Path Loss Models for Low-Power Wide-Area Networks: Experimental Results using LoRa

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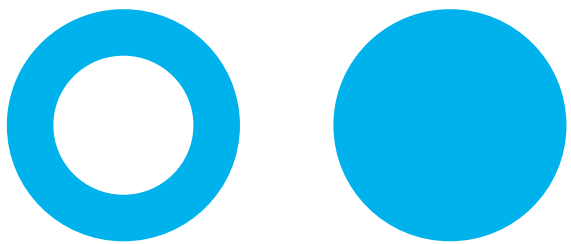

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Forecasting Appropriate Locations

Long Range IoT Networks are moving more and more into the centre of attention.

- ✓ Network-Protocol, Software, Hardware
- \- Intelligent Gateway Placement?

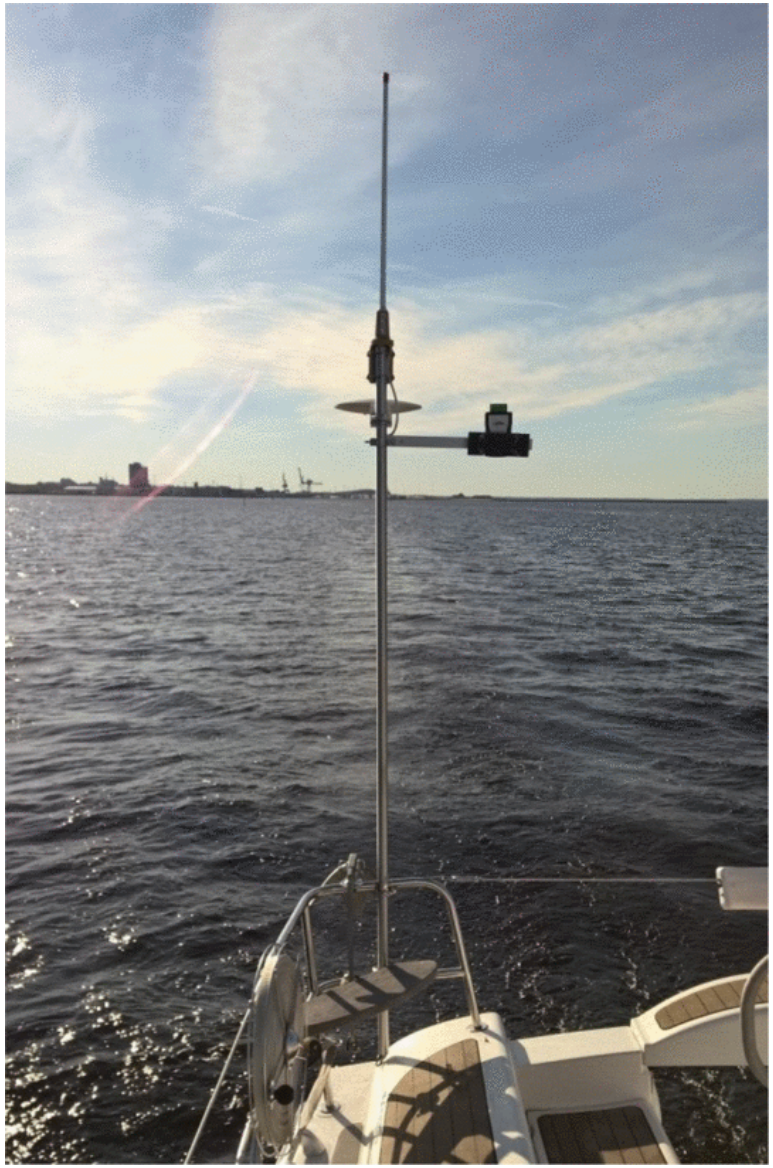
Forecasting Appropriate Locations

- Multiple water-sensors along a river: **Waterlevel, Temperature**

Forecasting Appropriate Locations

- Using LoRa as example technology:
  - **Predicting signal strength.**
  - **Find locations for necessary gateways.**

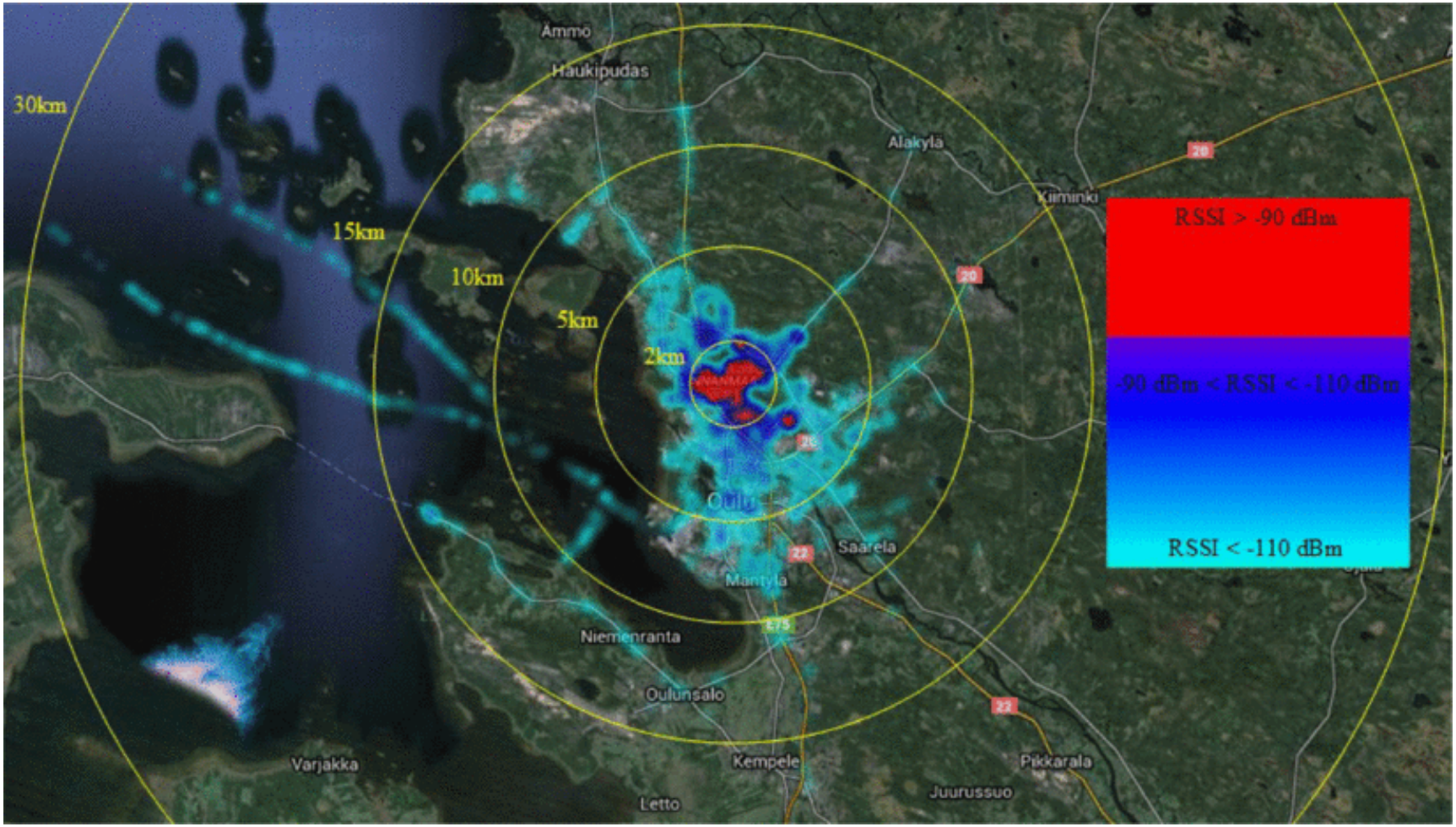
Related Work: Evaluated path-loss models



