cmcc
Centro Euro-Mediterraneo sui Cambiamenti Climatici

Climate Change in the Future, Fast Changing World

The CMCC vision towards 2029

Strategic Plan 2019 - 2029

Mission

To investigate and model our climate system and its interactions with society to provide reliable, rigorous, and timely scientific results to stimulate sustainable growth, protect the environment and develop science driven adaptation and mitigation policies in a changing climate. To develop foresights and quantitative analysis of our future planet and society.

Values

CMCC is committed to scientific integrity and independence, to foster scientific progress and innovation.

CMCC is committed to inform and facilitate the dialogue between scientists, decision makers and the general public to support decisions and actions for the benefit of society and the environment.

CMCC is committed to encourage discipline convergence to spur new and creative ideas and to ensure that environmental observations, analysis, predictions and services meet the needs of society most effectively.

CMCC is an equal opportunity employer, actively promoting diversity in the workplace.

CMCC is a non advocacy institution.

Global Challenges

The science of climate has developed enormously in the last few years and it has been shown to be even more relevant and essential to inform policies and develop strategies that will allow for the growth of welfare around the world, consolidating mature economies and opening the path to prosperity for advancing countries. The challenge that we are facing has been embodied by the presentation of the UN Sustainable Development Goals (SDG) that represent the 17 major issues that are crucial for this program. Not surprisingly climate change appears as one of them recognizing the growing role that humanity has in interfering with the working of our planet and the necessity to deploy measures and policies that will insure the maintenance of a healthy equilibrium between our planet and ourselves.

The weight that climate will have in shaping economic and political decisions is also reinforcing the need for further understanding of the climate system. It is placing a large responsibility on the scientific community. Science is expected to provide the knowledge base for most of these decisions and therefore the demand for accurate, timely and honest information is growing. Standards are also rising as well as a growing demand for spatial and temporal details, localized information and extension of our predictive power to longer time scales and to the oceans.

A careful analysis of the SDGs reveals that climate and in general atmospheric, oceanic and hydrographic variations have a general influence on many of the other SDGs. It is fair to say that the variations of the fluid envelopes of our planet play a role in almost all of them. The extensive interdisciplinary research work of the recent years has shown clearly that climate change can have a potential impact on a large variety of human activities and it is very difficult to consider them without taking into consideration the human impact on the atmosphere and oceans. Conversely, it is difficult to obtain a meaningful evaluation of climate change impacts without having a more precise idea of the kind of societies and international relations we will have in the future.

A number of big challenges show how intimately related environmental issues and major geopolitical processes are. The evolution of global conflicts is likely to be influenced by climate changes and competition for access becomes dominant. Especially large shifts in the availability of water resources caused by climate change may impact food production and food security leading to enhanced conflicts and over competition. These same stress factors may become major players in defining demographic transformations and large migratory processes.

Mitigation and adaptation measures however will not appear in a vacuum, but in a world that will be experimenting strong transformation forces as a new industrial revolution, led by automatization in transactional and white collar jobs (artificial intelligence) will transform the job market, destroying traditional paths to upward social mobility and job creation. Economic and social inequality may be on the rise and this factor will interact with the climate change combating policies in ways that we cannot immediately imagine now. Inequalities, labor and poverty will interfere with the strategies for addressing climate change and the vulnerability of natural systems in unexpected ways. Climate change may be reinforcing health challenges that will have to be met in a complex, conflict prone and stressed world that may become likely if we do not find cooperative strategies to address them. The continuous economic development in mature economies and the explosive economic growth in advancing economies have to be considered within the decarbonization process that would mitigate the effects of climate change.

Future World

The realization of the diffuse role of climate change and the demand posed to the scientific community to produce reliable scenarios of the natural and societal world are profoundly affecting the way in which research will have to be conducted over the next decade. The climate system, the atmosphere, the oceans, the land, will continue to be investigated to understand the processes, produce better and more predictive numerical models, comprehensive scenarios of the long term evolution and comparison with observations will provide validation, proof of hypothesis and hints to better models and scenarios. On the other hand, the task of evaluating the impacts on the world and society will have to consider the transformation and the kind of future society that we will have in the next decades. We will have to consider the Future of our planet in in an all-encompassing way to be able to produce meaningful results that will be useful in shaping policies and strategies. Society needs critical information about interconnected environmental and societal risks and how to manage them, including how to protect life and property, make decisions about trade-offs between different socio-environmental management options, and transition to sustainable economies. This will require science-based knowledge about the impacts of global environmental change at the scales at which decisions are taken.

To maximize benefit to policy and business, provision of this information will need to be co-designed in partnership with all relevant stakeholders, with influential societal decision-making systems, internationally and at regional scales through participatory approaches for a full social acceptability. By providing the foresight and knowledge to enable innovative technical and societal solutions to environmental change, research will drive opportunities for equitable economic and social development.

The next decade will require from us that we consider the Future in a more quantitative way, taking into account new trends and processes and trying to evaluate how they will interact in the future society. This Strategic Plan is laying out a vision that attempts to match this challenge, identifying a number a key Strategic Imperatives that will have to be met in order to rise to the challenge considering also the economic, social and political structure of the Future World.

New Challenges

Providing the knowledge, predictions and decision-support tools, in a reasonable time span, is an enormous intellectual and technical challenge. Understanding the workings of the ‘Human Earth System’ across its physical-chemical-biological- societal-economic dimensions and across spatial and temporal scales, and leveraging this understanding to predict changes and inform policies and decisions, will require interdisciplinary conceptual frameworks of enormous complexity. Understanding what environmental information is most crucial to address, and what measurements, technologies, and models are needed, is a significant challenge in its own right.

Delivering the required data collection and provision, modelling and stakeholder engagement will require a step-change in technical capabilities (particularly in high-performance computing, data management, sensor technologies, and interactive communication tools). It will also require investing in the process of translating and communicating new scientific knowledge; creating a “safe, authorized space” for routine dialogue between stakeholders and researchers. The activities in the past decade have partially realized this program leading to significant advances in the quality of the information provided and in the level of dialogue between decision-makers and scientists.

CMCC is very well placed to do that because we have built a conceptual and promising environment to address these challenges. The action of CMCC in the past years has allowed us to develop a unique approach characterized by three elements:

- **I** **an ability to consider the long term view in several fields,**
- **II** **an approach characterized by quantitative and predictive methods,**
- **III** **the framing of a problem as a multi-risk evaluation and management.**

These elements, that consist of a set of methodologies, numerical models, theoretical understanding and practices are the basis on which we can build a study of the Future of the planet and of our society that is going to be not merely qualitative, but quantitative.

Opportunities for CMCC

The realization of this vision will require a major effort by CMCC, but also stronger collaborations and partnerships with other research institutions. We will continue to collaborate across institutions to coordinate resources and conduct research of the scale and complexity that no single entity can achieve alone. Transdisciplinary collaborations will have to become even closer to address the coupled environmental and socio-economic solutions to environmental change, guided by the vision that these sciences are converging toward a ”climate science” that will encompass several separate disciplines of today, linked by shared methods and principles. The collaboration between research and operational service providers will still be crucial to deploy resources efficiently and accelerate transfer of research results to users.

In particular we can identify few broad areas of development:

- We will need to continue pushing the predictability boundaries, from days to years, of the atmosphere-ocean-land system, identifying new sources and types of predictability.

- We will need to investigate the predictability of the human-earth system with a new generation of integrated models that will take into account societal dynamics and innovations.

- We will need to refine and provide consistent observations data sets of the Earth system that can validate models, provide early warning of change and support decision-making – requiring advanced data assimilation systems aimed at integrating environmental and socio-economic data, quantitative and qualitative data, and historical and contemporary data at a high-enough resolution to detect systematic change and capture extreme events.

- We will need to investigate the impact of technical and socio-economic innovations whose interactions with the path toward sustainability are likely to include options for regulating international trade in the Earth System. We will need to understand in which way disruptive technologies, international conflicts national and international inequalities can interact with the technological response to the climate problem;

