Wind Turbine Clutter Mitigation Research

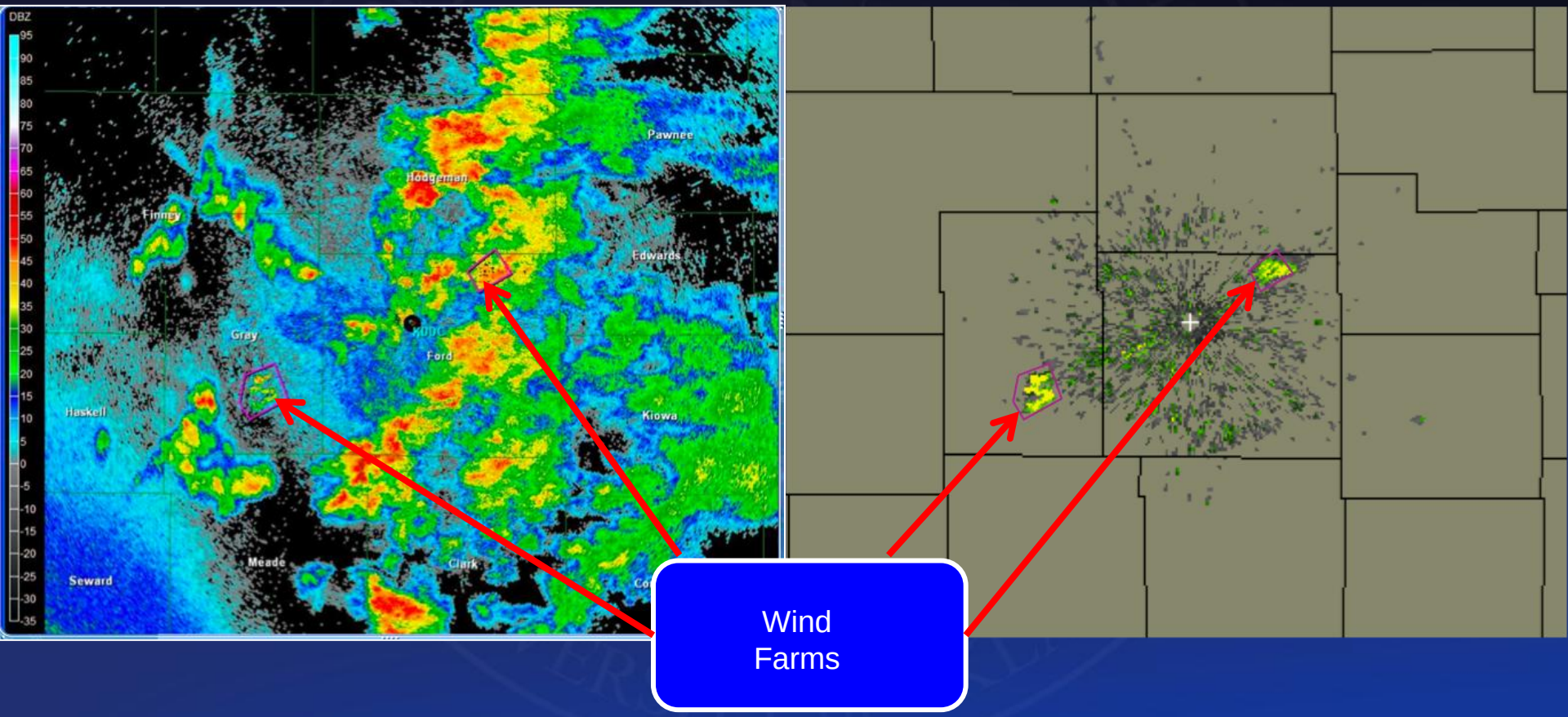
Robert D. Palmer
Tommy C. Craighead Chair & Professor, School of Meteorology
Director, Atmospheric Radar Research Center
The University of Oklahoma

Sebastian Torres
CIMMS/National Severe Storms Laboratory
Adjunct Assistant Professor, School of Electrical and Computer Engineering
Associate Director, Atmospheric Radar Research Center
The University of Oklahoma

Rockee Zhang
Assistant Professor, School of Electrical and Computer Engineering
Atmospheric Radar Research Center
The University of Oklahoma

Boonleng Cheong
Adjunct Assistant Professor, School of Electrical and Computer Engineering
Research Scientist, Atmospheric Radar Research Center
The University of Oklahoma

Impacts of Wind Farms on Weather Radar



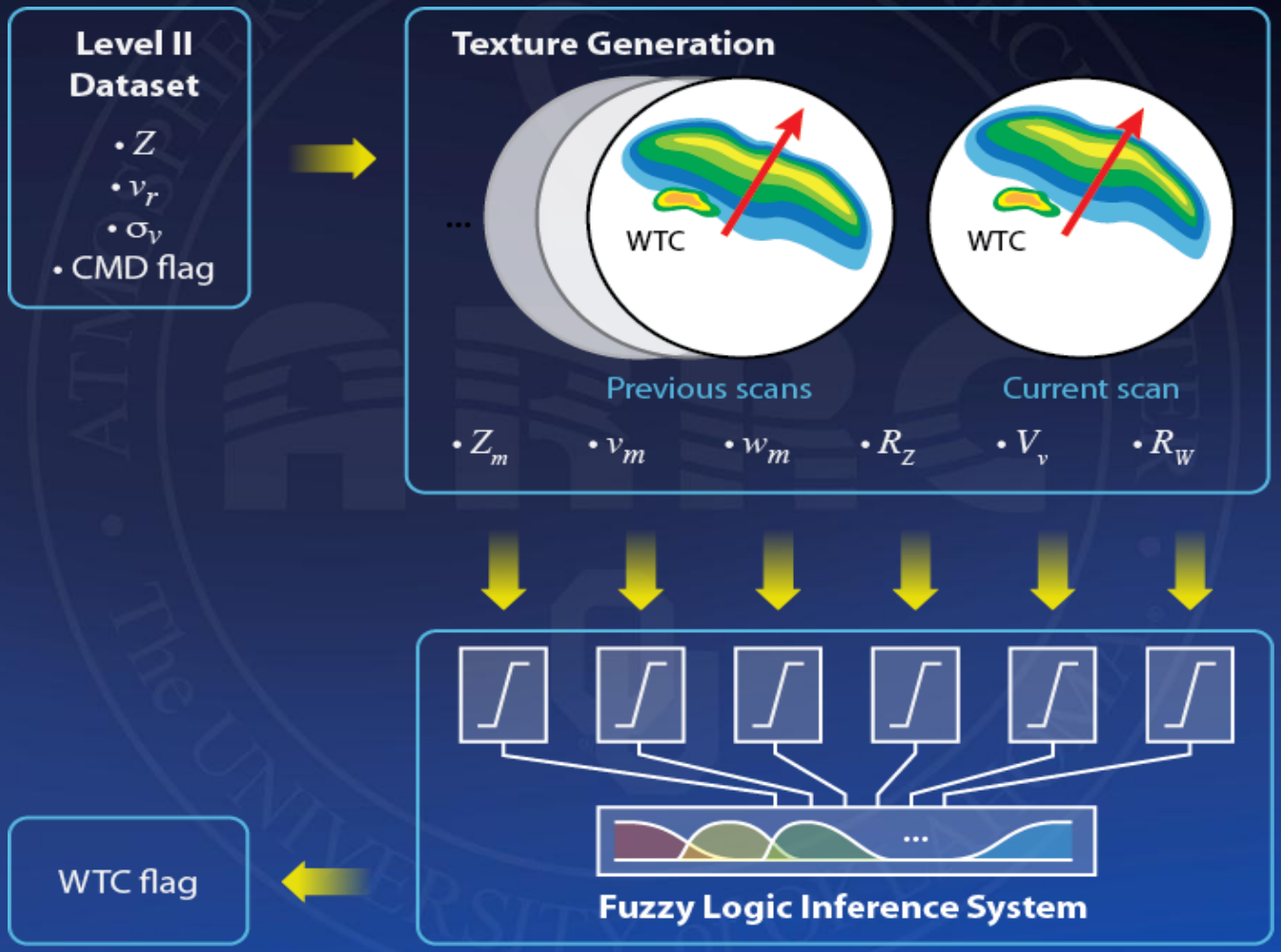
Outline of Recent Work

- Level-II Automatic Detection of WTC Based on Temporal Evolution – *Weather Advects While WTC is Stationary*
- Radar Wind Turbine Testbed (RWT^2) – Laboratory *Demonstration of Template-Based Mitigation*
- Range-Doppler Spectral Mitigation – *Exploiting Continuity of Weather Signals in Range*

Outline of Recent Work

- Level-II Automatic Detection of WTC Based on Temporal Evolution – *Weather Advects While WTC is Stationary*
- Radar Wind Turbine Testbed (RWT^2) – Laboratory *Demonstration of Template-Based Mitigation*
- Range-Doppler Spectral Mitigation – *Exploiting Continuity of Weather Signals in Range*

