

**CINECA**

**MLWP**

**AI applied to meteorological research**

**Matteo Angelinelli**

30 May 2024

# NOT-FOR-PROFIT CONSORTIUM

SINCE 1969 CINECA SUPPORTS THE ITALIAN ACADEMIC SYSTEM



## 112 MEMBERS

2 Ministries, 69 Universities, 41 Academic and Research Institutions



## 5 OFFICES

Bologna, Milan, Rome, Naples, Chieti



## ≈ 1000

Employees



## ≈ 110 MLN €

Yearly Revenue in 2021



# 50+ YEARS OF IT SERVICES

1969

## SUPERCOMPUTING



4 founding Universities  
Bologna, Florence,  
Padua, Venice

IT Systems for the  
Italian Ministry of  
Universities and  
Research



## MINISTRIES

'80

'90

## UNIVERSITIES



IT Systems for the  
Italian Academic  
System

Technological Transfer  
to Healthcare  
Public Administration  
Industry



## PA & INDUSTRY

2000

2020

## HPC PRE-EXASCALE



Artificial Intelligence  
Big Data  
Quantum Computing



# HPC DATA ANALYTICS TEAM



## OUR GOALS

**Support researchers, data scientists and organisations** in using high-performance computing resources to advance data analysis and artificial intelligence projects.



## OUR SERVICES

Access to computing infrastructure  
Access to data  
**PoC development**  
**Consulting**  
Training



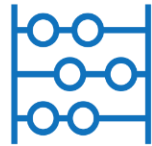
## OUR DOMAINS

Industry 4.0  
**Meteorology and Climate**  
Cultural Heritage  
Agrifood  
Health and Society

# AI APPLIED TO METEOROLOGICAL RESEARCH

- ✓ **FROM NWP TO MLWP:** AI applied to weather forecasting
- ✓ **THE BASICS OF AI:** data and computing power
- ✓ **THE DOWNSCALING PROBLEM:** from global to local forecasts
- ✓ **WEATHER FORECASTING:** multi-framework approaches for Italian MLWP models
- ✓ **WHAT'S NEXT?:** from forecast to social impact

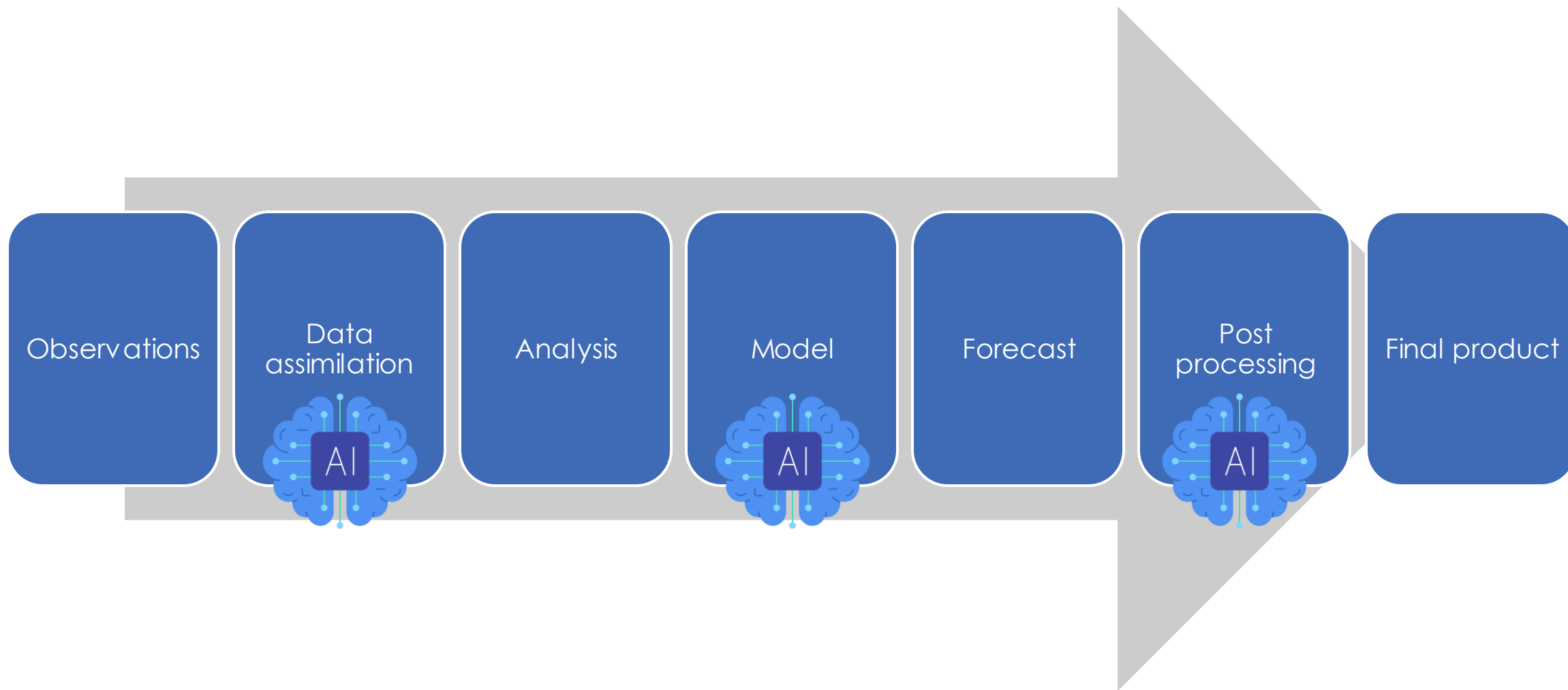
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# FROM NWP TO MLWP

AI applied to weather forecasting

# FROM NWP TO MLWP



# FROM NWP TO MLWP

Training Data	Approach	Inference input	Lead time	Resolution	Example
Observations	ML	Observations	Nowcasting (0-6 hrs)	Regional (sub-km/km)	GPTCast, LDCast
Observations Analysis	ML	Observations Analysis	Short Range (12-24 hrs)	Regional (km)	MetNet
Re-Analysis (ERA5)	ML	Analysis	Medium Range (10-15 days)	Global (0.25°)	GraphCast, Pangu, FourCast
Re-Analysis (ERA5)	ML Physics	Analysis	Medium Range (10-15 days) Long Range (months/years)	Global (0.7°)	NeuralGCM



# FROM NWP TO MLWP

## PROS

Accuracy

Forecast computational resources

Forecast computational time

Open-source

## CONS

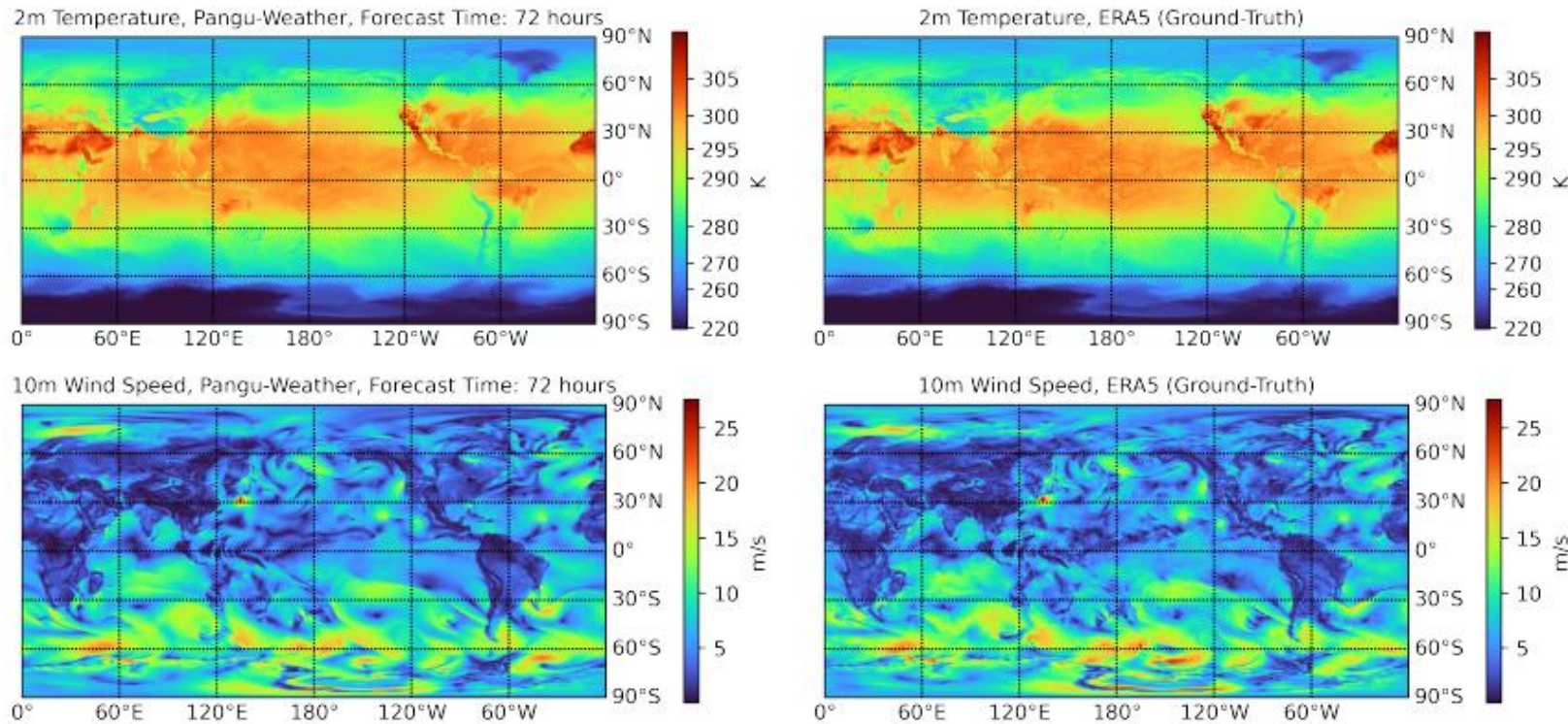
Strongly dependent on the re-analysis quality

