P3.4 SELECTING THE SITES FOR CASA NETRAD, A COLLABORATIVE RADAR NETWORK

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1. INTRODUCTION

During the summer of 2005 the Center for Collaborative Adaptive Sensing of the Atmosphere (CASA) will begin deploying a four-node array of low-cost, low-power X-band radars as a proof-of-concept test bed. This network, named NetRad, is designed to demonstrate a radar network that responds *adaptively* and *collaboratively* to the data that is sensed (McLaughlin et al. 2005, Brotzge et al. 2005). In other words, the observing system is being designed so that the radars will detect weather features or areas of developing weather hazards and the system will adapt scanning strategies to optimize the subsequent measurement and tracking of the features. Such a system is needed to more quickly identify and track hazardous weather in radar data as well as to provide the spatial and temporal data resolution necessary for improvement in small-scale numerical weather prediction. The ability of NetRad to collaboratively detect hazardous features depends on the characteristics of the radar hardware (frequency, power, beamwidth, etc), the sampling resolution, the network spacing and configuration. In this paper we describe the process used to determine the sites for the first four sites in this new network.

2. GENERAL REGION OF DEPLOYMENT

The general area for NetRad was chosen based on several factors, including severe weather climatology, existing infrastructure, and proximity to end-users. One of the primary goals of this NetRad deployment is to improve detection of severe thunderstorm winds, including tornadoes; thus, the network was placed in Oklahoma due to the relatively frequent occurrence of severe thunderstorms and tornadoes in the area (Brooks et al., 2003). Oklahoma was also selected because of the extensive weather-observing networks already deployed within the state. In addition to the standard operational suite of observing systems, Oklahoma is home to the Oklahoma Mesonet, the Atmospheric Radiation Measurement (ARM) Program Southern Great Plains (SGP) Network and the Agricultural Research Service Rainguage Micronetwork. These networks can be used for rainfall validation and to provide supplemental data for numerical weather prediction experiments using the NetRad data.

In narrowing the location further we strongly considered the impact to the end users including emergency managers, the broadcast media, and the general public. This led to a focus on the area upstream (generally west and southwest) of Oklahoma City, the state's largest metropolitan area.

Finally, in order to provide the best supplement to the existing operational NEXRAD radar coverage, it is desirable to that NetRad be situated about midway between existing NEXRAD radars. In this way the NetRad radars will see the area of the atmosphere that is below the lowest (0.5º elevation angle) beam of the NEXRAD radar. For the area being considered this would be midway between the NEXRAD radars at Frederick and Twin Lakes (Norman), Oklahoma.

3. OPTIMIZATION CALCULATIONS

The selection of network spacing and configuration was guided by the results of optimization experiments. The collaborative operation of the NetRad radars should allow for multi-Doppler analysis for improved detection resolution and wind retrieval. Such calculations are sensitive to the relative viewing angles of any pair of radars viewing a point in the domain (Lhermitte and Miller, 1970, Dowell and Shapiro, 2003). Because each radar measures only the wind component in the radial direction, in order to get a complete measure of the horizontal wind, at least two separate observations are required. Ideally each point in the domain of interest would be observed by two radars with beams intersecting at an angle of 90º. This can only occur at a few select points, but it is sufficient for many applications if the beams

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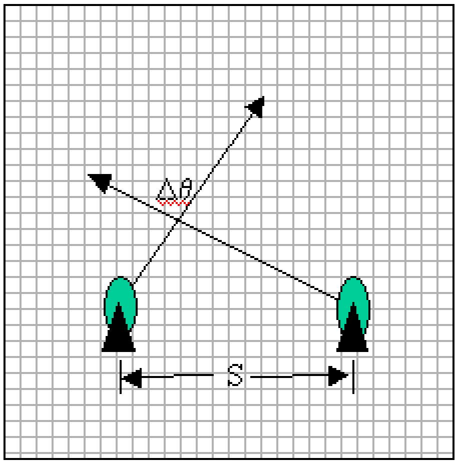

Fig 1. Schematic of calculation of intersecting angle, Δθ, on a grid for a pair of radars separated by distance S. For clarity, a subset of the grid is shown here; the grid extends horizontally beyond the maximum range of both radars.

