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Use of NWP Model Products and Metsat Images Data for Quantitative Precipitation Forecast

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Abstract: Quantitative Precipitation Forecast (QPF) from Numerical Weather Prediction (NWP) model products combined with geostationary meteorological satellite (metsat) data as input to a flood forecasting system has great potential to provide improved lead time for warning. In this study, a QPF Model is developed using the artificial multilayer neural network with data inputs from selected NWP model products combined with the metsat image features such as cloud top brightness temperature and albedo to forecast precipitation for a flood-prone area in a tropical region. The model was used to forecast intense rainfall episodes in Kelantan and Klang River Basins of Peninsular Malaysia. The results indicate that the model can satisfactorily produce 1h forecast with improved accuracy for larger forecast area. Performance of the model is better for Klang River Basin with r^2 of 0.89 as compared to Kelantan River Basin with r^2 of 0.67.

Key words: Numerical Weather Prediction (NWP), Quantitative Precipitation Forecast (QPF), geostationary Meteorological Satellite (METSAT), model products, tropical region

INTRODUCTION

The unusual heavy rainfall episodes at Kelantan River Basin end of 2014 had caused massive destruction and several deaths. The unprecedented storm events at the North-Eastern Peninsular Malaysia and many other places intensify the need for more accurate storm forecasting to improve disaster preparedness among the civilian. In the recent years, there have been increasing efforts to improve the rainfall forecast ability and accuracy. One of the most potential tools is the high resolution non-hydrostatic mesoscale model of Numerical Weather Prediction Models (NWP). The dynamical meteorology model of NWP provides the equations that represent the development processes of the atmosphere. NWP Model uses numerical approximations to predict the future states of the atmospheric circulation from the knowledge of its present state.

The initial boundary value inputs describe the current state of the atmosphere which represents many different characteristics of the atmosphere such as: humidity, temperature, wind velocity, pressure and other aspects of the region for forecast. Several modeling systems have been implemented as global, hemispheric or Limited Area Models (LAMs). LAMs run with a higher resolution over a smaller area and take boundary conditions from a larger hemispheric or global model.

During the last decades, several regional LAMs have been developed such as the MM4 and later the MM5 (Grell *et al*., 1994) and the new WRF Model. Today, NWP has become the most widely used weather prediction system and can predict future states for up to 10 days. However, though the model can produce qualitatively good prediction, it is still unable to produce spatially and temporally accurate quantitative forecast of intense rainfall especially on a smaller scale. Previous study on Kelantan River Basin had shown that NWP can produce quite satisfactory intense rainfall pattern but the accuracy is still very low (Wardah *et al*., 2011a, b). The current work is an effort to improve the QPF accuracy by integrating selected NWP model products with other additional information such as Infrared (IR) and Visible (VIS) data from the geostationary meteorological satellite images.

Metsat images for precipitation estimation: All visible and infrared precipitation-estimation schemes are necessarily indirect; a cloud's brightness or equivalent blackbody temperature may be related to the rain falling from it but the raindrops themselves are not directly sensed. Averaging reduces noise, hence satellite precipitation estimates averaged over large areas or long time periods will compare better with 'truth' than will estimates for smaller areas or shorter times (Kidder and Haar, 1995).

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Even though satellite based rainfall estimation techniques are well established, until present researchers consider that their abilities to generate products at high spatial and temporal resolutions are limited (Barrett and Martin, 1981). Continuous, high temporal resolution, satellite data is only available from sensors mounted on geostationary platforms, thus limits the available wavelengths to those in the infrared and visible parts of the electromagnetic spectrum. The geostationary weather satellites are positioned above the equator at 5-6 positions around the globe to provide complete coverage. Both geostationary weather satellite infrared and visible imagers provide the swift temporal update cycle needed to capture the growth and decay of precipitating clouds (Levizzani *et al*., 1990). Although, satellite IR algorithms benefit from high temporal sampling, IR radiances from cloud tops have only an indirect relationship with surface rainfall, resulting in weak statistical relationships between cloudiness and precipitation. The most commonly employed techniques count cloudy pixels colder than a given threshold temperature. It is assumed that such pixels are associated with probably precipitating cumulonimbus clouds possessing cold, high tops. High level cirrus and other non-precipitating cloud forms interfere with this simple relationship. Previous work on Malaysian case study indicated that the satellite based rainfall estimation has good potential to be further developed as QPF for flood forecasting at Klang River Basin (Wardah *et al*., 2008, 2012).

