PMEL Ocean Climate Stations

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1. Abstract

The NOAA Pacific Marine Environmental Laboratory (PMEL) Ocean Climate Station (OCS) program maintains two Ocean Sustained Interdisciplinary Time series Environmental Observatory (OceanSITES) time series reference stations: The Kuroshio Extension Observatory (KEO) at 32.3°N, 144.5°E and Station Papa at 50°N, 145°W. The J-KEO site at 38°N, 146.5°E is now operated by JAMSTEC, and phase 1 funding to PMEL terminated in FY09. Likewise, during FY09, funding support for Station Papa transitioned from National Science Foundation to NOAA Climate Programs funding so that both OCS sites are now funded exclusively through NOAA Climate Programs. The PMEL OCS group had three cruises in FY09: a 3-day cruise aboard the crab vessel Aquila to recover the drifting Papa-2008 buoy, an 18-day cruise aboard the CCGS John P. Tully to deploy the Papa-2009 mooring, and a 15-day cruise aboard the JAMSTEC R/V Kaiyo to recover KEO-2008 and deploy KEO-2009. OCS moorings have redundant meteorological sensors with one set telemetered through the ATLAS "tube" using Service Argos and one set telemetered through the new FLEX "box" using Iridium. The FLEX box was also used for telemetering the high resolution subsurface temperature, conductivity, pressure and current measurements beginning in FY09. While the potential capability is far greater with the new FLEX system over the legacy ATLAS system, the subsurface telemetry from the new system has had some transmission problems that we hope to resolve in future deployments. The new FLEX system has required substantial testing, and the development of new hardware, software, and data processing procedures. Data from the recovered KEO-2008 mooring and Papa-2008 buoy have been processed and made available in a variety of formats including the standard OceanSITES netcdf format. OCS data are being used in a wide range of analyses. In particular, the KEO data were presented by Cronin at an invited talk at the Fall 2008 American Geophysical Union annual meeting, at a workshop on Air-sea interaction in western boundary current extensions workshop in January 2009, and at the KESS workshop at University of RI in June 2009. Cronin presented the Papa data at a Carbon Cycle workshop at University of

Washington in March 2009. Due to her experience with KEO, Cronin was lead author for the OceanObs09 Community White Paper (CWP) "Monitoring Air-Sea Interaction in Western Boundary Current Extensions", presented in Venice, Italy in September 2009. All told, during FY09, OCS has been involved in 2 OceanObs09 CWP, 1 Plenary White Paper, 2 publications, 1 in press publication, 4 submitted publications, several in progress, and several non-refereed publications.

2. Project Summary

High-quality, in situ reference time series are needed to assess uncertainties in the NOAA Office of Climate Observations global climate analysis deliverables of air-sea exchanges of heat, momentum, and freshwater, ocean carbon uptake, surface currents and other. To this end, the NOAA Pacific Marine Environmental Laboratory (PMEL) Ocean Climate Station (OCS) program maintains two Ocean Sustained Interdisciplinary Time series Environmental Observatory (OceanSITES) reference stations: The Kuroshio Extension Observatory (KEO) at 32.3°N, 144.5°E and Station Papa at 50°N, 145°W (see Fig. 1). OceanSITES reference stations provide high quality data that can be used: to assess biases and uncertainties in forecasting model and observational product analyses; to detect rapid changes and episodic events, as well as long-term changes, in the climate system; and to identify mechanisms and relationships within the climate system. Both OCS reference stations are in distinct oceanic regimes. The KEO mooring is located in the Kuroshio Extension recirculation gyre, which has some of the largest air-sea heat, moisture and carbon dioxide fluxes found in the entire basin. The Station Papa mooring is located in the Gulf of Alaska at the site where a weathership was stationed from 1949-1981 and where the impacts of ocean acidification, resulting from increasing levels of atmospheric carbon dioxide, are expected to be felt first. Both stations were also 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 partnership with the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) was formed and the mooring deployment and recovery operations have since been performed on JAMSTEC cruises. Station Papa was initially funded through an NSF grant to Dr. Emerson (University of Washington) to study the North Pacific Carbon Cycle. At the conclusion of the NSF process study, NOAA Office of Climate Observations took over support of this site. Shiptime for the Station Papa mooring has been provided by the Canadian Fisheries and Oceans Canada, Pacific Region, Line-P program. Both moorings carry a suite of sensors to monitor air-sea heat, moisture, momentum, and CO_2 fluxes, as well as the upper ocean temperature, salinity, and currents. Most surface and subsurface data are telemetered to shore in near-realtime and made available through the project website: http://www.pmel.noaa.gov/OCS/ in a variety of formats including the standard OceanSITES data format. The OCS data are served through the PMEL OceanSITES Data Assembly Center (DAC) and also through the OceanSITES Global DAC (GDAC). A subset of the surface meteorological data are also made publicly available in near-realtime through the Global Telecommunications System, used by operational data centers. The data serve a broad community of researchers and operational centers in the US and internationally.

