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An Experimental Numerical Weather Prediction in Indochina Region with a Meso-Scale Model

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Synopsis

We perform a downscaling hindcast experiment in Indochina region with a fine-mesh meso-scale regional model under the assumption of the "perfect forecast" produced by a global numerical weather prediction model. The experiment is done for July and August in the wet Southwest Monsoon period. Validations of the downscaling hindcasts are done with surface station data of temperature and accumulated rainfall in Lao PDR. Some improvements in the downscaling hindcast are attained as a result of the better resolution of the surface topography. Further application of this kind of downscaling forecasts is discussed.

Keywords: Numerical weather prediction, Indochina region, meso-scale model, downscaling

1. Introduction

The climate of Lao PDR in Indochina (e.g., Thalongsengchanh and Sokhathammavong, 2002) is tropical with distinct dry and wet seasons corresponding to two major wind regimes similar to that observed in South East Asia i.e. the Northeast Monsoon which prevails during November to March and the Southwest Monsoon which are active from May to September. In addition, there are transition periods during the boreal spring (April) and autumn (October). The driest season in Lao is characterized by low temperature, low-level cloudiness, and low visibility but there are still many days with light rain or drizzle.

Being an inland country, Lao PDR is protected from strong wind and typhoon-induced storm surge. However, active monsoon and tropical depressions during the Southwest Monsoon period have very often brought heavy rainfall due to the dynamic cooling and orographic lifting effects of the western side of the mountain range along the Lao-Vietnam border.

Weather conditions during the wet season in Lao have large year-to-year variations with potential water-related disasters such as flooding and drought. Statistical records from 1966 to 2004 show that floods have caused more damages. The flood frequency of the Mekong Mainstream River has been widely discussed under Mekong River Commission Secretariat (MRCs) on the Water Utilization Program (WUP) of Lower Mekong Basin Mainstream. A variety of statistical models to forecast by using hydrological data have been proposed from each country along Mekong River and Indochina Region.

In Lao PDR, seasonal forecast schemes have evolved over periods through trial and error. Current forecasts schemes rely on various predictors and their relative influence on the future state of event. El Nino/Southern Oscillation (ENSO) has been one of the major drivers of climate variability in most parts of South East Asia. The prediction of El Nino several months to one year in advance will provide greater opportunity to improve seasonal prediction schemes. However, it will also depend on capacity of each nation to downscale the ENSO parameters with reference to local micro-climate conditions and to translate the information into a usable format for users. For example, statistics based on long-term characteristics of ENSO and other interannual variations are very informative on its relationship with hydro-meteorological phenomena.

Operational forecasts from monthly to seasonal time scales based on numerical model output are available at global scale. However, information with more sufficient spatial resolution is needed in the estimation of hydrological afflux, particularly river run-off that may potentially produce severe floods under extreme weather conditions. This study is the first attempt to apply a meso-scale Numerical Weather Predictions (NWP) model for weather or climate forecasting in Lao PDR. The main concern of this work is to validate the model performance through dynamical downscaling of the global model output for weather forecasting in Indochina region.

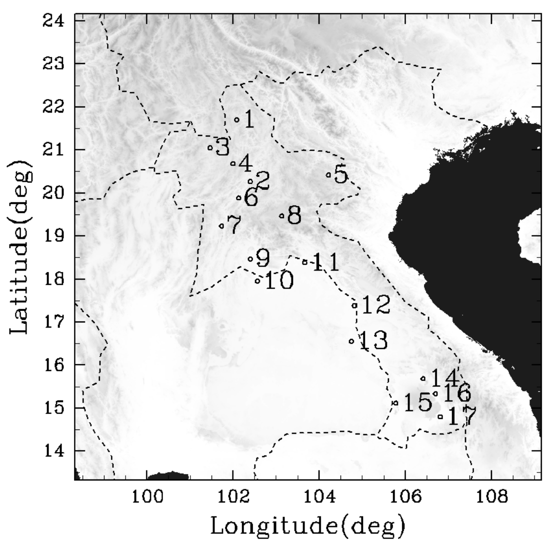

Fig. 1 Map of Lao PDR and neighboring countries with terrain. The locations of 17 observation stations of which data are used in this study are plotted.

