7.5 SENSING THE STABLE BOUNDARY LAYER IN A TOWING TANK

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1. INTRODUCTION & BACKGROUND

The atmospheric stable boundary layer (SBL) remains a complex subject of study. At night, both radiative surface cooling and turbulent transport govern the SBL development and structure. Moreover, for low winds, additional small scale processes as gravity waves, drainage flows, intermittent turbulence, land surface heterogeneity, (sub-)mesoscale flow interact also. These processes cause ambiguous interpretation of field observations, and as a consequence, parameterization development for the SBL is difficult and progress has been slow.

Therefore it is not surprising that the performance of NWP and climate models show a relatively poor skill for stable conditions (Steeneveld et al., 2008; Walsh et al, 2008; Richardson, 2009). For example, the DJF model climate for the Arctic by the EC-Earth climate model shows a typical bias of 6 K. It is evident that such model skill has negative consequences for end users in agriculture (Prabha & Hoogenboom, 2006), fog and air quality forecasting (Tie et al., 2007; Van der Velde et al., 2010). Thus improved understanding and representation of the SBL is desirable.

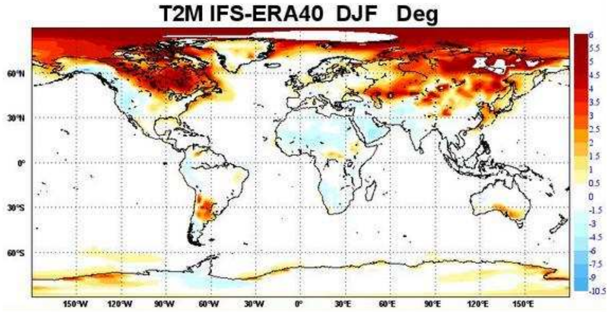

Fig 1: Modelled temperature bias (EC-Earth) for the DJF climate (ecearth.knmi.nl).

Several studies have shown that NWP and climate models are relatively sensitive to the formulation of the turbulent diffusion. Models have to allow for more turbulent mixing in the SBL (Louis et al. 1982) than can be explained by field observations (e.g. McVehil, 1964; Dyer 1974, Beljaars & Holtslag, 1991; Handorf et al. 1999, Cheng & Brutsaert, 2005). Assuming 1st order local closure, the eddy diffusion K for momentum is as follows:

$$K = \frac{(kz)^2}{\phi_m^2}\left|\frac{dU}{dz}\right| = (kz)^2\left|\frac{dU}{dz}\right| F(Ri) \qquad (1)$$

Multiplicity of nocturnal processes as well as the non-stationarity has lead to uncertainties and relatively large discrepancies in F(*Ri*) and ϕ_m from field observations (e.g. Nieuwstadt, 1984;Mahrt, 2009).

In order to examine whether laboratory experiment can assist to clear the fog on these uncertainties, we report on a simulation of a SBL in a water tank, and retrieve nondimensional turbulent fluxes and variances, and compare with atmospheric measurements from different field campaigns listed above. In addition, we aim to estimate *F*(*Ri*) from the laboratory experiment.

2. EXPERIMENTAL SETUP

The following experiment has been conducted at the CNRM-GAME Toulouse stratified water flume, which is 22 m long, 3 m wide, and 0.8 m deep (Fig. 2). A plate (3 x 3 m^2) covered with LEGO (Fig. 3, 4) blocks of 1 cm height (giving a roughness length of 0.0014 m) is towed in the flume (towing tank configuration), while orgasol particles are injected on the upstream part of the plate. A pulsed laser illuminates a vertical plane, and a camera acquires pair of images separated by 3-7ms at a frequency of 7.25 or 14Hz, in order to retrieve 2D-velocity in the flow from PIV technique. In addition, 7 density probes are placed in a non-equidistant grid (0.02; 0.035; 0.05; 0.065; 0.095; 0.125; 0.185 m from the plate) behind the plate to measure mean density and perturbations at 500 Hz.

Two type of experiments were conducted: First a number of neutral runs were performed on order to test the designed set-up, and to determine the optimal orgasol particle concentration, time interval for PIV, and towing speed. In the second phase a stratification was initiated by using different salt concentrations at different water layer (Fig. 5). With this set-up different runs were performed (Table 1).

