THE INFLUENCE OF MODEL RESOLUTION ON AN EXPRESSION OF THE ATMOSPHERIC BOUNDARY LAYER IN A SINGLE-COLUMN MODEL

P3.1

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1. INTRODUCTION

Japan Meteorological Agency (JMA) has joined the second intercomparison project of the GEWEX Atmospheric Boundary Layer Study (GABLS). This intercomparison that had a purpose of understanding a representation of the diurnal cycle in atmospheric boundary layer (ABL) over land revealed the difference in expressions of the ABL between various numerical models. It was pointed out in the project that the different results between models may partly come from difference in their model resolutions (Svensson, 2005).

A Numerical model expresses natural phenomena like a flow of atmosphere using finite grid points, that is, its governing equations are transformed into finite difference expressions. Therefore model resolution (spatial resolution and time step length) may influence on an expression of the ABL. The resolutions of JMA operational global NWP model (GSM) is 55 km (horizontal), 40 layers (vertical) and 900sec (time step length). Due to the limited computer power, it is not easy to upgrade our model to higher resolution. In this study, we reveal the influence of vertical resolution and time step length on representation of ABL using the single-column model (SCM).

2. EXPERIMENTS

We research the influence of number of vertical layers and time steps on expression of a boundary layer and surface weather (temperature and wind speed) using the GABLS second intercomparison experimental case. Major features of the case are:

-Single-column version of JMA GSM is used.

-Surface skin temperature changes diurnally and is given as a boundary condition.

-Geostrophic wind blows constantly with time and height.

Turbulence scheme of SCM is Mellor and Yamada level 2.0, which is almost the same as the one used in JMA operational NWP model.

In this study, vertical layers of SCM is decided by the following equation,

$$Z_{n+1} = Z_n + r(Z_n - Z_{n-1}). \qquad (1)$$

Z_n means an altitude of n-th layer. Factor r in eq.(1) is selected using the three parameters (KMAX, Z_1, and Z_{KMAX}). The first parameter KMAX is the number of vertical layers, Z_1 is a thickness of lowest layer, and Z_{KMAX} is the height of the top layer. In present study, we set 2 m and 10 km to Z_1 and Z_{KMAX}, respectively, and investigate the impact by various KMAXs.

3. RESULTS

3.1 *Flux Richardson Number*

Figure 1 (a to c) shows vertical profiles of flux Richardson number (Rf) by vertical resolution. The height where Rf reaches a minimum value increases with the number of vertical layers in the daytime (Fig.1 b). For example, in the case where the number of vertical layers (KMAX) is 20, this height is about 40 m (6th model layer, 32-51m), and in the case where KMAX is 300, this height is about 70 m (27th model layer, 68-70m) at local time (LT) 10 (15UTC, 20 hours after starting time integration). The height where

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Rf reaches 0 also increases with the number of vertical layers. In other words, unstable layers expand upward with increase of the resolution. This influence is significant particularly when the atmospheric boundary layer grows up. The height of Rf=0 is about 100 m and 170 m in the case where KMAX are 20 and 300 at LT 10, respectively (Fig.1 b). The minimum values of flux Richardson number decreases with increase of KMAX at LT 10 (Fig.1 b). These features are not clearly in stable stratification at LT 07 (Fig.1 a).

Flux Richardson number also depends on time step length (Fig.2 a). Profiles of flux Richardson number with longer time steps shows similar characteristics to low vertical resolution.

3.2 *Heat Flux*

Profiles of heat fluxes are strongly influenced by the number of vertical layers. In figure 1(d), the negative heat flux tends to grow with increased KMAX in the early morning (LT 07). After 3 hours, the positive heat flux also tends to grow with the number of vertical layers at LT 10 (Fig.1 e). The height where heat flux reaches maximum (LT 10, 13) or minimum (LT 07) rises with the number of vertical layers (Fig.1 d to f). This feature is consistent with the resolution dependency seen in the flux Richardson number profiles.

3.3 *Momentum Flux*

The influence on momentum flux by the vertical resolution is similar to the one on heat flux in the daytime (Fig.1 h and i). The momentum flux near the surface with high resolution is about twice as large as the one with low resolution. Although the signs of momentum flux and heat flux are in the opposite, shapes of the profiles are similar to each other at LT 07 (Fig.1 d and g).

Momentum and heat flux expressions depend on also time step length (Fig.2 b and c). The profile with long time steps is closer to the one with low vertical resolution.

