Applications of Radar-Derived Shear Products Using an Updated Linear Least-Squares Derivative Technique

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The LLSD Approach

The **Linear Least-Squares Derivative (LLSD)** method is an approach to calculating gradients across 2D radar data. Mathematically, an LLSD gradient is the slope of the least-squares plane fit to a neighborhood of data points.

$$\begin{bmatrix} \Sigma \Delta r_i^2 & \Sigma \Delta r_i \Delta s_{ij} & \Sigma \Delta r_i \\ \Sigma \Delta r_i \Delta s_{ij} & \Sigma \Delta s_{ij}^2 & \Sigma \Delta s_{ij} \\ \Sigma \Delta r_i & \Sigma \Delta s_{ij} & \Sigma\, 1 \end{bmatrix} \begin{bmatrix} u_s \\ u_r \\ u_0 \end{bmatrix} = \begin{bmatrix} \Sigma \Delta r_i u_{ij} \\ \Sigma \Delta s_{ij} u_{ij} \\ \Sigma u_{ij} \end{bmatrix}$$

Eq. 1. *System of LLSD governing equations in matrix form, where r is the range, s is the radial, i and j are the coordinates of each gate, and u is the measurement at a gate. Each summation is taken over each gate in the neighborhood, from m=1 to m=n. This system may be solved for both across-azimuth (u_s) and along-azimuth (u_r) components of shear.*

These equations have recently been refined, replacing previous, simplified versions. While (at the time of this work) it is applied operationally only to the development of azimuthal (rotational) shear (**AzShear**) products, the relative accuracy and flexibility of the method allows it to be applied in a wide variety of radar data, as outlined here.

Across-Azimuth Velocity Shear

The across-azimuth component of LLSD radial velocity shear produces rotational wind shear. This yields the widely-used 2D AzShear product, which itself can be accumulated over multiple radar scans to track rotation features over time.

