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Heavy Rainfall Events on Southwest Monsoon over Thailand Simulation by WRF Single Moment Microphysics Scheme

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Abstract

This study used the Weather Research and Forecasting (WRF) model to simulate heavy rainfall over Thailand during the Southwest monsoon period (rainy season), which start from mid of May to mid of October. Sensitivity test was conducted to examine performance of six different single moment microphysics scheme for the rainfall simulation. The simulations were compared with the Tropical Rainfall Measure Mission (TRMM) grid data and the observed data from the metrological stations over Thailand operated by the Thai Metrology Department (TMD). The spatial patterns of rainfall given by the simulations of the six different microphysics scheme present good estimation of rainfall over the Northern Thailand, the

Northeastern Thailand, and the lower part of Southern Thailand. In summary, the SBU-YLin scheme shows a better performance of rainfall simulation over Thailand than the other schemes.

Keywords: Single moment microphysics scheme, Southwest monsoon, Tropical-Rainfall Measure Mission, Thai Metrology Department, Weather Research and Forecasting model

1. Background/ Objectives and Goals

Heavy rainfall is one of severe weather phenomena, and can be the causes of flash flood over the region. Good estimation of rainfall amount by the model is necessary for providing early warning before the occurring of flash flood events. This is useful to avoid or minimize disasters (Afandi, E. A., *et al.* 2013). There are studies focusing on microphysics such as (Lin, Y. L., *et al.* 1983). They study on cloud particles and precipitation drops of a bulk microphysics scheme. (Hong, S. Y., *et al.* 2004) implemented the revised ice-microphysics in the Weather Research and Forecasting (WRF) model. Their schemes are the WRF single moment schemes. Microphysics scheme influence on improvement in high-cloud amount, surface rainfall, and large-scale mean temperature. Thus, a microphysics scheme is main factor of surface rainfall variation.

The WRF model is a famous dynamical atmospheric model, which has many microphysics scheme including the single moment microphysics scheme. They were predicted only the particle mixing ratios or specific humidity. The microphysics scheme represents processes in the micro-scale of cloud. The parameters involving cloud and precipitation processes are water vapor, cloud water, cloud ice, snow, rain, graupel, and hail. The processes of microphysics scheme are condensation, accretions evaporation, ice and snow aggregation, vapor deposition, melting, and freezing (Warner, T. T. 2011). In general, microphysics scheme use for modeling when the grid size is less than 10 km (Skamarock, W. C., *et al.* 2008). Hence, microphysics scheme are important for the small scale rainfall simulation. There are many researches using the WRF model, and focusing on rainfall simulation for Thailand. But, their studies do not emphasize on microphysics scheme examination related to changing of rainfall over Thailand.

This work aims to use the WRF model version 3.4 to simulate heavy rainfall over Thailand with six different single moment microphysics scheme on 10th September 2011, because there was maximum amount of rainfall. The simulation day is in the period of the rainy season that caused by the southwest monsoon that prevails over Thailand. The result of simulation was compared with rainfall amount from the Tropical Rainfall Measure Mission (TRMM) and from the Thai Meteorological Department (TMD). These will provide information for improvement of rainfall simulation over Thailand.

2. Methods

2.1 Model Configuration

The WRF model is a numerical weather prediction and atmosphere simulation system model developed by the National Center for Atmospheric Research (NCAR). It is capable of creating simulation using real time data or idealized atmospheric simulations. The model contains with a terrain following sigma coordinate is used in the vertical coordinate, Arakawa C-grid staggering for horizontal grid, initial conditions, boundary condition, multiple-nested domain, mapping to sphere, and full set of physical parameterization options. The dynamics solver integrates the compressible, non-hydrostatic, Euler equations. The equations are cast in flux form using variables that have conservation properties, the momentum equations (1)-(3), the mass conservation equation (4), geopotential equation (5), the conservation equations for the potential temperature (6), scalars (7), and equation of state (8) written as:

