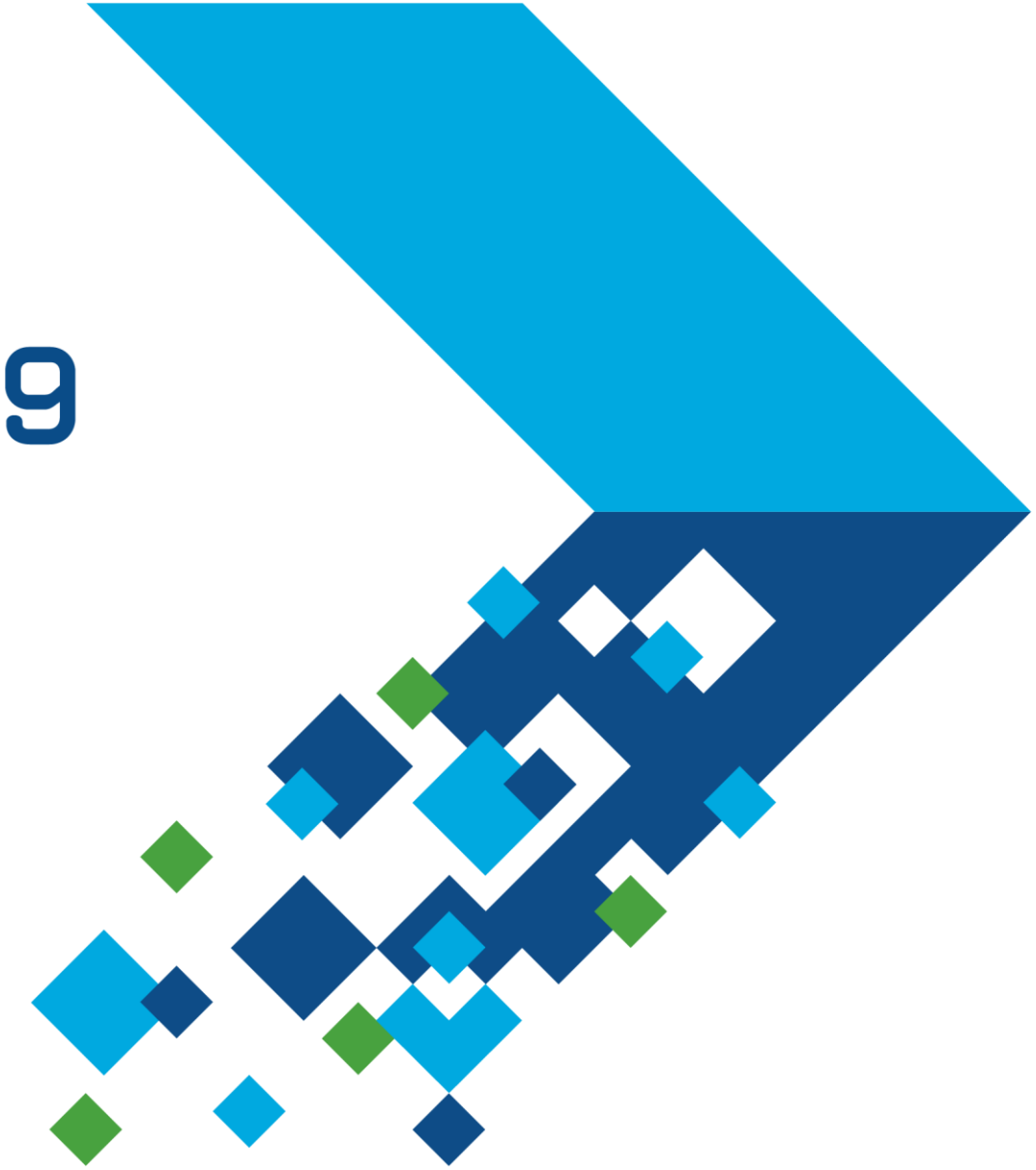
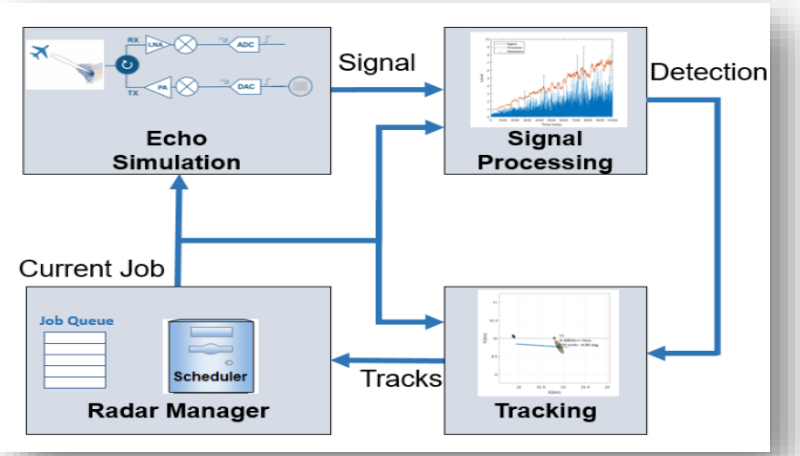
MATLAB EXPO 2019

Sensor Fusion and Tracking for Next Generation Radar

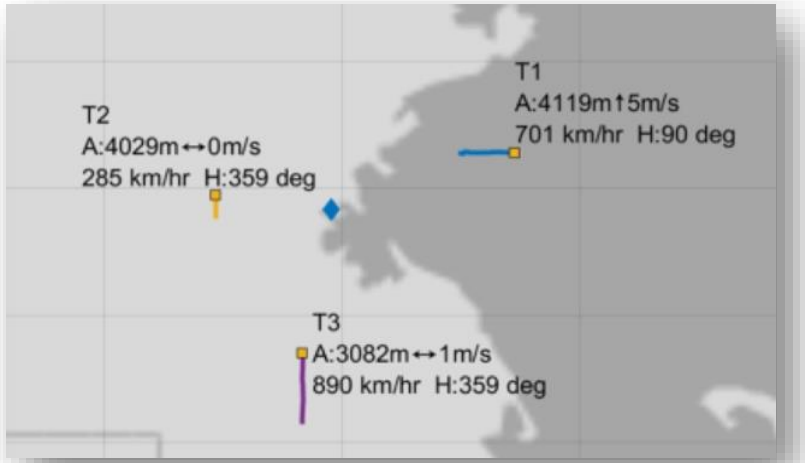
Abhishek Tiwari
Pilot Engineering
Signal Processing and Communication



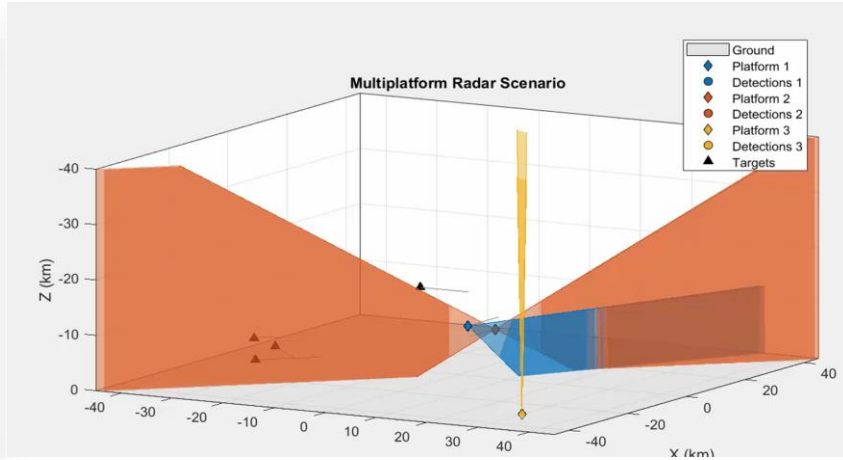
Agenda



- Closed-loop Multifunction Radar



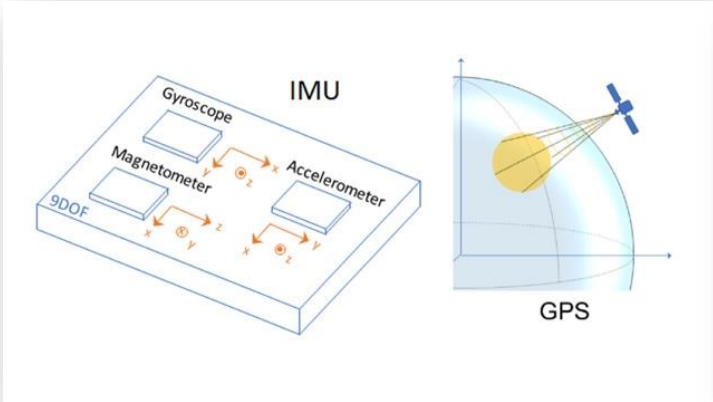
- Target Tracking & Evaluation Metrics,
- Tracking Extended Objects & Large number of Objects
- Passive Sensor Angle Only Tracking



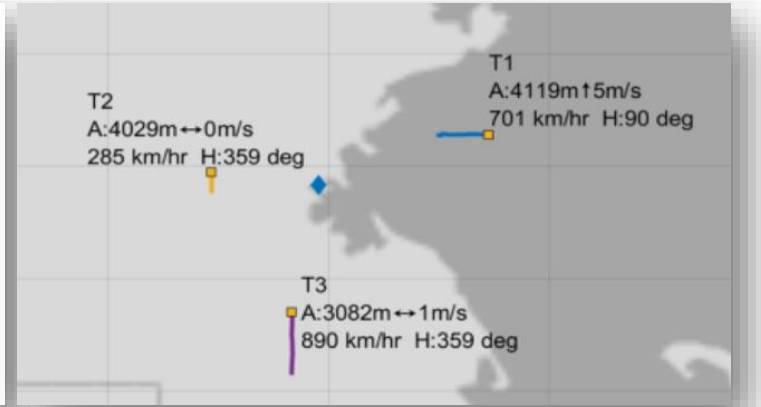
- Multisensor Detection Generation & Fusion
- Localization

Sensor Fusion and Tracking is…

Self- awareness



Situational awareness



Accelerometer, Magnetometer, Gyro, GPS…

Radar, Camera, IR, Sonar, Lidar, …

Signal and Image Processing

Sensor Fusion and Tracking

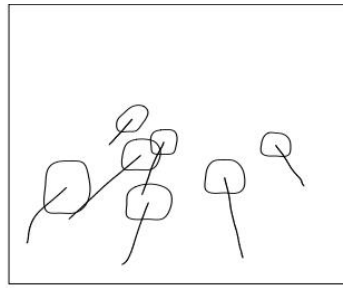
Control

Sensor Fusion and Tracking Toolbox NEW PRODUCT

Timeline of Technology Advances

Multi-object tracking

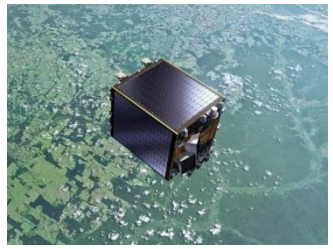
Air Traffic Control



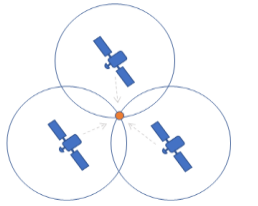
Computer Vision for Transportation

Multi-sensor Fusion for Autonomous Systems

Localization



Military



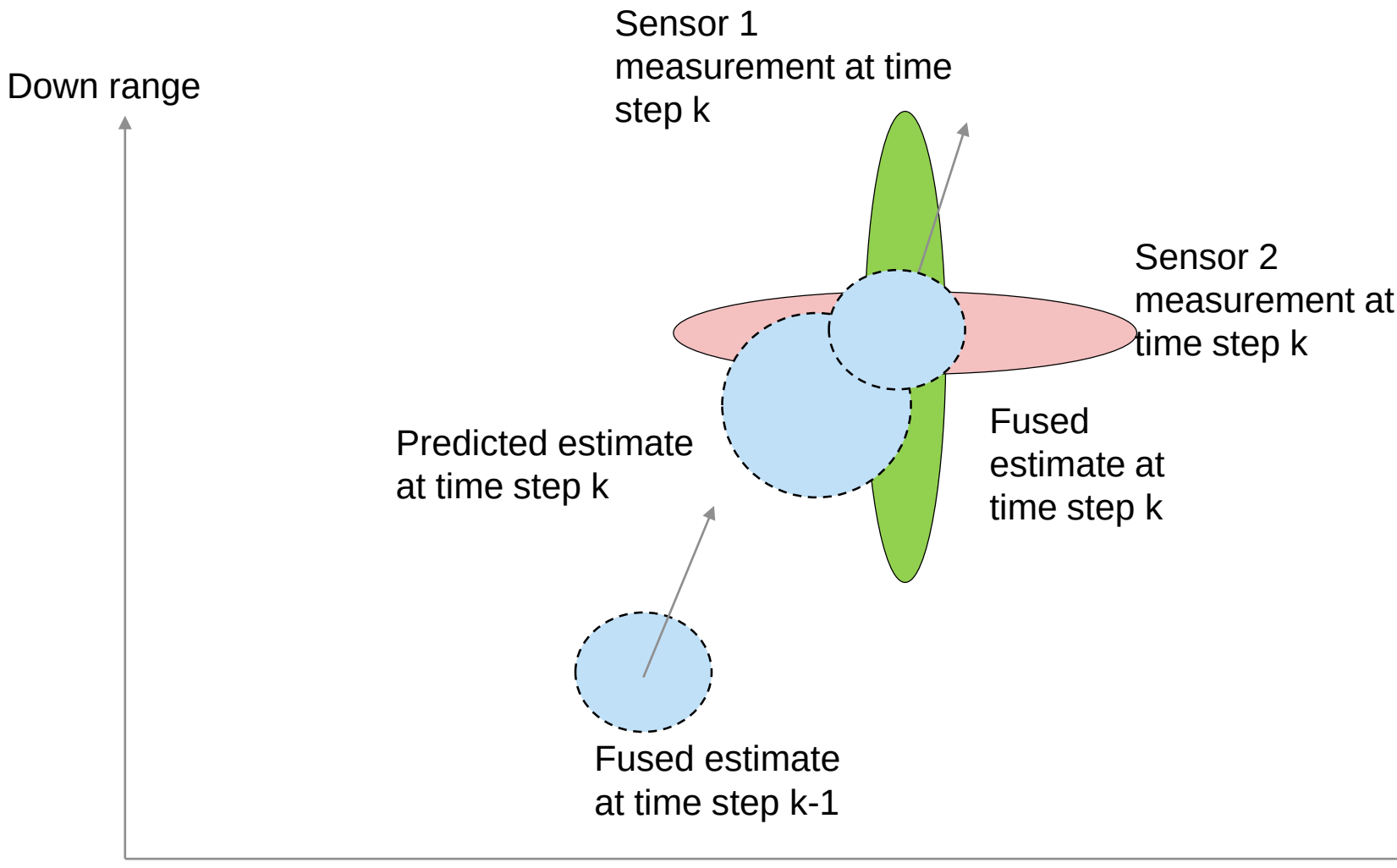
Commercial

Ubiquitous

Today

Timeline

Fusion Combines the Strengths of Each Sensor

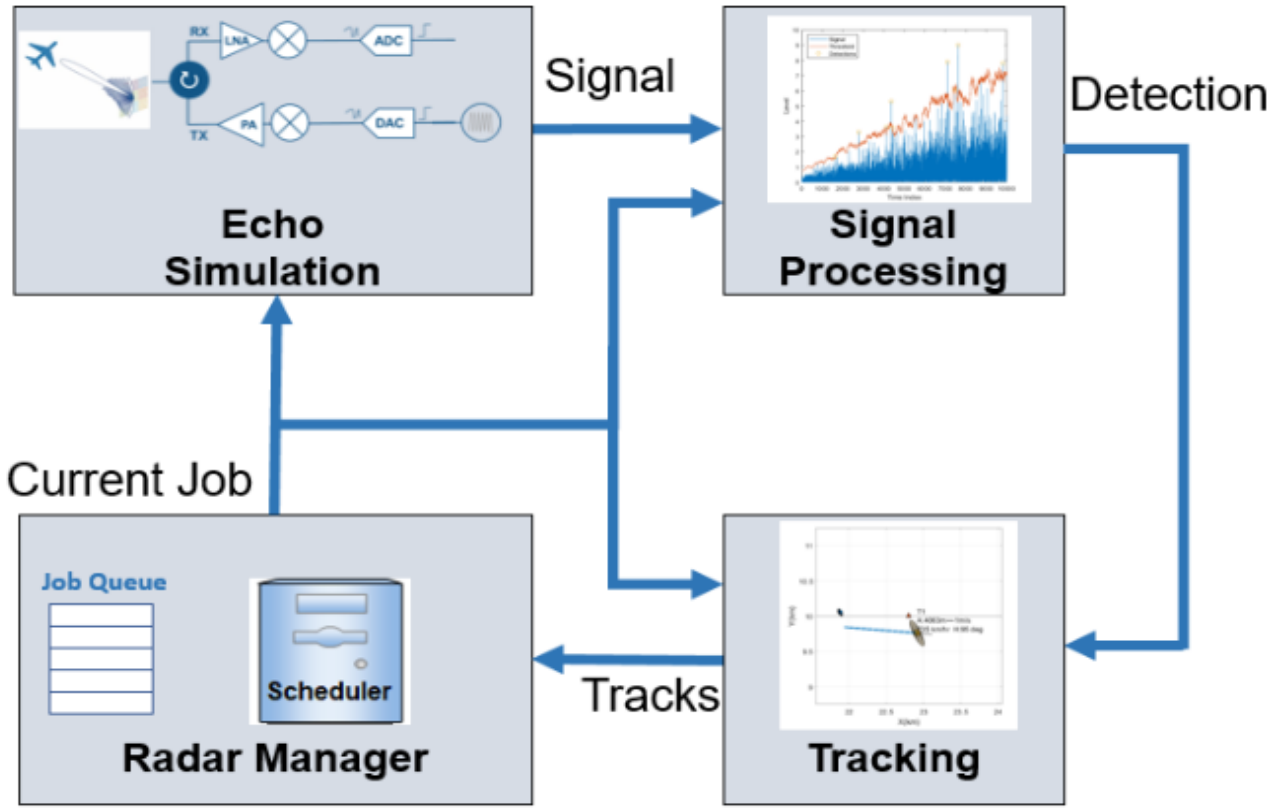


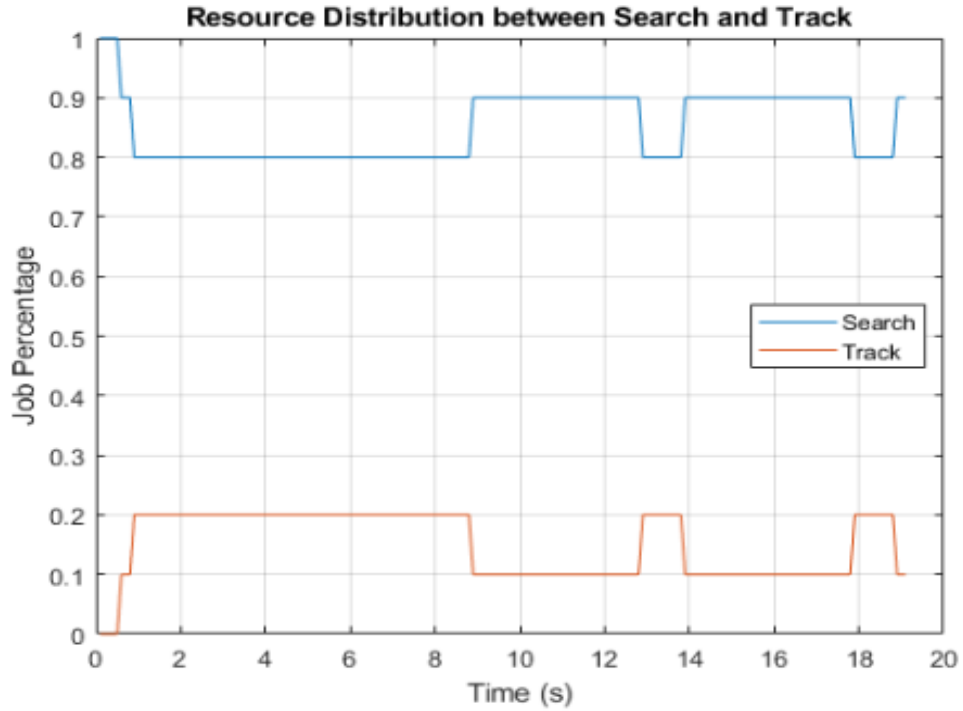
Legend

- Sensor 1 Measurement
- Sensor 2 measurement
- Track (fused estimate)

