Hybrid Spectrum Width Estimator

(Decision Briefing)

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TAC Meeting Norman, OK
November 19, 2009

TAC Decision

- Recommend implementation of the proposed hybrid spectrum width estimator discussed in this presentation to replace the existing pulse-pair (R0/R1) estimator (where used)

Benefits

- Improved spectrum width estimation
  - Decreased bias and variance in areas of low SNR and/or small true spectrum widths
  - Decreased contamination from weak trip echoes

Background

- People working on NEXRAD Turbulence Detection Algorithm (NTDA) "discovered" that the currently implemented Spectrum Width estimator (pulse-pair R0/R1) had serious deficiencies for lower signal to noise ratios and/or narrow true spectrum widths.
- This, along with an early prototype hybrid spectrum (FAA funding) width estimator was presented to TAC in March 2007. From minutes:

  3. Spectrum Width Estimator Problems:
  a) The TAC endorses the requirement for a more rigorous specification for the spectrum width estimator over a wider range to support the detection capabilities of the turbulence detection algorithm.
  b) The TAC recognizes the requirement for improving the quality of base data as stated in TN-32: System Performance, and that a basic deficiency in the present implementation exists for use quantitatively by algorithms over a wide spectral range.
  c) The TAC furthermore supports the effort to continue the analysis and validation of the proposed hybrid technique but would require more information before endorsing a Particular method.
- NCAR, with funding from ROC, further developed the hybrid spectrum width estimator presented today.
- At the September 2008 TAC meeting, the TAC requested that more case studies be presented before a decision could be made regarding the readiness of the algorithm to deploy on NEXRAD.

Relevant Requirements and Needs

From NEXRAD Active Technical Needs

- **TN-31: Evolution of WSR-88D hardware and software to implement advances in technology and science**
  (Priority # 1, March 2003 ranking)
  Description: Ensure the continued capability of the WSR-88D system to implement desired mission support improvements, by employing an ongoing program to plan and execute WSR-88D upgrades.
- **TN-32: System Performance**
  (Priority # 2, March 2003 ranking)
  Description: System Performance includes assessing and improving (1) the performance of system hardware; (2) *the quality of base data*; and (3) the *performance of the algorithms*.
- **TN-17: Turbulence Analysis Techniques**
  (Priority # 9, March 2003 ranking)
  Description: Develop an algorithm that will locate and quantify turbulence that is hazardous to aircraft.

Relevant Requirements and Needs (cont.)

From WSR-88D System Specification (REV G, May 2007)

	Accuracy	**Precision (Note 2)**
Spectrum Width	For a true spectrum width (Note 1) of 4 ms^{-1} the standard deviation in the estimate of the spectrum width will be less than or equal to 1.0 ms^{-1} including quantization errors, for SNR greater than 10 dB.	0.50 ms^{-1}

Note 1: True spectrum width is defined as one standard deviation of the meteorological phenomenon spectrum width within a sampled volume for which the indicated accuracy applies. Stated accuracy values apply for Nyquist velocities of the system. (Gaussian spectrum assumed.)

Note 2: Precision is defined as the quantization, the smallest resolvable increment.

Note 3. Significant biases introduced by the computational technique should be minimized.

Deficiencies:

- Doesn't limit relative error for lower SWs
- Doesn't really address estimator bias for lower SWs (bias cannot be removed by averaging)
- Doesn't address saturation

EXISTING PULSE-PAIR ESTIMATOR

R0/R1 Pulse-Pair Estimator

- R0/R1 (used on NEXRAD, both on Legacy and ORDA except at times in SZ-2):

$$\frac{\sqrt{2}v_a}{\pi}\left|\log_{10}\left(\frac{R_0}{|R_1|}\right)\right|^{1/2}$$

$$R_0 = P_T - P_N$$

P_T – mean power
P_N – noise power

Good:

- Simple and fast
- Generally good results
- Saturation at large fraction of Nyquist velocity
- Saturates "gracefully"

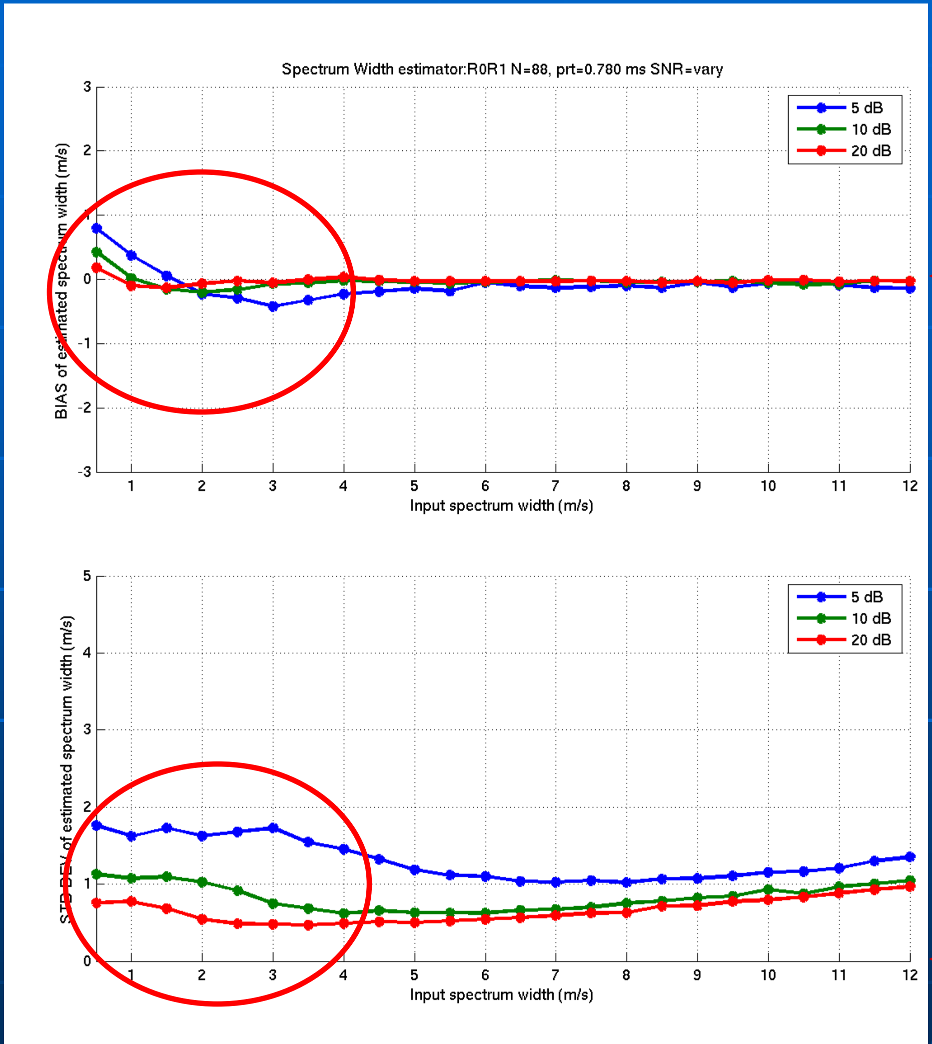
Bad:

- **Sensitive to estimate of Noise Power P_N for low SNRs**
- **Sometimes R0<R1 (especially for narrow spectra)**
- Assumes exactly 1 Gaussian shaped signal

The problems with R0/R1 (VCP 21 PRI 8)

Bias (m/s)

Std (m/s)



Vertical Ticks 1 m/s

Optimal

Horizontal Ticks 2 m/s

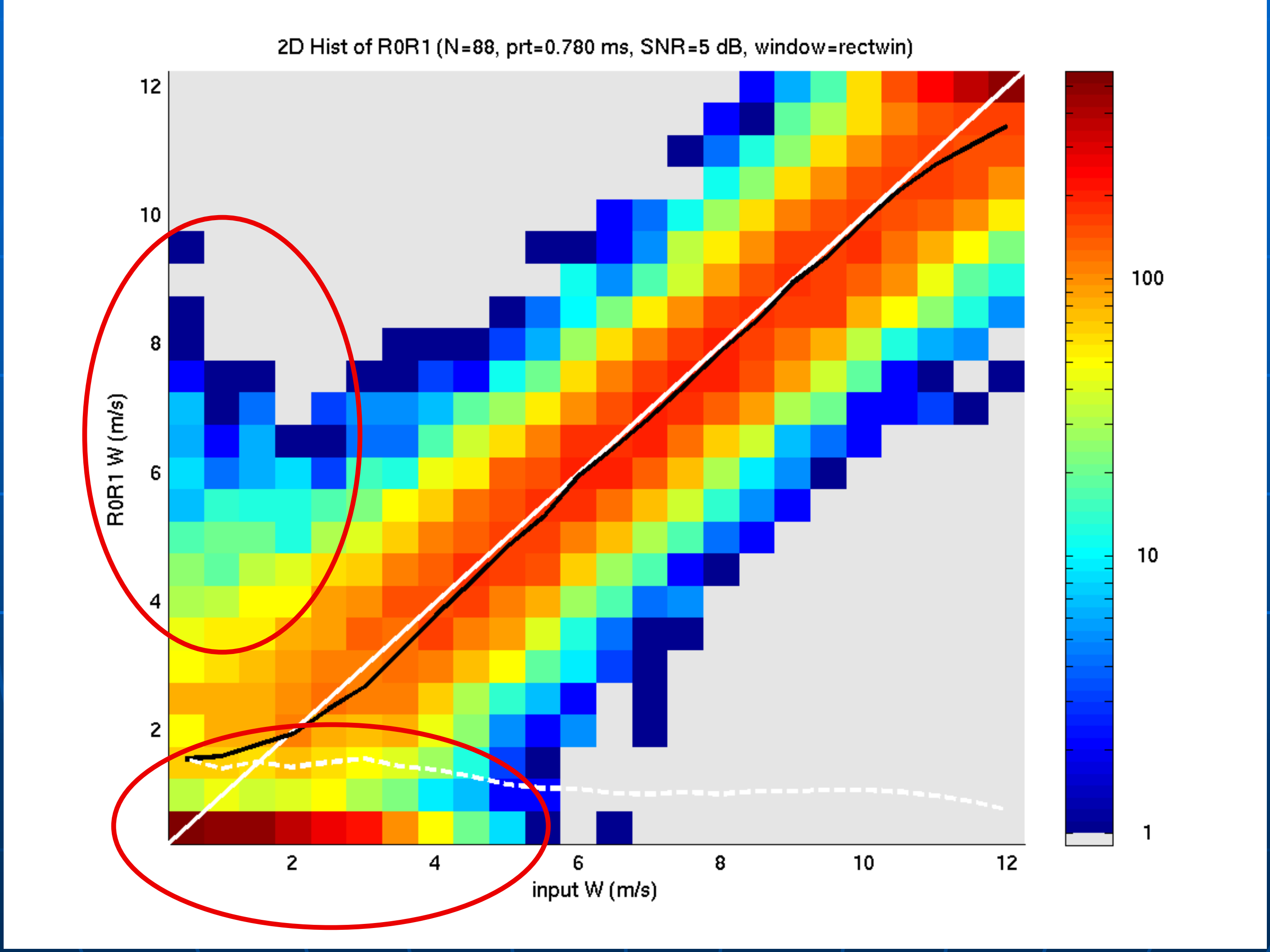
Vertical Ticks 1 m/s

Optimal

Input W (m/s)

NCAR

The problems with R0/R1 (VCP 21 PRI 8)



Proposed Hybrid Estimator

- Uses R0/R1, R1/R2, R1/R3 depending on guessed magnitude of spectrum width

Good:

- Fast
- Very good results
- improvements for low SNR and/or small W
- Less sensitive to estimate of noise power P_N
- Saturates like R0/R1

Bad:

- Slightly more complex
  - uses table based on number of points
  - Requires 4 estimates
- Tuning is required
- Assumes exactly 1 Gaussian shaped signal
- Can have misclassifications

Why the hybrid approach?

- The various pulse-pair estimators have distinct regimes where performance is superior.
- Spectral techniques are great but have trouble for short dwell times (spectral broadening due to window effect).
- Idea is to stick to well-understood techniques and stitch them together.

Hybrid Spectrum Width Estimator

Algorithm Outline

- Compute pulse-pair spectrum width estimators (R0/R1, R1/R2, R1/R3, PPLS 2)
  - PPLS 2 is pulse pair based on LS fit of R0/R1/R2
- Decide whether the (normalized) spectrum width is "large", "medium", or "small"
  - Based on R0/R1, PPLS 2, and R1/R3
  - Logic design via decision trees
- Use best estimator for that spectrum width size (R0/R1, R1/R2, R1/R3)

EVALUATIONS

Evaluation Methodology

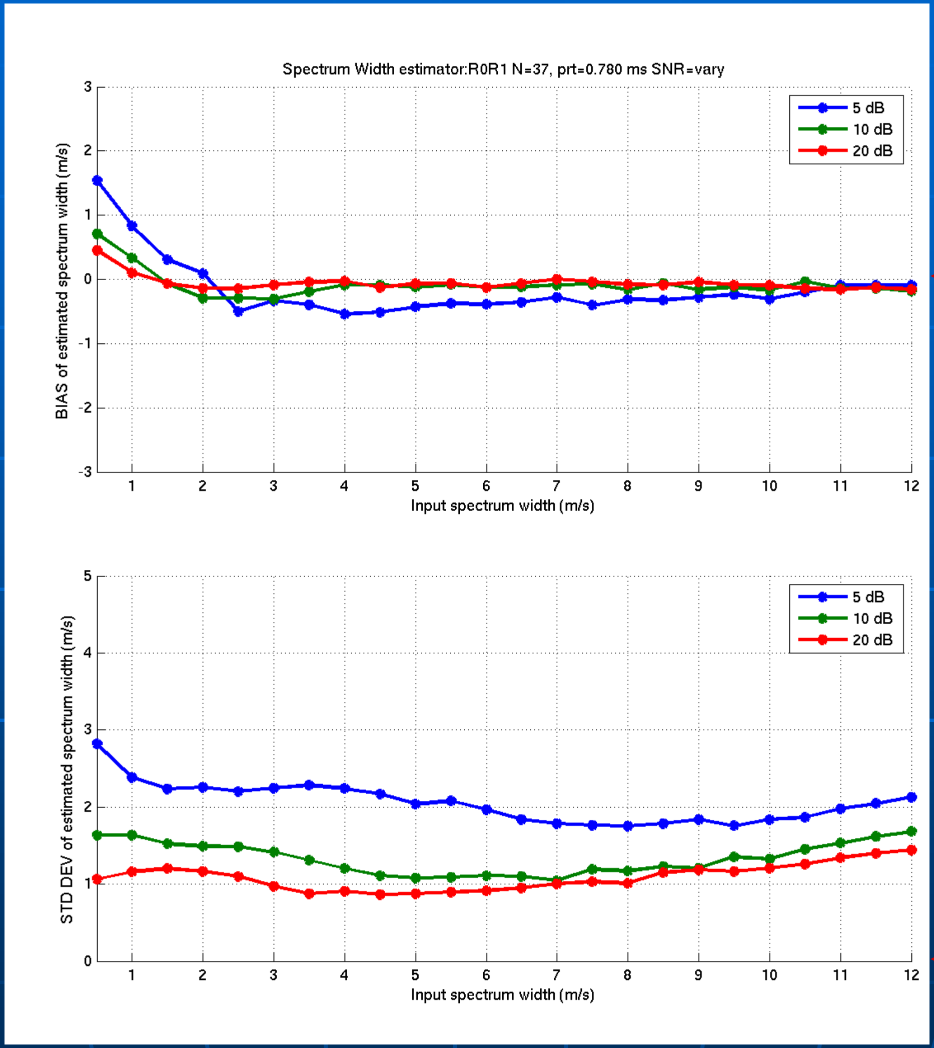
- Simulations
  - For each N, input W, varying SNR's and PRTs generate 1000 time-series.
  - For each time-series calculate R0/R1 and hybrid spectrum widths.
- Case studies

SIMULATIONS FOR VCPS 12, 11, 21, 31, AND 32

R0/R1 VCP 12, PRI 8

Bias (m/s)

Std (m/s)



Vertical Ticks 1 m/s

Optimal

Horizontal Ticks 2 m/s

Vertical Ticks 1 m/s

Optimal

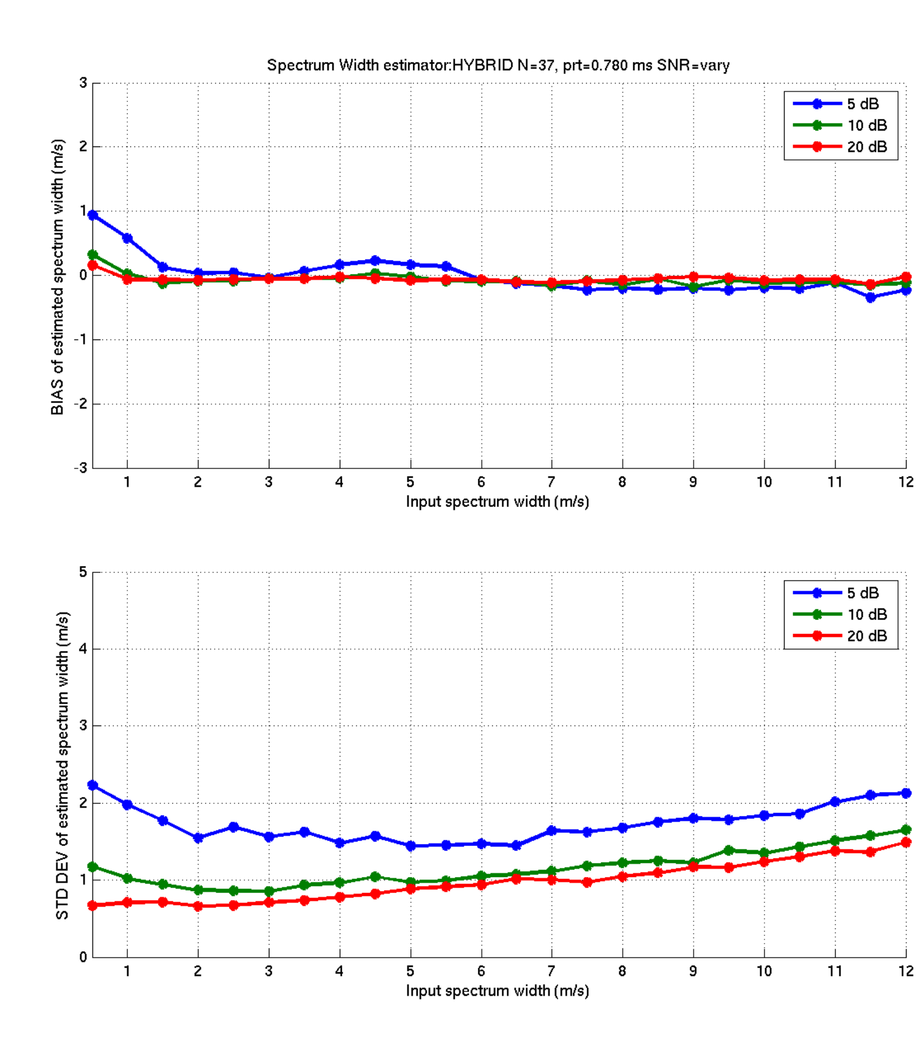
Input W (m/s)

NCAR

Hybrid VCP 12, PRI 8

Bias (m/s)

Std (m/s)



Vertical Ticks 1 m/s

Optimal

Horizontal Ticks 2 m/s

Vertical Ticks 1 m/s

Optimal

Input W (m/s)

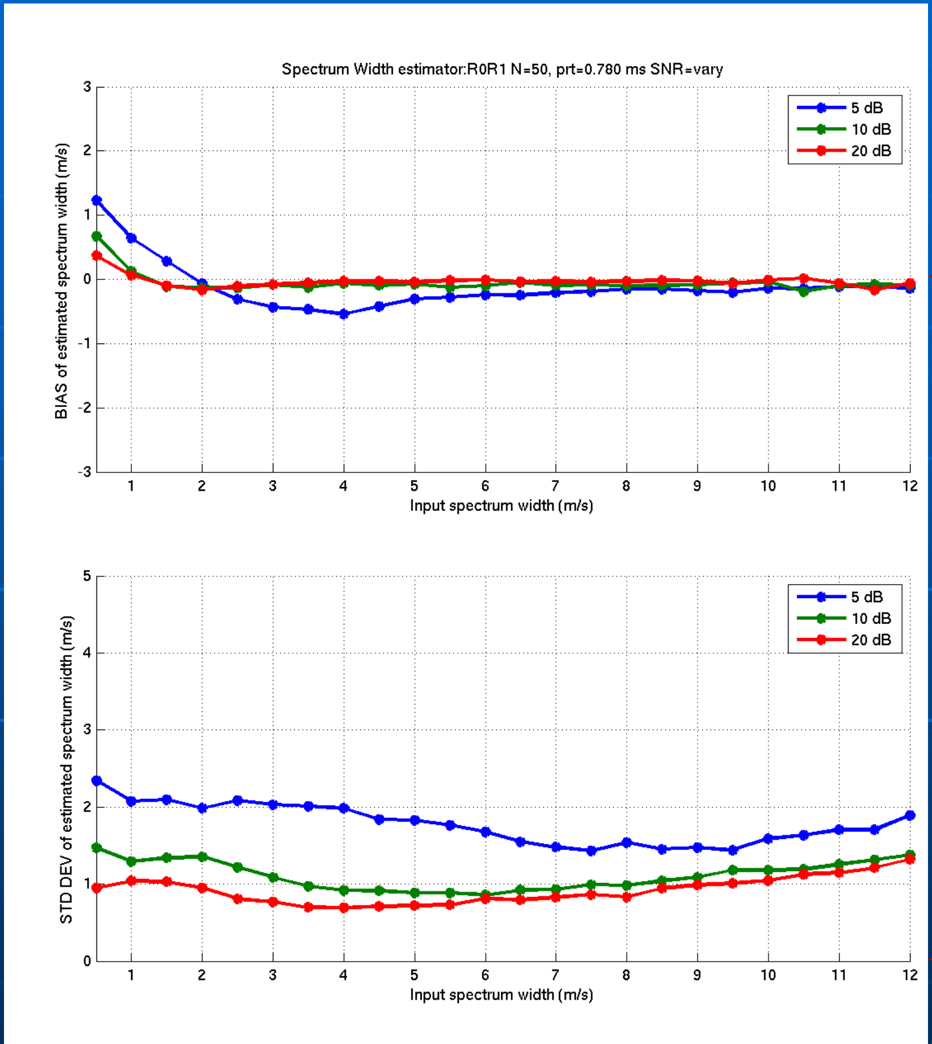
NCAR

R0/R1 VCP 11, PRI 8

Vertical Ticks 1 m/s

Optimal

Bias (m/s)



Horizontal Ticks 2 m/s

Std (m/s)

Vertical Ticks 1 m/s

Optimal

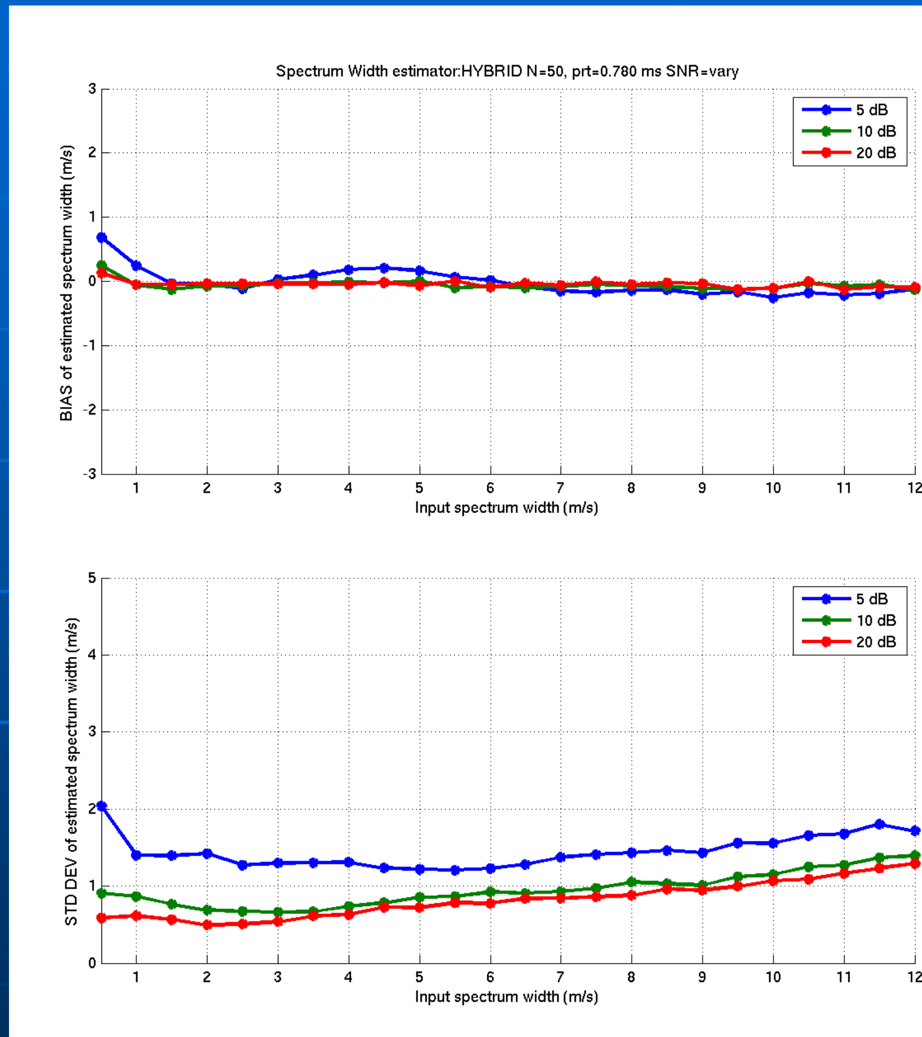
Input W (m/s)

NCAR

Hybrid VCP 11, PRI 8

Bias (m/s)

Std (m/s)



Vertical Ticks 1 m/s

Optimal

Horizontal Ticks 2 m/s

Vertical Ticks 1 m/s

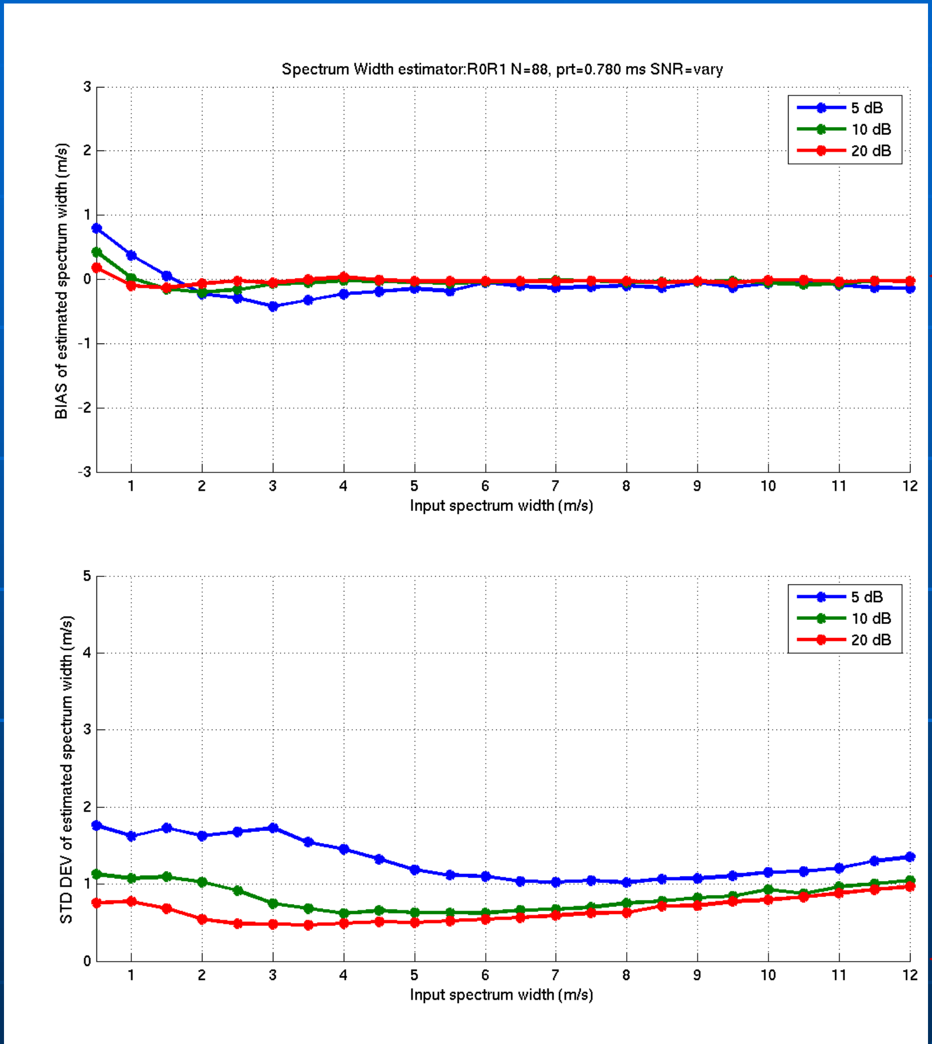
Optimal

Input W (m/s)

R0/R1 VCP 21, PRI 8

Bias (m/s)

Std (m/s)



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Horizontal Ticks 2 m/s

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Optimal

Input W (m/s)

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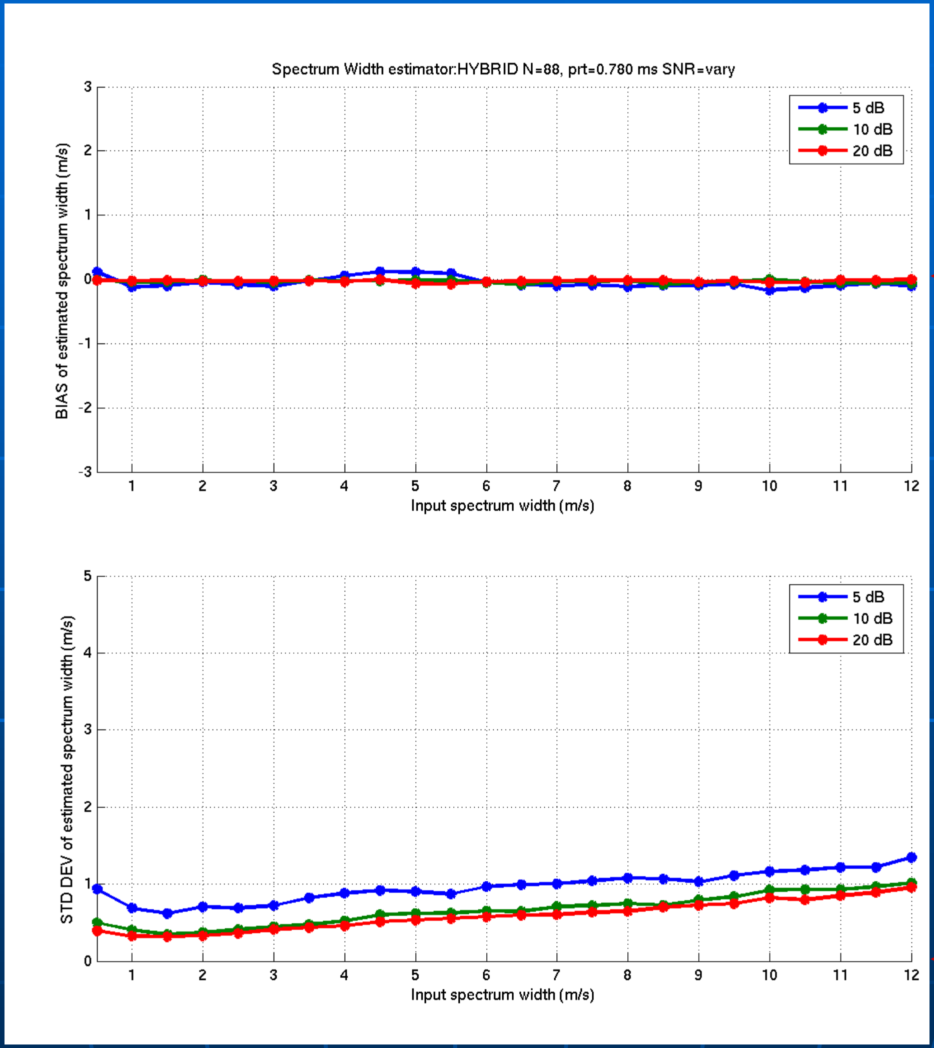
Hybrid VCP 21, PRI 8

Vertical Ticks 1 m/s

Bias (m/s)



Optimal

Horizontal Ticks 2 m/s

Std (m/s)

Vertical Ticks 1 m/s

Optimal

Input W (m/s)

