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A scaling analysis of the turbulent boundary-layer in a shallow urban lake

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The turbulent boundary-layer (TBL) has been the focus of countless experimental and numerical studies. Due to its complex nature the dynamics of the TBL are still far from being understood. Thus, to study, in particular the scaling properties of a TBL, we use a three-dimensional velocity time-series measured from an Acoustic Doppler Current Profiler(ADCP). The ADCP is particularly useful for analysing the TBL as it is able to measure the 3D velocity in the vertical, 127 cells over 3 meters.

The ADCP is positioned next to a storm water discharge point at the bottom of a shallow urban lake in Créteil, a region in Paris. The positioning of the ADCP, in a stable, stratified lake, with a strong turbulent flow occurring close to the surface has given us a unique situation in which a turbulent bounded-layer can be analysed. Vertical profiles measured in the atmospheric boundary-layer are typically intrusive due to the requirement of masts and other complex measuring structures. Moreover atmospheric profilers are normally coarsely spaced in the vertical.

In order to analyse the scaling properties of the velocity we compute its energy spectrum. In a log-log plot, if the velocity is scaling, the spectral exponent is its slope. It frequently that in the presence of a boundary-layer, a -1 spectral exponent is observed. Dimensional arguments suggest a -1 spectral exponent when the energy flux becomes dependent on the friction velocity instead of the length-scale.

Due to the fine vertical spacing of the measurements we are not only able to observe a -1 spectral exponent, but observe a smooth transition from a free-stream turbulent regime (spectral exponent close to -5/3) to a boundary-layer -1 exponent. Because the transition shows such a strong a depth dependence we are able to propose a general model based on dynamical equations for the scaling exponent as a function of height. This generalised scaling boundary-layer model allows one to easily reproduce the turbulent statistics in the boundary-layer.