# Are there two types of La Nina?

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[1] In this study, the existence of two types of La Nina events is examined using observations and model output. We find that cold events in the central and eastern Pacific SST, are highly correlated unlike the corresponding warm events. When two types of La Nina are defined based on the same criteria for the types of warm events, the SST and precipitation patterns between the two types of La Nina are much less distinctive or less independent. In other words, there is a strong asymmetric character between warm and cold events. This asymmetric character is also examined in 20 climate models that participate in the CMIP3. Most climate models have difficulty in simulating independently the two types of El Nino and La Nina events; however, they simulate the two types of El Nino more independently than they simulate the two types of La Nina, supporting our observational arguments to some degree. **Citation:** Kug, J.-S., and Y.-G. Ham (2011), Are there two types of La Nina?, *Geophys. Res. Lett.*, *38*, L16704, doi:10.1029/2011GL048237.

## 1. Introduction

[2] Many recent studies have argued that there exists more than one type of El Niño (or El Niño-Southern Oscillation; ENSO), based on spatial distributions of SST [*Larkin and Harrison*, 2005a, 2005b; *Ashok et al.*, 2007; *Kao and Yu*, 2009; *Kug et al.*, 2009, 2010; *Ren and Jin*, 2011]. They agreed that one type of El Niño event has action centers of atmospheric and oceanic variables primarily located over the central Pacific and warm pool region, which is quite distinctive from the traditional canonical feature of ENSO (or the conventional El Niño) as in the work of *Rasmusson and Carpenter* [1982] and *Wallace et al.* [1998]. So far, various nomenclatures have been used for this new type of El Niño event, such as "dateline El Niño" [*Larkin and Harrison*, 2005a, 2005b], "El Niño modoki" [*Ashok et al.*, 2007; *Weng et al.*, 2007], "Central Pacific El Niño" [*Kao and Yu*, 2009; *Yeh et al.*, 2009] and "Warm-Pool El Niño" [*Kug et al.*, 2009], even though it is recently reported that two types of ENSO events are nonlinearly related [*Takahashi et al.*, 2011]. Since there is no consensus in terminology, we will use the term Warm-Pool (WP) El Niño.

[3] Most previous studies agreed on overall features of WP El Nino, and they also mostly focused on distinctive features on warm events (El Nino). Even though some studies [*Ashok et al.*, 2007; *Kao and Yu*, 2009] revealed the existence of new-type cold events (La Nina), their major attentions were on the warm events. In addition, *Kug et al.* [2009] argued that the La Nina events are hard to separate into two types due to the similarity of SST patterns. The objective of the present study is to examine whether or not the La Nina events can be separated into two types, as compared to the El Nino events.

[4] In addition to the observational evidence, numerical models are used for testing hypotheses about two types of La Nina to overcome the limitation of short analysis period in the observation. Several studies have tried to use model outputs for examining two types of El Nino [*Ashok et al.*, 2009; *Yeh et al.*, 2009; *Yu and Kim*, 2010]. In particular, *Yu and Kim* [2010] investigated how well two ENSO types are captured in the CMIP3 models. In this study, we also use the CMIP3 model simulations, and further to report some systematic problems of the state-of-art coupled models to simulate two types of ENSO.

## 2. Data

### 2.1. Observational Data and Model Outputs

[5] The SST data are the improved Extended Reconstructed Sea Surface Temperature Version 2 (ERSST V2) [*Smith and Reynolds*, 2004] from the National Climate Data Center (NCDC). The period for SST data is 40 years from 1970 to 2009. The monthly-mean precipitation data of the Modern ERa Retrospective-analysis for Research and Applications (MERRA) are used from 1980 to 2009 (M. M. Rienecker et al., MERRA—NASA's Modern-Era Retrospective Analysis for Research and Applications, submitted to *Journal of Climate*, 2010). MERRA is a NASA reanalysis for the satellite era using a new version of the Goddard Earth Observing System Data Assimilation System, Version 5 (GEOS-5). The data are detrended after removing monthly-mean climatology.

[6] Pre-industrial integrations produced by the CMIP3 models are analyzed in this study, in which greenhouse gases are held fixed at pre-industrial levels (i.e. 280 ppm for all integration period). Twenty CGCMs are analyzed in this study. The integration period is more than 100 years for all the models.

