Potential of representing the diurnal cycle of local-scale precipitation in northeastern Thailand using 5-km and 2-km grid regional climate models

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Abstract:

The diurnal cycle of precipitation over northeast Thailand during the Southeast Asian summer monsoon season was examined using non-hydrostatic (5-km grid) and convection-permitting (2-km grid) regional climate models. The results indicate that these fine grid models exhibit a better performance in terms of representing the diurnal cycle of precipitation due to the realistic orographic representation. The models successfully simulated the local circulation corresponding to the intensification of precipitation and were consistent with the satellite-based observed diurnal cycle of precipitation. The model simulation indicated that the convergence area over the mountain on the south of the Khorat Plateau occurred in the afternoon in association with the occurrence of precipitation. The convergence area migrated northward and contributed to the precipitation peak over the plateau during the nighttime. A bias in terms of the amount of precipitation in the 5-km grid model was partially removed through the convection-permitting 2-km grid model.

KEYWORDS Thailand; diurnal cycle of precipitation; convection permitting model; Indochina Peninsula; NHRCM; dynamical downscaling

INTRODUCTION

In subtropical regions, hydrological cycles are characterized by diurnal cycles in precipitation (e.g. Wallace, 1975; Murakami, 1983; Nitta and Sekine, 1994; Nakaegawa et al., 2019), streamflow (Lundquist and Cayan, 2002), and sap flow (Kume et al., 2006). The diurnal cycles in precipitation are largely due to the specific orographic effects or the land–sea contrast (Yang and Slingo, 2001; Ohsawa et al., 2001). The mechanisms related to the diurnal cycles in precipitation have been assessed using in-situ or remote sensing data systems such as satellite-based systems (Satomura, 2000; Okumura et al., 2003; Mori et al., 2004; Arakawa and Kitoh, 2005; Wu et al., 2009; Hara et al., 2009). Satomura (2000) applied a two-dimensional non-hydrostatic numerical model and found that the peak of the precipitation observed at around midnight in the northern Indochina Peninsula moved eastward as it organized as a convective cloud system during the nighttime. This was later confirmed through the analysis of the attendant radar echoes (Okumura et al., 2003). Elsewhere, Takahashi et al. (2010) investigated the diurnal cycle in precipitation using tropical rainfall measuring mission-precipitation radar (TRMM-PR) data and demonstrated that the precipitation peak occurred in the early afternoon in the mountain ranges and along the coast, while the peak at the foot of the mountains or in the plane occurred in the evening and then retreated before midnight. However, the diurnal cycle of convective activity over northeastern Thailand has not been fully addressed, including the attendant mechanism.

In Southeast Asia including Thailand, CORDEX-East Asia experiments have been conducted using 25-km grid regional climate models (Tangang et al., 2020; see also Supplement Text S1). However, a 25-km resolution is too low to represent the sub-daily precipitation (Takayabu et al., 2016). In fact, Niu et al. (2019) analyzed the CORDEX-East Asia products and suggested that the insufficient representation of the precipitation process in the models influences the probabilistic density function or the intensity of the precipitation. Furthermore, several studies demonstrated that the parameterization of the precipitation influences the representativeness of the diurnal cycle in precipitation (e.g. Hara et al., 2009). Here, we focus on the representativeness of the diurnal cycle in precipitation over northeastern Thailand using a 5-km grid non-hydrostatic model (Arpornrat et al., 2018) and a 2-km grid convection-permitting model (CPM).

METHODS

Model

A 5-km grid non-hydrostatic and 2-km grid convection-permitting regional climate model system (NHRCM; Sasaki et al., 2011; Ishizaki et al., 2012) was used. The Meteorological Research Institute (MRI) has developed NHRCM from the Non-Hydrostatic Model (NHM) then operationally used in the Japan Meteorological Agency

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(JMA). This development is intended for long-term simulation such as for future climate projection under global warming (Sasaki et al., 2011).

The Kain–Fritsch convective parameterization scheme (Kain and Fritsch, 1993) was used for the NHRCM05 or NHRCM with 5-km grid spacing, while the NHRCM02 or NHRCM with 2-km grid spacing was employed as a CPM. The cloud microphysical scheme used in NHRCM consists of cloud ice, snow, and graupel (Ikawa and Saito, 1991) based on Lin et al. (1983). Further details are found in Saito et al. (2001).