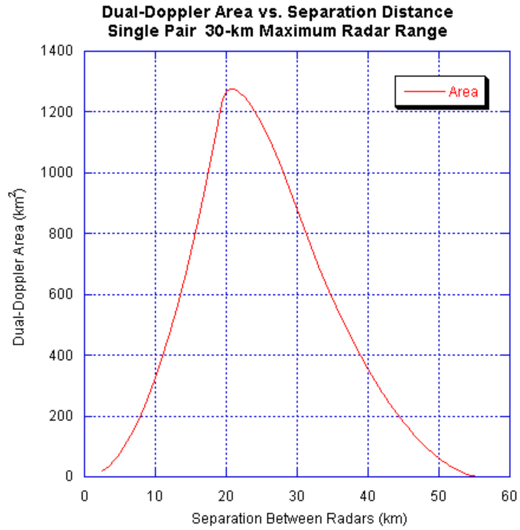

Fig. 2. Dual-Doppler coverage area for a pair of radars with 30-km maximum range as a function of the distance between the radars.

intersect at angles within about 50-60º of orthogonal (absolute value of 30-40º or more).

To assess any prospective network arrangement, we consider a high-resolution Cartesian grid in a rectangular domain including all of the area within the maximum range of all radars. For each grid point in the domain the intersecting angles of all possible radar pairs are calculated, and the intersection angle of the most orthogonal pair is recorded (see Fig 1). The area over which the best intersecting angle is 40º or better is then integrated (40º being a conservative cut-off for acceptable intersecting angle). We refer to this as the valid dual-Doppler radar area. For the hypothetical experiments, a grid spacing of 400 m on a Lambert Conformal map projection is used. Spherical geometry (great-circle path) is used to determine the observation angles.

Calculations of the dual-Doppler area were first done considering hypothetical networks of a fixed number of NetRad radars. The NetRad radars are expected to have a maximum range of about 30 km for typical weak precipitating hydrometeor targets (20 dBZ).

Figure 2 is the result of calculation of the dual-Doppler area for a simple network consisting of two radars. For such a pair of radars, the dual-Doppler radar area increases rapidly with separation distance from 10-20 km and is a maximum for a pair spaced 21 km apart. The area is within 10 percent of the maximum from 19 to 25 km.

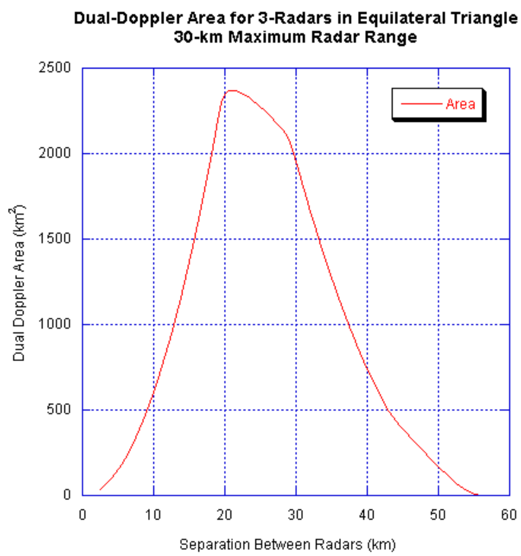

Fig. 3. Dual-Doppler coverage area as a function of radar spacing for a three-radar network arranged in an equilateral triangle.

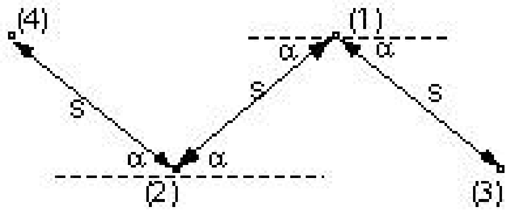

Fig. 4 Arrangement of a hypothetical four-radar network (radars labeled 1,2,3,4), with constant radar separation, S, and radar orientation angle, α.

Considering a network of three equally-spaced radars in an equilateral triangle configuration, the dual-Doppler area as a function of separation distance (Fig. 3) has a similar shape as found with the two-radar network, with a maximum at spacing of 21 km. The area declines 12% between 21 and 29 km before falling off more rapidly for separation distances greater than 29 km.