Ellipse represents uncertainty

Multifunction Radar: Search and Track

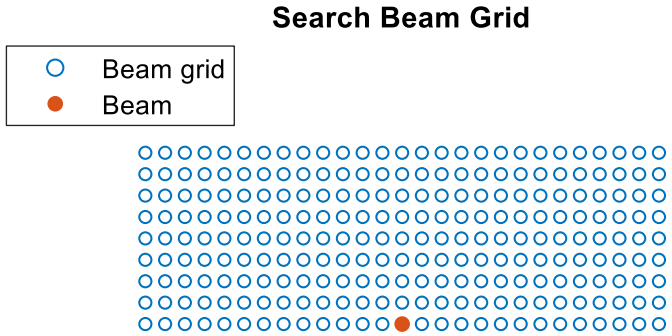


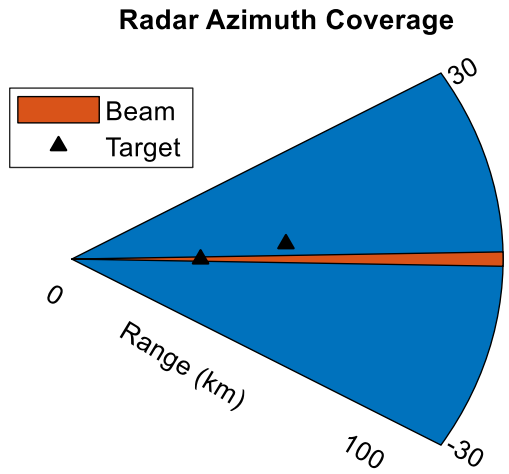


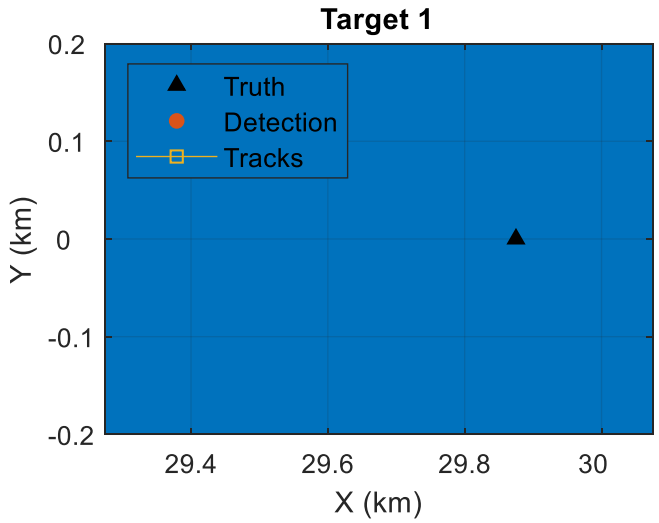
- Initially, all resources spent on search
- Once targets are detected, resources split 80% to 20% (search vs. track)
- Once second target moves farther away, resources freed up for search

Sensor Fusion and Tracking Toolbox ™
Phased Array System Toolbox ™

Target 1 Detected

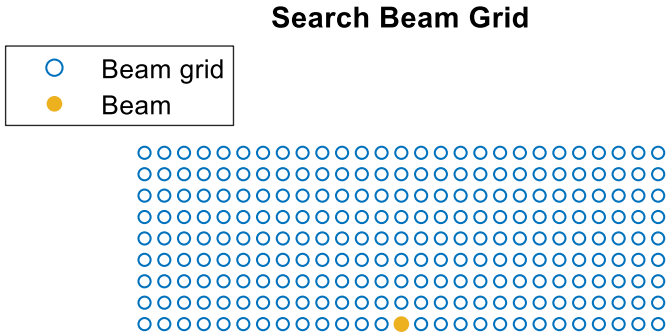


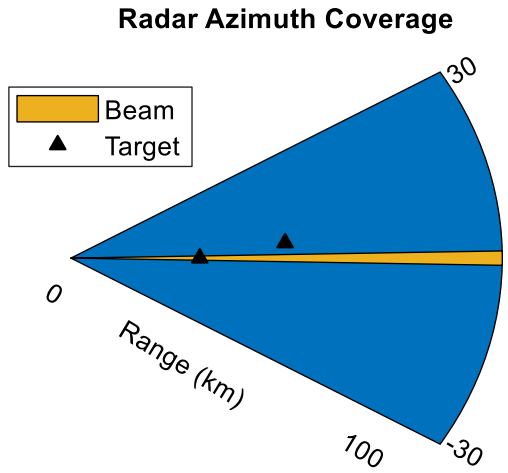


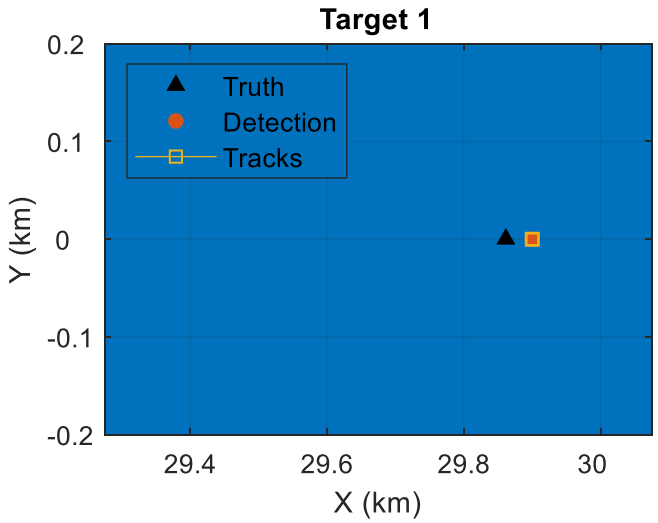



```
0.000000 sec:    Search   [-30.000000 0.000000]
0.010000 sec:    Search   [-27.692308 0.000000]
0.020000 sec:    Search   [-25.384615 0.000000]
0.030000 sec:    Search   [-23.076923 0.000000]
0.040000 sec:    Search   [-20.769231 0.000000]
0.050000 sec:    Search   [-18.461538 0.000000]
0.060000 sec:    Search   [-16.153846 0.000000]
0.070000 sec:    Search   [-13.846154 0.000000]
0.080000 sec:    Search   [-11.538462 0.000000]
0.090000 sec:    Search   [-9.230769 0.000000]
0.100000 sec:    Search   [-6.923077 0.000000]
0.110000 sec:    Search   [-4.615385 0.000000]
0.120000 sec:    Search   [-2.307692 0.000000]
0.130000 sec:    Search   [0.000000 0.000000] Target detected at 29900.
```

Detection Confirmed and Track 1 Created








```
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0.020000 sec:    Search   [-25.384615 0.000000]
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0.040000 sec:    Search   [-20.769231 0.000000]
0.050000 sec:    Search   [-18.461538 0.000000]
0.060000 sec:    Search   [-16.153846 0.000000]
0.070000 sec:    Search   [-13.846154 0.000000]
0.080000 sec:    Search   [-11.538462 0.000000]
0.090000 sec:    Search   [-9.230769 0.000000]
0.100000 sec:    Search   [-6.923077 0.000000]
0.110000 sec:    Search   [-4.615385 0.000000]
0.120000 sec:    Search   [-2.307692 0.000000]
0.130000 sec:    Search   [0.000000 0.000000] Target detected at 29900.000000 m
0.140000 sec:    Confirm  [-0.000586 -0.000034]   Created track 1 at 29900.000000 m
```
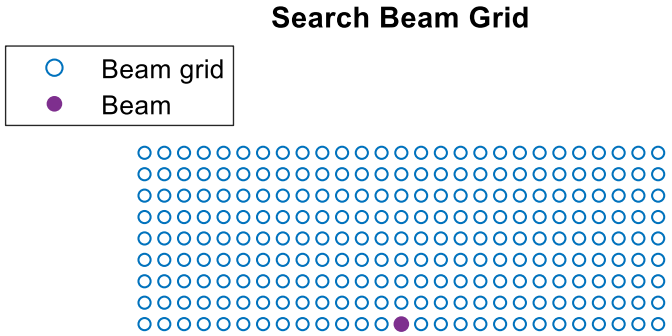
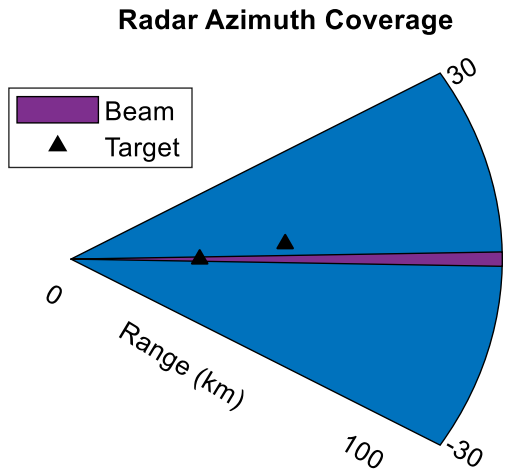
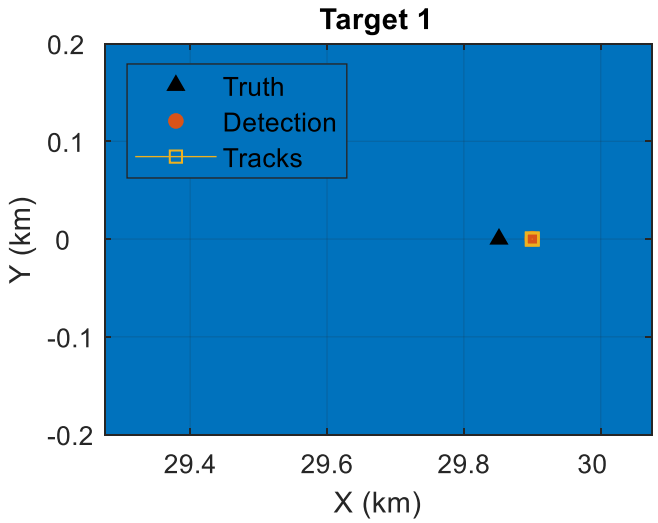
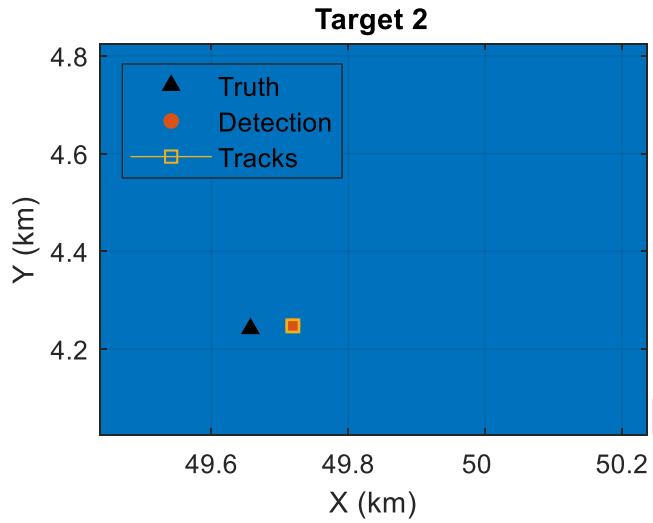

Track 1 Updated










```
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0.010000 sec:   Search   [-27.692308 0.000000]
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0.030000 sec:   Search   [-23.076923 0.000000]
0.040000 sec:   Search   [-20.769231 0.000000]
0.050000 sec:   Search   [-18.461538 0.000000]
0.060000 sec:   Search   [-16.153846 0.000000]
0.070000 sec:   Search   [-13.846154 0.000000]
0.080000 sec:   Search   [-11.538462 0.000000]
0.090000 sec:   Search   [-9.230769 0.000000]
0.100000 sec:   Search   [-6.923077 0.000000]
0.110000 sec:   Search   [-4.615385 0.000000]
0.120000 sec:   Search   [-2.307692 0.000000]
0.130000 sec:   Search   [0.000000 0.000000] Target detected at 29900.000000 m
0.140000 sec:   Confirm  [-0.000586 -0.000034]   Created track 1 at 29900.000000 m
0.150000 sec:   Search   [2.307692 0.000000]
0.160000 sec:   Search   [4.615385 0.000000] Target detected at 49900.000000 m
0.170000 sec:   Confirm  [4.881676 0.000739] Created track 2 at 49900.000000 m
0.180000 sec:   Search   [6.923077 0.000000]
0.190000 sec:   Search   [9.230769 0.000000]
0.200000 sec:   Search   [11.538462 0.000000]
0.210000 sec:   Search   [13.846154 0.000000]
0.220000 sec:   Search   [16.153846 0.000000]
0.230000 sec:   Search   [18.461538 0.000000]
0.240000 sec:   Track    [-0.000399 0.000162]    Track 1 at 29900.000000 m>>
```
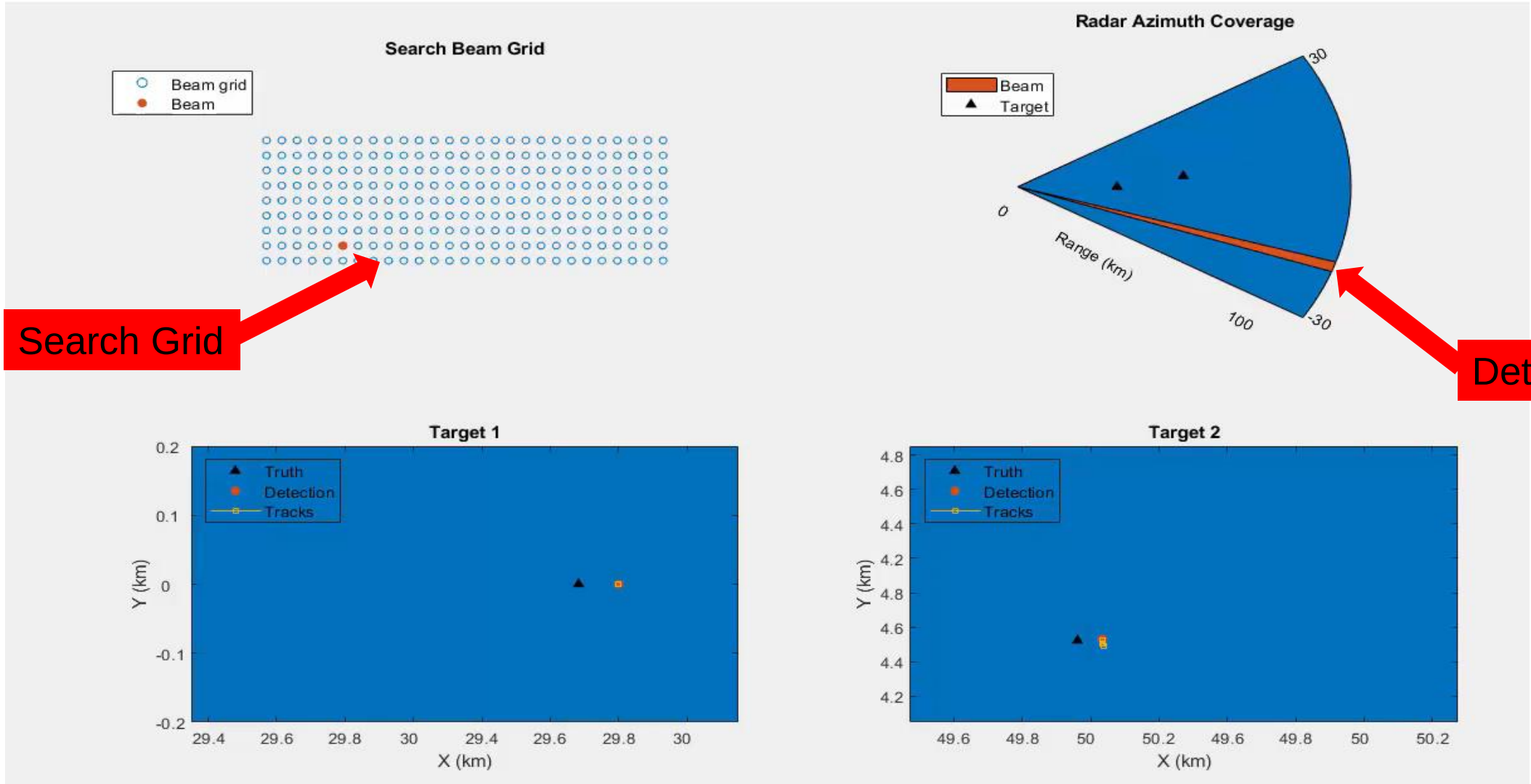

Integrate trackers into Larger Radar System Simulation



Search

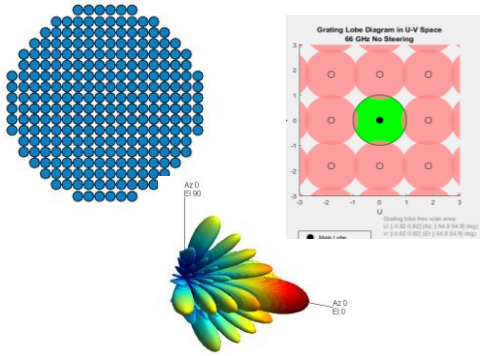
Track (confirm)

Track (update)

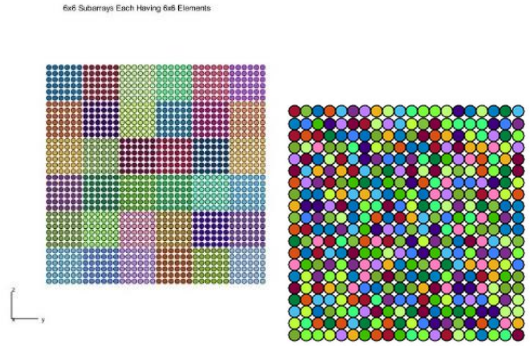
Radar System Design with MATLAB and Simulink