Resolution determined by the training dataset

Rain forecast

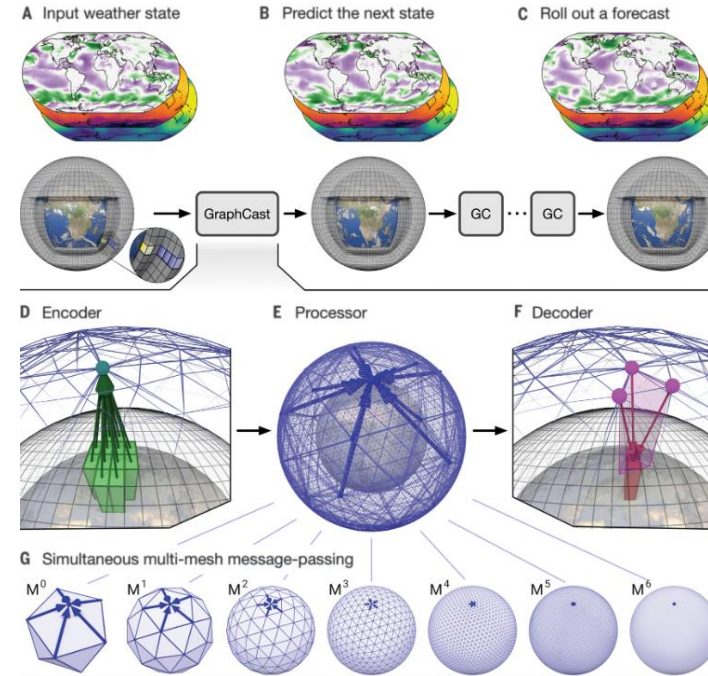
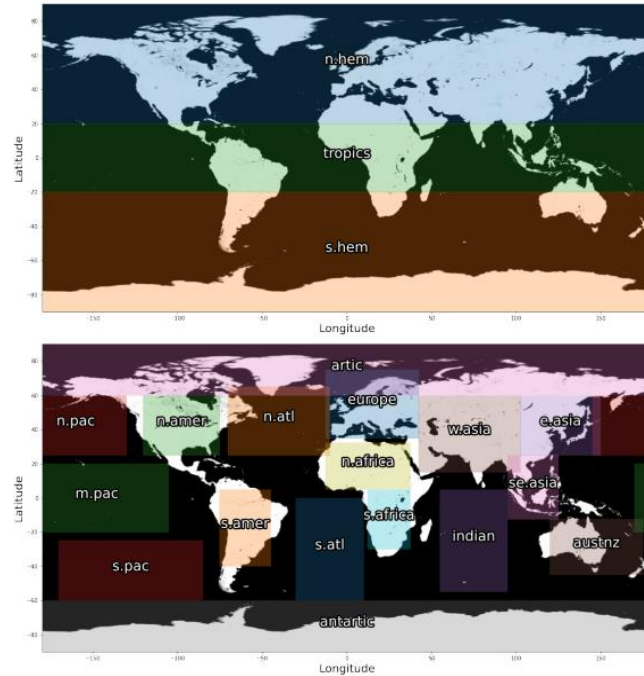
Extreme events

# PANGU-WEATHER



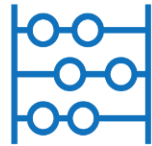
Developed by HUAWEI, PanguWeather uses a **Swin transformer** and a new algorithm based on the 3D Earth-specific transformer (3DEST), an encoder-decoder architecture derived from a variant of a vision transformer. This model features an Earth-specific positional bias that replicates the physical structure of the Earth. The input consists of 4 surface variables and 5 at 13 altitude levels, while the output includes 4 models with different lead times (1, 3, 6, and 24 hours). Training this model requires **approximately 16 days** on a cluster of 192 Nvidia Tesla-V100 GPUs.

# GRAPHCAST



Developed by DeepMind (Google), this model is based on **graph representation**: the Graph Neural Network (GNN). It employs an encoder-process-decoder architecture with 36.7 million parameters. GNNs, coupled with fluids, have demonstrated remarkable capabilities in learning the dynamics of systems described by partial differential equations. The input comprises 5 surface variables, 6 at 37 altitude levels, observed every 6 hours. The output consists of a family of models utilizing two subsequent states of the atmosphere to generate forecasts. Training this model takes **approximately 4 weeks** on a cluster of 32 TPUs.

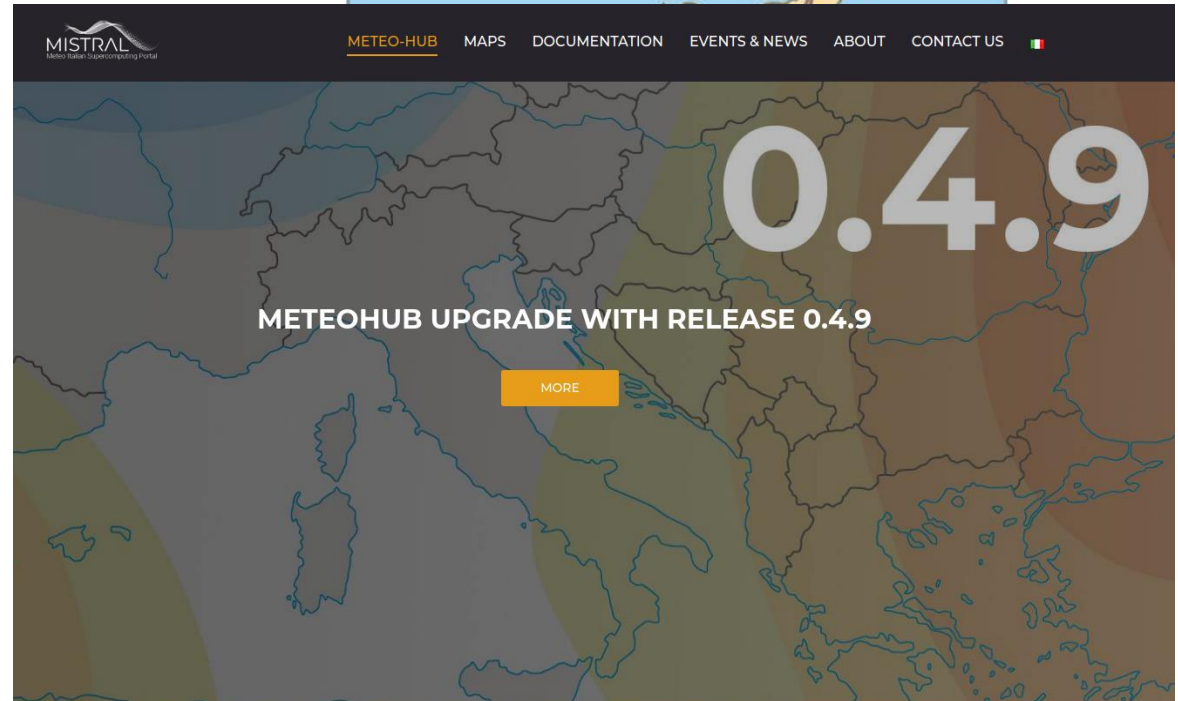
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# THE BASICS OF AI

Data and computing power

The objective of the MISTRAL portal is to **facilitate and promote the re-use of datasets by the meteorological community and related communities to provide value-added services using HPC resources**, thus creating new business opportunities. The data will be available as gridded fields, probabilistic products (such as rainfall forecasts for flash flood prediction) or point time series derived from the Italian operational forecast modelling chain and post-processed fields (such as thunderstorm probability).



MISTRAL  
Meteo Italian Supercomputing Portal

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# 0.4.9

METEOHUB UPGRADE WITH RELEASE 0.4.9

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# Highlander

High performance computing  
to support smart land services

Through the use of high performance computing, **Highlander** will make it possible to process data for climate forecasting and reducing the risks associated with climate change, for more intelligent and sustainable management of natural resources and the territory.

