multi-Risk sciEnce for resilienT commUnities undeR a changiNgclimate

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1. Technical references

Project Acronym	RETURN
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* PU = Public

PP = Restricted to other programme participants (including the Commission Services)

RE = Restricted to a group specified by the consortium (including the Commission Services)

CO = Confidential, only for members of the consortium (including the Commission Services)

1.1. Document history

Version	Date	Lead contributor	Description
0.1	03/05/2025	Alberto Tasso (CIMA)	First draft
0.2	20/05/2025	Marco Menapace (CIMA)	Critical review and proofreading
0.3	25/05/2025	Francesco Ballio (POLIMI)	Edits for approval
1.0		Alberto Tasso	Final version

2. ABSTRACT

This document details the design and prototyping of crucial components for the visualization and exploration of hazards' forecasts, risks, and their impacts within the RETURN Digital Ecosystem. The core objective is to empower users to effectively leverage the diverse tools and services offered by the ecosystem, fostering resilience in communities facing a changing climate.

The proposed solution focuses on enabling seamless access and interaction with vast geospatial data and complex models. It includes a robust framework for ecosystem exploration through both standard and guided navigation, facilitating intuitive discovery of available resources. Furthermore, the document outlines functionalities for efficient data extraction, flexible model execution with comprehensive parameter selection, and sophisticated results analysis. This analysis is supported by background processing orchestrated by an integrated Workflow Engine and intuitive visualization within a workspace utilizing GeoTool services.

By providing an intuitive and efficient interface, this design significantly enhances the accessibility and interpretability of geospatial data and models, thereby supporting informed decision-making and contributing directly to the Spoke VS1 in the “Return” project's overarching goal of multi-risk science for resilient communities. This work represents a significant step towards creating a dynamic and responsive platform capable of addressing contemporary climate-related challenges.

3. Table of contents

1. Technical references 2
1.1. Document history 3
2. ABSTRACT 4
3. Table of contents 5
2.1. List of Figures 5
4.Introduction 6
3. Ecosystem exploration 7
3.1. Standard navigation 7
3.2. Guided navigation 8
4. Data extraction 10
5. Model execution 11
6. Results analysis 12
7. Conclusions 14

2.1. List of Figures

Figure 1 - Ecosystem exploration, standard navigation 8
Figure 2 - Ecosystem exploration, guided navigation 9
Figure 3 - Data extraction 10
Figure 4 - Model Execution 11
Figure 5 - Requests list 12
Figure 6 – Workspace 13

4.Introduction

In the context of the Digital Ecosystem, the visualisation feature plays a fundamental role in enabling users to make the most of the tools and services provided.

This document focuses on the proposed solution for managing the data and services to be integrated into the Digital Ecosystem. The overarching goal of the "multi-Risk sciEnce for resilienT commUnities undeR a changiNg climate" (RETURN) project is to enhance community resilience against climate change impacts through advanced multi-risk science. A critical enabler for this vision in the context of Spoke VS1is a robust Digital Ecosystem that allows diverse stakeholders – from climate scientists and emergency managers to urban planners and policymakers – to seamlessly access, analyze, and visualize complex geospatial data and model outputs.

Currently, users often face significant challenges in discovering relevant data, executing sophisticated models, and interpreting intricate results due to fragmented data sources, disparate tools, and steep learning curves. This document addresses these pain points by outlining a user-centric design for the ecosystem's front-end components, ensuring that the powerful backend capabilities are accessible and actionable.

By leveraging the WASDI platform's integration features, it will be possible to connect existing data sources and deploy existing models directly onto the platform. While this addresses fundamental needs, the Digital Ecosystem also requires dedicated features to enable seamless data integration and workflow execution beyond WASDI's core offerings. This document details the design and prototyping of these essential components, specifically focusing on:

- **Ecosystem Exploration**: Providing intuitive interfaces for discovering available resources (data, services, models).
- **Data Extraction**: Facilitating the search and retrieval of relevant geospatial data.
- **Model Execution**: Enabling users to configure and run complex simulation models.
- **Results Analysis**: Offering tools for the visualization and interpretation of model outputs and extracted data.

The Digital Ecosystem operates on a layered architecture designed for scalability and interoperability. At its foundation, data sources and computational models are either federated via the WASDI platform or directly ingested. The components described in this document serve as the primary user interface layer, enabling interaction with these underlying services. An integrated Workflow Engine orchestrates complex operations, while GeoTool services provide advanced geospatial processing and visualization capabilities. This holistic design ensures a cohesive and powerful environment for multi-risk assessment.

