Finally There: CARPET 3

Arne Theil

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1 Introduction

The performance assessment of radar systems is a complicated task because of the interaction of many subsystems and the presence of a complex environment. Knowledge and experience gained from several disciplines are necessary to complete the task successfully. All aspects of the radar-environment-target chain, illustrated in Figure 1.1, must be studied in adequate detail.
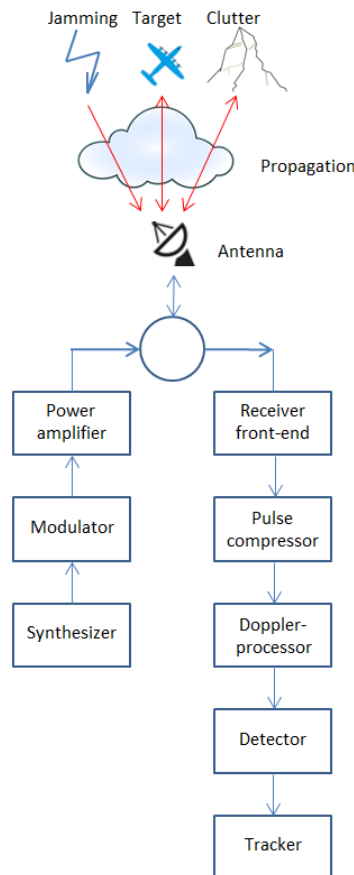

Figure 1.1: Radar-environment-target chain. The radar has been divided into several subsystems.

Because of the complexity of the task, computer support for radar system design and performance assessment is indispensable. Since its release date in 1993, the program CARPET (Computer Aided Radar Performance Evaluation Tool, [1]) provides such support. CARPET quickly became the most widely used radar performance assessment program. Its popularity was unmistakably related to its attractive price. Also helpful was the fact that the use of CARPET was advised by IMO, the International Maritime Organization. A side-effect of the low price was, however, a lack of funds for further developments of CARPET. A crowd-funding initiative, proposed to IALA, representing the VTS (Vessel Traffic Services) community, in 2011 failed.

TNO now comes with CARPET 3, a substantially more powerful radar performance assessment program compared to its precursors CARPET 1 (DOS) and CARPET 2 (Microsoft Windows, since 2003). While the so-called 'base version' of CARPET 3 is still very affordable, just like CARPET 1 and 2, CARPET 3 comes with a series of plug-ins, or extensions, which

are more costly. Furthermore, the life-time of a CARPET license has been limited to a two-year period. This price strategy is intended to 'strengthen the business case' so that program maintenance and further developments will become more easy.

This document provides a brief description of CARPET 3. The various plug-ins are discussed in Section 2 and new features of the base-version are considered in Section 3. Conclusions are formulated in Section 4, abbreviations are clarified in Section 5.[1]

