Regression Clutter Filtering:

A New Clutter Mitigation Solution

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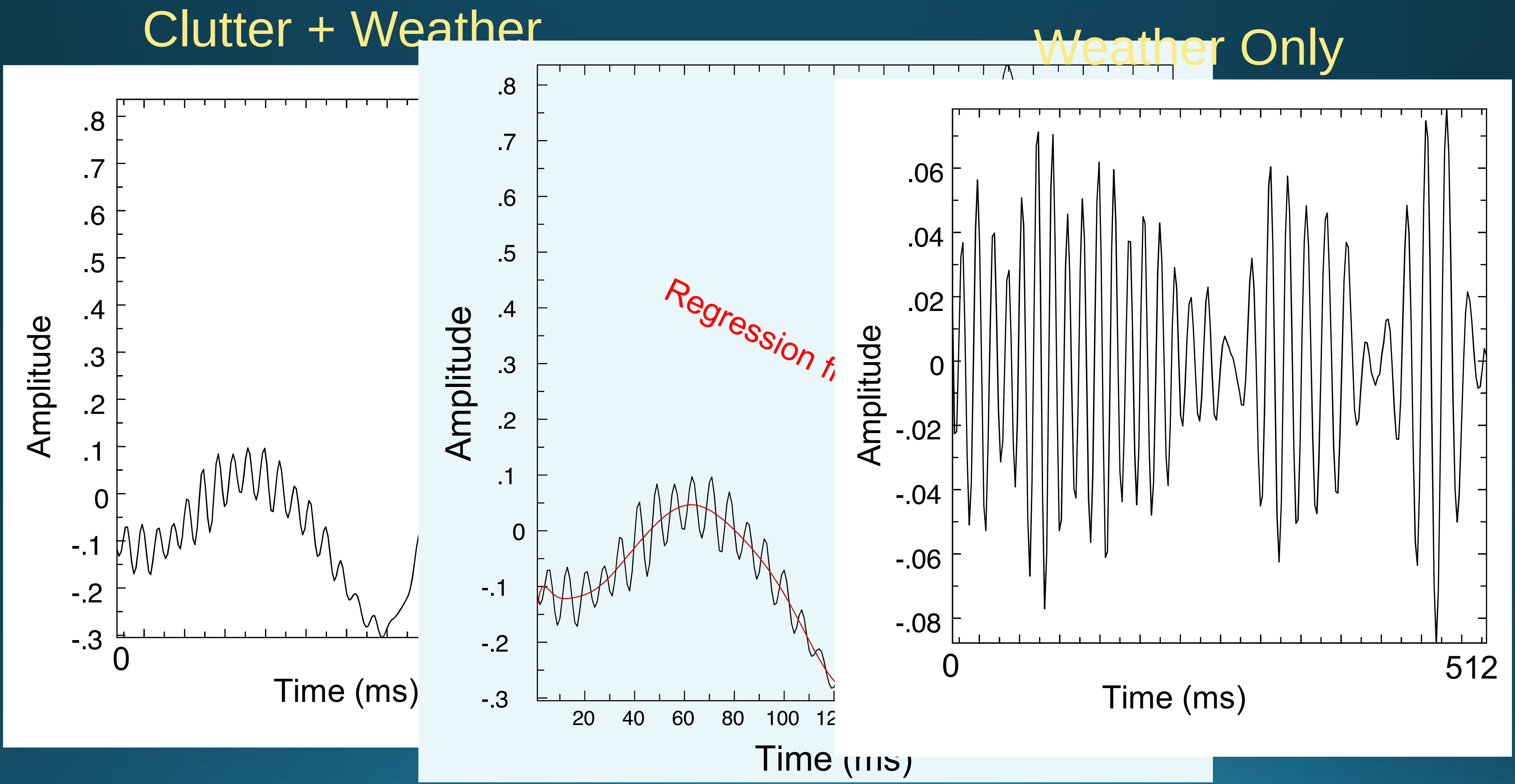
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
Boulder, Colorado

Technical Advisory Committee Meeting for the Radar Operations Center

Virtual Meeting

25 March 2022

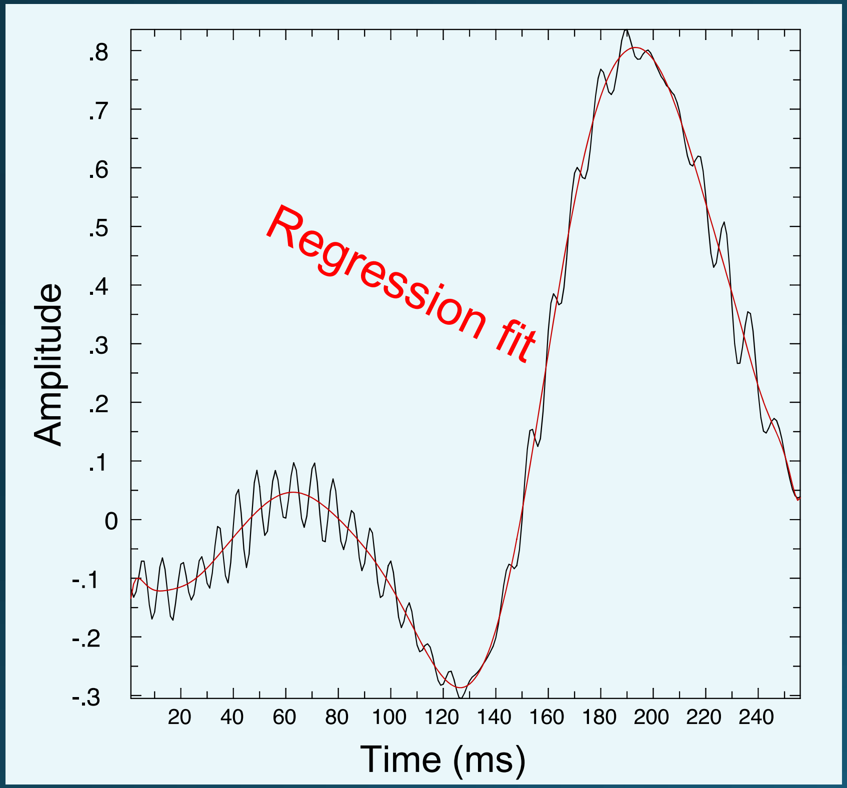
What is Regression Clutter Filtering?



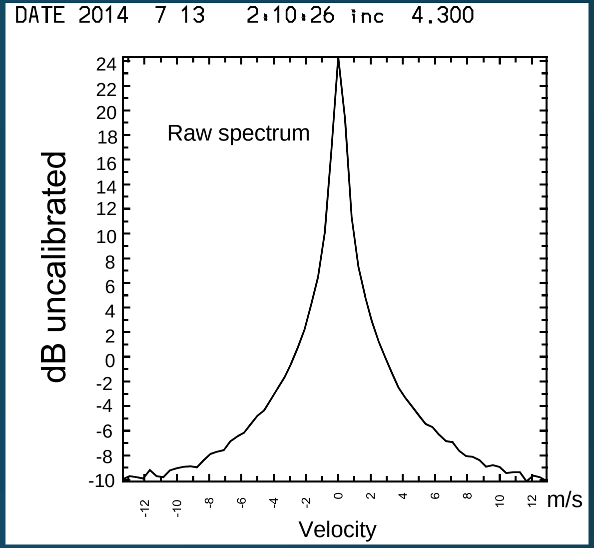
Time Domain

Frequency Domain. i.e., GMAP

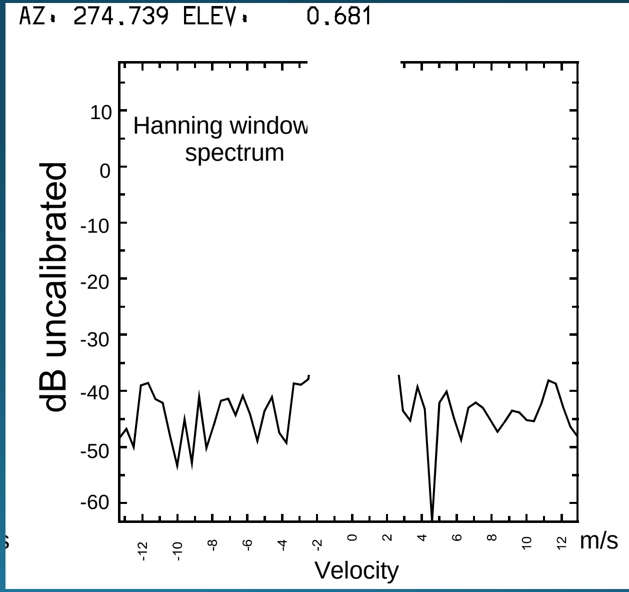
Regression/Forsythe Polynomials



NOT Savitzky-Golay



Windowed



and notched

Fast, low round off error algorithm: http://jean-pierre.moreau.pagesperso-orange.fr/

Why Regression?

Improved Signal Statistics

- Blackman window: 5.23dB attenuation

  About 50% increase in variance!

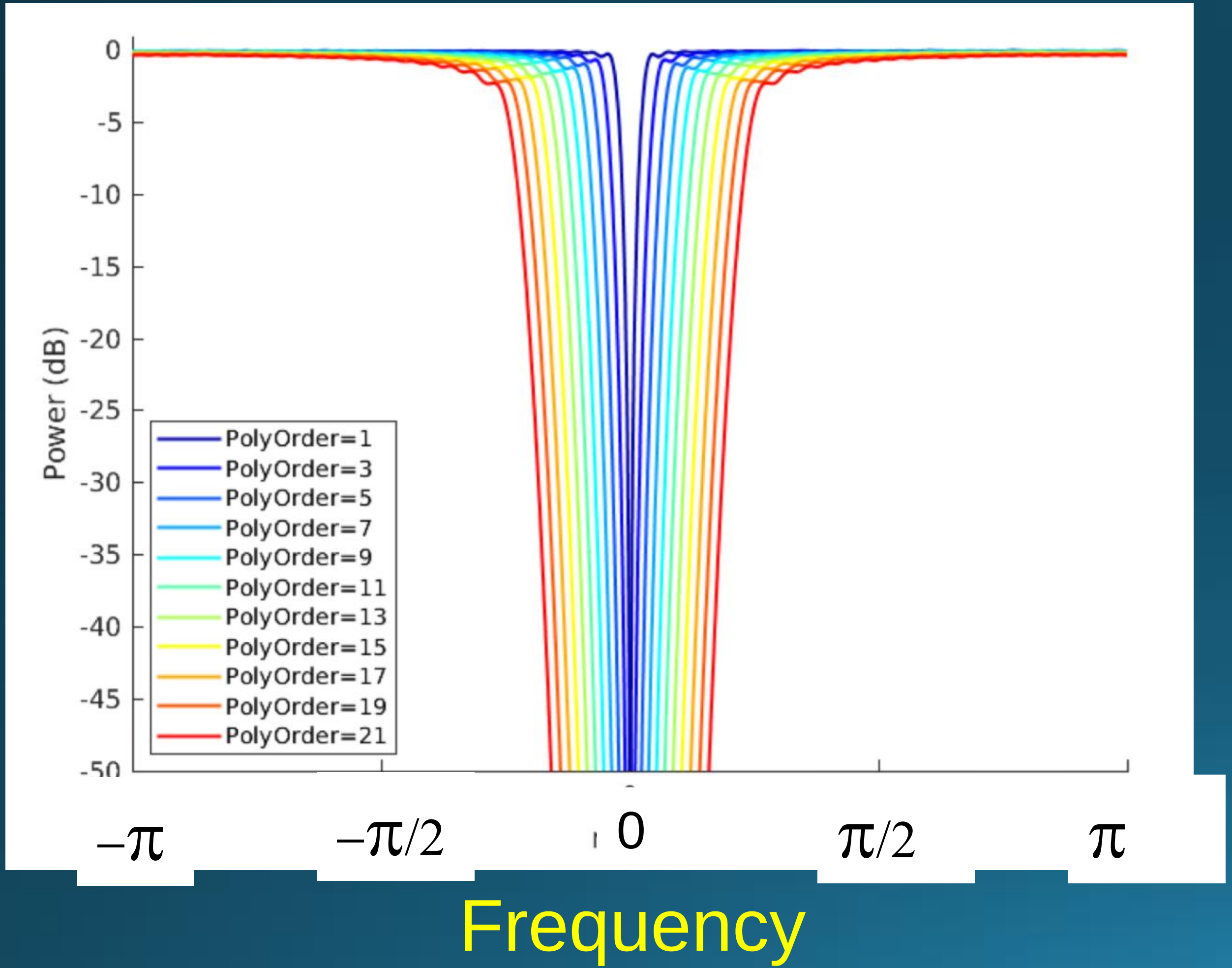
- Hanning window: 4.19 dB attenuation

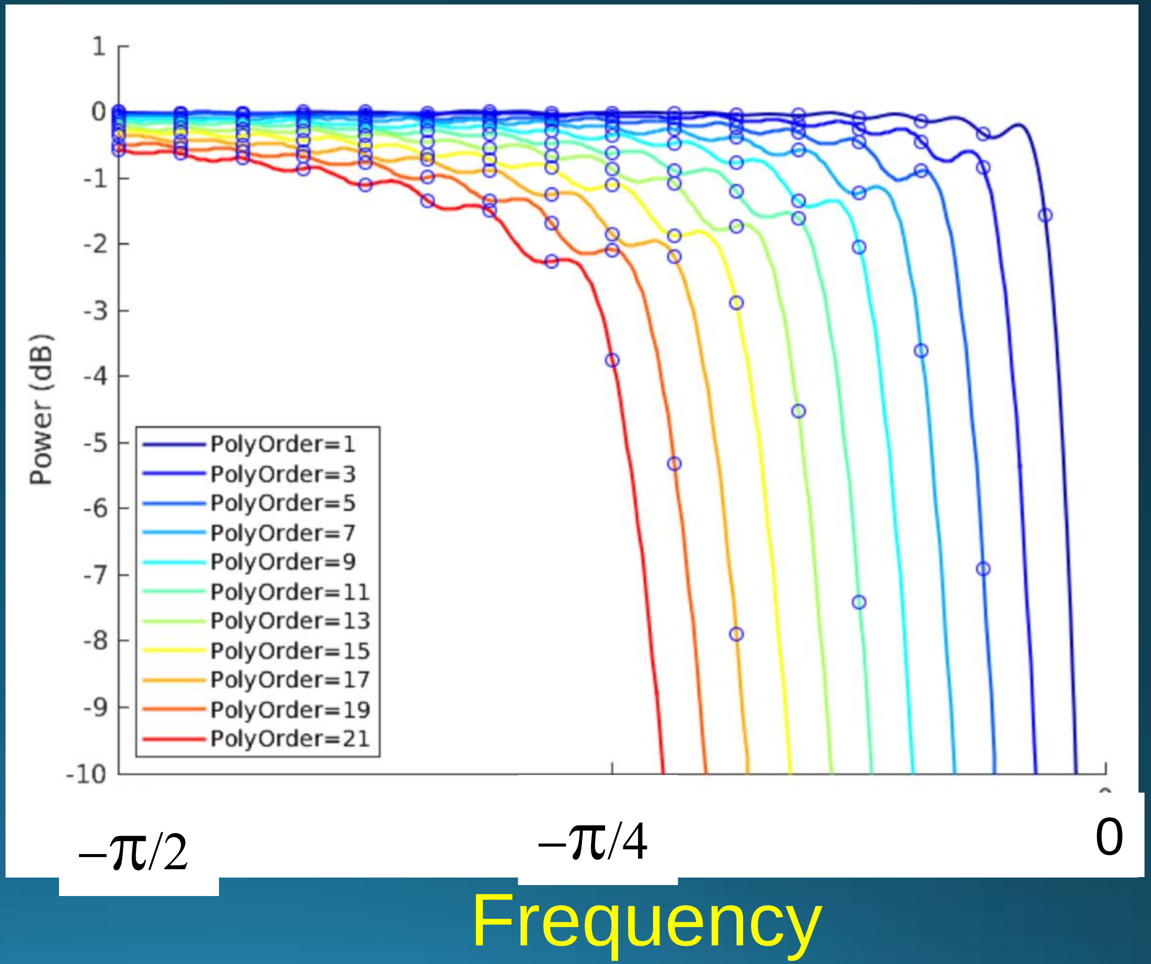
  About 35% increase in variance!

Regression Filter Frequency Response (N=64)

A function of the number of points and the polynomial order

Control stop bandwidth with the polynomial order





Regression Implementation Issues

- ✓ The regression filter order selection needs to be automated
- ✓ Design an interpolation scheme across the zero velocity gap created by the filter
- ✓ Verify the filter with simulations

Normalized Poly. Order vs Normalized Clutter Spectrum Width

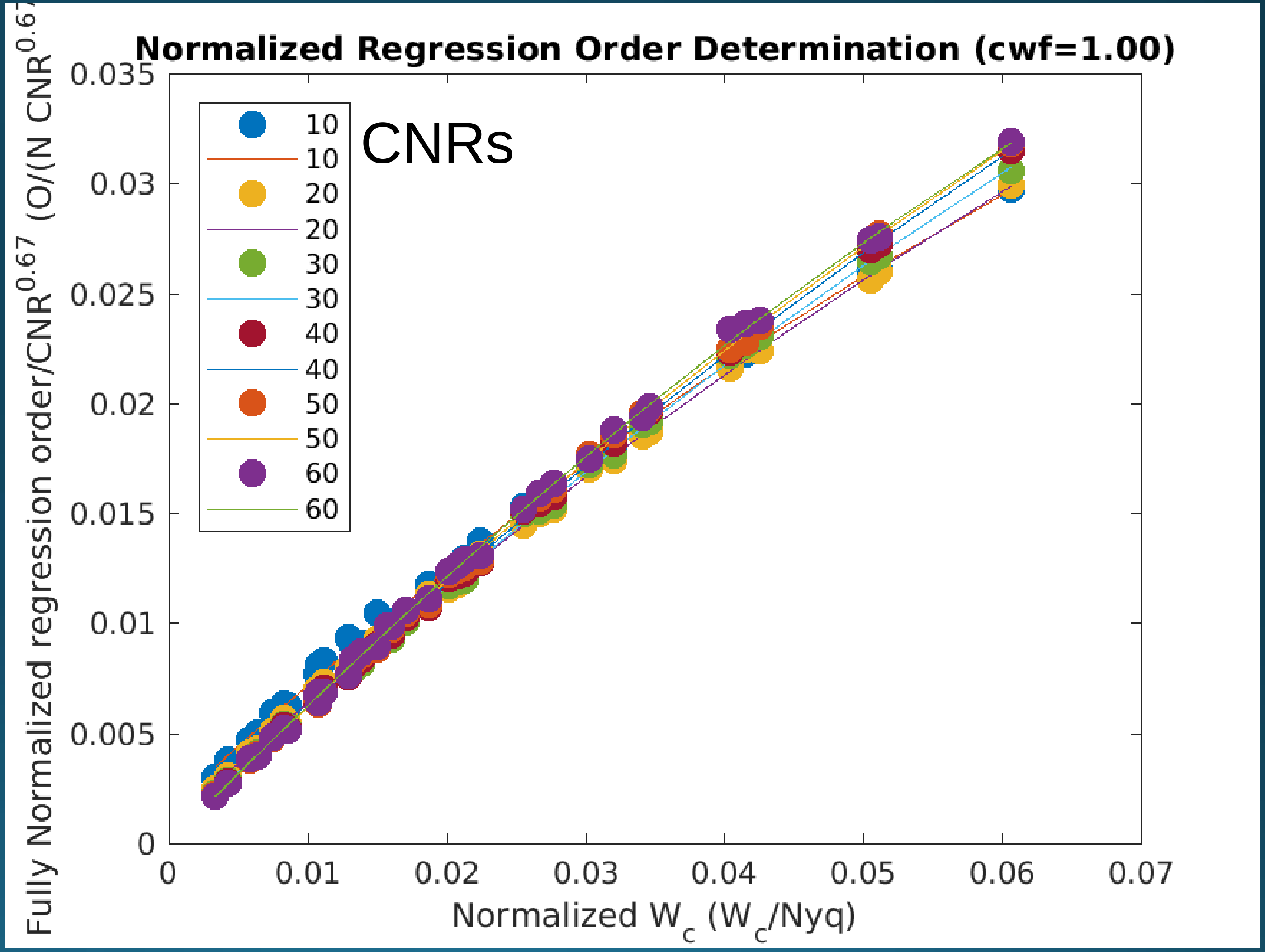
Varying the relevant variables over a large space yields the relationship in the graph.

Thus knowing the

1. no. of samples,
2. SW,
3. CNR,
4. Nyquist vel.

The needed polynomial order can be predicted.

Order/CNR.067

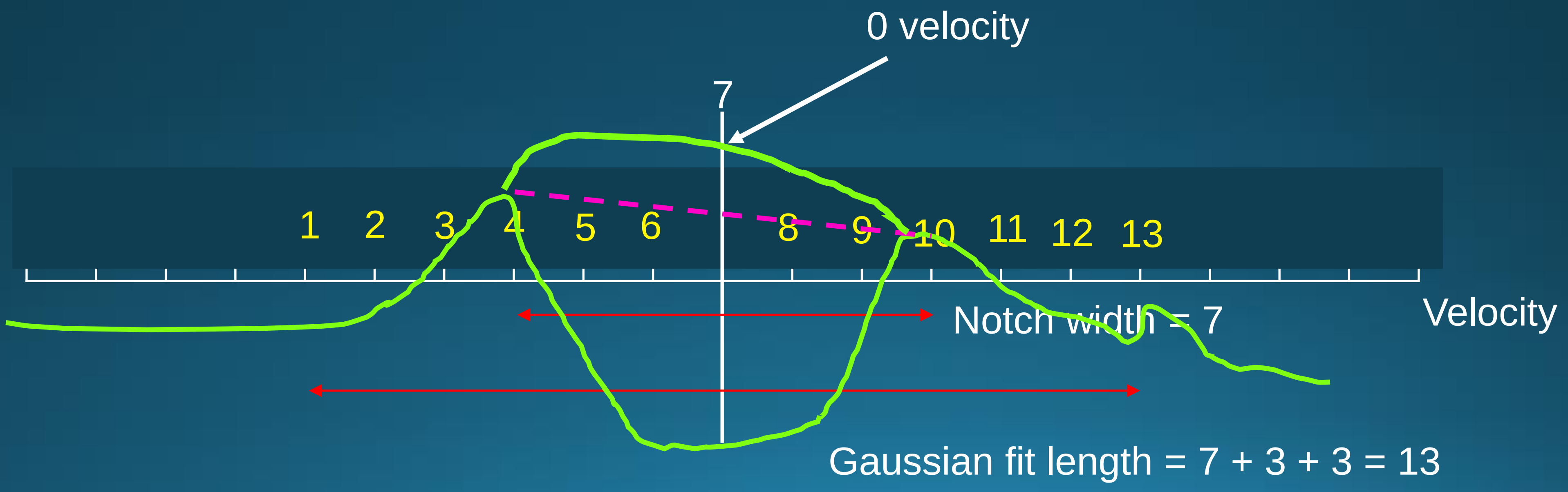


Analysis by G. Meymaris

Gaussian Interpolation Example

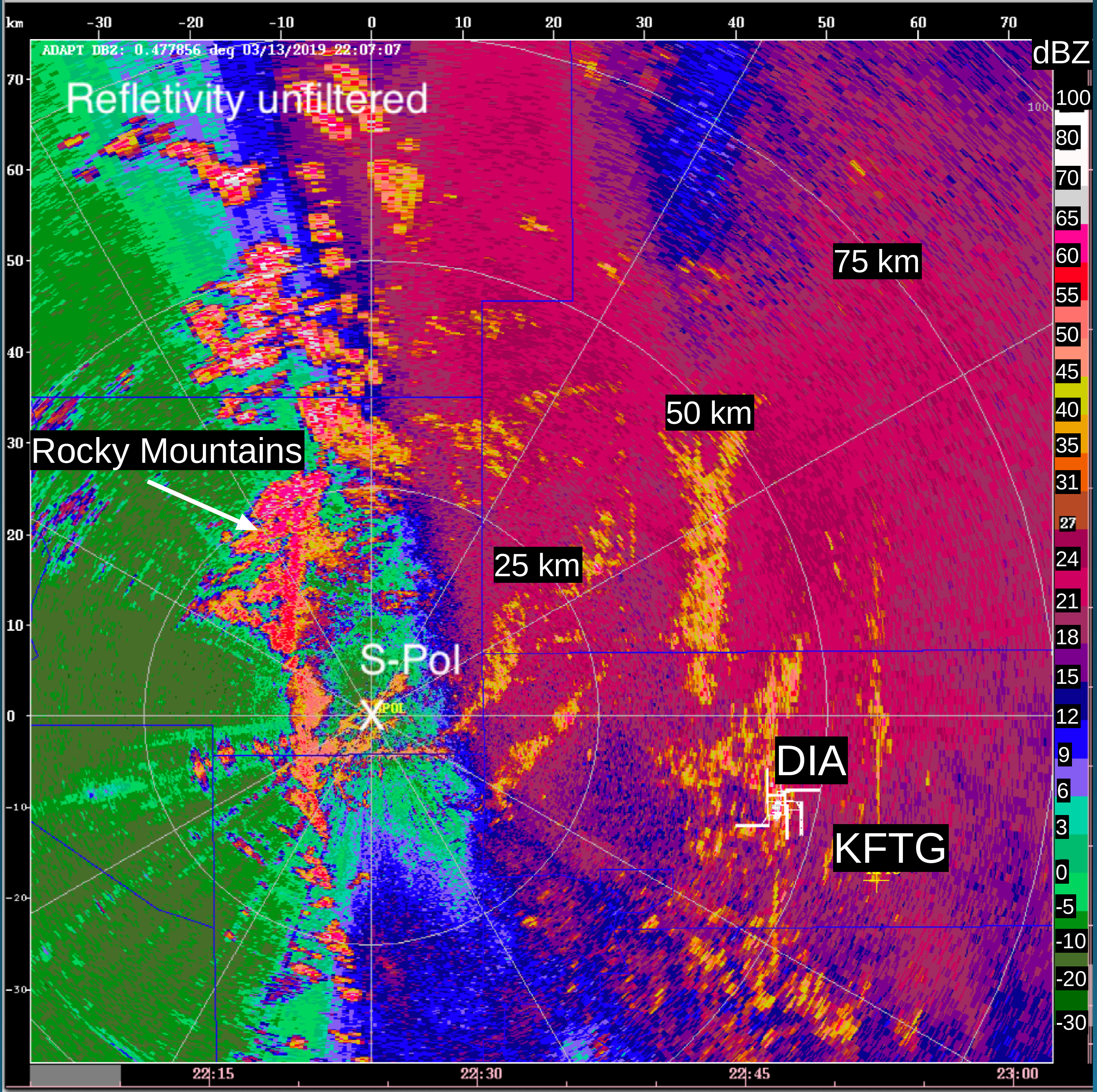
1. E.g., 7-point interpolation gap
2. Use 3 points on each side of the gap
3. Initialize points in gap with linear interpolation
4. Calculate velocity. Only do Gauss fit for V_{est}/V_{nyq} < Thres.
5. Calculate Gaussian fit
6. Replace interior 7 points with fit
7. Repeat Gaussian fit. 5 iterations should be sufficient