- Measurements in the city of Oulu (Car/Boat) [1]
- Regression analysis

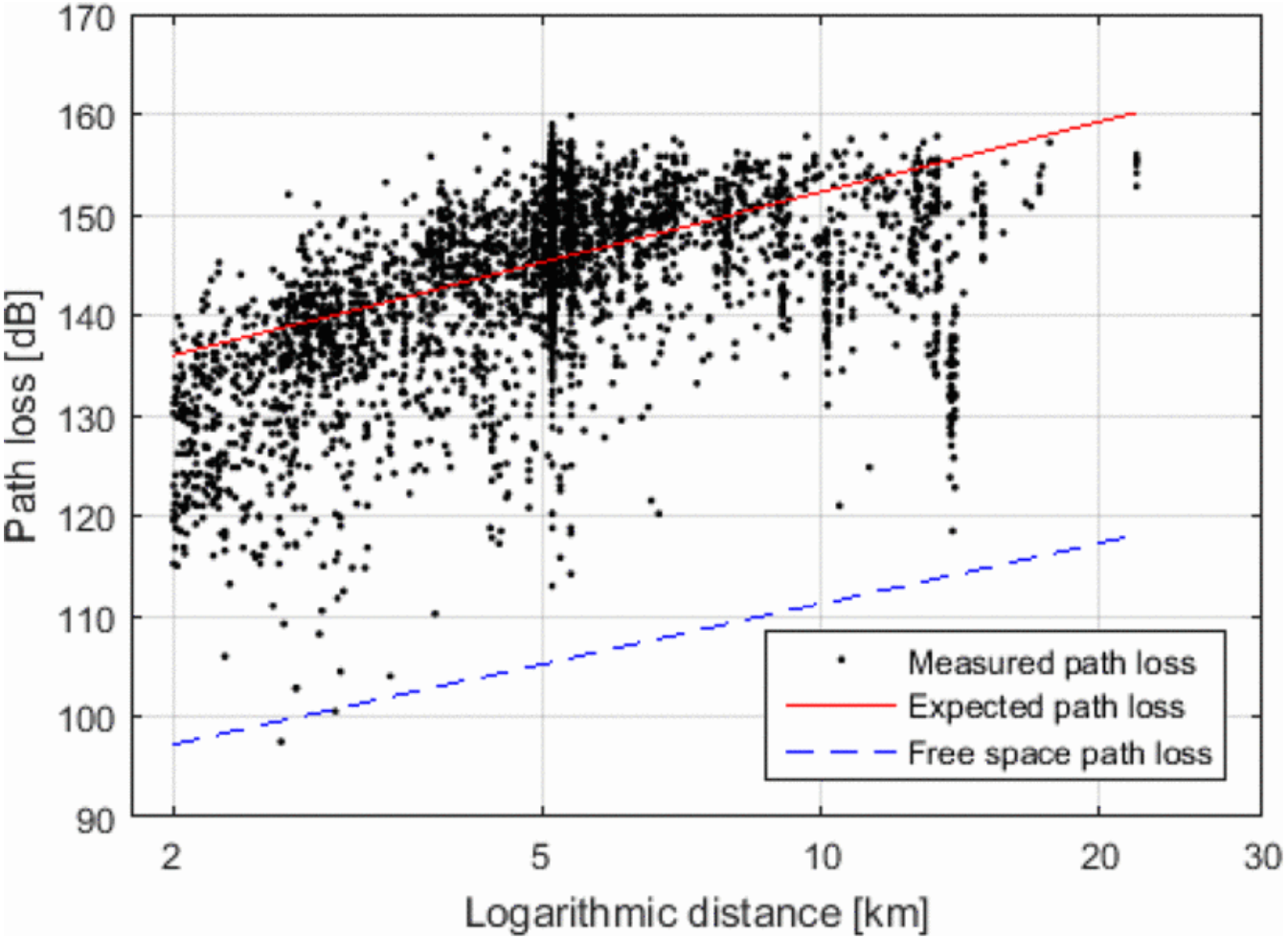
$$PL_{coeff} = 128.95 + 10 * 2.32 * log_{10}(\frac{d}{d_0})$$

Related Work: Evaluated path-loss models



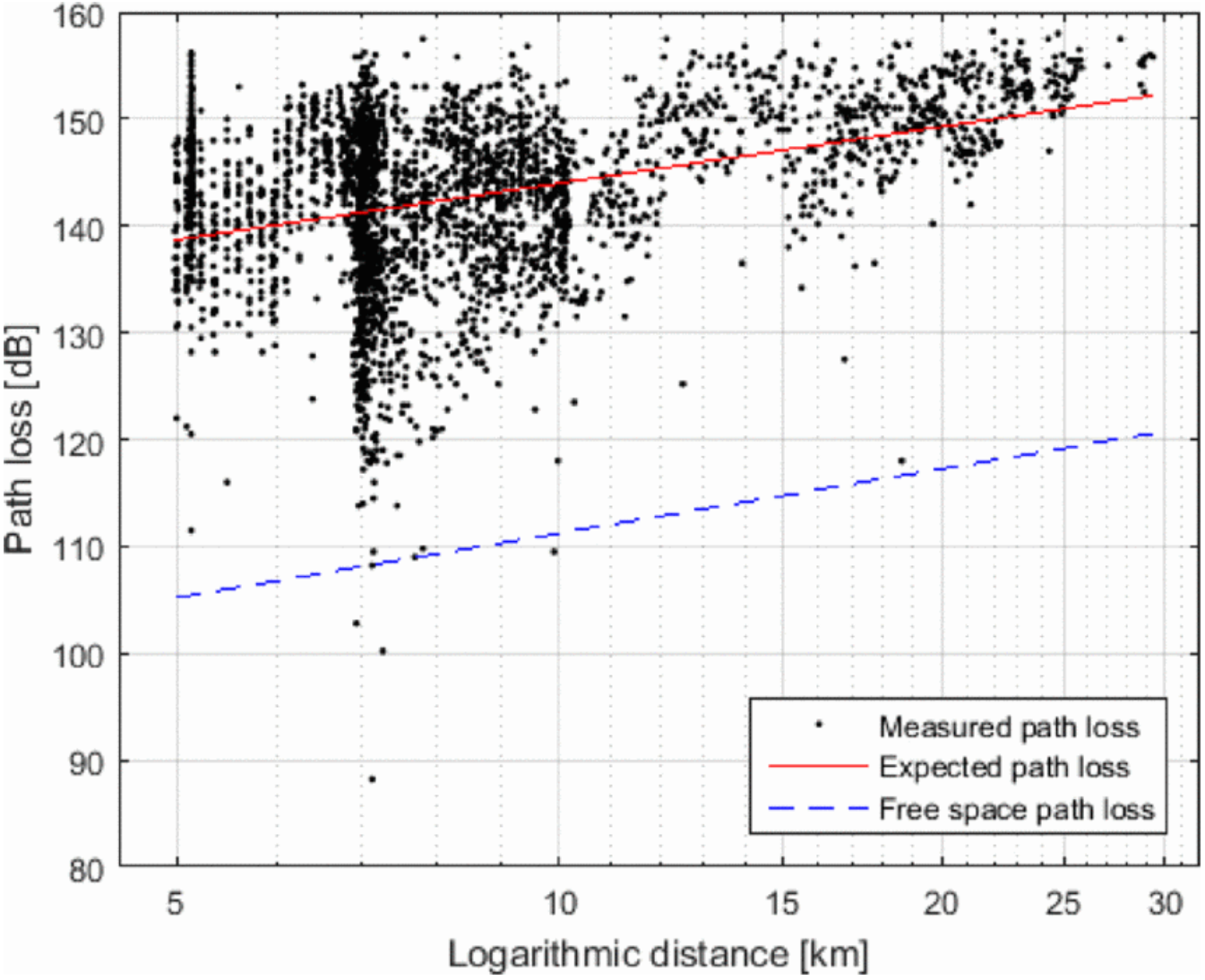
Signal reception (Oulu) [1]

Related Work: Evaluated path-loss models



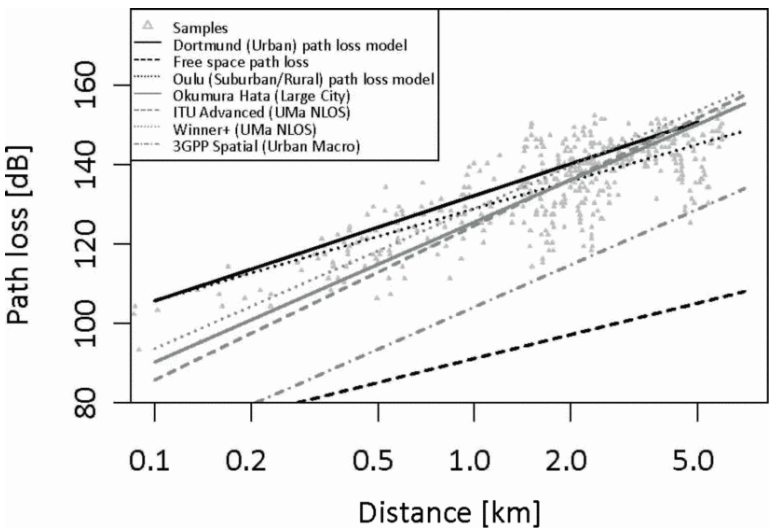
Car measurements [1]

Related Work: Evaluated path-loss models



Boat measurements [1]

Related Work: Evaluated path-loss models



- Measurements in Dortmund [2]
- Regression analysis

$$PL_{coeff} = 132.25 + 10 * 2.65 * log_{10}(\frac{d}{d_0})$$

Related Work: Evaluated path-loss models

Dortmund [2]:

- Okumura Hata Model
- ITU-Advanced Channel Model for Urban Macro NLOS Areas
- Winner+ Channel Models for Urban Macro NLOS Areas
- 3GPP Spatial Channel Model for Urban Macro Areas
- Oulu channel model proposed
- Dortmund (urban) path loss model

Oulu [1]:

- Oulu Model

North Denmark [3]:

- 3GPP Rural Macro non-line-of-sight (NLOS) model (rural areas)
- 3GPP Urban Macro NLOS model (urban areas)

