Turbulent Ekman Flow as a Virtual Lab for the Atmospheric Boundary Layer

Cedrick Ansorge (University of Cologne), 23 Oct 2018

The atmospheric boundary layer is ubiquitously turbulent, and turbulence is commonly modeled as a mixing agent in analogy to molecular diffusion. Flow regimes exist, in which this analogy does not hold and modelling approaches based on self-similarity arguments along the turbulence cascade in Large-Eddy simulation fail. A particular instance where this happens is the localized absence of turbulence on scales commensurate to the boundary layer depth due to the entrainment of non-turbulent fluid from non-turbulent regions aloft or stabilizing body forces [1]. In such conditions, the physical problem can be approached through the direct numerical simulation (DNS) of turbulent flow, that is, the direct solution of the incompressible Navier–Stokes equations—without a model for the small-scale turbulence. The physical processes causing co-existence of turbulent and non-turbulent sub-volumes of flow within the boundary layer are explicitly resolved.

In this talk, I will introduce the canonical flow problem of turbulent Ekman flow studied through DNS as a physical model for turbulence in the atmospheric boundary layer. There are two key benefits of Ekman flow with respect to simpler flow configurations: First, rotation is considered, which leads to a veering of the wind with height and breaks the span-wise symmetry. Second, external effects are incorporated as a non-turbulent region aloft the turbulent layer is part of the flow. While computational feasibility still constrains analyses to intermediate scale separation—manifest in Reynolds numbers that are orders of magnitude smaller than in the real geophysical problem—, recent simulation using a massively parallel flow solving algorithm provide high-quality and 4-dimensionally resolved data at sufficient scale separation to yield a well-developed logarithmic layer [2]. These data are sufficiently resolved to evaluate higher-order statistics and derivatives and thus allow for a partitioning of the flow to turbulent and non-turbulent patches. Using conditioned data, the von-Kármán constant is shown to be only applicable in the turbulent partition of external boundary layers. Further, I demonstrate that large-scale intermittent turbulence as a consequence of density stratification is quantitatively similar to non-intermittent turbulence if only data conditioned to the turbulent partition of the flow are considered [3].

Publications related to this presentation:

[1] **2014** **C. Ansorge**, J. P. Mellado: Global intermittency and collapsing turbulence in the stratified atmospheric boundary layer, *Boundary-Layer Meteorol* (**153**): p.89–116 [10.1007/s10546-014-9941-3].

[2] **2018** **C. Ansorge**: Scale dependence of surface–atmosphere coupling through similarity theory. *Boundary-Layer Meteorol* (**in press**) [10.1007/s10546-014-9941-3].

[3] **2016** **C. Ansorge**, J. P. Mellado: Analyses of external and global intermittency in the surface layer of Ekman flow. *J Fluid Mech* (**805**): p. 611–635, 2016 [10.1017/jfm.2016.534].