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Honeybee colonies are vital to ecosystems and agriculture, pollinating over 75% of food crops. However, environmental pressures, pathogens, and climate change pose serious threats to their survival. Early disease detection is essential to preventing colony losses and limiting pathogen spread. An ideal solution would forecast pathogen risks before an outbreak, allowing beekeepers to proactively protect their colonies through targeted supplementation or increased vigilance, especially for diseases with no available treatments or with treatments of limited efficiency.

Apisense has developed an innovative system integrating IoT sensors, artificial intelligence (AI), and satellite data to predict disease outbreaks and enhance apiary biosecurity. In-hive IoT sensors analyze volatile organic compounds (VOCs) and other environmental parameters, providing real-time insights into colony health. The collected data is transmitted to a cloud-based platform, where AI-driven algorithms detect patterns linked to key bee diseases, including Varroosis, Nosemosis, and American and European Foulbrood. At the same time, satellite imagery and meteorological data help assess environmental risk factors such as vegetation phenology, nectar availability, and climate conditions. Machine learning models process these multi-source datasets to predict outbreaks and map disease spread, providing early warnings for beekeepers and regulatory agencies. Field tests confirmed the system's effectiveness, achieving 86% accuracy in Varroa detection and 88% accuracy for Nosema identification.

Early warnings enable beekeepers to take preventive action, particularly against highly contagious diseases such as foulbrood, where timely intervention is critical. By enhancing early detection and leveraging predictive analytics, the solution supports sustainable beekeeping, by reducing chemical treatments and strengthening hive biosecurity across large areas. Since a single set of devices can cover up to 30 km², a country the size of Denmark would need only 1,500 sets to monitor and control the spread of diseases effectively.



Integrating IoT, AI, and satellite data
for predicting the spread of bee diseases
and enhancing apiary biosecurity.



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Introduction

Current methods for predicting bee disease spread

- Poland: American foulbrood

Existing modelling tools:

- Main focus: honey bee colony development,
- Some focused on specific behaviours (e.g., swarming, nest selection).



Why it matters?

Pollinator health = global food security

Diseases

Varroa destructor

Nosema spp.

American & European foulbrood

Chalkbrood

Spread driven by:

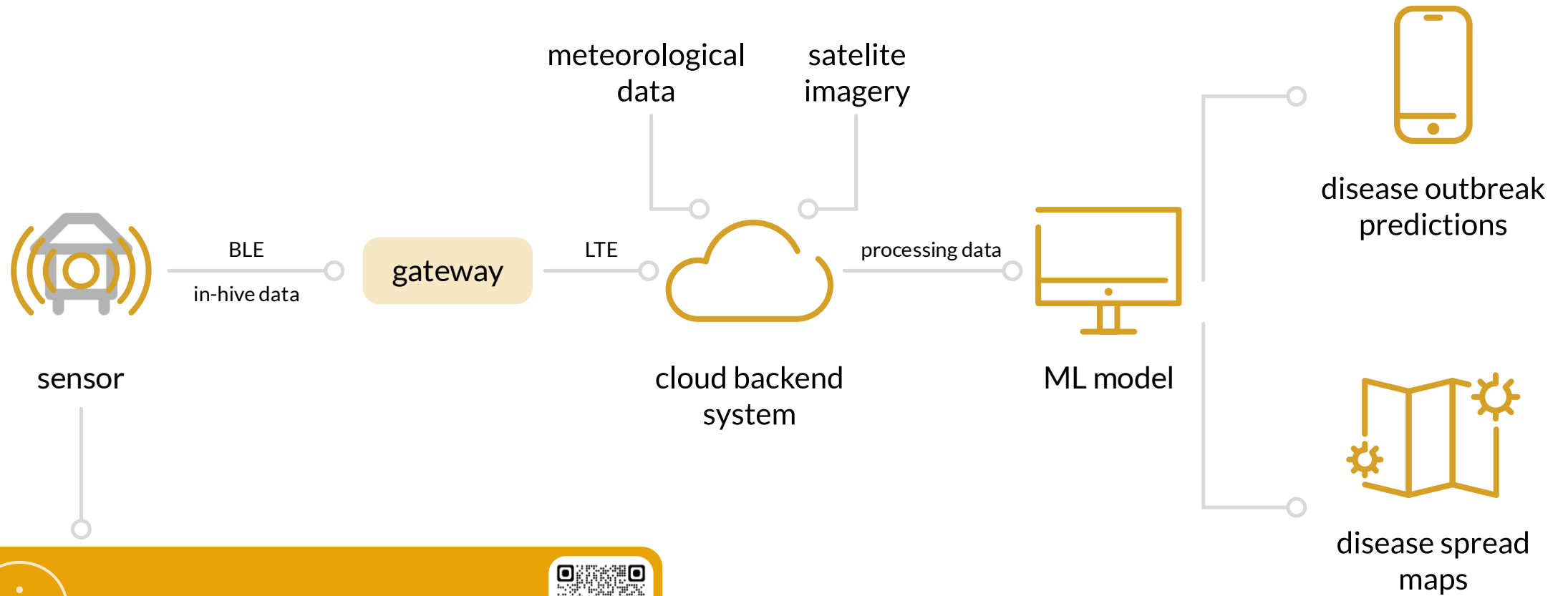
- Bee foraging overlap
- Beekeeping practices
- Environmental conditions