$$\frac{\partial U}{\partial t}+m\left[\frac{\partial(Uu)}{\partial x}+\frac{\partial(Vu)}{\partial y}\right]+\frac{\partial(\Omega u)}{\partial\eta}+\mu_d\alpha\frac{\partial p}{\partial x}+\left(\frac{\alpha}{\alpha_d}\right)\frac{\partial p}{\partial\eta}\frac{\partial\phi}{\partial x}=F_U, \tag{1}$$

$$\frac{\partial V}{\partial t}+m\left[\frac{\partial(Uv)}{\partial x}+\frac{\partial(Vv)}{\partial y}\right]+\frac{\partial(\Omega v)}{\partial\eta}+\mu_d\alpha\frac{\partial p}{\partial x}+\left(\frac{\alpha}{\alpha_d}\right)\frac{\partial p}{\partial\eta}\frac{\partial\phi}{\partial y}=F_V, \tag{2}$$

$$\frac{\partial W}{\partial t}+m\left[\frac{\partial(Uw)}{\partial x}+\frac{\partial(Vw)}{\partial y}\right]+\frac{\partial(\Omega w)}{\partial\eta}-\frac{g}{m}\left[\left(\frac{\alpha}{\alpha_d}\right)\frac{\partial p}{\partial\eta}-\mu_d\right]=F_W, \tag{3}$$

$$\frac{\partial\Theta}{\partial t}+m^2\left[\frac{\partial(U\theta)}{\partial x}+\frac{\partial(V\theta)}{\partial y}\right]+m\frac{\partial(\Omega w)}{\partial\eta}=F_\Theta, \tag{4}$$

$$\frac{\partial Q_m}{\partial t}+m^2\left[\frac{\partial(Q_m)}{\partial x}+\frac{\partial(Q_m)}{\partial y}\right]+m\frac{\partial(\Omega Q_m)}{\partial\eta}=F_{Q_m}, \tag{5}$$

$$\frac{\partial\mu_d}{\partial t}+m^2\left[\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}\right]+m\frac{\partial\Omega}{\partial\eta}=0, \tag{6}$$

$$\frac{\partial\phi}{\partial t}+\frac{1}{\mu_d}\left[m^2\left[U\frac{\partial\phi}{\partial x}+V\frac{\partial\phi}{\partial y}\right]+m\Omega\frac{\partial\phi}{\partial\eta}-mgW\right]=0, \tag{7}$$

$$p=p_0\left(\frac{R_d\theta}{p_0\alpha}\right)^{\gamma}, \tag{8}$$

where $U = \mu U / m$, is coupled horizontal component of velocity in x-direction, $V = \mu V / m$, is is coupled horizontal component of velocity in y-direction, $W = \mu W / m$, is is coupled vertical component of velocity, $\Omega = \mu_d \dot{\eta} / m$, is couple coordinate velocity, $\Theta = \mu_d \theta / m$ is couple pontential temperature, $\omega = \dot{\eta}$ is the contravariant 'vertical' velocity. Also appearing in the governing equations of the ARW are the non-conserved variables $\phi = gz$ is the geopotential, p is pressure, θ is the potential temperature, m is map scale factor, $\gamma = c_p / c_v = 1.4$ is the ratio of the heat capacities for dry air, R_d is the gas constant for dry air, and p_0 is a reference pressure (typically 10^5Pascals), $\alpha = (1/\rho)$ is the inverse density, $\alpha_d = (1/\rho_d)$ is the inverse density of the dry air and the right-hand-side (RHS) terms F_U, F_V, F_W, F_Θ and F_{Q_m} are represent forcing terms arising from model physics, turbulent mixing, spherical projections, and the earth's rotation respectively. The WRF equations are formulated using a terrain-following hydrostatic-pressure vertical coordinate denote by η and defined by $\eta = (p_h - p_{ht}) / \mu$, while $\mu = p_{hs} - p_{ht}$ is the mass per unit area with the column in the model domain, p_h is the hydrostatic pressure, p_{ht} is the hydrostatic pressure at the top of the model, p_{hs} is the hydrostatic pressure at the model surface.

