# CORRESPONDENCE

## Comments on "Characterizing ENSO Coupled Variability and Its Impact on North American Seasonal Precipitation and Temperature"

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ABSTRACT

El Niño and La Niña seasonal weather anomaly associations provide a useful basis for winter forecasting over the North American regions where they are sufficiently strong in amplitude and consistent in character from one event to another. When the associations during La Niña are different than El Niño, however, the obvious quasi-linear-statistical approach to modeling them has serious shortcomings. The linear approach of L'Heureux et al. is critiqued here based on observed land surface temperature and tropospheric circulation associations over North America. The La Niña associations are quite different in pattern from their El Niño counterparts. The El Niño associations dominate the statistics. This causes the linear approach to produce results that are inconsistent with the observed La Niña–averaged associations. Further, nearly all the useful North American associations have been contributed by the subset of El Niño and La Niña years that are identifiable by an outgoing longwave radiation (OLR) El Niño index and a distinct OLR La Niña index. The remaining "non-OLR events" exhibit winter weather anomalies with large event-to-event variability and contribute very little statistical utility to the composites. The result is that the linear analysis framework is sufficiently unable to fit the observations as to question its utility for studying La Niña and El Niño seasonal temperature and atmospheric circulation relationships. An OLR-event based approach that treats La Niña and El Niño separately is significantly more consistent with, and offers an improved statistical model for, the observed relationships.

### 1. Introduction La Niña

Tropical Pacific sea surface temperature (SST), sea level pressure (SLP), and outgoing longwave radiation (OLR) all provide measures of ENSO state, but of these OLR is most closely connected to the ENSO-associated atmospheric heating anomalies that drive extratropical atmospheric circulation anomalies. Recently L'Heureux et al. (2015, hereafter LH15) examined the seasonal weather (temperature and precipitation) associations of ENSO over North America, with a focus on the Niño-3 SST anomaly index and an OLR index different from those introduced by Chiodi and Harrison (2013, 2015a, hereafter CH13 and CH15a, respectively). In the LH15 approach, their OLR index was motivated by an analysis of the linear covariability of tropical Pacific SST and OLR, and a single index is used to jointly represent both ENSO phases. The LH15 analysis used a linear statistical regression to model the connection between ENSO state and associated seasonal weather anomalies, and evaluated the connection with a correlation analysis. The choice of a linear regression model in this case implicitly assigns the same pattern of seasonal weather anomaly to El Niño and La Niña events, just with opposite sign. The accuracy of this assumption, however, was not tested by LH15. Looking over a previous study period, Hoerling et al. (1997; see also Peng and Kumar 2005) found

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substantial asymmetry between the El Niño and La Niña wintertime weather (regional atmospheric circulation and temperature) patterns over North America. This motivates the question of how consistent a linear regression model is with the observed weather associations.

We have looked further at the differences in the North American seasonal temperature patterns, as well as midtropospheric circulation anomalies, associated with El Niño and La Niña during the LH15 study period, with a focus on winter [December–February (DJF)], when ENSO events typically reach their peak anomaly state in the tropical Pacific (Larkin and Harrison 2002) and the strongest seasonally averaged weather associations are found over North America. We have previously shown that tropical Pacific OLR exhibits a behavior that is distinct in character from that of the underlying SST and SLP (Chiodi and Harrison 2008, 2010) and have used separate indices for each phase to identify event years based on characteristic differences seen in their respective OLR behavior over the tropical Pacific; the identified ''OLR EL Niño'' and ''OLR La Niña'' events consist of subsets of the satellite-era years conventionally identified as ENSO events.

We recently showed that the OLR-identified subsets of event years almost entirely account for the familiar El Niño and La Niña seasonal precipitation composite associations over North America (CH15a). The remaining ''non-OLR events'' contribute very little statistical utility to the composites. Further, a quasi-linear approach to modeling wintertime precipitation associations was shown in CH15a to be significantly less consistent with the observed associations than an OLR event–based approach.

We here present the surface temperature and midtropospheric circulation (500-mb geopotential height; 1 mb = 1 hPa) anomalies associated with the OLR La Niña event year composites over North America. We compare these associations to their non-OLR La Niña, as well as OLR El Niño counterparts, and also reproduce the LH15 results in their original form, as well as a modified one that illustrates the dominance of the (handful of) OLR El Niño years on the regression statistics for the full study period. Our results suggest that the LH15 linear regression analysis framework deserves reconsideration.

We show that the asymmetries between the OLR El Niño and OLR La Niña wintertime temperature composites, which are not accounted for in the LH15 regression model, are strong enough that the surface temperature associations resulting from the regression analysis are fundamentally different from the observed composite anomalies; the linear statistical approach yields a La Niña wintertime temperature and atmospheric circulation association that is inconsistent with the observed La Niña average.

