OBSERVATIONAL EVALUATION OF PBL PARAMETERIZATIONS MODELLED BY MM5

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1. Introduction

A clear convective boundary layer (CBL) developed successively over the Cabauw observational tower (*Beljaars and Bosveld* (1997))(The Netherlands) during the 2nd and 3rd May 1995. The CBL was characterized by well mixed thermodynamic variables, high entrainment rates and high subsequent growth of the mixing layer. The development and evolution of this CBL were monitored in detail. Specifically, the driven sensible heat flux (SH) and latent heat flux (LE) were measured at the surface by the eddy covariance methode. The height of the boundary layer (z_i) was observed by boundary-layer profile measurements, *i.e.* wind profiler/RASS system. In addition, vertical profiles of wind, temperature and moisture were taken every six hours by radiosoundings. These measurements were completed with observations at the tower of the same variables at 6 different heights (up to 200 m).

In the study described in this paper, the PBL schemes implemented in the mesoscale model MM5 are evaluated with this observational data set. Mesoscale models are currently used to simulate and to forecast short-range meteorological and air pollution problems. For such length and time scales, such models will only yield accurate results if they represent realistically the main characteristics and variables in the atmospheric boundary layer. Previous studies (*Seaman et al.* (1989); *Berman and Rao* (1999); *Braun and Tao* (2000)) have investigated whether MM5 was able to simulate succesfully the main ABL variables and the growth of the mixing layer. However, these boundary layers studies occured under meteorological situations with a high degree of complexity: urban area, coastal zone, ABL in a hurricane. Moreover, the observational validation was not as complete as in this current study. *Zamora et al.* (2000) also studied using MM5 the evolution of a CBL at Nashville. However, they did not perform a sensitivity analysis of the various PBL representations available at MM5. Our research extends the previous studies and is focused on critically evaluate the performance at surface and upper air levels of the PBL descriptions compared to the complete observational data set.

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2. Synoptic Situation

At the beginning of May 1995, a high pressure system was established over the north of Germany. The presence of this synoptical system provide the optimal conditions to develop a clear (convective and stable) boundary layer above the almost homogeneous flat terrain of Cabauw. During the days under study the main geostrophic winds were easterly to southeasterly. The modelled subsidence velocities between 11 UTC to 16 UTC range from -0.08 ms^{-1} to -0.14 ms^{-1}. A sea breeze developed after 12 UTC, but its penetration inland (20-30 km) did not reach the Cabauw mast.

3. Model Configuration

A numerical experiment is set up to investigate whether a mesoscale model (the non-hydrostatic Model MM5, *Dudhia* (1993); *Grell et al.* (1994)) is able to reproduce the situation described above. Four domains, two-way nested, are defined using the following resolution: 27, 9, 3 and 1 km. The smallest domain is centred at the Cabauw tower. The initial and boundary conditions are updated every six-hours with information obtained from the 0.5^o x 0.5^o ECMWF model. For the two inner domains, we use a topography and land-use data base with a 30 sec resolution. For the two outer domains the resolution is 1 min. In the ABL, fourteen vertical levels are prescribed of approximately 100 m of grid spacing. Because our main aim is to analyse the performance of the planetary boundary layer parameterization, we decide not to use the model option to nudge surface and radiosound observations during the simulations.

The same physical descriptions are prescribed for all the simulations, except the boundary layer parameterization. At MM5, one can classify the ABL parameterizations in two groups. The first group includes PBL-schemes based on surface layer and bulk layer variables, namely the one developed by *Blackadar* (1976) (from now on BLA) and the one known as Medium Range Forecast (MRF) (*Troen and Mahrt* (1986), *Holtslag and Boville* (1993)). In the other group, the turbulent fluxes are a function of the turbulent kinetic energy, *i.e.* one-and-half order closure. They are: the one implemented in the ETA model (*Janjić* (1994)) and the one developed by *Burk and Thompson* (1989) (BRT).

The parameterization of the surface fluxes differ in the prescription of the three bulk transfer coefficients for momentum, heat and moisture. In our simulations, we have used similar formulas for the BLA, ETA and MRF, and it is only the BRT scheme which uses different expressions for the coefficients (see *Braun and Tao* (2000) for a more thorough discussion).

4. Discussion

The forcing, which drive the evolution and development in the ABL, are the heat and moisture flux at the surface and the entrainment flux at the boundary layer top. For the surface variables, the partitioning of the incoming radiation into sensible and latent heat flux is a determining factor. The entrainment of warmer air from the free troposphere into the ABL is the second forcing which specifically contributes to heat and to dry the ABL. The growth of the mixing layer is dependent on these bottom and top boundary layer fluxes.

Figure 1 shows the time evolution of the sensible heat flux. The calculated surface fluxes for momentum (not shown), heat and moisture (not shown) are larger than the observed fluxes. The overestimation can be due to the relatively higher values of the modelled friction velocity. For u_* the values calculated between 9 UTC and 12 UTC with the four parameterizations are 25 % higher than the observed values. Only slight differences were found between the two scheme groups. However, MRF and BLA yielded always the higher values for the momentum and heat fluxes. An opposite behaviour is found for the moisture flux. For the latent heat flux, sensitivity to soil moisture availability was previously examined by *Oncley and Dudhia* (1995). In our study, we have modified the standard value (30%) for a more appropiate to the Cabauw conditions (60%). With this higher soil moisture content, the LE model results agree better with the observations.

