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Increasing intensity of El Niño in the central-equatorial Pacific

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[1] Satellite observations suggest that the intensity of El Niño events in the central equatorial Pacific (CP) has almost doubled in the past three decades, with the strongest warming occurring in 2009–10. This is related to the increasing intensity as well as occurrence frequency of the so-called CP El Niño events since the 1990s. While sea surface temperature (SST) in the CP region during El Niño years has been increasing, those during neutral and La Niña years have not. Therefore, the well-documented warming trend of the warm pool in the CP region is primarily a result of more intense El Niño events rather than a general rise of background SST. **Citation:** 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.

1. Introduction

[2] El Niño is the oceanic component of the dominant mode of interannual climate variability called El Niño-Southern Oscillation, originating in the tropical Pacific due to ocean-atmosphere interaction. El Niño events have world-wide influence and important socioeconomic consequences. Knowledge about changes of El Niño behaviors is important to the understanding and prediction of El Niño and its impacts. Classical El Niño events are associated with maximum warm anomaly occurring in the eastern equatorial Pacific Ocean, referred to as canonical or eastern-Pacific (EP) El Niño. In the 1990s and 2000s, there have been frequent occurrences of a new type of El Niño with maximum warm anomaly occurring in the central equatorial Pacific [e.g., *Latif et al.*, 1997], known variously as central-Pacific (CP) El Niño [*Kao and Yu*, 2009; *Yu and Kim*, 2010], warm-pool El Niño [*Kug et al.*, 2009], dateline El Niño [*Larkin and Harrison*, 2005], or El Niño Modoki [*Ashok et al.*, 2007]. These two types of El Niño have different teleconnections and climatic impacts [e.g., *Weng et al.*, 2009; *Kim et al.*, 2009; *Ashok and Yamagata*, 2009]. A recent study [*Yeh et al.*, 2009] has suggested that CP-El Niño events could occur much more frequently under the projected global warming scenarios. While previous studies have discussed an increasing frequency of CP-El Niño events in recent decades, changes in the magnitude of these events have not been documented.

[3] The maximum warming associated with EP-El Niño events occurs in the EP region, so that EP-El Niño events are suitably described by the so-called Niño3 index (SST anomaly averaged within 150°–90°W, 5°S–5°N) or Niño3.4 index (170°–120°W, 5°S–5°N). CP-El Niño events, having maximum warming in the CP region, are better described by the Niño4 index (160°E–150°W, 5°S–5°N) [e.g., *Kao and Yu*, 2009; *Yeh et al.*, 2009]. The CP region encompasses much of the climatically important western-Pacific warm pool. This region has experienced a well-documented warming tendency for at least a few decades [e.g., *Cane et al.*, 1997; *Cravatte et al.*, 2009], which appears to be consistent with theoretically predicted change of the background SST under global warming scenarios [*Cane et al.*, 1997]. *Cravatte et al.* [2009] also discussed the implications of warming trend in the warm pool to ocean-atmosphere interactions and El Niño events. Here we use satellite observations of SST in the past three decades to examine SST in the CP region, distinguishing between the increases in El Niño intensity and changes in background SST.

2. Data and Methods

[4] The SST product used for the analysis is the Reynolds's $^1/_4$° Group for High Resolution SST (GHRSST) Level 4 AVHRR OI daily SST product from 1982 to February 2010 (available from http://ghrsst.jpl.nasa.gov and http://ghrsst.nodc.noaa.gov), which is based on measurements from Advanced Very High Resolution Radiometers (AVHRR) on board of NOAA series satellites, calibrated by and blended with in-situ observations [*Reynolds et al.*, 2007]. The Niño4 and Niño3 indices (Figure 1) are computed from SST anomalies that are referenced to the 1982–2008 daily seasonal climatology. The intensities of El Niño and La Niña events in the CP (EP) region are determined from the peak values of the three-month smoothed Niño4 (Niño3) index shown in Figure 1a (Figure 1b) associated with individual events listed in Table 1 of *McPhaden and Zhang* [2009]. Most of the peak values occur in December, a typical month for El Niño and La Niña events to reach their maximum amplitude. However, there are events that peak either earlier or later.

[5] Previous studies [*Kim et al.*, 2009; *Yeh et al.*, 2009] have classified the 1991–92, 1994–95, 2002–03, and 2004–05 events as CP-El Niño. *Yeh et al.* [2009] classified an event as a CP-El Niño event if the Niño4 index exceeded the Niño3 index for December–January–February (DJF) average (i.e., the mature phase of El Niño events). Figure 2 displays the DJF SST anomaly for the 2009–10 El Niño. It has a clear signature of a CP-El Niño because the center of maximum SST anomaly falls within the CP (Niño4) rather than the EP (Niño3) region. The DJF value of Niño4 exceeds that of Niño3 by 0.2°C, meeting the criterion used by *Yeh et al.* [2009] to be classified as a CP-El Niño.