Table 1: Overview of experimental set-up (for neutral runs, more speed available for stable runs)

Towing speed (m/s)	Δt camera (s)
0.065	0.0075
0.147	0.0033
0.262	0.0020

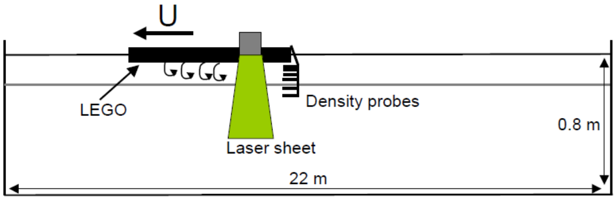

Fig 2: Schematic of the towing tank configuration.

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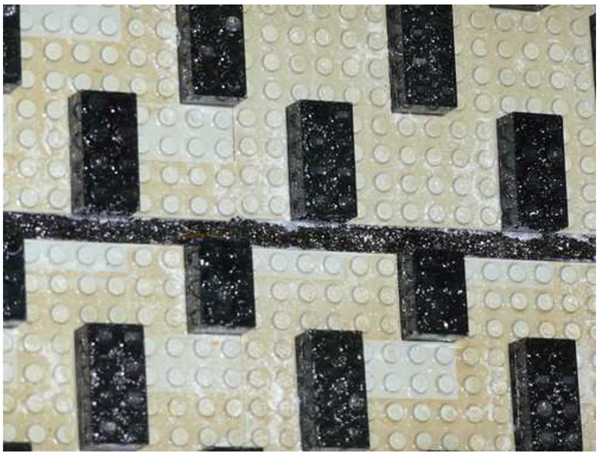

Fig 3: Schematic of the roughness elements

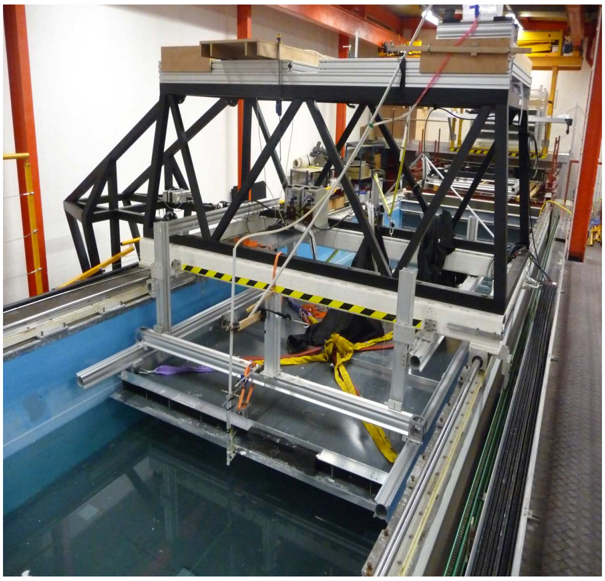

Fig 4: The towing bank, with plate and injection mechanism at the water level.

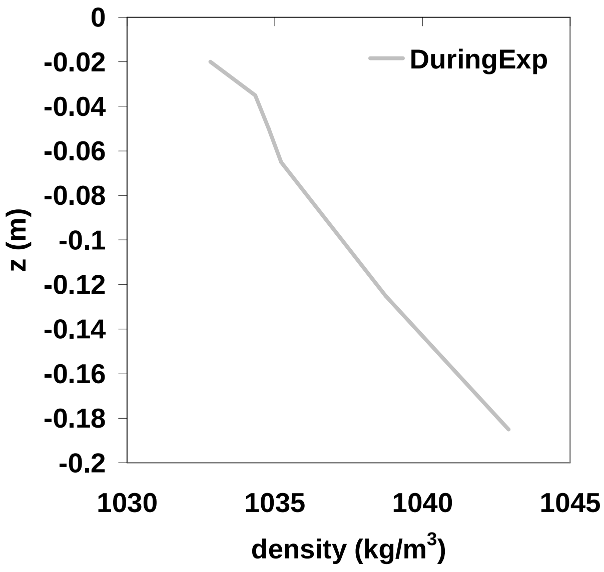

Fig 5: Measured density profile before and during stably stratified run (See section 3B).

