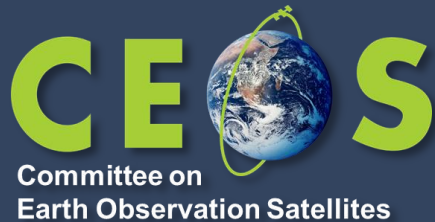
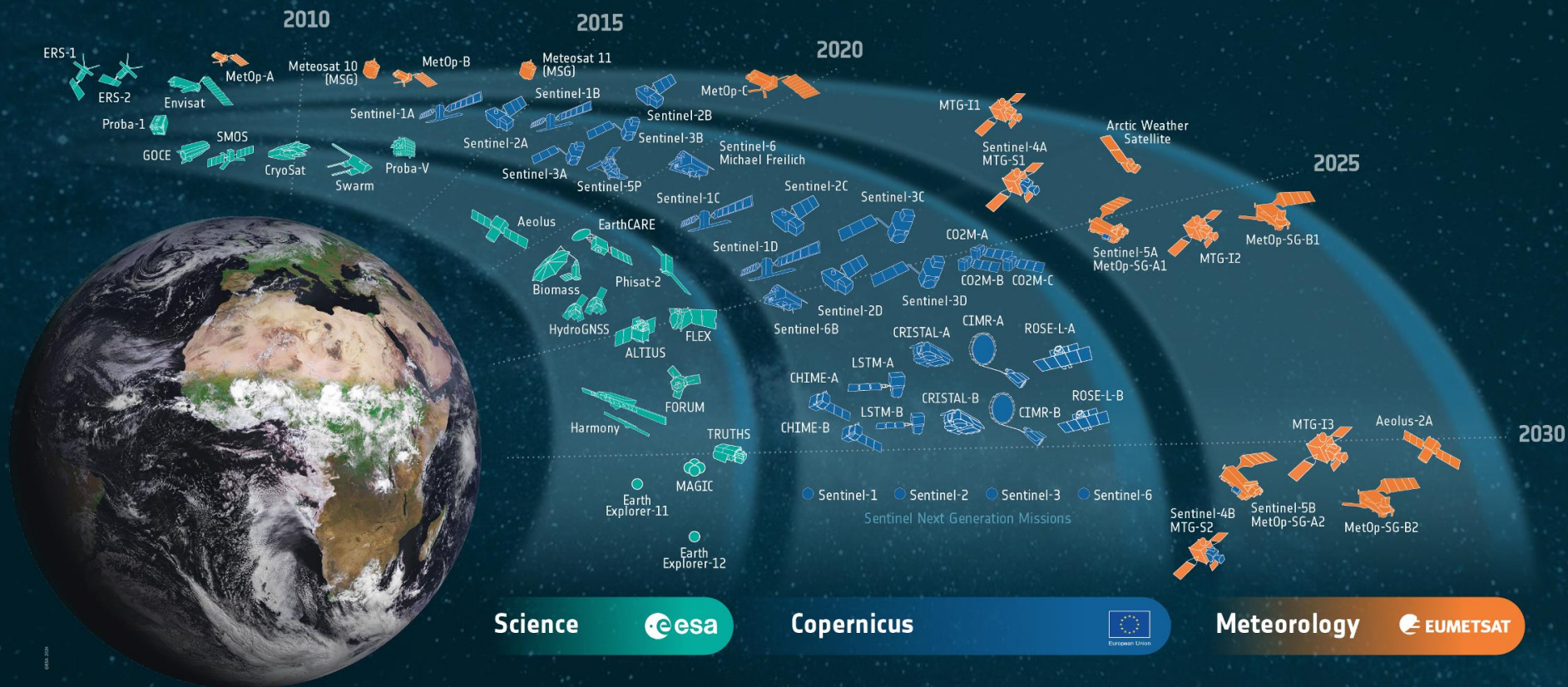


