cmcc
Centro Euro-Mediterraneo
sui Cambiamenti Climatici

Institute for Earth System Predictions

IESP

Climate Sciences in the **21st 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

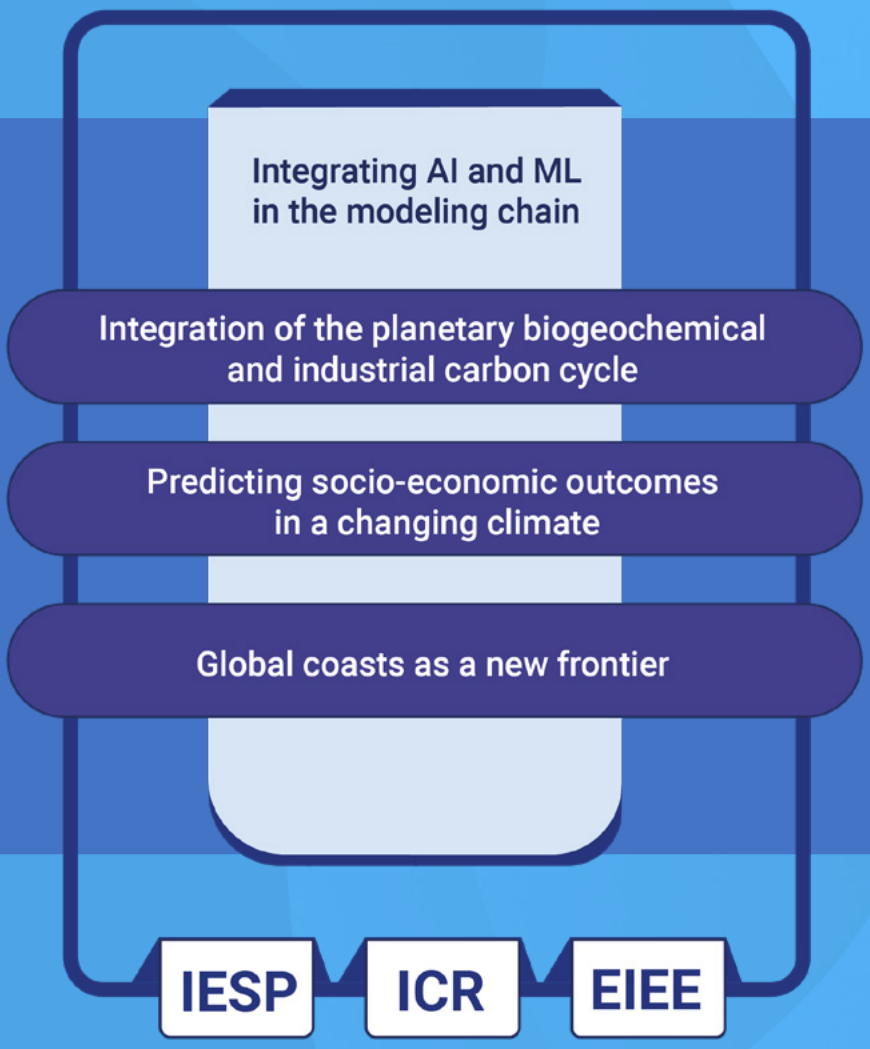
From models to solutions: our research

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.



Simona Masina

Director Institute for Earth System Predictions
IESP

The Institute for the Earth System Prediction

(IESP)

committed to **improving CMCC's climate modeling capabilities** and **turning scientific knowledge into advanced predictive tools.**

IESP contributes to an advancement in the understanding of the climate system and how it changes across both spatial and temporal scales, whilst **supporting local and national responses to emerging climate risks.**

The institute **tackles critical climate science questions that are relevant to society** delivering seamless Earth system predictions that **support science-based decision-making.**

A shift in focus beyond climate modeling and predictions

IESP drives climate science by combining interdisciplinary research and advanced computational resources to create practical, impactful solutions to real-world climate challenges.

In March 1950 a group of meteorologists at the Aberdeen Proving Ground, a U.S. army facility in Maryland, were conducting weather forecasting experiments using the computational resources of ENIAC - the Electronic Numerical Integrator and Computer. This effort led to the first-ever one-day numerical weather forecast, which took 33 days to code and 24 hours to produce.

Another foundational moment in climate science occurred in the 1960s, when Syukuro Manabe, a young Japanese researcher, joined the Geophysical Fluid Dynamics Laboratory in Princeton. Manabe pioneered the concept of simulating climate systems through computational modeling, leading to a breakthrough in the field that would earn him the Nobel Prize in Physics in 2021 for his contributions to physical climate modeling and global warming predictions.

These early innovations continue to inspire IESP's work, further contributing to CMCC's role as an internationally recognized leader in climate science and Earth system predictions which started in 2005.