2.2 Domain Configuration

The WRF model is a numerical weather prediction and atmosphere simulation modeling system developed by the National Center for Atmospheric Research (NCAR). The horizontal resolution of three domain for this study are 36 km (Domain 1), 12 km (Domain 2), and 4 km (Domain 3) as shown in Fig. 1. The finest domain completely covers Thailand with consideration of the boundary condition influence given by corresponding larger domain. The vertical resolution is 27 vertical levels ~~that~~ are 1000 millibar (mb), 975 mb, 950 mb, 925 mb, 900 mb, 850 mb, 800 mb, 750 mb, 700 mb, 650 mb, 600 mb, 550 mb, 500 mb, 450 mb, 400 mb, 350 mb, 300 mb, 250 mb, 200 mb, 150 mb, 100 mb, 70 mb, 50 mb, 30 mb, 20 mb, 10 mb, and 0 mb. The two-way nesting was used for this simulation. The initial and boundary conditions used the 1.0×1.0 degree gridded NCEP FNL (Final) Operational Global Analysis (Vaid, B. H., 2013).

The corresponding mixing ratio (Q_x), where $x = v, c, i, s, g,$ and h (v is water vapour, c is cloud water, r is rain, i is cloud ice, s is snow, g is graupel and h is hail). The simulations were performed with six distinct combinations of physical schemes as shown in Table 1.

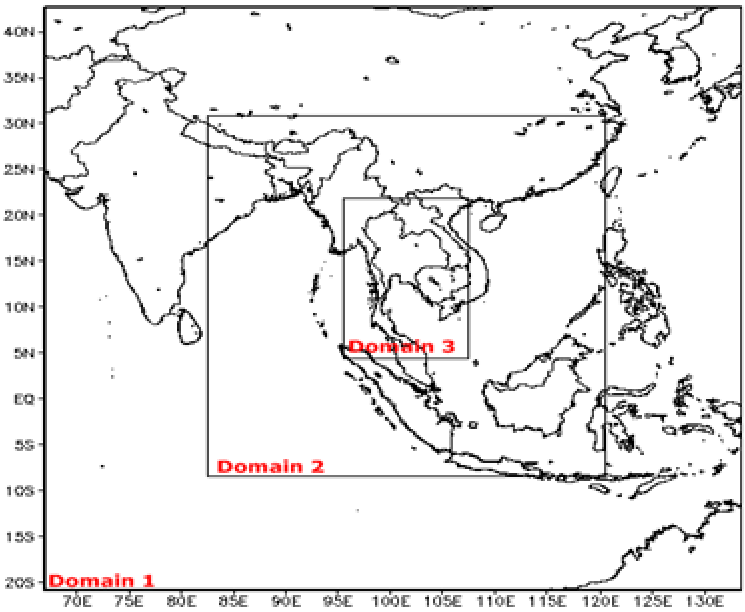


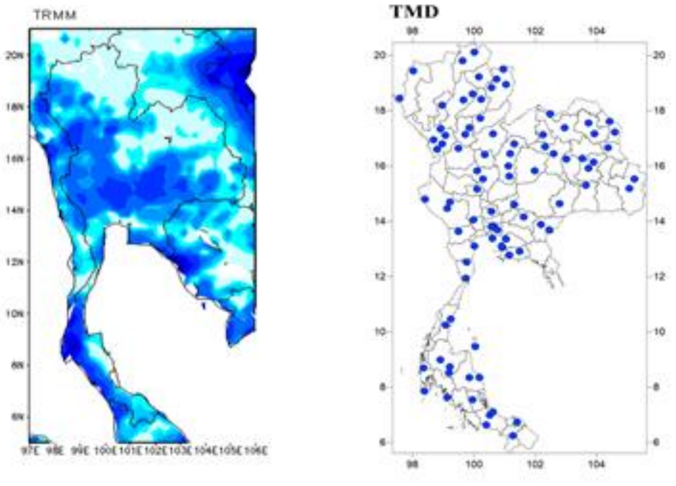
Fig. 1: WRF model three nested domain in this study

Table 1. The simulations were performed with six distinct combinations of physical schemes

