Collaborative Research: Towards predicting persistent drought conditions associated with consecutive La Niña years

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Results and Accomplishments

One out of two La Niña events lasts 2 years or longer, a feature that has been challenging to predict and could be responsible for multi-year droughts over southern tier of the United States. Our project produced new understanding of the dynamics, predictability, and impacts of persistent drought associated with these multi-year La Niña events. Below is a summary of the activities performed throughout the duration of our 3-year project:

Activity 1: Dynamics of 2-year La Niña

We studied the dynamics of 2-year La Niña events using the Community Climate System Model Version 4 (CCSM4,), a computer model developed at the National Center for Atmospheric Research, capable of simulating 2-year La Niña with great fidelity (Fig. 1).

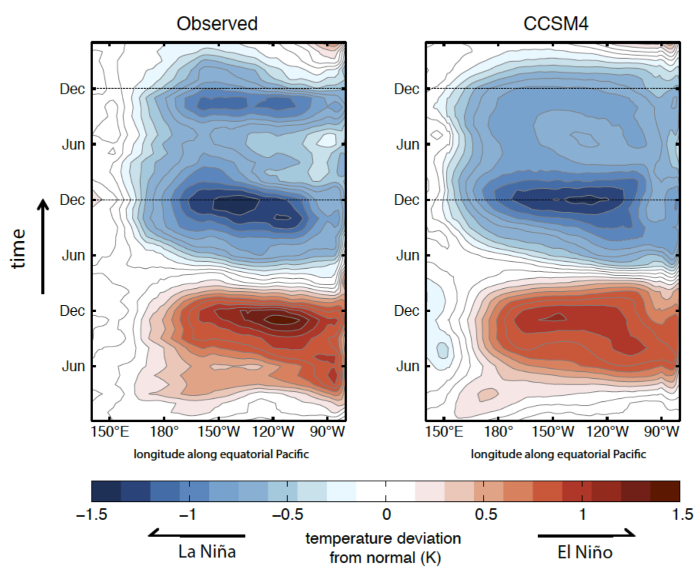

Figure 1 – Observed and simulated evolution of La Nina. Sea-surface temperature (SST) anomalies along the equator during a composite La Niña event in observations (left) and CCSM4 control simulation (right). CCSM4 reproduces the tendency for La Nina to be preceded by El Nino and persist into a second year. From DiNezio and Deser (2014).

Longstanding theories predict that La Niña develops when the equatorial thermocline rises closer to the ocean's surface, allowing cold waters to be mixed upwards cooling the ocean's surface. Conversely, La Niña decays when the thermocline returns to deeper depths, allowing the surface to warm up. In DiNezio and Deser (2014) we showed that a deepening thermocline is less effective at influencing SSTs compared to a shoaling thermocline. This asymmetry is more pronounced when strong El Niño events precede La Niña events, leading to their multi-year persistence. We found that the strength of the second year La Niña is correlated with the depth of thermocline before the onset of the first year La Niña. These results are key to our project because they suggest that the return of La Niña, and hence its duration, could be skillfully predicted up to 18 months in advance.

Activity 2: Predictability of 2-year La Niña

The previous results motivated us to explore the predictability of 2-year La Niña in more depth. In this task we used the Community Earth System Model V1 (CESM1), which like CCSM4, simulates very realistic 2-year La Niña. Since the magnitude of initial thermocline shoaling is linked to the amplitude of previous El Nino, we also explored whether skillful predictions could be performed when the forecasts are initialized at the peak of El Niño. These forecasts would have a lead-times of 24 months and were motivated by the possibility that the record-breaking 2015-16 El Niño event would lead to a 2-year La Niña.

In DiNezio et al. (2017a) we showed that skillful predictions of 2-year La Niña could be achieved initializing our model at the peak of a preceding strong or moderate El Niño. We selected 3 El Niño events from a long control simulation and used them as surrogates for nature. For each case we performed 20 forecasts, each one initialized from the same ocean state taken from the control simulation, but with slightly different atmospheric conditions. These "perfect model" forecasts allow the estimation of the maximum potential predictive skill of CESM1. Our results confirm that strong El Niño events drive initial conditions that lead to highly skillful predictions of 2-year La Niña events (Fig. 2).

