Research Report 2016-04

Development of APCC-PAGASA Regional Prediction System (APCC-PRePS) over the Philippines: Pilot Study

Yoo-Bin Yhang

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발간사

계절 예보는 국가의 정책을 결정하는 데 있어 중요한 정보이므로 보다 고해상도의 신뢰도 높은 계절 예측 정보의 중요성이 높아지고 있다. 세계 여러 현업 기관에서 전지구 모형을 이용하여 계절 예측 정보를 생산하고 있지만 기후연구는 물론 수자원, 농업과 같은 응용연구에서 필요로 하는 지역적 특성이 고려된 예측 정보가 부족하며, 악기상과 같은 기상 이변에 대한 예측력은 높지 않은 것으로 알려져 있다.

컴퓨팅 소스의 발달로 모형의 적분 시간이 단축되고 있음에도 불구하고 지역기후모형을 이용한 계절예측정보의 생산은 시간 대비 예측성을 담보하기 힘들다는 이유로 잘 이루어지지 않고 있다. 대부분의 기관에서 과거 자료를 바탕으로 찾아낸 경험식을 이용한 통계적 기법을 통해 예측자료를 생산하고 있으나 통계모형을 통한 예측 역시 역학모형의 예측력이 담보되어야 할 것이다.

본 연구보고서는 필리핀 기상청과의 공동연구로 진행될 지역기후모형을 이용한 계절예측 시스템 구축의 첫 번째 단계로, 지역기후모형을 계절예측에 적용하기 위해 고려해야 할 관점들을 논의하고자 하는 취지에서 기획되었다. 이 연구결과를 바탕으로 향후 필리핀 기상청과의 지속적인 논의를 통해 예측성을 검증하고 개선하기 위한 노력이 계속될 것이다.

본 연구보고서가 발간되기까지는 많은 분들의 도움이 있었다. 보고서의 수준을 제고하도록 좋은 논평을 해주신 익명의 검토자들과 연구가 순조롭게 진행될 수 있도록 다방면으로 도와준 임창묵 연구원, 그리고 본 연구보고서를 총괄하고

최종집필한 본원의 양유빈 박사에게도 감사의 뜻을 전한다. 본 연구보고서가 밑거름이 되어 향후 관련 연구들이 지속되고 부족한 부분들을 계속 채워나가길 바란다.

2017년 1월
APEC 기후센터
원장 **정 홍 상**

ABSTRACT

This study is a part of the APCC-PAGASA Regional Prediction System (APCC-PRePS) project aimed at providing valuable high-resolution seasonal forecasts, using downscaling techniques. The purpose of this study, as a pilot study, is to test model setup and feasibility before inter-comparison of regional climate models.

Dynamical downscaling was carried out by the WRF, RegCM, and GRIMs-RMP with the same horizontal resolution and domain for May-June-July-August 1998. The results were evaluated by Tropical Rainfall Measuring Mission (TRMM) Multi-Satellite Precipitation Analysis (TMPA) in order to focus on simulated precipitation. This pilot study was done to address some issues with the operational use of the regional climate model. As part of the research strategy, the following issues are discussed prior to the main study:

(1) Dynamical core

The results from parallel runs using the WRF and RegCM showed that the differences between the hydrostatic and non-hydrostatic model appear mostly over mountainous areas, even at a resolution of 30 km. We have to decide whether or not we have to pay extra computation resources to run the non-hydrostatic model for certain resolutions.

(2) Domain size

The results showed that monthly precipitation and daily evolution in terms of

spatial and temporal correlation generally improve when the domain size is reduced. It is well known that the limited area over which a model is integrated must be large enough to allow for the full development of small-scale features. On the other hand, simulations in small domains with strong orographic forcing or land-sea contrast may enhance the accuracy of a regional climate model, and correct some errors at small scales.

(3) Physical options

The use of three convection schemes and their combinations showed that regional climate simulations are very sensitive to the physical parameterization schemes employed. An appropriate convective parameterization scheme should be used in dynamic models for realistic simulations.

(4) Spectral nudging

As an alternate method to mitigate systematic large-scale errors, the technique of large-scale spectral nudging was applied. If simulations over a large domain or for a period longer than one month are accessible, we may consider adapting a large-scale nudging approach in the regional climate model.

CONTENTS

1. INTRODUCTION

The APEC Climate Center (APCC) aims to increase regional prosperity in the Asia-Pacific region through the climate information service by protecting lives and property, reducing economic losses, and enhancing economic opportunities. APCC utilizes up-to-date scientific knowledge and applies innovative climate prediction techniques to its climate prediction, interdisciplinary research, climate information services, and international cooperation. To this end, APCC's mission and vision are closely connected to the Philippine Atmospheric, Geophysical and Astronomical Services Administration's (PAGASA) efforts toward disaster risk reduction.

As skillful seasonal forecasts are essential for natural resource management and decision making, producing an accurate and precise high-resolution seasonal forecast is more necessary than ever. Global climate models (GCM) have provided useful climate information on the past, near present, and future, which is important in assessing potential impacts of global climate change. However, GCMs have coarse spatial resolutions, typically ranging from 100 to 250 km, which may be inadequate in representing some regional climate features. Particularly in archipelagic regions like the Philippines, topography, land use, and coastlines need to be properly resolved in the model as these features affect climate on a local scale.

Studies have shown that regional climate models (RCMs) can provide added value to GCMs, especially for areas with complex topography and coastlines (Feser et al. 2011). For the Philippines, RCMs have been used to examine historical climate and to downscale climate projections (e.g., Im et al. 2008; Robertson et al. 2012). For example, the Abdus Salam International Centre for Theoretical Physics Regional Climate Model version 3 (RegCM3) was used to examine the summer monsoon precipitation over the country and the model sensitivity to lateral boundary conditions and ocean flux schemes (Francisco et al. 2006). In addition, the UK Met Office Hadley Centre Providing Regional Climates for Impacts Studies (PRECIS) model and the Weather Research and Forecasting (WRF) model have been used to project future changes in temperature and rainfall over the Philippines and in Southeast Asia (Philippine Atmospheric, Geophysical and Astronomical Service Administration (PAGASA) 2011; Chotamonsak et al. 2011). Cruz et al. (2015) evaluated the performance of the non-hydrostatic regional climate model (NHRCM) over the Philippines and investigated the sensitivity to the boundary condition and the convective schemes.

The previous RCM studies on the Philippines' climate are limited to climate projection or reproduction. The APCC-PAGASA Regional Prediction System (APCC-PRePS) project aims to provide valuable high-resolution seasonal forecasts using downscaling techniques. The purpose of this study, as the first step of the APCC-PRePS project, is to test model setup and feasibility before conducting an inter-comparison of regional climate models. RCMs have their own characteristics due to varying dynamics and physical processes. Therefore, it is necessary to investigate the performance of regional climate models over the Philippines. This study is a pilot experiment and a part of the first year's plan to inter-compare the RCMs for operational use in the future. The purpose of this study is to test model setup and feasibility before inter-comparison and provide basic information of regional climate models. In addition, we can figure out the issues related to the setup of the regional model in advance through this pilot study. These results will be shared with PAGASA and will aid in the functioning of regional models.

Details on the APCC-PRePS project are given in the next section. In section 3, we present data and methodology, section 4 provides results from three regional climate models, and in section 5 we summarize and discuss the results.

2. APCC-PRePS PROJECT

The ultimate goal of this project is to increase the reliability of action plans against possible climate-induced risks in the Philippines by delivering more accurate seasonal prediction information. This will be achieved through the building and installation of a downscaling system on PAGASA's supercomputer.

The APCC-PRePS project will be going on for the next 3 years in four steps, as shown in Fig. 1.

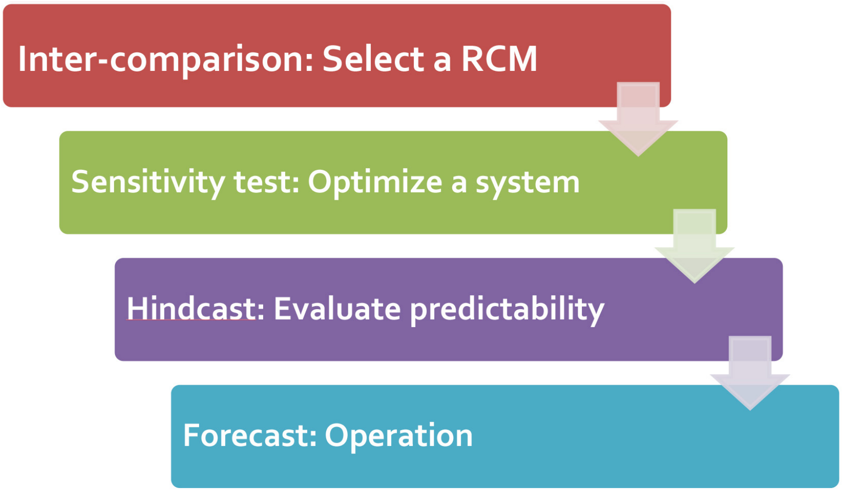


Figure 1 Steps for the APCC-PRePS project

Strategic plans for each year are shown below.

- 1st year:
  - Analyze the characteristics of regional climate models over the Philippines
  - Inter-compare the predictability of regional climate models
  - Select the best model for the prediction system
  - Convert observation (station to grid) to evaluate the results

- 2nd year:
  - Perform the sensitivity teststo boundary condition, domain, and physics using a selected model
  - Investigate predictability
  - Decide model configuration considering practical and operational aspect
- 3rd year:
  - Produce hindcast
  - Evaluate hindcast
  - Test operation
  - Run the operational system

3. DATA AND METHODOLOGY

3.1 Model

We selected three regional climate models: WRF, RegCM, and GRIMs, for inter-comparison in the Philippines.

The Weather Research and Forecasting (WRF) model v3.7 released in April 2015 was used in this study. The WRF employs fully compressible non-hydrostatic equations with hydrostatic option, and WRF v3.3 has been used for numerical weather prediction at PAGASA. It is developed as a collaborative effort among several universities and federal research agencies in the USA. It is the next generation of the PSU/NCAR fifth generation mesoscale model, known as MM5 (Chen and Dudhia 2001; Barker et al. 2004; Ishak et al. 2013). The WRF has significant improvement over the MM5 and includes recent physics parameterizations. WRF is designed to serve and support both atmospheric research and operational forecasting needs (Dai et al. 2013; Islam et al. 2013; Srivastava et al. 2013a, b; Islam et al. 2014).

The latest version of the International Centre for Theoretical Physics (ICTP) regional climate model, RegCM4 (Giorgi et al. 2012), is an upgrade of the model originally developed by Giorgi et al. (1993a, 1993b) and Pal et al. (2007). RegCM4 is a hydrostatic, compressible, and sigma-p vertical coordinate model. A time-splitting explicit integration scheme is used, in which the two fastest gravity modes are first separated from the model solution and then integrated with smaller time steps. This allows the use of a longer time step for the rest of the model. Essentially, the model dynamics is the same as that of the hydrostatic version of MM5.

The Global/Regional Integrated Model System (GRIMs; Hong et al. 2013) has been created for use in numerical weather prediction, seasonal simulation, and climate research projects, from global to regional scales. The primary version of global and regional models is rooted in the NCEP seasonal forecast model (Kanamitsu et al. 2002) and regional spectral model (Juang et al. 1997), but with subsequent developments of model physics and dynamics, along with the re-configuration of code structure. The model system is developed and practiced by taking advantage of both operational and research applications. The regional part of the GRIMs, namely RMP (hereafter GRIMs-RMP), has been successfully employed as a tool to better understand the precipitation mechanisms of the Asian monsoon (Koo and Hong 2010; Hong et al. 2012).

3.2 Experimental design

Dynamical downscaling is carried out by the WRF, RegCM, and GRIMs-RMP with the same horizontal resolution and domain. Experimental designs for the three regional models are shown in Table 1. The experiments were conducted during the rainy season (May-June-July-August) of an El-Nino year, 1998, to examine the applicability of the RCMs in the Philippines. Modeled precipitation obtained from the experiments are compared with the Tropical Rainfall Measuring Mission (TRMM) Multi-Satellite Precipitation Analysis (TMPA; Huffman et al. 2007). The TMPA provides a detailed distribution of precipitation with higher spatial and temporal resolutions (0.25° × 0.25° and 3-hour, respectively). For evaluation, basic statistics such as temporal and spatial correlation are tabulated against the TMPA data.

Table 1 Experimental design

	WRF	RegCM	GRIMs-RMP
Initial & bdy	CFSR (Saha et al. 2010)	NCEP/DOE (Kanamitsu et al. 2002)	CFSR (Saha et al. 2010)
CPS	KF (Kain 2004)	Emanuel (Emanuel and Zivkovic-Rothman 1999)	SAS (Hong and Pan 2006)
Microphysics	WSM3 (Hong et al. 2004)	SUBEX (Pal et al. 2000)	WSM1 (Hong et al. 1998)
PBL	YSU (Hong et al. 2006)	Holtslag PBL (Holtslag et al. 1990)	YSU (Hong et al. 2006)
Land surface	Noah (Chen and Dudhia 2001; Ek et al. 2003)	BATS (Dickinson et al. 1993)	Noah (Chen and Dudhia 2001; Ek et al. 2003)

4. RESEARCH RESULTS

In this section, the simulated precipitation from the WRF, RegCM, and GRIMs-RMP are organized by purpose.

