Signatures of coherent flow structures in the atmospheric surface layer over Lake Geneva

Mehrshad Foroughan*, Ulrich Lemmin*, David Andrew Barry*

* Ecological Engineering Laboratory (ECOL), Environmental Engineering Institute (IIE), Faculty of Architecture, Civil and Environmental Engineering (ENAC), Ecole Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland (mehrshad.foroughan@epfl.ch)

Reliable estimates of air-water exchange of momentum, heat, and gas are vital for understanding boundary layer dynamics and for developing accurate global and regional climate and weather forecasting models. Spatiotemporal variability of physical processes, below and above the water surface and at the interface, contribute to the uncertainty of these estimates. Air-side exchange processes are closely related to various phenomena in the Atmospheric Boundary Layer (ABL), which frequently manifest themselves as coherent structures in turbulent flow fields. The identification of such structures and their dynamics is essential for determining their role in the variability of air-water fluxes.

A Doppler wind LiDAR (Light Detection And Ranging) was deployed on the south side of the LéXPLORE platform in Lake Geneva, two meters above the lake surface water. It provided the line-of-sight (radial) component of wind velocity (spatial resolution of 18 m, Fig.1). The LiDAR was configured for both horizontal arc sector and staring scans, i.e., sequential sweeps and a fixed direction of the laser, respectively, aligned with the mean wind direction. The results presented here are from measurements taken during a *Bise* event, a regularly occurring strong wind (U_{10} > 5 m s^{-1}), blowing from the northeast over most of the lake surface (Lemmin & D'Adamo, 1996). Empirical Orthogonal Function and Continuous Wavelet Transform analyses were used for data post-processing. These techniques allowed decomposition of the time series of radial wind data into modes of spatial variability of the fluctuations and temporal variations of the different time-scales embedded in the flow field, thereby providing the dimensions of structures coexisting in the wind field and their corresponding time-scales.

It was found that the horizontal radial wind field over Lake Geneva is "patchy" and can be decomposed into large-scale horizontal coherent structures (Fig. 1). In particular, coherent structures of high velocity are evident. They were always elongated in the wind direction, extending several hundred meters in length. The shape and the spatial distribution of these structures changed continuously in time. The radial velocity magnitude in any scan varied by a factor of two or more. This indicates that macro turbulence in the ABL, as documented by these coherent structures, is well developed and is the dominant feature of the near-surface boundary layer of the wind field. Even though the three-dimensional nature of the ABL wind vector cannot be determined from these measurements, it is clear that the strong spatio-temporal variability observed here will have important consequences for the dynamics of the air-water exchange of momentum, heat and gas. This variability will affect surface shear stress and thus surface renewal and the production of turbulence in the near-surface water boundary layer. Furthermore, it will affect the surfactant distribution in the surface micro layer, which in turn will again modify the exchange processes.

Our results agree with similar studies on coherent structures in the atmospheric surface layer under near-neutral stability conditions (Hutchins & Marusic, 2007). However, here we document for the first time in the open lake the presence of large-scale near-surface wind structures whose shape and pattern continuously change in time and space. This was not reported in a previous near-shore LiDAR study on Lake Geneva (Calaf et al., 2013).

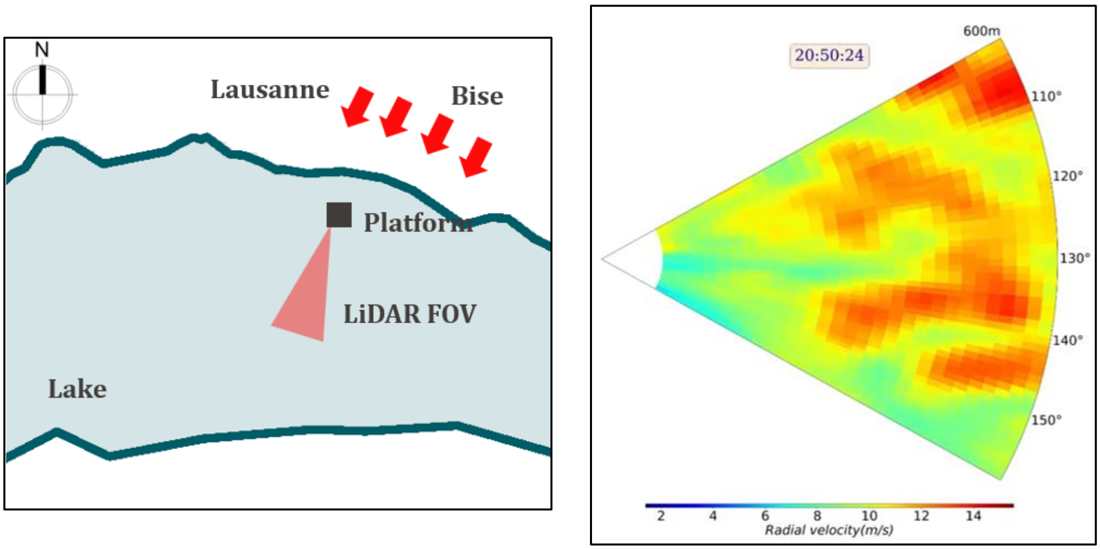

Figure 1. (left panel) A schematic of the LiDAR configuration on the LéXPLORE platform showing the Field Of View (FOV; red triangle), Red arrows indicate the Bise wind. (right panel) An example of the 600-m horizontal arc sector LiDAR measurements of the wind field (taken at 20:50:24 on 14.04.2020) degrees are measured from the East). The color bar indicates the range of the velocities.

Acknowledgement
We would like to sincerely thank Peter Brugger from the WIRE Laboratory EPFL, for making available the LiDAR and teaching us how to operate the instrument.

REFERENCES

Calaf, M., Hultmark, M., Oldroyd, H. J., Simeonov, V., Parlange, M.B. 2013: Coherent structures and the k^{-1} spectral behaviour. Physics of Fluids, 25(12)

Hutchins, N., Marusic, I. 2007: Evidence of very long meandering features in the logarithmic region of turbulent boundary layers. Journal of Fluid Mechanics, 579, 1–28

Lemmin, U., D'Adamo, N. 1996: Summertime winds and direct cyclonic circulation: Observations from Lake Geneva. Annales Geophysicae, 14(11), 1207–1220