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Letter

Distinct East Asian precipitation variability and predictability in coupled and uncoupled El Niño events

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Abstract

Previous studies have shown different impacts of eastern (EP) and central (CP) Pacific El Niños on the East Asian precipitation. This study reveals distinct precipitation anomalies over East Asia in coupled and uncoupled El Niños. The uncoupled warm events in 1979, 2004, 2014, 2018, and 2019, which occurred in the autumn–winter transition, represent an unusual form of El Niño diversity. The sea surface temperature anomalies (SSTA) in the western North Pacific (WNP) appear to be an important factor leading to the different distribution of precipitation anomalies over East Asia and the WNP. In coupled El Niños, anomalous lower-level anticyclone over the WNP is a result of combined effects of warm SSTAs in the equatorial CP and EP and cold SSTAs in the WNP. The cold SSTAs are attributed to surface heat flux anomalies that in turn are associated with convection and wind anomalies. The lack of cold SSTAs in the WNP in the uncoupled El Niños leads to a weaker anomalous anticyclone with a northwestward location. The different features of an anomalous anticyclone over the WNP induce discrepancy in the distribution of precipitation anomalies and the associated predictability over East Asia between coupled and uncoupled El Niños. The prediction skill tends to be lower for the uncoupled El Niño events than the coupled ones, which further indicates the necessity to distinguish uncoupled from coupled warm events.

1. Introduction

The El Niño-southern oscillation (ENSO) is the consequence of basin-wide coupled interactions between the ocean and the overlying atmosphere (Bjerknes 1969) and it exhibits diversity in intensity, spatial pattern, and temporal evolution (Capotondi et al 2015). ENSO affects people’s lives and environment through inducing various types of disasters (National Research Council 2010). In recent years, the different features and impacts of various types of El Niño events have received extensive attention (Kao and Yu 2009, Kug et al 2009, Ren and Jin 2013, Chiodi and Harrison 2013, 2015, Zheng et al 2014, Hu et al 2019, 2020). The different impacts on precipitation in the extratropics have been identified among El Niño events (Zhang et al 1996, 1999, Hu et al 2012, Wu et al 2014, Feng et al 2016, Xu et al 2019, Liu et al 2020a, 2020b). For example, the maximum wet center in boreal winter shifts northward from the southeastern coast of China to the lower reaches of the Yangtze River in central Pacific (CP) El Niño events compared to eastern Pacific (EP) El Niño events (Su et al 2013, Liu et al 2020a). The different distributions of precipitation anomalies in EP and CP El Niño events are attributed to differences in anomalous Walker circulation and low-level anticyclone around the Philippines (Feng et al 2010, Liu et al 2020b). The distinctive impacts of EP and CP El Niño events on the East Asian precipitation anomalies (Yuan et al 2012, Ke et al 2019) need to be taken into account for predicting precipitation anomalies in East Asia (Wang et al 2000, Wu et al 2003, Hu et al 2005, Zhou and Wu 2010, Clarke 2014, Liu et al 2019). Recently, Hu et al (2020) proposed a new type of El Niño: an uncoupled El Niño event in which
the ocean warming is not accompanied by corresponding atmospheric anomalies, i.e. the atmosphere and ocean remain uncoupled. Without coupling, the impact of the warming in the central and eastern tropical Pacific on extratropical climate is different from that of the coupled counterpart (Hu et al 2020). That is expected to lead to different predictability of climate in extratropical regions. However, it is unclear whether the East Asian precipitation variability and predictability differ for the coupled and uncoupled El Niño events. In this study, thus, we investigate the relationship between the East Asian precipitation anomalies and different types of El Niños, including EP and CP El Niño events, with a focus on the contrasts between the coupled and uncoupled El Niño events. The possible mechanisms leading to the differences in the climate variability and predictability between the coupled and uncoupled El Niño events are examined as well.

In the following, we describe the data, model, and definition of El Niño events in section 2. Then, we compare precipitation variability in different types of El Niño events, and address the possible mechanisms of different impacts of the coupled and uncoupled El Niño events in section 3. Section 4 provides a summary and discusses the challenges for prediction.