In this study, we perform downscaling hindcast experiments for several months in the wet Southwest Monsoon period under the assumption of the "perfect forecast" produced by a global NWP model. The downscaling is done with a fine-mesh meso-scale regional model. Validations of the downscaling hindcasts are carried out using surface station data of temperature and accumulated rainfall in Lao PDR. Figure 1 shows the map of Lao PDR and neighboring countries; terrain height and the locations of 17 observation stations of which data are used in this study are also depicted.

2. Model and numerical procedures

We use the Fifth-Generation NCAR/Penn State Mesoscale Model (MM5), which is a non-hydrostatic regional model nested to a global dataset. The model domain covers the Indochina Region including the South China Sea (85°E – 125°E in longitudes and Equator – 30°N in latitudes) on a Mercator projection as shown in Fig. 2 (top). The computational domain has 230×170 grids with the grid distance of about 20 km. The model has 23 vertical levels from the surface to 100 hPa with nonuniform vertical resolutions. We used a cumulus parameterization scheme "Kain-Fritsch 2" and micro-physics "Mixed-Phase" with rain, cloud water, ice, and snow. Both longwave and shortwave radiation are calculated, including longwave radiation from clouds.

The model set-up is in general similar to that has been used by Otsuka and Yoden (2005) and Hadi et al. (2005). As model input, we use the NCEP Global Troposphere Analysis (FNL) for the initial condition as well as lateral boundary conditions which are necessary for the entire time-integration period. The NCEP FNL has 1×1 degree resolution and available at 6 hr time interval. We split time integration into 5-day sub integrations. Model output is stored every 3-hour simulation time. Results from consecutive 4-day integrations (after the initial one day is discarded) are then combined to get longer period of hindcast.

To demonstrate the model performance, Fig. 2 (top) shows an example of outgoing longwave radiation (OLR) produced by the model at 09 UTC 17 August 2004, after 33 hours from the initial time of the integration. The horizontal distribution of OLR shows similar patterns as the infrared image of geostationary satellite picture at the same time as shown in Fig. 2 (bottom), which is available online (e.g., Kochi Univ. "Weather home"). In this case, cloud band structures and clusters over Indochina region are particularly well represented by the model. Thus, we further perform the time integrations from July to August (which is the wet season of Southwest Monsoon) in 2002 and in 2004.

3. Results

3.1 Surface temperature hindcasts in August 2004

We firstly analyze the model output data of August 2004 and examine the hindcast results by comparing with the coarse NCEP FNL based on the observation data at 17 main synoptic surface stations in Lao PDR.

Figure 3 shows the day-to-day variations of the daily averaged surface temperature for observation (thick solid line), the MM5 output (thin solid line), and NCEP FNL (dashed line) at Station No. 4 in the northern part of Lao PDR with the latitude 20°41'N, the longitude 102°00'E, and the altitude 636 m above msl. As it is shown by the scatter diagram of Fig. 4, correlation between the surface observation and the MM5 output is as high as 0.708. This is higher than the correlation between the observation and NCEP FNL. Note that the cold bias of about 2K of the NCEP FNL is largely reduced in the MM5 hindcasts. This improvement is mainly due to the better resolution of the topography in the mountain area

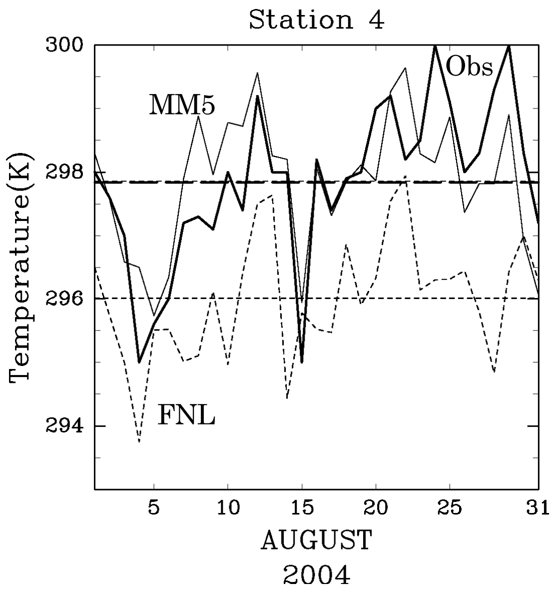

Fig. 3 Day-to-day variations of the daily averaged surface temperature in August 2004 at Station No. 4 for the three datasets: observation (thick solid line), the MM5 output (thin solid line), and NCEP FNL (dashed line).

