

A Satellite-Based Climatology of Fog and Low Stratus to Support Nature-Based Water Harvesting in Arid Areas of Morocco

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Abstract

Addressing water scarcity in arid Morocco, this study maps fog and low stratus (FLS) clouds using 2020–2024 SEVIRI/MSG satellite hourly data to identify potential water-harvesting sites. By applying a validated, high-resolution nighttime detection algorithm to this climate and geography heterogenic region (Fig.1), we set up the first comprehensive FLS climatology. The analysis identified two major, persistent FLS hotspots along the Atlantic coast, with high detection reliability. These hotspots coincide with high fog-water harvesting potential, offering a climate-resilient solution to water shortages. These findings are crucial for pinpointing high-potential areas for future water-harvesting infrastructure.

Background & Objectives

- Background & problem statement

- Morocco is facing recurring droughts, as confirmed by its third national communication to the United Nations Framework Convention on Climate Change, which warns against the depletion of its water resources.
- Seawater desalination and waterways have been implemented. But these solutions require significant budgets and have an environmental impact.
- Fog and low stratus (FLS), despite their impact on air, sea and road transport, constitute a valuable natural water resource by the more cost-effective and eco-friendly harvesting fog method.
- Implementing this solution requires mapping FLS distribution nationwide to identify target areas. However, this is challenging due to Morocco's diverse landscapes and climate, coupled with a sparse ground-based observation network.
- Satellite remote sensing is a pertinent approach, offering consistent spatial and temporal monitoring capabilities.

- Objectives

- Develop a climate-adaptive, nighttime FLS detection algorithm specific for Morocco's diverse environmental zones;
- Produce the first high-resolution climatology detailing FLS occurrence at night, spanning 2020–2024;
- Assess satellite detection accuracy using SYNOP ground observations;
- Identify high-yield areas for implementing fog harvesting infrastructure.

