4.7 # COMPARISON OF LIDAR DATA WITH TOWER, PROFILER, RADIOSONDE, AND TETHERSONDE DATA

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1. INTRODUCTION

During July 2004, the Institut fuer Meteorologie und Klimaforschung, Tropospheric Section (IMK-TRO), Forschungszentrum Karlsruhe / Universitaet Karlsruhe, Germany, and the Lidar group of Arizona State University (ASU) collaborated to obtain a dataset for the comparison of IMK's new coherent Doppler lidar with data from a radar profiler, a 200m tower, tethersondes, radiosondes, and a sodar. The experiment took place near Karlsruhe, Germany, and was centered at the Forschungszentrum just north of the city of Karlsruhe. All field instruments were provided and operated by IMK, while ASU assisted in planning, post-processing, and some operation of the IMK coherent Doppler lidar and tethersondes. During the experimental period, occasional convective storms passed through the measurement domain providing at times relatively strong wind velocities. Mean and instantaneous velocities were compared between the instruments. In addition to mean velocities, the spectral properties of lidar "staring" scans were explored. For the "staring" scans, the lidar beam focused on two levels of the local 200 meter meteorological tower at which sonic anemometers obtained wind data at 20 Hz.

2. EXPERIMENTAL SETUP

The purpose of the field experiment was to obtain a dataset allowing comparison between more traditional atmospheric measurement systems such as profilers and tethersondes and IMK's new coherent Doppler lidar – and to use this data to better understand the convective storm conditions that prevailed during the month of July in 2004 in the Karlsruhe region of Germany.

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The field instruments used in the experiment are listed below.

Table 1. Major instruments used in field study.

Lidar	Coherent Doppler, (*WINDTRACER, Coherent Technologies, Inc.*)
200m Tower	Two ultrasonic anemometers at 100m and 200m, SOLENT 20 Hz, *Gill Instruments*
Tethersondes	AIR ADAS 3C
Radiosondes	Graw GK90 with DFM-97 PTU/RDGPS Sondes
Profiler	FMCW Radar Profiler at 1290 MHz, 6.4 kW power, and 40m height resolution
Sodar	Radian Echosonde 600 PA

The study took place mainly in early July, 2004. However, supplementary data were taken in early October 2004. The profiler was situated next to the meteorological tower at 8°25'29''E, 49°05'29''N, 110 m asl. The lidar, sodar and tethered balloon were operated 1.4 km northeast (Fig. 1). Radiosondes were launched at a measurement site near Bruchsal 11 km east of the lidar at 250 m asl. Apart from the two balloon systems, our goal was to achieve continuous measurements over the planned experimental period, but a defective system management unit of the lidar caused several gaps within the lidar dataset. Table 2 shows the periods with lidar data available (in UTC). Vertical profiles from radiosondes are available from 08-18 UTC during July 6th and from 09-15 UTC during July 7th every 90 minutes. The operaton of the tethered balloon during the same period was limited by the weather conditions. For July 6th, eight ascending and descending profiles up to 600m asl were available. Higher windspeeds during July 7th forced a different operational mode taking data in regular intervals at a fixed balloon height. Data from the meteorological tower are available as 10 minute mean values at 2, 20, 30, 40, 60, 80, 100, 130, 160 and 200 m Additionally, 20 Hz data from the sonic anemometers situated at 100 and 200 m are available for 07/09 and 10/04-06. The sodar and the profiler were operated during the whole July period.

Figure 1, View from the roof of the lidar shelter with meteorological tower (background) and tethered balloon. The white device is the lidar scanner.

The sodar delivered vertical profiles in 25 m steps every 10 minutes up to 500 m during daytime and 700 m at night. Every 30 minutes, the profiler delivered measurements for 48 range gates with 40 m vertical resolution. The lidar performed a number of different scanning methods. In addition to "staring" scans for comparison with sonics on the tower, both PPI-based and RHI-based volumetric scans were used. Examples of a single PPI and RHI from such scans are shown if Figures 2 & 3.

Table 2. Measurement dates and times.

