8.8 MESOSCALE MODEL INTERCOMPARISON AND OBSERVATIONAL EVALUATION FOR THREE CONTRASTING DIURNAL CYCLES IN CASES99: FOCUS ON THE STABLE BOUNDARY LAYER

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1. INTRODUCTION

The planetary boundary layer (PBL) connects the land surface with the free atmosphere through turbulent transport of momentum, heat and moisture. Therefore, the PBL should be well represented in numerical weather prediction (NWP) and climate models to obtain good forecast results. However, the current PBL description in NWP models is rather poor (Holtslag, 2006), especially in the stable PBL (SBL) and for the representation of the diurnal cycle (Zhang and Zheng, 2004). GABLS was set-up to improve these PBL models. This study extends the current GABLS activities by comparing three mesoscale models, in addition to the LES and 1D model intercomparison studies. An important advantage of 3D modeling is the realistic PBL forcing obtained rather than an idealistic (as in the 1D intercomparison) forcing. The aim is to gain insight why certain models are in favor to others in certain conditions. Hence there is need to compare mesoscale model results with observations to understand the models limitations as well as their strengths.

Here the PBL schemes implemented in the mesoscale models MM5, COAMPS and HIRLAM are evaluated against observations. Because these models share the commonality of purpose, it is possible and useful to apply different models to the same prediction test. 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 PBL. Previous studies (e.g. Braun and Tao, 2000) have investigated whether MM5 was able to simulate successfully the main PBL variables. However, these PBL studies occurred under meteorological situations with a high degree of complexity: urban area, coastal zone, PBL in a hurricane. Our research extends the previous studies and focuses on critical model evaluation of the surface and PBL schemes during stable stratification.

2. OBSERVATIONS AND SYNOPTICS

We study the period of 23-26 Oct 1999 during the CASES-99 (Poulos et al, 2002, Kansas, USA).The convective boundary layer (CBL) was characterized by well-mixed thermodynamic variables and typically 800 m deep. The SBLs differ considerably and are intermittently turbulent, continuous turbulent and radiative driven respectively (Steeneveld et al, 2006). The geostrophic wind (from soundings at z=1000 m) is about 6, 20 and 4 ms^{-1} for the successive (clear) days.

CASES99 was conducted near Leon, Kansas, U.S.A. (37.64º N, -96.73º E, 436 m ASL) from 1-31 October 1999. The area consists of gently rolling homogeneous terrain (mean slope 0.2º) with a relatively dry soil, and lacks obstacles in the near surroundings. The roughness length for momentum is 0.03 m.

The ground based observations consist of profiles of temperature, humidity and wind along a 60 m mast, and turbulent and radiative surface fluxes (2.6 m). Radiosondes were taken irregularly at night, but hourly during IOPs.

3. MODEL CONFIGURATION

A numerical experiment is set up to examine whether the selected mesoscale models:
-MM5 (Dudhia and Bresch, 2002, v 3.6)
-COAMPS (Hodur, 1997) and,
-KNMI-HIRLAM (Unden et al, 2002, v6.3.5, refered to as “HIRLAM”) can predict the boundary-layer structure for the current case-study.
For MM5, four domains, two-way nested, are defined using the resolution: 27, 9, 3 and 1 km. The smallest domain is centered at the CASES-99 tower. COAMPS and HIRLAM utilizes 3 km and 11 km in the inner domain respectively. Although the three models do not have exactly the same resolution, they all use high resolution. Consequently, their results should be interpreted as best as possible nowadays.
The initial and boundary conditions are updated every six-hours with information obtained from

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the 0.5º x 0.5º ECMWF operational analysis. We use a 30'' topography and landuse database (USGS).

One can classify the used PBL schemes in two groups. The first group includes PBL-schemes with the mixing based on surface layer and *bulk* layer variables, namely the one developed by Blackadar (1976, henceforth BLA) and the Medium Range Forecast (MRF, Troen and Mahrt, 1986; Holtslag and Boville,1993). In the other group, the turbulent fluxes depend on the turbulent kinetic energy, i.e. 1.5 order *local* closure: Mellor&Yamada-ETA model (Janjic, 1994) and Burk-Thompson (BT, 1989). Both COAMPS and HIRLAM are of the second type.

