WRF Sensitivity to Simulate EMP in the Diurnal Cycle of Precipitation over the North Coast of West Java

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Abstract. The Early Morning Precipitation (EMP) over coastal region is an uncommon pattern in the diurnal cycle due to land-sea breeze regular mechanism. This phase shift of diurnal cycle could hinder a numerical weather prediction to capture precipitation. This study aims to investigate sensitivity of WRF model on simulating EMP over north coast of West Java. Some cases (26 January 2006, 4 February 2008) representing heavy precipitation have been simulated in capturing EMP over the north coast of West Java to examine model sensitivity on convection scheme and domain size. The results showed the Betts–Miller–Janjić (BMJ) scheme could simulate EMP quite well on phase, whereas the Kain-Fritsch (KF) scheme capture out of phase on diurnal cycle. For model sensitivity on domain size, the larger domain displayed more realistically in phase to simulate EMP. For synoptic condition during heavy precipitation, it appeared that Cross Equatorial Northerly Surge (CENS) which is enhanced by South China Sea-Cold Tongue (SCS-CT) played main role to develop EMP.

1. Introduction

Most of the precipitation over the land occur over the coastal region (34%). In the tropics, 29% precipitation occurs over the landside coast, while 71% evolves over the offshore region [1]. Documentation of the characteristics of diurnal precipitation over the seaside and landside of the coast has previously been explained by [2] which showed that propagation pattern clearly identified over the coastal region in the Maritime Continent. Over offshore region, diurnal precipitation has landward propagation in the morning from 0900-1200 LT. Furthermore, the maximum precipitation rapidly expands and propagates landward at 1500 LT. On the seaside, diurnal precipitation propagates seaward from 0000 LT to 0600 LT over the ocean.

EMP, hereinafter referred to as EMP, is climatologically significant (~19%) exhibited over the coastal area of northern West Java [3]. The maximum precipitation that occurs in the early morning over the north coast of West Java evolves due to propagation both of seaward and landward, which has a
relationship with the background conditions, namely the phenomenon of the Cross-equatorial Northerly Surge (CENS) and South China Sea Cold Tongue (SCS CT) [3]. In this case, SCS CT becomes a background condition, while CENS plays a major role in generating the EMP. This is in accordance with the previous finding [4] which states that the direction of propagation over the coast is determined and influenced by background winds.

On the other hand, numerical weather prediction still fails to simulate diurnal cycle of precipitation in the Maritime Continent [5, 6], especially in terms of phase and speed of propagation. This is likely due to the inability of the model to capture EMP over the coast. On the other hand, research on EMP over the coastal region are still very limited because in general diurnal cycle of precipitation is considered by regular circulation in time in accordance with the thermal heating process which contrasts between the land and the sea. This study aims to evaluate the sensitivity of WRF model on convection schemes and domain sizes in simulating EMP over the north coast of West Java.

2. Data and Method
In the current research, we used the Tropical Rainfall Measuring Mission (TRMM) Real-Time Multi-satellite Precipitation Analyses (TMPA-RT), the so-called TMPA-RT dataset with a spatial resolution of 0.25° × 0.25° at an hourly time interval for comparing the model output to satellite data observation. A series of preparations to test model sensitivity were conducted to running the first simulation scenario, which was to simulate EMP regarding selected case studies of EMP samples. We then used Weather Research and Forecasting (WRF) version 3.9.1.1 with model input data derived from NCEP-FNL data which has a spatial resolution of 111 km and a time resolution of 6 hours. The FNL data consisted of three periods of EMP morning for case study of heavy rainfall namely: 26 January and 4 February 2008. We were then using the input data for running model in two different convection schemes, namely: Kain-Fritsch (KF) as a default scheme of WRF model and the Betts–Miller–Janjić (BMJ) [7]. The KF cumulus parameterization has been widely studied and comparable to simulate tropical cyclones in India [8], the storm generated by topography complex in the Rocky Mountains, United States [9], and heavy rainfall that triggering floods in India [10], although the results showed underestimates compare to observation data. Explanation in detail for KF scheme is described below in Table 1.

For BMJ scheme (Table 2), we followed [7] which is described as follow. The cumulus parameterization scheme used BMJ [11] while microphysics was chosen as a five-class double moment [12]. For short and long wave radiation, the Rapid Radiative Transfer Model for Global models (RRTMG) was chosen as the scheme [13], the Planetary Boundary Layer was changed to Yonsei University [14] with Monin-Obukhov on the surface layer [15] and Four-Layer Noah LS for the schematic at ground level, but after an error was obtained, PBL still uses the standard scheme in the WRF model that has been used previously. All selection of the combination of these schemes are explained in Table 2 below.

