OBSERVATIONS OF TURBULENCE IN THE WIND TURBINE LAYER FROM WIND PROFILING RADARS

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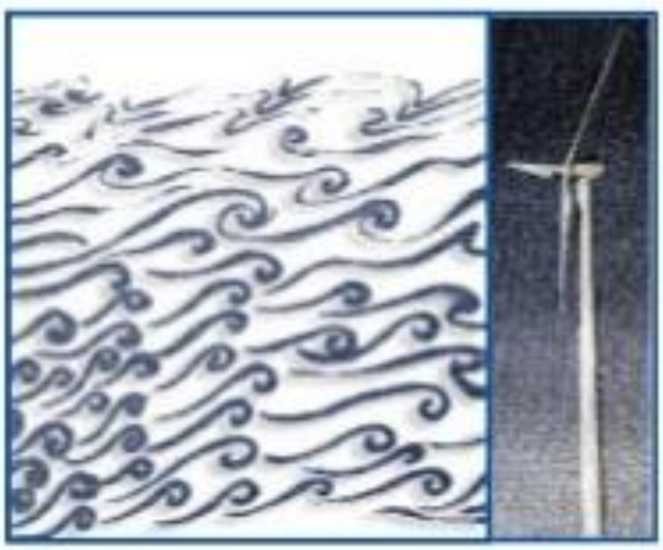
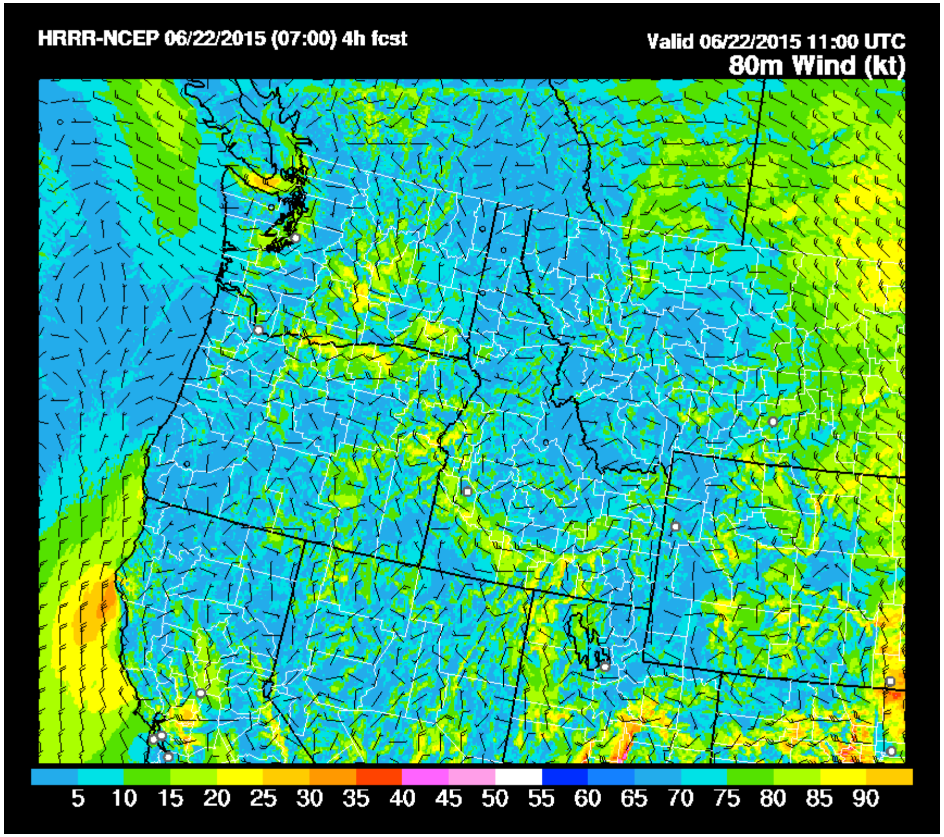
Turbulence, Wind Energy, and NWP

- Vertical profiles of turbulence dissipation rate are currently unavailable
- Wind Profiling Radars (WPRs) are commonly used for average winds, so the ability to “simply” turn some knobs on the current instruments to measure turbulence will provide:
  - Turbulence encountered by a turbine
  - Invaluable information for verification and improvements to sub-gridscale parameterizations in mesoscale weather models like the NOAA HRRR





XPIA: eXperimental Measurement Committee's Planetary Boundary Layer Inter-comparison Assessment

Two-month field campaign at the NOAA-ESRL/PSD Boulder Atmospheric Observatory:

