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) is the principal component of the Global Surface Drifting Buoy Array, a branch of NOAA's Global Ocean Observing System (GOOS) and 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 and a joint body of the World Meteorological Organization (WMO) and Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO).

The overall objectives of the GDP are to: 1) maintain a near-operational ocean-observing network of at least 1250 Lagrangian drifters that, through the Argos and Iridium satellite systems, returns data of meteo-marine variables including near-surface ocean currents, sea surface temperature (SST), sea surface salinity (SSS), sea-level atmospheric pressure (SLP), sea-level winds (SLW) and subsurface temperature (Tz) and 2) to provide a data processing system for the scientific use of the 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; Nicholls 2003). The threats to coastal communities include a variety of short-term (severe weather, hurricanes, marine pollution) and long-term (climatic changes and coastal erosion) natural and anthropogenic conditions. The GDP array provides data which are readily available 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, SST and SSS to improve Numerical Weather Prediction and hurricane forecasts. On longer time scales, examples include climate records of ocean currents, SST, Tz, SLP and SLW. 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 that are carried by several satellites.

1.2 Scientific and Technical Rationales

a. Specific GDP Science Objectives

• Provide to the Global Telecommunication System (GTS) of the World Weather Watch (WWW) a near-real time data stream (it takes less than 2 hours with Argos and approximately 10 minutes with Iridium between transmission and delivery of measurements to the data center) of SST, SLP and near-surface currents for use in operational forecast and climate models.

• Measure the mixed layer currents on a global basis and provide colleagues at the Atlantic Oceanographic and Meteorological Laboratory (AOML) with data to produce maps of the World's ocean circulation able to resolve seasonal and inter-annual variations.

• Provide the scientific community and the 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 and are corrected for the wind-induced velocity bias (slip).

• Support programs of national interest, such as the recently launched Aquarius mission to measure SSS from space.

• Analyze the GDP drifter data and provide a scientific interpretation of the results. Publish our findings in peer-reviewed journals.

b. Specific Technical Objectives

• Monitor and evaluate the performances of the GDP drifters 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 deployment packaging. Special emphasis is given to the implementation of new sensors and aerial deployment methods for hurricane observations and to SSS measurements.

• Share the technological advances with the drifter manufacturer community (both commercial and university based) in order to support a healthy GDP array.

GDP drifter data and products availability:

• Data and products are available from the GDP Data Assembly Center at AOML (http://www.aoml.noaa.gov/phod/dac/dacdata.php);

• Data and products, updated through September 30th, 2011, are updated approximately every three months, 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).

The main users of the GDP data include:

- ☐ ***Weather Services: (US, UK, Fr, Au, NZ, Br, Ca, In, RSA). Data used: Sea SST, SLP and SLW for weather and tropical cyclones forecast.***
- ☐ ***Climate research centers (US, UK, Br, Ca, Fr, NZ, RSA). Data used: SST for climate models.***
- ☐ ***National Climate Data Center (NCDC, US). Data used: SST for satellite data cal./val.***
- ☐ ***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 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 Requirements to maintain the "Global Surface Drifting Buoys" array at Status Quo (deliverable from Dr. Niiler work plan)

Since September 2005 the fully implemented global drifter array has consisted of between 1100-1400 drifters. This 'required' global drifter array size by JCOMM is based on the need to return instrumental observations of daily average SST (+/- 0.1^0C) over the global ocean at a 5º resolution, or the spatial scale of the error covariance function of operational NOAA satellite infrared SST sensors. Surface pressure sensors are also supported by national meteorological agencies based on regional needs. On January 9, 2012 there were 416 GDP-T (Temperature) drifters, 544 GDP-TB (Temperature-Barometer), and 13 GDP-S (Salinity) for a total of 974 instruments, operational on the array. The status of the GDP array can be seen at the AOML website: http://www.aoml.noaa.gov/phod/dac/index.php

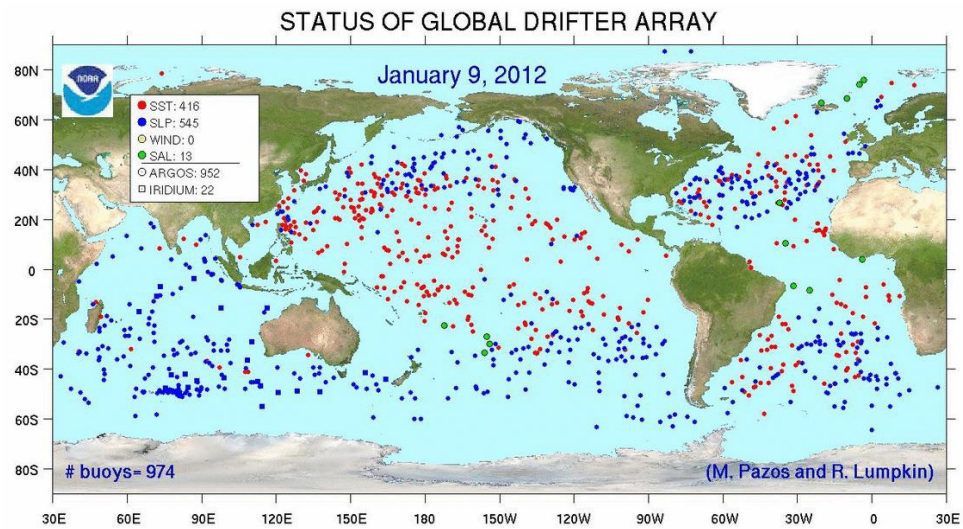

Figure 1: Status of the global drifter array as of 1/9/2012.

