Visualizing X3D Radar Beam Model Dynamics

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Motivation and Goals

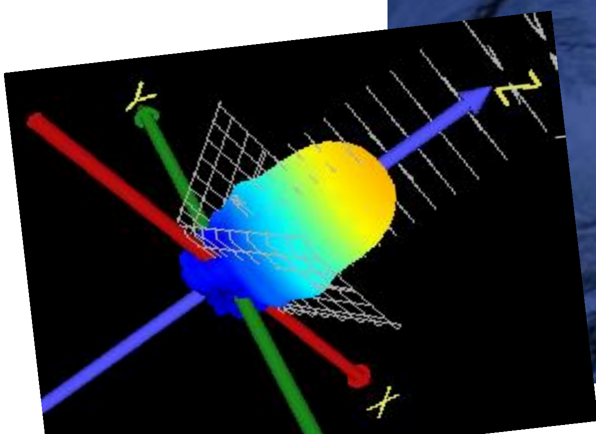
- Motivation
  - Explore various 3D visualization techniques for presenting dynamic radar characteristics.
  - “The purpose of computing is insight, not numbers.” by Richard. W. Hamming, 3rd winner of the Turing Award.

- Goal
  - Improve understanding of radar through meaningful, dynamic, physics-based presentations.
  - We will not find one single technique - it doesn’t exist! Visualization is exploration using multiple approaches.

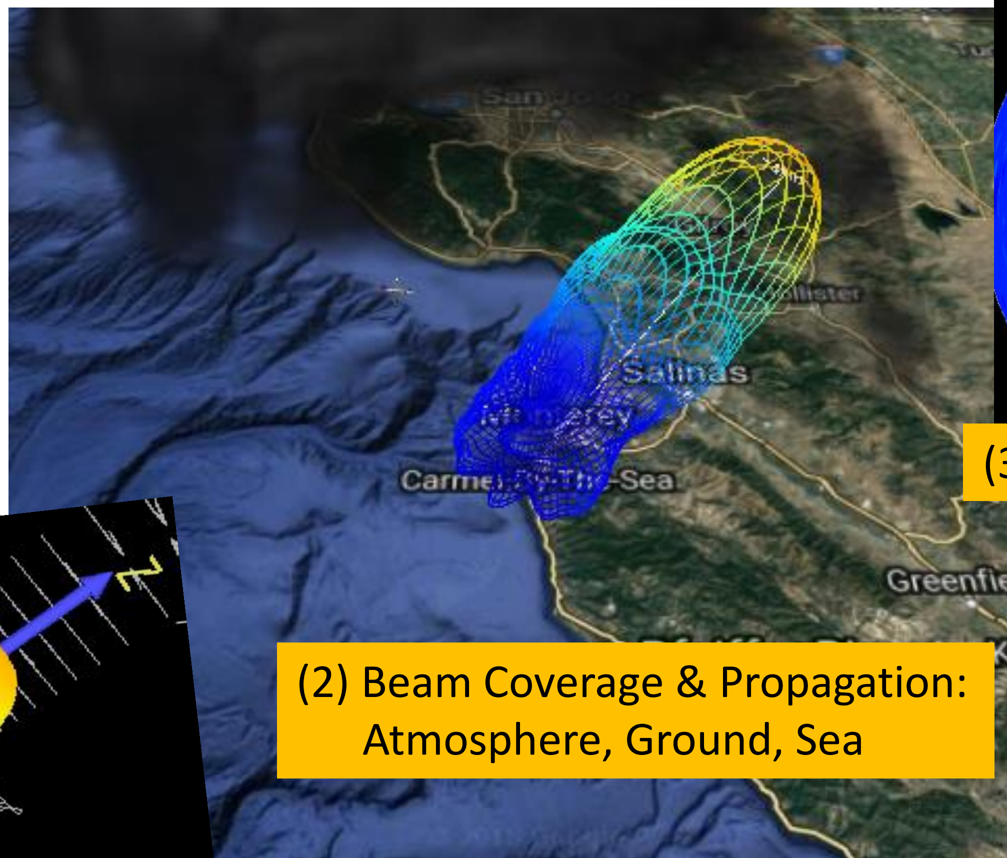
- Purpose of this briefing: we seek expert feedback on radar and 3D visualization to improve further.

