Comparison of the 2015/16 El Niño with the Two Previous Strongest Events

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Abstract

The 2015/16 El Niño is compared with the two previous strongest events, the 1982/83 and 1997/98 El Niños. The 2015/16 winter features a basin warming in the Indian Ocean, a negative sea surface temperature (SST) anomaly shifted to the north in the western Pacific Ocean in addition to a positive SST anomaly shifted to the west in the eastern Pacific Ocean. These SST distributions lead to suppressed convection in the Maritime Continent, and to a weakened Hadley circulation in the western Pacific Ocean. The eastern Asian monsoon in the 2015/16 winter was also weakened due to the dominance of the western Pacific (WP) pattern. On the other hand, the third and fourth centers of action of Pacific/North American (PNA) pattern in the 2015/16 case are obscure. This may be due to weak divergence in the eastern Pacific Ocean.

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1. Introduction

A spectacular El Niño occurred from the summer of 2014 to the spring of 2016. In the 2015/16 winter, it became the strongest El Niño case of this century and the third strongest after the 1982/83 and 1997/98 cases. Furthermore, this El Niño has recently received broad attention due to the process of uncanonical development. In the 2014/16 El Niño, the El Niño index defined by the Japan Meteorological Agency (JMA) did not increase much during the 2014/15 winter and rapidly developed starting in the spring of 2015. Thus, it is possible to distinguish the 2014/15 from 2015/16 winters although the NINO.3 index had always maintained +0.5°C or higher.

Ren et al. (2017) investigated seawater temperature anomaly development and the upper-ocean heat budget in the 2015/16 case and compared them with those of the 1982/83 and 1997/98 cases. In the mature phase of the 2015/16 case, the center of the sea surface temperature (SST) anomaly in the equatorial eastern Pacific Ocean was displaced westward and the SST was tending to be high in the whole Pacific Ocean compared with that in the previous two cases. Moreover, the positive subsurface water temperature anomalies in the equatorial eastern Pacific Ocean had the smallest amplitude, but spread westward most extensively among the three strongest events. Saji et al. (2018) argued that the strong decadal variability enhanced the SST anomalies in the Pacific Ocean during the 2015/16 case. These previous studies focused on the seawater temperature in the Pacific Ocean and did not mention impacts on the Indian and Atlantic Oceans and on the atmosphere.

Halpert and Ropelewski (1992) showed that ENSO teleconnections influence on the global temperature field. The Far East typically experiences a warm (cold) winter during El Niño (La Niña). Wang et al. (2000) proposed a mechanism for anomalously warm winter in East Asia due to a negative SST anomaly in the Philippine Sea during El Niño. The negative anomaly develops from developing fall to winter during the El Niño. As a direct response to the negative SST anomaly, a positive sea level pressure (SLP) anomaly in the Philippine Sea is generated and the anomalous southerly winds on the west side of the positive SLP anomaly influence on the winter climate in the Far East.

Some previous studies pointed out the influence of the other Oceans on the Pacific Ocean. Watanabe and Jin (2002) proposed a mechanism for the enhancement of the SLP anomaly in the Philippine Sea due to the Walker circulation modified by the Indian Ocean warming. Keenlyside and Latif (2007) pointed out that the negative SST anomaly in the equatorial Atlantic Ocean precedes the positive SST anomaly in NINO.3 by approximately a half year.

Takaya and Nakamura (2013) investigated the relationship between the eastern Asian winter monsoon (EAWM) associated with the winter climate in the Far East and the upper tropospheric circulation. They showed that a Western Pacific (WP)-like pattern and a Eurasian (EU)-like pattern appear during anomalous winters in the Far East. Their results do not necessarily suggest that an anomalous winter in East Asia is of mid-latitude origin because their analysis includes not only neutral but also ENSO cases.

The purpose of this study is to investigate the influence on atmospheric circulation in the 2015/16 case in comparison to the 1982/83 and 1997/98 cases, examining the previously proposed mechanisms for warm winter in the Far East. Furthermore, we investigate the surface and subsurface water temperature anomalies in the Indian and Atlantic Oceans and their influence on the variability of SST anomaly in the Pacific Ocean.

The datasets and analysis methods used for this study are shown in Section 2. Section 3 analyzes and compares the three cases. We discuss the differences in atmospheric responses between the three cases and their causes, based on their distributions of surface and subsurface temperature anomalies in Section 4. Hereafter, the cases are denoted as the 82/83, the 97/98, the 15/16 cases, and so on.

