Postdoctoral position: 4 projects on Mediterranean, oceanic, coastal, and island ecosystems

PROJECT 1: Groundwater-Energy-Seawater Dynamics in Coastal Regions under Future Climate Change

GROUP: Global Change Research Group

HOSTING PI: Víctor Vilarrasa Riaño

Ensuring freshwater availability (SDG6), renewable energy generation (SDG7), climate change mitigation (SDG13), and life below water (SGD14) are critical challenges that society has to face. Population growth and coastal urbanization results in increasing freshwater and energy demand. This growth faces challenges for achieving sustainability, carbon neutrality, and smart cities. In particular, Europe's heating/cooling demand accounts for 50% of the energy use. Utilizing renewable heat from the ground represents a unique opportunity to significantly reduce European CO2 emissions. This opportunity has led to the emergence of Low-Enthalpy Geothermal Energy (LEGE) as a promising solution. However, the driving mechanisms that control the performance of LEGE and its interaction with other anthropic uses of the subsurface are poorly understood, resulting in underperformance and potential negative environmental impacts (Figure 1). In particular, aquifer overexploitation in densely populated areas, like coastal cities, combined with variations on aquifer recharge rates and sea level rise resulting from climate change, reduce the natural groundwater flux that discharges into the sea, exacerbating seawater intrusion and affecting marine ecosystems. Strategic LEGE design could help mitigate these issues.

The proposed transversal research line aims at achieving a sustainable use of groundwater and energy resources while minimizing environmental impacts. This interdisciplinary research line will (1) bring new concepts to IMEDEA related to hydrogeology, geochemistry and the interaction of groundwater with seawater and key benthic ecosystems; (2) consolidate synergies among existing research lines at IMEDEA in the fields of marine ecology, geo-energies and oceanography, bringing together researchers from the Global Change Research Group (Núria Marbà, Iris Hendriks, Andrea Antón and the PI) and the Marine Technologies, Operational and Coastal Oceanography Group (Alejandro Orfila); and (3) contribute to meet the goal of the María de Maeztu of creating a unique interdisciplinary research environment in coastal and insular ecosystems. The research will focus on understanding the dynamics of coastal aquifer systems and the disturbances caused by LEGE, to provide knowledge and raise awareness to public authorities and citizens regarding the benefits of sustainable LEGE systems in the challenging mission of decarbonizing society, particularly in insular systems, and restoring marine biodiversity. The innovation lies in strategically designing LEGE systems to ensure the sustainable implementation of LEGE in coastal aquifers, while minimizing adverse effects, and even improving thermal conditions, on discharge

zones. Multidisciplinary investigations will focus on (1) quantifying the advance of seawater intrusion due to LEGE operations in a scenario of overexploitation of coastal aquifers and variation in aquifer recharge rates due to climate change, (2) understanding the role of groundwater discharge in the balance of coastal aquifers for water resources management in islands; and (3) investigating mitigation measures to reverse the increasing trend in the mortality of heat-sensitive marine ecosystems due to marine heatwaves, such as *Posidonia oceanica* meadows, by controlling the altered groundwater discharge temperatures to the sea. By understanding and managing subsurface resources effectively, we aim to strike a balance between meeting energy demands and preserving water resources and biodiversity. Collaboration with local authorities is vital for achieving carbon neutrality, sustainable subsurface resource use, enhancement of monitoring networks, and sustainable urban development. The outcomes of the proposed research line will permit a widespread deployment of sustainable geothermal exploitations to significantly reduce CO2 emissions, while minimizing their effects on the environment.

