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Updates on Radar Refractivity Retrieval – Quality Control Improvements and the 2009 Field Experiment to Determine Causes of Bias

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What is Refractivity?

Refractivity is a variable derived from atmospheric temperature (T), pressure (p) and water vapor (e):

$$N = 77.6\frac{p}{T} + 3.73x10^5\frac{e}{T^2}$$

Weather radar can extract atmospheric refractivity at high spatial and temporal resolution (see Fig. 1). Refractivity is most sensitive to changes in water vapor present in the atmosphere when the temperature is warmer, such as in the summer months. This is a critical realization, which shows how refractivity (among other uses) can € be used as a proxy for atmospheric vapor content.

Radar-Derived Refractivity

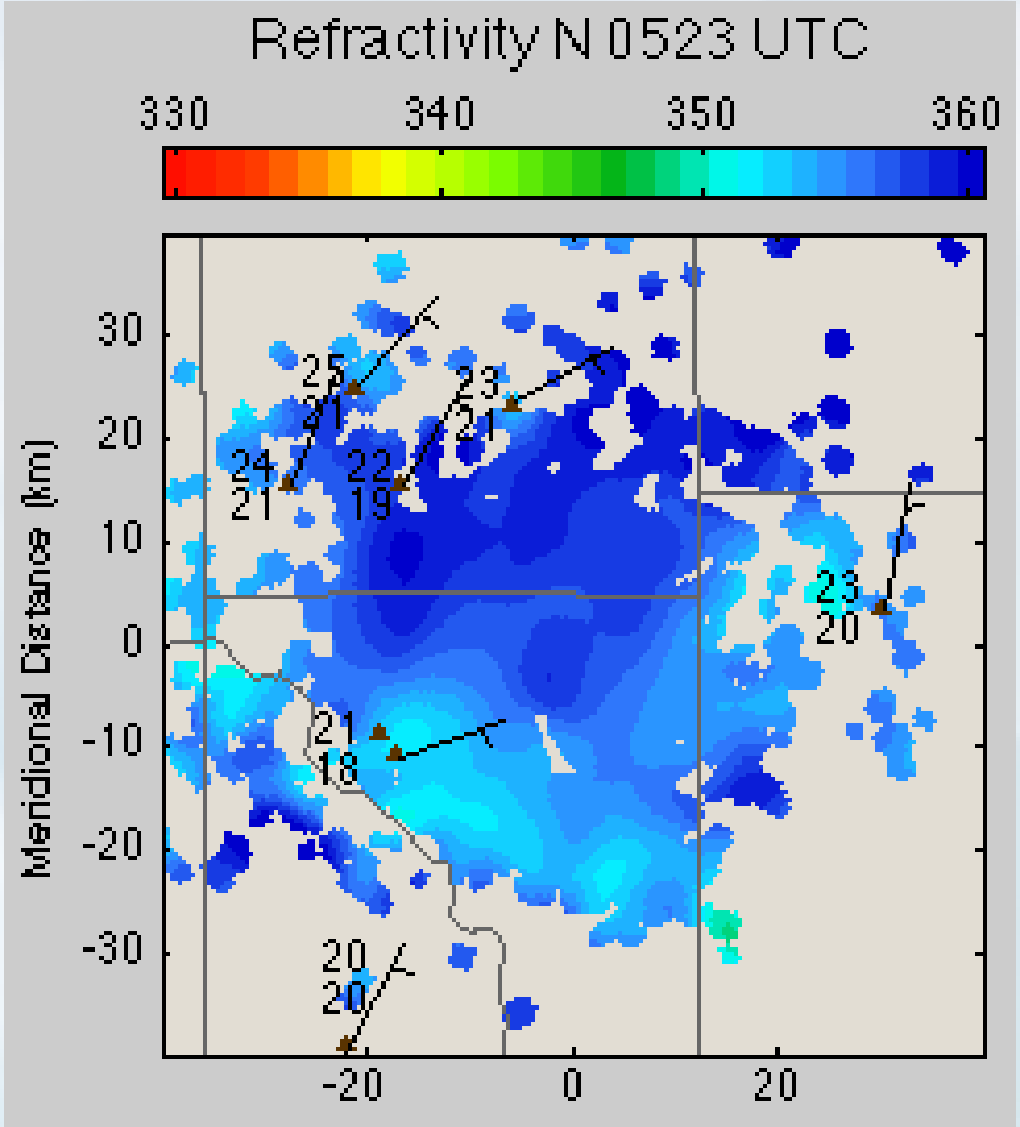


Fig. 1. Plot of radar-derived refractivity (color shaded), 0523 UTC, July 4 2008. Oklahoma Mesonet station observations of wind, T and T_d plotted. Resolution of gradients within the moisture field is apparent in radar refractivity, while such gradients may be lost in conventional surface observational data.

Phase data from gates deemed acceptable (spectral moments and phase steadiness representative of ground clutter) are processed and values of refractivity change (from the reference time t_0) are calculated.

$$\Delta N = -10^6\frac{c}{4pf}\frac{d}{dr}[f(r,t_1) - f(r,t_0)]$$

The absolute value of refractivity (N) is derived by adding the “baseline” value of N (obtained from Mesonet observations) from the reference time t_0 to the change in N since the reference time (ΔN).

How can Refractivity be used?

If we have high-resolution refractivity measurements from a radar, we can view moisture gradients and perturbations, which may signal boundary layer structures which may lead to sufficient lift and/or instability for convection initiation (Bodine et al. 2009). This signal may or may not be present in the surface observational network due to limited coverage, placing value in the use of radar-derived refractivity.

Based on these considerations, we can see how refractivity measurements may aid in diagnosing and predicting convection initiation location and timing. Ongoing efforts with N. Gasperoni and M. Xue include assimilating radar-derived refractivity into a high-resolution weather forecasting model (ARPS) and predicting convection initiation with the added radar data versus conventional observations alone.

Radar-Derived Refractivity Bias

Over time it has been observed that the absolute values of radar and surface-based refractivity are in good agreement. However, certain periods of time show a significant deviation between the two platforms (see Figure 2).