3. Results

[6] The intensity of El Niño events in the CP region has been increasing in the past three decades (Figure 3a). The

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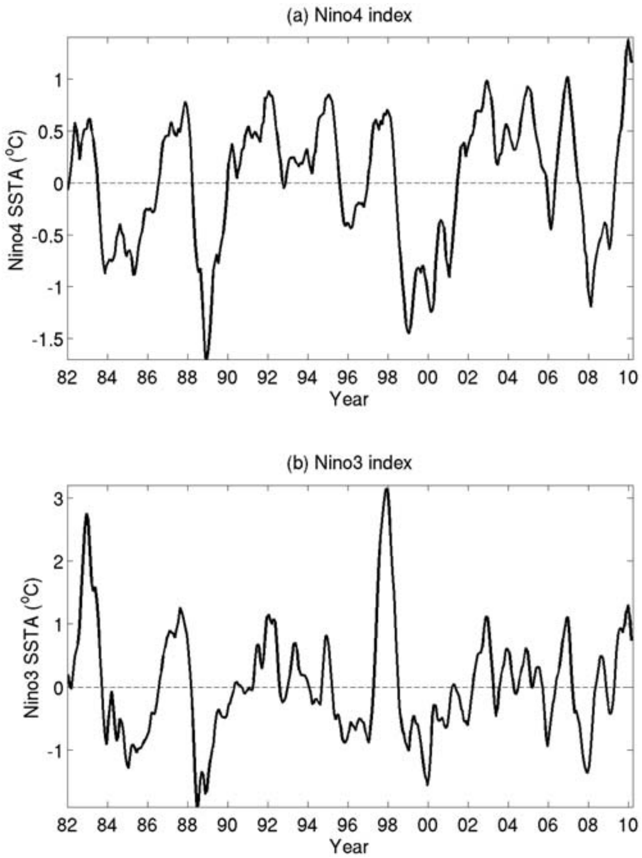

Figure 1. Three-month smoothed (a) Niño4 and (b) Niño3 indices, describing SST anomalies in the central equatorial and eastern equatorial Pacific, respectively.

estimated linear increasing trend of the El Niño intensity is approximately 0.2°C/decade, which is significant at the 90% confidence level. The intensity increases by nearly a factor of two, from about 0.6°C in the early 1980s to 1.2°C in 2010. When the large event in 2009–10 is excluded, the linear trend weakens to 0.13°C/decade but is still significant at the 90% confidence level. The intensity of La Niña events in the region, however, shows no significant trend (Figure 3a).

[7] As a consistency check for the increasing amplitude of El Niño in the CP region, we examine the linear trends of three-month smoothed total SST in December (a typical month where El Niño and La Niña events reach their maximum amplitude) during El Niño, La Niña, and neutral years (Figure 3). Prolonged La Niña events (1983–1984, 1998–2000, 2007–2008) tend to have multiple local minima in different years (Figure 1a). This tendency was discussed by *McPhaden and Zhang* [2009] (their Figure 2f and related discussion). The December values for the multiple local minima of these prolonged La Niña events are all considered La Niña values because these years are too cold to be considered neutral years. The trend of December SST during El Niño years is 0.24°C/decade (Figure 4), similar to the upward trend for the peak magnitudes of El Niño events (Figure 3). The trends of December SST during La Niña and neutral years are about four times smaller and are not statistically different from zero (Figure 4). Note that the trends of December total SST during El Niño and during La Niña years shown in Figure 4 are slightly different from the trends of the peak intensities of El Niño and La Niña events presented in Figure 3 because not all the peaks of El Niño and La Niña events occur in December. However, the small differences are not statistically significant. Moreover, the analysis of total SST in November and in January yields results that are very similar to those for total SST in December. So the analyses of SST anomaly and total SST both lead to the same conclusion.

