

A digital twin for geophysical extremes: Interim results from the DT-GEO project

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DT-GEO



This project has received funding from the European Union's Horizon research and innovation programme under the grant agreement No 101058129

DT-GEO project Information

Type of Action	HORIZON-RIA	
Call	INFRA-2021-TECH-01	Next generation of scientific instrumentation, tools and methods
Topic	INFRA-2021-TECH-01-01	Interdisciplinary digital twins for modelling and simulating complex phenomena at the service of research infrastructure communities
Dates	From Sep 2022 to Aug 2025	
Budget	15,1 M€	
Consortium	Geophysics domain	Research, Academia, Private
	Research Infrastructures	  



INFRA-2021-TECH-01-01



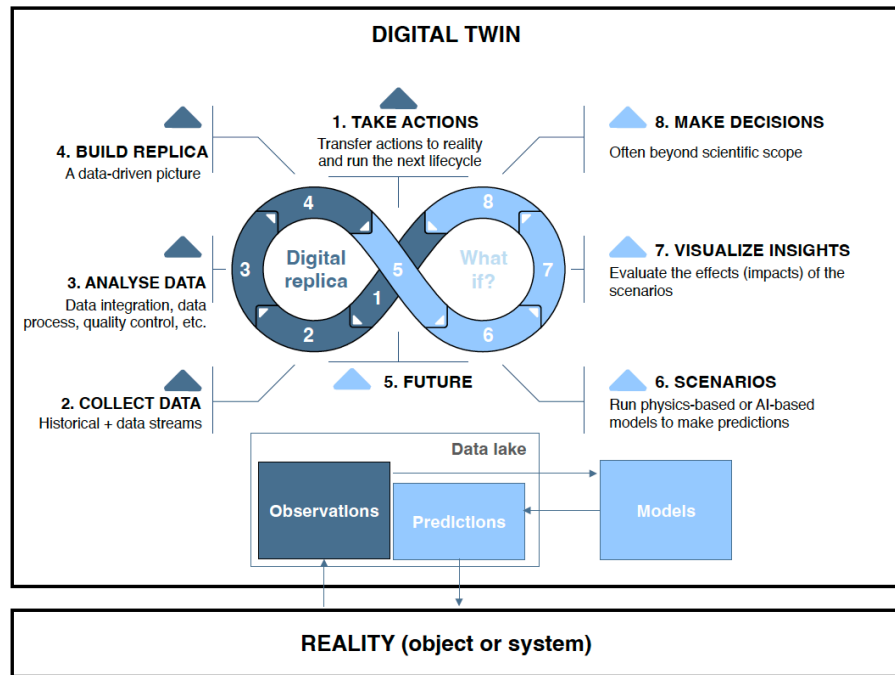
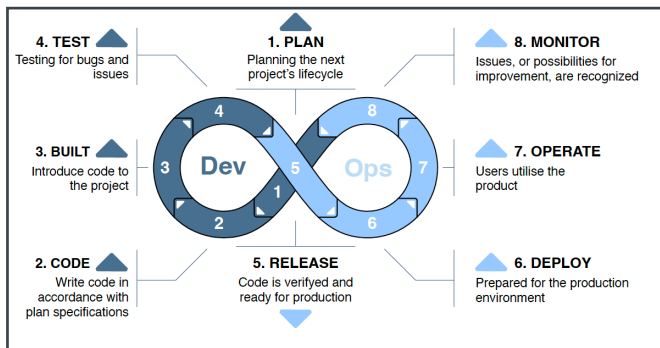




The concept of Digital Twin (DT)

A Digital Twin is a **virtual lifecycle environment** that contains a data-informed **replica** of a real system, model-based **prediction** capabilities (scenarios) and, **ideally, can provide feedback** (decisions) to **modify** the real system (i.e. to close the lifecycle loop)

Analogy with the DevOps cycle in software engineering



DT-GEO general objectives

01

Deploy a pre-operational prototype of **Digital Twin (DT) on geophysical extremes** (potential integration in the Destination Earth flagship initiative)

02

Implement 12 **Digital Twin Components (DTCs)** addressing specific hazardous phenomena from **volcanoes, tsunamis, earthquakes**, and anthropogenically-induced extremes in order to conduct data-informed:

1. Early Warning Systems (EWS)
2. Short-term forecasts
3. Long-term hazard assessments

03

Provide a flexible framework for **automated FAIR-validation** of Digital Assets (DAs) and its integration in 2 Research Infrastructures (RIs)

04

Verify the DTCs in operational environments at 13 **Site Demonstrators** (SDs) of particular relevance located in Europe and beyond



DTC	Hazard	Name
1	Volcano	Volcanic unrest
2		Volcanic ash clouds
3		Lava flows
4		Volcanic gas dispersal
5	Tsunami	Tsunami Forecasting
6	Earthquake	Seismic Hazard
7		Earthquake forecasting
8		Tomography
9		Fault rupture
10		Shaking simulation
11	Aftershocks	
12	Anthropogenic	Anthropogenic seismicity

The DT-GEO structure

WP2	Workflows and data architecture
WP3	Computational infrastructure
WP4	Metadata and automated FAIRness evaluation of Digital Assets