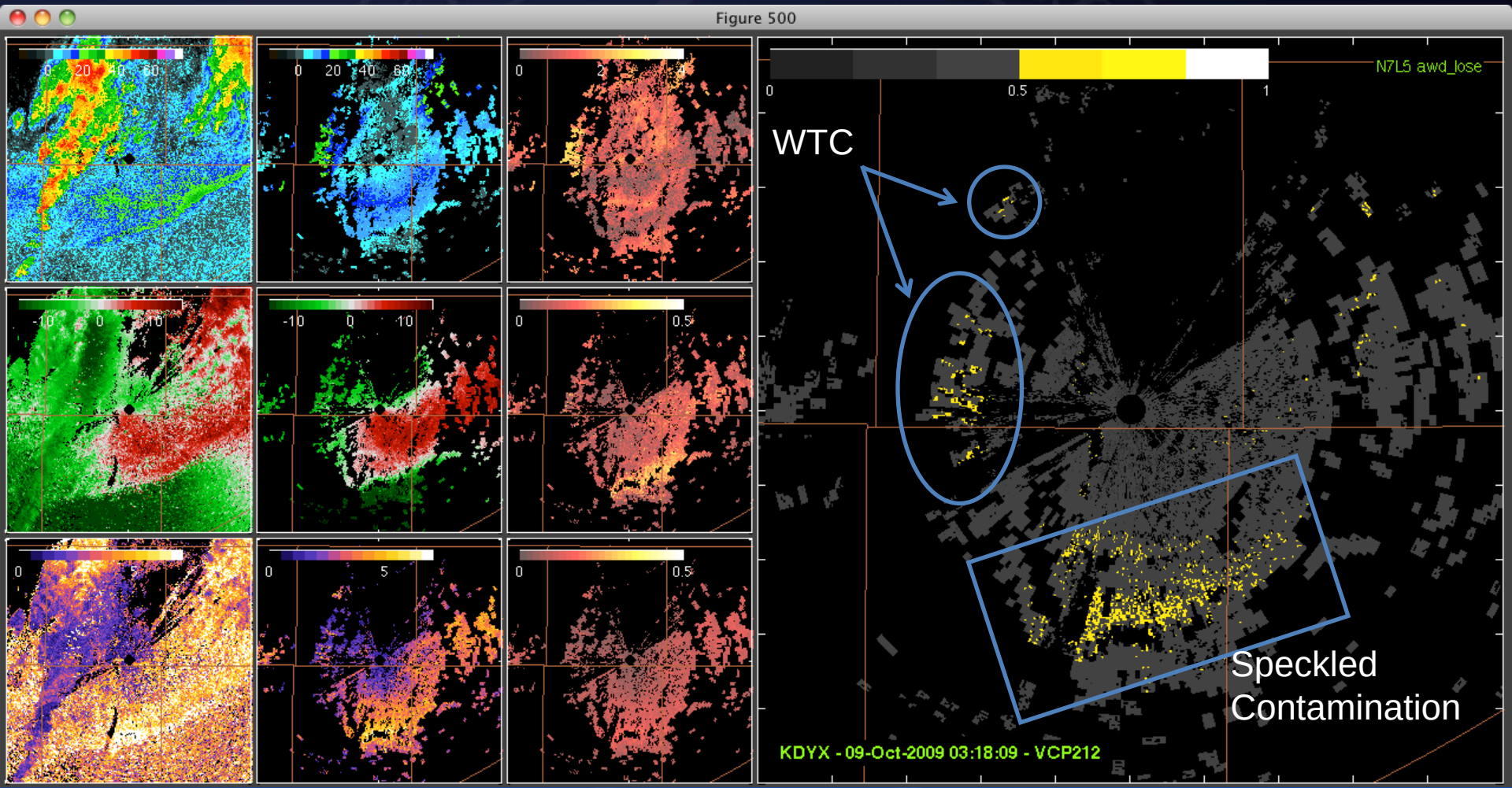
General Algorithm Description



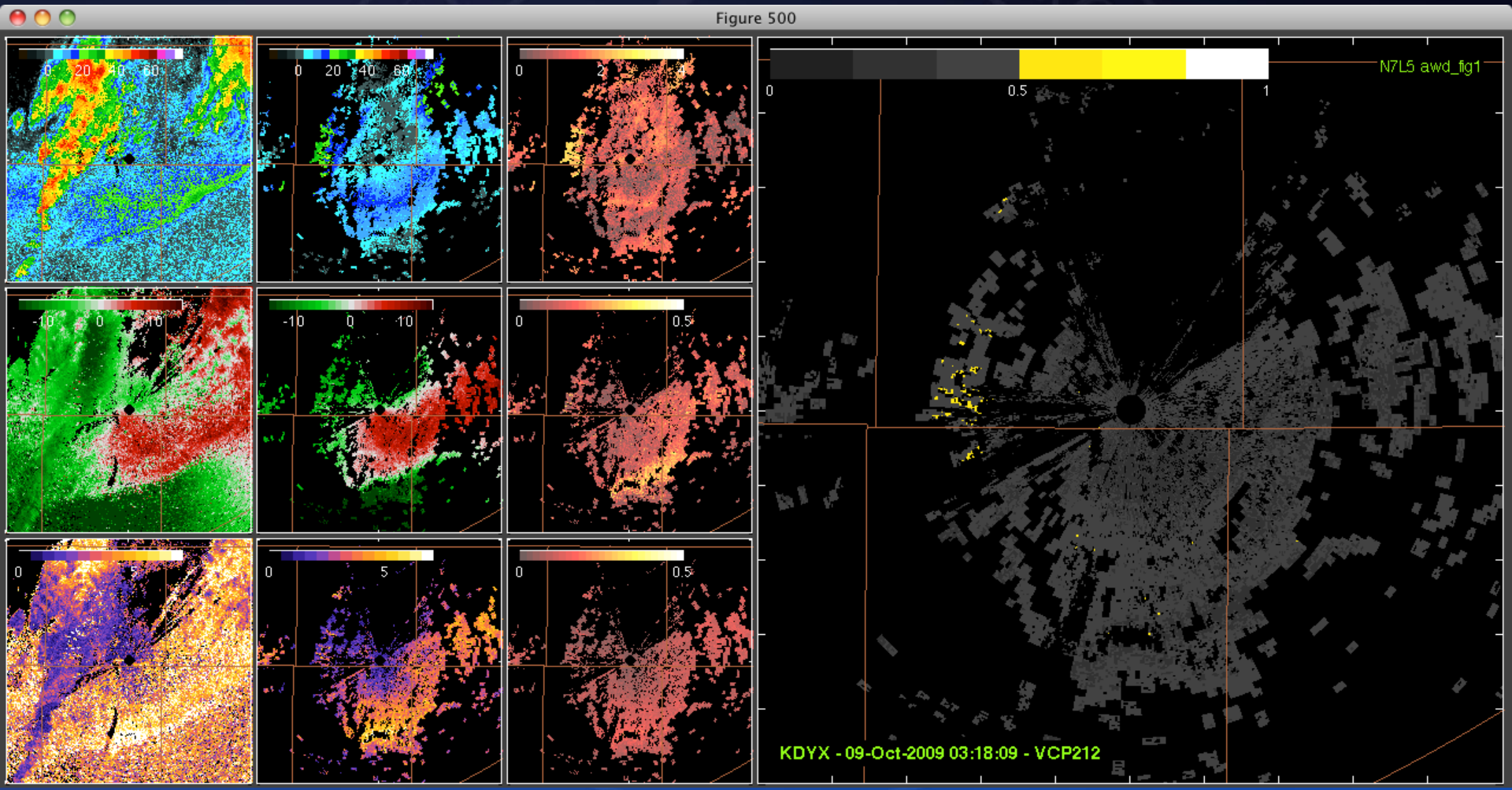
Temporal Textures

- Average of Reflectivity (Z_m)
  - Scattered cells get washed out but not wind farms
- Average of Velocity (v_m)
  - Besides the zero isodop, weather signals usually have non-zero velocity but wind farms exhibit zero-mean velocity fields
- Average of Spectrum Width (w_m)
  - Much higher spectrum width for wind farm due to the flashes
- Correlation of Reflectivity (R_Z)
  - Weather moves but wind farms stay
- Variance of Velocity (V_v)
  - Flashes have wide spectrum width and occur intermittently
- Correlation of Spectrum Width (R_w)
  - Advection of spectrum width pattern

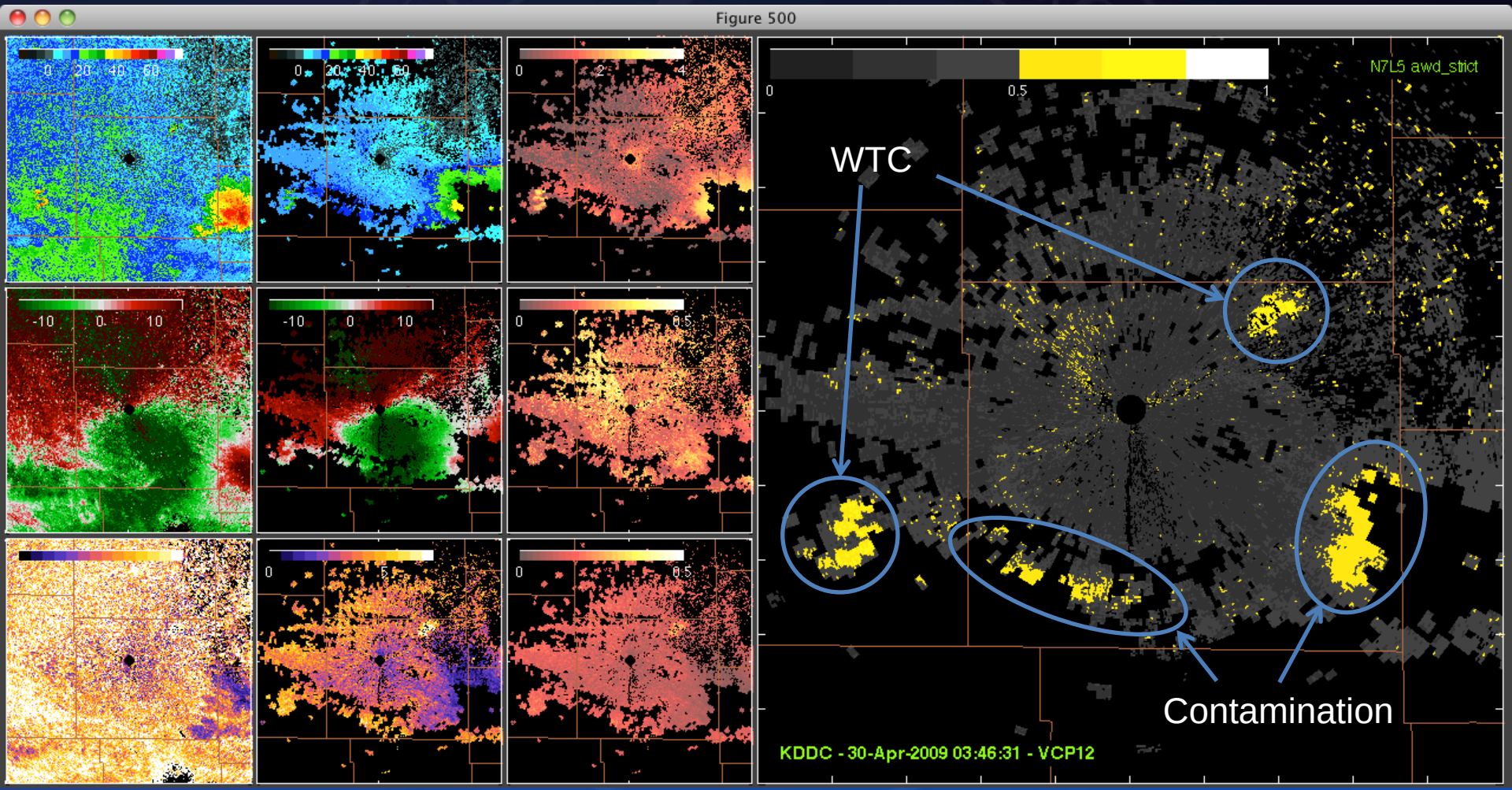
Example of Poor Identification (KDYX)