Antenna Toolbox ™
Phased Array System Toolbox ™

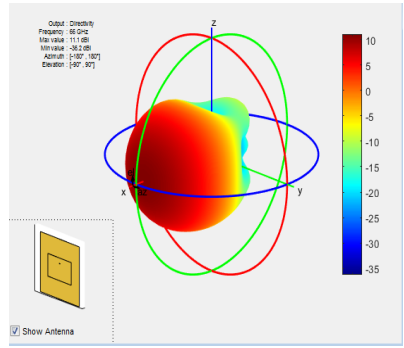
Design an array



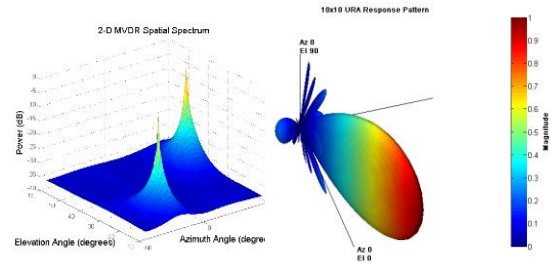
Design subarrays



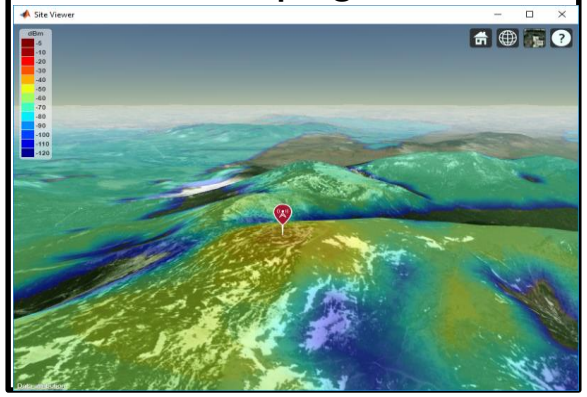
Import antenna patterns



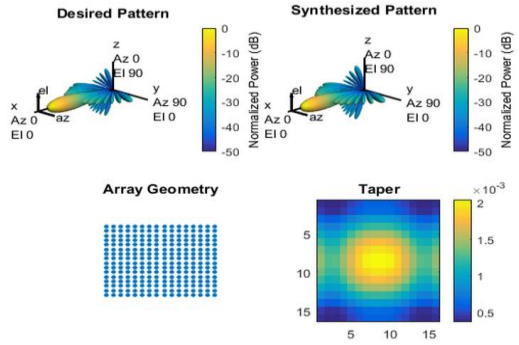
Spatial signal processing



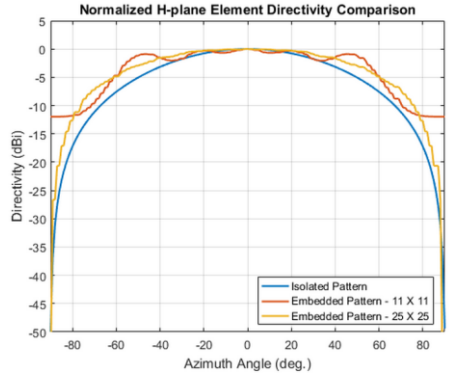
RF Propagation



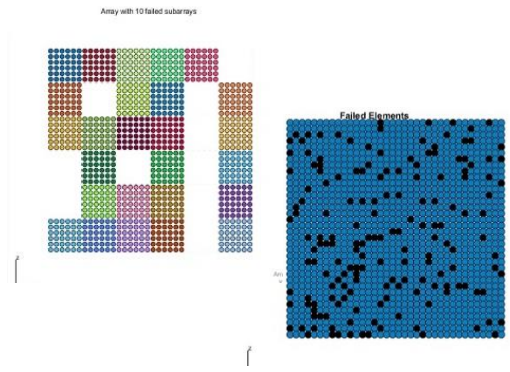
Synthesize arrays



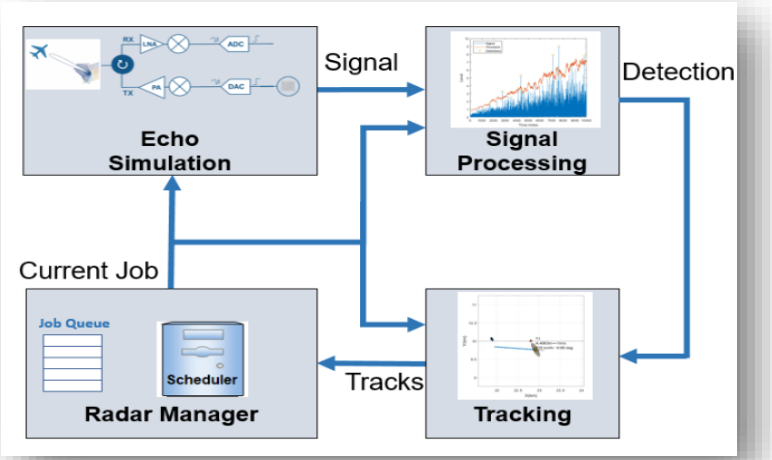
Model mutual coupling



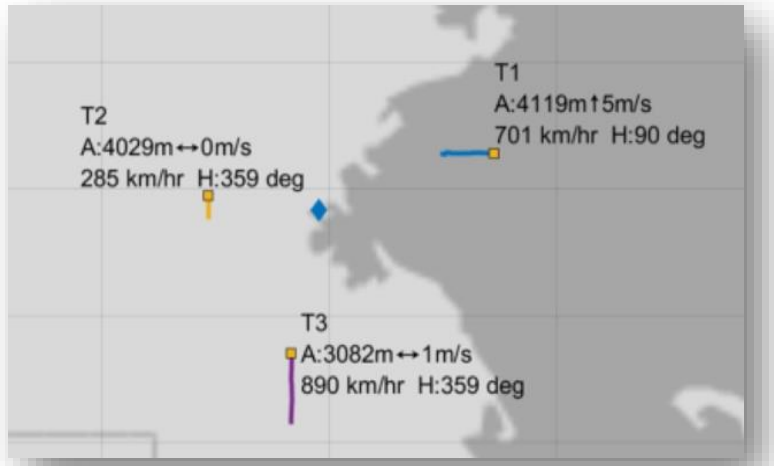
Model failures



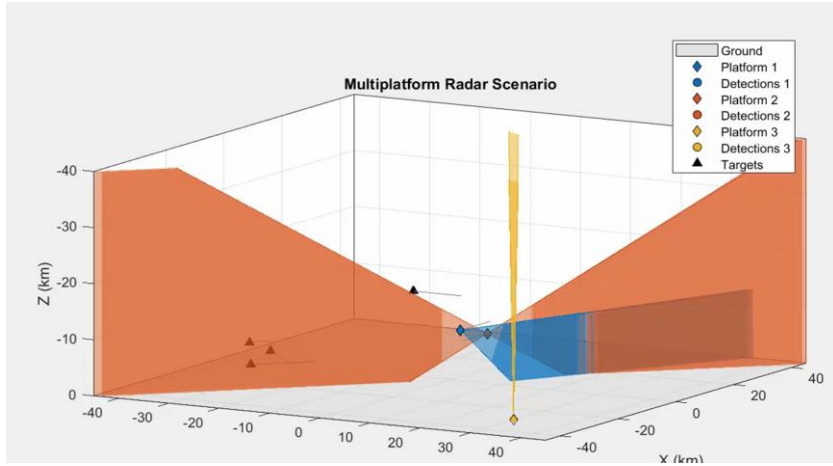
Agenda



- **Closed-loop Multifunction Radar**

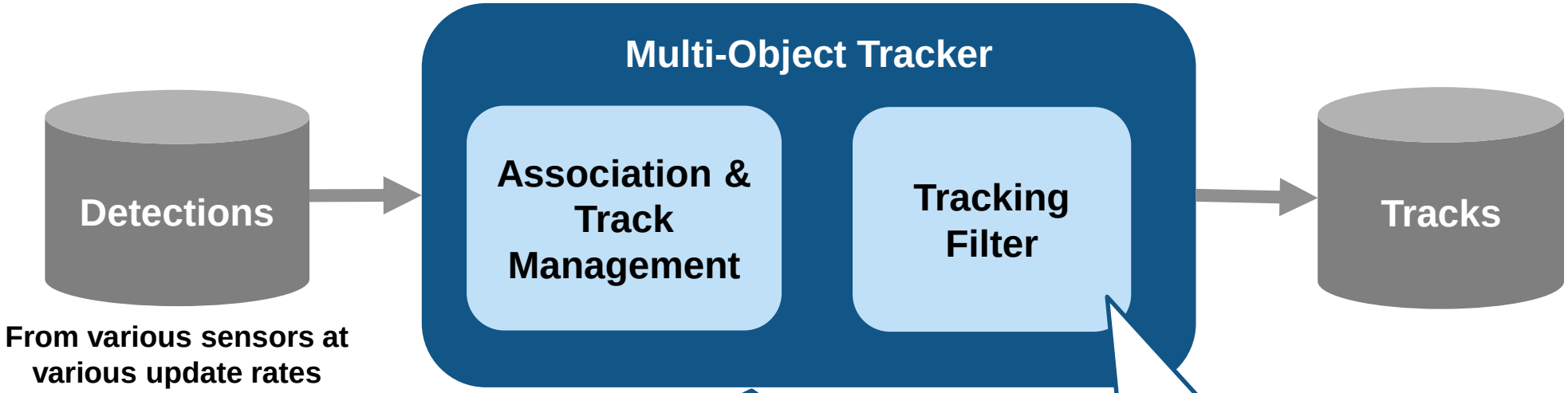


- **Target Tracking & Evaluation Metrics,**
- **Tracking Extended Objects & Large number of Objects**
- **Passive Sensor Angle Only Tracking**



- **Multisensor Detection Generation & Fusion**
- **Localization**

Design multi-object trackers



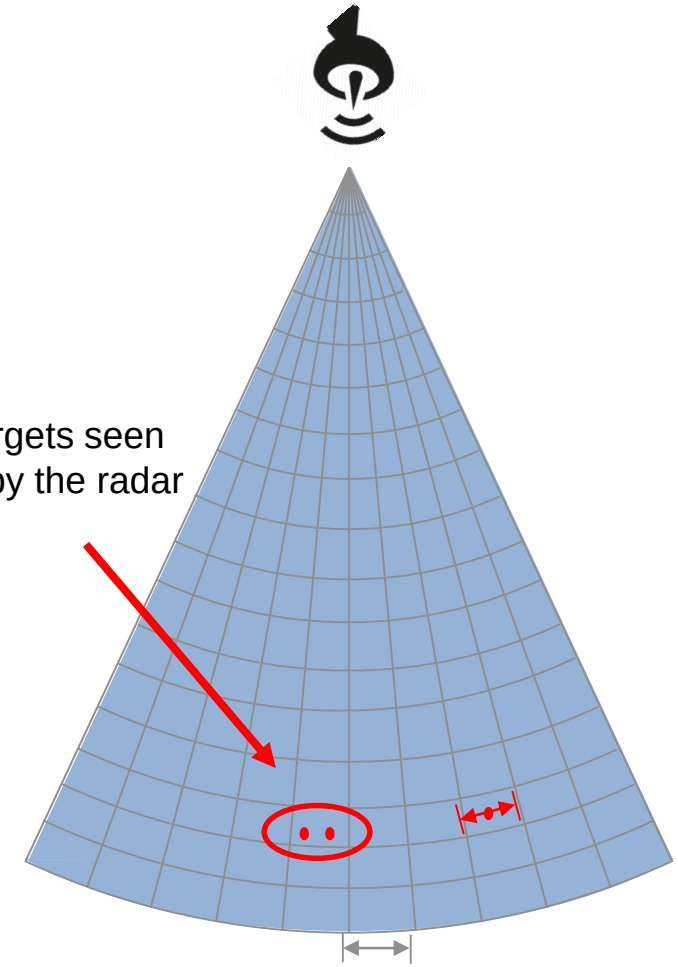
- Global Nearest Neighbor (GNN) tracker
- Joint Probabilistic Data Association (JPDA) tracker
- Track-Oriented Multi-Hypothesis Tracker (TOMHT)
- Probability Hypothesis Density (PHD) tracker

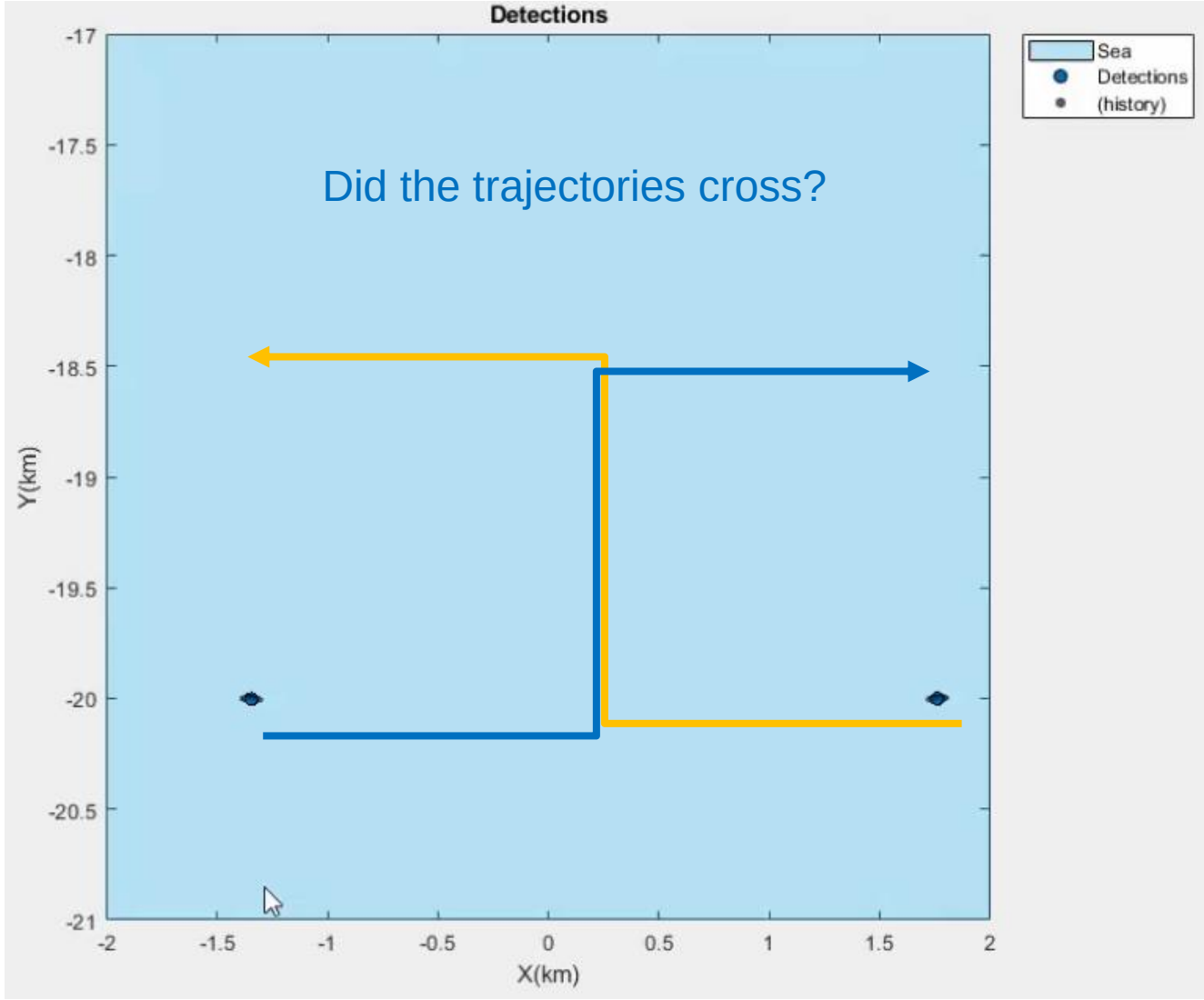
- Linear, extended, and unscented Kalman filters
- Particle, Gaussian-sum, IMM filters

Sensor Fusion and Tracking Toolbox™

Phased Array System Toolbox ™

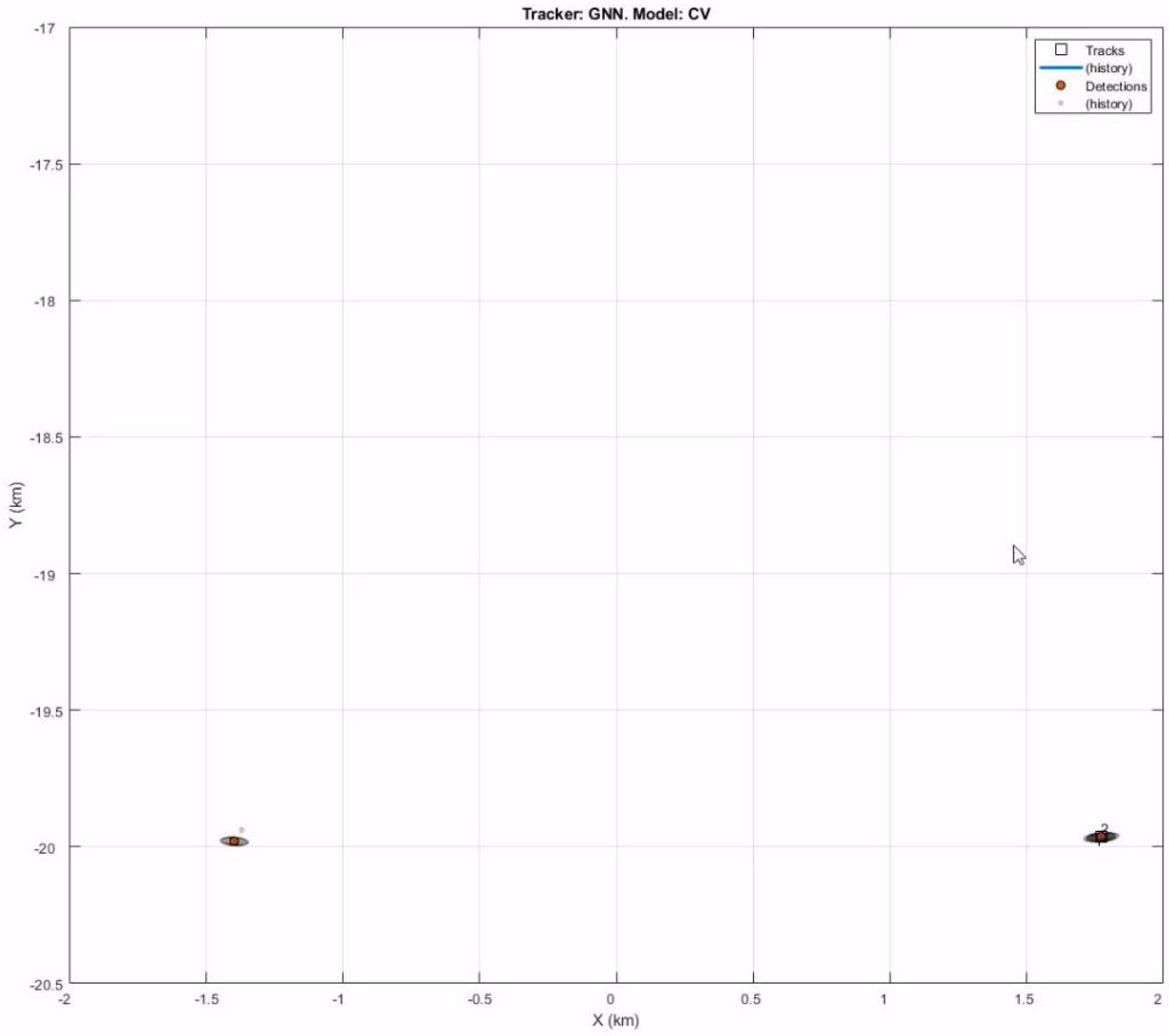
Performing What-If Analysis



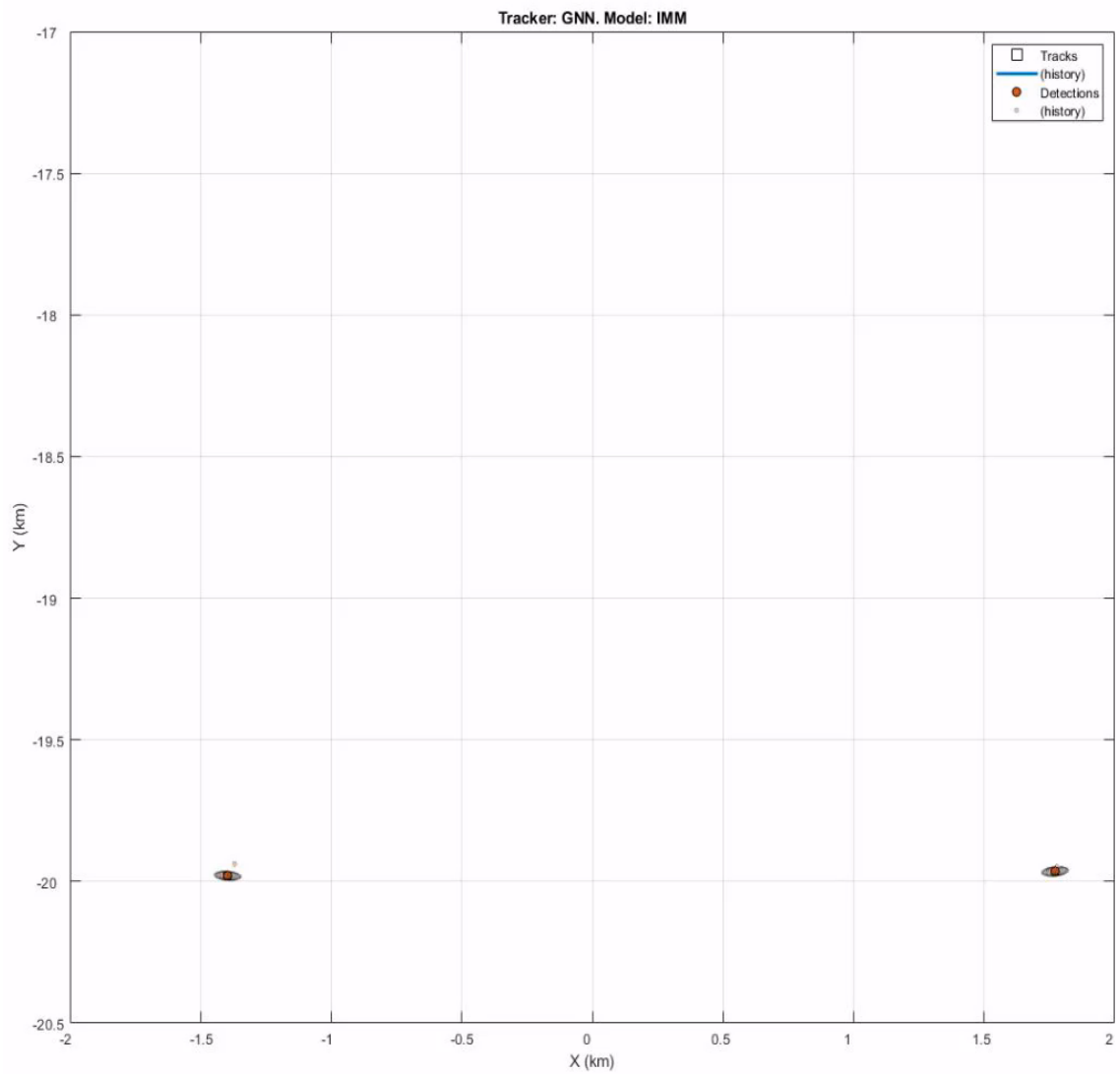


Performing What-If Analysis: Same Tracker, Different Model

GNN with CV



GNN with IMM



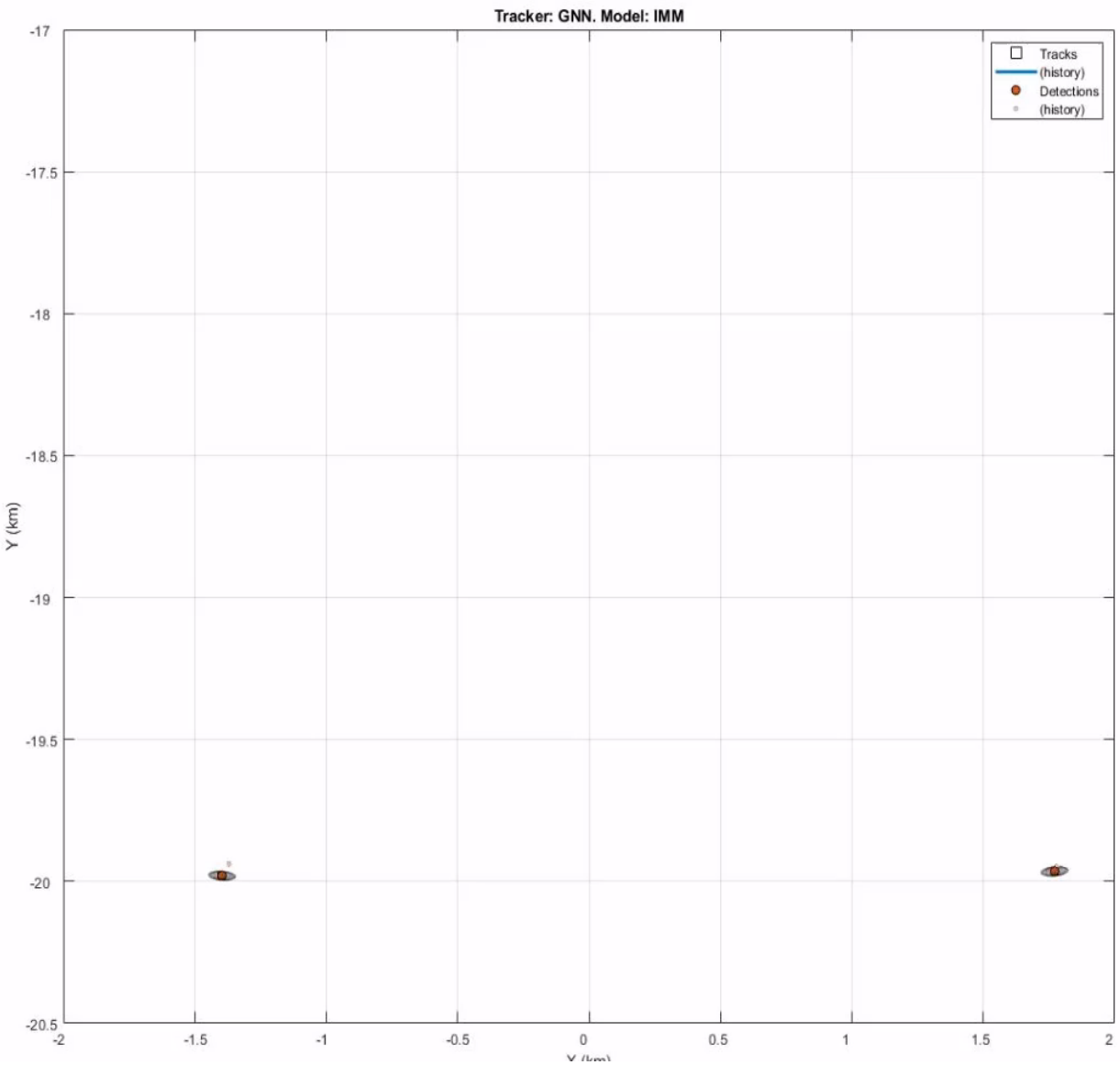
Performing What-If Analysis: Same Tracker, Different Model

```
tracker = trackerGNN( ...
  'FilterInitializationFcn',@initCVFilter,...
  'MaxNumTracks', numTracks, ...
  'MaxNumSensors', 1, ...
  'AssignmentThreshold',gate, ...
  'TrackLogic', 'Score', ...
  'DetectionProbability', pd, ...
  'FalseAlarmRate', far, ...
  'Volume', vol, 'Beta', beta);
```

