FUTURE CHANGE OF TROPICAL CYCLONE INDUCED RAINFALL OVER THE TOKACHI RIVER BASIN, NORTHERN JAPAN USING DATABASE FOR POLICY DECISION MAKING FOR FUTURE CLIMATE CHANGE (d4PDF)

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ABSTRACT

Previous studies have shown that the acceleration of global warming will intensify the intensity of rainfall induced by tropical cyclones (TCs) (hereinafter referred to as “TC-induced rainfall”). TC-induced rainfall is affected by TC intensity, position and topography (slope shape and direction). It means that TC-induced rainfall is expected to vary by sub-basin due to varying topographies. However, relationships between TC intensity, position and topography have not been explained, as historical TCs, which occurred several decades earlier, do not exhaustively encompass all TC intensities and positions that could potentially affect each basin. In this study, we used large ensemble regional climate model experiments with 5 km grid spacing, which enabled us to prepare a huge TC database for understanding the characteristics of TC-induced rainfall over sub-basins. We quantified the characteristics of TC-induced rainfall (relationship between TC position and rainfall intensity, and contribution of TC intensity on rainfall) over two sub-basins in the Tokachi River basin, central Hokkaido, northern Japan. The results reveal differences in TC-induced rainfall characteristics between the two sub-basins. In addition, the large ensemble data under a future climate scenario were used to evaluate future changes in the characteristics of TC-induced rainfall for the sub-basins.

Keywords: heavy rainfall, tropical cyclone, climate change, large ensemble climate experiment, d4PDF

1. INTRODUCTION

Tropical cyclones (TCs) are the primary cause of heavy rainfall events in Japan. Several studies (e.g. Walsh et al., 2015) have investigated the effects of global warming on TC-induced rainfall. They concluded that the acceleration of global warming will cause TC-induced rainfall to increase. Thus, predicting changes in rainfall caused by TCs (hereinafter, referred to as “TC-induced rainfall”) attributable to global warming is important for estimating future flood risks. TC-induced rainfall is dependent on factors such as topography, TC intensity, and TC position. The rainfall intensity caused by TC position and TC intensity varies between sub-basins as adjacent sub-basins can vary in slope shape and direction. Thus, to understand and predict risks of TC-induced rainfall over sub-basins, rainfall and TC data (position and intensity) are required. However, these risks have not been explained from existing observational data as historical TCs that occurred several decades earlier do not exhaustively encompass all TC positions that could potentially affect each basin. In recent years, a large ensemble climate dataset was released as the Database for Policy Decision Making for Future Climate Change (d4PDF), which consists of several thousand years of simulation with both a historical climate and climates following the progression of global warming (Mizuta et al., 2017). This database is suitable for estimating future changes in infrequent and extreme weather events.

In this study, we utilized large ensemble regional climate model experiments with 5 km grid spacing for understanding the characteristics of TC-induced rainfall over two sub-basins in the Tokachi river, central Hokkaido, northern Japan (Figure 1). We quantified the characteristics of TC-induced rainfall (relationship between TC position and rainfall intensity and contribution of TC intensity on rainfall) over the two sub-basins in the Tokachi River basin. In addition, the dataset under future climatic conditions was used to evaluate future changes in the characteristics of TC-induced rainfall over each sub-basin.

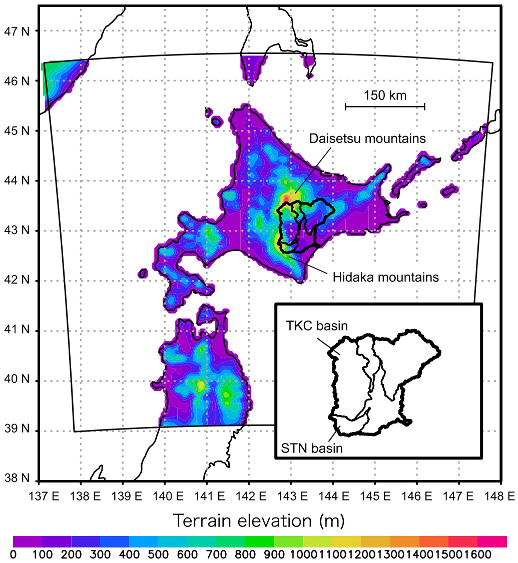

Figure 1. Simulation area and the target basins. The thick line indicates the entire Tokachi River basin. The inner solid lines indicate the area of the target sub-basins (TKC basin and STN basin). The outer solid line indicates the simulation area for d4PDF-DS5. The colors represent the terrain elevation used in the dynamical downscaling.