## 2. Data and methods

Seasonal (3-month average) temperature anomalies were computed from the GHCN CAMS (Global Historical Climatology Network, version 2, and Climate Anomaly Monitoring System) monthly averaged 2-m land temperature dataset (Fan and van den Dool 2008). This dataset is based on station observations interpolated to a 0.5° × 0.5° grid. GHCN CAMS data are made available by the NOAA/Oceanic and Atmospheric Research (OAR)/Earth System Research Laboratory (ESRL) Physical Sciences Division (PSD), Boulder, Colorado, at http://www.esrl.noaa.gov/psd/data/gridded/data.ghcncams.html. The base (full study) period of 1982–2013 is used for calculating anomalies. The same study–base period (as well as land surface temperature dataset) was used by LH15.

OLR data were obtained from NOAA/OAR/ESRL PSD at http://www.esrl.noaa.gov/psd/data/gridded/data.interp_OLR.html. This is a satellite-derived product available on a 2.5° × 2.5° grid and at daily average resolution. Details of the interpolation technique are described by Liebmann and Smith (1996). The results (in this case, years identified as OLR El Niño and OLR La Niña events) based on NOAA interpolated OLR data have been verified with a second set of results based on the High Resolution Infrared Radiation Sounder OLR climate dataset (Lee 2014; CH15a), which provides near-real-time daily averages of OLR and can be found at http://olr.umd.edu/.

The OLR El Niño and OLR La Niña events are identified by the OLR index for El Niño (CH13) and a separate OLR index for La Niña (CH15a). The OLR El Niño index (30-day running mean OLR averaged over 5°S–5°N, 160°–110°W) looks for the eastward spread in equatorial Pacific deep-atmospheric convection activity that is specific to El Niño events. This clearly identifies 1982/83, 1986/87, 1991/92, and 1997/98 as OLR El Niño events.

The OLR La Niña index was motivated by our phenomenological understanding of La Niña atmospheric convection conditions and their connection to the easterly wind surges that have been shown to drive La Niña cooling of the oceanic waveguide (Chiodi and Harrison 2015b). The OLR La Niña index looks for changes in equatorial Pacific deep-atmospheric convection activity specific to La Niña development, and is calculated by tabulating the number of days, beginning 1 March of each ENSO year, with OLR averages over the region 5°S–5°N, 50°E–180° that are less than 260 W m$^{-2}$. In this way, the index tabulates synoptic-scale breaks in convection over the equatorial Pacific region of normally intense deep atmospheric convection activity. A subset of 4 yr in the 1982–2013 period is identified as OLR La Niña years (1988/89, 1998/99, 1999/2000, and 2010/11). At the time of manuscript preparation, the NOAA historical ENSO definition, which is based on 3-month averages of Niño-3.4 SSTA amplitudes exceeding 0.5°C for five or more consecutive months, identified these four years plus seven others (1983/84, 1984/85, 1995/96, 2000/01, 2005/06, 2007/08 and 2011/12) as La Niña years. We refer to these other 7 yr as the non-OLR La Niña years, hereafter. Recent changes to the NOAA historical ENSO definition, which is now based on ERSST, version 4 (ERSST.v4; but previously used ERSST.v3b), have altered the Niño-3.4 SSTA values so only five of these seven years currently meet the NOAA criteria (1983/84 and 2005/06 are no longer considered La Niña years under ERSST.v4). We have repeated the analyses described below with this modified subset of (five) non-OLR La Niña years and found that the results are qualitatively unchanged from those described below, so we present just the original results here.

The alternative LH15 central Pacific OLR (CP-OLR) index is based on 3-month average OLR anomaly, spatially averaged over the region bounded by 170°E–140°W and 5°S–5°N. In the LH15 analysis of ENSO seasonal-weather associations, contemporaneous seasonal averages of CP-OLR are used for linear regression with seasonally averaged land surface temperature (e.g., DJF-averaged CP-OLR regressed with DJF-averaged temperature). We have reproduced the LH15 CP-OLR and temperature analysis herein.

Monthly average 500-mb-level geopotential height (z500) fields were obtained from the NCEP reanalysis data (Kalnay et al. 1996) and are provided by NOAA/OAR/ESRL PSD from their website http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html. We also compared our NCEP-based results with a second set based on monthly averaged z500 fields obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) interim reanalysis (ERA-Interim; Dee et al. 2011), available at http://apps.ecmwf.int/datasets/data/interim-full-moda/levtype=pl. We found the two sets of results to be quantitatively similar. For example, the difference between the NCEP-based OLR La Niña z500 composite anomaly field (as described below) and same composite based on ERA-Interim data has a root-mean-square value of 2.7 m averaged over the study region, with peak differences (located within the 40°–45°N, 140°–160°W region) of less than 10 m. Because these two sets of results are quantitatively consistent with one another, we have presented just one (NCEP) herein.