Case study: Peninsular Malaysia is situated in the tropics between 1° and 7° North of the equator and at eastern longitude from 100-103°E. The climate of Peninsular Malaysia is characterized by uniform temperature between 21-32°C and very much influenced by the monsoons. The South West Monsoon (SWM) occurs from May to August while the North East Monsoon (NEM) occurs from November to February. The period of the SWM is a drier period for the whole country while during the NEM, the eastern areas of Peninsular Malaysia receive heavier rains than the other parts of the country. Heavy rainfalls are also expected during the two inter-monsoons: March to April and September to October. The study will focus on two major river basins in Peninsular Malaysia, namely Kelantan and Klang River Basin. Figure 1 shows the location of the two river basins.

Kelantan River system flows northward passing through such major towns as Pasir Mas and Kota Bharu, before finally discharging into the South China Sea. The basin receives annual rainfall of about 2700 mm during the northeast monsoon between October and January. Klang River Basin is located at the south-western part of Peninsular Malaysia and one of the busiest areas in Malaysia. The area receives annual mean rainfall around 1900-2600 mm. Klang River system passes through the capital city of Malaysia, Kuala Lumpur and flowing Southward to the Straits of Malacca.

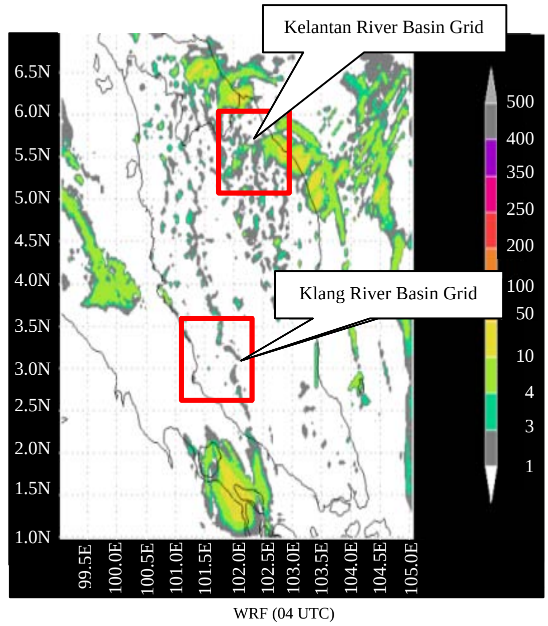

Fig. 1: Location of Kelantan and Klang River Basin on WRF output display (dated 21st November, 2009) covering Peninsular Malaysia

MATERIALS AND METHODS

The research methodology involved the data acquisition from NWP model and image features from the geostationary meteorological satellite (metsat). The model was developed using the Artificial Neural Network (ANN) technique. Hourly rainfall data for year 2009 have been acquired from the Drainage and Irrigation Department (DID) of Malaysia for 18 gauging stations in Kelantan and Klang River Basin. MTSAT/FY-2C hourly meteorological satellite images have been acquired from the Space Science and Engineering Center (SSEC), Wisconsin, USA. The SSEC received these images from the Japanese National Space Development Agency and China Meteorological Department. The images used for this study are the hourly FY-2C IR image (channel 10.8 μm) and MTSAT VIS image (channel 0.73 μm) with a spatial resolution of about 4-1 km. In the VIS image, the gray scale is represented white for high reflectance and black for low reflectance. In the IR image, it is represented black for high temperature and white for low temperature same as the gray scales in ordinary use. Brighter or colder clouds in infrared images are more likely to precipitate than darker or warmer clouds since colder clouds have higher tops. Bright clouds in visible images are more likely to precipitate than dark cloud since the cloud thickness is related to its brightness. Tall and thick clouds signify the cumulonimbus raining cloud.

