cmcc
Centro Euro-Mediterraneo
sui Cambiamenti Climatici

Institute for Climate Resilience

ICR

The Climate Research Center of the XXI Century

CMCC is an international institution producing advanced research on climate modeling **whilst at the same time developing transversal and multidisciplinary competencies that combine first-class climate modeling with climate change impact modeling and environmental economics**.

Three multidisciplinary research institutes

Four strategic programs on frontier topics

A computing infrastructure dedicated exclusively to the study of climate change

Two specialized centers on digital innovation, and high-level education and training

Over 200 international research projects
A management structure that supports research

Guaranteeing **globally relevant** results for:

- **the scientific community**
- **decision-makers**
- **stakeholders**
- **civil society**

Supporting decisions and actions that promote sustainable development.

Antonio Navarra
President

Giulio Boccaletti
Scientific Director

Laura Panzera
Operations Director

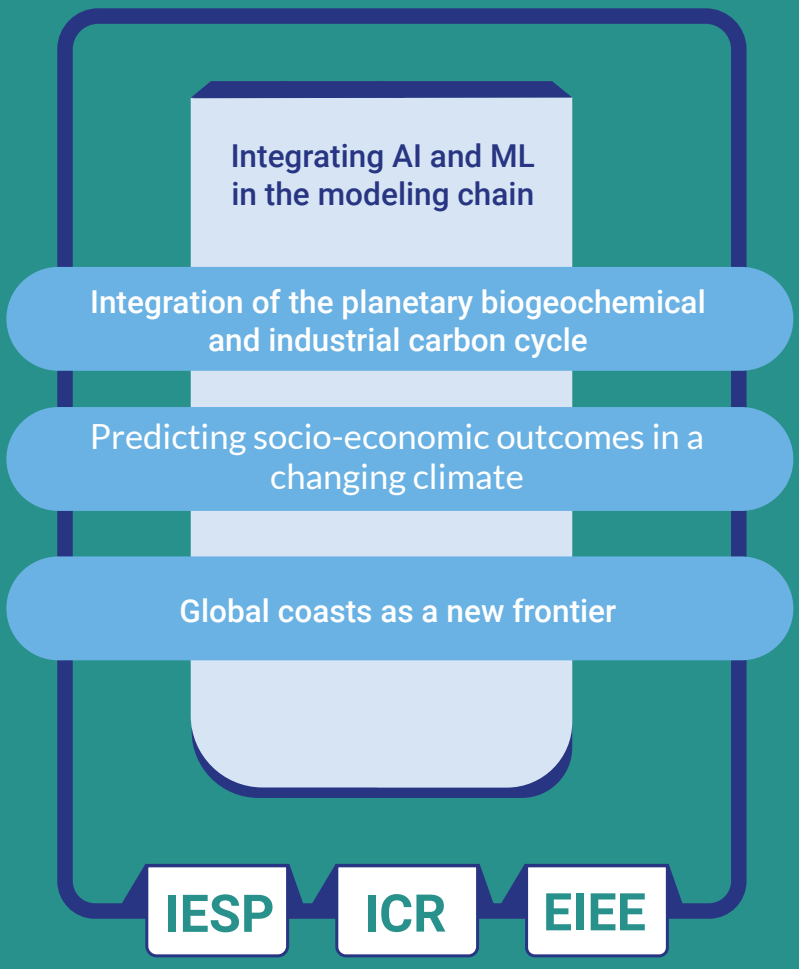
From models to solutions: our research

Our research is organized into three institutes that are home to Earth's sciences and social sciences researchers worldwide:

- **Institute for Earth System Predictions - IESP**
- **Institute for Climate Resilience - ICR**
- **European Institute on Economics and the Environment - EIEE**

A set of strategic programs addresses frontier issues crucial to understanding the challenges facing socio-economic systems in an environmental and social context characterized by a changing climate.

This setup ensures cross-disciplinary research that, leveraging the advanced technology of CMCC's High Performance Computing Center, making CMCC a standout in climate studies covering the entire chain of climate research (from drivers to impacts), as well as the social, economic and technological dimensions.



Monia Santini

Director Institute for Climate Resilience – ICR

The Institute for Climate Resilience

(ICR)

is at the forefront of **interdisciplinary research that connects climate, ecosystems and society**. Its mission is to empower decision-makers with the knowledge they need for both immediate actions and long-term planning, so as to help guide planning and investments toward a **climate-resilient future**.