The present drifter array is 22% smaller than the nominal size. In late summer 2011 and alarming failure rate was noticed by AOML, with drifters stopping functioning on, or within weeks from, deployment. The cause was identified in two companies, Clearwater Inc. and Technocean,

installing battery packs made of defective cells (Rayovac). Both companies issued a voluntary recall to retrofit the drifters with new battery packs, an action that has caused a decline in the stock of drifters available for deployment. At the time of writing, Technocean still has not fixed the battery problem and the issue is being investigated by the PI's lab to assess the drifters' assembly workmanship and the quality of the components.

The drifters manufacturing process is closely monitored at SIO. The battery problem has been addressed by requiring that only industrial grade Duracell batteries be used for battery pack construction. A second issue was noticed by the PI in late 2010 with regard to the fabric used by Pacific Gyre to make drogues. It was noted that the fabric was too light, easy to rip and with poor stitching throughout the holey-sock. The PI enforced a drogue retrofit for 235 Pacific Gyre drifters. Additionally, specific guidelines with regard to the drogue's assembly, addressing fabric material, the number of stitching lines, folding and end-tacking, the composition of the middle (stiffener) and bottom rings and ballast as well as a more robust drogue attachment, were issued to the manufacturers. The manufacturers were also asked to improve the accuracy of the SST measurements. Only Clearwater Inc. has responded so far.

With the 2010-2011 funding, 844 drifters with SST sensors are being built and delivered by JIMO/CIMEC to AOML for deployment in the global ocean, 215 of which have barometer upgrades and 46 with salinity upgrades in support of the NASA SSS mission.
Note that the number of drifters purchased is lower and different than in the proposal's budget. The reasons are 1) an increase of $50 per drifter not planned in the budget submitted by the previous PI and 2) SIO reducing the number of barometer upgrades by 70 units to support drifter technology development as explained below.
During early 2011, the difficulty to troubleshoot drifters of significantly different designs that are composing the GDP array and the long time occurring between the identification of a technical problem and subsequent corrective actions, highlighted the urgent need to rationalize and minimize the differences in the SVP/GDP drifter's design. SIO is currently leading this effort. To this end, a new drogue buoy attachment has been designed as well as a new surface buoy and electronics to support both Argos and Iridium communications. New drogue wheels are being tested as well as tethers of different types to address the problem of early drogue losses that was detected in 2010 and addressed at the 27th DBCP meeting in Geneva. The first two iridium drifters entirely made by SIO were deployed on October 13, 2011, in the Mediterranean Sea (Figure 2) and are still operating.

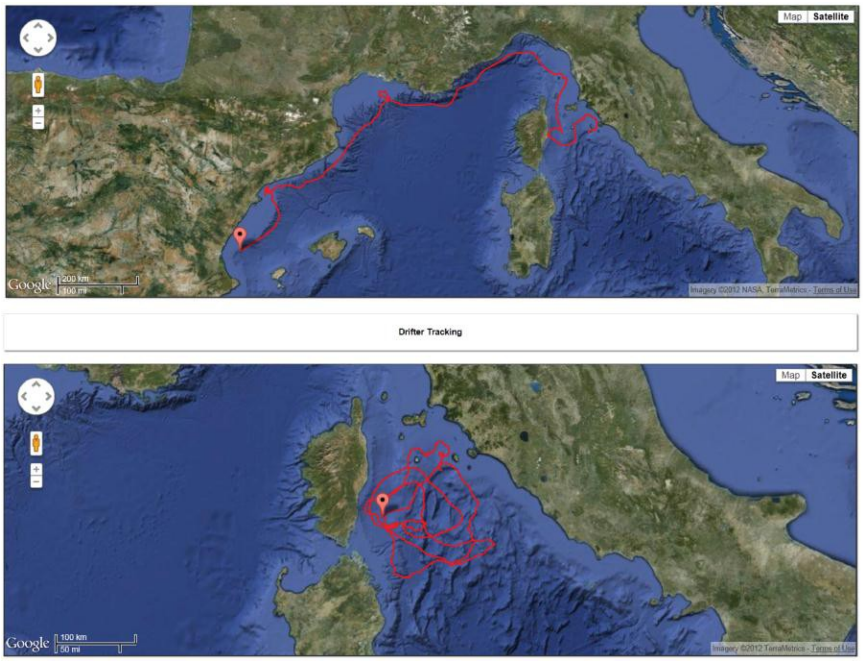

Figure 2: Tracks of SIO Iridium GDP drifters #1 and #2 as of 1/16/2012 20:32 UTC.

At the time of writing, nine more SIO-Iridium drifters are being shipped to Taiwan for deployment in the Philippine Sea and the first 27 SVP Argos drifters will be shipped from SIO at the end of February, 2012. The SST fitted to the SIO drifters is accurate within 0.05°C, with a resolution of 0.01°C, in response to the request of the satellite SST groups for better in situ SST data. Clearwater Inc., is producing drifters with similarly accurate SST probes.
The main benefits resulting from SIO engaging in the construction of GDP drifters are:

1) Regain of total control over the drifter technology guidelines, which are more strictly enforced on drifter orders issued to private manufacturers. The technical innovations resulting from the SIO activities will be made public and enforced after the test phase;
2) Better control over the pricing of the drifters.

In the past, troubleshooting of the drifter array due to technical problems was occurring yearly. Early in 2011 SIO (Mr. Lance Braasch, development engineer with the SIO drifter group) has implemented a real-time drifter data viewer which now allow us to troubleshoot every drifter in the array in near-real time, by comparing the air-pressure and SST data with several re-analysis products.
In summary, this deliverable is partially accomplished due to the increased drifter price and technical issues, which have been aggressively addressed as explained above.