3.4 *Potential Temperature*

As a number of vertical layers decreases, the potential temperature below 400 m level increases at LT 07 (Fig.1 j). The difference in potential temperatures at 100 m level between low resolution (20 layers) and high resolution (300 layers) is more than 1.5 K at LT 07 (Fig.1 j). However, the difference between KMAXs is obscure in the vicinity of surface at LT 10 (Fig.1 k). In the daytime, as number of vertical layers decreases, the potential temperature below 400 m level also decreases at LT 13 (Fig.1 l). The difference in the profile of potential temperature is regarded as a result of different expressions of the vertical heat flux.

3.5 *Wind Speed*

Although the difference of wind speed between vertical resolutions is obscure at LT 07 (Fig.1 m), it is clear in the daytime (Fig.1 n and o). The difference of wind speed at 400 m level between low resolution (20 layers) and high resolution (300 layers) is more than 1.5 m/s at LT 13 (Fig.1 o). Wind speed with low resolution is always higher than the one with high resolution near the surface (Fig.1 m to o), and is closer to the geostrophic wind (about 9.5m/s in this study). The feature well corresponds with the characteristics of resolution dependency in momentum flux.

The dependency of time steps on wind speed and potential temperature is small compared with the Richardson number and vertical fluxes (Fig.2 d and e).

3.6 *Boundary Layer Height*

The boundary layer height (BLH) is defined as the height, where the value of momentum flux falls to 95% of its surface value, divided by 0.95. This definition is the same as the GABLS experiment. The BLH tends to increase with KMAX (Fig.3 a), especially in the night-time.

3.7 *Surface Wind Speed*

Wind speed at 10 m above ground (U10m) is estimated by Monin-Obukhov similarity theory with a surface roughness length of 0.03m. U10m is strongly influenced by the vertical resolution (Fig.3 b). U10m with 20 layers is about 30% higher than the one with 300 layers. The influence of vertical resolution on U10m is consistent with the result presented in section 3.5, that wind speed in the low level of the ABL tends to decrease with increased KMAX (Fig.1 n and o)

3.8 *Surface Air Temperature*

Temperature at 2 m above ground (T2m) is also estimated by the same manner as wind. The influence of vertical resolution on T2m is consistent with the result of the potential temperature (3.4). In the night, T2m with low resolution is higher than one with high resolution, and, on the other hands, the relationship goes into reverse in the daytime (Fig.3 c). In other words, the amplitude of the diurnal cycle of T2m with low resolution is smaller than the one with high resolution.

4. DISCCUSION

It is not easy to compare the ABL between observations and numerical models. Since a boundary layer grows above 1000 m level in the daytime over land, it is difficult to directly observe it up to such a height. The height of tower observations does not reach more than hundreds of meters. Therefore, in this study, we assume the profile with high resolution to be more correct.

We found the following features of influence by model resolution.

-The difference of flux Richardson number due to resolutions is emphasized when stratification is unstable ($Rf < 0$) (Fig.1 b and c).

-The absolute values of heat flux and momentum flux tend to increase with the resolution (Fig.1 d to i).

-The differences of boundary layer height in resolutions is emphasized in the night (Fig.3 a).

-The amplitude of the diurnal cycle of surface temperature with low resolution is smaller than the one with high resolution (Fig.3 c).

-The influence of time steps on flux Richardson number and flux is larger than the one on potential temperature and wind speed (Fig. 2).

In the case where the vertical resolution is low, Rf is large (Fig.1 b) or unstable layer is shallow (Fig.1 c). As a consequence, ABL stratification represented with low resolution is not unstable compared to the high resolution. Therefore heat and momentum flux are weak (Fig.1 d to i), and the diurnal cycle of surface temperature (Fig.3 c) and wind speed (Fig.1 m to o) also is small.

The vertical resolution of JMA operational GSM is 40 layers from surface to 0.4 hPa. JMA operational model is perhaps influenced by the vertical resolution, since its resolution is much lower than the resolution used in this study. The next operational model is planed to enhance to 60 layers from surface to 0.1 hPa in 2007.

5. CONCLUSION

We researched the influence by the vertical resolution (the number of the vertical layers) and time step length on potential temperature, wind speed, flux Richardson number, momentum flux, heat flux, surface wind, surface air temperature, and boundary layer height. All of the elements depended on vertical resolution. This influence was especially clear in lower resolution and longer time steps. The magnitude of the influence depends on the element and local time. JMA operational model is perhaps influenced by the vertical resolution. If it is not easy to improve the model resolution, we should tune up the representation of ABL to correspond with high resolution model.

