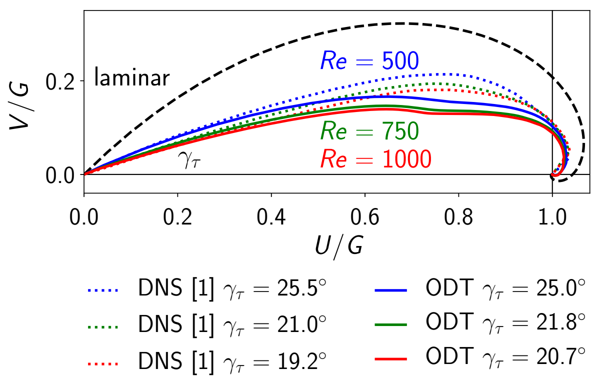
SIMULATING NEUTRALLY AND STABLY STRATIFIED TURBULENT EKMAN FLOWS WITH A STOCHASTIC TURBULENCE MODEL

Heiko Schmidt[1] & Marten Klein[1]
[1]*Department of Numerical Fluid and Gas Dynamics, Brandenburg University of Technology (BTU) Cottbus-Senftenberg, Cottbus, Germany*

We investigate turbulent Ekman flows as canonical problem related to the atmospheric boundary layer. The configuration is given by a rotating wall (fixed in the rotating frame of reference), a geostrophically balanced bulk flow G above this wall, and a buoyant scalar to account for stratification effects. Dirichlet boundary conditions are used for all variables similar to [1]. The coupling of the wall and the fluid is accomplished by a thin layer of size $\delta = \sqrt{\nu/\Omega}$ (laminar Ekman layer thickness), where ν is the kinematic viscosity and Ω the background rotation rate. The length scale δ imposes strong resolution requirements and considerably limits the numerically accessible Reynolds numbers. In the case of strong stratification, further complications arise due to intermittency [1], which cannot be modeled with standard gradient-diffusion closures (e.g. [2, 7]).

We address these challenges by the lower-order, stochastic, so-called one-dimensional turbulence (ODT) model [3]. ODT aims to resolve all scales of a turbulent flow but reduces the dimensionality. The computational domain is a 1-D line, which is here oriented vertically, and reaches from the wall up into the unperturbed bulk flow [4]. Along this line, diffusive transport and the Coriolis effect are resolved directly, wheres the effects of turbulent advection and pressure fluctuations are modeled by stochastic mapping events. These events are selected with highest probability where shear and buoyancy yield net extractable energy. Here we use an adaptive ODT implementation [6].

In the talk, we consider first the case of neutral stratification in order to validate the model. After that, we discuss in more detail the effects of stratification. For both cases, various statistical quantities will be shown and compared to available reference data. Preliminary ODT results for neutrally and stably stratified Ekman flows are shown in figure 1.



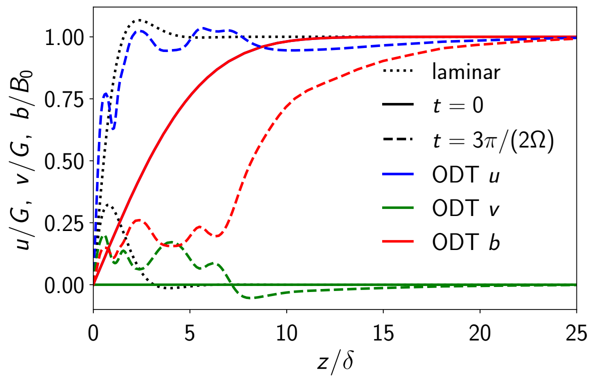


Figure 1. *Left — neutral stratification:* Hodographs of the mean velocity (U, V) and the corresponding values of the wall-shear stress angle γ_τ for various $Re = G\delta/\nu$. The unphysical 'kink' around $U/G \approx 0.8$ is currently further investigated but $\gamma_\tau(Re)$ is fairly well captured by ODT. *Right — stable stratification:* Instantaneous vertical profiles of the buoyancy b, the streamwise u and the spanwise v velocity component for the laminar initial state ($t = 0$) and a snapshot after 1.5 inertial periods. These ODT results are in qualitative agreement with available reference data (not shown). Here, we have used the ODT model parameters of turbulent channel flow [5].

References

[1] C. Ansorge and J. P. Mellado. Global intermittency and collapsing turbulence in the stratified atmospheric boundary layer. *Boundary-Layer Meteorol.*, **153**:89–116, 2014.
[2] M. A. Jiménez and J. Cuxart. Large-eddy simulations of the stable boundary layer using the standard Kolmogorov theory: Range of applicability. *Boundary-Layer Meteorol.*, **115**:241–261, 2005.
[3] A. R. Kerstein. One-dimensional turbulence: Model formulation and application to homogeneous turbulence, shear flows, and buoyant stratified flows. *J. Fluid Mech.*, **392**:277–334, 1999.
[4] A. R. Kerstein and S. Wunsch. Simulation of a stably stratified atmospheric boundary layer using one-dimensional turbulence. *Boundary-Layer Meteorol.*, **118**:325–356, 2006.
[5] M. Klein and H. Schmidt. Stochastic modeling of passive scalar transport in turbulent channel flows at high Schmidt numbers. In *Proc 10th Int Symp Turb Shear Flow Phen (TSFP10)*, **1**, Chicago, IL, 2017. 1B-2.
[6] D. O. Lignell, A. R. Kerstein, G. Sun, and E. I. Monson. Mesh adaption for efficient multiscale implementation of one-dimensional turbulence. *Theor. Comp. Fluid Dyn.*, **27**(3):273–295, 2013.
[7] L. Mahrt. Stably stratified atmospheric boundary layers. *Annu. Rev. Fluid Mech.*, **46**(1):23–45, 2014.