

# *Mitigation of Wind Turbine Clutter on the WSR-88D Radars Using Spectral Processing and Non-Linear Filtering*

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# Outline

- Observed Effects of Wind Turbine Clutter (WTC) in Level-II Data
- Importance of the ORDA Revealed Through the *Doppler Spectrum*
- Preliminary Results from March, 2006 KDDC Experiment: Spotlight and VCP 21 Data

# Gray County Wind Farm



- Located 25 miles SW of Dodge City, Kansas
- 170 towers
- Height of Tower: 217 feet (66m)
- Length of Blades: 77 feet (23.5m)
- RPM: 28.5
- Tip Velocity:  $70.14 \text{ ms}^{-1}$





# Outline

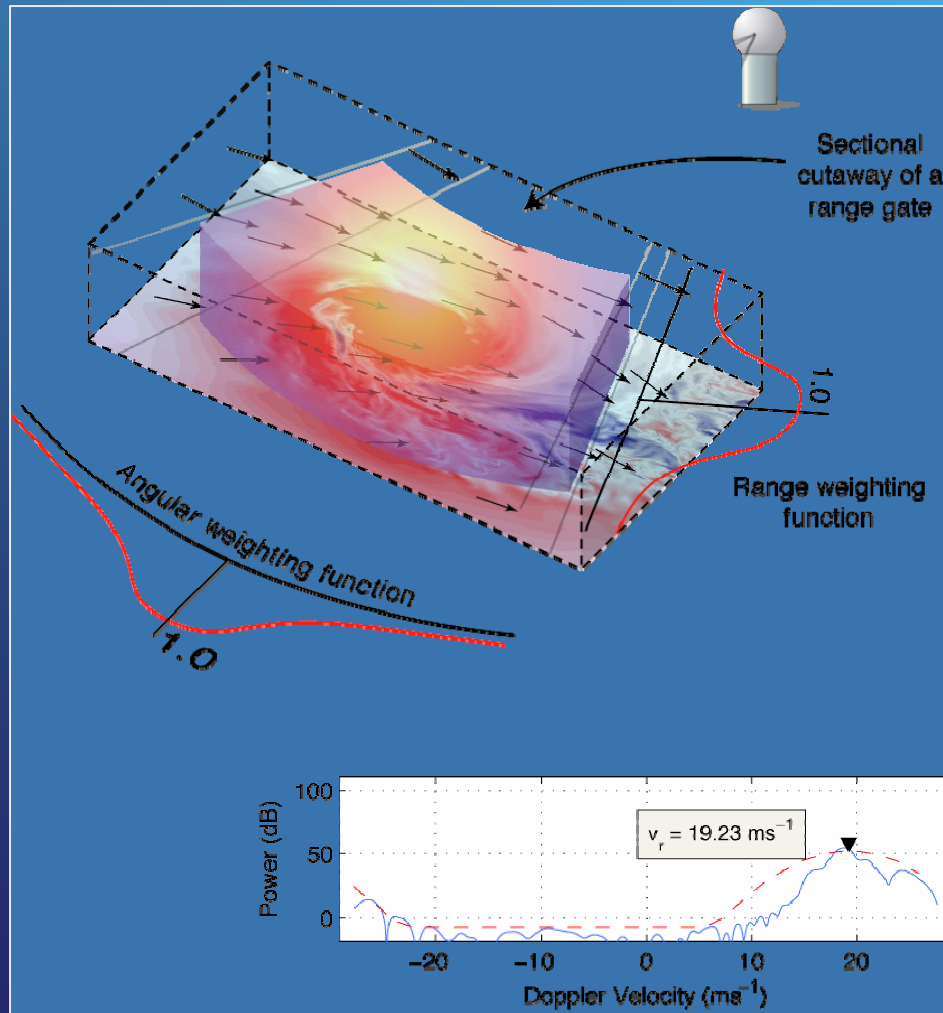
- Observed Effects of Wind Turbine Clutter (WTC) in Level-II Data

• Importance of the ORDA Revealed Through the *Doppler Spectrum*

- Preliminary Results from March, 2006 KDDC Experiment: Spotlight and VCP 21 Data

# The Doppler Spectrum

## *Unraveling radial velocities*



*The Doppler spectrum is a power-weighted distribution of radial velocities within the resolution volume*

*Examples of unique velocity distributions:*

- *Tornados*
- *Ground Clutter*
- *Sea Clutter*
- *Birds*
- *Wind Turbine Clutter (WTC)*