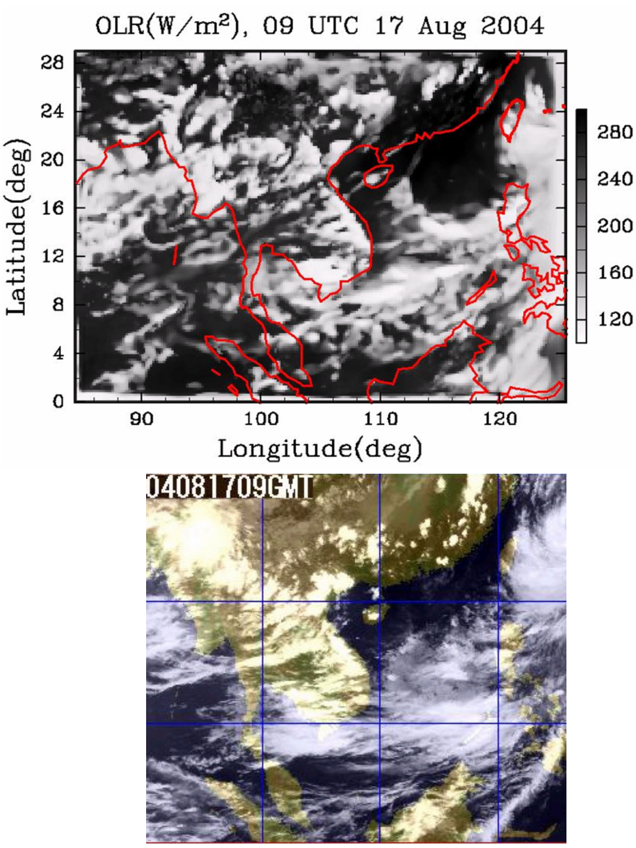

Fig. 2 Outgoing longwave radiation (OLR) at 09 UTC 17 August 2004: (top) the MM5 model output, (bottom) satellite observation (Kochi Univ. "Weather home").

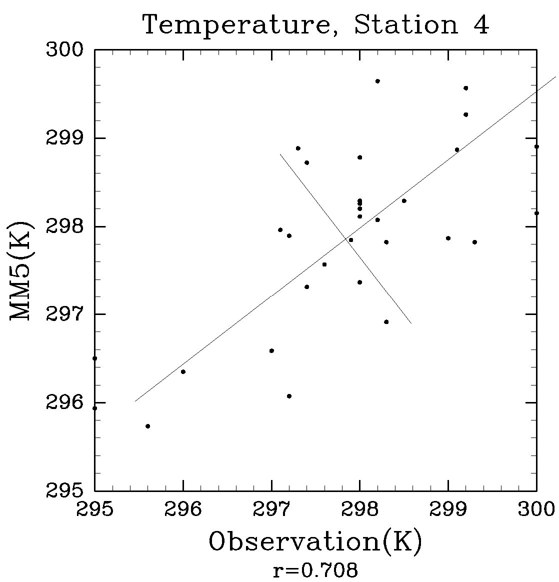

Fig. 4 Scatter diagram of the day-to-day variations of the daily averaged surface temperature in August 2004 at Station No. 4 between the observation and the MM5 output.

