# Passive Radar Performance Analysis Tool


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## *ABSTRACT:*

*The performance of a Passive Radar system is highly dependent on the properties of the chosen illuminators and the multistatic geometries which involve illuminators, receiver(s), targets and the surrounding terrain. To predict the Passive Radar performance at a given receiver position and with a predefined set of illuminators, a performance analysis tool has been developed, which uses models for illuminators, targets reflectivity, wave propagation, signal processing and tracking algorithms based on a given geometry.*


## 1. INTRODUCTION & MOTIVATION

Various measurement campaigns during the last years showed, that the performance of Passive Radar is highly dependent on site properties, surrounding terrain and illuminators.

One objective of the Performance Analysis Tool is therefore the prediction of Passive Radar performance during the preparation of measurement campaigns. In this process the functionality of a given receiver position can be tested off-site and optimized if needed. In addition the model can be used to select adequate illuminators, which allow a large-scale and optimized coverage for the given surveillance task. Furthermore the simulation tool facilitates the evaluation of measured data and supports advanced Passive Radar operating modes like dynamic transmitter switching. Additional objectives are to define performance parameters in abstract territory and illuminator environment and to analyze the possibility to combine several sensors in a sensor cluster to enhance range and localization accuracy.

To keep computing time low and to enable real-time operation for the dynamic transmitter switching operation, the simulation tool was realized as a performance model, i.e. based on analytic models. An extensive evaluation of the model versus real-world measurements with the Cassidian Passive Radar demonstrator is ongoing and shows already very promising results.

## 2. OVERVIEW

The Performance Analysis Tool has been developed to predict and enhance the performance of the Cassidian Passive Radar demonstrator. Therefore it actually handles signals emitted by FM, DAB and DVB-T transmitters. It can nevertheless be easily adopted for further waveforms.

Figure 1 shows an overview of the Performance Analysis Tool.

There are two possible modes in which the tool can be operated. The first possibility is to run the code in the coverage mode. The result is then given by a map, which shows track probability depending on geographical coordinates. In the trajectory mode a particular reference trajectory is considered.

The whole model can be divided into 3 parts. The first part is called wave propagation model and includes wave propagation and the analogue part of the receiver. The results are used for the sensor performance model, the second part, which covers signal processing methods and detection. This part has been evolved in cooperation with Fraunhofer FHR. Depending on the chosen mode the third part of the model can be a tracker performance model in the case of coverage analysis which has been developed by Fraunhofer FKIE. If a particular trajectory shall be analyzed the output format of the sensor performance model has to match the real plot data. In this case the standard tracker is applied.

