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Research paper

Statistical Verification of Numerical Weather Prediction (NWP) for Rainfall Estimation in the East Coast Region

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Abstract

Intense hydrological event such as floods are increasing lately especially in Peninsular Malaysia. Therefore, it is important to forecast the intense rainfall as part of flood preparedness and mitigation measures. In this study, Numerical Weather Prediction (NWP) model precipitation outputs using Weather Research and Forecasting (WRF) with horizontal resolution of 3 km have been validated against observed rainfall data measurements for its performance measurement. Forecasted rainfall event data of three (3) states in the East Coast Region; Kelantan, Terengganu and Pahang were evaluated and compared with the observed rainfall data before statistically verifying their accuracy using False Alarm Ratio (FAR) and Probability of Detection (POD). The results indicate a very promising potential of the models in producing quantitative precipitation forecast (QPF) for flood forecasting purpose in Kelantan, Terengganu and Pahang. Since these three states, which are located in the East Coast region of Peninsular Malaysia experienced annual flood event, accurate forecast rainfall data can be used to improve forecast information for flood indicator.

Keywords: *Numerical Weather Prediction (NWP); Peninsular Malaysia; Quantitative precipitation forecast (QPF); Rainfall; WRF Model.*

1. Introduction

Numerical Weather Prediction (NWP) is the most recent weather prediction technique that is available worldwide. The advanced technology in computing techniques and data assimilation has increased the use of NWP models as a tool for flood forecasting. Numerical weather models such as WRF estimate the state of the near-future atmosphere by solving atmosphere dynamic and thermodynamic equations, based on initial conditions. [1]. The WRF model is one of the most advanced mesoscale NWP model, designed in collaborative partnership, principally among the National Centre for Atmospheric Research (NCAR) and the National Oceanic and Atmospheric Administration. WRF is suitable for research and operational forecasting. [2].

Many studies had indicated the ability of WRF to provide a better forecast. [3, 4, 5, 6, 7]. There are many forecasts outputs from the WRF model such as rainfall, humidity, wind speed and a range of other derived variables, which may be useful for flood forecasting. These sequences can be used as input to rainfall- runoff model for flood prediction and could also be used in integrated system like WRF-Hydro. [8, 9].

Rainfall prediction using NWP models like Fifth Generation Mesoscale Model (MM5) or Weather Research and Forecast model (WRF) had been introduced in Malaysia by Malaysian Meteorological Department (MMD). MMD used NWP namely Weather Research and Forecasting (WRF) model to estimate the weather forecasting throughout the country. The working mechanism of WRF used by MMD can be referred to Fig. 1. Initial data in a specified format is provided into the model as an External Data sources. These data are formatted by OBSGRID and WPS system as a pre-processing system. Generated results from WPS system are then provided into the model processing system. Finally, analyzed model outputs are represented by different post-processing tools which are provided with the model installation.

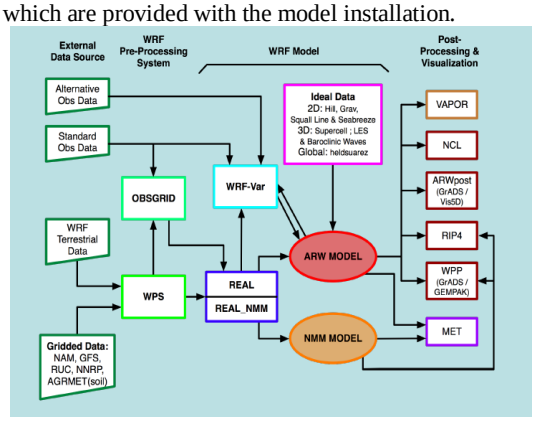


Fig.1: Weather Research and Forecasting model system overview [10]