2. Datasets and analysis methods

To analyze atmospheric responses, JRA-55 (Kobayashi et al. 2015) on a 1.25° × 1.25° horizontal grid for 1958 to 2018 is used. COBE-SST (Ishii et al. 2005) on a 1° × 1° horizontal grid for 1928 to 2018 is used to analyze the SST anomalies and their developments. In addition, NCEP Global Ocean Data Assimilation System (GODAS) (Behringer and Xue 2004) on a 0.333° longitude × 1° latitude horizontal grid for 1980 to 2018 is used to investigate the subsurface water temperature anomalies.

Anomalies were calculated as the differences from the global warming trend, which was calculated by the linear least-squares method from 1958 to 2018. The average of all El Niño cases (hereafter, ALL) is the mean of 15 cases that occurred since 1958: 58, 63/64, 65/66, 69/70, 72/73, 76/77, 82/83, 86/87, 87/88, 91/92, 97/98, 02/03, 09/10, 14/15, and 15/16. The identification of El Niño was carried out following the definition by the JMA. The El Niño index for each month is the 5-month running mean of area-averaged SST differences in NINO.3 (5°N–5°S, 90°W–150°W) from the 30-year climatology until the previous year. If the index continues to be higher than or equal to +0.5°C for 6 consecutive months or longer, the corresponding period is determined to be an El Niño event.

Because the GODAS is available after 1980, the anomaly

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resembles that in the 82/83 case. In these two cases, there is the WP and meridional dipole in East Asia and these height anomalies compose a quadrupole. The center of action on Japan corresponds to the weakening of the EAWM because the height anomaly in the mid-latitudes is dominantly barotropic. However, the temperature anomaly averaged in the Far East is not warmer than normal winter in the 82/83 and the 15/16 cases because China is covered with the negative height anomaly which is one of the height anom-

3. Results

The following differences are found between the 15/16 case and the two strongest El Niño cases as well as the ALL.

3.1 The relationship between the NINO.3 index and the temperature anomaly in the Far East

The intensity of the three strongest cases is confirmed by the NINO.3 index. The peak values are 2.77 in December for the 82/83 case, 3.29 in November for the 97/98 case and 2.75 in November for the 15/16 case. Thus, the 15/16 case is the third strongest El Niño since 1958. The rank is also consistent with the DJF averages: 2.66 for the 82/83 case, 2.93 for the 97/98 case and 2.35 for the 15/16 case.

Figure 1 shows the relationship between the NINO.3 indices and the 850-hPa temperature anomalies in the Far East (25°N–40°N, 100°E–140°E). This plot clearly shows that El Niño does not necessarily bring warm winter to the Far East, although the Far East tends to be warm with high NINO.3 indices, as shown by the regression line. The influences on the Far East are very different in the three El Niño cases; warmer than normal in the 97/98 case, near normal in the 15/16 case, and colder than normal in the 82/83 case.

3.2 Teleconnection patterns

The 500-hPa height anomalies exhibit outstanding teleconnection patterns in the three cases, (Fig. 2). The distribution of the height anomalies over the Pacific Ocean such as the strengthening of the Aleutian cyclone and the extension of the positive height anomaly toward Japan are common to the ALL and three cases. In the 15/16 case, the distribution of the height anomaly in East Asia

![Fig. 1. Relationship between the NINO.3 indices (x-axis) and the 850-hPa temperature anomalies in the Far East (y-axis). The red, white and blue dots denote El Niño, neutral and La Niña, respectively. A number to the upper-left of a dot shows the year based on January. The regression line is estimated from all points.](image1)

![Fig. 2. Height anomalies (contours, m) at 500-hPa in DJF for the a) ALL, b) 82/83, c) 97/98, and d) 15/16 cases, respectively. Hatches in a) show regions with statistical significance (> 90%). The dots in black, red, and blue indicate the centers of action of the PNA, WP, and EU, respectively.](image2)
as in the quadrupole. According to these characteristics and the teleconnection pattern indices (Table 1), the PNA is dominant in the three cases. However, the third centers of action in the 82/83 and the 97/98 cases are shifted to the east and the third and fourth of centers in the 15/16 case are obscure. The EU only appears in the 97/98 case. The EU in the ALL disappears, indicating that the EU is an internal variation in the mid-latitudes.

