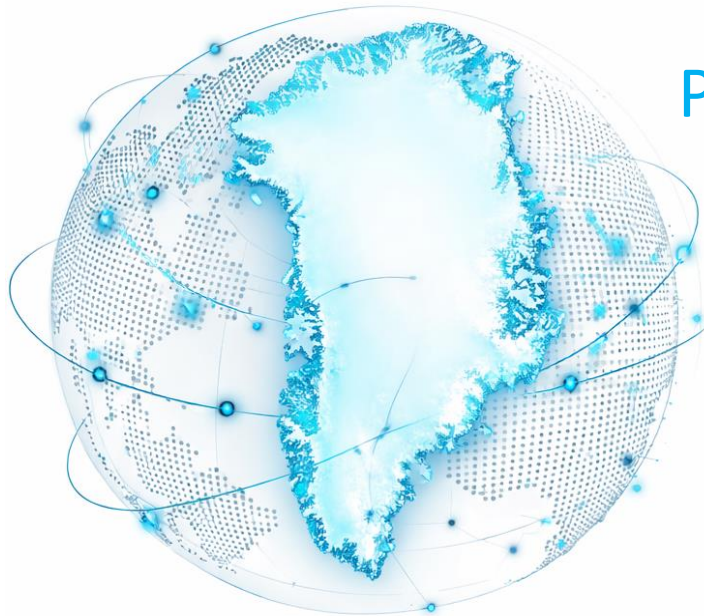


EO-Driven Digital Twin Ice Sheets:

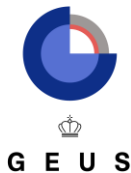


Prototype
Demonstration

Sebastian B. Simonsen, John Palmer, Tabea Rettelbach, Amber Leeson, and the DTC Ice Sheets Team



THE UNIVERSITY
of EDINBURGH



Why Ice Sheets are Essential

- A Critical Link:** A central pillar connecting Cryosphere, Ocean, and Atmosphere.
- Uncertainty Factor:** Resolving the single largest source of uncertainty in climate projections.
- The Gravity Paradox:** Lowers local sea levels but drives far-field rise due to gravity shifts.



Surface climate & hydrology: Super-resolution surface modeling to support climate science, hydropower planning, and local fisheries.



Ice shelves, state & fate: Early-warning system for ice-shelf instability via ice-ocean feedback insights.



Sea-level fingerprint: Improved ice-sheet-driven sea-level projections for regional coastal planning.



Store ~64 meters
of potential sea level rise in ice.



~2.5 meters
of local sea level drop
around Greenland by 2100.
Lewright et al. (2026) Nat Commun



DTC Ice Sheet Stakeholders

Policymakers, Climate Scientists, Industry, and Coastal Communities.



Key Stakeholder Needs:

Improve Climate Resilience: Enhanced projections for coastal flooding and infrastructure risk.

Real-Time Monitoring & Prediction: Super-resolution surface modeling for near real-time insights.

Optimize Energy Planning: Hydropower forecasting via precise meltwater runoff estimates.

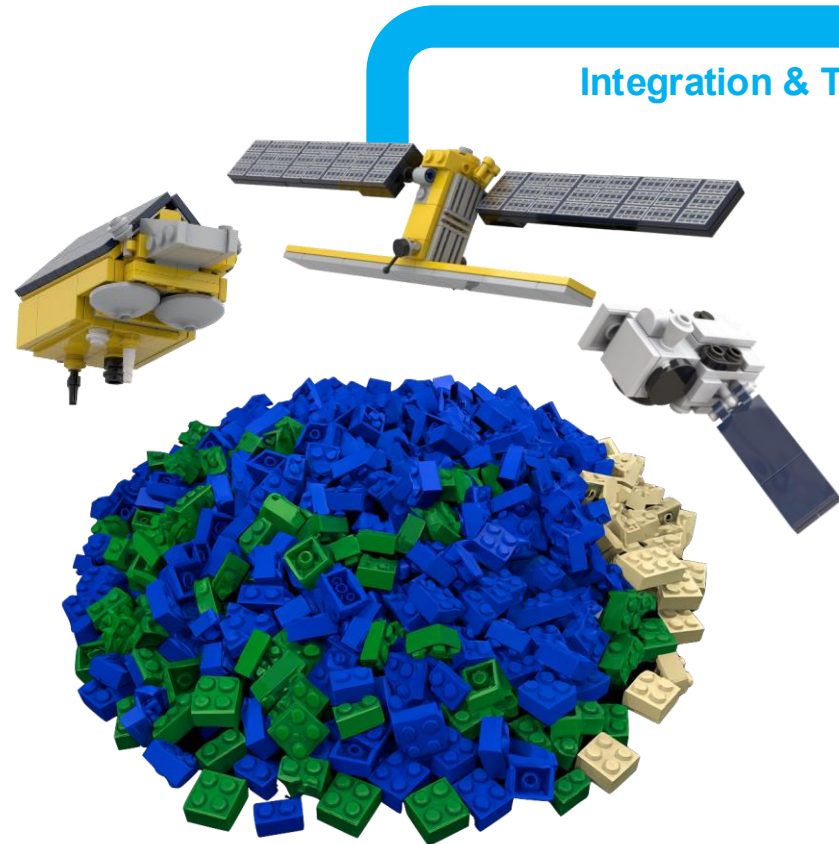
A Single, Reusable Digital Twin: A high-res process replica, serving as a testbed for bridging observations and models.

Building the Ice Sheet Digital Twin Component

Fusing observations and AI algorithms into a unified system.

