

# A REVIEW OF AI ACTIVITIES AT CNRM MOROCCO

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# Context

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## International Context

- New Era of fully data driven weather models:
  - 2022: First global Data Driven weather models launched (FourCastNet, Pangu).
  - 2023: Google Launched GraphCast, first based GNN weather model.
  - 2024: AIFS model of ECMWF
  - 2025: Aurora foundation cross-sector model launched by Microsoft.
  - 2025: MetNo launched the first high resolution (2.5km) weather model based on AIFS architecture.
- Climate Emulators.
- Ensemble Fully Data Driven Models based on diffusion (AIFS-ENS, GenCast, FourCastNet-ENS).
- PINN for weather parametrization.
- ECMWF Anemoi & MLPP.
- WMO AINPP.

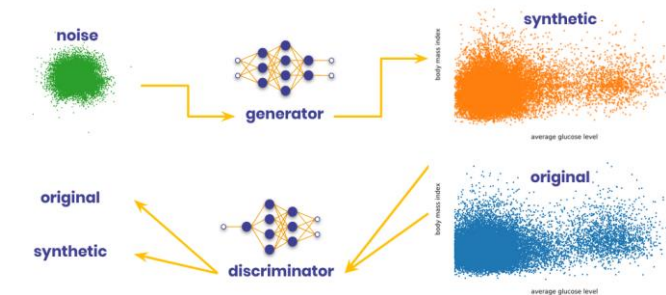
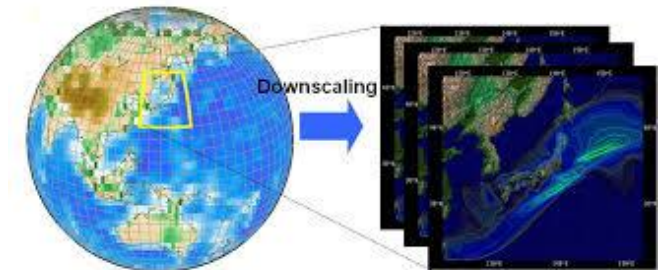
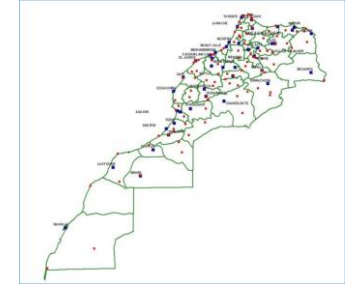
## National Evolution on AI related to NWP :

- 2016-2019: AI first activities started on 2016 with works of (Bari Driss) on fog and visibility parametrization.
- 2020-2023: AI applications to ensemble prediction (Analog Ensemble Method) (Alaoui & Bari).
- 2024: Using AI for nowcasting, satellite images labelling and classification (Alaoui) + PINN works on visibility and model outputs calibration (Bari Driss).
- 2025: Wind Gust, Tmin and Tmax adjustment and forecasting (El Ouardi, Sahlaoui and Hdidou)
- Mid-2025: Starting inferences of fully data driven AI models locally, Anemoi usage on EWC (Alaoui).
- End-2025 : MLPP Membership

# AI Projects

- **Analog Ensemble Extension for AROME and ERA5-IFS on 44 synoptic stations and over Morocco Domain (2D)**
- **Analogs on Weather Satellites Images**
- **Deep Learning Weather Satellites Images Classification**
- **Weather Satellite Images Labelling APP**
- **Clustering IFS Ensemble Couplers using AI.**
- **Generative AI in creating ICs from ERA5 for WRF-EPS**
- **ANEMOI – AIFS**
- **GNN Based Morocco LAM Model**
- **Downscaling/ Inter-comparaison of GNN Global Models over Morocco (GraphCast, AIFS, FourCastNet, Pangwu...)**

ANEN  
SATELLITE IMAGES  
GENERATIVE-IC  
ANEMOI-GNN



Examples: CTGAN, DoppelGANger

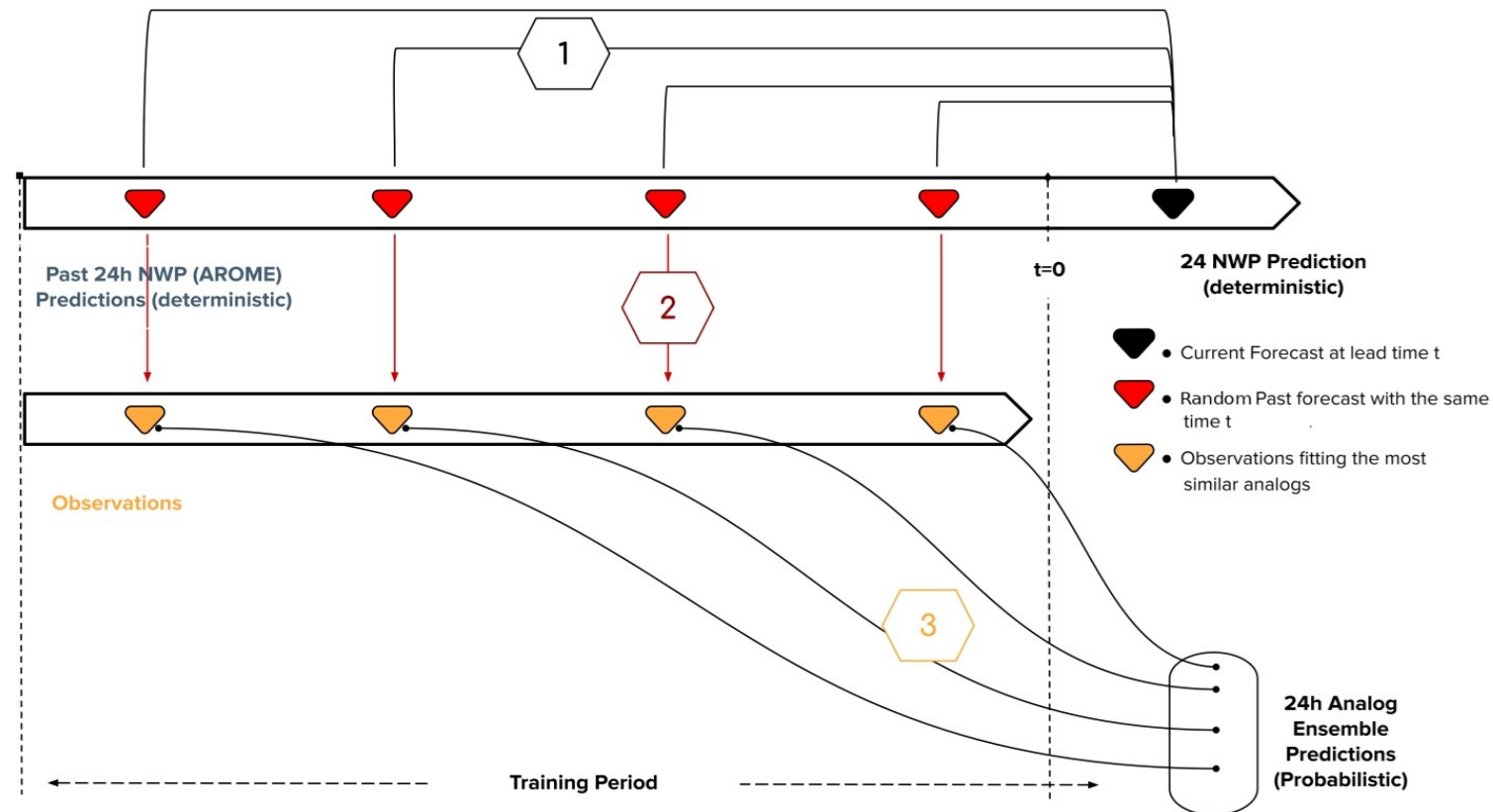
# Analog Ensemble Method

[Step 0] : Choosing a station  $s$  and a lead time  $t$  + Access to archives of past forecasts and observations

[Step 1] : Searching for all the past forecasts similar to the actual forecast at time  $t$

[Step 2] : Finding the past observations associated with the best analogs

[Step 3] : Constructing AnEn Ensemble using observations of the best analogues



# Contributions

## Predictors

8 surface weather parameters (in place of 3)

## Analogs Search Space

Spatial Extension of analogs search space

### Similarity Metric

$$\| \mathbf{F}_t, \mathbf{A}_{t'} \| = \sum_{i=1}^{N_p} \frac{w_i}{\sigma_i} \sqrt{\sum_{j=-\tilde{t}}^{\tilde{t}} (F_{i,t+j} - A_{i,t'+j})^2}$$

### Predictor's Weighting Strategies

- Same weight for all predictors in literature / Expensive weighting strategies **Brute Force (Junk et al 2015)**
- New predictors weighting strategies based on AI Feature importance
- Algorithms:
  - Linear Regression (**Hope 2020**),
  - Random Forest (**Brieman 2001**)
  - Xgboost (**Chen and Guestrin 2016**)

Goal: Improving AnEn performance in forecasting Surface weather parameters using AI

