A Digital Twin for Climate Extremes using Artificial Intelligence

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***Abstract*—A novel approach and methodology is developed to detect and characterize the changes in climate extreme events using Artificial Intelligence. These machine learning techniques, especially neural networks, can process large climate simulation ensembles better than traditional statistical methods. They therefore better assess uncertainties associated with the various projected IPCC (Intergovernmental Panel on Climate Change) scenarios and climate assessments, in a Digital Twin environment. The tool will enable end users to perform on-demand what-if scenarios in order to better evaluate the impact of climate change on several real-world applications in specific regions to better adapt and prepare the society.**

***Index Terms*—climate change, climate extreme events, impacts, machine learning, deep neural networks, variational autoencoders, geospatial data, climate, climate crisis, adaptation, artificial intelligence**

I. Introduction

Climate change related extreme events are happening all around the world today. It is important to better assess the change of characteristics of those extreme events in the upcoming future climate. Several characteristics are important: frequency of occurrence, intensity, spatial extent, duration. In order to be useful, a large number of climate simulations and scenarios must be analyzed to properly assess the different types of uncertainties. Using classical data analysis, it can be overwhelming and very time consuming to perform such an analysis. It is proposed to use Artificial Intelligence (AI) methods in order to speed up the analysis and have a greater performance, unlocking the use of large climate ensembles. This will also enable users to perform on-demand data analysis, and to evaluate what-if scenarios, in a Digital Twin (DT) environment that will be shared among several scientific domains.

Using AI methodologies is a novel approach in climate extreme events detection, and the literature on this subject is very recent and exploratory. A few very recent papers are of interest, because research in this domain is evolving very fast with the methods' developments and papers get outdated very quickly. Reference [1] is itself a very good recent review of the state of the art in the analysis, characterization, prediction and attribution of extreme atmospheric events with machine learning (ML). It has been decided in the current context to explore first the use of a Variational Auto-Encoder (VAE) method for the current work. But other methods are also being evaluated, for example classification methods.

The development and implementation context here is in a DT environment, within the Horizon Europe interTwin project, that will be shared among several applications. It will provide functions and methods both in the climate change scientific domain and also in other scientific domains. Those core DT engine (DTE) libraries will be generic in order to provide useful capabilities to each specific DT.

II. Designing the method: basic principles

The goal is to provide end users an interactive on-demand DT to assess the change of characteristics of generic extreme events in the future climate, to evaluate impacts for specific applications. Several climate extremes are standardized through climate indices and indicators by the international community. Examples are climate indices definitions from ECA&D (European Climate Assessment & Dataset), the Expert Team on Sector-Specific Climate Indices (ET-SCI) from the WOrld Meteorological Organization (WMO). Several implementations of those climate indices exists, such as icclim (https://github.com/cerfacs-globc/icclim) in python.

Since this is a novel approach, simple climate indices are selected to first design the method, such as "Number of days when Maximum Temperature >90th percentile (tx90p)" or "Days with cumulated precipitation >95th percentile of daily amounts (rr90)". Those can be calculated analytically using icclim, but it is not suitable as a method to analyze very large ensembles of climate simulations. However it is used as a mean of verification for the novel method based on VAE.

The ML-based method is using VAE, and the reader is encouraged to read two excellent references on ML-based methods for climate extremes: [2] and [3] (the latter being in french). The basic principles of this approach is that the 2D fields are assimilated as images (2-bits or 64-bits) and are convoluted into a space with a smaller dimensions (the latent space) and then reconstructed. Errors in reconstructions are anomalies, and are linked to the extreme values.

The method being developed right now, details are not yet available at this time of writing, but a first implementation will be available in October 2023 and will be described in a

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project report. The method implementation will be available on github as xtclim (https://github.com/cerfacs-globc/xtclim).

III. Applications

The method xtclim will be used in the context of the interTwin project, using CMIP6 datasets (Coupled Model Intercomparison Project Phase 6) as input. Data of several global climate models as well as greenhouse gas emission scenarios can be analyzed, depending on users' needs and requests. This approach can also be used to analyze higher resolution climate simulations, such as output from Regional Climate Models (RCM), bias-corrected or spatially downscaled datasets.

IV. Poster presentation

The poster will present the main approach, the Digital Twins context, and the methodology as well as a discussion why this specific methodology was chosen. An evaluation of its performance and limitations will also be shown, and preliminary results will be discussed.

References

[1] S. Salcedo-Sanz, et al. "Analysis, characterization, prediction and attribution of extreme atmospheric events with machine learning: a review." arXiv preprint arXiv:2207.07580, 2022.

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