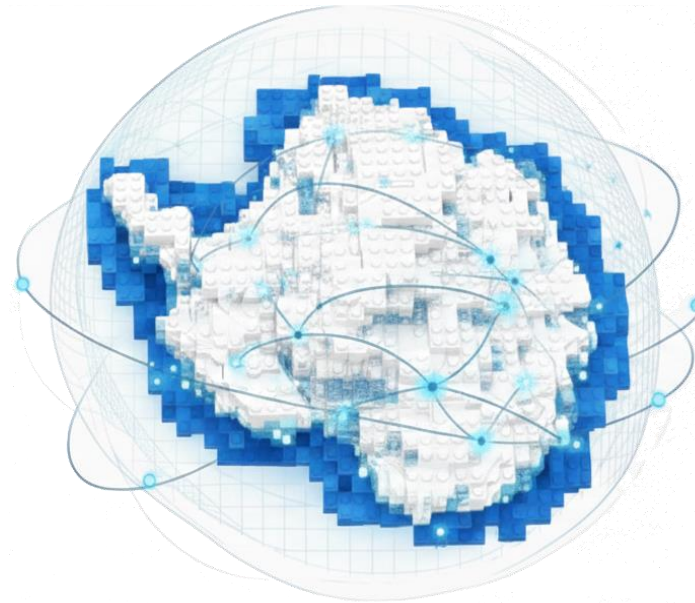
Integration & Training

Coupling & Upscaling



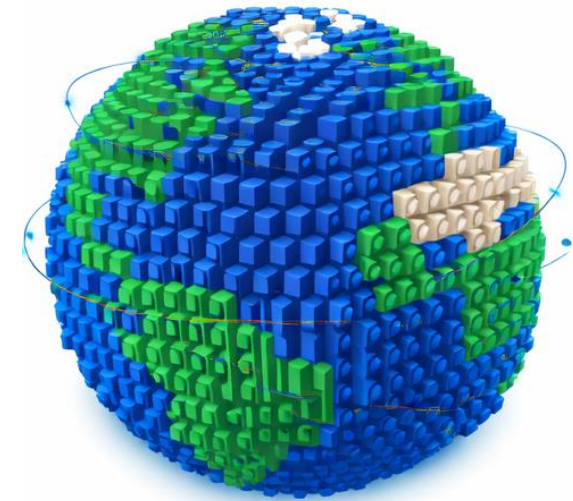
The Building Blocks

EO, In-situ data & algorithms.



The Component

A specialized Ice Sheet Replica.

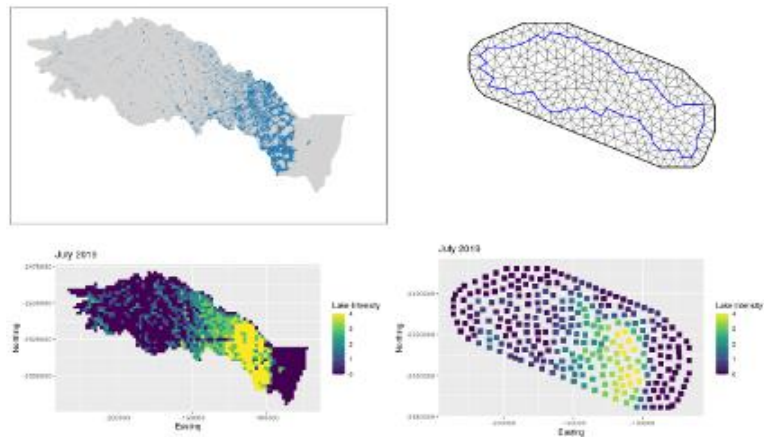
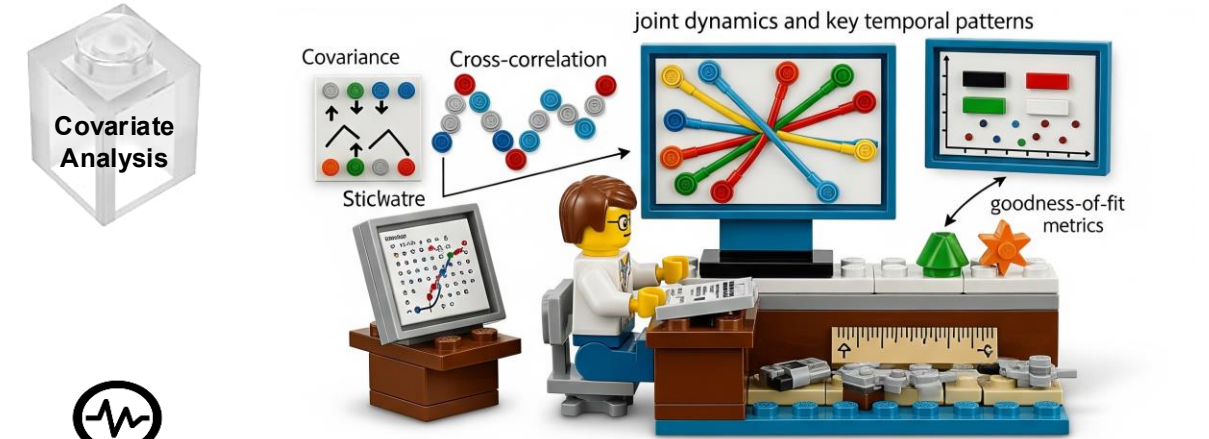


The Ecosystem

Integrated into the full Digital Twin Earth.