Combination	Microphysics scheme	Other Physics Schemes
1. (Q_v, Q_c, Q_r)	Kessler scheme (Kessler, E., 1969)	Cumulus scheme: Betts – Miller – Janjic scheme (Janjic, Z. I., *et al.* 1994) only Domain 1 and Domain 2, Long wave radiation scheme: Rapid Radiative Transfer Model scheme (Mlawer, Eli. J., *et al.* 1997), Short wave radiation scheme: The Duhia scheme (Dudhia, Y. L., *et al.* 1989), Planetary boundary layer scheme: the Yonsei University planetary boundary layer schemes (Hong, S. Y., *et al.* 2006b)
2. $(Q_v, Q_c, Q_r, Q_i, Q_s, Q_g)$	Purdue Lin scheme (Lin, Y. L., *et al.* 1983)	
3. (Q_v, Q_c, Q_r)	WSM3-class scheme (Hong, S. Y., *et al.* 2004)	
4. $(Q_v, Q_c, Q_r, Q_i, Q_s)$	WSM5-class scheme (Hong, S. Y., *et al.* 2004)	
5. $(Q_v, Q_c, Q_r, Q_i, Q_s, Q_g)$	WSM6-class scheme (Hong, S. Y., *et al.* 2006a)	
6. $(Q_v, Q_c, Q_r, Q_i, Q_s)$	SBU-YLin 5-class scheme (Lin, Y. L., *et al.* 2011)	

2.3 Grid and Station Observations Data

The TRMM (3B42, V7) daily rainfall data provide by a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA). The data have $0.25^\circ \times 0.25^\circ$ resolution, with time scale covering the period of the 10th September 2011. The TRMM data often used for comparison with the WRF-ARW model output (Raktham, C., *et al.* 2015, Vaid, B. H., 2013, Kumar, O.S.R.U. B., *et al.* 2012, Deb, S. K., *et al.* 2008). Therefore, we will use it for comparison. The comparison considers the value in terms of area average. The spatial distribution of interesting area covers Thailand and neighbor (Fig. 2 (a)). Another data set is the station data provided by the Thai Metrology Department (TMD). In this research, 90 stations of TMD were used because their station data are completely and location of stations is shown in Fig. 2 (b).



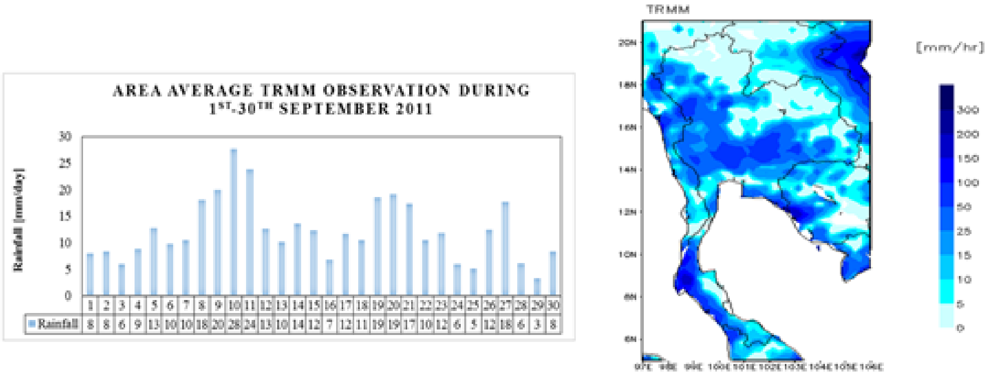
(a) **(b)**

Fig. 2: (a) The spatial rainfall (TRMM data) over Thailand, and (b) the locations of complete data from TMD stations.

2.4 Selection of Simulation Date

To select the simulation date of heavy rainfall, the TRMM data was calculated to see the maximum area average of accumulate rainfall. Among the values from the year 2000 to 2012, the highest maximum area average of accumulate rainfall value is about 2,288 mm/year in 2011 and the peak presents on September 2011 (367 mm/month)

The daily rainfall on September 2011 presenting in Fig. 3 show that the heavy rainfall (highest value) is on 10th September 2011 and has the maximum area average value is 28 mm/day. The spatial rainfall pattern of TRMM data on 10th September 2011 is shown in Fig. 3 (b).



