VRE and digital twins: the state of the art and challenges

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Outlines

- Intro: Digital revolution in Earth sciences
- Virtual research environment: definitions and examples
- Digital twins of systems and processes: definitions and examples
- Challenges and opportunities

Earth science as a data intensive domain

Big data (observations + modelling)
5V (Volume, Velocity, Variety, Veracity, Value)

Data usage in Earth science

Data → Information → Knowledge → Services → Control?

First step : services for researchers
Virtual Research Environment as result

→

Next step: services for all users (researchers , decision makers, industry, population) Digital twins of systems/processes

Definitions

A **virtual research environment** (**VRE**) or **virtual research laboratory** is an **online system helping researchers collaborate. Features usually include collaboration support (Web forums and wikis), document hosting, and some discipline-specific tools, such as data analysis, simulation management, visualisation, teaching tools and publication management.**

Synonyms: “information-computational infrastructure”, "collaborative e-research community", "collaboratory“,"virtual research community", scientific gateways/portals VREs - web-based, community-oriented, comprehensive, flexible, and secure working environments conceived to serve the needs of modern science.

Virtual Research Environments (VREs) - a method of collaboration by researchers that is enhanced through the systematic use of information and networking technology.

Many funding organisations have established programmes that pilot VREs in discipline-specific contexts over the past years

agenda is promoting the European Research Area; creating transnational VRE-structures helps create a real ERA.

"A Europe-wide Interoperable Virtual Research Environment to Empower Multidisciplinary Research Communities and Accelerate Innovation and Collaboration" **VRE4EIC**

Funder: European Commission

1) understanding complex user requirements across domains;
2) improving the quality of VRE user experience by providing user centred, secure, privacy compliant, sustainable environments for accessing data, composing workflows and tracking data publications;
3) increasing VRE usage in multidisciplinary research domains;
4) improving the interoperability of heterogeneous discovery, contextual and detailed metadata; and
5) promoting the exploitation of VRE4EIC solutions to different research communities and commercially.

VRE4EIC covers all EU member states and EFTA countries, and will affect 70,000 researchers all over Europe.

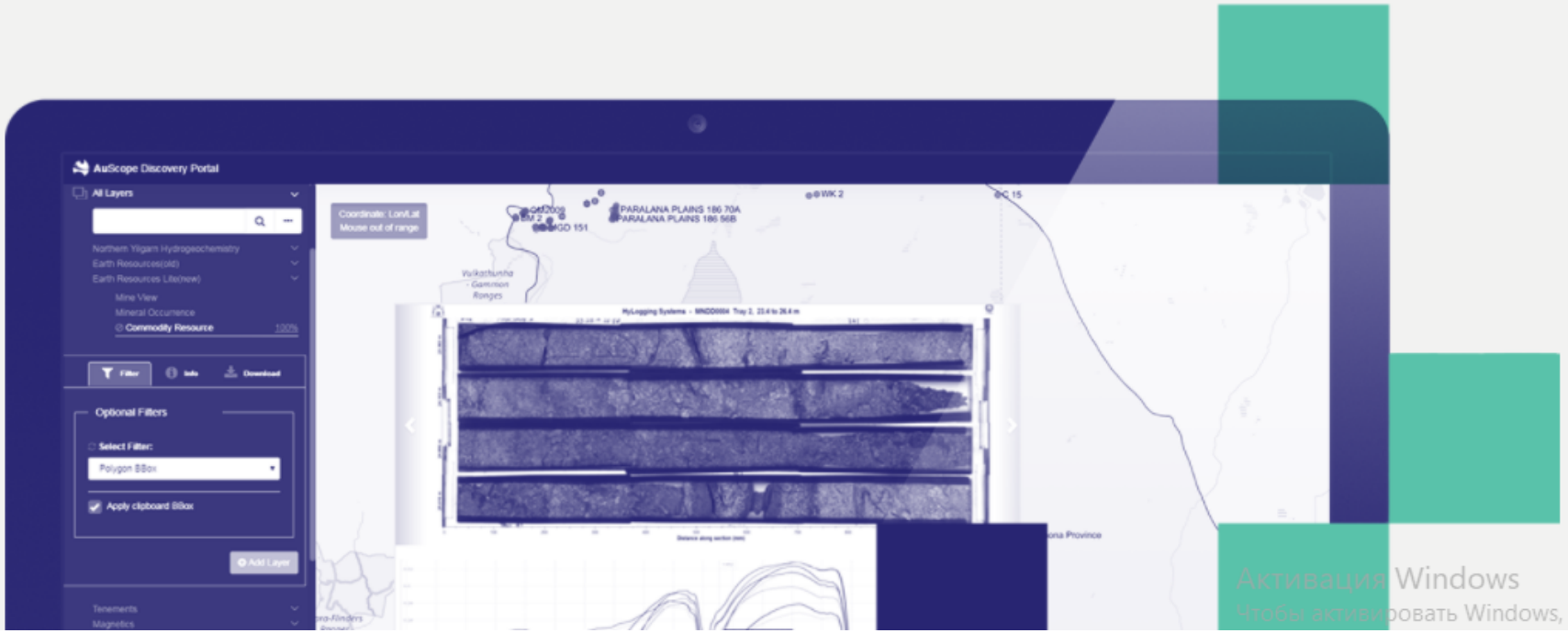
The EVER-EST VRE provides services to share Earth Science data and information allowing researchers to discover, access, and process heterogeneous data, algorithms, results and experiences

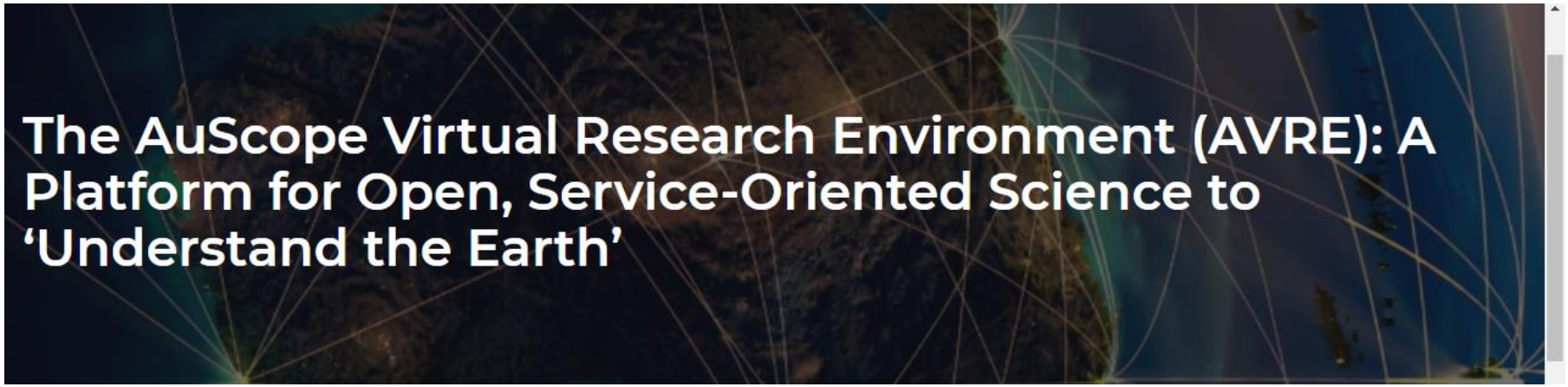
AuScope Virtual Research Environment (AVRE)

Data, Visualisation & Analytics

Visit the AVRE Store

Click here to get straight to data, visualisation & analytics.