Need

Early warning & spatial risk prediction

How to predict the bee disease spread?



More details on poster PP-213



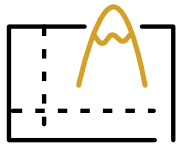
Data sources



Apiary registry: location, colonies count



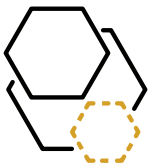
In-hive disease AI predictions



Remote sensing: LULC, DEM, slope



Weather forecasts: weekly updates (Weather API)



H3 grid: hexagonal spatial index

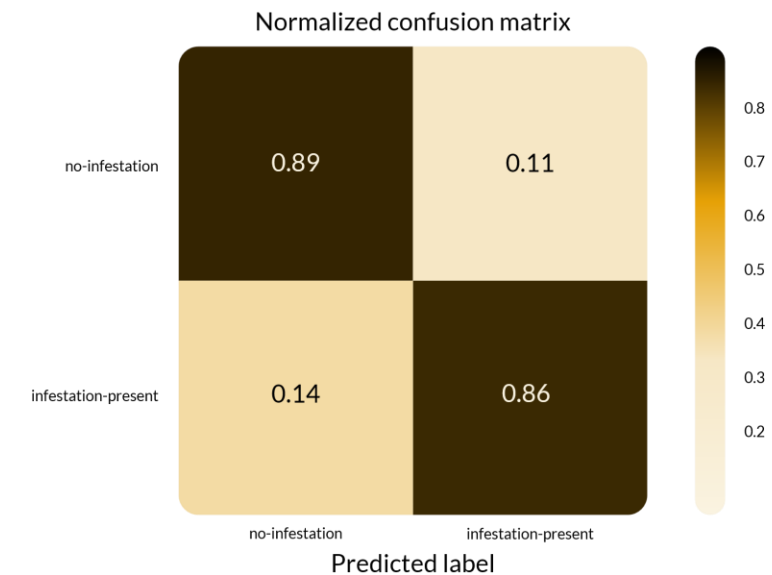
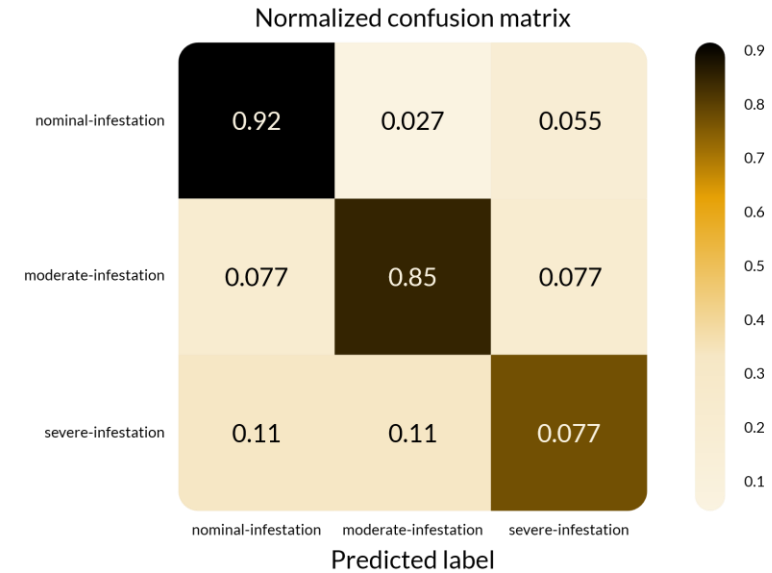