Spectral Processing  
Possible With ORDA

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# KDDC Level I Experiment

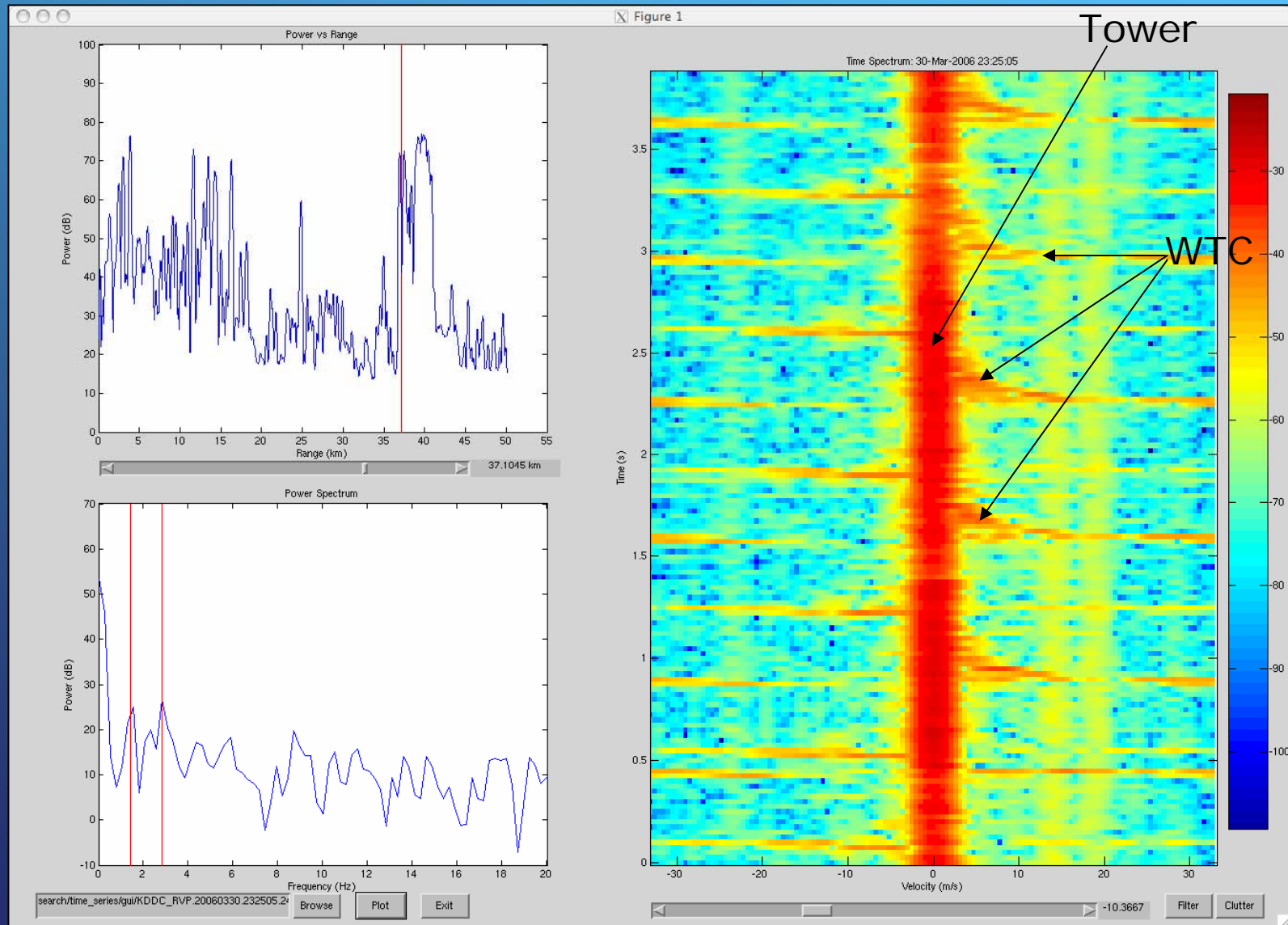
March 30-31, 2006

- ◆ Spotlight (stationary antenna)
  - ◆ Oversampled to achieve 25 meter range gates
  - ◆ Used the highest PRF: 1282 Hz (PRT = 0.78 ms)
  - ◆ Selected azimuth angles to isolate turbines
- ◆ VCP 21
  - ◆ Approximately 16 hours of Level-I scanning
  - ◆ Used for testing of mitigation algorithm under operational conditions
- ◆ Range-Height Indicator (RHI)
  - ◆ 10 elevation angles: 0.5-2.9°
  - ◆ Shows negligible effect of WTC on sidelobes (88D only)

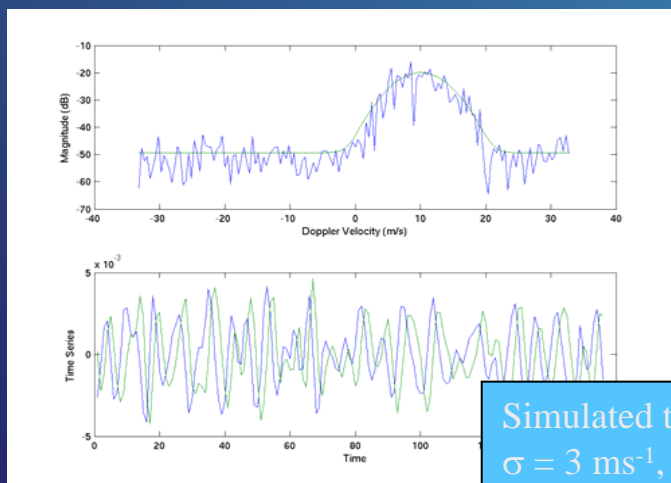
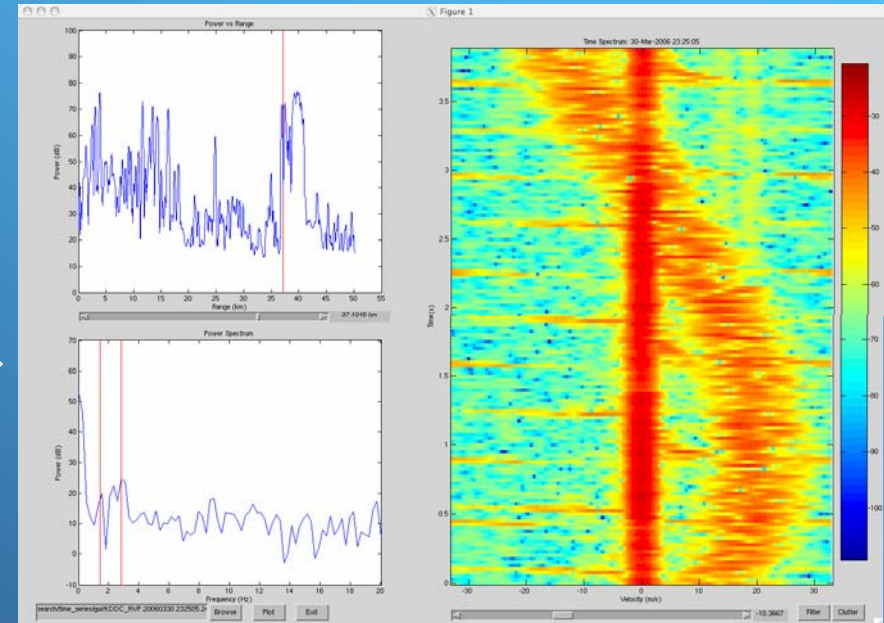
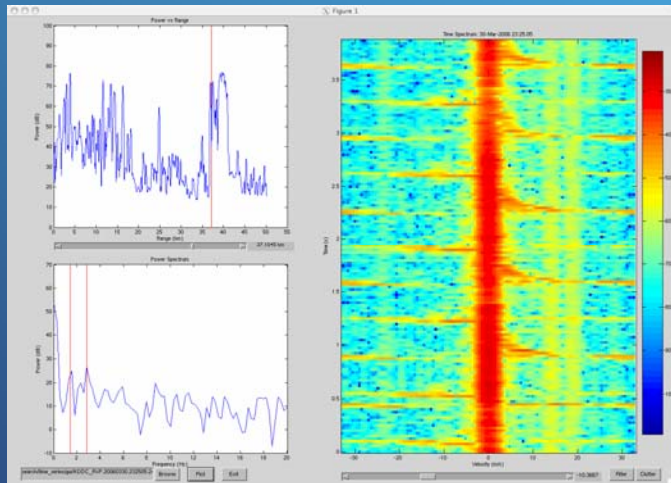