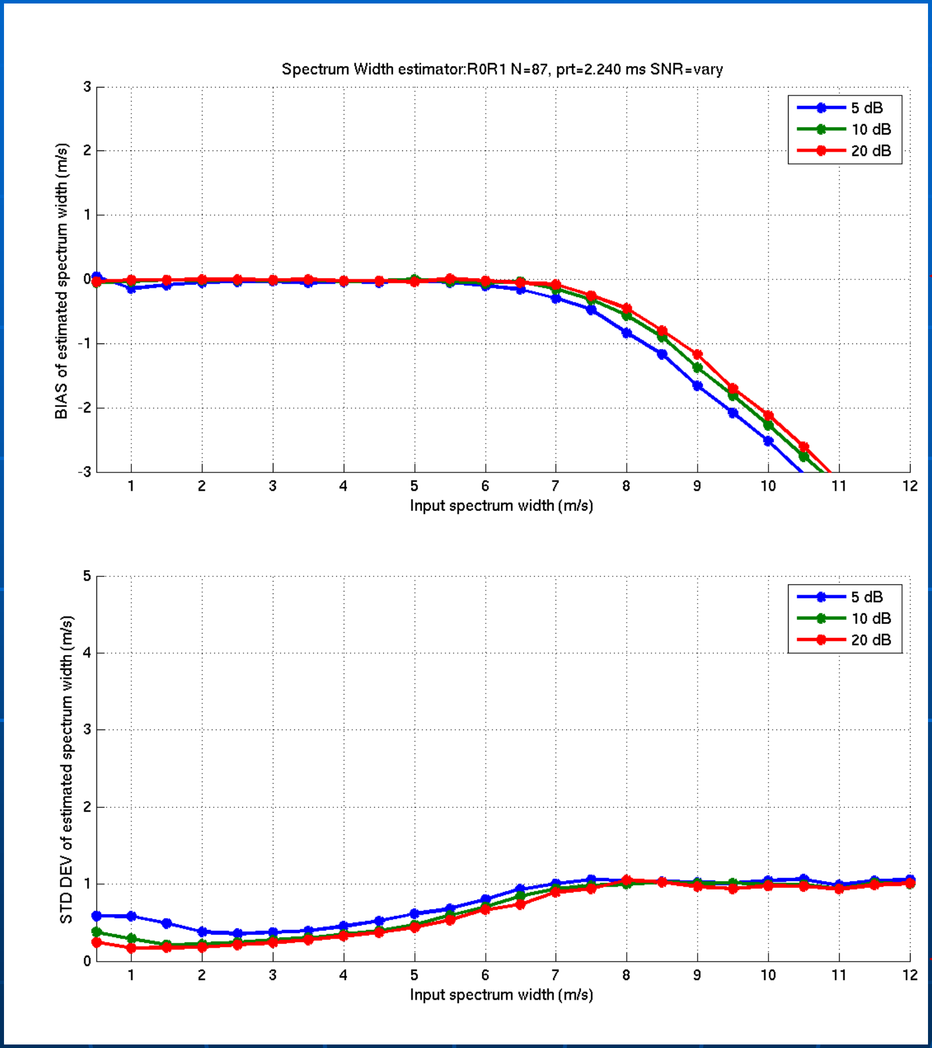
NCAR

R0/R1 VCP 31, PRI 2

Vertical Ticks 1 m/s

Bias (m/s)

Optimal



Horizontal Ticks 2 m/s

Std (m/s)

Vertical Ticks 1 m/s

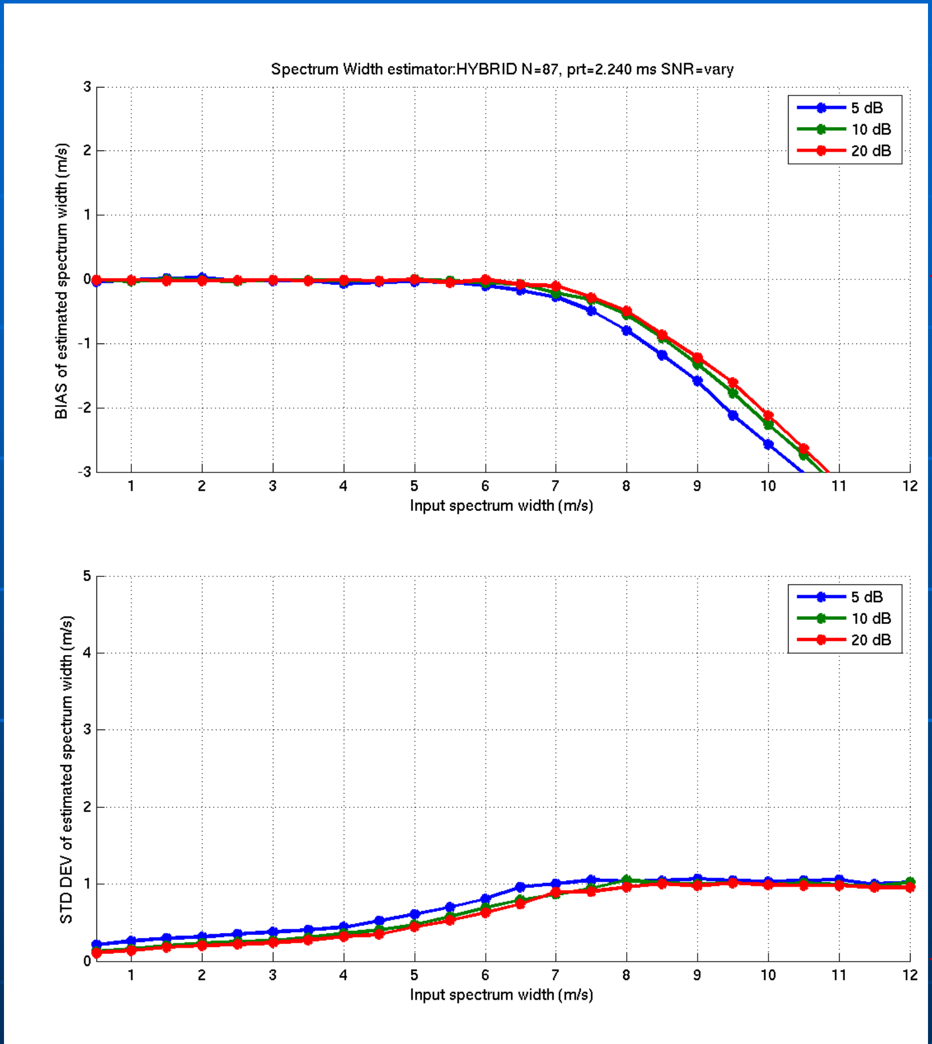
Optimal

Input W (m/s)

Hybrid VCP 31, PRI 2

Bias (m/s)

Std (m/s)



Vertical Ticks 1 m/s

Optimal

Horizontal Ticks 2 m/s

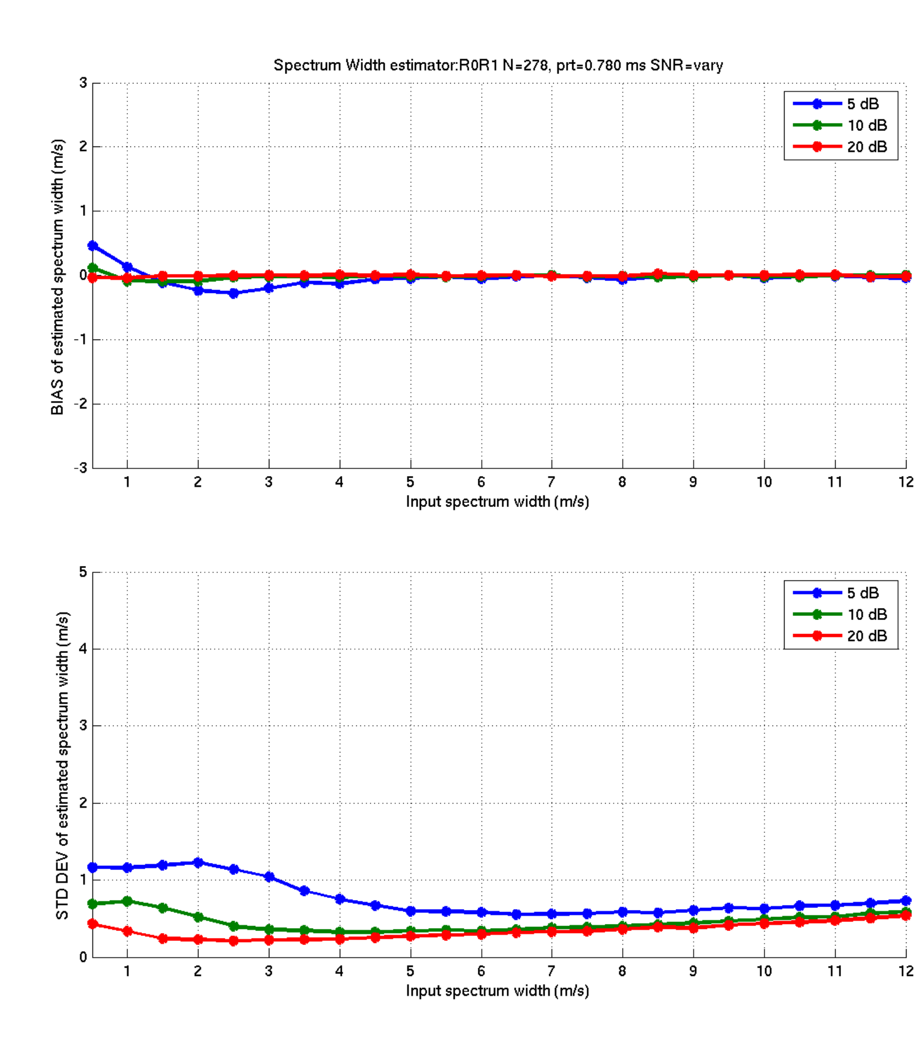
Vertical Ticks 1 m/s

Optimal

Input W (m/s)

NCAR

R0/R1 VCP 32, PRI 8



Bias (m/s)

Std (m/s)

Vertical Ticks 1 m/s

Optimal

Horizontal Ticks 2 m/s

Vertical Ticks 1 m/s

Optimal

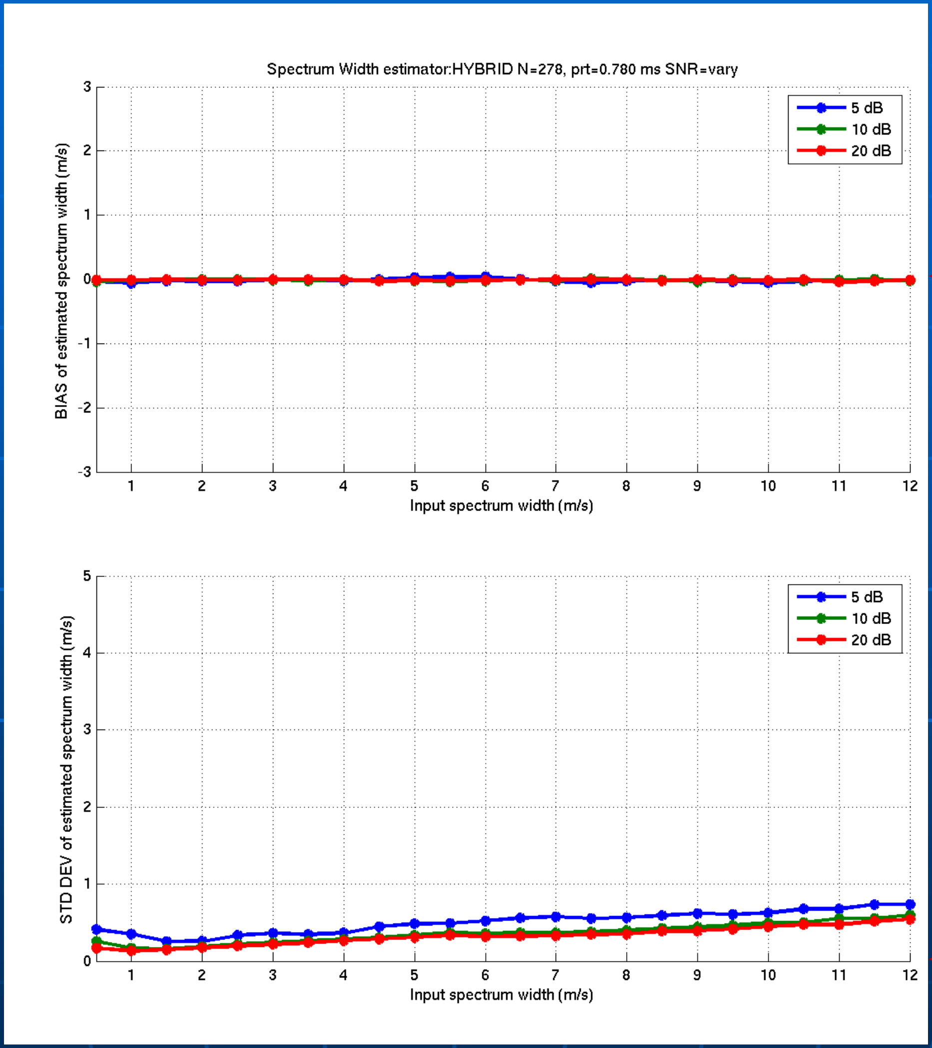
Input W (m/s)

NCAR

Hybrid VCP 32, PRI 8

Bias (m/s)

Std (m/s)



Vertical Ticks 1 m/s

Optimal

Horizontal Ticks 2 m/s

Vertical Ticks 1 m/s

Optimal

Input W (m/s)

NCAR

CASE STUDIES

Case Studies

- Have evaluated on 30 cases, spanning the VCPs 11, 12, 21, 31, and 32. (from standpoint of PRT/dwell times evaluation of VCPs 121, 211, 212, and 221 are "covered" by these cases)
- These case studies span a range of weather phenomena including convective (including tornadic) storms, stratiform rain, winter weather, strong low level jet, etc.)

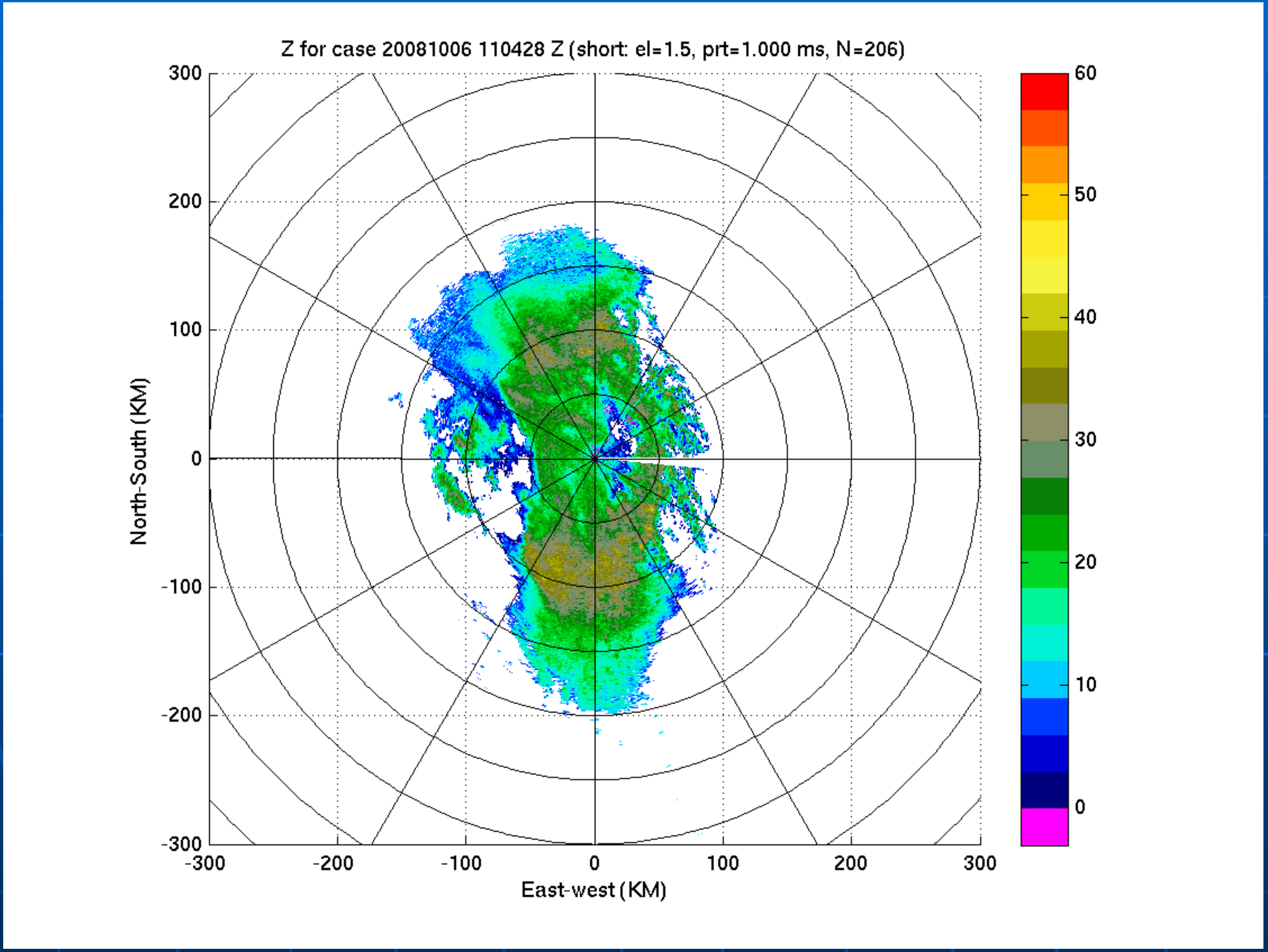
Case Studies

- Clutter filtering has been applied (map based on CMD)
- Range un-folding was not performed so that data is all contained within one range ring.
- Data censoring: Z<0, SNR<0 are shown blank. PR<5, strong CSRs are colored purple.
  - These are lower than normal operational settings.
- Presented here are some spectra with Gaussian fits using both R0/R1 and Hybrid estimators. These come from “gates” where there was a significant difference between the two estimators.

“A strong cold front was located in western OK. Convective storms and widespread rain developed along and ahead of the advancing cold front.” - NSSL/ROC I&Q archive

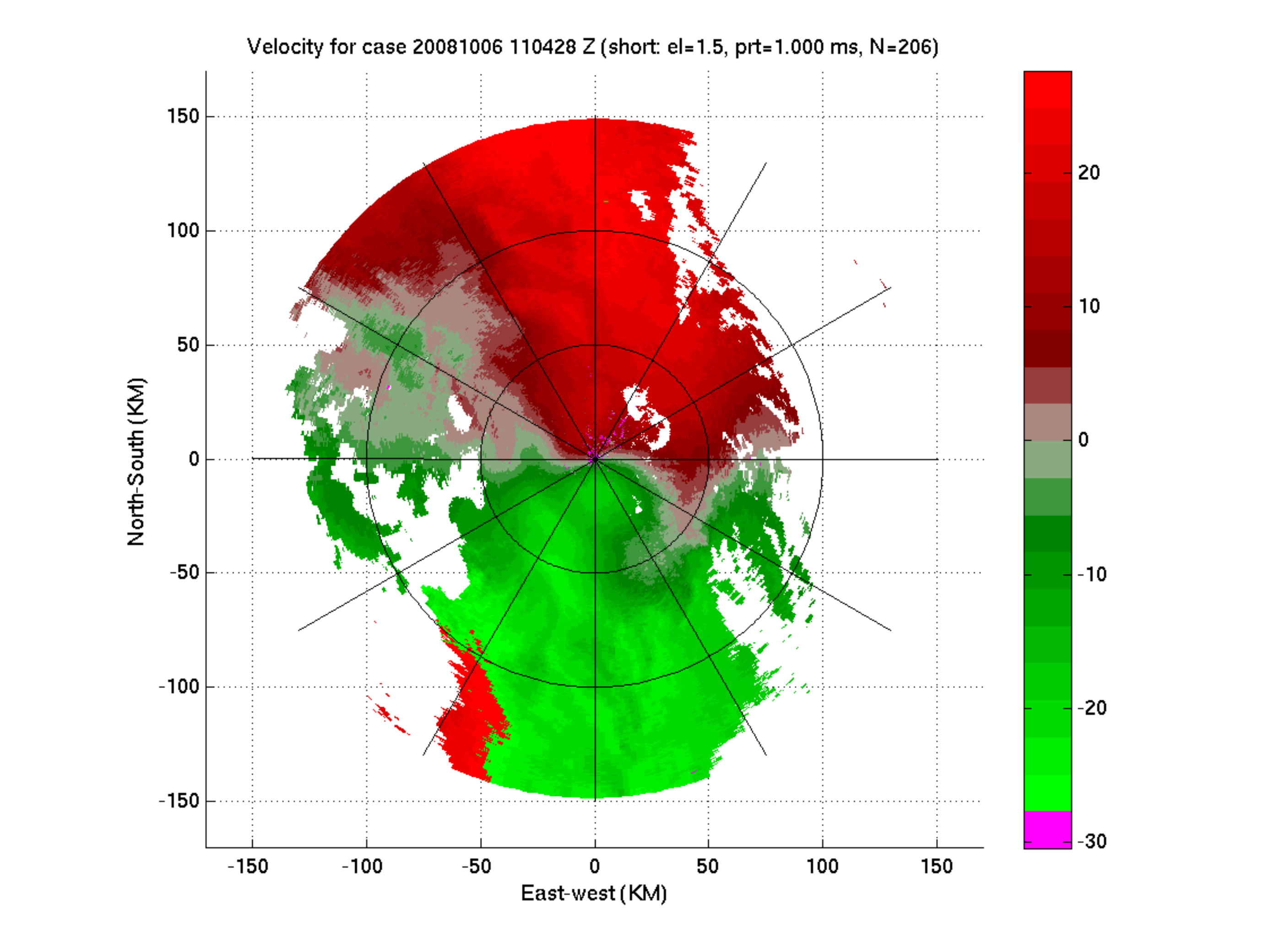
CASE 1: KOUN 2008/10/06 1100Z VCP 32, PRI 5