3.3 Surface and subsurface sea temperature anomalies

In the 15/16 case (Fig. 3d), an amplitude and an area of a negative horseshoe-shaped SST anomaly in the Pacific Ocean are smallest in the three cases and a negative SST anomaly in the Philippine Sea is weaker than the previous two cases (Figs. 3b and 3c). Moreover, an anticyclonic circulation in the Philippine Sea is shifted to the north. In the Indian Ocean, a basin warming occurs in the 15/16 case (Fig. 3d) and in the 82/83 case (Fig. 3b), in which the southeastern Indian Ocean has a peak. By contrast, an Indian Ocean dipole mode (IOD) occurred in the 97/98 case (Fig. 3c). The SST anomalies in the northwestern Atlantic Ocean do not share common features.

In the 15/16 case (Fig. 4d), anomalous subsurface temperatures along the equator are found in the Indian and Atlantic Oceans in addition to the westward shift of a subsurface positive temperature anomaly in the Pacific Ocean (Ren et al. 2017). A negative anomaly in the eastern Indian Ocean is weaker than the previous two cases (Figs. 3b and 3c). Moreover, an anticyclonic circulation in the Philippine Sea is shifted to the north. In the Indian Ocean, a basin warming occurs in the 15/16 case (Fig. 3d) and in the 82/83 case (Fig. 3b), in which the southeastern Indian Ocean has a peak. By contrast, an Indian Ocean dipole mode (IOD) occurred in the 97/98 case (Fig. 3c). The SST anomalies in the northwestern Atlantic Ocean do not share common features.

In the 15/16 case (Fig. 4d), anomalous subsurface temperatures along the equator are found in the Indian and Atlantic Oceans in addition to the westward shift of a subsurface positive temperature anomaly in the Pacific Ocean (Ren et al. 2017). A negative anomaly in the eastern Indian Ocean is shifted downward. Thus, the positive anomaly in the western Indian Ocean is more exposed to the surface, consistent with the basin-wide warming at the surface. In the Atlantic Ocean, common features with the 82/83 and 97/98 cases (Figs. 4b and 4c) are not found as at the surface. In the 15/16 case, a negative anomaly in the Atlantic Ocean is most conspicuous in the three cases.

The positive SST anomaly in the eastern Pacific Ocean begins to expand westward in spring (Figs. 5a, 5c, and 5d) except for the 82/83 case (Fig. 5b), in which the expansion starts in summer. Westerly wind anomalies in the developing spring in approximately 120°E–180°E act as a trigger for the expansion. In spite of the difference at the beginning of expansion, the positive SST anomalies peaks in the three cases coincide in December. Westerly wind anomalies in the 15/16 case peak near the dateline, but the anomalies in the other two cases peak in the east of the dateline, implying the difference in the Walker circulation. In addition, in the 15/16 case, the easterly wind anomalies peak near the dateline, but the anomalies in the west more than the other cases and the amplitude of the SST anomalies in the Philippine Sea is smaller.

In the Indian Ocean, the IOD occurred from developing summer to fall in the 82/83 and the 97/98 cases but not in the 15/16 case (Figs. 5b, 5c, and 5d). The westerly winds act to suppress the occurrence of the IOD. In the Atlantic Ocean, negative SST anomalies reach the peak in the developing summer in the ALL and three cases, preceding the peak of the positive SST anomaly in the eastern Pacific Ocean by approximately a half year (Keenlyside and Latif 2007). However, the negative SST anomalies persist in the 82/83 case.

Table 1. Teleconnection pattern indices in each case.

| index | ALL  | 82/83 | 97/98 | 15/16 |
|-------|------|-------|-------|-------|
| PNA   | 0.79 | 1.15  | 1.32  | 1.13  |
| WP    | −0.63| −1.02 | −0.72 | −2.02 |
| EU    | −0.07| 0.41  | −1.10 | 0.28  |

Fig. 3. As in Fig. 2 but for the SST (shades, K), SLP (contours, hPa) and 850-hPa wind (arrows, m/s) anomalies. The hatches and arrows in (a) indicate points with statistical significance (> 90%).

Fig. 4. As in Fig. 2 but for the seawater potential temperature (shades, K) anomalies averaged between 5°N and 5°S.
3.4 Walker circulation and heating anomalies

The results in the previous subsections show that there are differences in the surface and subsurface water temperature anomalies among the three cases. The differences involve anomalous atmospheric circulation in the tropics.