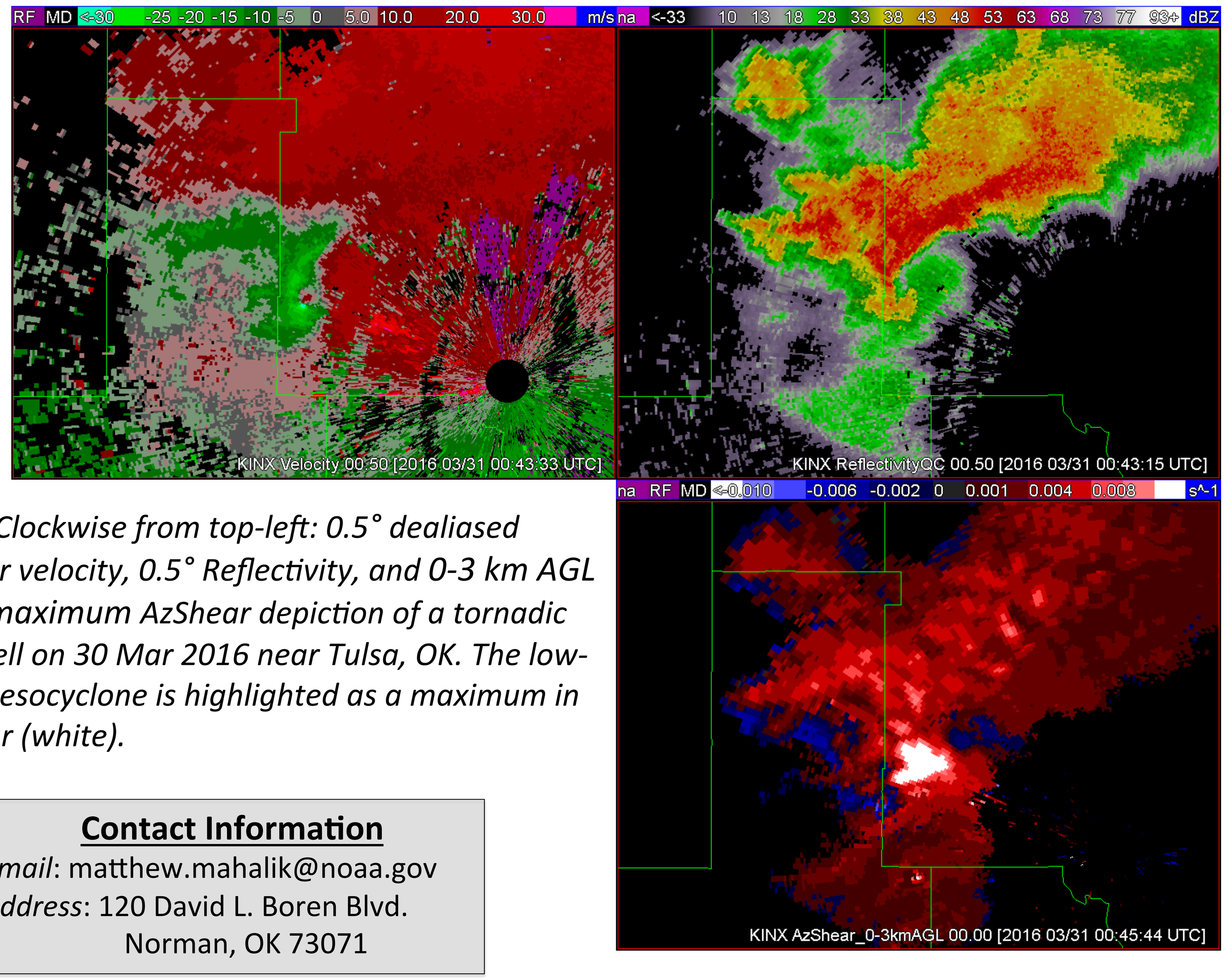

***Fig. 1**. Clockwise from top-left: 0.5° dealiased Doppler velocity, 0.5° Reflectivity, and 0-3 km AGL layer-maximum AzShear depiction of a tornadic supercell on 30 Mar 2016 near Tulsa, OK. The low-level mesocyclone is highlighted as a maximum in AzShear (white).*

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Along-Azimuth Velocity Shear

In addition to rotational shear, the same governing LLSD equations can be solved for the along-azimuth shear component, which (when applied to radial velocity data) yields a 2D LLSD **divergence** (positive) and **convergence** (negative) field. Below are examples of applications for this data.