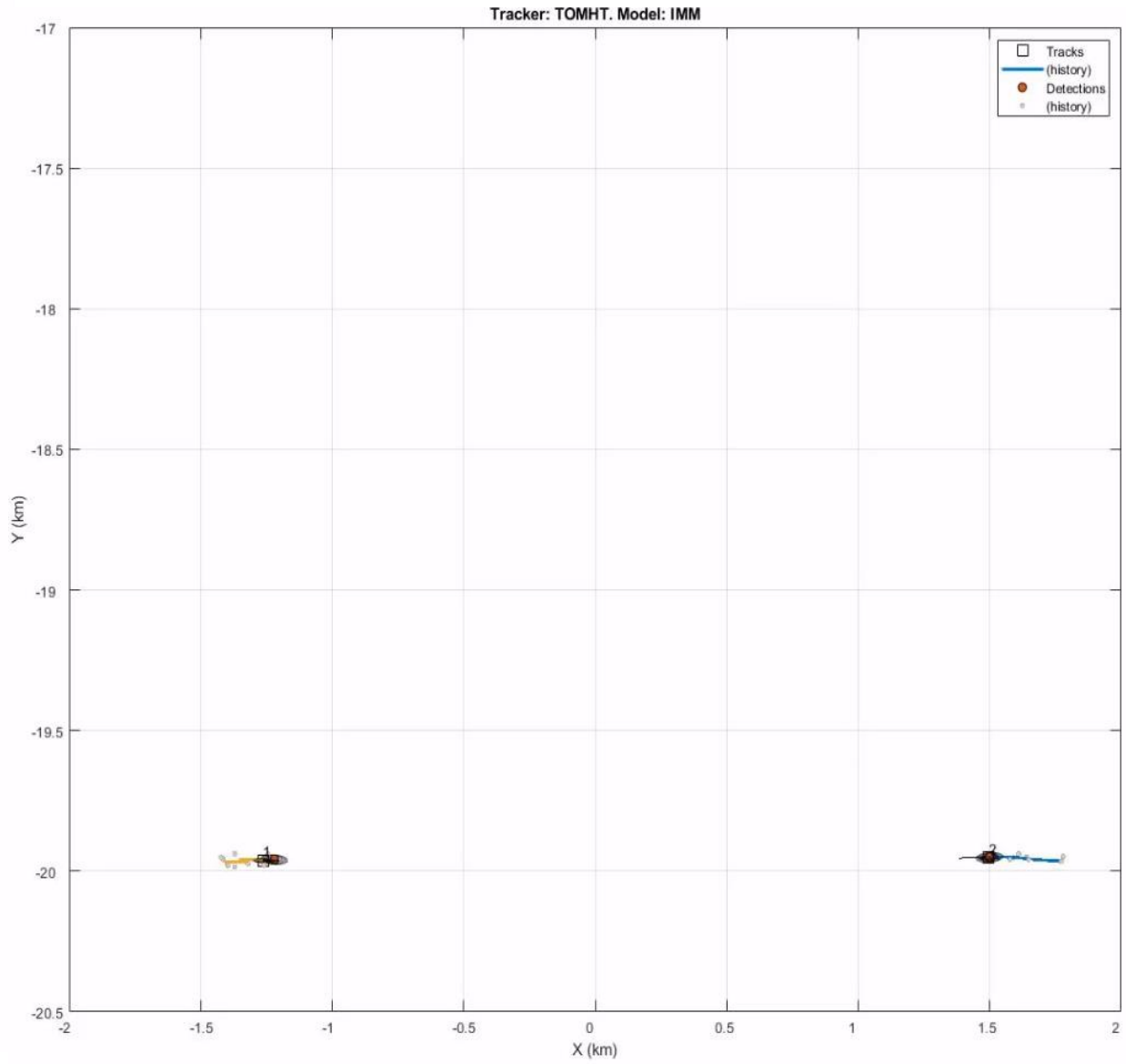
```
tracker = trackerGNN( ...
  'FilterInitializationFcn',@initIMMFilter,...
  'MaxNumTracks', numTracks, ...
  'MaxNumSensors', 1, ...
  'AssignmentThreshold',gate, ...
  'TrackLogic', 'Score', ...
  'DetectionProbability', pd, ...
  'FalseAlarmRate', far, ...
  'Volume', vol, 'Beta', beta);
```

Performing What-If Analysis: Different Trackers, Same Model

GNN with IMM



TOMHT with IMM



Performing What-If Analysis: Different Trackers, Same Model

```
tracker = trackerGNN( ...
  'FilterInitializationFcn',@initIMMFilter,...
  'MaxNumTracks', numTracks, ...
  'MaxNumSensors', 1, ...
  'AssignmentThreshold',gate, ...
  'TrackLogic', 'Score', ...
  'DetectionProbability', pd, ...
  'FalseAlarmRate', far, ...
  'Volume', vol, 'Beta', beta);
```

```
tracker = trackerTOMHT( ...

'FilterInitializationFcn',@initIMMFilter,..
.
  'MaxNumTracks', numTracks, ...
  'MaxNumSensors', 1, ...
  'AssignmentThreshold',[0.2,1,1]*gate, ...
  'TrackLogic', 'Score', ...
  'DetectionProbability', pd, ...
  'FalseAlarmRate', far, ...
  'Volume', vol, 'Beta', beta, ...
  'MaxNumHistoryScans', 10, ...
  'MaxNumTrackBranches', 5,...
  'NScanPruning', 'Hypothesis', ...
  'OutputRepresentation', 'Tracks');
```

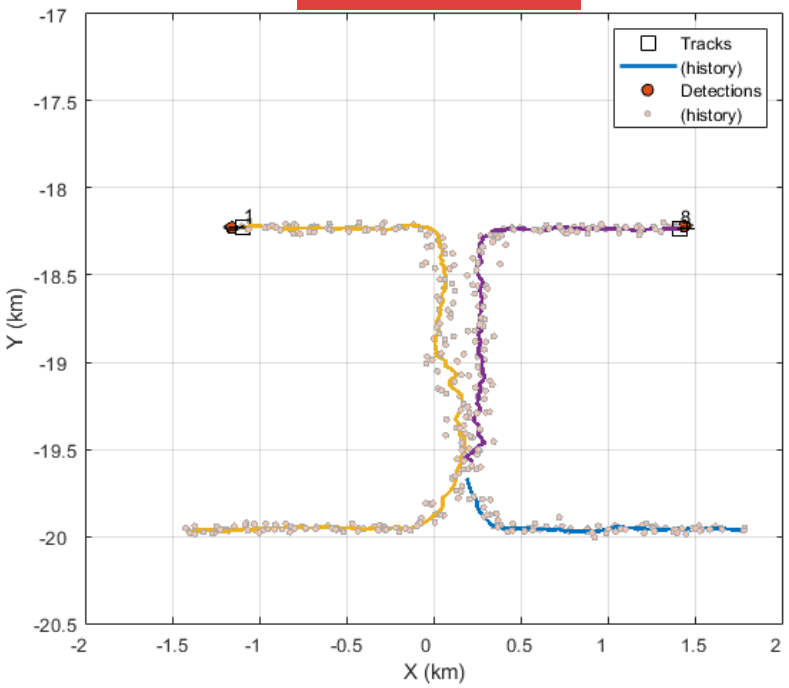
Comparing Trackers and Tracking Filters

False track
Dropped track

TrackID	AssignedTruthID	Surviving	TotalLength	DivergenceStatus
1	2	true	190	false
2	NaN	false	77	true
8	3	true	111	false

TruthID	AssociatedTrackID	TotalLength	BreakCount	EstablishmentLength
2	1	192	0	4
3	8	192	1	2

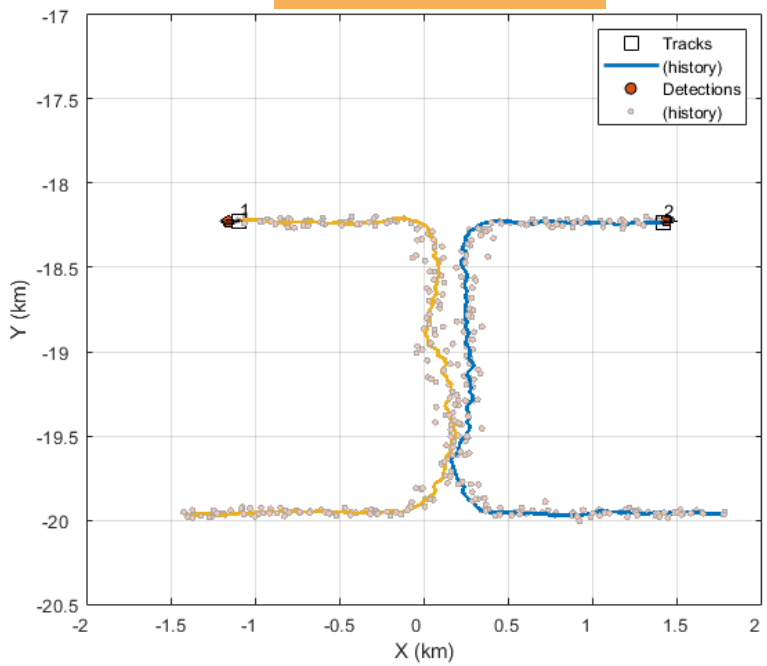
GNN with IMM



TrackID	AssignedTruthID	Surviving	TotalLength	DivergenceStatus
1	2	true	190	false
2	3	true	191	false

TruthID	AssociatedTrackID	TotalLength	BreakCount	EstablishmentLength
2	1	192	0	2
3	2	192	0	2

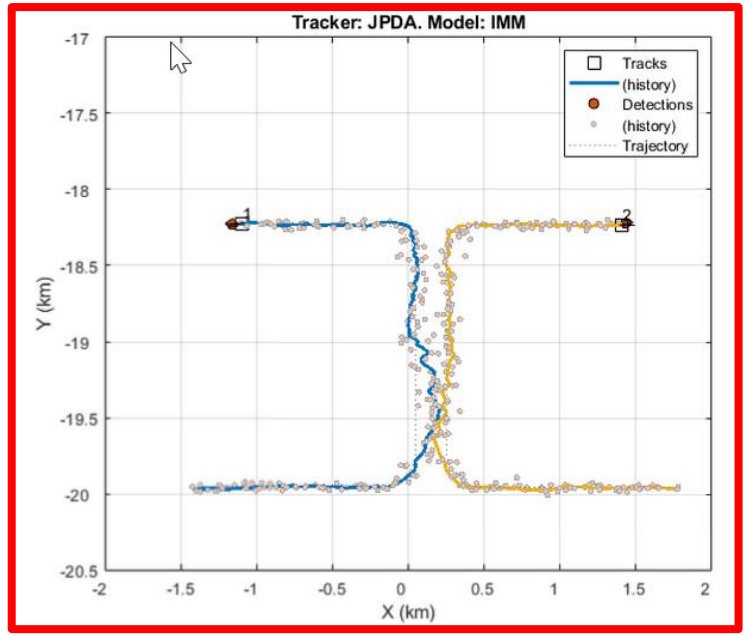
TOMHT with IMM



TrackID	AssignedTruthID	Surviving	TotalLength	DivergenceStatus
1	2	true	191	false
2	3	true	191	false

TruthID	AssociatedTrackID	TotalLength	BreakCount	EstablishmentLength
2	1	192	0	1
3	2	192	0	2

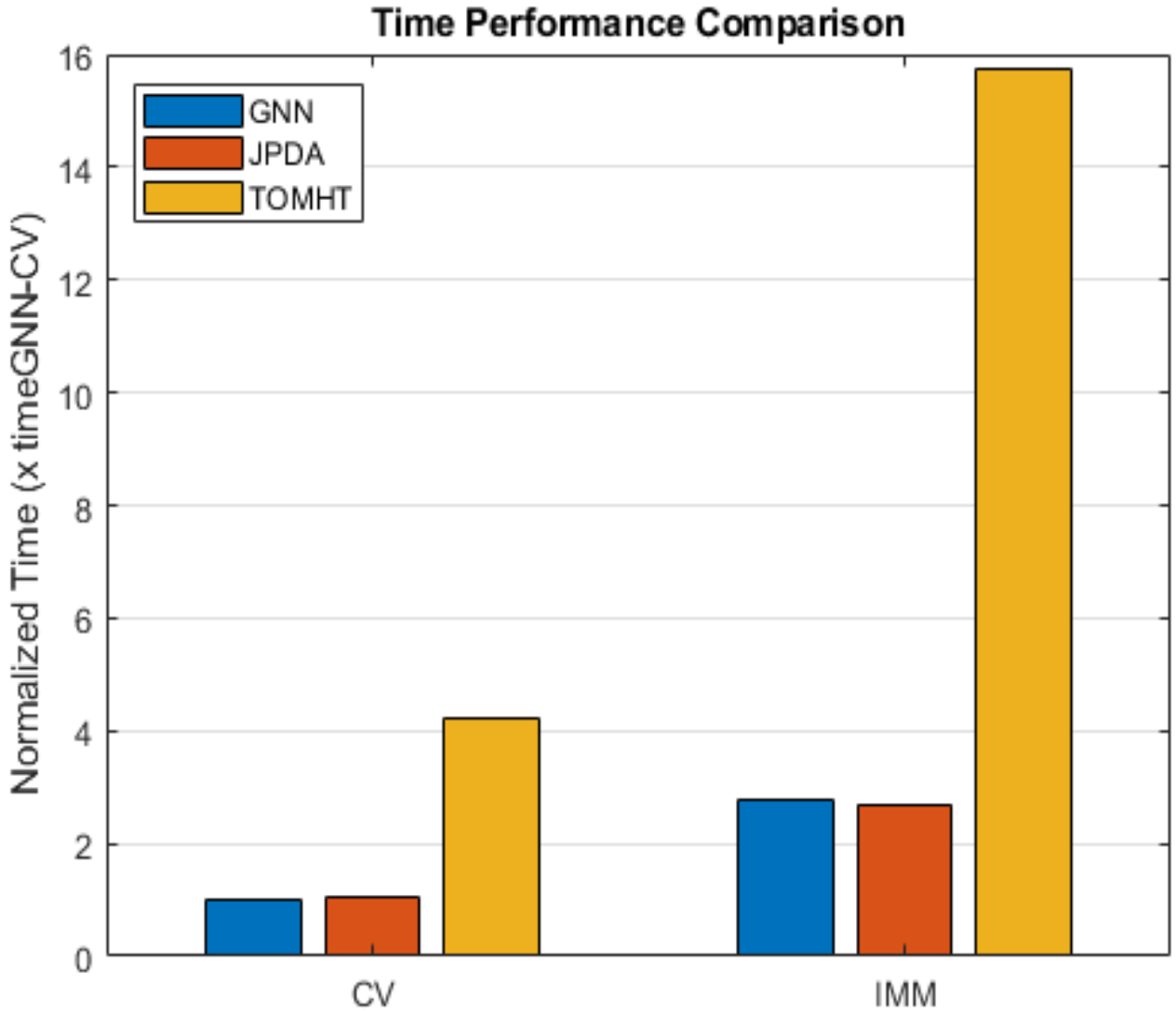
JPDA with IMM



Slower

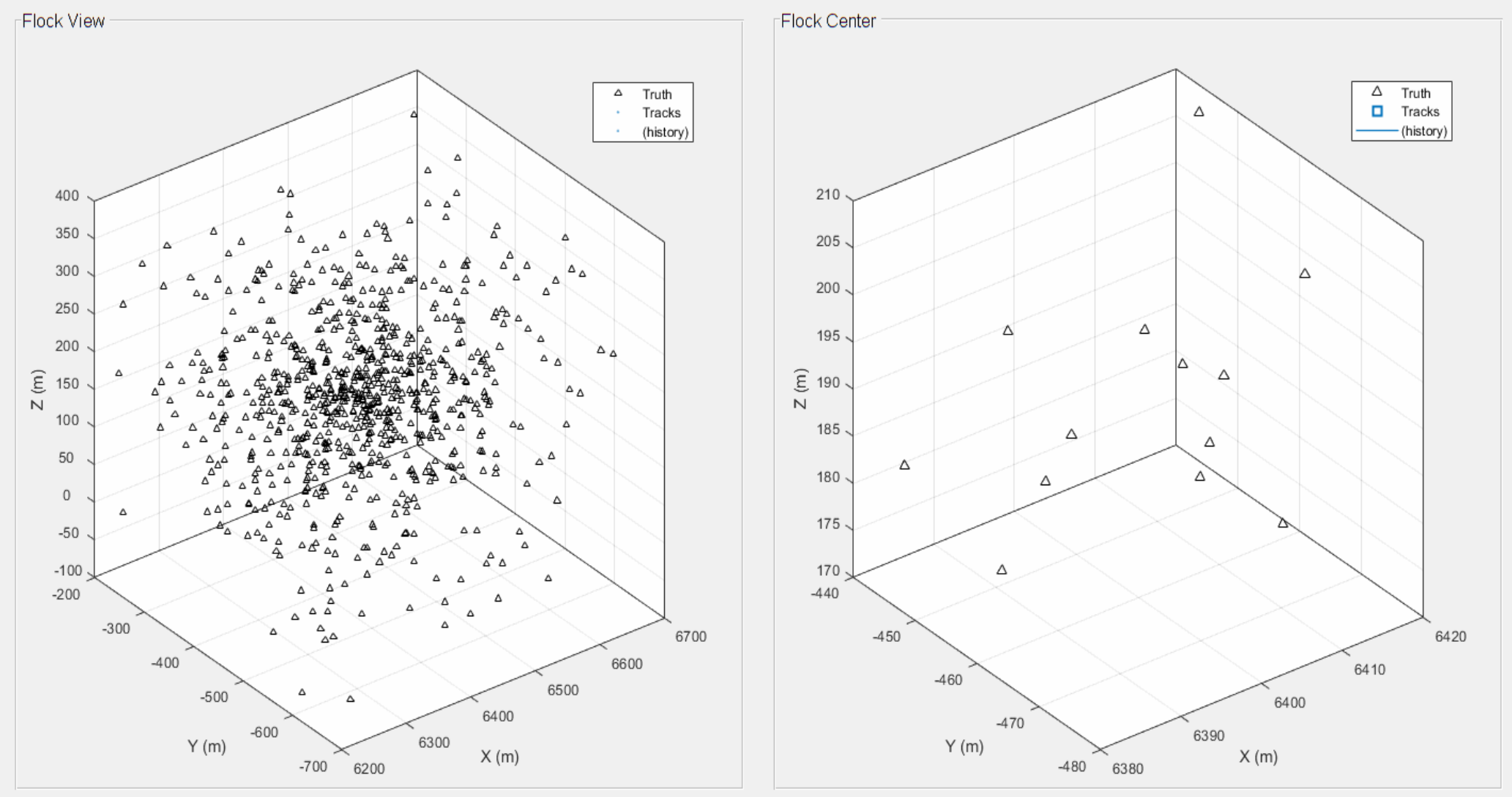
Faster

Tracker Performance Comparison

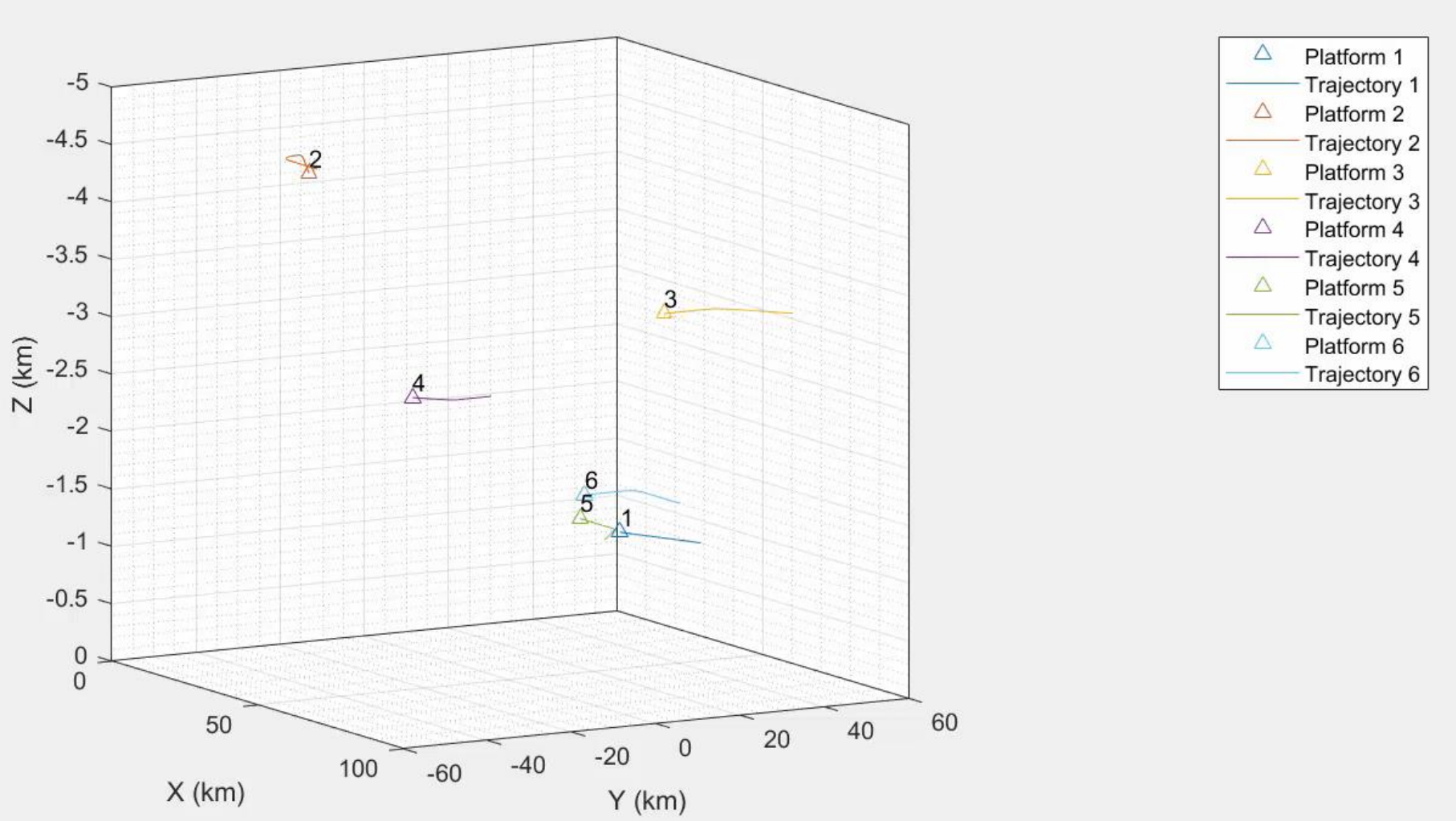


- GNN and JPDA can track the targets 5 to 6 times faster than MHT depending on the motion model
- The IMM motion model makes all three trackers run 3 to 4 times slower
- Tracker processing time varies differently depending on the scenario's number of target, density of false alarms, density of targets

