MATLAB EXPO 2021

Radar Systems Engineering: Making the Right Design Choices for Next Generation Designs

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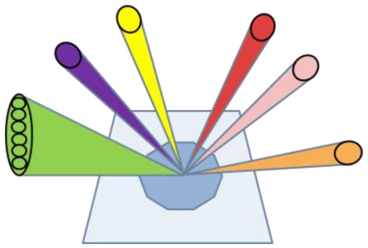
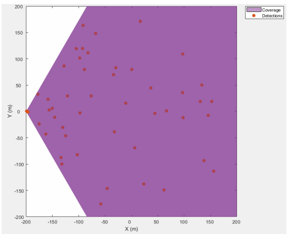
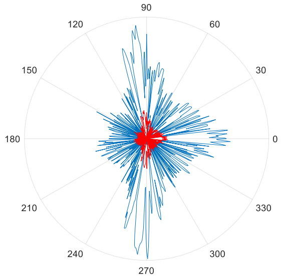
Mike Rudolph

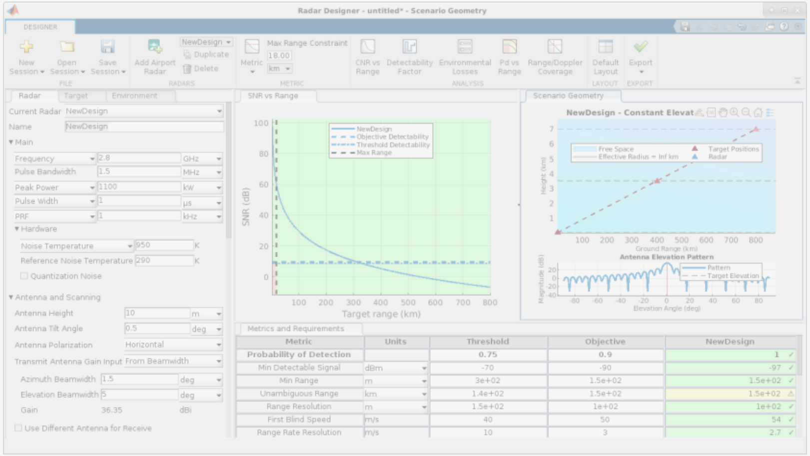
MathWorks®

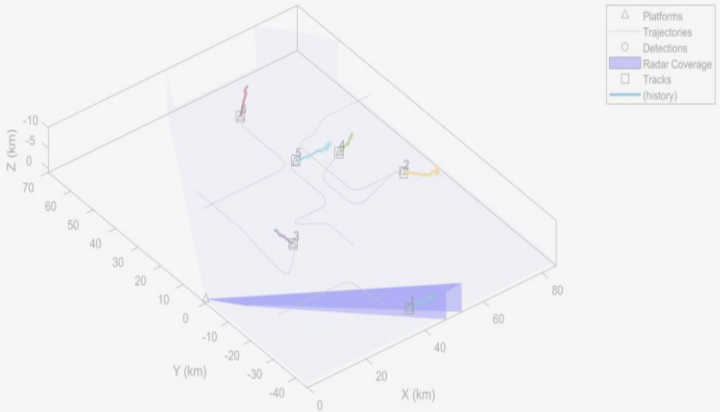
3 Things We'll Cover Today









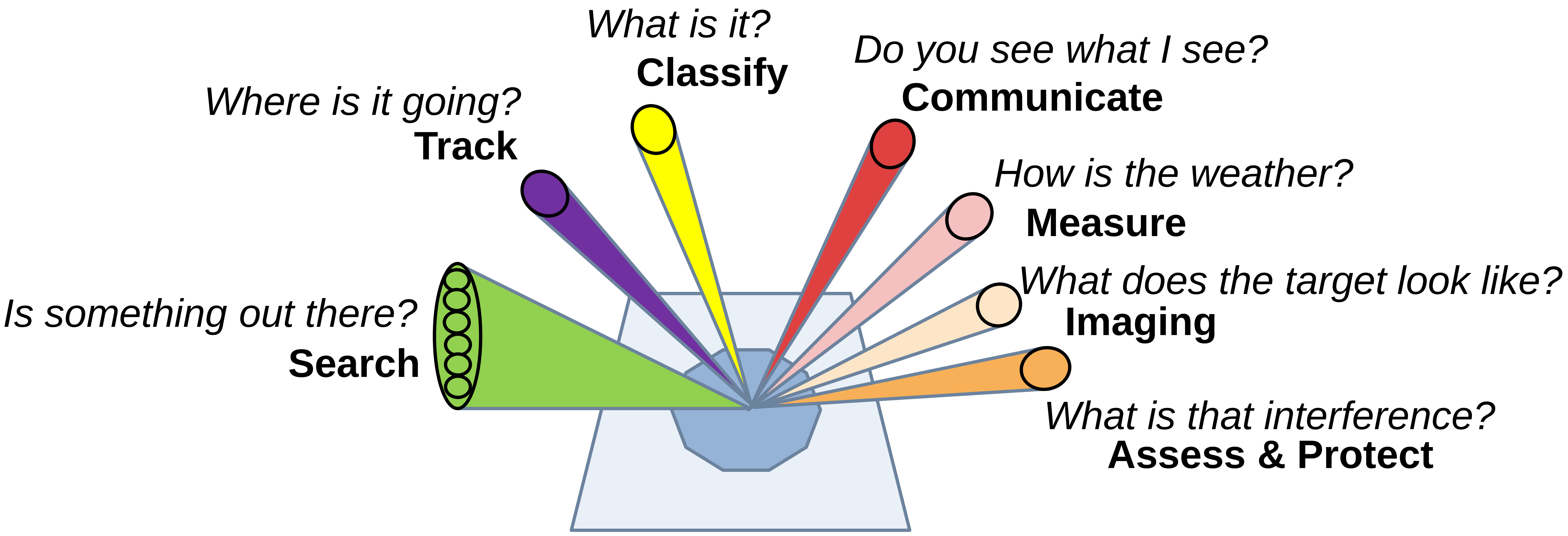


Challenges
Multifunction operations in harsh environmental conditions for smaller targets

Radar System Engineering
Making engineering trade-offs early in the design cycle

Modeling and Simulation
Selecting the right level of model abstraction

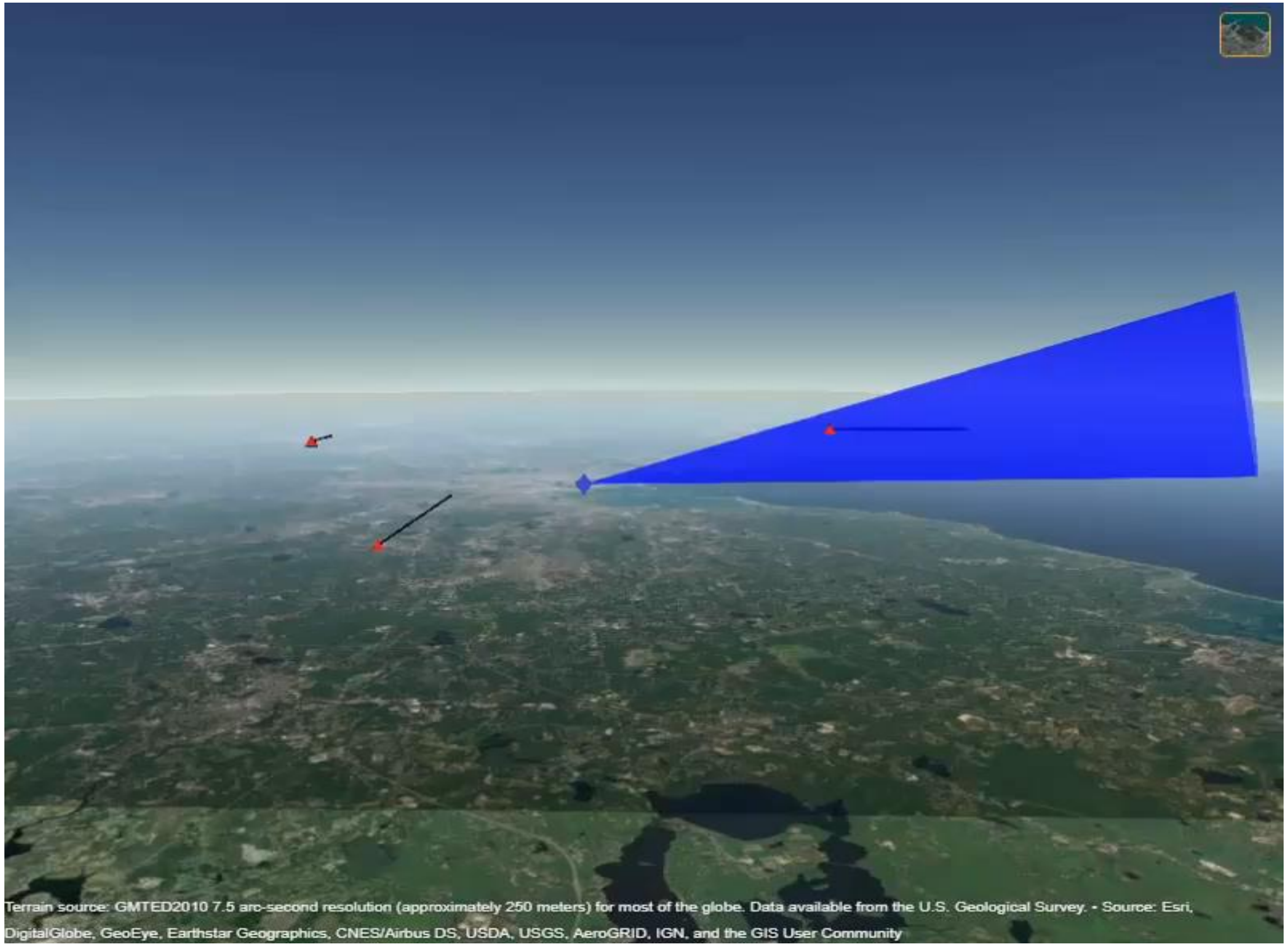
Today’s radar systems perform multiple functions

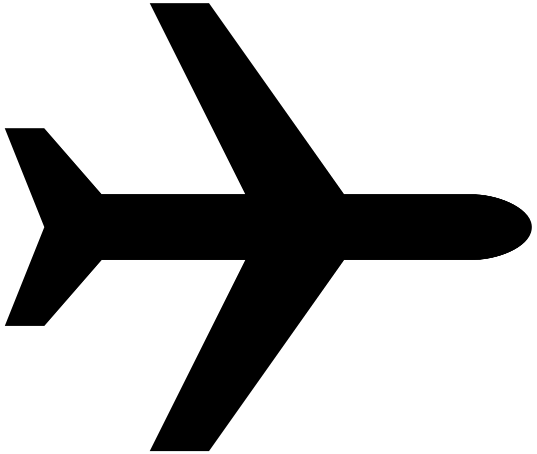


Multifunction Radar

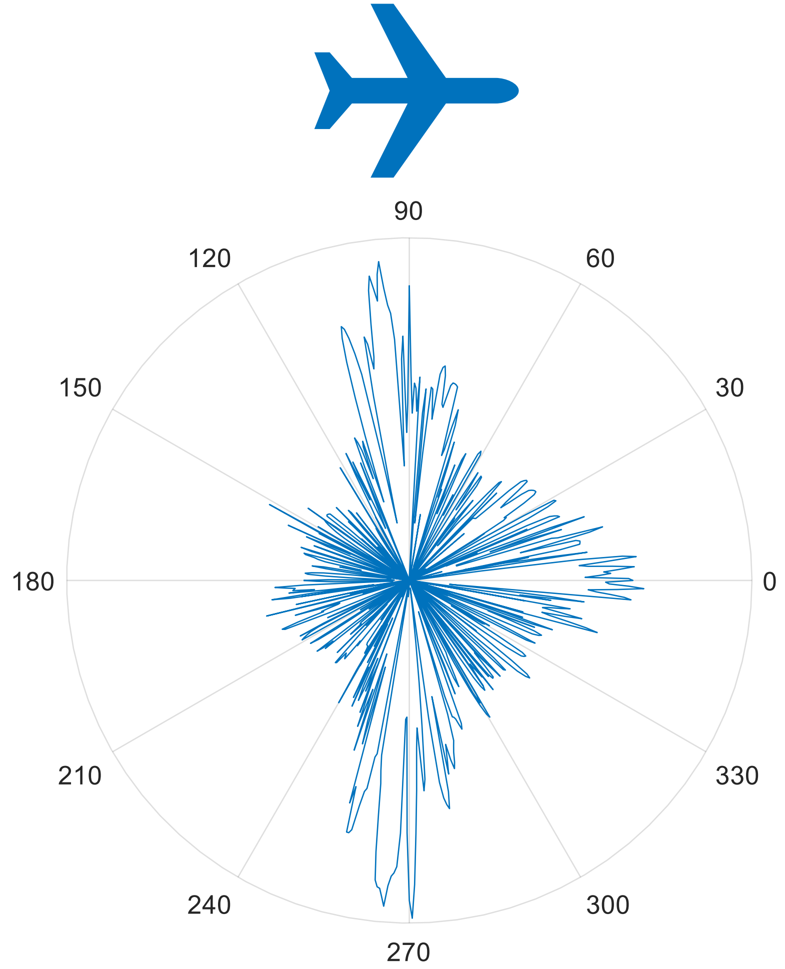
What are we missing? Where are you focused?

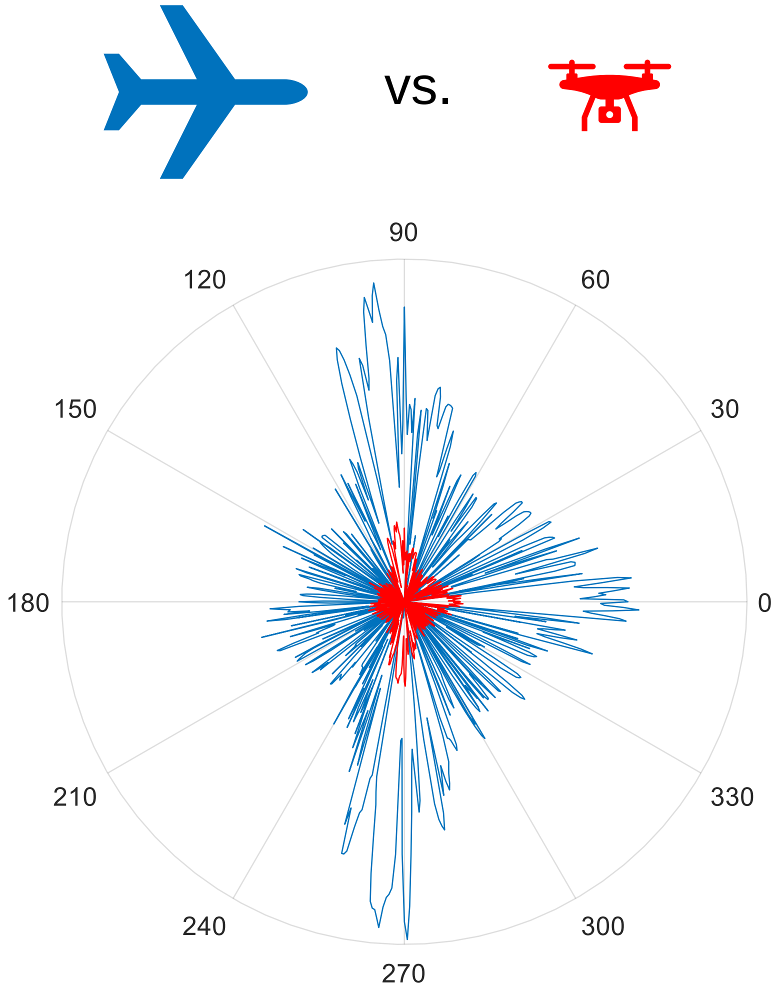
Radar systems need to detect smaller targets





Smaller targets are harder to detect

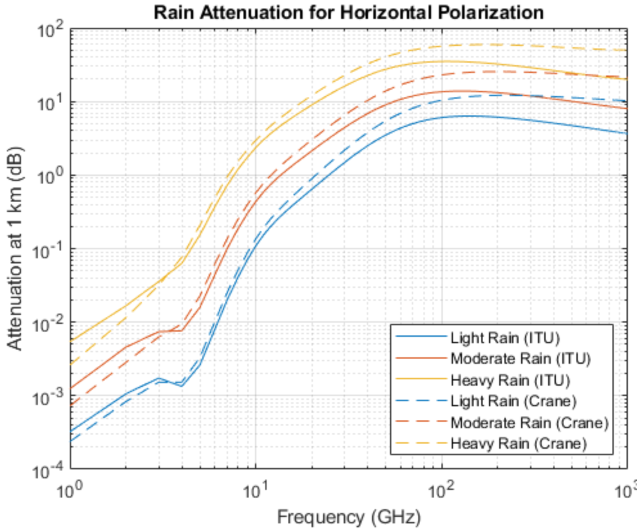


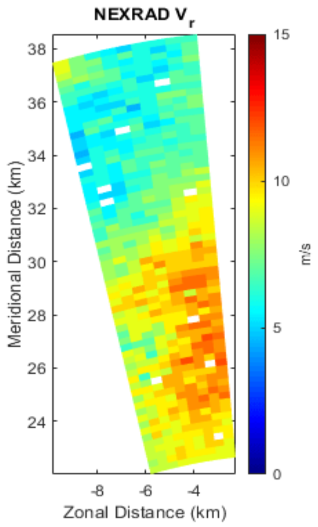


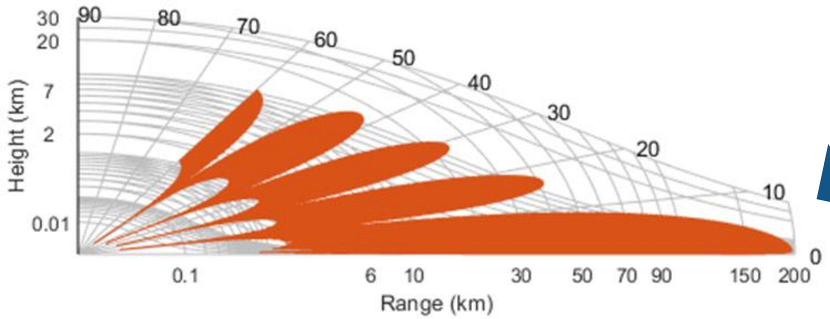
Radar cross section: dBsm vs. aspect angle

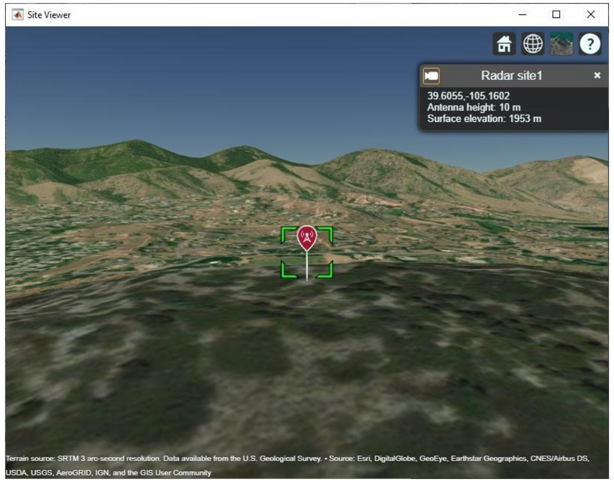
<u>Typical RCS (m^2)</u>
Large aircraft 100
Small UAV <<1

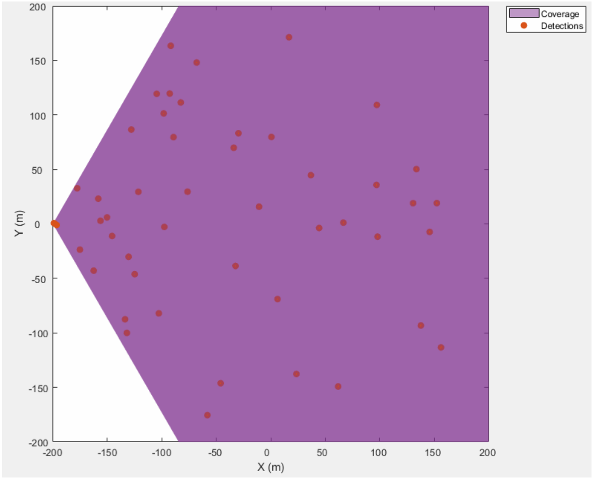
Smaller targets fly at lower altitudes where environmental conditions are a factor