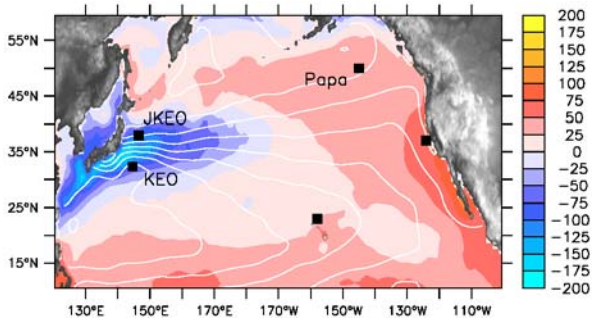

Figure 1. The network of OceanSITES reference stations in the North Pacific are shown relative to the mean net air-sea heat flux in Watts per meter square and mean sea level height contours.

3. Scientific Accomplishments

The OCS project has 3 broad deliverables, each described below. Co-PI Bond was supported for 3 months in FY09 through a NSF-funded KESS project titled "Kuroshio Extension System Study (KESS) – Upper and deep ocean response to atmospheric forcing in the Kuroshio Extension". As described below, he is involved in many of the KEO analyses. As a synoptic meteorologist, he also provides invaluable advice on how to make this data set most useful to operational centers and has been a vocal advocate of the OCS program within the climate community, helping the program connect with a wider user base. The Carbon component of KEO is described separately in the progress report for Sabine's "High-Resolution Ocean and Atmosphere pCO_2 Time Series Measurements" project.

Deliverable 1: Calibrated surface meteorological and subsurface temperature, salinity and currents at KEO and Station Papa

Operation of OCS moorings require refreshing the system at least once a year, pre- and post-calibrating all sensors, processing realtime data and making it available in near-realtime through the OCS website, processing delay-mode high resolution data and making it available with 6 months through the OCS website.

In November 2008 the Papa-2008 buoy broke away from its anchor and began drifting in the Gulf Alaska. As a result, the PMEL OCS group had three cruises (rather than two) in FY09: a 3-day cruise in January 2009 aboard the crab vessel Aquila to recover the drifting Papa-2008 buoy, an 18-day cruise in June 2009 aboard the CCGS John P. Tully to deploy the Papa-2009 mooring, and a 15-day cruise in September 2009 aboard the JAMSTEC R/V Kaiyo to recover KEO-2008 and deploy KEO-2009. The Papa rescue required 3-days of charter funds and KEO required 2-days of charter funds. The Papa Tully shiptime was provided by the Canadian DFO Line P program. Post-recovery analysis of the Papa-2008 buoy showed that the break was caused by excessive torque applied to the cable just below the bridle. The torque was likely caused by the NSF Principal Investigator Dr. Emerson's large CTD-GTD-O2 package attached to the line at 10 m to obtain measurements of temperature, conductivity, gas tension and oxygen. For the Papa-2009 deployment, the CTD-GTD-O2 package was moved to the bridle (Figure 2). Dr. Emerson also continued the pH measurements at Papa, and plans to enhance KEO-2010 with a pH sensor. The OCS group enhanced both Papa-2009 and KEO-2009 with downward looking Sentinel Acoustic Doppler Current Profilers (ADCPs) on loan from the TAO and PMEL Fisheries-