The surface flux schemes differ in the prescription of the bulk transfer coefficients for momentum, heat and moisture. In our simulations, we use Monin-Obukhov for BLA, ETA and MRF, while BT (Braun and Tao, 2000), HIRLAM and COAMPS utilize the Louis 1979-scheme to obtain surface fluxes.

4. RESULTS AND DISCUSSION

A. Surface fluxes

At first we should realize compensating errors in models can be a significant problem in model evaluation, and thus here as well.

Incoming longwave radiation ($L^{\downarrow}$) is well-estimated by the MM5-cloud radiation scheme (not shown). Surprisingly COAMPS and HIRLAM predict 30 Wm^{-2} less $L^{\downarrow}$ than observed, although the radiation schemes in the former are more sophisticated than MM5-cloud. Hence, nighttime net radiation is 40 Wm^{-2} too low in COAMPS and HIRLAM. Friction velocity (u_*, Fig 1a) is well estimated by all MM5 schemes during daytime, but overestimated at night. In contrast, HIRLAM is correct at night but underestimates u_* during daytime. COAMPS slightly overestimates u_* (0.1 m s^{-1}) for the whole period, a well-known deficiency of the Louis scheme.

The sensible heat flux (*H,* Fig 1b) is on average well estimated during the 1st night. HIRLAM and COAMPS overestimate the magnitude of *H* during the 2nd night. HIRLAM is the only model that let *H* vanish in the last night. Note COAMPS overestimate *H* by 50 W m^{-2} at noon. A characteristic feature for all schemes is the underestimation of the amplitude of the diurnal cycle (T_s, Fig 1c) for all schemes: the daytime T_s is underestimated. COAMPS shows the largest amplitude. All MM5 schemes except BT overestimate T_s during the 3rd night, while HIRLAM and BT perform well.

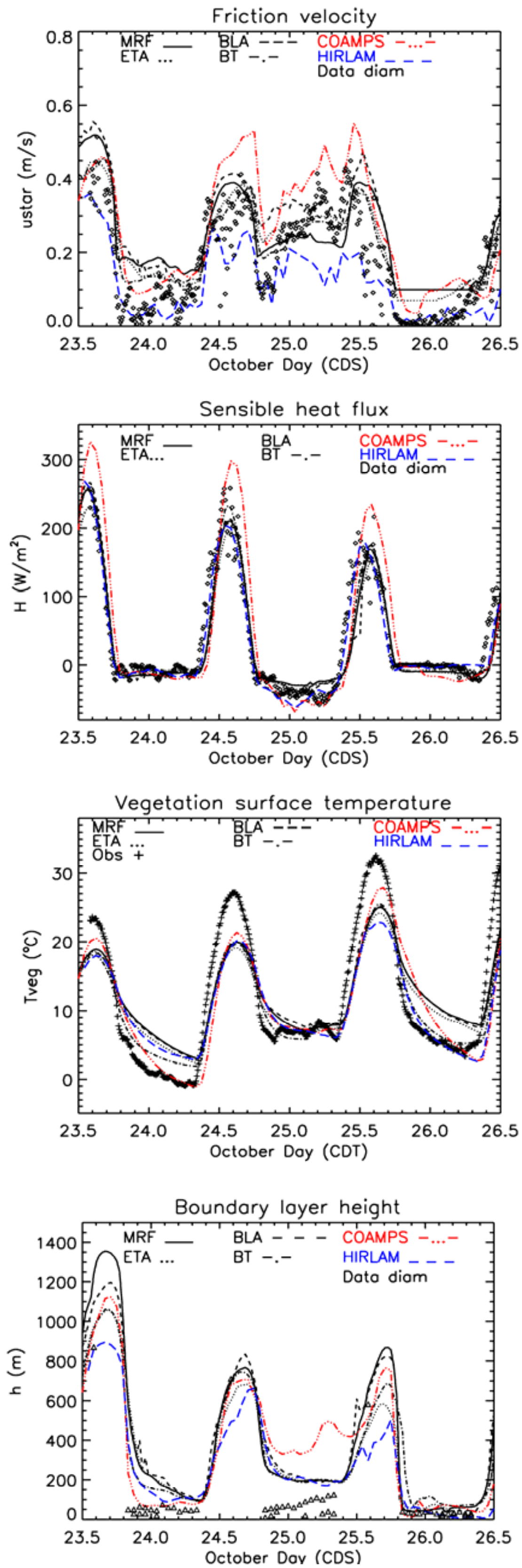

Figure 1: Observed and modeled u_*,H,T_s and h for 23-26 Oct 1999

During daytime observed T_s increases faster than predicted by any scheme.