Reliable forecast of intense rainfall episodes is extremely challenging and can play significant role in flood warning and disaster management. The accuracy of the model is extremely important in rainfall forecasting estimation in order to reduce the flood risk and other physical characteristics of flood. [11]. Previous study conducted by [12] using statistical verification method in comparing the forecast rainfall data of two NWP model namely Fifth Generation Penn State/NCAR Mesoscale (MM5) and WRF with the observed rainfall data in Kelantan indicates that the models able to perform for low and moderate rainfall but it is not the case for heavy rainfall. However, the case study only focuses in Kelantan

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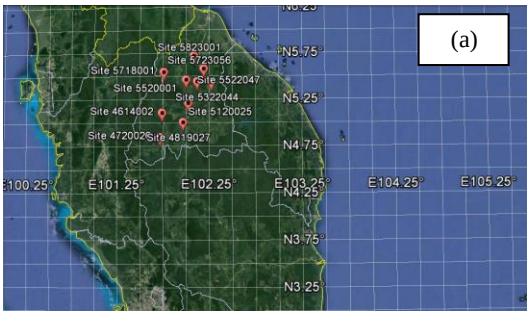
River Basin and the accuracy of performance are not being compared within the other states around Kelantan region.
The objectives of this study are to assess the performance measurement of rainfall forecasting from WRF model by comparison analysis with observed rainfall; to determine the performance measurement of rainfall forecast data from Numerical Weather Prediction (NWP) WRF model using POD and FAR and compare the performance of WRF model between three states in the East Coast region of Peninsular Malaysia. Accurate forecast rainfall data then can be used to improve forecast information for flood indicator.

2. Method

Three (3) states (as shown in Fig.2) in the East Coast region of Peninsular Malaysia are selected as the study area. The rainfall forecasting data using NWP WRF model are determined from the MMD while the observed rainfall data are obtained from the Department of Irrigation and Drainage (DID). Ten rainfall stations from each state in the East Coast region; Kelantan (10), Terengganu (10) and Pahang (10) are selected based on the stations that have complete rainfall data during August 2016. The latitude and longitude for each selected rainfall stations in Kelantan, Terengganu and Pahang are then being determined in order to complete the analysis for forecast rainfall data and observed data. Selected rain gauge stations are shown in Table 1 to Table 3.
Firstly, the rainfall forecast data produced from WRF model are compared with the observed data by using comparison analysis. By comparison analysis, the patterns and trends of the both data can be determined and evaluated. The accumulated rainfall data from UTC 12 at 10th August 2016 until 15th August 2016 which are equivalent to 120 hours or 5 days are obtained. After the comparison analysis, the accuracy of forecast and observed rainfall data are statistically verified by using Probability of Detection (POD) and False Alarm Ratio (FAR). The mean hourly forecast and observed rainfall data for each state are calculated and then the statistical verification analysis is being done. The perfect score for POD is 1 while the perfect score for FAR is 0. These statistical verification data are then being used to compare the performance of WRF model between three (3) states in the East Coast region of Peninsular Malaysia to determine which state gives the best performance accuracy between forecast and observed rainfall data. Fig. 3 illustrate the work stages adopted in this study.

Table 1: Location of selected raingauge stations in Kelantan

Station	Latitude	Longitude
4614002 Lojing	4.60000	101.4000
4720026 LadangMentara	4.45200	102.0100
4819027 GuaMusang	4.87917	101.9694
5120025 Balai Polis Bertam	5.08450	102.0255
5322044 Kg Lalok	5.30830	102.2750
5520001 UluSekor	5.33500	102.0030
5522047 JPS Kuala Krai	5.31550	102.1210
5718001 Kg Gemang Bahru	5.45400	101.5200
5723056 Telusan	5.45300	102.1920
5823001 Ibu Bkln Tiga Daerah	5.51500	102.2040





