# Observing System Research Studies

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## 1. Abstract

This project has continued to investigate the utility of the global observing system for climate, with particular attention on characterizing anomalies relevant to understanding or forecasting US or global weather anomalies and projections of climate variability and change and implications for needed observing system actions. In FY09 we have published or done research on characterizing multi-decadal trends in upper ocean temperature and the planetary carbon sink; on the ability of the Argo array to monitor large scale ocean temperature anomalies; on ways of defining El Nino events that have the strongest connection with US winter weather anomalies; on understanding our ability to model high latitude ocean surface temperature; on recent changes in equatorial Pacific zonal wind anomalies that have produced changes in cold tongue warming patterns related to El Nino; on ENSO related changes in atmospheric CO2 concentration increase. We have also made available via PMEL the "State of the Ocean" web site which presents weekly or monthly updates of the amplitudes of a range of ocean and atmosphere and cryospheric anomalies relevant to global and US climate. The PI also was co-organizer of the OceanObs09 conference and chairman of the Ocean Observations Panel for Climate (co-sponsored by the Global Climate Observing System program, the Global Ocean Observing System program and the World Climate Research Program) and was active in the management committee of the Joint Commission for Oceanography and Marine Meteorology.

## 2. Project Summary

The Observing System Research Studies group performs data and modeling studies to identify climatically significant ocean-atmosphere interaction patterns, identify indices that usefully

characterize their amplitudes and study their linkages to US and global weather anomalies, with the goals of improving our awareness and understanding of present climate conditions and the effectiveness of the global observing system for climate. We seek to identify useful climate indices/indicators of the state of the climate system, together with estimates of their uncertainty, that help society understand, forecast and project seasonal and longer term weather and climate anomalies. We 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.

We also work within the NOAA, US, international and intergovernmental ocean and climate organizations to develop agreed international plans for the climate observing system, and 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 mirror at PMEL, and collaboration with the Observing System Monitoring Center project led by Steve Hankin.

## 3. Scientific Accomplishments

***A. Characterizing warm-ENSO events using outgoing longwave radiation.*** We showed that outgoing longwave radiation (OLR) information can be used to give rather unique perspective on recent El Nino-Southern Oscillation (ENSO) behavior. This OLR perspective has a distinctly event-like character, not seen in the indices most-commonly used describe the anomaly state of the tropical Pacific, such as Nino 3.4 region SSTA or the Southern Oscillation Index. This makes determination of "event-status" based on OLR less ambiguous than using other commonly used ENSO indices, which show a continuous interannual distribution of neutral-to-secondary-to-large anomalies. In OLR, the most commonly agreed upon warm-events stand out. OLR also offers a more dynamically-direct connection to the global seasonal weather anomalies caused by ENSO, which are of the more general societal concern than specific tropical Pacific conditions. Examination of atmospheric geopotential height anomalies from numerical weather prediction models confirms that significant and robust atmospheric circulation anomalies are driven over the North Pacific and North America in years distinguished by eastern central pacific OLR variability. Groups of years considered "El Nino" based on some other ENSO indices, but not particularly distinctive based on OLR behavior, do not show such anomalies. This work suggests that eastern central Pacific OLR information be used, both operationally and historically, to identify the El Nino events that are most likely to have substantial and predictable effects on N. American weather (see Chiodi and Harrison, 2010a, for more information.)

***B. The annual range of Southern Hemisphere SST and reasons for the high latitude fall-off.*** Explanations for the observed structure of the seasonal range of sea surface temperature (SST) can be found in classic oceanographic texts, but are found here to be incomplete. Results show newly available ocean mixed layer depth estimates, made possible by the Argo observing system, can be used to reasonably predict the observed zonal mean SST seasonal range structure in the ice-free latitudes of the Southern Ocean. Analysis shows that the deepening of the ocean mixed layer with latitude and its temporal behavior are both key to understanding the observed

structure, but the models used in this study were unable to adequately reproduce the observed behavior, suggesting that we have more to learn about the ways ocean dynamics control the annual range of surface temperature at high latitudes (see Chiodi and Harrison, 2010b, and figure below for more information). Because IPCC models suggest that climate change will be evident first at higher latitudes, improving our ability to evaluate model behavior at high latitudes is important. Accurate observations of SST and ocean mixed layer depth, and improved estimates of air-sea heat flux components are important contributions from the ocean observing system.

