LES modeling of a diurnal cycle

Umberto Rizza[1], C. Mangia[1], M. Miglietta[1], A. Moscatello[1], J. C. Carvalho[2], G. A. Degrazia[3], F. S. Puhales[3], E. P. Marques Filho[4]

[1]*ISAC-CNR - Lecce, Italy*
[2]*UFPel - Pelotas, RS*
[3]*UFSM - Santa Maria, RS*
[4]*UFRJ - Rio de Janiero, RJ*

1. Introduction

Over the last decades, the Large-Eddy Simulation (LES) of the Planetary Boundary Layer (PBL) has evolved in a significant way. Being a powerful generator of high-resolution four-dimensional turbulence data, LES has gained a better understanding of some of the complex PBL phenomena. In this work we aim to investigate the daily cycle of heating/ cooling of a clear-sky boundary layer with a well known PBL-LES, which is widely used in literature (Moeng 1984, Sullivan et al, 1996).

2. Large-Eddy Simulation model

The LES model utilised is based on the incompressible Boussinesq form of the Navier-Stokes equations and considers a horizontally homogeneous boundary layer. The boundary layer variables (mean wind components, pressure, temperature etc…) are spatially filtered to define resolved component and sub-grid scale (SGS) component. The large-scale motion is explicitly solved while the smallest scales (typically in the inertial range) are parameterized in terms of the resolved large-scale velocity and temperature fields.

3. Description of simulations: WRF case study and the LES setup

Employing idealized initialization (Moeng and Sullivan 1994) we have “ingested” into the LES the vertical profiles of wind and temperature taken from a simulation performed by the model WRF (http://www.wrf-model.org/index.php) in the southern Italy (fig.I(a)). The WRF simulation lasted three days, from 16 to 18 May 2005, and it was characterised by typical spring weather with no clouds. Figure I(b) shows the daily cycle of ground-level (2 meters) temperature as simulated by WRF during the second day of simulation (17 may). This is a typical profile for a spring period at mid-latitude in the northern hemisphere with a minimum at 6:00 a.m., an average warming rate of 0.884 °K/h from 06:00 a.m. to 4:00 p.m, and an average cooling rate of 0.714°K/h from 5:00 p.m to 12 p.m.

In Figures I(c) and (d) the interpolated mean wind speed and potential temperature profiles at 6:00 a.m. are shown. The temperature profile shows a capping inversion above 200 meters with a stable profile in the upper part. The computational setup for the LES model is summarised in Table I, together with the micro-meteorological parameters taken from WRF simulation. The extension of domain (3,3,1) km and the number of grid points in each direction (96,96,96) is a compromise between the need to resolve the physics (in particular during stable conditions) and the computational costs. The LES run started the 17 May 2005 at 06:00 a.m. in correspondence of the minimum of the temperature profile and end after 18 hours at 12:00 p.m. covering almost all the stability regimes. The warming rate and the cooling rate were derived from the temperature profile and discussed above.

4. Results and discussions

Figures II (a-d) and III (a-d) show the results obtained during convective (from 6:00 a.m. until 4:00 p.m.) and stable conditions (4:00 pm until 12:00 pm) respectively. Figure II (upper left) shows the temporal evolution of the total (resolved+subgrid) turbulent kinetic energy averaged over all the domain. Figures II (lower left and right) show the simulated horizontal mean wind speed ($M = (U^2 + V^2)^{1/2}$) and temperature profile at different hours. It is evident the formation of the CBL due to the heating (figure II, lower right). This injection of TKE is also confirmed by the increasing of the vertical velocity variance showed (figure II, upper right, CBL 1 through CBL 6). During the formation of the CBL it is interesting to point out the evolution of the mean wind with and the sub-geostrophic balance (CBL 4). Starting at 4:00 pm we cooled the CBL of almost 6°K in 8 hours. Due to inertial oscillation a low-level jet (LLJ) developed with a magnitude of the maxima increasing in time SBL 1 –SBL6 and decreasing from SBL 6 to SBL 8.

Results indicate that LES run realistically captures at least qualitatively the development of the PBL and of the LLJ.