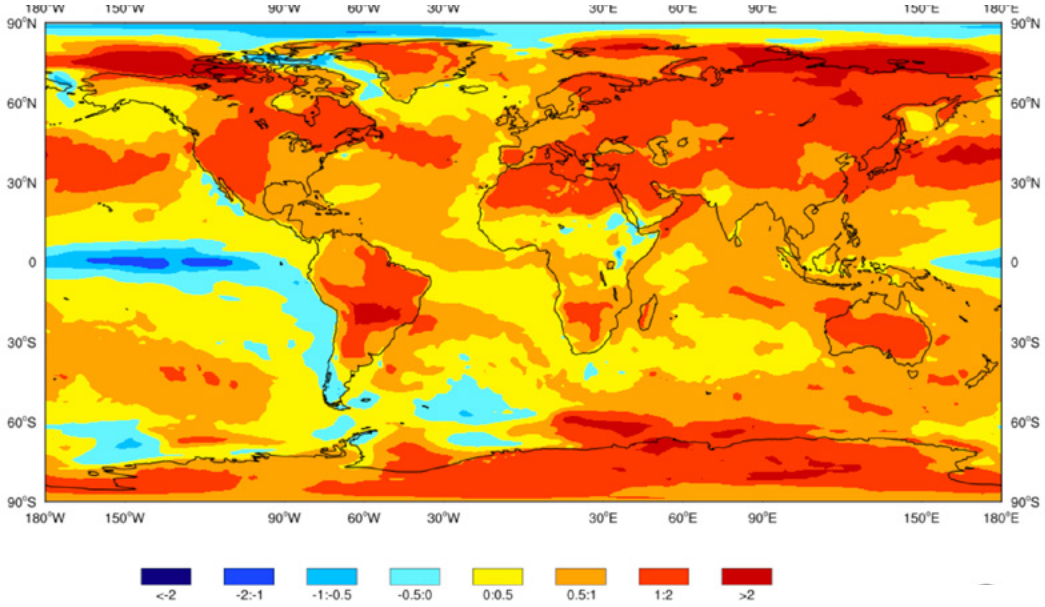
> This success stems from a vision centered on interdisciplinary collaboration and problem-focused research. At CMCC, researchers have access to vital computational resources that drive breakthroughs in climate modeling and Earth system predictions.

Despite significant advances in climate science since the 1950s and 60s, we now find ourselves at a standstill. Climate science has become both central to political discussions and at the same time runs the risk of being overlooked and ineffective when it comes to decision-making processes.

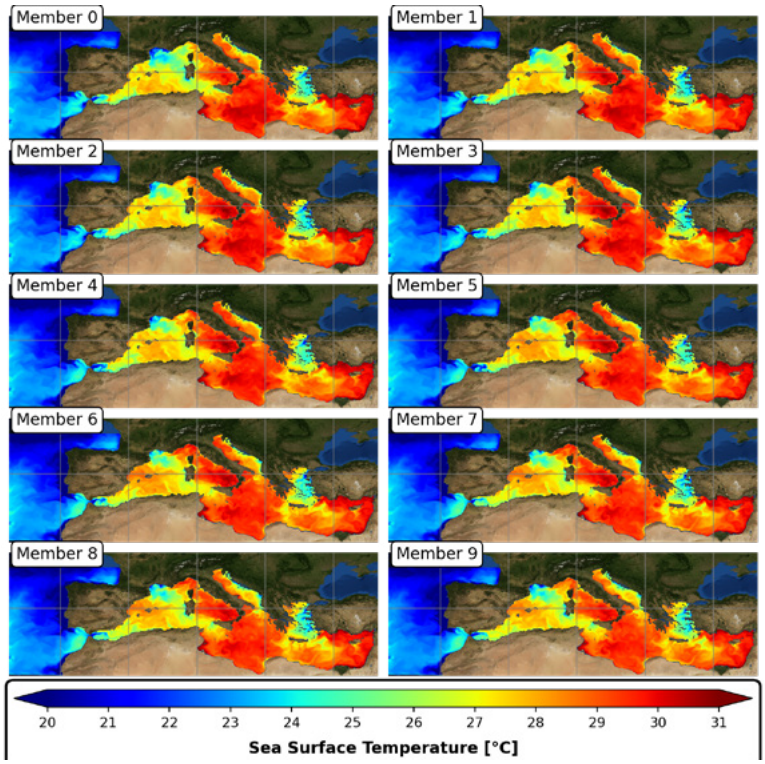
There is a need for a shift in focus so that we can move beyond predictions and high-resolution models and instead provide practical, comprehensive, and impactful solutions that address real-world problems and threats. Climate science must provide actionable strategies that help tackle the challenges posed by climate change.

A wide range of world-class forecasts

CMCC's IESP research team develops and uses state-of-the-art models on diverse geographic and temporal scales. The following are two examples from the seasonal forecasting system and the ensemble forecasting system for the Mediterranean Sea.



Seasonal (Sept-Nov 2024) 2-meter temperature anomaly in °C (reference period 1993-2016). Map based on CMCC Seasonal Prediction System (SPS3.5) initiated on August 1st 2024. See also https://sps.cmcc. it/forecast/