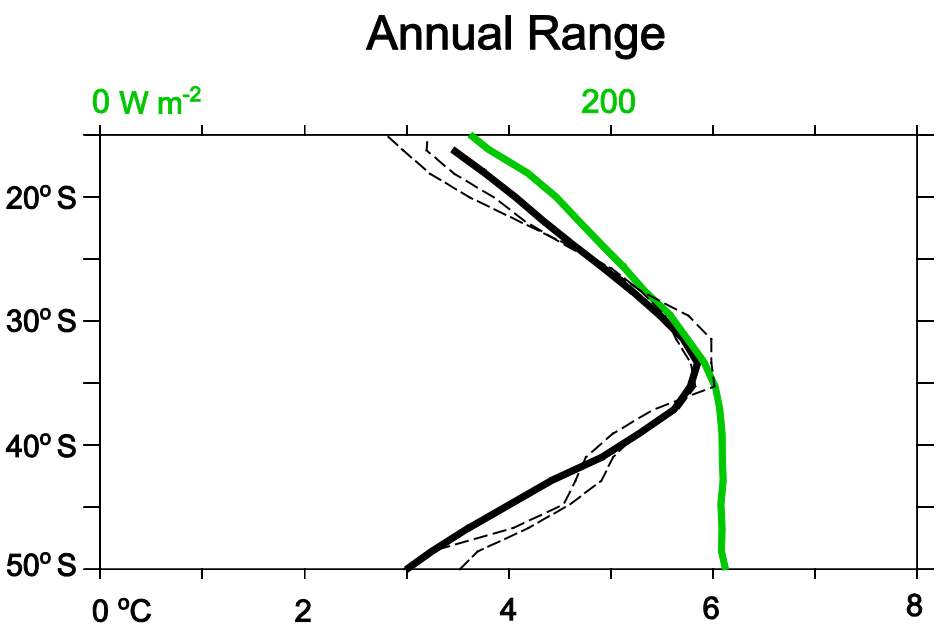


**Figure Caption**. Annual range of zonally averaged SST (solid black curve), zonally averaged net air-sea heat flux (green curve) and zonally averaged SST from a simplified 1-dimensional ocean model that resolves only the heating of the ocean mixed layer (OML) by the surface fluxes (dashed curves; each uses a different contemporary data set for OML information). It is notable that although the structure of the ranges of fluxes and SST roughly agree between 15S and about 35S, the SST range decreases with latitude south of 35S, while the annual range in the fluxes does not. We showed that this behavior can be explained by our present knowledge of observed OML behavior, but that it is difficult to reproduce this behavior with a prognostic OML model. Thus, important questions remain about the physics that control fundamental aspects of upper ocean behavior at high latitudes.

***C. Differences between pre- and post- 1997/1998 Westerly Wind Events and cold tongue warming***. We showed that there has been a change in the wind patterns associated with westerly wind events over the tropical Pacific since the major 1997-98 El Nino event, and that these seem sufficient to explain why we have been having more 'Dateline El Nino' than 'conventional El Nino' events since then. We used numerical ocean model experiments to obtain the latter conclusion. This work suggests a new index that takes into account the basin scale wind anomaly conditions present during a westerly wind event might be developed for tracking the likelihood of an El Nino appearing in any given year. Presentation of this work at national scientific conferences has been successful in generating considerable interest in the phenomena documented by this study among the research and forecasting/monitoring communities (see Harrison and Chiodi, 2009, for more information.) We shall work further on possible wind stress indices in FY10.

***D. Effectiveness of the Argo observing system in measuring upper ocean heat content and temperature examined in an ocean general circulation model.*** We have confirmed that over most of the ocean, the current Argo observing system, consisting presently of approximately 3200 profiling floats, is very capable of resolving the large scale variability of several key oceanic quantities, such as temperature, salinity, upper ocean heat content and mixed layer structure. Results show, however, that in some regions characterized by strong currents and horizontal gradients, improvements to the system, such as more floats or efforts to counter the spatial-sampling effects of float movements, would substantially increase the capacity of the observing system to measure interannual variability in these regions (see Kamenkovich et al. 2009, for more information.)