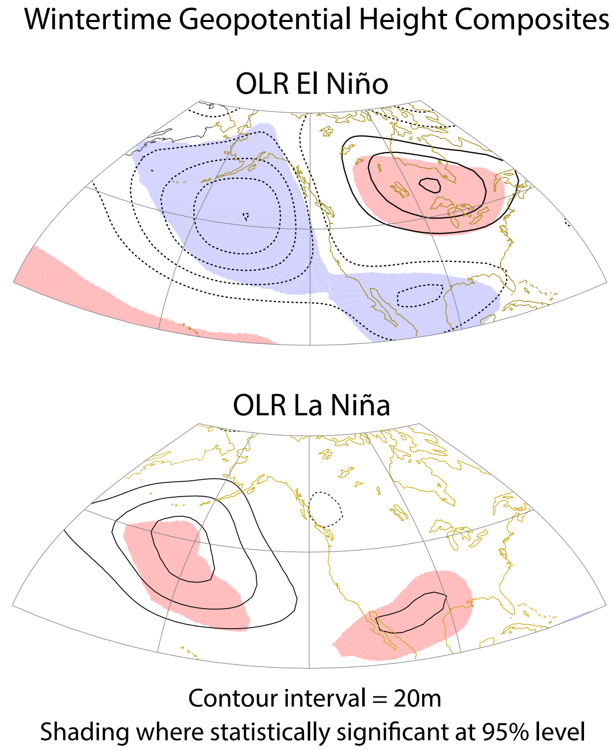


FIG. 1. Wintertime (DJF) 500-mb geopotential height anomaly composites based on the (top) OLR El Niño and (bottom) OLR La Niña years. Solid (dashed) contours for positive (negative) anomaly. Anomalies are shaded where they reach statistical significance at the 95% confidence interval; blue (red) for negative (positive) anomalies. Period is 1982–2013.

The (local) statistical significance of composite anomaly amplitude is estimated based on the Monte Carlo–bootstrap method described previously by CH13 and CH15a. The overall or "field" significance (Livezey and Chen 1983) of the composites over the North American region (taken here as 170°–60°W and 20°–70°N) is also estimated as described previously. In a study, such as this, which simultaneously examines many different regions with different types of seasonal weather anomalies, some (locally) statistically significant anomalies should be expected based on chance alone (the null hypothesis). Field significance tests are important in this case because they determine the amount of statistically significant anomaly that must be reached to reject the null hypothesis at the selected confidence interval.

## 3. Results

### *a. La Niña and El Niño wintertime atmospheric circulation anomalies*

The wintertime El Niño midtropospheric circulation anomaly pattern is associated with a now familiar (Horel and Wallace 1981; Hoerling and Kumar 2002) and highly statistically significant (CH13) atmospheric circulation anomaly pattern over the North Pacific–North American region, which is especially evident in 500-mb geopotential height anomaly (Fig. 1, top). We have shown previously that the OLR El Niño subset of the years is responsible for the familiar El Niño atmospheric circulation pattern, and that little useful connection is found for the remaining subset of warm-event years (CH13). We have also shown that there is not nearly as much useful connection in the other seasons over this region, even for the OLR El Niño subset.

The wintertime La Niña height composite based on the OLR-identified subset of years is shown in Fig. 1 (bottom). In this case, a statistically significant anomaly is seen over much of the North Pacific and some of the southern United States and Mexico. Similar statistically significant features are not seen in these same regions, however, in the non-OLR La Niña composite (cf. Fig. A1). Thus, like their OLR El Niño counterparts, the OLR La Niña years account for most of the statistically significant features of the atmospheric circulation anomaly composite for all La Niña years. We have also looked over the other 3-month seasons (12 in a sliding-window sense), and found that the La Niña composites are strongest (i.e., contain the most statistically significant anomaly) in winter [DJF and January–March (JFM)], when they reach field significance at the 90%, but not 95%, confidence level (other seasons not shown for brevity).

Although the La Niña and El Niño wintertime height anomaly patterns have some similarities (especially over the southwestern United States and Mexico) they are fundamentally different from one another over the northern interior of the continent, where the wintertime La Niña atmospheric circulation pattern lacks large-amplitude, statistically significant anomalies, but highly statistically significant and coherent anomalies are clearly seen in the OLR El Niño composite.

### b. *El Niño and La Niña wintertime temperature composites*

The wintertime North American OLR El Niño composite temperature anomaly pattern is a largely familiar one (e.g., Halpert and Ropelewski 1992) that includes statistically significant warm anomalies over much of the northern interior of North America, where the associated amplitudes (>4°C peak) are large enough to have important socioeconomic impacts. The OLR El Niño land surface temperature composite presented here, which includes Canada, as well as Alaska and Mexico, expands upon the previous one from CH13 by showing the extent to which the statistically significant warm anomaly seen along the north-central United States extends into Canada. The U.S. portion of this interior-continent warm anomaly was found by CH13 to be a remarkably consistent feature of the individual OLR El Niño years (each of the four such years in this study period exhibits >3°C winter temperature anomalies over the north-central United States).

