Verification of AROME 1.3 km over Morocco

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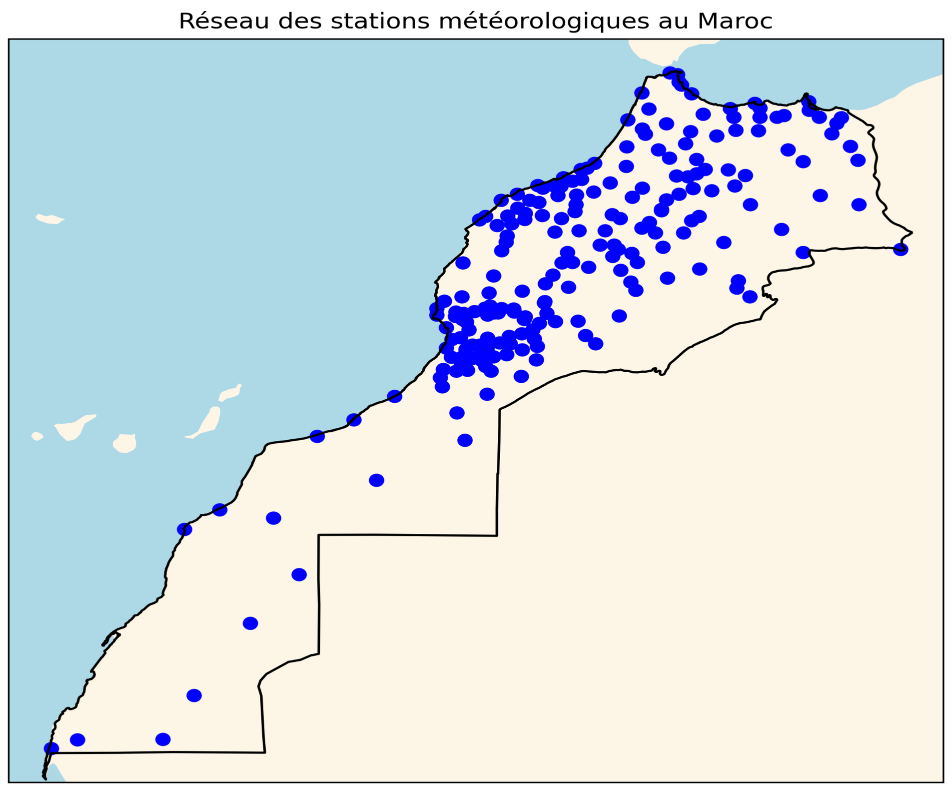
Introduction

AROME 1.3 km is a convection-permitting model operational in Morocco. Due to complex terrain, verification is essential to assess model performance.
This study evaluates temperature, humidity, wind, and precipitation.

Methodology and Observation Network

The verification is based on a comparison between model outputs and observations from surface stations (SYNOP) and radiosondes (TEMP).
Observations are extracted from the operational BUFR database used in data assimilation, ensuring consistency with the operational system.
The evaluation is performed using the HARP tool, allowing standardized verification.

- Variables: temperature, humidity, wind, precipitation
- Levels: surface and vertical profiles
- Metrics: Bias and RMSE

