PMEL Ocean Climate Stations

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1. Project Summary

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.

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

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. Primary Achievements

Successful ongoing operation of OCS moorings, and continued international partnerships
In FY14, the OCS group successfully performed deployment/recovery operations for all OCS moorings. The KEO mooring, first established in 2004, has now been deployed for its 11th year. Data from the KEO mooring has become valuable for improving understanding of the effects of tropical cyclones and typhoons. For Station Papa, 2014 was the eighth 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. It now also serves as the central mooring of an OOI global node established at Station Papa in July 2013. 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.

Upgrades to OCS moorings allow hourly data telemetry, and added capabilities
The OCS moorings began as adapted ATLAS moorings, using primary technologies originally developed in 1994. These systems telemetered spot values and daily-averages of the primary meteorological sensors when a satellite signal was available. The systems had become outdated, and were limiting the growth of project capabilities.

Through a proposal that was awarded Sandy Supplemental Funds, both OCS moorings were updated for the 2014 deployments. The old ATLAS data acquisition systems were replaced with updated Flex systems, called TFlex. Real-time data loss issues caused by a systemic problem in the existing Flex system were also addressed and resolved for the 2014 deployments. Flex/TFlex transmit hourly data via Iridium, and have expanded instrumentation capabilities. In early August, 2014, hourly data telemetered from the primary Flex system were made available on the GTS, using the new BUFR format template 315008. According to Pierre Blouch at Meteo-France, it appears that OCS moorings are the first to use this new template, which was declared operational by WMO in May 2014.

Now that the data systems on both moorings have been upgraded, new capabilities can be added more easily. One of the main features of the Flex system is the ability to add code and hardware to communicate with new instrumentation. A major future goal is to add a sensor capable of making direct flux measurements. By comparing fluxes based on direct observations to fluxes computed by models, the models may be improved to more accurately reflect actual conditions.

Data from KEO mooring used in typhoon forecasting exercise
As part of the proposal awarded the Sandy Supplemental Funds described above, transmissions from the primary data system on the KEO mooring were increased to once per hour. This allows data from the mooring to be monitored by researchers in near real-time, which becomes valuable during storm events. Direct measurements can be compared to model outputs, in hopes of identifying and decreasing forecasting errors.

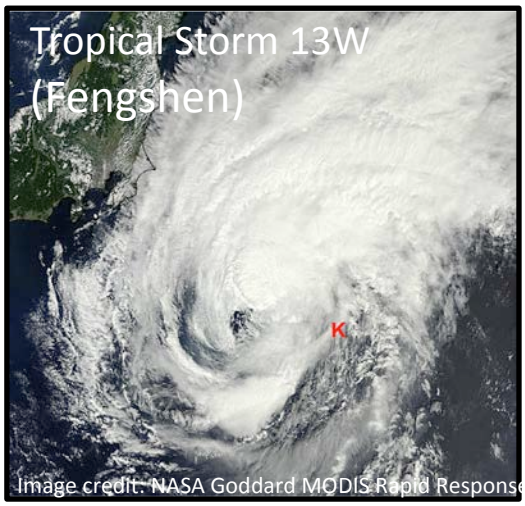

Figure 2: Tropical Storm Fengshen passed the KEO mooring on September 9, 2014.

The KEO mooring is routinely in the path of typhoons and tropical cyclones, making it ideal for this type of storm monitoring. It has already survived three tropical storms since being deployed in July. Complete hourly data sets were successfully reported throughout the storms.

During the passage of the second storm, named Kammuri, Co-PI Dr. Bond coordinated with Dr. Hyun-Sook Kim at NOAA's Environmental Modeling Center to perform a real-time typhoon forecasting exercise. Actual measurements of conditions from the KEO mooring were compared to the conditions predicted by the models. KEO data showed a deeper and warmer mixed layer, and a more sharply defined thermocline than the HYCOM model. As expected based upon these biases, the model predicted cooling was about 1°C greater than what was observed. The model

simulation also included stronger currents than observed, contributing to the excessively strong turbulent mixing in the simulation.

This exercise mainly focused on the feasibility of carrying out a real-time comparison. With hourly data now available on the GTS, the value of using high-resolution time series data for improved forecasts will continue to be investigated in future efforts. Any lessons learned may potentially be applied to forecasts for hurricanes impacting the U.S.