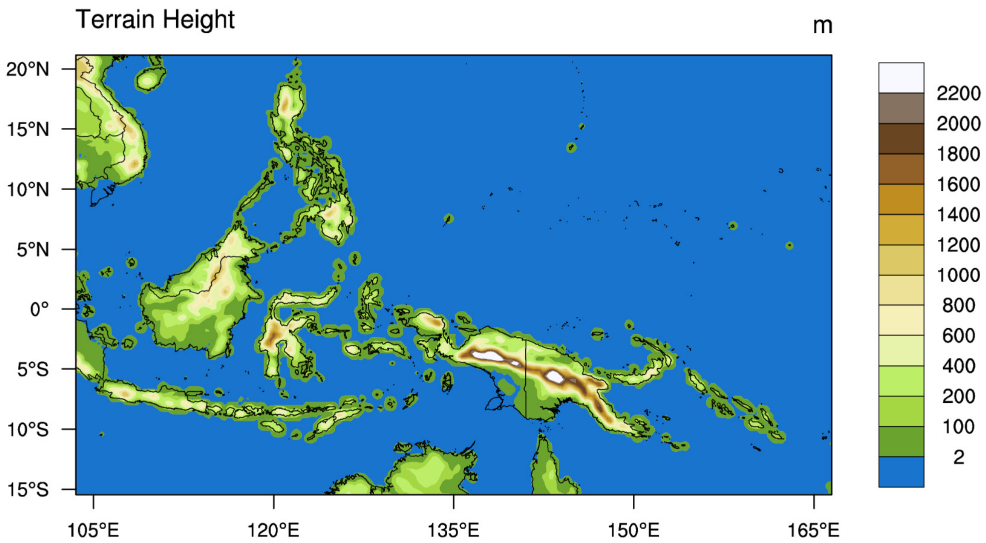
4.1 WRF

We performed two sets of experiments with the same physics options for the climate run. For this study, we used the WRF model version 3.7, the physics options being: the Kain-Fritsch convective parameterization, the WRF Single-Moment 3-Class Microphysics Scheme, the Yonsei University planetary boundary layer (PBL) scheme, and the Noah land surface model (See Table 1). The simulations used time-varying sea surface temperatures.

4.1.1 Big domain vs. Small domain

To provide forecast data for the Philippines, we can either focus solely on the Philippines or set a big domain including the Philippines. Figure 2 shows two domains with the same resolution of 30 km. Two experiments with the same configurations except for domain size were performed and compared with the observations. Figure 3 presents monthly precipitation from observation and big- and small-domain experimentation. Rainfall maxima are located on the west coast of Luzon in May and August (Fig. 3). The experiment using the big domain simulates more precipitation than that using the small domain. Overestimated rainfall is prominent in north Luzon. The experiment using the smaller domain simulates decreased rainfall, which results in a higher value of the correlation coefficient (Table 2). Figure 4 is a time-series of 5-day running mean precipitation averaged over the Philippines. The observation shows four peaks. Even though the two experiments underestimate the rainfall peaks, the experiment using the small domain follows the variation well. The temporal correlation of the two experiments is 0.42 and 0.62, respectively. Figure 5 shows the probability of rainfall intensity distribution obtained from the TMPA observation and WRF simulations. The big-domain experiment overestimates the precipitation above the 10 mm/day intensity level. The small-domain experiment matches the observation well except for a slight overestimation in the mid-range of 10-100 mm/day.

(a)



(b)

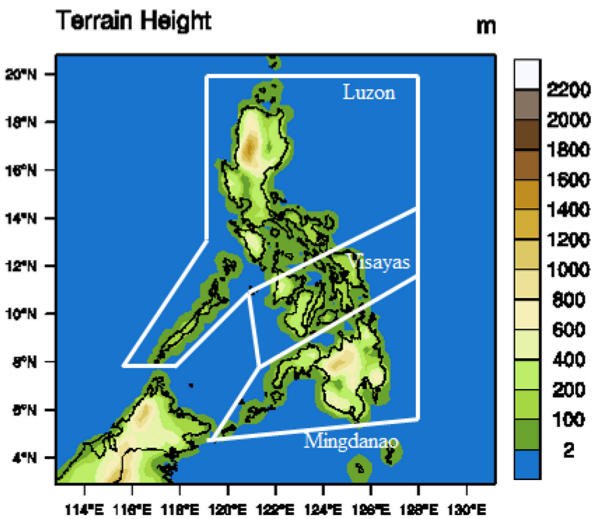


Figure 2 Experimental domain of (a) big domain and (b) small domain.

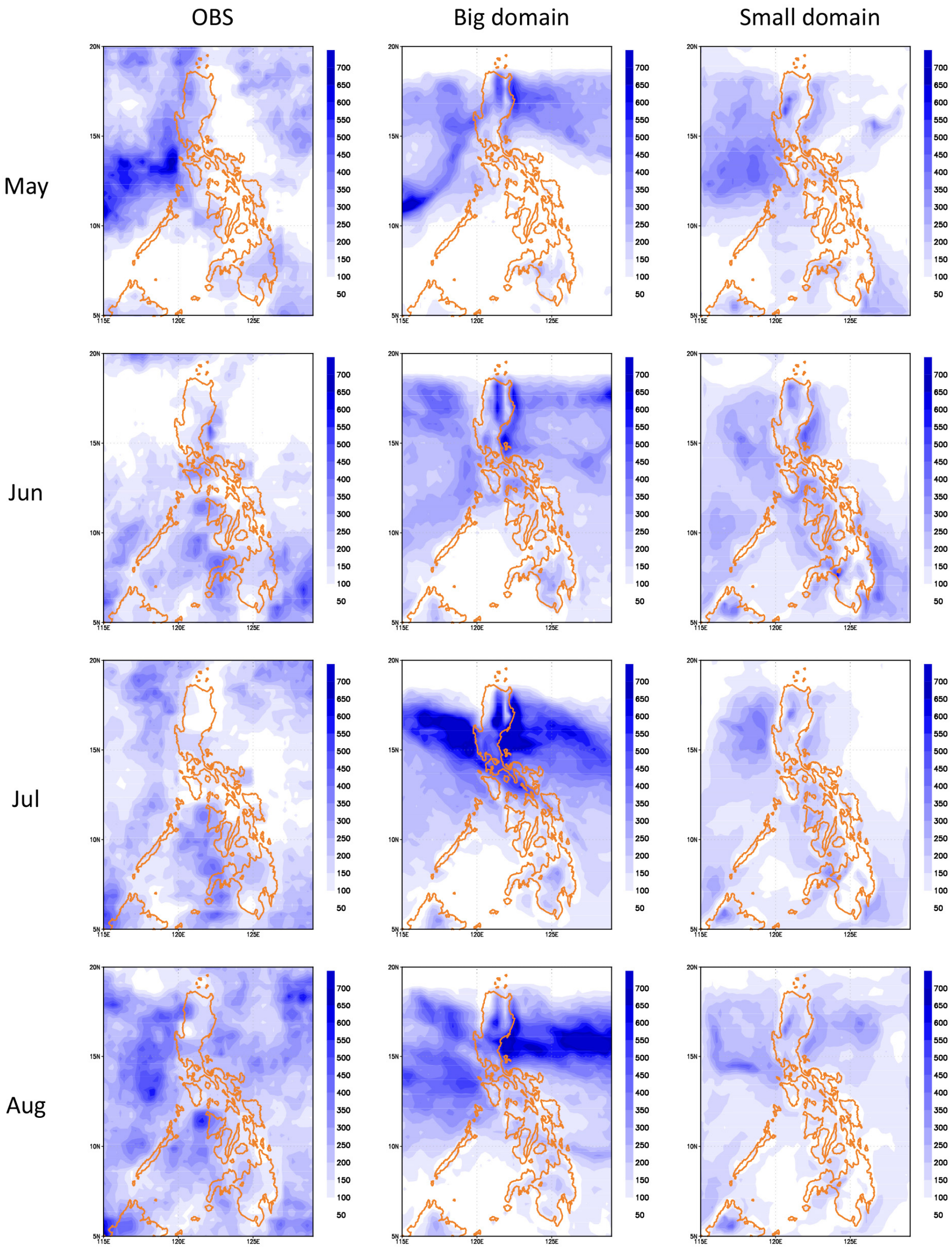


Figure 3 Monthly mean precipitation (mm) from observation and WRF simulations with big and small domains over the Philippines.

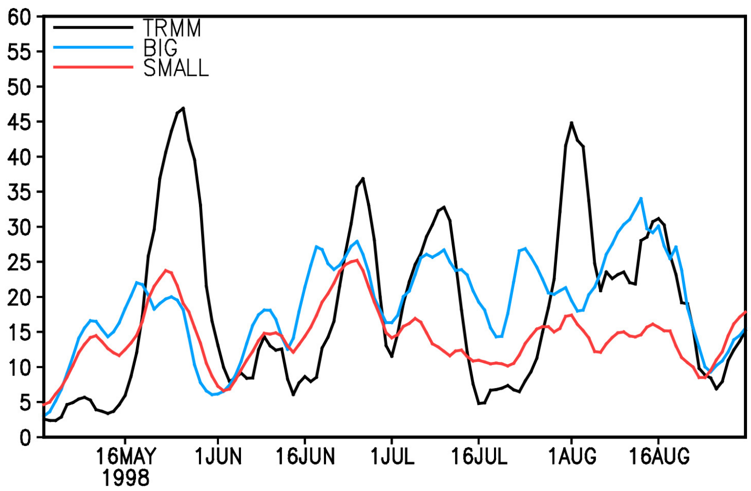


Figure 4 Time-series of 5-day running mean precipitation averaged over the Philippines.

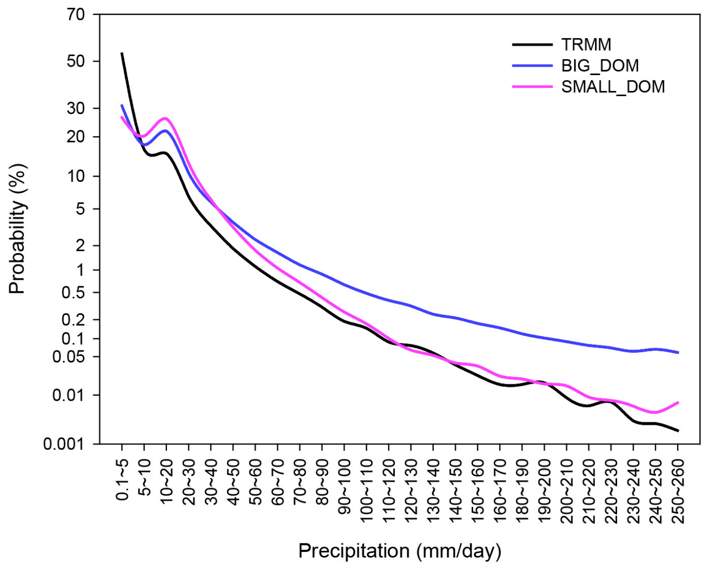


Figure 5 Probability distribution function (PDF) for daily precipitation over the Philippines.

Table 2 Root mean square error (RMSE) and correlation coefficients over the Philippines

	RMSE (mm/day)		Spatial correlation		Temporal correlation	
	BIG	SMALL	BIG	SMALL	BIG	SMALL
May	1.68	1.34	0.45	0.61	0.42	0.62
Jun	2.27	1.63	-0.26	0.43		
Jul	3.13	1.51	-0.32	0.25		
Aug	2.59	1.06	0.35	0.35		

4.1.2 Hydrostatic vs. Non-hydrostatic core

The other set of WRF experiments is for the dynamical core of the model. In this chapter, we will compare hydrostatic and non-hydrostatic dynamic formulations. To run the hydrostatic or non-hydrostatic WRF, the following component should be changed in namelist.input (see Appendix A for complete namelist.input).

Hydrostatic WRF

```
&dynamics
non_hydrostatic                    = .ture., .true., .true.,
```

Non-hydrostatic WRF

```
&dynamics
non_hydrostatic                    = .false., .false., .false.,
```

In the hydrostatic approximation, the vertical momentum equation is replaced by the following relationship of the hydrostatic equilibrium:

$$\partial p/\partial z = -\rho g$$

This is a balance between the vertical pressure gradient force and gravity with no net acceleration. This tends to hold for atmospheric phenomena that are much wider than they are tall. This holds true for synoptic scales where vertical motions are of the order of 1cm/sec, but not for thunderstorms where updrafts can attain speeds of 100m/sec.

Non-hydrostatic atmospheric models use non-hydrostatic model formulations where hydrostatic balance in a concurrent hydrostatic model is replaced by a vertical momentum equation (Janjic et al. 2010), creating additional terms in the non-hydrostatic formulation. Non-hydrostatic treatments are important especially where complex topography and thermal heating of unstable convective boundary layers (Molemaker and Dijkstra 2000) and cloud dynamics (Cotton and Anthes, 1989) are involved. As we reduce grid spacing (increase resolution) and start to resolve non-hydrostatic features (thunderstorm updrafts, downdrafts, etc.), we need to make sure we are using a non-hydrostatic solver. The non-hydrostatic solver is more computationally expensive than a hydrostatic solver.