Convergence Boundaries

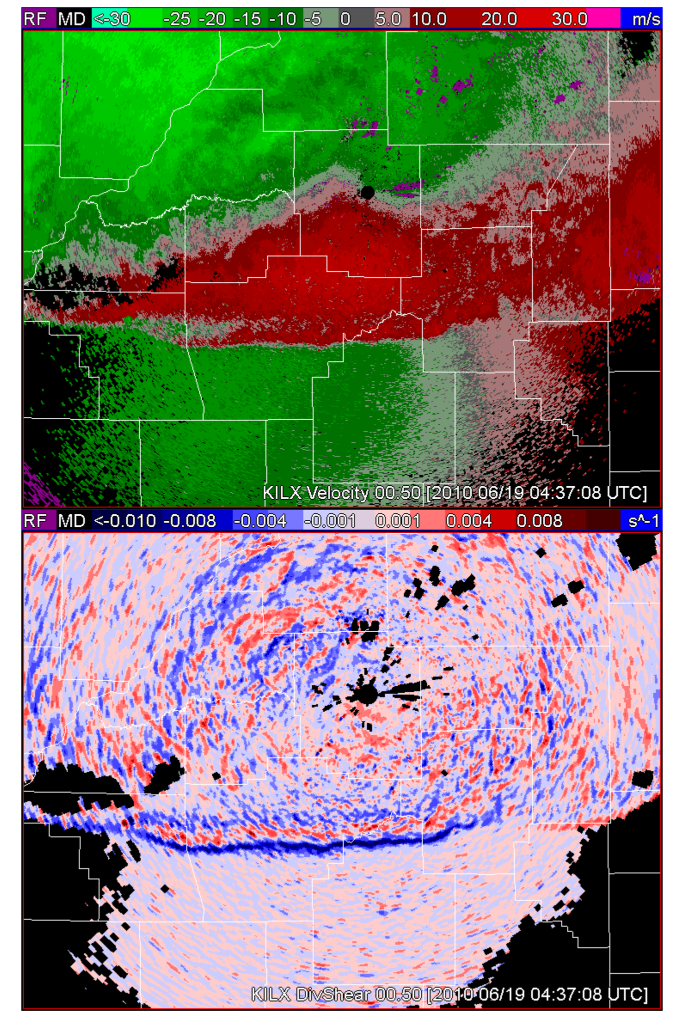

***Fig. 2**. 0.5° dealiased Doppler velocity (top) and 0.5° Divergent Shear depiction of a southward-moving gust front on 18 Jun 2010 in Central Illinois. The gust front appears as strong convergence (blue).*

Supercell Structure

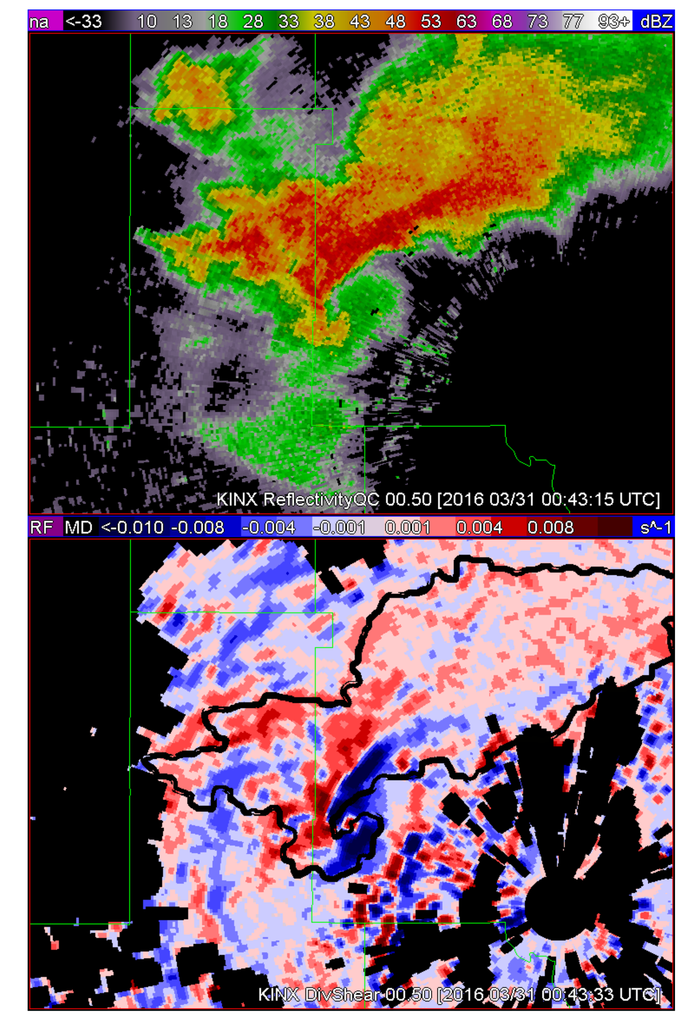

***Fig. 3**. 0.5° Reflectivity (top) and 0.5° Divergent Shear (with 25 dBZ reflectivity contour in black) depiction of a tornadic supercell on 30 Mar 2016 near Tulsa, OK.*