When considering networks with more than three radars, there are innumerable ways to arrange them, even if the separation distance is held constant. To reduce the parameter space when considering a four-radar network, we considered an arrangement of the radars as depicted in Fig. 4. The radars are arranged with constant spacing, *S*, and arrangement angle α. When α is 0º the configuration forms a straight line; when α is 60º the network can be described as two adjacent equilateral triangles. For α larger than 60º there exist pairs of radars that are closer to one another than the prescribed spacing, so 60º is the maximum angle considered.

Figure 5 shows the dual-Doppler area for such four-radar networks as a function of these two parameters. Consistent with previous results, the dual-Doppler area is maximized for radars spaced approximately 20-25 km. The dependence on the orientation angle is weaker than the dependence on separation, with largest dual-Doppler area found for a network in configuration with α=60º, but the maximum dual-Doppler area calculated for a straight-line configuration was nearly as high. The smallest areas are found for a network with α=40º, though the maximum area for that orientation is within 10 percent of the maximum for the 60º orientation angle.

For α=60º, the maximum area was found at 22.5 km, the area declined just 6% from 22.5 to 29 km, and then more rapidly after that. At 30-km spacing the area was 89% of the peak.

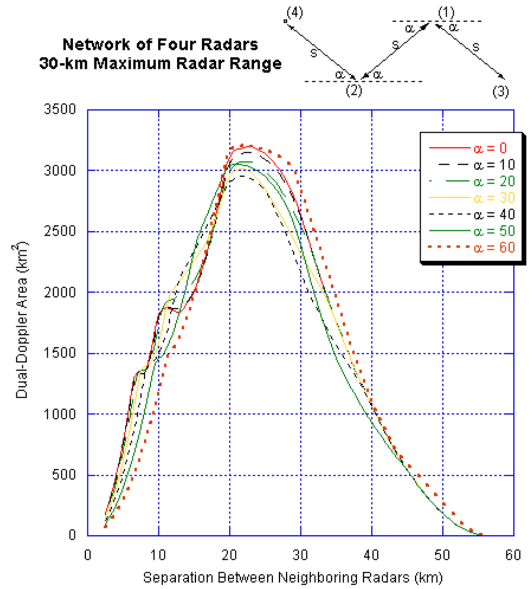

Fig. 5 Dual-Doppler Area as a function of radar spacing for a general 4-radar equally-spaced array.

To allow for other network configurations outside of the constraints of the layout presented in Fig 4, and for networks with a greater number of radars, another set of experiments was done. In these experiments, the locations of a fixed number of radars are specified randomly within a square domain 150 km on a side. The networks producing the largest dual-Doppler areas are examined. These calculations differ slightly from the previously-described experiments in that they use plane geometry, but for this relatively small domain the difference should be negligible.

The maximum value of the dual-Doppler areas found in the experiments for three-radar networks and 4-radar networks were similar to that of the previous work, though the three-radar network maximum was found for an array that was close to linear in arrangement rather than the equilateral triangle considered in producing Fig 3. The arrangement for the four-radar network is somewhat different than that constrained in our previous four-radar experiment (see Fig. 6), but the maximum value was similar to that determined for the constrained arrangement with orientation angle 60º.

Random configurations were also generated for networks with larger numbers of radars. For example, the result for a six-radar network is shown in Fig 7. One interesting result from these experiments is that a graph of maximum dual-Doppler area as a function of the number of radars in the network shows a clear linear trend; see Fig 8.

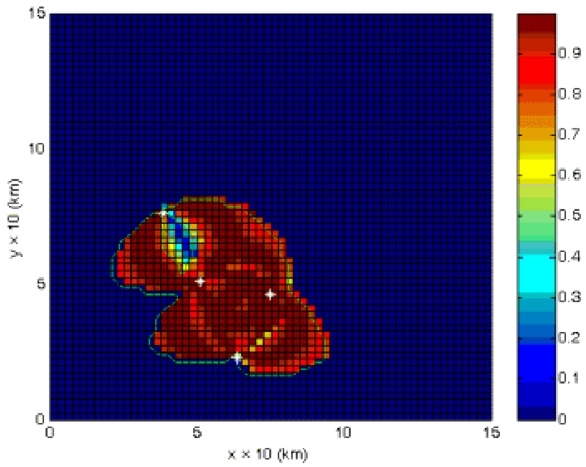

Fig 6. Result of a four-radar random network experiment showing the locations of the network with the greatest dual-Doppler area. Color indicates the sine of the intersecting angle.

