

Debris-Flow prediction using Digital Twins: the IRIDE Cyber Italy Framework

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ASI – CEOS WGD International Workshop on Earth Observation for Disaster Risk Management
ASI, Rome – 16 September 2026

Introduction - Hazard & DRM Phase

1 The IRIDE CyberItaly Framework in a nutshell

2 Digital Twin #4: a Landslides DT

HAZARD ADDRESSED:

Fast-moving landslides,
debris-flows, in alpine
areas.

DRM PHASE:

Preparedness
Early Warning

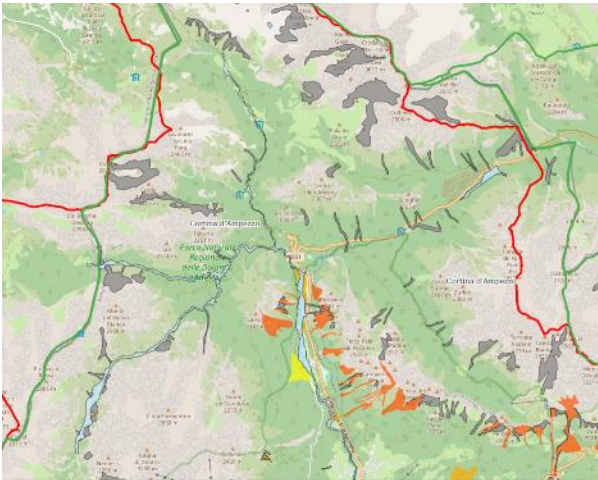
CASE STUDY

Cortina d'Ampezzo,
Dolomites
Belluno Province, Italy

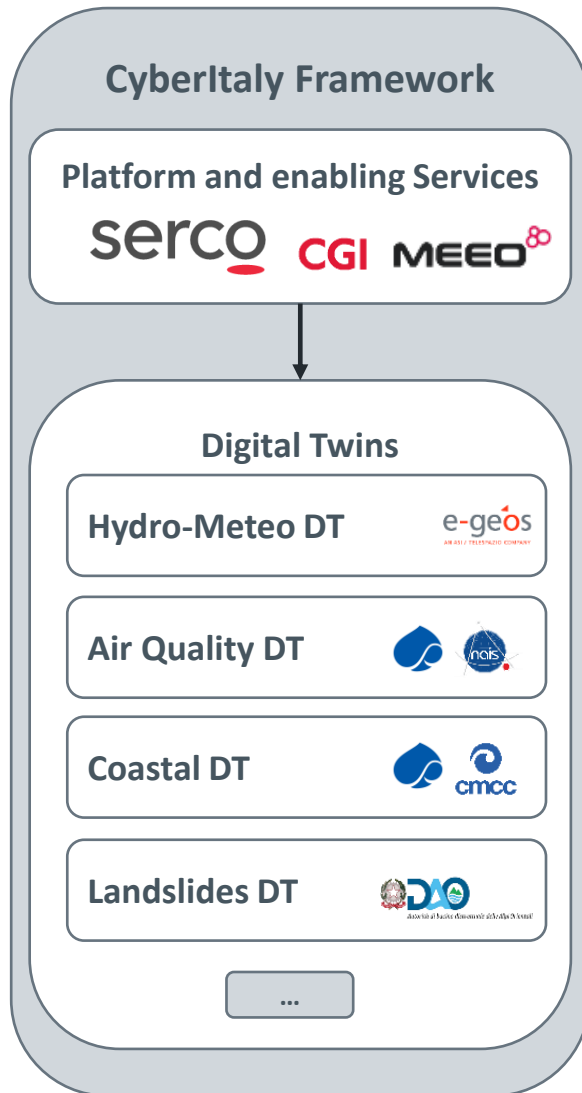
END USER

Eastern Alps District Basin
Authority

Supporting operational and
decision-processes



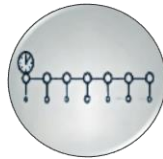
The IRIDE CyberItaly Framework



The project is part of the **IRIDE** programme, the Italian Earth Observation (EO) space programme, funded through the National Recovery and Resilience Plan (PNRR) and managed by ESA in collaboration with ASI.



CyberItaly has the objective to represent a national **Platform as a Service (PaaS)** to enable the operation of multiple **Digital Twins** - virtual replicas of the Earth's systems and processes - capable of providing stakeholders with **predictive** information to support **territorial planning** and **decision-making** across different operational scenarios (**What-If**).



Development timeline: mid **2023 - 2026**
Now the system is in **Preliminary Operations**



The platform provides enabling services (data retrieval, data collection, data mining, data processing, etc.), lives in a Cloud-based infrastructure and is designed to be completely **scalable** (through orchestration via Kubernetes) and **interoperable** with other systems (via standardized APIs and OGC-compliant interfaces).

Benefits of IRIDE Cyber Italy

IRIDE CyberItaly represents an opportunity to deliver benefits both to Digital Twin developers and to End Users (organizations with territorial planning needs).