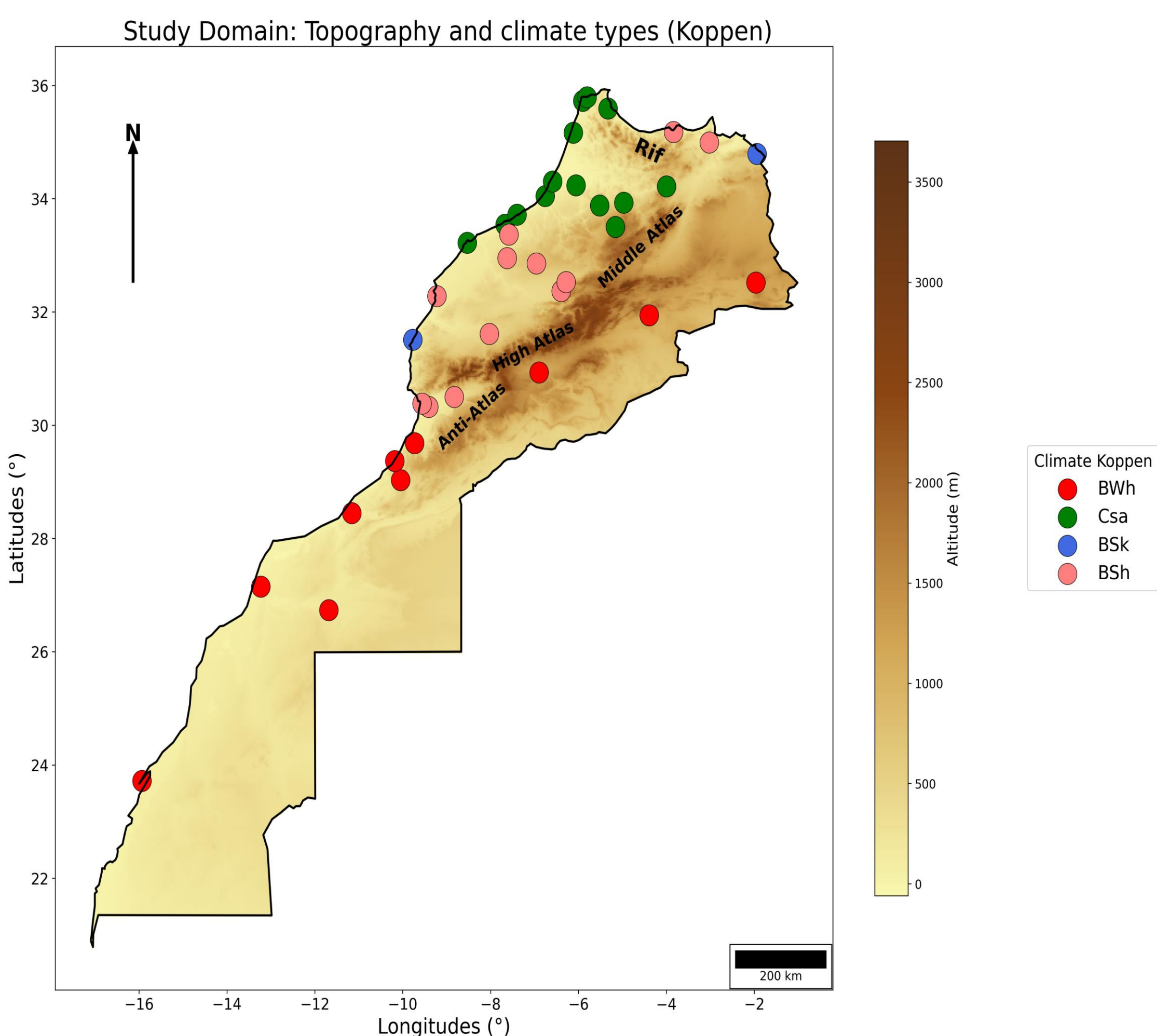


Fig. 1. The map illustrates the primary topography of Morocco. Plotted circles represent Moroccan synoptic station locations, color-coded by their 1991–2020 Köppen climate classification. Csa = Mediterranean climate with hot summers, BSh = hot semi-arid climates, BWh = hot desert climates, and BSk = cold semi-arid climates. The different mountain ranges are also indicated.

Methodology

- To establish a complete, continuous spatial climatology of nocturnal fog over Morocco, specific detection thresholds must first be defined
- Threshold definition relies on analyzing radiative signal evolution during transitions between clear surfaces, fog layers, and upper cloud layers
- Hourly Meteosat Second Generation (MSG) SEVIRI data, spanning 2020 to 2024, were utilized, with particular focus on the 3.9, 8.7, 10.8, and 12.0 μm infrared channels
- This method identifies fog and low stratus (FLS) by analyzing brightness temperature profiles (BT/BTD) along a linear transect, leveraging the low spatial variability of FLS compared to heterogeneous backgrounds, making it a physically relevant detection approach.