[8] The above analysis reaffirms that the SST in the CP region during El Niño years is getting significantly higher while those during La Niña and neutral years are not. Therefore, the increasing intensity of El Niño events in the CP region is not simply the result of the well-documented background warming trend in the western-Pacific warm pool as reported by *Cane et al.* [1997] and *Cravatte et al.* [2009]. In fact, it is the increasing amplitude of El Niño events that causes a net warming trend of SST in the CP region. We find that the warming trend of the Niño4 index for all months from 1982 to February 2010 is about 0.11°C/decade. This is close to the warming trend in the same region of approximately 0.07–0.08°C/decade during 1955–2003 as reported by *Cravatte et al.* [2009, Figure 3a]. Our results suggest that, at least for the past three decades, the warming of the warm pool in the CP region is primarily because of more intense El Niño events in that region. Even so, we cannot rule out the possible existence of a weak warming trend in background SST since the trends for neutral and La Niña years, although small and insignificant, are positive. It may be that such a background trend, if it exists, is too weak to be detected with confidence in our relatively short record of satellite observations. In contrast to the CP region, the intensity of El Niño events in the EP region does not have a warming trend, and even has a cooling trend (though not significant at the 90% level of confidence) over the three-decade period (Figure 3b). This is consistent with the finding of *Cravatte et al.* [2009]. The warming trend of the Niño4 SST and the lack of it for Niño3 SST correspond a trend of enhanced

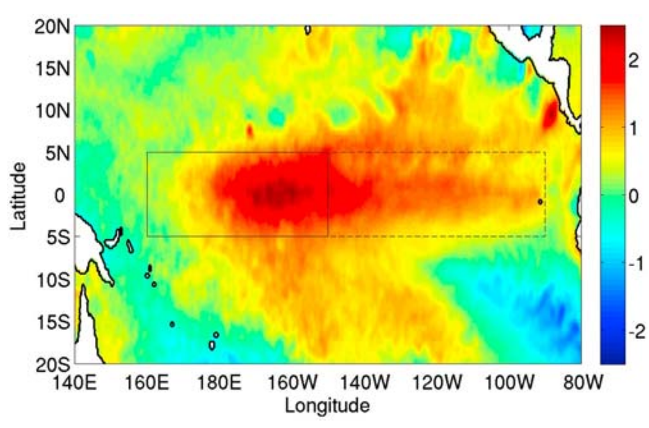

Figure 2. December–January–February averaged SST anomaly of the 2009–10 El Niño event. The boxes show the Niño4 (solid) and Niño3 (dashed) domains, respectively.

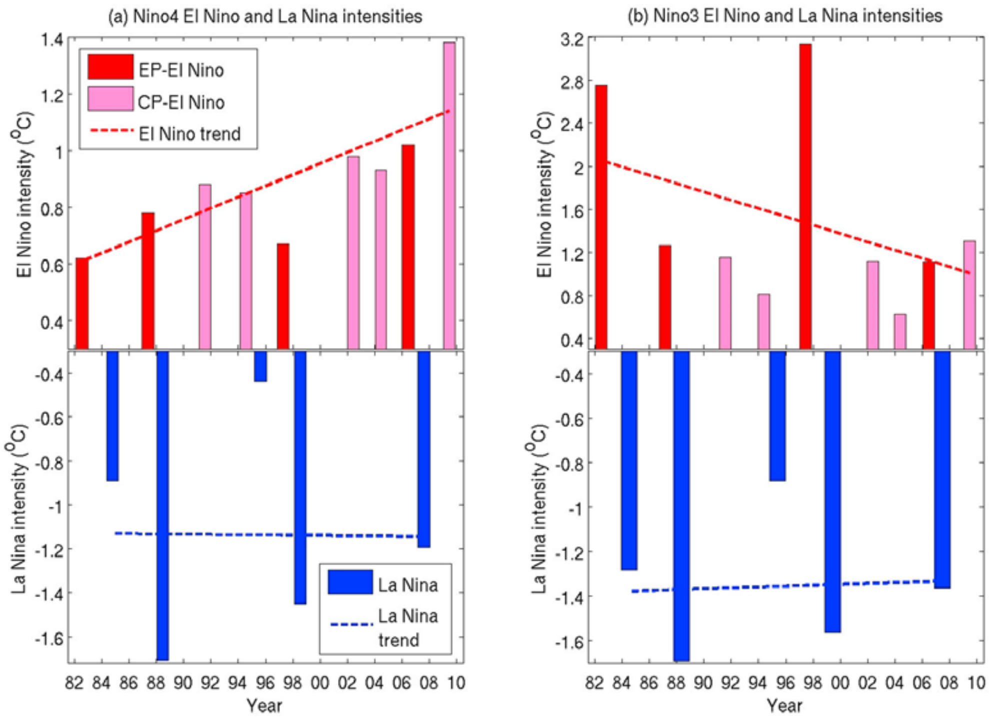

Figure 3. (a) Intensities of El Niño and La Niña events in the central equatorial Pacific (Niño4 region) and the estimated linear trends, which is 0.20(±0.18)°C/decade for El Niño and −0.01(±0.75)°C/decade for La Niña events. (b) Intensities of El Niño and La Niña events in the eastern equatorial Pacific (Niño3 region) and the estimated linear trends, which is 0.39(±0.71)°C/decade for El Niño and 0.02(±0.47)°C/decade for La Niña events. The uncertainty ranges reflect the 90% confidence intervals estimated from a Student's t-test. Note that the vertical scales start from ±0.3°C and that the scales are different for the Niño3 and Niño4 time series.