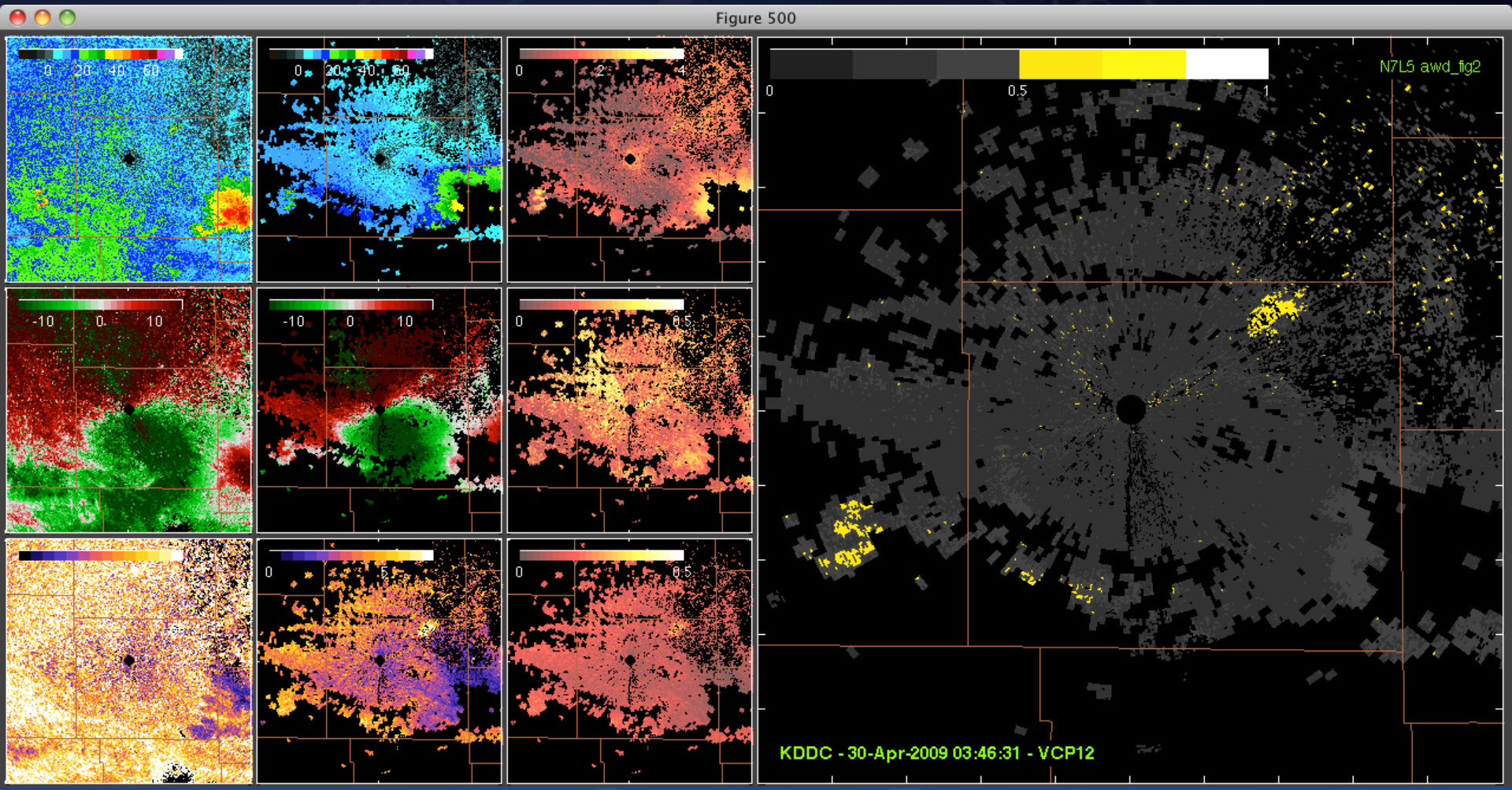
… With FIS Retuned



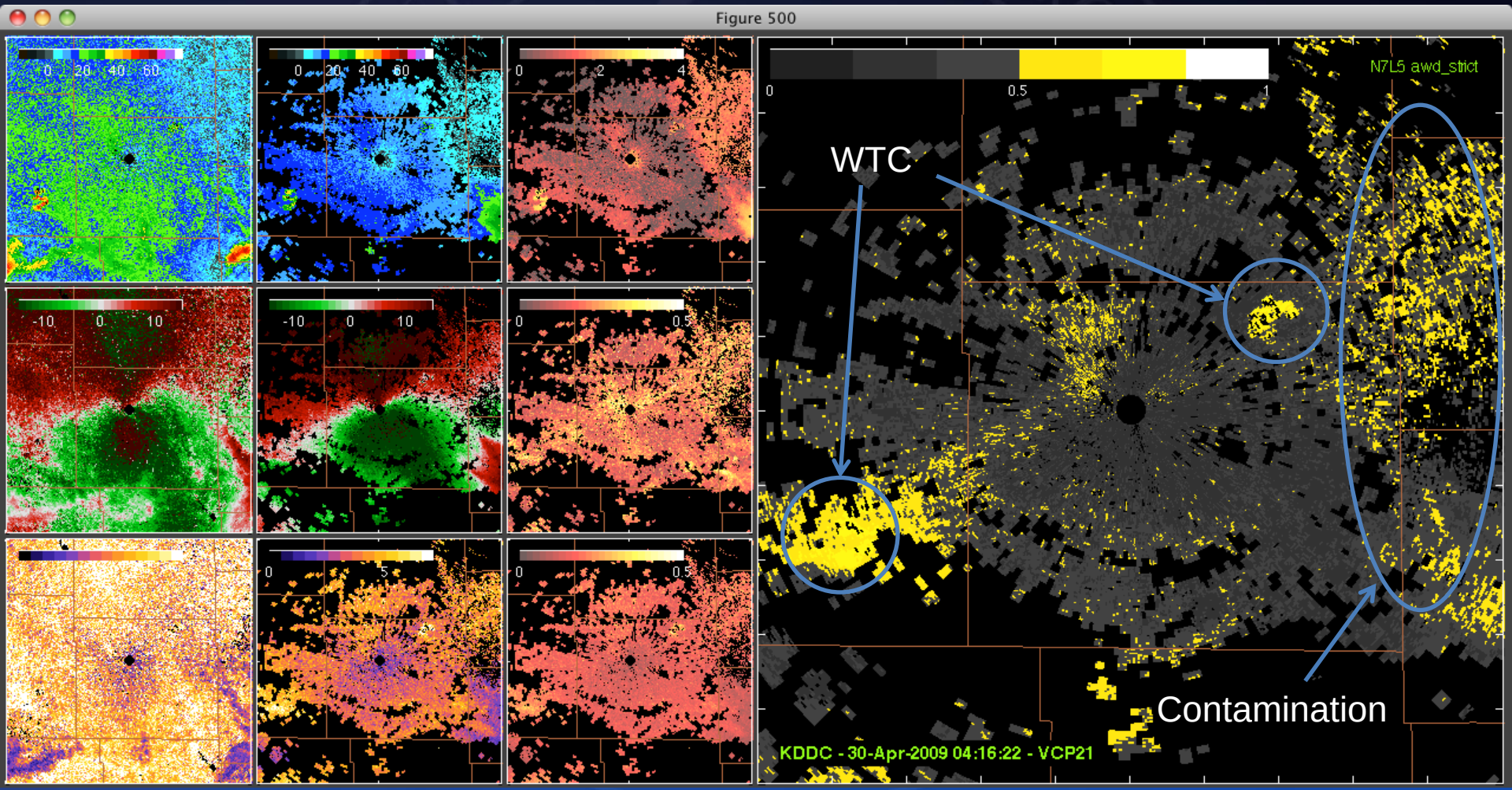
Example of Poor Identification (KDDC)



