11 CALCULATIONS: RADAR COVERAGE

11.1 INTRODUCTION

The Radar Coverage tool enables the user to calculate the long-range coverage based on target height and radar cross section. The tool performs the following calculations:

- Radio-optical visibility
- Free space coverage
- Radar cross section with or without jammers
- Probability of detection with or without jammers
- Post-processing of probability of detection calculations

The calculation area may be specified around a radar station or defined in the Map Viewer. The calculations are performed on one radar station at time. Different radar parameters may be changed (power, antenna height, elevation etc.) to obtain as optimum radar coverage as possible. It is possible to define if the radar shall be directed to the calculation point or if the antenna direction shall be fixed.

When selecting one radar station and initiating a coverage calculation, the user will only have to define how the actual calculation shall be performed. All necessary technical parameters are retrieved from the project or the database.

The Radar Coverage tool features the following:

- User definable calculation area: Circle, Polygon, Line, Point(s)
- Different calculation resolutions. WRAP makes it easy for the user since only the desired degree of resolution needs to be specified, refer to **Table 4.5**.
- An arbitrary number of levels and colours for the result.

Results for calculations over an area can be displayed either in the 2-D or the 3-D map.

Results for calculations along a line defined in the Map Viewer are presented as an X/Y diagram in the Profile Viewer, together with the terrain profile along the line.

Results for calculations at defined points are presented in a table.

Refer to **[A28]** for a detailed specification of the calculation methods.

11.1.1 Radio-optical visibility

The calculation is based upon a user-defined target height and optionally the effective earth radius factor. The calculations are performed in the same way as in the tool Coverage – Clearance. The result is the area with radio-optical visibility for the selected values of first Fresnel zone clearance.

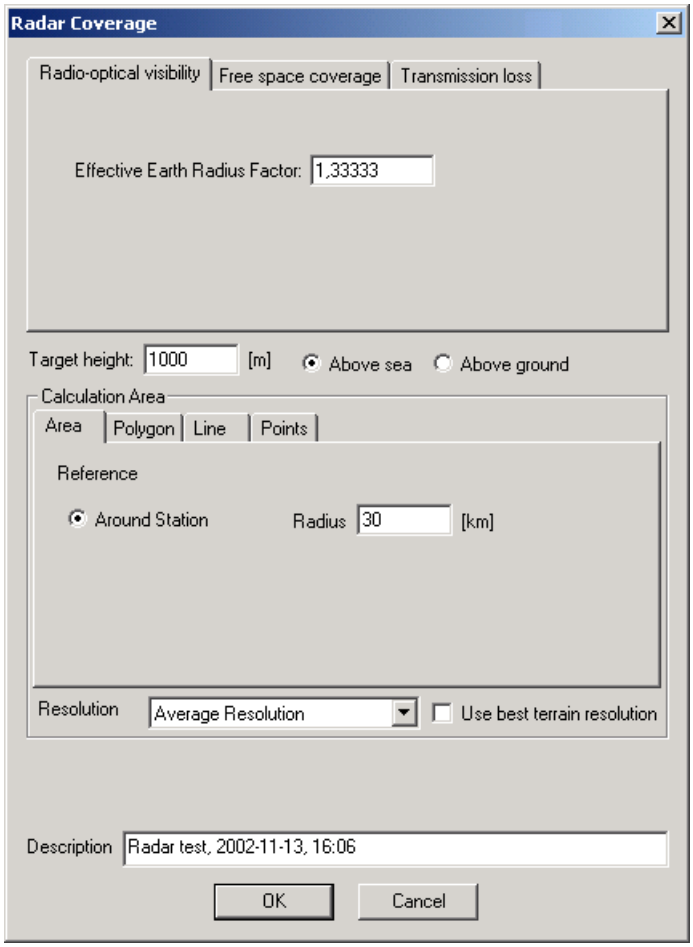

Figure 11.1: *Radar Coverage, Radio-optical visibility.*

11.1.2 Free space coverage

The tool calculates and presents the maximum radar coverage using free space propagation based on user selected radar cross section. The tool also calculates the required target height to fulfil the free space propagation conditions.

