Significant Atmospheric Circulation Anomalies over the North Pacific Associated with the Enhanced Pacific ITCZ during the Summer–Fall of 2014

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Abstract

We describe the atmospheric features observed over the North Pacific during the summer–fall of 2014 and investigate their association with the convective activity in the intertropical convergence zone (ITCZ) and underlying oceanic conditions. During this duration, while the NINO.3 index, the area-averaged sea surface temperature anomalies (SSTAs) in the eastern equatorial Pacific, fluctuates around the threshold value for the onset of El Niño events, off-equatorial SSTAs display an equatorial antisymmetric pattern with positive (negative) anomalies north (south) of the equator. As expected from the wind–evaporation–SST feedback, the equatorial antisymmetric SSTAs accompany with anomalous southerlies, converging into a zonal belt of 5°N–10°N that induces enhanced convection in the ITCZ. Thus, the oceanic and atmospheric features in the eastern tropical Pacific are different from those in the typical El Niño events. In contrast, the observed weaker subtropical high and the shallower upper-tropospheric trough over the North Pacific are similar to the features typically found during the El Niño events. The amplitude of those anomalies, however, is much larger than that of regressed anomalies onto the NINO.3 index. A linear baroclinic model experiment indicates that the enhanced convective heating in the ITCZ contributes to sustain the anomalous atmospheric circulation.

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1. Introduction

The El Niño-Southern Oscillation (ENSO) is the most dominant interannual climatic variability phenomenon in the Earth’s climate system and has huge sociological and economic repercussions globally (McPhaden et al. 2006). Therefore, to deepen our understanding of the ENSO and its association with the atmospheric circulation is important to improve operational climate monitoring and numerical seasonal forecasting.

After two relatively strong westerly wind events in February and March 2014 considered as the potential trigger of the El Niño onset (Vecchi and Harrison 2000), the numerical climate models of many operational climate centers predicted that the El Niño would grow substantially during the second half of 2014. However, the observed sea surface temperature anomalies (SSTAs) in the eastern equatorial Pacific were much smaller than those predicted. Meanwhile, equatorially antisymmetric SSTAs with positive (negative) anomalies north (south) of the equator prevailed in the central and eastern tropical Pacific during the summer–fall 2014.

Maeda et al. (2016) suggested that the intensified evaporative cooling of SST as a result of the prevailing southerly surface wind across the equator contributed to the suppression of the El Niño growth in 2014. They insisted that the wind–evaporation–SST (WES) feedback (Xie and Philander 1994) is the physical background of the surface southerlies in the near-equatorial region and the equatorially antisymmetric SSTAs. They also showed that convection in the northern intertropical convergence zone (ITCZ) enhanced by the convergent surface flow of the anomalous southerlies contributed to sustain the prevailing anomalous southerlies. These results indicated that the convective activity over the eastern Pacific could also be enhanced by the WES feedback during the non-El Niño years, as well as by the Bjerknes feedback (Bjerknes 1966) during the typical El Niño years. The enhanced convection would force large-scale atmospheric circulation. Hence, in the present study, we investigate the relation between the features of the anomalous atmospheric circulation over the Northern Hemisphere during the summer–fall 2014 and remote impacts of the enhanced convection in the northern ITCZ.

2. Data

We used the Japanese 55-year reanalysis dataset (JRA-55; Kobayashi et al. 2015) to analyze the large-scale atmospheric circulation. The COBE-SST (Ishii et al. 2005) data were used for the SST analysis. Outgoing long-wave radiation (OLR) data provided by NOAA were used as a proxy of the convective activity. As climatological values, monthly averages over the 30-year period 1981–2010 for each variable were used. Monthly anomalies were defined as departures from the respective climatological values. We also analyzed the output of the numerical experiment using a linear baroclinic model (LBM). The experimental design was documented by Maeda et al. (2016).

