Large-Eddy Simulation of the planetary boundary layer under baroclinic conditions during sunset turbulence

Umberto Rizza[1], Gervasio A. Degrazia[2], Otávio C. Acevedo[2], Antonio G. Goulart[3]

[1]Istituto di Scienze dell'Atmosfera e del Clima, CNR, Lecce, Italy
[2]Universidade Federal de Santa Maria, Brazil;
[3]Universidade Federal do pampa, Alegrete, RS, Brazil.
e-mail: u.rizza@isac.cnr.it

1. Introduction

The investigation of the evening transition and the stably stratified atmosphere with LES is in general very challenging, and there have been few studies related to this topic (Nieuwstadt and Brost, 1986; Sorbjan, 1997; Goulart et al. 2010). The principal aim of this work is to investigate the effects of the baroclinic setup in the LES study of a sunset PBL. The baroclinicity is related to temperature gradients through the well-known "thermal wind" equations and consequently it would require the adaptation of model equations in order to incorporate the thermal advection, with adjustment for the effects of buoyancy (Sorbjan, 2004).

2. The case study

The LES domain is localised around the city of Candiota (-31.40, -53.70) that corresponds to the point of coordinate (x, y)=(35, 28) of the outer WRF grid. The region around Candiota is the South American lowlands or Pampa, in which the dominant vegetation types are grassy prairie. We assume homogeneous surface fluxes within the LES domain that has a horizontal extension of 5x5x3 km. Concerning the geostrophic forcing two different setups are employed. The first (BCL) utilises a baroclinic geostrophic wind profile and the second (BTP) the more common barotropic geostrophic profile.

3. Discussion

The temporal evolution around the transition may be analysed by considering the PBL vertically averaged TKE, calculated following

Nieuwstadt and Brost (1986) as:

$$[\langle TKE\rangle] = \frac{1}{hL^2}\int_0^h\int_0^L\int_0^L TKE(LES+SFS)\,dxdydz \tag{1}$$

where LE and SFS are respectively the resolved and subfilter components of the kinetic energy.

The results are scaled by
$W_*(16Z) = W_{*0} = 1.5ms^{-1}$,
$h(16Z) = h_0 = 1000m$
and $\overline{(w'\theta')}$ $(16Z) = 0.1$ ms^{-1}K,

so that $t^* = 11$ min, while $\tau_f = 180\,\text{min}$, where $t^* = h/w_*$ and is the time required for the sensible heat flux to switch signs. This is equivalent to the intermediate case simulated by Sorbjan (1997), who found, in agreement with Nieuwstadt and Brost (1986), that TKE decays as:

$$\frac{[\langle TKE\rangle]}{w_{*0}^2} = F\left(\frac{t}{t^*},\frac{\tau_f}{t^*}\right) \propto (t-t_0)^{-2} \tag{2}$$

In the present study, it is found that eq. 2 is a good representation of the TKE decay for both the LES-BTP and LES-BCL cases. This is in spite of the fact that the mid afternoon TKE magnitudes are appreciably different in both cases, being larger when it is baroclinic. However, once the transition starts, both curves collapse to a -2 power law, as described by equation (11). Goulart *et al.* (2010) proposed an analytical expression for the TKE decay considering the wind shear production term, which is in close agreement with the LES-BCL results during the afternoon (Figure 1), and also decaying as a -2 power of the dimensionless time during the transition. These results show that the wind shear obviously affects the afternoon TKE magnitude, but does not interfere with the decaying rate, which seems to be universal.

The principal result obtained by the present study is that the use of geostrophic wind shear profiles improves the description of the decay of the TKE at sunset.

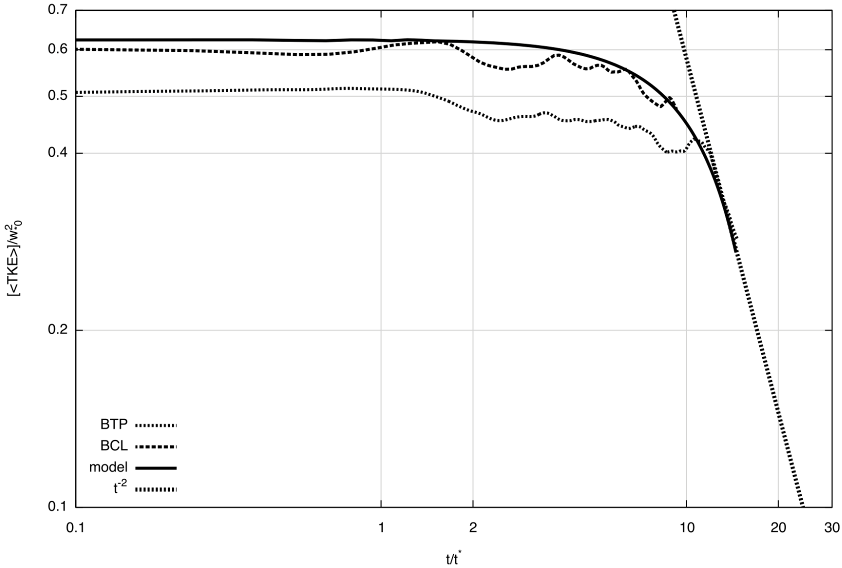

Figure 1. TKE decay for LES-BCL (thick dashed line) and LES-BTP (thin dashed line). The continuous line represents the analytical model of Goulart et al (2010), the -2 power law is also shown for comparison.

References

Goulart A, et al. 2010. On the Time Evolution of the Turbulent Kinetic Energy Spectrum for Decaying Turbulence in the Convective Boundary Layer. *Boundary-Layer Meteor.* **138**: 61-75.

Nieuwstadt FTM, Brost RA. 1986. The decay of convective turbulence. *J.Atmos. Sci*. **43**: 532-546.

Sorbjan Z. 1997. Decay of convective turbulence revisited. *Boundary-Layer Meteor.* **82**: 501–515.

Sorbjan Z. 2004. Large-Eddy Simulations of the Baroclinic Mixed Layer. *Boundary-Layer Meteor*. **112**: 57-80.