3D Visualization of Radar

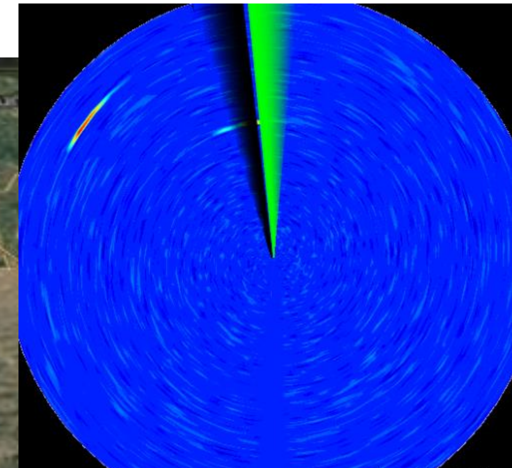
- Three categorized presentations



(1) Antenna Radiation Pattern: Shape and Power



(2) Beam Coverage & Propagation: Atmosphere, Ground, Sea

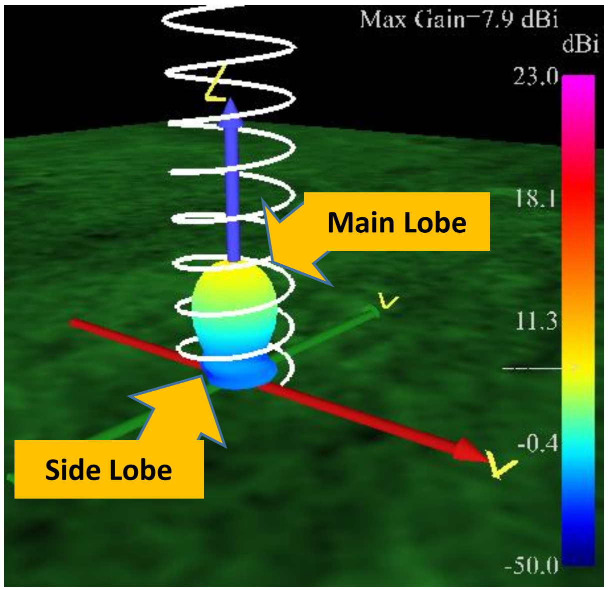


(3) Simulated Radar Screen

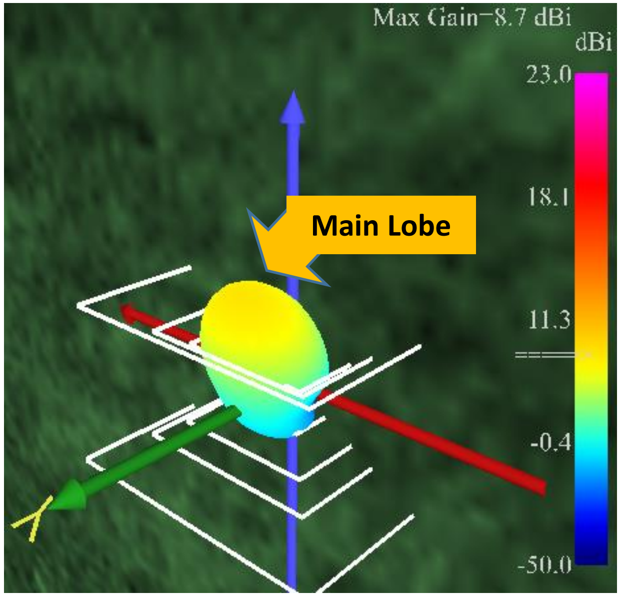
(1) Antenna Radiation Pattern

- Useful techniques
  - Fixed color map for surfaces: for easy comparison and beam consistency
  - Explicitly presentation of max gain: for easy comparison
  - Z axis beam propagation in logarithmic scales: for easy comparison
  - Line properties also can be mapped to characteristics.

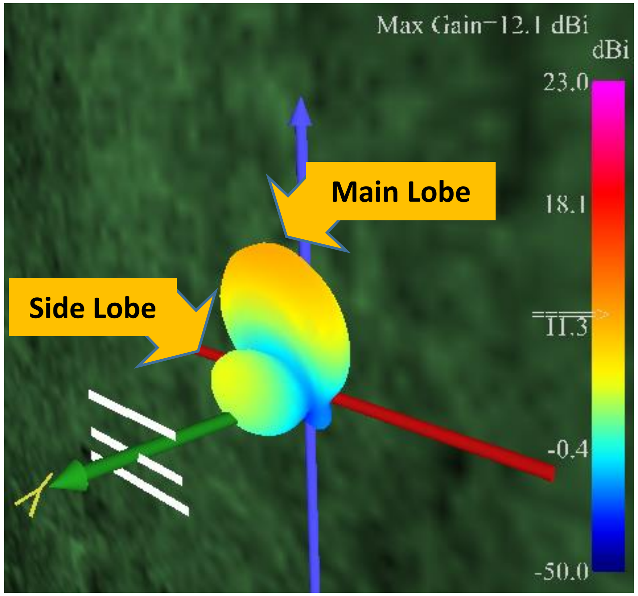
→ X3D visualizations using beam pattern examples from **4nec2.exe [1]**



