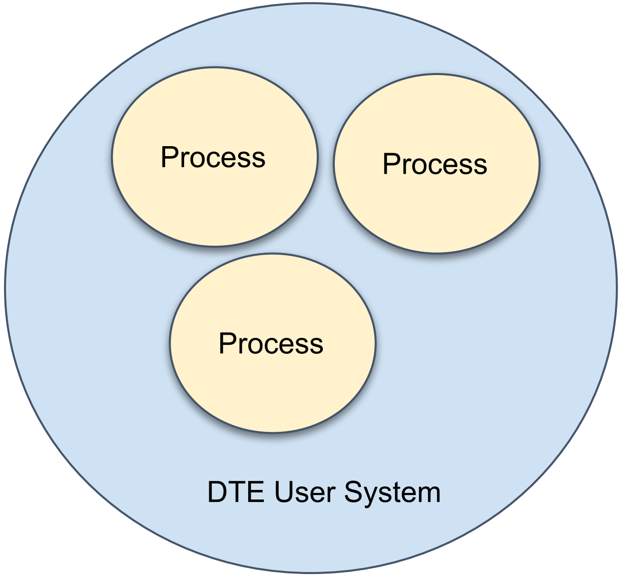
Interop Framework

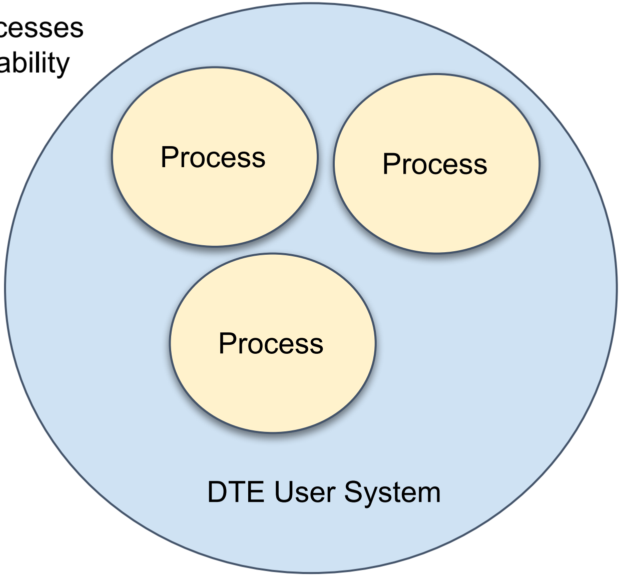


Critical Understanding #1: **Process** as a **Dataset**



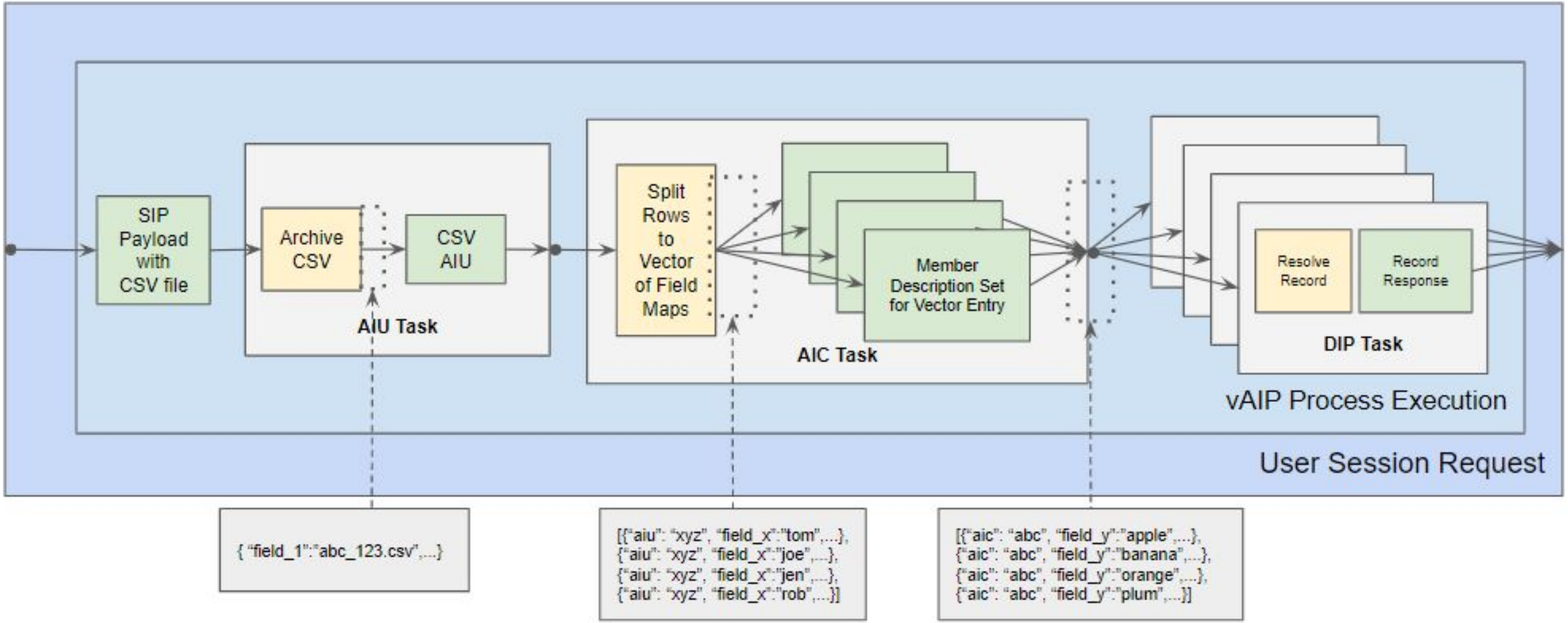
- Process is 'space complete'
- We can describe any system as a set of processes
- Process-as-data enables syntactic interoperability
    - Request/Response/Records



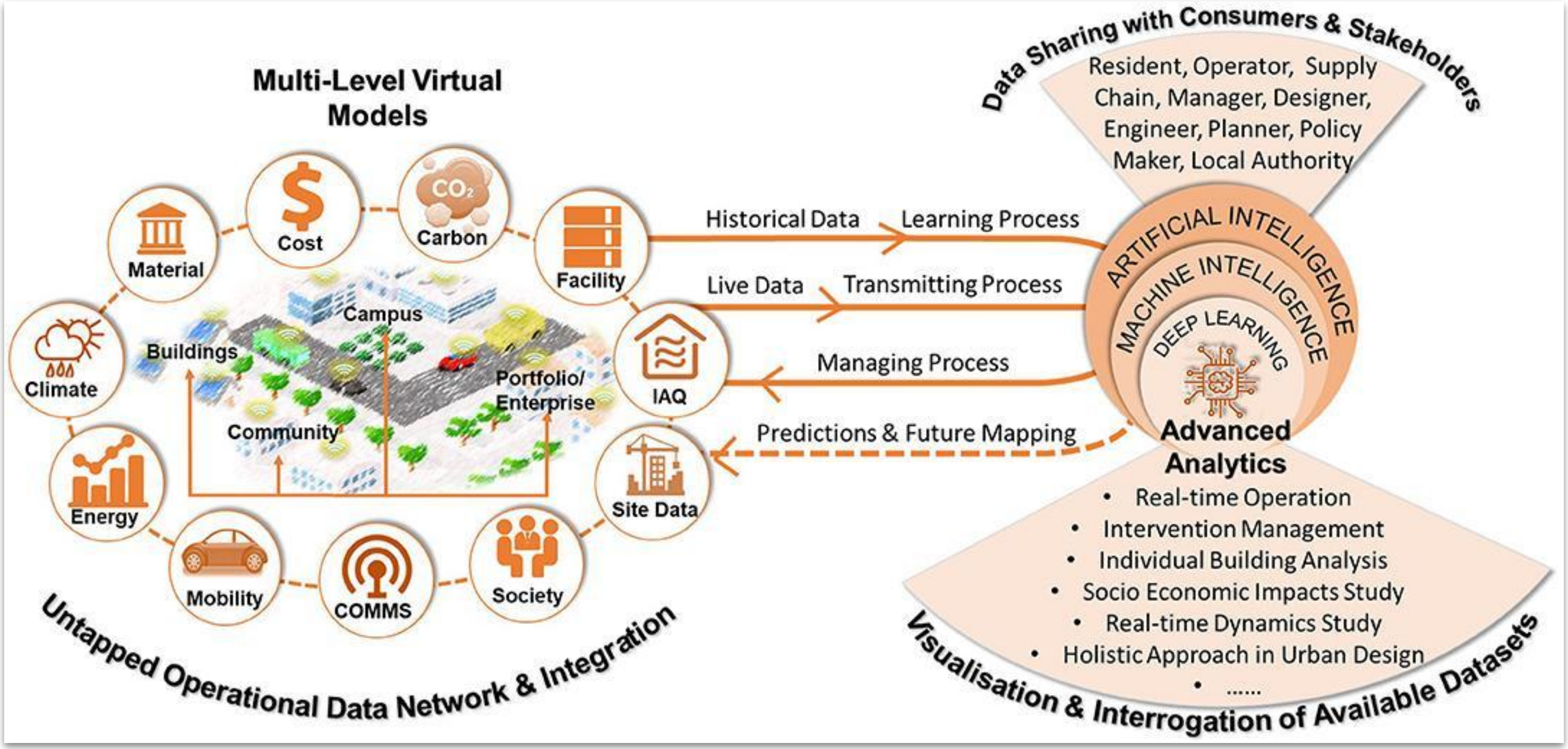


I can **create** processes
I can **share** processes
I can **discover** processes
I can **inspect** processes
I can **evolve** processes
I can **copy** processes
I can **link** processes
I can **process shop**
My machine can do all these things, too!

Illustrative Example - Dynamic Process Provenance



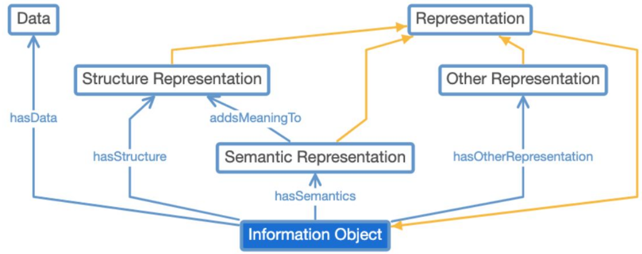
Process Basis for Information Sharing



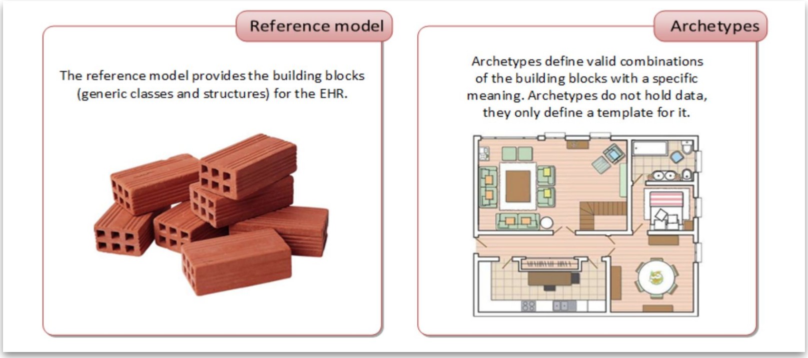
https://www.frontiersin.org/articles/10.3389/frsc.2021.663269/full

Critical Understanding #2: **Semantic Interoperability**

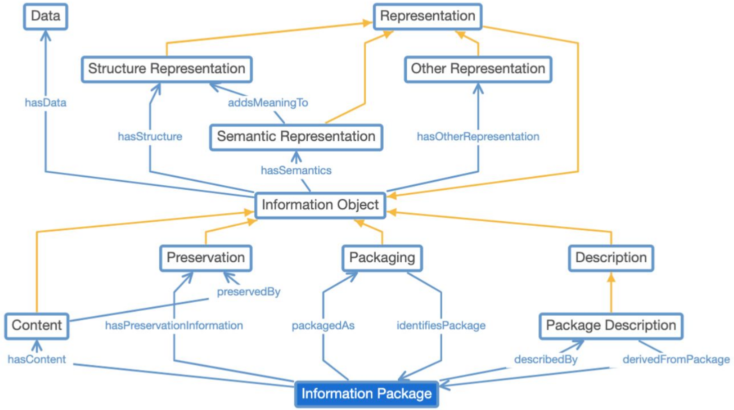
- Process-as-data alone cannot solve interoperability
- Semantic interoperability within a shared reference model is required to enable automated terminology resolution, value transformation, and evolutionary governance
- Critically, Semantic interoperability enables **higher order legal interoperability automation**
- Critically, Semantic interoperability enables decision definition and capture, enabling automated feedback and introduces observability to system improvement



A basic foundational building block - recursive and generic

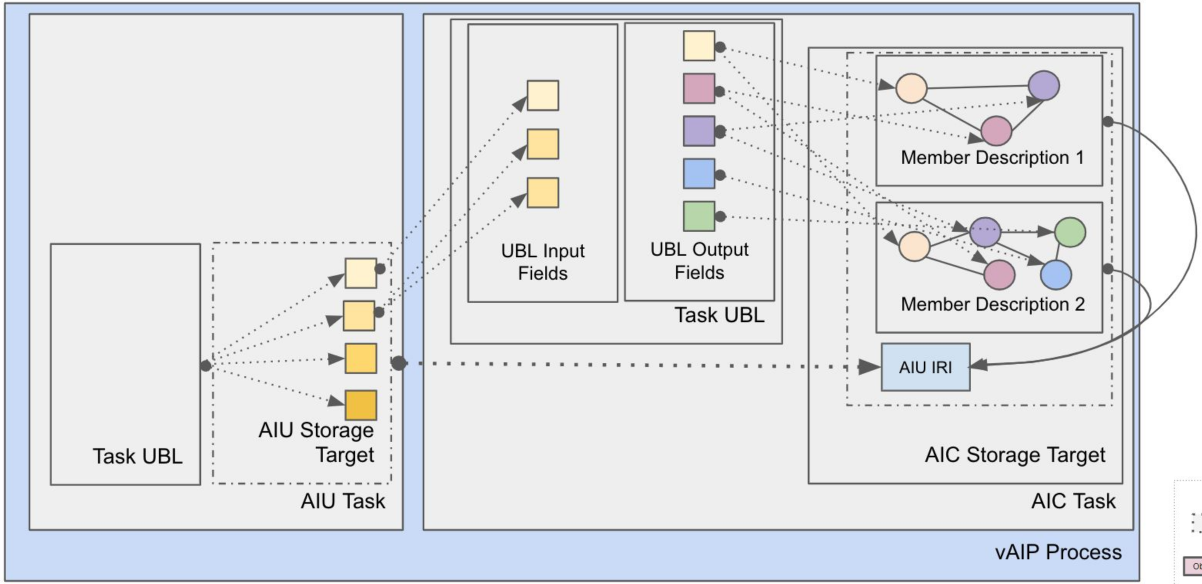


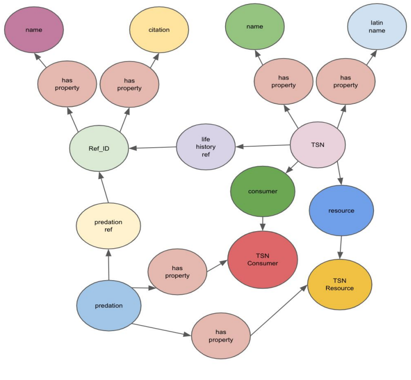
[Archetypes: Constraint-based Domain Models for Future-proof Information Systems]() ISO 13606

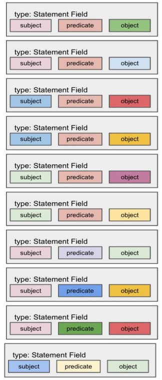


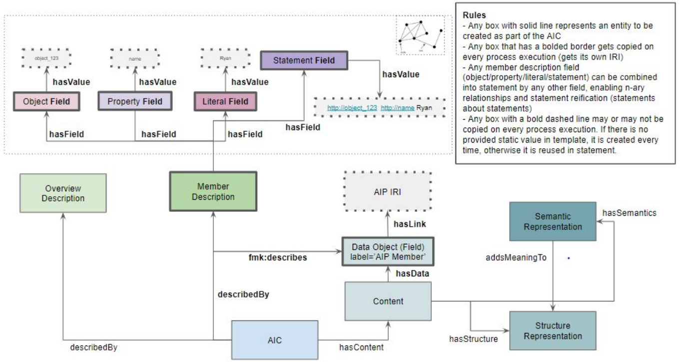
A complete generic model for DTE-FS data

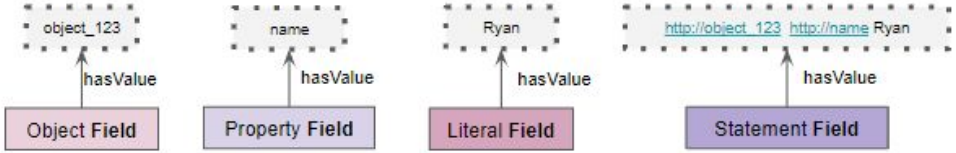
Schematic Interoperability Enables a universal API to Contextualized and Fully Linked Semantic Spaces







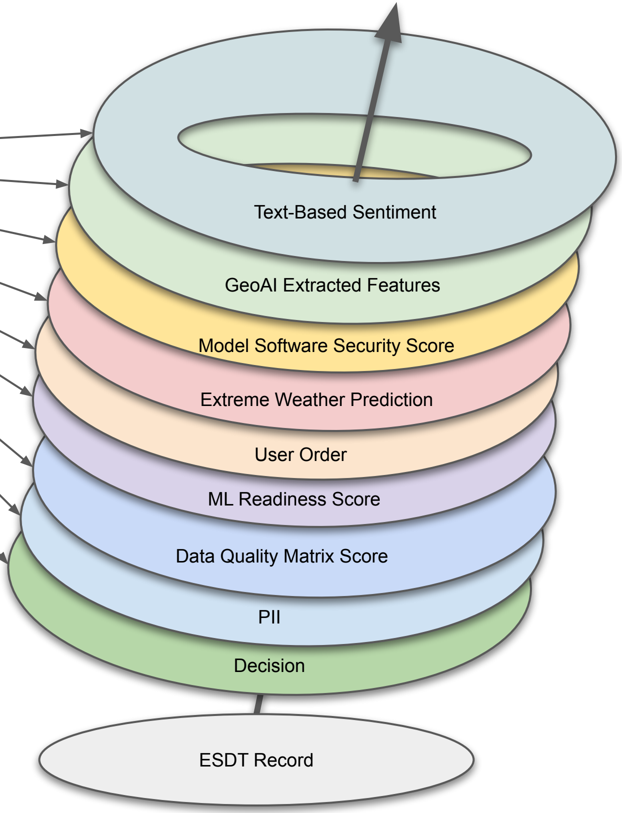




Critical Understanding #3: **Process-Linked, Standards Based, Contextual Information Models**

- Structured KOS
- FAIR
  - Findable
  - Accessible
  - Interoperable
  - Reusable
- CARE
  - Fine-grain access rights
- Knowledge Graph held
- Independent spaces
- API Discovery

- Composing and linking identity, transformation, and delivery tasks that use ontologies available on the semantic web (e.g. SSN, SOSO, Schema.org, SensorML, Dublin Core, GCMD, etc.), and/or make use of newly minted, user defined ontologies
- Root cause analysis
- Full provenance for reproducibility
- Dynamic 'at a distance' composability
- Process shopping
  - Pre-flight cost estimation via describe plans
- Evolutionary plug-and-play



Step Changes to an Interoperable Open OneNOAA

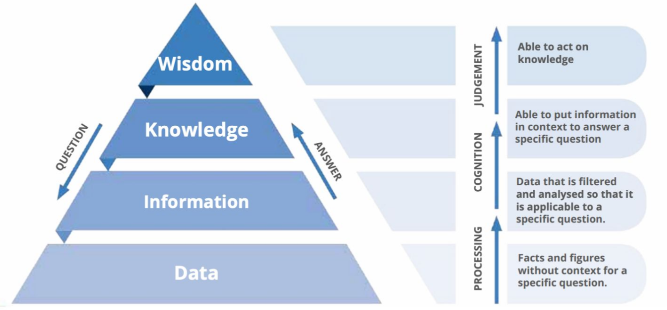
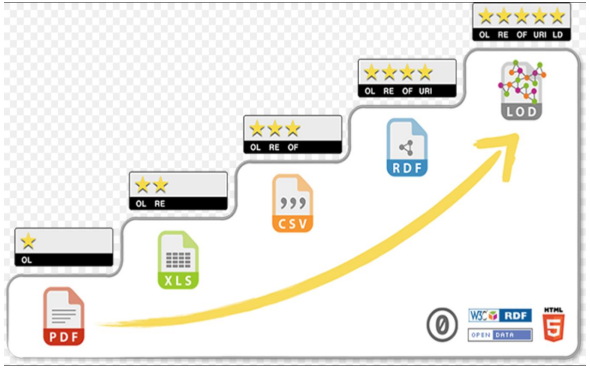


Figure 4. From data to information, knowledge and wisdom. Adapted from DIKW Model for knowledge management and data value extraction.



