Final Report

Collaborative Research: Toward operational predictions of persistent drought driven by multi-year La Niña

Lead PI: Clara Deser

Reporting Period: 09/01/2017 - 09/30/2020
Grant #: NA17OAR4310145

Accomplishments

Atmospheric teleconnection associated with the El Niño-Southern Oscillation (ENSO) is one of the leading causes of climate variability over the US. Long-lasting ENSO events can prolong climate anomalies and exacerbate the climate impact. In particular, multiyear La Niña events often lead to persistent droughts over the southern tier of the US, causing significant socioeconomic damage (Okumura et al. 2017b). Therefore, it is critical to predict the occurrence of multi-year ENSO events well in advance to mitigate the climate impact. However, the current operational ENSO predictions are limited to 12 months of lead times, precluding the predictions of multi-year events. The major goal of this project was to assess the multi-year predictability of ENSO and its climate impact. To this end, we first conducted a comprehensive diagnostic study of observational data and long climate model simulations to understand the dynamical processes controlling the duration of individual ENSO events. We also evaluated the uncertainties of ENSO teleconnections over North America during boreal winter using long observational data. Secondly, we tested potential multi-year predictability of the ENSO event duration through idealized climate model experiments. Finally, we tested multi-year predictability of the ENSO event duration in the real world by conducting a suite of hindcast experiments for the period of 1954-2015. For this project, we mainly used the Community Earth System Model version 1 (CESM1), which is one of the best models in simulating the observed ENSO based on the metrics developed by the Pacific Region Panel of the CLIVAR Project (https://pcmdi.llnl.gov/pmp-preliminary-results/interactive_plot/portrait_plot/enso_metric/enso_metrics_interactive_portrait_plots_v20200720.html).

<u>What was accomplished under these goals?</u>

Mechanisms controlling the duration of ENSO events

To understand the dynamical processes affecting the duration of both El Niño and La Niña events, we conducted a comprehensive diagnostic study using a suite of observational datasets and long preindustrial control simulations performed with CESM1 (Wu et al. 2019; Figs. 1 and 2). The duration of La Niña was found to be strongly influenced by the amplitude of preceding El Niño in both observations and models, consistent with our previous studies (DiNezio et al. 2017a; Okumura et al. 2017a). The duration of El Niño, on the other hand, is primarily affected by the timing of onset. In addition to oceanic adjustments within the tropical Pacific, interactions with the tropical Indian and Atlantic Oceans through the atmospheric bridge were shown to play a critical role in determining the evolution of ENSO events. La Niña preceded by strong El Niño almost certainly lasts two years or longer, and El Niño developing before early boreal summer typically terminates after one year. However, the duration of other events varies considerably from event to event. Our analysis identified several additional factors affecting the ENSO event duration, including tropical Atlantic and Indian Ocean variability unrelated to the ENSO and the North Pacific meridional mode.

Potential predictability of El Niño duration

To test the potential predictability of El Niño duration based on the onset timing, we performed perfect model experiments with CESM1 (Wu et al. 2020; Fig. 3). We selected two (one) El Niño events that onset in April (September) from the CESM1 control simulation and conducted 30-member ensemble forecast experiment for each case by initializing the model with the same oceanic conditions in the onset month. In agreement with the diagnostic study, the April-initialized experiments consistently predicts termination of El Niño in the second year, whereas the September-initialized experiment predicts continuation of El Niño through the second year, albeit with a large ensemble spread. Together with our previous perfect model study for La Niña (DiNezio et al. 2017a), this result indicates potential multi-year predictability of the ENSO event duration.

Multi-year predictability of ENSO event duration during 1954-2015

Our pilot study using CESM1 indicated that some observed multi-year La Niña events preceded by strong El Niño could be predicted up to two years in advance (DiNezio et al. 2017b). We have significantly expanded this study to explore the multi-year predictability of both El Niño and La Niña duration during 1954-2015 (Wu et al. 2021; Figs. 4 and 5). We made use of existing CESM1 Decadal Prediction Large Ensemble that consists of 40-member decadal forecasts initialized on every November 1st during 1954-2015 and generated two additional ensembles of 2-year forecasts initialized on March and June 1st (20 and 10 members, respectively). Analysis of these forecast ensembles shows that the duration of both El Niño and La Niña events are predictable with lead times ranging from 13 to 25 months, greater than the maximum lead time of the current operational ENSO forecasts. In particular, multiyear La Niña events preceded by strong El Niño are highly predictable with 2-year lead times. This result indicates the feasibility of extending the current operational ENSO forecasts by one additional year.

Other significant accomplishments

<u>What opportunities for training and professional development has the project provided?</u>

The project supported two female graduate students at UT Austin (Xian Wu and Tianyi Sun). Both students have successfully defended PhD dissertations and moved onto postdoc positions. In particular, Xian Wu, who was mainly supported by this grant, was awarded a prestigious NCAR ASP Postdoctoral Fellowship in recognition of her research accomplishments. Both Wu and Sun received Outstanding Student Presentation Awards at major national conferences. The project also provided opportunities for professional development of two early-mid career scientists (Okumura and DiNezio) and helped them to develop mentoring skills.