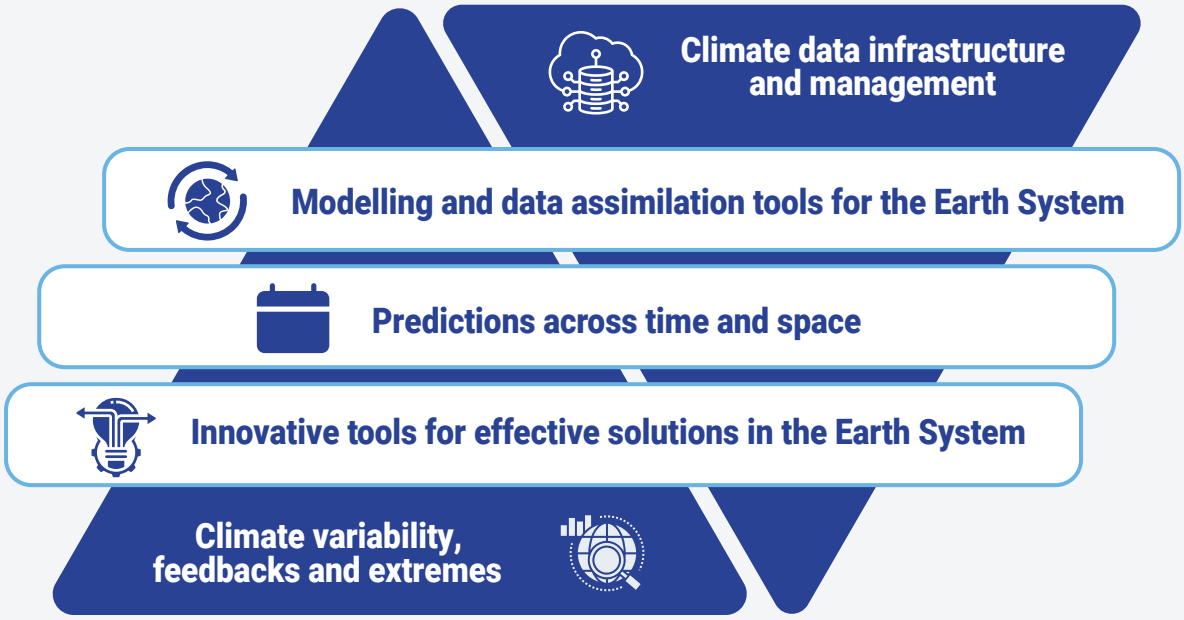
Mediterranean Sea Surface Temperature Ensemble (10 members) from the MedENS Forecasting System (https://medens.cmcc.it/) displays temperature variations from cooler (blue) to warmer (red) shades. The figures depict the surface temperature for the 1st day of forecast (August 20, 2024) provided by each of the 10 ensemble members at 1/16 degrees resolution. This ensemble system explores the forecast predictability of the first type by perturbing the initial condition used to produce the forecast. The 10 different realizations offer an insight into the system's uncertainty.

What does IESP do?

IESP's climate modeling work advances understanding, improves predictions and supports climate risk responses through cutting-edge tools and comprehensive data integration.

IESP provides the climate modeling capacities for CMCC, advancing our understanding of the climate system and improving predictive skills by fostering and sharing scientific insights. Our diverse team of scientists from the fields of physical science, environmental science, and engineering work together to offer a comprehensive and integrated view of the Earth system.

IESP supports responses to emerging climate risks by integrating new tools and methodologies, including artificial intelligence and Earth observations. Our central goal is to work as a fully integrated modeling institute, capable of managing vast amounts of data from various sources to address emerging climate challenges.



Three pillars represent the broad research areas within IESP.

IESP's research focuses on:

- Earth system modeling and simulation
- Prediction across time and space
- Innovative tools for real-world solutions

These areas are supported by two key pillars: advanced climate data infrastructure and management; and cutting-edge research on climate variability, feedbacks and extremes.

> The CMCC Institute for Earth System Predictions is committed to pushing boundaries with bold, innovative research and enhanced interdisciplinary collaboration.

IESP's strength lies in a diverse array of dynamical, statistical, and data-driven modeling approaches, powered by advanced computational science.

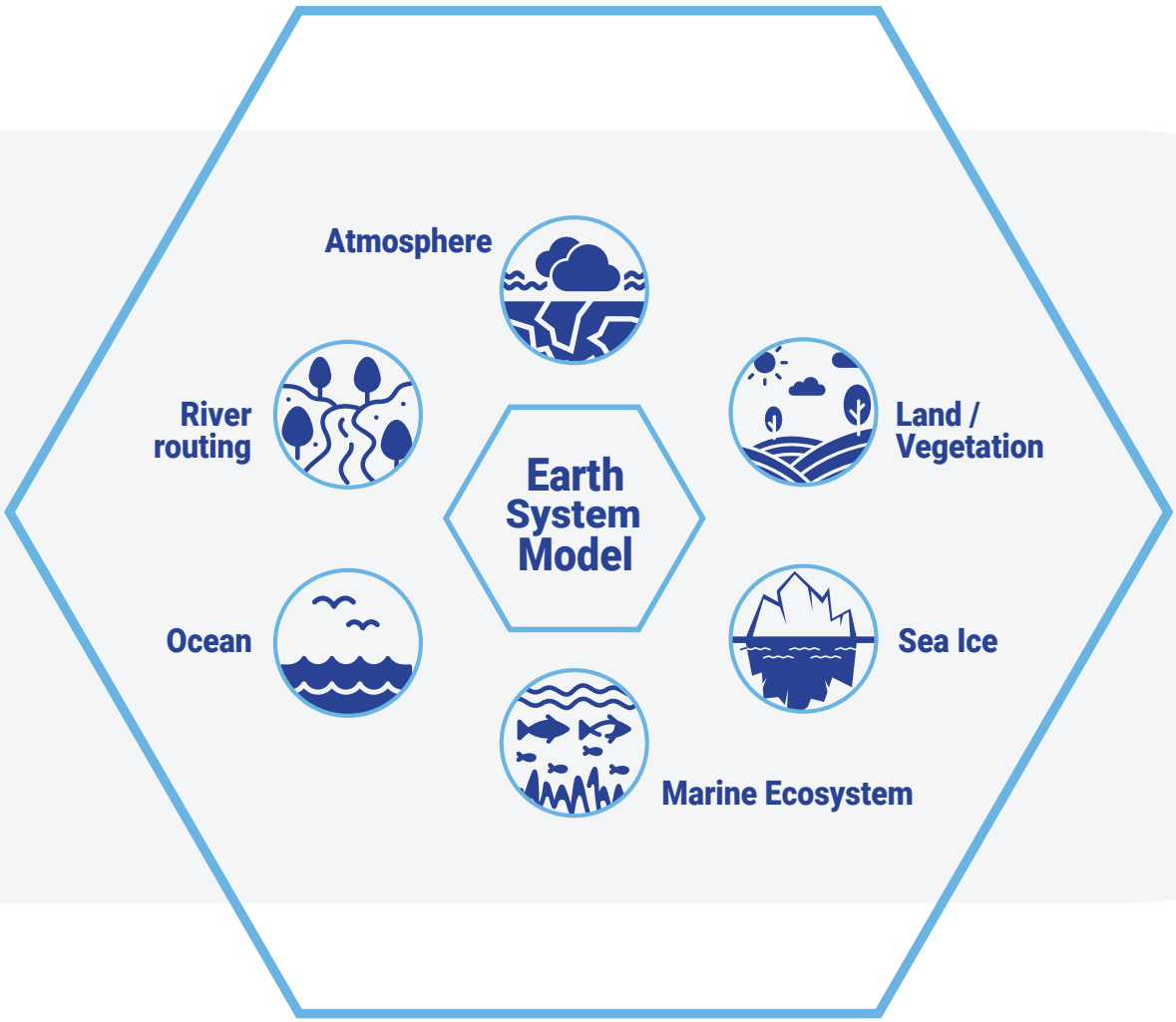
These include multi-scale modeling and predictions from sub-seasonal to multi-decadal forecasts. IESP provides global, regional and coastal ocean operational forecasting services and integrates data assimilation across various climate system components, including ocean, sea ice, atmosphere, and land.