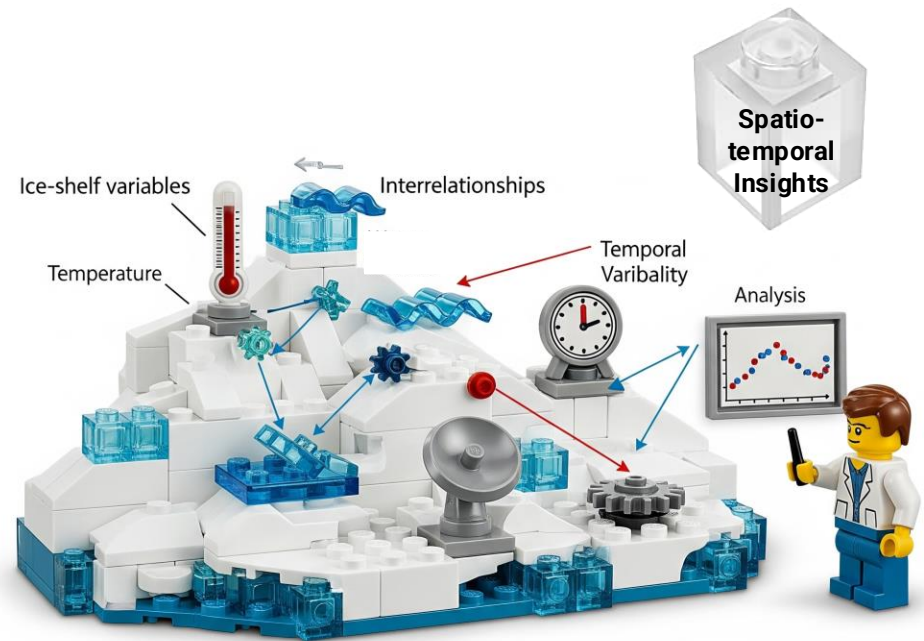
DTC Ice Sheets: A Unified, Reusable Digital Replica

Standardized building blocks shared across the Digital Twin ecosystem.



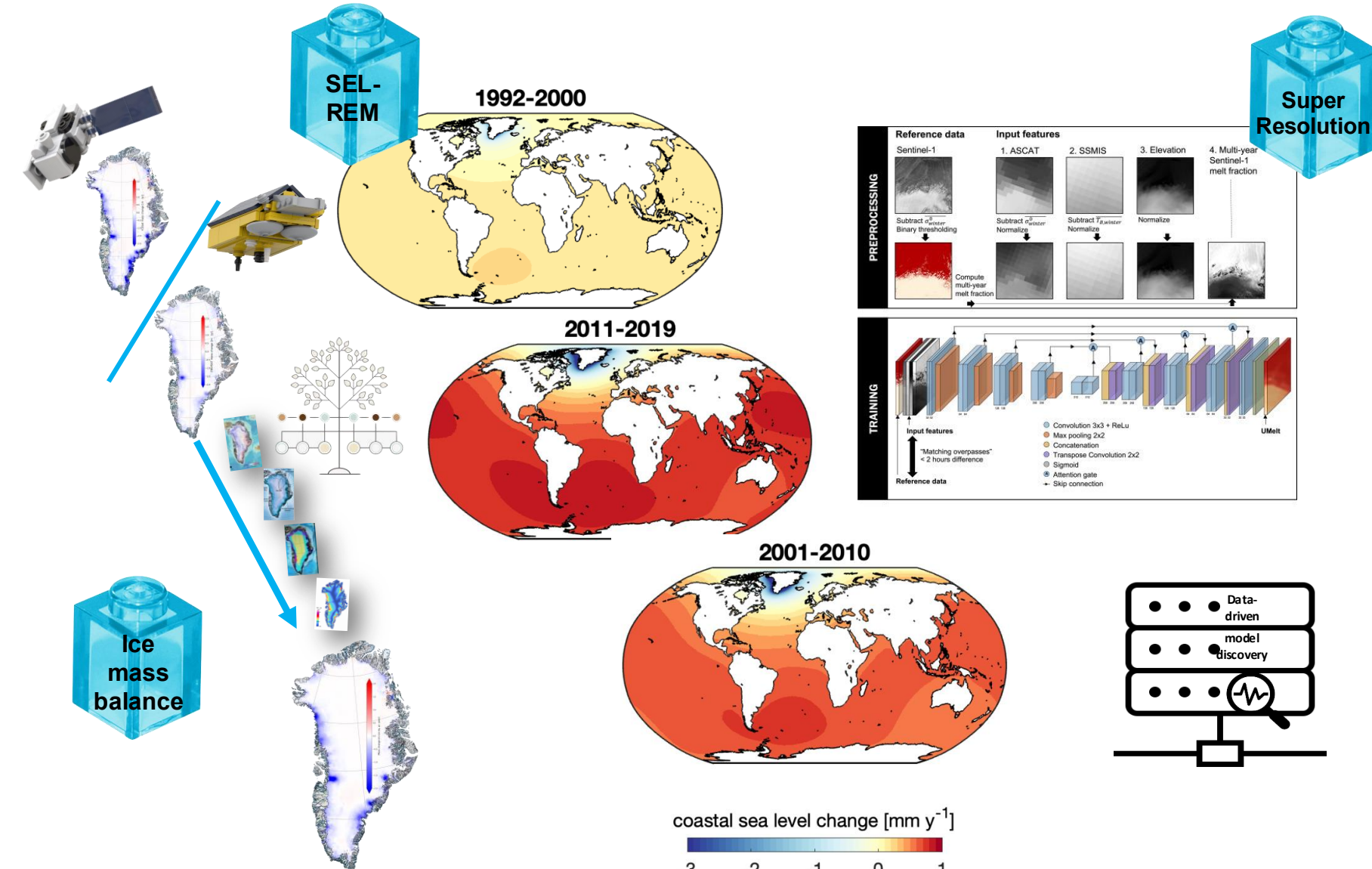
Cross-Twin Compatibility: Developed for ice sheets, but generic enough to be published and used by other Digital Twin components.

Community Library: A growing repository of analysis tools (e.g., Covariance, GRF) ready for reuse.