2. DATA

In this study, we utilized the Database for Policy Decision Making for Future Climate Change (d4PDF) (Mizuta et al., 2017) which consists of simulations from the atmospheric general circulation model (AGCM) with a horizontal resolution of approximately 60 km (d4PDF-60km), and dynamical downscaling (DDS) of the results of the AGCM to a horizontal resolution of 20 km using the regional climate model (RCM) targeted over Japan (d4PDF-DS20). The experimental settings of d4PDF consist of a past climatic condition (past experiment; 50 ensembles x 60 years (1951–2010)) and a 4 °C warmer climatic condition (+4K experiment; 6 sea surface temperature patterns x 15 ensembles x 60 years), which has a 4 °C warmer global mean air temperature than the preindustrial period. To prepare rainfall data that accurately reflect basin and topography shapes with respect to the target sub-basins, this study employed dynamical downscaling to convert annual maximum rainfall events from d4PDF-DS20 to a horizontal resolution of 5 km (d4PDF-DS5). This study utilized TC track data (Yoshida et al., 2017) extracted from d4PDF-60km.

The target river basins for this study are the Tokachi River sub-basins, which are located in the northernmost island in Japan. The target sub-basins are the sub-basin of the Tokachi River (TKC basin; the catchment area at the Obihiro reference point and the north-west of the Tokachi River basin including the Daisetsu mountains and the Hidaka mountains), and the Satsunai River basin (STN basin; the catchment area at the Nantaibashi reference point; the south-western part of the Tokachi River basin and including the Hidaka mountains) (Figure 1).

3. RESULTS

3.1 Relationship between TC position and hourly rainfall intensity

Figure 2 illustrates the relationship between TC position and hourly rainfall intensity over the sub-basins. The points in Figure 2 (a) show the 72 h cyclone tracks for the events producing annual maximum TC-induced rainfall in each river basin over 43 years (1976 to 2018). The colors indicate the basin-average rainfall intensity over the river basins when the cyclone was at the point indicated. Figure 2 (a) shows that among all TCs, those located to the south-west of the Tokachi River basin caused the heaviest rainfall over the target sub-basins. However, the small sample size of observed data for annual maximum rainfall events over 43 years makes it difficult to assess the relationship between the TC position and rainfall intensity. Figure 2 (b) shows the simulated result averaged over all cyclone tracks in the ensemble on a 0.56-deg lat-lon grid from d4PDF-DS5 for the past experiment. These figures show that both sub-basins experience a similar increase in rainfall intensity owing to the influence of TC on the region south-west of the Tokachi River basin (hereinafter, the high-rainfall-intensity area is referred to as a "hotspot"). This area is located along the track of Typhoon Lionrock (2016), which caused heavy rainfall over the Tokachi River basin (199.3 mm/72 h over the TKC basin). The rainfall intensity in the hotspot increased by approximately 5 mm/h over the STN basin.

Figure 2 (c) is same as Figure 2 (b) but represents the +4K experiment. The figure shows that there is the hotspot whose position is almost the same as that in the past experiment for each sub-basin, though the rainfall intensity is different. Figures 2 (d) shows the differences between the past experiment and +4K experiment (the +4K experiment minus the past experiment). An increasing trend was observed for rainfall intensity over every sub-basin when a TC was located in the hotspot. The STN basin exhibited notable rainfall intensification, with the rainfall intensity increasing from 5 mm/h to 10 mm/h in the hotspot. This shows that in the future, the target sub-basins should be on higher alert when a TC approaches.