<u>How were the results disseminated to communities of interest?</u>

The results from the project were disseminated to the climate research communities through journal publications and conference presentations. Our research was also featured in the news media, including the Washington Post and the NOAA Climate Program Office News (please see #32 Other Product for links to these articles).

Publications, conference papers, and presentations

Publications

Power, S., and Coauthors (include Y. Okumura), 2021: A review of decadal climate variability in the tropical Pacific: Characteristics, causes, predictability and prospects. Science, in revision.

Wu, X., Y. M. Okumura, C. Deser, and P. DiNezio, 2021: Two-year dynamical predictions of ENSO event duration during 1954-2015. J. Climate, revised.

Capotondi, A., C. Deser, A. Phillip, Y. Okumura, and S. Larson, 2020: ENSO and Pacific decadal variability in CESM2. Journal of Advances in Modeling Earth Systems, 12, doi: 10.1029/2019MS002022.

An, S.-I., E. Tziperman, Y. Okumura, and T. Li, 2020: ENSO irregularity and asymmetry. El Niño-Southern Oscillation in a Changing Climate, Geophysical Monograph, No. 253, American Geophysical Union, 153-172, doi: 10.1002/9781119548164.ch7. Fedorov, A., S. Hu, A. Wittenberg, A. Levine and C. Deser, 2020: ENSO low-frequency modulations and mean state interactions. El Niño-Southern Oscillation in a Changing Climate, Geophysical Monograph, No. 253, American Geophysical Union, 173-198, doi: 10.1002/9781119548164.ch8.

Wu, X., Y. M. Okumura, and P. DiNezio, 2020: Predictability of El Niño duration based on the onset timing. J. Climate, doi: 10.1175/JCLI-D-19-0963.1.

Sun, T., and Y. M. Okumura, 2020: Impact of ENSO-like tropical Pacific decadal variability on the relative frequency of El Niño and La Niña events. Geophysical Research Letters, 47, doi: 10.1029/2019GL085832.

Okumura, Y. M., 2019: ENSO diversity from an atmospheric perspective. Current Climate Change Reports, 5, 245-257, doi: 10.1007/s40641-019-00138-7.

Wu, X., Y. Okumura, and P. DiNezio, 2019: What controls the duration of El Niño and La Niña events? J. Climate, 32, 5941-5965, doi: 10.1175/JCLI-D-18-0681.1.

Deser, C., I. R. Simpson, A. S. Phillips and K. A. McKinnon, 2018: How well do we know ENSO's climate impacts over North America, and how do we evaluate models accordingly? J. Climate, 30, 4991-5014, doi: 10.1175/JCLI-D-17-0783.1. DiNezio, P. N., C. Deser, A. Karspeck, S. Yeager, Y. Okumura, G. Danabasoglu, N. Rosenbloom, J. Caron, and G. A. Meehl, 2017b: A 2 year forecast for a 60-80% chance of La Niña in 2017-2018. Geophysical Research Letters, 44, 11,624–11,635, doi: 10.1002/2017GL074904.

Publications from the previous MAPP-funded project cited in this report

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, 49, 4237–4261, doi: 10.1007/s00382-017-3575-3.

Okumura, Y. M., P. DiNezio, and C. Deser, 2017b: Evolving impacts of multi-year La Nin~a events on atmospheric circulation and US drought. Geophys. Res. Lett., 44, 11,614–11,623, doi: 10.1002/2017gl075034.

Okumura, Y. M., T. Sun, and X. Wu, 2017a: Asymmetric modulation of El Nin~o and La Nin~a and the linkage to tropical Pacific decadal variability. J. Climate, 30, 4705-4732, doi: 10.1175/jcli-d-16-0680.1.

Deser, C., I. R. Simpson, K. A. McKinnon and A. S. Phillips, 2017: The Northern Hemisphere extra-tropical atmospheric circulation

Other products

Press Releases/Media Coverage

The Washington Post, Capital Weather Gang, “Lingering La Nin~a may help forecasters spot costly weather patterns two years away”, December 10, 2020 (https://www.washingtonpost.com/weather/2020/12/10/la-nina-two-year-predictions/) NOAA Climate Program Office ENSO Blog, “More U.S. drought in a second-year La Nin~a?”, February 1, 2018
(https://www.climate.gov/news-features/blogs/enso/more-us-drought-second-year-la-niña)
Weather Underground Category 6, “U.S. drought risk rising as a second La Nin~a winter kicks in”, December 22, 2017
(https://www.wunderground.com/cat6/us-drought-risk-rising-second-la-nia-winter-kicks)
Environmental Monitor, “NCAR model gives U. of Texas researchers advanced tool for predicting La Nin~a drought impact”, December 14, 2017
(http://www.fondriest.com/news/ncar-model-gives-u-texas-researchers-advanced-tool-predicting-la-nina-drought impact.htm)
The Sacramento Bee, “Dry weather continues in California. Time to start worrying about another drought?”, December 12, 2017
(http://www.sacbee.com/news/state/california/water-and- drought/article189397799.html)
Water Deeply, “Second La Nin~a winter could extend drought across the west”, December 11, 2017
(https://www.newsdeeply.com/water/articles/2017/12/11/second-la-nina-winter-could-extend-drought-across-the-west) US CLIVAR Research Highlights, “Impact and predictability of multi-year La Nin~a events”, November 28, 2017
(https://usclivar.org/research-highlights/impact-and-predictability-multi-year-la-niña-events)
Austin’s NPR Station (KUT 90.5) interview on La Nin~a drought (Y. M. Okumura), November 16, 2017 NOAA Climate Program Office News, “Multi-year La Nin~a presents opportunity to predict drought impacts out to 2 years”, November 16, 2017
(http://cpo.noaa.gov/News/News-Article/ArtMID/6226/
ArticleID/1581/Multi-year-La-Ni241a-presents-opportunity-to-predict
drought-impacts-out-to-2-years)
UT News, “New research could predict La Nin~a drought years in advance”, November 16, 2017
(https://news.utexas.edu/2017/11/16/new-research-could-predict-la-ni-a-drought-years-in-advance)