WGISS-61 Destination Earth and ESA Digital Twin Earth



Claudia Vitolo, ESA
Agenda Item 7.8
WGISS-61
16-20 March, 2026
Dehradun, India

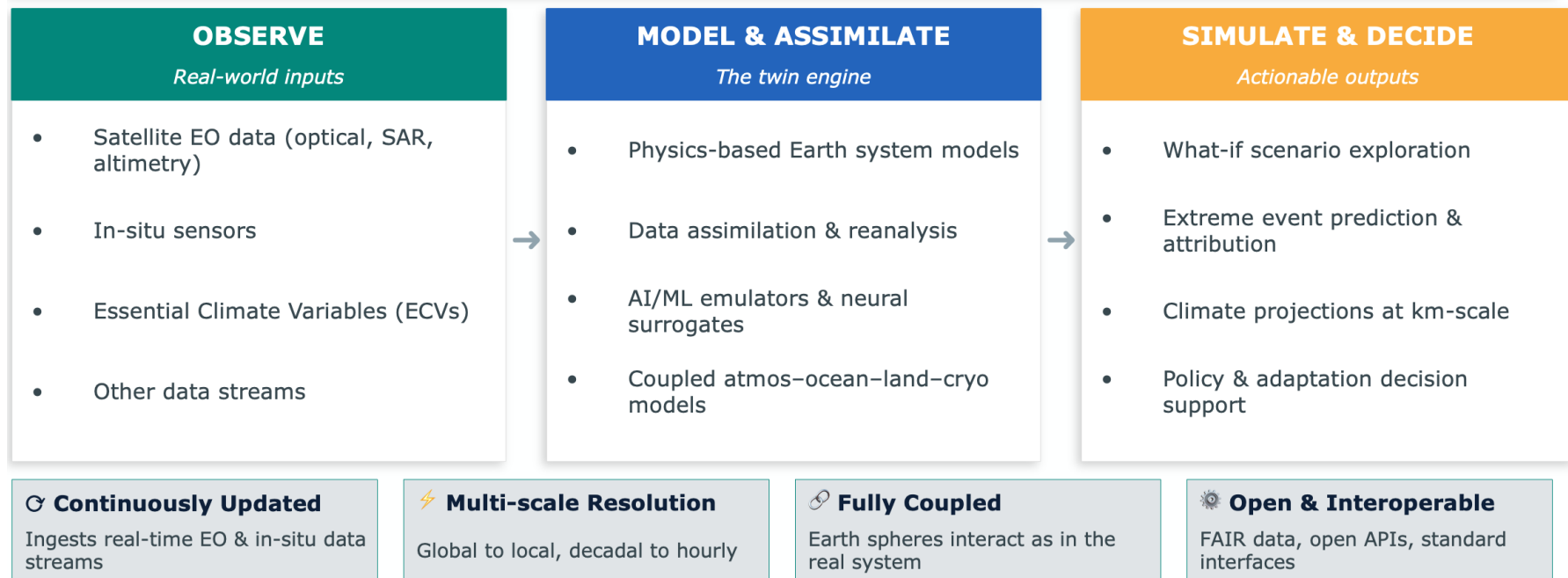
ESA & EO missions



What is a Digital Twin?



A Digital Twin of the Earth System is a high-fidelity, continuously updated virtual representation of the physical Earth — integrating observations, physics-based models and AI — to simulate past, present and future states of the atmosphere, ocean, land, cryosphere and biosphere.



What is Destination Earth?



Destination Earth (DestinE) is a European Commission initiative to develop a high-precision digital replica of Earth — enabling monitoring, simulation and prediction of natural and human systems to support the green and digital transitions.

Vision

A digital twin of Earth at unprecedented resolution to tackle climate change, natural disasters and societal challenges.

Timeline

Phase 1 (2022–2024): foundation.
Phase 2 (2024–2026): first operations.
Phase 3 (2026–2028): expansion.
By 2030 → full operations.

Core Entrusted Entities

- ESA - DestinE Platform & Services
- ECMWF - First two Digital Twins
- EUMETSAT - Data Lake

CLIMATE DT - OVERVIEW

Led by CSC and ECMWF the Climate Change Adaptation Digital Twin (Climate DT) operationalises the production of global multi-decadal climate projections, leveraging the supercomputing facilities of the EuroHPC Joint Undertaking

Technical Framework

- Introduces climate projections (from 1990 to ~2050) at very high spatial resolutions (5-10km)
- Updating projections routinely (~yearly) compared to the current 7-10 years cycles
- Uses next-generation, high-resolution Earth-system models (ICON, IFS-NEMO, IFS-FESOM)
- Delivers an hourly temporal output, compared to the traditional 6-hourly

