Software for Space, Defense & Intelligence

Wind Turbine/Radar System Modeling and Analysis

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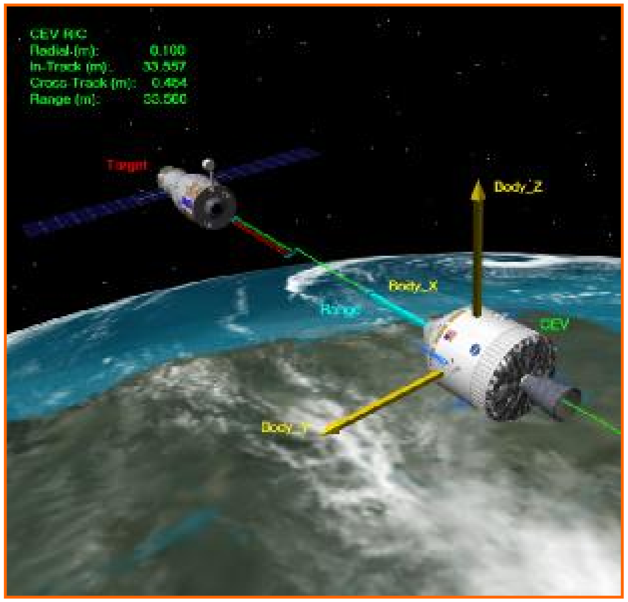
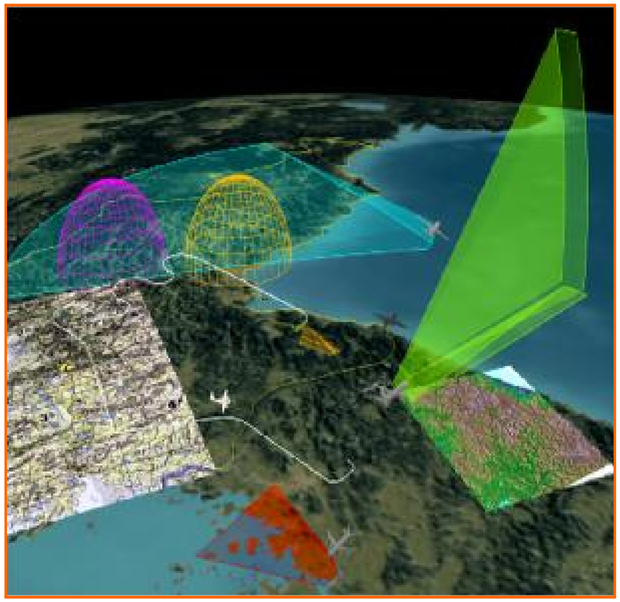
Presented to the Long Island Chapter of the IEEE Antennas & Propagation Society on October 24th, 2013

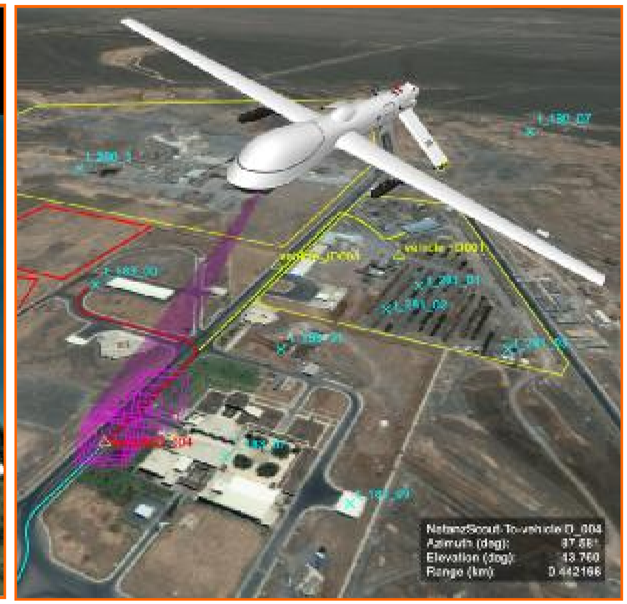
Agenda

- AGI overview
- Encroachment and Operational Concerns
- Modeling Impacts of Renewable Energy
  - Wind Turbines
  - Solar Reflectors
- Wind/Radar Customized Solutions
  - AGI Wind/Radar Plugin for Developer
  - DHS WT/RMT
  - NORAD ROEMS
- Summary

SPACE	DEFENSE	INTELLIGENCE







SPACE

- Space Mission design
- Space Operations
- SSA
- Launch Operations
- Conjunction Analysis

DEFENSE

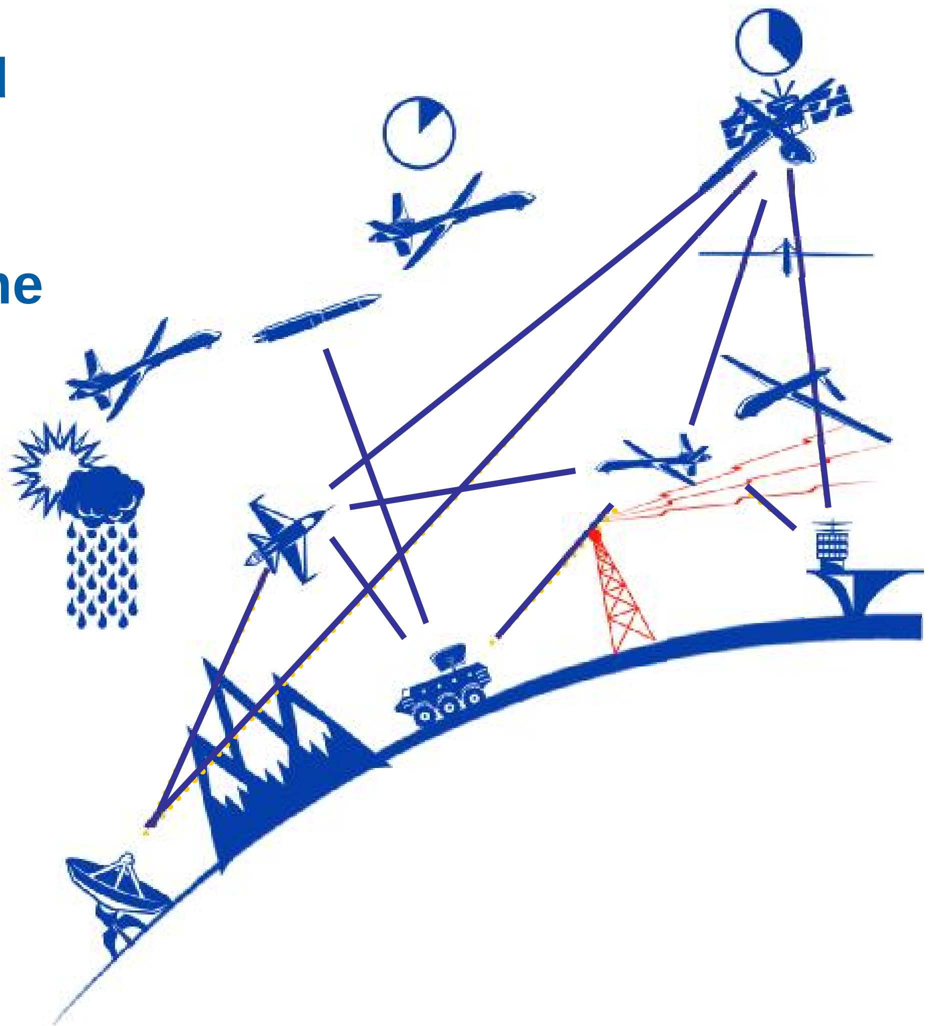
- Multi Asset Management
- TMD/BMD
- Battlespace planning
- Mission Planning
- Electronic Warfare

INTELLIGENCE

- Mission planning
- C4ISR
- Sensor/Collection planning
- Geospatial Intel

AGI Basics

- COTS software for analysis and visualization
- Models object in space over time
- Analyze and understand relationships
- Constrain relationships
- High fidelity 4D visualization

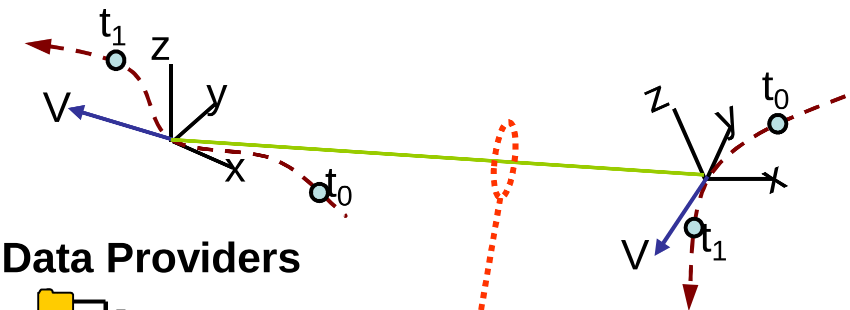


STK Paradigm

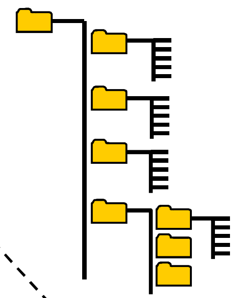
Objects & Properties

- Missiles
- Ground vehicles
- Ships
- Facilities
- Aircraft
- Satellites
- Sensors
- Transmitters
- Receivers
- Radars

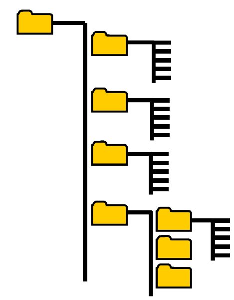
Physics based object modeling

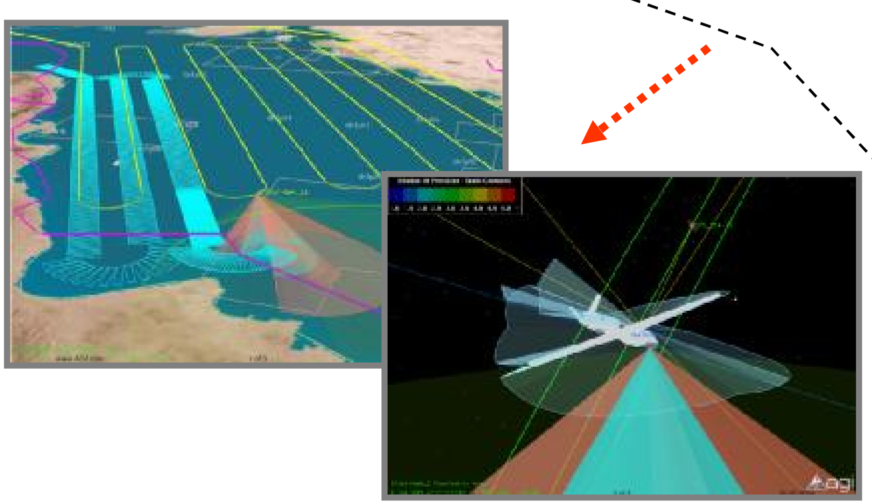


Object Data Providers



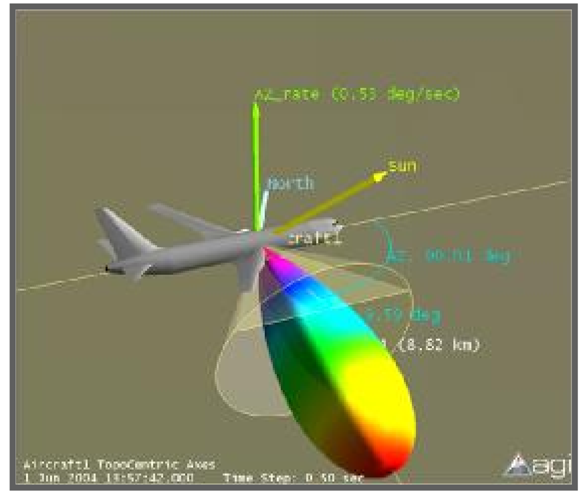
Inter-Object Data Providers

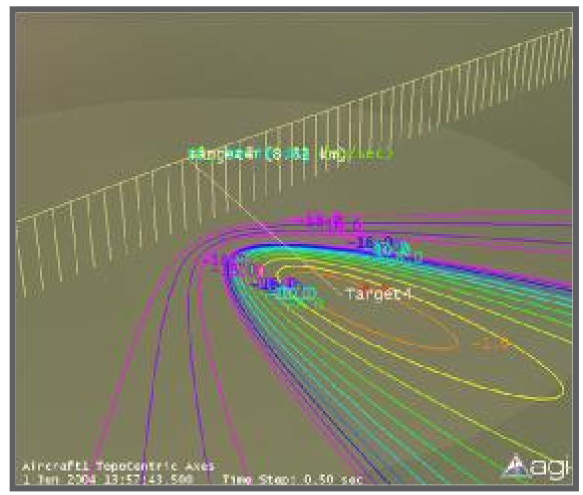




STK Predictive Computation

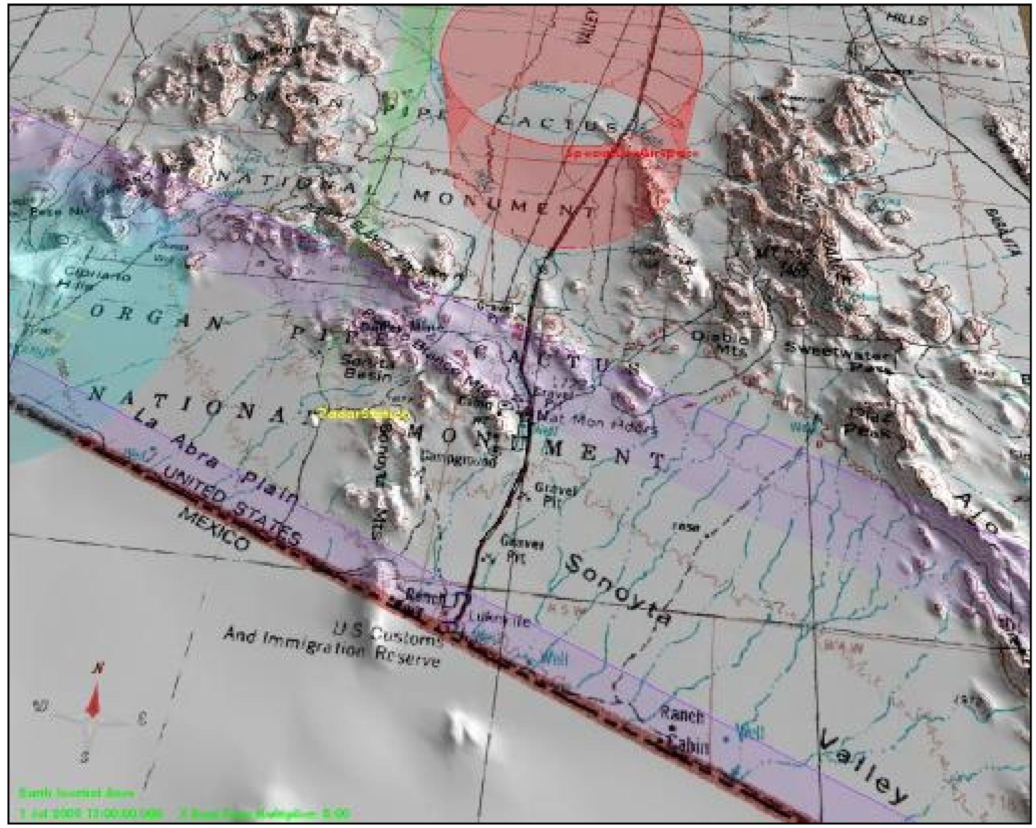
- **Determine values of, and "constraint" satisfaction time periods that meet mission objectives**
  - Geometric
  - Proximity
  - Pointing
  - Lighting
  - Line-of-sight atmospheric conditions
  - Inter-object geometry
  - Comm link quality, Jamming values
  - Radar performance measures
  - Terrain vertical profile
  - GPS DOP and Nav accuracy prediction





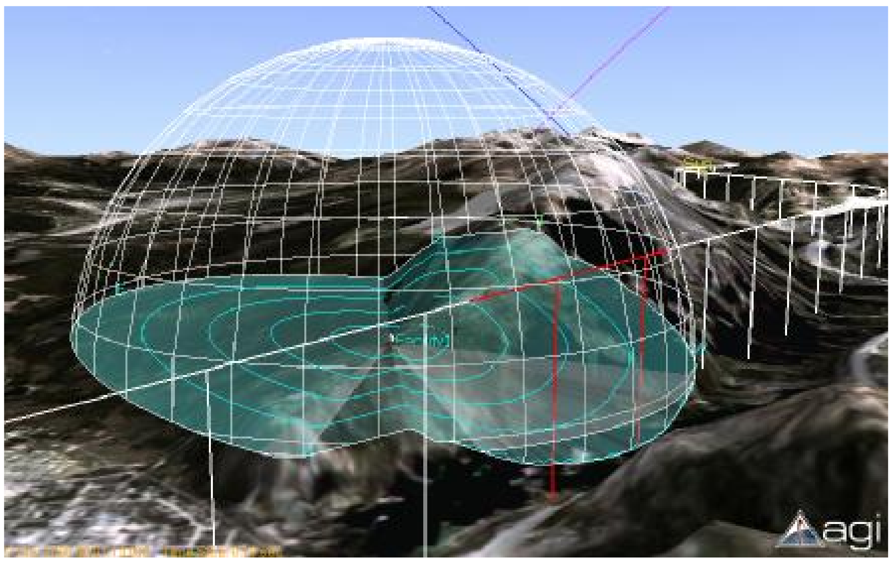
STK Capabilities for GIS

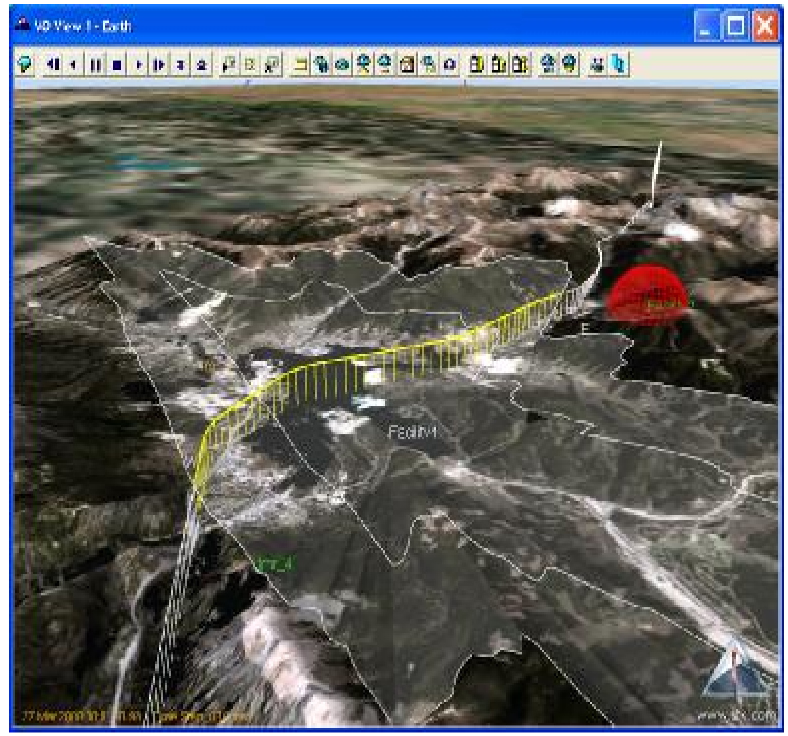
- **Maps**
  - .kml, .shp, .mxd
  - geodatabases
  - custom GIS (e.g., DAFIF)
- **Models**
  - COLLADA
- **Imagery**
  - .ecw, .img, .jp2, .ntf, .sid, .tif
  - CADRG, & CIB
- **Terrain**
  - DTED, DEM, ArcInfo, GTOPO, MOLA, MUSE, GEODAS
- **2D/3D Visualization**