Good threshold ~ 0.2 to 0.3 Vel/Nyquist

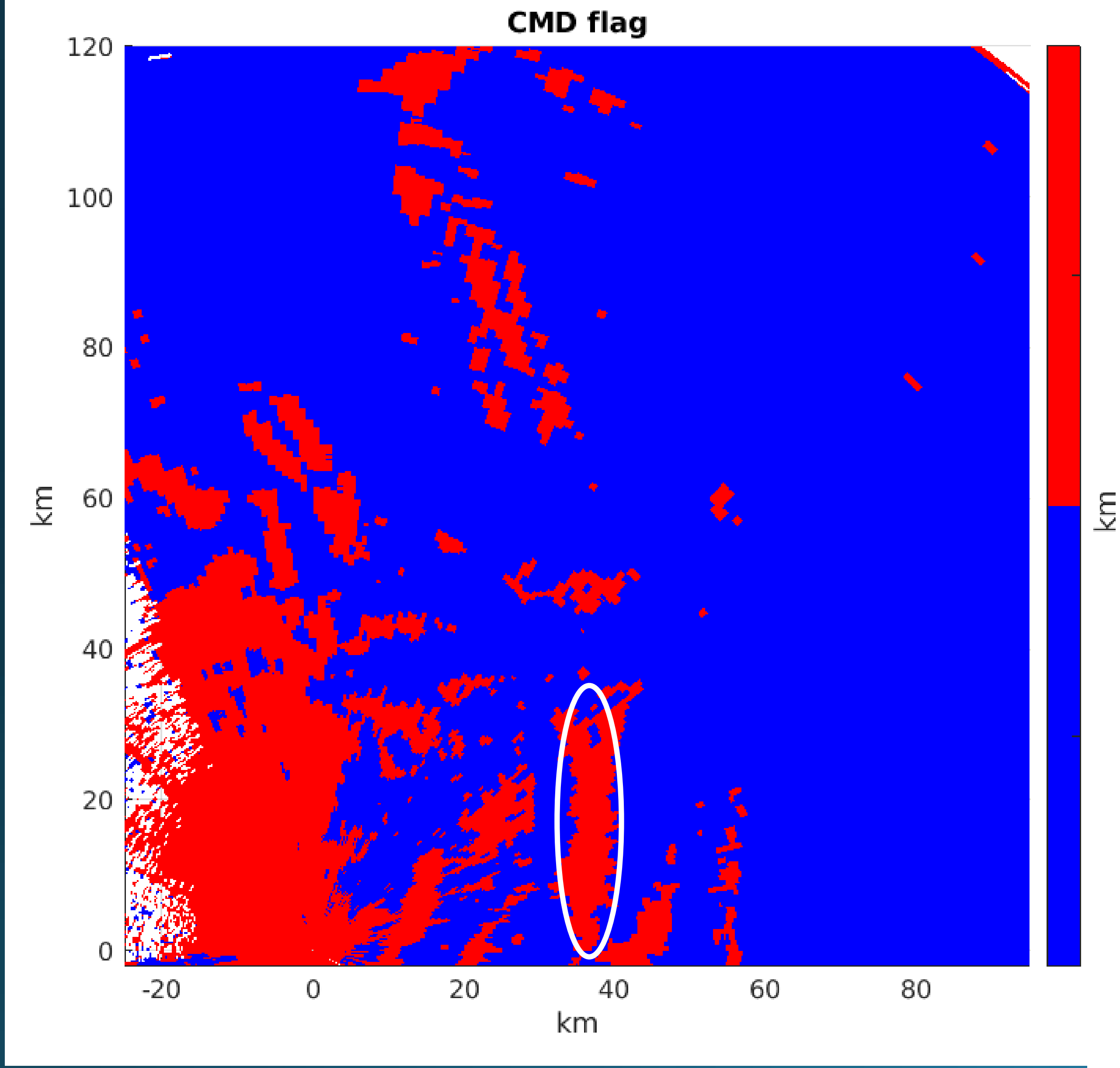


S-Pol

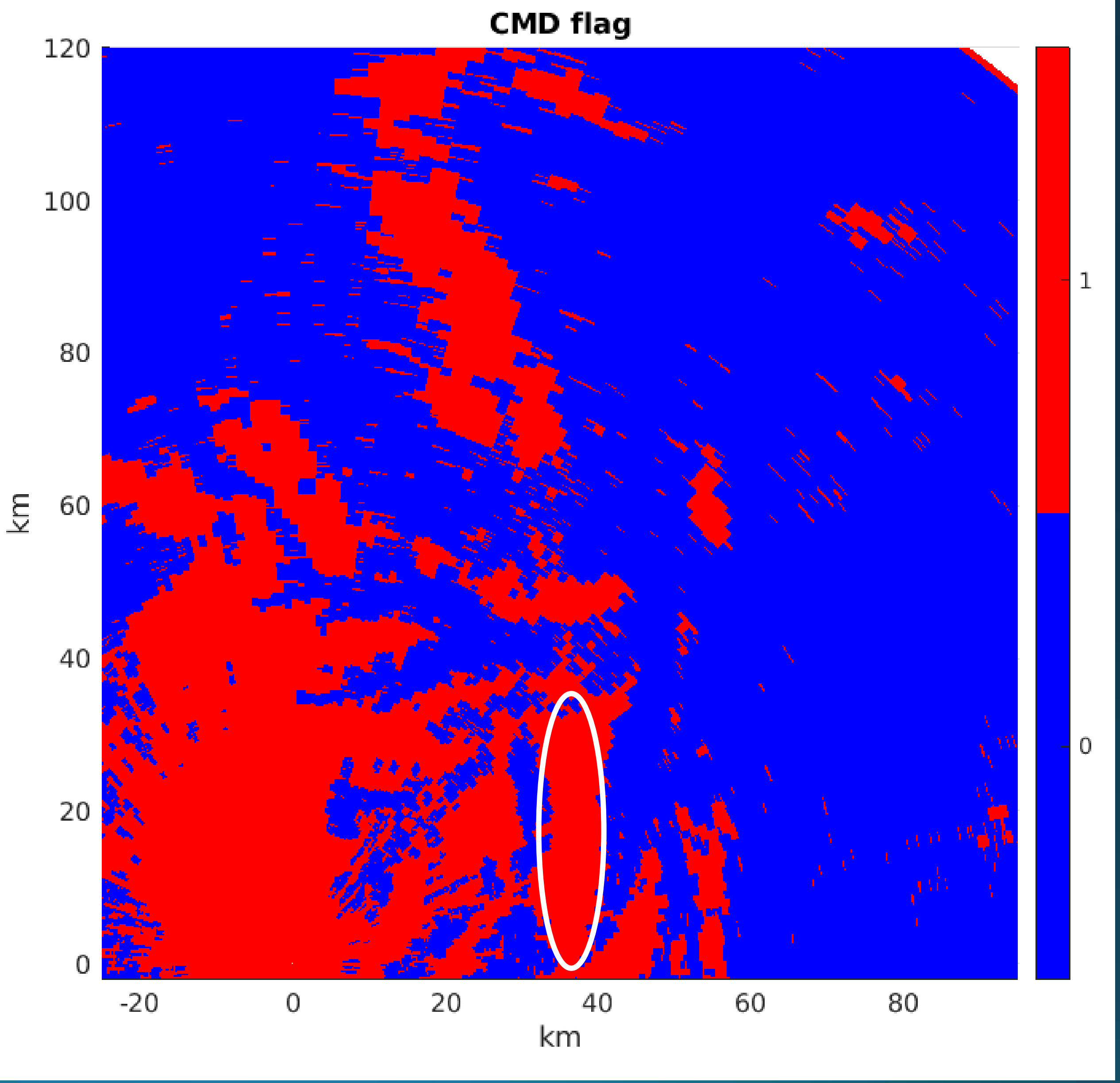
13 March 2019



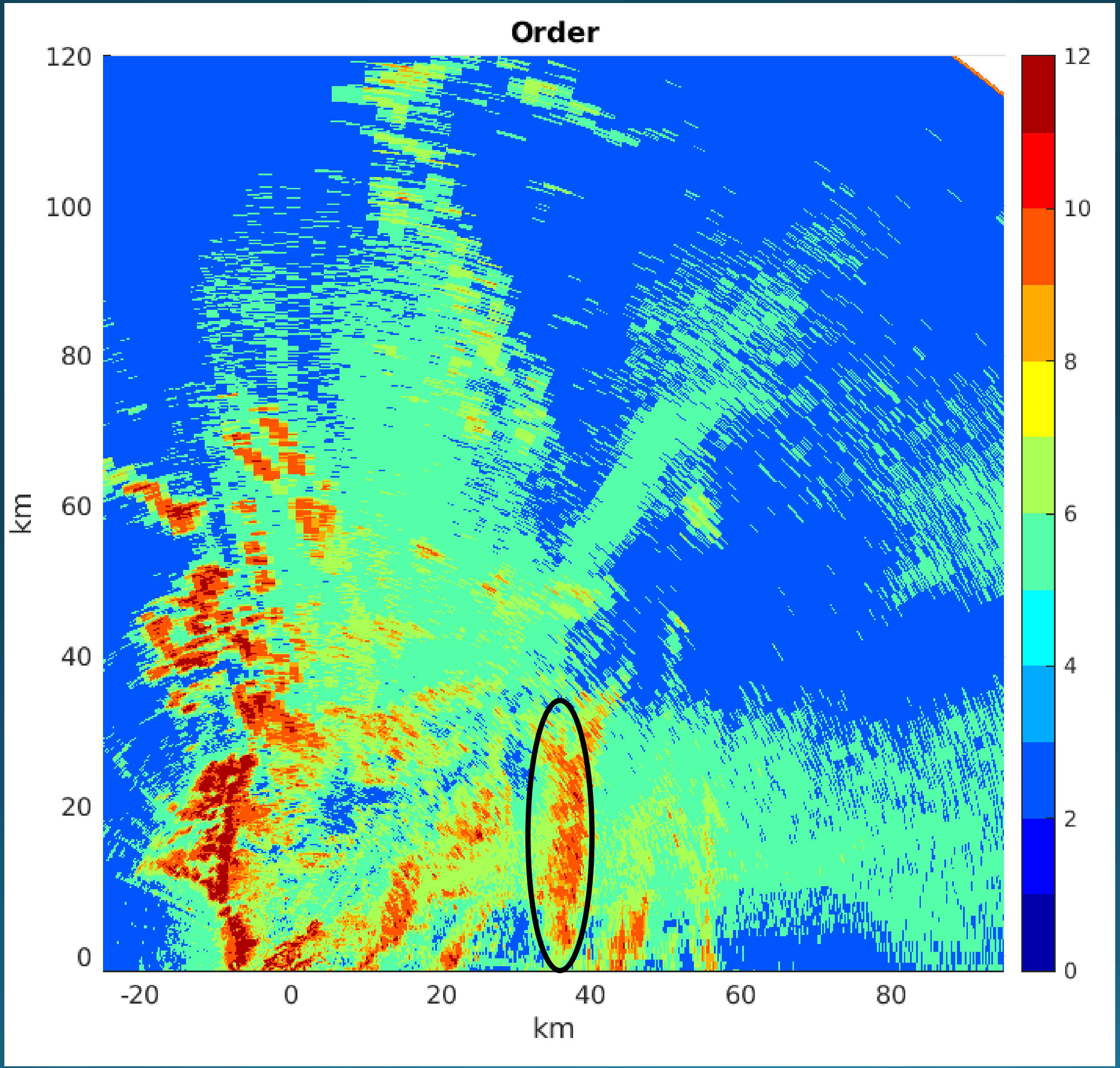
WN Filter (GMAP–like)