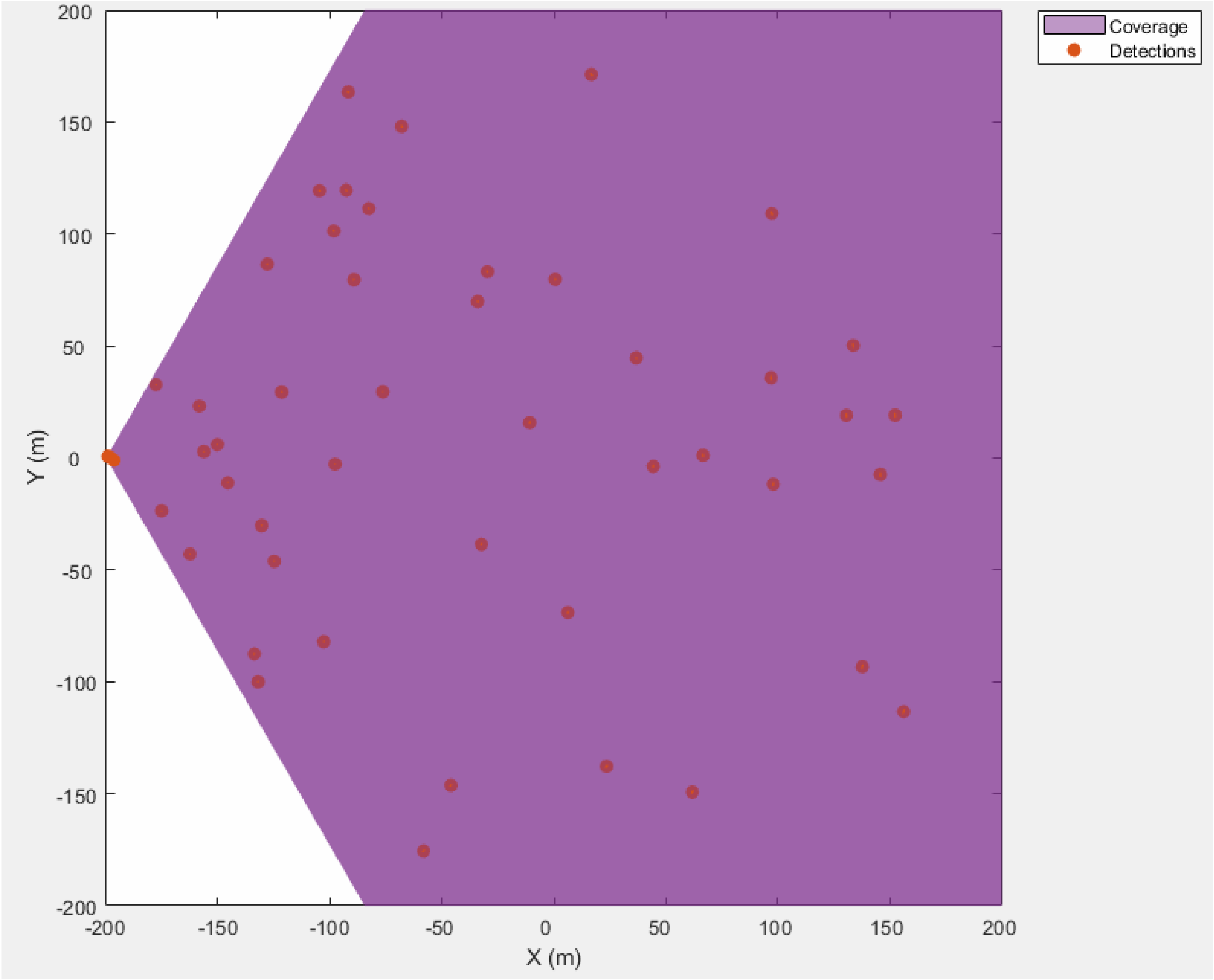


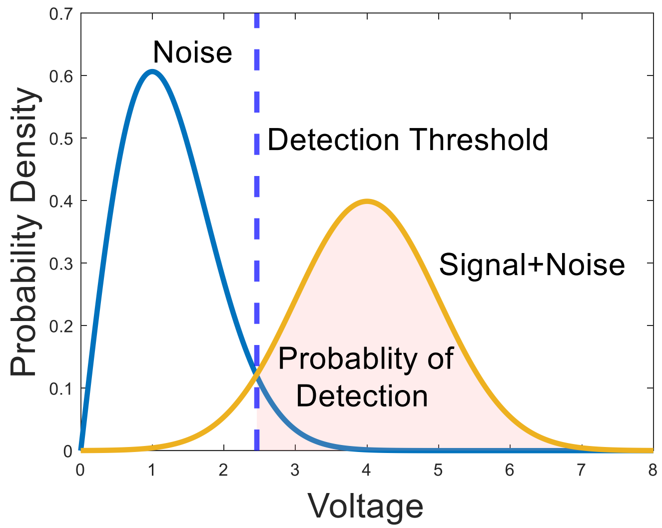


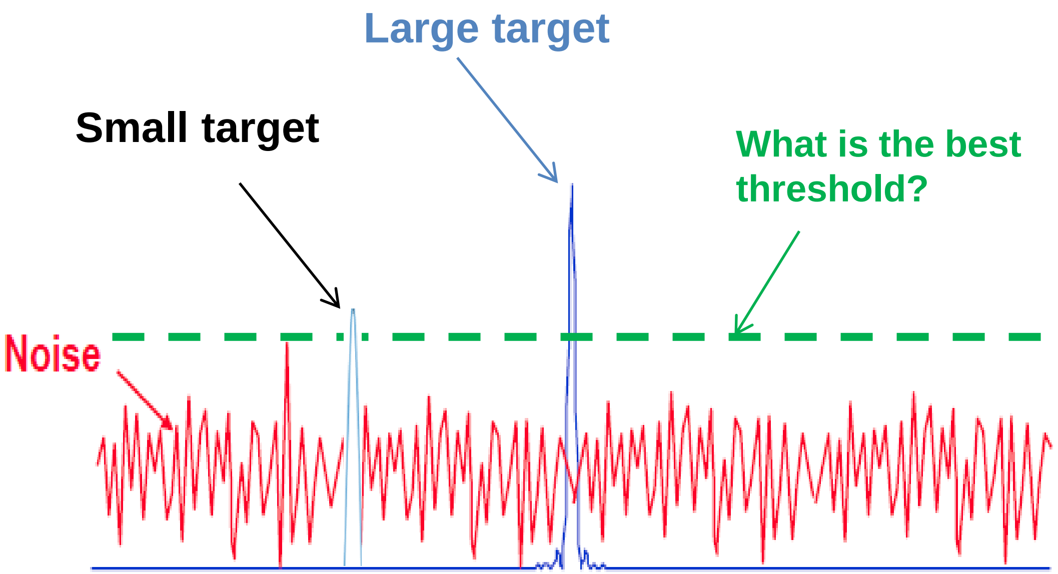
Propagation losses & clutter

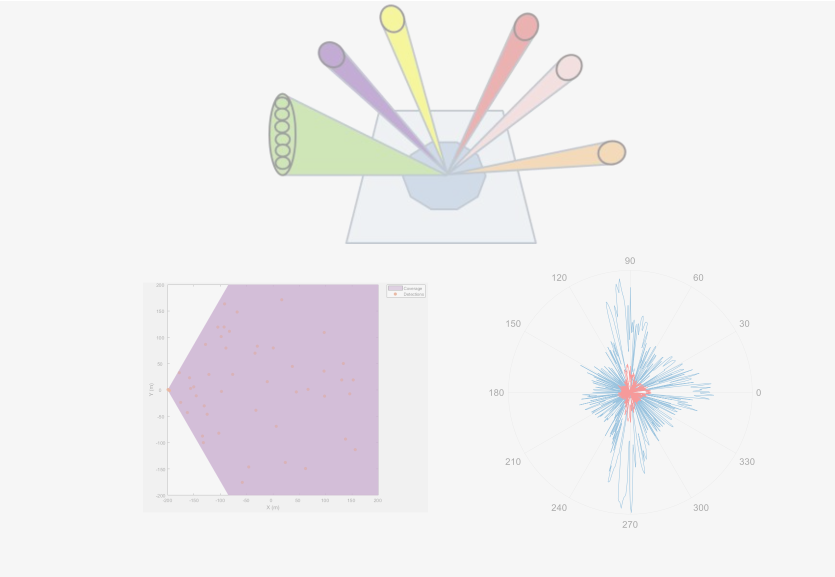
Clutter returns from the terrain

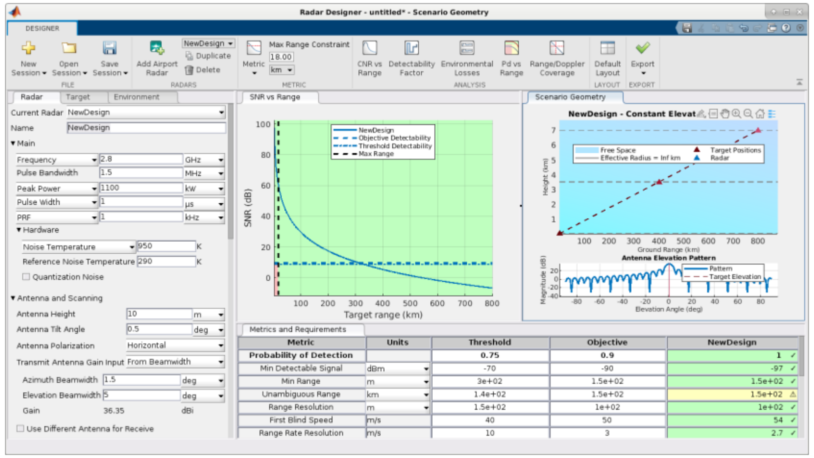
A trade must be made between detections and false alarms

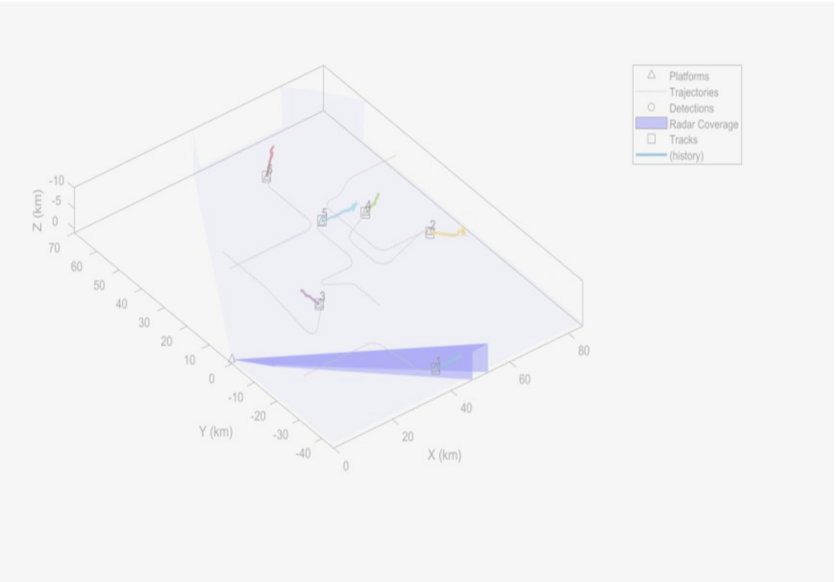












Challenges

Multifunction operations in harsh environmental conditions for smaller targets

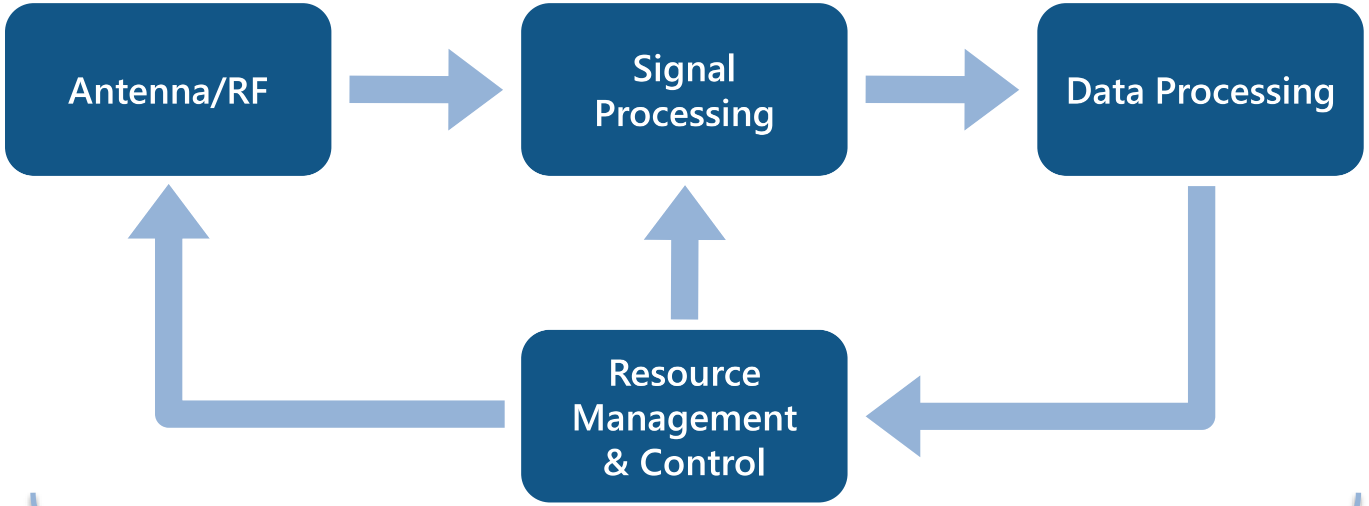
Radar System Engineering

Making engineering trade-offs early in the design cycle

Modeling and Simulation

Selecting the right level of model abstraction

The design must work in for a range of environments and scenarios



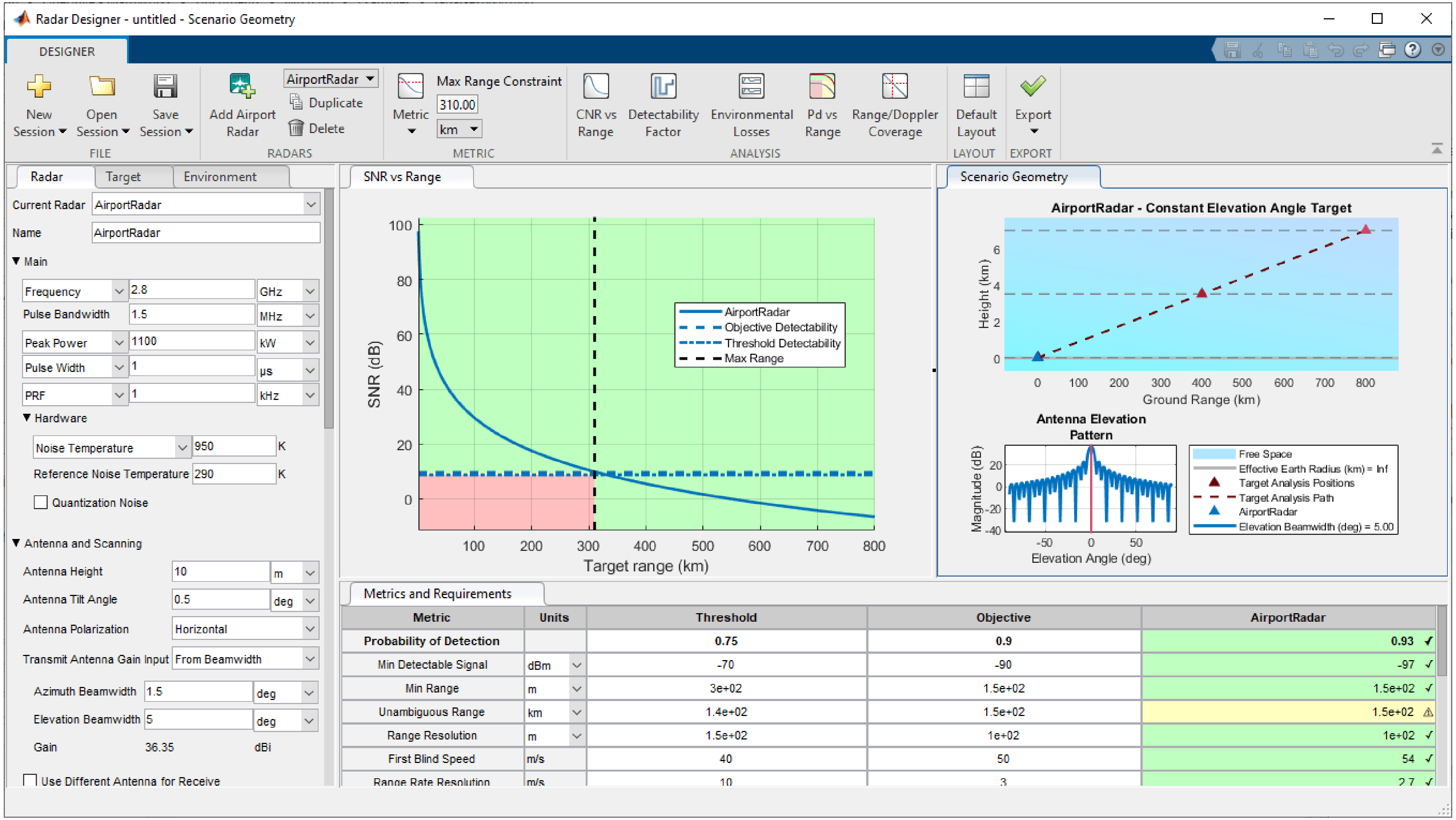
- **Target attributes**
- **Surface clutter**
- **Atmospheric conditions**
- **Precipitation**

- **Operating parameters**
- **Hardware**
- **Processing**
- **Scanning**

Radar Designer App can help you interactively evaluate tradeoffs

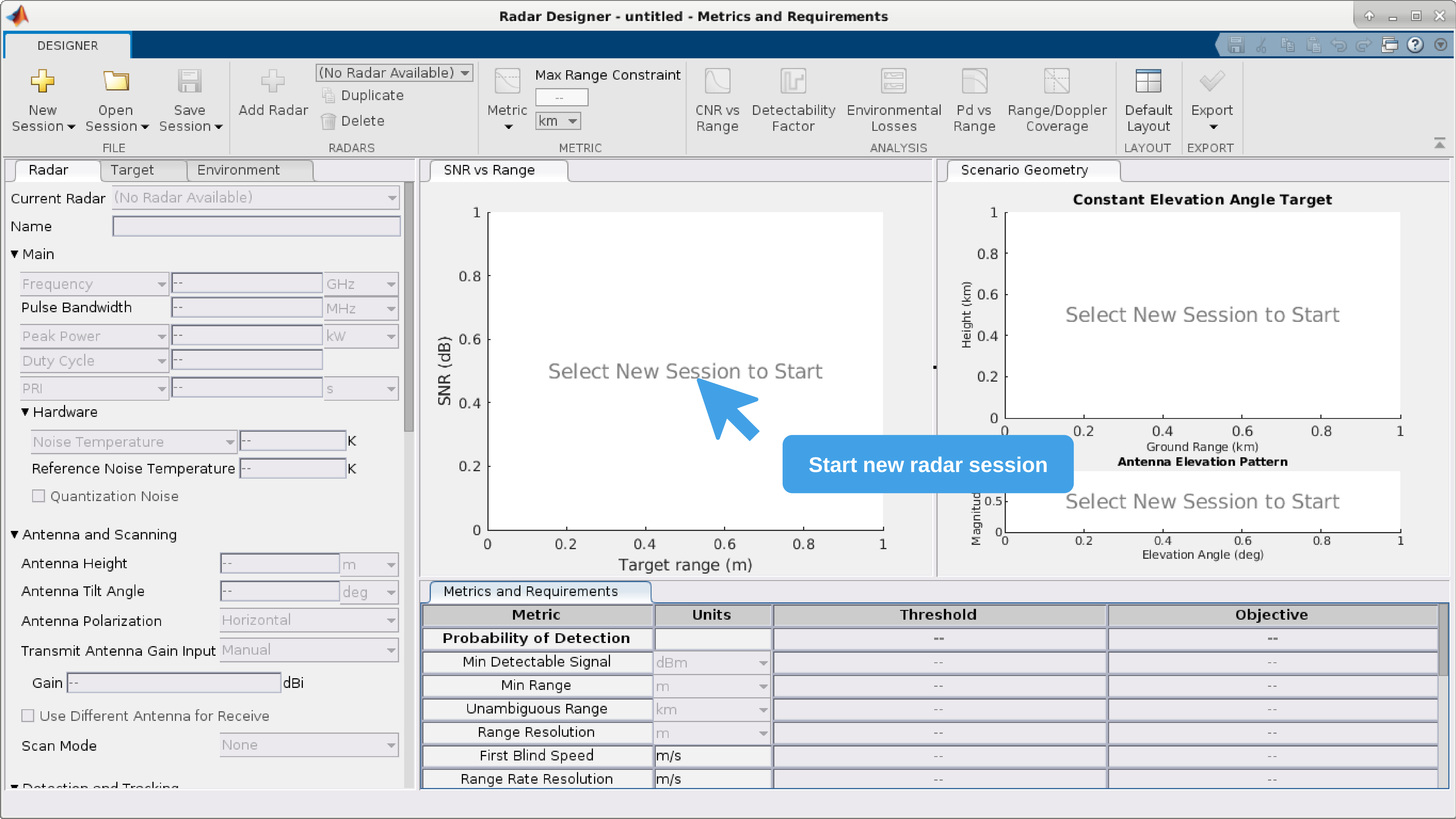
Quick start with **5 built-in configurations**