The MRI-JMA Simple Biosphere scheme (MJ-SiB) is implemented in NHRCM to simulate the land-surface hydrological process, land surface temperature, snow depth, and others (Hirai et al., 2007) and is suitable for long-term simulations. The land surface properties of the MJ-SiB such as properties of the land surface radiation, soil, and vegetation are assigned as a function of land covers with 13 categories retrieved from visible imagers boarded on a satellite, although such a dataset contains some uncertainties (Nakaegawa, 2011).

Here, we first employed NHRCM05 over the Indochina Peninsula, which was driven by a 20-km grid atmospheric general circulation model (MRI-AGCM3.2) in order to project future climate changes (Arpornrat et al., 2018), and then NHRCM02 was nested in the NHRCM05 (Figure 1). The spectral boundary coupling method is applied to the field of horizontal winds and air temperature above a height of 5 km every 20 min (Kida et al., 1991). The domain for NHRCM02 in Figure 1 corresponds to Area 1, one of the key vulnerable areas in the second phase of CORDEX-Southeast Asia experiments (Figure S1).

A 20-year time-slice experiment (from 1980 to 2000) was conducted using the one-way nesting method. Experiments involving the NHRCM05 were conducted for 14-month periods every year from April 1, while the first two months were excluded as a spin-up period. Downscaling experiments involving the NHRCM02 model were initiated from April 19 every year, and the calculations were carried out up to the end of May of the next year. Such a modeling system and experimental setups have already been applied to the Philippines (Cruz et al., 2016) and to Vietnam (Kieu-Thi et al., 2016) as well as Japan (e.g. Kawase et al., 2020).

Data

We used global satellite mapping of precipitation data (GSMaP Gauge v.5; hereafter referred to as GSMaP; Kubota et al., 2007, 2020; https://sharaku.eorc.jaxa.jp/GSMaP/gauge.html#09) for the observation dataset. This dataset involves the adjustment of the satellite data bias using ground truth data. It has a spatial resolution of 0.1 degrees and a temporal resolution of one hour. This dataset is only available from 2000 to 2010 for the target season. We compared the climatological feature of diurnal cycle between NHRCMs and GSMaP. Thus, we consider there are no problems with the difference of reference period. Gridded daily precipitation data of APHRODITE with horizontal resolution of 0.25 degrees (Yatagai et al., 2020) are also used as ground-based observation to evaluate the uncertainty in precipitation datasets. The climatological mean data for 30 years from 1981 to 2010 were used. The Japanese 55-year Reanalysis (JRA-55) (Kobayashi et al., 2015) were also used to check the time marching of circulation. The model topography is produced from Global 30 Arc-Second Elevation (GTOPO30), a global 30 arc-second elevation dataset in raster digital form (https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-global-30-arc-second-elevation-gtopo30?qt-science_center_objects=0#qt-science_center_objects; DOI: 10.5066/F7DF6PQS). Topography in Figure 1 is drawn with this dataset.

Climatology

The average precipitation and wind speed along the 100–105°E zone were used to analyze the time evolution of meteorological fields around the Indochina Peninsula (Figure S2a). Here, we can see a clear contrast between the rainy and dry seasons typical of a monsoon climate. From May, when the westward wind became prominent, a precipitation of over 200 mm/month was observed over the Indochina Peninsula (10–25°N). The rainy season ended in September as the westward winds decrease. We defined May to September as a rainy season and show the mean states in (Figures S2b and S2c). The rainy season, which was characterized by the southwesterly winds coming from the Bay of Bengal (Ishizaki and Ueda, 2006), also appeared in South China and the Indian sub-continent. A large amount of precipitation occurred along the western coast of the peninsula or the windward side of the Annamite Range. However, in the dry season, the wind direction became eastward, and the amount of precipitation became lower in the whole area, with precipitation occurring only in the windward side of the Annamite Range (Vietnam side).