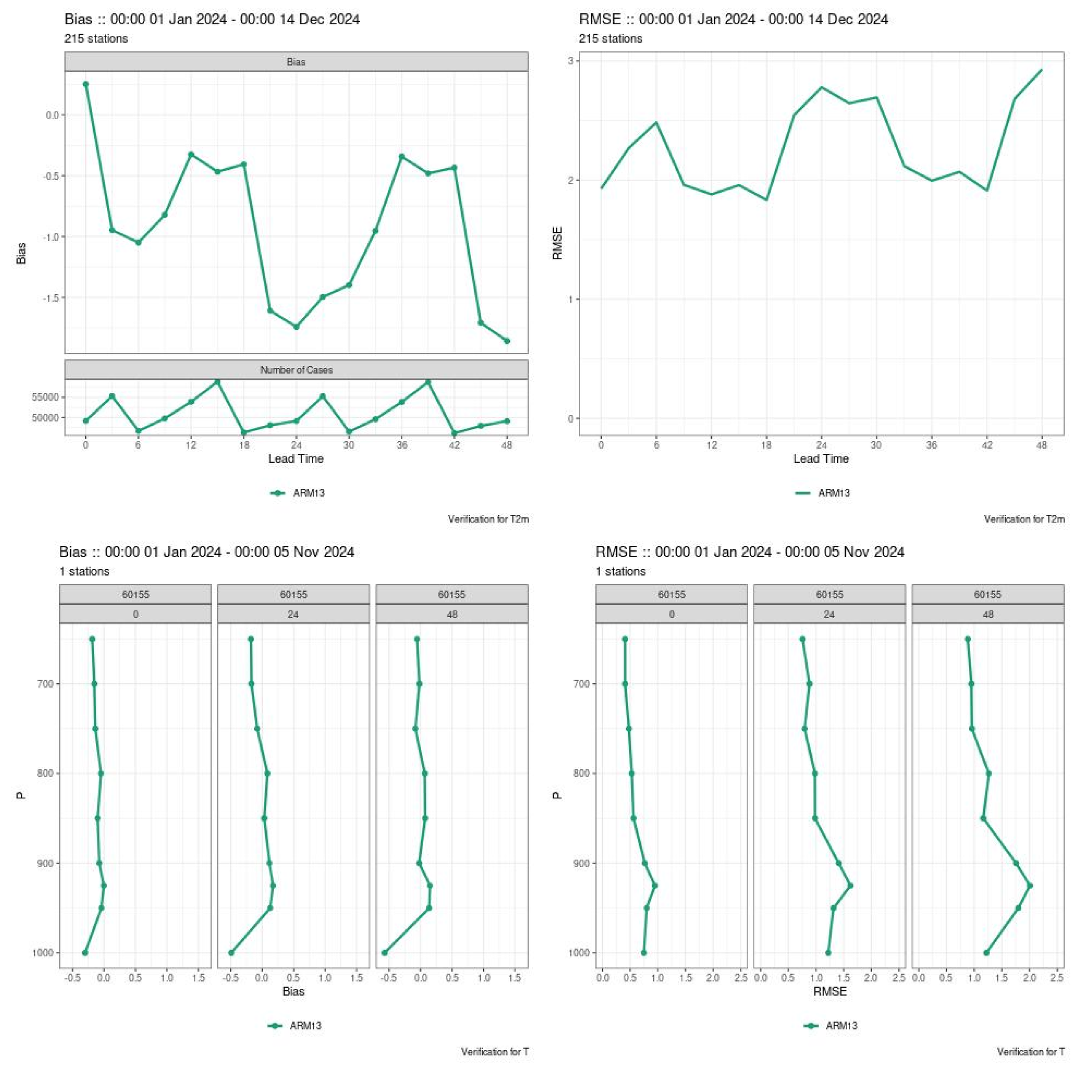


Spatial distribution of observation stations over Morocco.

Temperature (Surface and Upper-Air)

Temperature is evaluated at the surface (2 m) and along the vertical profiles using radiosonde observations. The model shows a systematic cold bias at the surface, which persists across all forecast lead times. This bias indicates a general underestimation of near-surface temperature. The error magnitude increases with forecast range, as shown by the RMSE. In the vertical profiles, the largest errors are observed in the lower troposphere, while the model performs better at higher levels.