# KDDC Spotlight

## Single Isolated Turbine



# Addition of Simulated Weather



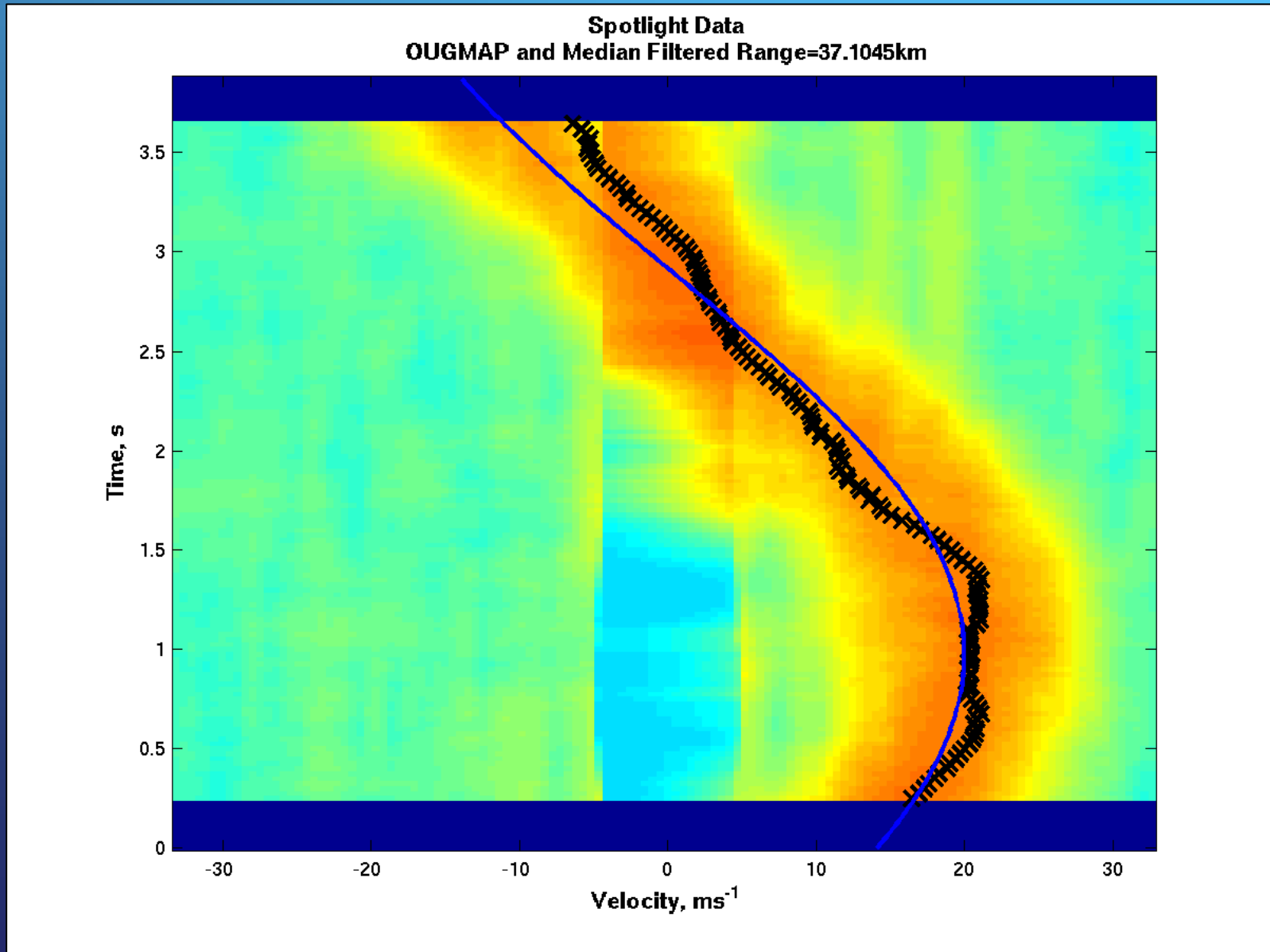
Simulated time-series weather signal [Zrnic, 1969];  
 $\sigma = 3 \text{ ms}^{-1}$ ,  $v_r$  varies with time, SNR = 20 dB

# Non-Linear Filtering Methods

- ◆ Unwanted WTC signals are transient (0.1 sec)
- ◆ Wx echoes should be approximately stationary over seconds (temporal continuity)
- ◆ We will exploit this difference by using the continuity in the Wx signal
- ◆ Solution for Spotlight Data: Use a simple variation of a median filter to remove the artifacts

