Evaluation of planetary boundary layer schemes on weather research forecasting by using intensive observation at kototabang

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Abstract. This study examined Weather Research and Forecasting (WRF) simulation with different closure type of Planetary Boundary Layer (PBL) in six PBL schemes. This study aimed to evaluate the performance of PBL scheme in representing the vertical profile of the atmosphere over Kototabang. Intensive observation during boreal spring in 2002 using radiosonde and Automatic Weather Station (AWS) provided were used to verify the results of WRF. Our finding showed that most of PBL scheme successfully simulated diurnal variations of PBL, temperature and relative humidity. However, the bias in magnitude were found during the daytime. This study shows that ACM2, applying mixed local and non-local closure type, performed more realistic temperature and relative humidity profile with minimum bias compared to other schemes.

1. Introduction

The Planetary Boundary Layer (PBL) is a bottom layer region of troposphere near the earth’s surface. The PBL height varies from less than 100 meter up to several kilometers [1]. During the day, the PBL reaches its maximum height in response to heating of the surface by incoming solar radiation that generates unstable layers and the turbulences. These allow exchange and transport of energy, heat, momentum and moisture from lower boundary to upper atmosphere layers. At night, the surface cooling by outgoing longwave radiation creates less stable and shallow PBL height. The turbulences occurs in complex way that is too expensive and too small to be represented explicitly in Numerical Weather Prediction model [2]. This requires a method to represent these unresolved physical processes with resolved variables at grid scale [3]. This method is generally known as parameterization.

As the next generation NWP, Weather and Research Forecasting (WRF) [4] parameterized PBL processes either by local or non-local closure. These two closures differ in a way to estimate the unknown fluxes. Local closure estimates the unknown fluxes at relative grid using known values at the same point or the adjacent points in the vertical. Meanwhile, non-local closure estimates the unknown values by considering many points that are far away in the vertical [5, 6]. Previous studies have showed the evaluation of local and non-local PBL schemes [7] showed the characteristic of local and non-local PBL scheme in WRF simulation over United states. [8] argues that Mellor-Yamada Janjic (local closure) scheme outperforms other schemes for simulating variation of surface meteorological variables during active convective periods in Gadanki. In contrast, [9] showed that non-local closure represents the
surface variables better than local scheme in complex topography area near the sea. These previous findings indicate that there is no consensus of the best PBL closure for all environment conditions. In addition, evaluation of PBL schemes over Indonesia region were rarely discussed. Considering complex topography and active convection in Indonesia, evaluation of PBL scheme are very important study as part to improve prediction skill of WRF simulation.

Therefore, this study will evaluate six PBL schemes where most of the schemes were used in previous studies that consist of three local schemes, one non-local and two mixed schemes. In order to do evaluation, continuous observation of atmospheric vertical profile and surface meteorological observation were needed. The availability of intense radiosonde, which launched eight times in a day and continuous observation of surface variables during observation campaign at Kototabang gave opportunity to verify our WRF simulation results.

2. Methodology
In this study we implemented variation of six PBL schemes in WRF to evaluate their performances validated with surface and vertical observations at Kototabang. The schemes were Mellor-Yamada-Janjic (MYJ)[10], Mellor-Yamada-Nakanishi (MYNN)[11,12], and University of Washington (UW)[13] as local schemes; Yonsei University (YU)[14] as nonlocal scheme; Asymmetric Convective Model 2 (ACM2)[15] and Shin-Hong (SH)[16] as mixed of both local and nonlocal schemes. Other used schemes were shown in Table 1. Initial and boundary condition data for the model used was ERA-Interim with ~0.75° horizontal resolution. The vertical level used was 32. The number of horizontal grids were 121 x 100 grids with 18km horizontal resolution for the first domain and 103 x 88 grids with 6km horizontal resolution for the second domain (Figure 1). One-way interaction was employed in this WRF simulations. Only the output of the second domain were evaluated in this study.

| Options                               | Schemes                               |
|---------------------------------------|---------------------------------------|
| Cumulus                               | Kain Fritsch [17]                     |
| Microphysics                          | WSM-3 class [18]                      |
| Long-wave / Short-wave radiation      | RRTM/ Dhudia [19, 20]                 |
| Boundary layer                        | YU, MYJ, MYNN, ACM2, UW, SH           |

All six PBL schemes used in this study have different methods to calculate PBL height. Even when the simulation’s configurations are matched exactly, these different methods may cause different PBL height results [21]. Hence, the 1.5-theta-increase method [22] was used to calculate simulated and observed PBL height. The 1.5-theta-increase method is a method to find PBL heights as the level at where potential temperature value first exceeds minimum potential layer value in the boundary layer by 1.5 K.