The PBL height (*h*) as given directly by the models differ substantially, often because of sudden regime changes in the model or because different definitions are applied. When *h* is calculated from the modeled profiles using the Troen and Mahrt (1986) method, we obtain more similar and realistic results (Fig 1d). In general PBL growth is slower with local and TKE schemes (because of the slower diffusion and because the predicted TKE does not allow for a deeper CBL), and the same holds for PBL decrease in the evening. The nocturnal PBL height is typically overestimated by all models by a factor 2. The COAMPS PBL is deeper than the other models during the 2nd night because only COAMPS predicts a strong LLJ. The CBL depth is better predicted by the non-local schemes MRF and BLA.

B. Temperature and wind speed profiles

We focus on the representation of the Low-Level Jet (LLJ) and the temperature profile during weak winds, since these are currently key problems in SBL modeling. Nighttime profiles for strong wind (2nd night) are well reproduced by all models (not shown). Fig 2a shows that the temperature profile (3rd night) is best modeled by HIRLAM and BTwhile the other models lack the strong surface inversion. This is due to the ability to switch off the turbulence at night, and the presence of a vegetation layer in the HIRLAM surface scheme (ISBA) while this is lacking in COAMPS and MM5.

The magnitude of the LLJ in the 2nd night is best modeled by COAMPS (Fig 2b) with a LLJ of 22 ms^{-1} at 500 m height, although this is higher than in the observation. The other models predict the altitude correctly, but these underestimate the LLJ speed by a factor 2. A time height plot of the modulus wind speed revealed that ETA, BT and HIRLAM predict a sharper and fast jet (at 200 m) compared to BLA and MRF. The wind direction is forecasted well by all models. The predicted TKE structure corresponds between models, although the maximum TKE vary from 0.8-1.6 J kg^{-1}. Nighttime TKE is largest for BT during the 2nd night. The specific humidity in the PBL is about 1 g kg^{-1} larger in the TKE models than in the other models. Note that because the surface evaporation is small, the relative impact of entrainment on the humidity profiles during daytime is large. Since entrainment of humidity is still not well understood, the predicted profiles diverge considerably.