Terrain analysis

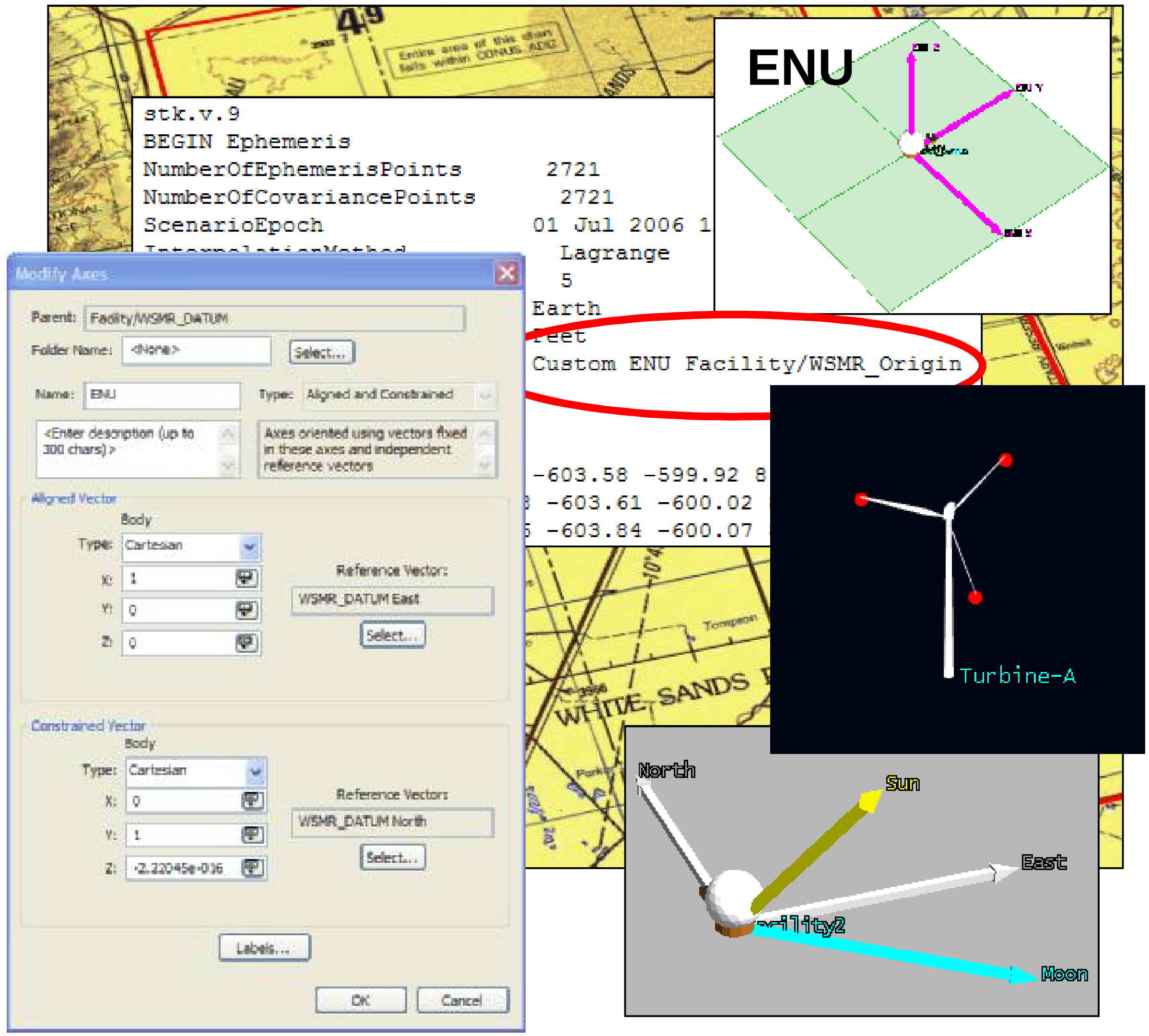
- **AzEl Terrain masking (to range, to altitude)**
  - Colorize flight paths within view of detection mask





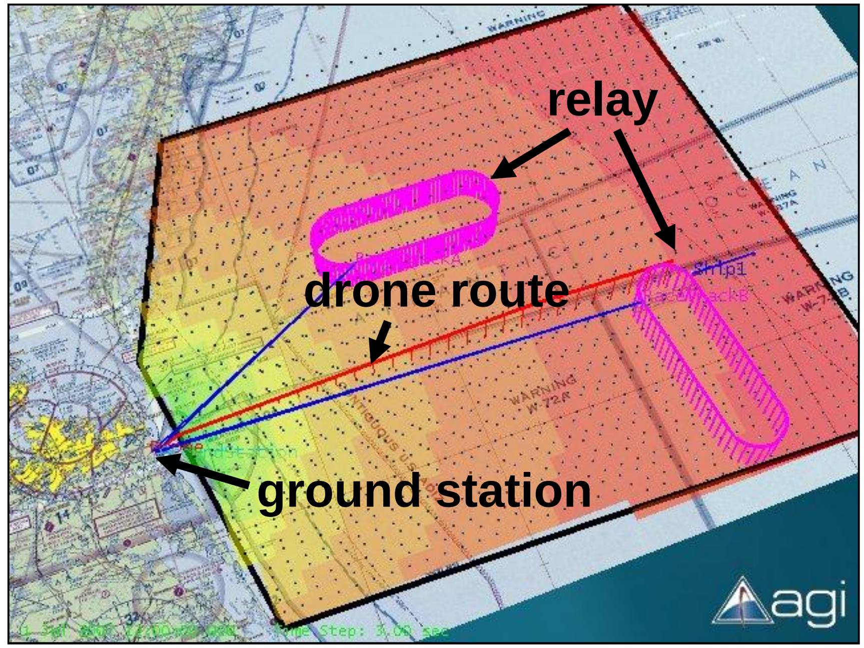
Dynamic Geometry Modeling

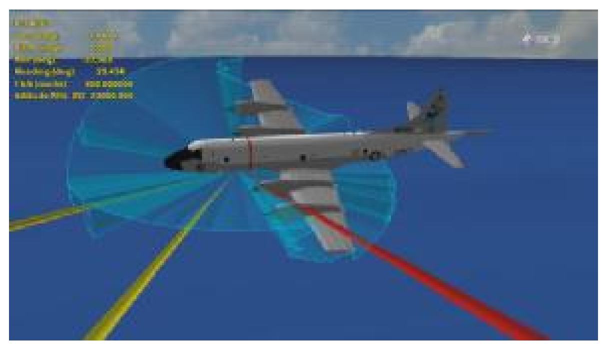
- **Time systems**
  - UTCG, LCL, IRIG, GPS, Julian
- **Coordinate Systems**
  - ECI, ECF, ENU, NED, Custom
- **Vector geometry tool**
  - Points, Vectors, Angles, Planes, Axes
- **Relative position information**
  - RIC, AER, Intervisibilty, Doppler
- **Celestial**
  - Sun, moon, etc.

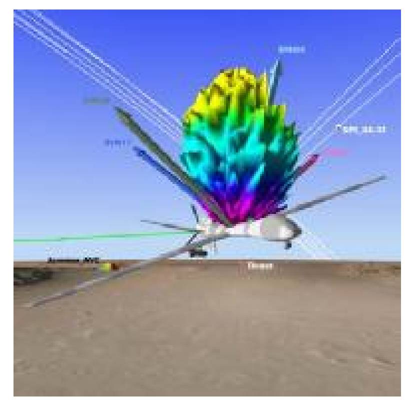


RF Analysis

- Dynamics
  - Position/Velocity
  - Orientation
- Transmitter/Receiver
  - Power
  - Frequency
  - Delay
  - Waveform
  - Filtering
- Antenna
  - Dynamic Gain
  - Polarization
  - Losses
- Environment
  - Terrain (TIREM)
  - Absorption and refraction
  - Ionosphere
  - Obscuration and Diffraction (terrain, objects, etc.)
  - Weather models
- Visualization
  - Coverage
  - Antenna Gain Volumes

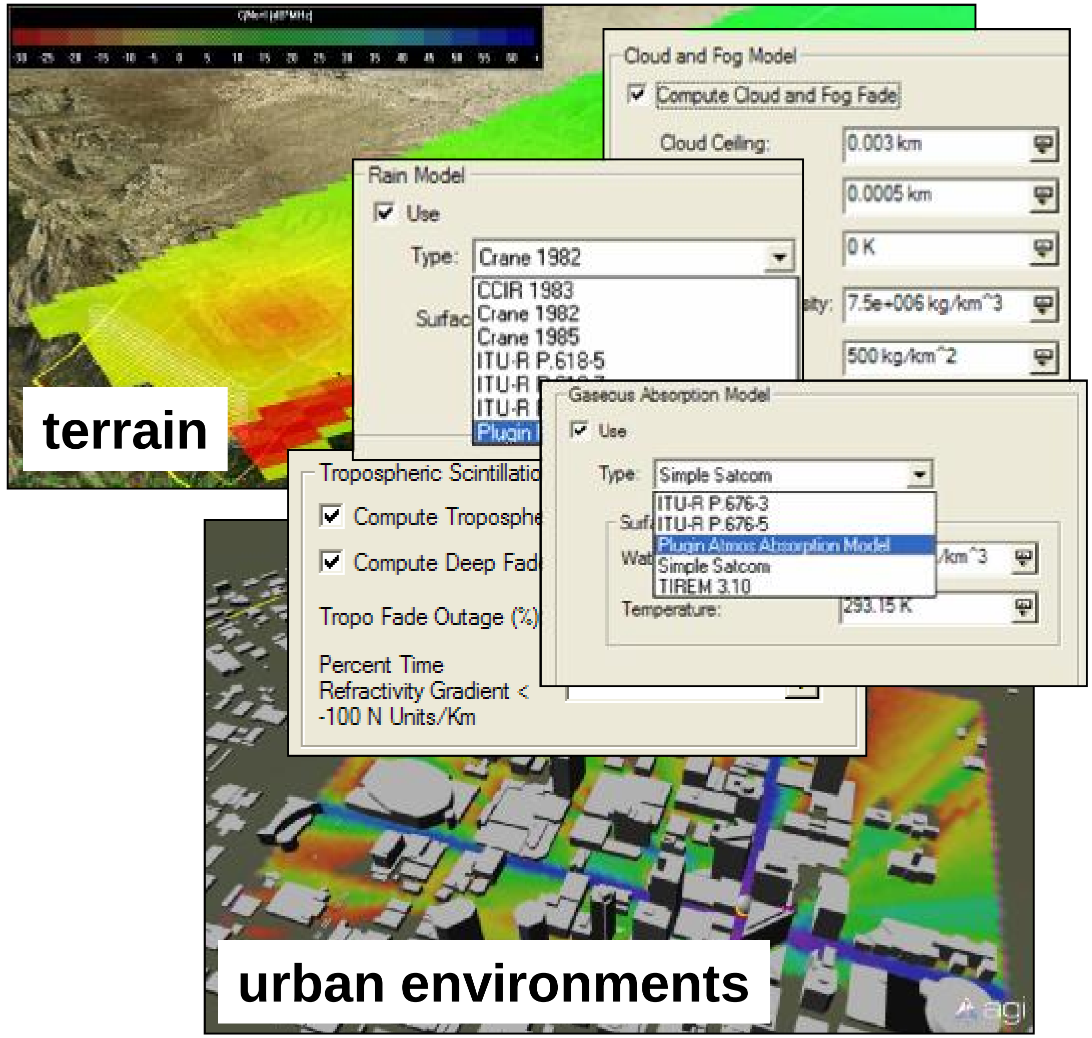




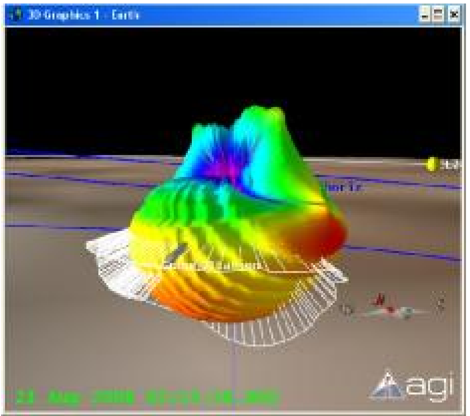


RF Environmental Effects

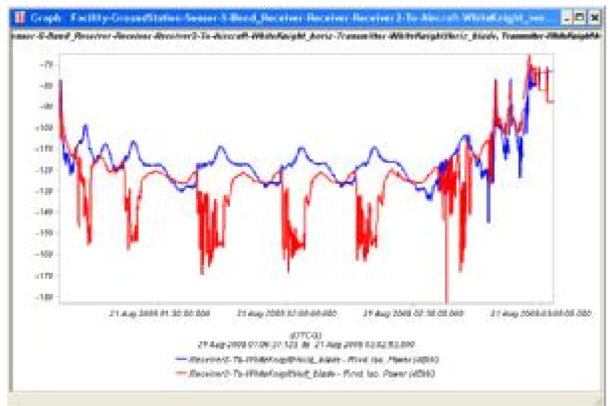
- Rain, Gaseous Absorption, Cloud/Fog, Tropospheric
- Terrain diffraction with TIREM
- Urban environment modeling (REMCOM Wireless Insite RT)
- Plugin points for external RF models



