# Observing Systems Research Studies: Climate Phenomena and Impacts

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## 1.Project Summary

NOAA's ongoing investment in sustained observations of the global ocean is justified by its importance in documenting the characteristics of climate variability and change, improving scientific knowledge about climate variability and change, and improving awareness of the weather and climate anomalies associated with patterns of climate variability and change. The Observing System Research Studies group performs data and modeling studies to identify climatically significant ocean-atmosphere interaction patterns and indices that usefully characterize their amplitudes and their linkages to US and global weather and climate anomalies, with the goals of improving our awareness and understanding of present climate conditions, improving the effectiveness of the global observing system for climate, and helping to improve forecasts and projections of seasonal and longer term weather and climate anomalies. We also provide guidance about the specific activities required of the global climate observing system to meet its goals as well as work to help understand developing user needs. Often this involves estimating the uncertainty in our present ability to make statements of scientific and societal relevance with the historical ocean and climate data sets.

We also work with NOAA, US, international and intergovernmental ocean and climate organizations, (with particular focus on the Global Climate Observing System program, the Joint Commission on Oceanography and Marine Meteorology and the CLIVAR program), to develop and advance agreed international plans for the climate observing system, standards for making the observations and for sharing data among all interested parties, and for internationally coordinated activities to exploit the data collected, for the good of all nations.

This project does not collect any observations, but does make ocean and climate information available via the State of the Ocean website at PMEL, and collaboration with the Observing System Monitoring Center project led by Steve Hankin.

## 2. Scientific and Observing System Accomplishments

*Summary*

*We met most of the research and submission for journal review milestones of our FY12 work plan. We also met our goals for continued participation in national, international and intergovernmental climate observing, coordination and planning activities.*

*As projected in our FY12 work plan, group work has led to publication of a paper that defines a novel outgoing longwave radiation(OLR)-based El Niño index that identifies, in an operationally useful manner (without false alarm and prior to the strong wintertime U.S. impacts), the years in recent decades that have El Nino-like impacts on U.S. seasonal weather conditions, and unambiguously distinguishes them from the other years in record that are also identified by the commonly used definitions as "El Nino" but do not have these impacts.*

*Also as projected in our FY12 work plan, further work conducted over the previous year has also shown that the Chiodi and Harrison (2012) OLR-El Niño index will be directly useful to seasonal weather forecasting efforts not just over the U.S., but in other affected regions around the globe. This body of work has also been expanded to now include identification of a novel and operationally useful OLR-based index for La Niña that has a closer connection to seasonal weather anomalies than is available from the commonly used ENSO indices.*

*Because most of our climate forecasting skill at seasonal timescales derives from associations with the ENSO phenomenon, in addition to seeking to understand better how to identify and make use of these associations (as described above), we have also continued work to better understand and disseminate group research results about the roles that different classes of sub-seasonal tropical Pacific variability have in the development and maintenance of El Niño events and what this means for their predictability.*

*Also as projected in our FY12 work plan, our work has also revealed new information about the variability of the global carbon cycle. We have examined the prospects for reliably determining trends in the fraction of emitted $CO_2$ that remains airborne ("airborne fraction") from the available historical records. This has led to publication of a manuscript that shows that uncertainties associated with some of the lesser types of emissions currently prevent a reliable determination of the airborne fraction trend; even the sign is in doubt. This means previous claims that the airborne fraction is increasing, and even that decreases in ocean uptake are responsible, are alarmist at this point.*

*Also as projected in our FY12 work plan, group work has also carefully reexamined the historical emission and concentration records to provide stricter observational constraints about the atmospheric $CO_2$ changes that have taken place during each El Niño and La Niña event, as well as in the average. This improves upon our understanding of the impacts that El Niño and La Niña events have on the global carbon cycle and provides useful benchmarks for the ongoing development and evaluation of ocean-land-atmospheric models that resolve the global carbon cycle, which will be needed to better understand the processes responsible for the ENSO-$CO_2$ link and project future concentration levels.*

*Also as projected in our FY12 work plan, we have worked to understand better the risks of extrapolating from multi-decadal sub-segments of geophysical records to longer (e.g. centennial) periods (Chiodi and Harrison, 2012d). An aspect of this work takes a look at whether or not there is evidence for a centennial scale trend in ENSO.*

*We have contributed to outreach about climate variability and trends to the global oceanic fishery management community, emphasizing with examples the extent to which interannual to decadal variability will, in most places, dominate long term trends for the next couple of decades (Harrison and Carson, 2012).*

*We also have partnered with colleagues to better characterize a class of summertime rainfall events in Oregon and Washington that affects wildland fire management (Bond et al., 2012).*

*Budget cuts forced termination of our work to analyze the NLOM water level data to investigate the statistics of multi-decadal trend variability in these long tide gauge records. Should resources permit this work will be taken up again in FY13.*

