A Preliminary Comparison of MDA and LLSD Performance and Properties

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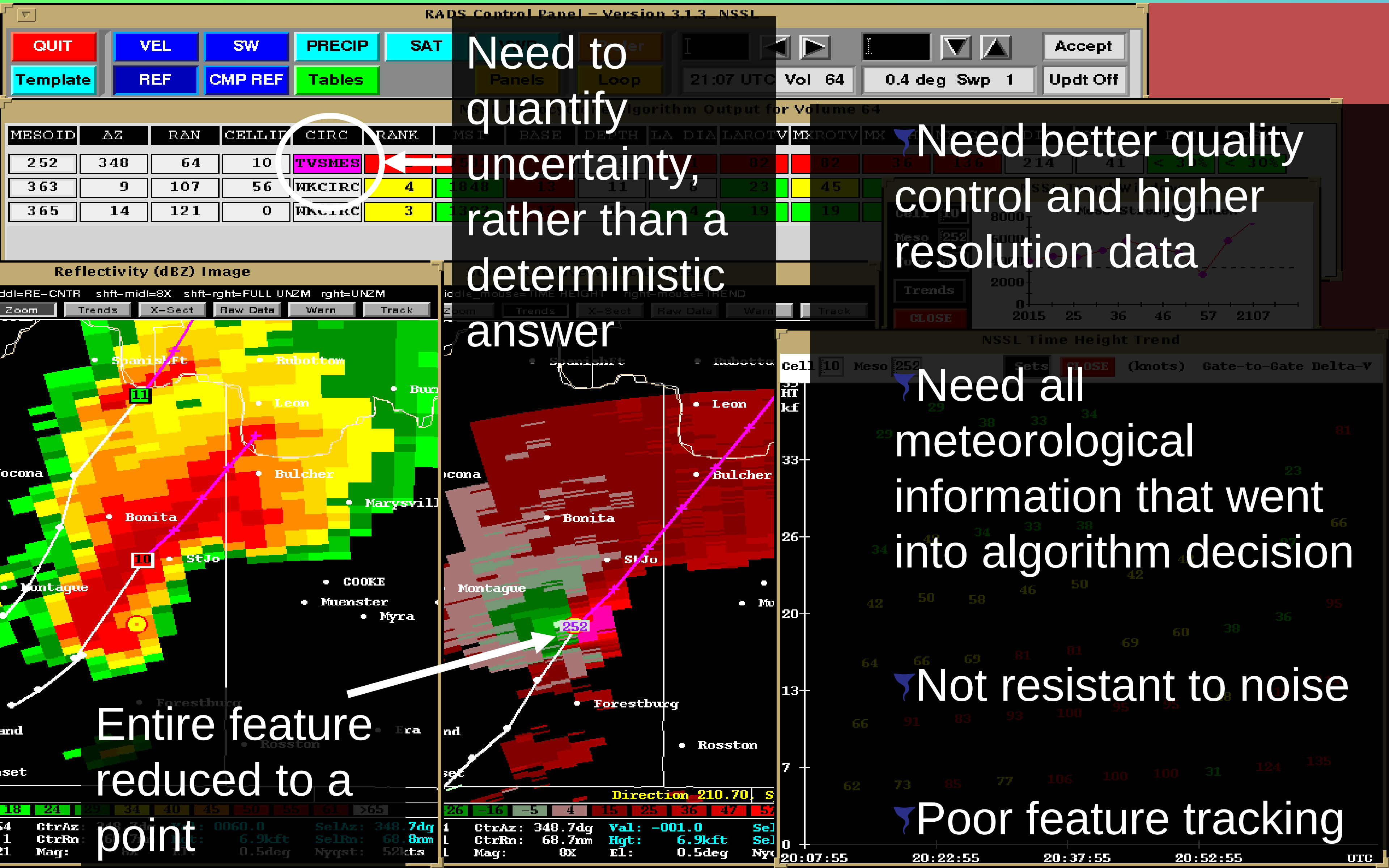
Inference Engines

- To identify mesocyclones in single Doppler radar an "inference engine" must identify areas of azimuthal shear, fundamentally a derivative of radial velocity w.r.t. azimuthal distance:

$$\frac{\partial u}{\partial \theta_d}$$

  where *u* is radial velocity and θ_d is the distance in azimuth bewteen samples (approximately $\Delta\theta$ x r).
- MDA relies on a peak-to-peak derivative estimate.
  - NOT resistant to noise.
- A local linear least squares derivative (LLSD) estimate is more resistant to noise, especially if *u* is first filtered to remove extreme values

Current MDA



Need to quantify uncertainty, rather than a deterministic answer

- Need better quality control and higher resolution data
- Need all meteorological information that went into algorithm decision
- Not resistant to noise
- Poor feature tracking

Entire feature reduced to a point

Local Linear Least Squares Derivative (LLSD)

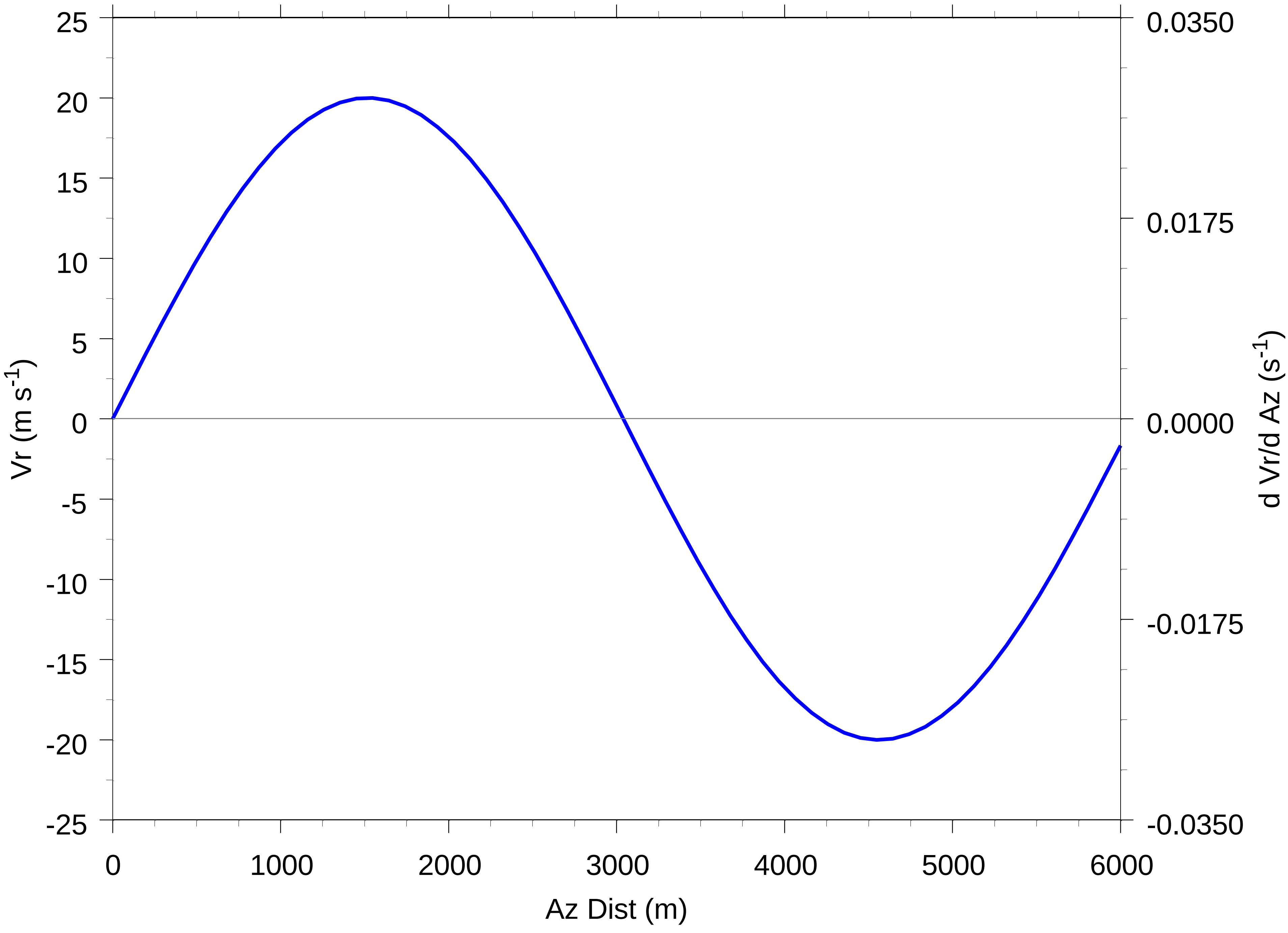
- Draws upon long standing techniques that use local regression fits, rather than global fits, as filtering operations.
- Fits are first order, thus the regression coefficient is used as the derivative estimate:

$$y = mx + b,$$

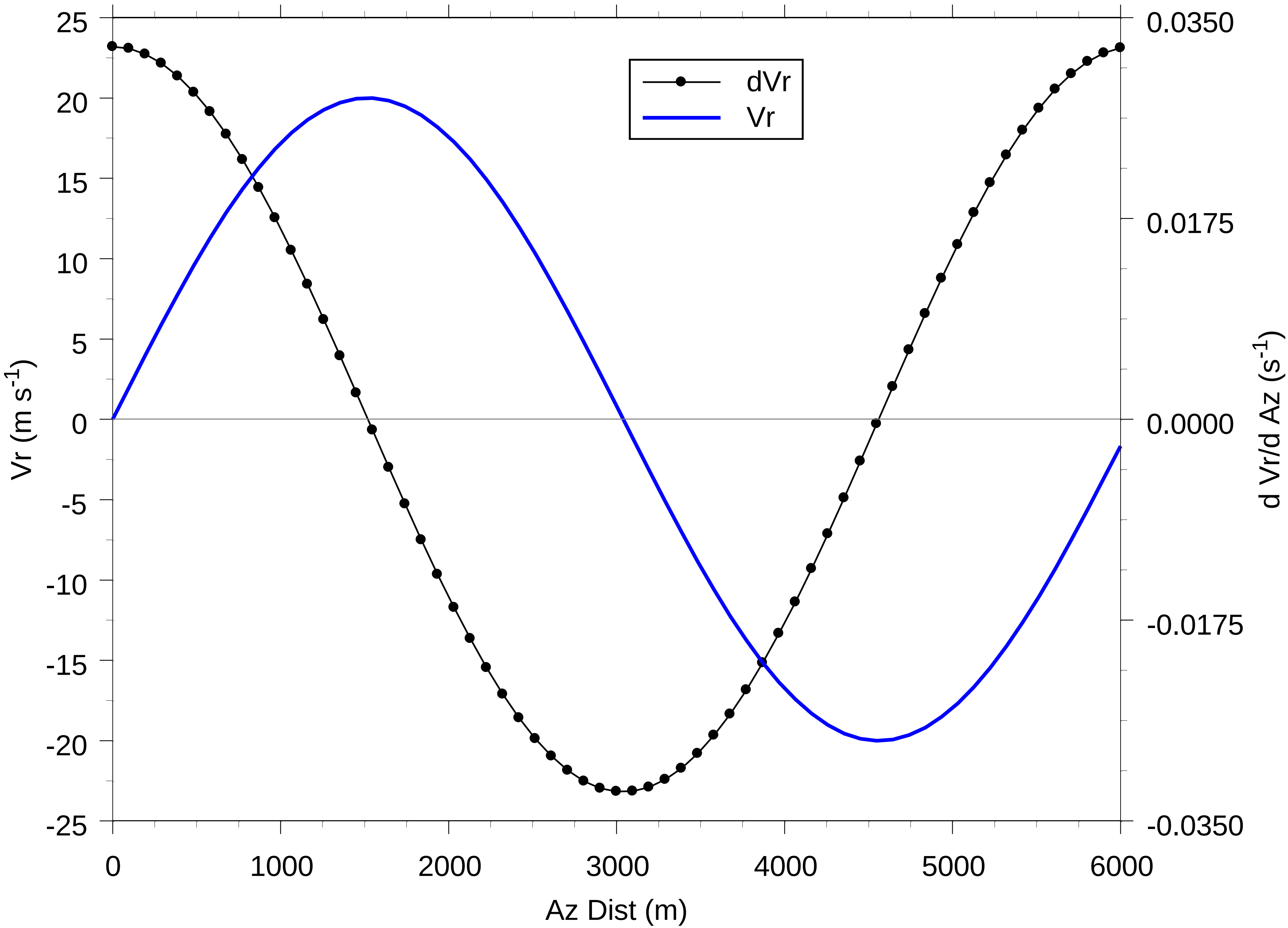
where y is, say, radial velocity and x is location. The regression coefficient is approximately the local derivative, y_x.

A Toy Example in 1D

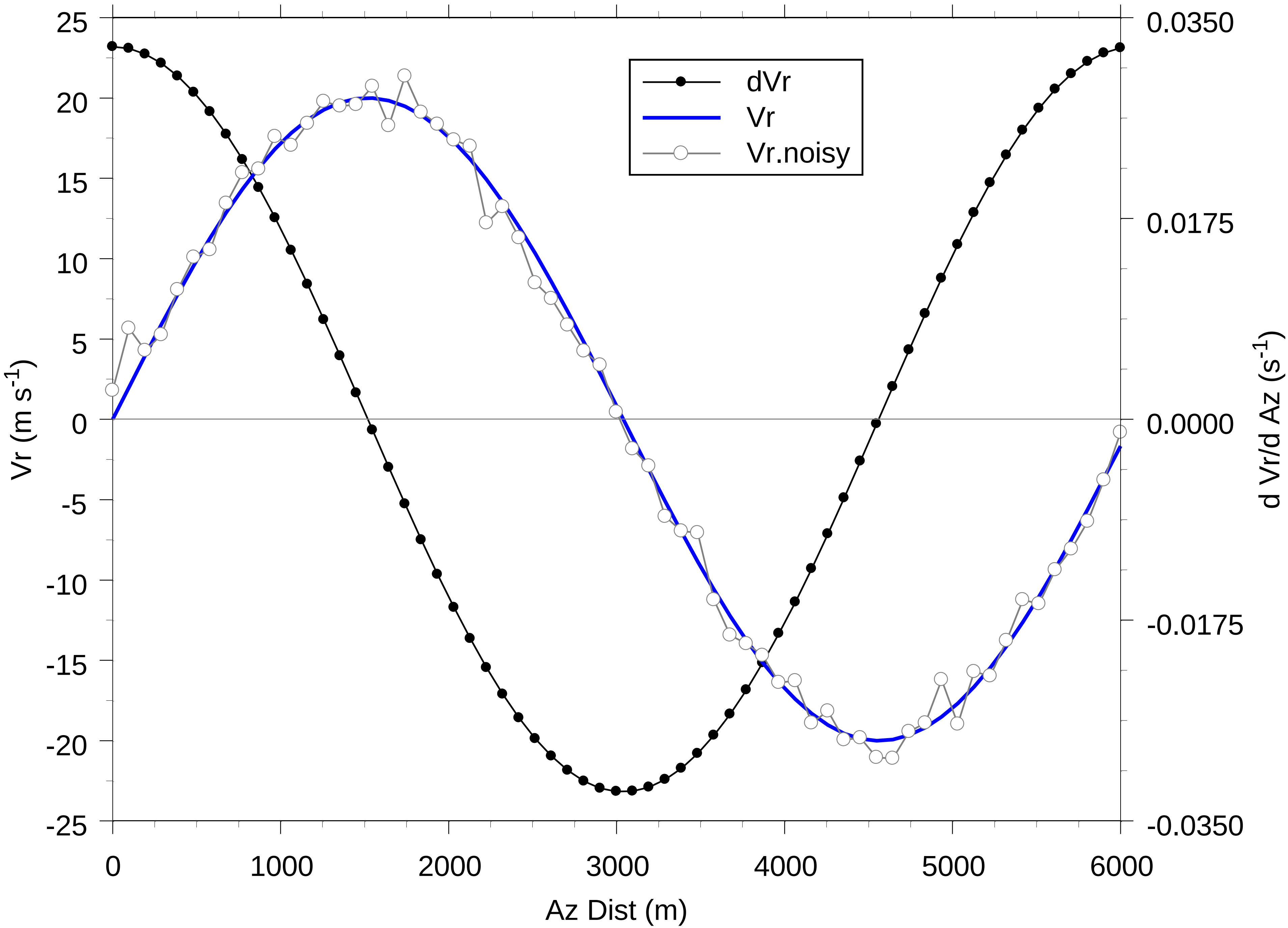
- Procedure:
  - Start with an analytic function (sine)
  - Add noise (Gaussian)
  - Estimate derivative using peak-to-peak and LLSD
  - Show difference between analytic derivative, peak-to-peak, and LLSD