Figure 6 shows monthly precipitation from observation and WRF simulations with hydrostatic and non-hydrostatic solvers. Overestimated precipitation shown in the hydrostatic WRF is decreased in non-hydrostatic WRF. Even though spatial distribution of precipitation is improved (Table 3), the improvement is not significant in terms of daily evolution (Fig. 7). Temporal correlations over the whole domain and the Philippines are decreased in the hydrostatic run (Table 2). Also, the probability distribution functions between the hydrostatic and non-hydrostatic simulations are very similar (Fig. 8). Both hydrostatic and non-hydrostatic WRF overestimate precipitation above the 10mm/day intensity level.

Given the 30 km resolution, these experiments may not be enough to show the effect of non-hydrostatic treatment on the simulated climate. Despite the features being better resolved, and the topographic effects present, the accuracy may have been reduced.

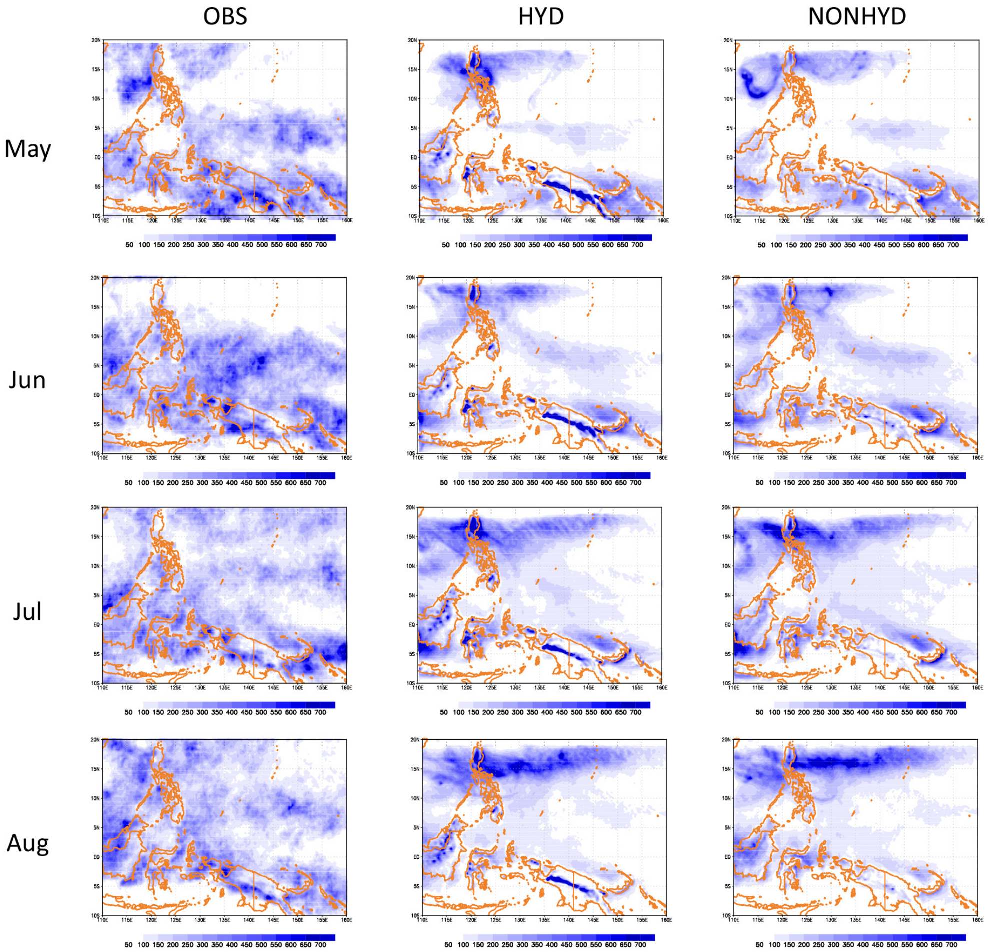


Figure 6 Monthly mean precipitation (mm) from observation, hydrostatic, and non-hydrostatic WRF simulations.

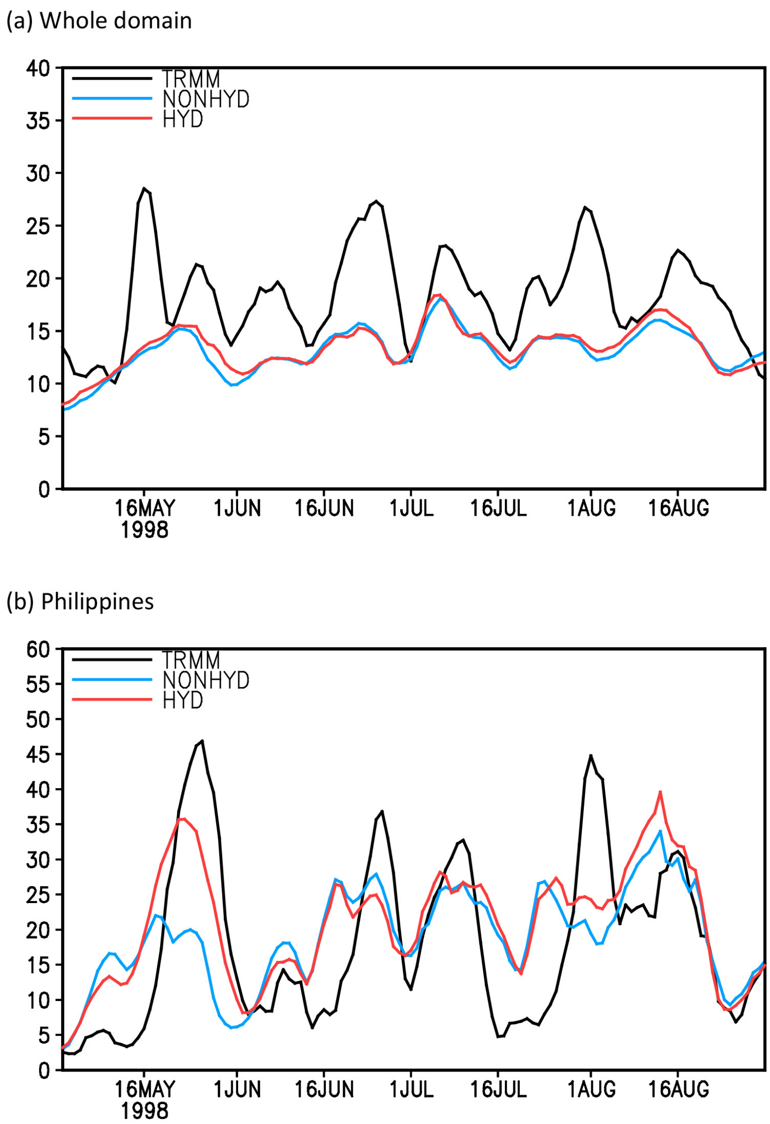


Figure 7 Time-series of 5-day running mean precipitation averaged over (a) whole domain, and (b) the Philippines.

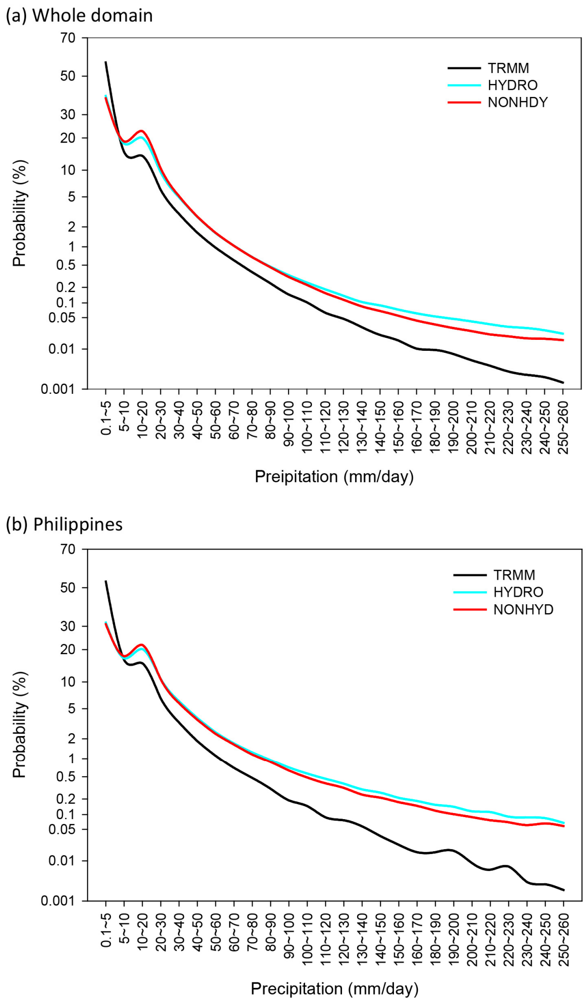


Figure 8 Probability distribution of daily precipitation over (a) whole domain, and (b) the Philippines.

Table 3 Root mean square error (RMSE) and correlation coefficients over the whole domain. Values in parenthesis of temporal correlation are calculated over the Philippines.

	RMSE (mm/day)		Spatial correlation		Temporal correlation	
	HYD	NONHYD	HYD	NONHYD	HYD	NONHYD
May	2.06	1.28	0.32	0.52	0.54 (0.69)	0.56 (0.42)
Jun	2.01	1.44	0.19	0.34		
Jul	2.12	1.85	0.11	0.12		
Aug	2.01	1.74	0.27	0.33		

4.2 RegCM

In this chapter, we determine the effect of parameterization as well as that of the non-hydrostatic core. Parameterization in a climate model is a method of replacing processes that are too small-scale or complex to be physically represented in the model by a simplified process.

We used the newly released RegCM version 4.5. One of the main new technical features of version 4.5 is that the MM5 non-hydrostatic dynamical core has been ported to the RegCM without removing the existing hydrostatic core. We can control which dynamical core is used in the model through editing coreparam namelist (See Appendix B). The physics options applied in this study are the Biosphere-Atmosphere Transfer Scheme (BATS) (Dickinson et al., 1993) as a land surface model, and PBL scheme, modified by Holtslag et al. (1990) (See Table 1).

In addition, RegCM includes a number of options for representing cumulus convection schemes, such as the Massachusetts Institute of Technology (MIT) scheme (Emanuel, 1991; Emanuel and Zivkovic-Rothman, 1999), the Tiedtke scheme (Tiedtke, 1989), and the Kain-Fritsch (KF) scheme (Kain and Fritsch 1990; Kain, 2004). In the MIT scheme (hereafter referred to as the Emanuel scheme), convection is initiated when the level of buoyancy is higher than the cloud base. The Kain-Fritsch scheme is a mass-flux deep convection parameterization in which clouds are considered as two steady state circulations including an updraft and a downdraft. When convection is triggered, the Kain-Fritsch scheme removes all convective available potential energy (CAPE) within the relaxation time. Similarly, the Tiedtke scheme is a comprehensive mass-flux convection scheme (Tiedtke, 1989); however, it considers a number of cloud types as well as cumulus downdrafts that can represent deep, mid-level and shallow convection. The closure assumptions for the deep and mid-level convection are maintained by large-scale moisture convergence, while the shallow convection is sustained by the supply of moisture derived from surface evaporation.

In order to examine the effect of the two dynamical cores and convection schemes on the simulated precipitation over the Philippines, twelve experiments were performed. The twelve experiments consisted of six combinations of cumulus convection schemes over land and the oceans (Table 4).

We will not discuss each experiment separately, because we want to temporarily apply a better scheme, rather than investigate the physical meaning or the dynamics. All experiments with non-hydrostatic core reduce precipitation over the mountains of New Guinea, Sulawesi, Borneo (Figs. 9), which isthe same result given by the WRF simulation with non-hydrostatic cores. In the experiment using the KF scheme in the ocean (TDK_KF, KF_KF, EM_KF), non-hydrostatic simulations show decreased precipitation over the Philippines (Figs. 10). This is due to the fact that overestimated precipitation in north Luzon is decreased, which is close to the observation. The EM_TDK, EM_EM, and KF_EM experiments do not represent daily variation in either one of the hydrostatic and non-hydrostatic simulations (Fig. 10). These three experiments simulate much less amount of precipitation than observation over the oceans (Fig. 11). In Figure 12, temporal and spatial correlation was calculated. The experiments with the KF scheme in the ocean (TDK_KF, KF_KF, EM_KF) showed better correlation when hydrostatic formulation was applied. On the other hand, the core in the EM_TDK, EM_EM, and KF_EM experiments, correlation coefficients were improved when we used the non-hydrostatic simulation.