3. PRELIMINARY RESULTS

A. No stratification.

In order to test the facility and the configuration, a number of runs have been performed using a neutral stratification. Fig 6 shows the mean profile and the momentum flux profile for a run with a towing speed of 21.2 cm/s. We observe a well developed boundary layer of ~0.25 m, although both profiles indicate that close to the surface the profile deviates from the expected logarithmic shape, although is highly likely due to the relatively poor quality of the speed vectors from PIV for these small movements relative to the towing plate. A more careful selection results in a close to logarithmic shape (see next section). The momentum-flux profile is approximately linear, although at z = 0.15 m the variance is relatively large. Close to the plate, the flux deviates from its slope (Fig 6b).

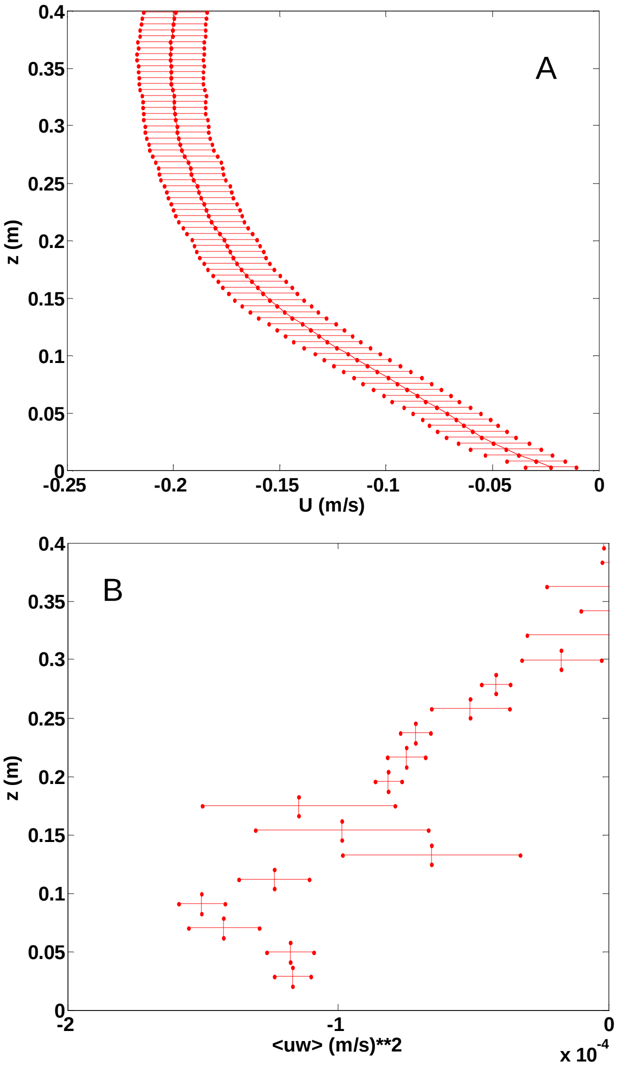

Fig 6: Speed (a) and momentum flux profile (b) for a neutral run with a towing speed of 21.2 cm/s.

B. Stratification.

In this section, results of a stratified run with a towing speed of 26.2 cm/s is analyzed. In order to examine the degree of stationarity reached. For the run discussed below, it was found that at the end of the run dU/dt in the profile amounted approximately 0.0015 ms^{-2} at the 0.05 m; 0.0011 ms^{-2} at 0.12 m, -0.0010 ms^{-2} at 0.20 m from the plate. Hence, it seems not unreasonable to state the experiment has reached a nearly stationary state.