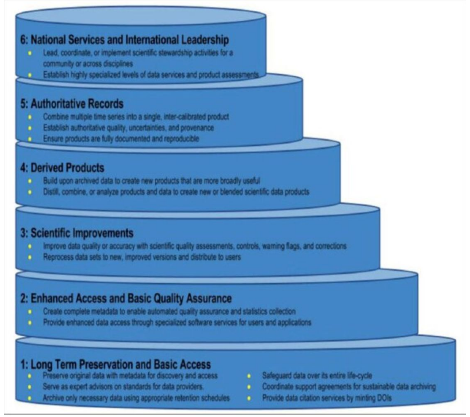
Level 4 - Exemplary Integration - Domain Standards Alignment

Level 3 - Full Integration - Interoperable Information Models

Level 2 - Step Change Integration - Interoperable Resources

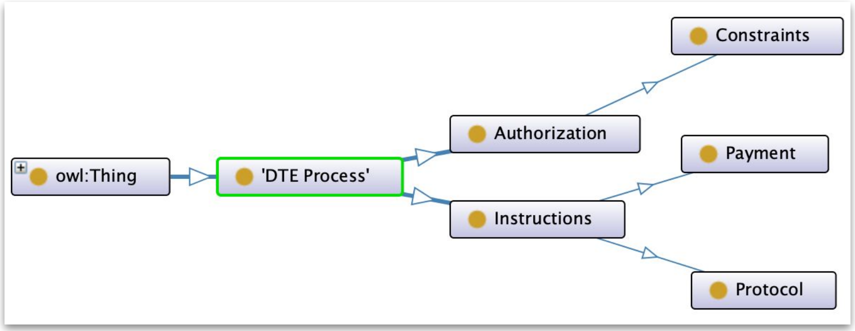
Level 1 - Baseline Integration - Knowledge of Resources

Level 0 - No integration - Baseline NCCF Sandbox Requirements



Critical Understanding #4: **Legal Interoperability**

- This is critical to address communications paradigm shift
- Legal interoperability deals with ability to
    - discover other processes
    - understand access rights of processes
    - understand payment requirements for using processes
    - use processes and pay for them automatically
- Approaching legal interoperability in this way, in combination with a process-as-data view, allows us to federate globally
- Legal interoperability allows us to democratize existing funding models
    - More agile
    - Better results
    - Credit where credit is due
    - Fair use
    - Trusted use



Recommendation - Look at Geoverse as Standards Framework

UN-GGIM Geoverse - Global Vision and Leveling Framework

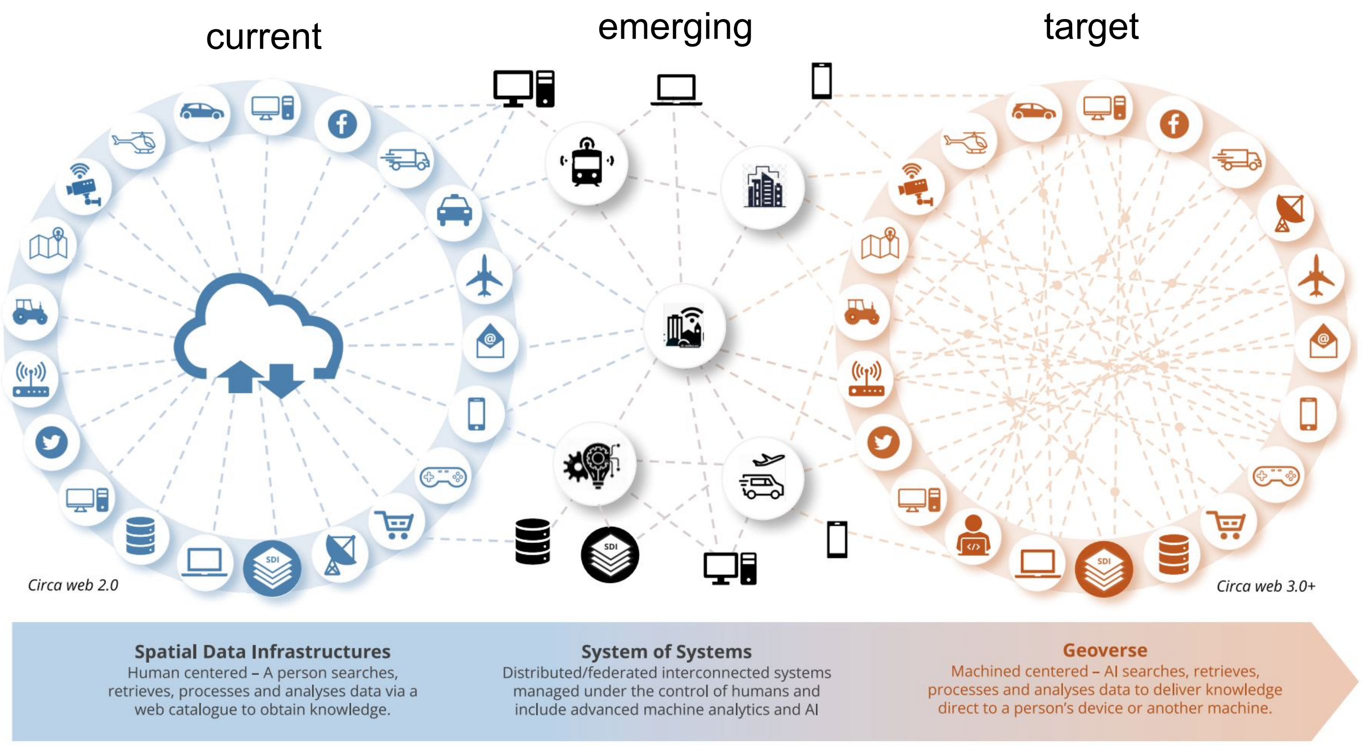


Figure 3. The future geospatial information ecosystem comprising SDIs, SoS and the Geoverse.

[Future Geospatial Information Ecosystem: From SDI to SoS and on to the Geoverse]

- A democratized system of systems powered by machine to machine communication
- An ecosystem in which all users can both consume and contribute information
- A federated framework of universally useful understanding

Backups

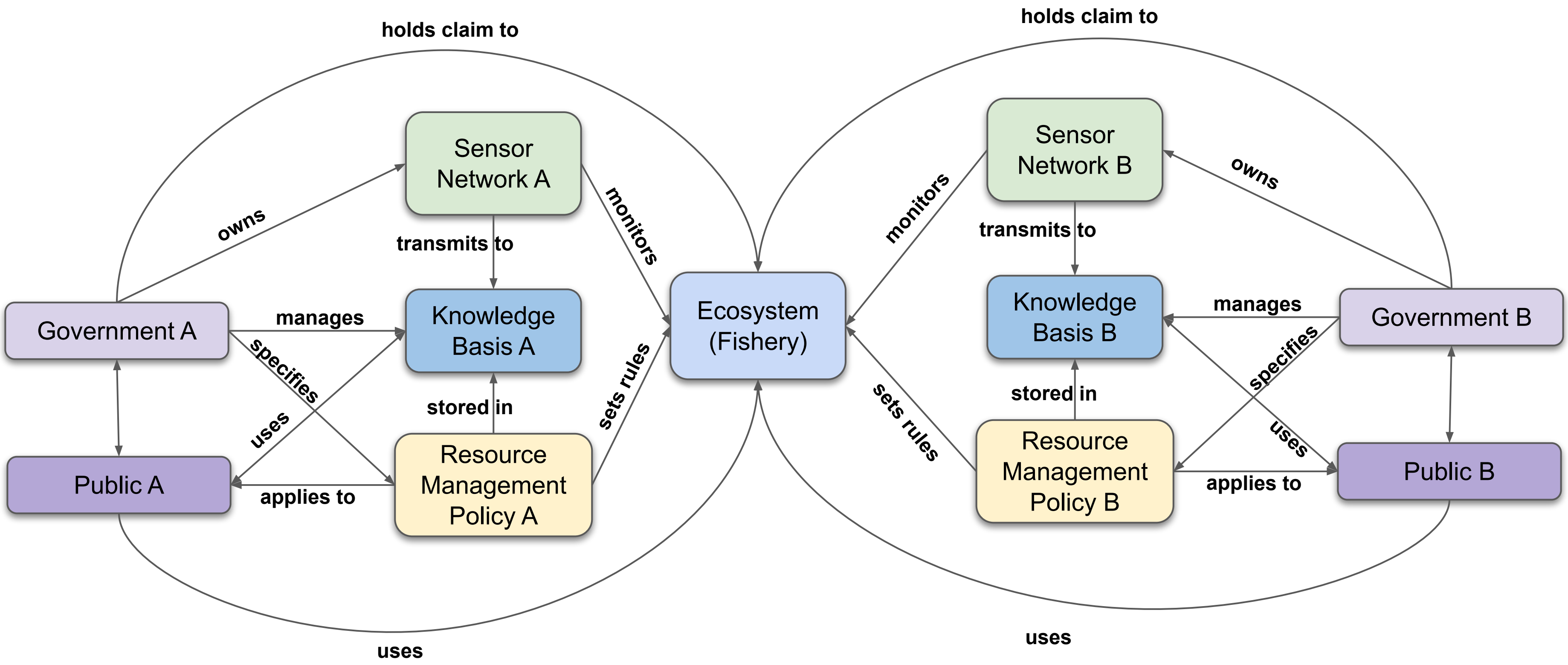
Example

North Star Use Case - Horizon Enablement Opportunities

Government A and **Government B share** the same fishing location and **resources**. Recently, **Government A has noticed an increase in fishing activity** by Government B, **raising concerns about** the **sustainability** of the shared marine ecosystem. **Government A must address** this issue **to ensure responsible resource management**.

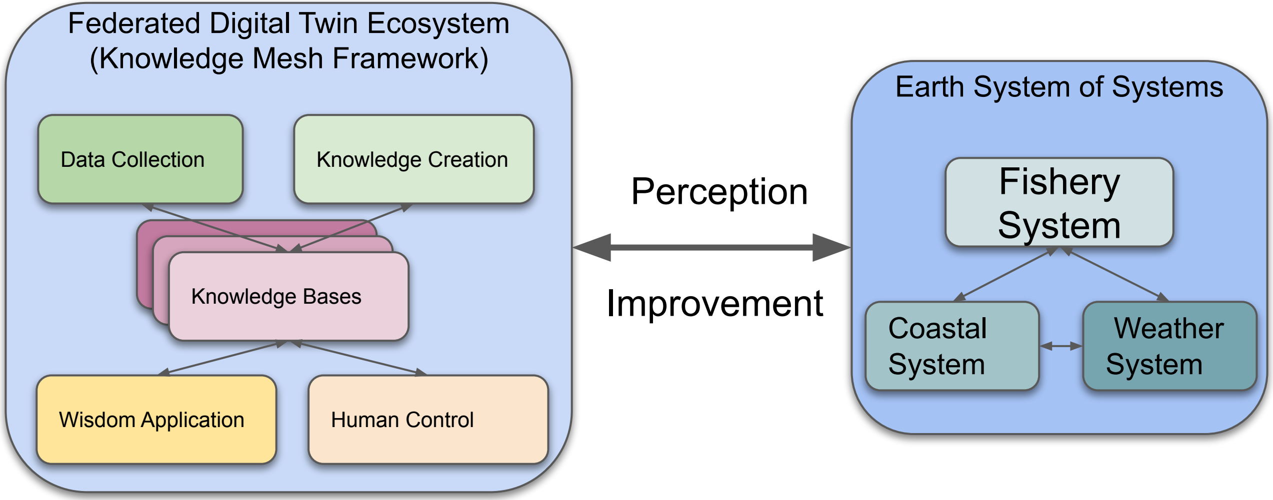
In an optimal future state, the Government A response maximizes internal automation and minimizes uncertainty in actions taken - simulations, sensor reconfigurations, policy updates, and public dissemination performed by machine. If interoperability can be broadened beyond internal systems, Government A and Government B may both benefit from orchestrated and (partially) automated resolution.

Simplified Topology



Capability and Resource Requirements

- **Data Collection**
  - Physical Sensor Networks
  - Fishing Vessel Tracking
  - Pan-Domain Knowledge Contribution
- **Knowledge Creation**
  - Data Integration
  - Environmental Modeling
  - Human Impact Modeling
  - Response Modeling
- **Wisdom Application**
  - Shared Knowledge Mesh
  - Automated Alert System
  - Automated Sensor Control
- **Human Control**
  - Decision making Dashboard
  - Human Intervention
  - Knowledge Consumption
- **Knowledge Bases**
  - Historical Data
  - Ecological Knowledge
  - Adjacent Inferred Knowledge
  - Socioeconomic Knowledge
  - Regulatory Policy Knowledge
- **Improvement of the Earth System**
  - Sustainable Resource Management
  - Ecosystem Preservation
  - Collaborative Governance



Data Collection

- **Physical Sensor Networks**: Both Governments deploy satellite-based and shipborne sensors to collect real-time data on ocean temperature, salinity, chlorophyll levels, and fish stock distribution.
- **Fishing Vessel Tracking**: AIS (Automatic Identification System) data from fishing vessels of both Governments are continuously monitored to track their movements and fishing activities.
- **Pan-domain Knowledge Contributions**: The public, including both domain experts and human users, contribute contextual knowledge of stake and directly or indirectly relevant information (e.g. recreational use patterns, studies on the area of concern, studies on areas coupled to the area of concern, etc.)

Knowledge Creation

- **Data Integration**: The collected data from various sources is integrated into a central repository within each Government's Knowledge Creation Network.
- **Environmental Modeling**: Advanced modeling algorithms analyze the integrated data to create predictive models of fish migration patterns, population dynamics, and potential impacts of increased fishing activity.
- **Human Impact Modeling**: Advanced modeling algorithms analyze the integrated data to create highly contextualized and integrative predictive models of effects on human populations based on environmental modeling scenarios.
- **Response Modeling:** Advanced modeling algorithms analyze outputs from human impact and environmental modeling predictions to suggest courses of mitigation and policy adjustment

Wisdom Application

- **Shared Knowledge Mesh**: Both Governments establish a Federated Knowledge Mesh, securely connecting their Knowledge Creation Networks. This mesh allows the exchange of anonymized data and relevant knowledge while respecting data privacy and sovereignty.
- **Automated Alert System**: A sophisticated automated system continuously monitors the fishing activity of both Governments in the shared location. When the system detects a significant increase in fishing effort by Government B, it triggers an alert to Government A's fisheries management authority.
- **Automated Sensor Control System**: A sophisticated automated system may adjust and reconfigure sensor networks to holistically rebalance monitoring patterns.

Human Control Features

- **Decision-Making Dashboard**: Upon receiving the alert, Government A's fisheries management authority accesses a decision-making dashboard. The dashboard provides an overview of the situation, presenting real-time data, predictive models, and potential implications of increased fishing activity on the ecosystem.
- **Human Intervention**: The fisheries management authority reviews the information provided by the system and decides on the appropriate course of action. They may choose to initiate diplomatic communications with Government B or implement temporary fishing restrictions to safeguard the shared resources.
- **Knowledge Consumption**: All updates captured in the knowledge bases can trigger processes to transform and populate contextual public-side interfaces, including models, websites, and collaborative

Knowledge Bases

- **Historical Data**: The system incorporates historical fishing data to analyze long-term trends and identify patterns of sustainable fishing practices.
- **Ecological Knowledge**: Knowledge bases on marine ecology, fish migration patterns, and ecosystem interactions are essential for developing accurate predictive models.
- **Adjacent Inferred Knowledge:** Knowledge bases for other potentially coupled systems may be leveraged for integrating effect inferences on decision making processes.
- **Regulatory Policies**: Information about existing fishing regulations and international agreements related to resource management is incorporated into the system to ensure compliance.
- **Socioeconomic Knowledge**: Knowledge bases for human stake in the system may be leveraged for aiding in impact response simulations and decision making recommendations

Improvement of the Earth System

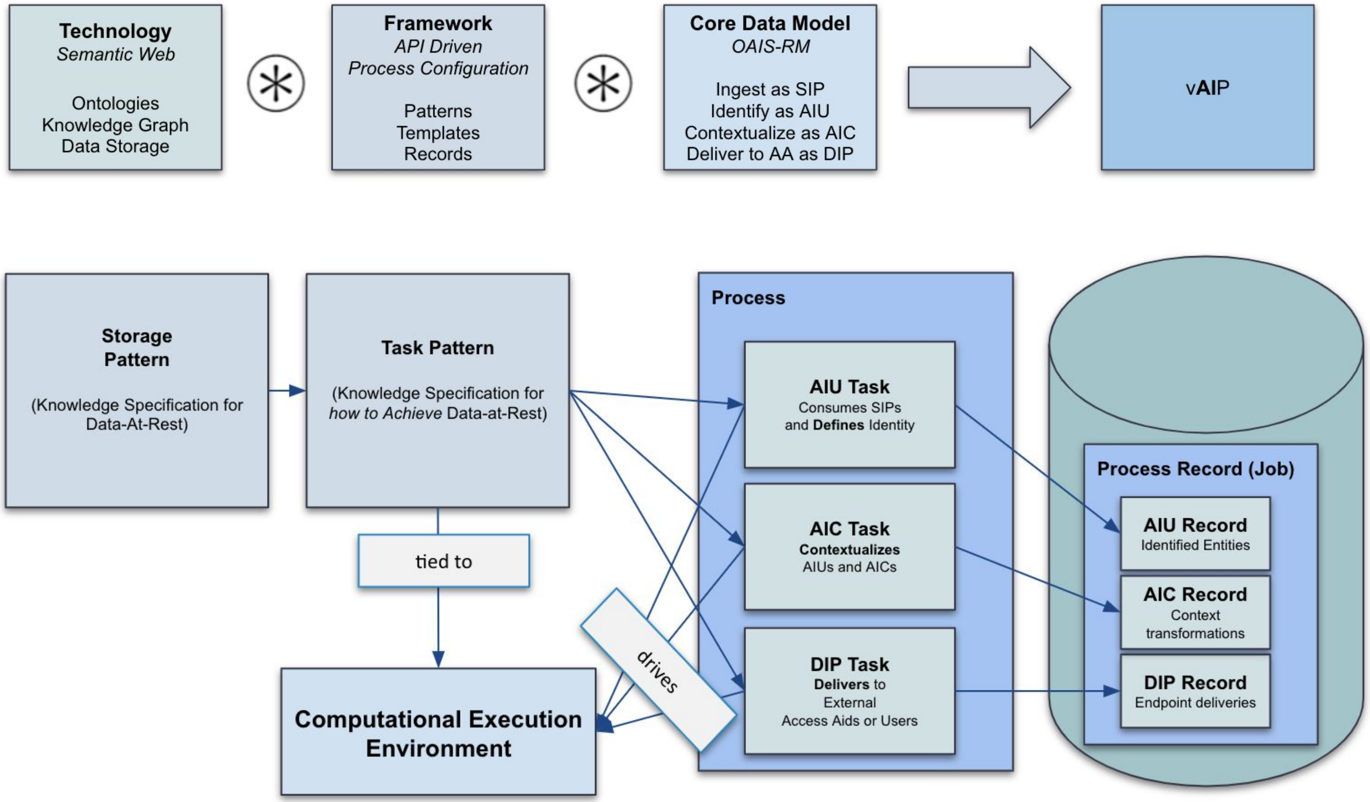
- **Sustainable Resource Management**: By leveraging the Federated Knowledge Mesh, Government A can respond proactively to changes in fishing activity, fostering responsible fishing practices and sustainable resource management.
- **Ecosystem Preservation**: The automated system and predictive models help identify potential threats to the marine ecosystem, enabling timely interventions to prevent overfishing and preserve biodiversity.
- **Collaborative Governance**: Through a Federated Knowledge Mesh, Governments A and B foster collaboration, data sharing, and transparent decision-making, laying the foundation for effective cross-border resource management.

