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Evaluation of a Mesoscale Short Range Ensemble Forecast System for Peninsular Malaysia during the 2010/2011 Northeast Monsoon Season

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Abstract: A short-range ensemble prediction system (SREPS) consisting of ten members from the Weather Research and Forecasting Model (WRF) developed by the National Center for Atmospheric Research (NCAR) was constructed to run over the Malaysian region with 12-km horizontal resolution. The period of study was the 2010/2011 Northeast Monsoon season. The 10-member SREPS consists of four members (referred to as PY) with varying cumulus parameterizations and planetary boundary layer (PBL) schemes. Three of the PY members were negatively perturbed as well as positively perturbed to form three negatively perturbed members (NEG) and three positively perturbed members (POS) respectively thus giving a 10-member ensemble (ALL). The Breeding Growth Mode (BGM) initial perturbation technique adopted from (Kalnay and Toth 1991; Anderson 1996) was used in generating the perturbed members, known as “bred members”. The lateral boundary condition (LBC) data used was from the 00 UTC National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) runs. Verification against observed data was performed on the 24-hour accumulated precipitation forecast obtained from the PY, NEG, POS and ALL ensemble members for 3 precipitation thresholds greater than 10mm, 20mm and 40mm. The results show that ALL ensemble members was more skillful compared to POS, NEG and PY ensemble members respectively, indicating that the bred members introduced errors into the SREPS. The SREPS has indicated that it was capable of distinguishing low probability events from high probability events during the 2010/2011 Northeast Monsoon season.

1. Introduction

The Malaysian Meteorological Department (MetMalaysia) has been running routinely twice per day (00 UTC and 12 UTC) 72-hour operational deterministic forecast for the 36-km, 12-km, and 4-km domains on the Weather Research and Forecasting Model version 2.2 (WRF) and the Fifth-Generation National Center for Atmospheric Research (NCAR) / Penn State Mesoscale Model version 3 (MM5) atmospheric models since September 2008. In January 2010, an ensemble prediction system (EPS) based on the WRF and MM5 numerical weather prediction models were operationalised. This EPS consists of 10 members from WRF and 10 members from MM5.

In this study, the performance of the 10 ensemble members of WRF during the 2010/2011 northeast monsoon was evaluated. The WRF ensemble members were divided into four groups whereby the first group consists of all the 10 ensemble members and were named ALL. The second group consists of the physics ensemble group with 4 members named as PY. The third group consists of 3 negatively perturbed members known as the NEG and the fourth group consists of 3 positively perturbed members known as POS. These groupings were selected based on (Ebisuzaki and Kalnay 1991).

The main motivation of this study is to gauge how well all these individual groups perform for the 24-hour precipitation forecast over Peninsular Malaysia during the 2010/2011 northeast monsoon and also to investigate how the ensemble skill is influenced by individual member biases.

2. Data and Methodology

A 1-day (24 hours) ensemble forecast consisting of 10 members from the WRF model with 12-km horizontal resolution (**Figure 1**) was generated for the Malaysian domain (97.9°E to 121.5°E, 1.8°S to 12.0°N). The initial and boundary conditions data were obtained from the National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) model forecast. The initial state perturbations were provided by random perturbations and the breeding growth mode, adopted from (Kalnay and Toth 1991; Anderson 1996). The entire period of November 2010, December 2010, January 2011 and February 2011 during the 2010/2011 Northeast Monsoon were selected to study the performance of the Ensemble Prediction System (EPS) for Peninsular Malaysia. The data used for precipitation verification are the 24-hour accumulated rainfall data from the MetMalaysia's surface observation stations.

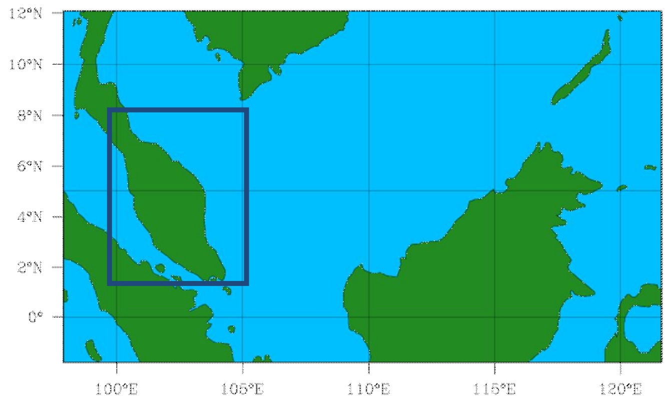

Figure 1. Ensemble Prediction System Domain. Box indicates the area of study.

Table 1 below illustrates the Ensemble Prediction System set-up.