Advanced research and expertise

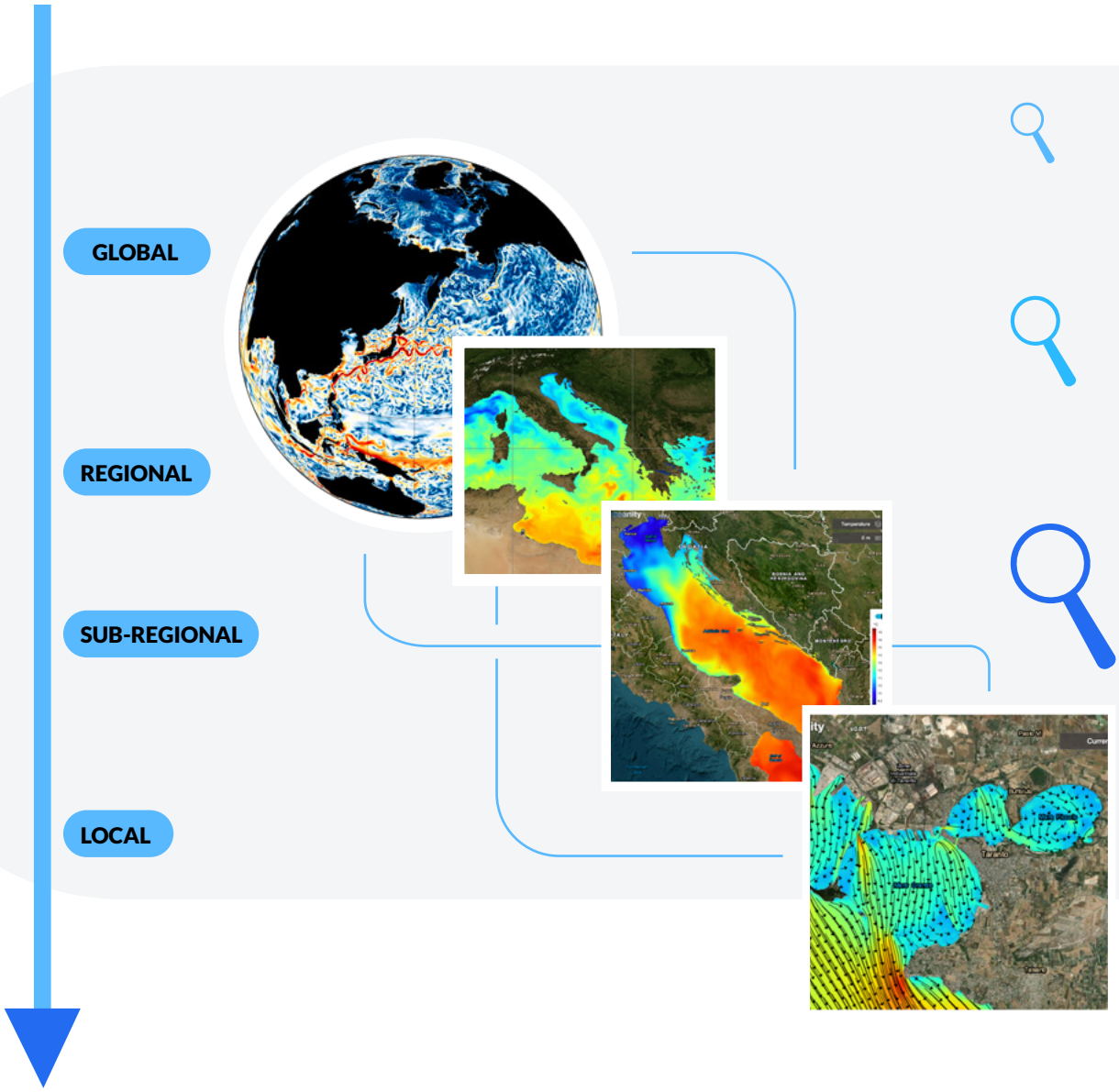
IESP has dedicated significant effort to enhancing its Earth System Model (CMCC-ESM) as part of its work in the area of modeling and data assimilation. Recent advancements include new modules for modeling land and vegetation, river routing and marine biogeochemistry, all aimed at closing the carbon cycle more accurately. IESP has also advanced data assimilation systems for the ocean, sea ice, atmosphere and land, working toward a fully integrated assimilative approach.