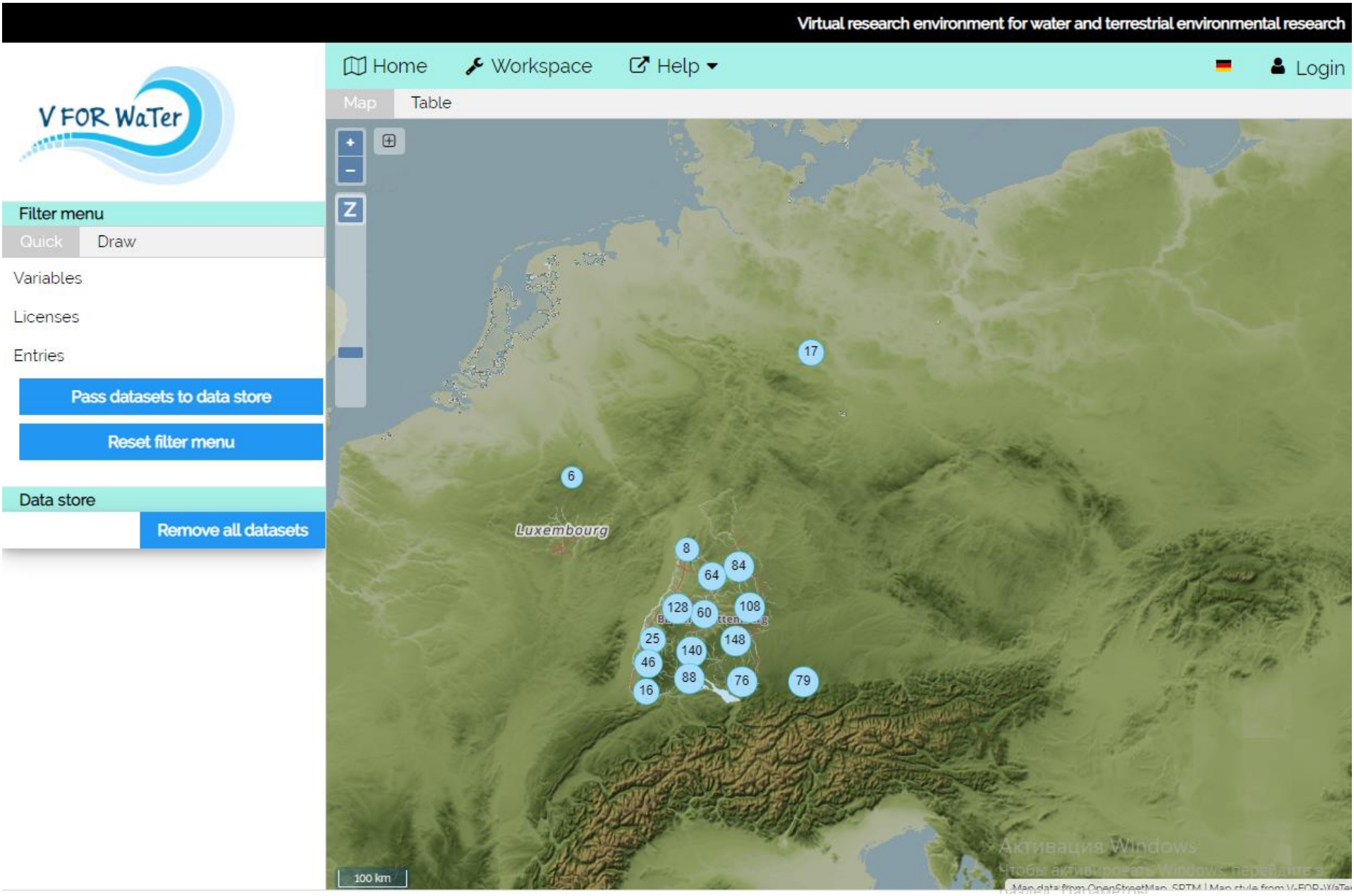




Since 2006, NCRIS projects (AuScope, NCI, ANDS, Nectar, RDS), and Government have collaborated on building a suite of data portals, tools, software and virtual laboratories to support a diverse community of Earth scientists operating on a range of computational facilities including HPC, cloud, on-premise servers and desktops.

The aspiration was to realise a service-oriented science platform that will empower data assimilation and modelling across three networks: geophysics, geochemistry and geology.

The end goal is to ensure Australian Earth science data and analytics can play a leadership role in next-generation transdisciplinary research to more comprehensively 'Understand the Earth'.


Virtual research environment for water and terrestrial environmental research
V FOR WaTer
Home
Workspace
Help
Login
Map
Table
Filter menu
Quick
Draw
Variables
Licenses
Entries
Pass datasets to data store
Reset filter menu
Data store
Remove all datasets
Luxembourg
17
6
8
64
84
128
60
108
25
140
148
46
88
76
79
16
100 km

The virtual research environment V-FOR-WaTer aims at making this data abundance available in an easy-to-use web portal. Environmental scientists get access to data from different sources, e.g. state offices or university projects, and can share their own data through the portal.

Tools help to easily pre-process and scale the data and make them available in a consistent format. Tools for more complex scientific analyses and uncertainty propagation will be included.

The possibility to store workflows together with the tools and respective data ensures reproducible data analysis. Additionally, interfaces with existing data repositories enable easy publication of the scientists' data directly from the portal.

V-FOR-WaTer addresses the needs of researchers of hydrology and environmental science to not only find and access datasets but also conduct efficient data-based learning with standardised tools and reproducible workflows.

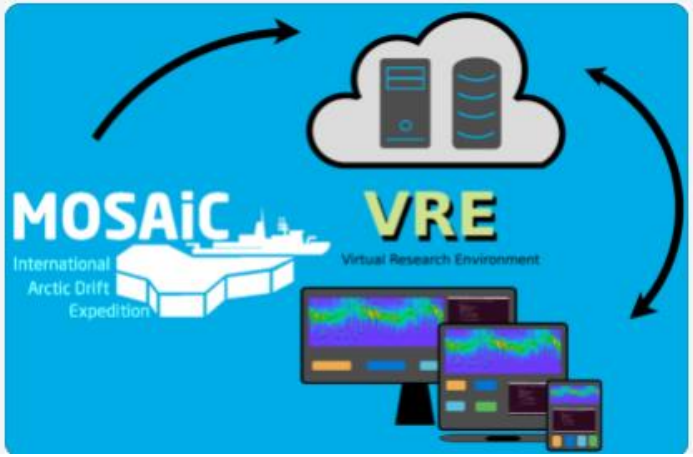
M-VRE About Dashboard Team Contact Privacy Legal Notice

About

M-VRE: The MOSAiC - Virtual Research Environment

The M-VRE project is funded by the German BMBF initiative „MARE:N – Polarforschung/MOSAiC“ from July 2021 to June 2024. This project is a collaboration of AWI Bremerhaven, DKRZ Hamburg and DLR Jena.

The main goal of the M-VRE project is to provide novel methods and software tools for the MOSAiC consortium, the global climate community, and the general public for efficiently exploring, analysing, and visualizing MOSAiC data in an online and user-friendly manner. This enables scientists to exploit large, complex, and heterogeneous data sets to answer fundamental research questions of the MOSAiC expedition.



The VRE offers online data analysis, exploration (data cubes), and visualization (maps, scatter plots, time series, section plots and more) of MOSAiC data as well as automated data quality control through Deep Learning methods.

D4Science Thematic Gateways supporting Projects

The following Infrastructure Gateways serve a number of Research Communities, Initiatives, and Projects, each of which having a specific scientific domain and dedicated Virtual Research Environments Virtual Research Environments for Data-Driven Research

AGINFRAPlus Gateway, 14 VREs / VLabs

AGINFRA+ aims to exploit core e-infrastructures such as D4Science, EGI.eu, OpenAIRE and EUDAT, towards the evolution of the AGINFRA data infrastructure, so as to provide a sustainable channel addressing adjacent but not fully connected user communities around Agriculture and Food. AGINFRAPlus Gateway helps the project to develop and provide the necessary specifications and components for allowing the rapid and intuitive development of variegating data analysis workflows, where the functionalities for data storage and indexing, algorithm execution, results visualization and deployment are provided by specialized services utilizing cloud based infrastructure(s).