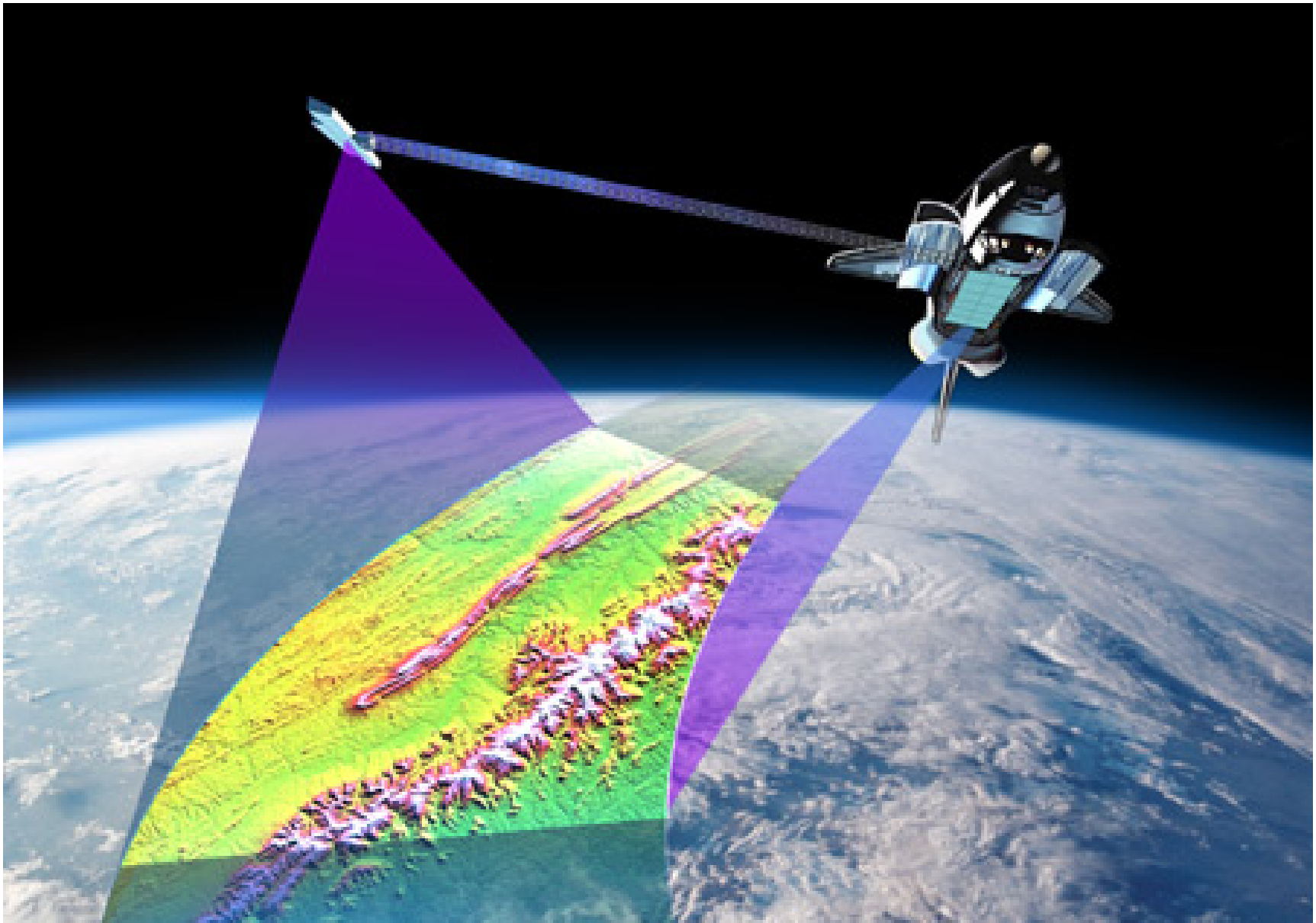
Longley-Rice Irregular Terrain Model

- Additional parameters to increase the accuracy of path-loss predictions
- Soil condition, the climate, refraction and diffraction due to obstacles and terrain
- 20 MHz up to 20 GHz
- Widely used in the context of TV broadcasting

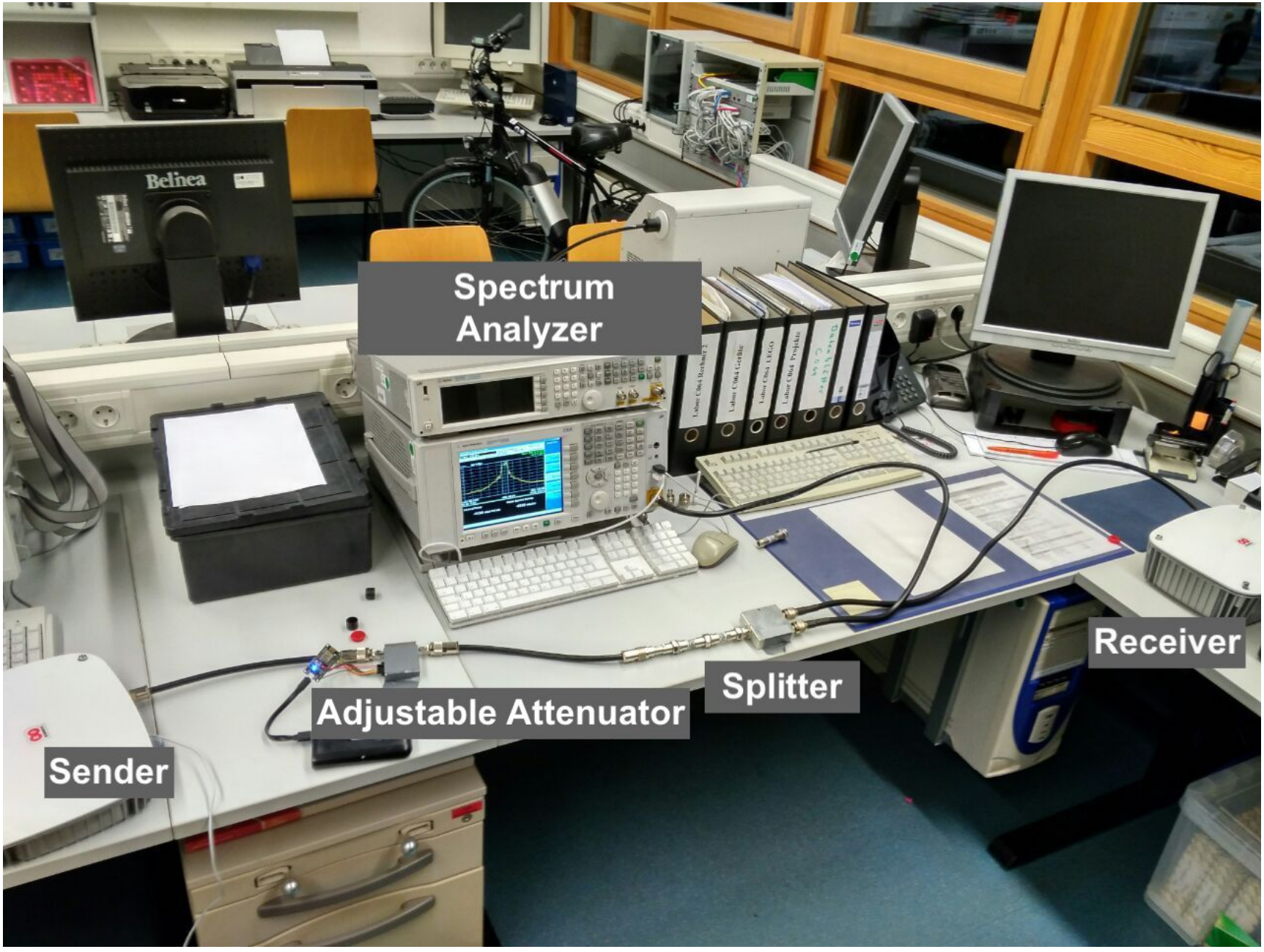
$$PL_{ITM} = PL_{fs} + A_{ref}$$

Longley-Rice Irregular Terrain Model - SRTM

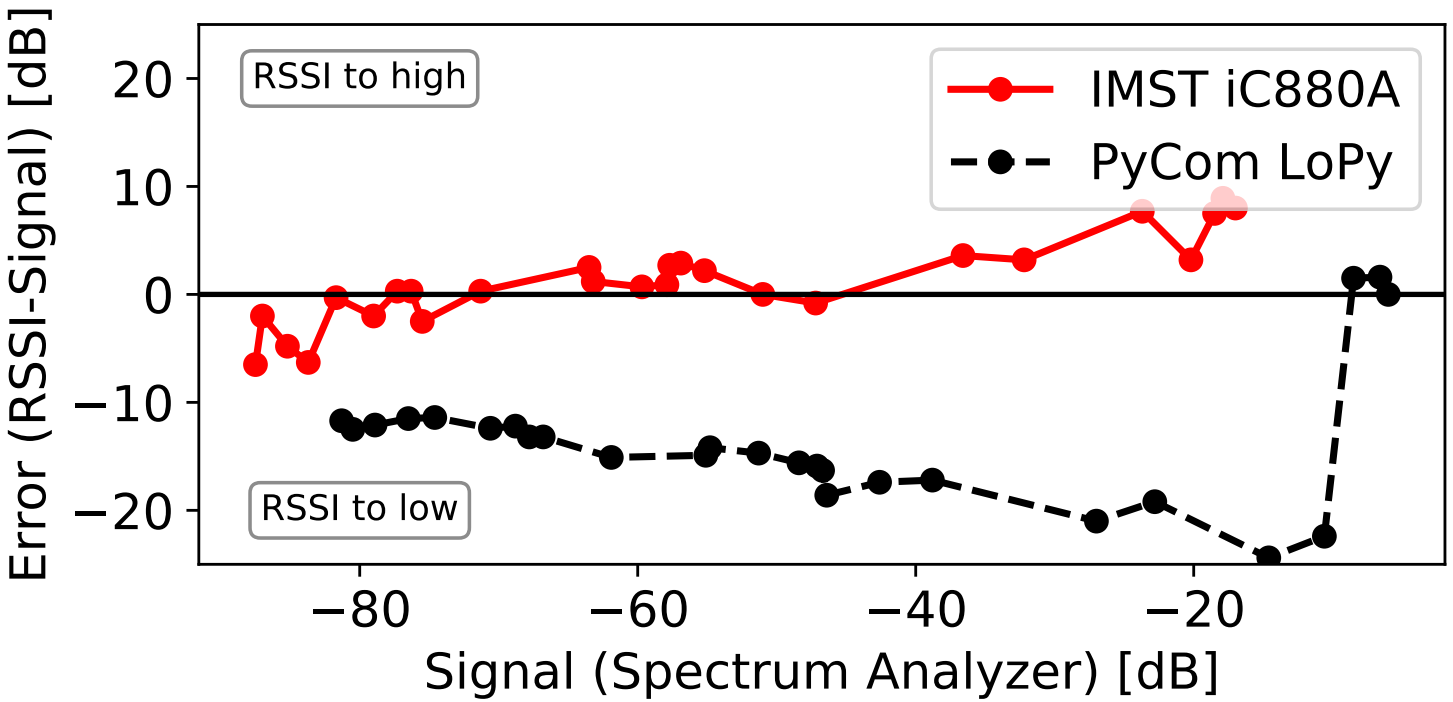
Resolution of 1 arc second ($\approx 30\ m$) between $60^\circ N$ and $57^\circ S$