New Regression CMD



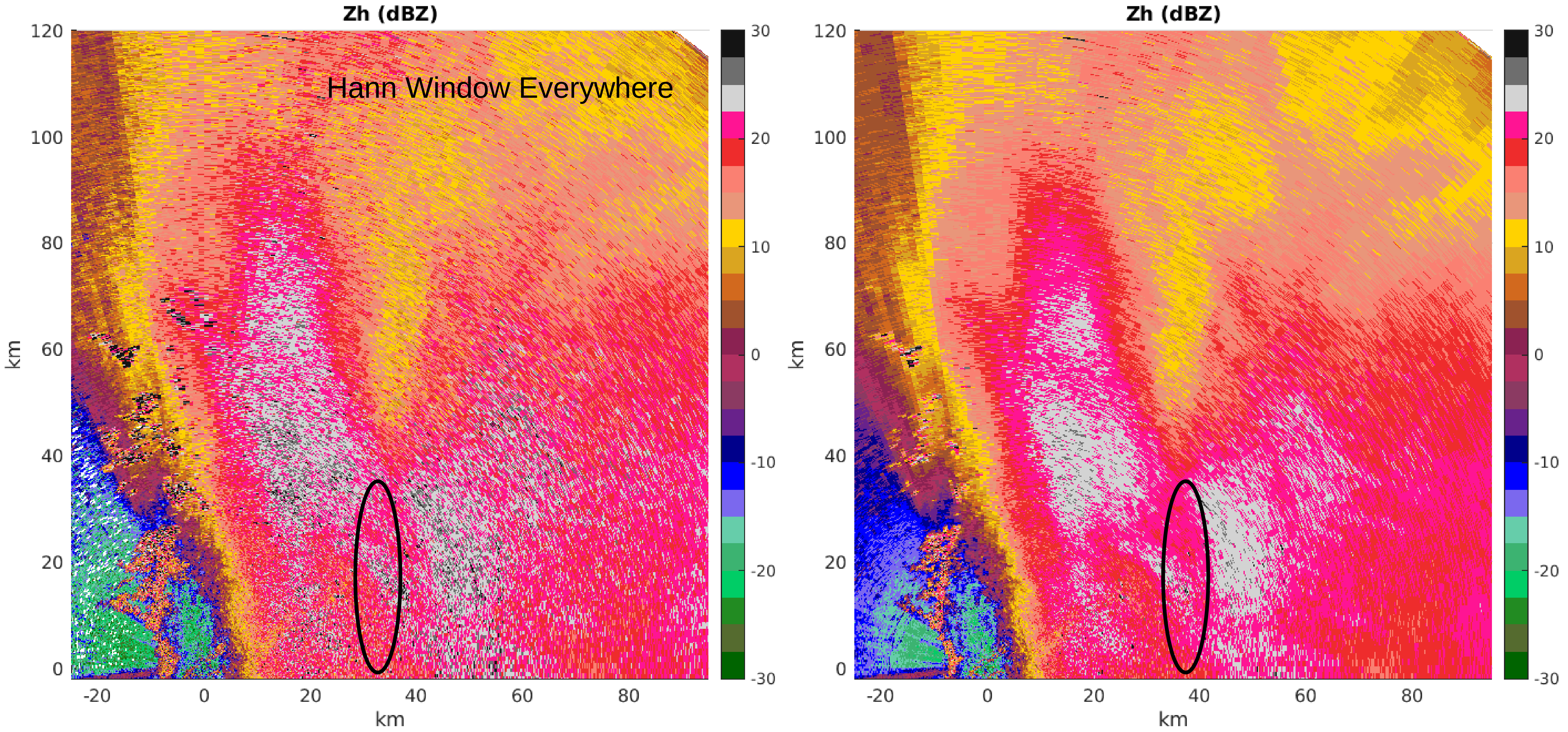
Automated Order Selection



dBZ

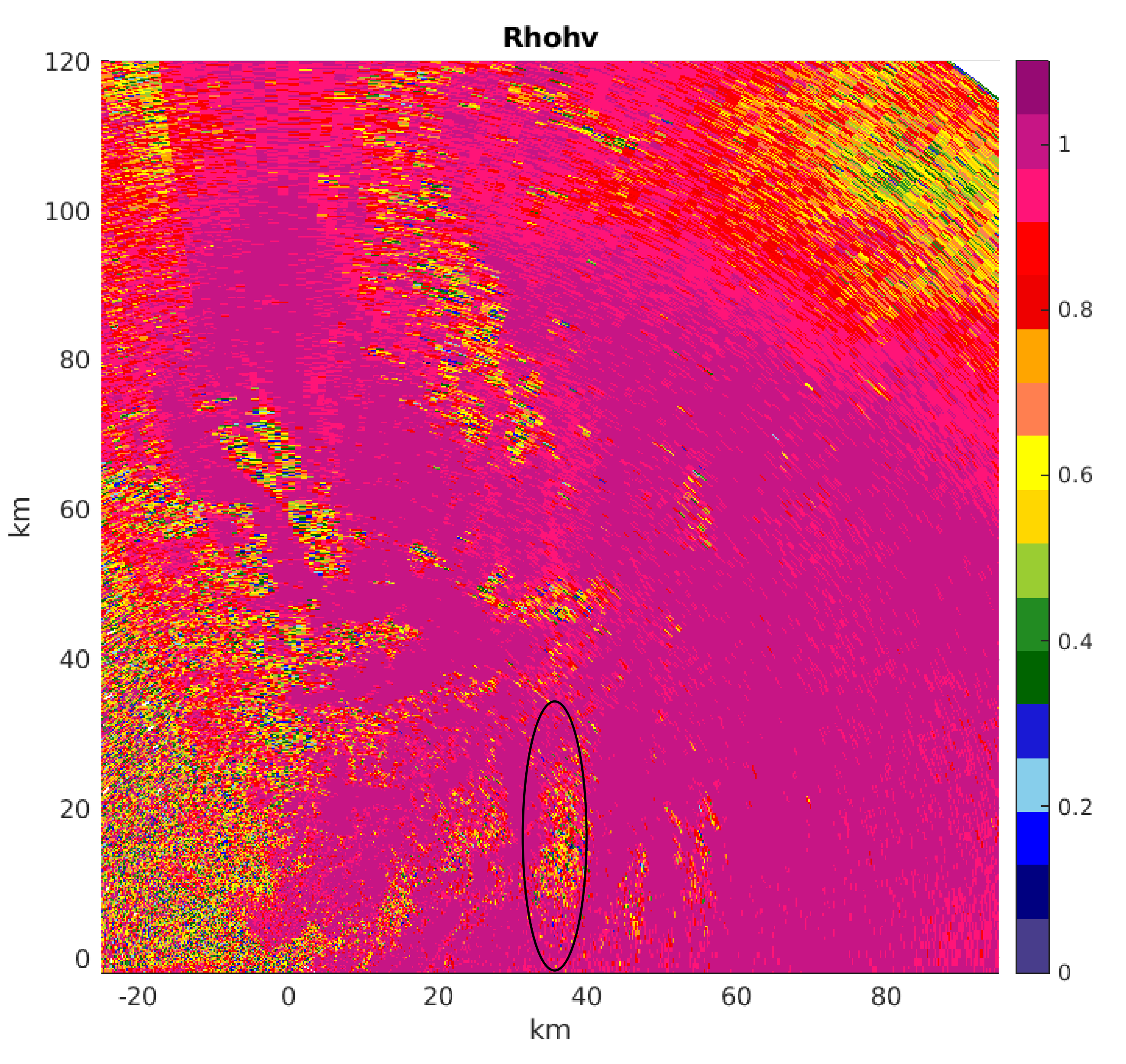
Original CMD, GMAP-like

New regression

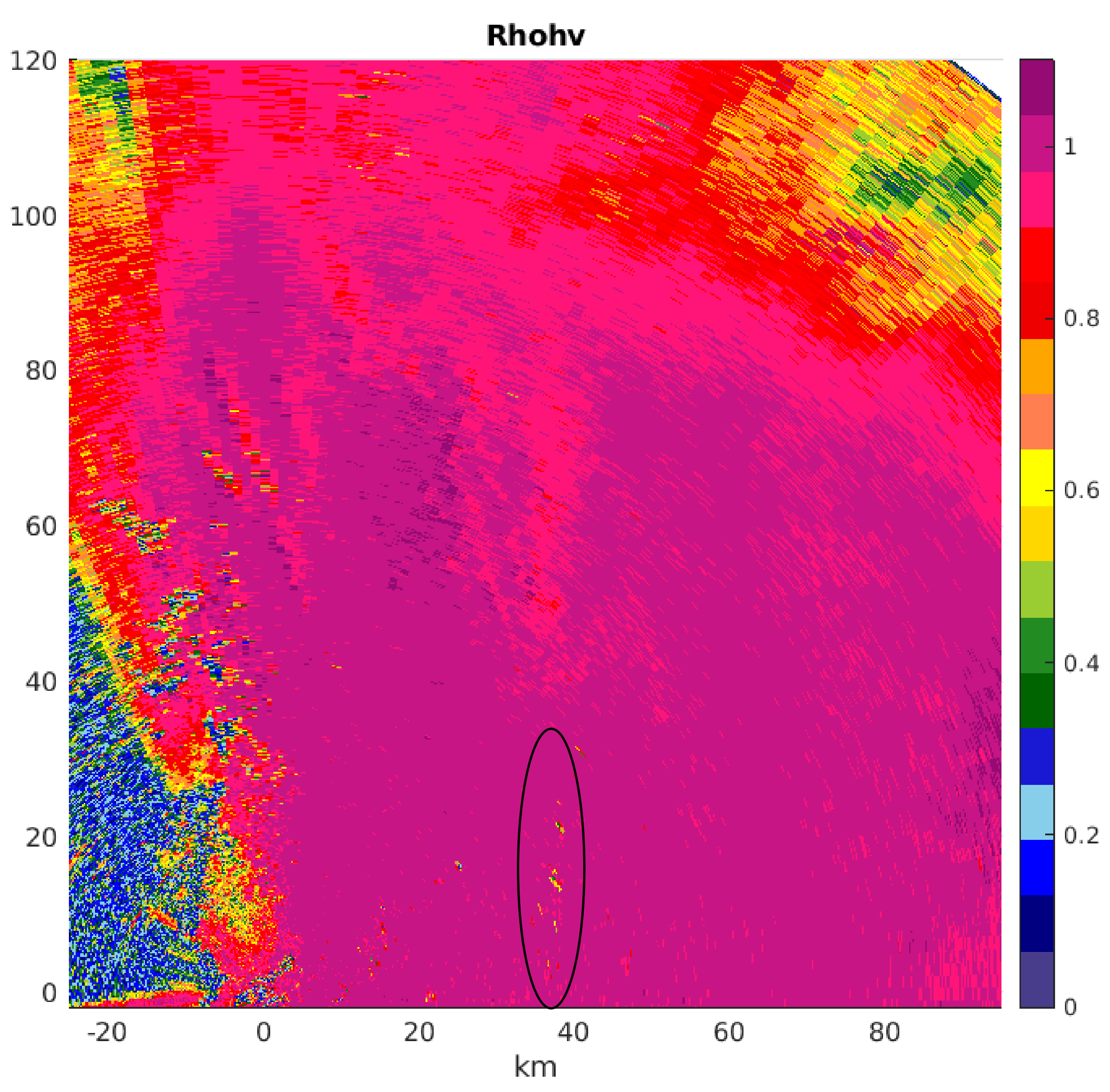


Rhohv

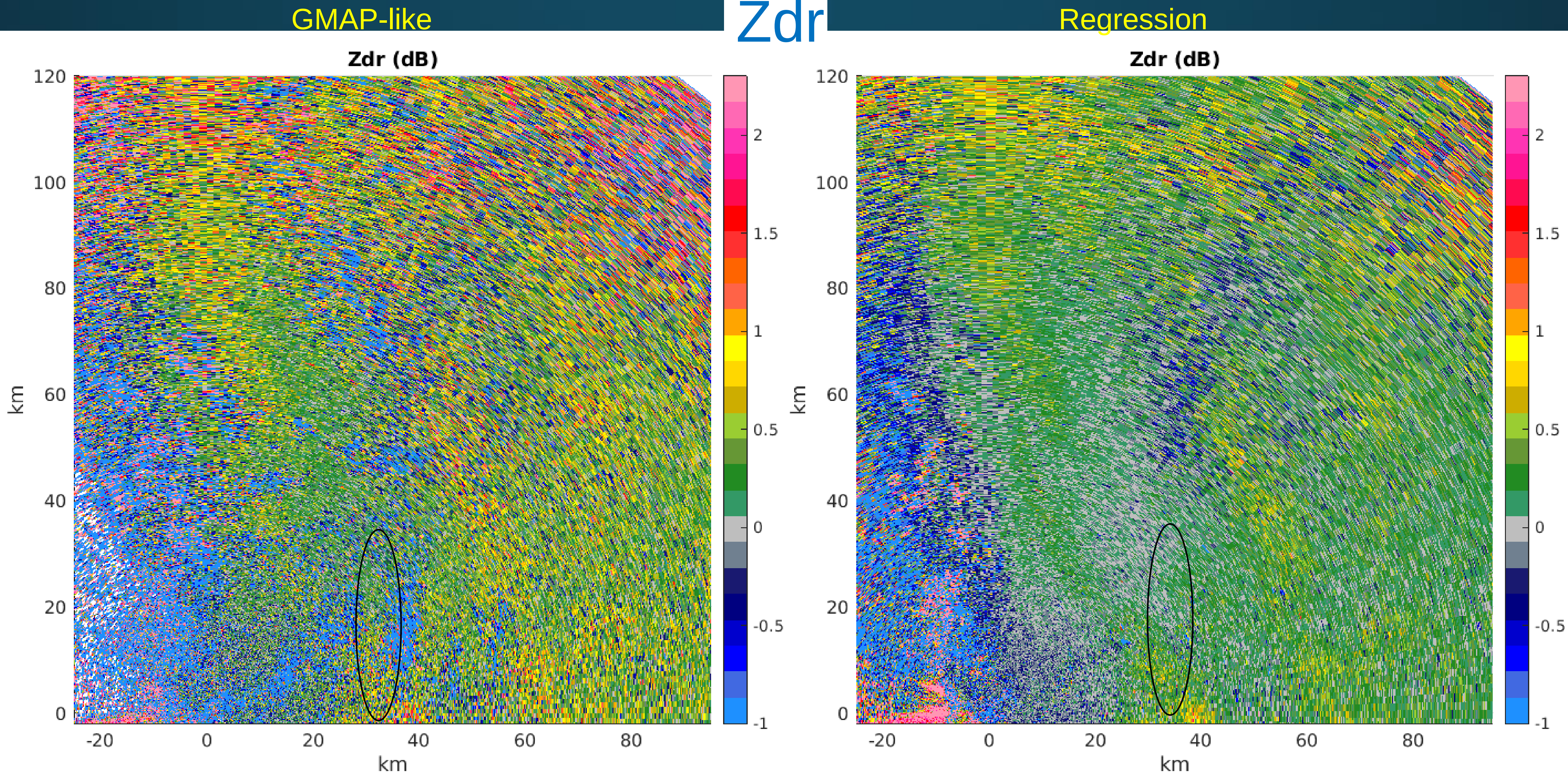
GMAP-like



Regression



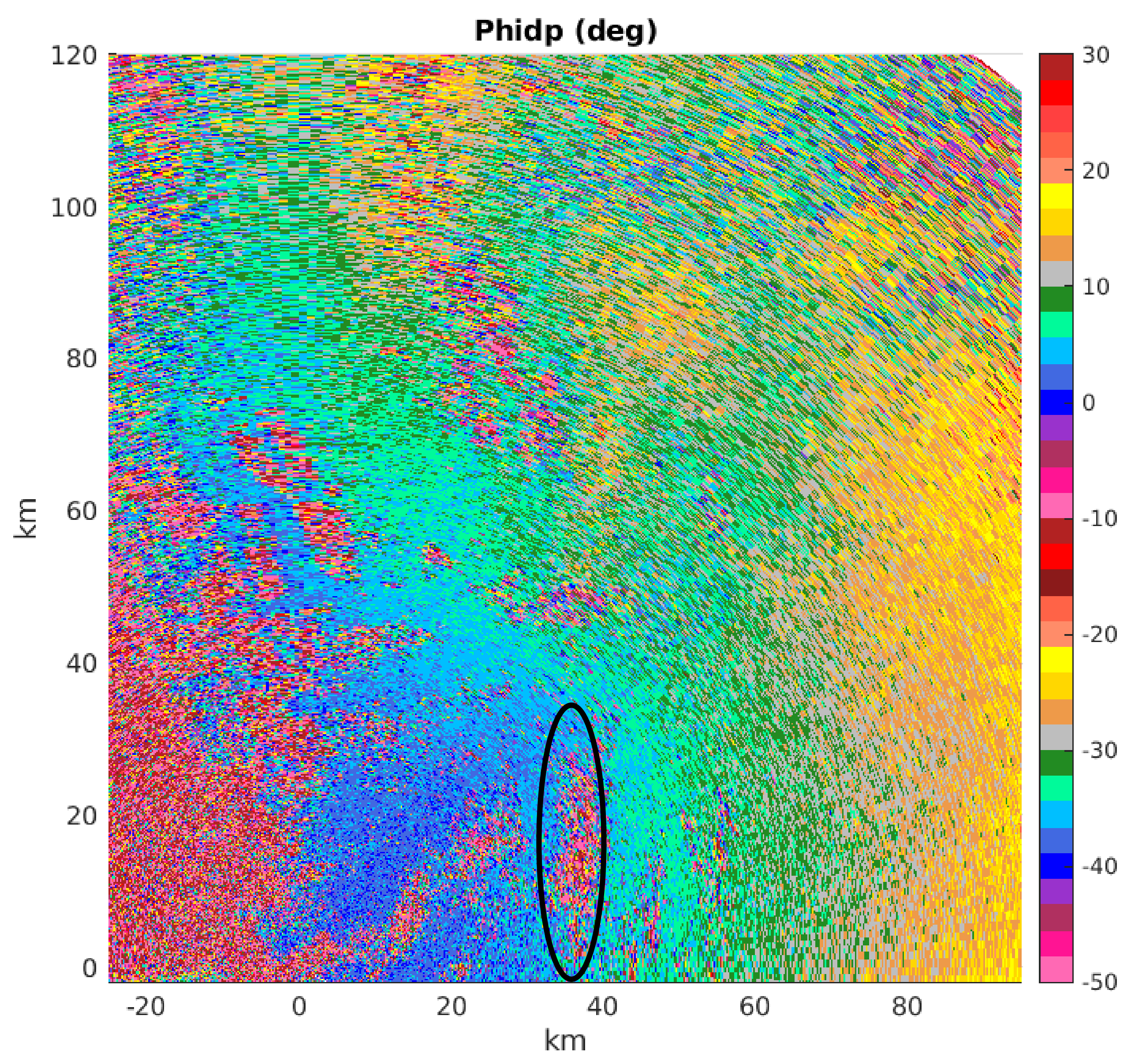
Zdr



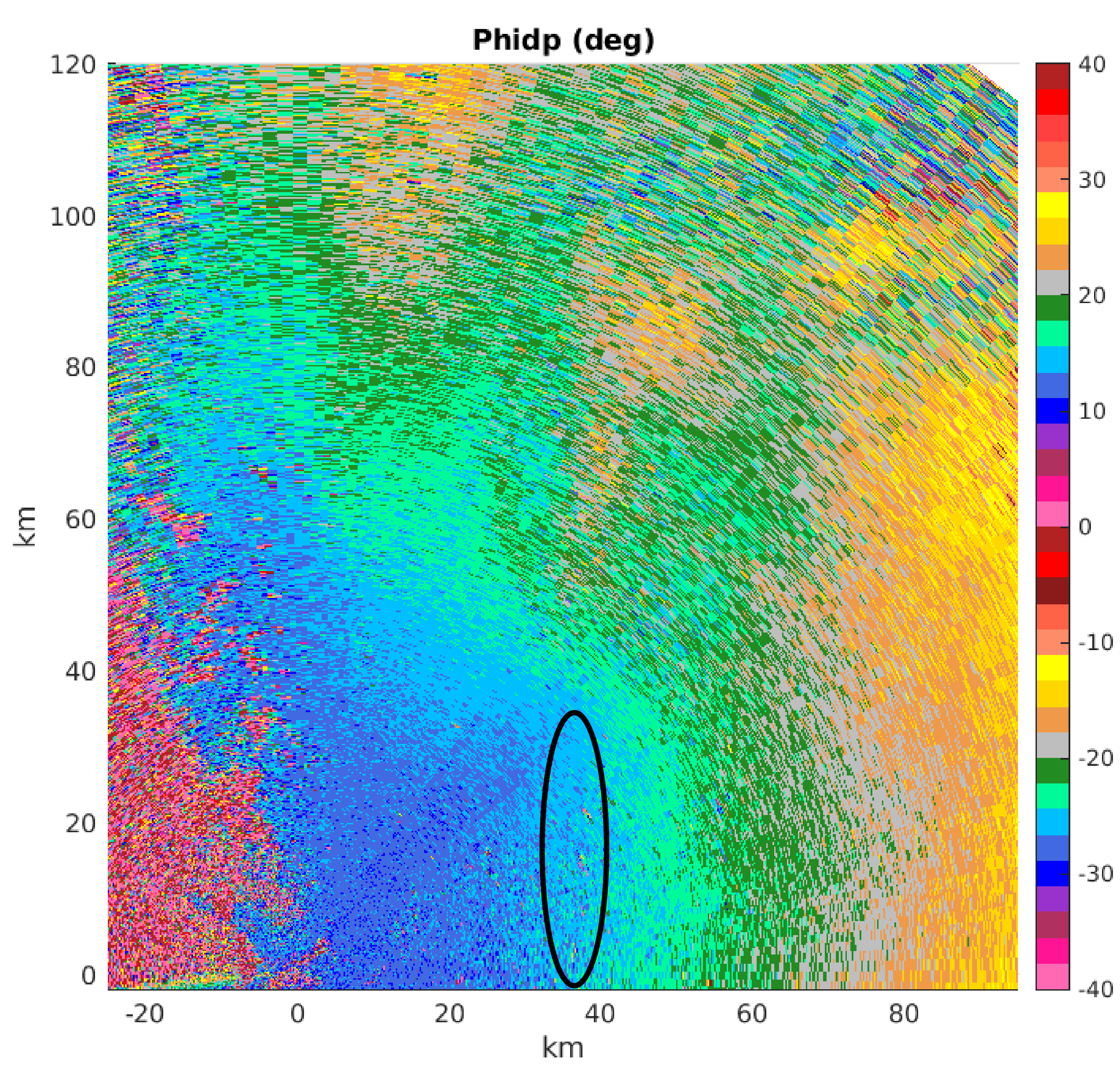
GMAP-like
Regression
Zdr (dB)
Zdr (dB)
km
km
km
km
120
100
80
60
40
20
0
-20
0
20
40
60
80
2
1.5
1
0.5
0
-0.5
-1

Phidp

GMAP-like

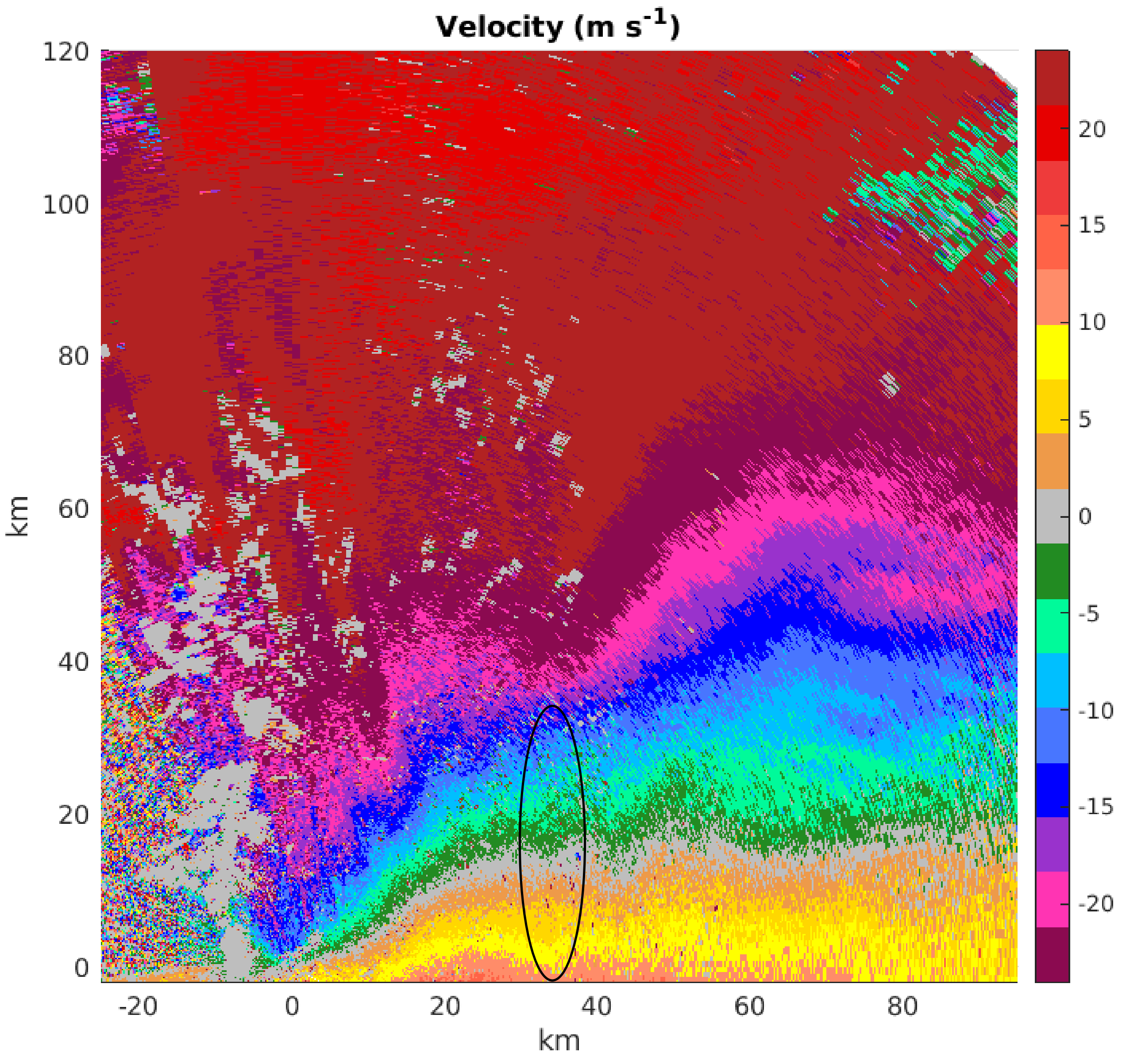


Regression

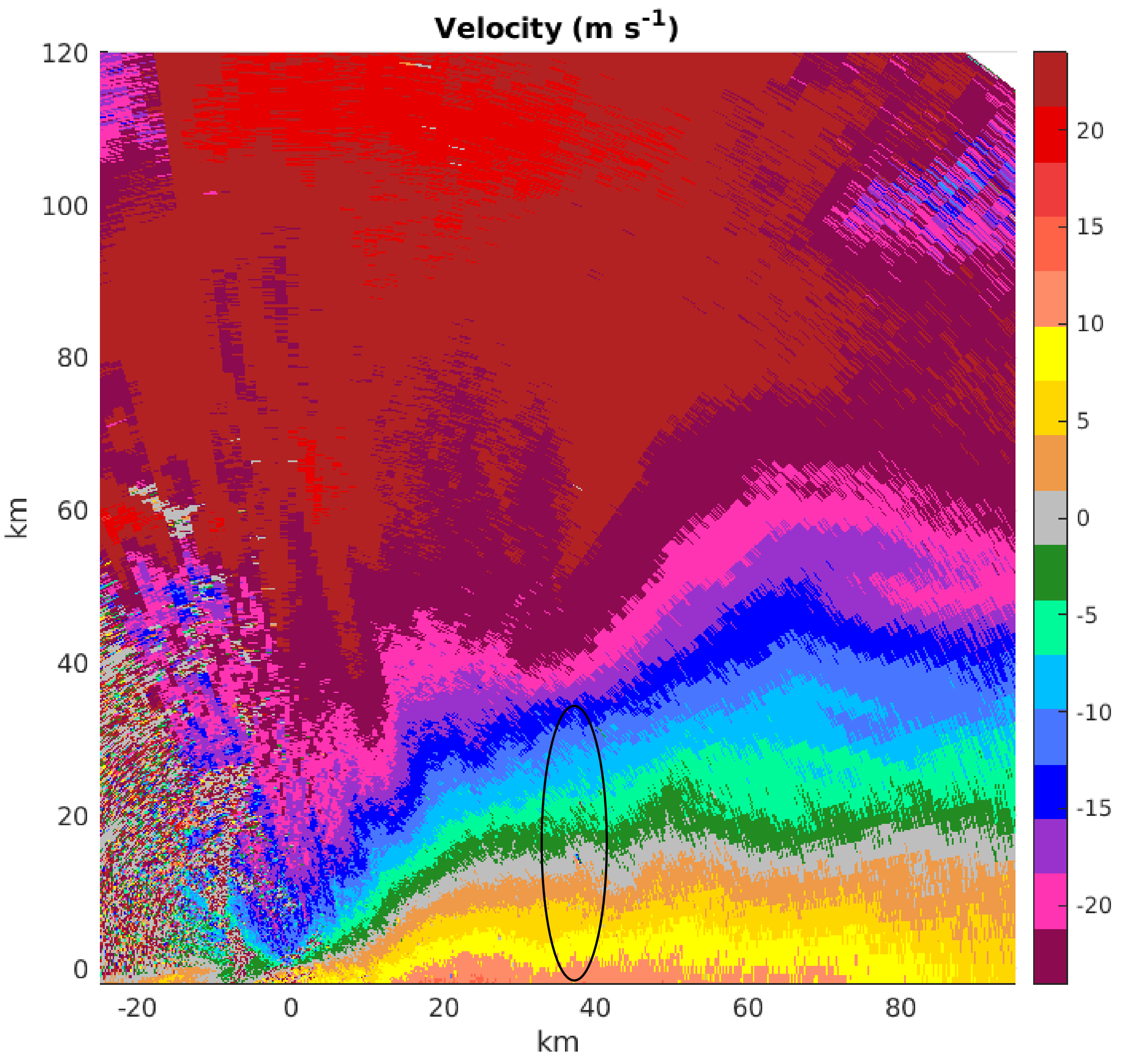


Velocity

GMAP-like

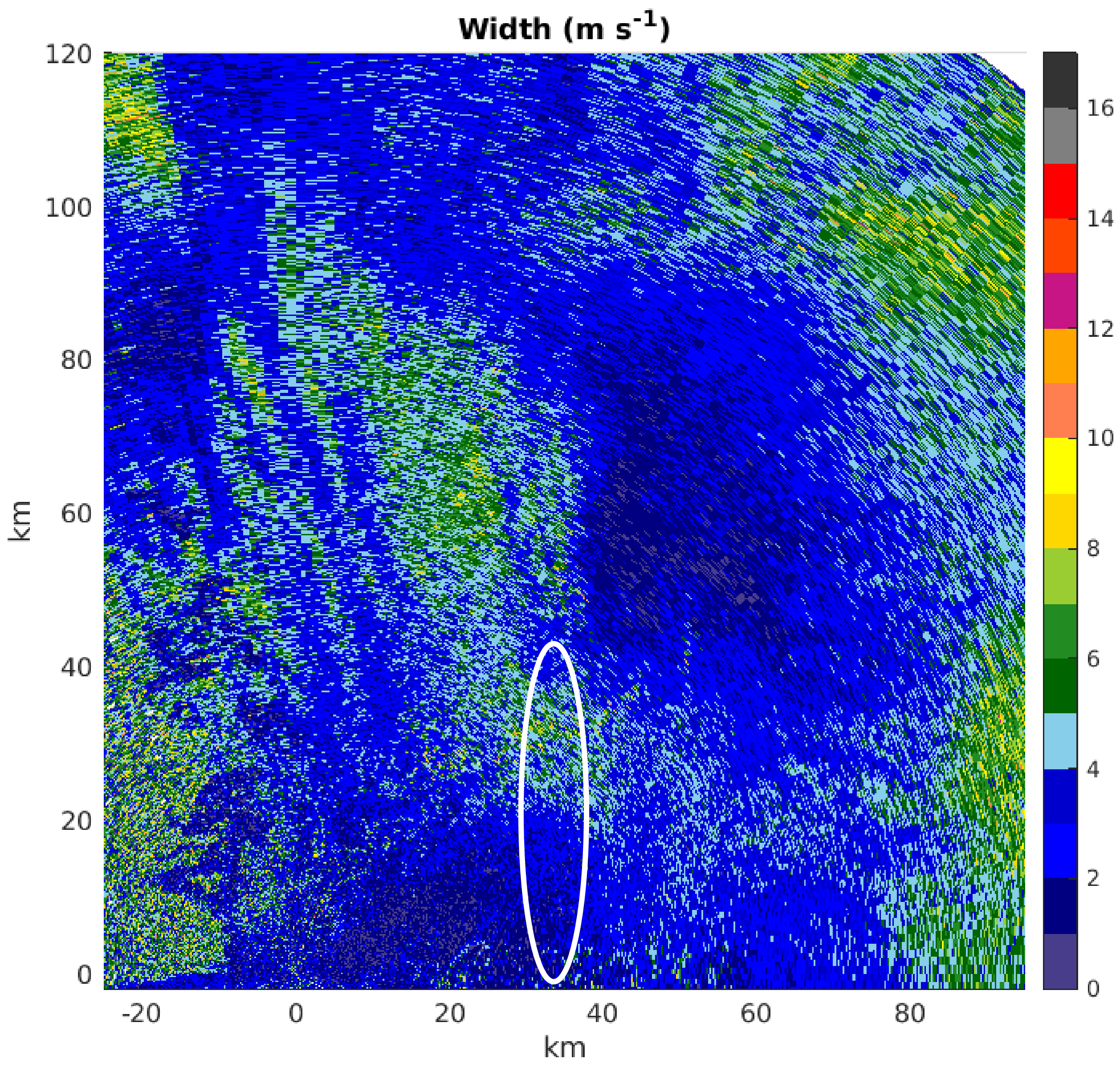


Regression

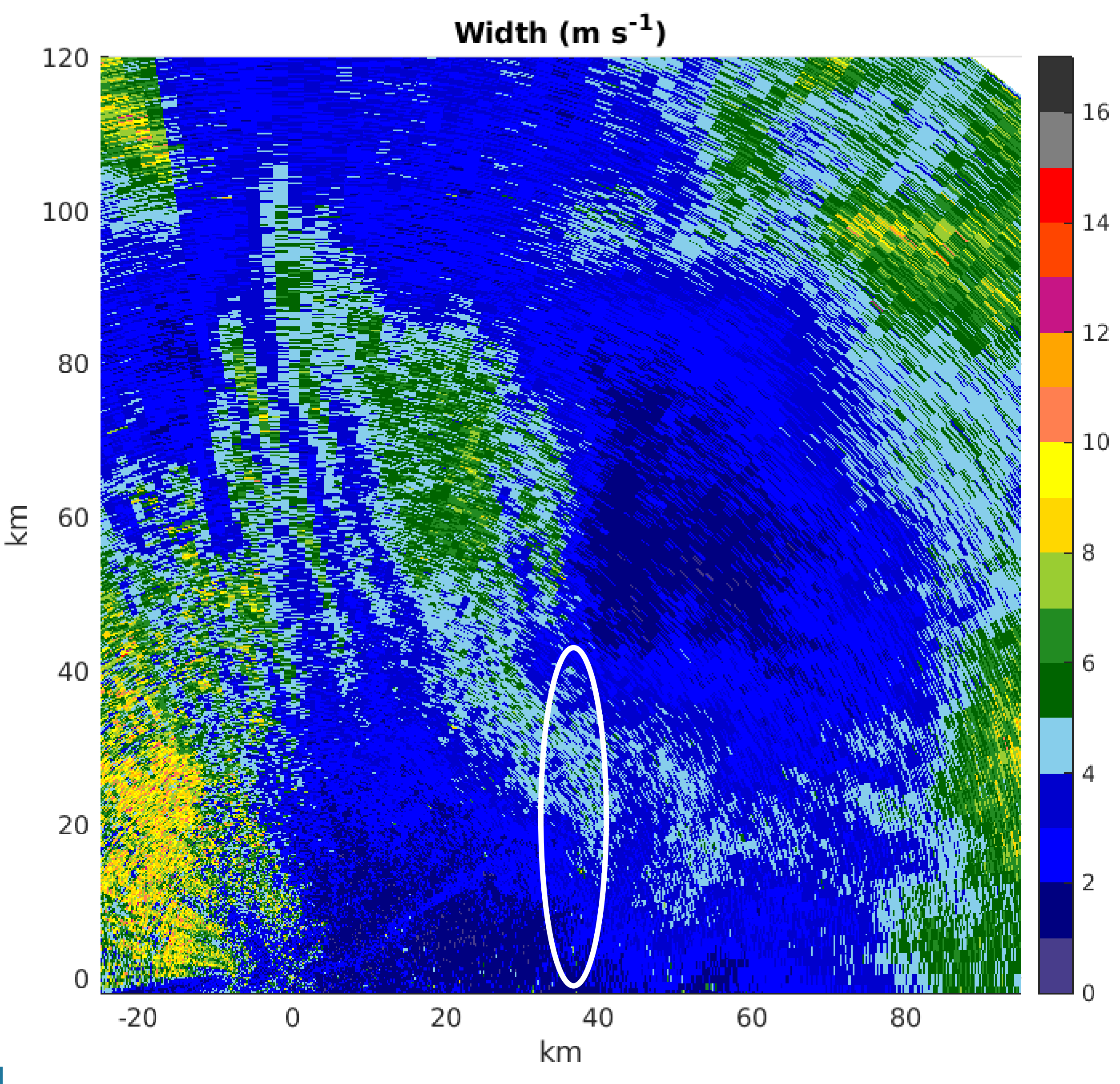


SW

GMAP-like



Regression



Most Areas in NEXRAD will be Like the S-Pol Case

In the batch, and higher cuts 1.9º and above, there are no overlapping windows (super res.) and a Blackman window is used when the GCF is applied (von Hann was used in the S-Pol case).