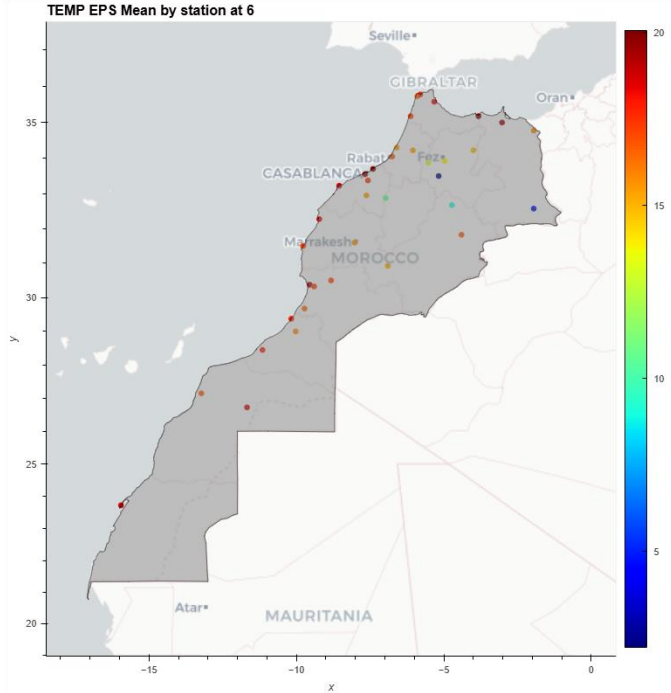
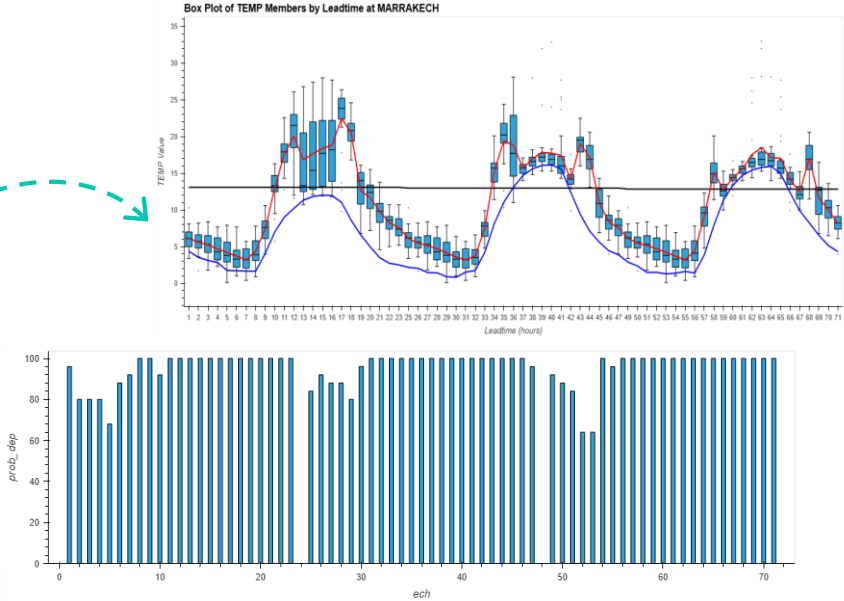
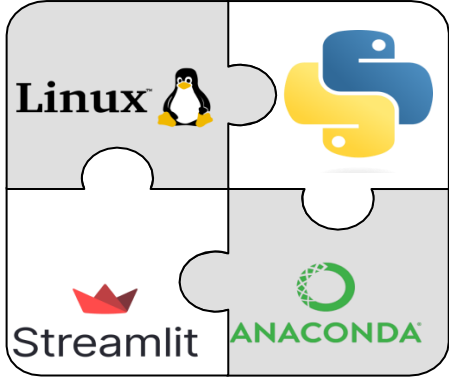
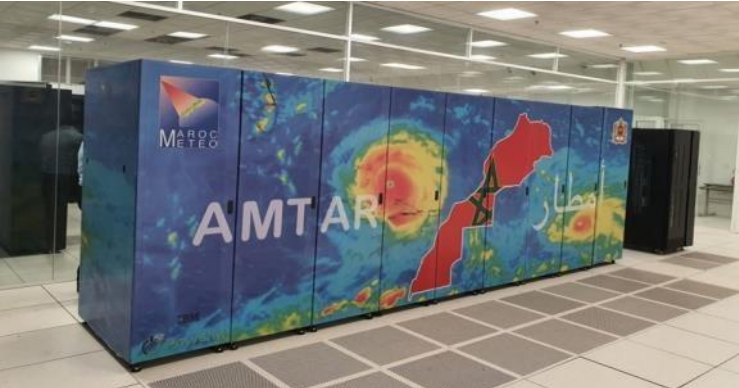
### Related Papers:

- Alaoui, B., Bari, D. & Ghabbar, Y. Surface Weather Parameters Forecasting Using Analog Ensemble Method over the Main Airports of Morocco. *J Meteorol Res* 36, 866–881 (2022). DOI: 10.1007/s13351-022-2019-0
- Alaoui, B.; Bari, D.; Bergot, T.; Ghabbar, Y. Analog Ensemble Forecasting System for Low-Visibility Conditions over the Main Airports of Morocco. *Atmosphere* 2022, 13, 1704. DOI: 10.3390/atmos13101704
- Alaoui, B., Bari, D. & Ghabbar, Y. Space Analog's Searching to Improve Deterministic Forecasting Using Analog Ensemble Method Over Morocco, Recent Advancements from Aquifers to Skies in Hydrogeology, Geocology, and Atmospheric Sciences. DOI : 10.1007/978-3-031-47079-0

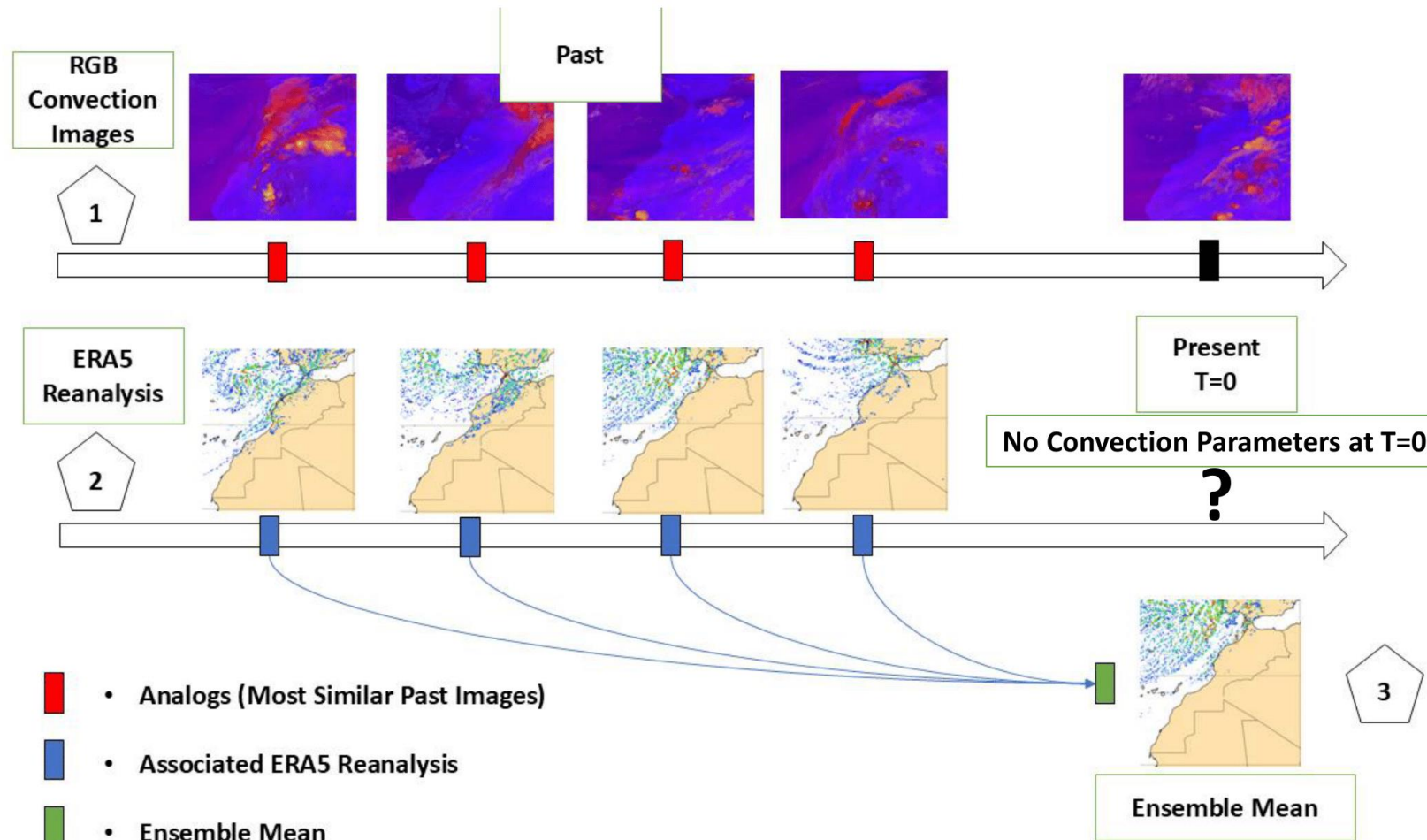
# AnEn in Operation

- 25 members.
- Archive : 2016-2024
- 72h.
- 44 stations.
- 2 min on 1 node.
- Operational since July 2023.
- Portable / Low Cost
- + 50% BIAS and +30% RMSE

