Active Role of the ITCZ and WES Feedback in Hampering the Growth of the Expected Full-Fledged El Niño in 2014

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Abstract

We investigated features of the atmosphere and ocean to seek a possible candidate that suppressed the growth of the El Niño event in 2014. In the boreal summer–fall season, equatorially antisymmetric sea surface temperature (SST) anomalies with a positive (negative) sign to the north (south) of the equator prevailed in the central and eastern tropical Pacific. In association with the SST anomalies, cumulus convective activity was enhanced in the region of the climatological Intertropical Convergence Zone (ITCZ). Anomalous southerly surface winds flowing across the equator toward the ITCZ induced upward latent heat flux anomalies and lowered SST in the near-equatorial region. These coherent spatial patterns between SST, wind, and latent heat flux anomalies suggested that the wind–evaporation–SST (WES) feedback sustained the suppression of the El Niño growth. A linear baroclinic model experiment indicated that the enhanced convective heating in the ITCZ also contributed to sustain the anomalous surface southerlies across the equator by the intense meridional atmospheric circulation over the equator. These results indicate that the anomalous southerlies across the equator sustained by the WES feedback and intense convective heating in the ITCZ contributed to the suppression of the El Niño growth.

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1. Introduction

The El Niño-Southern Oscillation (ENSO) is the most dominant interannual climate variability in the earth climate system and has huge sociological and economic impacts globally (e.g., McPhaden et al. 2006). Therefore, ENSO is the main target of seasonal forecasting in operational climate centers. In February and March 2014, two relatively strong westerly wind events (WWEs; Harrison and Vecchi 1997), which are known to be the precursors of El Niño events, occurred in the western tropical Pacific. After these events, the numerical climate models of many operational climate centers predicted that the El Niño would show substantial growth during the second half of the year. Indeed, the WWE events forced a downwelling oceanic Kelvin wave that propagated eastward with large amplitudes in the ocean subsurface layer. The subsequent arrival of the Kelvin wave in the eastern equatorial Pacific induced increases in the sea surface temperature (SST) during the early summer of 2014. However, the SST rise was temporary and a full-fledged El Niño event did not occur. These features observed during the summer–winter season of 2014 have not been predicted by many climate forecast models.

Menkes et al. (2014) investigated the reason for the stagnation of the El Niño growth. From data analysis and ocean model experiments, they indicated that the lack of WWEs from April to June of 2014 significantly limited the growth of the El Niño. Their results show that the dynamical ocean response to internal atmospheric variability during the onset phase of the El Niño was the key process for the subsequent El Niño growth. Conversely, Imada et al. (personal communication) indicated, by numerical experiments using a Coupled General Circulation Model: MIROC.5 (Watanabe et al. 2010), that the inclusion of negative temperature anomalies in the ocean subsurface in the area from the tropical South Pacific to the equatorial Pacific suppressed the El Niño growth. The negative sea subsurface temperature anomalies were related to a negative phase of the Interdecadal Pacific Oscillation (IPO; Power et al. 1999) in recent years. The study indicated that ocean dynamics rather than internal atmospheric variability was the key factor in the stagnation.

By numerical experiments with atmospheric general circulation models coupled with slab ocean models, Kitoh et al. (1999) and Clement et al. (2011) demonstrated that ENSO-like variabilities could develop without atmosphere–ocean dynamical coupling. Zhang et al. (2014) described the South Pacific meridional mode (SPMM): the underlying physical processes of this mode involve trade wind variability over the South Pacific and its effects on SST by modulating latent heat fluxes. The SPMM has a strong expression in the equatorial Pacific and directly perturbs the zonal gradient of SST. These studies indicate that thermodynamic coupling between the atmosphere and ocean modifies ENSO variability. Recently, Min et al. (2015) showed that the anomalous easterly oceanic current, which was forced by the easterly wind anomalies associated with the SPMM, hindered the El Niño in 2014. Their study focused on the oceanic dynamic responses to wind stress anomalies.