Compared to the El Niño case, the OLR La Niña patterns are generally smaller in amplitude and different in character (shape), and they reach statistical significance over a much smaller area. Peak (cool) temperature anomaly amplitudes are seen in the La Niña case over the Alaska–Yukon region, were they were also seen in the previous-period La Niña composite described by Hoerling et al. (1997). This suggests that this feature has been a stable La Niña association for at least ~60 years. The wintertime temperature anomaly composite based on the seven non-OLR La Niña years of our study period lacks any similar statistically significant features over this region (Fig. A1). As for atmospheric circulation, most of the highly statistically significant features of the La Niña temperature composite are associated with the OLR-identified subset of cool-event years.

The wintertime OLR El Niño composite contains statistically significant anomaly over 28% of the land surface (Fig. 2), making it field significant at the 95% confidence level in this season. The OLR La Niña composite contains significant anomaly amplitudes over just 4% of the land area and does not reach field significance in this season, or any other (results based on the OLR La Niña and El Niño lists of years over each season are listed in Table 1). The OLR El Niño temperature anomaly composite reaches field significance (at 95%) only in winter. Evidently, North American land surface temperature anomaly patterns are much more strongly affected by El Niño than La Niña, with peak impacts occurring in winter.

The results described above highlight significant asymmetries between the North American temperature anomaly patterns associated with El Niño and La Niña events. In stark contrast to the OLR El Niño case, the La Niña temperature patterns lack highly statistically significant anomalies over the northern interior of the continent. These asymmetries are not taken into account in the linear regression statistics of LH15. The linear approach also does not take into account the fact that the familiar weather associations are predominantly accounted for by just a handful of the years in this study period. We examine some of the implications of this below.

### c. *Comparison with linear regression results*

We have reproduced, using the statistical methods described in section 2, the previous LH15 finding that

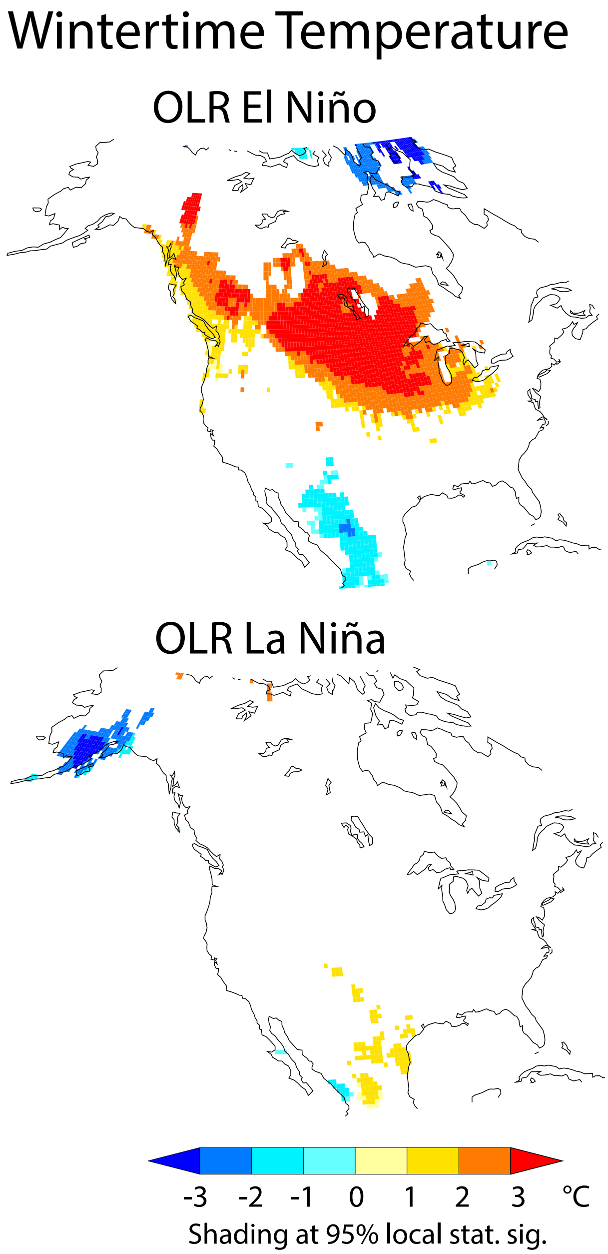


FIG. 2. Wintertime temperature anomaly composite based on the (top) OLR El Niño and (bottom) OLR La Niña years. Anomalies are shaded where they reach statistical significance at the 95% confidence level. Period is 1982–2013.

the correlation between their OLR index and North America wintertime surface temperature is statistically significant over enough land area to reach field significance at the 95% confidence level (Fig. 3, top).

We offer some perspective on this result by additionally considering the correlation produced by an index that adopts an alternative model for the temperature associations (one based on a binary OLR El Niño–event model), as well as looking at what happens when the correlations are based on the same LH15 OLR index, except with the four OLR El Niño event years omitted (leaving 28 rather than 32 DJF periods). The results obtained in each case illustrate the dominant effect that the four OLR El Niño events have on the regression statistics, especially over the northern interior of the continent where the El Niño association is strong and La Niña much less so.