Some Products



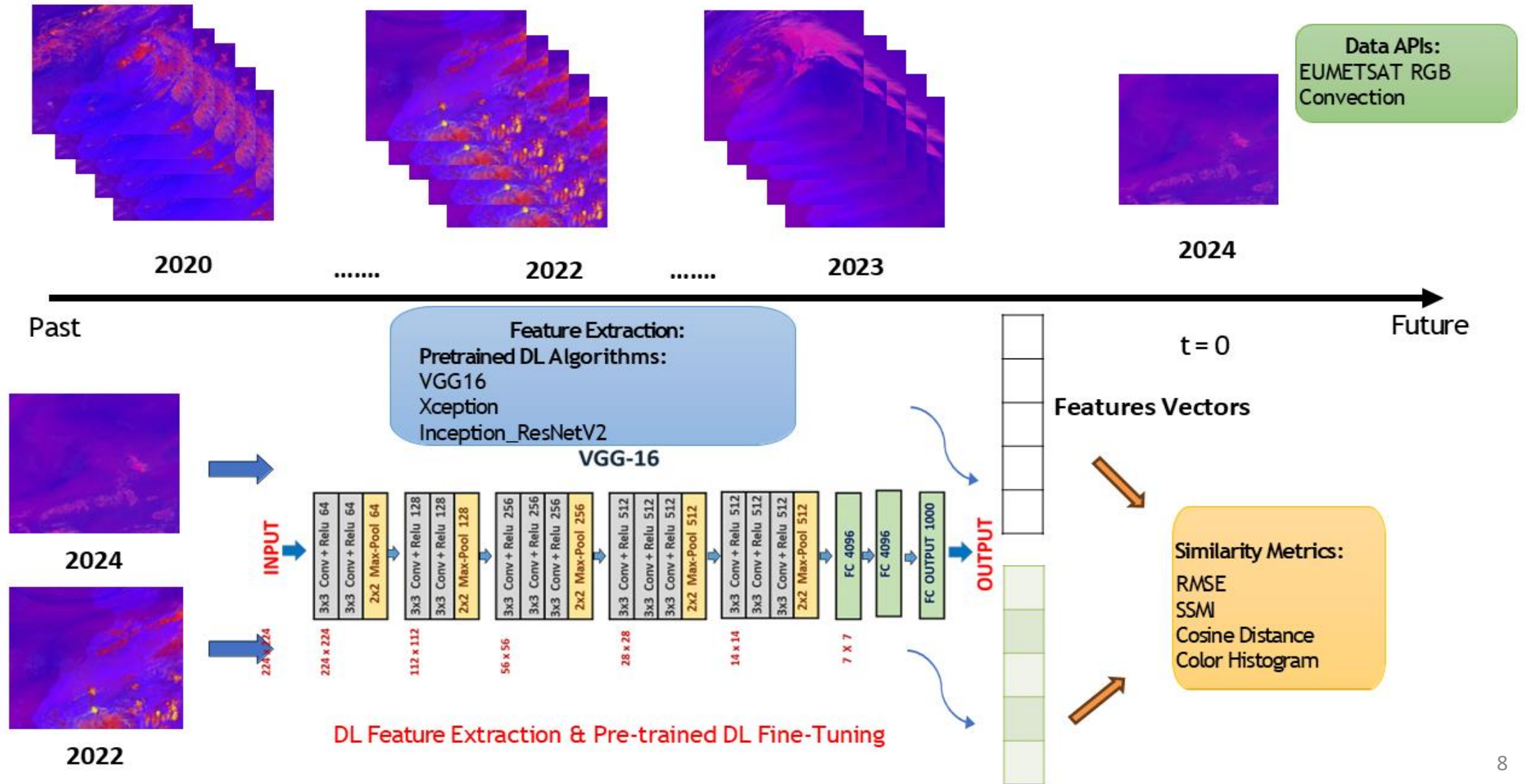
# Analog Observational Framework for Convection Diagnostic



## Related Papers:

- Badreddine Alaoui, Driss Bari, Chakib Bounoun, A novel deep learning semi-observational analog framework for diagnosing convection over Morocco using satellite imagery and ERA5-reanalysis, Atmospheric Research, Volume 338, 2026, 108969, <https://doi.org/10.1016/j.atmosres.2026.108969>.
- Alaoui, B., Bounoun, C., and Bari, D.: Leveraging Pretrained Deep Learning Models to Extract Similarities for the Analog Ensemble Method Applied to Convection Satellite Imagery, EGU General Assembly 2025, Vienna, Austria, 27 Apr–2 May 2025, EGU25-7258, <https://doi.org/10.5194/egusphere-egu25-7258>, 2025.

# Analog Observational Framework for Convection Diagnostic

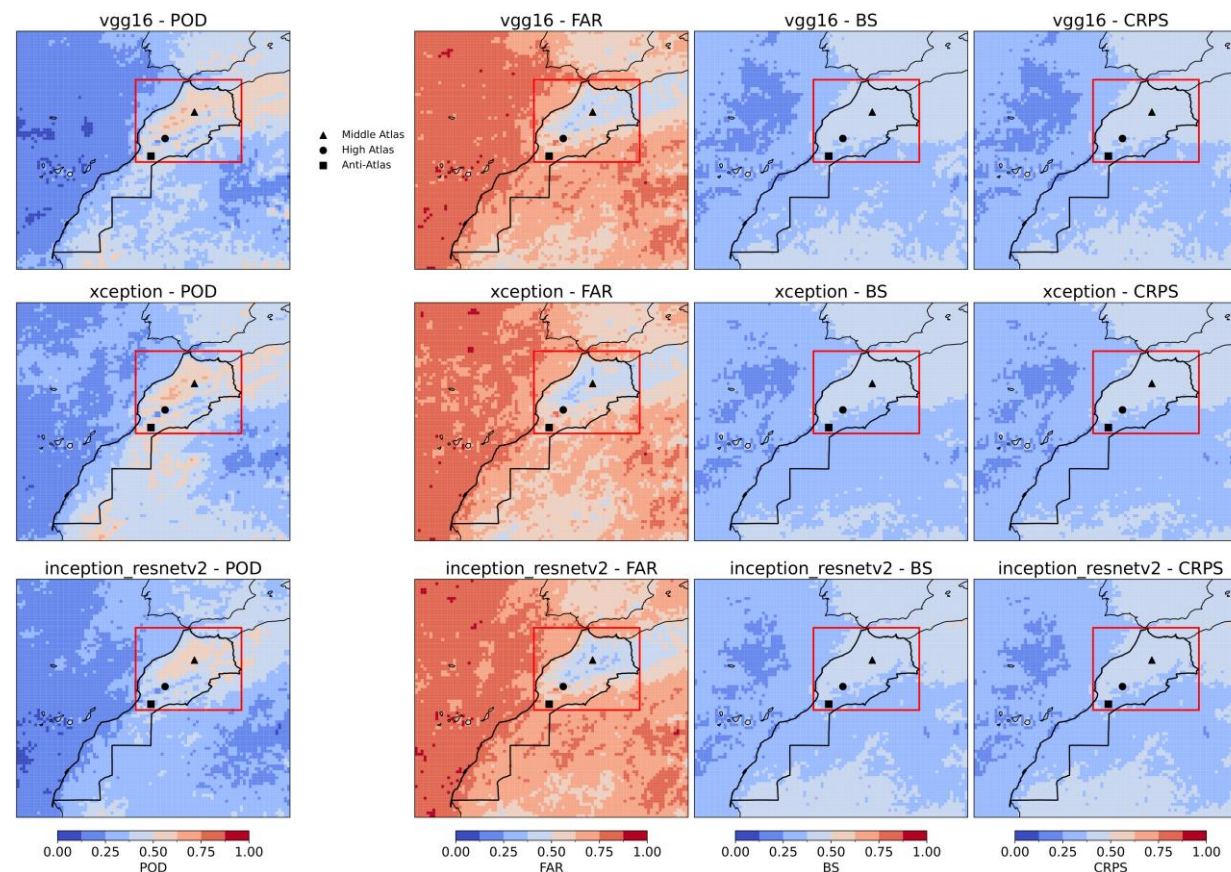


# Analog Observational Framework for Convection Diagnostic

- Training 2020-2023 (12h, 15h, 18h).
- 10 analogs
- Test : Full 2024 & 50 Extreme Use Cases.
- Fuzzy Logic of Convection Occurrence's (Thresholds from Operation) .