west–east SST gradient, a pattern that is consistent with theoretical prediction of the impact of global warming [*Cane et al.*, 1997]. However, our results suggest that the warming trend in the CP region is primarily due to more intense El Niño events rather than a general rise of background SST. The overall increasing trend of El Niño intensity in the CP region is related to two factors. First, CP-El Niño events have become more intense (e.g., the events in the 2000s are stronger than those in the 1990s). Secondly, EP-El Niño events occurred more frequently in the earlier part of the data record and they tend to have smaller SST anomaly in the CP region than those associated with CP-El Niño events. Therefore, the warming trend in the CP region is due to the increasing intensity and as well as frequency of CP-El Niño events over the past 30 years.

4. Concluding Remarks

[9] Our results provide an important insight about the nature of the warming trend of the warm pool in the CP region. Previous studies attributed this warming trend to a general rise of the background SST. Our analysis suggests that the warming trend in the Niño4 region is primarily a consequence of more intense and frequent CP-El Niño events, since SSTs during La Niña and neutral years have not become significantly warmer like those during El Niño years.

[10] Why these changes are occurring and what accounts for them are important questions. Theories have suggested that the intensity of El Niño could be affected by changes in background conditions such as the depth of the thermocline [e.g., *Fedorov and Philander*, 2000]. More generally, it is important to know if the increasing intensity and frequency of CP-El Niño events are related to changes associated with natural decadal-to-multi-decadal variability [e.g., *McPhaden and Zhang*, 2002; *Lee and McPhaden*, 2008] or whether the changes are due to anthropogenic greenhouse gas forcing [*Yeh et al.*, 2009]. *Yu et al.* [2010] suggested that the increase in CP-El Niño events in the past few decades is related to processes originating in the northeastern subtropics that affect the surface layer heat balance via wind driven advection and surface heat fluxes. *Yeh et al.* [2009] on the other hand proposed that a more frequent occurrence of CP-El Niño events under projected global warming scenarios would result from a shoaling of the thermocline in the CP region that enhances vertical exchange processes. However, no studies have addressed possible causes for an increasing intensity of CP−El Niños. Further investigation is therefore needed to understand these issues better given the uncertainty surrounding causal mechanisms and the implications the observed changes have for global climate and societal impacts.