LoRa-Chipset



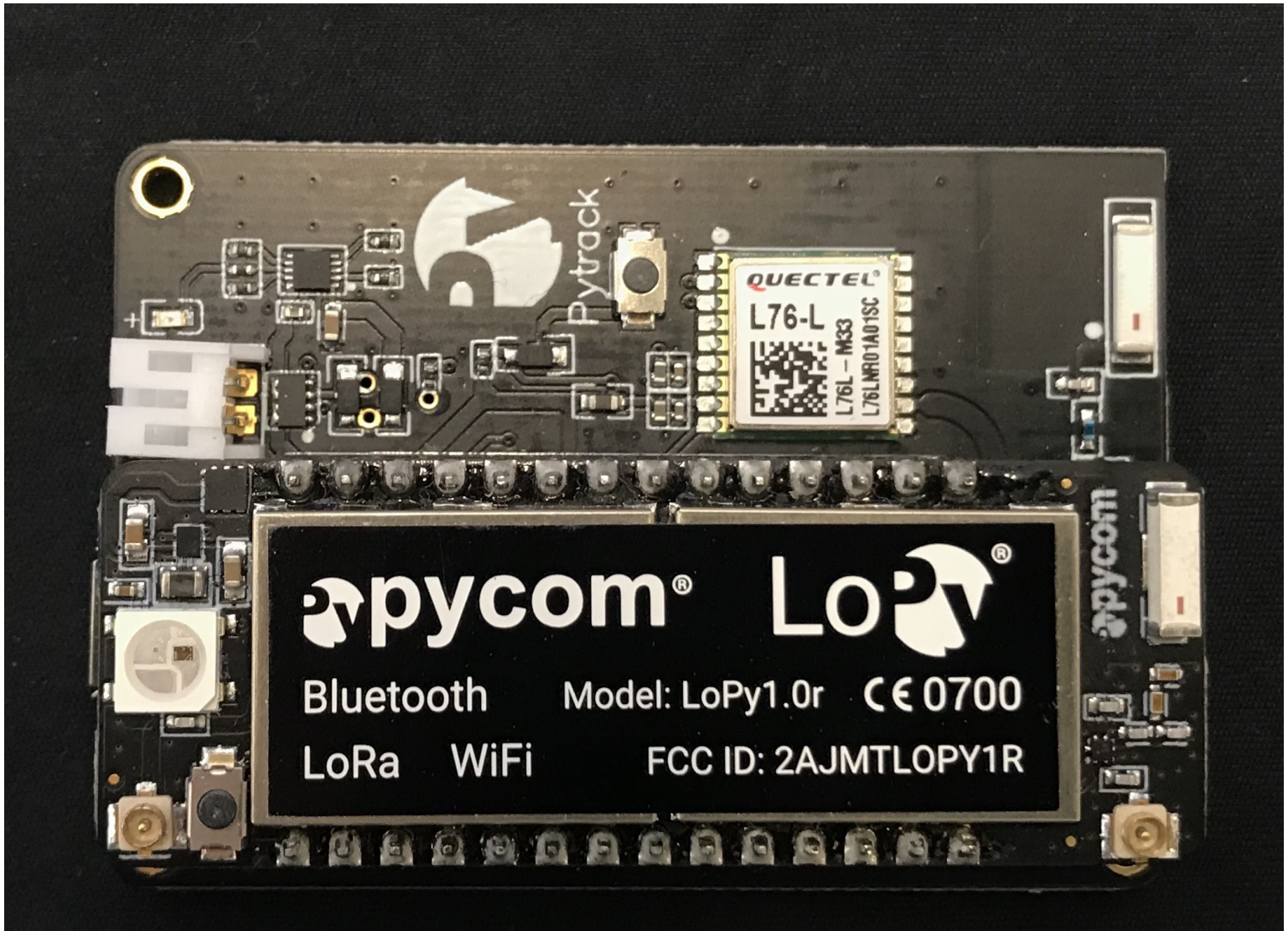
LoRa-Chipset



Chipset RSSI accuracy verification.

GPS-Chipset

- L76-L chipset
- Geodetic measuring point: Deviation of 4 m



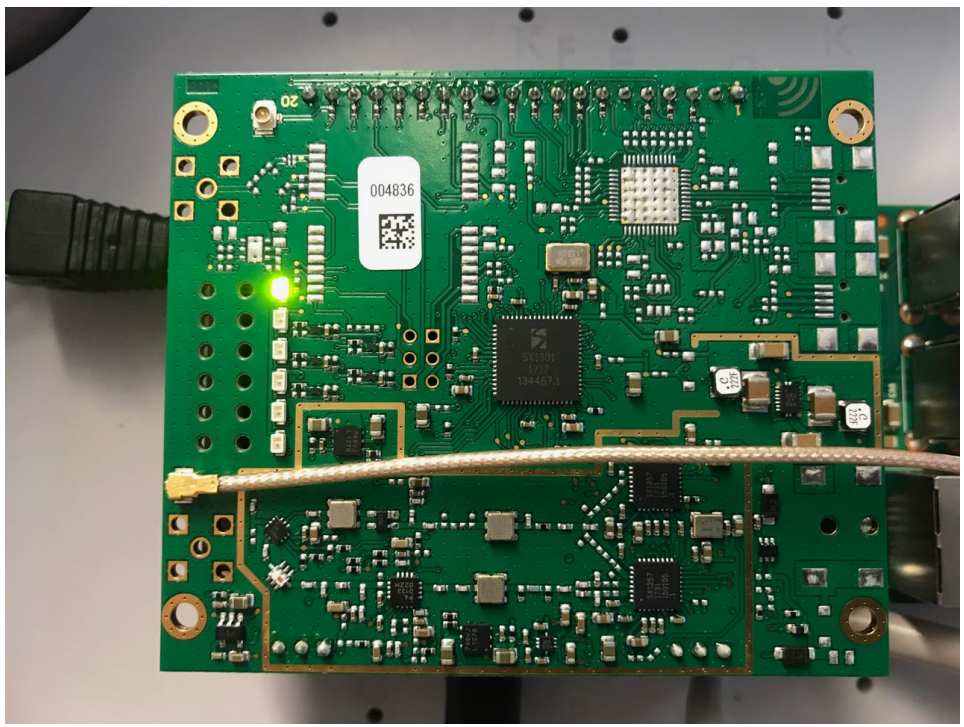
Testbed

Fixed LoRa transceiver.

Moving LoRa transceiver.