(a) (b)

Fig. 3: Area average accumulate rainfall value of TRMM observation data (a) during 1st to 30th September 2011 first row of is a date and second row is a rainfall [mm/day] in each day (b) the rainfall pattern of TRMM observation data in 10th September 2011

For simulation, the simulation on 9th September 2011was considered as spin-up, and the simulation on 10th September 2011 was used for analysis.

3. Results

3.1 Comparison between Model Results and Gridded Observation Data (TRMM)

The different spatial patterns of model result to the TRMM as shown in Fig. 4. The model results were produced by six different simulations of microphysics scheme. There are Kessler scheme, Purdue Lin scheme, WSM3 scheme, WSM5 scheme, WSM6 scheme, and SBU-Y Lin scheme. The pattern of the Kessler scheme (Fig. 4 (a)) shown wide spatial distribution of rainfall over Northern, Northeastern, and lower Southern Thailand. However, the magnitude of rainfall was overestimate by about 10-30 mm over central Thailand. The regions that have difference of rainfall amount more than 30 mm, are Southern Myanmar, Eastern coast and Southern of Cambodian, and upper Southern Thailand. On the other hand, the magnitude of rainfall was underestimate by less than -30 mm along Eastern Laos including some part Vietnam, Western, Southern West Coast, Western and lower Northern Thailand.

For Purdue Lin scheme (Fig. 4b), WSM3 scheme (Fig. 4c), WSM5 scheme (Fig. 4d), WSM6 scheme (Fig. 4e), and SBU-YLin scheme (Fig. 4f), they were show spatial distribution that have the overestimate value 10-30 mm as same as Kessler scheme. However, the spatial distribution for overestimate value more than 30 mm of their schemes are wider than the spatial pattern given by the Kessler scheme. The differences of wider areas are Eastern Coast, Western, and some part Southern East Coast Thailand, and Northern Malaysia.

But, SBY-LIN scheme (Fig. 4f) give smaller bias over Western Thailand than another five schemes. However the magnitude of Purdue Lin (Fig. 4b), WSM3 scheme (Fig. 4c), WSM5 scheme (Fig. 4d), WSM6 scheme (Fig. 4e), and SBU-YLin scheme (Fig. 4f) were underestimate by less than -30 mm than Kessler scheme.

From those results, simulations using all of different microphysics scheme are acceptable over Northern, Northeastern, and lower Southern Thailand. But, the results show more variability over Southern Myanmar, Eastern Laos include some part Vietnam, Eastern coast and Southern in Cambodian, along Western, Southern West Coast, Western and lower Northern Thailand.

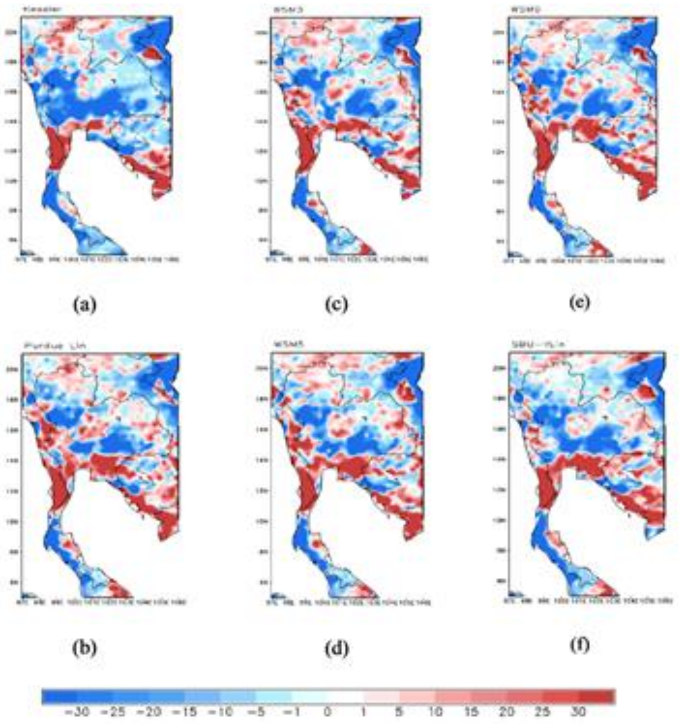


Fig. 4: The different spatial patterns rainfall (mm) between the simulated from WRF model and the TRMM using (a) Kessler scheme, (b) Purdue Lin scheme, (c) WSM3 scheme, (d) WSM5 scheme, (e) WSM6 scheme, and (f) SBU-YLIN on 10th September 2011

