The Global Drifter Program
Drifter Measurements of Surface Velocity, SST, SSS, Winds and Air Pressure

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1. Project Summary

The NOAA funded Global Drifter Program (GDP hereafter, Niiler 2001) 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. The DBCP was created 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 ***long term objectives*** of the GDP are to:

1) maintain a global 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 and operational 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; 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 should be as small as possible. Currently it 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 GDP partners 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. At present, 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; 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°, 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 real time to identify early signs of, and troubleshoot, technical issues.
- 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 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). 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. The GDP data and are available from SIO upon request to Luca Centurioni (lcenturioni@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

1. *(D1) provide 1015 SVP drifters (720 SVP and 295 SVPB) to AOML for maintaining the GDP array level of 1250 drifters.*
   Accomplished. The drifters were ordered from private companies or fabricated at SIO. Several hundred of drifters purchased in FY 11 were also retrofitted with Argos 3 modems and improved battery packs. Drifters were ordered from the flowing companies: Pacific Gyre, (130 SVPB, 150 SVPB, 355 retrofits) DBi (190 SVP, 80 SVPB), Metocean (40 SVP) and Clearwater (100 SVP, 162 retrofits). SIO fabricated 150 SVP and 80 SVPB. The GDP array, depressed in FYs '11 and '12, is now recovering because long-lived drifters are being deployed, but is still below the target threshold of 1,250 drifters.

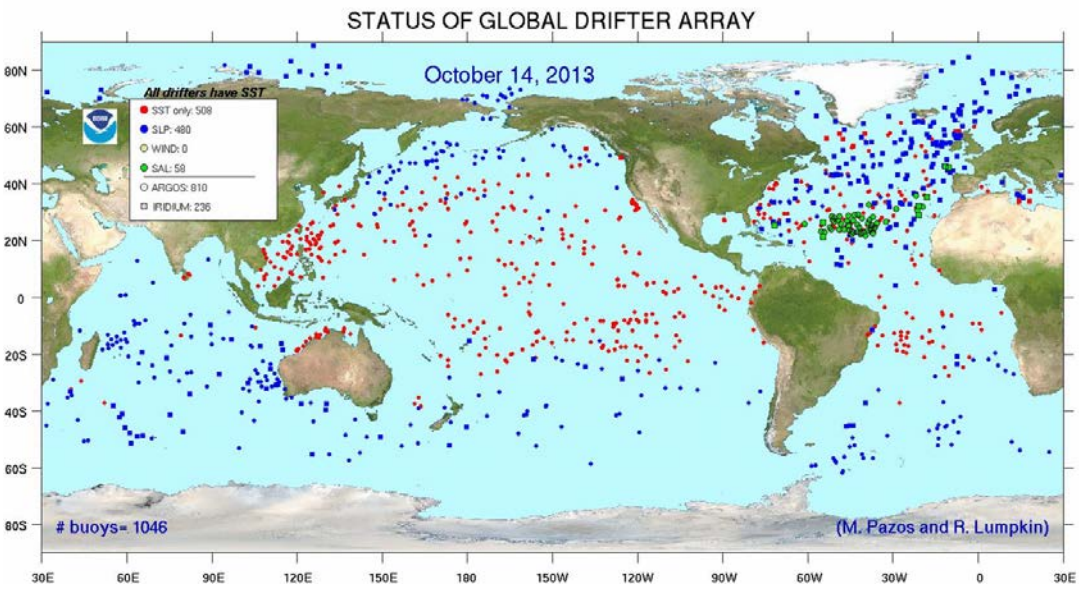

Figure 1: Global population of drifters as of October 14, 2013.