Simplified Concept of Operations

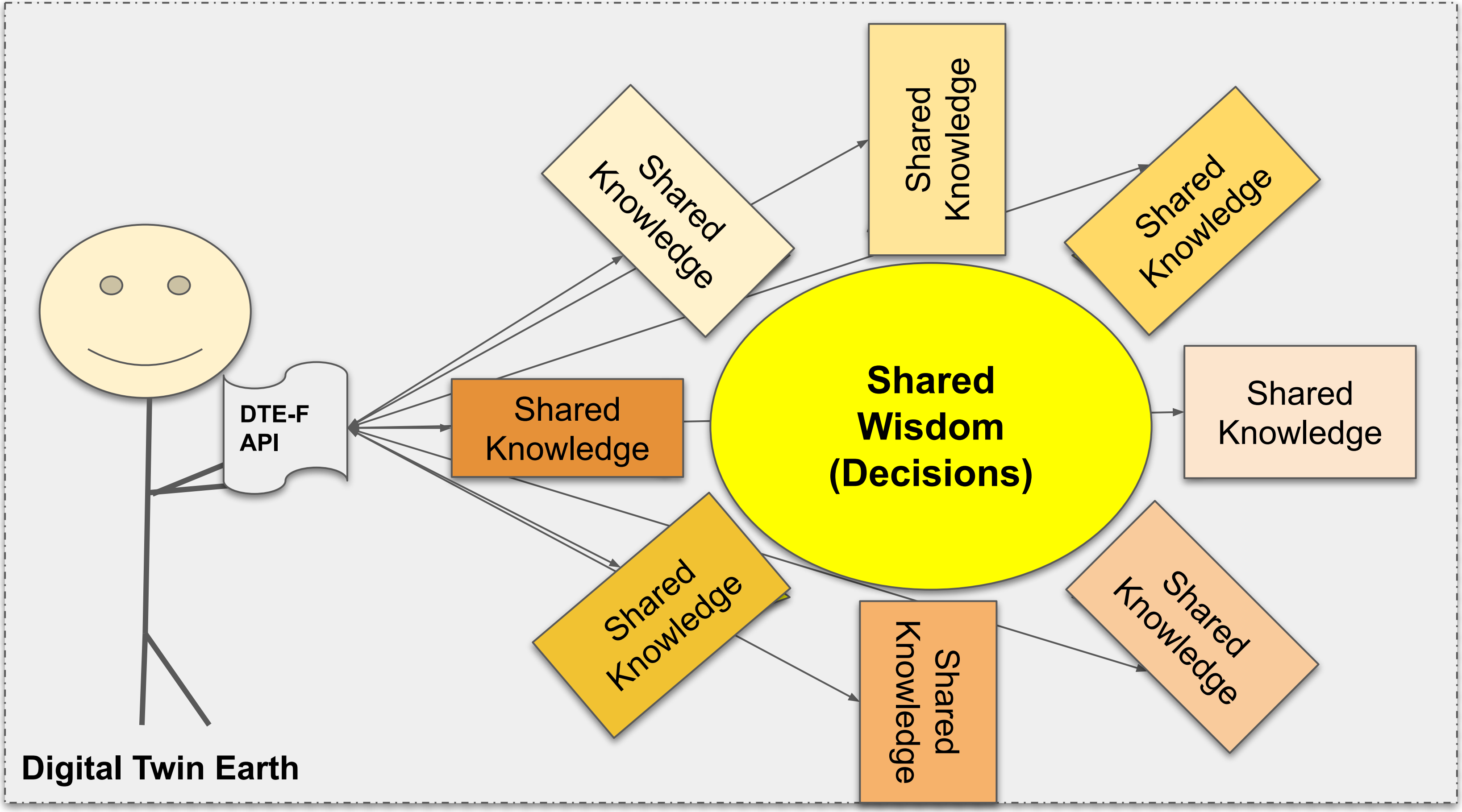
- **Various physical sensor networks** are deployed to gather data from spaceborne, airborne, and ground-based sensors. These sensors continuously monitor weather patterns, seismic activities, ocean currents, and more, generating vast amounts of real-time data.
- **The collected data is transmitted to Knowledge Creation Networks**, where sophisticated algorithms, AI-driven analysis tools, and human experts process the information. These networks combine and transform raw data into actionable insights, such as identifying potential disaster hotspots, predicting storm trajectories, assessing earthquake risks, identifying and adjusting to fishing system changes, etc.
- Through the Federated Knowledge Mesh, the **generated knowledge is shared in near real-time** with all partner agencies and their users. In a disaster scenario, this interconnected ecosystem allows instant access to critical information for all stakeholders involved in the response efforts.
- **Automation and Adaptation**: With the Federated Knowledge Mesh, the system can automatically respond to changing conditions. For instance, if a severe storm unexpectedly changes direction, the sensor networks can dynamically reconfigure to focus on the new threat area. This adaptation is based on near real-time published policy adjustments and mission needs, ensuring an agile and responsive disaster response.
- **Holistic Human Wisdom**: By adhering to FAIR and CARE principles, decision-makers have confidence in the accuracy and reliability of the shared knowledge. This holistic human wisdom enables better-informed decisions, leading to more effective disaster response strategies and improved coordination among agencies.

Miscellania

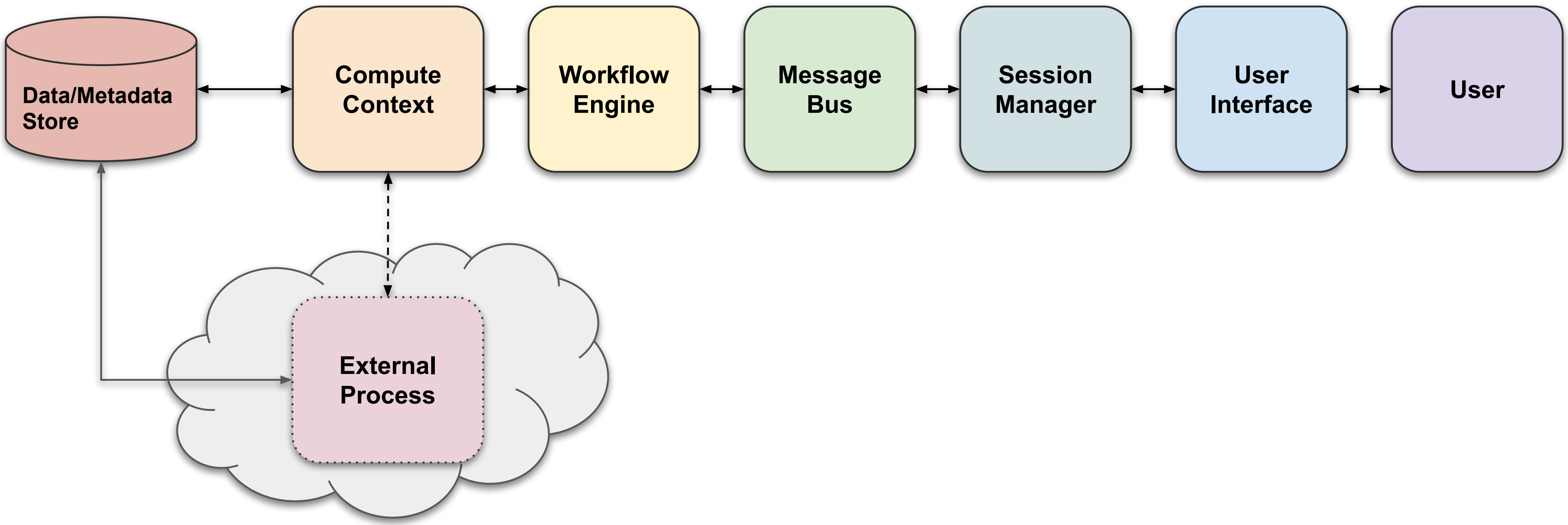
Trainable Workflow-Focused **Knowledge Graph** Architecture



Framework **API** - Syntactic Gateway to Semantic Interoperability



Evolved Compute Architecture for the Interoperability Framework (2023)



source: New Cloud Archive Fundamentals

Opportunities - Everything as Data in a Process Framework enables Democratic Participation (Contribution and Consumption)

LLMs and Multi-Modal Models as Front Ends for Framework-Driven Federated Models

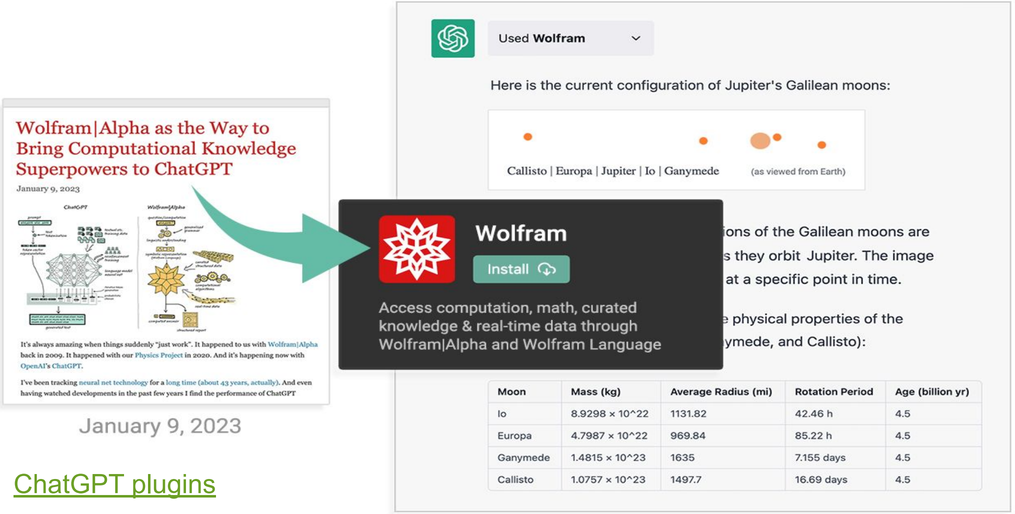
“Hey interface, can you tell me where I should plan a camping trip next spring? I want to see some rare blooms and don’t want to have any risk of rain. Please plan my itinerary and draw me a map on how to get there and get around.”

“Hey interface, can you tell me what potential 50-100 year climate impacts this border wall policy might have if it’s implemented and all other things remain the same?”

“Hey interface, we have a looming RFI problem due to 6G/7G. What are some solutions to how to collect NWP data? What might happen if uncertainty rose by 10%?”

ChatGPT Gets Its “Wolfram Superpowers”!

March 23, 2023



Moon	Mass (kg)	Average Radius (mi)	Rotation Period	Age (billion yr)
Io	8.9298 × 10^22	1131.82	42.46 h	4.5
Europa	4.7987 × 10^22	969.84	85.22 h	4.5
Ganymede	1.4815 × 10^23	1635	7.155 days	4.5
Callisto	1.0757 × 10^23	1497.7	16.69 days	4.5

January 9, 2023

March 23, 2023

[ChatGPT plugins]

[ChatGPT Gets Its “Wolfram Superpowers”!]

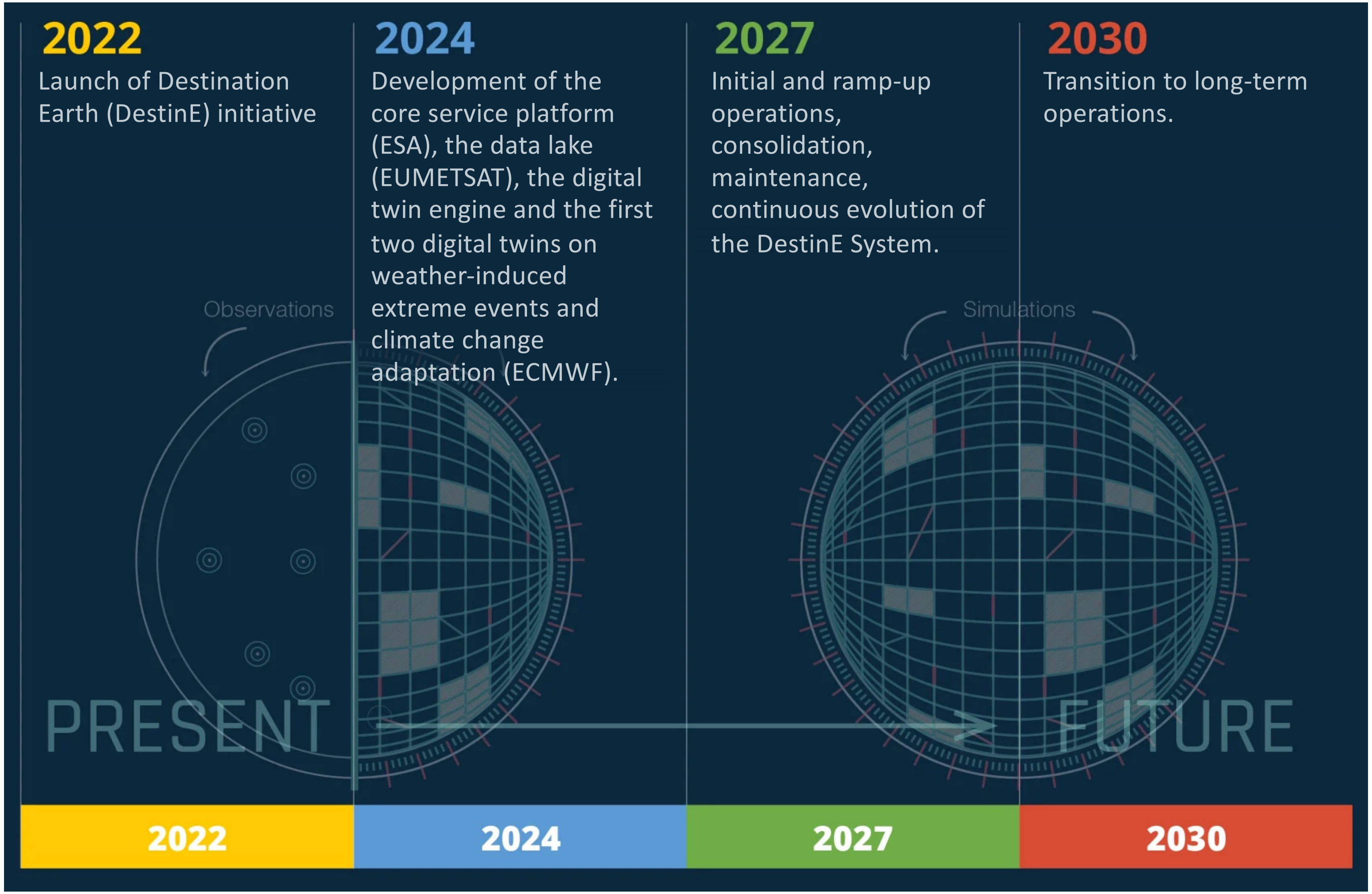
[LLM’s Closing the KG Gap. I have been doing successful knowledge… | by Dean Allemang | Mar, 2023 | Medium]

DESTINATION EARTH INTEROPERABILITY

Thomas Geenen etal.

Funded by the European Union Destination Earth implemented by ECMWF esa EUMETSAT

Implementation: Phasing and Responsibility



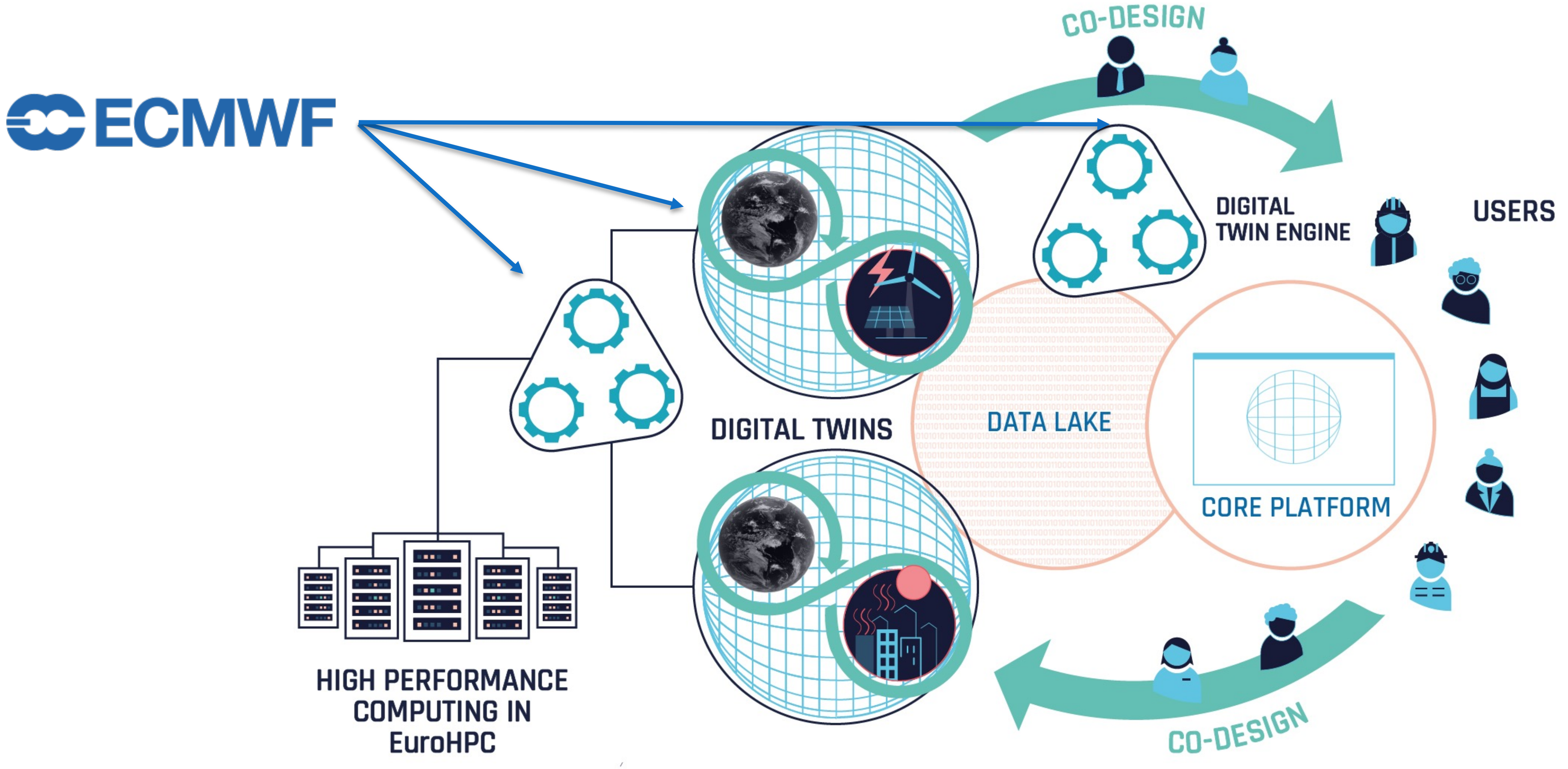
Entrusted entities

ECMWF
esa
EUMETSAT

Key elements

- Digital Twin Engine
- Digital Twins
- Data lake
- Core platform

KEY COMPONENTS OF DESTINE, ECMWF ROLE



DIGITAL TWINS

Two high-priority Digital Twins

Weather-induced **Extremes**

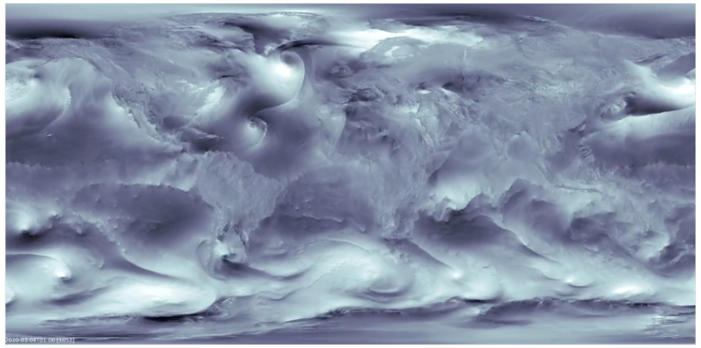
- Support disaster risk management
- **Continuous** and **on-demand** configurations
- **High-resolution** (~2-4km) to sub-km regionally, 2-5 days ahead
- Implemented by ECMWF and a consortium led by Meteo France

