Enhancing Meteorological Observation Through Location Optimization of Mobile Radar Deployment

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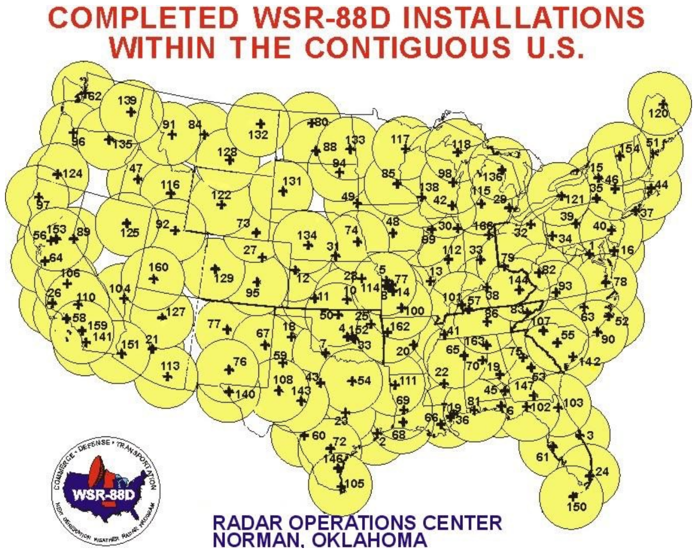
Weather radars

- Have improved our understanding of, and ability to forecast, increasingly frequent catastrophic weather events.

- Fixed Radar: the Next Generation Weather Radar (NEXRAD), which encompasses a network of 160 operational Weather Surveillance Radar - 1988 Doppler (WSR-88D) systems



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

Mobile radars

- Deploying mobile ground-based radars has become routine for field experiments.
  - Geerts et al. 2017; McMurdie et al. 2022
- Produce better observations when they are parked at close range to where precipitation systems occur.
  - Weadon et al. 2009; Pazmany et al. 2013; Kurdzo et al. 2017
- Increase the probability of capturing storm-specific features (e.g., tornadoes, severe storms, etc.)
- Are usually equipped with pedestals that support faster mechanical azimuth scanning.
  - Bluestein et al. 2010; French et al. 2013; Kurdzo 2015

Rapid-Scanning X-band Polarimetric (RaXPol) mobile radar

- Advanced Radar Research Center (ARRC), has used RaXPol in dozens of field campaigns since its initial deployment.
- Is mounted on a Chevrolet Kodiak 5500 truck.
- Can be quickly deployed (2-3 mins).

The RaXPol radar during a weather data collection experiment in Norman, OK.

Where to park the mobile radar vehicle?

- Capture high-quality data & ensure the safety of researchers and vehicles.
- The current site selection process usually depends on the intuition, experience, and judgment of practitioners.
- However, people are not always rational in decision-making.