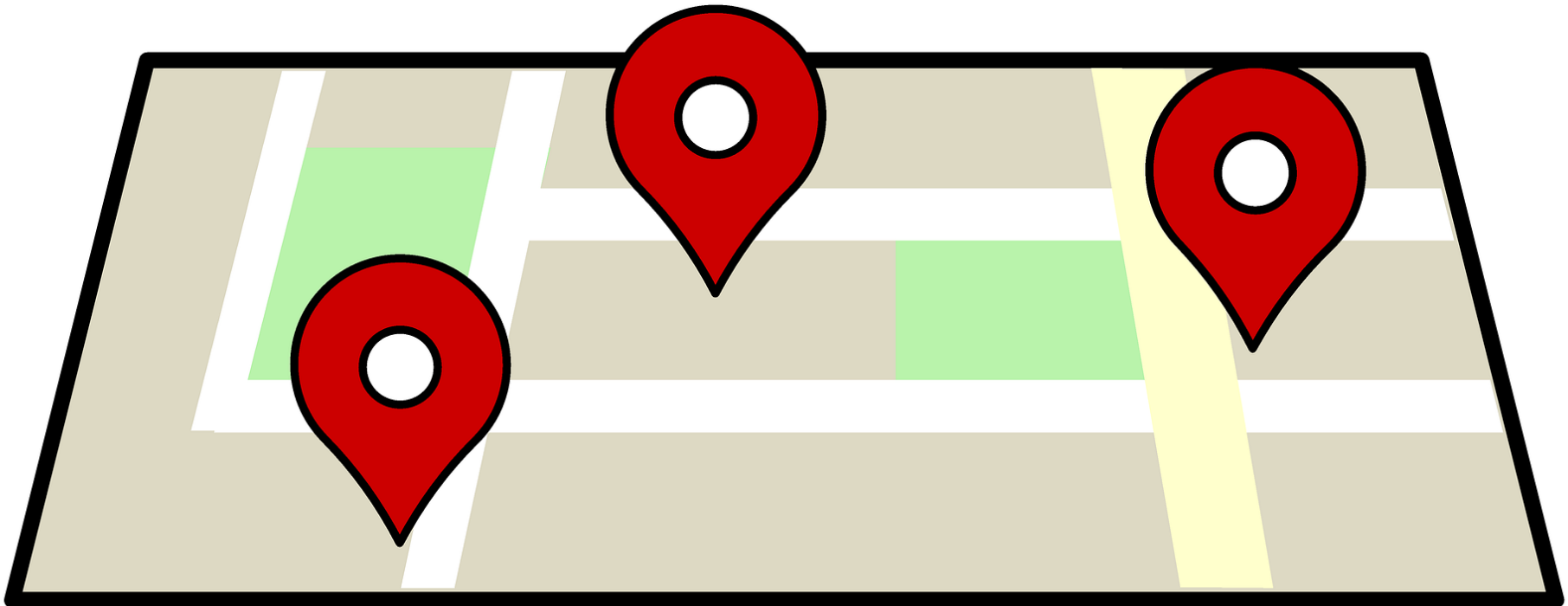
Acquisition of data

- Ten measurement points
- LoRa message size: 11 bytes
- Spreading factor: 12
- Coding rate: 4/5
- Bandwidth: 125 kHz
- 3,819 different measurements (Downlink)



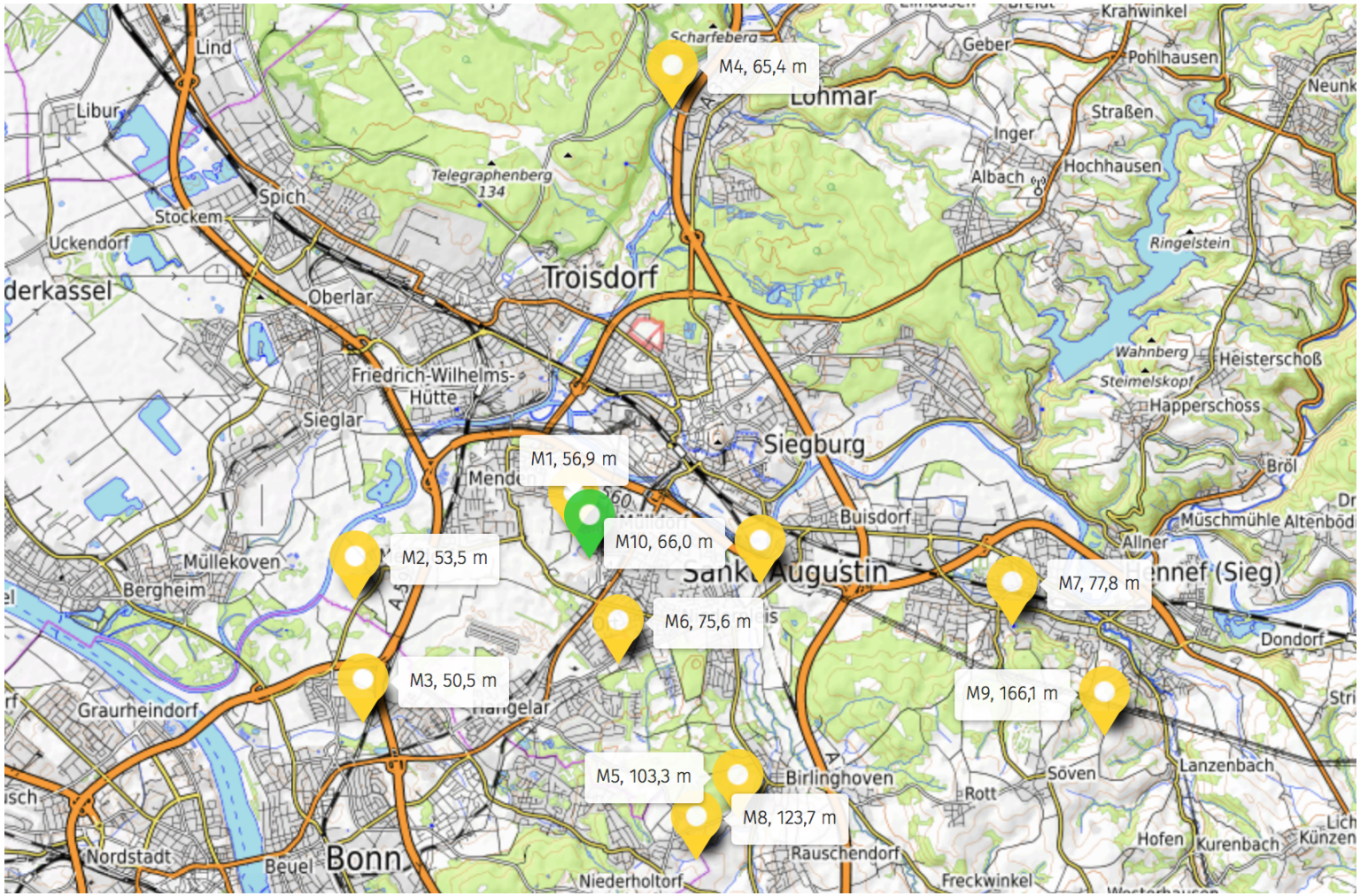
Acquisition of data

- Lost signals are included
- For multiple measurements on one location (10^{-3} decimal degrees $\approx$ 100m) we use the mean value to account different fading effects
- Measurements with no signal reception between two valid LoRa transmission are considered interference or collisions



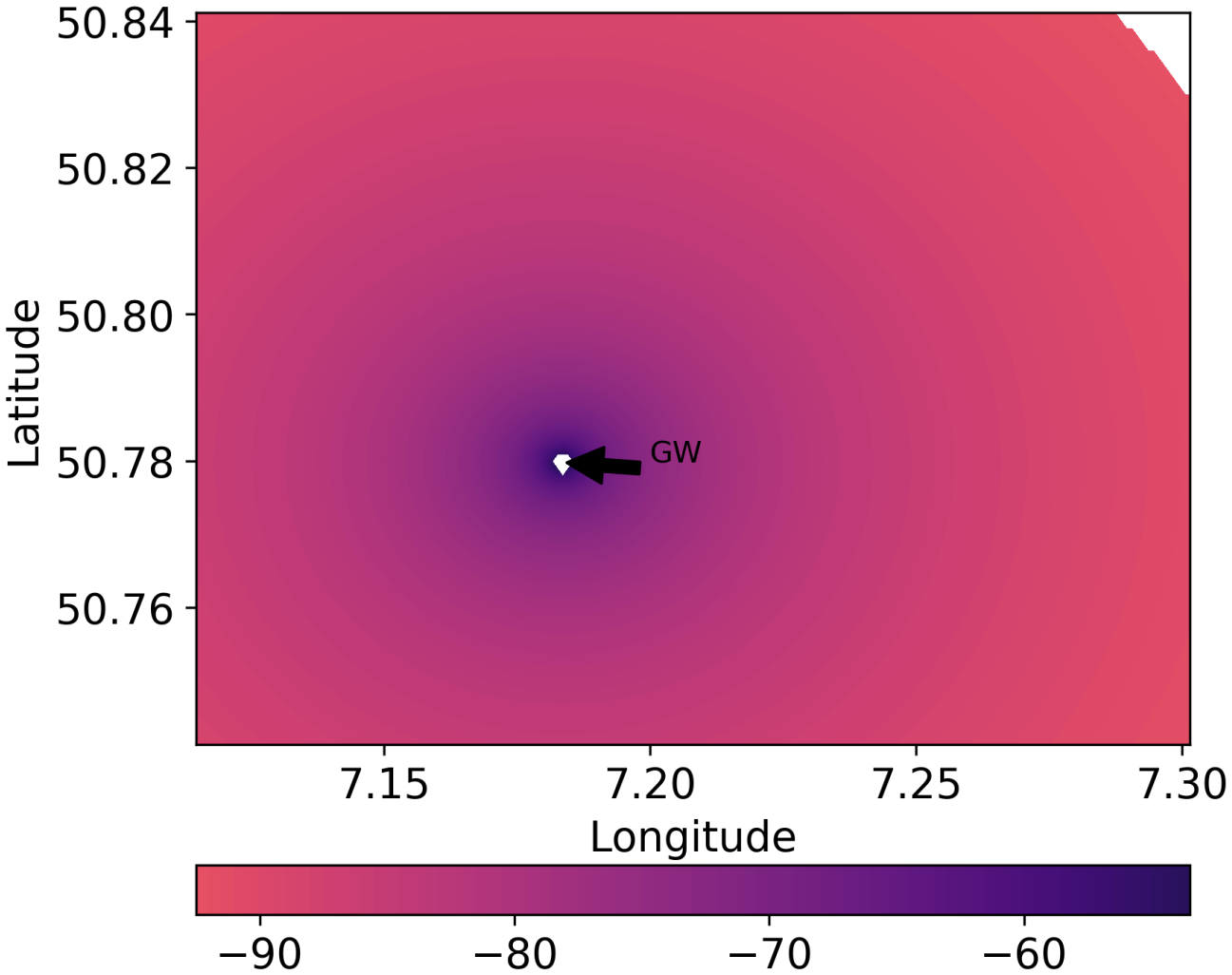
Location

- The test was conducted at the Bonn-Rhein-Sieg University of Applied Sciences, Germany