In the 15/16 case (Fig. 6d), an anomalous positive diabatic heating and associated divergent winds in the upper troposphere is peaked near 165°W as in ALL (Fig. 6a), located more to the west than that of the other two cases (Figs. 6b and 6c), to strengthen the local Hadley circulation in the central Pacific Ocean. The convergence concentrated over the maritime continent strengthens the SLP anomaly and weakens the local Hadley circulation in the western Pacific Ocean. The Walker circulation is weakened and has a narrower zonal extent than in the other cases as indicated by the wind anomalies in the upper (Figs. 6a and 6d) and lower troposphere (Figs. 3a and 3d).

In the tropical eastern Pacific Ocean, consistent with the SST anomalies, a diabatic heating anomaly is small (Fig. 6d). Associated weak divergent wind anomalies may explain obscure centers of action of PNA over North America in the 15/16 case (Fig. 2d). In the 97/98 case (Fig. 6c), the diabatic heating is large in the western Indian Ocean due to the IOD (Fig. 3c). In the 82/83 and 15/16 cases (Figs. 6b and 6d), the Indian Ocean is weakly divergent, consistent with the basin warming (Figs. 3b and 3d), which has a secondary role to enhance the SLP anomaly in the western Pacific Ocean.

Fig. 6. As in Fig. 3 but for the heating (color, K/day), velocity potential (contour × 10^6 m^2/s), and divergent wind (arrows, m/s) anomalies.
4. Summary and discussions

Outstanding features in the surface and subsurface anomalies of the 15/16 case are the occurrence of the Indian Ocean basin warming and the negative subsurface anomaly in the Atlantic Ocean (Figs. 3d and 4d), in addition to the westward shift of the positive surface and subsurface anomalies in the eastern Pacific Ocean (Ren et al. 2017). Additionally, in the atmosphere, the WP was dominant and the Walker circulation was suppressed in narrower zonal extent due to the westernmost positive SST anomaly in the eastern Pacific Ocean (Figs. 3d and 6d). The westward shift of the positive SST anomaly in the eastern Pacific Ocean and the basin warming (Watanabe and Jin 2002) play a primary and subsidiary role in the suppression in the western Pacific Ocean, respectively (Fig. 3d). The convergence in the maritime continent and divergence in the central Pacific Ocean results in weakened and strengthened local Hadley circulations in the western and central Pacific Oceans, respectively (Fig. 6d).

The weakened local Hadley circulation in the western Pacific Ocean may have excited the southern center of action of the WP which is a part of the quadrupole in East Asia (Fig. 2d) due to the divergence of the divergent wind anomalies in the westerly jet in the northwestern Pacific Ocean (Sardeshmukh and Hoskins 1988). The southern zonal dipole of the quadrupole can be understood from the linearized vorticity equation in the steady-state.

\[ \ddot{\zeta} + \frac{\partial \zeta'}{\partial x} = -\pi \frac{\partial \zeta'}{\partial x} \]

where \( \zeta' \) is the vorticity anomaly, \( \pi \) is the zonal wind average, \( \zeta' \) is the meridional wind anomaly, and \( \beta \) is the beta effect. This equation indicates that the advection of the planetary vorticity by the southerly wind anomaly of the quadrupole has to balance the advection of the relative vorticity by the westerly wind. That is, if an anticyclonic anomaly, the southern center of action of WP, is excited, a cyclonic anomaly, with positive relative vorticity has to appear in China.

In the 15/16 case, the southerly winds toward Japan are more likely to be due to the weakened local Hadley circulation rather than the SLP anomaly in the Philippine Sea because the negative SST anomaly below is weaker than the other cases and shifted to the north (Fig. 3d).

In sharp contrast, in the 97/98 case, the heating anomaly due to the IOD excites a divergence in the Middle East (Fig. 6c). Thus, the negative height anomaly spreads on the Eurasian continent and the height anomaly distribution in East Asia in the 97/98 case (Fig. 2c) differ from that in the 82/83 (Fig. 2b) and the 15/16 cases (Fig. 2d). These lead to the disparate influence in the three cases on the winter climate in the Far East: colder than normal in the 82/83 case, warmer than normal in the 97/98 case and normal in the 15/16 case.

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