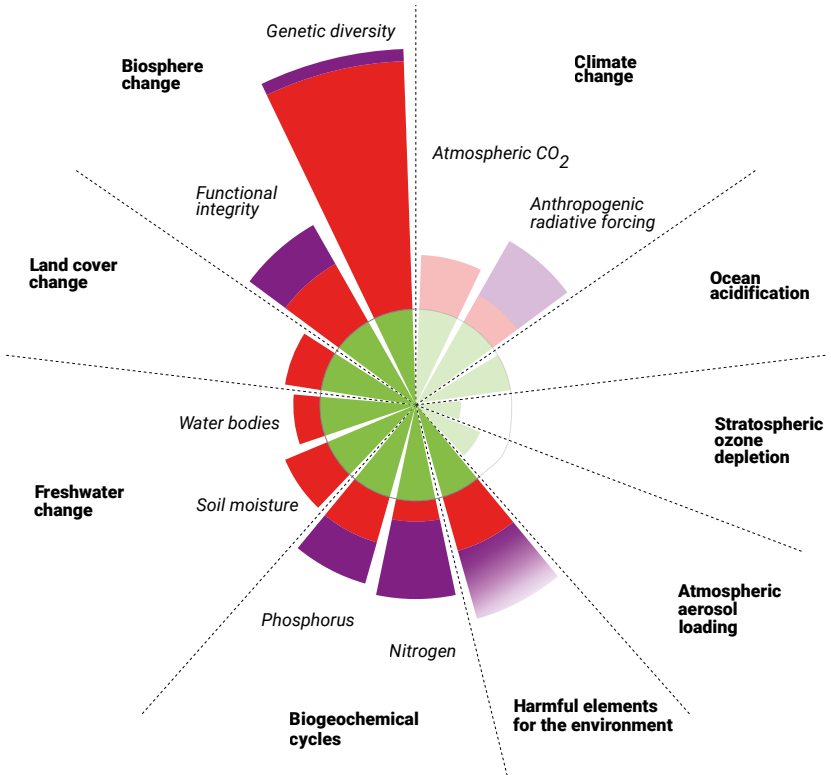
Resilience refers to the ability of systems to withstand, recover and adapt to shocks and changing conditions in ways that both safeguard existing progress and forge innovative future paths. This concept lies at the heart of the ICR's mission. In a world facing climate change, resilience requires **integrated approaches to mitigation, disaster risk reduction and adaptation**.

Beyond safe limits: Building climate resilient futures

ICR addresses the growing pressures humanity exerts on the planet. Its primary mission is to understand and mitigate these pressures so that we can enhance planetary resilience and ensure sustainable development.

Recent data reveals a concerning trend: six out of nine planetary boundaries – critical processes that are used to gauge Earth's health – have crossed the so-called safe operating space (represented in green in the figure below), and four of them are now in the high-risk zone (represented in purple). ICR deals with five of the overshot boundaries, namely biogeochemical cycles, freshwater use, land system changes, biosphere integrity, and harmful elements for the environment, referred to as novel entities in previous research (see figure below), all of which interact and amplify their respective impacts on the climate itself and hence the overall resilience of the planet.

Although the boundaries between safe, unsafe, and high-risk are not clear cut, the underlying message is: immediate and significant efforts are required to safeguard our planet's future.



Freely adapted from: Richardson et al. (2023), https://doi.org/10.1126/sciadv.adh2458.

Resilience beyond climate adaptation

> Integrating efforts across different systems — land, water, ecosystems, urban areas, societies and energy — paves the way for sustainability.

This comprehensive approach is essential for building a resilient future where everyone can thrive despite the challenges presented by a changing climate.

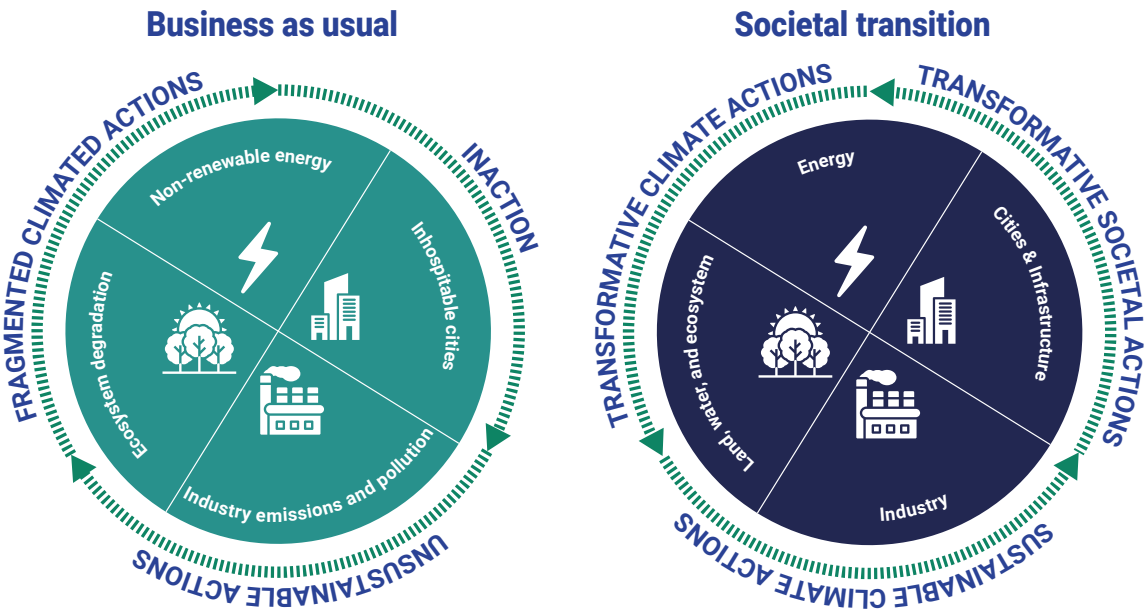


Figure adapted from: Schipper et al.(2022), https://doi.org/10.1017/9781009325844.027.