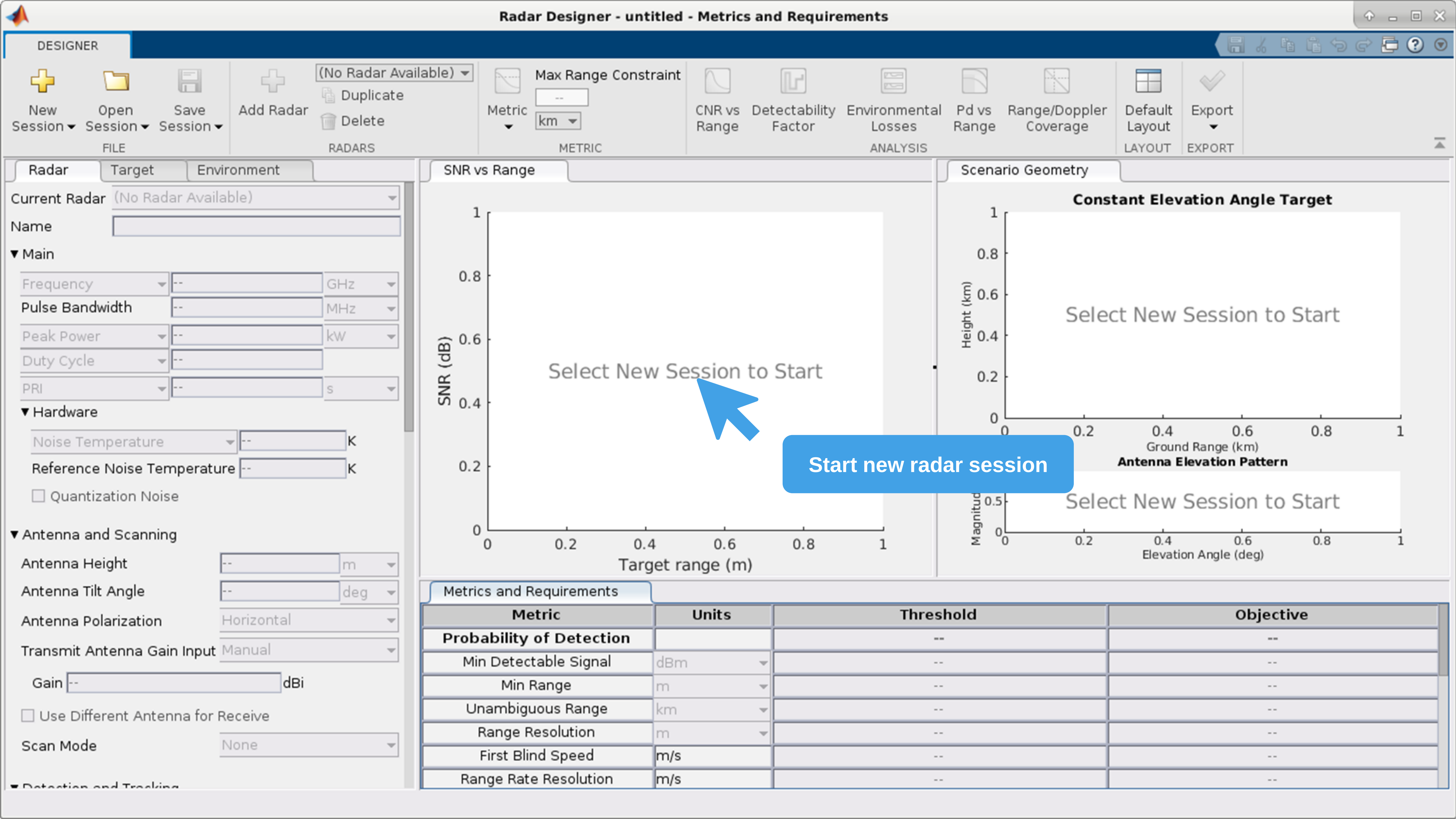
Export MATLAB script or formatted report

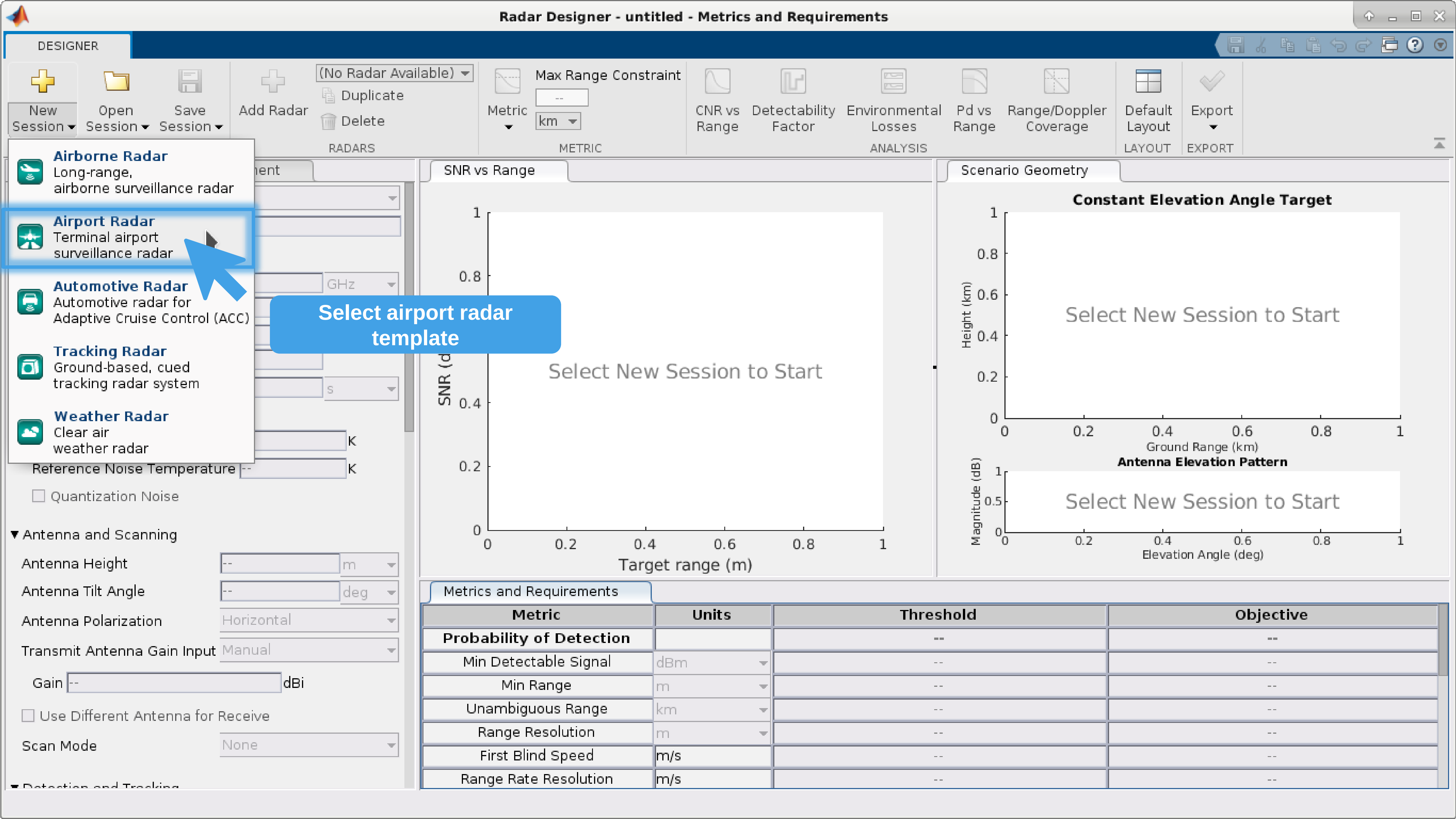


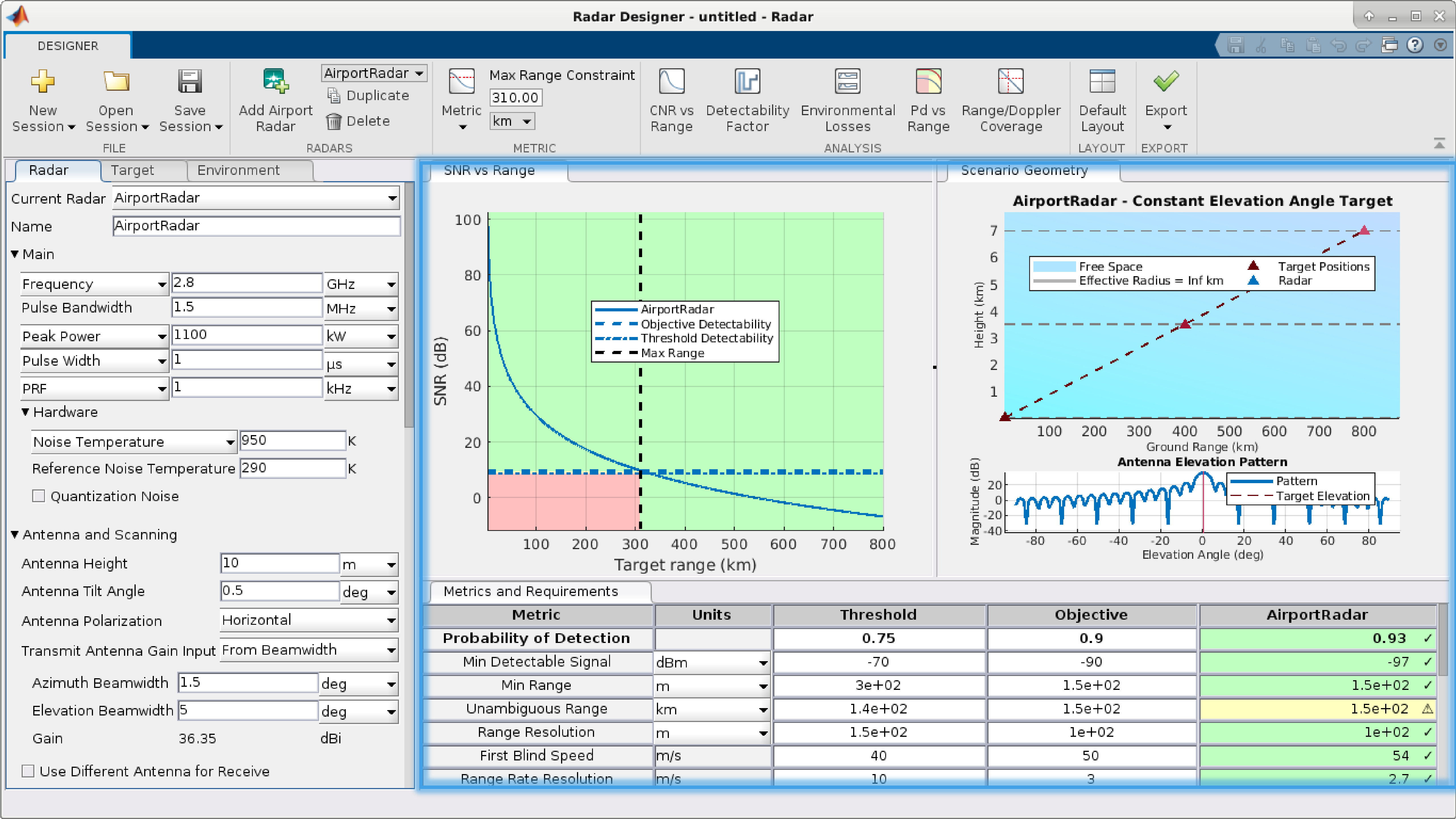
Poll question

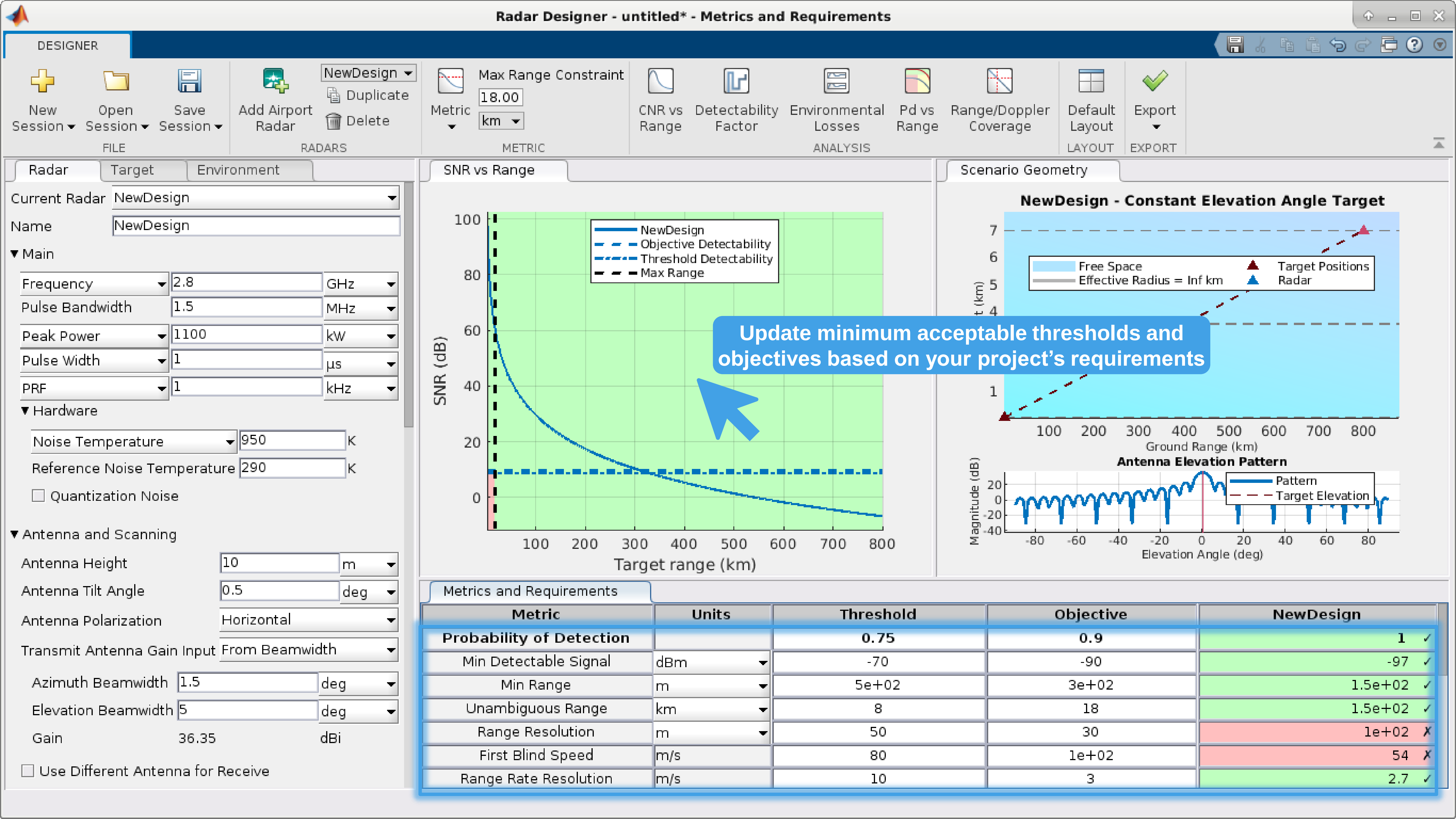
What tools do you currently use for your preliminary radar system design?

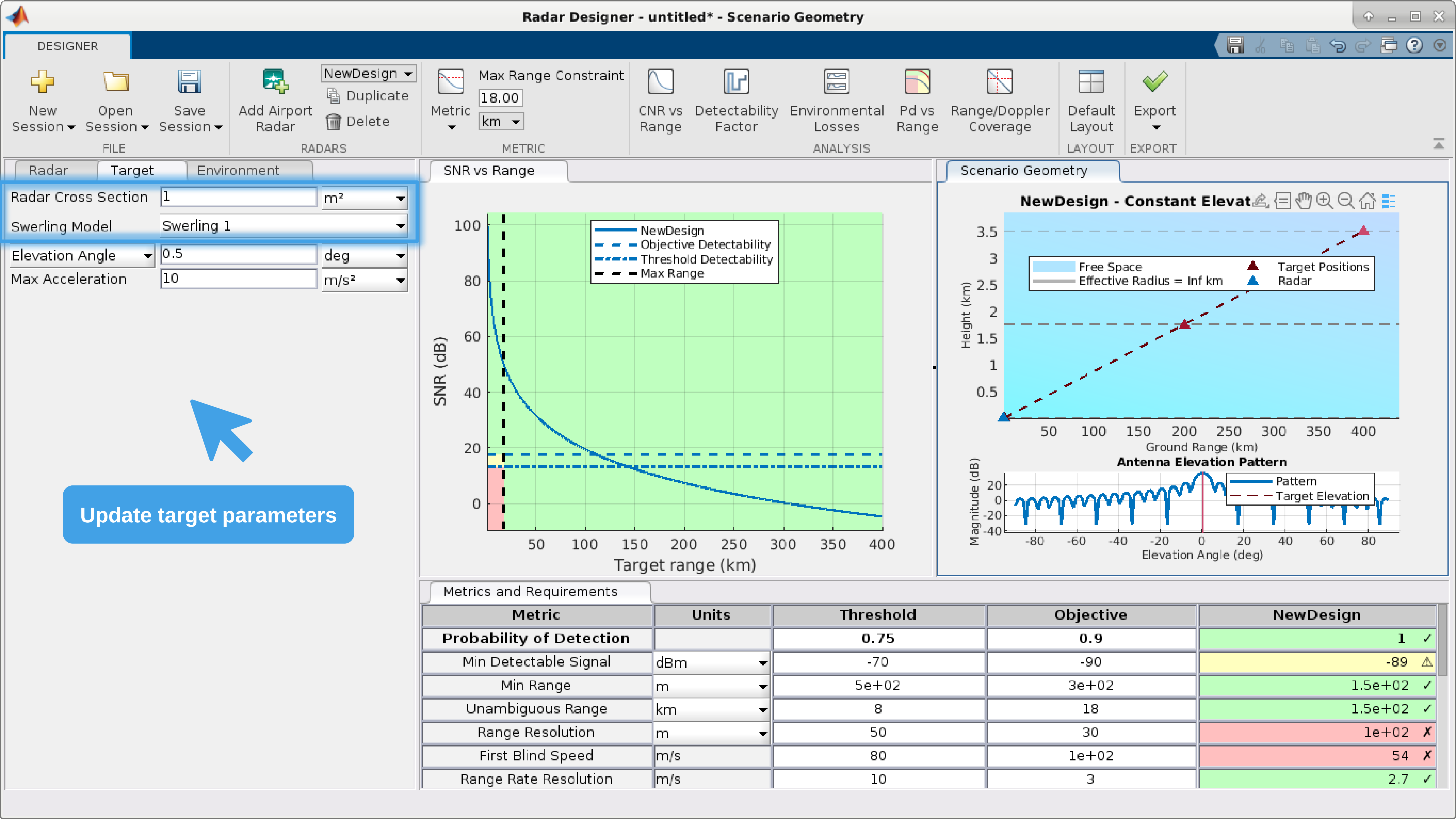

Radar Designer - untitled - Metrics and Requirements
DESIGNER
New Session
Open Session
Save Session
FILE
Add Radar
(No Radar Available)
Duplicate
Delete
RADARS
Metric
Max Range Constraint
km
METRIC
CNR vs Range
Detectability Factor
Environmental Losses
Pd vs Range
Range/Doppler Coverage
ANALYSIS
Default Layout
LAYOUT
Export
EXPORT
Radar
Target
Environment
Current Radar
(No Radar Available)
Name
Main
Frequency
GHz
Pulse Bandwidth
MHz
Peak Power
kW
Duty Cycle
PRI
s
Hardware
Noise Temperature
K
Reference Noise Temperature
K
Quantization Noise
Antenna and Scanning
Antenna Height
m
Antenna Tilt Angle
deg
Antenna Polarization
Horizontal
Transmit Antenna Gain Input
Manual
Gain
dBi
Use Different Antenna for Receive
Scan Mode
None
SNR vs Range
SNR (dB)
Target range (m)
Select New Session to Start
Start new radar session
Scenario Geometry
Constant Elevation Angle Target
Height (km)
Ground Range (km)
Select New Session to Start
Antenna Elevation Pattern
Magnitude
Elevation Angle (deg)
Select New Session to Start
Metrics and Requirements
Metric
Units
Threshold
Objective
Probability of Detection
Min Detectable Signal
dBm
Min Range
m
Unambiguous Range
km
Range Resolution
m
First Blind Speed
m/s
Range Rate Resolution
m/s