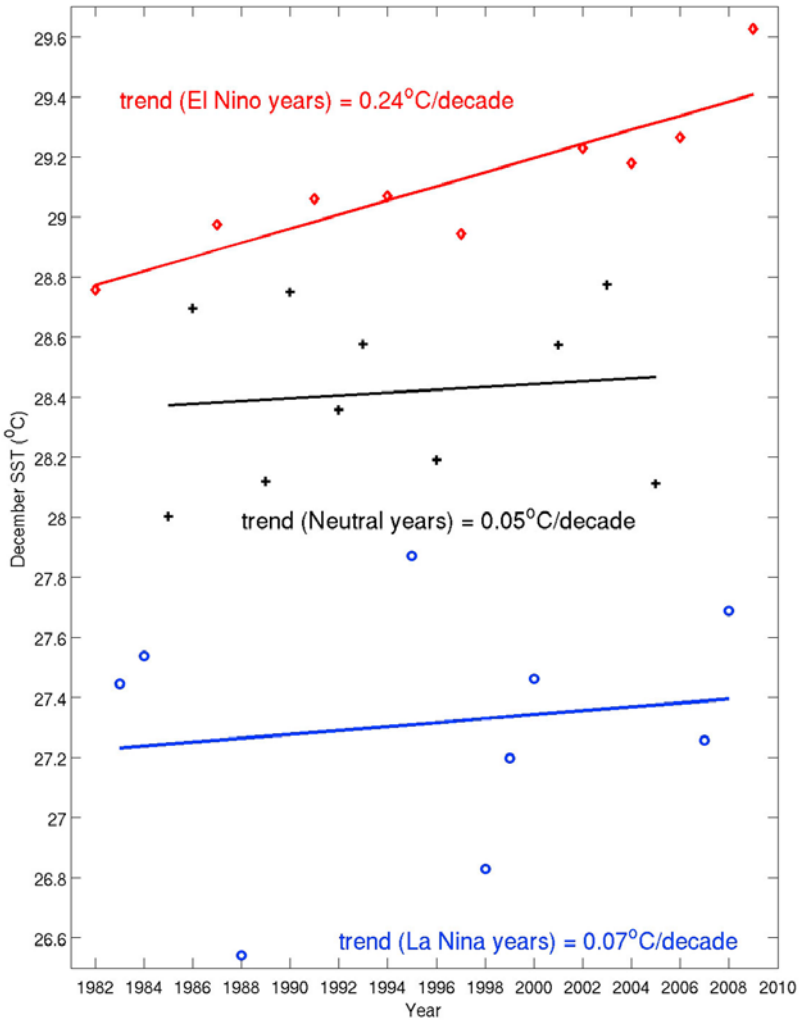

Figure 4. November–December–January values of total SST in the central equatorial Pacific (from total Niño4 SST) during El Niño (red), La Niña (blue), and neutral (black) years. The 90% confidence intervals (based on Student's t-test) for the trends are 0.18°C/decade for El Niño, 0.33°C/decade for La Niña, and 0.27°C/decade for neutral years. Note that El Niño SST in this figure is centered on December, whereas the El Niño intensity in Figure 3 is defined as the month when an El Niño event reaches maximum intensity, which could be slightly before or after December.

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References

Ashok, H., and T. Yamagata (2009), Climate change: The El Niño with a difference, *Nature*, *461*, 481–484, doi:10.1038/461481a.
Ashok, K., S. K. Behera, S. A. Rao, H. Weng, and T. Yamagata (2007), El Niño Modoki and its possible teleconnection, *J. Geophys. Res.*, *112*, C11007, doi:10.1029/2006JC003798.
Cane, M. A., A. C. Clement, A. Kaplan, Y. Kushnir, D. Pozdnyakov, R. Seager, S. E. Zebiak, and R. Murtugudde (1997), Twentieth-century sea surface temperature trends, *Science*, *275*, 957–960, doi:10.1126/science.275.5302.957.
Cravatte, S., T. Delcroix, D. Zhang, M. McPhaden, and J. Leloup (2009), Observed freshening and warming of the western Pacific warm pool, *Clim. Dyn.*, *33*, 565–589, doi:10.1007/s00382-009-0526-7.
Fedorov, A. V., and S. G. H. Philander (2000), Is El Niño changing?, *Science*, *288*, 1997–2002, doi:10.1126/science.288.5473.1997.
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.
Kim, H.-M., P. J. Webster, and J. A. Curry (2009), Impact of shifting patterns of Pacific Ocean warming on North Atlantic tropical cyclones, *Science*, *325*, 77–80, doi:10.1126/science.1174062.
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.
Larkin, N. K., and D. E. Harrison (2005), Global seasonal temperature and precipitation anomalies during El Niño autumn and winter, *Geophys. Res. Lett.*, *32*, L16705, doi:10.1029/2005GL022860.
Latif, M., R. Kleeman, and C. Eckert (1997), Greenhouse warming, decadal variability, or El Niño? An attempt to understand the anomalous 1990s, *J. Clim.*, *10*, 2221–2239, doi:10.1175/1520-0442(1997)010<2221:GWDVOE>2.0.CO;2.
Lee, T., and M. J. McPhaden (2008), Decadal phase change in large-scale sea level and winds in the Indo-Pacific region at the end of the 20th century, *Geophys. Res. Lett.*, *35*, L01605, doi:10.1029/2007GL032419.
McPhaden, M. J., and D. Zhang (2002), Slowdown of the meridional overturning circulation in the upper Pacific Ocean, *Nature*, *415*, 603–608, doi:10.1038/415603a.
McPhaden, M. J., and X. Zhang (2009), Asymmetry in zonal phase propagation of ENSO sea surface temperature anomalies, *Geophys. Res. Lett.*, *36*, L13703, doi:10.1029/2009GL038774.
Reynolds, R. W., T. M. Smith, C. Liu, D. B. Chelton, K. Casey, and M. G. Schlax (2007), Daily high-resolution-blended analyses for sea surface temperature, *J. Clim.*, *20*, 5473–5496, doi:10.1175/2007JCLI1824.1.
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. 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), Three evolution, patterns of central Pacific El Niño, *Geophys. Res. Lett.*, *37*, L08706, doi:10.1029/2010GL042810.
Yu, J.-Y., H.-Y. Kao, and T. Lee (2010), Subtropics-related interannual sea surface temperature variability in the equatorial central Pacific, *J. Clim.*, *23*, 2869–2884, doi:10.1175/2010JCLI3171.1.

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