The Global Drifter Program

"Drifter Measurements of Surface Velocity, SST, SSS, Winds and Air Pressure"

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1. Project Summary

The Global Drifter Program [GDP hereafter, *Niiler*, 2001] is a NOAA funded program and the principal component of the Global Surface Drifting Buoy Array, a branch of NOAA's Global Ocean Observing System (GOOS). The GDP is also a scientific project of the Data Buoy Cooperation Panel (DBCP). The DBCP is an international program coordinating the use of autonomous data buoys to observe atmospheric and oceanographic conditions over ocean areas where few other measurements are taken. The DBCP was formed in 1985 as a joint body of the World Meteorological Organization (WMO) and of the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO). The DBCP constitutes the data buoy component of the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM).

The ***broad objectives*** of the GDP are to:

1) maintain an ocean-observing network of 1250 Lagrangian drifters with a nominal resolution of 5°X5° that, through the Argos and Iridium satellite systems, return data of meteo-marine variables including near-surface ocean currents (15 m depth), sea surface temperature (SST), sea surface salinity (SSS), sea-level atmospheric pressure (SLP), sea-level winds (SLW) and subsurface temperature (Tz) and

2) provide a data processing system for the scientific use of the drifter data.

1.1 Societal Rationale

Approximately 53% of the US population lives in coastal counties (estimated in 2003, source: NOAA http://oceanservice.noaa.gov/programs/mb/supp_cstl_population.html) and, globally, the density of the population is significantly higher in coastal areas than inland [*Small and Nicholls*, 2003]. The threats to coastal communities include a variety of short-term (i.e. severe weather, hurricanes, marine pollution) and long-term (i.e. climatic changes and coastal erosion) natural and anthropogenic conditions. The GDP array provides data which are readily available, either in real-time or near-real-time, for direct analysis or to be assimilated by a variety of models designed to understand, forecast and mitigate the impact of the Earth system and of pollution on people's lives, including commercial and recreational activities. On short time scales, examples include measurements of ocean currents to track pollutants such as oil and marine debris, to support fisheries management, to aid commercial and Navy's ship operations, as well as measurements of SLP, SLW, SST and SSS to improve Numerical Weather Prediction (NWP) and hurricane forecast. On longer time scales, examples include climate records of ocean currents, SST, SLP for use in climate models. Accurate measurements of the global distribution of the SLP, which is the weight of the atmosphere over the ocean –also called the inverse barometer effect- are important to accurately determine the global sea-level which is measured by the altimeters fitted to several satellites.

1.2 Scientific and Technical Rationales

1.2.1 Specific Science Objectives of the GDP

- Provide the Global Telecommunication System (GTS) of the World Weather Watch (WWW) with a stream of near-real time data of SST, SLP, SSS, SLW and Tz for use in climate, NWP and tropical cyclones forecast models. The data latency, i.e. the time between collection and availability on the GTS, ranges from ~2 hours with the Argos satellite system to ~10 minutes with if the Iridium telemetry is used.
- Measure the mixed layer currents globally and provide colleagues at the Atlantic Oceanographic and Meteorological Laboratory (AOML) of NOAA with data to produce maps of the World's ocean circulation that resolve seasonal and inter-annual variations. The quality-controlled ocean current data are available in delayed mode.
- Provide the scientific oceanographic, climate and meteorological communities and the general public with enhanced, research-quality data sets of ocean currents that incorporate drifter data from individual research programs, including historical data from instruments that differ from the Surface Velocity Program (SVP) Lagrangian drifter design corrected for the wind-induced velocity bias, also known as "slip" [*Niiler and Paduan*, 1995].
- Support programs of national and international interest, such as the recently launched Aquarius mission to measure SSS from space and NWP efforts worldwide.
- Analyze the GDP drifter data and provide a scientific interpretation of the results. Publish the findings in peer-reviewed, easily accessible journals.

1.2.2 Specific Technical Objectives of the GDP

- Maintain the nominal array resolution of 5°X5°, which is needed to keep the potential SST satellite bias error smaller than 0.5ºC [*Zhang et al.*, 2009].
- Monitor and evaluate the performances of the GDP array in order to identify and troubleshoot technical issues as soon as possible.
- Develop and introduce drifter' construction technological advances in sensors, electronics, power, methods of assembly and packaging for deployment. Special emphasis is given to the implementation of new sensors, air deployable instruments and methods for hurricane intensification research, SSS measurements, and technical solutions to increase the endurance of the drifters.
- Share the technological advances with the drifter manufacturer community (commercial, university and federal agencies) with the goal to maintain a healthy GDP array.

1.3 Data and Products Accessibility/Archiving

- A subset of the GDP data, SST, SLP, SSS, SLW and Tz are publicly available through the GTS of the WWW.

All GDP data and products are available from the GDP Data Assembly Center at AOML (http://www.aoml.noaa.gov/phod/dac/dacdata.php), where some details of GDP data

management can be found and the drifter data management plan is described in the OceanObs'09 Community White Paper "Data Management System for Drifting Buoys" by Keeley, Pazos and Bradshaw, available at http://www.oceanobs09.net/blog/?p=225.