IESP contributes to innovative platforms and tools for data analysis and management, optimizing numerical models on high-performance computing (HPC) and cloud architectures developed by CMCC, and to the development of artificial intelligence and machine learning methods to boost our predictive capabilities.

A comprehensive Earth System Model that mirrors the complexity of the climate system, integrating various components.



IESP's vision is to create an integrated modeling infrastructure that can operate across global, regional, sub-regional and local coastal scales. Current projects include building a regional coupled model for the Mediterranean and Black Sea regions, developing an ensemble system for the Mediterranean, and establishing downscaling facilities and local coastal modeling infrastructure down to the catchment basin level. The ultimate goal is to develop an adaptable framework using an unstructured grid model that can be tailored to any given region of interest.

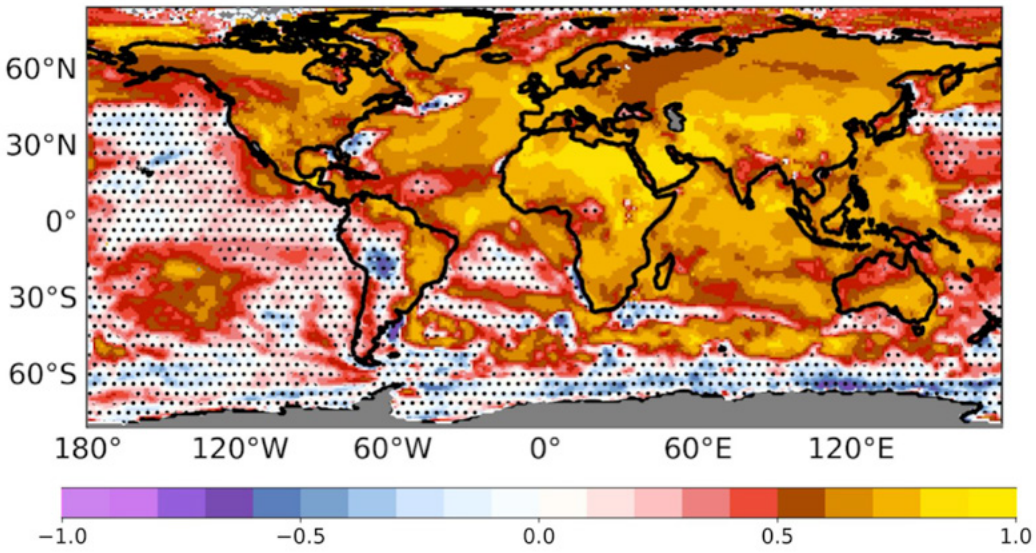


From the global ocean to the Mediterranean basin, Adriatic Sea and even port area simulations and predictions, IESP's modeling capabilities span across all scales, offering fore-casts worldwide.

Effective simulations of climate variability

IESP contributes to CMCC's wide range of temporal and spatial predictive capabilities.
The CMCC decadal prediction system is part of the Coupled Model Intercomparison Project (CMIP), which provides long-term climate simulations for the Intergovernmental Panel on Climate Change (IPCC).

CMIP aims to deepen our understanding of historical, current and future climate change, arising from natural and unforced variability or in response to changes in radiative forcing, in a multi-model context. In CMIP6, the latest phase that informed the most recent IPCC report for the global climate policy community, CMCC provided a 20-member suite of decadal hindcasts and long term climate simulations under different climate scenarios with the CMCC-CM2 model.
Several studies on extreme events under different climate conditions have been performed thanks to the high horizontal resolution of the CMCC model participating in the HighResMIP protocol. Also, the results on the decadal time horizon show that CMCC model reproduces surface and subsurface temperature variability around the globe effectively. Ongoing research in the field aims to bridge the gap between seasonal and decadal forecast horizons, extending initialized decadal predictions up to 20 years ahead and beyond.

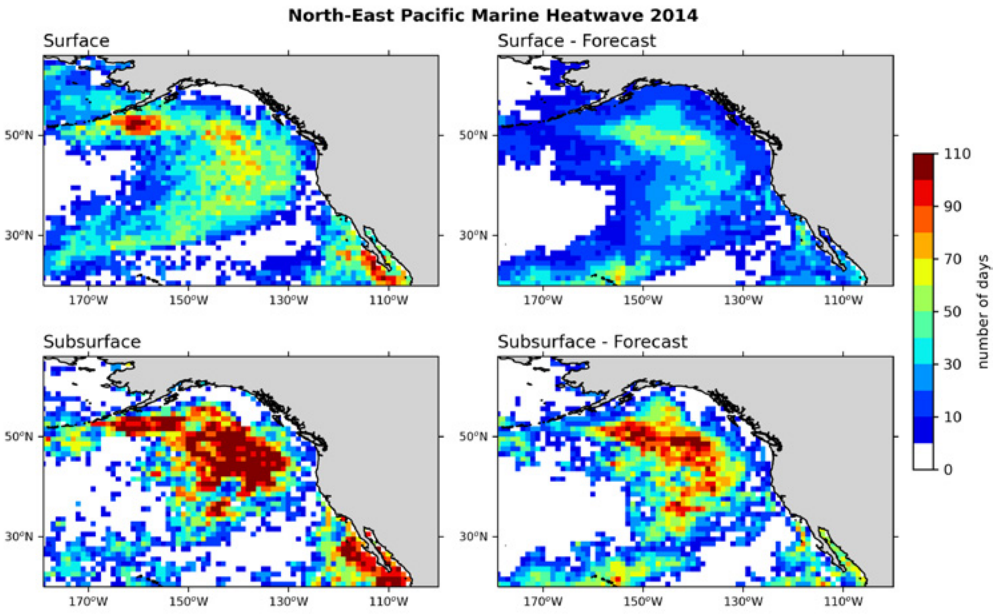


Anomaly correlation coefficient (ACC) of the 20-member hindcast ensemble for annual surface temperature (two meter temperature over land and sea surface temperature over ocean) for forecast years 1–5.
Figure from Nicolì et al. (2023), https://doi.org/10.5194/gmd-16-179-2023.