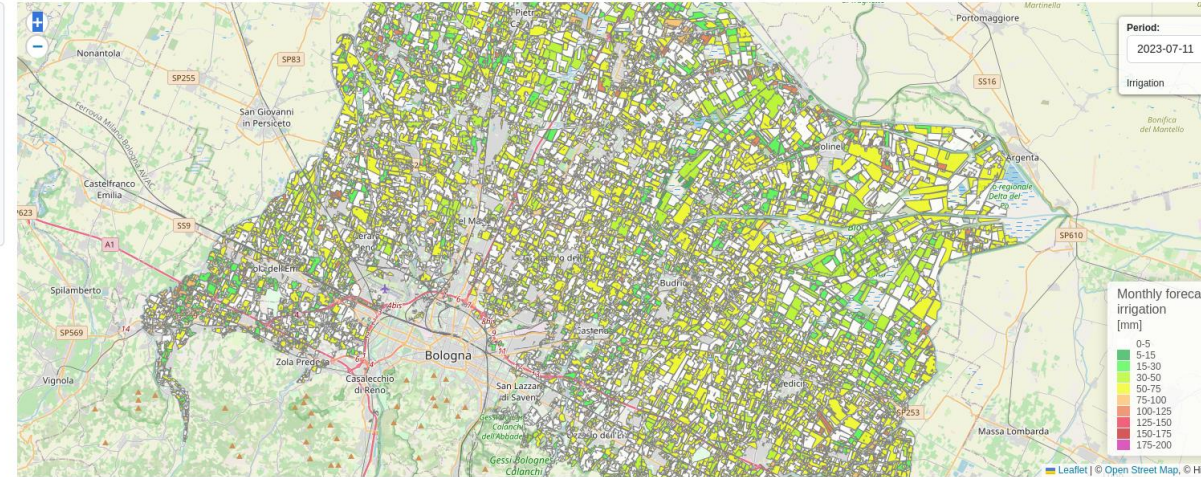
## Sub-seasonal irrigation forecasts

Crop water requirements forecast

AREA:  
Renana

LAYER:  
Irrigation

PERCENTILE:  
50



## Datasets

Type to filter the dataset name...



### Downscaling of ERA5 @2.2 km over Italy

⌘ This work presents a new dataset for recent climate developed within the Highlander project by dynamically downscaling ERA5 reanalysis, originally available at ≈31 km horizontal resolution, to ≈2.2 km resolution (i.e., convection permitting scale). Dynamical downscaling was applied through Regional Climate Model (RCM) COSMO5\_0\_CLM9 and INTZLM 2.06. The temporal resolution of output is hourly (like for ERA5). Runs cover the whole Italian territory to provide a very detailed (in terms of space-time resolution) and comprehensive (in terms of meteorological fields) dataset of climatological data for at least the **last 42 years (01/1981-12/2022)**. These types of datasets can be used for (applied) research and downstream services (e.g., for decision support systems).

#### References

Raffa, M., Reder, A., Marras, G.F., Mancini, M., Scipione, G., Santini, M., Mercogliano, P. VHR-REA\_IT Dataset : Very High Resolution Dynamical Downscaling of ERA5 Reanalysis over Italy by COSMO-CLM. Data 2021, 6, 88. <https://doi.org/10.3390/data6080088>



### Dynamical Downscaling with COSMO-CLM of historical (1981/2005) and future climate (2006/2070) projections

⌘ This climate projection dataset, named "VHR-PRO\_IT" and produced within the Highlander project, has a horizontal resolution of ≈ 2.2 km resolution (i.e., Convection Permitting Scale) thanks to dynamical downscaling with CMCC-CM global model over the period 1981-2070, adopting the IPCC historical plus RCP8.5 scenario. An intermediate dynamical downscaling has been conducted through the configuration of regional climate model (RCM) COSMO-CLM at ≈ 8 km over Italy, previously provided by Fondazione CMCC. The temporal resolution of outputs is hourly. Runs cover the whole Italian territory (and neighbouring areas according to the necessary computation boundary), so to provide a very detailed (in terms of space-time resolution) and comprehensive (in terms of meteorological fields) dataset of projected climatological data for at least 90 years (01/1981-12/2070). All output variables (reported in the following table) are on single levels except soil water content that is provided for 7 soil levels.

#### References

Raffa, M., & Mercogliano, P. (2022). Dynamical Downscaling with COSMO-CLM of historical (1989/2005) and future climate (2006/2050) data under scenario RCP8.5 at 2.2 km over Italy [Data set]. Fondazione CMCC. <https://doi.org/10.25424/CMCC-J90A-SP12> Paper in preparation.



### Downscaling of ERA5 using ECMWF's ecPoint post-processing

⌘ ERA5 ecPoint products are the first ever (probabilistic) global reanalysis products for point scales. They are based on the ECMWF ERA5 reanalysis, run at ≈0.3° horizontal resolution (31km), but downscaled to point scale using ecPoint post-processing. The products comprise 24-h rainfall and 24-h minimum and maximum 2m temperature, and are probabilistic in nature, being stored as percentiles (1, 2, ..., 99) for each grid box. Downscaling means that values stored are fully compatible with in-situ measurements (i.e. from rain gauges and thermometers), whilst the raw ERA5 output refers instead to average values for the modelled grid scale - i.e. over regions measuring about 31km by 31km. ecPoint is a new and innovative statistical post-processing technique specifically developed by ECMWF to downscale relatively low-resolution numerical model output (e.g. from global models). All ecPoint products explicitly incorporate the expected sub-grid variability, and bias correction for gridbox means (which both vary according to grid-box weather types).

#### References

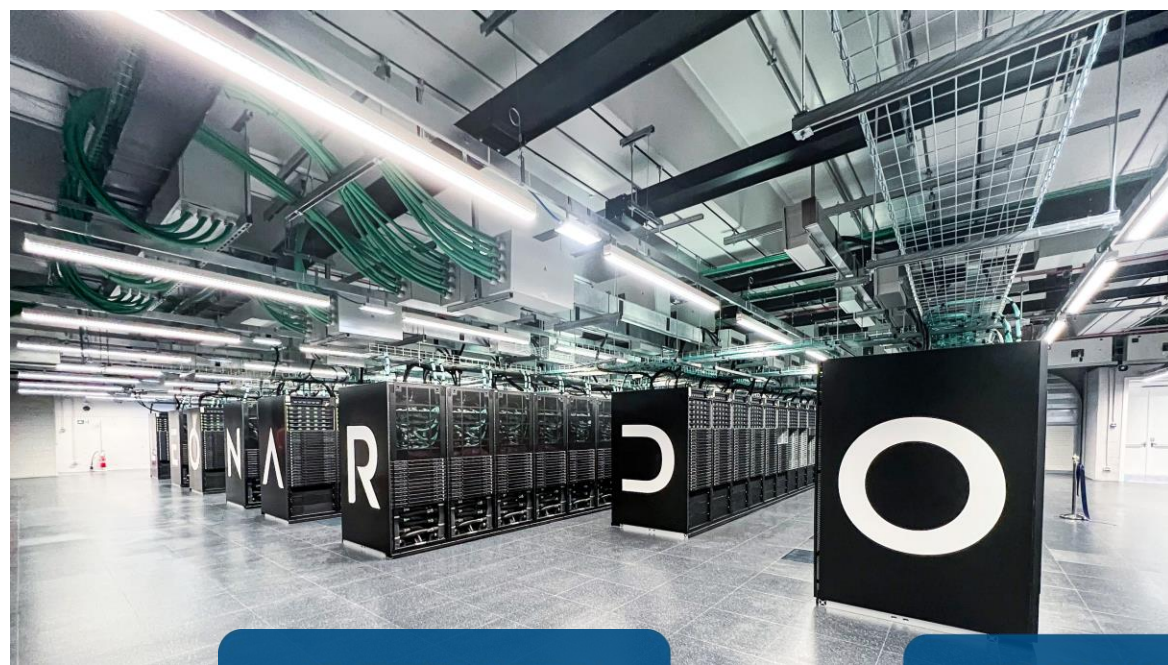
Hewson, T.D., Pilosu, F.M. A low-cost post-processing technique improves weather forecasts around the world. Commun Earth Environ 2, 132 (2021). <https://doi.org/10.1038/s43247-021-00185-9>



### Soil Erosion Indicators (1991-2050) @2.2 km over Italy

Soil erosion

⌘ Extreme climate conditions affect the maintenance of soil functions, especially in areas particularly subject to rainfall-induced erosion. The case study on Soil Erosion in HIGHLANDER is based on a consolidated empirical model (RUSLE) to generate assessment (1991-2020) and projections (2021-2050) about the rainfall erosivity and potential loss of soil on both forest and agricultural lands at very high spatial resolution (@2km for rainfall erosivity and 250 m for soil loss). Such a dataset with very high resolution at national scale will support in identifying areas particularly at risk under changes in climate variability and extreme events, so to formulate strategies to reduce soil erosion through appropriate management of forests and agricultural fields, also in terms of working practices and soil protection measures.