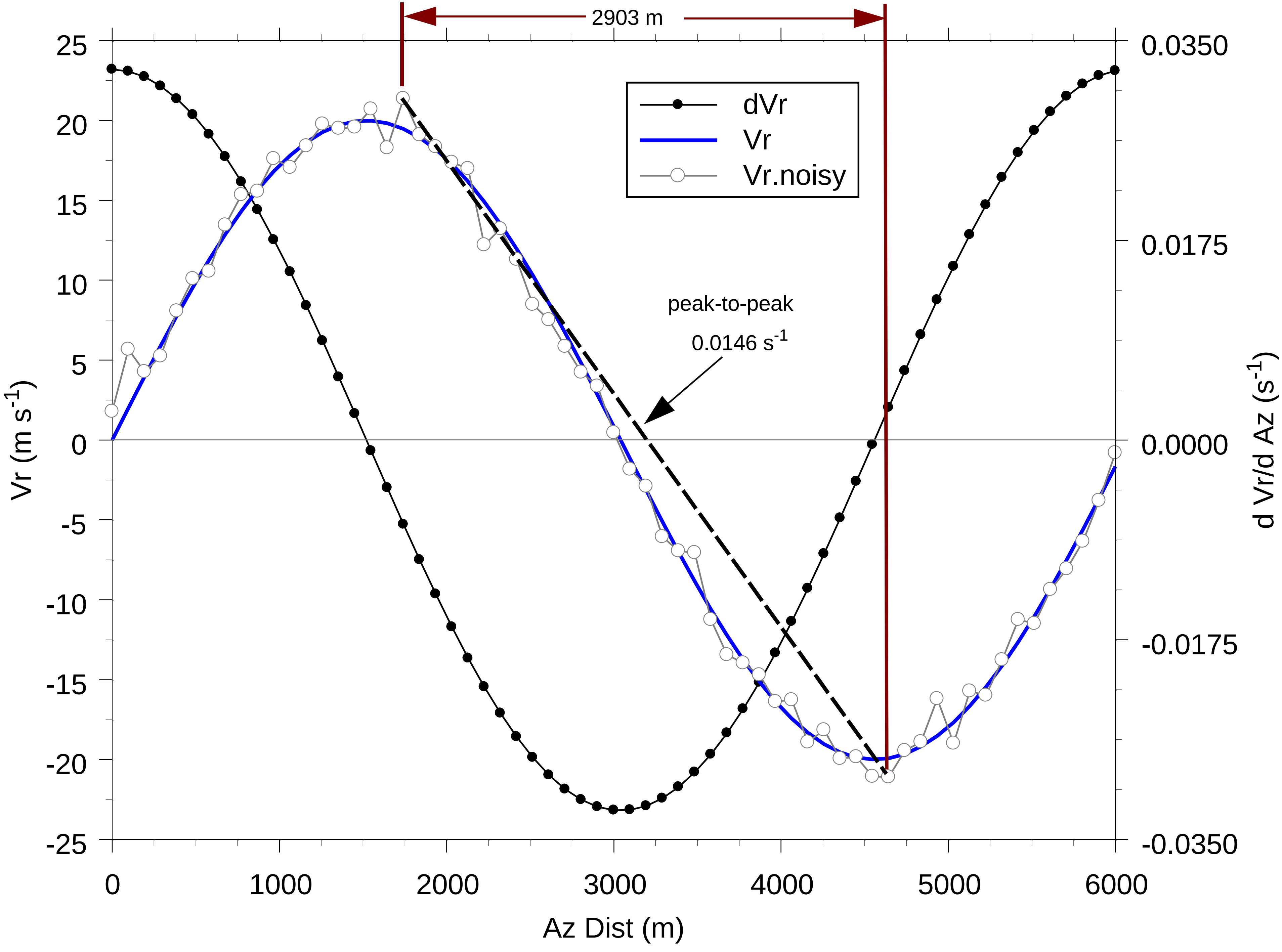
25
20
15
10
5
0
-5
-10
-15
-20
-25
Vr (m s^{-1})
0.0350
0.0175
0.0000
-0.0175
-0.0350
d Vr/d Az (s^{-1})
0
1000
2000
3000
4000
5000
6000
Az Dist (m)



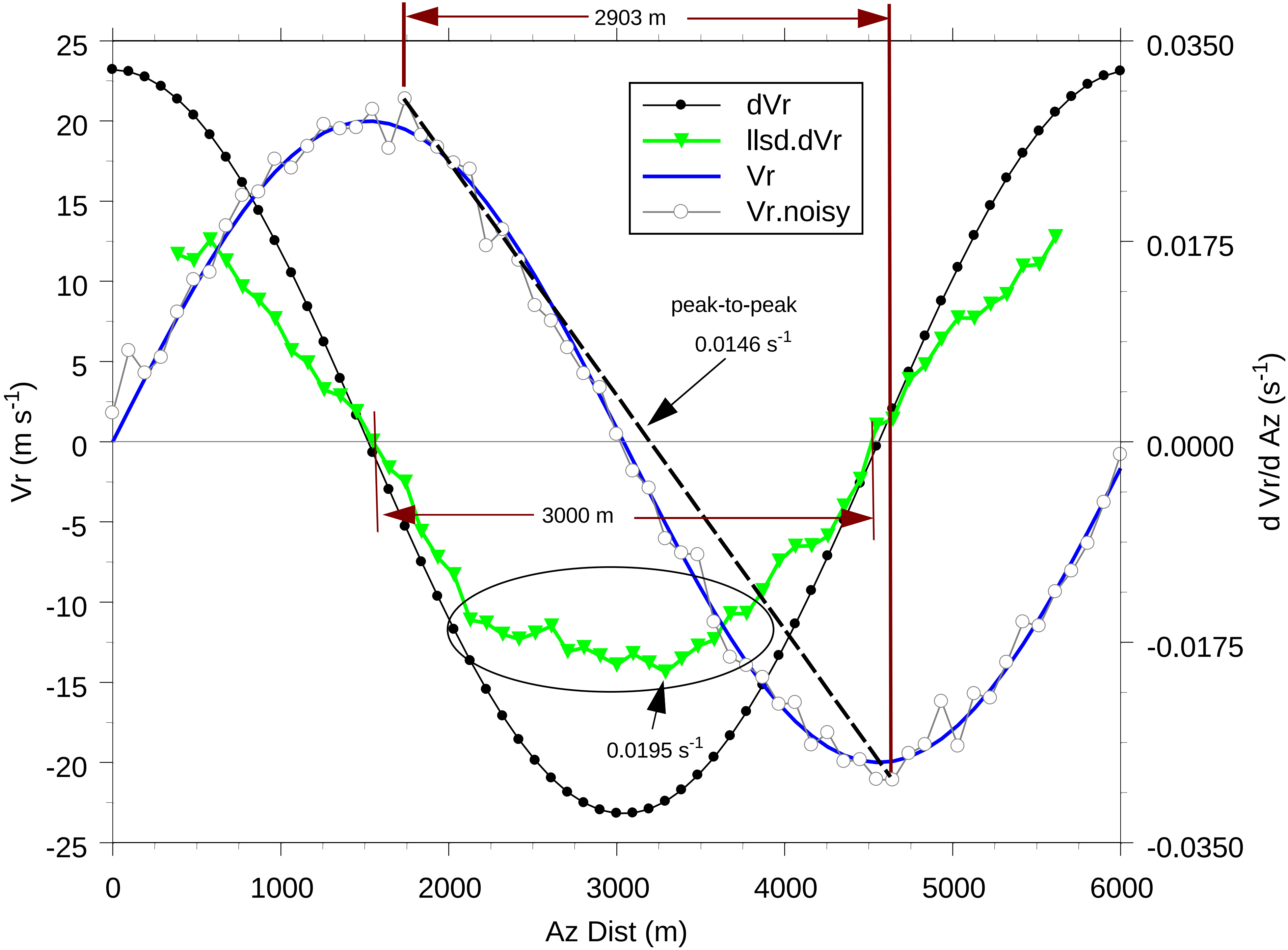
dVr
Vr
Vr (m s^{-1})
d Vr/d Az (s^{-1})
Az Dist (m)
25
20
15
10
5
0
-5
-10
-15
-20
-25
0.0350
0.0175
0.0000
-0.0175
-0.0350
0
1000
2000
3000
4000
5000
6000