KDDC Case

Super Resolution

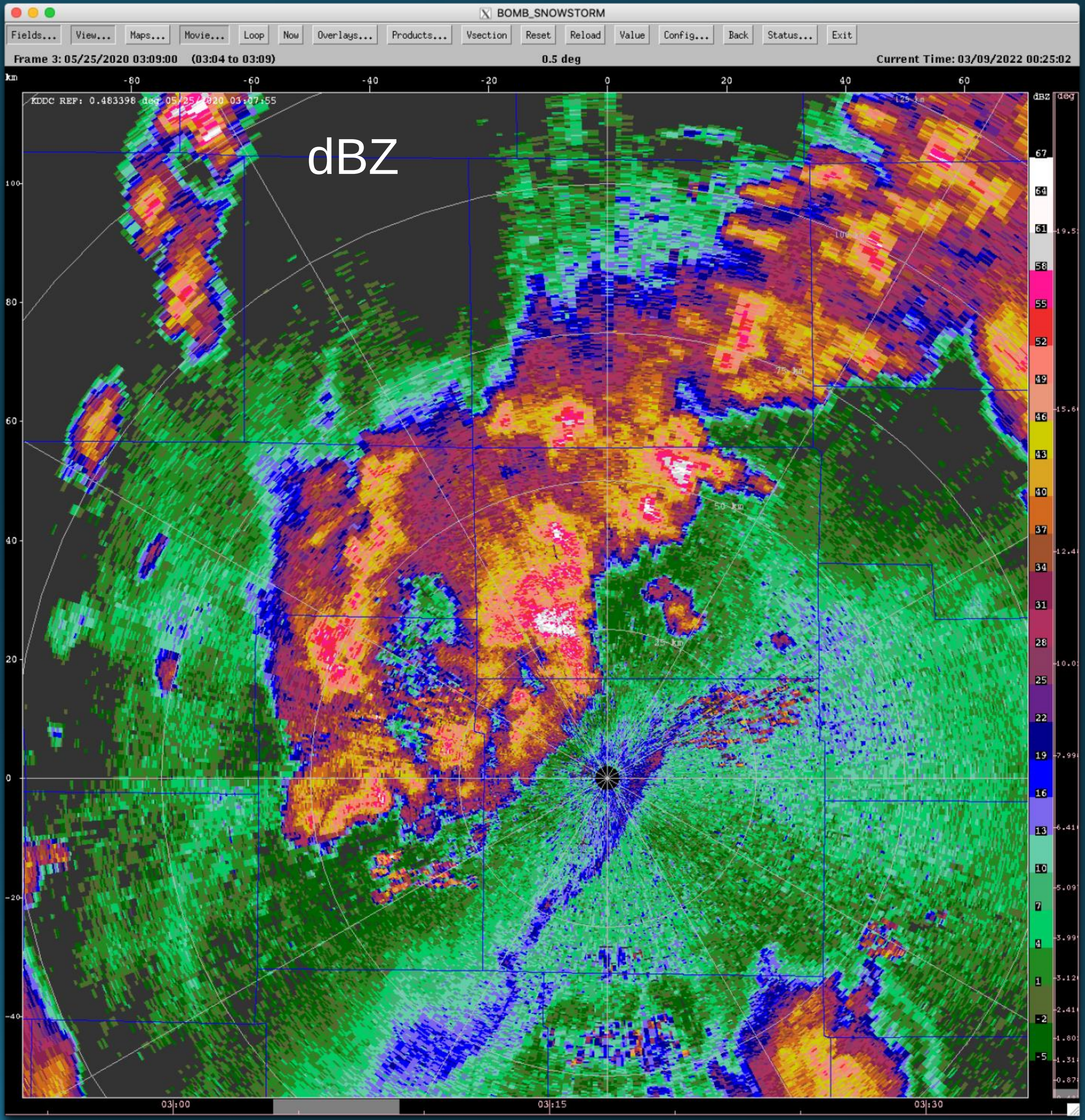
25 May 2020   03:07:55

VCP 212

Uses Split cut with SZ2
LPRT: Z, Zdr, Phidp, Rhohv
Doppler: Vel, SW

Elev. = 0.48 deg.

NCAR obtained Level 1 data for this case

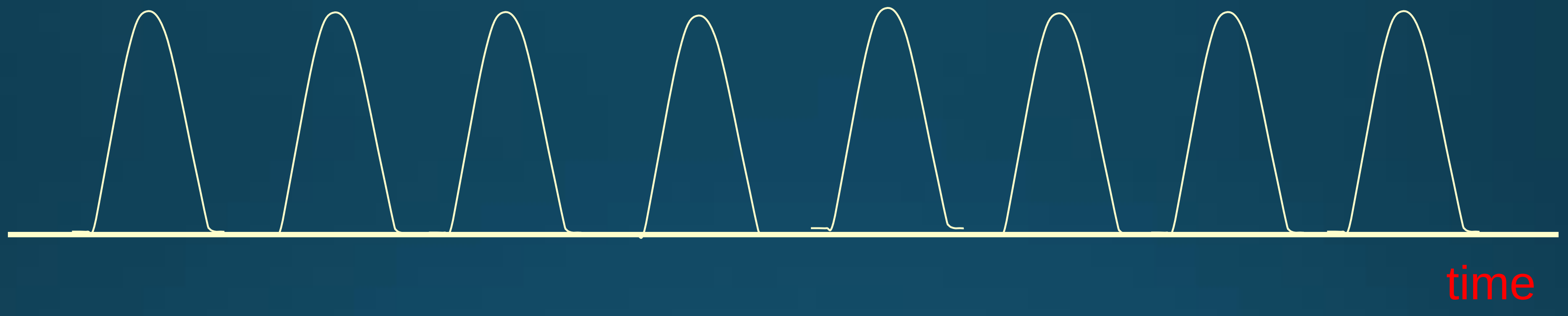


Super Resolution Case

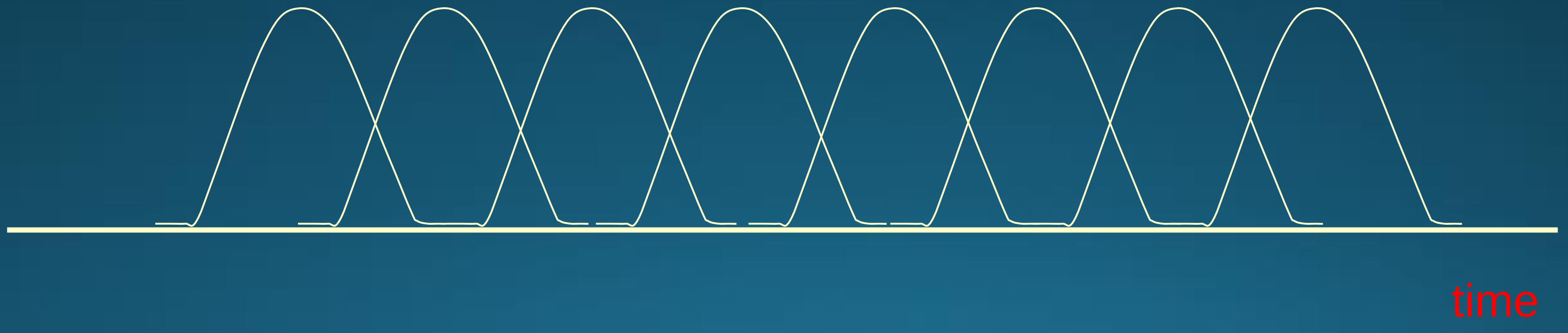
1. There are overlapping 64-point, von Hann windows which slide 32 points at a time for the Doppler scan (PRT=1 ms)
   - For calculating Velocity and spectrum width
2. Likewise for the Long PRT scan (3.1 ms), 16-point von Hann window sliding 8 points at a time
   - For Z, Zdr, Phidp, Rhohv

Super Resolution and SZ(8/64) Phase Coding

Non overlapping windows



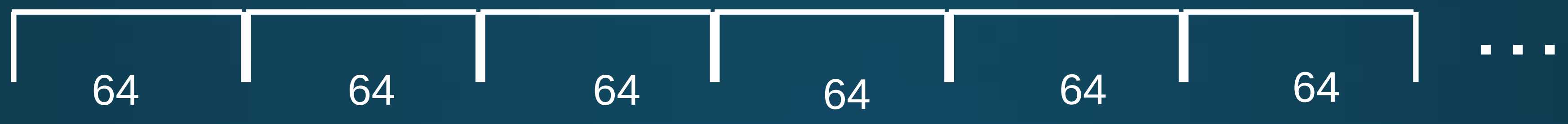
Overlapping windows



64 point von Hann window sliding 32 points at a time

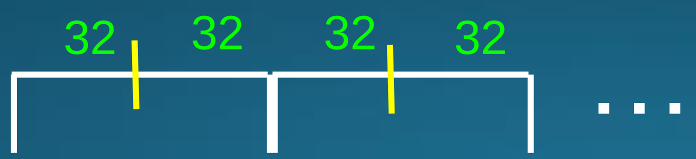
Regression Filtering and Super Resolution

Process 64 points at a time, i.e., use contiguous rectangular window



1. Clutter filter on 64 points

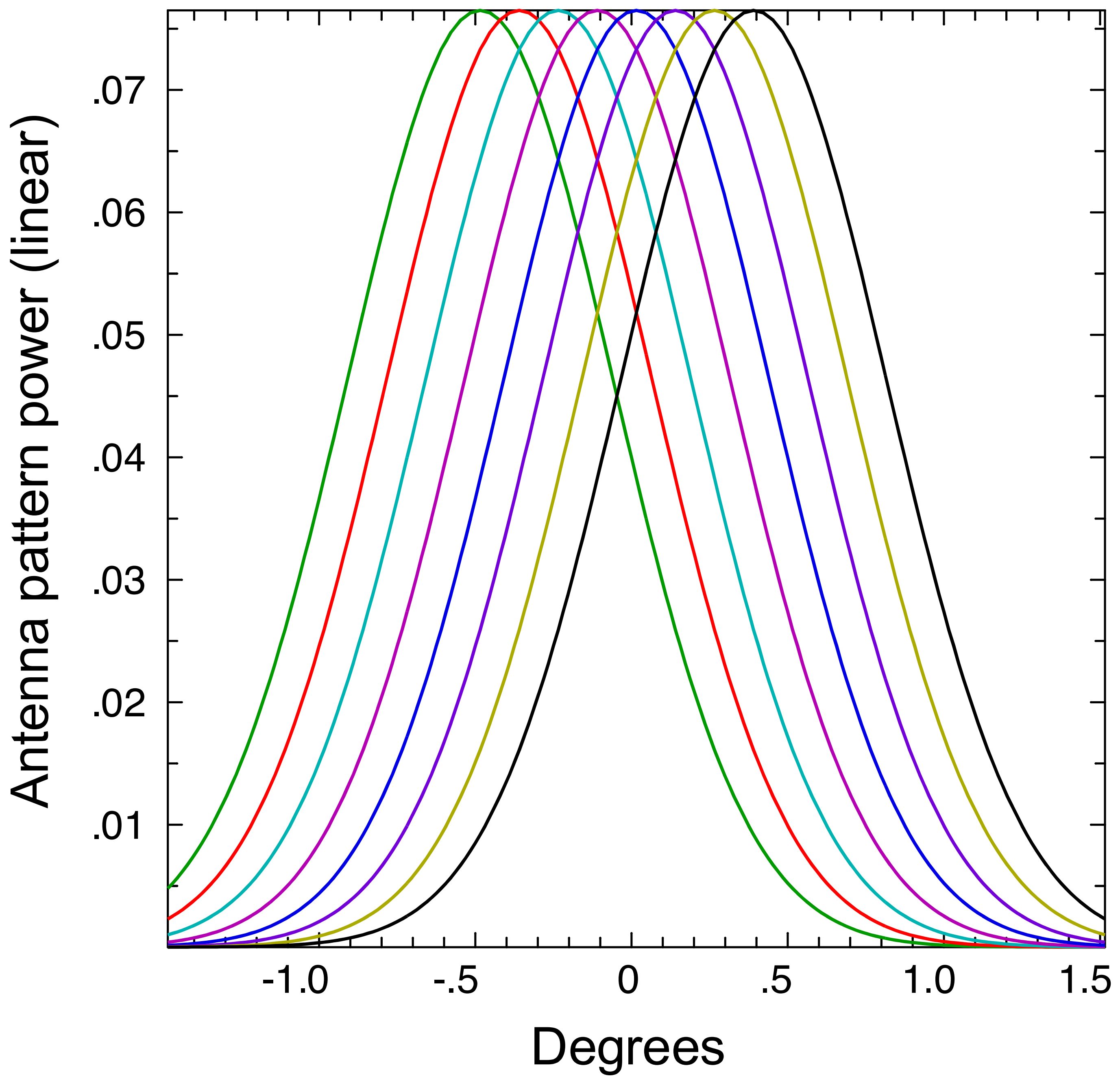
2. But, calculate variables on 32 points for super resolution



The effective 2-way antenna pattern

$$f^4_{eff}(\phi) = c \sum_m f^4(\phi - m\,\Delta\phi)\, Win^2(m)$$

(based on Zrnic and Doviak, 1976)

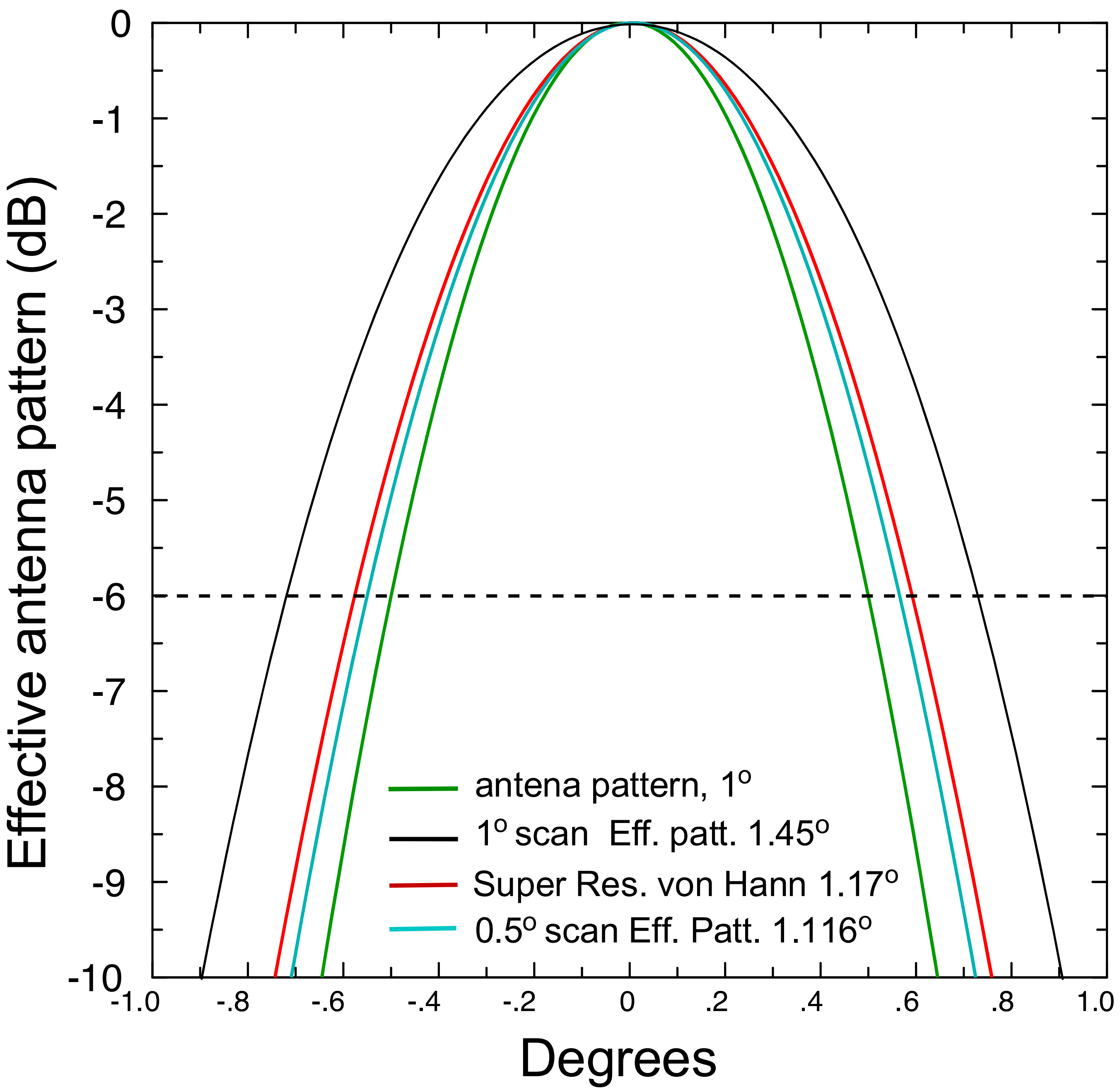


Super Resolution

red line	64 point von Hann
blue line	32 point rectangular

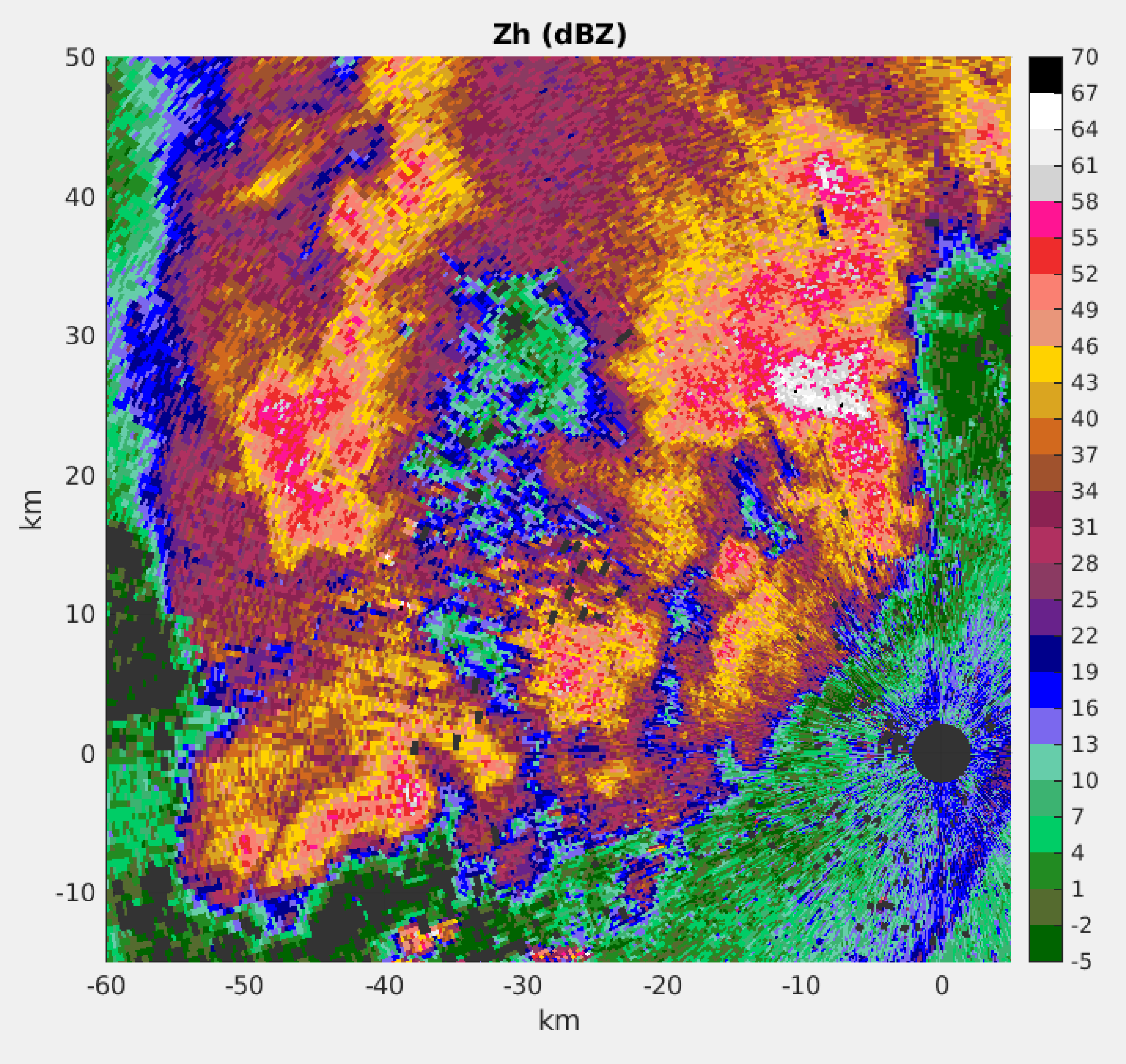
$$f_{eff}^{4}(\phi) = c \sum f^{4}(\phi - m\,\Delta\phi)\,\mathrm{Hann}^2(m)$$

These curves are in agreement with Torres and Curtis 2006, ERAD



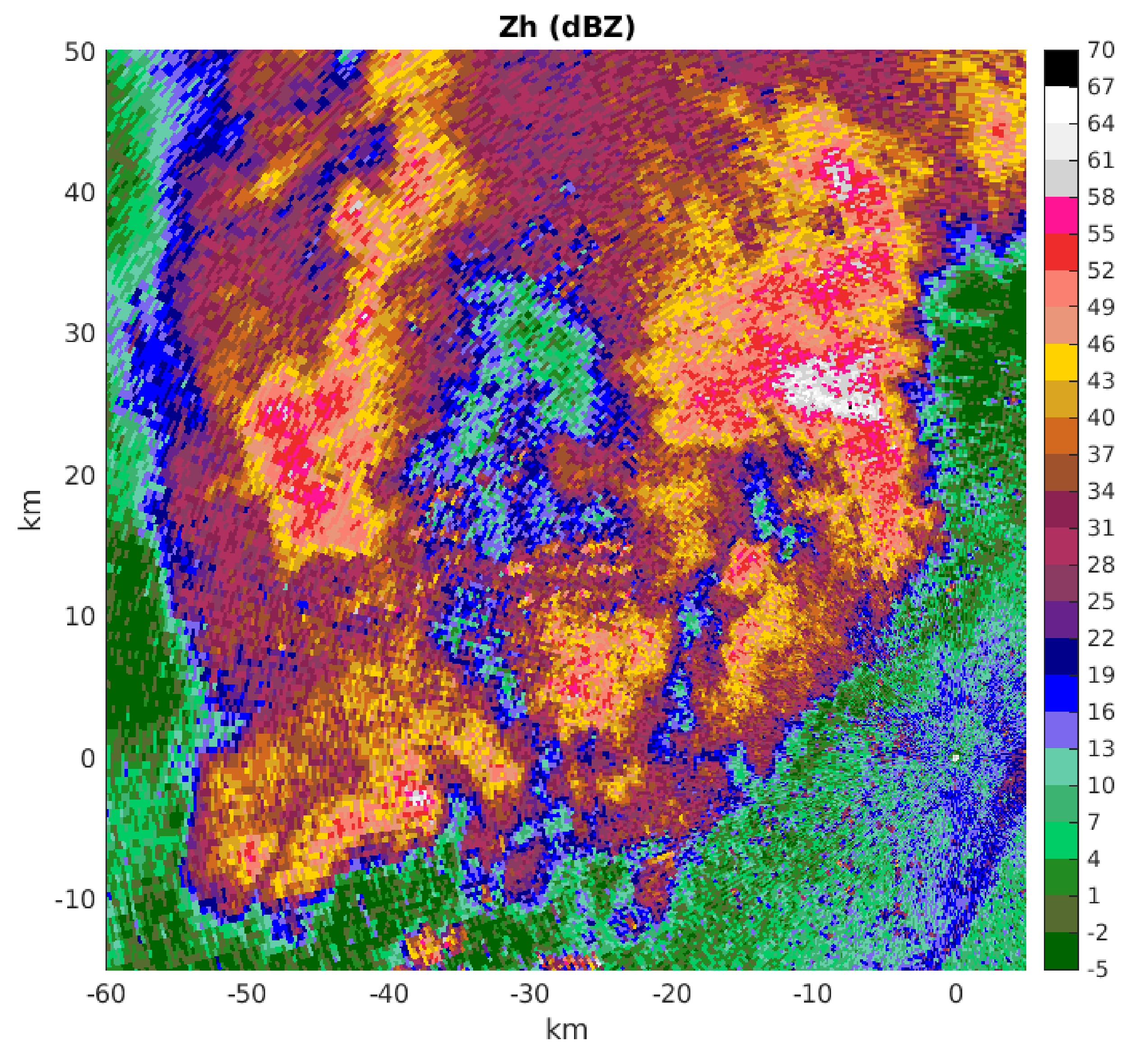
Thus 64 point with von Hann window has a comparable effective resolution as a 32 point rectangular window *but the 32 point resolution is better*

