4.1 AN INTERCOMPARISON OF LARGE-EDDY SIMULATIONS OF THE STABLE BOUNDARY LAYER

Robert Beare[1*], Malcolm MacVean[1], Albert Holtslag[2], Joan Cuxart[3],
Igor Esau[4], Jean-Christophe Golaz[5], Maria Jimenez[3], Marat Khairoutdinov[6],
Branko Kosovic[7], David Lewellen[8], Tom Lund[9], Julie Lundquist[7], Anne McCabe[1],
Arnold Moene[2], Yign Noh[10], Siegfried Raasch[11], Peter Sullivan[12]

[1]Met Office, UK; [2]Wageningen University, The Netherlands; [3]Universitat de les Illes Balears, Spain;
[4]Nansen Environmental and Remote Sensing Center, Norway;
[5]National Research Council, Naval Research Laboratory, Monterey, CA, USA;
[6]Colorado State University, USA; [7]Lawrence Livermore National Laboratory, USA;
[8]West Virginia University, USA; [9]Colorado Research Associates, USA; [10]Yonsei University, South Korea;
[11]University of Hannover, Germany; [12]National Center for Atmospheric Research, USA.

1. INTRODUCTION

The large-eddy simulation (LES) of the stable boundary layer (SBL) is a very challenging task. Whilst much progress has been made in simulating the convective cloudy boundary layer over the last decade, progress with modelling the stable boundary layer has been slower. Whilst the SBL is difficult for LES, the parametrization of SBLs in large-scale models is important for various aspects of Numerical Weather Prediction (NWP) and Climate modelling. Examples include: surface temperature forecasting over land at night, fog prediction, the timing of convection, and polar climate. Motivated by the need to improve and understand the parametrization of SBLs in large-scale models, the GABLS initiative was launched in 2002 (Holtslag, 2003). One question motivating this study was: why do climate models require more mixing in their SBL schemes relative to Monin-Obukhov theory and observations? Since LES has proved a useful guide for other physical parametrizations in the past, one component of the initiative was to perform the first intercomparison of large-eddy models for the SBL. The role of the intercomparison study was to assess the reliability and sensitivity of different models for a SBL case based on observations. Also, the results would provide further guidance for SBL parametrization.

2. CASE DESCRIPTION

In order to provide a useful test-case for intercomparison, the situation studied by Kosovic and Curry (2000) was chosen. This was adopted because it used initial conditions consistent with the BASE (Beaufort Sea Arctic Stratus Experiment) observations, was moderately stable and thus likely to be mainly continuously turbulent, and had previously been successfully simulated. The initial potential temperature profile consisted of a mixed layer (with potential temperature 265K) up to 100m with an overlying inversion of strength 0.01 Km^{-1}. A prescribed surface cooling of 0.25 Kh^{-1} was applied for 9 hours, and the geostrophic wind was set to 8 ms^{-1} in the East-West direction. The domain size was set to 400m x 400m x 400m. An isotropic grid was used, and simulations were performed at grid lengths of 12.5 m, 6.25 m, 3.125 m, 2 m, and 1 m, depending on the computer power and time available to the contributors. Profiles averaged over the horizontal domain and over the final and penultimate hours of the simulation were calculated. Time series data were provided for the entire simulation.

3. OVERVIEW OF RESULTS

A large amount of data was made available by the participants and comprehensive details of the case and results are available online at **www.gabls.org**, and in a paper submitted to *Boundary Layer Meteorology*. As an example, mean profiles of the potential temperature at 6.25m resolution and wind speeds at 2m resolution are shown in Figures 1 and 2 respectively. The profiles exhibit a positive curvature in the potential temperature near the top of the SBL, and a pronounced super-geostrophic jet peaking near the top of the boundary layer. These features are con-

*Corresponding author address: Bob Beare, Met Office, Exeter, Devon, EX1 3PB, U.K.; email: bob.beare@metoffice.com

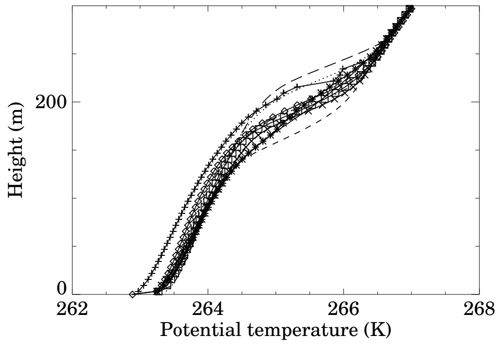

Figure 1: Mean profiles of potential temperature at 6.25m resolution for the final hour of simulation.

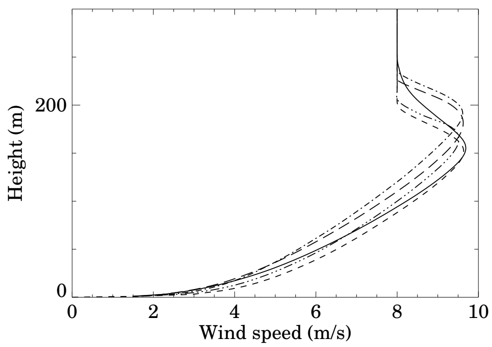

Figure 2: Mean profiles of wind speed at 2m resolution for the final hour of simulation.