The data used for validation of model’s scheme variation results were from radiosonde and Automatic Weather Station (AWS) with period of data was from 8 April 2002 (18Z) to 22 April 2002 (18Z). The period was chosen because radiosonde was launched eight times in a day (00Z, 03Z, 06Z, 09Z, 12Z, 18Z, 21Z). The AWS data was hourly data with parameters used were surface temperature, pressure and relative humidity. The AWS was located in Kototabang, West Sumatera which was the same location of radiosonde launch.
3. Results and Discussion

Diurnal variation of surface meteorological variable is displayed in Figure 2. AWS observation shows surface temperature and relative humidity peaks in 06 UTC (13 LT) and 09 UTC (16 LT) respectively. At this time, strong mixing occurs which forms highest PBL height during the day (Figure 3). When surface heating of incoming solar radiation reduced, surface temperature cools and relative humidity decreases. These conditions create more stable atmosphere and less turbulences PBL layers. Thus, PBL height decreases.

Figure 2. Diurnal average for (a) Surface Temperature and (b) Surface relative humidity.

In general, WRF successfully captures the diurnal variations of surface meteorological variables regardless of used schemes. Except, the values are either overestimated or underestimated. WRF
underestimates the peak of surface temperature around 06 UTC. ACM2 scheme (non-local closure) displays smaller bias compared to others. For relative humidity, MYJ and MYNN scheme display moist bias before 09 UTC which decreases earlier than the observation. The ACM2 displays the driest bias followed by UW scheme. After 09 UTC, most of the schemes simulate drier bias, except MYNN. Diurnal variation of PBL height (Figure 3) height is successfully simulated. ACM2 display higher PBL height comparable to the observation about ~1200 m height on 06 UTC, while SH and MYNN display lower PBL height about ~1000 m heights.

![Figure 3. Diurnal average of PBL height for observation and models.](image)

Figure 4 displays average of vertical profile of potential temperature from WRF and radiosonde observations. It is shown that the surface warms first followed by the warming the adjacent layers above as shown in 03 to 09 UTC. All schemes display warmer potential temperature below 1000 m height in 03 to 06 UTC. This clearly simulates cool bias in potential temperature below 2000 m height in 09 to 12 UTC. Apparently, models show smaller variation of potential temperature compared to observation in 03 to 12 UTC. Consistent with diurnal surface temperature variation (Figure 2a), potential temperature of ACM2 is the warmest.

![Figure 4. Average vertical potential temperature (K) for observation and models.](image)
Diurnal variation of vertical profile of relative humidity is shown in Figure 5 that shows consistency with variation of surface relative humidity (Figure 2b). The lower atmosphere contains less moisture around 06 UTC, which is less than 80% below 300m height. This could be related to increase of surface evaporation. Most of the schemes show large discrepancies compared to radiosonde profile in 00 to 09 UTC periods. In 00 UTC, they show relatively drier humidity below 1800m. In 03 to 09 UTC, they underestimate drying process below 1000 m height. These are confirmed both in surface (Figure 2b) and vertical profile observation (Figure 5). ACM2 shows smaller bias vertical profile of relative humidity while MYNN2 and MYJ show wetter bias during this period. These findings are consistent with surface humidity record. For the rest of the time, all schemes show comparable relative humidity profile to observation.

**Figure 5.** Average vertical relative humidity (%) for observation and models.

Warm and dry bias contribute to higher PBL as shown by ACM2 schemes. These findings support [23] and [24] where strong surface heating produce strong sensible heat flux, while less humid near surface air indicates low latent heat flux. This condition is favourable for greater buoyancy and subsequently creates strong PBL mixing. In contrast, MYNN3 and MYJ display cold and dry bias which in opposite produces less buoyant condition. As a result, the PBL height is lower. However, this study shows that YU scheme, as pure non-local closure scheme, displays quite similar result with local closure schemes. This is also displayed by SH scheme, although it applies mixed local and non-local closure similar to ACM2.

4. Conclusion
This study evaluated WRF output with different type of PBL closure: local and non-local closure and mixed closure. This study was carried out by the use of intensive observation campaign that was held at Kototabang as references. Our result shows that all PBL schemes display similar bias in simulating the near surface temperature and relative humidity during the day. Of the used PBL schemes, the ACM2 seems better simulate the diurnal variations of PBL height. This is confirmed by less bias in both in surface and vertical profile of potential temperature and relative humidity. This study also supports
previous finding by [7] where the scheme that displays warmer (cooler) and drier (wetter) in near surface layers tend to produces higher (lower) PBL height. This study also shows that the scheme with less bias is not related to the choice of PBL closure type, either local, non-local or mixed. Combination of PBL scheme with other parameterization e.g. cumulus, land surface scheme, could give different effect in PBL layers which become an interesting study in the future.

5. Reference
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