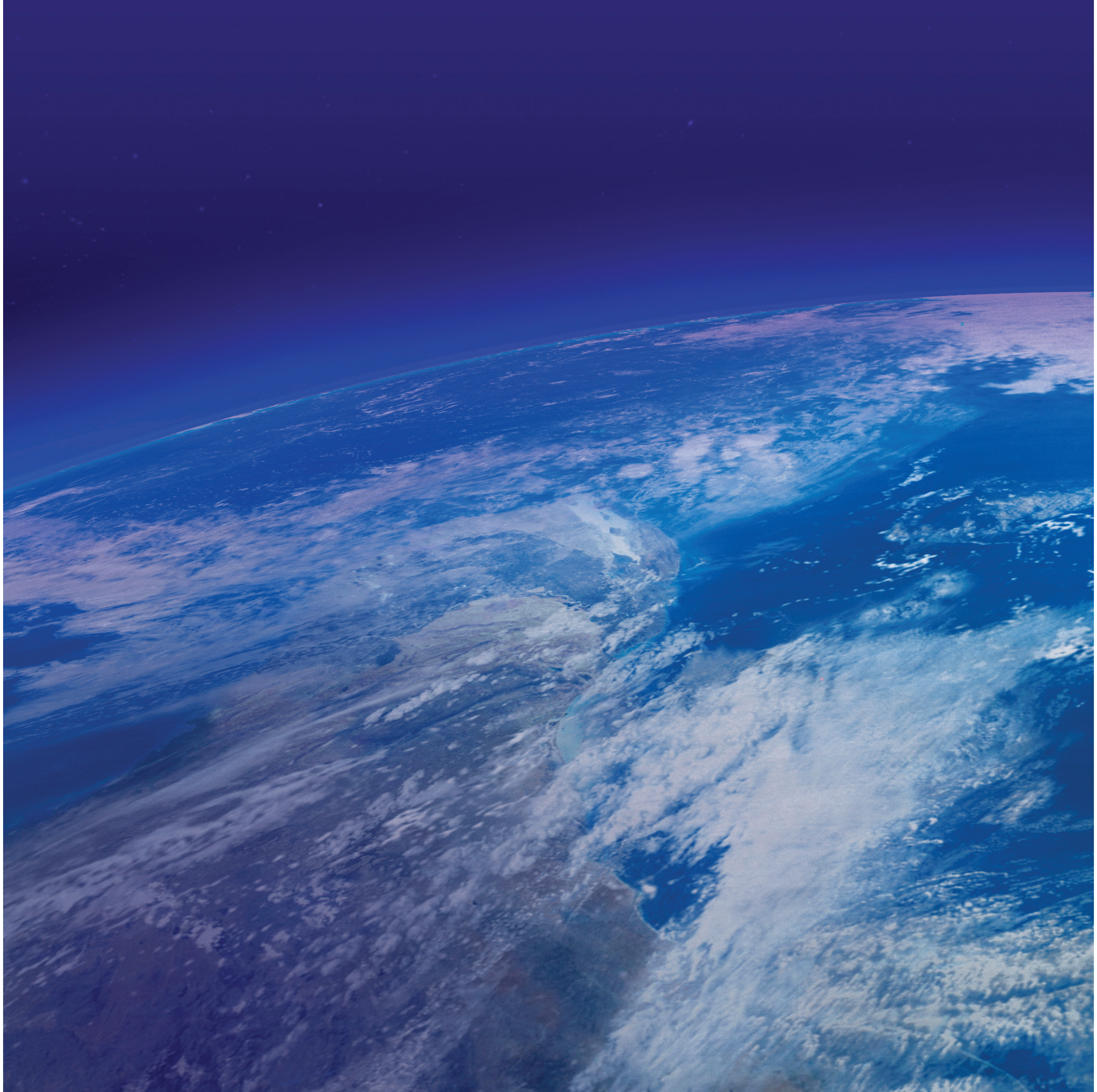
- We will need to continue the development of two-way information and communication tools that support the needs of sectors such as agriculture, energy, insurance, health, transport, etc. for information on forecasts, impacts, vulnerability and adaptation, bridging activities and capabilities, including mechanisms to enable science to be directed in response to user-identified needs.

***CMCC** is positioning itself to become a leading agent in this global process.*

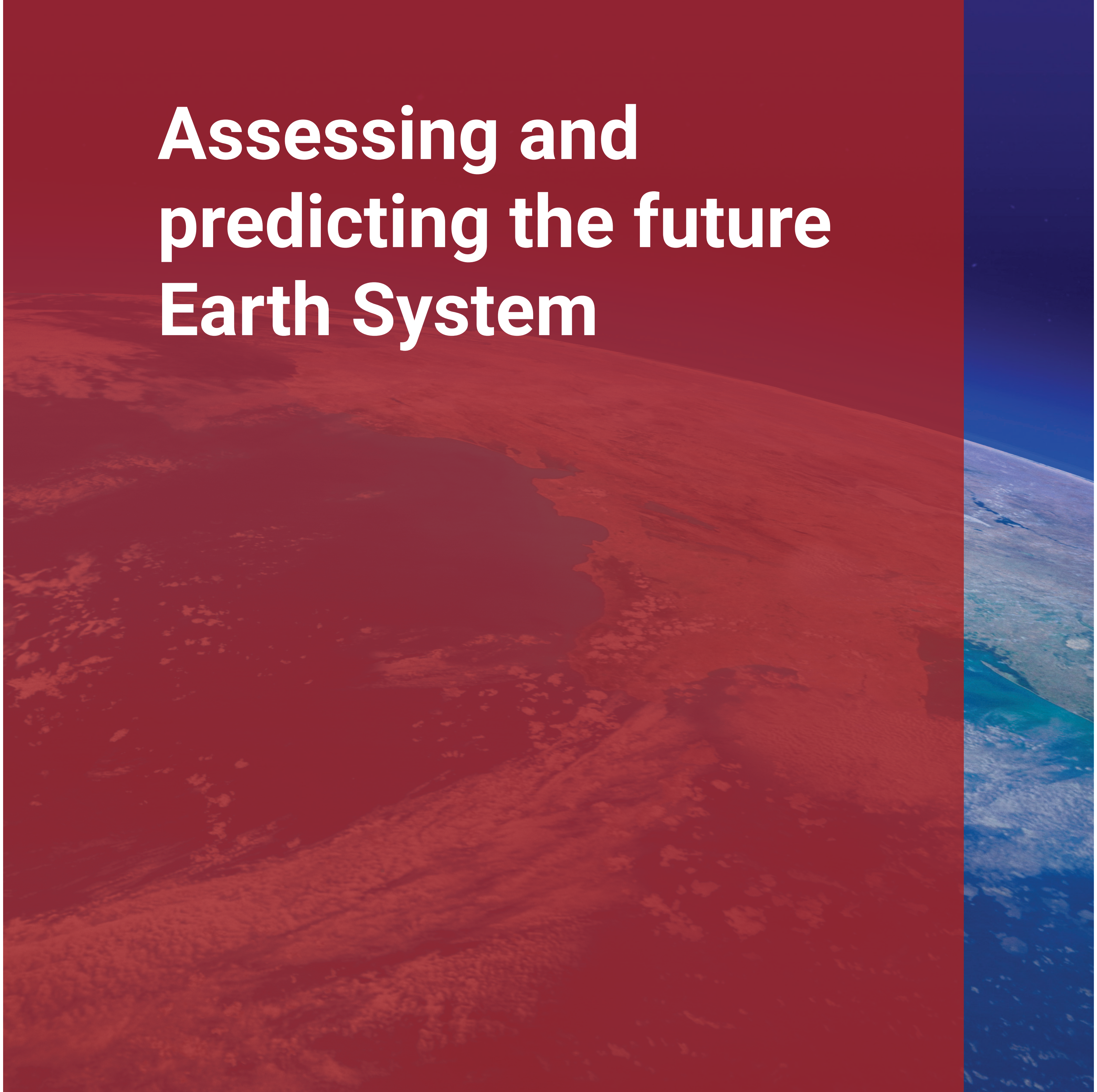
Strategic Imperatives

A clear understanding of the strategic direction is an essential part of the CMCC development pathway. In the following sections we outline the CMCC Strategic Imperatives that will drive and define our actions for the future.

In presenting our Strategic Imperatives, we will make use of a comprehensive set of indicators. The use of indicators is now widely accepted as an important management tool also for research and knowledge-related institutions. We are strongly committed to the achievement of these results and to maintaining tight communication channels with our stakeholders.



Assessing and predicting the future Earth System



Predictions have driven the development of atmosphere and ocean dynamics for most of the 20th century. They have provided powerful narratives that have framed the motivations and context of the research within a path of ambitious quest for knowledge and high societal relevance. The challenge in the next decade will be to build on the predictions expertise to consolidate and improve existing capacity and exploit this knowledge to launch new quantitative predictions in other interdisciplinary fields.

Develop unprecedented predicting capacity

The development of predictions in the Earth System has been overwhelming and the fusion of atmosphere and ocean predictions is now the norm. We will need to develop atmospheric models at spatial resolutions that will be beyond the threshold of 5km needed to describe convection explicitly. These models will be coupled with ocean models at similar or higher resolution that will allow consistent spatial resolutions in the atmosphere and oceans. In cooperation with the computer scientists, improved workflow and data storage and analysis techniques will ease the design, execution and analysis of numerical experiments and predictions.

Observations and Data Assimilation

We will continue to expand our capacity for data assimilation, building on the existing expertise in the ocean and adding data assimilation in the atmosphere, aiming at developing a coupled data assimilation system. The goal will be both preparation of initial states for deterministic and ensemble predictions and optimal state estimation for long term series of global data (reanalyses). A Data Curator program will be established to manage, collect and maintain observations, both in the atmosphere and in the ocean.

Global seamless predictions in the atmosphere, land, oceans and ecosystems

A seamless predictions system will be developed, linking short term predictions, to medium and extended range and seasonal. Investigation of the appropriate predictions for each range, from first kind predictions (deterministic) in the deterministic range to second kind (probabilistic) beyond that range. The investigation of scale interactions, between the sub seasonal and seasonal, time scale will be pursued and extended to atmosphere, ocean, land and their ecosystem. Research will be expanded also in investigating the predictability of non-traditional quantities like, for instance icebergs, degree days etc..

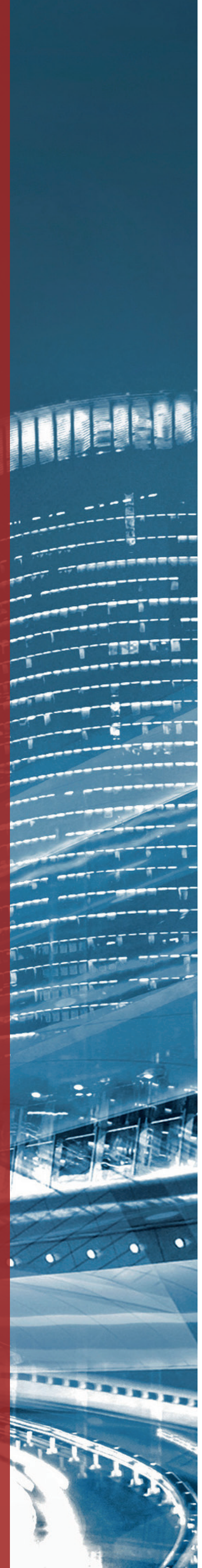
Regional and local seamless predictions in the atmosphere, land, oceans and ecosystems

Seamless predictions will be developed also for regional areas. Research on short term predictions will be included to increase confidence in longer simulations and to explore the limits of predictability at regional scale and in parallel work to improve the current ability to accurately simulate weather and climate in specific context, such as urban area. Regional models will be coupled to ocean models, aiming at a relocatable coupled regional model. Regional models will continue to be used for downscaling global models at all predictive and simulation scales, from short range to climate scenarios. New, fast statistical techniques for downscaling will also be investigated and evaluated against dynamical approaches.