Published study explores the role of mixed layer depth in oceanic frontogenesis

In a study by Tozuka and Cronin (2014), it was found that meridional variations in the mixed layer depth could affect frontogenesis of the sea surface temperature (SST). This study is the first to show that the mixed layer depth structure plays a role in modifying the SST front.

In the 40°E – 50°E band of the Agulhas Return Current region off the coast of Africa, frontal variations in the surface heat flux may relax the oceanic SST front. It was observed that during austral summer (January) relaxation of the SST front due to mixed layer depth variations counteracts strong frontogenesis associated with oceanic processes. In contrast, during winter (July), mixed layer depth frontal variations cause air-sea fluxes to have only a small relaxation effect on the SST front, allowing oceanic current frontogenesis effects to dominate (Figure 3).

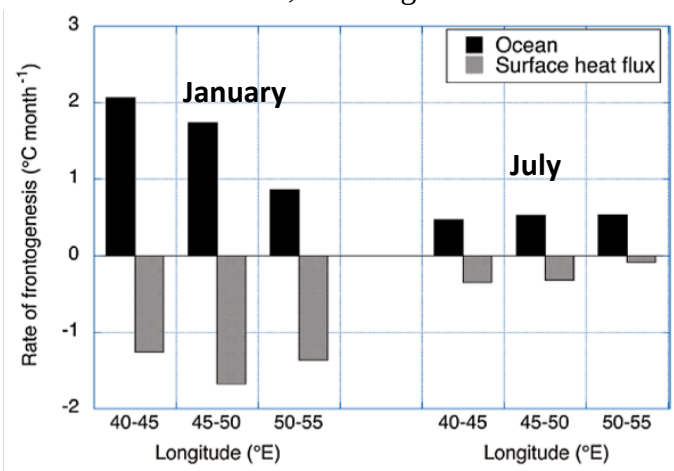

Figure 3: Observed rate of frontogenesis (in °C / month) of the SST front by the oceanic terms (black bar) and the surface heat flux term (gray bar) in (left) January and (right) July. A negative rate of frontogenesis indicates frontolysis (relaxation of the front).

From Tozuka & Cronin, 2014.

These findings have implications for model studies of the atmospheric response to ocean fronts. If the coupled model does not properly resolve the mixed layer depth, the ocean frontogenesis may be degraded and reduce the modeled impact of the SST front on the atmosphere. This study highlights the importance of understanding the processes affecting mixed layer variability. A similar study for the Kuroshio Extension region is in progress.

KEO data used to track origin of high-salinity near-surface water in KE region

Dr. Cronin collaborated with JAMSTEC partners in a study of the origins of a near-surface salinity anomaly in the Kuroshio Extension (KE) region. Using hydrographic data from the KEO and JKEO moorings and from ship observations in the KE region from 2008 to 2010, Nagano et al. (2014) showed large year-to-year variability in the near-surface salinity in this region, including a very large anomalous event in February 2010. During this event, the deep winter mixed layer in the southern KE region had higher salinity than had existed during the previous summer. Analysis showed that this was the result of advection from the Philippine Sea, along

the southwestern branch of the North Pacific subtropical gyre. This process, taking approximately nine months as shown in Figure 4, contributes to the inter-annual salinity and temperature variability in the southern KE region.