- Persistent cold bias at surface
- RMSE increases with lead time
- Errors decrease with altitude

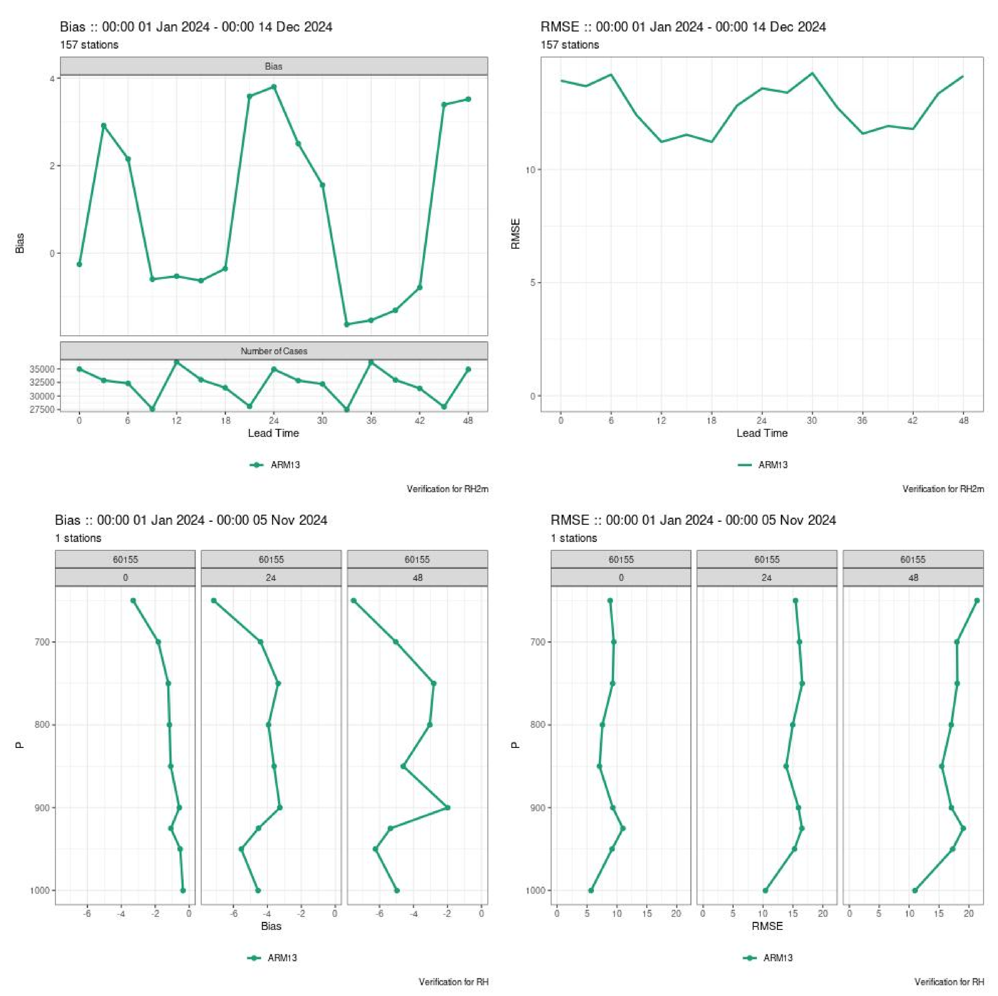


Surface (top) and vertical profiles (bottom)

Relative Humidity (Surface and Upper-Air)

Relative humidity is evaluated at both surface and upper-air levels, showing different behaviors depending on altitude. At the surface, the bias exhibits strong spatial variability, with both positive and negative values across the domain, indicating no clear dominant tendency. In contrast, the vertical profiles reveal a systematic negative bias, indicating an underestimation of relative humidity throughout the troposphere. This underestimation is more pronounced in the lower layers (1000–850 hPa). The RMSE remains relatively high, especially in the lower troposphere, and increases with forecast lead time.