Z: KOUN 2008/10/06 1100Z VCP 32, PRI 5

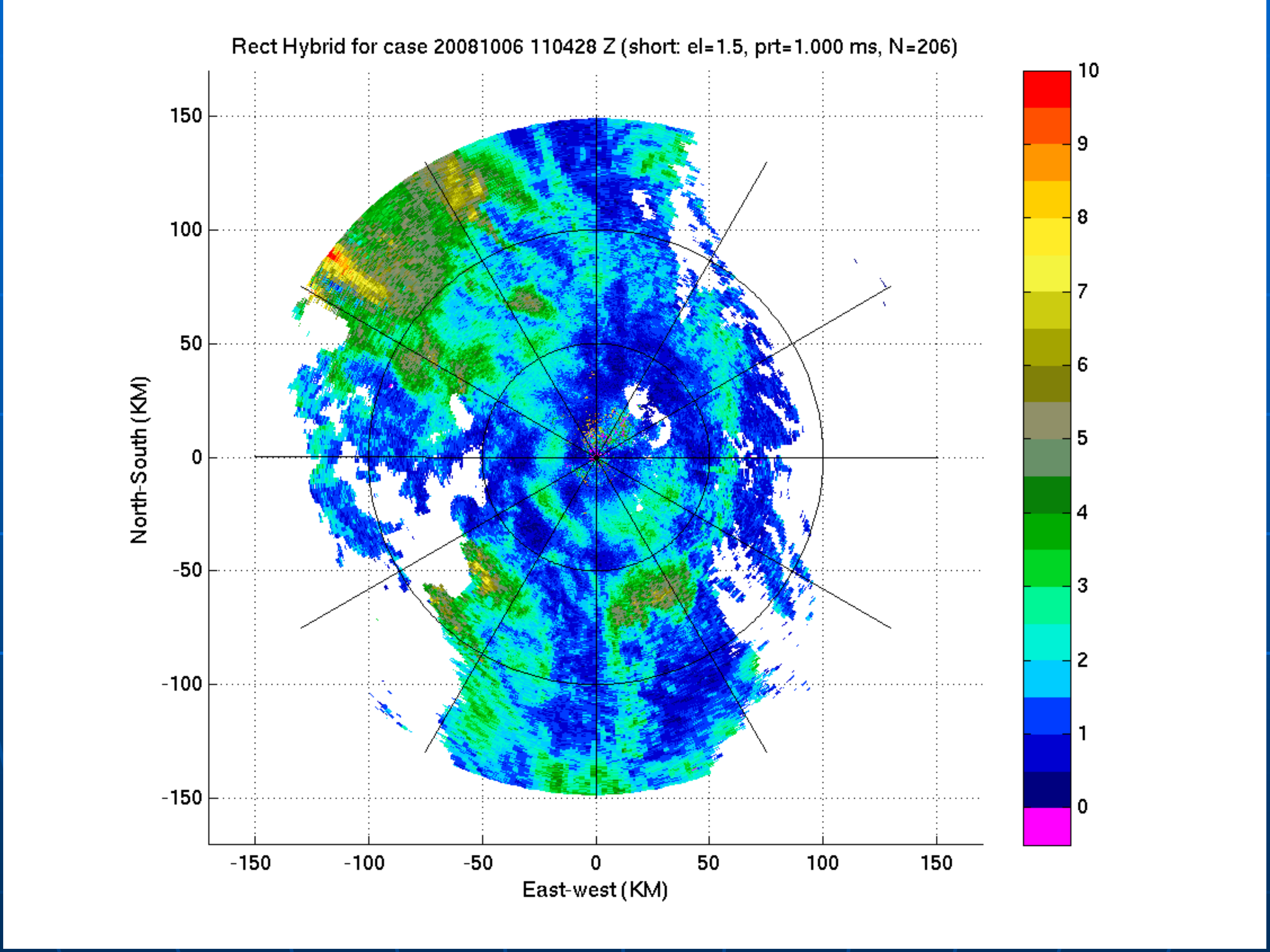


NCAR

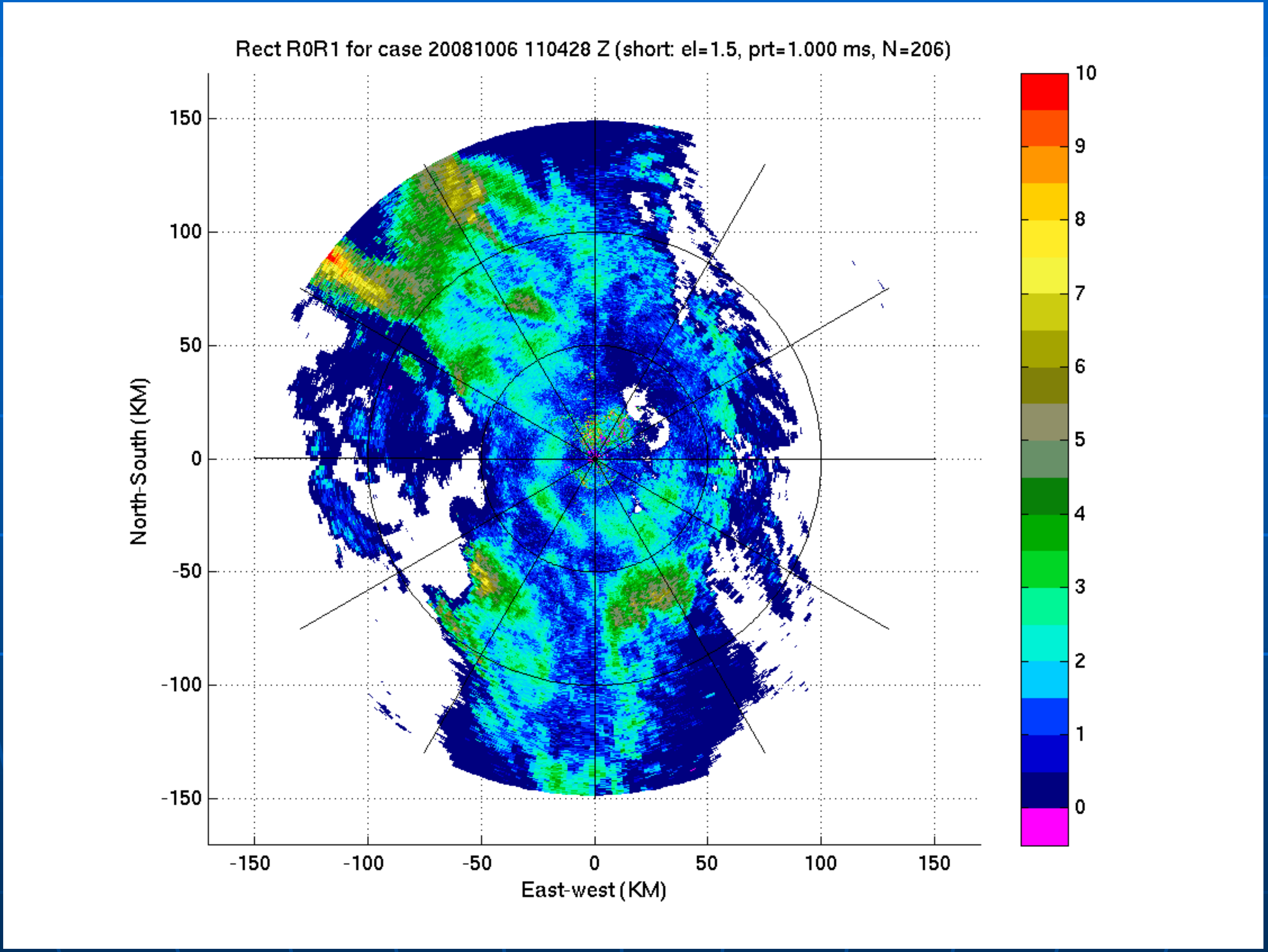
V: KOUN 2008/10/06 1100Z VCP 32, PRI 5



HYBRID: KOUN 2008/10/06 1100Z VCP 32, PRI 5

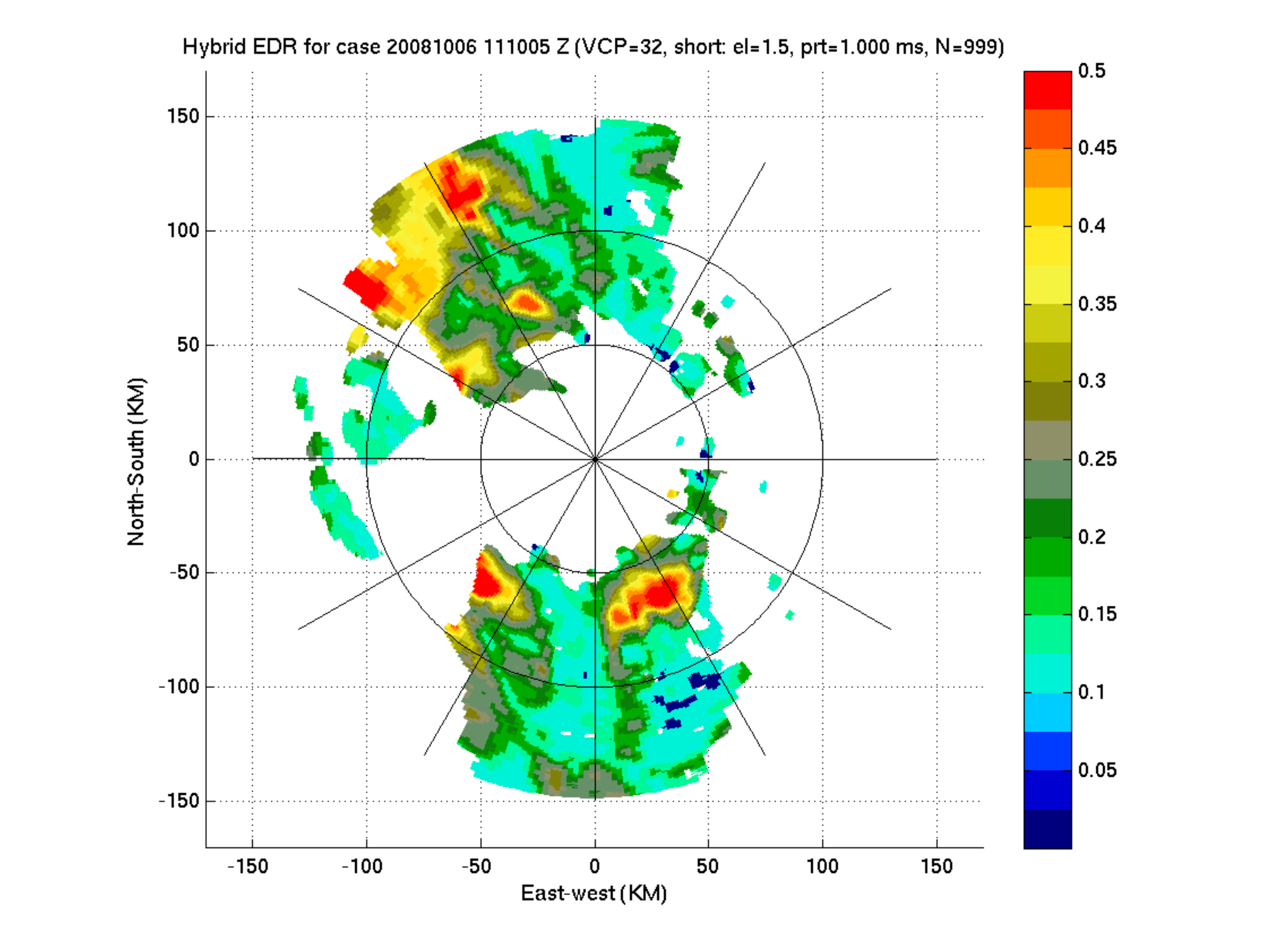


R0/R1: KOUN 2008/10/06 1100Z VCP 32, PRI 5



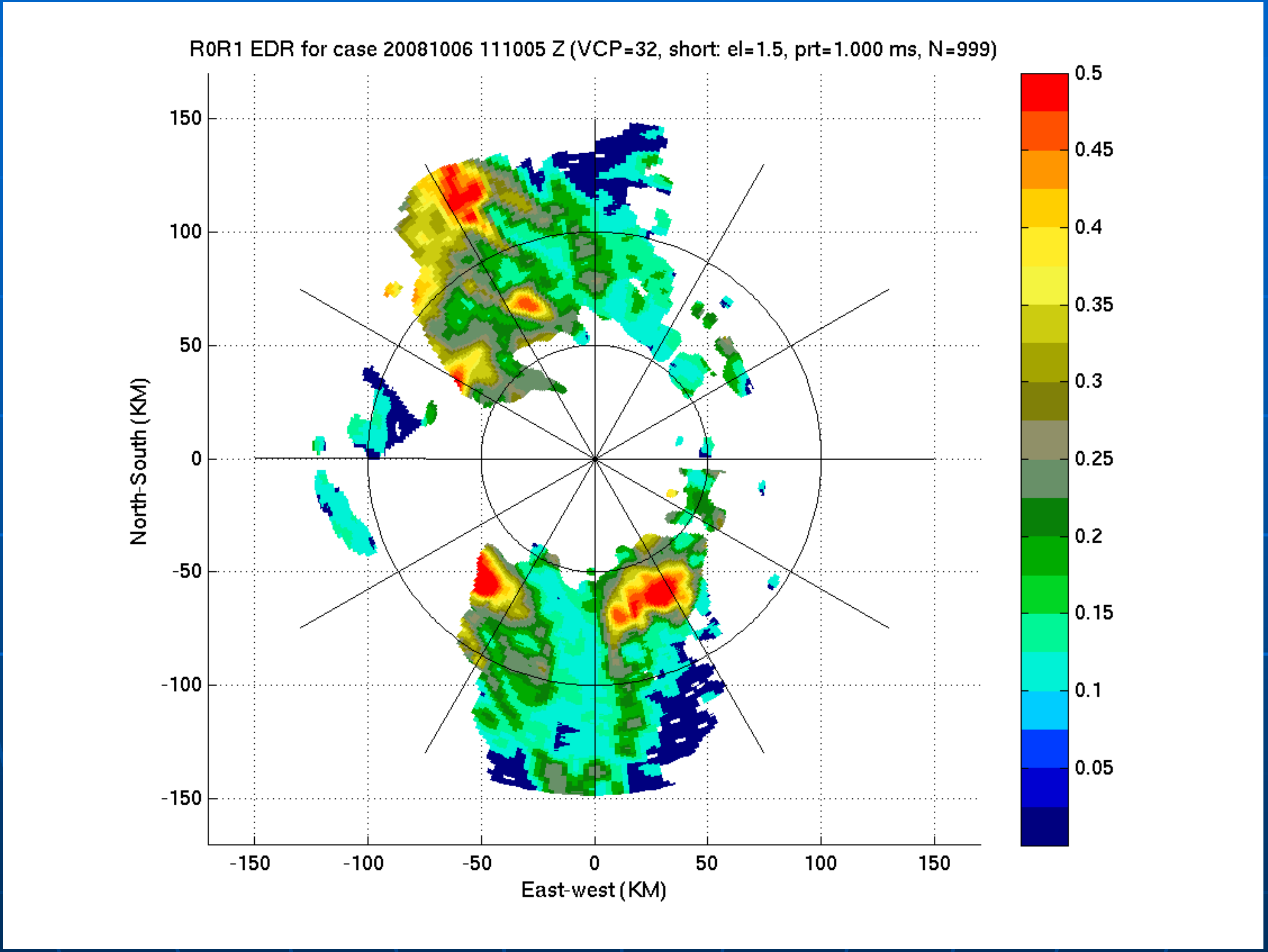
NCAR

EDR HYB: KOUN 2008/10/06 1100Z VCP 32, PRI 5



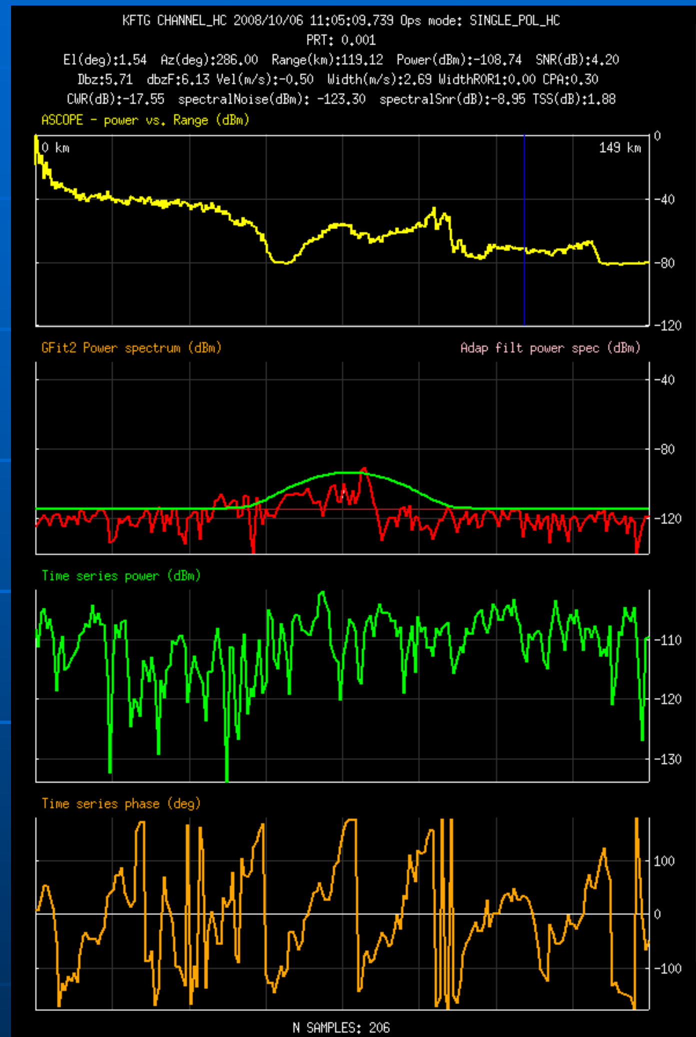
NCAR

EDR R0R1: KOUN 2008/10/06 1100Z VCP 32, PRI 5



SPECTRA: KOUN 2008/10/06 1100Z VCP 32, PRI 5

Spectrum Power (dbM)



Red = Empirical Spectrum

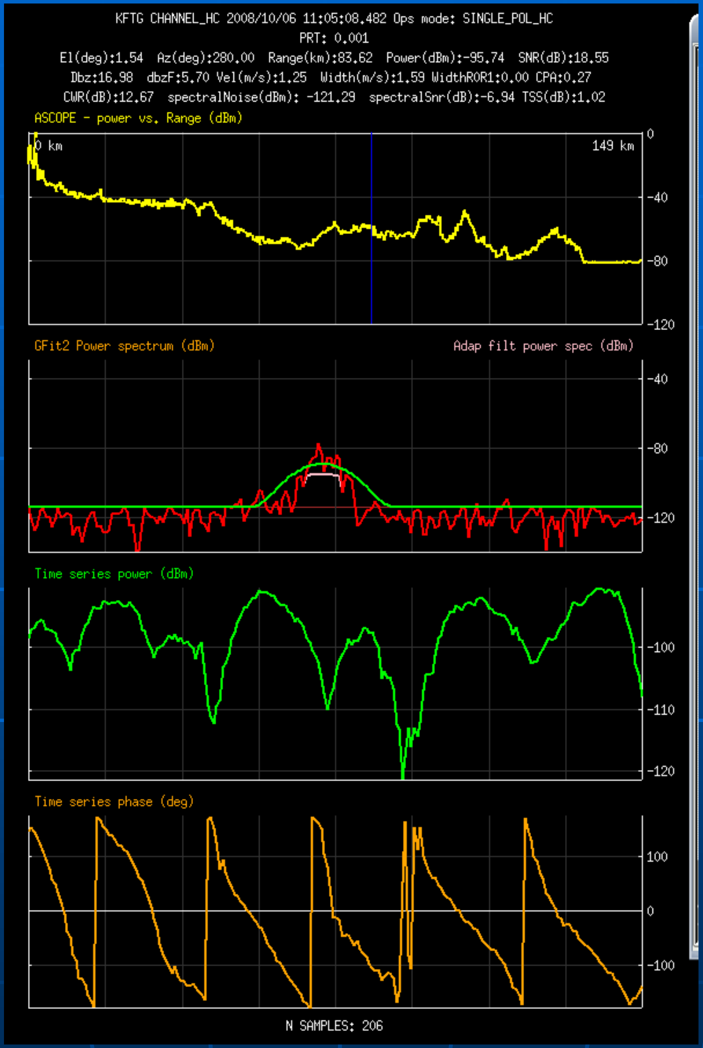
Green = Gaussian fit using Hybrid

Brown = Gaussian fit using R0/R1

Comment: low SNR. R0R1 says 0 m/s

SPECTRA: KOUN 2008/10/06 1100Z VCP 32, PRI 5

Spectrum Power (dbM)



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NCAR

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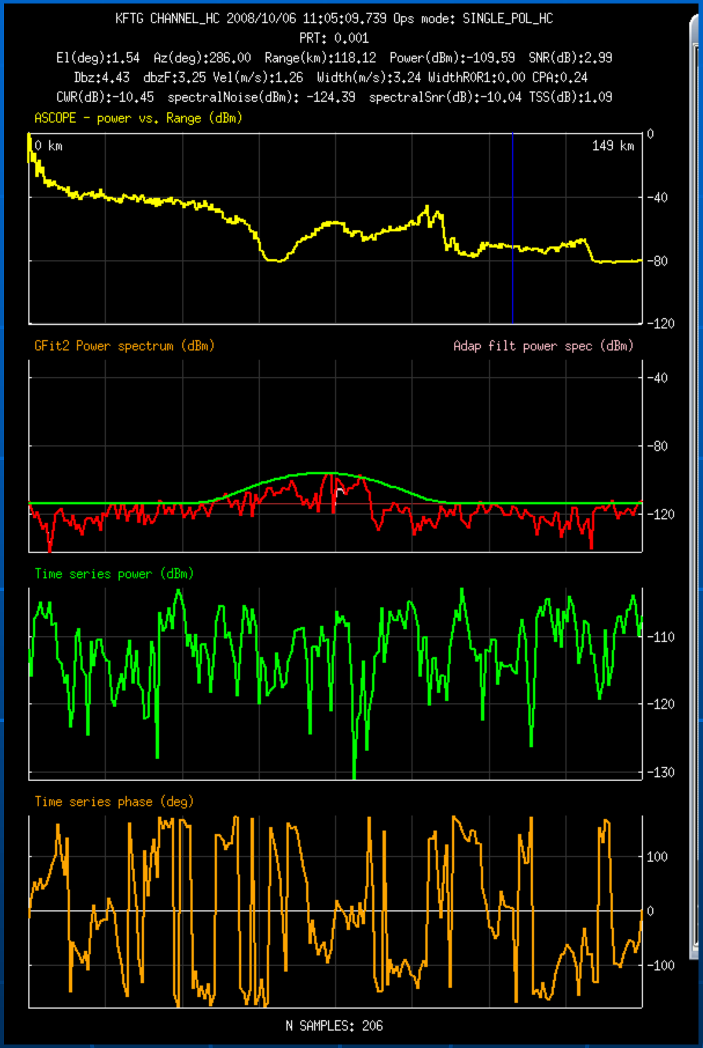

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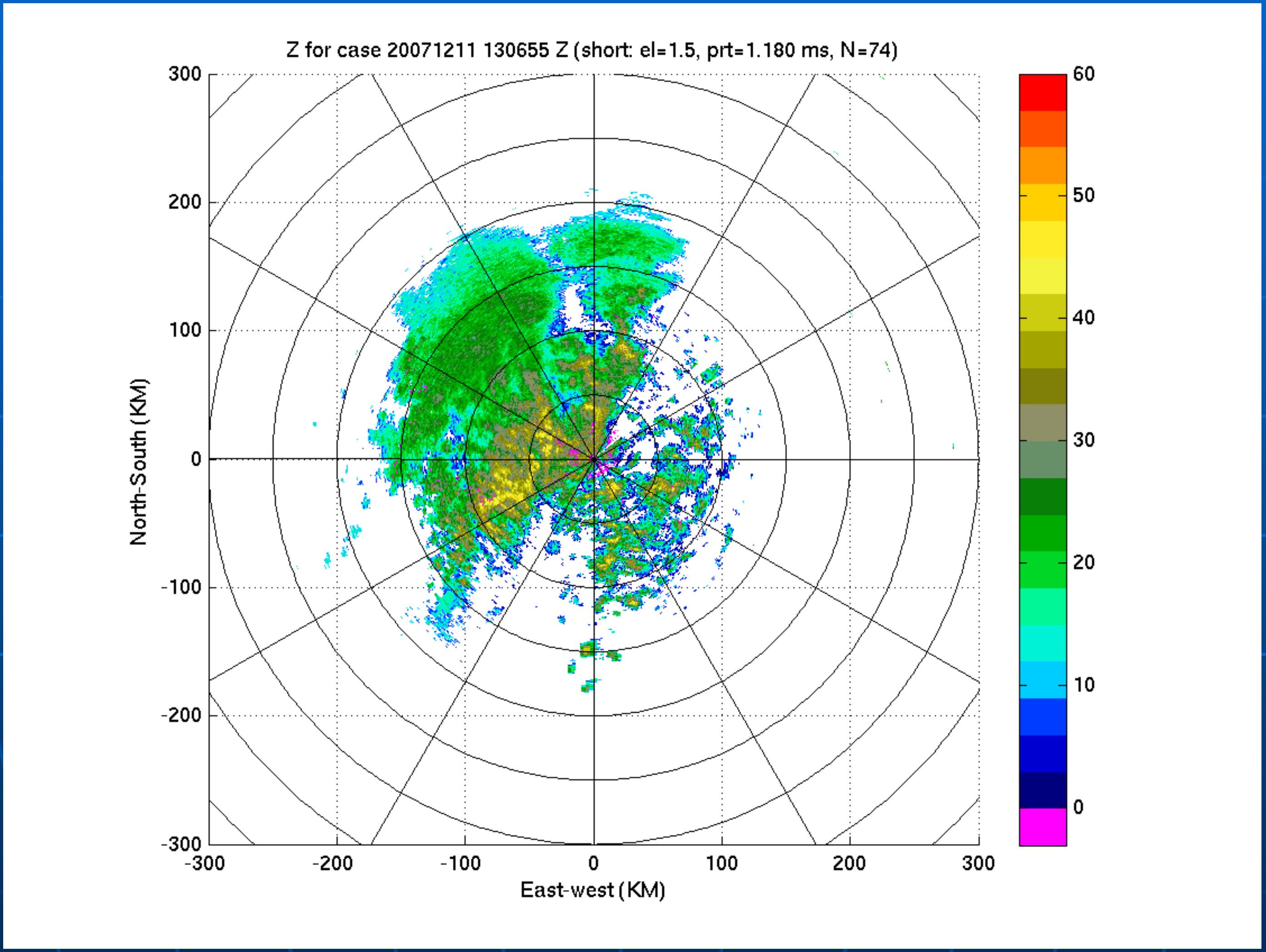
NCAR

"During the data collection period, a very powerful upper level storm was located over NM. Cold surface and low level temperatures led to mixed precipitation over a large part of OK. Strong overrunning conditions lead to substantial amounts of freezing rain. Embedded convective cells streamed over OK dropping heavy liquid/freezing precipitation…. Sunrise, 75% of state covered by rain"

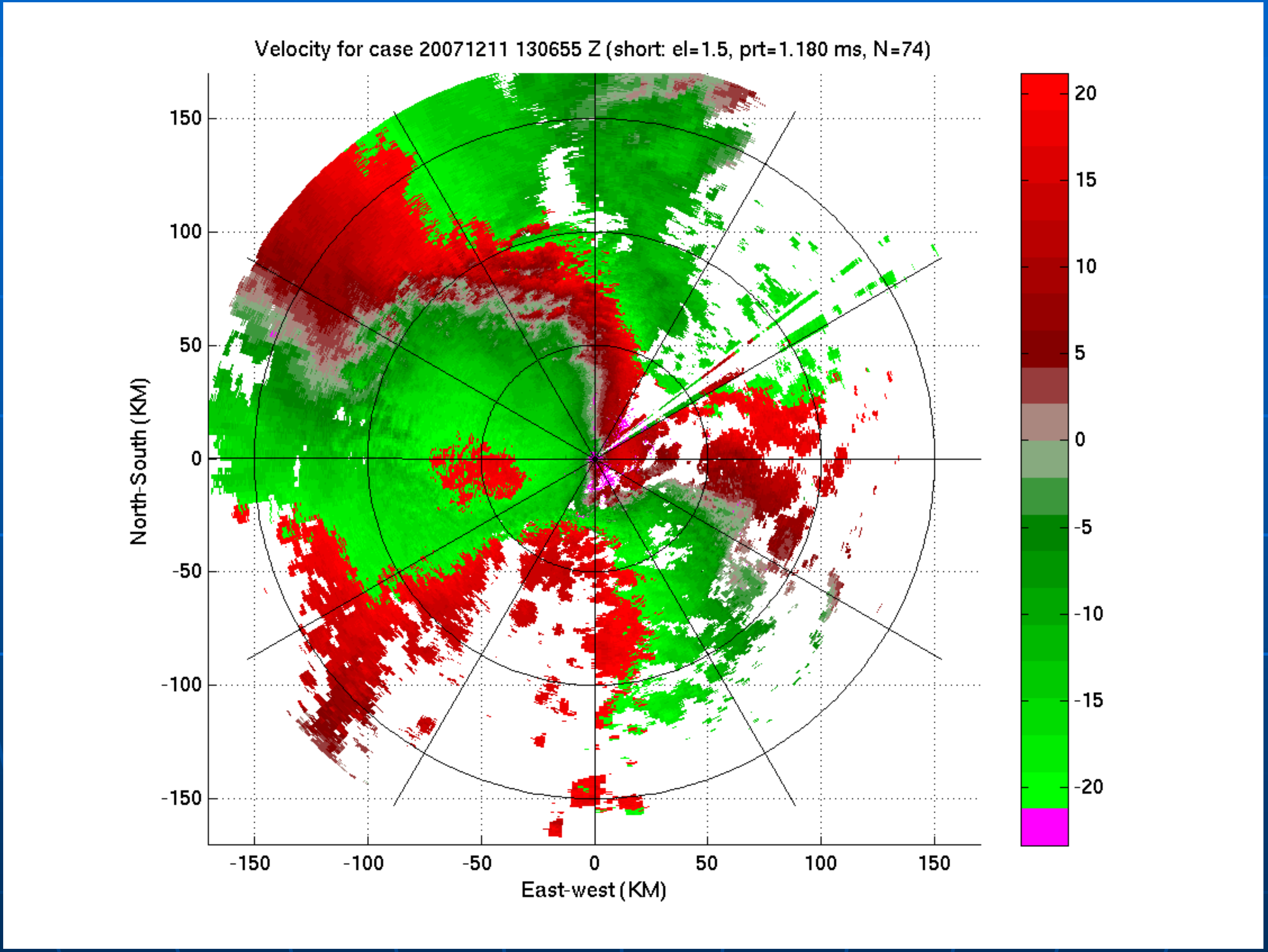
CASE 2: KCRI 2007/12/11 1302Z VCP 22 (LIKE 21), PRI 4