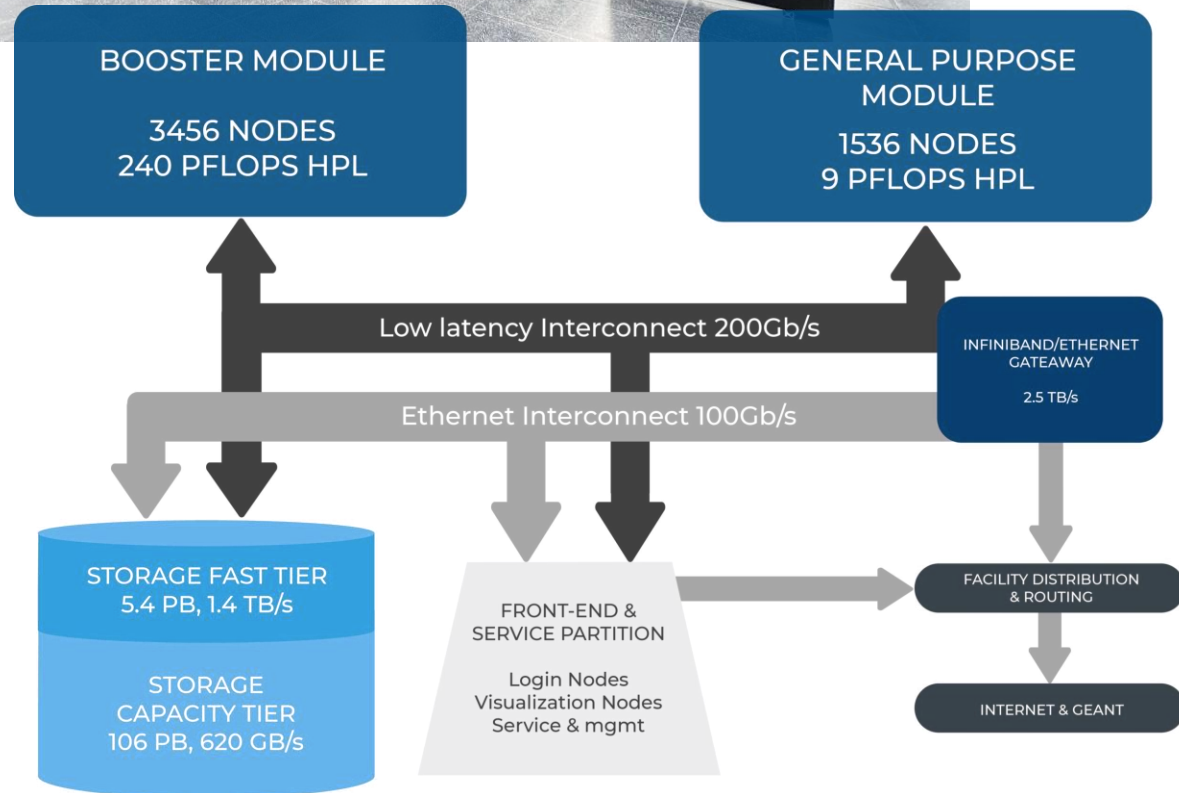


### Booster module

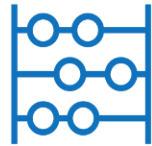
Nodes: 3456  
 Processors: Intel Xeon 8358 32 cores,  
 2.6 GHz  
 Cores: 110592 (32 cores/node)  
**Accelerators:** 4XNvidia custom Ampere GPU  
 64GB HBM2  
 RAM: (8×64) GB DDR4 3200 MHz

### General purpose module

Nodes: 1536  
 Processors: Intel Sapphire Rapids 2×56 cores, 4.8 GHz  
**Cores:** 172032 (112 cores/node)  
 RAM: (48×32) GB DDR5 4800 MHz



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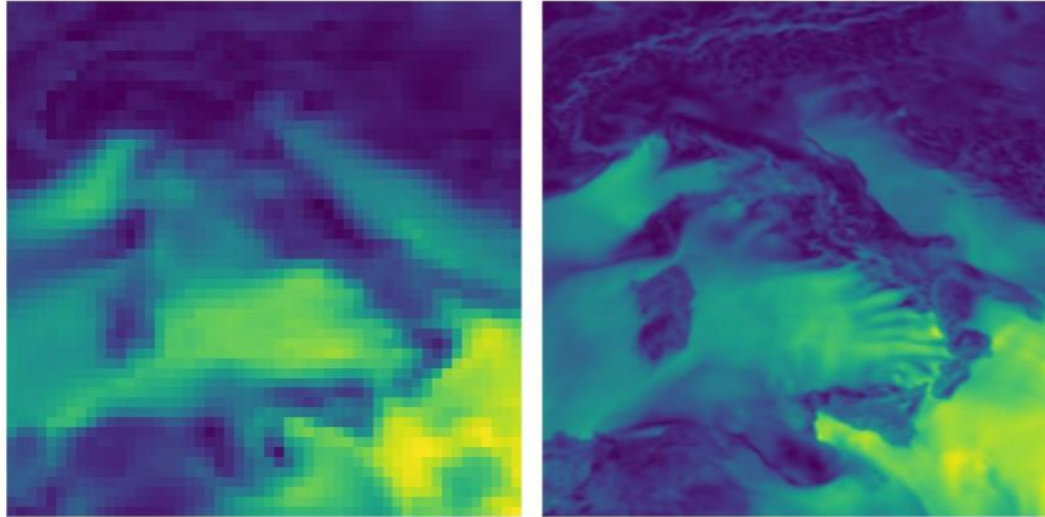


# THE DOWNSCALING PROBLEM

From global to local forecasts



# DOWNSCALING: FROM GLOBAL TO LOCAL FORECAST



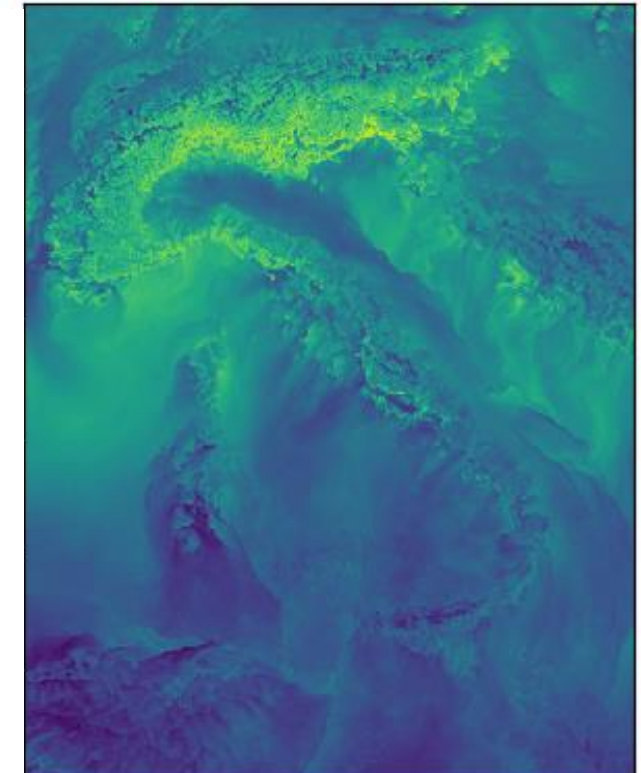
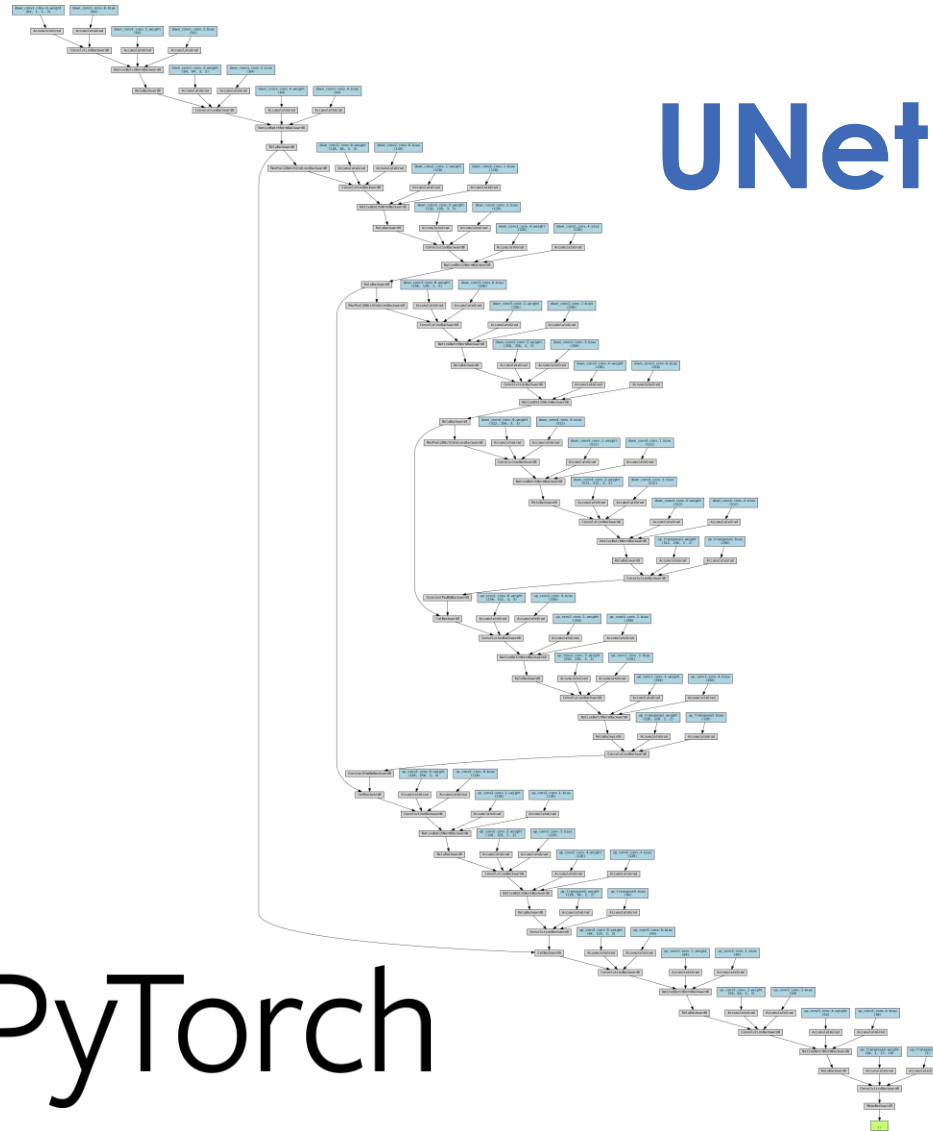
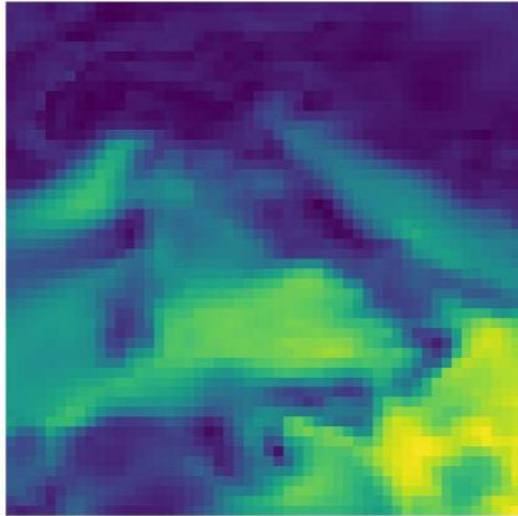
ERA5 ~ 31km

