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Novel use of EO satellite data and AI in railways: SPATRA Project

EUSPA AI week 2026

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EUSPA
European Union Agency for the Space Programme

Usage of satellite data in railways

- The use of satellite data in railways primarily revolves around navigation and the application of Global Navigation Satellite Systems (GNSS).
- Using of Earth Observation (EO) data is a cutting-edge approach that leverages satellite technology to enhance efficiency and safety of rail networks.
- Advanced satellite sensors delivering detailed EO data, combined with AI, enable rail network management to become more efficient, effective, and safer.

Using of EO data for railway infrastructure monitoring

Existing operational EO-based solutions

- Vegetation monitoring (e.g. LiveEO)
- Ground movement monitoring (e.g. SatSense)

Fulfilled User needs

- Identification of obstructive vegetation
- Detection of ground movements

No current EO applications designed for rail temperature monitoring

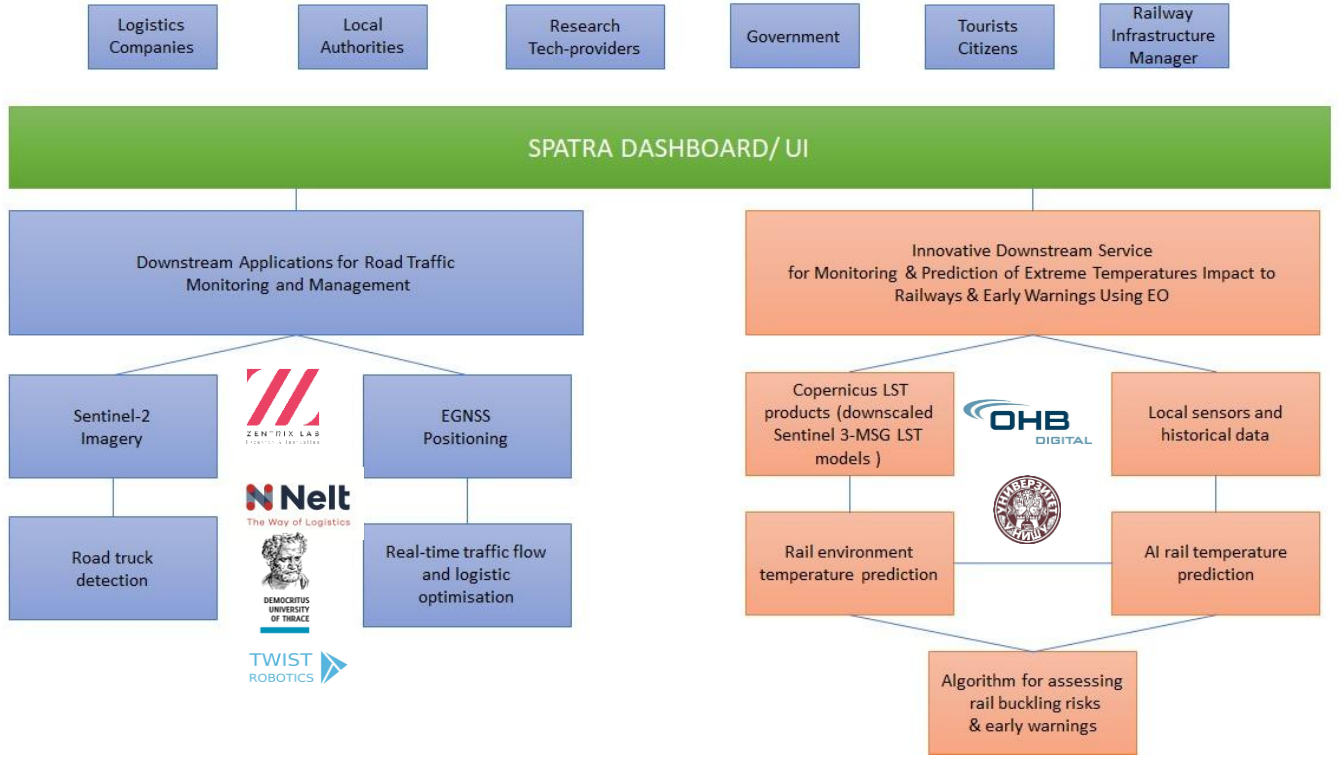
Unfulfilled User needs

- Affordable large-scale monitoring solution
- Assessment of extreme temperature induced problems

SPATRA: Space-based applications for transport monitoring and management

- **Use-case 1 - Road**
  - Combining the positioning, navigation, and timing with Earth Observation services through the use of EGNSS and Copernicus for the real-time monitoring of road traffic flow and prediction of logistics networks

- **Use-case 2 - Rail**
  - Space-based service predicting the risk of rail buckling based on downstream application for estimation of the rail temperature that can support rail management plan to prevent track buckling induced train derailments



Cross border road congestion

Lateral buckling of the track due to high temperatures

Funded by The European Union

SPATRA project has received funding from the European Union's Horizon Europe Research and Innovation Programme and EUSPA under grant agreement 101129658