Table 4 Summary of RegCM4 experiments

EXP	Cumulus convection scheme	
	Land	Ocean
TDK_KF	Tiedtke	KF
EM_TDK	Emanuel	Tiedtke
EM_EM	Emanuel	Emanuel
KF_EM	KF	Emanuel
KF_KF	KF	KF
EM_KF	Emanuel	KF

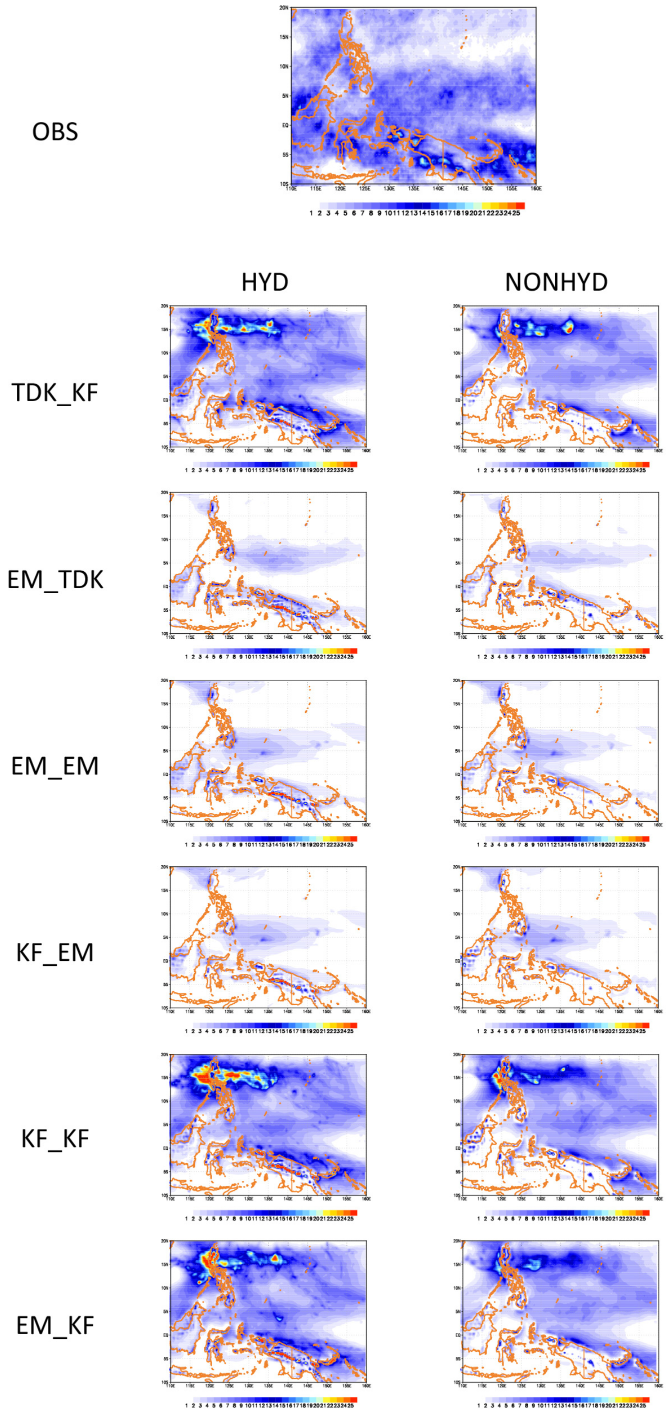


Figure 9 MJJA precipitation (mm/day) from observation, hydrostatic, and non-hydrostatic RegCM simulations.

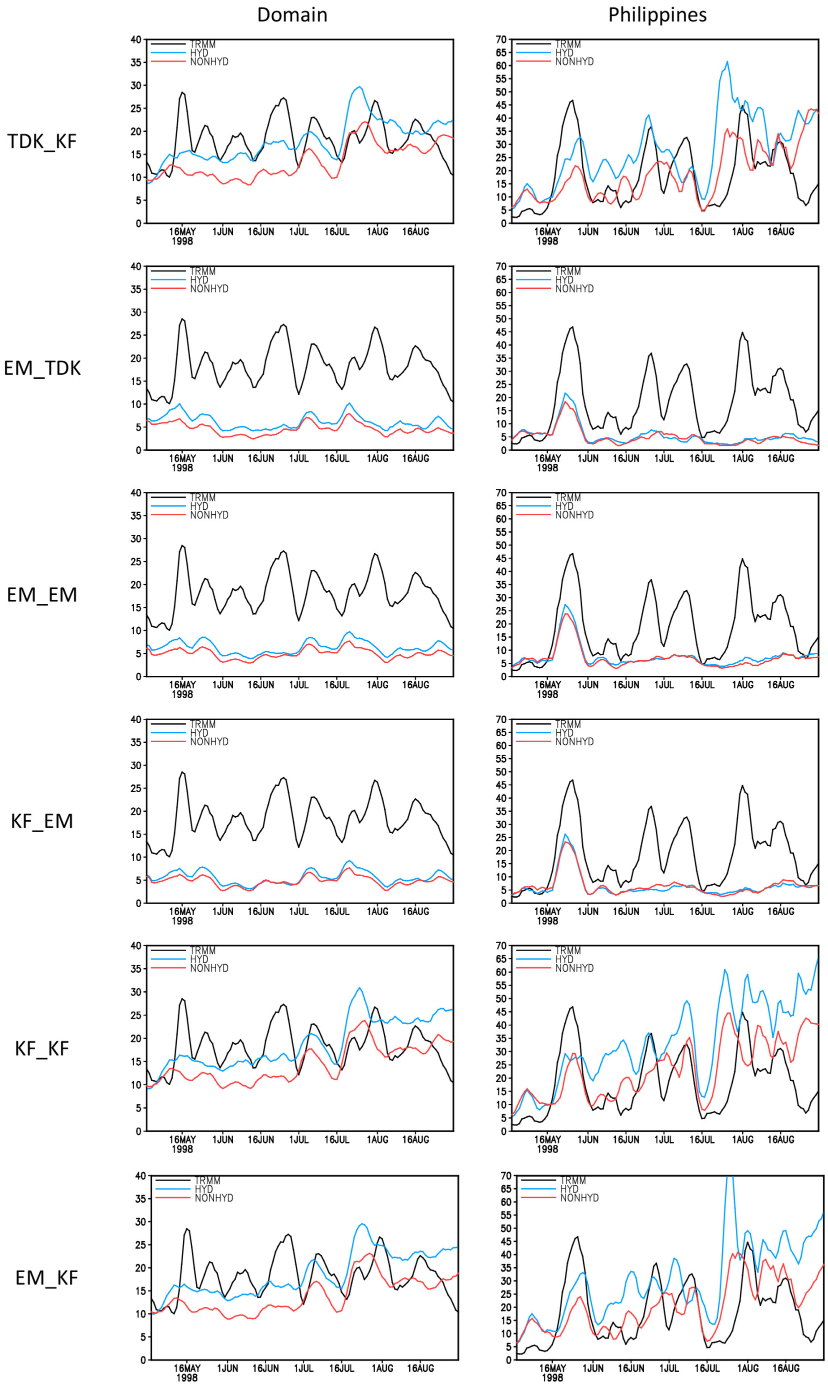


Fig. 10 Time-series of 5-day running mean precipitation (mm/day) obtained from observation and RegCM simulations.

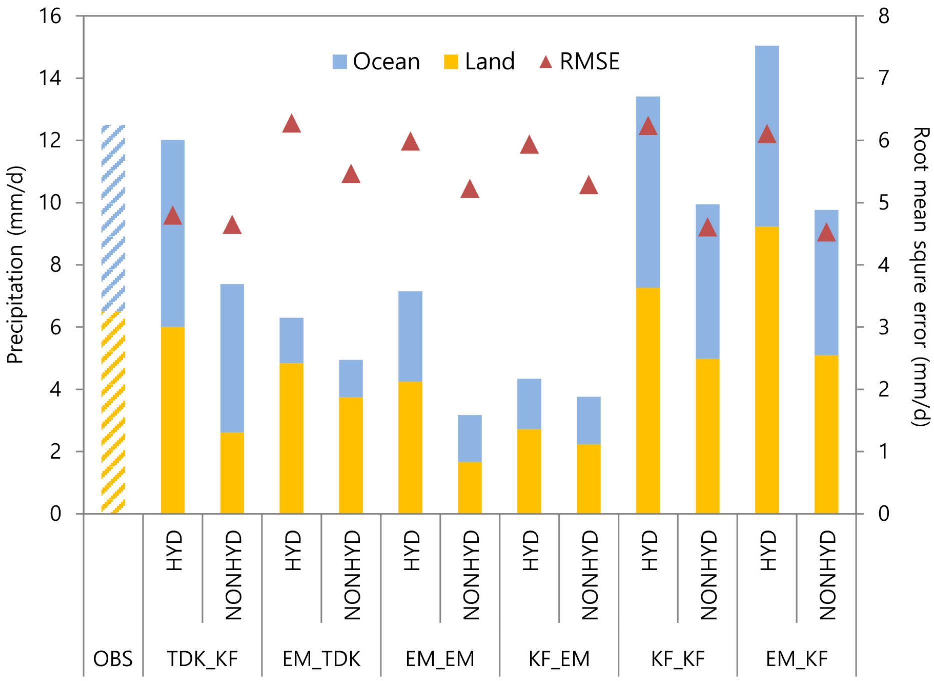


Figure 11 Rainfall amount over land (yellow) and the oceans (blue) from observation and RegCM simulations. Root mean square errors (RMSE) are calculated over the whole domain.

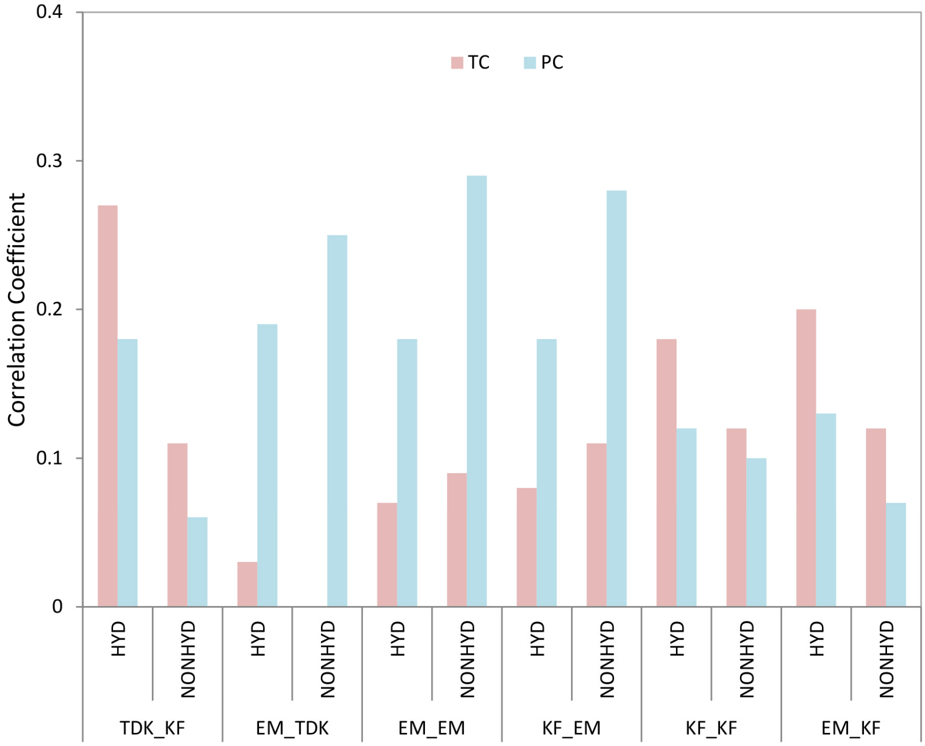


Figure 12 Spatial and temporal correlation of MJJA precipitation.

4.3 GRIMs-RMP

The physics package of the RMP used in this study is version 3.2 (See Table 1), which employs the Simplified Arakawa-Schubert (SAS) convection scheme (Hong and Pan 1998) for convective parameterization, a diagnostic microphysics scheme (Hong et al. 1998), the Yonsei University planetary boundary layer (YSUPBL) scheme (Hong et al. 2006), the National Centers for Environmental Prediction (NCEP)–Oregon State University–US Air Force–National Weather Service Office of Hydrologic Development (NOAH) land surface model (Chen and Dudhia 2001; Ek et al. 2003), and longwave (Chou et al. 1999) radiation parameterizations.

One of the distinctions from the other regional climate models used in this study is the application of the spectral nudging approach. To prevent the distortion of large-scale fields, the scale selective bias correction (SSBC) method has been applied (Hong and Chang 2012). Compared to other spectral nudging techniques (e.g., von Storch et al. 2000; Miguez-Macho et al. 2004; Bowden et al. 2011), the method proposed by Hong and Chang (2012) allows more freedom in the RMP by nudging only the large-scale vorticity component with a vertical weighting, which permits the lower troposphere component to be more ageostrophic.

The GRIMs-RMP result follows the precipitation pattern of the observations representing concentrated areas of orographic precipitation over New Guinea and the coastline (Fig. 13). Highly localized, narrow, and strong rainfall regions occur over the center of New Guinea, Indochina, and the Philippines (Fig. 14). This pattern arises due to convections generated by narrow mountain ranges (~1 km in height, ~500 km width), which are referred to as "meso-scale mountains" (Xie et al. 2006). Through satellite observation analysis and sensitivity experiments on a numerical model, Xie et al. (2006) determined that in addition to the Himalayas, the meso-scale mountains play an important role in the Asian monsoon system. Therefore, it is imperative that the regional climate model accurately captures these orographic characteristics.

