El Niño and intense tropical cyclones

ARISING FROM F.-F. Jin, J. Boucharel & I.-I. Lin *Nature* **516,** 82–85 (2014); doi:10.1038/nature13958

The El Niño/Southern Oscillation (ENSO) influences global climate as well as extreme weather events such as floods, droughts, and tropical cyclones, leading to large societal impacts globally[1–3]. Jin *et al.*[4] have shown that El Niño—the warm phase of ENSO—effectively discharges oceanic heat into the central to eastern North Pacific basin through the subsurface ocean after its wintertime peak, resulting in high tropical cyclone activity during the following tropical cyclone peak season in the eastern North Pacific, which has significant implications for seasonal prediction of tropical cyclone activity in the eastern North Pacific. However, we question the robustness of their hypothesis on the following grounds: (1) the correlation between subsurface ocean heat delivered by El Niño and tropical cyclone activity is statistically exaggerated; and (2) wintertime ENSO conditions, which are claimed to have predictive value, are not strongly correlated with tropical cyclone activity during the subsequent summer. These factors imply that the hypothesis of ref. 4 has limitations in practical seasonal tropical cyclone prediction. There is a Reply to this Brief Communication Arising by Jin, F.-F., Boucharel, J. & Lin, I.-I. *Nature* **526,** http://dx.doi.org/10.1038/nature15547 (2015).

Our first concern is the data smoothing used in their correlation analysis (figure 3 and supplementary figures 10 and 12 of ref. 4). In general, smoothing is a useful tool for removing high-frequency noises in order to focus on long-term variations, but smoothing can also tend to increase correlations artificially (http://climateaudit.org/2008/02/12/data-smoothing-and-spurious-correlation/). Jin *et al.*[4] used a three-year smoothing, which is a suitable technique when the physical variations being examined are multiannual. However, the use of three-year smoothing is not appropriate in this case because ref. 4 examined interannual variations of tropical cyclone activity, focusing on interseasonal connections between wintertime ENSO and summertime tropical cyclones. It turns out that the smoothing significantly increased the correlation between subsurface ocean heat delivered by El Niño (based on the principal component of the second empirical orthogonal function mode in ref. 4, PC2) and tropical cyclone activity (accumulated cyclone energy, ACE[5]) from 0.29 to 0.62 (see Fig. 1a and figure 3b of ref. 4). The smoothing also enhanced the correlation of a bilinear regression model of ref. 4 (see figure 3e of ref. 4) from 0.37 to 0.64 (not shown).

A second concern is their way of comparing tropical cyclone activity between high and low subsurface heat content (PC2 active) periods. Jin *et al.*[4] showed a surprisingly distinct difference in the number of intense tropical cyclones between the two groups (see figure 2, tables 1 and 2, and supplementary figures 5–9 of ref. 4), but the results were overstated by unequal sampling. Jin *et al.*[4] sampled 43 months for high-heat-content periods, but only sampled 25 months for low-heat-content periods. The monthly distributions of the sampled month were also different. For example, in the climatological lowest (June) and highest (August) tropical cyclone genesis months for the eastern North Pacific season, the numbers of selected months were 8 (19% of total) and 7 (16%) for high-heat-content periods, but 8 (32%) and 2 (8%) for low-heat-content periods, respectively (Table 1). Using this unequal sampling, the total numbers of tropical cyclones are compared for the selected months of the two groups. This is an unfair comparison, leading naturally to a higher number of tropical cyclones in the high-heat-content periods. An impartial comparison should examine the differences in terms of mean values for each month rather than the total number of tropical cyclones. Our monthly comparison with mean values revealed that there are no significant differences in intense tropical cyclone numbers between the high-

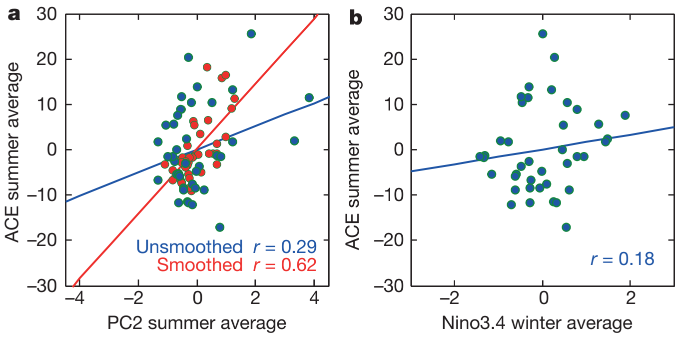

Figure 1 | Relationships of subsurface ocean heat delivered by El Niño (PC2) and the ENSO signal (Niño3.4) with tropical cyclone activity in the eastern North Pacific. a, Scatter plot of ACE against PC2 with smoothed (red) and unsmoothed (blue) data. **b,** Scatter plot of ACE against the Niño3.4 index. ACE and PC2 are averaged over the boreal summer and autumn (June to November) and Niño3.4 is averaged over the ENSO peak period (December to February) before the summer tropical cyclone season. Linear regressions (straight lines) and correlation coefficients *r* are shown. All data sets are detrended, and are unsmoothed except for the smoothing discussed above. For consistent comparisons with ref. 4, we used the same analysis period (1970–2009), methods, and data as in ref. 4, except for the smoothing. The subsurface ocean heat over the upper 105 m (T105) represents all the existing subsurface ocean conditions in the eastern North Pacific, whereas PC2 explains only 56% of the T105 variations through a process delivered by El Niño. Therefore, PC2 is the index explaining the relationship between subsurface ocean heat delivered by El Niño and tropical cyclone activity in ref. 4, although T105 is more closely related to tropical cyclone activity than PC2.