The NHRCM05 well simulated the seasonal march of precipitation over the Indochina Peninsula (Figure 2),

![Figure 1. Model domain for NHRCM05 (outer domain) same as the figure frame and NHRCM02 (inner domain) with the buffer zones drawn by the gray area. The cross sections S1 and S2 are used in Figures 4 and 5. Red circle denotes the location of Doi Inthanon.](image-url)
although the precipitation amount in the rainy season is underestimated. The NHRCM05 did a good job for the local minimum in June and two peaks in May and August which is seen in many ground observation stations because the intertropical convergence zone migrates to the north in May and to the south in August and September. The representativeness of the behavior of the precipitation around the Indochina Peninsula was good from the viewpoint of spatial pattern and seasonal march and allows us to further investigate the precipitation characteristics. On the other hand, GSMaP is one of the observations but is not a conventional ground-based observation with rain gauges. Figure 2 shows that GSMaP has overestimated precipitation and NHRCM05 has small bias when APHRODITE is set as reference value. Therefore, we focus on the diurnal cycle in GSMaP but not on amount after intense scrutiny described in Supplement Text 2 with Figure S3. In this paper, we focus on the diurnal cycle in the precipitation around northeast Thailand in the rainy season (from May to September).

**MODEL RESULTS**

*The 5km-grid model results in relation to the GSMaP observation*

Figure 3 (GSMaP) shows a clear diurnal cycle in the precipitation in the Indochina Peninsula. The precipitation area was spread across the peninsula in the late afternoon and intensified at the western side of the Annamite Range.
while it remained until the next morning around the east-north side of the Khorat Plateau (Figure 3d).

In the NHRCM05 model, the precipitation ended in the afternoon around the Annamite Range. In contrast, in the Cardamom mountain range of Cambodia, the precipitation intensified in the afternoon, and the precipitation area spread to the Chao Phraya River Basin and the Khorat Plateau in the nighttime. The precipitation area in the Chao Phraya River Basin disappeared until the following morning but continued in the Khorat Plateau.

A good correspondence between the convergence pattern of the horizontal anomalous wind and the precipitation area exists. In the morning, the divergence of the wind dominated in the central part of the peninsula. However, in the late afternoon, in the mountain ranges around Thailand, including the Cardamom mountain range, a convergence zone appeared and propagated northward, and the convergence zone then appeared in the Chao Phraya River Basin and the southern part of the Khorat Plateau, which induced some precipitation there. This qualitatively represents the diurnal cycle in the precipitation.

To grasp the propagation of the precipitation area in the

Figure 4. Time-longitude section of the average precipitation for 15–15.5°N (S1 in Figure 1) in the wet season derived from (a) GSMaP, (b) NHRCM05, (c) NHRCM02, and (d) GCM. Note that the gray area in (c) indicates the outside of the NHRCM02 domain. (e) shows the average altitude for S1 calculated using GTOPO30. Arrows in (b) to (d) denote the wind fields

south-eastern part of Thailand, an east-west cross section along the 15–15.5°N zone of Thailand is shown in Figure 4. Figure 4a presents the attendant GSmaP observation data. It is clear that a strong precipitation region over the Andaman Sea occurred, which diminished in the late afternoon. In contrast, in the surrounding mountain ranges, a strong precipitation area appeared from the morning until the afternoon, when it moved eastward. This resulted in a precipitation peak at around 20 local time (LT) in the Chao Phraya River Basin. While another precipitation area in the Dangrek Mountains was observed at around 20LT, it was separate to the aforementioned precipitation area.

The NHRCM05 model represents well the change in precipitation pattern around the Indochina Peninsula (Figure 4b). The anomalous wind pattern overlay in the figure indicates that the precipitation intensified when the wind direction changed from northward to southward, which indicates that the precipitation occurred due to the local convergence.

Figure 5 presents the cross section of the mean pattern along the 102.5–103.0°E zone, which indicates that the cause of the precipitation moved in a latitudinal direction. The GSMaP observation indicated a peak of precipitation occurring at around 14°N in the early afternoon, which propagated in a northward direction and demonstrated a peak at around 20LT at around 15°N. The northward propagation continued to 18°N until the following morning. The precipitation corresponded with the change in anomalous

Figure 5. Same as Figure 4, but for the time-latitude section over 102.5–103°E (S2 in Figure 1)
wind direction, which indicates that local circulation induced by topography, in addition to the larger scale southwesterlies, contribute to the occurrence of precipitation over the southern part of Khorat Plateau.

