Global warming shifts Pacific tropical cyclone location

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1. Introduction

Tropical cyclones (TC), called typhoons in the western Pacific and hurricanes in the Atlantic and the central and eastern Pacific, are among the most devastating weather phenomena that can affect human life and economy. How global warming will affect TC activity is a hotly debated topic (Webster et al., 2005; Emanuel, 2005; Landsea et al., 2006).

A widely accepted theory for explaining the oddness is that the decrease of TC frequency is attributed to an increase of atmospheric static stability. This is because the global warming leads to a larger increase of air temperature in the upper troposphere than in the lower troposphere; as a result, the atmosphere becomes more stable, which suppresses the TC frequency (Sugi et al., 2002; Bengtsson et al., 2007). If this is true, then one would expect the decrease of TC frequency throughout all ocean basins. However, as showed by this high-resolution modeling study, there are opposite trends of TC frequency between the western and central Pacific. Thus by comparing the regional characteristics of TC activity changes under global warming, we suggest another explanation for TC frequency changes rather than the stability argument. This study investigates the cause of shift of TC locations in the Pacific in a warming climate based on a high-resolution atmospheric general circulation model (AGCM).

2. Model Description

AGCM used in this study is ECHAM5 at a horizontal resolution of T319 (about 40-km grid). This high-resolution global model is run at Japan’s Earth Simulator. SST, the lower boundary condition of the model, is derived from a lower-resolution (T63) coupled version of the model (ECHAM5/MPI-OM) (Jungclaus et al., 2006), which participated in the fourth assessment report of intergovernmental panel for climate change (IPCC-AR4). Two different climate change scenarios (20C3M and A1B) were applied. In 20C3M scenario, increasing historical greenhouse gases in 20th century were prescribed as a radiative forcing. In A1B scenario, carbon dioxide concentration was increased at a rate 1% per year till it reached 720 ppm and was then kept constant. A ‘time-slice’ method (Bengtsson et al., 1996) was applied, in which the high-resolution AGCM is forced by SST during two 20-year periods (1980-1999 and 2080-2099). The two periods are hereafter referred to as 20C and 21C, respectively. Following Thorncroft, and Hodges (2001), TCs in the model are determined based on the following three criteria: 1) 850-hPa vorticity is greater than

1.75x10-6 s-1, 2) warm core strength (represented by the difference between 850 and 250 hPa vorticity) exceeds 0.8x10-6 s-1, and 3) duration time exceeds 2 days. The selection of the parameter values is based on the least square fitting of the observed TC number in northern hemisphere in 20C.

3. Results

Figure 1 shows the geographical distribution of TC genesis locations in the Pacific in the 20C and 21C simulations. In 20C, TCs form primarily over the western and eastern Pacific, similar to the distribution of the observed genesis locations. In 21C, however, more TCs shift their genesis locations to the Central Pacific. As seen from the difference map (Fig. 1c), there are two notable TC decrease and increase regions over the Pacific. One is over the North western Pacific (NWP) and the other the North central Pacific (NCP). The numbers of TCs over NWP and NCP are 303 and 201 during 1980-1999 but become 208 and 331 during 2080-2099. This indicates a decrease of 31% over NWP but an increase of 65% over NCP. Thus the high-resolution AGCM simulations illustrate two opposite TC trends in NWP and NCP. Given that SST increases in both the regions under global warming, why do the NWP and NCP experience opposite TC trends?

To understand the cause of the distinctive TC behaviors, we diagnose in the following the dynamic and thermodynamic conditions in northern summer (July – October), when a majority of TCs occur, over the NWP (5-25°N, 110°E-160°E) and NCP (5-25°N, 180-130°W) regions, respectively. First we examine the change of atmospheric static stability in both the regions. Figure 2 shows the vertical profile of the averaged atmospheric potential temperature over NWP and NCP. Note that the upper-level air temperature increases at a greater rate than that at lower levels in both the regions. As the static stability is measured by the vertical gradient of the potential temperature, the result implies that the atmosphere becomes more stable under the global warming in both the regions. Thus, the stability change cannot explain the opposite trends of TC frequency between NWP and NCP.