CERRA ~ 5.5km

Downscaling in meteorology is a technique used to obtain **high-resolution weather forecasts** for specific areas by refining information from global or regional-scale weather models. Global weather models often have relatively low resolutions, typically spanning tens of kilometers, which may not capture local or detailed weather phenomena adequately. Downscaling involves employing high-resolution weather models to provide more detailed forecasts for smaller geographical areas. These models refine input data from global or regional models to produce **more precise predictions for small geographic areas**.

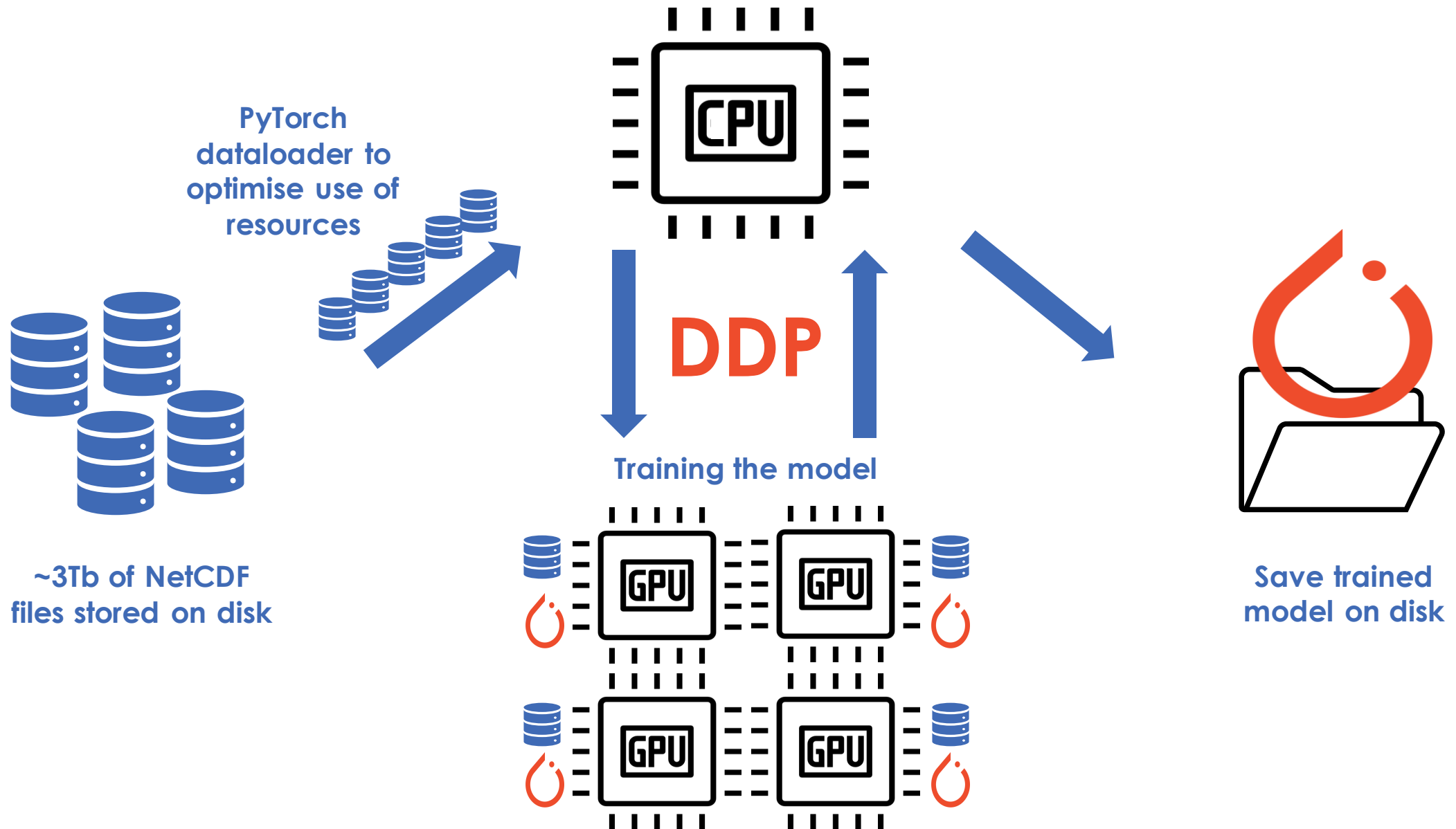
Downscaling aims to enhance the accuracy and detail of weather forecasts for specific regions or areas of interest.

# OUR DEEP LEARNING APPROACH FOR DOWNSCALING

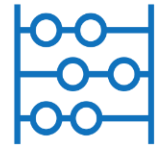


 PyTorch

# HOW WE USED PYTORCH FOR DOWNSCALING



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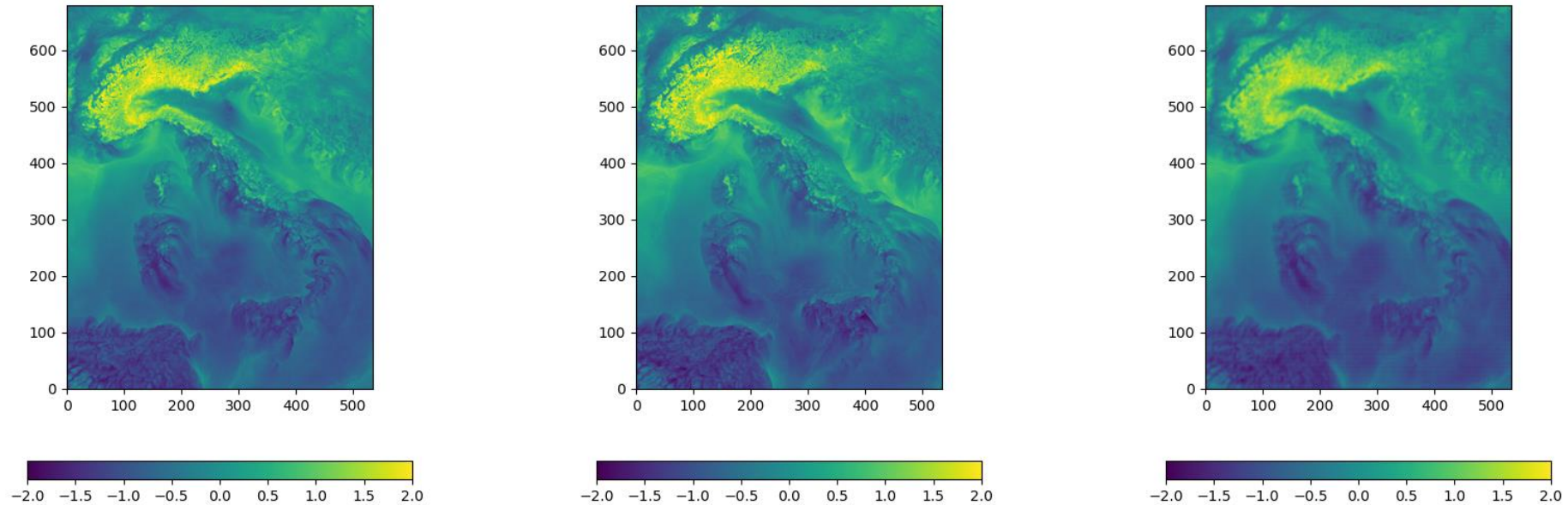