Level 2 Data



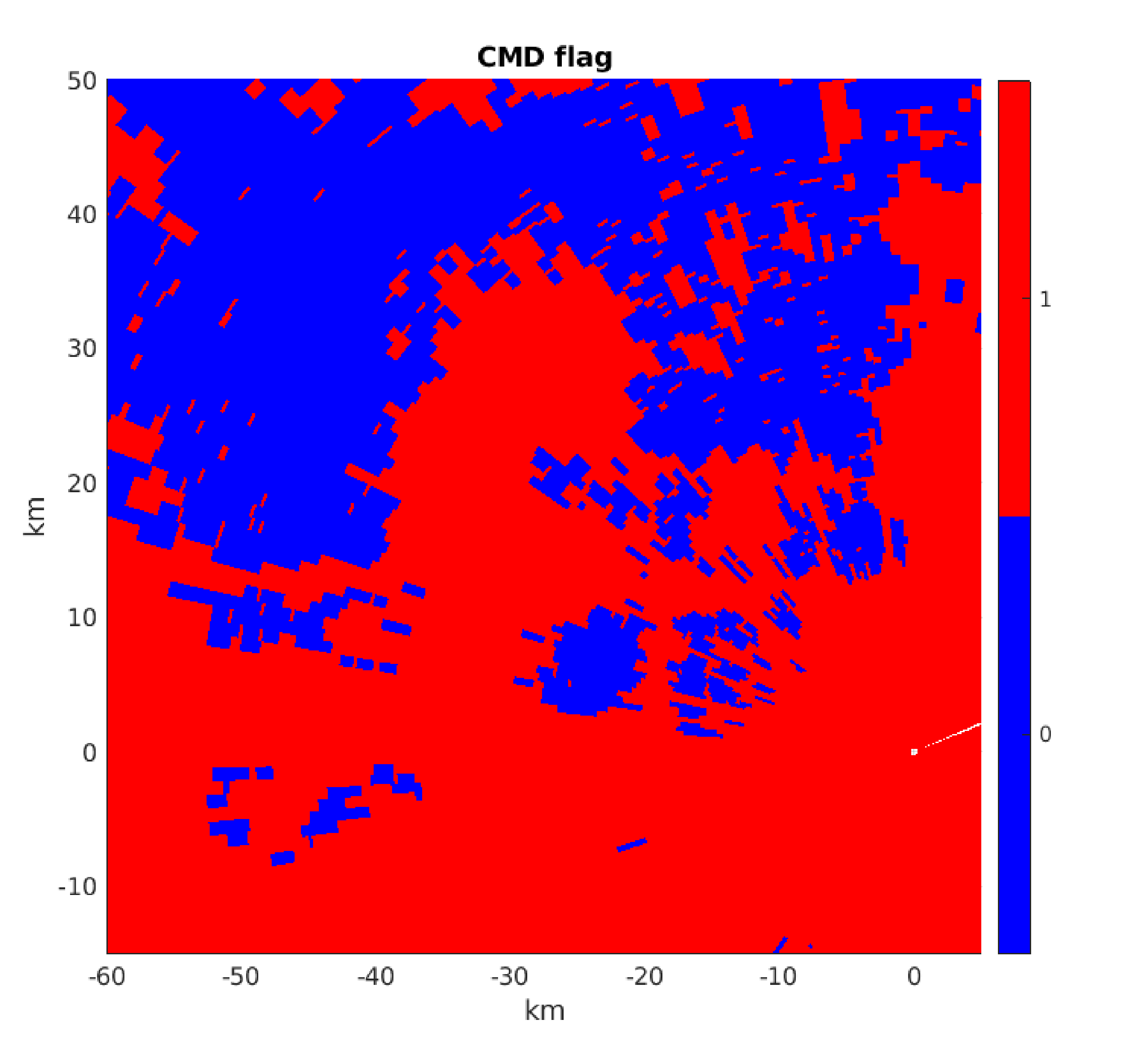
Regression Level 1 Data

(no SZ processing)