Oceanography Coordinated Investigations (FOCI) groups. At present ADCP data is internally recorded and therefore is available only in delay mode. KEO-2009 was also enhanced with several additional current meters on loan from RDI Teledyne. The redundancy of current measurements allows for important intercomparisons and performance testing of these sensors.

As with the 2008 deployments, the 2009 OCS moorings each include two independent data logger and telemetry systems for surface meteorological sensors: the legacy “ATLAS tube” which transmits daily average and hourly meteorological measurements to shore through Service Argos, and the newer “FLEX box”, which transmits hourly subsurface and meteorological data through Iridium. The KEO and Papa meteorological measurements from their primary data logger are shown in Figure 3. ATLAS is considered primary, unless it is unavailable, in which case the FLEX data becomes primary. After our post-recovery evaluation of redundant data, this ordering may be changed for some measurements. ATLAS surface meteorological measurements include: wind speed and direction from a sonic anemometer, air temperature, relative humidity, rainfall, and solar and longwave radiation. The FLEX system for 2009 moorings include barometric pressure and multiple measurements from the Vaisala WXT520 weather transmitter sensor, in addition to the standard suite of surface meteorological measurements.

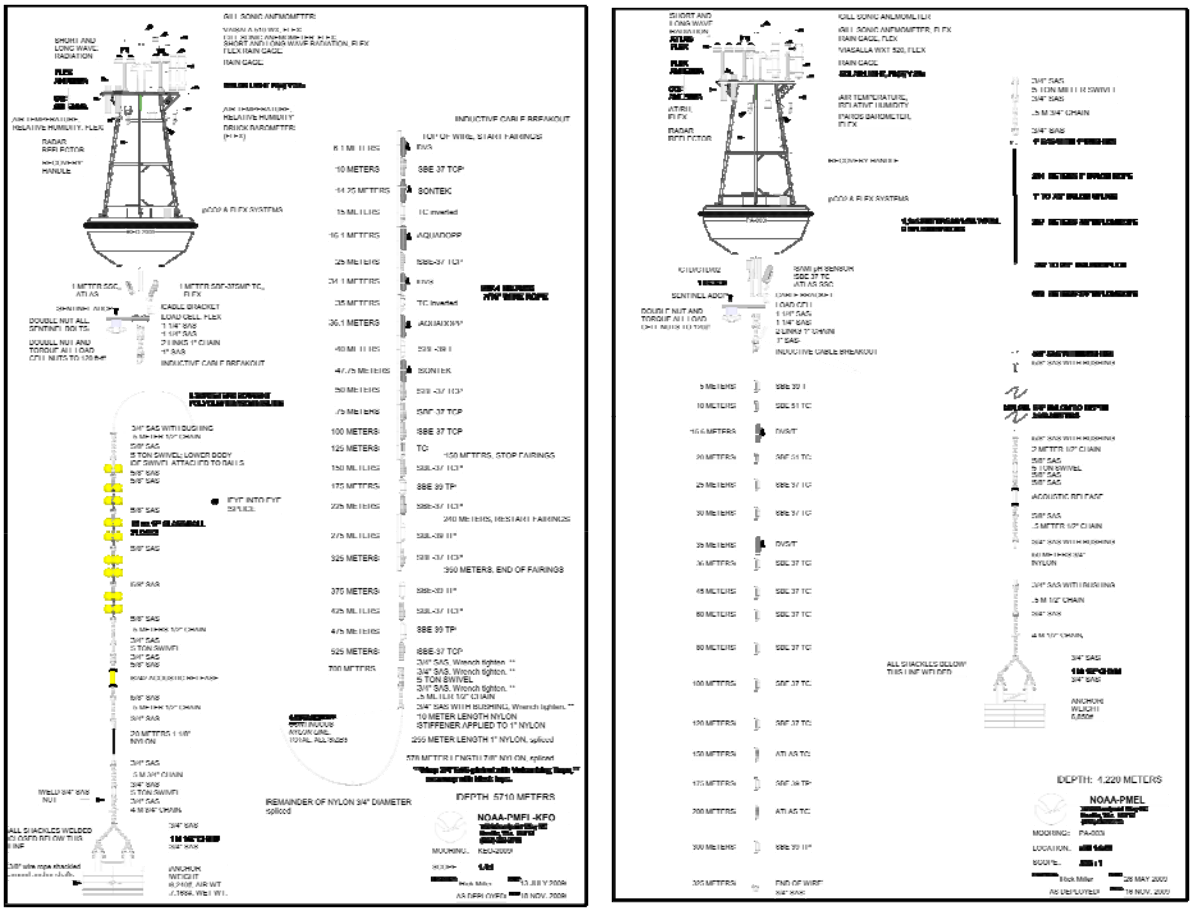

Fig. 2. KEO-2009 and Papa-2009 diagrams.

Beginning with the 2008 deployments, telemetry of subsurface data was switched from ATLAS system to the new FLEX system. This represents a major upgrade from the ATLAS system. ATLAS modules have many components that are now obsolete and the telemetry is limited to daily-averages of a fixed number of sensors, while the new FLEX system works with more off-the-shelf instruments and allows telemetry of hourly data of a greatly expanded number of surface and subsurface sensors. For example the KEO-2009 has 10 subsurface salinity sensors with inductive modems for telemetering hourly measurements (3 more depths than available on the ATLAS system). As the FLEX system develops each additional sensor model must be tested and any upgrades or change to the sensor's software requires additional testing. Unfortunately, despite significant benchtop, outdoor, and in-the-lake testing, the FLEX subsurface telemetry has been intermittent. We are working with the engineers to identify problems and test updates as discussed in the Work Plan.