Downburst Signatures

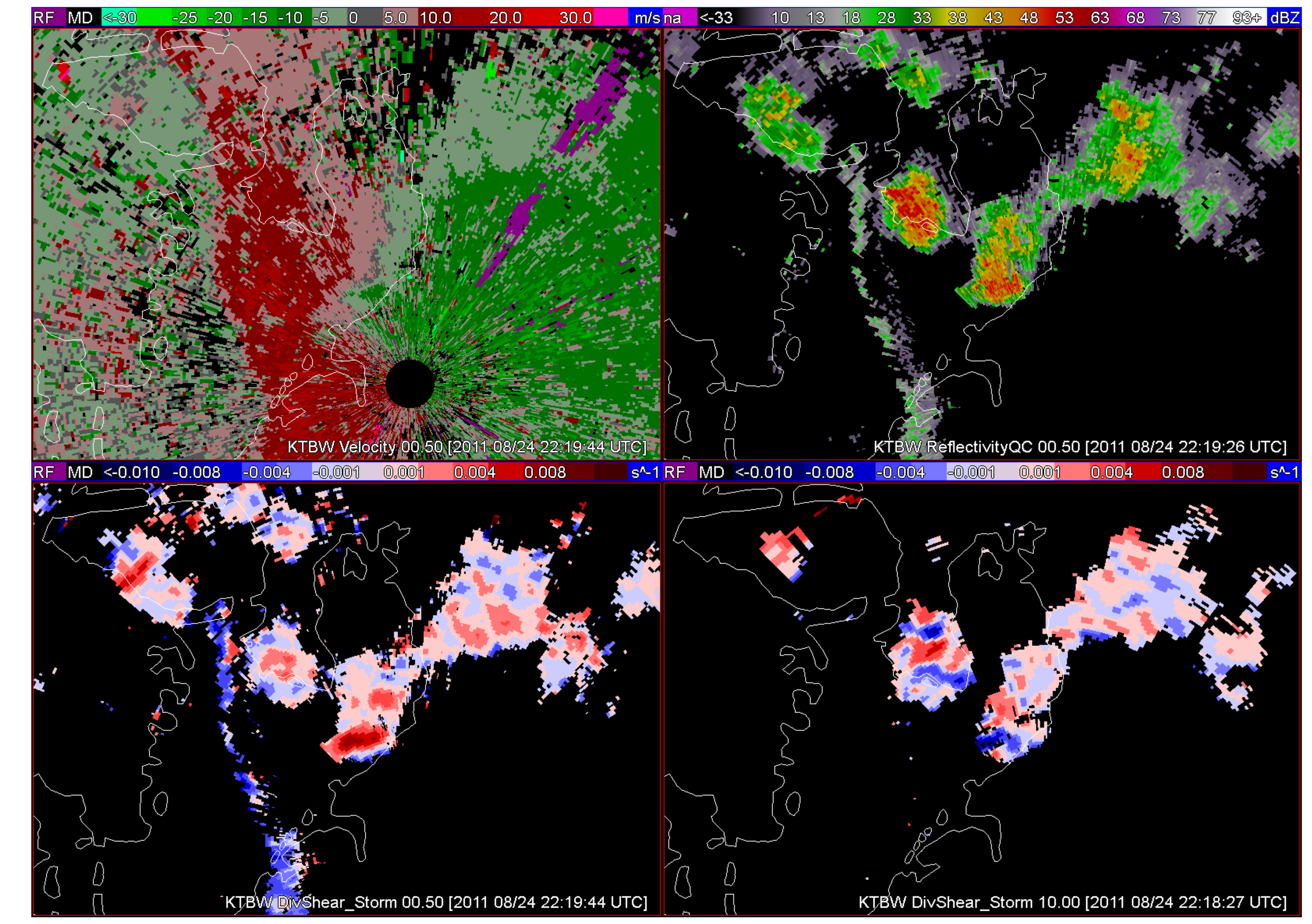

***Fig. 4**. Clockwise from top-left: 0.5° dealiased Doppler velocity, 0.5° Reflectivity, 10.0° Divergent Shear, and 0.5° Divergent Shear depiction of a damaging downburst and outflow boundary on 24 Aug 2011 near Tampa, FL. The downburst is collocated with strong divergence (red) near the ground and convergence (blue) aloft.*