- Surface: strong spatial variability of bias
- Upper-air: systematic underestimation
- Larger errors in lower troposphere
- RMSE increases with lead time

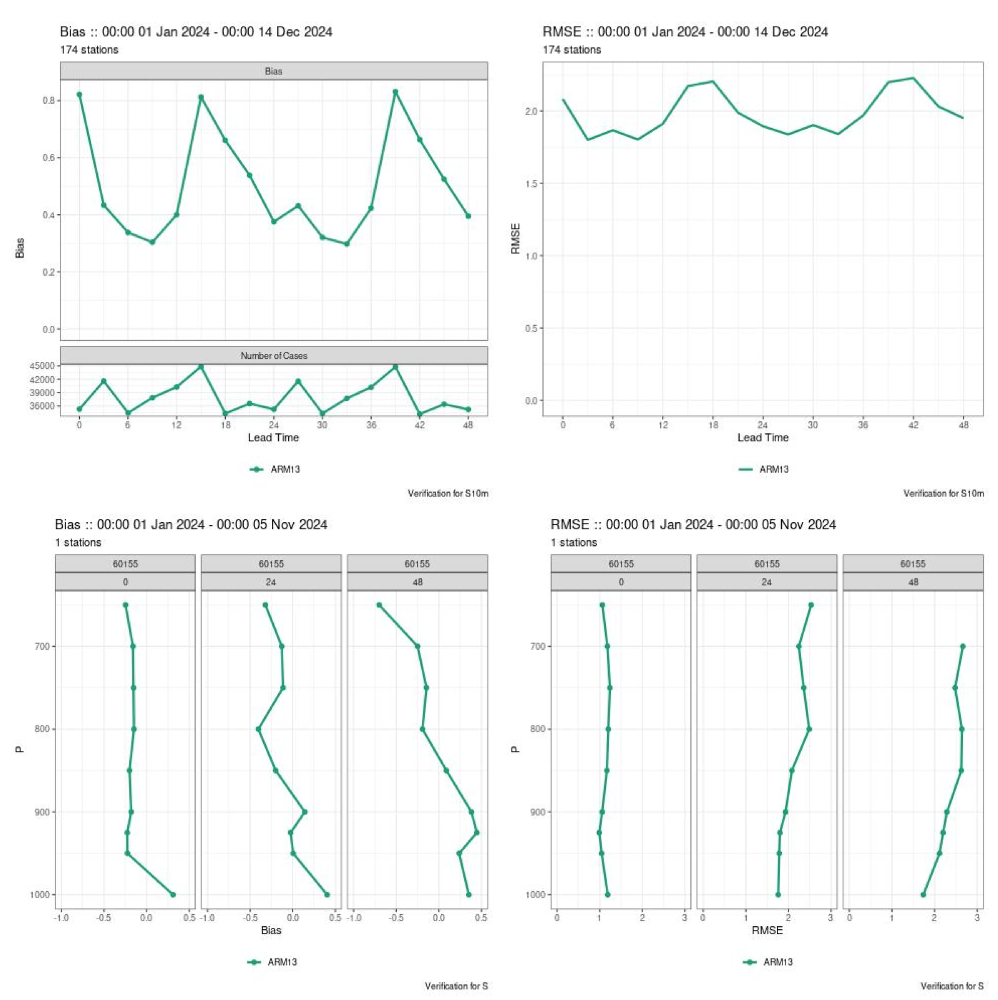


Surface (top) and vertical profiles (bottom)

Wind (Surface and Upper-Air)