Free space coverage is calculated using a basic form of the radar equation.

$$P_r = P_t G_t G_r \sigma \lambda^2 / (4\pi)^3 R^4$$

where

P_r = Received echo signal power [W]
P_t = Transmitted signal power [W]
G_t = Antenna gain at Tx
G_r = Antenna gain at Rx
σ = Radar cross section of the target [m^2]
$\lambda = 3 \cdot 10^8$ / frequency in Hz [m]
R = Range to the target [m]

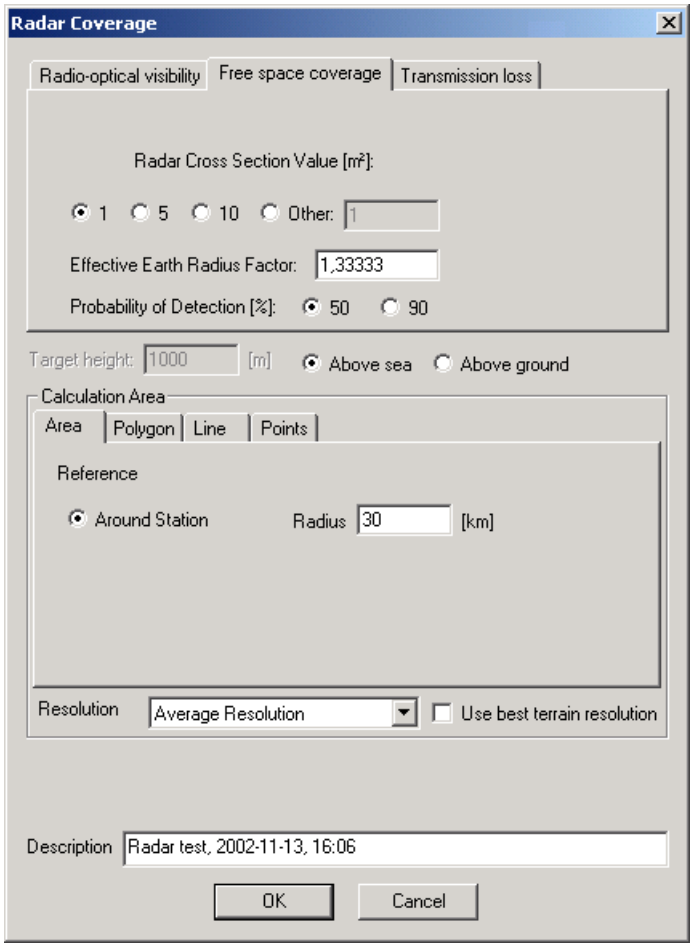

Figure 11.2: *Radar Coverage, Free space coverage.*

The maximum radar range for the selected radar cross section is presented as a circular line around the radar station.

The calculation of required target height is based on calculations in the tool Coverage - Required Antenna Height. The calculations are performed with a clearance of 100 %. It is possible to show the free space coverage based on different target heights based on the calculated results.

11.1.3 Radar cross section (RCS)

The tool calculates and presents the long-range coverage including more than free space loss, such as diffraction, reflection, rain attenuation etc. The calculation is performed for a specific target height entered by the user. The user also specifies the propagation model. It is possible to choose a 50 % or 90 % probability of detection, provided that the required Signal-to-Noise ratios for both values are entered as equipment data.