7/2/04	16:28-23:56	Lidar, profiler, sodar, tower
7/5/04	11:35-19:08	Lidar, profiler, sodar, tower
7/6/04	6:05-11:57 12:48-18:40	Lidar, profier, sodar, tower tethered balloon, radiosonde
7/7/04	7:12-14:44	Lidar, profiler, sodar, tower tethered balloon, radiosonde
7/8/04	10:49-23:59	Lidar, profiler, sodar, tower
7/9/04	00:00-23:59	Lidar, profiler, sodar, tower
10/4/04	16:00-23:59	Lidar, tower
10/05/04	00:00-23:59	Lidar, tower
10/06/04	0010:00-09:00	Lidar, tower

3. LIDAR PERFORMANCE

Apart from the downtimes due to a defective system control unit, the lidar performed very well during these first measurements with the new system. Under typical summer conditions in the Rhine valley, measurements up to 2.3 km in vertical direction and 6 to 8 km radial within the boundary layer can be realized. Reliable measurements are available up to frequencies of 10 Hz – corresponding with 50 pulse averaging of the raw 500 pulses per second that the lidar produces (500 PRF). The data are continuously available and free from bias or short term drift. Figure 4 shows a one hour nocturnal measurement under slow wind speed conditions with the lidar beam pointing vertically upwards. As expected the measured vertical wind velocity varies around zero and does not exceed values of a few cm s^{-1}.

4. RESULTS

The intercomparison of lidar and sonic anemometer measurements demonstrates the notable performance of the lidar system. For a 18 h sequence starting October 5^{th} at 16:00 UTC, the lidar was pointing at 228.3° azimuth and 4.1° elevation directly to the sonic anemometer installed at the 100m level of the meteorological tower. The wind speed in the lidar beam direction is calculated from the 20 Hz sonic data by coordinate transformation and compared with the 10 Hz measurements of range gate 10 which corresponds best to the position of the sonic anemometer. For both the lidar and sonic time series, one minute average mean values, as well as the standard deviation, are presented in Figure 5.

During the night from 0 – 640 min, the horizontal wind velocity rises from 3 to 8 ms^{-1} keeping its direction around 220° which matches nearly ideally the lidar beam direction. Within this period the difference between lidar and sonic data is mostly within only +- 0.5 ms^{-1} and never exceeds 1 ms^{-1}. This is remarkable accuracy considering the different measuring techniques. Starting at 650 min the atmospheric turbulence rises as manifested in the standard deviation rising from values around 0.25 ms^{-1} to 1.25 ms^{-1} for both systems. This leads to higher differences in the measured wind speed due to the different measurement approaches of these instruments. Whereas the sonic anemometer represents a point measurement, the lidar data of a singe range gate represents the mean wind velocity of a cylindrical volume of around 10 cm diameter and 100 m length. Under these conditions an averaging interval of one minute is not long enough to obtain complete statistics. The one minute averaged lidar data, therefore, likely represent more converged statistics than that obtained with the sonics over the same time period. Between 720 and 780 minutes the measurements of the sonic anemometer are influenced by the tower which yields a reduced wind velocity and a higher standard deviation compared to the lidar measurements. On the other hand, the lidar measurements were disturbed by rainfall in the morning at 820 and 890 minutes which leads to outliers in the dataset and to peaks in standard deviation.

As discussed above, the lidar produces velocities averaged over an unusual volume – a cylinder 10 cm in diameter and approximately 60-100 m long. However, the 10 Hz signal that is produced can be analyzed to produce velocity spectra and power spectral density (PSD) versus frequency plots in a manner similar to how turbulent signals are traditionally treated in turbulence research. Plots corresponding with range gate number 10 are shown in Figures 6 to 8. The data was acquired during a stare scan toward the 100m sonic on the 200m tower on October 4, 2004 between approximately 16:00 and 17:00 UTC. An averaging time of 600 seconds was chosen so that larger-scale turbulent structures were captured. (Experiments with shorter averaging times such as one or two minutes did not yield a turbulent spectrum.) Given the 10 minute averaging time, means were calculated for each range gate, and perturbation velocities, as a function of range gate and time. Discrete fast fourier transforms were calculated on the perturbation velocities and power spectral densities from the result of the FFT calculation. The PSD represents the distribution of signal energy over frequency.

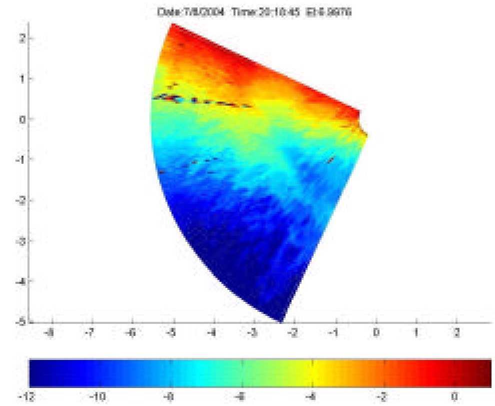

Figure 2. Example PPI scan on July 8, 2004. Note relatively high velocities.

