CIVIL AND ENVIRONMENTAL ENGINEERING

OGS/DIATI - Numerical simulation of pattern formation and complex networks for climate studies

Funded By	Istituto Nazionale di Oceanografia e di Geofisica Sperimentale [P.iva/CF:00055590328] Centro Interdipartimentale SmartData@PoliTO

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Context of the research activity	The PhD will focus on novel pattern formation mechanisms. Deterministic and stochastic processes will be considered, and patterning dynamics will occur both on continuous domains and on complex networks. Particular applications in the fields of of climate, biosphere-climate interactions and vegetation patterns will be studie. To this end it will include the development of simulation software and its application on HPC platforms.

	This PhD will bring together two important and bleeding-edge fields of study: complex networks and pattern formation, which take particular importance in the context of climate change and ecohydrological biosphere-climate interactions in drylands. Complex networks represent a rapidly-growing field of study which finds applications in a broad range of sciences. A solid theory, combining graph theory and statistical physics, has been developed, providing a synthetic and powerful tool to study complex systems with an elevated number of interacting elements and with several applications to real existing networks. A relevant example is represented by the climate networks, where different meteorological series have been transformed into networks to disentangle the global atmospheric dynamics. A field where complex network theory may represent an innovative and useful approach is the study of climate-biosphere interactions and in particular the formation of of ecological and vegetation patterns. The self-organization of vegetation in drylands, when the water resource is limited, is a phenomenon which has triggered great interest in the past 20 years and has been investigated extensively also through the numerical integration of simple spatially extended mathematical models. These studies have identified the main feedback mechanisms which originate the formation of patterns with mechanisms like the well-known Turing mechanism. Vegetation pattern formation takes a particular importance in the context of

Objectives	climate changes, as pattern formation may increase the resilience of vegetation, allow coexistence of multiple species, and can be associated to early warning signals for abrupt shifts. Several open issues remain, in particular related to the role of biosphere-climate feedbacks of patterned vegetation for the climate system at larger scales and to the role of environmental stochastic forcings (e.g., rainfall, fires, temperatures). It has been further shown that these mathematical models for pattern formation in drylands, originally developed for the study of regular patterns, are also capable under a range of conditions to explain the formation of scale-free vegetation distributions. In these cases, the role of long-range interactions and of global competition for the limited water resource take an important role but the identification of specific mechanisms to understand natural vegetation distributions with a broad patch-size distribution is still lacking. This research work will investigate in particular the development of a complex network approach in the context of pattern formation, including the topic of patterns on networks. A particular application will be the use of this tool to better understand resilience of patterns to external forcing changes, particularly in scenarios of climate change and a better understanding of scale-free or broad vegetation patch distributions. This will require the development of innovative simulation software, using advanced and performant numerical methods, possibly including machine-learning approaches. The resulting codes will be used to perform an extensive parameter-space exploration by numerical simulation on HPC platforms. The use of GPUs/accelerators to increase performance will be explored in a later phase of the thesis. This PhD will be performed with cofunding from OGS in the framework of the NextGenerationEU - PNRR project “Terabit network for Research and Academic Big data in ITaly” (TeRABIT) and with cofunding from SmartData@PoliTO.

Skills and competencies for the development of the activity	The Ph.D. candidate must have a background in physics, environmental engineering, earth system science, or similar, and a good level of written and spoken English. Useful competencies include statistics, mathematical methods, numerical methods, physics of complex systems. Programming skills are required, preferably in one of the following languages: Python, R, Julia, Matlab or others.