Sea Surface Velocity

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1. Project Summary

The Integrated Ocean Observing System (IOOS) includes an array of moored and drifting buoys that measure SST and near-surface currents throughout the world's oceans. The success of the IOOS in resolving SST variations and reducing satellite SST bias is quantified in a quarterly report (Zhang et al., 2004). However, until this project was initiated, no comparable evaluation was performed for surface currents even though surface currents carry massive amounts of heat from the tropics to subpolar latitudes, leading (and potentially improving prediction of) SST anomalies. Current anomalies can also be an early indicator of phase shifts in the ENSO, NAO, and possibly other climate cycles. The GOOS/GCOS (1999) report specified that the IOOS should resolve surface currents at 2 cm/s accuracy, with one observation per month at a spatial resolution of 600 km. There is currently no requirement for potential satellite bias in surface currents.

The primary goal of this project is to maintain a quarterly "Observing System Status Report for Surface Currents", which evaluates how well the IOOS satisfied the GOOS/GCOS requirements, and evaluate the evolution of the globally averaged potential satellite bias. This product is being used as a guide for future drifter deployments in conjunction with NOAA/AOML's Drifter Operations Center, a branch of the Global Drifter Program, and may demonstrate where future moored observations are necessary in order to meet these requirements.

The secondary goal of this project is to exploit recent research developments in order to derive high quality surface current products for the research community and general public. Specifics will evolve from year to year, and will be provided in the annual reports and work plans.

2. Scientific and Observing System Accomplishments

2.1 Deliverables

The FY13 work plan outlined the following deliverables:

1. *On a quarterly basis, produce a report of how well the GOOS is succeeding at monitoring global near-surface currents, using observations from the moored and drifting buoy networks.*
   Status: Accomplished. Final report for July—September 2013 was delayed by the government shutdown and will be produced before the end of the next quarter and the Oct-Dec report.
2. *Exploit research results to improve the quality of sea surface current data from the Global Drifter Program array.*
   Status: Accomplished.

Evaluating the observing system for Sea Surface Velocity (SSV)

The GOOS includes an array of moored and drifting buoys that measure SST and near-surface currents throughout the world's oceans. The success of the GOOS in resolving surface currents is evaluated by an add-task to AOML's Surface Drifter Program, $18,000 for FY12. This evaluation is motivated by the climate significance of surface currents, which carry massive amounts of heat from the tropics to subpolar latitudes, leading (and potentially improving prediction of) SST anomalies. Current anomalies can also be an early indicator of phase shifts in the ENSO, NAO, and possibly other climate cycles. The GOOS/GCOS (1999) report specified that the GOOS should resolve surface currents at 2 cm/s accuracy, with one observation per month at a spatial resolution of 600 km. There is currently no requirement for potential satellite bias in surface currents.

The goal of the SSV add-task is to maintain a quarterly "Observing System Status Report for Surface Currents", which evaluates how well the GOOS satisfied the GOOS/GCOS requirements, and evaluate the evolution of the globally averaged potential satellite bias. Near-real time drifter data is obtained at weekly resolution from the Global Drifter Program's drifter Data Assembly Center (DAC). The DAC identifies drifters which have run aground or been picked up, and removes these from the data stream. The DAC separate maintains a metadata file documenting the drogue-off date (date when each drifter lost its sea anchor). When a drifter has lost its drogue, it is significantly affected by direct wind forcing and no longer satisfies the GOOS/GCOS quality requirement for surface current measurement accuracy. We thus eliminate drogue-off drifters from our analysis. Because of the recent reevaluation of drogue presence (see section 2.5 of this report) which determined earlier drogue off dates for many drifters in the historical data set, the assessment of the GOOS's performance has become more pessimistic than prior to this reevaluation.

Moored current measurements are collected by near-surface point acoustic meters on the Tropical Atmosphere-Ocean (TAO) array in the Pacific, the Prediction and Research moored Array in the Tropical Atlantic (PIRATA), the sustained array of ATLAS moorings in the tropical

Indian Ocean (RAMA), the Kuroshio Extension Observatory (KEO) mooring at 32.3ºN, 144.5ºE and the PAPA mooring at 50°N, 145°W. Currents at daily resolution are downloaded from the TAO Project Office at PMEL each quarter to quantify the number of observations at each site, and the TAO office separately provides a record of days of observations per site, per quarter.