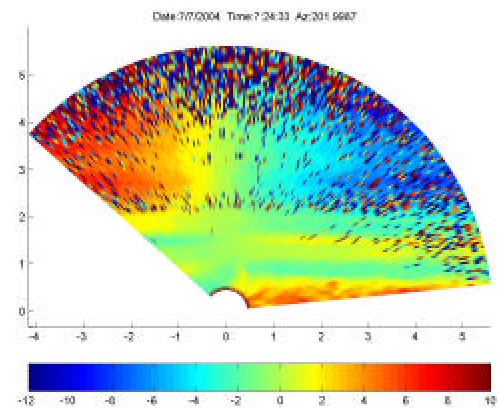

Figure 3. RHI Scan showing unusually high vertical range for this type of lidar.

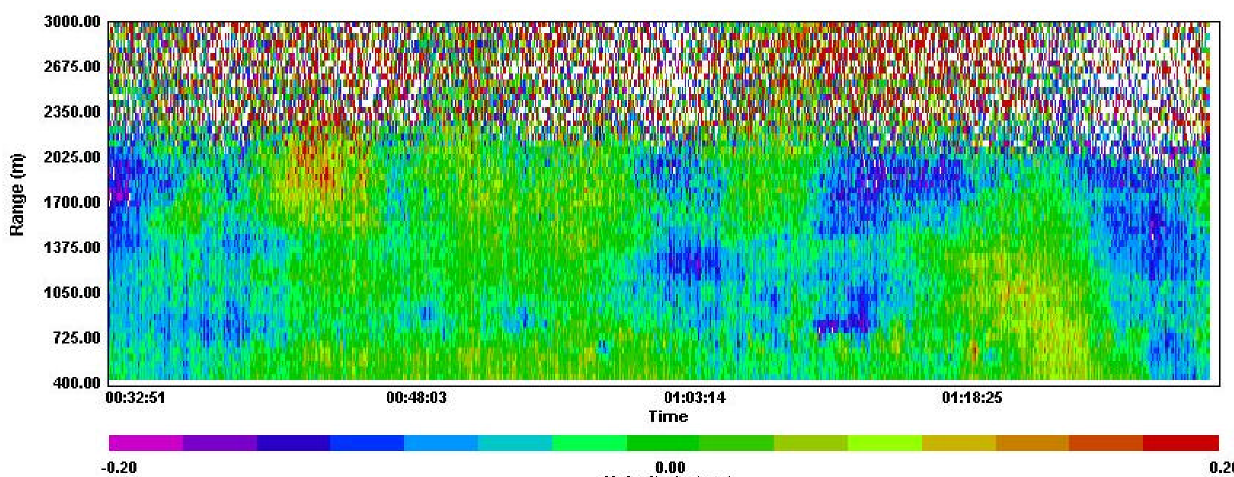

Figure 4. Vertical wind velocity during night measured with vertical pointing lidar beam