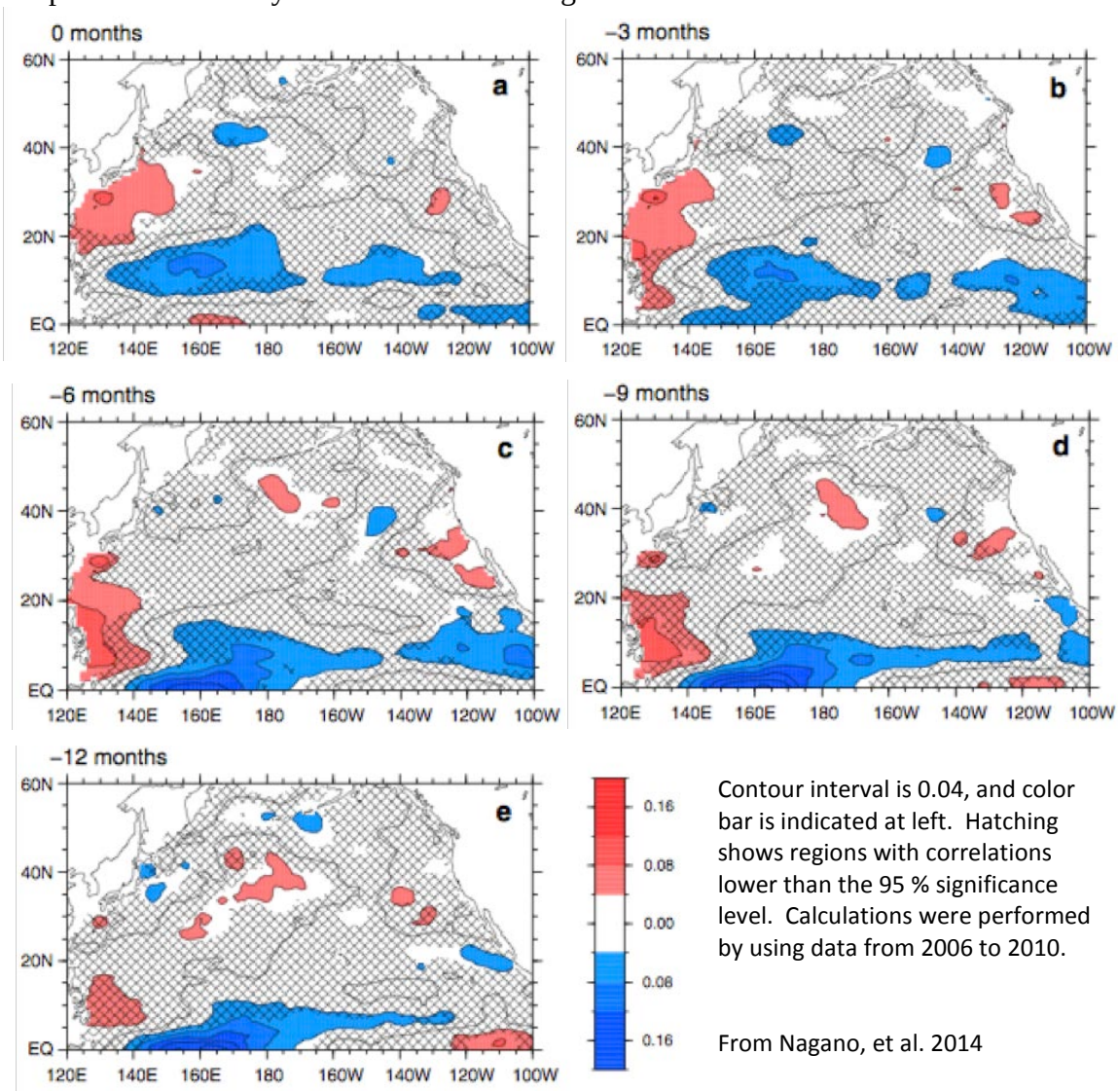

Figure 4: (a) Simultaneous covariance of salinity relative to that measured at KEO shows a significant peak in the region southeast to south of Japan, exceeding 0.04 (in red). Modeling the preceding 3–9 months, the covariance peak is seen to move in from the southward direction. (b) 3 months in advance near the Ryukyu Islands around 25°N, 130°E. (c) 6 months in advance near the eastern region of Taiwan. (d) 9 months in advance near the Philippines. (e) The covariance in the Philippine Sea is insignificant at 12 months lead time.

The results of the Nagano study provide information about the life history of the water mass occupying the near-surface layer in the KE region. Past studies on the water mass properties in this region have generally focused on local or regional ventilation processes. Effects of water masses remotely generated in the tropics east of the Philippines were not previously taken into account, but should not be ignored. Long-term monitoring of hydrographic variations in both key areas, the KE region and Philippine Sea, may provide new insight into the mid-latitude ocean–atmosphere interaction.

Dr. Nagano has submitted a proposal to move the JKEO mooring from its current location north of the KE jet, to a location much further south, at 13°N, 137°E, to more directly monitor these interactions in the Philippine Sea. The KEO mooring would remain in place to provide measurements from the KE region. If the proposal is funded, there would be a meridional line of observing stations extending from the equator up to KEO. An observing array would provide additional opportunities to form research partnerships with Japanese colleagues at JAMSTEC.

2.2. Data Collection and Distribution

Calibrated surface meteorological measurements, and subsurface temperature, salinity and current data acquired at KEO and Station Papa

The moorings maintained by the OCS project deliver continuous instrumental records for measurements of surface meteorology, upper ocean temperature, salinity, and currents. Deep ocean temperature and salinity have also been measured since the 2012 deployments. These data sets are a foundational part of the Climate Observation Division's priority to provide 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. As stated previously, the ATLAS system was replaced with an updated Flex system (called TFlex) during the summer 2014 servicing cruises.