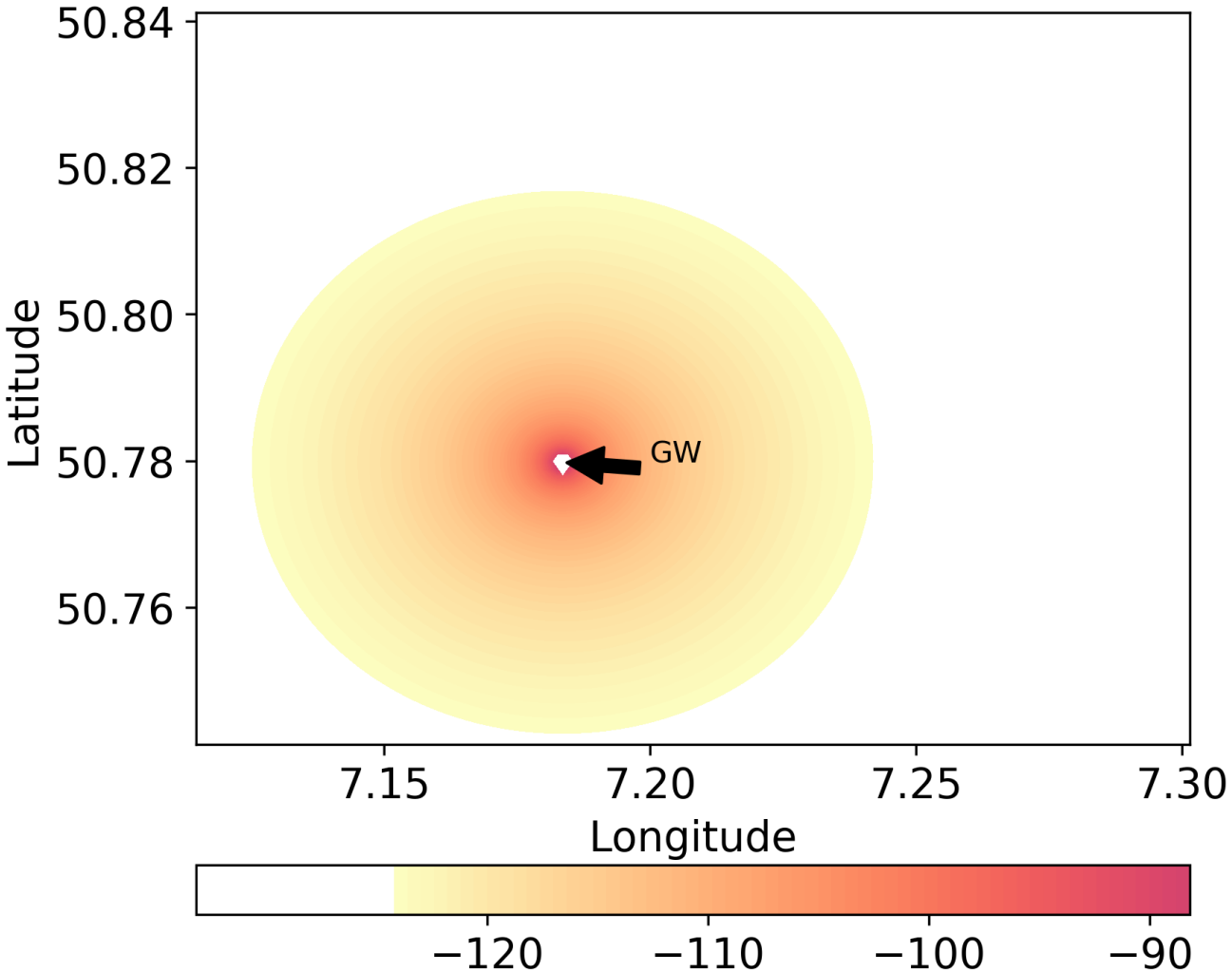
Map of Sankt Augustin.

Model-Comparison



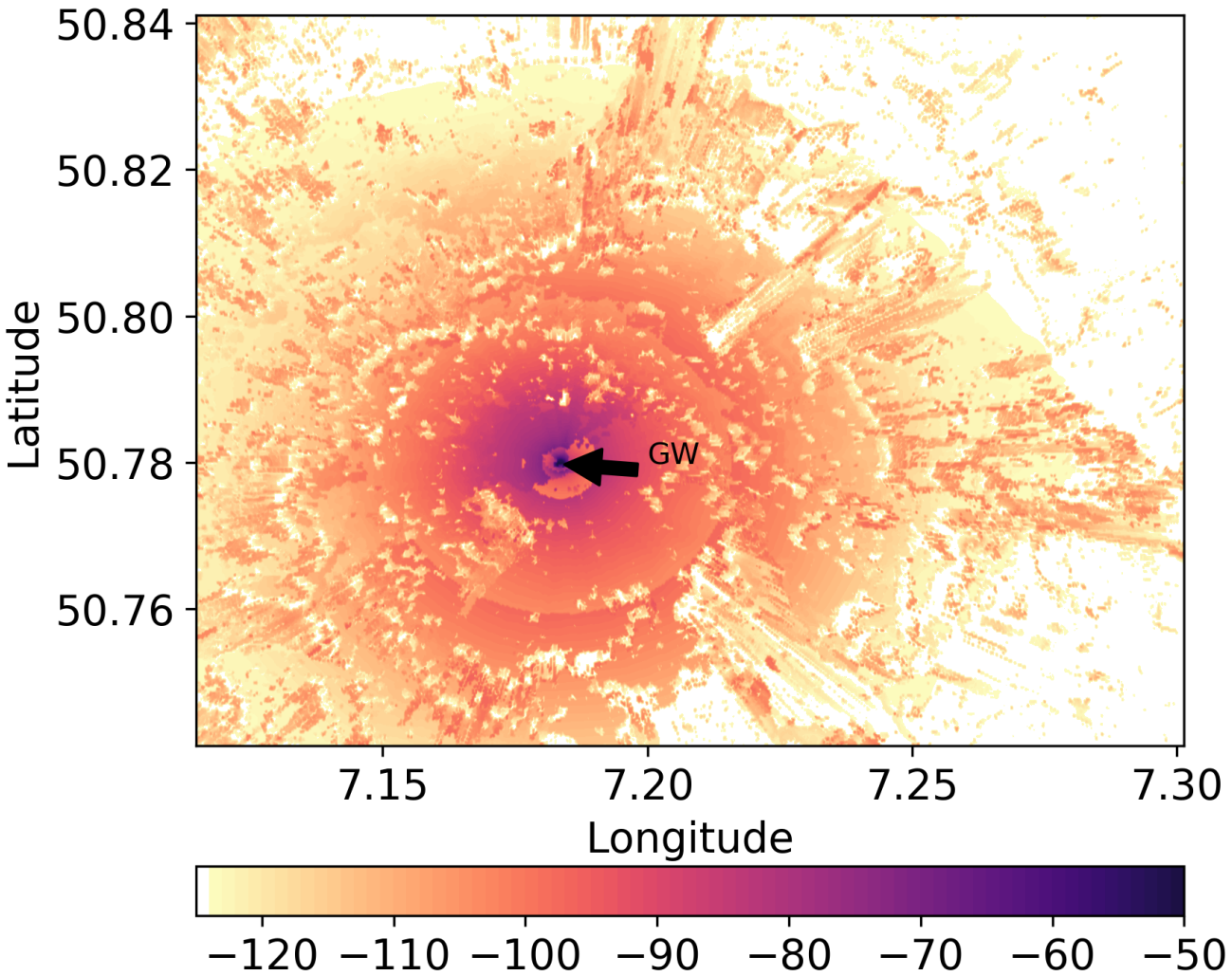
Free Space Path Loss prediction.