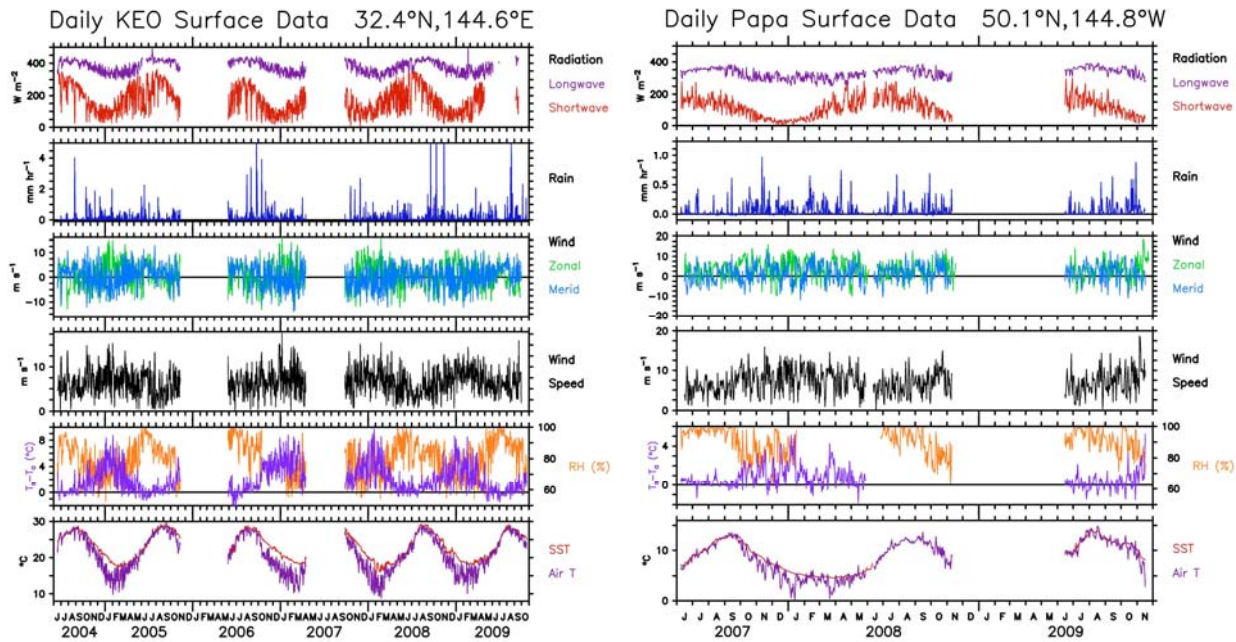

Fig. 3. KEO and Papa meteorological daily-averaged data through October 21 2009 for KEO and November 15 for Papa.

	Stn P Data Return	KEO Data Returns
Met variables (ATLAS)	40.9% (99.3%)	55.8%
Met variables (FLEX)	48.4% (92.7%)	98.1%
Upper ocean temperature (FLEX)	41.0% (81.3%)	31.7%
Upper ocean salinity (FLEX)	57.7% (93.6%)	32.7%
Near surface currents (FLEX)	10.8% (34.7%)	16.8%

Table 1. KEO and Papa data return for FY09 based upon ATLAS realtime daily-averaged and FLEX realtime hourly averaged data. Data returns for when Papa was on site are also shown in parentheses.

As can be seen in Table 1, the FY09 data return from both the ATLAS and FLEX systems have been less than 100%. A large portion of the Papa data loss was to the failure of the mooring line

in November 2008. However additional data loss occurred to intermittent subsurface FLEX transmissions. Although intermittent subsurface FLEX transmissions also occurred at KEO, because the sensors were recovered, we expect the delay mode temperature and salinity data to have much higher data returns than listed in Table 1. Data returns for the current meters continue to be very disappointing. We are evaluating other options options for montoring currents on KEO-2009, which carries 3 different types of current meters (DVS, Aquadopp, Sontek) as well as a downward looking Sentinel ADCP. The KEO-2008 ATLAS data return was low because the system went into fail safe mode due to battery drain caused by incursion of water into the GILL wind sensor attached to the ATLAS tube. This has been a problem on earlier deployments and must be addressed by engineering. The KEO-2009 ATLAS system also went into fail safe mode for the same reason following the direct hit of typhoon Choi-Wan on September 19 2009. Wind gusts observed by KEO during this typhoon were up to 93 miles per hour. The high resolution surface and subsurface data telemetered through the FLEX system provides an incredible data set and will be used in a manuscript on ocean response to a typhoon described in the FY10 work plan. Unfortunately FLEX telemetry has since become intermittent.