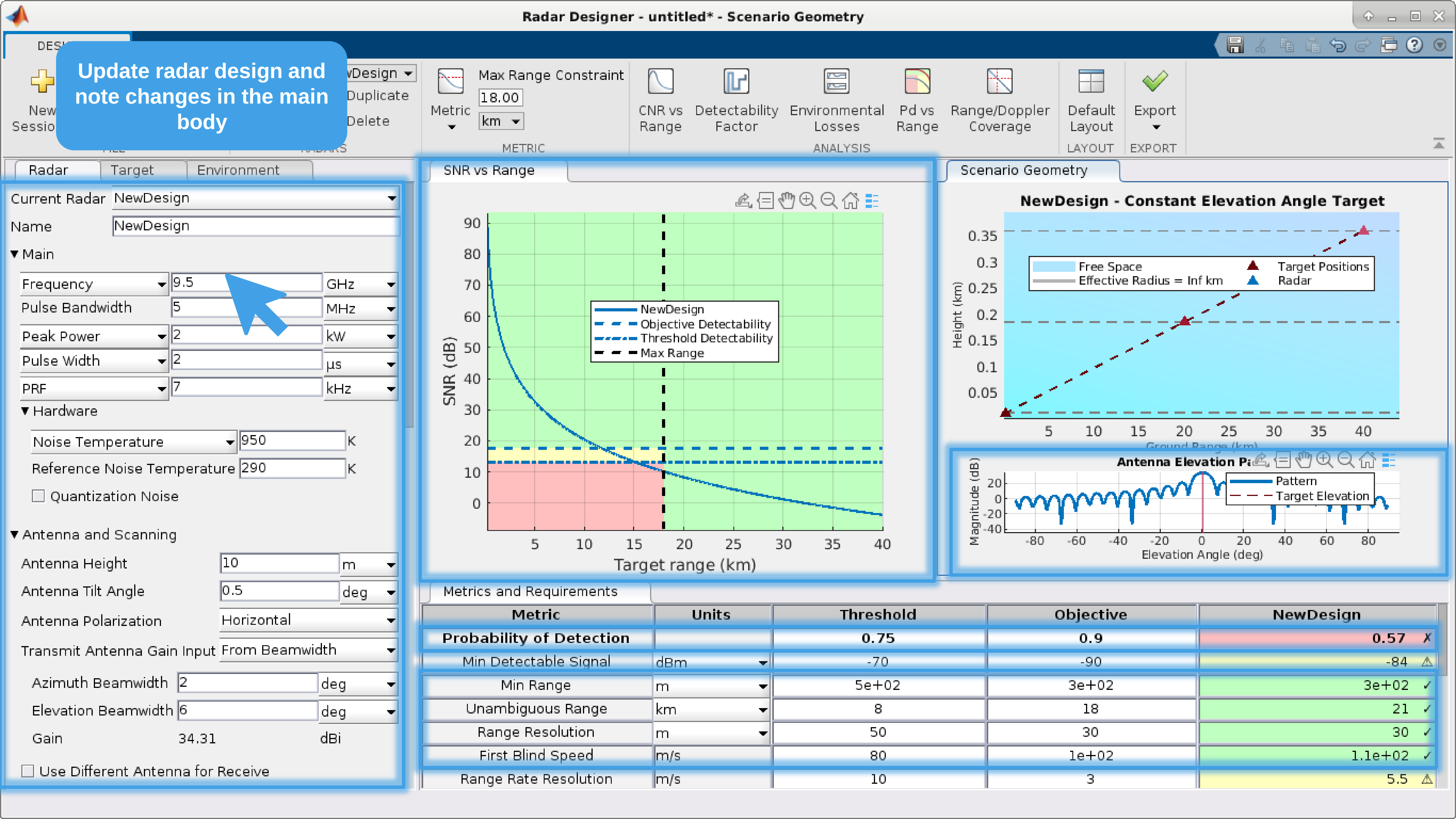

Radar Designer - untitled - Metrics and Requirements
DESIGNER
New Session
Open Session
Save Session
FILE
Add Radar
(No Radar Available)
Duplicate
Delete
RADARS
Metric
Max Range Constraint
km
METRIC
CNR vs Range
Detectability Factor
Environmental Losses
Pd vs Range
Range/Doppler Coverage
ANALYSIS
Default Layout
LAYOUT
Export
EXPORT
Radar
Target
Environment
Current Radar
(No Radar Available)
Name
Main
Frequency
GHz
Pulse Bandwidth
MHz
Peak Power
kW
Duty Cycle
PRI
s
Hardware
Noise Temperature
K
Reference Noise Temperature
K
Quantization Noise
Antenna and Scanning
Antenna Height
m
Antenna Tilt Angle
deg
Antenna Polarization
Horizontal
Transmit Antenna Gain Input
Manual
Gain
dBi
Use Different Antenna for Receive
Scan Mode
None
SNR vs Range
SNR (dB)
Select New Session to Start
Target range (m)
Scenario Geometry
Constant Elevation Angle Target
Height (km)
Select New Session to Start
Ground Range (km)
Antenna Elevation Pattern
Select New Session to Start
Magnitude
Elevation Angle (deg)
Start new radar session
Metrics and Requirements
Metric
Units
Threshold
Objective
Probability of Detection
Min Detectable Signal
dBm
Min Range
m
Unambiguous Range
km
Range Resolution
m
First Blind Speed
m/s
Range Rate Resolution
m/s

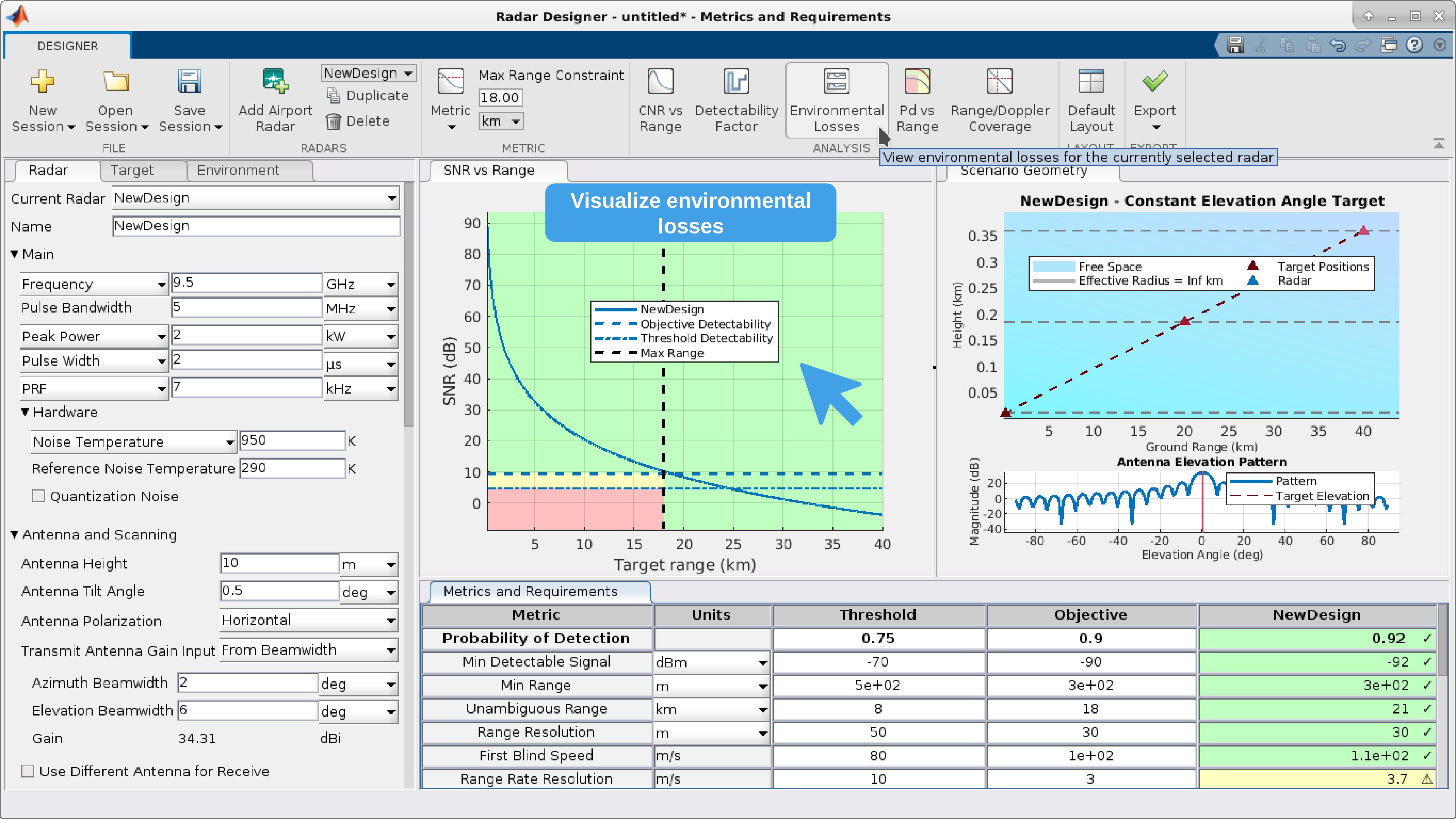

Radar Designer - untitled - Metrics and Requirements
DESIGNER
New Session
Open Session
Save Session
Add Radar
(No Radar Available)
Duplicate
Delete
RADARS
Metric
Max Range Constraint
km
METRIC
CNR vs Range
Detectability Factor
Environmental Losses
Pd vs Range
Range/Doppler Coverage
ANALYSIS
Default Layout
LAYOUT
Export
EXPORT
Airborne Radar
Long-range, airborne surveillance radar
Airport Radar
Terminal airport surveillance radar
Automotive Radar
Automotive radar for Adaptive Cruise Control (ACC)
Tracking Radar
Ground-based, cued tracking radar system
Weather Radar
Clear air weather radar
Select airport radar template
SNR vs Range
Select New Session to Start
Target range (m)
Scenario Geometry
Constant Elevation Angle Target
Height (km)
Ground Range (km)
Antenna Elevation Pattern
Magnitude (dB)
Elevation Angle (deg)
Reference Noise Temperature
Quantization Noise
Antenna and Scanning
Antenna Height
Antenna Tilt Angle
Antenna Polarization
Horizontal
Transmit Antenna Gain Input
Manual
Gain
dBi
Use Different Antenna for Receive
Scan Mode
None
Metrics and Requirements
Metric
Units
Threshold
Objective
Probability of Detection
Min Detectable Signal
dBm
Min Range
Unambiguous Range
Range Resolution
First Blind Speed
m/s
Range Rate Resolution

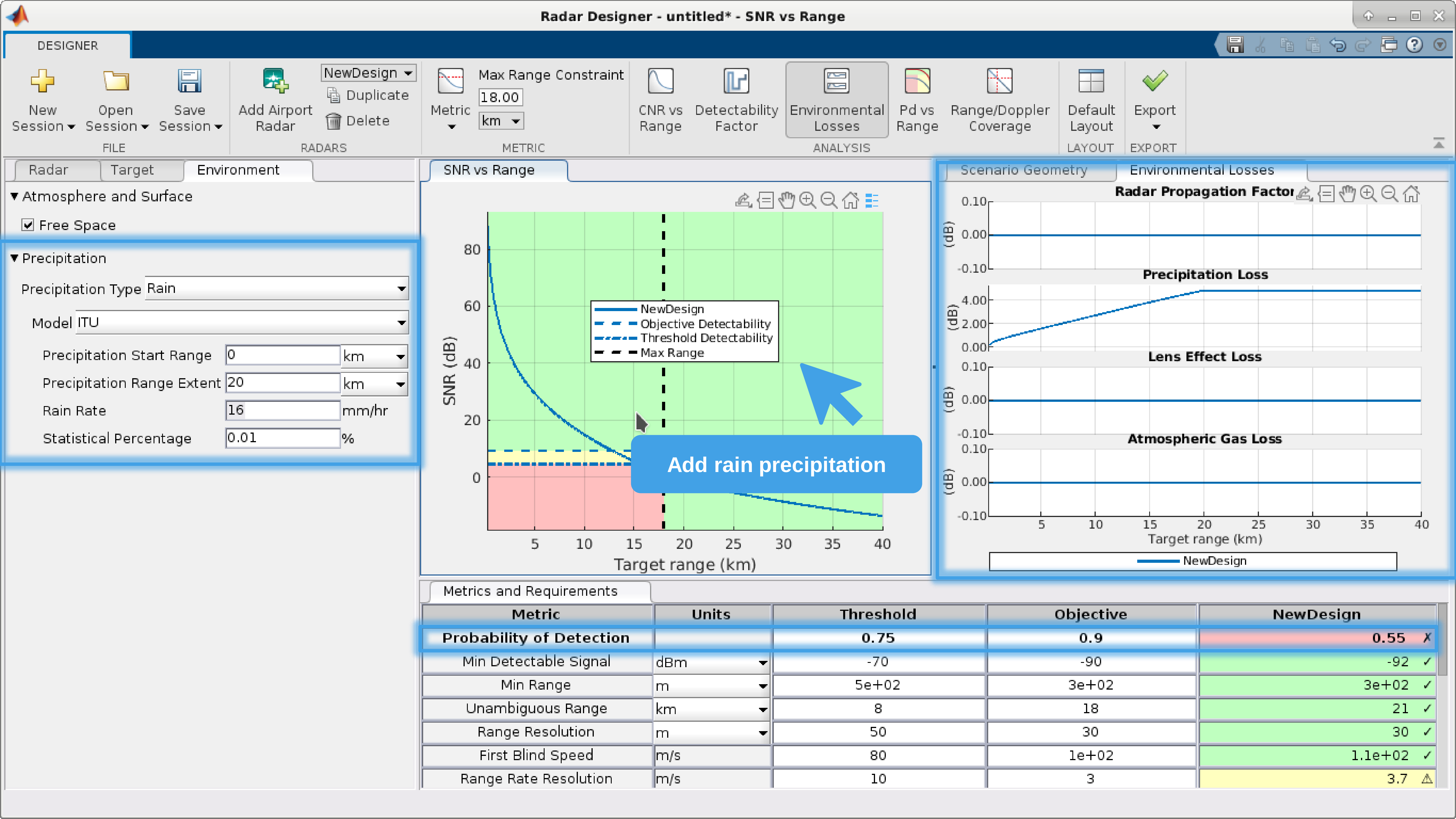

Radar Designer - untitled - Radar
DESIGNER
New Session
Open Session
Save Session
FILE
Add Airport Radar
AirportRadar
Duplicate
Delete
RADARS
Metric
Max Range Constraint
310.00
km
METRIC
CNR vs Range
Detectability Factor
Environmental Losses
Pd vs Range
Range/Doppler Coverage
ANALYSIS
Default Layout
LAYOUT
Export
EXPORT
Radar
Target
Environment
Current Radar AirportRadar
Name AirportRadar
Main
Frequency 2.8 GHz
Pulse Bandwidth 1.5 MHz
Peak Power 1100 kW
Pulse Width 1 µs
PRF 1 kHz
Hardware
Noise Temperature 950 K
Reference Noise Temperature 290 K
Quantization Noise
Antenna and Scanning
Antenna Height 10 m
Antenna Tilt Angle 0.5 deg
Antenna Polarization Horizontal
Transmit Antenna Gain Input From Beamwidth
Azimuth Beamwidth 1.5 deg
Elevation Beamwidth 5 deg
Gain 36.35 dBi
Use Different Antenna for Receive
SNR vs Range
AirportRadar
Objective Detectability
Threshold Detectability
Max Range
SNR (dB)
Target range (km)
Scenario Geometry
AirportRadar - Constant Elevation Angle Target
Free Space
Effective Radius = Inf km
Target Positions
Radar
Height (km)
Ground Range (km)
Antenna Elevation Pattern
Pattern
Target Elevation
Magnitude (dB)
Elevation Angle (deg)
Metrics and Requirements
Metric | Units | Threshold | Objective | AirportRadar
Probability of Detection | | 0.75 | 0.9 | 0.93
Min Detectable Signal | dBm | -70 | -90 | -97
Min Range | m | 3e+02 | 1.5e+02 | 1.5e+02
Unambiguous Range | km | 1.4e+02 | 1.5e+02 | 1.5e+02
Range Resolution | m | 1.5e+02 | 1e+02 | 1e+02
First Blind Speed | m/s | 40 | 50 | 54
Range Rate Resolution | m/s | 10 | 3 | 2.7


Radar Designer - untitled* - Metrics and Requirements
DESIGNER
New Session
Open Session
Save Session
FILE
Add Airport Radar
NewDesign
Duplicate
Delete
RADARS
Metric
Max Range Constraint
18.00
km
METRIC
CNR vs Range
Detectability Factor
Environmental Losses
Pd vs Range
Range/Doppler Coverage
ANALYSIS
Default Layout
LAYOUT
Export
EXPORT
Radar
Target
Environment
Current Radar NewDesign
Name NewDesign
Main
Frequency 2.8 GHz
Pulse Bandwidth 1.5 MHz
Peak Power 1100 kW
Pulse Width 1 μs
PRF 1 kHz
Hardware
Noise Temperature 950 K
Reference Noise Temperature 290 K
Quantization Noise
Antenna and Scanning
Antenna Height 10 m
Antenna Tilt Angle 0.5 deg
Antenna Polarization Horizontal
Transmit Antenna Gain Input From Beamwidth
Azimuth Beamwidth 1.5 deg
Elevation Beamwidth 5 deg
Gain 36.35 dBi
Use Different Antenna for Receive
SNR vs Range
NewDesign
Objective Detectability
Threshold Detectability
Max Range
SNR (dB)
Target range (km)
Scenario Geometry
NewDesign - Constant Elevation Angle Target
Free Space
Effective Radius = Inf km
Target Positions
Radar
Ground Range (km)
Antenna Elevation Pattern
Pattern
Target Elevation
Magnitude (dB)
Elevation Angle (deg)
Update minimum acceptable thresholds and objectives based on your project’s requirements
Metrics and Requirements
Metric | Units | Threshold | Objective | NewDesign
Probability of Detection | | 0.75 | 0.9 | 1 ✓
Min Detectable Signal | dBm | -70 | -90 | -97 ✓
Min Range | m | 5e+02 | 3e+02 | 1.5e+02 ✓
Unambiguous Range | km | 8 | 18 | 1.5e+02 ✓
Range Resolution | m | 50 | 30 | 1e+02 ✗
First Blind Speed | m/s | 80 | 1e+02 | 54 ✗
Range Rate Resolution | m/s | 10 | 3 | 2.7 ✓

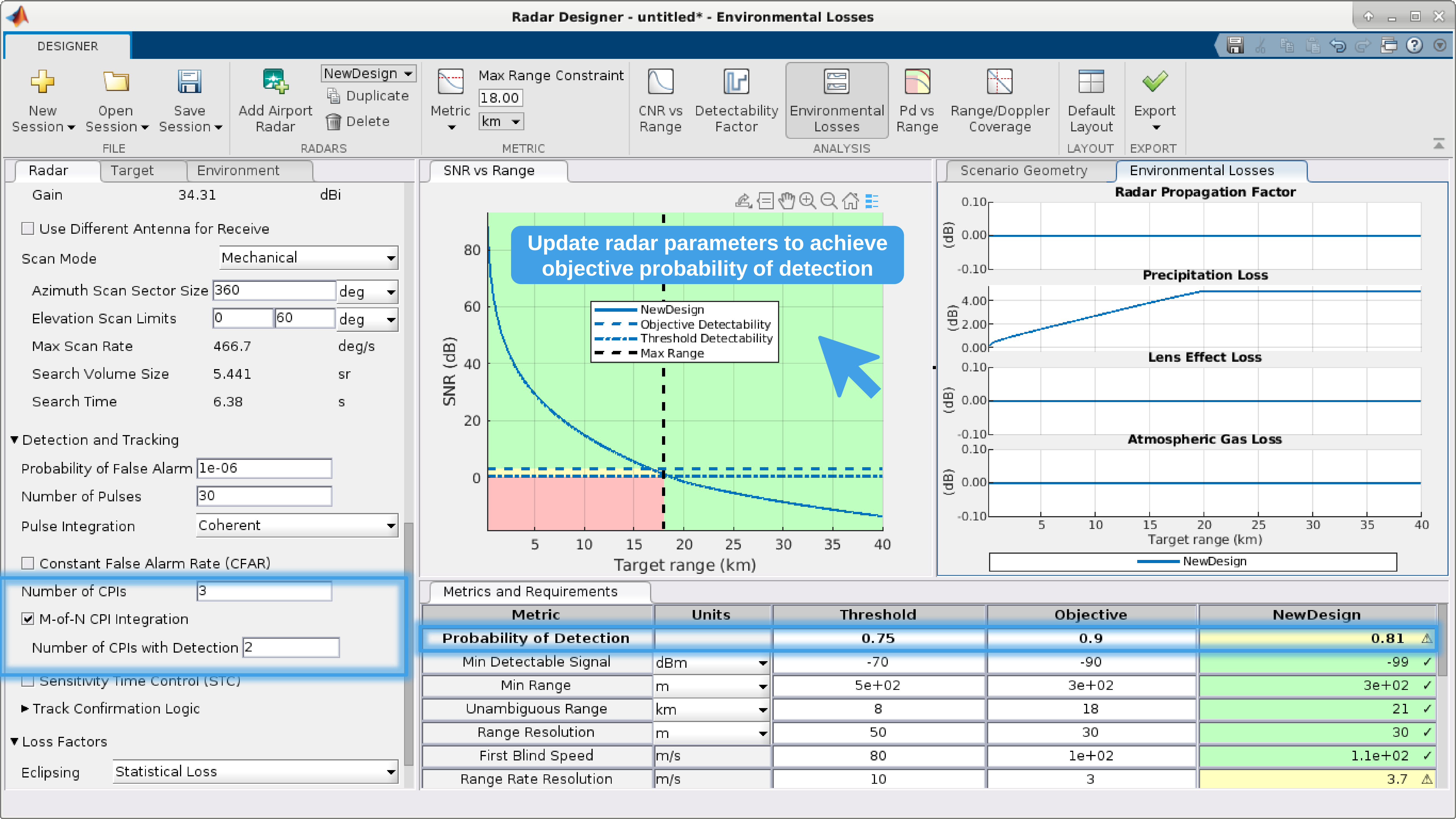

Radar Designer - untitled* - Scenario Geometry
DESIGNER
New Session
Open Session
Save Session
FILE
Add Airport Radar
NewDesign
Duplicate
Delete
RADARS
Metric
Max Range Constraint
18.00
km
METRIC
CNR vs Range
Detectability Factor
Environmental Losses
Pd vs Range
Range/Doppler Coverage
ANALYSIS
Default Layout
LAYOUT
Export
EXPORT
Radar
Target
Environment
Radar Cross Section
1
m²
Swerling Model
Swerling 1
Elevation Angle
0.5
deg
Max Acceleration
10
m/s²
Update target parameters
SNR vs Range
NewDesign
Objective Detectability
Threshold Detectability
Max Range
SNR (dB)
Target range (km)
Scenario Geometry
NewDesign - Constant Elevat
Free Space
Effective Radius = Inf km
Target Positions
Radar
Height (km)
Ground Range (km)
Antenna Elevation Pattern
Pattern
Target Elevation
Magnitude (dB)
Elevation Angle (deg)
Metrics and Requirements
Metric | Units | Threshold | Objective | NewDesign
Probability of Detection | | 0.75 | 0.9 | 1
Min Detectable Signal | dBm | -70 | -90 | -89
Min Range | m | 5e+02 | 3e+02 | 1.5e+02
Unambiguous Range | km | 8 | 18 | 1.5e+02
Range Resolution | m | 50 | 30 | 1e+02
First Blind Speed | m/s | 80 | 1e+02 | 54
Range Rate Resolution | m/s | 10 | 3 | 2.7