Data returns for all systems in the water during FY14 are shown in Table 1. The passage of a typhoon during the fall of 2013 caused some instrument damage on the KEO mooring, which lowered the data returns. Since being serviced in 2014, the primary sensors on both Flex and TFlex at KEO have been fully functional. The lower Flex data returns at Papa were also due to issues with the system deployed in 2013. This was repaired for the 2014 deployment.

	KEO FY14		**Papa FY14**	
Acquisition System	Real Time	All Available	Real Time	All Available
Flex (Primary Sensors)	84.9%	86.8%	39.3%	81.0%
TFlex (Deployed 6/14)	99.9%	99.9%	99.5%	99.5%
ATLAS (Recovered 6/14)	55.5%	71.4%	99.6%	99.6%

Table 1: FY14 data return statistics for KEO and Papa moorings.

Real-Time and Delayed-Mode data available online

Public data access is made simple through the OCS website. 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 5 and 6 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 moorings deployed in 2013, which were recovered in June 2014.

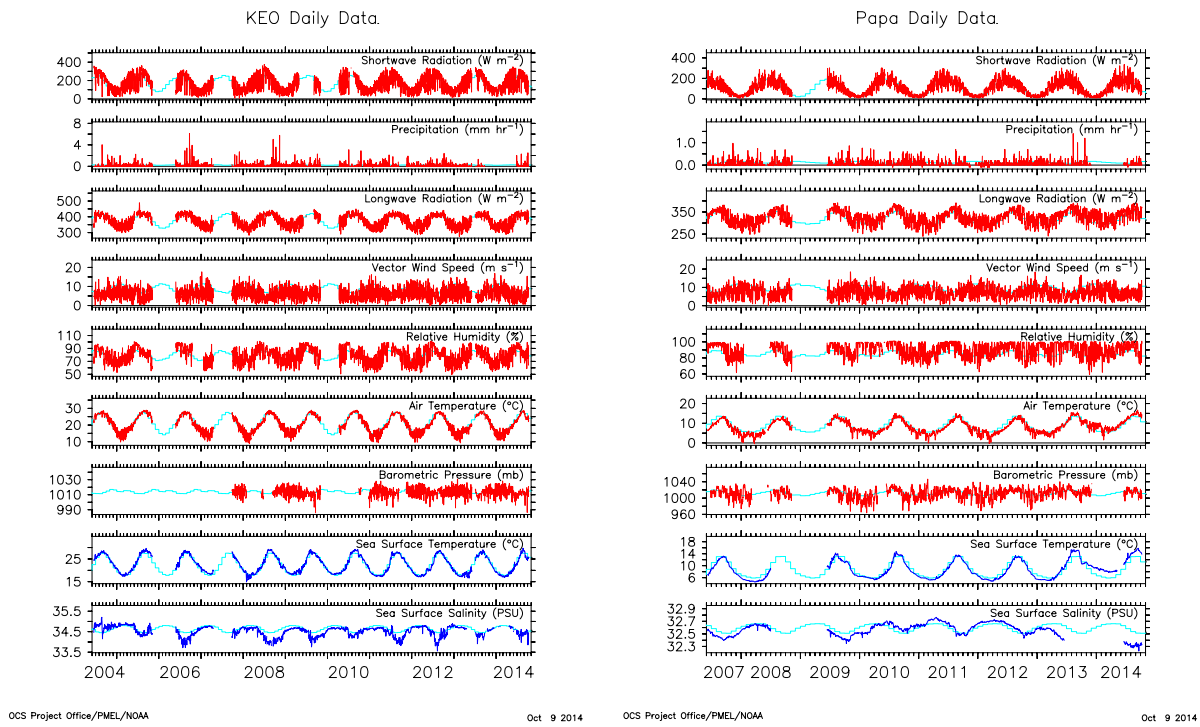

Figure 5: Data plots created from the OCS data web page of daily meteorological observations from the KEO mooring, 2004 to present (left), and from the Papa mooring, 2007 to present (right). Seasonal cycles are apparent in all parameters.