The metsat data processing is aided by McIDAS (Man computer Interactive Data Access System). The McIDAS is a suite of sophisticated software packages that perform a wide variety of functions with satellite imagery, observational reports, numerical forecasts and other geophysical data. Those functions include displaying, analyzing, interpreting, acquiring and managing the data. Figure 2 shows an example of infrared image and visible image to be processed using McIDAS.

Data from MM5 and ARW-WRF NWP models which consisted of atmospheric variables were obtained from the Malaysian Meteorological Department (MMD). Data output from the NWP model such as accumulated precipitable water was in units of millimeter of water and average relative humidity was in percentage. The selected output of the NWP products were from 00UTC and 12UTC for year 2009 with forecast range of hourly, 3, 6, 12 and 24 hourly up to a period of 72 h. These NWP model output cover area lat 0.98-6.99 N, lon 99.04-105.098 E at resolution of 4 km and the area consists of 168×168 grid points. This high resolution data in temporal and spatial domains provide good opportunity to study the rainfall characteristics especially in the humid tropics. Figure 3 shows the display of 24 h accumulated rain.

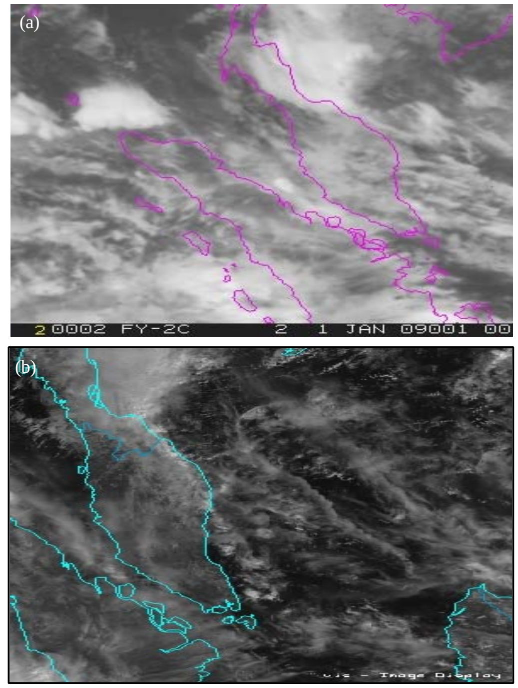

Fig. 2: a) FY-2C infrared image and b) MTSAT visible image

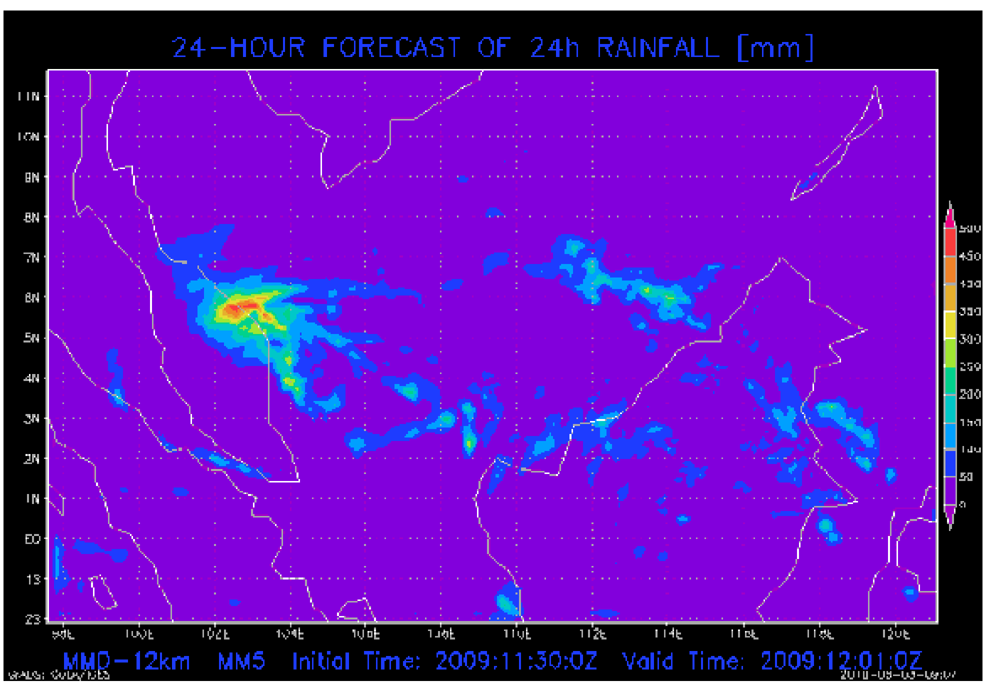

Fig. 3: Sample of 24 h accumulated rainfall data

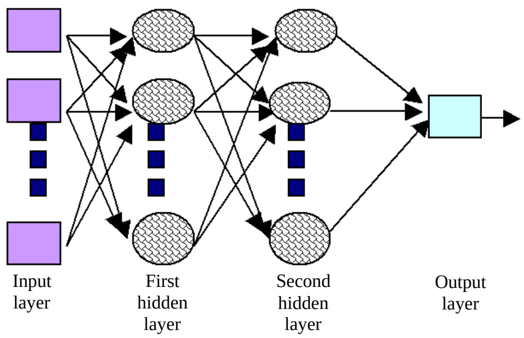

Fig. 4: Multi-layer ANN Model of QPF

