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High-resolution regional climate simulations of the long-term decrease in September rainfall over Indochina

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Abstract

We address the long-term decrease in September rainfall over the Indochina Peninsula. Distinct long-term decreases in rainfall along the monsoon trough across the Indochina Peninsula have been observed. We performed long-term simulations and discuss the effects of long-term changes in both the local surface conditions and large-scale circulation. Using a 30-year simulation for September for the period from 1966 to 1995 with land-use conditions fixed at present-day values and neglecting the recorded deforestation, we successfully simulated the observed long-term decrease in rainfall. We therefore conclude that the weakening tropical-cyclone activity over the Indochina Peninsula region is probably responsible for the decrease in rainfall. Copyright © 2008 Royal Meteorological Society

Keywords: regional climate change; rainfall; tropical cyclone; deforestation; regional climate model

1. Introduction

Climate change is an extremely important issue regionally, as well as globally. However, because the horizontal resolution of global climate models is coarser than 100 km, these models cannot be used to determine detailed regional climate changes. Specific approaches to the analysis of these processes are therefore needed.

In Thailand, on the Indochina Peninsula, Kanae *et al*. (2001) (hereafter KA01) found a decreasing trend in rainfall using rain-gauge observations for the period from 1951 to 1994. Two explanations have been proposed for this trend. First, KA01 performed a regional climate-modelling experiment and suggested that the decrease might have been caused by changes in the land surface conditions, arguing that deforestation could decrease evapotranspiration and rainfall in September. Second, Takahashi and Yasunari (2006) and Fudeyasu *et al*. (2006) investigated seasonal conditions in the Indochina Peninsula region. They reported that August and September were the most active months for westward-moving tropical-cyclone (TC) activity. Moreover, Takahashi and Yasunari (2008) (hereafter TA08) highlighted the large contribution of TCs to the total rainfall in September and suggested that the weakening of TC activity over the Indochina Peninsula region could be responsible for the observed long-term decrease in rainfall.

Because KA01 conducted experiments for only three Septembers (1992, 1993 and 1994), they did not investigate the effect of long-term changes in the large-scale circulation. The primary motivation for our study was the following question: Which mechanisms can coherently explain the observed long-term decrease in September rainfall over Indochina, TC activity or deforestation? To address this question, we performed a long-term (30 years from 1966 to 1995) simulation for September, excluding the effects of deforestation.

2. Experimental design

We used a high-resolution model to simulate a realistic distribution of rainfall and the local circulations related to complex terrain and land use. The Advanced Research Weather Research and Forecasting (WRF) modelling system (Skamarock *et al*., 2005), which was developed at the National Center for Atmospheric Research (NCAR), was chosen for this purpose. The 40-year reanalysis (ERA-40, Uppala *et al*., 2005) data set of the European Centre for Medium-Range Weather Forecasts (ECMWF) and the Extended Reconstructed SST V2 (Smith and Reynolds, 2004) data sets of the National Oceanic and Atmospheric Administration (NOAA) were used as initial and boundary conditions. Soil moisture and temperature data from ERA-40 were also used. The model domains are shown in Figure 1(a). The horizontal grid increment of the coarse domain was 25 km, and that of the two-way nested domain was 5 km. Both domains had 31 terrain-following vertical levels. Because preliminary experiments with cumulus convective parameterisation showed a very unrealistic distribution and total amount of rainfall, we did not apply cumulus convective parameterisation in either domain. The WRF single-moment six-class microphysics scheme (Hong