3. Ecosystem exploration

To manage the potentially vast and diverse catalog of resources within the Digital Ecosystem, a robust and intuitive exploration interface is paramount. This interface is designed to significantly enhance user experience by simplifying resource discovery. Our approach incorporates two complementary navigation modes: Standard Navigation, offering comprehensive search and filtering capabilities for detailed exploration, and Guided Navigation, providing streamlined pathways for specific user needs. These modes are designed to efficiently connect users with the relevant data, models, and services, regardless of their familiarity with the ecosystem's full breadth.

3.1. Standard navigation

The Standard Navigation mode provides users with granular control over their search, acting as a comprehensive catalog browser. The underlying metadata schema, which adheres to established geospatial standards, ensures that all registered resources are consistently described. This facilitates robust filtering by:

- **Resource Category**: Allowing users to filter by broad classifications (e.g., "Climate Data," "Hydrological Models," "Impact Assessments").
- **Resource Type**: Distinguishing between data products, services, computational models, demonstrators and methodologies.
- **Resource Geographical Location**: Enabling selection of specific areas of interest via an interactive map component, supporting bounding box, polygon drawing or automatic basin identification.
- **Textual Search**: Utilizing a full-text indexing mechanism for keyword-based searches across resource names, descriptions, and associated tags, ensuring highly relevant results.

Each retrieved resource is presented in a standardized "card" component. This card offers a concise yet informative summary, including the resource name, a brief description, a relevant thumbnail or graphical abstract, key metadata (e.g., temporal coverage, spatial resolution, data provider), and direct commands to interact with the resource.

This design ensures that even with a vast number of resources, users can quickly identify and access what they need. Scalability for a large catalog is addressed through efficient database indexing and optimized search algorithms, ensuring fast retrieval times.