The binary model we use here can be thought of as a mathematical device representing the situation where there is a high degree of event-to-event consistency among the OLR El Niño years, but different (perhaps yet to be determined) sources of variability control the weather anomalies seen at other times. The binary index thus has a value of 1 in each of the OLR El Niño years and a value of 0 in the other years (see Fig. A2 in the appendix). A value of 1 in this case is equivalent to applying the OLR El Niño composite anomaly pattern in the OLR El Niño years. A value of 0 is equivalent to expecting climatological average conditions (0 anomaly) in the other years.

The correlation coefficient field produced by correlating the binary (OLR El Niño event) model with DJF-averaged land surface temperature is shown in Fig. 3, middle. In this case, the correlation coefficients, which are still computed over all 32 yr, remain statistically significant over enough of the land area to reach field significance at the 95% level. Specifically, a statistically significant correlation is seen over 28% of the land when the binary index is used to model the observed anomalies. This percentage is larger than the base-case LH15 OLR index result of 23%. Thus, modeling the seasonal temperature association by applying the OLR El Niño composite in the four OLR El Niño years and ignoring (applying the climatological average to) the rest of the years yields a correlation with the observed anomalies (computed over all years) that is somewhat stronger than the original LH15 result.

Correspondingly, when the four OLR El Niño years are omitted from the LH15 OLR index, the linear regression over the remaining 28 yr is no longer field significant. Without the four OLR El Niño years, statistically significant correlation coefficients are seen over just 3% of North America (Fig. 3, bottom). The LH15 approach does not offer a basis to reliably predict wintertime temperature anomalies over these 28 (the vast majority of) yr, and there are far more useful methods (Chiodi and Harrison 2010; CH13) of identifying the OLR El Niño years.

We have confirmed that the LH15 approach performs poorly over these 28 yr even after the best-fit linear trend, calculated based on the 32 DJF-averages of surface temperature, is removed at each land grid point prior to analysis. In this case, the LH15 index still does

TABLE 1. Percentage of North American (20°–70°N, 170°–60°W) land area with statistically significant ($p > 0.95$) 3-month average temperature anomaly based on the OLR El Niño composite (second row) and OLR La Niña composite (third row). The percentage of land area needed to reach statistical significance in an overall (''field'') sense at the 95% confidence level is listed in the fourth row. Only the overlapping DJF and JFM OLR El Niño composites reach field significance at the 95% confidence level (boldface type).

| Months | JJA | JAS | ASO | SON | OND | NDJ | DJF | JFM | FMA | MAM | AMJ | MJJ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| El Niño | 3.8 | 10.1 | 10.6 | 8.9 | 6.2 | 6.0 | **27.6** | **28.2** | 16.7 | 14.5 | 8.8 | 5.1 |
| La Niña | 2.6 | 5.0 | 4.7 | 10.9 | 9.9 | 7.5 | 3.9 | 3.6 | 5.8 | 4.7 | 1.8 | 1.6 |
| 95% | 15.8 | 17.8 | 17.1 | 18.7 | 19.0 | 20.3 | 18.6 | 19.9 | 18.2 | 19.2 | 17.5 | 16.4 |

not reach field significance with statistically significant correlation seen over just 4% of North America. On the other hand, the OLR El Niño–event binary model still reaches field significance, with a statistically significant anomaly seen in this case over even more (37%) of North America.

These results show that 1) the linear regression results of LH15 are largely dominated by the associations of the few OLR El Niño years, and 2) these associations are not very usefully representative of the seasonal weather anomalies seen at other times.

We were encouraged by one of the reviewers to look further at how likely or unlikely it is that a system that is basically linear in character might exhibit weather associations like these, with a handful of years dominating the regression results. The rationale here being that even in a linear system (say, some $x$ is basically linearly related to $y$, with some finite correlation) it should be expected that the larger-amplitude values of $x$ account for a larger amount of the linear relationship (correlation) than the lesser values, and perhaps this plus the effects of randomness might account for the dominance of the OLR El Niño years in the observed statistics. It was suggested that we look at regression with the commonly used Niño-3.4 SSTA index in this context.

The coherent patch of statistically significant warm anomaly associated with the OLR El Niño years (Fig. 2, top), stands out as the dominant ENSO-temperature association over North America in this study period. We find it useful to first consider some corresponding metrics based on averages over this region. Over the 32 DJF periods considered, the DJF Niño-3.4 SST anomaly is correlated with DJF temperature, averaged over this region (coherent warm-color shading in Fig. 2, top) at the 0.37 level. The binary model is correlated with this same (32 yr) temperature average at the 0.55 level, and correlating DJF Niño-3.4 over just the 28 yr that remain after the OLR El Niño years are omitted, yields a value of 0.02. Should it be expected that a system that is basically linear in character often produces metrics like these, in which a handful of years dominate the linear relationship as strongly as the OLR El Niño events do?