Participants & other collaborating organizations

What individuals have worked on this project?

Yuko Okumura (PI, UT Austin)
Pedro DiNezio (co-PI, UT Austin)
Clara Deser (co-PI, NCAR)
Xian Wu (Graduate student, UT Austin)
Tianyi Sun (Graduate student, UT Austin)

Adam Phillips (Associate Scientist, NCAR)

<u>What other organizations have been involved as partners?</u>
UT Austin

<u>Have other collaborators or contacts been involved?</u>
Alicia Karspeck, Stephen Yeager, Gokhan Danabasoglu, Nan Rosenbloom, Julie Caron, and Gerald A. Meehl (all at NCAR)

<u>What was the impact on the development of the principal discipline(s) of the project?</u>
The project had a significant impact on the development of the climate dynamics discipline by uncovering the mechanisms controlling the duration of El Niño and La Niña events and by demonstrating the predictability of ENSO event duration with lead times of up to 2 years. Our studies contributed to an increased interest in multi-year climate predictions among the climate research and forecast communities, as demonstrated by the first Workshop on Societally-Relevant Multi-Year Climate Predictions planned for June 2-4, 2021 (https://usclivar.org/meetings/multi-year-workshop) and new CESM2 multi-year hindcasts being conducted by the CESM Earth System Prediction Working Group (https://www.cesm.ucar.edu/events/workshops/2020/files/espwg-co-chairs.pdf).

<u>What was the impact on other disciplines?</u>
The El Niño-Southern Oscillation (ENSO) phenomenon affects precipitation and temperature around the world and causes significant socioeconomic impacts, including agriculture, marine and terrestrial ecosystems, energy resources, and wild fire hazards. As long lasting ENSO events exacerbate the impacts, the predictability of such events has important implications to wide range of disciplines.

<u>What was the impact on the development of human resources?</u>
The project had an impact on the development of human resources by supporting two early-mid career scientists and training two graduate students. The project also helped to increase diversity in human resources by supporting two female scientists and two female graduate students.

<u>What was the impact on physical, institutional, and information resources that form infrastructure?</u>
The project helped early-mid career scientists (Okumura and DiNezio) develop mentoring skills.

<u>What was the impact on society beyond science and technology?</u>
Long-lasting ENSO events have significant socioeconomic impacts. The ability to predict the occurrence of such events well in advance is critical to mitigate the damage. The project provided dynamical basis for long-range ENSO forecasts and demonstrated the feasibility of operational multi-year ENSO forecasts.

What were the outcomes of the award?

Highlights of the outcomes of the award:

• Identified oceanic and atmospheric processes controlling the predictable and unpredictable components of ENSO event duration • Demonstrated potential predictability of the duration of El Niño events based on the onset timing

• Demonstrated predictability of the duration of both El Niño and La Niña events in the real world with lead times ranging from 13 to 25 months • Showed internal atmospheric circulation variability as a leading source of uncertainty in ENSO teleconnection and associated climate impact over North America

• Proposed a mechanism by which tropical Pacific decadal variability affects the relative frequency of El Niño and La Niña events

Supplemental Information for Section #29 of the Final Report for NA17OAR4310149 & NA17OAR4310145

Conference presentations/lectures

Okumura, Y. M., and T. Sun, "Tropical Pacific decadal variability and ENSO modulation: Role of stochastic atmospheric forcing from the extratropics", AGU Fall Meeting (online), December 2020 (invited)

Wu, X., Y. M. Okumura, C. Deser, and P. DiNezio, "Predicting the duration of El Niño and La Niña events during 1954-2015", AGU Fall Meeting (online), December 2020.

Wu, X., Y. M. Okumura, P. DiNezio, and C. Deser, "Duration of El Niño and La Niña events: Dynamics and multiyear predictability", AGU Fall Meeting (online), December 2020 (invited)

Okumura, Y. M., X. Wu, and P. DiNezio, "Two-year predictions of ENSO event duration during 1954-2015", CESM Climate Variability and Change Working Group Meeting (online), March 2020

Okumura, Y. M., and T. Sun, "Impact of ENSO-like tropical Pacific decadal variability on the relative frequency of El Niño and La Niña events", Ocean Science Meeting, San Diego, February 2020

Okumura, Y. M., and X. Wu, "Two-year predictions of ENSO event duration during 1954-2015", AGU Fall Meeting, San Francisco, December 2019

Wu, X., Y. M. Okumura, and P. DiNezio, "Predictability of El Niño duration based on the onset timing", AGU Fall Meeting, San Francisco, December 2019 (selected for an Outstanding Student Presentation Award).