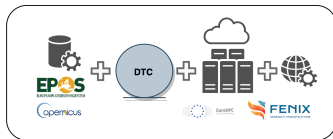
Transversal elements: provide homogeneity and interoperability across the DTCs (leveraged from other projects)

WP5	WP6	WP7	WP8
<p>Volcanoes</p> <ul style="list-style-type: none"> • 4 DTCs for volcanoes • 3 SDs 	<p>Tsunamis</p> <ul style="list-style-type: none"> • 1 DTCs for tsunamis • 4 SDs 	<p>Earthquakes</p> <ul style="list-style-type: none"> • 6 DTCs for earthquakes • 4 SDs 	<p>Anthropogenic</p> <ul style="list-style-type: none"> • 2 DTCs for anthropogenic • 2 SDs

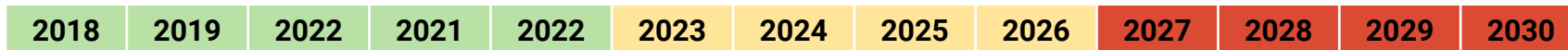
Vertical pillars

12
Digital Twin Components
(DTCs)

13
Site Demonstrators
(SDs)



An ecosystem of European projects



Pillar use cases (earthquakes and tsunamis)

eFlows4HPC
 workflow software stack
 (pillar on natural hazards)

DT architecture, services and software stack

DT-GEO
 Digital twin components

DT on geophysical extremes ?