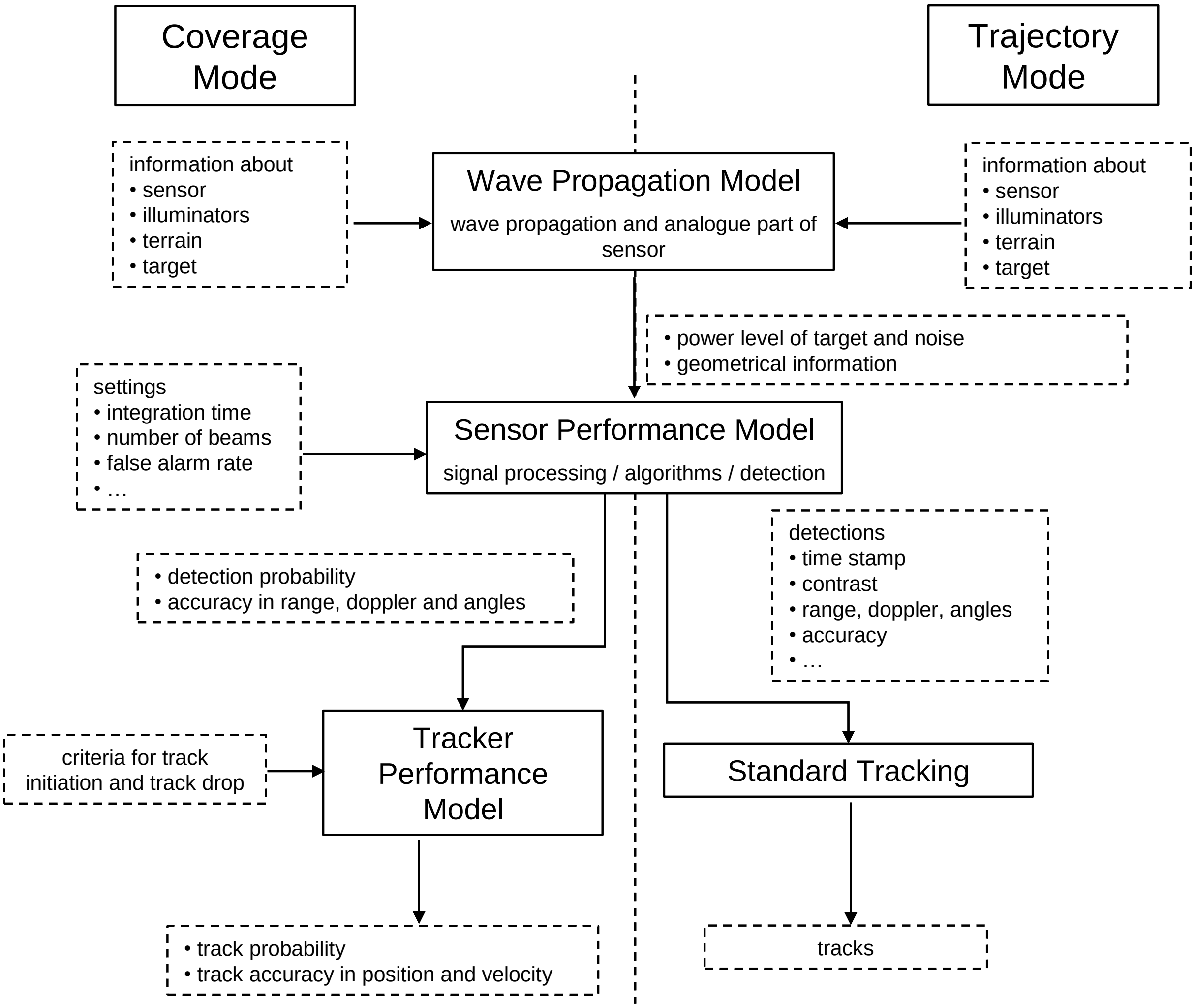


**Figure 1: Schematic overview of the Performance Analysis Tool**

## 3. WAVE PROPAGATION MODEL

As mentioned before the first part of the simulation includes wave propagation and the analogue part of the receiver. It passes information about target signal and noise to the Sensor Performance Model. Therefore illuminators, receiver, terrain and targets have to be defined.

The Federal Network Agency provides information about illuminators such as position, type, polarization, height and the horizontal antenna diagram. The vertical diagram is given by measured data of typical antennas (see [4]). The gain of the receiving antenna has been measured in dependency of frequency, polarization, azimuth and elevation.

DTED-data of resolution level 1 is used to generate a realistic terrain model. One pixel assumes a size of about 92 m x 92 m near the equator which describes the terrain in adequate preciseness. The target is either defined by a constant velocity vector, a depolarization factor and a constant RCS positioned in each pixel of a grid covering the analyzed map in the case of coverage analysis or by loading a reference track (e.g. GPS or ADS-B) and defining only RCS and depolarization in the trajectory mode.

Due to the low frequencies Passive Radar is working with, it is not sufficient to decide whether a target lies within line-of-sight to illuminator and sensor. Instead the knife-edge model for diffraction losses has to be included. This is realized by consideration of the Fresnel-ellipsoids ([5]). Atmospheric diffraction is taken into account by using the effective radius of the earth.

The target power level is now calculated by applying the bistatic radar equation as well as considering the described additional losses and effects.

Noise consists of thermal noise and man made noise. Man made noise is of particular importance for low frequencies as used in the FM-band. It is caused amongst others by industrial thermal processes and communication and broadcasting systems. Man made noise depends on the type of environment (residential, rural, industrial etc.) and the frequency used ([6]).

## 4. SENSOR PERFORMANCE MODEL

As the Sensor Performance Model reproduces the signal processing and detection, each of the functions and its influence on the power levels of target and noise has to be considered. Figure 2 shows a rough overview of the signal processing implemented in the demonstrator.