<Helical Antenna>



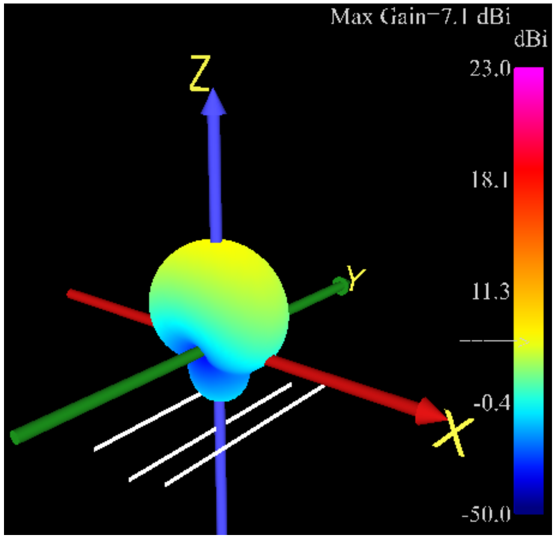
<Spider Quad Antenna>



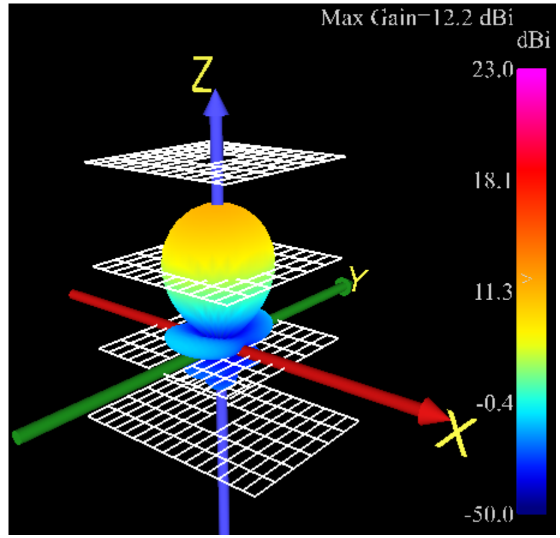
<3-Element Yagi Antenna>

[1] Arie Voors, http://www.qsl.net/4nec2/

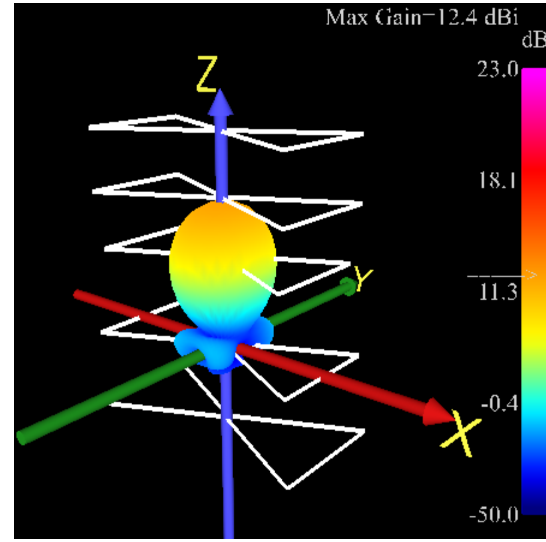
Examples continued for various antenna



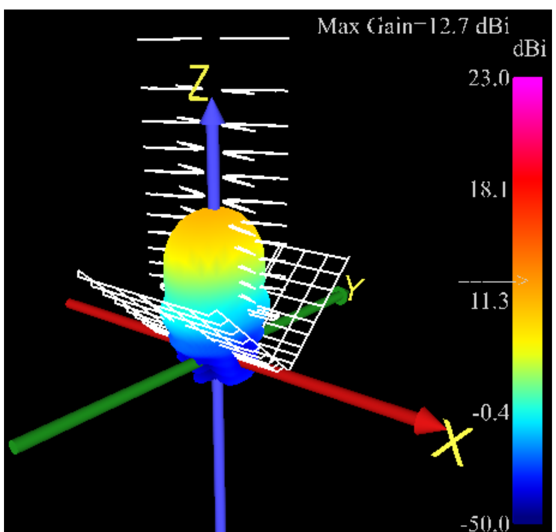
<NecVerticalYagi3Element.x3d>



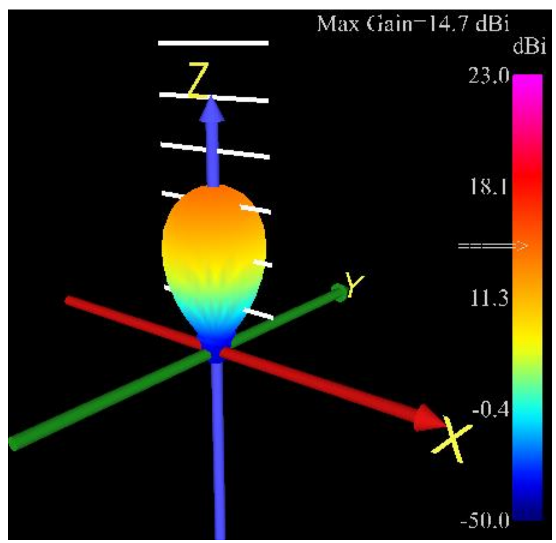
<NecGridYagiWireFence.x3d>



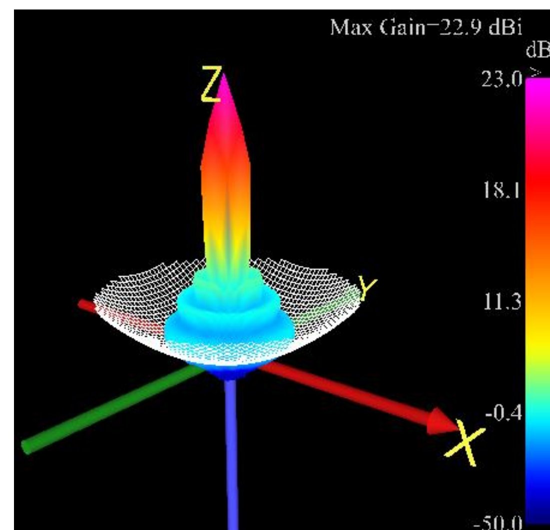
<Nec5ElementTwinDeltaLoop2m.x3d>



<NecBowtieXg91a.x3d>



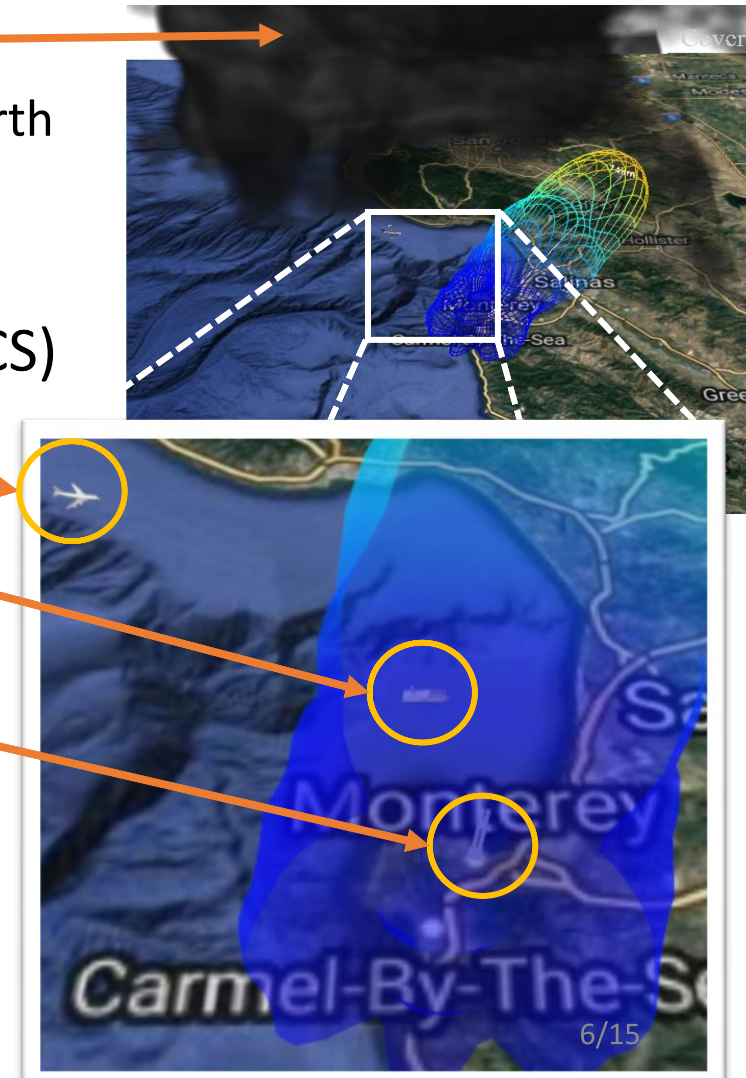
<NecTvUhf.x3d>



<NecParabola50x50.x3d>

(2) Beam Coverage & Propagation - Scenario for proposed techniques

- Weather Effects
  - Thick precipitation cloud [2] to the North
  - Additional parameters possible