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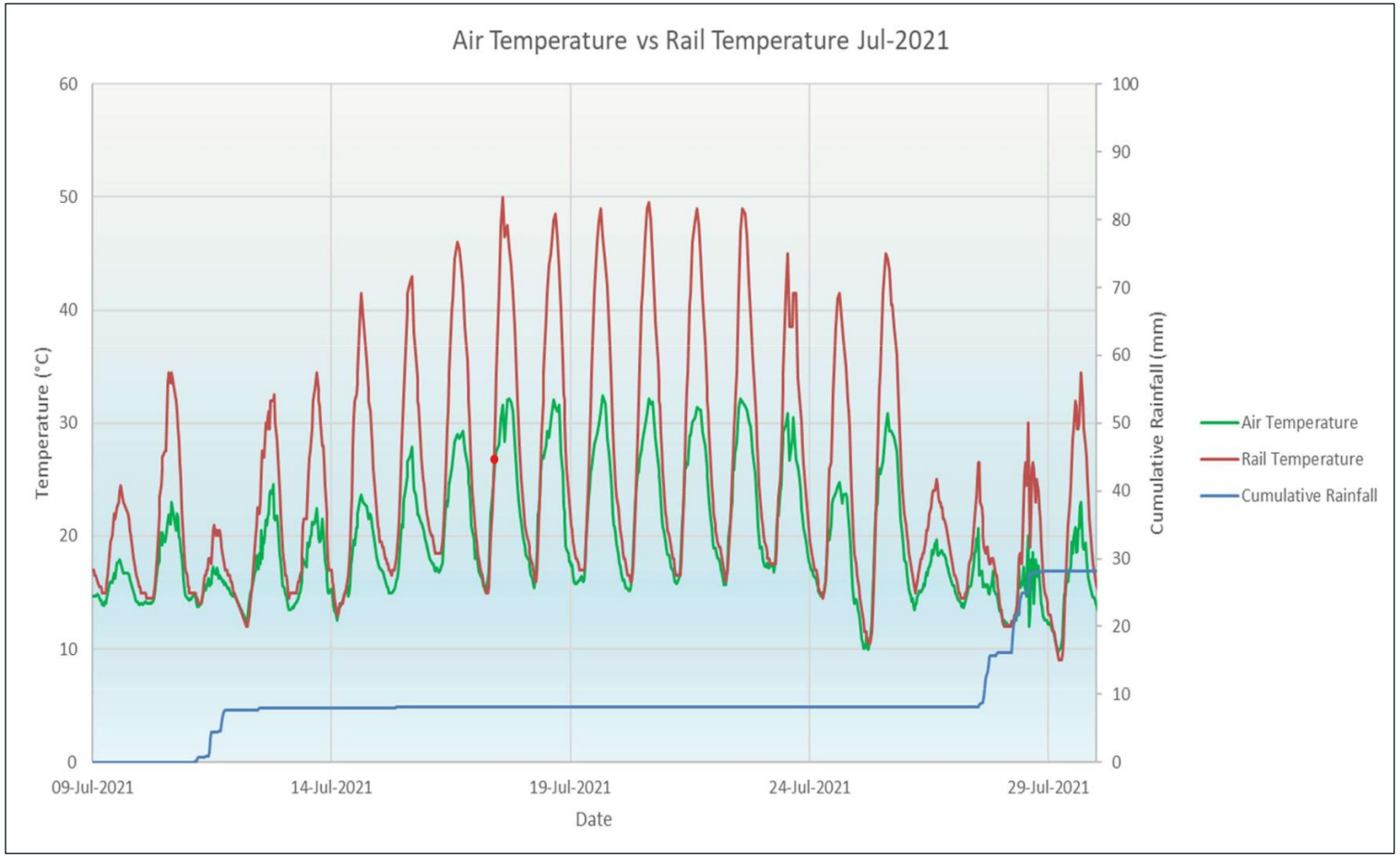
Impact of extreme temperatures to rail infrastructure

! The rail temperature can significantly exceed the air temperature.

! Especially in high temperature ranges, differences of over 20°C occur



Source: Tren Trace (2021*)

*|Trentrace. (2021). Comparison Between Air Temperature and Rail Temperature. Abgerufen 27. Mai 2024 von https://www.railtemperature.com/Research/AirRailTempCorrelation.pdf

Impact of extreme temperatures to rail infrastructure

! Temperatures above approx. 60°C are classified as critical

Quelle: DZSF(2020)

! Possible consequence: track distortions / „buckling“

Source: ABproTWE (2013)

Impact of extreme temperatures to rail infrastructure

Safety risks

- Danger of derailments
- Failure of signalling and control technology
- Increased risk of fire
- Health risks for employees and passengers

Costs

- Delays/cancellations
- Maintenance and repairs
- Energy costs

! In 2024, NetworkRail reported that buckled rails caused by hot weather led to more than 350,000 minutes – or 240 days of delays.

