Geophysical Research Abstracts, Vol. 8, 05897, 2006
SRef-ID: 1607-7962/gra/EGU06-A-05897

Stable stratification in wall bounded turbulence

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One of the main characteristics of environmental flows is the fact that, in general, their temperature and/or the concentration of a dissolved species is a function of the depth within the fluid column. This makes the column stratified. As well known, when the mean density increases with the depth, the fluid is stably stratified and vertical mixing of mass and momentum is inhibited. Due to the many practical applications, stably stratified flows are of great importance in environmental fluid mechanics. As an example, thermal inversion in the low atmosphere causes the stagnation of pollutants and particulates that degrades the quality of air, whereas in the oceans, stable stratification suppresses vertical mixing of nutrients. Generally, stable stratification can strongly influence the dynamic and the anisotropic characters of turbulence, leading to qualitative and quantitative changes in the small-scale mixing not only of momentum and mass, but also of salinity, pollutant and nutrients in the oceans.
Most numerical and experimental studies dealing with the interaction between a mean shear, that is the source of turbulent mixing, and a mean, stable, density gradient acting toward the suppression of turbulence, have been carried out in the very simple case of unbounded homogeneous turbulence, and considering the density gradient aligned with the mean shear. Few investigations have been devoted to the study of stable stratification in wall-bounded turbulence, where with wall we intend either an interface or a solid wall. In this case additional complications arise, namely:

- inhomogeneity in the wall-normal direction that makes the key parameters (like the gradient Richardson number) to be a function of the distance from the wall;
- the effect of boundary conditions for temperature and velocity at the walls, that may dramatically affect the wall normal characteristics of the turbulent field.

In the talk we'll discuss some recent results of large eddy simulation studies of wall bounded stably stratified turbulence.

First we discuss the effect of inhomogeneity in the turbulent field in the case of constant-temperature, horizontal solid walls. This flow is archetypal of a stably stratified atmospheric boundary layer (SABL) where the ground surface cools the bottom layers of air. Specifically we analyze the turbulent flow that develops between two parallel, horizontal and infinite solid plates, with imposed temperature at the solid walls. In this case the shear and the density gradient are aligned, and they are function of the vertical position in the channel;

Further we consider a different case, characterized by different boundary conditions at the horizontal walls. We consider a free surface channel flow with adiabatic boundary conditions (zero heat flux) at the bottom solid wall and constant positive heat flux at the free surface. This flow is archetypal of a marine application, namely a shallow water basin heated from the top in absence of wind induced mixing. We'll discuss how the difference in the boundary conditions (that on the other hand correspond to different physical conditions) may change the response of the flow field to stratification.

Finally a case in which the mean shear is not aligned with the vertical density gradient is discussed. In this case we consider the turbulent flow between two parallel vertical walls, in presence of stable stratification. This problem is characterized by the fact that the mean shear and the density gradient are orthogonal to each other. This flow is archetypal of a canyon-like geometry with stable stratification. Specifically in this case the mean shear is supplied by two vertical solid walls and the ambient mean density gradient is considered constant in time and space.

In the talk the role of the key parameters and scaling in the three different cases are also discussed.