2 Plug-ins

2.1 TERPEM-light

The specific plug-in that TNO considers to be most eminent is a product of Signals Science Ltd, UK: TERPEM-light. The plug-in provides a quantitative numerical model for calculating the effects of ducting and refraction in the atmosphere, which is a vast improvement compared to the 'EREPS-like' propagation model which uses a qualitative/semi-empirical approach. Furthermore, the plug-in provides import capabilities of meteorological data, being either a refractivity M-profile, a refractivity N-profile, WMO radiosonde code or TERMET-output. TERMET is a Signal Science product that makes available a global database of duct statistics, *i.e.*, 'worldwide' profiles that have been measured in different periods of the year. Thus, CARPET 3 is able to consider up-to-date meteorological conditions. Thirdly, the TERPEM-light plug-in provides 'in situ' radar performance assessment. CARPET 3 can be utilized to perform siting studies (Where should I place the radar? How tall must the radar mast be? What is the horizontal coverage?). Figure 2.1 shows an impression of this functionality. The DTED (Digital Terrain Elevation Data) information is NASA's 3 arc second SRTM (Shuttle Radar Topography Mission) elevation data, that the user can download from http://dds.cr.usgs.gov/srtm/.
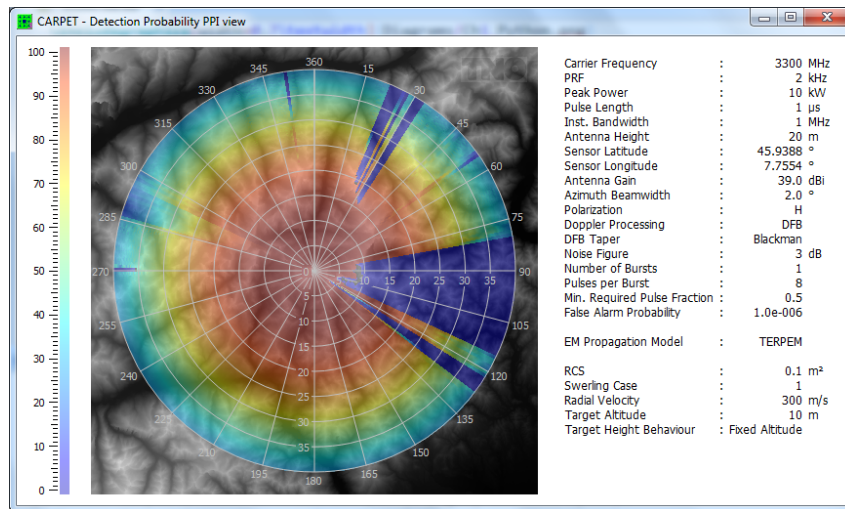

Figure 2.1: Example of the siting functionality of CARPET 3, which requires the TERPEM plug-in. The radar antenna is on a 20 m high tower, on top of Mount Matterhorn, Switzerland. The target travels at a constant altitude, 10 m above the top. The colour represents the single scan detection probability. The diagram reveals (not surprisingly) that it would better to install the radar on top of the Monte Rosa massif, approximately 8 km east of the Matterhorn.

TERPEM is not as fast as EREPS-like, let alone free space propagation. Thus, PPI-view diagrams, such as the one presented above, take a while to calculate. To speed up the process, the processing load is distributed over the available CPU-cores. In case one wants to apply siting studies a fast multi-core CPU is therefore advised.

TERPEM-'light' means that not all functionality of the original TERPEM program is available. The main limitations are that only one vertical refractivity profile (which determines the

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[1]No rights can be derived from the contents of this document.

propagation environment) and one set of ground parameters (numerical, perfect conductor, wet ground, medium dry ground, very dry ground) can be specified for a path. The full TERPEM model allows these to vary with range. Also, some of the TERPEM sub-models that allow computational speed-ups for certain path geometries (such as high terminals) are not available.

Apart from the refractivity profile import capabilities, multiple ways to specify a refractivity profile are provided. The import capability of radiosonde code is illustrated in the figures 2.2 and 2.3. The top diagrams shows quantities measured by a weather balloon that was launched in the Gulf Region. These quantities appear in the so-called TTBB-part of the WMO radiosonde code. The effect that the meteorological conditions have on the detection performance of a non-coherent VTS radar is shown in the bottom-diagram. The specific meteorological conditions give rise to an elevated layer (surface duct). The 'gap' around 34 NM range is caused by the reception of seaclutter; since the PRF of the VTS radar is 2.4 kHz, a target beyond 33.7 NM is 'second-trace' and its response competes with near-by seaclutter.
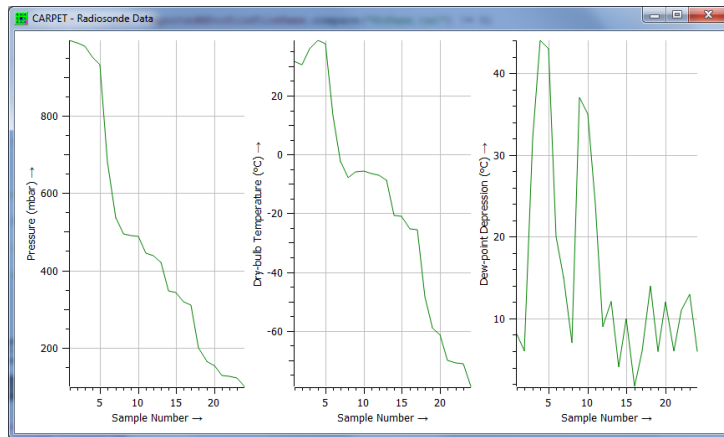