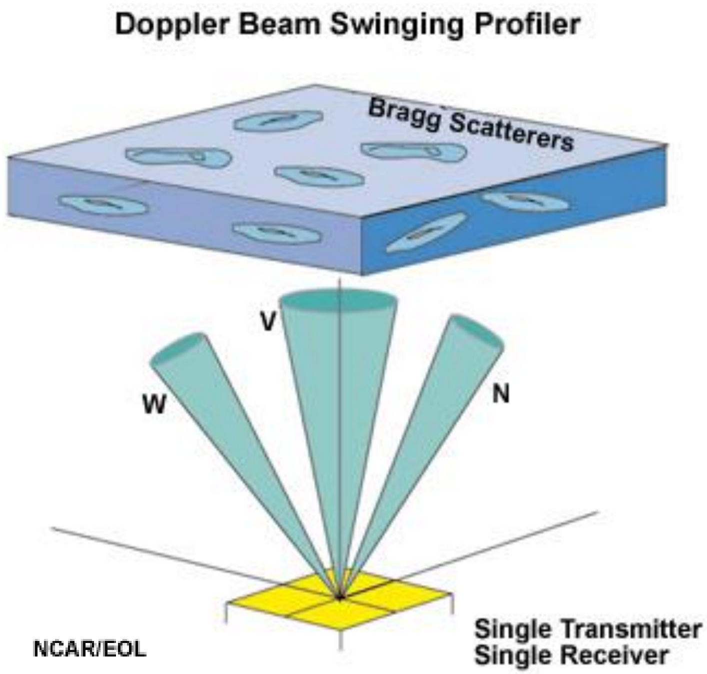
To assess remote sensing instrumentation for their temporal and spatial resolution capability to capture PBL and intra-array wind plant flow characteristics for validation and verification of mesoscale, LES, and wind plant flow models

300m Tower with 12 Sonic Anemometers at 6 heights

Wind Profiling Radars

Also:
Radiometers
Radiosondes
Scanning and Profiling Lidars
Scanning Radars

Wind Profiling Radars

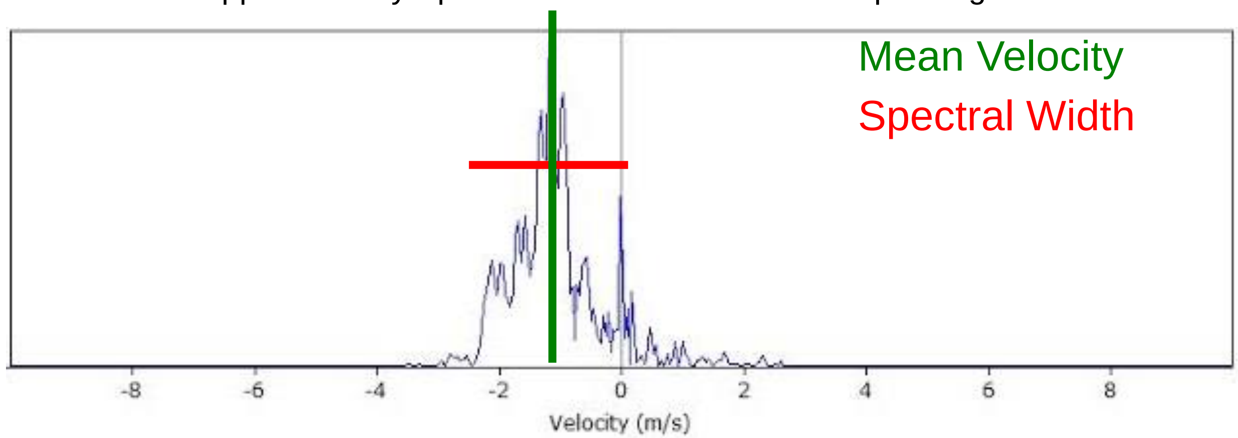


WPRs measure a spectrum of velocities observed in the sampled volume.

Average winds (first moment) create the largest peak, while the spread (second moment) is from turbulence.

Turbulence is measured with a vertically-pointing beam, with high spectral resolution, based on several radar parameters.

Doppler velocity Spectrum from a 915-MHz wind profiling radar



Dissipation rates from Doppler spectral widths

- First introduced by Hocking (1982) and improved by others, up to White (1997)
- Measured spectral widths contain both turbulent and non-turbulent effects:

$$s_m^2 = s_r^2 + s_T^2$$

- Removing the shear-broadening and beam-broadening effects from the radar, the turbulent contribution remains, and can be related to the turbulence dissipation rate, ε:

$$s_T^2 = \frac{a e^{2/3}}{4p} I$$

where *I* is a triple integral in spectral space based on radar parameters and mean wind speed and shear (White 1997).