Z: KCRI 2007/12/11 1302Z VCP ~21, PRI 4

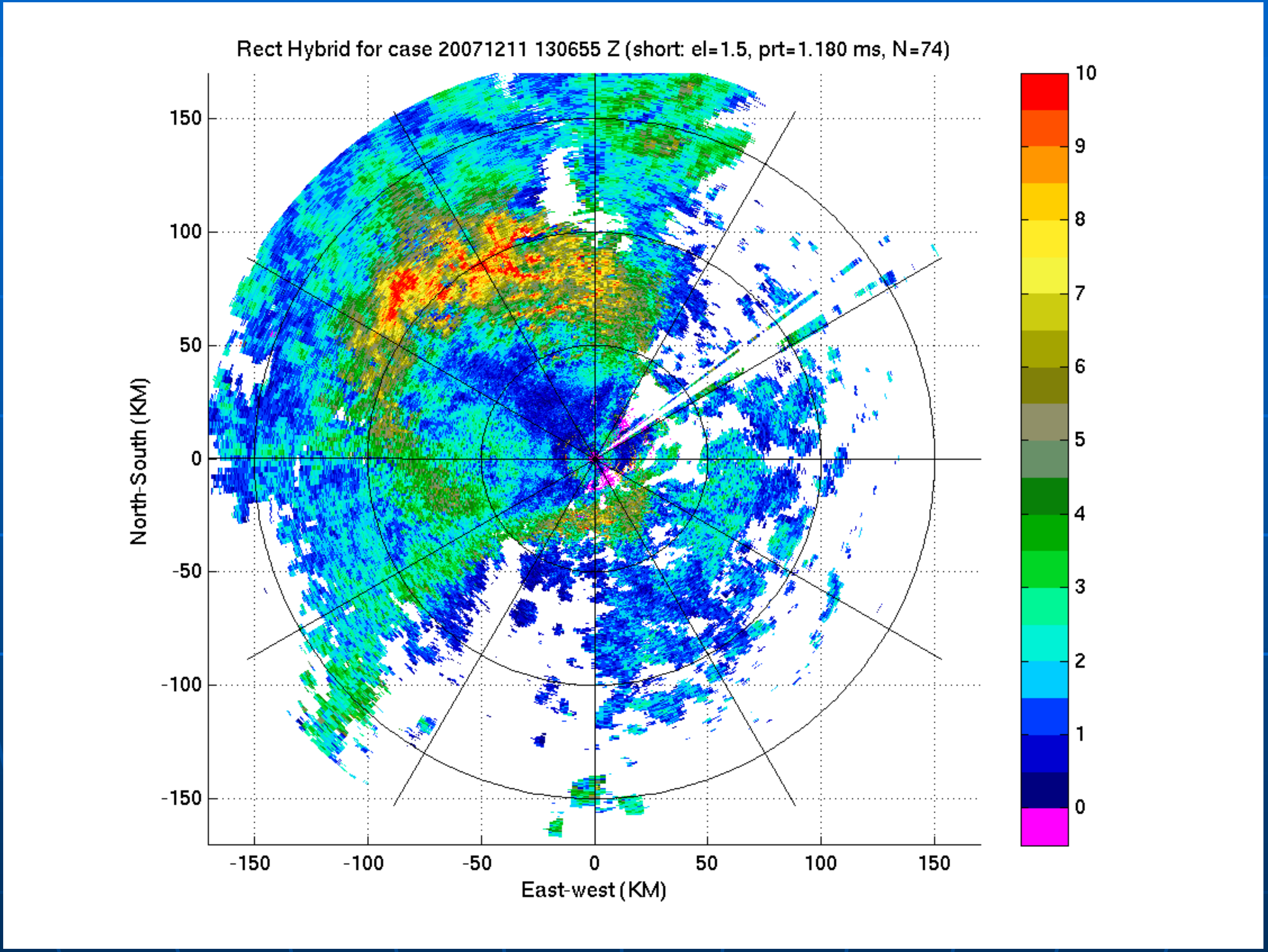


NCAR

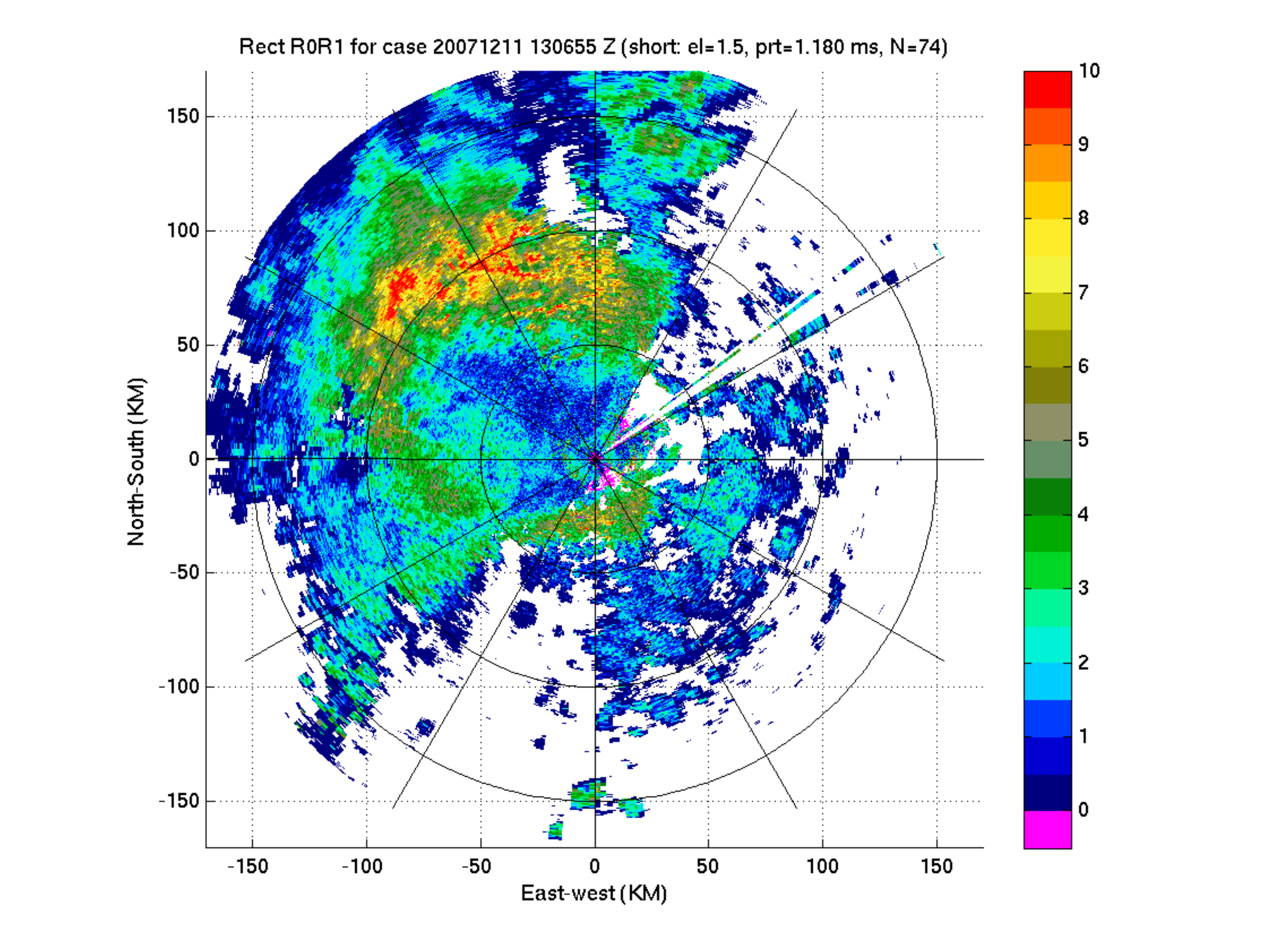
V: KCRI 2007/12/11 1302Z VCP ~21, PRI 4



HYBRID: KCRI 2007/12/11 1302Z VCP ~21, PRI 4

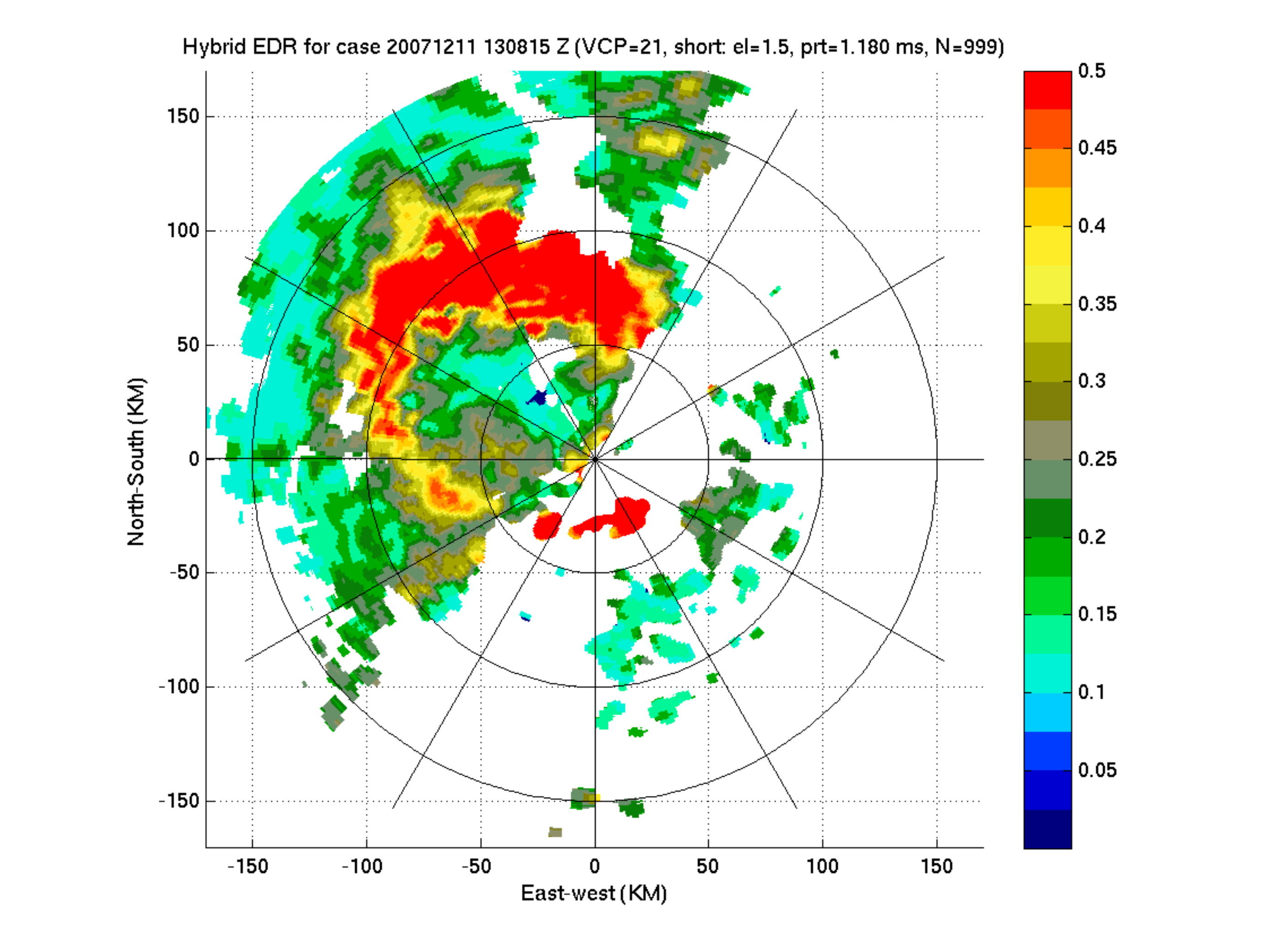


R0/R1: KCRI 2007/12/11 1302Z VCP ~21, PRI 4

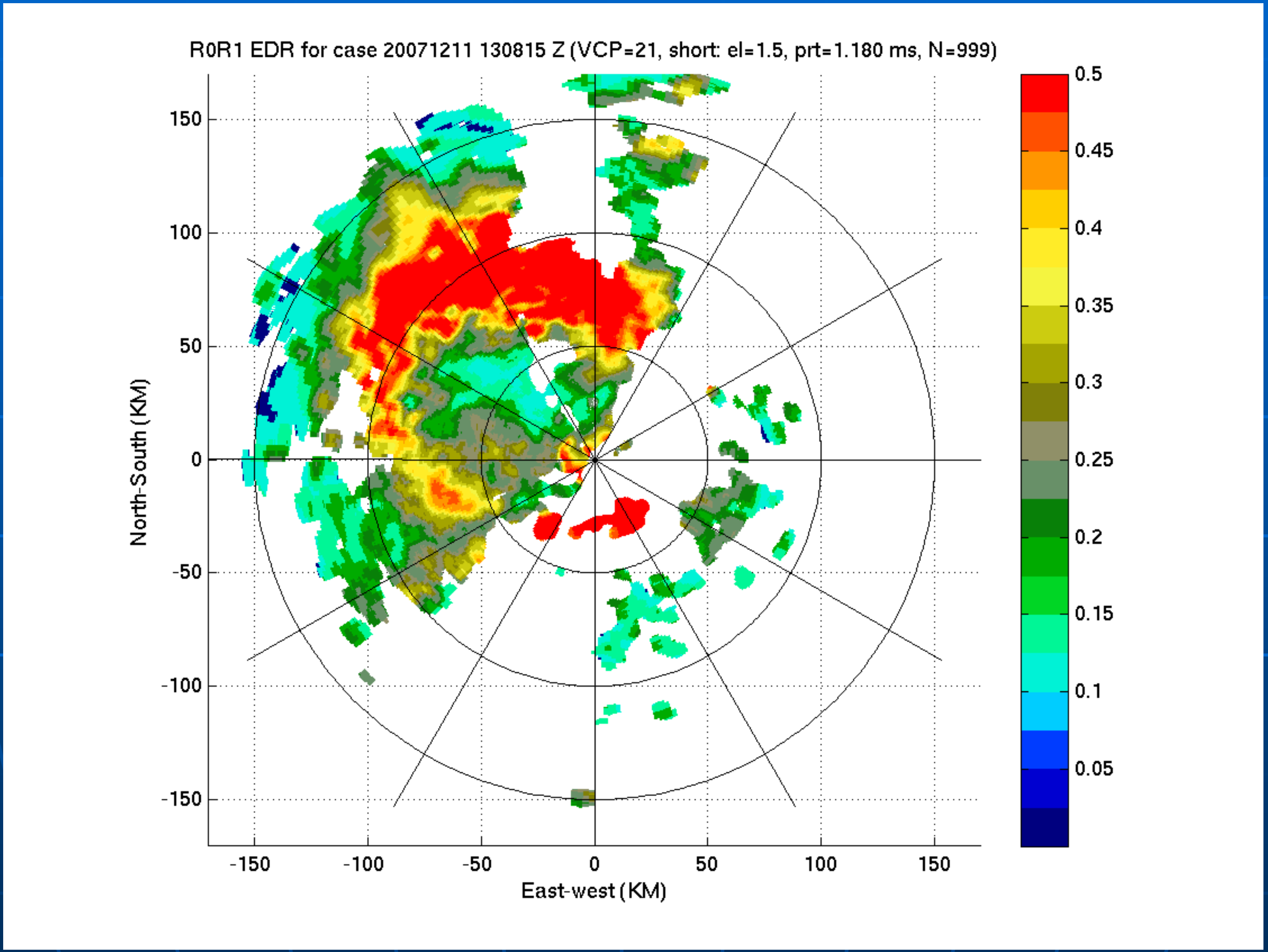


NCAR

EDR HYB: KCRI 2007/12/11 1302Z VCP ~21, PRI 4



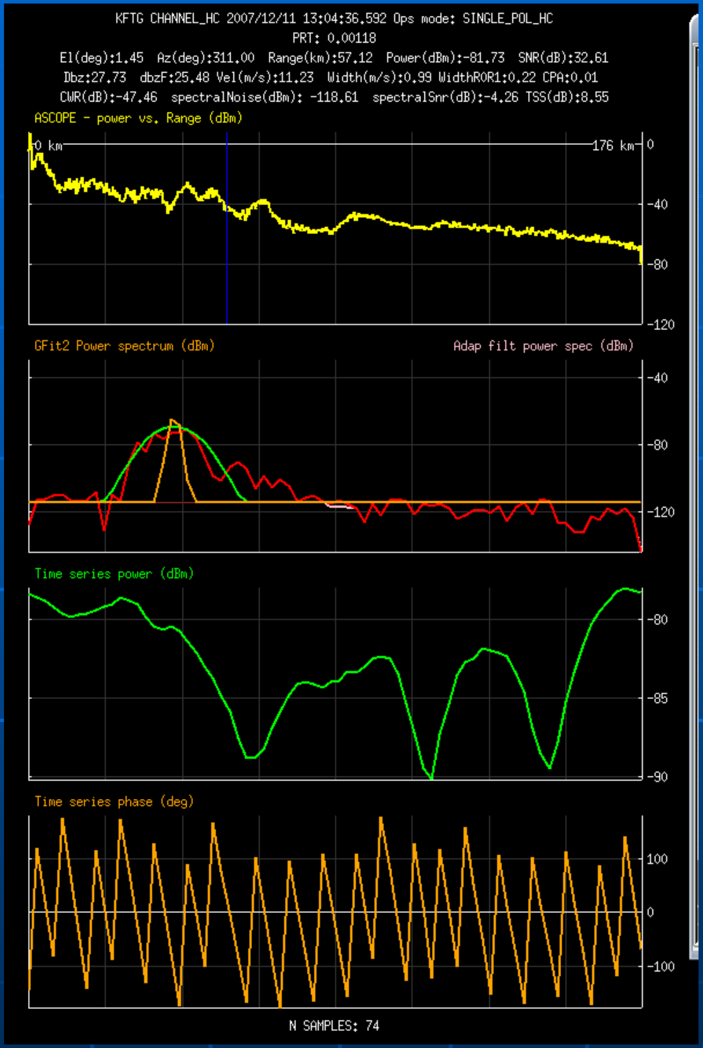
EDR R0R1: KCRI 2007/12/11 1302Z VCP ~21, PRI 4



NCAR

SPECTRA: KCRI 2007/12/11 1302Z VCP ~21, PRI 4

Spectrum Power (dbM)



Red = Empirical Spectrum

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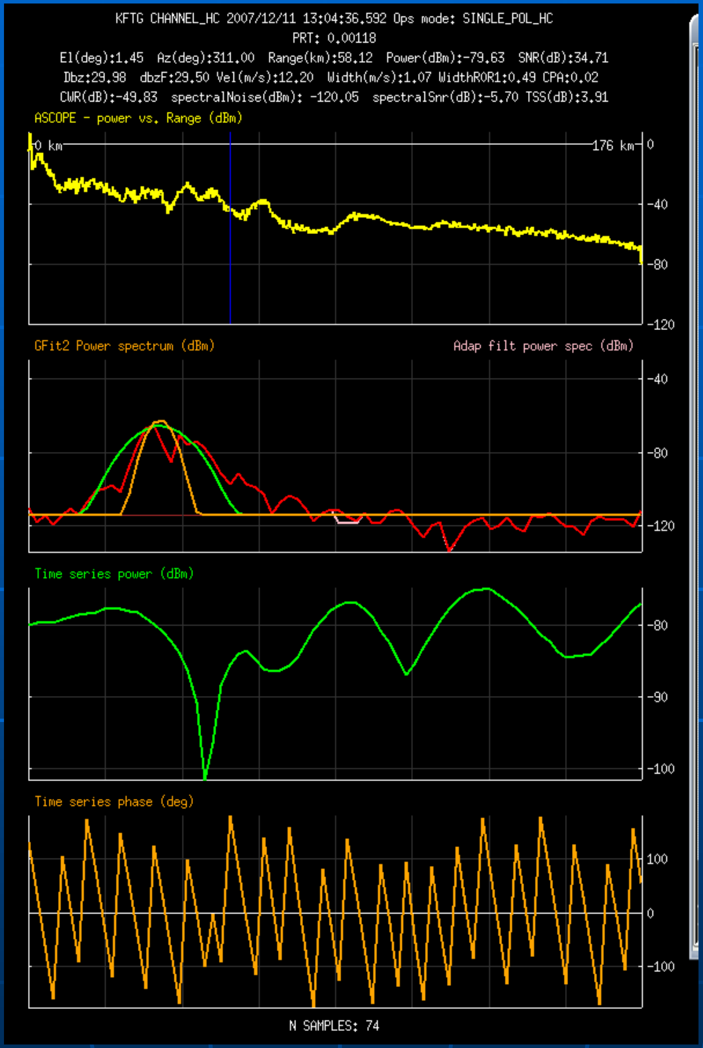
Brown = Gaussian fit using R0/R1

Comment: narrow spectrum. R0R1 underestimating

NCAR

SPECTRA: KCRI 2007/12/11 1302Z VCP ~21, PRI 4

Spectrum Power (dbM)



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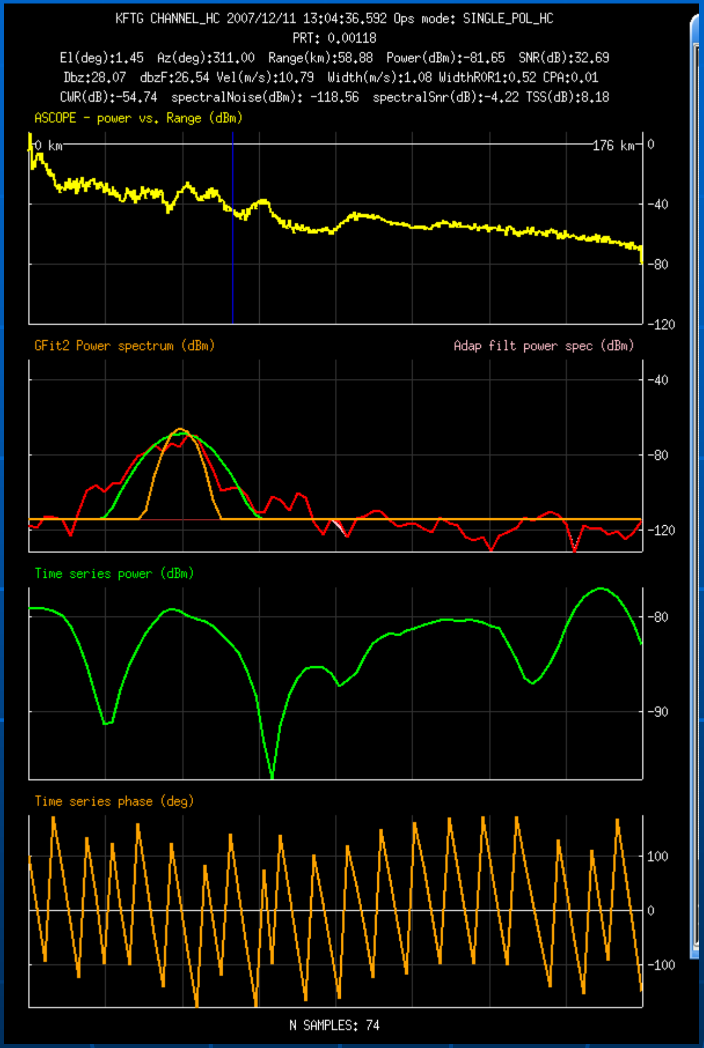

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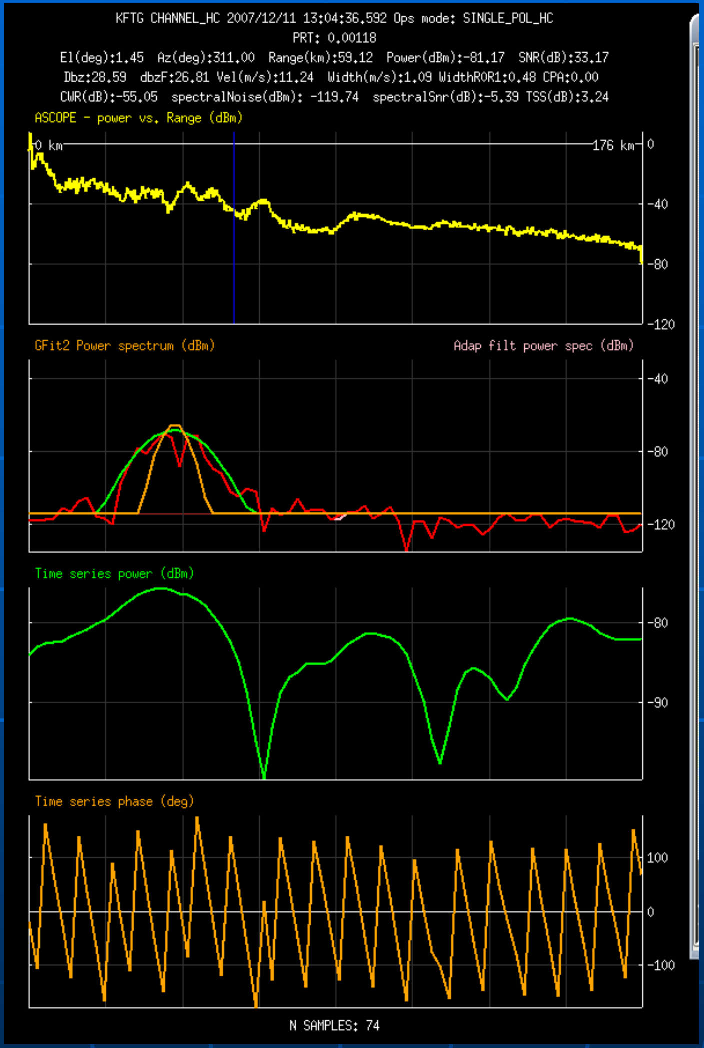

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Spectrum Power (dbM)

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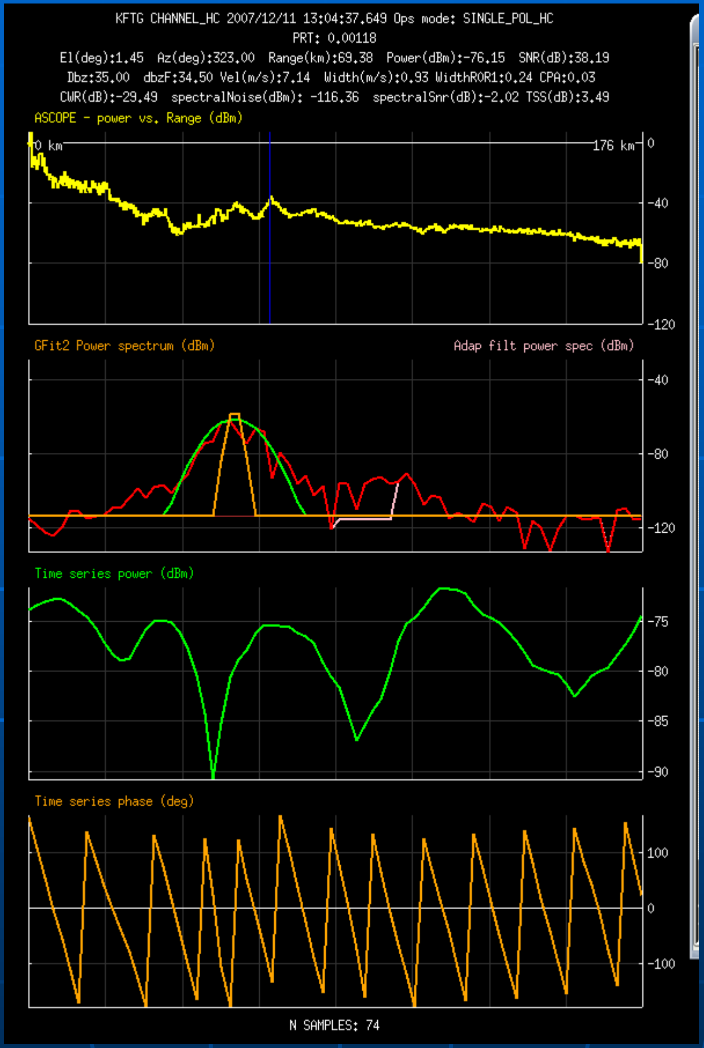
Comment: Wide spectrum. Both underestimating

SPECTRA: KCRI 2007/12/11 1302Z VCP ~21, PRI 4

Spectrum Power (dbM)



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Comment: Wide spectrum. Both underestimating, though hybrid fits better

NCAR

SPECTRA: KCRI 2007/12/11 1302Z VCP ~21, PRI 4

Spectrum Power (dbM)

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NCAR

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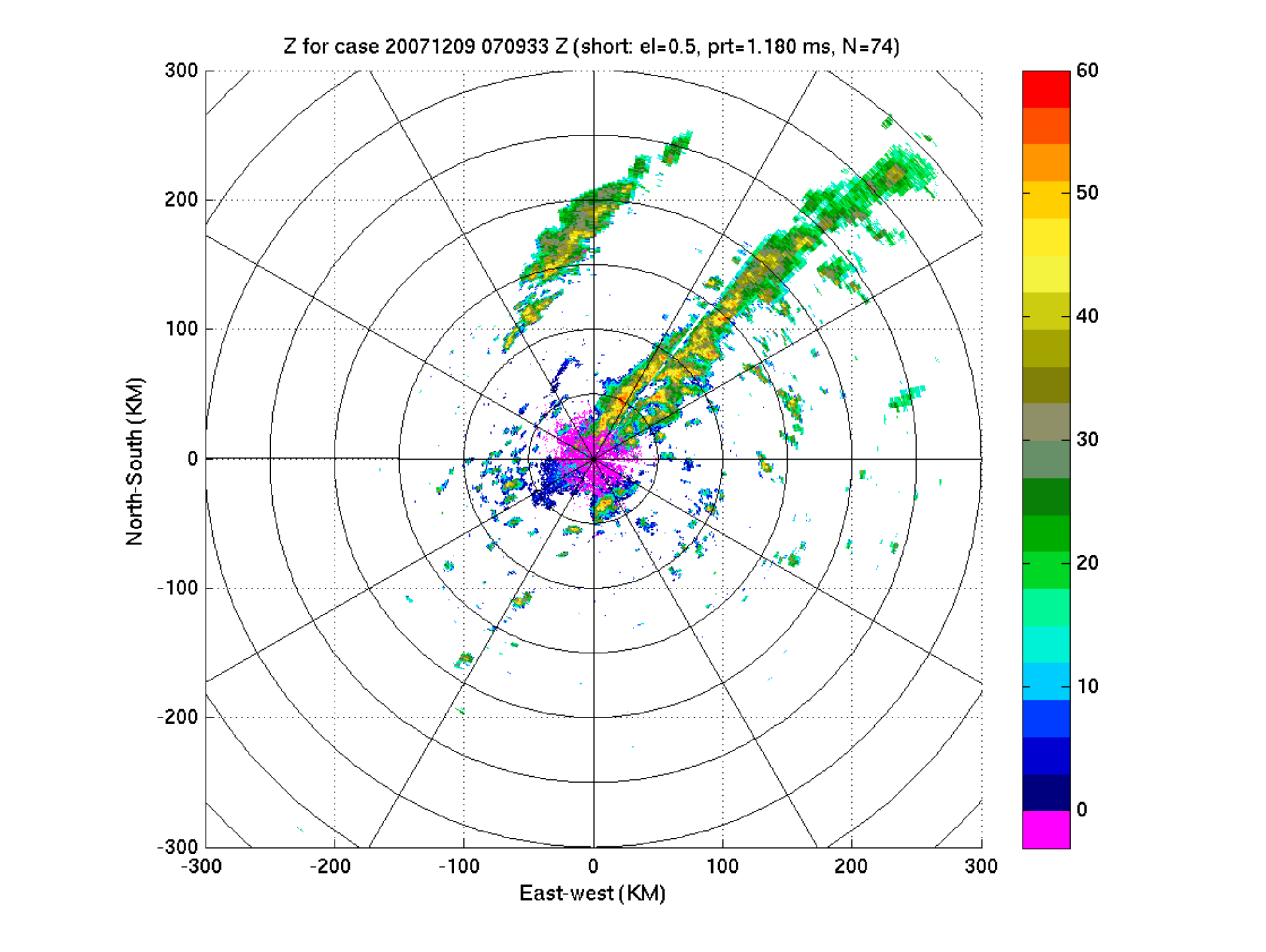
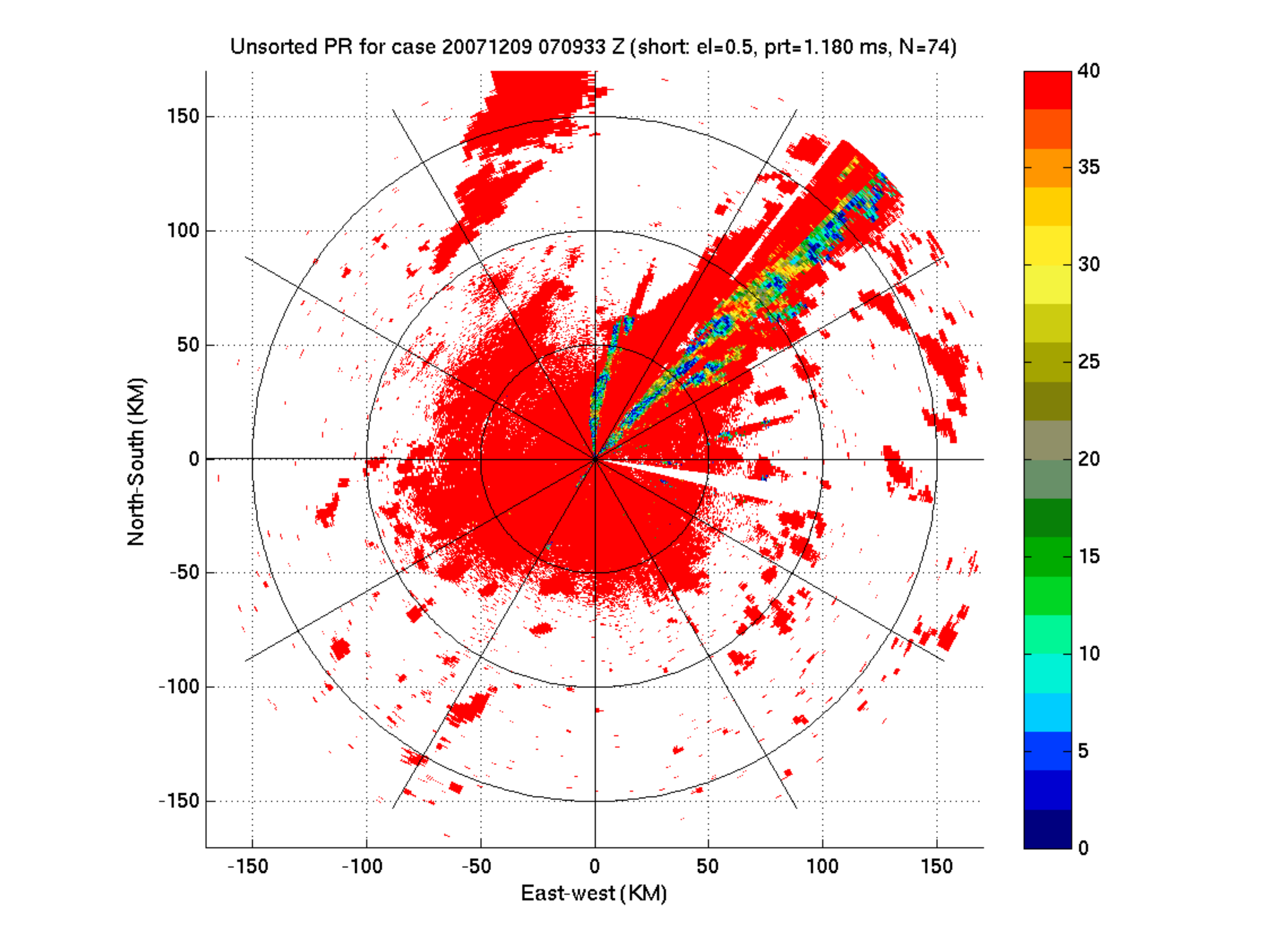
CASE 3: KCRI 2007/12/09 0705Z VCP 22 (LIKE 21), PRI 4

Z: KCRI 2007/12/09 0705Z VCP ~21, PRI 4



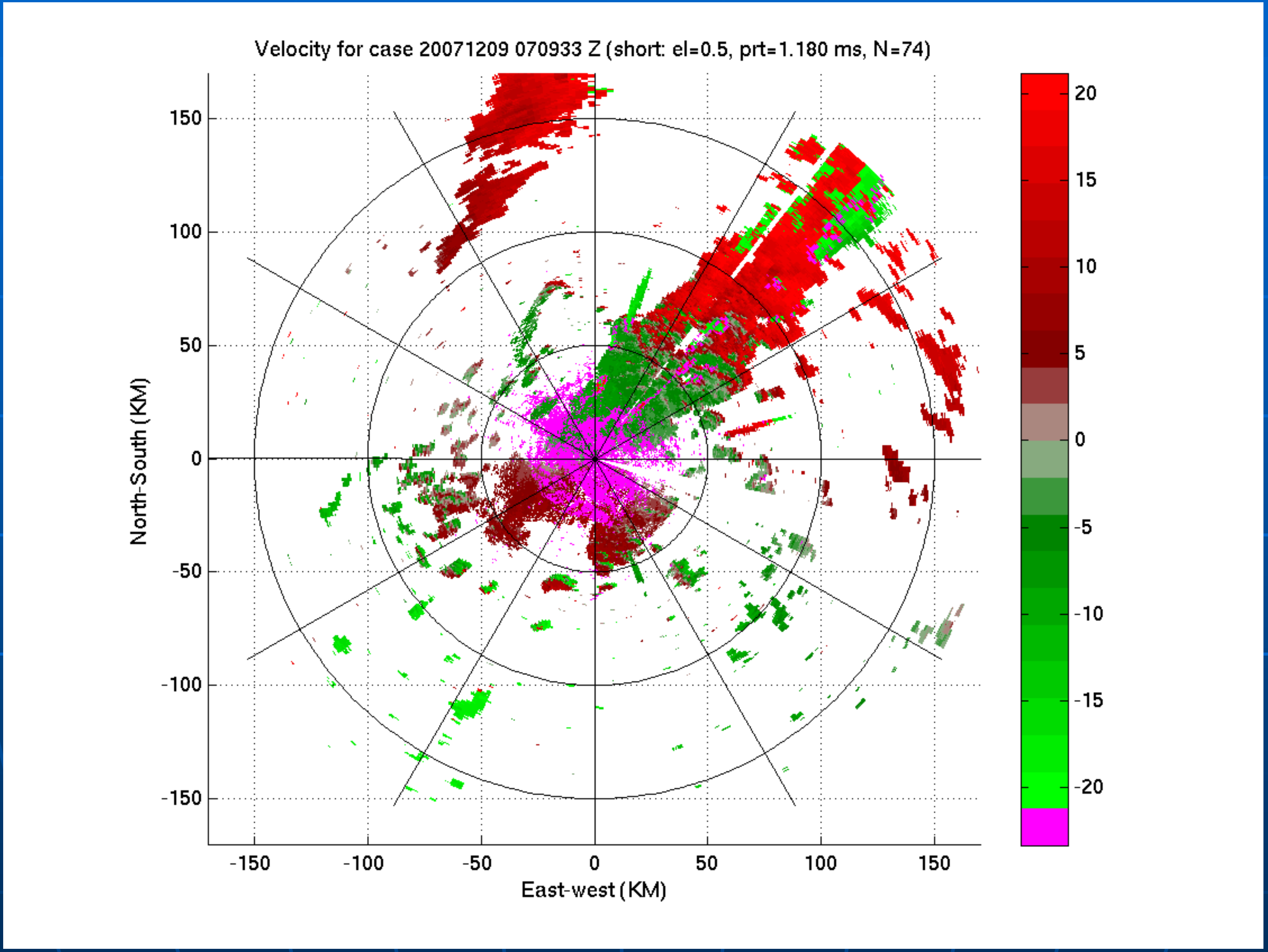
NCAR

POWER RATIO: KCRI 2007/12/09 0705Z VCP ~21, PRI 4



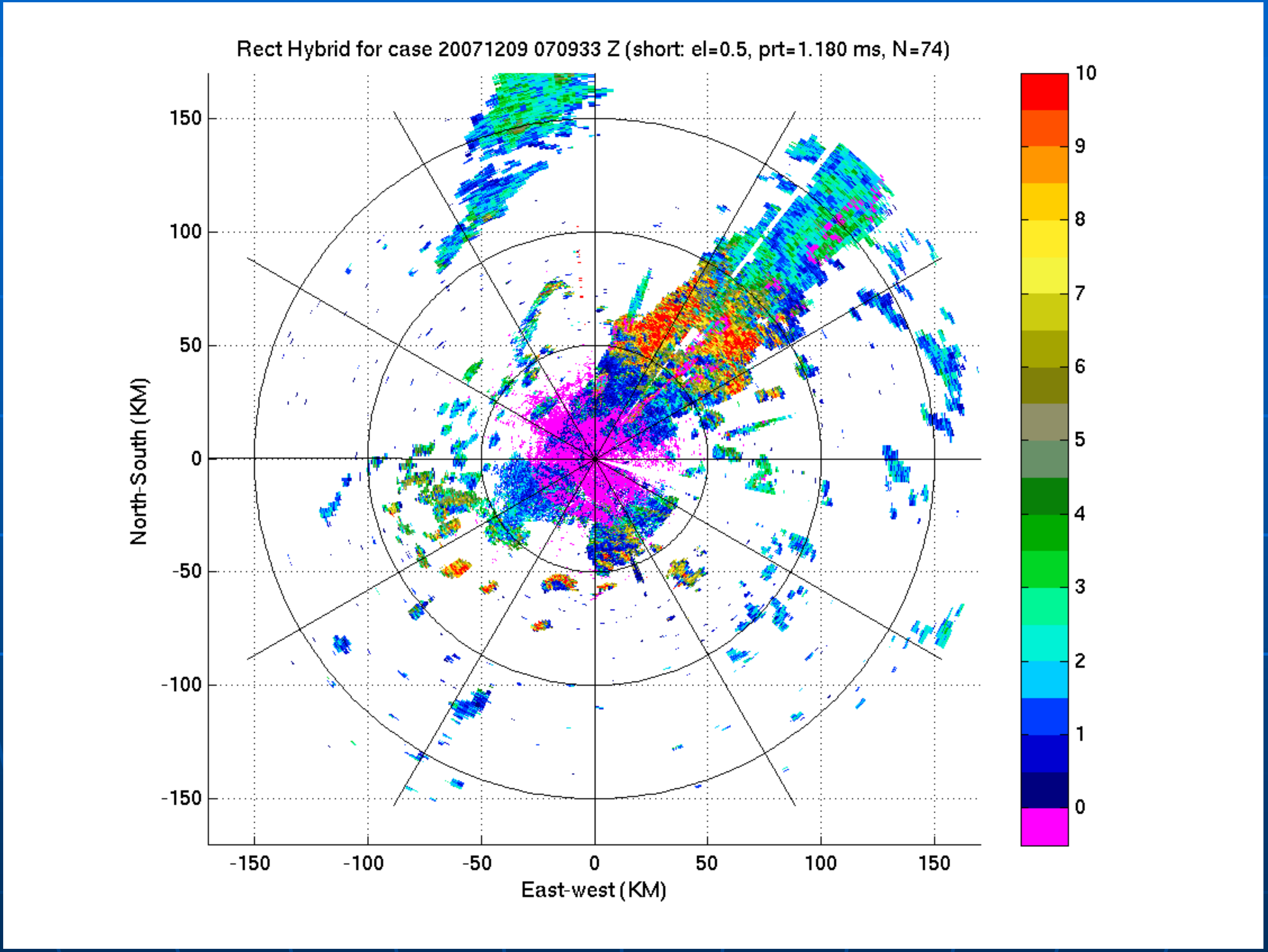
Power Ratio is the strong trip divided by the weak trip. The weak trip will contaminate the strong trip estimators when PR is smaller.