2.2Logistical requirements (deliverable from Dr. Niiler work plan)

Most drifters were deployed by "Volunteer Observing Ships" and during research cruises. Shaun Dolk at AOML co-ordinates the drifters deployment. SIO also facilitates the deployment of drifters from research cruises. No drifters were deployed during this hurricane season due logistical difficulties. **Status: accomplished.**

2.3Technical developments and data enhancements (deliverable from Dr. Niiler work plan)

"SSS Sensors: …Dr. Rick Lumpkin and Peter Niiler have decided to not build additional Hurricane drifters in 2010, but rather use these funds to add 55 SEACAT SSS sensors to SVP drifters. These will be used in a study planned jointly by NASA and NOAA for the verification of processes that determine SSS variability in the subtropical gyre of the North Atlantic. Also, data from these sensors will be used for calibration and validation of the "AQUARIUS" SSS satellite mission". **Status: partially accomplished. Only 46 drifters were purchased due to increased cost of SSS upgrades.**

"Thermistor Chains: The second technical objective is to design and manufacture a new rugged thermistor (or subsurface data chains) chains for drifters. …". **Status: accomplished. A new, more accurate and reliable thermistor chain ws designed by PacificGyre.**

2.4Real time data distribution, datasets and data storage (deliverable from Dr. Niiler work-plan)

Service Argos, Inc., within 2 hours of measurement, applies a quality control to the drifter data from the array of 1250 units and distributes these on GTS for operational applications. Within three months, AOML's Drifter Data Assembly Center performs a re-analysis of the data and distributes the six hourly interpolated observations upon request to the international scientific community. CIMEC-SIO maintains files for surface currents in which a wind slip correction has been applied and these are distributed also upon request. Such data are updated through September 30th, 2011 and further updates occur approximately every three months, Every year, AOML files a "Global Drifter Program Report" on the statistics of survivability of power,
drogues and sensors with the DBCP, which is available on the DBCP web site. Status: accomplished.

2.5Use of GDP data for SST reanalysis

The drifter data is the most extensive and accurate in situ instrumental data set of SST that is used as the ground truth for the construction of the 7-day average SST maps of the ice-free oceans (Zhang et al. 2009). This product is used globally for analysis of climate, long-range weather prediction and for initialization and verification of ocean circulation models.
There is no systematic accounting maintained on the number of research papers, reports or practical products that result from the use of 'Reynolds' data.

2.6Argos 3 Pilot Project

The Argos 3 Pilot Project (A3PP) has ended and the conclusions support the use of the PMT in Argos 2 mode. Argos 3 PMTs are now being used throughout the GDP fleet, including the SIO drifters.

2.7Synergies and scientific interpretation of the data

2.7.1 Study on the origin of the Kuroshio and Mindanao current, sponsored by the Office of Naval research and supported by the GDP

The principal scientific objective of the drifter component of this project is to map the near surface circulation that leads to the seasonal formation of the Kuroshio in the South Philippines Sea. The methodology is to enhance the historical data by deploying drifters from Korean merchant vessels that cross the Luzon Strait and the South Philippines Sea about every 35 days on a route from Kaohsiung, Taiwan to eastern Australia. The HYUNDAI Shipping Co picks up the drifters in Taiwan from Professor Ruo-Shan Tseng at National Sun Yat-sen University. The deployments started in August 9, 2010 and twelve deployment cruises (9 drifters for each deployment) have been made successfully.

From historical drifter observations, a strong westward Winter Subtropical Current (WSC) is found in the Northwestern Pacific between 18□N and 23□N. The decadal strengthening of negative wind stress curl in the subtropical area north of Hawaii and west of 150□E is the main forcing of this newly observed seasonal current. The annual fluctuation of the WSC transport is reflected in the springtime Kuroshio transport in the south of Japan (Figure 3). The annual variation of the transport by WSC is also correlated with the North Pacific Index (NPI), which represents the strength of the Aleutian Low before the 1988/89 climate shift, but the correlation with teleconnection patterns or climate indices is not found after the 1988/89 shift. The paper on the results is in preparation for the Geophysical Research Letters.

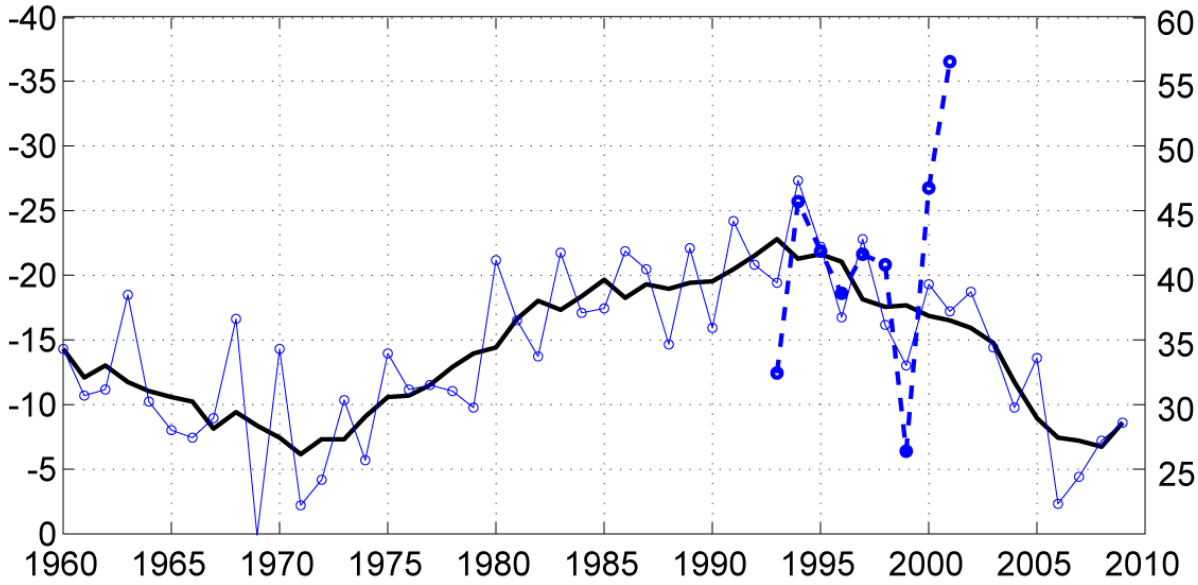

Figure 3: Mean Sverdrup transport in winter (October-March) near western boundary between 18°N and 23°N and the Kuroshio transport (dashed line with right axis). The thick line is 5 year running mean transport.