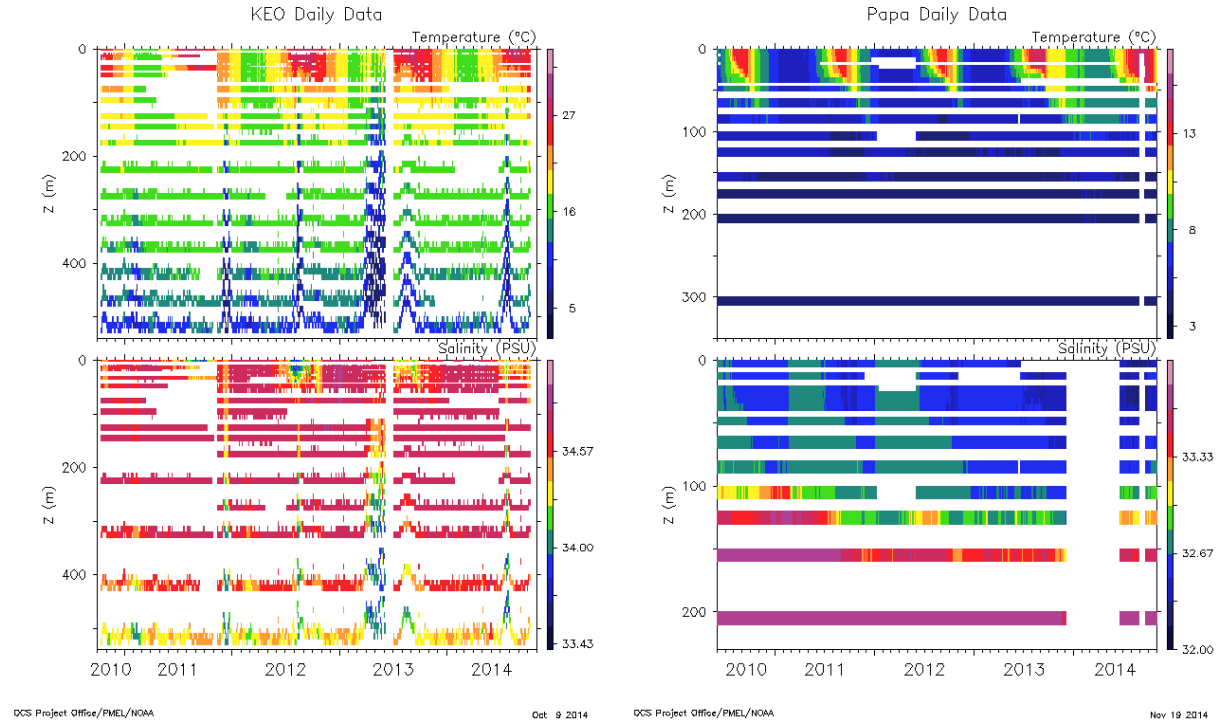

Figure 6: Data plots created from the OCS data web page of daily averaged subsurface temperature and salinity observations from the KEO mooring, October 2010 to present (left), and from the Papa mooring, June 2010 to present (right). The large gap in the Papa salinity data in 2014 was caused by a problem with real-time transmissions. This will be filled when the recovered delayed-mode data are completely processed.

OCS data are available in a variety of formats, including the OceanSITES standardized format. 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: 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. All data from the primary systems 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 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 , 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
Observing System Monitoring Center: http://www.osmc.noaa.gov
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

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

Uptake and use of project data

During FY14, OCS made substantial changes to its websites and online data download portals. The individual mooring sites now redirect users to a newly revamped central website. In FY14, OCS web pages received over 174,000 site hits, with over 247 GB of text and data downloaded by visitors. The OCS Data Display and Delivery page had over 500 download requests, yielding over 1900 data files to users from around the world (US, Japan, Canada, UK, India, Norway, Belgium, France, China, Russia, Germany). Compared to FY13, this is more than a factor of two increase in the number of data file requests, and more than a factor of three increase in the number data files provided.

Usage descriptions voluntarily provided by the users included model and satellite data validation, sensor and parameter verification, oceanographic instrument diagnostics, research (acoustic rainfall analysis, seasonal thermocline study, physical-biological coupling, air-sea interactions, wind calculations, gas saturation rates), data for advanced statistical methods instruction, and student projects.

It should be noted that most users were anonymous and their domain names were not tracked. A request for user information appears as a pop-up window when data are downloaded, but completing the form is not required for data access. Information for users accessing data from other websites is not currently captured.