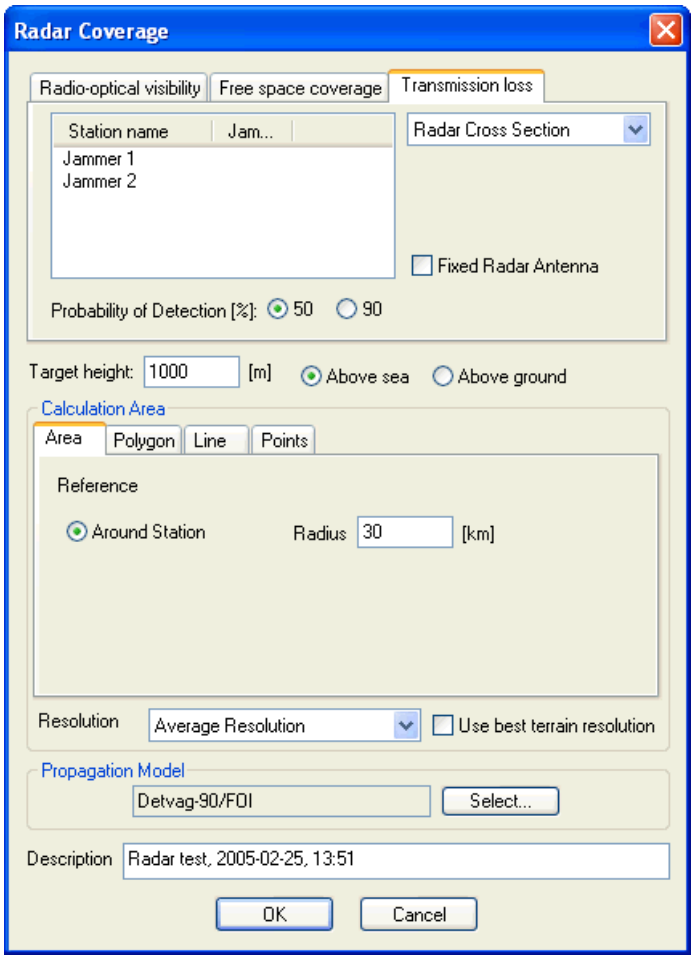

Figure 11.3: *Radar Coverage, Transmission loss.*

The calculations are based on comparing the received signal, at each distance from the radar to the target, with the interference from the jammer and the noise. When the radar station is chosen the user may select none, one, or several interferers or jammers from all the stations defined in the project. This makes it possible to take e.g. radio links into consideration.

Parameters included in the calculations are the effects of radar antenna pattern in azimuth, elevation and tilt; antenna rotation, as well as the complete pattern of the jamming antenna. There are two options for the radar antenna in the azimuth plane (horizontal plane). The first is that the radar antenna is directed to the target and the second is that the radar antenna has a fixed horizontal direction. The complete 3D-pattern is accounted for by an interpolation between the horizontal and vertical antenna pattern.

The minimum detectable radar cross section is calculated at each raster point. The result is presented as a coverage plot with different radar cross sections. The effect of jamming is that a larger radar cross section is required for a given distance to the target.

11.1.4 Probability of detection (P_d)

The calculation is similar to radar cross section. Differences are the parameters to the calculation and the result. Here you enter the radar cross section value in m² and the probability of detection is calculated assuming Swerling case 1. The result is unit-less. Swerling case 1 assumes slowly fluctuating target.

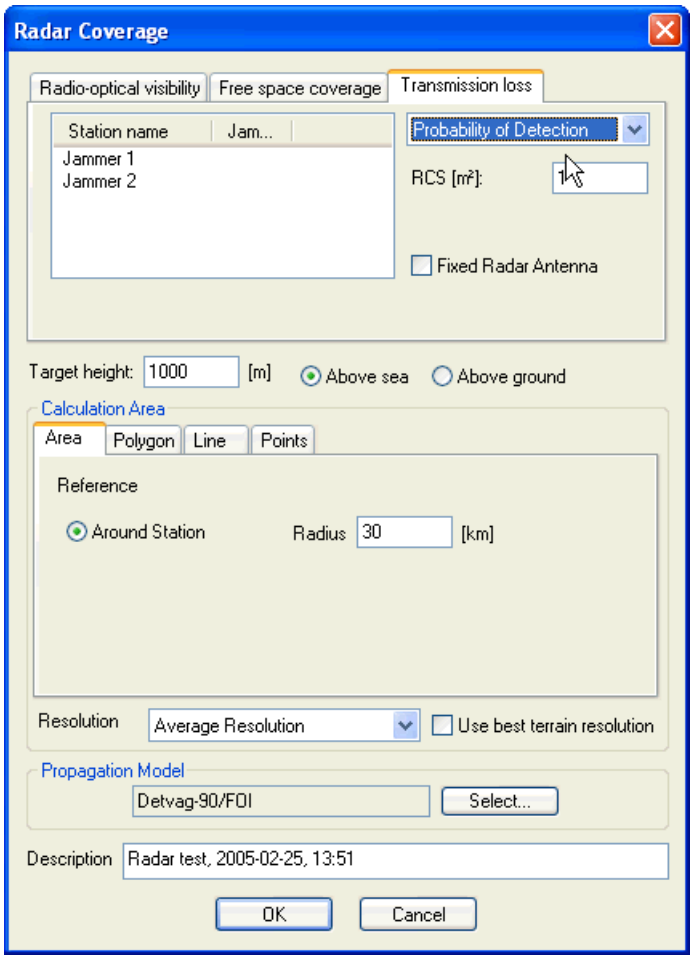

Figure 11.4: *Probability of detection.*

The probability of detection for the given radar cross section is calculated at each raster point. The result is presented as a coverage plot with different probability of detection values.

11.1.5 Post-processing of P_d-maps

This is an advanced extension to the normal Radar Coverage tool. The radar tool looks as for the calculation of P_d. The difference is that the right-click menu item "Set Radar" becomes active.