What we offer to DT developers

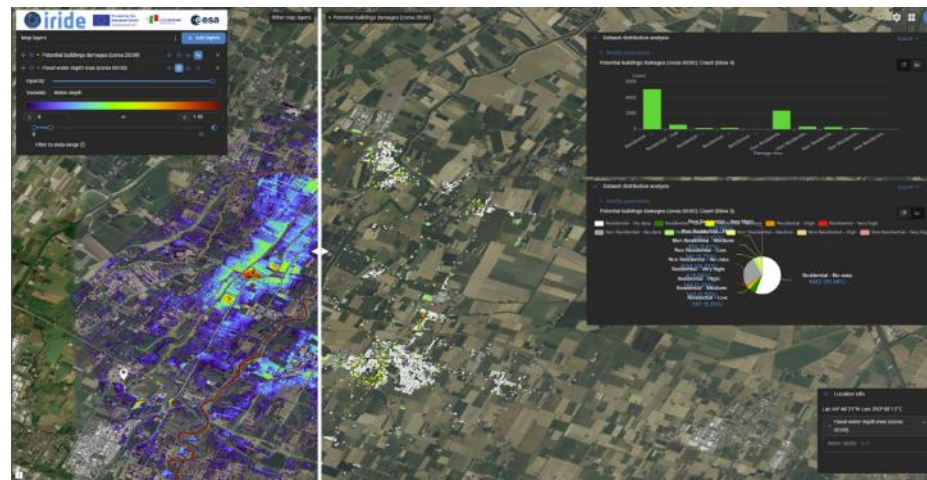
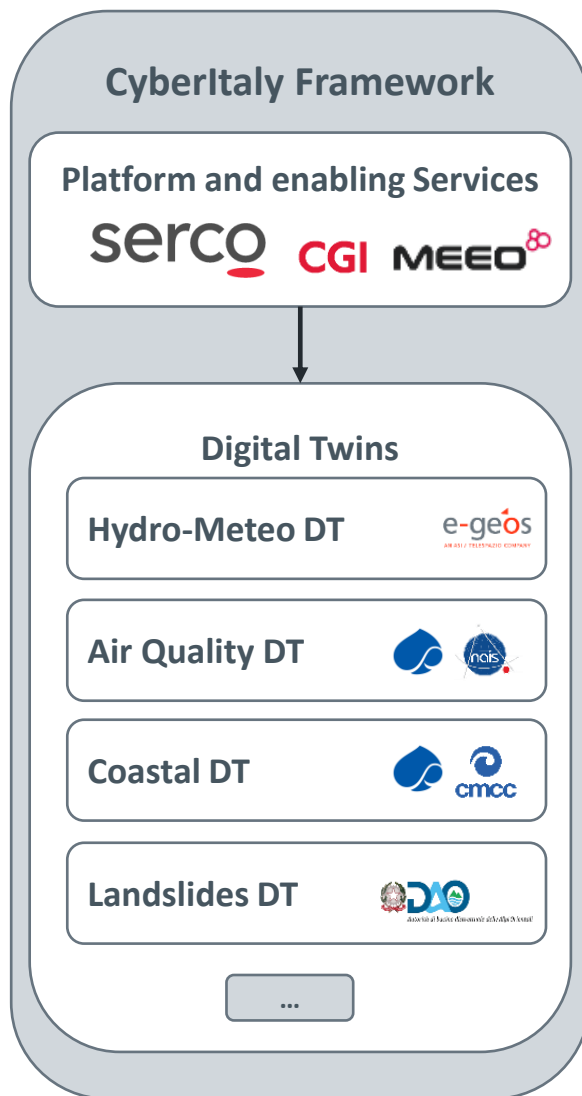
- Customized suite of services for **satellite** and **non-satellite** data, enabling data management, transformation, and processing
- Manual or automated execution of **algorithms** and **models**, **orchestrated** and **scalable**
- Access to **Cloud Computing** services
- A **streamlined integration** of new Digital Twins through standardization and containerization
- **Interoperability by design**, fostering reusability and scalability across Digital Twins and IRIDE services



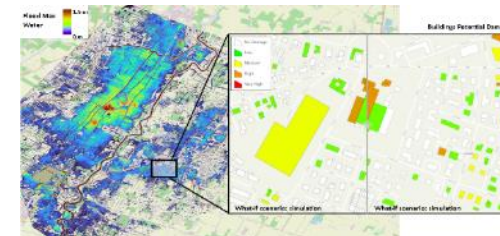
What we offer to End Users

- Access to **multiple applications and scenarios** through a single interface.
- A **user-friendly** and intuitive web interface.
- Advanced data **visualization** and **analysis** tools.
- Decision support through **systematic** and **automated** "what-if" scenario simulations, or available **on-demand** or triggered by **specific events**.
- Creation of customized **thematic dashboards** for monitoring specific phenomena and supporting decision-making processes.