Climate adaptation

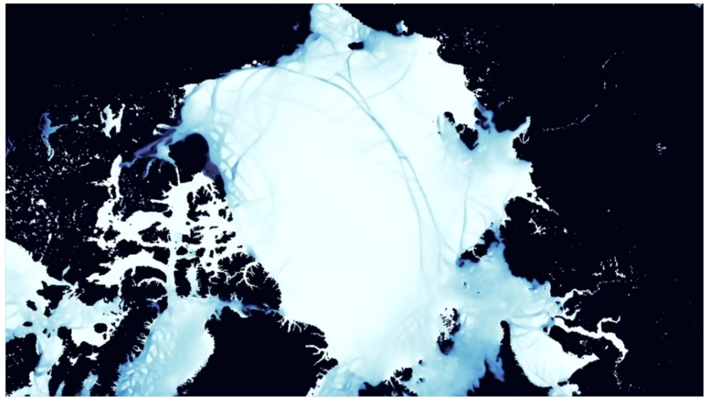
- Support Climate adaptation
- **Regular** climate simulations
- **High-resolution** (~5km), multi decadal timescales (2040/50)
- Implemented by a consortium led by CSC, contracted by ECMWF

DIGITAL TWIN FEATURES

QUALITY

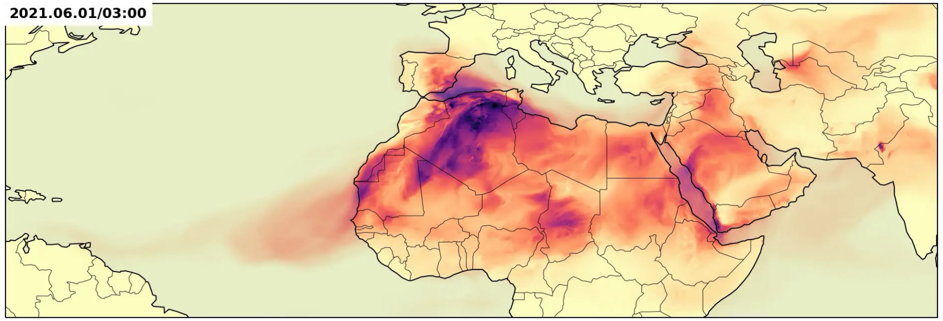


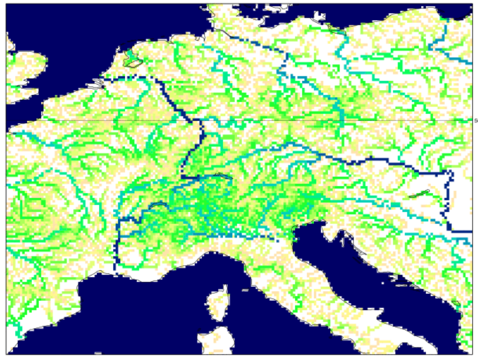
More realistic at global scale



More realistic at local scale

IMPACTS

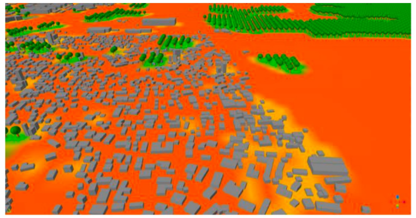




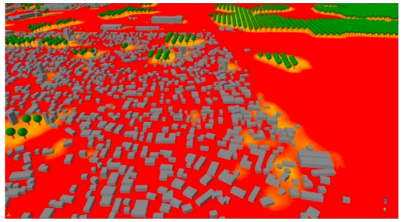
Include impacts where they matter

INTERACTIVITY

City A in a +2 world



City A in a +4 world

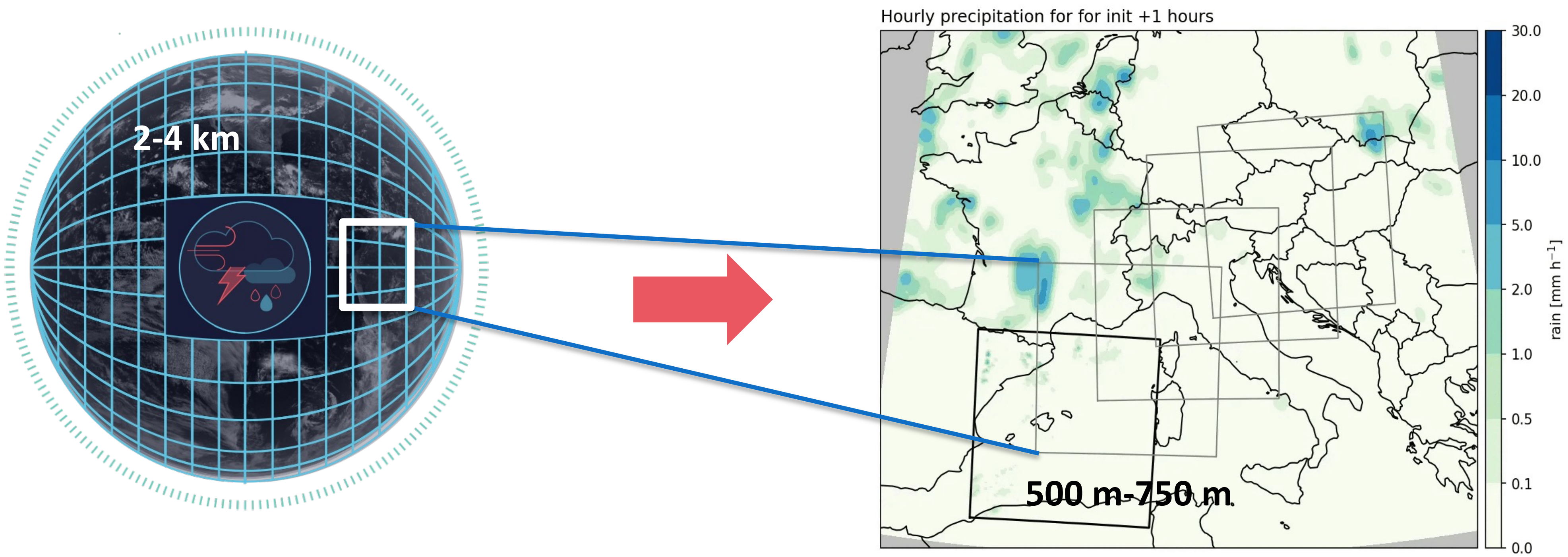


Trial different scenarios

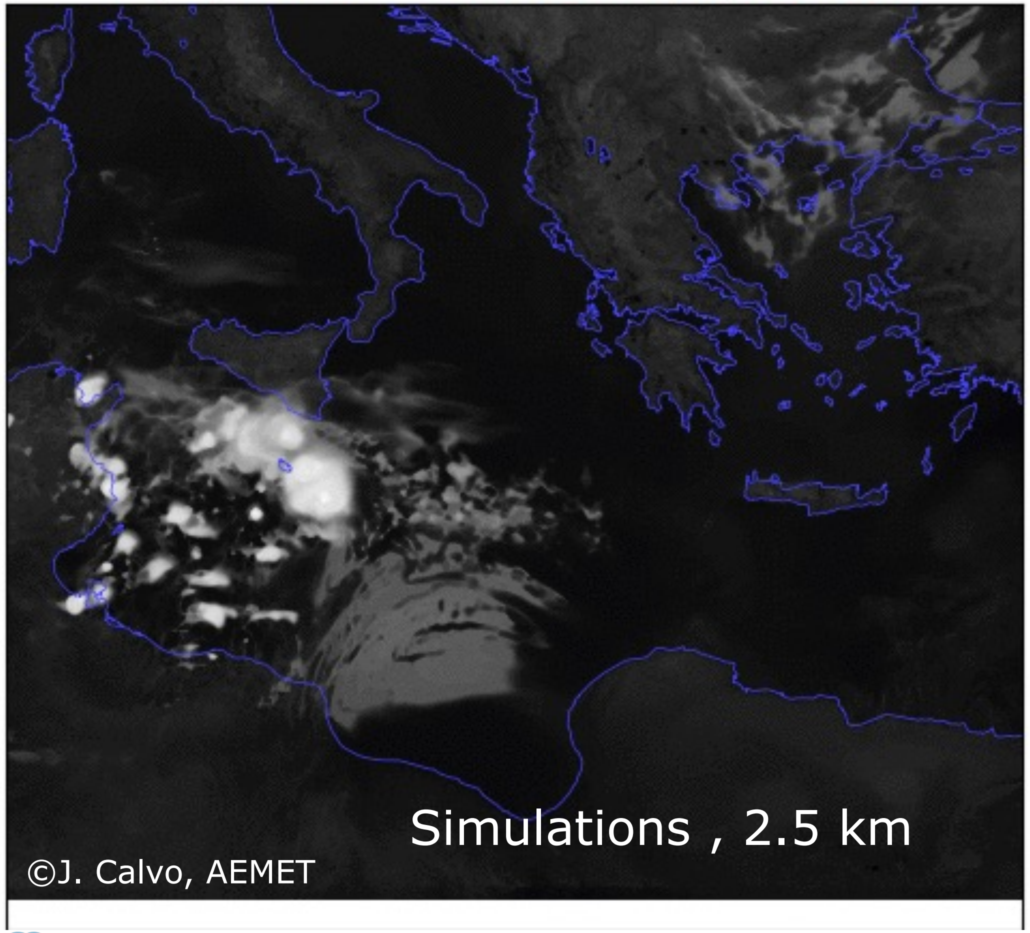
EXTREMES DT: CONTINUOUS AND ON DEMAND

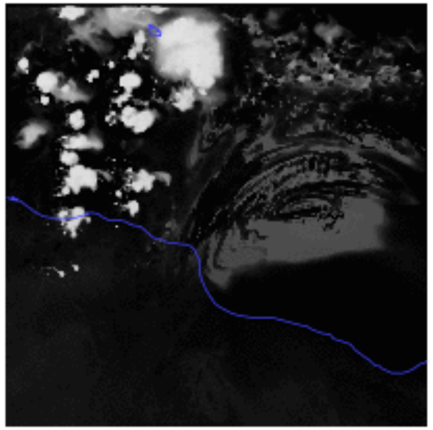
Continuous global component

On-demand regional component



ON-DEMAND EXTREMES DT

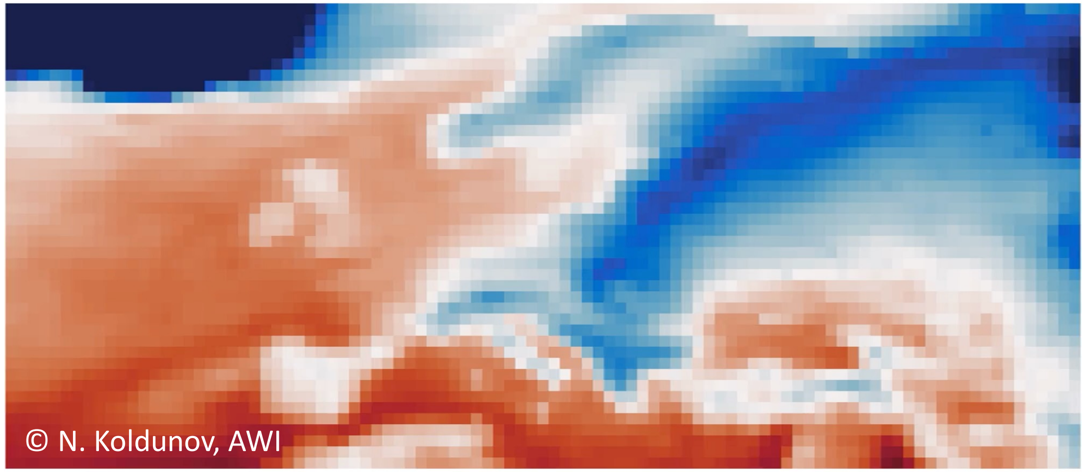




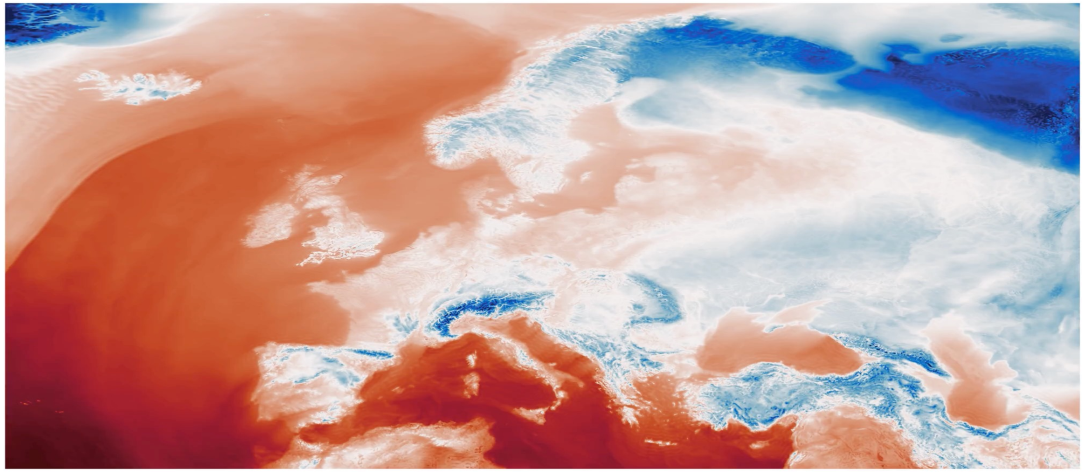
simulations, 500m

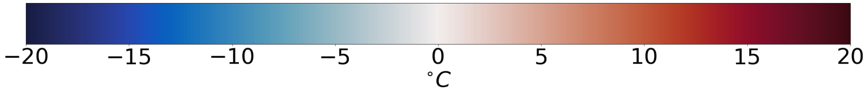
GLOBAL INFORMATION WITH LOCAL GRANULARITY

IPCC AR6 (2021), 100km

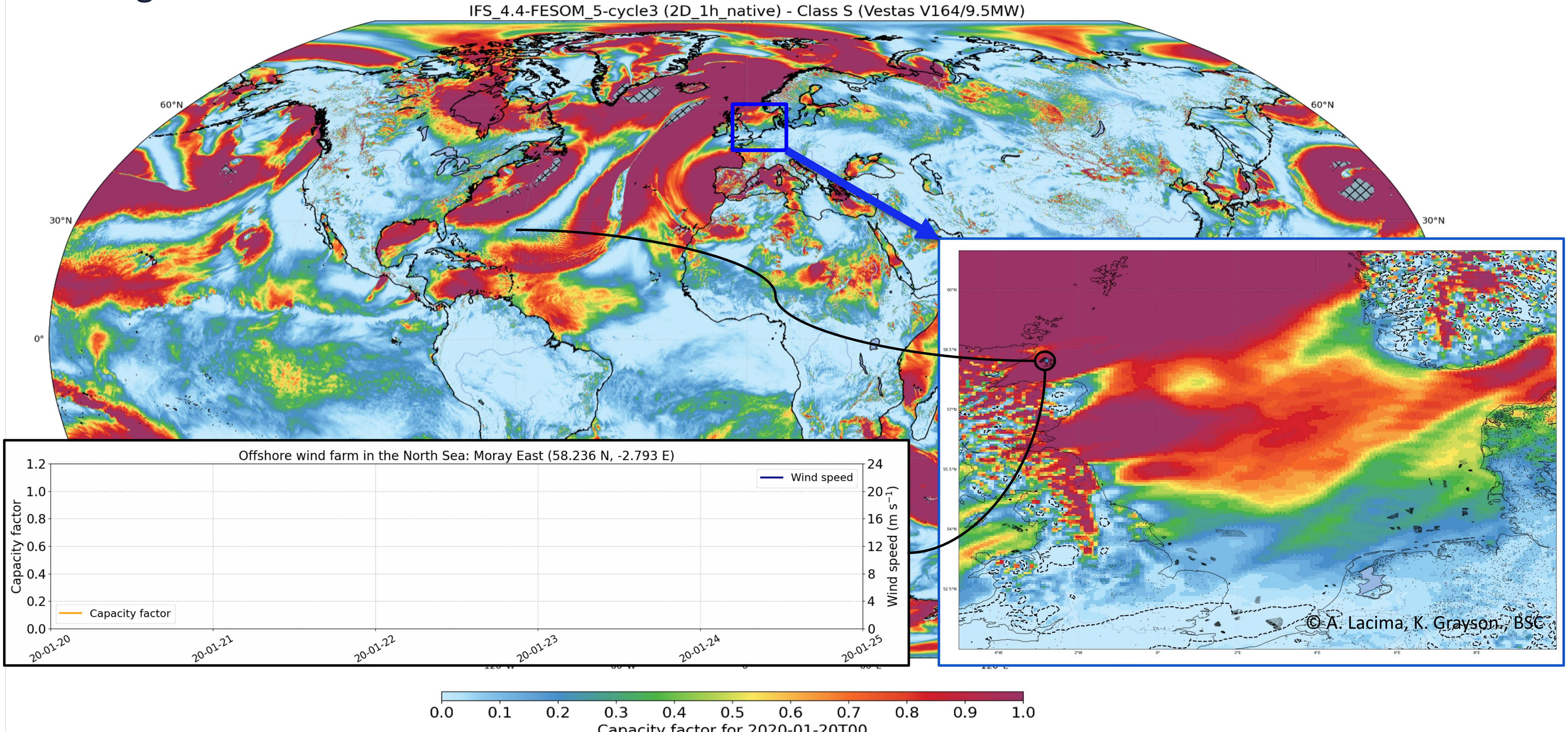


Digital Twin, 5km



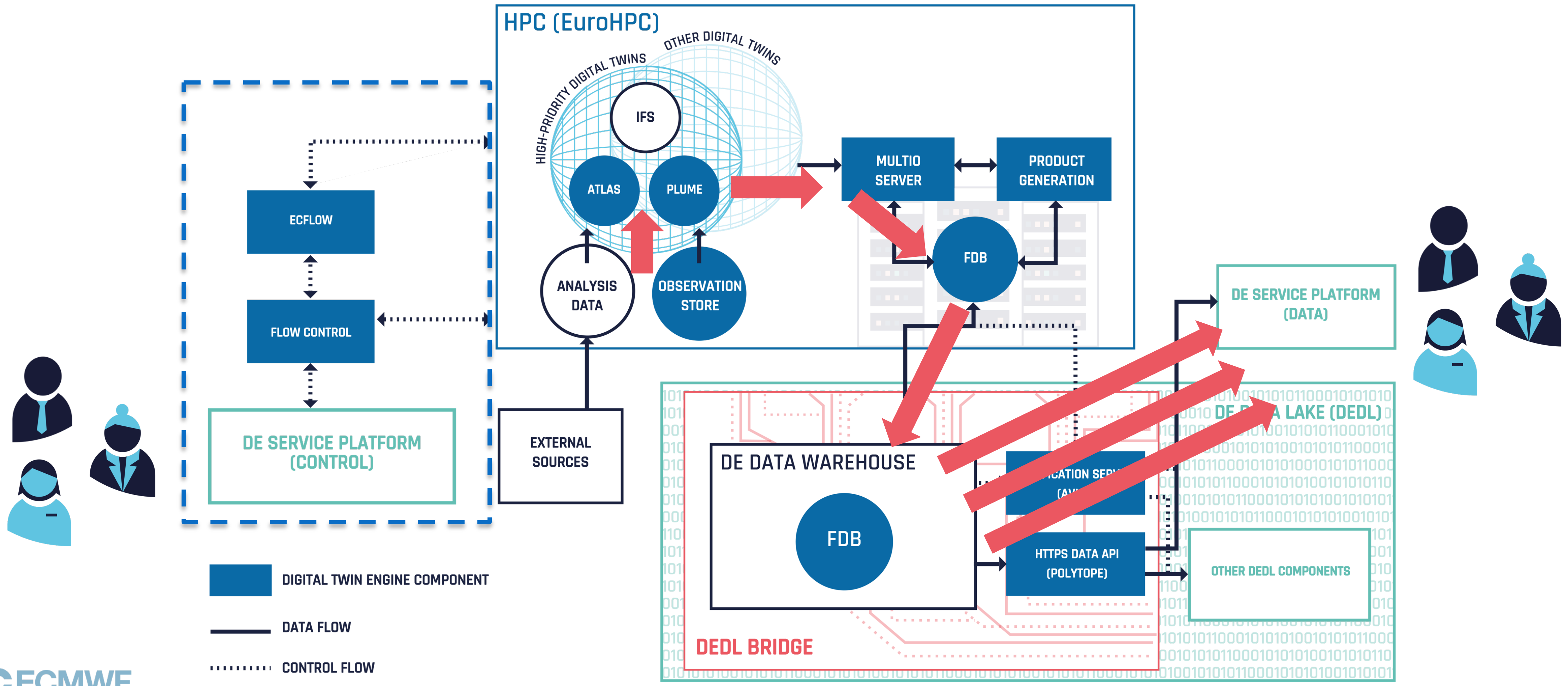


Tailoring the information to user needs



DIGITAL TWIN ENGINE INTEROPERABILITY

RUNNING DTS & MANAGING BIG DATA



Different types of Integration

Full Integration mode
Directly integrated in the DestinE simulation and data handling system

Coupling mode
Integrated in a workflow where Digital Twins have their own simulation and data fusion tasks interfacing with DestinE

Post-processing mode
Integrated as data post-processing application without own Earth-system simulation

Integration continuum

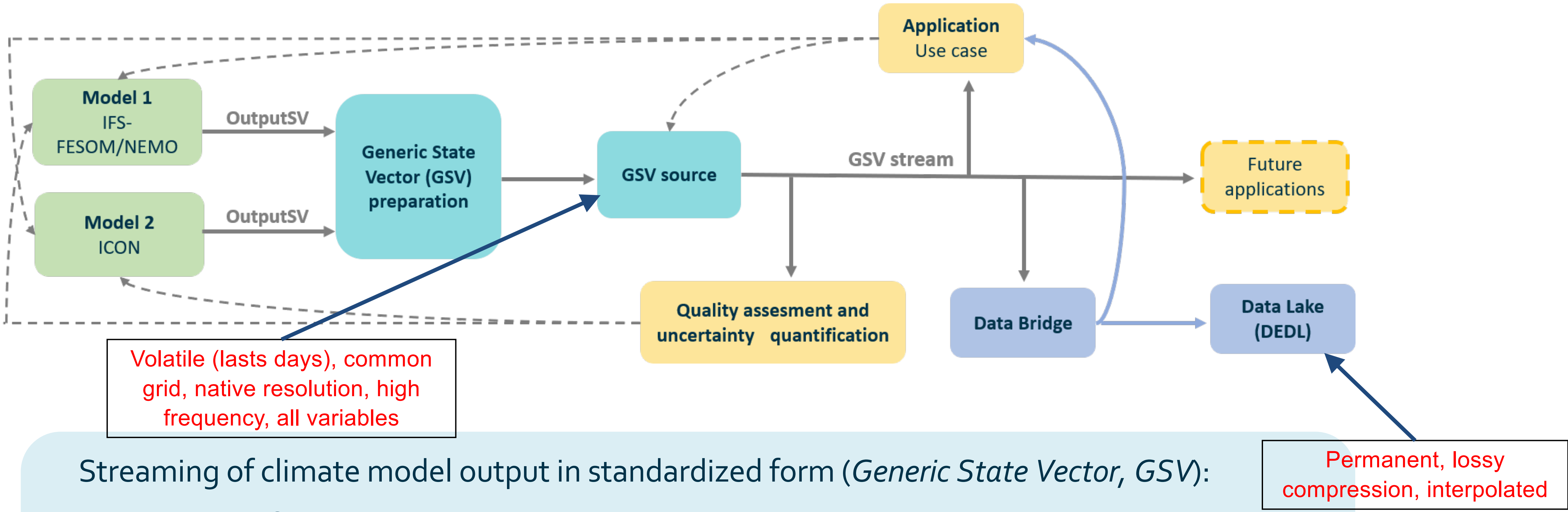
Use DTE
Workflow management, HPC and data handling software infrastructures

Compatible with DTE
Workflow management, HPC and data handling software infrastructures