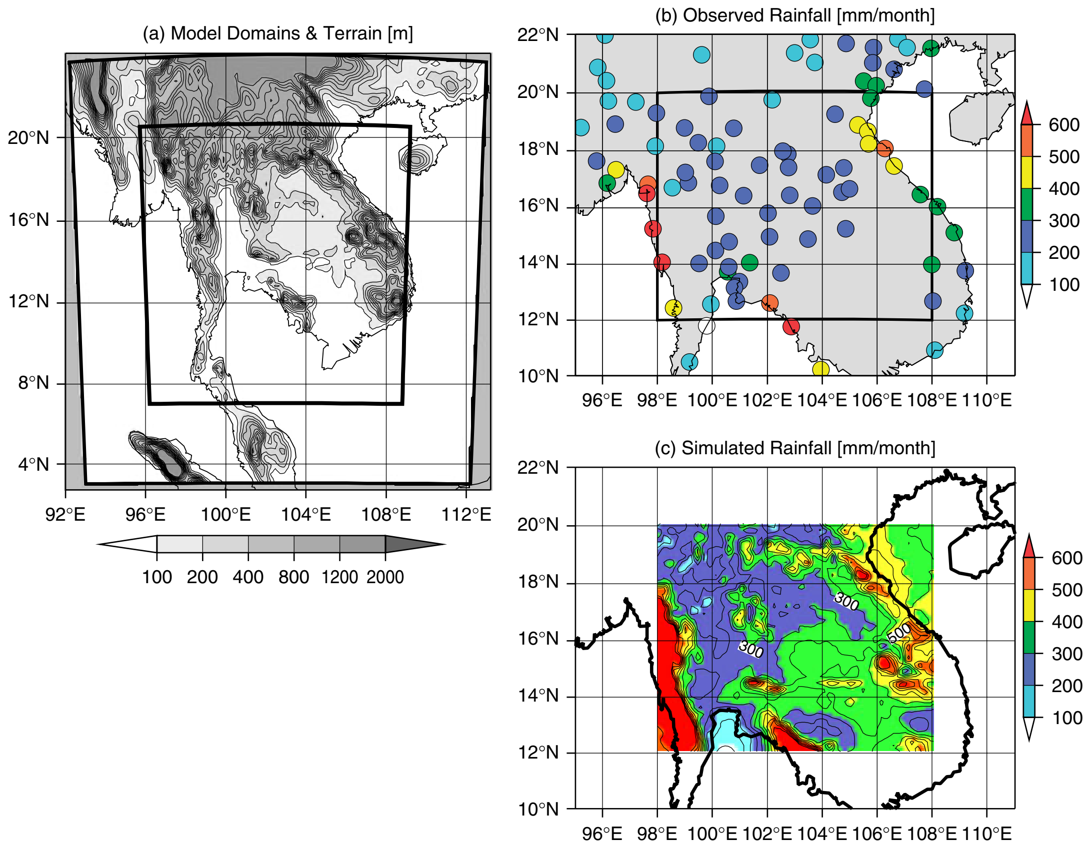

Figure 1. Model domains are shown in (a). The inner thick box showed nested domain. Right panels show total amounts of September rainfall over the Indochina Peninsula. (b) The observed September rainfall averaged over 30 years (1966–1995) in September, and (c) the equivalent simulated rainfall. The black box in (b) corresponds to the display range of (c). Less than 10% of the rain-gauge station data (b) were missing. The units of rainfall are in millimetres per month.

and Lim, 2006) and the Noah land-surface model (Chen and Dudhia, 2001) were also used.

To investigate the long-term changes in rainfall, we defined two periods: Term 1 (T1), from 1966 to 1980; and Term 2 (T2), from 1981 to 1995. They were chosen because TA08 showed a decrease in rainfall from T1 to T2. These periods were thus appropriate for investigating the long-term changes in rainfall. The simulation with current land-use and vegetation was performed 30 times from 30 August to 30 September from 1966 to 1995. For the duration of the simulation, the land use was fixed. The current land use was taken from 1992 data that were obtained from the United States Geological Survey (USGS). In the past, Thailand was highly forested, whereas the 1992 data categorised the majority of Thailand as under cultivation. Thus, if the effect of deforestation was the most significant factor, a long-term decrease in rainfall would not be apparent in the model.

We used a 30-year period of gauge-observed rainfall data that were collected from 1966 to 1995 as part of the Global Energy and Water Cycle Experiment (GEWEX), Asian Monsoon Experiment (GAME) and Monsoon Asian Hydro-Atmosphere Scientific Research and Prediction Initiative (MAHASRI). The previous studies of changes in rainfall used rainfall data only from Thailand. In contrast, we used rainfall data from Vietnam, Laos, Thailand and Myanmar. The rain-gauge observations demonstrated the extent of the long-term change in rainfall over the Indochina Peninsula.