Vulnerability and feedbacks of ecosystems

In predicting future pathways of climate change, biosphere feedbacks influence the relationship between emissions (of CO2 and other GHGs) and concentrations, and thus the effect of emissions on climate. Biosphere feedbacks are therefore directly relevant for mitigation policy. Uncertainty about the magnitude of feedbacks is a problem for climate policy because the usefulness of climate projections is limited if the quantitative relationship between emissions and concentrations is unclear. A range of positive feedbacks (amplìfication) are expected including permafrost thawing, ocean reduced carbon uptake by thermal stratification, methane emissions from wetlands stimulated by higher temperatures, increase of CO2 emissions by forest fires etc. They may be balanced by negative feedbacks such as CO2 fertilization, changes in albedo, aerosols loading etc. Still such feedbacks and in particular those those that are induced by humans more directly (i.e. land use changes, land - ocean transport etc.) are not yet fully included in earth system models, a task that CMCC should undertake in its future research developments.

Understanding, predicting and managing the future society



The concentrations of greenhouse gases in the atmosphere are at the highest they have been in the past 800 million years. These changes are mainly caused by human activities. Agriculture and food will play a prominent role in the 2030 development agenda. The agro-food sector alone accounts for some 80% of total freshwater use, 30% of total energy demand, and about 30% of man-made greenhouse gas emissions worldwide. With global food production expected to increase 70% by 2050 (coupled with meat dietary changes), the sector is facing unprecedented resource pressures and strong perturbations to the climate systems. Human population is growing at an unprecedented pace. Since 1960 we are growing at a constant net rate of about 80 million per year which will hit 9 billion of people by 2050. For the first time in human history most of the people will live in large urban areas (80% by 2050) and only a few in rural ones. Digitization of society production and services will change dramatically the labour market and lifestyles throughout the current century. A new generation of science is needed, starting from multidisciplinarity and integration of social and natural domains, to solution based approaches where competence and tools are integrated to solve emergent and new societal problems and finally take advantage of new big data analytical tools both for observations and models to improve systems behavior, manage the risk and provide robust decision support for policy and business stakeholders.

Decarbonization, jobs and labor relations

The demographic and economic changes will shape the way labour markets will work in the future. Another two billion people will need to be accommodated, with increasing standards of living and a population which will age in some countries but will remain young in others. Climate change will affect labour market dynamics via regulatory policies aimed at lowering our carbon footprint, but also through the direct impacts on natural and built environments. Decarbonization policies will have an ambiguous, policy dependent, effect on total employment. However, they will change the composition of the workforce, and will require new green skills which are currently missing. In this sense, a well designed decarbonization strategy can not only reduce CO2 emissions, but have positive effectson on the economy and the employment, including weaker parts of the society.

Decarbonizing the power, industry and building sectors

The issue of decarbonizing the total energy supply is central to analyzing the world's major research institutes and many governments' policies and practices. The process of decarbonization has therefore begun, and it is twofold. Firstly, it implies the reduction of the share of fossil fuels to total supply through targeted policies. According to the IEA, 85% of the additional energy supply from now to 2040 will be due to natural gas and sources labelled low carbon (i.e. all that is not fossil, including nuclear power). Secondly, there are concerns about a further increase in productivity in the use of energy. Regarding this, action has already been taken. However, it is necessary to follow up with a mix of investments, technologies and public policies that can advance the process of decarbonizing the total energy supply.

Therefore decarbonization requires major technological evolutions in the generation of power, energy storage, management of intermittency and uncertainty. Even more so in the transport sector, where the dependence from fossil fuels is most overwhelming and low-carbon alternatives are still far from competitiveness. Likewise in a number of crucial industrial sectors (like cement or steel) where CO2 emissions are intrinsically related to the production process, making Carbon Capture and Storage (CCS) imperative.

Buildings in industrialized societies represent still at least one third of the fossil primary energy consumption. The need to decarbonize the urban fabric requires then the transition to a new economic paradigm based on: 4th or 5th generation district heating, near zero energy buildings and high rates of buildings renovation, increasing electrification of heating and cooling sectors. The increasing cooling demand and the electrification of services, a potential burden for the traditional power system, can be key in a smart and integrated energy system that needs to accommodate the fluctuation of renewable sources.

Identifying the most promising and cost-effective technologies and processes amongst the host of options now being pursued is crucial to build a low-carbon, sustainable future.

Securing the water and food supply

CMCC is putting effort into the the development of innovative methodologies able to integrate different domains (e.g. climate, hydrology, economics, planning, environmental, and social sciences) and potential responses/feedbacks to tackle competition among nexus components and avoid unwanted cascading effects and feedbacks. The complex linkages between water, food, and other resources across different sectors is pivotal in a fast changing world, since their demand is increasingly driven by economic growth, rising population, urbanization, and climate change. Food production is tightly dependent on water, and as water resources become more and more limited, tools to assist new adaptive forms of water management in agriculture, water basin management, ecosystem conservation need to be explored and implemented in a comprehensive way.

Forest Management

Forests play an important role in ecosystem services - from supporting to cultural – but the offer of this wide range of services is threatened by multiple, interrelated, and simultaneous socio-economic and climate changes. Sustainable forest management can maintain forest functions and services while having a central role in climate change mitigation and adaptation in the long-term, broadly contributing to SDGs. Emerging research to integrate the double role of forest management is based on 1) the development of methodologies and tools for quick identification of areas prone to natural and climate induced hazards; 2) modeling activities to assess the vulnerability of forests and ecosystem function and services to climate change, also taking into account socio-economic activities as relevant stressors and source of uncertainties; 3) the development, support, and implementation of appropriate strategies and measures for forest conservation and ecosystem-based risk reduction, climate change adaptation and mitigation and SDG adoption; 4) the enhancement and improvement of protection and preparedness, underlying dynamic process involving the relevant public and private actors in co-designing new protocols and guidance adapted to changing local and regional constraints.

Local pollution versus global warming

Understanding of climate change and its outstanding effect on global temperatures cannot be disconnected from scientific investigations on local pollution sources and impacts. The latter might be even more damaging on local communities and their future socio-economic evolution than global changes. Knowledge of local sources of pollution, together with adequate numerical modelling and predictions at the scales of urban and coastal settlements has to be developed coherently with global modelling. Local and global pollution data sets should be collected together with environmental information to be integrated in hybrid models (deterministic models coupled with empirical ones and artificial intelligence) that will be able to consider local and global pressures. For example, it has been demonstrated recently that ocean acidification might be exacerbated by municipal treated wastewater inputs in some coastal areas.

Health

Many diseases (including those caused by pathogens noxious to humans, free-living animals and plants, and agricultural systems) are inextricably linked to climate. In a few cases the impact may be direct due to extreme high temperatures such as for the heat wave that hit Europe in 2003 that caused an estimated toll of 70,000 deaths. However, in the majority of cases the impact is indirect. In fact, many infectious agents or the vectors of those agents (ticks, mosquitoes, flies etc.) have life cycles that are influenced by temperature and humidity. Also, exposure to diarrheal diseases, such as cholera, which affect millions of people each year, is linked to warmer temperatures and heavy rainfall. Coastal Vibrio infections are often associated with zooplankton blooms and warmer water. Human mosquito-borne diseases, such as malaria and dengue fever, are also cases where vector and disease expansion could follow from climate warming, although this can be mitigated by vector control, medical treatments, and educational campaigns.

Disentangling the various anthropogenic pressures that facilitate the introduction and establishment of novel pathogens or increase the transmission and the range of old pathogens is not easy. Land-use changes, globalization of trade and travel, as well as the introduction of new host species, act as synergistic drivers together with climate change. Developing predictive models that account for the various drivers is thus of paramount importance. The availability of georeferenced data on population density and mobility, land use, water body networks, and vegetation facilitates the production of space-explicit eco-epidemiological models that are driven by meteo-climatic models downscaled to the appropriate regional level and account for the synergism with other global change impacts. Short-term models are fundamental to cope with epidemics, while long-term models are basic to planning measures that prevent the endemic establishment of pathogens that cause permanent disability.

The exposome and climate

The concept of the exposome, introduced in 2005 by Christopher Wild, encompasses environmental exposures and concomitant biological responses throughout the life course. It allows the assessment of the totality of the life-long environmental influences that individuals are exposed to and their health impacts. Exposome-based approaches will provide new insights into environmental health sciences, addressing some key scientific questions. Besides that, the understanding of the human exposome is a brand-new attempt at improving health and reducing the burden of disease. This will require improved knowledge of health risks, including combinations of several risk factors, and the mechanisms by which they affect health at different stages throughout the life course, including exposures in fetal life. Climate change can be seen as a primary factor affecting the exposome. Finally, it is worth noticing that the development of the "human exposome" requires the use of high performance and high throughput computing resources as well as appropriate data mining tools, including statistical analysis of complex data and suitable machine learning approaches. The research topics described above are going to be more relevant in the future regarding research activities and investigations aimed at decoding the role of the environment, including climate change, for human health and well-being, including using machine learning methods and strategies.