Satellite-based solutions vs current practice

Weather forecast

+ Cost-effective
+ Scalable
+ Predictive
- Imprecise
- Delayed in time
- Not localised

In-situ sensors

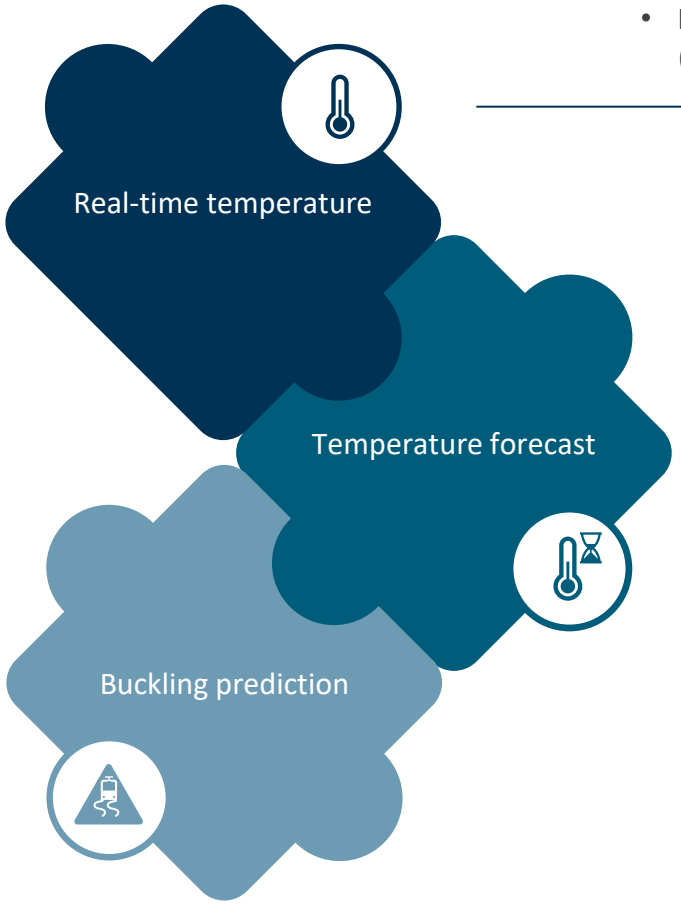
+ Precise
+ Real-time information
+ Localised
- Not scalable
- Maintenance intensive

Satellite-based Rail Temp estimation

+ Cost-effective
+ Scalable
+ Predictive
+ Precise
+ Real-time information
+ Localised

SPATRA solution for rail buckling risk estimation - Novel use of EO satellite data and AI in railways

- High-resolution Land Surface Temperature (LST) data in rail environment



- Rail track temperature prediction (RTTP)

- Rail lateral displacement prediction

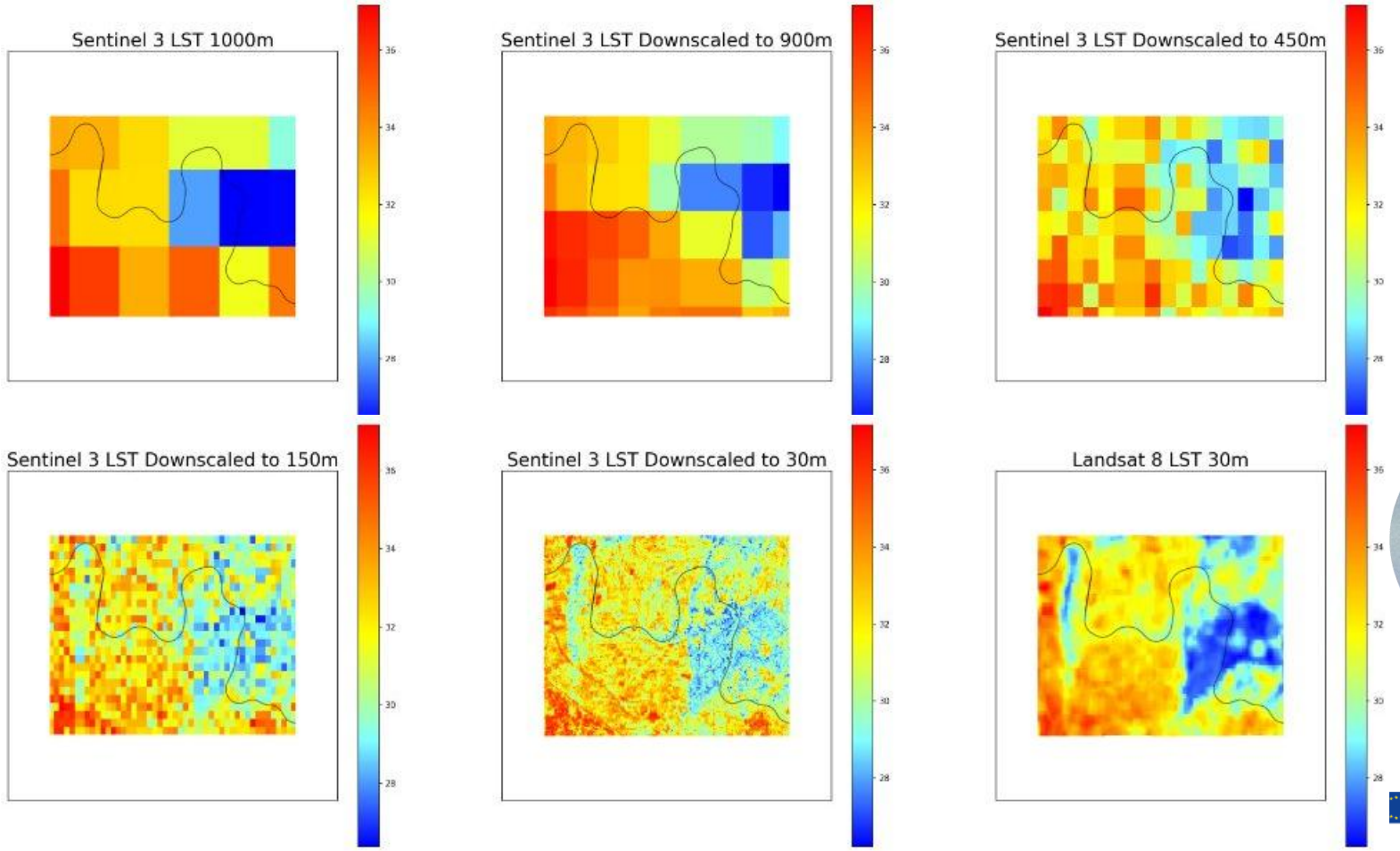
High-resolution LST data in rail environment