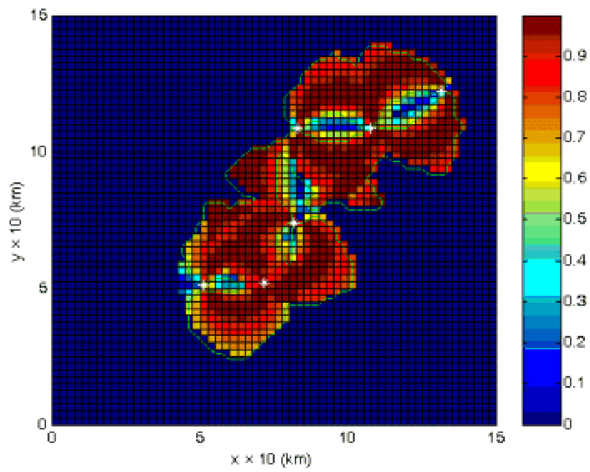

Fig 7. As in Fig. 5m but for the Result of a six-radar random network experiment.

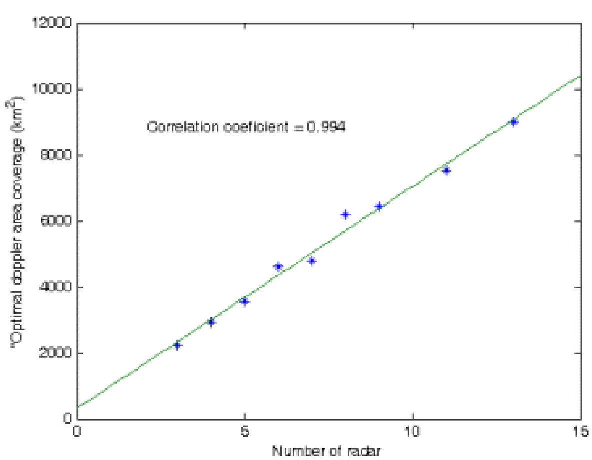

Fig 8. Maximum dual-Doppler area as a function of number of radars in the network.

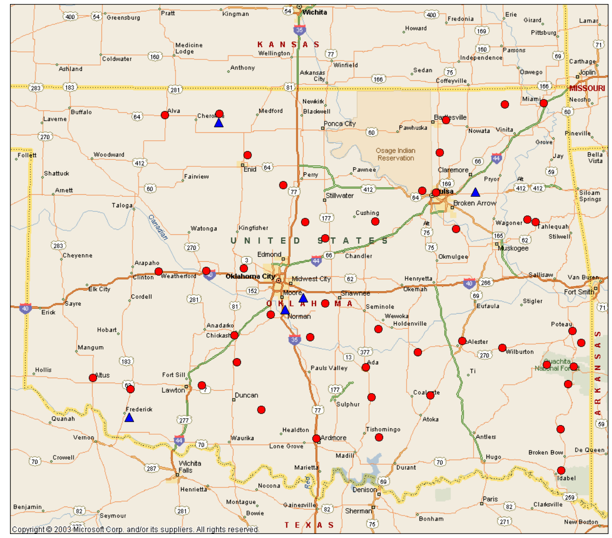

Fig. 9 Map of OneNet tower locations in Oklahoma.

4. MATCHING HYPOTHETICAL RESULTS TO EXISTING INFRASTRUCTURE

For cost and other considerations it is desirable to make use of existing communications and real estate assets. The Oklahoma State Regents for Higher Education operates OneNet, a modern high-speed digital communications network. OneNet is a valuable strategic partner in CASA. OneNet consists of fiber optic and microwave communications links covering the state of Oklahoma. The microwave communications are accomplished using antennas on towers. Many of these same towers could be used to elevate a NetRad radar above local terrain and to provide a direct connection to the OneNet network.