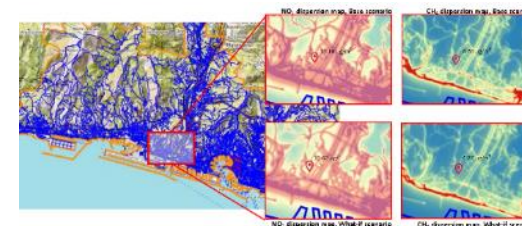
IRIDE CyberItaly - Services and Digital Twins integrated



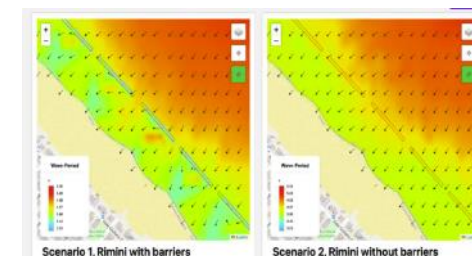
DT#1
HydroMeteo



DT#2
DT Air Quality
Third-party



DT#3
Coastal DT
Third-party



DT#4
Landslides



DT#4: Debris Flow Prediction

Demonstrative Case and Hazard Context

Fiames site, Cortina d'Ampezzo (BL)

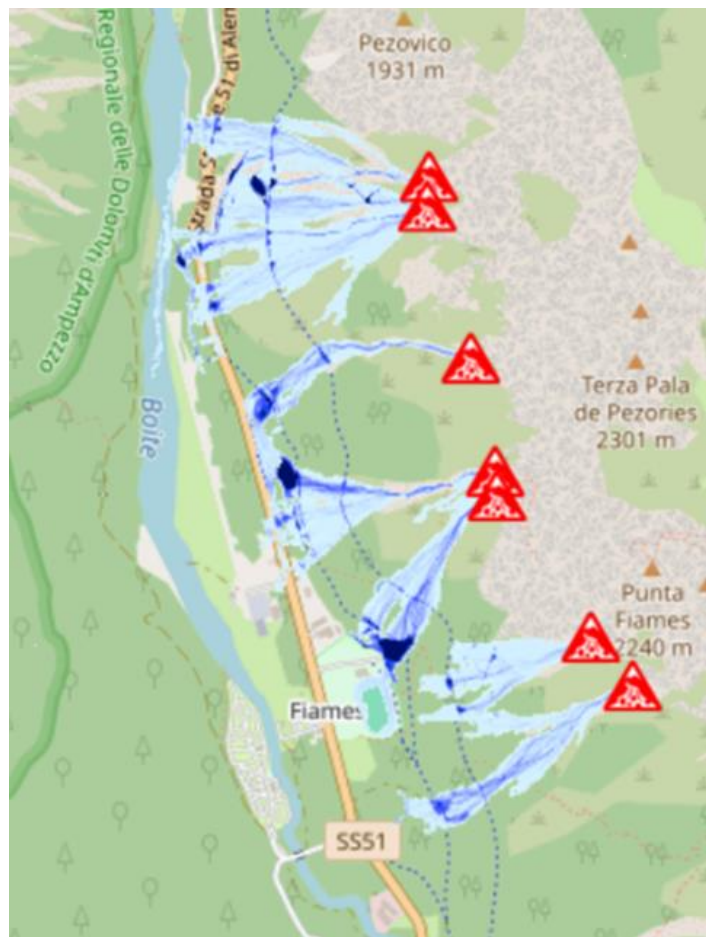


Western slope of Pomagagnon, characterized by steep basins and abundant debris availability.

FRMP* classification: presence of high-energy biphasic flows with potential impact on roads and infrastructure.

Historical events: rapid hydrological response and debris-flow activation during intense precipitation.

Objectives of the Digital Twin



PREDICT DEBRIS-FLOW
ACTIVATION AND
PROVIDE EXPECTED
IMPACT MAPS



DETECT RELEVANT PHYSICAL
INDICATORS: INTENSITY
(MM/H), CUMULATIVE
RAINFALL (MM), DURATION,
CATCHMENT CONDITION



SUPPORT EVENT MANAGEMENT
WITH READY-TO-USE,
REAL-TIME-UPDATED
SCENARIOS

Data Inputs and Sources



NWP forecasts up to 96h (ISPRA – MOLOCH): rainfall intensity, cumulative rainfall, temperature, spatial patterns from Cyber Italy (ItaliaMeteo as fall back solution)



Weather station (DAO): 1-minute-frequency rainfall data for threshold calibration and validation from Cyber Italy (DAO as fall back solution)