- All GDP data and products are updated quarterly and are available from SIO upon request to Luca Centurioni (lcenturioni@ucsd.edu), Chris McCall (cmccall@ucsd.edu) or Lance Braasch (lbraasch@ucsd.edu). A SIO web page for data viewing is available at http://gdp.ucsd.edu/dashboard.html (password protected).
- All GDP raw and processed data and metadata are archived at AOML from the beginning of the program, and at SIO (starting from FY'11 for the raw data).

1.4 Users of the GDP data

The main users of the GDP data include:

- ***Weather Services: (including US, UK, France, Australia, New Zealand, Brazil, Canada, India, Republic of South Africa). Data used: Sea SST, SLP, Tz and SLW for weather and tropical cyclones forecast.***
- ***Climate research centers (US, UK, Brazil, Canada, France, New Zealand, Republic of South Africa). Data used: SST for climate models.***
- ***National Climate Data Center (NCDC, US). Data used: SST for satellite data for calibration/validation.***
- ***AOML (US). Near surface velocity (15 m depth) for annual and seasonal mean currents and anomalies.***
- ***Researchers (worldwide). Drifter velocity data for enhanced 15 m depth velocity dataset for oceanographic and climate research.***
- ***US Coast Guard. Near surface velocity data and sea surface temperature to aid commercial navigation in high latitude (icebergs drift).***
- ***Space Agencies (EU, US) Sea Surface Salinity to calibrate/validate satellite data.***
- ***Satellite altimetry scientific community. The atmospheric pressure data from drifters contribute to the calculation of the inverted barometer effect needed to estimate sea-level rise from altimeter data. The drifter velocity data are also used for sea level computations.***

Drifter velocity data are also used by operational agencies (e.g. UK MetOffice) for ocean current models and by schools worldwide for outreach programs (see for example NOAA's "Adopt a Drifter Program" http://www.adp.noaa.gov/)

2. Scientific and Observing System Accomplishments

2.1 Maintaining the target size of the GDP array at 1250 drifters (D1)

Partially accomplished. The GDP addresses the general program deliverable to: "provide Sea Surface Temperature and Surface Currents, to identify significant patterns of climate variability and change".

Since September 2005 the fully implemented global drifter array has consisted of between 1100-1400 drifters. This 'required' global drifter array size is based on the need to return instrumental

observations of daily average SST (+/- 0.1^{0}C) over the global ocean at a 5º resolution, or the spatial scale of the error covariance function of operational NOAA satellite infrared SST sensors, sufficient to keep the potential SST satellite bias error smaller than 0.5ºC [*Zhang et al.*, 2009]. Surface pressure sensors are also supported by national meteorological agencies based on regional needs. On November 12, 2012 there were 492 GDP-T (Temperature) drifters, 532 GDP-TB (Temperature-Barometer), and 55 GDP-S (Salinity) for a total of 1083 instruments, operational on the array. The status of the GDP array is updated weekly can be seen at the AOML website: http://www.aoml.noaa.gov/phod/dac/index.php

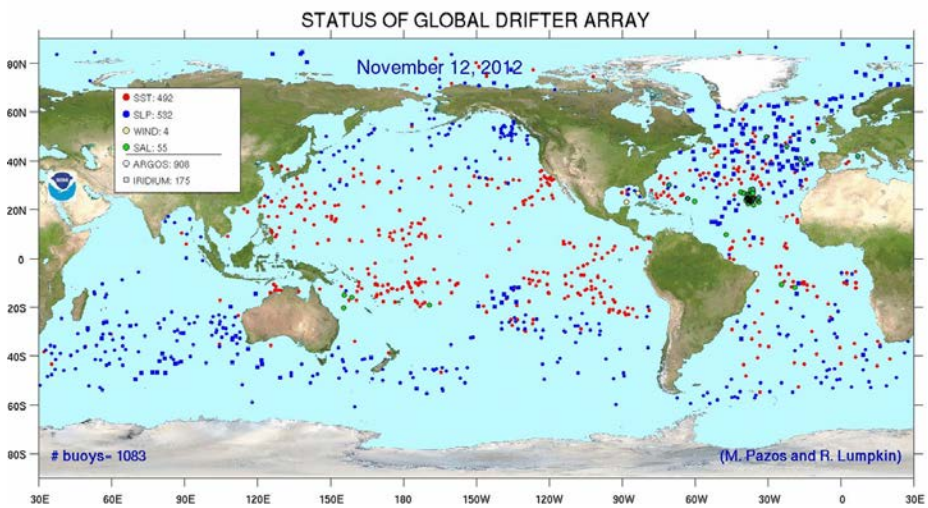

Figure 1: Status of the global drifter array as of 11/12/2012.

The present drifter array is 13% smaller than the nominal size. The technical issues behind the declining array were discussed in the FY11 report and were addressed. The size of the array has been steadily increasing (from -22% in January 2012 to -13% at the time of writing).