Resilience of urban systems

Cities are considered major contributors to climate change, consuming most of global energy and emitting most of anthropogenic greenhouse gases, thus experiencing a significant alteration in climate patterns. This poses the urgency for cities and communities to collaborate in order to address the challenges of climate change mitigation and adaptation and sustainable management. Climate-sensitive urban design (CSUD) is crucial to mitigate urban climate risks and vulnerability and risk assessments at local scale are key points to support the development and implementation of effective adaptation measures, in particular centered on Nature- Based Solutions (NBSs), to make well-adapted and climate-resilient cities.

We need a process of knowledge co-production involving researchers, stakeholders, decision-makers and in general practitioners and people to be able to cope with climate change impacts and increase city resilience. This process involves the development of different tools with different objectives. Additional efforts are required by the scientific community in the coming years to improve simulation models to be able to represent urban climate. New accurate models, capable of accounting for urban parameterizations through bulk or more sophisticated approaches, could overcome the lack of observation data.

Specific features and peculiarities of cities need to be taken into account, especially for studying the impacts of extreme events (e.g. urban pluvial flooding, urban heat island and heat waves), which is made more complicated by a lack of well-consolidated tools to assess these impacts at urban scales. Improving existing methodologies and creating new ones for analyzing urban climate change impacts is then suggested.

Evolving world relations in a fast changing world

The world is changing and it is changing fast. The drivers of change are multiple. Climate change is certainly one of the main drivers, but it is not the only one. Demography, technology, inequalities, scarce resources, and migrations are also drivers of changes in international relations, societal stability and economic development. The dynamics of future world relations therefore depend on a large set of intertwined factors, from technological innovation to concentration of financial resources, from income distribution to climate change.

All these factors interact to make the world riskier and more unstable. Understanding and modeling these interactions is crucial to design policies to manage risk. For example, when dealing with policies to mitigate the effects of climate change, we need technologies to enhance agriculture productivity, or to make water and energy available to a growing population, and we need accurate information to prevent natural disaster and extreme events. When dealing with policies addressing the causes of climate change, we need to model the evolution of a new energy system, a cultural transformation in consumption, and different cities with sustainable transport systems.

All these changes, transformations and transitions have impacts on geopolitical equilibria, on migrations and urbanization phenomena, and on economic growth, with related implications on employment and welfare.

Global Conflicts

Impacts of climate change will modify resource availability in various regions of the world. It is therefore likely to observe the emergence of new conflicts, induced by water scarcity for example, or by lack of food, because changed climatic conditions will shift productions of crops to different areas. Resource scarcity will induce both movements of production, particularly in agriculture, and movements of persons, looking for food and jobs. These migratory phenomena will be essentially internal, because concentrated in more vulnerable and poor regions. However, they will increase the number of internal and regional conflicts in developing countries – a phenomenon that can already be observed. As political and economic powers will try to increase their influence on poor regions of the world (e.g. by providing infrastructures or weapons) climate change will increase global instability by destabilizing these countries. The economic development of these countries will be jeopardized, with negative consequences on global demand and growth, which crucially depends on stable and balanced development in less favored regions (those that are presently growing more than any others, thus driving economic growth worldwide). Hence, it is crucial to study how climate change will affect conflicts and, at the same time, how conflicts will enhance impacts of climate change (e.g. by reducing adaptation capacity in many regions).

Domestic and External Inequalities

Linked to the aforementioned climate-related phenomena, internal and external inequalities are another important factor of change. External inequalities, namely inequalities across countries, have become lower and lower in the last decades, thanks to globalization. However, internal inequalities have increased in almost all world countries. The top 10 percent of income recipients owns a larger and larger share of total income and wealth. This share has doubled in the last three decades, thus creating frustrations in middles classes around the world (this phenomenon characterizes almost all developed countries and the main developing ones). This situation is the origin of social and political instability in both developed and developing regions. Populist and nationalist parties are gaining support, particularly in Europe, whereas dictatorships and conflicts re-emerge in developing countries. Most importantly, inequalities are drivers of concentrations in markets and skewed, and slowly growing, economic demand. These phenomena are exacerbated by climate change that reduces income opportunities for low and middle classes (even though this effect can be mitigated by technical change).

Migrations and Demographic Changes

Population is increasing and will increase until the end of the century, reaching ten billion people. Three more billion people will increase pressure on natural resources and on human infrastructures, particularly in cities. Indeed, by 2050, about 80% of total population will live in cities. This crucial change calls for a re-design of cities to provide a sustainable wellbeing to large agglomerations of citizens, taking also into account technical change (e.g. self-driving cars and all their implications on ownership, parking space, gas station, etc.; or drones and their effects on urban deliveries and freight transports). Population increase will also exacerbate the pressure on natural and economic resources, thus making it even more difficult to survive in areas more vulnerable to climate change.

Lack of resources, conflicts and increased population will induce large migratory phenomena (the World Bank estimates 134 million migrants by 2030). A first wave of migrations will be mostly internal, affecting cities in the developing world. A second one will be international, with large effects on richer areas of the world. Again, climate change is one of the causes, but adaptation capabilities, development, and therefore emissions, will also be affected my migratory phenomena.

Economic Development

All these changes, transformations and transitions have impacts on geopolitical equilibria, on migrations and urbanization phenomena, and on economic growth, with important implications on employment and welfare. Climate change can be seen as a driver of instability and losses, but at the same time as providing important business opportunities that stimulate economic growth.

The transition to a new energy system is already attracting important investments, as technological change makes the cost of renewables cheaper and cheaper. The re-design of cities and transport infrastructures, driven again by technological change and related changes in consumption habits, will also attract important investments. Adaptation of coastal zones, of agriculture production and of tourism infrastructures will also drive huge investments. These investments, coupled with a fast-changing innovation, could be the engine of a new and sustainable economic growth, with positive effects on employment.

It is crucial however to properly manage these investments and for policy to provide the appropriate signals and rules to investors. It is also crucial to design policies to increase the speed of transition, to avoid irreversible effects on natural resources, forestry and oceans in particular. While at the same time creating safety nets for those who will be negatively impacted by the transformations, both the digital and the sustainability ones (e.g. workers in fossil fuel industries, and low skilled workers more generally).

Delivering world class computations and analytical capacity

Accelerating the prediction and simulations workflows

Improving the efficiency and productivity for global Earth system modelling in HPC environments will need the support of proper end-to-end workflow mechanisms. HPC systems provide the compute and storage infrastructure that enables scientists to address questions of relevance to fundamental research, industry and the most complex social challenges. At such scale, scientific workflows will need the capability to handle 100k of processors with millions of threads while producing or reading extreme-scale data. The current state of the art needs strong enhancements in terms of fault tolerance, resilience, robustness, efficiency. Additionally, data centres are seeing challenges supporting mixed workflows of HPC and data analytics, with machine learning and deep learning to accelerate knowledge discovery. The general consensus is that this needs to change and requires new thinking about how to access storage, describe data, streamline processing, analytics and learning as well as manage workflows.

Delivering Petabyte data handling power to scientists' desks

The exponential growth in data and storage systems is making available unprecedented amounts of data for scientific investigation. However, only a fraction of the power of the data is currently exploited by scientists, because the access and manipulation technologies have not kept the pace with the increase in the data volume. To address the limitations of current storage environments, new storage interface and data models should (i) embed performance sensitivity and provide higher usability, (ii) enable the definition of managed workflows, (iii) allow storage to exploit that semantic information to improve performance and fault-tolerance. Challenges to be addressed on such topics are related to: (i) the delivery of a high- productivity environment for researchers targeting exascale I/O and storage through new abstraction levels for scientific data, semantics features; (ii) performance portability across different storages, and interoperability; (iii) multiple tiers of data storage, allowing storage of data on heterogeneous storage types and media with smart data placement mechanisms; (iv) real time in situ/in transit processing: allowing data streams to be processed while they are transferred.

Active storage management research would also allow moving the analytics at the storage layer, drastically reducing I/O transfers via in-storage computations. This will require a strong involvement of both hardware and software knowledge linked with interdisciplinary groups, to efficiently address multi-dimensional array data structures on modern storage devices.

Next Generation Data Analysis

Peta-exascale data requires a different workflow based on data-intensive facilities close to data storage and server-side analysis capabilities. Only the final results of an analysis (e.g., images, maps, reports and summaries typically megabytes or even kilobytes) will need to be downloaded—and even then data may be server-side managed (it could even be stored in a cloud-based environment). Such an approach will reduce (i) the downloaded data, (ii) the makespan for the analysis task, and (iii) the complexity related to the analysis software to be installed on client machines. Moreover, server-side services will spur development of new “client” software (like visualization tools) strongly decoupling the front-end aspects (focusing on presentation and visualization), from back-end ones (targeting more on running the analytics primitives on the scientific datasets). Finally, to address interoperability, a strong emphasis should be devoted to the interfaces provided by the analytics services, which should implement and exploit well-known standards and protocols.

Real-time analysis at CMCC

At CMCC, key challenges will relate to real-time analysis at scale, extreme-scale data analytics benchmarks, novel array-based data structures for structured and unstructured grid models, parallel and distributed analytics approaches managing extreme-scale experiments with tens/hundreds of thousands of parallel jobs, large- scale I/O with both in-memory and active storage approaches moving towards heterogeneous storages with a co-design flavor given by the interaction with industrial partners (vendors), computational scientists and climate scientists.