Simulation protocols

- Builds on HighResMIP/CMIP6 conventions, supporting historical reconstructions and scenario-based projections

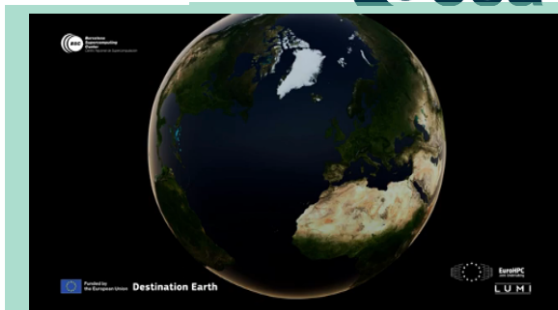
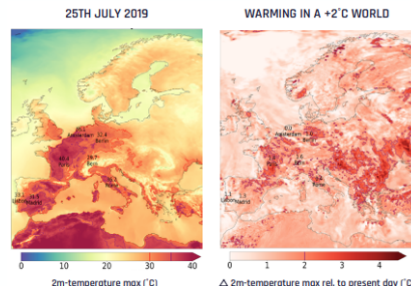
Use Cases

- High-resolution application for wind energy (on-shore/offshore), demonstrating benefits of increased spatial/temporal granularity over standard 1° models

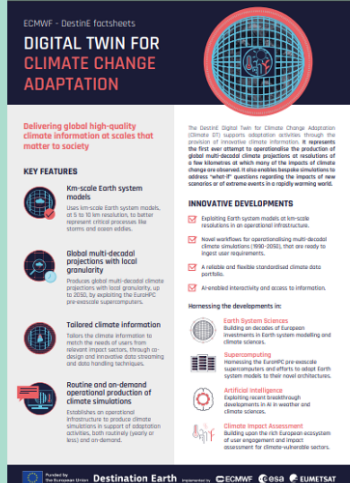
Addressing 'What-if?' questions

Example of a simulation answering the question:
"What would the 2019 European heatwave look like in a +2° C world?"

The European heatwave of 25th July 2019 (left panel) along with the additional warming in a +2°C world compare to present-day conditions (right panel). The results are based on novel kilometre-scale storyline simulations with IFS-FESOM on LUMI.



Comparison of the resolution within DestinE and the 1° standard resolution



For this service, an upgraded access is needed

Climate DT - Three climate models available

ICON The ICOSahedral Non-hydrostatic model developed by the German Meteorology (MPI-M), the German Climate Computing Centre (DKRZ), the Karlsruhe Institute of Technology (KIT), and the Center for Climate Systems Modeling (C2SM)

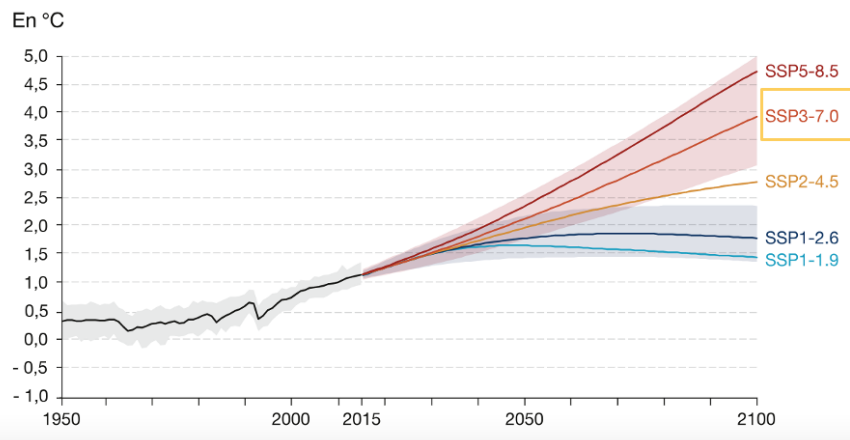
IFS-FESOM ECMWF's Integrated Forecasting System (IFS) coupled to the latest release of the NEMO ocean model implemented by BSC in collaboration with ECMWF

IFS-NEMO ECMWF's Integrated Forecasting System (IFS) coupled to the Alfred Wegener Institute's Finite-Volume Sea ice-Ocean Model