2. Data, model, and classification of El Niño events

This work uses NOAA’s precipitation reconstruction dataset (Chen et al 2002), monthly mean winds at 850 and 200 hPa levels from the National Centers for Environmental Prediction Department of Energy (NCEP-DOE) Reanalysis (R2) (Kanamitsu et al 2002), monthly mean outgoing longwave radiation (OLR) data (Liebmann and Smith 1996) that are used to represent deep convection. The three datasets are all on 2.5° × 2.5° grids. Monthly mean sea surface temperature (SST) on a 2° × 2° resolution is extracted from the NOAA extended reconstructed SST version 5 (ERSSTv5; Huang et al 2017). Moreover, monthly mean surface shortwave radiation, longwave radiation, latent heat flux, and sensible heat flux used in this work are from NCEP-DOE R2 (Kanamitsu et al 2002) on T62 Gaussians grids. All these data span the time period from January 1979 to December 2020. Anomalies are computed with reference to the climatological monthly mean for the period 1981–2010.

According to Hu et al (2020), an uncoupled El Niño event is defined when SST in the central tropical Pacific is warm enough to be considered as an El Niño event, but the atmospheric deep convection anomaly in the central tropical Pacific is absent. Specifically, an uncoupled warming event is defined as an event with a monthly mean Niño3.4 SST index ≥0.5 °C and a CP OLR (CP_OLR) index >0.0 that persist for at least three consecutive months (see figure 2 in Hu et al 2020). The Niño3.4 SST index is defined as SST anomalies (SSTAs) averaged over the region of 5° S–5° N and 170° W–120° W, and the CP_OLR index is defined as OLR anomalies averaged over the region of 5° S–5° N and 170° E–140° W, following L’Heureux et al (2015). Table 1 presents the years of various El Niño events, including coupled and uncoupled El Niño events as well as EP and CP El Niño events (Kug et al 2009, Ren and Jin 2013). The uncoupled warm events typically occur in the autumn–winter transition (Hu et al 2020), and October–November–December (OND) is the common 3 months in all the uncoupled warming events. Thus, the OND period is selected for this study.

Prediction skills are compared for anomalies of East Asian precipitation and related atmospheric circulation under different types of El Niño events based on ensemble means of predictions (hindcasts in 1982–2011 and real-time forecasts since 2012) initiated from January 1982–December 2019 from the NCEP Climate Forecast System version 2 (CFSv2) (Hu et al 2013, Xue et al 2013, Saha et al 2014). The ensemble means of model predictions include 28 members each month, out to 9 months. The ocean component of CFSv2 has 40 vertical layers with a meridional resolution of 1/4° between 10° S and 10° N, gradually increasing to 1/2° poleward of 30° S and 30° N. The atmospheric model has a spectral triangular truncation of 126 waves in the horizontal and a finite differencing in the vertical with 64 sigma-pressure hybrid layers (Saha et al 2014).

3. Results

3.1. Precipitation variability in different types of El Niño events

Climatologically, East Asian precipitation in the autumn–winter transition is mainly concentrated in the Philippine Sea, South China Sea, and southern China (south of the Yangtze River) with a seasonal mean amount of 150–200 mm (figure S1 available online at stacks.iop.org/ERL/16/094014/mmedia). To examine the impacts of different types of El Niño events, figure 1 displays composite OND precipitation anomalies in different types of El Niño events. Excessive precipitation occurs in southern China and

| Table 1. The years of four different El Niño classifications. |
|-------------------------------------------------------------|
| **EP El Niño** | **CP El Niño** | **Coupled El Niño** | **Uncoupled El Niño** |
|----------------|----------------|--------------------|-----------------------|
| 1982, 1986     | 1979, 1991     | 1982, 1986         | 1979, 2004            |
| 1987, 1997     | 1994, 2002     | 1987, 1991         | 2014, 2018            |
| 2006, 2015     | 2004, 2009     | 1994, 1997         | 2019                  |
| 2014, 2018     | 2002, 2006     | 2002, 2006         | 2009, 2015            |
| 2019           |                |                    |                       |
deficit precipitation in the South China Sea and Philippine Sea (south of 20° N) in both EP and coupled El Niño years (figures 1(a) and (c)). In CP El Niño years, there are deficit precipitation anomalies in the South China Sea and the Philippine Sea as well (figure 1(b)), similar to EP El Niño and coupled El Niño years (figures 1(a) and (c)) but with smaller regions reaching the 95% confidence level based on one sample Student t-test. Positive rainfall anomalies over southern China are smaller and less significant and cover a smaller region. Above-normal precipitation is observed over Japan, which is different from EP El Niño and coupled El Niño events. In uncoupled El Niño years (figure 1(d)), below-normal precipitation is observed to shrink westward but extend northward to cover most of southern China, which differs from the other three types of El Niño years. Above-normal precipitation is seen over Japan, which is similar to the CP El Niño years. Overall, the precipitation anomalies over East Asia in the autumn–winter transition display more prominent differences between coupled and uncoupled El Niño events than between EP and CP El Niño events. Thus, in the following section, we focus on analyzing the different impacts of the coupled and uncoupled El Niño events on the East Asian precipitation and the associated mechanisms. Here, we note that the precipitation anomalies display similarity between EP and coupled events and between CP and uncoupled events due to overlapping years (table 1).