The simulated precipitation follows the observed temporal evolution (Fig. 15, Table 5). Even though the GRIMs-RMP simulates more precipitation over the whole domain, the model reproduces daily variation (Fig. 15a). In addition, GRIMs-RMP simulation captures rainfall peaks in the Philippines (Fig. 15b).

Figure 16 shows the frequency of heavy rainfall events and the probability distribution of rainfall intensity obtained from the TMPA observation, and GRIMs-RMP simulation. Compared to the observed data results, the GRIMs-RMP tends to overestimate light precipitation (5–50mm/day). For moderate precipitation (50–100mm/day), the experiment slightly underestimates the probability relative to the observed data, while the model overestimates heavy rainfall (over 110mm/day). The GRIMs-RMP output provides a more realistic probability distribution over the Philippines (Fig. 16b).

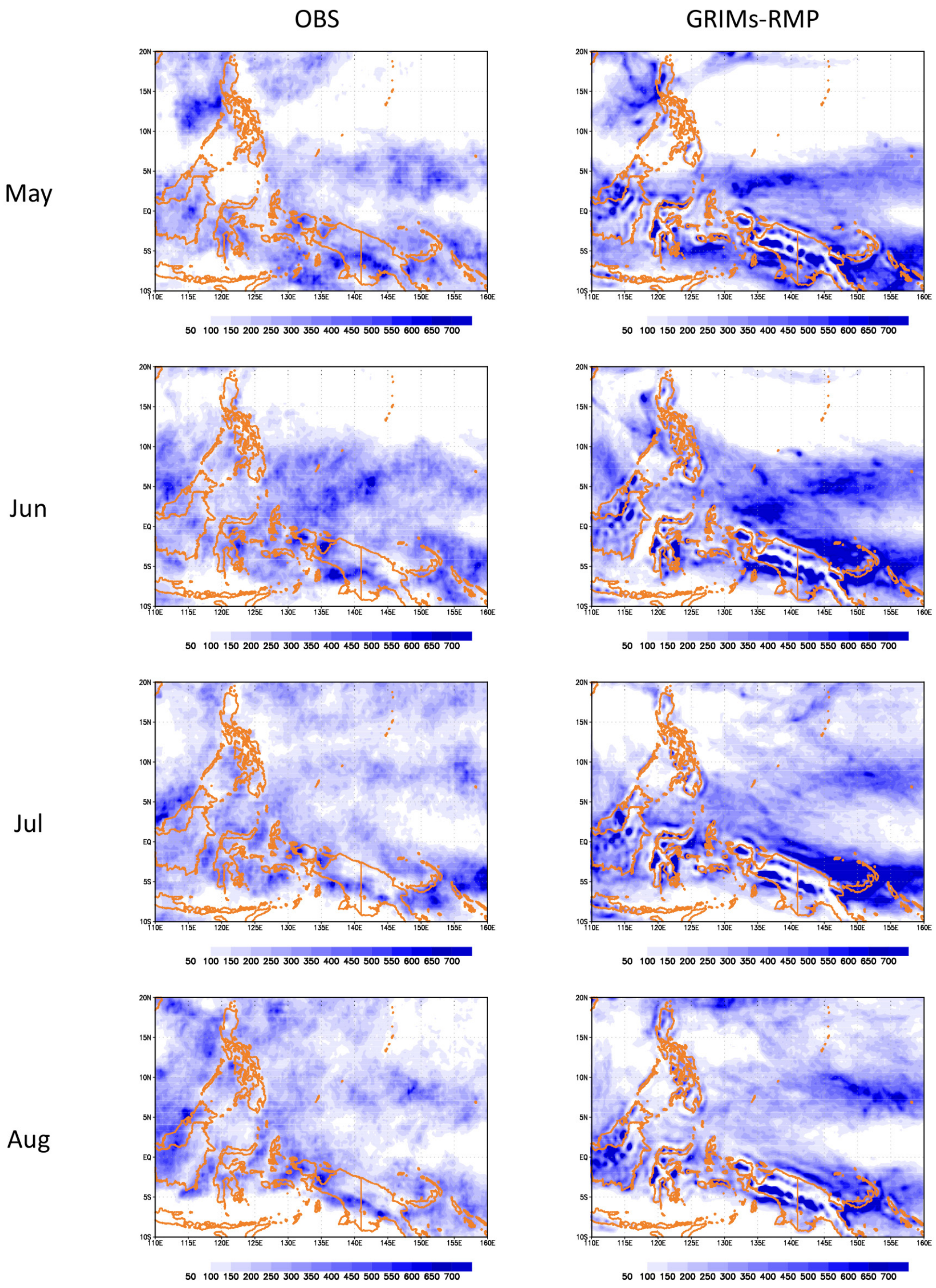


Figure 13 Monthly precipitation (mm) from observation and GRIMs-RMP simulation.

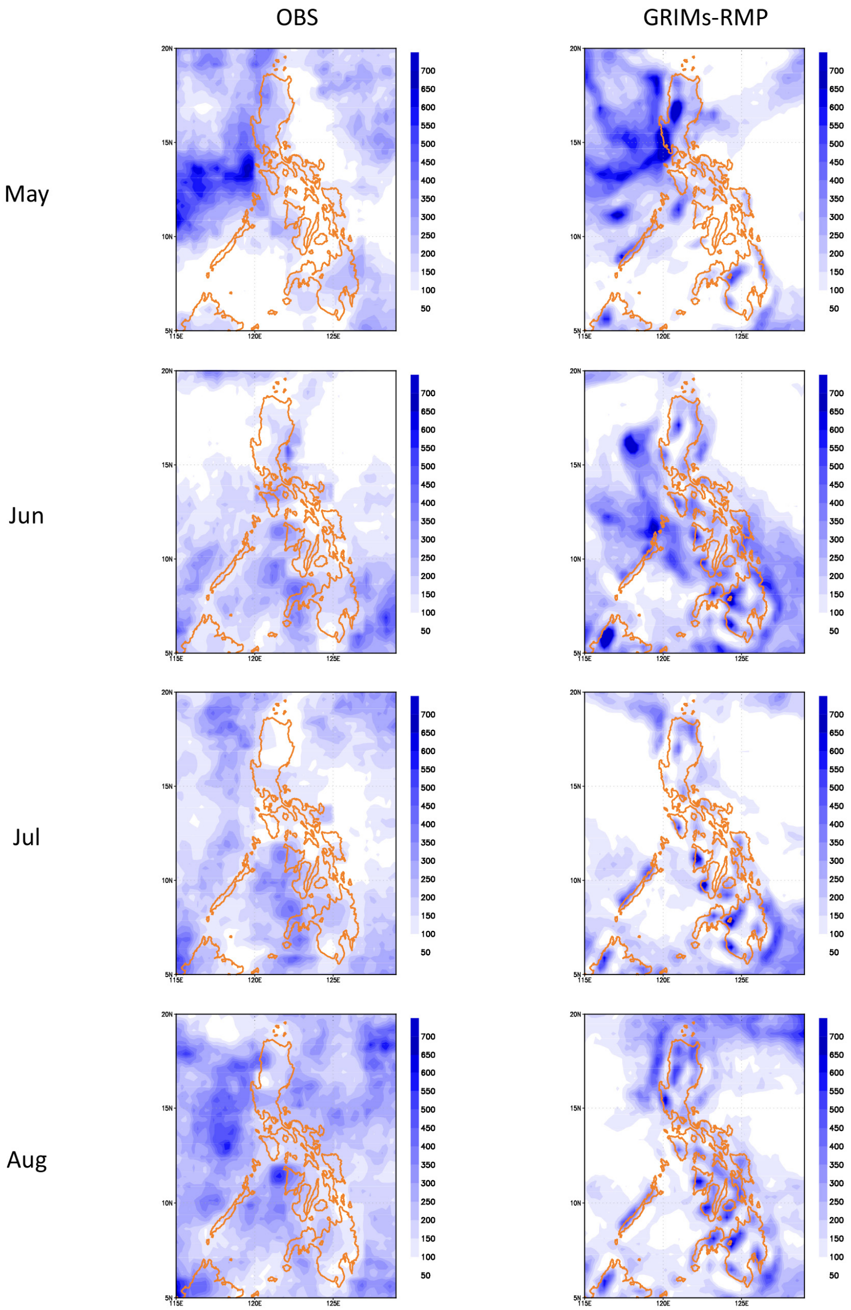
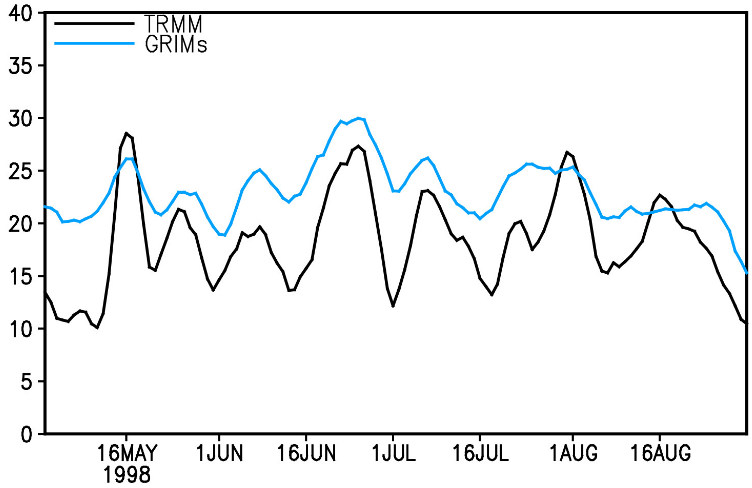


Figure 14 Same as in Fig. 25 except for over the Philippines

(a) Whole domain



(b) Philippines

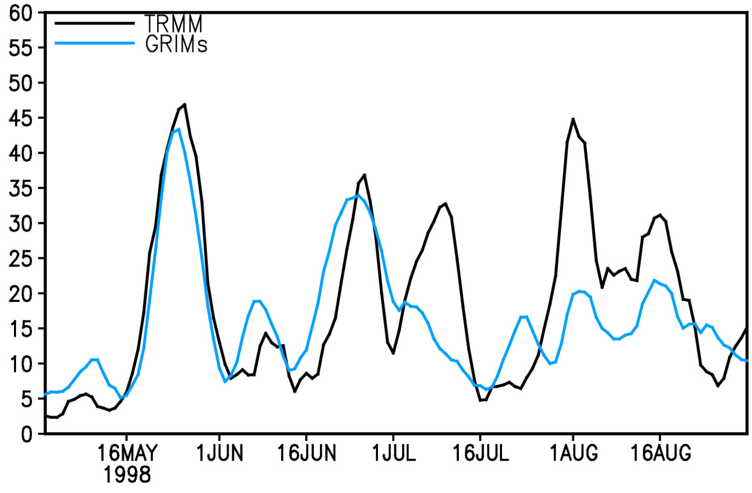


Figure 15 Time-series of 5-day running mean precipitation (mm/day) averaged over (a) whole domain, and (b) the Philippines.

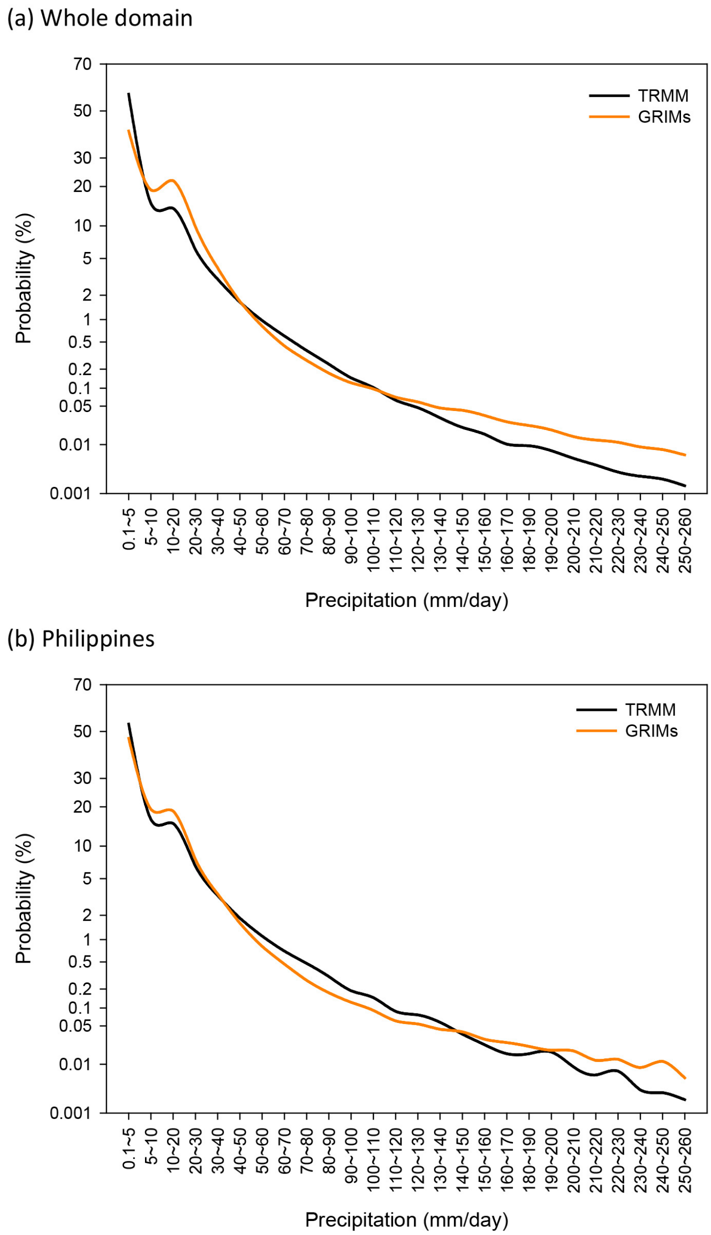


Figure 16　Probability distribution of precipitation averaged over (a) domain and (b) the Philippines.