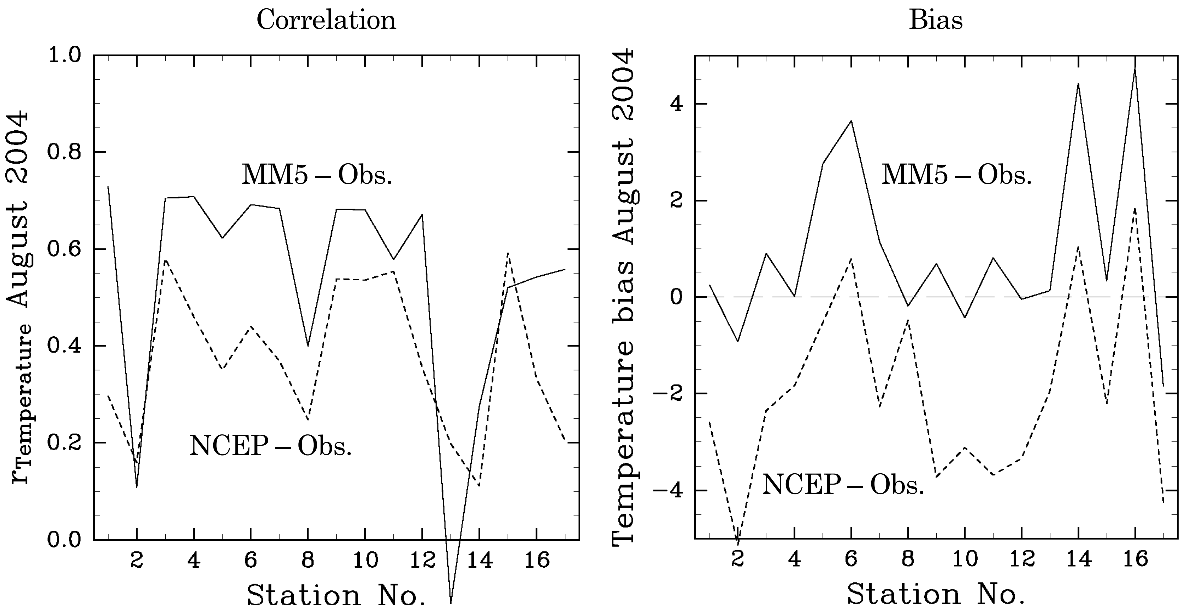

Fig. 5 Correlations (left panel) and biases (right panel) between the surface observation and the MM5 output (solid line) and those between the surface observation and NCEP FNL (dashed line) at all the 17 stations.

of the northern part of Lao.

In Fig.5, correlations and biases between the surface observation and the MM5 output (solid line) at all the 17 stations are compared with those between the surface observation and NCEP FNL (dashed line). By the downscaling hindcasts with MM5, correlation increases and bias becomes close to zero at most stations except some stations in the southern part, e.g., Station 13. This station is located in a gap area between plain and mountains near the Lao-Cambodia border with the latitude 16° 33'N, the longitude 104° 45'E, and the altitude 144 m above msl. The exact reason for the poor result of downscaling hindcast in this region is yet to be investigated. Nevertheless, better correlation and reduced bias in most stations has prospective indicators of the present downscaling method.

3.2 Rainfall hindcasts in August 2004

We performed similar analysis methods for accumulated rainfall. Figure 6 shows the day-to-day variations of the daily rainfall for observation (thick solid line) and the MM5 output (thin solid line) at Station No. 4 in the northern part of Lao PDR. Three of four major peaks of heavy precipitation in this month is well simulated. The scatter diagram (not shown) for these time series indicates that the correlation between the surface observation and the MM5 output is as high as 0.626.

High correlation in the daily rainfall is also obtained for some other observation stations as shown in Fig. 7. The correlation is greater than 0.5 at most of the stations in the northern part, and the highest value exceeds 0.9 at Station 7. These high correlations in the wet Southwest Monsoon period are very impressive, because we generally expect the predominance of small scale features in the spatial pattern of heavy precipitation.

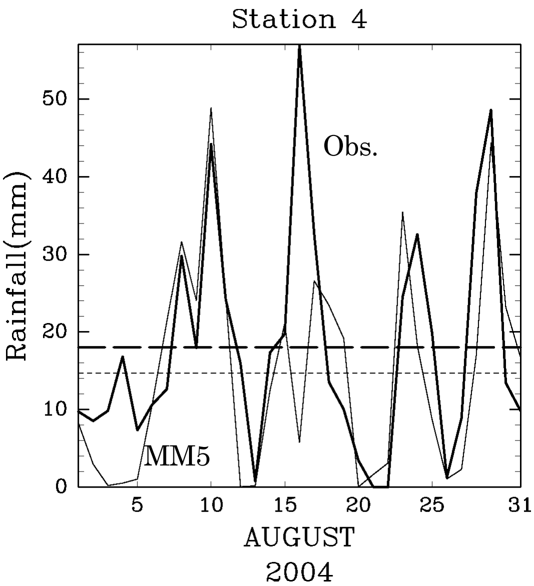

Fig. 6 Day-to-day variations of the daily rainfall in August 2004 at Station No. 4 for the two datasets: observation (thick solid line) and the MM5 output (thin solid line).