The spread of OND precipitation anomalies and signal-to-noise ratio (SNR) are further compared between coupled and uncoupled El Niños events (figure 2). Here, the signal is represented by composite anomalies, and the noise is represented by the standard deviation of individual anomalies with respect to respective composite anomalies. The SNR is a measurement for the robustness of composite
anomalies as well as predictability (Kumar and Hoerling 2000, Wu and Kirtman 2006, Kumar and Hu 2014). A larger (smaller) SNR corresponds to a higher (lower) reliability of the composite anomalies and thus a higher (lower) predictability. In coupled El Niño composites (figure 2(a)), the absolute values of SNR exceeding 0.72 (95% confidence level of ten coupled El Niño cases) are mainly located over southeast China, South China Sea, and the western North Pacific (WNP). In the uncoupled El Niño composite (figure 2(b)), the area with an absolute value of SNR greater than 1.24 (95% confidence level of five uncoupled El Niño cases) is confined to the southwest–northeast band off southeast China. The difference of SNR values between coupled and uncoupled El Niño events is prominent in the southeast coast of China though the spread in the above region is comparable in coupled and uncoupled El Niño events.

3.2. The mechanisms of different impacts of coupled and uncoupled El Niño events

East Asian precipitation is closely linked to water vapor transported from the tropics, which is associated with an anomalous anticyclone in the lower troposphere over the WNP (Wang et al 2000, Wu et al 2003, Liu et al 2019, 2020c, Ding et al 2021, Liu et al 2021). In coupled El Niño composites, there are lower-level westerly wind anomalies over the equatorial CP and EP Ocean, and an anomalous lower-level anticyclone is located over the South China Sea and Philippine Sea (figure 3(a)). The lower-level anomalous southwesterlies over southern China favor more water vapor transported to southern China, conducive to more precipitation there during coupled El Niño events (figure 1(c)). In uncoupled El Niño events, an anomalous lower-level cyclone span most of the tropical WNP and anomalous lower-level displays a further northwestward shift to the coast of

Figure 2. (a), (b) Spread (mm d$^{-1}$) and (c), (d) SNR of OND precipitation anomalies for (a), (c) coupled and (b), (d) uncoupled El Niño events. The signal is represented by composite anomalies, and the spread (noise) is represented by the standard deviation of individual anomalies with respect to respective composite anomalies. Green dots indicate the value of SNR exceeding the 95% confidence level according to one tailed Student $t$-test.

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southeast China with a weaker intensity (figure 3(b)).
As such, southeastern China is under the control of anomalous anticyclone, leading to less precipitation there (figure 1(d)).

The wind and precipitation anomalies in the coupled El Niño years are attributed to SSTAs in the tropical Pacific (figure 3(a)). On one hand, the positive SSTAs in the equatorial CP–EP induce lower-level westerly wind anomalies and enhanced deep convection over the equatorial CP through a Gill-type response (Wang et al 2000). The upper-tropospheric outflow associated with the enhanced convection over the equatorial CP flow westward to the tropical western Pacific where the resultant descending motion suppresses convection and generates an anomalous lower-level anticyclone over the South China Sea and Philippine Sea (Hu et al 2020).

Figure 3. Anomalous composites of (a), (b) OND SST (shading, ◦C) and 850 hPa horizontal winds (vector, m s−1), and (c), (d) OLR (W m−2, shading) and 200 hPa divergent winds (vector, m s−1) for (a), (c) coupled and (b), (d) uncoupled El Niños. Green dots in (a), (b) indicate the value of shading exceeding 95% confidence level according to one sample Student t-test. Only wind anomaly vectors that are significant at the 95% confidence level are shown.