Table 5 Root mean square error (RMSE) and correlation coefficients over the domain and the Philippines.

	RMSE		Spatial correlation		Temporal correlation	
	Whole domain	Philippines	Whole domain	Philippines	Whole domain	Philippines
May	6.30	4.17	0.52	0.56	0.73	0.73
Jun	6.60	4.57	0.58	0.38		
Jul	6.64	4.09	0.47	0.21		
Aug	5.76	5.26	0.42	−0.08		

5. SUMMARY AND DISCUSSION

This study is a pilot experiment of the APCC-PAGASA Regional Prediction System (APCC-PRePS) project. It aims to provide valuable high-resolution seasonal forecasts using downscaling techniques. The summary and discussion of the results are as follows.

[1] Although non-hydrostatic limited-area models are widely used for operational short-term weather forecasting and hydrostatic limited-area models are widely used for "regional climate downscaling", non-hydrostatic simulations that cover large regional areas and are integrated over seasonal timescales remain rare (Leung et al., 2003; Trapp et al., 2011; Zhang et al., 2009; Lebassi-Habtezion et al., 2011; Comarazamy and González, 2011; Zhao et al., 2011; Mahoney et al., 2012; Oglesby et al., 2010; Lucas-Picher et al., 2012). Non-hydrostatic treatments are important, especially where complex topography and thermal heating of unstable convective boundary layers (Molemaker and Dijkstra 2000) and cloud dynamics (Cotton and Anthes, 1989) are involved.

The results from parallel runs using the WRF and RegCM showed that the differences between the hydrostatic and non-hydrostatic model are found mostly over mountainous areas, even with a resolution of 30 km. It suggests that the non-hydrostatic effect with this resolution may not be negligible over mountains. Thus, the optimal resolution for running a non-hydrostatic model may not be easily determined by a static scale analysis. In the future, we will attempt to elucidate whether or not we have to pay extra computation resources to run the non-hydrostatic model for a given resolution through various simulations.

[2] Regional climate models are increasingly used to add small-scale features that are not present in their lateral boundary conditions. It is well known that the limited area over which a model is integrated must be large enough to allow the full development of small-scale features. On the other hand, integrations on very large domains have shown important departures from the driving data, unless large scale nudging is applied. Two experiments with the same resolution using the WRF were performed to study the issue of domain size.

The results showed that monthly precipitation and daily evolution in terms of spatial and temporal correlation generally improve when the domain size is reduced. When RCM simulations are restricted to use small domains (smaller than 100 × 100), underestimations in the small-scale transient variance must be expected over a great part of the domain. This effect can, however, be reduced when simulations are run over a region with strong orographic forcing or land-sea contrast that may enhance the accuracy of a regional climate model and correct some errors at small scales (Antic et al. 2004; Diaconescu et al. 2007; Leduc and Laprise 2009). If simulations over a larger domain are accessible, one must seriously consider the large-scale nudging method (e.g. Miguez-Macho et al. 2004) to prevent important departures from the driving data.

[3] Much of the precipitation occurring in the South Asian region, particularly during the summer season, is associated with convective cloud formation. These convective clouds play an important role in the development of the South Asian summer monsoon system by redistributing heat and moisture (Mohanty et al., 2005). Thus, an appropriate convective parameterization scheme can be used in dynamic models for realistic simulations. Numerous studies have shown that the regional climate simulations are very sensitive to the physical parameterization schemes employed, particularly over the tropics where convection plays a major role in monsoon dynamics (e.g., Dash et al., 2006; Singh et al., 2011; Srinivas et al., 2013).

Three convection schemes, namely, Emanuel, Tiedtke, KF, and their combinations (e.g., Emanuel over land and KF over the oceans) were compared in the RegCM at 30 km resolution. The results showed that the KF scheme over the oceans overestimates the MJJA precipitation, whereas the Emanuel and the Tiedtke schemes underestimate it. Extensive test experiments revealed that different schemes have different performance over different regions, particularly over land versus ocean areas (Giorgi et al. 2012). These preliminary tests suggested that a mixed convection approach by which, for example, the Tiedtke scheme is used over the oceans and the Grell scheme is used over land, might be the most suitable option to pursue. In addition, we can consider resolved scale precipitation. Traditionally, RegCM has shown a tendency to produce excessive precipitation, especially at high resolutions (Im et al. 2010, Torma et al. 2011), and optimizations of these parameters have proven effective at improving this problem (Torma et al. 2011).

[4] When the downscaling technique is applied, the common expectation is that the large-scale information resolved by the global model is retained, and the smaller-scale information resolved by the regional model is added to the large-scale solution. However, no regional model is perfect. Systematic large-scale errors due to regional model error can develop within the regional domain and contaminate the large-scale solution (Takle et al., 1999; Wang et al., 2004). As an alternate method to mitigate such errors, the technique of large-scale spectral nudging was proposed (e.g., von Storch et al., 2000; Kanamaru and Kanamitsu 2006).

The correlation coefficients of precipitation simulated by the GRIMs-RMP were overall closer to the observations than the other two models. The spectral nudging technique was only applied in the GRIMs-RMP simulation. It is difficult to compare the GRIMs-RMP results directly with the results from RegCM and WRF because the initial and boundary conditions were different. Considering these limitations, we nevertheless suggest that the adaptation of a large-scale nudging approach can be considered in other regional climate models.

6. FUTURE PLANS

APCC will have meet with PAGASA next year to discuss a detailed plan for the seasonal prediction system. Based on the preliminary results of this year, we will consider the potential use of three regional climate models within the PAGASA's supercomputer system. Figure 17 presents a flow chart used to decide the experimental design. The first question is how many CPUs can be used, because it is mandatory to calculate running time under available CPUs. Later, resolution, domain size, and simulated period (lead time) can be set. The other question is determining which is the most important component for accurate forecasts in the Philippines (e.g., intensity, frequency, amount, onset/offset, etc.). Evaluation metrics will be chosen accordingly.

Model inter-comparison will continue next year. First, a conversion program will be developed as a pre-process in RegCM to use CFSR data as an initial and boundary condition. To provide general conclusions, further experiments under various climates will be performed. In addition, large-scale circulations as well as precipitation will be evaluated.

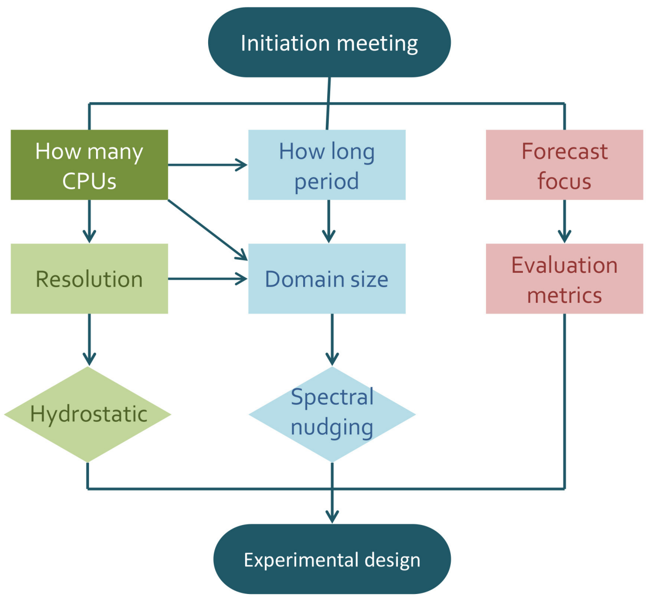


Figure 17　Flow chart to decide the experimental design

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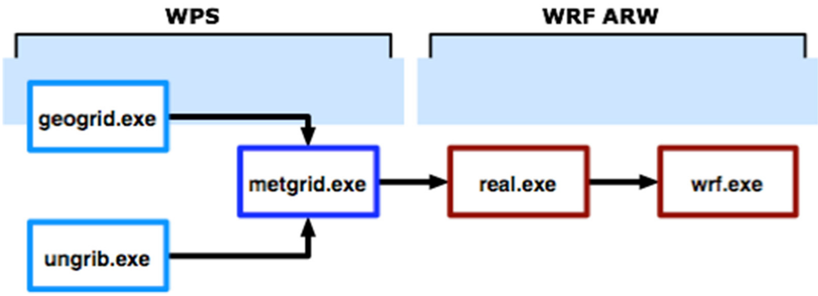
APPENDIX A. WRF MANUAL

Below is a depiction of the program flow during a typical model run.



WPS

geogrid.exe creates terrestrial data (static).

ungrib.exe unpacks GRIB meteorological data and packs it into an intermediate file format.

metgrid.exe interpolates the meteorological data horizontally onto your model domain.

Output from metgrid.exe is used as input to WRF.

WRF ARW

real.exe vertically interpolates the data onto the model coordinates.

wrf.exe generates the model forecast.

✓ How to run WRF

We have two directories: /WPS, /WRFV3

Move to /WRFV3 directory

1) Configure WRF

```
./configure
```

Choose the number for your computer

ex: 15. INTEL (ifort/icc) dmpar in APCC HPC

Once we have made this choice, we will be asked to choose the type of nesting run we are interested in:

```
Compile for nesting? (0=no nesting, 1=basic, 2=preset moves, 3=vortex following) [default 0]:
```

Choose the (1) basic

The above will create a *configure.wrf* file.

2) Compile WRF

```
./compile em_real >& compile.log
```

Check the *compile.log* file for any errors.

If our compilation is successful, we should see the following executables created in the *main/* directory:

main/ndown.exe
main/nup.exe
main/real.exe
main/wrf.exe

If you have problems with configure wrf, repeat the process:

```
./clean -a
./configure
./compile em_real >& compile.log
```

Move to /WPS directory

3) Configure WPS

```
./configure
```

Choose the number for your computer

ex: 19. Linux x86_64, Intel compiler (dmpar) in APCC HPC

The above will create a *configure.wps* file.

4) Compile WPS

```
./compile >& compile.log
```

Check the *compile.log* file for any errors.
Search for the word 'Error', with a capital 'E'.

If our compilation is successful, we should see the following executables created:

geogrid.exe
metgrid.exe
ungrib.exe

5) Geogrid

The purpose of GEOGRID is to define the simulation domain, and interpolate various terrestrial data sets to the model grids.

The simulation domain is defined using information specified by the user in the "share" and "geogrid" sections of the WPS namelist; See below and Edit *namelist.wps*.

```
&share
 wrf_core = 'ARW',
 max_dom = 1,Total number of domains
 io_form_geogrid = 2,Format of geogrid data (2: netCDF)
/

&geogrid
 parent_id = 1,Domain number, parent_id should be 1
 parent_grid_ratio = 1,Nesting ratio to the parent domain, parent_grid_ratio should be 1.
```

```
i_parent_start = 1,X and Y coordinates of the lower-left corner.
j_parent_start = 1,For the coarsest domain, a value should be 1.
e_we = 235,Number of west-east
e_sn = 140,and south-north grids
geog_data_res = '10m',Resolution of static terrestrial data
dx = 30000,Grid distance in the x
dy = 30000,and y directions
map_proj = 'mercator',Map projection of the domain
                      (ex: lambert, polar, mercator, lat-lon)
ref_lat = 3.0,Center point of the coarse domain in x
ref_lon = 135.00,and y directions
truelat1 = 2.5,First true latitude for the Lambert map projection
truelat2 = 60.0,Second true latitude for the Lambert map projection
stand_lon = -98.0,
geog_data_path = '/home/apcc/apcc03/WRF/geogDirectory of geographical data
```

```
./geogrid.exe
```

Output is ‘geo_em.d*xx*.nc’

6) Ungrib

The purpose of UNGRIB is to unpack GRIB (GRIB1 and GRIB2) meteorological data and pack it into an intermediate file format.