3.2 Comparison between Results from WRF Model and TMD Station Observation Data

The different spatial patterns of model result to the TRMM as shown in Fig. 5. The model results were produced by different simulations of microphysics scheme. There are Kessler scheme, Purdue Lin scheme, WSM3 scheme, WSM5 scheme, WSM6 scheme, and SBU-YLin scheme. The pattern of the Kessler scheme (Fig. 5a) shown wide spatial distribution of rainfall over Northern, Northeastern, and lower Southern Thailand. However, the magnitude of rainfall was overestimate by about 12-30 mm over central Thailand. Region that have difference of rainfall amount more than 30 mm, is upper Southern Thailand. On the other hand, the magnitude of rainfall was underestimate by less than -30 mm along Western, Southern West Coast, Western and lower Northern Thailand.

For Purdue Lin scheme (Fig. 5b), WSM3 scheme (Fig. 5c), WSM5 scheme (Fig. 5d), WSM6 scheme (Fig. 5e), and SBU-YLin scheme (Fig. 5f), they show spatial distribution that have the overestimate value 12-30 mm as same as Kessler scheme. However, the spatial distribution for overestimate value more than 30 mm of their schemes are wider than the spatial pattern given by the Kessler scheme. The differences of wider areas are Eastern Coast, Western, and some part Southern East Coast Thailand.

But, SBU-YLIN scheme (Fig. 5f) gave smaller bias over Western Thailand than that of five schemes. However the magnitude of the Purdue Lin scheme (Fig. 5b), WSM3 scheme (Fig. 5c), WSM5 scheme (Fig. 5d), WSM6 scheme (Fig. 5e), and SBU-YLin scheme (Fig. 5f) were underestimate by less than -30 mm as Kessler scheme.

From those results, simulations using all of different microphysics scheme are acceptable over Northern, Northeastern, and lower Southern Thailand. But, the results show more variability over Western, Southern West Coast, Western and lower Northern Thailand

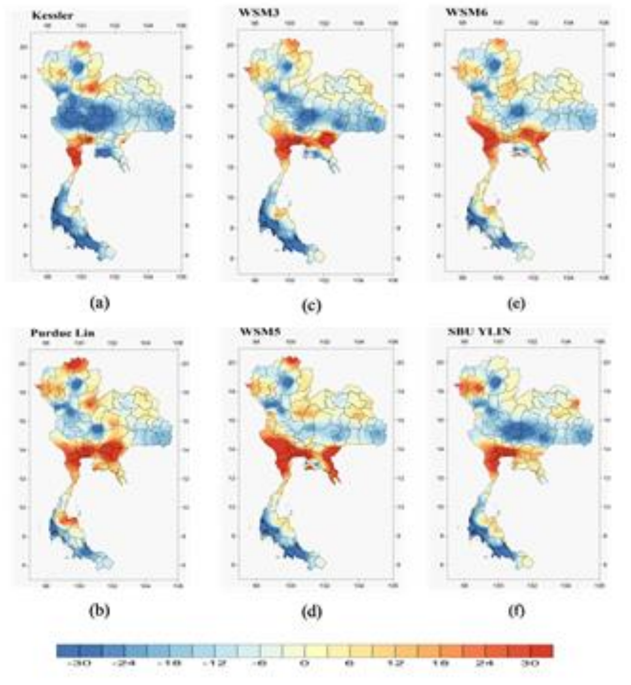


Fig. 5: The different spatial patterns rainfall (mm) between the simulated from WRF model and the TMD using (a) Kessler scheme, (b) Purdue Lin scheme, (c) WSM3 scheme, (d) WSM5 scheme, (e) WSM6 scheme, and (f) SBU-YLIN on 10th September 2011

