Determining NEXRAD Coverage for Airport Approaches

David Mayer, December 2017

Introduction

The WSR-88D network is comprised of >150 sensors which operate in various altitude scan patterns on a continuous basis. Figure 1 presents the station locations in the continental United States. It has recently been upgraded to dual polarization which adds several additional variables to the dataset allowing classification of scatterers in the atmosphere. One of these classifications is biological targets, which includes birds and insects. CEAT research has shown that this classification can be improved upon, separating out hazardous bird targets from the remainder. Thus, the NEXRAD is a suitable tool for determining hazard when it has coverage near an airport. Using existing resources from the National Weather Service, NOAA, and the FAA it is possible to calculate the NEXRAD coverage for critical phases of flight at every airport in the country.

Figure 1: NEXRAD locations (red) in continental United States.

Methods

A key component to determining NEXRAD coverage at an airport is identifying the closest radar sensor to the airport. The maximum theoretical range of a sensor is 230 km so having an airport within that range is the first step of this process. Using the FAA's Airport Data and Contact information [4] along with NOAA's Historical Observing Metadata Repository [9] it was possible to calculate the ground distance from every airport to every NEXRAD station in the country as each location has recorded longitude and latitude values. A matrix was constructed with airports as rows, NEXRADs as columns and the calculated distance between them as the data within the matrix, figure 2.

X1	KABR	KABX	KAKQ	KAMA	KAMX	KAPX	KARX	KATX	KBBX	KBGM	KBHX	KBIS
DAL	1410.030...	954.89886	1865.29...	520.806906	1785.677...	1701.264...	1317.205446	2739.483...	2337.77...	2107.953922	2581.316...	
DAY	1313.265...	2058.429...	707.4920	1625.203726	1629.913...	558.68523	723.847914	3162.048...	3181.02...	736.732005	3378.207...	
DBQ	704.58182	1610.895...	1317.44...	1241.996089	2093.038...	557.03678	162.936894	2551.263...	2605.49...	1211.089659	2791.883...	
DCA	1903.768...	2667.972...	207.9208	2221.853798	1507.511...	926.47302	1303.764491	3754.118...	3809.07...	383.235848	4004.145...	
DEC	1000.207...	1666.296...	1081.05...	1242.570356	1768.151...	659.45409	484.022628	2822.192...	2792.27...	1112.317945	2994.214...	
DEN	805.99815	557.82823	2424.27...	577.761189	2755.913...	1728.870...	1200.164032	1695.279...	1451.37...	2411.749724	1666.717...	
DFW	1403.040...	936.64241	1879.77...	503.124291	1803.873...	1706.549...	1318.114431	2723.422...	2319.67...	2118.878501	2563.300...	
DHN	1932.535...	2031.136...	1000.39...	1572.585771	804.11557	1513.799...	1480.096801	3634.486...	3381.83...	1474.075113	3616.094...	
DIK	370.01831	1339.512...	2385.40...	1290.580685	3077.041...	1414.520...	966.319965	1485.302...	1725.78...	2178.484659	1860.202...	

Figure 2: Example distance matrix of airport and NEXRAD stations.

With this matrix constructed, the closest NEXRAD to each airport can be determined by arranging each individual row of the matrix in ascending order. It is also possible to identify the 2nd, 3rd, etc closest in this manner.

Within the same FAA dataset is runway information for every Public-Use facility in the country. This contains information such as:

- Runway Base and Reciprocal End lon/lat
- Runway Base and Reciprocal End elevation
- Runway bearing
- Glide Path angle from runway end

Using this information, a stepwise function was created in R that looped through the distance matrix of airports and calculated the NEXRAD beam dimensions for aircraft on approach for each runway at that facility.

First, runways at each facility were extracted from the FAA database, and a runway map was constructed that highlighted the runways at the facility, figure 3.