V: KCRI 2007/12/09 0705Z VCP ~21, PRI 4



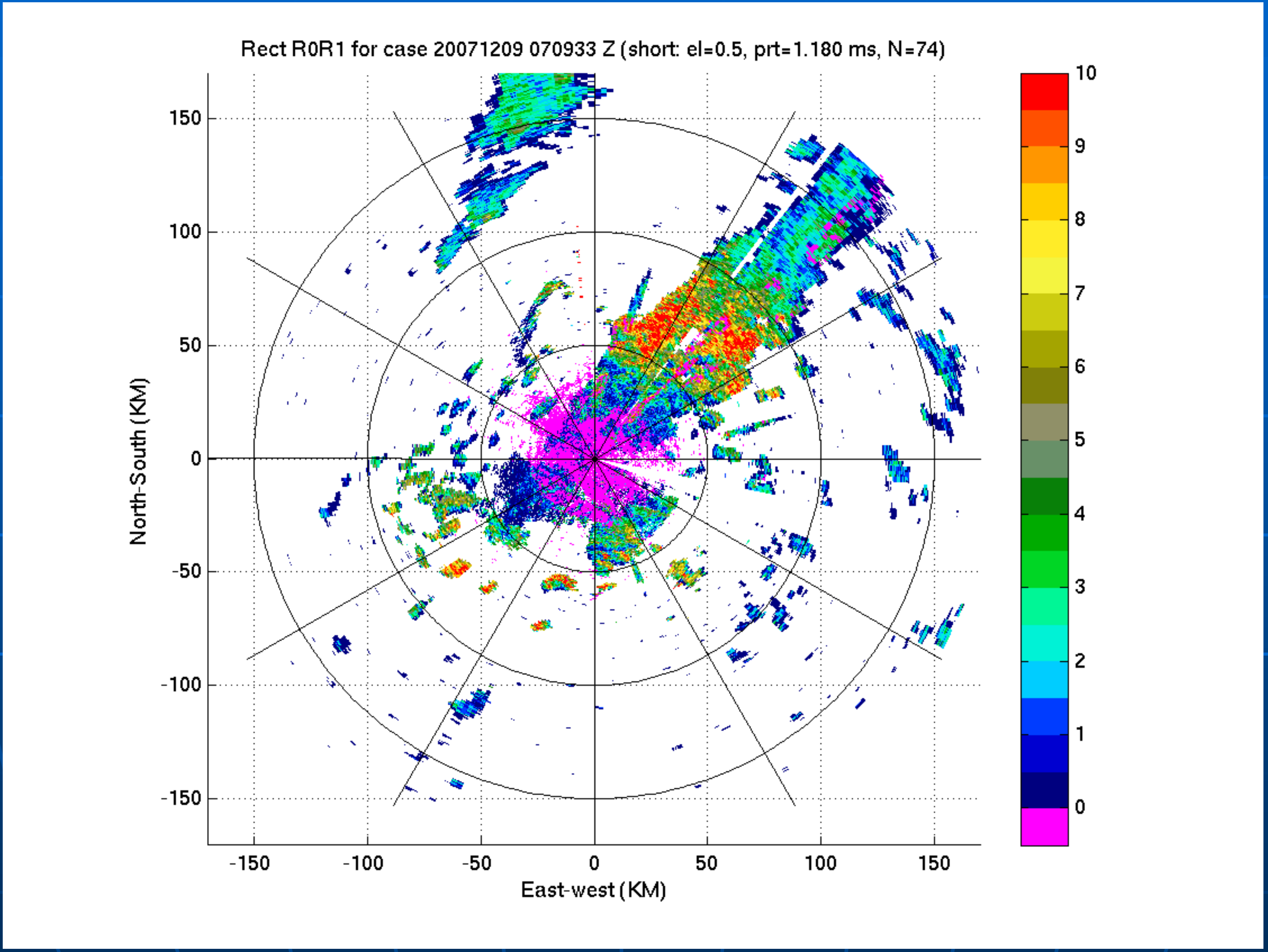
NCAR

HYBRID: KCRI 2007/12/09 0705Z VCP ~21, PRI 4



NCAR

R0/R1: KCRI 2007/12/09 0705Z VCP ~21, PRI 4



SPECTRA: KCRI 2007/12/09 0705Z VCP ~21, PRI 4

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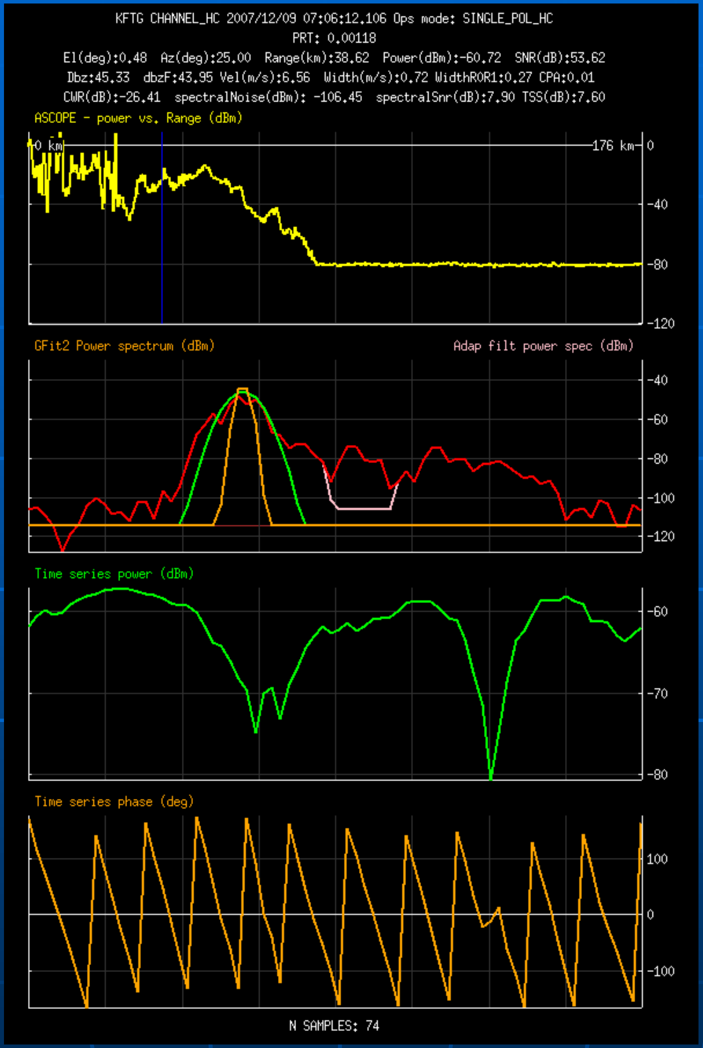
SPECTRA: KCRI 2007/12/09 0705Z VCP ~21, PRI 4

Spectrum Power (dbM)



Red = Empirical Spectrum

Green = Gaussian fit using Hybrid

Brown = Gaussian fit using R0/R1

Comment: Wide spectrum. Both underestimating, though Hybrid somewhat better

SPECTRA: KCRI 2007/12/09 0705Z VCP ~21, PRI 4

Spectrum Power (dbM)

Red = Empirical Spectrum

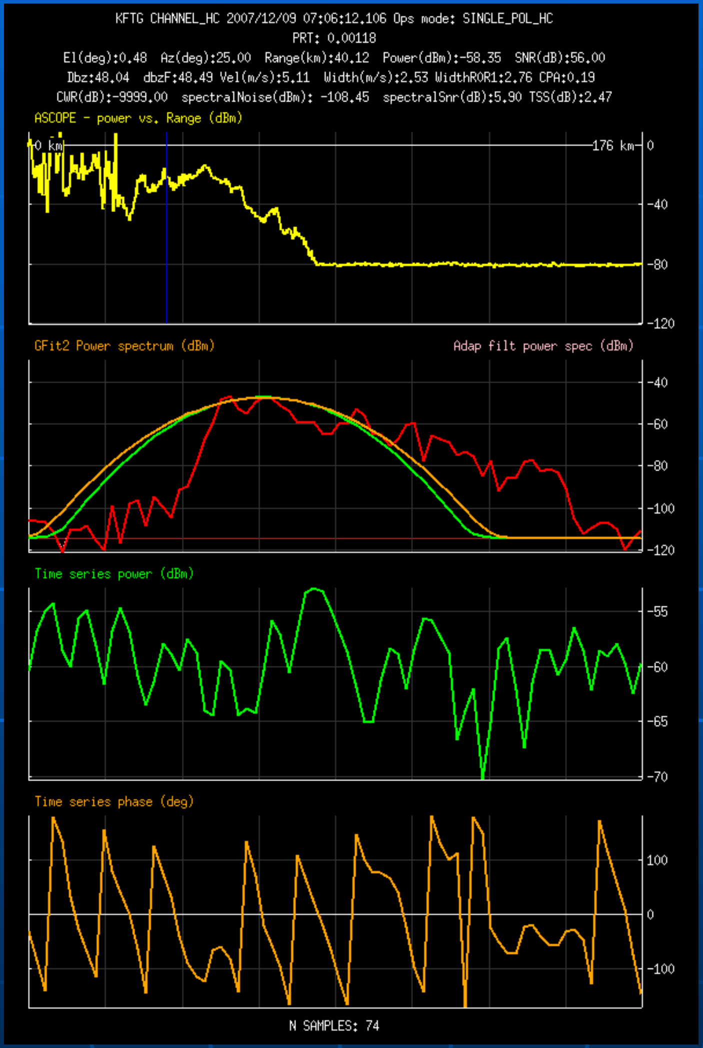
Green = Gaussian fit using Hybrid

Brown = Gaussian fit using R0/R1

Comment: Wide spectrum. Both underestimating.

SPECTRA: KCRI 2007/12/09 0705Z VCP ~21, PRI 4

Spectrum Power (dbM)



Red = Empirical Spectrum

Green = Gaussian fit using Hybrid

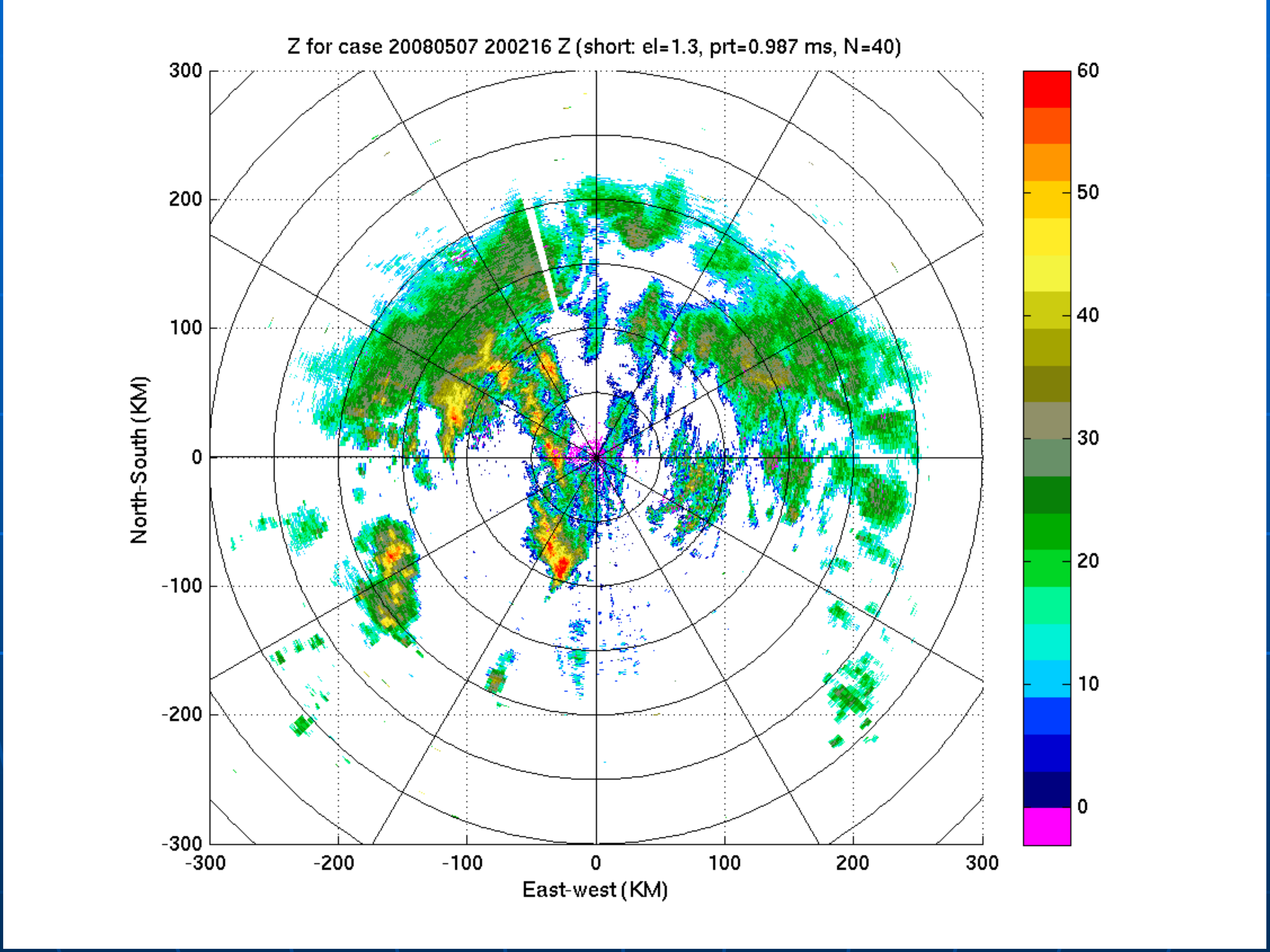
Brown = Gaussian fit using R0/R1

Comment: Wide spectrum. Both doing OK.

"Strong storms were embedded in stratiform precip all day…. Ap began at 2022Z and lasted until at least 2246Z."

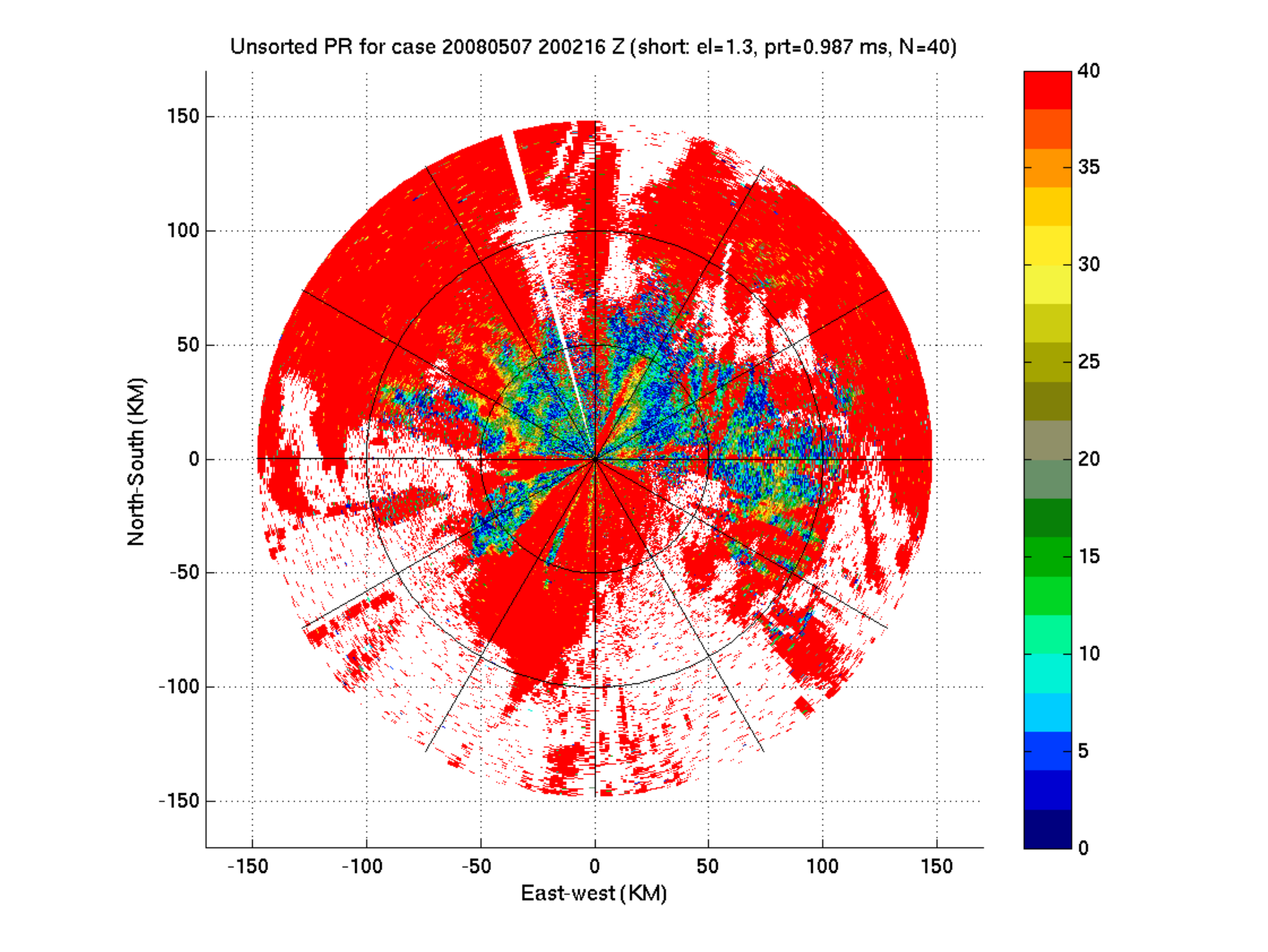
CASE 4: KCRI 2008/05/07 2000Z VCP 12, PRI 5

Z: KCRI 2008/05/07 2000Z VCP 12, PRI 5

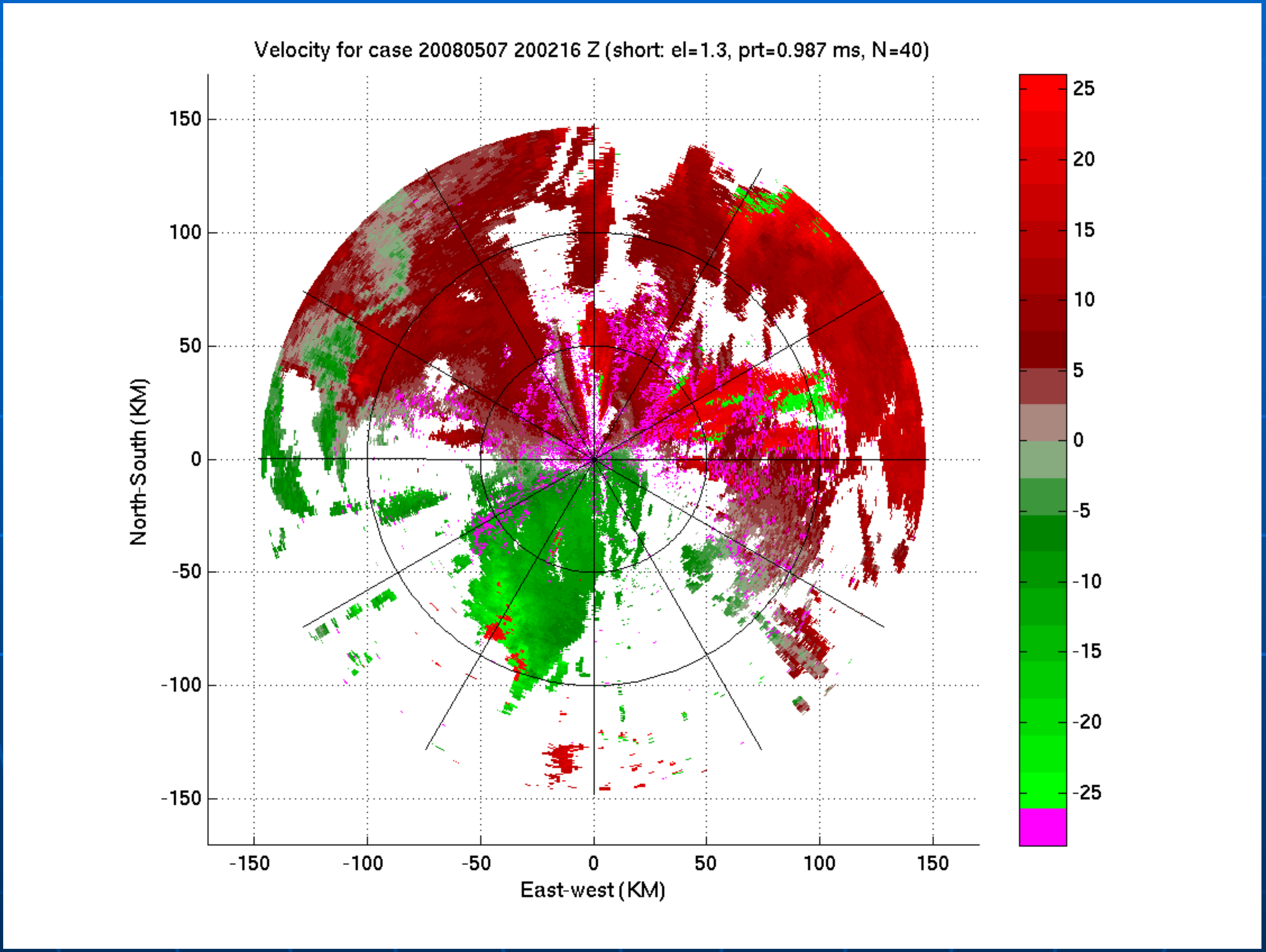


NCAR

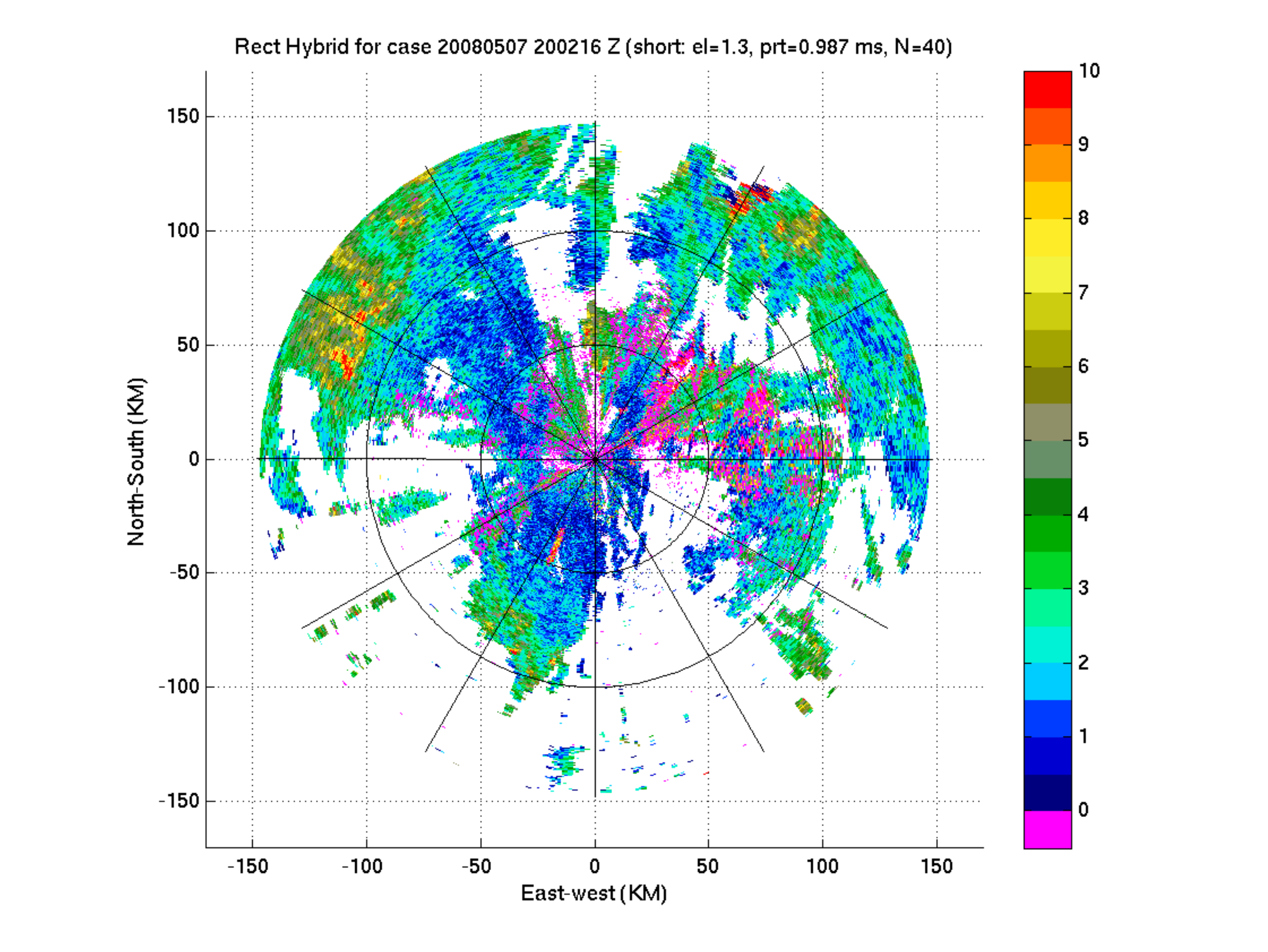
POWER RATIO: KCRI 2008/05/07 2000Z VCP 12, PRI 5



V: KCRI 2008/05/07 2000Z VCP 12, PRI 5

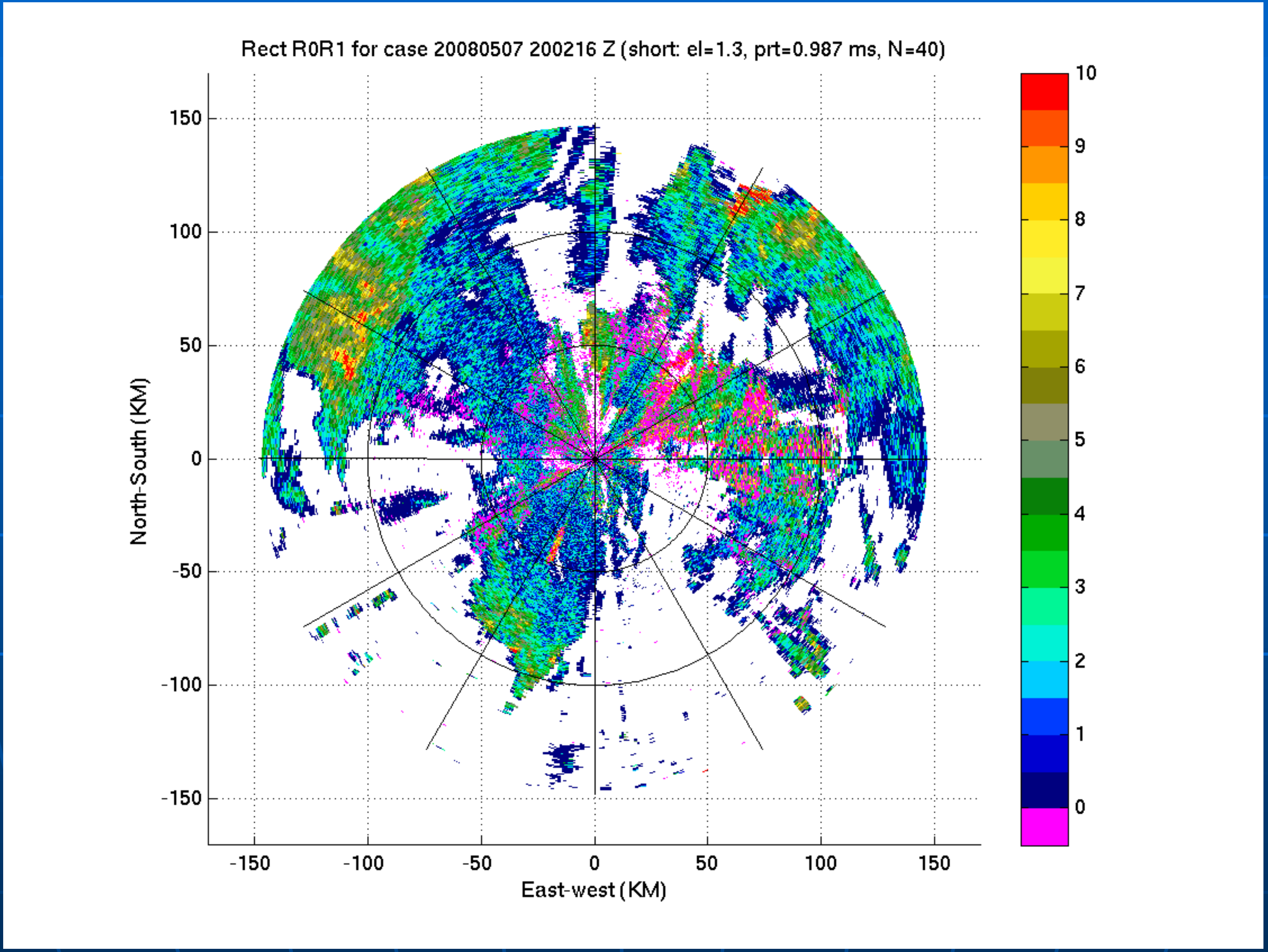


HYBRID: KCRI 2008/05/07 2000Z VCP 12, PRI 5



NCAR

R0/R1: KCRI 2008/05/07 2000Z VCP 12, PRI 5

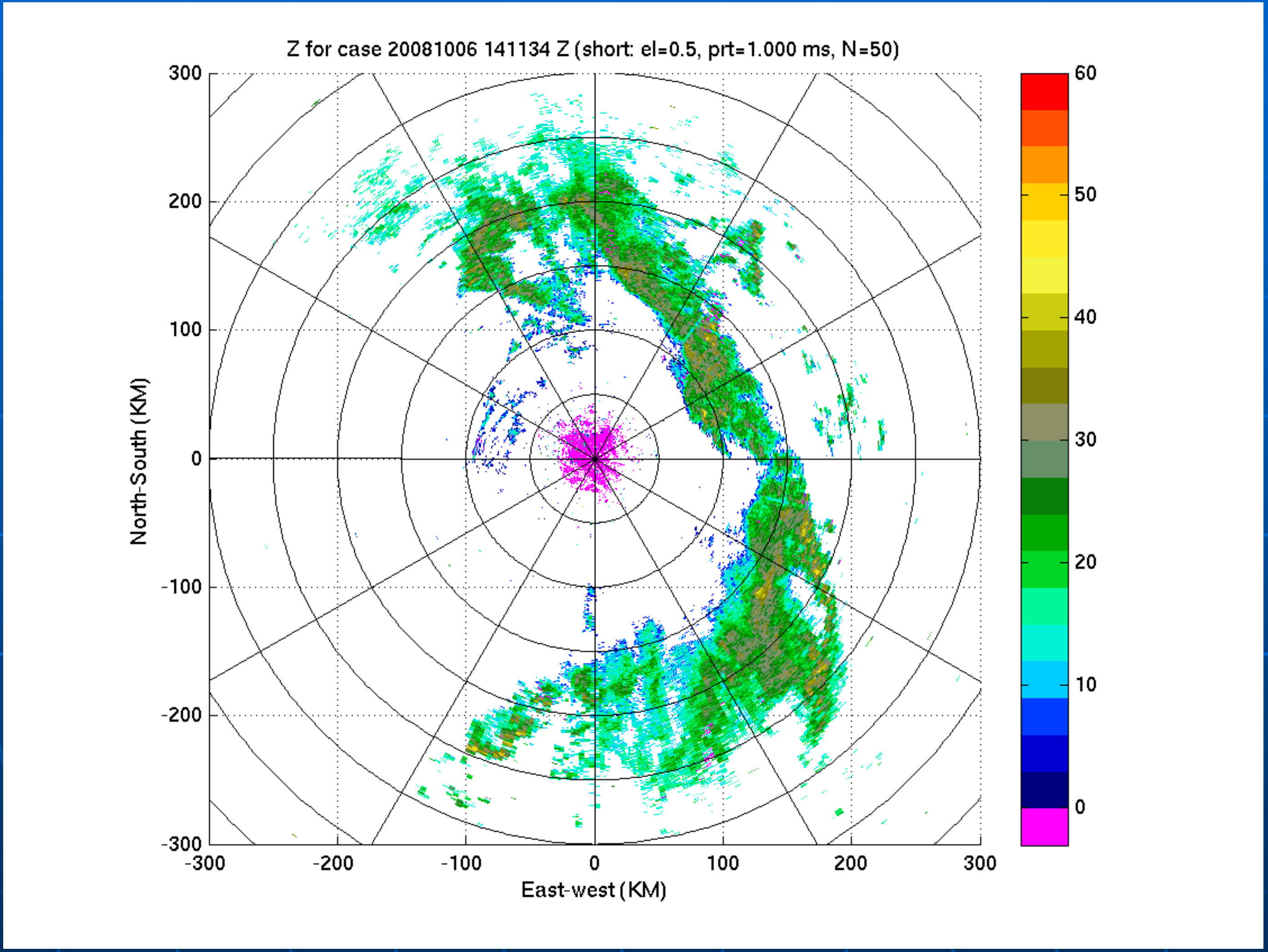


NCAR

“At beginning of data collection period, a strong cold front was located in western OK. Convective storms and widespread rain developed along and ahead of the advancing cold front.”