- Note: when radar effects are larger than the measured width, the datum is removed.

Improvements to WPR Spectral Width Method

Possible steps toward improvement

1. Radar set-up: Temporal and spectral resolution
2. Time series processing
   - Wavelet & Gabor filtering
3. Spectral averaging: Dwell Averaging
4. Moments' calculations
   - Standard vs Multiple Peak Processing
   - Fuzzy Logic

Radar Parameters: Spectral Resolution

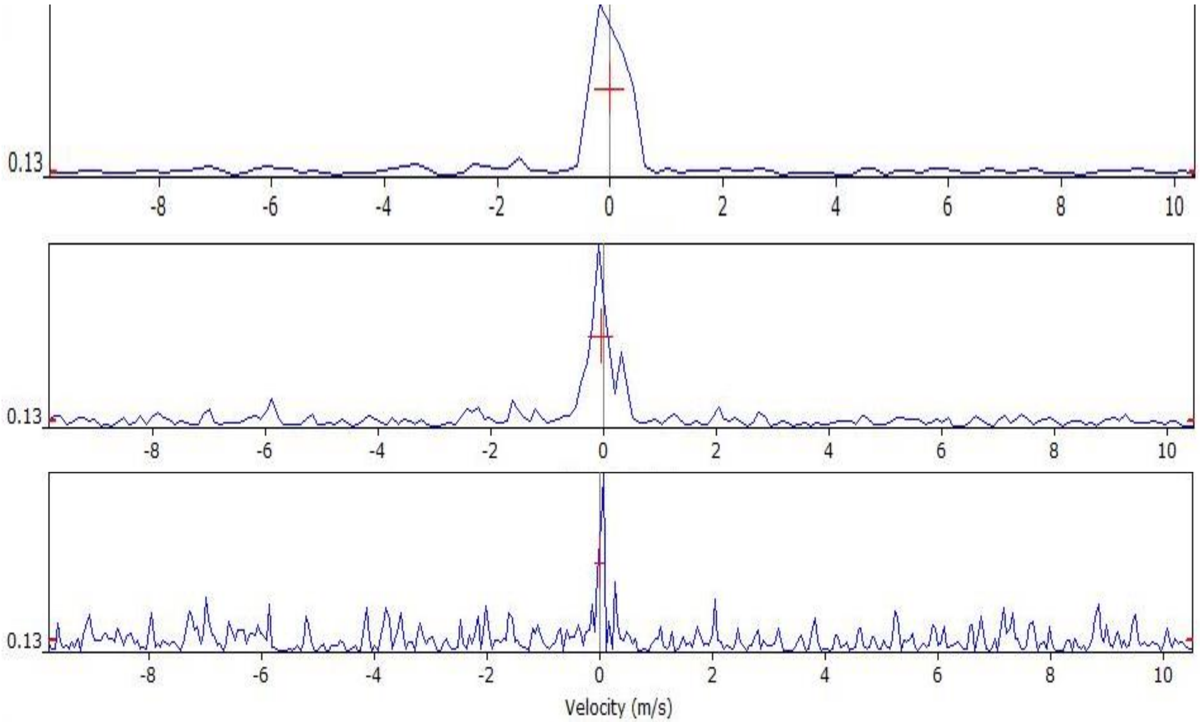
- Based on interpulse-period, number of coherent integrations, and number of FFT points in the spectrum, the resolution of each dwell is determined.
- Higher resolution allows for more accurate widths, but requires more memory for each dwell.