Sun, T., and Y. M. Okumura, "Impact of ENSO-like tropical Pacific decadal variability on the relative frequency of El Niño and La Niña events", AGU Fall Meeting, San Francisco, December 2019

Okumura, Y. M., and T. Sun, "Decadal variability in the frequency and duration of El Niño and La Niña events and the linkage to tropical Pacific decadal variability", 2nd Tropical Pacific Decadal Variability Workshop, Paris, France, April 2019 (invited).

Okumura, Y. M., and T. Sun, "Decadal variability in the frequency and duration of El Niño and La Niña events: Comparison between CESM2 and CCSM4", CESM Climate Variability and Change Working Group Meeting, Boulder, February 2019

Wu, X., Y. M. Okumura, and P. DiNezio, "Predictability of El Niño duration in a coupled general circulation model", AMS 99th Annual Meeting, Phoenix, January 2019

Sun, T., and Y. M. Okumura, "Impact of stochastically forced tropical Pacific decadal variability on the El Niño-Southern Oscillation", AMS 99th Annual Meeting, Phoenix, January 2019 (selected for an Outstanding Oral Presentation Award)

Okumura, Y. M., and T. Sun, "Role of stochastic atmospheric forcing in tropical Pacific decadal variability and ENSO modulation", IV International Conference on El Niño Southern Oscillation, Guayaquil, Ecuador, October 2018 (invited)

Okumura, Y. M., and T. Sun, "Tropical Pacific decadal variability and ENSO decadal variability in CCSM4" and "Role of stochastic atmospheric forcing from the extratropical Pacific in tropical Pacific decadal variability and ENSO decadal variability in CCSM4", 1st Tropical Pacific decadal variability Workshop, San Pedro de Manglaralto, Ecuador, October 2018 (invited)

Deser, C., P. DiNezio, Y. Okumura et al., "Predicting multi-year La Niña events", 2nd International Conferences on Subseasonal to Decadal Prediction, Boulder, September 2018

DiNezio, P., "Bridging theory, observations, and models of the El Niño/Southern Oscillation", Natural Variability in the Pacific Summer School, Princeton University, August 2018 (invited)

DiNezio, P., "Asymmetries in the predictability of El Niño and La Niña: Implications for TPOS2020", TPOS2020 Workshop, Boulder, May, 2018 (invited)

DiNezio, P., "How early could the current La Niña have been predicted?" International Research Institute for Climate and Society, Columbia University, Palisades, April 2018 (invited)

Okumura, Y. M., X. Wu, and P. DiNezio, "What controls the duration of El Niño and La Niña events?", CESM Climate Variability and Change Working Group Meeting, Boulder, January 2018

Okumura, Y. M., "El Niño and La Niña: Asymmetries, impacts, and decadal variability", Institute for Geophysics Seminar, University of Texas at Austin, November 2017

Toward operational predictions of persistent drought driven by multiyear La Niña

Principle Investigators: Yuko M. Okumura[1], Pedro DiNezio[1,2], and Clara Deser[3]
[1] University of Texas at Austin Institute for Geophysics, [2] University of Colorado Boulder, [3] National Center for Atmospheric Research

Final Report for Grants # NA17OAR4310149 (UT) & NA17OAR4310145 (NCAR)

