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# Quantitative Analysis of the Turbulent Structure of Convection and its Relation to Thunderstorm Electrical Properties

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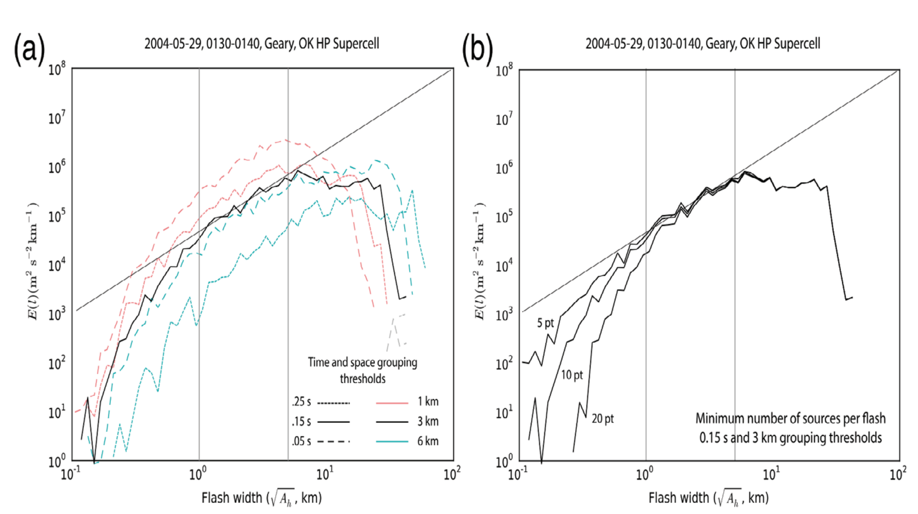
## Motivation

Previous work has suggested a tie between the electrical and kinematic properties of a thunderstorm. Energy spectra created for an ensemble of lightning flashes (Bruning & MacGorman, 2013) demonstrate both a 5/3 slope in the inertial subrange and a peak at 10 km, which is similar to what is expected from TKE spectra. Spatial spectra of mean Doppler velocities can be used to examine the characteristics of turbulent eddies (Brewster & Zrnic, 1986). It is hypothesized that these turbulent eddies serve to organize the potential distribution discharged by lightning flashes in thunderstorms. The similarities between the two spectra could further prove this relation between the properties of the deep convective motions within a thunderstorm and the organization of charge.

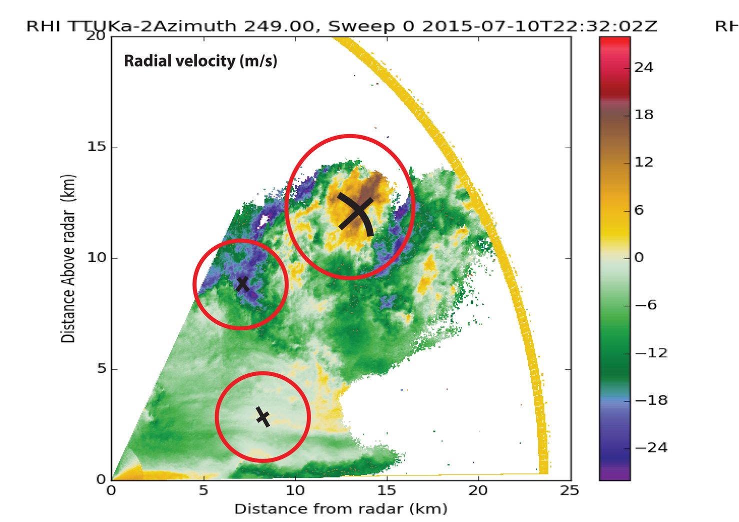
**Goal:**
Quantitative analysis of the link between electrical and kinematic motions, which would serve as a validation not only for linking radar textures with the lightning characteristics, but also in examining where the inertial subrange begins.

**Methodology:**
Perform Fourier analysis on the distriubtion of velocities from an RHI scan of different thunderstorm structures, creating spectra to examine the turbulent energy at the different scales.