*These contributions are described in more detail below. Additionally, our group partners with Steve Hankin's group to maintain and upgrade the State of the Ocean Climate website (http://stateoftheocean.osmc.noaa.gov) which gives an at-a-glance view of the amplitudes of (primarily surface, at present) ocean climate indices, along with estimates of their uncertainty, that can be linked to major patterns of climate variability. We do not maintain a web site for this research project.*

**Detailed Descriptions**

The El Niño-Southern Oscillation (ENSO) is a now well known pattern of climate variability that has gained notoriety outside of the scientific literature because the impacts that its warm (El Niño) and cool (La Niña) extremes have on seasonal weather conditions in the U.S., as well as in other affected regions around the world, forms the basis for skillful long-lead (a season or more) forecasts. But there is still more to learn about how tropical Pacific anomaly conditions influence weather over the U.S. Because some, but not all, of the years identified as ENSO years by the commonly used definitions have discernible impacts on U.S. weather, there is currently debate about how best to identify the tropical Pacific anomaly patterns that are most likely to influence weather conditions in the U.S. (and elsewhere). Amidst this debate, group work has shown that outgoing longwave radiation conditions in the eastern equatorial can be used to form an index for El Nino that has a closer connection to seasonal U.S. weather impacts than is available from the commonly used indices. Over the time for which OLR information is available (since the 1970s), this index distinguishes the group of El Nino events that have consistent and significant impacts on U.S. weather from the other years that do not. This is usually done (3 out of 4 cases) prior to the strong wintertime impacts, meaning that a major enhancement of statistical seasonal forecasting skill over the contiguous US states appears possible by incorporating these results into existing seasonal forecasting efforts [see Fig. 1, and Chiodi, A.M., and D.E. Harrison, 2012: El Niño impacts on seasonal U.S. atmospheric

circulation, temperature and precipitation anomalies: The OLR-event perspective. J. Climate, doi: 10.1175/JCLI-D-12-00097.1. (In press)]

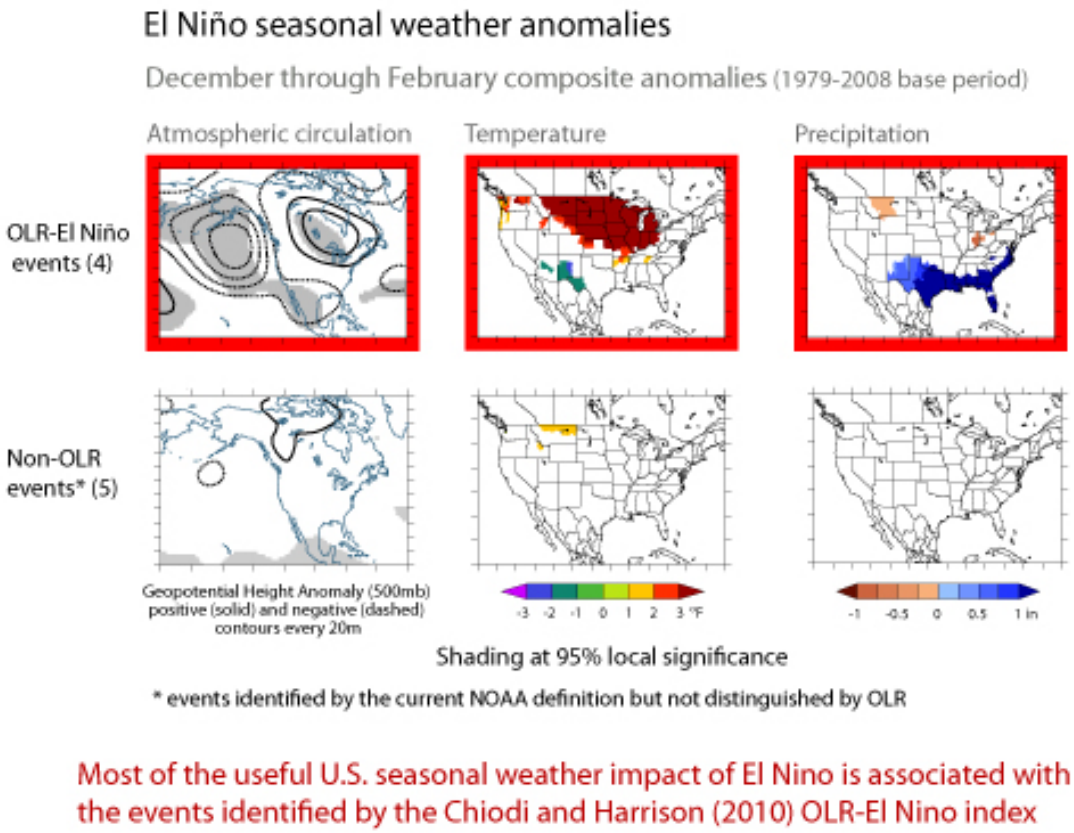


Figure 1: Composites of wintertime atmospheric circulation, temperature and precipitation anomaly over the U.S. associated with OLR El Niño events (compared with the non-OLR case results).