3. Results

3.1 Atmospheric circulation anomalies during the summer–fall 2014

Figures 1a, 1b, 1c, 1d, and 1e show SSTAs and atmospheric circulation anomalies averaged over June–October 2014 when the El Niño event was expected to grow. In the equatorial eastern Pacific, however, the observed positive SSTAs are much smaller than the predicted ones (Fig. 1a). Indeed, the NINO.3 index, the area-averaged SSTAs in the eastern equatorial Pacific (5°S–5°N, 150°W–90°W) in 2014 is close to the threshold value (+0.5 K) for the onset of El Niño events based on the definition of the Japan Meteorological Agency, and is lower than the values for the typical El Niño years such as 1982, 1987, and 1997 (Fig. 1f). Instead of the tongue-like pattern of positive SSTAs observed during typical El Niño years, off-equatorial SSTAs east of the date line display an equatorial antisymmetric pattern with positive (negative) anomalies to the north (south) of the equator. Although zonal gradients of SSTAs ordinarly dominate in the tropical Pacific when El Niño occurs, meridional gradients of SSTAs dominated in 2014. Corresponding to the equatorially antisymmetric SSTAs and the convergence of surface wind anomalies (Fig. 1a),
convective activities over the central and eastern tropical Pacific are enhanced in a zonal belt 5°N–10°N, where the climatological mean of ITCZ in the Northern Hemisphere is located (Fig. 1b). Chiang and Vimont (2004) found the Pacific meridional mode in which the anomalous SSTA gradient across the climatological mean latitude of the ITCZ is coupled to the anomalous displacement of the ITCZ toward the warmer flank of the SST. However, observed anomaly patterns of SST and ITCZ in 2014 show apparent differences from the characteristics of this mode. In 2014, the meridional SSTA gradient is obvious across the equator rather than across the mean latitude of the ITCZ. Besides, convective activity in 2014 is enhanced in the mean latitude of the ITCZ rather than the warmer flank of SST.

Because convective activities in the northern ITCZ would force the first baroclinic Rossby wave that extends northwestward (e.g., Gill 1980), the observed enhanced convection is expected to affect the subtropical North Pacific. Indeed, a baroclinic anomalous circulation is observed in the subtropical North Pacific with a weak surface anticyclone (Fig. 1c) and a shallow upper-tropospheric trough (Whitfield and Lyons 1992) (Fig. 1d); the positive geopotential height anomalies around the central subtropical North Pacific are indicative of the shallower upper-tropospheric trough. The baroclinic structure anomaly over the western and central portions of the subtropical North Pacific is clearly found in the height–longitude cross-section of meridionally averaged (10°N–30°N) stream function anomalies (Fig. 1e). In contrast, a baroclinic structure anomaly is not observed in the subtropical South Pacific (Figs. 1c and 1d). This equatorially asymmetric nature between the hemispheres is similar to the remote impact forced by the off-equatorial convective activities (Gill 1980).

To identify how the tropical and subtropical conditions are anomalous, the time series of the OLR anomalies over the central and eastern tropical Pacific and the geopotential anomalies at 1000 and 200 hPa levels over the subtropical North Pacific are plotted in Fig. 2. While the values in 2014 in Figs. 2a and 2b are close to the minimum value, the values in Fig. 2c are the highest over 36 years. This means that during the summer–fall of 2014, the

![Fig. 1. Observed oceanic and atmospheric fields averaged from June to October 2014. (a) SST [K] and 10 m wind [m s⁻¹] anomalies, (b) OLR anomalies [W m⁻²], (c) SLP normal (contours) and anomalies (color shading) [hPa], (d) geopotential height at 200 hPa normal (contours) and anomalies (color shading) [m], and (e) height–longitude cross-section of meridionally averaged (10°N–30°N) stream function anomalies [10⁸ m² s⁻¹]. Ordinate of (e) is pressure [hPa]. (f) Interannual variability of area-averaged SST anomaly in the eastern equatorial Pacific (5°S–5°N, 150°W–90°W) during the period from 1979 to 2014 and averaged from June to October. The 10 m wind in (a) is relative to the scale vector [m s⁻¹] shown below in (a).](image)

![Fig. 2. Same as Fig. 1f, but for (a) OLR [W m⁻²] averaged in (5°N–15°N, 180°W–120°W), (b) Geopotential height [m] at 1000 hPa, and (c) geopotential height [m] at 200 hPa (black line) and thickness height [m] between 200 and 1000 hPa (red line) averaged in (20°N–30°N, 150°E–120°W).](image)
convective activities in the ITCZ are significantly enhanced, and a large-amplitude baroclinic structure anomaly is observed over the subtropical North Pacific. In the next subsection, we statistically and dynamically examine the relationship between the enhanced convection in the northern ITCZ and baroclinic structure anomaly in the subtropical North Pacific in 2014.