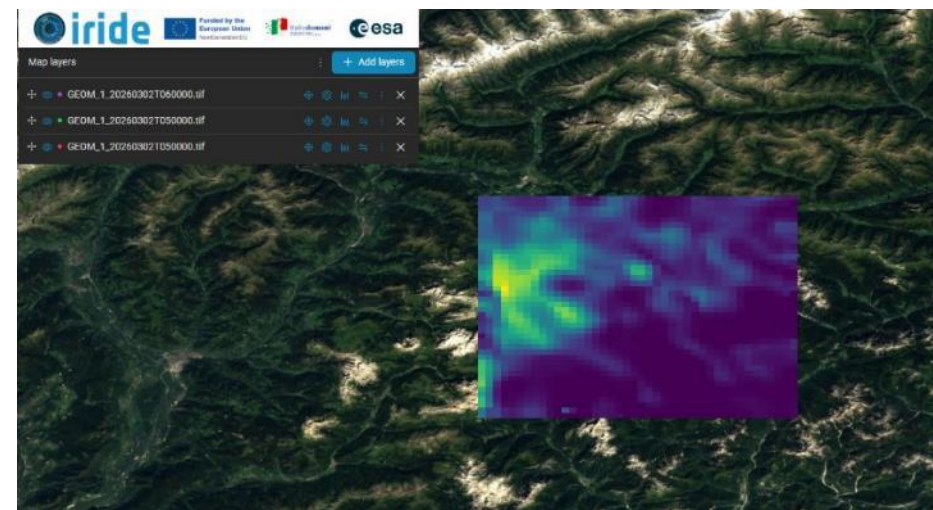
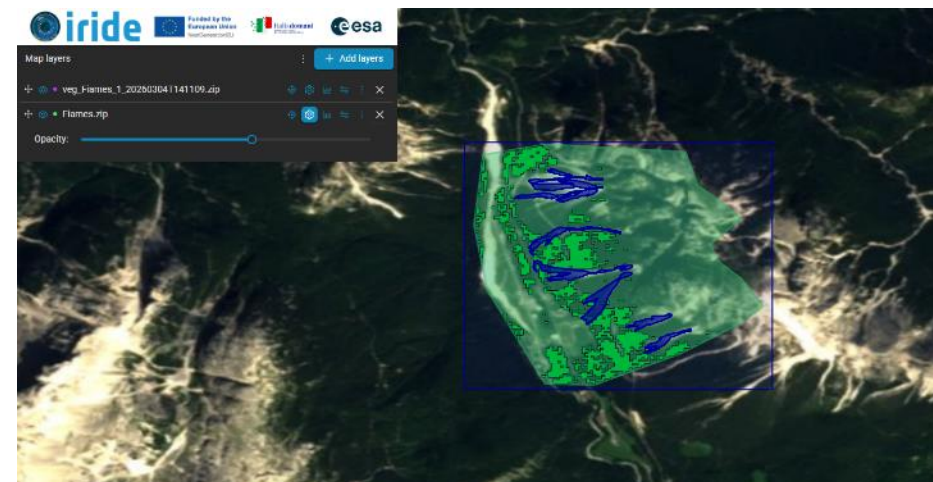


Copernicus Sentinel-2 EO: snow cover, surface/vegetation conditions

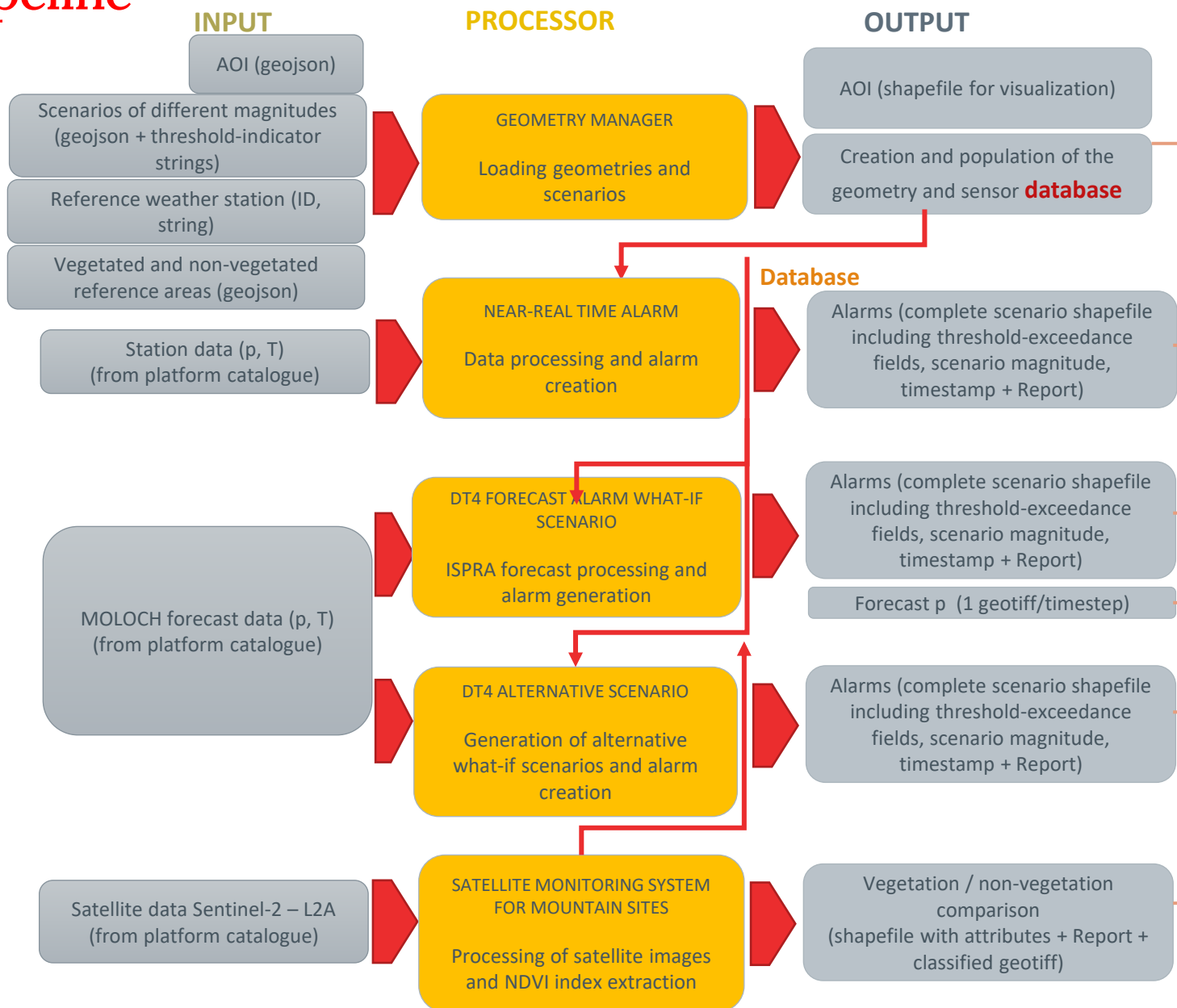
Copernicus DEM for temperature correction (SRTM 30m as fall back solution)