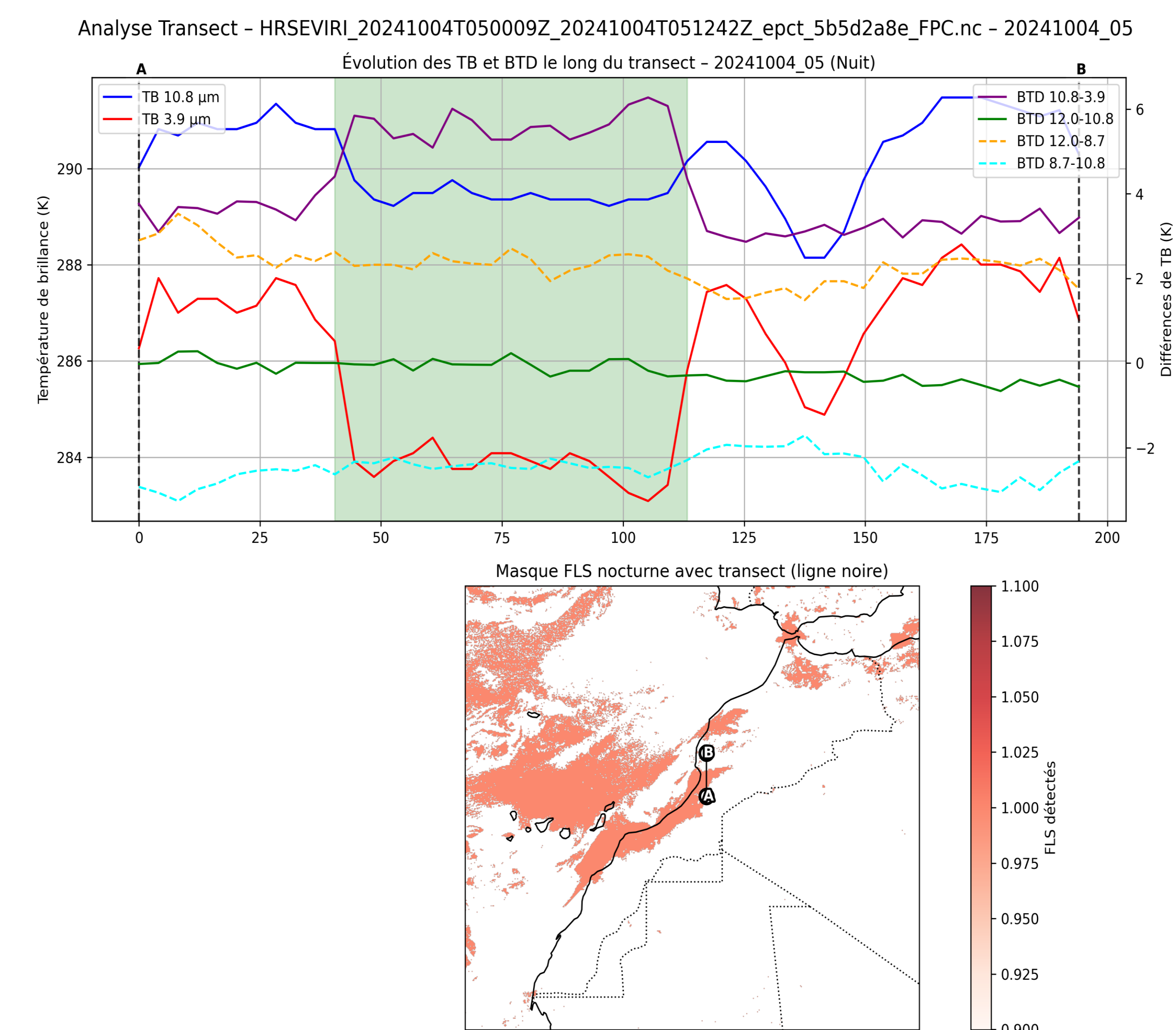


Fig. 2. Analysis of TB (10.8, 3.9 μm) and BTD (12.0–10.8, 12.0–8.7, 10.8–3.9, 8.7–10.8 K) evolution along cross-section A-B (top) and corresponding map (below) of the FLS event in the Agadir region (Oct 4, 2024, 05:00 UTC). Shaded region indicates the FLS zone.

Assessment

Algorithm performance was evaluated against surface meteorological observations (SYNOP) using a contingency table to classify results as true positives (TP), true negatives (TN), false positives (FP), and false negatives (FN). Four standard verification indicators were then calculated to determine the relevance threshold:

- ✓ The Probability of Detection (POD), representing the proportion of observed FLS events correctly identified by the algorithm;

$$POD = \frac{TP}{TP + FN}$$

- ✓ The False Alarm Ratio (FAR) quantifies the proportion of detected events not corroborated by observations;

$$FAR = \frac{FP}{TP + FP}$$

- ✓ The Bias metric evaluates the ratio of detected to observed events;

$$Bias = \frac{TP + FP}{TP + FN}$$

- ✓ The Critical Success Index (CSI) provides a comprehensive measure of detection accuracy by accounting for both false alarms and misses.

$$CSI = \frac{TP}{TP + FP + FN}$$

Results

Discrimination of FLS from Sandy Areas

The application of the regionally adapted thresholds yielded a substantial improvement in the remote sensing detection of FLS over Morocco. This advancement is clearly illustrated by the analysis of the 4 October 2024, 05:00~UTC case: pixels corresponding to desert sandy surfaces, which were previously misclassified as FLS when applying generic thresholds, are now correctly excluded.