Track Large Numbers of Objects (Efficiently)

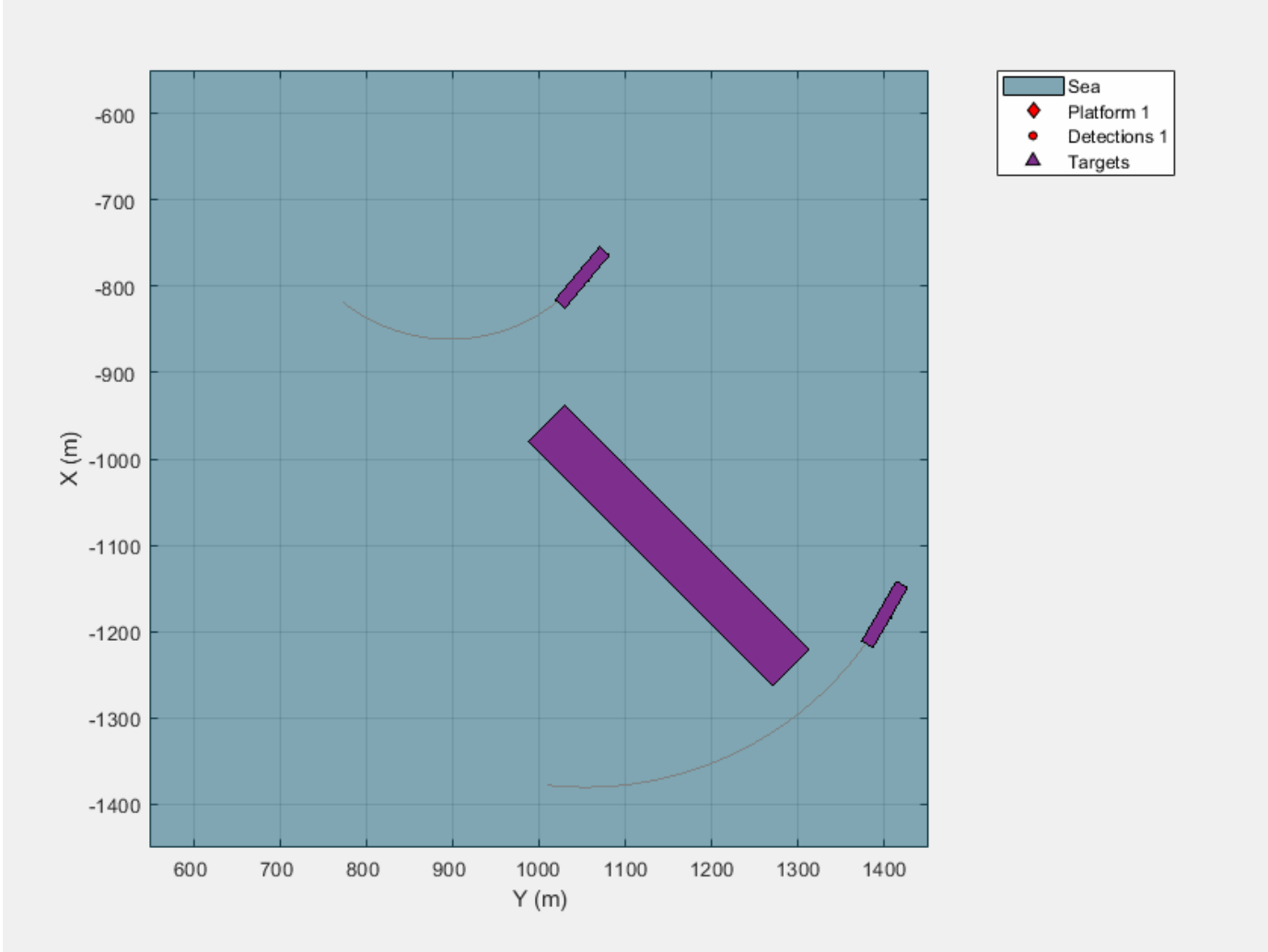


Test Tracker Performance on Pre-Built Benchmark Trajectories



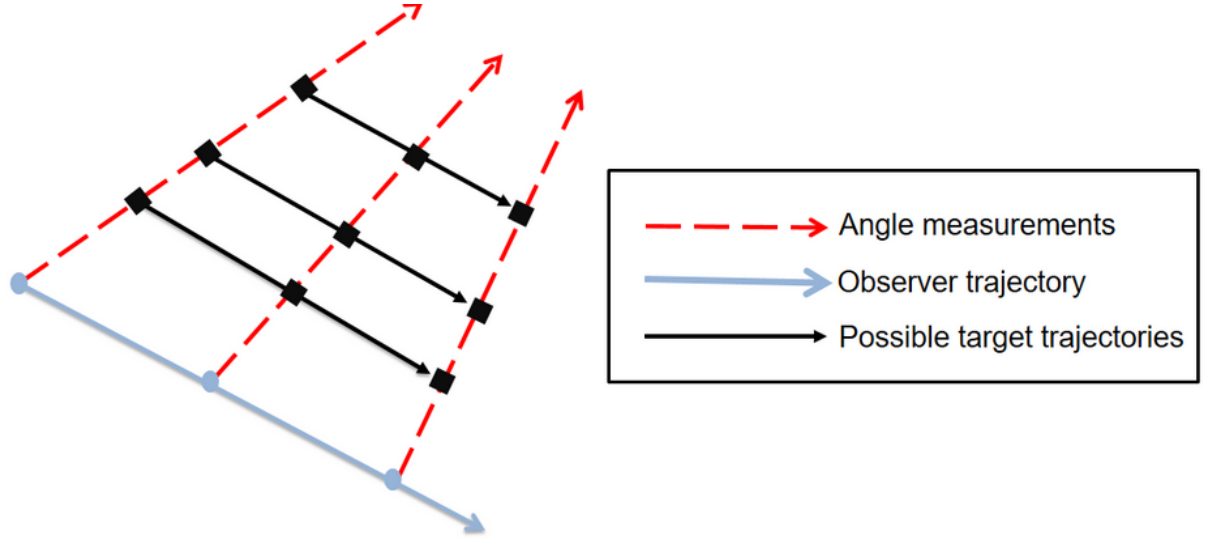
Track Extended Objects with Marine Radar

- Estimate position, velocity, size and orientation
- Maintain tracks through occlusions

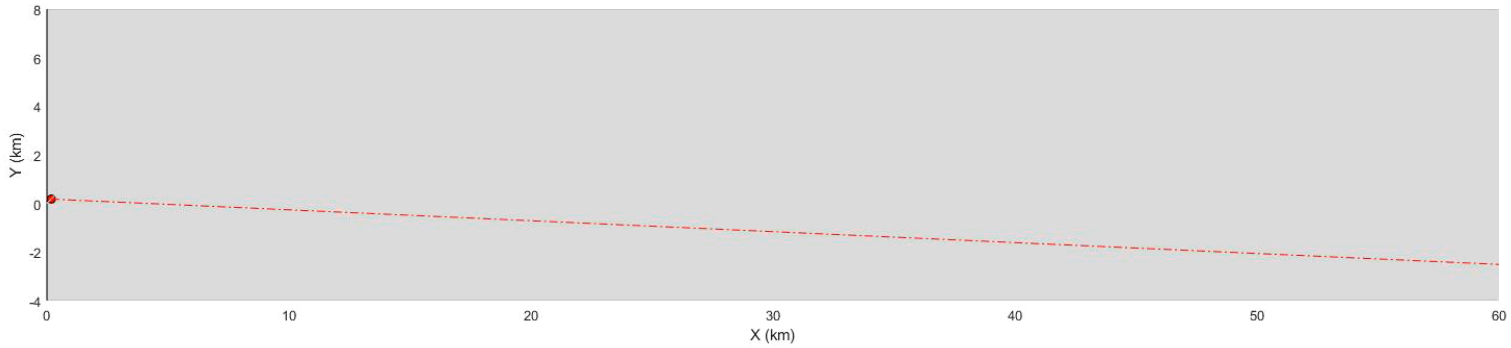


Challenges of Passive Ranging Using a Single Maneuvering Sensor

Sensor must out-maneuver the target



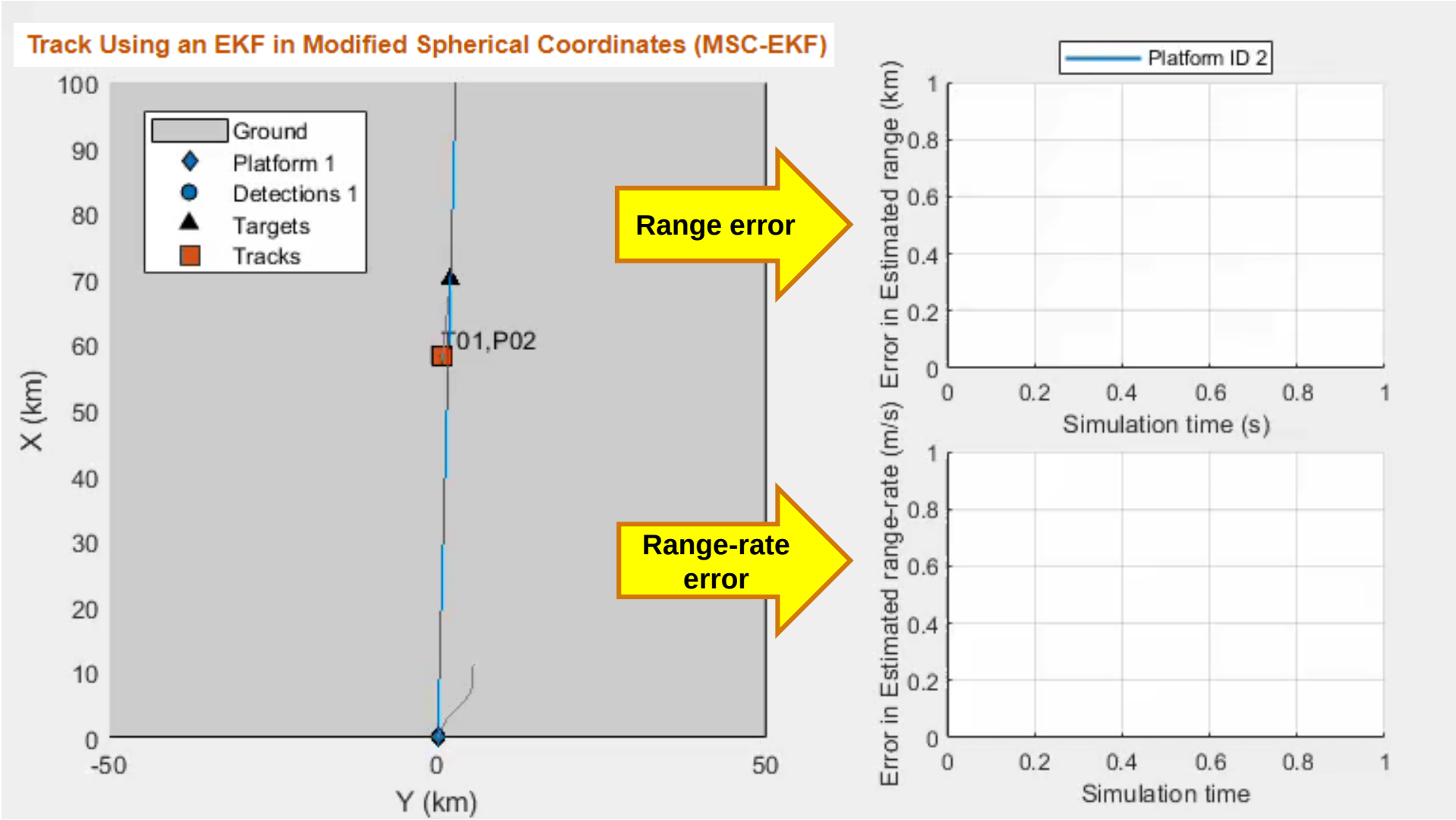
ESM (RWR), EO/IR, or sonar sensor



Target

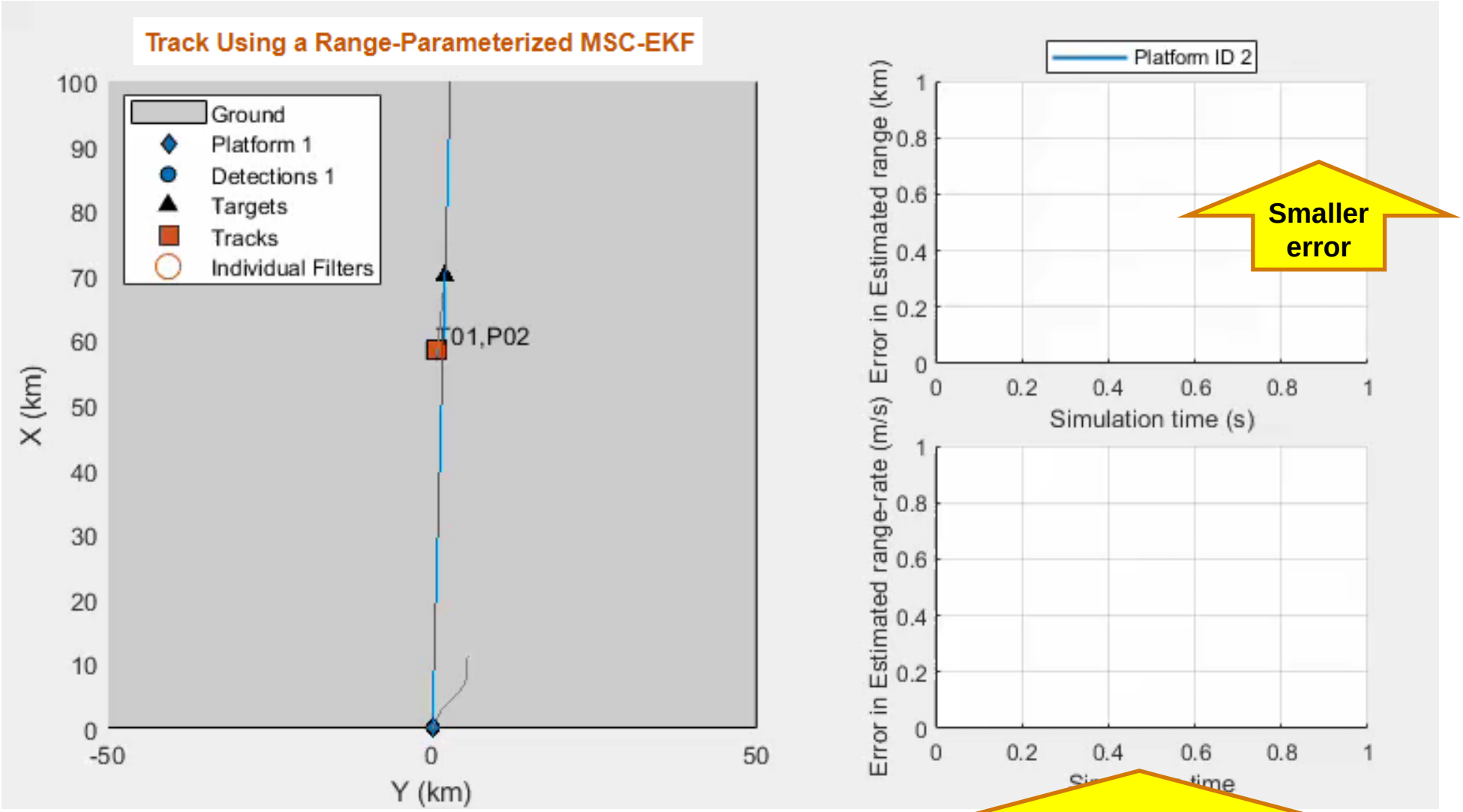
Passive Ranging Using a Single Maneuvering Sensor

MSC or cartesian coordinates?



Tune and Compare Passive Ranging Trackers with Error Metrics

Range-parameterized MSC-EKF converges faster than single MSC-EKF



Flexible Workflows Ease Adoption: Wholesale or Piecemeal

Recorded Sensor Data

Scenario Definition and Sensor Simulation

Ownship Trajectory Generation → INS Sensor Simulation

Actors/ Platforms → Radar, IR, & Sonar Sensor Simulation

Documented Interface for detections

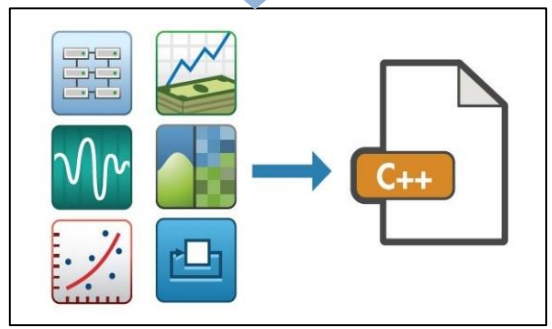
Algorithms

GNN,TOMHT, JPDA ,PHD etc..