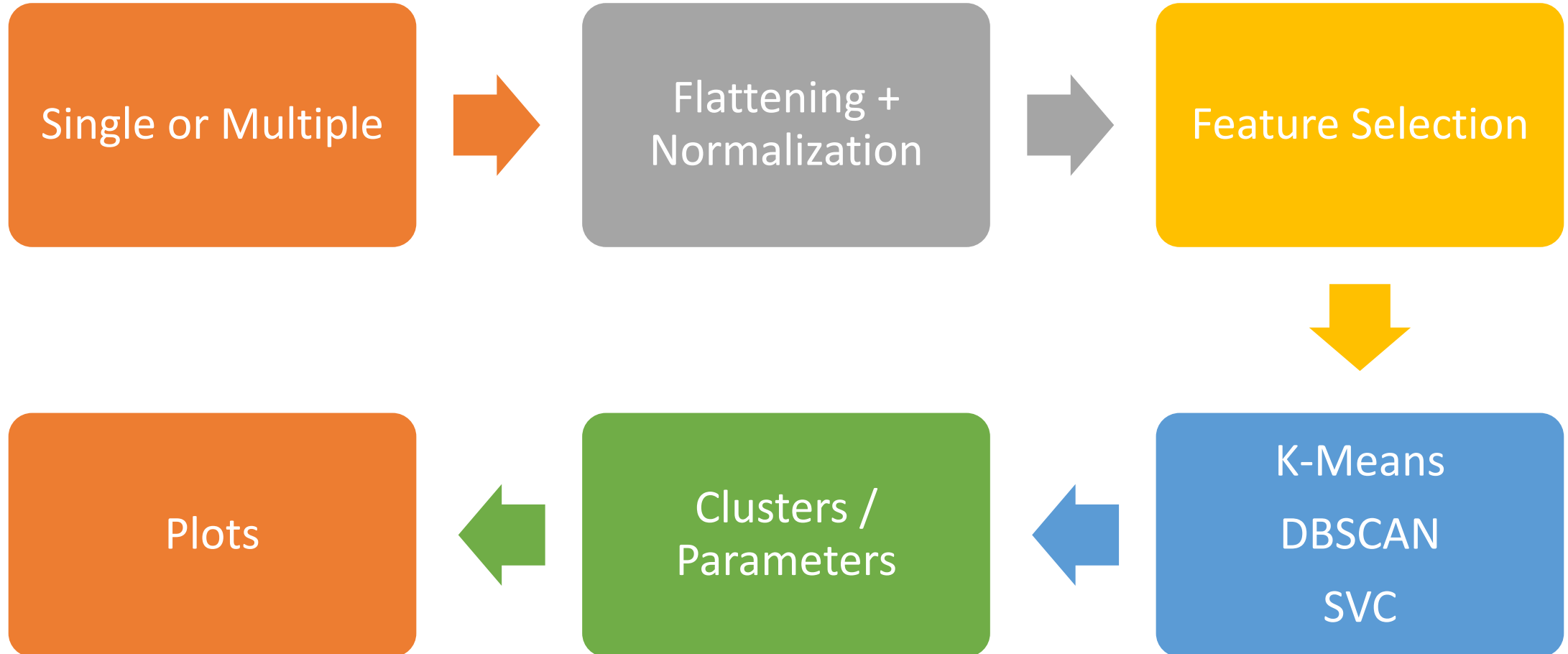
$$P(\text{Likely Convection}) = \frac{P(\text{CAPE} > 1000\text{J/kg}) + P(\text{W600} < -0.2\text{Pa/s}) + P(\text{TCWV} > 30\text{mm}) + P(\text{LI} < -2^\circ\text{C})}{4}$$

- Observed Occurrences vs Diagnosis Occurrences applying the same rule
- 20 days for training on CPU.
- DL Algorithms : VGG16, Xception, InceptionResNetV2
- 0.75 POD, 0.25 FAR in convection mountainous zone.
- Portable with slight finetuning / Low Cost (No GPU) (Africa Generalization)



# Clustering of AROME-EPS Couplers/ Outputs

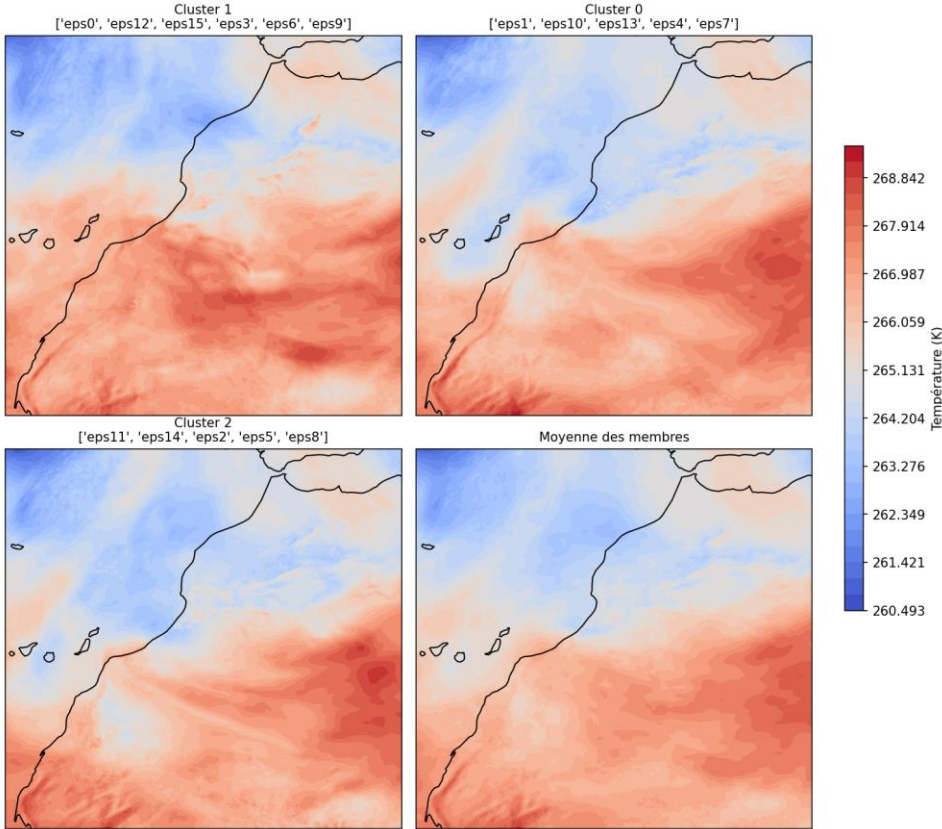
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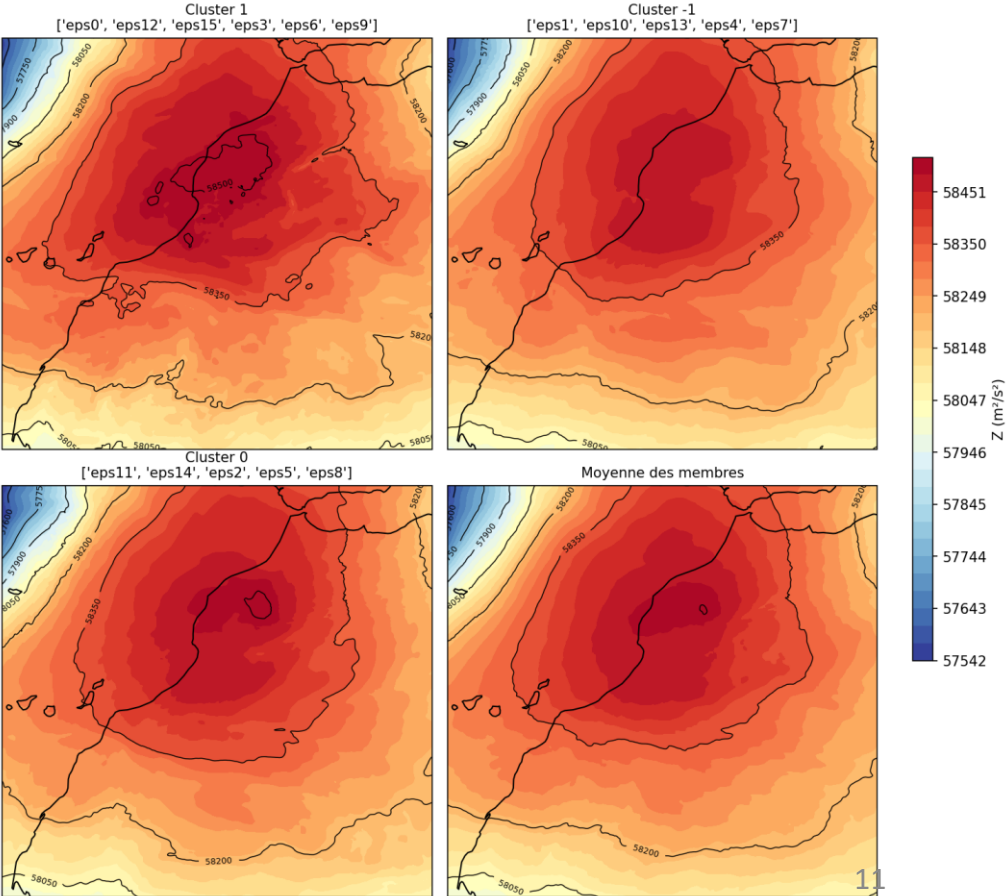
# Clustering of AROME-EPS Couplers/ Outputs