Thermal Downscaling

Data: Land Surface Temperature (LST) from
- Sentinel-3 (1km)
- Copernicus Land Monitoring Service (CLMS) (5km)
- Aqua/Terra MODIS (1km)

combined with optical data from Sentinel-2

Method: stepwise random forest algorithm for improvement from 1km/5km spatial resolution to 500m or finer[1]



1|Li, X.; Zhang, G.; Zhu, S.;Xu, Y. Step-By-Step Downscaling of Land Surface Temperature Considering Urban Spatial Morphological Parameters. Remote Sens. 2022, 14, 3038. https://doi.org/10.3390/rs14133038

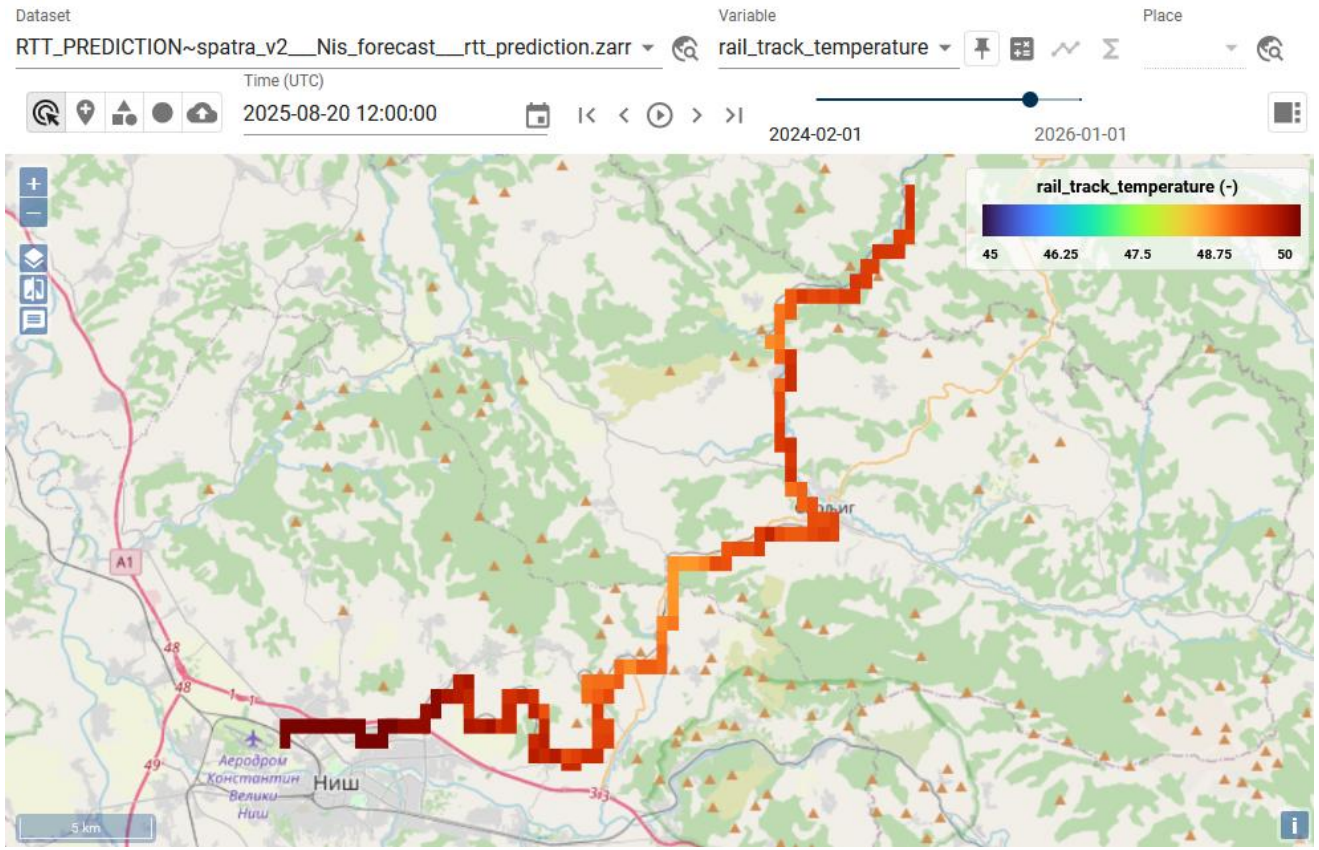
Rail track temperature prediction

Rail Track Temperature (RTT) Prediction

Data:
- in situ RTT measurements
- downscaled high-res. LST
- weather forecasts
- solar effects