***E. Effects of surface forcing on the seasonal cycle of the eastern equatorial Pacific***. We have examined the effects of the various components of surface forcing on the seasonal cycle in the eastern equatorial Pacific. Much attention has been paid in the literature to the importance of the component of the seasonal cycle driven by meridional wind variability. Our results show that zonal wind variability is key, but that accurate knowledge of both wind components and surface heat flux is necessary for ocean models to accurately resolve many aspects of the observed seasonal cycle (see Harrison et al., 2010, for more information.) We also argue that surface current information is critical to evaluating the utility of model studies, and that having 5m depth currents at the TAO array equatorial mooring sites (even for just a few years) could be very helpful for evaluation of model results.

***F. Improved land use change emission estimates needed to reliably determine $CO_2$ airborne fraction trend and whether the efficiency of the planetary carbon sink is changing.*** The increase of atmospheric carbon dioxide due to emissions from anthropogenic sources is less than it would be if all emission remained in the atmosphere because, on average, about half of the emitted carbon is taken up by natural land and ocean processes. Determining the behavior of this planetary sink is a first step toward predicting future atmospheric carbon dioxide levels because the strength of the sink must also be forecast. The strength of the sink can be inferred from measured increases in atmospheric carbon concentration and estimates of total anthropogenic emissions, but some of the emission sources are known better than others. Particularly, there has been a wide range of published estimates of emissions resulting from land use change practices, such as tropical deforestation. Results of this work show that, over the period of the Mauna Loa CO2 record, trends in the strength of the sink can be either positive or negative depending on the land use change scenario; the more that the land use emissions have increased over time, the more likely it is that the strength of the sink has increased. This shows that some recent work claiming that the strength of the sink is decreasing depends crucially on its choice of land use change scenario (see Harrison and Chiodi, 2010c and figure below, for more details.) It appears that oceanic carbon inventory measurements, while of intrinsic interest for many reasons, will not be sufficient to settle the question of whether the efficiency of the planetary carbon sink is changing.