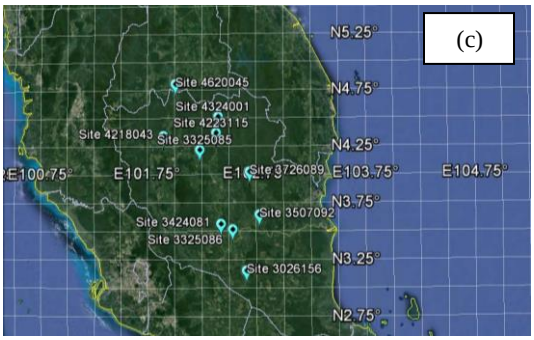


Fig.2: Map of Malaysia showing the East Coast region which are a) Kelantan b) Terengganu and c) Pahang (Source: Google Maps, 2017)

Table 2: Location of selected raingauge stations in Terengganu

Station	Latitude	Longitude
4232002 Jambatan Air Puteh	4.16150	103.11550
4434093 Sek Keb Temasek	4.25400	103.2705
4734079 Sek Men Sultan Omar	4.45450	103.2510
4834001 K. Bidan Kuala Abang	4.49400	103.2500
4931061 Ldg Koko Jerangau	4.58400	103.0930
5029036 Rmh Pam Paya Kemat	5.00300	102.5810
5128001 Sg Gawi	5.08350	102.5040
5230041 S.K Kuala Telemong	5.12100	103.0155
5328043 Kg Bukit Berangan	5.19000	102.5020
5428001 Kg Batu Hampar	5.26500	102.4855

Table 3: Location of selected raingauge stations in Pahang

Station	Latitude	Longitude
3726089 JKR Jempol	3.72778	102.6444
3325086 Kg Kuala Bera	3.39028	102.5333
3325085 Kg Batu Che Mek	3.32778	102.5069
3424081 JPS Temerloh	3.43889	102.4264
3026156 Pos Iskandar	3.02778	102.6583
4223115 Kg Merting	4.24306	102.3833
4324001 Kuala Tahan	4.38611	102.4028
4218043 Paya Tepuai	4.21667	101.9000
4620045 Paya Laloh	4.67778	102.0083
3527092 Lubok Paku	3.51944	102.7778

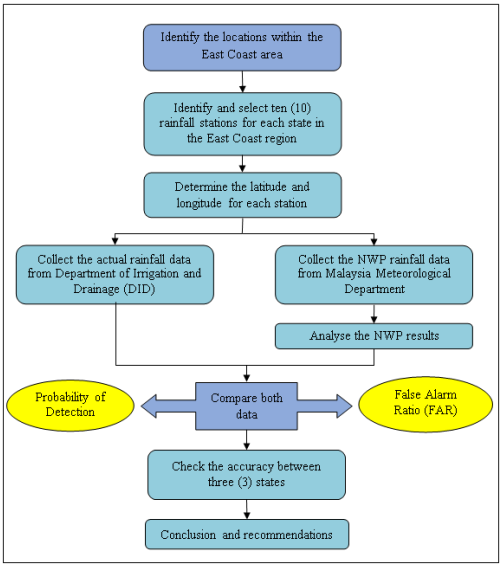


Fig.3: Research methodology be adopted for this study

3. Results And Discussion

The hourly forecast rainfall data starting from UTC 12 on 10th August 2016 until 15th August 2016 have been obtained from the Malaysia Meteorological Department (MMD). Total forecast and observed rainfall data from each station in Kelantan, Terengganu and Pahang are shown in Fig. 4. Fig. 5(a) shows the mean hourly rainfall events in Kelantan for 120-hours durations for overall 10 stations. Though the forecast model shows an overestimate forecasting events for example during 69th hour (4.75 mm/h) mean hourly rainfall, the forecast and observed rainfall data indicate similar pattern. From 10th August to 15th August 2016, Kelantan experienced highest mean hourly rainfall events during 21st hour (3.5 mm/h) and then it fluctuates until 71st hour before having non-rainfall events until hour 120.