The most recent SSV quarterly report (Fig. 4) presents the overall spatial coverage of surface current measurements for that quarter (top right), the spatial distribution of success at meeting GOOS/GCOS requirements (bottom left, requirements stated in top left panel), and a time series showing the month-by-month fraction of the world's oceans that were measured at the resolution and accuracy stated by these requirements (bottom right). Since 1995, the success of the GOOS as hovered at 30—40% of complete global coverage. This curve has not increased with the increase in the global drifter array size in 2003—2006, primarily because the phase-in of the less expensive mini drifter design was associated with a sharp decrease in drogue lifetimes (Lumpkin et al., 2012). The Global Drifter Program is focusing attention on improving drogue lifetimes in FY14 (see Global Drifter Program reports for details).

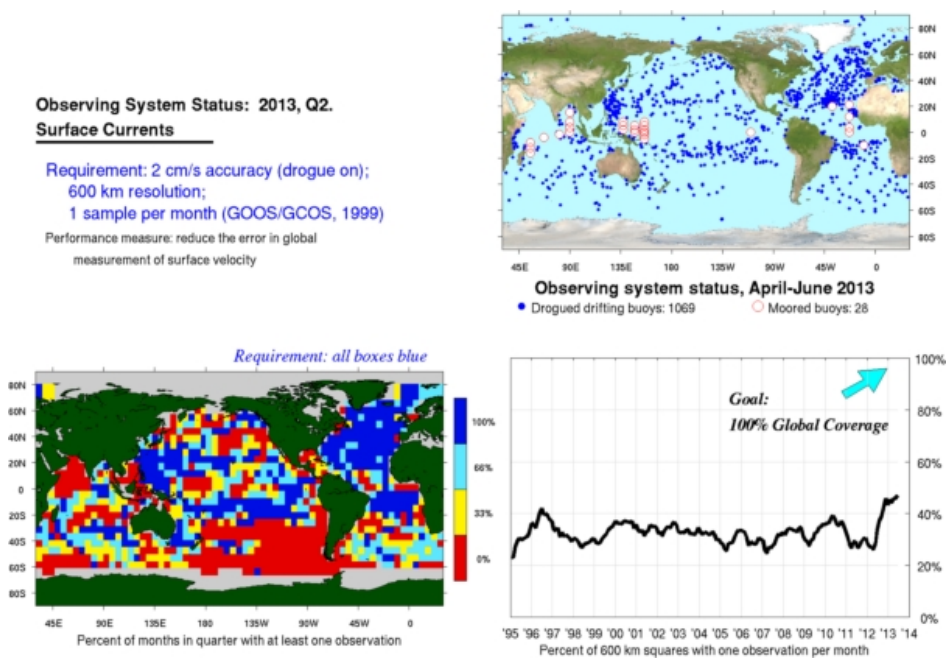

Fig. 4: GOOS performance for SSV measurements.

Drogue detection and lifetimes

While a drifter's drogue is attached, it slips downwind at <1 cm/s in 10 m/s wind. Once the drogue is lost, however, this increases by approximately a factor of 10 and wind forcing can significantly contaminate drifter-derived currents. Drogue presence is detected by either a submergence sensor, as the drogue frequently pulls the surface float underwater, or more directly by a tether strain sensor at the tether/surface float connection.

As reported in earlier years' reports, drogue detection was hampered for many years by extremely noisy submergence values. Since the implementation of tether strain by all

manufacturers, the GDP has been able to assess drogue presence more reliably. These improved drifters were deployed and represented a significant fraction of the global array by late 2008. During this same period of transition, the fraction of drifters identified as "drogue on" fell from around 70% to approximately 50% (see FY09 report). This indicated that a significant fraction of drifters in the pre-2008 period were misdiagnosed as "drogue on", when in fact they had lost their drogues. Because drifters without drogues are more strongly affected by direct wind forcing, misdiagnosis has the potential to bias ocean currents derived from drifters. This problem was the subject of a three-year NOAA Climate Change Data and Detection-funded project which started in 2010 (Principal Investigators Rick Lumpkin, NOAA/AOML, and Jim Carton and Semyon Grodsky, Univ. Maryland) and concluded in 2012.

The fraction of "drogue on" drifters (as evaluated by the GDP) that had actually lost their drogues was estimated in Grodsky, Lumpkin and Carton (2011). In this paper, we compared the downwind speed of "drogue on" drifters to (a) drifters which had lost their drogues, and (b) "drogue on" drifters <90 days old, which were likely to still have their drogues attached. The resulting ratio as a function of time dropped from ~100% in 1990—2004 to ~20% in 2006—2007, and then climbed to ~80% by 2010 with the phase-in of the tether strain drifters. At the 2011 Data Buoy Cooperation Panel meeting, Marie-Helene Rio (CLS) presented a methodology to evaluate when individual drifters lost their drogue, using results from Grodksy et al. (2011). This methodology, with improvements by R. Lumpkin (Lumpkin et al., 2013), has been implemented at AOML and was used in FY13 to conduct a systematic manual reevaluation of all drogues in the post-altimeter time period.