Figure 2.2: Radiosonde data, *i.e.*, pressure, dry-bulb temperature and dew-point depression, as gathered by a weather balloon.
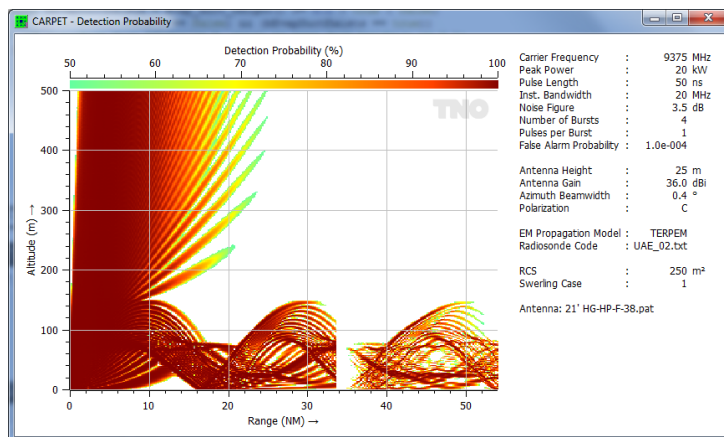

Figure 2.3: The effect of anomalous propagation to the detection performance of a non-coherent VTS radar. The gap at 34 NM is caused by near-by seaclutter.

2.2 Multi-burst

Modern radar systems apply the efficient coherent Doppler integration of multiple responses. Often, different bursts per dwell are applied, in order to eliminate blind velocities and sometimes also blind range spans; PRFs, RFs and also pulse lengths can vary (stagger) from burst to burst, long pulses are compressed, short pulses are not. A widely applied processing scheme is that

detection is done after Doppler integration, and that detections obtained from multiple bursts are combined using 'post-detection M-out-of-N integration'. CARPET 3 supports this scheme.

In case a modern VTS 'solid state' radar systems is involved or in case a radar that is designed to operate in a military domain is applied, the multi-burst plug-in is advised. Figure 2.4 shows the Transmitter dialogbox of CARPET 3. In case the multi-burst plug-in is not active, only a single line of the dialogbox can be edited. Figure 2.5 shows the received powers over range, in case two different bursts are applied.
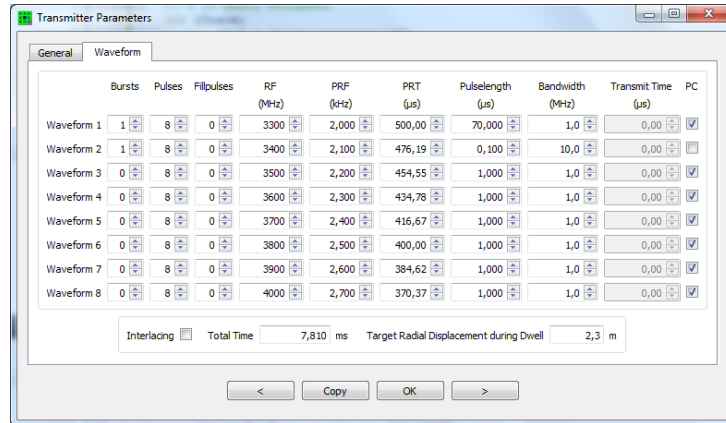

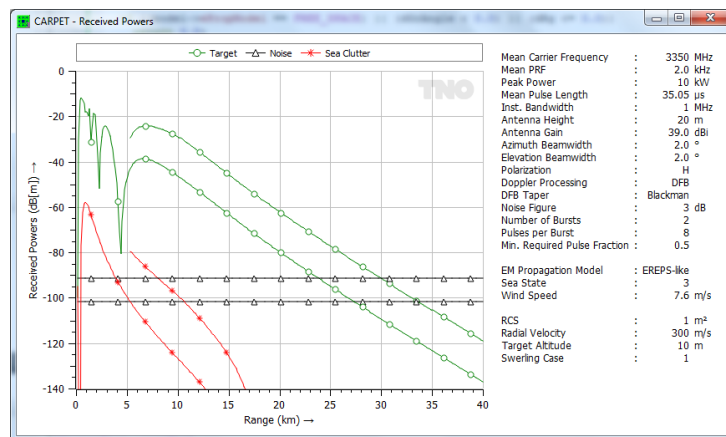Figure 2.4: The Transmitter dialogbox in case the multi-burst plug-in is active.