> Resilience is a blend of "mitigation and adaptation options to support sustainable development for all."

Taken from the latest IPCC report, these words point to the need for a comprehensive approach to tackling climate change.

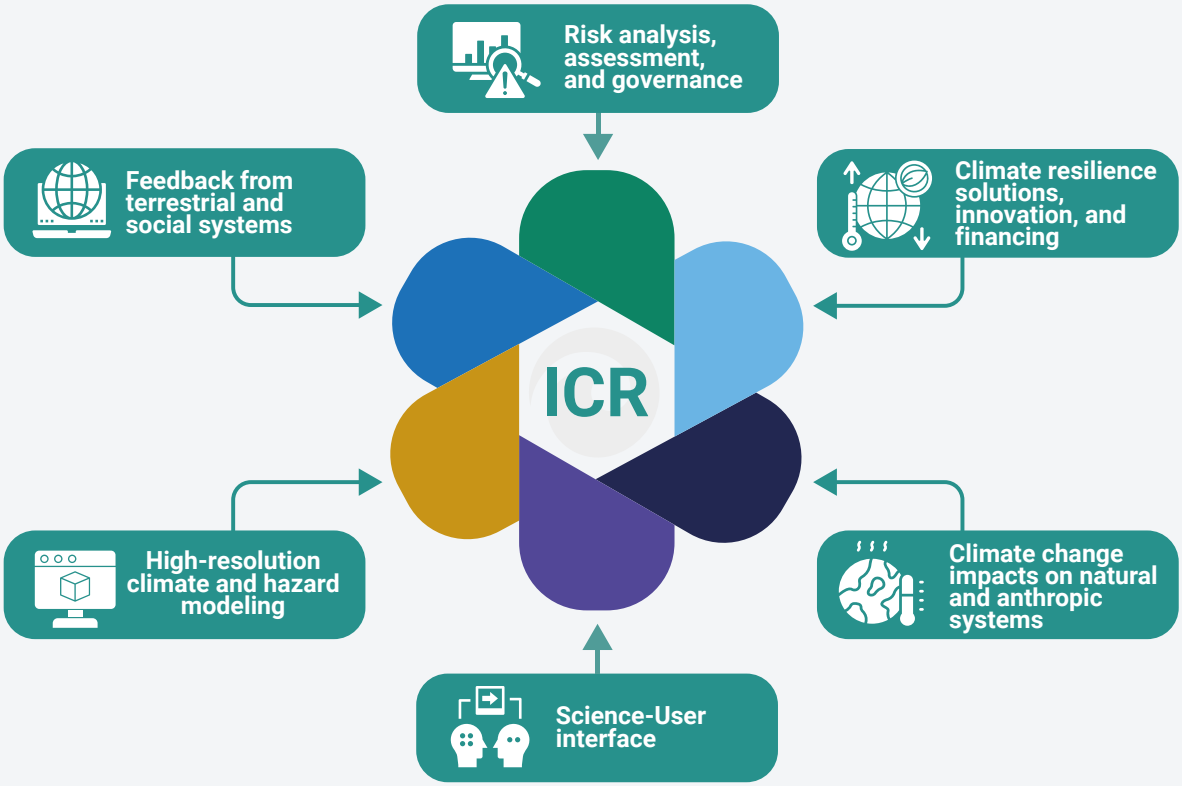
Climate-resilient development depends on transformative actions and systemic transitions. Societal choices can either perpetuate a business as usual scenario or lead to a cross-sectoral transition towards sustainable processes. Fragmented and unsustainable climate action and inaction, undermine mitigation and adaptation efforts.

What does ICR do?

ICR builds on years of expertise and a diverse array of observations and models to create digital representations of the Earth and human systems, constantly improving data, methodologies and tools.

ICR actively leads and participates in numerous international projects focused on climate mitigation and adaptation, resilient socio-economic systems and sustainable resource management.

With a strong track record in securing Horizon Europe funding, ICR plays a key role in advancing the Horizon Europe Mission on Climate Adaptation.



The ICR's work is organized into key thematic areas that are all highly interconnected and represent cutting-edge priorities in climate resilience research. From high-resolution modeling to tailoring scientific results to user needs, ICR covers the entire resilience research process.

ICR research is aligned with the evolving global post-pandemic landscape and integrates new EU and international initiatives, strategies and policies, including:

> the Common Agricultural Policy, Climate Law, Green Deal, Digital Strategy, Copernicus, DestinE, Horizon Europe, Recovery Plans, Sustainable Development Goals, and One Health.

CMCC stands out as **Europe's top research institution** when it comes to the number of projects in the "EU Mission: Adaptation to Climate Change" sub-program of Horizon Europe. Through ICR, CMCC participates in 9 out of the 34 projects, coordinating 2 of them, and therefore emerging as a leader in the field.