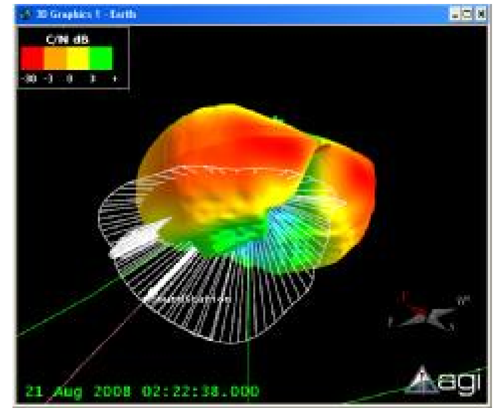
Communications Link Modeling



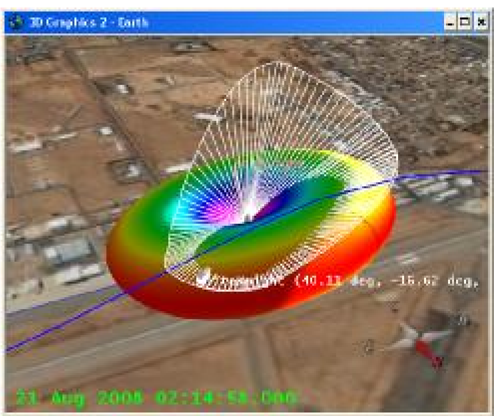
Horizontal Polarization



C/N Plot – Horiz & Vert



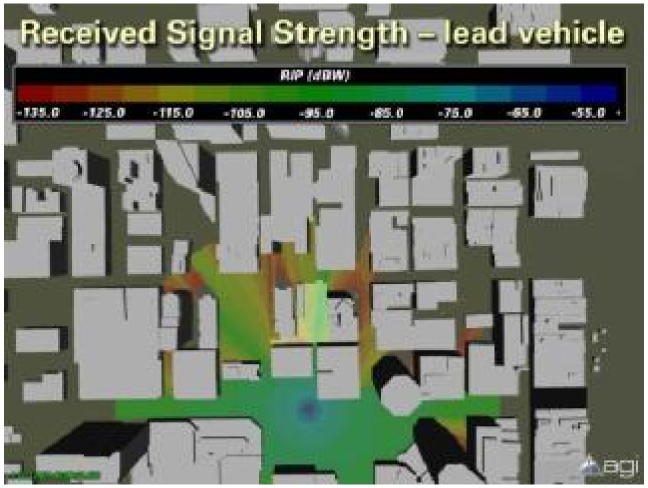
Vertical Polarization

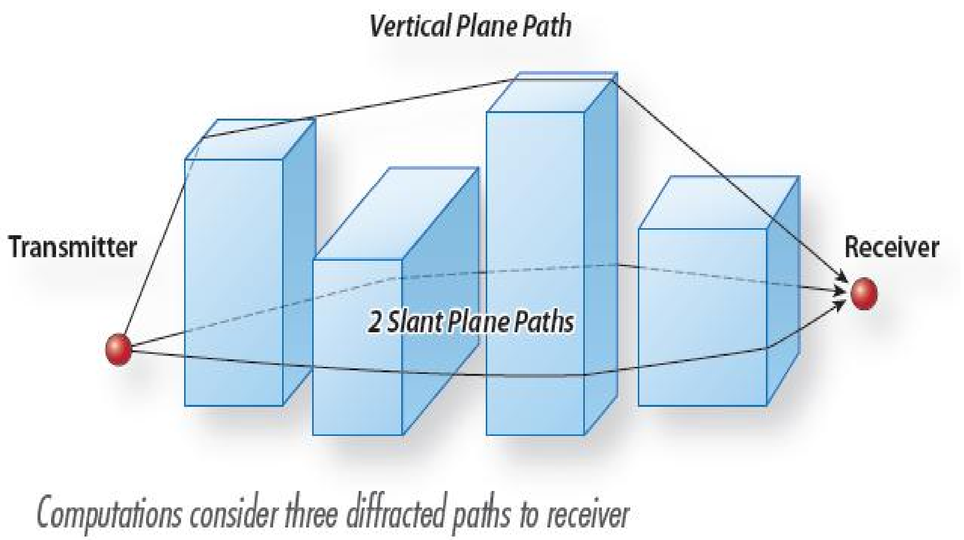


Ground Omni

Urban communications

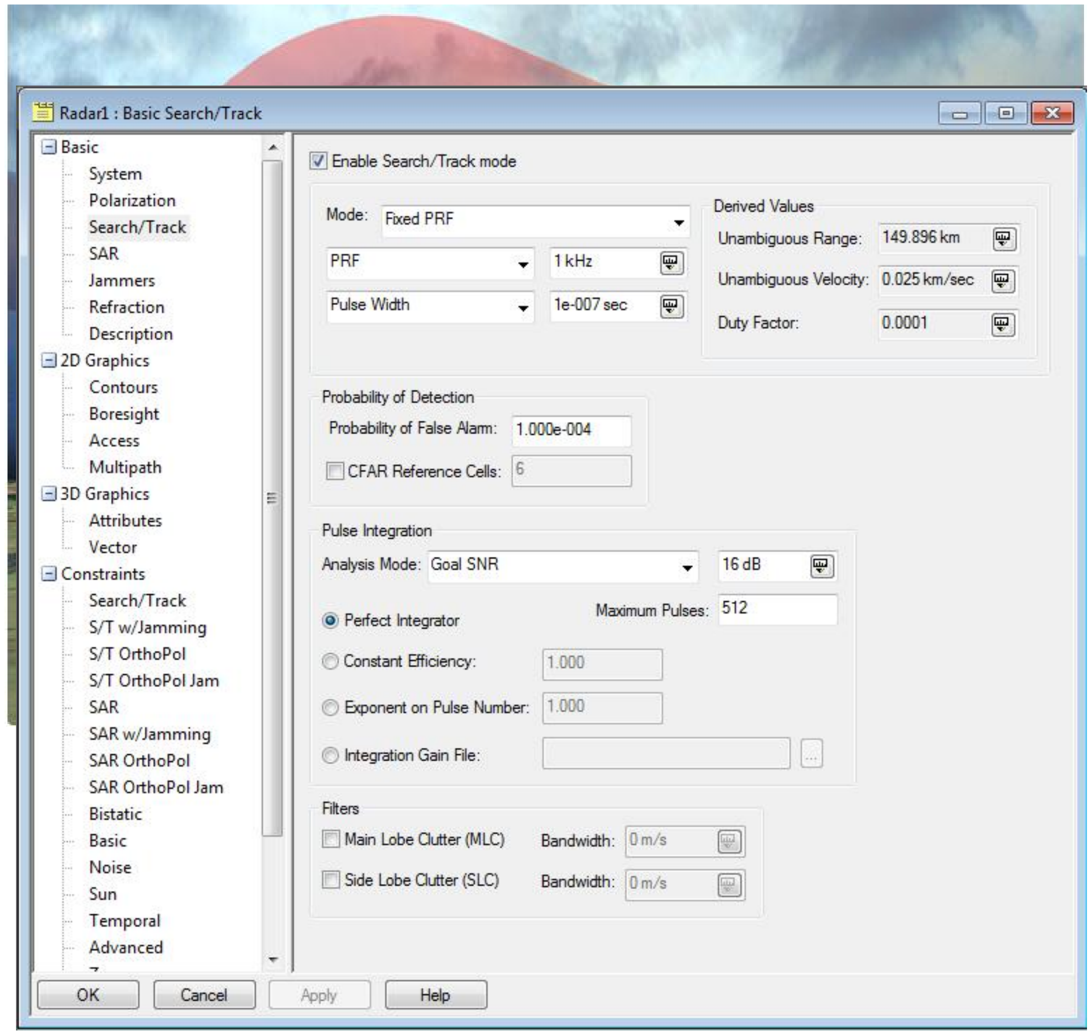
- Assess signals in urban environments
- Analyze loss using multiple paths
- Site specific



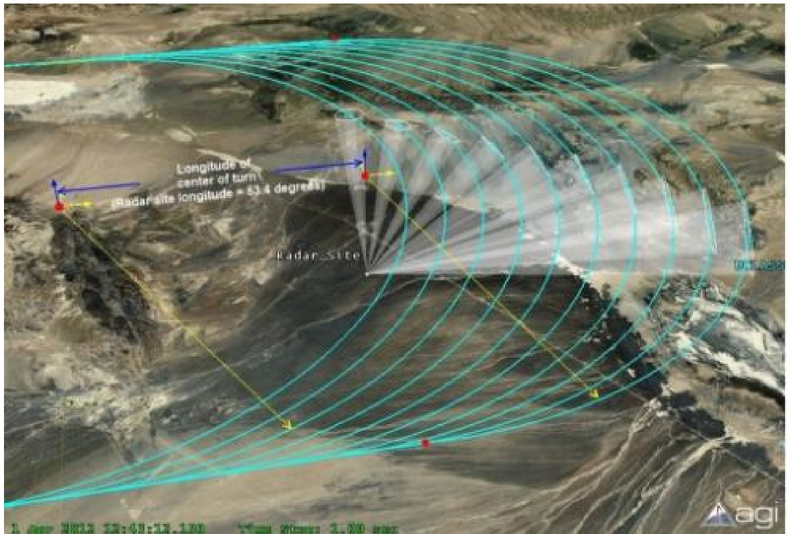


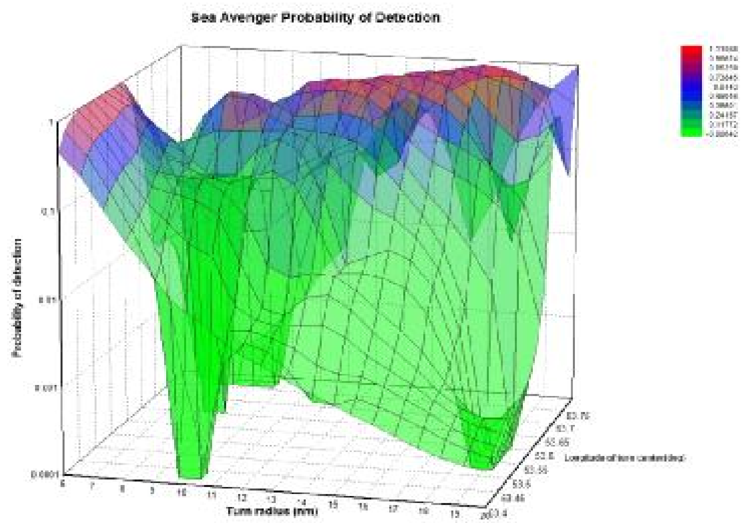
Radar

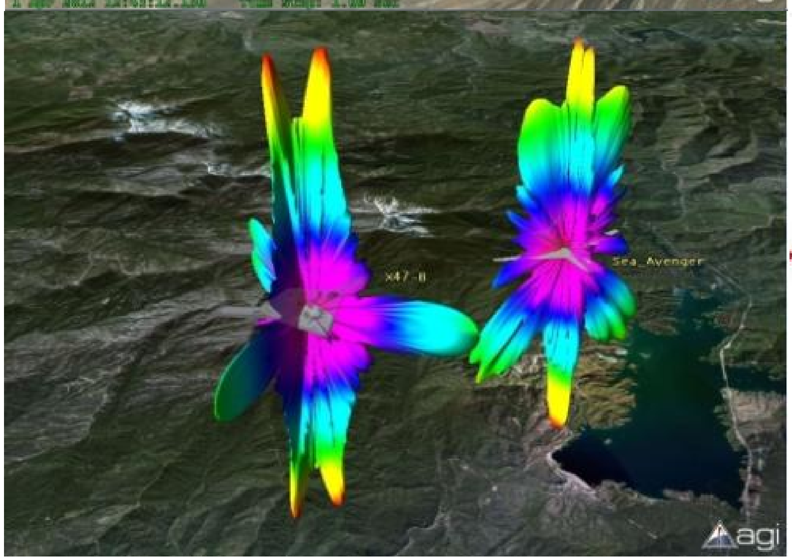
- **Types**
  - Mono-static
  - Bi-static
  - SAR
- **Power**
  - Peak
  - Losses
  - Antenna
- **Operating Modes**
- **Search/Track**
  - Fixed PRF
  - Continuous
- **Filters**
- **Detection**
  - SNR
  - Aspect dependent RCS
  - Complex Scattering Matrix
- **Interference** (C/No+I, J/S)
  - Clutter
  - Noise
  - Jammers

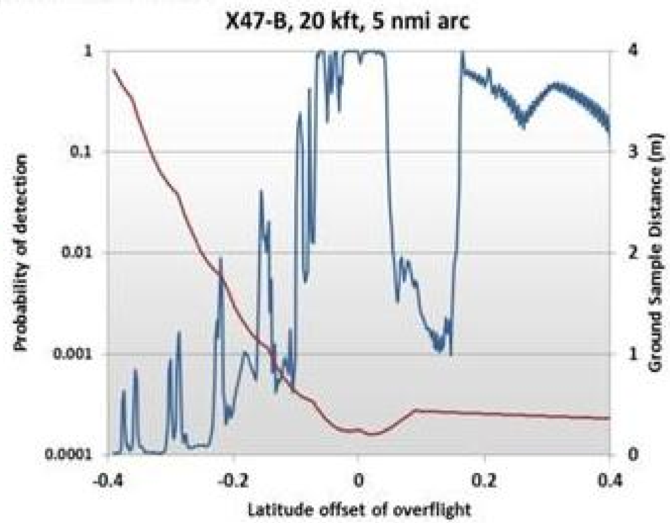


Aircraft RCS Modeling

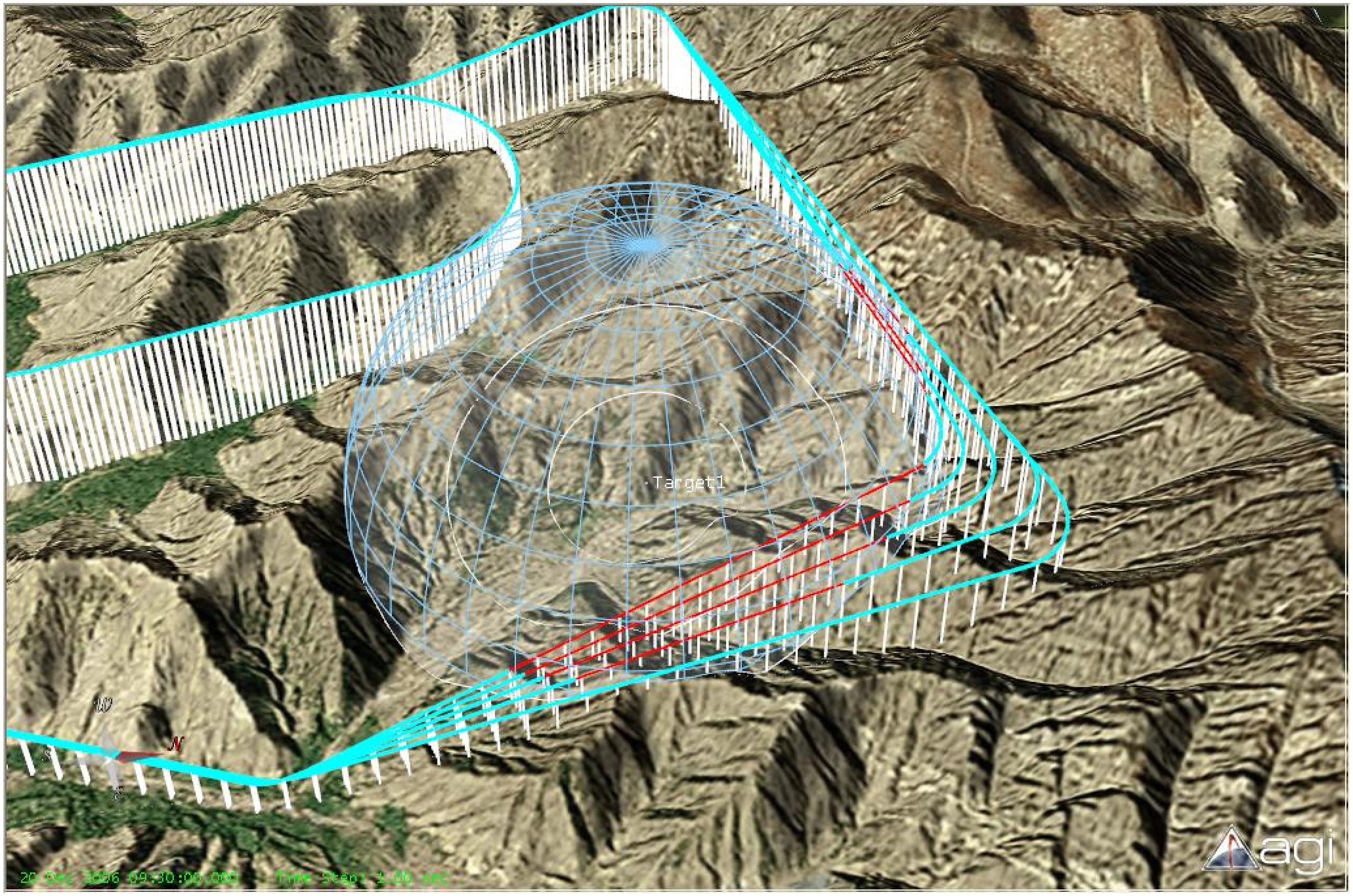








Route Design / Optimization



Software for Space, Defense & Intelligence

Modeling Impacts of Renewable Energy

Encroachment Concerns

- **Population Growth**
  - Zoning/Planning
  - Noise (acoustic, RF)
- **Airspace / Waterways**
  - NAS Policy / Coast Guard
  - Deconfliction
- **Spectrum Management**
  - Spectrum Visualization
  - Spectrum Deconfliction
  - RFI Monitoring
- **Renewable Energy**
  - Wind Turbines
    - Airborne Radar
    - Ground Based Radar
    - Microwave Communications
  - Solar Power
    - IR Effects
    - Reflectivity Effects

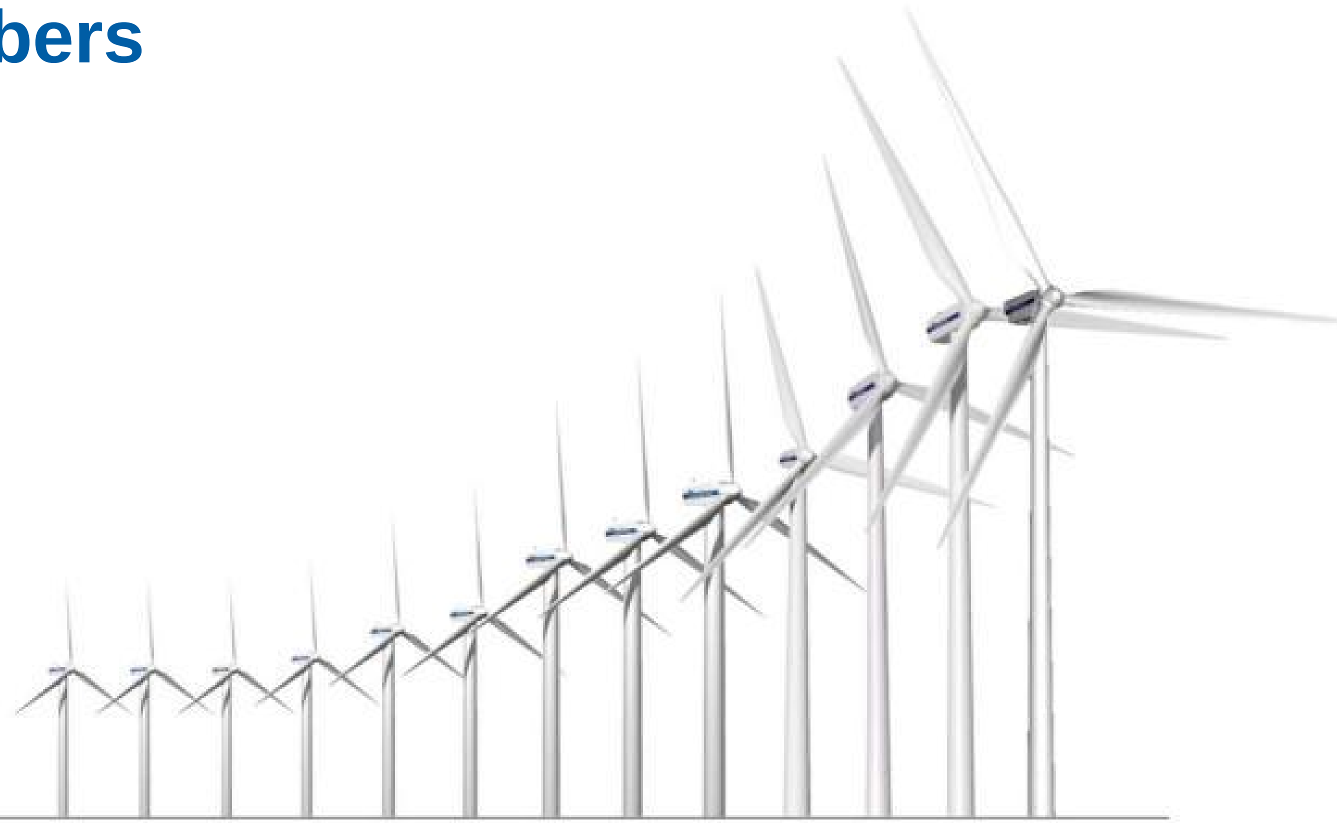
GIS

RF Analysis

Dynamic Geometry

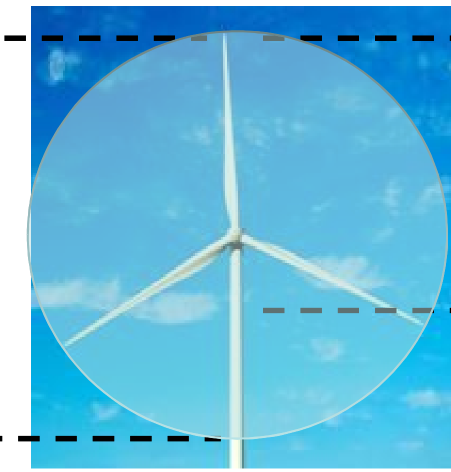
Wind Turbines

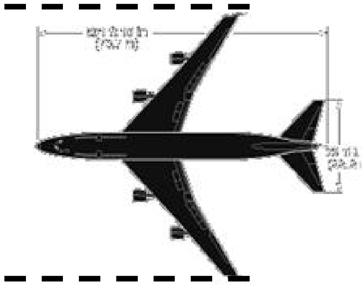
Wind turbines are continuously growing in size and in numbers



Product/Rotor diameter (m)	V15	V17	V19	V20	V25	V27	V39	V44	V47	V52	V66	V80	V90
Year of installation	1981	1984	1986	1987	1988	1989	1991	1995	1997	2000	1999	2000	2002
Capacity (kW)	55	75	90	100	200	225	500	600	660	850	1750	2000	3000
MWh/year	217	265	301	346	481	647	1304	1581	1947	2530	4705	6768	9152

The Vestas V90 is 90 meters (98.4 yds/295 ft) in diameter or 45 meters to the center of the hub.