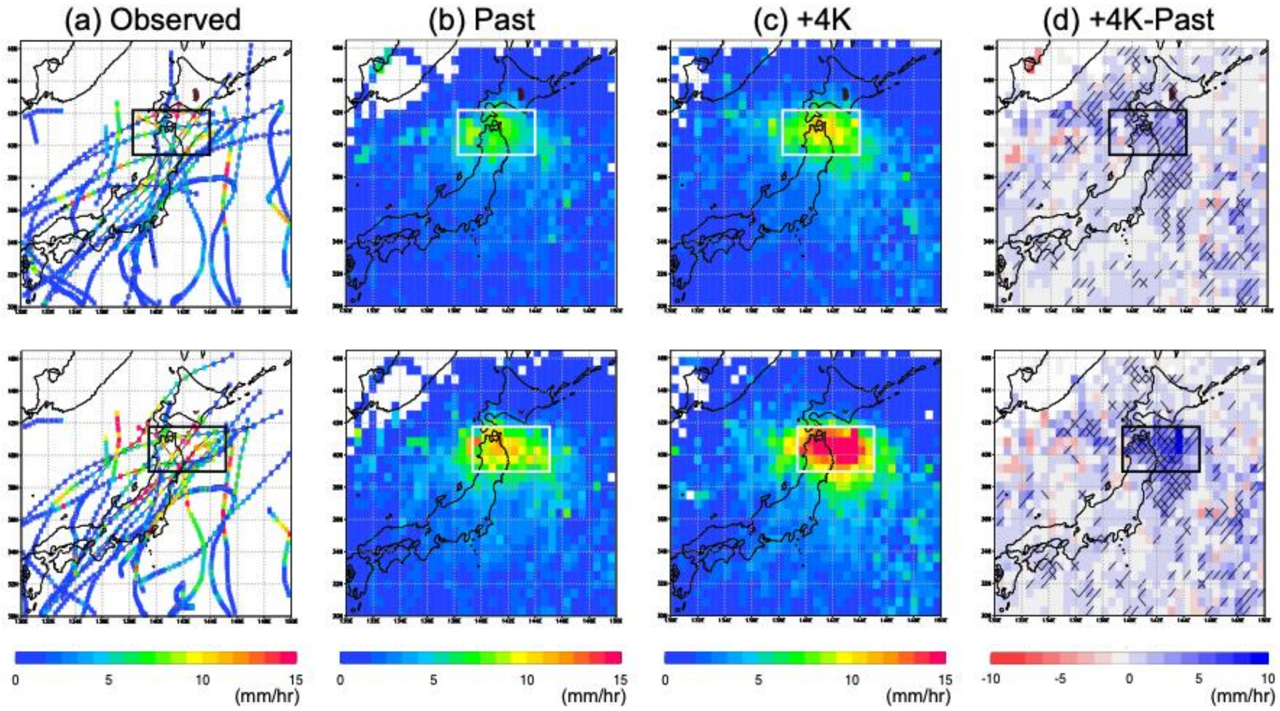

Figure 2. Area-averaged rainfall intensity over the sub-basins at the TC position (Hoshino et al., 2020). From the left: (**a**) Observed data (1976–2018), (**b**) past experiment, (**c**) +4K experiment, and (**d**) +4K experiment minus past experiment (diagonal lines (upper right to lower left) represent grids that satisfy a 5% significance level using Welch's t-test, diagonal lines (upper left to lower right) represent grids on which rainfall intensifies under the all six sea surface temperature patterns from the +4K experiment). From the top: area-average rainfall over the TKC basin and STN basin. The black fills indicate the target basins. The solid line boxes indicate the hotspot for each basin; the TKC basin (138.40° E–144.00° E, 39.52° N–42.32° N) and STN basin (139.52° E–145.12° E, 38.96° N–41.76° N).

3.2 Effect of TC intensification and atmospheric moisture increase

This study examined the differences between the TC-induced rainfall in the hotspots of the Past and +4K experiments by separating the increase of the TC-induced rainfall into the effect of TC intensification and atmospheric moisture increase, following previous study (Hasegawa and Emori, 2005). Figure 3 shows the frequency (top bars extending downward) and basin-averaged rainfall intensity (lower box and whiskers) of TCs as a function of central pressure when located in the hotspots of each basin (green denotes the observed, blue the past experiment, and red the +4K experiment). The hotspot regions are indicated by the boxes in Figure 2 for the TKC basin (138.40° E–144.00° E, 39.52° N–42.32° N) and STN basin (139.52° E–145.12° E, 38.96° N–41.76° N). The result of d4PDF-DS5 showed that the strongest TCs (lowest pressure TCs) tend to produce the heaviest rainfall over all the basins. The figure shows an increase in the strong TC frequency in the +4K experiment, which leads to more frequent heavy rainfall events (hereinafter, the effect is called "dynamic change"). The figure also shows that the heavier rainfall tends to occur between the same strength TCs (hereinafter, the effect is called "thermodynamic change"). The dynamic and thermodynamic changes both contribute to intensification of the TC-induced rainfall over all the basins. Both changes were stronger in the STN basin.