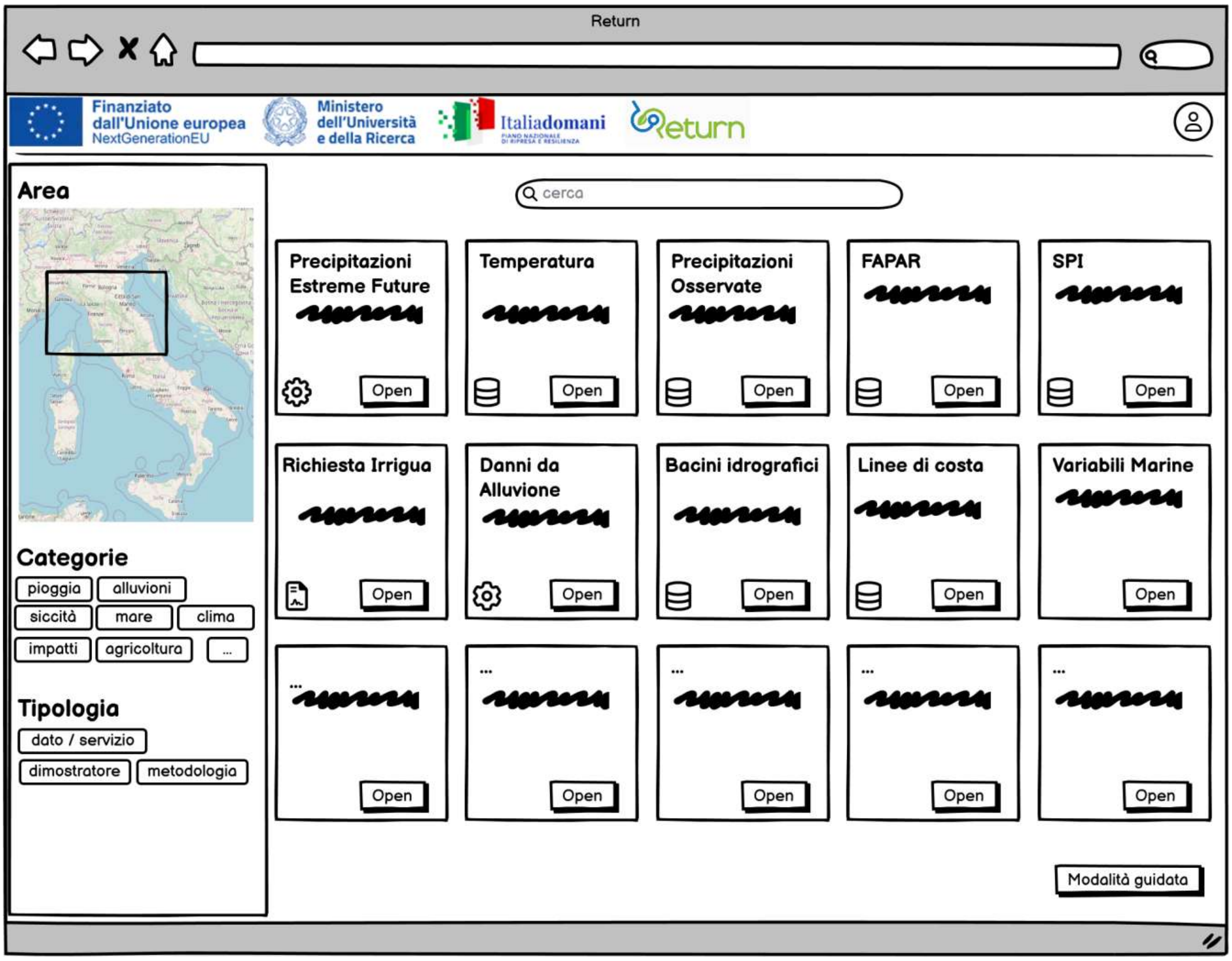

Figure 1 - Ecosystem exploration, standard navigation

3.2. Guided navigation

Guided Navigation mode is designed for users with specific operational questions or who are less familiar with the full range of available resources. It provides simplified workflows based on common user needs and pre-defined scenarios. These 'predetermined filtering criteria' are developed from extensive user research and analysis of typical use cases within the project, such as 'Assess flood risk in an urban area', 'Evaluate drought impacts on agriculture' and 'Predict future extreme precipitation events'.

Once a specific need has been selected, the user interface dynamically presents a curated list of relevant resources (data, models and services) that are directly applicable to that context. This streamlines the discovery process and significantly reduces the cognitive load for users who may not be familiar with the exact technical terms or resource types. The interactive map component is still available to refine geographical areas of interest within the guided context.

This feature is particularly beneficial for non-expert users or individuals seeking rapid solutions to specific problems, accelerating their journey towards actionable insights. The system is designed to allow for the future expansion and customisation of these guided paths based on evolving user requirements.