CMCC's portfolio of activities includes a wide and varied range of topics that gather critical challenges for resilient transitions, such as:

- climate adaptation in the Mediterranean using nature-based solutions and multi-level collaboration to strengthen local resilience
- mitigation through the leveraging of sustainable land management options
- promotion of best practices, innovative approaches, community empowerment, and equity to accelerate climate resilience across Europe.

ICR contributes to the COordinated Regional Downscaling EXperiment (CORDEX) — sponsored by World Climate Research Program (WCRP) — to produce and deliver regional-scale climate projections for impact assessment and adaptation studies, and to the Integrated Carbon Observation System (ICOS) European Research Infrastructure to measure and analyze data on greenhouse gas (GHG) fluxes, as well as coordinating the Ecosystem Thematic Centre (ETC).

Research pillars

ICR's research is dedicated to advancing climate resilience through a wide range of thematic areas, which are grouped into three main pillars:

- climate change impacts on natural and human systems
- natural and managed ecosystem feedback on climate
- climate risk assessment, adaptation and governance.

The CMCC Institute for Climate Resilience focuses on practical solutions including resource management, transformative adaptation, climate-proofing and Nature-based Solutions..

ICR studies climate change impacts and the overall health of a variety of ecosystems, such as forests, agricultural land, water bodies, coasts and soil.

On the other hand, ICR also investigates how ecosystems influence the climate (particularly through the carbon cycle), and monitors greenhouse gas emissions from both natural and managed environments including agricultural and urban areas.

Our research also delves into the interactions between science, society and policy by exploring risk analysis, adaptation, governance and finance to support informed decision-making and foster climate resilience.

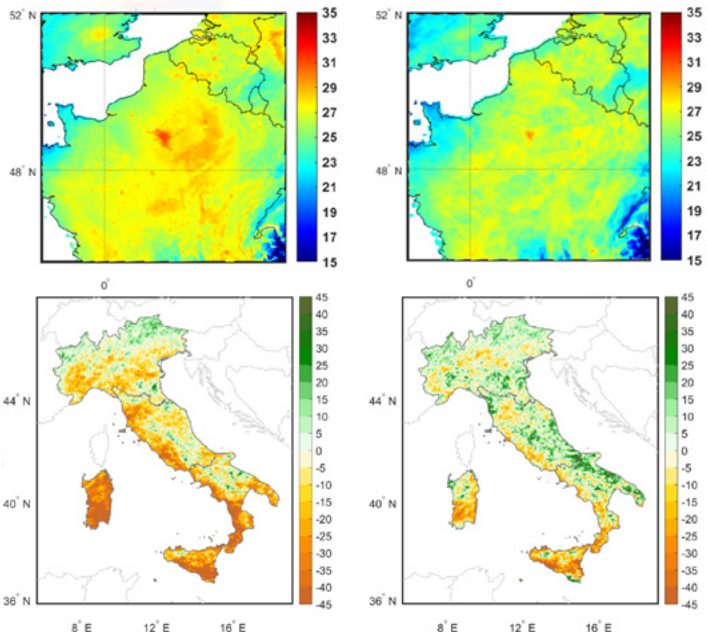
By bridging the gap between science and society, ICR contributes to informed decision-making and a sustainable future.

ICR translates complex findings into actionable strategies for policymakers, businesses and communities; explores financial mechanisms, such as insurance and liability, to build resilience against climate shocks; and also promotes social acceptance and behavioral change through tailored communication and engagement.

Advanced research and expertise

ICR is at the forefront of climate research, and collaborates with other pillars of CMCC research — the Institute for Earth System Predictions (IESP), and the European Institute on Economics and the Environment (EIEE) — to develop innovative solutions.

Notably, ICR contributes to the production of regional climate simulations to localize extremes and impacts in various sectors, participates in international authoritative initiatives like Copernicus and DestinE to produce data and indicators, and works on analyzing measurements and delivering tools to support the assessment of mitigation potential of ecosystems and land-based sectors.



Top: 2 meter temperature analysis for the city of Paris during August 2020 obtained by the regional climate model ICON at 3 km of resolution (left) and by the CERRA reanalyses at 5,5 km of resolution (right).

Bottom: 2km resolution projection for Italy: mean change (%) over 2021-2050 vs. 1989–2018 for the summer heavy hourly precipitation, under medium (left) and high (right) emission scenarios.
Raffa et al. (2023), https://doi.org/10.1038/s41597-023-02144-9.