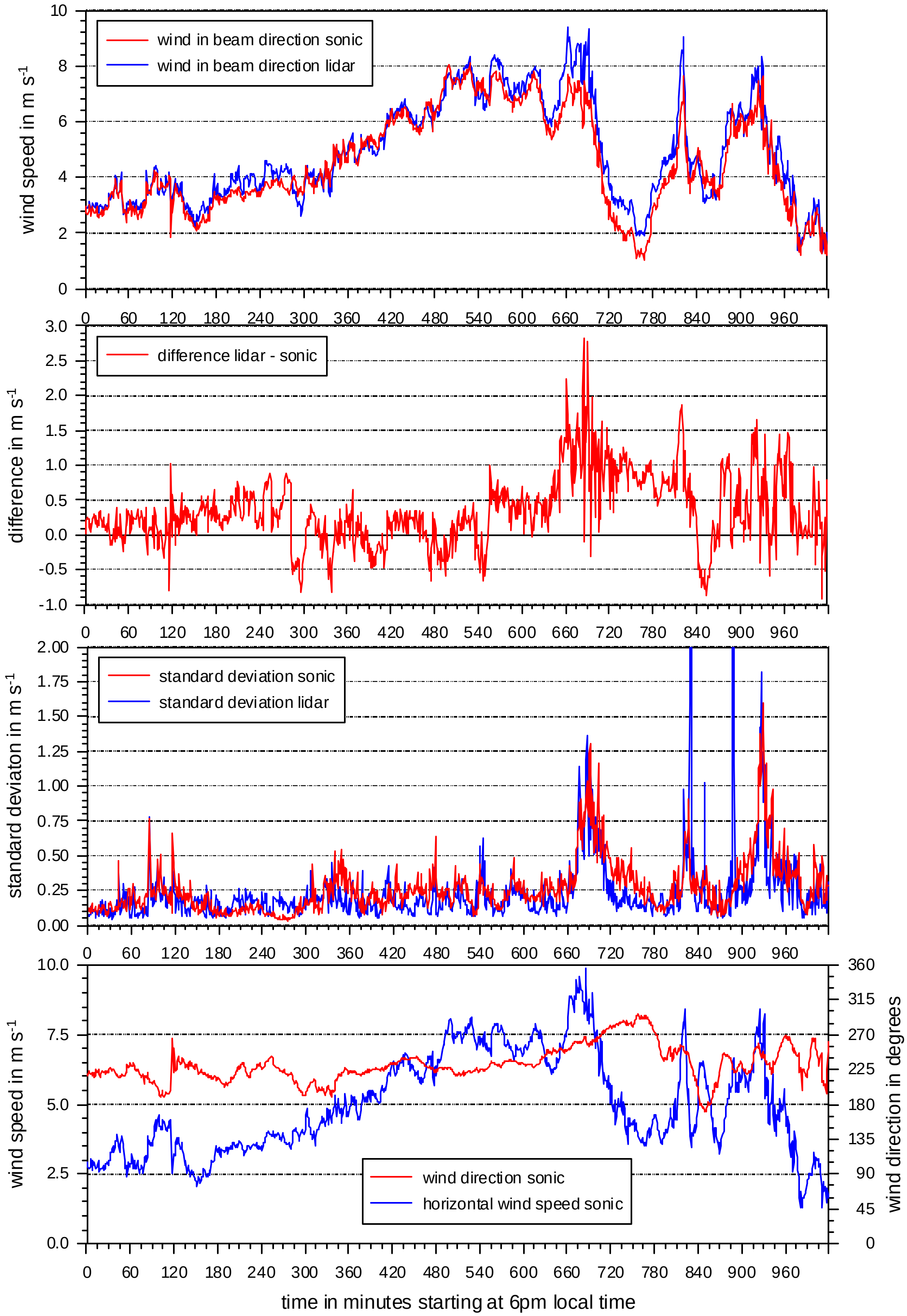

Figure 5. Comparison of measurements from the lidar and the 200m tower (at the 100m level) from October 5th to 6th, 2004. Time starts at 16:00 UTC.

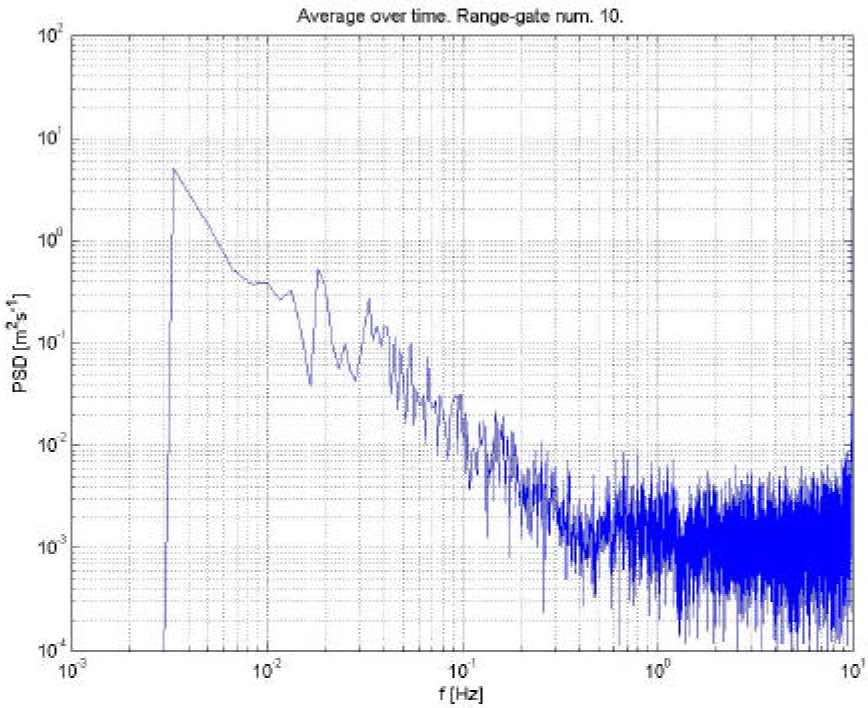

Figure 6. Power Spectral Density (PSD) averaged over all time intervals for range gate number 10.