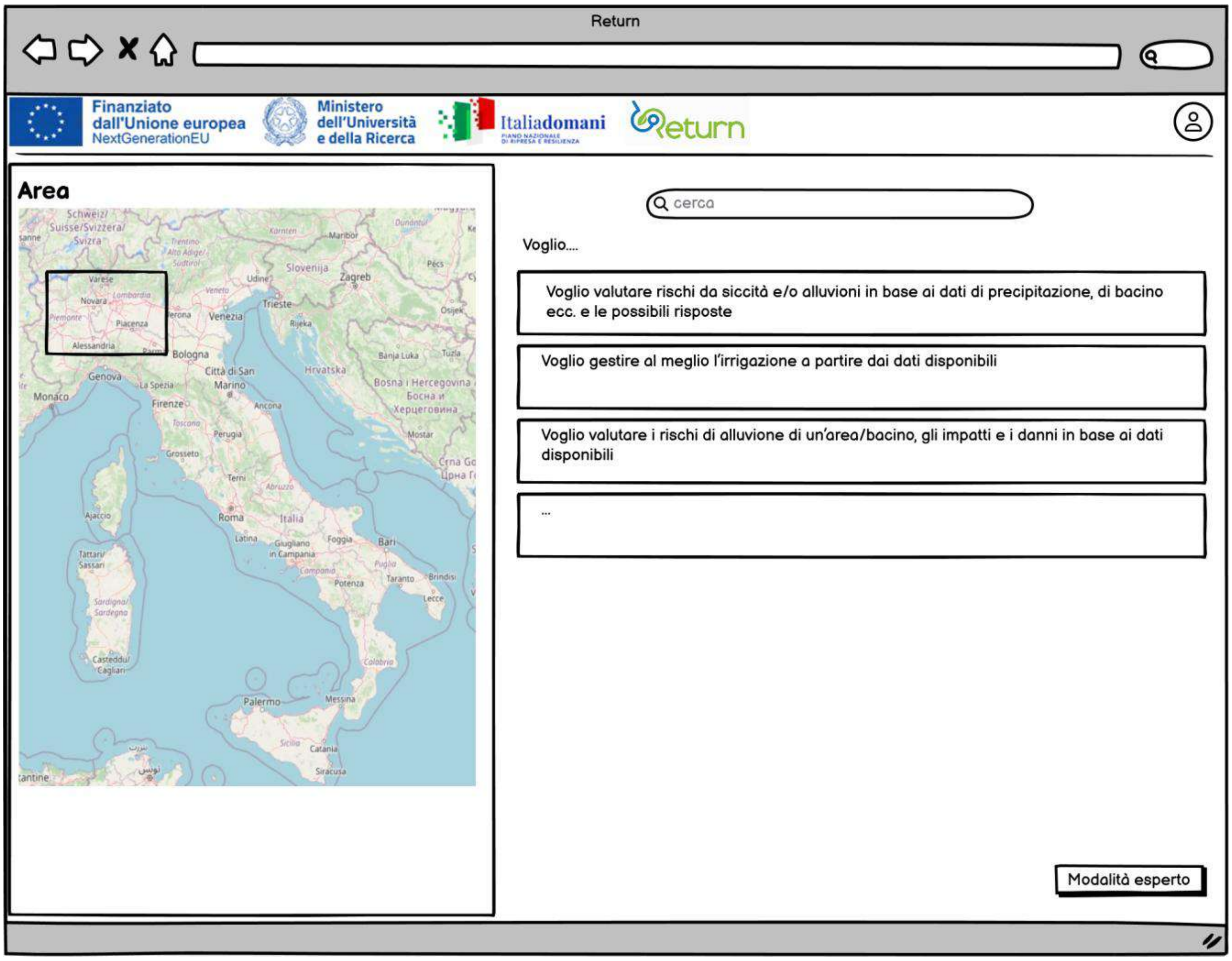

Figure 2 - Ecosystem exploration, guided navigation

4. Data extraction

The Data Extraction component provides a harmonized interface for searching and retrieving geospatial data products from diverse sources, irrespective of their native metadata structures. This is achieved through a metadata harmonization layer that translates disparate source metadata into a common pattern understood by the Digital Ecosystem.

Users will be presented with a comprehensive set of filtering criteria, which typically include:

- **Temporal Range**: Allowing selection of specific time periods (e.g., historical, present, future projections).
- **Spatial Extent**: Defining the area of interest through map interaction (bounding box, polygon draw) or by selecting predefined administrative units.
- **Data Resolution**: Specifying spatial or temporal granularity.
- **Data Type/Format**: Filtering by specific data formats (e.g., NetCDF, GeoTIFF, Shapefile) or types (e.g., satellite imagery, climate model outputs).
- **Provider/Source**: Identifying specific data origins.
- **Keywords/Tags**: Leveraging free-text search for additional relevance.

Once criteria are applied, the system presents a dynamic list of matching data products. From this list, users can select items for either direct download in standard formats or for immediate analysis within the platform. The system supports a variety of data source integration strategies, including direct API connections, federation through the WASDI platform, and file ingestion. Data provenance information (origin, transformations, last updated timestamps) is meticulously tracked and displayed to ensure data traceability and quality assurance.