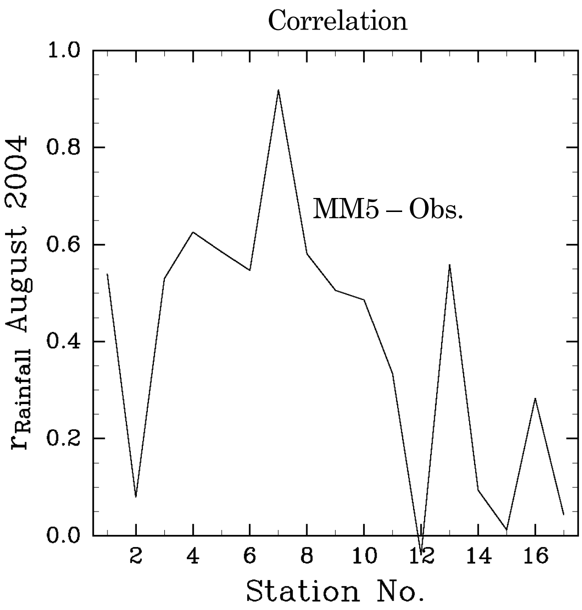

Fig. 7 Correlations of daily rainfall between the surface observation and the MM5 output at all the 17 stations.

3.3 Another month or another year

We have also analyzed the MM5 output of July 2002, July 2004, and August 2004 in the same way. Figure 8 is the summary of the four experiments: Correlations between the surface observation and the MM5 output (solid line) and those between the surface observation and NCEP FNL (dashed line) at all the 17 stations for (a) July 2002, (b) August 2002, (c) July 2004, and (d) August 2004. The last panel (d) is identical to Fig. 5 (left). From this figure it is clear the present downscaling method does not always guarantee better results compared with the original coarse NCEP FNL. In July of both 2002 and 2004, the NCEP FNL already has high correlations of about 0.7, so that improvement by the downscaling method is rather limited.

Careful diagnoses of the synoptic- and meso-scale flow fields on daily basis are very necessary for each month and year in order to understand the time variations of the effectiveness of the downscaling method, particularly for the poor result in August 2002.

4. Concluding remarks

In this study, we performed a downscaling hindcast experiment in Indochina region with a fine-mesh meso-scale regional model for July and August in the wet Southwest Monsoon period in 2002 and 2004. This is a first attempt in Lao PDR to use an advanced meso-scale model MM5 under the assumption of the "perfect forecast" using NCEP Global Troposphere Analysis (FNL). Validations of the downscaling hindcasts were done with 17 surface station data of temperature and accumulated rainfall in Lao. The higher correlations between surface observations and the downscaling model outputs in surface temperature and rainfall were obtained in some sub-periods and some stations in Lao. In some months and stations the downscaling method showed some improvements in correlation and bias as shown in Fig. 5 compared to the original NCEP FNL. This is a result of the better resolution of the surface topography in the meso-scale model.

We need further tunings of the MM5 to get better score in other months or years, for example, as shown in Fig. 8, by finding an optimal distribution of numerical grids within the given computer resources and by choosing the best combination of schemes for sub-grid scale parameterizations and their constant parameters. We have to pay attention to hot and humid conditions in the tropics in the latter tuning process.

We used surface observation data only in Lao PDR for validation. If we could use the data observed in neighboring countries as well, we can argue the appropriateness of the tuning and validation based on more independent data sampled in a wider region including some countries of Indochina region or Asian monsoon countries. Coordination of the exchange of observed data between these countries will bring better results in developing numerical weather prediction models and implementing operational numerical weather forecasting in Indochina region. In this study we compared surface temperature and accumulated rainfall for validation, but we would like to analyze other important meteorological quantities, e.g., dew point temperature, wind speed/direction, surface pressure or sunshine etc. We need to collect and archive these observation data over Asian monsoon countries for as many years as possible not only for the wet Southwest Monsoon periods but also for the dry Northeast Monsoon periods.

In this study, we did not pay much attention for the formation factors of heavy rainfalls during the wet Southwest Monsoon season, but they are interesting scientific subjects using a high-resolution meso-scale model in the tropics. Organization of cloud clusters and