### 2.2. Definition of Two Types of El Nino and La Nina

[7] So far, there are several definitions to indentify the two types of El Nino and La Nina. In this study, we adopt the definition of *Kug et al.* [2009]. *Kug et al.* [2009] defined WP El Nino events when the normalized NINO4 SST (160°E–150°W, 5°S–5°N) is greater than one and the normalized NINO3 SST (90–150°W, 5°S–5°N). In the same way, Cold-tongue (CT) El Nino events are defined when the normalized NINO3 SST is greater than one and the normalized NINO4 SST. The NINO3 and NINO4 SSTs are defined as average

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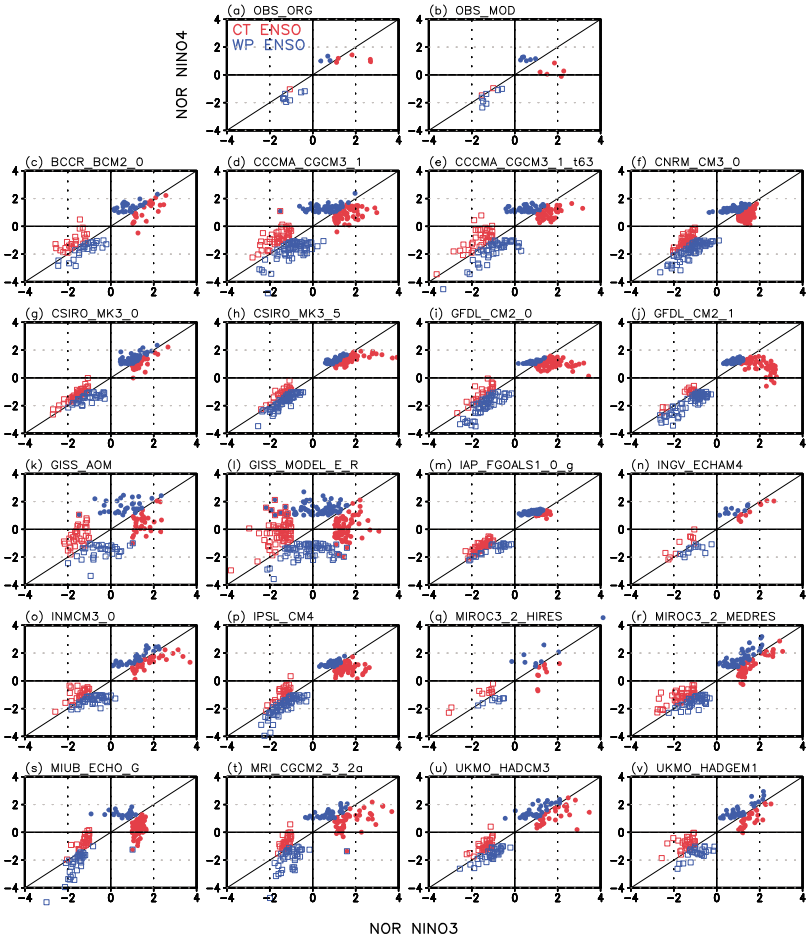


**Figure 1.** The scatter plots between normalized NINO3 and NINO4 indices during the ENSO in boreal winter season (Dec.–Feb.): (a) observation, (b) scatter plot using modified NINO indices in the observation, and (c–v) the CMIP3 models. The definition of modified NINO3 (NINO4) is seasonal-mean SST anomalies averaged over 170°W–110°W, 5°S–5°N (140°E–170°W, 5°S–5°N). Note that the blue (red) dots denote the cases for WP (CT) El Nino, respectively.

during the Dec.–Feb. WP and CT La Nina events are also defined in the same way except for negative SST anomalies. These definitions are applied to observational data and long-term model outputs. We also used EMI (El Nino Modoki Index) suggested by *Ashok et al.* [2007], but main conclusions are not changed.

[8] *Kug et al.* [2010] suggested that modified NINO3 and NINO4 SST indices that are shifted westward by 20° are more appropriate to define the two types of El Nino in the coupled models. This is because most current models have a bias in simulating ENSO anomalies, which tend to shift toward the west [*AchutaRao and Sperber*, 2002]. Therefore, we use both original and modified NINO3 and NINO4 SST indices to define the two types of El Nino and La Nina.