DestinE
 High-resolution operational digital twins

EOSC-Synergy
 e-infrastructures

FAIR evaluators and SQAaaS

EuroHPC
 tier-0
 tier-1



ChEESE-1P
 Codes, Pilot Demonstrators and services on geohazards

ChEESE-2P
 Codes, Pilot Demonstrators and services on geohazards

ChEESE

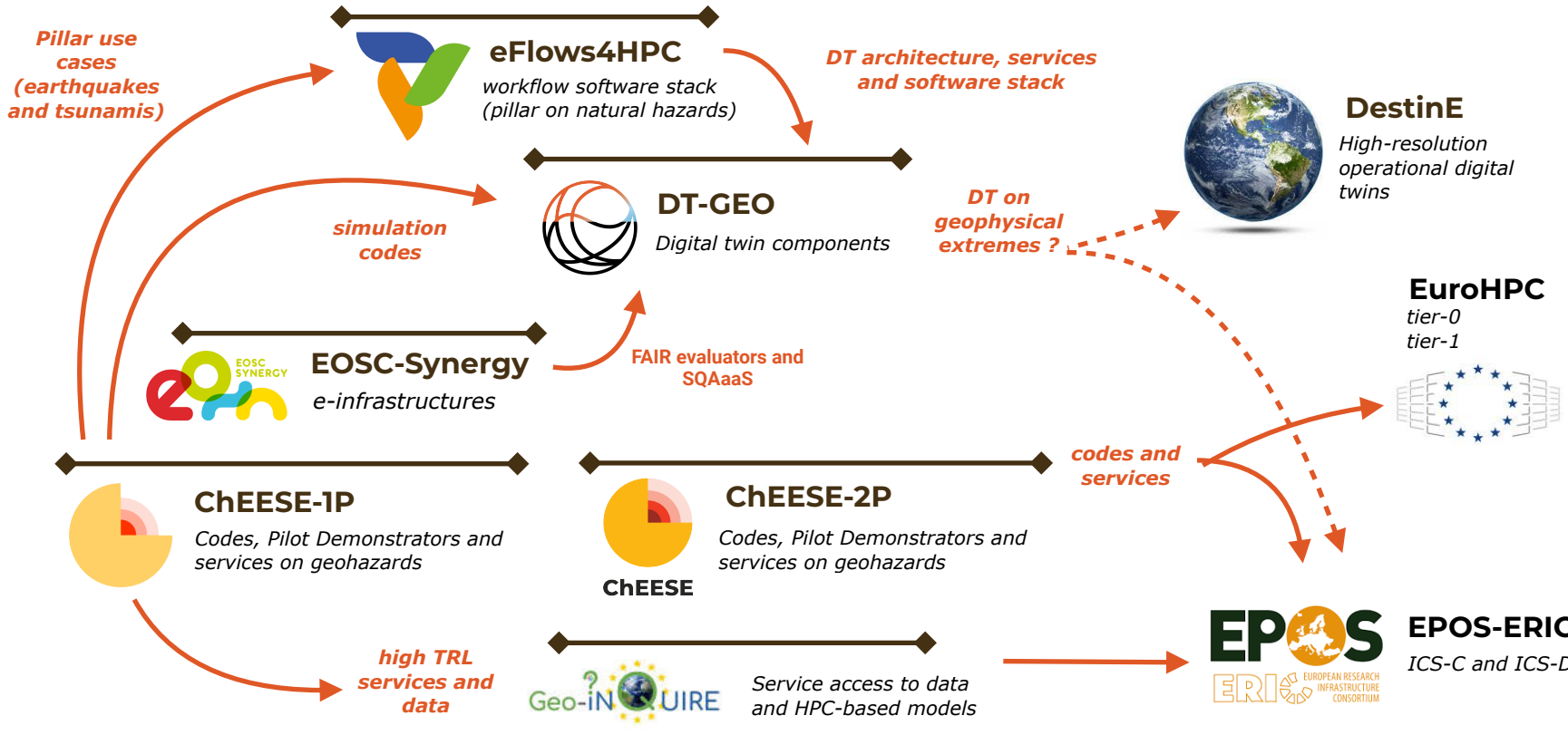
codes and services

high TRL services and data

Geo-INQUIRE
 Service access to data and HPC-based models

EPOS-ERIC
 ICS-C and ICS-D

ERI EUROPEAN RESEARCH INFRASTRUCTURE CONSORTIUM



DT-GEO: current status

1

Phase 1

2

Phase 2

3

Phase 3

From M1 to M12

From M13 to M24

From M25 to M36

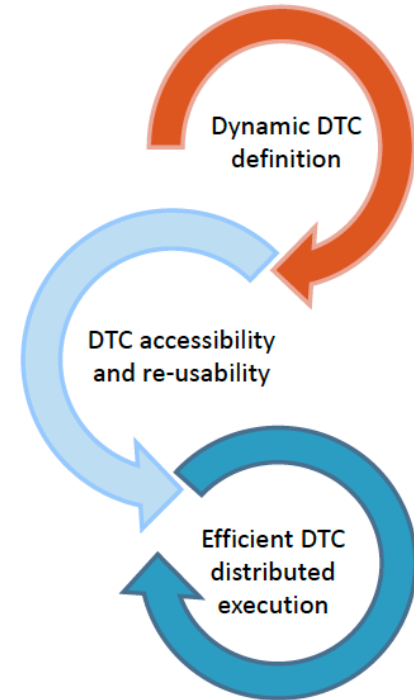
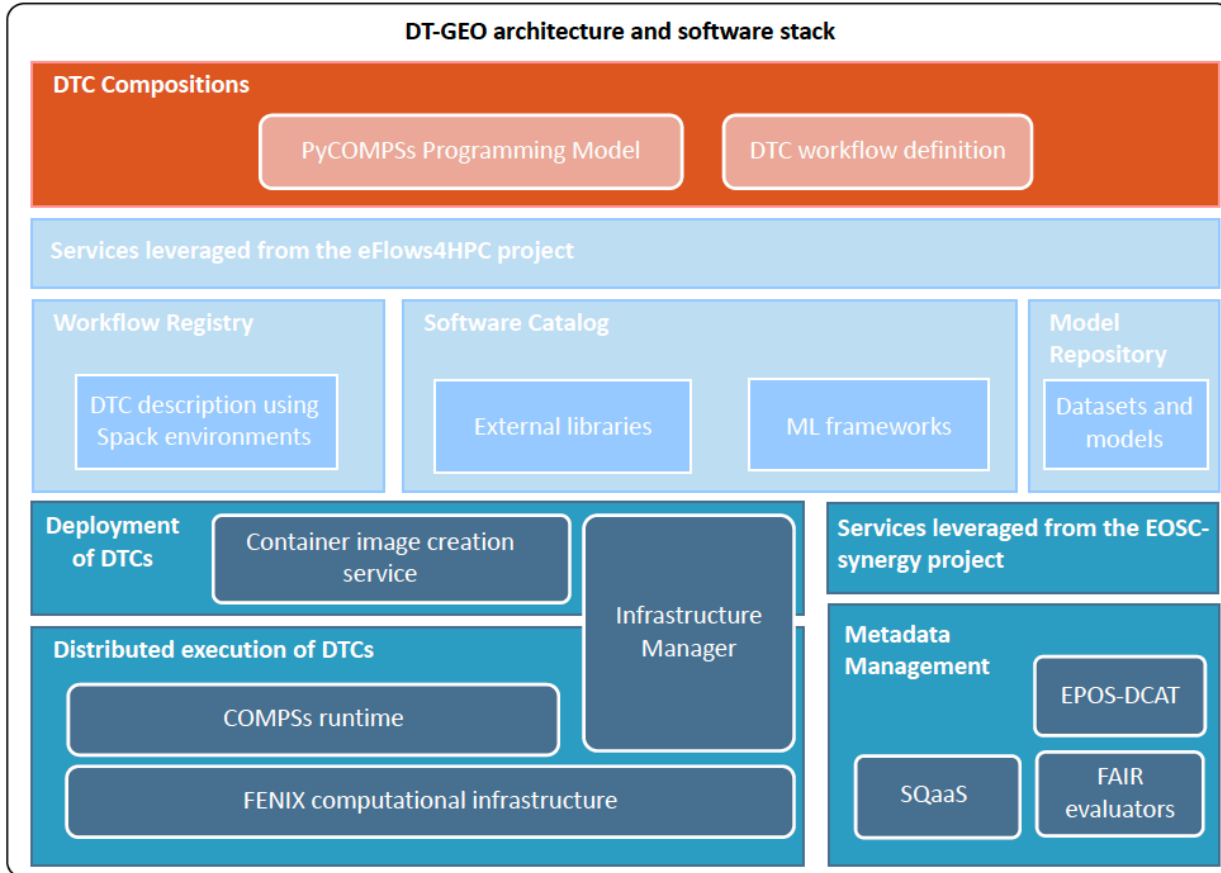
- ✓ Project setup
- ✓ Collection of requirements
- ✓ Define the computational infrastructure
- ✓ Blueprint of DT architecture
- ✓ Metadata scheme
- ✓ FAIR quality-based ecosystem