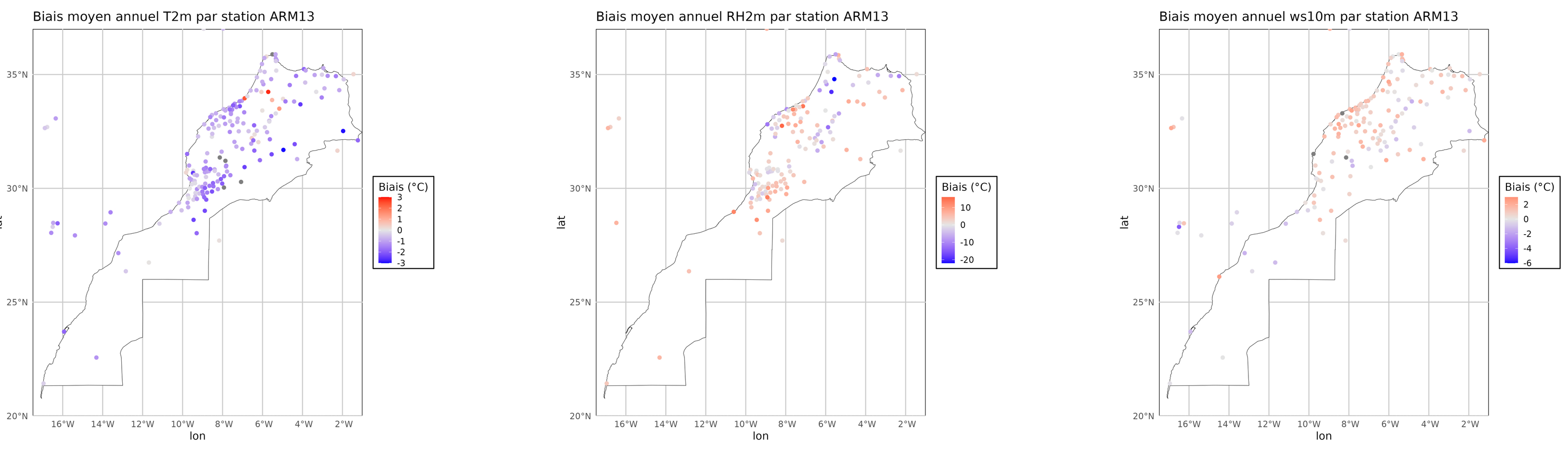
Wind is showing a consistent behavior across forecast lead times. At the surface, the bias is systematically positive, indicating a persistent overestimation of wind speed with moderate variability depending on lead time. The RMSE remains relatively stable, around 2 m/s, suggesting moderate and consistent errors.
In the vertical profiles, the bias is weak and generally close to zero, with slight negative values in the lower troposphere. The vertical structure remains similar across all lead times. The RMSE ranges between 1.5 and 3 m/s, with higher values in the lower troposphere.

- Surface: systematic overestimation
- Upper-air: weak bias, near zero
- Larger errors in lower troposphere
- RMSE relatively stable with lead time



Surface (top) and vertical profiles (bottom)

Spatial Distribution of Mean Bias (Surface)



Temperature (left), humidity (center), and wind (right)

The spatial distribution of mean bias highlights significant regional variability in model performance across Morocco. Temperature shows a predominantly negative bias over most stations, indicating a systematic underestimation across the domain. Humidity exhibits a highly heterogeneous pattern, with both positive and negative biases, reflecting strong spatial variability and no clear dominant tendency. Wind bias is generally positive over a large number of stations, indicating a tendency of the model to overestimate wind speed, with some localized negative values.

- Temperature: widespread negative bias
- Humidity: strong spatial variability (mixed bias)
- Wind: predominantly positive bias