With the 2011-2012 funds, 936 drifters with SST sensors are being built and delivered by JIMO/CIMEC to AOML for deployment in the global ocean, 475 of which have barometer upgrades (from the add-on funds) and 41 with salinity upgrades in support of the NASA SSS mission. The number is smaller than the stated deliverable of 1250 drifters because of the development costs sustained during FY11/FY12 by SIO. Note that the GDP has no funds allocated for technical developments.

2.2 Coordinate GDP Activities Between Partners and Support of other efforts (D2)

Accomplished.

SPURS-NASA

Thirty-seven salinity drifters were deployed in the tropical Atlantic in support of NASA's SPURS experiment (Figure2). The experiment is underway and the deployment of the full array should complete in FY13. See also http://spurs.jpl.nasa.gov/SPURS/ .

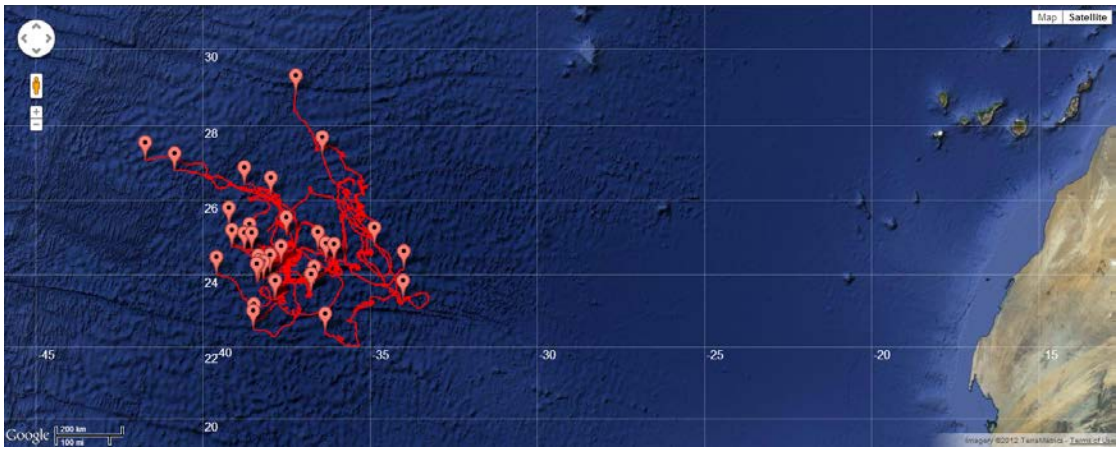

Figure 2: Tracks of the 37 SVP-S drifters deployed in support of SPURS. August 2012-November 2012.

Four drifters were sent to the National Aquatic Resources Research and Development Agency of Sri-Lanka and deployed starting from August 2012 (Figure 3).

Figure 3: Tracks of the 4 SVP drifters deployed off Sri-Lanka. Two drifters were picked-up right after deployment.

Several drifters were also deployed in support of CalCoFi cruises, specifically CalCoFi cruise of March 2012 (14 drifters), CC-LTER (August 2012, 8 drifters, Figure 4), and CalCoFi/Ocean Starr cruise (September 2012, 9 drifters, Figure 5)

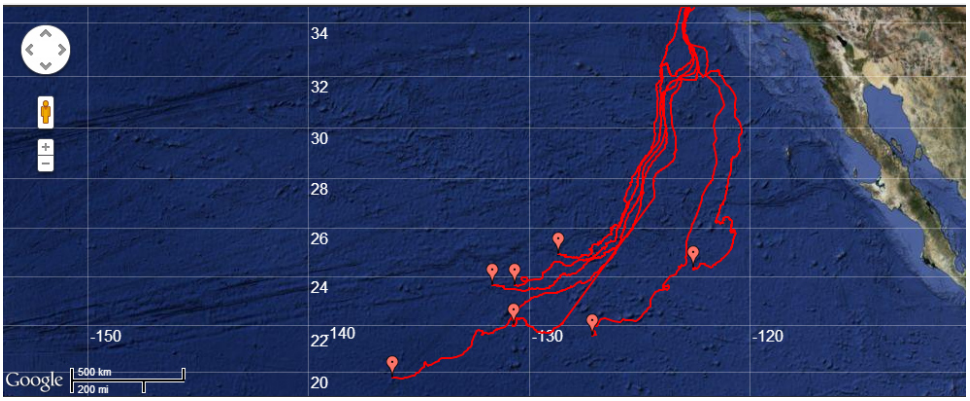

Figure 4: track of the drifters deployed off the CCE-LTER/CalCoFi in August 2012 in support of fish larvae dispersion studies.