Weak DTE coupling
independent Workflow management, data management support

DTE in the background
implicit data handling software infrastructure use By the end user from the DESP

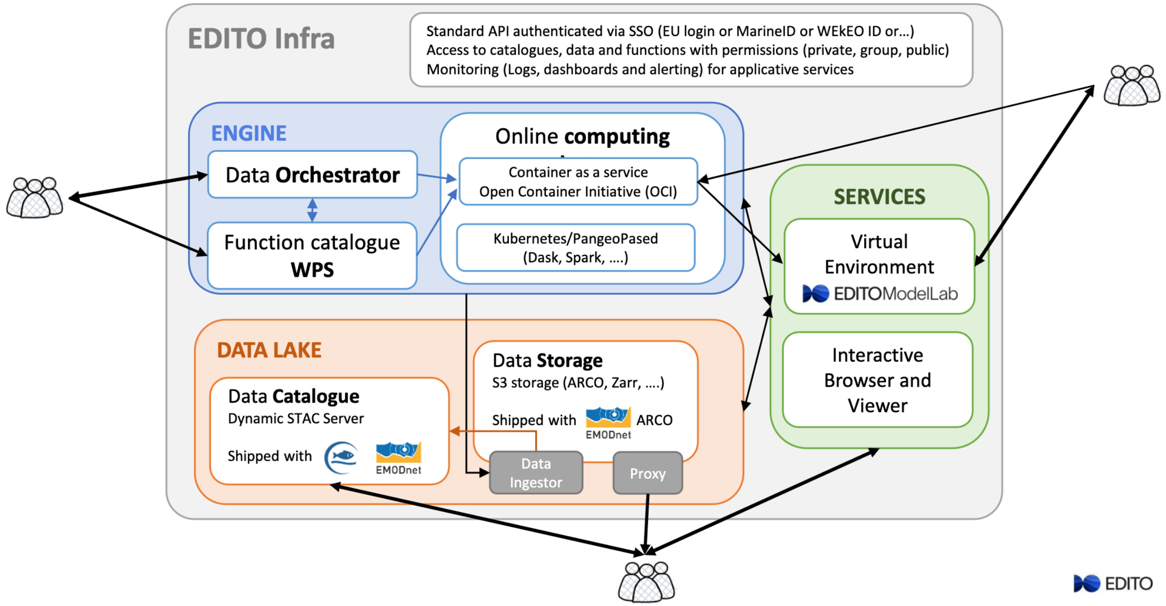
Climate DT – a novel workflow

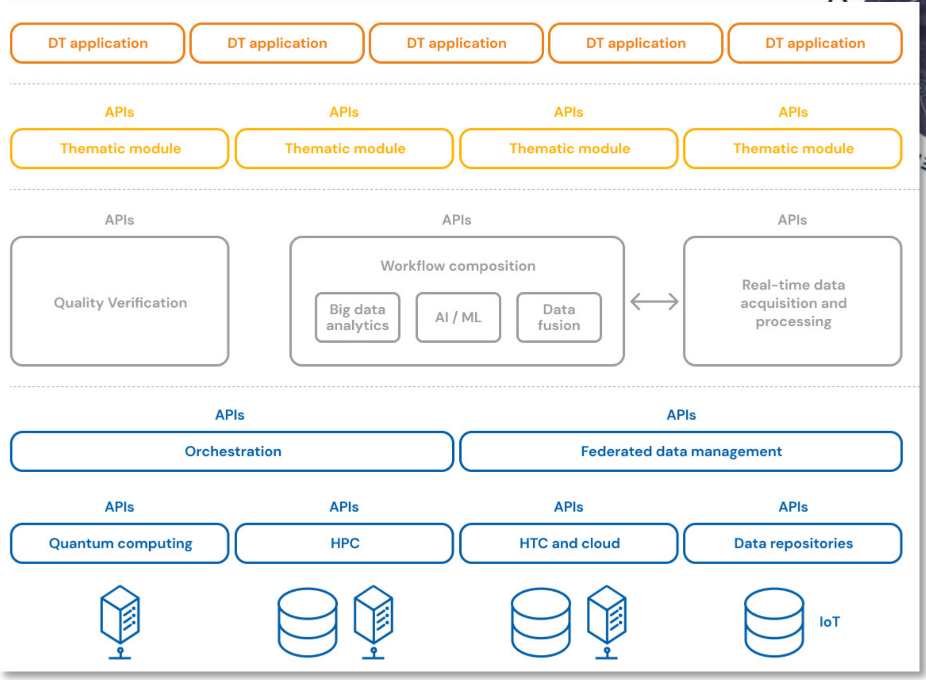


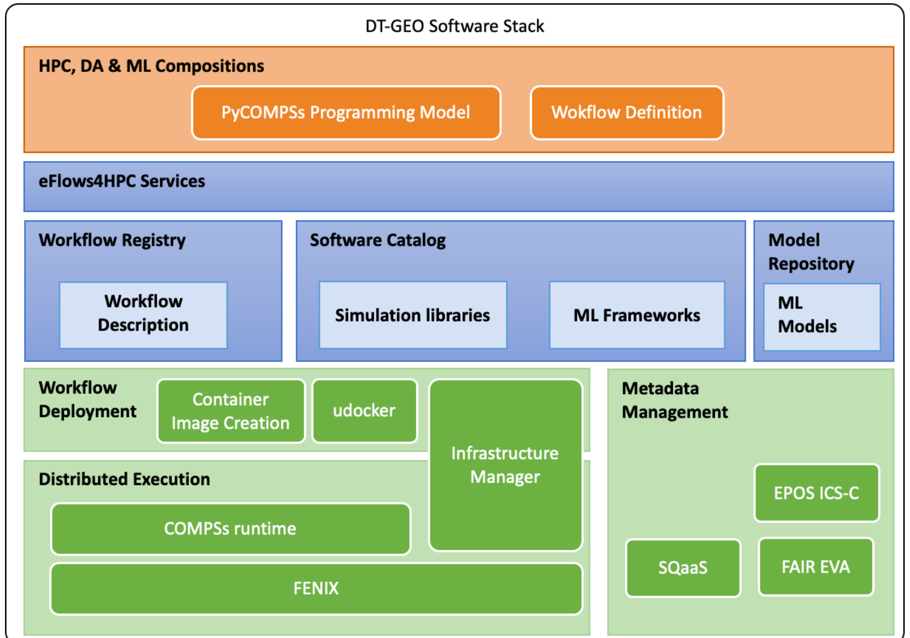
Streaming of climate model output in standardized form (*Generic State Vector, GSV*):

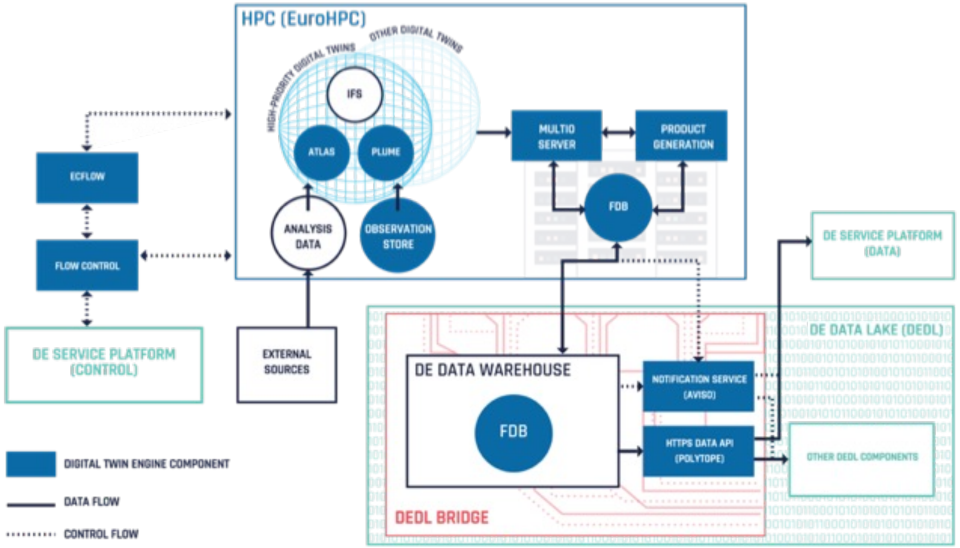
- **access the full model state** as soon as it is available
- **scalability** – new applications can be added
- (**interactivity** – in future phases users may request simulations based on their needs)

Digital twin Engine architectures in Europe









ed by the
ean Union

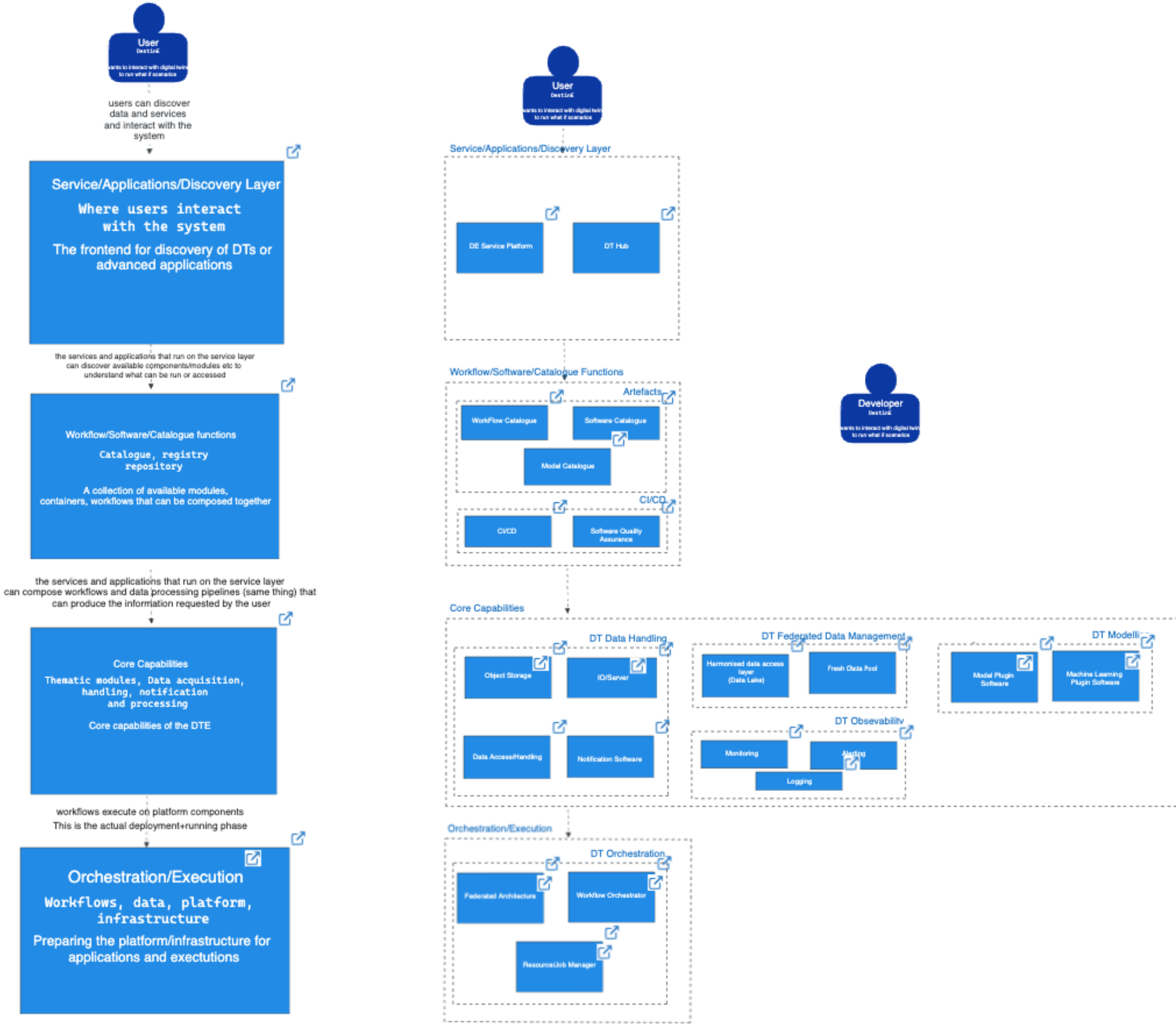
Common architecture language

Technology transfer between DT projects

Driven by the European commission
DG-CNECT (Digital Europe program)

Work with Horizon Europe funded projects
To allow for
- Integration
- Interoperability

Select usecase for each project
Run integration and interoperability pilots




Second Destination
Earth User eXchange
13–14 November
Bonn, Germany
Registration open
destination-earth.eu/event/2nd-destination-earth-user-exchange/
Funded by
the European Union
Destination Earth
implemented by
ECMWF
esa
EUMETSAT

SINTEF

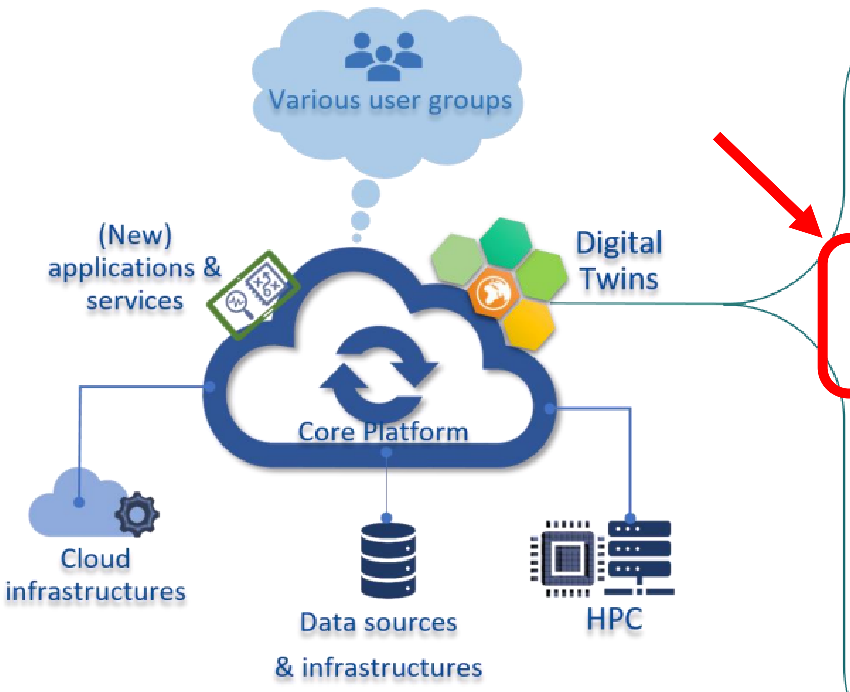
STANDARDS FOR INTEROPERABILITY WITH FEDERATED ILIAD AND EDITO DIGITAL TWINS OF THE OCEAN AND EARTH

Enabling Semantic Interoperable Digital Twins through Data Spaces, Data Lakes and relevant APIs and Ontologies - with IoT and AI technologies – ISO SC41 IoT and Digital Twin, ISO SC42 AI and Big Data, DTC, IEEE, OGC and ISO TC211

Arne.J.Berre@sintef.no, ISO 19119 (editor), September 18th, 2023

DestinE baseline architecture & DTs

Projects in progress with ESA + ECMWF, EUMETSAT, ..



