Geophysical Research Abstracts, Vol. 7, 00590, 2005
SRef-ID: 1607-7962/gra/EGU05-A-00590

Parameter phase space of idealized shear-driven planetary boundary layer

I. Esau (1,2) and S. Zilitinkevich (1,2,3)

(1) Nansen Environmental and Remote Sensing Centre, Thormohlensgate 47, 5006 Bergen, Norway (igore@nersc.no / Fax +47 55 205801 / Phone +47 55 205876)

(2) Bjerknes Centre for Climate Research, University of Bergen

(3) Division of Atmospheric Sciences, Department of Physical Sciences, University of Helsinki (Sergej.Zilitinkevich@fmi.fi / Phone: +358-9-1929-4678)

Introduction

In preface to the classical book "Statistical Fluid Mechanics", Monin and Yaglom (1974) distinguished two types of turbulence: (i) the small-scale turbulence, which is thought to be a universal function of dissipation rate in high Re flows; and (ii) large-scale turbulence, which depends considerably on the boundary conditions and external forces in the flow. Monin and Yaglom claimed that the problem of the small-scale turbulence is largely solved, at least in the sense of self-consistent statistical description. For environmental applications however, the universal description of the large-scale turbulence is far more important. Such a description is still missing. As acknowledged by Monin and Yaglom, it is partially because of "considerable statistical scatter in measurements in nature". In our work, we show that this scatter in the traditional data collection and representation could be largely attributed to improper accounting for external governing parameters in the idealized shear-drive planetary boundary layer (PBL).

Complete Set of Non-Dimensional External Parameters

Every observational campaign unavoidably provides data on a combination of both case-specific and universal properties of the flow. Often the case-specific properties dominate so that a theoretical value of the data is significantly reduced. As the result, we have to base our analysis of the large-scale turbulence on large eddy simulation

(LES) data from the LESNIC code.

To further simplify the analysis, we consider only incompressible, Boussinesq LES of barotropic, steady state, shear-driven PBLs over homogeneous, aerodynamically rough surfaces where constant temperature flux was prescribed. Such and idealized PBL is governed by the following dimensional parameters:

- The geostrophic wind, U_g [m/s]
- The Brunt-Vaisala frequency of the ambient flow, N [1/s]
- The Coriolis force parameter, f [1/s]
- The temperature flux at the surface, F_s [K m/s]
- The surface roughness, z_0 [m]

Since there are three independent dimensions, (m;s;K), the π-theorem states possibility to construct a complete set of three independent external non-dimensional parameters. They are:

- The Rossby number, Ro=$U_g/(fz_0)$
- The surface Richardson number, Ri= $f\beta F_s/(U_g)^2$
- The ambient Richardson number, Rs= $(z_0 N)^2/(U_g)^2$

This independent parameters characterize the consumption of the mean kinetic energy of the dynamic instability, given by U_g, by three independent stabilization mechanisms, namely, the rotational stabilization (Tritton, 1992), given by Ro, the thermal stabilization (Monin and Obukhov, 1954), given by Ri, and the radiative stabilization (Zilitinkevich, 2002), given by Rs. Since the parameters are independent, they represent dimensions of the parameter phase space (Ro;Ri;Rs), which is a convenient framework for the theoretical analysis of turbulence.

Universal Functions and Universal Length Scale

In order to show credibility of the proposed phase space decomposition, we consider two bulk characteristics of the PBL, namely, the geostrophic drag coefficient, C_D, and the surface geostrophic angle, α. Both quantities show large scatter in all kinds of traditional representations. We show that C_D and α are indeed well defined universal functions in every one-dimensional subspace. Hence, they are also universal functions in (Ro;Ri;Rs). The analytical form of these functions is of direct interest for the environment modelers.

Every stabilization mechanism limits a possible scale, l, of the typical turbulence eddies in the PBL. The length scale in (Ro;0;0) phase space can be constructed as U_g/f (external scaling) and u_*/f (internal or the Rossby and Montgomery scaling), in (0;Ri;0) – $(U_g)^3/\beta F_s$ (external scaling) and L= $(u_*)^3/\beta F_s$ (internal or Monin and Obukhov scaling), and in (0;0;Rs) – U_g/N (external scaling) and u_*/N (internal or Zilitinkevich scaling). Understandably, those mechanisms dominate which limit l the strongest. Thus, the universal length scale can be constructed through interpolation of squared reciprocals as in Zilitinkevich and Esau (2004).

We show considerably better collapse of the turbulence data as functions of the universal length scale than any of a traditional length scale.

References

Monin, A.S., and Yaglom, A.M.: 1971, *Statistical fluid mechanics: Mechanics of turbulence*, The MIT Press

Monin, A.S., and Obukhov, A.M.: 1954, Main characteristics of the turbulent mixing in the atmospheric surface layer, *Trudy Geophys. Inst. AN. SSSR*, **24**(151), 153-187

Tritton, D.J.: 1992, Stabilization and destabilization of turbulent shear flow in a rotating fluid, *J. Fluid Mech.*, **241**, 503-523

Zilitinkevich, S.S.: 2002, Third-order transport due to internal waves and non-local turbulence in the stably stratified surface layer, *Q.J.R.M.S.*, **128**, 913-925

Zilitinkevich, S.S., and Esau, I.N.: 2004, Resistance and heat transfer laws for stable and neutral planetary boundary layers: Old theory, advanced and re-evaluated, *Q.J.R.M.S.*, submitted