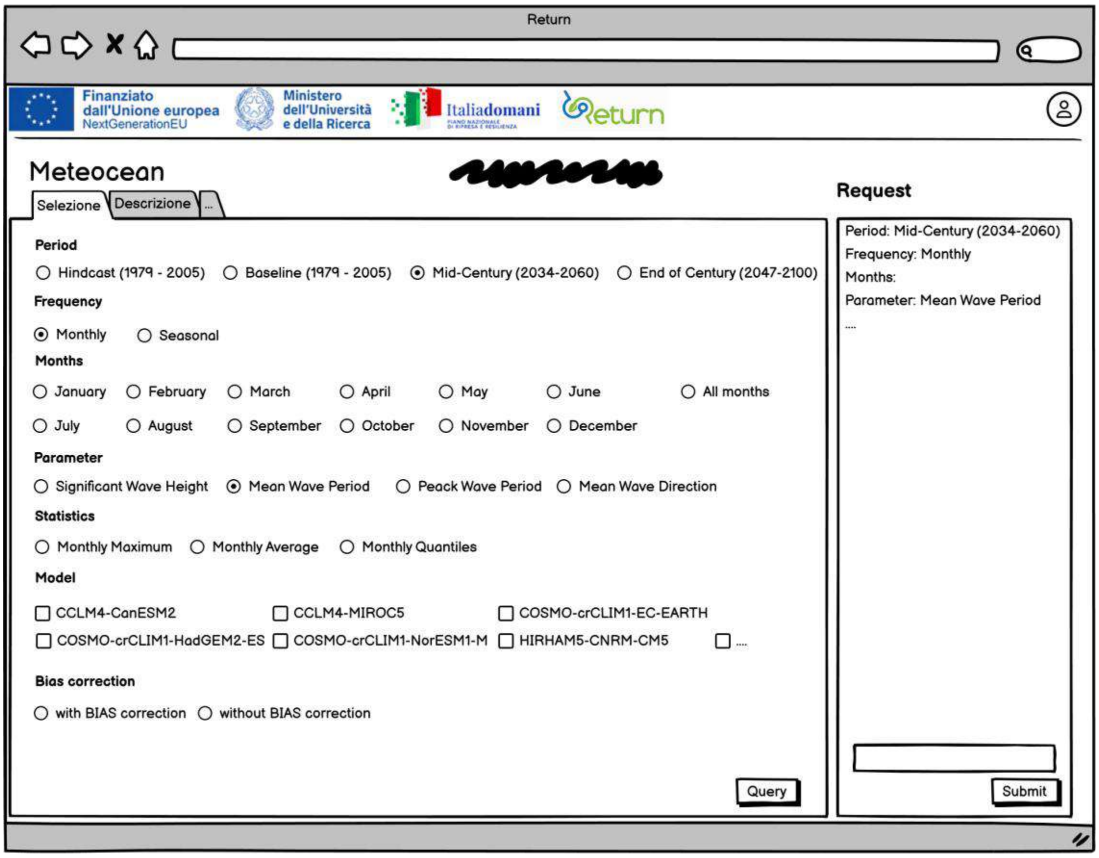

Figure 3 - Data extraction

5. Model execution

The Model Execution component provides a standardized and user-friendly interface for configuring and running various computational models integrated within the Digital Ecosystem. While models inherently differ in their parameter requirements, a common pattern for parameter definition and execution has been established, leveraging a standardized model registry and metadata schema for each registered model.

For each selected model, the system dynamically presents all necessary parameters, which can include:

- **Numerical Inputs**: Discrete or continuous values (e.g., duration, return period).
- **Categorical Inputs**: Dropdown selections (e.g., frequency, month, model variant).
- **Spatial Inputs**: Definition of an Area of Interest (AOI) via an interactive map, allowing manual drawing of polygons or selection of pre-defined geographic regions. The AOI can also be automatically defined based on model constraints or data availability.
- **Temporal Inputs**: Selection of specific time ranges or periods for simulation.

A robust validation logic is applied client-side and server-side to ensure that only valid requests are forwarded to the underlying execution environment. This includes checks for data type consistency, parameter range constraints, and spatial/temporal coherence with available input data.

Model execution is orchestrated by the integrated Workflow Engine, which interfaces with WASDI processors and other computational backends. Users will receive real-time updates on execution progress, and detailed logs will be available for troubleshooting. The outputs from model executions will be stored in standard geospatial formats, ready for subsequent analysis and visualization within the Results Analysis workspace.