Step 1: Detect the disease

- IoT in-hive sensors:
 - temperature, humidity, pressure, NO_x, CO₂, VOC
- Aggregated into daily statistics
- Tree-based classifiers
 - XGBoost, LightGBM, CatBoost
- Disease detection accuracy (F1-Score):
 - *Varroa*: 84%
 - *Nosema*: 87%
- Evaluated using data from an experimental apiary at University of Life Sciences in Lublin



More details on poster PP-213

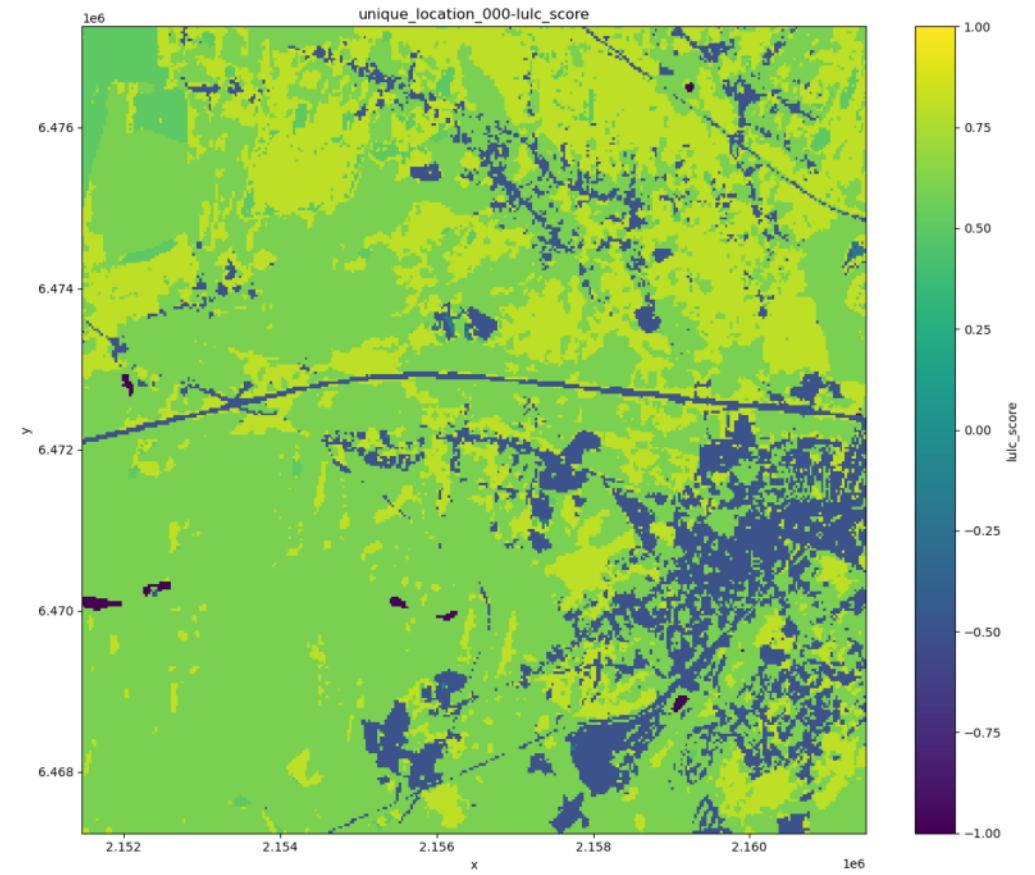
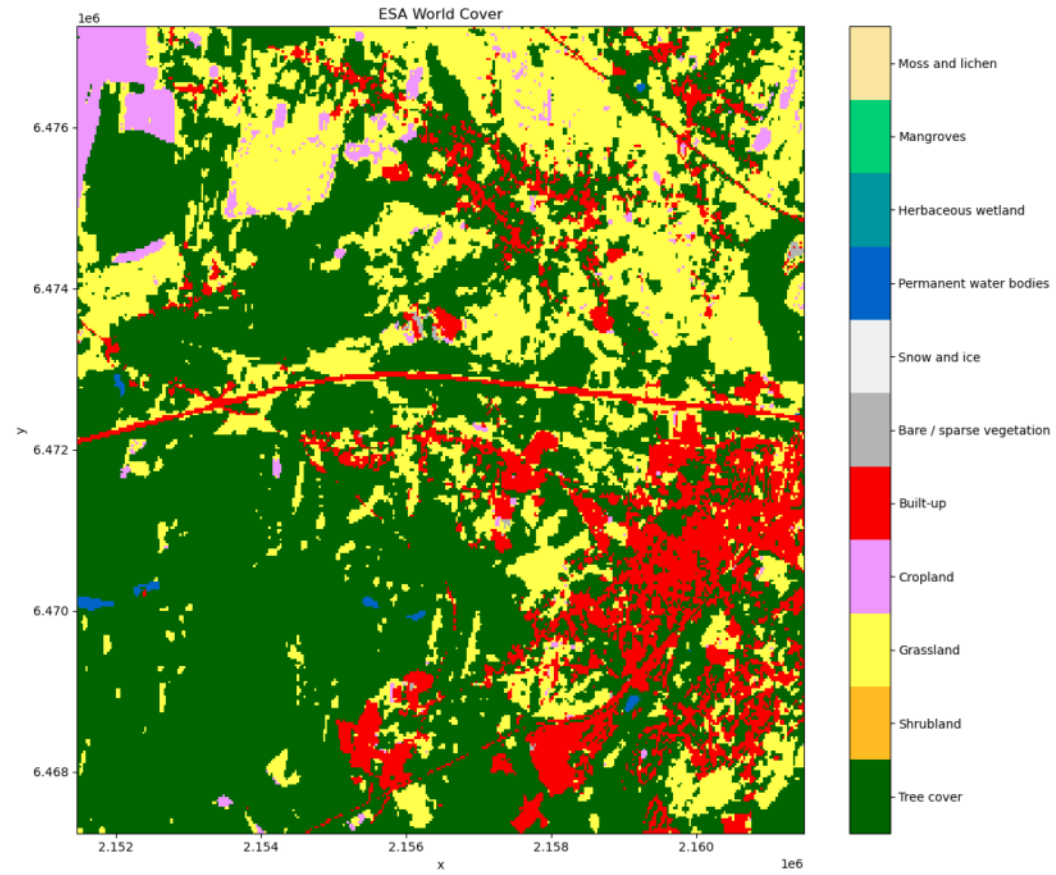