2.7.2 Impact of typhoons in the Pacific Ocean (ITOP), sponsored by the Office of Naval research and supported by the GDP, and hurricanes observations with GDP drifters.

The analysis of ITOP data continued in FY11 (D'Asaro et al. 2011). The most notable results to data include the very good performances of the new acoustic anemometer that was fitted to the ADOS (Centurioni 2010) systems (Figure 4) and the success of the drifter array in mapping the cold wake of typhoon Fanapi and the atmospheric pressure associated with the storm (not shown).

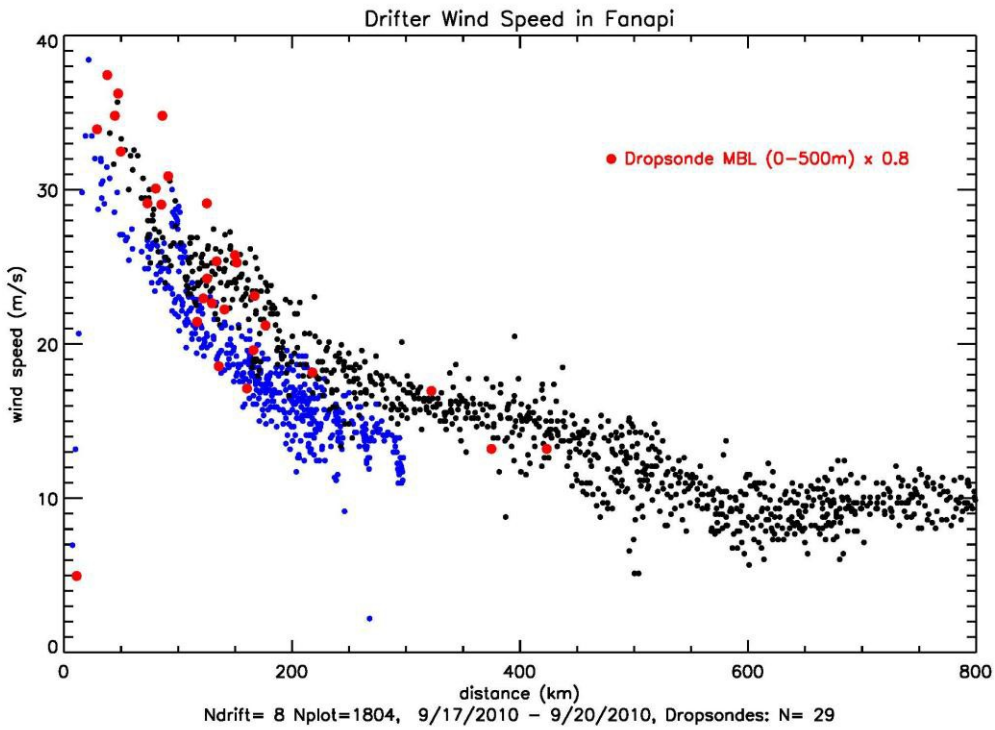

Figure 4: Wind speed corrected at 10m observed from the air-deployed ITOP array with a 2-D Gill sonic anemometer. In red are the dropsondes reference data. Blue dots are ADOS observations in front of the storm, while ADOS observations in the wake of the strengthening storm are marked by black dots.

This is an important step towards obtaining research quality in situ data of hurricane strength winds. The Gill sonic anemometer will be included in the design of a mini-ADOS system deployable from a standard A-XBT chute.

In FY'11 the GDP continued to provide important data for hurricane research and forecasts. Although no targeted deployments of ADOS systems were possible in front of hurricane Irene, 13 GDP-TB drifters were located nearby the hurricane and provided useful data (Figure 5) available to hurricane forecast centers in near-real time through the GTS.