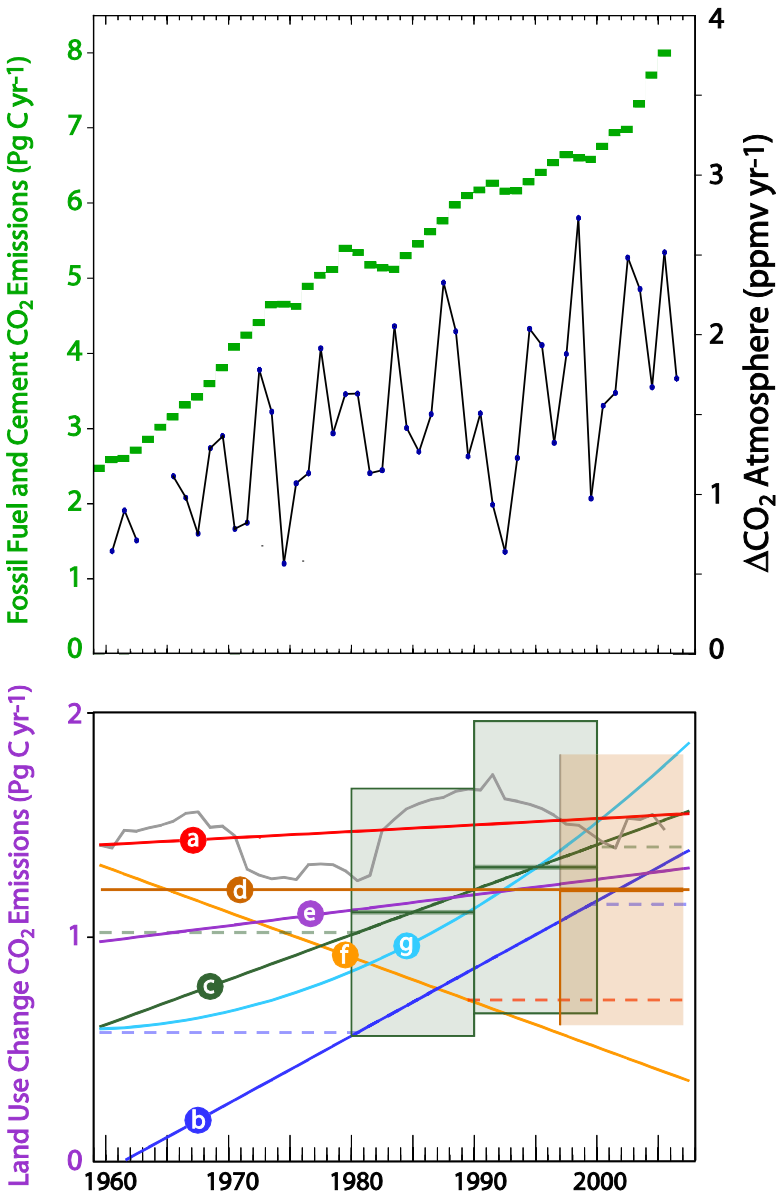


**Figure Caption**. Upper: Annual emissions from fossil fuel burning and cement production (green bars) and CO2 growth rate at Mauna Loa (black curve.) These are the better known aspects of this issue. Lower: land use change emissions from a "bookkeeping" model based on United Nations Forest and Agriculture Organization assessment reports (gray curve) and the best estimates and 50% uncertainty levels (shading) from recently revised International Panel on Climate Change Working Group I (IPCC WGI) (green) and IPCC WGIII (brown) decadal averages. Lines (a), (b), (c), (d), (e) and (f) are linear fits to previously published land use change emission estimates (dashed lines for alternate scenarios considered.) This type of emission must be specified to infer trends in the efficiency of the planetary sink, but as one can see, varies greatly among recently published estimates. We have shown that, although each of these scenarios is at least roughly consistent with the current uncertainty of this type of emission, inferred planetary sink efficiency can be either decreasing or increasing over the period shown depending on which historical scenario is assumed. Scenarios that show increasing land use change emissions are among those that produce increasing trends in inferred sink effectiveness (e.g. scenario "b"), while scenarios that show decreasing land use change emissions (e.g. scenario "f") suggest recent decreases in the effectiveness of the planetary sink. Reliably determining this trend is fundamentally important to determining future atmospheric CO2 levels.

***G. Regional interdecadal trend variability in ocean temperature data***. Accurately quantifying interdecadal ocean variability is an important first step toward reliably determining trends over the historical record. We have explored the effects that some bias corrections have on estimates of interdecadal temperature variability in different oceanic regions. Recent research indicates that, based on comparison with instruments that measure depth (pressure) and temperature concurrently, our reliance in previous decades on expendable bathythermographs (XBTs) for temperature information produces a decadally-varying temperature bias. Results have shown that new XBT bias corrections significantly reduce the level of interdecadal variability in globally-averaged ocean temperature. We have shown that bias-corrected regional temperature data still contains strong interdecadal variability, and that the bias corrections are smaller than the interdecadal signal on regional scales (see Carson and Harrison, 2010, for more information). This work shows the extreme importance of long-time accurate observations of the ocean in order to get a reliable picture of long-term trends. Trends over even a 20year period can be strongly aliased by interdecadal variability.

***H. ENSO effects on the amount of anthropogenically emitted carbon dioxide that is absorbed each year by the natural planetary sink***. The annual growth rate of atmospheric carbon dioxide ($CO_2$) shows variability on interannual timescales that can not be explained by carbon emissions from industrial processes. Evidently most of this variability is driven by year-to-year changes in the amount of carbon taken up by natural planetary processes. Though a large variety of regional seasonal climate anomalies occur each year, in some regions there are strong statistical linkages between extremes of the El Nino-Southern Oscillation (ENSO) phenomenon and some of these seasonal climate anomalies. One of the more interesting, but not yet fully understood, of these linkages can be inferred from the relationship between extremes in the growth rate of atmospheric $CO_2$ and ENSO-state. We have revisited this relationship and confirmed results from many (but not all) previous related studies, showing that there is a strong relationship between ENSO and growth rate extremes, especially in the warm-event (El Nino) case, where it can be argued that over the last 50 years, the years with the lowest planetary $CO_2$ uptake anomalies (bottom 20%) all have warm-ENSO status. This relationship offers a unique opportunity to test for the successful inclusion of biogeochemical processes in coupled atmosphere-ocean-land models (see Chiodi and Harrison, 2010c, for more information.)