DFRM* scenarios from the FRMP (DAO): debris-flow extent for different return periods.

Geometries and parameters for the alert-generation algorithm.



DT#4 Pipeline



✓✓ COMPLETATO CON SUCCESSO

Pipeline: genalarm_forecast -> wif_engine

Riepilogo esecuzione

Data esecuzione	2026-08-17
Avvio	2026-08-17 09:55:46
Fine	2026-08-17 09:56:44
Durata totale	00h 00m 58s
Esito	OK

Allarmi generati

Totale allarmi: 0 | Report PDF: 2 | Shapefile: 0

Nessun allarme rilevato.

Stato precipitazione per area

Area	Previsione Precipitazione	Dettaglio	Fonte
Flumes (ID 1)	Precipitazione presente	Cumulata: 23.5 mm Max intensita': 18.5 mm/h	C7B82
Flumes (ID 1)	Precipitazione presente	Cumulata: 23.5 mm Max intensita': 20.2 mm/h	C4B82

Ultimi log di esecuzione

DASHBOARD CYBERITALY
Visualization of alarms and
scenarios and validation of
scenarios

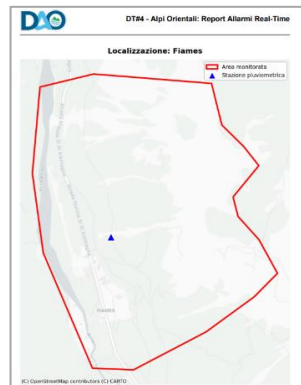
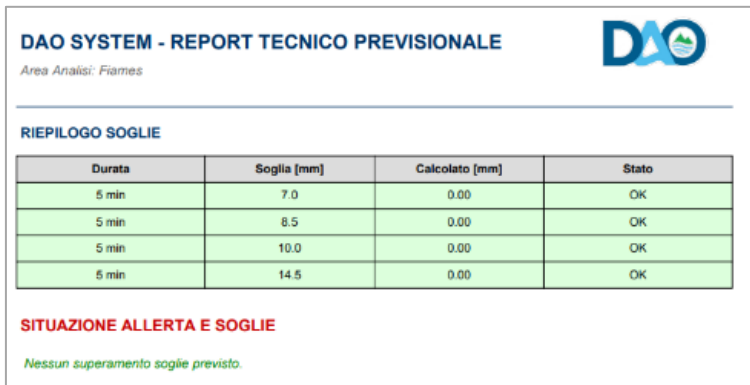
We receive every day
a report on the
expected situation and
some predefined
what-if scenario with
any alerts

DT#4 Forecast scenarios and near real time scenarios

INPUT

PROCESSOR

OUTPUT



MOLOCH forecast data (p, T)
(from platform catalogue)

Station data (p, T)
(from platform catalogue)