In this study, we investigate the features of the atmosphere and ocean in the tropical Pacific in boreal summer–fall season of 2014 and discuss the stagnation of the El Niño growth, focusing on thermodynamic coupling between the atmosphere and ocean. We also evaluate the impacts of anomalous condensation heating over the tropics on the tropical atmospheric circulation using a linear baroclinic model (LBM). Subsequently, using empirical orthogonal function (EOF) analysis, we demonstrate the relevance between the observed pattern and a statistically dominant mode. The 55-year Japanese reanalysis data set (JRA-55, Kobayashi et al. 2015) is used to analyze large-scale atmospheric circulation and latent heat flux from the ocean to the atmosphere. We also employ the JRA-55 as the forcing data to conduct the numerical experiments by the LBM. The COBE-SST (Ishii 2005) data are used for SST. Climatological normal values are defined as the 30-year averages for the period from 1981 to 2010. Anomaly means deviation from the normal.

2. Results

2.1 Atmospheric circulation and SST in the tropical Pacific

Figure 1 shows SST and atmospheric circulation anomalies averaged over June–October 2014, i.e., the boreal summer–fall season during which the El Niño had been expected to grow. East of the date line, SST anomalies are positive (negative) in the trop-
Evaporative cooling is intensified (reduced) there. This meridional contrast in the latent heat flux anomalies induces further amplification of the meridional gradient of SST anomalies. Currently, WES feedback is well recognized as one of the fundamental processes driving the meridional modes in the tropical Pacific and Atlantic (e.g., Zhang et al. 2014). The coherent anomaly pattern between SST, wind, and latent heat flux observed in the summer–fall season 2014, shown in Fig. 1, is consistent with the WES mode, which is the pattern governed by WES feedback in a simple model (Xie 1996). Thus, it is suggested that this feedback is the key physical process for the maintenance of the observed anomaly pattern.

Figure 2 shows interannual variabilities from 1979 to 2014 on area average values in the central and eastern Pacific: SST-NS is meridional differences in SST anomalies in the tropics, V10m-EQ is 10m meridional wind (V10m) near the equator, and omg500-N is vertical p-velocities in the mid-troposphere to the north of the equator. Each value is averaged from June to October. For the 36 years in the dataset, the value of SST-NS was by far the highest, that of V10m-EQ was the strongest, and that of omg500-N was the second lowest in 2014.

These features indicate that a coherent anomaly pattern such as the WES mode dominated with significantly large amplitude in 2014 and played a role in the stagnation of the El Niño growth.

### 2.2 Linear response to condensation heating anomalies

The WES feedback is a process that operates mainly between the ocean and the atmospheric boundary layer. However, as convective activities in the northern ITCZ were active in 2014, it is possible that anomalous diabatic heating in the free atmosphere played some role in the maintenance of the observed coherent anomaly pattern. To assess these effects, we conducted an experiment using a LBM developed by Watanabe and Kimoto (2000, 2000).
The LBM uses the spherical harmonics method with truncation wave number T42 and 40 sigma levels in the vertical direction. Newtonian damping terms are introduced to mimic boundary-layer processes. The atmospheric basic state is defined as the monthly average of the JRA-55, and the thermal forcing is the monthly anomaly of the condensation heating of the JRA-55. The steady linear response to the thermal forcing for each month from June to October 2014 was calculated using the basic state for each month. In the experiment, the sum of the cumulus and large-scale condensation heating was used as the thermal forcing. Since stationary linear response to stationary forcing is deterministic, we conducted the LBM experiment with one member run.