747-400
wingspan:

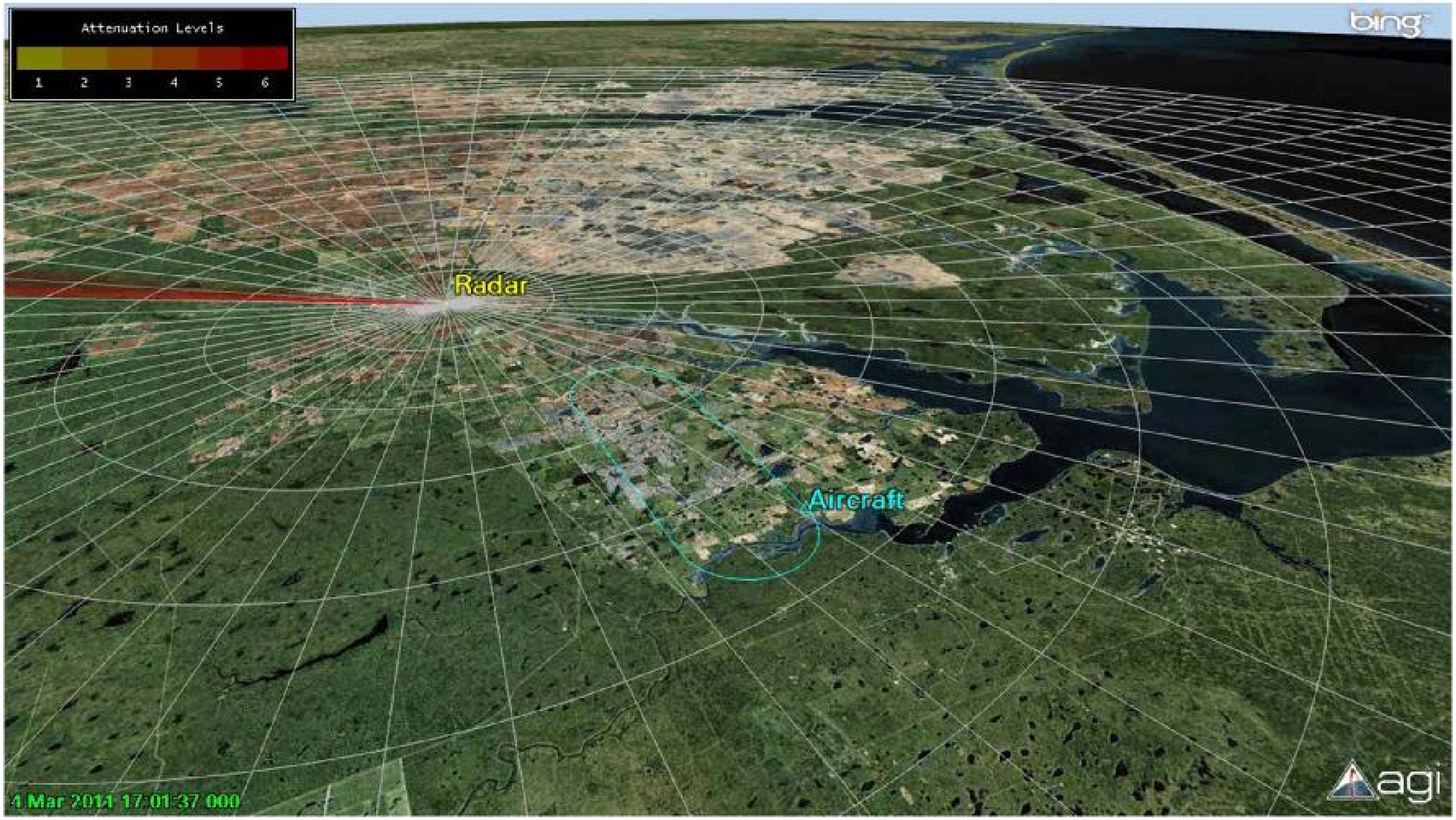
211 feet
65 meters

Wind Turbine Implications

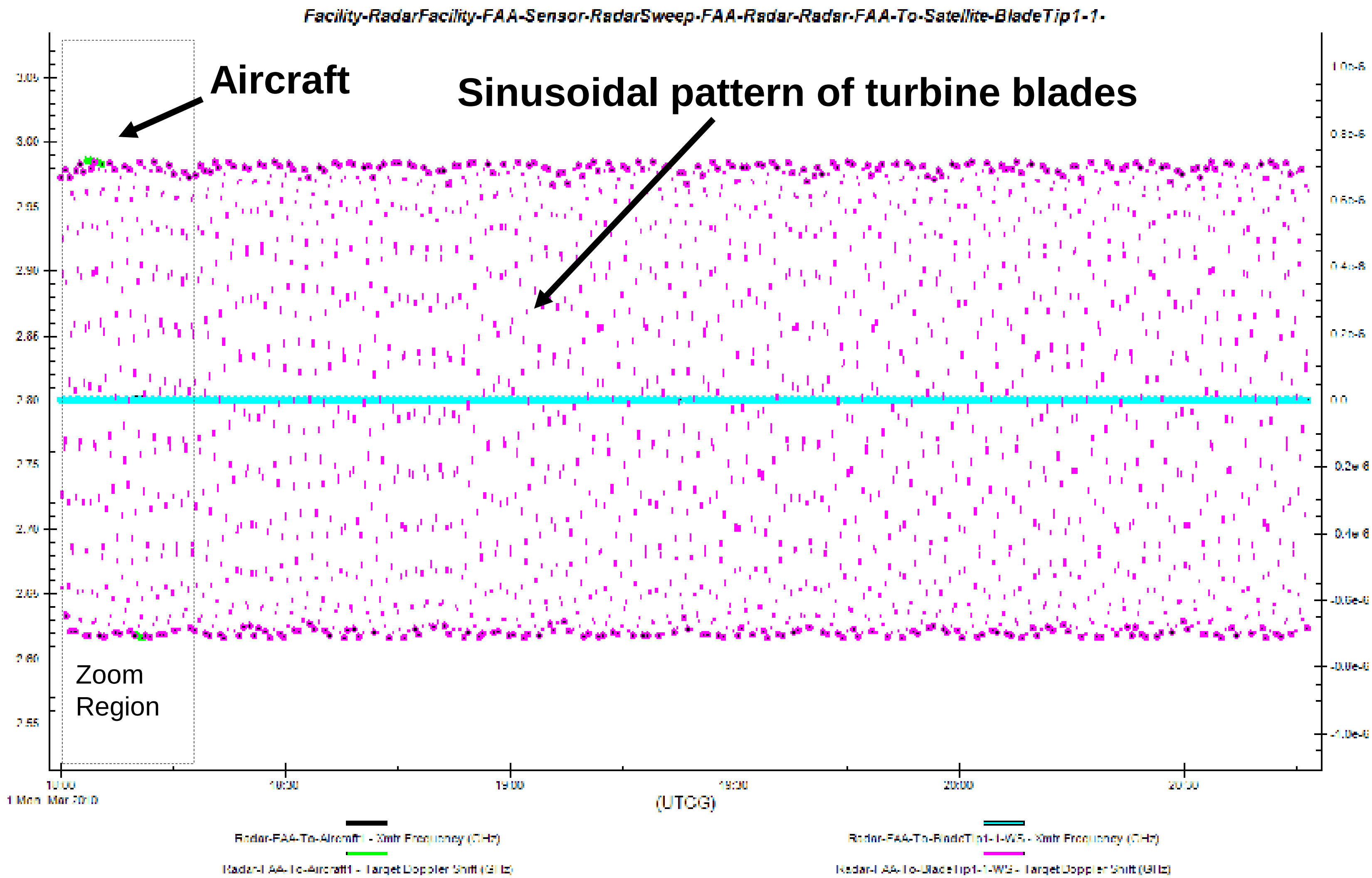
Turbines can be an issue because

- Speed of turbine blades closely match that of aircraft. (~150-250 mph) exhibiting spectral similarities.
- Radars perceive turbines as false targets and/or a source of noise, thus degrading sensitivity to cancel effect.
- Degradation of sensitivity is so severe it is sufficient to mask actual aircraft.
- Results in radar obscuration at various altitudes above each turbine site, depending on the radar beam width.

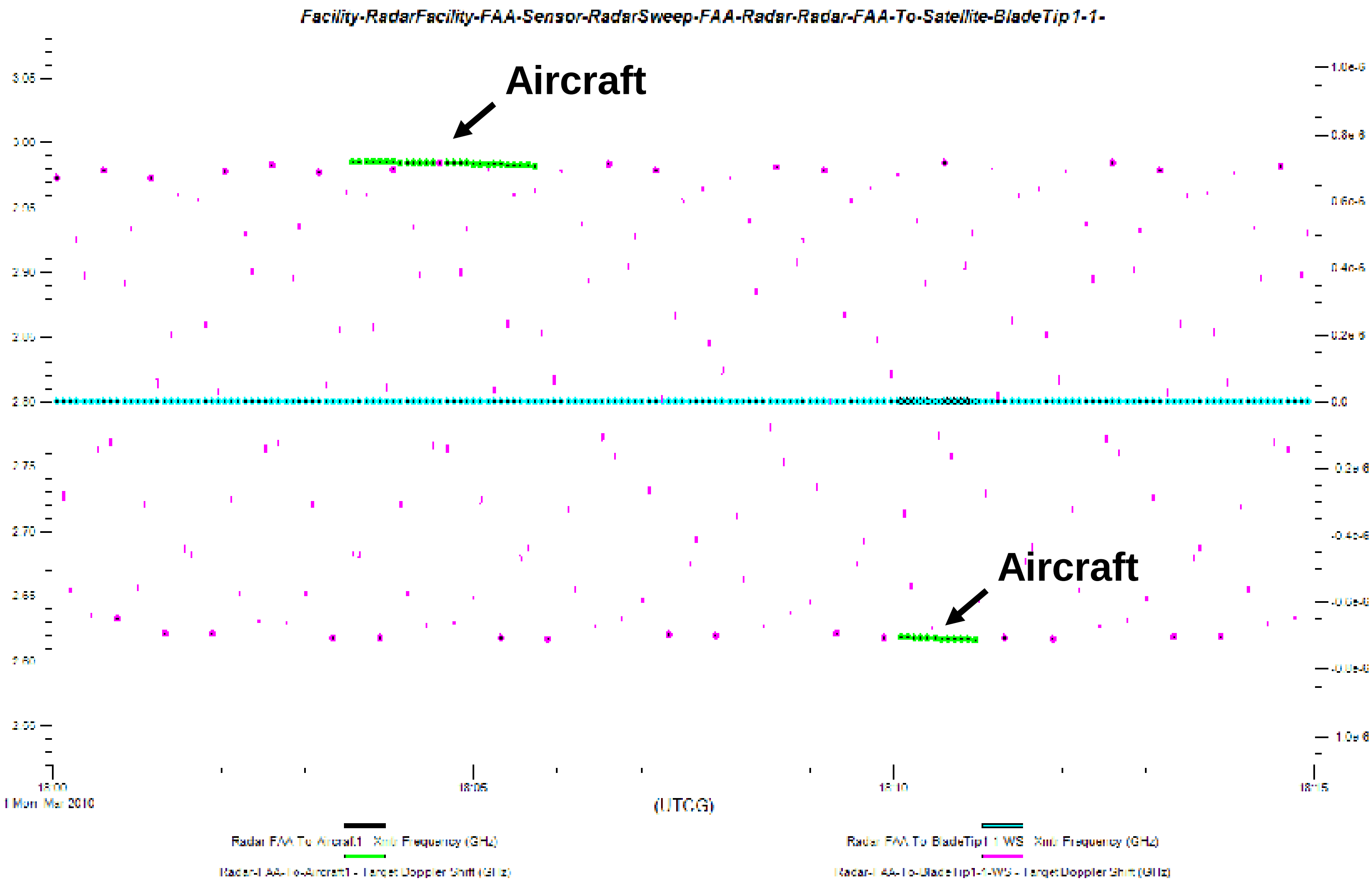
AGI Windturbine and Radar Modeling



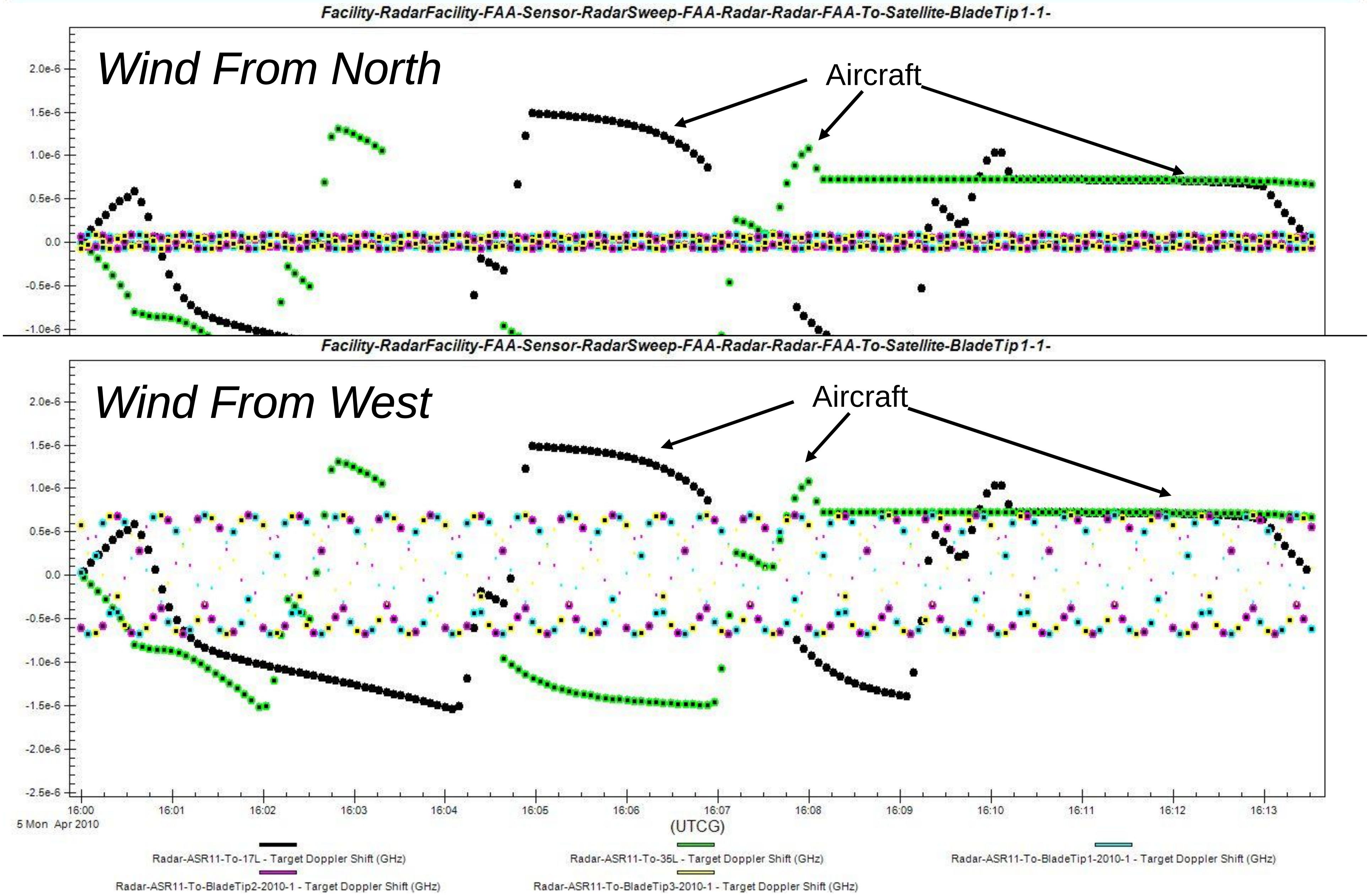
Turbine Blade Tip Doppler, with Aircraft



Zoomed in: Tip Doppler with Aircraft :