ARIADNEPlus Gateway, 6 VREs / VLabs

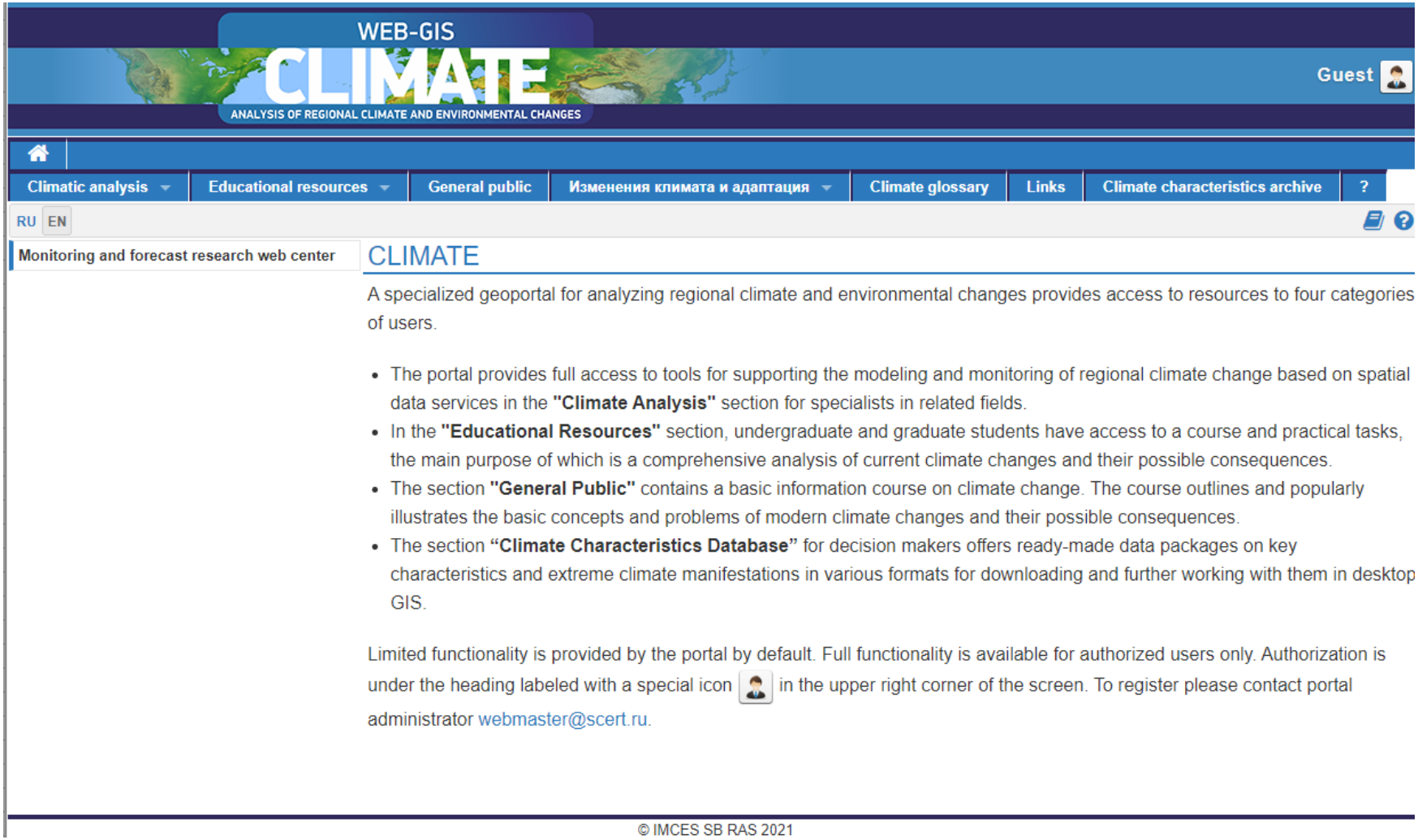
The ARIADNEplus Project builds on the ARIADNE results, extending and supporting the research community that the previous project created and further developing the relationships with key stakeholders such as the most important European archaeological associations, researchers, heritage professionals, national heritage agencies and so on. The ARIADNEPlus Gateway helps the project to develop a data infrastructure embedded in a cloud that offer the availability of Virtual Research Environments where data-based archaeological research may be carried out. The project will furthermore develop a Linked Data approach to data discovery, making available to users innovative services, such as visualization, annotation, text mining and geo-temporal data management. Innovative pilots will be developed to test and demonstrate the innovation potential of the ARIADNEplus approach.

Blue-Cloud Gateway, 10 VREs / VLabs

Blue-Cloud, a thematic EOSC cloud to better understand and manage the ocean sustainability, through a set of five compelling pilot Blue-Cloud demonstrators. It develops and deploys, the Pilot Blue Cloud as a cyber platform bringing together and providing access to: 1) multidisciplinary data from observations and models, 2) analytical tools, 3) computing facilities essential for key blue science use cases.

D4Science.org Gateway, 42 VREs / VLabs

D4Science is a Data Infrastructure connecting +7000 scientists in 44 countries, integrating +50 heterogeneous data providers, executing +13,000 models & algorithms/month; providing access to over a billion quality records in repositories worldwide with 99.7% service