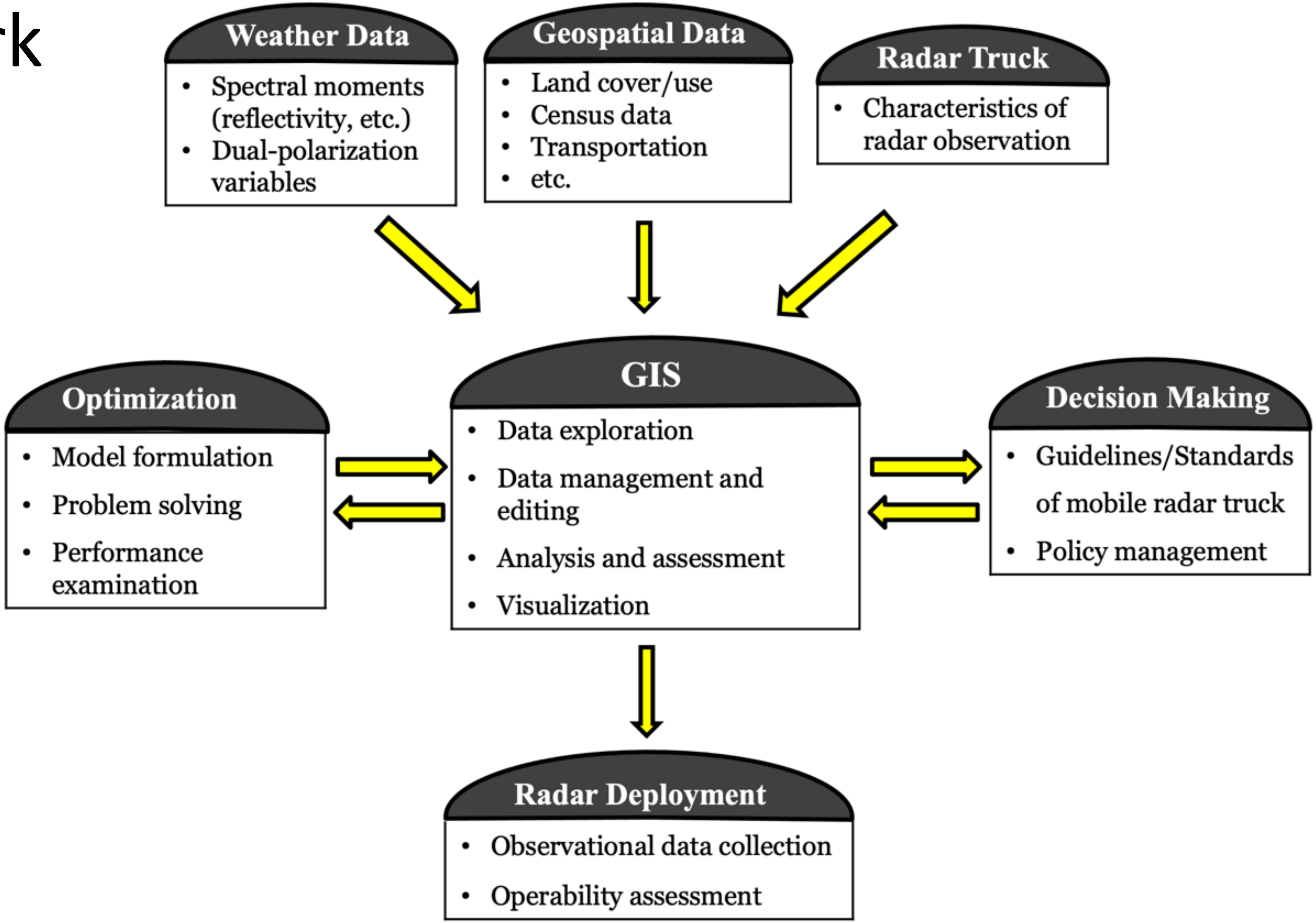
“location, location, location”

- Primary location decisions involving where to site a facility within a given service system will directly influence its efficiency.
  - e.g.,Church & Murray, 2009
- For fixed radars, location optimization used in an appropriate manner is often key to guaranteeing efficient investment and operation of a radar system.
  - e.g., Leone et al., 1989; Minciardi et al., 2003; Raisanen & Whitaker, 2003; Kurdzo & Palmer, 2012; Kurdzo et al., 2020.
- However, there has been very little work on the location optimization of mobile radars.

This paper:

- Provides a structured and systematic approach to decision-making.
- Process and analyze various data without being influenced by biases, emotions, or personal values.
- Complement human judgment by making the siting process logical, rational, transparent, and reproducible.

Framework


Weather Data
Spectral moments (reflectivity, etc.)
Dual-polarization variables
Geospatial Data
Land cover/use
Census data
Transportation
etc.
Radar Truck
Characteristics of radar observation
Optimization
Model formulation
Problem solving
Performance examination
GIS
Data exploration
Data management and editing
Analysis and assessment
Visualization
Decision Making
Guidelines/Standards of mobile radar truck
Policy management
Radar Deployment
Observational data collection
Operability assessment

Three Phases of the Siting Process

- Delineates the initial feasible areas.
- Derive local optimal positions by solving an optimization model.
- GIS assist in determine the precise location by integrating detailed geospatial data.

Mathematical model

$$\min \quad T = \iint_{(x,y)\in\mathcal{R}} g(x,y,X,Y) \times d^2(x,y,X,Y)\,\mathrm{d}x\,\mathrm{d}y, \tag{1}$$

$$\text{subject to} \quad (X,Y) \in \Psi.$$

(x, y) = location of a point in the continuous space
(X, Y) = location of the mobile radar vehicle to be determined
$d^2(x, y, X, Y) = (X - x)^2 + (Y - y)^2$ = Euclidean distance square norm
$\mathcal{R}$ = entire region of study or a specified area
$\Phi_{(X,Y)}$ = observation area of sited mobile radar
Ψ = feasible area capable of siting mobile radars determined in phase 1
$g(x, y, X, Y)$ = reflectivity value at point (x, y) when radar sited at (X, Y)

Aims to locate a single mobile radar vehicle within a feasible area for efficient observation.