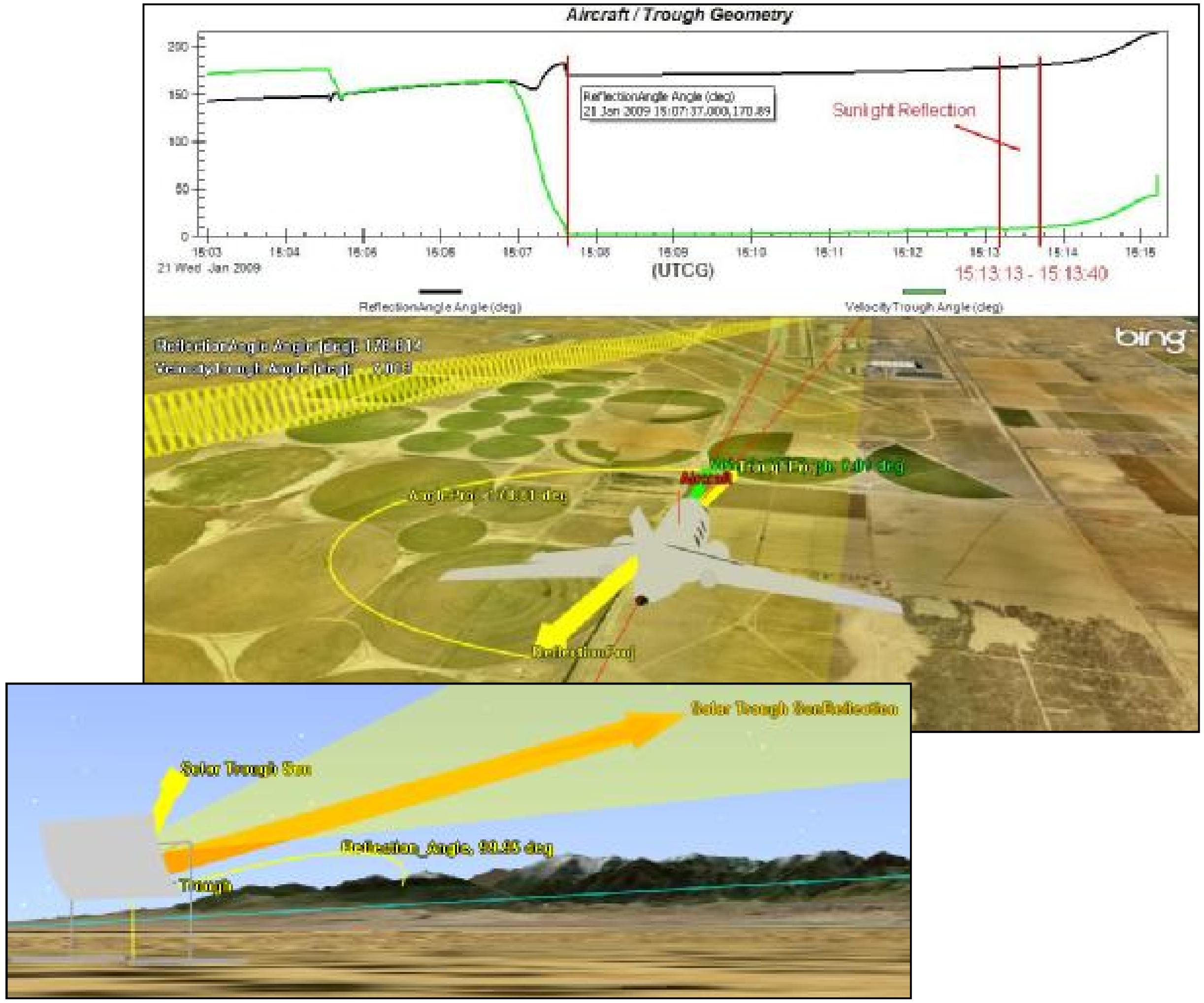


Tip Doppler with Aircraft: Wind Effect



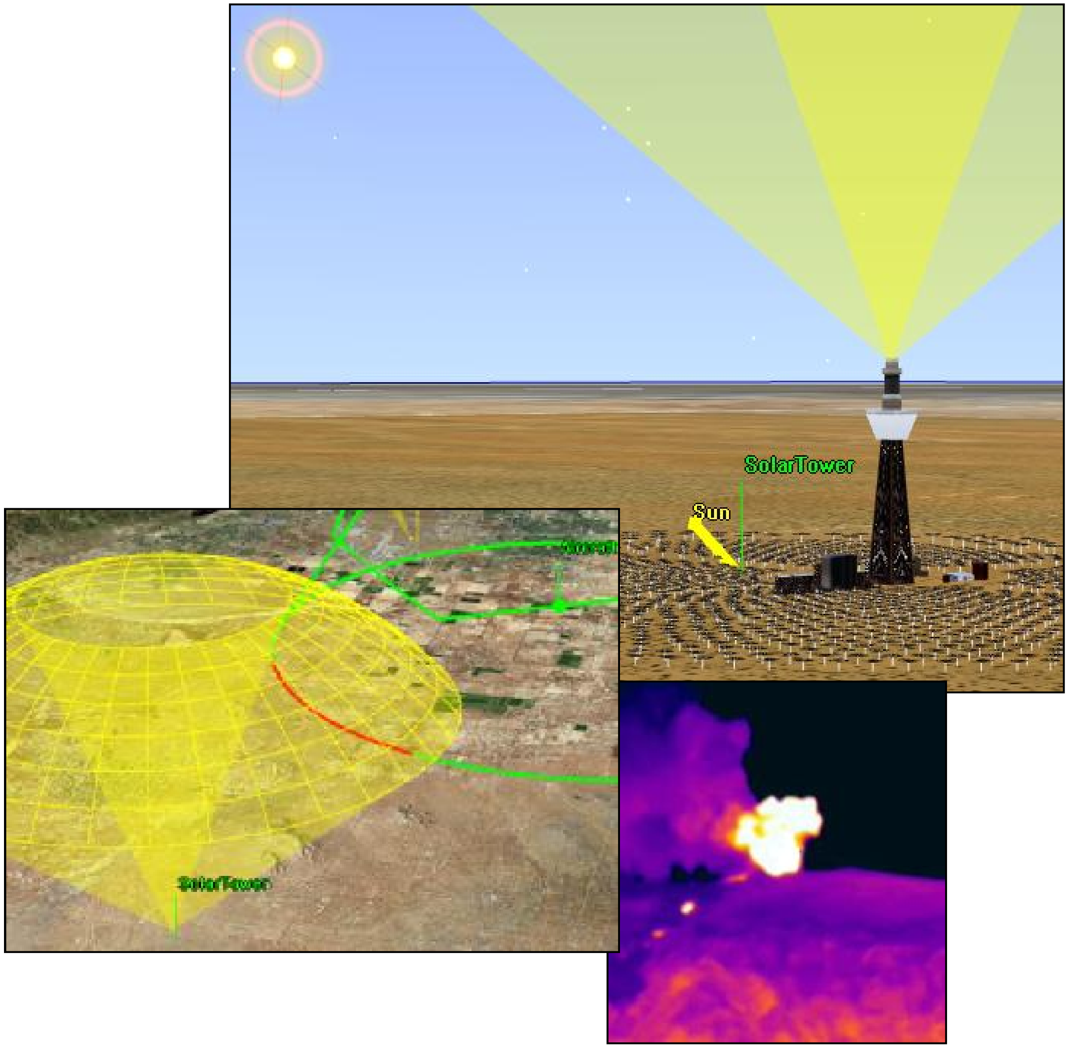
Solar Power Reflectivity Effects

- Sun position
- Reflector orientation
- Solar reflection angle
- Relative position of Asset
- Determination of Hazard



Solar Power IR Effects

- Sun position
- Reflector orientation
- Collector temperature
- IR signature
- Thermal blooming
- Relative position of Asset

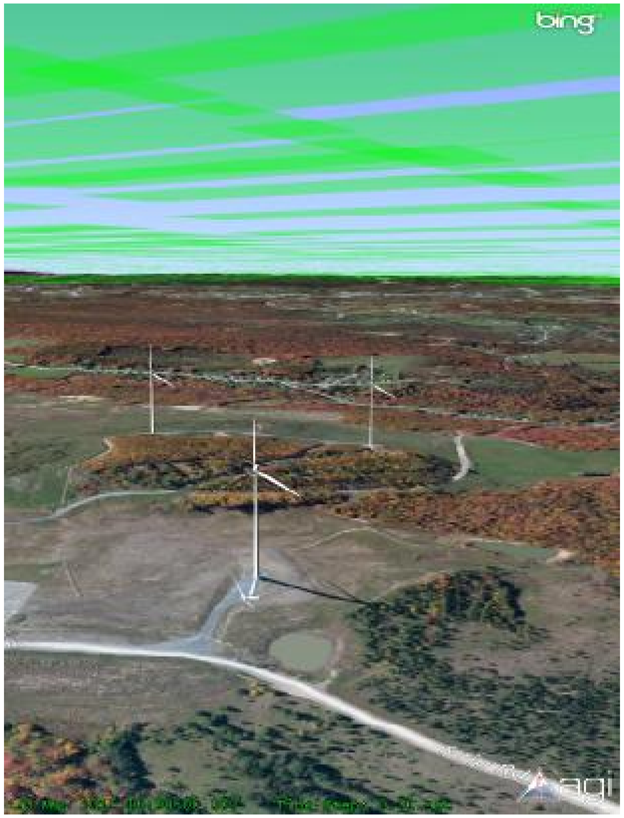


Software for Space, Defense & Intelligence

Wind/Radar Customized Solutions

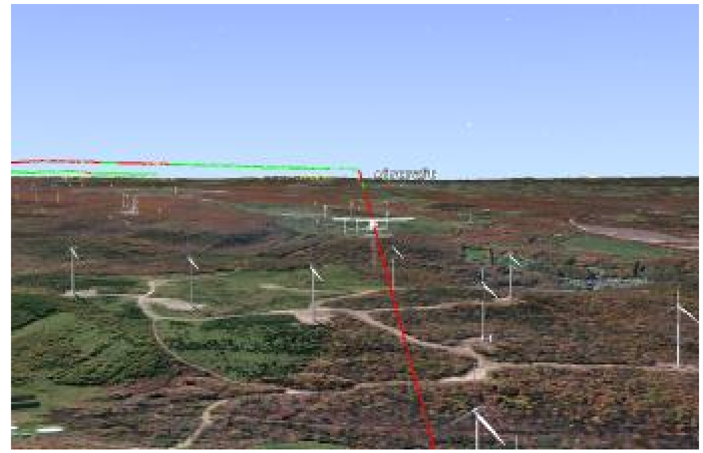
Radar Obstructions - Overview

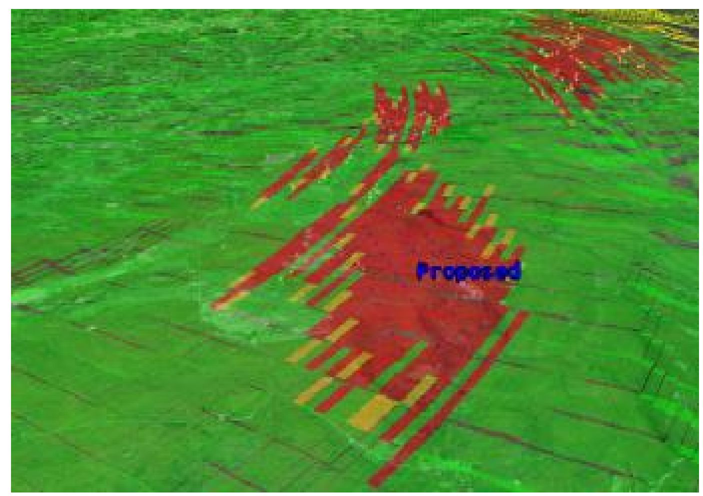
- **Wind turbines in line of sight degrade radar performance**
  - Primary wind turbine effects
    - Reduced Sensitivity (Clutter sources)
    - Screening / Shadowing
    - False Targets (Doppler spectrum)
- **Radar Advanced Processing Plugin (RAPP) capabilities**
  - Spatial / Temporal and RF Environment
    - Radar, target, and turbine location/orientation
      - Dwell/pulse, RCS, nacelle/blade relationship
    - Atmospheric propagation and refraction
    - Terrain masking and diffraction
  - Land Clutter: Billingsley Surface Clutter Model
    - Various land/surface classifications
  - Turbine Clutter
    - Interferer size, shape, speed (RCS and Doppler)



Usage of the Wind/Radar UI Plugin

- **Rapid evaluation of existing or proposed wind farm effects to radar detection capabilities**
  - Along routes: Performs a flight path analysis along a specific route.
  - Over areas: Performs an area analysis in a circular grid surrounding a radar at a defined altitude.
- **Measurable Results**
  - Probability of detection
  - Turbine interference power
  - Integrated signal power
  - Clutter power
- **Supported activities**
  - Air traffic and defense planning
  - Range sustainment
  - Wind farm developer planning
  - Radar designers/manufacturers/consultants

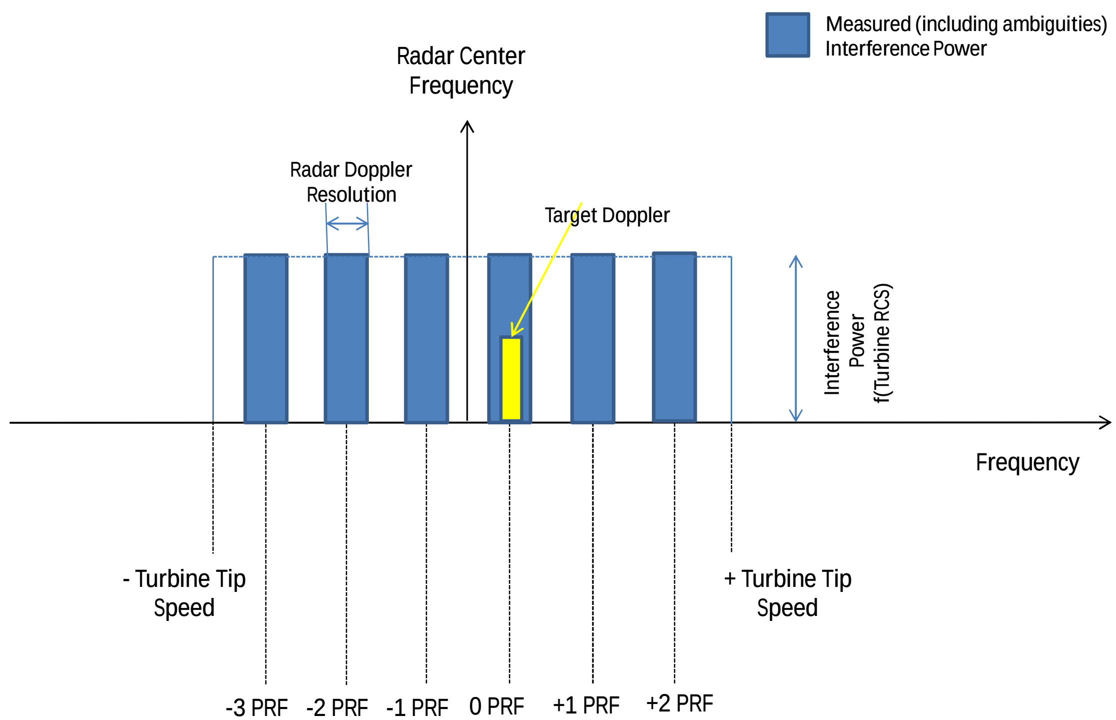




Radar Advanced Processing Plugin (RAPP)

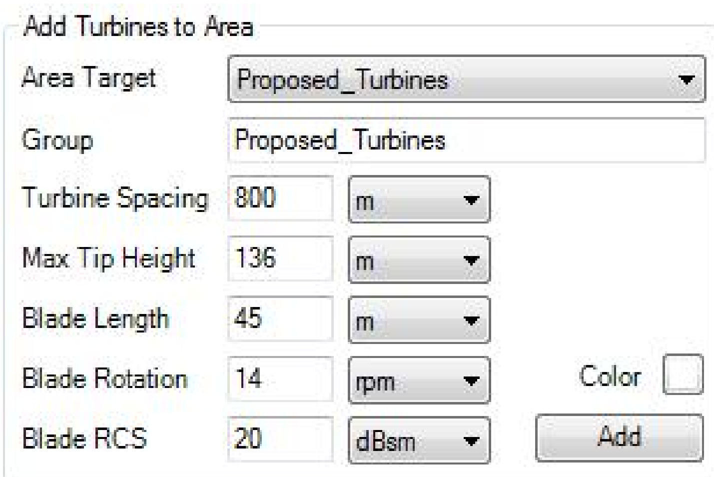
- **Turbines are modeled as interference sources with a power spectrum.**
  - Turbine Blade Length and RPM - This determines the tip speed of the turbine blades which affects the width of the Doppler spectrum before accounting for turbine nacelle orientation relative to the radar
  - Turbine Nacelle Orientation – This is determined by wind direction and affects the blade orientation relative to the radar.
    - When the turbine disk is normal to the radar line of sight (LOS), there will be no width to the spectrum.
    - When the disk is parallel to the LOS, the radar will see both retreating and advancing blades at the full tip speed, resulting in a spectrum spanning the corresponding Doppler shifts of advancing and retreating tips.
  - Turbine Visibility - Terrain may limit visibility of the wind turbine blades.
    - If the top of the turbine disk is below the radar horizon, the disk is excluded from consideration.
    - If the midpoint of the turbine (the nacelle) is below the radar horizon, the reflected power from the turbine is reduced in half. The spectrum is not modified. This results in a conservative “worst case” calculation
  - Turbine RCS - In combination with the incident radar power, this determines the amplitude of the spectrum.

RAPP - Turbine Frequency Spectrum

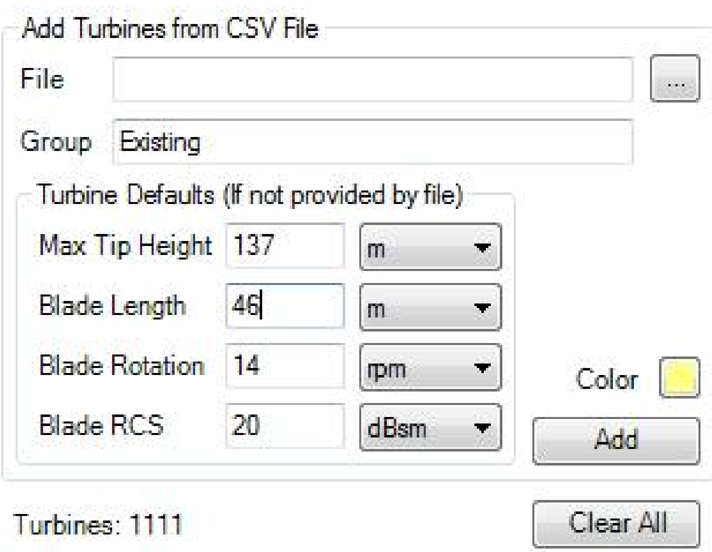


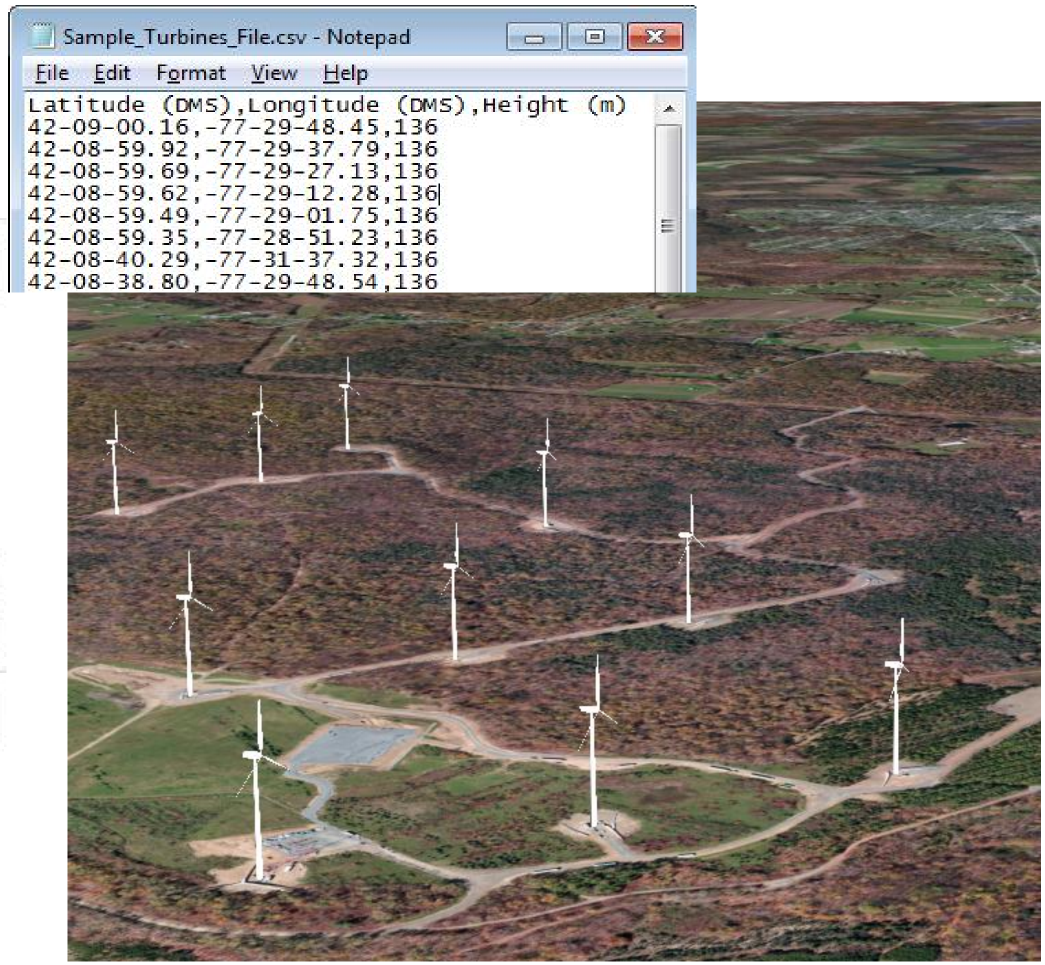
- The turbine frequency spectrum exhibits constant power over the bandwidth defined by the min/max Doppler of the turbine blade tips.
- In the future, the RAPP will apply blade RCS spectral scaling and aspect-dependency, where blade velocity, visibility, and orientation will provide for power variation across the bandwidth