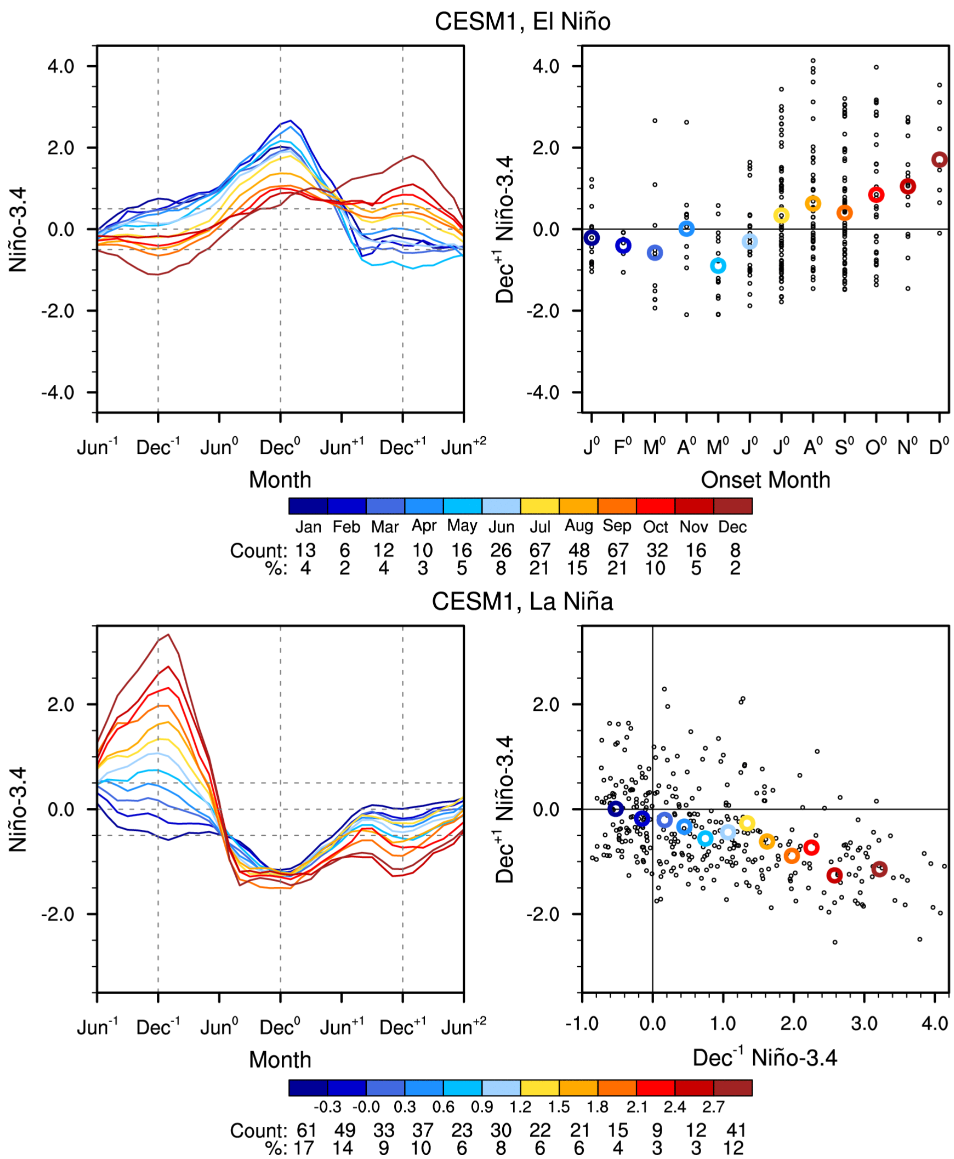

Figure 1. Primary factor affecting the duration of El Niño (onset timing) and La Niña (amplitude of preceding El Nino) in the CESM1 control simulation. (left) Time series of the Niño-3.4 index composited for (top) El Niño events categorized by onset month and (bottom) La Niña events categorized by the amplitude of the Dec^{-1} Niño-3.4 index. The colors of composite curves correspond to the categorization criteria shown on color bars. The numbers under the color bars indicate the count and percentage of composited events. (right) Scatterplot of the Dec^{+1} Niño-3.4 index vs (top) the onset month for El Niño events and (bottom) the Dec^{-1} Niño-3.4 index for La Niña events. Small black circles indicate individual events, and large colored circles represent composite events categorized as in (left). Adapted from Wu et al. (2019).