Digital Twins

1. Weather-induced and Geophysical Extremes
Environmental extremes at very high spatial resolution and close to real-time decision-making support (e.g. floods, wild fires, hurricanes, earthquakes, volcano eruptions)

2. Climate Change Adaptation
Climate change adaptation policies and mitigation scenario testing at decadal timescales aiming at a real breakthrough at the level of reliability at regional and national levels, for understanding the causes and explaining the feedback mechanisms of change, predicting possible evolution trajectories and identifying irreversible tipping points

Oceans DT

AI-powered Urban DTs

Biodiversity DT

More DTs… (e.g. migration)

+ Freshwater/Water cycle

HORIZON EUROPE

Digital Europe Programme funding (150M€ for the first phase 2021-2024)

Horizon Europe calls to support research related to Destination Earth (modelling, DTs…)

Strategic Union initiative for EuroHPC

European Commission

Digital Twins of the Ocean - DITTO

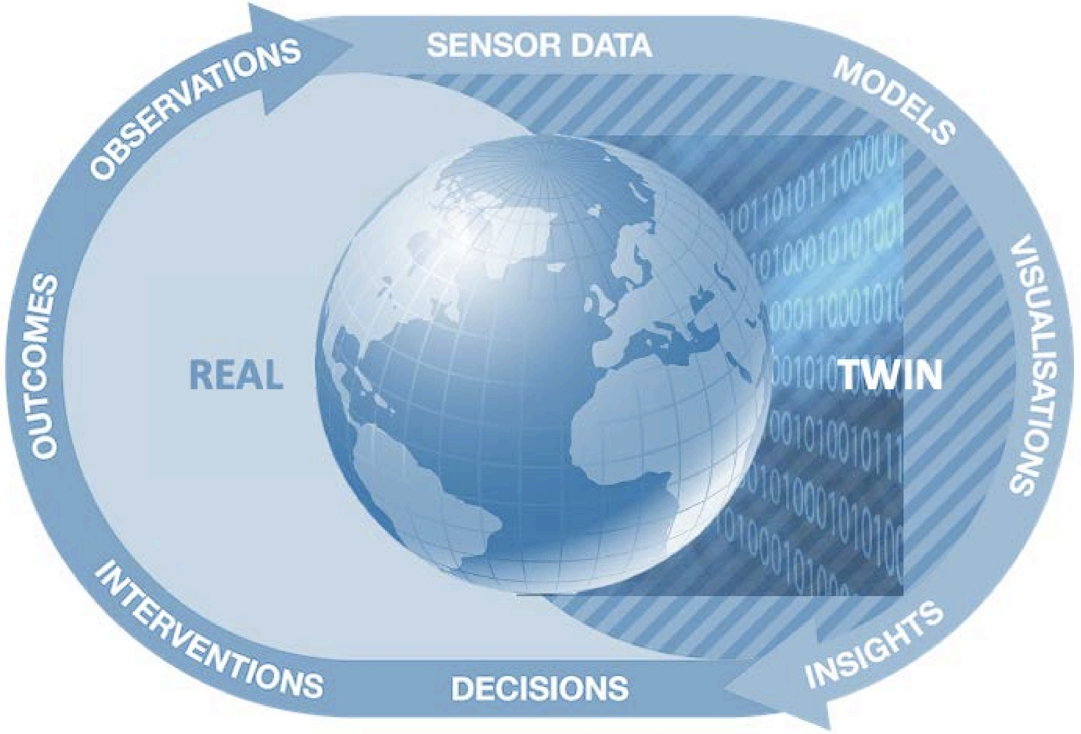
An **accessible ocean** with open and equitable access to data, information, and technology and innovation.

Develop a comprehensive digital representation of the ocean.

- **Digital Twins of the Ocean** are a virtual representation of the real ocean and have a two-way connection with it. Observations from the real ocean change and refine the twin; manipulating the twin can highlight regions of the real ocean in need of better or different observations.

- **Digital Twins** will enable users to address **'What if' questions** based on shared data, models and knowledge.

- **Digital Twins** empower ocean professionals, citizen scientists, policymakers, and the general public alike to visualise and explore ocean knowledge, data, models and forecasts.



Digital Twins of the Ocean

https://ditto-oceandecade.org

Ocean Information **assessing Interventions**

What – If Scenarios
How will the ocean change if humans act?

SINTEF

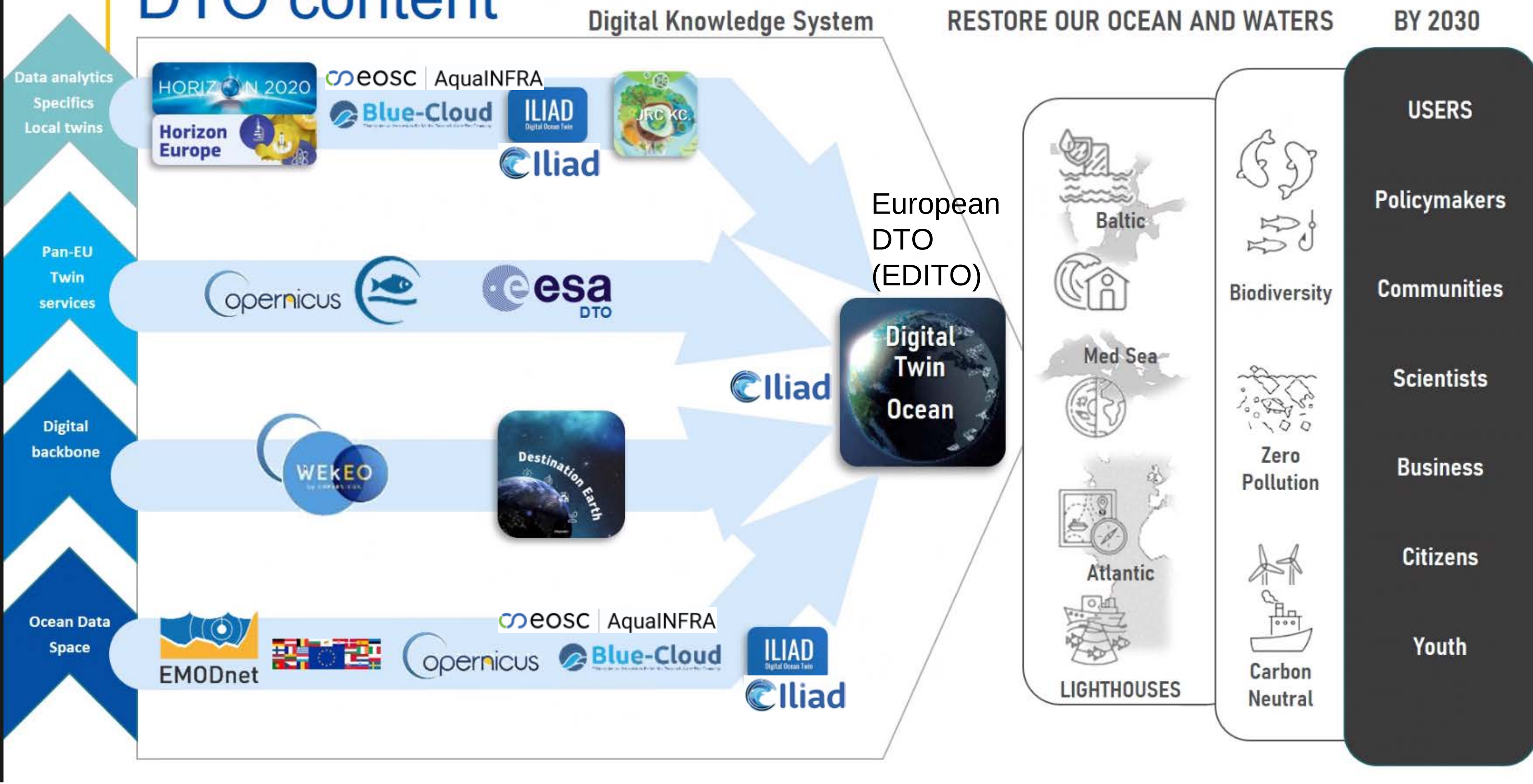
DITTO – DIGITAL TWINS OF THE OCEAN

Working Groups 1-7

ditto-oceandecade.org

WG1. Supportive ocean observations and data systems
WG2. Data analytics and prediction engines
WG3. Data lakes and interoperability
WG4. Interactive layers and visualizations
WG5. Framework – architecture, design and implementations (TURTLE)
(Led by Ute Brönner, SINTEF Ocean and Arne J. Berre, SINTEF Digital, ILIAD project)
WG6. Education, training and capacity development
WG7. Outreach and communication

DTO content



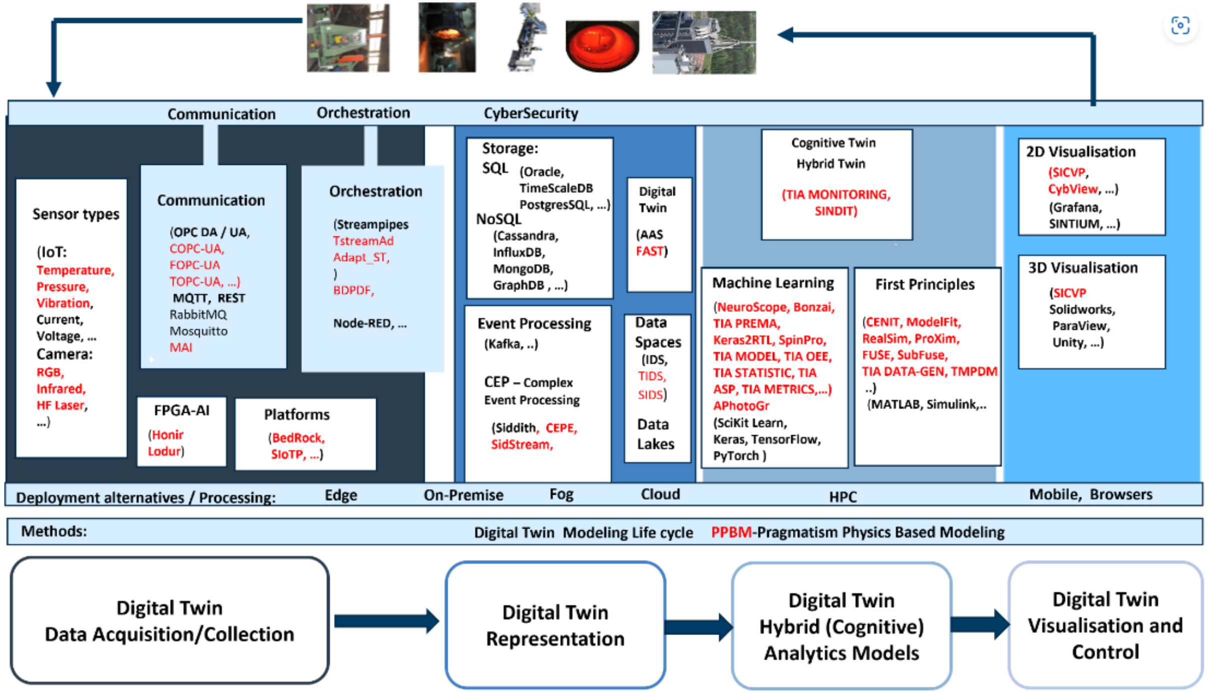
Digital Knowledge System
RESTORE OUR OCEAN AND WATERS
BY 2030
Data analytics
Specifics
Local twins
Pan-EU
Twin
services
Digital
backbone
Ocean Data
Space
HORIZON 2020
Horizon Europe
eosc
AquaINFRA
Blue-Cloud
ILIAD
Digital Ocean Twin
Iliad
JRC KC
opernicus
esa
DTO
WEKEO
Destination Earth
EMODnet
European
DTO
(EDITO)
Digital
Twin
Ocean
Baltic
Med Sea
Atlantic
LIGHTHOUSES
Biodiversity
Zero
Pollution
Carbon
Neutral
USERS
Policymakers
Communities
Scientists
Business
Citizens
Youth

Marina Tonani (MOi)

COGNITWIN Toolbox Portal

The COGNITWIN Toolbox is structured according to a defined Digital Twin pipeline, comprising a set of different Digital Twin (DT) supporting components. These component will typically be connected and configured together in different ways for different pipeline instances in various application contexts.

As shown in the figure, four main steps for the pipeline have been defined, corresponding to 1) DT data acquisition tools & services, 2) DT representation tools & services, 3) DT analytics tools & services, and 4) DT visualization and control tools & services that will be explained below.

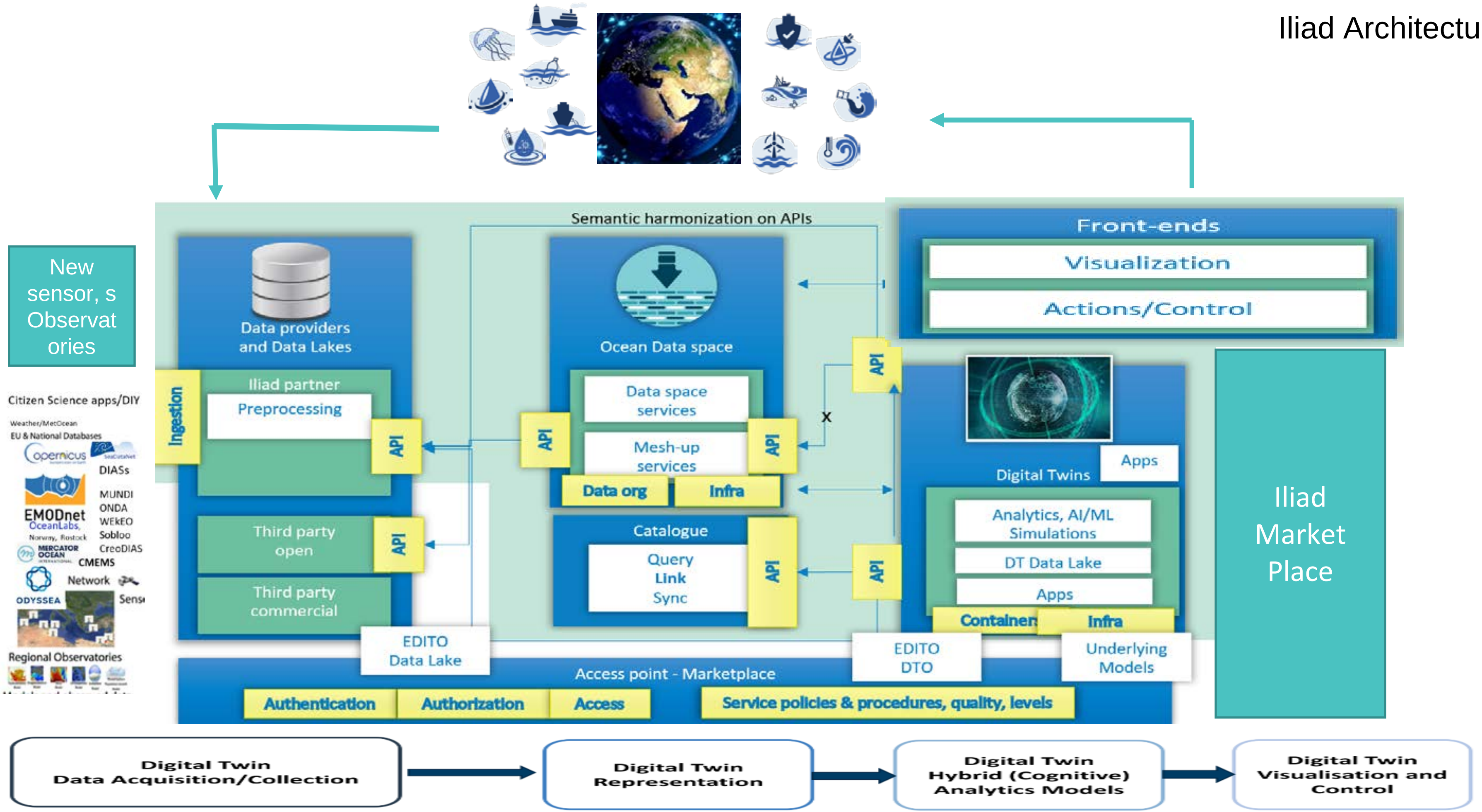


cognitwin.eu

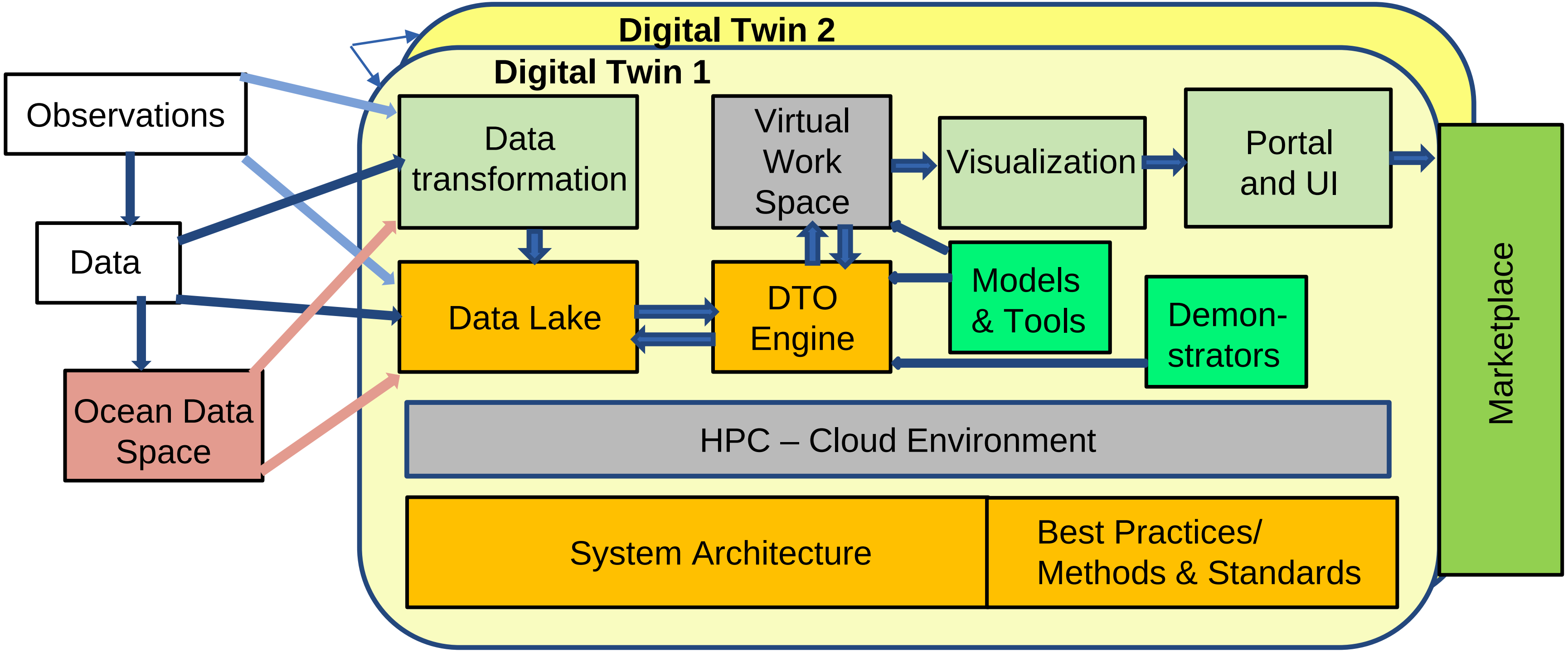
Hybrid and Cognitive Digital Twins

(for process Industry)