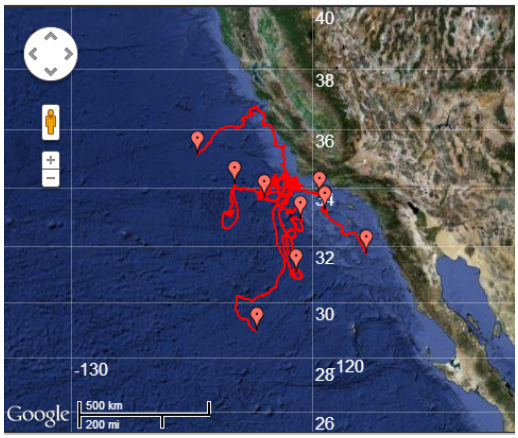

Figure 5: Track of the drifters deployed off the Ocean Starr/CalCoFi cruise in support of the wake-island study.

2.3 Enhance the GDP Array with Matching Contributions (D3)

Accomplished. The GDP supported the ONR funded experiment OKMC with the goal to map the seasonal surface circulation in the South Philippines Sea and to understand the seasonal migration of the separation point in the western boundary of the North Equatorial Current. To enhance the historical near surface current data in the study area, deployments of surface drifters from the merchant vessels from Kaohsiung to eastern Australia were performed. Professor Ruo-Shan Tseng at National Sun Yat-Sen University is a local contact point in Taiwan to store, prepare and deliver the drifters to the ship. The deployments continued in 2011 and six deployment cruises (9 drifters for each deployment) have been made successfully. The Hyundai Shipping Co. cancelled the regular route from Kaohsiung to Australia, in February 2012 because of global recession and five deployments were skipped starting from February, 2012. Fortunately drifter deployments by the Global Drifter Program supplemented this study. We deployed a total of 54 drifters since October, 2011 and 8 drifters failed on deployment (Figure 6). Half of these drifters were funded by the GDP.

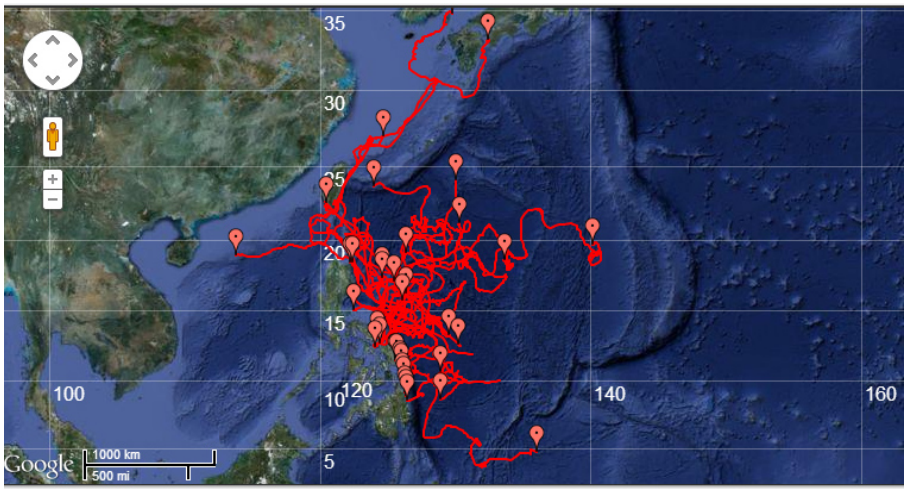

Figure 6: drifter deployed in synergy with the OKMC experiment.

2.4 Monitor and Advise the Drifter Manufacturers to Ensure Drifter are Built According to Specifications (D4)

Accomplished. Dr. Centurioni and the engineers at the Lagrangian Drifters Laboratory of SIO have entertained constant technical exchanges with drifter manufacturers (Pacific Gyre, DBI, Clearwater and Metocean) with regard to drifter technology improvements.

In spring 2012 a new issue affecting the endurance of the drifters was identified by SIO engineers. The new Argos transmitter (PMT) designed to work with Argos 3 satellites was discovered to use a very high amount of energy when used in Argos 2 mode. Since all the drifters were programmed to work as Argos 2 units as per CLS recommendations, the recovery of the array has been slower than expected. Our findings were also communicated to CLS, who designed the transmitter. All the drifters still on land are now being retrofitted to work as Argos 3. All new drifters are now being built as Argos 3 units. A pilot array of 175 drifters is being built by the GDP to field-test the efficiency of the drifters equipped with Iridium modems.

In consideration of the modularity of the SVP drifter platform, a complete SVP drifter design was developed in-house at SIO. The hardware platform was developed with a re-sealable surface float and strain relief utilizing injection molding technology. Additionally, an inexpensive micro-controller unit (MCU) was designed with support circuitry for onboard GPS, SST, drogue detection, external barometer, multiple satellite communication systems, and other developmental sensors. Field tests were conducted in the Mediterranean Sea, British Columbia, Canada, as well as short-term tests off the coast of San Diego, California to evaluate system performance in the field.