Discretization

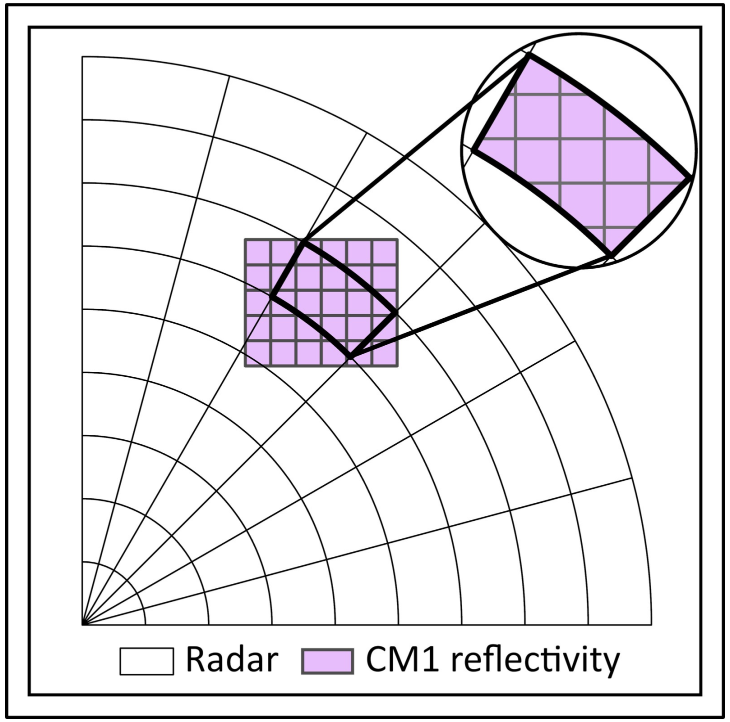
A discretized form of the objective function is defined as:

$$\min \quad T^{(n+1)} = \sum_i g(x_i, y_i, X^{(n)}, Y^{(n)}) \times d^2(x_i, y_i, X, Y) \times Area_{PG(x_i, y_i)} \tag{2}$$

To find the optimal location, we calculate the gradient of the objective function with respect to X and Y, setting each component to zero to solve for the coordinates:

$$\frac{\partial T^{(n+1)}}{\partial X} = 0 \tag{3a}$$

$$\frac{\partial T^{(n+1)}}{\partial Y} = 0 \tag{3b}$$

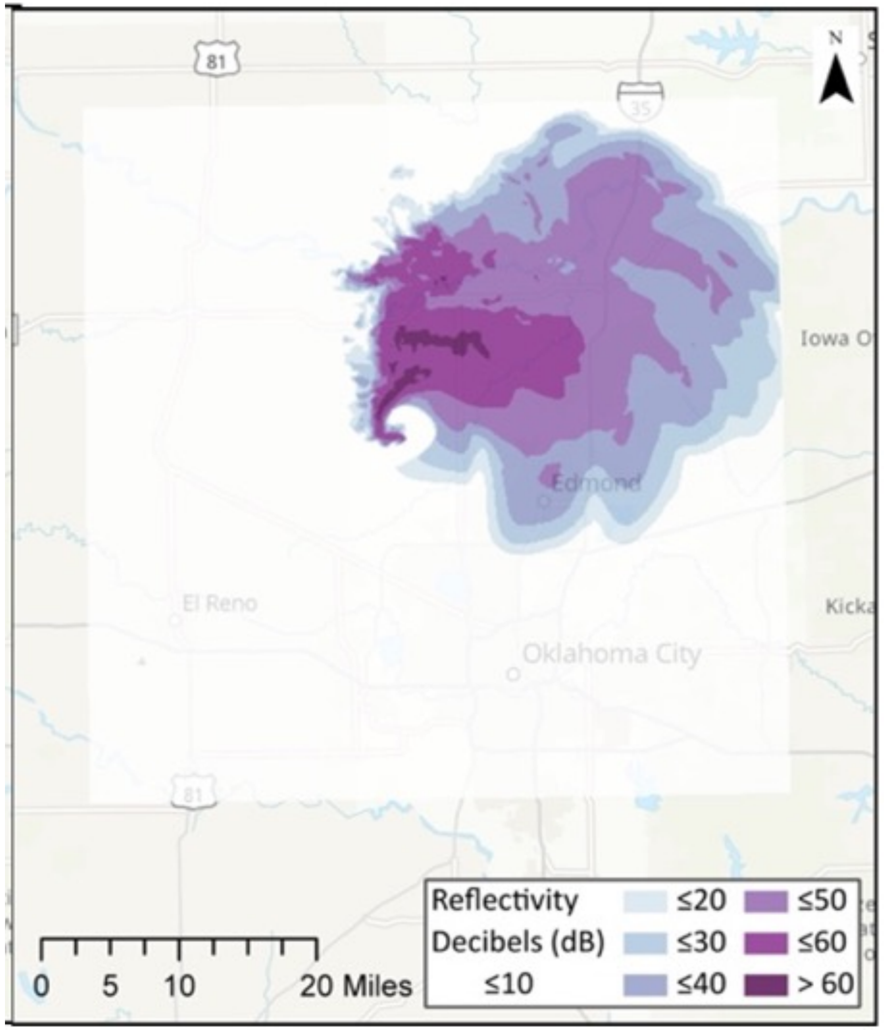


Solution

- The mobile radar vehicle will move to location $(X^{(n+1)}, Y^{(n+1)})$ having the minimum $T^{(n+1)}$ through:

$$X^{(n+1)} = \frac{\sum_i x_i \times g(x_i, y_i, X^{(n)}, Y^{(n)}) \times Area_{PG(x_i, y_i)}}{\sum_i g(x_i, y_i, X^{(n)}, Y^{(n)}) \times Area_{PG(x_i, y_i)}} \quad (4)$$

$$Y^{(n+1)} = \frac{\sum_i y_i \times g(x_i, y_i, X^{(n)}, Y^{(n)}) \times Area_{PG(x_i, y_i)}}{\sum_i g(x_i, y_i, X^{(n)}, Y^{(n)}) \times Area_{PG(x_i, y_i)}} \quad (5)$$

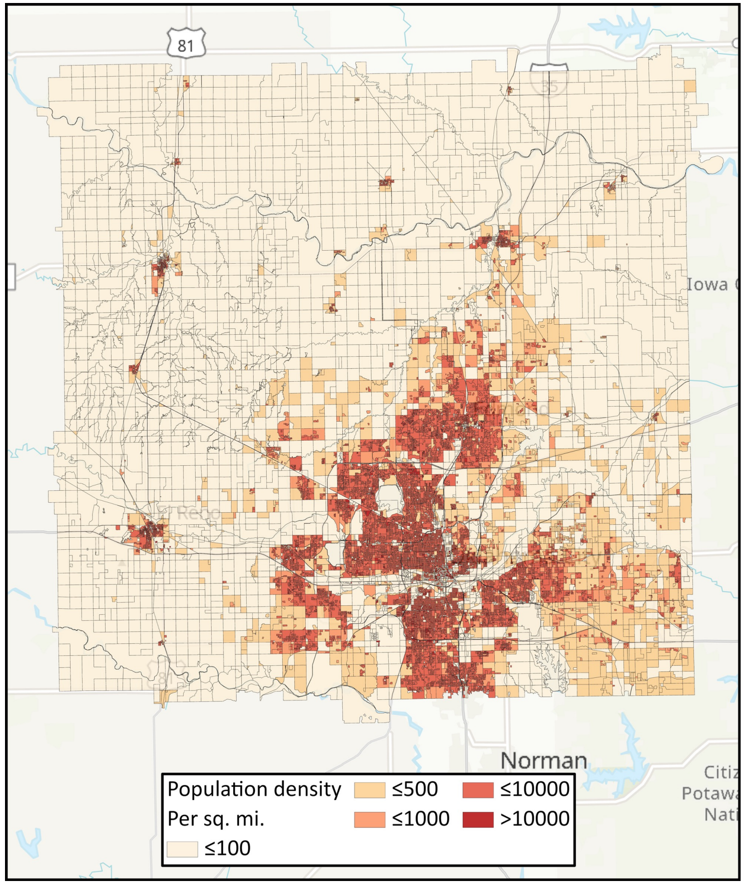


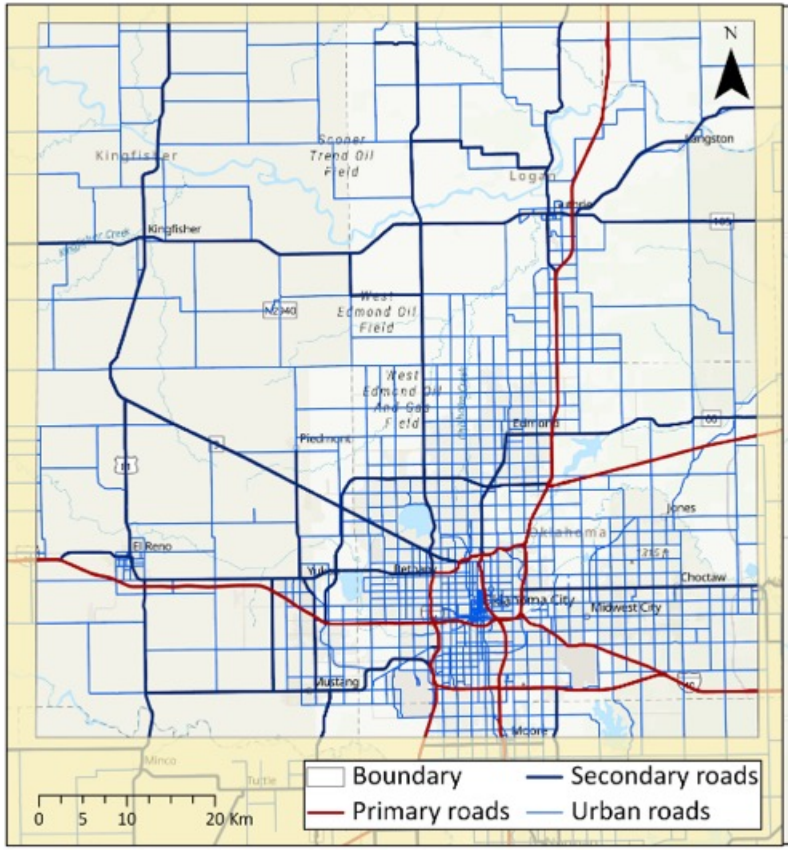
CM1-simulated reflectivity fields for a supercell storm