Iliad Architecture

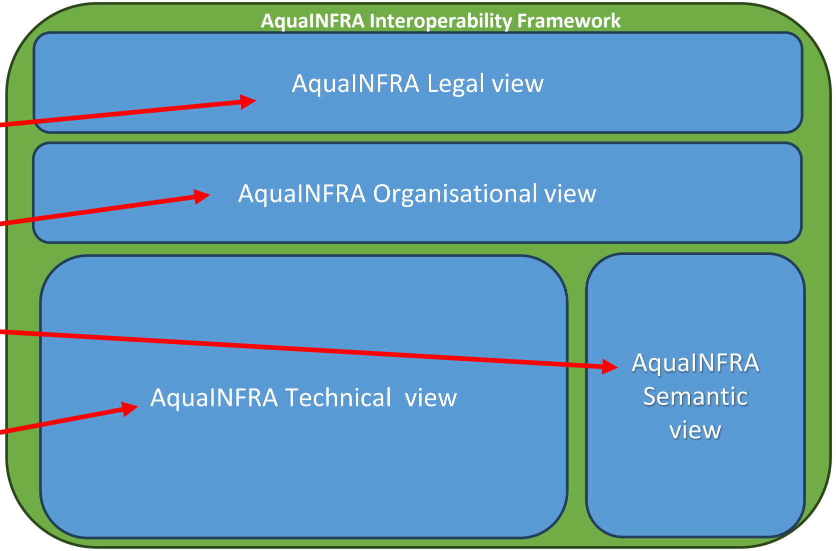


Digital Twins



AquaINFRA Interoperability Framework (AIF)

European Interoperability Framework (EIF)



https://aquainfra.eu/

Relevant standards and initiatives

ISO SC41 IoT and Digital Twins – WG6 Digital Twins (ISO 30173 Concepts&Terminology,
ISO 30186 Digital Twin Maturity Model, ISO NWI Digital Twin Reference Architecture, ISO 30172
Digital Twin Use cases) + ISO 30179 IoT for Ecological Environment Monitoring +
ISO 23247 (Manufacturing) Digital Twins
IDTA – Asset Administration Shell (AAS) for Industry 4.0 Digital Twins (DIN IEC 63278)

ISO SC42 AI and CEN CENELEC JTC21 AI – ISO 22989 Concepts, ISO 23053 AI Framework,
ISO 20546 and ISO 20547 Big Data, ISO 24030 AI Use cases
(+Digital Twins), ISO 5259 AI and Data Quality + Data Spaces NWIP + EU AI ACT

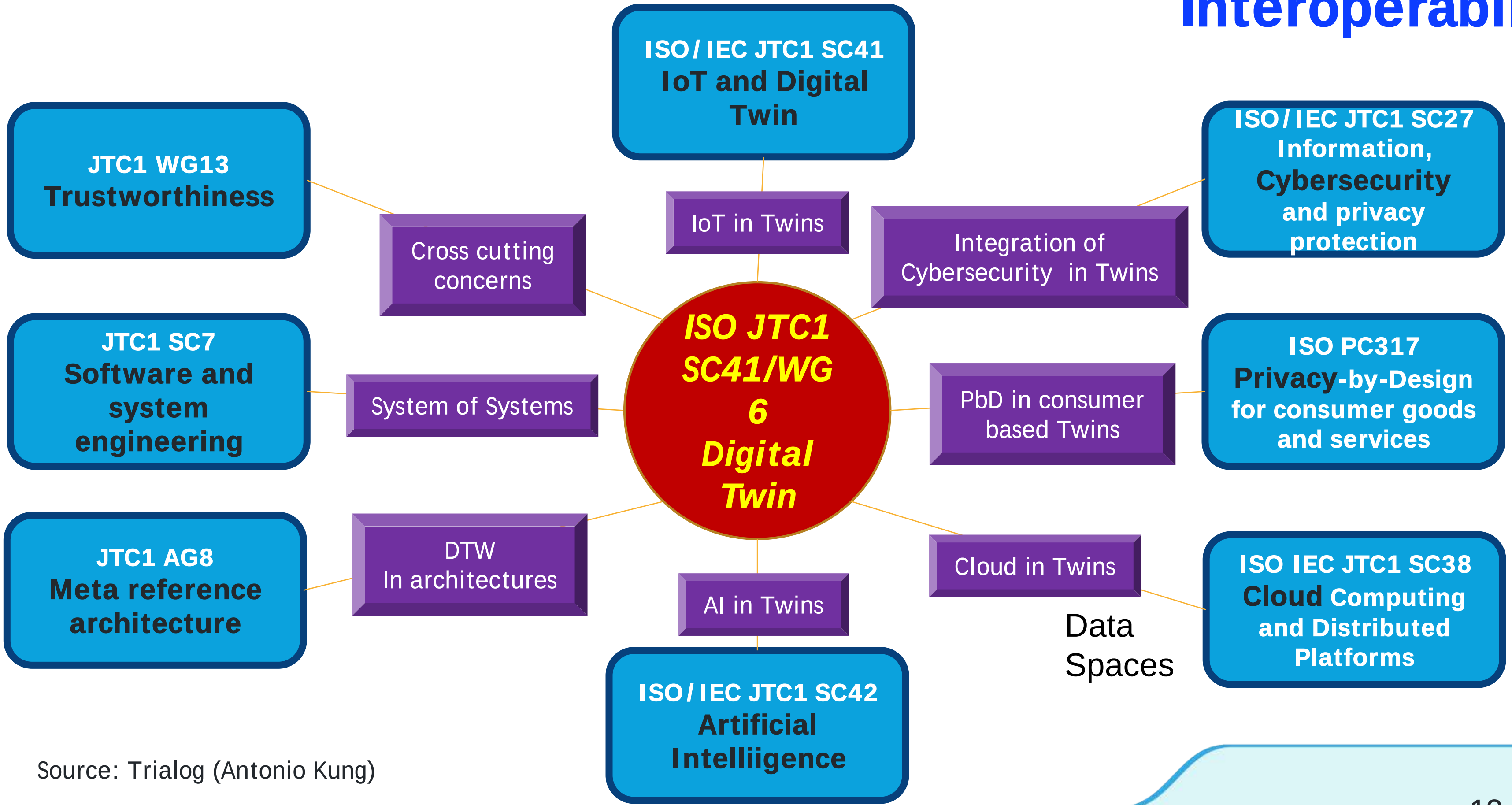
Data Spaces – DSSC.EU – GAIA-X and IDSA International Data Spaces Association – European
Common Data Spaces – Data Spaces for Green Deal, GREAT/AD4GD projects
IEEE – Recommended Practice for the Development of Digital Twins of the Earth (IEEE partner in Iliad)

OGC and ISO/TC211 Geospatial API standards + AIM – Agriculture Information Model + UML and ArchiMate
-> OIM – Ocean Information Model (+ ISO/TC211 ISO 19119 Geospatial Services (to be updated) (OGC partner in Iliad)
EOSC – European Open Science Cloud – Data/Service Marketplace + EMODNET with ERDAP
UK Environmental Digital Twin Information Framework – British Standards

DTC – Digital Twin Association (DT Vocabulary and Periodic Table)

StandICT.eu 2023
ICT STANDARDISATION OBSERVATORY AND SUPPORT FACILITY IN EUROPE

IoT/Digital Twin Interoperability



Source: Trialog (Antonio Kung)

ISO SC41 landscape (standards in progress)

Digital twins

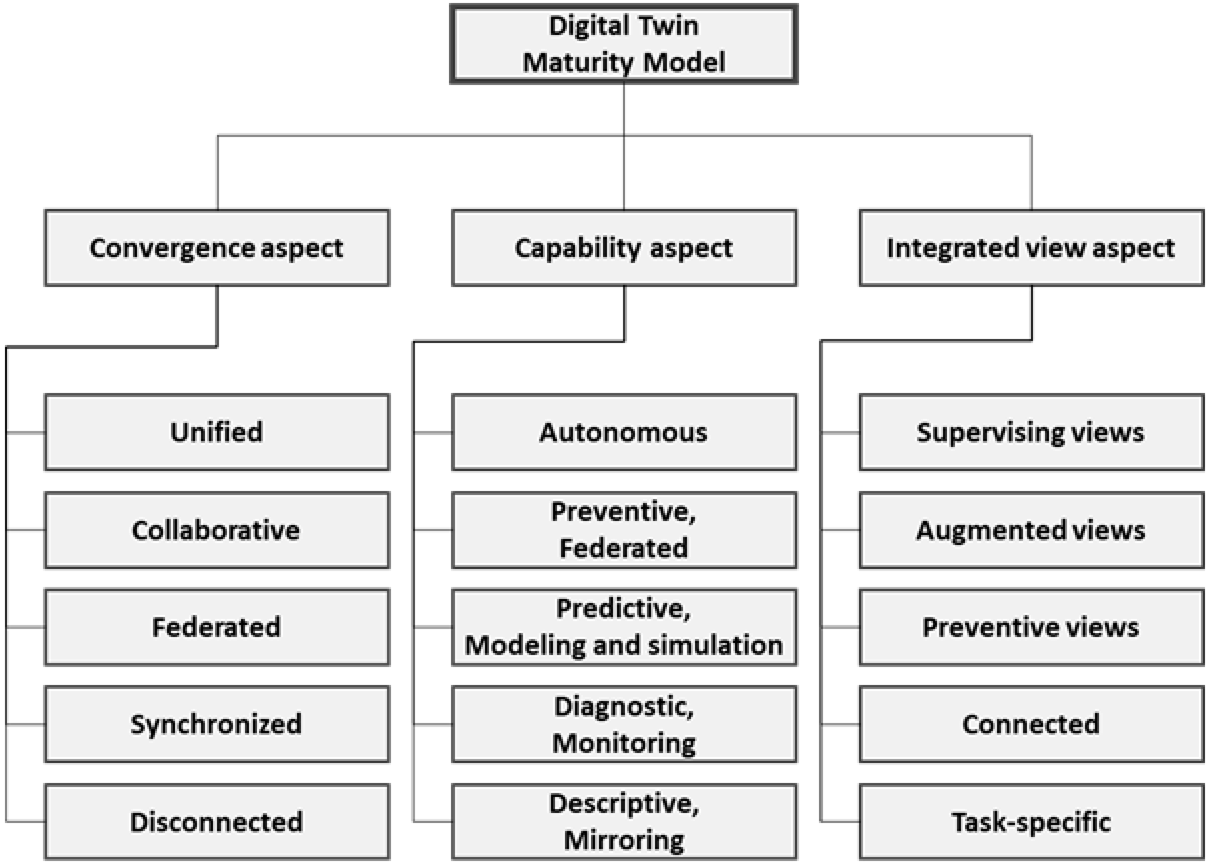
- 20924 Ed3 IoT and Digital twin - Vocabulary
- 30172 Digital twin use cases
- 30173 Digital twin concepts and teminology
- 20924 Ed3 IoT and Digital twin - Vocabulary
- 30186 Maturity model
- 30188 Digital twin Reference Architecture
- Correspondence measure of DT twinning

Interoperability

- 21823-1 IoT interoperability - framework
- 21823-2 IoT transport interoperability
- 21823-3 IoT semantic interoperability
- 21823-4 IoT syntactic interoperability
- 30181 Functional architecture for resource ID interoperability
- 21823-X Behavioral and policy interoperability

IoT

- 20924 Ed2 IoT - Vocabulary
- 30141 Ed1 IoT reference architectures
- 30166 Industrial IoT
- 30165 Real-time IoT
- 30164 IoT Edge computing
- 30147 Integration of IoT trustworthiness in ISO/IEC/IEEE 15288
- 30176 Integration of IoT and DLT/ blockchain: use cases
- 22417 IoT – Use cases
- 30141 Ed2 IoT reference architecure
- 30149 IoT trustworthiness principles
- 30187 Evaluation indicator for IoT systems


Digital Twin Maturity Model
Convergence aspect
Capability aspect
Integrated view aspect
Unified
Collaborative
Federated
Synchronized
Disconnected
Autonomous
Preventive, Federated
Predictive, Modeling and simulation
Diagnostic, Monitoring
Descriptive, Mirroring
Supervising views
Augmented views
Preventive views
Connected
Task-specific

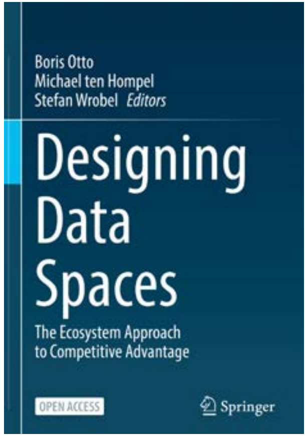
ISO/IEC JTC 1/SC 41 N2335

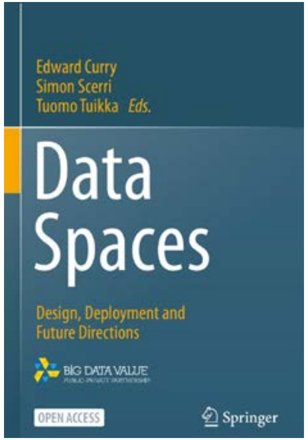
ISO/IEC JTC 1/SC 41

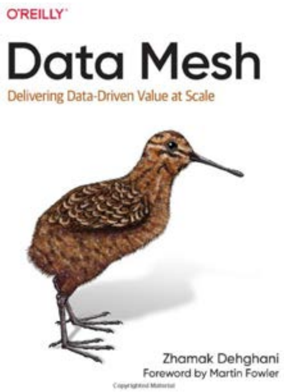
Internet of Things and Digital Twin

Secretariat: KATS (Korea, Republic of)

Document type:	Other document
Title:	PWI on Guidance on IoT and digital twin integrations in data spaces
Status:	For your information.
Date of document:	2023-06-15
Source:	AG 31 Convenor







OPEN DEI design principles position paper on Resources

Public Reports

INTERNATIONAL DATA SPACES ASSOCIATION

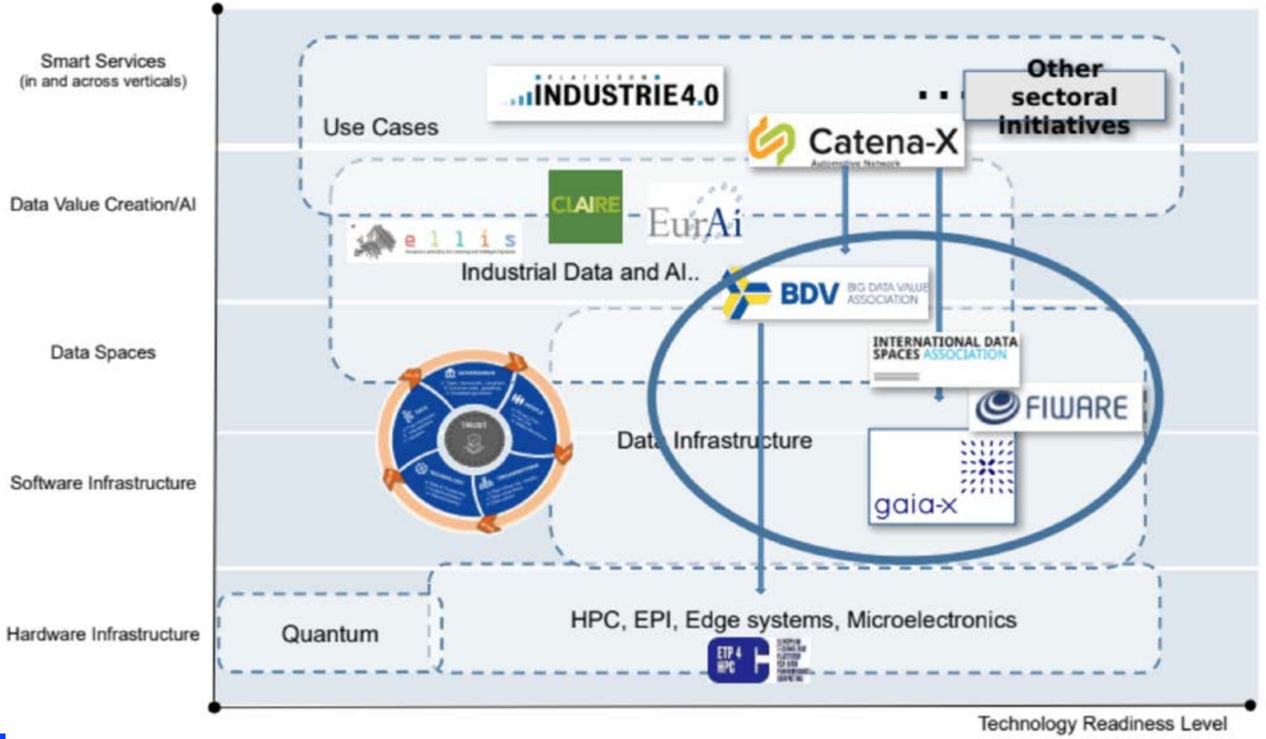
gaia-x

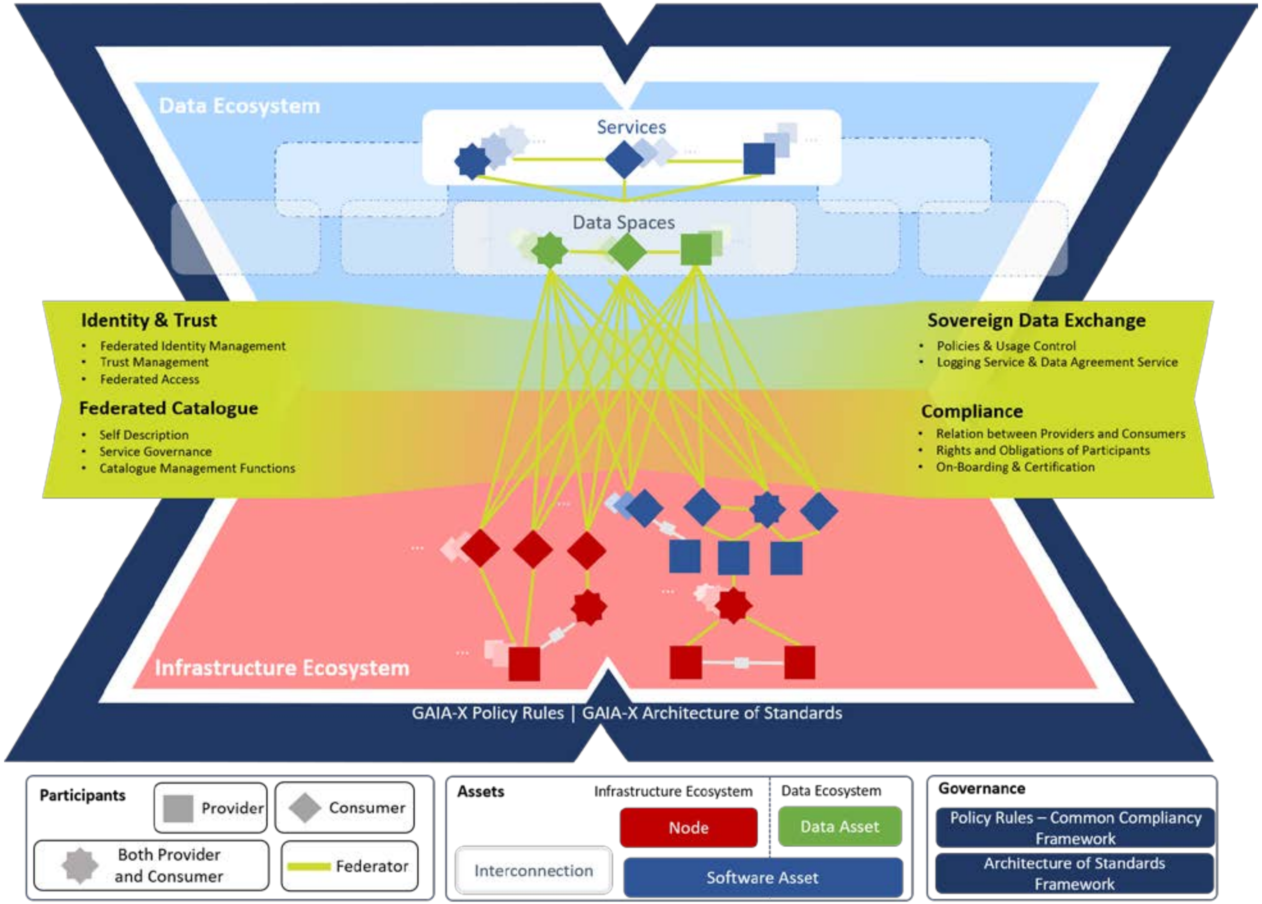
Design Principles for Data Spaces

1. Data sovereignty
2. Data level playing field
3. Decentralised soft infastructure
4. Public-private governance

DATA Spaces

- Data spaces initiative
  - IDSA | Gaia-X |European commission
- References
  - IDSA reference architecture
  - Gaia-X technical architecture
  - BDVA position papers – v1 and v2
    - Towards a European-Governed Data Sharing Space. Enabling data exchange and unlocking AI potential. April 2019
    - Towards a European-Governed Data Sharing Space. Enabling data exchange and unlocking AI potential. November 2020.
  - AIOTI strategic foresight
  - H2020 OpenDei support action: design principles for data spaces