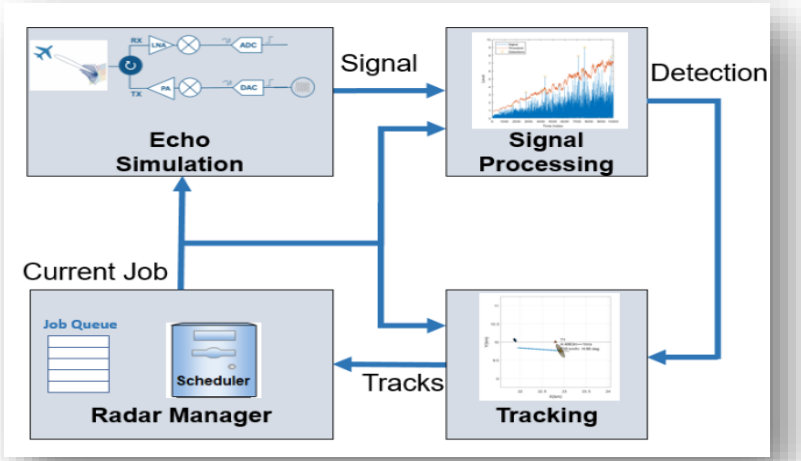
Documented Interface for tracks

Visualization & Metrics

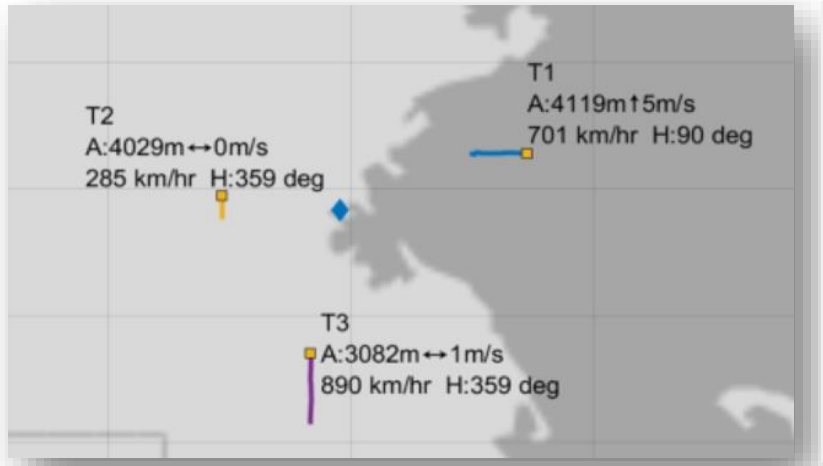
Generate C/C++ code **with MATLAB® Coder™**



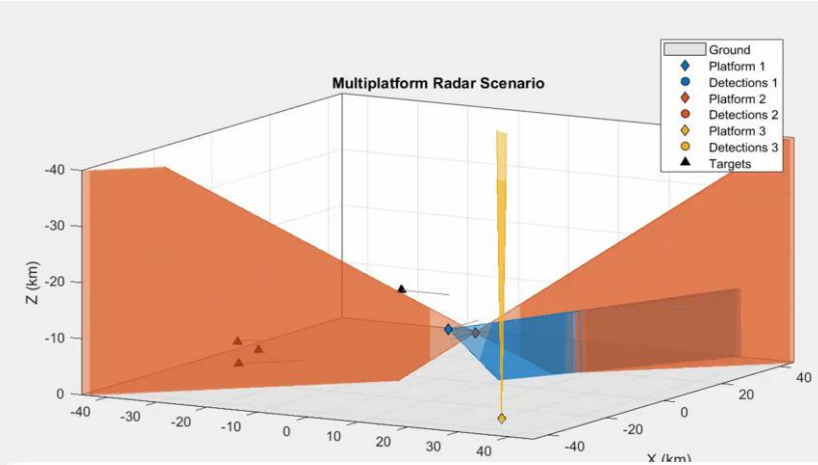
Agenda



- **Closed-loop Multifunction Radar**



- **Target Tracking & Evaluation Metrics,**
- **Tracking Extended Objects & Large number of Objects**
- **Passive Sensor Angle Only Tracking**



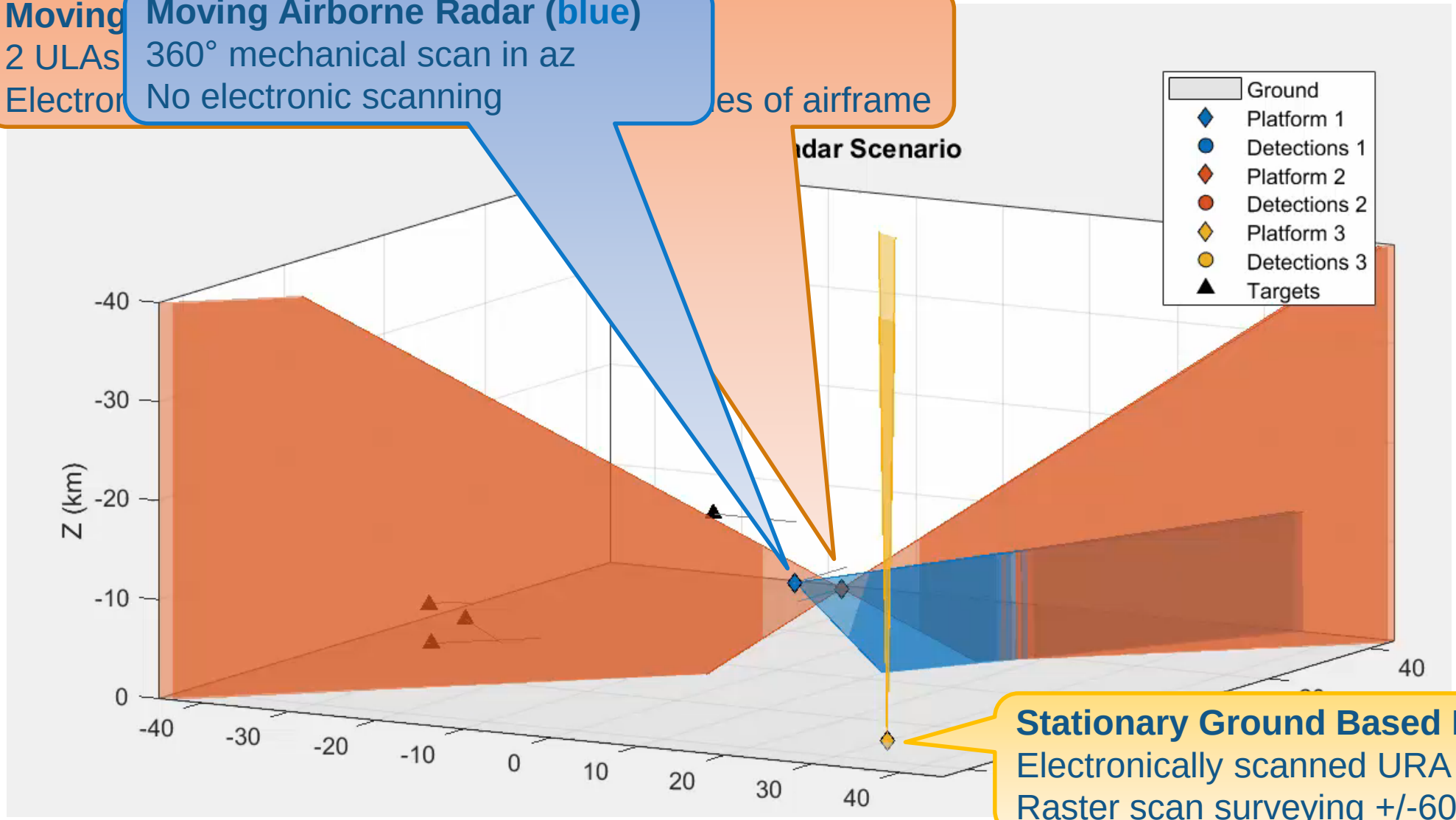
- **Multisensor Detection Generation & Fusion**
- **Localization**

Multiplatform Detection Generation and Fusion

Moving
2 ULAs
Electron

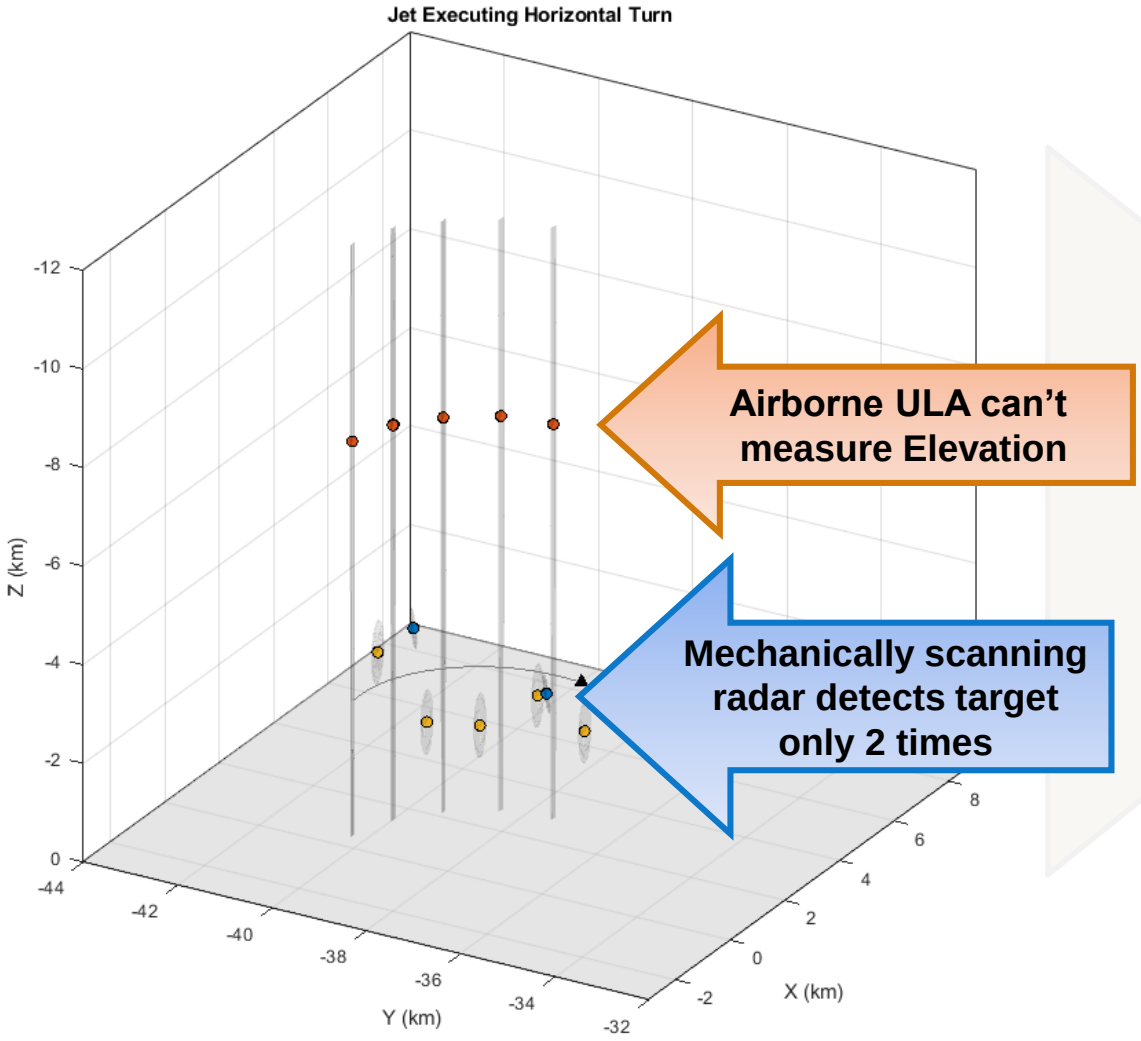
Moving Airborne Radar (blue)
360° mechanical scan in az
No electronic scanning

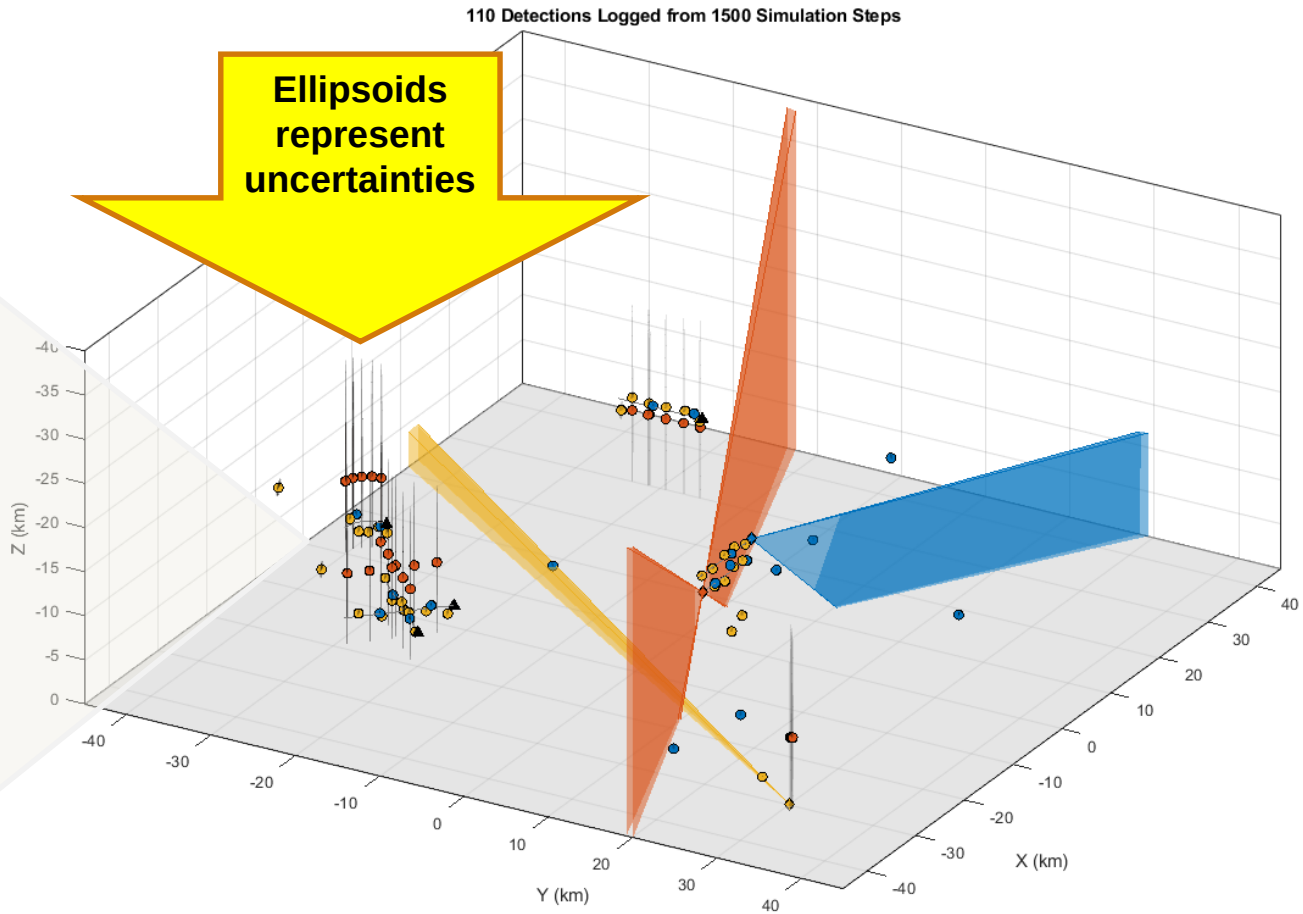
es of airframe



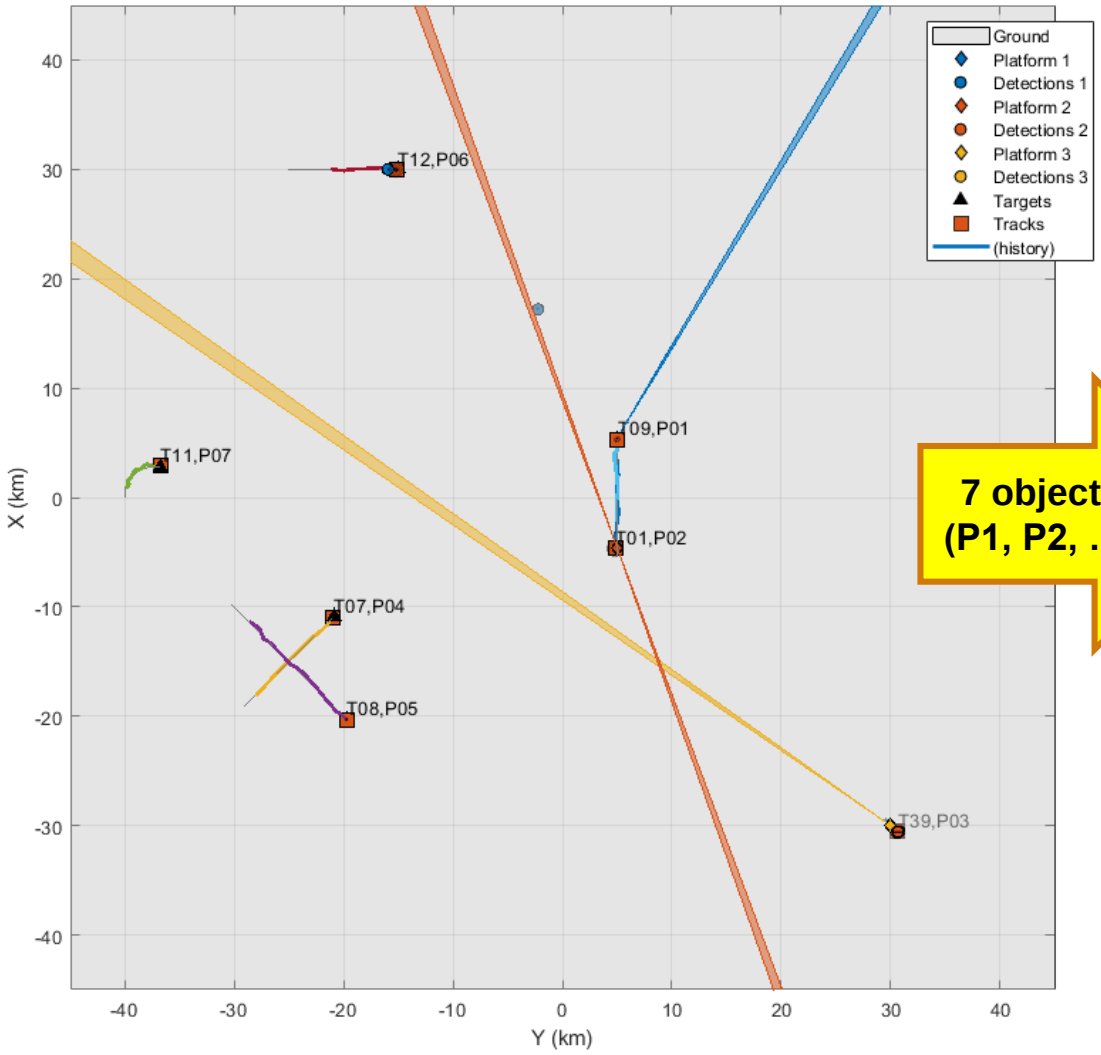
Stationary Ground Based Radar (yellow)
Electronically scanned URA
Raster scan surveying +/-60° az and -20 to 0° el

Visualize Detections and Measurement Uncertainties

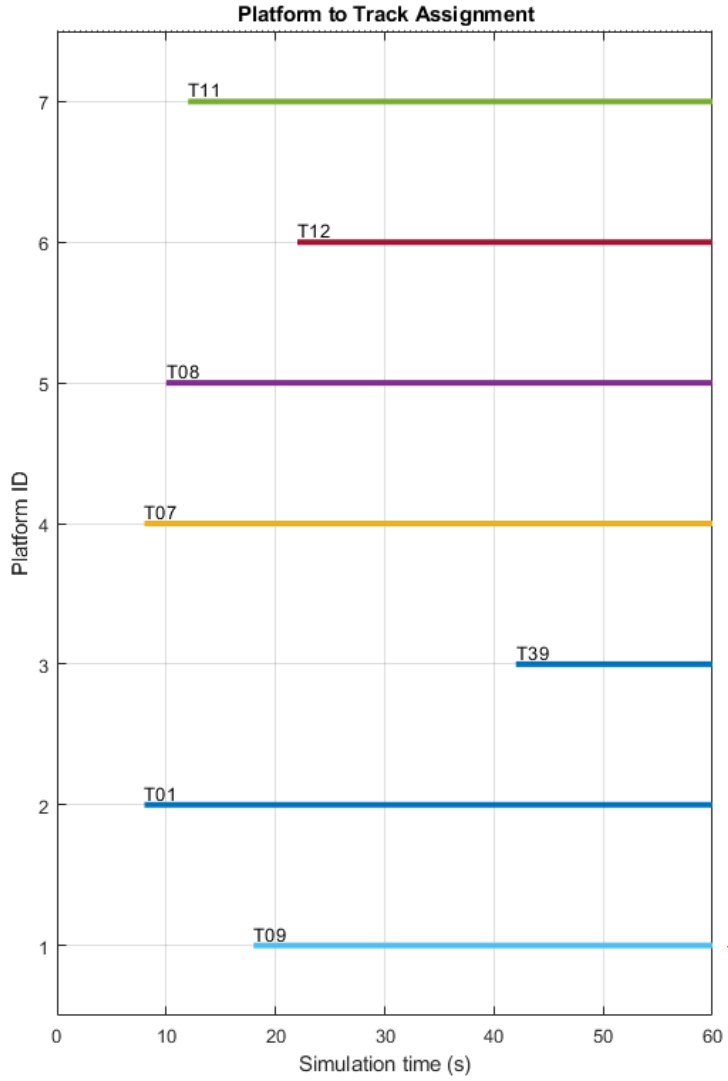




Tune and Compare Trackers with Assignment Metrics



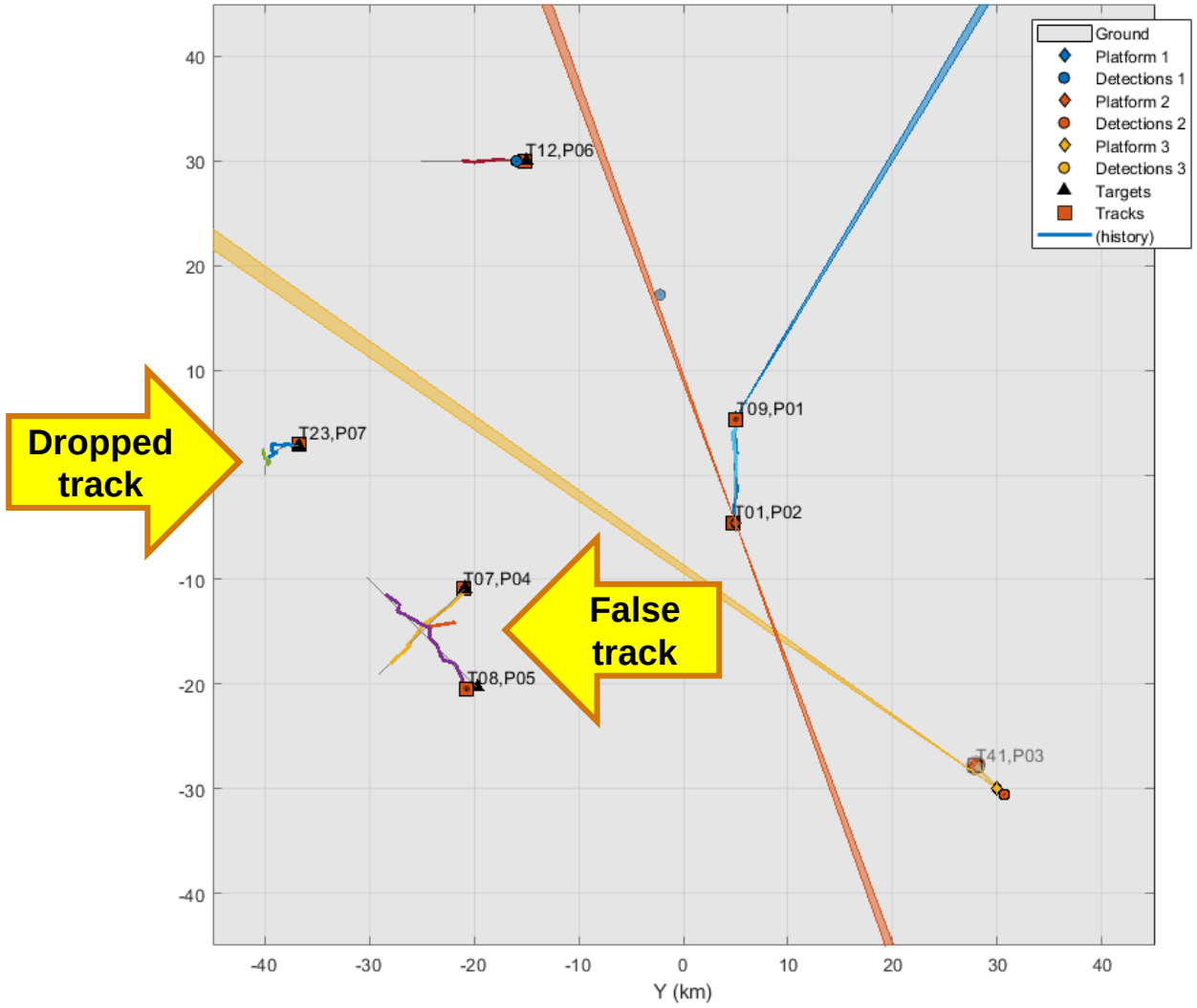
7 objects (P1, P2, …)