## 3. Two Types of El Nino and La Nina

[9] In order to define two types of El Nino and La Nina, we first checked the distribution of NINO3 and NINO4 SSTs. Figure 1 shows scatter diagrams between normalized NINO3 and NINO4 SSTs when the amplitude of either index is greater than their standard deviation. According to our El Nino definition, we can separate two types of El Nino and La Nina events from these scatter diagrams. In the observation, all warm events exhibit positive NINO3 and NINO4 SST, implying that SST patterns for two types of El Nino are not orthogonal. However, some CT El Nino events have quite strong NINO3 SST, while their NINO4 SSTs are moderate. Overall, the relation between NINO3 and NINO4 is not linear for the warm events. For instance, the magnitude NINO4 SST is not proportional to that of NINO3 SST. This indicates that the NINO3 and NINO4 SSTs have some independence, implying existence of two types of El Nino.

[10] On the other hand, NINO4 SST for the cold events is mostly larger than NINO3 SST, so the CT La Nina events are hard to be defined based on our criteria. Furthermore, it seems that NINO3 SST is linearly proportional to NINO4 SST for the cold events. This means strong (weak) cold events have strong (weak) cooling in the both eastern and central Pacific, indicating less independence between negative NINO3 and NINO4 SSTs. Therefore, the two types of La Nina events are relatively less distinctive, compared to the two types of El Nino. When the modified indices are used, the independence for the two types of El Nino becomes clearer as shown in Figure 1b. However, for the

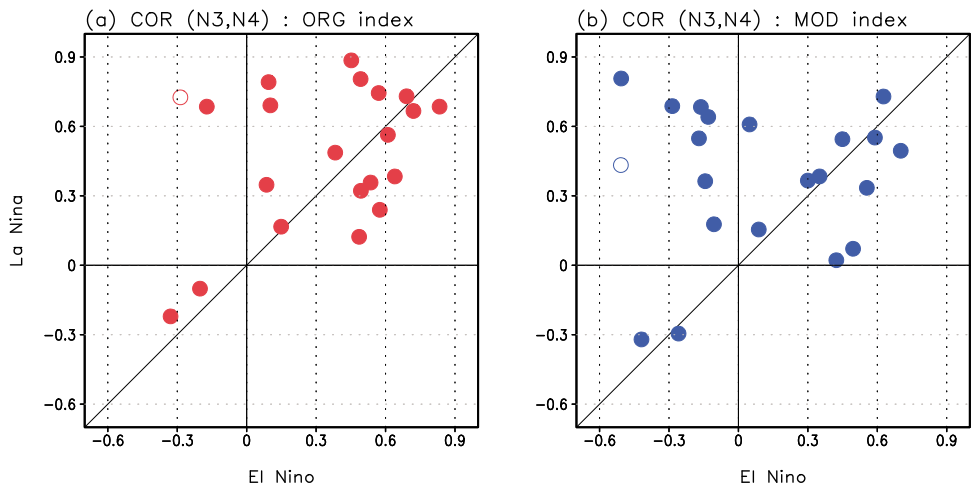


**Figure 2.** The scatter plots of the correlation between NINO3 and NINO4 during El Nino and that during La Nina in the observation (open circle), and CMIP3 models (closed circle) (a) drawn using original NINO indices and (b) using modified NINO indices.

cold events it seems the modified NINO4 SST is still highly correlated with the modified NINO3 SST, indicating the strong similarity in SST pattern between the two types of cold events.

[11] Figure 1 also shows the two types of ENSO events simulated in climate models participating in CMIP3. As *Ham and Kug* [2011] point out, many of these models have a problem in simulating the independence of the two types of El Nino events. It is partly because some models fail to produce the CT El Nino as the dominant statistical mode. Besides, more common problem is the climate models tend to simulate stronger coherence between NINO3 and NINO4 SSTs than what is observed. However, several models, such as MIUB_ECHOG, CCCMA_CGCM3_1_t63, GFDL_CM2.1, CNRM_CM3_0, CCCMA_CGCM3.1, and MIROC3_2_HIRES, have the ability in simulating independently the two types of El Nino events. Even in these models, the NINO3 SST tends to be highly correlated with NINO4 SST for the cold events. This indicates that these models simulate more distinctively the two types of El Nino and less distinctively the two types of La Nina, consistent with the observational results presented earlier.