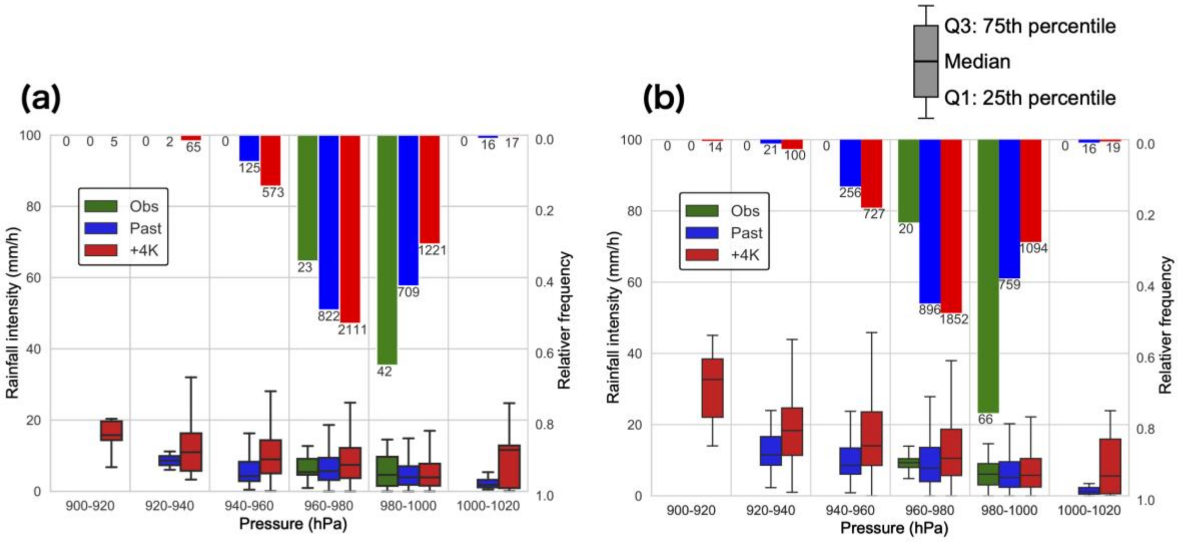

Figure 3. Basin-averaged rainfall intensity as a function of central pressure of TCs (shown in boxplot) and relative frequency of the central pressure of TCs (shown in bars) when the TC is located in the hotspot of (**a**) TKC basin and (**b**) STN basin (Hoshino et al., 2020). The upper whisker of the box plot is the heaviest rainfall intensity smaller than 1.5(Q3-Q1) above the Q3. Similarly, the lower whisker of the box plot is the smallest dataset number larger than 1.5(Q3-Q1) below the Q1. The numbers of corresponding cases are shown in bars placed at the bottom of the plot.

4. CONCLUSIONS

This study elucidates the TC-induced rainfall characteristics (relationship between TC position and rainfall intensity, and contribution of TC intensity on rainfall intensity) over the sub-basins of the Tokachi River, using the large ensemble regional climate model experiments with a 5 km grid spacing. The relationship between TC position and hourly rainfall intensity over the sub-basins was examined from d4PDF-DS5. The result showed that among all TCs, those located to the south-west of the Tokachi River basin (hotspot) caused strong rainfall over the target sub-basins. These relationships are difficult to assess from the small sample size during the observation period. However, the relationships were accurately assessed by using d4PDF-DS5.

In warmer climates, the risk of heavy rainfall from TCs is projected to increase, based on the +4K experiments that simulated increased rainfall intensity during these events. In the +4K experiment, there was an increasing trend of rainfall intensity over both sub-basins when TCs were located in their hotspots. The STN basin, where the past experiment exhibited high rainfall intensity owing to the influence of the TC, showed a remarkable increase in rainfall intensity. This study examined the differences of the TC-induced rainfall in the hotspot between the past and +4K experiments. The result shows that both dynamic and thermodynamic changes contribute to intensify the TC-induced rainfall over the basins and that both the changes were stronger over the STN basin.

By using a large volume of high-resolution ensemble data, it was possible to assess the characteristics of the TC-induced rainfall over the sub-basins. This type of analysis had previously been difficult to conduct using just the observational data. The combination of this relationship with the TC track forecast can be used to assess the hazards from heavy rainfall over each sub-basin in advance. In addition, the data can also contribute to adaptation planning by focusing on a target rainfall level for each sub-basin. The use of data with climatic conditions that reflect advanced global warming made it possible to assess which sub-basins will experience prominent increases in the TC-induced rainfall under the future climate.

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