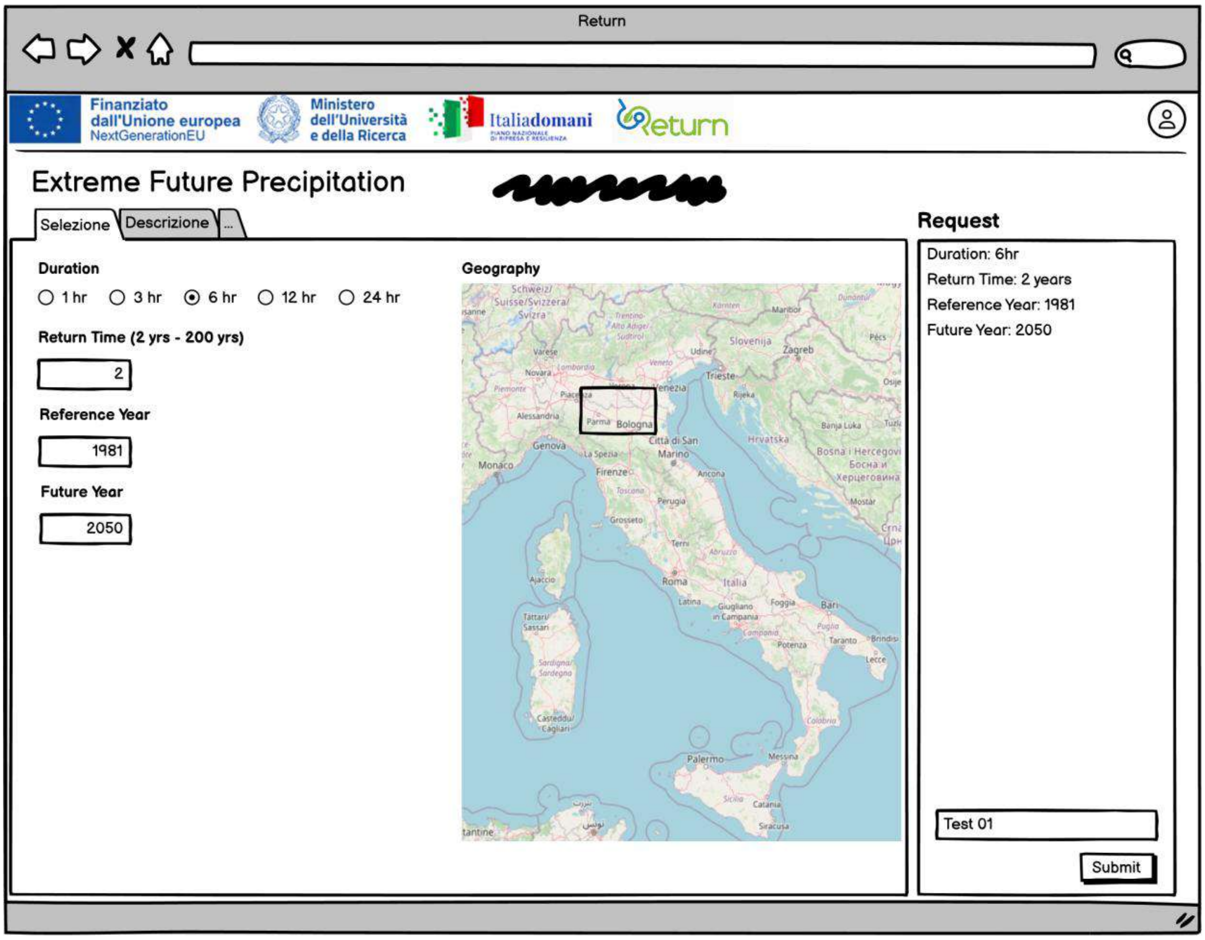

Figure 4 - Model Execution

6. Results analysis

The Results Analysis component is designed to provide a comprehensive and intuitive environment for visualising, exploring and interpreting geospatial data, whether it is derived from direct data extraction or generated as an output from model execution.

To accommodate varying processing times, all data ingestion and initial processing operations are performed asynchronously in the background. Users are provided with a dedicated 'Requests List' to monitor the real-time progress of their data extraction and model execution requests, including status updates and options to manage or retrieve results.