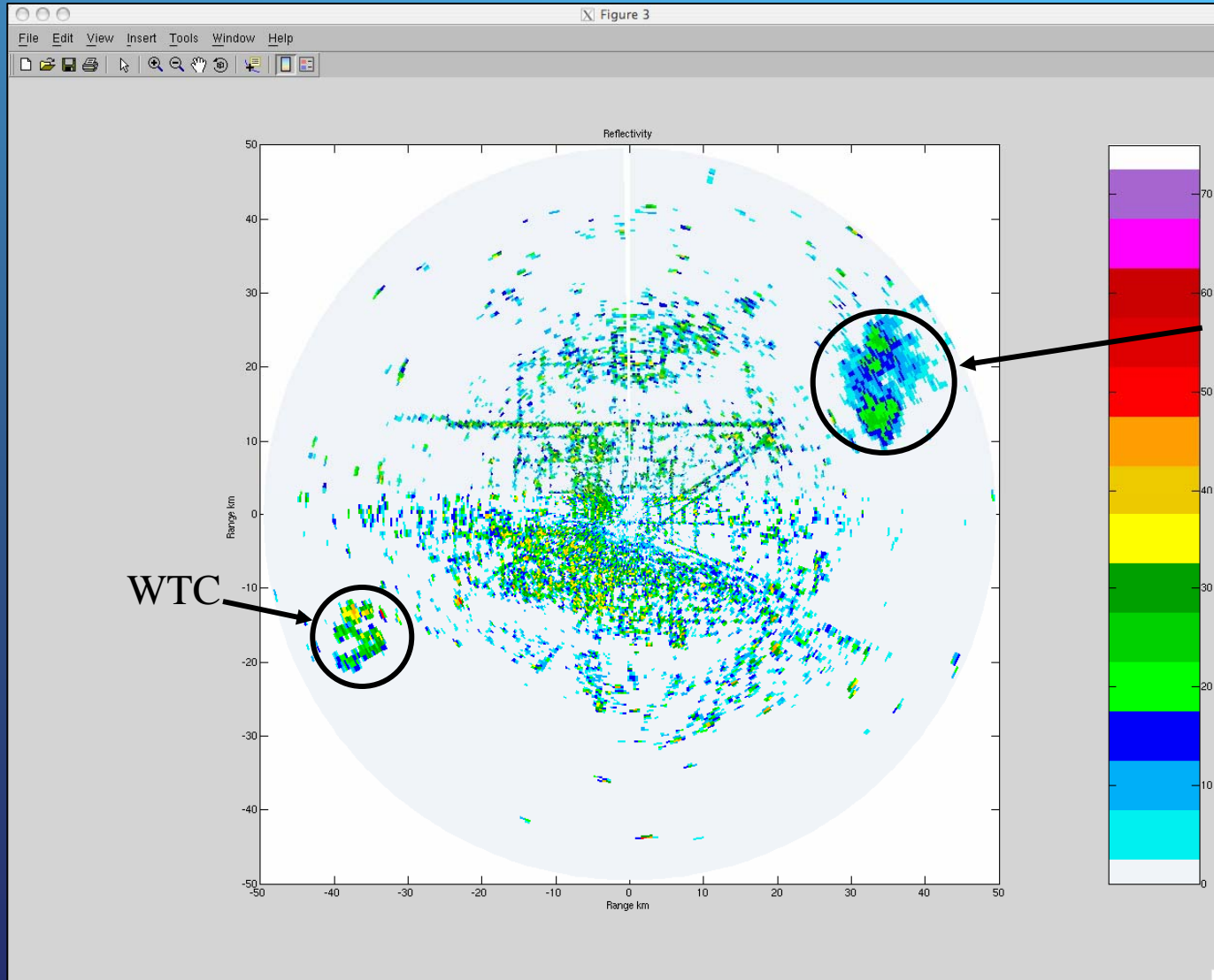
# KDDC Spotlight: OUGMAP/Median Filter

## *Single Isolated Turbine*