2. *(D2) coordinate GDP activities between the following entities: US manufacturers of drifters, AOML, SIO engineers, ONR and NASA for joint observational programs.*
   Accomplished. To this end, the PI has attended several ONR and NASA meetings and workshops. 46 salinity drifters were deployed in support of the SPURS experiment. This concluded the GDP involvement in SPURS started in 2011. 2001-2013 experimental work included surface circulation studies in the South China Sea, in the Philippine Sea and in the Bay of Bengal with drifters funded by ONR. Constant exchanges with AOML included closely monitoring the drifters' survivability. The GDP has also assisted AOML with shipping costs at the beginning of the fiscal year ($15K)
3. *(D3) enhance the GDP array by encouraging principal investigators to purchase SVP drifters for their studies and make their data available to the international community on the GTS. In exchange, Centurioni will send these PIs drifters purchased by GDP to be deployed in concert with the special projects to enhance their Lagrangian dataset.*
   Dr Yu Chia Chien (Sun Yat-Sen University) has purchased three drifters for typhoon studies, the data from these drifters will be posted to the GTS. The GDP will make three more drifters available to Dr. Chen as part of the matching program.
4. *(D4) monitor and advise the drifter manufacturers to ensure that the specifications required for the GDP drifters are respected.*
   Accomplished. A thorough evaluation of the Argos 3 technology and of the method of assembly of the battery pack into the drifters was conducted was the main focus of this funding cycle. The GDP worked closely with CLS France, Pacific Gyre and DBi to rectify such technical issues. Note that Clearwater is now out of business.
5. *(D5) update and maintain the enhanced GDP dataset, corrected for wind slip and drogue losses.*
   Accomplished. There were 14 requests for data this year: Cione, Chen, Maximenko, Jinadasa, Chao, Bingham, Brassington. Quartly, St Laurent/Merriefield, Ohlmann, Peacock, Reverdin, Lilly and Poulain. The GDP at SIO also maintains and serves data and plots in support of several investigators and for specific projects:

   http://gdp.ucsd.edu – GDP tracking of all MFG, public
   http://gdp.ucsd.edu/drake_passage
   http://gdp.ucsd.edu/hurricane
   http://gdp.ucsd.edu/labrador_sea
   http://gdp.ucsd.edu/navy_3rd_fleet
   http://gdp.ucsd.edu/semesteratsea
   http://gdp.ucsd.edu/spurs
   http://gdp.ucsd.edu/sri_lanka
   http://gdp.ucsd.edu/whoi_sl

6. *(D6) maintain real-time statistics of drifter performances.*
   Accomplished. Real time statistics are now available at the gdp.ucsd.edu website and constitute an invaluable tool for the PI to detect early signs of drifters' technical issues.

7. *(D7) test the hurricane drifters stored at the Keesler AFB for sensors and hardware functionality and inspect the deployment packages and parachute riggings to ensure they*

are ready for deployment.
Accomplished. Mr. Lancelot Braasch and Mr. Lance Curtiss travelled to Keesler AFB for routine maintenance of the GDP hurricane array between July 9 and July 12, 2013.

8. *(D8) report GDP's activities, scientific findings and technology advances in the DBCP "Technical Session".*
   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) .

9. *(D9) continue the scientific analysis of the GDP velocity, salinity and hurricane/typhoon datasets.*
   Accomplished. See special section.

Other accomplishments

- The GDP at SIO is currently applying to open an account to insert the drifter data intto the GTS. Automated scripts to compile both FM18-BUOY and FM94-BUFR have been created and tested by Mr. Lance Braasch.
- A large number of SVP and SVPB Iridium drifters have been ordered from Pacific Gyre (175), from DBi (5) and were built by SIO (10). These drifters are currently being deployed to evaluate their performances against the Argos 3 technology.
- The GDP partnered with the 3rd Fleet of the US NAVY. Ten Surface Velocity Program drifters were released in May 2013 from USS Pearl Harbor during Pacific Partnership 2013. As of October 17, 2013 all drifters are operational, are measuring near-surface ocean currents and sea surface temperature and are sending their data in real-time to the Global Telecommunication System of the World Weather Watch.