[ Single Parameter ]

[10\_08\_2025] - Température à 500 hPa et 15h - [KMeans]



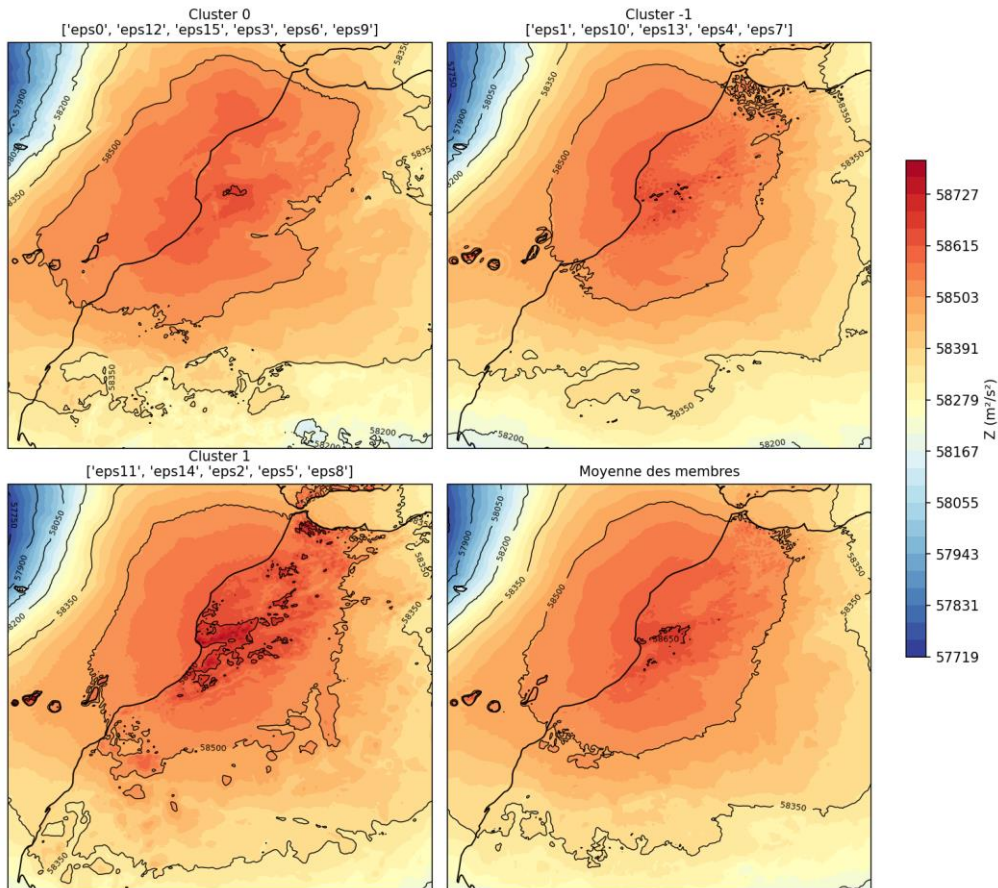
[10\_08\_2025] - Géopotentiel à 500 hPa et 06h - [DBSCAN]



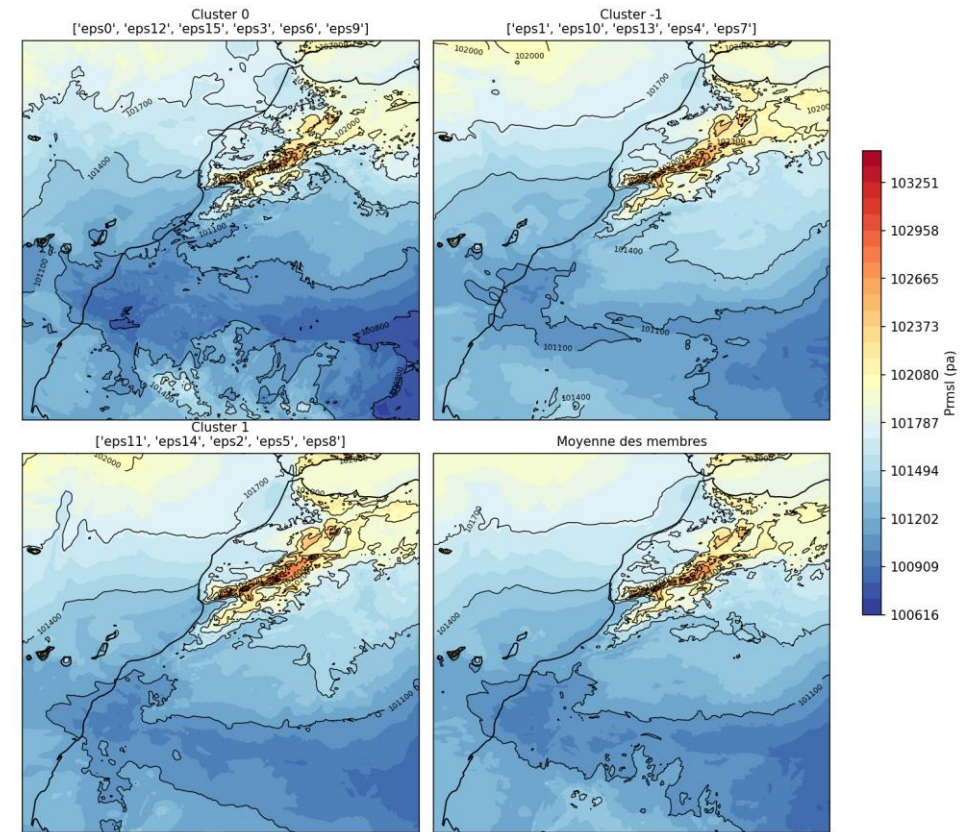
# Clustering of AROME-EPS Couplers/ Outputs

[ Multi-Parameter ]

[10\_08\_2025] - Géopotentiel à 500 hPa et 00h - [DBSCAN]

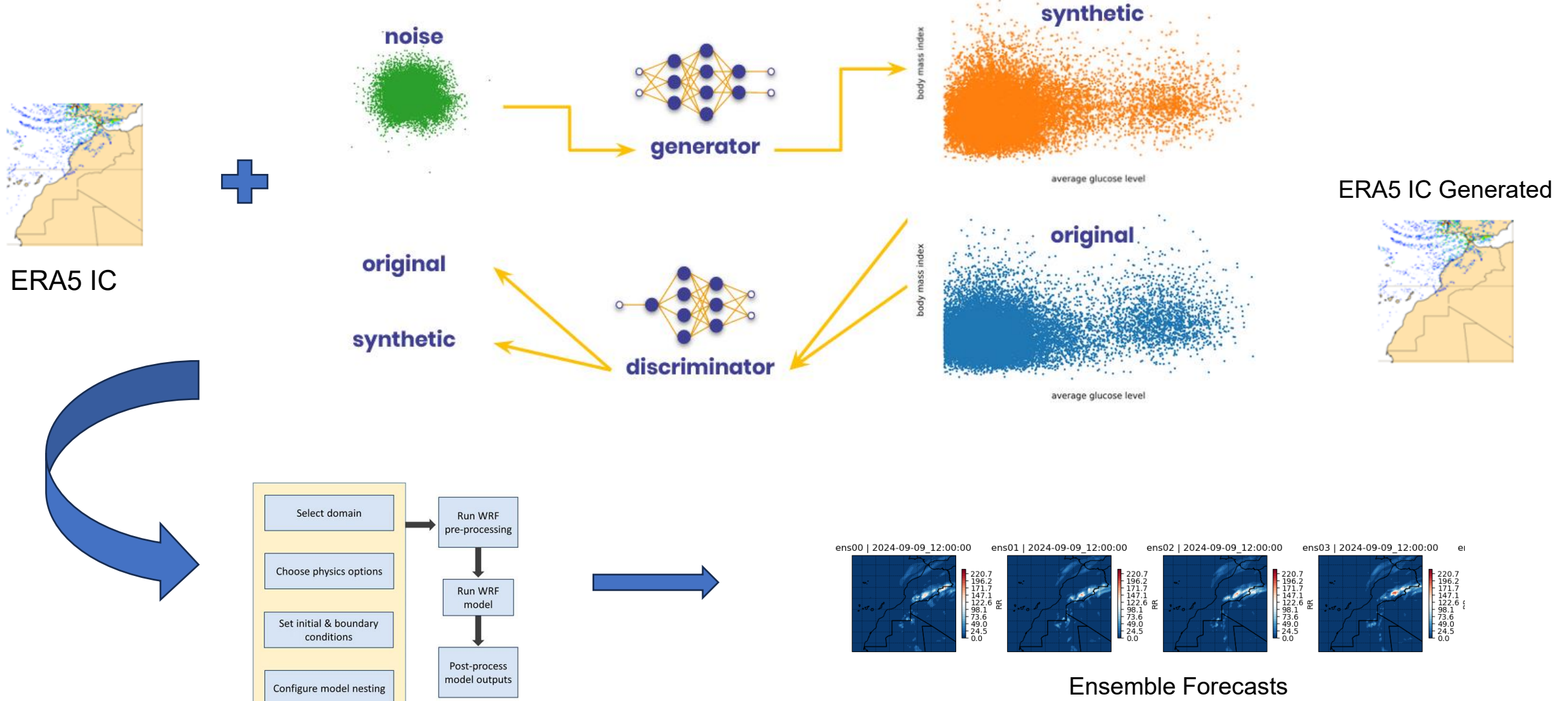


[10\_08\_2025] - Pression réduite au niveau moyen de la mer à 00h - [DBSCAN]