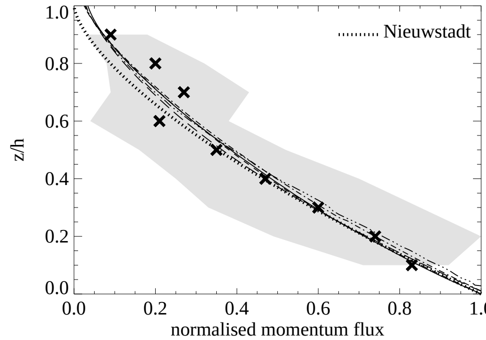

Figure 3: Momentum flux plotted against height normalised by boundary layer depth for resolution 2 m. Mean observations of Nieuwstadt (1984) shown as crosses, with standard deviation as shaded area. Theoretical profile of Nieuwstadt (1985) shown as dotted line.

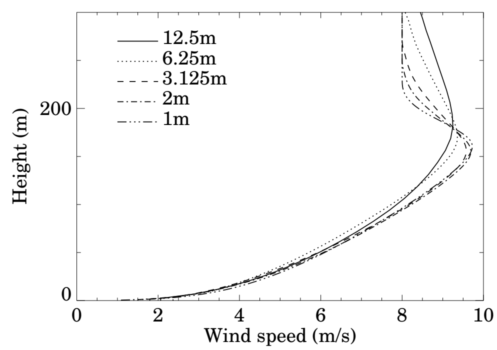

Figure 4: Mean wind speed at different resolutions for final hour of Met Office simulations.

sistent with the theoretical 1D model of Nieuwstadt (1985).

Figure 3 compares the normalised mean momentum fluxes of the LESs at 2m resolution with the observations of Nieuwstadt (1984). The normalised profiles have a much smaller spread than the standard deviation of the observations, and lie close to the mean observations and the theoretical profiles of Nieuwstadt (1985).

Figure 4 shows the mean wind speeds for the Met Office model (similar tests were performed for other models) at different resolutions down to a grid length of 1m. With increased resolution, there is a general decrease of boundary layer depth, and increase of jet strength. For resolutions of 3.125 m or less, the profiles are closer than the profiles at larger grid lengths.

First-order parametrizations of the SBL are often used in operational NWP and climate models, following, for example, Louis (1979). These express the parametrized vertical diffusivities of momentum (K_m) and heat (K_h) as functions of mixing length (λ), vertical wind shear (S), and functions of gradient Richardson number (Ri):

$$K_m = \lambda^2 S f_m(Ri), \quad K_h = \lambda^2 S f_h(Ri). \qquad (1)$$

Figure 5 shows the 'long tails' type of function typically used in NWP and a sharper function sometimes used for research, compared with the large-eddy simulations of the momentum Richardson number functions for 6.25m resolution. Typically, the large-eddy simulations are much closer to the sharp profile than the long tails; from this evidence, the LES thus implies less mixing than typically used in operational NWP and climate models. One reason for the difference may be that shallow SBLs are often poorly resolved in NWP models. The Richardson numbers calculated at poor resolution might be larger than

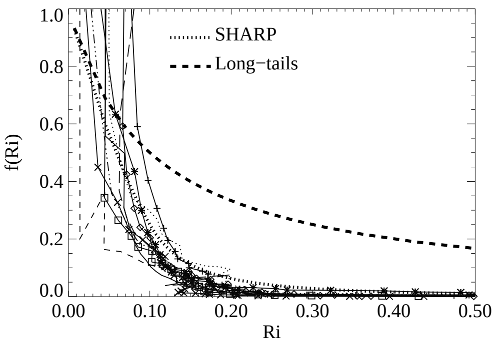

Figure 5: Effective momentum Richardson number stability functions for 6.25m resolution compared with the long tails and sharp functions.

those for the fully resolved flow, and thus the stability function needs to decrease less rapidly with increasing Richardson number.

4. SUMMARY

An overview was presented of the first intercomparison of LES of the stable boundary layer as part of the GABLS initiative. Using a moderately stable case inspired by the BASE Arctic observations, the outputs from eleven LES models were compared for a range of resolutions. A more complete picture of reliability and sensitivity than could be provided by one model was thus gained. It was shown that LES of the SBL is reliable for a quasi-equilibrium moderately stable case, provided sufficient resolution is used. A full description of model and resolution sensitivity and comparison with observations are in a paper submitted to *Boundary Layer Meteorology*.

It was shown that the implied mixing functions from the LES were much less than that typically used in NWP and climate models, when using asymptotic mixing lengths typically used in NWP. The LES is thus in accord with Monin-Obukhov theory and observations. The results provide a basis for future parametrization developments. Bridging the gap between the stability functions and mixing lengths used in coarse resolution NWP and climate models and those derived from high resolution LES is an important issue. The high resolution LESs provide a limit to which the NWP models should converge when run at much higher resolution in the future.

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