We took an initial look at what should be expected from a basically linear system using a Monte Carlo approach where we first generated 32-sample $x(i)$ and $y(i)$ pairs ($i = 1$ to 32) that are Gaussian-distributed and correlated at the 0.37 level (as are DJF Niño-3.4 and the area-averaged DJF land temperature discussed above). We did this by randomly selecting an $x(i)$ time series from a Gaussian distribution and computing its paired $y(i)$ term as

$$y(i) = 2.5 \times r(i) + x(i), \qquad (1)$$

where $r(i)$ is also a 32-yr-long, randomly selected, Gaussian distributed sequence, representing noise in the system. We generated 1000 $x$ and $y$ pairs in this way, which have been confirmed to have a correlation of 0.37 ($\pm$0.01). For each pair selected, we also created a corresponding binary-event model with 1's at the positions of the four largest $x$'s and zeros otherwise, along with a 28-yr truncated version (i.e., same $y$ and $x$, except omitting the years with top-four $x$ values). Next we computed the associated correlations and found that the average (expected) correlation for the 28-yr case in this linear scenario is somewhat lower (0.30) than the overall population correlation of 0.37, and the expected binary-event model correlation is lower still (0.24). Perhaps more interestingly, we found that the simulated binary correlation reaches the observed 0.55 level, or higher, only about 1% of the time. We also found that the simulated 28-yr correlation reaches a level of 0.02, or lower, only about 1% of the time. Thus, the Niño-3.4-based linear regression model is inconsistent with both of these aspects of the observed associations at standard (e.g., 95%) confidence levels.

We looked further at the regression approach (as was also proposed by the reviewer) by examining the relationship between DJF Niño-3.4 SSTA and the time series produced by 1) first regressing DJF Niño-3.4 on DJF land temperature and then 2) projecting the resulting regression pattern back on to DJF land temperature to produce a second time series of Niño-3.4-regression-pattern amplitudes. It bears noting here that this suggested two-step analysis lacks cross validation, in the sense that the year being modeled is always included in the regression pattern used to model it. In this case, especially, it is important to be aware of what kind of results (level of correlation between original index and resulting

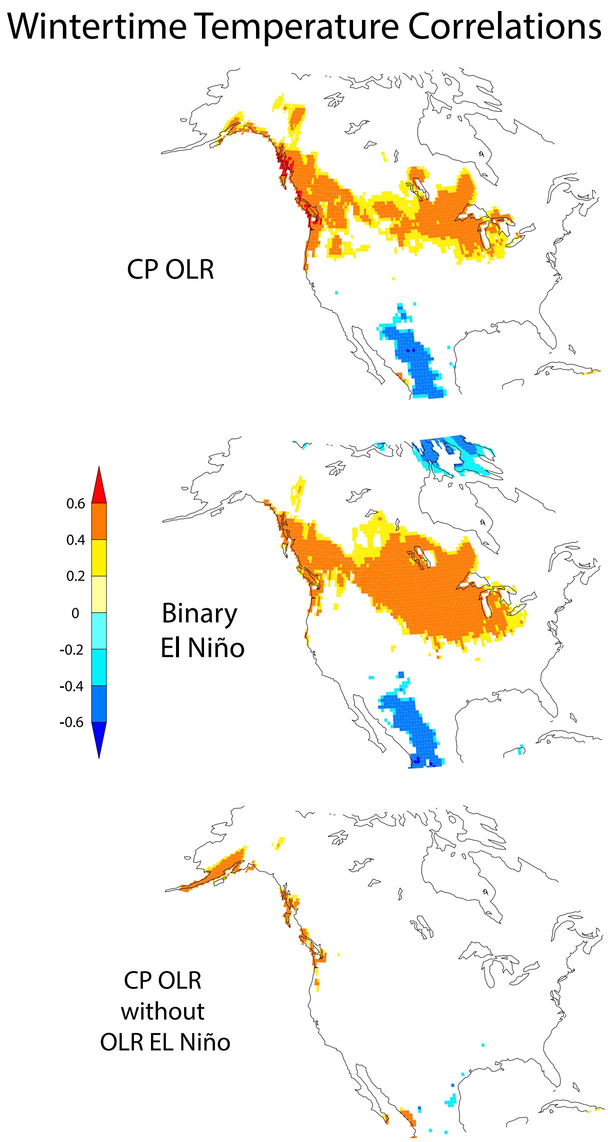


FIG. 3. Correlation between wintertime temperature anomaly and (top) LH15 OLR index, (middle) binary OLR El Niño index, and (bottom) LH15 OLR index with the four OLR El Niño years removed. Anomalies are shaded where the correlation reaches statistical significance at the 95% confidence level. Period is 1982–2013.

regression-pattern amplitudes) should be expected under the null hypothesis of zero connection between the chosen index and observed field. We calculated the null-hypothesis results using a Monte Carlo approach based on repeating ($N = 1000$) the two-step regression-amplitude calculation listed above after substituting a randomly selected 32-yr Gaussian time series for the observed Niño-3.4 time series.