Doppler velocity spectra from a 915-MHz wind profiling radar at 130m

4096 FFT points

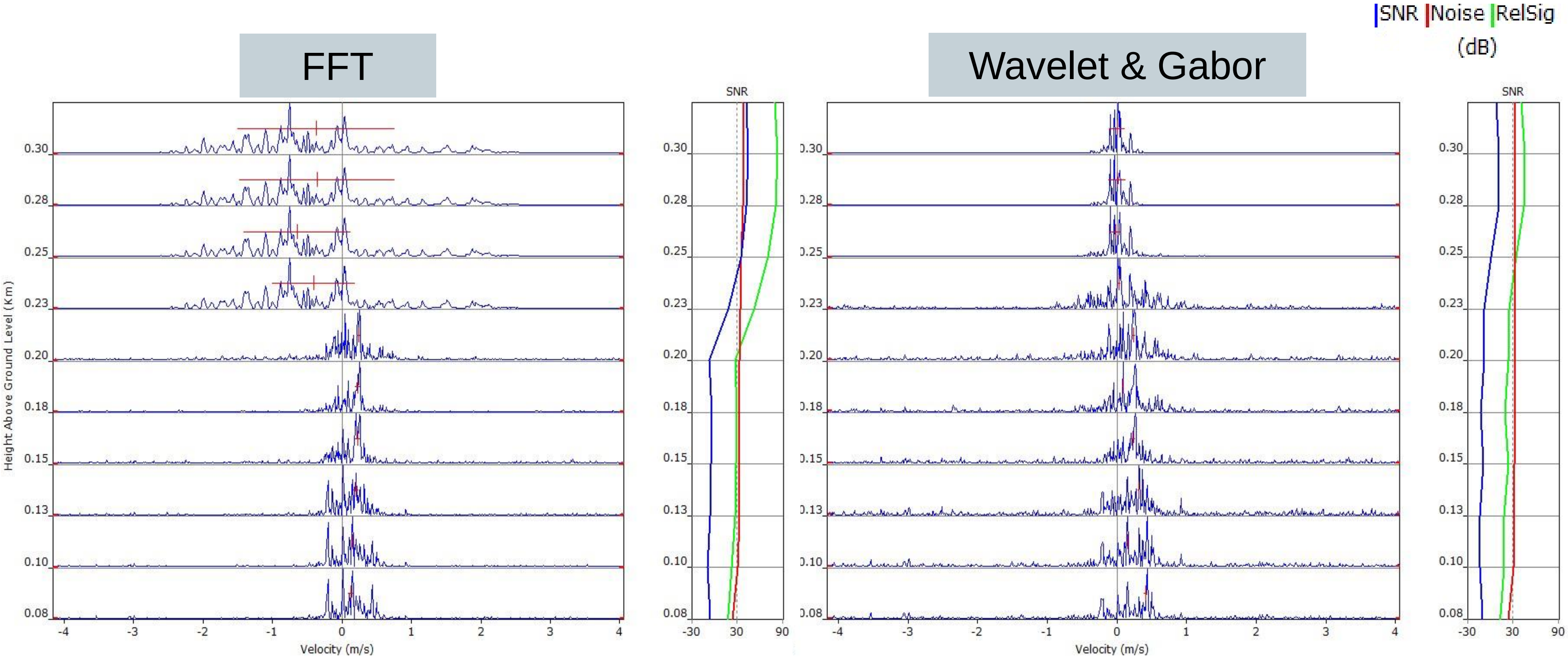
8192 points

16384 points



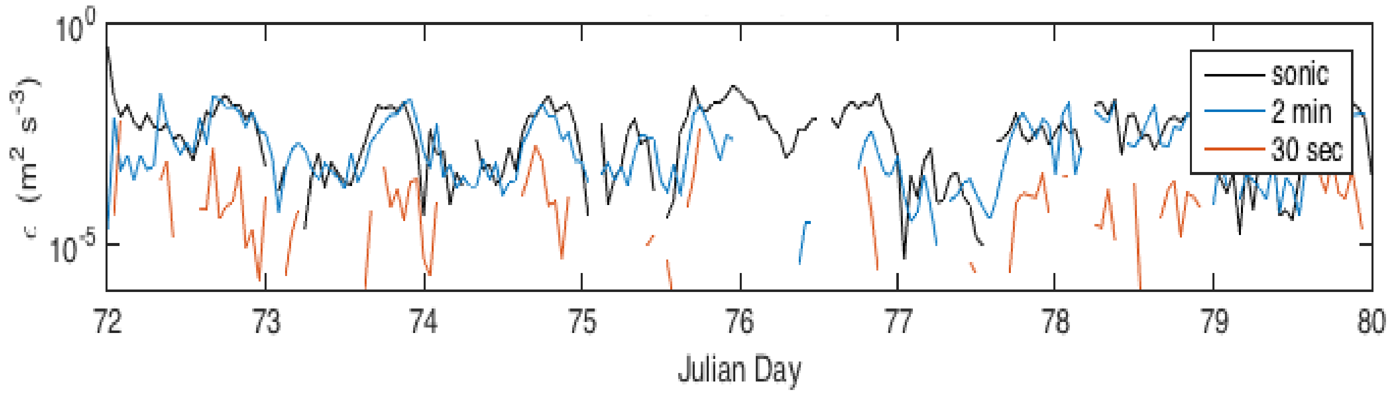
Time-series filtering and post-processing