DestinE Climate DT high-resolution Earth-system models (ICON, IFS-NEMO, IFS-FESOM)

Climate model	Simulation type	Time period	Status
ICON, IFS-FESOM, IFS-NEMO	Historical (hist)	1990 – 2019	Available
ICON, IFS-FESOM, IFS-NEMO	Future (SSP3-7.0)	2020 – 2039	Available
IFS-FESOM, IFS-NEMO	Control (cont)	1990 – 2006	Available
IFS-FESOM	Storylines	2017 – 2024	Available
-	Phase 2 upgrade (future)	2020 - 2020	Coming mid-2026

- Currently only scenario SSP3-7.0 is being used on DestinE
 - The projections carried out so far are initialised in 2020 from reanalysis followed by a 5-year ocean spin-up
 - In the future, alternative future scenarios will be explored with extended historical simulations:
- "Simulations with upgraded climate models, that will also follow more closely the HighResMIP protocol, will become available early 2026. Work on evaluation and uncertainty quantification is also ongoing"



Evolution of temperatures following the IPCC scenarios
Source : IPCC, 1^{er} groupe de travail, 2021

Weather-Induced Extremes Digital Twin

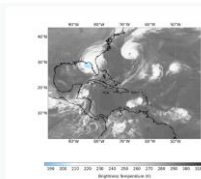
EXTREMES DT - OVERVIEW

The Weather-Induced Extremes Digital Twin (Extremes DT) is designed to support rapid response and adaptation to extreme weather, hydrological, and air quality events by providing tailored, high-resolution simulations of such extremes

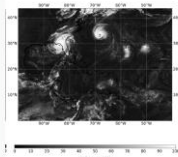
Technical Framework

- Provides regular (global) and on-demand (regional, zoom) simulations depending on user needs
- Global component developed by ECMWF, offers simulations at 4,4km resolution, up to four days ahead
- Regional component developed by a large consortium led by [MétéoFrance](#), provides sub-kilometre (500-750m) simulations over Europe for up to two days ahead
- Operates using world-leading [EuroHPC](#) supercomputing resources

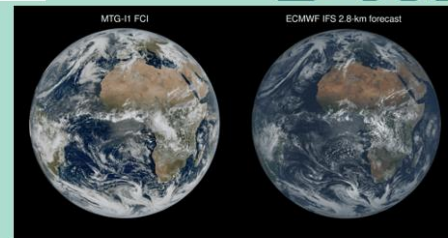
Use case



Simulation of the hurricane Idalia during landfall, as well as the eye structure of hurricane Franklin (36-hour forecast)



Satellite observations of hurricane Franklin just two hours before Idalia makes landfall



First official MTG-FCI visible image from EUMETSAT (left) and 12-hour simulation with ECMWF's Integrated Forecasting System (IFS) at 2.8 km resolution (right), valid for 18 March 2023 at 12:00 UTC

ECMWF - Essential factsheets

DIGITAL TWIN FOR WEATHER-INDUCED EXTREMES

Sharpening our vision of extreme weather and its impacts

KEY FEATURES

- Km-scale Earth system models**
 - Uses two state-of-the-art models to better represent extreme weather events and deliver information on hazards and risks that are not available from other data sources.
- Routine production of global simulations**
 - Produces global simulations at a 4.4 km resolution for a 10-day forecast, providing a comprehensive view of extreme weather events.
- On-demand refinement over Europe**
 - Produces on-demand regional simulations at 2.8 km resolution for a 10-day forecast, providing a more detailed view of extreme weather events over Europe.
- From weather to impact sector information**
 - Integrates weather, hydrology, and air quality information to provide a comprehensive view of the impacts of extreme weather events on different sectors.

INNOVATIVE DEVELOPMENTS

- Integration of on-demand weather modelling with machine learning to improve forecast accuracy.
- Development of new tools for the analysis and visualization of extreme weather events.
- An advanced detection and attribution module for the identification of extreme weather events.
- An advanced assessment module for the quantification of the impacts of extreme weather events.

Harnessing the latest developments in:

- Building on decades of experience in the development of weather forecasting and impact modelling.
- Supercomputing resources and expertise from the EuroHPC project.
- Artificial intelligence: Building upon the expertise of the EuroHPC project in the field of machine learning and data science.