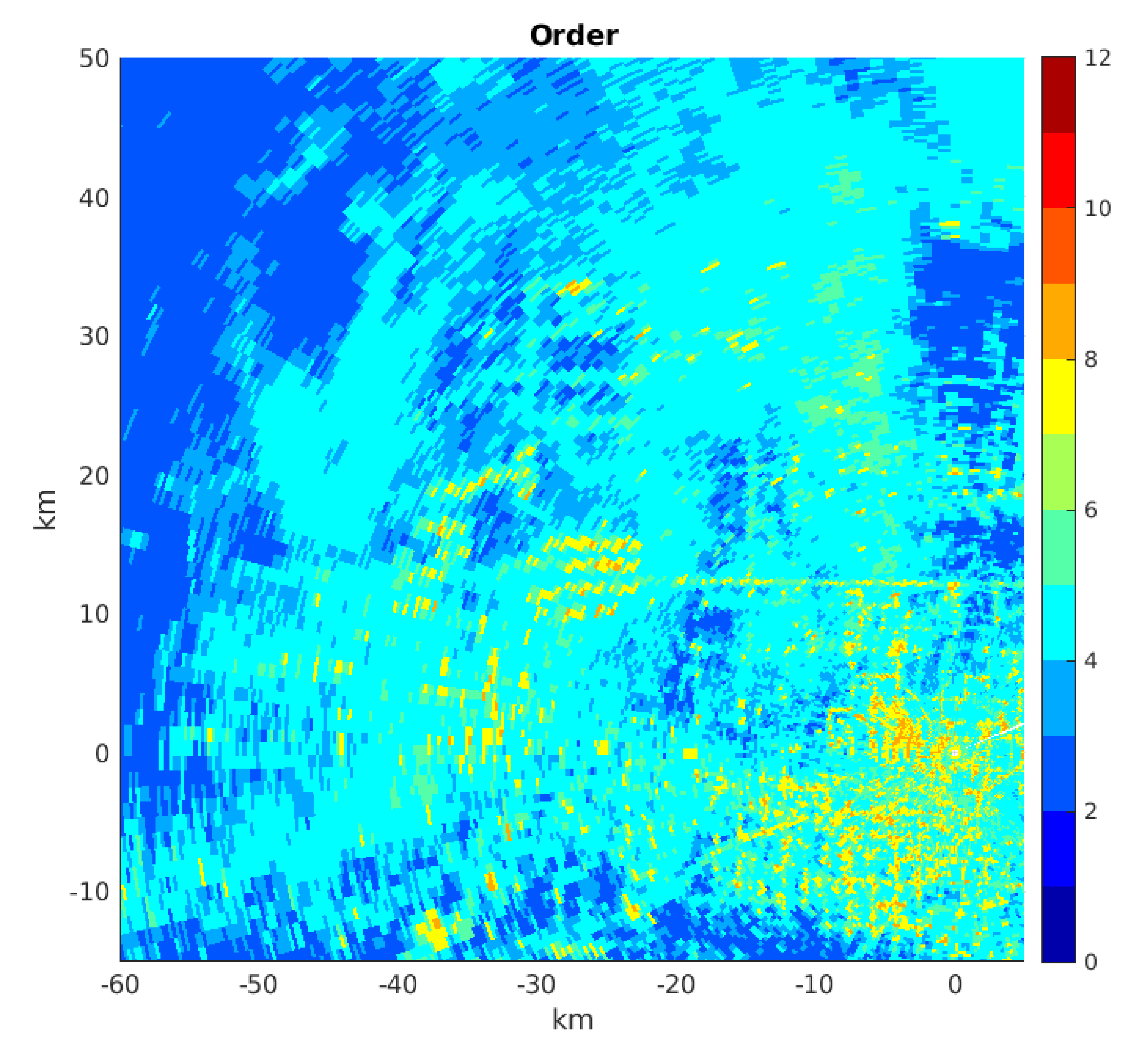


Long PRT

Regression

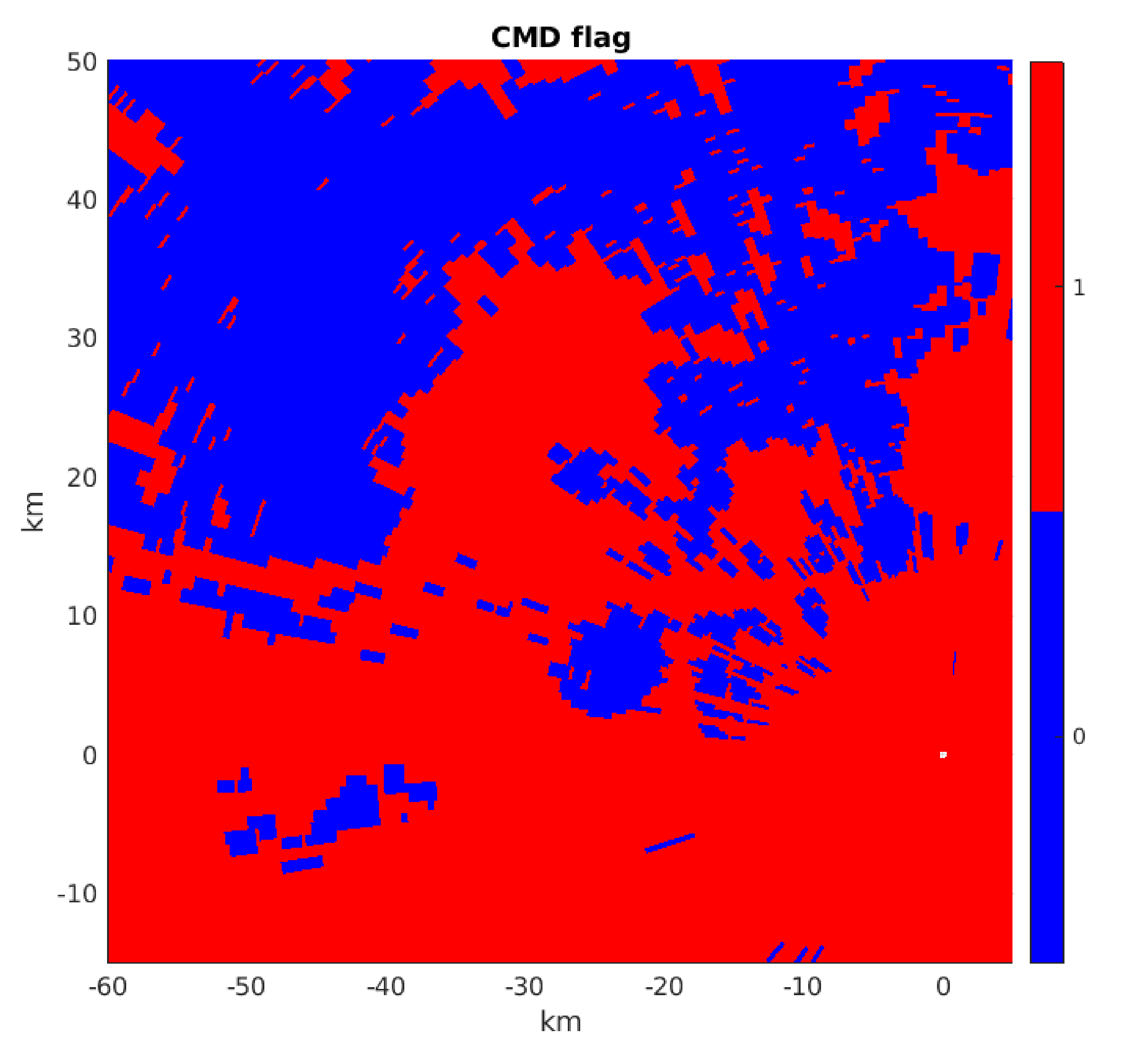


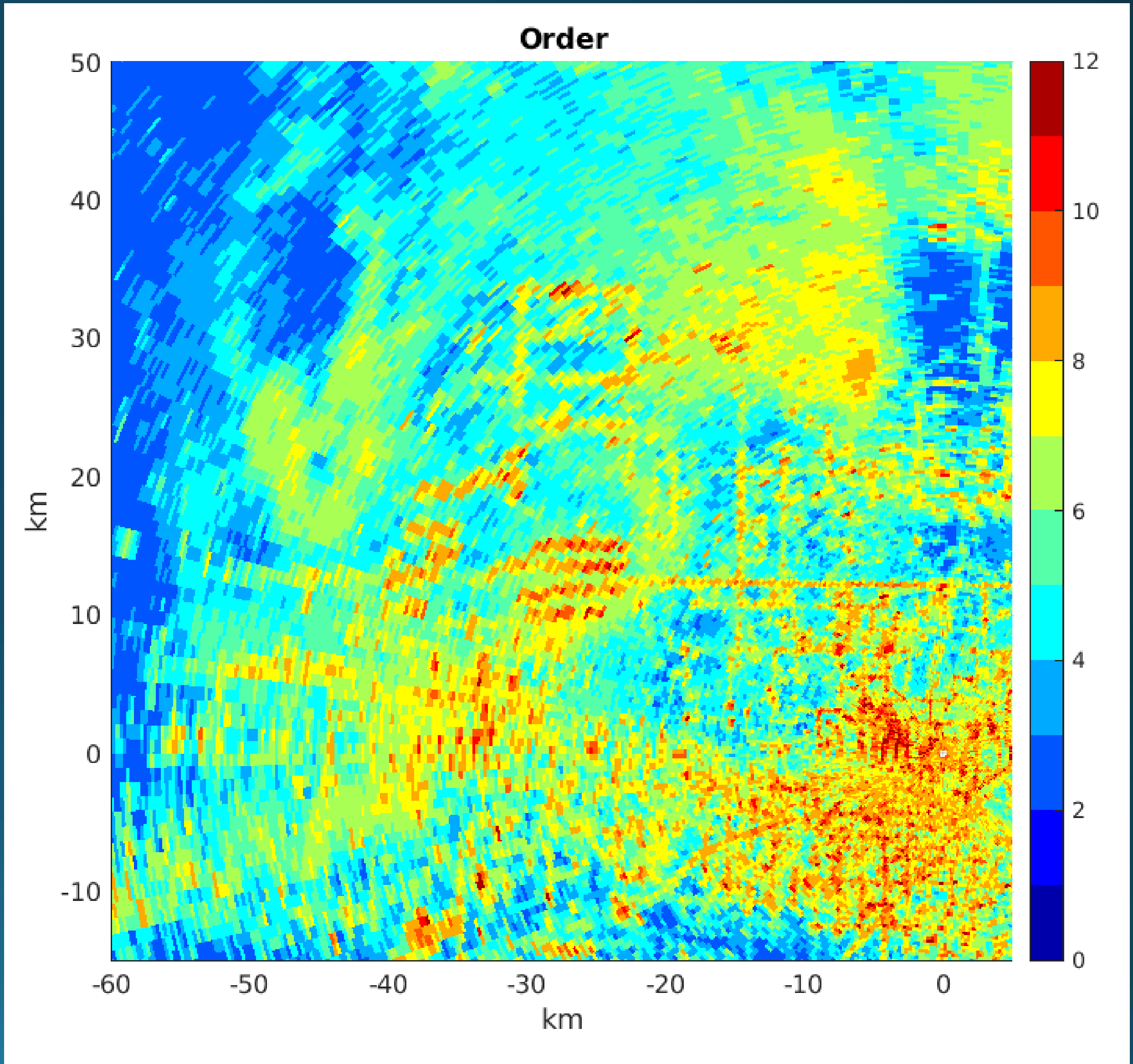
Automated order selection



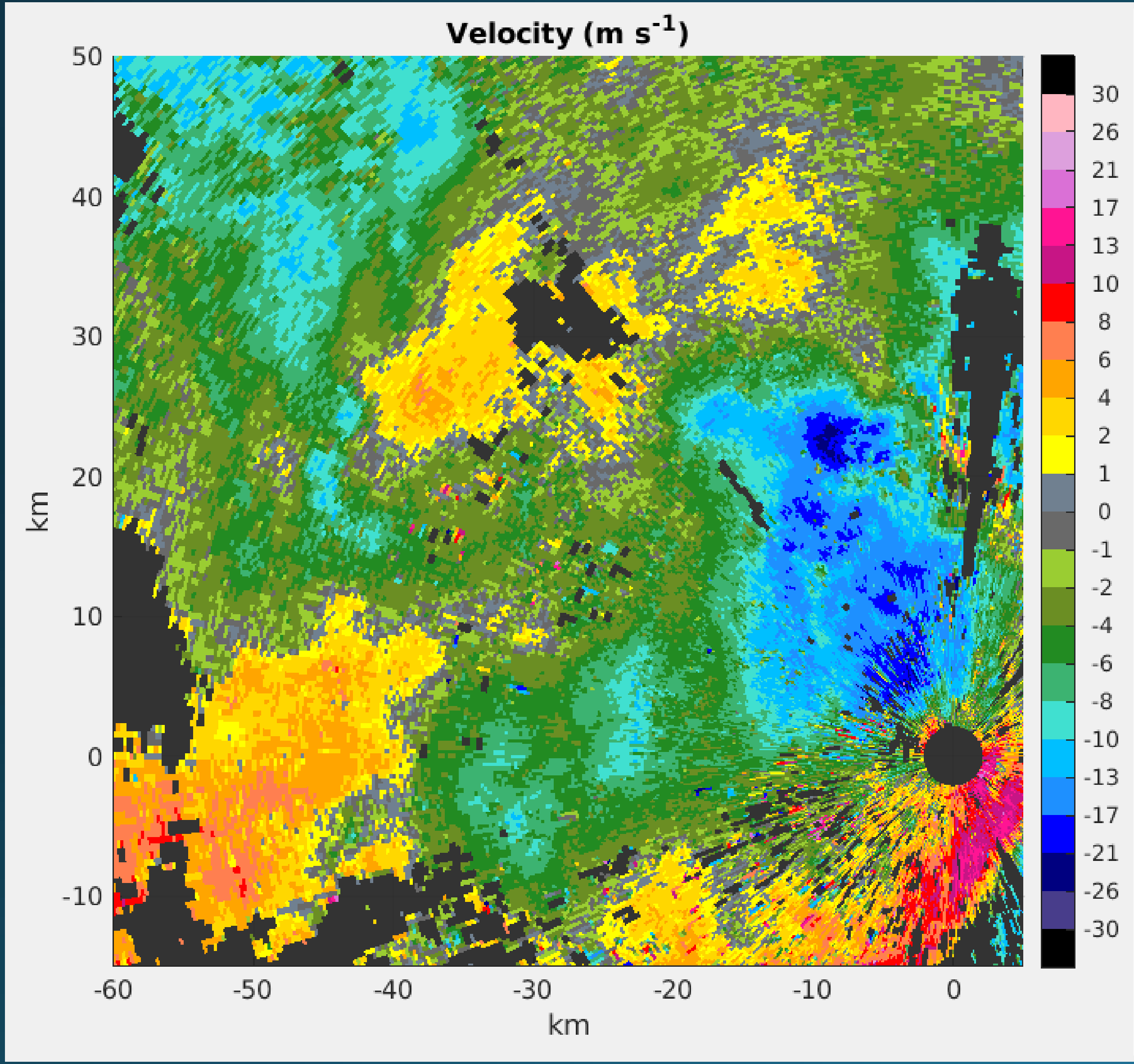
Doppler Scan

Automated order selection

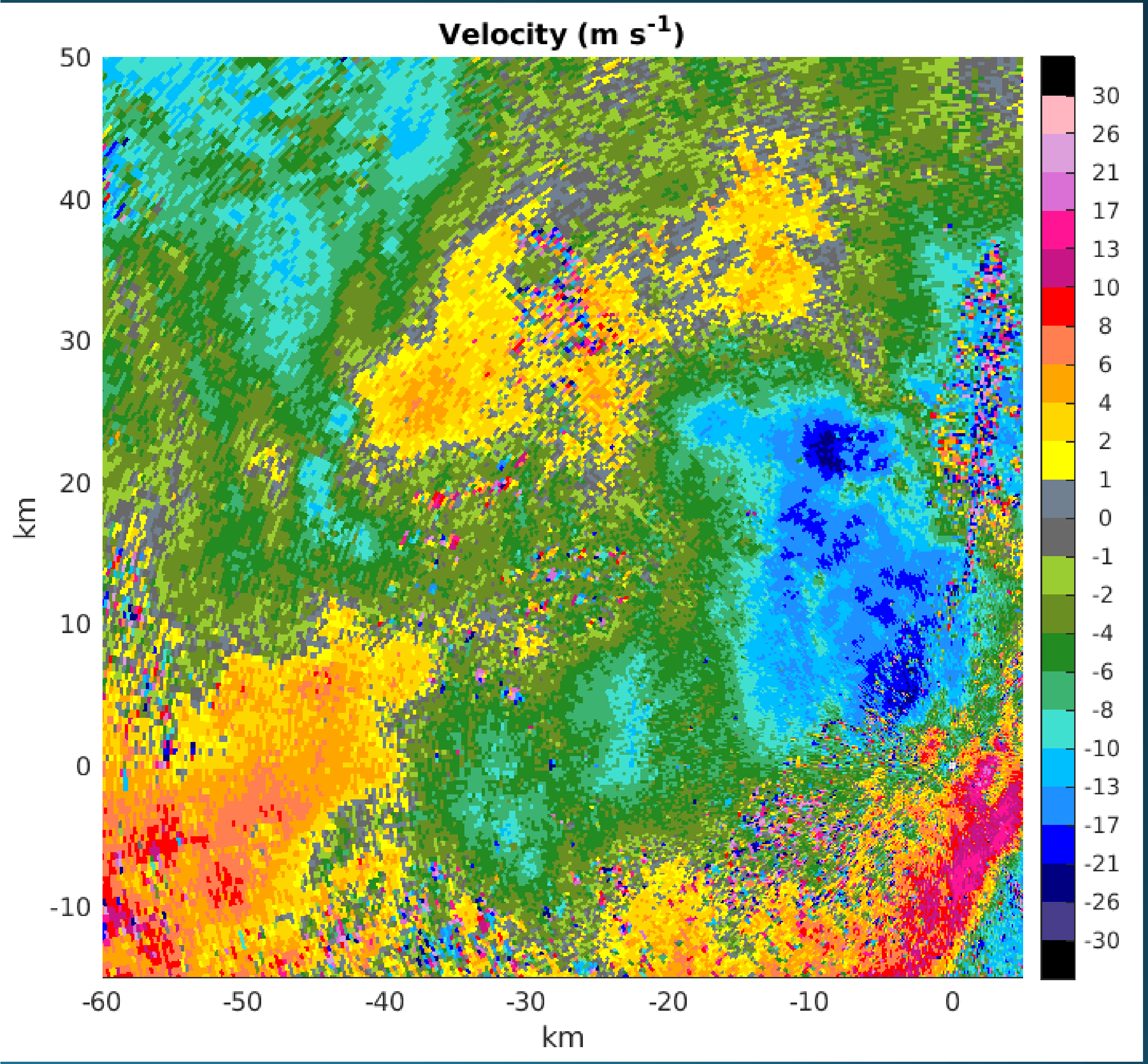




Level 2 Data



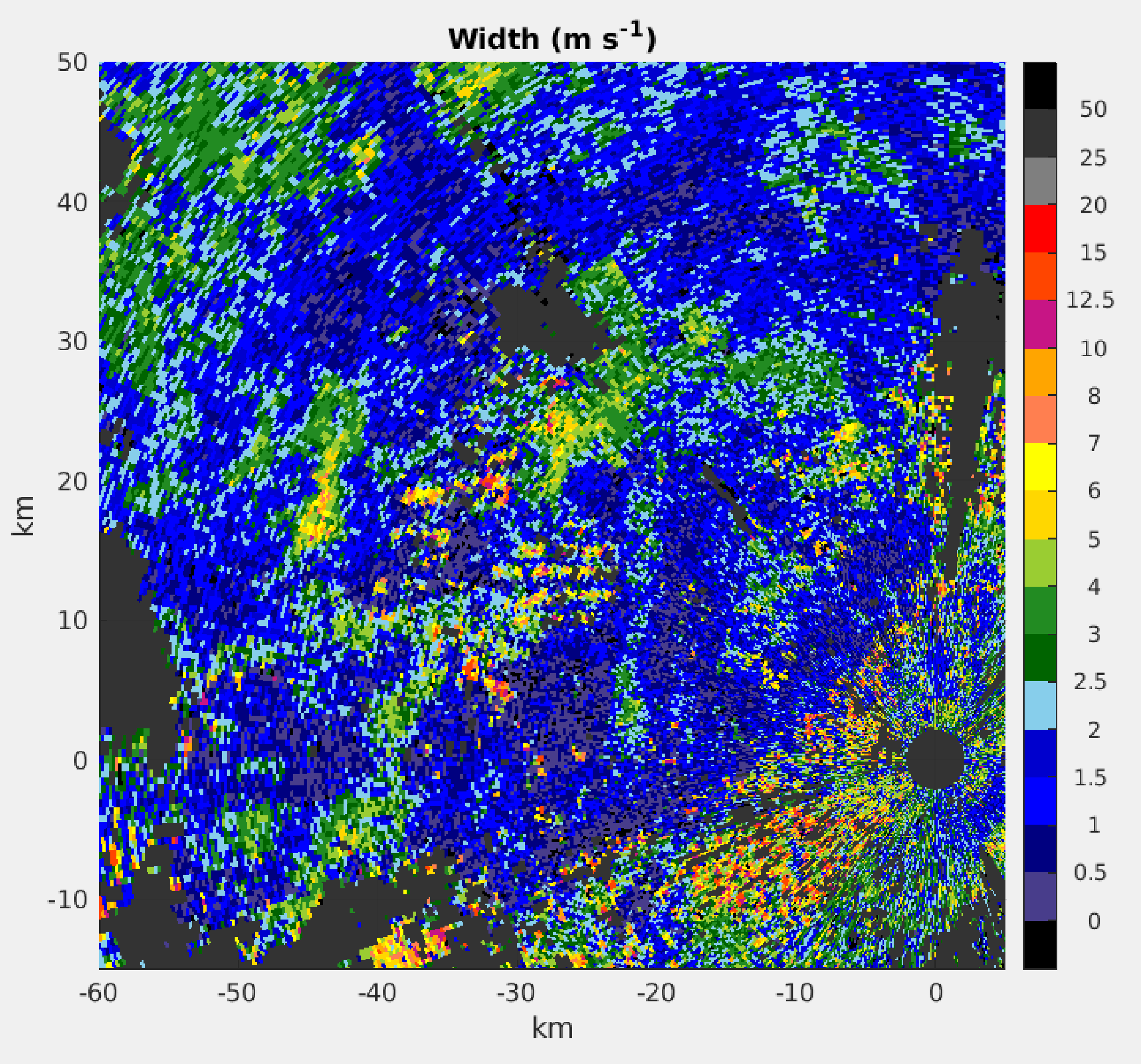
Regression Level 1 Data

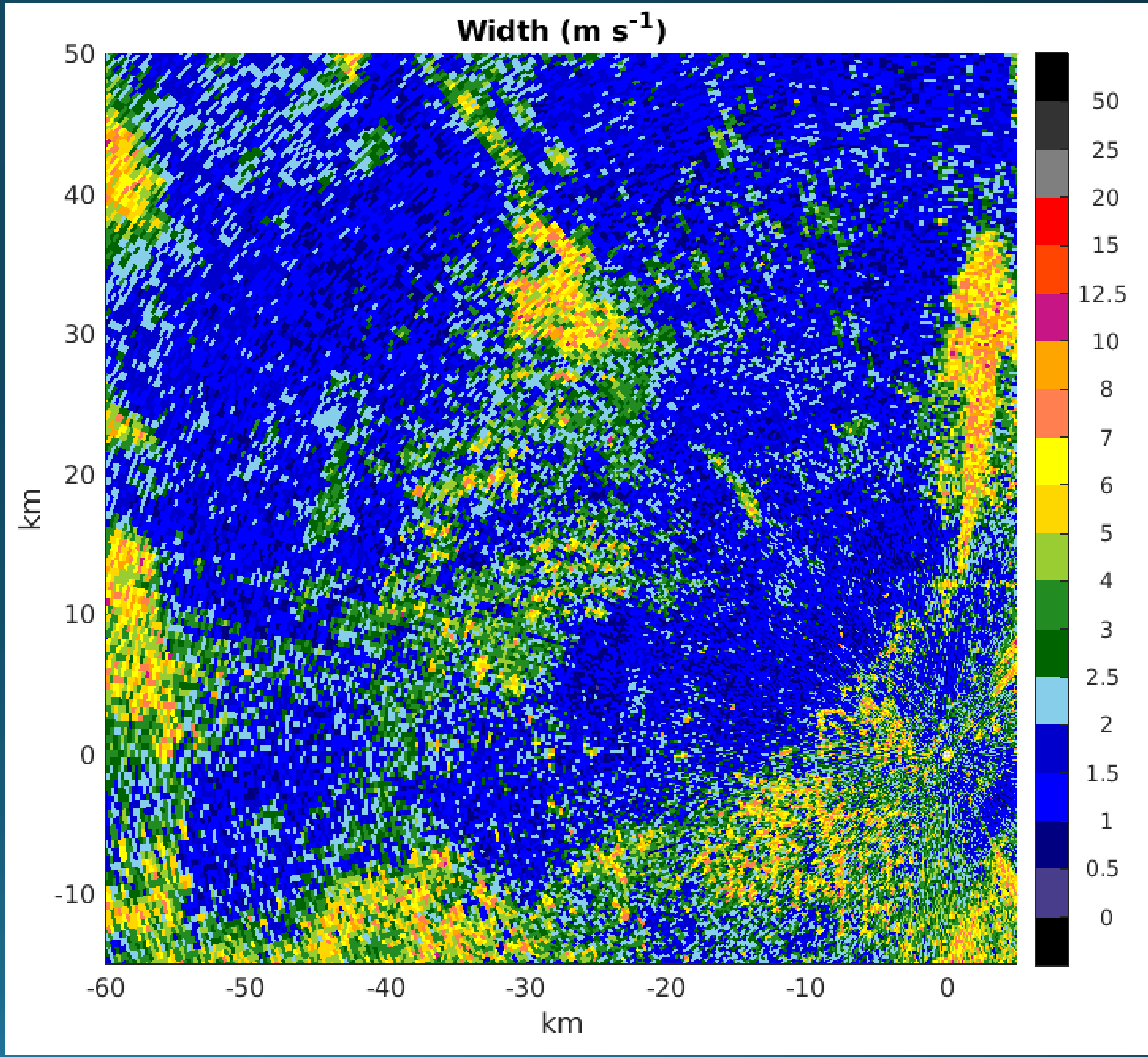


Level 2 Data. (HSW)

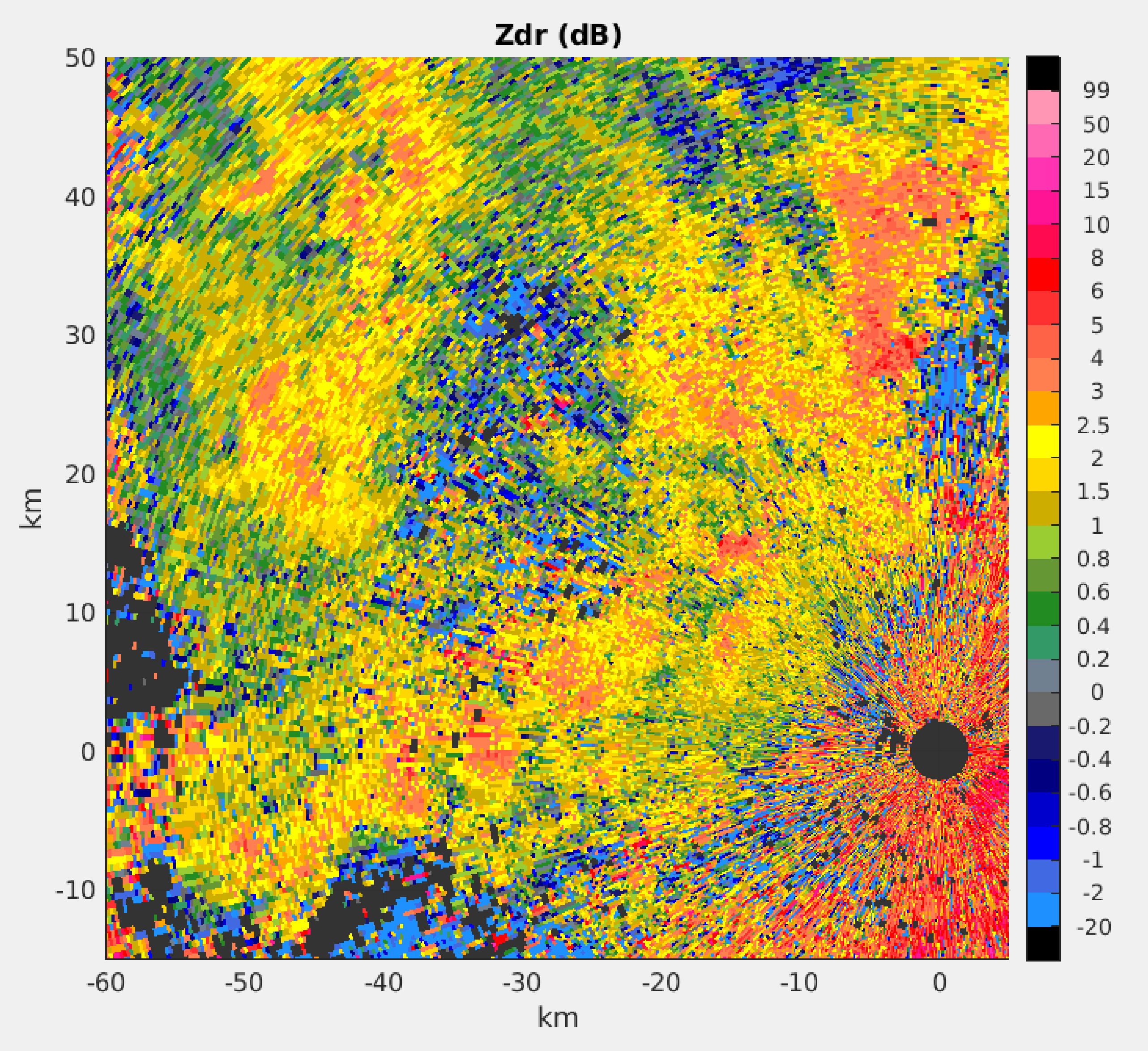
Regression Level 1 Data (R1/R2)

Difficult to compare

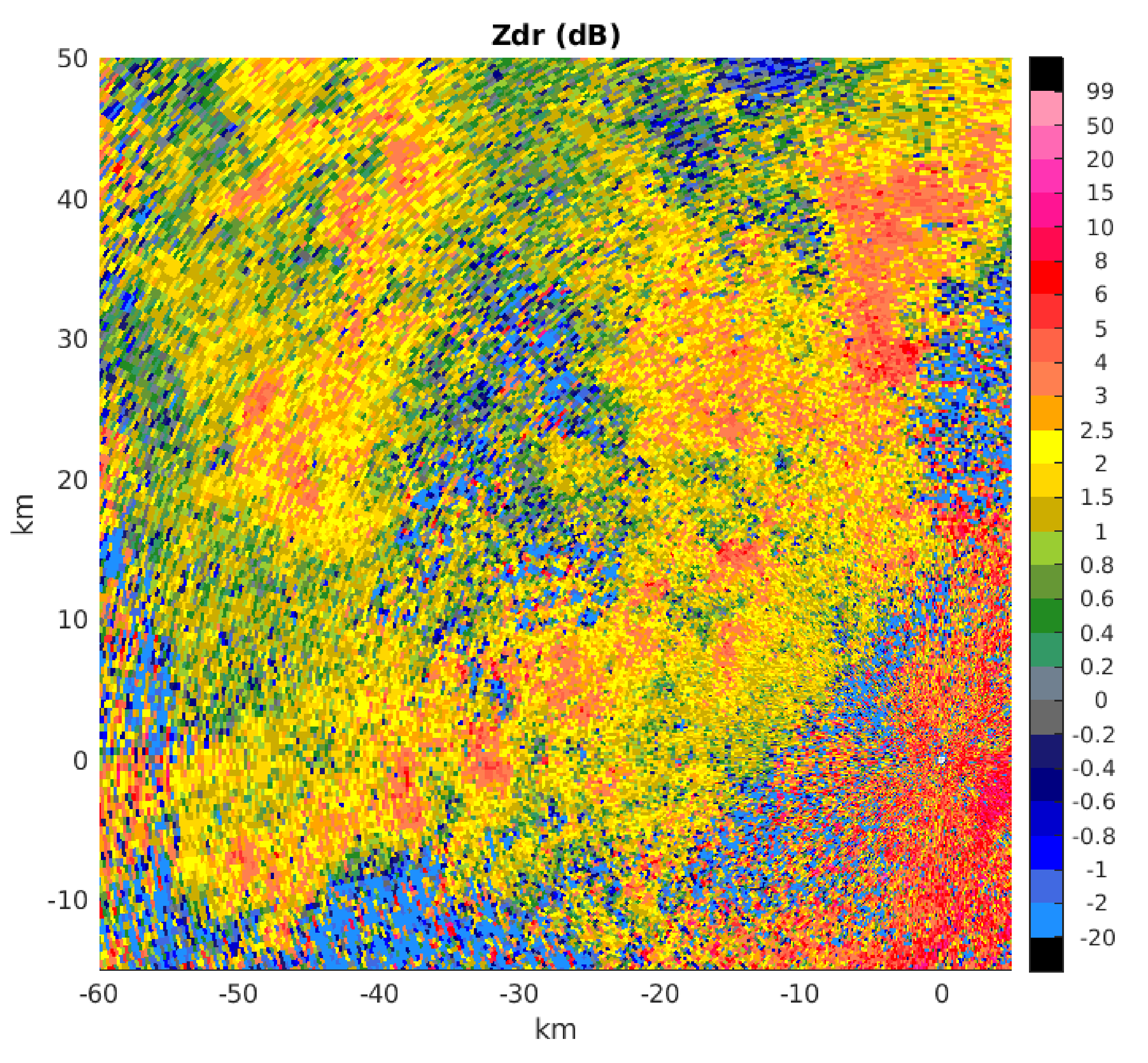




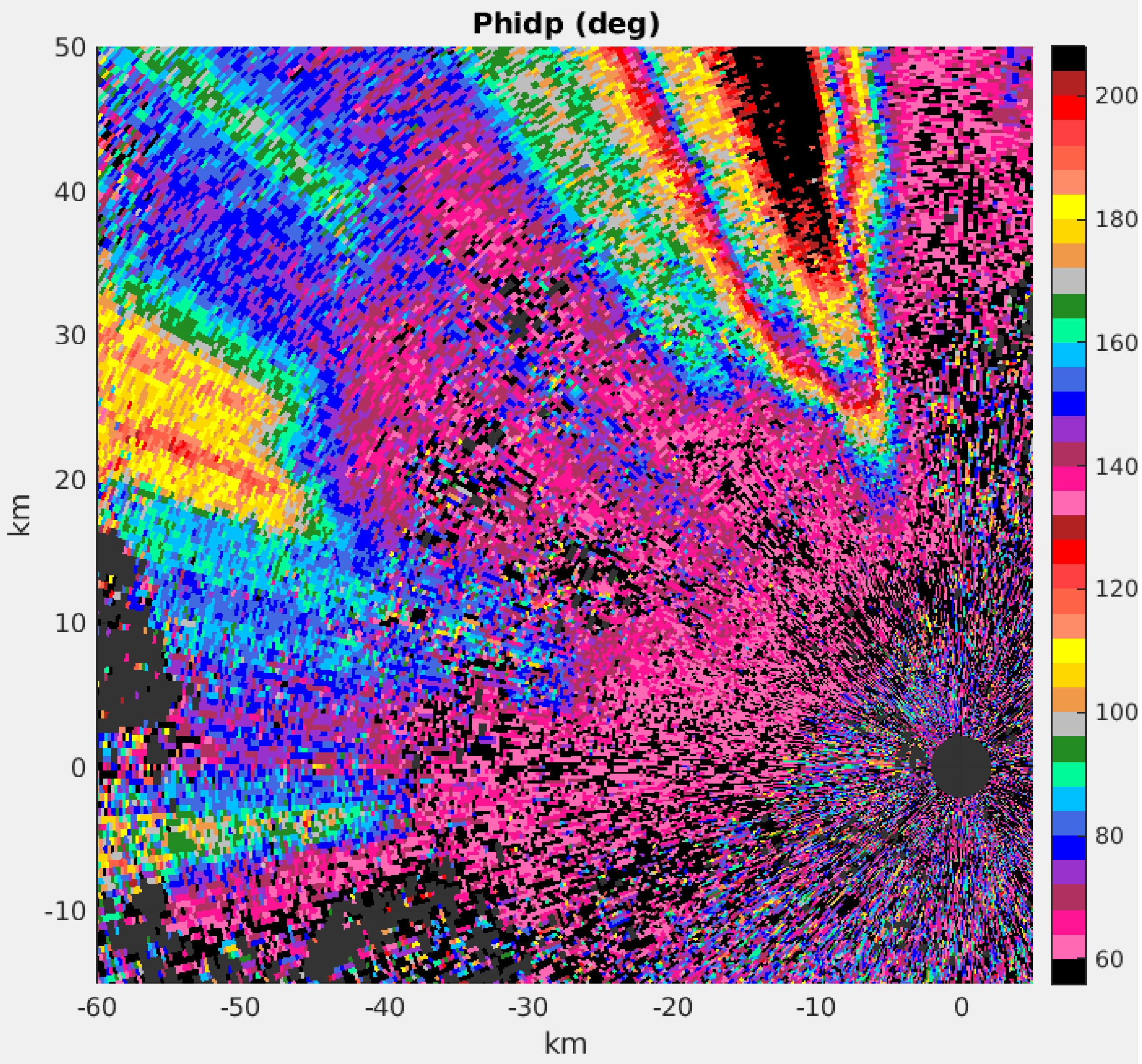
Level 2 Data



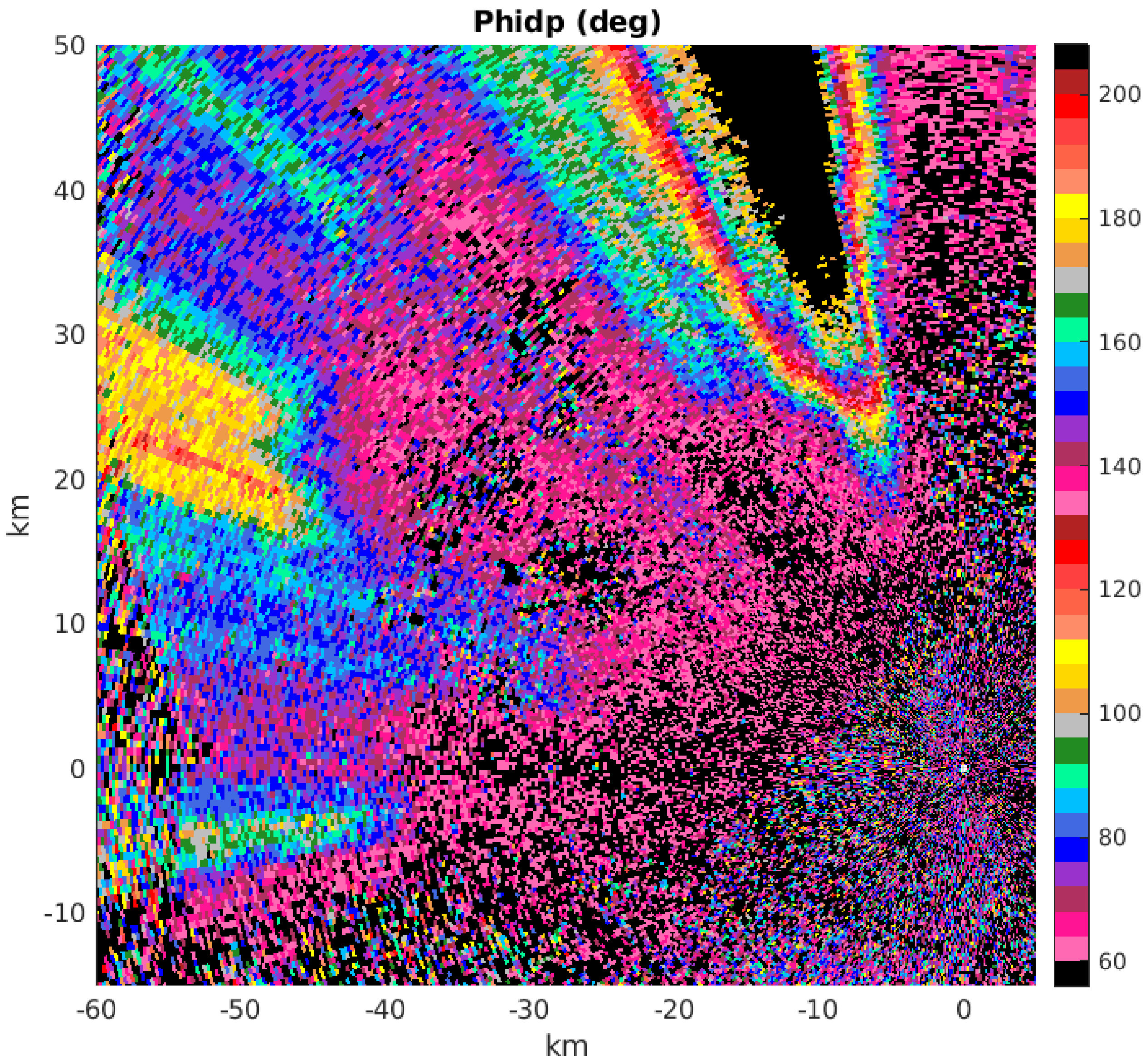
Regression Level 1 Data



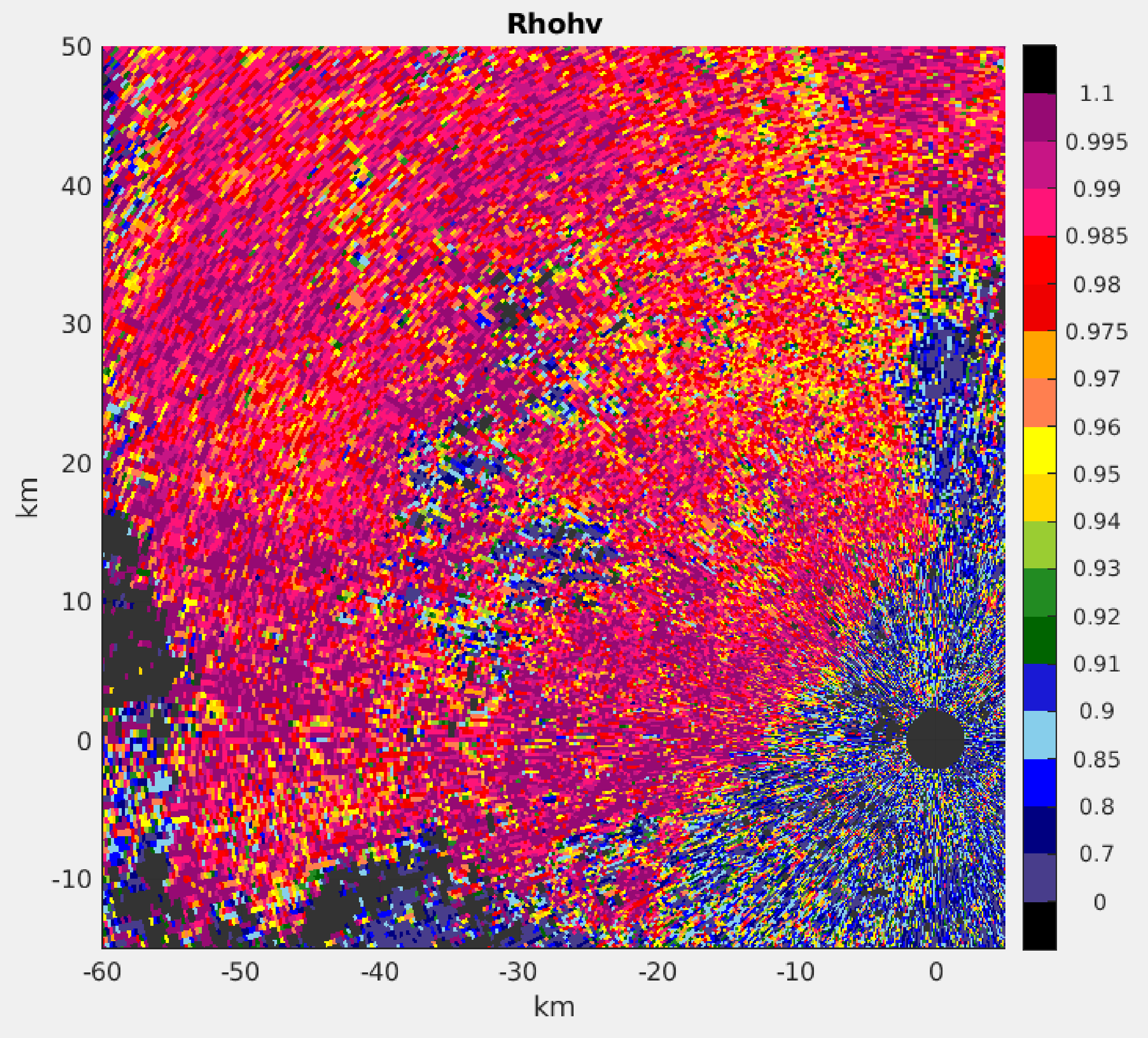
Level 2 Data



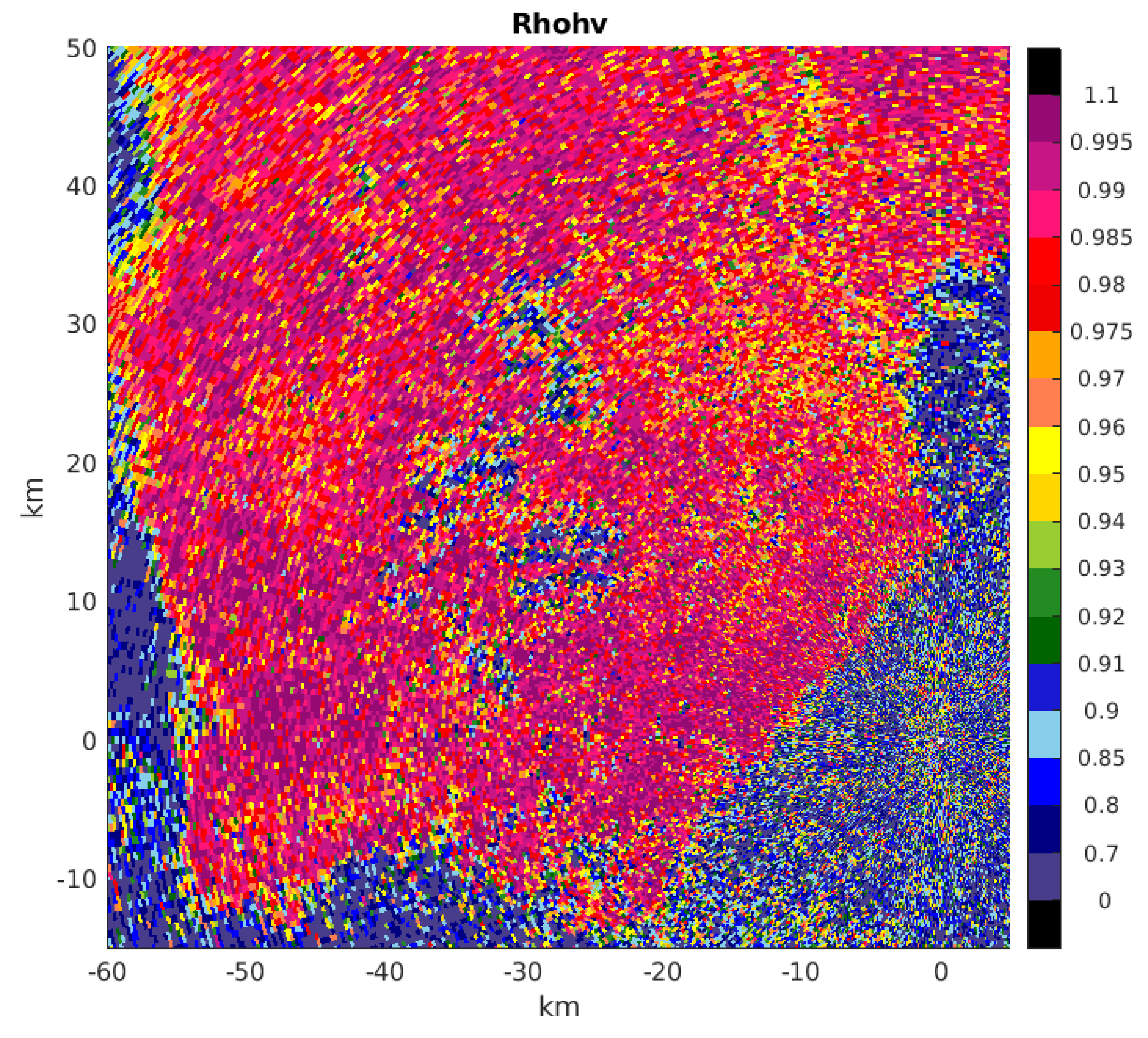
Regression Level 1 Data



Level 2 Data



Regression Level 1 Data



What about the variable recovery statistics???