- ✓ Beta implementation of the DTCs
- ✦ Early execution of SDs in the FENIX cloud infrastructure (testing/staging)
- ✓ Design and development of the DT architecture, second iteration loop

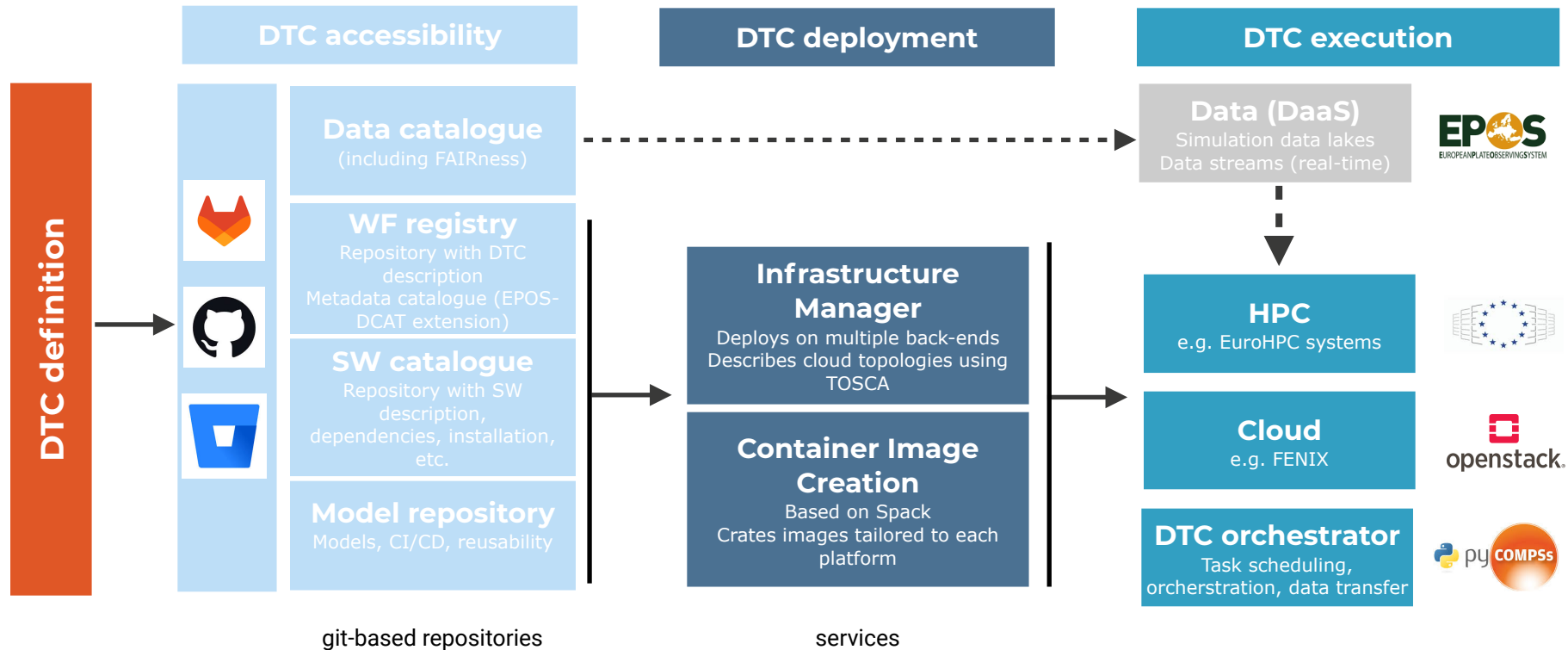
- Further implementation of the DTCs (some coupled)
- Run the SDs in operational environments using HPC

DT-GEO blueprint architecture

DT-GEO architecture and software stack



DT-GEO blueprint architecture



Workflow architecture

- Set up an organization (<https://gitlab.com/dtgeo>) in GitLab including **Workflow Registry** and the **Software Catalog**.
- Set up of Container Image Creation tool (for specific target machines).
- CI/CD approach to validate the DTCs in the staging environment and generate push-driven container images.

dtgeo

©2022 A Digital Twin for GEophysical extremes (DT-GEO) is a European project that aims to analyse and forecast the impact of tsunamis, earthquakes, volcanoes, and anthropogenic seismicity. This project has received funding from the European Union's Horizon Europe research and innovation programme under [Grant Agreement n° 101058129](#).