Table 1 | Monthly and summer mean numbers of intense tropical cyclones during periods of low and high subsurface heat content

Periods	Total number of selected months	Monthly mean numbers of intense tropical cyclones (number of selected months)						Summer-mean intense tropical cyclone numbers
		June	July	August	September	October	November	
High PC2	43	0.50 (8)	1.38 (8)	1.14 (7)	1.43 (7)	0.86 (7)	0.00 (6)	5.30
Low PC2	25	0.25 (8)	1.14 (7)	1.00 (2)	1.00 (2)	1.00 (2)	0.00 (4)	4.39
Climatology		0.31	0.86	0.90	0.75	0.43	0.00	3.25
Confidence level for difference between periods (%)		67	27	8	31	16	0	67

Intense (category 3, 4 and 5) tropical cyclones represent tropical cyclones at category 3 or above according to the Saffir–Simpson hurricane scale. Input data and methods are the same as in supplementary table 1 of ref. 4 except that we used monthly mean values. Owing to the different monthly distributions in sampling between two periods, summer-mean intense tropical cyclone numbers are calculated by using the sum of monthly mean tropical cyclone numbers, not the total summer tropical cyclone number divided by the total number of selected months. This method has the advantage of not being influenced by the months without tropical cyclones (such as November). High (low) PC2 indicates a period of high (low) subsurface heat content, which is based on the principal component of the second empirical orthogonal function mode in ref. 4.

heat-content and low-heat-content periods based on PC2 (all confidence levels are less than 67%, Table 1).

A third concern is the limitation in the seasonal prediction of tropical cyclone activity. Jin *et al.*[4] argued that observed ENSO signals (the Niño index) in the winter are good indicators of tropical cyclone activity during the subsequent summer in the eastern North Pacific. However, the correlation between the Niño index in the winter and ACE during the subsequent summer is very low ($r = 0.18$, Fig. 1b), which implies that the subsurface ocean heat delivered by El Niño has very little contribution (~3%) to the total variations of tropical cyclone activity in the subsequent summer. Consequently, ref. 4's theory has limitations in practical seasonal tropical cyclone prediction.

In spite of these concerns, we agree that the delivery of subsurface ocean heat for specific big El Niño events does have an influence on tropical cyclone activity in the eastern North Pacific. In these cases, there is no doubt that ocean thermal control can be used as a predictor for seasonal prediction of tropical cyclones in the eastern North Pacific. However, we consider that ref. 4's claims of a direct connection between the subsurface ocean thermal control delivered by El Niño and tropical cyclone activity are premature for general ENSO events. The connections are not robust enough to apply for the seasonal prediction for all types of ENSO events. An analysis classified according to the types of ENSO (El Niño or La Niña; cold tongue or warm pool El Niño[6,7]) will be required to improve the correlations and reliability of prediction.

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Author Contributions I.-J.M. conceived the idea, designed the study, and wrote the Comment. S.-H.K. conducted most of the analysis and discovered main results. C.W. contributed to the interpretation of the results and editing of the manuscript.

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Jin *et al.* reply

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Observational and modelling studies suggest that subsurface ocean temperature plays a major part in tropical cyclone intensification[1,2]. In a recent Letter[3] we reported that through the El Niño/Southern Oscillation (ENSO) recharge–discharge mechanism, the subsurface heat of ENSO can directly affect intense tropical cyclones in the eastern Pacific[3,4]. In the accompanying Comment[5], Moon *et al.* questioned the robustness and relevance of our results.

First, ref. 5 questioned our use of a three-year running mean. However, this simple smoothing is actually physically relevant. It effectively filters out the 'noise' from warm pool El Niño events[6], which do not effectively discharge heat into the eastern Pacific and thus have little control on eastern Pacific tropical cyclone intensity[7]. By focusing on the slow and strong events, we delineated a clear physical mechanism: canonical ENSO events, which mostly have significant discharge of heat, exert a strong oceanic control on tropical cyclone activity in the eastern Pacific. However, we acknowledge that we should have explicitly indicated this point in ref. 3 to avoid confusion. Furthermore, it should be emphasized that although not every ENSO event delivers a great amount of heat to the eastern Pacific region, subsurface heat anomalies do have a strong impact on the overlying tropical cyclone activity. Using unfiltered data (that is, without the three-year running mean), a strong correlation ($r = 0.62$) between monthly subsurface ocean heat over the top 105 m (T105) of depth and monthly tropical cyclone intensity is still evident (Fig. 1), clearly supporting a strong relationship between subsurface heat and the eastern Pacific tropical cyclone intensity. We also note that the quality of both tropical cyclone and ocean data sets is problematic in the earlier period (1959–1978), as there exist few subsurface observations[8], and there were no systematic satellite tropical cyclone observations before the 1980s[9]. Thus, these low-quality data sets can contribute to lower correlations in the earlier period (Fig. 1b). In summary, we do not agree with the contention of ref. 5 that the impacts of subsurface thermal control on tropical cyclone activity are largely exaggerated owing to the smoothing regardless of the period.