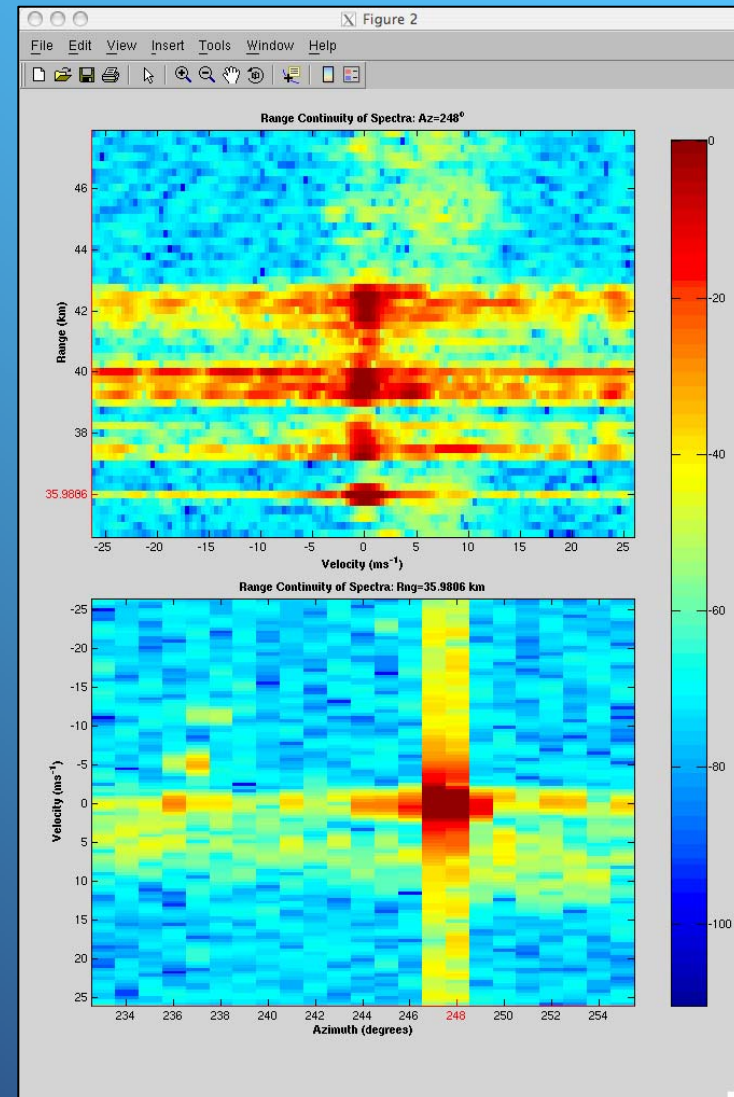
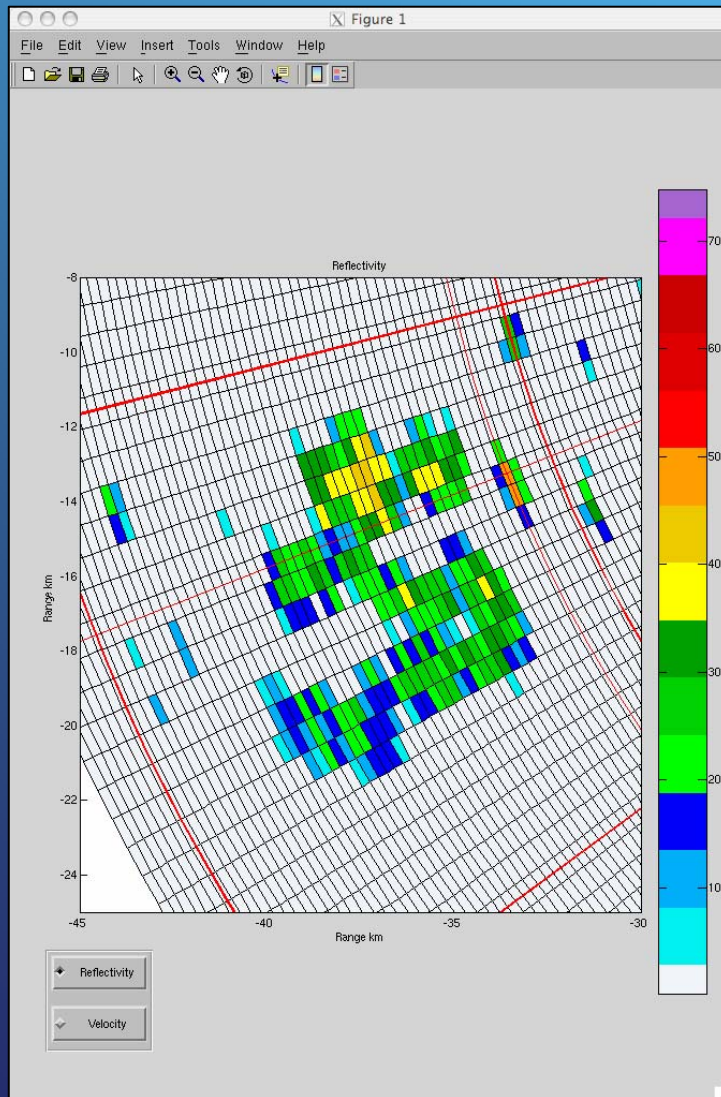
# KDDC VCP 21 Scanning Data