Reflectivity Gradients

LLSD shear can also be calculated for non-velocity radar products. For example, individual storms can be "stenciled" using 2D LLSD **reflectivity gradients**. This product highlights sharp changes in reflectivity, such as tornado "debris ball" reflectivity maxima.

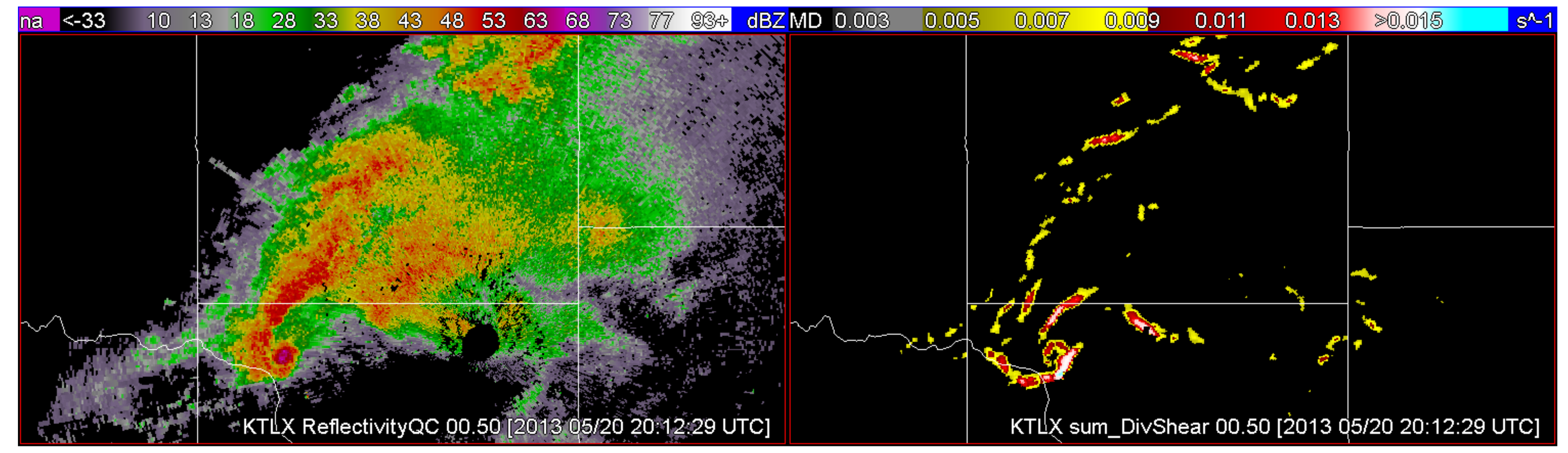

***Fig. 5**. 0.5° Reflectivity (left) and 0.5° LLSD reflectivity gradient (stencil) depiction of a tornadic supercell on 20 May 2013 near Moore, OK.*

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Summary and Future Work

The examples shown here are a first look at applications of the LLSD governing equations beyond traditional rotational shear products.

Limitations. The accuracy of the algorithms used to calculate LLSD gradients is subject to the quality of input radar data. The effects on along-azimuth gradient calculations from noisy and/or bad velocity data as well as range from the radar have yet to be examined in detail.

Future Work. Validation of these products is currently in the early stages; a quantitative analysis of their performance, including optimal neighborhood size for divergence calculations, will follow. LLSD-derived gradient fields shown here are being designed for wider use in future applications, including detection, tracking, and trending algorithms. In addition, exploratory LLSD use will be expanded to include the calculation of gradients in dual-polarimetric fields.