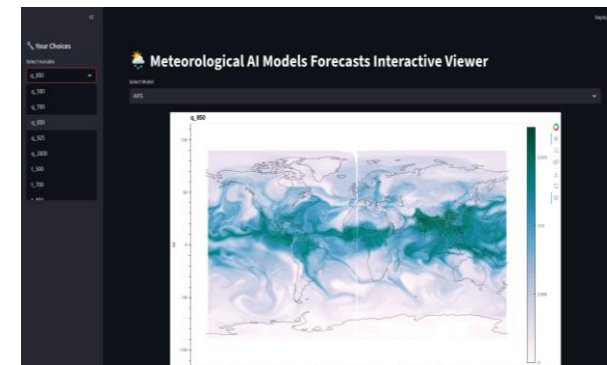
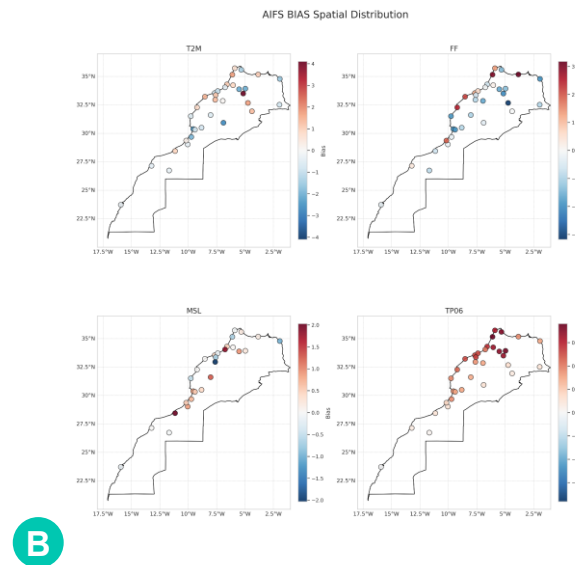
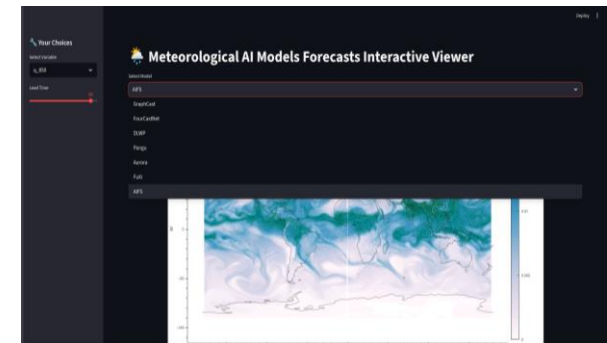
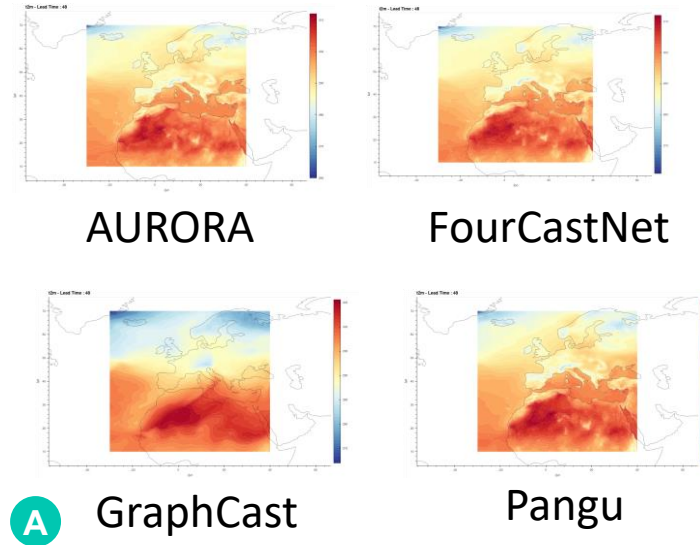
# Generative IC Ensemble WRF

On-Going Publication



# Data-Driven Models

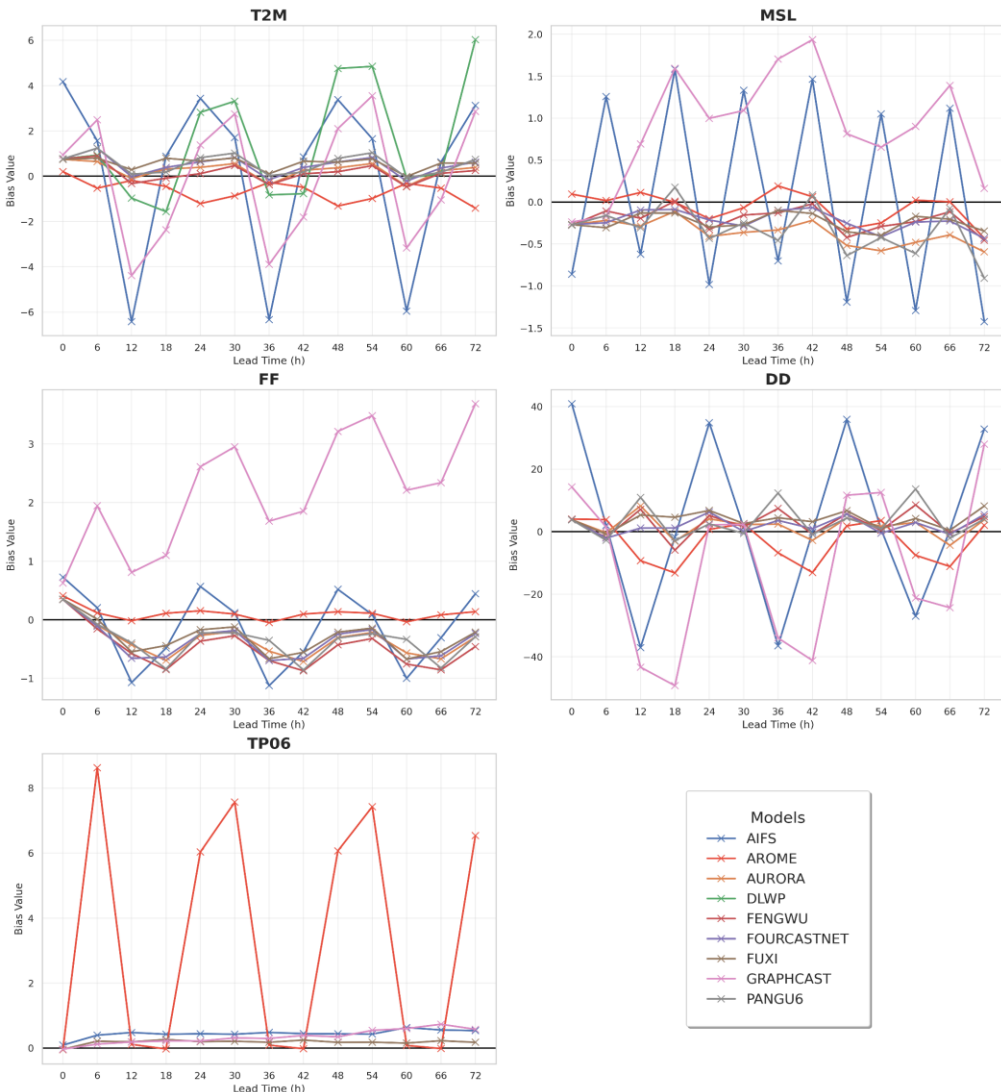
- ANEMOI Installation
- Extracting/Loading Data (IFS, GFS)
- Customizing Namelists
- Transfer Learning / AIFS Global Version Loading (Hugging Face)
- Running Inferences AI global models (AIFS, GraphCast, FourCastNet, Pangu...).
- Parallelisation and adaptation to local resources
- Visualization APP for AI models
- Inter-Comparison of AI models over Morocco, and Verification with Moroccan Observation
- MLPP Membership



