PMEL Ocean Climate Stations

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1. Project Summary

Figure 1: Ocean Climate Stations mooring sites. KEO: 32.3°N, 144.6°E; Station Papa: 50°N, 145°W.

NOAA's Ocean Climate Stations Project (OCS) currently maintains two reference station moorings in the North Pacific (Figure 1): The Kuroshio Extension Observatory (KEO) and Station Papa. KEO is located in the North Pacific's western boundary current region, which is characterized by extremely large ocean heat losses to the atmosphere and carbon dioxide uptake by the ocean. Station Papa is where an ocean weather ship was stationed from 1949-1981. Ocean measurements at Station Papa extend back almost six decades making it one of the longest ocean data sets in the world. These moorings are part of the Ocean Sustained Interdisciplinary Time series Environmental Observatory (OceanSITES) global network of ocean reference stations. Data from OCS moorings provide the foundation blocks for NOAA's Climate Observation Division's program deliverables of global climate analysis products.

OCS surface moorings carry a suite of sensors on the buoy tower and underwater on the buoy bridle. Sensors are also mounted on the mooring line and on the release connecting the mooring line to the chain above its anchor. Instruments on the buoy measure winds, air temperature, relative humidity, barometric pressure, rainfall, atmospheric and seawater carbon dioxide, downward infrared radiation from the sky, incident light (heat) from the sun, as well as sea surface temperature, salinity, dissolved oxygen, and pH. Sensors attached to the mooring line measure upper ocean temperature, salinity, and near surface ocean currents. A sensor mounted on the anchor release measures bottom water temperature, salinity and pressure. All of these co-located measurements, made over an extended time period, allow researchers to study exchanges of heat, moisture, momentum, and carbon dioxide between the sea and the air and their influence. These exchanges (referred to as air-sea fluxes) both depend on and impact the oceanic and atmospheric environments. Interactions between the ocean and atmosphere affect weather, local and global climate patterns, as well as ecosystems and the environment.

Users of OCS data range from school children to Ph.D. researchers around the world. Purposes for data use include validation of satellite products, validation and improvement of weather and climate models, detection of ocean and atmospheric interactions during typhoons and winter storms, and monitoring longer term changes in the climate system. Data from OCS moorings are also used in the study of ocean acidification resulting from rising levels of carbon dioxide concentrations in the atmosphere, and its impact on ocean ecosystems. Understanding climate processes and biases in models helps scientists to improve the numerical models used to predict weather patterns and potential risks to society. Better forecast models can help reduce vulnerability to weather and climate extremes, predict potential risks to coastlines and coastal infrastructure, and prepare a weather-ready nation.

2. Scientific and Observing System Accomplishments

2.1. Accomplishments

Successful ongoing operation of OCS moorings, and continued international partnerships
In FY13, the OCS group successfully performed deployment/recovery operations for all OCS moorings. The KEO mooring, first established in 2004, has now been successfully deployed ten times. For Station Papa, 2013 was the seventh year an OCS buoy was deployed at the site. The OCS mooring at Station Papa has become the primary observing platform at a site where weather has been monitored in some form since 1949. The long term data sets being established at these sites are valuable for monitoring ocean climate, both in the short term for improving weather forecasts, and long term for understanding and predicting climate variability and change.

All OCS moorings were initiated during large collaborative process studies, and have strong international partners. KEO was first deployed in June 2004 as part of the National Science Foundation (NSF) funded Kuroshio Extension System Study (KESS). At the conclusion of KESS, a NOAA partnership with the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) was formed. JAMSTEC now contributes shared time on their research vessels to perform KEO mooring maintenance operations. Station Papa was initially funded in 2004 through an NSF grant to Dr. Steve Emerson at the University of Washington (UW) to study the North Pacific Carbon Cycle. When the NSF process study ended, NOAA's Office of Climate Observations took over support of this mooring in 2009. The Canadian Fisheries and Oceans Canada, Pacific Region, Line-P program, provides ship time on the CCGS JOHN P TULLY for the Station Papa mooring maintenance. The OCS project values these international partnerships, which foster collaborations and broad use of the data from OCS moorings.