- Objects and Radar Cross Section (RCS)
  - Airplane (RCS : 1.6)
  - Cruise ship (RCS : 2.2)
- Long Range Antenna
  - Spanagel Hall, NPS, Monterey
  - 1 revolution per 12 sec.
  - 1 revolution for Cruise ship and 1 resolution for Airplane



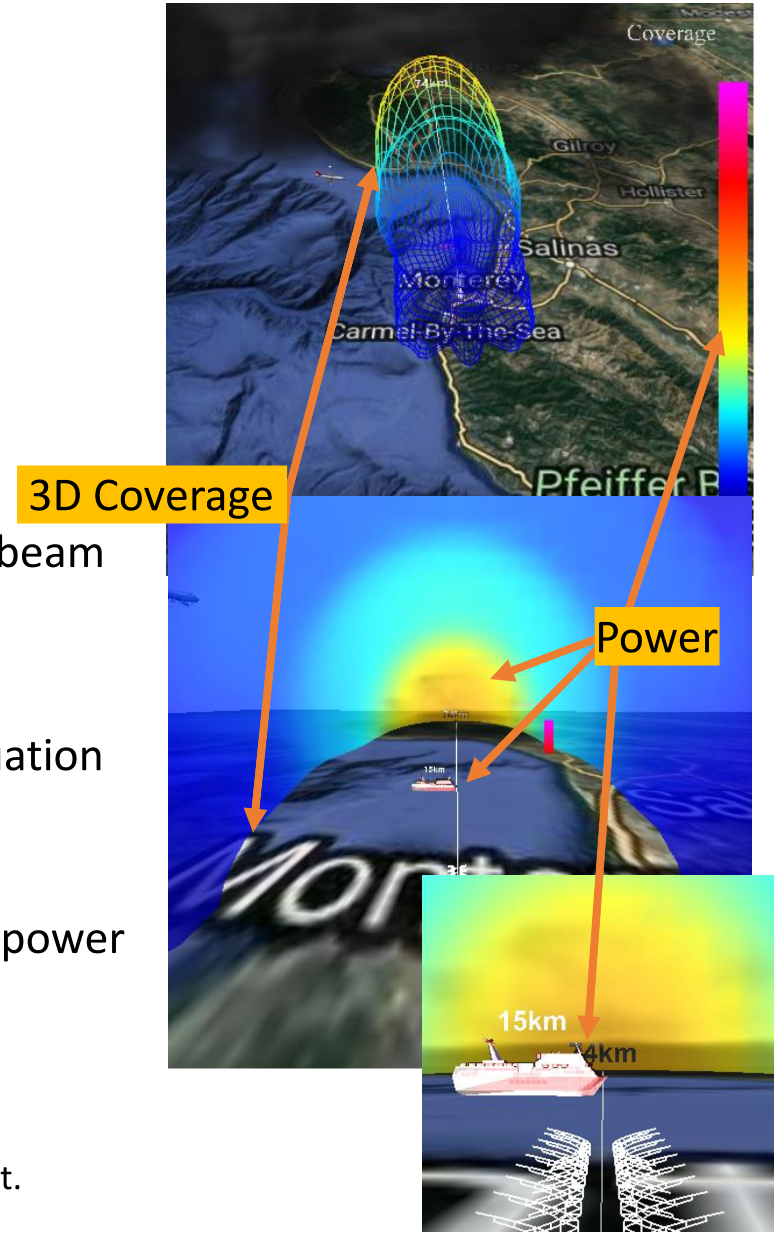
[2] Yeonsoo Yang, http://examples.x3dom.org/example/RadarVolumeStyle

Useful techniques

- **3D coverage envelop over the map**
  - To present 3D range that radar can detect
- **Variant color on objects**
  - To present power level to be delivered
  - Intuitive way to visualize power inside radar beam
- **Bent radar beam**
  - To show effects of weather condition (attenuation and refractive)
- Goal : Effective Visualization to show 'how much power is delivered to some point?'