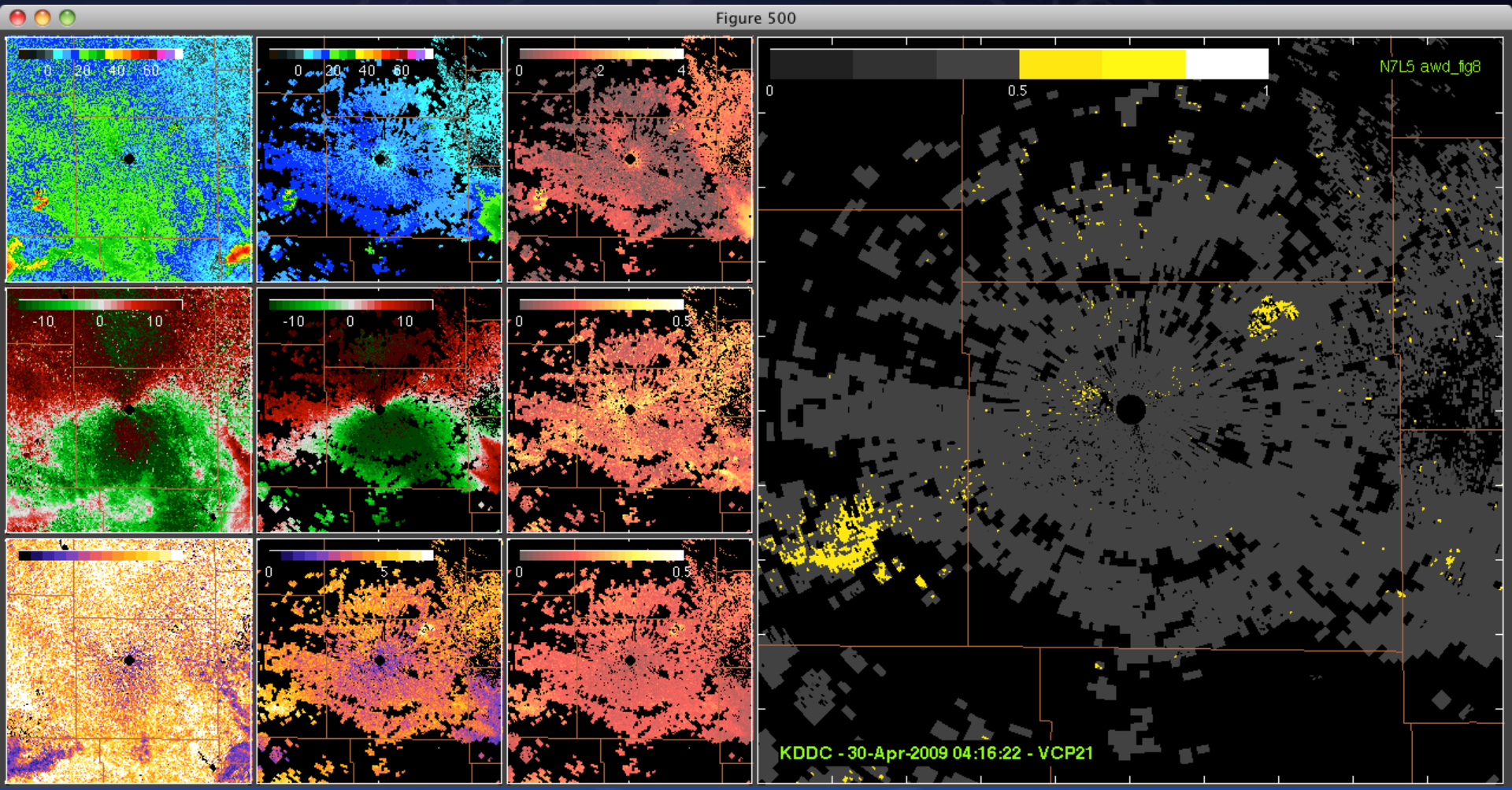
… With FIS Retuned



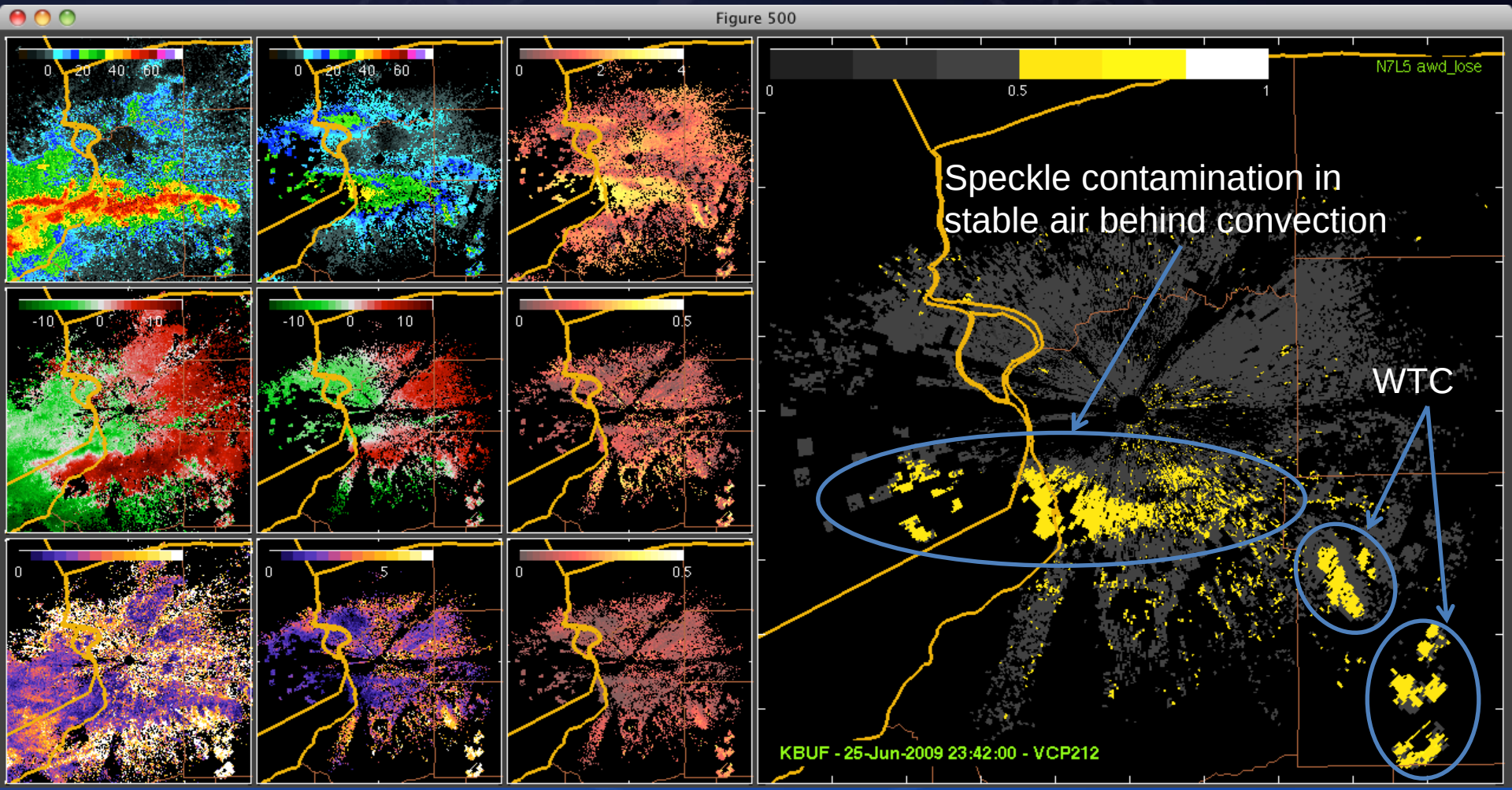
Example of Poor Identification (KDDC)



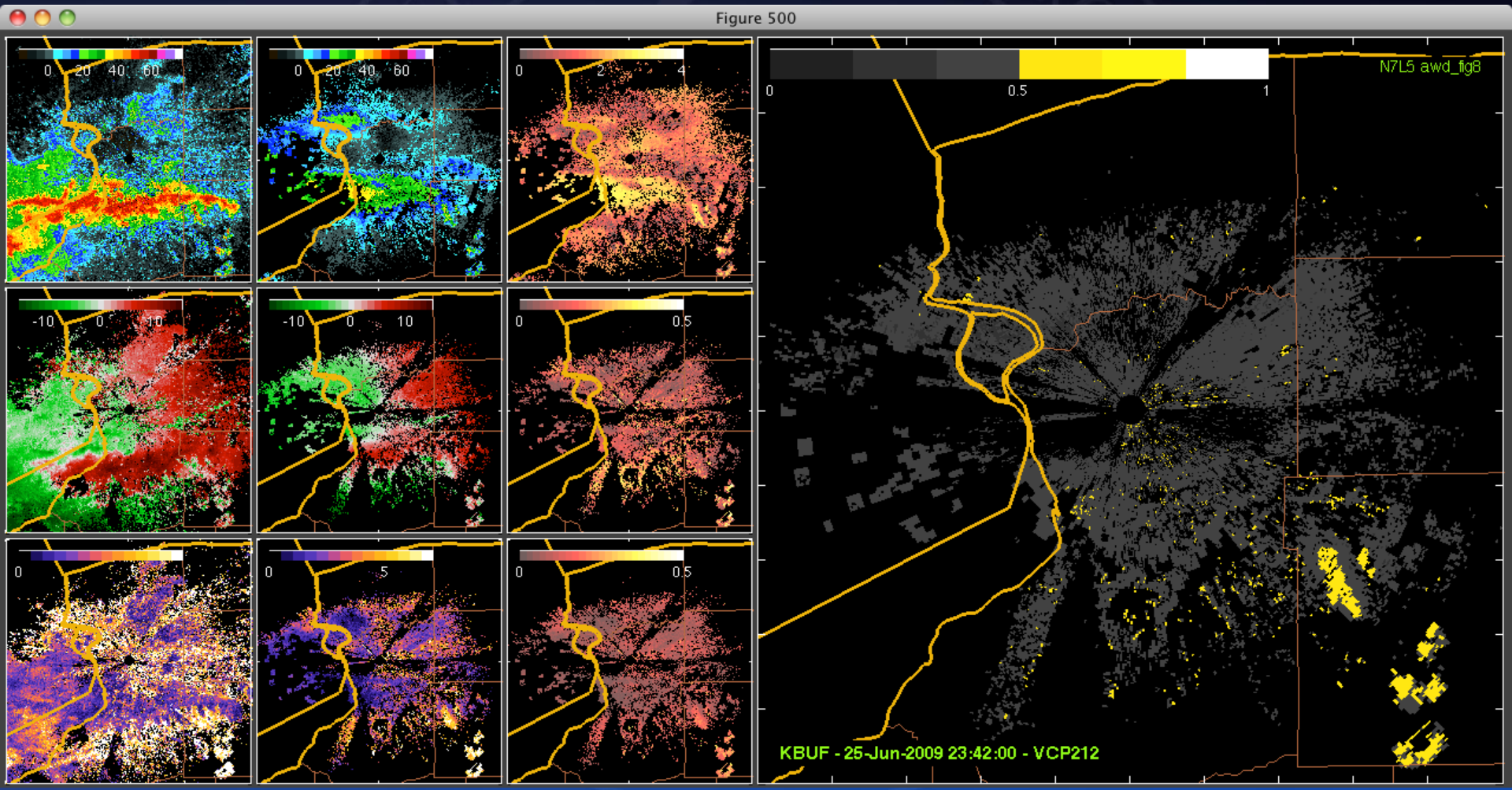
… With FIS Retuned



Example of Poor Identification (KBUF)