3. Outreach and Education

3.1. Outreach

Since launching the new project website in November 2013, additional focus has been placed on improving outreach to the community through an enhanced online presence. Three short online news articles were written for the PMEL "What's New" page (see Publications), with links to longer versions and further explanation provided on the OCS web pages. These are intended to be basic yet informative messages, targeted to the interested public.

Of interest to the local community was the article on unusually warm surface water in the Northeast Pacific, posted on June 16, 2014. Based on information from Co-PI Dr. Bond, the State Climatologist for Washington State, this story discussed the effects warm surface water would have on local weather and fisheries. Similar stories were published in the *Washington Post*, *Seattle Times*, and *Bellingham Herald* newspapers, and other media outlets. The Papa mooring sits in the midst of this anomaly, providing measurements of the present conditions, as well as a record of historical ocean surface temperatures.

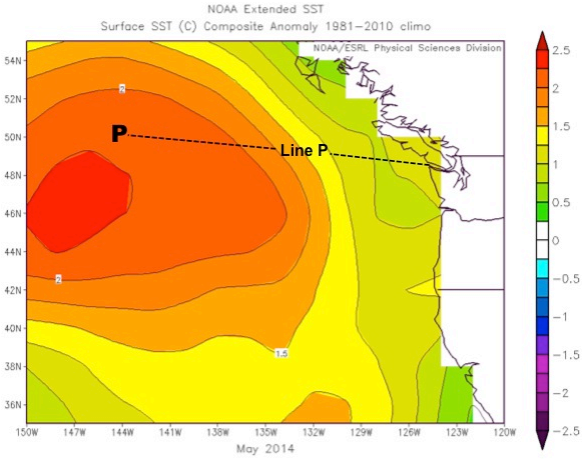

Figure 7: Warm water anomaly in NE Pacific, May 2014. OCS Papa mooring location marked by "P".

The most recent "What's New" article, posted on September 18, 2014, described the success of the KEO mooring recording and transmitting data during the passage of Tropical Cyclone Fengshen. Keith Ronnholm, the OCS project manager, notified NASA of the story, and it was then linked on the NASA Hurricane Facebook and Twitter accounts, which reach over 350,000 followers (www.facebook.com/NASAHurricane).

As part of outreach to the local community, Keith Ronnholm also participated in the NOAA open house at the Western Regional Center in Seattle on May 16, 2014. He led tour groups through the facility, discussing ocean engineering, the Weather Service, and work done in the Ocean Climate Stations project.

Dr. Cronin is also passionate about bringing scientists together. She serves as the co-organizer of the UW NE Pacific Brownbag Lunch series, inviting local scientists involved in NE Pacific research from a range of disciplines. She was also the co-convener and session organizer for the "Air-sea interactions in western boundary current systems and marginal seas" session at the 11th Annual Meeting of the Asia Oceania Geosciences Society, held July 28 – August 1, 2014, in Sapporo, Japan.

3.2. Education

Dr. Cronin is involved in helping to train the next generation of ocean scientists. She serves as a committee member for two Ph.D. candidates at the UW, and also provides individual scientific guidance to several other UW graduate students. During FY14, she attended over 18 individual meetings with seven different students. Data from OCS moorings are being used in four UW

Ph.D. dissertations. Dr. Cronin also acts as a Mentor Leader for the Mentoring Physical Oceanography Women to Increase Retention (MPOWIR) group, participating in monthly teleconferences.

During the summer of 2014, Dr. Cronin served as mentor for Hollings Scholar Kelly Balmes. An undergraduate meteorology major from Pennsylvania State University, Ms. Balmes performed a research project evaluating the effects of clouds on solar and longwave radiation measurements on the OCS moorings. Her project produced a poster, and publication-quality findings, which she will be presenting at the annual AGU conference in December 2014, and the AMS conference in January 2015. Ms. Balmes is interested in pursing graduate studies at the University of Washington, and Dr. Cronin would like to have her as a student if funding is available.

This research was so successful and valuable to the OCS project that another Hollings Scholar will work with OCS during the summer of 2015. Mr. Ryan Creedon, another undergraduate meteorology major from Pennsylvania State University, will compare data from the OCS moorings to results from the K Profile Parameterization model, to study how accurately changes in upper ocean stratification can be estimated from a one-dimensional mixing model.

4. Publications and Reports

A full publication list for FY14 is provided below, and a bibliography of relevant publications using OCS data is also supplied online through the OCS website.