Empowering capacity with human and artificial intelligence

A major challenge faced nowadays by climate scientists is how to efficiently make sense of the extraordinary amount of data produced continuously by all sorts of interconnected sensors and devices around the globe. The sheer amount of data, together with their sparsity and heterogeneity, pose formidable computational problems that simply cannot be solved using conventional techniques and call for radically new approaches. Recent stunning advances in Artificial Intelligence (AI) have been made possible thanks to the development of powerful machine learning algorithms, whose distinctive feature is precisely to improve in performance as the amount of data they analyze grows. At CMCC we believe that the interaction between AI and climate science holds enormous promise and we want to be at the forefront of research in this highly interdisciplinary area. In particular, we aim to develop next-generation machine learning methods for prediction and simulation, for the monitoring and management of ecosystems, and for risk assessment and decision support. We also aim to study the economic implications of AI-based computational climate models.

AI-assisted prediction and simulation methods

The development of climate and forecasts simulations has led to increasing complexity in the formulation of models and a modification of the practices of numerical experimentation. The meaning of “numerical experiment” has changed from a single simulation to ensembles and clusters of several simulations and/or forecasts. Analyzing the results and monitoring the execution of these experiments, that can take several months of calculations, is however still based on human ingenuity and observation. The complexity of the models and the size of the data sets can make a scientific consideration of the simulations unmanageable. AI can be useful to help setting up autonomous monitoring agents for the simulations, design autonomous storage strategies for large numerical data sets, design alert and trigger mechanisms for targeted events and circumstances.

Artificial Intelligence for Climate Simulation

Machine learning approaches, based on the use of Neural Networks, have already been successfully adopted to speed up the calculations of atmospheric and ocean model physics parameterizations. Moreover, new emerging approaches based on machine learning neural networks approximations have been used for accurate and fast approximation of atmospheric radiative processes, and for the emulations of model physics in ocean and atmospheric numerical models. Machine learning approaches, based on Convolutional Neural Network, have also been used for precipitation nowcasting, for the detection of extreme weather patterns in climate data and for the classification of tropical cyclones, atmospheric rivers and weather fronts. The results from this study can be used to quantify the trend of climate extreme events in current day and future climate scenarios, as well as investigating the changes in dynamics and thermodynamics of extreme events in the global warming context.

Hybrid numerical approaches at CMCC

CMCC research activities on hybrid numerical approaches for climate modeling are also strategic to understand if deterministic and statistical learning approaches can lead to new opportunities in climate simulations. Clearly, this investigation on hybrid approaches for climate modeling should carefully check if the approximations achieved using machine learning solutions are close enough to the original physical/chemical parameterizations and if they are fast enough to significantly accelerate calculations of model physics/chemistry. Moreover, it is important to analyze if these statistical/machine learning techniques can successfully coexist with deterministic components of ESMs, so that their combination can be efficiently used for accurate and fast climate simulations without any negative impact on their quality.

AI for monitoring and management of ecosystems

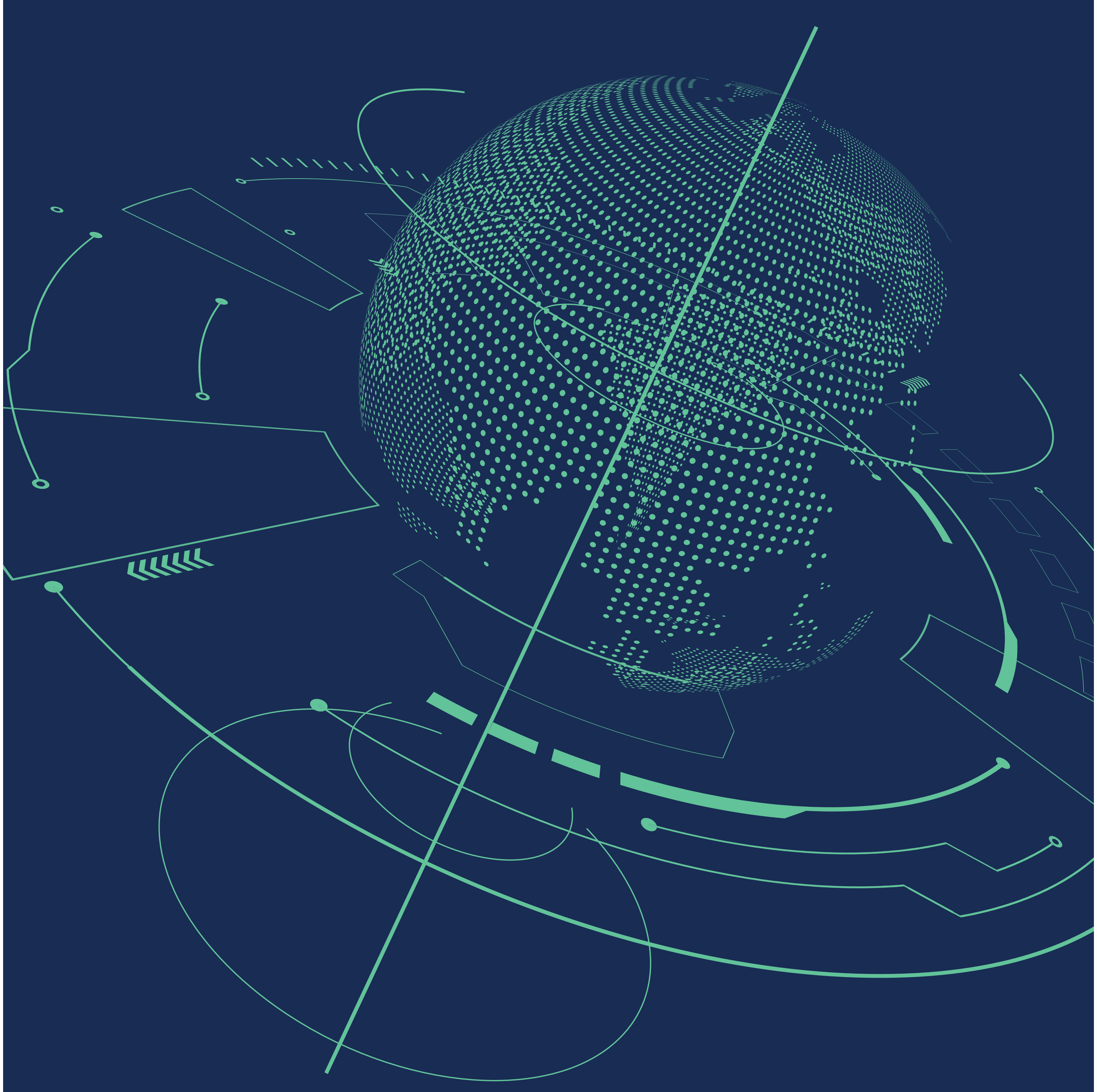
Recently Internet of Things technologies (IoT) and Big Data Analytics have grown rapidly and represent today a unique opportunity for improving our environmental monitoring capabilities at extremely low cost and at unprecedented spatial and temporal scales of observation. Although these these technologies make Industry 4.0 fast growing, applications to understand natural processes and biogeochemical related interactions with the Climate System are still lacking. We intend to develop IoT technologies for ecosystem monitoring and associated data assimilation algorithms to promote a new Nature 4.0 concept, starting from successful prototypes currently used in some projects (TreeTalkers).

Artificial Intelligence, decarbonization and adaptation

Ongoing transformations are closely interlinked. For example, changes in demography and urbanization processes are likely to have deep effects on future GHG emissions and on climate change. At the same time, climate change is going to affect population dynamics, migrations, health and other social variables. Similarly, digital transformations are closely linked with climate change. Artificial intelligence is likely to strongly modify the way we live and therefore the level of GHG emissions and our capacity to adapt to climate change.

Artificial intelligence will boost energy efficient production and mobility processes, as well as energy efficient consumption patterns. The internet of things will reduce our use of domestic energy. Smart meters and other artificially intelligent devices will help lowering optimising energy distribution and therefore reducing production. Self-driving cars will reduce fuel and/or electricity consumption. Artificial intelligence applied to health care, a very promising avenue even in the short-term, will help control the effects of climate change on human beings, whereas applications in agriculture will reduce water needs. Even Artificial Intelligence in finance is likely to have relevant effects on climate related variables. Fintech, namely AI applied to lending and payments, will facilitate investments in decarbonization and adaptation particularly in developing countries.

It is therefore important to address the implication of artificially intelligent processes and devices on mitigation and adaptation to quantify how policy-independent, market-led technological improvements will affect future GHG emissions and socio- economic systems resilience.



Innovative applications

Climate change introduces a new type of risk that has to be taken into account in a roster of human activity, especially those regarding planning, strategic outlooks and prevention. Resilience to climate variability and change has become a common goal for many international and European policies, upon which more coherent actions can be built. Building the culture and practice of resilience goes beyond reducing the consequences of foreseeable events and builds resilience into systems to recover and adapt when adverse events occur.

CMCC produces innovative data sets about the climate system and its subcomponents in all these dimensions to produce innovative applications that will better inform society of the hazard and the risk. Climate scenarios, Atmospheric, oceanic and ecosystem analyses, reanalyses, projections and forecasts form the basis for hazard and risk mapping, emergency alert systems and in general all kind of decision support systems that require state-of-the-art environmental information to compose the end-user products.

Ocean Applications

CMCC is at the forefront of the production of analyses, reanalyses and forecasts for the global ocean, the Mediterranean Sea, the Black Sea regions and the Adriatic Sea coastal areas. Out of this basic environmental information end-user products have been and will be developed to meet user needs and reduce risk of disasters. Three are the targeted major application sectors: the first is the maritime transport and safety, where new advanced systems are being developed for low carbon and safer routes for variable environmental conditions and search and rescue decision support systems. The second is the marine environmental health assessment where CMCC develops oil spill hazard mapping, plastic pollution hazard mapping and climate hazard indicators. The third is marine resources where CMCC develops support systems for mariculture based upon environmental condition monitoring and forecasting.