2.7 Scientific advances

Lumpkin, R. and G. Johnson (*J. Geophys. Res.-Oceans*, **118** (6), 2992-3006, doi:10.1002/jgrc.20210) derived a global climatology of monthly near-surface currents from the drifter data, revealing their structure and dependence on the ENSO cycle at higher resolution than available previously. The resulting products and additional documentation are available at http://www.aoml.noaa.gov/phod/dac/dac_meanvel.php.

This project (SSV) provided the support necessary for PI R. Lumpkin to create the surface current climatology products in various formats and to offer them on the GDP web page.

Lumpkin, R., S. Grodsky, M.-H. Rio, L. Centurioni, J. Carton and D. Lee (*J. Atmos. Oceanic Techn.*, **30** (2), 353—360, doi:10.1175/JTECH-D-12-00139.1) described a methodology to detect drogue loss, applied it to the drifter data set, and demonstrated that the results remove spurious low-frequency variations previously present in the data due to drogue detection problems. This methodology was used to reevaluate drogue loss dates in FY13, and results are reflected in the current GDP metadata files.

Lumpkin, R. and P. Flament (*Oceanography*, **26** (1), 58—65) described the structure and seasonal evolution of the Hawaiian Lee Countercurrent using drifter data. Anomalies from climatology revealed that a significant barotropic eddy-to-mean flux of energy acts to reinforce

this countercurrent which runs approximately from the dateline to immediately west of the Big Island of Hawaii.

Beal, L., V. Hormann, R. Lumpkin and G. R. Foltz (*J. Phys. Oceanogr*., **43** (9), 2008-2022, doi:10.1175/JCLI-D-13-00037.1) used drifter observations to characterize monsoon-driven changes in surface circulation in the otherwise poorly-observed northeastern Indian Ocean.

Hormann, V., R. Lumpkin and R. C. Perez (*J. Atmos. Oceanic Techn*., **30**, 1884-1895, doi:10.1175/JTECH-D-12-00173.1) derived a generalized method for estimating the structure of the equatorial Atlantic cold tongue and applied it to drifter observations to generate an estimate of the cross-frontal velocity at the ocean surface.

2.8. FY12 Meetings

PI R. Lumpkin attended the following meetings:

Data Buoy Cooperation Panel Meeting, October 2—6, Fremantle, Australia; presented GDP report and results of drogue reanalysis (Lumpkin et al., 2013), attended working group meetings, and coordinated GDP activities with international partners. Travel funded by Surface Drifters project.

NSF workshop on inertial oscillations, November 7—9, Miami, FL; presented overview of drifter observations and results of recent analyses. No travel funding required.

Ocean Tracks advisory board meeting, January 28—29, Monterey, CA; worked with Education Development Center, Inc. members to incorporate drifter data into education-focused interface. Travel supported by EDC.

Workshop on modeling, observing, and assimilating submesoscale dynamics, April 2—4, Abu Dhabi; presented observations of submesoscale dynamics by global drifter array. Travel supported by the Center for Prototype Climate Modeling.

US CLIVAR Summit, July 8—11, Annapolis, MD; attended Phenomenon, Observation and Synthesis (POS) panel meetings and discussions. Travel funded by NOAA/CPO via direct BOP.

Data Buoy Cooperation Panel Meeting, September 23—27, Paris, France; presented US and GDP reports and results of global and regional drifter analyses (Lumpkin and Johnson, 2013; Lumpkin and Flament, 2013; Beal et al., 2013), attended working group meetings, and coordinated GDP activities with international partners. Travel funded by Surface Drifters project.

2.9. Education and Outreach

PI R. Lumpkin worked with Dr. Diane Stanitski, Shaun Dolk, and members of Education Development Center, Inc (EDI). to incorporate drifter data in the Ocean Tracks project. This project aims to allow student access to the data with accompanying exercises of increasing difficulty, to guide comfort and spur curiosity and familiarity with data analysis.

R. Lumpkin served as a panel member on a Climate Science Café meeting in Miami, FL on 21 February 2013, sponsored by CLEO (http://www.cleoinstitute.org/). Lumpkin also served on the

Rosenstiel Award Committee (Univ. Miami) as an outside member, served on a Ph.D. thesis committee for student Greta Leber (Lisa Beal, advisor), reviewed numerous manuscripts and proposals, and collaborated with authors from NOAA's ClimateWatch Magazine for a recent article on the value of drifter data (http://www.climate.gov/news-features/climate-tech/doing-their-part-drifter-buoys-provide-ground-truth-climate-data).