Subgroups and projects Shared projects Inactive

Search (3 character minimum) Name

Project Name	Description	Stars	Created
DT-GEO Documentation	DTGEO: Trainings and wikis	0	1 month ago
Metadata	DT-GEO: Metadata, SQAaaS and EPOS Turtle Files	0	3 months ago
EPOS Turtle files		0	1 hour ago
QA_tracking	Hosts SQAaaS assessment reports for digital objects created during DT-GEO	0	2 months ago
SQA Assessment CI Template	Collection of pipeline templates designed to easily integrate SQAaaS inside projects for Software Qualit...	0	1 week ago
Site Demonstrators (SD)	DTGEO: catalogue of Site Demonstrators	0	13 months ago
Workflow Management System	DTGEO: Workflow registry, software catalog and COMPSs config	0	5 months ago
COMPSs Config		0	1 month ago
Image Creation	Service for creating container images for eFlows4HPC platform	0	1 day ago
software-catalog	Repository to store the description of the software to be used in DTC workflows using the Spack metho...	0	1 month ago
workflow-registry	Repository to store the Workflow descriptions using the Spack environment methodology	1	2 hours ago
Repository Documentation	DT-GEO: repository documentation and templates	0	1 month ago
SQA Assessment Image		0	2 weeks ago

SQAaaS reports for the different DAs

SQAaaS pipeline templates

Configuration files to submit COMPSs jobs to Slurm in different clusters

Description of the software from DTCs using the Spack methodology

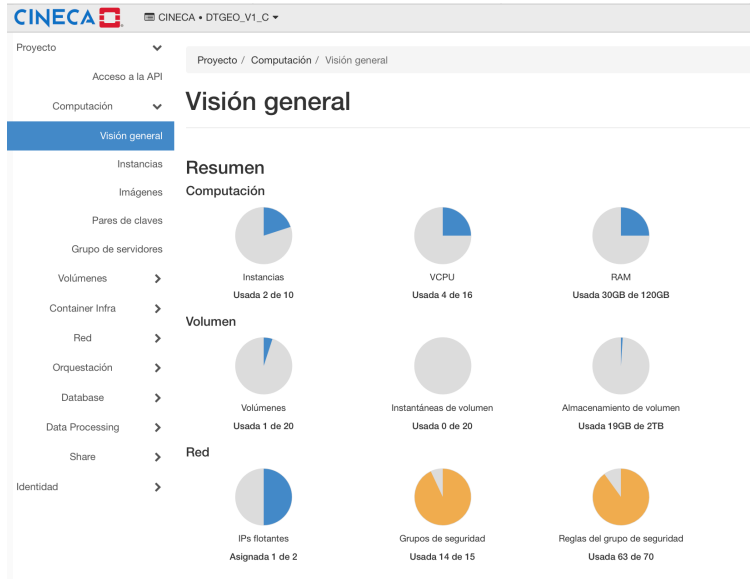
Store the WF descriptions using the Spack environment methodology (at least the TOSCA description of the WF), the code of the different steps, and the required software per step

Computational architecture

- DT-GEO uses an **Infrastructure Manager (IM)** to deploy DTCs execution in cloud environments.
 - Open stack @CINECA ADA cloud service (IaaS) for DTC testing (cloud).
- The DTC execution (SDs) will rely on HPC.
- Configuration of Spack modules on the HPC clusters and support for PyCOMPSs module configuration.

ADA OpenStack dashboard: <https://adacloud.hpc.cineca.it>
Documentation: [link](#)

Interactive computing service: <https://jupyter.g100.cineca.it/hub>
Documentation: [link](#)



Interactive session parameters setting

? User Guide

Slurm Reservation: None

Slurm Account: dtgeo_v1

Number of cores: 1

Memory (MB): 4096

GPU configuration: None

Time (hours): 1,0

ICE4HPC Backend Environment: Release 2023.10

User interface: Jupyterlab

AVAILABLE COMPUTATIONAL RESOURCES

	Nodes	Total Number of cores	Total Free Memory (MB)
No available GPUs	0	/	/
1 available GPU	0	/	/
2 available GPUs	9	432	3.467.700

Start

FAIRness evaluation of DTCs

- Services for DTC reusability (catalogues, registries, and repositories), including the creation of a **Workflows Hub Registry**.
- Recording of workflow provenance: **capture the details of a DTC execution as metadata**.
- The interoperability of the generated metadata is guaranteed by the use of the RO-Crate specification.
- RO-Crate (Research Object Crate) is a method for aggregating and describing research data with associated metadata.

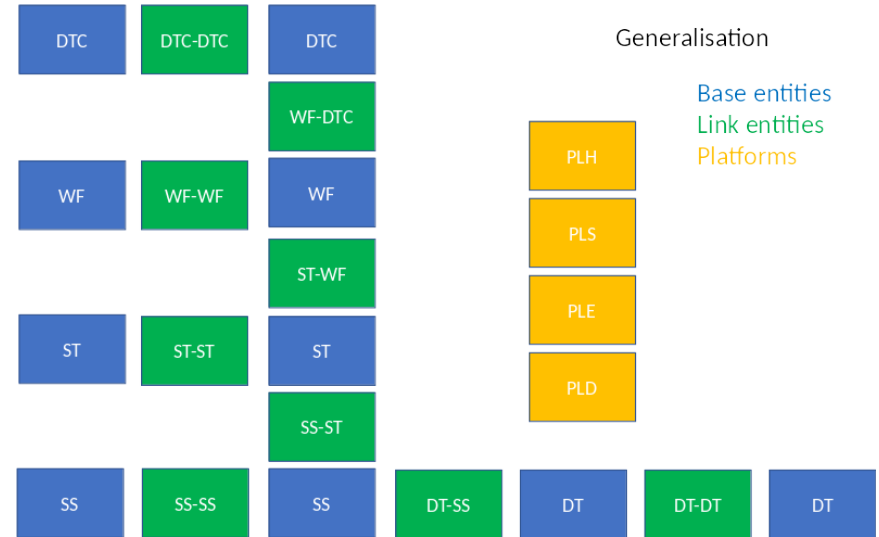
The screenshot shows the WorkflowHub interface for the project 'A Digital Twin for GEOPhysical extremes (DT-GEO)'. The page includes a search bar, navigation links (About, Help, Register, Log in), and a 'Related items' section. The 'Related items' section lists four work packages (WPS) with their descriptions, space information, and public web pages.