Although the PMEL TAO group plans to begin developing a tropical-FLEX in FY10, the burden of testing and developing the new hardware and software procedures has thus far been carried by the OCS group. This engineering and system development is far beyond the scope of the original project and as a result the OCS team has been under significant strain. During FY09, one team member quit, in large part because of this strain. Some tasks such as developing a data display webpage (see Deliverable 2) have not been accomplished. Likewise, in our FY09 Work Plan we stated that "Realtime surface and subsurface data from the FLEX box (wind speed and direction, air temperature, relative humidity, rain rate, barometric pressure, subsurface temperature, salinity and pressure, and near-surface currents) will be made available in near-realtime after the initial period of validation of this new system is completed and software is created to automate this data stream." Because of the magnitude of this task and because some this comparison can only be done after the ATLAS high resolution data becomes available (post-recovery, if functional), the initial validation period for FLEX has extended into FY10 (see FY10 Work Plan for more details). Thus while some telemetered FLEX data have been made public in near-realtime (e.g. barometric pressure and gustiness at Papa), in general, primary measurements that come through the FLEX system have been made publicly available in FY09 only in delay mode. Software development that automates the FLEX processing was not completed in FY09 and at this point we cannot determine in near-realtime if the redundant FLEX meteorological data should be considered primary. By default, we consider the ATLAS real time system to be primary.