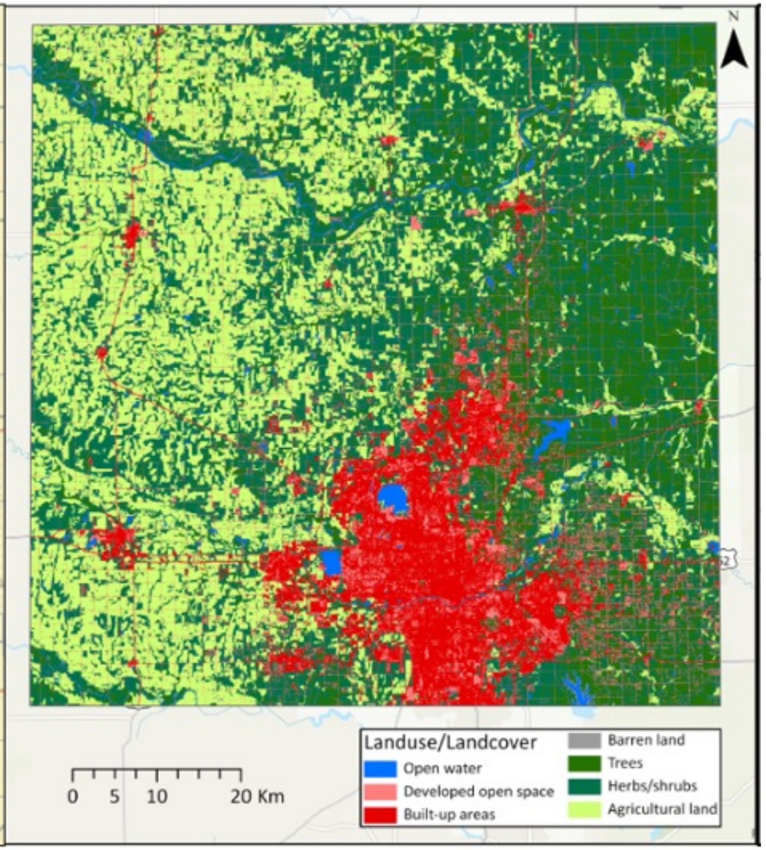
(4.308 km elevation from the ground)

Case study:

- Four counties in central Oklahoma, USA: Canadian County, Oklahoma County, Logan County, and Kingfisher County
- This region has experienced severe weather conditions, including hailstorms and tornadoes, for many years.
  - Moore tornado on May 20, 2013
  - Oklahoma City hailstorm on May 16, 2010