- Saving the time series instead of spectral points allowed for testing of post-processing methods
- Wavelet filtering: removes artificial signals by frequencies (Jordan et al 1997)
- Gabor filtering: removes birds and intermittent clutter (Bianco 2013)
- Both processes increase signal-to-noise ratios, making it easier to identify the true atmospheric signal



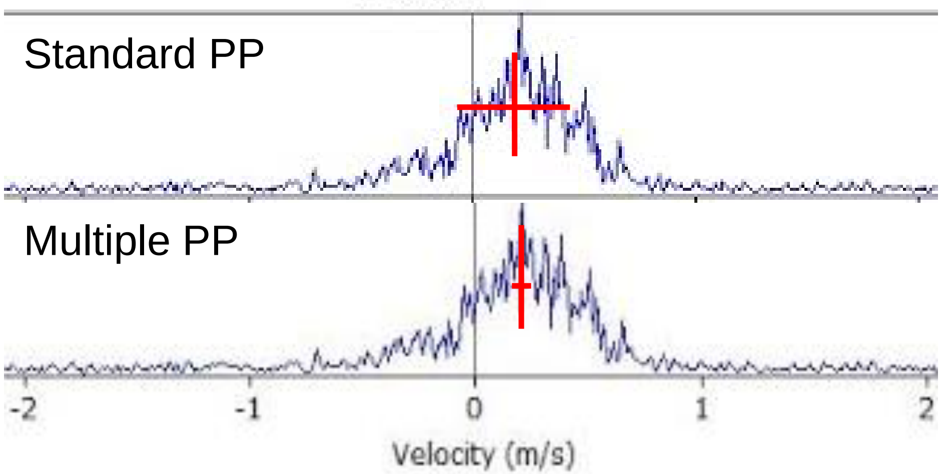
Dwell Time: Spectral Averaging

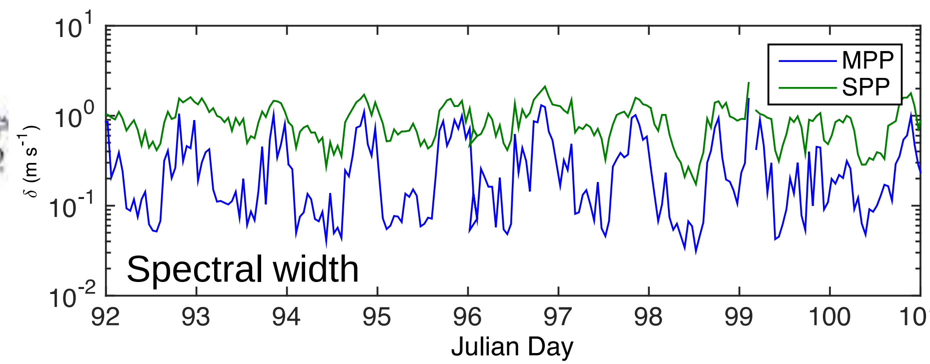
- One dwell's spectrum contains velocities over 6-15 seconds
- Spectra can be averaged by:
  - reduced number of FFT points (reducing the resolution)
  - Averaging in time
- Averaging spectra across multiple dwells (6-15 seconds each) can reduce the noise, and capture the true atmospheric fluctuations
- Short dwells are too "random" and long dwells contain changing mean winds in their width

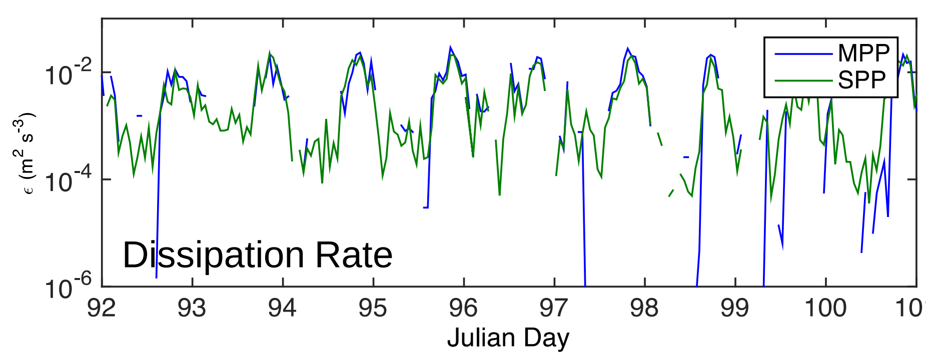


Moments Calculations

- Standard vs Multiple Peak Processing (Griesser & Richner, 1998)