March 30, 2006 20:34:17 UTC



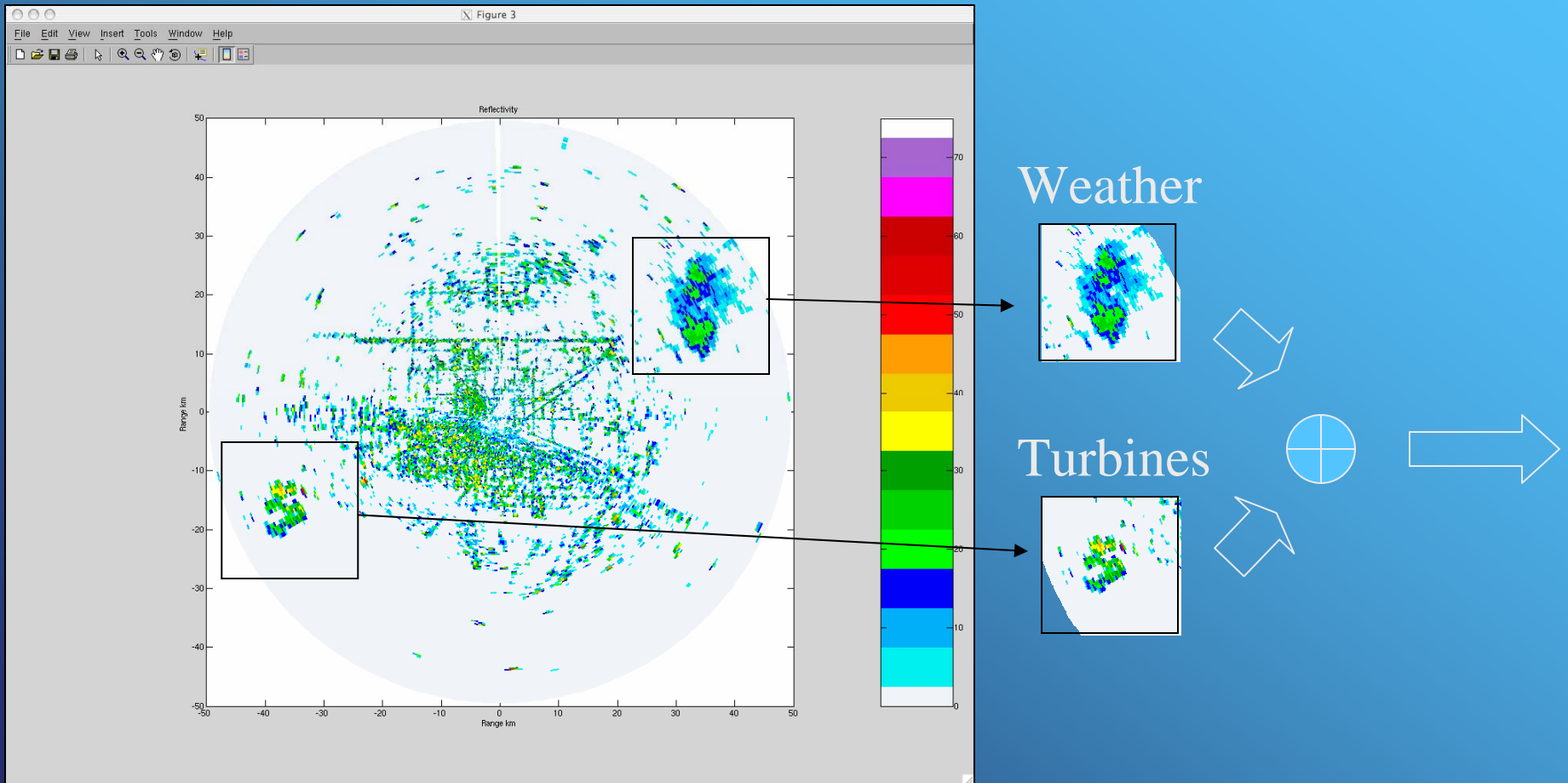
# KDDC VCP 21 Scanning Data

## *WTC ONLY: Spatial Evolution of Doppler Spectra*



# KDDC VCP 21 Scanning Data

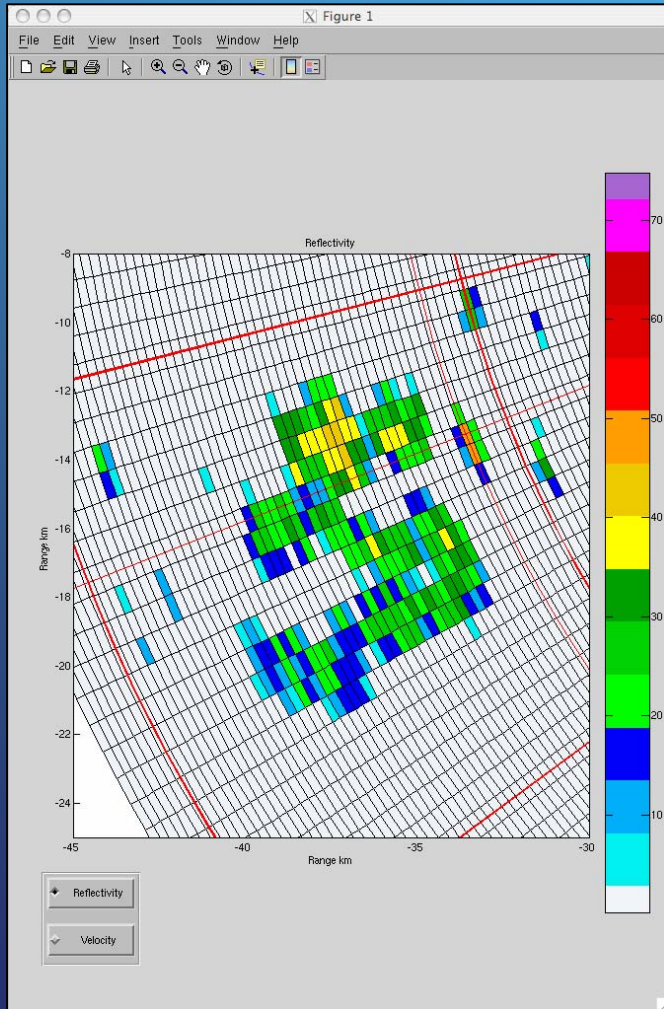
## *Mixed Wx and WTC*



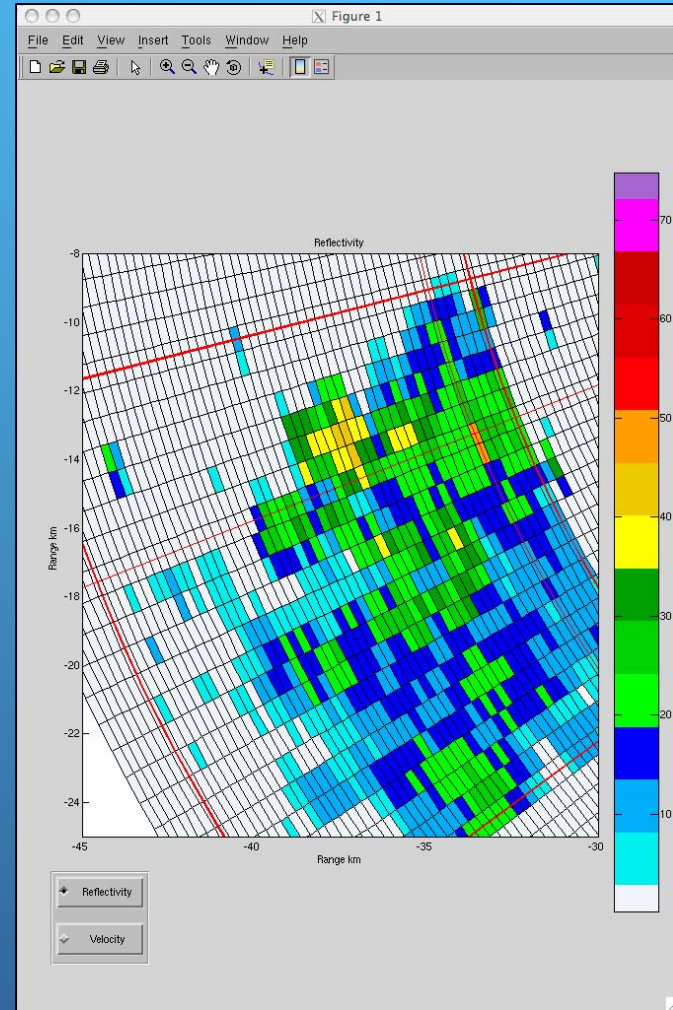
*Given Level-I data, it is possible combine the Wx and WTC signals*