Figure 9 is a map of OneNet assets in the state of Oklahoma; 45 radio towers exist in the OneNet network. Nearly all are tall enough to provide 360° horizons from their top. Also, each is constructed to support considerably more weight than would be added by NetRad radars. Each is secured with torsion stabilizers near the top of the tower to prevent winds from twisting the tower more than 0.5°. The design of these guy assemblies resulted in excellent wind loading characteristics making them good candidates for radars.

The geographic layout of the OneNet towers in the target region was compared to the analyticly-determined best spacing distances, and possible network configurations were evaluated using the same software as the analytic experiments on the Lambert Conformal map. In addition to the dual-Doppler area calculations made in the analytic experiments, other statistics are generated for the real-world tests, including 1) total areal coverage of the network, 2) two- and three-radar overlap areas, 3) mean height above terrain for the NEXRAD radar beams (0.5 elevation angle) in the NetRad coverage area, 4) mean height of the NetRad radar beams above terrain (1.0º elevation angle), 5) fraction of area where one or more of the NetRad radar beams is below the lowest NEXRAD beam height. For the beam height calculations the four-thirds-earth approximation is used (e.g., Doviak and Zrnic', 1993), and a 3-second resolution terrain database from the United States Geological Survey (USGS) interpolated to the map grid is used for terrain elevation. The NetRad radars collocated with OneNet towers are assumed to be mounted atop the existing tower (20-100 m AGL), and any new sites are assumed to be mounted on 27-m tall towers.

Three existing OneNet towers were found that fit the desired spacing characteristics in the region of interest (Lawton, Chickasha and Rush Springs, see Figs 10-12). There was not a fourth tower in the area that would overlap with that trio of stations and meet the other desired criteria, so it was determined that that a new tower would need to be constructed, and the location of that tower needed to be specified.

Fig. 10 Photograph of OneNet tower (right) east of Lawton, Oklahoma.

Fig. 11 Photograph of OneNet microwave tower (right) near Rush Springs, Oklahoma.

Fig. 12 Photograph of OneNet tower at the University of Arts and Science in Chickasha, Oklahoma.

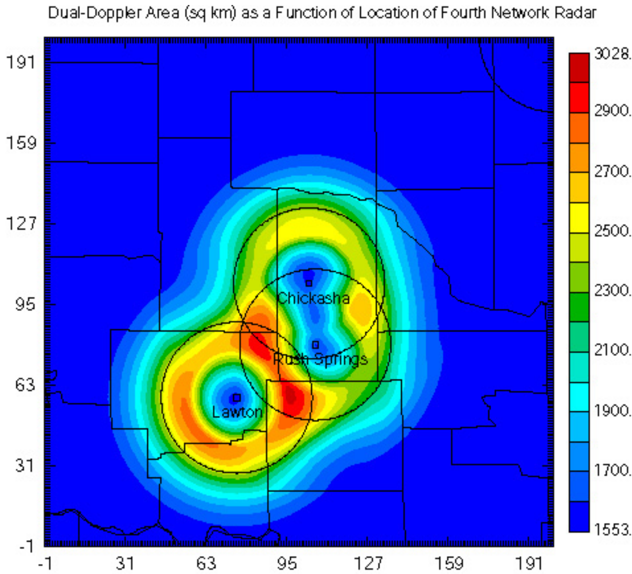

Fig. 13 Map of Southwestern Oklahoma showing the dual-Doppler area (km^2) for a four-radar network as a function of position of the fourth radar, given three existing OneNet tower sites at Chickasha, Rush Springs and Lawton, Oklahoma.

We then considered the total dual-Doppler area for a network consisting of those three existing sites combined with a fourth site assuming the fourth site could be at any grid point in the domain. Figure 8 is a map showing the total dual-Doppler area as a function of the location of the fourth site. The map suggests the network could be extended to the southwest of Lawton, but the greatest area would be achieved by adding a site north-northeast of Lawton or due east of Lawton. The area to the southwest is covered well by the Frederick NEXRAD radar, and a site north-northeast of Lawton would be more in line with a storm track toward the Oklahoma City metropolitan area and allow for some areas of triple overlap. Therefore, site near the town of Cyril, in southeastern Caddo County, was sought for this initial NetRad network.

5. PRACTICAL CONSIDERATIONS

Once the general area for the fourth site had been identified, several practical factors were considered to determine the specific site on which to build the tower.