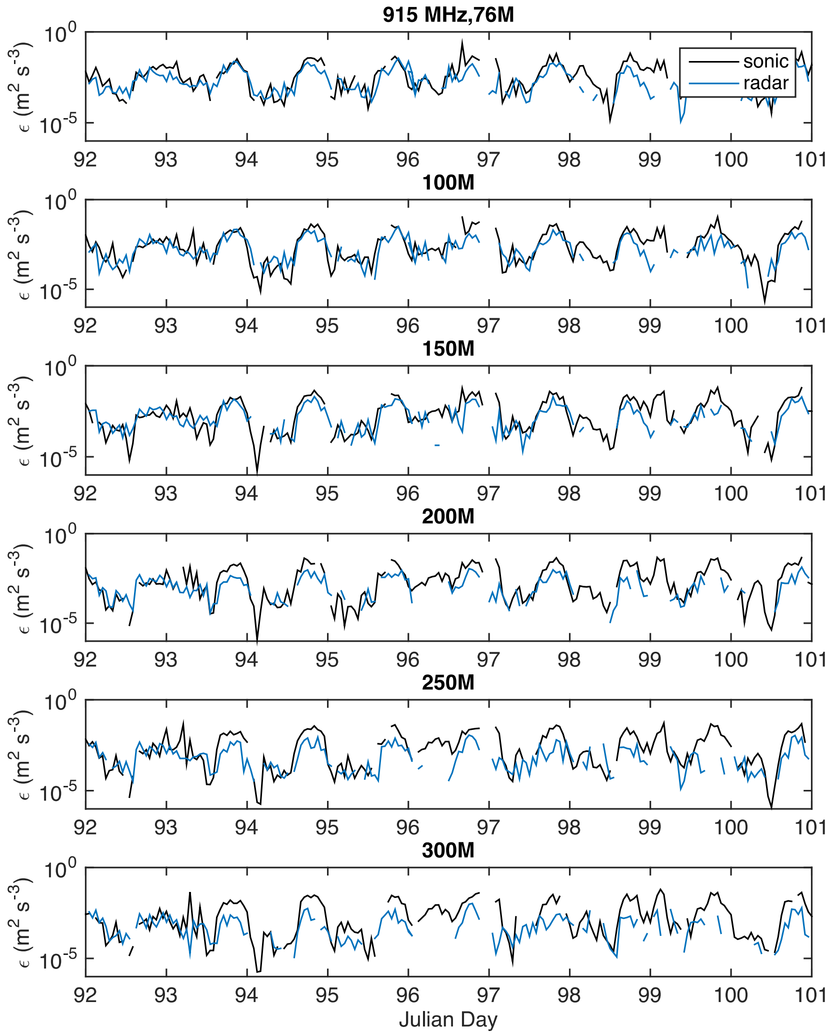




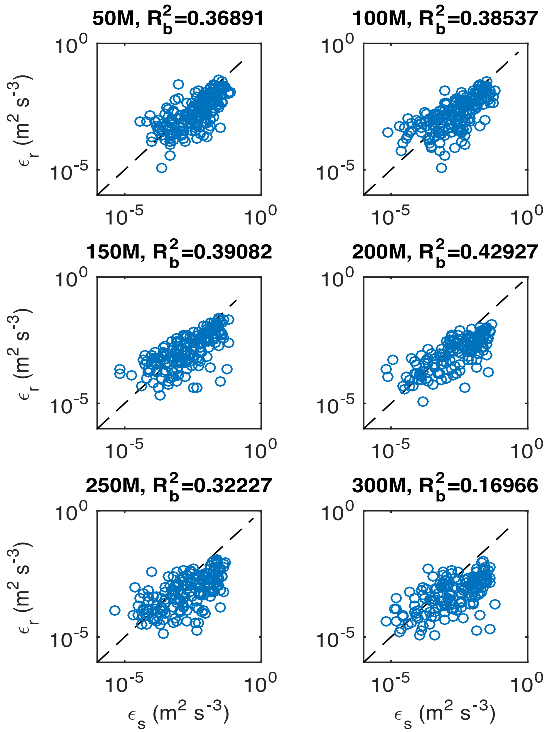


- MPP identifies one peak as multiple, and therefore widths are too small
- Large values of ε match, but small ones are lost
- Radar broadening effects are larger than “observed” widths