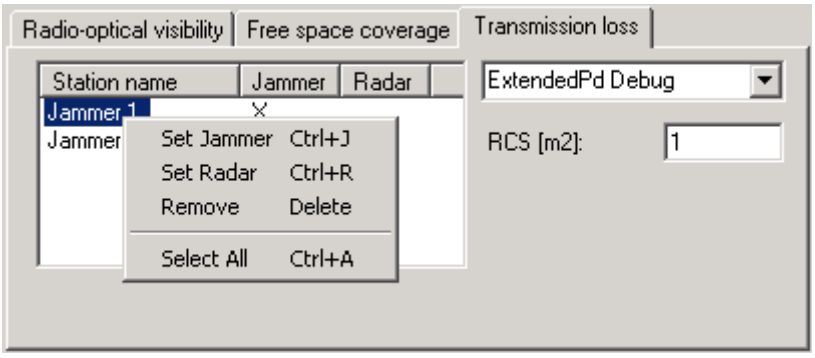

Figure 11.5: *Post-processing of P_d-maps.*

In this mode it is possible for the user to calculate several P_d-maps and post-process the results to one result, which WRAP may present the normal way. The selected radar station will not appear in the list but will be one of the radar stations that are used in the calculation.

WRAP International does not deliver any post-processing plug-in files with WRAP.

11.1.6 Example 1: Calculating the radio-optical visibility

Most radar calculations can be performed by just considering the radio-optical visibility and the free-space transmission loss. The atmospheric attenuation should be considered in addition to the free-space loss, at least for radars operating at high GHz frequencies. The maximum radar range is in this case limited by the terrain mask that shadows the radar visibility. The following example illustrates how WRAP can be used to determine the radar range against targets with different heights above ground or sea and varying radar cross sections.

- Open the project ***Radar.WPR***. This project contains one radar operating at 9900 MHz and two jammers. Mark the radar station in the project and show it on the map.

- Creating a new radar is done as follows:
  - Set the desired TX position in the Map Viewer
  - From the menu bar, select <**Station**>-<New...>.
  - Select the desired type of radar
  - Enter name, transmitter and receiver frequencies etc. Specific characteristics of the radar receiver are found under the **Miscellaneous** tab of the receiver in the **Edit receiver** window and under the radar tab in **Edit station** window.
  - Enter the integration factor and the sensitivity for 90% probability of detection (if calculations at the 90% probability are needed. The sensitivity for 50% probability of detection is entered in the Main tab.
  - The sensitivities may be calculated based on the

receiver noise figure and bandwidth.

However, for the following example the radar that already is available in the project will be used.

- Mark the radar station in the project and click on the  **Radar Coverage** button in the Menu bar.

- Make the following settings and selections:
  - Effective Earth Radius Factor: 1.33
  - Target height: 300 m above ground
  - Calculation Area: Area, Around Station, Radius 100 km
  - High resolution and Use best terrain resolution. For these kinds of geometrical calculations, the best terrain resolution gives a more reliable result.
  - And a suitable result description.

  See **Figure 11.6.**

  Click on **[OK]** to start the calculation and close the window.