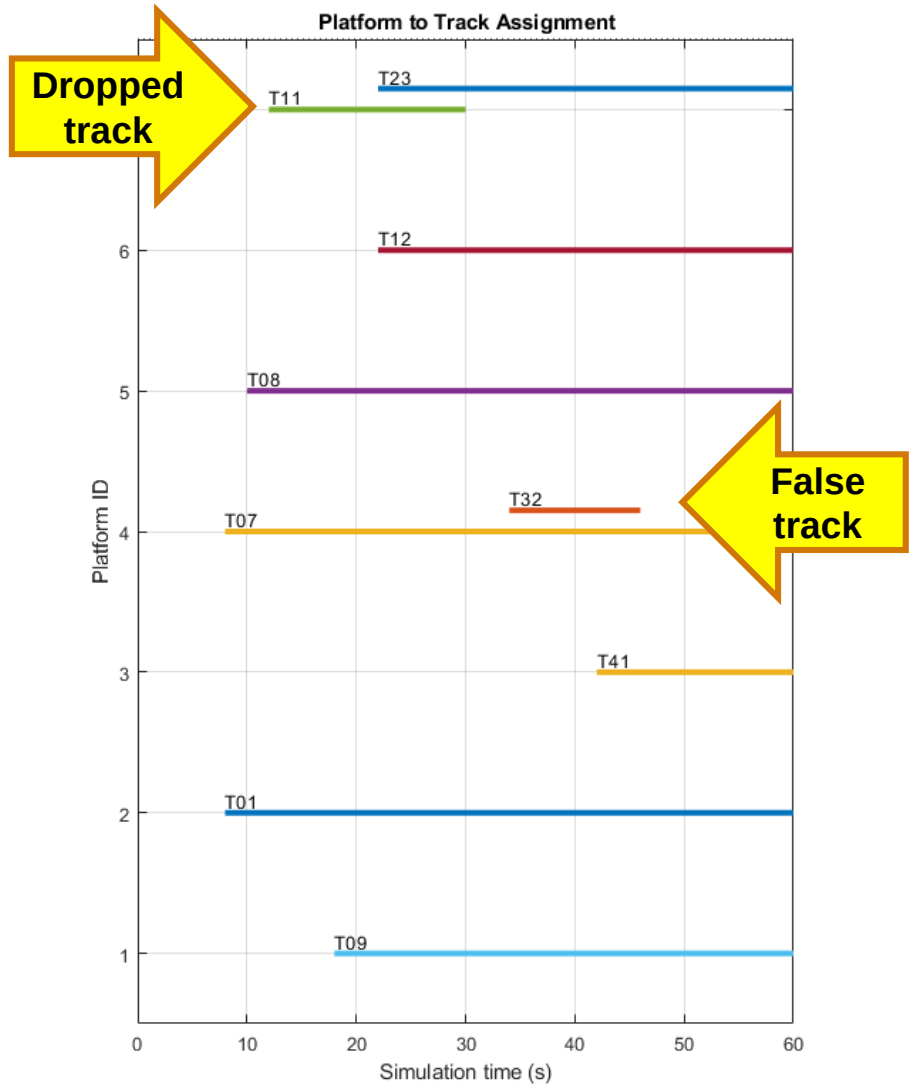


Track T09 for P1

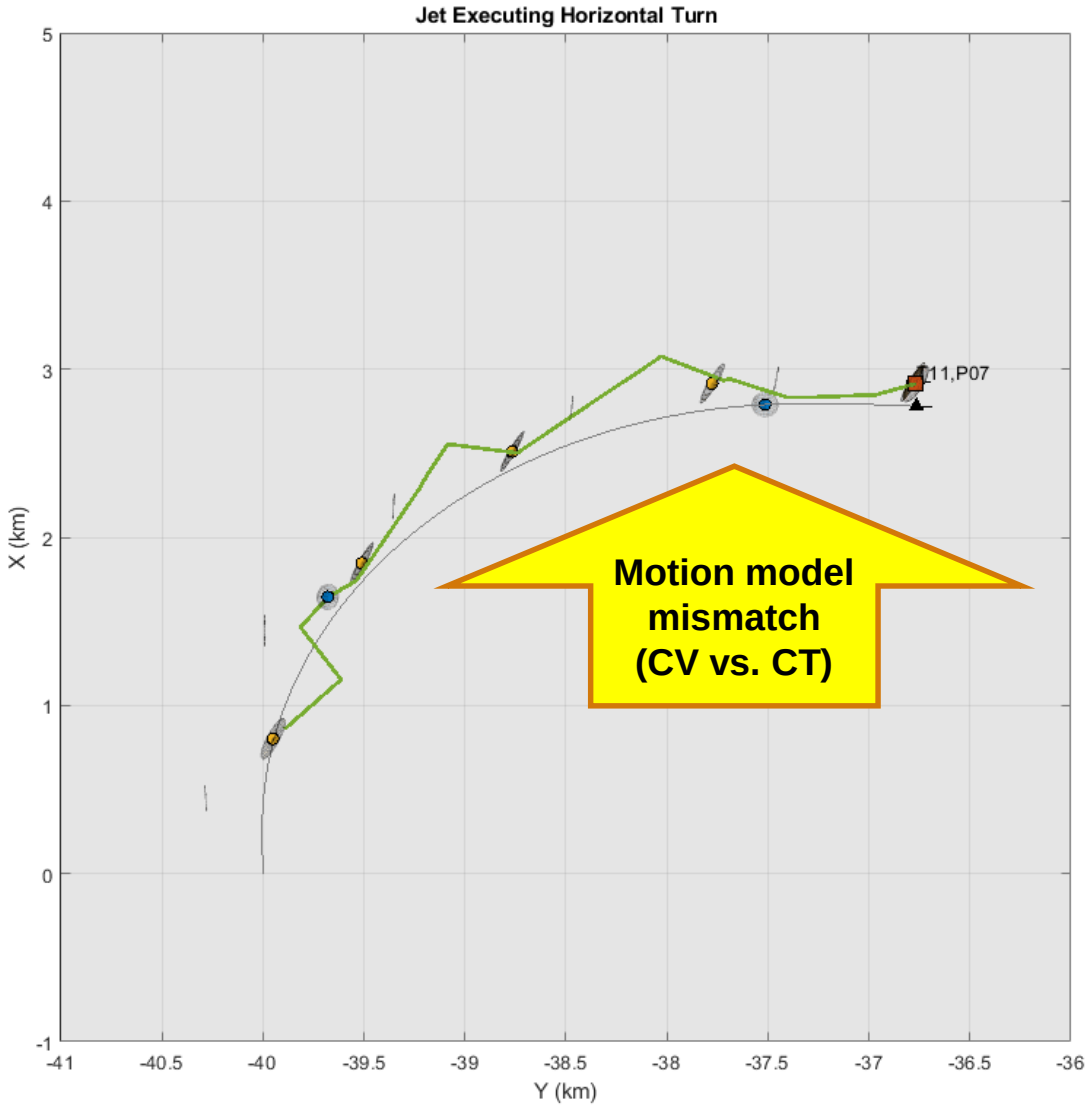
Time to confirm tracks

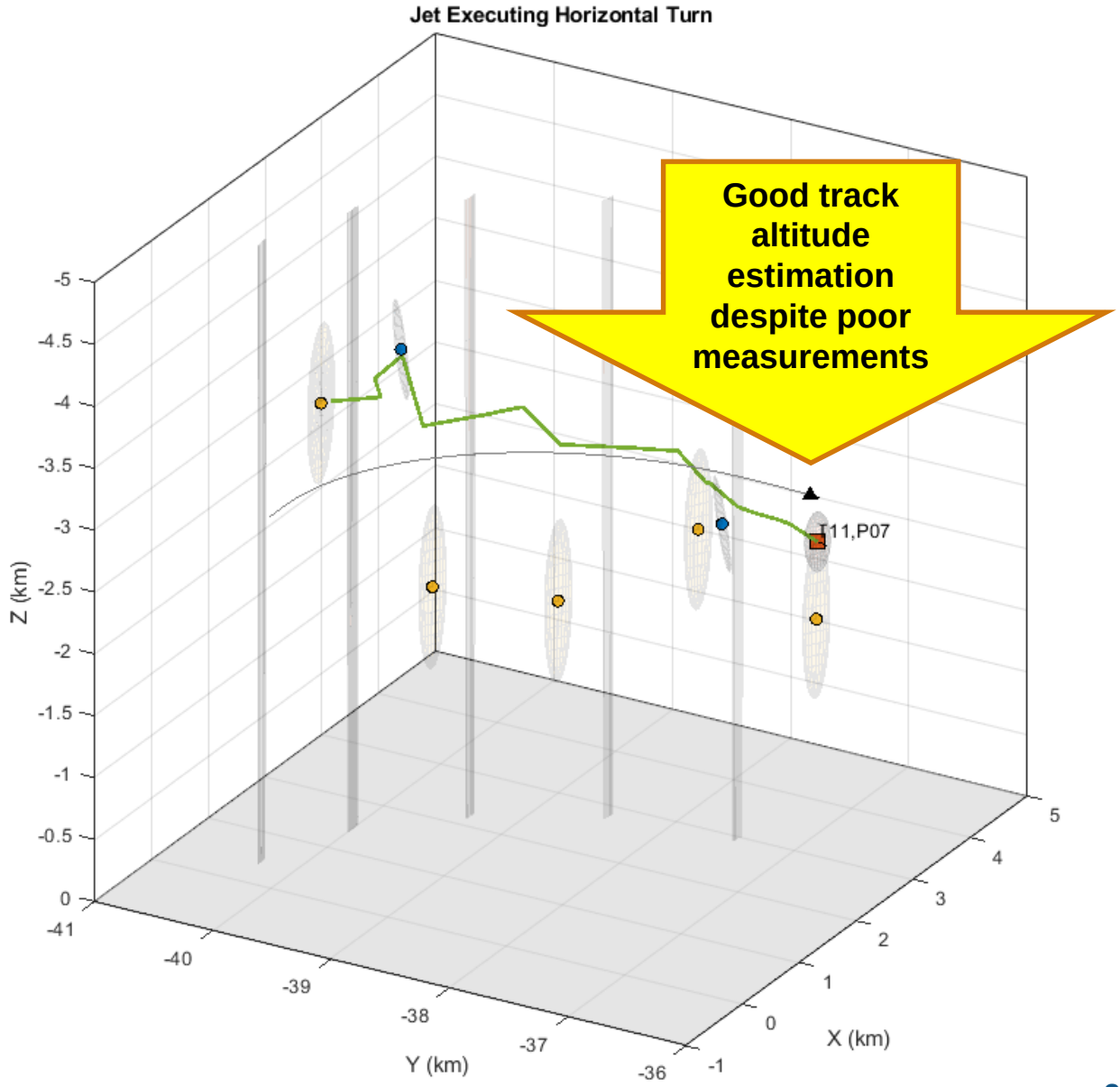
Assess Tracker Performance with Assignment Metrics



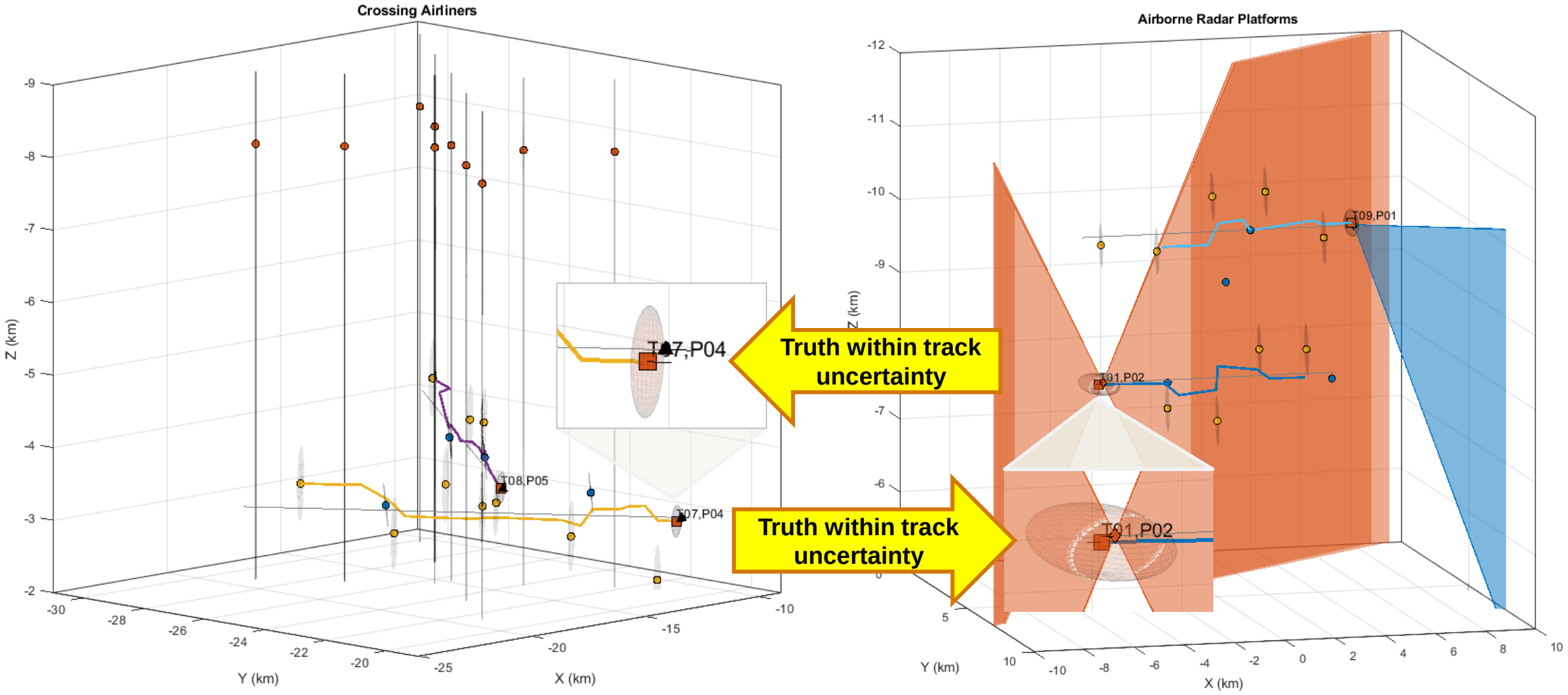


Visualize Track Accuracy

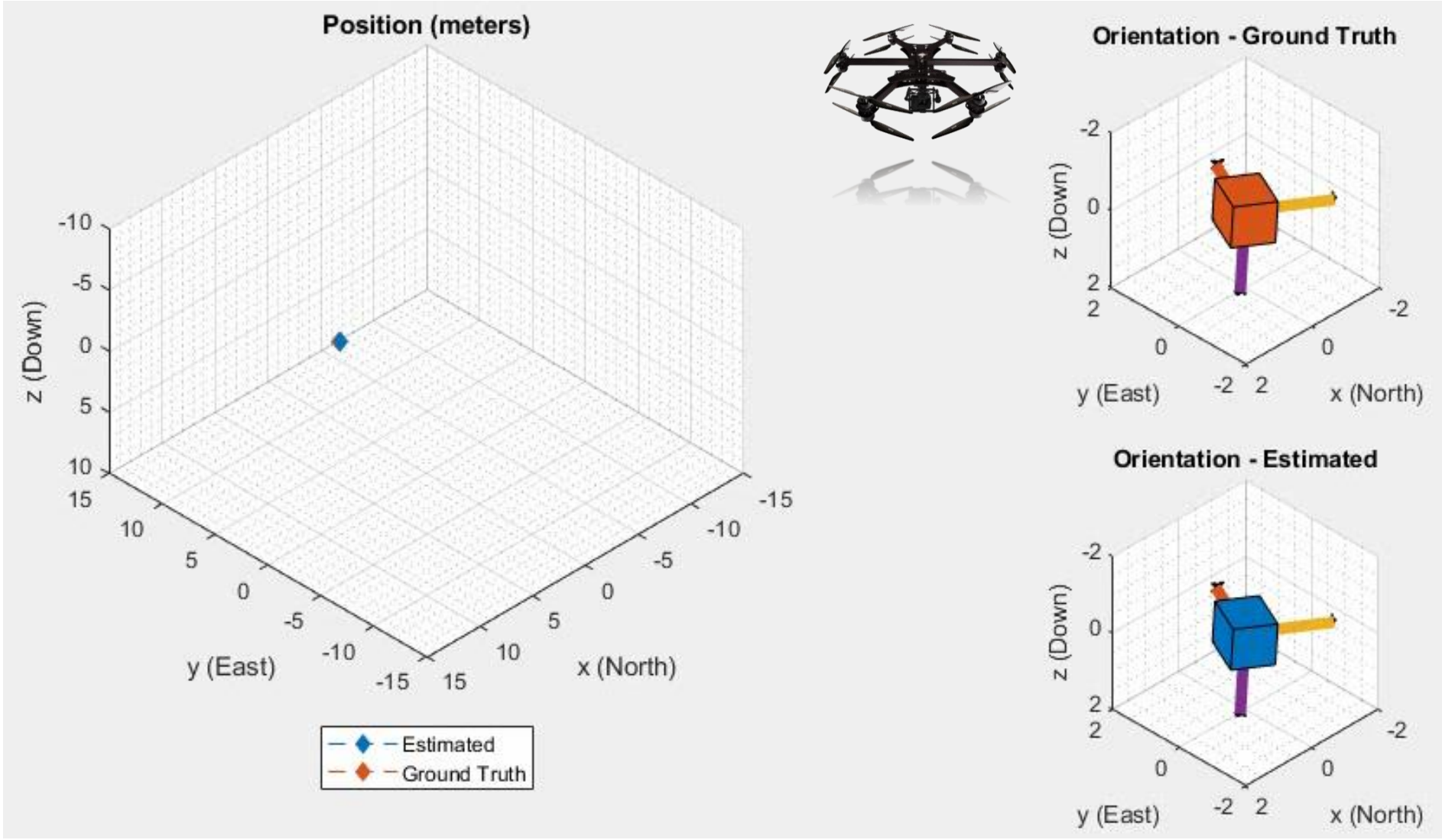




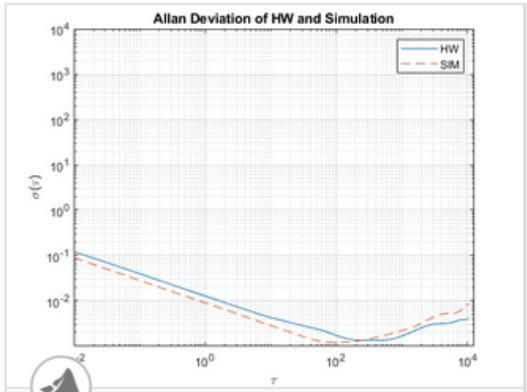
Visualize Track Accuracy and Uncertainty



Fuse IMU & GPS for Airborne Platform



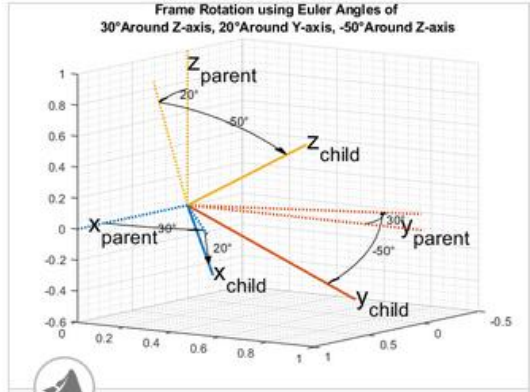
To go further on localization, see also



Inertial Sensor Noise Analysis Using Allan Variance

Use the Allan variance to determine noise parameters of a MEMS gyroscope. These parameters can be used to model the gyroscope in

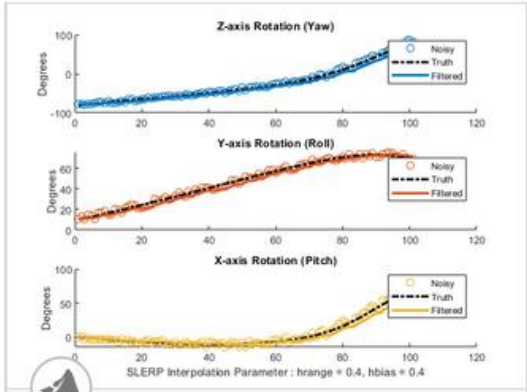
R2018b Open Script



Rotations, Orientation and Quaternions

Reviews concepts in three-dimensional rotations and how quaternions are used to describe orientation and rotations.