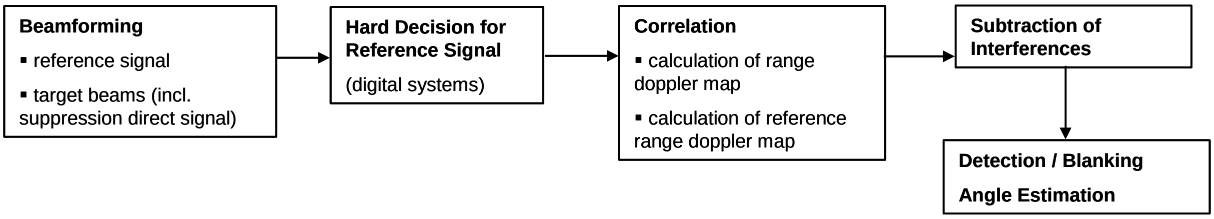


**Figure 2: Overview of Passiv Radar signal processing**

Assuming that the scaling keeps the target signal on a constant level while suppressing the noise power, the target signal is modified by the target beams, the suppression of the direct signal and by blanking in regions where Doppler or range assume values beyond or below certain thresholds. The noise level is in contrast reduced by correlation and beamforming.

In order to obtain the accuracy in range and Doppler the CRLB (which depends on resolution and SNR) and the standard deviation, caused by the discretization of range and Doppler, must be combined.

Regarding the output of the Sensor Performance Model, one has to differentiate between the two modes. In case of concentrating on a particular trajectory the output of the Sensor Performance Model is adjusted to the integration time and discretization of range and Doppler. The values time stamp, range, Doppler, azimuth, elevation, contrast and accuracies are needed to generate a realistic dataset for the tracker.

In the coverage mode further information is required. Assuming Swerling case 1 the detection probability can be calculated by applying

$$P_D = \exp\left( - \frac{P_{FA}}{S/N} \right),$$

where $P_{FA}$ is the false alarm rate, $S$ the target level and $N$ the noise level. Output values are here supposed to be matrices in the size of the grid which defines the target positions.

## 5. TRACKER PERFORMANCE MODEL

In a Passive Radar system 3-dimensional localization of the target is done during tracking by multilateration, which means intersection of several constant-range-ellipsoids generated by different receiver illuminator combinations. The Tracker Performance Model therefore represents an essential part of the Performance Analysis Tool.

The real tracker follows a three-stage strategy: RD-tracking for each receiver-illuminator pair, deghosting (resolving of ambiguities regarding targets and illuminators) and tracking in cartesian coordinates. Due to the permitted assumptions that a single target scenario is given and a detection is clearly assigned to the responsible illuminator, the second stage can be omitted in the model. Instead information about tracking accuracies in 3D-position and velocity is required. The calculation is performed by using the CRLB.

## 6. EXAMPLE

In the following an example for coverage analysis in the FM-band is shown. First of all it is necessary to define target, illuminator and receiver position.

The receiver is supposed to be located near Ulm in rural environment with an antenna height of 12 m. The results given by the Wave Propagation Model and Sensor Performance Model are illustrated for an FM transmitter located in Aalen which lies in a distance of 54 km to the receiver and has a transmit power of 43 dBW.

The target shall move towards the receiver in a height of 1000 m above ground with a speed of 100 m/s. As indicated by height and velocity, the target is supposed to be a light aircraft. Therefore a RCS of 7 dBsm is fixed.

Figure 3 gives an overview of the surrounding terrain and the position of receiver and transmitter. Further illuminators which are later used for the Tracker Performance Model are already depicted as well. The diffraction losses that occur between transmitter and target or receiver and target are shown in Figure 4. Here it becomes clear that in the lower right side of the image the losses increase due to the Alps. This is also obvious in the next plot which illustrates the received power of the target before any functions of the signal processing part are applied. Another effect that is shown here are the sidelobes that appear in the elevation diagram of the transmitter.

The total noise power before application of correlation and beamforming methods can be calculated by adding about 13 dB man made noise (rural environment) to the thermal noise.

To understand the results of the Sensor Performance Model further information is required. In this example the beamformer is working with 7 beams. These are clearly visible considering the received target power after the signal processing (see Figure 6). One can also see the region where the bistatic range assumes values below 500 m as a blue area between transmitter and receiver. Calculating the detection probability by using the target signal, noise and a false alarm rate of $10^{-6}$ the result in Figure 7 is obtained.

As tracking uses intersection of multiple ellipsoids while angles only serve as additional information, further illuminators are needed to localize targets in 3D. Figure 8 depicts the detection probabilities of the three additional illuminators already shown in Figure 3.

Currently the Tracker Performance Model assumes that range Doppler tracks of minimum three illuminators lead to a cartesian track of the target. When examining the track probability in Figure 9, it becomes clear that the probability increases when four illuminators contribute. In pixels where less than three detection probabilities assume satisfactory values, the track probability remains nearly zero. The position accuracy in Figure 10 shows a similar behavior.