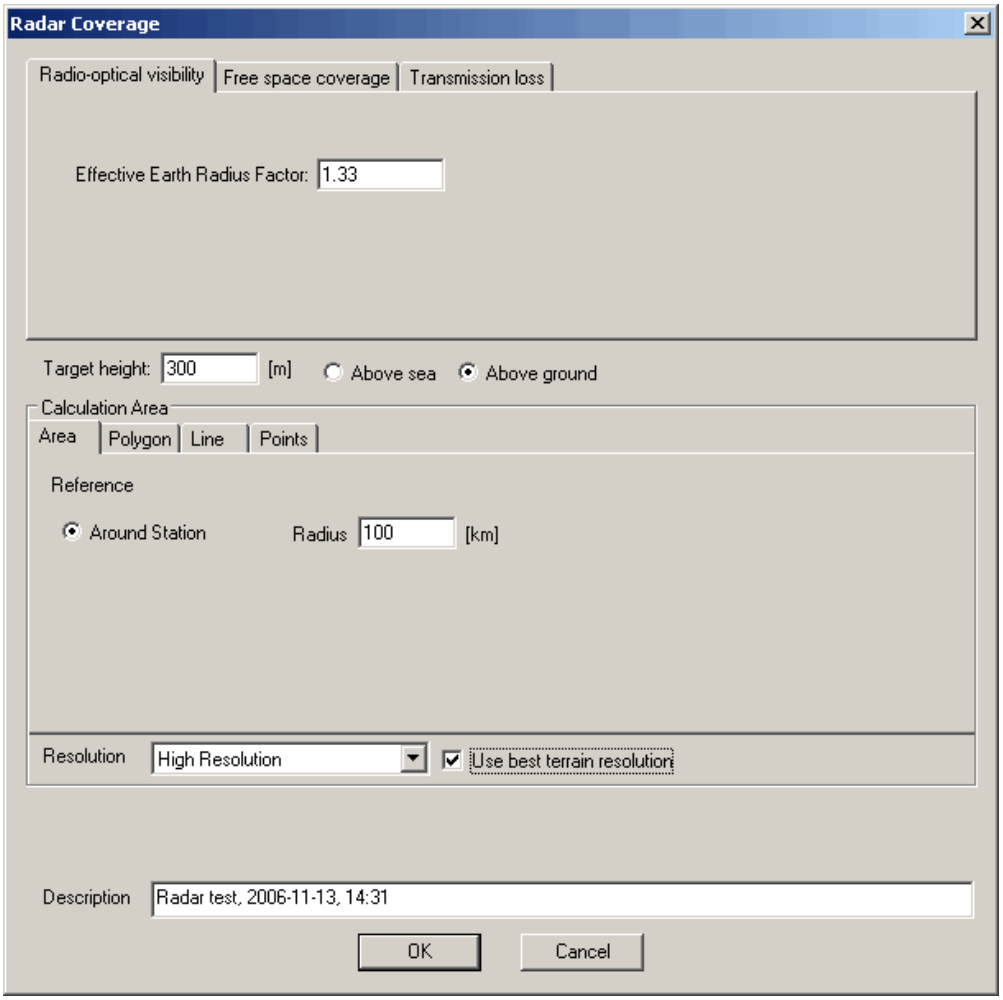

Figure 11.6: *Input data for calculation of Radio-optical visibility for the radar station.*

- Open the folder **This project - Radar Coverage Results Area**. Double-click on the result that was just calculated. It might take a while depending on the computer used.

- The **Edit Result** window gives statistics on the result, expressed in percentage of the first Fresnel zone clearance. 0% clearance means that half the first Fresnel zone is obstructed and 100% means that the full first Fresnel zone is just clear of obstructions. Select to show these two contours in the **Presentation** tab and show the result in the Map Viewer. See **Figure 11.7.Note that the map may look different due to differences in the geographical data used in the calculations.**

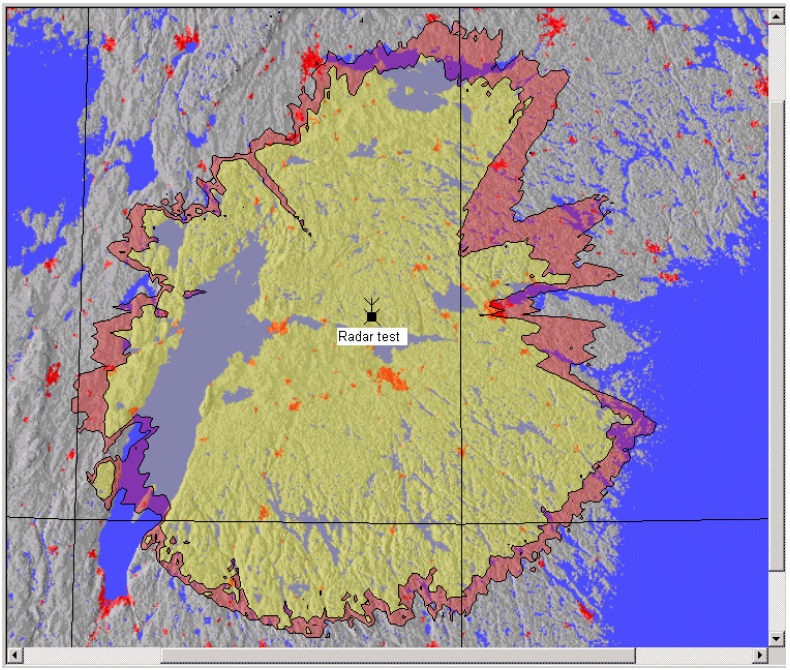

Figure 11.7: *Radio-optical coverage for radar station for target 300 m above ground level.*

The radio-optical coverage result does not consider power levels of the radar or the radar cross section of the target. However, it provides valuable input for the suitability of the radar location as it gives the maximum visibility range against targets at a given height.

11.1.7 Example 2: Maximum free-space range and coverage for various target heights

The following example considers the power budget of the radar system, the radar cross section of the target and the required target height to allow detection.