Published study of strong bottom currents and their effect on the global energy budget
In a study of ocean bottom currents off the coast of Africa, Cronin et al. (2013a) analyzed deep current meter data and output from two high-resolution global ocean circulation models. The study revealed the presence of strong currents at the bottom of the ocean in this area. These benthic storms are in many ways equivalent to atmospheric storms (Figure 2). Results suggest

that in regions with strong surface jets, energy can be transferred to the deep ocean, where it is dissipated through friction, making these regions important in the global energy balance.

The study was motivated in part to determine a good location for a new OCS mooring site in the region south of Africa. It would be difficult to maintain a surface mooring in regions where both strong surface currents and deep ocean storms are prevalent. Figure 2 suggests that a good location for an OCS mooring might be near 37°E, 36°S. This mooring would be highly valuable for direct measurements of ocean and atmospheric interactions in an area where the Indian, Atlantic, and Southern Oceans meet.

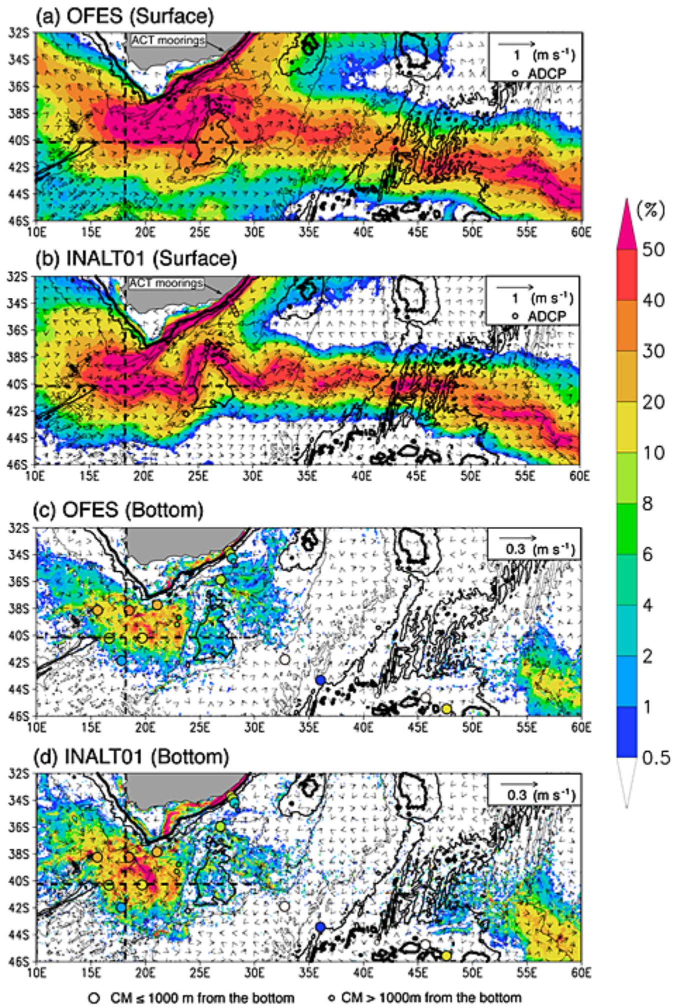

Figure 2:

Maps of currents greater than 0.5m/s at the surface (a and b), and greater than 0.2m/s at the bottom (c and d). Color represents percent of time when the current is above the listed threshold. Arrows indicate mean surface (a and b) and bottom (c and d) currents.

Panels a and c show values from the OFES model; panels b and d are from the INALT01 model.

Filled circles across the Agulhas Current near 30°E in panels a and b indicate surface measurements by Acoustic Doppler Current Profilers (ADCPs) on the Agulhas Current Time-Series (ACT) moorings.