Second, ref. 5 questioned the statistical significance of tropical cyclone activity changes between periods of high and low subsurface heat over the eastern Pacific region. Our original choice (ref. 3) of a broad temporal measure in terms of simple accounts of tropical cyclone number per decade displays significant differences between these periods (periods of high and low subsurface heat are referred to as high PC2/low PC2; see ref. 3 for details). Moon *et al.*[5] argue that this significance is severely degraded when their 'accurate' counting of total number per month is used. However, we believe that their counting ignored one important fact: there are many months without any tropical cyclone (hurricane) occurrence in the record. We argue that those 'hurricane-empty' months should be removed for a truly accurate counting. If we use the

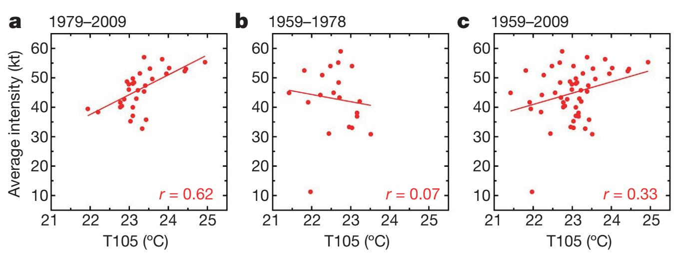

Figure 1 | Relationships between heat content and tropical cyclone intensity in the northeast Pacific. **a**, Correlation based on the unsmoothed data from 1979–2009. **b**, Correlation based on the earlier period (1959–1978). **c**, Correlation based on the entire period (1959–2009).

Table 1 | Changes in tropical cyclones statistics between high- and low-heat-content periods in the northeast Pacific

		Number of sampled month	Mean of the number of category 3–5 tropical cyclones	Confidence level (two-tailed)	Confidence level (one-tailed)
a	High PC2	29	1.34	93%	96.5%
	Low PC2	21	0.76		
		Mean (%)	Variance	Number of months in sample	*t* value (confidence level)
b	High PC2	11.24	139.02	34	3.368 (>99.75% for one-tailed; >99.5% for two-tailed)
	Low PC2	3.21	38.29	24	

a, Comparison of intense (category 3–5) tropical cyclone count between high and low PC2 active periods, using category 1 as a minimum threshold.
b, *t*-test result for the percentage of intense tropical cyclone grid count—that is, grid count of category 3–5 tropical cyclones divided by the grid count of total tropical cyclones (from tropical depression to category 5)—in the tropical cyclone region.

conventional definition of tropical cyclone (category 1 or above) to filter out tropical depressions and storms that have little interactions with the subsurface ocean, and then remove all 'hurricane-empty' months from the counting, the number of tropical cyclones per month again passes the 95% confidence level (Table 1a). Furthermore, using a stricter grid-by-grid approach, a precise measure of intense tropical cyclone activity giving the percentage of intense tropical cyclones over all tropical cyclone grids, we obtained an even stronger statistical significance (above the 99.5% confidence levels, see Table 1b). Both the broad measure in our earlier analysis and the stricter measures we present here give consistent results regarding the significance of this statistical test.

Third, Moon *et al.*[5] questioned the usefulness of our finding in the prediction of tropical cyclones. It is known (and expected to continue to be so) that a major El Niño event is followed by a highly predictable heat discharge into the eastern Pacific. For instance, as this year's El Niño develops into a strong event likely to peak in the coming boreal winter in the equatorial eastern Pacific, there is a high chance (75%) of a significant heat discharge into the eastern north Pacific to fuel intense tropical cyclones when next year's tropical cyclone season arrives. Should a weak warm pool El Niño event occur, it would discharge little heat to affect the eastern Pacific tropical cyclone activity. Information about each El Niño and its heat content discharge is known long before the Northern Hemisphere tropical cyclone season, so it has a clear predictive value.

In conclusion, we reaffirm the physical mechanism evidenced by ref. 3, that is, the impact of ocean heat content discharged from major El Niño events on the eastern Pacific tropical cyclone intensity and its value for tropical cyclone predictions beyond the seasonal timescale.

Methods

This work uses single-tailed significance while ref. 5 uses double-tailed. If the mean of the first group is expected to be larger than the second, a single-tailed approach is used. However, if the mean of the first group is different from the second in either direction, a double-tailed approach is used. In the context of this study, we expect the group 1 (high PC2) mean to be larger than the group 2 (low PC2) mean, so we used a single-tail approach. In the revised Table 1, we present results using both approaches.

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