Dissipation Rates from WPR and Sonic Anemometers

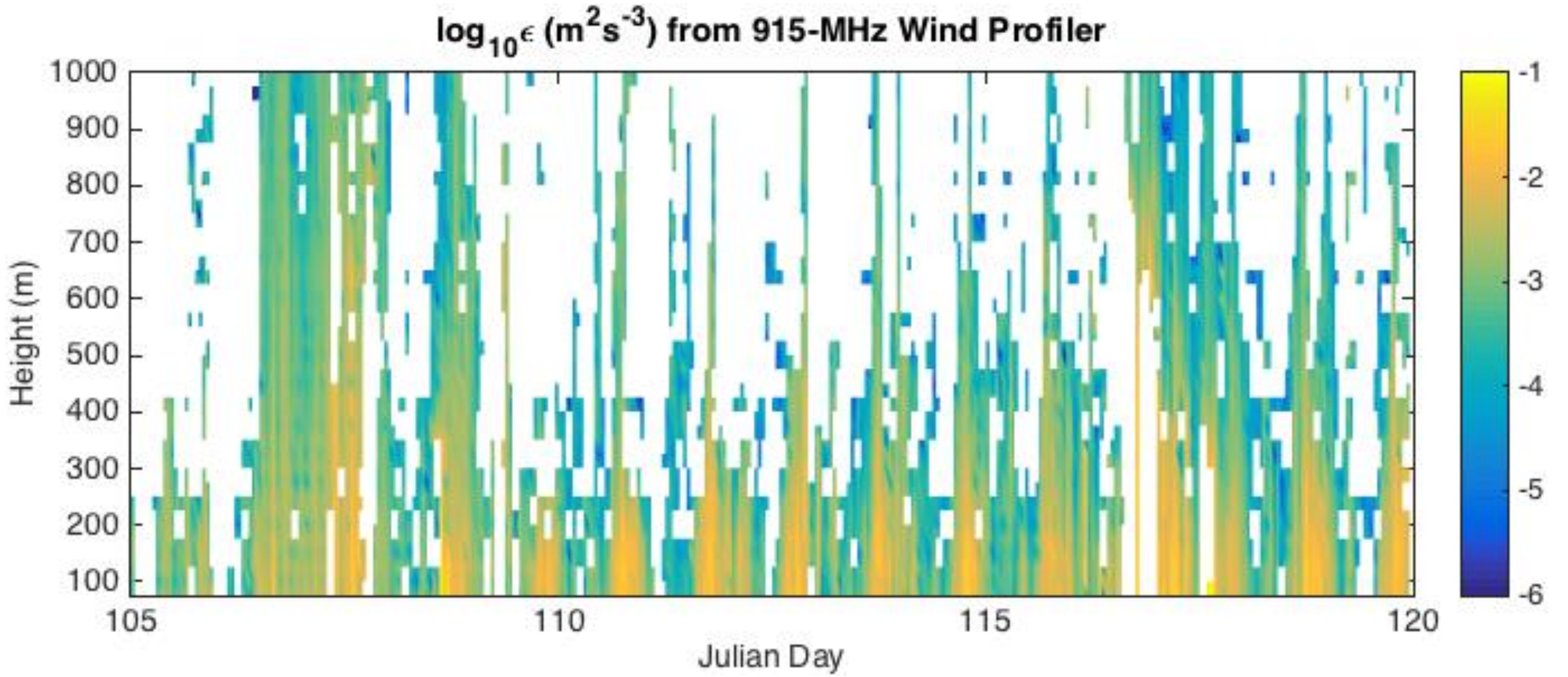


- Good agreement in time, with clear diurnal cycle
- R^2 values are skewed low by some days when one instrument doesn't follow the diurnal cycle



Profiles

- Dissipation rates up to 500m, sometimes 1km (and higher!)
- Diurnal cycle evident
- Smallest dissipation rates are lost in noise and beam/shear broadening effects



Conclusions

- Turbulence dissipation rates are calculated using the spectral width method.
- Implementing Wavelet and Gabor filtering, averaging over 2 minutes, and using standard peak processing produced the best results.
- Agreement is seen with sonic anemometer measurements down to 10^{-5} m^2 s^{-3}.
- Low spectral resolution and signal-to-noise ratio can prevent clean measurements of spectral widths.