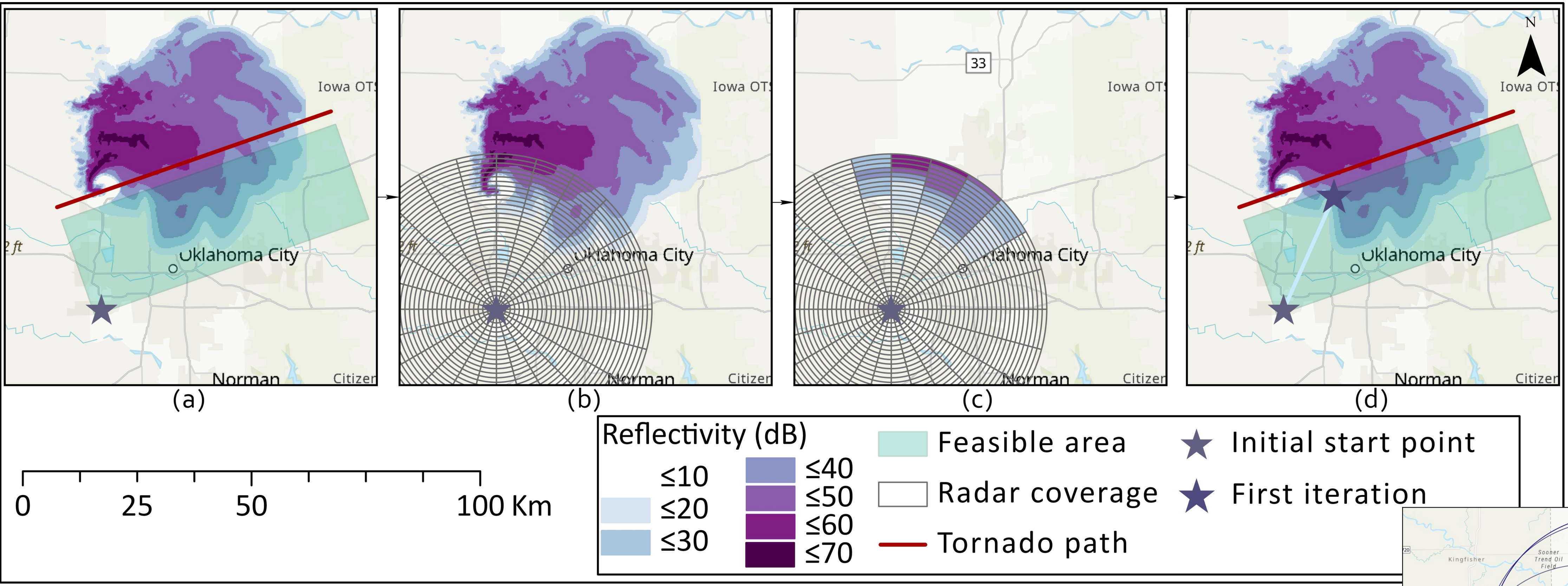

81
Iowa
Norman
Population density
Per sq. mi.
≤100
≤500
≤1000
≤10000
>10000


N
Kingfisher
Logan
Langston
Piedmont
Edmond
Jones
El Reno
Yukon
Bethany
Oklahoma City
Midwest City
Choctaw
Mustang
Moore
0 5 10 20 Km
Boundary
Primary roads
Secondary roads
Urban roads


N
0 5 10 20 Km
Landuse/Landcover
Open water
Developed open space
Built-up areas
Barren land
Trees
Herbs/shrubs
Agricultural land