DT4 FORECAST ALARM WHAT-IF
SCENARIO

ISPRA forecast processing and
alarm generation

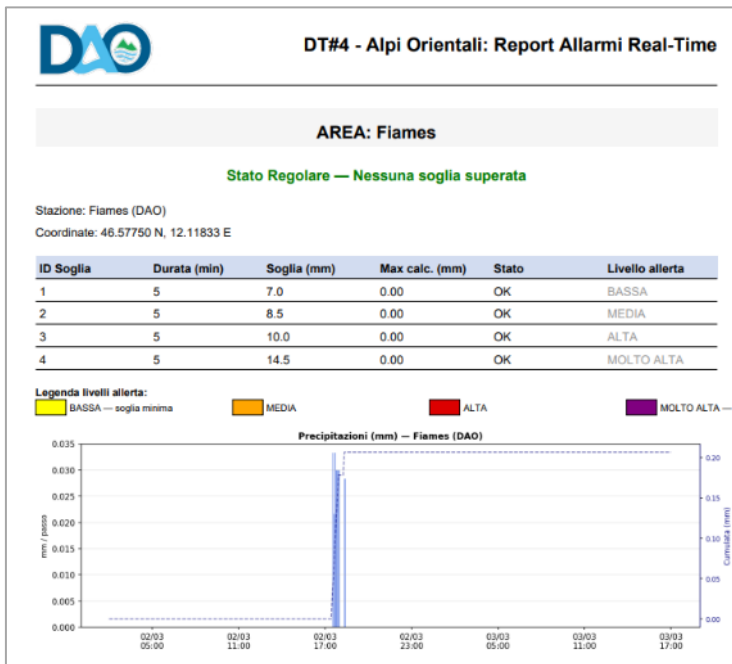
NEAR-REAL TIME ALARM

Data processing and alarm
creation

Alarms (complete scenario shapefile
including threshold-exceedance
fields, scenario magnitude,
timestamp + Report)

Forecast p (1 geotiff/timestep)

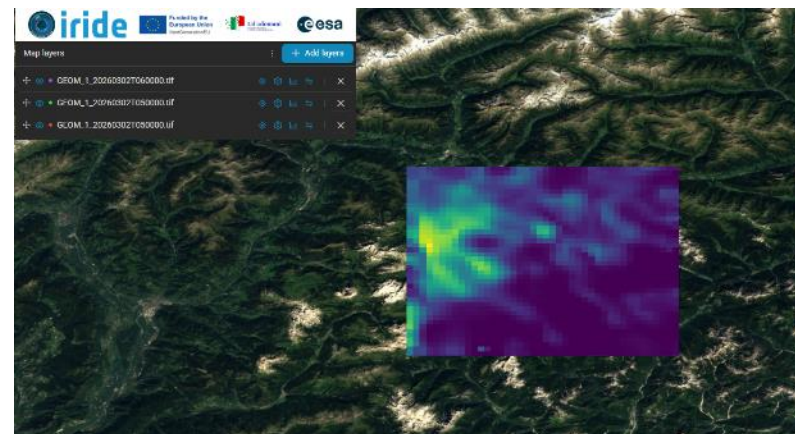
Alarms (complete scenario shapefile
including threshold-exceedance
fields, scenario magnitude,
timestamp + Report)



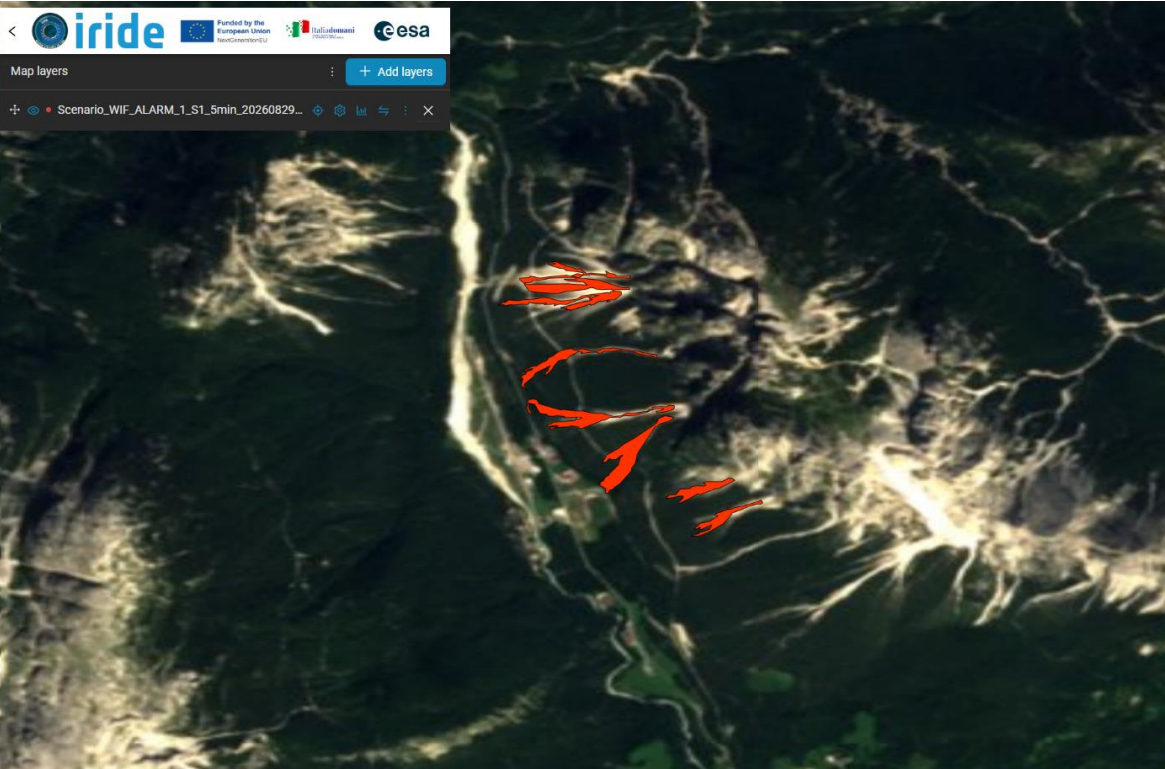
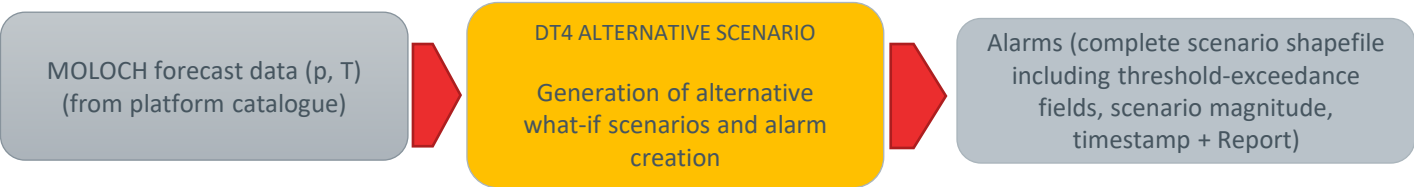
DAO SYSTEM - REPORT TECNICO PREVISIONALE