dVr
Vr
Vr.noisy
Vr (m s-1)
d Vr/d Az (s-1)
Az Dist (m)
25
20
15
10
5
0
-5
-10
-15
-20
-25
0.0350
0.0175
0.0000
-0.0175
-0.0350
0
1000
2000
3000
4000
5000
6000



2903 m
dVr
Vr
Vr.noisy
peak-to-peak
0.0146 s-1
25
20
15
10
5
0
-5
-10
-15
-20
-25
0.0350
0.0175
0.0000
-0.0175
-0.0350
0
1000
2000
3000
4000
5000
6000
Az Dist (m)
Vr (m s-1)
d Vr/d Az (s-1)



2903 m
dVr
llsd.dVr
Vr
Vr.noisy
peak-to-peak
0.0146 s-1
3000 m
0.0195 s-1
Vr (m s-1)
d Vr/d Az (s-1)
Az Dist (m)
25
20
15
10
5
0
-5
-10
-15
-20
-25
0.0350
0.0175
0.0000
-0.0175
-0.0350
0
1000
2000
3000
4000
5000
6000

What about 2D?

- Expansion to 2D results in fitting a plane to a n x n "window" or kernel of *u* rather than simply n points along each a ring of constant range.
- Advantages: a single application yields both azimuthal and radial derivatives.
  - Azimuthal is analogous to vorticity
  - Radial is analogous to divergence
  - Both derivatives are locally orthogonal.
- LLSD acts as a filter on the entire radial velocity field. Width of the kernel filter is dependent on range from the radar.
- The LLSD used in the report is 2D, using a 5 x 5 window (five gates in range and five beams in azimuth).

2D LLSD: Nuts and Bolts

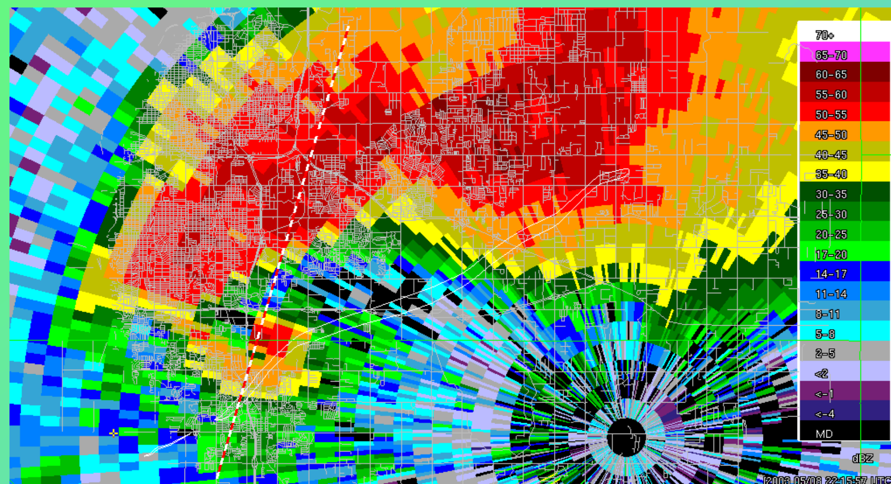
- The LLSD is a filter applied to the entire radial velocity field. Width of the kernel filter is dependent on range from the radar. With some algebra, the orthogonal derivatives u_r and u_s *are*:

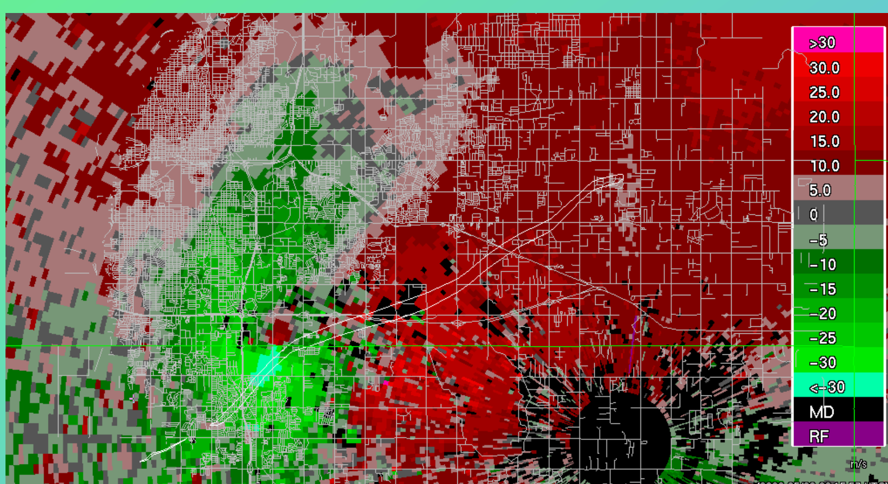
$$u_r = \frac{\sum i u_{ij} w_{ij}}{\Delta r \sum i^2 w_{ij}} \qquad u_s = \frac{\sum s_{ij} u_{ij} w_{ij}}{\sum (\Delta s_{ij})^2 w_{ij}}$$

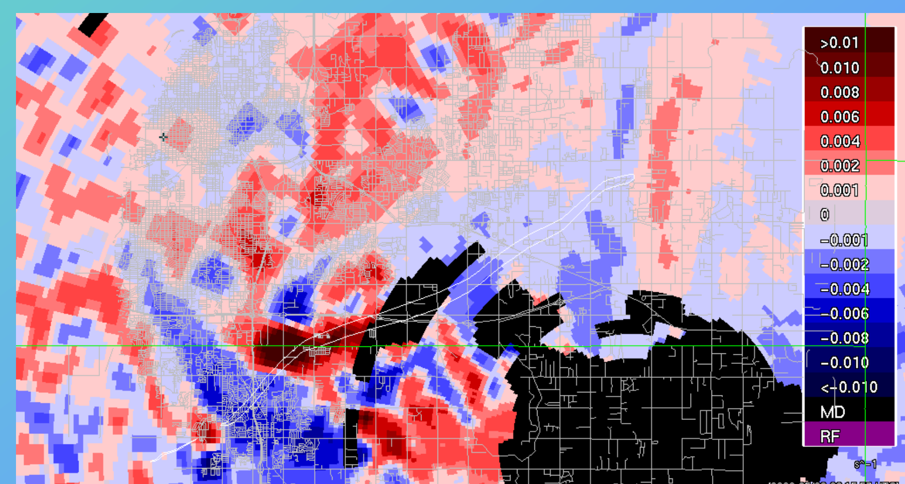
- where u_{ij} is the radial velocity at (i,j), Δr is the pulse volume depth in range, s_{ij} is the azimuthal distance from the center of the window to the point (i,j), and w_{ij} is a uniform weight function.
- Because u_r and u_s are derived from only the radial component of the wind, they are approximations of one half the horizontal divergence and vertical vorticity, respectively, assuming a locally symmetric wind field.