# KDDC VCP 21 Scanning Data

## *Wx/WTC Interaction*



WTC Only

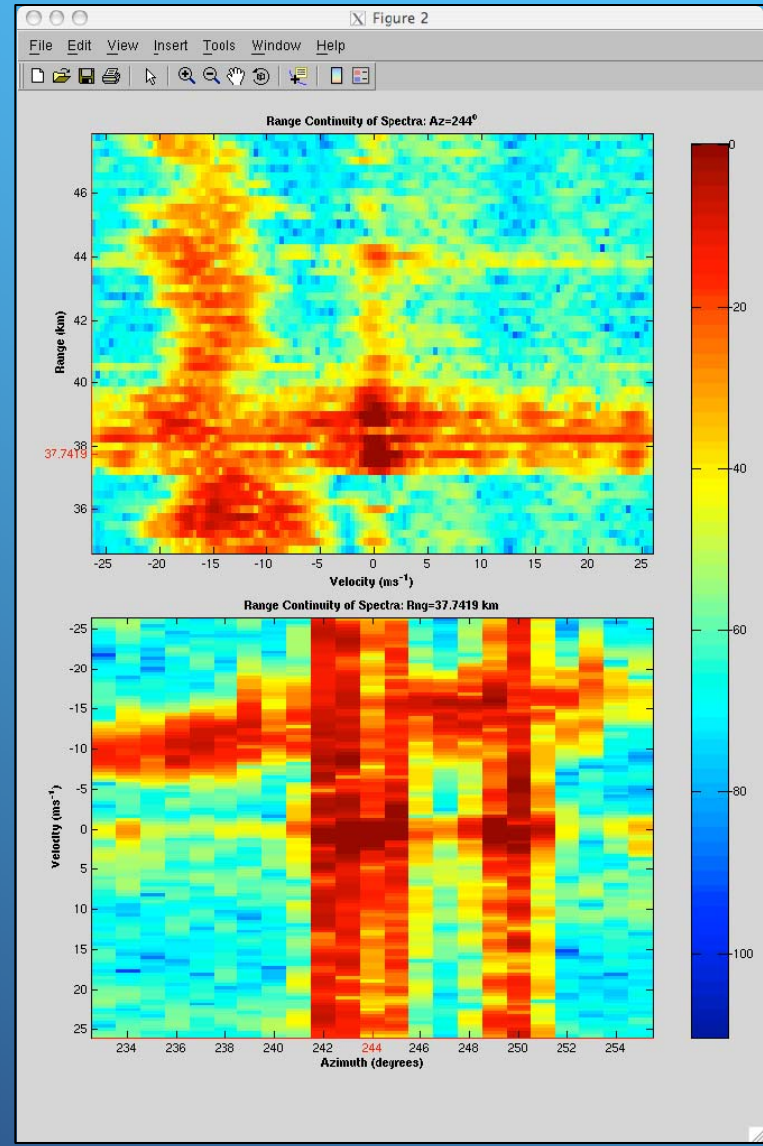
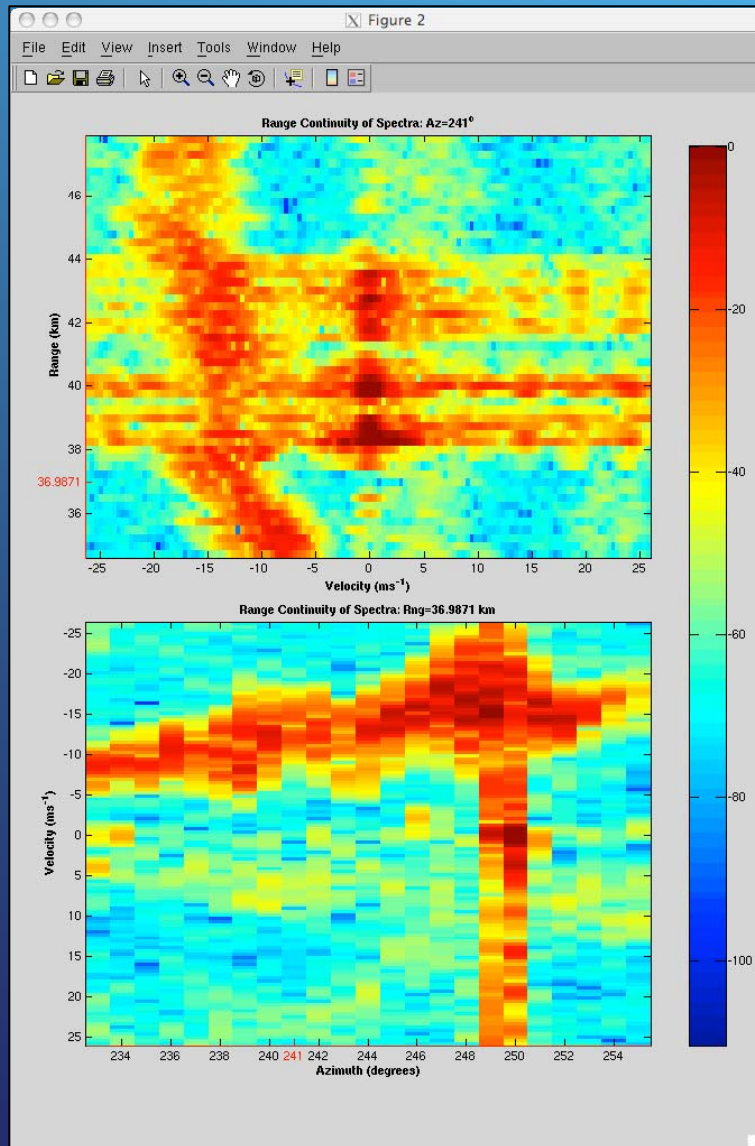