3.2 Relationship between enhanced convection in northern ITCZ and baroclinic structure anomaly in the subtropical North Pacific

In order to assess the relevance of the above-mentioned enhanced convection in the northern ITCZ to the baroclinic structure anomaly in the subtropical North Pacific statistically, we perform linear regression analysis. The data used in the analysis refer to the interval 1979–2014, and the seasonal averages over June–October are used.

Figure 3 presents the regressed SLP and stream function anomalies onto time series of the area-averaged (5°N–15°N, 180°W–120°W) OLR anomalies shown in Fig. 2a. Hereafter, we refer to this index as the OLR-N. For easier inter-comparisons with Figs. 1c and 1e, regressed anomalies in Figs. 3a and 3b are regression coefficients multiplied by the normalized 2014 value of the OLR-N. As observed from the anomaly pattern in 2014 (Fig. 1), the weaker subtropical surface anticyclone in the subtropical North Pacific is closely related to the enhanced convection in the northern ITCZ. This suggestion is supported by a numerical experiment using an LBM developed by Watanabe and Kimoto (2000, 2001).

3.3 Relationship between oceanic conditions and atmospheric circulation in the North Pacific area

In order to assess the relationship between the atmospheric circulation anomalies over the North Pacific and the oceanic conditions in the eastern Pacific, we conduct a linear regression analysis using two indices of the oceanic conditions. We use the June–October averages of the SST anomalies from 1979 to 2014.

The SST-NS index is related to the equatorially antisymmetric SSTAs prevailing in 2014. The SST-NS is defined as the meridional difference in area-averaged SST between the central and eastern tropical North Pacific (5°N–20°N, 180°W–90°W) and the South Pacific (20°S–5°S, 180°W–90°W). In order to reduce the variability associated with the typical ENSO events, SSTAs in the equatorial area are excluded in the calculations of the SST-NS. For the 36 years in the dataset, the SST-NS value of 2014, which is drawn by a green closed square in Fig. 5a, is the highest (Fig. 3b, and 3d) and the regressed anomalies onto the OLR-N (Fig. 3). In the Southern Hemisphere, by contrast, the baroclinic structure circulation is not simulated, which is consistent with the observations. Since the anomalous heating is located north of the equator, the substantial response is mainly found in the Northern Hemisphere. The results of the numerical experiment indicate that the enhanced condensation heating in the northern ITCZ contributes to the observed pattern in the subtropical North Pacific during the summer–fall 2014.
correlation coefficient between OLR-N and SST-NS is −0.62, whereas the same coefficient between OLR-N and NINO.3 is −0.47. This means that the convective activity in the northern ITCZ is significantly correlated with the equatorially antisymmetric SSTAs in the central and eastern tropical Pacific rather than with the equatorially symmetric SSTAs in the same region (Figs. 5a and 5b).

One may cast a doubt if the meridional gradient of SSTA between the northern off-equatorial area and the on-equatorial area rather than the SST-NS might be more important for the correlation with the OLR-N index. We check the relation between OLR-N and a new index which is defined by the meridional difference in area-averaged SSTA between the central and eastern tropical North Pacific (5°N−20°N, 180°W−90°W) and the equatorial Pacific (5°S−5°N, 180°W−90°W). It is confirmed that OLR-N is more correlated with SST-NS than the new index, because the correlation coefficient with the new index is 0.35, which is lower than the absolute value of the correlation coefficient with SST-NS. Besides, the fact that the new index value of 2014 is near zero (no figure) indicates that the meridional gradient of SSTA between the northern off-equatorial area and the on-equatorial area is not a key factor of OLR-N of 2014.