Step 2: Predict the spread

- Transmission risk model:
 - Expert-labeled H3 cells
 - Classes: None / Low / Moderate / High risk per cell
 - Metric: F1-Score (main), Accuracy, Precision, Recall
- Spread prediction model:
 - Pairs of overlapping-buffer apiaries
 - $\text{Precision} = \text{TP} / (\text{TP} + \text{FP})$

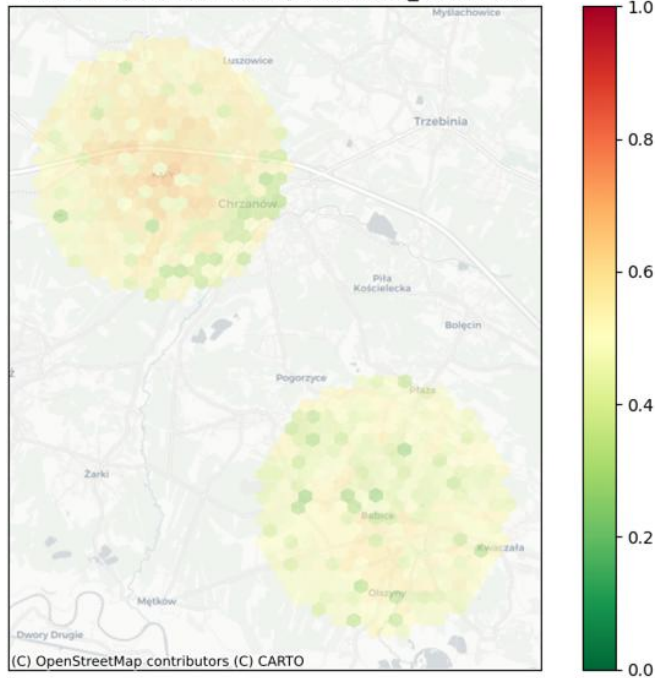


Consider land use and cover

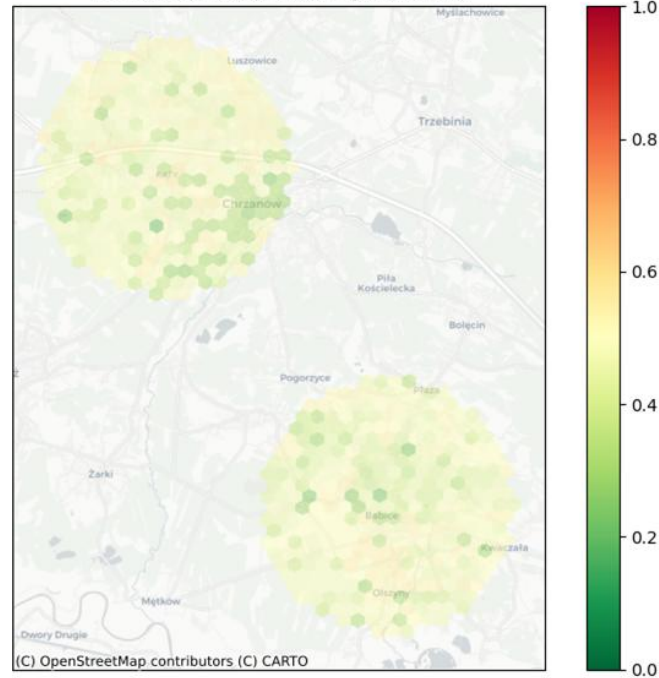


Include disease-specific differences

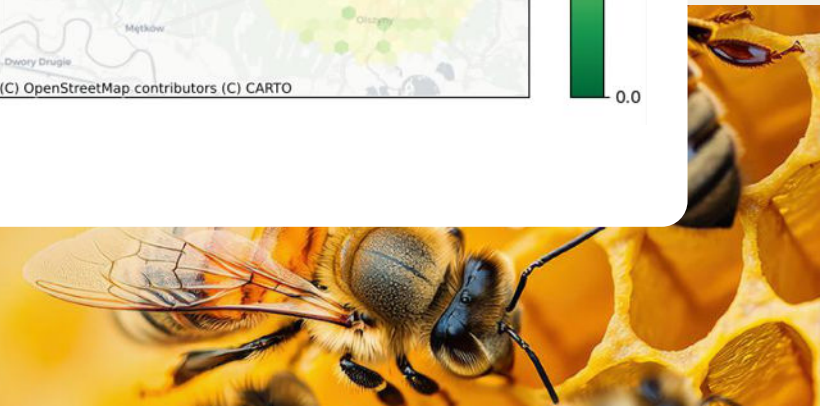
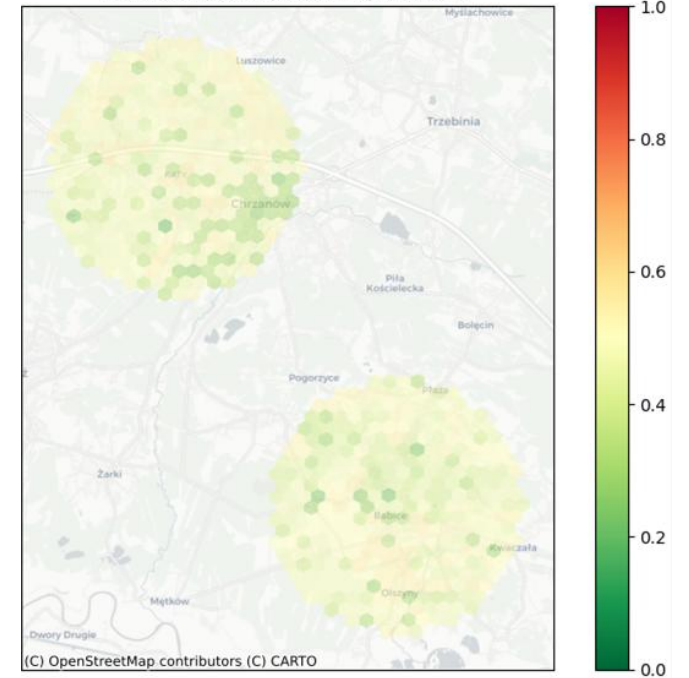
Disease spread probability (american_foulbrood)