Figure 2.5: Received powers over range. There are two bursts within the dwell, as indicated in Figure 2.4. The short pulse is for the detection at very short range. The long pulse (70 μs) is compressed and for the detection at long ranges.

2.3 Multi-scatterer target

Thirdly, the target model has been extended. In CARPET 1 and 2 this was a single point target model, with the five Swerling cases. Consequently, deep multipath fades are predicted over sea with moderate sea states, which is not always realistic, *e.g.*, in case large maritime surface targets (vessels) are observed. For these extended targets, CARPET offers a point-cloud target model, see Figure 2.6. For each scatterer in the list, the detection probability is determined, and subsequently the maximum of these detection probabilities is taken. Note that the Swerling case can differ from scatterer to scatterer. Results of the multi-scatterer model are shown in Figure 2.7.
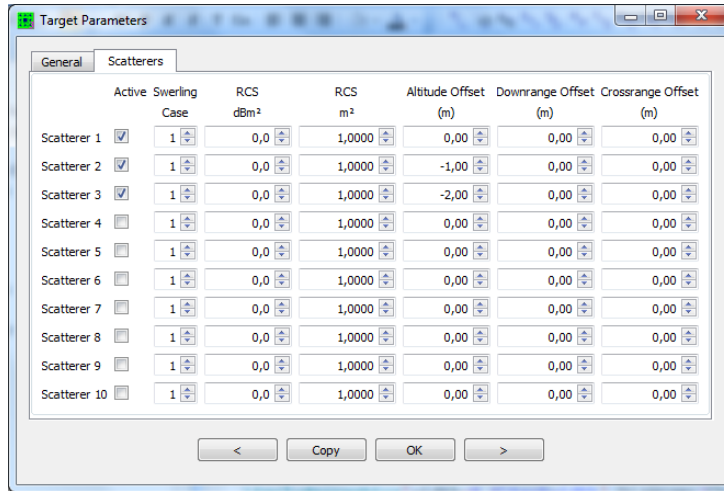
Figure 2.6: Target dialogbox in which a target made up of three point scatterers is defined. Note that for each individual point a Swerling case can be defined. In case the multi-scatterer target plug-in is not active, only this fields of the first line can be edited.
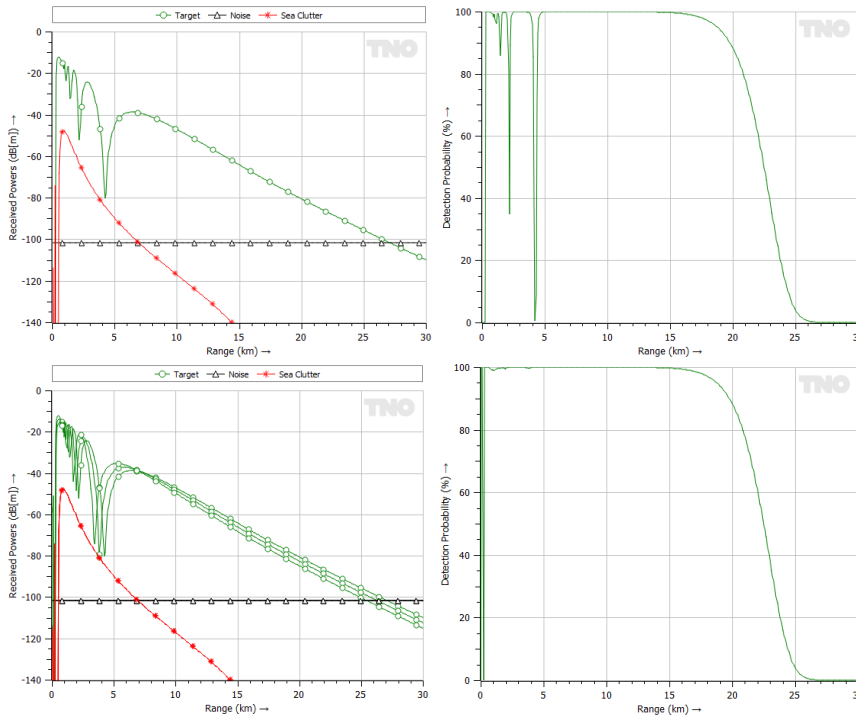