u_s from Real Data

3 May 1999





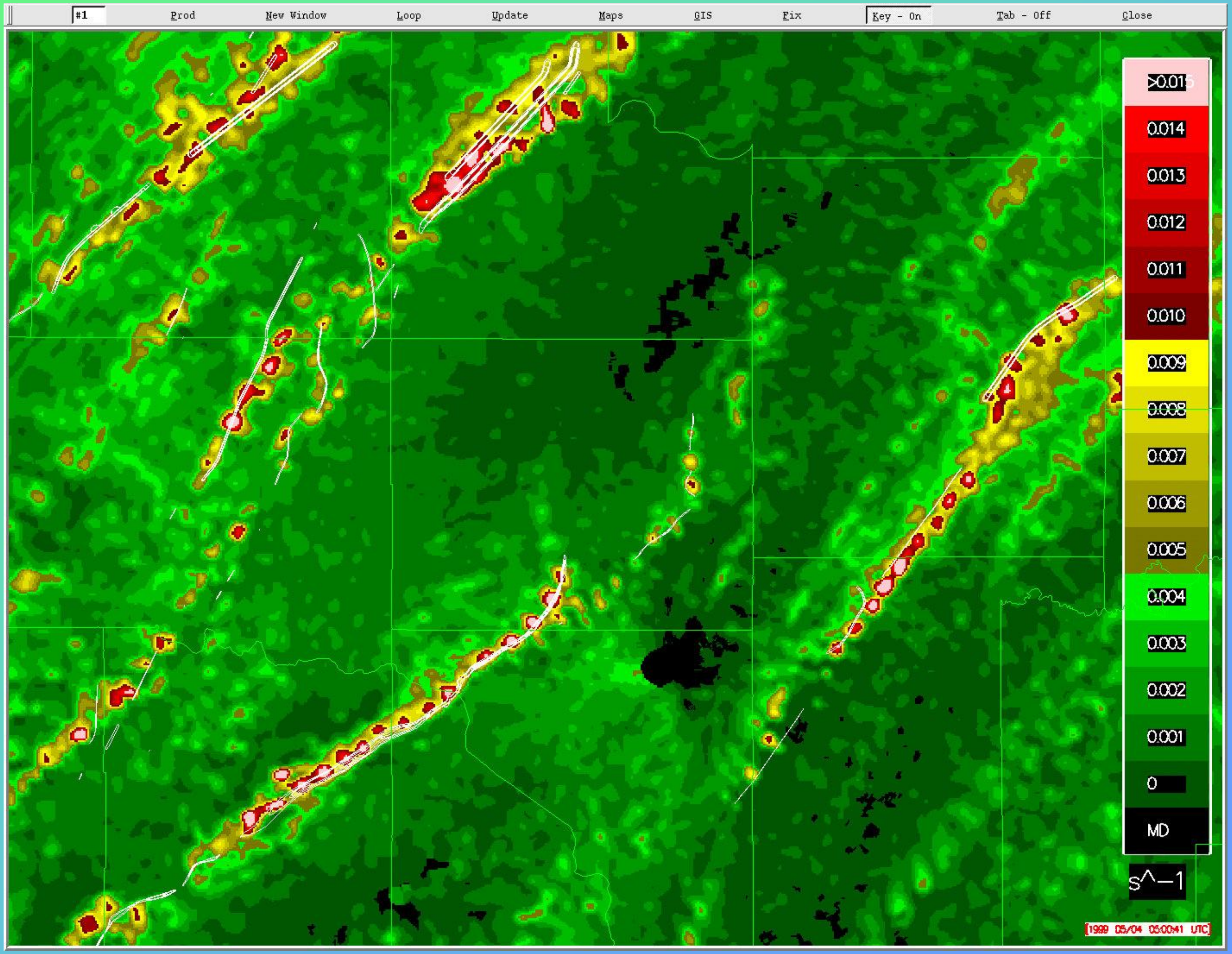


Algorithm Outline for Mesocyclone Tracks from 2D LLSD

- Calculate u_s
- Remove sharp "spikes" caused by dealiasing errors and bad velocity data
- Threshold based on reflectivity
  - Include only data in and near storms; non-precipitation echoes removed as well
- Generate layer maxima
  - Max in 0-3 km AGL
  - Max in 3-6 km AGL

Mesocyclone Tracks 3 May 1999

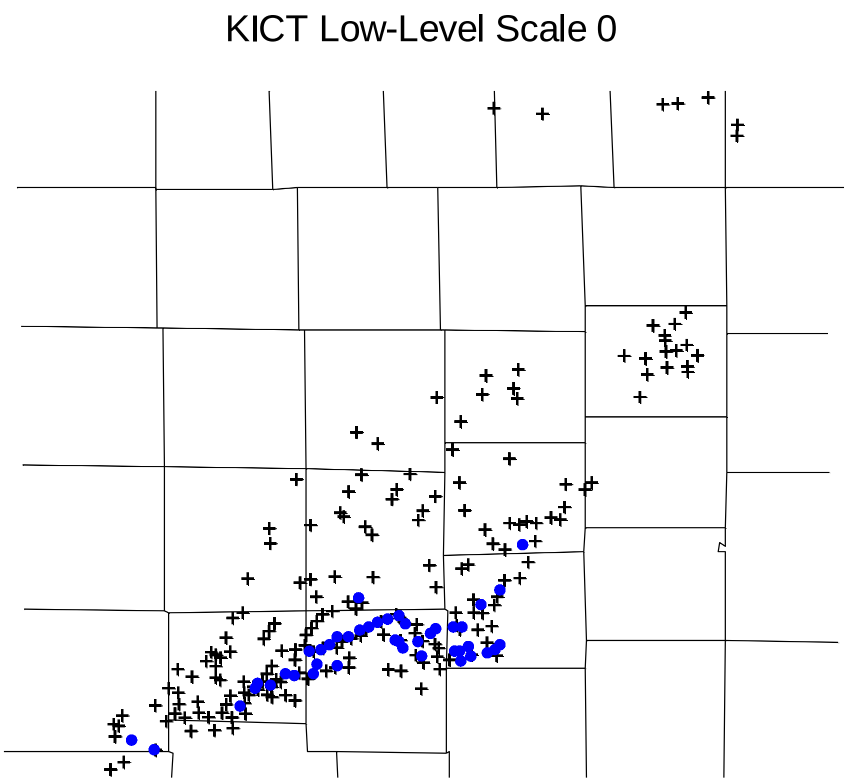
The 6-hour maxima of u_s shows the tracks of strong circulations. The overlaid white lines show the tracks of tornado damage for this case, as determined from ground and aerial surveys.



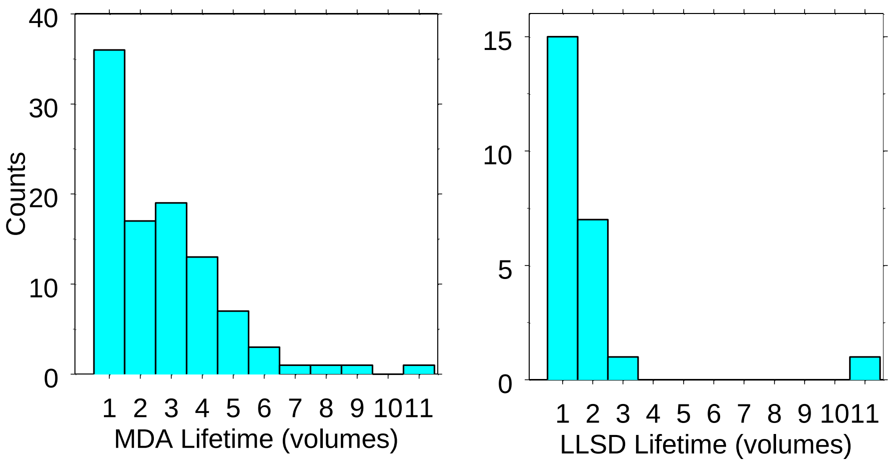
The Report

- Compare Build 12 ORPG MDA to a rudimentary LLSD inference engine run on WDSSII system.
- VCP 12 used throughout
- Seven cases, all from Witt (2008): KICT, KDDC, KDMX, KFTG, KGLD, KMPX
- Output: lat, lon, strength rank (MDA only) and circulation ID number (used to assess coherency)
- LLSD values subject to K-means clustering to identify contiguous areas of cyclonic shear of cyclonic shear greater than 0.006 s^{-1} for areas of 25, 60 and 90 km^2 (in report scales 0, 1, and 2). Two levels: 0-3 km AGL and 3-7 km AGL. Note: no optimization for circulation coherency for LLSD.