Area Analisi: Fiammes

PARAMETRO METEO	VALORE
Fonte dati	GRIB2 MOLOCH Meteohub [FALLBACK]
Inizio previsione	2028-03-02 05:00
Fine previsione	2028-03-04 01:00
Cumulata prevista	1.1 mm
Intensità max	0.14mm/60min = 0.1mm/h
Intensità media	0.02 mm/h
Risoluzione temp.	60 min/passio
Unità precipitazione	kg m ⁻² (mm/passio) - GRI2 MOLOCH Meteohub
Punto max pioggia	46.5776N / 12.1691E
Punto temperatura	46.5776N / 12.1691E [FSTERNO + T cumulata]
T corretta bacino	applicata
Passi neve esclusi	45/45
Temperatura GRI2	12m (K->°C) I corr. quota +3.1°C (pt=2085m->bac=160...
Tipo geometria	Multil'olygon
Punti DO scritti	39,420



DT#4 What-if scenarios



DAO SYSTEM ANALISI WHAT-IF SCENARIO Area: Fiames

[*] ANALISI WHAT-IF - MATRICE SCENARI

Area	Fiames
Run previsione	tutti
Inizio previsione	n.d.
Fine previsione	30/08/2026 02:00
Ora attuale (NOW)	28/08/2026 12:02
Stato NOW	n.d.
Punto Critico (Lat/Lon)	46.5903N, 12.0710E
Cumulata originale	80.3 mm
T punto -> T bacino	pt=1771m -> bac=1498m Dz=273m DT=+1.77 C
Scenari generati	4
Scenari con allarmi	2
Totale superamenti	2

[TAB] RIEPILOGO SCENARI

Scenario	K	Shift	Distribuzione	Allarmi	Max 1h (mm/h)
K1.00_S+0h_UNI	1.00	+0h	Uniforme	OK	29.5
K1.10_S+0h_UNI	1.10	+0h	Uniforme	OK	32.5
K1.00_S+0h_CHI	1.00	+0h	Chicago Storm	1	29.5
K1.10_S+0h_CHI	1.10	+0h	Chicago Storm	1	32.5

DAO SYSTEM ANALISI WHAT-IF SCENARIO Area: Fiames

SCENARIO 3/4: K1.00_S+0h_CHI 1 ALLARMI
K=1.00 | Shift=+0h | Chicago Storm (Pico Centrale)

80.3 mm Cum. Originale	80.3 mm Cum. Scenario	29.5 mm/h Max 1h (h)	x1.00 K-Factor	6.6 C T-Media
---------------------------	--------------------------	-------------------------	-------------------	------------------

K-Factor x1.00	Shift +0 ore
Distribuzione Chicago Storm (Pico Centrale)	Max Orario 29.5 mm
Cumulata Scen. 80.3 mm	Max Int. 1h 29.5 mm/h
T MIN/MAX 6.6/6.6 C	Passi neve Nessuno

[!] SUPERAMENTI SOGLIE - Scenario 3

Durata	Soglia	Valore	Temp (C)	Eccedenza	Data/Ora Pico
5 min	7.0 mm	7.4 mm	6.6 C	+0.38 mm	2026-08-29 18:19:00

Distribuzione asimmetrica con picco intenso al centro dell'ora. Simile eventi convettivi intensi con rapida intensificazione e decadimento. Ideale per temporali estivi.