To test domain size sensitivity, we designed two types of domains, namely A and B domain. The larger domain (B domain) is designed considering that the CENS and SCS CT signals must be caught by the simulation results. The difference between the A and B domains is shown in Figure 1. The A and B domains one has a spatial resolution of 27, 9, and 3 km, from outer to inner domain, respectively. For domain 3, no cumulus parameterization is performed because it had a spatial resolution of 3 km. Based on previous research [16], cumulus parameterization cannot be used in models with grid sizes less than 4 km because the results of rain and cloud simulations obtained are not realistic. For microphysics parameters, the scheme of Lin et al. used on all three domains. PBL parameterization used the Mellor-Yamada-Janjić scheme in all three domains, while other parameters use a scheme that has become the default model. The use of a combination of these three types of parameterization was chosen because it was a combination with the results closest to satellite data or observations for weather conditions with disturbances on the meso scale such as storms [9].

Furthermore, in domain A, a simulation was conducted for a case study of heavy rainfall in Jakarta for the period of January 26, 2006 using the KF and BMJ convection schemes based on previous research
that claimed to successfully simulating monthly rainfall on the Maritime Continent [7]. On February 4, 2008 a simulation was carried out using the KF and BMJ schemes with different domains A and B.

![Figure 1](image_url)

**Figure 1.** Scale conducted for simulating: (a) A domain; (b) B domain. Horizontal grid resolution: 27, 9, and 3 km.

| Parameterization          | Domain 1  | Domain 2  | Domain 3   |
|---------------------------|-----------|-----------|------------|
| Cumulus                   | Kain-Fritsch | Kain-Fritsch | -          |
| Microphysics              | Lin et al. | Lin et al. | Lin et al. |
| Planetary Boundary Layer (PBL) | Mellar-Yamada-Janjic | Mellar-Yamada-Janjic | Mellar-Yamada-Janjic |

**Table 1.** Model configuration for cumulus Kain-Fritsch scheme (1, 2, 3 domain resolution)
Table 2. Model configuration for BMJ scheme (1, 2, 3 domain resolution) following Fonseca et al. (2017)

| Parameterization       | Domain 1     | Domain 2     | Domain 3     |
|------------------------|--------------|--------------|--------------|
| Cumulus                | Kain-Fritsch | Kain-Fritsch | -            |
| Microphysics           | Lin et al.   | Lin et al.   | Lin et al.   |
| PBL                    | Mellor-Yamada-Janjic | Mellor-Yamada-Janjic | Mellor-Yamada-Janjic |
| Shortwave Radiation    | RRTMG        | RRTMG        | RRTMG        |
| Longwave Radiation     | RRTMG        | RRTMG        | RRTMG        |
| Surface Layer          | Monin-Obukhov| Monin-Obukhov| Monin-Obukhov|
| Land Surface           | Four-layer Noah LS | Four-layer Noah LS | Four-layer Noah LS |

3. Results and Discussion

Figure 2 shows that KF and BMJ schemes with A domain could capture timing of EMP (EMP) over coastal area. However, KF scheme (Figure 21b) seem more overestimated than BMJ scheme in capturing late afternoon phase of diurnal cycle of precipitation, compared to TMPA-RT result (Figure 1a). Moreover, KF scheme shows seaward propagation and strong link between land and ocean convective system that probably could produce EMP (Figure 2b). For this case, BMJ and KF were running in the same domain (A domain, the smaller one). However, the satellite observation shows more a stationary convection system over coastal region (Figure 2a). According to the previous finding, a stationary convection system shows interaction process between land-sea breeze and background condition which triggering rainfall concentrate over land as well as offshore region [5].

Whereas in Figure 3, we simulated EMP in both of KF and BMJ schemes with different domain, namely A and B domain (the larger one), respectively. Modification of the domain from A to B has to be done regarding previous research about relationship between EMP and synoptic background due to Cross-Equatorial Northerly Surge (CENS) and South China Sea-Cold Tongue (SCS CT) [3]. In this case, B domain was modified with consideration to include areas where CENS and SCS CT exhibited. Figure 3 shows that BMJ scheme with B domain (Figure 2c) could capture EMP with the similar timing regarding satellite observation. Whereas Figure 2b appears 2-4 hours earlier in timing for capturing the EMP. On the other hand, the BMJ scheme result seems more consistent in capturing stationary precipitation system over coastal region. However, both of KF and BMJ schemes also show propagation signal from ocean to coastal. These strong propagation signals of EMP in appropriate with the EMP characteristics which show the strong connectivity between the land and oceanic convection system [3].