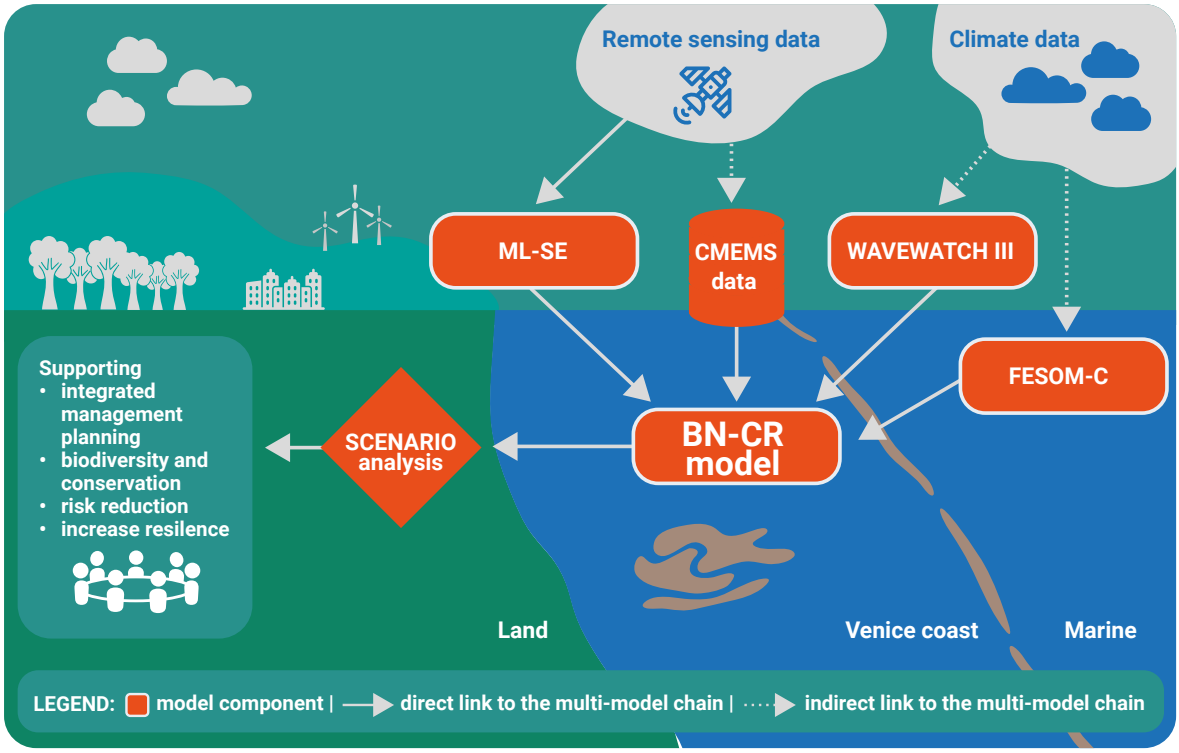
ICR expertise lie in high-resolution climate and impact modeling, which enable accurate prediction and understanding of climate patterns and their consequences. By combining cutting-edge modeling with Earth Observation (EO) methods, ICR can assess climate hazards like floods, droughts and wildfires, providing crucial insights for risk management.

Understanding the societal and economic impacts of climate risks is another crucial aspect to ICR's work. This involves developing comprehensive risk analyses, including through the use of AI-driven methods to address multi-risk and compound risk scenarios, that promote transformative adaptation and just transitions.

Protecting Venice: Machine learning and big data for coastal risk management

ICR produces models and disseminates verified results that integrate artificial intelligence and remote sensing data to support effective coastal management in the face of growing climate risk.

Dynamical coastal zones are susceptible to a wide range of climate change impacts, especially due to increasing extreme weather events. CMCC researchers elaborated an advanced Bayesian Network-based coastal risk assessment model to analyze shoreline evolution and seawater quality. The innovative multi-model chain integrates regional and global climate models with machine learning and satellite imagery. The model was developed based on historical data and applied to assess potential changes in the Metropolitan City of Venice's shoreline. The validated model outputs and flexibility represent a promising advancement for cutting-edge coastal risk management.



Graphical representation of the Bayesian Network-based coastal risk assessment model and its integrated components. The innovative framework supports effective decision-making for adaptation.
Figure adapted from: Pham et al. (2023), https://doi.org/10.1016/j.scitotenv.2023.166310.

From data to infrastructure: The case of railways

Railways are both particularly vulnerable to climate change and carry approximately 4 billion people and 10 billion metric tons of goods per kilometer every year. CMCC risk analysis can be used to inform policy-makers and stakeholders in the implementation of adaptation strategies aimed at infrastructure such as rail networks.

Specific and localized information about the present and future impacts of climate change can prove to be essential for policy-makers, particularly when planning infrastructure management and development in the context of a sustainable transition. Railway infrastructure is critical to sustaining local to global policies for sustainable mobility. In this field, CMCC research focuses on the Italian coastal railway and operates in close collaboration with the companies managing the infrastructure to provide detailed risk analyses for different railway segments and determine priorities for adaptation strategies and interventions.

The risk map below shows the coastal areas at risk of being submerged in the future due to sea level rise (light blue). The different colors indicate the level of risk expected for each section of the coastal rail network and therefore how they may be affected considering their susceptibility to hazard, exposure and vulnerability. Darker colors (purple, red, and orange) represent higher and medium levels of risk, and yellow represents a low level of risk.