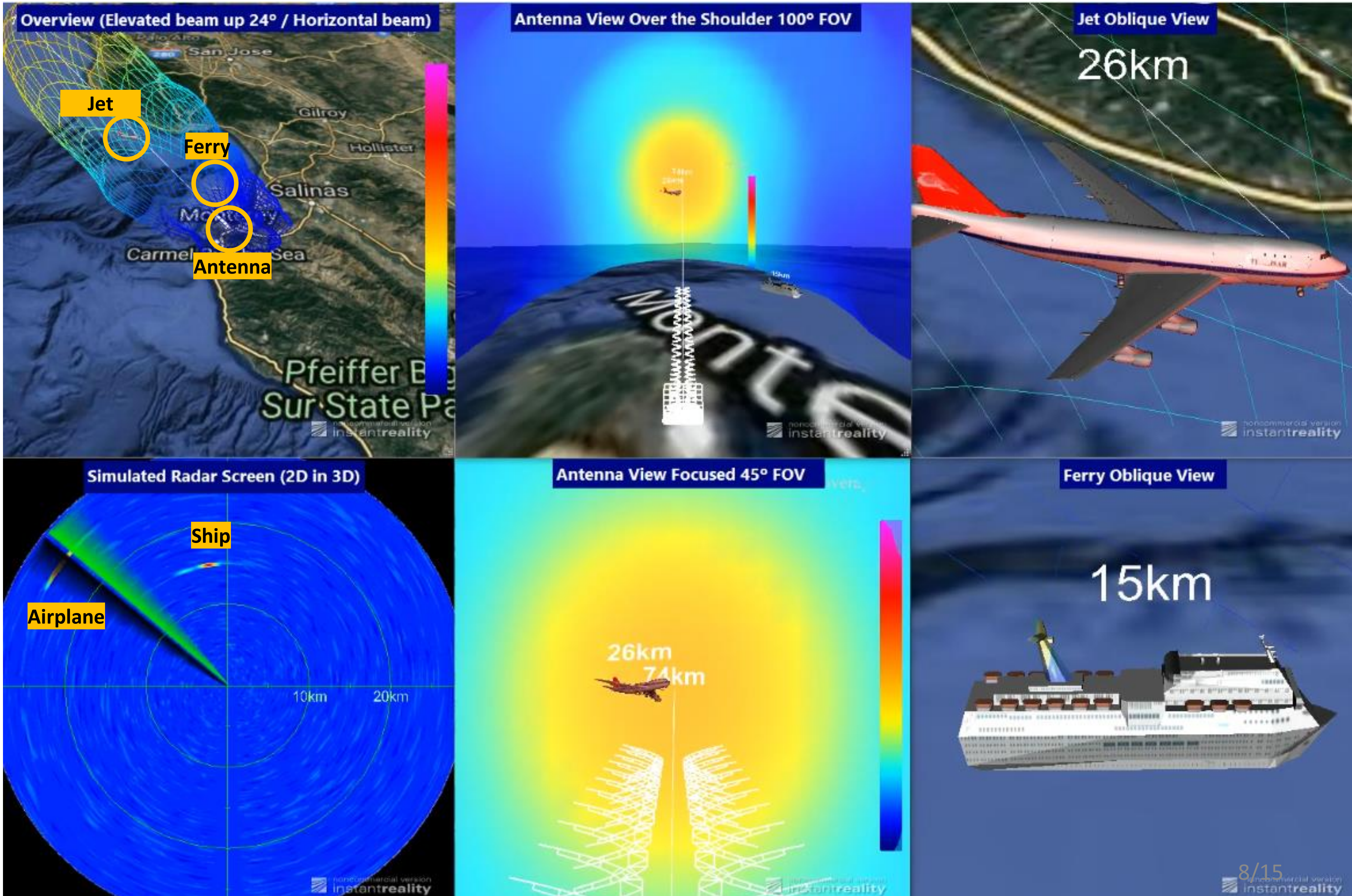
→ Need more study to calculate accurate power

- Simple calculations are used to show visualization concept.
- Ongoing study using AREPS 3.0[3]



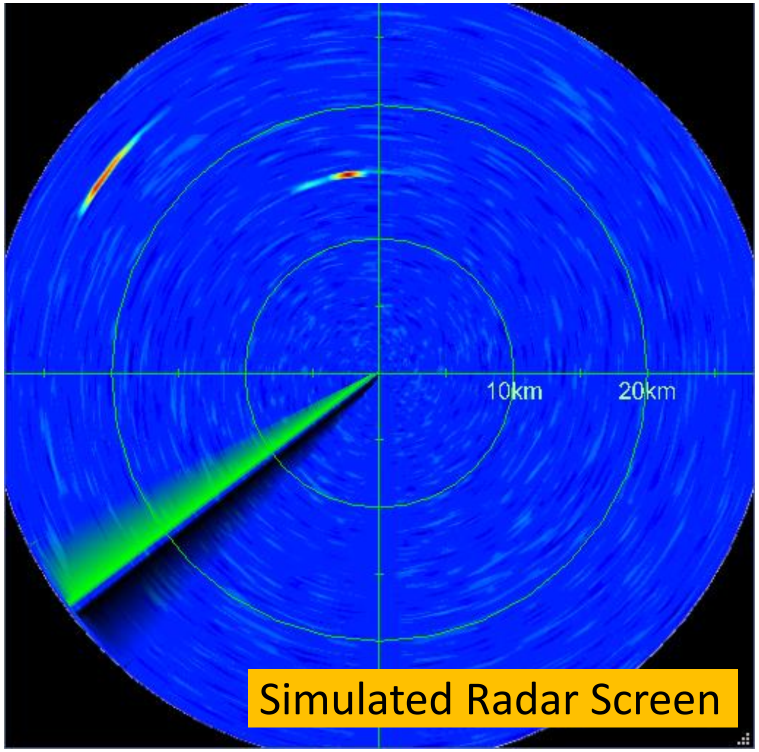
[3] W.L.Patterson, "Advanced refractive effects prediction system (AREPS)," Conf. 2007 IEEE Radar, pp. 891–895, 2007.