Table 1. EPS Configurations

Model used	WRFV3
Horizontal resolution	12km
Vertical Levels	28
Grid Points	220 X 130
Members	10
Cloud Microphysics	WSM-3
Time interval (Δt)	60 s
Perturbation method	Breeding Growth Method
Domain	97.935°E～121.457°E 1.77072°S ～11.957°N
Forecast range	1day
Forecast initialization	12UTC

The first 4 ensemble members have different physics options and have been classified as the PY ensemble members. From this 4 ensemble members, members 1, 2 and 3 have been selected to perform perturbations. These 3 members have been negatively perturbed to form the NEG ensemble members and positively perturbed to form the POS ensemble members. The summary of the ensemble members are shown in **Table 2** below.

Table 2. Classification of Ensemble Members

Member	**Cumulus parameterization**	**PBL Scheme**	**Surface Layer Physics**
1 (**PY**)	KF Eta	Mellor-Yamada-Janjic (MYJ)	Monin-Obukhov (Janjic) scheme
2 (**PY**)	Grell - Devenyi	MYJ	Monin-Obukhov (Janjic) scheme
3 (**PY**)	Betts-Miller-Janjic	MYJ	Monin-Obukhov (Janjic) scheme
4 (**PY**)	Grell - Devenyi	Yonsei University(YSU)	Monin-Obukhov scheme as required by YSU
p01 (positive perturbation of member 1) **(POS)**	KF Eta	MYJ	Monin-Obukhov (Janjic) scheme
n01(negative perturbation of member 1) **(NEG)**	KF Eta	MYJ	Monin-Obukhov (Janjic) scheme
p02(positive perturbation of member 2) **(POS)**	Grell - Devenyi	MYJ	Monin-Obukhov (Janjic) scheme
n02(negative perturbation of member 2) **(NEG)**	Grell - Devenyi	MYJ	Monin-Obukhov (Janjic) scheme
p03(positive perturbation of member 3) **(POS)**	Betts-Miller-Janjic	MYJ	Monin-Obukhov scheme
n03(negative perturbation of member 3) **(NEG)**	Betts-Miller-Janjic	MYJ	Monin-Obukhov scheme

Three methods have been used to verify the EPS probabilistic forecast. The methods selected for verification are the equitable threat score (ETS) from (Hamill 2001), Brier Skill Score (BSS) and the reliability diagram (RD) (Jolliffe and Stephenson, 2003) and (Hamill 1997). Verifications were performed for precipitation thresholds exceeding 10mm, 20mm and 40mm. These thresholds were selected based on the frequency of occurrence during the northeast monsoon season.

3. Results and Discussion

Figure 2 shows Equitable Threat Scores (ETS) scores for the 2010/2011 northeast monsoon 24-hour Quantitative Precipitation Forecast (QPF). CTL indicates the control experiment from the deterministic run of the WRF model. The PY members have greater skill than the rest of the ensemble members for thresholds greater than 10 mm. ALL ensembles has the best ETSs for thresholds greater 20 mm and 40 mm. There is a great disparity between the NEG and POS members to the PY members. The performance of the PY members is much better than the perturbed members indicating the existence of biases in the perturbations during the 2010/2011 northeast monsoon season.

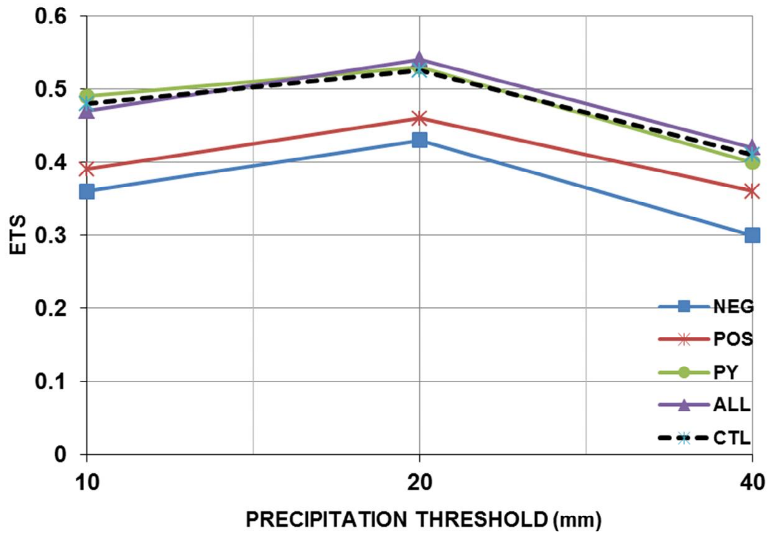

Figure 2. Equitable Threat Score for The 2010/2011 Northeast Monsoon 24-hour Quantitative Precipitation Forecast

Figure 3 depicts Brier Skill Score (BSS) for the 2010/2011 Northeast Monsoon 24-hour Precipitation Forecast. The BSS decreases gradually with increasing precipitation amount. The PY ensembles show skill with respect to the sample climatology at all thresholds. NEG and POS ensemble members lack skill for higher thresholds and perform rather poorly compared to the PY ensemble. The ALL ensembles have slightly better skill than the perturbed members primarily due to the performance of the PY members. The perturbed members seem to introduce error into the ensemble forecast and reduce the skill of the complete EPS.