WEB-GIS
CLIMATE
ANALYSIS OF REGIONAL CLIMATE AND ENVIRONMENTAL CHANGES
Guest
Climatic analysis
Educational resources
General public
Изменения климата и адаптация
Climate glossary
Links
Climate characteristics archive
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EN
Monitoring and forecast research web center
CLIMATE
A specialized geoportal for analyzing regional climate and environmental changes provides access to resources to four categories of users.
The portal provides full access to tools for supporting the modeling and monitoring of regional climate change based on spatial data services in the "Climate Analysis" section for specialists in related fields.
In the "Educational Resources" section, undergraduate and graduate students have access to a course and practical tasks, the main purpose of which is a comprehensive analysis of current climate changes and their possible consequences.
The section "General Public" contains a basic information course on climate change. The course outlines and popularly illustrates the basic concepts and problems of modern climate changes and their possible consequences.
The section "Climate Characteristics Database" for decision makers offers ready-made data packages on key characteristics and extreme climate manifestations in various formats for downloading and further working with them in desktop GIS.
Limited functionality is provided by the portal by default. Full functionality is available for authorized users only. Authorization is under the heading labeled with a special icon in the upper right corner of the screen. To register please contact portal administrator webmaster@scert.ru.
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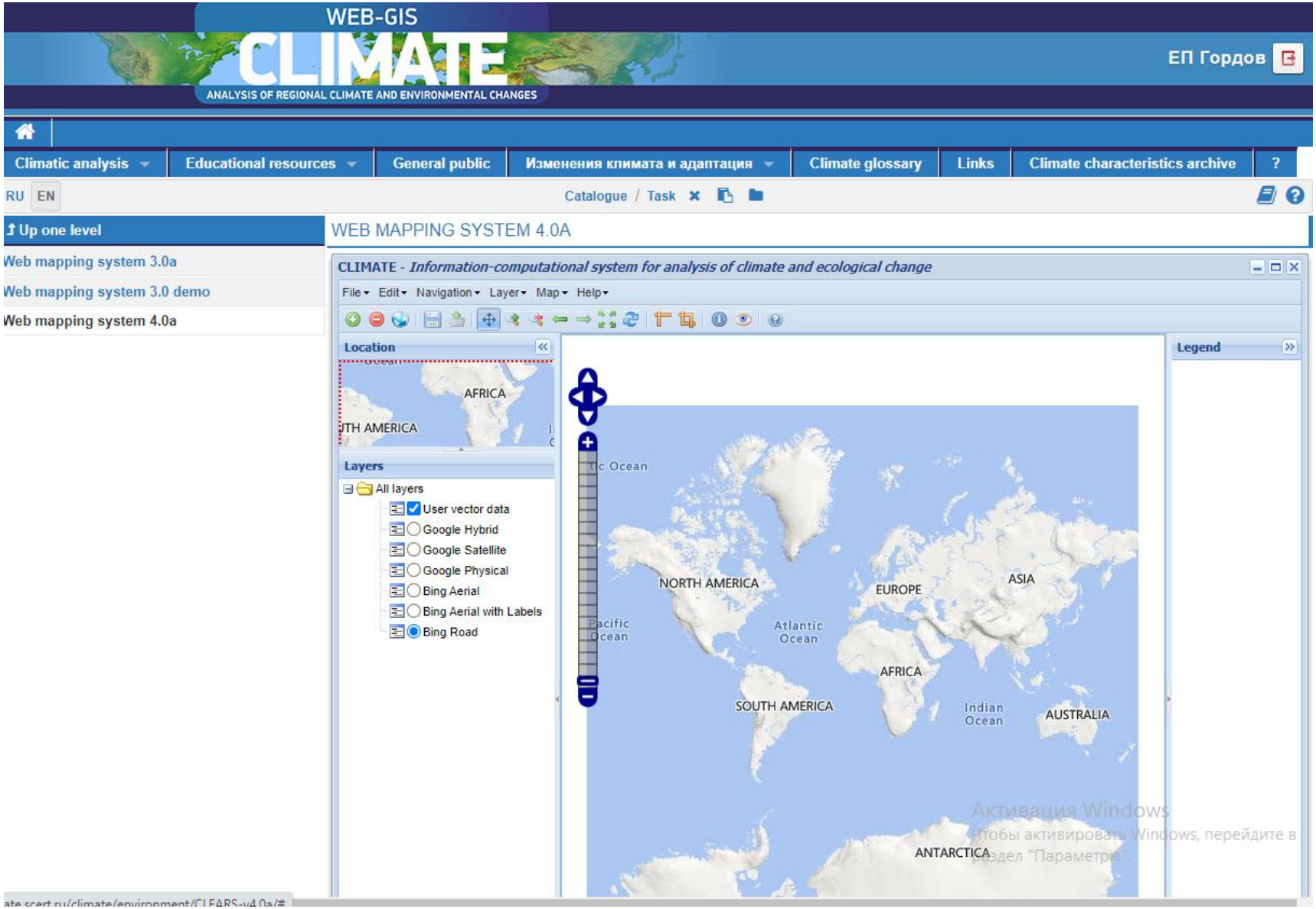
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ANALYSIS OF REGIONAL CLIMATE AND ENVIRONMENTAL CHANGES
ЕП Гордов
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Links
Climate characteristics archive
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Catalogue / Task
Up one level
Web mapping system 3.0a
Web mapping system 3.0 demo
Web mapping system 4.0a
WEB MAPPING SYSTEM 4.0A
CLIMATE - Information-computational system for analysis of climate and ecological change
File
Edit
Navigation
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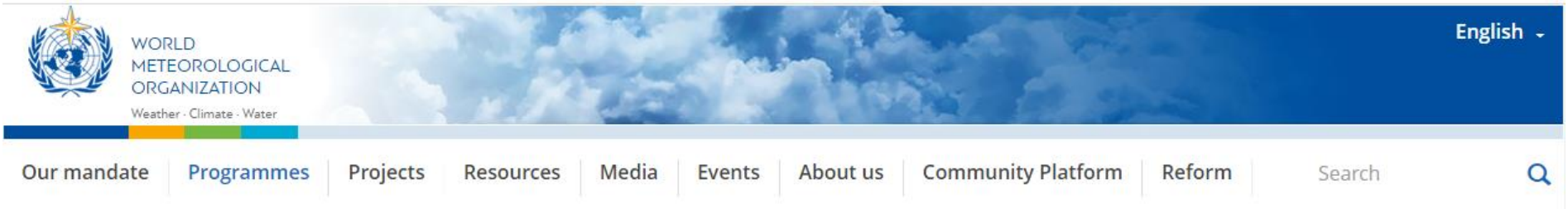
Map
Help
Location
AFRICA
Layers
All layers
User vector data
Google Hybrid
Google Satellite
Google Physical
Bing Aerial
Bing Aerial with Labels
Bing Road
Legend
NORTH AMERICA
EUROPE
ASIA
Pacific Ocean
Atlantic Ocean
AFRICA
SOUTH AMERICA
Indian Ocean
AUSTRALIA
ANTARCTICA
Активация Windows
Чтобы активировать Windows, перейдите в раздел "Параметры".

New challenge - necessity of adaptation to climate change

Climatic services

Additional users: decision makers, population, agriculture, industry, etc.

First responses



World Climate Services Programme

The World Climate Services Programme (WCSP) contributes to improving the availability of, and access to, reliable climate data, monitoring and forecasts. The Programme promotes the development of appropriate institutional mechanisms and operational infrastructure to generate, exchange and disseminate quality information on climate **and provides guidance on related applications and services**.

The WCSP spans four inter-related areas:

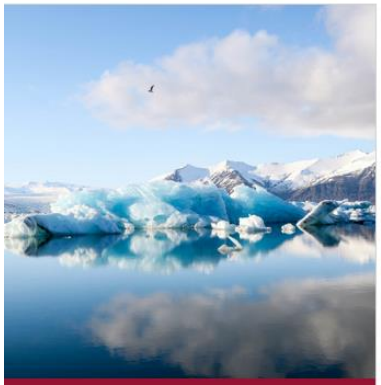
- Climate data and analysis;
- Climate monitoring, watch and prediction;
- Climate system operation and infrastructure; and
- **Climate adaptation and risk management.**

Implemented by ECMWF as part of The Copernicus Programme

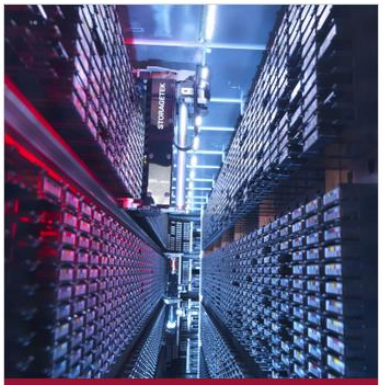
Climate Change Service

We provide authoritative information about the past, present and future climate, as well as tools to enable climate change mitigation and adaptation strategies by policy makers and businesses.

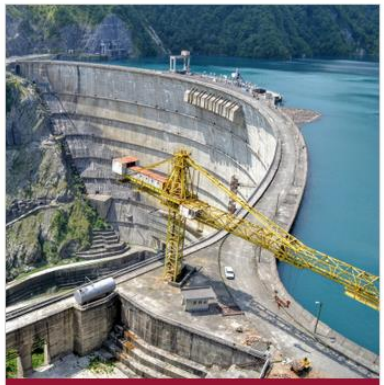
Key products and services



Climate bulletins



Climate Data Store



Data in action

In focus

The *European State of the Climate 2018*, an essential snapshot of the region and a useful benchmark for future assessments of the environment.