Powered by the European Space Agency - Destination Earth, in partnership with ECMWF, ESA, and EUMETSAT



For this service, an upgraded access is needed



DESTINE'S OFFER

The DestinE Data Portfolio is tailored to user needs and composed of:

- Federated data
 - DestinE Digital Twins data*
 - DestinE user generated data (if agreed)
- The Data Portfolio grows along DestinE lifecycle.

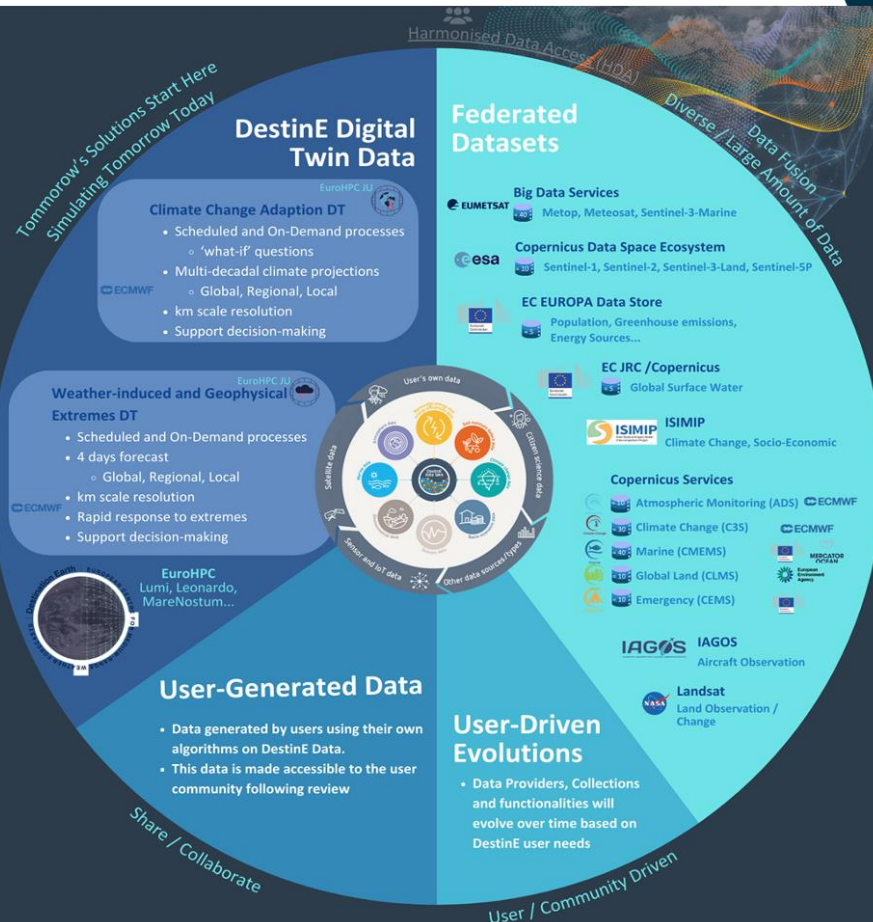
DETAILS

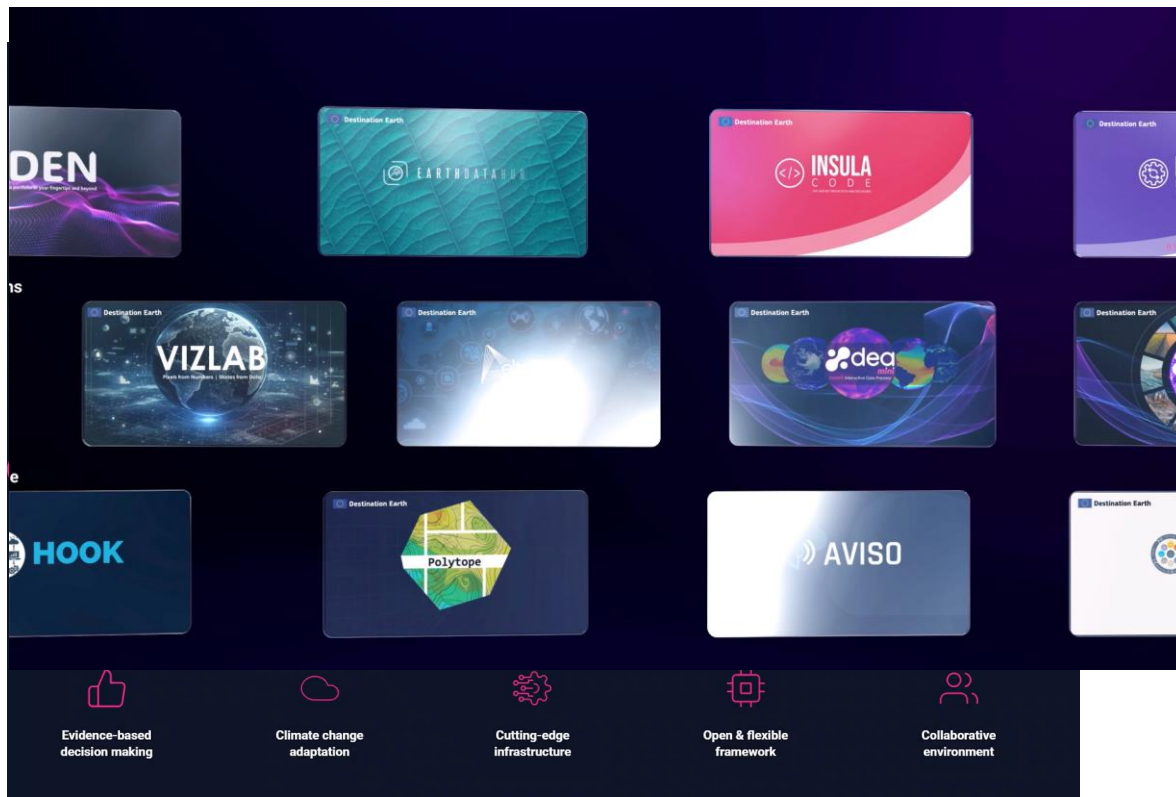


DT three main features

- ✓ Quality data, from global to local scale
- ✓ Integration with sectorial models to assess impact
- ✓ Interactivity to play scenarios for decision making

*Climate adaptation Digital Twin
Weather-induced Extremes Digital Twin





platform.destine.eu

The DestinE Platform represents a **flexible ecosystem of services** allowing to discover DestinE data and exploit them locally through:

- A catalogue of applications to support climate actions
- AI frameworks available as a Service,
- A continuity with Copernicus, one of the largest existing EO system, and
- Scalable services fostering the upscaling by Industry.
- ... and growing ...

Example services: GeoAI



Flexible: train AI models for your specific EO use case (detection or segmentation) and apply them to similar objects.

Works across EO data diversity: supports various resolutions, image types, and sensors.

Accessible: no-code — users can create & deploy models without AI / geospatial expertise.

Built on DestinE data portfolio (e.g. DestinE Climate Adaptation DT datasets), including Copernicus Sentinel-2 Level-2A MSI.