We have gathered and reviewed the history of the drogue design changes. As previously mentioned (FY11 report) SIO has re-designed the tether attachment in order to make it more resistant to stress, torque, and has enhanced the waterproofing seal. The GDP has now issued recommendations to the manufacturers, and the aim is to use the SIO drifter as a reference design after the test phase is concluded. SIO has revised the instructions for drogue construction, which calls for 600 den or higher rip-stop cordura nylon, double fabric along seams, end tacking, schedule 40 PVC rings all-over and spider wheel. The use of synthetic rope is being evaluated, since the wire rope is most likely the weakest aspect of the drogue design. SIO has built 20 drifters with alternate material. Several pilot arrays with these modifications will be deployed to rigorously field-test the drogue lifetime of this modification.

2.5 Update and Maintain the Enhanced GDP dataset/GDP data distribution (D5)

Accomplished. The enhanced drifter dataset was updated quarterly. Dr. Dong-Kyu Lee has downloaded the archived data from AOML with success. There were 13 requests from scientists for drifter data during the funding cycle reported here. This is on top of the data distributed by AOML and available in real time or near-real time though the GTS.

2.6 Maintain Real-time Statistics of Drifter Performances (D6)

Partially accomplished. In FY 2012, the 2 year old SIO server hardware was updated with a new server with increased memory and disk space. The updated hardware increases memory from 32 to 96 GB of RAM. Disk space was increased from 8 to 16 TB of storage. As the web

interface is developed to further enable sensor quality control, multi-year datasets are accessed and database performance is of high importance. In transitioning to the new server, previous disk space and memory (RAM) limitations are no longer of concern. SIO is able to scale accordingly with a quickly growing database of drifter observations, and meta-data. Real-time statistics functions will be refined in FY12-13. Currently, drifter statistics are produced manually or are obtained from colleagues at AOML.

The new server also handles the specification sheet of all of the drifters produced at SIO and it will be expanded to ingest the specification sheet from all the other manufacturers that supply drifters for the GDP. The rationale is to create an organized database in which all relevant information can be easily accessed in order to correlated technical issues and, more importantly, biases of SST, ocean currents etc., with drifter design changes. This is critical for creating a reaserc-quality record of climate data gathered by the GDP.

2.7 Test of Hurricane Drifters (D7)

Accomplished. Mr. Christopher McCall and Mr. Lance Braasch, engineers at the Lagrangian Drifter Laboratory at SIO traveled to Keesler AFB in July 2012 to inspect and refurbish the Hurricane drifters stored there. A list of drifters cleared for deployment was produced.

2.8 Report of GDP Activities ate the DBCP Meeting (D8)

Accomplished. Dr. Luca Centurioni, Dr. Dong-Kyu Lee and Mr. Lance Braasch of SIO traveled to Fremantle, Australia, to present several papers at the technical DBCP workshop (October 2nd) at the DBCP sessions. Copies of the presentations and reports can be found at (http://www.jcomm.info/index.php?option=com_oe&task=viewEventRecord&eventID=1071) .

2.9 Analysis of the GDP data (D9)

Intrusions of the Kuroshio on the continental shelf of the East China Sea were investigated with the drifters' data historical archive and with targeted weekly and bi-weekly drifter deployments from southern Taiwan in 2008 and 2009 (Velez et al., 2012, submitted to JMR). Combined drifter and altimetry data revealed how westward propagating cyclonic eddies trigger pronounced Kuroshio intrusions approximately every three months. Possible mechanisms responsible for the intrusion include the Kuroshio acquiring cyclonic vorticity, as measure with drifter data, due to the interaction with the apparently coalescing eddies, thus veering towards the shelf-break of the southern East China Sea (figure 6). This work, accepted with revisions by JMR, was supported by the ONR-QPE and the GDP, and the data were analyzed in collaboration with Dr. Pedro Velez, an EU-funded training scientist from Spain.