Unpacking the data is controlled via the "share" and "ungrib" sections of the WPS namelist.

a) For atmospheric variables:

Link the correct Vtable

```
ln -sf ungrib/Variable_Tables/Vtable.CFSR2_web Vtable
```

Link the input GRIB data

```
./link_grib.csh path_to_data
```

Output is *GRIBFILE.AAA, GRIBFILE.AAB, …, GRIBFILE.ZZZ.*

See below and Edit *namelist.wps*.

```
&share
 start_date = '1998-05-01_00:00:00',Start dates of the data you are unpacking
 end_date   = '1998-09-01_00:00:00',End dates of the data you are unpacking
 interval_seconds = 21600Frequency of incoming data (seconds)
/

&ungrib
 out_format = 'WPS',Intermediate file format
 prefix = 'FILE',Prefix to be used for intermediate files
/
```

Run ungrib.exe

```
./ungrib.exe
```

Output is 'FILE: *YYYY-MM-DD_HH*'

b) For SST:

Link the correct Vtable

```
ln -sf ungrib/Variable_Tables/Vtable.SST Vtable
```

Link the input GRIB data

```
./link_grib.csh path_to_data
```

Output is *GRIBFILE.AAA, GRIBFILE.AAB, …, GRIBFILE.ZZZ*.

See below and Edit *namelist.wps*.

```
&ungrib
 out_format = 'WPS',
 prefix = 'SST',
/
```

Run ungrib.exe

```
./ungrib.exe
```

Output is 'SST: *YYYY-MM-DD_HH*'

7) Metgrid

The purpose of METGRID is to horizontally interpolate the meteorological data onto your model domain.
Output from metgrid.exe is used as input to WRF.

Input to METGRID is the *geo_em.dxx.nc* output files from GEOGRID, and the intermediate output files from UNGRIB.

Edit *namelist.wps*

```
&metgrid
 fg_name = 'FILE','SST'Prefix used when intermediate files were created
 io_form_metgrid = 2,Format of metgrid data (2: netCDF)
/
```

Run metgrid.exe

```
./metgrid.exe
```

Output is 'met_em.d01.*YYYY-MM-DD_HH:00:00*.nc'

Move to /WRFV3/test/em_real directory

8) Real

This program vertically interpolates the *met_em** files (generated by metgrid.exe), creates boundary and initial condition files, and does some consistency checks.

Link the *met_em* files to this directory.

```
ln -sf path_to_met_em_files/met_em.d0* .
```

Edit *namelist.input*

```
&time_control
 run_days              = 124,
 run_hours             = 0,
 run_minutes           = 0,
 run_seconds           = 0,
 start_year            = 1998,
 start_month           = 05,
 start_day             = 01,
 start_hour            = 00,
 start_minute          = 00,
 start_second          = 00,
 end_year              = 1998,
 end_month             = 09,
 end_day               = 01,
 end_hour              = 00,
 end_minute            = 00,
 end_second            = 00,
 interval_seconds      = 21600Frequency of incoming data (seconds).
                            Must have met_em files for all times you are processing
 input_from_file       = .true.,
 history_interval      = 180,Frequency to write output data (wrfout; minutes)
 frames_per_outfile    = 1,How many times periods must be written to the output file
                         If 1, each file will contain 1 output time
 restart               = .false.,
 restart_interval      = 1440,
 io_form_history       = 2Output format for output / restart / input & boundary files
 io_form_restart       = 2(1: binary format, 2: netCDF, 4: PHDF5,
 io_form_input         = 25: GRIM1, 10: GRIB2, 11: parallel netCDF)
 io_form_boundary      = 2
 debug_level           = 0Larger values give increasing prints

 io_form_auxinput4     = 2IO format for wrflowinp (2: netCDF)
 auxinput4_inname      = "wrflowinp_d<domain>"Name of sst input
 auxinput4_interval    = 360,Frequency for sst boundary (minustes)
 /
```

```
&domains
 time_step                   = 180,Time step (seconds) for integration
                                   (recommended 6*dx in km for a typical case)
 time_step_fract_num         = 0,
 time_step_fract_den         = 1,
 use_adaptive_time_step      = .true.,
 step_to_output_time                   = .true.,
 target_cfl                            = 0.8,
 max_dom                               = 1,
 e_we                        = 235,
 e_sn                        = 140,
 e_vert                                = 51,
 p_top_requested             = 1000,Pressure top (Pa) to use in the model
 num_metgrid_levels          = 38,Number of vertical levels in WPS output
 num_metgrid_soil_levels     = 4,Number of soil levels or layers in WPS output
 dx                          = 30000,
 dy                          = 30000,
 grid_id                     = 1,
 parent_id                             = 1,
 i_parent_start              = 1,
 j_parent_start              = 1,
 parent_grid_ratio           = 1,
 parent_time_step_ratio      = 1,
 feedback                    = 1,
1: Feedback from nest to its parent domain, 0: no feedback (use for one-way nested runs)
 smooth_option            = 0
0: no smoothing, 1: 1-2-1 smoothing option for parent domain (with feedback=1), 2:
smoothing-desmoothing option for parent domain (with feedback=1)
 /
```

Run real.exe

```
./real.exe
```

Output is *wrfinput_d01, wrfbdy_d01, wrflowinp_d01*.

Edit *namelist.input* for physics

```
&physics
 mp_physics           = 6,Microphysics
 ra_lw_physics        = 3,Longwave radiation
```

```
 ra_sw_physics         = 3,Shortwave radiation
 radt                  = 30,Minutes between radiation physics calls
 sf_sfclay_physics     = 1,Surface layer
 sf_surface_physics    = 2,Land surface model
 bl_pbl_physics        = 1,Planetary boundary layer
 bldt                  = 0,Minutes between boundary layer physics calls
 cu_physics            = 1,Cumulus parameterization
 cudt                  = 5,Minutes between cumulus physics calls
 isfflx                = 1,
 ifsnow                = 1,
 icloud                = 1,
 surface_input_source  = 1,
 num_soil_layers       = 4,
 sf_urban_physics      = 0,

 sst_update            = 1,Read time-varying sst and update these fields
 /

&dynamics
 w_damping             = 0,Vertical velocity damping (0: no damping, 1: damping)
 diff_opt              = 1,Turbulence and mixing option
 km_opt                = 4,Eddy coefficient options
 diff_6th_opt          = 0,      0,      0,6th-order numerical diffusion
 diff_6th_factor            = 0.12,    0.12,    0.12,
 base_temp             = 290.
 damp_opt              = 0,
 zdamp                 = 5000.,  5000.,  5000.,
 dampcoef              = 0.2,     0.2,     0.2
 khdif                      = 0,       0,       0,
 kvdif                      = 0,       0,       0,
 non_hydrostatic   = .true., .true., .true.,Model in hydrostatic or non-hydrostatic mode
 moist_adv_opt         = 1,       1,       1,
 scalar_adv_opt             = 1,       1,       1,
 /

&bdy_control
 spec_bdy_width        = 10,Total number of rows for boundary nudging
                            (spec_zone + relax_zone)
 spec_zone             = 1,Number of points in specified zone
 relax_zone            = 9,Number of points in relaxation zone
 specified                  = .true.,
 nested                = .false.,Nested boundary conditions
```

```
 /
 spec_exp                  = 0.33

&namelist_quilt
 nio_tasks_per_group = 0,
 nio_groups = 1,
 /
```

Run wrf.exe using job scheduler.

```
qsub job
```

APPENDIX B. RegCM4 MANUAL

✓ How to run RegCM4

Move to /RegCM-4.5.0 directory

1) Configure RegCM4

Run the *configure* script giving as arguments the chosen compilers:

```
./configure CC=  FC=
```

CC = C compiler command
FC = Fortran compiler command

Ex: ./configure CC=icc FC=ifort in APCC HPC

The above will create a *config.log* file.
Check the *config.log* file for any errors.

2) Build RegCM4

```
make >& make.log
```

Check the *make.log* file for any errors.

To copy model tree (PreProc, Main and PostProc) to a *bin* directory in the model root:

```
make install
```

If our compilation is successful, we should see the following executables created in the *bin/* directory:

average chem_icbc emcre_grid GrADSNcPlot GrADSNcPrepare icbc interp_bionox interp_emissions interp_pollen regcmMPI regrid sigma2p sigma2z sst terrain

3) Setting up the run environment

Establish a convenient directory (*run/*, *input/*, and *output/*) on a disk partition with enough space to store the input and output files:

```
mkdir run
cd run
mkdir input output
```

Link the executable files and copy the input namelist file

```
ln -sf RegCM-4.5.0/bin  .
cp RegCM-4.5.0/Testing/test_001.in  .
```

See below and Edit *test_001.in*

a) dimparam namelist

This namelist contains the base X, Y, and Z domain grid information:

```
&dimparam
 iy     = 140,        Number of points in the N/S direction
 jx     = 246,        Number of points in the E/W direction
 kz     = 23,         Number of vertical levels
                 (hydrostatic : 18, non-hydrostatic: 23)
 nsg    = 1,          For subgridding, number of points to decompose
                 If nsg=1, no subgridding is performed
 /
```

b) coreparam namelist

This namelist controls dynamical core (hydrostatic or non-hydrostatic core)

```
&coreparam
 idynamic = 2,                 Choice of dynamical core (2: non-hydrostatic core)
/
```

c) geoparam namelist

This namelist is used by the *terrain* program to geolocate the model grid on the Earth's surface. The values here are used by the other model programs to lend consistency with the geolocation information written by the *terrain* program in the domain file.

```
&geoparam
 iproj = 'NORMER',          Domain cartographic projection (NORMER: Normal Mercator)
 ds = 30.0,                 Grid point horizontal resolution in km
 ptop = 5.0,                Pressure of model top in cbar
 clat = 3.0,                Central latitude of model domain in degrees
                  (North hemisphere is positive)
 clon = 135.0,              Central longitude of model domain in degrees
                  (East is positive)
 plat = 3.0,                Pole latitude (only for rotated Mercator Projection)
 plon = 135.0,              Pole longitude (only for rotated Mercator Projection)
 truelatl = 2.5,            Lambert true latitude (low latitude side)
 truelath = 60.0,           Lambert true latitude (high latitude side)
 i_band = 0,                Use this to enable a tropical band
 /
```

d) geoparam namelist

This namelist is used by the *terrain* program to know you want to generate the domain file. You can control its work using a number of parameters to obtain what you consider to be the best representation of the physical reality.

```
&terrainparam
 domname = 'R2_nonhydro',   Name of the domain or experiment(naming of input)
 smthbdy = .false.,         Smoothing control flag
                            (True: Perform extra smoothing in boundaries)
```

```
lakedpth = .false.,             If using lakemod (see below),
                                produce from terrain program the domain bathymetry
fudge_lnd   = .false.,          Fudging control flag, for landuse of grid
fudge_lnd_s = .false.,          Fudging control flag, for landuse of subgrid
fudge_tex   = .false.,          Fudging control flag, for texture of grid
fudge_tex_s = .false.,          Fudging control flag, for texture of subgrid
dirter = './input',             Output directory for terrain files
inpter = '$RegPath/globedat',Lambert true Input directory for surface dataset
/
```

globedat consist of *CLM*, *CLM45*, *SST*, *SURFACE* and *initial dataset*

CLM / *CLM45*: Global land surface characteristics datasets

SST: Global SST datasets

SURFACE: Static surface datasets (topography, land type classification and optionally lake depth and soil texture classification)

initial dataset: Initial and boundary conditions datasets (*EIN15*: era-interim, *NNRP2*: NCEP/NCAR Reanalysis version 2, etc..)