Operated by **FlyPix AI**.



Example services: DEA



DEA (DestinE Storytelling) Copilot

No-code: create interactive data stories to make EO/climate/statistical data accessible to non-expert users.

DEA Copilot / AI Assistant: users can create sample stories using natural language directly from the DEA landing page via “Ask AI” (sign-in required).

Multimodal prompting: choose a suggested prompt, type, or use voice; then visualize or edit the generated story.

Coming: Ask → Analyse → Insert

Operated by **Alia Space System**



What is ESA Digital Twin Earth?



- An optional ESA Programme
- Funded by ESA Member States,
- Continuation confirmed at CM25



- Complements Destination Earth with **Digital Twin Components** that leverage novel **EO** assets
- Develops **innovative services** for the DestinE Platform
- Supports **national Digital Twin** initiatives
- More information: <https://eof.esa.int/dte/>



- Close **coordination** with Destination Earth
- **One ESA team** responsible for Destination Earth and ESA Digital Twin Earth

ESA DTE Programme

■ Participating States





**Digital Twin Earth
Framework**



**Earth Observation
Digital Twin Components**



**Interoperability with
initiatives of ESA Member
States**

Pillar #1: DTE Framework



① Integration of mission data

- Automating the daily ingestion, registration, indexation and traceability of EO data from ESA legacy and current missions into the HIGHWAY environment: EarthCARE, SMOS, CryoSat, SWARM, Aeolus, Proba-V and more to come