While the change in precipitation pattern was well represented in the NHRCM05 model simulation, a large difference would appear to occur in terms of precipitation amount compared to that recorded through the GSMaP observation. In fact, the precipitation was overestimated both in the mountain range and over the ocean, while that in the plane and the plateau was underestimated. The latter underestimation may be attributed to excess precipitation in GSMaP seen in Figure 2. Given that the area where the precipitation was overestimated was where the wind convergence following to the mountain was dominant, the NHRCM05 model clearly overestimates this type of precipitation. This overestimation is due to the model being too sensitive to the topography in NHRCM, which is also seen in complicated topographical regions in Japan.

The 2-km grid model results compared with the 5-km grid model results

Here, we used the NHRCM02 model as a CPM and compared the results to those derived from the NHRCM05 model. As discussed above, the NHRCM05 model effectively represented the behavior of the diurnal cycle in precipitation around the Indochina Peninsula. Here, we must ascertain whether the precipitation amount is more accurately presented by the higher resolution model.

In fact, the presentation was partially improved by the NHRCM02 model compared with that of the NHRCM05 model. Figure 6 shows the precipitation amount derived through the NHRCM02 model. Here, it is clear that the precipitation amount in the northeastern part of Thailand was still underestimated. Meanwhile, while the precipitation amount in the northern part of the Annamite Range was better represented by the NHRCM02 model, the precipitation in the southern part of the mountain range was still too large. The diurnal cycle in precipitation on the Khorat Plateau was controlled by the attendant diurnal cycle in the anomalous convergence, as was the case with the NHRCM05 model, and the propagation of the convergence center was well represented. As shown in Figure 4c (east-west cross section), the precipitation amount at the western edge of the Annamite Range estimated by the NHRCM02 model was much larger than that estimated by the NHRCM05 model. This precipitation responds to the local-scale orographic data, meaning it relates to the representative difference in the orographic data caused by the difference in the resolution of the two models. Here, we can state that this also explains why the precipitation amount in the southern part of the Khorat Plateau is better represented compared with the NHRCM05 model.

However, the north-south cross section (Figure 5c) indicates that the peak value of the precipitation in the northern edge of the Khorat Plateau was much lower here than with the NHRCM05 model. The amplitude of the diurnal cycle was also underestimated. Here, given that the local oro-
graphic effect was not so large, the local-scale convergence would have been the main driver of the precipitation. The anomalous wind amplitude with the NHRCM02 model was much smaller than that of the NHRCM05 model and was most likely the cause of the underestimation of the precipitation. The attendant anomalous water vapor flux pattern and the strength of the precipitation may have exhibited positive feedback. As the NHRCM02 model was nested into the NHRCM05 model, the lower representativeness of the water vapor flux in the latter may have contributed to the lower precipitation presented in the former. In the NHRCM05 model, the precipitation was restricted to the mountainous and ocean areas, and the water vapor was thus less than in the real world, which resulted in the underestimation in the one-way nested 2-km grid model.

DISCUSSION

The 2-km grid model results compared with the 5-km grid model results

By using the high-resolution non-hydrostatic regional model, a consistent anomalous circulation signal with the precipitation was identified. This result was in line with the TRMM-PR satellite observation data (Takahashi, 2016). As shown in Figure 4, around the Chao Phraya River Basin, the precipitation center propagated from the surrounding western mountains, which induced the precipitation peak at around midnight. However, around the southern part of the Khorat Plateau, the precipitation originated in the southern mountain range, before it propagated northward and led to the precipitation peak at around midnight. This was synchronized with the anomalous wind direction change and thus suggests that the diurnal cycles in precipitation were strongly related to the local circulation. Satomura (2000) suggested that the convective cloud organized around the western-central part of the Indochina Peninsula propagated eastward, which caused the precipitation peak at around midnight inland from the peninsula. Here, we can conclude that in the more southerly part of the peninsula, the precipitation center propagated to the north.