Precipitation

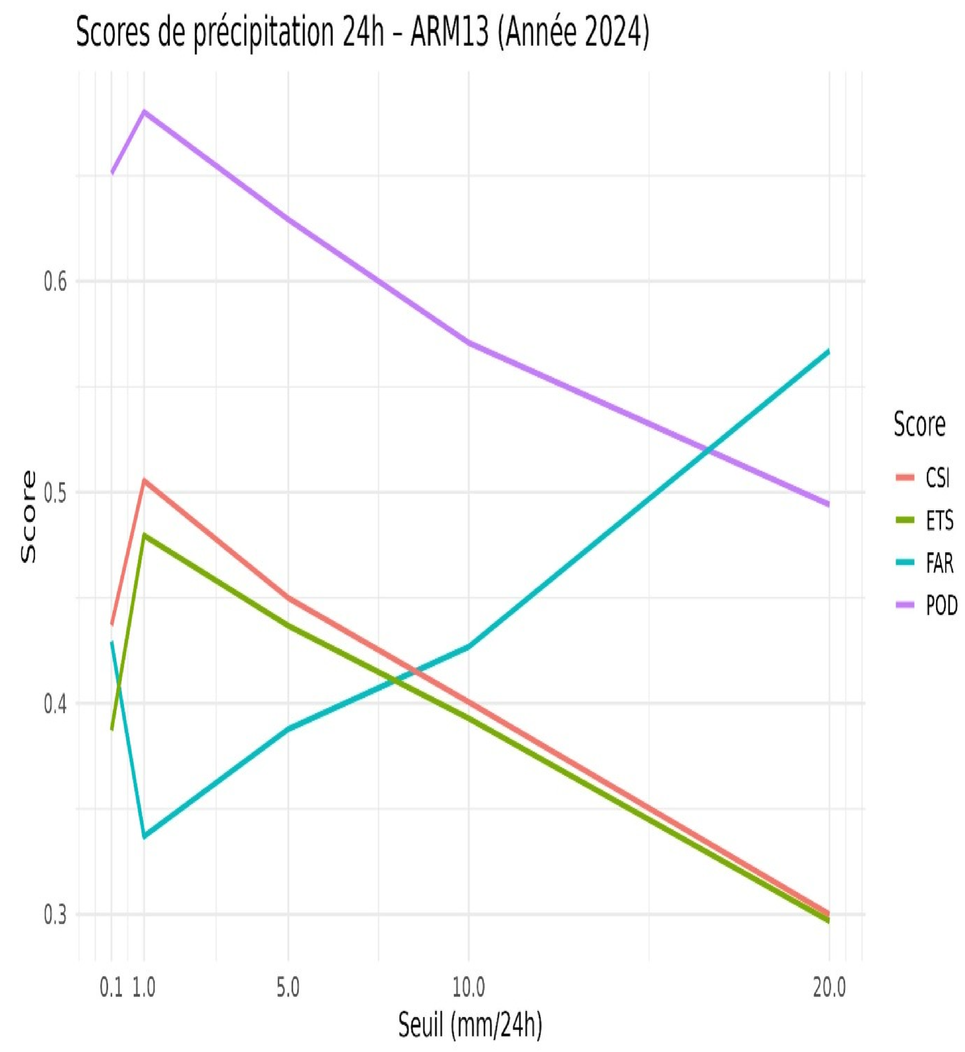
Precipitation is evaluated using categorical verification scores, which assess the ability of the model to detect rainfall events.

Scores used:

- CSI (Critical Success Index): overall forecast skill
- ETS (Equitable Threat Score): accounts for random hits
- FAR (False Alarm Ratio): proportion of false alarms
- POD (Probability of Detection): ability to detect events

The results show a strong dependence on precipitation intensity.

