Large eddy simulations of boundary layer turbulence during the late afternoon

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The Boundary Layer Late Afternoon and Sunset Turbulence (BLLAST) campaign took place in France in June and July 2011 focusing on the evening collapse of the boundary layer. In an effort to guide the BLLAST experimental design, the present numerical study aimed at answering basic questions such as: What is the start-time of the late afternoon transition (LAT)? Which atmospheric layers have to be experimentally investigated in priority? To address these questions, two Large Eddy Simulations (LES) codes were used to simulate the decaying atmospheric boundary layer (ABL).

Objectives

1/ Comparing two LES and their ability to simulate the late afternoon transition (LAT)
2/ Studying the turbulence characteristics during the LAT: results found in the literature are revisited and further analyzed.

This comparison investigates:

- the evolution of turbulent length scales.
- the 'S' shape of the buoyancy flux.
- the decay of turbulent kinetic energy (TKE).
- the time evolution of turbulent length scales.

Large eddy simulations

- Two LES models: NCAR and Meso-NH (LA/CNRM/GAME)
- Same equations for both models (Navier-Stokes)
- No cloud developing
- No large scale forcing (i.e. advection, subsidence) and no geostrophic wind
- No coupling with a surface model: sensible and latent heat fluxes are imposed at surface

Study case IHOP

- Data-set collected on 14 June 2002 during the International H2O Project field experiment (Southern Great Plains, US)
- Initialization with wind, temperature and humidity profiles at 7am, as well as sensible and latent heat fluxes.
- Size of the simulated domain: 10 km x 10 km x 4.8 km
- Regular grid of 100 m (horizontal) and 40 m (vertical)
- Time increments: Meso-NH: dt = 1 s, NCAR: dt = 2.5 s

Comparison of the two simulations NCAR and Meso-NH

- There is a good agreement between the two simulations.
- The main differences come from:
  - Larger values of entrainment in Meso-NH simulations, implying:
    - A slightly warmer and drier mixed layer
    - A slightly higher ABL height (Fig. 2a.)
  - A larger variance of the vertical velocity.

Validity of the normalization scales during the LAT

- The evolution of zi is very similar for both models. However, after 1700LT, zi is not well defined by the minimum buoyancy flux (fluctuations of 400 m are observed, Fig. 2a). However, zi is well defined by the height of the mixed layer.
  - From 1600LT, the convection decreases and induces an exponential decrease of L. At 1600LT, 15 minutes are necessary for a thermal to go through the ABL whereas at 1900LT, double time is required.

Decay of TKE

- The decay of TKE is a function of two time scales, t = t * 0 and t = 0 (Fig. 5) is a function of two time scales.
  - The temporal scales t are different after 1600LT.
  - The decay of the volume averaged total TKE, scaled by w*0, t = t * 0, is a function of the convective time scale, t = t * 0.
  - In our simulation, we obtain a similar function, with a decrease of t = t * 0.

Evolution of the TKE at different heights in the ABL

- The analysis of the time evolution of the TKE at different heights in the ABL points out that in our case, there is an increase of the TKE at the top of the ABL, starting from 1500LT. At that time, zi reaches the sheared layer above (Fig. 1) - the entrainment of momentum might explain the increase of TKE at the top of the ABL, which progressively propagates down to the surface.

Conclusion

The results of two simulations (NCAR and Meso-NH) have been investigated, for a convective boundary layer, without cloud, during the LAT. On the whole, both simulations give very similar results for mean parameters and fluxes.
- Determining the development of the ABL in the LAT is challenging. Some ways to evaluate the ABL height do not work in the LAT. In our case, the most fitting method consists in determining the summit of the ML.
- The diminishing w* inducing an exponential increase of L after 1600LT indicate that these normalization scales might not be relevant during the LAT. van Driel and Jonker (2011) suggest new normalization scales in transitional situations, based on the surface heat flux and its past.
- The universal linear profiles of buoyancy fluxes are not maintained in the LAT from 1700LT and become S-shaped.
- As Sorbjan (1997), we found that the decay of the TKE is a function of two time scales, t and t = t * 0.
- The evolution of the TKE at different heights points to the same TKE at the top of the ABL. From 1600LT, a threshold of the convective velocity scale w*0, as the summit of the ABL, the area of the surface heat flux and the testing time scale, t = t * 0.