In the uncoupled El Niño events, warm SSTAs in the equatorial CP are smaller and there are no apparent cold SSTAs in the WNP (figure 3(b)) compared to the coupled El Niños (figure 3(a)). Such a distribution of SSTAs indicates a smaller zonal SST gradient across the tropical Pacific, without apparent anomalous deep convections over the central and eastern equatorial Pacific (Hu et al 2020). Correspondingly, anomalous upper-level convergence is hardly seen over the WNP (figure 3(d)). The convection anomalies over the WNP are weaker and the anomalous lower-level anticyclone over the WNP is weaker (figure 3(b)) than those in the coupled El Niño events (figure 3(a)). Also, the anomalous anticyclone shifts northwestward. Under the above conditions, southern China is under the influence of weak and northwestward shifted anticyclonic wind anomalies in the uncoupled El Niño events.

The development of the negative SSTAs in tropical WNP is associated with surface heat flux anomalies (Wang et al 2000, Wu et al 2014). A comparison of the monthly SST tendency and corresponding net surface heat flux, surface shortwave radiation, and latent heat flux anomalies is conducted between the coupled and uncoupled El Niño events from June to December (figures not shown). Notable differences are detected during early autumn (August–September–October, ASO), about 2 months earlier than OND (figure 4).

Here, monthly SST tendency is used to indicate the SST development, which is calculated by the central difference of SSTA in the succeeding month minus that in the preceding month divided by two. In ASO, the negative SST tendency in the WNP (around 150◦E) is more obvious in the coupled El Niño events than in the uncoupled El Niño events (figures 4(a) and (b)), which explains the difference of SSTAs between the two types of El Niño events (figures 3(a) and (b)). In the coupled El Niño events,
Figure 4. Composite of ASO (a), (b) SST tendency (0.01 °C month\(^{-1}\)), (c), (d) net surface heat flux (positive for downward flux, Wm\(^{-2}\)), (e), (f) net surface shortwave radiation (positive for downward flux, Wm\(^{-2}\)), and (g), (h) latent heat flux (positive for upward flux, Wm\(^{-2}\)) in (a), (c), (e) and (g) coupled and (b), (d), (f) and (h) uncoupled El Niños, respectively. Green dots indicate the value of shading exceeding 95% confidence level according to one sample Student t-test.

Net surface heat flux plays a large role in the SST tendency (figure 4(c)). The reduction of net shortwave radiation has the main contribution to the net surface heat loss over the Philippine Sea (figure 4(e)), with a supplementary positive contribution of surface latent heat flux around 150° E (figure 4(g)). This explains the maintenance of the cold SSTAs in the WNP in OND (figure 3(a)). The effects of longwave radiation and sensible heat flux over the WNP can be ignored with small values (figures not shown). The reduction of shortwave radiation is related to the anomalous lower-level cyclone during the developing stage of coupled El Niño events (Wang et al 2000, Wu et al 2014). The enhanced surface latent heat flux around 150° E is associated with surface wind speed increase under anomalous northeasterly winds. The above features suggest air-interaction processes over the tropical WNP. In the uncoupled El Niño events, however, negative SST tendency is limited in the WNP (figure 4(b)), which explains small SSTAs and weak zonal tropical SST gradient in OND (figure 3(b)). The negative net shortwave radiation anomalies are located westward over the WNP (figure 4(f)). Latent heat flux anomalies are positive over the WNP (figure 4(h)). Thus, both the reduction of net shortwave radiation and the increase of latent heat flux contribute to net surface flux loss (figure 4(d)). Note, however, that net surface heat flux anomalies are negative west of 150° E (figure 4(d)), inconsistency with the SST tendency (figure 4(b)), which may suggest
effects of the oceanic process, which needs further investigation.

From the above comparison of distributions of SSTAs, surface heat flux, and atmospheric circulation anomalies between the coupled and uncoupled El Niño events, the zonal SST gradient with cold SSTAs in the WNP and warm SSTAs in the equatorial CP and EP may be largely responsible for anomalous anticyclone over WNP, with accompanying upper-tropospheric convergence and suppressed convective activities over the WNP. Such a distribution of anomalous circulation is conducive to abundant precipitation over southern China and deficient precipitation over the South China Sea and the Philippine Sea. In coupled warm events, both large positive SSTAs in the equatorial CP and EP and cold SSTAs in the WNP contribute to a larger zonal SST gradient, conducive to stronger wind and precipitation anomalies over East Asia and the WNP. In uncoupled warm events, the zonal SST gradient is smaller due to smaller positive SSTAs in the equatorial CP and smaller negative SSTAs in the WNP. As such, wind anomalies are weaker over the WNP.