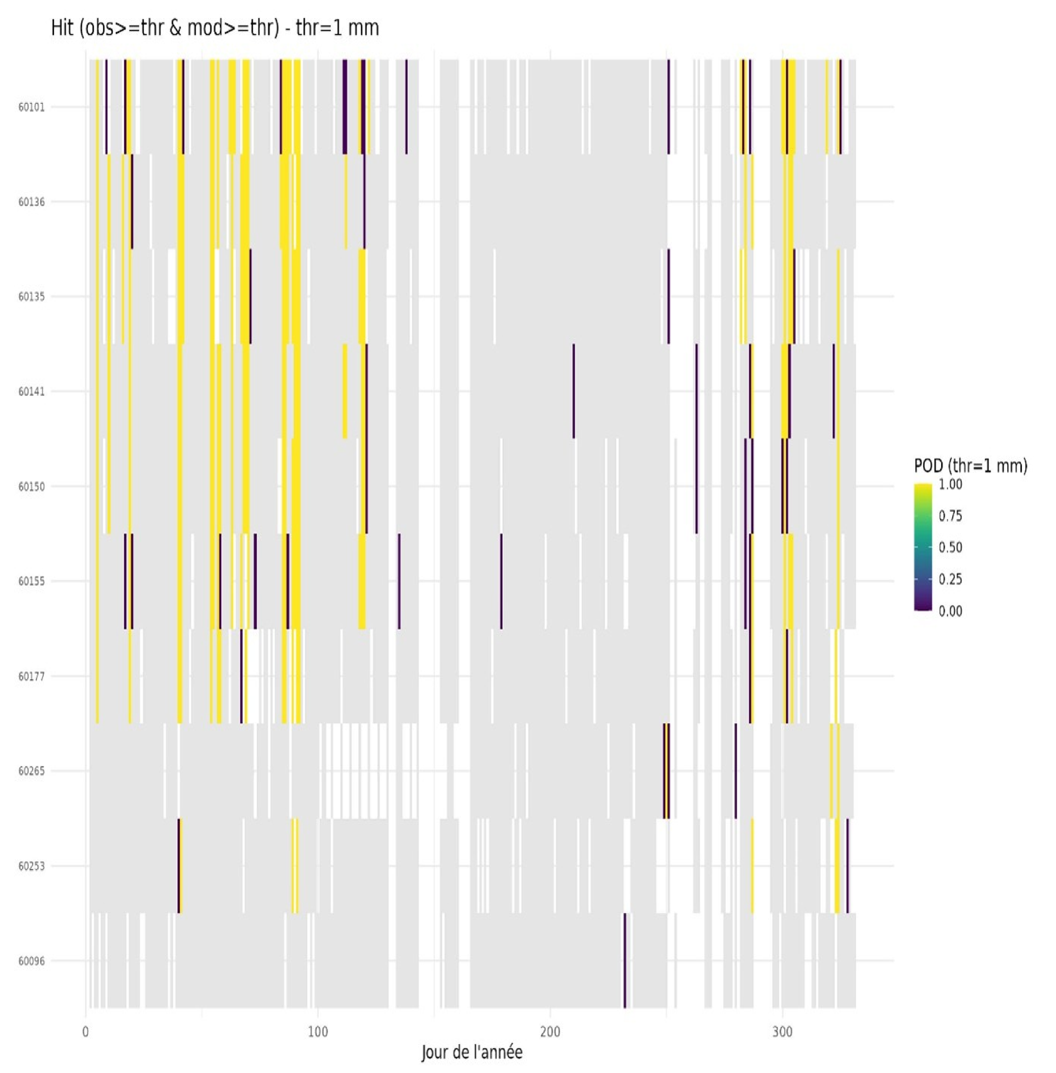
- CSI and ETS decrease with increasing thresholds
- FAR increases for heavy rainfall
- POD remains higher for light precipitation



Evolution of verification scores with thresholds

The hit diagram provides a detailed view of detection performance for precipitation events. It highlights the relationship between hits, misses, and false alarms. The model shows good detection for light precipitation events, while performance decreases for more intense rainfall.

- Good detection of weak events
- Increasing false alarms for stronger events
- Reduced performance for heavy precipitation



Event detection performance

Conclusion and Perspectives

Conclusion

This study provides a comprehensive evaluation of the AROME 1.3 km model over Morocco using surface (SYNOP) and upper-air (radiosonde) observations.

At the surface, the model shows a systematic underestimation of temperature, while relative humidity exhibits strong spatial variability without a clear dominant bias. Wind speed is generally overestimated, although errors remain moderate.

In the vertical profiles, temperature is well represented with limited bias, while relative humidity shows a systematic underestimation, especially in the lower troposphere. Wind presents a weak bias close to neutral, with moderate errors.

For precipitation, the model demonstrates a good ability to detect light rainfall events, but skill decreases as the threshold increases, with higher false alarm rates for heavy precipitation.

Overall, the largest errors are concentrated in the lower troposphere, highlighting the sensitivity of near-surface processes.

Perspectives

Several perspectives can be considered to improve model performance:

- Extend verification to extreme events (temperature, wind, heavy precipitation)
- Improve representation of near-surface processes and boundary layer dynamics
- Refine precipitation verification using advanced scores and event-based approaches
- Strengthen observation network quality and coverage for more robust validation
- Move toward higher spatial resolution (500 m) to better capture local-scale processes

This work contributes to improving high-resolution forecasting over Morocco and supports future developments toward more accurate and locally adapted prediction systems.