The rainfall pattern between forecast and observed data in Terengganu also shows encouraging result as shown in Fig. 5(b). The WRF model able to obtain the pattern even though it did not able to forecast correctly. For example, the highest mean hourly rainfall event occurs at 49th hour (6.75 mm/h) but the model forecast zero rainfall occurrence and this is vice versa to the non-event occurrence during 2nd to 15th hour. Fig. 5(c) shows the mean hourly rainfall events in Pahang. There are two times where the heavy rainfall is less than 3 mm/h occurs which during the 1st hour and 27th hour. Both time gives almost the same rainfall event, which is around 2.5 mm/h. As a result, for the Pahang state, the WRF model did not correctly forecast the rainfall event and pattern during these two hours. The forecast model was not satisfactorily performing during heavy rainfall event for Pahang state.

Two statistical verification method are used which are POD and FAR to compare the performance of WRF model between three states in the East Coast region of Peninsular Malaysia. The POD and FAR results analysis for each state in the East Coast region are shown in Fig. 6. For POD analysis in Kelantan, the ratio is about 0.4545 while 0.2188 for FAR analysis which is almost 0. In Terengganu, the POD value indicates higher event that are correctly forecasted with ratio of 0.5870. Meanwhile, the FAR analysis in Pahang shows highest ratio which is 0.6800 that indicates high probability of false detection. The performance of WRF model in Kelantan is the most satisfying compared to Terengganu and Pahang. Kelantan shows the most significant ratio for both value of POD and FAR. However, none of the three states give the good score for both statistical verification analyses.

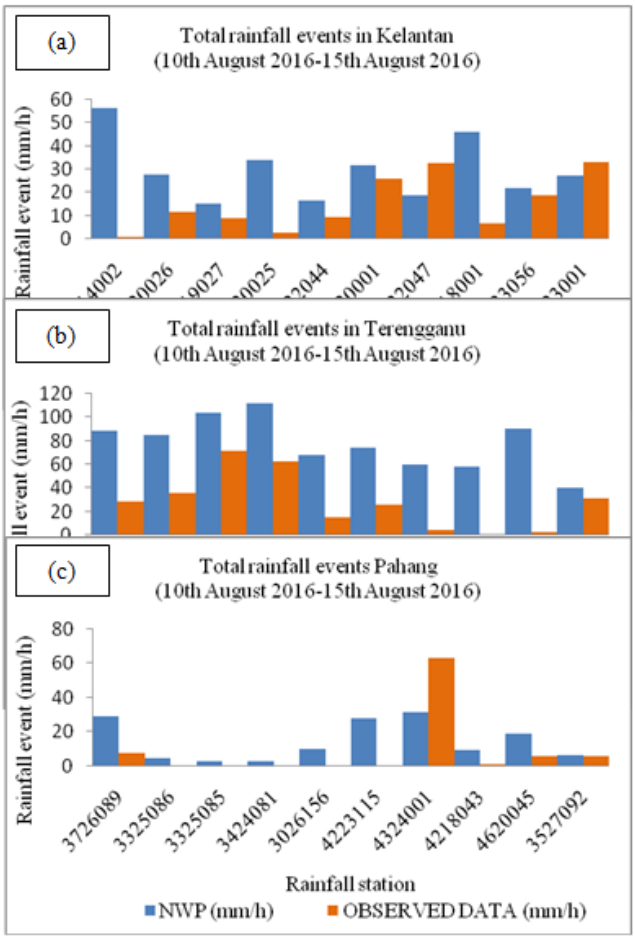
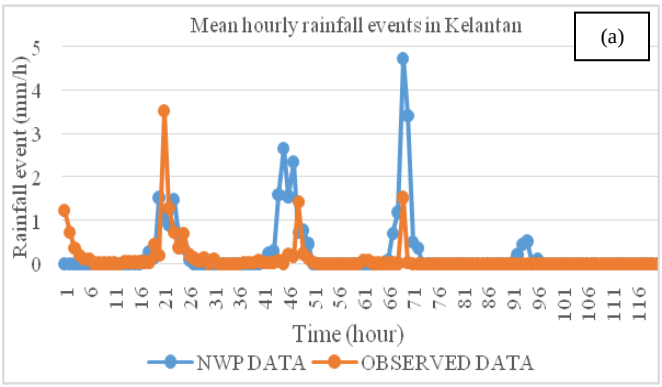
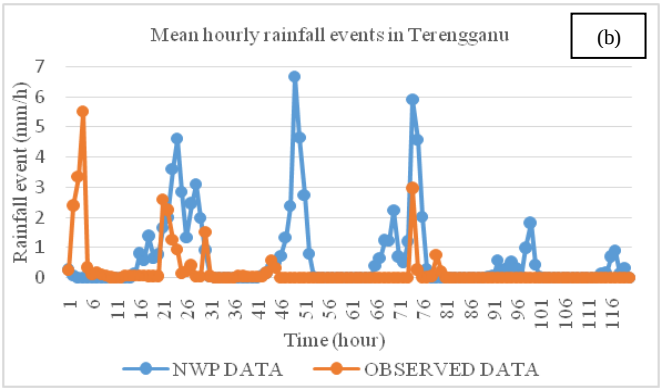