Filling an area target and with turbines for a rapid “what if” analysis



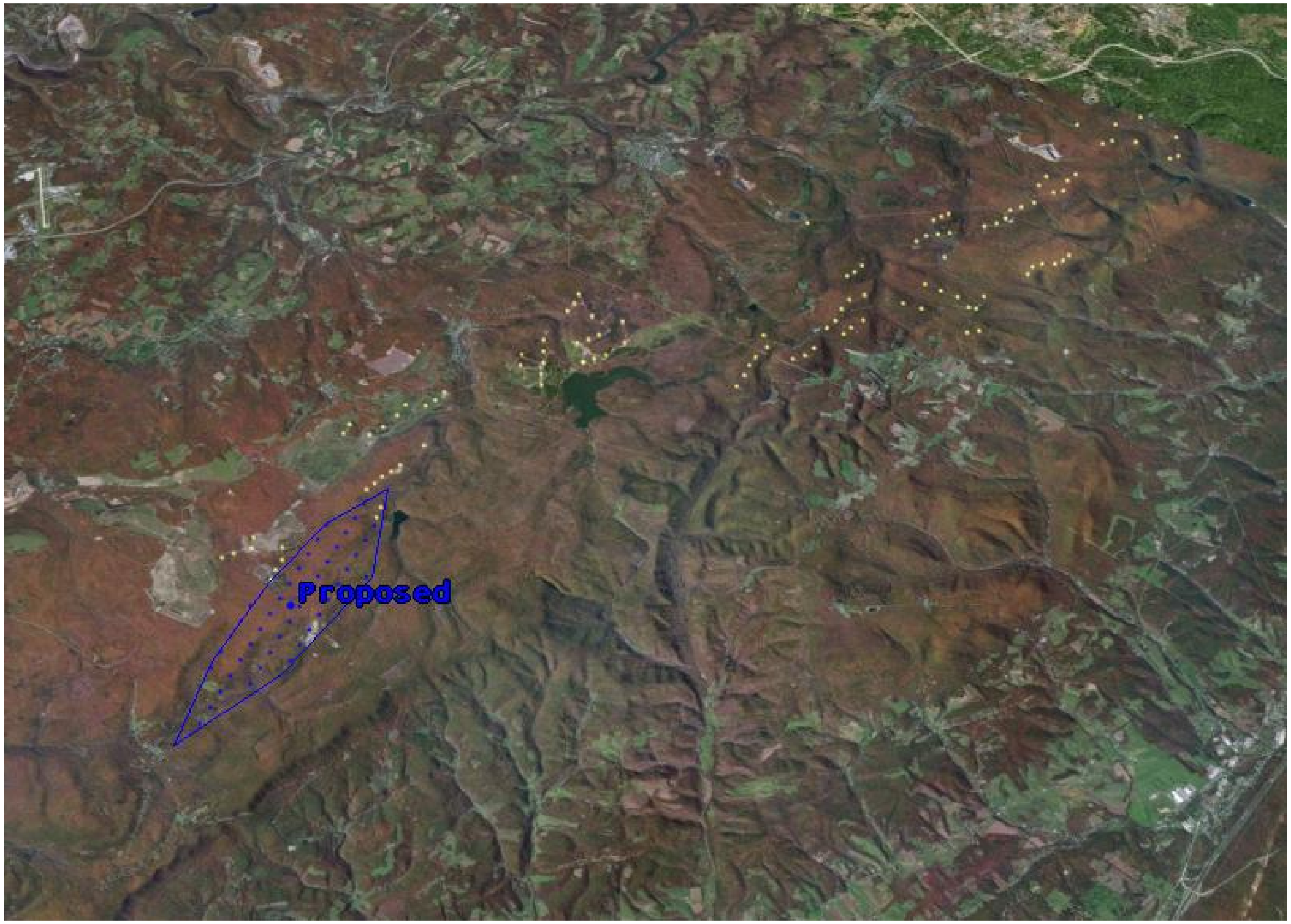
If available, coordinates can be imported via a text (CSV) file.





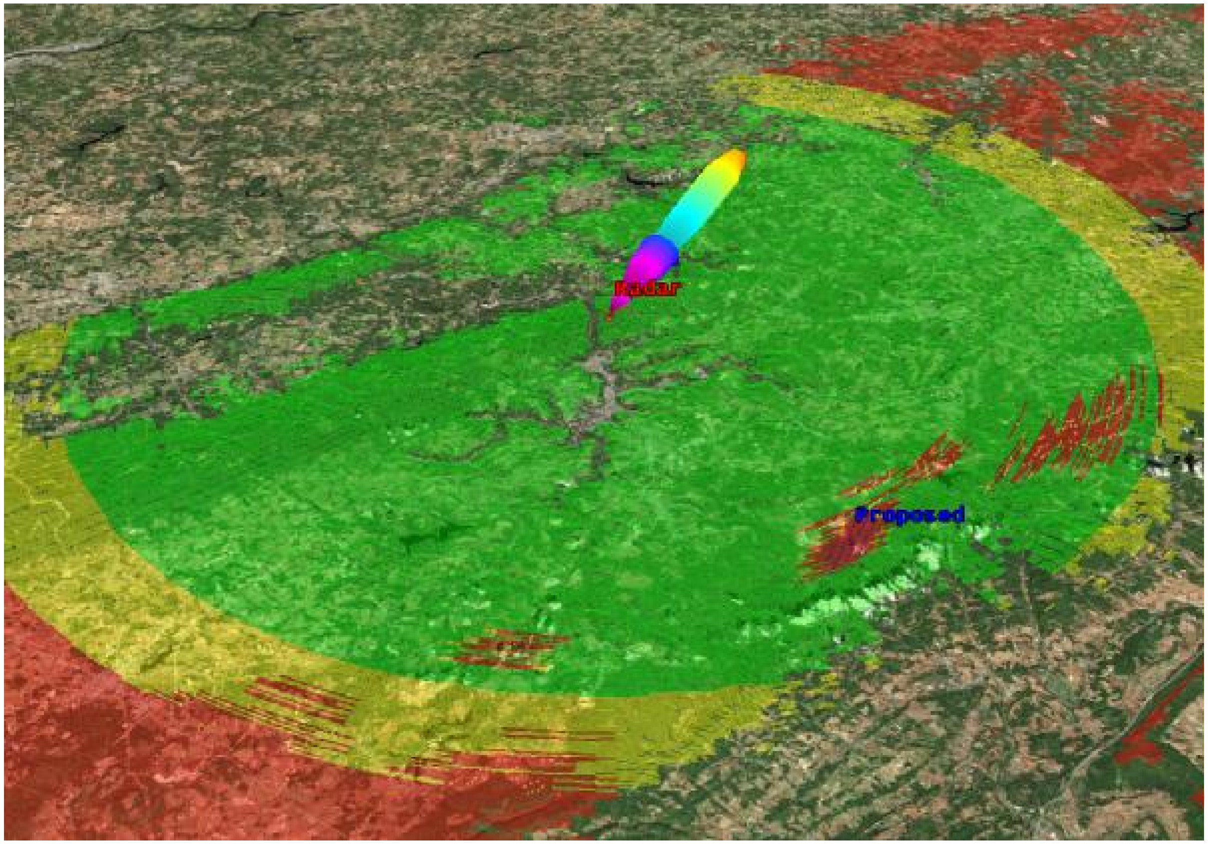
Turbine Group Identification

Turbines can be grouped for analyses

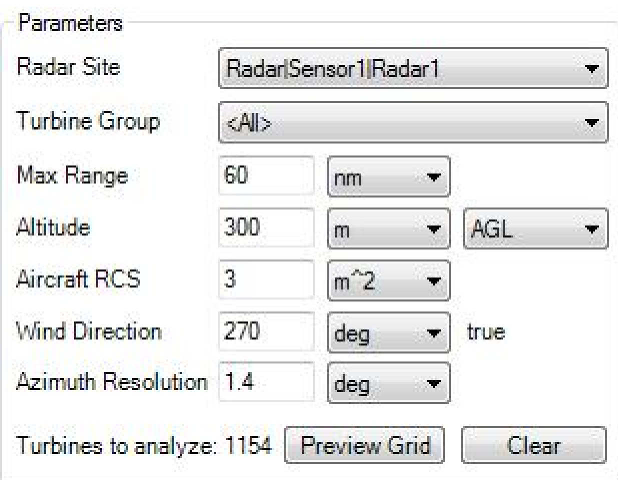


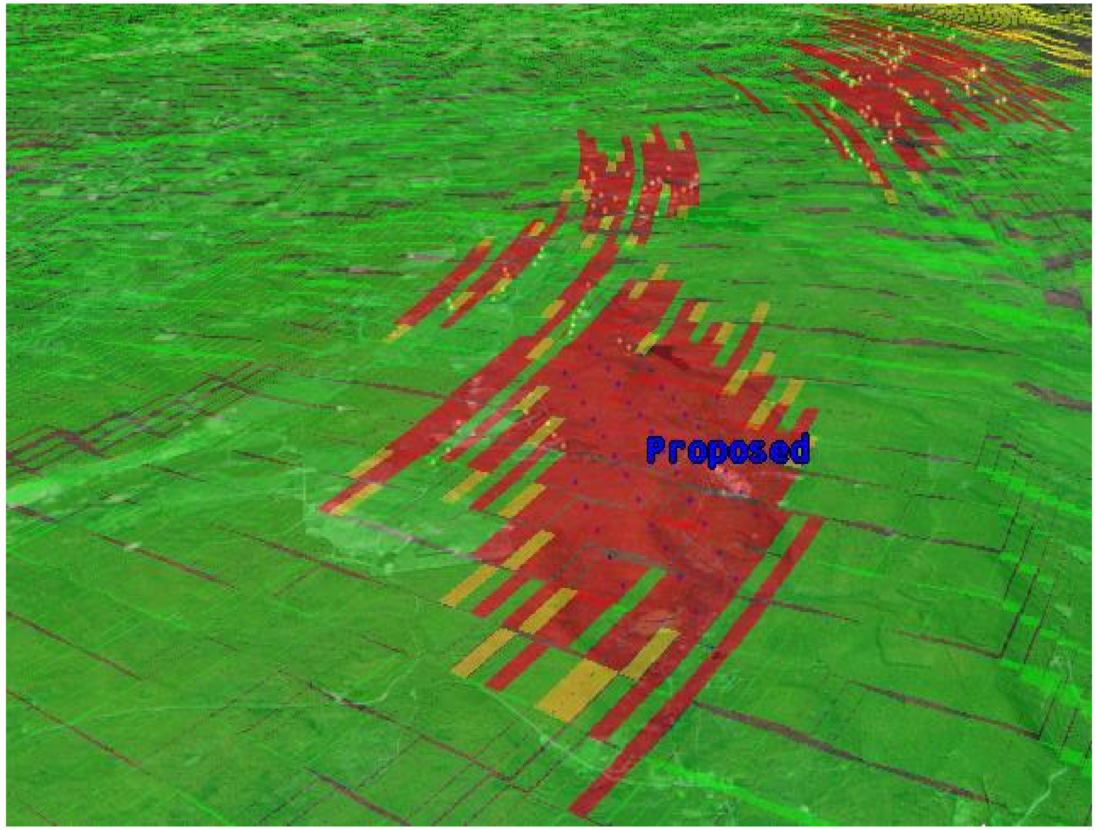
Area Analysis

Area analysis plots around the radar according to the radar's azimuth/range resolutions, propagation loss, and terrain diffraction.



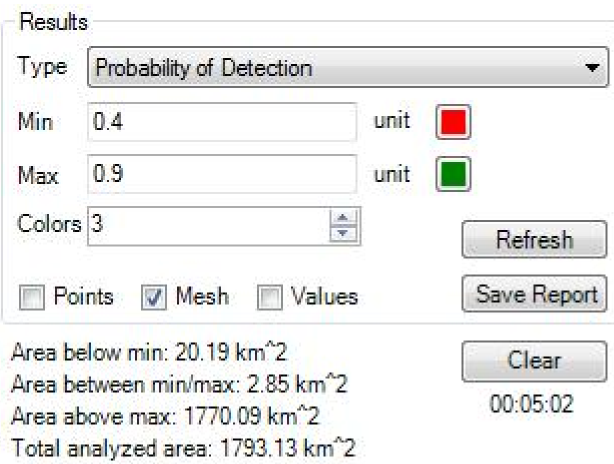
§ User configurable parameters

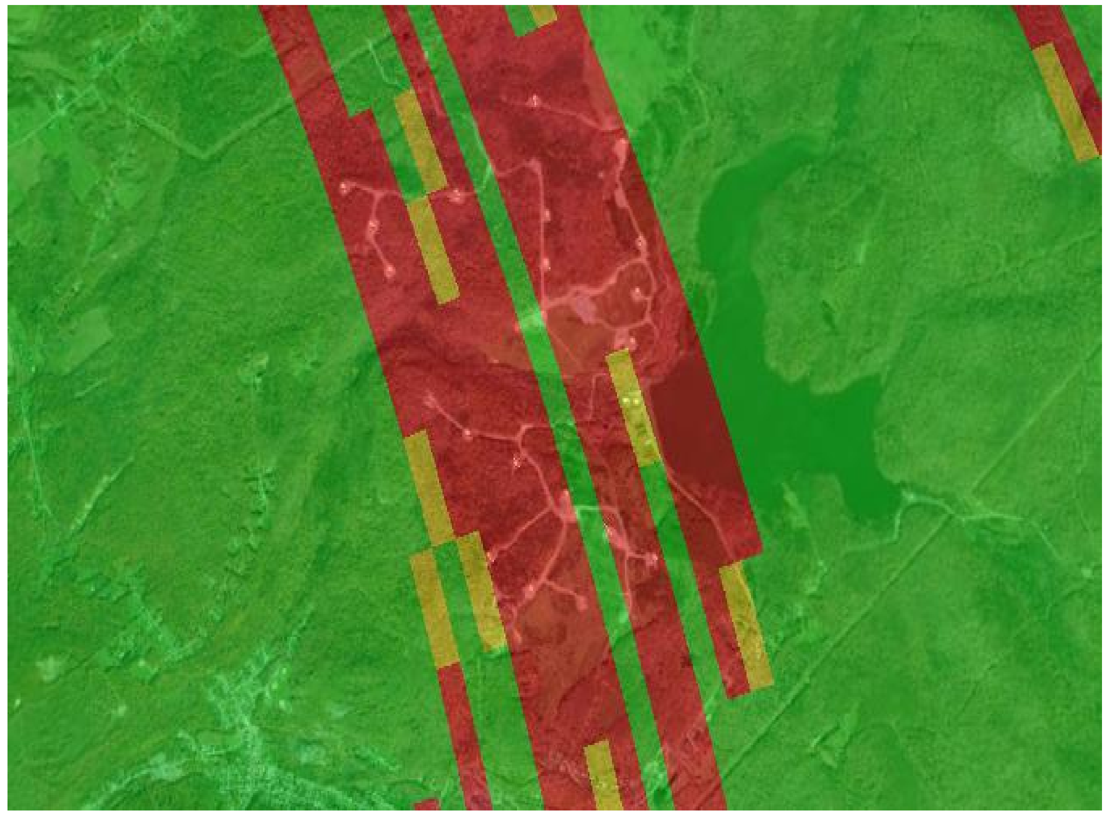




Area Analysis

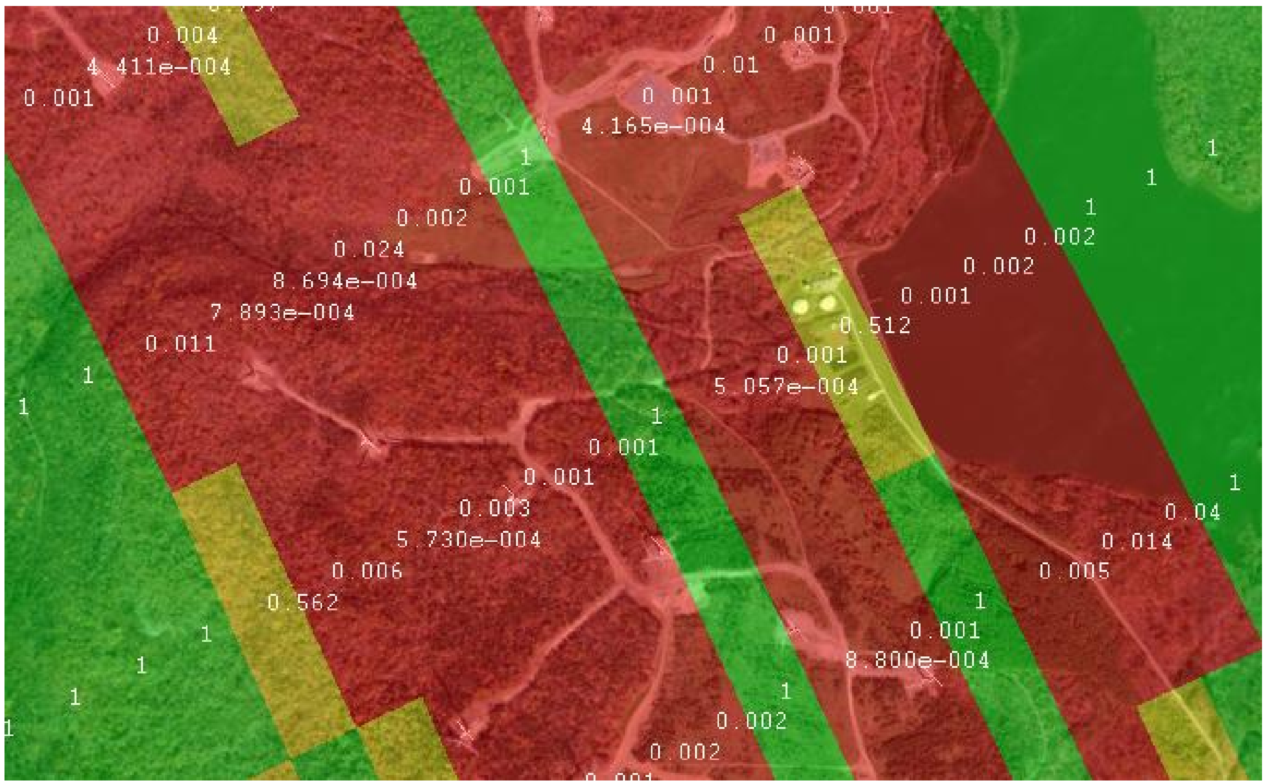
§ Colors ranges of plots are user selectable.