Recent work has identified a complimentary OLR-based cool-ENSO (La Niña) index and evaluated this pair of OLR-based ENSO indices for their respective connections to global seasonal precipitation and atmospheric circulation anomalies using composite analysis. Results show, that as in the U.S. case, over the period for which satellite-based OLR observations are available, almost all of the useful (statistically significant and consistent from event to event) ENSO impacts on seasonal precipitation are due to the years distinguished by the OLR-based ENSO indices (“OLR El Niño”; “OLR La Niña”). On the other hand, composites based on other years with ENSO status based on the current NOAA definition (“non-OLR El Niño”; “non-OLR La Niña”) do not have nearly as robust or statistically significant anomaly patterns as the OLR ENSO events. Outside of some far western Pacific regions, their usefulness to continental seasonal precipitation forecasting efforts is much more limited than that of the OLR-events. As in the OLR El Niño index case, the OLR La Nina index distinguishes events from background variability by the beginning of northern winter, and offers direct benefit to subsequent seasonal forecasting efforts in the affected regions [see Figure 2 and Chiodi, A.M., and D.E. Harrison,

2012: OLR-based El Niño and La Niña indices for impacts on global seasonal precipitation anomaly. J. Climate (submitted)]

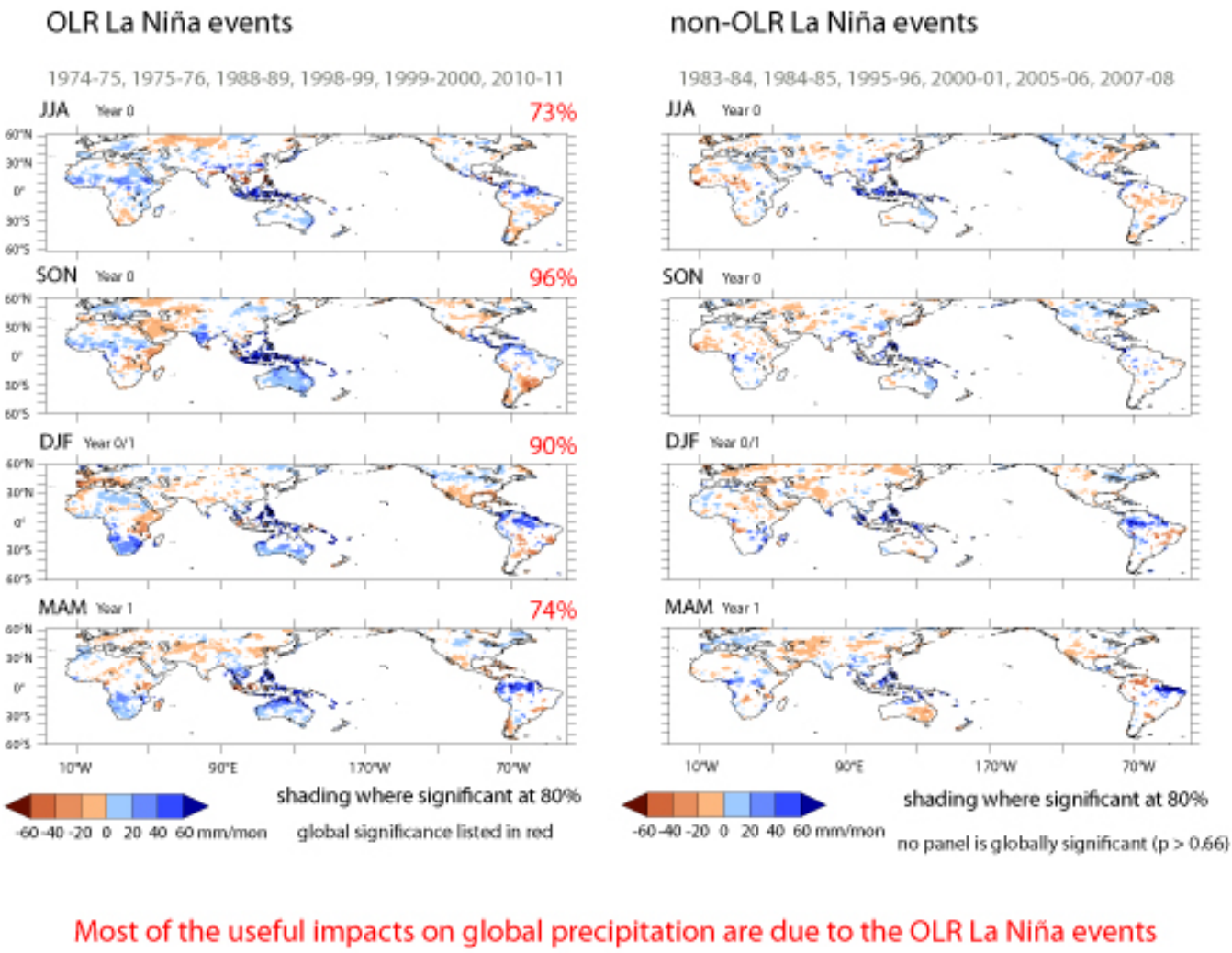


Figure 2: Seasonal composites (June-August, September-November, December-February and March-May) of precipitation anomaly associated with the OLR La Niña (left), and other La Niña events (right). Based on the percentage of locally significant anomaly (p>0.8) the overall global "field" significance is determined in each case from Monte Carlo methods (see red numbers to the upper right of some panels). Panels that do not have red numbers do not have enough locally significant anomaly to disprove the null hypothesis that the anomaly pattern seen is obtained by chance alone; that is, that the events in this group have no impact on precipitation anomaly.

We have re-examined the roles that various types of subseasonal wind events play in the initiation, and hence predictability, of warm-ENSO (El Niño) events. Specifically, we have analyzed the historical records of sea surface temperature anomaly in the equatorial tropical Pacific for the changes that follow Westerly Wind Events, and times in which the Madden Julian

Oscillation is active. The Westerly Wind Events (WWEs) we consider are characterized by average zonal wind anomalies of about 7 m/s over 7 or so days that occur in the western and central equatorial Pacific, whereas the Madden Julian Oscillation (MJO) is characterized by oscillatory wind anomalies, with an easterly and westerly phase, at lower amplitudes, but longer (30-90 day range) periods. Because both classes of intra-seasonal wind event have expression in the equatorial Pacific, where wind stress anomalies are known to be an effective means of driving equatorial waveguide warming, there has been much confusion about the relationship between WWEs, the MJO and waveguide warming in the tropical Pacific. Our results show that understanding the sources and predictability of tropical Pacific Westerly Wind Events remains essential to improving predictions of the onset of El Nino events. Westerly Wind Event effects and frequency is unaffected by the state of the Madden Julian Oscillation [see Chiodi, A.M. and D.E. Harrison, 2012: Subseasonal atmospheric variability and El Nino waveguide warming; observed effects of the MJO and Westerly Wind Events. J. Climate (In revision)]