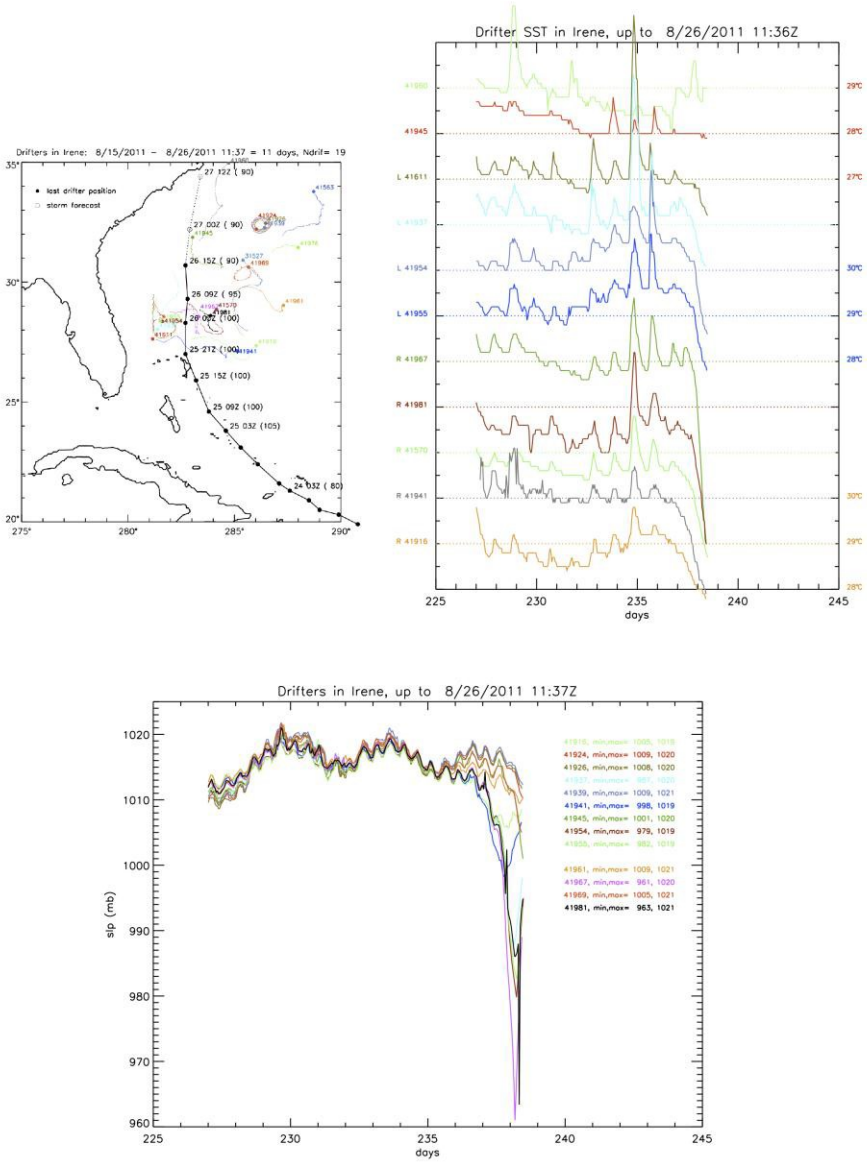

Figure 5: Upper left: tracks of GDP-TB drifter nearby hurricane Irene on August 26, 2011. Upper right: SST as measured by the drifters and; lower panel: SLP measurements from drifters.

2.7.3 Study on the intrusion of the Kuroshio on the continental shelf of the East China Sea (QPE project), supported by the Office of Naval Research and the GDP

Starting on April 7, 2008, two GDP drifters per week were released within the Kuroshio off Taitung City (south-east Taiwan) by the Taiwanese coast guard and from January 14, 2009, only one drifter per week was released. This drifter release time-series ended on September 16, 2009 with a total of 112 drifters released. During the IOP 88 more SVP drifters were released in a tight array (25°N-26°N, 120°E-123.5°E) north and north-east of Taiwan in less than one month. The first deployments of 44 units occurred from the Taiwanese R/V OR2 and OR3 in early August 2009, in support of the data collection operations to establish proper boundary conditions for

numerical modeling efforts; the second deployments of 44 SVP-GPS drifters occurred from the R/V Roger Revelle in the IOP box in August and September 2009.

The westward propagating eddies within the north Pacific subtropical gyre are responsible for the region of enhanced eddy kinetic energy found between 120°E-160°W and centered at approximately 23°N (Maximenko et al. 2009) and are thought to affect the Kuroshio in the Luzon Strait region and along the coast of Taiwan. The transport and the meandering patterns of the Kuroshio measured with the WOCE PCM-1 moored current meter array (Johns et al. 2001) are correlated with the arrival of the large westward propagating eddies east of Taiwan (Zhang et al. 2001). The maximum correlation 0f 0.83 between the WOCE PCM-1 Kuroshio transport and the AVISO gridded weekly Mean Sea Level Anomaly (MSLA) data is found at 23.9°N, 123.2°E, thus suggesting that the MSLA can be taken as a good proxy for the Kuroshio transport variability through the East Taiwan Channel (ETC. Figure 6). The meandering pattern of the Kuroshio triggered by the coalescing cyclonic eddies within the latter is well described by more than 20 years of drifter tracks crossing the ETC, which show how a pronounced meander of the Kuroshio develops north East of Taiwan in the shallow water of the East China Sea (ECS) continental shelf during times of low MSLA (and transport) at 23.9°N, 123.2°E.
During the Intense Observation Period phase of QPE, between August and September 2009, the MSLA proxy and the weekly drifter releases from offshore Taitung indicated the absence of a near surface Kuroshio intrusion on the IOP area, a feature confirmed by the dense drifter array released north and north-east of Taiwan (figure 7). The 15 m depth circulation mapped from the drifter data by bin-averaging the available observations within 0.15°X0.15° bins suggests the existence of a northeastward flow through the Taiwan Strait, part of which joins the Kuroshio right north of Taiwan, and a somewhat closed circulation cell at 25.3°N, 122° E. The surface expression of the Kuroshio flows along the shelf break (figure 8). Several drifters also move south between the coast of Taiwan and the northeastward flowing Kuroshio within a transient countercurrent (figure 2), probably generated by the localized wind forcing associated with the typhoon Morakot.
Two research articles describing the results of this experiment are in preparation for submission on a special issue of the Journal of Marine Research.