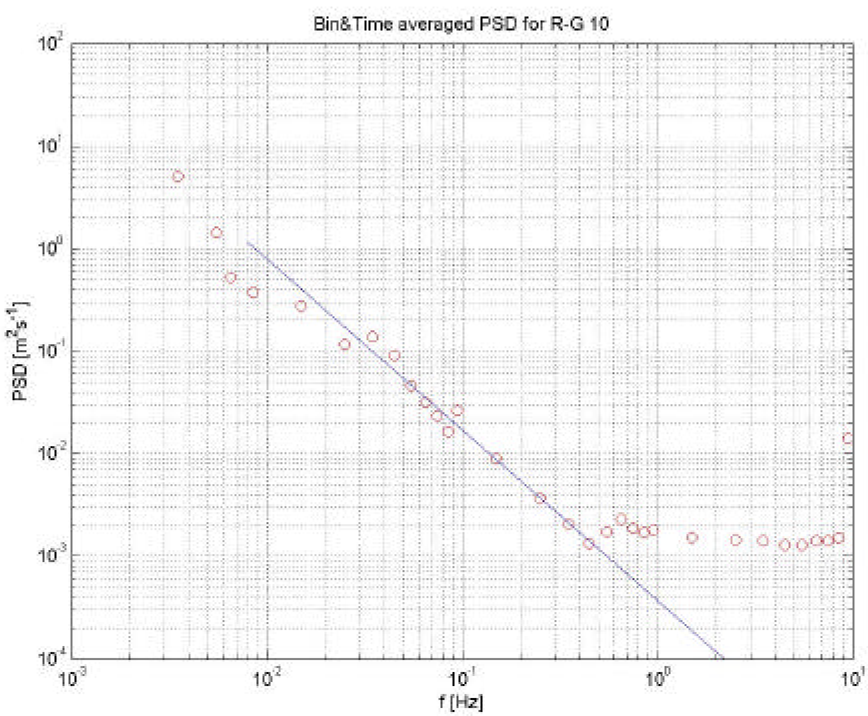

Figure 7. Bin averaged Power Spectral Density for range gate number 10. Also given is the best fit of -5/3 law (inertial subrange).