Currently, about half of the carbon emitted to the atmosphere by human activity each year is absorbed by the ocean and land reservoirs. Consequently, there is significant scientific and policy-relevant interest in gaining a better understanding of the natural processes responsible and whether they might be changing. Some studies have suggested that the fraction of emitted $CO_2$ that remains in the atmosphere (airborne fraction) will increase as $CO_2$ is accumulated on land and in the ocean, but there is disagreement on whether any change has been observed. Our work shows that uncertainties in the rate of emissions from land use changes (e.g. deforestation) mean that airborne fraction trend cannot be determined reliably at present. The null hypothesis should remain that there is no trend. It will be at least decades before the most recently published trend will become statistically significant compared to the natural interannual variability in the system, and even then, we will not be able to trust it unless our knowledge of the time history of land use change emissions is somehow greatly improved [see Chiodi, A.M., and D.E. Harrison, 2012: Determining $CO_2$ airborne fraction trends with uncertain land use change emission records. International Journal of Climate Change: Impacts and Responses, 3(1), 79–88.]

The interannual variability of atmospheric $CO_2$ concentration represents a major component of global carbon cycle variability, exhibiting amplitudes comparable to the long-term trend (~1.5 ppmv $yr^{-1}$ since 1960) and the seasonal cycle (range ~5ppmv $yr^{-1}$). It has been known since the 1970s that interannual changes in $CO_2$ concentration are strongly correlated with ENSO. Interest in the ENSO-carbon cycle link has tangentially been renewed by the strong and growing interest in better understanding the natural processes that remove much of the anthropogenically emitted $CO_2$ from the atmosphere. Recent efforts to explain the processes that link ENSO and atmospheric $CO_2$ variability have focused on the effects that ENSO impacts on seasonal weather conditions might have on the net terrestrial ecosystem exchange of $CO_2$; the ENSO influence on the oceanic exchange is currently thought to be smaller than and out of phase with the net $CO_2$ fluxes needed to explain the link. Through careful examination of the annual and seasonal differences in atmospheric $CO_2$ concentration measured at the Mauna Loa site (a good proxy for global mean $CO_2$ concentration) group work has revealed substantial asymmetry between the changes typical of El Niño and La Niña event. We find La Niña changes involve about half as much $CO_2$ concentration change and begin sooner in the calendar year than the El Niño changes, but the changes persist for a similar number of seasons in each case; La Niña changes typically

occur primarily over September of ENSO Year 0 (e.g. 1998 of the 1998-99 La Niña event) to May of ENSO Year 1, while El Niño changes occur over December-August (ENSO Year 1). Our results are different than and improve upon the existing ENSO-$CO_2$ change composites that have been used to evaluate terrestrial biosphere model performance and confirm some recent findings that tropical land-atmosphere net fluxes of $CO_2$ are more strongly affected by El Niño than La Niña. We also showed that the La Niña changes, though statistically significant in their own right, are not nearly as robust (consistent from event-to-event) as the El Niño effects; over the time for which the Mauna Loa record is available, each of the (11) years in the top 20% in terms of anomalous concentration growth (notwithstanding the anthropogenic rise) has El Niño status based on the common definitions. This is not nearly true in the opposite sense for the La Niña case.