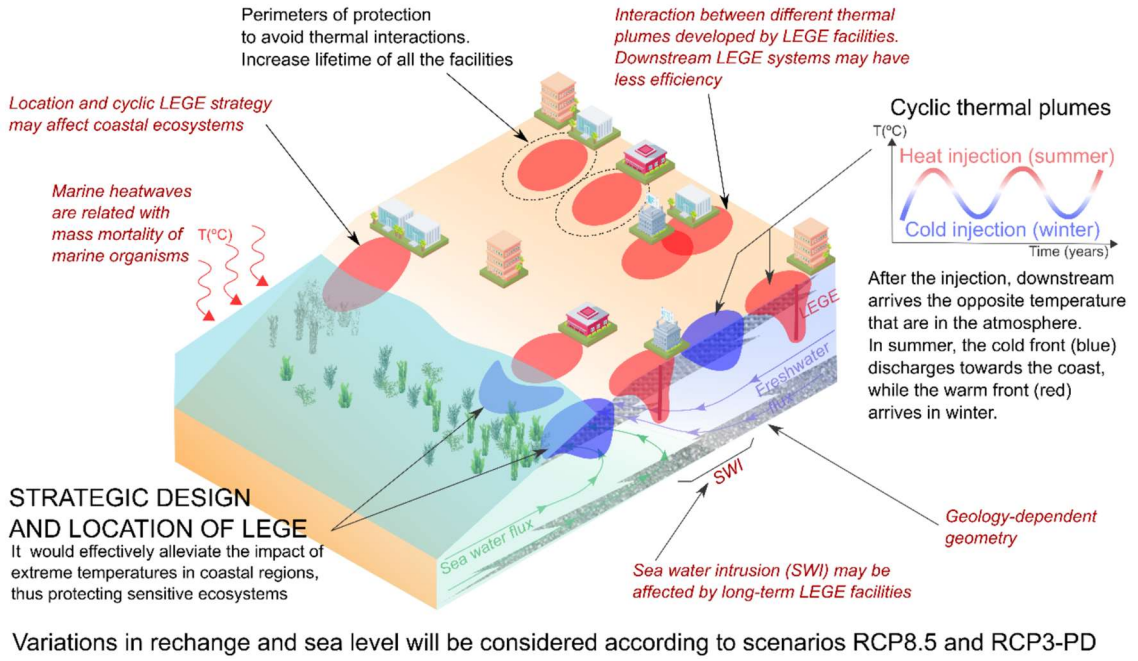


Figure 1. Proposal concept (normal font) and issues for the environment and LEGE efficiency: geology, sea level, freshwater pumps, aquifer recharge, marine heatwaves, LEGE system design/location (*in red italics*).

PROJECT 2: Application of AI techniques for the analysis of extreme climatic episodes in the ocean

GROUP: Marine technologies, operational and coastal oceanography (TMOOC)

HOSTING PI: Alejandro Orfila

The variability of climate patterns and the complexity of the different scales involved in coastal processes, together with the limited availability of in situ observations, make the study of marine dynamics a challenge. In this context, artificial intelligence (AI) offers a novel and exciting approach to study complex dynamical systems where initial conditions and data assimilation to control eventual deviations due to the non-linearity of the governing equations are essential.

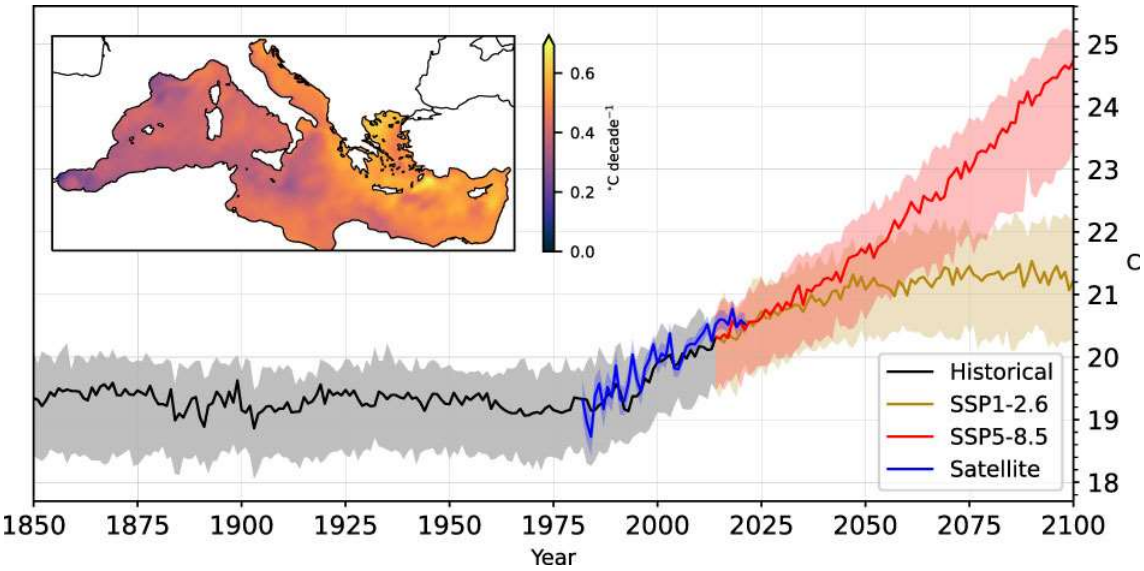
Multidimensional data processing from direct meteo-ocean observations as well as from numerical models allows us to infer hidden patterns and relationships among different variables involved in the dynamics of oceanic and climatic systems. Nowadays, the application of AI techniques is becoming a powerful tool that contributes to the understanding of the links between ocean and atmosphere in coastal areas. This is of paramount importance to analyze for instance climate extremes and marine heatwaves which have special impacts on marine ecosystems (i.e. *P.oceanica*).