Method: : eXtrem Gradient Boosting (XGBoost) algorithm to predict hourly rail track temperature[2]

Validation: using the internal - in situ data with a training-/test-data split and thermal drone measurements for validation at larger scale

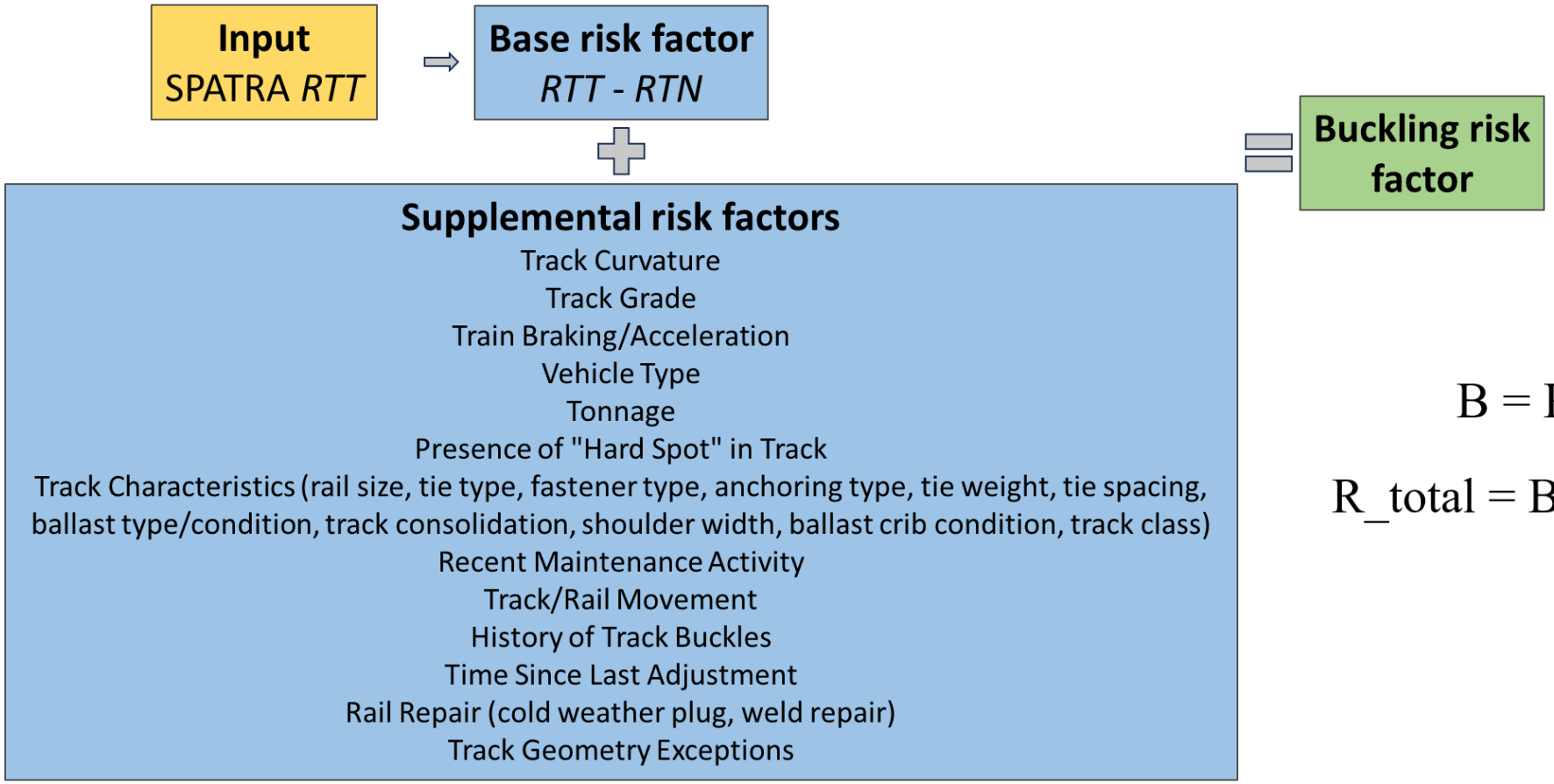


Predicted rail track temperature for test track from Niš to Svrljig, Serbia

2|Hong, S.; Park, C.; Cho, S. A Rail-Temperature-Prediction Model Based on Machine Learning: Warning of Train-Speed Restrictions Using Weather Forecasting. Sensors 2021, 21, 4606. https://doi.org/10.3390/s21134606