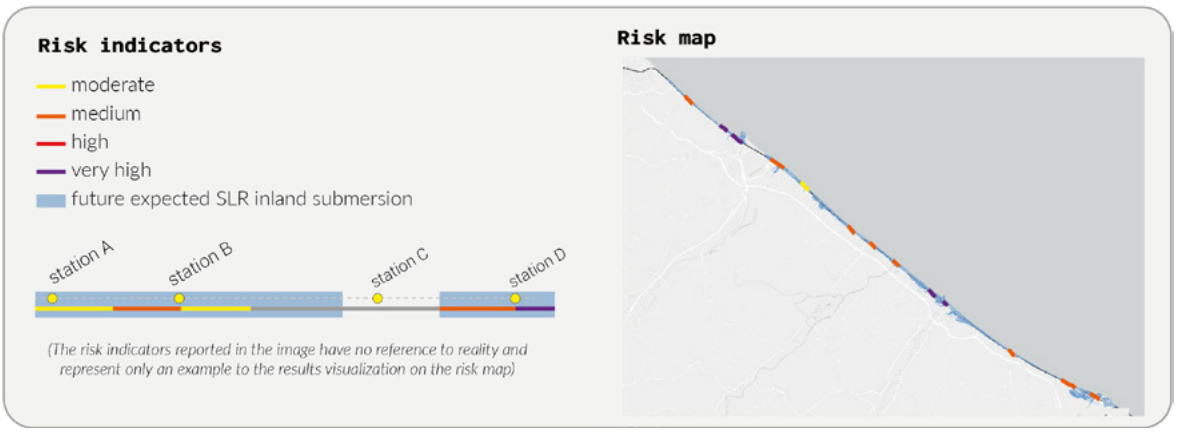


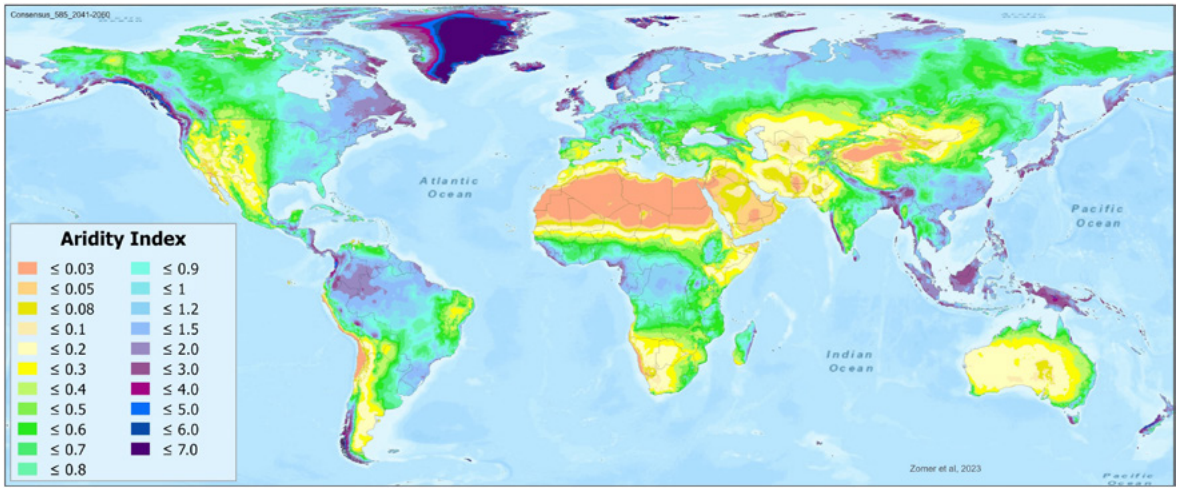
Figure from: Ricciardi et al. (2024), https://doi.org/10.1007/s10661-024-12942-2.

Detailed data and tools to map global climate risks

High-resolution data offers new possibilities for tackling the most advanced challenges posed by rapidly changing environmental conditions. This is the case with the Global Aridity Index map, which allows for the global mapping of climate-related risks.

CMCC's cutting-edge models contribute the most advanced international research to building tools and databases that support detailed descriptions and informed decisions for better land-use planning.

Continuously updated with the best available science and applying the most innovative technologies, these tools and datasets are used to measure the ability of specific environmental and social contexts to adapt to changing climatic conditions, describe scenarios that anticipate vulnerabilities and risk, as well as to design solutions. The resulting information is used for applications at the global to local scale and on specific issues affecting various sectors of society. For example, the Global Aridity Index is used in applications concerning agricultural production, water management, drought and fire management, human migrations, desertification, ecosystem restoration, human and animal mortality, and epidemiological research.



Global Aridity Index for the entire globe based on the ratio of precipitation upon evapotranspiration, for an ensemble of future (2036-2065) climate projections conditions. Source: Zomer et al. (2019), https://doi.org/10.1038/s41597-022-01493-1.