… With Fuzzy Logic Inference System Retuned



Outline of Recent Work

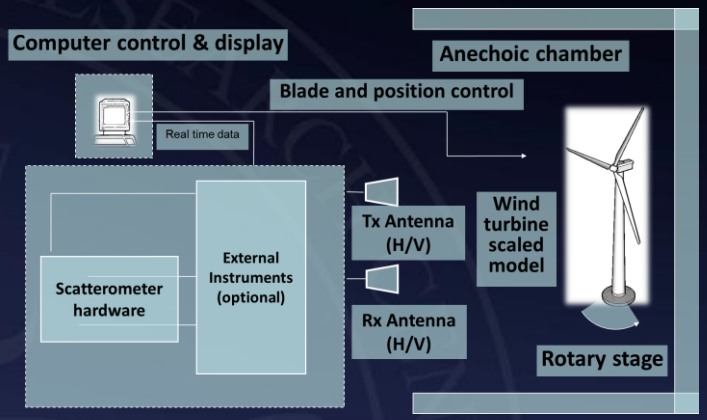
- Level-II Automatic Detection of WTC Based on Temporal Evolution – *Weather Advects While WTC is Stationary*
- Radar Wind Turbine Testbed (RWT^2) – Laboratory *Demonstration of Template-Based Mitigation*
- Range-Doppler Spectral Mitigation – *Exploiting Continuity of Weather Signals in Range*

Radar Wind Turbine Testbed (RWT^2)

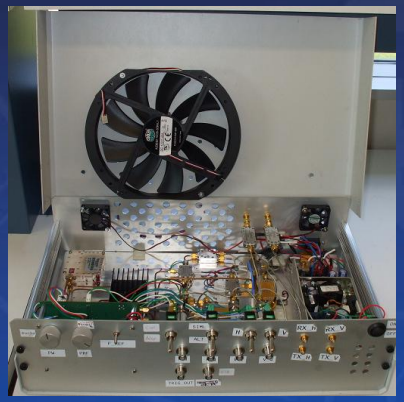
Scaled wind turbine and weather radar for controlled laboratory measurements: Testbed for algorithm development and validation

Wind turbine

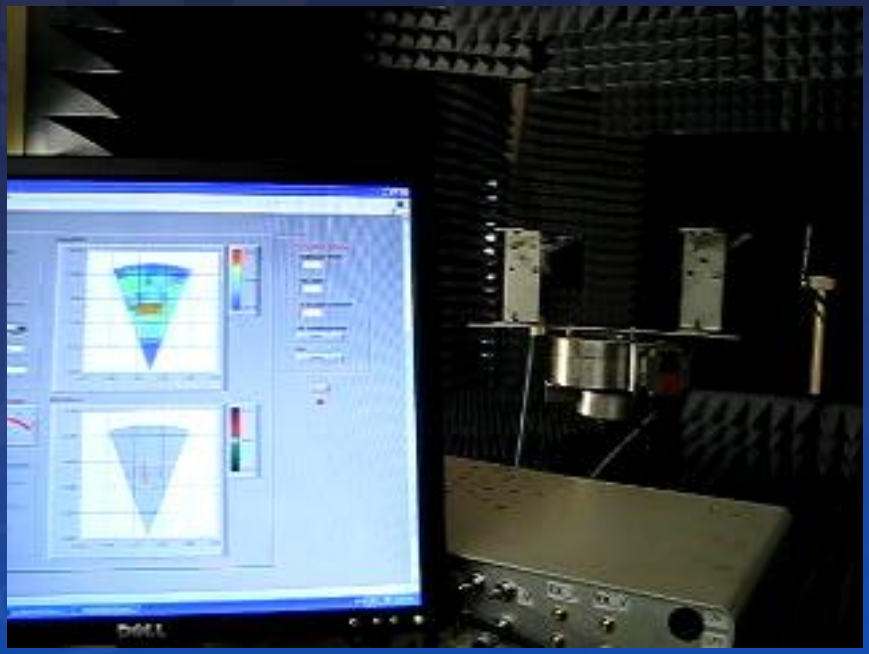
Scaled model



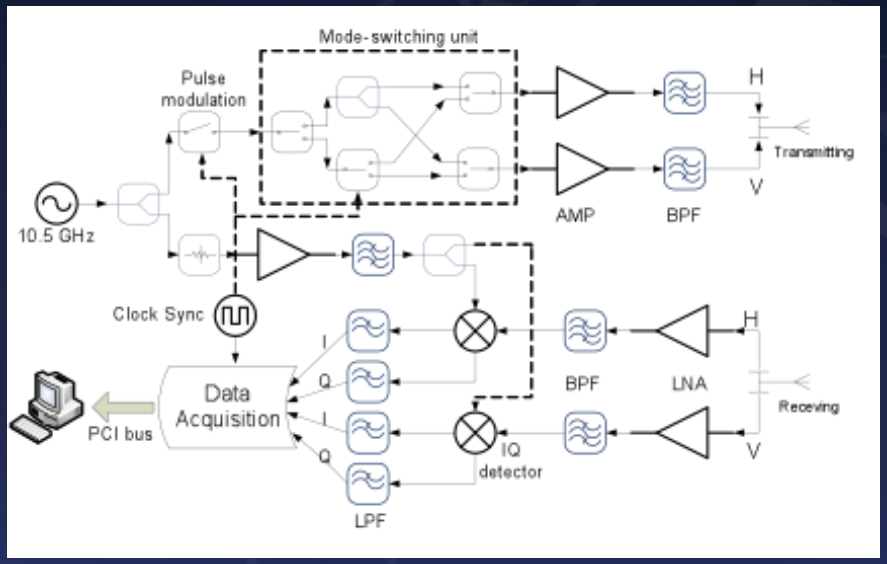
Weather radar



Scatterometer



Scatterometer System

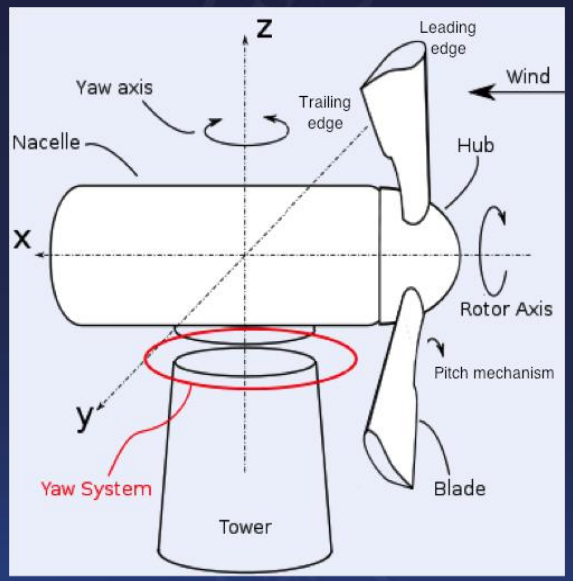


- A laboratory polarimetric pulsed-Doppler radar used for characterizing target scattering signatures in a controlled environment
- Fine range resolution: Better than 1.2 m
- Polarimetric: Simultaneously dual-pol Alternatively dual-pol

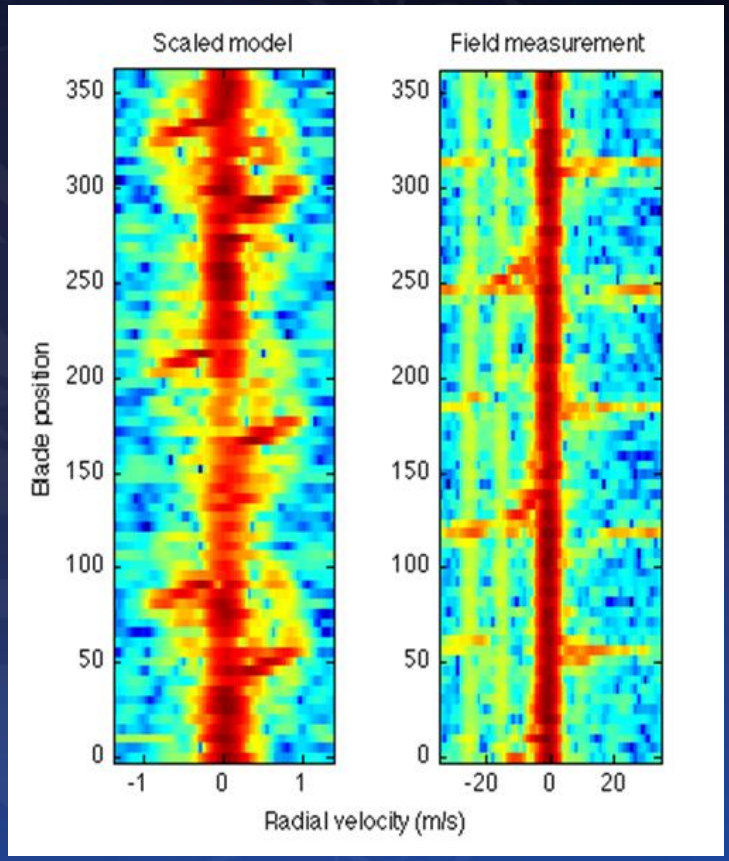
Table-1 System specification of the scatterometer

System Parameter	Value	Unit
Operating frequency	10.5	GHz
Peak power	126	mW
Antenna gain	12	dBi
Antenna 3dB beam width	30	degrees
Transmit pulse width	8~ 20	ns
Pulse repetition frequency	95~24400	Hz
System bandwidth	100	MHz