AI techniques can provide new insights in the analysis of extreme climatic episodes in the coastal ocean, including the study of extra tropical, heatwaves, and natural oscillations. Some examples of the use of AI include:

- Predictive Modeling and Early Warning Systems: AI can be used to develop advanced predictive models that forecast the onset, intensity, and track of extreme oceanic events. Machine learning algorithms can analyze historical climate data, ocean temperature, pressure, and wind patterns to provide more accurate and timely warnings to coastal regions, helping communities prepare and evacuate if necessary.
- Pattern Recognition: AI can help identify patterns and anomalies in vast datasets related to oceanic and atmospheric conditions. By detecting subtle changes in temperature, salinity, and other parameters, AI can identify the early signs of extreme events, enabling scientists to take preventive measures and improve our understanding of their triggers. Besides AI can be used to identify different species (fish, submerged plants, etc.)
- Oceanic AI algorithms can process this data to monitor changes in sea surface temperature, ocean currents, and chemical composition, which are critical for tracking extreme events and understanding their evolution.
- Climate and ocean Modeling and Simulation: AI can enhance climate and ocean models by improving their accuracy and resolution. Deep learning techniques can be applied to simulate complex ocean-atmosphere interactions more realistically, helping researchers better understand how extreme climatic episodes develop and their long-term impacts.

- Risk Assessment and Mitigation: AI can assess the vulnerability of coastal areas to extreme climatic events by analyzing factors such as topography, population density, infrastructure, and historical data. This information can be used to develop risk mitigation strategies, including coastal defenses and disaster response plans.
- Resource Management: AI can assist in the sustainable management of ocean resources by predicting the impact of extreme events on fisheries, aquaculture, and marine ecosystems. This information can guide policy decisions to protect vulnerable species and maintain food security.
- Data Integration and Visualization: AI can help integrate data from various sources, including satellites, buoys, and sensors, into a unified platform. Advanced visualization techniques can provide decision-makers with clear and actionable insights, making it easier to respond effectively to extreme climatic events.

In summary, AI has the potential to revolutionize our understanding of extreme climatic episodes in the ocean and improve our ability to monitor, predict, and respond to these events. By harnessing AI techniques, we can enhance our resilience to the growing challenges posed by climate change.



Reconstruction using AI of the SST for the Mediterranean Sea using CMIP6 models and satellite data (from Rossello et al., 2023).

This postdoc is intended to be a nexus between the different groups working at IMEDEA since AI techniques can provide answers to the research currently performed at the Institute. Besides, several ongoing projects from the TMOOC Research Group will demand the use of such profile (CLS-SEALEVEL, LAMARCA, Tech2Coast, DETECT, Life-Adapta, FastSWOT). This postdoc also will be in close collaboration with the recently created DataLab providing new developments for the general use of the research developed at the Institute.

PROJECT 3: Bioinformatics and genomic analyses for biodiversity research in coastal environments

GROUP: Ecology and Evolution Group (EEG)

HOSTING PI: Joan Pons

In recent decades, genomics has emerged as one of the most critical fields at the frontiers of science. Currently, even the simplest genomic experiment generates massive datasets that demand advanced computational methods for analysis. The position we propose requires a candidate with advanced expertise in bioinformatics to meet the challenge of processing and interpreting high-throughput genomic information, transforming large amounts of raw data into meaningful scientific results. The proposed multidisciplinary research will span multiple fields, combining the marine ecology and coastal hydrodynamics expertise of the MArine Research in Ecological and Social systems (MARES) group, the molecular and evolutionary background of the Ecology and Evolution Group (EEG), with the genomics and bioinformatics toolset provided by the candidate. The main aim of this proposal is to advance research by effectively managing massive genomic data, extract valuable information, and applying scientific knowledge to improve biodiversity conservation.