Figure 3 shows the vertically integrated thermal forcing and the LBM responses to the forcing averaged in June to October in 2014. As expected, zonally elongated heating anomalies prevail along the northern ITCZ in the central and eastern tropical Pacific (Fig. 3a). The forced atmospheric circulation near the surface (Fig. 3b) is similar to the observed anomalies of 2014 (Fig. 1): a cross-equatorial southerly wind with an easterly (westerly) component to the south (north) of the equator. Forced meridional circulation averaged in the central and eastern Pacific (Fig. 3c) is upward in the northern ITCZ, a cross-equatorial northerly wind in the upper troposphere, downward to the south of the equator, and a cross-equatorial southerly wind in the lower troposphere. The simulation mostly reproduced the pattern observed in 2014 (Fig. 3d).

The results from the experiment qualitatively indicate that the enhanced condensation heating in the northern ITCZ also contributed to maintaining the observed pattern by inducing meridional atmospheric circulation across the equator.

Waliser and Somerville (1994) suggested that a positive feedback between mid-tropospheric condensation heating and induced low-level convergence of moist energy is a key process for the continuation of ITCZ activities. The results from our experiment (Figs. 3b, c) are consistent with their argument and indicate that feedback played a role in sustaining the anomalous ITCZ activities observed in 2014.

2.3 Statistical meridional mode

As the observed meridional anomaly pattern has dynamical origins, such as the WES feedback and the mid-tropospheric heating/circulation feedback, it is expected that the pattern could be identified as a recursive statistical mode.

To statistically verify the presence of a meridional mode, we conducted EOF analysis using V10m anomalies in the central and eastern tropical Pacific (20°S−20°N, 180°W−90°W). The data period for the EOF analysis was 1979 to 2014, and averaged V10m anomalies from June to October were used. As preprocessing for the EOF analysis, we removed the linear part of ENSO, which is defined by a linear regression of V10m on SST anomalies averaged in the NINO.3 region (5°S−5°N, 150°W−90°W).

Fig. 2. Interannual variability of SST anomalies, 10-m meridional wind, and vertical p-velocity at 500 hPa averaged in the central and eastern Pacific (180°W−90°W) during the period from 1979 to 2014. Each value is averaged from June to October. (a) Difference in averaged SST anomalies [K] between the northern tropics (0°N−20°N) and the southern tropics (20°S−0°S), (b) 10 m meridional wind [m s^{-1}] averaged in the equatorial region (5°S−5°N), and (c) vertical p-velocity at 500 hPa [hPa/s] averaged in the northern tropics (5°N−15°N).

Fig. 3. Observed vertically integrated heating anomalies and the LBM response to the heating. (a) Observed vertically integrated condensation heating anomalies [W m^{-2}] averaged from June to October 2014. (b) LBM response in surface wind and vertical p-velocity at 500 hPa [10^{-1} Pa/s]. Surface winds are relative to the scale vector [m/s] shown below the figure. (c) LBM response in meridional circulation averaged in the central and eastern Pacific (180°W−90°W). Contours are vertical p-velocities [10^{-1} Pa/s] and meridional winds are represented by the horizontal component of arrows relative to the scale vector [m s^{-1}]. (d) Same as (c), but for observed anomalies averaged from June to October 2014.
This preprocessing eliminates the linear relation to ENSO, which is the most predominant mode of the climate system in the tropics, from the EOF modes obtained in the analysis. Subsequently, we describe the first EOF mode, which is free from the orthogonality constraint limiting the physical interpretation of EOFs.

Figure 4 shows the principal component (PC) of the first EOF mode and the regression maps of 10 m wind, latent heat flux, vertical velocity, SLP, and SST on the PC. The mode explains 29% of the total variance. The features of the regression maps in the central and eastern Pacific are as follows: a cross-equatorial southerly wind and enhanced south-easterly trades to the south of the equator (Fig. 4a); upward latent heat flux to the south of and near the equator (Fig. 4b); upward motion along the northern ITCZ and downward motion to the south of the northern ITCZ in the mid-troposphere (Fig. 4c); and positive SLP in the subtropical South Pacific (Fig. 4d). The regressed SST pattern shows negative anomalies in the tropical South Pacific (Fig. 4e). The coherent structure between the regressed SST, wind, and latent heat flux implies an association with the WES feedback. The first PC (Fig. 4f) tends to vary on a time scale longer than interannual and to be positive approximately after 2000.