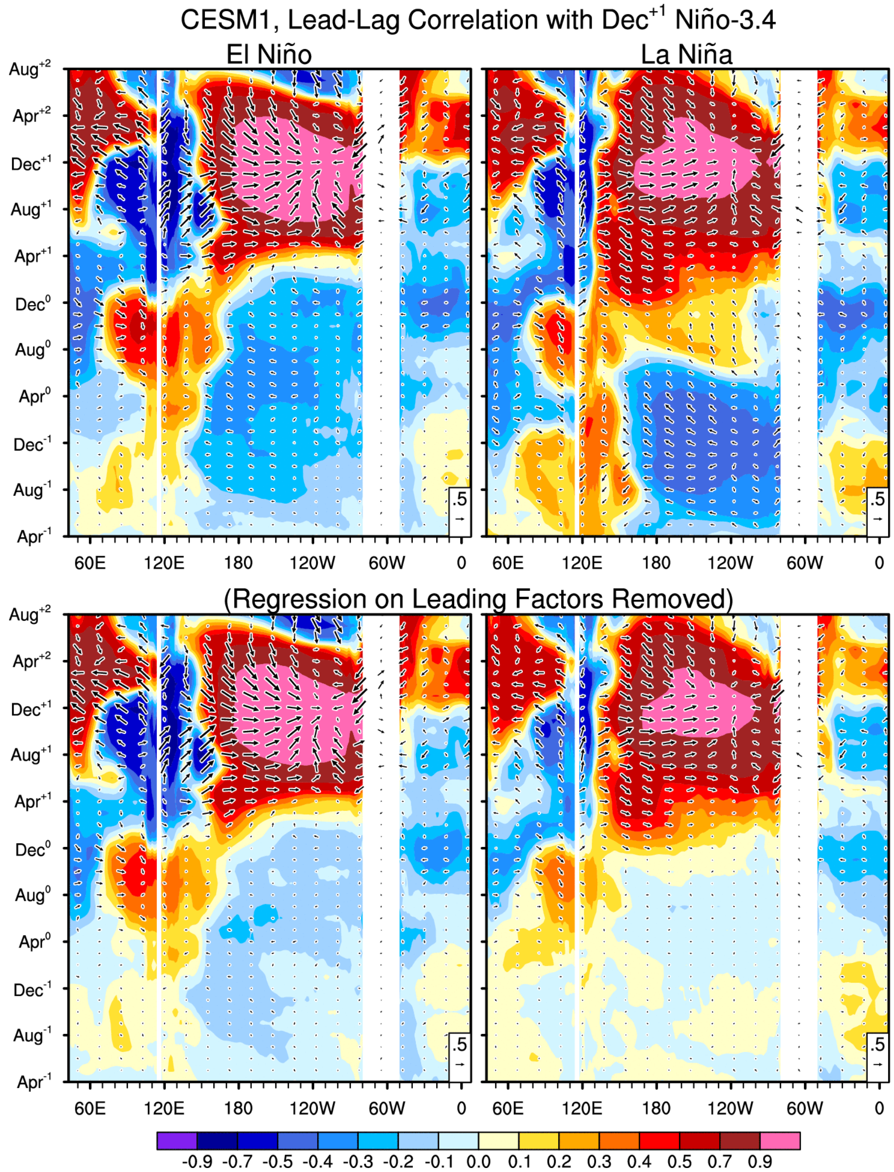

Figure 2. Additional factors affecting the duration of El Niño and La Niña events in the CESM1 control simulation. (top) Lead-lag correlations of the Dec^{+1} Niño-3.4 index with SST (°C; shading) and surface wind (m s-1; vectors) anomalies along the equator (3°S–3°N; 10°S-0° in the Indian Ocean) from Apr^{-1} to Aug^{+2} for (left) El Niño and (right) La Niña events. (bottom) Same as in (top), but linear regressions on the onset month for El Niño and the Dec^{-1} Niño-3.4 index for La Niña are removed from the Dec^{+1} Niño-3.4 index and equatorial SST and surface wind anomalies prior to the correlation analysis. The duration of both El Nino and La Nina are influenced by tropical Atlantic and Indian Ocean variability unrelated to the ENSO. Adopted from Wu et al. (2019).

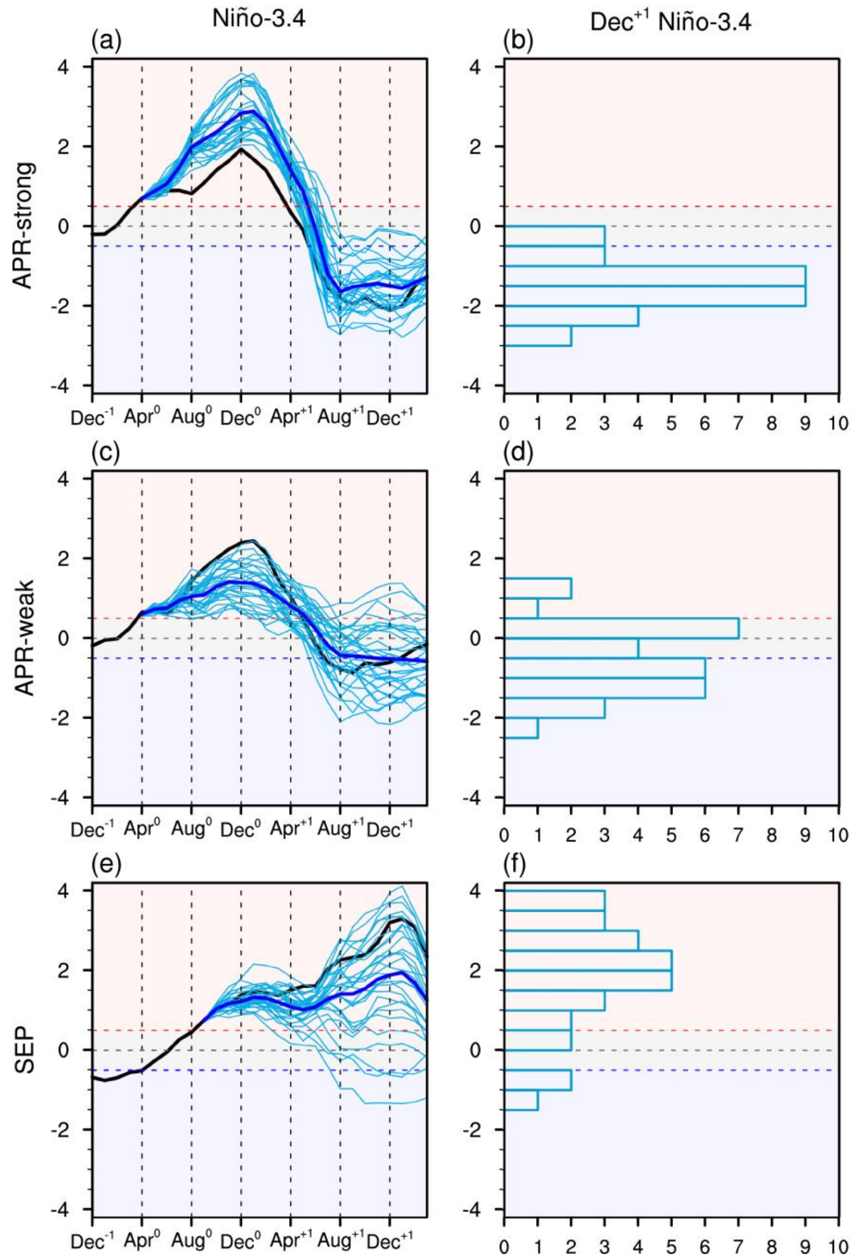

Figure 3. Perfect model forecasts of the El Niño event duration based on the CESM1 control simulation. (a),(c),(e) Time series of the Niño-3.4 index (°C) from the initialization month to Mar^{+2} and (b),(d),(f) histograms of the Dec^{+1} Niño-3.4 index (°C) in the (a),(b) APR-strong, (c),(d) APR-weak, and (e),(f) SEP ensembles. In (a), (c), and (e), the mean and individual members of the ensembles are indicated by thick blue and thin light blue curves, respectively. The time series of the Niño-3.4 index in the CESM1 control simulation are also shown by black curves. Each ensemble consists of 30-member forecasts initialized with the same oceanic condition in the onset month but with slightly different atmospheric conditions. The initial conditions are based on selected El Nino events that onset in April (APR-strong/weak ensembles) and September (SEP ensemble) in the control simulation. Adopted from Wu et al. (2020).