In FY09, the OCS group hired its first full-time person: K. Ronnholm. As the OCS project manager, Ronnholm's initial focus has been on Deliverable 1. Although paying for partial FTEs to perform specific jobs was very efficient and cost-effective when the jobs were identical to those performed by TAO personnel, the OCS program has grown into a very complex program and many of the OCS tasks at present have no equivalent within the TAO group. This may change when the TAO group itself begins to develop the Tropical-FLEX system. Their upgrade to FLEX is likely to be much smoother, following on the heels of the OCS group.

Deliverable 2: Access to KEO and Station Papa data and metadata in a format and through linked webpages to encourage broad use of data

KEO and Station P data are all in compliance with the OceanSITES data standard. Cronin participated in the OceanSITES meeting in Venice in September 2009 where these standards were evaluated and refined. At present we provide only ATLAS tube data in near-realtime through project webpages and the GTS. These and the post-processed high resolution surface and subsurface data are publicly available in both ascii and OceanSITES netcdf formats through the project webpages:

For KEO: http://www.pmel.noaa.gov/keo/data.html
For Station Papa: http://www.pmel.noaa.gov/stnP/data.html

To date, there is no user registry and so we have no way of monitoring the number of data downloads.

An OCS webpage was developed that describes PMEL Ocean Climate Stations goals and provides links to the KEO and Station Papa websites: http://www.pmel.noaa.gov/OCS/. Although we had hoped to also develop a display page for OCS data, the page is still under development, as discussed earlier, and is not yet public. This is discussed under the FY10 Work Plan.

Beginning in FY07, the PMEL Ocean Climate Station surface met data from the ATLAS data logger have been distributed to operational meteorological centers via the Global Telecommunications System (GTS). This allows operational meteorological centers to use all available data in operational weather forecasts. The OCS project strongly believes however that the reference site data should be withheld from reanalysis products so that the products will remain independent of the time series reference site data used to assess them. Each time series reference station has a unique World Meteorological Organization (WMO) identifying number containing the digits "84" for this purpose. Cronin has discussed the feasibility of putting the FLEX Iridium data onto GTS with several groups and individuals and has come to the conclusion that this is beyond the scope of the OCS project. If the TAO group develops this capability for tropical-FLEX, OCS can leverage that to make OCS FLEX data available on GTS.

Deliverable 3: Scientific analyses utilizing KEO data

KEO was an element of the Kuroshio Extension System Study (KESS) (see: http://uskess.org) and its data are a critical component of several studies. In particular, FY09 represents the first year of a new 3-year NSF project titled "Role of Air-Sea Interaction in the Kuroshio Extension Recirculation Gyre" that has N. Bond as a co-I and Cronin as a collaborator. During FY09, both Cronin and Bond participated in the U.S. CLIVAR working group on Air-Sea Interactions in Western Boundary Currents (http://usclivar.org/Organization/wbc-wg.html), convening an open workshop held in Phoenix AZ in January 2009. As part of this workshop, ideas for "Monitoring Ocean-Atmosphere Interactions in Western Boundary Current Extensions" were vetted and Cronin became lead author on an OceanObs09 Community White Paper (CWP) by this title. Through this effort Cronin presented this CWP in poster form at the September 2009 OceanObs09 conference in Venice. The Cronin et al. (2010) CWP also contributed to a Plenary White Paper (Gulev et al. 2010) and OCS reference data were discussed in the CWP on surface currents (Dohan et al. 2010).