Because the ocean observing system predates the current efforts by climate scientists to determine which aspects of climate are undergoing very long term trends, it is often difficult to find long climate-quality records to support these efforts. The widespread use of satellite-based observations starting in the 1980s or 1990s has increased the amount of information available in recent decades, but reliably determining whether or not the effects of a very long term change are evident in a few decades of geophysical observations is difficult; geophysical variables often have considerable amounts of non-trend variance at longer timescales. Inhomogeneous records are sometimes used to estimate earlier period behavior, but reliably determining trends from these types of records is difficult because of the artifacts introduced by changes in sampling density and/or observing technology. We have performed work that revisits the question of whether or not there is evidence for a long-term (> 100yr) change in the state of the El Nino-Southern Oscillation (ENSO) and examines the prospects for reliably determining the observed full record-length trend from decadal and multi-decadal sub-segments of the now 136-yr long, record of sea level pressure at Darwin, Australia (a high-quality record and a good proxy for ENSO-state). We find that over the full record the best-fit trend is not statistically significant, although many of the decadal and multi-decadal sub-segment trends are. The sub-segment trends generally have much larger amplitudes than in the full-record case and are positive and negative in roughly equal proportion. For Darwin, multi-decadal records are not long enough to provide reliable information about the observed long-term (100yr +) behavior. For variables like Darwin, sustained, long-term, climate-quality observation is the only reliable way to know the long-term trend behavior. Examination of the difficulties involved in performing trend statistical significance tests on record-length trends suggests that for many geophysical records it is unwise to impute meaning to record-length trends based on the outcomes of these types of tests; that is, even if a record-length trend is found to be statistically significant, it is still very risky to assume that it will persist [see Chiodi, A.M., and D.E. Harrison, 2012: Estimating multi-decadal trends in the El Niño-Southern Oscillation: A case study with Darwin SLP. J. Climate. (submitted)].

Harrison and Carson, in preparation for a keynote presentation at the Climate Change and Oceanic Fisheries workshop at Rarotonga (held in Oct 2011), prepared a survey of recent results on oceanic trends and variability as well as some new results on variability and trends in the Cook Islands region of the tropical South Pacific ocean. This work emphasizes that the smaller

the space scale of interest, the more likely interannual to decadal variability are to dominate oceanic conditions of relevance to fisheries management. Too often, because of relatively short fisheries time series observations, managers have assumed that recent trends can be associated with climate change and can be projected to continue. We show that when longer records are available this is generally an unwise assumption. This work has now been published [see Harrison, D.E., and M. Carson (2012): Recent sea level and upper ocean temperature variability and trends; Cook Islands regional results and perspective. Climatic Change, doi: 10.1007/s10584-012-0580-8.]

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In partnership with the US Forest Service, the co-investigator has also performed work to characterize the regional atmospheric conditions associated with the summertime heavy precipitation events that occur along the forested slopes of the Columbia River Basin in eastern Washington and Oregon. Results have identified categories of rainfall events that are more or less likely to be accompanied by lightning and more or less likely to occur at the higher/lower elevations, depending on the direction of their anomalous flow over the defining Columbia Basin Region. Although the more intense wintertime storms of this region have received more attentions, a moderate rain event in the early summer serves to postpone the start of the wildland fire season; such a rain event in late summer/early fall can effectively end that threat. This work is partly intended to aid wildland fire management efforts and is in revision for publication in the peer reviewed literature (A. Bond, A.M. Chiodi, N.K. Larkin and J. Barbour, 2012: Summertime Rainfall Events in Eastern Oregon and Washington).

### *2.1. Outreach and Education*

The Ocean Observations 2009 Proceedings were published and distributed to all symposium participants as well as many libraries, agencies and program offices around the world.