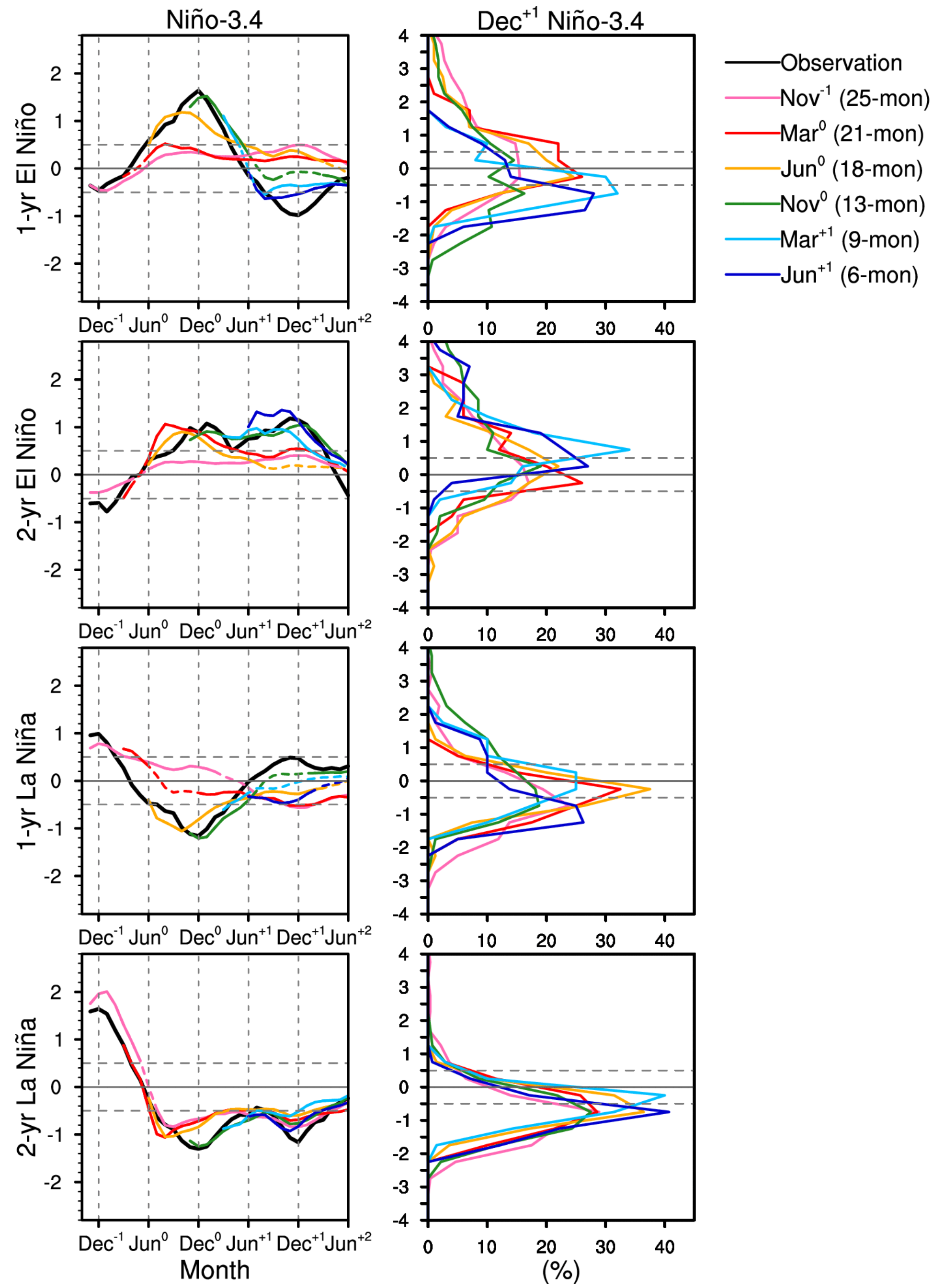

Figure 4. Predictions of the duration of observed El Niño and La Niña events during 1954-2015 using CESM1. (left) Time series of the Niño-3.4 index (°C) in observations (black curves) and ensemble-mean forecasts (colored curves) composited for all (first row) 1-yr El Niño, (second row) 2-yr El Niño, (third row) 1-yr La Niña and (fourth row) 2-yr La Niña events during 1954–2015. The forecasts are initialized in Nov^{-1} (pink), Mar^{0} (red), Jun^{0} (yellow), Nov^{0} (green), Mar^{+1} (light blue), and Jun^{+1} (dark blue), with lead times ranging from 25 (Nov^{-1}) to 6 (Jun^{+1}) months relative to Dec^{+1}. The solid colored curves indicate that the composite forecasts are significantly different from zero at the 95% confidence level. (right) Histograms of the Niño-3.4 index (°C) in Dec^{+1} constructed from all ensemble forecast members of all events that make up each composite, expressed as a percentage of the total number. Adopted from Wu et al. (2021).