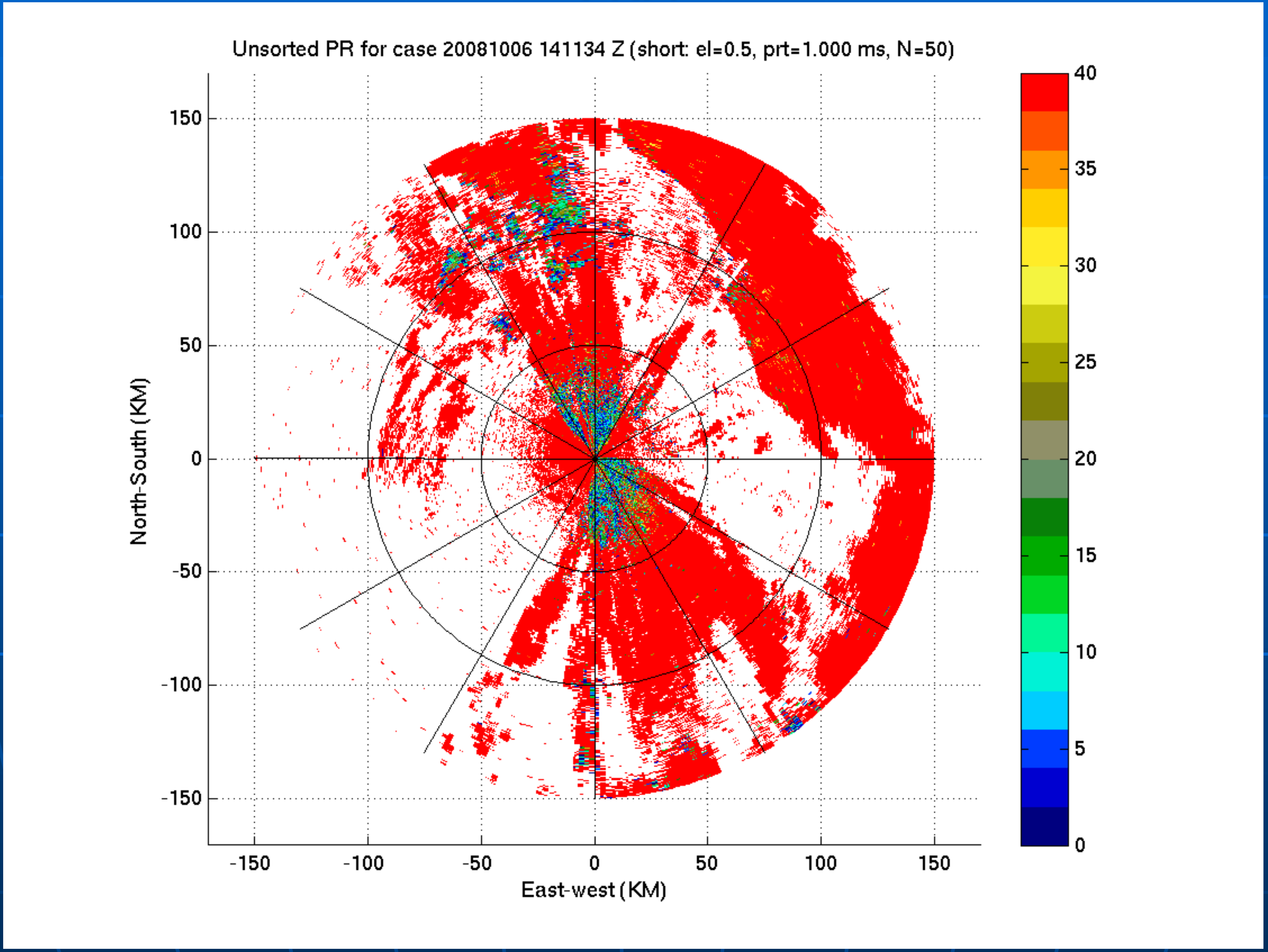
CASE 5: KOUN 2008/10/06 1410Z VCP 11, PRI 7

Z: KOUN 2008/10/06 1410Z VCP 11, PRI 7



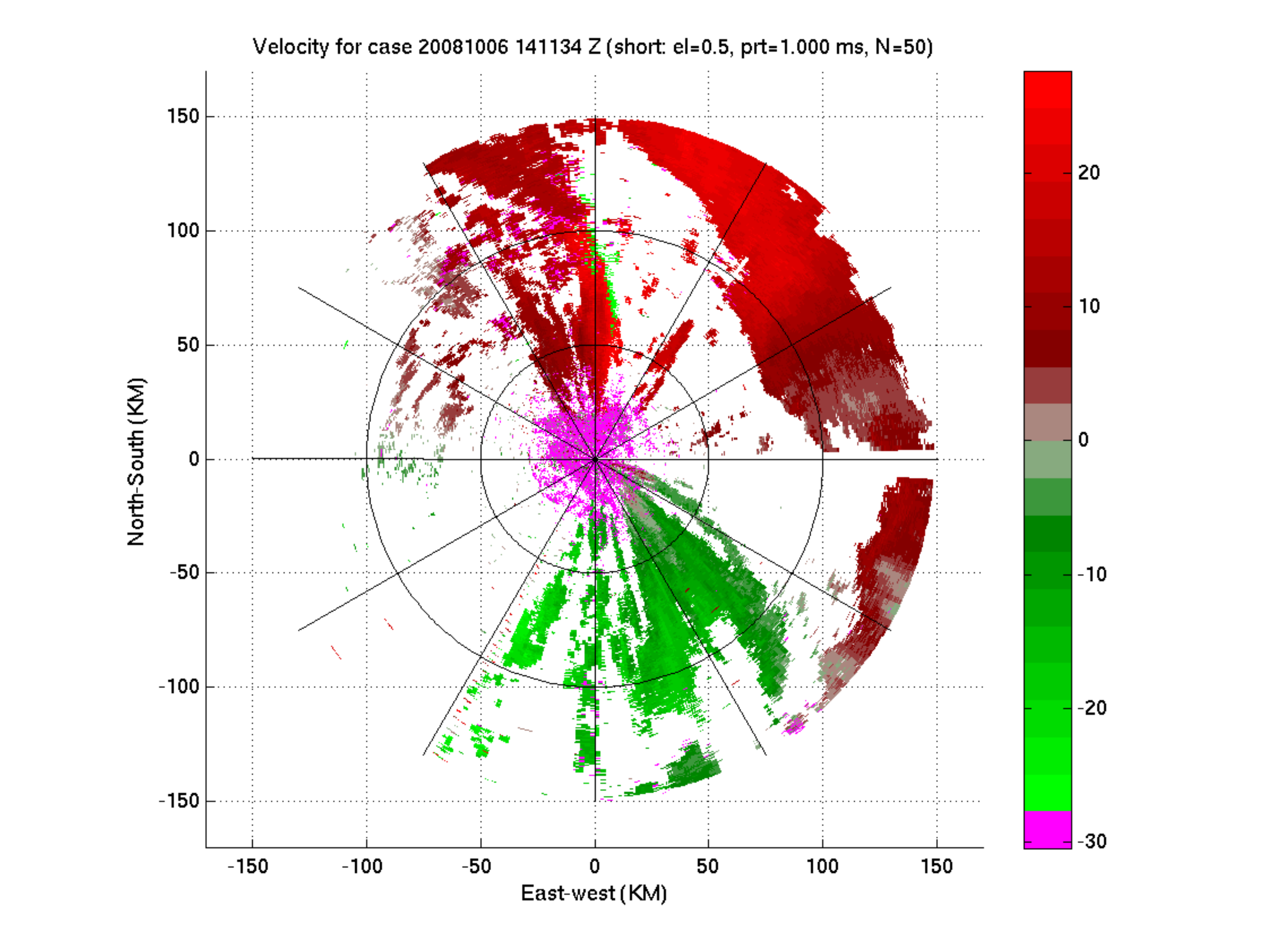
NCAR

POWER RATIO: KOUN 2008/10/06 1410Z VCP 11, PRI 7



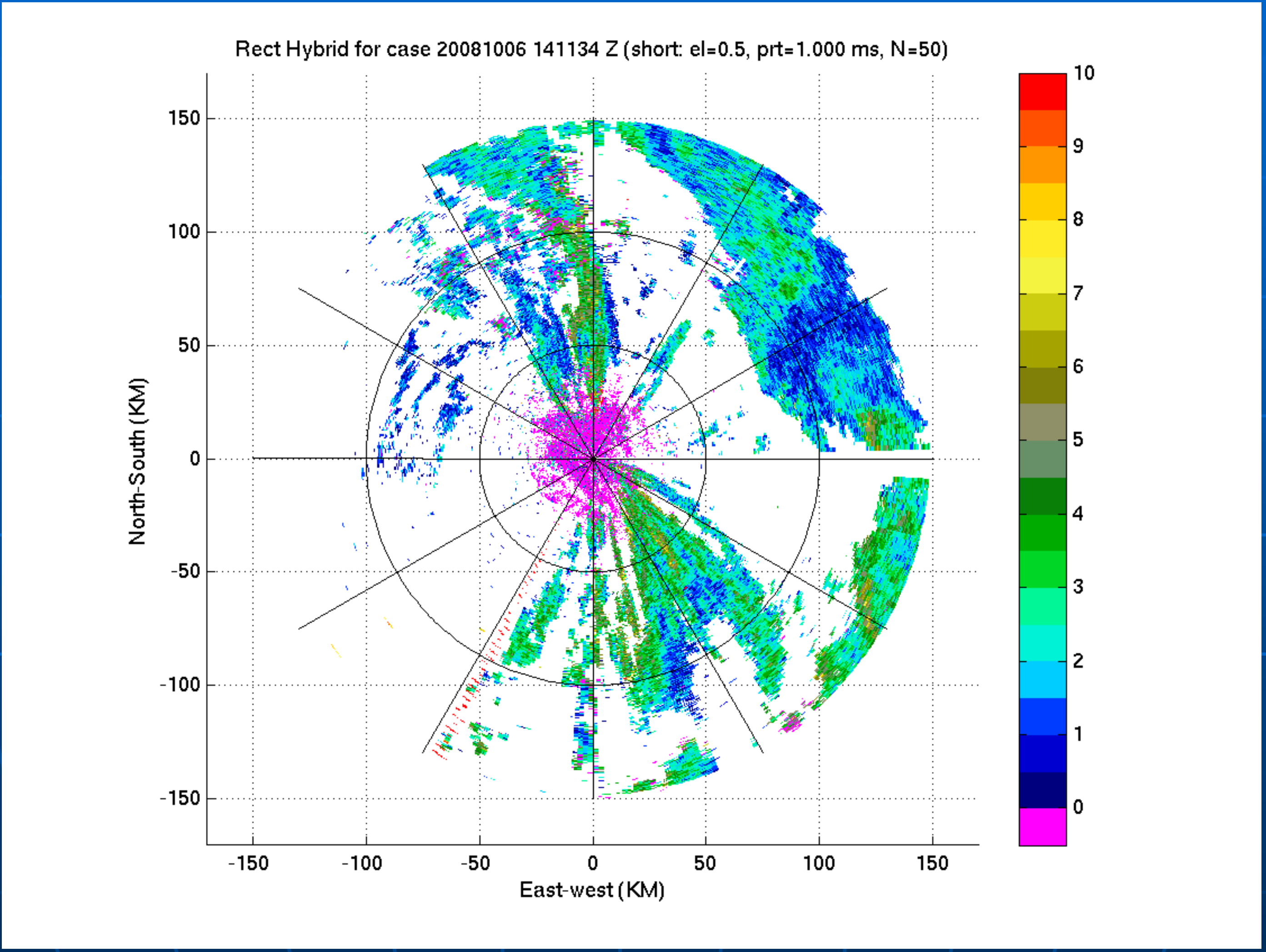
NCAR

V: KOUN 2008/10/06 1410Z VCP 11, PRI 7



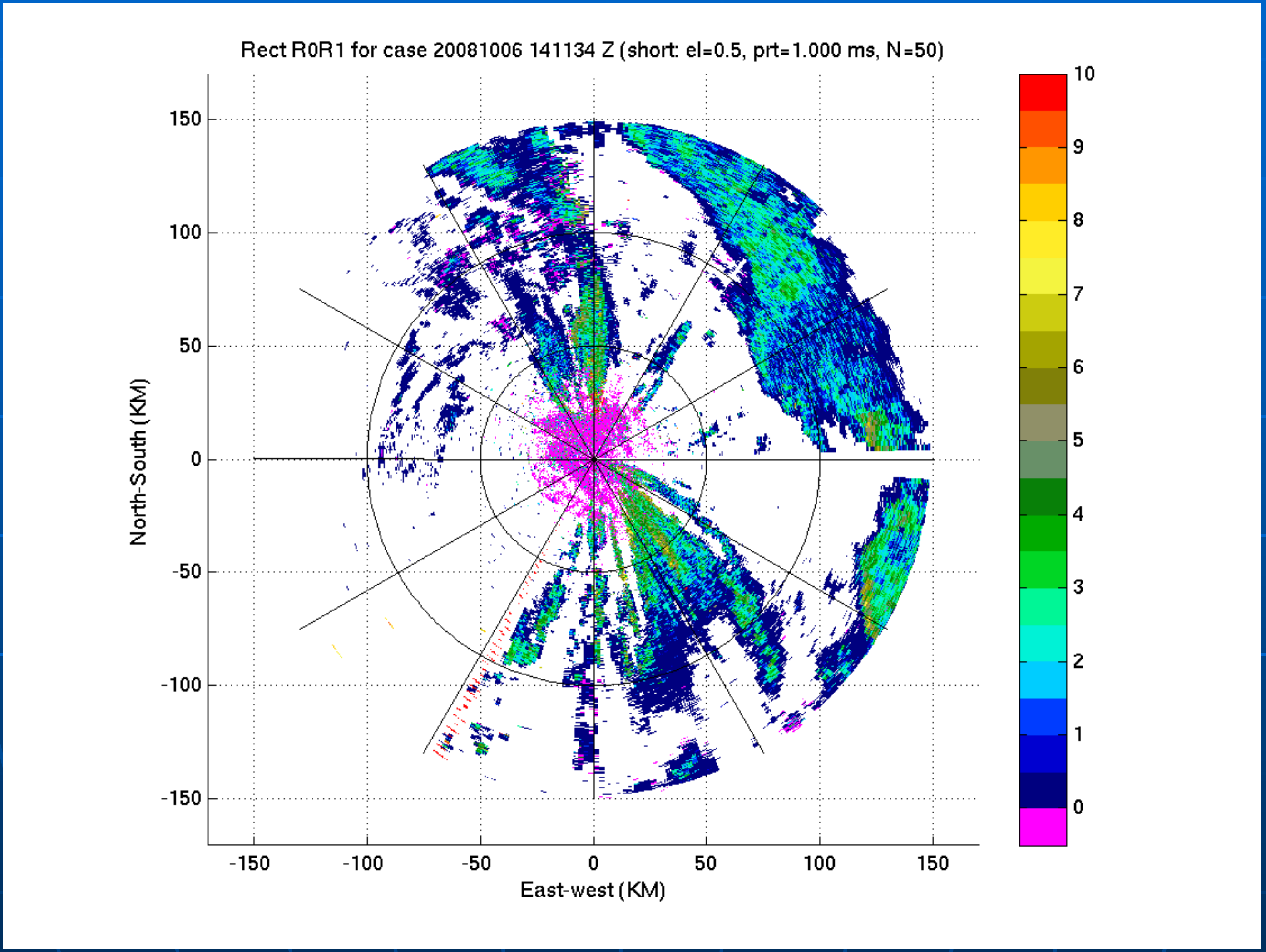
NCAR

HYBRID: KOUN 2008/10/06 1410Z VCP 11, PRI 7



NCAR

R0/R1: KOUN 2008/10/06 1410Z VCP 11, PRI 7



Summary and Conclusions

- Pulse Pair R0/R1 performs poorly for low SNRs and/or small spectrum widths.
- Proposed hybrid estimator generally outperforms the R0/R1.
  - Much lower biases and lower variances for low SNR’s and small spectrum widths.
  - Relatively insensitive to overlaid echoes.
  - Occasionally performs worse (e.g. very non-Gaussian spectra), but overall benefit outweighs cost.
- Computational complexity, impact on estimator run-time is minimal.
- Improved performance means greater coverage of usable SWs (e.g. for NTDA)
  - Significant aviation user benefit since aircraft frequently fly in low-reflectivity clouds.

Recommendation

- Implement the proposed hybrid spectrum width estimator discussed in this presentation to replace the existing pulse-pair (R0/R1) estimator (where used)

Questions?

EXTRAS

One Note:

- All work presented here presupposes the changes suggested by Torres in previous TAC meetings are implemented.
  - Linear Auto-Correlation Function (ACF) rather than circular
  - Window correction factor for ACF
  - Removal of other correction factor

EDR and turbulence severity

EDR ($m^{2/3}$ s^{-1})	SW (5 km) (m s^{-1})	SW (150 km) (m s^{-1})	Severity
0.0 – 0.1	0.0 – 0.4	0.0 – 1.2	Null
0.1 – 0.3	0.4 – 1.3	1.2 – 3.9	Light
0.3 – 0.5	1.3 – 2.2	3.9 – 6.6	Moderate
0.5 – 0.7	2.2 – 3.1	6.6 – 9.3	Severe
> *0.7*	> 3.1	> 9.3	Extreme

Accurate estimation of small spectrum widths is essential for distinguishing null from light or moderate turbulence. This is not addressed by the current SW specification.

R0/R1/R2 Least Squares Estimator

- Poly-Pulse Pair method using R0, R1, and R2
- Proposed to be used as part of hybrid estimator.

Good:

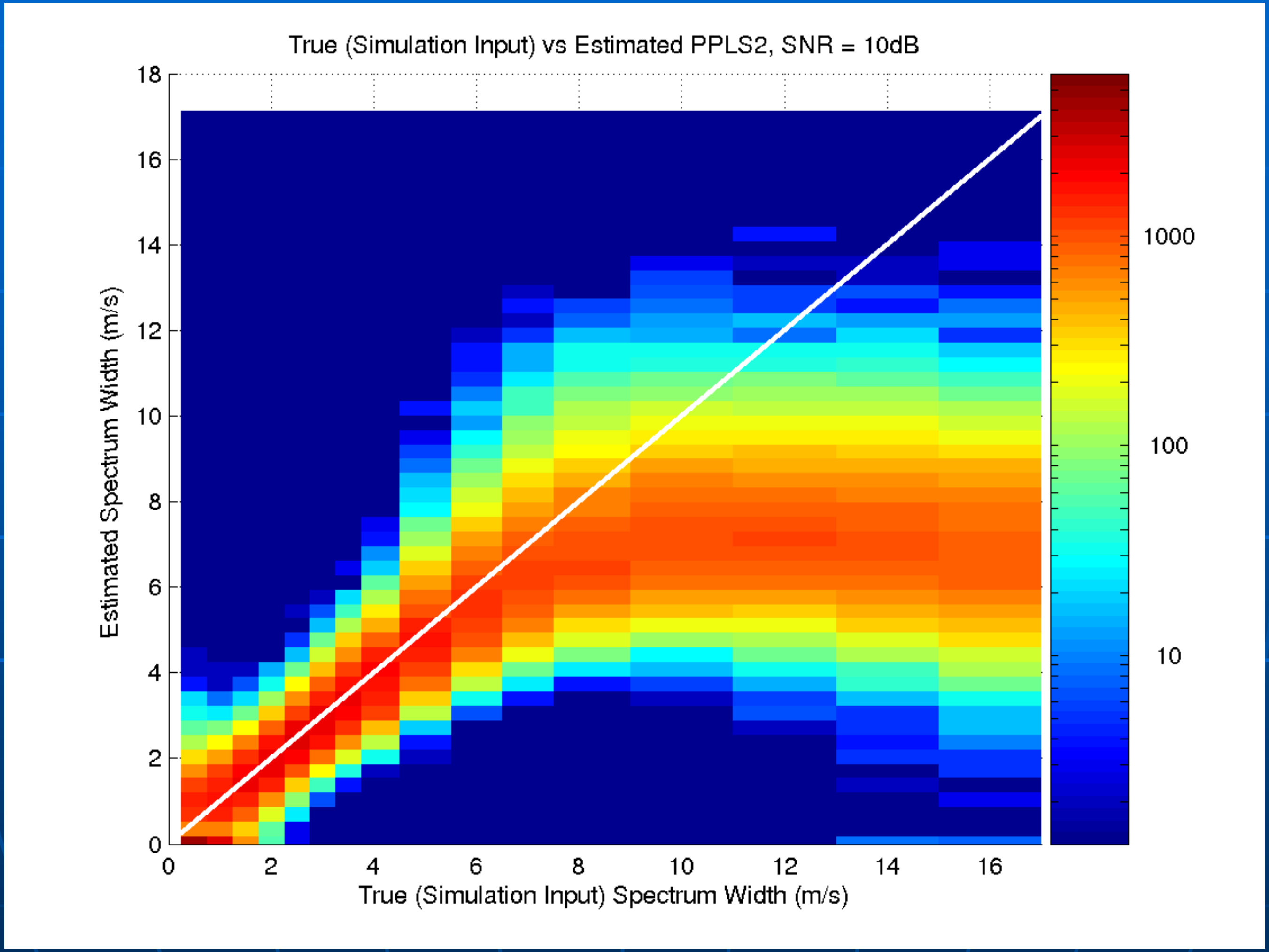
- Simple and fast
- Generally good results
- Less sensitive to estimate of noise power P_N
- Saturates more gracefully than R1/R2

Bad:

- Assumes exactly 1 Gaussian shaped signal
- Saturates for spectrum widths above ~1/3 Nyquist

PPLS2 2D Histograms – True vs. Estimated:

SNR = 10dB



Simulation Studies for Tuning and Evaluation

- Used I&Q simulator as detailed by R. Frehlich and M. J. Yadlowsky*
- Varied SNR's, N, PRT's and input ("true") spectrum widths
- Computed estimator bias and standard deviation using 10000 time-series per scenario

* Frehlich, R. and M. J. Yadlowsky, 1994: Performance of mean-frequency estimators for Doppler radar and LIDAR. *Journal of Atmospheric and Oceanic Technology*, 11, 1217-1230; corrigenda, 12, 445-446.

Design Issues

- Decision logic tuning must take into account that some misclassifications are worse than others.
- Large parameter space that one could optimize decision logic over (PRT, N, SNR)
- Keep it simple

Design Approach

- To simplify:
  - Work with normalized spectrum widths to mostly eliminate PRT dependence
    - PRF #8 (780 μs) is *still* the hardest case for a given N and SNR so this PRT is used for tuning the decision logic.
  - Tuned using SNR=12 dB

Tuning Methodology

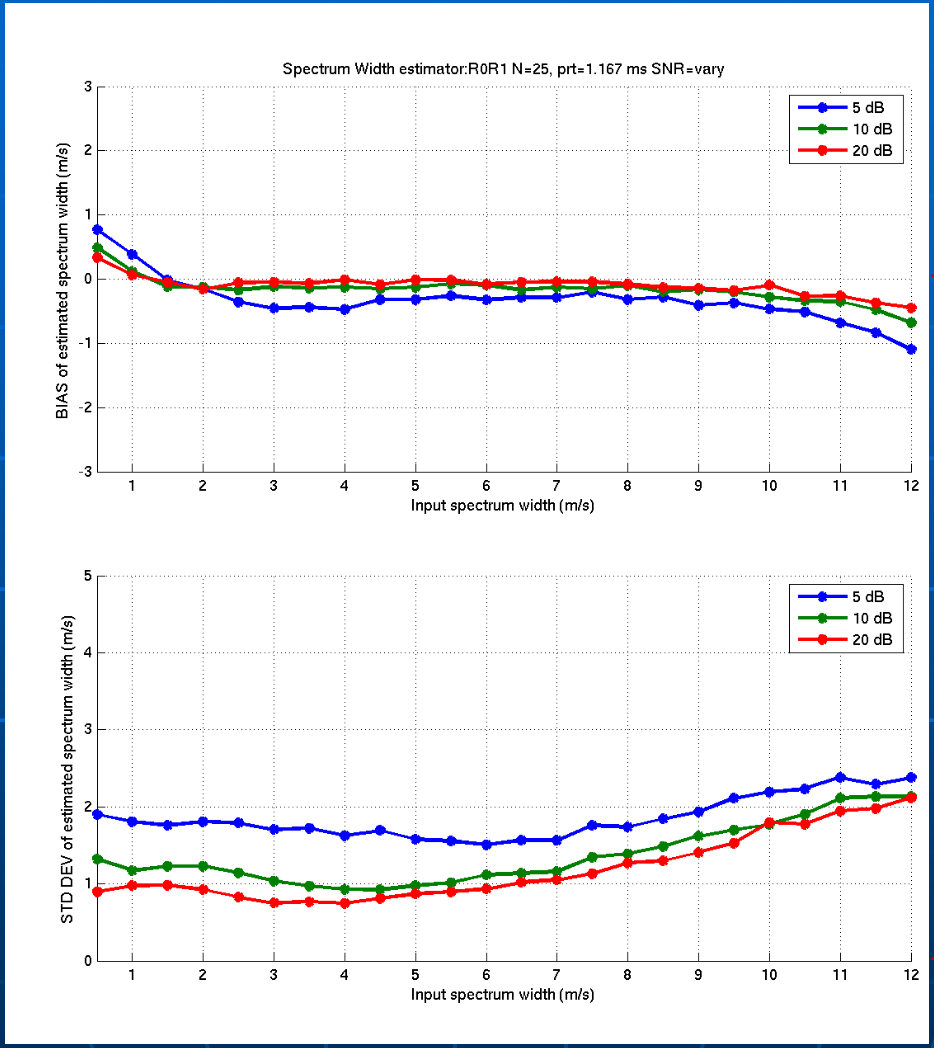
- For each N, input W, (SNR=12, PRT= 780 μs) simulate 10000 time-series.
- For each time-series calculate 10 different spectrum width estimators as well as its "category" (from true W)
- Throw estimators and classification into Decision Tree
  - Tries to find which estimator works the best as well as the "optimal" cutoffs to use.
  - Used cost matrix to weight the different misclassifications differently

SIMULATIONS FOR VCPS 12, 11, 21, 31, AND 32 (WINDOWED)

R0/R1 VCP 12, PRI 4

Bias (m/s)

Std (m/s)



Vertical Ticks 1 m/s

Optimal

Horizontal Ticks 2 m/s

Vertical Ticks 1 m/s

Optimal

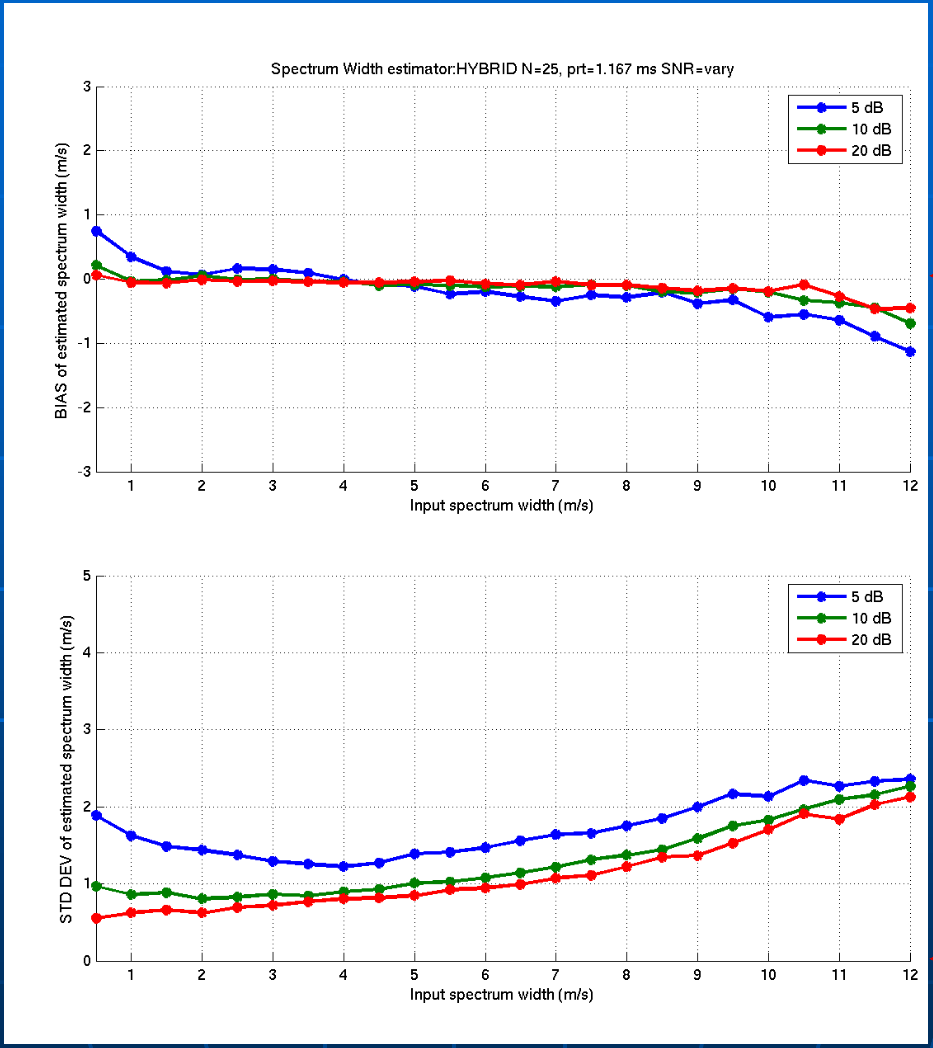
Input W (m/s)

NCAR

Hybrid VCP 12, PRI 4

Bias (m/s)

Std (m/s)



Vertical Ticks 1 m/s

Optimal

Horizontal Ticks 2 m/s

Vertical Ticks 1 m/s

Optimal

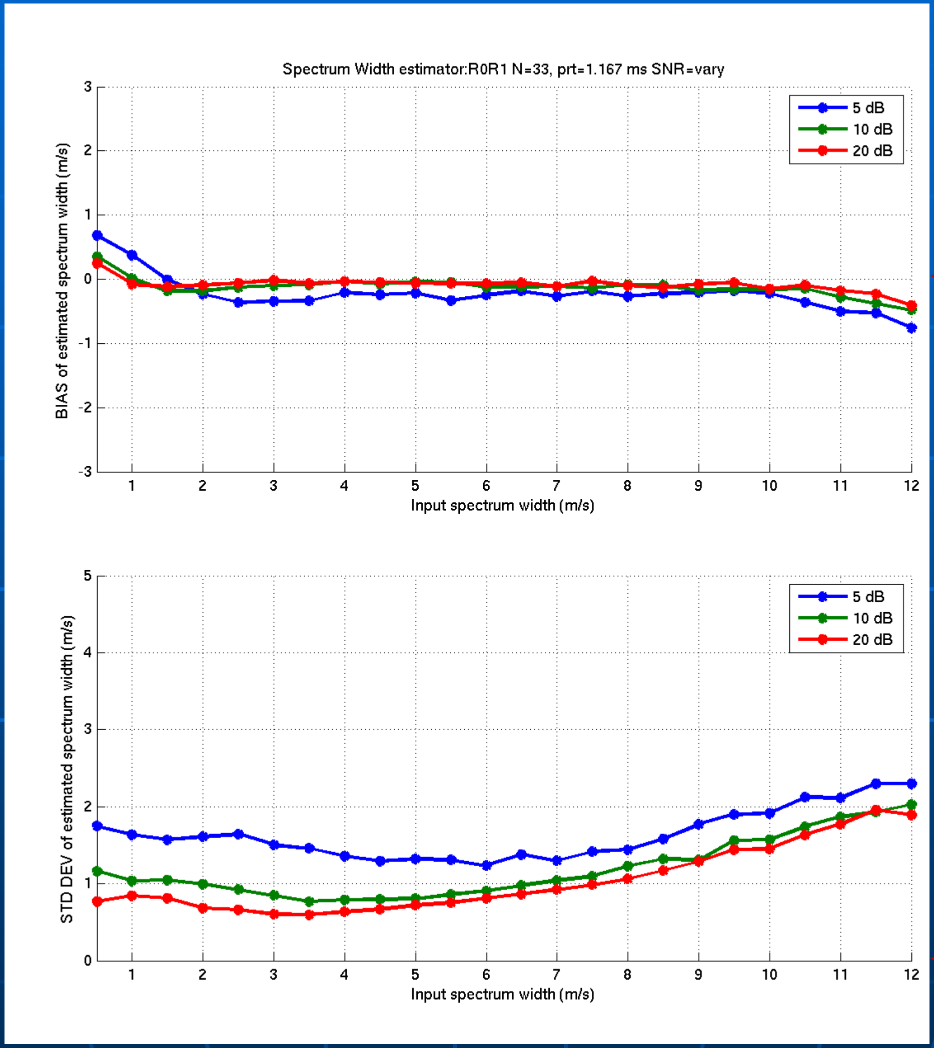
Input W (m/s)

NCAR

R0/R1 VCP 11, PRI 4

Bias (m/s)

Std (m/s)