Work Package	Description	Space	Organisms
WPS - Anthropogenic geophysical extremes	Develop and implement 1 DTC for Anthropogenic Geophysical Extreme Forecasting (AGEF) with 4 workflow outcomes: forecasting of long-range responses of geoservisors (TC-AGEF1), forecasting of late responses of geoservisors (TC-AGEF2), modeling of the largest magnitude (TC-AGEF3), and induced seismic hazard map estimation (TC-AGEF4). Test the DTC-A through demonstrators at 2 relevant European sites: Strasbourg geothermal site in France (SD12) and KGRM copper ore mine in Poland (SD13).	Space: A Digital Twin for GEOPhysical extremes (DT-GEO) Public web page: https://dtgeo.eu/	Organisms: Not specified
WPS - Earthquakes	Provide an integrated, comprehensive, modular modelling and testing framework Develop multi-scale workflows applicable beyond the identified test-areas enabling improved physical understanding and progress beyond state-of-the-art in the earthquake process. Develop and implement 6 DTCs covering earthquake-related aspects over long and short time scales Test the 6 DTC-E at 4 relevant sites: Euro-Med (SD8), Central Apennines and Alto-Tiberina (SD6), Bedretto Lab (SD10) and the Alps (SD11).	Space: A Digital Twin for GEOPhysical extremes (DT-GEO) Public web page: https://dtgeo.eu/	Organisms: Not specified
WPS - Tsunamis	Develop and implement 1 DTC for data-informed Probabilistic Tsunami Forecasting (PTF) (DTC-T1) Test the DTC-T1 through demonstrators at 4 relevant sites: Mediterranean sea coast (SD4), Eastern Sicily (SD5), Chishan coast (SD6), and Eastern Honshu coast in Japan (SD7).	Space: A Digital Twin for GEOPhysical extremes (DT-GEO) Public web page: https://dtgeo.eu/	Organisms: Not specified
WPS - Volcanoes	Develop and implement 4 DTCs for volcano-related extremes: volcanic unrest (DTC-V1), threat of volcanic ash clouds and fallout (DTC-V2), lava flows (DTC-V3), and volcanic gases (DTC-V4). Test the 4 DTC-V through demonstrators at 3 relevant European sites: Mt. Etna in Italy (SD1), and Grimsvötn and Fagradalsfjall in Iceland (SD2 and SD3 respectively).	Space: A Digital Twin for GEOPhysical extremes (DT-GEO) Public web page: https://dtgeo.eu/	Organisms: Not specified

<https://workflowhub.eu/programmes/36#projects>

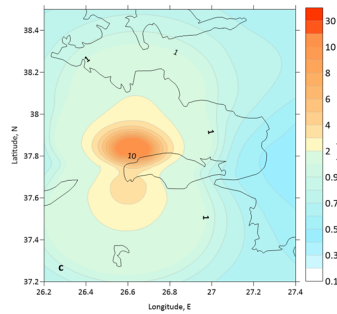
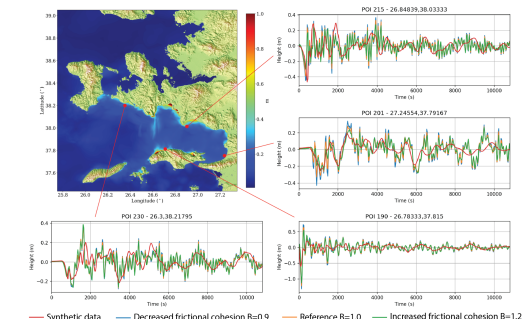
Data architecture

- Metadata schemes to characterise the DTCs and their relationships (aligned with geo-INQUIRE):
 - **DCAT**: Data Catalog vocabulary for publishing data catalogs on the web (<https://www.w3.org/TR/vocab-dcat/>).
 - **EPOS-DCAT-AP**: an extension of the DCAT Application Profile for Research Infrastructures in the solid-Earth domain based on the Common European Research Information Format (CERIF).
 - **DT-GEO**: further extension of EPOS-DCAT to accommodate metadata for new entities in the DT-GEO schema such as Workflow and Step.
- Adoption and extension of the EOSC-synergy SQAaaS platform for assuring quality on DAs (e.g. FAIR-EVA has been extended with a specific plugin to integrate with the EPOS-DCAT catalog).



What's next?