*Energy spectra of an ensemble of lightning flashes, taken from Bruning and MacGorman (2013). The scale range of 1-10 km fits well to the 5/3 power law relationship.*

## Testing of Kolmogorov Hypothesis




*Example of the selection of gates from an RHI scan used to perform the correlation tests. (not to scale)*

We want to examine the range of turbulence scales known as the "inertial subrange", in which there are no sources or sinks of energy. In this range, energy is transferred downscale; the slope of this inertial subrange is proportional to a 5/3 power law relationship, according to the Kolmogorov hypothesis.

The Kolmogorov hypothesis requires that turbulence is both isotropic and homogeneous. This doesn't necessarily hold true outside of the inertial subrange of turbulent scales. If our data do not meet these requirements, it would suggest that we shouldn't even consider trying to find a 5/3 slope in the inertial subrange.

**Strategy:**
In order to show that this assumption holds true enough for our analysis, we performed two sets of Fourier analysis surrounding a given point on the RHI scan, examining the same distance horizontally along a range of gates, and quasi-vertically along the elevation angle. We then ran a correlation test between the two sets of Fourier results to determine how similar the spectrum of variance was over the chosen distance.

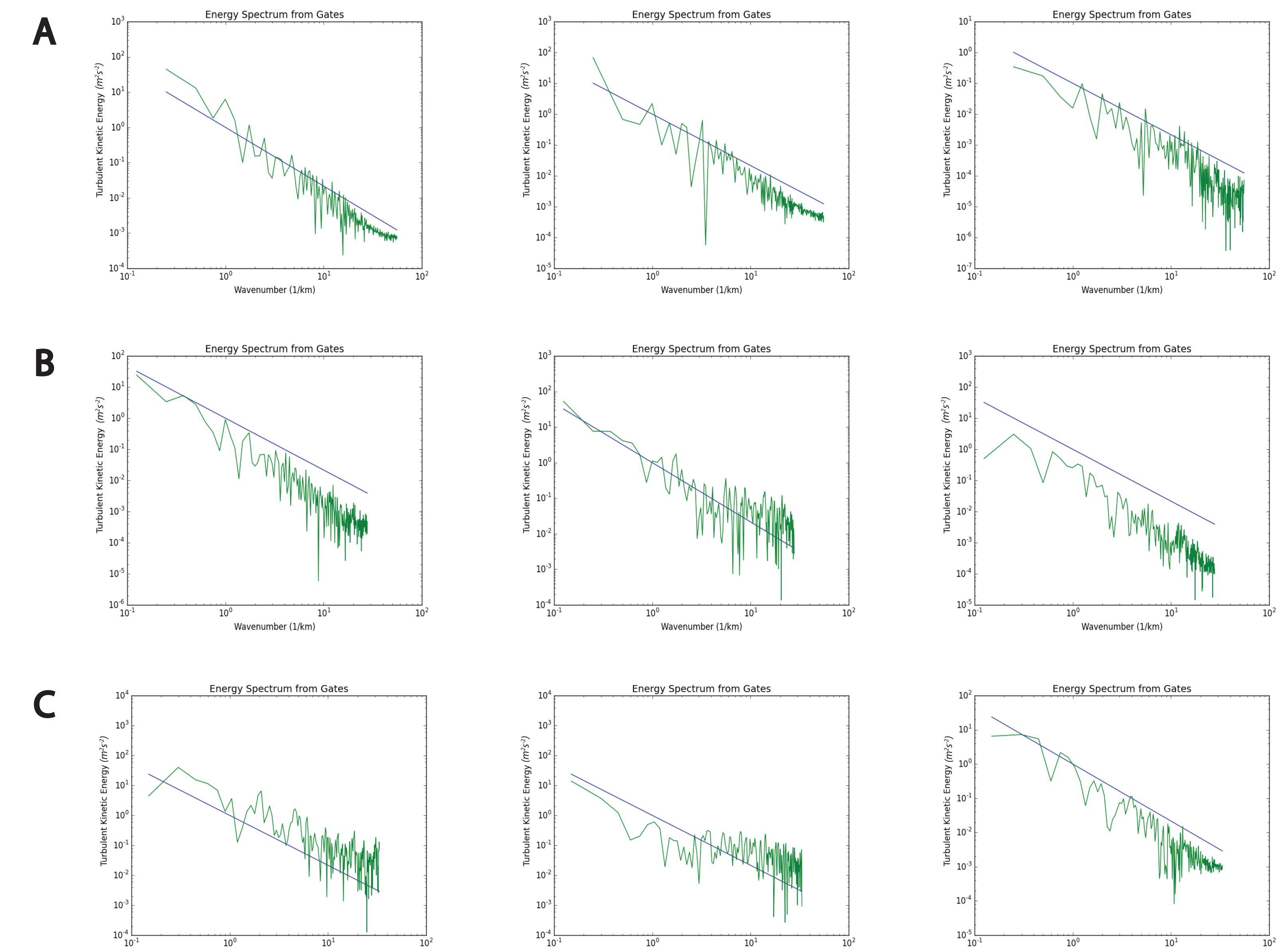
## Correlation Tests

| Date/Time | Radar | Distance (km) | Inbound Maxima Cor() | Outbound Maxima Cor() | Laminar Flow Cor() |
|---|---|---|---|---|---|
| 07/10/15 - 2231 UTC | Ka-2 | 1 | 0.9999568 | 0.9943738 | 0.9600209 |
| | | 1.5 | 0.9938645 | 0.9999712 | .-- |
| 07/10/15 - 2247 UTC | Ka-1 | 1 | .-- | 0.999867 | 0.9965331 |
| | | 1.5 | .-- | 0.9997877 | 0.9977219 |
| | | 4 | .-- | 0.9790846 | 0.9993835 |

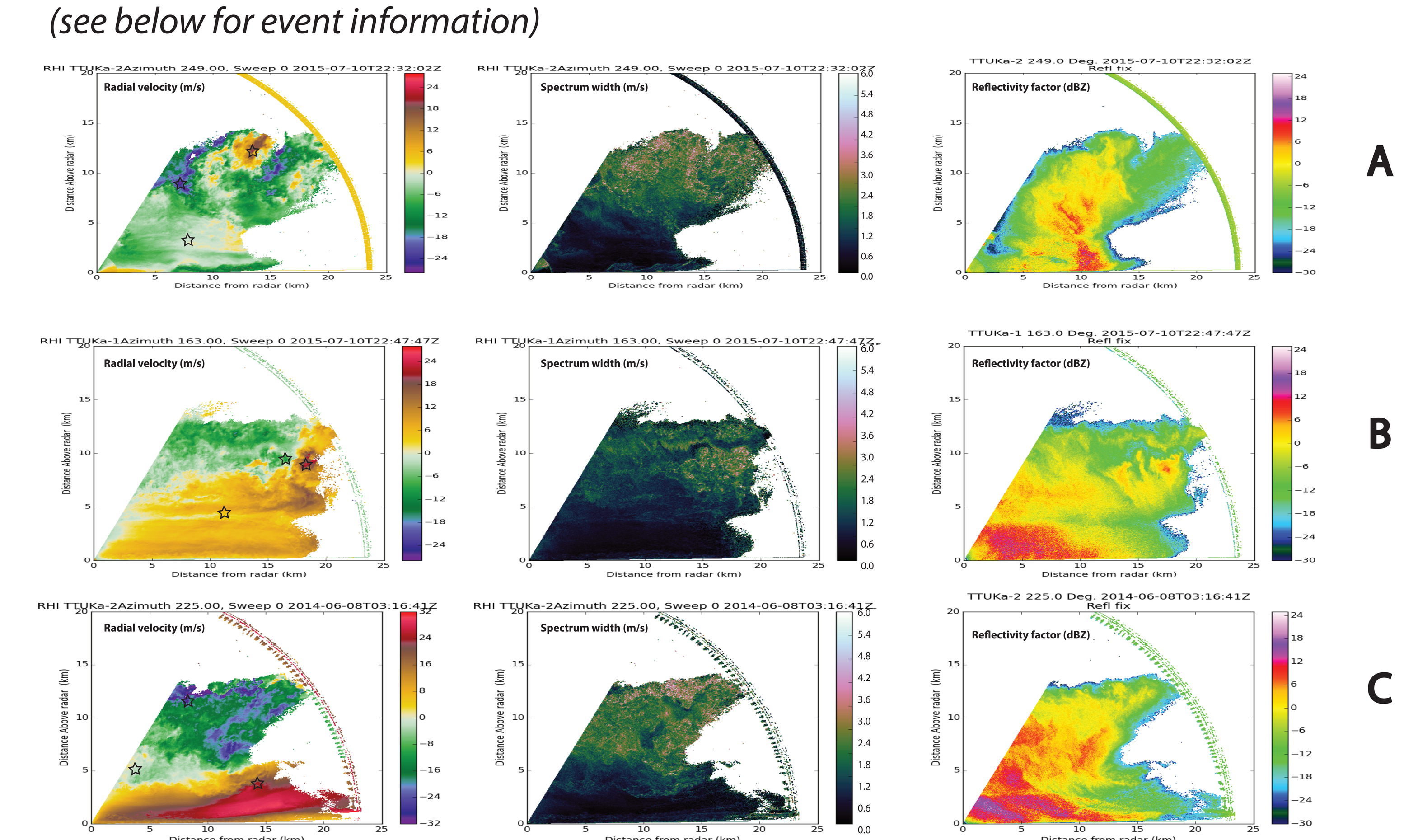
*Results show a high correlation between the vertical and horizontal ranges of variance of velocities. This high correlation holds even over a larger range of 4km, and it is consistent among different radar scans and different regions within the scan.*