The PI continued to serve as the Chair of the NOAA/OAR/CPO/COD Climate Observing System Council and as a steering committee member on the Global Climate Observing System steering committee. He continues also as member of the Commission of Climatology Expert Team on Climate Change Detection and Indices and as a member of the JCOMM/WMO Commission on Agriculture Climate and Fisheries Expert Team; as a member of the National Weather Service Climate Test Bed Science Advisory Board; and as a member of the CLIVAR task team on ocean climate indices. He is also Senior Fellow of the Joint Institute for the study of the Atmosphere and Ocean (NOAA/UW), Senior Fellow of the Joint Institute for Marine and Atmospheric Research (NOAA/U Hawaii) and External Fellow of the Joint Institute for Marine Observations (NOAA/UCSD and others)

We presented our work in numerous national, international and intergovernmental fora during FY12. These presentations include:

An OLR-based El Nino Index for effects on U.S. seasonal weather anomalies, A.M. Chiodi and D.E. Harrison, The Open Science Conference of the World Climate Research Program, in Denver, CO, USA, 24-28 October 2011 [Poster]

Determining airborne fraction trend with uncertain land use emission estimates, A.M. Chiodi and D.E. Harrison, The Open Science Conference of the World Climate Research Program, in Denver, CO, USA, 24-28 October 2011 [Poster]

Subseasonal Variability and El Nino waveguide warming; observed effects of the MJO and Westerly Wind Events, A.M. Chiodi and D.E. Harrison, The Open Science Conference of the World Climate Research Program, in Denver, CO, USA, 24-28 October 2011 [Poster]

Seasonally averaged U.S. atmospheric circulation, temperature and precipitation anomalies, The OLR-El Nino perspective. A.M. Chiodi and D.E. Harrison, 2011 Fall American Geophysical Union Meeting, San Francisco, CA, USA, 5-9 December 2011. [Poster]

The interannual variability of atmospheric CO2 concentration and its response to La Nina and El Nino events, A.M. Chiodi and D.E. Harrison, 2011 Fall American Geophysical Union Meeting, San Francisco, CA, USA, 5-9 December 2011. [Talk]

El Niño and La Niña impacts on American seasonal weather anomalies: the OLR perspective, A.M. Chiodi and D.E. Harrison, CLIVAR VAMOS Workshop on Modeling and Predicting Climate in the Americas, Petropolis, Brazil, 4 June, 2012 - 6 June, 2012 [Talk]

Estimating multi-decadal trends in ENSO: A case study using Darwin SLP, A.M. Chiodi and D.E. Harrison, National Taiwan University International Science Conference on Climate Change: Multidecadal and Beyond, Taipei, Taiwan, 17-21September 2012. [Talk]

# 3. Publications and Reports

## *3.1. Publications by Principal Investigators*

- Published

Chiodi, A.M., and D.E. Harrison, 2012: Determining $CO_2$ airborne fraction trends with uncertain land use change emission records. *International Journal of Climate Change: Impacts and Responses*, **3**(1), 79–88.

Harrison, D.E., and M. Carson, 2012: Recent sea level and upper ocean temperature variability and trends; Cook Islands regional results and perspective. *Climatic Change*, doi: 10.1007/s10584-012-0580-8.

- In press

Chiodi, A.M., and D.E. Harrison , 2012: El Niño impacts on seasonal U.S. atmospheric circulation, temperature and precipitation anomalies: The OLR-event perspective. *J. Climate*, doi: 10.1175/JCLI-D-12-00097.1.

- In revision

Chiodi, A.M., D.E. Harrison, and G.A. Vecchi, 2012: Subseasonal atmospheric variability and El Niño waveguide warming; observed effects of the Madden-Julian Oscillation and Westerly Wind Events. *J. Climate.*

Chiodi, A.M., and D.E. Harrison, 2012: The effects of La Nina and El Nino events on the growth rate of atmospheric carbon dioxide.

Bond, N.A., A.M. Chiodi, N.K. Larkin, and J. Barbour, 2012: Summertime rainfall events in eastern Oregon and Washington. *J. Hydrometeorology*

- In Preparation

Chiodi, A.M., and D.E. Harrison (2012): OLR-based El Niño and La Niña indices for impacts on global seasonal precipitation anomalies. To be submitted to *J. Climate*.

Chiodi, A.M., and D.E. Harrison (2012): Estimating multi-decadal trends in the El Niño-Southern Oscillation: A case study with Darwin SLP. To be submitted to *J. Climate*.

### *3.2. Other Relevant Publications*

*This section lists some significant publications, published in the past year, in which an Ocean Observing System Studies project investigator's work (since 2005) is cited (the project investigators are not authors of the papers listed below).*


Hu, Z.-Z., A. Kumar, B. Jha et al., 2012: An analysis of warm pool and cold tongue El Niños: air-sea coupling processes, global influences, and recent trends. *Climate Dynamics*, **38**, 2017-2035.

Kennedy, J.J., R.O. Smith and N.A. Rayner, 2012: Using AATSR data to assess the quality of in situ sea-surface temperature observations for climate studies. *Remote Sensing of Environment*, **116**, 79-92.

Kataoka, T., T. Tozuka, Y. Masumoto et al, 2012: The Indian Ocean subtropical dipole mode simulated in the CMIP3 models. *Climate Dynamics*, **39**, 1385-1399.