Figures 5c and 5e (5d and 5f) present the regression anomalies on the SST-NS (NINO.3) index. As the same as the regressed anomalies in Fig. 3, the normalized 2014 SST-NS and NINO.3 values are multiplied with the respective regression coefficients. In the North Pacific, the regressed SLP anomalies on SST-NS (Fig. 5c) and NINO.3 (Fig. 5d) are both similar to the observed anomaly pattern in 2014, while the amplitude of the regressed pattern is higher on SST-NS than on the NINO.3. The height–longitude cross-section of meridionally averaged stream function [10^6 m^2 s^{-1}] on NINO.3. The normalized SST-NS (NINO.3) values for 2014 are multiplied with the respective regression coefficients in (c) and (e) (in (d) and (f)). Hatching indicates the area where the regressions are statistically significant at the 90% confidence level. The data period is from 1979 to 2014, and averaged values from June to October are used.

The amplitude of the regressed anomaly on SST-NS (Fig. 5e) is approximately twice higher than that on NINO.3 (Fig 5f). These statistical results indicate that the dominant atmospheric circulation anomalies over the North Pacific in 2014, which are forced by the enhanced convection in ITCZ, are associated closer with the equatorially antisymmetric SSTAs than with the SSTAs in the eastern equatorial Pacific.

4. Summary and discussion

In the present study, we investigated the atmospheric features during the summer–fall 2014. In this period, the equatorially antisymmetric SSTAs with positive (negative) anomalies in the Northern (Southern) Hemisphere prevailed in the central and eastern tropical Pacific. Consistent with the equatorially antisymmetric SSTA pattern, convective activity in the northern ITCZ was significantly enhanced. Over the North Pacific, the subtropical high was weaker than normal, and the subtropical upper-tropospheric trough was significantly shallower than normal. These baroclinic structure anomalies are typically observed during El Niño years. However, the amplitudes of the observed patterns were much higher than those statistically expected based on the NINO.3 index in the eastern equatorial Pacific, which fluctuated around the threshold value for the onset of El Niño events. An LBM experiment indicated that the enhanced convective heating in the northern ITCZ contributed to produce significant atmospheric features over the subtropical North Pacific.

We also showed that the enhanced convection in the ITCZ and the prevailed atmospheric circulation anomalies over the subtropical North Pacific in 2014 were associated with equatorially antisymmetric SSTAs, which were sustained by the WES feedback. These results mean that an atmospheric variability associated with the WES feedback prevailed over the subtropical North Pacific in the summer–fall of 2014.
The wind stress curl anomalies associated with the observed weaker subtropical high may have an impact on the ENSO cycle through inducing of oceanic northward Sverdrup flow which discharge thermal energy from the equatorial region. However, in 2014, the positive curl anomalies associated with the weaker Pacific High was limited to north of 25°N. The result suggests that wind stress anomalies associated with the weaker Pacific High did not contribute to the ocean dynamics in the equatorial areas related to the ENSO.

Approximately after 2000, the negative phase of the Pacific Decadal Oscillation (PDO; Mantua et al. 1997) and the Inter-decadal Pacific Oscillation (IPO; Power et al. 1999) had persisted until around 2013. The negative SSTA in the eastern tropical south Pacific in 2014 may be related to the negative phase of IPO. Detailed analysis of the relationship between PDO/IPO and the observed equatorially antisymmetric SSTAs in 2014 is beyond the scope of this paper and left for future study.

The global-average surface temperature for 2014 was comparable to the warmest years in the 165-year instrumental record (WMO 2015). In 2014, the eastern North Pacific basin saw above average activity 143% of normal accumulated cyclone energy (WMO 2015). The western part of Japan experienced wet and cool summer. The Indian summer monsoon rainfall in 2014 was below normal (WMO 2015). These climate anomalous events may be directly or indirectly associated with the enhanced convection in the ITCZ and underlying oceanic conditions, although there is few studies on this matter (e.g., Murakami et al. 2015). Relationship between such anomalous climate conditions and the enhanced convection should be investigated further.

The time scales of climatic variations based on ocean–atmosphere feedbacks, such as the Bjerknes feedback, are longer than those of atmospheric internal variations. Therefore, these variations are important for operational climate monitoring and seasonal forecasting. Among these variations, ENSO, which is closely related to the Bjerknes feedback, is the most important, and many operational climate centers in the world monitor and forecast ENSO and its impact on climate. Whereas, in 2014, as shown in this study, variability related to the WES feedback prevailed over the North Pacific. The present results imply that more studies on the WES feedback-related variability and its impacts on climate will improve climate system monitoring and seasonal forecasting.

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