Model development: The study used a multilayer neural network as shown in Fig. 4 as the model architecture combining three inputs from NWP model products (MM5 forecast rain, WRF forecast rain, relative humidity) and two parameters from the metsat images (cloud top brightness temperature and albedo) to forecast rain of one hour ahead. There are input layer, hidden layer and output layer. Each layer consists of one or more neurons. There are two types of neuron. First are passive neurons that relay data input as data output. Another is active neuron that computes data input using Activation Transfer Function (ATF) and produces an output. The most commonly use of ATF in the hidden and output neuron is sigmoid function. The input into an active neuron is a summation of previous neuron's output and its weight and the output is a computation of sigmoid function on the input. The 1779 data sets for Kelantan River Basin and 918 for Klang River Basin have been divided into training and testing sets to come up with the optimum architecture.

RESULTS AND DISCUSSION

Cloud top brightness temperature and albedo values from the metsat images over the Kelantan and Klang River Basins are plotted against the areal average rainfall events. Example correlation can be observed from Fig. 5a and b. The graphs show that the albedo increases and the temperature decreases with increase in rainfall depth.

Figure 6 shows correlation of cloud top brightness temperature with albedo for selected rainy and non-rainy days for both catchments. Both figures indicate that rainfall occur at low temperature, around 250 K and below. The graphs also show that the rainfall has positive correlation with the albedo values. The observation is supported by the work carried by Lovejoy and Austin in 1979 on using SMS/GOES visible and infrared data to determine whether it was raining (Grell *et al*., 1994). Figure 7a and b indicate good correlation for areal