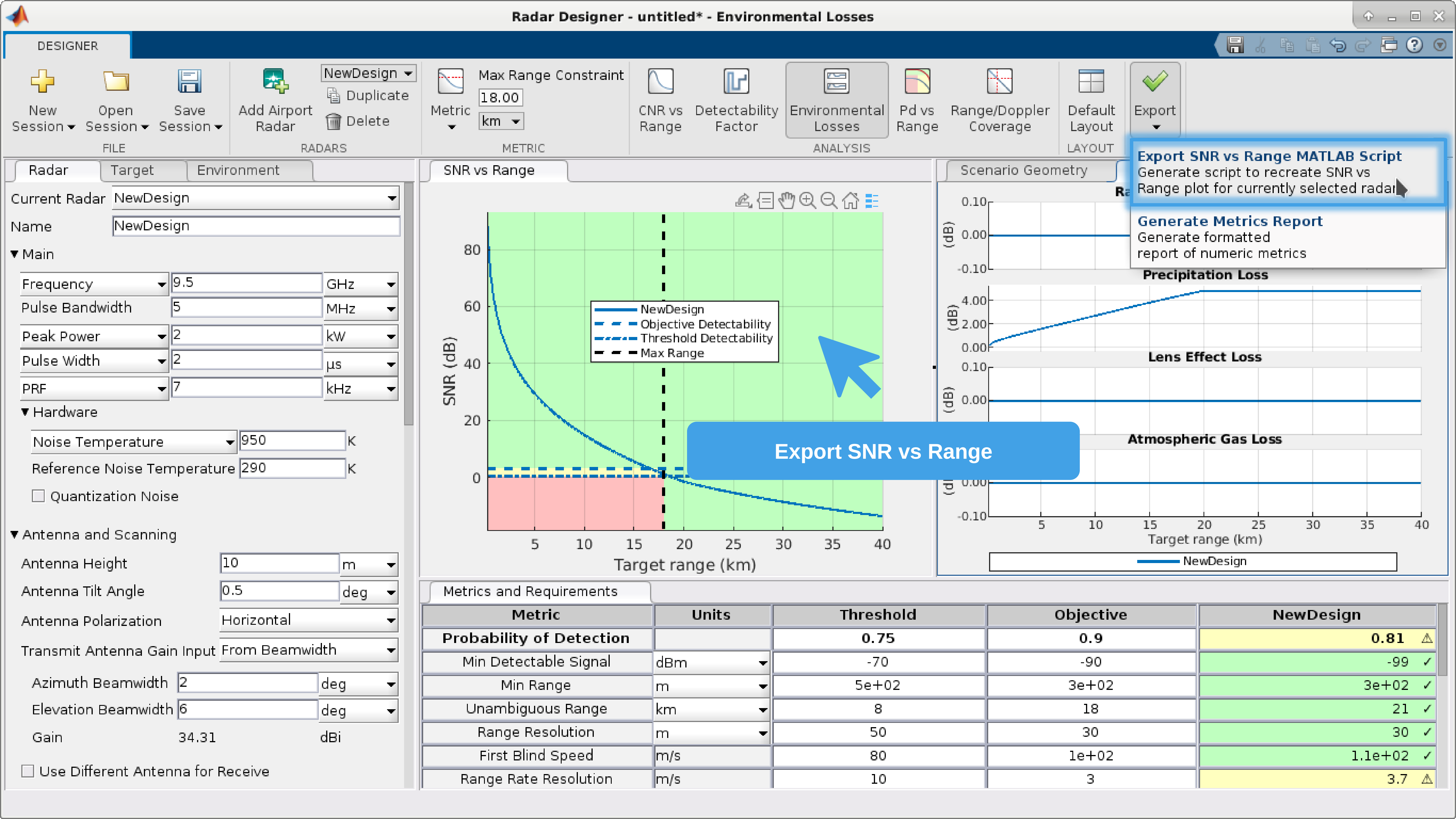

Radar Designer - untitled* - Scenario Geometry
Update radar design and note changes in the main body
New Session
Duplicate
Delete
Metric
Max Range Constraint
18.00
km
METRIC
CNR vs Range
Detectability Factor
Environmental Losses
Pd vs Range
Range/Doppler Coverage
ANALYSIS
Default Layout
LAYOUT
Export
EXPORT
Radar
Target
Environment
Current Radar NewDesign
Name NewDesign
Main
Frequency 9.5 GHz
Pulse Bandwidth 5 MHz
Peak Power 2 kW
Pulse Width 2 μs
PRF 7 kHz
Hardware
Noise Temperature 950 K
Reference Noise Temperature 290 K
Quantization Noise
Antenna and Scanning
Antenna Height 10 m
Antenna Tilt Angle 0.5 deg
Antenna Polarization Horizontal
Transmit Antenna Gain Input From Beamwidth
Azimuth Beamwidth 2 deg
Elevation Beamwidth 6 deg
Gain 34.31 dBi
Use Different Antenna for Receive
SNR vs Range
NewDesign
Objective Detectability
Threshold Detectability
Max Range
SNR (dB)
Target range (km)
Scenario Geometry
NewDesign - Constant Elevation Angle Target
Free Space
Effective Radius = Inf km
Target Positions
Radar
Height (km)
Ground Range (km)
Antenna Elevation Pattern
Pattern
Target Elevation
Magnitude (dB)
Elevation Angle (deg)
Metrics and Requirements
Metric | Units | Threshold | Objective | NewDesign
Probability of Detection | | 0.75 | 0.9 | 0.57
Min Detectable Signal | dBm | -70 | -90 | -84
Min Range | m | 5e+02 | 3e+02 | 3e+02
Unambiguous Range | km | 8 | 18 | 21
Range Resolution | m | 50 | 30 | 30
First Blind Speed | m/s | 80 | 1e+02 | 1.1e+02
Range Rate Resolution | m/s | 10 | 3 | 5.5

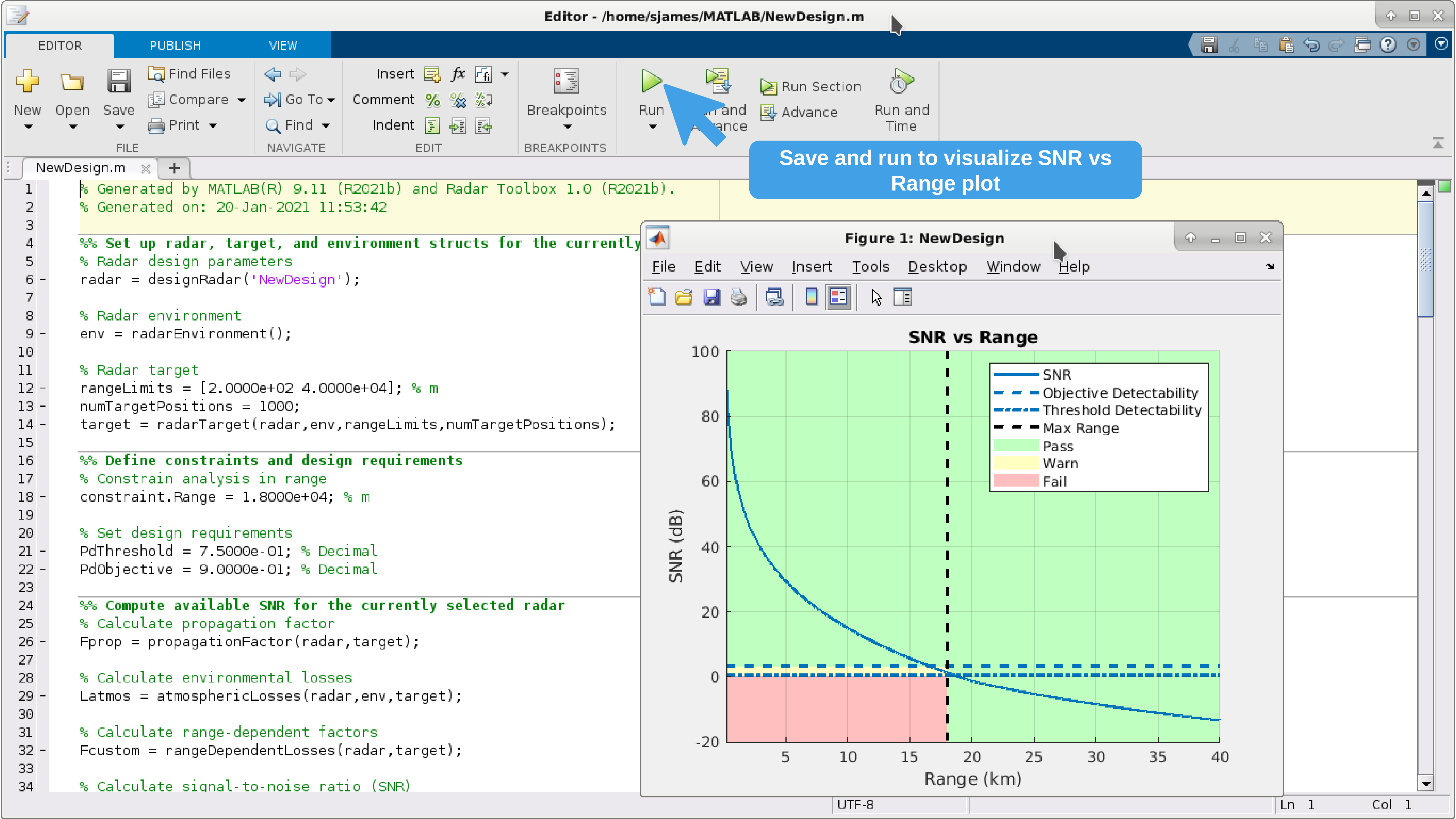

Radar Designer - untitled* - Metrics and Requirements
DESIGNER
New Session
Open Session
Save Session
FILE
Add Airport Radar
NewDesign
Duplicate
Delete
RADARS
Metric
Max Range Constraint
18.00
km
METRIC
CNR vs Range
Detectability Factor
Environmental Losses
Pd vs Range
Range/Doppler Coverage
ANALYSIS
Default Layout
Export
View environmental losses for the currently selected radar
Radar
Target
Environment
Current Radar NewDesign
Name NewDesign
Main
Frequency 9.5 GHz
Pulse Bandwidth 5 MHz
Peak Power 2 kW
Pulse Width 2 µs
PRF 7 kHz
Hardware
Noise Temperature 950 K
Reference Noise Temperature 290 K
Quantization Noise
Antenna and Scanning
Antenna Height 10 m
Antenna Tilt Angle 0.5 deg
Antenna Polarization Horizontal
Transmit Antenna Gain Input From Beamwidth
Azimuth Beamwidth 2 deg
Elevation Beamwidth 6 deg
Gain 34.31 dBi
Use Different Antenna for Receive
SNR vs Range
Visualize environmental losses
SNR (dB)
Target range (km)
NewDesign
Objective Detectability
Threshold Detectability
Max Range
Scenario Geometry
NewDesign - Constant Elevation Angle Target
Free Space
Effective Radius = Inf km
Target Positions
Radar
Height (km)
Ground Range (km)
Antenna Elevation Pattern
Magnitude (dB)
Pattern
Target Elevation
Elevation Angle (deg)
Metrics and Requirements
Metric | Units | Threshold | Objective | NewDesign
Probability of Detection | | 0.75 | 0.9 | 0.92 ✓
Min Detectable Signal | dBm | -70 | -90 | -92 ✓
Min Range | m | 5e+02 | 3e+02 | 3e+02 ✓
Unambiguous Range | km | 8 | 18 | 21 ✓
Range Resolution | m | 50 | 30 | 30 ✓
First Blind Speed | m/s | 80 | 1e+02 | 1.1e+02 ✓
Range Rate Resolution | m/s | 10 | 3 | 3.7 ⚠



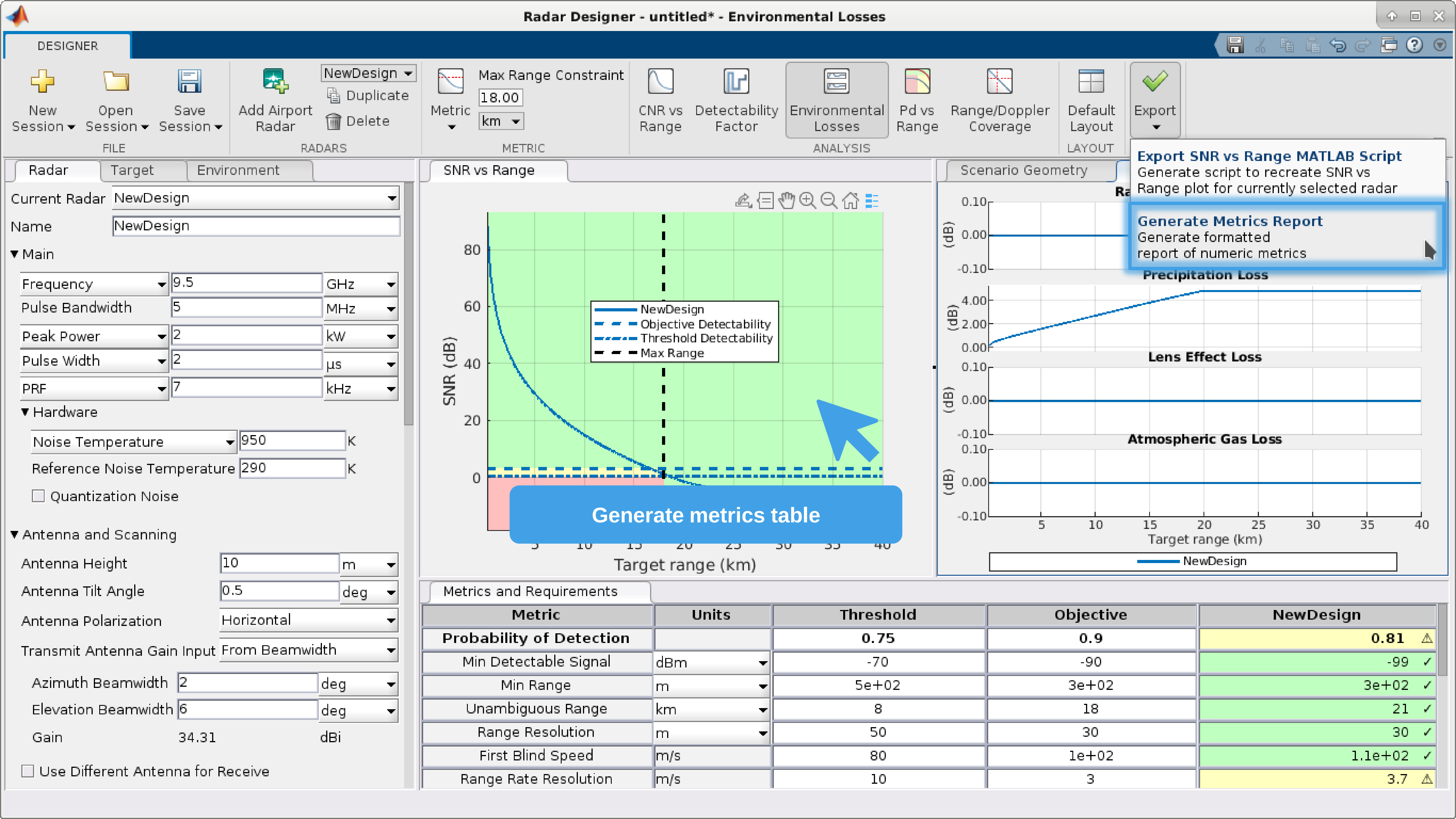
Radar Designer - untitled* - SNR vs Range
DESIGNER
New Session
Open Session
Save Session
FILE
Add Airport Radar
NewDesign
Duplicate
Delete
RADARS
Metric
Max Range Constraint
18.00
km
METRIC
CNR vs Range
Detectability Factor
Environmental Losses
Pd vs Range
Range/Doppler Coverage
ANALYSIS
Default Layout
LAYOUT
Export
EXPORT
Radar
Target
Environment
Atmosphere and Surface
Free Space
Precipitation
Precipitation Type Rain
Model ITU
Precipitation Start Range 0 km
Precipitation Range Extent 20 km
Rain Rate 16 mm/hr
Statistical Percentage 0.01 %
SNR vs Range
NewDesign
Objective Detectability
Threshold Detectability
Max Range
SNR (dB)
Target range (km)
Add rain precipitation
Scenario Geometry
Environmental Losses
Radar Propagation Factor
Precipitation Loss
Lens Effect Loss
Atmospheric Gas Loss
(dB)
Target range (km)
NewDesign
Metrics and Requirements
Metric | Units | Threshold | Objective | NewDesign
Probability of Detection | | 0.75 | 0.9 | 0.55
Min Detectable Signal | dBm | -70 | -90 | -92
Min Range | m | 5e+02 | 3e+02 | 3e+02
Unambiguous Range | km | 8 | 18 | 21
Range Resolution | m | 50 | 30 | 30
First Blind Speed | m/s | 80 | 1e+02 | 1.1e+02
Range Rate Resolution | m/s | 10 | 3 | 3.7

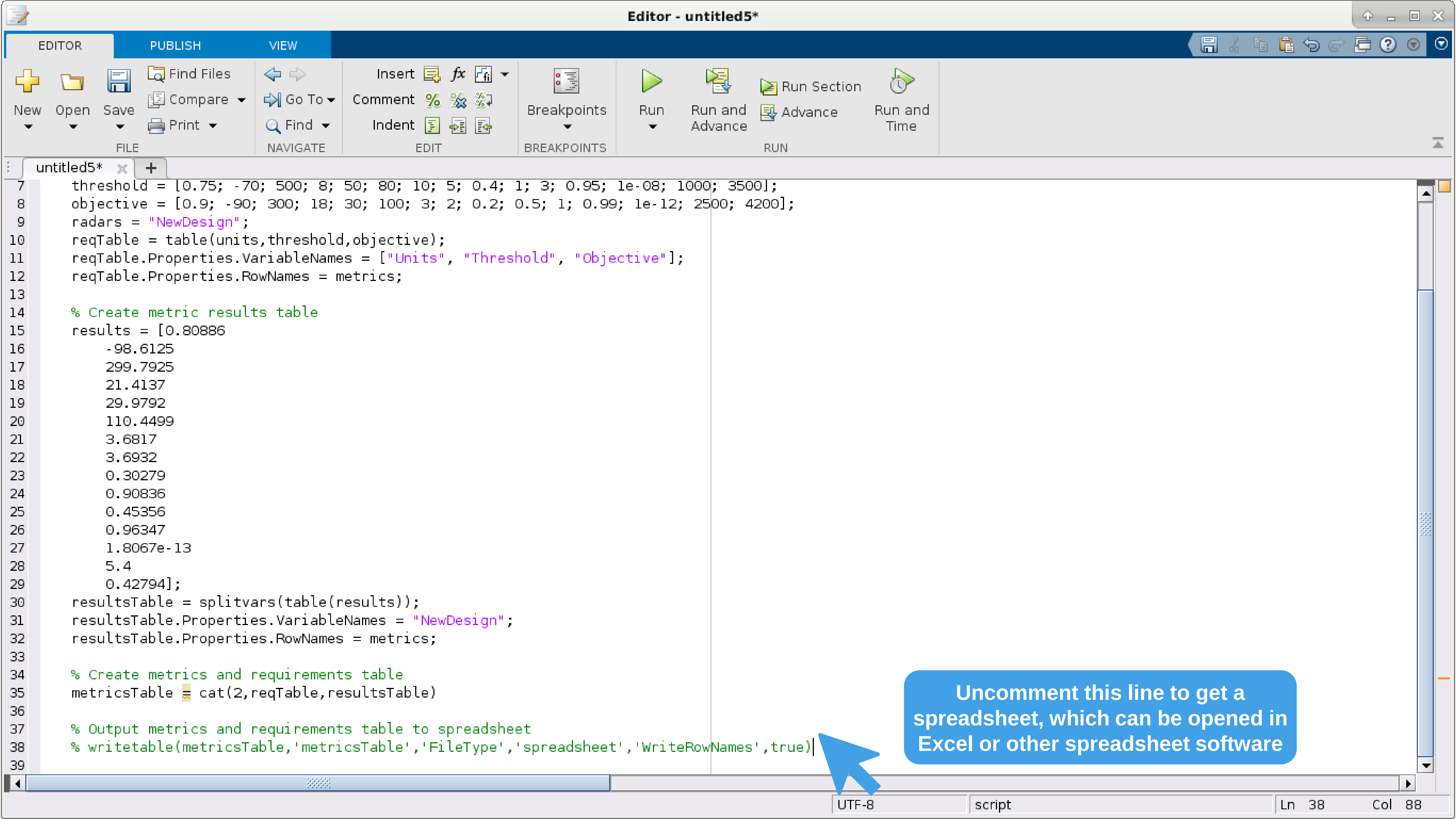

Radar Designer - untitled* - Environmental Losses
DESIGNER
New Session
Open Session
Save Session
FILE
Add Airport Radar
NewDesign
Duplicate
Delete
RADARS
Metric
Max Range Constraint
18.00
km
METRIC
CNR vs Range
Detectability Factor
Environmental Losses
Pd vs Range
Range/Doppler Coverage
ANALYSIS
Default Layout
LAYOUT
Export
EXPORT
Radar
Target
Environment
Gain 34.31 dBi
Use Different Antenna for Receive
Scan Mode Mechanical
Azimuth Scan Sector Size 360 deg
Elevation Scan Limits 0 60 deg
Max Scan Rate 466.7 deg/s
Search Volume Size 5.441 sr
Search Time 6.38 s
Detection and Tracking
Probability of False Alarm 1e-06
Number of Pulses 30
Pulse Integration Coherent
Constant False Alarm Rate (CFAR)
Number of CPIs 3
M-of-N CPI Integration
Number of CPIs with Detection 2
Sensitivity Time Control (STC)
Track Confirmation Logic
Loss Factors
Eclipsing Statistical Loss
SNR vs Range
Update radar parameters to achieve objective probability of detection
NewDesign
Objective Detectability
Threshold Detectability
Max Range
SNR (dB)
Target range (km)
Scenario Geometry
Environmental Losses
Radar Propagation Factor
Precipitation Loss
Lens Effect Loss
Atmospheric Gas Loss
(dB)
Target range (km)
NewDesign
Metrics and Requirements
Metric | Units | Threshold | Objective | NewDesign
Probability of Detection | | 0.75 | 0.9 | 0.81
Min Detectable Signal | dBm | -70 | -90 | -99
Min Range | m | 5e+02 | 3e+02 | 3e+02
Unambiguous Range | km | 8 | 18 | 21
Range Resolution | m | 50 | 30 | 30
First Blind Speed | m/s | 80 | 1e+02 | 1.1e+02
Range Rate Resolution | m/s | 10 | 3 | 3.7