[12] There are two models (GISS_AOM and GISS_MODEL_E_R, Figures 1k and 1l), which simulate independent two types of La Nina events as well as the two types of El Nino events. The distributions of NINO3 and NINO4 SSTs exhibit a rectangular shape, which denotes that NINO3 and NINO4 SSTs are nearly orthogonal. Note that the two models simulate unrealistically weak SST variability (less than 0.5) over the tropical Pacific [*Joseph and Nigam*, 2006]. If the SST signal is too weak, it is harder to have a basin-wide response, so it favors unrealistically small spatial scale. Therefore, the central Pacific SST variability in these models can be independent of eastern Pacific variability, and vice versa. If we discard these two extremes, the other models tend to simulate quite similar SST patterns between the two types of La Nina events, while some of these models have the ability in simulating independently the two types of El Nino.

[13] *Ham and Kug* [2011] used correlation between NINO3 and NINO4 SSTs for only warm event cases in order to evaluate the independence of the two types of El Nino. In the present study, in order to compare the independence of the two types of El Nino and La Nina events we also use correlation coefficients for warm and cold events, respectively. Figure 2 shows the distribution of these correlation coefficients. In the observation, the correlation is −0.28 for the warm events, but it becomes positive (0.72) for the cold events. This indicates that SST patterns between the two types of El Nino are more distinctive than those between the two types of La Nina, indicating asymmetric character between warn and cold phases of ENSO. Note that these results are still valid to which area is selected to define NINO3 and NINO4 SST indices. Furthermore, this asymmetric character is still shown with weaker criteria for the definition of ENSO events (i.e. ENSO is defined when NINO index is greater than 0.5 standard deviation, not shown).

[14] On the other hand, the current climate models do not seem to simulate this asymmetric character to some extent, that is, the correlation coefficients for warm and cold events are comparable in most models, indicating that the current models have a systematic bias in simulating the two types of ENSO events. However, among the 20 models, 12 models simulate stronger correlation during La Nina events than during El Nino events, while 8 models simulate stronger correlation during El Nino events than during La Nina events. Furthermore, three models, having quite observed independency for warm events, exhibit strong correlation for cold events.

[15] Once we use the modified indices, the models show better performance in mimicking observed asymmetric character for independence of the two types of El Nino and La Nina events. 14 models simulate more independent two types of El Nino events, while 6 models simulate the two types of La Nina events more independently. Moreover, about 7 models exhibit weak correlation for the warm events and strong correlation for the cold events, quite similar to the observed. In summary, the current models have a systematic bias, but they tend to simulate relatively more independent two types of El Nino events than the two types

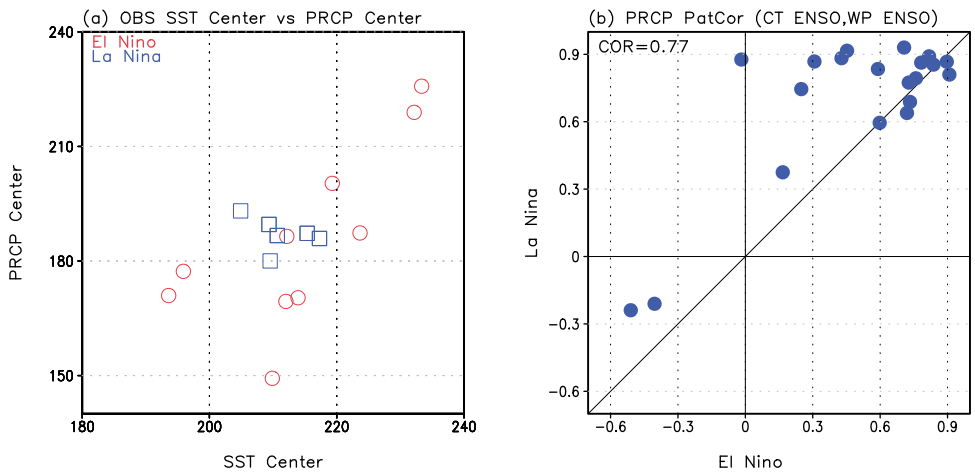


**Figure 3.** (a) The scatter plots between SST center (x-axis) and precipitation center (y-axis) for El Nino (red) and La Nina (blue) in the observation. Note that both types of the El Nino (or La Nina) are drawn. (b) The pattern correlation of precipitation between the composite map of CT and WP El Nino (x-axis) and that between the composite map of CT and WP La Nina (y-axis) in the CMIP3 models. Note that the pattern correlation is performed over the tropical Pacific region (120°E–80°W, 10°S–10°N).