3. Long-term change in rainfall

Before analysing the long-term change, we compared the simulated rainfall with the observed climatology. Abundant rainfall was observed along the coast of the Bay of Bengal, the Gulf of Thailand and the eastern coast of northern Vietnam (Figure 1(b)). The peaks of the simulated rainfall were closely correlated with the peaks indicated by rain-gauge observations. In addition, the total simulated amount of rainfall was generally very close to that observed using rain gauges. Because the rainfall along the eastern coast of northern Vietnam was very likely associated with the westward-moving TCs, the peak in the simulated rainfall there suggests that the model can simulate both TCs and the rainfall pattern caused by TCs. Thus, the simulation captured the climatology of both the amount and distribution of rainfall in the Indochina Peninsula. The high resolution of the simulation also allowed the very fine structure of the rainfall distribution to be captured.

To evaluate the interannual variation and long-term change in September rainfall, we plotted a ten-point

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average of rain-gauge rainfall and area-averaged simulated rainfall over the Khorat Plateau (Figure 2). The reference area chosen was an area (101°–105 °E, 15°–18°N) in which rainfall decreased significantly (KA01). Both time series showed clear interannual variation, with close agreement. The year-to-year correlation was 0.70, which was significant at the 99% confidence limit. The total amount of simulated rainfall in T1 and T2 over the reference area was 343.8 and 293.0 mm month^{-1}, respectively. The observed rainfall in T1 and T2 was 273.7 and 214.8 mm month^{-1}, respectively. These differences were statistically significant at a 90% confidence limit, as determined using Student's t-test. The 15% decrease in simulated rainfall was close to the 21% decrease in the observed rainfall. Thus, the model well simulated the long-term change in rainfall. The simulated rainfall amount was larger than observational one, and the simulated long-term changes are somewhat less than the observation. The simulated rainfall was the area average, whereas observations are point measurements located at plain field or valley, which could explain the difference.

We examined the spatial distribution of the long-term change in rainfall between T1 and T2 (Figure 3). Over the Khorat Plateau, rainfall was decreased in T2 (Figure 3(a)), which was consistent with KA01. Decreases were observed along the latitudinal band between 15° and 22°N of the Indochina Peninsula, showing that a long-term decrease was observed not only over inland Thailand, but also across the Indochina Peninsula. This decrease was observed along the major route of the westward-moving TCs. The simulated rainfall was in close agreement with the observations in both spatial distribution and quantity (Figure 3). The regional long-term climate change was simulated without inclusion of the recorded deforestation. In addition, a significant decrease in rainfall

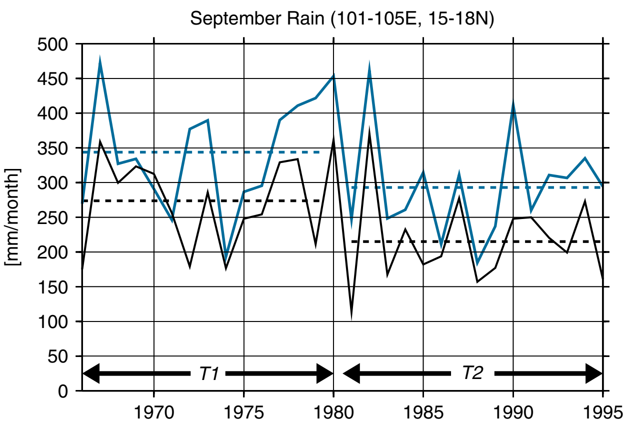

Figure 2. Time series of the observed September rainfall ten-point average (black) and the simulated September rainfall domain average (blue). The ten stations were located within an area at 101–105 °E, 15–18°N. The simulated rainfall was domain-averaged within the box. The units of rainfall are in millimetres per month. The blue (black) dashed lines denote 15-year averages of simulated (observed) rainfall for each term.