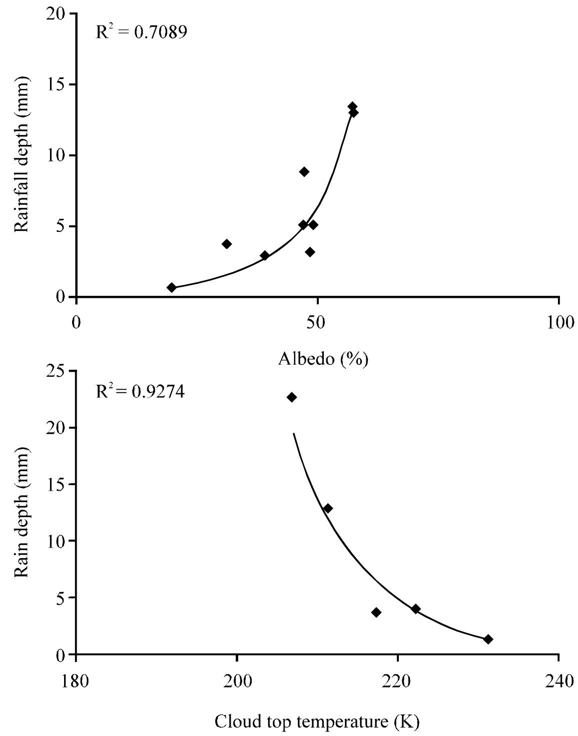

Fig. 5: Rainfall depth versus: a) Albedo and b) Cloud top temperature

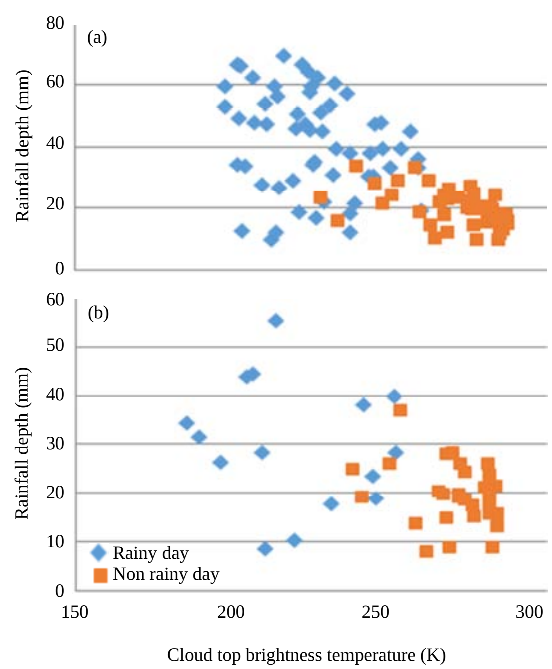

Fig. 6: Albedo versus cloud top temperature plotted for selected events occurring at: a) Kelantan River Basin and b) Klang River Basin

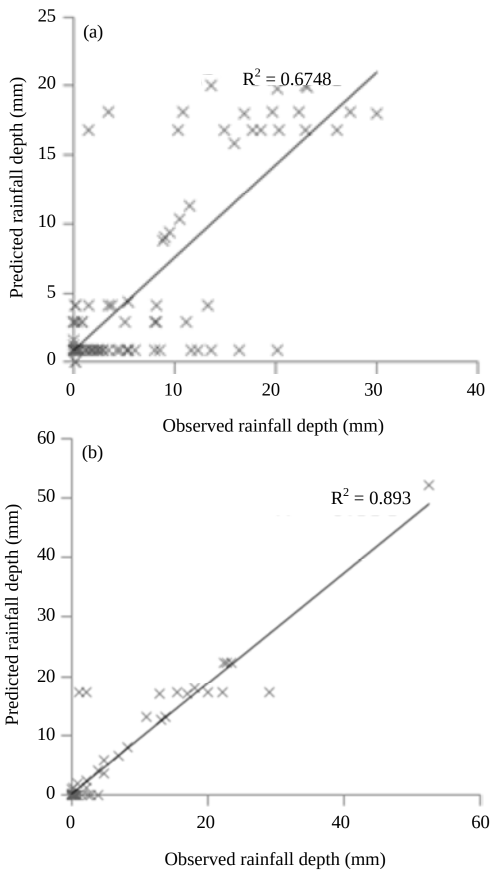

Fig. 7: Forecasted 1 h rainfall plotted against observed rainfall for areal averaged rainfall at: a) Kelantan River Basin and b) Klang River Basin