La Nina events to some extent. This supports the observed asymmetric character of ENSO.

[16] In order to examine the asymmetric character between El Nino and La Nina, we checked individual El Nino and La Nina events. *Kug et al.* [2009] showed SST pattern of individual El Nino and La Nina events, and pointed out that it is hard for the La Nina events to be separated into the two types based on zonal distribution of SST as for the El Nino events, because most La Nina events have similar spatial distributions. In addition, individual La Nina events do not show distinctive precipitation pattern. Figure 3 shows the zonal center of SST and precipitation anomalies for individual El Nino and La Nina events. The centers of precipitation anomalies are calculated based on the following equation:

$$\text{PRCP Centroid} = \frac{\int_{120E}^{90W} \text{PRCP}(x) \cdot x \, dx}{\int_{120E}^{90W} \text{PRCP}(x) dx}$$

where PRCP(x) denotes the precipitation anomaly averaged over 5°S–5°N and x denotes the longitude. Qualitatively, this equation calculates longitudinally weighted average of PRCP anomaly. The zonal integration is executed over 120°E–90°W. The calculated the centroid of PRCP anomaly approximately estimates a longitudinal center of precipitation anomaly during ENSO events. Note that the centroid of SST is calculated using the same procedure. As shown in Figure 3, individual El Nino events exhibit quite diverse distributions of SST and precipitation centers. The SST centers distribute from 170°W to 125°W, and the precipitation center appears from 150°E to 135°W. This difference can lead the different teleconnections of ENSO in the extratropics and midlatitudes [*Ashok et al.*, 2007; *Weng et al.*, 2009; *Yeh et al.*, 2009; *Taschetto and England*, 2009]. However, SST and precipitation centers of individual La Nina events are gathered into similar location (near 150°W). The zonal ranges of the centers for SST and precipitation are within 20°. Even though the caution is needed due to the smaller number of La Nina event, this indicates that every La Nina event has similar SST and precipitation pattern, so it is quite difficult to separate it into one type or the other based on these spatial distributions. Consistent with previous results, this asymmetric character is also shown with weaker criteria for the definition of ENSO events (i.e. ENSO is defined when NINO index is greater than 0.5 standard deviation, not shown). We also checked that these features are consistent when the EMI in the work of *Ashok et al.* [2007] is used for the WP El Nino events (not shown here).

[17] As in the observation, most climate models simulate more distinctive SST and precipitation patterns for the two types of El Nino and less distinctive for La Nina. Among the 20 models, 15 models have the observed asymmetric character (i.e. stronger pattern correlation during La Nina than that during El Nino) in precipitation pattern over the tropical Pacific (120°E–80°W, 10°S–10°N) as shown in Figure 3b. In particular, except for three models, the climate models simulate quite similar precipitation pattern between the two types of La Nina events, exhibiting higher pattern correlation (0.6). The similar precipitation pattern indicates a similar teleconnection pattern between CT and WP La Nina events. These results support the observed asymmetric character between the two types of El Nino and La Nina events.

## 4. Summary and Discussion

[18] Recently, many studies have focused on the two types of El Nino events, while the existence of the two types of La Nina events remains uncertain. In this study, we examined the asymmetric character of the two types of ENSO events. While the SST and precipitation patterns associated with WP and CT El Nino events are more distinctive, the SST and precipitation patterns for the cold events are less distinctive (that is, the NINO3 and NINO4 SSTs are closely correlated). Therefore, one may define two