The first objective involves studying the molecular mechanisms underlying both plastic (i.e. behavior) and genetic adaptations to challenging environments, using coastal marine fish species as study models. This will be achieved through measurements of gene expression variability via transcriptomic analyses and their relation to epigenetic markers. The role of epigenetics in transcription regulation, which leads to phenotypic plasticity, allowing organisms to adapt to changing conditions, remains largely unexplored in marine environments. Understanding the precise mechanisms that drive individual adaptation and, in turn, population resilience to environmental change, is of most importance in establishing the foundation of healthy and diverse coastal ecosystems facing the challenges of the Anthropocene.

The second objective involves studies at the genomic level on populations under different human pressures. Advanced genomic techniques and specifically-designed bioinformatic tools can help uncover genomic peculiarities of species perfectly adapted to challenging environments. Understanding the current genomic landscape of target model species under different conditions, such as populations affected by trait-selective harvesting induced by fisheries in comparison with populations living within Marine Protected Areas (MPA) can shed light onto the genomic changes resulting from fisheries-induced selection and local adaptation.

The third objective extends the genetic studies at a temporal scale. It is possible to investigate genetic diversity across time and examine extinct genomic landscapes through ancient DNA techniques. This approach would provide a comprehensive perspective on the changes experienced by species over time, allowing us to evaluate

the effects of human disturbances, such as climate change, on genome evolution as well as the effectiveness of conservation efforts in preserving genetic diversity.

This multidisciplinary position requires a candidate with experience in using bioinformatic resources and programing skills to work with high-throughput genomic, epigenomic and transcriptomic data, genomic laboratory skills to tailor generic genomic protocols to resolve particular needs, and a profound understanding of coastal ecology, behavioral biology and evolution. The project proposed here will contribute to a deeper comprehension of coastal biodiversity and the conservation strategies required to protect our precious island's ecosystems, one of the main principles of our institution.

PROJECT 4: Socio-ecological dynamics and connectivity in highly complex ecosystems

GROUP: Marine Research in Ecological and social Systems (MARES)

HOSTING PIs: Silvia de Juan & Hilmar Hinz

This position focuses on exploring intricate connections within complex ecosystems, bridging terrestrial and marine environments, and investigating the socio-economic implications of the globalization of natural resources. Our research initiative transcends geographical boundaries and scales, ranging from Mediterranean insular ecosystems to a planetary scale. The primary goal is to enhance regional and global ecosystem resilience while informing spatial planning approaches that promote both population and ecosystem service connectivity.

Key areas of focus for this research line include:

1. Network Analysis and modelling: You will utilize advanced network analysis and modelling techniques to dissect complex socio-ecological systems. This involves unravelling interactions among species, habitats, environmental factors, and society. Your expertise will be crucial in elucidating the complexities of socio-ecological connections, ranging from species connectivity between highly impacted ecosystems to the provision of ecosystem services to society.

2. Ecosystem Resilience: Investigate the factors contributing to ecosystem resilience in the face of environmental changes and human activities. This includes assessing the role of biodiversity, habitat connectivity, and ecosystem functions in bolstering ecosystem stability.

3. Socio-Economic Implications: Analyse the socio-economic consequences of the globalization of natural resources, with a particular focus on Mediterranean natural resources. You will explore economic dependencies on these resources and assess potential impacts of management strategies.

4. Spatial Planning: Collaborate with spatial planners to inform and develop strategies that enhance population connectivity within ecosystems, the resilience of functions at the seascape, and promote the flow of ecosystem services across diverse landscapes.

This postdoctoral research line offers an opportunity to work on cutting-edge research that addresses pressing global environmental and socio-economic challenges, with a particular focus on Mediterranean insular ecosystems. By joining the IMEDEA, you will play a pivotal role in advancing our understanding of the intricate connections within complex ecosystems and contribute to the development of sustainable management strategies.