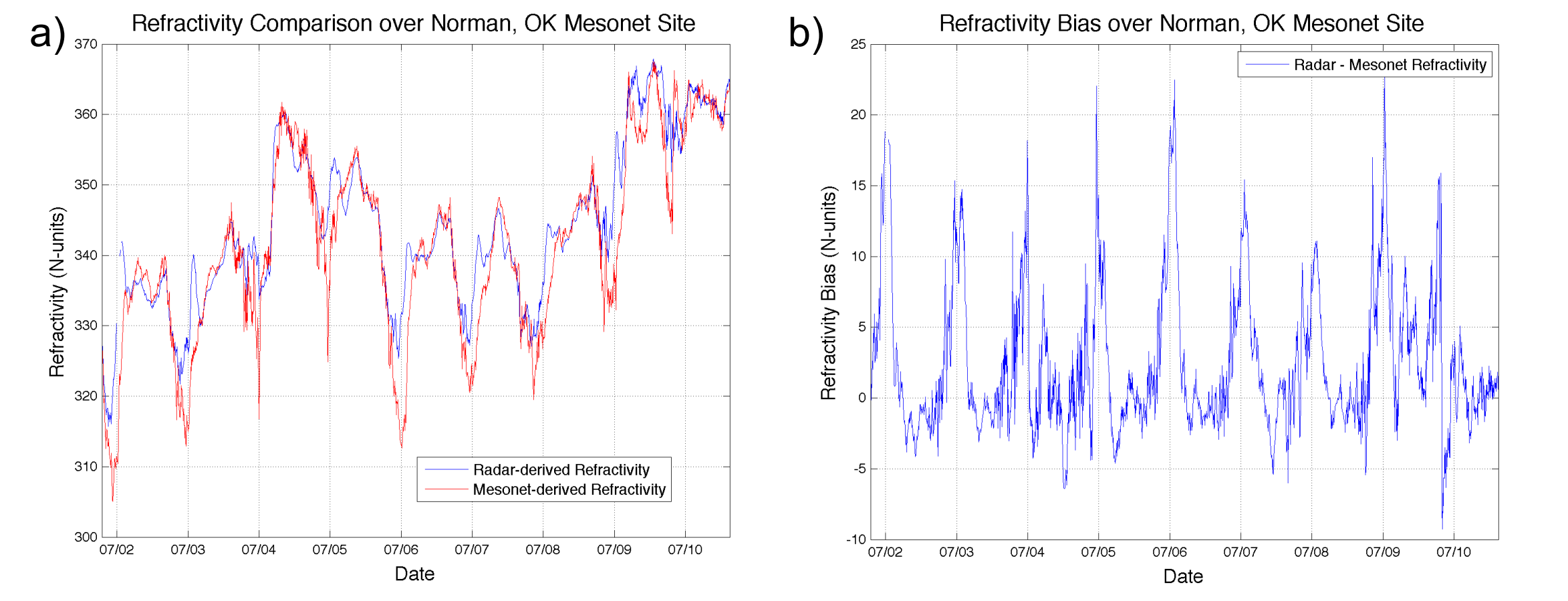


Fig. 2. Time series of refractivity from radar and mesonet (a) and the radar refractivity bias (b), using Mesonet data as “ground truth”.

It can be very problematic for numerically predicting convection initiation if the radar-derived refractivity field has any bias, since the model assumes the observations are unbiased. Also, ARPS needs a quantified analysis of variance in order to estimate potential observational errors in the radar data. It turns out that the variance is fairly steady in space and time. However, bias fluctuates significantly in time, and the physical mechanisms which cause this bias are investigated in the following sections.

It can be seen that a substantial bias is present at times, with bias occasionally exceeding 5% of refractivity. Understanding the causes of this bias will be critical in order to successfully model convection initiation using refractivity data.

Potential Causes of Radar-Derived Refractivity Bias

The bias observed above is fairly typical of the bias pattern, in that the bias tends to peak around 00 UTC, or 7 pm local time in the warm season. Sunset occurs between 8:00 and 8:50 pm in central Oklahoma during this period. It has been shown through Mesonet temperature data at 1.5 and 9 meters that an inversion begins to develop at the same time that the bias occurs.

The bias tends to occur more frequently during the warm season, with an accompanying increase in magnitude. Additionally, it appears as if the bias occurs during periods of rapid changes in absolute refractivity (Figure 4).

These factors lead us to consider the following potential causes of the radar refractivity bias:

- Changes in radar beam propagation

- Changes in vertical refractivity and temperature gradients

- Evaporation and mixing changes near time of sunset

Resources to be used in determining Bias Cause

- Mesonet tower, adapted to include a humidity sensor @ 9m, which allows for high-resolution (1-minute) vertical gradients of refractivity as well as temperature.

- Unmanned Aerial Vehicle (UAV), provided by P. Chilson. Instrumented with temperature, humidity and pressure sensors, this vehicle can sample well over 100 meters in the vertical.