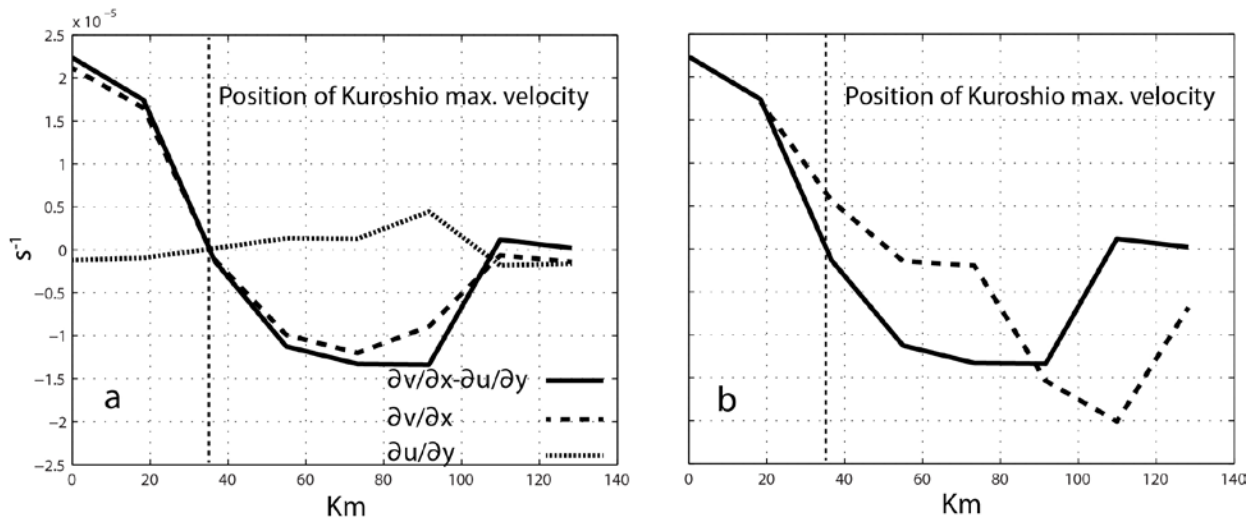

Figure 6: (a) Mean velocity of the Kuroshio during the non-intrusion (black vectors) and large intrusion (blue vectors) periods. The bins used to compute the average are shown in in gray. (b) Averaged down-stream velocity across the ETC during the non-intrusion (black line) and large intrusion (blue line) periods.

Other studies of the surface circulation in the NW Pacific Ocean are addressing the circulation of the East China Sea during the Kuroshio intrusion [*Gawarkiewicz et al.*, 2011] and the passage of typhoon Morakot that induced a freshwater pulse off north-east Taiwan, when the drifters recorded a rarely occurring southwestward countercurrent located between the coast of Taiwan and the Kuroshio (figure 7, Jan et al. 2012, JMR, under revision)

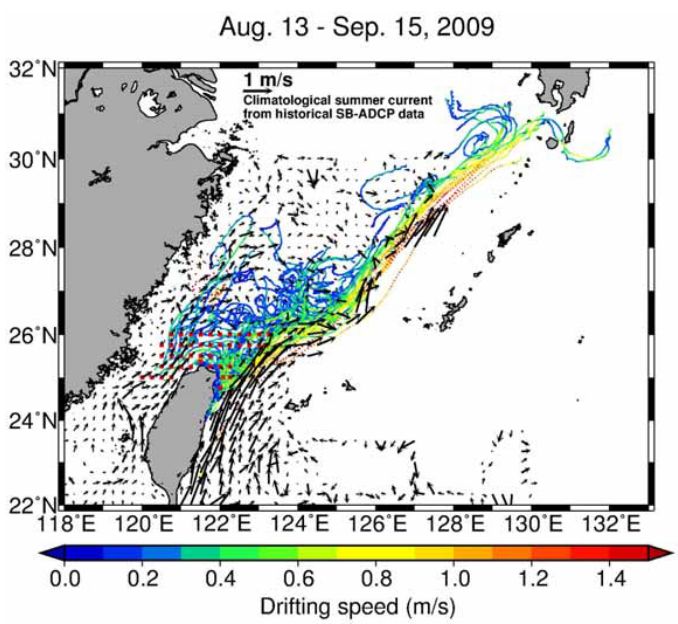

Figure 7: Trajectories and corresponding drifting speed (colored dots) of 44 drifters deployed at the red squares in the northern Taiwan Strait and north of Taiwan from 8/13 to 9/15, 2009. The

mean summer current velocity vectors at 30 m (black arrows) derived from the shipboard ADCP data collected by Taiwan's research vessels during 1991 to 2010 are overlaid on the map.

An invited contribution to the 2nd edition of the Ocean Circulation and Climate (Maximenko et al. 2012, accepted with revisions), describes the history and recent progress in observations of surface circulation of the ocean, primarily obtained from drifters' observations (figure 8).