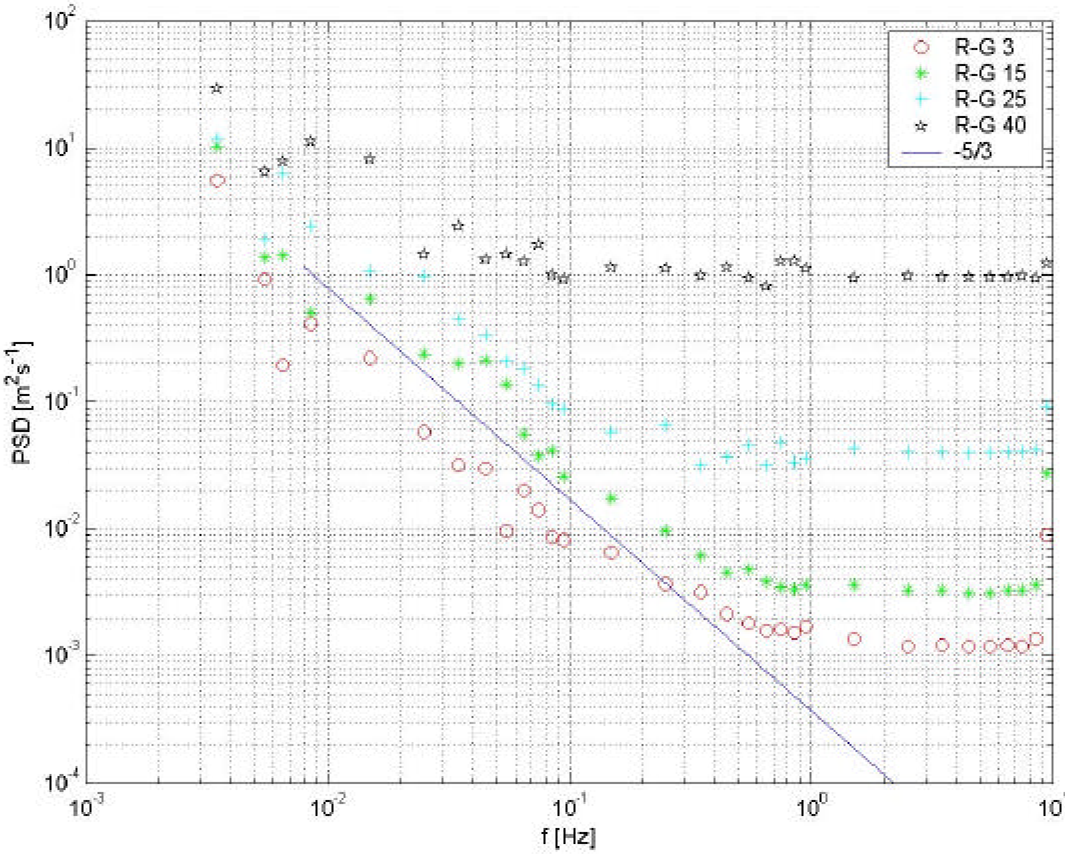

Figure 8. Comparison of Power Spectral Density curves for range gates at different distances from the lidar. Note noise increases with larger distance from the lidar and this affects the smaller scales most dramatically.

The -5/3 line in the plots refers to the slope of the well-known inertial sub-range from turbulence theory. This result is familiar both from analysis of sonic anemometer and other point-sensor data, and as a famous result from turbulence and similarity theory.

Lidar data is inherently noisy. It is typical to deal with noise in lidar processing using various averaging techniques. Not surprisingly, the PSD plots are also noisy, but several different averaging approaches have made trends more easily visible. First, note that averaging over the range-gates is ineffective because of the increasing noise content in more distant range gates eventually entirely obscures the spectrum. See Figure 8 for evidence of this effect – where the smaller scale portion of the spectrum becomes increasingly washed out by random noise. Time averaging the results over the hour (a time average of the PSD's for each range-gate) yields results without obscuring the smaller-scale portion of the frequency spectrum. Interesting, Figure 6 shows evidence of an inertial subrange. Applying both frequency bin-averaging and time-averaging for each range-gate yields a clear correspondence with the familiar inertial sub-range.

4. ONGOING WORK AND CONCLUSIONS

Our research groups at IMK and ASU have only begun to explore the datasets collected in July and October 2004. Our plans are to proceed with analyzing the sodar, profiler, radiosonde, and tethersonde data – comparing with VAD processed lidar data which will produce vertical profiles of the wind velocity vector. The sonic data will be analyzed for PSD versus frequency and compared with the lidar data given above. We will continue to explore the effects of more extensive cleaning and de-trending of the lidar data on these results. We plan to test a somewhat experimental method for estimating dissipation. Because of the following relation, we can make estimates of the dissipation using curve fits to the PSD versus frequency plots.

Eqn 1: $PSD(f) = Cu \cdot (2p)^{-5/3} \cdot (eU)^{2/3} \cdot f^{-5/3}$

Therefore, eU and a full velocity vector obtained from the sonics at the tower can be used to calculate dissipation. This will be compared with similar estimates obtained from sonic data (see Bozier & Collier 2004, and Gal-Chen et al. 1992 for related techniques).

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5. REFERENCES

Barthlott, C., and F. Fiedler, 2003, Turbulent structure in the wake of a meteorological tower, Boundary-Layer Meteorology, 108, 175-190.

Bozier, K. and C. Collier, 2004: Observations of the diurnal variation of energy dissipation in the urban boundary layer using Doppler lidar, AMS 4th Symposium on the Urban Environment, Jan. 11-15, Seattle, Washington.

Frehlich, R., S. Hannon, and S. Henderson, 1998: Coherent Doppler Lidar Measurements of Wind Field Statistics, Boundary-Layer Meteorology, 86, 233-256.

Gal-Chen, T., Xu, M. and Eberhard, L., 1992: Estimations of atmospheric boundary layer fluxes an other turbulence parameters from Doppler lidar data. J. Geophys. Res. 97, D17, 18409-18423.

Princevac M., R.J. Calhoun and H.J.S. Fernando 2004: Doppler-Lidar deployment during JU2003 experiment, XXI *International Congress of Theoretical and Applied Mechanics*, August 2004, Warsaw, Poland, EU.

Wieser, A., R. Calhoun, 2004: First Measurements with the new Karlsruhe Doppler Lidar. 3rd Workshop of the Lidar Expert Network "Lidar Research Water Vapour and Wind" 15-16th Sept. 2004 Stuttgart-Hohenheim.