Morioka, Y., T. Tozuka, S. Masson et al., 2012: Subtropical Dipole Modes Simulated in a Coupled General Circulation Model. *J. Climate*, 25, 4029-4047.

Junqiao, F.; D. Hu, L., 2012: Low-frequency coupled atmosphere-ocean variability in the southern Indian Ocean, *Adv. Atmos. Sci.*, **29,** 544-560.

Ash, K.D. and C. J. Matyas, 2012: The influences of ENSO and the subtropical Indian Ocean Dipole on tropical cyclone trajectories in the southwestern Indian Ocean, *Int. J. Climatology*, 32, 41-56.

Robson, J., R. Sutton, K. Lohmann, D. Smith, M.D. Palmer, 2012: Causes of the Rapid Warming of the North Atlantic Ocean in the Mid-1990s. *J. Climate*, **25**, 4116-4134.

Kobayashi, T, K. Mizuno, T. Suga, 2012: Long-term variations of surface and intermediate waters in the southern Indian Ocean 32S. *J. Oceanogr*., **68**, 243-265.

Singh, A, T. Delcroix, 2011: Estimating the effects of ENSO upon the observed freshening trends of the western tropical Pacific Ocean. *Geophys. Res. Lett.*, 38, doi: 10.1029/2011GL049636

Yin, J.J., J.T. Overpeck, S.M. Griffies, A.X. Hu, J.L. Russell, R. J. Stouffer, 2011: Different magnitudes of projected subsurface ocean warming around Greenland and Antarctica, *Nature Geosci.*, 4, 524-528.

Hansen, J, M. Sato, P Kharecha, K. von Schuckman, 2011: Earth's energy imbalance and

implications, *Atmos. Chem. Phys*., **11**, 13421-13449.

Dewitte, B.; Vazquez-Cuervo, J.; Goubanova, K.; et al., 2012: Change in El Nino flavours over 1958-2008: Implications for the long-term trend of the upwelling off Peru. *Deep-Sea Res. II*, **77-80**, 143-156.

Welker, J.M., 2012: ENSO effects on delta O-18, delta H-2 and d-excess values in precipitation across the U.S. using a high-density, long-term network (USNIP), Rapid Communications in Mass Spectrometry, 26, 1893-1898.

Wang, D. Y. Qin, X. Xiao et al. 2012: El Nino and El Nino Modoki variability based on a new ocean reanalysis, *Ocean Dynamics*, **62**, 1311-1322.

Yu, J.Y., Y. Zou, S.T. Kim et al., 2012: The changing impact of El Niño on U.S. winter temperatures, *Geophys. Res. Lett*., **39**, DOI: 10.1029/2012GL052483.

Qi, L. and Y. Wang, 2012: Changes in the Observed Trends in Extreme Temperatures over China around 1990. *J. Climate*, **25**, 5208-5222.

Ham, Y.-G. and J.-S. Kug, 2012: How well do current climate models simulate two types of El Niño? *Climate Dynamics*, **39**, 383-398.

Jeong, H.-I., Lee, D. Y., K. Ashok et al., 2012: Assessment of the APCC coupled MME suite in predicting the distinctive climate impacts of two flavors of ENSO during boreal winter. *Climate Dynamics*, **39**, 475-493.

Lee, S., 2012: Testing of the Tropically Excited Arctic Warming Mechanism (TEAM) with Traditional El Niño and La Niña. *J. Climate*, **25**, 4015-4022.

Kim, J.-S., K.-Y. Kim, S.-W. Yeh, 2012: Statistical evidence for the natural variation of the central Pacific El Niño. *J. Geophys. Res.*, **117,** doi: 10.1029/2012JC008003.

Kim, S.T. and J.-Y. Yu, 2012: The two types of ENSO in CMIP5 models, *Geophys. Res. Lett*., **39**, doi: 10.1029/2012GL052006.

Dewitte, B., J. Choi, S.-I. An et al., 2012: Vertical structure variability and equatorial waves during central Pacific and eastern Pacific El Niños in a coupled general circulation model. Climate Dynamics, 38, 2275-2289.

Kim, S.T., J.-Y. Yu, A. Kumar, 2012: Examination of the Two Types of ENSO in the NCEP CFS Model and Its Extratropical Associations. *Mon. Wea. Rev*., **140**, 1908-1923.

Deng, Y., T.W. Park and M. Cai, 2012: Process-Based Decomposition of the Global Surface Temperature Response to El Nino in Boreal Winter. *J. Atmos. Sci.*, **69**, 1709-1712.

Shinoda, T., 2012: Observation of first and second baroclinic mode Yanai waves in the ocean. *Q. J. Roy. Met. Soc.*, **138**, 1018-1024.