Legacy Super Resolution versus Regression Super Resolution

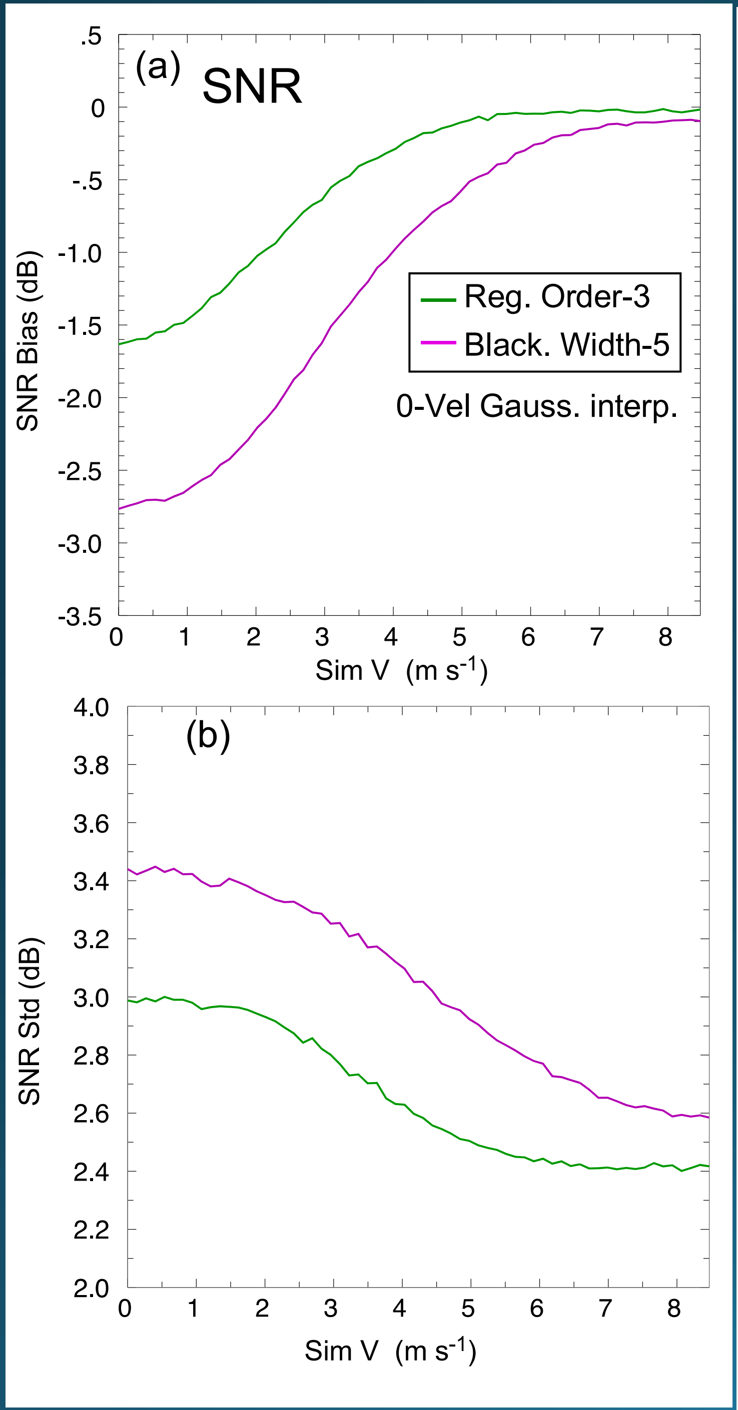
Simulation parameters:

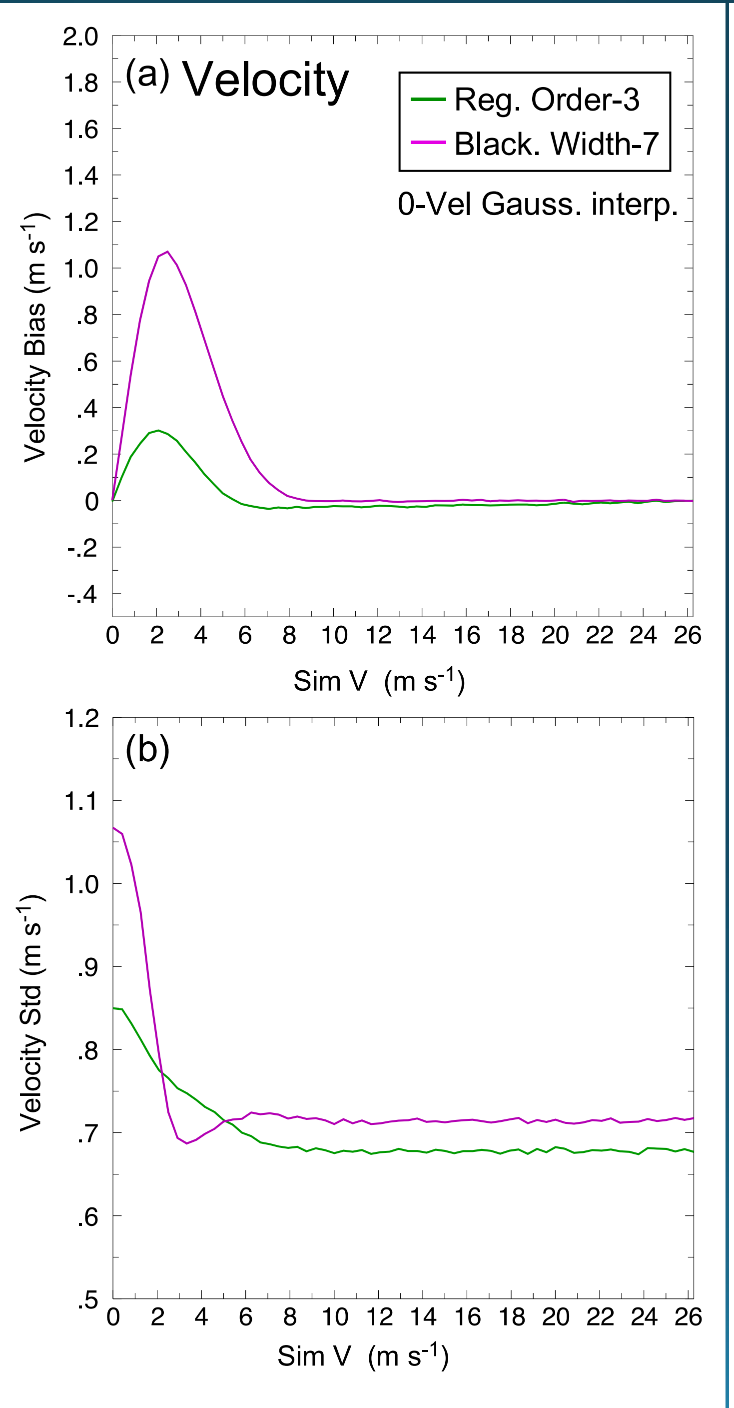
SNR = 45dB
CNR = 45 dB
SW wea. = 2m/s
SW clut. = 0.28 m/s

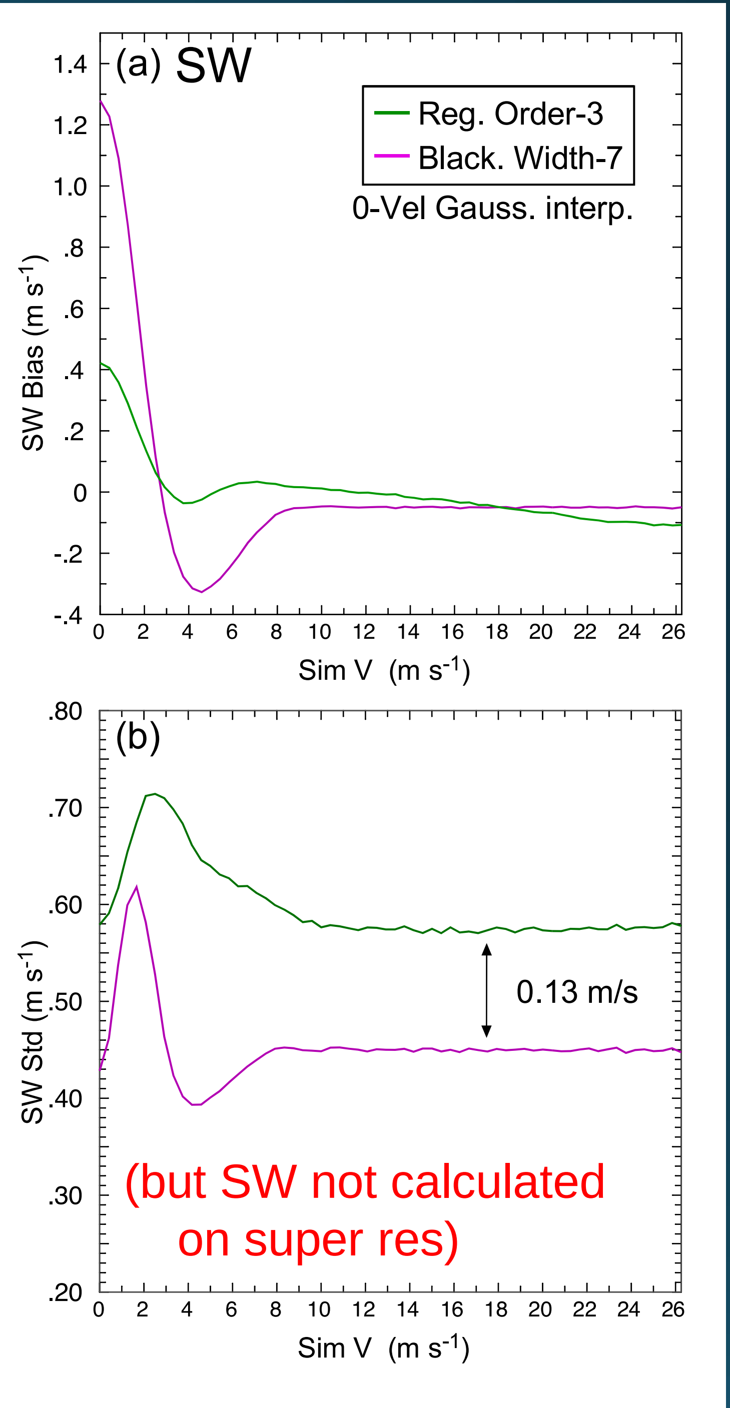
PRT = 3.1 ms (LPRT)   for Z, Zdr, Phidp, rhohv
PRT =   1 ms (Doppler) for Vel, SW

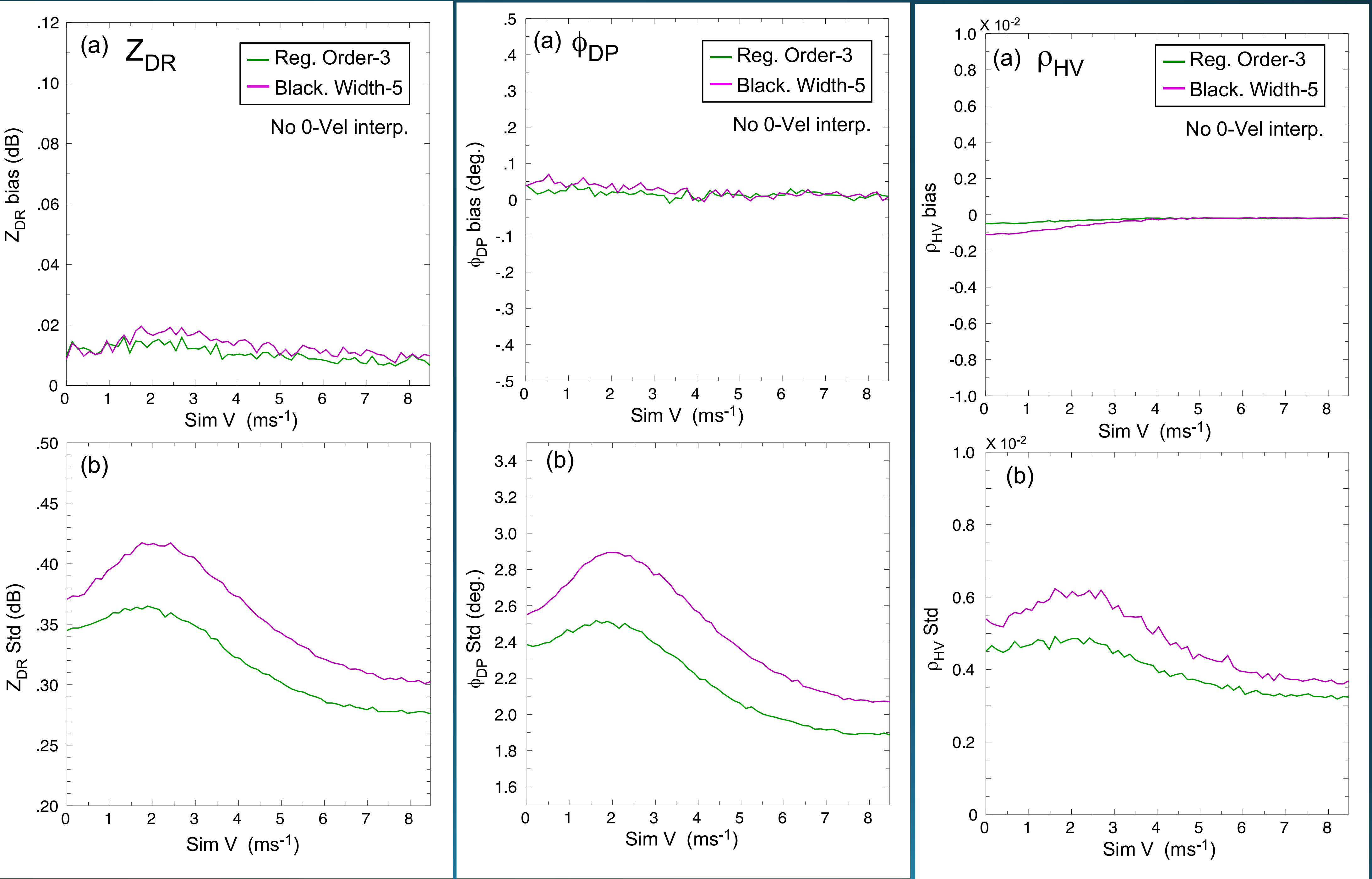
Next Slides Compare:

64 point, Blackman window, and notch filtering (GMAP) to
64 point regression filtering but using *32 points for variable calculation*


(a) SNR
Reg. Order-3
Black. Width-5
0-Vel Gauss. interp.
SNR Bias (dB)
Sim V (m s-1)
(b)
SNR Std (dB)
Sim V (m s-1)


(a) Velocity
Reg. Order-3
Black. Width-7
0-Vel Gauss. interp.
Velocity Bias (m s-1)
Sim V (m s-1)
(b)
Velocity Std (m s-1)
Sim V (m s-1)


(a) SW
Reg. Order-3
Black. Width-7
0-Vel Gauss. interp.
SW Bias (m s-1)
Sim V (m s-1)
(b)
0.13 m/s
(but SW not calculated
on super res)
SW Std (m s-1)
Sim V (m s-1)


(a) Z_{DR}
Reg. Order-3
Black. Width-5
No 0-Vel interp.
Z_{DR} bias (dB)
Sim V (ms^{-1})
(b)
Z_{DR} Std (dB)
Sim V (ms^{-1})
(a) ϕ_{DP}
Reg. Order-3
Black. Width-5
No 0-Vel interp.
ϕ_{DP} bias (deg.)
Sim V (ms^{-1})
(b)
ϕ_{DP} Std (deg.)
Sim V (ms^{-1})
X 10^{-2}
(a) ρ_{HV}
Reg. Order-3
Black. Width-5
No 0-Vel interp.
ρ_{HV} bias
Sim V (ms^{-1})
X 10^{-2}
(b)
ρ_{HV} Std
Sim V (ms^{-1})

Regression Filtering with Super Resolution

- Offers a small amount of increased resolution according to calculated effective antenna patterns
- Offers better recovery statistics
- Offers reduced processing times since the regression clutter filter is applied to contiguous 64-point (Doppler scan) and 16-point (LPRT scan), i.e., half of the number of time series as compared to overlapping windows

But What About SZ Recovery Statistics?

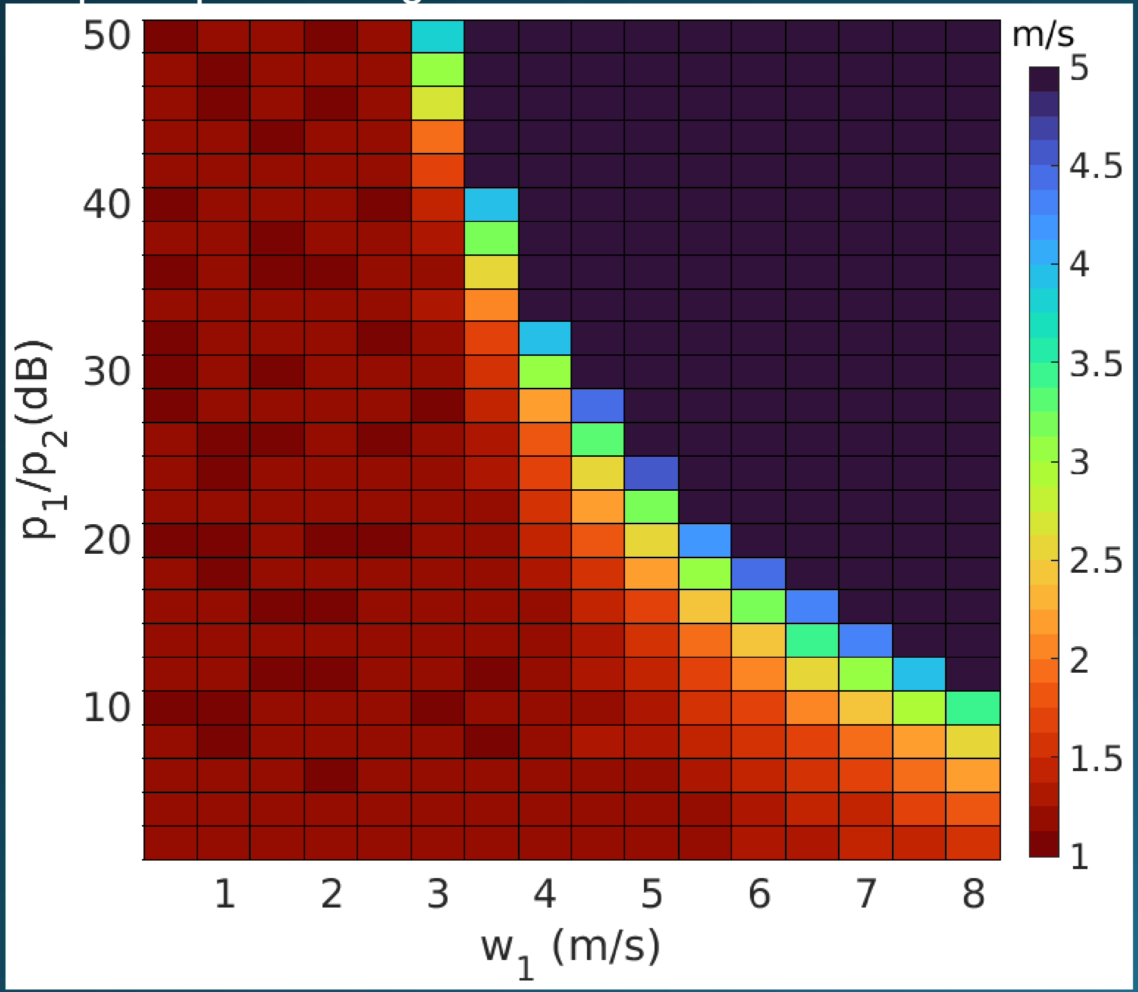
From Sachidananda and Zrnic 1999, Systematic Phase Codes…

PRT = 780μs
SW(st) = .5 to 8m/s
SW(wt) = 4m/s
P1/P2 = 0 to 50dB dB
$\lambda = 0.1067$ m
Nyqt. Vel = 32.0 m/s
Poly. Order = 37
1000 simulations
Weak trip SNR =20dB

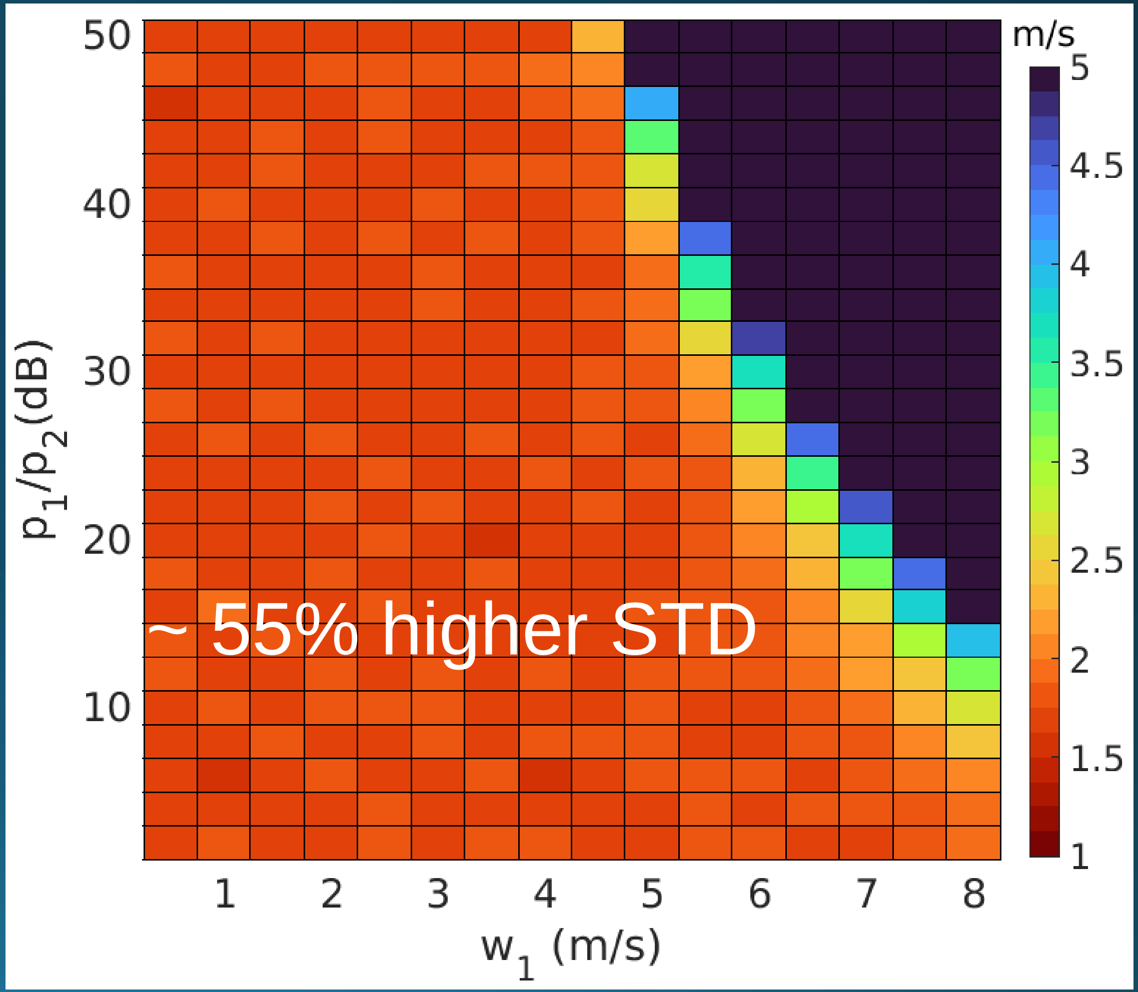
Standard Deviation of SZ Weak Trip Velocity