3.3 Statistical Comparison between Results from WRF Model and Station Observation Data

The Mean Absolute Error (MAE) was used for comparison. Fig. 6 show MAE values for all microphysics scheme on 10th September 2011. The comparison with TRMM data revels that the MAE of Kessler scheme, Purdue Lin scheme, WSM3 scheme, WSM5 scheme, WSM6 scheme, and SBU-YLIN scheme are 28.31, 26.08, 25.10, 25.84, 24.82, and 24.46, respectively. The SBU-YLIN scheme performs better than other schemes on simulation of heavy rainfall event.

For comparison with the station data, the MAE of Kessler scheme, Purdue Lin scheme, WSM3 scheme, WSM5 scheme, WSM6 scheme, and SBU-YLIN scheme are 18.12, 16.54, 17.09, 19.86, 16.40, and 16.07, respectively. The SBU-YLIN scheme performs better than other schemes on simulation of heavy rainfall event.

Therefore, SBU-YLIN scheme is the appropriate scheme to simulate heavy rainfall events during Southwest Monsoon (rainy season) over Thailand due to both comparison with grid observation data and station data.

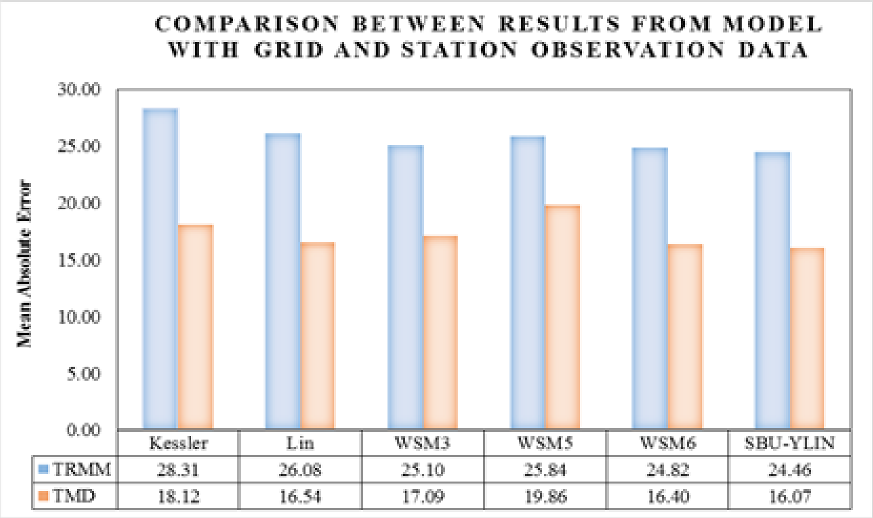


Fig. 6: Mean Absolute Error of simulation with different microphysics scheme to the TRMM data and TMD data on 10th September

4. Conclusion

This research investigates the WRF model simulations with six different single microphysics scheme for simulation rainfall over Thailand. The results imply that the application of Numerical Weather Prediction (NWP) for simulating heavy rainfall over Thailand should account for microphysics scheme to get better simulation of heavy rainfall in high resolution. The spatial patterns of simulated rainfall using six different single microphysics scheme show good performance over Northern, Northeastern, and lower Southern Thailand for both comparisons with TRMM and TMD data. The statistical comparison method, which is Mean Absolute Error shows that the SBU-YLin scheme presents the best of rainfall simulation over Thailand during rainy season. Therefore, SBU-YLin scheme was suggest to the best microphysics for rainfall simulation over Thailand in terms of spatial distribution and quantitative simulation.

4.1 Acknowledgments and Legal Responsibility

Authors acknowledge the NCEP for FNL data sets, NASA&JAXA for TRMM observation data set, TMD for station data set, and NCAR for WRF model. This research was partially supported by the International Research Network (IRN) (IRN5701PDW0002), Thailand Research Fund (TRF), National Research Council of Thailand (NRCT) (2557-66).

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