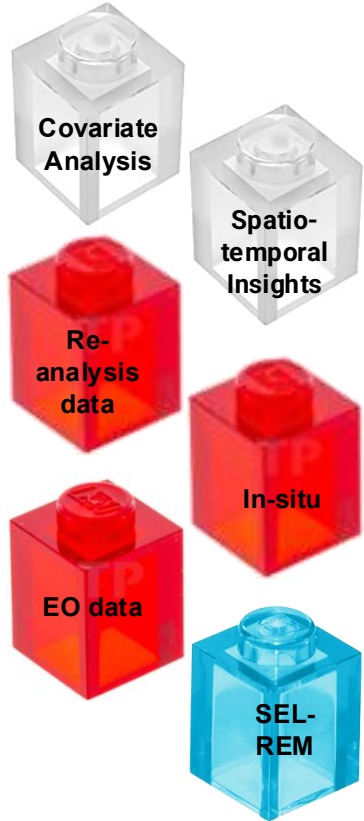
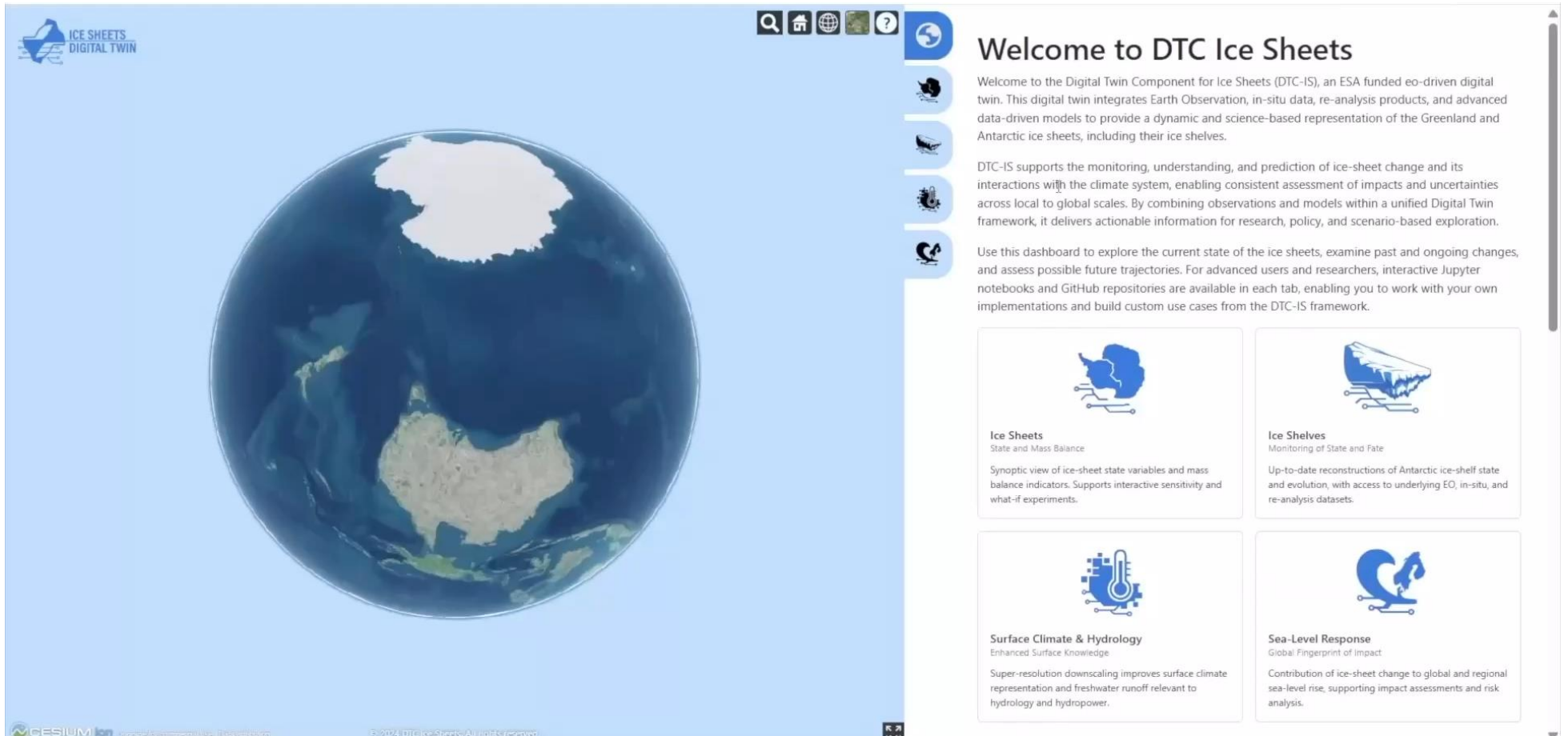
DTC Ice Sheets: A Unified, Reusable Digital Replica

Data-driven AI for mass balance, sea level, and super-resolution.



Let's ask the DTC Ice sheet:

Which ice shelves are vulnerable today, and what are the impacts on the EU sea level

Welcome to DTC Ice Sheets

Welcome to the Digital Twin Component for Ice Sheets (DTC-IS), an ESA funded eo-driven digital twin. This digital twin integrates Earth Observation, in-situ data, re-analysis products, and advanced data-driven models to provide a dynamic and science-based representation of the Greenland and Antarctic ice sheets, including their ice shelves.

DTC-IS supports the monitoring, understanding, and prediction of ice-sheet change and its interactions with the climate system, enabling consistent assessment of impacts and uncertainties across local to global scales. By combining observations and models within a unified Digital Twin framework, it delivers actionable information for research, policy, and scenario-based exploration.

Use this dashboard to explore the current state of the ice sheets, examine past and ongoing changes, and assess possible future trajectories. For advanced users and researchers, interactive Jupyter notebooks and GitHub repositories are available in each tab, enabling you to work with your own implementations and build custom use cases from the DTC-IS framework.