average rainfall compared to point rainfall for both catchment areas for which R^2 for Kelantan River Basin is 0.674 and for Klang River Basin is 0.893. The use of QPF for point areal rainfall is considered to be less accurate with R^2 for Kelantan River Basin is 0.392 and for Klang River Basin is 0.495. The results tallied with the findings in the previous studies whereby it was found that accuracy of satellite based rainfall estimates and forecast will increase with larger areas of estimation (Kidder and Haar, 1995; Wardah *et al.*, 2008, 2012).

The values of MAE and RMSE for the areal rainfall for both catchments are relatively low than point rainfall with a range value of 2.589-3.436 for RMSE and 0.8651-1.872 for MAE. It was also observed that the performance of the ANN based QPF is better at Klang River Basin compared to Kelantan River Basin. The finding could be related to the observation of more prevalent occurrences of convective rainfall type in Klang River Basin as compared to the Kelantan River basin whose rainfall type is more influenced by the variation of the Northeast monsoon.

CONCLUSION

The research had used the NWP model products and the geostationary meteorological satellite infrared and visible data for QPF Model development. The model had been developed using the multilayer ANN and performance was measured for two different river basins in Peninsular Malaysia. The QPF ANN based techniques had performed satisfactorily in forecasting areal-average rainfall depth for convective rainfall in a given duration and output results had been validated against the gauged rainfall. The best performance of the model is for forecasting 1 h ahead of areal rainfall event for Klang River Basin with r^2 = 0.893. The study found that the combination of NWP model products and metsat image features has great potential for enhanced QPF Model.

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REFERENCES

Barrett, E.C. and D.W. Martin, 1981. The Use of Satellite Data in Rainfall Monitoring. Academic Press, San Diego, California, ISBN:9780120796809, Pages: 340.

Grell, G.A., J. Dudhia and D.R. Stauffer, 1994. A Description of the Fifth Generation Penn State-NCAR Mesoscale Model (MM5). National Center for Atmospheric Research, Boulder, Colorado, Pages: 121.

Kidder, S.Q. and V.T.H. Haar, 1995. Satellite Meteorology, an Introduction. Academic Press, San Diego, California, ISBN:0-12-406430-2, Pages: 466.

Levizzani, V., F. Porcu and F. Prodi, 1990. Operational rainfall estimation using meteosat infrared imagery: An application in Italy's Arno. ESA. J., 14: 313-323.

Wardah, T., A.A. Kamil, A.S. Hamid and W.I. Maisarah, 2011. Quantitative precipitation forecast using MM5 and WRF models for Kelantan River Basin. Int. J. Environ. Chem. Ecol. Geol. Geophys. Eng., 1: 712-716.

Wardah, T., A.A. Kamil, A.S. Hamid and W.W.I. Maisarah, 2011. Statistical verification of numerical weather prediction models for quantitative precipitation forecast. Proceedings of the IEEE Conference on Humanities, Science and Engineering (CHUSER), December 5-6, 2011, IEEE, Shah Alam, Malaysia, ISBN:978-1-4673-0021-6, pp: 88-92.

Wardah, T., R. Suzana and S.S.N. Huda, 2012. Multi-sensor data inputs rainfall estimation for flood simulation and forecasting. Proceedings of the 2012 IEEE Conference on Humanities, Science and Engineering (CHUSER), December 3-4, 2012, IEEE, Shah Alam, Malaysia, ISBN:978-1-4673-4615-3, pp: 374-379.

Wardah, T., S.A. Bakar, A. Bardossy and M. Maznorizan, 2008. Use of geostationary meteorological satellite images in convective rain estimation for flash-flood forecasting. J. Hydrol., 356: 283-298.