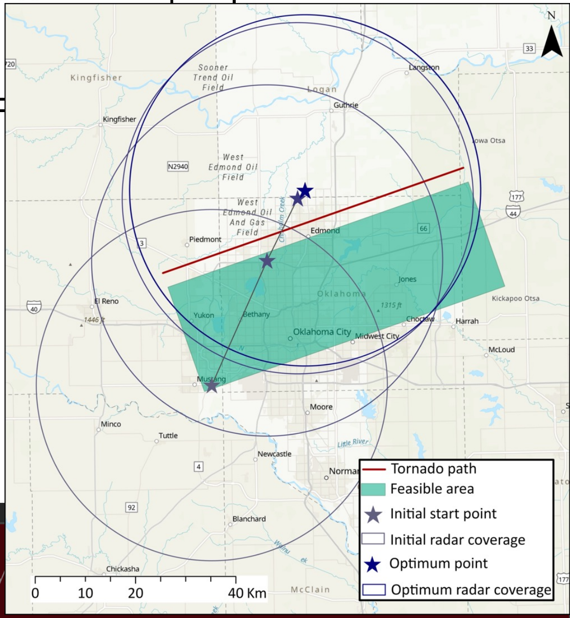
Other data

One iteration of updating the mobile radar position

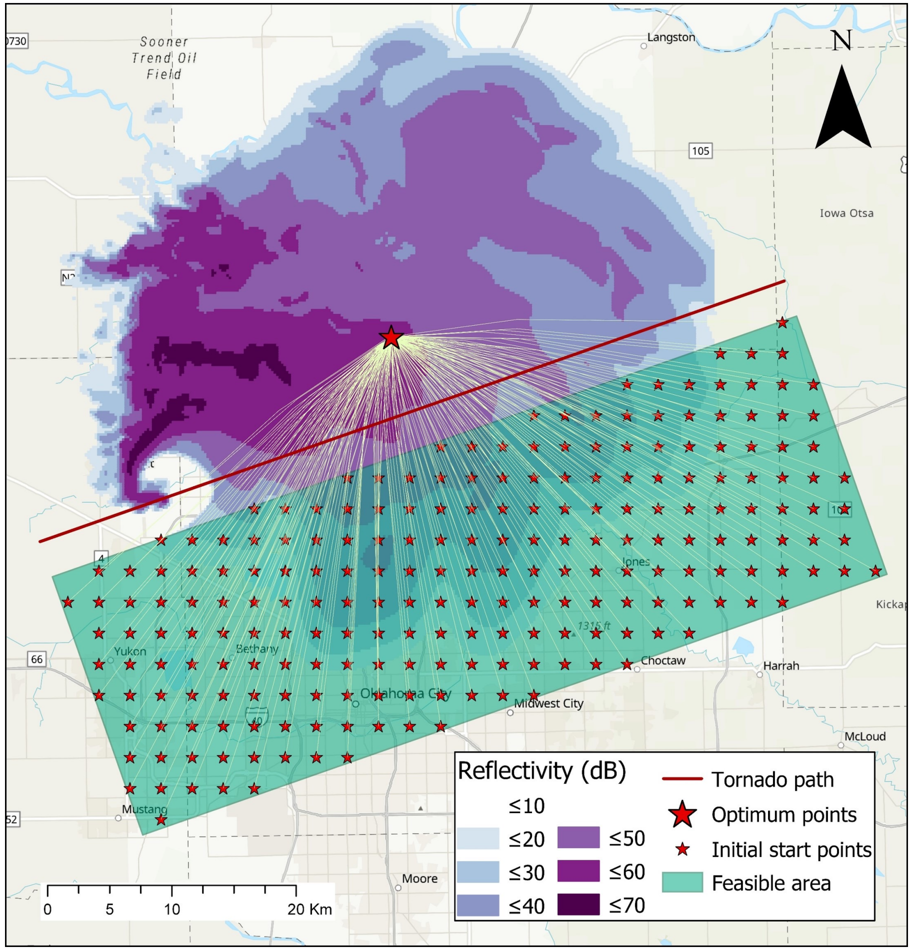


- Simulated supercell:
- Over the northern area of Oklahoma City
- Move from the southwest to the northeast

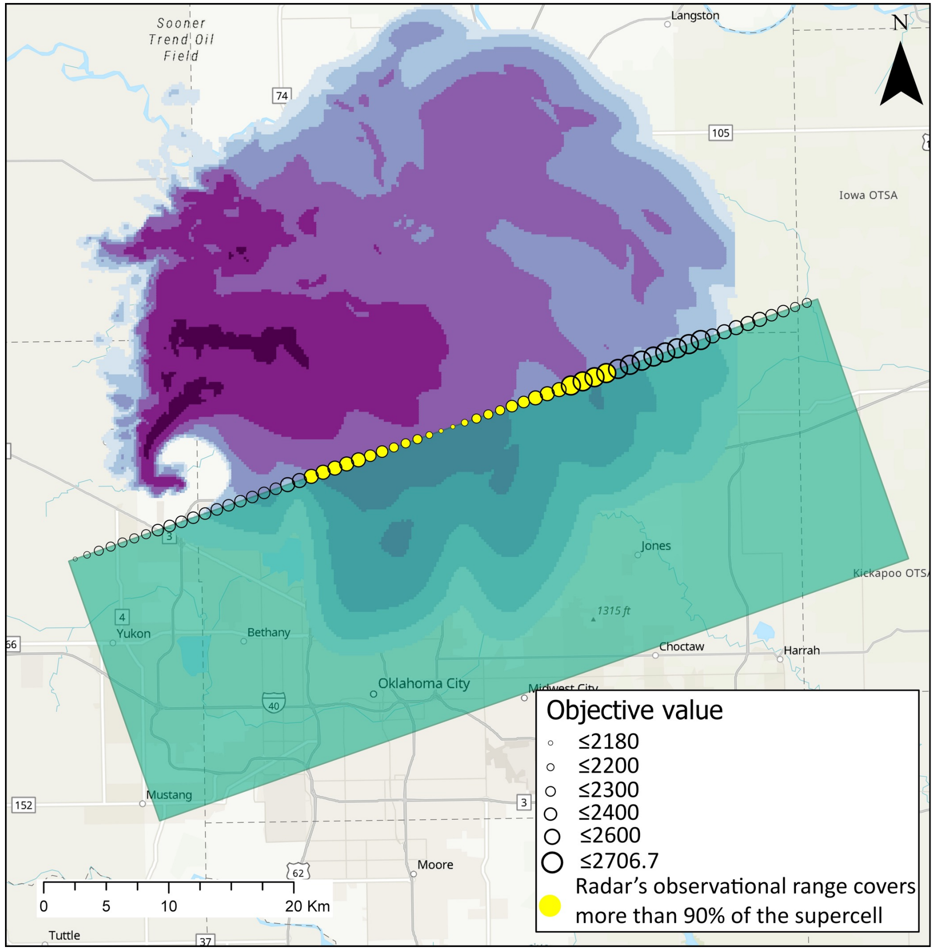
A converge process



Murray et al. (2020).