Values from historical current meters (CM) located within 1000m of the bottom are indicated by large filled circles in panels c and d, while small filled circles indicate values from current meters located more than 1000m above the bottom. Thick, medium, and thin solid contours represent bottom depths of 1500, 3000, and 4500m, respectively.

From Cronin et al. (2013a).

Studies of the influence of surface waves on ocean and atmospheric interactions at Station Papa submitted for publication

Scientists from University of Washington Applied Physics Laboratory (UW APL) have been making surface wave observations near the OCS Papa mooring since 2010. This location was specifically chosen for its proximity to the OCS mooring in order to utilize OCS meteorological measurements, particularly wind stress. The studies and collaborations at this site have resulted in two papers submitted for publication in FY13, on which Dr. Cronin is a coauthor.

Thomson et al. (2013) investigated the dynamic balance between energy dissipation by breaking waves and energy input by wind stress. At moderate wind speeds (5 to 15 m/s) the wave observations appear to be in equilibrium with the wind stress measurements computed using standard drag laws. At high wind speeds (> 15 m/s), however, the wave energy is lower than that from the computed bulk wind stress, pointing to either deficiencies in the parameterizations of the wind stress or disequilibrium between the wind stress and wave field.

D'Asaro et al. (2013) showed that waves generate small-scale circulations that enhance the upper ocean turbulence. This type of turbulence is not accounted for in climate models, which may explain why climate models produce a mixed layer depth that tends to be too shallow, especially in the Southern Ocean.

Scientific advances with new research partners at Ocean Station Papa

The NOAA OCS Papa mooring will have a central role in the NSF Ocean Observatories Initiative (OOI) global node at Station Papa. In July 2013, OOI deployed a profiling mooring, two flanking moorings, and three gliders near the NOAA OCS mooring at Station Papa. Station Papa is the first of four planned OOI global nodes. Uniquely at this site, the NOAA OCS mooring serves as the central mooring of the OOI array, providing all meteorological data and additional subsurface measurements for the node.

Research collaboration encouraged through a science workshop hosted by OCS

Dr. Cronin organized a science workshop, "Holistic Ocean Balances at Station P," held at PMEL in Seattle, WA on April 4, 2013. Participants from PMEL, UW, and the Monterey Bay Aquarium Research Institute (MBARI) shared information about their various Station Papa research projects. This included four UW graduate students using the NOAA Station Papa data in their dissertations. The basic premise of the workshop was that each of the individual studies depends upon the observations and results of the others. By coming together to share techniques, results, and insights, the workshop helped each move forward and broaden their scope.

Data from OCS moorings made publicly available in standardized OceanSITES format

Special funding was provided to the OCS project in late FY12 to develop tools to provide OCS data in a standardized format expected of all OceanSITES data. In FY13, a database for OCS metadata was created, and formatted files were generated for the KE001 and PA003 deployments. These data files are in the NETCDF format (OS v1.2), and contain all OCS data, including redundant measurements. The files also contain complete metadata information, such as instrument serial numbers, calibration information, and contact information. While the OCS project believes that most users will access OCS data through the easy to use OCS data display and delivery pages, the OceanSITES format for the deployment files provides an excellent archival of all OCS data and relevant metadata needed to use the data.

Launch of updated OCS web pages

The Ocean Climate Stations public website has been completely redesigned in FY13. The new format is simple to navigate, and includes detailed information about the Ocean Climate Stations project, presented in an understandable way for any user, not just ocean scientists. The updated web pages can be viewed at http://www.pmel.noaa.gov/OCS/.

*NOTE: Due to the government shutdown, launch of the updated website has been delayed until November 8.

2.2. Deliverables

Calibrated surface meteorological measurements, and subsurface temperature, salinity and currents at KEO and Station Papa

The moorings maintained by the OCS project are foundation blocks for NOAA's Climate Observation Division's program deliverables of global climate analysis products. OCS moorings provide high quality reference data with excellent rates of return. Due to the harsh conditions of the North Pacific, all OCS moorings carry redundant meteorological sensors and two data acquisition systems. The ATLAS system is the primary system, and the Flex system provides secondary measurements and all data from the subsurface sensors.