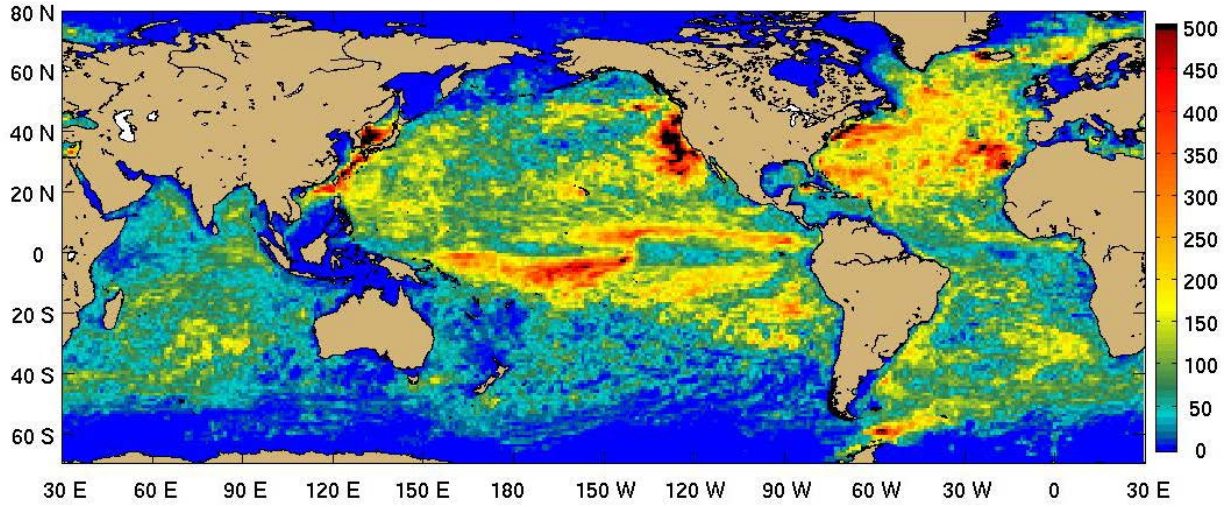

Figure 8: Density of drifter observations (drifter days per square degree) in the quality-controlled GDP database, with observations spanning the period 15 February 1979 - 1 July 2011. Black indicates >500 drifter days per square degree.

In this paper, the complexity of the dynamics of surface currents is also illustrated through a careful look at particular regions where the PI has conducted focused experiments in the past decade, including the NW pacific and the California Current system (figure 9).

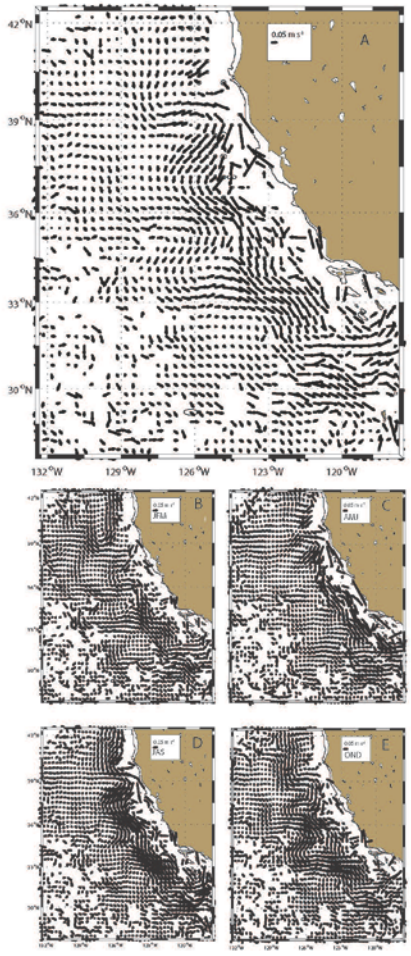

Figure 9: Near-surface unbiased geostrophic velocity field. Year-long (left) and seasonal (four smaller panels on the right) ensemble-average between July 1992 and June 2011. Note the increase of the intensity of the currents in summer (JAS) and the larger extent of the meanders in fall (OND).

A technical paper which addresses the issue of misdiagnosed drogue presence detection offers a method to recover drifter velocity data from instruments for which the drogue presence indicator did not work correctly[*Lumpkin et al.*, 2012]. The methodology is based on a model that determines the departure from expected downwind ageostrophic motion as well as by detection of increased variance of the Argos transmitted frequency, probably due to anomalous solar heating of drogue-less drifters, which tend reside at the ocean surface more than drogued drifters (figure 10). The application of such methodology has resulted in the removal of significant biases in the estimates of the zonal current in the Antarctic Circumpolar Current region, and is thought to significantly improve the quality of the delayed mode, quality controlled, ocean currents data in the GDP archive.

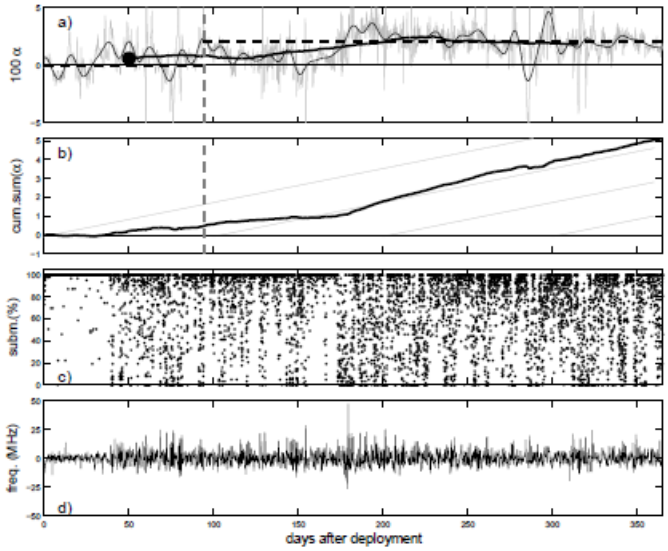

Figure 10: (a) Time series of (residual downwind component of drifter velocity divided by wind speed) for drifter ID=62587, unfiltered (gray) and low-passed with a 100 day running mean (heavy black line) and low-pass with period cut-off of 10 days (thin black line). Vertical dashed line indicates drogue-off date determined by a least-squares fit of a step function (horizontal dashed lines). Black dot indicates the first date that the 100 day low-pass exceeds 0.3%, the criterion used by Rio (2012). (b) Cumulative sum of used for manual evaluation of results. Vertical dashed line repeated from (a). Sloping gray lines indicate □=0.018, a ty drogue loss, for visual reference. (c) Submergence record from drifter. (d) Transmission frequency anomalies (highpassed at 2 days).