Scatterometer Validation: Qualitative Comparison to Real Data

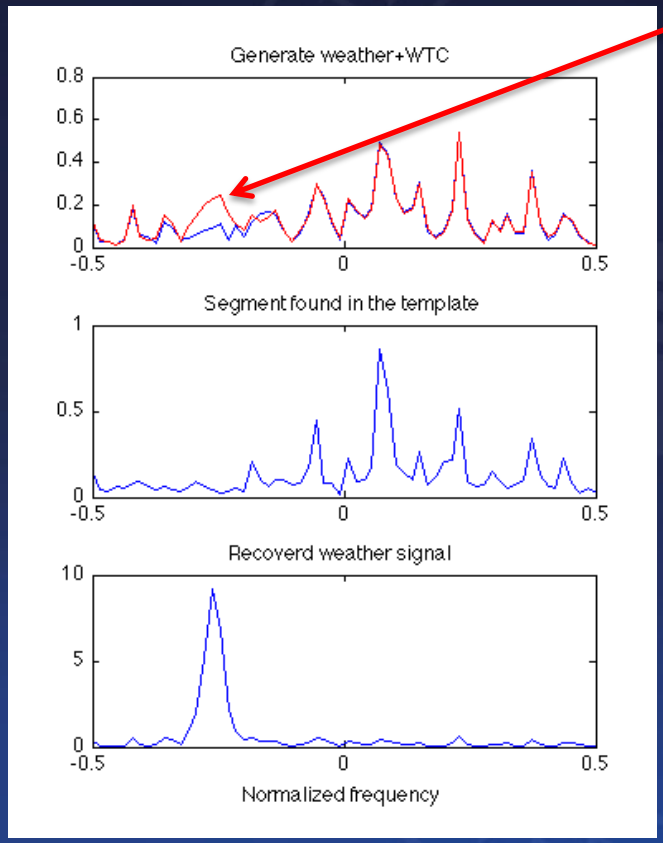


Wind turbine motion mechanism

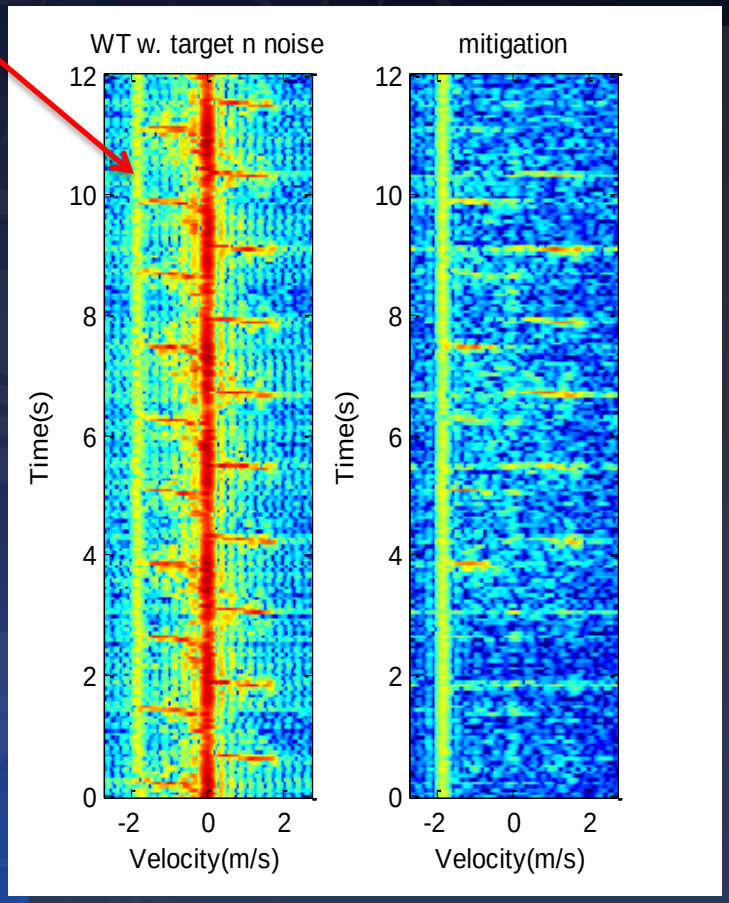


Spectrogram - One of the most important WTC radar signatures: scaled measurement vs. full-size wind turbine weather radar measurement (KDDC 2006)

Demo of adaptive filter using pre-stored WTC library



Simulated weather signal



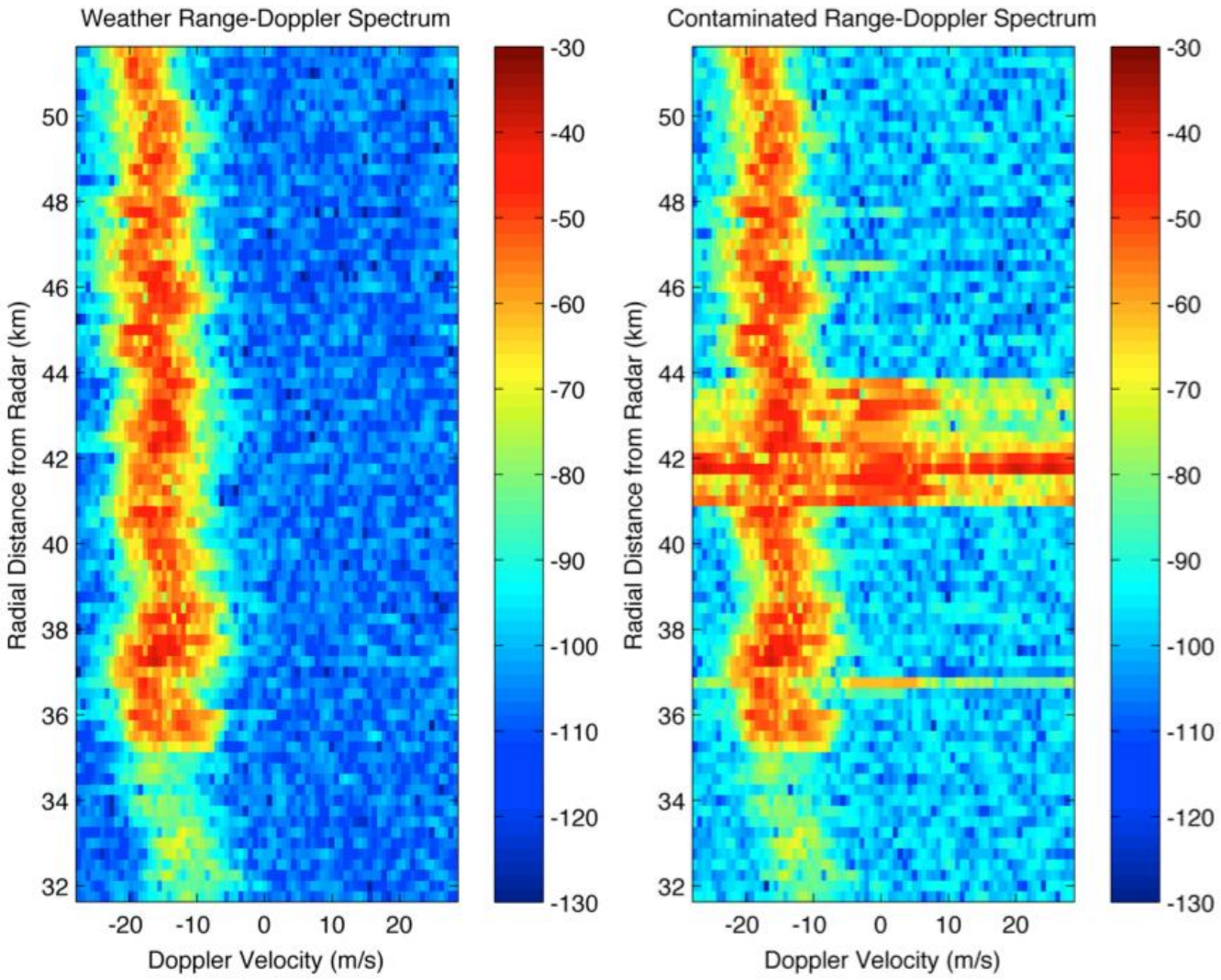
Mixed simulated weather signal with wind turbine measurements from dwell to dwell, find the most correlated in 'WTC' library, construct filter response.

Mitigation of WTC from dwell to dwell by retrieving WTC signature from template and use of adaptive Wiener filter

Outline of Recent Work

- Level-II Automatic Detection of WTC Based on Temporal Evolution – *Weather Advects While WTC is Stationary*
- Radar Wind Turbine Testbed (RWT^2) – Laboratory *Demonstration of Template-Based Mitigation*
- Range-Doppler Spectral Mitigation – *Exploiting Continuity of Weather Signals in Range*

Why use the Range-Doppler Spectrum?