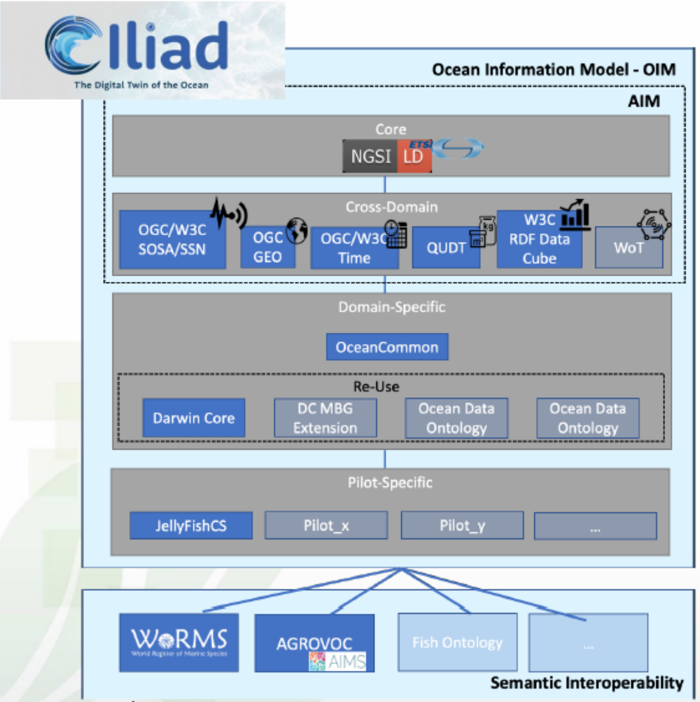


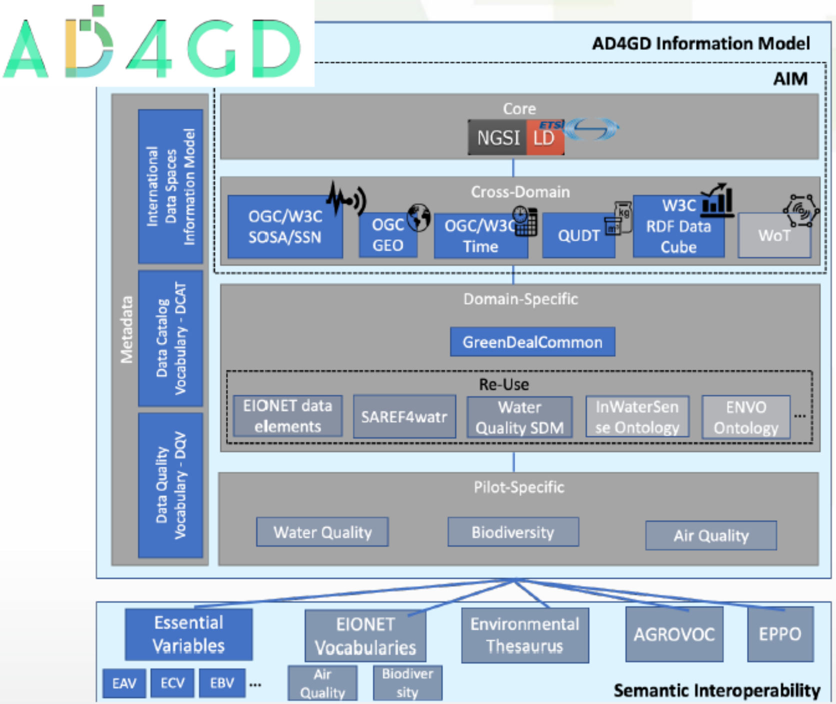

Data Ecosystem
Services
Data Spaces
Identity & Trust
Federated Identity Management
Trust Management
Federated Access
Federated Catalogue
Self Description
Service Governance
Catalogue Management Functions
Sovereign Data Exchange
Policies & Usage Control
Logging Service & Data Agreement Service
Compliance
Relation between Providers and Consumers
Rights and Obligations of Participants
On-Boarding & Certification
Infrastructure Ecosystem
GAIA-X Policy Rules | GAIA-X Architecture of Standards
Participants
Provider
Consumer
Both Provider and Consumer
Federator
Assets
Infrastructure Ecosystem
Data Ecosystem
Node
Data Asset
Interconnection
Software Asset
Governance
Policy Rules – Common Compliancy Framework
Architecture of Standards Framework

(AIM - Agriculture Information Model)

AIM as basis for other domains

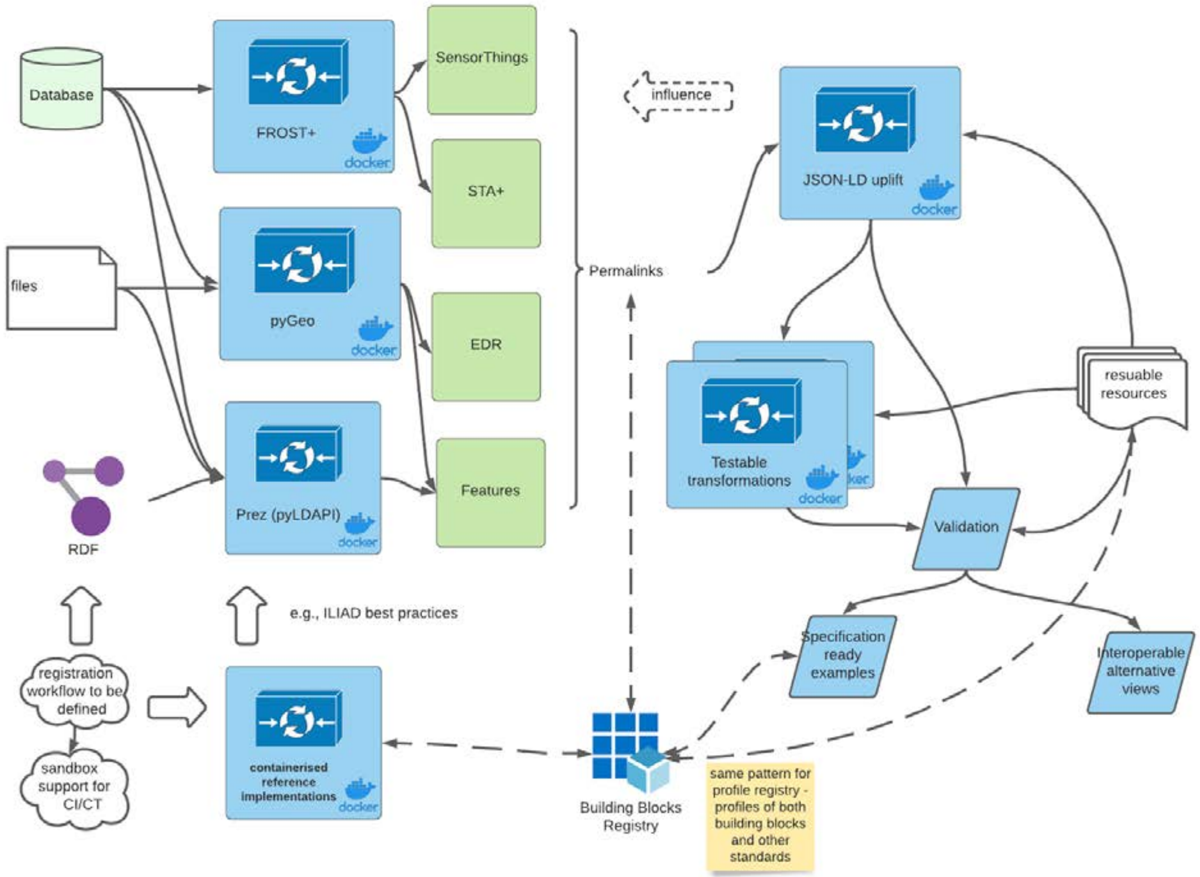
Emerging OGC standard

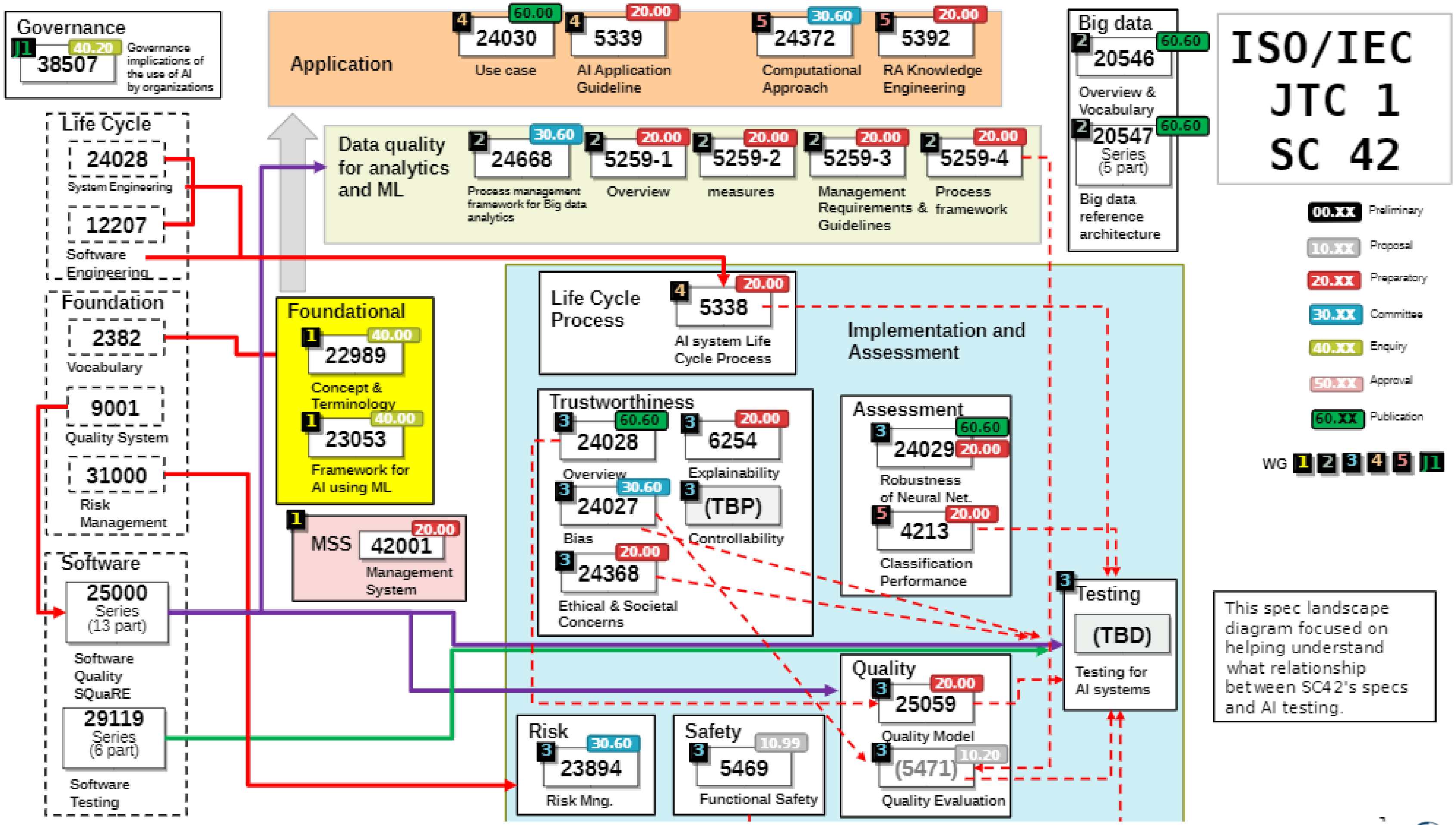




Iliad DTO use of OGC services and new APIs

- Aggregates and derivates need
- Breadcrumbs of provenance
- Common APIs and connectors
- Vocabularies of service and data description
- Alignment with conceptual and system Building Blocks

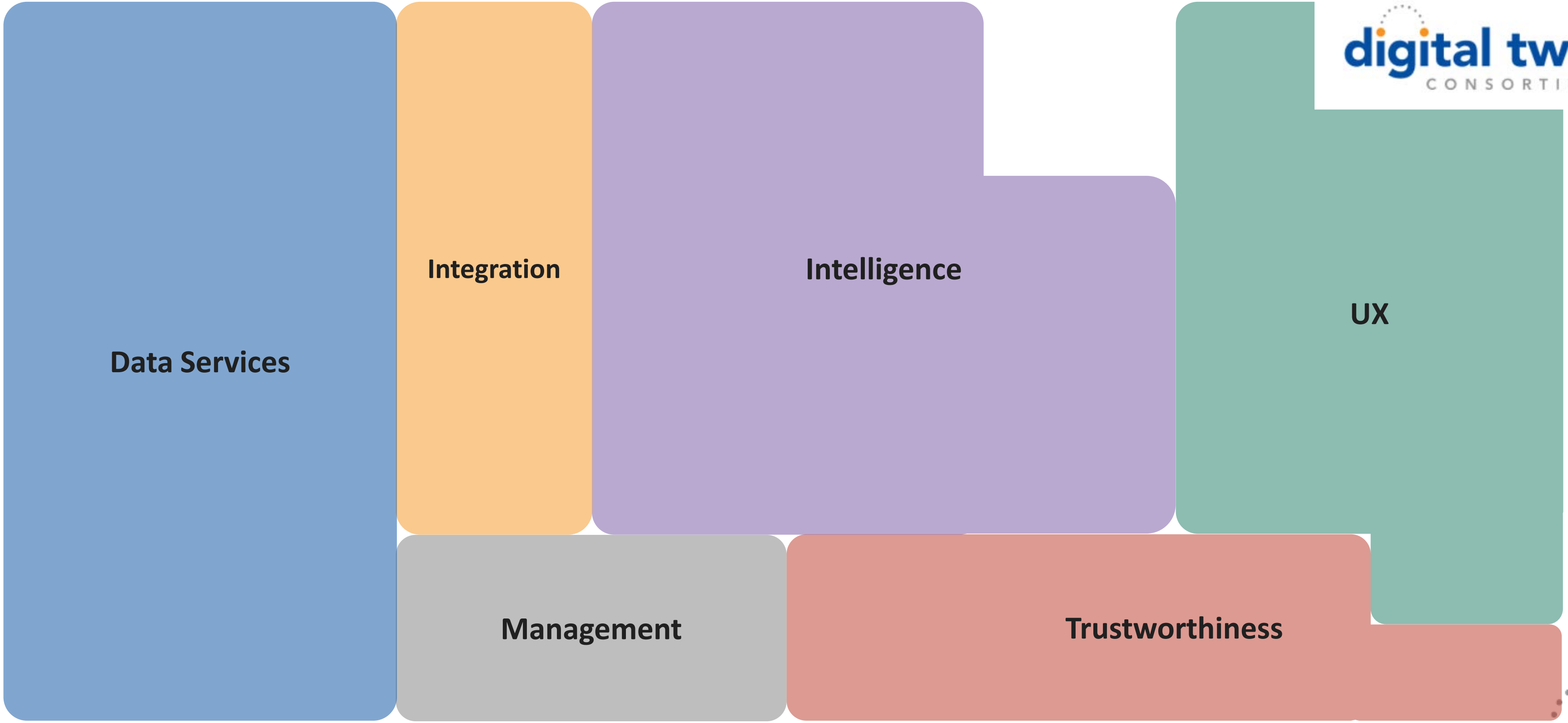




This spec landscape diagram focused on helping understand what relationship between SC42's specs and AI testing.

SINTEF

Periodic Table for Digital Twin Ecosystem Capabilities



Periodic Table for Digital Twin Ecosystem Capabilities

1 Data Acquisition & Ingestion	9 Synthetic Data Generation	17 Enterprise System Integration	23 Edge AI and Intelligence	29 Prediction		39 Basic Visualization	45 Dashboards
2 Data Streaming	10 Ontology Management	18 Eng. System Integration	24 Command and Control	30 Machine Learning ML		40 Advanced Visualization	46 Continuous Intelligence
3 Data Transformation	11 Digital Twin (DT) Model Repository	19 OT/IoT System Integration	25 Orchestration	31 Artificial Intelligence AI	35 Prescriptive Recommendations	41 Real-time Monitoring	47 Business Intelligence
4 Data Contextualization	12 DT Instance Repository	20 Digital Twin Integration	26 Alerts and Notifications	32 Federated Learning	36 Business Rules	42 Entity Relationship Visualization	48 BPM and Workflow
5 Batch Processing	13 Temporal Data Store	21 Collab platform integration	27 Reporting	33 Simulation	37 Distributed Ledger & Smart Contracts	43 Augmented Reality AR	49 Gaming Engine Visualization
6 Real-time Processing	14 Data Storage & Archive Services	22 API Services	28 Data Analysis and Analytics	34 Mathematical Analytics	38 Composition	44 Virtual Reality VR	50 3D rendering
7 Data PubSub Push	15 Simulation Model Repository	52 Device Management	54 Event Logging	56 Data Encryption	58 Security	60 Safety	51 Gamification
8 Data Aggregation	16 AI Model Repository	53 System Monitoring	55 Data Governance	57 Device Security	59 Privacy	61 Reliability	62 Resilience

Data Services · Integration · Intelligence · UX · Management · Trustworthiness