Figure 1.2.4. Location and definition of the 13 Site Demonstrators (SD) used to validate the 12 DTC in relevant and operational environments (TRL 6 and 7)



WP5	3 SDs
WP6	4 SDs
WP7	4 SDs
WP8	2 SDs

SD2 Grímsvötn volcano (Iceland)
Used by DTC-V2

Grímsvötn is a subglacial volcano which sits in the middle of Vatnajökull glacier. Its activity is characterized by frequent phreato-magmatic eruptions with the last eruption that occurred in 2011. Typical eruptions produce tephra fallout, volcanic clouds, lightnings and glacial floods as the main hazards. It is currently in a pre-eruptive status and an eruption is expected in the coming months. This DTC may be changed on-the-fly if another Icelandic volcano erupts during the project.

SD3 Fagradalsfall volcano (Iceland)
Used by DTC-V3 and DTC-V4

Since March 19th 2021, an eruption is ongoing at Fagradalsfall volcano which belongs to the Krysuvik volcanic system in the Reykjanes peninsula (SW of Iceland). The eruption is featuring an effusive eruption accompanied by a constant release of volcanic gases. Given its vicinity to inhabited areas (less than 30 km from key sites), occurrences of low air quality event are the main hazard.

SD12 Strasbourg geothermal site (France)
Used by DTC-A1

SD12 is located in Strasbourg, France where 4 projects of deep geothermal energy have been initiated. One of them (GEOVEN in Vendenheim, 10 km to the North of Strasbourg) is facing a major seismic crisis after a series of earthquakes (3-M<3.9) since Nov 2019 that have create a large number of building damages in the area. A moratorium on all the projects have been stated by the legal authorities before an extended investigation for which the DT-GEO project could be an important contribution.

SD8 Euro-Med (Continental)
Used by DTC-E1, DTC-E2, DTC-E3, DTC-E5, DTC-E6

The European-Mediterranean is a complex tectonic region, with seismicity ranging from very active to very quiet, and a long history of catastrophic events shaping the economy and social structure of entire regions; seismicity is monitored by national agencies and the European-Mediterranean Seismological Center (EMSC/EPOS) and all knowledge on seismicity and faults converge in the European Seismic Hazard Model 2020 (ESHM20, www.efeh.org)

SD1 Etna volcano (Italy)
Used by DTC-V1 and DTC-V3

Mount Etna is one of the most active volcanoes in the world, and arguably the most monitored and studied one. The most frequent activities characterizing Mount Etna span from eccentric vent opening and lava flows menacing the several villages along its flanks and the city of Catania, to lava fountains and ash-rich volcanic plumes causing risks for the nearby international airport and air traffic circulation, to damaging earthquakes on its eastern foothills. A dedicated volcano observatory managed by INGV provides 24/7 surveillance as well as maintenance and development of a highly sophisticated multi-parametric monitoring network.

SD10 Bedretto (Switzerland)
Used by DTC-E4

The Bedretto Deep Underground Laboratory was established by ETH in a tunnel located under the Gotthard Massif, with a large cavern located at over 2 km from the entrance at over 1200 m depth (www.bedretto.ethz.ch), enabling experiments for geo-energies and earthquake physics on scales of 50-400 m, including the ERC Synergy project Fault Activation and Earthquake Rupture (FEAR).

SD13 KGHM ore mine (Poland)
Used by DTC-A1

Copper-ore mines of KGHM Polska Miedź S.A. in Poland, which is facing severe problems of dynamic and continuous mining-induced deformation. The mines are very active seismically, with induced earthquakes of magnitude occasionally exceeding 4.0 and with major rockbursts. In addition to resultant in-mine damage, this seismicity has also damaging consequences for buildings and other surface objects. Subsidence and other surface deformation effects also occur.

SD11 Alps
Used by DTC-E5

The Alparray Seismic Network (www.alparray.ethz.ch) covered the whole alpine region with the densest high-quality seismic array ever installed globally, with over 700 broad-band seismic stations, extending over 8 countries and with 24 participating national institutions, to integrate present-day Earth observables with high-resolution geophysical imaging of 3D structure.

SD9 Central Apennines and Alto-Tiberina (Italy)
Used by DTC-E1, DTC-E2, DTC-E3, DTC-E4

Due to the long history of catastrophic earthquakes, including the recent sequence Amatrice-Norcia (2016-2017), this area is the best monitored in the Euro-Med region (www.gm.ingv.it) and includes the Alto-Tiberina Near-Fault Observatory (DOI:10.4401/ag-6426, EPOS) offering dense multi-parameter real-time observations on a very active fault.

SD5 Eastern Sicily (Italy)
Used by DTC-T1

Testing the PTF for both earthquake and coupling to earthquake induced landslide sources along the Eastern Sicily coast. This includes also coupling to modelling tsunami inundation for landslide sources. Here, the main testing will devoted to test the entire DTC-T1 workflow functionality, and synthetic events will be used.