Read More ►

The Data Library offers free access to hundreds of high-value datasets (climate, geophysical, health and agriculture) and provides the tools and training to perform analysis. It can revolutionize the way individuals and organizations approach their work.

iridl.ldeo.columbia.edu/?Set-Language=en

IRI/LDEO Climate Data Library

Google Custom Search

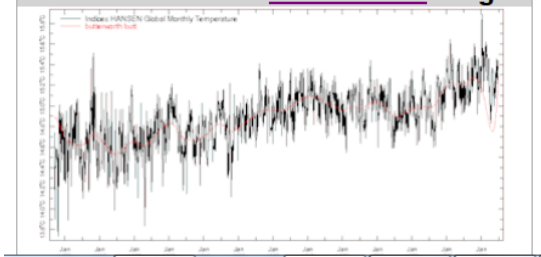
IRI/LDEO Climate Data Library

The IRI Data Library is a powerful and freely accessible online data repository and analysis tool that allows a user to view, analyze, and download hundreds of terabytes of climate-related data through a standard web browser.

It is a powerful tool that offers the following capabilities at no cost to the user:

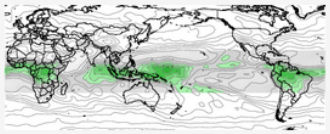
- access any number of datasets;
- create analyses of data ranging from simple averaging to more advanced EOF analyses using the Ingrid Data Analysis Language;
- monitor present climate conditions with maps and analyses in the Maproom;
- create visual representations of data, including animations;
- download data in a variety of commonly-used formats, including GIS-compatible formats.

Latest from our What's New blog



IRI Climate and Society Map Room

The climate and society maproom is a collection of maps and other figures that monitor climate and societal conditions at present and in the recent past. The maps and figures can be manipulated and are linked to the original data. Even if you are primarily interested in data rather than figures, this is a good place to see which datasets are particularly useful for monitoring current conditions.



Data by Source

Datasets organized by source, i.e. creator and/or provider.

Data By Category

Selected Datasets for particular topics

Dataset and Map Room Browser

Find datasets and maps organized by many characteristics and keywords

Navigating Through the IRI Data Library: A Tutorial

The goal of this tutorial is to introduce you to the structure of the Data Library and the many ways to navigate through it.

Statistical Techniques in the Data Library: A Tutorial

Statistical techniques are essential tools for analyzing large datasets; this statistics tutorial thus covers essential skills for many data library users.

Function Index

Index for functions that can be used to analyze data within the Data Library.

Help Resources

The Help Resources include basic and statistics tutorials, function documentation, and other resources to help you get the maximum utility out of the Data Library

IRI for Climate and Society https://iri.columbia.edu/resources/data-library/

Климатический центр Росгидромета

Сценарные прогнозы на основе глобальных моделей

Up one level
Anomalies of meteorological characteristics
Climate Indices
Hydrothermal coefficients

DATA LIBRARY OF CLIMATE CHARACTERISTICS INCL. EXTREMES

TO CALCULATE THE CHARACTERISTICS OF THE MODERN PERIOD ARE USED:

1. High spatial resolution 0.25x0.25 (~30 km) reanalysis data **Era5** (Fifth generation of ECMWF atmospheric reanalyses of the global climate, https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5) from 1979 to 2020 years.

TO CALCULATE THE CHARACTERISTICS OF THE FUTURE PERIOD ARE USED:

1. High spatial resolution data T359 (~50 km) **CMIP6** project data (Six phase of Coupled Model Intercomparison Project, https://www.wcrp-climate.org/wgcm-cmip/wgcm-cmip6) of subproject **HighResMIP** (High Resolution Model Intercomparison Project) according to the global model **CNRM-CM6-1-HR** (Centre National de Recherches Météorologiques (CNRM) and Cerfacs) according to the RCP 8.5 scenario for the period from 2015 по 2050 years.
2. High spatial resolution data 0.22x0.22 (~25 km) from the **CORDEX** (The Coordinated Regional climate Downscaling Experiment, https://www.cordex.org) project for Central Asia (CAS-22) according to the global model of the Earth system **MPI-ESM-LR** (model of the Max Planck Institute for Meteorology), the calculation results of which were used as the basis for downscaling using the regional model **REMO2015** of the GERICS center (Climate Service Center Germany); according to the RCP 8.5 scenario for the period from 2006 по 2100 years.
3. Spatial resolution data T127 (~100 km) **CMIP6** project (Six phase of Coupled Model Intercomparison Project, https://www.wcrp-climate.org/wgcm-cmip/wgcm-cmip6) data according to the global model of the Earth system **MPI-ESM-HR2** (model of the Max Planck Institute for Meteorology) according to the SSP585 scenario for the period from 2015 to 2100 years.

>> Anomalies of meteorological characteristics

>> Climate Indices

Digital twins as a response to the challenge

A **digital twin** (**DT**) is
- a virtual representation that serves as the real-time digital counterpart of a physical object or process.
- a digital representation of a physical objects or process
- *also referred to as digital shadow, digital replica or digital mirror - is a digital representation of a physical asset.*

DT optimally combines simulations and near-real-time observations to monitor the evolution of a system or process. *Linked to each other, the physical asset and digital twin regularly exchange data.*

DT strongly relies on geospatial data, and the processing and analytics thereof. Cloud environments provides the flexibility and scalability needed to cope with the potential enormous geospatial datasets.

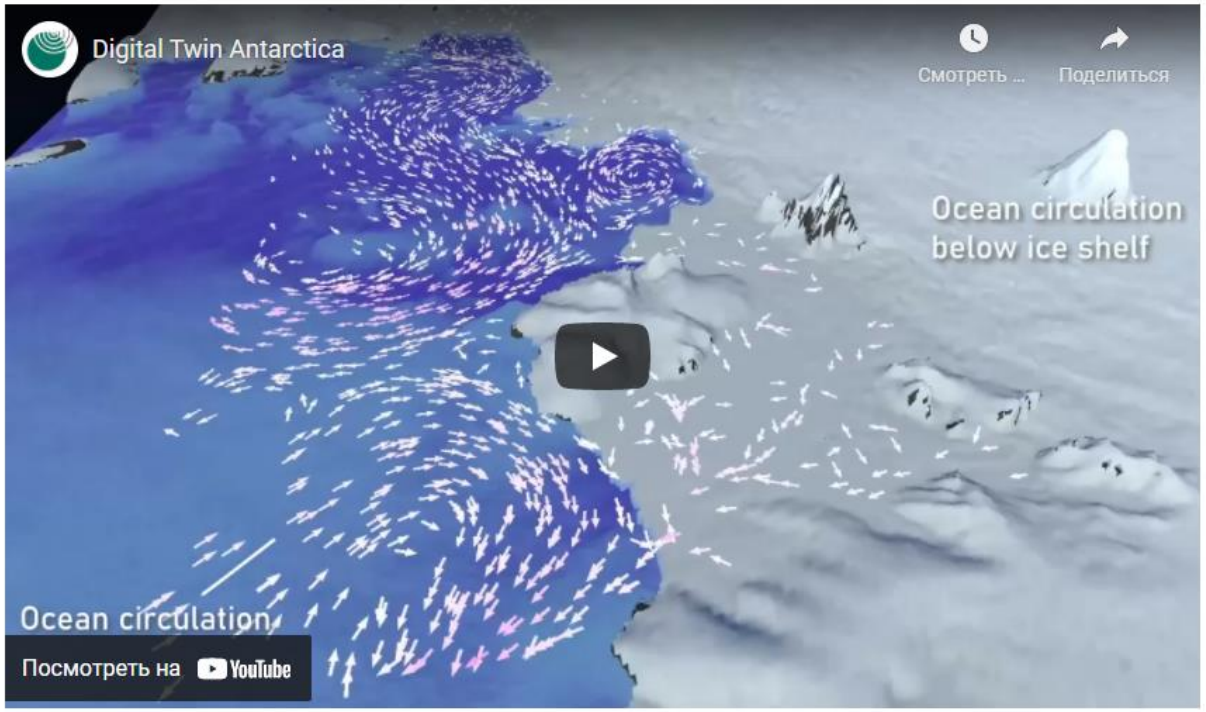
Technology like AI, machine learning, sensors and IoT allow for dynamic data gathering and right-time data exchange to take place

Digital twins enables analysis of current state, future predictions and simulations of possibilities of objects in cyberspace. Based on observation and simulation results DT also enables feedback to real world to enable an intelligent control the real world object.