Model-Comparison



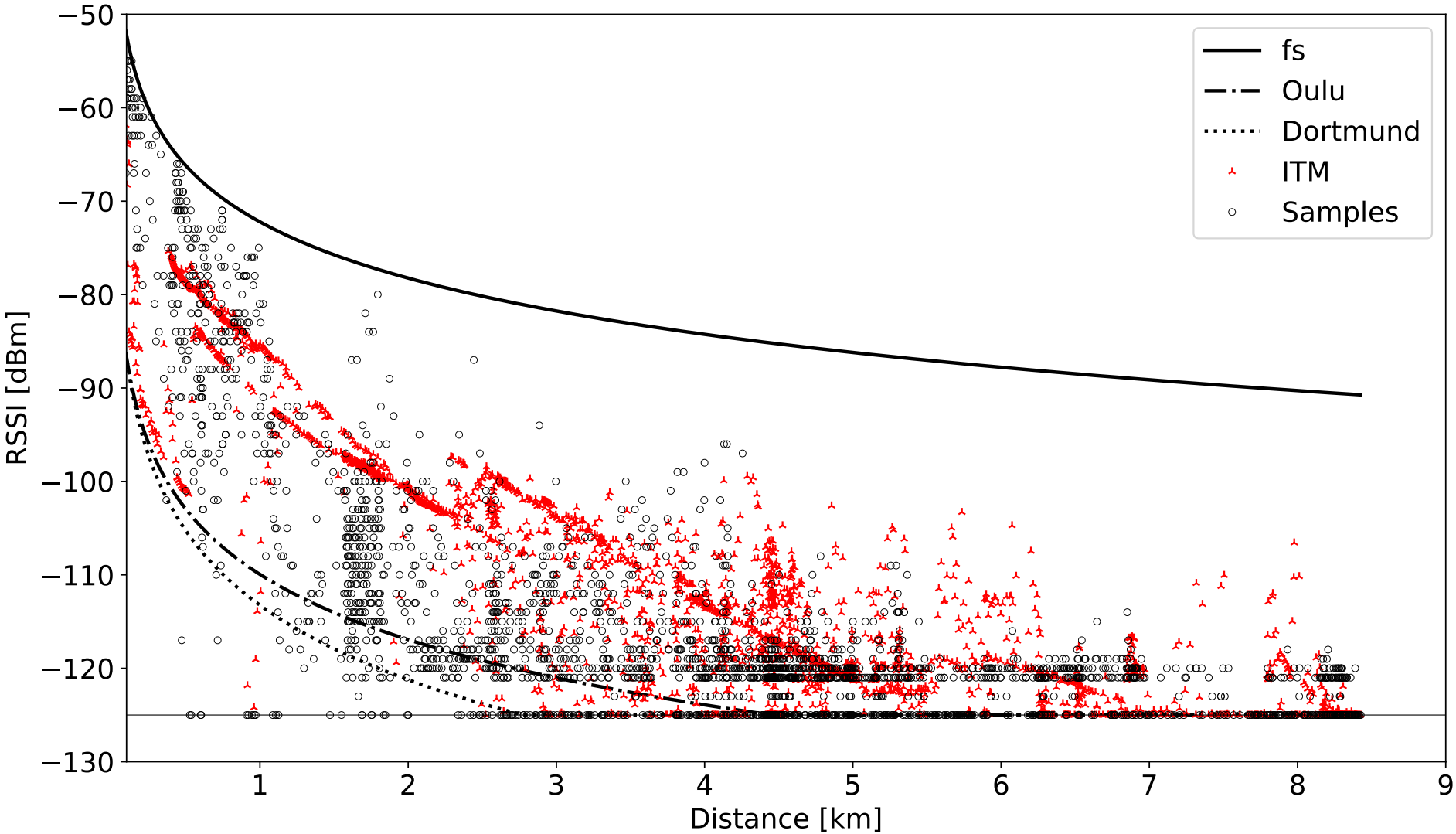
Oulu prediction.

Model-Comparison



ITM prediction.

Model-Comparison



Model-Comparison

False positive:

Signal reception predicted, no signal received

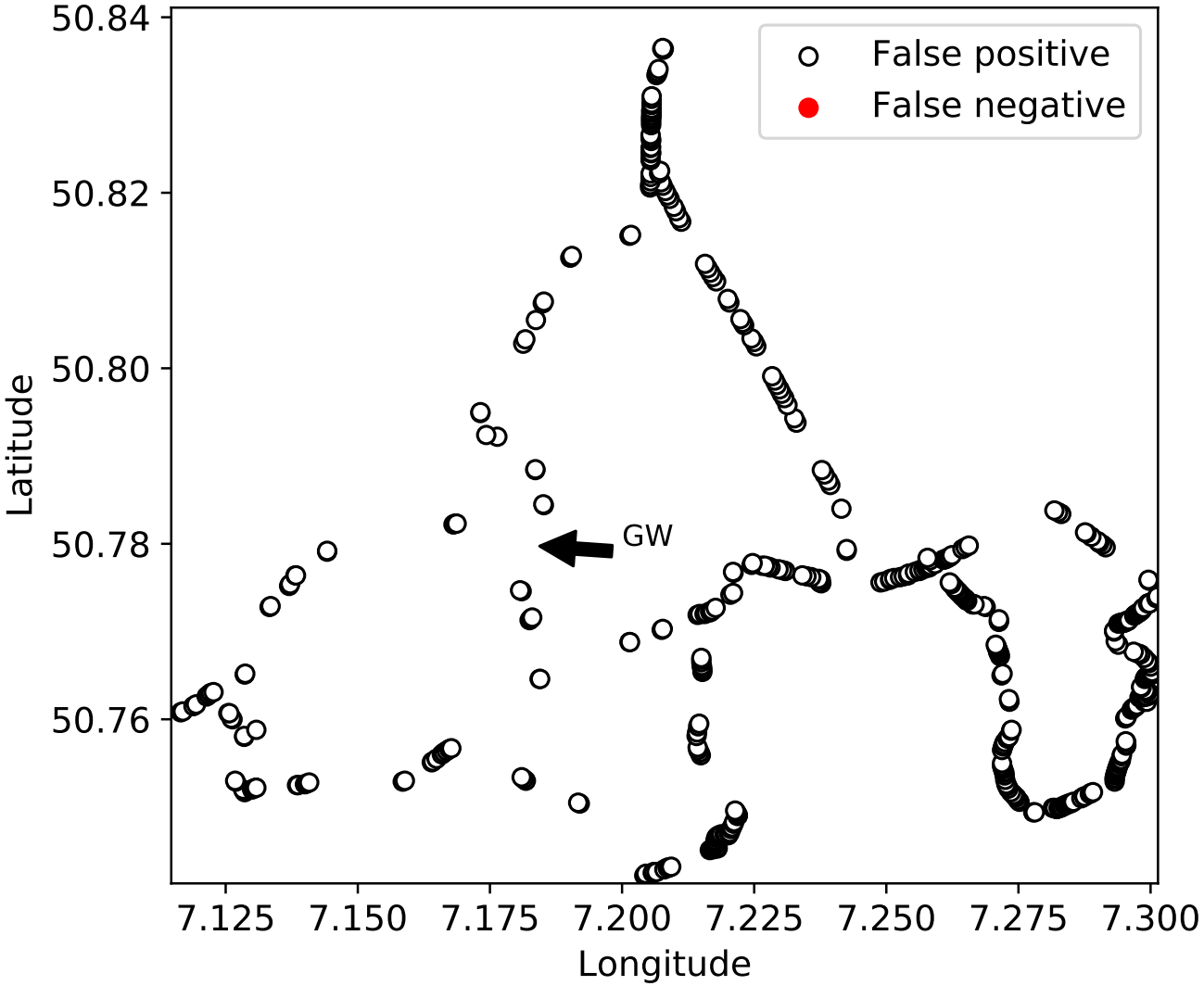
False negative:

No signal reception predicted, signal received

	ITM	FSPL	Oulu
False positive	12%	19%	5%
False negative	6%	0%	31%

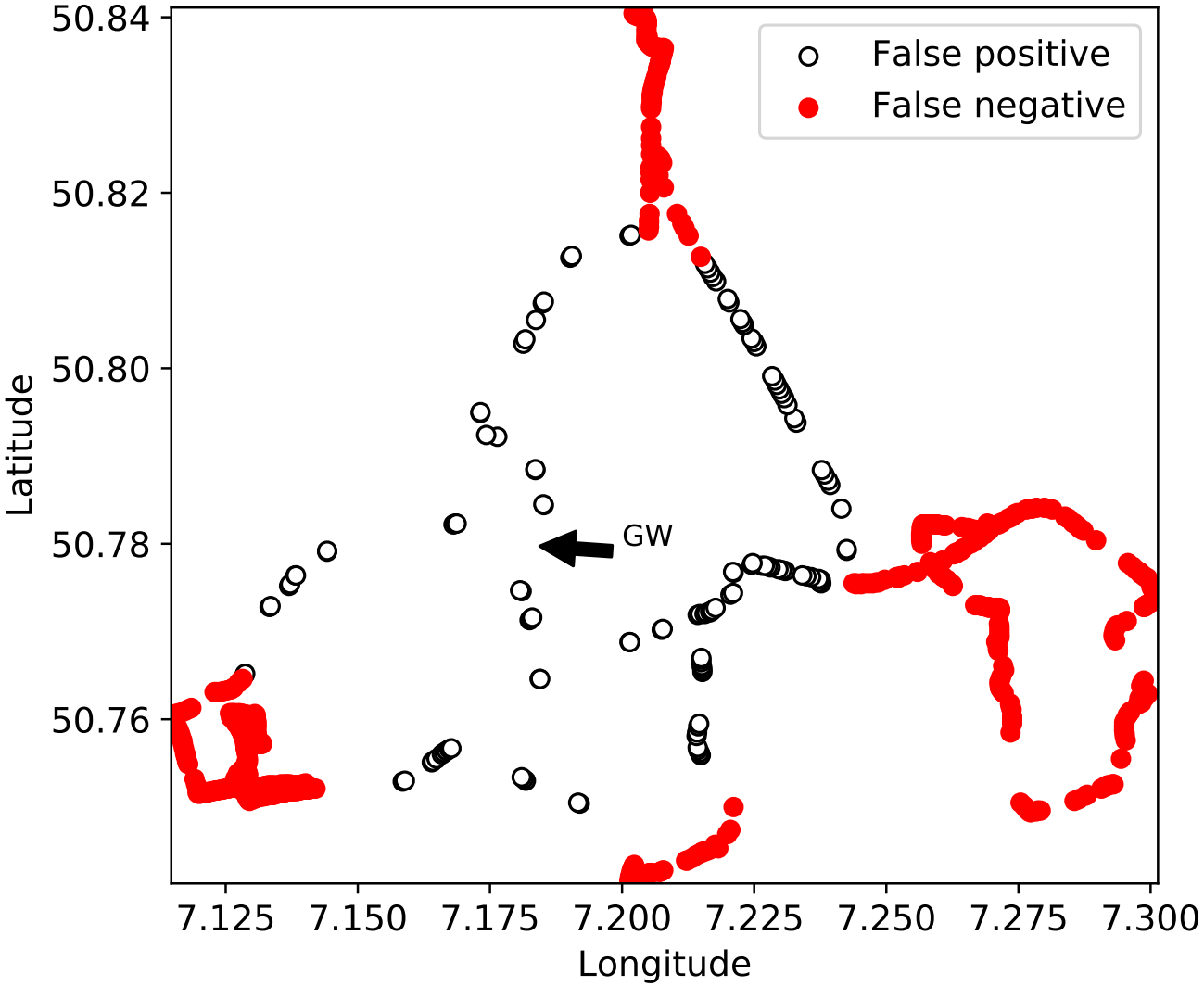
Percentage share of false positives and false negatives.