- Ice Sheets**
State and Mass Balance
Synoptic view of ice-sheet state variables and mass balance indicators. Supports interactive sensitivity and what-if experiments.
- Ice Shelves**
Monitoring of State and Fate
Up-to-date reconstructions of Antarctic ice-shelf state and evolution, with access to underlying EO, in-situ, and re-analysis datasets.
- Surface Climate & Hydrology**
Enhanced Surface Knowledge
Super-resolution downscaling improves surface climate representation and freshwater runoff relevant to hydrology and hydropower.
- Sea-Level Response**
Global Fingerprint of Impact
Contribution of ice-sheet change to global and regional sea-level rise, supporting impact assessments and risk analysis.

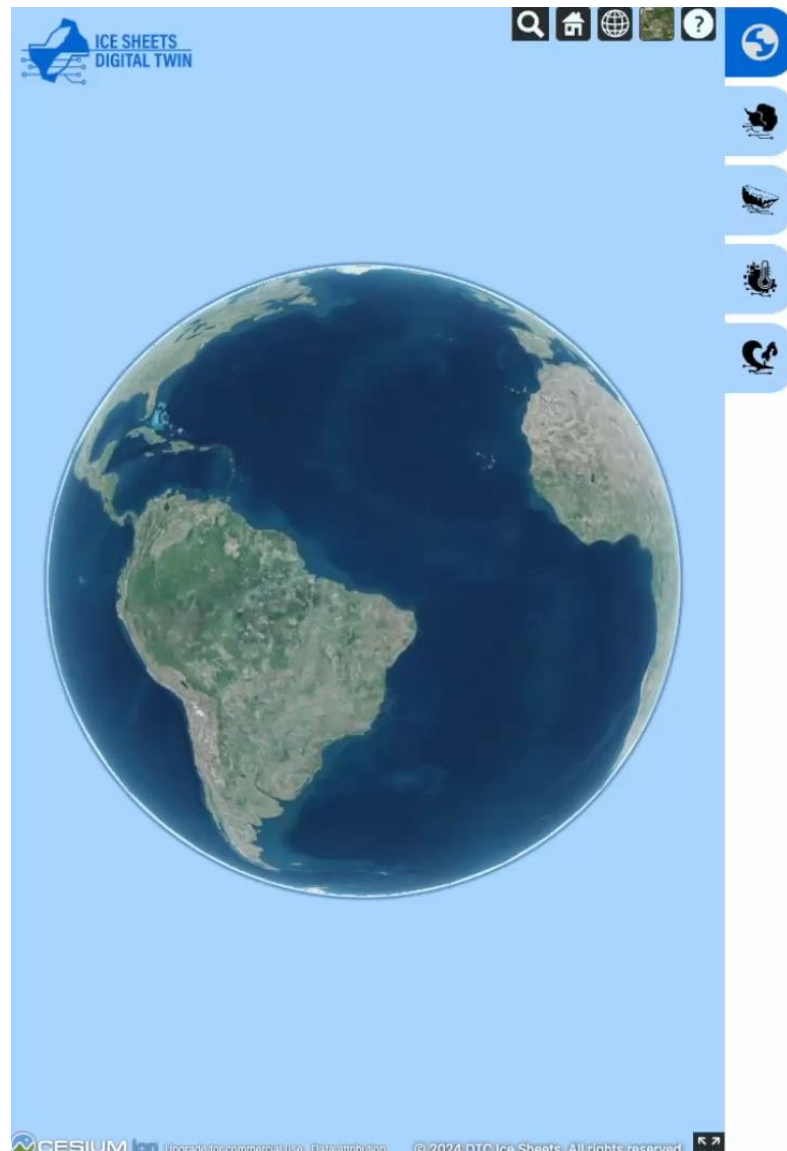
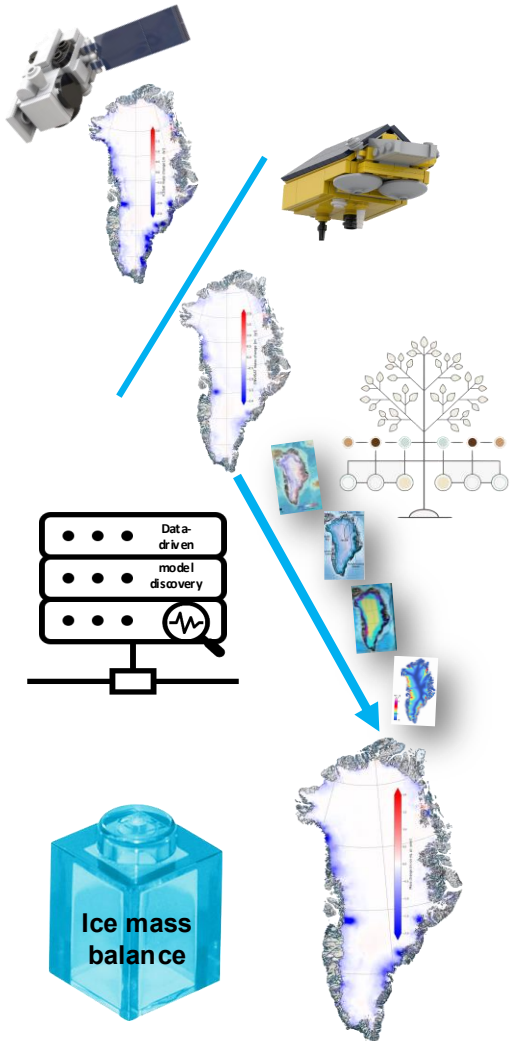


John Palmer Data Scientist, Earthwave
Tabea Rettelbach Postdoc, DTU Space

What can the data tell us about process, connection, and impacts?

Let's ask the DTC Ice sheet:

What if Greenland warms by 2 °C ?