Video compares multiple presentation techniques for single real-world scenario in single X3D scene



Consideration

- Simulated Radar Screen
  - 3D as 2D presentation
  - Until now calculated by Matlab example [4].
  - Need digital radar data to validate



[4] www.mathworks.com/help/phased/examples/scan-radar-using-a-uniform-rectangular-array.html

Media assets availability

- All research products are published as open source.
- These models, imagery and video are all online at
  - https://savage.nps.edu/Savage/CommunicationsAndSensors/Radar

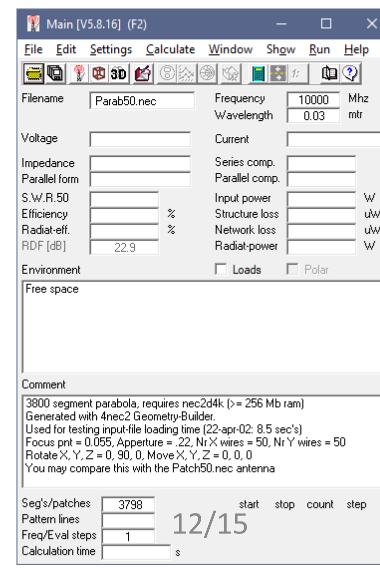
Reference

[1] 4nec2.exe Program

- NEC-2 based antenna modeler and optimizer
  - Arie Voors encapsulates NEC2 code with windows-based GUI and provides good environment to use NEC2 code.
  - You can get this program free. (ver 5.8.16)
  - http://www.qsl.net/4nec2/

- NEC (Numerical Electromagnetics Code)
  - Popular antenna modeling system for wire and surface antennas
  - It was originally written in FORTRAN in the 1970s by Gerald Burke and Andrew Poggio of the Lawrence Livermore National Laboratory.
  - By far the most common version is **NEC-2**, the last to be released in fully public form

  https://en.wikipedia.org/wiki/Numerical_Electromagnetics_Code



4nec2.exe Output for Antenna Examples

- Input/output files are ascii text files and easy to read.
- 4nec2.exe is good software for a beginner of Antenna beam pattern to understand.