The use of sections to divide the text of the paper is optional and left as a decision for the author. Where the author wishes to divide the paper into sections the formatting shown in Table 2 should be used.
Figure 2. Hovmöller diagram of Time-Latitude cross section of diurnal cycle of precipitation in 26 January 2006: a) TMPA-RT satellite data; b) WRF with KF scheme; c) WRF with BMJ scheme. The rectangular of black dashed line represents the coastal region. The elliptical of black solid line shows the timing of EMP. The elliptical of dashed line shows maximum precipitation occurred during the late afternoon.

The stationary pattern could be captured by BMJ scheme, despite narrower in precipitation region system compared to TRMM satellite result. Through these two case studies, it emerges that the WRF model simulation using the BMJ convection scheme shows better results in capturing EMP over coastal area in timings and is more realistic in representing stationary of precipitation convergence systems which is trapped over coastal areas. This might be related to the differences between the two schemes in simulating a process on a synoptic scale that represents the background conditions as show in Figure 4.

Figure 3. Same as Figure 2, but for 4 February 2008

In synoptic scale as a background condition (Figure 4), regarding to the input data, it shows that strong CENS and SCS CT exhibit over South China Sea influence strong advection of surface wind and cold SST triggering convergence over the coastal area. Similar with the condition, CENS and SCS CT also occurred in 4 February 2008, but for weaker intensity and penetration (Figure 5).

Furthermore, Figure 5 also shows that CENS on 4 February 2008 does not appear to be connected with cold surge from Northern Hemisphere. However, for areas from 15°N to the equator, there appears that CENS unconnected and reinforced so that the CENS can propagate cross the equator (Figure 5a). The disconnection mentioned causes less of strong support from cold SST in the area around equator, because SCS CT has a weak intensity (Figure 5b).

Moreover, to compare how the convection schemes and domain sizes influence physical processes in the atmosphere, we analysed Hovmöller diagram of vertical-Latitude cross sections that shows in Figure 6 dan 7. Figure 6(a-d) show that in KF scheme, convective activity more intensify over offshore than coastal area. Consequently, KF scheme seems underestimated capture the EMP over the coastal
area. On the other hand, BMJ scheme is better for capturing the EMP over the coastal region (Figure 6(e-g)) and shows that synoptic background of northerly surge converges with the land breeze and triggering convective activity over coastal area (Figure 6(g-h)). Similarly, Figure 6 exhibits that BMJ scheme (Figure 7(e-h)) more thoroughly convective activity over the coastal, than KF scheme (Figure 7(a-d)). Furthermore, B domain shows clearer and stronger in capturing vertical convective processes, than A domain.

**Figure 4.** Spatial patterns of 26 January 2006 for: a) Wind vector at 925 mb which is overlaid with meridional wind component (red color shaded); b) SST and SST anomaly relative to the SCS CT threshold (26.5°C)

**Figure 5.** Same as Figure 4, but for 4 February 2008
Figure 6. Height-Latitude cross section of meridional-vertical of vector wind (m/s), equivalent of potential temperature (K) (red colour of values), total column-integrated water vapor and cloud (g/kg) (yellow to red colour) in 0000-0300 LT of 26 January 2006 for: (a-d) KF scheme with A domain; (e-h) BMJ scheme. The rectangular of black dashed line represents the coastal region. The elliptical of black solid line shows the vertical motion which represent convection activity over landside as well as seaside of coastal region.

Figure 7. Same as Figure 6, but for 4 February 2008
4. Conclusion
For timing of precipitation, the BMJ scheme could simulate EMP quite well on phase whereas KF scheme capture out of phase on diurnal cycle of precipitation. For intensity of precipitation, the KF tends to overestimate in capturing maximum intensity of EMP whereas BMJ could reduce more overestimate of maximum precipitation over coastal region. For domain size sensitivity, the B domain has more realistic in phase to simulate EMP than the A domain. The two real cases of heavy rainfall showed that the CENS influences more significantly to develop EMP over coastal region and the SCS-CT provides a suitable background condition for enhancing the CENS to extend over the Java Island.

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5. References
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