Algorithm for assessment of rail track buckling risk

Classical approach



$$B = RTT - RTN$$

$$R\_total = B + \Sigma(Supplemental)$$

Algorithm for assessment of rail track buckling risk

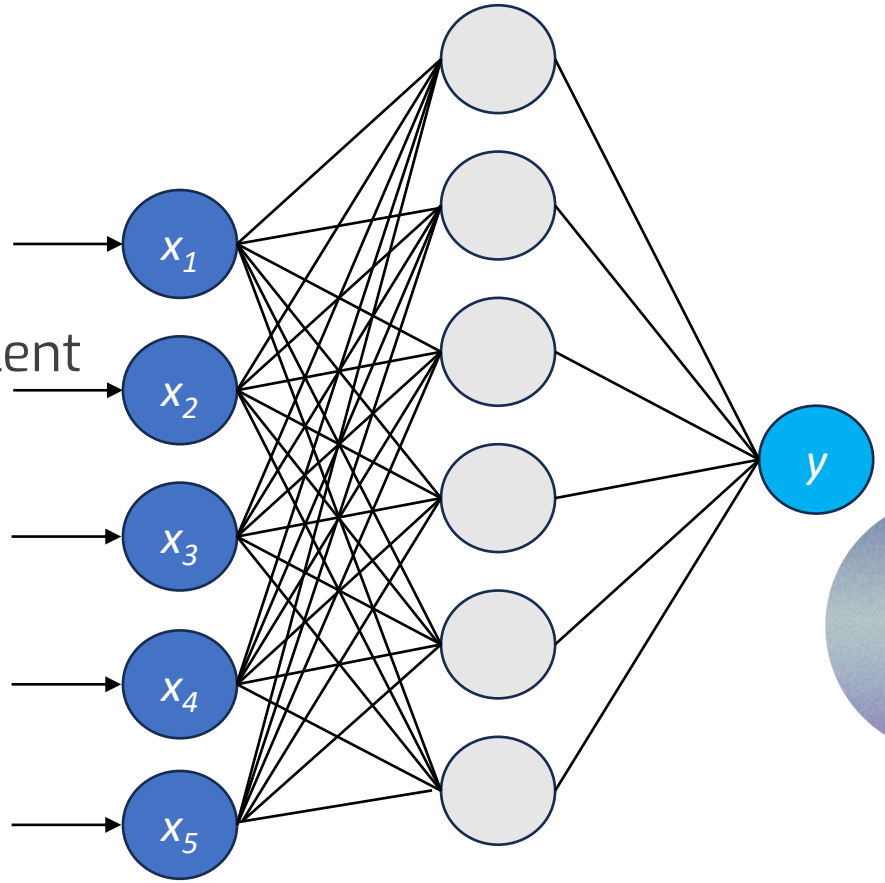
Machine learning - artificial neural network (ANN) model

Inputs:

- sleeper type (x_1) - binary; 1 = concrete, 0 = wood
- track curvature (x_2) - continuous
- rail track condition (x_3) - ordinal 1–10; 1 = very poor, 10 = excellent
- hard point (x_4) - binary; 1 = present, 0 = absent
- rail track temperature (RTT – x_5) - continuous

Output:

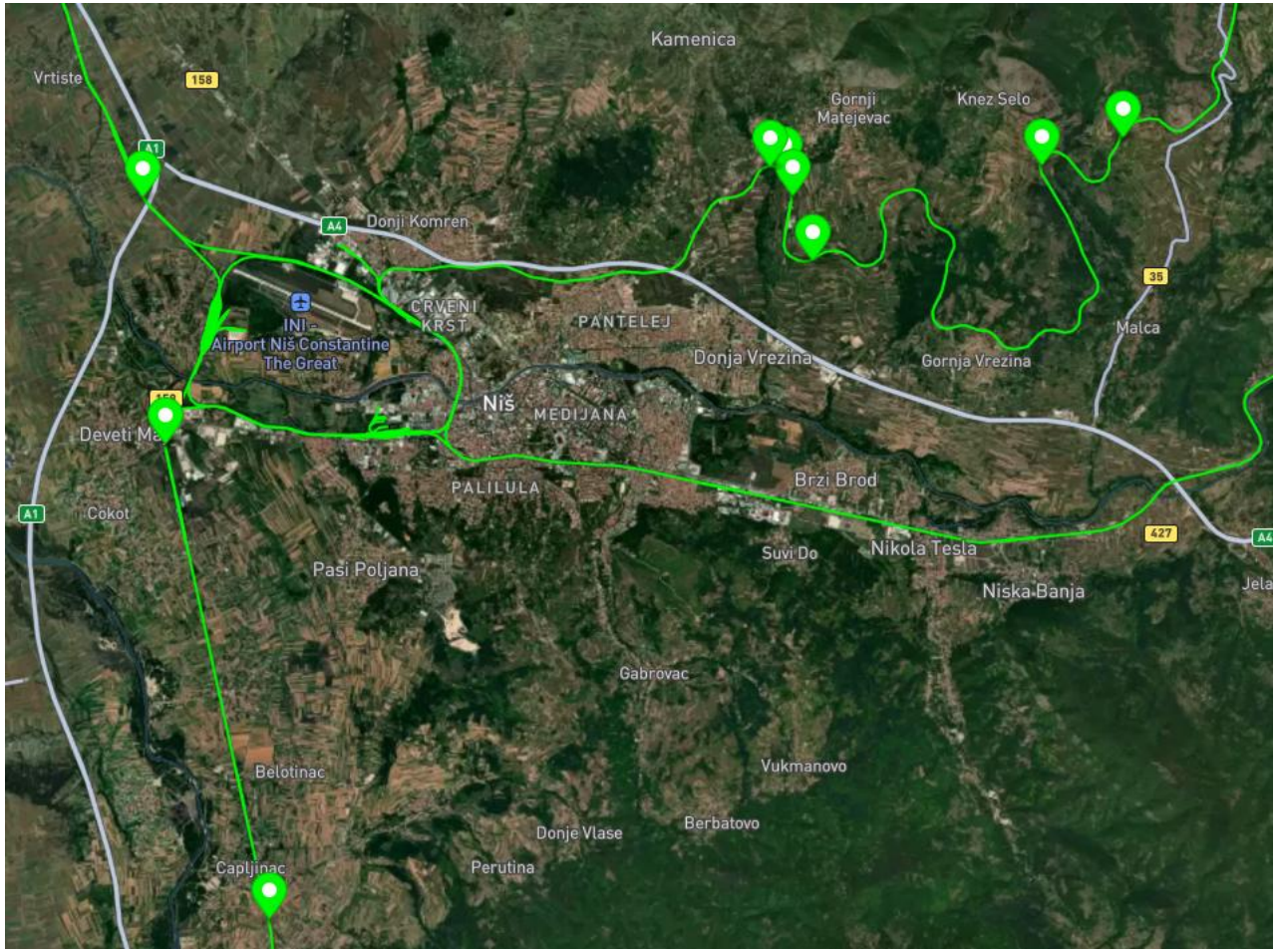
- rail lateral displacement (y)