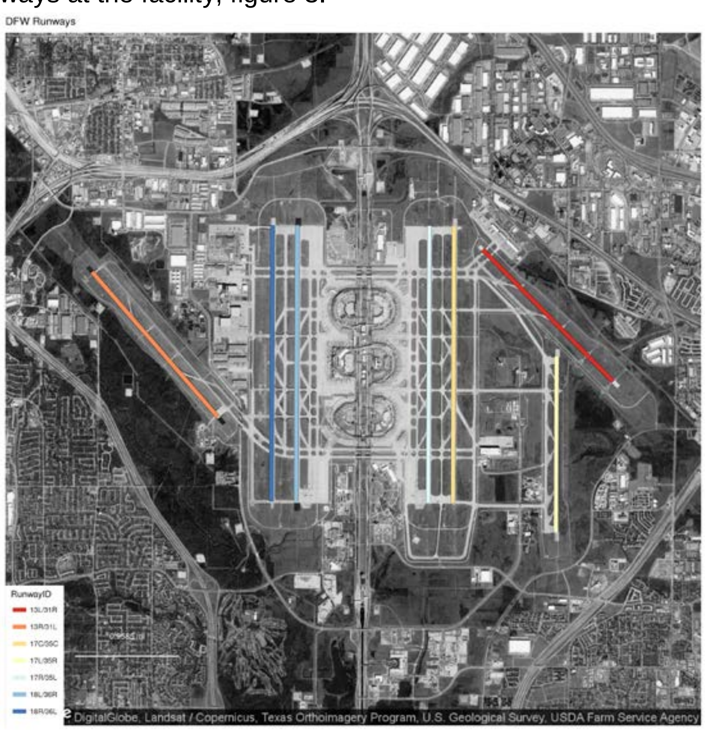

Figure 3: Example runway map for Dallas Ft. Worth International Airport.

Next, using the approach bearing, elevation angle, and runway end coordinates and elevation, aircraft position was determined for varying altitudes within the critical phase of flight (ground to 10,000ft). Ground range from runway end was determined using trigonometry, where the aircraft height above runway end and glide path angle are known. Ground range is thus:

Ground Range = Aircraft Altitude above runway end / TAN(Glide Path Angle)

With the distance from runway end at approach altitude known as well as the approach bearing, a longitude and latitude position of the aircraft can be derived. This was derrived using the 'destPointRhumb' function in R, part of the Geosphere package [11]. This calculates the coordinates of the destination point when traveling along the surface of an ellipsoid (Earth) given a start point, direction, and distance.

Now that the aircraft's 3D position in space is known, it can be related to the nearest NEXRAD station. The distance from the aircraft's position on approach is then determined by the 'distGeo' function. This takes two longitude latitude pairs and calculates the shortest distance between them across the surface of an ellipsoid. Now that this dimension is known, it is possible to calculate the nearest NEXRAD's beam center altitude at the aircraft's position on approach according to the following formula provided by the National Weather Service [8]:

$$h = (R*\sin(PHI)) + (R2 /2*IR*Re)$$

where:
h = height of the beam centerline above radar-level (ARL) in km,
R = slant range observed on radar in kilometers (km),
PHI = radar elevation angle (in degrees),
IR = refractive index (1.21), and
Re = radius of the earth (6371000 m)

Once the beam center altitude is determined, the beamwidth at this location can be determined according to the following formula:

$$\Theta = s/r$$

where:
Θ = the angular beamwidth
s = the beamwidth (or arc length)
r = the distance of the range gate from the antenna.

Once all of this information is known, it is possible to solve for the vertical components (perpendicular to the ground) of the beamwidth:

$$s_{\perp} = s * \cos(PHI)$$

For this report, the beam characteristics of the NEXRAD were calculated for the lowest elevation scanned, PHI = 0.5 degrees. The beamwidth, s, was also assumed to be 0.925. Atmospheric conditions can also affect these calculations dependent on the Refractive Index. This value is constantly changing, but for the purposes of this report was assumed to be 1.21 [8]. Using these calculations as well as the NEXRAD tower height and elevation above SEA level, it can be determined if an aircraft at a specified elevation on approach falls within the beam of the NEXRAD sensor. A table of NEXRAD beam characteristics is generated, detailing the beam bottom, center, and top at the aircraft's location for a given airport runway.

Finally, a map is generated, showing the aircraft position at approach altitude and whether or not it is expected to be within the NEXRAD beam. To be considered in the beam, the aircraft must be above the bottom of the beam, below the top, and within 230 km of the NEXRAD sensor.