Future activities are foreseen to further expand the risk and hazard mapping tools in the different marine and maritime socio-economic sectors in particular advancing the production of coastal reanalysis and forecasting systems, downscaling climate scenarios at the local scale of ports and bays. Hazard mapping will be further developed with ensemble simulations considering both new hazard indices and their uncertainties.

Design of innovative sensors for data assimilation systems

Ocean monitoring from physics to biogeochemistry and fish is one of the big challenges of this century. Old monitoring platforms, such as ship of opportunity and fixed buoys, and their associated measurement technology is incapable of meeting the interdisciplinary requirements and needs of the modern earth system monitoring. Autonomous vehicles and new measurement techniques, i.e. optics and new materials, are replacing most of the open ocean measuring sensors, platforms and networks.

Observational data also should fit the needs of predictive models and partly be decided on the basis of the model validation and data assimilation. Last but not least observational in situ monitoring should complement the earth satellite information system which which also needs to be constantly upgraded in terms of innovative sensors. CMCC is planning to work on new marine sensors and study the impact of the different ocean observations on the quality of analyses and reanalyses via Observing System Simulation Experiments, for new sensors, and via Observing System Experiments for present day measurements in order to assess the fitness for use in data assimilative models.

Agriculture and forestry applications

The diagnosis and prediction of climate change impacts and vulnerability on agriculture and forest ecosystems, and the identification of efficient solutions to reduce impacts and improve sustainability, will rely on the application of innovative tools, technologies and methodologies, spanning from basic to applied research, characterized by a highly added value in terms of information provided to end-users and user-friendliness, which are finalized to meet user needs.

IoT and ICT technologies will be applied increasingly in the broad field of water management, based on the "nexus" holistic approach, exploring the potential responses and feedbacks among multiple water-consumer sectors and enabling a more efficient use of this resource at multiple scales.

The research on climate-smart solutions aimed at supporting sustainable development of the agricultural sector (by optimizing farmer income, minimizing inputs, and reducing environmental impacts of farming activities) will be further explored through the application of information technology (guidance systems, recording and reacting technologies) to orient the decision-making system. Innovative tools and methodologies will be developed and applied with the purpose of optimizing irrigation scheduling, by computing crop water requirements and soil water balance with the latest "smart" farming approaches, empowering growers and farmers to reduce resource waste and enhance productivity (more-crop-per-drop).

CMCC will produce tools and climate smart applications to achieve sustainable increase of agricultural and forest productivity and income, identify strategies to manage and reduce risks in agriculture and forest ecosystems, and to contribute to mitigation goals, with the aim to lead and advise users, stakeholders, and policy makers through the translation of scientific results in specific and operational programs and policies. Computing and data management facilities, coupled with short and medium term forecasts and projections, will allow to obtain insightful support for operational purposes toward securing water and food supply, ecosystem services maintenance, as well as increasing resource efficiency.

Supporting Adaptation Efforts

Adaptation is increasingly becoming a cornerstone of the fight against climate change. It is a central issue in international climate negotiation process and a pillar of climate change policies in developing countries. Adaptation planning is occurring in the public and private sectors, while efforts and initiatives to build adaptive capacity and resilience are being implemented at all levels of government: super national, national, regional, urban.

CMCC deems that it is fundamental to advance the knowledge on the following aspects related to adaptation which still remain insufficiently explored: (i) its real effectiveness in contrasting negative climatic impacts; (ii) its potential to promote social equity across countries and social groups due to its ability to tackle local undesired consequences, and thus, to correct more directly asymmetries in climate change costs; (iii) its ability to foster virtuous development patterns beyond environmental benefits.

CMCC will conduct this research further developing and applying its innovative climate, bio-geo-chemical, and socio-economic data sets, integrated modelling tools, and services (ranging from decision support systems to multi-risk management). These will serve to actively support governments and local communities in addressing climate-related impacts with tailor-made adaptation initiatives, substantiating operational plans and policies.

Assessment and Forecasts of Sustainability Indicators

Sustainability is a multidimensional concept, encompassing at least three paramount spheres of human existence on earth: the environmental, social and the economic domains. As such, it turns out to be hard to define, if not in very broad conceptual terms, and to measure sustainability. However, measuring and monitoring are crucial pre-requisites to enable the design, implementation and improvement of policies to promote sustainable development that allow an effective, efficient and equitable use of scarce resources. The path to measurability has led to the production of a wide range of indicators, compounded in "dashboards" or in more or less aggregate/composite indexes and to the identification of measurable goals and targets.

The UN "Agenda 2030" presented in 2015 setting 17 goals, 169 targets and more than 240 indicators substantiating the complex concept of sustainability. CMCC, already a member of the Italian Alliance for Sustainable Development (ASVIS), deems fundamental to contribute to this initiatives by:

- **Supporting** increased accuracy and reliability in the measurement of sustainability indicators;
- **Extending** the number and type of indicators that can be measured, as well as developing innovative aggregation methods to get to synthetic multidimensional and multisectoral indexes;
- **Proposing** innovative methodologies to anticipate the potential impact on future sustainability of different policy actions;
- **Increasing** the transparency and usability of indicator-based analyses of sustainability.

CMCC will contribute its solid quantitative modelling expertise that spans from the climate to social sciences, enabling a comprehensive treatment of sustainability highlighting where complementarities and trade off could arise. CMCC will also be able to draw on its consolidated expertise in scenario building, integrating climate change and social and economic projections, and allowing a prospective and not only a retrospective monitoring of policy action.

Using the high spatial resolution of its climatic, environmental and social economic databases CMCC will be able to push the analysis of sustainable development to the regional and local level. Finally, its long lasting collaboration with policy making at the international, national and local level will facilitate an easier translation of policy recommendation into policy action.

Risk management tools and indicators

Climate adaptation and disaster risk reduction contribute to closing the 'resilience gap' by helping to avoid unmanageable changes and managing them when they become unavoidable. Improved risk assessment methods and mutually beneficial approaches present opportunities for enhancing policy coherence. Hazard mapping and risk assessment are areas where integration between adaptation to climate change and disaster risk reduction is more advanced and recognised as a priority. A thorough understanding of risks, including their cascade and spillover effects, is also important for a better understanding of implicit and explicit government liabilities, and designing comprehensive risk financing strategies. However, risk assessment needs to be made responsive and sensitive to the needs of vulnerable communities, social strata and businesses. Supported by well-functioning system of public and private, user-driven climate services that connect short- and long-term climatic changes can help catalyze an economic and societal transformation that reduces risks and improves societal resilience.

Smart Cities

Cities are characterized by an ongoing process of demographic, urban and economic growth, which produces wealth and prosperity but at the same time can have some negative feedback on the urban climate. This is reducing the comfort of urban population and the high complexity of these issues requires the development of new innovative and integrated approaches. One of the key factors in this sense is represented by the development of tools aimed at quantifying the current state of climate in cities and at analyzing the impacts of variations in planning and/or design/retrofitting of infrastructures.

The increasing availability in computational resources and in urban environment monitoring, facilitated the development of two groups of numerical models, with a very high horizontal resolution (less than 1 km, up to 10 m) to study urban microclimate: (1) Energy-Based (EB) models (2) Computational Fluid Dynamics (CFD) models. These tools are able to account for any modifications of the urban geometry and architecture (e.g. Nature Based Solutions (NBSs), such as replacing part of a road cover by adding green areas or posing garden on the rooftops). A multidisciplinary approach is, indeed, required to support the smart city vision because different skills and competences are needed to manage this issue and to account for different aspects (physical impacts, economic issues social development, etc.).

The CMCC Structure

At the core of CMCC there is the integration of the physical, environmental and societal aspects of climate change.

The development of CMCC

CMCC was established in 2005 with the financial support of the Italian Ministry of Education, University and Research, and the Ministry of the Environment, Land and Sea and has been fully operative since 2006. The Center gathers the know-how and benefits from the extensive applied research experience of its members and institutional partners: Istituto Nazionale di Geofisica e Vulcanologia, Università degli Studi del Salento, Centro Italiano Ricerche Aerospaziali, Università Ca' Foscari Venezia, Università di Sassari, Università della Tuscia, Politecnico di Milano, Resources for the Future.

CMCC has submitted more than 800 research proposals under the EU Framework Program or other public funding agencies. At present, its research projects portfolio is composed of 268 national, European and International funded projects such as: 37 funded projects in FP6 and FP7 (6th and 7th Research Framework Program of the European Union), 37 funded projects in Horizon 2020, and 194 funded projects under national, other EU and international research grants (tot. of ca. 71M €). CMCC has coordinated about half of these research projects.

The activities are carried out in offices located in Lecce (the headquarters), Bologna, Venice, Viterbo, Capua, Sassari, Milan, Rome. The development of the various sites will be harmonized with the development of projects and resources.

The organization is well connected in the international context, both within and outside Europe having partners from more than 70 countries, in the European Union and in the Mediterranean countries, as well as Africa, India, China, United States, and Japan. CMCC has signed a Memorandum of Understanding with the National Center for Atmospheric Research (Boulder, Colorado, US), the National Marine Environment Forecasting Center, State Oceanic Administration of China (Beijing, China), the Geophysical Institute (GFI), University of Bergen, Norway, Istituto Zooprofilattico Sperimentale delle Regioni Lazio e Toscana (IZSLT), INGV, OGS (Istituto Nazionale di Oceanografia e Geofisica Sperimentale) and National Marine Environment Forecasting Center (NMEFC) – State Oceanic Administration (SOA) of China, UNCOMA (Universidad Nacional del Comahue – Argentina).