- Open the project ***Radar.WPR***. This project contains one radar operating at 9900 MHz and two jammers. Mark the radar station in the project and show it on the map.

- Mark the radar station in the project and click on the **Radar Coverage** button in the Menu bar.

- Select the **Free space coverage** tab and make the following settings and selections:
  - Radar Cross Section Value: Other, 100 m^2
  - Effective Earth Radius Factor: 1.33
  - Probability of Detection: 50 %
  - Target height reference: Above sea
  - Calculation Area: Around Station, Radius 100 km
  - High resolution and Use best terrain resolution
  - And enter a suitable result description.

See **Figure 11.8.**

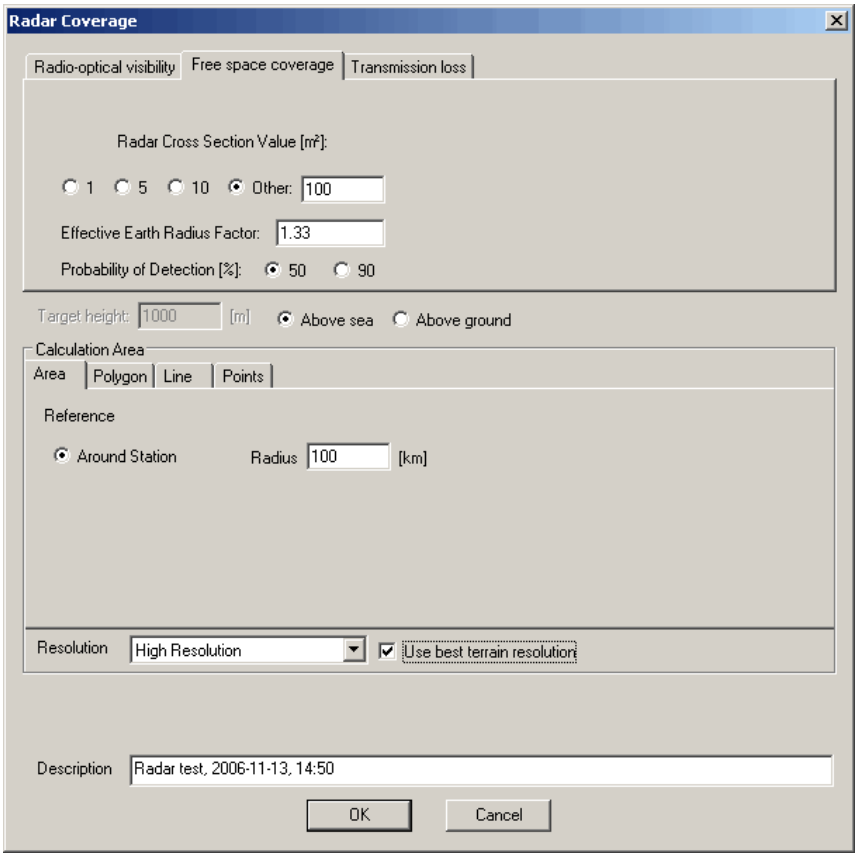

Figure 11.8: *Settings for the calculation of free-space coverage of the radar station.*

- Click **[OK]** to start the calculation and close the window.

- When the calculation is ready, open the folder **This project - Radar Coverage Results Area**. Double-click on the result that was just calculated and select to show areas for 100 m, 300 m and 1000 m target heights. The target height is defined above sea level in this result, since that was the selection made in the input data parameters. Show the result in the Map Viewer. See **Figure 11.9. Note that the map may look different due to differences in the geographical data used in the calculations.**