Ocean forecast: The case of marine heatwaves

The marine forecasts produced by CMCC's IESP team, such as those for the Mediterranean and Black Sea delivered using the Copernicus Marine Service and the seasonal system of the Copernicus Climate Change Service (C3S), provide vital information on marine heatwaves to all stakeholders.

Marine heatwaves (MHWs) are growing in intensity, duration and number across much of the global ocean, affecting ecosystems and economies. CMCC provides advanced forecasts for sea surface and undersurface temperatures, where MHWs have the greatest impacts. Being able to predict the likelihood of extreme heat conditions up to three months in advance, as shown in the research on seasonal forecasting of subsurface marine heatwaves, allows for an assessment of the ecological and economic impacts within depth ranges for fisheries, aquaculture and conservation areas. AI driven approaches are under development to complement the standard dynamical CMCC seasonal prediction system. The Mediterranean Sea is a focal point for studying MHWs as the basin is a hotspot for climate change whereby the number of events, their duration and intensity continues to increase. Furthermore, CMCC research addresses regional ocean conditions in a global context.

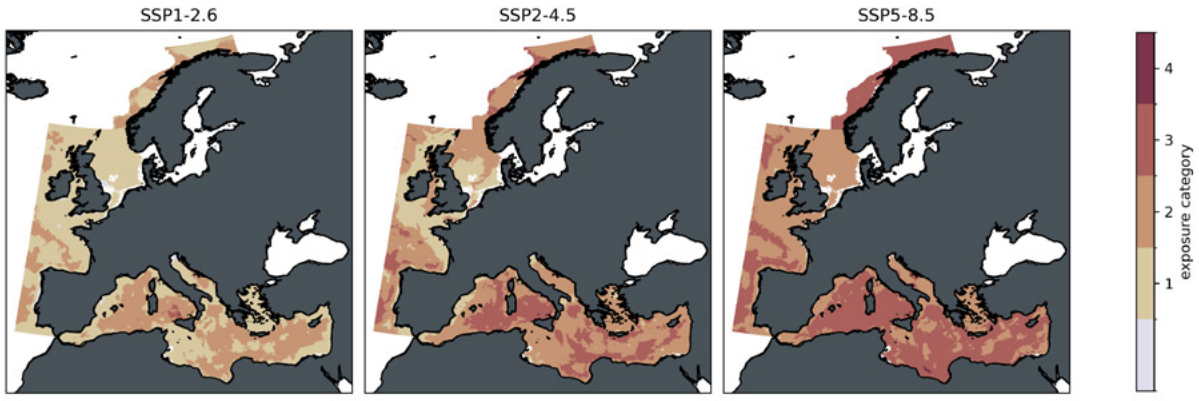


Seasonal forecasts of marine heatwaves (MHW) at and below the surface in the North Eastern Pacific during the summer of 2014. Surface events are defined using European Space Agency satellite-derived sea surface temperature (panel a), while subsurface events are defined using the Copernicus Marine Service Global Ocean Reanalysis Ensemble Product (panel b). Forecasts are provided by the CMCC's Seasonal Prediction System (panels c and d). Figure adapted from: McAdam et al. (2023), https://doi.org/10.1038/s43247-023-00892-5

The future of marine ecosystems

Fine-scale projections are crucial for planning and implementing the solutions needed to safeguard marine ecosystems and their associated services from the impacts of climate change. CMCC research is at the forefront of producing quantitative data that helps predict climate-driven pressures on marine ecosystems.

High-resolution data is vital to inform ecosystem-based management and environmental policy. CMCC is among the most advanced centers in the use of model ensembles that provide reliable data on the future and information on underlying uncertainties, both of which are essential for decision-makers implementing local adaptation policies, spatial planning, and ecosystem-based management strategies.
Projections are used to assess the potential success of measures aimed at safeguarding biodiversity, restoring the marine environment, better understanding expected impacts, and identifying future climate change hotspots.



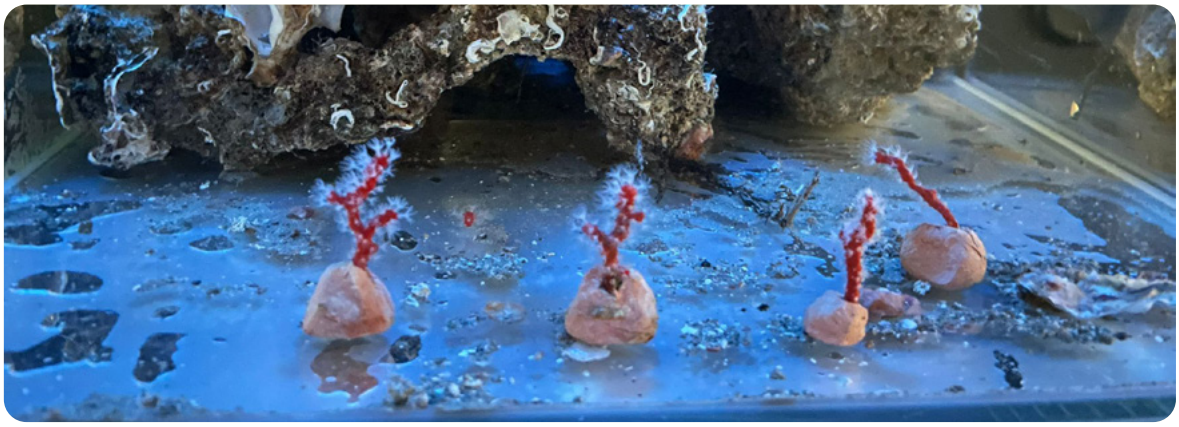
Category 1	Change exceeds natural variability
Category 2	Change exceeds twice the natural variability
Category 3	Change exceeds four times the natural variability
Category 4	Change exceeds eight times the natural variability

