I-7 Turbulence in Atmospheric Flows

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A CENTRAL ASSUMPTION in the classical Kolmogorov 1941 (K41) theory is the decoupling between the large, forcing scales, which are flow dependent, and the small, universal scales present at "sufficiently large" Reynolds numbers. Most laboratory flows are limited to moderate Taylor micro-scale Reynolds number $R_\lambda \leq 10^3$ and by carefully designing the turbulence generation mechanisms they try to minimize the effect of the large-scale flow on the small-scales. Atmospheric flows provide a high Reynolds number alternative for the study of the K41 hypothesis, however, with the caveat that, at the forcing scales, they depend strongly on the environment. Here we report examples from our year-long measurement campaign of the turbulent boundary layer at the Environmental Research Station Schneefernerhaus (UFS) at an elevation of 2700 m.

As shown in figure 1, our experimental setup consists of five ultrasonic anemometers that are arranged to form two nearly regular tetrahedra, on the roof of the Environmental Research Station Schneefernerhaus (UFS) near the top of Zugspitze, the highest mountain in Germany. For over a year, sampling synchronously at 10 Hz these sensors have been measuring the three components of the wind velocities and the (virtual) temperature. The distances between the sensors are approximately 2 m, well within the inertial range of the turbulent flow at UFS. We first examined the turbulence measured from the top sensor only, which is located approximately 6 m above the roof of UFS. As shown exemplarily in figure 2, the Eulerian velocity structure functions, measured with Taylor's frozen turbulence hypothesis, demonstrate a well-developed inertial range. Note that the dissipative scales are not resolved due to the size of the sensors. We determine the energy dissipation rate ε by fitting the structure functions to the inertial range $r^{2/3}$ scaling. The dissipation rate normalized by the integral scale L and the fluctuating velocity u, $C_\varepsilon = \varepsilon L/u^3$, is believed to be a constant and has been studied in various flows [1-3]. We found that for $1500 \leq R_\lambda \leq 3500$, C_ε remained constant at approximately 0.5 (see figure 3a). The value of $C_\varepsilon \approx 0.5$ agrees well with recent results from laboratory flows at $R_\lambda \leq 1200$ [3]. In figure 3, we distinguished winds coming from the east to those from the west, which are the two dominant wind directions at UFS. The difference in topography between the two directions results in different values of C_ε. As a measure of large-scale anisotropy, we plot in figure 3b the invariants of the Reynolds stress tensor on the so-called "Lumley-triangle" [4]. The flow is clearly anisotropic as expected for a boundary layer flow. It is interesting to note that in general the flow coming from the east is more iso-

Figure 1
The ultrasonic anemometers located at UFS, Zugspitze, Germany. The measurement station is approximately 2700 m above see level.

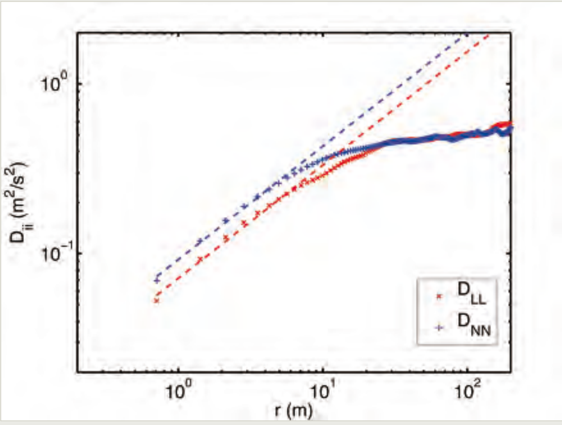

Figure 2
An example of Eulerian velocity structure functions measured by the top sensor, using Taylor's frozen flow hypothesis. The measurements consisted of 11 quasi-steady flow events between September and December 2010, which were coming from the west ±30 degrees, had a mean speed of 7±0.1 m/s and had been steady for at least 2 minutes (equivalent to 56 large-eddy sweeping times). The dashed lines are the fitted $r^{2/3}$ laws, from which the energy dissipation rate was determined to be 6.1×10^{-3} m^2/s^3. The Reynolds number of the flow, defined as $R_\lambda \equiv (15uL/v)^{1/2}$, was 2420.

tropic than that from the west. Moreover, when R_λ increases, the flow from the east shows a tendency to become more isotropic, while the flow from the west deviates more from isotropy. This is most likely due to the influence of the building structure and the closer vicinity of the mountain on the west side of the measurement site. It is worth to point out, however, that the degree of large-scale isotropy of the atmospheric flow at UFS is comparable to, and often better than, that of the often-used von Kármán swirling laboratory flow (not shown).

We are now studying the influence of the larger-scale flows on the inertial ranges by investigating multi-point Eulerian statistics. This includes the statistics of passive scalar fluctuations, which are related to the spatial structure of the flow [5, 6], and the velocity dynamics using the tetrad model proposed by Chertkov et al. [7]. This way we hope to gain further insights into the generic features of real world turbulence and to better understand how theoretical models, simulations and findings from laboratory experiments can be applied to flows found in the "real" world.

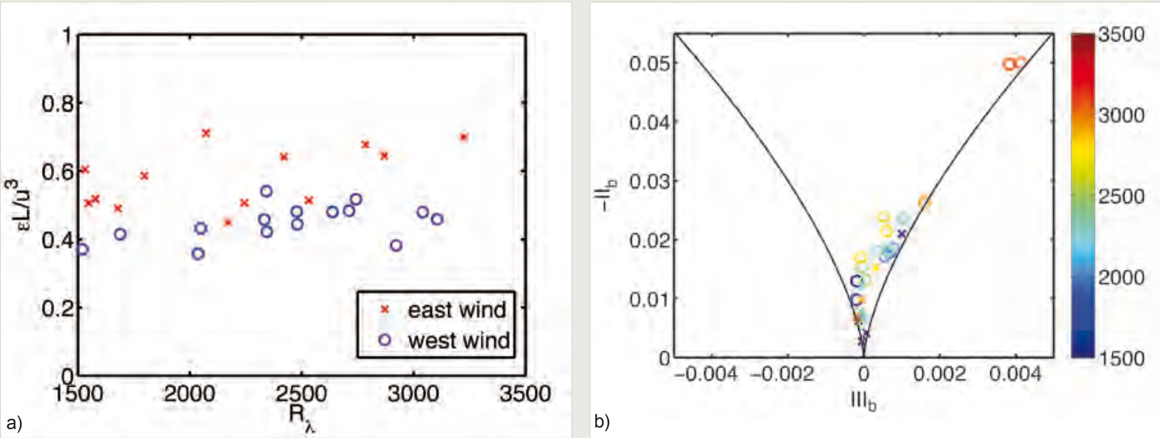

Figure 3
(a) Normalized energy dissipation rate C_ε as a function of R_λ. The circles are for winds coming from the west and the crosses are for winds coming from the east. (b) The invariants of the Reynolds stress tensors shown on the "Lumley triangle". Points closer to the origin represent flows more isotropic. As in (a), circles and crosses stand for flows from the west and the east, respectively. The symbols are color coded with the Reynolds number R_λ, as shown by the colorbar on the side.

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