Model-Comparison



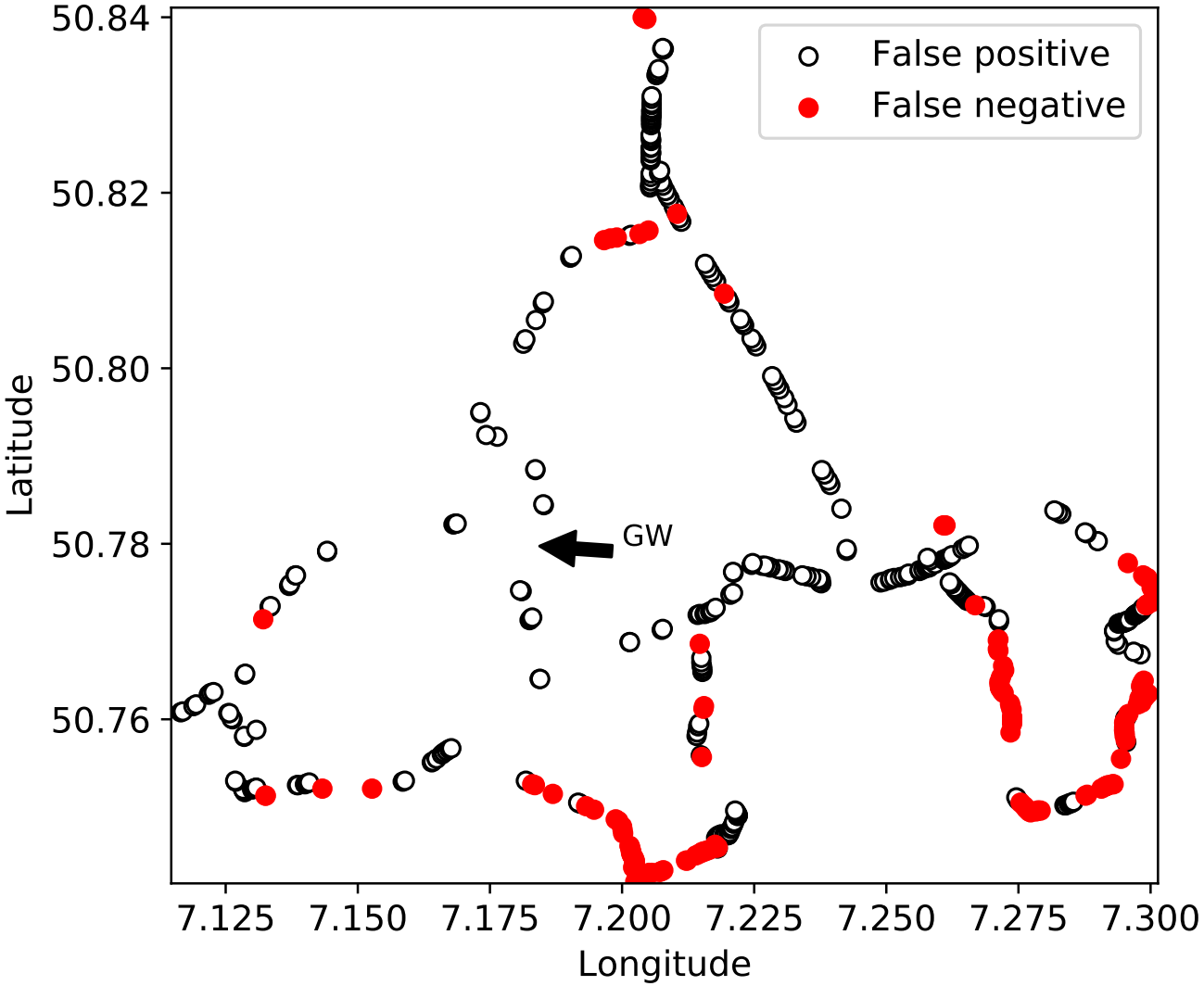
Free Space Path Loss prediction.

Model-Comparison



Oulu prediction.

Model-Comparison



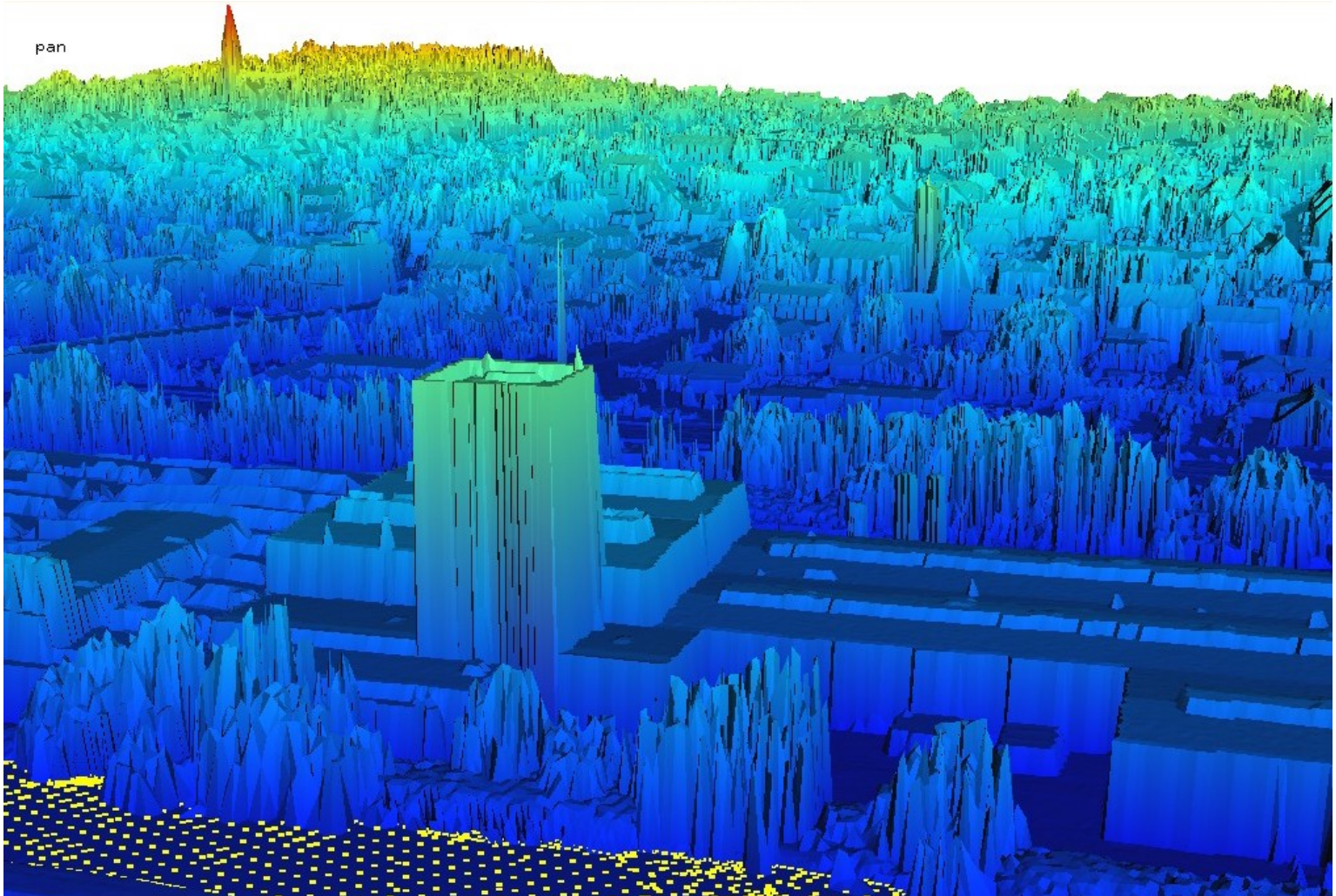
ITM prediction.

Conclusion

- No perfect model is apparent from a comparison of the results
- A model with a balanced ratio of false positives and false negatives could be the correct choice
- The ITM model generates this ratio and has the potential to significantly reduce this error at regions with huge elevation differences since especially mountains lead to many false negatives.
- It does not gratefully outperform other models for LPWAN but is especially useful in mountainous areas

Future work

- Using LIDAR dataset the accuracy could be increased
- The state of North Rhine-Westphalia made a such a dataset (several terabyte) available online



Thank you very much!

Are there any questions?

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