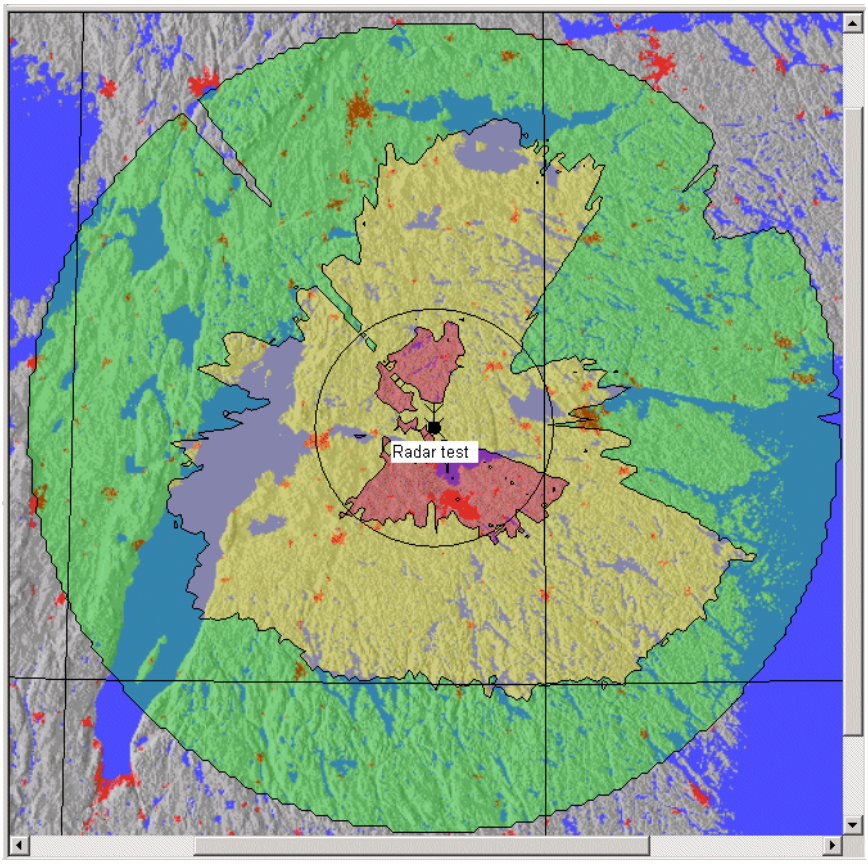

Figure 11.9: *Calculated free-space coverage for 100 m² RCS and target heights of 100, 300 and 1000 m above sea level.*

- The maximum range of the radar for a target with 100 m² radar cross section is shown with the black circle. This assumes that free-space propagation conditions are present, i e 100% first Fresnel zone clearance. Due to terrain obstructions this condition is however not fulfilled for target heights below about 300 m above sea level, which is shown by the coloured areas for the three selected target heights.

11.1.8 Example 3: Calculations considering jammers and selectable propagation models

For low-frequency radars there may be some coverage beyond the line-of-sight obstructions due to diffraction. In a situation where jammers must be considered there is a need to use a suitable propagation model that accounts for the one-way transmission loss between the jammer and the radar receiver. A good propagation model should be used in these cases to calculate the two-way radar loss and the one-way jammer-to-radar loss. The following example instructs on how to use WRAP for radar calculations in these applications.

- Open the project ***Radar.WPR***. This project contains one radar operating at 9900 MHz and two airborne jammers 500 m above ground. Mark the radar station and the two jammers in the project and show them on the map.

- Mark the radar station in the project and click on the  **Radar Coverage** button in the menu bar.

- Select the **Transmission loss** tab and make the following settings and selections:
  - Select RCS in the drop-down list
  - Right-click on Jammer 1 and select **Set jammer**
  - Repeat the above for Jammer 2
  - Probability of Detection: 50%
  - Interference Margin: 10 dB
  - Target height: 300 m above ground
  - Calculation Area: Around Station, Radius 100 km
  - High resolution and Use best terrain resolution
  - Propagation model: ITU-R P.526, with atmospheric attenuation for terrestrial (default values)
  - And enter a suitable result description.