e) debugparam namelist

This namelist is used by all RegCM program to enable/disable some debug printout.

```
&debugparam
 debug_level = 1,  Currently value of 2 and 3 control previous DIAG flag
 dbgfrq = 3,       Interval for printout ( >= 3)
/
```

f) boundaryparam namelist

This namelist is the buffer zone control for relaxation and diffusion terms:

```
&boundaryparam
 nspgx  = 12,  Currently nspgx-1 represents the number of cross point slices on the
               boundary sponge or relaxation boundary conditions
 nspgd  = 12,  Currently nspgx-1 represents the number of dot point slices on the
               boundary sponge or relaxation boundary conditions
/
```

g) globdatparam namelist

This namelist is used by the *sst* and *icbc* programs. The *icbc* program is used to create initial condition and boundary conditions for the model itself.

```
&glodatparam
 ibdyfrq = 6,                         Boundary condition interval (hours)
 ssttyp = 'OI_WK',                    Type of SST (GISST, OISST, EIN15, etc..)
 dattyp = 'NNRP2',                    Type of global analysis datasets
                              (NNRP2: NCEP/NCAR Reanalysis version 2)
 gdate1 = 1998050100,                 Start date for ICBC data generation
 gdate2 = 1998090100,                 End date for ICBC data generation
 dirglob = './input',                 Path for ICBC produced input files
 inpglob = '$RegPath/globedat',       Path for ICBC global input datasets
/
```

h) restartparam namelist

This namelist allows you to control the time period the model is currently simulating in this particular run. You may want to split the longer runs for which you have prepared the ICBC's into shorter runs, to schedule HPC resource usage in a more collaborative way with other researcher sharing it: the RegCM model allows restart, so it is compatible with other research projects that may not have this advantage:

```
&restartparam
 ifrest   = .false. ,          If a restart
 mdate0   = 1998050100,        Global start
 mdate1   = 1998050100,        Start date of this run
 mdate2   = 1998090100,        End date for this run
/
```

i) timeparam namelist

This namelist contains the model's internal timesteps, used by the model as basic integration timestep and triggers for calling internal parametric schemes:

```
&timeparam
 dtrad    =  30.,              Time interval solar radiation calculated (minutes)
 dtabem  =  18.,               Time interval absorption-emission calculated (hours)
```

```
 dtsrf    = 600.,           Time interval at which land model is called (seconds)
 dt       =  60.,           Time step in seconds
/
```

j) outparam namelist

This namelist controls the model's output engine, allowing you to enable/disable any of the output file writeout, or to modify the frequency with which the fields are written in the files:

```
&outparam
 ifsave   = .true. ,   Create SAV files for restart
 savfrq   = 7200.,  Frequency in hours to create them
 lfatm   = .true. ,  Output ATM
 atmfrq   = 3.,       Frequency in hours to create ATM
 ifrad    = .true. ,  Output RAD
 radfrq   = 6.,       Frequency in hours to create RAD
 ifsrf    = .true. ,  Output SRF
 ifsub    = .true. ,  Output SUB
 srffrq  = 3.,        Frequency in hours to create SRF
 ifchem   = .false., Output CHE
 chemfrq = 6.,        Frequency in hours to create CHE
 dirout='./output'    Path where all output will be placed
/
```

k) physicsparm namelist

This namelist controls the model's physics:

```
&physicsparam
iboudy = 5,                    Lateral boundary conditions scheme
                            0 : Fixed
                            1 : Relaxation, linear technique
                            2 : Time-dependent
                            3 : Time and inflow/outflow dependent
                            4 : Sponge (Perkey & Kreitzberg, MWR 1976)
                            5 : Relaxation, exponential technique
ibltyp = 1,                    Boundary layer scheme
                            0 : Frictionless
```

```
                          1 : Holtslag PBL (Holtslag, 1990)
                          2 : UW PBL (Bretherton and McCaa, 2004)
icup_lnd = 4,             Cumulus convection scheme over land
icup_ocn = 6,             Cumulus convection scheme over ocean
                          1 : Kuo
                          2 : Grell
                          3 : Betts-Miller (1986) Does not work!
                          4 : Emanuel (1991)
                          5 : Tiedtke (1996)
                          6 : Kain-Fritsch (1990), Kain (2004)
igcc = 1,                      Grell scheme / Cumulus closure scheme
                          1 : Arakawa & Schubert (1974)
                          2 : Fritsch & Chappell (1980)
ipptls = 1,                    Moisture scheme
                          1 : Explicit moisture (SUBEX; Pal et al, 1974)
                          2 : Explicit moisture Nogherotto/Tompkins
iocnflx = 2,                   Ocean flux scheme
                          1 : Use BATS1e Monin-obukhov
                          2 : Zeng et al (1998)
                          3 : Coare bulk flux algorithm
ipgf = 0,                      Pressure gradient force scheme
                          0 : Use full fields
                          1 : Hydrostatic deduction with pert. temperature
iemiss = 0,                    Use computed long wave emissivity
lakemod = 0,              Use lake model
ichem = 0,                     Use active aerosol chemical model
scenario = 'A1B',              IPCC scenario to use in A1B, A2, B1, B2
                               or RCP scenario in RCP2.6, RCP4.5, RCP6, RCP8.5
idcsst = 0,                    Use diurnal cycle sst scheme
iseaice = 0,                   Model sea-ice effects
idesseas = 0,                  Model desert seasonal albedo variability
iconvlwp = 0,                  Use convective algo for lwp in the large-scale
```

l) subexparam namelist

This namelist controls the SUBEX moisture scheme. The parameters below are the ones currently used at ICTP:

```
&subexparam
 qck1land = .250E-03,     Auto-conversion rate for land
 qck1oce = .250E-03,      Auto-conversion rate for ocean
```

```
 cevaplnd = .100E-02,        Raindrop evap rate coef land
 caccrlnd =  3.000,          Raindrop accretion rate land
 cftotmax =   0.75,          Max total cover cloud fraction for radiation
/
```

m) emanparam namelist

This namelist is Emanuel Cumulus scheme control part:

```
&subexparam
 elcrit_ocn   = 0.0011D0,    Auto-conversion threshold water content (ocean)
 elcrit_lnd   = 0.0011D0,    Auto-conversion threshold water content (land)
 coeffr   = 1.0D0,           Coefficient governing the rate of rain evaporation
/
```

n) clm_inparm namelist

The CLM45 configuration requires a separate entry in the namelist input file:

```
&clm_inparm
 fpftcon = 'pft-physiology.c130503.nc',
 fsnowoptics = 'snicar_optics_5bnd_c090915.nc',
 fsnowaging = 'snicar_drdt_bst_fit_60_c070416.nc',
/
```

4) Create the domain file using *terrain*

Create the domain file to localize the model on a world region. The program which does this for us by reading the global databases is *terrain*.

```
./bin/terrain test_001.in
```

If our compilation is successful, we should see the following two files created in the *input/* directory:

$domname_DOMAIN000.nc   *$domname_LANDUSE*

5) Create the SST file using the *sst* program

To create the Sea Surface Temperature for the model, reading a global dataset. The program which does this for us is the *sst* program, which is executed with the following commands:

```
./bin/sst test_001.in
```

If our compilation is successful, we should see the following file created in the *input/* directory:

$domname_SST.nc

6) Create the ICBC file using the *icbc* program

To create the ICBC (Initial Condition, Boundary Conditions) for the model itself. The program which does this for us is the *icbc* program, executed with the following command:

```
./bin/icbc test_001.in
```

If everything is correctly configured up to this point, the model should print something on stdout, and the last line will be:

Successfully completed ICBC

If our compilation is successful, we should see the following five files created in the *input/* directory:

$domname_ICBC.1998050100.nc   *$domname_ICBC.1998060100.nc*
$domname_ICBC.1998070100.nc   *$domname_ICBC.1998080100.nc*
$domname_ICBC.1998090100.nc

7) Run RegCM4

Run *regcmMPI* using job scheduler.
ex. Job script:

```
#! /bin/csh -f
#=====================================================
#  This is a RegCM4 batch job script
#=====================================================

#PBS -N RegCM4
#PBS -q normal
#PBS -l select=60
#PBS -l place=excl
#PBS -o regcm.log
##PBS -l walltime=2:00:00

#--------------------------------------------------------------------
# Determine necessary environment variables
#--------------------------------------------------------------------

cd /RegCM-4.5.0/run
time mpirun -np 60 ./bin/regcmMPI test_001.in >& log.R2
```

qsub job

APPENDIX C. GRIMs-RMP MANUAL

✓ How to run GRIMs

We have three directories: /libs_rmp, /srcs_rmp, /runs_rmp

1) Compiling the library

Move to /libs_rmp directory and edit *configure-lib* variables as follows:

MACHINE = linux_intel	Machine type (hp, cray, linux_pgi, linux_intel, … etc)
MARCH = mpi	Machine CPU usage type (single, thread, mpi, hybrid)
INSTITUTION = apcc	Machine environment for job submit(nml,kma,ncar, …)
USERNAME = baram	Username

Create a *Makefile*:

```
./configure-lib
```

The above will create *machine.h*, *Makefile*, and *seddat_libs* files.

Compile the library codes:

```
make>& make.log
```

Check the *make.log* file for any errors.

When we want to change configuration variables:

```
make clean
```

and repeat the above processes.

2) Compiling the source codes

Move to /srcs_rmp directory and edit *configure-src* variables as follows:

LIBS_DIR = GRIMs/libs_rmp	Library directory(libs_rmp) location path
MODEL = rmp	Model type
	sph : spherical harmonics GMP
	dfs : double Fourier series GMP
	nim : non-hydrostatic icosahedral model (NOAA/ESRL)
	rmp : regional model program
	gop : global ocean-atmosphere model program
	rop : regional ocean-atmosphere model program
	smp : single column model program
	ssi : spectral statistical interpolation data assimilation
	gsi : grid point statistical interpolation data assimilation
VERSION = v3.2	Physics package option
MARCH = mpi	Machine CPU usage type. (Should be same as in *configure-lib*)

Create a *Makefile*:

```
./configure-src
```

The above will create *define.h*, *define_mpi.h*, and *Makefile* files.

If you want change the dynamics or physics option, modify *define.h*

Compile the source codes:

```
Make >& make.log
```

Check the *make.log* file for any errors.

If our compilation is successful, we should see the following executables created in the *bin/* directory:

chgr.x co2.x common.a common_par.a rchgdates.x rfcst_par.x rfcst.x rgmp.a rgmp_par.a rinpg.x rmpi.a rmpl.a rmpl_par.a rmtn.x rpgb.x rpgb_par.x rsgb.x sfc0.x sfcl.a sfcl_par.a share.a

When we want to change configuration variables:

```
make clean
```

and repeat the above processes.

3) Running GRIMs

a) Edit *configure-run*

Move to /runs_rmp directory and edit *configure-run* variables as follows:

SRCS_DIR = `pwd`/../srcs_rmp	Source code (srcs_rmp) directory
OUTPUT_DIR = `pwd`	Output data directory
POST_DIR = `pwd`/post	Post-processes directory
WAVE = 254	Wave number(for GMP: SPH, DFS, and SSI)
MODEL_LAYER = 28	Number of model vertical layer (18, 28, 42, 64, 128)
POST_IGRD = 720	Number of pressure output x-axis
POST_JGRD = 361	Number of pressure output y-axis
POST_LAYER = 17	Number of pressure output level (12, 17, 21, 26, 30)
RMP_MAP = ./rmp_domain/rmp_243x141_30km_mer.philippines	Domain map projection information location path
IGRD = 243	Number of regional x-axis grids (domain)
JGRD = 141	Number of regional y-axis grids (domain)
ILONF = 768	Number of longitude grids of input surface file
ILATG = 384	Number of latitude grids of input surface file
IJCAP = 254	Wave number of input atmosphere file
ILEVS = 28	Number of vertical level of input atmosphere file
NCPUS = 1	Number of CPUs or threads ('MARCH' is not 'single')
NPES = 60	Number of processes ('MARCH' is 'mpi' or 'hybrid')
NCPU_PER_NODE = 12	Number of CPUs for each node
NCOL = 5	Number of separating columns of grids in horizontal domain when 'MARCH' is 'mpi' or 'hybrid'

To choose the RMP domain (RMP_MAP), namelists in 'runs_rmp/rmp_domain' are used. Namelists include domain information such as 'rmp_*east-west grid number*x*north-south grid number_deltax_map projection.area*':

$rdomain	
igrd = 243	Number of regional x-axis grids
jgrd = 141	Number of regional y-axis grids
proj = 0	Mapping projection index 0 : Mercator projection(mer) 1 : North polar stereographic projection(nps) -1 : South polar stereographic projection(sps) 2 : North lamber conformal conic projection(lcc) -2 : South lamber conformal conic projection(lcc)
truth = 15.0	Latitude where the map plane cuts through the earth's surface

```
cotru = 30.0              Latitude where the map plane cuts through the earth's surface
                          (only for lcc projection)
orient = 147.0            Domain orientation longitude
delx = 30000.             Grid spacing in meter in x-direction at TRUTH
dely = 30000.             Grid spacing in meter in y-direction at TRUTH
cenlat = 2.               Reference latitude
cenlon = 135.             Reference longitude
xleftgrd = 121.0          A grid number in x-direction from orient to left-lower corner
botmgrd = 70.0            A grid number in y-direction from pole to domain bottom or
          from center to domain bottom(mer)
$end
```

Ex. ./rmp_domain/rmp_243x141_30km_mer.philippines

b) Edit main run template script (*rsim.in*)

Move to /expsrc directory and edit *rsim.in* variables as follows:

```
RUNNAME = 1998_MJJA                 Name of model run.
EXPDIR = @OUTPUT_DIR@/$RUNNAME           Output data directory
SYYYYMMDDHH= 1998050100                  Starting forecast date (10-digit)
EYYYYMMDDHH= 1998083118                  Ending forecast date (10-digit)
SIGDIR='sigma and surface data path'  Sigma and surface input data location path
SSTDIR='SST data path'              Sea surface temperature input data location path
INITIAL_SIG_GLB=$SIGDIR/sig.anl.$SYYYYMMDDHH.ieee
INITIAL_SFC_GLB=$SIGDIR/sfc.anl.$SYYYYMMDDHH.ieee
                                    Initial boundary forcing files name
BASE_SIG=$SIGDIR/sig.anl.\$YYYYF\$MMF\$DDF\$HHF.ieee
                                    Boundary forcing files name
SST_ANL=$SSTDIR/gisst22.\$YYYYF.daily     SST forcing files name
SST_ANL_T0=$SSTDIR/gisst22.$YYYYS.daily  SST forcing files at the initial time
NESTING_HOUR=6                      Nesting time interval from the global files in hours
DELTAT_REG_'season'=                Model time step in second. It is prescribed in
                                    'configure-run' according to the model resolution
```

c) Make main run script

```
./configure-run   rsim
```

The above will create *cvar.env*, *namelist.rsim*, and *rsim* files.

d) Running model

```
./rsim >& print_log &
```

Check the *print.log* file for any errors.

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