Profilo dell'evento: Chicago Storm (Pico Centrale)

Evoluzione Temporale - Fiames | K=1.00 | Shift=+0h | Chicago Storm (Pico Centrale)

DT#4 Satellite monitoring system

INPUT

Satellite data Sentinel-2 – L2A
(from platform catalogue)

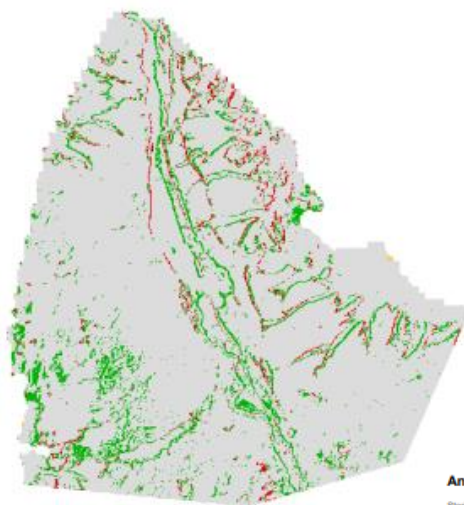
PROCESSOR

SATELLITE MONITORING SYSTEM
FOR MOUNTAIN SITES

Processing of satellite images
and NDVI index extraction

OUTPUT

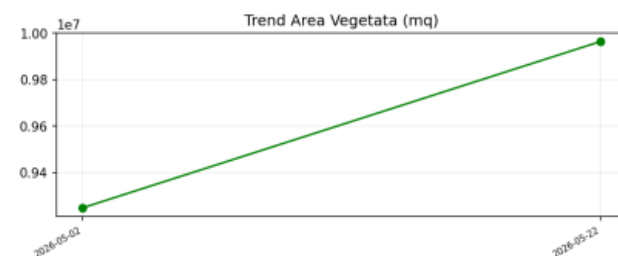
Vegetation / non-vegetation
comparison
(shapefile with attributes + Report +
classified geotiff)



Legenda mappe variazioni:
Guadagno vegetazione (Suolo -> Vegetazione)
Perdita vegetazione (Vegetazione -> Suolo)
Rilevati cambiamenti
Area coperta da neve/ghiaccio

Analisi Storica - Trend Area Vegetata

Storico: 1 rilevamento precedente



Area: Fiames (ID: 1)

Elaborazione: 2026-07-17 11:03:25

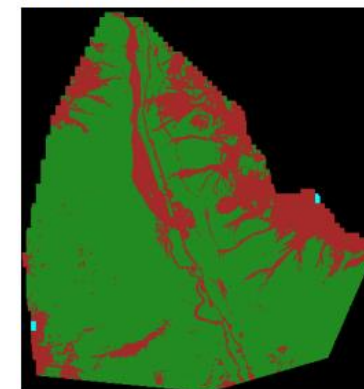
Immagine satellite: L2A_T32TQS_A048096_20260522T101019

Data acquisizione: 2026-05-22 10:10:19 UTC

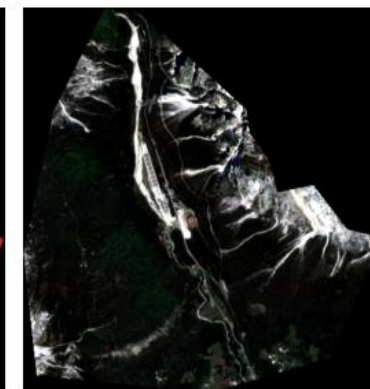
Risoluzione: 10.0m

Var. veg. rispetto al 2026-05-02: +7.8%

Area vegetata: 9,964,300.0 mq



Classificazione



Composito RGB (B04-B03-B02)

Distribuzione classi

Confronto vs acquisizione 2026-05-02 10:10:20 UTC - Tile T32TQS - Orbita 047810 (elaborato: 2026-07-14 06:29:48)

Veg: 9,964,300 mq (75.7%)
Soil: 3,181,700 mq (24.2%)
Cloud: 0 mq (0.0%)
Snow: 13,900 mq (0.1%)
Water: 0 mq (0.0%)
Nodata: 76,553 px

Analisi Variazioni Vegetazione

Guadagno vegetazione: 1,056,500 mq

Perdita vegetazione: 335,400 mq

Variazione netta: +721,100 mq

Zone coperte da neve: 36 pixel

Outcomes, Lessons Learnt & Next Steps

- **Key outcome:**

- In house development of an operative EWS on Debris-flow
- Contribution to Disaster Risk Reduction (DRR) and resilience policies
- EO as a key component for site characterization (scenario validation through Sentinel-2 and IRIDE*).
- **Full active monitoring service already in use inside CyberItaly platform**

- **Lessons learnt:**

- Multi-source integration into an operational Digital Twin: replicable across Europe
- Added value using EO data for complex monitoring contexts
- **This approach can lead to a large exploitability and transferability of the DT**

- **Next steps:**

- **Extension to other alpine basins (multi-site scalability).**
- Application to different scenario-generation models.
- Integration of AI module to improve forecast and scenarios.



CyberItaly platform:

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Digital Twin #4 – Landslides

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