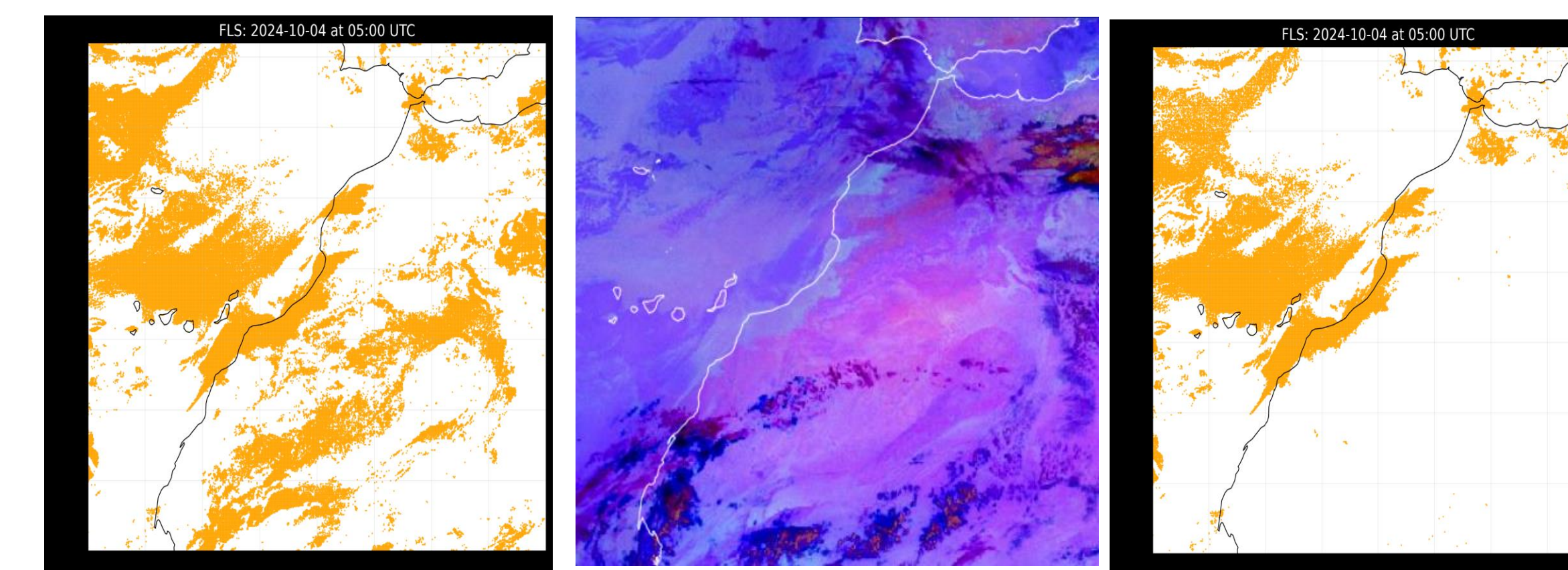


Fig. 3. Comparison of Fog/Low Stratus (FLS) detection: (Left) Generic threshold method, (Center) Reference Eumetview product (MSG infrared, FLS in green), and (Right) Developed algorithm results.
Date : 4 October 2024 at 05:00~UTC