The picture shows the cumulative stress of major ecosystem pressures (warming, acidification and deoxygenation) across European Seas under climate change in three contrasting mitigation scenarios, SSP1-2.6 (strong mitigation), SSP2-4.5 (moderate mitigation), SSP5-8.5 (no mitigation). Source: Butenschön et al. (2024), https://agu.confex.com/agu/OSM24/meetingapp.cgi/Paper/1487454.

Infrastructure and ecosystems: The future of coastal economies

Submarine drones, high-resolution modeling, satellite data, and innovative technologies are integrated to harmonize marine ecosystem protection with coastal area management and socioeconomic development. CMCC's multidisciplinary IESP team combines the most advanced methodologies for ocean observations, monitoring and analysis.

Coastal regions are key drivers of global economic growth. The balance between environmental pressures of human activities, ecosystem services, and the projected growth of coastal urbanization is critical to establishing development models that ensure societal well-being. Climate change, infrastructure development such as ports, communication and telecommunication routes, as well as urbanization processes all interact with other factors in exerting pressure on natural coastal environments at different geographic and temporal scales. This has repercussions on the quality of the environment and people's lives. CMCC research uses numerical models, observational data, and technological innovation to play a crucial role in providing predictions and information on the interactions between the sea, land and human activities. Research results provide data for decision-making processes aimed at restoring the functions and ecosystem services of marine environments that are impacted by coastal infrastructure, as well as supporting strategies for intervention, adaptation and mitigation of coastal impacts.



Some corals are restored in their natural habitat thanks to the Renovate project, coordinated by CMCC, which aims to restore damaged marine ecosystems and organisms accidentally caught in small-scale fishing nets, by rehabilitating and returning them to their natural habitat. This effort is part of a larger multidisciplinary initiative to repair seagrass meadows like Posidonia oceanica, damaged by human activities, using advanced, cost-effective technologies and high-resolution modeling to manage risks from natural and human impacts.

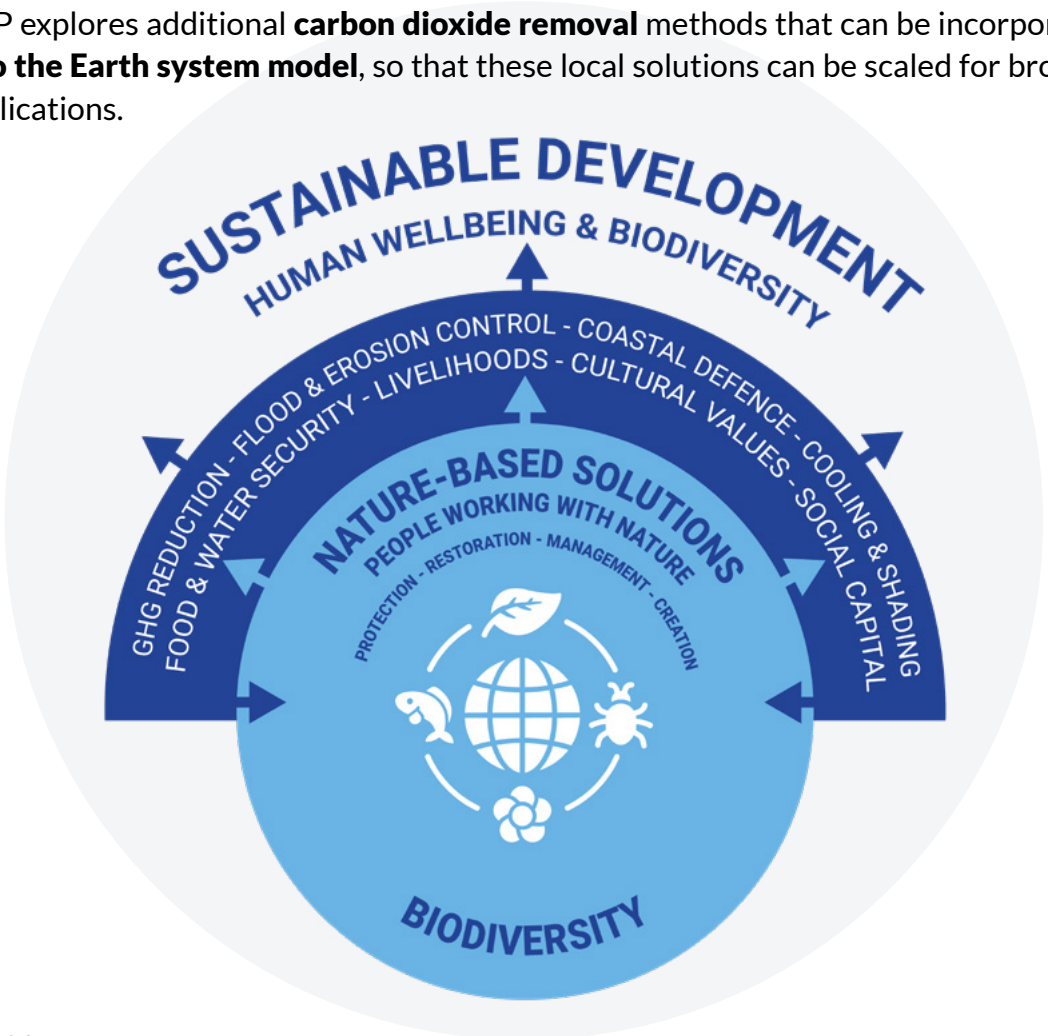
Future Goals. Simulating the Earth System to support solutions

IESP is a leader in integrating observational data and advanced modeling with a multidisciplinary approach that supports innovative solutions at the crossroads of environment, policy and socioeconomic systems.