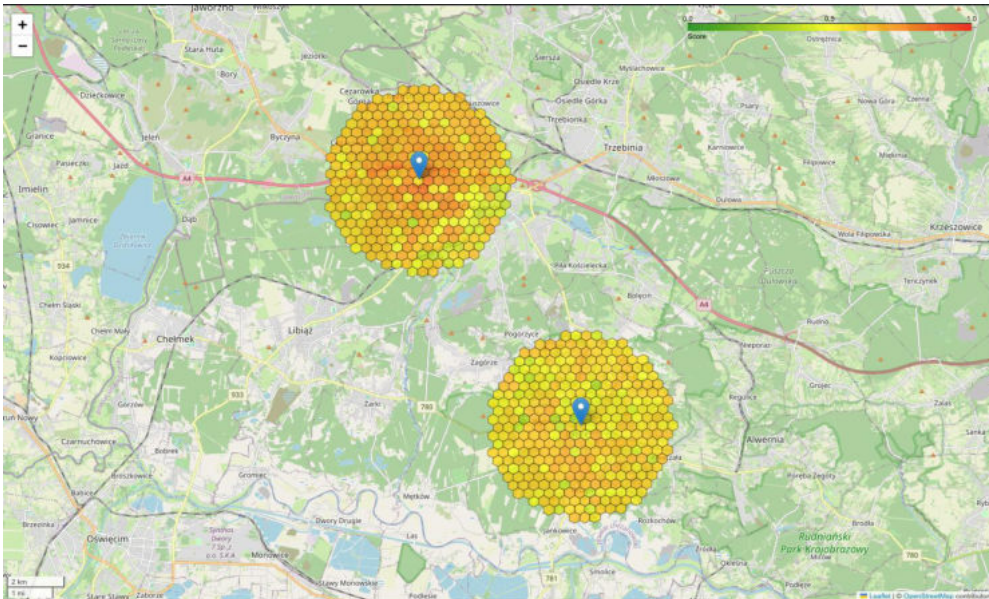
Disease spread probability (nosema)



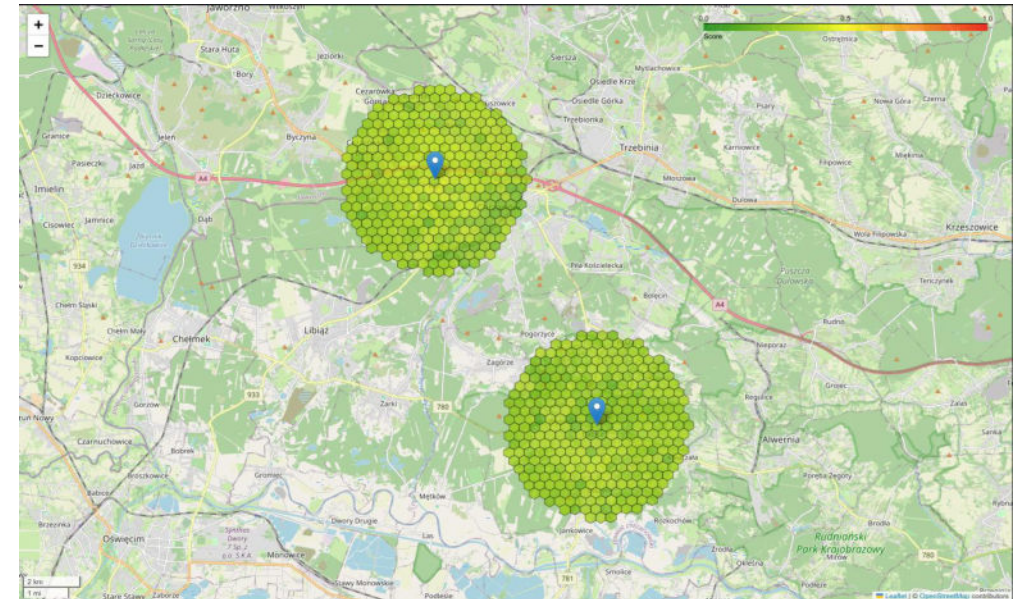
Disease spread probability (varroa)