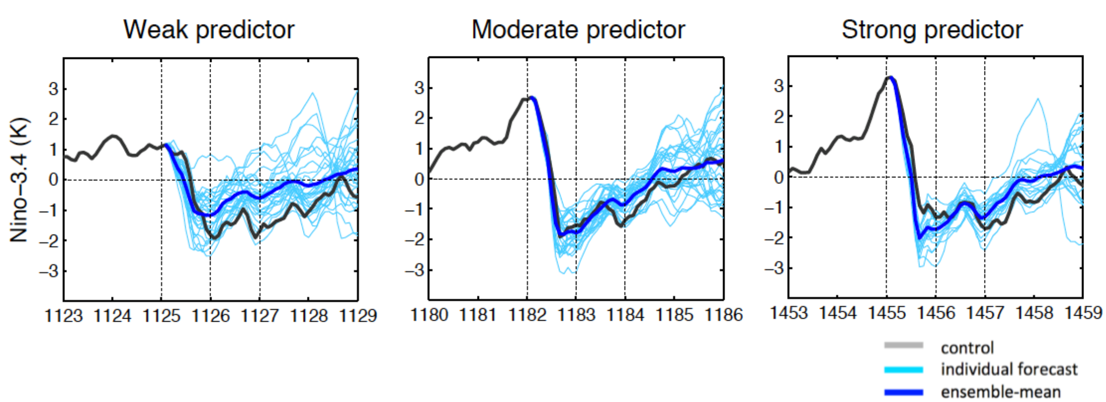

Figure 2 –Prediction plumes of Nino-3.4 index for three La Nina events simulated by CESM1. The Nino-3.4 index in the control simulation is shown in gray. All forecasts are initialized at the peak of the previous El Niño. The ensemble-mean forecast is shown in dark blue. The individual forecasts with perturbed atmospheric initial conditions are shown in light blue. Adapted from DiNezio et al. (2017).

To further understand the factors affecting the duration of individual La Niña events, we have also performed a diagnostic analysis of the CESM1 and CCSM4 control simulations, as well as a suite of observational data. The analysis shows that the amplitude of the preceding El Niño is indeed one of the leading factors controlling the duration of La Niña and that 2-year La Niña events become more frequent during decades of enhanced interannual ENSO variability (Okumura et al. 2017a). Besides the amplitude of the preceding El Niño, SST variability over the tropical Atlantic and Indian Oceans appears to affect the evolution of La Niña by modulating the inter-basin SST gradient and surface winds over the western Pacific. We are currently refining the analysis in preparation for a manuscript.

Activity 3: Predictions of the current La Niña

In DiNezio et al. (2017a) we showed that 2-year La Niña events could be skillfully predicted in a "perfect model" world, i.e. in the absence of uncertainty in the oceanic initial conditions, model drift, or initialization shocks. While not initially proposed in our project, we also explored the prediction of La Niña under realistic conditions using an experimental suite of decadal forecasts performed at NCAR. These forecasts were generated with the same CESM1 computer code used in our idealized forecasts described in Activity 2. The results presented in DiNezio et al. (2017b) show that CESM1 is capable of predicting the duration of La Niña events observed in nature when they are preceded by strong and moderate El Niño.

CESM1 forecasts initialized in November 2015, at the peak of one of the strongest El Nino on record, predicted a subsequent 2-year La Niña extending into the current boreal winter of 2017/18. Similar to other past 2-year events, the ensemble-mean Niño-3.4 SST index shows the onset of La Niña one year after the peak of El Niño, along with its return for a second year (Fig. 3). The predictions for the current event (Fig. 3a) show striking differences in the consistency of the predicted evolution of La Niña relative to the event initiated by the 1997 El Niño (Fig. 3d), which was a record breaking event at the time. CESM1 produced a consistent forecast of the second peak in NDJ of 1999, with 38 out of 40 members, a 95% probability of 2-year La Niña. In contrast, 24 out of 40 members, a 60% chance, predicted the return of La Niña for the current boreal winter, NDJ 2017 (Fig. 3, histograms). Despite this difference, both forecasts provided a low probability of a returning El Niño (0% and 7.5% chance respectively).