A further analysis reveals that the fundamental cause of the opposite TC trends lies in the change of the dynamic condition in the atmosphere. As we know, TCs originate from the tropical disturbances such as synoptic wave trains and easterly waves (Riehl, 1948; Frank 1982; Lau and Lau, 1990). The 21C simulation shows an increased variability of synoptic-scale disturbances over the NCP region but a decreased synoptic activity over the NWP region (Fig. 3). Here the strength of the synoptic-scale disturbances is represented by the variance of the 850-hPa vorticity field that is filtered at a 2-8 day band using Lanzcos digital filter (Duchon, 1979). The difference map (Fig. 3c) shows a remarkable decrease of the synoptic-scale variance over NWP but an increase of the variance in NCP. Thus, the decreasing trend in NWP is caused by the reduced synoptic-scale activity whereas the increasing trend in NCP is caused by the strengthening of synoptic disturbances.

4. References

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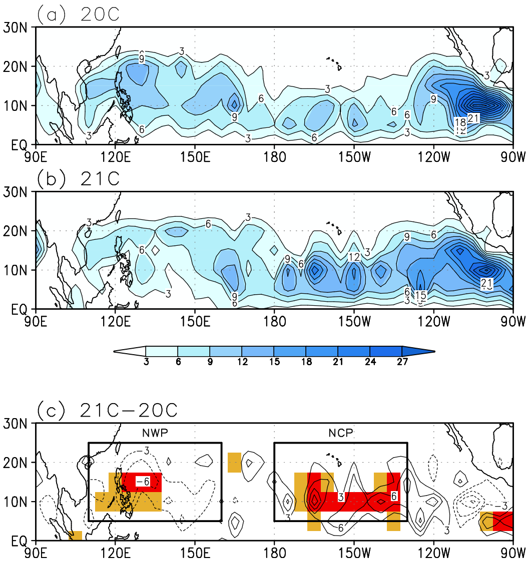

Figure 1 TC genesis number at each 2.5°x2.5° box for a 20-year period derived from T319 ECHAM5 for (a) 20C, (b) 21C, and (c) difference between (b) and (a) (21C-20C). In (c) orange and red color shaded areas indicate the 90% and 95% confidence level or above, respectively (with use of Student's t test).

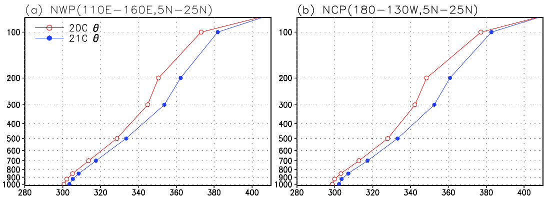

Figure 2 Vertical profiles of potential temperature (unit: K) at 20C and 21C averaged over (a) NWP and (b) NCP.

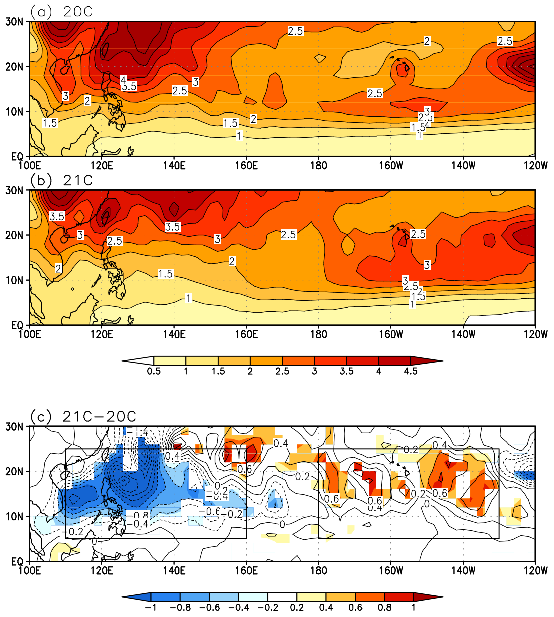

Figure 3 Variances of synoptic-scale (2-8-day) vorticity at 850 hPa (unit: 10^{-10} s^{-2}) in northern summer (July-October) for the 20C and 21C simulations and their difference (21C – 20C). In (c) shaded areas indicate the 95% confidence level or above (an F test is used for checking the significance of the variance difference field).