All Available (real-time and delayed) data returns from OCS moorings in FY13 were better than 90% (Table 1), except for the primary system at KEO. This was slightly lower due to an early battery failure in KE010. The Real Time Flex returns at Papa were also lowered, due to an issue with subsurface instrument transmissions. This was corrected with the June 2013 deployment.

	KEO FY13*		Papa FY13	
Acquisition System	Real Time	All Available	Real Time	All Available
Primary (ATLAS)	75.7%	81.1%	99.7%	99.7%
Secondary (Flex)	94.6%	96.3%	84.4%	91.5%

Table 1: FY13 data return statistics for KEO and Papa moorings. *Includes period when KE010 was drifting (7 June-28 June 2013).

Access to OCS data and metadata in a standardized format and through linked web pages to encourage broad use of data

With the updated OCS web pages, it is easier than ever for anyone to access OCS data. Anything from an auto-generated plot to a full high resolution data set with accompanying metadata in multiple file formats can be accessed at http://www.pmel.noaa.gov/OCS. Figures 3 and 4 were generated using the tools on the OCS Data web page.

Real-time data are available on the OCS web site almost immediately after transmission. Highest resolution data logged internally on the moorings cannot be made available until the mooring is recovered, calibrations are completed, and data processors fully examine the data. It is the project goal to make high-resolution data available to the public within 12 months of the recovery of the mooring. The most recent high-resolution data available on the web pages are from the KE009 (KEO2011) mooring, recovered on July 5, 2012.

OCS web pages had over 197,000 site hits in FY13, and over 170 GB of text and data were downloaded by visitors. The OCS Data Display and Delivery page had 221 download requests, yielding 610 data files to users from around the world (US, Japan, Canada, UK, Australia, Spain, China, Taiwan, Russia). It should be noted that most users were anonymous and their domain name could not be tracked. Usage descriptions provided by the users included model and satellite data validation, sensor and parameter verification (winds, lidar, flux), research (wave studies, physical-biological coupling, air-sea interactions, wind calculations), and student projects. OCS data are also available through web pages that do not require user registration, so data download estimates provided here are low.