Likewise at the U.S. CLIVAR workshop, two papers were vetted comparing the Gulf Stream system to the Kuroshio Extension system (Kelly et al. 2009, and Kwon et al. 2009). Several other KEO and KEO-related analyses were also submitted in FY09 with OCS authors: Bond et al. (2009), Tomita et al. (2009), and Konda et al. (2009). Bond et al. (2009) used a high resolution numerical weather prediction model to show that SST anomalies in the KEO region could affect the tropical-to-extratropical storm development and path. Tomita et al. (2009) using KEO and JKEO data showed that the satellite based J-OFURO2 heat flux product was much more accurate than the NCEP reanalyses products. Konda et al. (2009) analyzed the regional weather and climate patterns associated with anomalously high and low fluxes at KEO. There are also several underway analyses using KEO data: Rainville et al. in prep uses KEO data, ARGO hydrographic data and satellite sea level data to examine the properties of Subtropical Mode Water variability in the Kuroshio Extension recirculation gyre. Another Rainville et al. in prep. paper combines the KEO mooring data with the KESS ADCP mooring to look at how wind forcing generates near-inertial waves that can cause enhanced mixing. Tomita et al. in prep. uses KEO data to evaluate the role of summertime stratification for preconditioning winter mixed layer properties. In FY09, Cronin also delivered an invited talk titled "Upper ocean heat content and Subtropical Mode Water variations at the Kuroshio Extension Observatory" at the 2008 Fall American Geophysical Union conference, and participated in the "Changing Times: An international ocean biogeochemical time series workshop" at Scripps, a mini-workshop at UW on the North Pacific Carbon Cycle, and a KESS mini-workshop at URI. In addition, R. Kamphaus participated in the March 2009 P-Line planning meeting in Sydney B.C. Canada.

4. Education and Outreach

During FY09, Cronin gave 3 full-length seminars on the steady-state wind forced "Ekman" response in frontal regions, at: Scripps Institution of Oceanography, Woods Hole Oceanographic Institute, and the University of Rhode Island's Graduate School of Oceanography. This work is based on Cronin and Kessler (2009) and is directly relevant to the NOAA OCO program deliverable of providing global analyses of surface currents to identify significant patterns of climate variability.

Cronin also discussed how she came to be an oceanographer with a troop of Girl Scouts.

5. Publications and Reports

5.1. Publications by Principal Investigators

FY09 Bibliography

Bond, N. and M. F. Cronin, 2008: Regional weather patterns during anomalous air-sea fluxes at the Kuroshio Extension Observatory (KEO). *J. Climate*, **21**, 1680-1697.

Bond, N.A., M.F. Cronin, and M. Garvert, 2009: Atmospheric sensitivity to SST near the Kuroshio Extension during the extratropical transition of Typhoon Tokage. *Mon. Weather Rev.* [Submitted].

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Kelly, K.A., R.J. Small, R.M. Samelson, B. Qiu, T. Joyce, Y.-O. Kwon, and M.F. Cronin, 2009: Western boundary currents and frontal air-sea interaction: Gulf Stream and Kuroshio Extension. *J. Climate.* [Submitted].

Konda, M., H. Ichikawa, H. Tomita, and M.F. Cronin, 2009: Surface heat flux variations across the Kuroshio Extension as observed by surface flux buoys. *J. Climate.* [Submitted].

Kwon, Y.-O., M.A. Alexander, N.A. Bond, C. Frankignoul, H. Nakamura, B, Qiu, L. Thompson, 2009: Role of Gulf Stream, Kuroshio-Oyashio and their extensions in large-scale atmosphere-ocean interaction: A review. *J. Climate.* [Submitted].

Mickett, J.B., Y.L. Serra, M.F. Cronin, and M.H. Alford, 2009: Resonant forcing of mixed layer inertial motions by atmospheric easterly waves in the northeastern tropical Pacific. *J. Phys. Oceanogr.* [Accepted].

Tomita, H., M. Kubota, M.F. Cronin, S. Iwasaki, M. Konda, and H. Ichikawa, 2009: An assessment of surface heat fluxes from J-OFURO2 at the KEO/JKEO sites. *J. Geophys. Res.* [Accepted].

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5.2. Other Relevant Publications

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