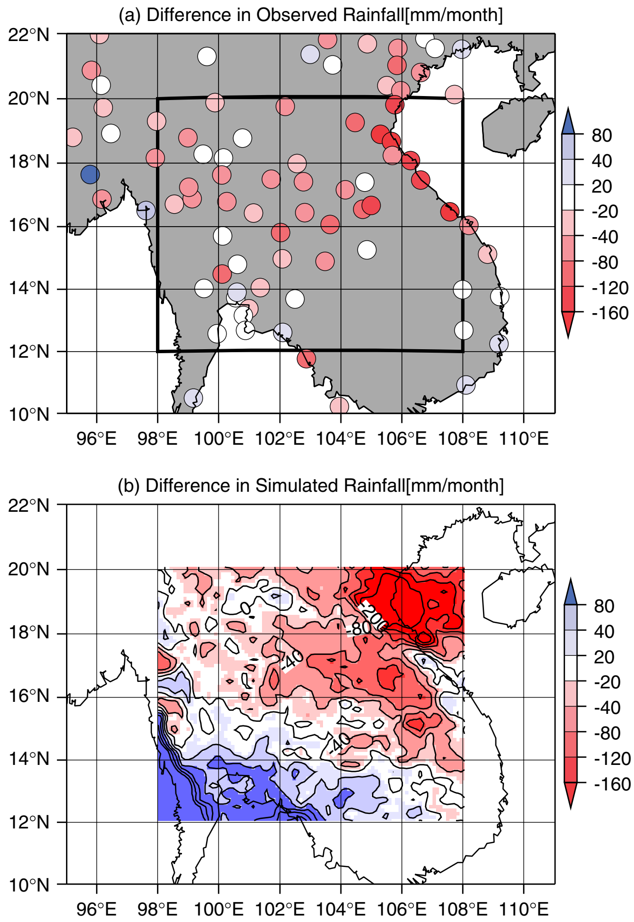

Figure 3. The same as Figure 1, but for differences in the (a) observed and (b) simulated September rainfall between T1 and T2 (i.e. T2 – T1).

was simulated along the eastern coast of northern Vietnam and offshore. The long-term decrease in rainfall exceeded 150 mm month^{-1}.

Finally, we examined the long-term changes in atmospheric circulation associated with the decrease in rainfall. Climatologically, the monsoon trough appears along the 15°–20°N zonal band because of TC activity (e.g. Takahashi and Yasunari, 2006). The trough in T2 was much weaker than that in T1 (Figure 4(a) and (b)). The difference clearly shows the anti-cyclonic circulation over northern Vietnam, which indicates a weakening of the monsoon trough (Figure 4(c)). The vertically integrated water vapour fluxes showed a similar pattern to the winds at 850 hPa (not shown). Weakening of the water vapour convergence over the northern Vietnam region presumably reduced the rainfall there. To examine the weaker monsoon trough formation in T2, the frequency of TC appearance was calculated. Because the anti-cyclonic circulation appeared over northern Vietnam (Figure 4), the frequency was examined there. The frequency was defined from the 925-hPa wind speed offshore of northern Vietnam (106–109 °E, 17–20°N). If any grid point in the region at 925 hPa had a wind speed greater than 12 m s^{-1}, a TC was defined as occurring on that day (Table I). We tested the effects of