3YAGI20.out - Notepad

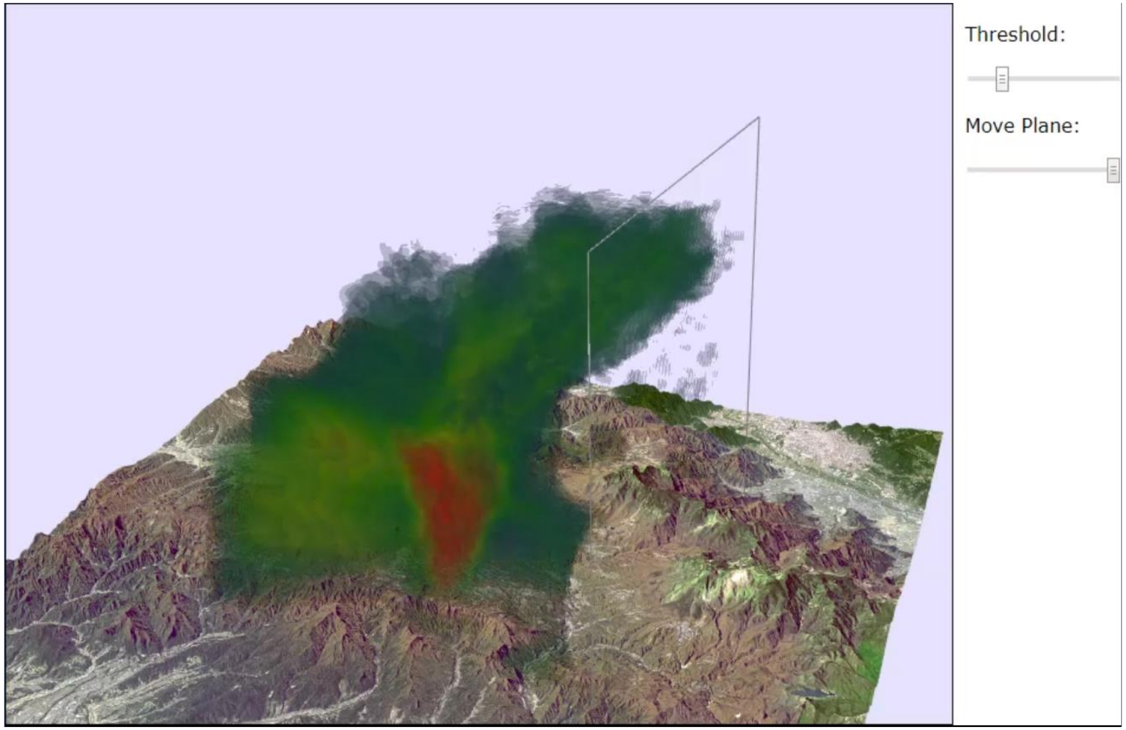
File Edit Format View Help

```
                    ********************************************

                    NUMERICAL ELECTROMAGNETICS CODE (NEC-2D)

                    ********************************************



                        - - - - COMMENTS - - - -


               3el Yagi for 20 meters @ 50 feet.



                    - - - STRUCTURE SPECIFICATION - - -

                        COORDINATES MUST BE INPUT IN
                        METERS OR BE SCALED TO METERS
                        BEFORE STRUCTURE INPUT IS ENDED


 WIRE                                                                    NO. OF    FIRST  LAST     TAG
 NO.       X1         Y1         Z1          X2         Y2         Z2      RADIUS   SEG.     SEG.   SEG.     NO.
   1   -4.83200    2.74320   15.24000     4.83200    2.74320   15.24000   0.00500     19        1     19       1
   2   -5.12020    0.00000   15.24000     5.12020    0.00000   15.24000   0.00500     19       20     38       2
   3   -5.52400   -1.82280   15.24000     5.52400   -1.82280   15.24000   0.00500     19       39     57       3

  TOTAL SEGMENTS USED=   57     NO. SEG. IN A SYMMETRIC CELL=   57     SYMMETRY FLAG=  0


       - MULTIPLE WIRE JUNCTIONS -
JUNCTION    SEGMENTS  (- FOR END 1, + FOR END 2)
 NONE



                    - - - - SEGMENTATION DATA - - - -

                          COORDINATES IN METERS

               I+ AND I- INDICATE THE SEGMENTS BEFORE AND AFTER I


 SEG.   COORDINATES OF SEG. CENTER     SEG.     ORIENTATION ANGLES    WIRE    CONNECTION DATA   TAG
 NO.       X          Y          Z      LENGTH     ALPHA      BETA    RADIUS    I-    I    I+    NO.
   1  -4.57768    2.74320  15.24000  0.50863   0.00000   0.00000  0.00500    0     1    2     1
```

```
  44     3  -0.1102  -0.0863   0.7218  0.02754  -5.2758E-03  6.1832E-03  8.1281E-03  130.472
  45     3  -0.0826  -0.0863   0.7218  0.02754  -5.9352E-03  6.8522E-03  9.0653E-03  130.898
  46     3  -0.0551  -0.0863   0.7218  0.02754  -6.4254E-03  7.3417E-03  9.7564E-03  131.192
  47     3  -0.0275  -0.0863   0.7218  0.02754  -6.7272E-03  7.6399E-03  1.0180E-02  131.365
  48     3   0.0000  -0.0863   0.7218  0.02754  -6.8291E-03  7.7400E-03  1.0322E-02  131.422
  49     3   0.0275  -0.0863   0.7218  0.02754  -6.7272E-03  7.6399E-03  1.0180E-02  131.365
  50     3   0.0551  -0.0863   0.7218  0.02754  -6.4254E-03  7.3417E-03  9.7564E-03  131.192
  51     3   0.0826  -0.0863   0.7218  0.02754  -5.9352E-03  6.8522E-03  9.0653E-03  130.898
  52     3   0.1102  -0.0863   0.7218  0.02754  -5.2758E-03  6.1832E-03  8.1281E-03  130.472
  53     3   0.1377  -0.0863   0.7218  0.02754  -4.4738E-03  5.3516E-03  6.9752E-03  129.895
  54     3   0.1652  -0.0863   0.7218  0.02754  -3.5629E-03  4.3777E-03  5.6443E-03  129.141
  55     3   0.1928  -0.0863   0.7218  0.02754  -2.5831E-03  3.2834E-03  4.1777E-03  128.192
  56     3   0.2203  -0.0863   0.7218  0.02754  -1.5758E-03  2.0873E-03  2.6153E-03  127.051
  57     3   0.2479  -0.0863   0.7218  0.02754  -5.5406E-04  7.6849E-04  9.4740E-04  125.791


                         - - - POWER BUDGET - - -

                           INPUT POWER   = 1.5581E-02 WATTS
                           RADIATED POWER= 1.5385E-02 WATTS
                           STRUCTURE LOSS= 1.9564E-04 WATTS
                           NETWORK LOSS  = 0.0000E+00 WATTS
                           EFFICIENCY    =  98.74 PERCENT



                                 - - - RADIATION PATTERNS - - -

 - - ANGLES - -          - POWER GAINS -      - - - POLARIZATION - - -    - - - E(THETA) - - -     - - - E(PHI) -
 THETA      PHI         VERT.   HOR.   TOTAL      AXIAL     TILT  SENSE     MAGNITUDE    PHASE      MAGNITUDE    PH
DEGREES   DEGREES        DB      DB      DB        RATIO     DEG.            VOLTS/M    DEGREES      VOLTS/M     DEG
 -90.00      0.00     -999.99 -999.99 -999.99    0.00000     0.00           7.81629E-12    58.16   0.00000E+00
 -85.00      0.00      -20.11 -999.99  -20.11    0.00000     0.00  LINEAR   9.54471E-02  -110.33   0.00000E+00
 -80.00      0.00      -16.14 -999.99  -16.14    0.00000     0.00  LINEAR   1.50772E-01   -85.37   0.00000E+00
 -75.00      0.00      -12.75 -999.99  -12.75    0.00000     0.00  LINEAR   2.22605E-01   -57.59   0.00000E+00
 -70.00      0.00       -9.69 -999.99   -9.69    0.00000     0.00  LINEAR   3.16807E-01   -37.94   0.00000E+00
 -65.00      0.00       -7.82 -999.99   -7.82    0.00000     0.00  LINEAR   3.92982E-01   -24.32   0.00000E+00
 -60.00      0.00       -7.36 -999.99   -7.36    0.00000     0.00  LINEAR   4.14282E-01   -11.87   0.00000E+00
 -55.00      0.00       -8.31 -999.99   -8.31    0.00000     0.00  LINEAR   3.71118E-01     4.73   0.00000E+00
 -50.00      0.00      -10.04 -999.99  -10.04    0.00000     0.00  LINEAR   3.04320E-01    34.83   0.00000E+00
 -45.00      0.00       -9.24 -999.99   -9.24    0.00000     0.00  LINEAR   3.33756E-01    79.44   0.00000E+00
 -40.00      0.00       -5.62 -999.99   -5.62    0.00000     0.00  LINEAR   5.05995E-01   109.56   0.00000E+00
 -35.00      0.00       -2.40 -999.99   -2.40    0.00000     0.00  LINEAR   7.33400E-01   124.22   0.00000E+00
 -30.00      0.00       -0.09 -999.99   -0.09    0.00000     0.00  LINEAR   9.56710E-01   132.17   0.00000E+00
 -25.00      0.00        1.50 -999.99    1.50    0.00000     0.00  LINEAR   1.14882E+00   137.06   0.00000E+00
 -20.00      0.00        2.57 -999.99    2.57    0.00000     0.00  LINEAR   1.29914E+00   140.31   0.00000E+00
 -15.00      0.00        3.26 -999.99    3.26    0.00000     0.00  LINEAR   1.40701E+00   142.53   0.00000E+00
 -10.00      0.00        3.68 -999.99    3.68    0.00000     0.00  LINEAR   1.47713E+00   143.99   0.00000E+00
  -5.00      0.00        3.91 -999.99    3.91    0.00000     0.00  LINEAR   1.51583E+00   144.84   0.00000E+00
   0.00      0.00        3.98 -999.99    3.98    0.00000     0.00  LINEAR   1.52811E+00   145.11   0.00000E+00
```