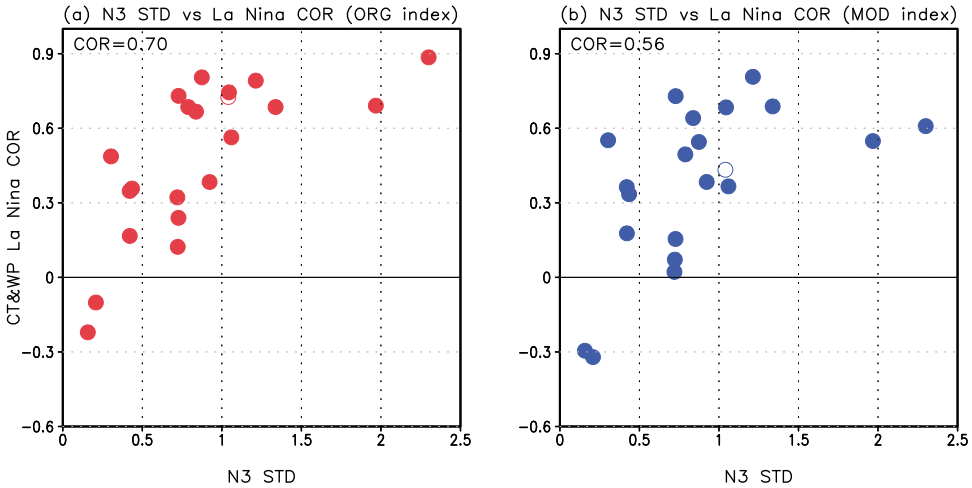


**Figure 4.** (a) The scatter diagrams of standard deviation of original NINO3 (x-axis) and correlation between original NINO3 and NINO4 during the La Nina (y-axis) in the observation (open circle) and CMIP3 models (closed circle). (b) Same as Figure 4a, but the modified NINO indices are used.

types of La Nina, but the independence between them will be quite weak, compared to the warm events.

[19] This asymmetric character is also examined here using 20 climate models that participated in CMIP3. We found that most climate models have a common problem in simulating independence of the two types of El Nino and La Nina events. That is, climate models tend to simulate more (less) independence of the two types of El Nino (La Nina), compared to the observation. In spite of the presence of the systematic bias, however, most of these models simulate the two types of El Nino more independently than the two types of La Nina, supporting our results based on observation to some degree.

[20] About the stronger relationship between the two types of El Nino, *Ham and Kug* [2011] pointed out that most climate models tend to simulate weak independence of the two types of El Nino. They further argued that dry bias over the eastern Pacific prevents the models from simulating observed independence. If the eastern Pacific is too dry, it suppresses anomalous convective activity there, so it provides unfavorable condition for the development of CT El Nino.

[21] Meanwhile, about the stronger independence (or weaker correlation) of the two types of La Nina events, it might be due to the weakly simulated ENSO magnitude. Figure 4 shows a relation between ENSO magnitude and independence of the two types of La Nina. It is evident that a weaker ENSO is related to strong independence of two types of La Nina. If the SST anomalies are too weak, it is hard to induce large-scale atmospheric responses. The small-scale atmospheric forcing will favor small-scale SST response, so it favors two types of SST pattern. On the other hand, if SST anomalies are strong enough, it can induce large-scale atmospheric responses, which may lead to basin-wide SST response. As shown in Figure 4, most models have a weaker ENSO magnitude compared to the observed, which may explain relatively strong independence of the two types of La Nina. On the other hand, the models that have strong ENSO magnitude mimic observed weak independence of the two types of La Nino well.

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## References

AchutaRao, K., and K. Sperber (2002), Simulation of the El Niño Southern Oscillation: Results from the coupled model intercomparison project, *Clim. Dyn.*, *19*, 191–209, doi:10.1007/s00382-001-0221-9.

Ashok, K., S. K. Behera, S. A. Rao, H. Weng, and T. Yamagata (2007), El Niño Modoki and its teleconnection, *J. Geophys. Res.*, *112*, C11007, doi:10.1029/2006JC003798.

Ashok, K., S. Iizuka, S. A. Rao, N. H. Saji, and W.-J. Lee (2009), Processes and boreal summer impacts of the 2004 El Niño Modoki: An AGCM study, *Geophys. Res. Lett.*, *36*, L04703, doi:10.1029/2008GL036313.

Ham, Y.-G., and J.-S. Kug (2011), How well do current climate models simulate two types of El Nino?, *Clim. Dyn.*, in press.