  See **Figure 11.10.**

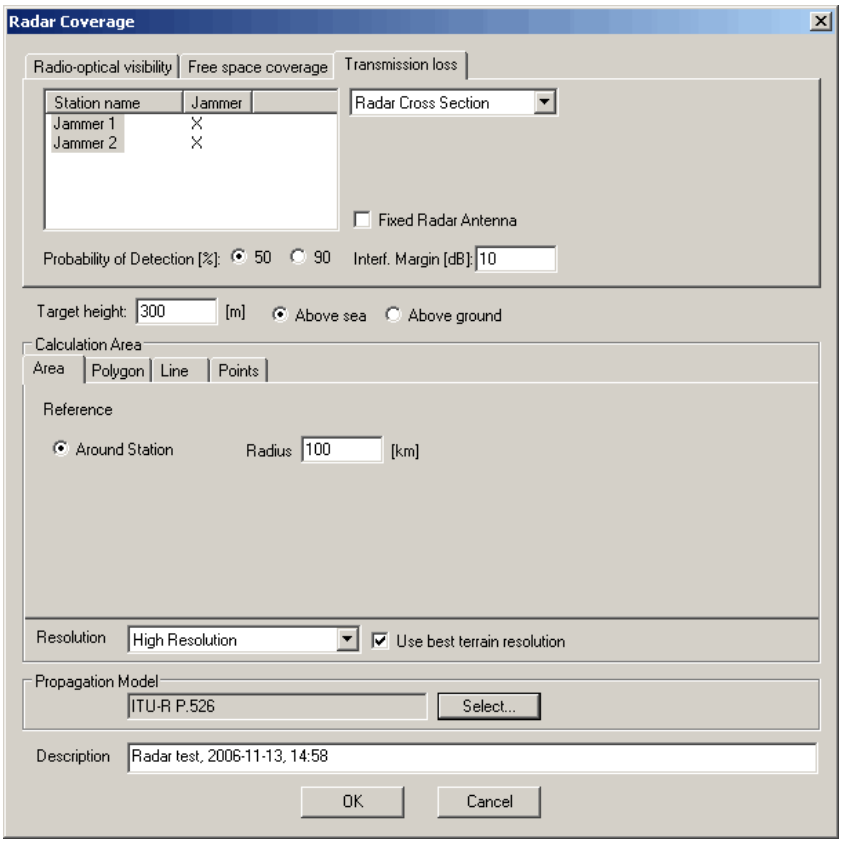

Figure 11.10: *Settings for the calculation of radar coverage under jamming.*

- Click **[OK]** to start the calculation and close the window.

- When the calculation is ready, open the folder **This project - Radar Coverage Results Area**. Double-click on the result that was just calculated and select to show areas for 10 m^2, 100 m^2 and 1000 m^2 radar cross section. Show the result in the Map Viewer. See **Figure 11.11**. **Note that the map may look different due to differences in the geographical data used in the calculations.**

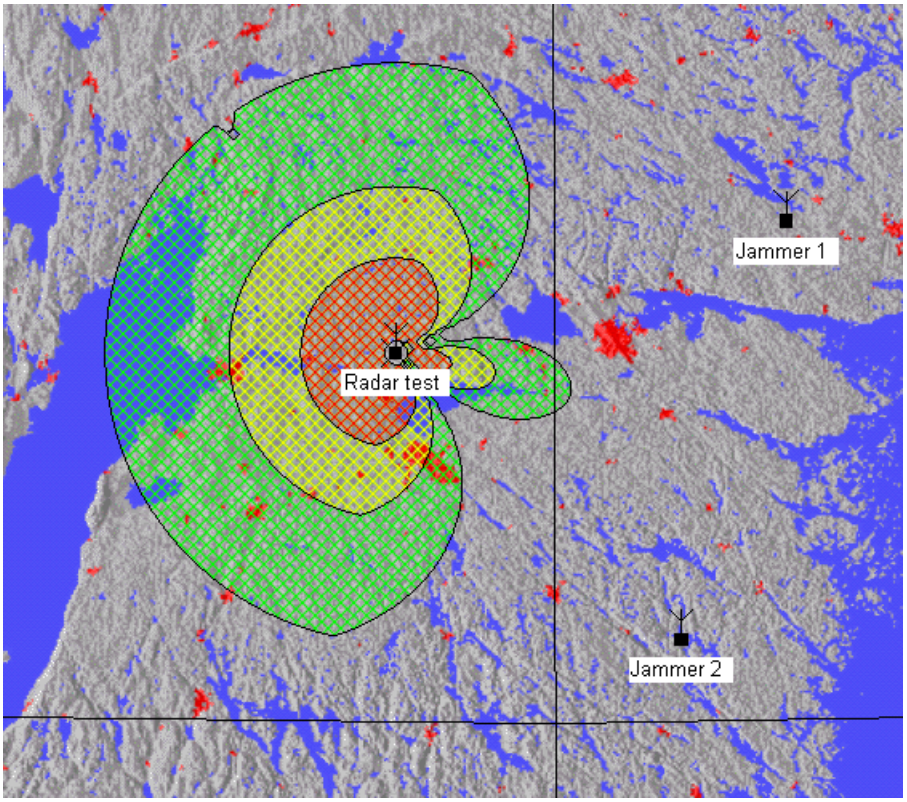

Figure 11.11: *Radar coverage under jamming for 10, 100 and 1000 m^2 target radar cross section.*

The significant impact of jamming can be seen as the large reduction in range in the directions towards the jammers. Jamming is severe since the jammers only suffer a one-way transmission loss while the radar is subject to the two-way transmission loss.

The circle around the radar station is an example of the minimum distance. Since the target height is defined as 300 m above ground level and the minimum distance is set to 1000 m there will be an area around the radar where the radar won't see anything.