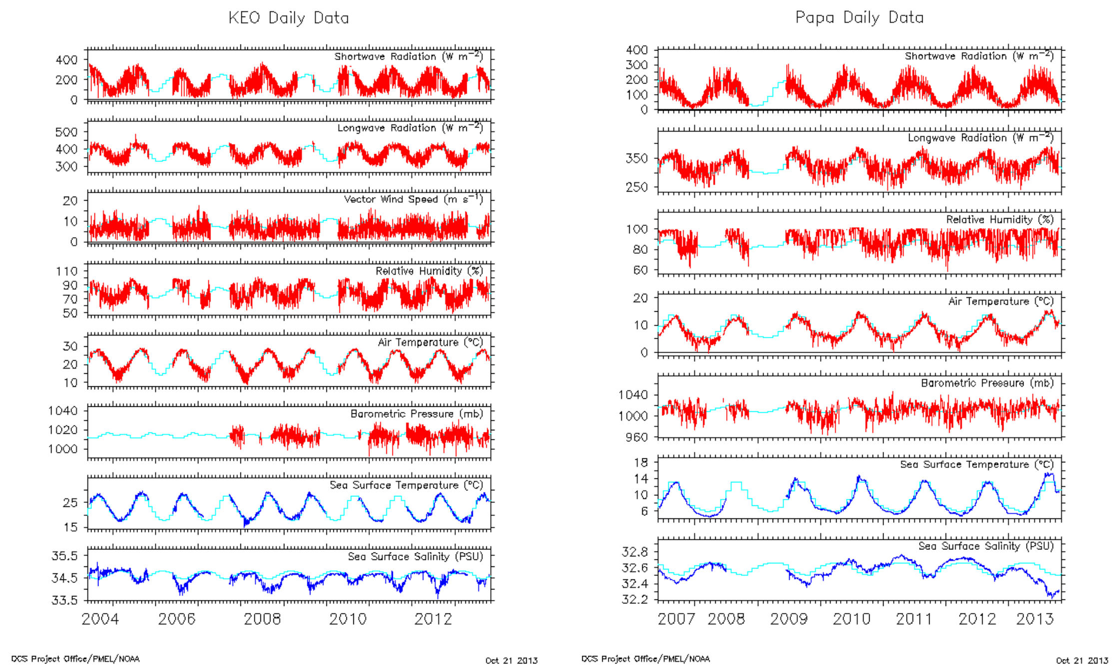

Figure 3: Data plots created from the OCS data web page of daily meteorological observations from the KEO mooring, 2004 to present (left), and from the Papa mooring, 2007 to present (right). Seasonal cycles are apparent in all parameters.

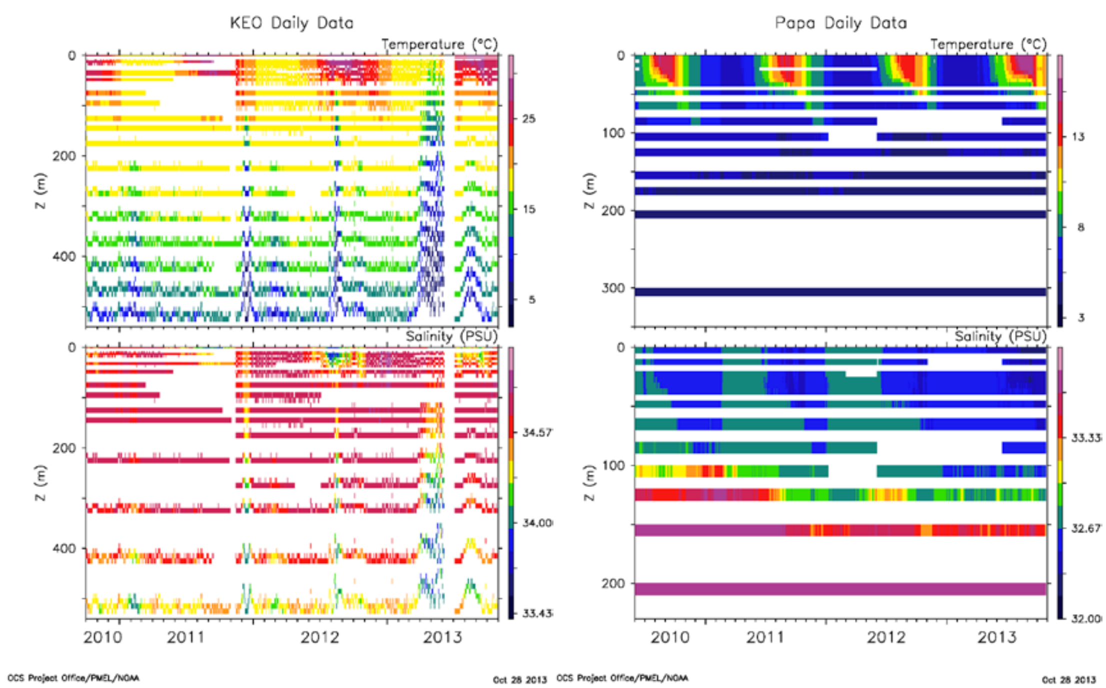

Figure 4: Data plots created from the OCS data web page of daily averaged subsurface temperature and salinity observations from the KEO mooring, October 2010 to present (left), and from the Papa mooring, June 2010 to present (right). The low temperature and salinity spikes observed at KEO (left) are caused by cold eddies and the Kuroshio Extension current passing the mooring.

OCS data are available in a variety of formats, including the OceanSITES standardized format discussed in Section 2.1. Files are available online from two Global Data Assembly Centers (GDACs), and links to the GDACs are on the "Data via OceanSITES" page of the OCS website (available after November 8, 2013): http://www.pmel.noaa.gov/OCS/data/oceansites_data.html

Use of OCS data by the broader community is encouraged by having multiple portals to the data. Surface meteorological data from the primary system are made available on the Global Telecommunications System (GTS) for use by operational data centers. OCS also works with several other partner groups, both within NOAA and internationally, that provide links to OCS web pages, as listed below. Websites that also serve OCS data are shown in bold.