Joseph, R., and S. Nigam (2006), ENSO evolution and teleconnections in IPCC's twentieth-century climate simulations: Realistic representation?, *J. Clim.*, *19*, 4360–4377, doi:10.1175/JCLI3846.1.

Kao, H. Y., and J. Y. Yu (2009), Contrasting eastern-Pacific and central-Pacific Types of ENSO, *J. Clim.*, *22*, 615–632, doi:10.1175/2008JCLI2309.1.

Kug, J.-S., F.-F. Jin, and S.-I. An (2009), Two types of El Niño events: Cold tongue El Niño and warm pool El Niño, *J. Clim.*, *22*, 1499–1515, doi:10.1175/2008JCLI2624.1.

Kug, J.-S., J. Choi, S.-I. An, F.-F. Jin, and A. T. Wittenberg (2010), Warm pool and cold tongue El Nino events as simulated by the GFDL 2.1 coupled GCM, *J. Clim.*, *23*, 1226–1239, doi:10.1175/2009JCLI3293.1.

Larkin, N. K., and D. E. Harrison (2005a), On the definition of El Niño and associated seasonal average U.S. weather anomalies, *Geophys. Res. Lett.*, *32*, L13705, doi:10.1029/2005GL022738.

Larkin, N. K., and D. E. Harrison (2005b), Global seasonal temperature and precipitation anomalies during El Niño autumn and winter, *Geophys. Res. Lett.*, *32*, L16705, doi:10.1029/2005GL022860.

Lee, T., and M. J. McPhaden (2010), Increasing intensity of El Niño in the central-equatorial Pacific, *Geophys. Res. Lett.*, *37*, L14603, doi:10.1029/2010GL044007.

Rasmusson, E. M., and T. H. Carpenter (1982), Variations in tropical sea surface temperature and surface wind fields associated with the Southern Oscillation/El Niño, *Mon. Weather Rev.*, *110*, 354–384, doi:10.1175/1520-0493(1982)110<0354:VITSST>2.0.CO;2.

Ren, H.-L., and F.-F. Jin (2011), Niño indices for two types of ENSO, *Geophys. Res. Lett.*, *38*, L04704, doi:10.1029/2010GL046031.

Smith, T. M., and R. W. Reynolds (2004), Improved extended reconstruction of SST (1854–1997), *J. Clim.*, *17*, 2466–2477, doi:10.1175/1520-0442(2004)017<2466:IEROS>2.0.CO;2.

Takahashi, K., A. Montecinos, K. Goubanova, and B. Dewitte (2011), ENSO regime: Reprinting the canonical and Modoki El Niño, *Geophys. Res. Lett.*, *38*, L10704, doi:10.1029/2011GL047364.

Taschetto, A. S., and M. H. England (2009), El Niño Modoki impacts on Australian rainfall, *J. Clim.*, *22*, 3167–3174, doi:10.1175/2008JCLI2589.1.

Wallace, J. M., E. M. Rasmusson, T. P. Mitchell, V. E. Kousky, E. S. Sarachik, and H. Von Storch (1998), On the structure and evolution of ENSO-related climate variability in the tropical Pacific: Lessons from TOGA, *J. Geophys. Res.*, *103*(C7), doi:10.1029/97JC02905.

Weng, H., K. Ashok, S. K. Behera, A. Rao, and T. Yamagata (2007), Impacts of recent El Niño Modoki on dry/wet conditions in the Pacific rim during boreal summer, *Clim. Dyn.*, *29*, 113–129, doi:10.1007/s00382-007-0234-0.

Weng, H., S. K. Behera, and T. Yamagata (2009), Anomalous winter climate conditions in the Pacific rim during recent El Niño Modoki and El Niño events, *Clim. Dyn.*, *32*, 663–674, doi:10.1007/s00382-008-0394-6.

Yeh, S.-W., J.-S. Kug, B. Dewitte, M.-H. Kwon, B. P. Kirtman, and F.-F. Jin (2009), El Niño in a changing climate, *Nature*, *461*, 511–514, doi:10.1038/nature08316.

Yu, J.-Y., and S. T. Kim (2010), Identification of central-Pacific and eastern-Pacific types of ENSO in CMIP3 models, *Geophys. Res. Lett.*, *37*, L15705, doi:10.1029/2010GL044082.

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