DT of the environment can help reaching sustainability goals and tackling climate change related issues.

The first practical definition of digital twin originated from NASA in an attempt to improve physical model simulation of spacecraft in 2010.

Digital Twin Antarctica



“By harnessing satellite observations, numerical simulations, and Artificial Intelligence, we have built a twin of the Antarctic ice sheet system, its hydrology, surrounding ocean, atmosphere, and biosphere. We have used the Antarctic twin to track the whereabouts of melt water on and under the ice sheet, and to explore how fringing ice shelves melt under various hydrology scenarios.” (Noel Gourmelen, University of Edinburgh)

Digital Twin Hydrology

Luca Brocca (NRC, Italy) “In the ESA Digital Twin Earth Hydrology project, we have developed a 4D reconstruction of dynamic hydrology at unprecedented resolution through the integration of Earth observation and an advanced modelling system. The DTE Hydrology Prototype has been used for water resources management and for identifying locations and times of risk for landslides and flooding in the Po River Basin, in northern Italy.”

Forest DTEP

Project aims to prototype a digital twin of forests using the existing scientific knowledge and capabilities.

The project consortium will work with Earth observation data to determine the structural and biological properties of forests.

The consortium will use this information to initialize a set of forest ecosystem models that include processes above and below the ground.

Further, the consortium will develop new interfaces and visualization tools, making the cloud platform easily accessible to end users. Goal of the system developed in the project is to bring together forest data and users interested in forests.

Digital Twin Earth

Dynamic interactive replica of past, present and future of our planet in the digital domain based on effective integration of observations (satellite, in-situ, IoT and socioeconomic data), Earth system science and simulations to bridge impact sectors science and simulations on the base of AI methodologies.

Outcomes

1. **Enhanced understanding of complex processes involving different components of the Earth system** across different scientific domains.

2. **Enhanced the scientific understanding and characterisation of the role of human activities as an integral part of the Earth system**.

3. **Enhanced understanding and characterisation of multi-scale connections** of complex processes from local scales to regional and global scale dynamics.

PERSPECTIVE
https://doi.org/10.1038/s43588-021-00023-0

nature computational science

The digital revolution of Earth-system science

Peter Bauer[1]✉, Peter D. Dueben[1], Torsten Hoefler[2], Tiago Quintino[3], Thomas C. Schulthess[4] and Nils P. Wedi[1]

Computational science is crucial for delivering reliable weather and climate predictions. However, despite decades of high-performance computing experience, there is serious concern about the sustainability of this application in the post-Moore/Dennard era. Here, we discuss the present limitations in the field and propose the design of a novel infrastructure that is scalable and more adaptable to future, yet unknown computing architectures.

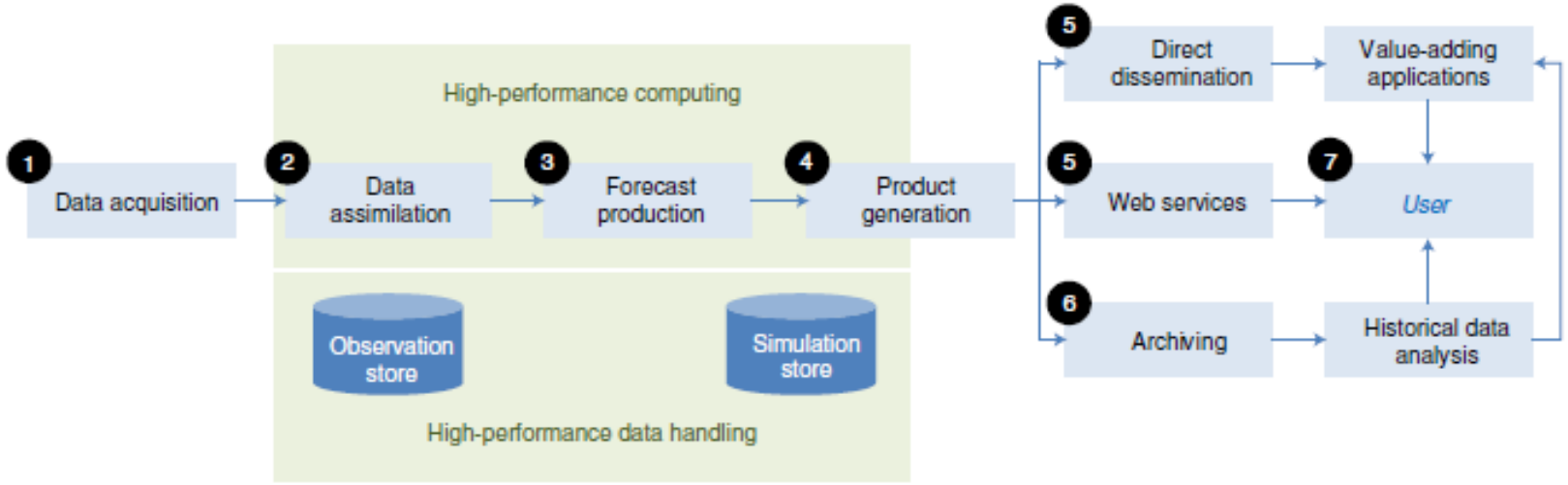


Fig. 1 | Typical production workflow in operational numerical weather prediction. (1) High-volume and high-speed observational data acquisition and pre-processing; (2) data assimilation into models to produce initial conditions for forecasts; (3) forecast production by Earth-system simulation models; (4) generation of output products tailored to the portfolio of weather and climate information users; (5) direct dissemination of raw output and web-products; (6) long-term archiving for reuse in statistical analyses and performance diagnostics; (7) user-specific applications and data-driven analytics.

Microsoft builds the **Planetary Computer** which will help to understand where and how we can best mitigate the impact of humans on the environment, as well as to support decision makers for climate adaptation measures.

The Planetary Computer consist of four major components that also can facilitate to build Environmental **Digital Twins**:

- Planetary Computer Data Catalog — to search and find open datasets
- Planetary Computer API's — to access data and retrieve data
- Planetary Computer Hub — for data processing
- Planetary Computer Applications — third party open and closed applications build on Planetary Computer infrastructure

Organizations can build their Environmental Digital Twins partly based upon the Planetary Computer.

The Earth Archive Initiative is an unprecedented scientific effort to create a digital twin of the entire surface of the Earth – and everything on it.
By scanning the planet's land surface with very high-resolution lidar, the Earth Archive will create a true three-dimensional digital twin of our world — an open source, digital record of the Earth that will reflect the landscape exactly as it was at the time of scanning.
The geospatial data captured will serve as the baseline for understanding and exploring our world.

Nvidia's Digital Twin Moonshot – Saving Planet Earth

By Todd R. Weiss

November 11, 2021

Nvidia is continuing to expand enterprise digital twin capabilities and features in its Nvidia Omniverse 3D virtual world design platform, but the company's nascent plans for its grandest digital twin yet might have even bigger impacts after its announcement at this week's Nvidia GTC21 virtual conference.