Welcome to DTC Ice Sheets

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<p>Ice Sheets State and Mass Balance</p> <p>Synoptic view of ice-sheet state variables and mass balance indicators. Supports interactive sensitivity and what-if experiments.</p>	<p>Ice Shelves Monitoring of State and Fate</p> <p>Up-to-date reconstructions of Antarctic ice-shelf state and evolution, with access to underlying EO, in-situ, and re-analysis datasets.</p>
<p>Surface Climate & Hydrology Enhanced Surface Knowledge</p> <p>Super-resolution downscaling improves surface climate representation and freshwater runoff relevant to hydrology and hydropower.</p>	<p>Sea-Level Response Global Fingerprint of Impact</p> <p>Contribution of ice-sheet change to global and regional sea-level rise, supporting impact assessments and risk analysis.</p>

Our Modules

Our system is composed of a suite of functional modules, each designed to address specific tasks that support understanding and predicting ice-sheet behavior.

Let's ask the DTC Ice sheet:

What is the seasonal distribution and year-to-year variability in proglacial discharge now, and how might it change in the future?

Unlock Greenland's Hydropower Potential

NAALAKKERSUISUT
GOVERNMENT OF GREENLAND



Supporting the Green Transition in Greenland

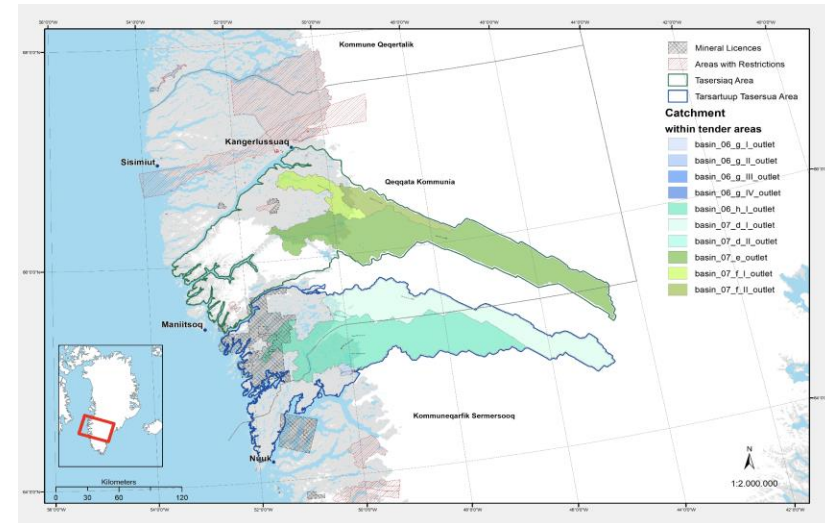


Supports to exploit untapped renewable energy and reduce fossil fuel dependency.

Dynamic Modeling for Water Resources

Past != Future: Historical data (last 30 years) can no longer predict future water availability.

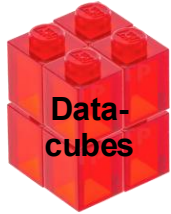
The DT Solution: Forward-looking, dynamic modeling of meltwater runoff ensures resilient, long-term energy planning.



High-Resolution Catchment Analysis

Let's ask the DTC Ice sheet:

What is the seasonal distribution and year-to-year variability in proglacial discharge now, and how might it change in the future?