OCS data display & delivery*: http://www.pmel.noaa.gov/OCS/disdel_v2/disdel_v2.html
OCS data display & delivery: http://www.pmel.noaa.gov/OCS/disdel/disdel.html
OCS ftp*: http://www.pmel.noaa.gov/OCS/data/ftpdata.html
OceanSITES: http://www.oceansites.org/data/index.html
KESS: http://uskess.org/data_public.html#buoy
JKEO/JAMSTEC: http://www.jamstec.go.jp/iorgc/ocorp/ktsfg/data/jkeo/
PMEL CO2: http://www.pmel.noaa.gov/co2/story/KEO and http://www.pmel.noaa.gov/co2/story/Papa
UW/APL Wave Measurements: http://www.apl.washington.edu/projects/station_papa/summary.html
UW/JISAO: http://jisao.washington.edu/research/oceanography-info
Surface Fluxes Analysis (SURFA) project: http://www.ncdc.noaa.gov/thredds/surfa.html
Integrated Ocean Observing System (IOOS): http://www.ioos.noaa.gov/data/other_data_portals.html
* These OCS websites will become available after November 8, 2013.

The OCS Data Management Plan further describes the storage and long term archiving of OCS data. This plan is available by request.

Scientific analyses utilizing OCS data

Dr. Cronin was an author on five peer-reviewed papers published in FY13, and three more that are under review. Findings from Cronin et al. (2013a), Thomson et al. (2013), and D'Asaro et al. (2013) are highlighted in Section 2.1. A full publication list is provided in Section 4.1.

In addition to Cronin et al. (2013a), Dr. Cronin was lead author on a paper using data from the Kuroshio Extension Observatory (KEO) to analyze upper ocean heat content and mixed layer temperature variations. Cronin et al. (2013b) found that during winter, cold, dry air blowing across the Kuroshio Extension current and its warm recirculation gyre, causes the ocean to rapidly lose heat to the atmosphere. Understanding how the heat is replenished and redistributed is critical for understanding the role of the ocean in the climate system. Long-term, high-resolution observations such as those made by the KEO surface mooring provide direct measurements for diagnosing these processes on time scales of minutes to decades in this highly variable region.

OCS data was also featured in several presentations at the CLIVAR/GSOP/WHOI Workshop on Ocean Syntheses and Surface Flux Evaluation, held in Woods Hole, Massachusetts, November 27-30, 2012. Recommendations from the workshop stressed the importance of using direct measurements from buoys to validate numerical models (Yu et al. 2013). The OCS KEO and Papa moorings were specifically chosen as high quality reference sites for this purpose.

Dr. Cronin is currently collaborating with NOAA scientists from the National Center for Environmental Prediction (NCEP)/Climate Prediction Center (CPC) to assess the Climate Forecast System Reanalysis (CFSR). This is a global, high resolution model of the coupled atmosphere-ocean-land surface-sea ice system. Data from the KEO mooring are being used to determine the realism of the CFSR air-sea heat exchanges in the western boundary current regime, where the ocean-atmosphere interactions can be very intense.

2.3. Issues

KEO mooring went adrift (recovered and redeployed)
On June 7, 2013, the OCS KEO mooring broke free from its anchor and went adrift. Fortunately, it was caught in an eddy south of the Kuroshio Extension current and remained within 250km of its nominal position. The servicing cruise was already scheduled to visit the KEO mooring at the end of June, and the buoy was successfully recovered on June 28, 2013, with all surface and subsurface instrumentation and gear. The replacement mooring was deployed on July 5, 2013. The recovered mooring was found to have broken in the nylon, and a failure analysis is being performed by PMEL's Engineering Development Division (EDD).