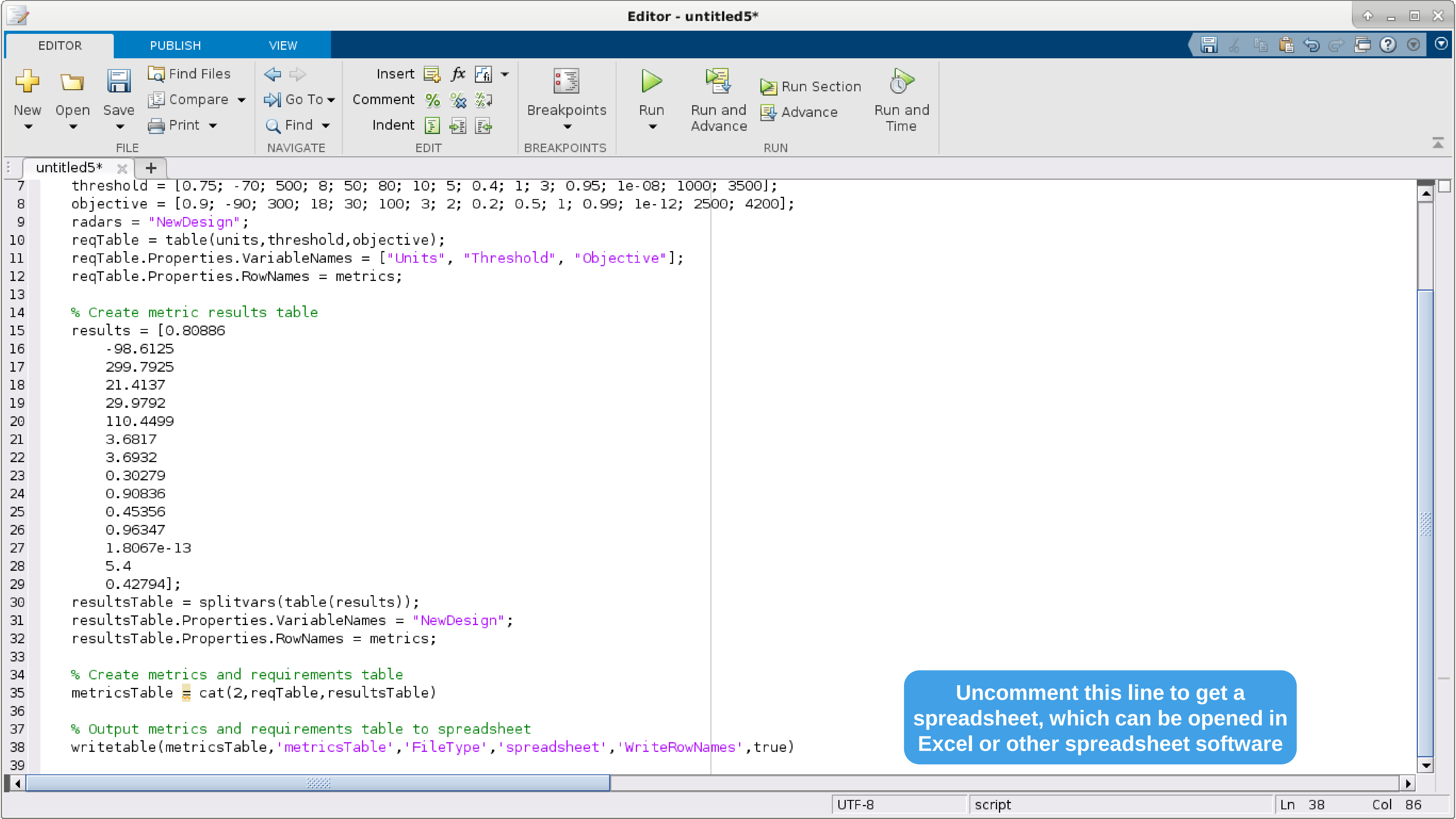

Radar Designer - untitled* - Environmental Losses
DESIGNER
New Session
Open Session
Save Session
FILE
Add Airport Radar
NewDesign
Duplicate
Delete
RADARS
Metric
Max Range Constraint
18.00
km
METRIC
CNR vs Range
Detectability Factor
Environmental Losses
Pd vs Range
Range/Doppler Coverage
ANALYSIS
Default Layout
LAYOUT
Export
Export SNR vs Range MATLAB Script
Generate script to recreate SNR vs Range plot for currently selected radar
Generate Metrics Report
Generate formatted report of numeric metrics
Radar
Target
Environment
Current Radar NewDesign
Name NewDesign
Main
Frequency 9.5 GHz
Pulse Bandwidth 5 MHz
Peak Power 2 kW
Pulse Width 2 µs
PRF 7 kHz
Hardware
Noise Temperature 950 K
Reference Noise Temperature 290 K
Quantization Noise
Antenna and Scanning
Antenna Height 10 m
Antenna Tilt Angle 0.5 deg
Antenna Polarization Horizontal
Transmit Antenna Gain Input From Beamwidth
Azimuth Beamwidth 2 deg
Elevation Beamwidth 6 deg
Gain 34.31 dBi
Use Different Antenna for Receive
SNR vs Range
SNR (dB)
Target range (km)
NewDesign
Objective Detectability
Threshold Detectability
Max Range
Export SNR vs Range
Scenario Geometry
Precipitation Loss
Lens Effect Loss
Atmospheric Gas Loss
(dB)
Target range (km)
NewDesign
Metrics and Requirements
Metric
Units
Threshold
Objective
NewDesign
Probability of Detection 0.75 0.9 0.81
Min Detectable Signal dBm -70 -90 -99
Min Range m 5e+02 3e+02 3e+02
Unambiguous Range km 8 18 21
Range Resolution m 50 30 30
First Blind Speed m/s 80 1e+02 1.1e+02
Range Rate Resolution m/s 10 3 3.7



Editor - /home/sjames/MATLAB/NewDesign.m
EDITOR
PUBLISH
VIEW
New
Open
Save
Find Files
Compare
Print
FILE
Go To
Find
NAVIGATE
Insert
Comment
Indent
EDIT
Breakpoints
BREAKPOINTS
Run
Run Section
Advance
Run and Time
Save and run to visualize SNR vs Range plot
NewDesign.m
% Generated by MATLAB(R) 9.11 (R2021b) and Radar Toolbox 1.0 (R2021b).
% Generated on: 20-Jan-2021 11:53:42
%% Set up radar, target, and environment structs for the currently
% Radar design parameters
radar = designRadar('NewDesign');
% Radar environment
env = radarEnvironment();
% Radar target
rangeLimits = [2.0000e+02 4.0000e+04]; % m
numTargetPositions = 1000;
target = radarTarget(radar,env,rangeLimits,numTargetPositions);
%% Define constraints and design requirements
% Constrain analysis in range
constraint.Range = 1.8000e+04; % m
% Set design requirements
PdThreshold = 7.5000e-01; % Decimal
PdObjective = 9.0000e-01; % Decimal
%% Compute available SNR for the currently selected radar
% Calculate propagation factor
Fprop = propagationFactor(radar,target);
% Calculate environmental losses
Latmos = atmosphericLosses(radar,env,target);
% Calculate range-dependent factors
Fcustom = rangeDependentLosses(radar,target);
% Calculate signal-to-noise ratio (SNR)
Figure 1: NewDesign
File
Edit
View
Insert
Tools
Desktop
Window
Help
SNR vs Range
SNR (dB)
Range (km)
SNR
Objective Detectability
Threshold Detectability
Max Range
Pass
Warn
Fail
UTF-8
Ln 1
Col 1


Radar Designer - untitled* - Environmental Losses
DESIGNER
New Session
Open Session
Save Session
FILE
Add Airport Radar
NewDesign
Duplicate
Delete
RADARS
Metric
Max Range Constraint
18.00
km
METRIC
CNR vs Range
Detectability Factor
Environmental Losses
Pd vs Range
Range/Doppler Coverage
ANALYSIS
Default Layout
LAYOUT
Export
Export SNR vs Range MATLAB Script
Generate script to recreate SNR vs Range plot for currently selected radar
Generate Metrics Report
Generate formatted report of numeric metrics
Radar
Target
Environment
Current Radar
NewDesign
Name
NewDesign
Main
Frequency
9.5
GHz
Pulse Bandwidth
5
MHz
Peak Power
2
kW
Pulse Width
2
μs
PRF
7
kHz
Hardware
Noise Temperature
950
K
Reference Noise Temperature
290
K
Quantization Noise
Antenna and Scanning
Antenna Height
10
m
Antenna Tilt Angle
0.5
deg
Antenna Polarization
Horizontal
Transmit Antenna Gain Input
From Beamwidth
Azimuth Beamwidth
2
deg
Elevation Beamwidth
6
deg
Gain
34.31
dBi
Use Different Antenna for Receive
SNR vs Range
SNR (dB)
Target range (km)
NewDesign
Objective Detectability
Threshold Detectability
Max Range
Generate metrics table
Scenario Geometry
Precipitation Loss
Lens Effect Loss
Atmospheric Gas Loss
(dB)
Target range (km)
NewDesign
Metrics and Requirements
Metric
Units
Threshold
Objective
NewDesign
Probability of Detection
0.75
0.9
0.81
Min Detectable Signal
dBm
-70
-90
-99
Min Range
m
5e+02
3e+02
3e+02
Unambiguous Range
km
8
18
21
Range Resolution
m
50
30
30
First Blind Speed
m/s
80
1e+02
1.1e+02
Range Rate Resolution
m/s
10
3
3.7


Editor - untitled5*
EDITOR
PUBLISH
VIEW
New
Open
Save
Find Files
Compare
Print
FILE
Go To
Find
NAVIGATE
Insert
Comment
Indent
EDIT
Breakpoints
BREAKPOINTS
Run
Run and Advance
Run Section
Advance
Run and Time
RUN
untitled5*
threshold = [0.75; -70; 500; 8; 50; 80; 10; 5; 0.4; 1; 3; 0.95; 1e-08; 1000; 3500];
objective = [0.9; -90; 300; 18; 30; 100; 3; 2; 0.2; 0.5; 1; 0.99; 1e-12; 2500; 4200];
radars = "NewDesign";
reqTable = table(units,threshold,objective);
reqTable.Properties.VariableNames = ["Units", "Threshold", "Objective"];
reqTable.Properties.RowNames = metrics;
% Create metric results table
results = [0.80886
-98.6125
299.7925
21.4137
29.9792
110.4499
3.6817
3.6932
0.30279
0.90836
0.45356
0.96347
1.8067e-13
5.4
0.42794];
resultsTable = splitvars(table(results));
resultsTable.Properties.VariableNames = "NewDesign";
resultsTable.Properties.RowNames = metrics;
% Create metrics and requirements table
metricsTable = cat(2,reqTable,resultsTable)
% Output metrics and requirements table to spreadsheet
% writetable(metricsTable,'metricsTable','FileType','spreadsheet','WriteRowNames',true)
Uncomment this line to get a spreadsheet, which can be opened in Excel or other spreadsheet software
UTF-8
script
Ln 38
Col 88


Editor - untitled5*
EDITOR
PUBLISH
VIEW
New
Open
Save
Find Files
Compare
Print
FILE
Go To
Find
NAVIGATE
Insert
Comment
Indent
EDIT
Breakpoints
BREAKPOINTS
Run
Run and Advance
Run Section
Advance
Run and Time
RUN
untitled5*
threshold = [0.75; -70; 500; 8; 50; 80; 10; 5; 0.4; 1; 3; 0.95; 1e-08; 1000; 3500];
objective = [0.9; -90; 300; 18; 30; 100; 3; 2; 0.2; 0.5; 1; 0.99; 1e-12; 2500; 4200];
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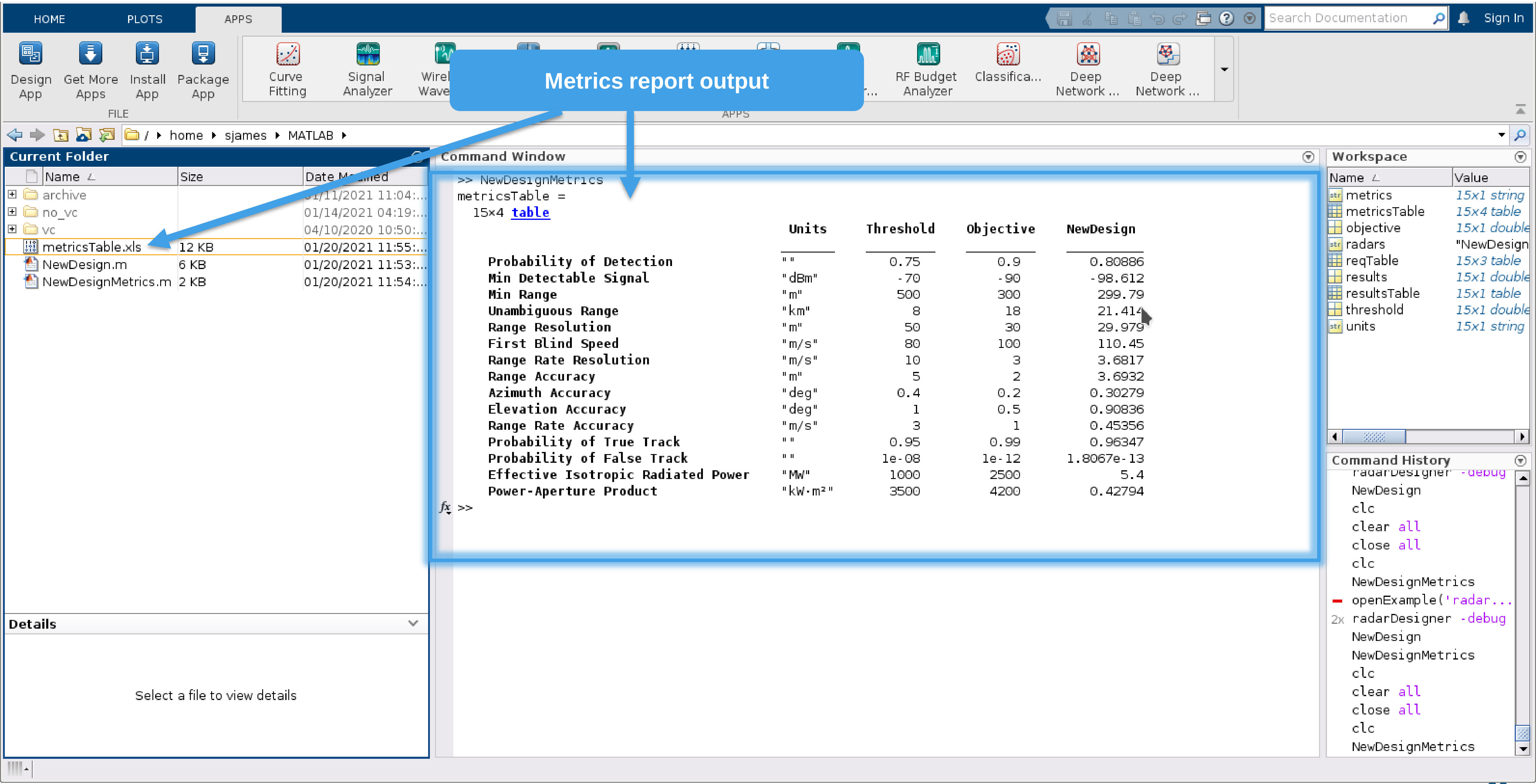
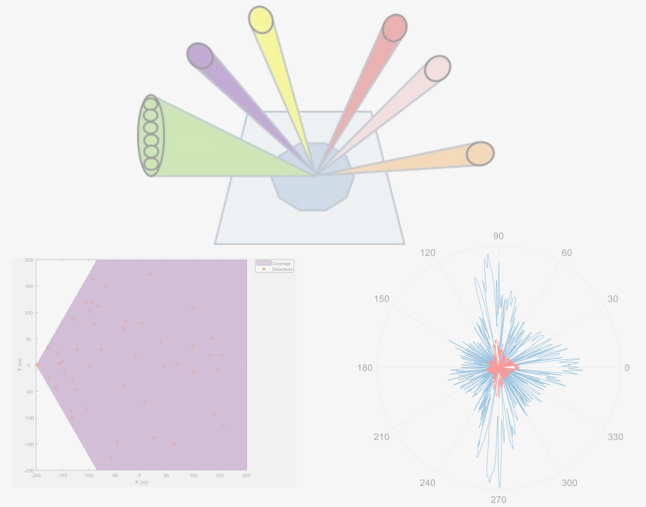
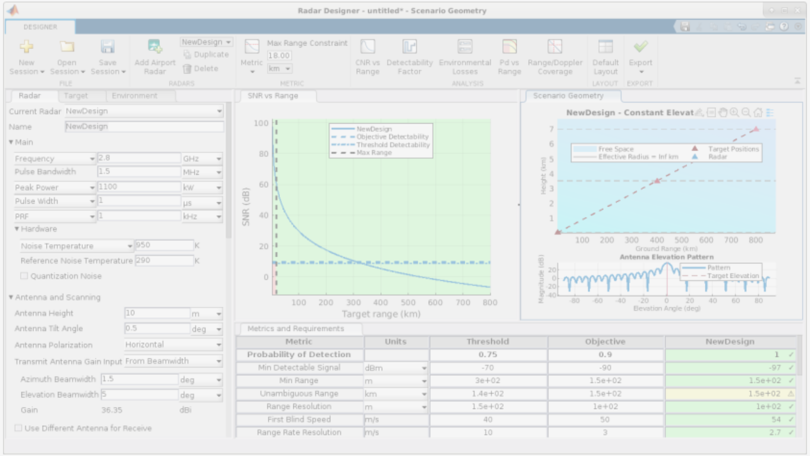
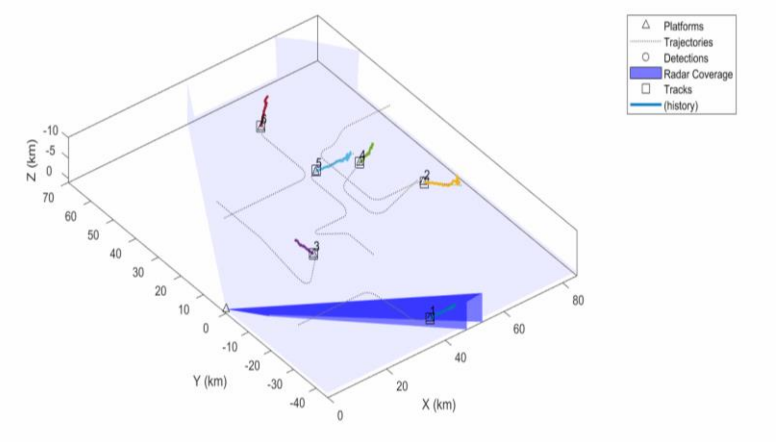
results = [0.80886
-98.6125
299.7925
21.4137
29.9792
110.4499
3.6817
3.6932
0.30279
0.90836
0.45356
0.96347
1.8067e-13
5.4
0.42794];
resultsTable = splitvars(table(results));
resultsTable.Properties.VariableNames = "NewDesign";
resultsTable.Properties.RowNames = metrics;
% Create metrics and requirements table
metricsTable = cat(2,reqTable,resultsTable)
% Output metrics and requirements table to spreadsheet
writetable(metricsTable,'metricsTable','FileType','spreadsheet','WriteRowNames',true)
Uncomment this line to get a spreadsheet, which can be opened in Excel or other spreadsheet software
UTF-8
script
Ln 38
Col 86


Metrics report output
HOME
PLOTS
APPS
Design App
Get More Apps
Install App
Package App
FILE
Curve Fitting
Signal Analyzer
RF Budget Analyzer
APPS
/ home sjames MATLAB
Current Folder
Name
Size
Date Modified
archive
no_vc
vc
metricsTable.xls 12 KB 01/20/2021 11:55:...
NewDesign.m 6 KB 01/20/2021 11:53:...
NewDesignMetrics.m 2 KB 01/20/2021 11:54:...
Details
Select a file to view details
Command Window
>> NewDesignMetrics
metricsTable =
15×4 table
Units Threshold Objective NewDesign
Probability of Detection "" 0.75 0.9 0.80886
Min Detectable Signal "dBm" -70 -90 -98.612
Min Range "m" 500 300 299.79
Unambiguous Range "km" 8 18 21.414
Range Resolution "m" 50 30 29.979
First Blind Speed "m/s" 80 100 110.45
Range Rate Resolution "m/s" 10 3 3.6817
Range Accuracy "m" 5 2 3.6932
Azimuth Accuracy "deg" 0.4 0.2 0.30279
Elevation Accuracy "deg" 1 0.5 0.90836
Range Rate Accuracy "m/s" 3 1 0.45356
Probability of True Track "" 0.95 0.99 0.96347
Probability of False Track "" 1e-08 1e-12 1.8067e-13
Effective Isotropic Radiated Power "MW" 1000 2500 5.4
Power-Aperture Product "kW·m²" 3500 4200 0.42794
>>
Workspace
Name Value
metrics 15x1 string
metricsTable 15x4 table
objective 15x1 double
radars "NewDesign
reqTable 15x3 table
results 15x1 double
resultsTable 15x1 table
threshold 15x1 double
units 15x1 string
Command History
NewDesign
clc
clear all
close all
clc
NewDesignMetrics
openExample('radar...
radarDesigner -debug
NewDesign
NewDesignMetrics
clc
clear all
close all
clc
NewDesignMetrics