SD4 Mediterranean Sea coast
Used by DTC-T1

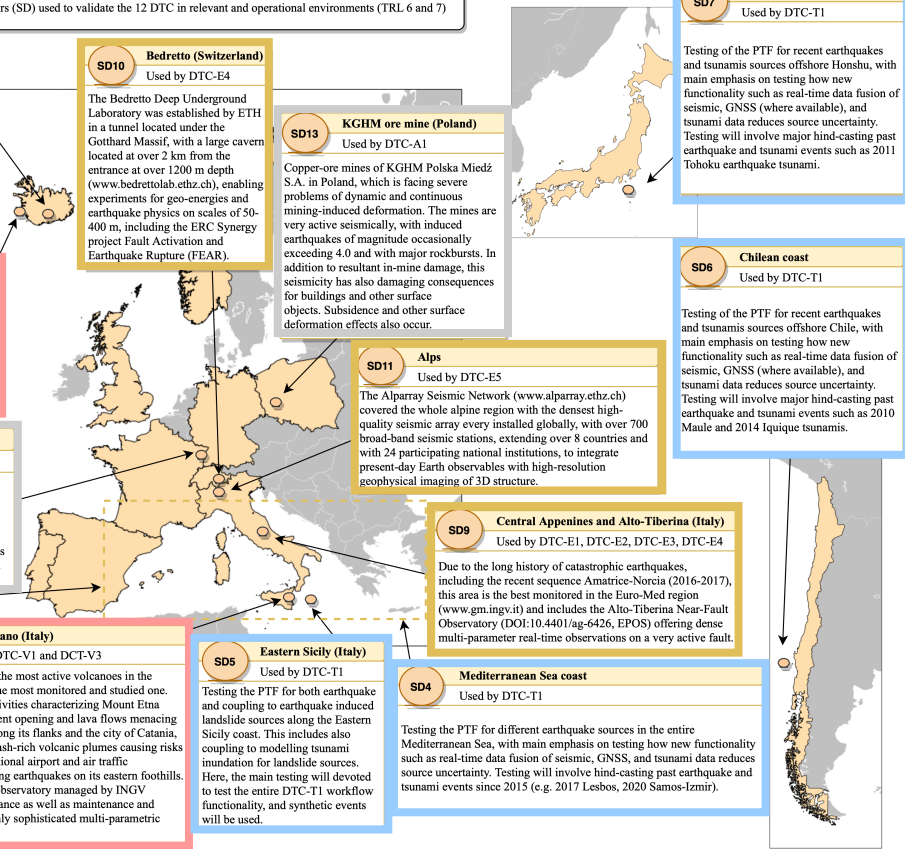
Testing the PTF for different earthquake sources in the entire Mediterranean Sea, with main emphasis on testing how new functionality such as real-time data fusion of seismic, GNSS, and tsunami data reduces source uncertainty. Testing will involve hind-casting past earthquake and tsunami events since 2015 (e.g. 2017 Lesbos, 2020 Samos-Izmir).

SD7 Eastern Honshu coast (Japan)
Used by DTC-T1

Testing of the PTF for recent earthquakes and tsunamis sources offshore Honshu, with main emphasis on testing how new functionality such as real-time data fusion of seismic, GNSS (where available), and tsunami data reduces source uncertainty. Testing will involve major hind-casting past earthquake and tsunami events such as 2011 Tohoku earthquake tsunami.

SD6 Chilean coast
Used by DTC-T1

Testing of the PTF for recent earthquakes and tsunamis sources offshore Chile, with main emphasis on testing how new functionality such as real-time data fusion of seismic, GNSS (where available), and tsunami data reduces source uncertainty. Testing will involve major hind-casting past earthquake and tsunami events such as 2010 Maule and 2014 Iquique tsunamis.



THANK YOU



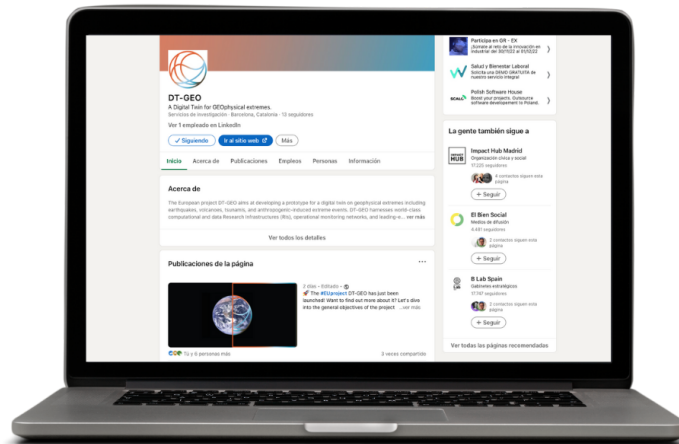
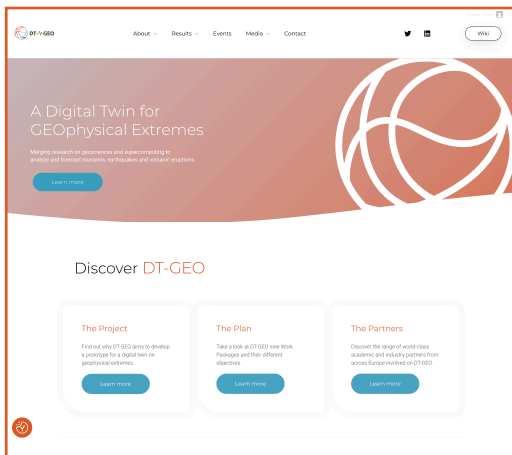
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