It is very important to recognize here that, because the regression-amplitude time series is defined based on the original index, the expected correlation between these two under the null hypothesis is not zero. In fact, we calculated the expected null-hypothesis value to be 0.44 in the case of the 32 DJF periods considered here. Thus, correlations that are perhaps high enough to be mistakenly interpreted as meaningful ones (if their statistical significance is not appropriately calculated) will often be seen in this case even when there is zero connection between the index and field. We find that the full 32-yr correlation between the Niño-3.4 regression amplitudes and original Niño-3.4 index is somewhat higher than the null-hypothesis expected value, but when the four OLR El Niño years are omitted and the correlation between the same two time series (based on the same full-period regression pattern) is calculated over the other 28 yr, the observed value is less than should be expected based on chance alone, even after accounting for the fact that the years with the four largest index values are the ones omitted from the final correlation calculation. Similarly, when the correlation is computed over just the years with negative DJF Niño-3.4 values, we find that the observed result is worse than would be expected if we just picked an index at random. This is not a useful way to model the ENSO–North American land surface temperature associations.

We also repeated the suggested two-step analysis as described above, except this time using the LH15 index. The primary result is qualitatively the same as in the Niño-3.4 case, in that the linear relationship (correlation) between the regression-amplitude time series and LH15 index over the 28 yr that do not include the four OLR El Niño events is weaker (has lower correlation amplitude) than should be expected based on randomness alone.

The results of these additional exercises confirm that the linear regression model is inconsistent, at standard confidence intervals, with the observed wintertime temperature associations. Knowing this, it is difficult to see how the regression model is very useful in this situation.

## 4. Discussion and conclusions

Recently LH15 have chosen a linear regression analysis approach to investigate the seasonal weather statistically associated with ENSO, which implicitly assumes that El Niño and La Niña associations have the same pattern, just different sign. They are clearly aware of the limitations of taking such an idealized perspective, but claim that this model of ENSO and seasonal weather anomalies is sufficiently encompassing to enable a useful investigation.

We disagree with the assertion of LH15, based on our atmospheric circulation and land surface temperature

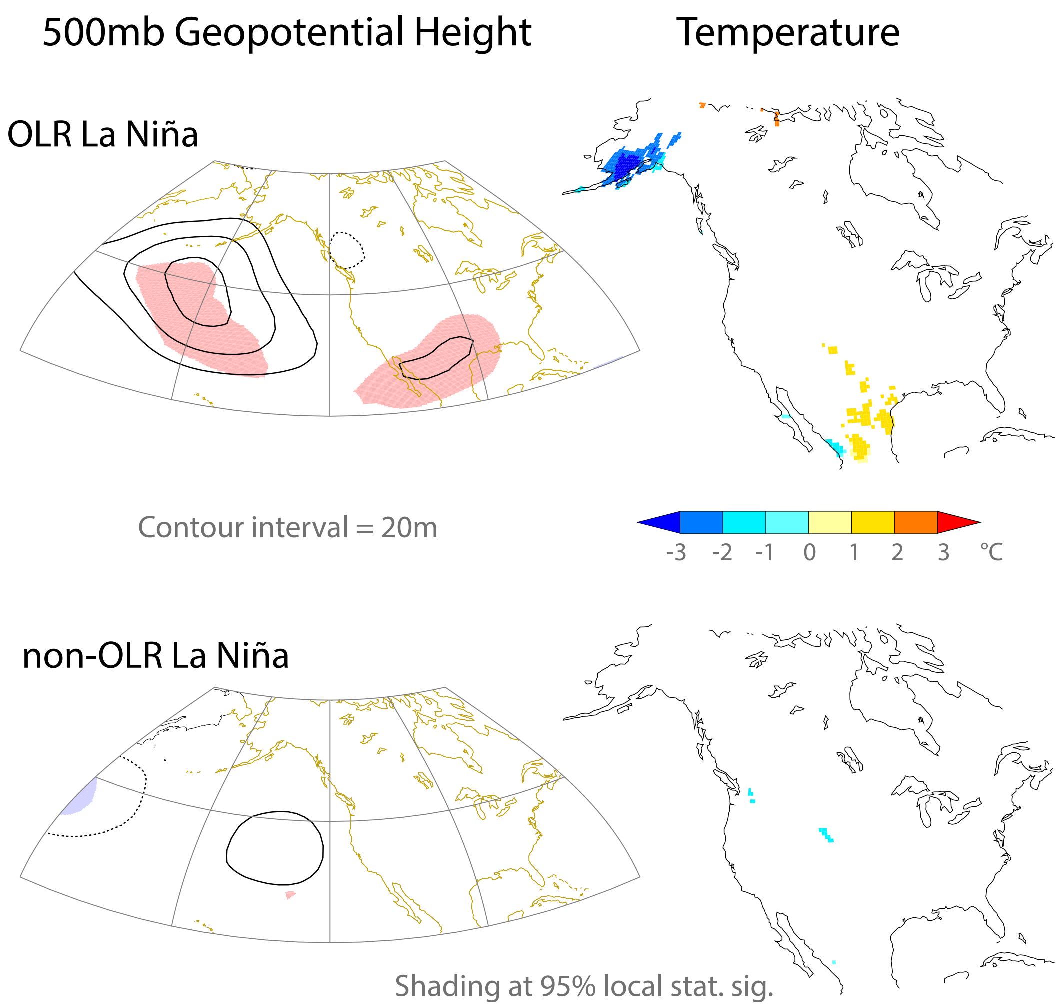


FIG. A1. (top) The OLR La Niña wintertime (left) 500-mb geopotential height and (right) temperature anomaly composites repeated from Figs. 1 and 2, respectively, for comparison purposes. (bottom) The corresponding non-OLR La Niña wintertime anomalies.