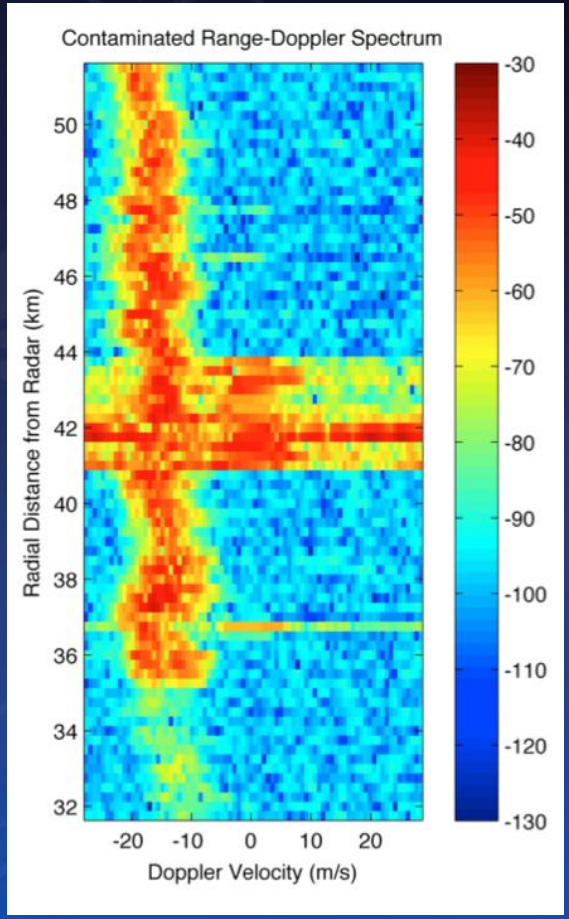


Range-Doppler Mitigation Technique 1

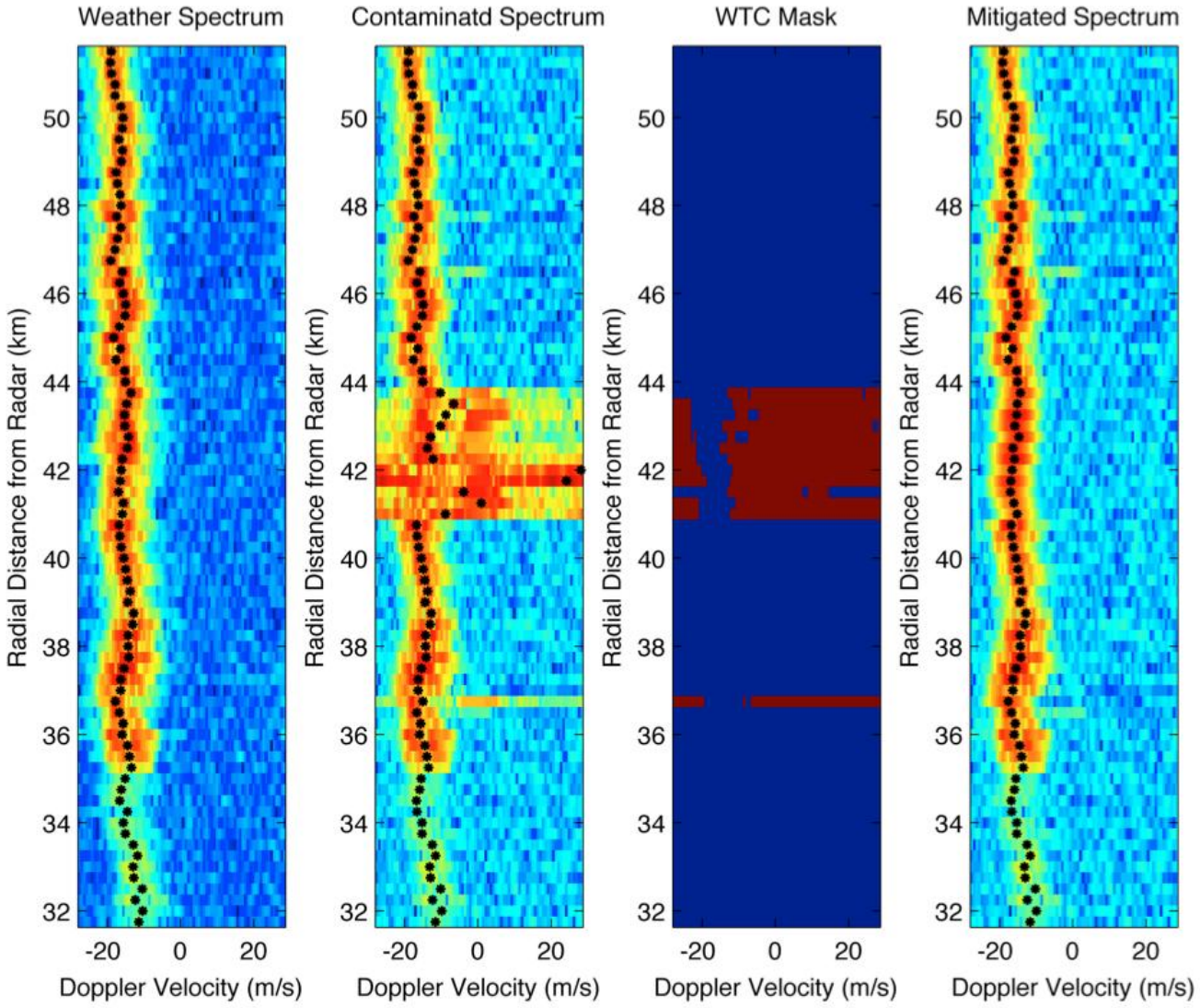
- The human eye can identify which pixels are weather and which are WTC
  - Exploit texture observed in image
  - Distinct discontinuity between noise and WTC
  - WTC effects extend over many velocity bins

- The goal is to classify each pixel in the image into three classes: Weather (Wx only and Wx+WTC), WTC only, and noise only

- Spectral moments can be estimated using only the pixels classified as weather (e.g. NIMA, Morse et al. 2002).

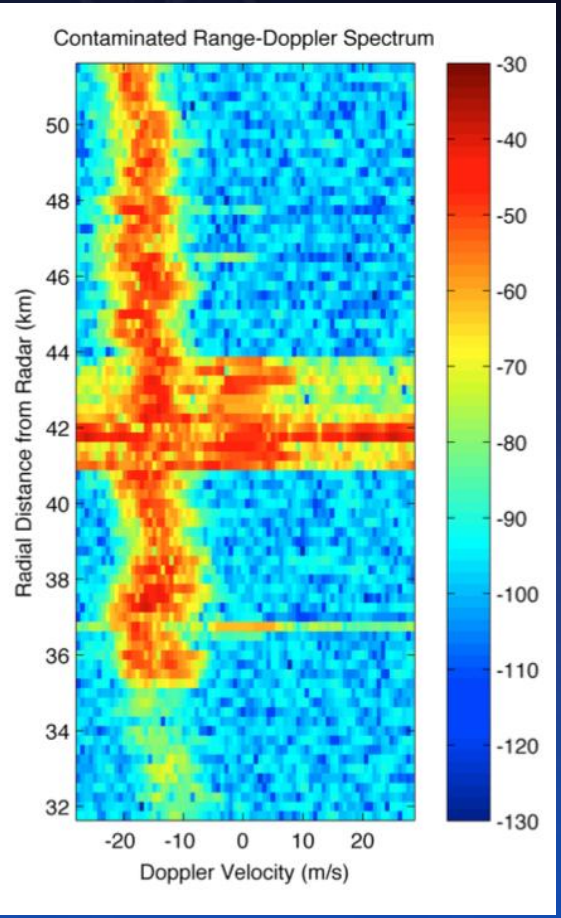


Technique I: Mitigation Results

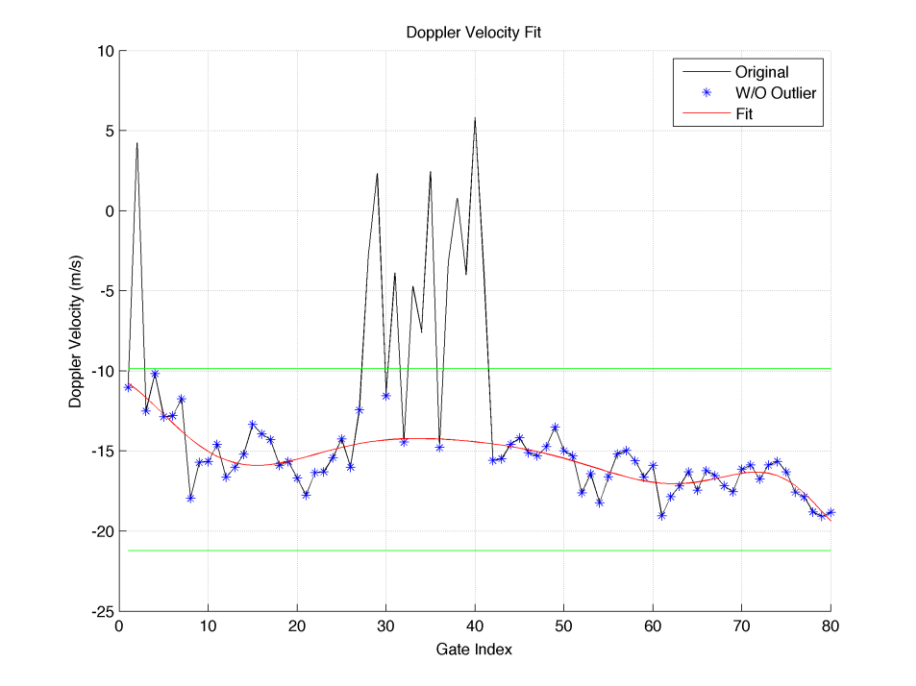


Range-Doppler Mitigation Technique II

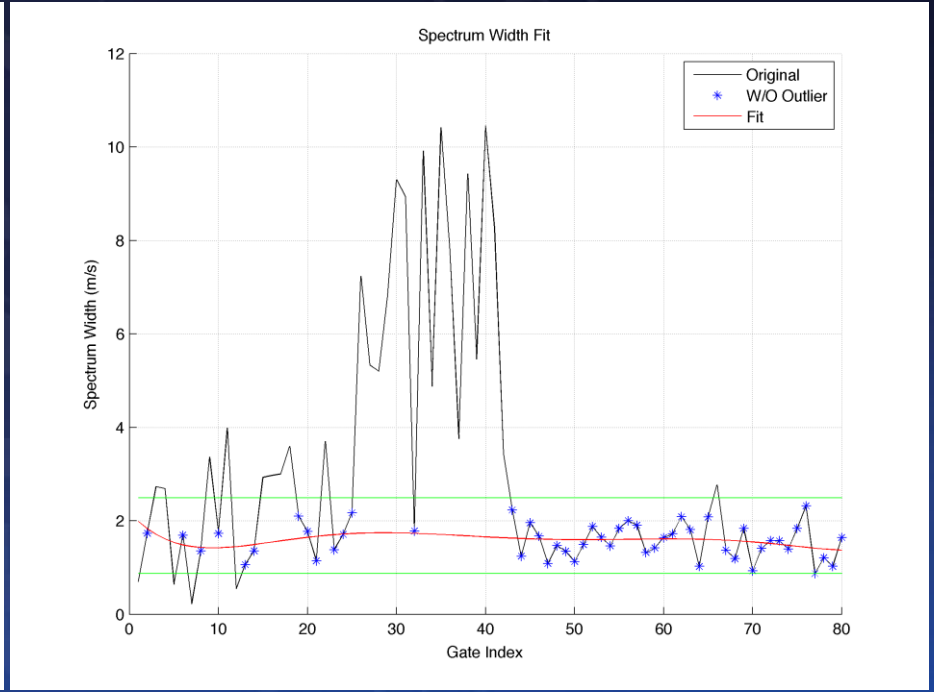
- The human eye can identify the *general* areas of the range-Doppler spectrum that have weather signals
- Exploit continuity of weather to obtain a "loose" window for the weather bins
  - Estimate moments from corrupted data
  - Eliminate outliers through sorting process
  - Obtain range-dependent "weather window" using polynomial fitting
- Use remaining data within this weather window to estimate moments