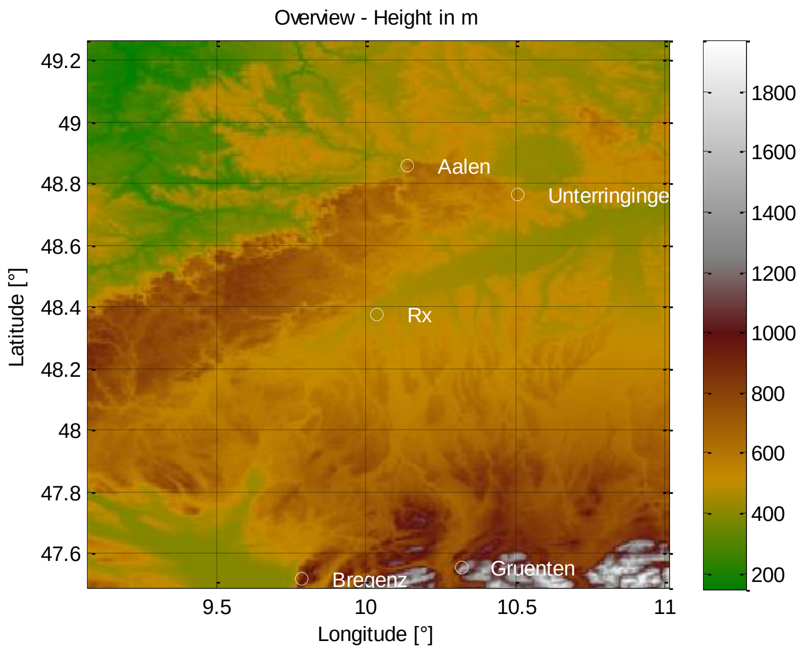


**Figure 3: Overview of Rx / Tx situation**

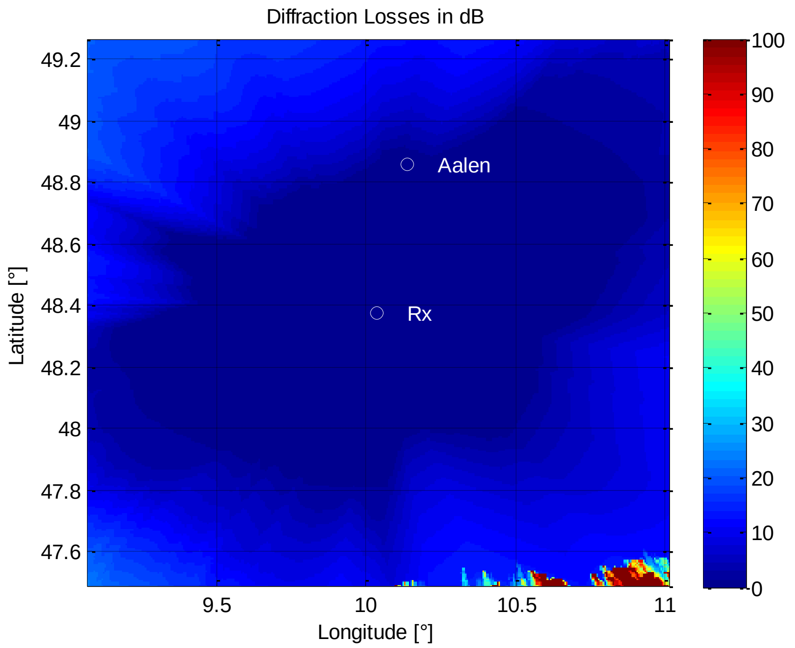


**Figure 4: Diffraction losses of target**

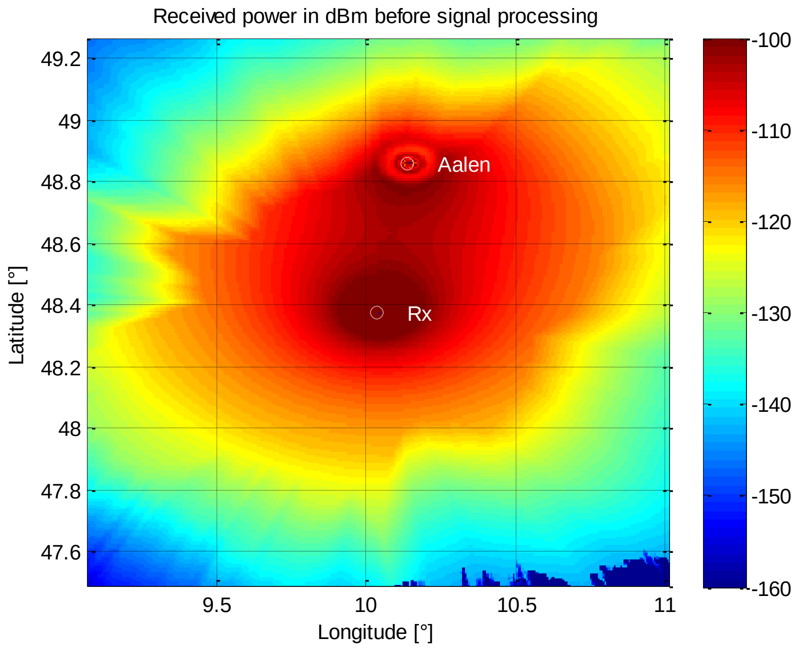


**Figure 5: Received power before signal processing**

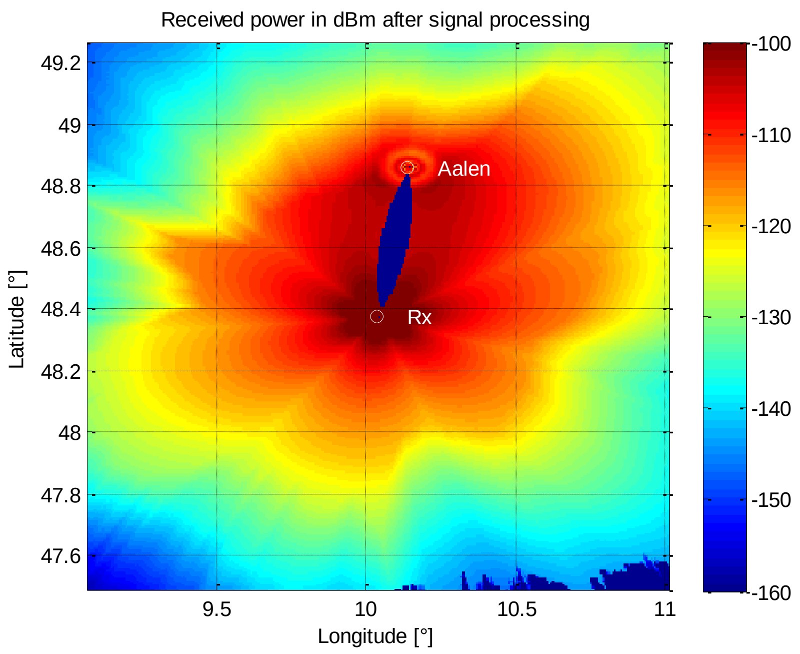


**Figure 6: Received power after signal processing**

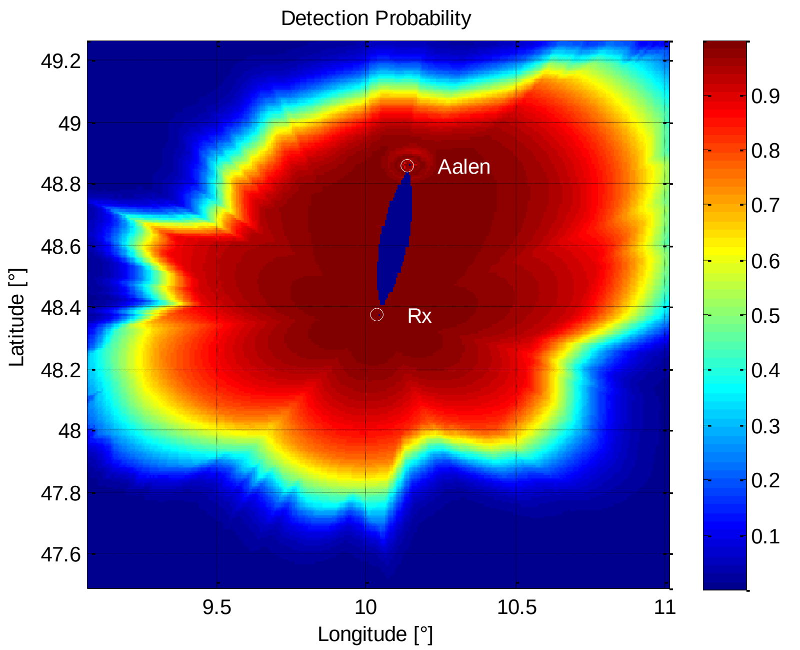


**Figure 7: Detection probability**

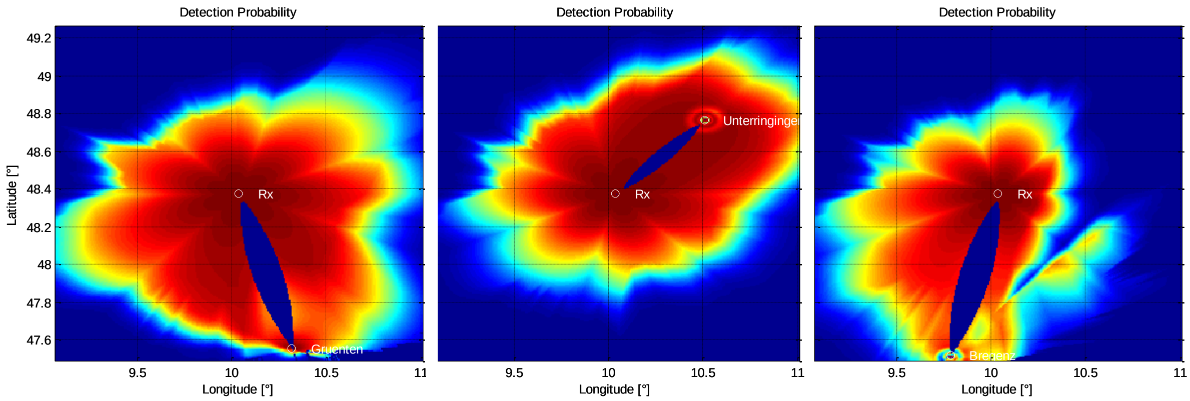