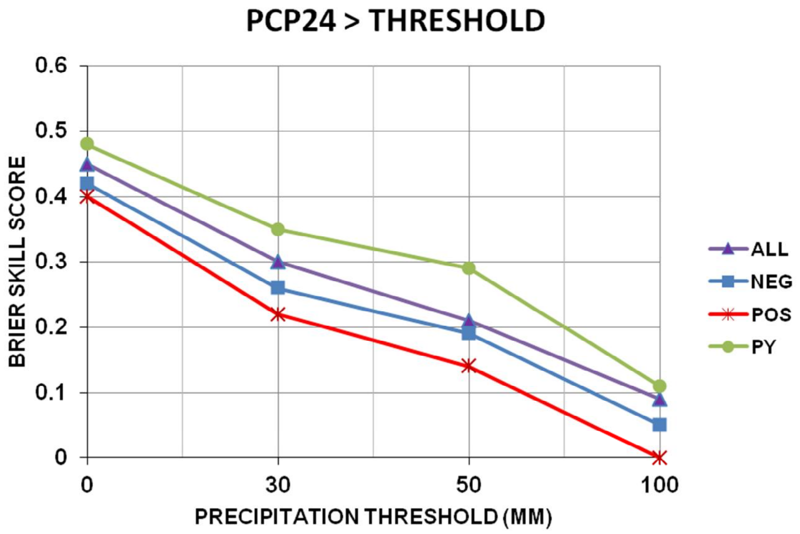

Figure 3. Brier Skill Score for The 2010/2011 Northeast Monsoon 24-hour Precipitation Forecast

The reliability diagrams for precipitation thresholds exceeding 10 mm, 20 mm and 40 mm are shown in **Figures 4**, **5** and **6** respectively. The solid diagonal line represents the skill line and the dashed line is the no skill line. **Figure 4** indicates that lower probabilities events tend to be under forecast and higher probabilities events tend to be over forecast for the POS, NEG and ALL ensembles. The PY ensemble is the most reliable compared to the others. At probabilities 0.25, the POS, NEG and ALL ensembles approaches the no skill line.

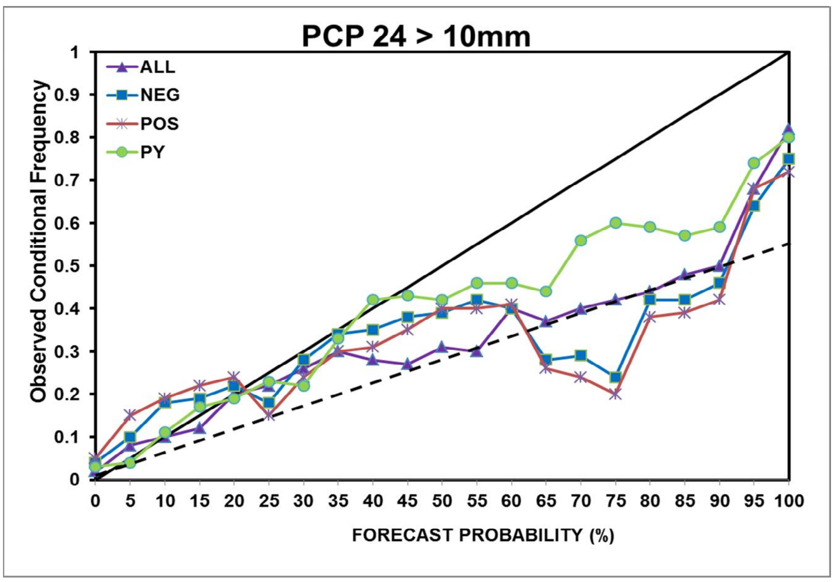

Figure 4. Reliability Diagram for 24-hour 10 mm Precipitation Threshold During The 2010/2011 Northeast Monsoon

Figure 5 also indicates that lower probabilities events tend to be under forecast and higher probabilities events tend to be over forecast for the POS, NEG and ALL ensembles. At probabilities greater than 0.4, the POS, NEG and ALL ensembles approaches the no skill line. Again, the PY ensemble is the most skillful.