3 Things We'll Cover Today







Challenges
Multifunction operations in harsh environmental conditions for smaller targets

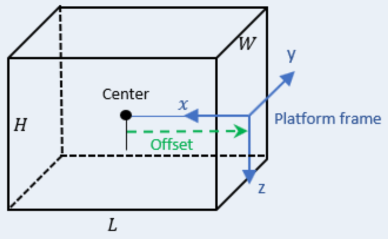
Radar System Engineering
Making engineering trade-offs early in the design cycle

Modeling and Simulation
Selecting the right level of model abstraction

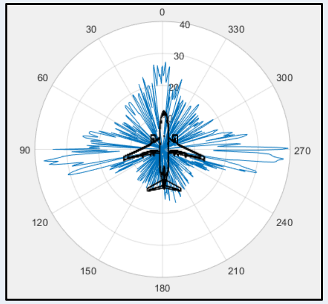
Authoring surface, air and space scenarios for radar applications

Model Platforms and Targets → Model Trajectories → Model Sensors → Simulate scenarios

Object Dimensions
bounding box



RCS signature
Az, el pattern
frequencies dependency

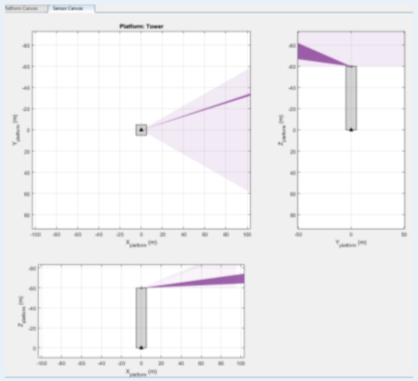


Use kinematic properties
acceleration, angular velocity

Use waypoints
position, orientation, time of arrival, ground speed, climb rate

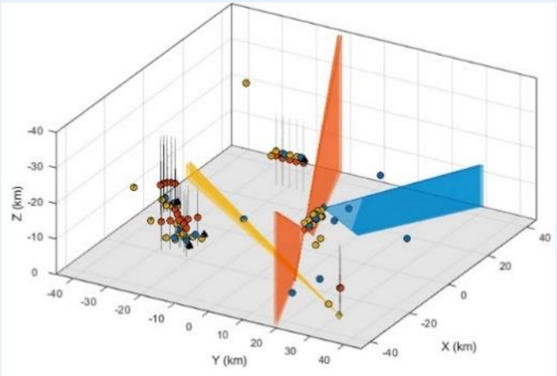
fixed NED or ENU frame (x,y,z) or, geo-referenced (lat, lon, alt)

Radars on platforms
Mounting position and orientation of radar sensor on platform



INS sensor
platform self-awareness
sensor to platform frame conversion

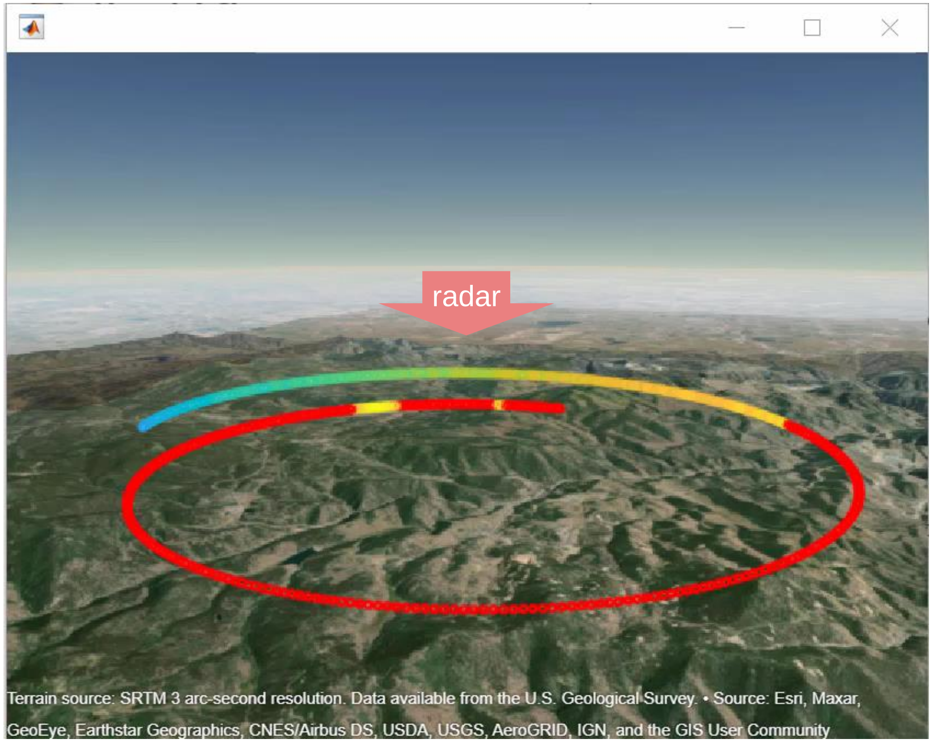
Generate radar data
I/Q signals, detections, tracks



Monte Carlo
perturb ground truth and sensor to increase testing robustness

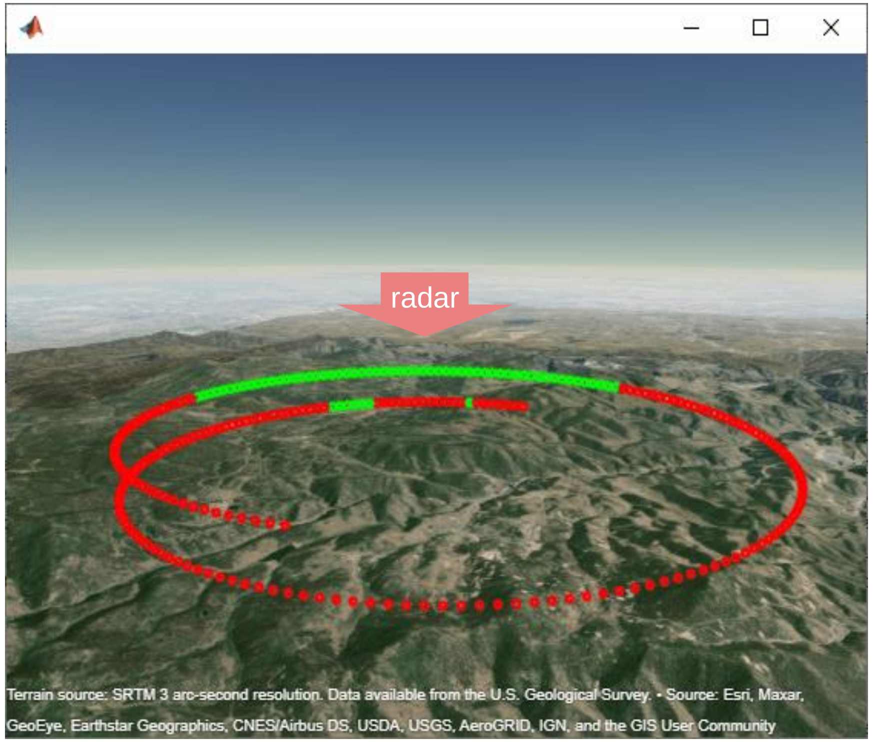
You can also evaluate detectability for the scenario

Line-of-sight (LOS) and SNR over terrain



Colors other than red: SNR
Red: No LOS

Iterate on design to increase detectability

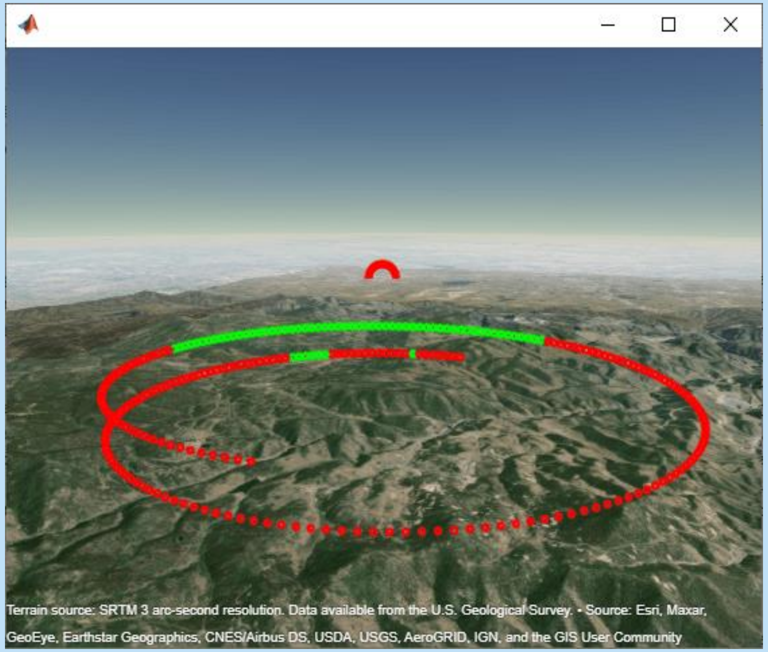


Green: Target detectable
Red: No LOS/target non detectable

Poll question

- What can we do to increase the target's detectability (select all that apply)?

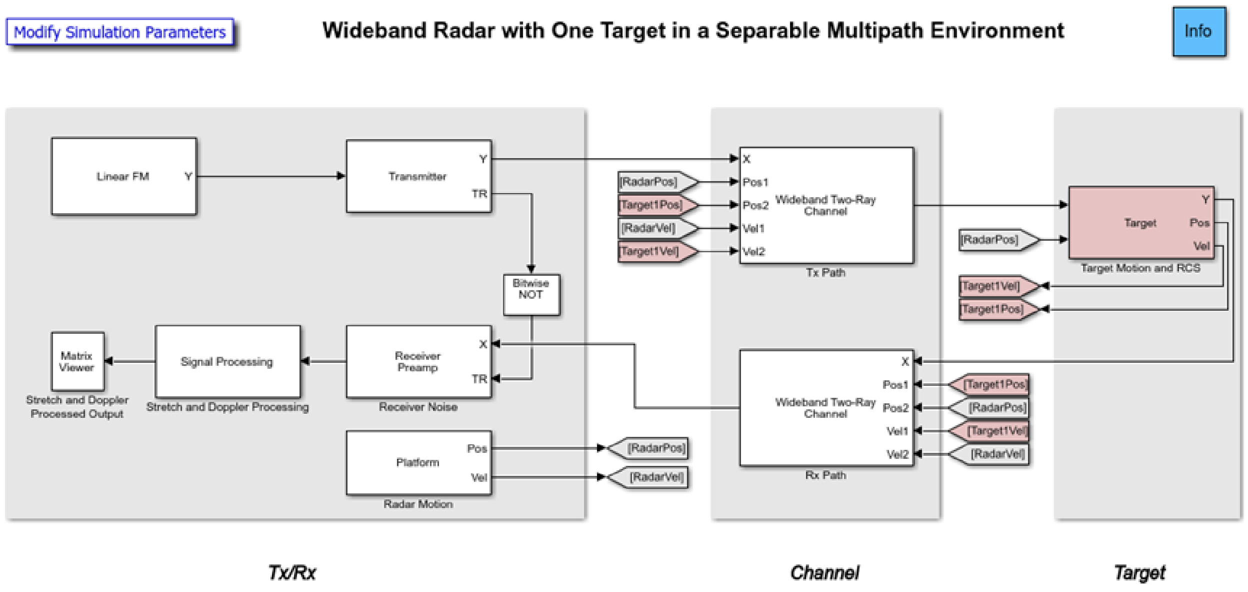
  a) Increase the radar transmit power
  b) Integrate the radar returns over multiple pulses
  c) Increase the height of antenna
  d) Turn off the target's cloaking device



Radar Modeling and Simulation

Model Platforms and Targets → Model Trajectories → Model Sensors → Simulate scenarios

```matlab
for m = 1:num_pulse_int

    % Update sensor and target positions
    [sensorpos,sensorvel] = sensormotion(1/prf);
    [tgtpos,tgtvel] = tgtmotion(1/prf);

    % Calculate the target angles as seen by the sensor
    [tgtrng,tgtang] = rangeangle(tgtpos,sensorpos);

    % Simulate propagation of pulse in direction of targets
    pulse = waveform();
    [txsig,txstatus] = transmitter(pulse);
    txsig = radiator(txsig,tgtang);
    txsig = channel(txsig,sensorpos,tgtpos,sensorvel,tgtvel);

    % Reflect pulse off of targets
    tgtsig = target(txsig);

    % Receive target returns at sensor
    rxsig = collector(tgtsig,tgtang);
    rxpulses(:,m) = receiver(rxsig,~(txstatus>0));
end
```



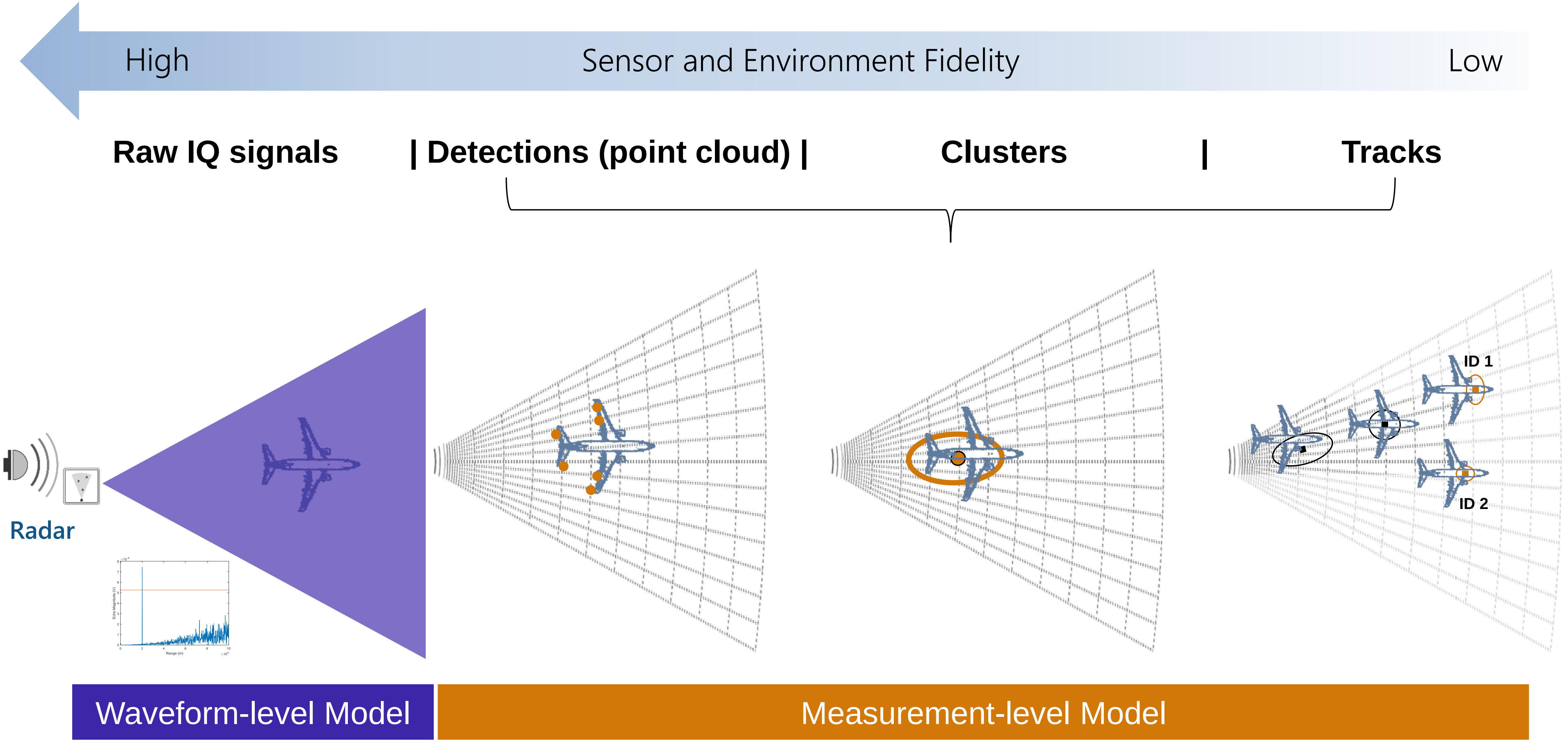
Radar Modeling and Simulation

Model Platforms and Targets → Model Trajectories → Model Sensors → Simulate scenarios

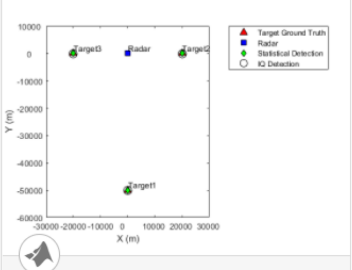
```
sensor =

  radarDataGenerator with properties:

                SensorIndex: 1
                 UpdateRate: 53.5714
              DetectionMode: 'Monostatic'
                   ScanMode: 'Mechanical'
         InterferenceInputPort: 0
          EmissionsInputPort: 0

           MountingLocation: [0 0 -15]
             MountingAngles: [0 0 0]

                FieldOfView: [1.4000 5]
                RangeLimits: [0 100000]

       DetectionProbability: 0.9000
             FalseAlarmRate: 1.0000e-06
             ReferenceRange: 100000

          TargetReportFormat: 'Clustered detections'

  Show all properties
```

```
sensor_iq =

  radarTransceiver with properties:

                      Waveform: [1×1 phased.LinearFMWaveform]
                   Transmitter: [1×1 phased.Transmitter]
               TransmitAntenna: [1×1 phased.Radiator]
                ReceiveAntenna: [1×1 phased.Collector]
                      Receiver: [1×1 phased.ReceiverPreamp]
            MechanicalScanMode: 'Circular'
    InitialMechanicalScanAngle: -0.1000
            MechanicalScanRate: 75
            ElectronicScanMode: 'None'
              MountingLocation: [0 0 -15]
                MountingAngles: [0 0 0]
          NumRepetitionsSource: 'Property'
                NumRepetitions: 1
```

Radar data synthesis spans a range of fidelity levels



Dynamically switch between waveform-level & measurement-level models



Transitioning From Statistical to Physics Based Radar Models

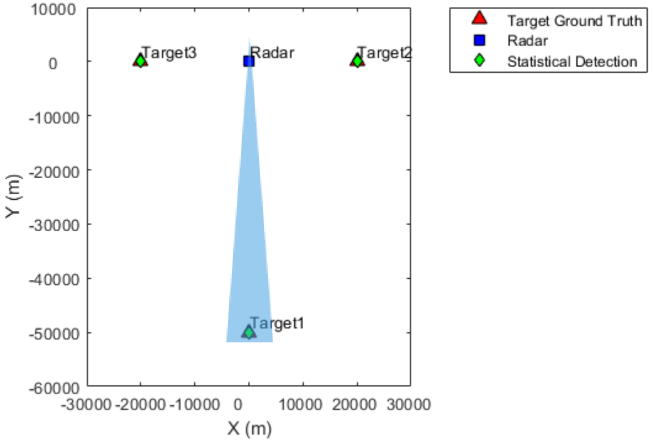
This treats a radar as a perception system that uses an antenna or antenna array to capture RF energy.