Deploying surface moorings in high latitudes, especially in areas of strong currents, is challenging, and equipment loss must be anticipated in these regions. For this reason, nearly all surface meteorological measurements on OCS moorings have redundant sensors. This has repeatedly proven to be extremely important. Most recently, typhoon Pabuk passed just west of KEO in September 2013, causing damage to several instruments on the buoy. Due to the presence of the redundant sensors, all parameters are still being measured.

Partners may lose ship time, leaving OCS with no funded ship time to service moorings
OCS relies on international partnerships for ship time to service the moorings. Without this free ship time, there is no money in the OCS budget to charter other vessels. If partners lose funding, or can no longer support the shared ship time, the OCS moorings may be in jeopardy.

3. Outreach and Education

Dr. Cronin is involved in helping to train the next generation of ocean scientists. On February 7, 2013, Dr. Cronin lectured to the UW Ocean 444C Course on the subject of "The Kuroshio Extension: A Hotspot to Visit." She serves as a committee member for two Ph.D. candidates, and one M.S. candidate at the UW, and also provides individual scientific guidance to three other UW graduate students. During FY13, she attended more than 25 individual meetings with these students. Dr. Cronin also acts as a Mentor Leader for the Mentoring Physical Oceanography Women to Increase Retention (MPOWIR) group.

To reach a younger generation, Dr. Cronin again participated in the NOAA Adopt-A-Drifter Program in FY13. She arranged for two adopted drifters to be deployed in the Agulhas Current on February 9, 2013. A University of Cape Town graduate student mentored by Dr. Cronin will use this drifter data in a study to be published in Geophysical Research Letters. Dr. Cronin also spoke about these drifter data with high school students from a township in South Africa via Skype on May 2, 2013. While participating in the Chapman Conference in South Africa during

October 2012, she visited a township high school and spoke with students about oceanography, and the Adopt-A-Drifter Program's science and goals. Additionally, Dr. Cronin's 13-year-old daughter visited two South African classrooms for peer-to-peer discussions. Dr. Cronin has helped Australian scientists develop a similar Adopt-A-Drifter program, and assisted South African scientists to develop a Teacher-At-Sea program modeled after the NOAA programs.

As part of outreach to the local community, Keith Ronnholm, the OCS project manager, participated in the NOAA open house at the Western Regional Center in Seattle on June 14, 2013. He led tour groups through the facility, discussing ocean engineering, the Weather Service, and work done in the Ocean Climate Stations project.

4. Publications and Reports

4.1. Publications by Principal Investigators

Published – Peer Reviewed

Wada, A., M. F. Cronin, A. Sutton, Y. Kawai, M. Ishii, 2013: Numerical simulations of interactions between Typhoon Choi-wan (0914) and the ocean. *J. Geophys. Res.*, **118**, 2667-2684, doi:10.1002/jgrc.20203.

Cronin, M. F., T. Tozuka, A. Biastoch, J. V. Durgadoo, L. M. Beal, 2013: Prevalence of strong bottom currents in the Greater Agulhas System. *Geophys. Res. Let.*, **40**, 1772-1776, doi:10.1002/grl.50400.

Bourassa, M., S. T. Gille, C. Bitz, D. Carlson, I. Cerovecki, M. F. Cronin, W. M. Drennan, C. W. Fairall, R. N. Hoffman, G. Magnusdottir, P. T. Pinker, I. A. Renfrew, M. Serreze, K. Speer, L. D. Talley, and G. A. Wick, 2013: High latitude ocean and sea ice surface fluxes: challenges for climate research. *Bull. Am. Meteorol. Soc.*, **94(3)**, 403-423.

Cronin, M. F., N. A. Bond, J. T. Farrar, H. Ichikawa, S. R. Jayne, Y. Kawai, M. Konda, B. Qiu, L. Rainville, H. Tomita, 2013: Formation and erosion of the seasonal thermocline in the Kuroshio Extension recirculation gyre. *DSR II*, **85**, 62-74, doi:10.1016/j.dsr2.2012.07.018.