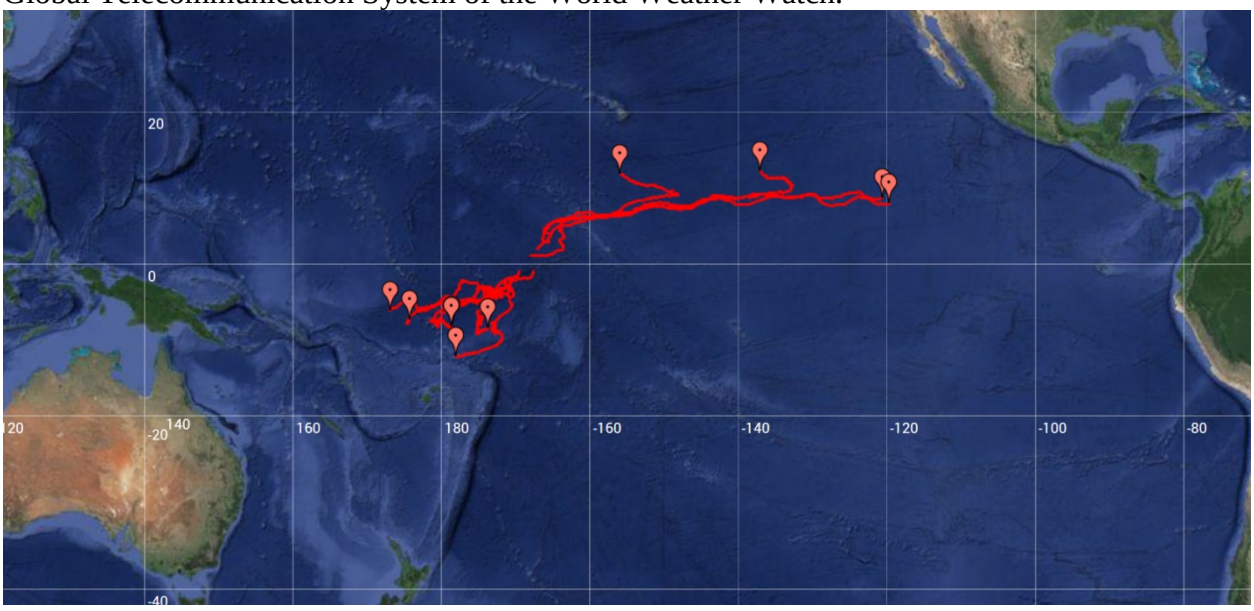

Figure 2. Tracks of the ten drifters (as of Oct 17, 2013) deployed from the USS Pearl Harbor during Pacific Partnership 2013

Selected scientific accomplishments

- A new wintertime subtropical current of the western north Pacific was identified from the analysis of drifter data and climatological datasets (satellite altimetry and reanalysis winds). The inter-annual variability of this current system was found to be correlated with the transport of the Kuroshio South of Japan. (Lee, D., and L. Centurioni, 2013).
- The relationship between the Kuroshio transport east of Taiwan (~24^{o}N) and the impinging mesoscale eddies is investigated using drifter data and a 8-year reanalysis of a dynamic ocean model that assimilates altimetry data. The coherence between the Kuroshio transport and eddy modes is significant especially for the first mode, a large eddy with some 500 km radius. Selected drifter trajectories were presented to illustrate the three eddy modes and the correspondence with the Kuroshio transport. Lee et al 2013).
- A detailed analysis on the evolution of the cold wake of typhoon Fanapi was performed using a large dataset provide by air deployed drifters. I was found that the cold wake was capped after 5 days, thus becoming invisible to SST satellites but it persisted for at least 3 weeks underneath the warm surface layer. (Mrvaljevicet al. 2013)

Travel funded by the GDP

- Fremantle, Australia,28th DBCP meeting, October 2012;
- SPURS workshop (1/16 through 1/18), co-funded by NASA;
- WIO-4 Workshop, Zanzibar, Tanzania 29 April – 3 May 2013;

3. Outreach and Education on GDP activities

- Radio interview, Pacific Beat, ABC radio, Melbourne, Australia, June 2, 2013 on the Pacific Partnership 2013 and the Global Drifter Program.
- Invited talk at the Taiwan Geosciences Union, Taipei, Taiwan, special session on the East China Sea attended by Taiwan's deputy Prime Minister.
- WIO-4 Workshop, Zanzibar, Tanzania 29 April – 3 May 2013, capacity building.
- 3 day teaching course at ISMARE summer school, Chios, Greece, 24th - 30th June, 2013.
- SIO graduate student open house, March 1, 2013, SIO, La Jolla, CA
- Presentation to the House Armed Services Committee Professional Staff Member Kevin Gates on August 30, 2013, SIO, La Jolla, CA

4. Publications and Reports

4.1. Publications by Principal Investigators

- Published

Centurioni, L., and D. Lee, 2013: Introduction to the special issue on upper ocean processes: Peter Niiler's contributions and inspirations. Oceanography, 26, 25-27.