In 2012 CMCC joined the United Nations Global Compact, the world's largest corporate responsibility initiative that networks business and non-business entities engaged in areas of human rights, labor, environment, anti-corruption and contributing to UN goals in order to achieve the common objectives of building a sustainable and inclusive global economy. By joining the UN Global Compact, CMCC declared declared to embrace, support and enact the ten principles derived from the Universal Declaration of Human Rights, the International Labour Organization's Declaration on Fundamental Principles and Rights at Work, the Rio Declaration on Environment and Development, the United Nations Convention Against Corruption.

The research structure

The Center aims at furthering knowledge in the field of climate variability, its causes and impacts and their interactions with the global climate, through the development of high-resolution simulations of the atmosphere and ocean, surface and underground hydrology, environmental and socio-economic impact models.

Nine research Divisions work together in an interdisciplinary manner pursuing their specific research objectives focusing on:

Advanced Scientific Computing

The Advanced Scientific Computing (ASC) Division carries out R&D activities on Computational Science applied to the Climate Change domain. In particular, it focuses on the optimization of numerical models on HPC architectures and the management of large volumes of scientific data looking forward at exascale scenarios. The main objectives of the research activities are: the optimization and the parallelization of the numerical models for climate change simulations (both climate and impacts models), and the design and implementation of open source solutions addressing efficient access, analysis, and mining of scientific data in the climate change domain.

Climate Simulation and Predictions

The Climate Simulation and Predictions (CSP) Division contributes to the development of the CMCC Climate and Earth System Models, and uses them to explore and improve our understanding of the mechanisms underpinning climate variability, climate predictability and climate change, by means of numerical simulations. In collaboration with the ODA Division, CSP produces climate change scenarios, contributing to the World Climate Research Programme (WCRP)'s Coupled Model Intercomparison Project (CMIP) to inform the Intergovernmental Panel on Climate Change (IPCC) assessments and in support of emerging climate service activities. Furthermore, CSP produces operational climate forecasts from seasonal to multi-annual time scales.

Economic analysis of Climate Impacts and Policy

The Economic analysis of Climate Impacts and Policy (ECIP) Division aims to translate into economic values climate scenarios and the subsequent quantification of

the impact of climate change, in collaboration with other divisions. The economic valuation is then the basis for designing the most appropriate policies to mitigate emissions and for adaptation to climate change.
The main objectives include: the development of the coupling among the economic, climate and land uses models of CMCC; the development of GHG emissions scenarios and low carbon scenarios; the assessment of the economic value of impacts of climate change at the global and regional level, with a focus on extreme events; the analysis of mitigation and adaptation policies on climate change; research and networking activities on governance of climate change.

Sustainable Earth Modeling and Economics

The Sustainable Earth Modeling and Economics (SEME) Division develops and manages the WITCH model which is one of the key global integrated assessment models used to perform global analysis of climate policies. In addition, the SEME division has extensive experience in studying empirically socio-economic drivers of emissions, energy technologies and individual behaviors in the face of energy and environmental choices. The SEME division is composed by researchers with very diverse disciplinary backgrounds which enable them to take on very interdisciplinary problems

Impacts on Agriculture, Forests and Ecosystem Services

The Impacts on Agriculture, Forests and Ecosystem Services (IAFES) Division focuses on the diagnosis and prediction of the climate change impacts on agriculture and on terrestrial natural and semi-natural ecosystems, and on the services they provide, at local to global scale. The activities comprise basic and applied research, up to operational purposes in the context of ecosystem services. Particular attention is paid to the monitoring, modeling, and analysis of: agriculture and the water and nutrients' requirement, including the ecological footprint; carbon cycle through soil-water-vegetation-human environment dynamics, including their feedbacks to the climate system; soil water balance and hydrological cycle at different scales, considering the different uses and services of water resources; land use and land degradation up to desertification; prevention, planning and managing wild fires and the consequent emissions; exposure, vulnerability and risk of vegetation and rural-urban and forest-urban interfaces to the fire danger. All these activities are supporting strategies for mitigation and adaptation to climate change.

Ocean modeling and Data Assimilation

The Ocean modeling and Data Assimilation (ODA) Division focuses on the development and improvement of the CMCC Earth System Model components with a particular emphasis on the physical and biogeochemical ocean models. Another major activity of the ODA Division is the development of data assimilation methods for the production of global marine reanalysis and forecasting. Finally, recently the ODA Division has also started to work on ice-sheet and paleoclimate modeling.

Ocean Predictions and Applications

The Ocean Predictions and Applications (OPA) Division deals with the development of models and methods for interdisciplinary research on marine operational forecasting, on the interactions between coastal areas and the open ocean, on the development of services and applications for all maritime economy sectors, including transport, security and management of coastal areas and marine resources, in the context of climate change adaptation problems.

Risk Assessment and Adaptation Strategies

The Division Risk Assessment and Adaptation Strategies (RAAS), brings together research groups with sizable expertise and long-standing experience in climate risk analysis and assessment, and development of adaptation strategies and policies, previously affiliated with other research divisions. The research priorities embrace three major themes that denote the main research units: economic analysis of risk and disaster risk reduction; environmental risk assessment and management; governance of climate related risks and adaptation.

Regional Models and Hydrogeological Impacts

The main activities of Regional Models and Hydrogeological Impacts (REMHI) Division include studies about: regionalization of the climatic signal through the development and use of statistical and dynamical downscaling approaches, and qualitative and quantitative evaluation of the effects of climate changes and anthropogenic pressure on the geohydrological hazards (such as landslides, floods and droughts). Furthermore, the Division develops and implements procedures able to optimize the link between climate and impacts models, and tools for the correct quantification of the associated uncertainty.

Activities at CMCC are supported by the **CMCC SuperComputing Center**, a high performance computing facility that has been recently updated to more than 150 Tflops and over 3 Petabytes of storing space. The SuperComputing Center allows for the execution of cutting edge research and it has been instrumental in allowing a significant contribution to the IPCC coordinated climate scenario experiments.

Reaching Out

Addressing exclusively the scientific community is no longer enough. In recent years, climate scientists have put a great deal of effort into supporting decision- making and enhancing public awareness of climate change. Consequently, climate sciences have increased their impact in implementing sustainable development, influencing people's welfare, the quality of the environment, and economics and finance. Communication is the door through which science goes beyond the borders of the community of peers and enters public discourse, bringing the results with new languages and tools to inform public policies - on a global and local scale - on issues related to climate change. Media play a crucial role in this process because they widely contribute - whether mono-directional and traditional (such as newspapers, TV, and radio), or interactive and multimedia (social media, web pages) - to shaping the way climate change is addressed and framed in the cultural and political context.

In such a framework, the way a corporate citizen of the global scientific community - such as CMCC - deals with media evolves in multiple directions. On the one hand, there is the dialogue with established and emerging institutions in the world of information (newspapers, blogs, tv broadcasting), and on the other hand, the creation of new tools that allow the Centre to speak directly to the public and to produce and disseminate content produced independently, according to criteria of reliability, accountability, and accuracy of information.

The evolution of communication technologies, of the media, of the way information is produced and used, call for a challenge that requires not only making scientific data available but also finding new narratives, interactive and multimedia methods to tell this data, make them comprehensible and usable by different audiences. The CMCC takes up this challenge and implements the work done in recent years with the aim of finding the synthesis of the multidisciplinary approach to scientific research to contribute to collective awareness with formats and narratives that will put climate change at the core of the story, as a protagonist of present and the future.

Communication activities are therefore designed to:

- Give visibility and maximum dissemination to the CMCC, to the excellence of its research and its impact on socio-economic systems at global, regional, national and local level;
- Be a leading player for raising public awareness toward the ability of scientific research to produce forecasts for a better understanding of the future world for the benefit of decision-making processes, with particular reference to climate change;
- Explore innovative tools and applications in the field of communication and information to stimulate an active stakeholder engagement and spread Climate Literacy in society as a whole, with a particular focus on education and schools, civil society, and thematic associations.

WEB-BASED OUTREACH

The web and the digital environment are the primary communication platforms in the global information diet. In the future, they will increasingly be the stage on which innovation and communication will develop their dialogue. For this reason, it is on the web that the strategic imperatives of the CMCC find a principal way of communicating with the diverse audiences interested in the various activities of the Centre. The period indicated by the strategic plan opens with a new website built specifically to meet this need, to allow users to navigate the CMCC world, to get in touch and easily select the information and pages that best suit their interests.

The site is a gateway to all information relating to the CMCC. It will contain all institutional information, an in-depth portrait of the scientific research (including applications, models, software, scientific publications, and projects), training and education initiatives, dissemination and communication. The editorial production will aim at providing both accessible language on the Centre's activities and an in-depth view of the international debate on climate change and how it will contribute to the future Planet.

Navigation through the information is designed to allow different paths of consultation and interaction that the user can choose according to his interests and the needs of his profile. The site, through a user-friendly and intuitive interface, is therefore proposed as a framework that integrates the strategic imperatives that shape the CMCC in the near future. A mix of content produced by the Centre's scientific research, news, events, and updates on international debate contributes to making the institutional website of the CMCC a global platform on climate change. Social media talso plays an ever-increasing role in the communication strategy of the CMCC.

In a communication environment in which information circulates quickly, social media are the privileged vehicles for the exchange, sharing of information and to stimulate conversations. The potentially global audience and technological convergence (audio, video, text, visuals) enhance the meeting od expertise, interests, and interactions

FORESIGHT

"Foresight is our look into the future." This sentence summarizes the identity and the mission of Foresight, the digital magazine edited and realized by CMCC to tell the world what the future will look like in the coming decades. The magazine hosts contributions from international experts on the diverse interdisciplinary fields. The magazine aims to study how climate change will impact the future world and tell it through a narrative aimed at a broad audience.