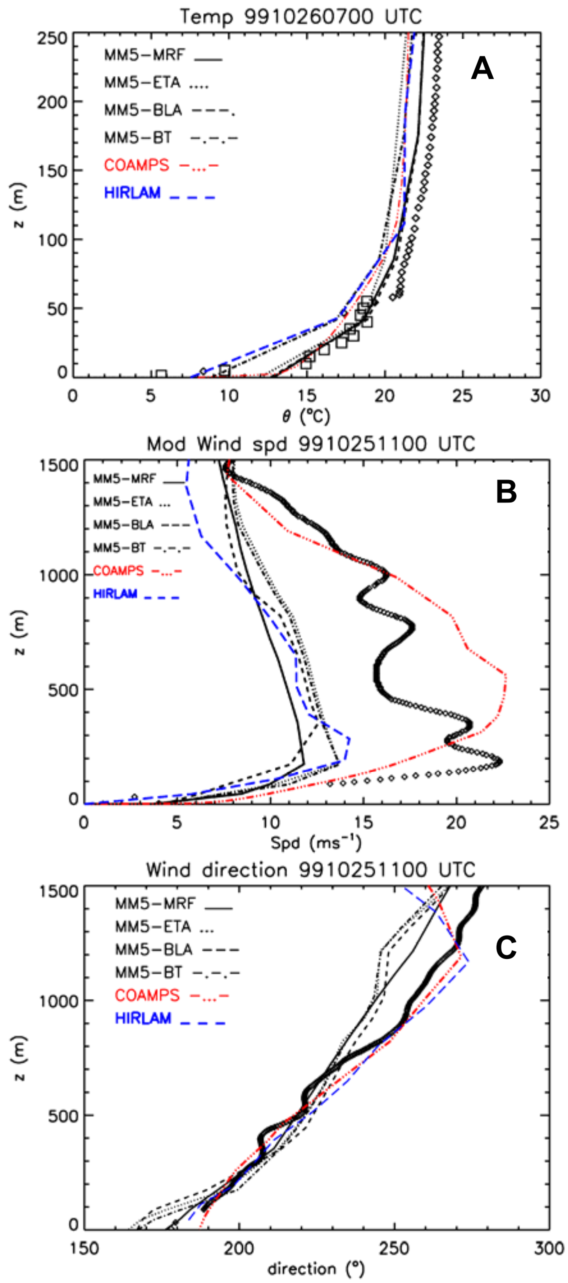

Figure 2: Modeled and observed (a) potential temperature 26 Oct, 2 LT and (b) wind speed and direction (c) 25 Oct 6 LT.□ = 60m mast.

5. RADIATION SCHEME SENSITIVITY

Both long- and shortwave radiation components are important to model the diurnal cycle. The sensitivity of the predicted T_s was tested in MM5 using three different radiation schemes (cloud, CCM3 and RRTM) for both the MRF and ETA PBL schemes (Fig 3). At night, we find a sensitivity of about 4 K on T_S during weak winds, as in Guichard et al (2002), with ETA-CCM3 outperforming the other schemes. This sensitivity is as large as for different mixing formulations in SBLs (e.g. King et al, 1997) and cannot be overlooked.

6. CONCLUSIONS & RECOMMENDATIONS

We tested the performance of three state of the art mesoscale models (MM5, COAMPS & HIRLAM) on three diurnal cycles with contrasting nighttime PBLs in CASES99. All models underestimate the diurnal cycle of the surface temperature, and all seriously overestimate the nocturnal PBL height. Although it is hard to judge on a single case-study, it seems that TKE models performs better during weak windy night and reproduce solely a sharp, but realistic surface inversion and surface fluxes. More intercomparison is needed to see whether this is a coincidence or structural. In addition, we found a large sensitivity of the predicted surface temperature (typically 4 K) to the chosen radiation scheme in MM5.

General recommendations for PBL model improvements for stable conditions are

-Use of vegetation layer

-Reduce turbulent mixing

For MM5 users we advice to use the BT scheme during stable stratification.

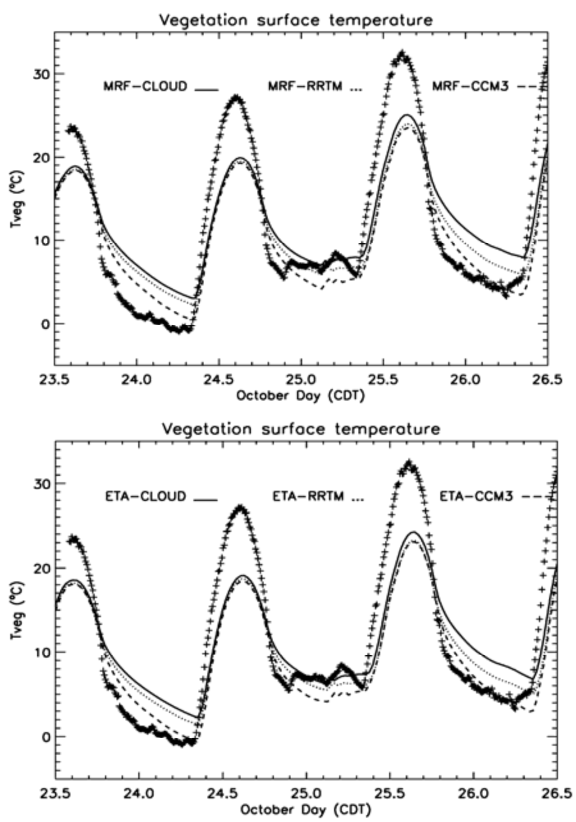

Figure 3: Model sensitivity of the predicted surface temperature to the choice of the radiation scheme in MM5, using two different turbulent mixing schemes (a) MRF, (b) ETA, + = obs.

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