DIRECT NUMERICAL SIMULATION OF LAMINARIZATION IN THE ATMOSPHERIC BOUNDARY LAYER

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Abstract A well-known phenomenon in the atmospheric boundary layer is the facts that winds may become very weak in the evening after a clear sunny day. In these quiet conditions usually hardly any turbulence is present. Consequently, this type of boundary layer is referred to as the quasi-laminar boundary layer. In spite of its omnipresence, the appearance of the laminar boundary layer is poorly understood and forms a long-standing problem in meteorological research. In the present study we investigate an analogue problem in the form of a stably stratified channel flow. The flow is studied by using direct numerical simulations (DNS). Simulations reveal that flow laminarization occurs when the normalized surface heat extraction h/L is larger than 1.23. In a companioning study this laminarisation is explained by the maximum sustainable heat flux theory (MSHF), which will be validated in the present research.

MODEL SET UP

In the present work we follow the setup of Nieuwstadt (2005) [1] and Flores and Riley (2011) [2]. A pressure driven non-stratified flow is suddenly cooled from below. The default Reynolds number is: $\mathrm{Re}_* = u_* h/\nu = 360$,with $u_* \equiv \sqrt{-(1/\rho)(\partial P/\partial x)h}$. The surface heat flux H_0 is prescribed by imposing the external stability parameter h/L, with $h/L = (\kappa g h H_0)/(T_{ref}\,\rho c_p u_*^3)$. A schematic picture of the configuration is given in Figure 1 below.

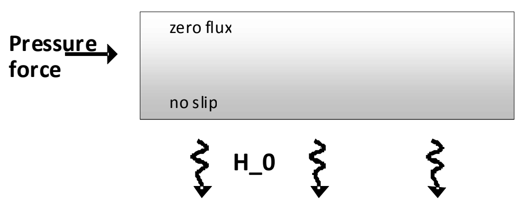

Figure 1. schematic picture of the channel flow configuration with the pressure gradient force and prescribed surface heat extraction as external parameters. Decreasing temperature is indicated by increasing grey-scale.

In the DNS the Navier-Stokes equations in the Boussinesq approximation are solved on a rectangular grid. Numerical characteristics: the domain size is 5h in the horizontal directions and 1h in the wall-normal direction; Both Reynolds number (360, 720,…) and resolution (100^3, 200^3, 400^3, …) are varied. Periodic conditions in the horizontal directions are applied and the initial condition is a neutral, steady flow.

RESULTS

For a case with moderate surface cooling (h/L=1) the evolution of the mean velocity and temperature profiles is given in Figure 2.

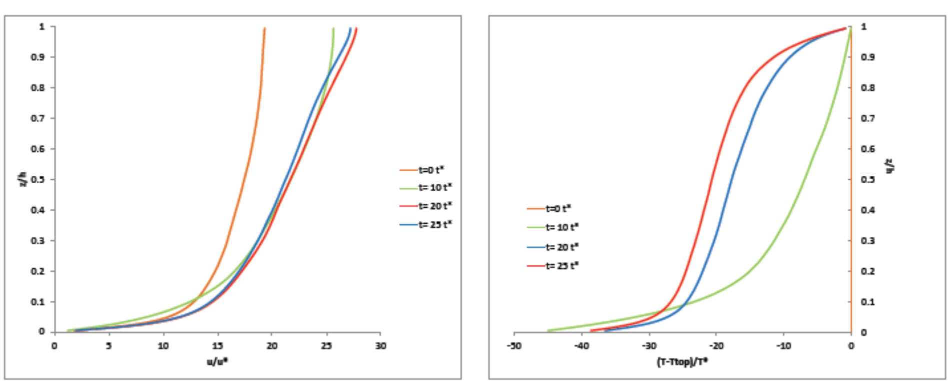

Figure 2. velocity (right) and temperature (left) profiles at t=0, 10, 20 and 25, for a dimensionless surface heat extraction h/L=1.

Because turbulent exchange of momentum is less efficient in stratified than in neutral conditions, large wind shears are needed to oppose the horizontal pressure gradient. The profile attains a log-linear shape resembling typical atmospheric flows [3,4]. The temperature profiles approaches a quasi-steady equilibrium after t~20.

The simulations were repeated for various values of the surface heat extraction. When the value of the surface heat extraction exceeded a critical value of h/L=1.24 turbulence in the flow cannot survive and the flow laminarizes. This is illustrated by Figures 3a,b and 4, below. In a companioning study this laminarisation is explained by the maximum sustainable heat flux theory (MSHF [3,4]), which will be validated in the present research.

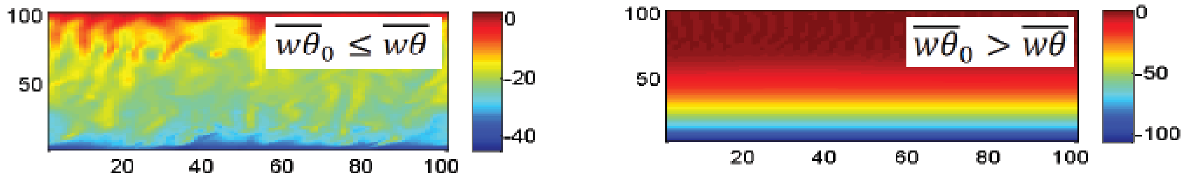

Figure 3 Snapshot of temperature distribution a in typical turbulent case (with surface heat extraction h/L=1) and a typical laminar case (h/L=1.24).

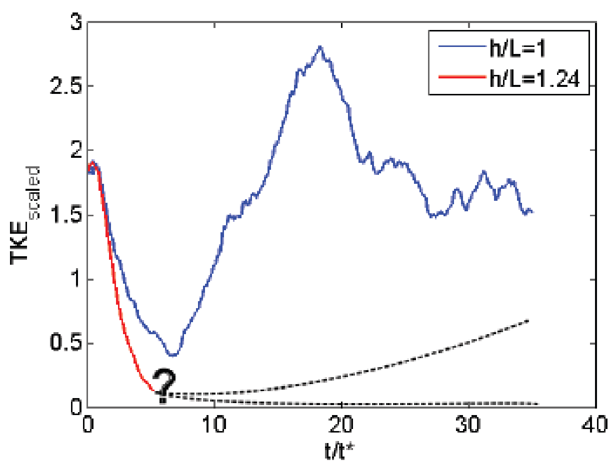

Figure 4. turbulent kinetic energy as a function of time. BLUE : surface heat extraction : h/L=1.0 ; RED : h/L=1.24.

References

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