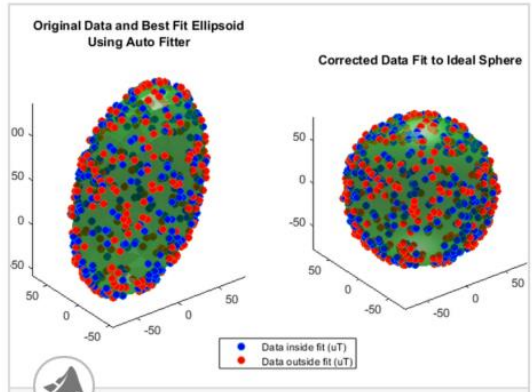
R2018b Open Script



Lowpass Filter Orientation Using Quaternion SLERP

Use spherical linear interpolation (SLERP) to create sequences of quaternions and lowpass filter noisy trajectories. SLERP is a commonly

R2018b Open Script

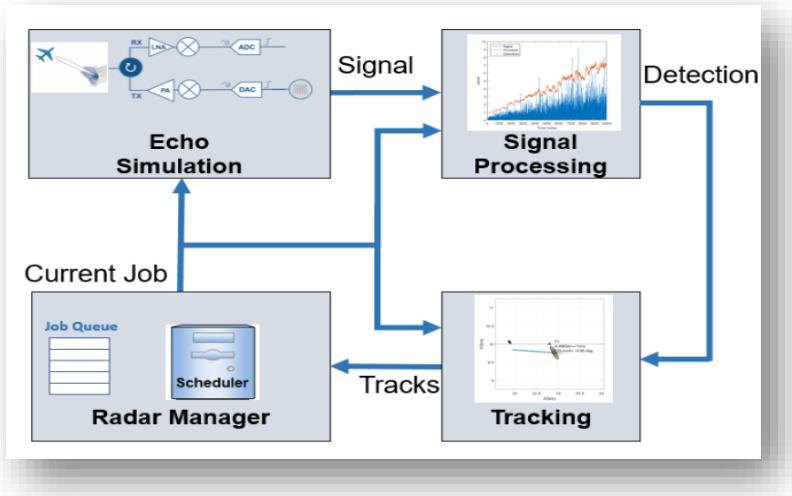


Magnetometer Calibration

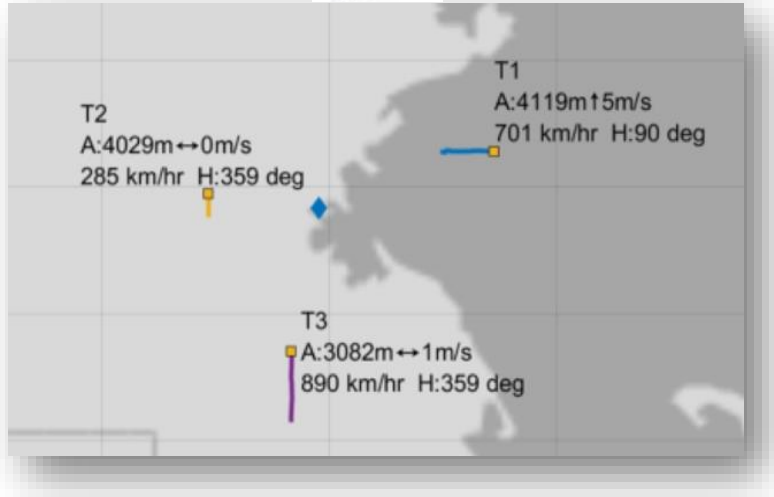
Magnetometers detect magnetic field strength along a sensor's X,Y and Z axes. Accurate magnetic field measurements are essential for

R2019a Open Script

Summary



- **Closed-loop Multifunction Radar**



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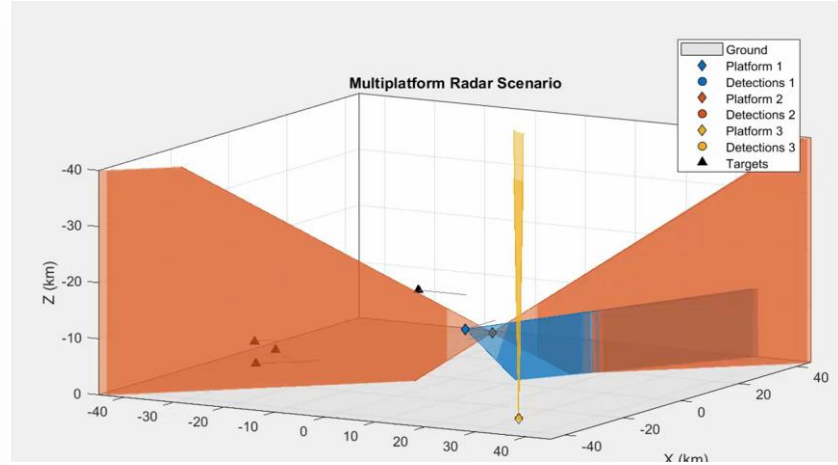
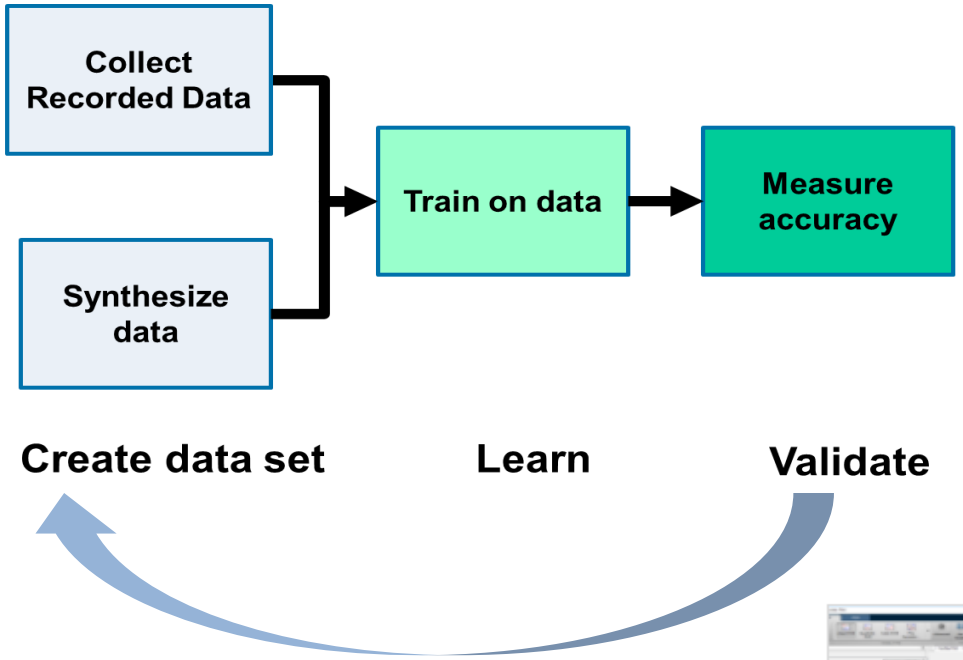
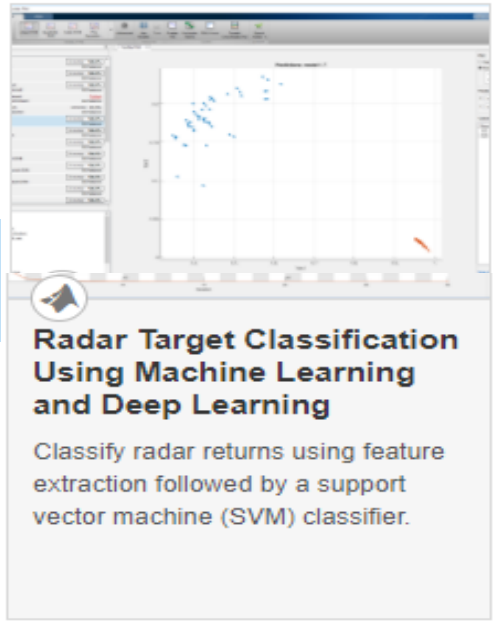


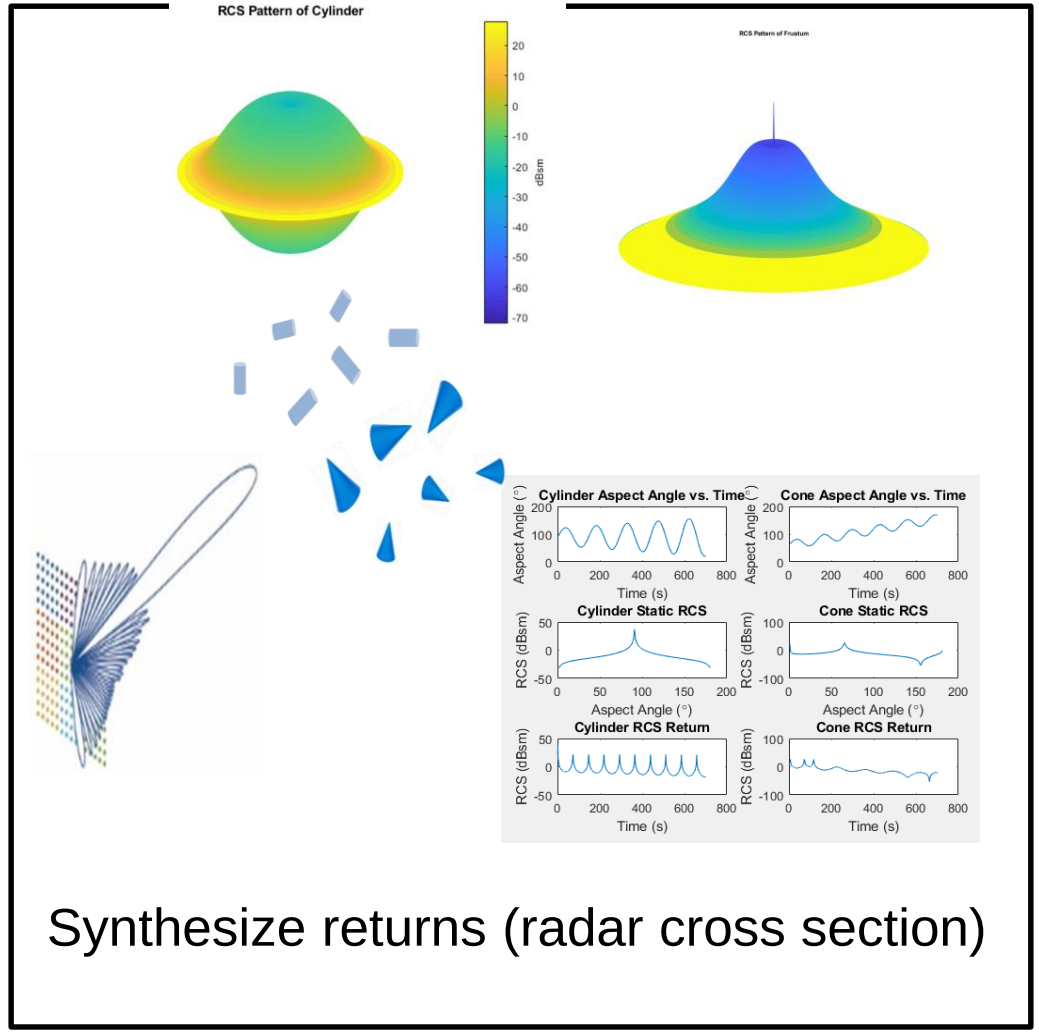
- **Multisensor Detection Generation & Fusion,**
- **Localization**

Extended Workflows – AI for Radar Target Classification



Statistics and Machine Learning Toolbox ™
Deep Learning Toolbox ™



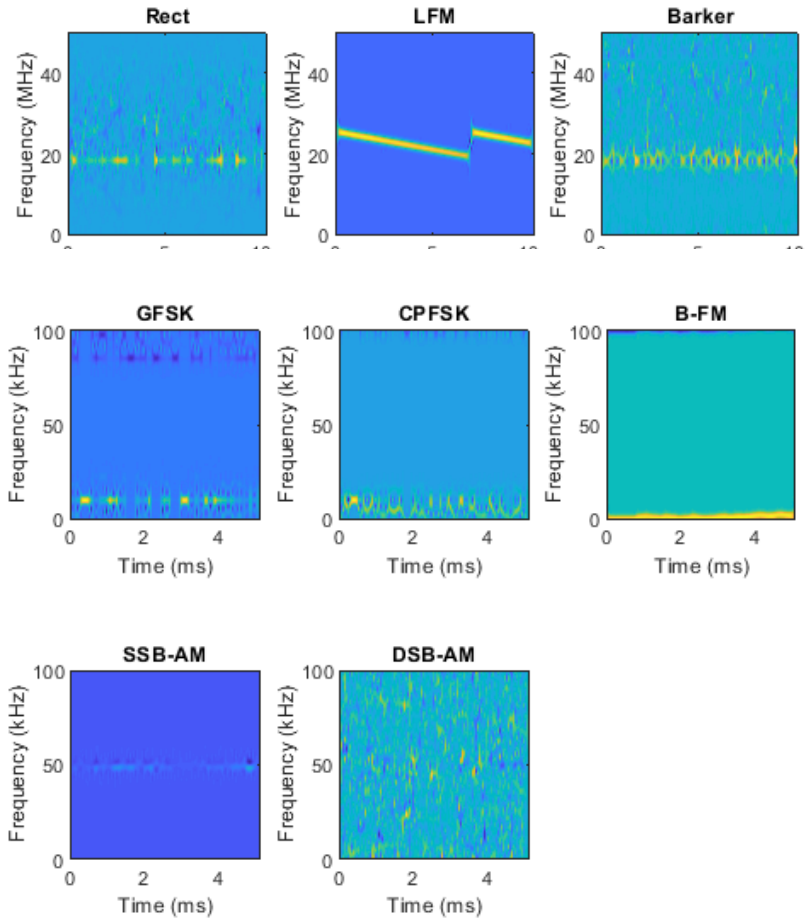


Synthesize returns (radar cross section)

MATLAB EXPO 2019

Waveform Classification Using Deep Learning (Radar and Comms)

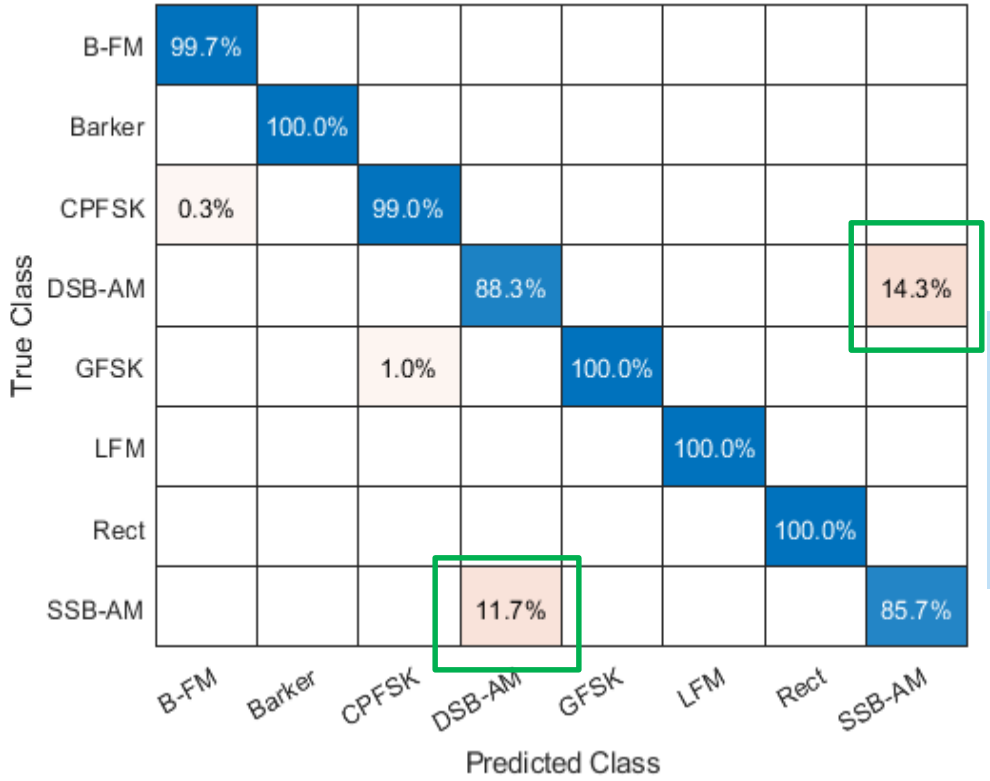
R2019a



Data synthesis for 3000 signals/ modulation type with random variations & impairments

Radar Waveform Classification Using Deep Learning

Classify radar waveform types of generated synthetic data using the Wigner-Ville distribution (WVD) and a deep convolutional neural network



Deep Learning Toolbox ™
Phased Array System Toolbox ™
Communications Toolbox ™
Signal Processing ™

DSB-AM signals misclassified as SSB-AM and SSB-AM as DSB-AM.

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This one-day course provides a comprehensive introduction to the Phased Array System Toolbox™. Themes including radar characterization and analysis, radar design and modeling and radar signal processing are explored throughout the course.

Topics include:

- Review of a Monostatic End-to-End Radar Model
- Characterize and analyze radar components and systems
- Design and model components of a radar system
- Implement a range of radar signal processing algorithms

Learn More

Phased Array System Toolbox

Sensor Fusion and Tracking Toolbox NEW PRODUCT

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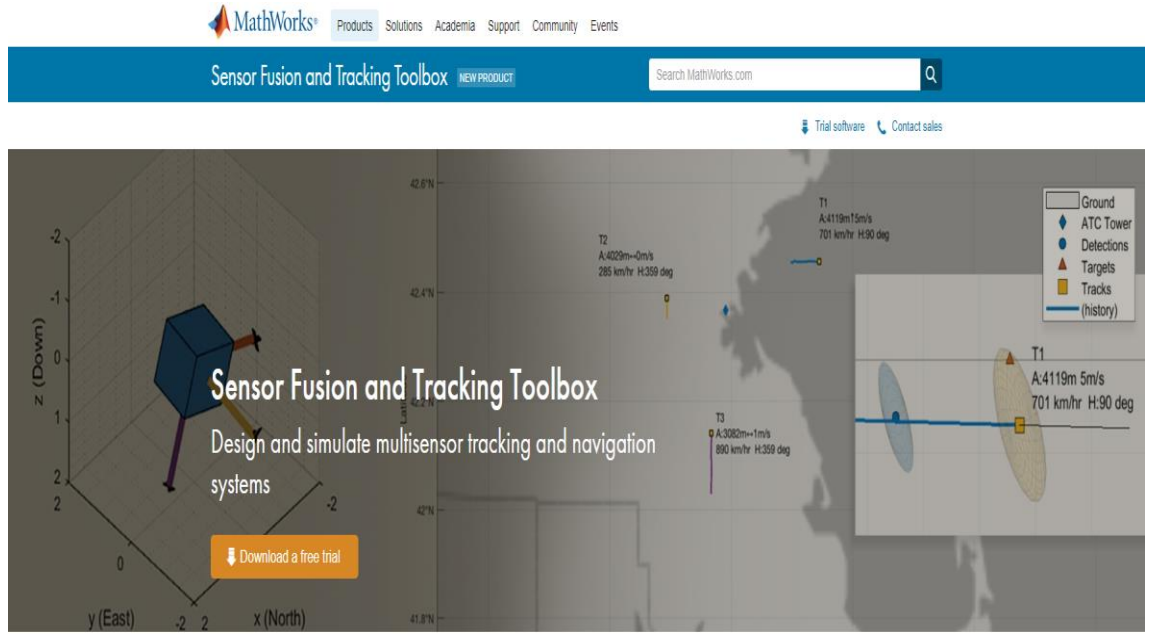

https://www.mathworks.com/products/phased-array.html

https://www.mathworks.com/products/sensor-fusion-and-tracking.html

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