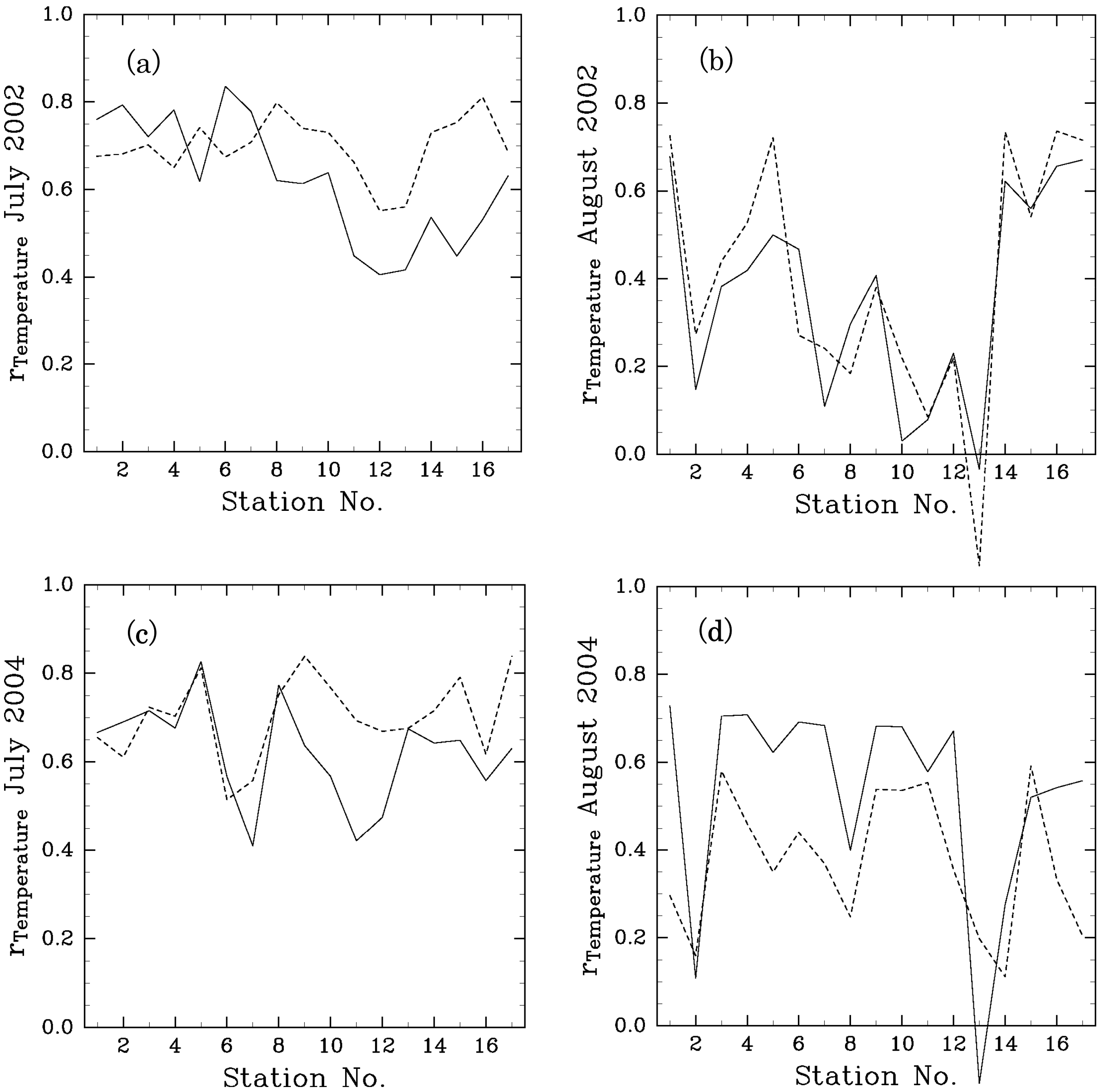

Fig. 8 Correlations (left panel) and biases (right panel) between the surface observation and the MM5 output (solid line) and those between the surface observation and NCEP FNL (dashed line) at all the 17 stations.

their multi-scale interactions including complicated lower boundary in the tropics have diversity in the appearance, and the understanding of the highly nonlinear interactions in which moist processes play important roles is a big challenge in the contemporary tropical meteorology. We did not show horizontal distributions of any field of temperature or rainfall and their time evolutions, but quick look on these fields raises much interesting both from basic science and operational application.

Operational real-time forecasts should be done every hour or so for high-impact meso-scale weather of heavy rainfall or tropical cyclones (e.g., Bender et al., 1993; Falcovich et al., 1995; Nagata et al., 2001), but the current internet infrastructure is not very enough for the data access to the operational global forecast results for such a short time interval. A dream in these days is to have such an operational global forecast center in the South East Asia. Practically the downscaling method could be applied for long-range forecasts firstly, because we have enough lead time for one-month or seasonal forecasts. Slow data access to global operational centers is permissible for the last week of one-month or seasonal forecasts. Data assimilation of locally obtained data such as Doppler radar observations in meso-scale numerical weather prediction is another important subject for the operational real-time forecasts.

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