Fig. 4: Total rainfall events in (a) Kelantan (b) Terengganu and (c) Pahang for five days





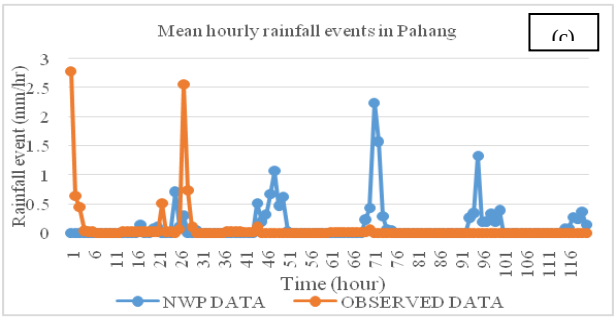


Fig. 5: Mean hourly rainfall events in (a) Kelantan (b) Terengganu and (c) Pahang

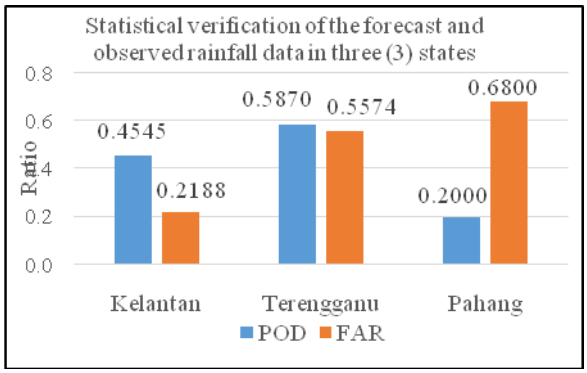


Fig. 6: Comparison of POD and FAR for Kelantan, Terengganu and Pahang

4. Conclusion

The mean hourly of each state for both forecast and observed data are evaluated before statistical verification process are being done. Kelantan shows the best pattern of forecast and observed rainfall data compared to the other state. The POD and FAR analysis of mean hourly rainfall data for each state are used to verify the rainfall accuracy between forecast and observed data. The statistical verification analysis also indicate that Kelantan has the best ratio compared to Terengganu and Pahang. Though the WRF model have performed quite satisfactorily in certain cases during heavy rainfall, the result for POD and FAR are less encouraging since none of the three states give good score. Hence it is recommended to use more data by increasing the period of time for more significant result for the future work. In addition, there are also improved WRF model products produced by the MMD that can be used in the future. The WRF model analysis indicate a very promising potential in producing QPF for flood forecasting purposes. These forecast sequences can be used as input to rainfall-runoff hydrological model as an alternative to the available rain-gauge system.

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