Kumar, P., B., J. Vialard, M. Lengaigne, V. S. N. Murty, M. J. McPhaden, M. F. Cronin, F. Pinsard, and K. Gopala Reddy, 2013: TropFlux wind stresses over the tropical oceans: Evaluation and comparison with other products. *Climate Dyn.*, 23 pp, DOI 10.1007/s00382-012-1455-4.

Submitted – Peer Reviewed

D'Asaro, E., J. Thomson, A. Shcherbina, R. Harcourt, M. F. Cronin, M. Hemer, B. Fox-Kemper, 2013: Quantifying upper ocean turbulence driven by surface waves. *Sub. to Geophys. Res. Let.*

Rainville, L., S. R. Jayne, M. F. Cronin, 2013: Variations of the Subtropical Mode Water in the Kuroshio Extension from direct observations. *Sub. to J. Clim.*

Thomson, J., E. D'Asaro, M. F. Cronin, E. Rogers, R. Harcourt, A. Shcherbina, 2013: Waves and the equilibrium range at Ocean Weather Station P. *Sub. to J. Geophys. Res.*

Newsletters – Online

Keene, J.A., 2013: Papa Mooring Central to Ocean Observatories Initiative Global Node. *PMEL Hot Items*, http://pmel.hotitems.noaa.gov/storyDetail.php?sid=657.

Cronin, M.F., 2012: PMEL Scientist Visits African Township School. *PMEL Hot Items*, http://pmel.hotitems.noaa.gov/storyDetail.php?sid=621.

Proceedings from Conferences

Yu, L., K. Haines, M. Bourassa, M. Cronin, S. Gulev, S. Josey, S. Kato, A. Kumar, T. Lee, and D. Roemmich, 2013: Towards achieving global closure of ocean heat and freshwater budgets: Recommendations for advancing research in air-sea fluxes through collaborative activities, *Report of the CLIVAR GSOP WHOI Workshop on Ocean Syntheses and Surface Flux Evaluation*, Woods Hole, MA, 27-30 November 2012, WCRP Informal/Series Rep. No. 13/2013, ICPO Informal Rep. 189/13, 42 pp.

Fairall, C.W., M.A. Bourassa, M.F. Cronin, S.R. Smith, R.A. Weller, G. Wick, S. Woodruff, L. Yu, and H.-M. Zhang, 2012: Observations to quantify air-sea fluxes and their role in global variability and predictability. *Proceedings of the IOOS Summit, Interagency Ocean Observation Committee (IOOC)*, Herndon, Virginia, 13-16 November 2012, http://www.iooc.us/summit/white-paper-guidelines/community-white-paper-submissions/.

Lumpkin, R., K. Dohan, M. Baringer, L. Centurioni, M. Cronin, G. Goni, G. Lagerloef, D. Lee, and N. Maximenko, 2013: Observing the global ocean surface circulation. *Proceedings of the IOOS Summit, Interagency Ocean Observation Committee (IOOC)*, Herndon, Virginia, 13-16 November 2012, http://www.iooc.us/summit/white-paper-guidelines/community-white-paper-submissions/.

Technical Reports

Keene, J.A., 2013: Flex Battery Depletion in PA006 Mooring, *PMEL OCS Tech. Note 8*, 3 pp.

Keene, J.A., 2013: Investigation of RH Calibration Method, *PMEL OCS Tech. Note 7*, 13 pp.

Keene, J.A., 2012: Ship Requirements for OCS Buoy Servicing, *PMEL OCS Tech. Note 6*, 3 pp.

Data Reports

Keene, J.A. M.F. Cronin, K.B. Ronnholm, H.P. Freitag, 2013: NOAA/PMEL/OCS Data Acquisition and Processing Report for KE001, 13 pp.

Cruise Reports

Keene, J. and M. Craig, 2013: Cruise Report PA1-13-TU: Deployment / Recovery of Papa Mooring at 50°N 145°W, 7 June – 24 June 2013, 10 pp.