4.1. Publications by Principal Investigator

Published – Peer Reviewed

D'Asaro, E.A., J. Thomson, A.Y. Shcherbina, R.R. Harcourt, M.F. Cronin, M.A. Hemer, and B. Fox-Kemper, 2014: Quantifying upper ocean turbulence driven by surface waves. *Geophys. Res. Lett.*, **41(1)**, 102–107, doi: 10.1002/2013GL058193.

Kawai, Y., H. Tomita, M.F. Cronin, and N.A. Bond, 2014: Atmospheric pressure response to mesoscale sea surface temperature variations in the Kuroshio Extension region: In situ evidence. *J. Geophys. Res.*, **119(13)**, 8015 – 8031, doi: 10.1002/2013JD021126, 8015–8031.

Nagano, A., K. Uehara, T. Suga, Y. Kawai, H. Ichikawa, and M.F. Cronin, 2014: Origin of near-surface high-salinity water observed in the Kuroshio Extension region. *J. Oceanogr.*, **70(4)**, 389-403, doi: 10.1007/s10872-014-0237-5.

Rainville, L., S.R. Jayne, and M.F. Cronin, 2014: Variations of the North Pacific Subtropical Mode Water from direct observations. *J. Climate*, **27(8)**, 2842–2860, doi: 10.1175/JCLI-D-13-00227.1.

Thomson, J., E. D'Asaro, M.F. Cronin, W.E. Rogers, R.R. Harcourt, and A. Shcherbina, 2013: Waves and the equilibrium range at Ocean Weather Station P. *J. Geophys. Res.*, **118(11)**, 5951–5962, doi: 10.1002/2013JC008837.

Tozuka, T., and M.F. Cronin, 2014: Role of mixed layer depth in surface frontogensis: The Agulhas Return Current front. *Geophys. Res. Lett.*, **41(7)**, 2447–2453, doi: 10.1002/2014GL059624.

Submitted – Peer Reviewed

Tomita, H., Y. Kawai, M.F. Cronin, T. Hihara, and M. Kubota, Submitted: Validation of AMSR2 sea surface wind and temperature over the Kuroshio Extension region. Submitted to *J. Oceanogr*.

Proceedings from Conferences – Non-Peer Reviewed

Cronin, M.F., and Co-authors, 2014: TPOS White Paper #11: Wind stress and air-sea fluxes observations: status, implementation and gaps. *In Proceedings of the Tropical Pacific Observing System 2020 Workshop, A Future Sustained Tropical Pacific Ocean Observing System for Research and Forecasting*, La Jolla, CA, 27–30 January 2014.

Technical Reports

Belka, D., M. Schwendeman, J. Thomson, and M.F. Cronin, 2014: Historical Wave and Wind Observations at Ocean Station P. *APL-UW Tech Report*, University of Washington Applied Physics Laboratory, Seattle, WA.

News Articles – Online

Keene, J.A., M.F. Cronin, K.B. Ronnholm, 2014: KEO Mooring Records Tropical Cyclone Fengshen. *PMEL What's New*, http://pmel.noaa.gov/news-story/keo-mooring-records-tropical-cyclone-fengshen.

Keene, J.A., M.F. Cronin, N.A. Bond, 2014: PMEL Researchers Monitor Unusually Warm Surface Water in Northeast Pacific, *PMEL What's New*, http://pmel.noaa.gov/news-story/pmel-researchers-monitor-unusually-warm-surface-water-northeast-pacific.

Keene, J.A., M.F. Cronin, 2013: KEO Mooring Survives Three Typhoons in One Month, *PMEL Hot Items*, http://pmel.hotitems.noaa.gov/storyDetail.php?sid=664.

4.2. Other Relevant Publications

Okuro, A., K. Marahisa, H. Tomita, and T. Hihara, 2014: Inter-comparison of various global sea surface temperature products, *International J. of Remote Sensing*, **35(14)**, 5394 – 5410, doi: 10.1080/01431161.2014.926415

Hosoda, K., 2013: Empirical method of diurnal correction for estimating sea surface temperature at dawn and noon, *J. Oceanogr.*, **69**, 631-646, doi:10.1007/s10872-013-0194-4.

Peng, G., H.-M. Zhang, H. P. Frank, J.-R. Bidlot, M. Higaki, S. Stevens, and W. R. Hankins, 2013: Evaluation of Various Surface Wind Products with OceanSITES Buoy Measurements, *Wea. Forecasting,*, **28**, 1281-1303, doi: 10.1175/WAF-D-12-00086.14