In sum, our results indicate a probability of La Niña returning this winter ranging from 60%, based on the CESM1 forecast initialized in November 2015, to 80%, based on an analysis of observed and simulated statistical predictors (DiNezio et al. 2017b). The CESM1 forecasts indicate that, due to the rather weak ensemble-mean signal, whether the tropical Pacific reaches La Niña conditions this winter is also be sensitive to the influence of stochastic variability. We will explore this question, as well as additional sources of predictability during the next phase of our project.

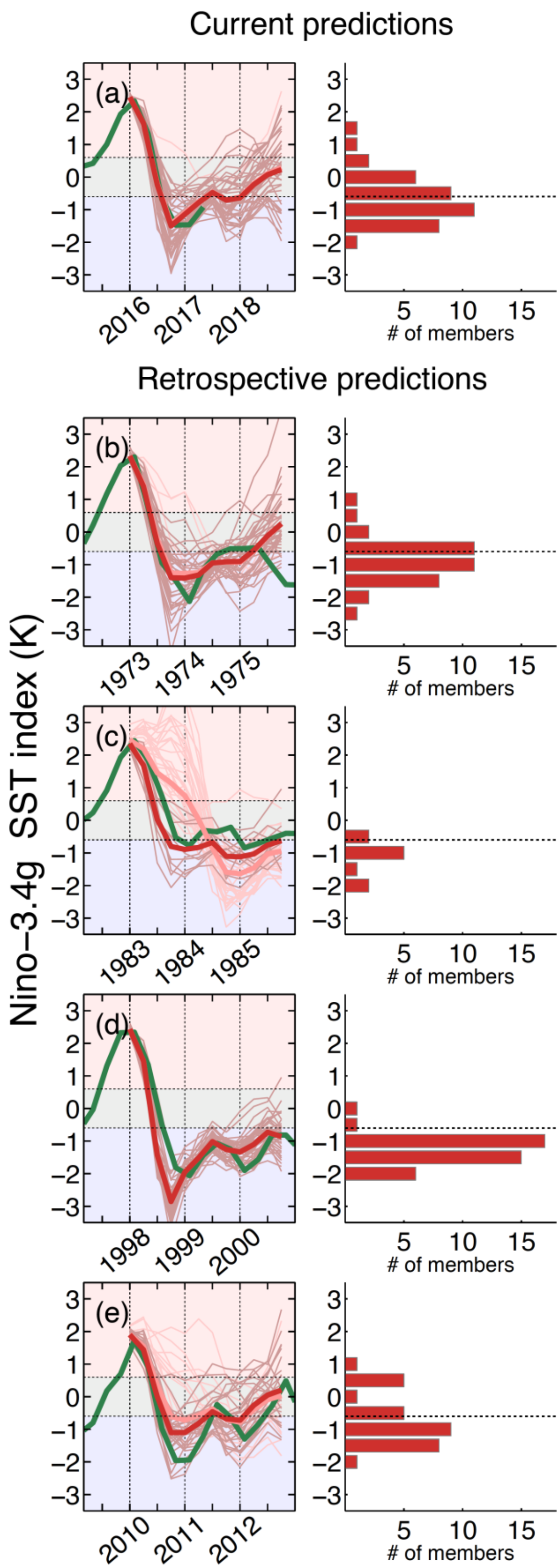

Figure 3 – Predicted and observed Niño-3.4 gradient SST index following the peak of moderate and strong El Niño events. Red thick lines are the ensemble-mean indices predicted by CESM1. Light colored thin lines are indices predicted by each individual member. Top panel shows the predictions initialized in Nov 2015, at the peak of the El Niño preceding the current La Niña. Lower four panels show retrospective forecasts for previous La Niña events. Solid green curves are the observed indices corresponding to each event. The observed indices are computed averaging data from the available datasets (ERSST3b, ERSST4 and HadISST1).