Reliable time series of dissipation rates at least to 500m, if not higher, will be greatly beneficial to improving the sub-gridscale parameterizations in mesoscale wind prediction models

Looking forward…

- A method of moments calculations based on fuzzy logic (Bianco dissertation) may improve widths

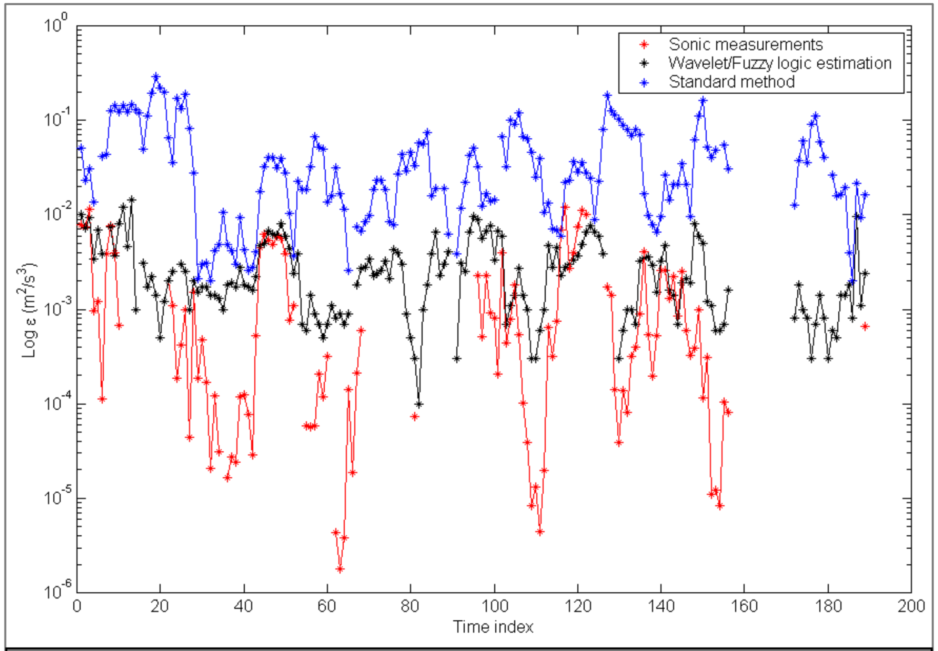
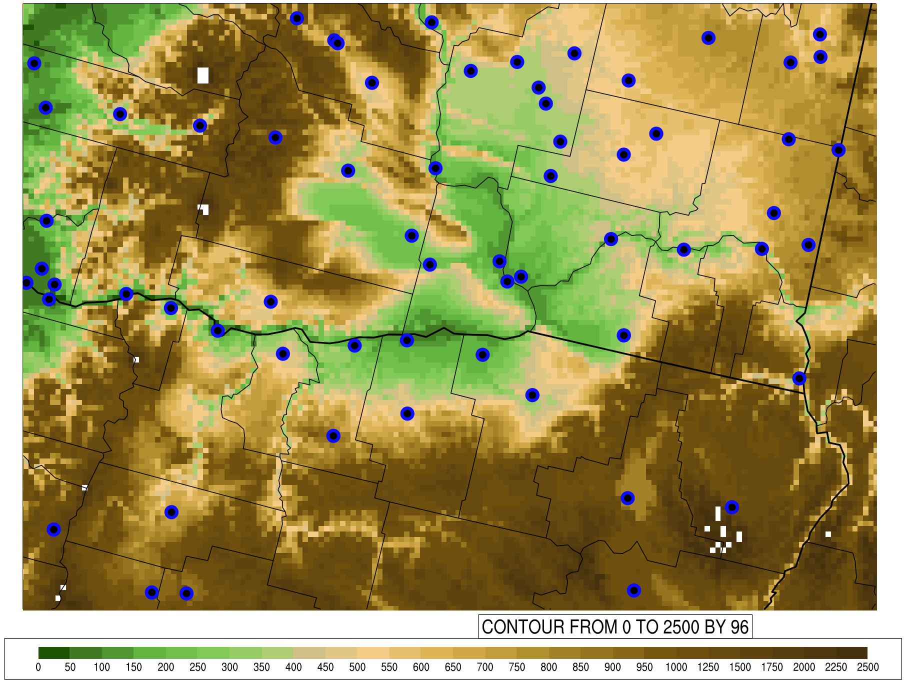


Fig. 4.7. Time series of the values of the eddy dissipation rate estimated from the sonic measurements (red), the standard procedure estimation (blue), and the Wavelet/Fuzzy logic combination (black).

- Wind Forecast Improvement Project 2: Complex Terrain
  - 8+ 449- and 915-MHz WPRs in Columbia River Gorge
  - Identify ideal radar set-up for extended field campaign
  - Collaborate with HRRR and LES modelers to improve models

3-km HRRR Terrain Elevation (m)



Eric James, NOAA

Thank you!

Any questions?

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