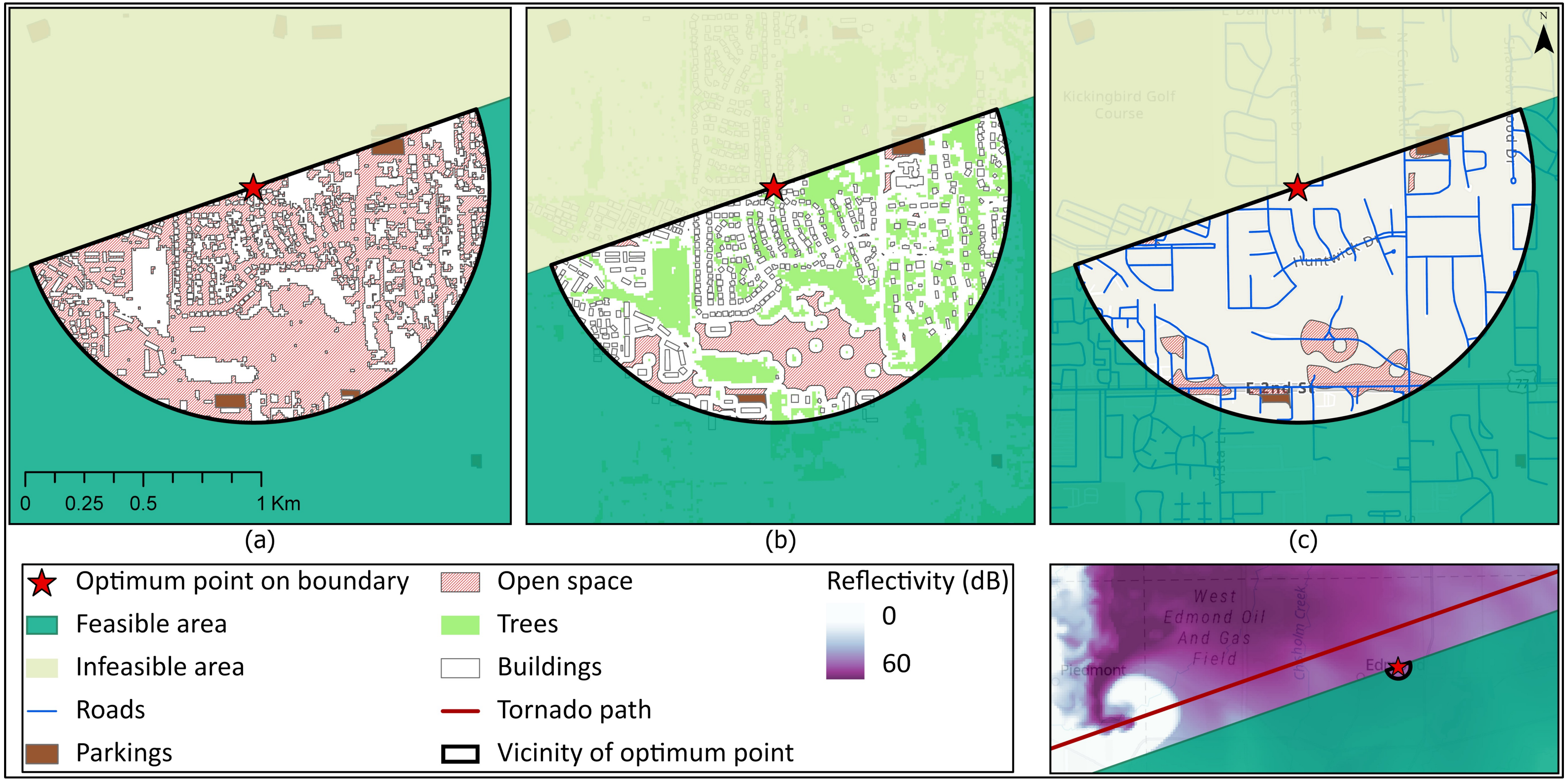


Finding convergent locations starting from different starting positions.



Focusing on locations on a boundary of the feasible area.

- Mobile radar vehicle parking spaces within 1 kilometer to our solution.
- Parking areas and open spaces are two significant land cover types: (1) at least 25 m away from buildings and trees (2) accessible by road (3) they are larger than 400 m^2



Conclusion

- Mobile ground-based polarimetric radars provide enhanced observations of severe weather phenomena when positioned near precipitation systems.
- A structured and systematic modeling approach is proposed using GIS and spatial optimization to support the decision-making process.
- By complementing human judgment with quantitative modeling, the process of selecting mobile radar locations is logical, rational, transparent, and reproducible.

Future work

- Including other radar variables or derived products (application-specific) in the objective function would be important.
- Optimizing multiple radars with different coverage and scattering properties would be important for field projects .
- Improve numerical weather prediction by locating mobile radar vehicles.

Thank you!

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