Activity 4: Drought impacts of 2-year La Niña events

We completed the analysis of observed climate impacts of 2-year La Niña. The interannual cooling of the equatorial Pacific associated with La Niña events has been known to cause wintertime precipitation deficit over the southern US by displacing the subtropical jet and storm track northward. To investigate the impacts of multi-year La Niña events on the extent and persistency of drought in the US, a suite of observational data is analyzed for the past century. Composite analyses based on 10 multi-year La Niña events reveal distinct seasonal evolution of oceanic and atmospheric anomalies during the course of events. The equatorial Pacific cooling associated with La Nina typically weakens from the first to the second year. Wintertime precipitation anomalies over the US, however, remain of similar magnitude and the region of reduced precipitation shifts northeastward in the second year (Fig. 4). Atmospheric circulation anomalies over the North Pacific become even stronger in the second winter. These features are robust across different datasets and compositing periods. This paradox is caused by subtle changes in the pattern of tropical Pacific cooling. During the second winter, the tropical Pacific cooling weakens in a narrow band along the equator but becomes meridionally broader. The broader cooling appears more effective at influencing the large-scale atmospheric circulation. This result has a broader implication and may help to understand the differing patterns of atmospheric teleconnections between the ENSO and Pacific decadal variability.

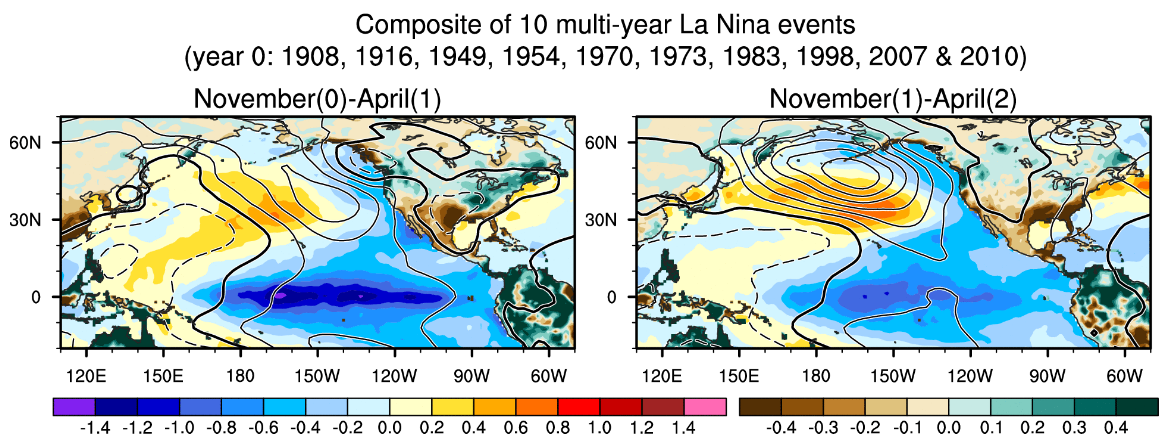

Figure 4 – Climate impacts of 2-yr La Niña. Observed ocean-atmosphere anomaly patterns during the first and second winters of a composite 2-year La Niña event. Sea surface temperature (shading over the ocean, °C), terrestrial precipitation (shading over land, mm day-1), and sea level pressure (contours at intervals of 0.5 hPa) anomalies are composited for November-April of 10 multi-year La Niña events during 1901-2012.