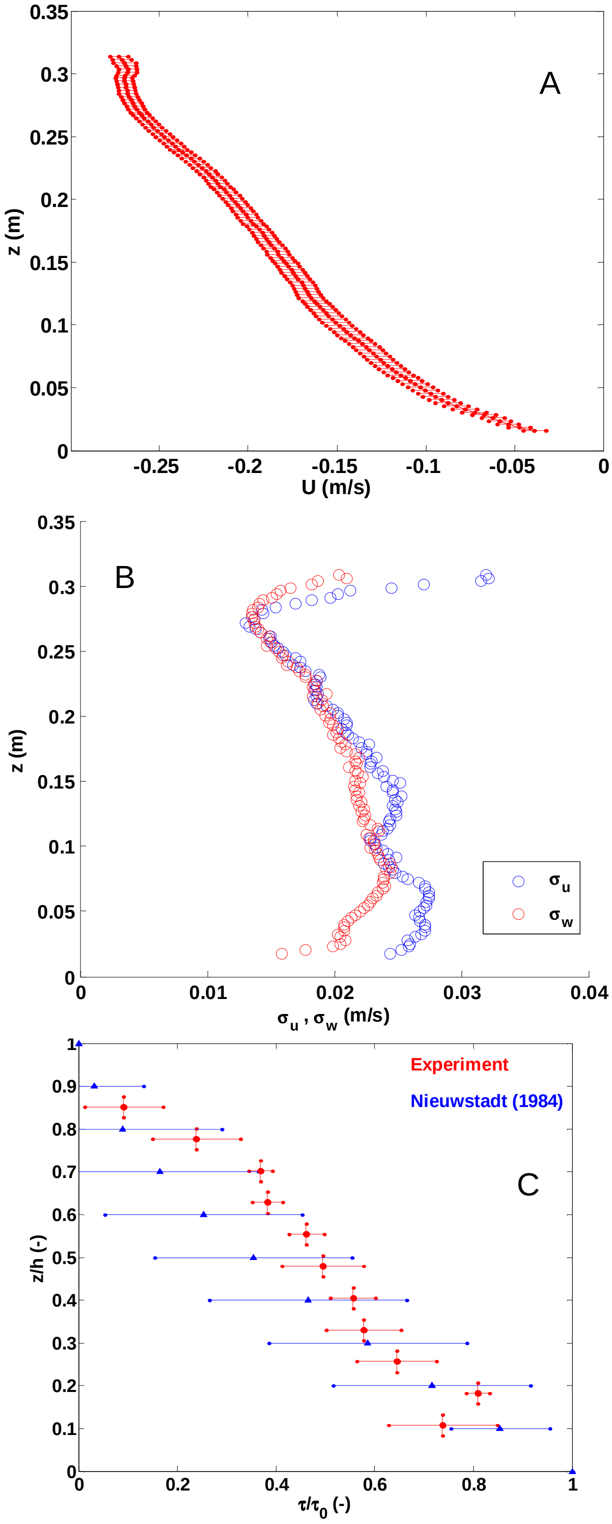

Fig 7: Mean flow, velocity variances, and non-dimensional momentum flux profile for a run with a towing speed of 26.2 cm/s.

Fig. 7 shows that the mean profile has developed a reasonably log-linear shape. At 0.12 m and 0.22 m two inflection points seem to be present, and the their origin should be further investigated. Wave action and/or bad vectors are possible candidates to explain these features.

Considering velocity variances, σ_u and σ_w increase with height close to the surface and decrease close to the boundary layer depth. Furthermore $\sigma_u/u*$ showed to be approximately constant with a typical value of 2, which corresponds to Stull, 1988. The large velocity variances at the boundary layer top do suggest large-scale motions (probably waves) are present. Future analysis will focus on high- and low pass filtering of the current data in order to obtain refined velocity variance profiles. The non-dimensional momentum flux profile lies within the uncertainty estimates by Nieuwstadt (1984). However, the surface flux seems to be relatively difficult to determine, and flux profile deviates from the Nieuwstadt (1984) result at the boundary layer top.

3. CONCLUSIONS

This paper reports a number of preliminary results of a towing tank experiment (CNRM-GAME Fluid Mech. laboratory in Toulouse) in which we aim to understand the turbulence in the stably stratified boundary layer, in having the opportunity to repeat experiments, to reach stationarity, and to limit the degree of disturbances as much as possible. A well-developed boundary layer develops and typical results as a log-linear mean profile. However, a number of aspects need further attention in ongoing analysis.

Acknowledgements

This work has been supported by European Community's Sixth Framework Programme through the grant to the budget of the Integrated Infrastructure Initiative HYDRALAB III within the Transnational Access Activities, Contract no. 022441. We thank B. Beaudoin, B. Bourdelles, J.-C. Canonici, M. Morera, F. Murguet, S. Lassus-Pigat and H. Schaffner of the CNRM-GAME (URA1357, METEO-FRANCE and CNRS) fluid mechanics laboratory, as well as B. Baumann and Y. Dossmann, for their kind support during the experiments.

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