## 4. Education and Outreach

Mark Carson continued to make progress toward a PhD in physical oceanography from the College of Oceanography and Fishery Science at the UW. He presented research results at two national meetings.

Andy Chiodi presented results from our work on using an El Nino index based on outgoing longwave radiation information at the 89$^{th}$ Annual American Meteorological Society Meeting, January 11-15, 2009 in Phoenix, AZ, and the Fall AGU meeting, December 15-19, 2008, San Francisco, CA. Results from our work on changes in the character and effects of recent period westerly wind event wind anomalies were also presented at the Fall AGU meeting.

The PI participated in 27 (see list below) steering committee meetings, workshops and fora on ocean and climate observations during the FY. He also was co-organizer of the OceanObs2009 Conference in Venice, Italy in Sept, 2009, which brought together over 600 participants from more than 30 nations to summarize the progress made in ocean observing over the past decade, identify community plans for actions that could be undertaken in the coming decade, and to envision a much more integrated sustained ocean observation and ocean information system, involving biology, biogeochemistry and physical climate in the coming decade. See www.oceanobs09.net for much more information.

The PI played a leading role in preparation of a new version of the Global Climate Observing System Implementation plan for the United Nations Framework Convention on Climate Change. The draft has been posted on the GCOS web site for external comment, and will be finalized in FY10 and submitted to the UNFCCC's Subsidiary Body for Science and Technology.

The PI also continued to lead the Ocean Observations Panel for Climate, co-sponsored by the Global Ocean Observing System project, the Global Climate Observing System project and the World Climate Research Program, handing the Panel off to Dr. Eric Lindstrom during the FY.

The PI also continued to lead the Climate Program Office's Climate Observing System Council, a discussion group that provides NOAA and non-NOAA climate science leaders and users to provide their perspectives to NOAA climate observation program leadership.

**Outreach and Education and Planning/Steering Meetings**
**D.E. Harrison FY09**

**2008**
Oct 6-7 OceanSynth-III Jamstec/Tokyo
Oct. 14-17 GlobClimOS SC GVA
Nov 12-15 Fall GODAE Final conf Nice, Fr
Nov 24-25 (26?) GCOS SBSTA Progress rpt GVA
Dec 2-4 COSC Autumn DC
Dec 8-12 JCOMM Mgmt Comm Melbourne
**2009**
Jan 5-9 POGO-10 Concepcion, Chile
Jan 21-22 OCO site visit Princeton
Feb 2-5 GCOS ImpPlan v.w GVA
Feb 23-28 GSSC-XII Perth
Mar9-11 JCOMM ObsCoordGp Paris
Mar 18-20 GCOS SBSTA Final GVA
Mar 27 OceanObs09 Planning Paris
Apr1 OCO visit HQ DC
Apr 14-16 COSC DC
Apr 20-22 JIMO External Board Review San Diego
April 27-1 May Atmos Obs Panel Climate. Geneva
May 11-15 EuroEnvironAgency Obs Workshp Copenhagen

May 19-23 CLIVAR SSG Madrid
June2-5 Ocean and Land primary Prod Wkshp Ispra,IT
June 10-12 I-GOOS SC Paris
July 7-10 OceanObs09 planningParis
July 20-22 GCOS Imp Plan v.2 GVA
Aug 13-14 OceanObs09 Planning DC
Aug 24-27 IOOS NatForumRegAssocs Seattle
Aug 31-4Sept WorldClimateConf-3 Geneva
Sept 21-25 OceanObs09 Conf. Venice

## 5. Publications and Reports

### *5.1. Publications by Principal Investigators*

*Summary:*

*4 Papers are in press or have appeared in refereed literature since the start of FY09.*
*3 Papers have been submitted to refereed journals.*
*2 Papers have made significant progress.*
*5 Papers are in press as part of the OceanObs09 conference publication process.*

**Publications accepted in refereed journals:**

Chiodi, A.M., and E.D. Harrison, 2010: Characterizing ENSO variability in the equatorial Pacific: An OLR perspective. J. Climate. [Accepted]

Chiodi, A.M., and D.E. Harrison, 2010: The annual range of southern hemisphere SST; Comparison with surface heating and possible reasons for the high-latitude fall off. J. Climate. [Accepted]

Harrison, D.E., and A.M. Chiodi, 2009: Pre- and post-1997/1998 westerly wind events and equatorial Pacific cold tongue warming. J. Climate, 22(3), 568–581.