Data-cubes



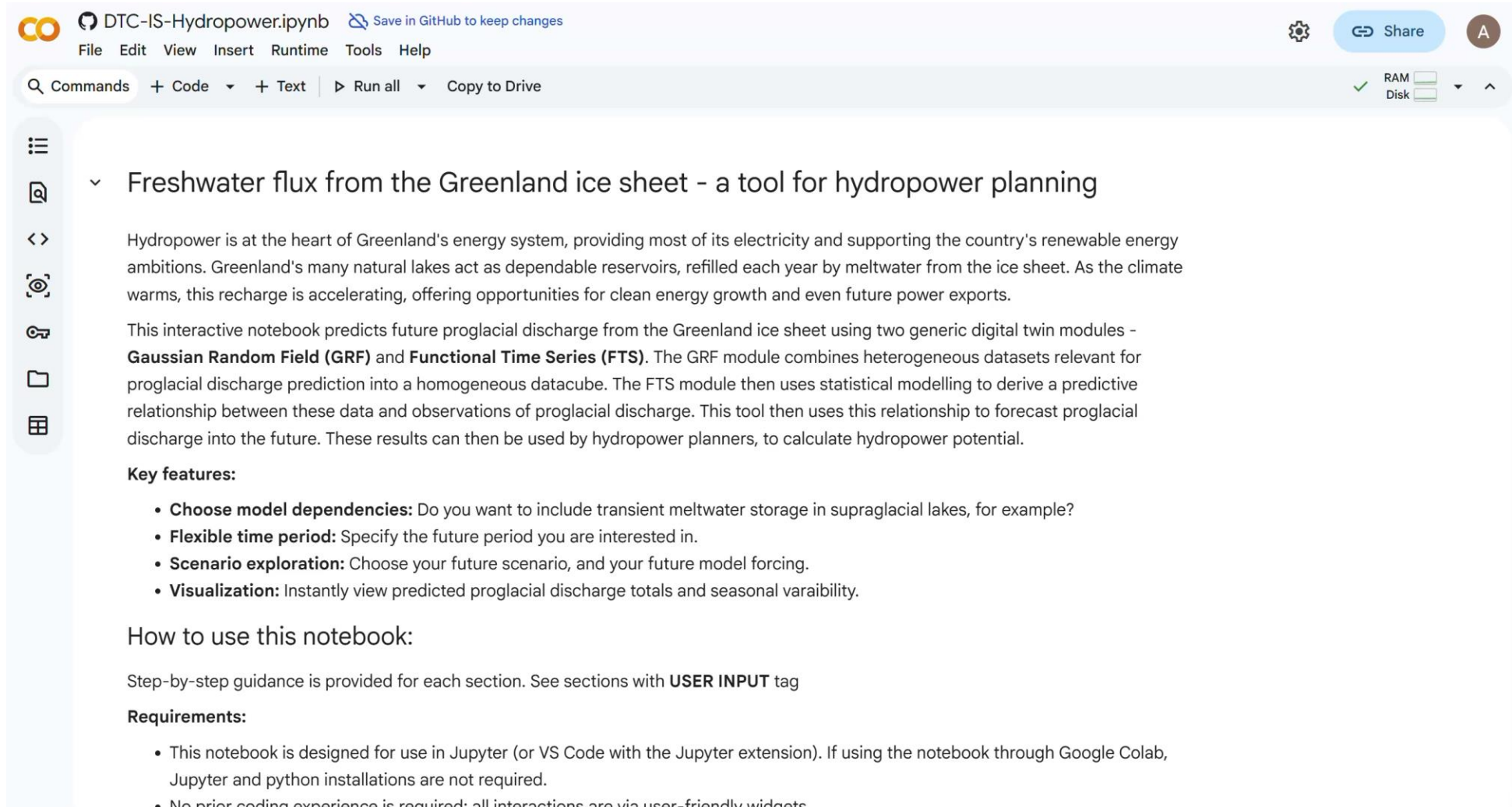
Gaussian Random Field



Functional time-series



Dr Amber Leeson
Reader in Glaciology,
Lancaster University



DTC-IS-Hydropower.ipynb Save in GitHub to keep changes

File Edit View Insert Runtime Tools Help

Commands + Code + Text Run all Copy to Drive

RAM Disk

Freshwater flux from the Greenland ice sheet - a tool for hydropower planning

Hydropower is at the heart of Greenland's energy system, providing most of its electricity and supporting the country's renewable energy ambitions. Greenland's many natural lakes act as dependable reservoirs, refilled each year by meltwater from the ice sheet. As the climate warms, this recharge is accelerating, offering opportunities for clean energy growth and even future power exports.

This interactive notebook predicts future proglacial discharge from the Greenland ice sheet using two generic digital twin modules - **Gaussian Random Field (GRF)** and **Functional Time Series (FTS)**. The GRF module combines heterogeneous datasets relevant for proglacial discharge prediction into a homogeneous datacube. The FTS module then uses statistical modelling to derive a predictive relationship between these data and observations of proglacial discharge. This tool then uses this relationship to forecast proglacial discharge into the future. These results can then be used by hydropower planners, to calculate hydropower potential.

Key features:

- **Choose model dependencies:** Do you want to include transient meltwater storage in supraglacial lakes, for example?
- **Flexible time period:** Specify the future period you are interested in.
- **Scenario exploration:** Choose your future scenario, and your future model forcing.
- **Visualization:** Instantly view predicted proglacial discharge totals and seasonal variability.

How to use this notebook:

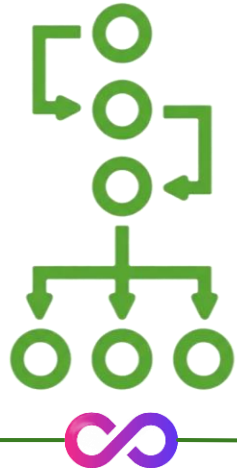
Step-by-step guidance is provided for each section. See sections with **USER INPUT** tag

Requirements:

- This notebook is designed for use in Jupyter (or VS Code with the Jupyter extension). If using the notebook through Google Colab, Jupyter and python installations are not required.
- No prior coding experience is required: all interactions are via user-friendly widgets.

Modules & Workflows

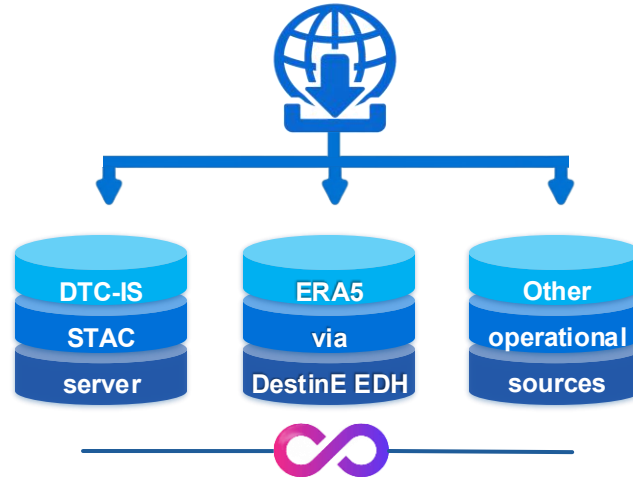
Containerised & Orchestrated
Standardised I/O schemas



Publishable to DeltaTwin & Insula Processing
Compatible with internal DestinE infrastructure

Data Layer

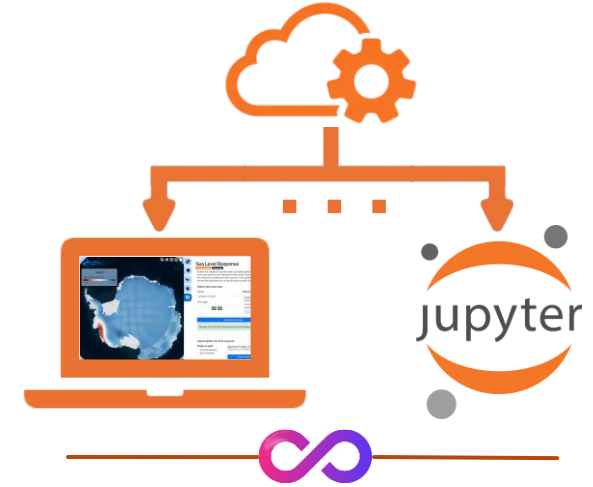
Abstracted data access
On-the-fly GeoZarr conversion



Extensible to other DestinE data access APIs
Internal STAC potentially publishable to DEDL