Figure 2.7: Top: Received powers and detection probability versus range, in case of a single point target. Bottom: Same diagrams, in case of a target made up of three point scatterers.

2.4 Python interface

Fourthly and finally, TNO offers a so-called Python plug-in that makes CARPET functionality available to Python programs. This feature serves users that wish to utilize CARPET to calculate and export numerical information that is not directly supported by the graphical user interface (GUI) of the program. Suppose you would like to have a diagram that shows firm track range (discussed in Section 3) versus sea state. The data can conveniently be gathered with the Python interface. CARPET 3 actually contains an editor in which Python programs can be developed, as shown in Figure 2.8.
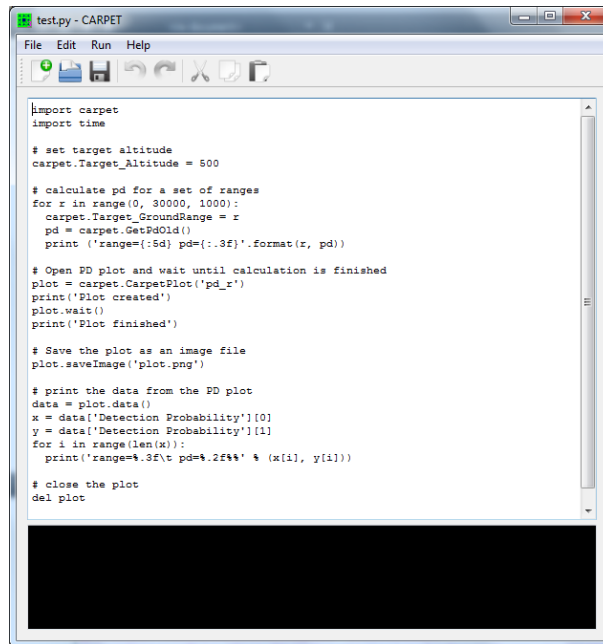
Figure 2.8: The Python editor of CARPET 3.

The Python interface offers the following capabilities:

- All CARPET parameters can be set.
- All CARPET diagrams can be generated and saved.
- The probably of detection and the firm track probability can be queried.
- The detection range and the firm track range can be queried. These are the farthest distances where the detection/firm track probability reaches a specified value.
- CARPET settings can be read from file.
- CARPET settings can be saved to file.

3 New features of the base-version

3.1 Backwards compatible

CARPET 3 can read CARPET 2 settings files. CARPET 3 writes settings files in an encrypted format.

3.2 GUI, graphics, operating systems

The GUI (Graphical User Interface) and the graphics have been modified. By utilizing Qt, Qwt and QwtPolar[2], the program is now also available for non-Microsoft Windows platforms, like Linux and OS-X. Furthermore, CARPET 3 is much more convenient to operate than the previous versions and extra features are offered, such as polar antenna diagrams and zoom-in capability.

3.3 More diagrams

CARPET 3 comes with the diagrams that are indicated below. The abbreviations R, V, A, T, F, ϕ and θ mean: range, radial velocity, altitude, time, frequency, azimuth angle and elevation angle. New are the $R\&\phi$ (or PPI-view) diagrams and diagrams that have time on the horizontal axis.