WTC and Wx



# KDDC VCP 21 Scanning Data

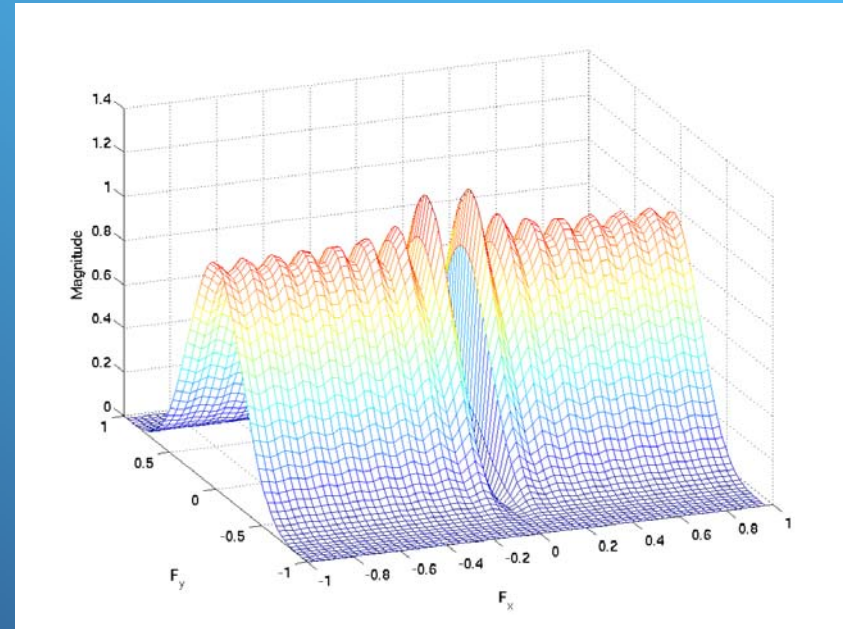
*WTC & Wx: Range/Azimuth Continuity in Doppler Spectra*



# KDDC VCP 21 Scanning Data

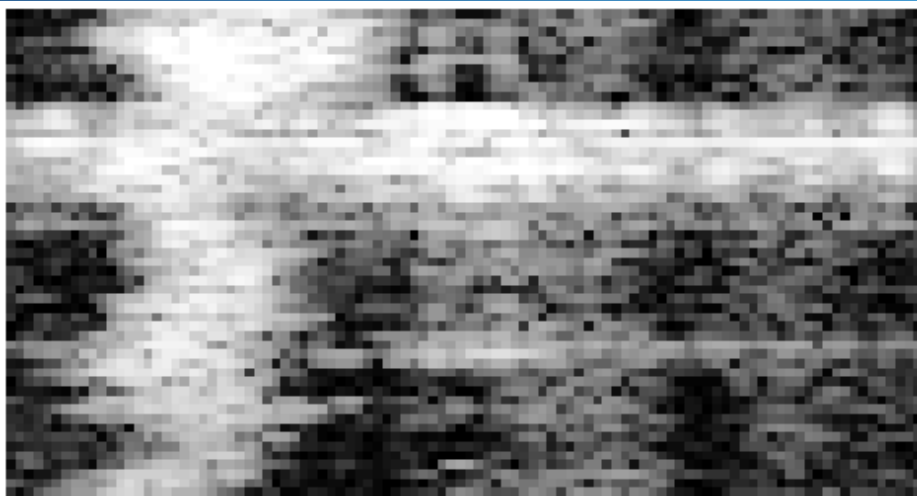
## *Standard Two-Dimensional Filtering?*

- Problem: Turbine Clutter close to constant level in frequency dimension
- Possible Solution: 2-D FIR Notch Filter at DC with smoothing in range/azimuth

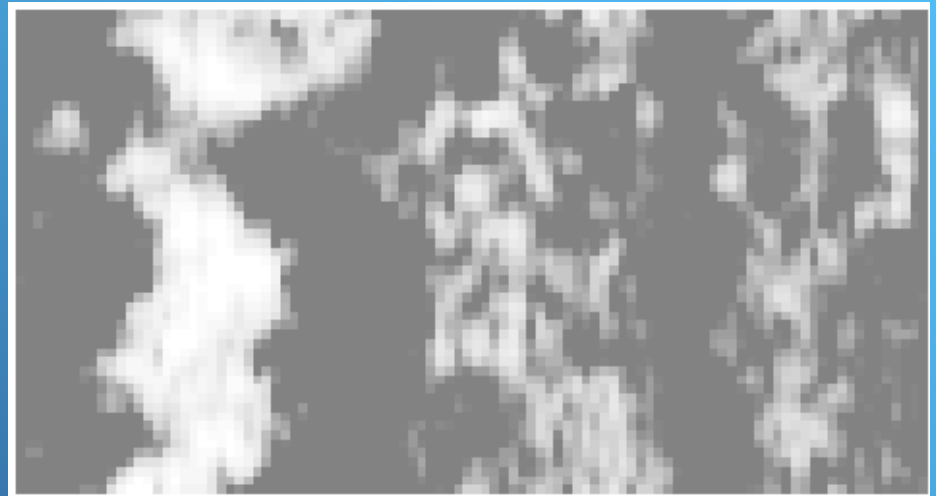


# KDDC VCP 21 Scanning Data

*Two-Dimensional Filtering: Preliminary Results*



Unfiltered WTC/Wx



Filtered WTC/Wx

# Summary and Future Work

- ◆ Explored advantages of Doppler spectral processing for mitigation of WTC
- ◆ Developed preliminary non-linear filtering scheme exploiting spatial/temporal continuity of weather signals
- ◆ Future Development Work:
  - ◆ Optimize processing scheme for exploiting three-dimensional continuity in Doppler spectra
  - ◆ Possible simulation study of adverse effects of non-linear filter
  - ◆ Future experiments may be needed for more difficult cases of multi-path scatter, multi-trip echoes, etc. KTFX Great Falls, Montana?
  - ◆ Begin to explore challenges with real-time implementation