# WEATHER FORECASTING

Multi-framework approaches for  
Italian MLWP models

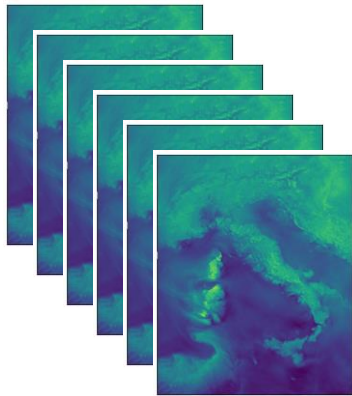
# AI-GCM

## AI General Circulation Model



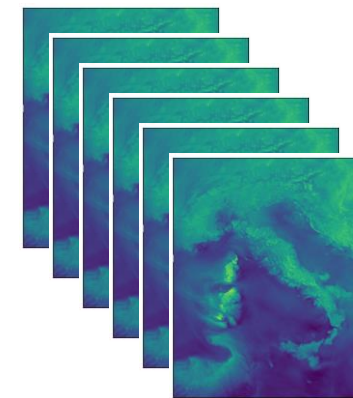
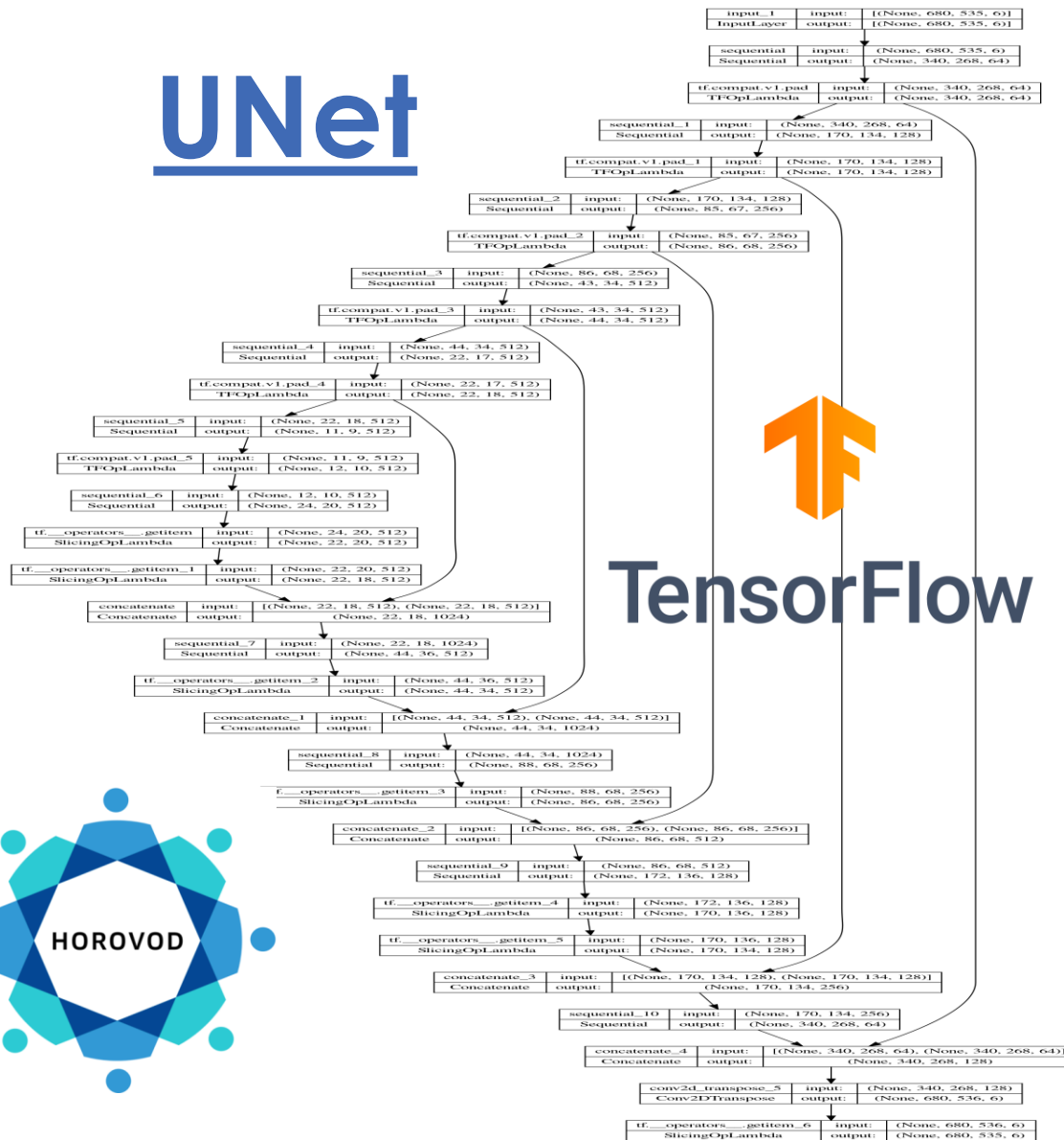
The project aims to construct a novel GCM approach **using recent developments in ML** and supported by intra-seasonal atmospheric signals. The aim is twofold. On the one hand, the potential to significantly reduce the run time of short-term forecasts. On the other hand, the possibility to increase the forecast skill for the medium term. The final objective is to produce a prototype model that could be further developed with future funding. The training process will use an ERA5 reanalysis dataset to develop different models based on **U-Net and Transformers technologies**. This project is funded by IFAB for 18 months. Cineca is involved by providing computational support and a suitable framework to run the model.