composite results and the demonstration that the statistically significant results yielded by their linear approach in this case are overwhelmingly contributed by just the four OLR El Niño years. Further, the La Niña associations are different enough from the OLR El Niño composite that the regression model approach yields a La Niña result that is inconsistent with the observed La Niña average.

Often a linearization offers a useful first look at weather or climate phenomena, but our results suggest that this is not the case for ENSO–North American seasonal weather associations. Further investigation of the reviewer-suggested two-step linearization approach (i.e., first correlate–regress an index with a field, then project the regression pattern back on the field to generate a second time series that correlates with the first) has revealed how linear relationships (e.g., correlations up to ~0.5) are easily generated in this case, without meaningful representation in the actual observations. The presentation of results from the suggested approaches without careful calculation of their statistical significance is potentially misleading and should be avoided.

Instead, identifying which are the El Niño and La Niña event years that will contribute significantly to the familiar weather associations appears to be key to issuing reliable ENSO-type seasonal weather forecasts. We have offered statistical methods that do this usefully over the time for which satellite-based OLR is available, in the sense that the vast majority (all but one) of the OLR El Niño years and OLR La Niña years are identifiable by OLR measurements available before the end of fall of ENSO year 0 (in time to be useful to winter forecasts). Whether or not OLR can be skillfully predicted at longer lead is yet unknown. ENSO statistics

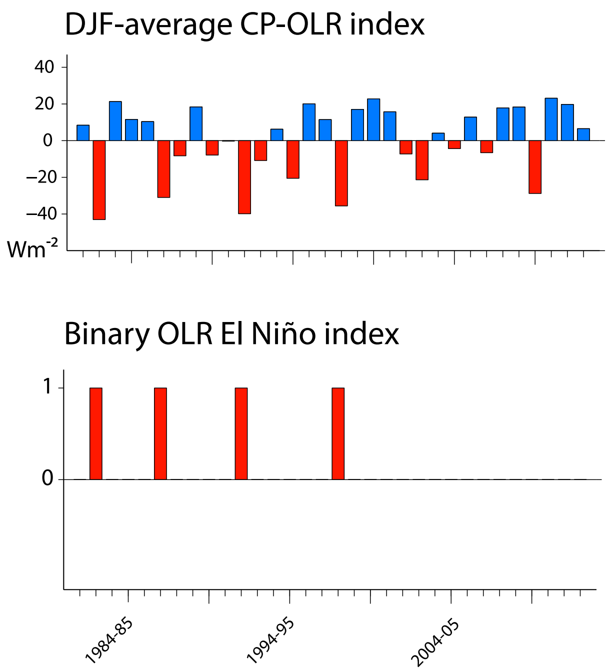


FIG. A2. (top) The DJF-average CP-OLR index, and (bottom) an idealized binary index with 1's in the OLR El Niño years of 1982/83, 1986/87, 1991/92, and 1997/98, and 0's in all other years.

also can change substantially from one multidecadal period to the next (e.g., Harrison and Chiodi 2015). Thus, the dynamical links between the tropical Pacific's coupled-anomaly state, its expression in OLR, and its influence on atmospheric conditions elsewhere, deserve further consideration. We have shown that the composite tropical Pacific OLR conditions associated with the identified OLR El Niño events have statistically significant anomalies that span the entire Pacific Ocean basin, and that the OLR La Niña events have substantial differences in amplitude and pattern from the El Niño case (Chiodi and Harrison 2015a) but there is more to be studied about which aspects of ENSO-associated atmospheric heating determine the character of its influence on North American seasonal weather anomalies, and how atmospheric heating anomalies are related to underlying surface conditions.

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## APPENDIX

### Ancillary Figures

Figure A1 compares the wintertime 500-mb geopotential height anomaly composite and wintertime temperature anomaly composite based on the OLR La Niña years with those based on the non-OLR La Niña years. Most of the statistically significant anomalies are associated with the OLR La Niña years.

Figure A2 shows two of the time series used in the correlation exercise described in section 3c. The first (Fig. A2, top) shows the wintertime-averaged OLR index of LH15. The second (Fig. A2, bottom) binary time series has a value of 1 in the four OLR El Niño years and a value of 0 otherwise. This binary case amounts to expecting the OLR El Niño composite in the OLR El Niño years and randomness in the other years (in which case, the climatological average is the appropriate prediction). The binary index produces a better correlation with wintertime surface temperature than the LH15 index.

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