KICT: a “moderate” case

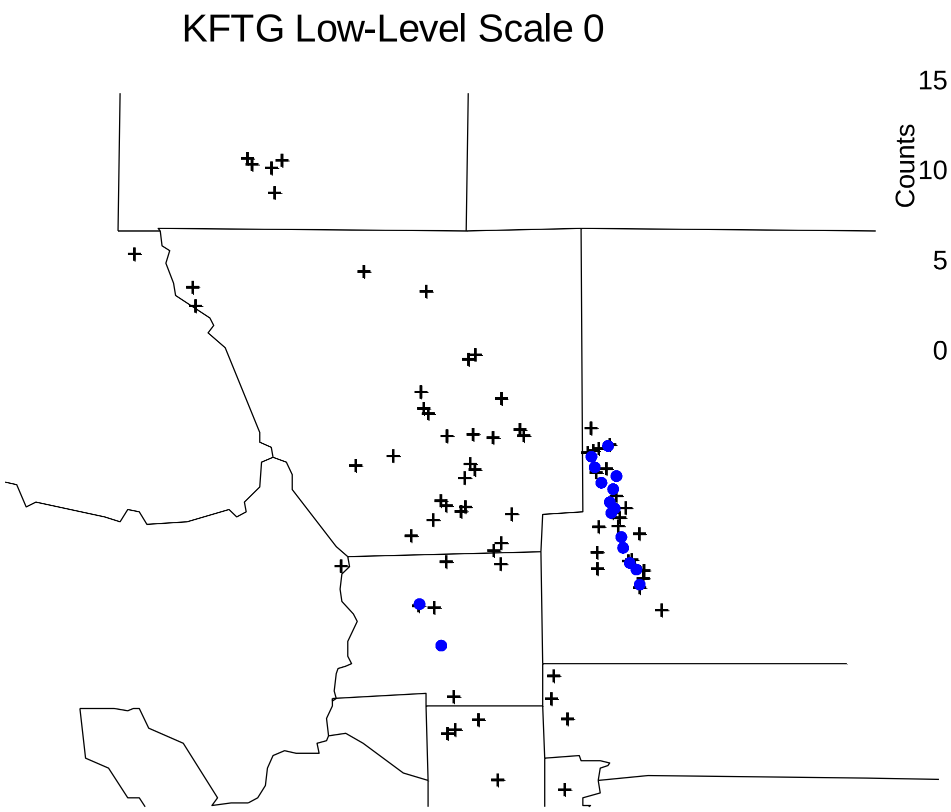


Circles = LLSD, + = MDA

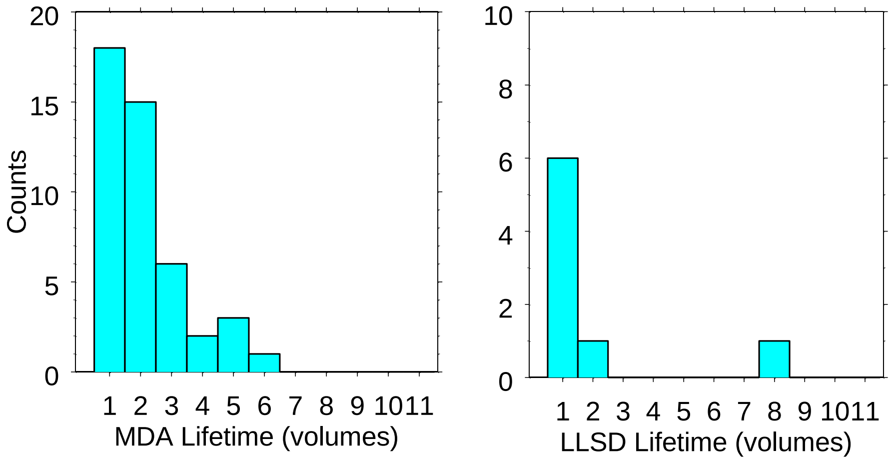


- Many more detections from MDA than LLSD
- MDA: 201 detections with 99 uniques.
- LLSD: 43 detections with 24 uniques
- Mean lifetime for MDA = 2.7 volumes, LLSD = 1.8 volumes
- Mean lifetime difference significant at $p = 0.03$

KFTG: a “light” case



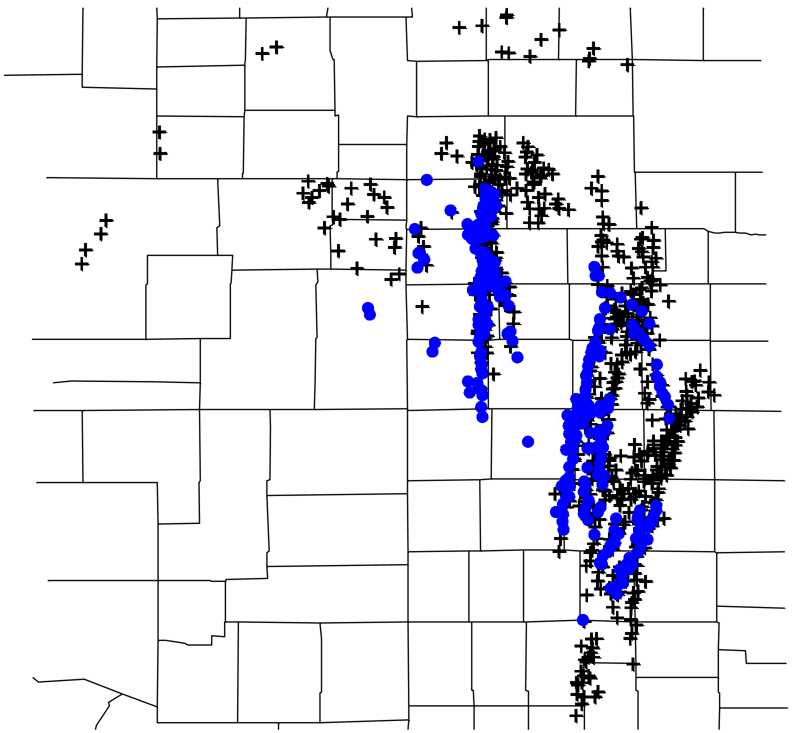
Circles = LLSD, + = MDA



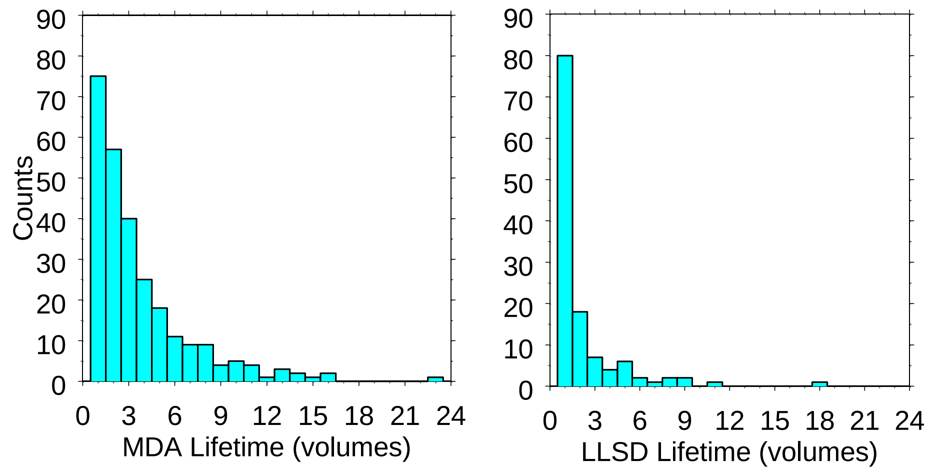
- Many more detections from MDA than LLSD
- MDA: 95 detections with 45 uniques.
- LLSD: 16 detections with 8 uniques
- Mean lifetime for MDA = 2.1 volumes, LLSD = 2.1 volumes
- Mean lifetime difference insignificant.