Metrics

Metric	POD	FAR	Bias	CSI
Value	81.2%	48.1%	1,58	0,46

Table.1. FLS detection performance metrics

Comparison between detected FLS and ground meteorological observation network

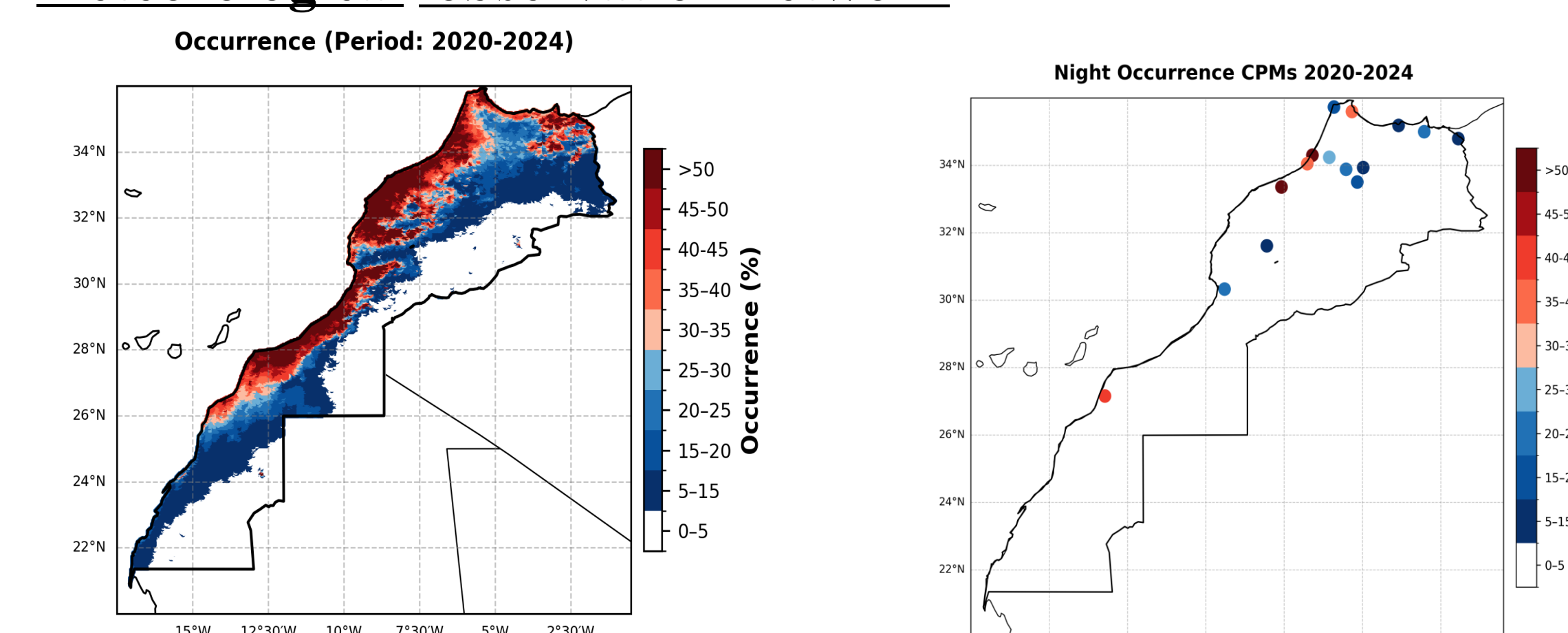


Fig. 4. (Left) Satellite-derived relative frequency (%) of nighttime FLS occurrence, 2020–2024. (Right) Ground-observed relative frequency (%) of nighttime FLS occurrence for the same period.