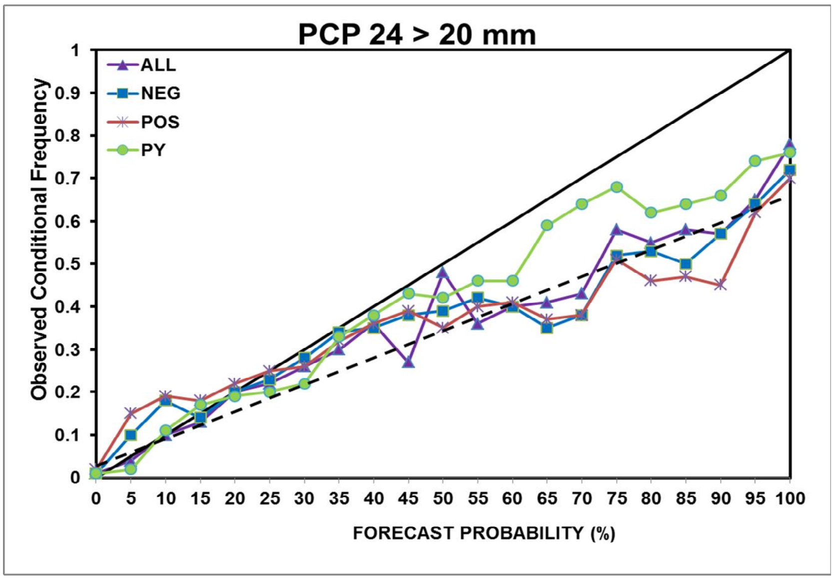

Figure 5. Reliability Diagram for 24-hour 20 mm Precipitation Threshold During The 2010/2011 Northeast Monsoon

Figure 6 also shows that lower probabilities tend to be under forecast. However, it also shows that for probabilities greater than 0.05 to 0.15, all the sub-ensembles show a tendency for over forecast. At probabilities 0.15 to 0.45 all the sub-ensembles are reliable. At probability greater 0.55 the ALL, POS and NEG sub-ensembles approaches the no skill line. Yet again the PY ensemble is the most reliable. The performance of the ALL sub-ensemble is influenced greatly by the performance of the perturbed sub-ensemble.

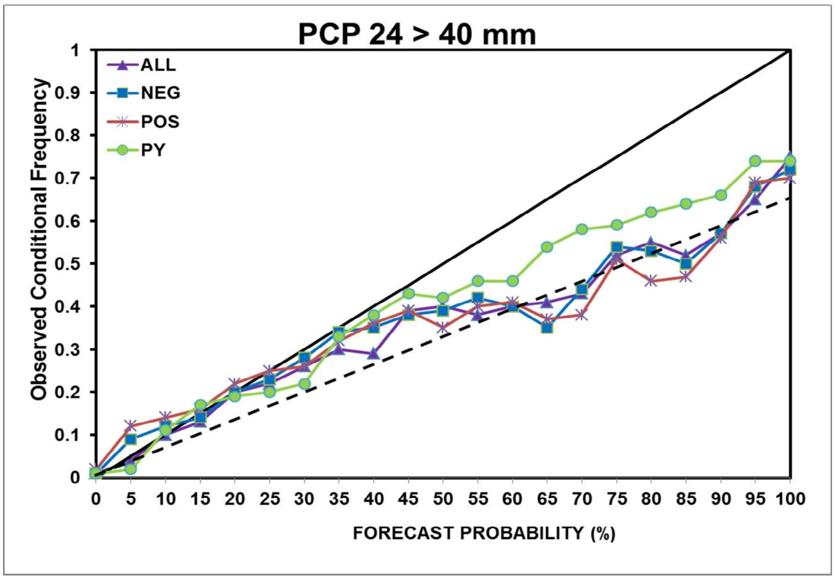

Figure 6. Reliability Diagram for 24-hour 40 mm Precipitation Threshold During The 2010/2011 Northeast Monsoon

4. Concluding Remarks

This work is the first step in understanding the ensemble performance during the Northeast monsoon. Evaluation of other surface parameters is underway. Based on the reliability diagrams in **Figures 4** to **6**, the PY members exhibit greater skill compared to the POS, NEG and ALL ensemble members for all thresholds. The ETS however indicates that the ALL ensemble members perform slightly better for the 20 mm and 40 mm thresholds respectively. The reliability diagrams offer a more comprehensive outlook on the performance of the ensemble members. There may be some biases but it gives the best representation of performance. All the sub-ensemble members have a tendency to over predict the 24-h precipitation probabilities for the medium and higher thresholds. The probabilistic skill and ensemble reliabilities indicate that there exist deficiencies in model physical parameterization and the generated perturbations. Further understanding is required to improve the performance of the perturbed members. The scaling factor of the error growth rate needs to be further studied to improve the performance of the perturbed members.

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