1) Safety and allowed access: The area must be safe for the radar operation and access to the specific site allowed.

- a) current use of the land
- b) proximity of housing, businesses
- c) willingness of landowner to cooperate with a scientific research project
- d) funds to purchase or lease the land

2) Accessibility: Since it is unlikely that the addition of a NetRad site will cause the county or state to improve road conditions, it is important to take into consideration the existing roads:

- a) proximity to roads
- b) road surface: a blacktop road is preferred, then gravel, then dirt, then open field drives

3) Radar Horizon: It is desirable that the radar be situated on higher terrain to avoid problems with beam-blockage.

- a) Determine lowest angle desired (0.5º for NetRad)
- b) Determine the percentage of horizon where that angle is blocked
- c) Determine improvement if radar is raised on towers of increasing height
- d) Compare costs of that structure to benefit of increased available horizon

4) Electric Power: The radar and communication equipment require reliable commercial power for operation. It is anticipated that 100-amp service at 220V will be needed.

- a) Reliability: number of miles of feeder line back to a main power-line intersection. Some rural power lines are miles long and serve only one or two residents. If disabled by wind, these lines will likely be low on the repair priority list for the electric company.
- b) 3-phase power is preferred.
- c) If power is not reliable and generator backup is required, then accessibility and roads become more important.

Four preliminary sites near Cyril were identified by examination of topographic maps and a drive-by/walk-around survey of the area (Fig. 14). Candidate site Cyril #1 is on a large hill north of town that is already occupied by several commercial and government radio transmission towers; Cyril #2 is near the local High School which might be an interested educational partner in the research project; Sites Cyril #3 and Cyril #4 are on the nearest ridge southwest of town in open country.

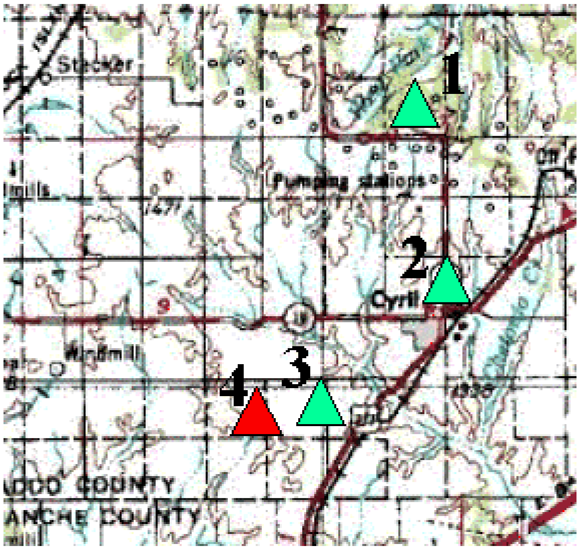

Fig 14. Topographic map of area near Cyril, Oklahoma, with four candidate sites identified. Elevations in feet above sea level. (map courtesy USGS).

We were very fortunate with our first new site acquisition in NetRad. Of the four candidate sites examined, one site scored high in all categories considered. The site we had named Cyril #4 is on the crest of a slight hill on the ridge between Cyril and Fletcher, Oklahoma. It is immediately adjacent to a gravel road with a fair power distribution system close by. Only one house is located nearby. The site for the tower would be in the middle of an open field that is currently used to graze cattle.

Cattlemen in this area are generally agreeable to oil wells and communications towers being installed on their land and most of them feel comfortable that the leaseholder will be able to protect the cattle from harm. Knowing this, and hoping that the landowners might be willing to support the weather research activities of the University of Oklahoma, we approached the family with a request to donate an easement to a portion of their land for the tower and a communications shed, and they agreed.

Figure 15 is a depiction of the four-radar network with the Cyril #4 site included. The colors indicate the best intersection angle for any pair of radar beams. Table 1 shows the relevant statistics for this radar network. From the indications of dual-Doppler area, beam height relative to terrain and relative to NEXRAD we believe we have a good network to test the CASA collaborative radar concept.