The magazine then presents itself as a forum for innovative ideas and solutions to face the challenges of the future, to create a bridge between science and decision-making processes, to experiment languages that, through the integration of texts, images, and infographics, offer in-depth and reliable content.

Foresight is a two-speed platform that has a fast pace of update to keep up with the daily news and current debate. At the same time, it also proposes a different in-depth study, which needs more time to be built, to be used, a longer time that ensures the possibility of dealing with a topic, discussing its future, and looking at the many details of its complexity.

The future is the horizon of the CMCC, as it is also for its magazine, which proposes itself as an observatory on tomorrow, a digital magazine that collects ideas, interviews, articles, art performances, and multimedia to tell the stories of the future.

Foresight

The CMCC observatory
on climate policies and futures

PRESS OFFICE AND MEDIA RELATIONS

While web-based communication provides direct access to target audiences, traditional media continue to play a significant role in the public sphere. The most outstanding and most followed information websites refer to traditional newspapers. The social media profiles of these newspapers continue to be the most followed, while an appearance on TV, in a newspaper, or on a radio show are opportunities for debate and raise attention on the web. Traditional media continue to be essential in stimulating the public debate and bringing attention to complex issues.

The CMCC focuses its commitment on the media to give visibility to its research and communication activities, the events it organizes and participates in, and to offer the media the expertise of its scientists. The CMCC contributions in the media, as well as the in-house production of content, is inspired by the mission of the Centre, by strategic imperatives and by a vision that aims to tell the future and climate change in a science -based manner, far from any excessive dramatization.

EVENTS

Events are opportunities to reach a diverse audience and to use the appropriate language needed in different circumstances. They are also occasions to strengthen the network and the collaborations of the Centre with other outstanding international entities. Over the years, the CMCC has developed capacity in the realization of events with different objectives such as: to raise a topic of particular interest to the public opinion, to highlight the results of specific research, to define the state of a scientific field, evaluate its future perspectives.

The CMCC will focus more effort on organizing events to reach an international audience and contribute to the debate on climate change and offer predictions for the future of the coming decades. For this reason, events related activities will focus not only on face-to-face (conferences, workshops, meetings) but also on the implementation of series of webinars that, thanks to digital platforms, facilitate the participation of an international audience, ensure a good quality of interaction and allow us to store store content for further dissemination on the web.

NETWORKS

CMCC is a member of the global scientific community and therefore is placing great value in scientific cooperation, both at organizational and individual scientist level. Wherever the conditions are favorable emphasis will be put on cooperation for the joint development of models, tools and experiments. The objective is to leverage the relational network to achieve programs and projects and a scale that goes beyond the capability of a single organization. CMCC is committed to participate in global efforts such as the Green Growth Knowledge Platform, a partnership between the Global Green Growth Institute (GGGI), the Organization for Economic Cooperation and Development (OECD), the United Nations Environment Program (UNEP), and the World Bank. CMCC also has a very important role in the IPCC Sixth Assessment Report, with several of its researchers selected as Lead Author, Contributing Author or Review Editor.

The level of cooperation within the European Union is already high due to the participation in the European Research Framework Program projects that results in cooperations at various levels with dozens of research organization, universities in the European region, however, the participation in consortia (NEMO – for ocean models development, CLM community – for development of regional climate model COSMO-CLM, IAMC – Integrated Assessment Modeling Consortium, ENES – for development of Earth System models, ESGF – distributed framework supporting CMIP5 data analysis and dissemination, ICOS – for carbon cycle studies, JPI for climate services and predictions) and the tighter cooperation with selected centers (like the cooperation agreement in place with NCAR – National Center for Atmospheric Research and the collaboration with LLNL – Lawrence Livermore National Laboratory) will be pursued for their greater strategic role.

BUSINESS WORLD

In the coming years, CMCC, will need to develop a dialogue with companies and businesses. A more efficient channel of communication will have to be created to better represent the value of the knowledge created by CMCC and to gather more efficiently the feedback on the needs, trends and direction of the economic sectors.

CMCC will also have to develop a network of cooperation with technology companies and enterprises to accelerate the exploitation of the research results in societal applications. CMCC will search aggressively for suitable partners for development projects, expansion into new sectors, markets and diverse sources of funding.

Our People

Human capital is our greatest strength.
A healthy organization must always be vigilant
for professional development opportunities
to maintain world-class experts.

Diversity and Internationalization

The CMCC workforce of the future will be high quality, productive, and increasingly diverse.

CMCC’s responsibilities as a national center include both advancing science and serving society. Our ability to do both will be enhanced if we diversify our staff to better reflect and leverage the changing demographics of Italy, Europe and the World. Evidence suggests that creativity and problem solving improve with diverse teams. Since both are prerequisites to scientific insight, this suggests that scientific teams will be well served by diversity.

CMCC recognizes that scientific excellence is enhanced by contributions from multiple perspectives. To that end, we affirm our responsibility to attract, retain, and advance individuals from disciplines historically underrepresented in our sciences, forming interdisciplinary harmonious and successful teams .
CMCC is also committed to engage as much as possible the international talent that is available in the science world market. Research can remain vital and fruitful only in a open, networked and international setting.

Research is fertilized by the ingenuity and freshness of young minds. The presence of graduate students and post-doctoral fellows will always be encouraged. Training graduate students is an activity that is positive both for the instructor and for the students as research can gain vigor and creativity from the interaction. CMCC is committed to expand the support for graduate programs and students via the established network of cooperation with universities and teaching institutions.

Staff and Visitor Balance

CMCC will stimulate the institution of a new class of visitors. Scientists from universities, research agencies and laboratories in Italy and Europe should be encouraged to visit CMCC for extended periods (6-12 months) before returning to their organizations. These class of visitors will strengthen our ties with the academic community, allow the development of specific projects and modules, create opportunities for professional growth.

Financial Sustainability

The financial sustainability of CMCC Research is based on the base funding provided by the italian legislation and on the vigorous fund raising effort of all CMCC staff and scientists.

CMCC is also in the list of the research infrastructures of italian national strategic relevance, reaffirming a central role in the italian research system. Leading sources for the Fund Raising are the European research and innovation programs that basically more than double the base funding allowing the full roster of CMCC activities.

CMCC continuously works with the aim to extend its network of cooperation with other Universities and research agencies by participating in the competitive funding process wherever possible, especially by applying for cohesion funds that are targeted to some of the areas where CMCC is present.

CMCC confirms its leading role as provider of technical support to the national Government and Ministries, and also to regional and local institutions, contributing with specialized scientific and technical expertise and information, helping to clarify implications of alternative policies and evaluating effects of different choices and supporting the development of national and local adaptation plans and measures.

European Funding

European research will continue to be funded by Union Programmes, like the upcoming Horizon Europe, the next research and innovation framework programme covering 2021-2027, an ambitious €100 billion research and innovation programme that will succeed the current Framework Program Horizon 2020.

It is crucial to maintain the current high level of participation in these programs that CMCC has shown until now, but it will also be strategic to be able to catch opportunities in the enhanced European Research Council programs and the other segments of Horizon Europe. In fact, the increasing competition will require an increasing diversification into the sources of funding. Transnational cooperation programmes encouraging a sustainable and balanced development of the European territory still represents an interesting source of funding, with the extra value of creating a network of interest with some stakeholders, e.g. local and regional government and agencies. In this regard CMCC will continue to apply and participate in the EU territorial funding programmes (INTERREG) and map all possible funding and cooperation opportunities, thus capitalizing the activities started through already funded projects but also develop new ideas and partnerships so as to set up innovative and frontier projects.

CMCC will also have to carry on its participation in the Copernicus Programme, through the continuous participation in the calls organized via the delegation agreements at ECMWF, MERCATOR OCEAN, ESA /EUMESTAT and other European Copernicus related funding programs. This will ensure the capitalization of the experience acquired by CMCC through its portfolio of active Copernicus services related projects.

The European Institute of Innovation and Technology (EIT) represent a significant opportunity and over the last years CMCC has increased its involvement and participation into the Climate KIC activities and funded programmes.

International Consulting and Tenders

Currently, a small number of CMCC project portfolios are from projects and consultancies funded by International Consulting and tenders (thus not including EU and national funds). Nevertheless high level consultancy work as it has been presented by international development institutions such as the World Bank, regional development banks, UNDP, and so on will present a particularly challenging direction of development especially considering the level of competition and the great effort requested by these very peculiar consulting services which are quite often expected to be performed by consulting companies rather than research institutions. This still represents a great challenge for CMCC and it will be a task for the Climate Service that will have to fully establish its activities.

Indicators

Science

- **S1** — Papers published in refereed Journals (top 20%)
- **S2** — Total Number of Papers Published
- **S3** — Report and Research papers Published
- **S4** — Presentation at Conferences
- **S5** — Data Sets Published
- **S6** — Citations by Division (Web of Science)

Applications

- **A1** — Reanalyses
- **A2** — Forecast systems
- **A3** — Skill of Forecasts
- **A4** — Risk Analysis systems
- **A5** — Monitoring systems
- **A6** — Decision Support Systems
- **A7** — Other Applications

Resources

- **R1** — European Funding
- **R2** — National Funding
- **R3** — Other Funding
- **R4** — Staff number and roles
- **R5** — Visitors
- **R6** — Students
- **R7** — Gender balance
- **R8** — Computational Resources

Dissemination

- **D1** — Analytics of Web Presence
- **D2** — Analytics of Social Media Presence
- **D3** — Seminars and Webinars organized
- **D4** — Events

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