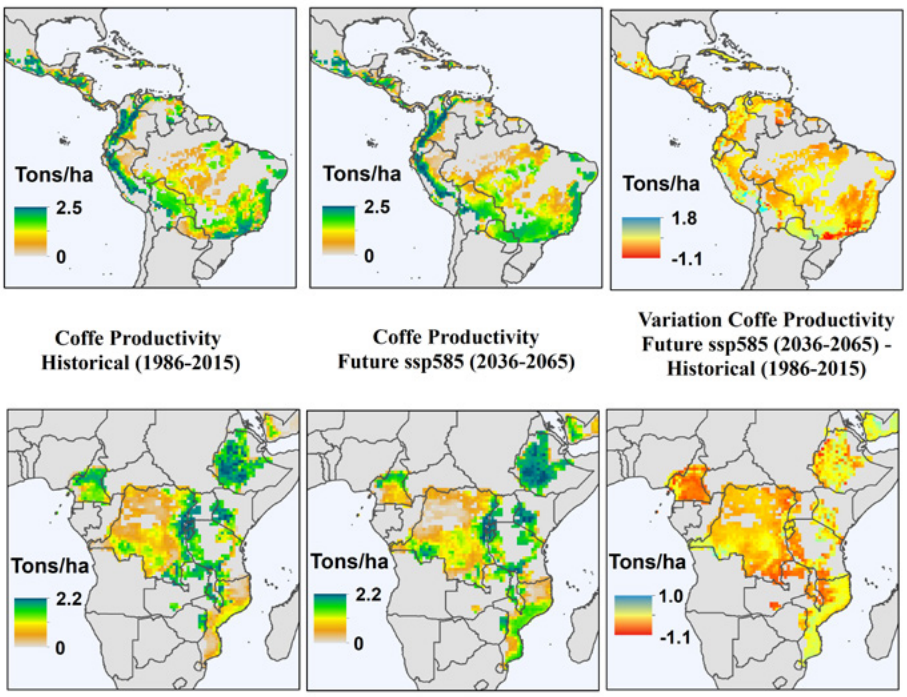
Climate-proof agriculture

Our research integrates process-based models, impact analysis, adaptation modeling, and socioeconomic indicators to identify climate risks and assess the adaptation potential of agronomic practices.

Accurate and reliable climate data is crucial for agricultural stakeholders to understand how the climate is changing, the impact this will have on agriculture, and the best local solutions to maintain productivity across the sector, influencing the socioeconomic dynamics of the regions involved.

CMCC's studies employ cutting-edge models to provide comprehensive analyses of various indicators and areas that are essential for understanding critical issues and developing timely adaptation strategies that benefit the entire economic structure of affected regions.

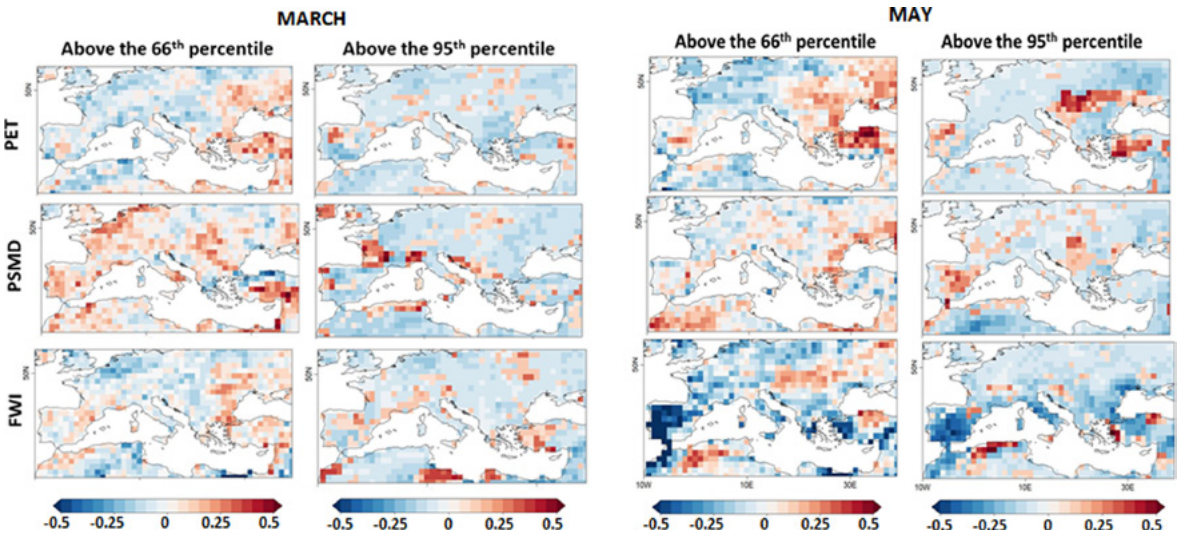
The figure below illustrates the case of Arabica coffee with a simulation of a management option aimed at improving resilience to climate risks.



Predicted variation of potential productivity of Arabica coffee in Latin America and Africa, in relation to historical climate (1985-2014) and ensemble of future climate projection (2036-2065) under business as usual scenario (SSP5-8.5). Della Peruta et al. (2024), https://doi.org/10.5194/egusphere-egu24-17914.

Future Goals. Radical science for a climate-resilient society

ICR is dedicated to fostering multidisciplinary collaboration and establishing new research directions that support both immediate actions and long-term strategic decisions for global climate-resilient development.



Seasonal forecasts (predicting climate conditions weeks and even months in advance) are powerful tools for anticipating climate risks and guiding decisions. The image above illustrates a CMCC study that estimates the fire weather index for the Mediterranean using seasonal forecasts. CMCC is actively working on enhancing the modeling and understanding of climate risks, guiding decision-making, and investigating innovative solutions to enhance climate resilience.
Source: Costa-Saura et al. (2022), https://doi.org/10.1016/j.agrformet.2022.108921.