- Received Powers versus R, V, A, T

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[2]See http://www.qt.io, http://qwt.sourceforge.net/, http://qwtpolar.sourceforge.net/

- SCNR versus R, V, A, T, $R\&V$, $R\&A$, $R\&\phi$
- Detection Probability versus R, V, A, T, $R\&V$, $R\&A$, $R\&\phi$
- Firm Track Probability versus R, T, $R\&\phi$
- One-way Path Loss versus R, A, T, $R\&A$, $R\&\phi$
- Two-way Path Loss versus R, A, T, $R\&A$, $R\&\phi$
- One-way Pattern Propagation Factor versus R, A, T, $R\&A$, $R\&\phi$
- Two-way Pattern Propagation Factor versus R, A, T, $R\&A$, $R\&\phi$
- Refractivity Profiles versus A, requires TERPEM
- Radiosonde Data, requires TERPEM
- Terrain Height Map, requires TERPEM
- Terrain Profile versus R for a specific bearing, requires TERPEM
- Doppler Filter Responses
- Synthesizer Spectrum
- Swerling cases versus SNR
- Antenna Elevation Pattern on Tx, Rx, Tx and Rx

3.4 Firm track probability

TNO has replaced the cumulative detection diagram of CARPET 1 and 2 by firm track probability, P_{ft}, diagrams. Having P_{ft} diagrams is important, since many modern radar systems provide plots (target reports) that associate with local tracks. TNO has implemented Richard Worsham's procedure to determine firm track probability, [2]. A Tracking dialogbox has been added to the GUI, as shown in Figure 3.1. Figure 3.2 shows firm track probability over target range. The single dwell detection probability is depicted in the diagram as well.
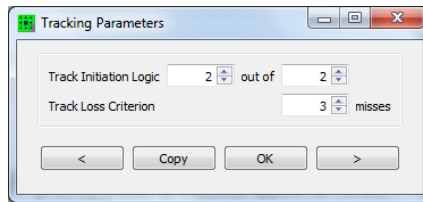

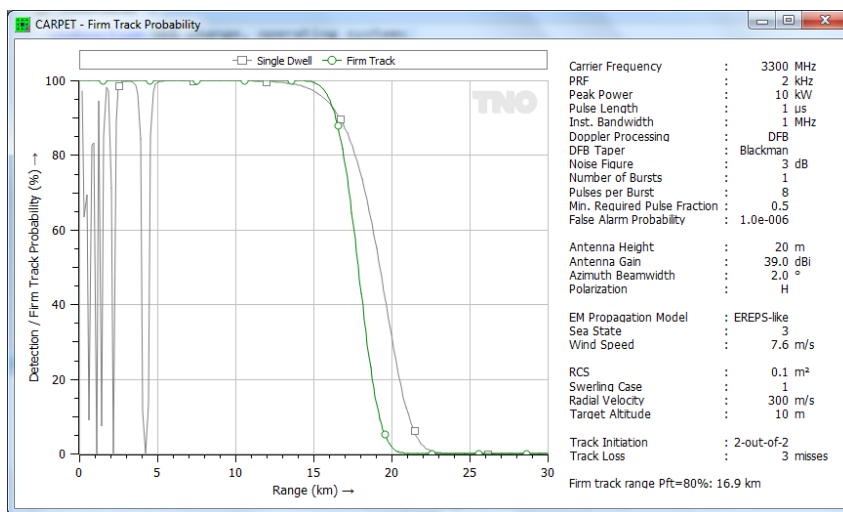Figure 3.1: The Tracking dialogbox of CARPET 3.

Figure 3.2: Firm Track Probability diagram.