Activity 5: Uncertainty in ENSO teleconnections due to internal atmospheric variability

We also investigated the uncertainty in pattern and amplitude of ENSO teleconnections to the Northern Hemisphere (NH) in winter (December-February), using a combined observational and modeling approach. Although the study did not focus on La Niña per se, the results have broad implications for the predictability of ENSO teleconnections during the cold phase of ENSO. In particular, we found that even with nearly 100 years of observational data comprising 18 El Niño and 14 La Niña events, the observed extra-tropical NH sea level pressure (SLP) response to ENSO in is subject to considerable uncertainty. While the observed SLP composite shows a robust ENSO response over the North Pacific and North America that is statistically significant (different from zero), its amplitude is uncertain by approximately a factor of two. Other regions, such as the Arctic, North Atlantic and Europe, show a larger range of uncertainty in both pattern and amplitude. The uncertainty in the observational target poses considerable challenges for the evaluation of ENSO teleconnections in models. We demonstrated an approach for evaluating ENSO teleconnections in models that allows for discrimination between true model biases in the forced response to ENSO and apparent model biases that arise from limited sampling of internal variability unrelated to ENSO. The results are published in Deser et al. (2017).

Highlights of accomplishments:

- Formulated a new mechanism governing the dynamics of 2-year La Niña events (DiNezio and Deser 2014).
- Thermocline depth anomalies prior to the onset of La Niña are significantly correlated to the magnitude of Nino-3.4 index 18 months later. This predictor could be used to forecast the return of La Niña with an 18-month lead-time (DiNezio and Deser 2014, Okumura et al. 2017a).
- CESM1 has high skill predicting the return of La Niña in cases where the preceding El Niño and attendant thermocline shoaling have large amplitudes (DiNezio et al. 2017a).
- CESM1 replicates this skill in a suite of retrospective forecasts initialized in November at the peak of El Niño events observed since 1954. This retrospective skill is high for 2-year Niña events following the strong El Niño (DiNezio et al. 2017b).
- Forecasts initialized in November 2015, at the peak of the recent record-breaking El Niño event, predict 2-year La Niña with a probability of 60%. Therefore returning La Niña conditions the current boreal winter could have been predicted 2 years in advance (DiNezio et al. 2017b).
- Multi-year La Niña cause persistent drought conditions over the southern tier of the US. The broad tropical Pacific cooling during the second year leads to widespread drought impacts over the southern US despite weakened equatorial cooling (Okumura et al. 2017b).
- ENSO teleconnections to the NH extra-tropics are subject to considerable uncertainty due to internal variability. This means that even with a perfect model forecast of La Niña, the climate impacts driven by the atmospheric circulation response to La Niña will be less predictable (Deser et al. 2017).

Publications from the Project

1. Deser, C., I. R. Simpson, K. A. McKinnon and A. S. Phillips, 2017: The Northern Hemisphere extra-tropical atmospheric circulation response to ENSO: How well do we know it and how do we evaluate models accordingly? J. Climate, 30(13), 5059-5082.
2. DiNezio, P. N., and C. Deser, 2014: Nonlinear controls on the persistence of La Nina. J. Climate 27, 7335–7355.
3. DiNezio P. N., C. Deser, Y. Okumura, and A. Karspeck, 2017a: Predictability of 2-year La Niña events in a coupled general circulation model. Climate Dynamics. doi:10.1007/s00382-017-3575-3.
4. DiNezio P. N., C. Deser, A. Karspeck, S. Yeager, J. Caron, N. Rosenbloom, Y. Okumura, G. Danabasoglu, G. Meehl, 2017b: A 2 Year Forecast for a 60–80% Chance of La Niña in 2017–2018. Geophys. Res. Lett. 44, https://doi.org/10.1002/2017GL074904.
5. Okumura, Y. M., T. Sun, and X. Wu, 2017a: Asymmetric modulation of El Niño and La Niña and the linkage to tropical Pacific decadal variability. J. Climate, http://dx.doi.org/10.1175/JCLI-D-16-0680.1.
6. Okumura, Y. M., P. DiNezio, and C. Deser, 2017b: Evolving Impacts of Multiyear La Niña Events on Atmospheric Circulation and U.S. Drought. Geophys. Res. Lett. 44, https://doi.org/10.1002/2017GL075034.

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