**MELTED - MachinE Learning for arcTic ice prEDiction**

## Project Synopsis

The Arctic region plays a vital role in the global climate system, it is strongly affected by climate change, and in turn one of its drivers. The Arctic is warming four times faster than the global average, transitioning into an entirely different climate than a few decades ago (Legg, 2021). Satellite data reveal that the September sea ice extent declined of ~13% per decade since 1979 causing major changes in the oceanic heat flux. Changes in the Arctic sea ice impact extreme weather and climate events beyond the Arctic region, favouring extreme Northern Hemisphere winters (Kretschmer et al., 2016) or wetter European summers (Screen, 2013). Arctic changes have a substantial socio-economical relevance (e.g. indigenous communities, shipping and tourism, fisheries), as well as a geopolitical dimension, in view of possible shipping routes and natural resources exploitation. Understanding the causes of these changes is thus of paramount importance yet substantial gaps still exist. Moreover, numerous studies have demonstrated the limitations of current-generation climate models in accurately representing essential aspects of polar climates, such as Arctic sea ice loss (Wang et al., 2016) or water mass changes (Ilicak et al., 2016).
Arctic processes have been traditionally modelled following physics-based frameworks that rely on theoretical knowledge of the evolution laws and parametrization of the unresolved scales. High computational requirements and limited knowledge of several physical processes constrain the models' skill. Nowadays, increased computational power and advances in statistical modelling and machine learning (ML) offers unprecedented opportunities for improving our ability to model Arctic processes. Such tools can be used to discover complex patterns hidden in the data and integrated with physics-based models, in hybrid configurations.
MELTED's goal is to improve our understanding of ice-related phenomena in the Arctic region by integrating physics-based models with ML to build more skilful forecasts over different spatio-temporal scales. MELTED will collect and analyse datasets of the Arctic region. It will then proceed along two research lines shaped along the issues of "interpretability" and "data sparseness". We will use interpretable ML to retrieve hidden physical processes from raw data to
unveil causal links between variables that are misrepresented or absent in current physical models. We will combat data sparseness by softly integrating data assimilation with ML to build hybrid physical and data-driven models making the most out of both to better characterize and predict sea-ice evolution.

## Work plan

The research assistant will be based at the Department of Physics of the University of Bologna. She/He will work on MELTED WP3 that is aimed at developing a hybrid DA-ML framework, with the ML model stacked on top of the DA system (Brajard et al., 2021). DA and ML are part of an iterative process: DA is used with the surrogate model to estimate the system's state from the observations, then ML estimates the

surrogate model from the analysis (estimated) state. The postholder will work in experimental scenarios of increasing complexity and computational demand. Starting from two test-bed low-dimensional models of respectively dynamic-thermodynamic geofluid conversion and vertical thermodynamic processes in the sea ice we will then consider estimating the model error in the state-of-the-art numerical representation of the ocean and sea-ice system, based on the NEMO platform (Madec and NEMO System Team, 2022). We will use regional and global ocean/sea-ice reanalysis. We will consider using the reanalysis increments to train an ML algorithm to estimate the model error in the sea-ice model used in the NEMO ORAs configuration.

## Project Cooperation and Network

The MELTED research team is a multidisciplinary working group involving expertise on different, yet complimentary, domains, ranging from ocean and sea ice modelling, through data assimilation and systems analysis, to artificial intelligence and machine learning. The team is composed of research staff from the Department of Electronics, Information, and Bioengineering (Politecnico di Milano), the Department of Physics and Astronomy (Università di Bologna; DIFA-UNIBO) and the Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC). MELTED will also rely on a consolidated network of international scientific collaborators. In particular, the research in WP3 related to the current vacancy will be conducted in liaison with and with Dr Laurent Bertino and Dr Julien Brajard at NERSC (Norway) and Prof Marc Bocquet at ENPC (France). The postholder will have the opportunity to carry out research visits at their institutions. The activities in MELTED will also be mirrored and put in connection with those of the large international research effort SASIP (https://sasip-climate.github.io/) co-directed by DIFA-UNIBO. MELTED will also benefit from the methodologies and tools developed in the H2020 CLINT (Climate Intelligence) project coordinated by POLIMI and focused on the development of innovative ML tools to enhance climate science and modelling.