**Conclusion:**
The assumption of homogeneous and isotropic holds well enough to use this method in order to further examine the energetic properties of the turbulent convective structure.

## TKE Spectra




*Resultant plots of turbulent kinetic energy spectrum from Fourier analysis. Plots were generated using velocities taken along a single ray, over a 4km distance. A -5/3 slope line is also plotted over the spectra. The left-hand column corresponds to spectra in areas of moderate to strong inbound velocities, the middle column corresponds to areas of strong outbound velocities, and the right-hand column corresponds to areas of weaker or more laminar flow. (see below for event information)*




*RHI radar scans from which velocity data were taken to create spectrum plots. Plot A is from TTU-Ka2 radar, taken on July 10, 2015 at 22:32:02 UTC; Plot B is from TTU-Ka1 radar, also taken on July 10, 2015, at 22:47:47 UTC; Plot C is from TTU-Ka2 radar, taken on June 8, 2014 at 03:16:41 UTC. Storm mode for the July 10th scans was multicell, while the June 8th storm was a supercell. Areas analyzed are marked on the velocity plots with a star.*

## Fourier Analysis

The Fourier analysis was performed using an interactive tool developed by the authors. On a click of the mouse on the image, it grabs a specified number of gates surrounding that point, along that given ray, and performs the Fourier analysis on those data points. The number of gates grabbed can be specified before the plot is created, allowing for a wide range of different scales and resolutions to be tested. Plots use the output of spectral densities of the velocity variance to calculate the turbulent kinetic energy.

## Results

Results show that the spectra of the turbulent kinetic energy follow very close to a 5/3 power law relationship, which is evident in spectra created for different types of textures on the RHI scans, as well as in different storm modes.

The -5/3 slope in the resultant TKE spectra plots suggests that the wavelengths being examined fall within the inertial subrange where energy is being transferred downscale. This demonstrates that the radars can resolve a spectrum which matches our expectation for velocities in the inertial subrange. It is this energy embedded within the turbulent eddies that is hypothesized to organize the potential distribution discharged by lightning flashes.

## Future Work

With the 5/3 power law present in the data, similarities between ightning flash energy spectra and TKE spectra will be further analyzed, as well as trying to determine the location of the peak in TKE. We also plan to use spectrum width to further examine the characteristics of TKE variability. Spectrum width looks at the distribution of velocities within a single gate, which will provide an additional data point alongside the resolved velocity variability among range gates. Overlays of lightning data with RHI radar scans will help to identify regions of flash initiation, helping to make further connections between sources of energy and the extent to which the electrical and kinematic energy are coupled.

Simultaneous radar scans from TTU-Ka1 and TTU-Ka2 were collected during the spring 2015 KTaL (Kinematic Texture and Lightning) field campaign. Time series analysis of dual-doppler retrievals along the intersection point will provide another means to assess the kinetic energy spectrum.