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3.5 PPI-view diagrams

Figure 2.1 is an example of a PPI-view diagram. It is a polar diagram, the target altitude behaviour is either 'terrain following' or 'fixed altitude'. This addition led to the necessity to specify the shape of volume clutter (rain or chaff) more precisely. Rather than specifying a start and stop range (in CARPET 2), the user now has the ability to specify the range to the center of the volume clutter, its diameter and its azimuth angle. Figure 3.3 shows how rain affects the radar coverage of an X-band radar, in a PPI-view diagram.
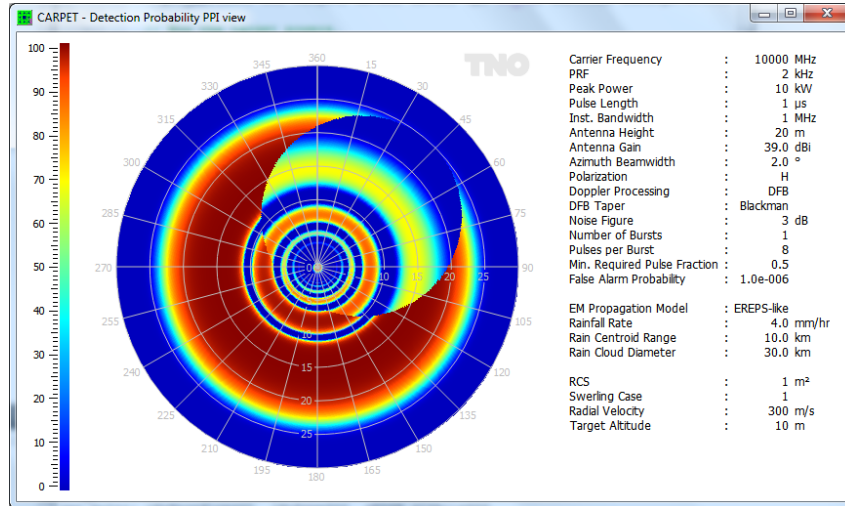

Figure 3.3: The influence of a rain cloud to the detection performance of an X-band radar is shown. The diameter of the rain cloud is 24 km.

3.6 Separate transmit and receive antenna

These two antennas do not have to be identical. Apart from built-in antenna elevation patterns, one can also import antenna patterns.

3.7 More jammers

The number of jammers has been increased to four, the bearing angles, ranges and altitudes of the jammers need to be specified, see Figure 3.4 and Figure 3.5.
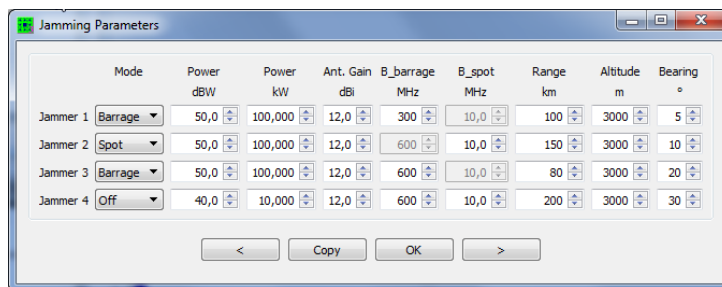

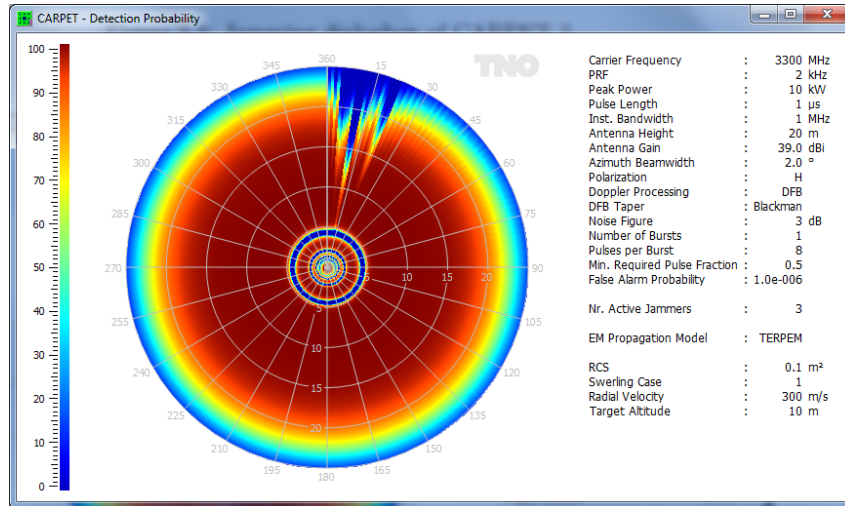Figure 3.4: Jamming dialogbox of CARPET 3.

Figure 3.5: The effect of three stand-off jammers (at bearings 5, 10 and 20°) on a radar's horizontal coverage.

3.8 Pulse eclipsing

A radar receiver is protected during the time intervals that pulses are transmitted. Modern radar systems are often able to process partially eclipsed pulses. CARPET 3 models pulse eclipsing, the user has to specified a minimum required pulse fraction.