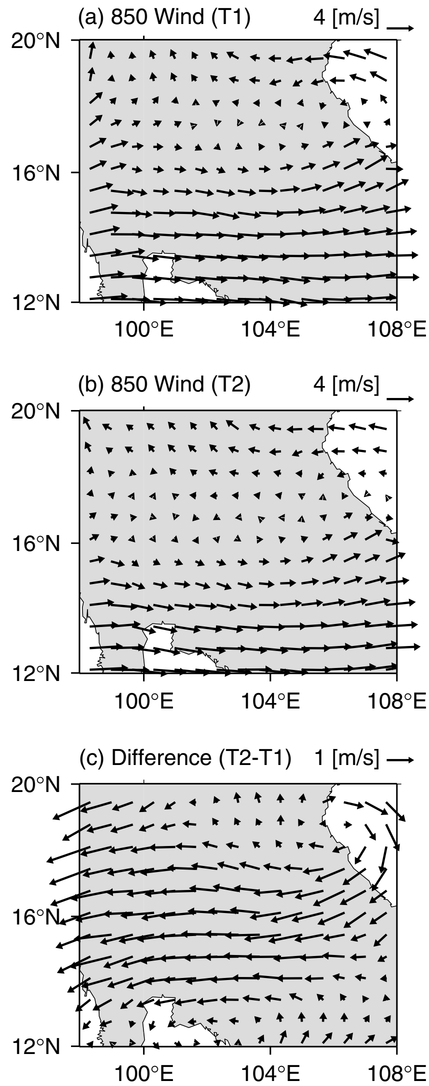

Figure 4. The 15-year mean 850-hPa winds in September during (a) T1 and (b) T2, and (c) the difference between the two terms (T2 – T1). The units of wind speed are metres per second.

using other thresholds such as 10 or 15 m s^{-1} and found no significant change in the results. The frequencies of appearance at T1 and T2 were 13.7 and 11.8 days $month^{-1}$, respectively, which was consistent with the observed tendency of TC activity (TA08). Therefore, the weakening of the monsoon trough was probably associated with the decrease in TC frequency there.

4. Discussion

In this section, we discuss the effect of deforestation. We emphasise that the regional long-term climate changes were simulated *without* consideration of the effect of the recorded deforestation. On the other hand, KA01 proposed that deforestation has caused long-term decreases in rainfall. However, signals were simulated only over the deforested region (KA01). Even if deforestation can reduce local rainfall, the effects on the Indochina Peninsula in September were likely to be spatially limited. Consequently, the effects of deforestation cannot explain the observed long-term change of September rainfall in the Indochina region.

Because of the prominent seasonal evolution of the Indochina monsoon (e.g. Takahashi and Yasunari, 2006), the effects of deforestation may show seasonality over the Indochina Peninsula. Sen *et al.* (2004) investigated local and remote effects of reforestation of the Indochina Peninsula in June, July and August on the East Asian climate. They showed increase in rainfall downstream of monsoon westerlies. Their results were not consistent with KA01. The difference between KA01 and Sen *et al.* (2004) would be possibly explained by the seasonal march of large-scale circulations, such as strength of the monsoon westerlies. Because a few numerical experiments on the effects of long-term changes in surface condition were conducted over Southeast Asia, a large number of high-resolution experiments are needed. The effect of deforestation over the Indochina Peninsula in the other season, using high-resolution models, should be the subject of further study.

5. Conclusion

We addressed the long-term decrease in September rainfall in the Indochina Peninsula. Two explanations for the phenomenon were proposed: long-term change in local surface conditions and long-term change in TC activity.

The long-term high-resolution simulation accurately captured the climatological rainfall distribution and quantity. A 30-year run simulated the interannual variation and long-term change in rainfall, both of which were in close agreement with observations. The spatial distribution of the long-term change in rainfall was also found to be in close agreement with

Table 1. Observed amounts of September rainfall averaged over ten stations. The ten stations are located within an area at 101–105 °E, 15–18 °N. The simulated rainfall is area-averaged within this area. The definition of simulated tropical-cyclone (TC) appearance is given in the text. The observed TC-days were counted by TA08, although the definition of TA08 was different from that of this study.

Category	observed rain (mm $month^{-1}$)	Simulated rain (mm $month^{-1}$)	Simulated TC appearance (days $month^{-1}$)	Observed TC-day from TA08 (days $month^{-1}$)
T1 (1966–1980)	273.7	343.8	13.7	16.6
T2 (1981–1995)	214.8	293.0	11.8	13.9

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observations. A long-term decrease in rainfall was observed along the major route of the westward-moving TCs, including the eastern coast of northern Vietnam, rather than just over Thailand. Finally, the simulated monsoon trough weakened from T1 to T2, which again was consistent with observations. All of these long-term changes in rainfall were realistically simulated without including the effects of deforestation in the model. The effects of deforestation over the Indochina Peninsula in September were likely spatially limited and hence are not likely to explain the observed decrease in rainfall.

The weakening of TC activity over and around the Indochina Peninsula could explain the spatial distribution of the observed decrease in rainfall. Therefore, we conclude that the observed long-term decrease in September rainfall has been caused by the change in TC activity, rather than by the changes in the local surface conditions.

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