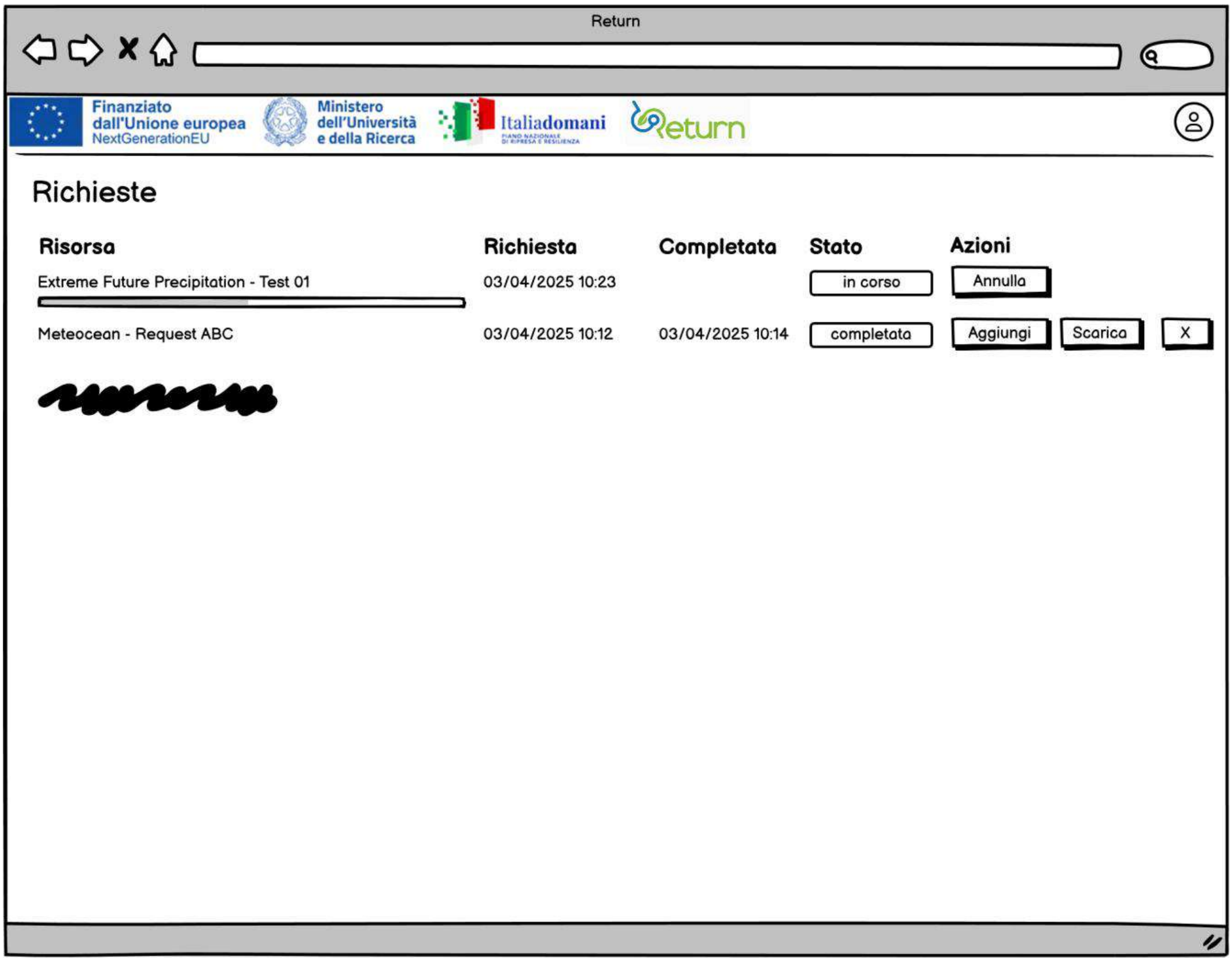

Figure 5 - Requests list

Upon completion of processing, results can be seamlessly loaded into a dedicated "Workspace" area for interactive visualization and in-depth analysis. The workspace leverages the powerful capabilities of the GeoTools service integrated within the Digital Ecosystem. These services provide a rich portfolio of geospatial operations and visualization capabilities, including:

- **Interactive Mapping**: Dynamic pan, zoom, layer management, and base map selection.
- **Time-Series Analysis**: For temporal datasets, interactive time-sliders and animation controls to visualize changes over time.
- **Basic Measurements**: Tools for distance, area, and coordinate identification.
- **Statistical Summaries**: Generating quick statistics for selected data regions.

The Workflow Engine plays a crucial role in orchestrating the background processing required to ingest, transform, and prepare the data for visualization. This includes format conversions, reprojection, and indexing. The workspace is designed for user flexibility, allowing different analysis options to be activated based on the selected geospatial product type. Analysis results and configured workspaces can be saved and shared with other users, fostering collaboration and knowledge dissemination