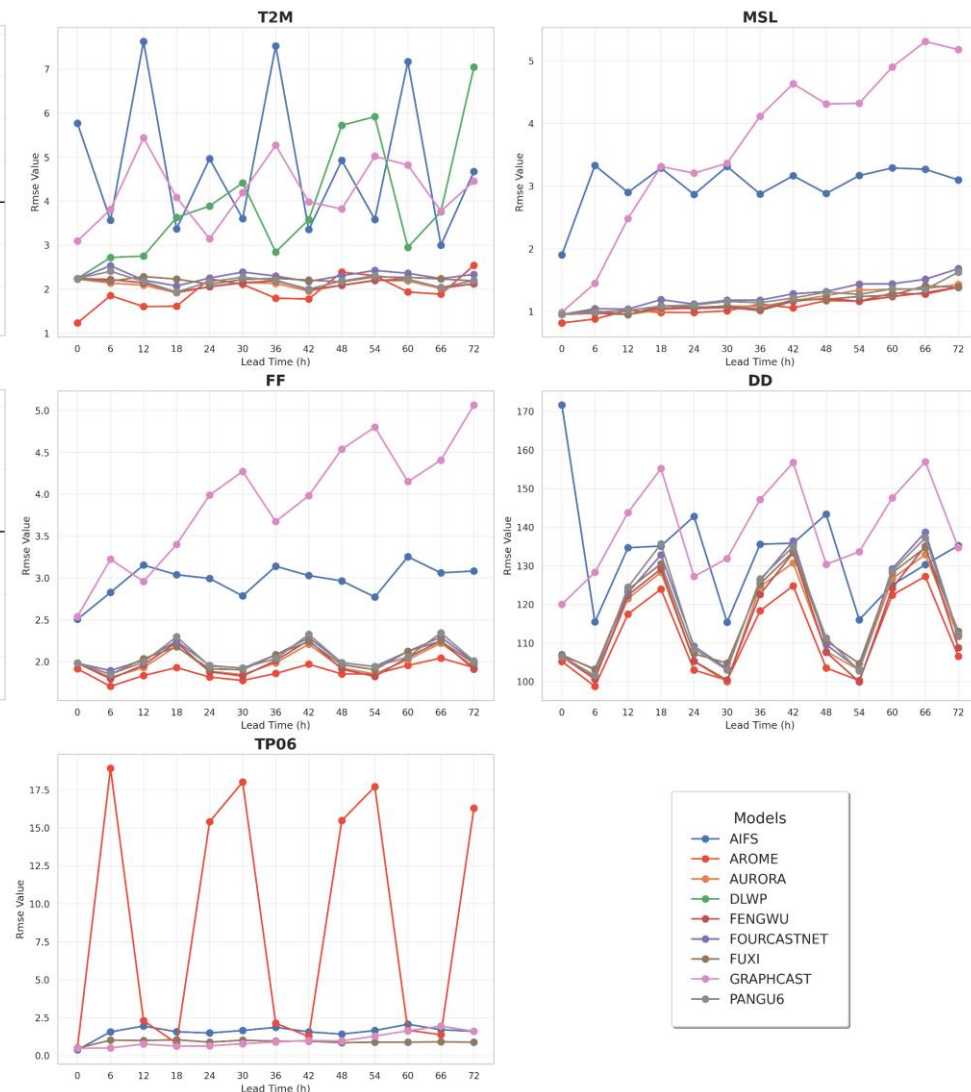
# Data-Driven Models Verification Results

Verification Period :  
04/09/2025 to 31/03/2026  
Each 6 Hour

Sequential BIAS Evolution (0-72h)



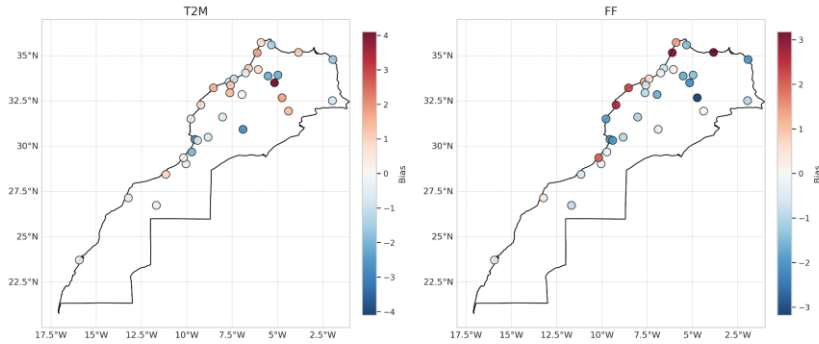
Sequential RMSE Evolution (0-72h)



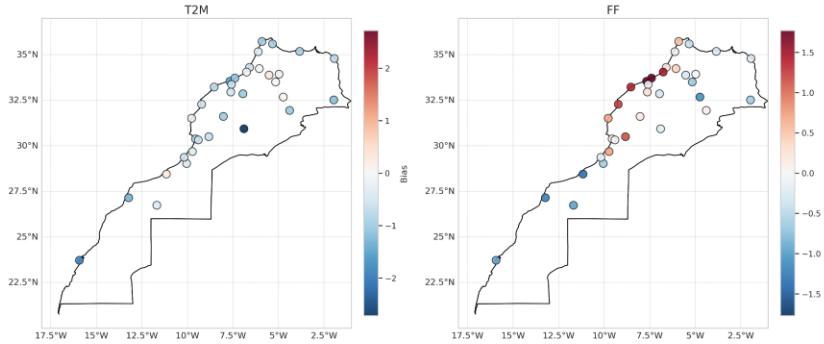
- Data-Driven Models provides close performances to AROME despite resolution (2.5km vs 31km)
- AIFS and GraphCast provides worst performances (GNN Architecture/ Generalization Issue)
- AI models based on transformers performs the best
- Physically respecting predictability along lead-times

# Data-Driven Models Verification Results

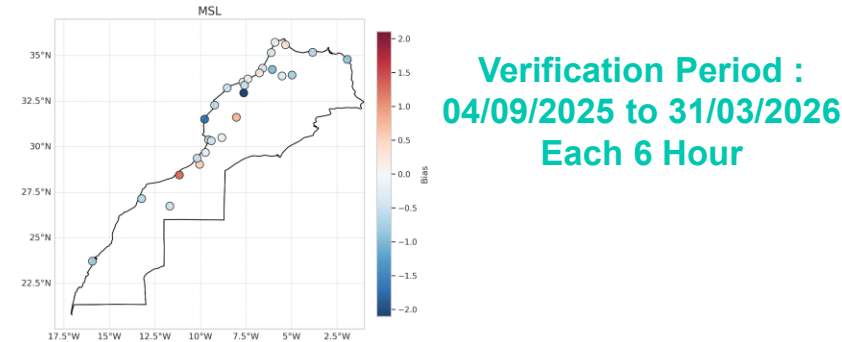
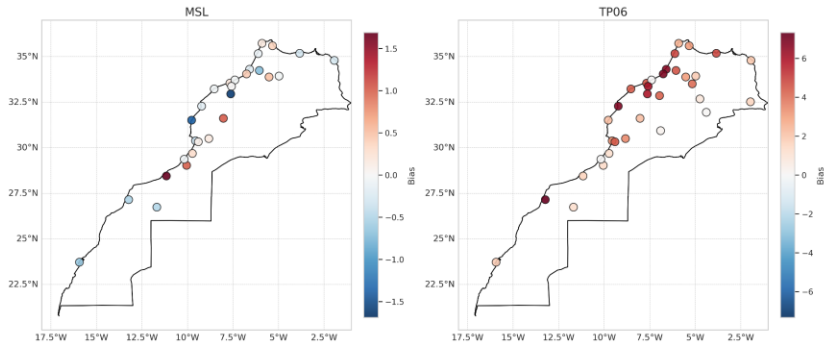
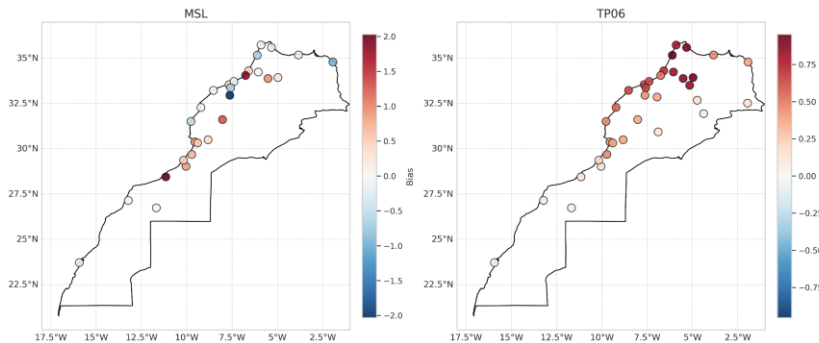
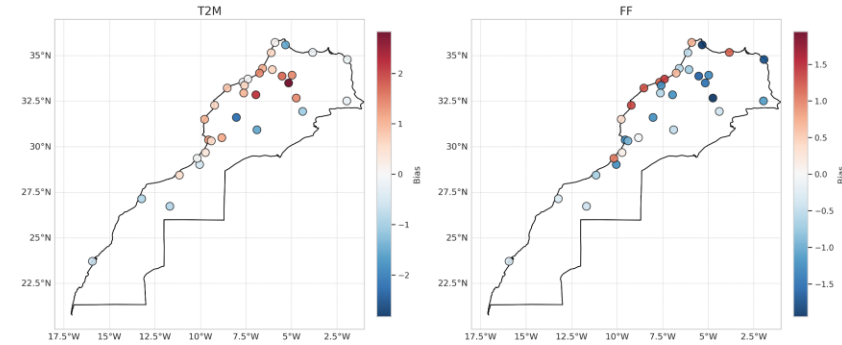
AIFS BIAS Spatial Distribution