IESP views **the coastal ocean as an integrated system** that provides critical services and faces climate threats such as storm surges and flooding.

IESP promotes **Nature-Based Solutions (NBS)**, such as reinforcing natural barriers like kelp forests, mangroves, and coral reefs that can mitigate climate risks and serve as natural carbon sinks.

IESP explores additional **carbon dioxide removal** methods that can be incorporated **into the Earth system model**, so that these local solutions can be scaled for broader applications.



Looking ahead, the IESP Institute aims to:

create a digital twin of the ocean, a virtual replica allowing users to simulate and evaluate “what if” scenarios, providing insights into the impact of solutions like NBS on the global system.

Contribute to the development of an integrated climate-socio-economic modeling framework that addresses climate challenges more-comprehensively and effectively.

Enriching and strengthening CMCC’s climate data infrastructure management, such as the CMCC data delivery system which provides users with access to data, simulation experiments and predictions.

Avancing our understanding of climate variability, feedbacks, andextremes, such as predicting tropical cyclones, medicanes and accurately forecasting damaging coastal events like the acqua alta phenomenon in Venice and storm surges across the global coastal ocean.

These efforts highlight IESP’s role in improving predictive capabilities and addressing climate risks.

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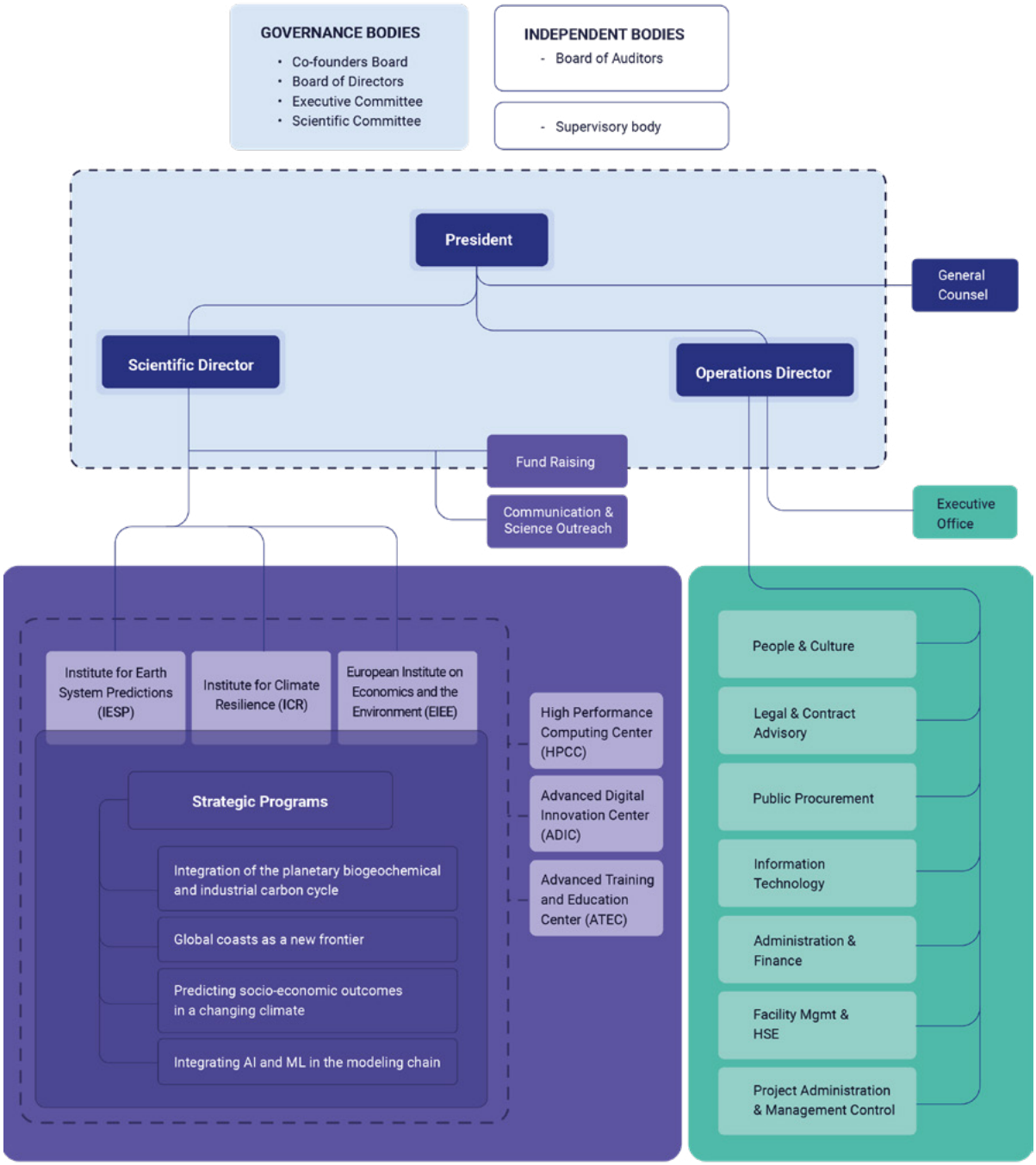

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