Geophysical Research Abstracts
Vol. 12, EGU2010-1546, 2010
EGU General Assembly 2010

Self-organization of the Ekman boundary layer turbulence forced by the horizontal component of the Coriolis force

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The Coriolis force is recognized as the major control factor in the shear-driven non-stratified turbulent boundary layer since the work of F. Nansen and V. Ekman in 1898. However, in geophysics (meteorology and oceanography), the central attention is paid to the vertical component of the force whereas the horizontal component is generally omitted. Contrary, in turbo-machinery, effects of the latter on certain types of the flow have been rigorously studied. Leibovich and Lele in 1986 pointed out on theoretically expected profound effect of the horizontal component of the Coriolis force on the vertical turbulent exchange in the geophysical boundary layers too. They also argued that it is the horizontal not the vertical component of the force which organizes the flow in a pattern of vortices rotated in the flow spanwise plain. This suggestion contradicts to earlier attribution of the roll pattern to the vertical component of the Coriolis force by R. Brown and many others. Since both hypotheses are based on the perturbation theory with different set of simplifications, and since the classical Ekman boundary layer cannot be easily observed in the field or reproduced in laboratories for different orientations of the frame angular velocity, it remained unclear to what degree those attributions are correct.

In this study, the large-eddy simulation codes PALM and LESNIC are used to understand the problem. The Ekman boundary layer (EBL) has been simulated with the full Coriolis force. It makes the EBL depend on the latitude and the angle between the latitude and the geostrophic wind direction. This relationship was studied with a number of independent runs. It has been shown that the vertical component of the Coriolis force has no effect on the flow. Self-organization of the flow in rolls at the pole was not found in simulated data. Contrary, near the equator, the EBL turbulence was organized in well-pronounced rolls for easterly winds. At the latitude 5 degree North, the EBL depth, the depth-integrated turbulent kinetic energy and the surface stress were found to be 3 to 5 times larger for easterly than for westerly winds. The result is in agreement with the Leibovich and Lele analysis. Moreover, the result indicates the very important role of the turbulence self-organization in the vertical mixing properties of the geophysical EBL.