Algorithm for assessment of rail track buckling risk

Dataset generation

- 14 positions, 25 measurement points
- new (4 points), reconstructed (13 points) and old track (8 points)
- two rail sizes
- wooden and concrete sleepers with appropriate fastening system
- 5 different quality (accessed by ISR maintenance personal based on measurement car results)
- different rail curvature
- different sun exposure during the day

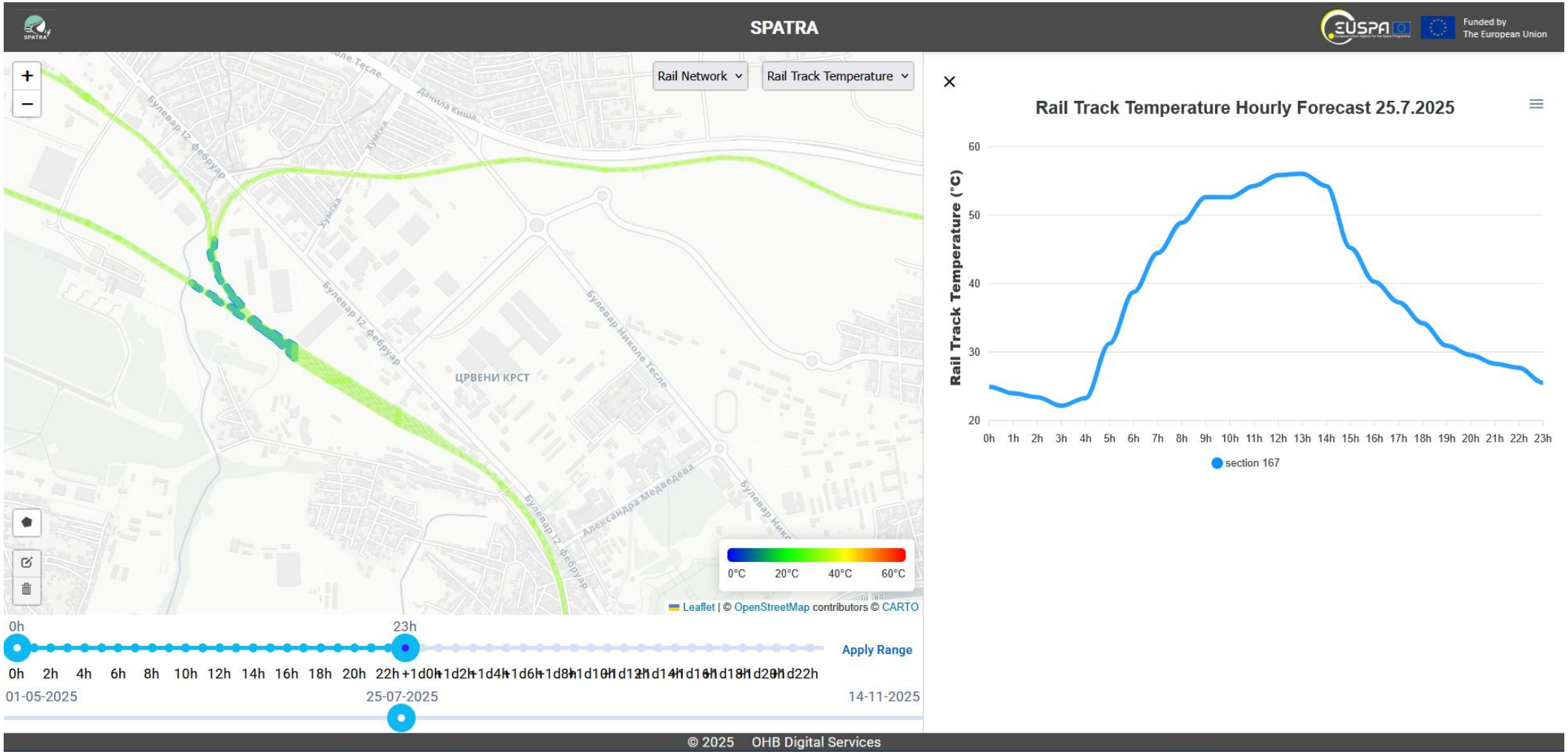


Algorithm for assessment of rail track buckling risk