6. REFERENCE

Svensson, G., 2005: Introduction second GABLS 1D Intercomparison case and set up, presentation in "GLASS and GABLS workshop on local land-atmosphere coupling".

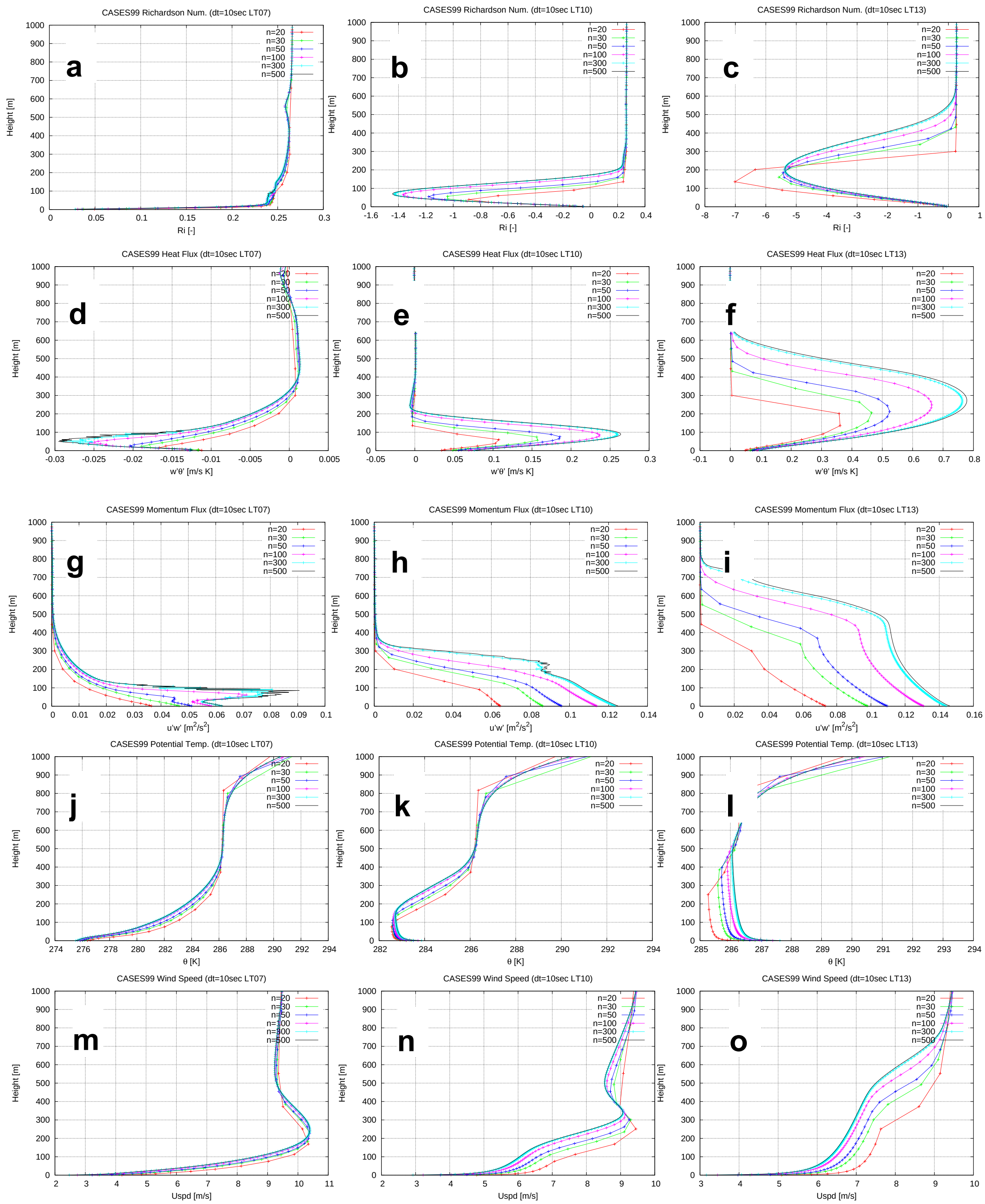

Figure 1. Expression of ABL by various vertical resolutions.