In our experiments, both the NHRCM05 and the NHRCM02 models underestimated the precipitation on the Khorat Plateau. In the NHRCM05 model, the Kain–Fritsch convection parameterization was used. The scheme was sensitive to the setting of the level of free convection and was originally tuned to NHRCM for mid-latitude environments. This may have led to a significant bias with the mountainous regions in the tropics. As the NHRCM02 model is a CPM, it bypassed the parameterization scheme, and the bias was thus reduced in several areas. However, as the NHRCM02 model was nested in the NHRCM05 model, the lack of water vapor in the calculations of the latter influenced those of the former. Thus, some underestimation occurred in terms of the precipitation estimated by the NHRCM02 model. To use our data for impact study research, this bias must be reduced. Here, obtaining more accurate observation data is required.

The NHRCM simulations can be affected by the lateral boundary conditions simulated by MRI-AGCM3.2 as mentioned in the Model, Data, and Method section. The underestimated precipitation in MRI-AGCM3.2 was consistent with that of NHRCM05 and NHRCM02 probably because the lateral water vapor flux into the target area of Figure 1 was underestimated in MRI-AGCM3.2. The diurnal cycles of precipitation in MRI-AGCM3.2 were seen in Figure 4d but the peak of precipitation occurs around 13LT with weak intensity. MRI-AGCM3.2 captured the diurnal cycles of wind but with about a half speed. Figure 5d shows the same as in Figure 4d but for longitudinally long domain (S2 in Figure 1). The features of MRI-AGCM3.2 are also seen in this figure. These results suggested that an AGCM such as MRI-AGCM3.2 simulated large-scale land-sea breeze circulation induced by surface air temperature contrast between the two more strongly than the actual circulation. In addition, the AGCM simulated weak local-scale circulation induced by complex topography in comparison to actual one probably due to weak thermal contrast with lower model elevation. However, NHRCM05 and NHRCM02 simulations outperformed those of MRI-AGCM3.2 in terms of the timing of diurnal peak of precipitation and total amount of precipitation, and of the wind speed irrespective of nesting NHRCMs in MRI-AGCM3.2, which is typical added value in the dynamical downscaling (e.g. Rummukainen, 2016; Takayabu and Hibino, 2016). These features are also seen on the Indochina Peninsula horizontal scale when we compare the diurnal cycles between NHRCM05 and GCM (Figures 3 and S4).

CONCLUSIONS

By using a NHRCM05 model nested into a MRI-AGCM3.2 model and a NHRCM02 model nested into the NHRCM05 model, we investigated the mechanism of the diurnal cycles in precipitation in the northeastern part of Thailand. Unlike in the northern part of Thailand, the precipitation peak in the Khorat Plateau was due to the northward propagation of the convergence zone and the associated precipitation appearing around the mountainous region in the southern periphery of the plateau in the afternoon. These sub-10-km grid models could be useful for discussing precipitation in more detail because they represent fine-scale orographic data and, in some cases, are free from the control of the convective parameterization scheme. This result confirms the typical added value in the dynamical downscaling from a global climate model with coarse horizontal resolution to a regional climate model with a fine horizontal resolution.

A decadal severe drought occurs in the Khorat Plateau for 2011 to 2019, which may modulate the phase and amplitude of the diurnal cycles of precipitation as well as the total precipitation amounts. It is very interesting to know both the decadal and future changes of diurnal cycles of precipitation in practice and in science, and this should be investigated with high priority.

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SUPPLEMENTS

Text S1. CORDEX
Text S2. Validity of satellite-based observations
Figure S1. The key vulnerable areas in the second phase of CORDEX-Southeast Asia experiments
Figure S2. (a) Latitude-time sections of average precipitation and wind on the 850 hPa over the Indochina Peninsula. Monthly precipitation and wind field on 850 hPa for (b) wet season (May–Sept.) and (c) dry season
Figure S3. Diurnal cycle in precipitation at Doi Inthanon for the wet season. Light green, black, and red lines represent hourly precipitation intensity of ground observation, GSMaP, and NHRCM05, respectively
Figure S4. Same as Figure 3, but for MRI-AGCM

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