Looking ahead, ICR aims to:

- Increase its focus on **Earth Observations**, shifting from the role of users of satellite and *in-situ* data to actively contributing new methods and products. This will support designing and addressing key scientific questions and produce valuable insights into climate dynamics.

- Deepen its understanding of **planetary boundaries** by recognizing compound soil and water systems as a crucial element at the interface between the climate system and the *Earth's critical zone* - where atmosphere, ecosystems, water, soil and rock interact, and which most of terrestrial life depend on.

- Contribute to advancing a comprehensive **Earth-Human System Model** that captures complex interactions and is therefore vital to understanding climate change and mitigating its impacts.

- Bridge research gaps in climate science by shifting from low-risk, incremental studies to high-risk, **radical science that explores new frontiers**, whilst remaining aligned with CMCC's broader goals.

Following these directions, ICR seeks not only to strengthen its capabilities but also to make a significant contribution to the global scientific community's efforts to develop **innovative solutions for climate resilience**.

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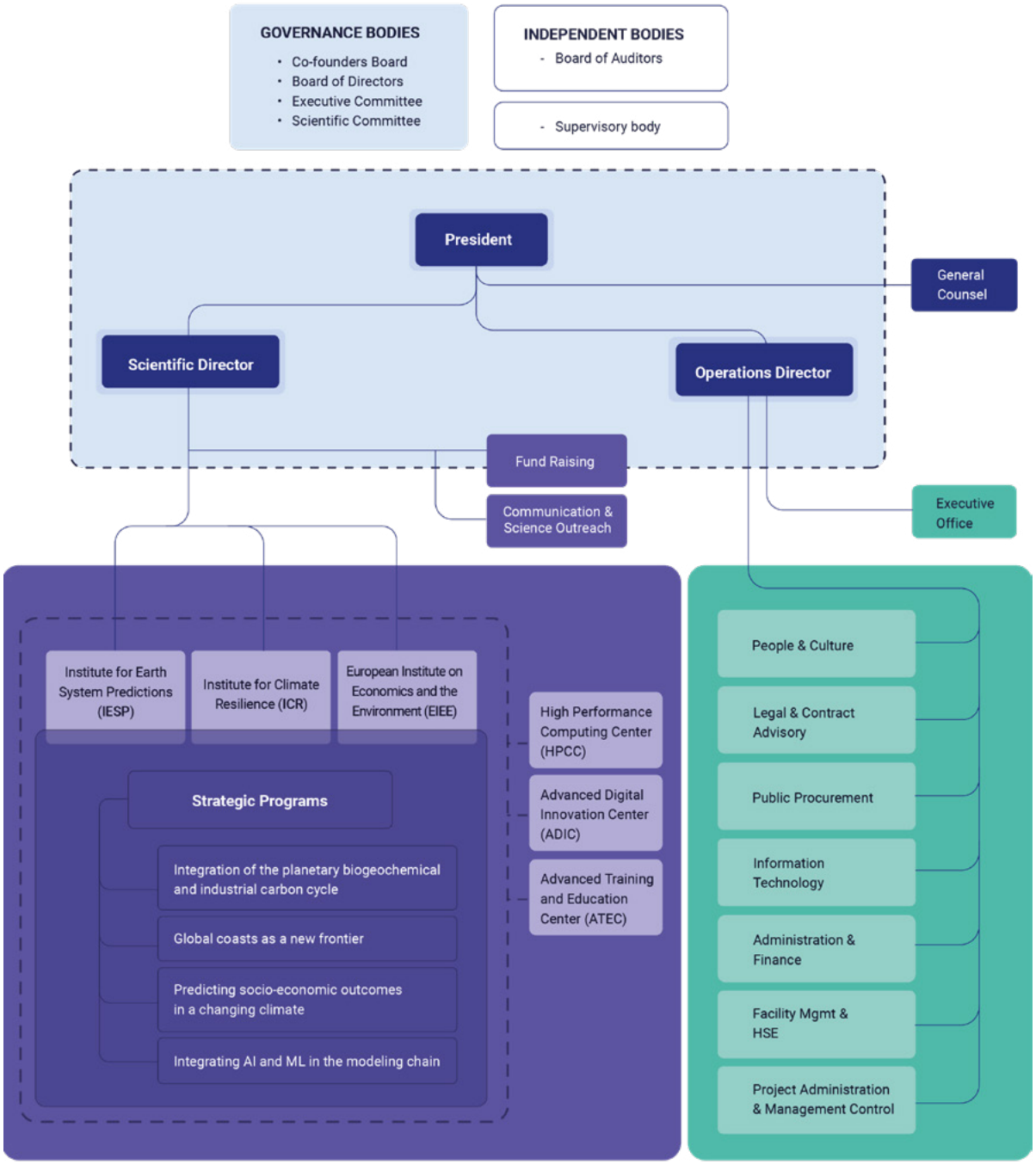

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