Delworth, T.L., A. Rosati, W. Anderson, 2012: Simulated Climate and Climate Change in the GFDL CM2.5 High-Resolution Coupled Climate Model. *J. Climate*, **25**, 2755-2781.

Khedun, C.P., A.K. Mishra, J.D. Bolten, et al. 2012: Understanding changes in water availability in the Rio Grande/Rio Bravo del Norte basin under the influence of large-scale circulation indices using the Noah land surface model. J. Geophys. Res.-Atmos., 117, doi: 10.1029/2011JD016590.

Sooraj, K.P., H. Annamalai, A. Kumar, et al. 2012: A Comprehensice Assessment of CFS Seasonal Forecasts over the Tropics. Weather and Forecasting, 27, doi: 10.1175/WAF-D-11-00014.1.

Graf, H-.F. and D. Zanchettin, 2012: Central Pacific El Niño, the "subtropical bridge," and Eurasian climate. *J. Geophys. Res.-Atmos*., **117**, doi: 10.1029/2011JD016493.

Li, G. and B. Ren, 2012: Evidence for strengthening of the tropical Pacific Ocean surface wind speed during 1979-2001. Theoretical and Applied Climatology. 107, doi: 10.1007/s00704-011-0463-3.

Shinoda, T., H. Hurlbert and J.E.Metzger, 2011: Anomalous tropical ocean circulation associated with La Niña Modoki. *J. Geophys. Res.-Oceans*, **116**, doi: 10.1029/2011JC007304.

Singh, A. and A. Palazoglu, 2011: A Statistical Framework to Identify the Influence of Large-Scale Weather Events on Regional Air Pollution. *J. App. Meteor. Clim*., **50**, 2376-2393.

Moore, G.W.K., J.L. Semple and G. Hoyland, 2011, Global Warming, El Nino, and High-Impact Storms at Extreme Altitude: Historical Trends and Consequences for Mountaineers. *J. App. Meteor. Clim.*, **50**, 2197-2209.

Boucharel, J., B. DeWitte, Y. du Penhoat et al., 2011: ENSO nonlinearity in a warming climate. *Climate Dynamics*, **37**, 2045-2065.

Zhang, W., F.-F. Jin, J. Li et al., 2011: Contrasting Impacts of Two-type El Nino over the Western North Pacific during Boreal Autumn. *J. Meteor. Soc. Japan*, **89**, 563-569.

McGregor, S., A. Timmermann, N. Schneider et al., 2012: The Effect of the South Pacific Convergence Zone on the Termination of El Nino Events and the Meridional Asymmetry of ENSO. *J. Climate*, **25**, 5566-5586.

Yeo, S.-R., K.-Y. Kim, S.-W. Wook, et al., 2012: Decadal changes in the relationship between the tropical Pacific and the North Pacific. *J. Geophys. Res.-Atmos*., *117*, doi: 10.1029/2012JD017775.

Lin, P., Q. Fu and D. L. Hartmann, 2012: Impact of Tropical SST on Stratospheric Planetary Waves in the Southern Hemisphere. *J. Climate*, **25**, 5030-5046.

Gierach, M.M., T. Lee, D. Turk et al., 2012: Biological response to the 1997-98 and 2009-10 El Nino events in the equatorial Pacific Ocean. *Geophys. Res. Lett*., **39**, doi: 10.1029/2012GL051103

Kim, D.-W., K.-S. Choi and H.-R. Byun, 2012: Effects of El Niño Modoki on winter precipitation in Korea. *Climate Dynamics*, **38**, 1313-1324.

Miyakoda, K., A. Cherchi, A. Navarra, et al., 2012: ENSO and its Effects on the Atmospheric Heating Processes. *J. Meteor. Soc. Japan*, **90**, 35-37.

Gallant, A.J.E., A.S. Kiem, D.C. Verdon-Kidd, et al. 2012: Understanding hydroclimate processes in the Murray-Darling Basin for natural resources management. Hydrology and Earth Systems Sciences, 16, 2049-2068.

Liao, X., J. Ma, H. Zhan, 2012: Effect of different types of El Nino on primary productivity in the South China Sea. *Aquatic Ecosystem Health and Management*, **15**, 125-143.

Ying, L. and N.-C. Lau, Impact of ENSO on the Atmospheric Variability over the North Atlantic in Late Winter-Role of Transient Eddies. *J. Climate*, **25**, 320-342.

Qian, C., Z. Wu, C. Fu, 2011: On Changing El Nino: A View from Time-Varying Annual Cycle, Interannual Variability, and Mean State. *J. Climate*, **24,** doi: 10.1175/JCLI-D-10-05012.1.

Montecinos, A., M.V. Kurgansky, C. Munoz, et al. 2011: Non-ENSO interannual rainfall variability in central Chile during austral winter. Theoretical and Applied Climatology, 106, 557-568. doi: 10.1007/s00704-011-0457-1.