Chang, Y.-C., G.-Y. Chen, R.-S. Tseng, L. R. Centurioni, and P. C. Chu, 2013: Observed near-surface flows under all tropical cyclone intensity levels using drifters in the northwestern Pacific. Journal of Geophysical Research: Oceans, n/a-n/a.

Jan, S., and Coauthors, 2013: Observations of a freshwater pulse induced by Typhoon Morakot off the northern coast of Taiwan in August 2009. J Mar Res, 71, 19-46.

Lee, D., and L. Centurioni, 2013: The Wintertime Subtropical Current in the northwestern Pacific. Oceanography, 26, 28-37.

Lee, I. H., D. Ko, Y.-H. Wang, L. Centurioni, and D.-P. Wang, 2013: The mesoscale eddies and Kuroshio transport in the western North Pacific east of Taiwan from 8-year (2003–2010) model reanalysis. Ocean Dynamics, 1-14.

Maximenko, N., R. Lumpkin, and L. Centurioni, 2013: Chapter 12 - Ocean Surface Circulation. International Geophysics, S. M. G. J. G. Gerold Siedler, and A. C. John, Eds., Academic Press, 283-304.

Mrvaljevic, R. K., and Coauthors, 2013: Observations of the cold wake of Typhoon Fanapi (2010). Geophysical Research Letters, 40, 316-321.

- In press

Eric D'Asaro, Peter G. Black; Luca R. Centurioni; Ya-Ting Chang; Shuyi Chen; Ralph C. Foster; Hans C. Graber; Patrick Harr; Verena Hormann; Ren-Chieh Lien; I.-I. Lin; Thomas B. Sanford; Tweng-Yung Tang; Chun-Chieh Wu, Impact of Typhoons on the Ocean in the Pacific: ITOP, BAMS.

- Technical reports

4.2. Other Relevant Publications

Publications in FY13 using Global Drifter Program data or products derived from the data, but not authored or coauthored by AOML Surface Drifter Program principal investigators:

Aranguren-Gassis, M., P. Serret, E. Fernández, J. L. Herrera, J. F. Domínguez, V. Pérez and J. Escanez, 2012: Balanced plankton net community metabolism in the oligotrophic North Atlantic subtropical gyre from Lagrangian observations. *Deep Sea Research Part I: Oceanographic Research Papers*, **68**, 116-122, http://dx.doi.org/10.1016/j.dsr.2012.06.004.

Atkinson, C. P., N. A. Rayner, J. Roberts-Jones, and R. O. Smith, 2013: Assessing the quality of sea surface temperature observations from drifting buoys and ships on a platform-by-platform basis. *J. Geophys. Res. Oceans*, **118**, 3507–3529, http://dx.doi.org/10.1002/jgrc.20257.

Beal, L., V. Hormann, R. Lumpkin and G. R. Foltz: The surface monsoon circulation of the Arabian Sea. *J. Phys. Oceanogr*., **43** (9), 2008-2022, http://dx.doi.org/10.1175/JCLI-D-13-00037.1.

Chiswell, S., 2013: Lagrangian timescales and eddy diffusivity at 1000 m compared to the surface in the south Pacific and Indian Oceans. *J. Phys. Oceanogr*., in press, http://dx.doi.org/10.1175/JPO-D-13-044.1.

Da-Allada, C. Y., G. Alory, Y. du Penhoat, E. Kestenare, F. Durand, and N. M. Hounkonnou, 2013: Seasonal mixed-layer salinity balance in the tropical Atlantic Ocean: Mean state and seasonal cycle. *J. Geophys. Res. Oceans*, **118**, 332–345, http://dx.doi.org/10.1029/2012JC008357.

Escudier, R., J. Bouffard, A. Pascual, P.-M. Poulain, and M.-I. Pujol, 2013: Improvement of coastal and mesoscale observation from space: Application to the northwestern Mediterranean Sea. *Geophys. Res. Lett.*, **40**, 2148–2153, http://dx.doi.org/10.1002/grl.50324.

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Jena, B., S. Sahu, K. Avinash and D. Swain, 2013: Observation of oligotrophic gyre variability in the south Indian Ocean: Environmental forcing and biological response. *Deep Sea Research Part I: Oceanographic Research Papers*, **80**, 1-10, http://dx.doi.org/10.1016/j.dsr.2013.06.002.

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