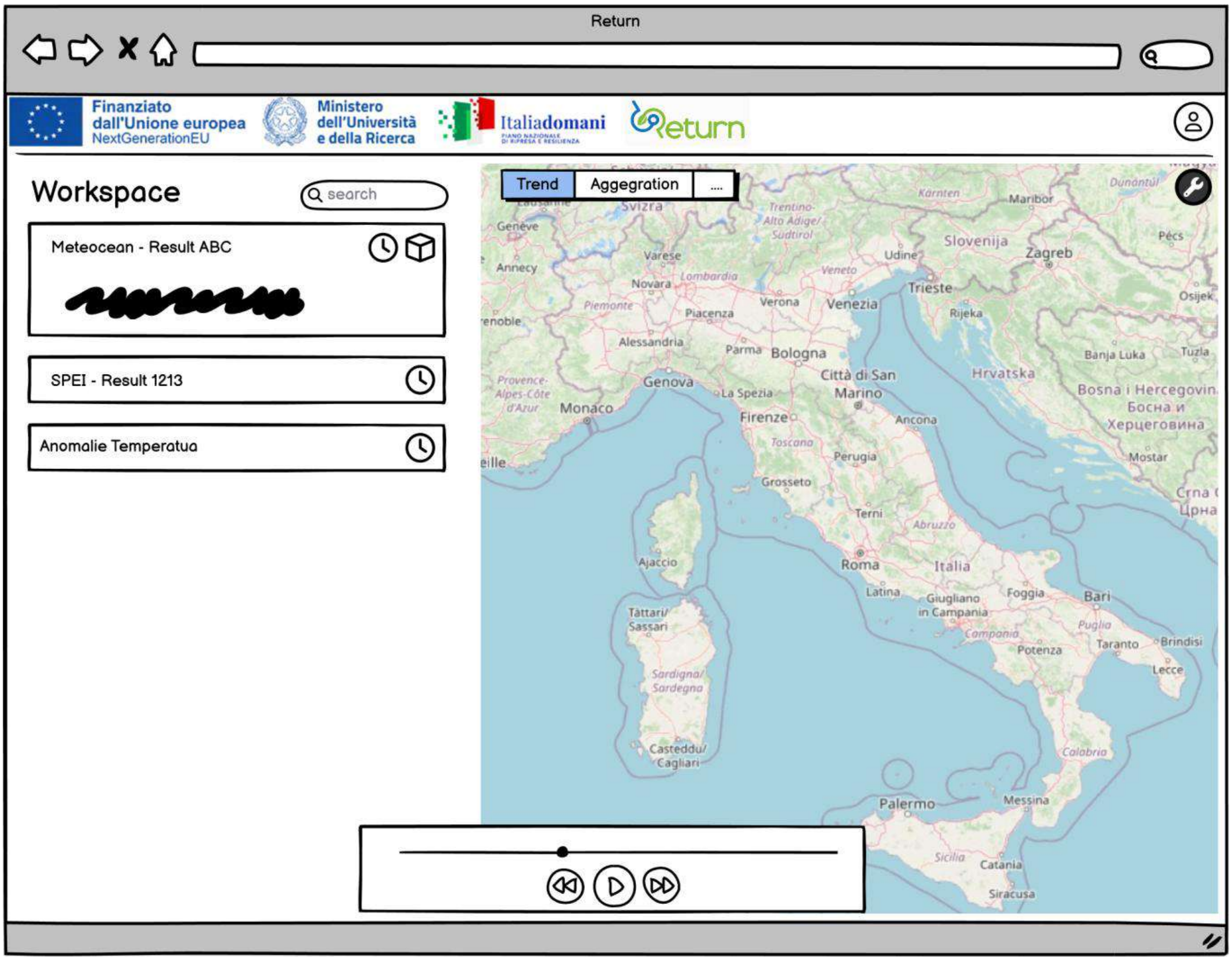

Figure 6 – Workspace

7. Conclusions

This document details a robust design and prototyping framework for the visualization and exploration components of the RETURN Digital Ecosystem. The proposed solution is a critical enabler for the project's mission of building resilient communities by making complex multi-risk science accessible and actionable. The seamless integration of standard and guided navigation, efficient data extraction, flexible model execution, and comprehensive results analysis, all orchestrated by a powerful Workflow Engine and intuitive GeoTools service, represents a significant advancement in facilitating scientific inquiry and informed decision-making.

This initial design successfully lays the groundwork for a user-centric platform that addresses key challenges in geospatial data interaction and model utilization. The emphasis on harmonized interfaces and automated background processing ensures a streamlined and efficient user experience, empowering a diverse range of stakeholders—from researchers to emergency responders—to derive valuable insights from complex environmental data.