As the regression patterns of the first PC are similar to the observed anomaly patterns in 2014 and the PC of the mode in 2014 is the second highest (Fig. 4f), it is suggested that the first mode dominantly appeared in 2014. However, there are obvious differences between the regressed (Fig. 4e) and observed (Fig. 1a) SST anomalies in the northern central and eastern tropical Pacific: negative (positive) anomalies in the regressed (observed) pattern. The regressed SST anomaly rather shows a meridional maximum around 5°N in 165°W−135°W. Looking at Figs. 1a, e, the observed SST anomaly also shows a weak maximum north of the equator between 180°W−120°W.

3. Summary and discussion

In this study, we indicated that the intensified evaporative cooling of SST in the equatorial central and eastern Pacific as a result of the prevailing southerly surface wind across the equator contributed to the suppression of the El Niño growth in the boreal summer–fall season of 2014. The observed coherent spatial pattern between SST, wind, and latent heat flux anomalies suggested WES feedback (Xie and Philander 1994) as the dynamical background of the prevailing southerly surface wind. In addition, the results of the LBM simulation indicated that the enhanced convection in the northern ITCZ also sustained the pattern by inducing meridional atmospheric circulation across the equator. The EOF analyses identified a dominant statistical mode that has a spatial pattern similar to that observed in 2014.

The ITCZ in the central and eastern Pacific varies with ENSO. In strong El Niño years such as 1987 and 1997, the northern ITCZ in summer–fall season tends to shift equatorward compared to the normal position and to enhance the air–sea dynamical coupling: this is called Bjerknes feedback (Bjerknes 1969). In contrast, in the summer–fall season of 2014, the active northern ITCZ remained centered over its normal position. The reason why the active northern ITCZ remained in place is speculated as follows. Figure 5a shows the meridional differences in SST anomalies in the tropical Pacific from January 2013 to December 2014. In October 2013, the differences already prevailed from the central to eastern Pacific, and zonally averaged differences in SST and latent flux anomalies were in the peak (Fig. 5b). Then the differences gradually decayed toward fall. These
SST anomaly differences in spring 2014 were a suitable precondition for the maintenance of the observed pattern resulting from WES feedback during the summer-fall season. As shown in Section 2.3, there are obvious differences between the observed SST anomaly pattern (Fig. 1a) and the regressed SST pattern on the first PC of V10m (Fig. 4e); negative (positive) anomalies in the regressed (observed) pattern in the northern central and eastern tropical Pacific. However, the feature of a local maximum SST anomaly to the north of the equator is common to them. This may suggest that the northern ITCZ tends to be positive approximately after 2000, when the IPO tends to be negative. Further study is required to clarify the relationship between SST patterns and ITCZ.

The regressed SST pattern on the first PC (Fig. 4e) of V10m is similar to that of the negative phase of the IPO. The PC tends to vary on a timescale that is longer than interannual and to be positive approximately after 2000, when the IPO tends to be negative. These spatial and temporal patterns indicate that there is some relationship between the statistical mode and the IPO.

Recently, Min et al. (2015) showed that anomalous easterly winds in the eastern equatorial Pacific, which were induced by the negative SST anomalies in the south-eastern tropical Pacific through the WES feedback, hindered the El Niño in 2014. The anomalous easterly oceanic current forced by the easterly wind anomalies zonally advected relatively low ocean temperature westward and interrupted the Bjerknes feedback. Their findings and our results together demonstrate the importance of the meridional SST anomaly pattern in the central and eastern tropical Pacific on El Niño stagnation by means of both dynamical and thermodynamical coupling between the atmosphere and the ocean.

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