3.9 Loss factors

Whereas CARPET 1 and 2 came with limited number of loss factors, CARPET 3 offers a more detailed specification, as shown in Figure 3.6.
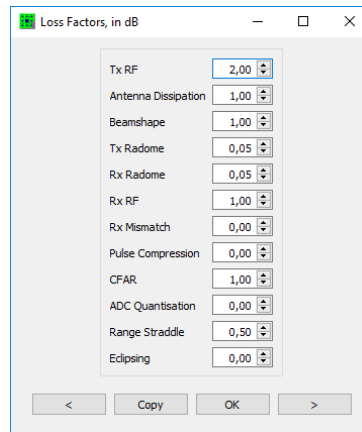

Figure 3.6: The Loss Factors dialogbox of CARPET 3.

3.10 Blake chart

The classical Blake chart has been added, as a worksheet, see Figure 3.7.

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Free Space Blake Chart — □ ✕

Detectability | System Noise | Range Factors

Frequency	3300,0	MHz				
Power	10,0	kW	40,0	dBW	40,0	dBW
Pulse Length (uncompressed)	1,0	µs			-60,0	dBs
Gain Transmit Antenna	39,0	dBi			39,0	dBi
Gain Receive Antenna	39,0	dBi			39,0	dBi
Target RCS	1,000	m²	0,0	dBm²	0,0	dBm²
Wavelength Squared	0,0083	m²			-20,8	dBm²
Required Single Pulse SNR					-17,9	dB
System Noise Temperature	728,4	K			-28,6	dBK
Losses	4,5				-4,5	dB
Range Equation Constant					195,6	dBJ/K
Column Total					181,8	dB
Free Space Range			19,0	NM	35,1	km

OK

Figure 3.7: Blake chart worksheet of CARPET 3.

4 Conclusions

The release of CARPET 3 represents a significant upgrade. Equipped with the multi-burst plug-in, CARPET 3 is fit to model modern solid-state radar systems. The inclusion of TER-PEM brought together expertise areas of two different groups (Signal Science's EM propagation modeling, TNO's radar system modeling). As a result, the EM propagation modeling has improved significantly, in-situ radar performance assessment is offered and CARPET 3 can consider imported radiosonde data. In case the capabilities that the GUI offers are considered to be insufficient, the Python plug-in offers additional flexibility.

The developers of CARPET 3 are aware of items still on the wish-list, such as modeling of STC (sensitivity time control), multi-beam radar, FMCW waveforms, multi-radar coverage, additional DTED formats, TERPEM-'heavy' and importable Doppler filter coefficients. TNO has changed the pricing strategy to ease the implementation of future upgrades. Requests to customize the program are more than welcome; please send your comments and suggestions to carpet@tno.nl.

5 Abbreviations

CARPET	Computer Aided Radar Performance Evaluation Tool
CPU	Central Processing Unit
DLL	Dynamic Link Library
DTED	Digital Terrain Elevation Data
EM	Electro Magnetic
EREPS	Engineer's Refractive Effects Prediction System
FMCW	Frequency Modulated Continuous Wave
IALA	International Association of Lighthouse Authorities
IMO	International Maritime Organisation
NASA	National Aeronautics and Space Administration
NM	Nautical Mile
PPI	Plan Position Indicator
PRF	Pulse Repetition Frequency
RF	Radar Frequency
SCNR	Signal to Clutter plus Noise Ratio
SRTM	Shuttle Radar Topography Mission
STC	Sensitivity Time Control
TNO	Netherlands Organisation of Applied Scientific Research
VTS	Vessel Traffic Services
WMO	World Meteorological Organization

References

[1] Albert G. Huizing, Arne Theil, *CARPET (Computer-aided Radar Performance Evaluation Tool): Radar Performance Analysis Software and User's Manual*, 1993 Artech House, Inc., ISBN 0-89006-636-1

[2] Richard Worsham, *The Probabilities of Track Initiation and Loss Using a Sliding Window for Track Acquisition*, 2010 IEEE Radar Conference, Baltimore, Maryland