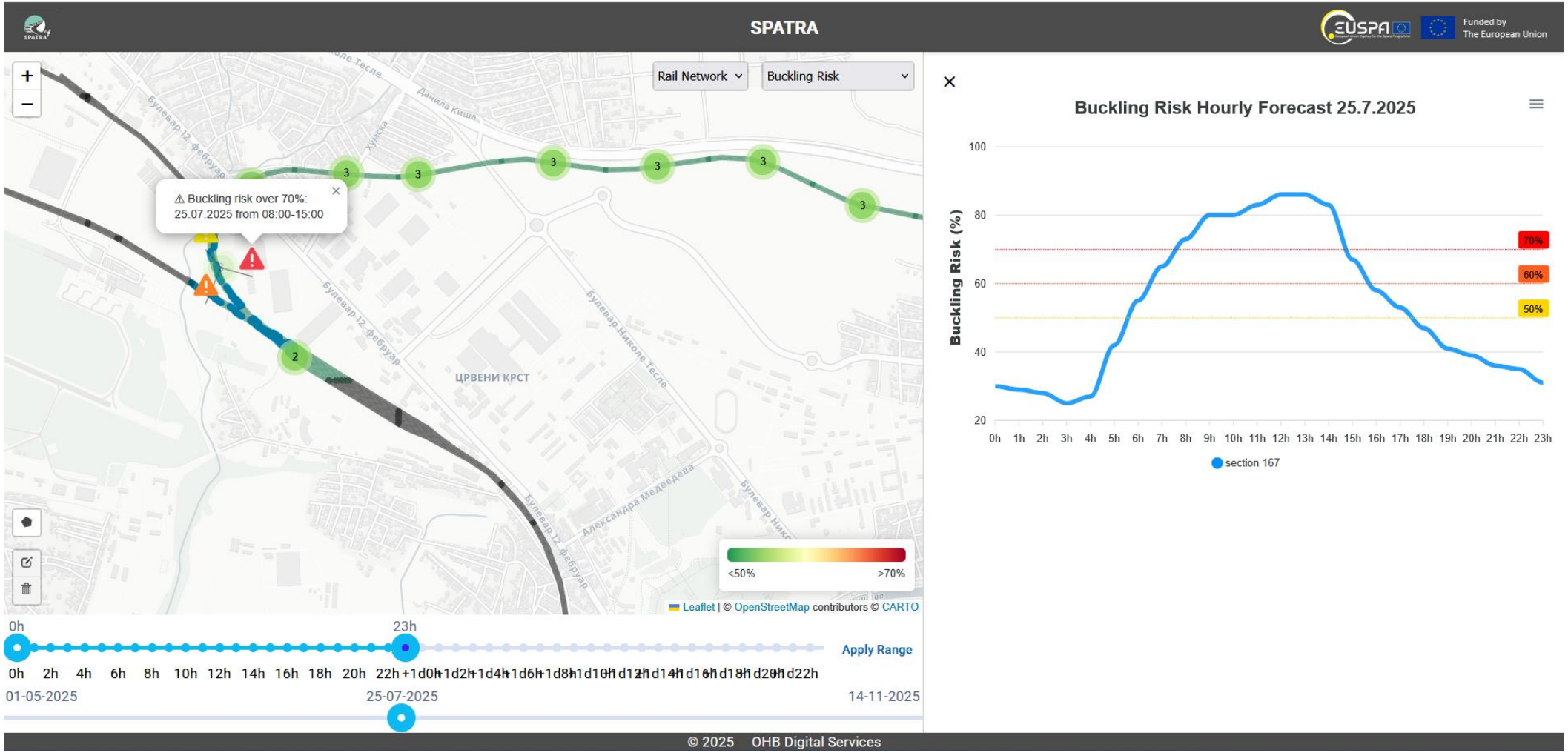
Mobile in situ measuring station

- Weather station (wind speed and direction, air temperature, pressure and humidity, solar radiation, rain fall, PM particles)
- Rail station, rail lateral deflection and temperature
- Data gather locally and transmitted to SPATRA cloud

SPATRA GUI- rail track temperature prediction



SPATRA GUI- rail track buckling risk



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THANK YOU!

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