② Data Transformation & Harmonisation

- Converted to Zarr using the EOPF data model
- Harmonised projection across missions
- Quality checked**
- Consistency, reliability, and traceability** for multi-mission analysis
- Ready for cloud-native access

③ Federated Catalogue Publishing

- Unified access to native + transformed EO datasets
- STAC and OpenSearch APIs for easy discovery

④ Exploration & Access Services

- Intuitive tools for browsing, previewing, and selecting data
- Supports APIs (STAC, WMS, WMTS)
- Enables rapid prototyping

⑤ Exploitation by DestinE & DTE Users

- Ready for modelling, AI, and simulations
- Seamless integration with DestinE Platform and services
- Enabling scalable, cross-domain Digital Twin applications
- Reducing effort across EO-based workflows

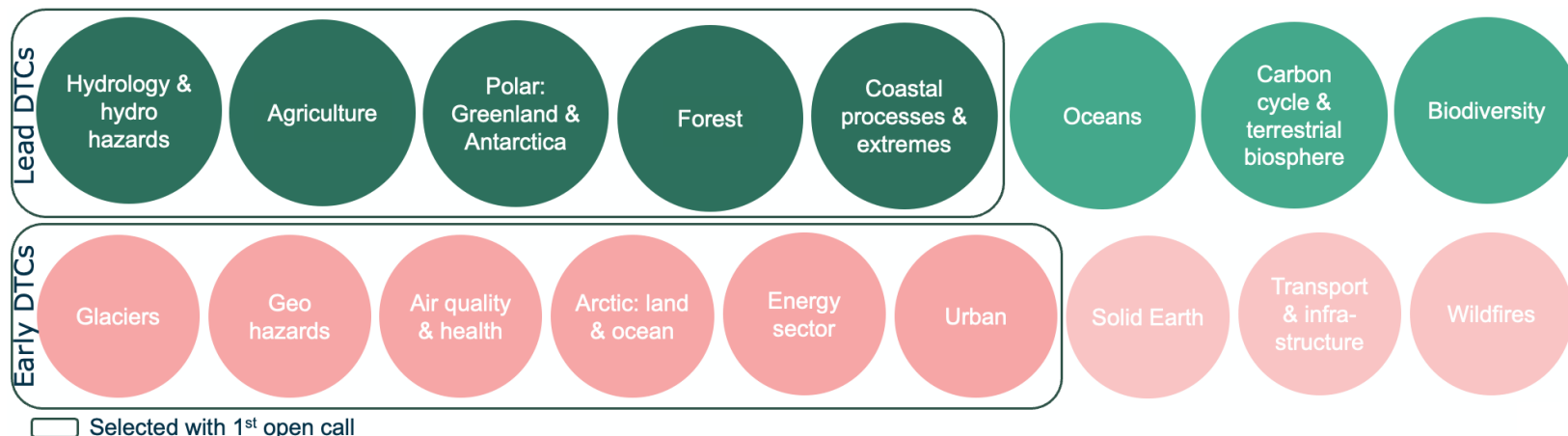
HIGHWAY delivers harmonised, federated and cloud-ready EO data from ESA EO missions to power DestinE and enable user innovation



Pillar #2: EO Digital Twin Components



- Showcasing the value of Earth Observation capabilities and the potential for future operational use in Digital Twin ecosystems, such as through DestinE
- Designed with a strong focus on users, emphasising practical applications rather than purely scientific research
- Potential integration into the DestinE system
- Priority thematic areas have been defined during the 1st ESA DTE Programme cycle



Collaboration with Member States aims at integrating relevant national activities and initiatives related to digital twins

Inclusion and technical integration into the DestinE Platform and within DTE





Destination Earth



- ESA DTE benefits from and contributes to DestinE
- ESA DTE focuses on developing innovative services and serves as a testbed for disruptive advancements in Earth Observation operations, such as large-scale data integration, AI, and quantum technologies
- ESA DTE supports the growth of DestinE
- ESA DTE is designed to support DestinE, with close coordination between the programmes to ensure aligned goals and effective collaboration

DestinE & ESA DTE Timeline