Vertical Ticks 1 m/s

Optimal

Horizontal Ticks 2 m/s

Vertical Ticks 1 m/s

Optimal

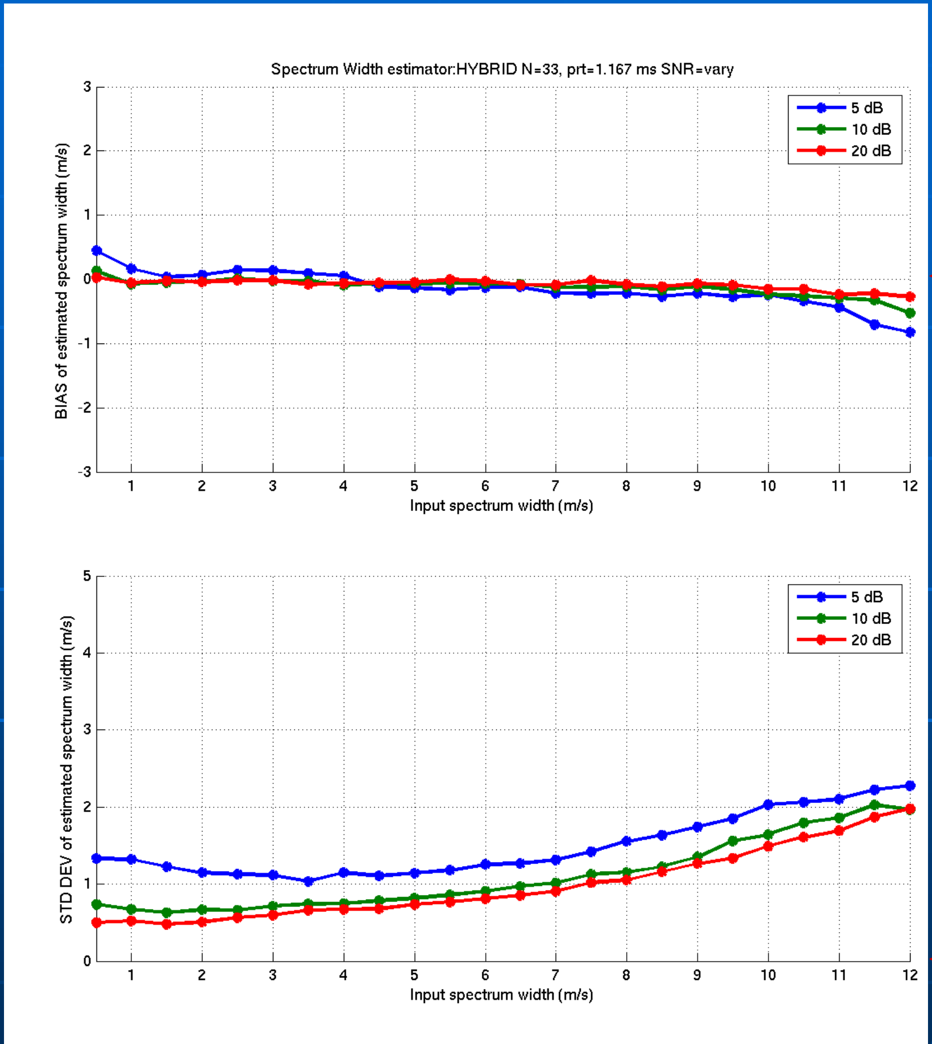
Input W (m/s)

NCAR

Hybrid VCP 11, PRI 4

Bias (m/s)

Std (m/s)



Vertical Ticks 1 m/s

Optimal

Horizontal Ticks 2 m/s

Vertical Ticks 1 m/s

Optimal

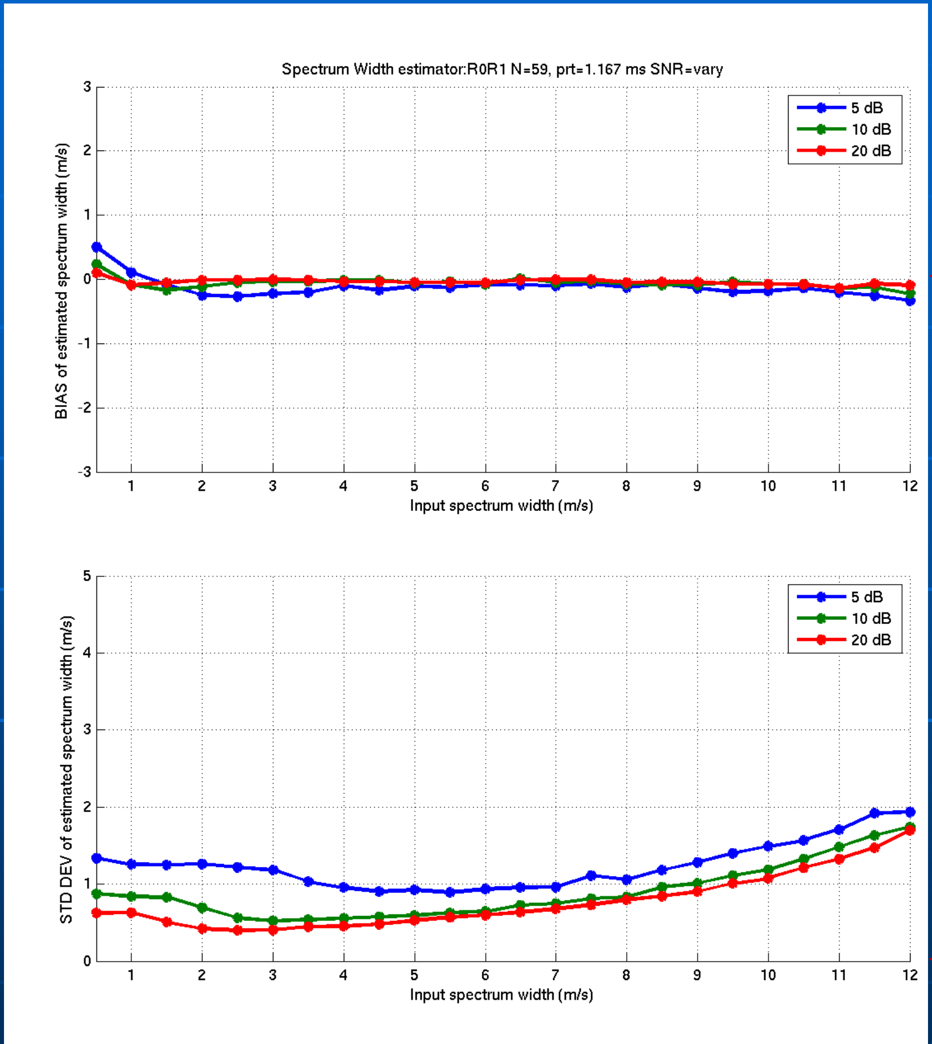
Input W (m/s)

NCAR

R0/R1 VCP 21, PRI 4

Bias (m/s)

Std (m/s)



Vertical Ticks 1 m/s

Optimal

Horizontal Ticks 2 m/s

Vertical Ticks 1 m/s

Optimal

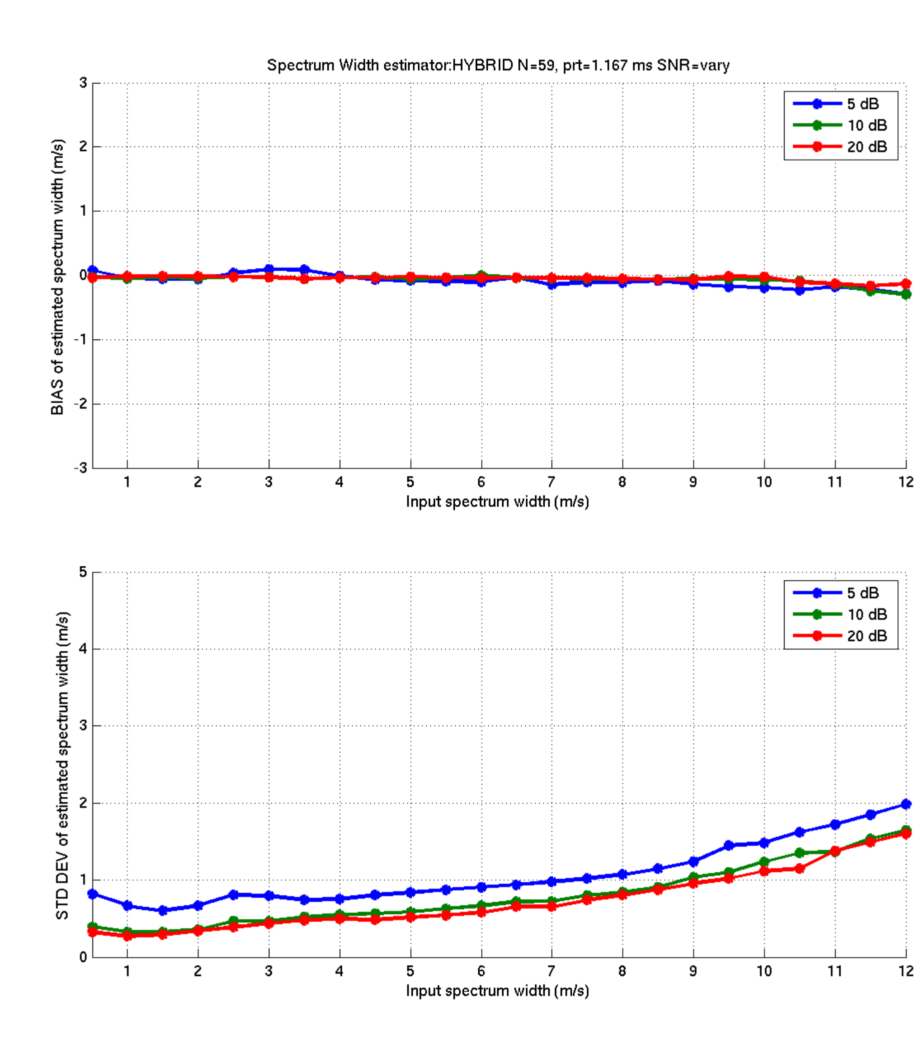
Input W (m/s)

NCAR

Hybrid VCP 21, PRI 4

Bias (m/s)

Std (m/s)



Vertical Ticks 1 m/s

Optimal

Horizontal Ticks 2 m/s

Vertical Ticks 1 m/s

Optimal

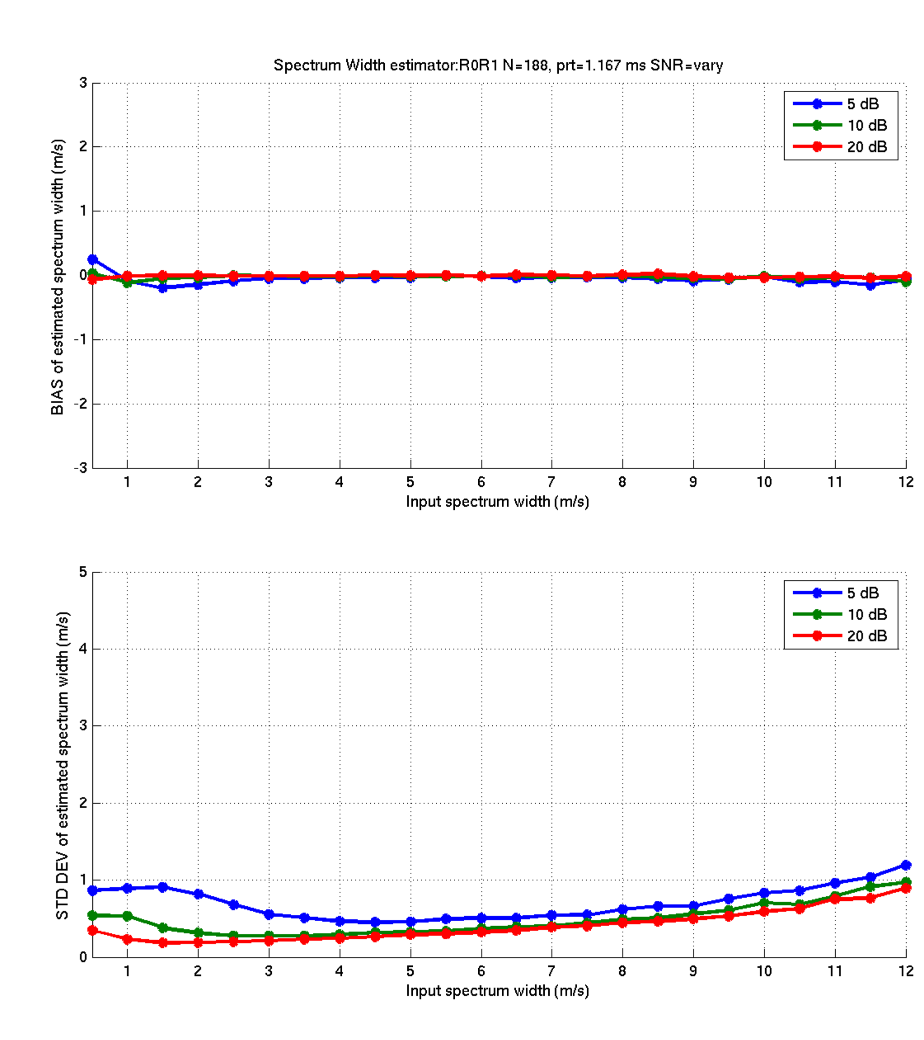
Input W (m/s)

NCAR

R0/R1 VCP 32, PRI 4

Bias (m/s)

Std (m/s)



Vertical Ticks 1 m/s

Optimal

Horizontal Ticks 2 m/s

Vertical Ticks 1 m/s

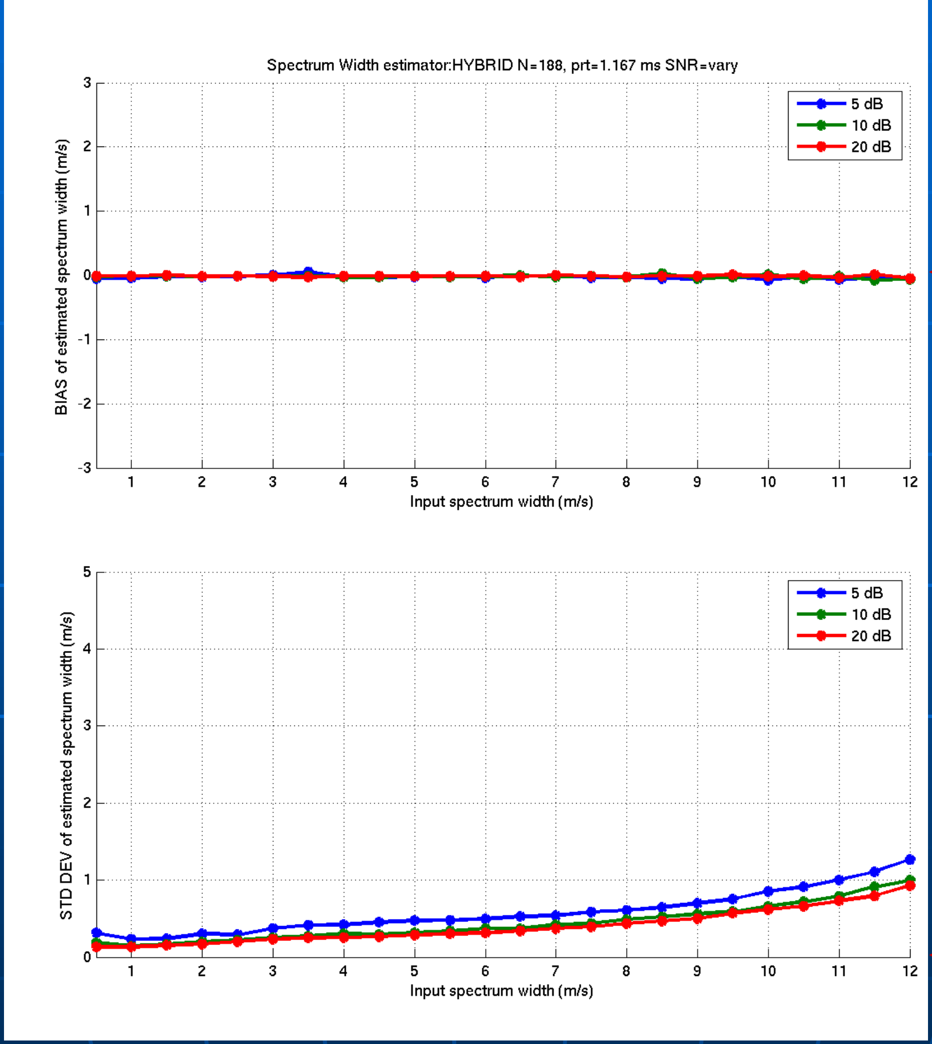
Optimal

Input W (m/s)

Hybrid VCP 32, PRI 4

Bias (m/s)

Std (m/s)



Vertical Ticks 1 m/s

Optimal

Horizontal Ticks 2 m/s

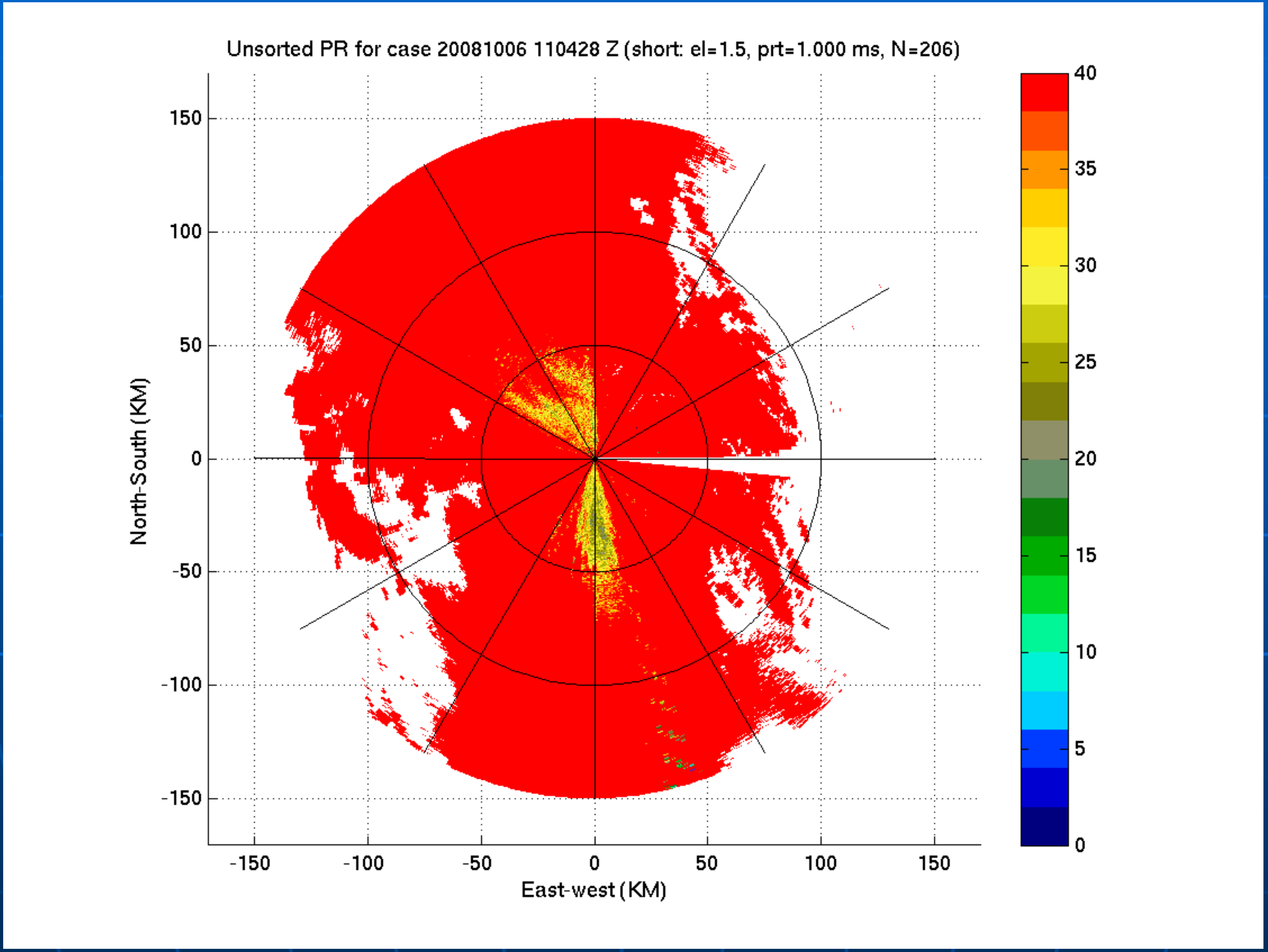
Vertical Ticks 1 m/s

Optimal

Input W (m/s)

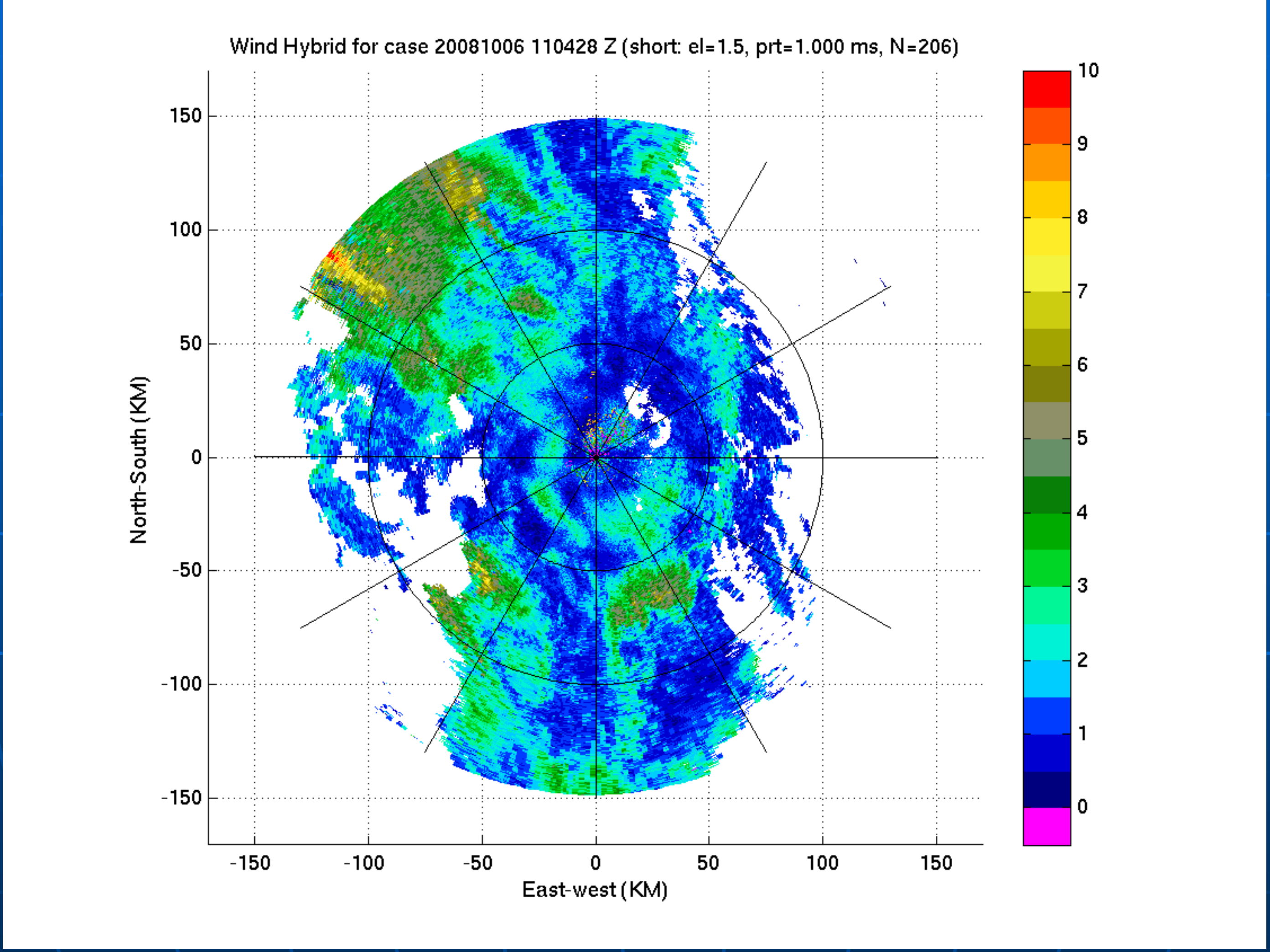
NCAR

CASE 1: KOUN 2008/10/06 1100Z VCP 32, PRI 5

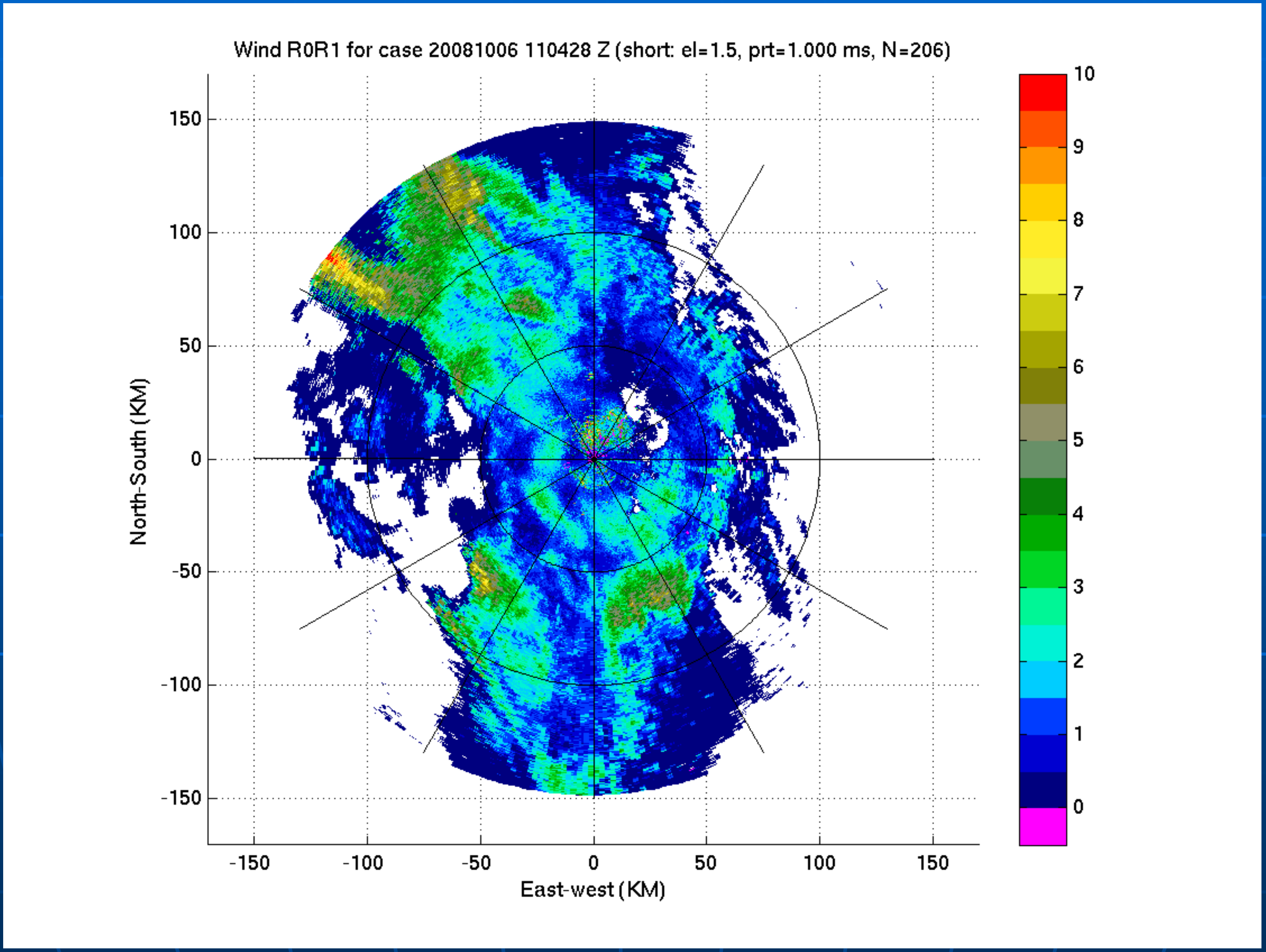


Unsorted PR for case 20081006 110428 Z (short: el=1.5, prt=1.000 ms, N=206)
North-South (KM)
East-west (KM)
150
100
50
0
-50
-100
-150
-150
-100
-50
0
50
100
150
40
35
30
25
20
15
10
5
0

NCAR


Wind Hybrid for case 20081006 110428 Z (short: el=1.5, prt=1.000 ms, N=206)
North-South (KM)
East-west (KM)
150
100
50
0
-50
-100
-150
-150
-100
-50
0
50
100
150
10
9
8
7
6
5
4
3
2
1
0

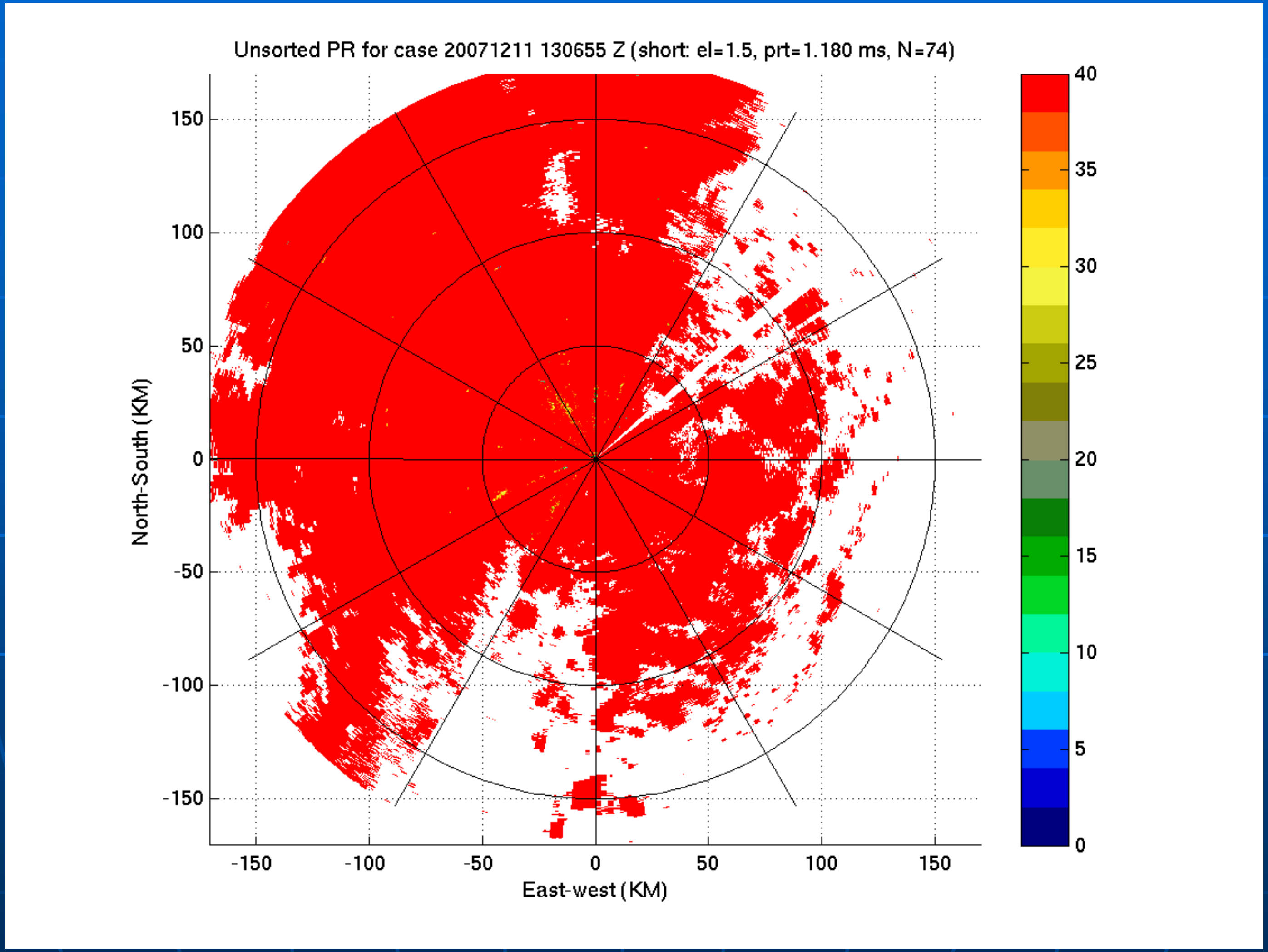
NCAR



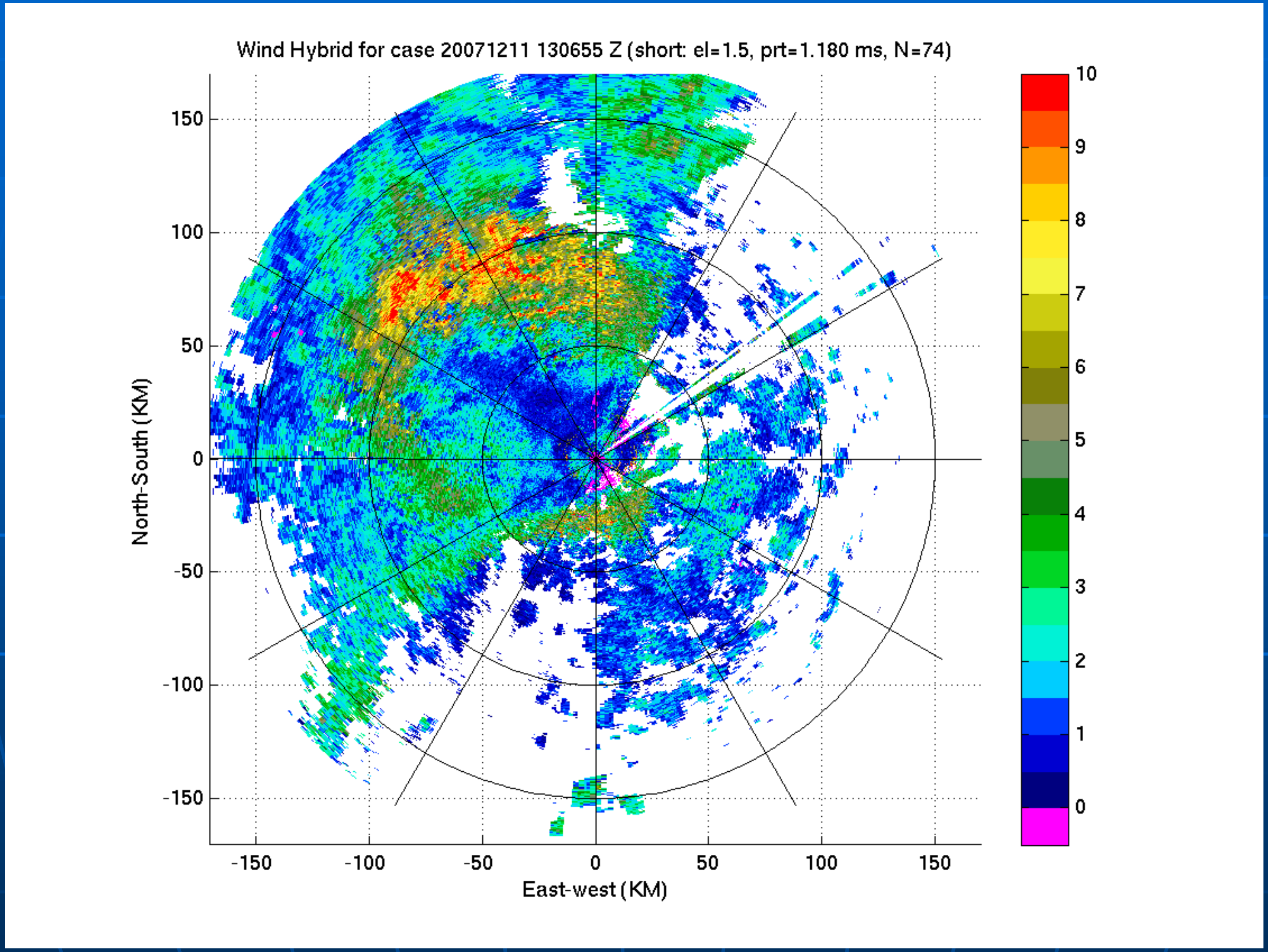
Wind R0R1 for case 20081006 110428 Z (short: el=1.5, prt=1.000 ms, N=206)
North-South (KM)
East-west (KM)
150
100
50
0
-50
-100
-150
10
9
8
7
6
5
4
3
2
1
0