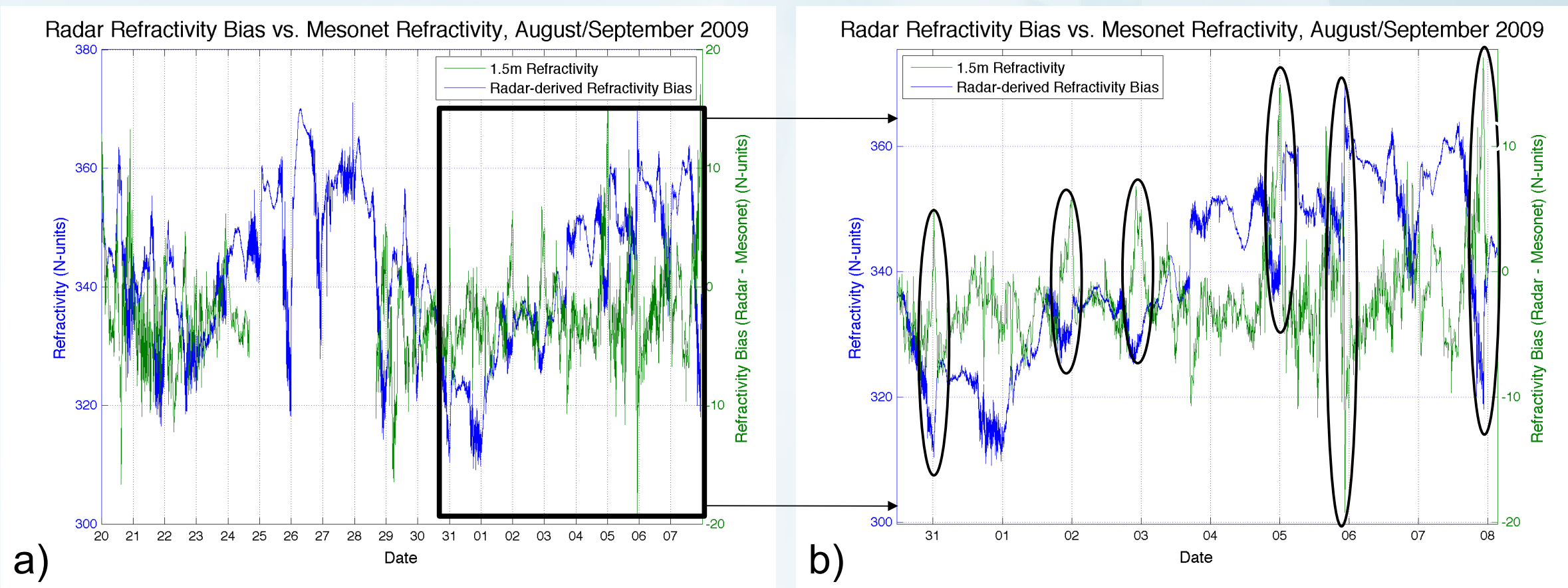
Fig. 3. Adapted NRMN Mesonet Tower.

Findings on the Cause of Radar-derived Refractivity Bias

So far, it has been determined that periods with sharp changes in refractivity (and consequently water vapor content) have been correlated with periods of bias (see Figure 3). During the evening, the nocturnal inversion (warming with height) begins at the surface and deepens with height as time progresses. During this period of rapid inversion intensification the vertical gradients of temperature and refractivity steepen significantly. Two factors may be at play at this time to cause a bias:

1) Changing refractivity gradients are rapidly changing the propagation path of the radar beam, sampling a different vertical level of the atmosphere and therefore a different value of refractivity, and

2) The steepening of the refractivity gradient also poses a problem if the sampling height of the radar beam changes. With a sharp gradient, even slight changes in sampling height may lead to significant changes in received refractivity measurements over short periods of time.



a) b)

Fig. 4. Time series of radar refractivity bias vs. absolute refractivity from Mesonet data (a) and a close-up showing several periods of coincident bias and sudden changes in refractivity at the surface station (b).

Future Work

UAV data will be analyzed for vertical refractivity gradients and their correlation with both the intensity and timing of radar refractivity bias. Correlation with Mesonet tower data will also help understand signals that may be present in Mesonet data, so that UAV data need not be present at all times in order to quantify radar refractivity bias.

Analysis of this and other available datasets will yield physical explanations for the bias in radar-derived refractivity.

It can also be shown that the targets' radar refractivity variance are deteriorated near the edge of the domain. This may be due to targets which are only partially illuminated and may have enough motion to render undesirable for calculating refractivity, yet are still entering the algorithm, which effectively smoothes undesirable phase throughout a radius of 4 km.

Currently the algorithm checks targets for spectral moments and for phase coherency in time. However, the moments are only analyzed in real-time, while phase steadiness is only checked at the reference time. A more rigorous solution would be to compute both censoring products in real-time, which will be done shortly.

Future work will also include a more rigorous procedure with which targets with desirable phase can be selected. Fuzzy logic and multilinear regression methods will be analyzed for this task. The model producing the best clutter classification will be used in real-time censoring of undesirable targets.

The two latter areas of research have the goal of improving variance throughout the radar refractivity domain and enlarging the domain of refractivity for assimilation into forecasting models.