**Figure 8: Detection probability of further illuminators**

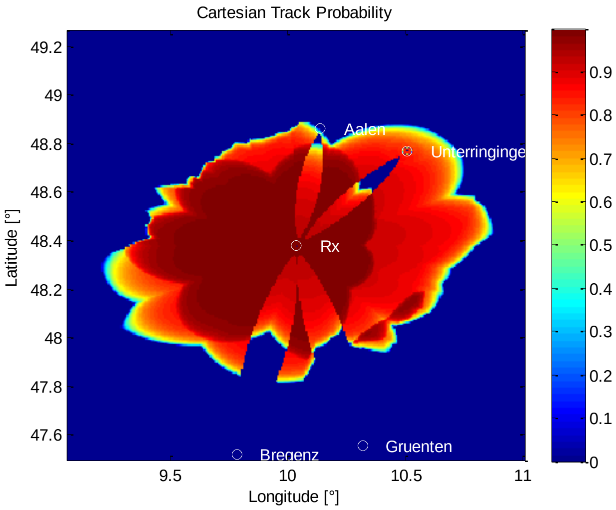


**Figure 9: Cartesian track probability**

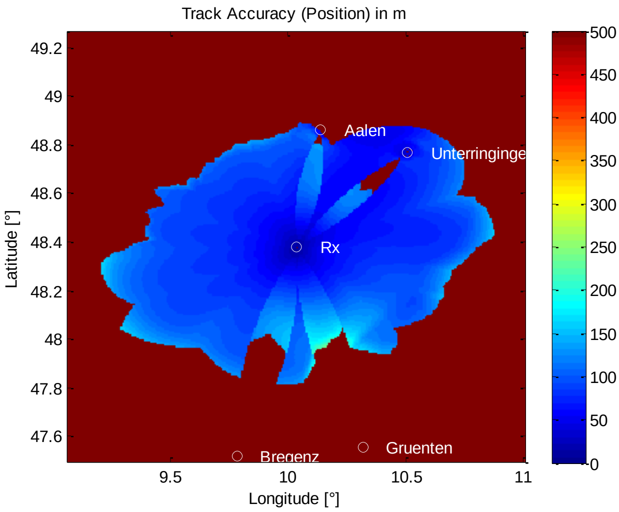


**Figure 10: Track accuracy (position)**

# 7. CONCLUSIONS & OUTLOOK

In this paper an overview of the Passive Radar Performance Analysis Tool is given. By using the tool the effort of preparing measurement campaigns could already be reduced considerably.

During the year 2013 extensive comparisons with real measurements will be carried out. Additionally a sensor cluster concept will help to improve Passive Radar performance especially regarding the interaction of the mobile Multiband Passive Radar Demonstrator (see [1], [2]) and the Stationary FM Passive Radar Demonstrator (see [3]) by Cassidian.

# 8. ACKNOWLEDGEMENTS

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