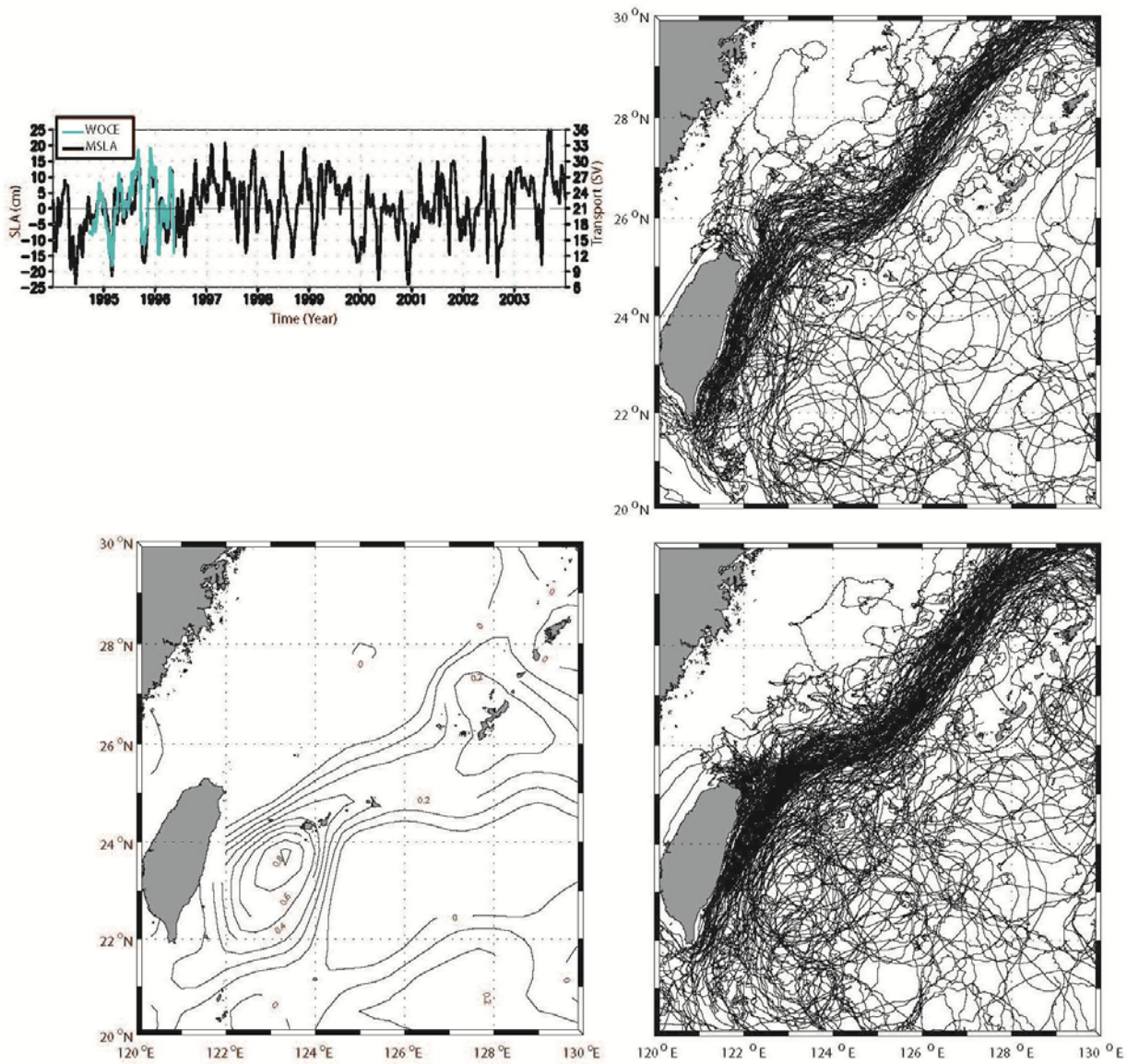

Figure 7: (top left) PCM-1 Kuroshio transport measurements (red) and Kuroshio transport estimated from MSLA (black). (Bottom left) zero-lag correlations between PCM-1 Kuroshio transport measurements and MSLA (which has zero mean). (Top right) drifter trajectories (July 1992- December 2010) when the MSLA at the location of maximum correlation with PCM-1 Kuroshio transport, as shown in the bottom left panel, is 0.3 times smaller than its standard deviation. (Bottom right) drifter trajectories (July 1992- December 2010) when the MSLA at the location of maximum correlation with PCM-1 Kuroshio transport, as shown in the bottom left panel, is 0.3 times larger than its standard deviation.