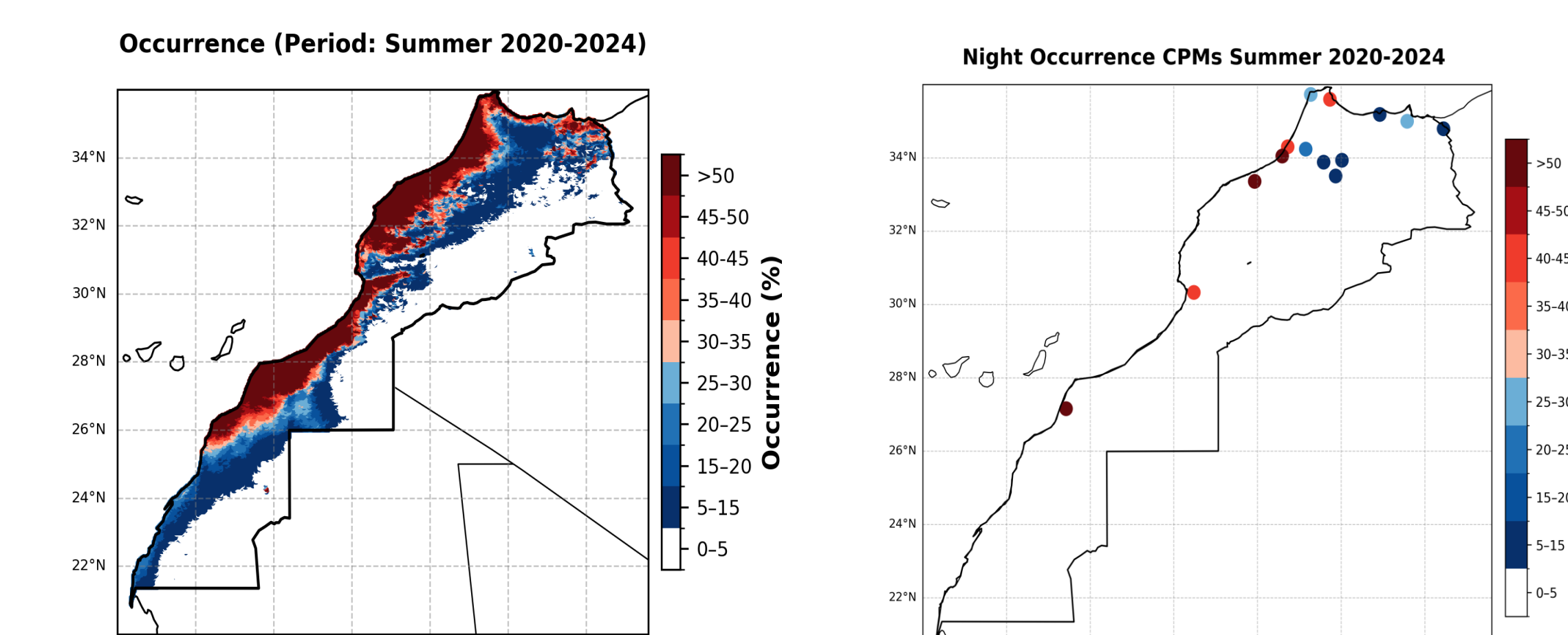


Fig. 5. Frequency of summer nighttime FLS detected by the (Left) developed algorithm and (Right) surface meteorological observations (period: 2020–2024).