Kamenkovich, I., W. Cheng, E.S. Sarachik, and D.E. Harrison, 2009: Simulation of the Argo observing system in an ocean general circulation model. J. Geophys. Res., 114, C09021, doi: 10.1029/2008JC005184

**Manuscripts submitted to refereed journals:**

Harrison, D.E., A. Chiodi, and G. Vecchi, 2010: Effects of surface forcing on the seasonal cycle of the eastern equatorial Pacific. J. Mar. Res. [Submitted]

Harrison, D.E., and A.M. Chiodi, 2010: Is the efficiency of the planetary $CO_2$ sink decreasing? The effects of uncertain land use change emission records. Geophys. Res. Lett. [Submitted]

Larkin, N.K., and D.E. Harrison, 2010: The 1997–98 El Niño and the post-WWII composite event. J. Climate. [Submitted]

**In preparation for submission to refereed journals:**

Carson, M., and D.E. Harrison, 2010: Regional interdecadal variability in bias-corrected ocean temperature data. J. Climate. [In preparation]

Chiodi, A.M. and D.E. Harrison, 2010: The effects of the El Nino-Southern Oscillation phenomenon on the growth rate of atmospheric carbon dioxide. J. Climate. [In preparation]

**OceanObs09 publications:**

Lee, T., D. Stammer, T. Awaji, M. Balmaseda, D. Behringer, J. Carton, N. Ferry, A. Fischer, I. Fukumori, B. Giese, K. Haines, E. Harrison, P. Heimbach, M. Kamachi, C. Keppenne, A. Köhl, S. Masina, D. Menemenlis, R. Ponte, E. Remy, M. Rienecker, A. Rosati, J. Schroeter, D. Smith, A. Weaver, C. Wunsch, and Y. Xue (2009): Ocean state estimation for climate research. In *Proceedings of the "OceanObs'09: Sustained Ocean Observations and Information for Society" Conference (Vol. 2)*, Venice, Italy, 21–25 September 2009, Hall, J., D.E. Harrison, and D. Stammer, Eds., ESA Publication WPP-306. [In press]

Palmer, M.D., J. Antonov, P. Barker, N. Bindoff, T. Boyer, M. Carson, C.M. Domingues, S. Gille, P. Gleckler, S. Good, V. Gouretski, S. Guinehut, K. Haines, D.E. Harrison, M. Ishii, G.C. Johnson, S. Levitus, M.S. Lozier, J.M. Lyman, A. Meijers, K. von Schuckmann, D. Smith, S. Wijffels, and J. Willis (2009): Future observations for monitoring global ocean heat content. In *Proceedings of the "OceanObs'09: Sustained Ocean Observations and Information for Society" Conference (Vol. 2)*, Venice, Italy, 21–25 September 2009, Hall, J., D.E. Harrison, and D. Stammer, Eds., ESA Publication WPP-306. [In press]

Rienecker, M.M., T. Awaji, M. Balmaseda, B. Barnier, D. Behringer, M. Bell, M. Bourassa, P. Brasseur, J. Carton, J. Cummings, L.-A. Breivik, E. Dombrowsky, C. Fairall, N. Ferry, G. Forget, H. Freeland, S.M. Griffies, K. Haines, D.E. Harrison, P. Heimbach, M. Kamachi, E. Kent, T. Lee, P.-Y. Le Traon, M. McPhaden, M.J. Martin, P. Oke, M.D. Palmer, E. Remy, T. Rosati, A. Schiller, D.M. Smith, D. Snowden, D. Stammer, K.E. Trenberth, and Y. Xue (2009): Synthesis and assimilation systems—Essential adjuncts to the Global Ocean Observing System. In *Proceedings of the "OceanObs'09: Sustained Ocean Observations and Information for Society" Conference (Vol. 1)*, Venice, Italy, 21–25 September 2009, Hall, J., D.E. Harrison, and D. Stammer, Eds., ESA Publication WPP-306. [In press]