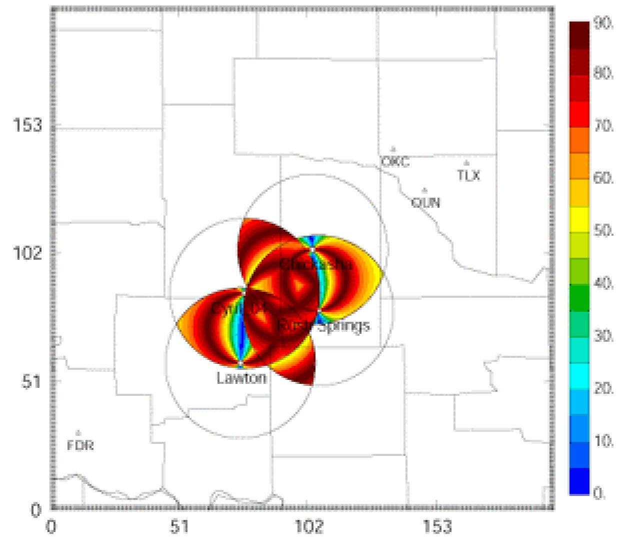

Fig. 15 Four-radar network for initial CASA deployment, including three existing OneNet towers and a new site southwest of Cyril. The locations of the NEXRAD sites at Frederick (FDR) and Twin Lakes (TLX), and the Oklahoma City Airport (OKC) are also indicated. Colors indicate the angle (degrees) of the most orthogonal intersection of any pair of NetRad radars at each point. Circles denote anticipated 30-km radar range. Distance scale in km.

Table 1.
Characteristics of Planned Four-Radar NetRad

Total Network Coverage	7062 km^2	
Two-radar overlap	3020 km^2	43%
Three-radar overlap	1090 km^2	15%
Dual-Doppler area (40º)	2771 km^2	39%
Avg Beam Height NetRad	364 m AGL	
Avg Beam Height NEXRAD	1002 m AGL	
Below NEXRAD	6912 km^2	98%

Engineering studies of the existing towers and planning for construction of a tower and communications shed at the new site have now begun.

6. SUMMARY AND FUTURE WORK

We have outlined a procedure for establishing siting for the first four sites of a new collaborative adaptive radar network. We believe the procedure to be applicable to larger networks. The

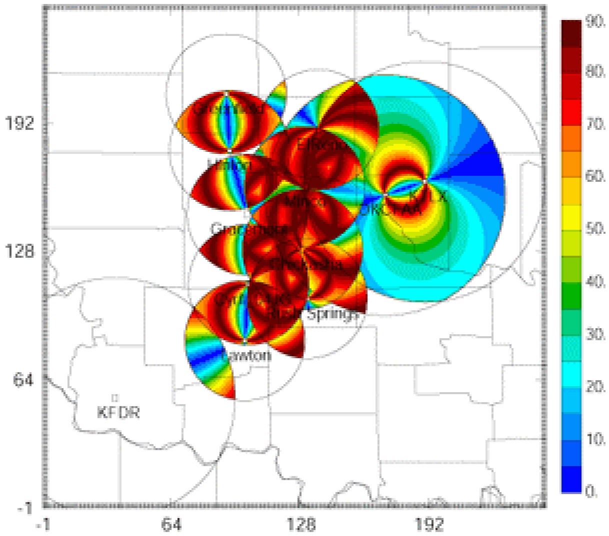

Fig 16. One possible layout for an 12-radar network, including nine NetRad radars, two NEXRAD radars (first 60 km range indicated), and the TDWR radar for the Oklahoma City airport.

NetRad network in Oklahoma will eventually be expanded to nine or more NetRad radars. We intend to use the procedures described here to plan sequential additions to the network as funds become available. Figure 16 is a depiction of how such an expanded network might look, including the effect of boundary-layer coverage of the NEXRAD operational radars (within 60 km of each) and the FAA Terminal Doppler Weather Radar (TDWR) near the Oklahoma City airport.

7. ACKNOWLEDGMENTS

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Table 2.
Characteristics of One Possible 12-Radar NetRad-NEXRAD-TDWR Combination Network

Total Network Coverage	32,688 km^2	
Two-radar overlap	16,543 km^2	60%
Three-radar overlap	5780 km^2	34%
Dual-Doppler area (40º)	9706 km^2	40%
Avg Beam Height NetRad	495 m AGL	
Avg Beam Height NEXRAD	875 m AGL	
Below NEXRAD	14841 km^2	45%

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