2.10 Other Accomplishments

The PI organized the deployment of 10 drifters ahead of tropical storm/hurricane Isaac. Of the 10 drifters deployed, 5 were equipped with thermistor chains. The deployment was coordinated with CARCAH and performed by the 53rd WRX "Hurricane Hunters" (figure 11). All data (SST, air pressure, sea-level wind and subsurface temperature was posted to the GTS as well as made available through a SIO ftp server and in graphic form through a SIO website.

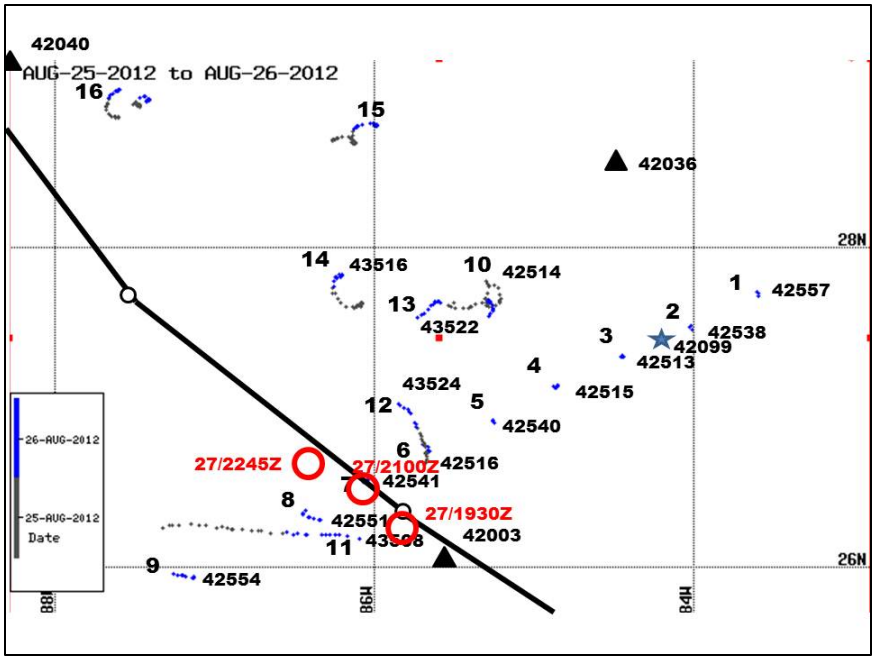

Figure 12: Drifters deployed in front of storm Isaac, whose track is depicted by the black solid line.

At the XXVII DBCP meeting in Geneva the PI pitched a pilot project on the impact of SLP measurements from drifters on NWP. He then organized a workshop to assess the state of the art and establish a robust background to support the pilot project operations. The workshop was held in Sedona, Arizona, on May 21, 2012, in conjunction with the fifth WMO Workshop on the Impact of Various Observing Systems on NWP. Workshop attendees : Carla Cardinali (ECMWF), Luca Centurioni (Chair, SIO), Ronald Errico (NASA), John Eyre (UKMO), Ron Gelaro (NASA), Rick Lumpkin (co-Chair, AOML), Jean-Francois Mahfouf (MeteoFrance), Wenjian Zhang (WMO). Several participants gave a presentation. A full report of the workshop and the presentations are available at: http://www.wmo.int/pages/prog/www/OSY/Meetings/Wshop-Impact-NWP-5/dbcp/dbcp_slp1.html.

The questions posed to the attendees were:

1) What is our understanding of the impact of SLP from drifters on NWP and are further investigations needed for a quantitative assessment?

2) What are the correct metrics to assess the impact?

3) Are we ready to summarize the state of the art on the subject in a manuscript that could be submitted to a peer-reviewed journal such as BAMS?

The discussion highlighted the high impact of GDP air pressure observations on NWP. Please refer to the full report for more details.

2.11 Outreach and education

- The GDP provided one drifter to the Adopt a Drifter Program (ADP), manufactured by DPI and modified ADP (Dr. Diane Stanitsky) by adding a side chamber to hold student essays. The drifter was presented at the BLUE Ocean Film Festival in Monterey CA and

deployed on September 25 in the California Current to be tracked by students (http://www.adp.noaa.gov/schools/118531.html).

- The GDP provided six drifters to the SEA Semester North Pacific plastic expeditions (http://www.sea.edu/plastics/sea-research.htm).

3. Publications and Reports

3.1. Publications by Principal Investigators

- Published

D'Asaro, E., P. Black, L. Centurioni, P. Harr, S. Jayne, I.I. Lin, C. Lee, J. Morzel, R. Mrvaljevic, P.P. Niiler, P.P., L. Rainville, S. Sanford, and T.Y. Tang, 2011. Typhoon-Ocean Interaction in the Western North Pacific: Part 1. Oceanography, 24, 24-31.

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