Remember about the impact of the weather



Prediction for “**GOOD**” weather week



Prediction for “**BAD**” weather week

Preliminary results

Spread prediction precision*

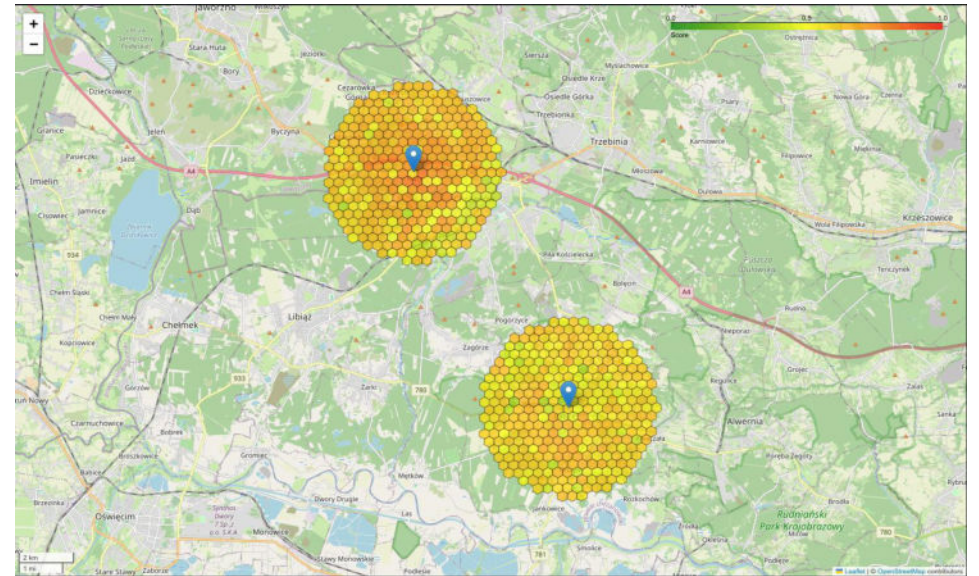
Varroa: 80%

Nosema: 84%

Transmission risk

F1 = 89%

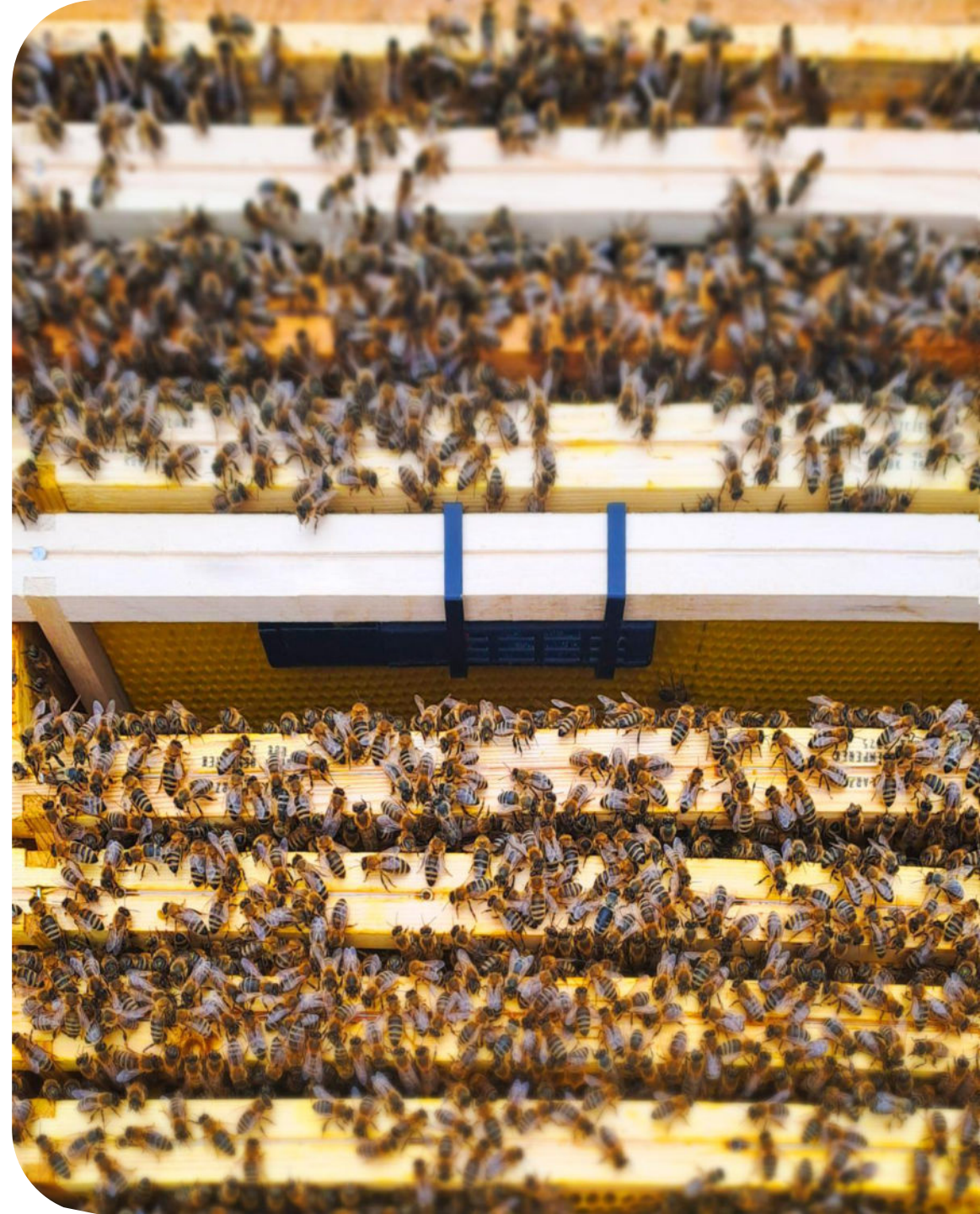
High compliance with expert risk classification



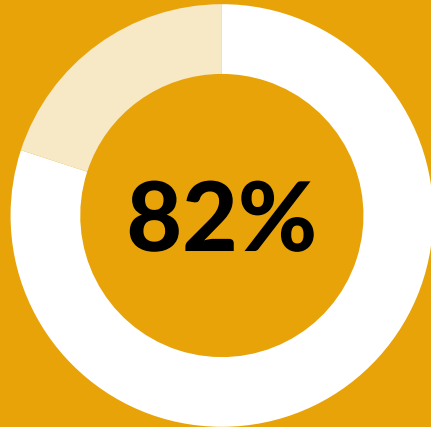
*based on 5 apiary pairs within our system

Takeaways & next steps

- IoT + spatial modeling = actionable early warnings
- Environmental layers → improved realism & accuracy
- H3 grid → scalable, consistent risk mapping
- **Next steps:**
 - Expanding dataset for monitoring and tracking inter-apiary transmission
 - Increasing frequency of model inference



Significance for beekeepers



Disease spread
prediction efficiency

Potential to reduce
colony losses

by up to **80%**



Early disease identification and
intervention possibility

Coverage of

1 sensor per
50 km²

~1 000
sensors

can cover entire
Denmark

~250k
sensors

can cover entire Europe