3. Publications and Reports

3.1. Publications by Principal Investigators

The following peer-reviewed publications by the Surface Drifter Program principal investigators rely upon the drifter data:

FY14

Submitted

Smith, R., E. Johns, G. J. Goni, J. Trinanes, R. Lumpkin, A. M. Wood, C. R. Kelble, S. R. Cummings, J. T. Lamkin and S. Privoznik: Oceanographic conditions in the Gulf of Mexico in July 2010, during the Deepwater Horizon oil spill. *Continental Shelf Research*, revision submitted March 2013.

Accepted/In Press

Fox-Kemper, B., R. Lumpkin and F. Bryan: Lateral Transport in the Ocean. Chapter 3.5 of "Ocean Circulation and Climate, 2nd Ed. A 21st century perspective", ed. G. Siedler, S. Griffies, J. Gould and J. Church, Academic Press.

Le Hénaff, M., V. H. Kourafalou, R. Dussurget and R. Lumpkin: Cyclonic activity in the eastern Gulf of Mexico: characterization from along-track altimetry and in situ drifter trajectories. *Progress in Oceanogr*., in press, doi:10.1016/j.pocean.2013.08.002.

Maximenko, N., R. Lumpkin and L. Centurioni: Ocean Surface Circulation. Chapter 4.2 of "Ocean Circulation and Climate, 2nd Ed. A 21st century perspective", ed. G. Siedler, S. Griffies, J. Gould and J. Church, Academic Press.

Perez, R., V. Hormann, R. Lumpkin, P. Brandt, W. E. Johns, F. Hernandez, C. Schmid and B. Bourles: Mean meridional currents in the central and eastern equatorial Atlantic. Climate Dynamics, accepted October 2013.

Published FY13

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.

Foltz, Gregory R., Claudia Schmid, Rick Lumpkin, 2013: Seasonal Cycle of the Mixed Layer Heat Budget in the Northeastern Tropical Atlantic Ocean. *J. Climate*, **26**, 8169–8188, http://dx.doi.org/10.1175/JCLI-D-13-00037.1.

Hormann, V., R. Lumpkin and R. C. Perez: A generalized method for estimating the structure of the equatorial Atlantic cold tongue: application to drifter observations. *J. Atmos. Oceanic Techn*., **30**, 1884-1895, http://dx.doi.org/10.1175/JTECH-D-12-00173.1.

Letscher, R. T., D. A. Hansell, C. A. Carlson and R. Lumpkin, 2013: Dissolved organic nitrogen in the global surface ocean: distribution and fate. *Global Biogeochem. Cycles*, 21 (1), 141—153, http://dx.doi.org/10.1029/2012GB004449.

Lumpkin, R. and G. Johnson: Global Ocean Surface Velocities from Drifters: Mean, Variance, ENSO Response, and Seasonal Cycle. *J. Geophys. Res.-Oceans*, **118** (6), 2992-3006, http://dx.doi.org/10.1002/jgrc.20210.

Lumpkin R., G. Goni and K. Dohan, 2013: State of the Ocean in 2012: Surface Currents. In "State of the Climate in 2012", *Bulletin of the American Meteorological Society*, **94** (8), August 2013.

Lumpkin, R., S. Grodsky, M.-H. Rio, L. Centurioni, J. Carton and D. Lee, 2013: Removing spurious low-frequency variability in surface drifter velocities. *J. Atmos. Oceanic Techn*., **30** (2), 353—360, http://dx.doi.org/10.1175/JTECH-D-12-00139.1.

Lumpkin, R. and P. Flament, 2013: On the extent and energetics of the Hawaiian Lee Countercurrent. *Oceanography*, **26** (1), 58—65.

3.2. Other Relevant Publications

Publications in FY13 using Global Drifter Program data not authored or coauthored by AOML Surface Drifter Program principal investigators include:

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.

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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. *J. Geophys. Res. Oceans*, **118**, 2367–2377, http://dx.doi.org/10.1002/jgrc.20187.

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.

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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.

Kersalé, M., A. A. Petrenko, A. M. Doglioli, I. Dekeyser, and F. Nencioli, 2013: Physical characteristics and dynamics of the coastal Latex09 Eddy derived from in situ data and numerical modeling. J. Geophys. Res. Oceans, 118, 399–409, http://dx.doi.org/10.1029/2012JC008229.

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