Area Analysis

Values optionally displayed upon zooming in close to resolution cells. *Note 100% PD (green) in image below, possible currently as ground clutter is not being considered. Future versions will take ground clutter into consideration.*

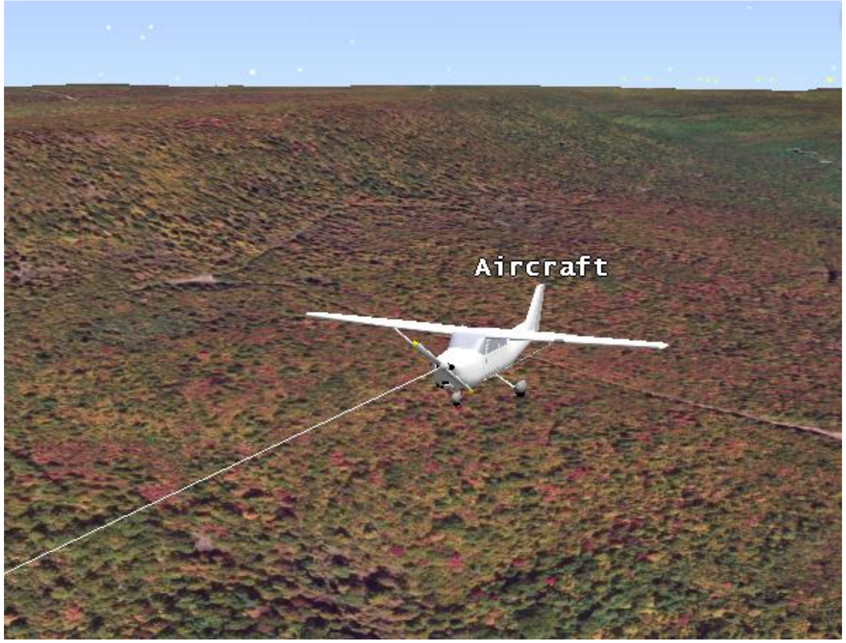


Flight Path Analysis

Example scenario is of a small aircraft flying at 300m AGL, exploiting terrain and wind farms to attempt to avoid detection en route to a target in Southwestern PA, USA.

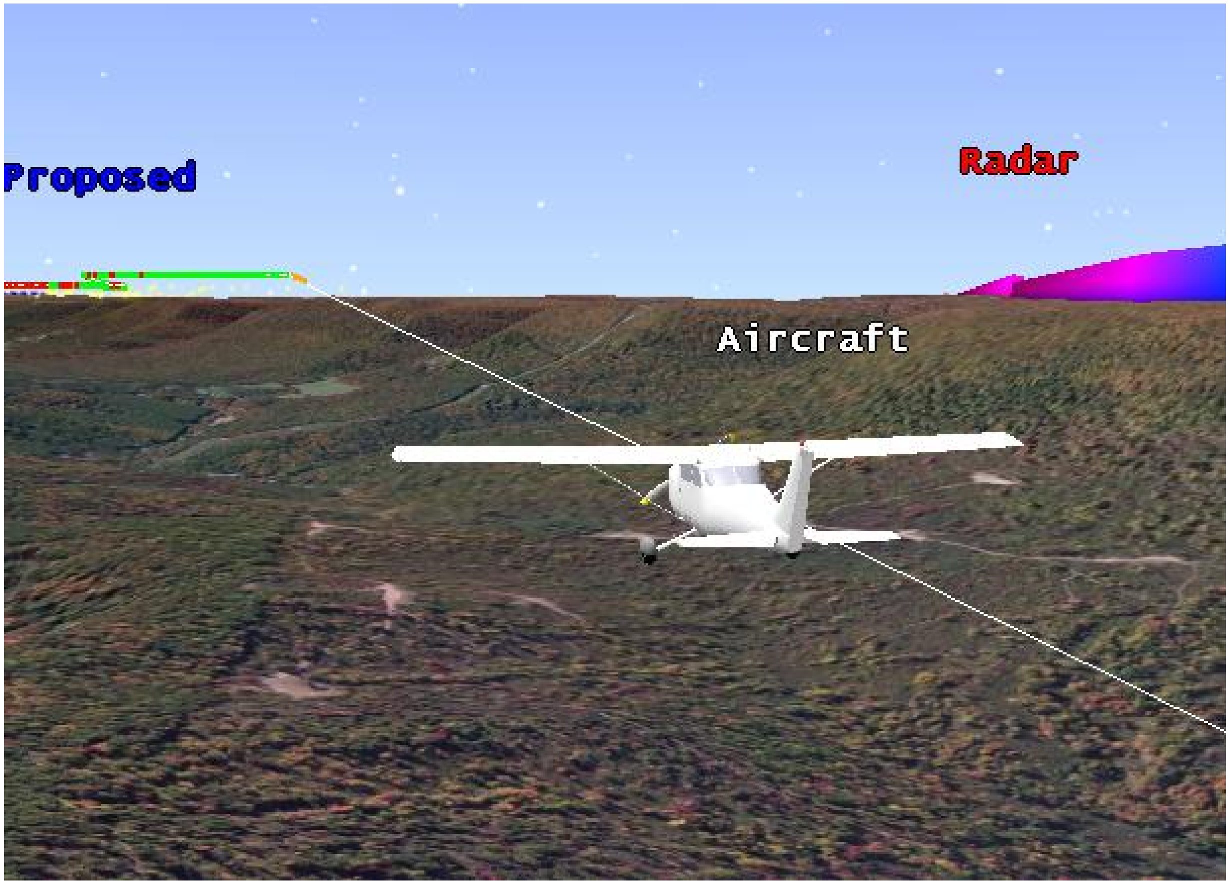
Notional data used, including the location of the radar.

Radar model is also completely notional.



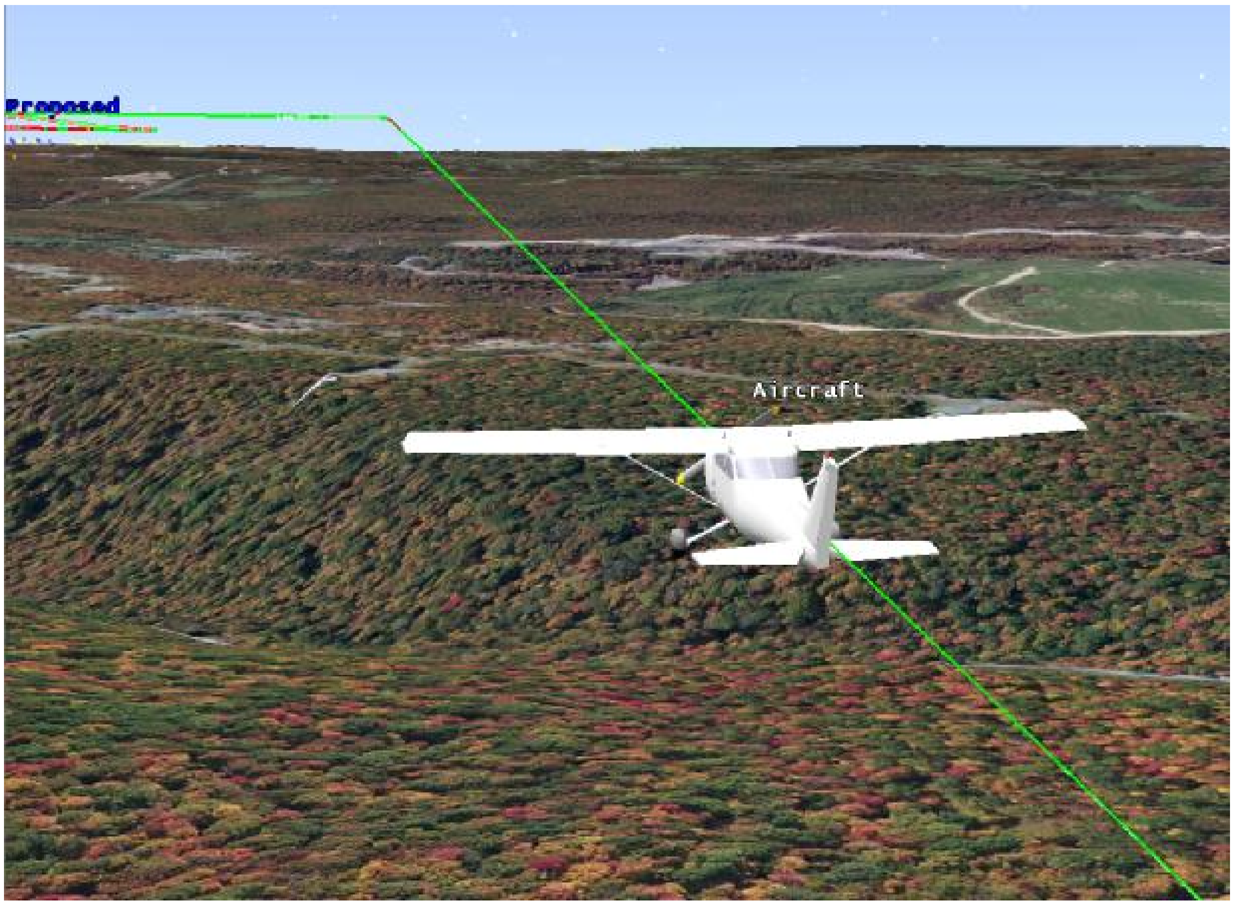
Flight Path Analysis

No color on flight path: Obscured by terrain



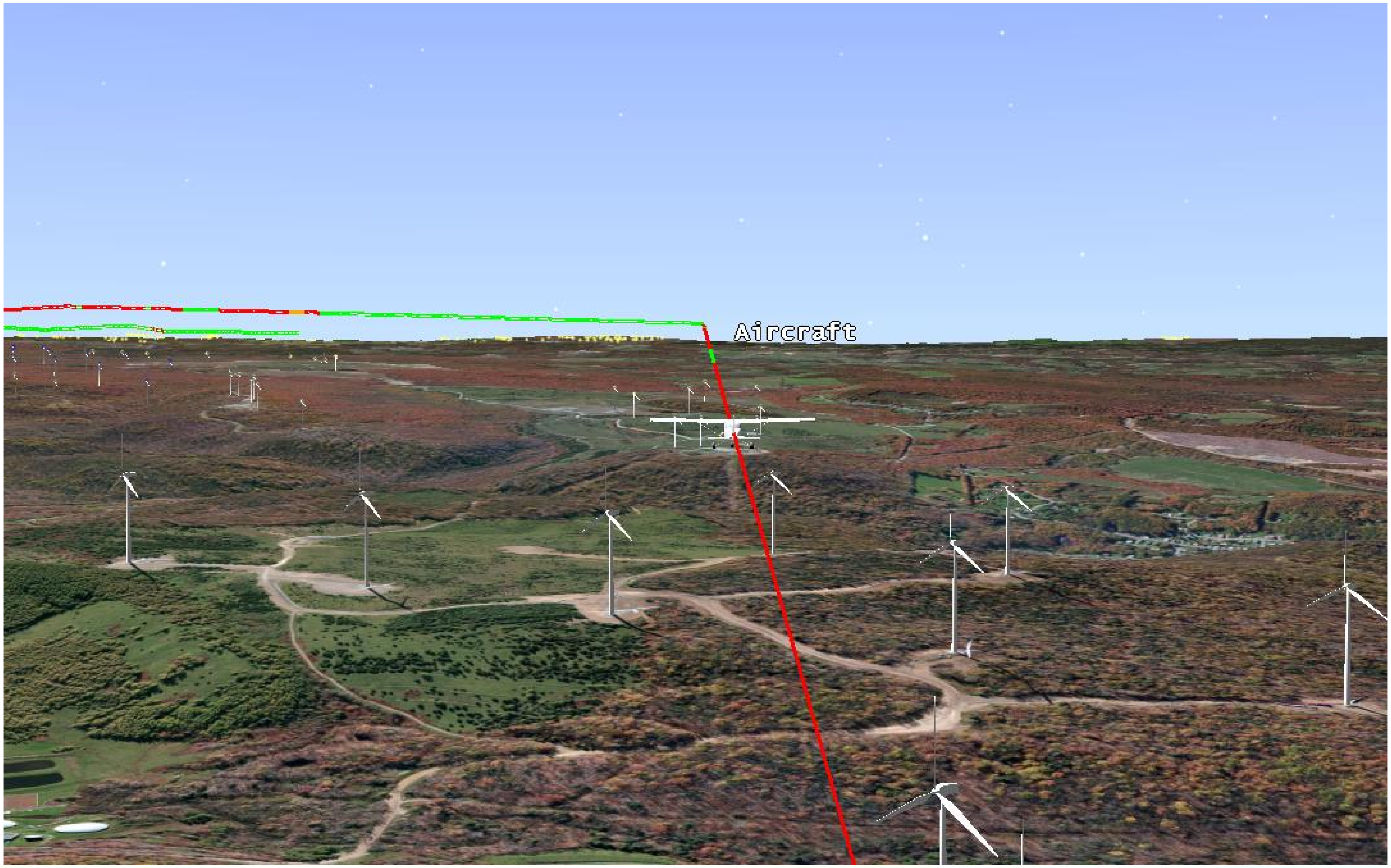
Flight Path Analysis

Colors on line below are a Propability of Detection (PD) analysis with green being > 90% PD.



Flight Path Analysis

PD degredation occurring above turbines. (Generic radar model used.)

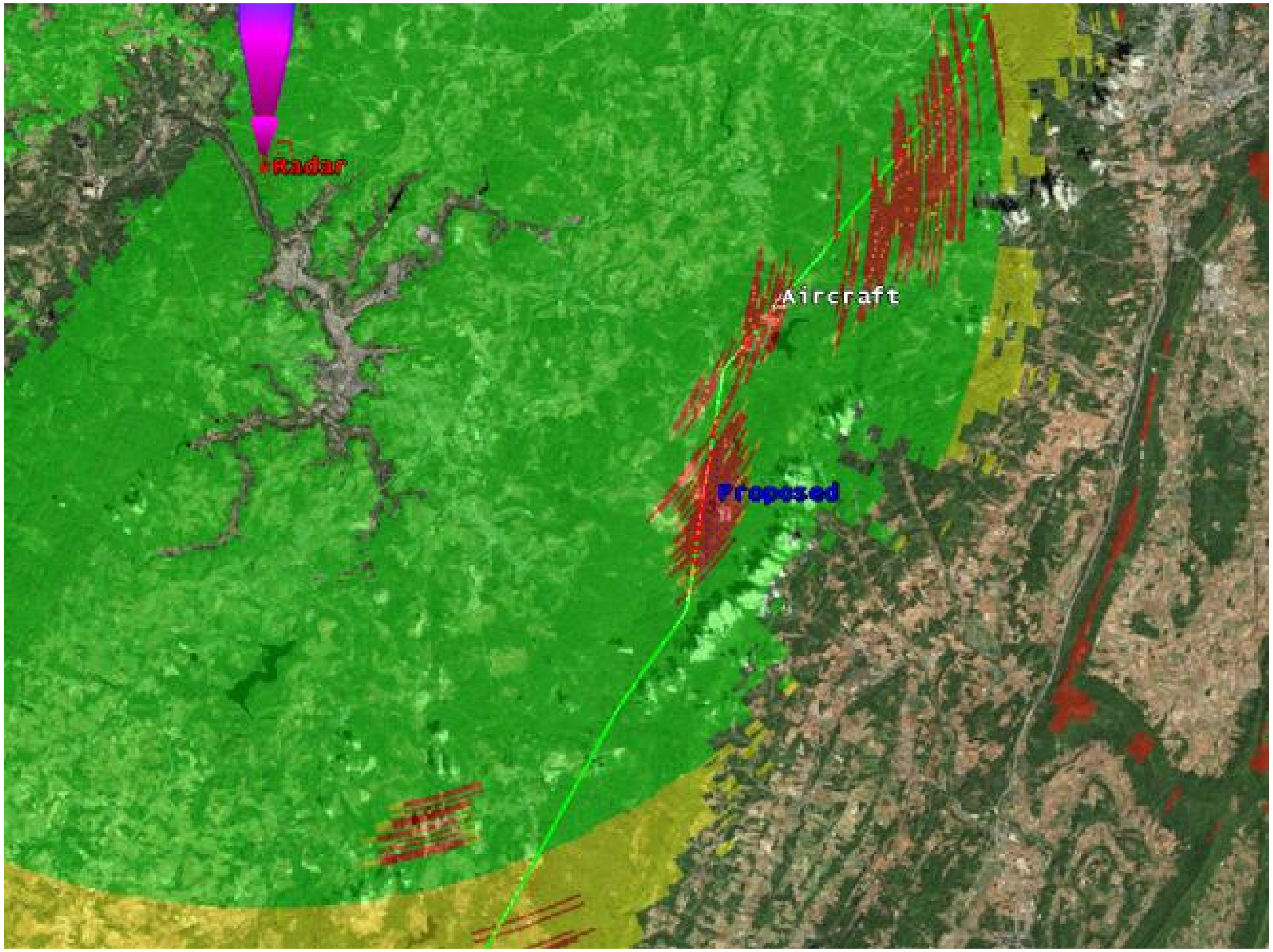


Flight Path Analysis

View from directly above. (Generic radar model used.)