NCAR

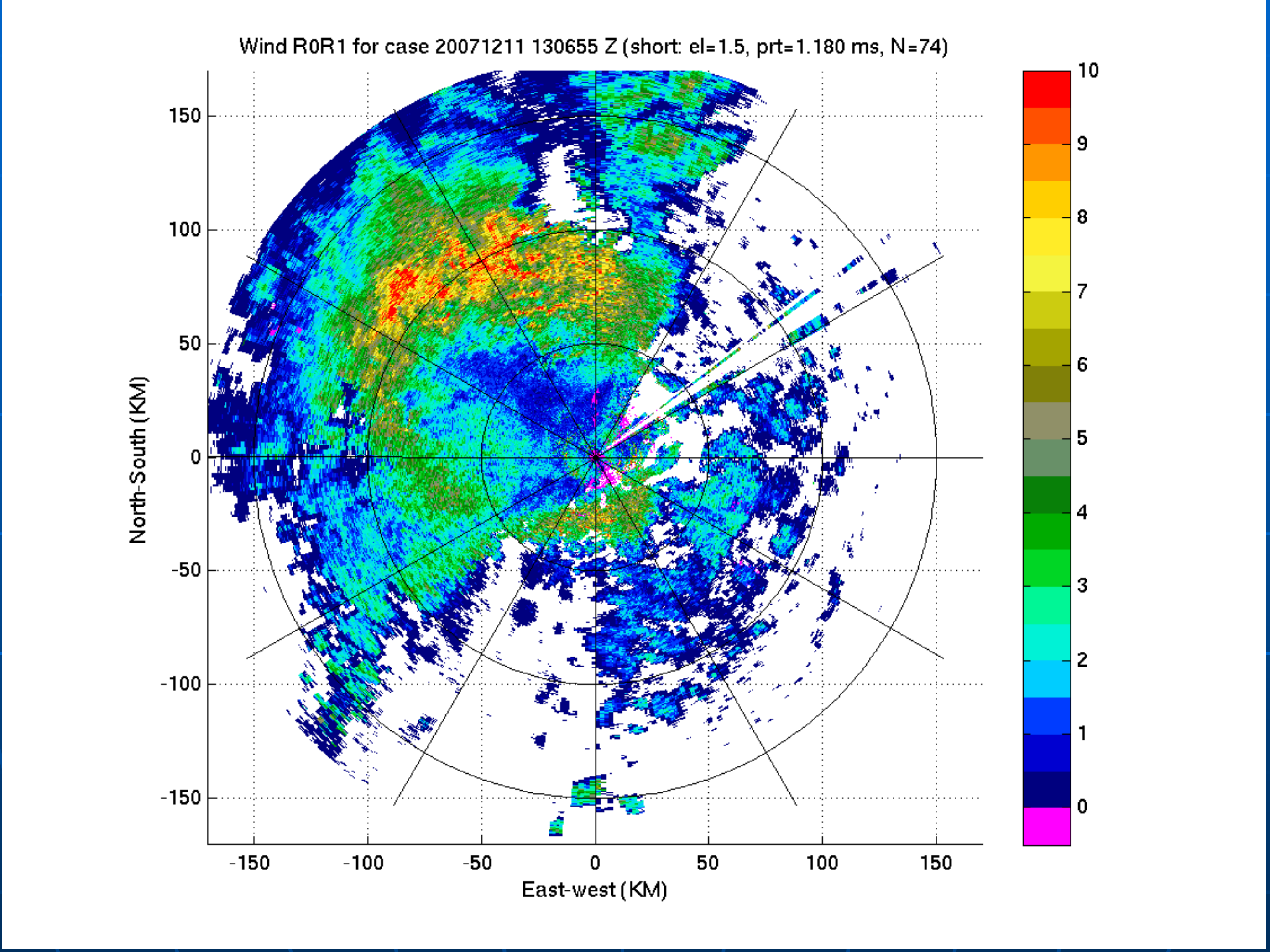
CASE 2: KCRI 2007/12/11 1302Z VCP 22 (LIKE 21), PRI 4


Unsorted PR for case 20071211 130655 Z (short: el=1.5, prt=1.180 ms, N=74)
North-South (KM)
East-west (KM)
150
100
50
0
-50
-100
-150
-150
-100
-50
0
50
100
150
40
35
30
25
20
15
10
5
0

NCAR



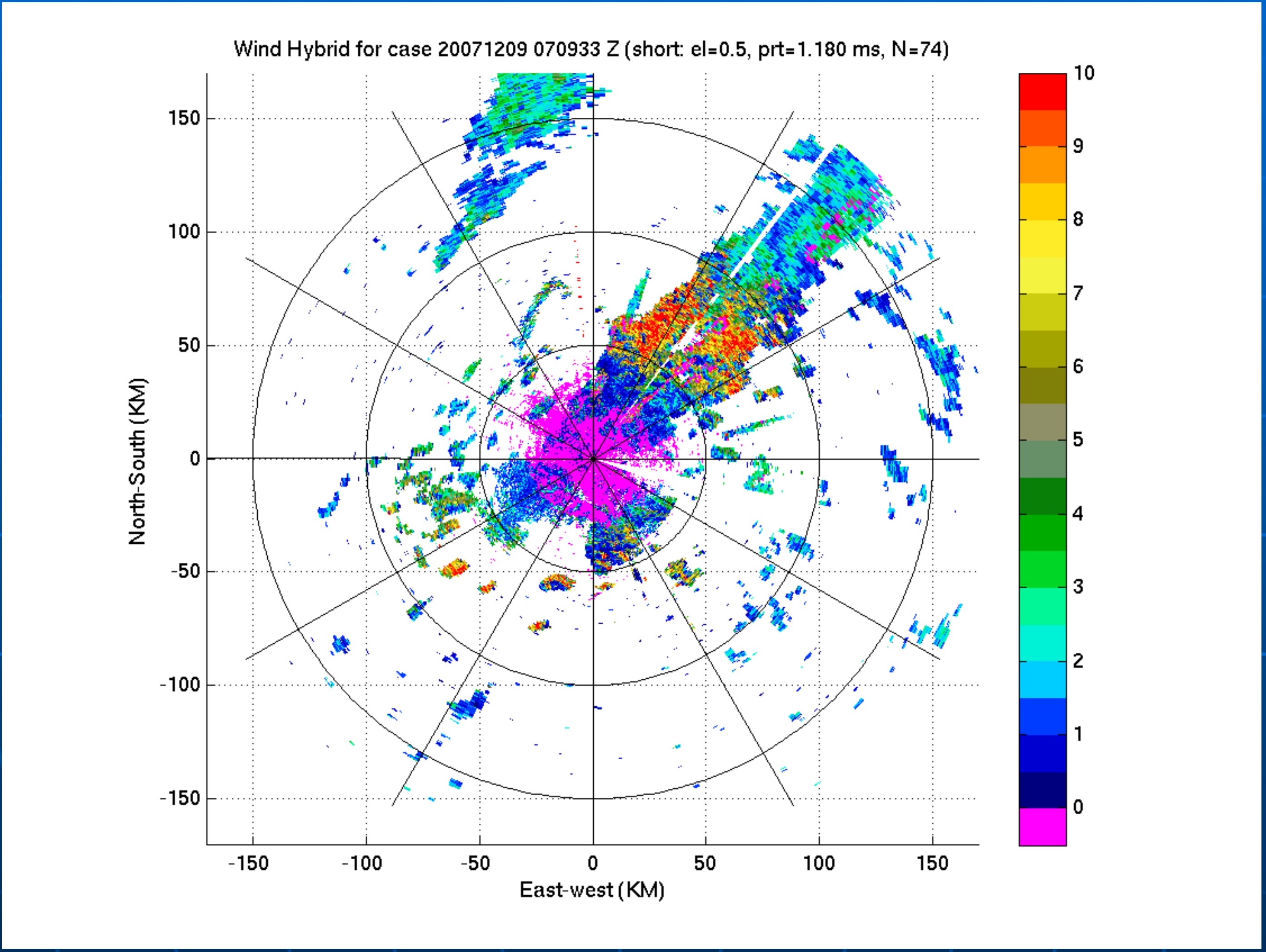
Wind Hybrid for case 20071211 130655 Z (short: el=1.5, prt=1.180 ms, N=74)
North-South (KM)
East-west (KM)
150
100
50
0
-50
-100
-150
-150
-100
-50
0
50
100
150
10
9
8
7
6
5
4
3
2
1
0
0



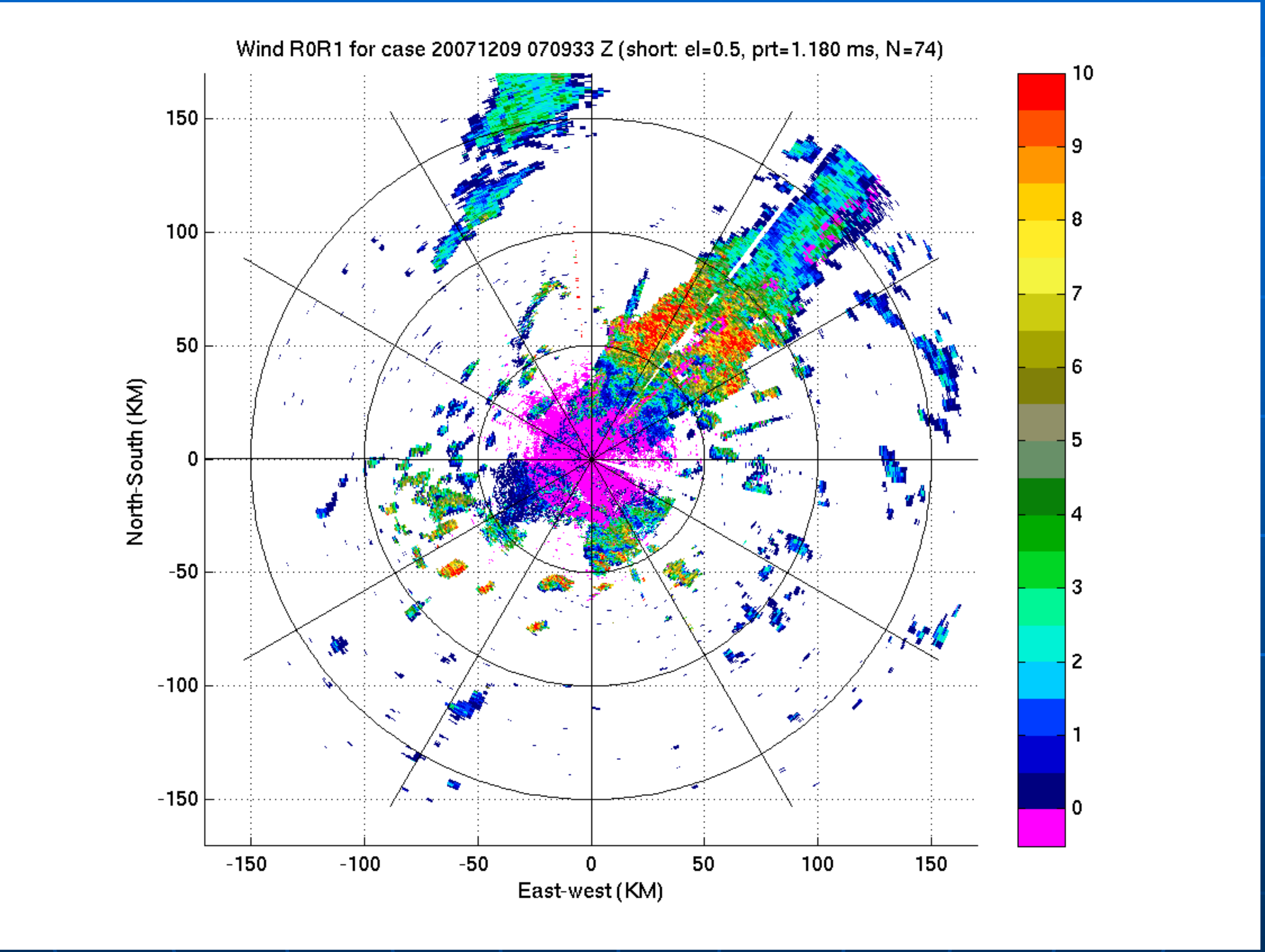
Wind R0R1 for case 20071211 130655 Z (short: el=1.5, prt=1.180 ms, N=74)
North-South (KM)
East-west (KM)
150
100
50
0
-50
-100
-150
10
9
8
7
6
5
4
3
2
1
0

NCAR

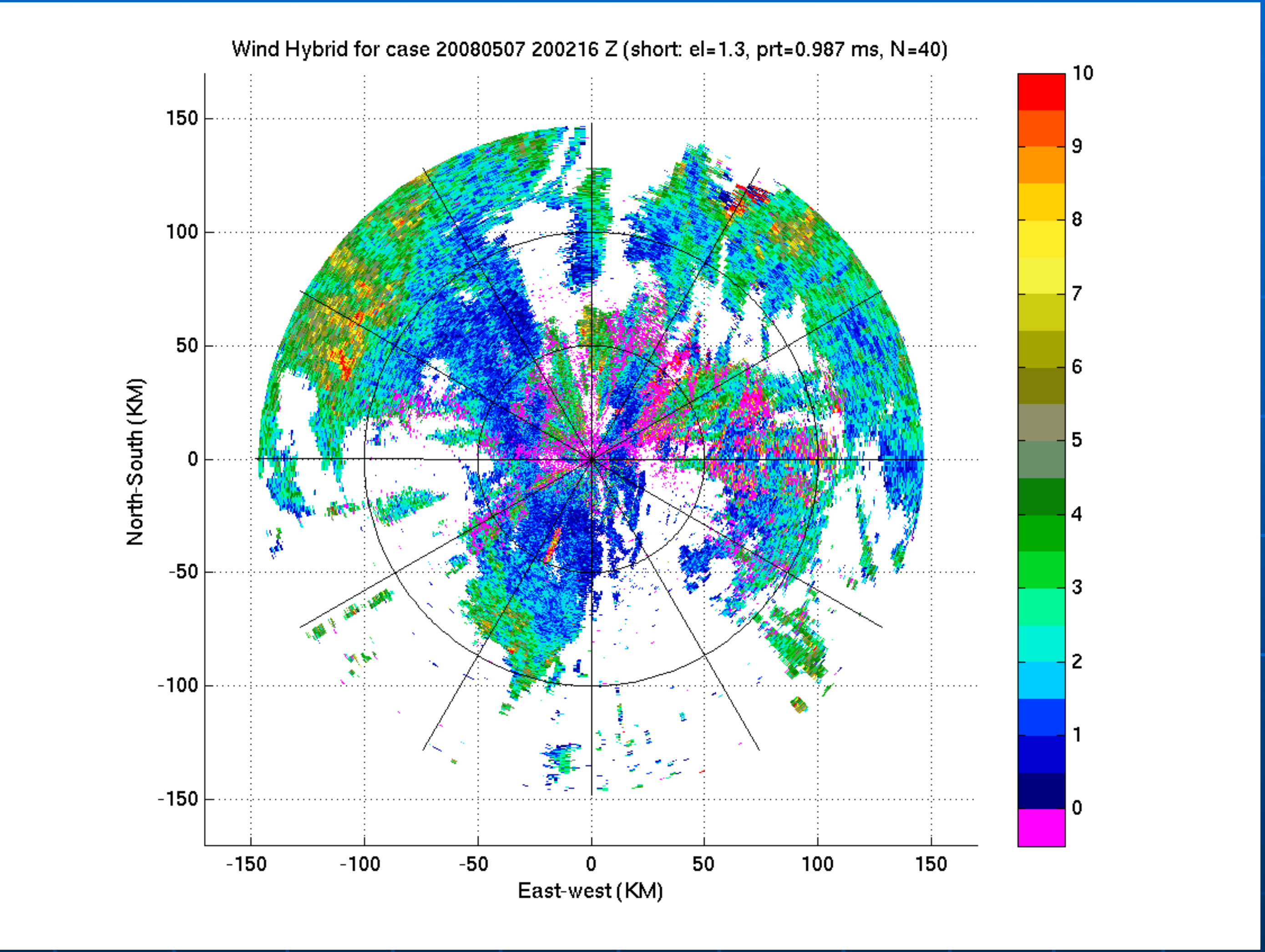
CASE 3: KCRI 2007/12/09 0705Z VCP 22 (LIKE 21), PRI 4


Wind Hybrid for case 20071209 070933 Z (short: el=0.5, prt=1.180 ms, N=74)
North-South (KM)
East-west (KM)
150
100
50
0
-50
-100
-150
-150
-100
-50
0
50
100
150
10
9
8
7
6
5
4
3
2
1
0

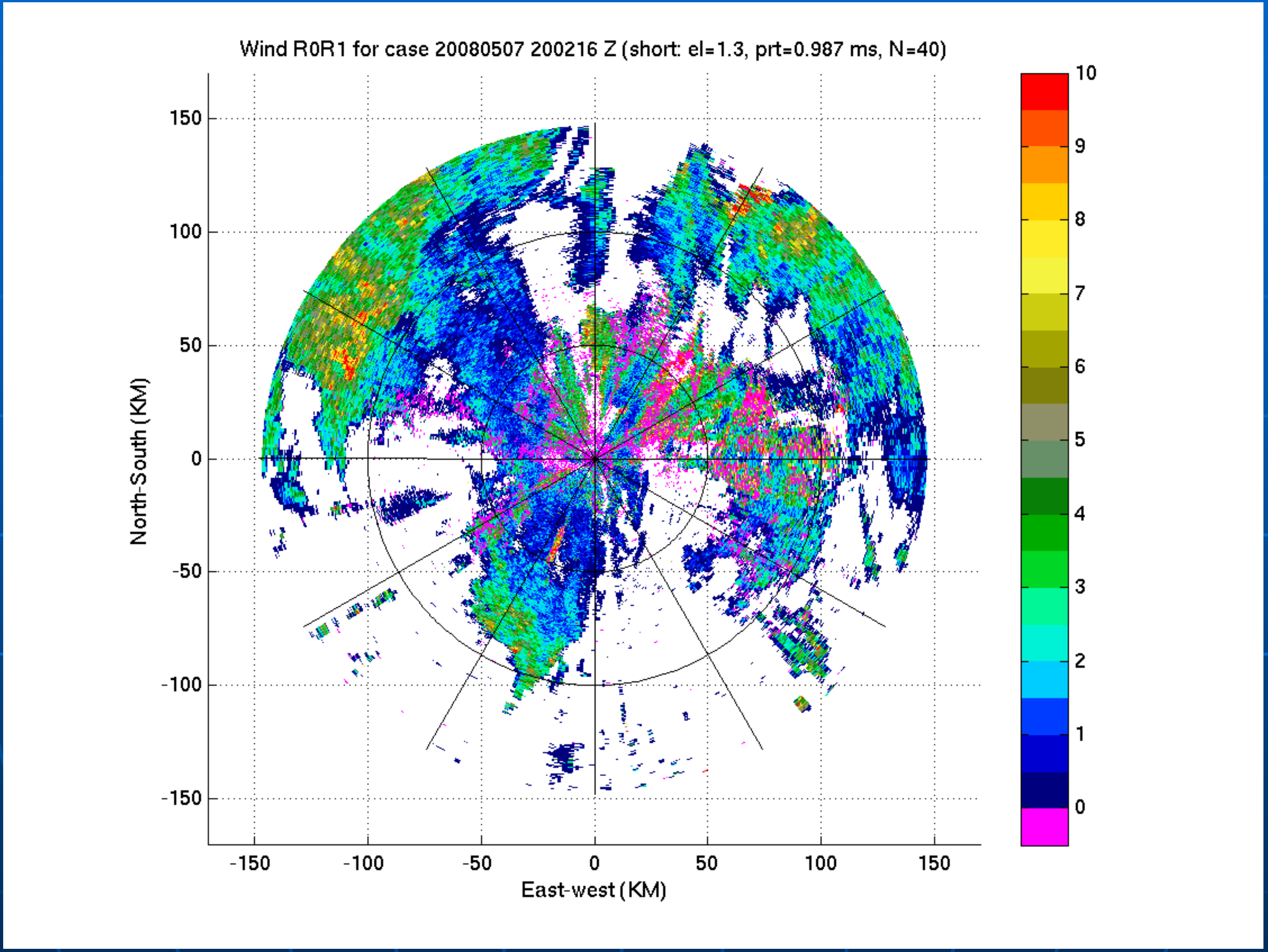
NCAR


Wind R0R1 for case 20071209 070933 Z (short: el=0.5, prt=1.180 ms, N=74)
North-South (KM)
East-west (KM)
150
100
50
0
-50
-100
-150
10
9
8
7
6
5
4
3
2
1
0

CASE 4: KCRI 2008/05/07 2000Z VCP 12, PRI 5

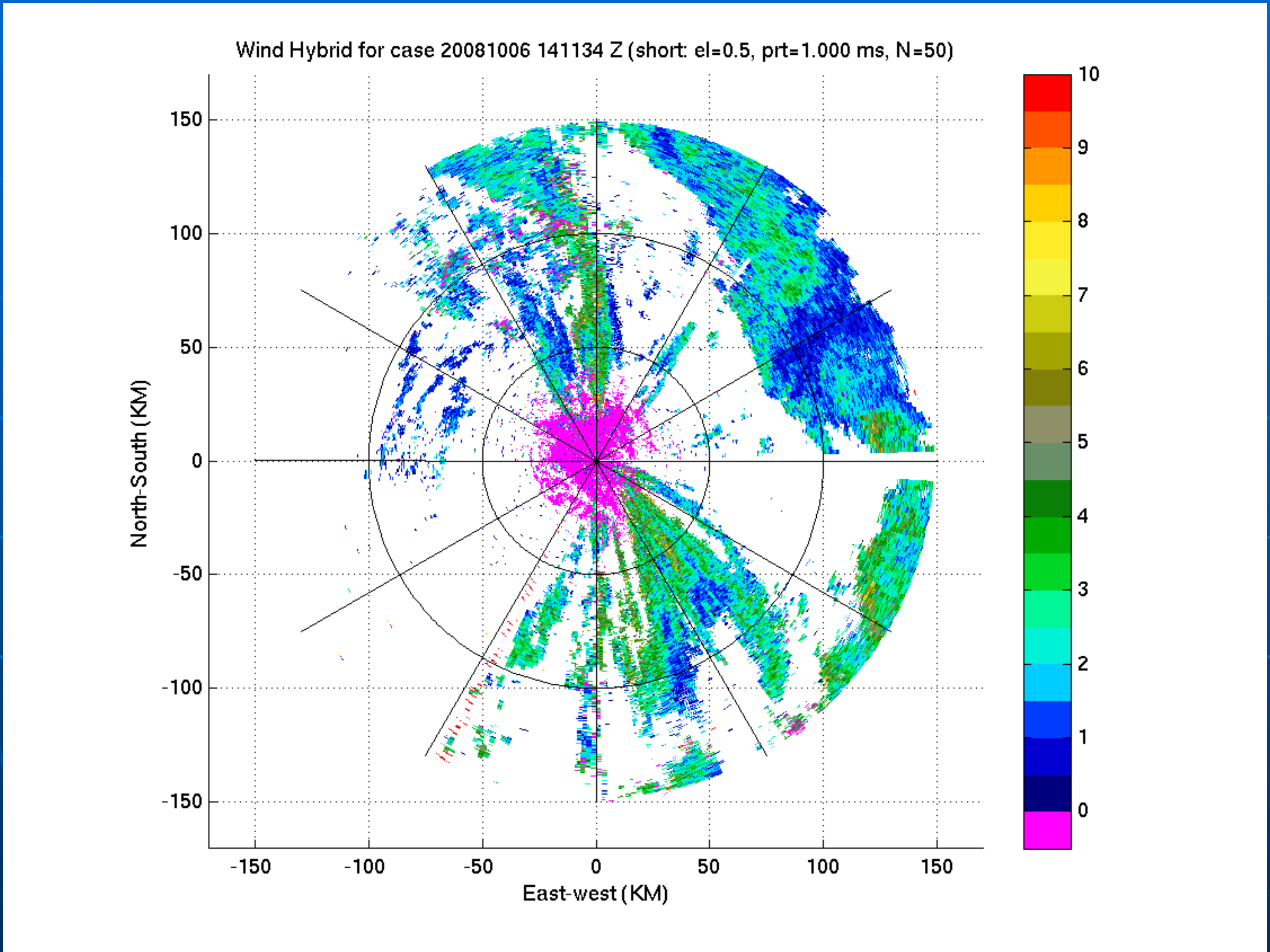

Wind Hybrid for case 20080507 200216 Z (short: el=1.3, prt=0.987 ms, N=40)
North-South (KM)
East-west (KM)
150
100
50
0
-50
-100
-150
150
100
50
0
-50
-100
-150
10
9
8
7
6
5
4
3
2
1
0

NCAR


Wind R0R1 for case 20080507 200216 Z (short: el=1.3, prt=0.987 ms, N=40)
North-South (KM)
150
100
50
0
-50
-100
-150
East-west (KM)
-150
-100
-50
0
50
100
150
10
9
8
7
6
5
4
3
2
1
0

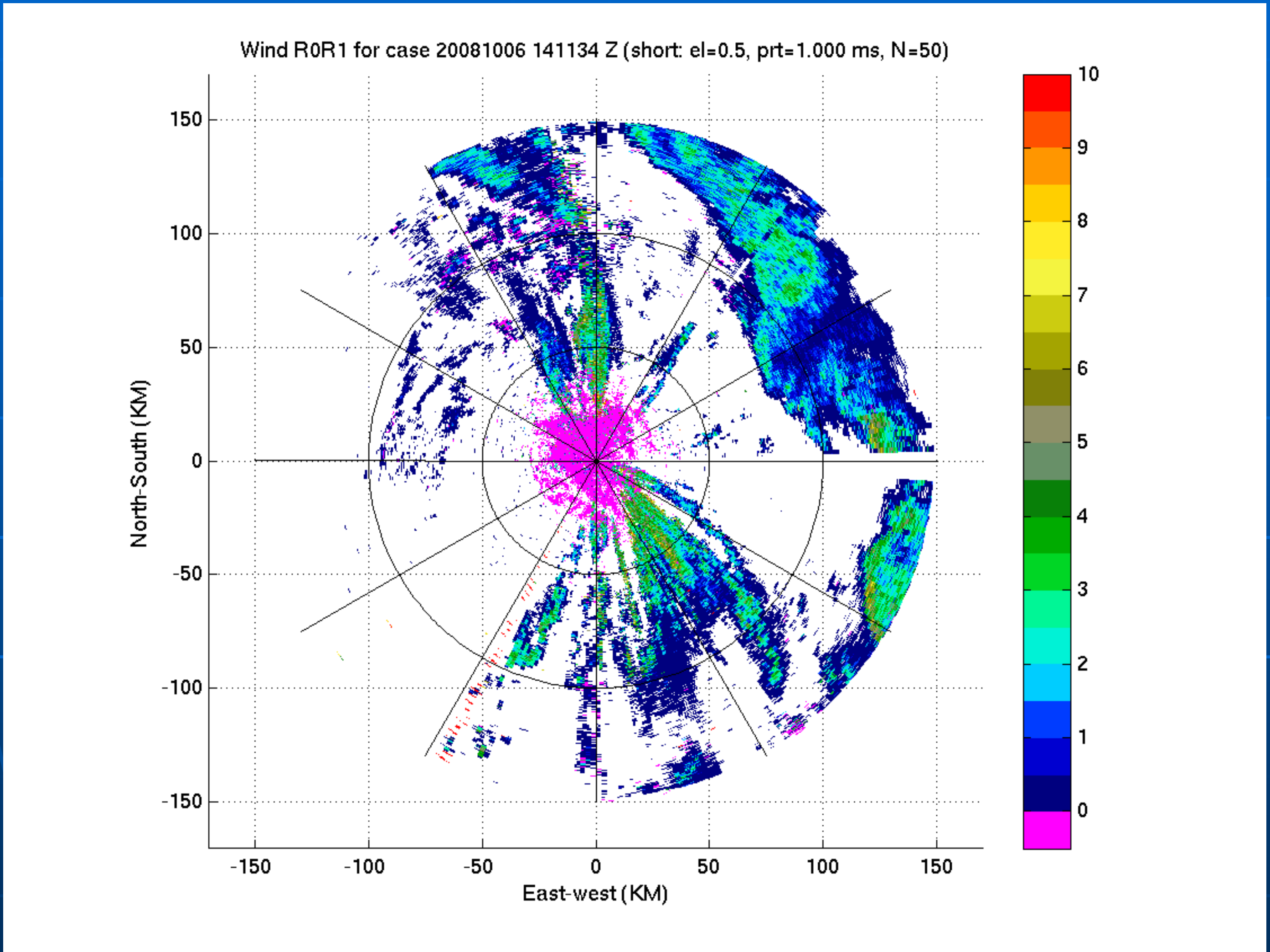
NCAR

CASE 5: KOUN 2008/10/06 1410Z VCP 11, PRI 7



Wind Hybrid for case 20081006 141134 Z (short: el=0.5, prt=1.000 ms, N=50)
North-South (KM)
East-west (KM)
150
100
50
0
-50
-100
-150
-150
-100
-50
0
50
100
150
10
9
8
7
6
5
4
3
2
1
0

NCAR


Wind R0R1 for case 20081006 141134 Z (short: el=0.5, prt=1.000 ms, N=50)
North-South (KM)
East-west (KM)
150
100
50
0
-50
-100
-150
-150
-100
-50
0
50
100
150
10
9
8
7
6
5
4
3
2
1
0

NCAR