Regression. (order 37)

64 point processing



Legacy (Window and Notch)

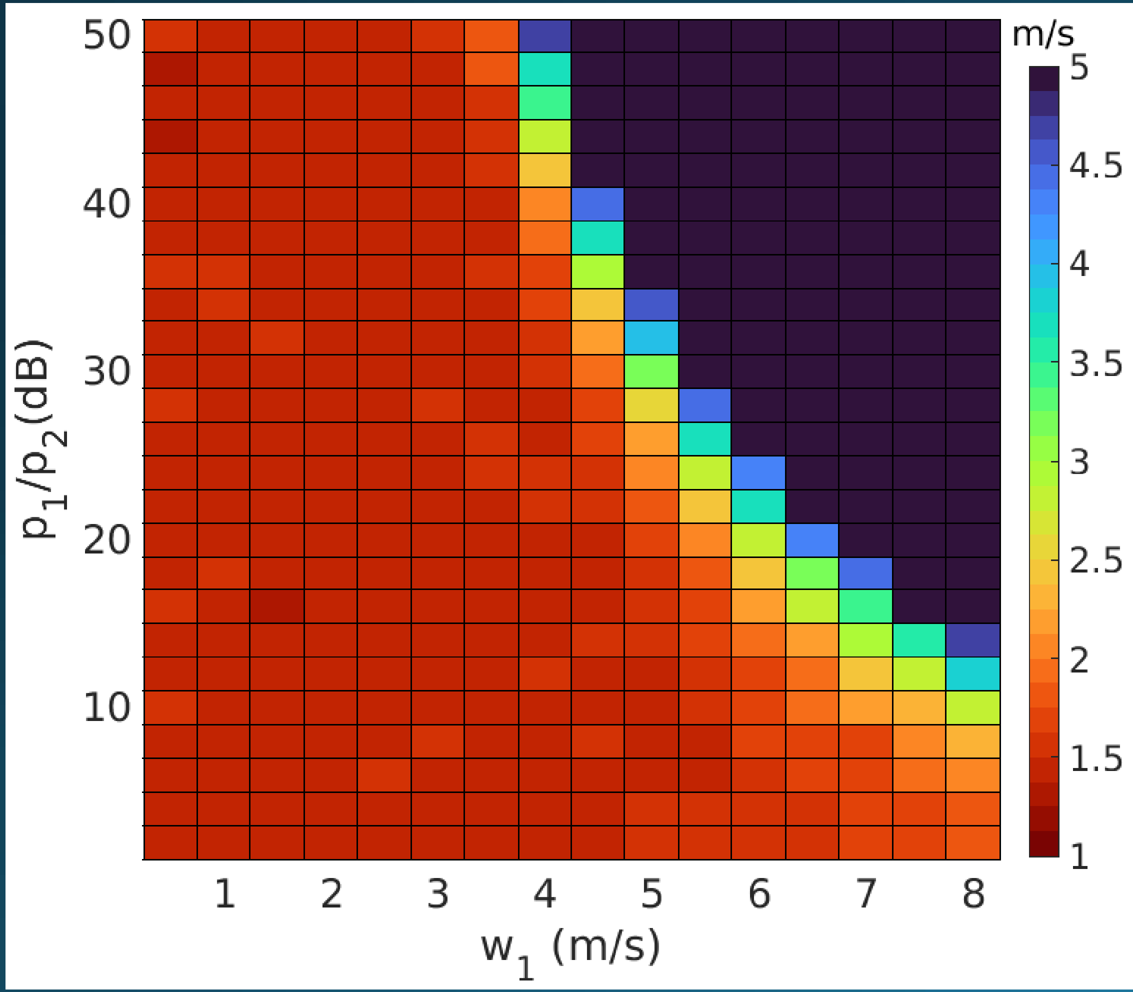


STD of SZ Weak Trip Velocity

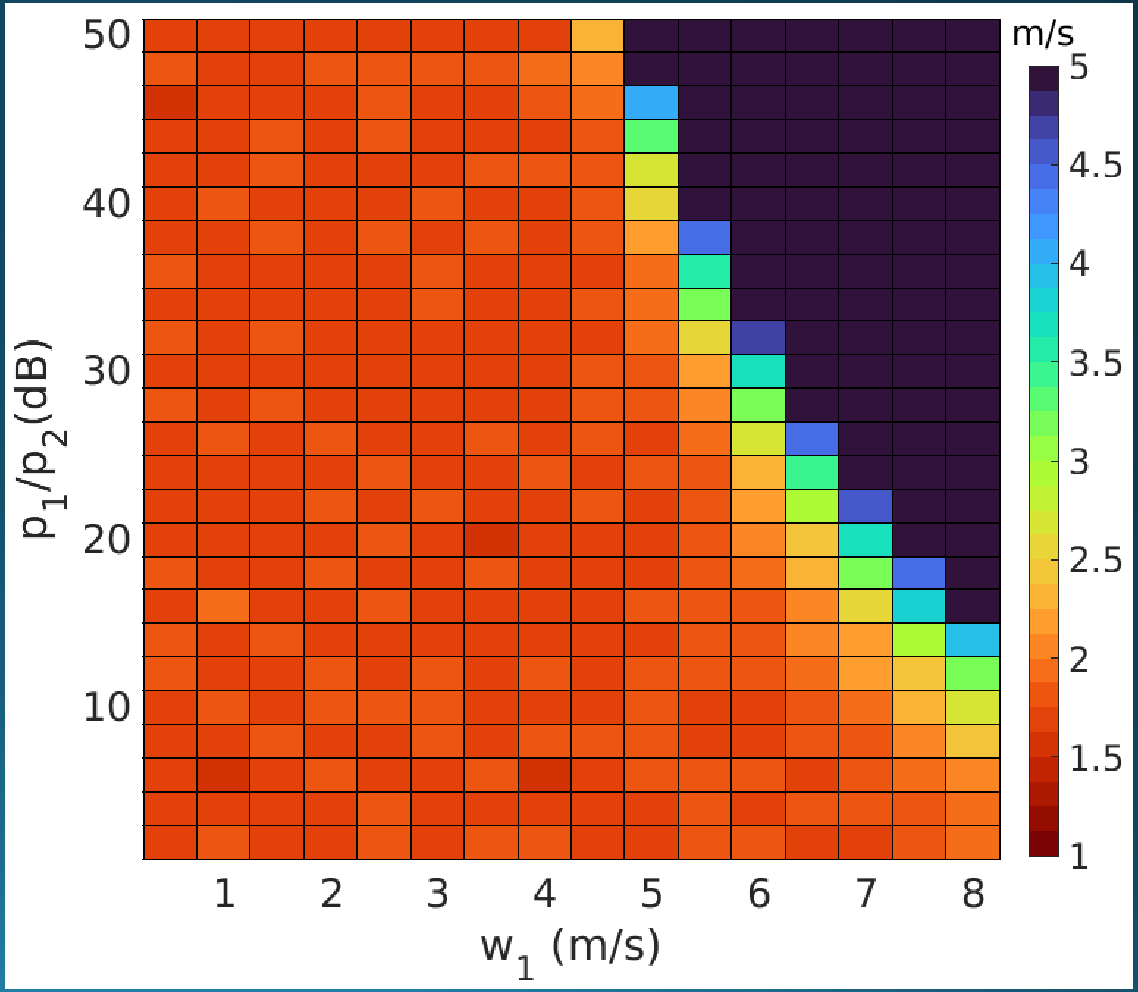
Can expand recovery area

47 Order Regression

64 point processing



Legacy (Window and Notch)



Weak trip SW = 6m/s

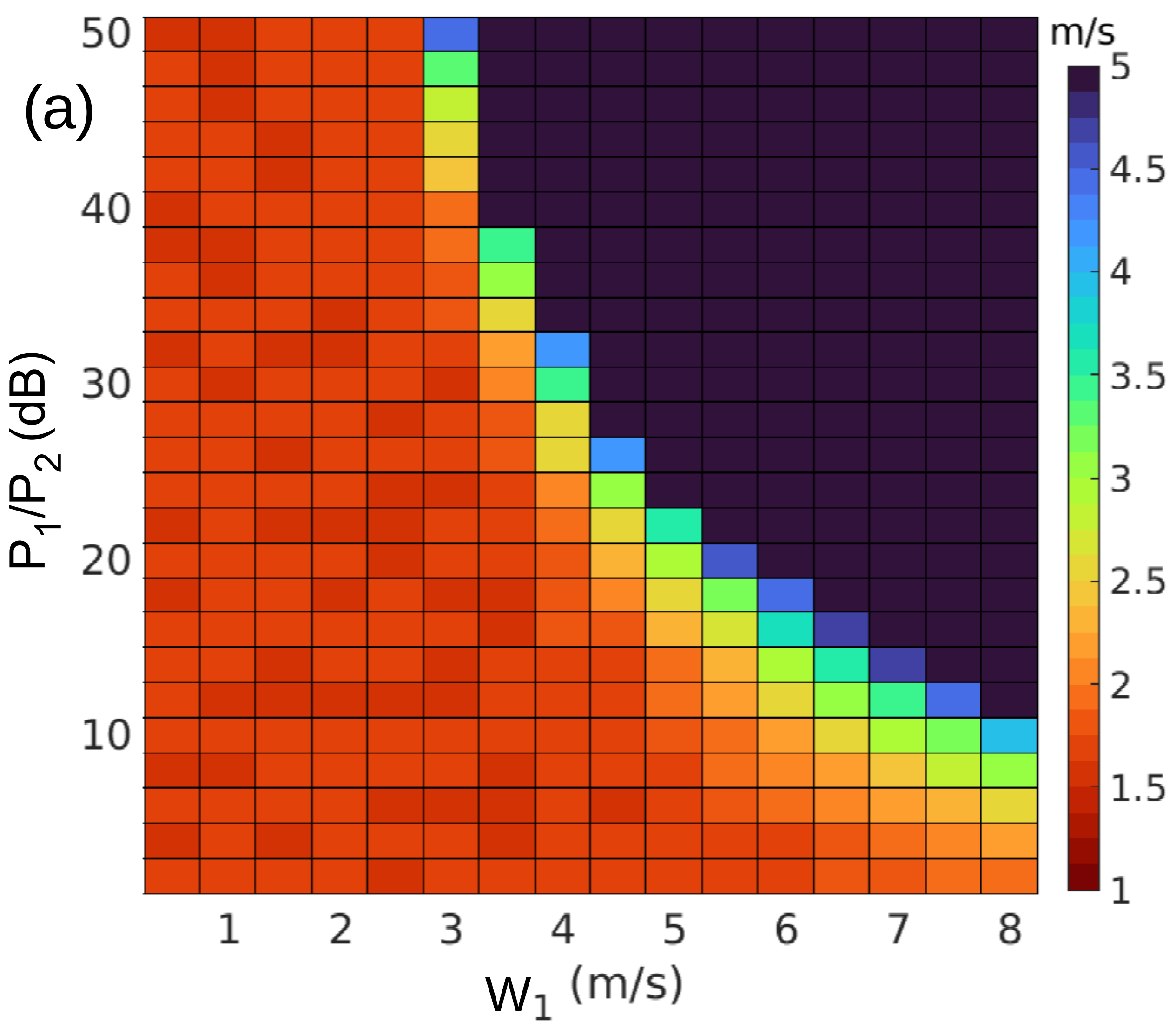
Sachidananda

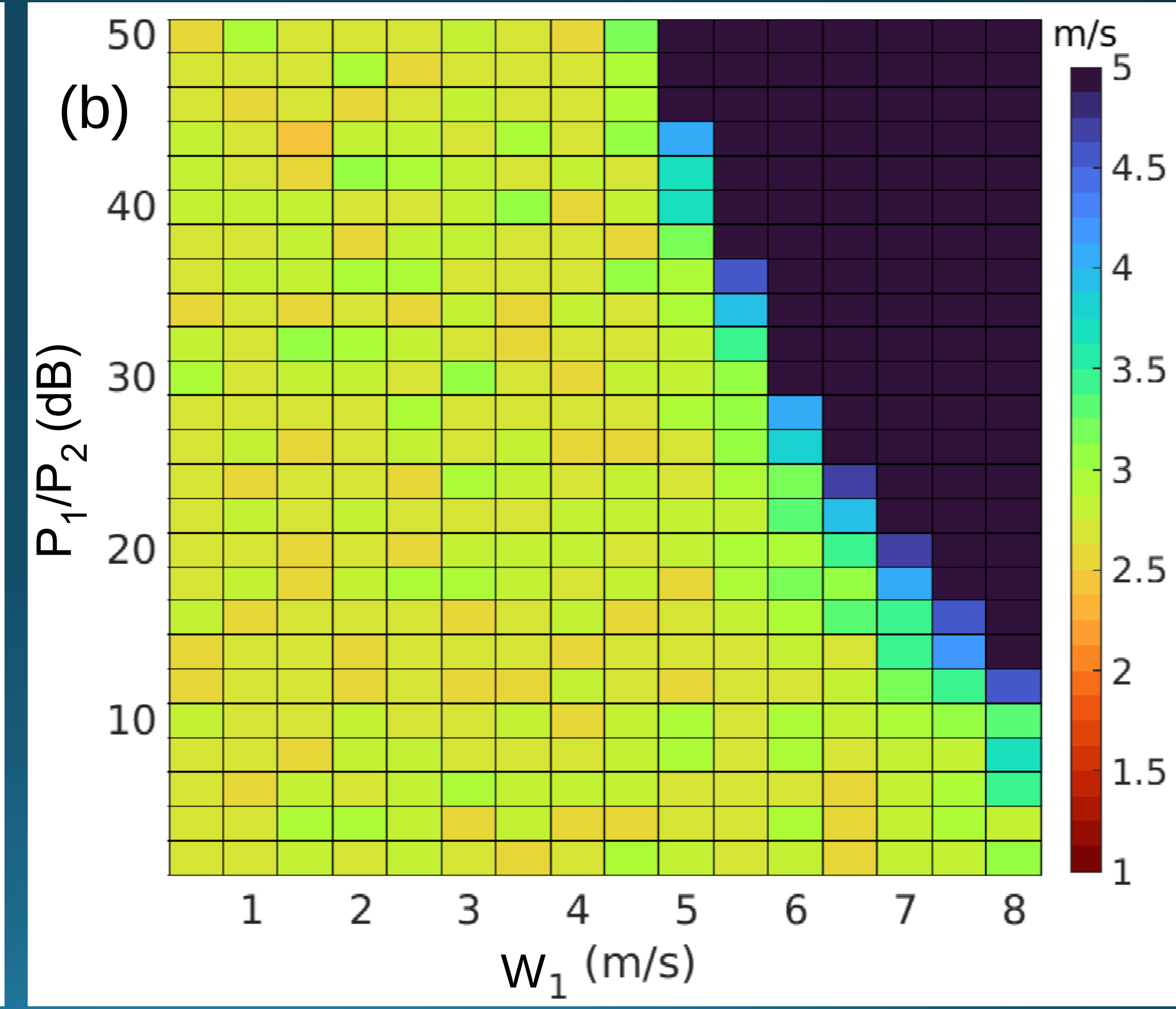
Regression Order is 37

64 point processing

Meets NEXRAD requirements

Does not meet NEXRAD requirements



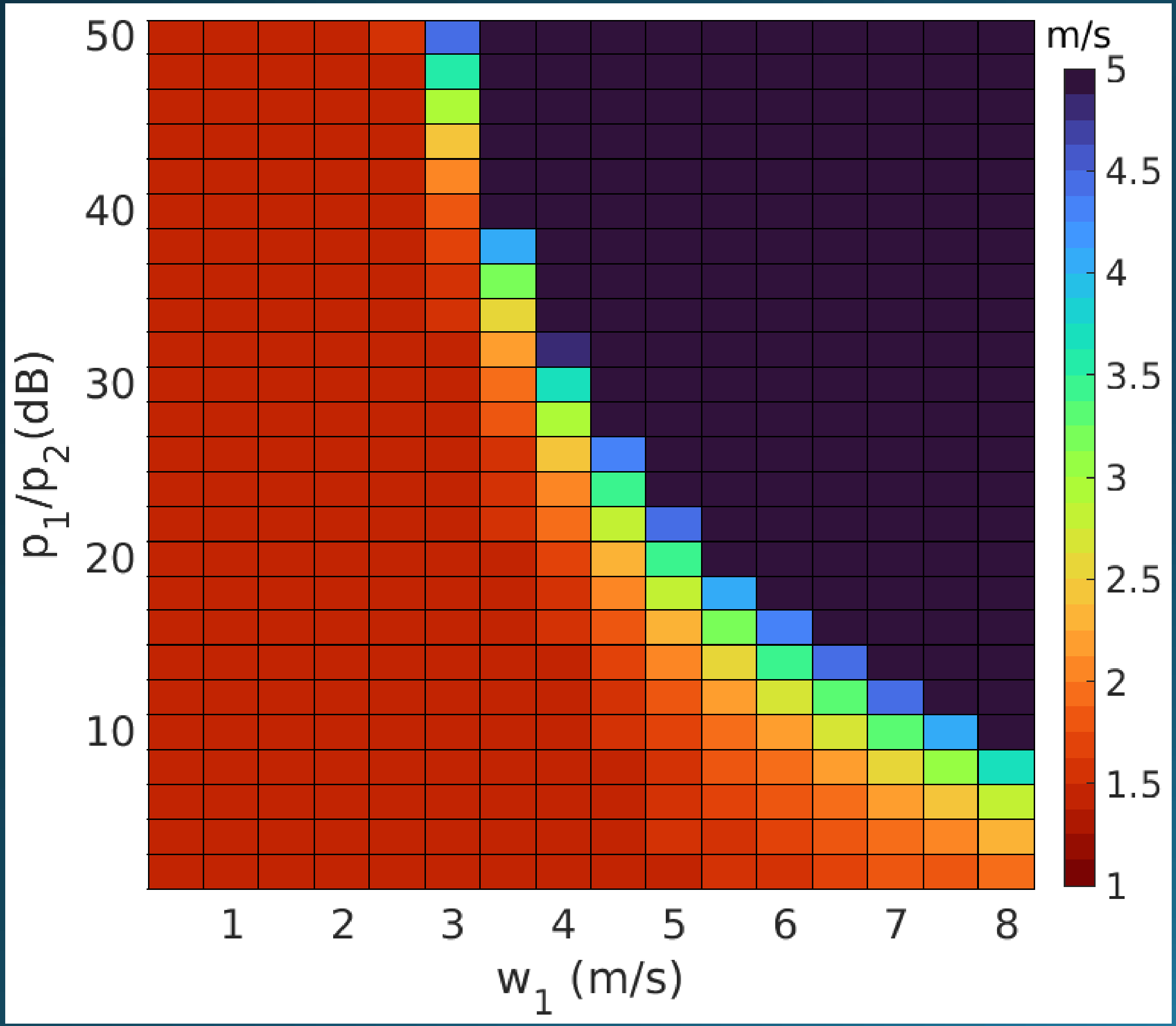


64 point SZ processing, 32 point statistics,

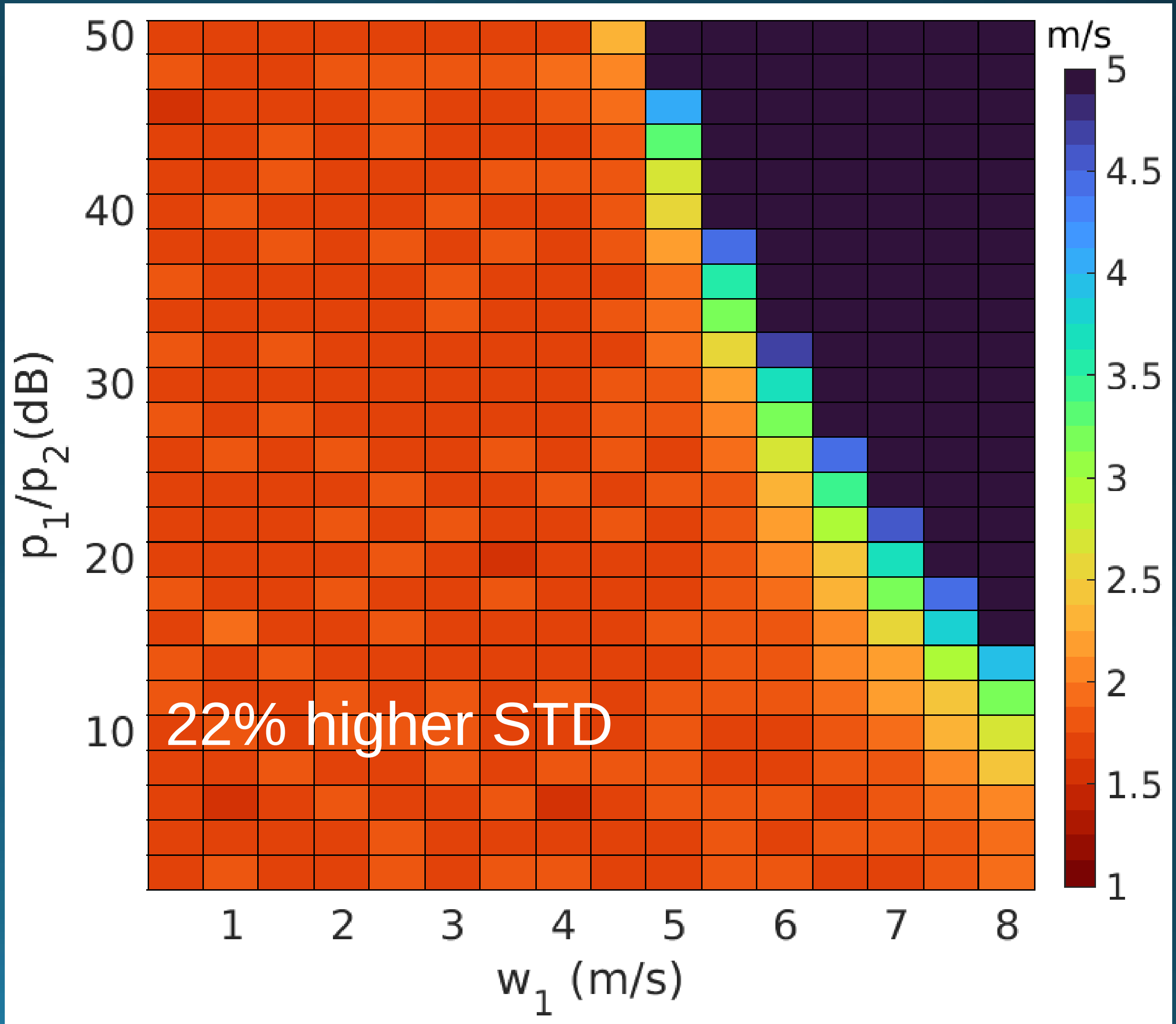
weak trip SW = 4m/s

37th order regression

(can use higher order to extend recovery range)



Sachidananda 1999



Conclusions and Summary

- Regression filtering on N points as compared to a WN filter on N points has *significantly* improved variable recovery statistics
- Statistics over a wide range of SNRs, CSRs, PRTs and samples have been carried out and demonstrate the advantages of regression filtering
- Comparisons to Ice et al. 2004 have been done – regression filtering is superior
- In these simulations the regression filter in general had significantly better recovery statistics.
- The practical aspects of regression filter: automated order selection, zero velocity interpolation have been implemented and verified
- The regression filter has been implemented on S-Pol data and compared to a GMAP-like filter and demonstrated the improved statistics
- Regression filtering can be used on super resolution data with improved statistics
- Regression filtering can be used in SZ(8/64) processing with improved statistic as shown by simulations
- Regression filtering with SZ processing needs to carried out on NEXRAD level 1 data and then compared to the corresponding level 2 data
- Identify more Level 1 data for regression processing
- Quantify Stds with NEXRAD and S-Pol experimental data.