KGLD: an "active" case

KGLD-A Low-Level Scale 0



Circles = LLSD, + = MDA



- Again, any more detections from MDA than LLSD
- MDA: 979 detections with 267 uniques
- LLSD: 265 detections with 124 uniques Mean lifetime for MDA = 3.7 volumes, LLSD = 2.1 volumes
- Mean lifetime difference significant at $p < 0.005$

Aggregate Characteristics

Algorithm	Detections	Uniques	Mean Lifetime	Max Lifetime
MDA	2159	687	3.14	23
LLSD 0 Low	573	285	2.01	18
LLSD 1 Low	351	186	1.89	18
LLSD 0 Mid	873	420	2.01	30
LLSD 1 Mid	515	222	2.13	18

Concluding Points

- LLSD produces more visually coherent detections than does MDA (even though MDA coherent lifetimes are longer)
- Difference due to years of work to make MDA coherent in space/time while almost no such work has been expended on LLSD (results shown here use an experimental K-means technique optimized for reflectivity cell tracking)
- Thus, LLSD performance is even more promising
- MDA that uses an LLSD inference engine will reduce workload and fatigue for operational meteorologists

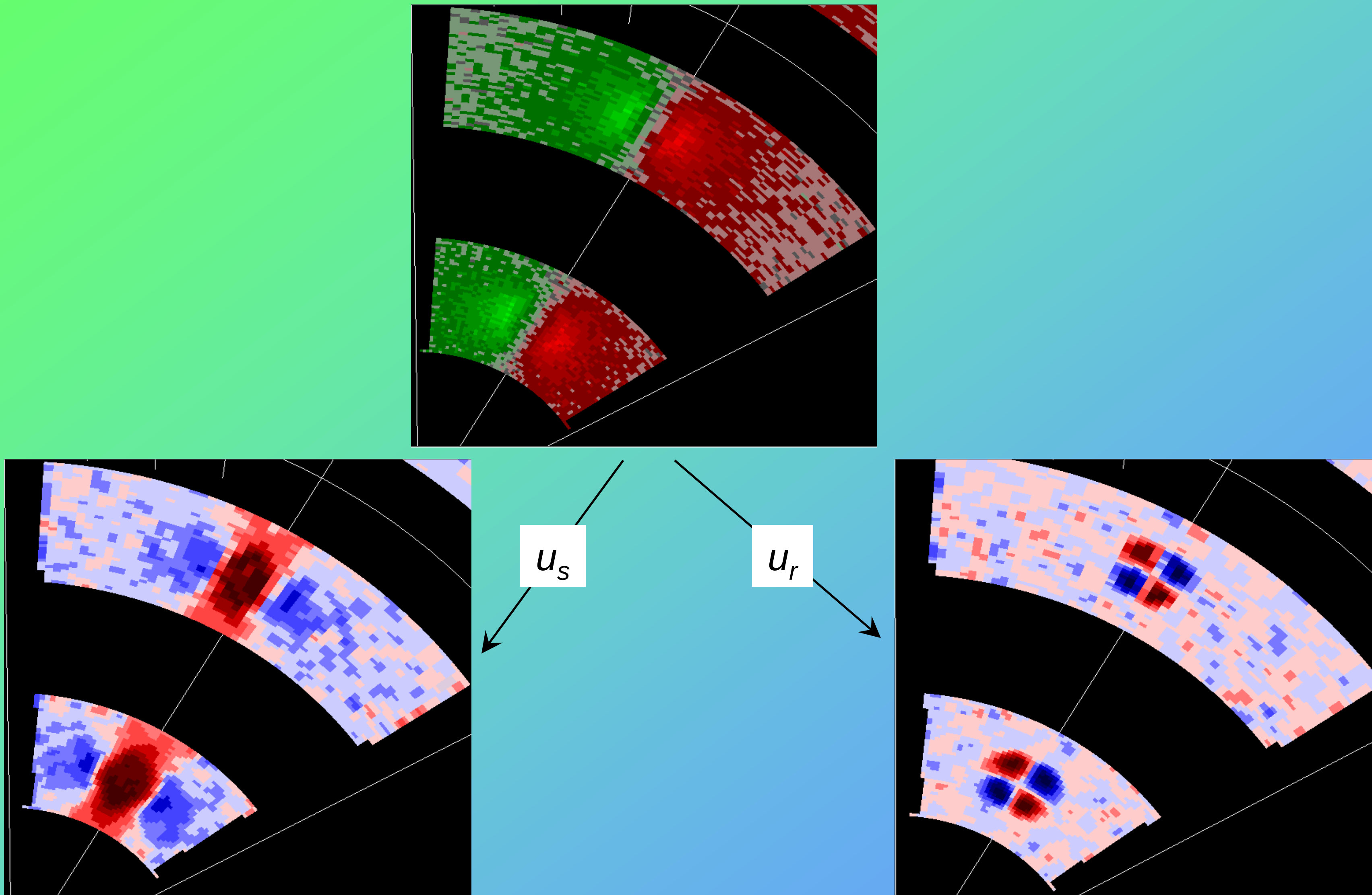
More Concluding Points

- Implementation will require:
  - Develop subject matter expert “truth” data sets for testing and development using super-res data
  - Develop optimal spatial scale and vertical association scales; spatial scales and thresholds for u_s may need to vary with height and/or range.
  - Optimize space/time tracking based on “truth” data sets.
  - LLSD offers a way to easily blend data from different radars.

Questions?