# UNET FOR WEATHER FORECASTS



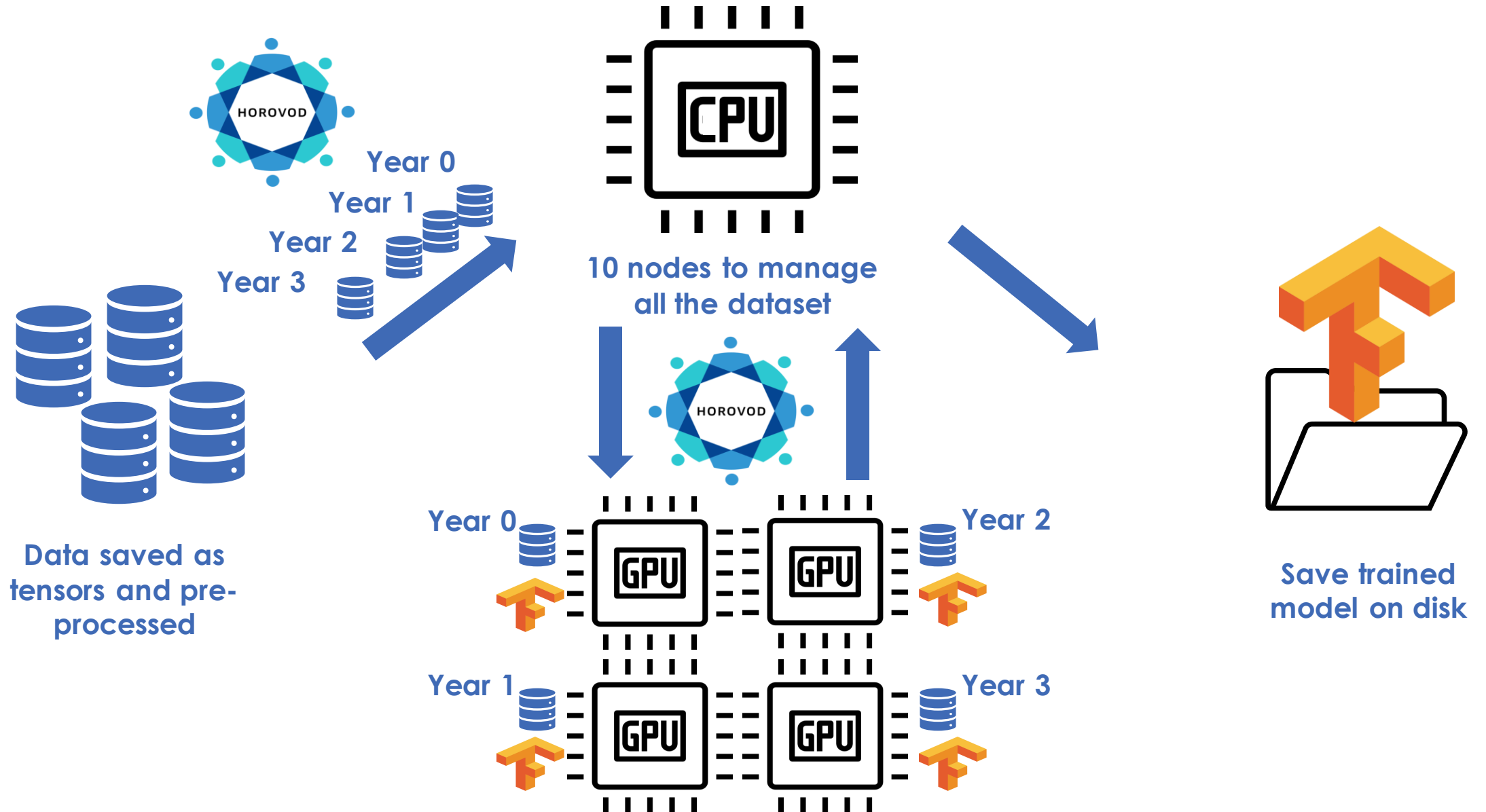
6 physical variable at t=0

## UNet

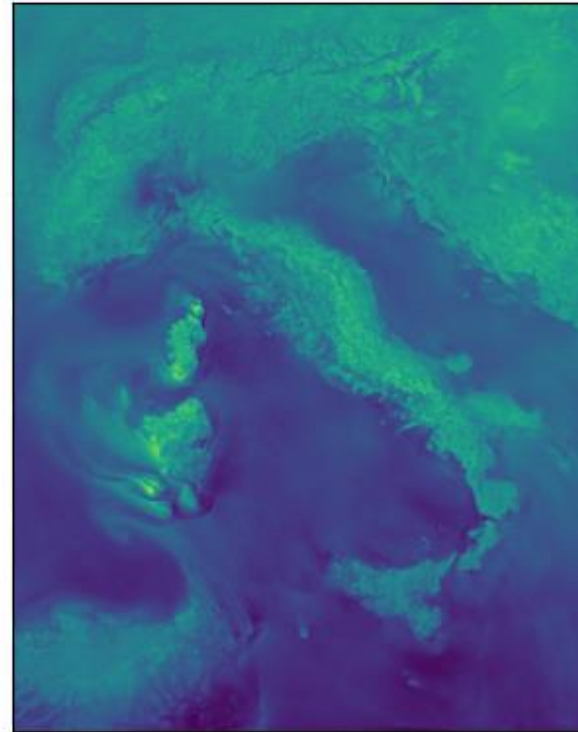
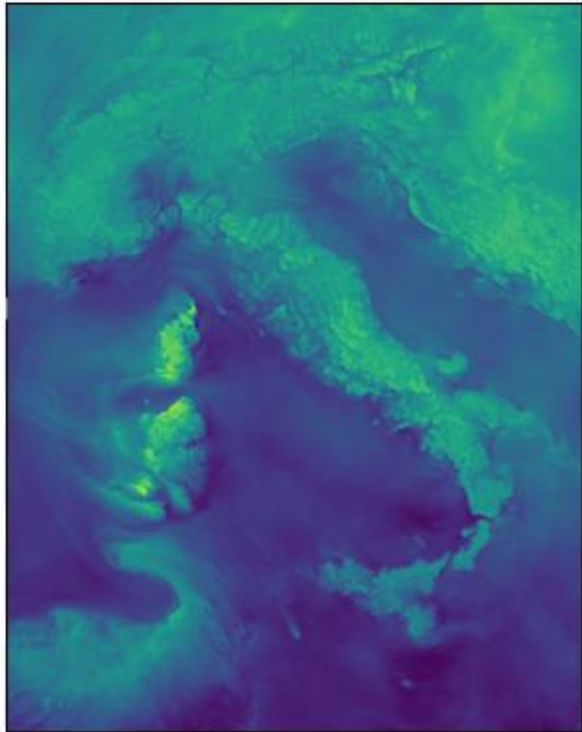


6 physical variable at t=+3

# OUR HPC IMPLEMENTATION



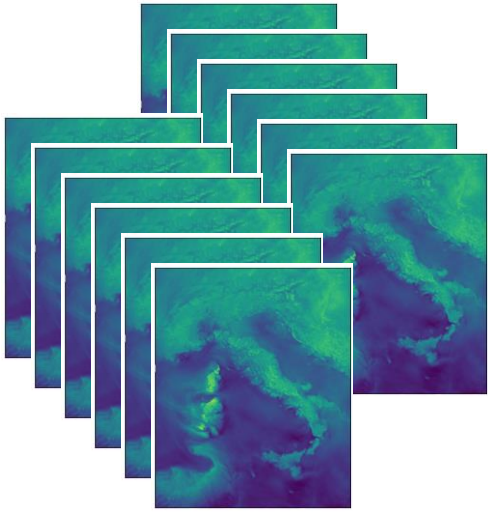
# SPATIO-TEMPORAL: MOVIES MAKE PREDICTIONS



Spatio-temporal learning algorithms are designed to analyze and understand **spatial and temporal patterns in data**. They consider both the spatial and temporal dimensions of data, enabling them to capture spatial relationships between different entities and temporal dynamics over time. Typically leveraging convolutional neural networks or transformer, **they automatically learn these relationships from data**. Widely applied across diverse sectors including environmental sciences, geospatial data analysis, social network monitoring, and financial forecasting, they aim to comprehend and forecast spatio-temporal behaviors and trends within data.