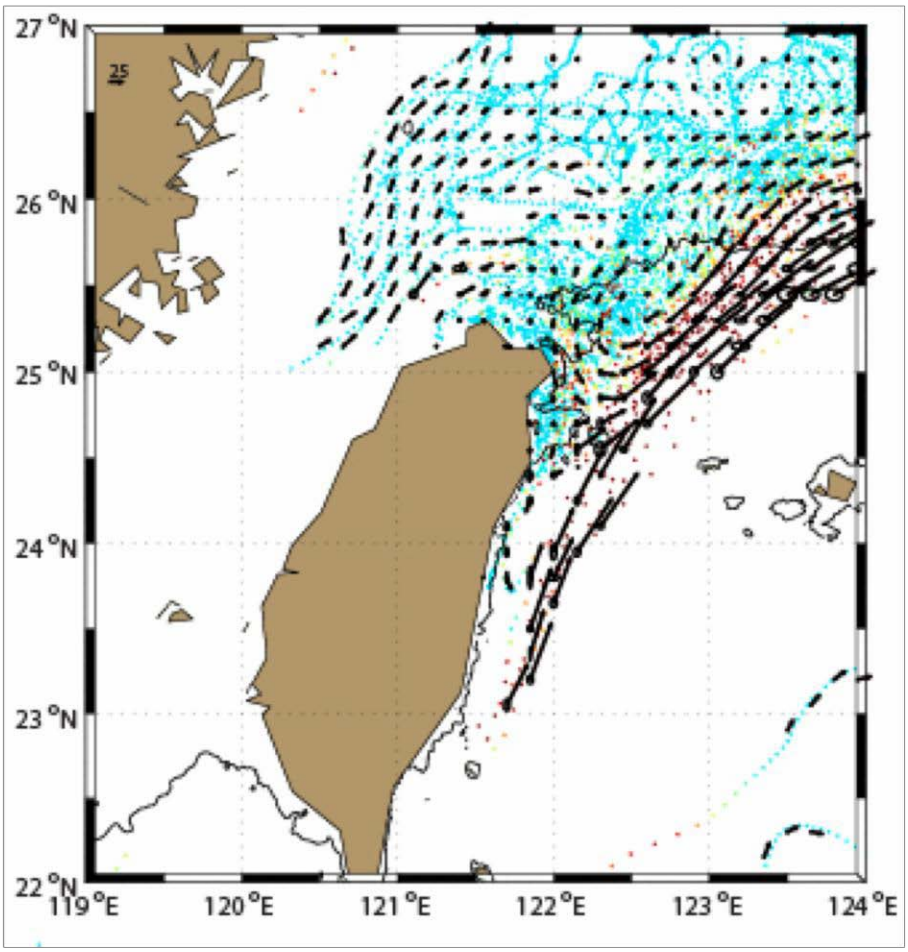

Figure 8: Locations of drifters color-coded in accordance with their 6-hourly instantaneous speed overlaid with bin-averaged drifter velocity from August through September, 2009. The spatial bins were 0.15^{o} latitude x 0.15^{o} longitude in width.

2.7.4 Drifters' deployments off Senegal(COCES) sponsored by the Office of Naval Research and supported by the GDP

The COCES project investigates the coastal dynamics off NW Africa in the tropical Atlantic Ocean by studying study the near-surface dispersion and circulation off the coast of Senegal, a region strongly influenced by coastal upwelling dynamics and affected by the runoff of an important river (Casamance). Lagrangian SVP drifters are currently being used to improve the description of the near surface circulation off the coast of Senegal. The emerging picture from more than two years of targeted drifter deployment off Senegal (Figure 9) is that of a year-round, off-shore directed near surface flow north of Cap Vert rich of filaments and eddies.

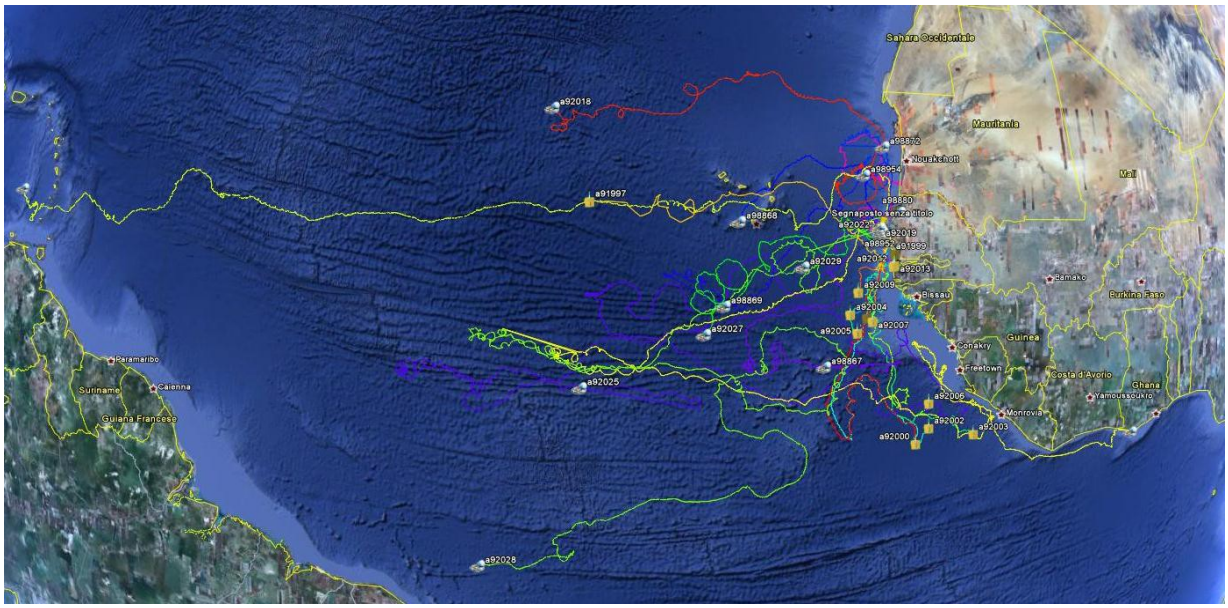

Figure 9: Trajectories of the SVP drifters in the tropical Atlantic Ocean between May 2009 and September 2011. Drifter identification numbers are posted at the end of the tracks (picture courtesy of Dr. Pierre-Marie Poulain).

2.7.5 Drifter deployment in the California Current system supported by the GDP and CORC

Please refer to the CORC report.

2.7.6 SPURS experiment, sponsored by NASA with contribution from the GDP. Implementation of SSS array

During this fiscal year, the GDP has allocated considerable resources in support of the SPURS project with the acquisition of 46 GDP-ST drifters which will be deployed in the tropical North-Atlantic in Spring 2012. A matching number of GDP-T drifters will also be deployed in the same area in support of SPURS and of AOML's effort of bringing the GDP array back to its target size in the shortest possible time.
The PI also visited the National Oceanographic Center of Southampton, UK, to set-up a series of tests for a state of the art, more economical salinity cell. The first tests of the implementation of this new technology on drifting buoys are planned for summer 2012.

2.8 Outreach and Education

Below is a list of activities aimed at publicizing and the role of the Global Drifter Program.