The red, green, blue, purple, sky blue, and gray lines indicate the expression by the model whose numbers of vertical layers are 20, 30, 50, 100, 300, and 500, respectively. Flux Richardson number, heat flux, momentum flux, potential temperature, and wind speed are given from top to bottom panels, respectively. Left, center, and right columns show snapshots at local time 07, 10, and 13, respectively.

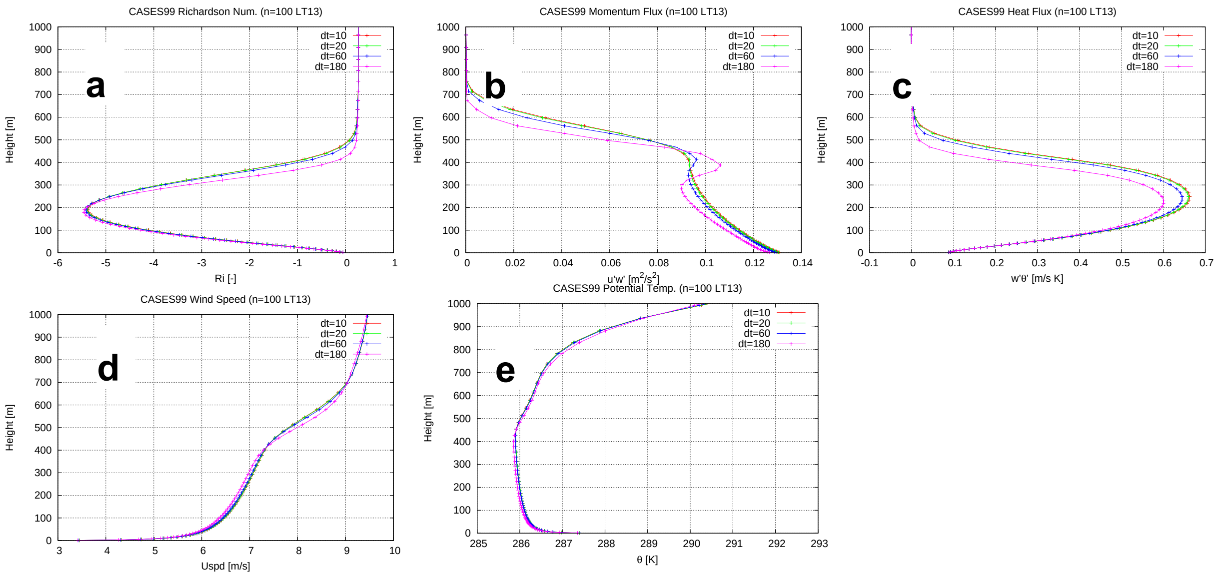

Figure 2. Expression of ABL by various time step length.

These panels show vertical profiles of (a) flux Richardson number, (b) momentum flux, (c) heat flux, (d) wind speed, and (e) potential temperature at local time 13. Red, green, blue, and purple lines indicate the time steps of 10sec, 20sec, 60sec, and 180sec, respectively.

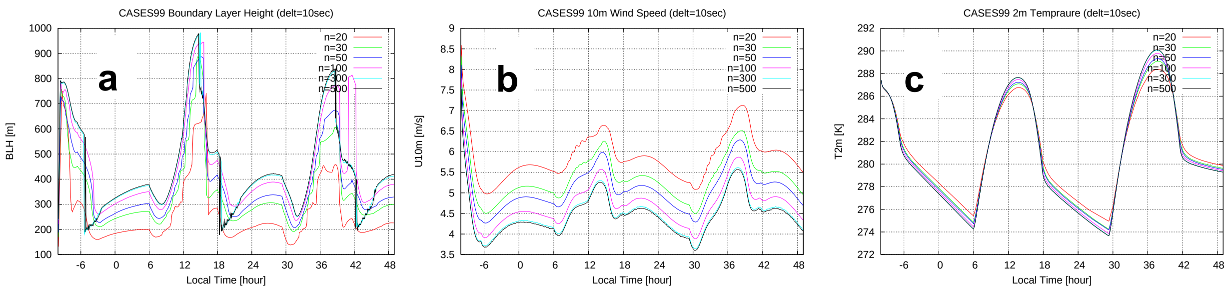

Figure 3. Time series of ABL by various vertical resolutions.

These panels show time series of (a) Boundary layer height, (b) wind speed at 10 m level, and (c) air temperature at 2 m level. The each color of line shows the same as figure 1.