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Decadal changes of the wintertime tropical tropospheric temperature and their influences on the extratropical climate

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Abstract A decadal change of the tropical tropospheric temperature (TT) was identified to occur in the winter of 1997. Compared with that in the former period (1979–1996), the wintertime TT was significantly high over most of the tropical regions except over the tropical eastern Pacific during the latter period (1997–2014) because the sea surface temperature (SST) exhibited a decadal La Niña-like pattern after 1997. The warm SST anomalies over the tropical western Pacific facilitated enhanced precipitation and increased heat release to the tropical atmosphere, leading to a warmer tropical troposphere in the latter period. In addition to the mean TT values, the interannual variability of the tropical TT changed in 1997. The leading mode of the tropical TT explained 72.9 % of the total variance in the former period. It led to significant warming over midlatitude North America via a Pacific-North America (PNA)-like wave train and off the coast of East Asia via an anomalous lower-tropospheric anticyclone around the Philippines. The mode remained a similar pattern but explained 85.4 % of the total variance in the latter period, and its location was slightly westward-shifted compared with that in the former period. As a result, the structure of the PNA-like wave train changed, leading to anomalous warming over northwestern North America and enhanced precipitation over the southern North America. Meanwhile, the anomalous lower-tropospheric anticyclone around the Philippines shifted westward, leading to increased precipitation and regional warming over East Asia. The decadal changes of the leading mode of the tropical TT and its influences on the extratropical climate can be attributed to the changes of the tropical SST variability.

Keywords Tropospheric temperature · Sea surface temperature · Decadal shift · Interannual variability · East Asia · North America

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1 Introduction

The free tropospheric temperature (TT) is a convenient proxy to reflect the diabatic heating that the tropical atmosphere receives from deep convections and other processes [1, 2]. Compared with the regional-scale patterns of the diabatic heating, the tropical TT and its anomalies often distribute uniformly over the global tropics because the tropical free atmosphere can be easily adjusted by fast equatorial waves and thereby cannot maintain horizontal pressure gradients [1, 3, 4].

The variations of the tropical TT often lead to changes of the extratropical circulation and climate via altering the Hadley circulation and atmospheric teleconnections [1, 5]. For example, below-normal TT over the Philippine Sea in boreal winter could excite an in situ anticyclonic Rossby wave response and lead to warm anomalies over East Asia [6, 7], and above-normal TT over the tropical eastern Pacific could excite a Pacific-North America (PNA)-like wave train and lead to warm and wet conditions over northwestern North America [5].

A major origin of the tropical TT variability can be attributed to the changes of the tropical sea surface temperature (SST) and the attendant deep convections [5, 8, 9]. The SST pattern linked to El Niño-Southern Oscillation (ENSO) is the most crucial to drive the tropical TT variability [1]. Nevertheless, other SST patterns such as the Indian Ocean warming are also important to alter the tropical TT [2]. Given the complex origins of the tropical TT variability, it is often insufficient to reproduce the extratropical circulation and climate responses to the tropical heating in atmospheric general circulation model (AGCM) even though the observed tropical SST is prescribed [10]. By contrast, much better results could be obtained in AGCM when the tropical atmosphere is released to observation via certain techniques [10]. This contrasting result suggests the advantage of using the tropical TT over the SST to investigate the influences of the tropical heating on the extratropical climate.

A decadal shift of SST towards La Niña-like pattern is observed over the tropical Pacific in the late 1990s and early 2000s [11]. Numerous studies have investigated the possible contributions of this decadal SST shift to the global warming hiatus [11, 12], while less attention was paid to address questions such as how the tropical TT behaves accompanied with this decadal change and what are the resultant influences on the extratropical climate. In this study, we will focus on boreal winter and give a brief answer to the above two questions.

2 Data and methods

The monthly mean atmospheric data, which has a 1.5° × 1.5° horizontal resolution and extends from 1000 to 1 hPa with 37 vertical pressure levels, are from the ERA-interim reanalysis dataset for the period 1979 to the present [13]. Monthly mean precipitation rate data are from the Climate Prediction Center Merged Analysis of Precipitation (CMAP), which has a 2.5° × 2.5° horizontal resolution for the period 1979 to the present [14]. The monthly mean SST data are from the Met Office Hadley Centre's sea ice and sea surface temperature (HadISST) dataset, which has a 1° × 1° resolution and spans from 1870 to the present [15]. The tropospheric thickness is proportional to the TT under the hydrostatic balance approximation, which is an excellent approximation for the large-scale motions in the real atmosphere [16]. Hence, the atmospheric thickness between 200 and 850 hPa is used to represent and referred to as the TT hereafter. When the diabatic heating (Q1) is evaluated, we follow the equation 6 in Trenberth and Solomon [17], which has been used in our previous studies [18]. The tropical strip is defined as the region between 20°S and 20°N, consistent with previous studies [1, 19]. In this study, we focus on boreal winter (December, January and February) for the period from 1979 to 2014, where the winter of 1979 refers to the winter of 1979/80.

3 Changes of the mean of the tropical TT

Figure 1a shows the Hovmöller diagram of the 9-year running mean of the wintertime tropical (20°S–20°N

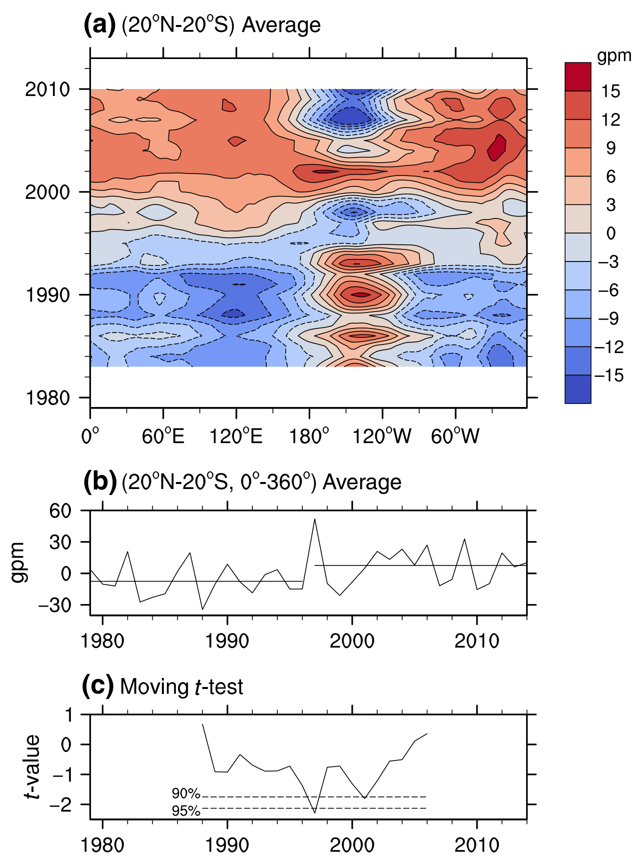

Fig. 1 **a** Hovmöller diagram of the 9-year running mean of the tropical (averaged over 20°S–20°N) TT for the winters 1979–2014. **b** Time series of the tropical (averaged over 0°–360°, 20°S–20°N) TT anomalies for the winters 1979–2014 and their average values (horizontal lines) for 1979–1996 and 1997–2014, respectively. **c** The moving *t* value of the time series in (**b**) with a 9-year window. Data in the first and last four years are omitted in (**a**). Contour intervals (CIs) are 3 gpm and negative values are dashed. The anomaly in (**b**) is defined as the departure from the mean of 1979–2014. Two dashed lines in (**c**) denote the 90 % and 95 % confidence levels based on a two-sided Student's *t* test, respectively