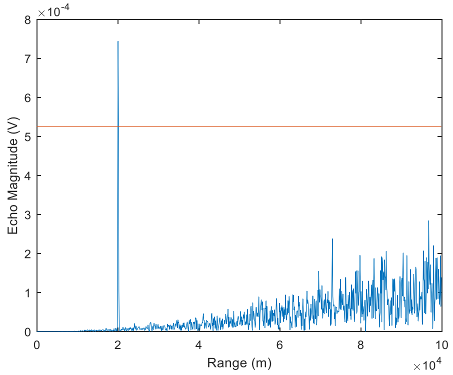
Open Live Script

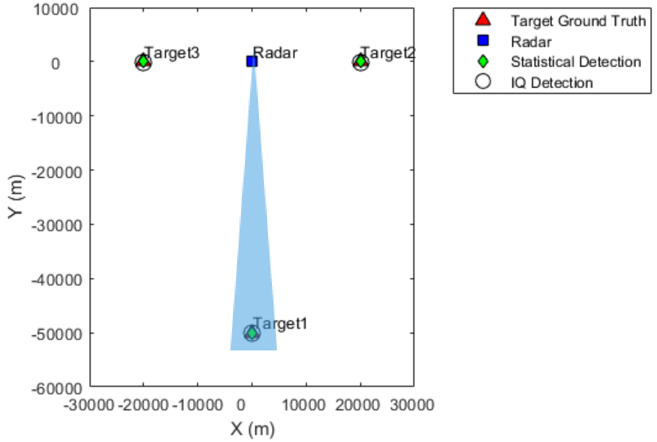
```
sensor =

  radarDataGenerator with properties:

              SensorIndex: 1
               UpdateRate: 53.5714
            DetectionMode: 'Monostatic'
                 ScanMode: 'Mechanical'
     InterferenceInputPort: 0
        EmissionsInputPort: 0

         MountingLocation: [0 0 -15]
           MountingAngles: [0 0 0]

              FieldOfView: [1.4000 5]
              RangeLimits: [0 100000]

     DetectionProbability: 0.9000
           FalseAlarmRate: 1.0000e-06
           ReferenceRange: 100000

       TargetReportFormat: 'Clustered detections'

  Show all properties
```

```
sensor_iq = radarTransceiver(sensor);
```

```
sensor_iq =

  radarTransceiver with properties:

                    Waveform: [1×1 phased.LinearFMWaveform]
                 Transmitter: [1×1 phased.Transmitter]
             TransmitAntenna: [1×1 phased.Radiator]
              ReceiveAntenna: [1×1 phased.Collector]
                    Receiver: [1×1 phased.ReceiverPreamp]
          MechanicalScanMode: 'Circular'
 InitialMechanicalScanAngle: -0.1000
          MechanicalScanRate: 75
          ElectronicScanMode: 'None'
            MountingLocation: [0 0 -15]
              MountingAngles: [0 0 0]
     NumRepetitionsSource: 'Property'
              NumRepetitions: 1
```





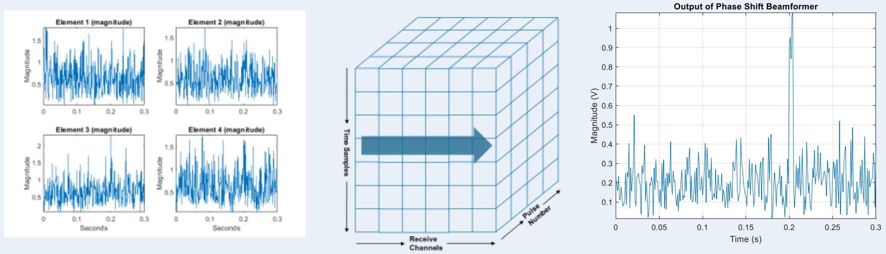


Measurement-level Model
(Statistical)

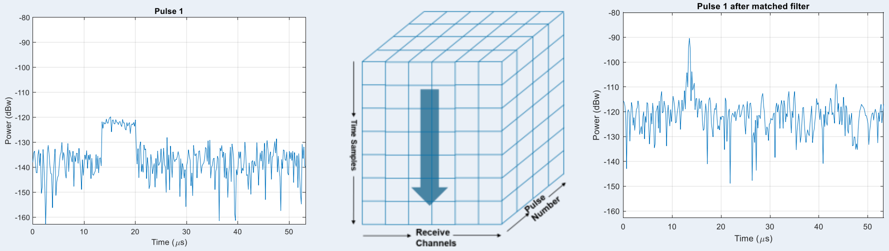
Waveform-level Model
(Physics-based)

You can then apply a range of signal and data processing algorithms

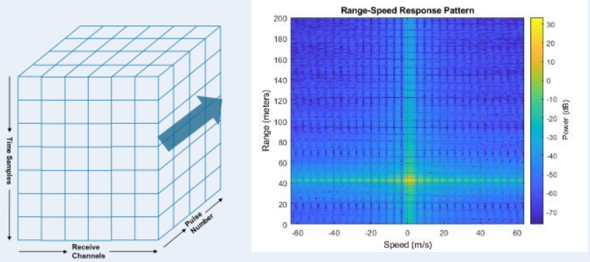
Beamforming



Matched filtering

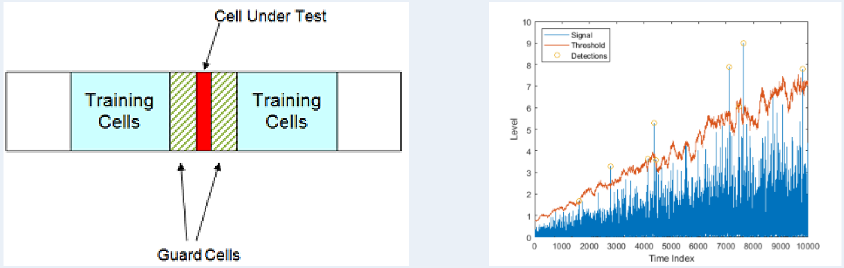


Doppler processing

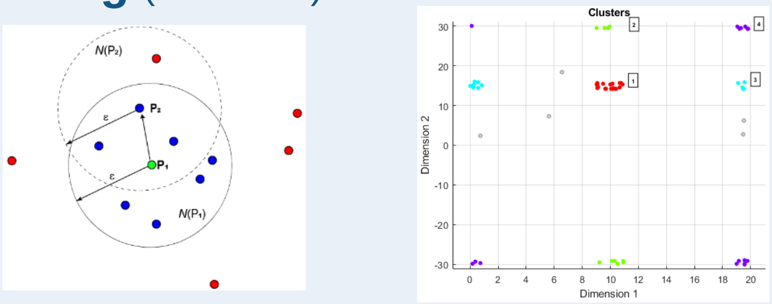


before *after*

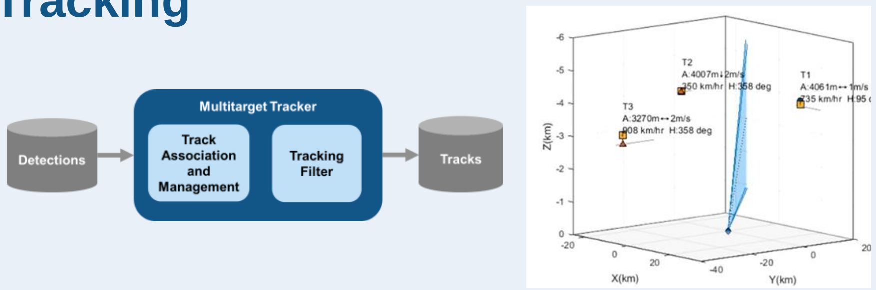
Detection (CFAR)



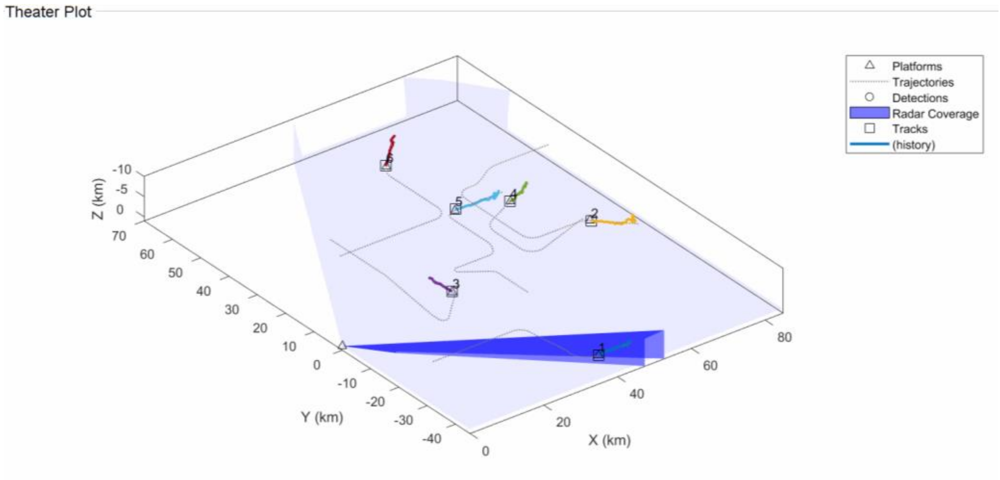
Clustering (DBSCAN)



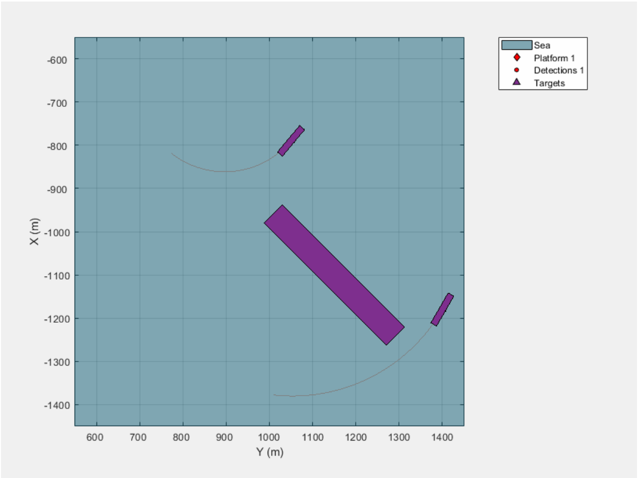
Tracking



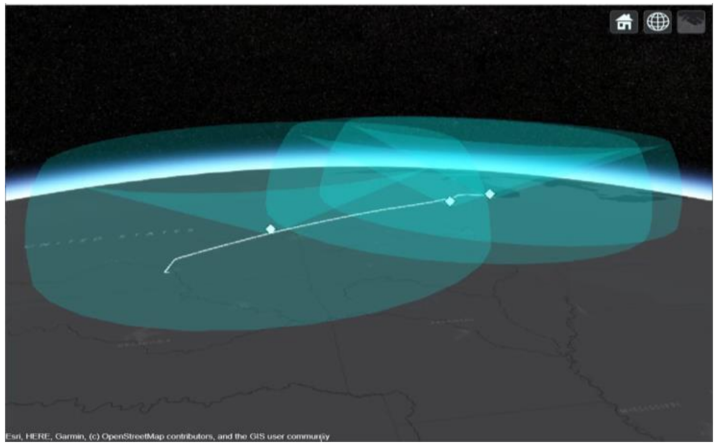
These types of models can scale to larger radar systems



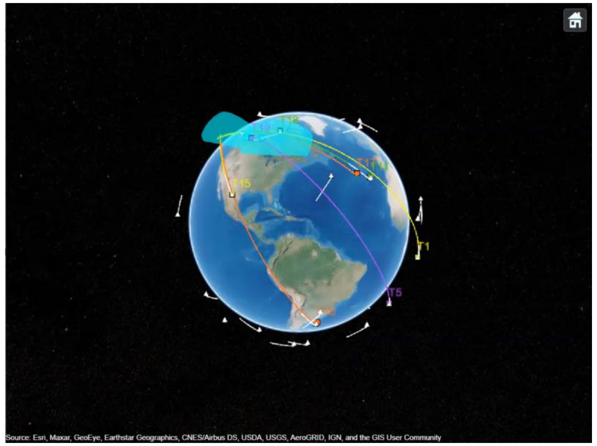
Multifunction Radar

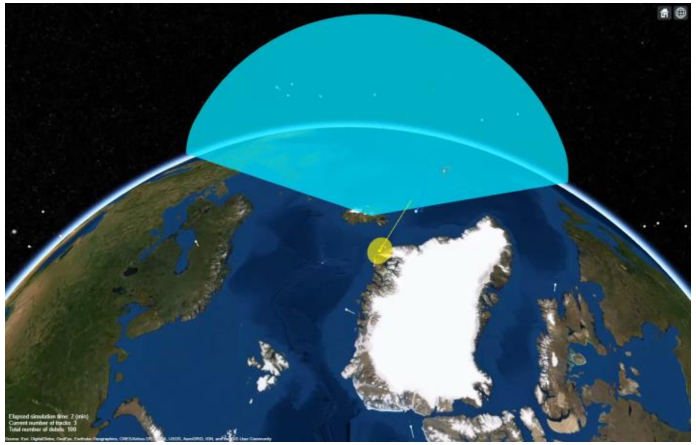


Maritime surveillance



System of radar systems





Space tracking

Download handout with more information related to this session

Radar Architecture Modeling: System partitioning & requirements allocation

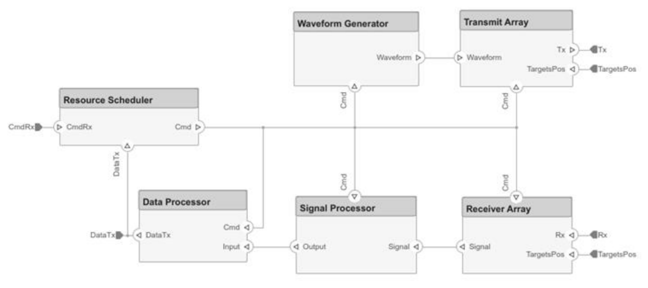
Define Requirements → Model System Architecture → Design Components and Virtual Test Bed → Link Requirements to Components

Detection

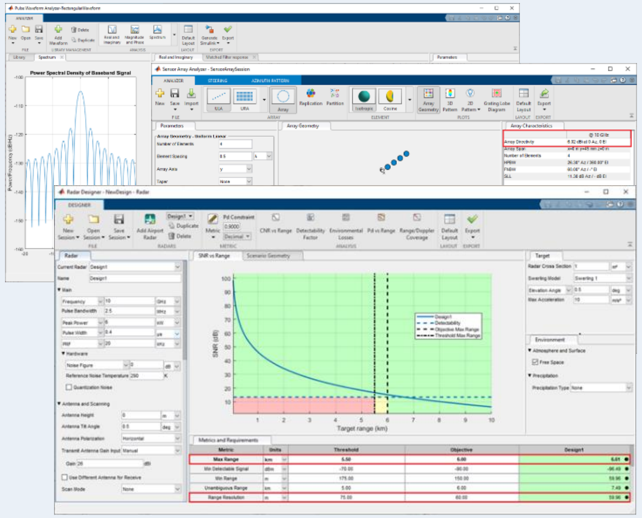
Detect a target with $1m^2$ RCS at 6 km
Pd must be at least 0.9
Pfa must be no more than 1e-6

Resolution

Resolve targets that are 70 m apart in range

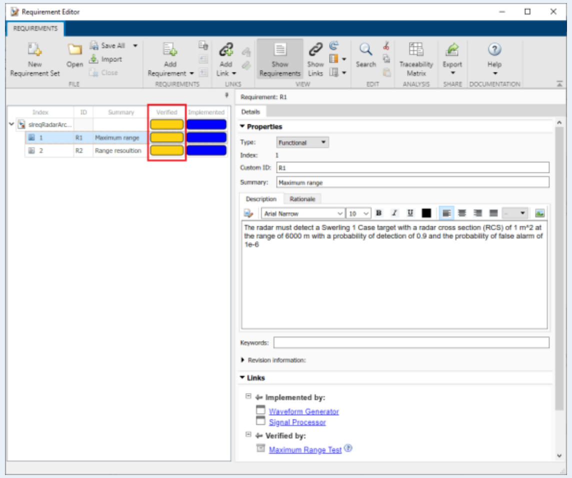


using System Composer ™



Apps

Pulse Waveform Analyzer
Sensor Array Analyzer
Radar Designer



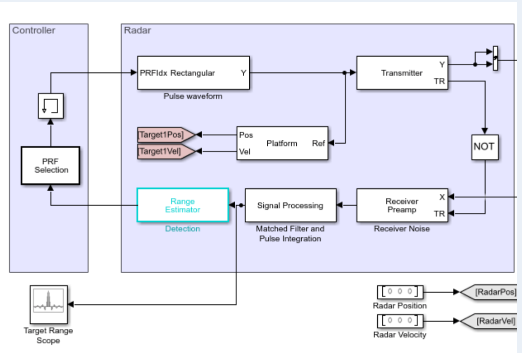
using Simulink Requirements ™

Test automation & requirements traceability: Manage changing requirements

Simulate Components → Author tests and manage test results → Trace tests results back to requirements → Manage changing requirements

Blocks Libraries

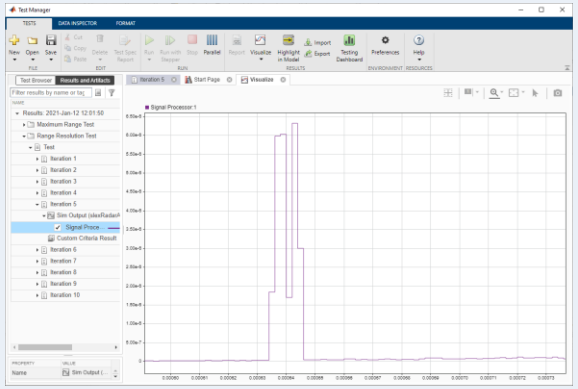
Waveforms, Tx/Rx arrays, signal processing algorithms, targets, channels, clutter, etc.



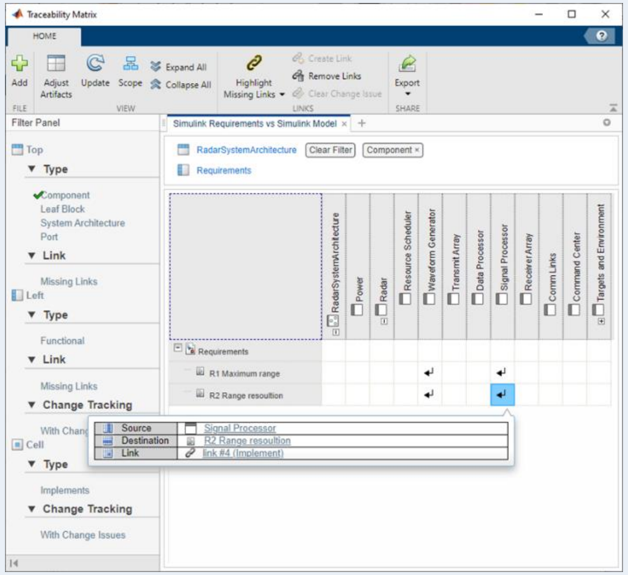
using Simulink

App

Test Manager

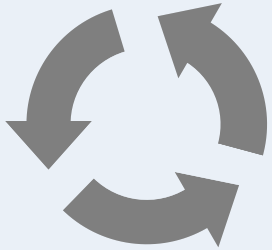


using Simulink Test ™



using Simulink Test ™
using Simulink Requirements ™

Automated process enables quick iterations



▾ PARAMETER OVERRIDES*

PARAMETER SET / WORKSPACE VARIABLE	OVERRIDE VALUE
▾ ✓ Parameter Set 1	
✓ tgtpos	[8000;0;0]
✓ tgtrcs	1
✓ tgtvel	[0;0;0]

using Simulink Requirements ™

1. System Engineering
   - Radar Toolbox R2021a
   - Mapping Toolbox
   - System Composer

2. RF Front-end
   - Antenna Toolbox
   - RF Toolbox
   - RF Blockset

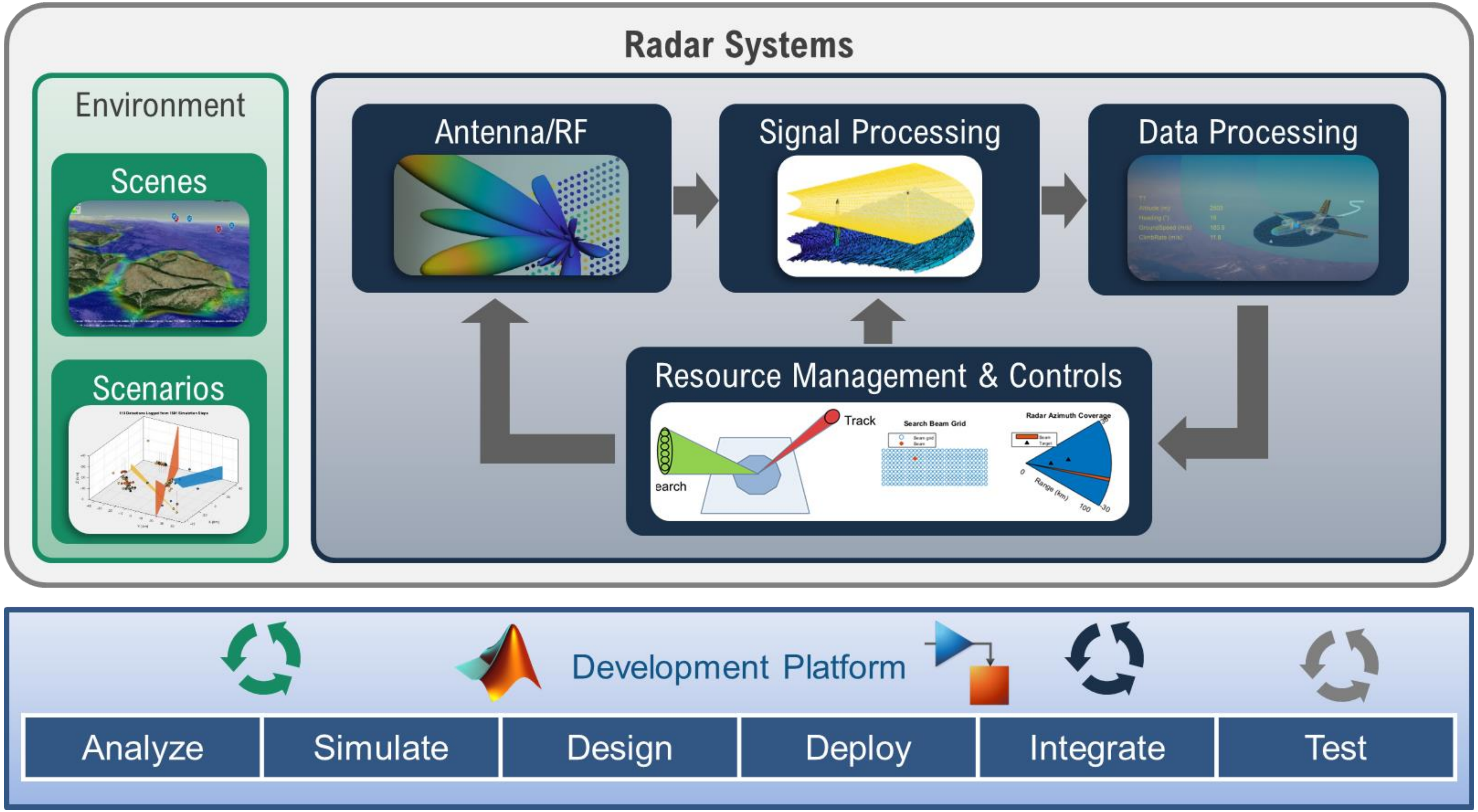
3. Signal Processing
   - Phased Array System Toolbox
   - LTE Toolbox
   - 5G Toolbox

4. Data Processing
   - Sensor Fusion & Tracking Toolbox
   - Signal Processing & Wavelet Toolboxes
   - Statistics & Machine Learning Toolbox
   - Deep Learning Toolbox

Antenna/RF → Signal Processing → Data Processing → Resource Management & Control → Antenna/RF, Signal Processing

Green indicates tools used in this session

MATLAB, Simulink, & Radar Toolbox can help you with radar system design



Please visit our website for more information

https://www.mathworks.com/solutions/aerospace-defense/radar-systems.html

MATLAB EXPO
2021

Thank you

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