



Developing a new Digital Twin for Destination Earth: Technical Progress of TerraDT in its First Year

Narayanappa Devaraju¹, Jenni Kontkanen¹, Jenni Poutanen¹, Juha Tonttila¹, Hendryk Bockelmann², Hauke Schmidt³, Nikolay Koldunov⁴, Daniel Klocke³, Etienne Tourigny⁵, Maria Giuffrida⁶, Harri Kokkola^{7,8}, Thomas Zwinger¹, Mario Acosta⁵, Anton Laakso⁸, and Sara Garavelli¹

¹CSC- IT Center for Science, Advanced Computing Facility Science and Technology Unit, Espoo, Finland

(devaraju.narayanappa@csc.fi)

²Deutsches Klimarechenzentrum GmbH (DKRZ) Bundesstraße 45a, 20146 Hamburg, Germany

³Max Planck Institute for Meteorology Bundesstr. 53, 20146 Hamburg, Germany

⁴Alfred Wegener Institute Klußmannstraße 3 27570 Bremerhaven, Germany

⁵Barcelona Supercomputing Center, 08034 Barcelona, Spain

⁶IT4Innovations national supercomputing center, VSB-TUO, 708 00 Ostrava-Poruba, Czech Republic

⁷University of Eastern Finland, Kuopio, Finland

⁸Finnish Meteorological Institute, Helsinki, Finland

High-resolution, kilometer-scale information on regional climate impacts is critical for effective adaptation and mitigation strategies. The European Commission's Destination Earth (DestinE) Climate Adaptation Digital Twin (Climate DT) aims to address this need; however, actionable impact assessments remain limited by incomplete representation of key Earth system components and their interactions. The Horizon Europe funded TerraDT project tackles these limitations by developing a state of the art Digital Twin focused on the cryosphere, land surface, aerosols, and their coupled processes, fully interoperable within the DestinE ecosystem.

TerraDT pursues three objectives: (1) build and deploy new Digital Twin Components (DTCs) to strengthen process realism and enable impact assessments; (2) deliver a modular, scalable, interoperable platform integrating advanced software, high-performance computing, and data workflows that can host physical models and Artificial Intelligence (AI)/Machine Learning (ML) emulators; and (3) foster user uptake through early engagement and a User centric Interface (UI).

In its first year, TerraDT achieved several milestones:

- **Cryosphere:** A prototype Land-Ice DTC was established by coupling Elmer/Ice with ICON climate model via YAC coupler, supported by curated glacier dynamics datasets. Development of the Sea-Ice DTC (FESIM) began in mid-2025, including YAC-mediated coupling and an AI sea-ice emulator capable of ~100-day to multi-year rollouts, producing smoother fields than physical models.
- **Land Surface:** A prototype time-varying land use dataset was generated for ECLand and ICON land surface models.

- **Aerosols:** A simplified Aerosol DTC was tested, with integration into (open) Integrated Forecasting System (IFS). ML components were prototyped in HAM-LITE to capture advanced aerosol physics (e.g., hygroscopicity) at reduced computational cost.

Impact modelling advanced across multiple domains:

- **Sea-ice:** Assessments of ice season duration, severe condition probabilities.
- **Forest:** Integration of 3PG and Prebasso models, calibration across European ecosystems, ML emulation of Prebasso, and characterization of old-growth forests.
- **Urban:** A carbon-sequestration emulator validated in Helsinki, with planned extensions to Lisbon, Barcelona, Munich, Paris, and Zurich. Key data sets required are prepared in combination with ML methods, and will be applied to build advanced Urban impact models for assessing climate extremes.

Infrastructure and interoperability were strengthened through YAC based coupling (ICON-Energy Balance Firn Model-Elmer/Ice on LUMI and Levante Supercomputers), and Sea Ice DTC I/O plans were aligned with DestinE workflows. A map-based UI architecture was designed to expose high resolution impact assessments for decision support.

By advancing new DTCs, AI/ML emulators, and generic coupling interface, TerraDT is being developed for full integration into the DestinE framework, ensuring compatibility and enhancing the overall ecosystem's capability to inform climate adaptation and mitigation strategies. This presentation will summarize first year progress, outline objectives, and present the roadmap toward fully coupled simulations, validation, and dissemination of impact indicators through TerraDT UI for policy and stakeholder communities.