The GPU-maker wants to accelerate its digital twin dreams from helping enterprises model products, factories, assembly lines and more – and rev it up to create the grandest digital twin so far – of the planet Earth itself that will continuously model, predict and track climate change in real-time so scientists can seek ways to reverse or stop the destructive effects of its spread.

"We will build a digital twin to simulate and predict climate change," said Nvidia CEO Jensen Huang during his Nov. 9 keynote at the virtual event. The work will be done using a powerful new supercomputer that the company is now building, called Earth-2, which will run AI physics created by the new Nvidia Modulus AI framework at million-X speeds on the Nvidia Omniverse platform, he said.

"All the technologies we have invented up to this moment are needed to make Earth-2 possible," said Huang. "I cannot imagine a greater and more important

nature climate change

Comment | Published: 01 February 2021

A digital twin of Earth for the green transition

Peter Bauer ✉, Bjorn Stevens & Wilco Hazeleger

Nature Climate Change **11**, 80–83 (2021) | Cite this article

For its green transition, the EU plans to fund the development of digital twins of Earth. For these twins to be more than big data atlases, they must create a qualitatively new Earth system simulation and observation capability using a methodological framework responsible for exceptional advances in numerical weather prediction.

A key element of the Green Deal is its dependence on the 'digital transformation' — an openly accessible and interoperable European dataspace as a central hub for informed decision making. The EU identified two landmark actions to support the necessary information systems: GreenData4All[2] and Destination Earth[3]. Whereas GreenData4All will develop the European approach to discover, manage and exploit geospatial information, Destination Earth aims to construct highly accurate models, or 'digital twins', of the Earth

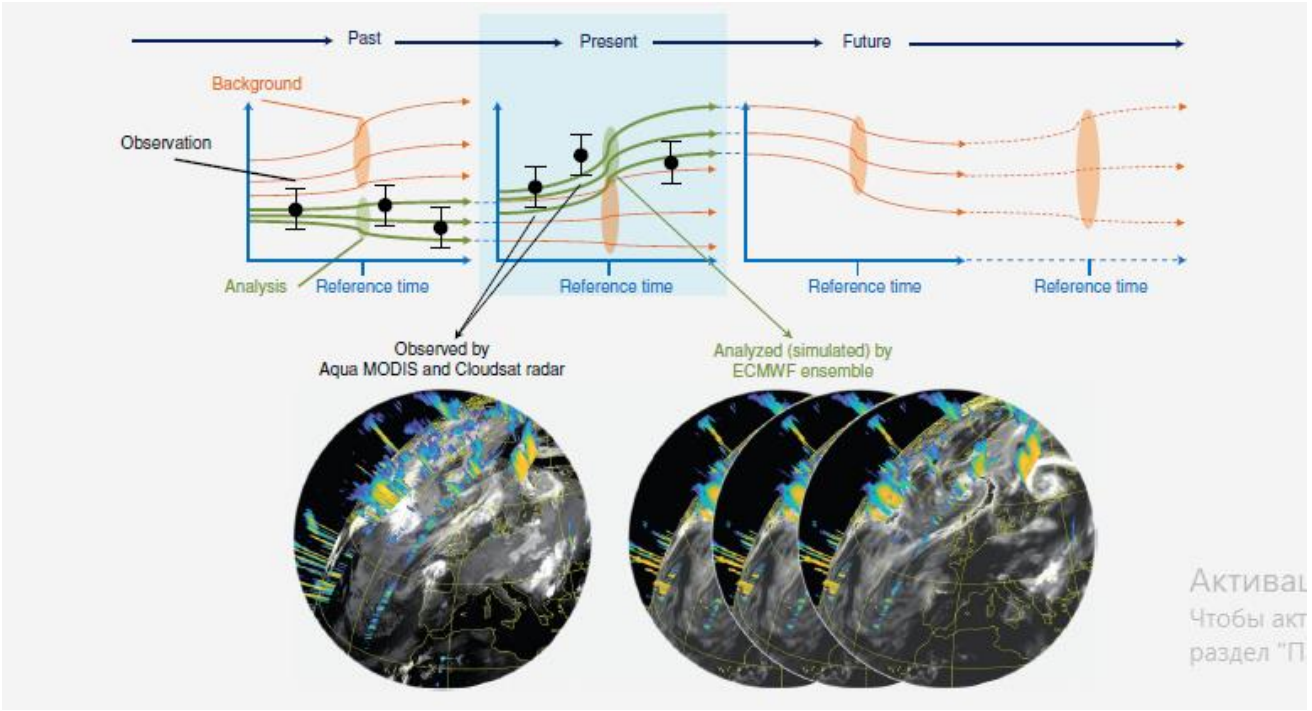
EU Megaproject Destination earth (Destine)

“The objective of the Destination Earth initiative is to develop a very high precision digital model of the Earth to monitor and simulate natural and human activity, and to develop and test scenarios that would enable more sustainable development and support European environmental policies.

At the heart of Destination Earth will be a federated cloud-based modelling and simulation platform, providing access to data, advanced computing infrastructure (including high performance computing), software, AI applications and analytics. The digital twins created in DestinE will give users access to high-quality information, services, models, scenarios, forecasts and visualizations. Digital twins are based on the integration of continuous observation, modelling and high-performance simulation, resulting in highly accurate predictions of future developments.”*

Implementation: 2021-2030

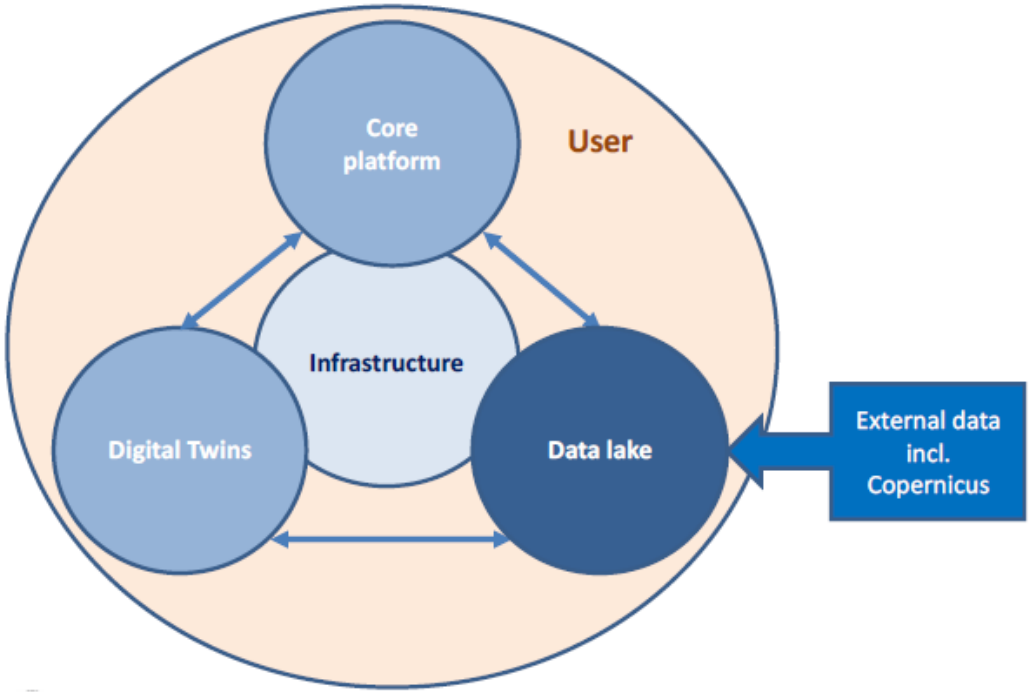
Optimally combined simulations and near-real-time observations to monitor the evolution of the Earth system. For each cycle, the simulation generates a background forecast ensemble (orange arrows) of the Earth system, which is compared to observations (black dots) throughout a time window and eventually corrected to an analysis ensemble (green arrows), which fits the observations better than the background. Uncertainties of forecasts (ellipses) and observations (error bars) are fully taken into account from ensembles, which are multiple, perturbed realizations of both model and observations.



