From Fluid Dynamics to Coastal Inundation: A Review of Climate Modeling for Sea-Level Rise Assessment

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This presentation traces a path of research in the field of climate modelling which, starting from studies on the dynamics of straits, has led to the development of sophisticated models of the Earth system capable of providing fundamental climate services. The body of work analysed here shows a progression driven by the need to understand the complex interaction between the ocean and the atmosphere, with a constant and particular focus on the Mediterranean Sea. This basin, with its complex geography and semi-enclosed nature, represents an ideal natural laboratory for studying the mechanisms of climate change and developing impact assessment methodologies with broader and more global relevance.

The initial research was rooted in the fundamental physics of fluid dynamics, particularly the processes governing water mass exchanges across the major Mediterranean straits. The first high-resolution three-dimensional modelling of the Strait of Gibraltar, which explicitly included tidal forces for the first time, revealed the dynamics of the average exchange and its variability. The focus on fine-scale physical processes established a fundamental principle that guided all subsequent work in broader climate simulations: the critical importance of model resolution and accurate representation of key physical factors for robust climate projections.

Building on this foundation, research has expanded to encompass the entire Mediterranean basin with the aim of accurately simulating its thermohaline circulation, the main driver governing its physical and biogeochemical properties. This effort has made significant progress through international collaborations such as the Med-CORDEX (Coordinated Regional Climate Downscaling Experiment) initiative. In this context, coupled atmosphere-ocean regional climate models have been developed and validated, demonstrating significant added value in representing key regional climate characteristics compared to coarser global models. These advanced simulations have provided a more holistic view of the Mediterranean as a complex regional Earth system, laying the foundation for a detailed analysis of climate impact.

A central theme of the research was to translate these advanced modelling capabilities into useful information related to one of the most obvious impacts of climate change: sea level rise. The work focused on producing high-resolution projections of sea level rise along the Italian coast for the 21st century. This effort goes beyond simply downscaling global projections. It includes a careful assessment of all factors contributing to the phenomenon, such as the thermal expansion of seawater (steric effects), the influx of fresh water from melting glaciers and ice caps (eustatic effects), and crucial local factors such as vertical ground movements (subsidence). By integrating these components, detailed coastal flooding scenarios have been developed for the most vulnerable Italian coastal plains. These risk assessments provide essential data for adaptation strategies at national and local level. The modelling results provide direct information for assessing coastal vulnerability and the effectiveness of adaptation measures.

The future of climate modelling lies precisely in its ability to provide credible, high-resolution, usable information to guide policymakers and stakeholders in addressing the complex challenges of the climate crisis. This presentation will weave together the different strands of research, offering a coherent perspective on the evolution of climate modelling and its indispensable role in building a more resilient future for our coastal communities.