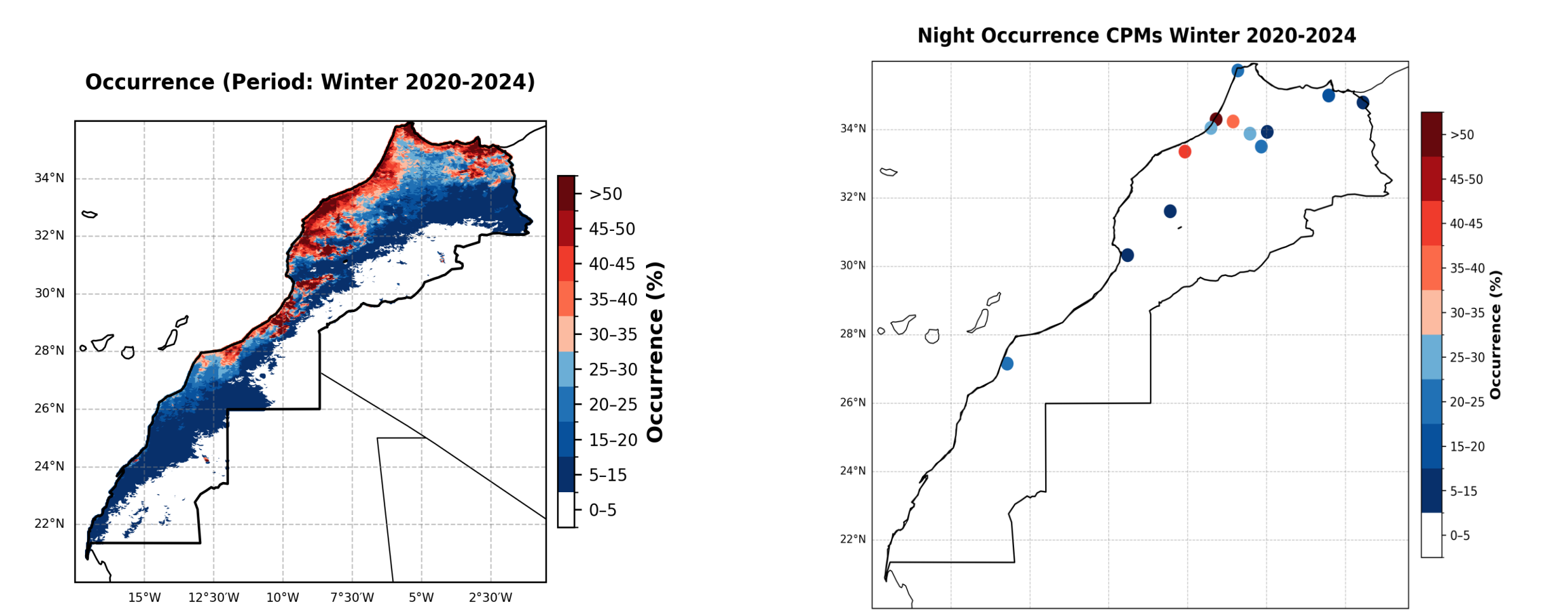


Fig. 6. Frequency winter nighttime FLS detected by the (Left) developed algorithm and (Right) surface meteorological observations (period: 2020–2024).

Discussion

- By resolving the radiative ambiguity between sandy deserts and low-level liquid clouds, the proposed algorithm achieves a detection probability over 0.80 and a critical success index of 0.46, matching the performance of operational satellite fog detection systems in other regions
- Reliable detection of night FLS over heterogeneous climates in Morocco is achieved using regionally optimized MSG-SEVIRI thresholding. This adaptable, multi-spectral method shows high effectiveness, making it suitable for implementation across other arid zones
- By analyzing five years of data, this method highlights stable, recurring spatial and seasonal patterns in nocturnal FLS events. These findings significantly help climate monitoring, transportation safety, and remote sensing. Furthermore, the method supports water management by identifying best, eco-friendly, and cost-effective locations for fog harvesting.

Conclusions

- Adapting spectral thresholds to local emissivity and manipulating the 8.7–10.8 μm brightness temperature difference (BTD) are effective for reducing false alarms in generic FLS detection algorithms over sandy deserts
- Validation against ground-based data confirms that thresholding techniques are highly effective for operational remote sensing in climatology heterogeneous, arid regions like Morocco. These methods offer a transparent, reliable alternative to 'black-box' machine learning models
- A five-year nighttime climatology, established using this adapted algorithm, reveals distinct spatial and seasonal zones of FLS occurrence. Areas of high persistent FLS concentration are identified along the northwest and southwest Atlantic coasts, with a marked decrease inland, corresponding to the region's dynamic meteorology
- Seasonal analysis reveals a summer maximum, providing essential data to optimize fog harvesting in arid regions and enhance transport safety
- By offering spatial continuity that overcomes the limitations of sparse ground networks, this satellite-derived product enables the identification of high-potential sites for water collection infrastructure
- As perspectives, the future work includes extending detection capabilities to daytime hours and deploying a pilot fog collector.

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