Earth Sciences Department
Barcelona Supercomputing Center
Centro Nacional de Supercomputación
Climate Change AI
NEURAL INFORMATION PROCESSING SYSTEMS

A modular framework to run AI-based models from high-resolution climate projections

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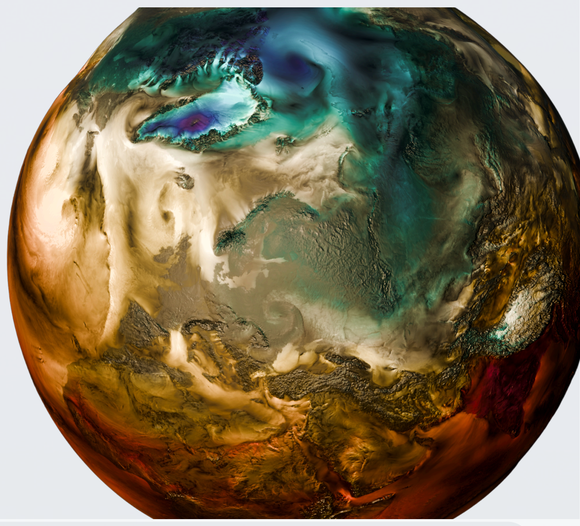


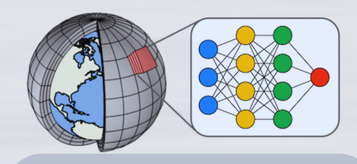
The challenge

- High-resolution climate simulations are key for understanding local climate impacts.
- Running large ensembles of physics-based simulations for uncertainty quantification is computationally expensive on HPC systems.
- These simulations are produced at 5 km resolution with specific grids, formats, and variable sets. The transformation of simulation outputs into formats compatible with AI models is required.
- Current **integration efforts between AI-based models and high-resolution simulations** are ad hoc, model-specific, and hard to reproduce, slowing research progress.

Proposed solution

- Build a framework to **systematically run AI-based climate models from heterogeneous data sources.**
- The framework builds on **established workflow practices** in climate science and leverages **containerization** for portability and reproducibility.
- It standardizes **data preparation**, automates **model execution**, and integrates **post-processing** and evaluation tools.
- The design is **modular** and extensible, allowing for the easy integration of **new models and datasets** while adhering to **FAIR data principles**.
- Researchers can **focus on scientific experiments rather than technical implementation** or HPC configuration.

Data-driven models used



NeuralGCM

ECMWF AIFS

Combines a differentiable solver for atmospheric dynamics with machine-learning components.

Based on a graph neural network (GNN) encoder and decoder, and a sliding window transformer processor.

Workflow architecture

Singularity containers to deploy and run the data-driven models

Running with Autosubmit as workflow manager in MareNostrum5

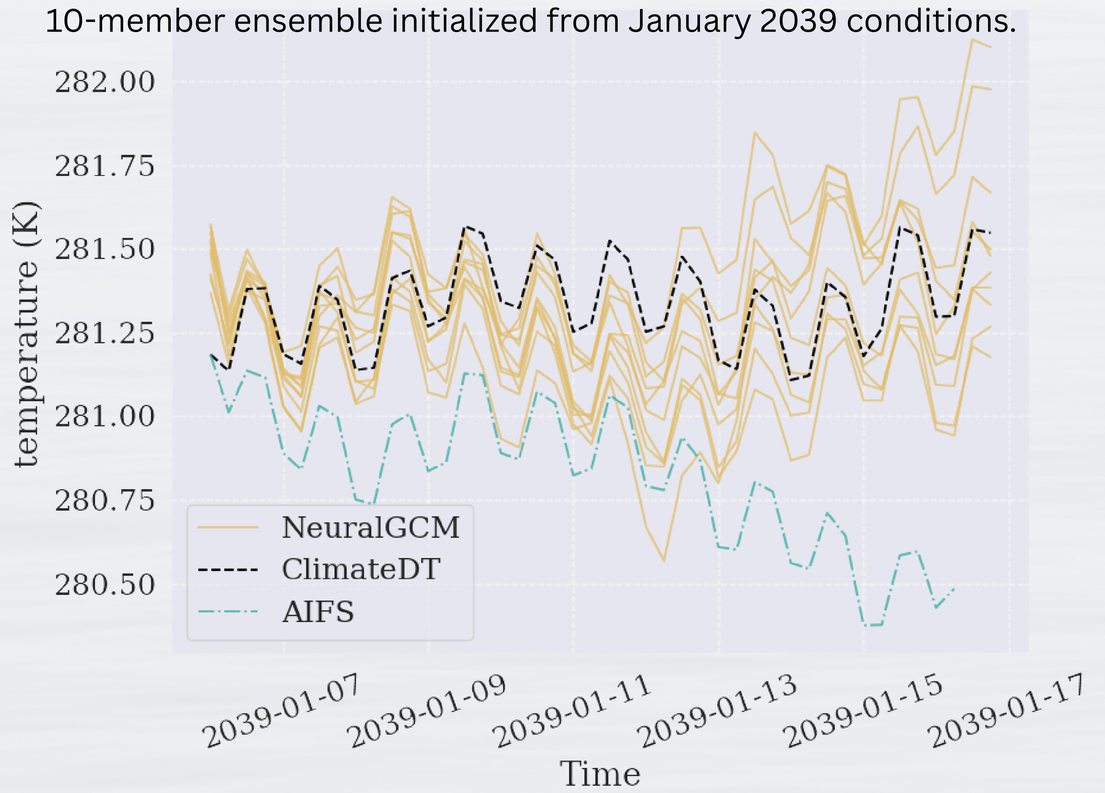
Goals

- Enable **reproducible** and **scalable** execution of **AI-based climate models across diverse datasets and HPC systems**.
- Support systematic experiments on:
  - Uncertainty quantification in high-resolution simulations.
  - Fairness assessment of AI-based forecasts across global regions.
- Provide a foundation for **operational adoption of AI models in climate workflows**.

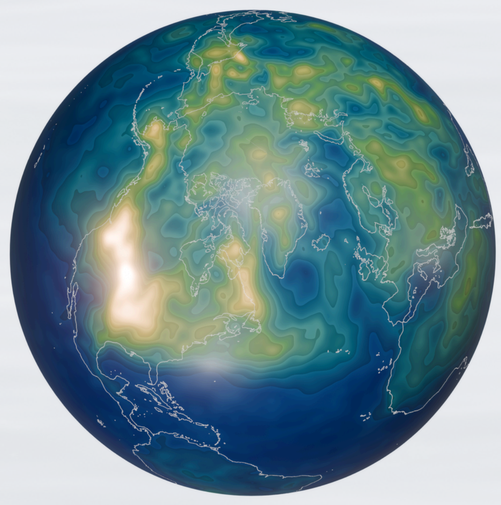
Preliminary results

- Implemented for AIFS and NeuralGCM, using initial conditions from the Destination Earth Climate Digital Twin and ERA5.
- Experiments: 10-day forecasts starting from January 2039, producing outputs every 6 hours.
- Results show:
  - AIFS drifts to a colder state, resembling its training regime.
  - NeuralGCM ensemble members follow trajectories closer to the physics-based Climate Digital Twin.
- Demonstrates that **the framework can reproduce and extend state-of-the-art experiments with minimal technical overhead.**

Global mean temperature at 1000 hPa over 10 days comparing ClimateDT reference data (physics-based), AIFS deterministic forecast, and NeuralGCM 10-member ensemble initialized from January 2039 conditions.



Average standard deviation of temperature at 1000 hPa from NeuralGCM daily-initialized ensembles for January 2039



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