Stammer, D., A. Köhl, T. Awaji, M. Balmaseda, D. Behringer, J. Carton, N. Ferry, A. Fischer, I. Fukumori, B. Giese, K. Haines, E. Harrison, P. Heimbach, M. Kamachi, C. Keppenne, T. Lee, S. Masina, D. Menemenlis, R. Ponte, E. Remy, M. Rienecker, A. Rosati, J. Schröter, D. Smith, A. Weaver, C. Wunsch, and Y. Xue (2009): Ocean information provided through

ensemble ocean syntheses. In *Proceedings of the "OceanObs'09: Sustained Ocean Observations and Information for Society" Conference (Vol. 2)*, Venice, Italy, 21–25 September 2009, Hall, J., D.E. Harrison, and D. Stammer, Eds., ESA Publication WPP-306. [In press]

### *5.2. Other Relevant Publications*

*Listed below are some papers that have appeared in refereed literature since the start of FY09 that cite recent (post-2005) work by Observing System Research Studies investigators:*

Du Y, Xie SP, G. Huang , et al., 2009: Role of Air-Sea Interaction in the Long Persistence of El Nino-Induced North Indian Ocean Warming. J. Climate, 22 (8), 2023-2038.

Schott F.A., S.P. Xie, J.P. McCreary, 2009: Indian Ocean Circulation and Climate Variability. Rev. Geophys., 47, RG1002.

von Schuckmann K, F. Gaillard and P.Y. Le Traon, 2009: Global hydrographic variability patterns during 2003-2008, J. Geophys. Res., 114, C09007.

Cravatte S, T. Delcroix, D.X. Zhang, et al., 2009: Observed freshening and warming of the western Pacific Warm Pool, Climate Dynamics, 33(4), 565-589.

McPhaden M.J., G. Meyers G and K. Ando, et al., 2009: RAMA The Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction. Bull. Amer. Meteorol. Soc., 90 (4), 459-+.

Alory G and G. Meyers, 2009: Warming of the Upper Equatorial Indian Ocean and Changes in the Heat Budget (1960-99), J. Climate, 22 (1), 93-113.

Lyman J.M. and G.C. Johnson, 2008: Estimating Annual Global Upper-Ocean Heat Content Anomalies despite Irregular In Situ Ocean Sampling, J. Climate, 21 (21) , 5629-5641

Hu Z.Z. and B.H. Huang, 2009: Interferential Impact of ENSO and PDO on Dry and Wet Conditions in the US Great Plains. J. Climate, 22, (22), 6047-6065.

Ashok K. and T. Yamagata, 2009: CLIMATE CHANGE The El Nino with a difference Nature, 461,(7263) , 481-+.

Yeh S.W., J.S. Kug, B. Dewitte, et al. El Nino in a changing climate, Nature, 461(7263), 511-U70.

Kim H.M., P.J. Webster and J.A. Curry, 2009: Impact of Shifting Patterns of Pacific Ocean Warming on North Atlantic Tropical Cyclones, Science, 325 (5936), 77-80.

Goodrick S.L. and D.E. Hanley, 2009: Florida wildfire activity and atmospheric teleconnections,

Int. J. Wildland Fire, 18(4), 476-482.

McPhaden M.J. and X.B. Zhang, 2009: Asymmetry in zonal phase propagation of ENSO sea surface temperature anomalies, Geophys. Res. Lett., 36, L13703.

Kug, J.S., F.F. Jin and S.I. An, 2009: Two types of El Nino Events: Cold Tongue El Nino and Warm Pool El Nino, J. Climate, 22(6), 1499-1515.

Ashok, K., S. Iizuka, S.A. Rao et al., 2009: Processes and boreal summer impacts of the 2004 El Nino Modoki: An AGCM study, Geophys. Res. Lett., 36, L04703.

Weng, H.Y., S.K. Behera, T. Yamagata, 2009: Anomalous winter climate conditions in the Pacific rim during recent El Nino Modoki and El Nino events, Climate Dyn., 32(5), 663-674

Please note: the requested manuscripts authored by members of the Ocean Observing Systems Research Studies group can be downloaded in Adobe PDF format at the following website:

http://staff.washington.edu/chiodi/manuscripts/manuscripts.shtml