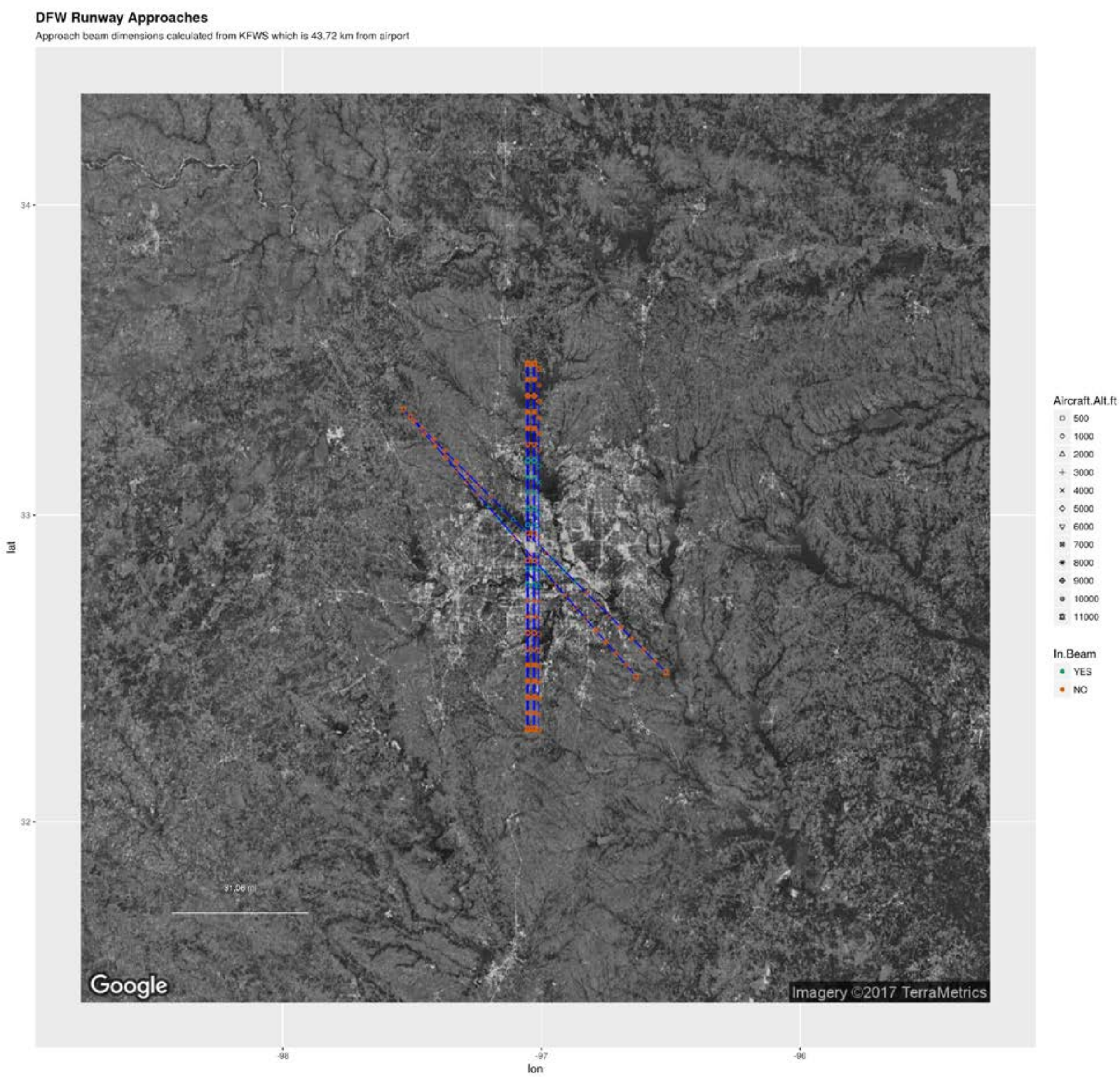

Figure 4: Aircraft on approach to Dallas Ft. Worth International Airport at various altitudes from runway end. Green symbols represent aircraft that would be within the nearest NEXRAD's beam, while red symbols would not for the lowest elevation slice.

These calculations are repeated for every airport in the distance matrix. A full archive of NEXRAD approach calculation maps and tables can be found at the following URL:

- https://uofi.box.com/s/z74zicmwvcwdwc8eqwiqp9thvb04y96j

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