AROME BIAS Spatial Distribution



AURORA BIAS Spatial Distribution

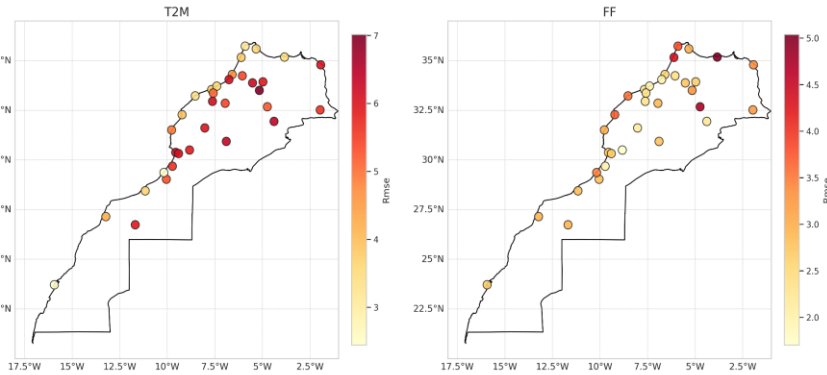


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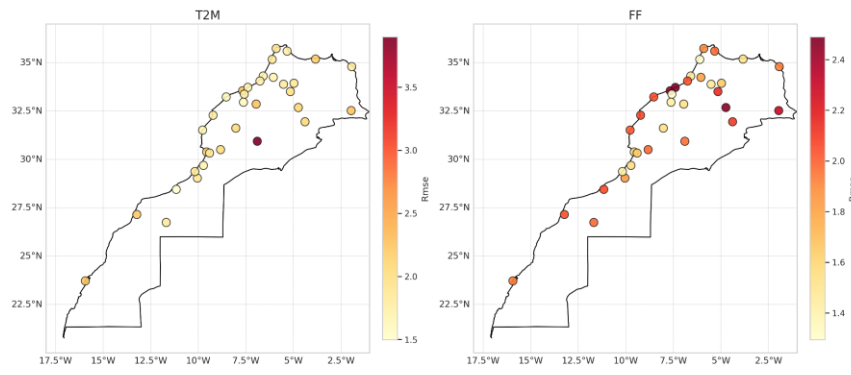
- Data-Driven Models provides close performances to AROME spatially despite resolution (2.5km vs 31km)
- Aurora and Arome provides same bias range for T2m, FF with local disparities
- Data-Driven Models outperforms AROME regarding TP06h (dominance of low precipitations during the verification period)

# Data-Driven Models Verification Results

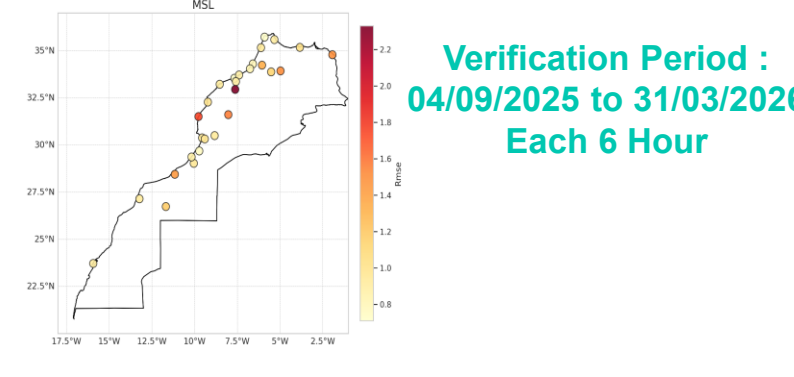
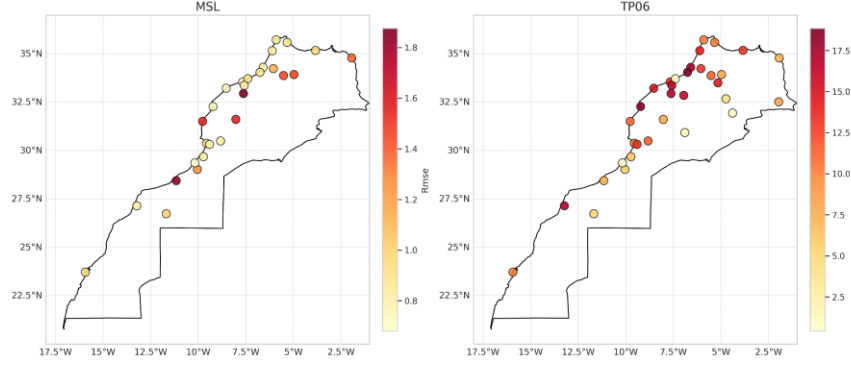
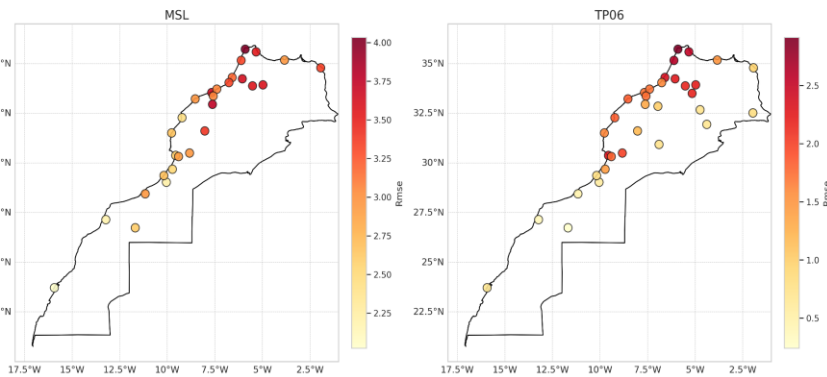
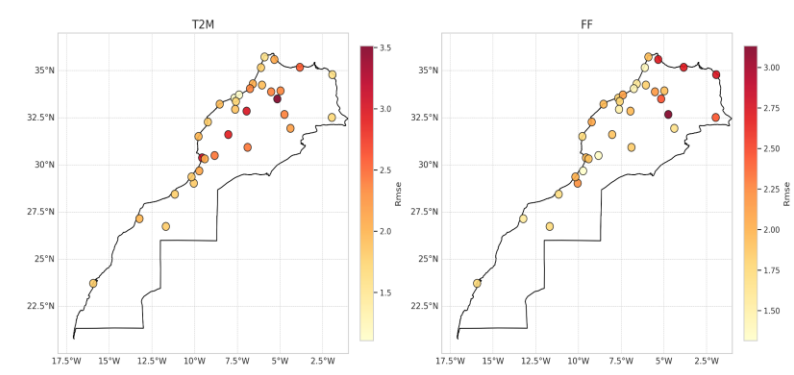
AIFS RMSE Spatial Distribution



AROME RMSE Spatial Distribution



AURORA RMSE Spatial Distribution



Verification Period :  
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# Conclusion & Perspectives

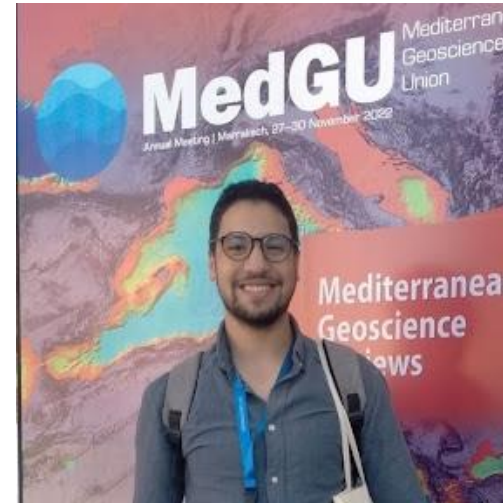
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- Low-cost analog ensemble system operational since 2023, over 44 synoptic stations => **Extension to more stations + Vertical Parameters**
- Deep Learning Computer Vision Based system for 2D observational convection parameters diagnosis => **convection observational forecast (ConvLSTM....)**
- Clustering AROME-EPS using AI algorithms, the best cluster provides close results to ensemble mean.
- Generative AI for ensemble creation WRF => **AROME (Up Coming)**
- Successful stable operational running of all data-driven weather models over Morocco => **Inferences for high resolution checkpoints (Bris, CERRA5)**
- Ground Stations Verification of AI models displays more stability for transformers compared to GNN ( Rollout issue)



Thank you!

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# References

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- Bi, K., Xie, L., Zhang, H., Chen, X., Gu, X., & Tian, Q. (2022). Pangu-weather: A 3d high-resolution model for fast and accurate global weather forecast. *arXiv preprint arXiv:2211.02556*.
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- Ling, F., Chen, K., Wu, J., Han, T., Luo, J. J., Ouyang, W., & Bai, L. (2024). FengWu-W2S: A deep learning model for seamless weather-to-subseasonal forecast of global atmosphere. *arXiv preprint arXiv:2411.10191*.
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