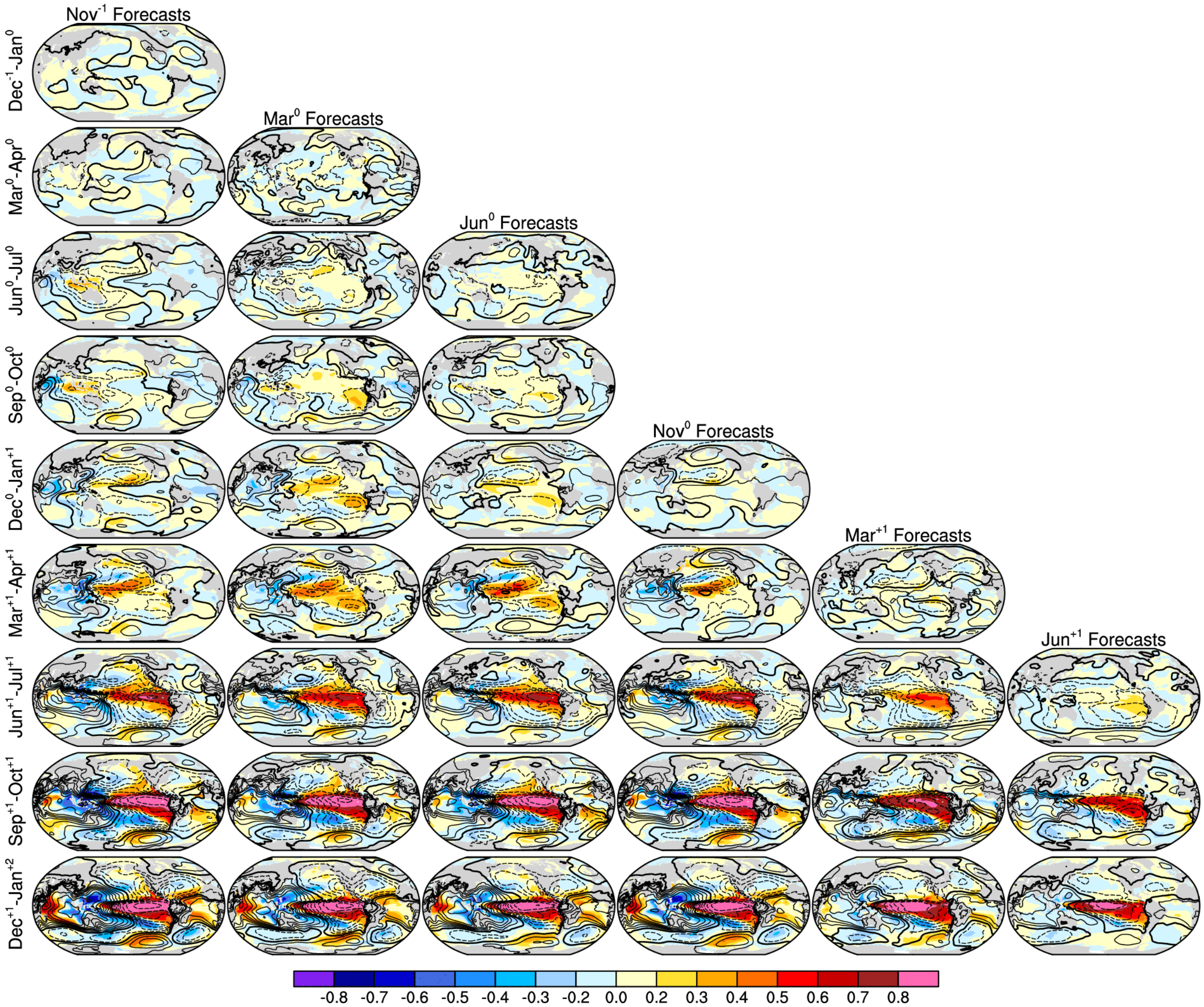

Figure 5. Origins of the forecast error of ENSO event duration in CESM1 ensemble forecasts during 1954-2015. Correlation maps of SST (color shading) and sea level pressure (contours at intervals of 0.1; zero contours thickened and negative contours dashed) anomalies with the Niño-3.4 index in Dec^{+1} from the CESM1 ensemble forecasts as a function of lead time [columns: (left) Nov^{-1} to (right) Jun^{+1} initialized forecasts] and verification time [rows: (top) Dec^{-1}–Jan^{0} to (bottom) Dec^{+1}–Jan^{+2}]. All members of the forecast ensembles for all El Niño and La Niña years are pooled together after removing the mean of each ensemble from the individual members of that ensemble. The forecast error growth originates mainly from atmospheric variability over the North Pacific in boreal winter. Adopted from Wu et al. (2021).