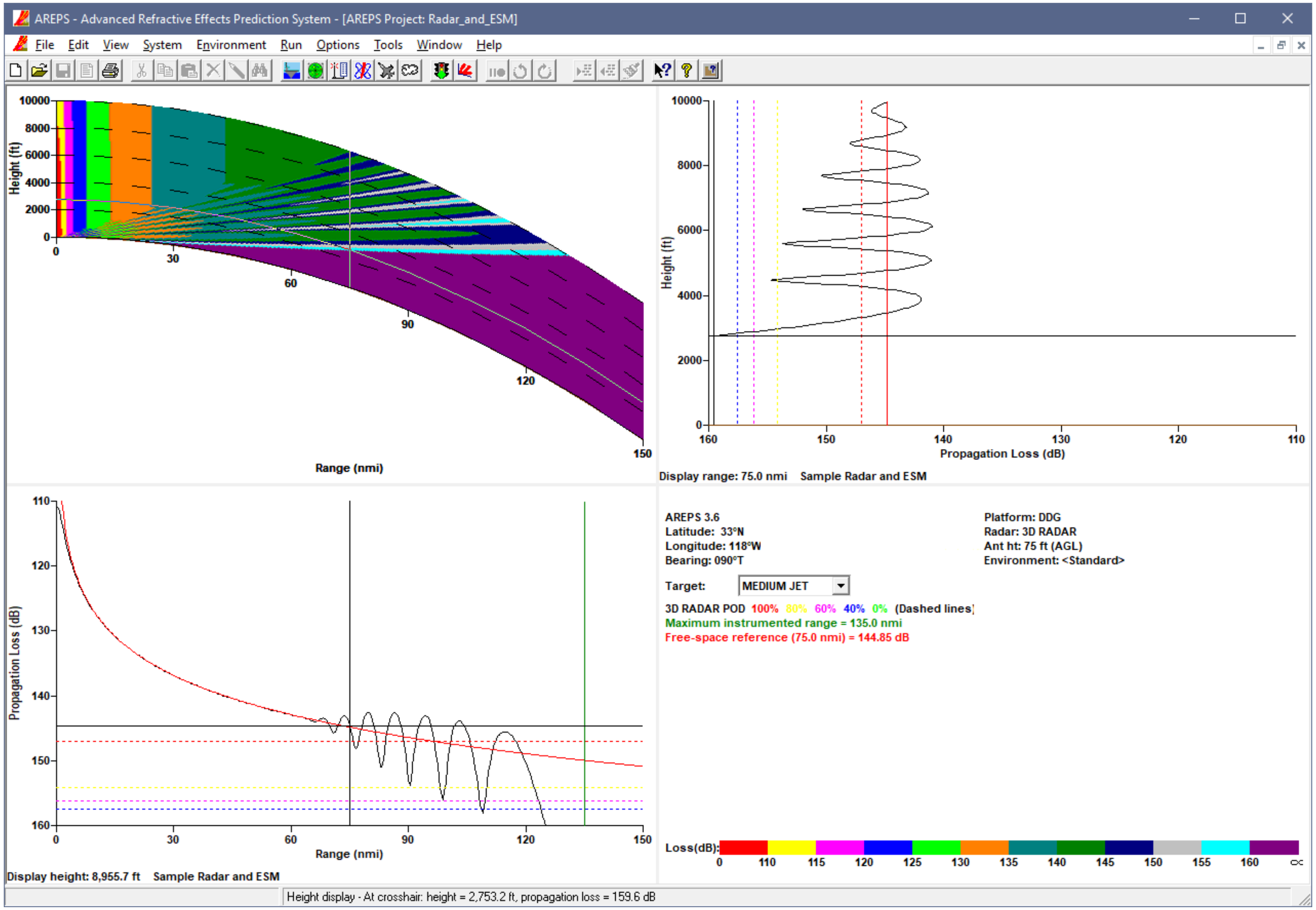
[2] Cloud data from Weather radar

- https://examples.x3dom.org/example/RadarVolumeStyle
  - with a fog of kansai_pawr_20120726175907.png
- https://dl.acm.org/citation.cfm?id=2775323
- https://vimeo.com/103145827



[3] AREPS 3.0 example

- W. L. Patterson, “Advanced refractive effects prediction system (AREPS),” Conf. 2007 IEEE Radar, pp. 891–895, 2007.



[4] Scan Radar Matlab Example

- www.mathworks.com/help/phased/examples/scan-radar-using-a-uniform-rectangular-array.html

To process the received signal, we first pass it through a matched filter, then integrate all pulses for each scan angle.

```
% Matched filtering
matchingcoeff = getMatchedFilter(waveform);
matchedfilter = phased.MatchedFilter(...
    'Coefficients',matchingcoeff,...
    'GainOutputPort',true);
[mf_pulses, mfgain] = matchedfilter(rxpulses);
mf_pulses = reshape(mf_pulses,[],int_pulsenum,numscans);

matchingdelay = size(matchingcoeff,1)-1;
sz_mfpulses = size(mf_pulses);
mf_pulses = [mf_pulses(matchingdelay+1:end) zeros(1,matchingdelay)];
mf_pulses = reshape(mf_pulses,sz_mfpulses);

% Pulse integration
int_pulses = pulsint(mf_pulses,'noncoherent');
int_pulses = squeeze(int_pulses);

% Visualize
r = v*fast_time_grid/2;
X = r'*cosd(scangrid); Y = r'*sind(scangrid);
clf;
pcolor(X,Y,pow2db(abs(int_pulses).^2));
axis equal tight
shading interp
axis off
```