<u>Website:</u>
A new website was created: http://gdp.ucsd.edu/dashboard.html. Near real time drifter data viewer, password protected

Communications

- ☐ Interview, Associated Press. To raise awareness of marine debris in the Pacific Ocean and the role of the GDP. http://www.msnbc.msn.com/id/42383112/ns/technology_and_science-science/t/japan-tsunami-debris-wash-west-coast/

- ☐ Interview with local TV channel. To raise awareness of marine debris in the Pacific Ocean and the role of the GDP. http://www.fox5sandiego.com/news/kswb-tsunami-trash-current,0,6389360.story

- ☐ Newspaper article. To raise awareness of marine debris in the Pacific Ocean and the role of the GDP. http://blogs.laweekly.com/informer/2011/04/radioactive_ocean_surf_la.php

- ☐ Magazine article. To raise awareness of marine debris in the Pacific Ocean and the role of the GDP. http://news.discovery.com/earth/radioactive-debris-japan-ocean-110414.html

- ☐ TV interview. To raise awareness of marine debris in the Pacific Ocean and the role of the GDP. http://video.app.msn.com/watch/video/top-chef-judge-stops-serving-japanese-seafood/629o5wf

- ☐ TV interview. To raise awareness of marine debris in the Pacific Ocean and the role of the GDP. http://www.sandiego6.com/news/local/story/Seafood-Safe-to-Eat-San-Diego-Seafood-Nuclear/gOIQkg3BHE2Wm77EvOmk_A.cspx

- ☐ TV interview. To raise awareness of marine debris in the Pacific Ocean and the role of the GDP. http://www.cbs8.com/story/15875194/tons-of-japanese-tsunami-debris-drifting-this-way

- ☐ TV interview. To raise awareness of the Global Drifter Program. Italian TV. Documents the deployment of the first two SIO drifters. http://www.youtube.com/watch?v=au7_rqdv5uw

Networking

- ☐ Attendance to a meeting in Boston (February 2010) to discuss the SPURS experiment with the purpose to launch systematic drifter's SSS program.
- ☐ Attendance to the Launch of Aquarius Satellite, Vandenberg AFB.
- ☐ Presentation at the Hydrodynamics if Marine Debris Workshop. "Lagrangian Projects and Their Results", Honolulu, HI March 20 20011.Raise awareness of potential of the Global Drifert Program for Debris tracking.

Funded international fellowships

- ☐ Marie Curie Action fellowship (European Union). The PI is hosting Dr. Pedro Velez, a senior researcher from Spain, for two years at SIO to work on drifters' related research.
- ☐ Programme "PEOPLE" (European Union), researcher mobility between US, Italy, Brazil, Bulgaria and Portugal to work on drifters' related research.

3. Publications and Reports

3.1. Publications by Principal Investigators

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Gawarkiewicz, G., S. Jan, P.F.J. Lermusiaux, J.L. McClean, L. Centurioni, K. Taylor, B. Cornuelle, T.F. Duda, J. Wang, Y.J. Yang, T. Sanford, R.-C. Lien, C. Lee, M.-A. Lee, W. Leslie, P.J. Haley Jr., P.P. Niiler, G. Gopalakrishnan, P. Velez-Belchi, D.-K. Lee, and Y.Y. Kim. 2011. Circulation and intrusions northeast of Taiwan: Chasing and predicting uncertainty in the cold dome. *Oceanography* 24(4):110–121, http://dx.doi.org/10.5670/oceanog.2011.99.

D'Asaro, E., P. Black, L. Centurioni, P. Harr, S. Jayne, I.-I. Lin, C. Lee, J. Morzel, R. Mrvaljevic, P.P. Niiler, L. Rainville, T. Sanford, and T.Y. Tang. (2011). Typhoon-ocean interaction in the western North Pacific: Part 1. *Oceanography* 24(4):24–31, http://dx.doi.org/10.5670/oceanog.2011.91.

an, S., C.-C. Chen, Y.-L. Tsai, Y. J. Yang, J. Wang, C.-S. Chern, G. Gawarkiewicz, R.-C. Lien, L. Centurioni, and J.-Y. Kuo (2011), Mean Structure and Variability of the Cold Dome Northeast of Taiwan, Oceanography, 24(4), 100-109

Maximenko, N., R, Lumpkin and L. Centurioni, 2012, Ocean Surface Circulation, submitted for publication in ““Ocean Circulation and Climate”, edited by G. Siedler and J.W. Gould.

Chang, Yu-Chia, Guan-Yu Chen, Ruo-Shan Tseng, Luca R. Centurioni Observed near-surface flows under category 4 and 5 typhoons using drifters in the northwestern Pacific, Submitted to *J. Phys. Oceanogr*.

3.2 Other Relevant Publications

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Dong, C., Y. Liu, R. Lumpkin, M. Lankhorst, D. Chen, J. McWilliams and Y. Guan, 2011: A Scheme to Identify Loops from Trajectories of Oceanic Surface Drifters: Application to the Kuroshio Extension Region. *J. Atmos. Ocean. Techn.*, **28**, 1167–1176, doi:10.1175/JTECH-D-10-05028.1.

Grodsky, S., R. Lumpkin and J. Carton, 2011: Spurious trends in global surface drifter currents. *Geophys. Res. Letters*, **38**, L10606, doi:10.1029/2011GL047393.

Lumpkin R., G. Goni and K. Dohan, 2011: State of the Ocean in 2010: Surface Currents. In "State of the Climate in 2010", J. Blunden, D. S. Arndt and M. O. Baringer (eds), *Bulletin of the American Meteorological Society*, **92**, S92-S95.

Lumpkin, R. and S. L. Garzoli, 2011: Interannual to Decadal Variability in the Southwestern Atlantic’s Surface Circulation. *J. Geophys. Res.-Oceans*, **116**, C01014, doi:10.1029/2010JC006285.

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