API & Access

Unified external API
Decoupled dashboards & notebooks



Notebooks to be published in Insula Code
Dashboard onboardable as DestinE service





Cloud-Native, Flexible & Portable Across Platforms

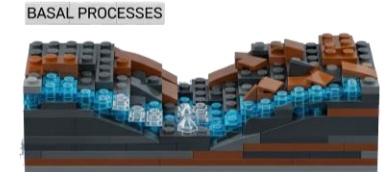


Future opportunities and next steps:

Towards a Full Ice Sheet Digital Twin

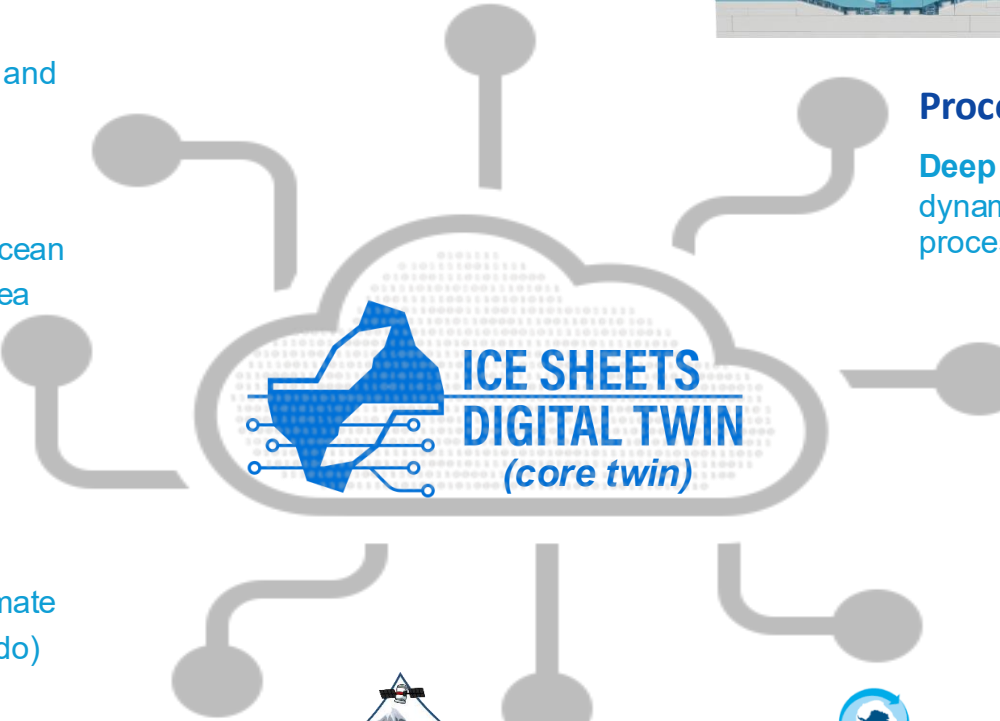
Scale-Up Existing Use Cases

-  **Hydrology:** Implement catchment delineation, water flow routing modeling, and basal melting estimation. Fishery as an added-value stakeholder group.
-  **Sea Level Fingerprint:** Integrate with Ocean DTCs to create holistic, region-specific sea level projections.
-  **Antarctic Ice Shelves:** Develop "early warning" functionalities and "Antarctic Companion" GPT.
-  **Surface Climate:** Broaden the set of climate variables (e.g., snow accumulation, albedo) and improve super-resolution modeling.

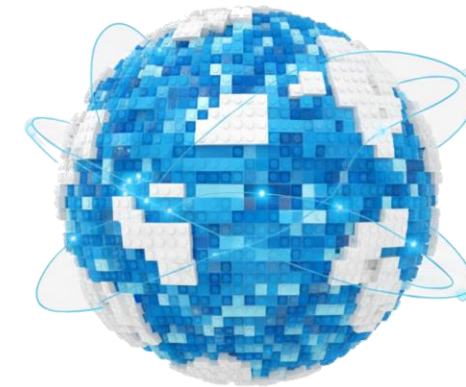
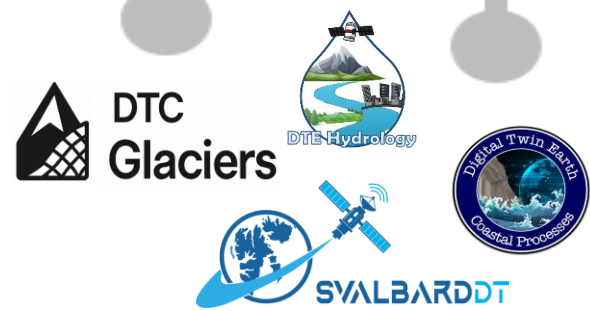


Process Gap:

Deep Physics: New modules for dynamic firn, internal flow & bedrock processes.



A Polar Ocean DTC

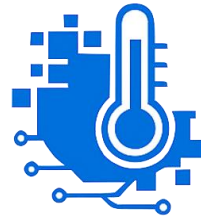

DTC Ice Sheets: A Unified, Reusable Digital Replica

Explore our four reference applications designed to demonstrate tangible value for stakeholders.

Antarctic Ice Shelves
The DT tracks ice-shelf change using satellite data and modeling to help assess risks and feedback between ice and ocean.

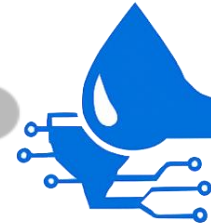


Enhanced Surface Climate
The DT leverages super-resolution modeling techniques to enhance the monitoring and prediction of surface climate conditions over Greenland and Antarctica.



Sea-Level Rise:
The DT improves projections of sea-level changes driven by ice-sheet melt to support regional coastal planning across the EU.

Hydropower in Greenland:
The DT estimates meltwater runoff, enabling better forecasting of hydrological resources for renewable energy planning.



dtc-ice-sheets.org