5. Conclusions

In this preliminary work we have simulated with LES the diurnal/nocturnal evolution of the atmospheric boundary layer. The initial conditions were obtained interpolating the wind and temperature fields (in one point of the numerical domain) from a mesoscale model (WRF) running for weather forecast on the southern Italy.

At this stage we present results on convective and stable PBL's features. Further developments will concern the transition between unstable to stable, i.e. the formation of the neutral PBL and the residual layer, together with the comparison with the mesoscale model outputs running on a finer grid.

6. References

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Table I

Ustar	qstar	$(z_i)_0$	T_0	(L_x,L_y,L_z)	(N_x,N_y,N_z)
ms^{-1}	mKs^{-1}	m	°K	10^3m	
0.26	0.0165	213	287.75	(3,3,1)	(96,96,96)

Internal parameters for LES taken from WRF simulation day2 at 06am, ustar is the friction velocity, qstar the kinematic heat flux at ground, $(z_i)_0$ is the initial capping inversion,T_0 the ground level temperature (2 meters), (L_x,L_y,L_z) is the extension of the LES domain and (N_x,N_y,N_z) the number of grid points.

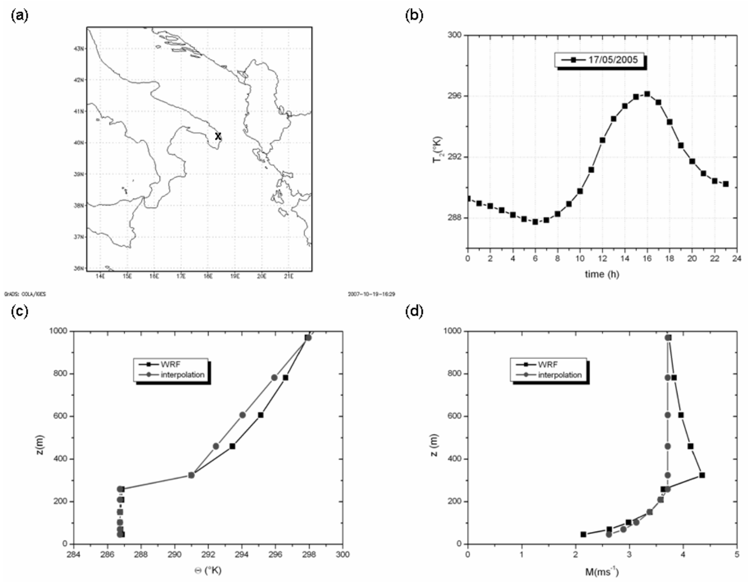

Fig.I : (a) WRF numerical domain, x represent the central point of the LES domain; (b) diurnal evolution of ground level (2 meters) temperature from WRF in the point X of the domain; (c) initial potential temperature profile from WRF in the point X of the domain and its interpolation used in LES; (d) initial wind profile from WRF ($M = (U^2 + V^2)^{1/2}$ in the point X of the domain and its interpolation used in LES

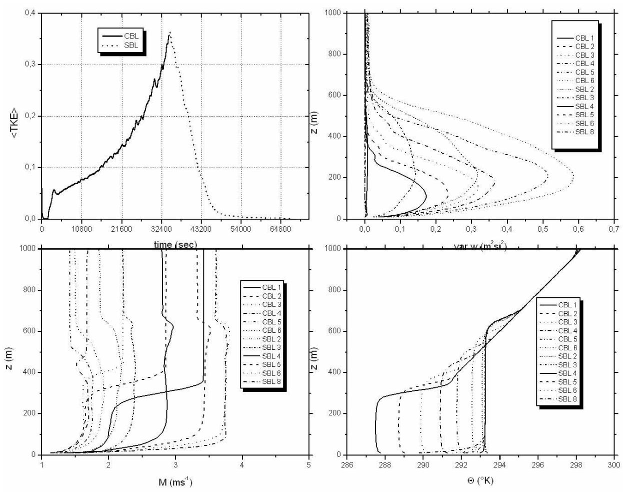

Fig.II: upper left: evolution of the mean turbulent kinetic energy; upper right: evolution of vertical variance; lower left: evolution of mean wind velocity; lower right: evolution of potential temperature profiles