The calculated and observed vertical profiles of potential temperature at 12 UTC (first day) are shown in Figure 2. For the four parameterizations, the profiles show a colder and wetter CBL compared to the observations. This a relative contradictory finding since the calculated surface fluxes were higher then the observed values. However, it can be an indication of the inadequate modelling of the entrainment flux at the top of the CBL. In our comparison, we also found that the PBL parametization which depend on the TKE variable (ETA and BRT) produced the coldest and wettest boundary layer since the modelled turbulent motions are not strong enough to model a well developed CBL.

Figure 3 shows the mixing height evolution observed by the wind profiler, the radiosonde estimation and the MM5 calculations. For the two latter, the mixing height was estimated by calculating the Richardson number from the wind and virtual potential temperature profiles. A critical number of 0.5 was used as a threshold to estimate the boundary layer height. For the two days, the rapid growth of the CBL (between 8 UTC and 13 UTC) is reasonably well modelled compared with the observations. However, none of the parameterizations reaches the maximum observed values. In particular for the second day, the calculated boundary layer height is surprisingly low, but during this day the wind was higher and it is probable that the boundary layer development is influenced by advection. If we concentrate on the first day, and as mentioned before for the vertical profiles, the weak turbulent motions produced by the ETA and BRT resulted in a relatively shallow layer compared (almost 200 m difference at the z_i peak) to MRF and BLA.

Concluding, the CBL modelled by MM5 strongly depends on the selected PBL scheme. For the case under study (1st day), the boundary layer height calculated by using the more simple MRF and BLA agreed better with the observations. However, the excesive turbulent mixing calculated by using the MRF scheme can give wors results than the other parameterizations in modelling other atmospheric flows (*Braun and Tao* (2000)). Future work should be addressed to correct the overestimation of the surface fluxes (*Pagowski and Moore* (2001)) and to study the role of the entrainment flux and its description in mesoscale models.

5. References

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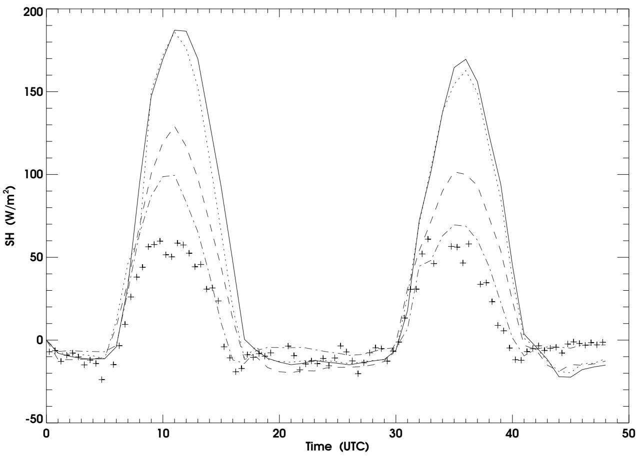

Figure 1: *Temporal evolution of the sensible heat flux. The observations are represented by a cross. The results of the PBL schemes are represented by lines: BLA (dotted), MRF (continuous), ETA (dashed), BRT (dased-dotted).*

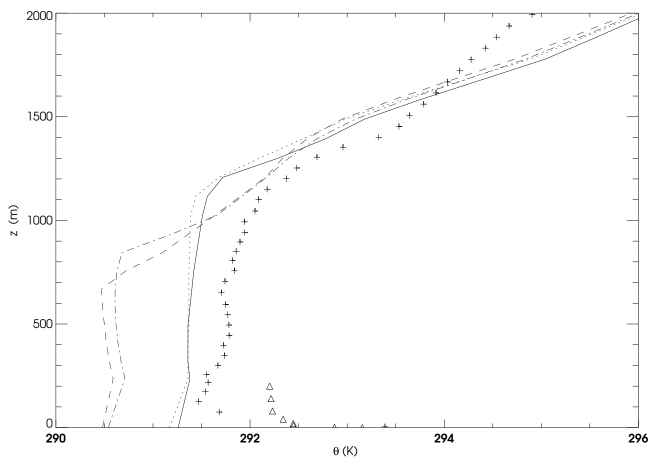

Figure 2: *Same as figure 1, but for the vertical profile of potential temperature at 12 UTC. The tower measurements are represented by triangles.*

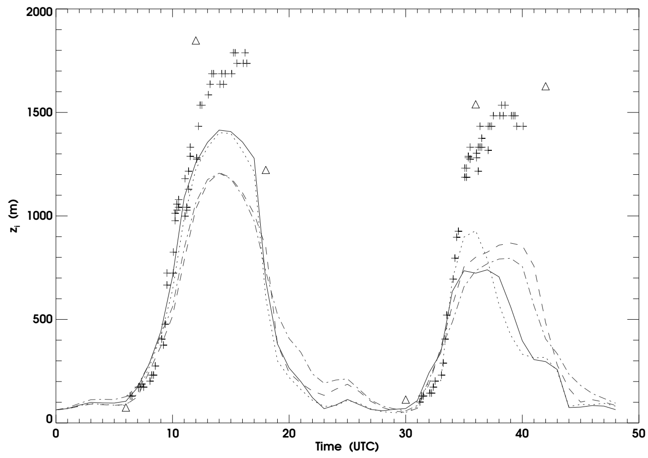

Figure 3: *Same as figure 1, but for the boundary layer heigth. The estimation from the radiosonde is represented with a triangle.*