Digital Twins in DestinE

Peter Bauer
ECMWF

Digital Twins

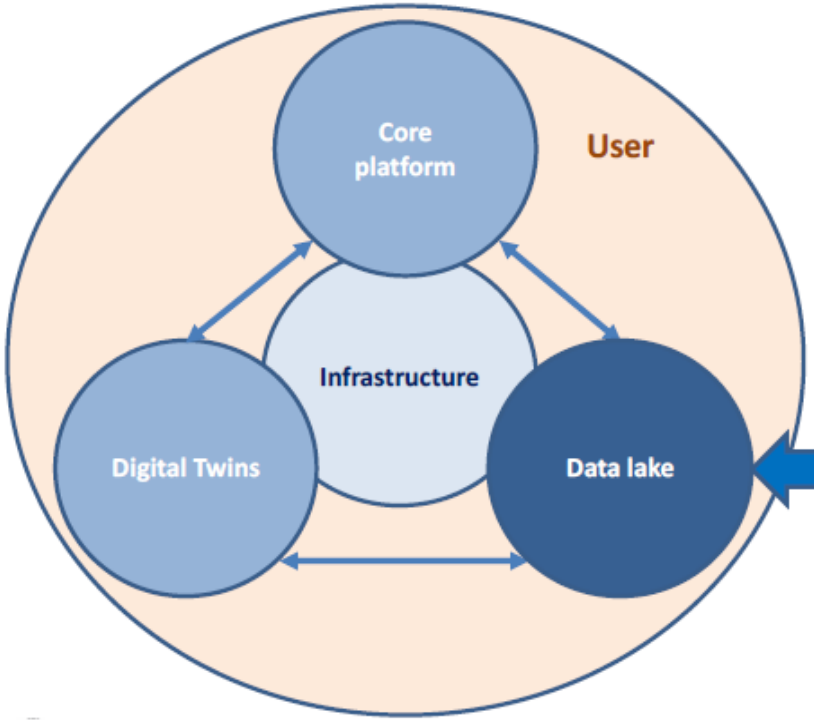


2 high-priority Digital Twins:

1. **Weather-induced and Geophysical Extremes:** Environmental extremes at very high spatial resolution and close to real-time decision-making support at continental, country, coastline, catchment and city scales in response to meteorological, hydrological and air quality extremes.

2. **Climate Change Adaptation:** Climate change adaptation policies and mitigation scenario testing at decadal timescales aiming at a real breakthrough at the level of reliability at regional and national levels, for understanding the causes and explaining the feedback mechanisms of change, and predicting possible evolution trajectories

Core Platform



- Portal to Users
- User Hosting (user space: MyDestinE)
- Catalogue and data access services
- PaaS & SaaS for analytics and modelling
- Community management (market place, annotations, open source)
- Advanced interface for interactive modelling (system dynamic, 3D,…)
- Operate the User Data API for Data Lake access and User DTs interface for on-demand production

PaaS (Platform as a Service) — модель предоставления облачных вычислений, при которой потребитель получает доступ к использованию информационно-технологических платформ: ОС, СУБД, ПО, и т.д.

SaaS (*software as a service* — одна из форм облачных вычислений, модель обслуживания, при которой подписчикам предоставляется готовое прикладное программное обеспечение, полностью обслуживаемое провайдером.

Role of users!

Core Platform

Users make use of the DestinE Core Service Platform (DESP) to produce answers to their problems*

Platform combines generic & user specific services …

- Unified access to data generated or collected/referenced by DestinE
- Applications to support development / modelling / analysis / visualization
- On-demand DT simulation / data retrieval / data transformation

… in a user customizable environment to :

- Develop & operate own applications / services
- Share results / data / applications / libraries

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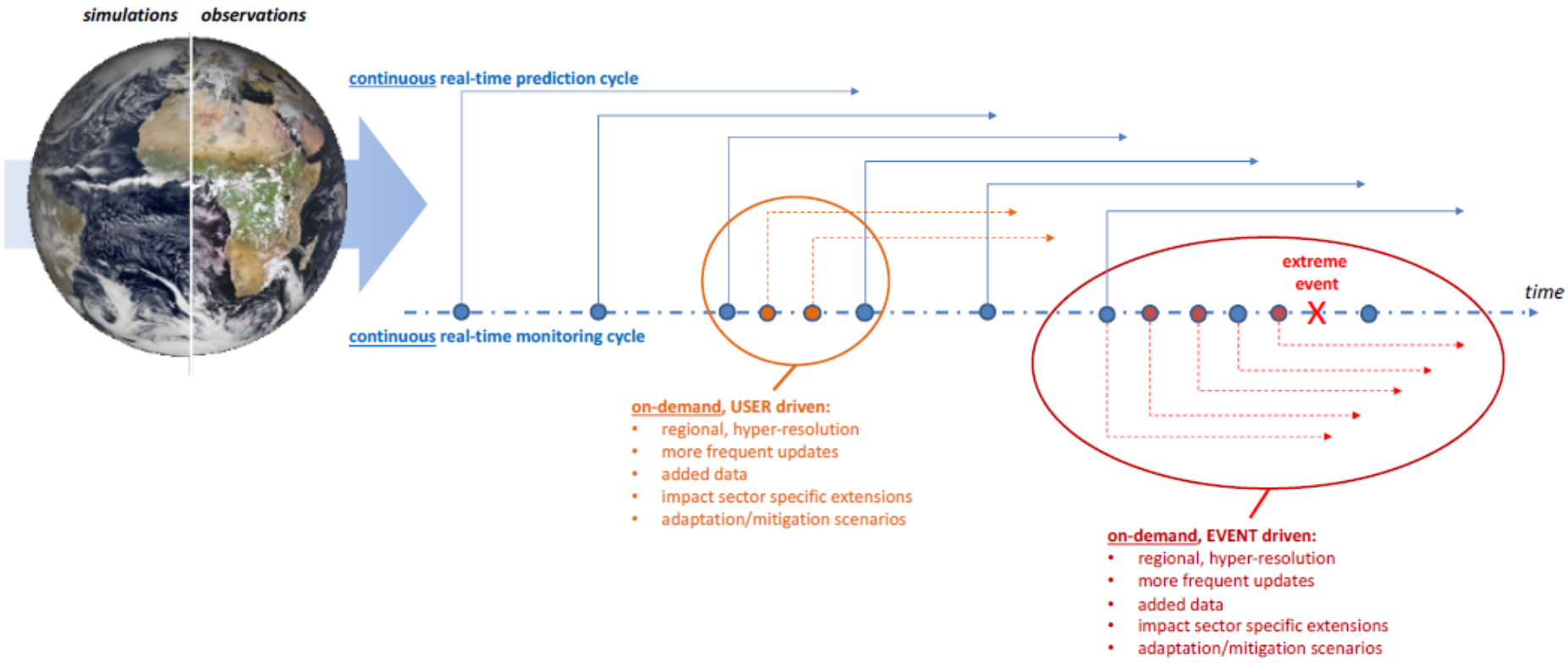
*in an open and extensible environment

Digital Twin production



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Current projects in Russia:

“Digital field” project (I.V. Oseledets, Scoltech)

Federal project “Digital Ob’-Irtysh catchment” (DT of river catchment - V.P. Potapov, FRC for Information and computational Technologies)

Possible activities

DTs of Northern Eurasia ecosystems for (bogs, forest, permafrost, etc.) as an instrument to “green” economic transition (should be used in Carbon polygons)!


Thanks for attention!