Example Sorting/Fitting Process

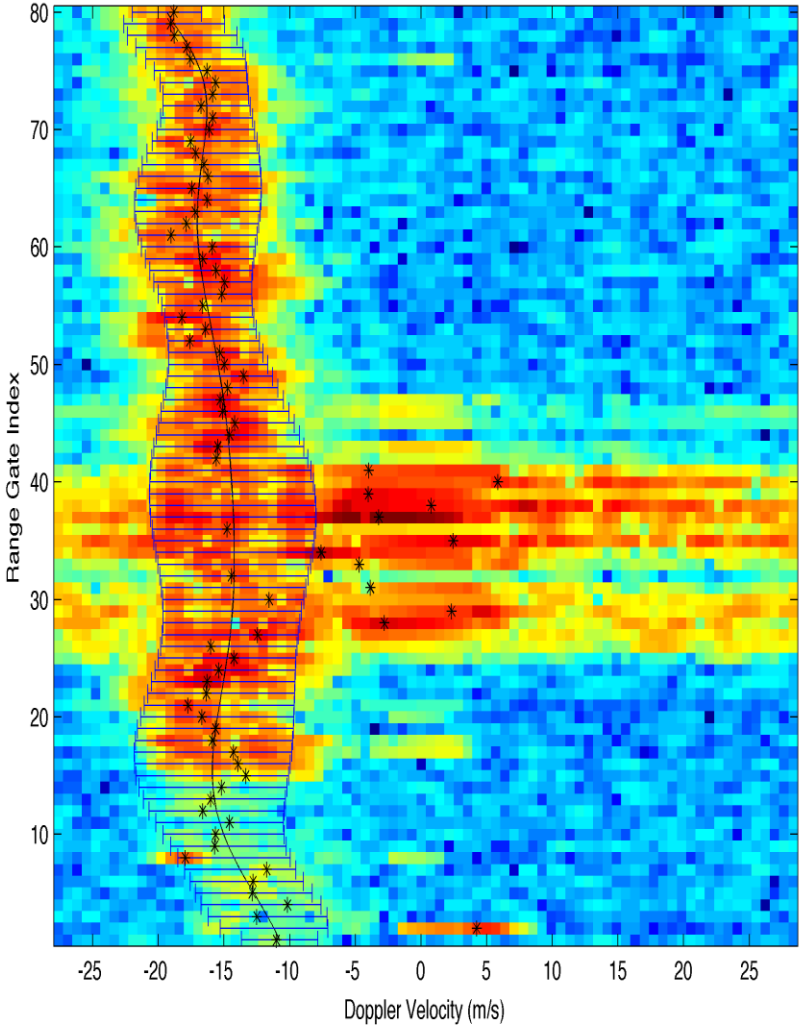


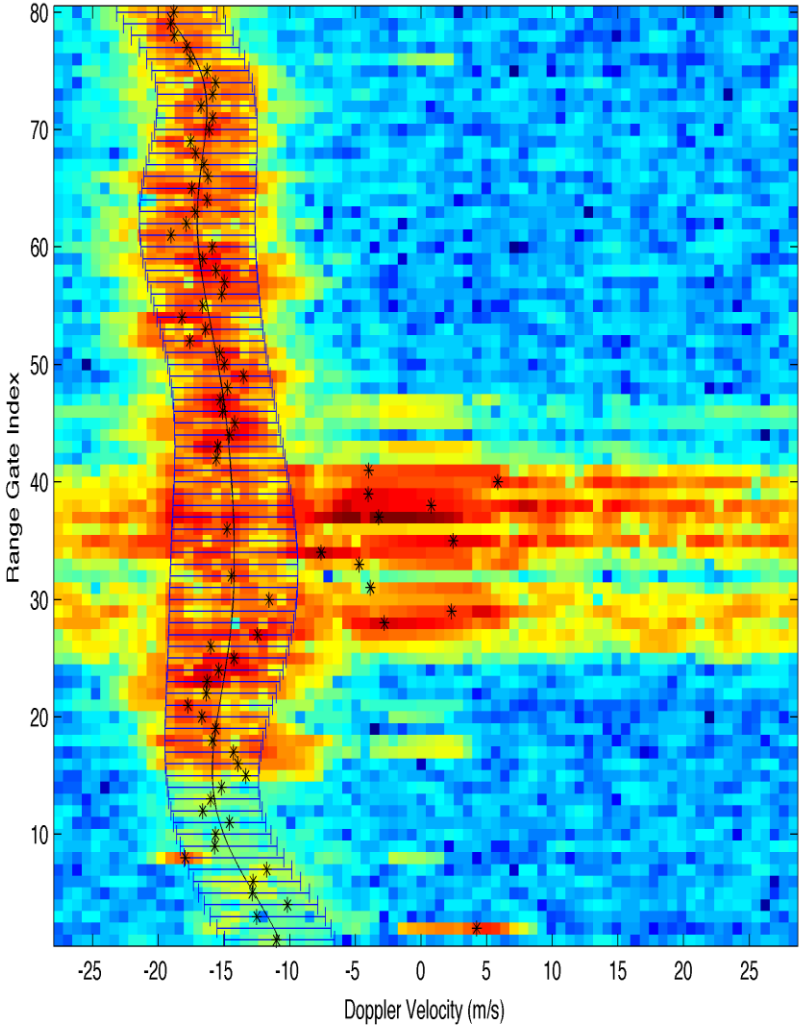
Radial Velocity



Spectrum Width

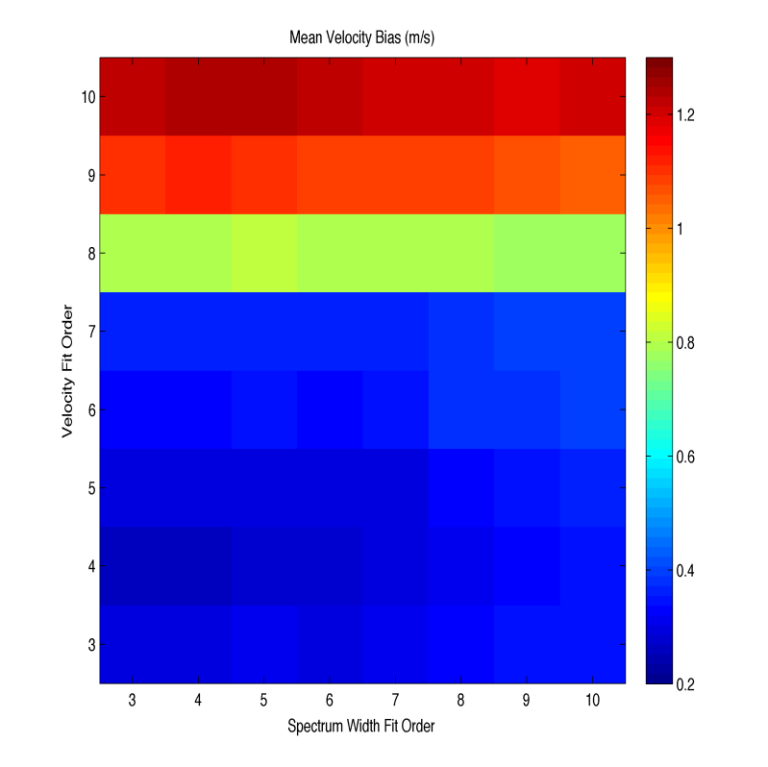
Technique II: Weather Window

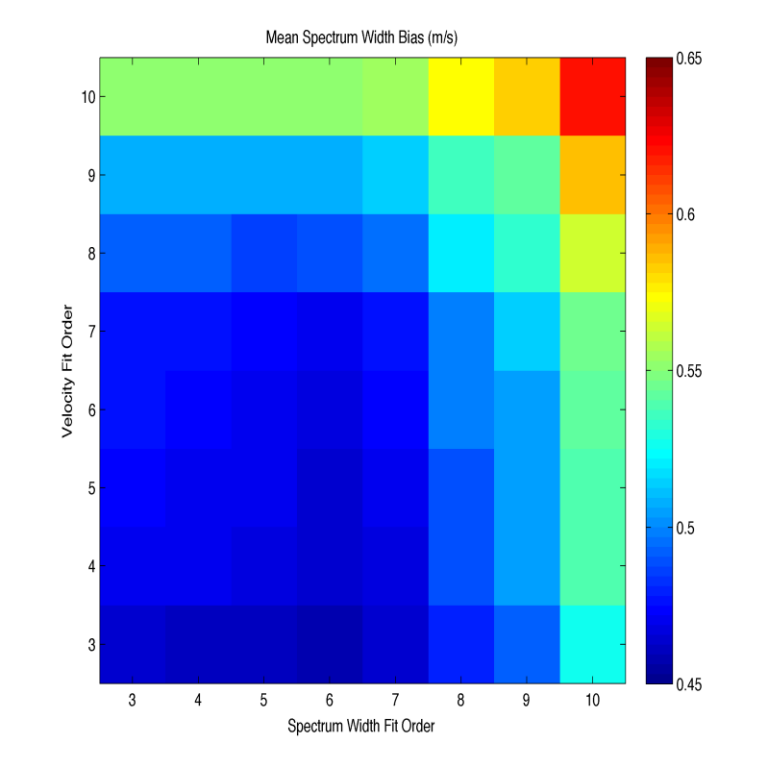




Determining Order of Fit

- Average Magnitude of Bias before processing over entire range extent
  - Velocity: 1.60 m/s
  - Spectrum Width: 1.41 m/s





Summary

- Level-II Automatic Detection of WTC Based on Temporal Evolution
  - Temporal texture does hold information useful for detection of WTC
  - Development of fuzzy-logic system has been completed
  - Detection performance can be improved by careful tuning of FIS
- Radar Wind Turbine Testbed (RWT^2)
  - X-band scatterometer has been built and tested
  - Scaling issue could be addressed by W-band up/down converter
  - EM simulations are on-going to refine model-based mitigation
- Range-Doppler Spectral Mitigation
  - Emulation of human vision – exploiting range continuity of weather signal
  - Technique I: Develop texture features for pixel classification
  - Technique II: Estimate “weather window” based on simple polynomial fitting
  - Both methods require further work related to biased power estimates