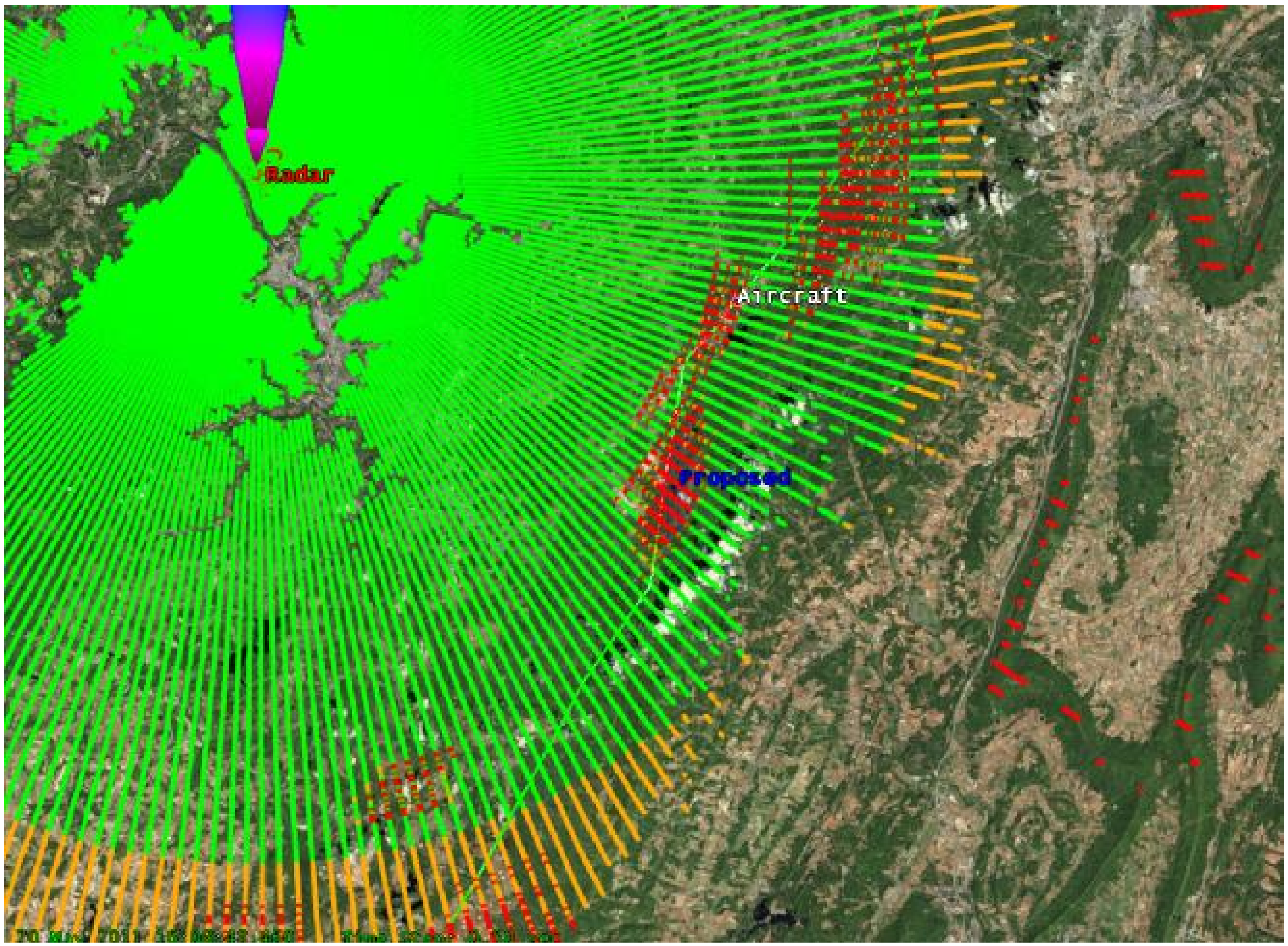
Additional Output Examples

Area plot and flight path combined.



Additional Output Examples

Points drawn vs. mesh.



Additional Output Examples

Area Analysis Data in CSV Format

	A	B	C	D	E	F	G	H	I	J
1	Area Analysis Report: Radar									
2										
3	Units:									
4	Angle: deg									
5	Distance: nm									
6	Height Reference: [WGS84]									
7										
8	Radar Coordinates									
9	Latitude: 40.394									
10	Longitude: -78.9599									
11	Height (WGS84): 0.390393068352809									
12										
13	Radar Azimuth Resolution: 1.4									
14	Radar Range Resolution: 0.0809371886509071									
15										
16	Analysis Surface Height: 0.329157607388609									
17	Analysis Surface Height Reference: AGL									
18										
19	Analysis Results									
20	Latitude	Longitude	Height (WGS84)	Azimuth from Ra	Range from Radi	Ground Clutter Po	Integrated Signal	Noise Power (W)	Probability of De	Single Pulse Sign
21	40.394	-78.9599	0.725550756	0	0.080937139	0	0	4.00E-15	0	0
22	40.394	-78.9599	0.725550756	0	0.161874077	0	0	4.00E-15	0	0
23	40.394	-78.9599	0.725550756	0	0.242811466	0	0	4.00E-15	0	0
24	40.394	-78.9599	0.725550756	0	0.323749055	0	0	4.00E-15	0	0
25	40.39880055	-78.9599	0.708297208	0	0.404687443	0	7.10E-15	4.00E-15	0.007157361	7.10E-15
26	40.40035106	-78.9599	0.697305999	0	0.485624932	0	7.38E-15	4.00E-15	0.013037583	7.38E-15
27	40.40214771	-78.9599	0.683345061	0	0.566562421	0	1.64E-16	4.00E-15	0.000136054	1.64E-16
28	40.40367164	-78.9599	[illegible]	0	0.647499909	0	1.58E-13	4.00E-15	[illegible]	1.58E-13
29	40.40503712	-78.9599	0.604247507	0	0.728437398	0	1.95E-14	4.00E-15	0.149679162	1.95E-14
30	40.40655841	-78.9599	[illegible]	0	0.809374887	0	1.31E-14	4.00E-15	[illegible]	1.31E-14
31	40.4080387	-78.9599	0.606178358	0	0.890312375	0	2.78E-13	4.00E-15	1	2.78E-13
32	40.40954096	-78.9599	0.670418554	0	0.971249864	0	7.78E-16	4.00E-15	0.000346146	7.78E-16
33	[illegible]	-78.9599	[illegible]	0	[illegible]	0	1.04E-12	4.00E-15	1	1.04E-12
34	40.41240736	-78.9599	0.628579222	0	1.133124841	0	1.73E-12	4.00E-15	1	1.73E-12
35	[illegible]	-78.9599	[illegible]	0	1.21406233	0	1.15E-12	4.00E-15	1	1.15E-12
36	40.41519716	-78.9599	0.644806034	0	1.294999819	0	7.55E-13	4.00E-15	1	7.55E-13
37	40.41656222	-78.9599	0.647766741	0	1.375937307	0	3.34E-13	4.00E-15	1	3.34E-13
38	40.41791353	-78.9599	0.644154606	0	1.456874796	0	4.13E-14	4.00E-15	0.642117064	4.13E-14
39	40.4193324	-78.9599	0.636085473	0	1.537812285	0	1.70E-20	4.00E-15	1.00E-04	1.70E-20
40	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Additional Output Examples

Flight Path Analysis Data in CSV Format

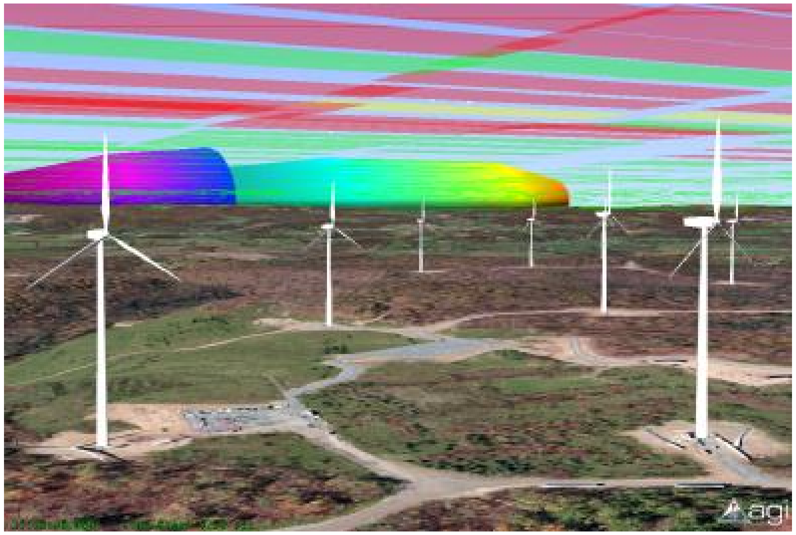
	A	B	C	D	E	F	G	H	I	J	K
1	Aircraft Analysis Report										
2	Radar: Radar										
3	Aircraft: Aircraft										
4											
5	Units:										
6	Angle: deg										
7	Distance: nm										
8	Height Reference: (WGS84)										
9											
10	Radar Coordinates										
11	Latitude: 40.394										
12	Longitude: -78.9599										
13	Height (WGS84): 0.396393088552856										
14											
15	Radar Azimuth Resolution: 1.4										
16	Radar Range Resolution: 0.0809374886609071										
17											
18	Analysis Results										
19	Latitude	Longitude	Height (WGS	Azimuth fron	Range from F	Ground Clutt	Integrated Si	Noise Power	Probability o	Single Pulse	Turbine Inter
20	40.62533016	-78.3706226	0.403355865	62.57999993	30.32568504	0	0	0	0	0	0
21	40.62481388	-78.3712329	0.403792961	62.57999993	30.28678286	0	0	0	0	0	0
22	40.62429759	-78.3718433	0.404230057	62.57999993	30.24788803	0	0	0	0	0	0
23	40.6237813	-78.3724536	0.404667153	62.71999993	30.2090006	0	0	0	0	0	0
24	40.62326501	-78.3730639	0.405104249	62.71999993	30.17012059	0	0	0	0	0	0
25	40.62274871	-78.3736742	0.405541345	62.71999993	30.13124803	0	0	0	0	0	0
26	40.62223241	-78.3742845	0.405978441	62.71999993	30.09238294	0	0	0	0	0	0
27	40.62171611	-78.3748948	0.406415537	62.85999993	30.05352537	0	0	0	0	0	0
28	40.6211998	-78.3755051	0.406852633	62.85999993	30.01467532	0	0	0	0	0	0
29	40.62068349	-78.3761154	0.407289729	62.85999993	29.97583285	0	0	0	0	0	0
30	40.62016718	-78.3767257	0.407726824	62.85999993	29.93699796	0	0	0	0	0	0
31	40.61965087	-78.3773359	0.40816392	62.85999993	29.8981707	0	0	0	0	0	0
32	40.61913455	-78.3779462	0.408601016	62.99999993	29.8593511	0	0	0	0	0	0
33	40.61861823	-78.3785564	0.409038111	62.99999993	29.82053918	0	0	0	0	0	0
34	40.6181019	-78.3791666	0.409475207	62.99999993	29.78173497	0	0	0	0	0	0
35	40.61758557	-78.3797768	0.409912303	62.99999993	29.74293851	0	0	0	0	0	0
36	40.61706924	-78.3803871	0.410349398	62.99999993	29.70414982	0	0	0	0	0	0
37	40.61655291	-78.3809973	0.410786493	63.13999993	29.66536893	0	0	0	0	0	0
38	40.61603657	-78.3816074	0.411223589	63.13999993	29.62659588	0	0	0	0	0	0
39	40.61552023	-78.3822176	0.411660684	63.13999993	29.5878307	0	0	0	0	0	0
40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	0	0

Availability

- Currently available only with a special pre-release version of STK 10.
- Will be fully available to install without any custom installation upon STK 10.1 release.
- Custom radar models can be built to customer provided specifications.

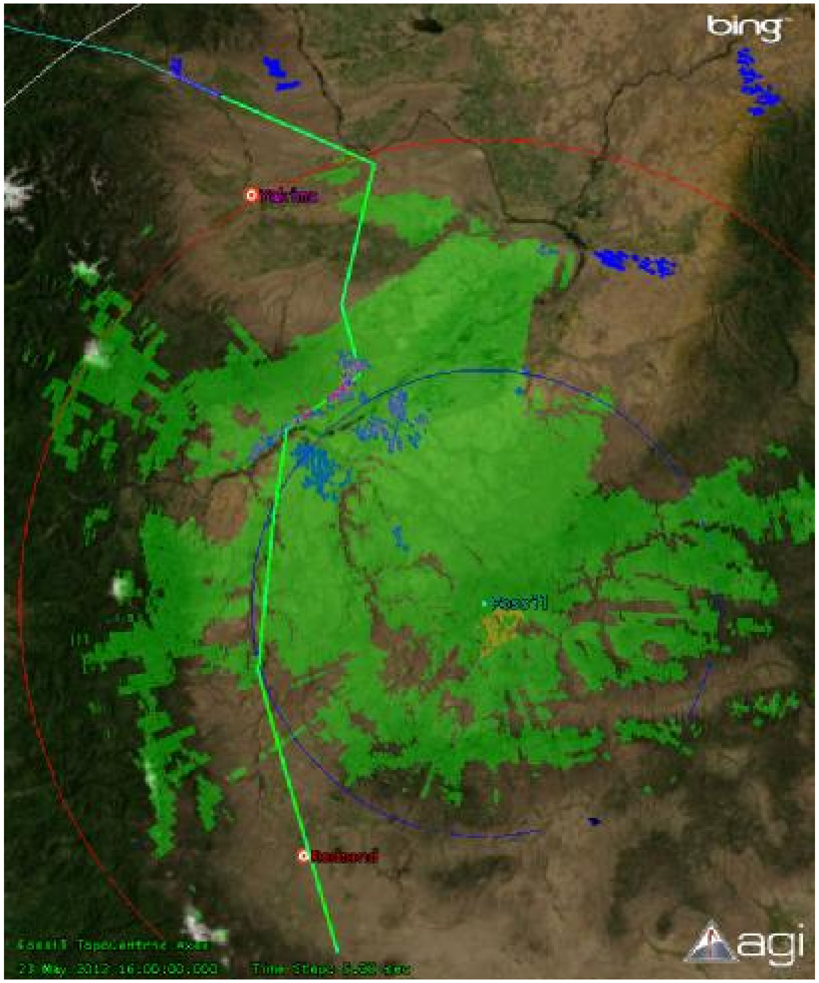
Future Plans

- Future radar processor models for the RAPP (Radar Advanced Processor Plugin)
- Ability to use aspect-dependent scattering matrix for the blades as opposed to simply scaling magnitude.

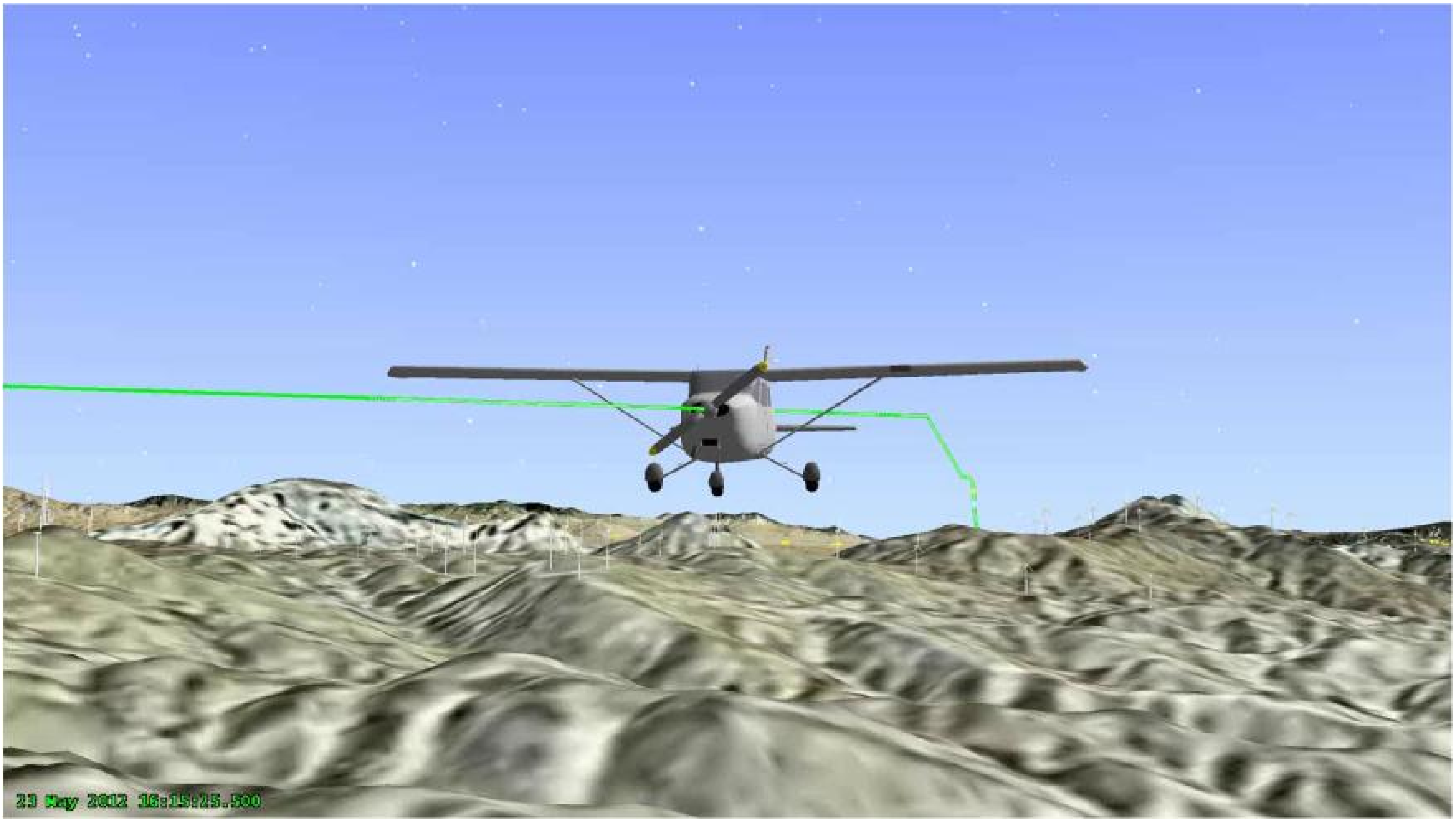


NORAD ROEMS

- **Radars modeled**
  - ARSR-4, ASR-8, ASR-9, ASR-11, CARSR, RYC-8405
- **Application**
  - STK Engine, CAF, SQL Server
  - Requires ROEMS Software Bundle
  - Distributable with NORAD permission only. NORAD is generally very willing to share with others (Five Eyes)



NORAD Radar Obstruction Evaluation Modeling System (ROEMS)



DHS WT/RMT Development

- Teamed with Raytheon and Remcom.
- Development started.
- 2 year development program.
- 4d Globe Thin Client Interface.
- Radar systems modeling.
- Ray Path analysis.
- RCS, turbine multi-bounce and multipath.
- Signal process simulators.
- A/C Doppler shift & turbine "clutter".
- Path loss propagation.
- Refraction and diffraction.