# VIT FOR WEATHER FORECASTS



1 physical variable  
from  $t=0$  to  $t=12$

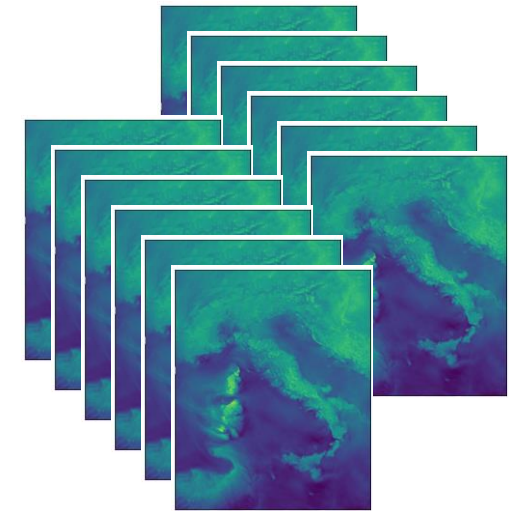


## OpenSTL

OpenSTL: A Comprehensive Benchmark of Spatio-Temporal Predictive Learning

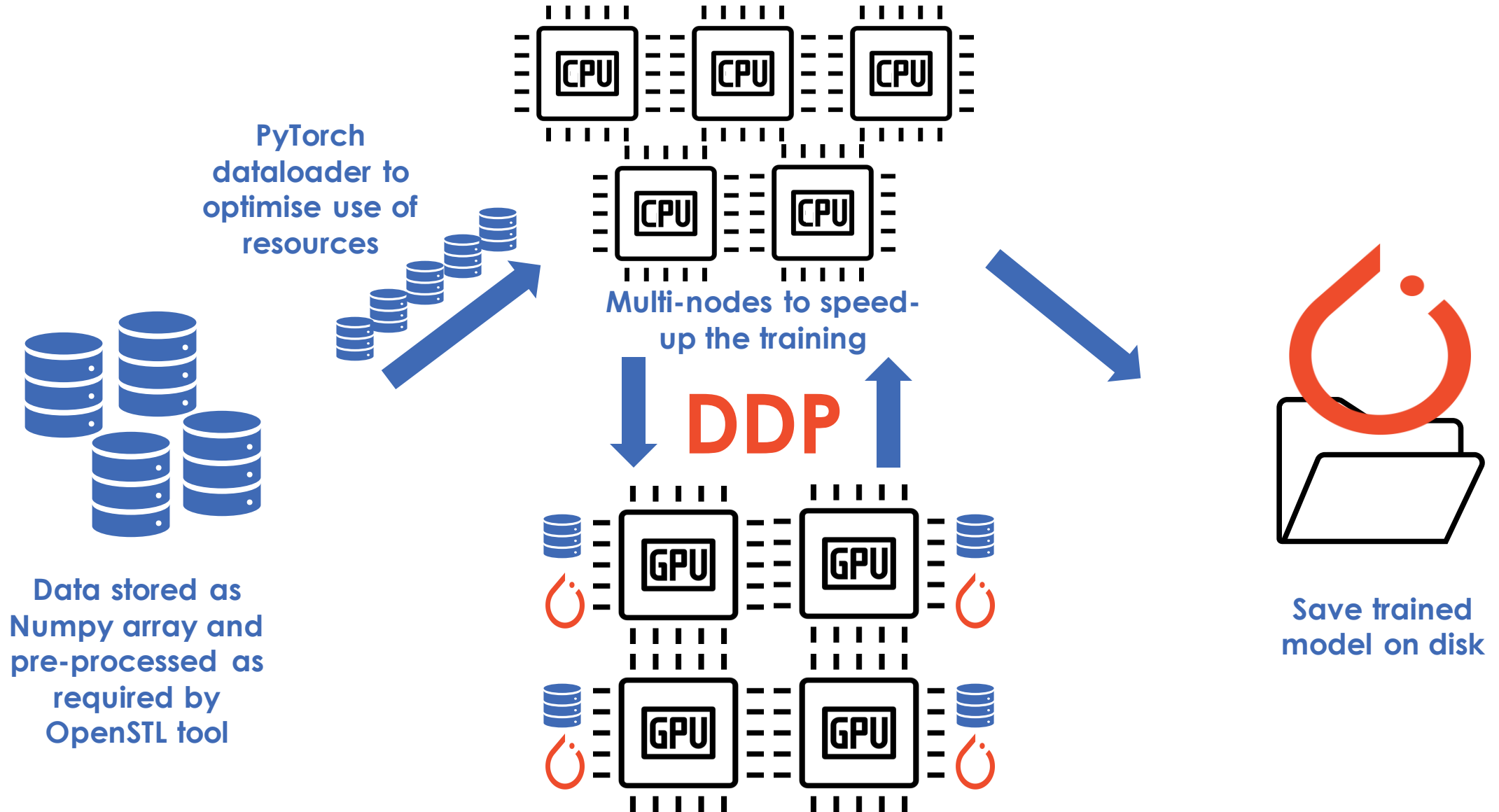
[OpenSTL paper](#)

 PyTorch

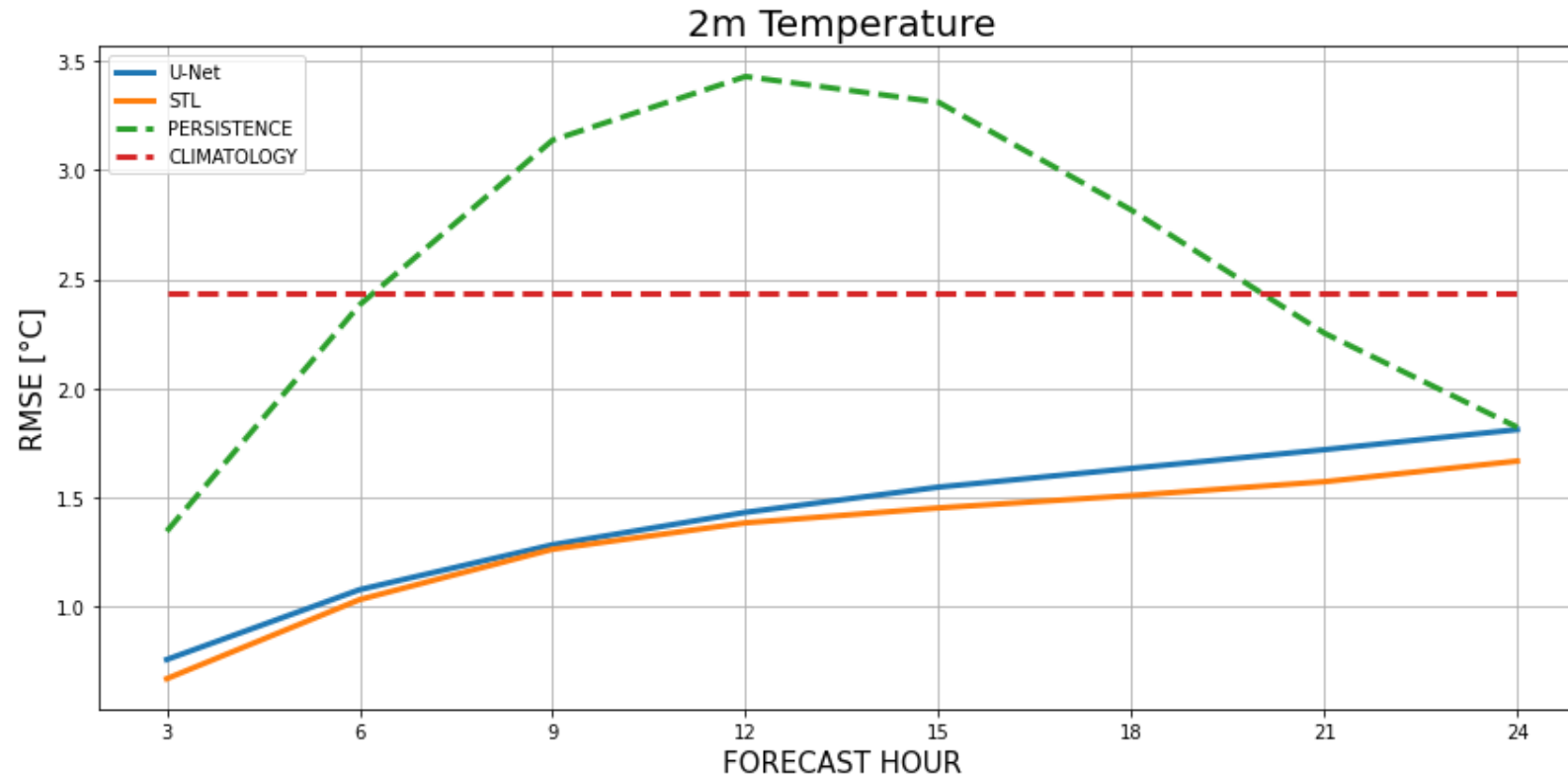


1 physical variable  
from  $t=12$  to  $t=24$

# OUR HPC IMPLEMENTATION

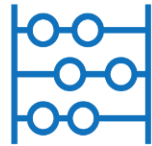


# COMPARE, EVALUATE AND UNDERSTAND



The first results seem very promising. Both models developed show metrics that are fully **comparable with those found in the literature and obtained by numerical methods**. In the last months of the project, the models will be optimised and compared with other ML models as well as with numerical models. In addition, thanks to Cineca's Mistral platform, the results obtained will be **compared with real data** from the observation stations.

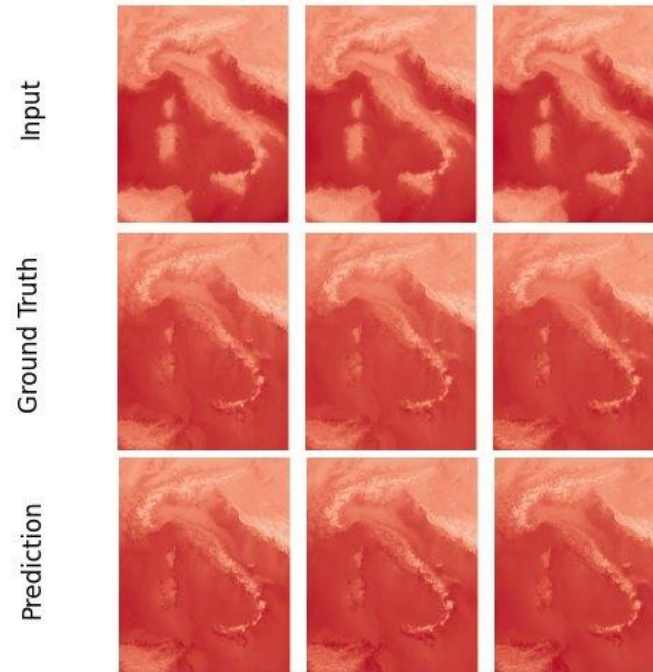
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# WHAT'S NEXT?

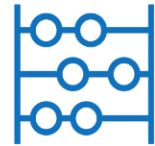
From forecast to social impact

# WEATHER4ENERGY



The project focuses on the efficient **translation of meteorological information into impacts**, providing accurate predictions of solar and wind power generation, power line capacity, hydrogeological hazards and potential threats to road infrastructure under future climate scenarios. The project is based on advanced meteorological models and involves the development of an innovative framework for translating meteorological information into concrete impacts, supported by high-performance infrastructure and cloud computing provided by the partnership with Cineca. This project is funded by the Innovation Grants within the scope of Centro Nazionale for a total of 24 months.

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**Questions**

**Doubts**

**Curiosities**



# GRAZIE

CINECA



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