4. Conclusion and discussion

In this work, we investigated the relationship between East Asian precipitation anomalies and different types of El Niño events, including EP and CP El Niño events with a focus on the contrasts of coupled and uncoupled El Niño events. Distinct precipitation anomalies are identified over southern China in coupled and uncoupled El Niño events. In coupled El Niños, cold SSTAs in the tropical WNP and warm SSTAs in the equatorial CP and EP work together in inducing anomalous lower-level anticyclone over the WNP. The southwesterly wind anomalies transport more moisture to southern China, leading to more precipitation there. In uncoupled El Niño events, the lack of cold SSTAs in most of the WNP region may be a primary factor for weaker and westward shifted anomalous lower-level anticyclone over the WNP. Southern China is under the influence of the border of the anomalous anticyclone and thus precipitation anomalies are small there.

The difference of the tropical WNP SSTAs is likely related to whether there are the air–sea interaction processes over the WNP. In coupled El Niño events, the reduction of shortwave radiation associated with anomalous lower-level cyclone and the increase of latent heat flux due to enhanced northeasterly contribute to the negative SST tendency in the developing stage of El Niño events. This leads to the formation and maintenance of cold SSTAs in the tropical WNP. The negative SSTAs in turn favor the intensification and sustenance of the anomalous lower-level anticyclone over the South China Sea and the Philippine Sea. In uncoupled El Niño events, in association with the lack of strong convection anomalies over the equatorial CP, convection anomalies over the tropical WNP are weak and shift westward. Accordingly, shortwave radiation and latent heat flux anomalies are small over the eastern Philippine Sea, leading to limited negative SST tendency in the WNP. Accordingly, cold SSTAs are small in most of the WNP region.

The results indicate that ocean warming in the central and eastern tropical Pacific has different impacts on precipitation over East Asia with and without atmosphere–ocean coupling. Thus, it is necessary to distinguish uncoupled from coupled warming events, which may also lead to differences in forecasting skills in extratropics. Here, we analyze further the NCEP CFSv2 model forecasts (Hu et al 2013, Xue et al 2013, Saha et al 2014). Figure S2 displays the prediction skills (anomaly linear correlation coefficient) of OND precipitation over East Asia (5° N–35° N, 100° E–150° E) in both coupled and uncoupled El Niño events with different lead times from the NCEP CFSv2 model. The averaged prediction skills of OND precipitation are 0.60, 0.47, and 0.36 with 1–3 months lead time in ten coupled El Niño events (1982, 1986, 1987, 1991, 1994, 1997, 2002, 2006, 2009, and 2015), which is much better than that of 0.22, 0.30, and 0.20 in four uncoupled El Niño events (2004, 2008, 2018, and 2019). That is consistent with the differences of the SNR shown in figure 2. It implies that forecasting climate variability is more difficult during uncoupled El Niños than during coupled El Niños. It may be partially attributed to the prediction skill of the zonal SST gradient across the equatorial Pacific, which is much lower than that of the Niño3.4 index (Hu et al 2020). Thus, predicting the zonal SST gradient, active convection in the central equatorial Pacific and WNP, and associated atmosphere–ocean coupling is still a challenge for climate models. As a result, forecasting East Asian climate variability seems more difficult during uncoupled El Niño years than during coupled El Niño years.

However, the model cannot reproduce the observed differences of atmospheric circulation and precipitation anomalies (figures S3 and S4) between the coupled and uncoupled El Niño events. In uncoupled El Niño events (figures S3(b) and S4(b)), the precipitation anomalies over southern China and the wind anomalies over southern China and the South China Sea are more like the observations in coupled El Niño events (figures 1(c) and 2(a)) with large uncertainty. In future work, we will conduct numerical experiments to verify observational diagnostic analysis.

Data availability statement

No new data were created or analyzed in this study.

NCEP-DOE reanalysis, OI SST v2, OLR, and PREC data used in this work are available online for
download from https://psl.noaa.gov/data/gridded/data.ncep.reanalysis2.html, https://psl.noaa.gov/data/gridded/data.ncei.oisst.v2.html, https://psl.noaa.gov/data/gridded/data.interp_OLR.html, https://psl.noaa.gov/data/gridded/data.prec.html, respectively. The CFSv2 forecasts are available from https://rda.ucar.edu/datasets/ds094.2.

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