Backup/Reserve Slides

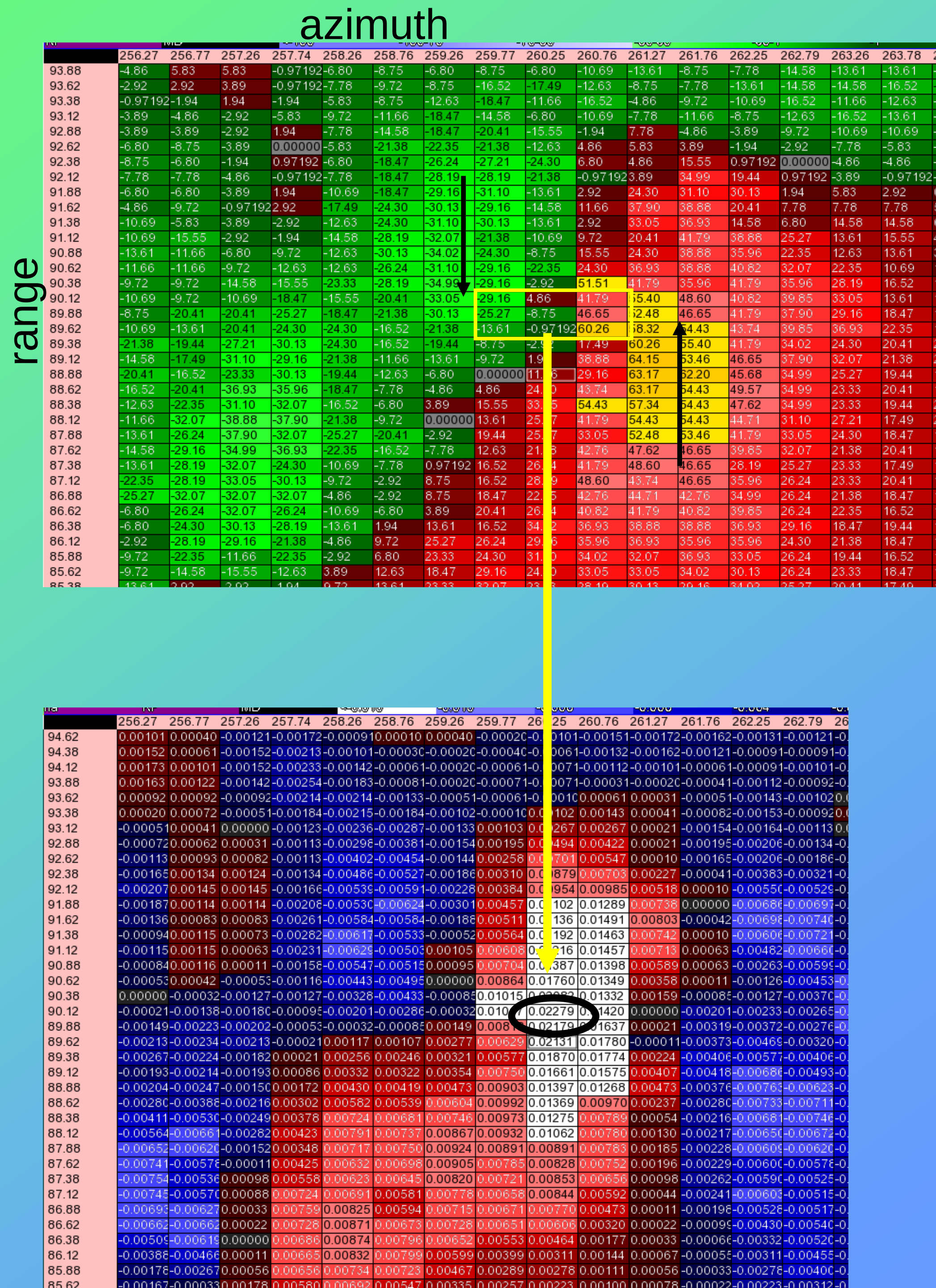
Some 2D Synthetic Data Results



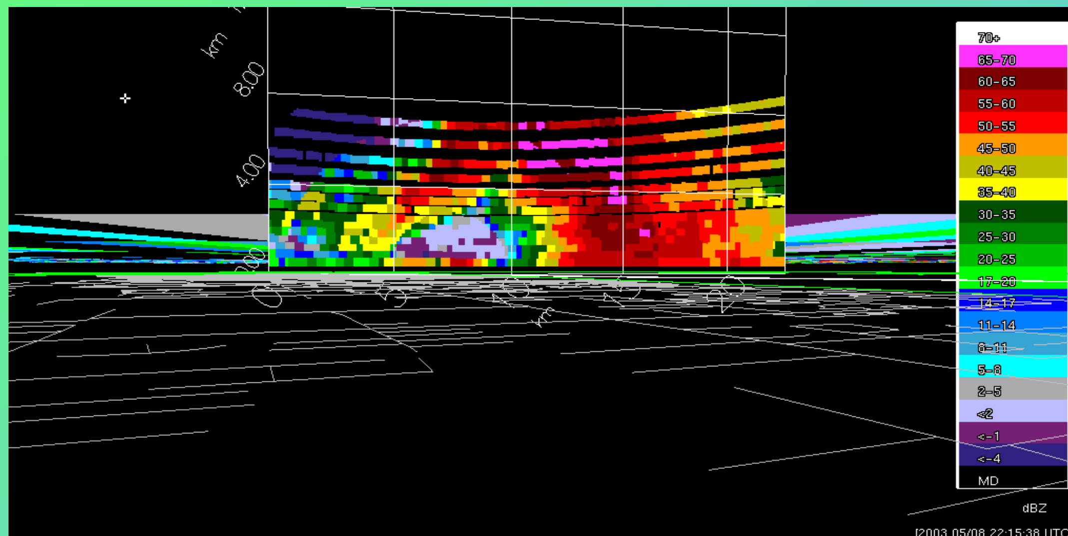
Azimuthal shear

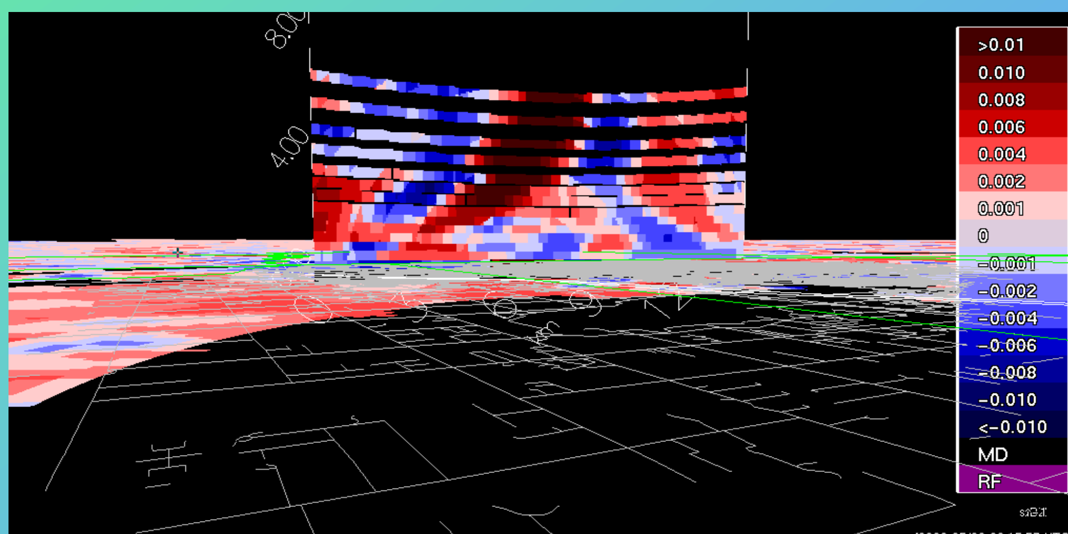
Divergence

An early example of LLSD for u_s in B-scan coordinates using a 3x3 kernel.

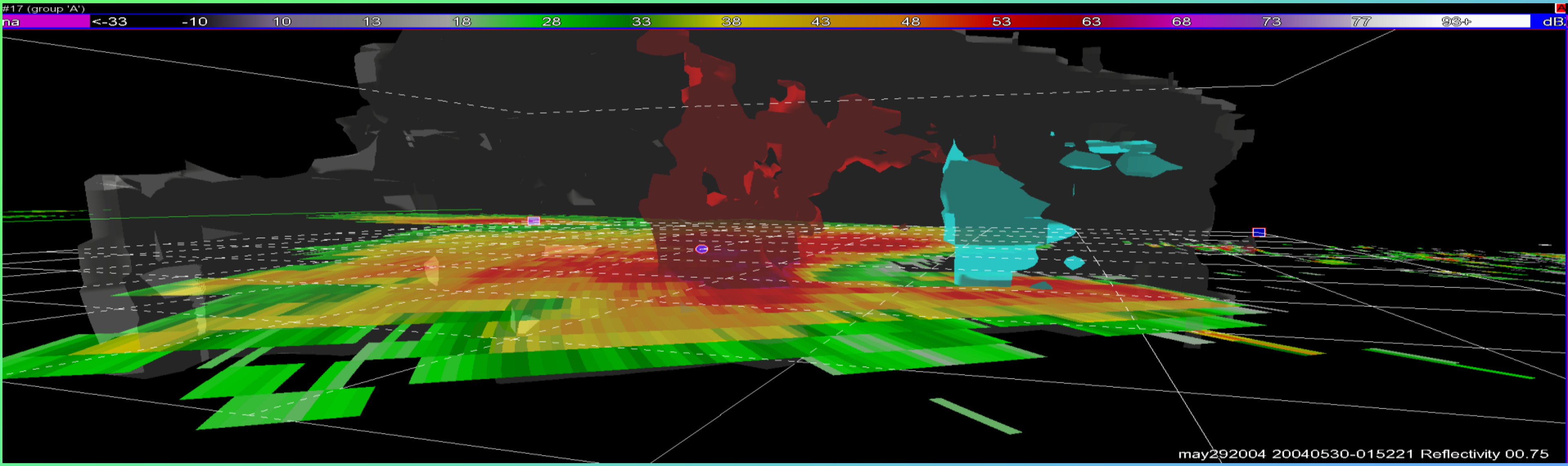


Vertical Cross-Section of u_s





3D Reconstructions



Azimuthal shear (aqua) may be viewed in 3D alongside the high-reflectivity core (red isosurface), 20 dBZ shell (grey isosurface) and 0.5 degree reflectivity scan of a storm. The vertical depth of the storm is about 20 km.

Circulation Center Location