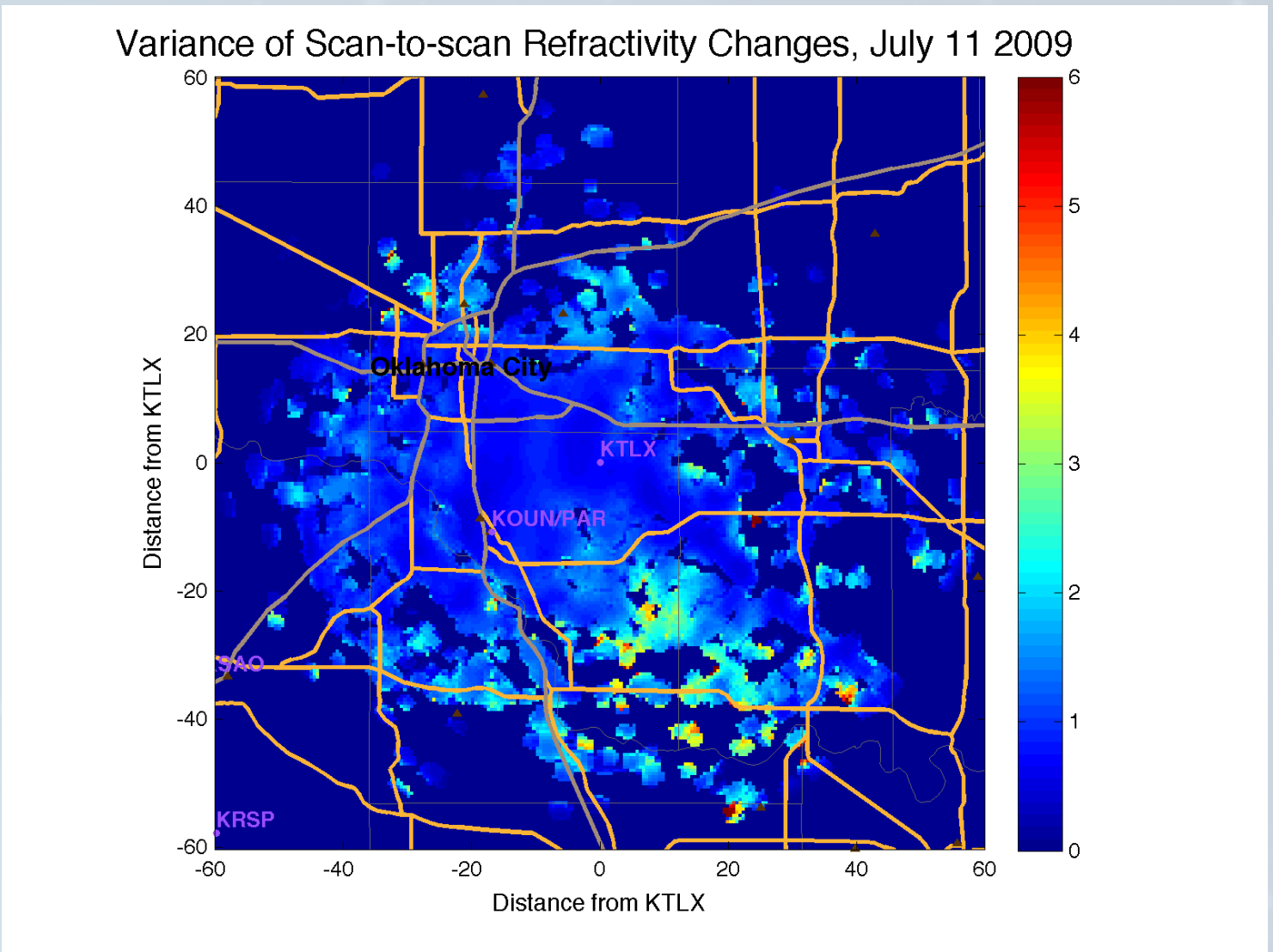


Fig. 5. Map of radar-derived refractivity variance over all radar scans (n=161) on July 11 2009. Note the high variance near the domain boundaries, especially southeast of KTLX.

Further quantification (and reduction) of the bias and variance will be assessed for assimilation into ARPS by N. Gasperoni and M. Xue over the coming months. Increased data accuracy will produce higher quality fields during assimilation. The ultimate goal is successfully modeling convection initiation using radar-derived refractivity data as an additional data source.

Acknowledgements

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http://arrc.ou.edu

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