Evaluating the Ocean Observing System
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 (1998) implementation 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

Deliverables

The FY12 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.
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 FY13 (see Global Drifter Program reports for details).

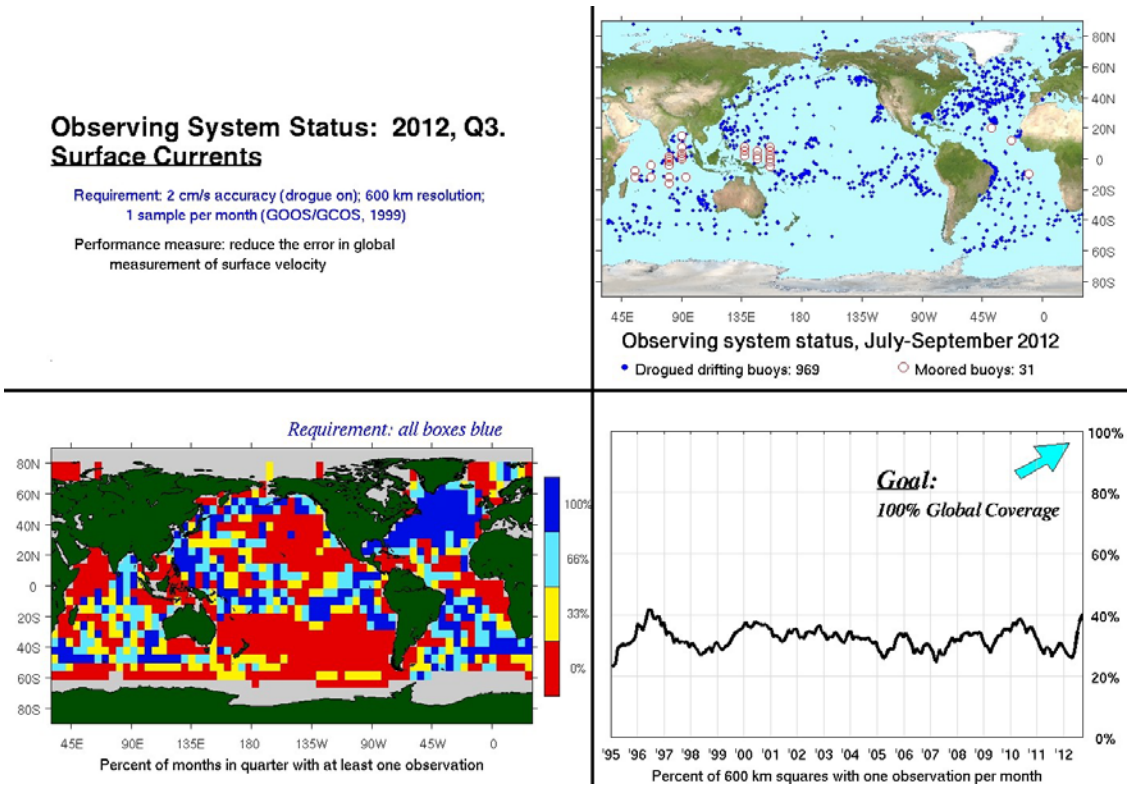

Fig. 4: GOOS performance for SSV measurements.

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.

Drogue detection was hampered for many years by extremely noisy submergence values, especially problematic for many Technocean drifters. 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%. 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 for the period 2010—2012 (Principal Investigators Rick Lumpkin, NOAA/AOML, and Jim Carton and Semyon Grodsky, Univ. Maryland).

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) averaged over all the array (i.e., their methodology did not allow identification of specific drifters). The fraction 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, has been implemented at AOML and has now being used in a systematic manual reevaluation of all drogues in the post-altimeter time period. This reevaluation was completed at the end of 2012, and results were published in Lumpkin et al (2013) (Fig. 5).

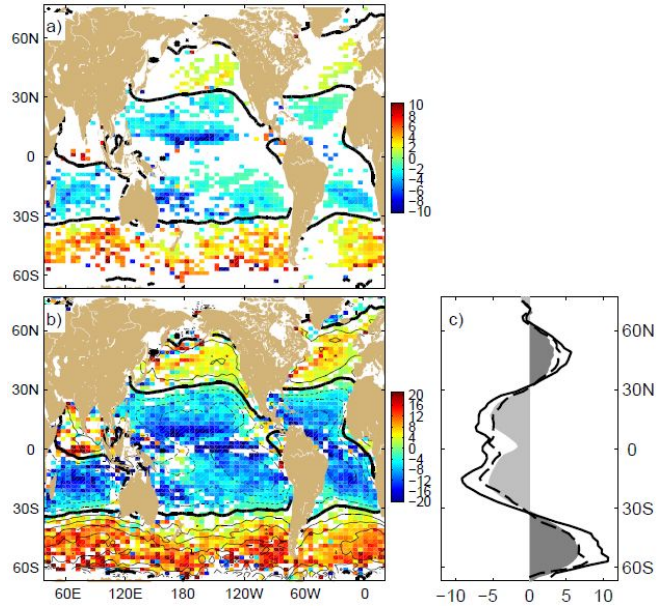

Fig. 5: a) Mean zonal current of "drogue on" drifters **before** minus **after** (cm/s), zero contour of time-mean zonal wind superimposed. b) Drogue off minus drogue on (**after**), time mean zonal wind superimposed (2 m/s contours). c) Time-longitude average of mean zonal wind interpolated to the drifters (shading, m/s) and drogue-off minus drogue-on zonal drifter speed (cm/s) **before** (dashed) and **after** (solid) automatic drogue reanalysis. From Lumpkin et al. (2013).

Scientific advances

Hormann, Lumpkin and Foltz (2012) examined interannual to decadal variations in the strength and position of the Atlantic's North Equatorial Countercurrent (NECC) using a synthesis of drifters, satellite winds, and altimetry. This study showed that zonal propagation of NECC variations is consistent with long Rossby waves forced in the northeast tropical Atlantic, that northward (southward) shifts of NECC core are correlated with positive (negative) meridional mode events, strenghtening (weakening) of NECC is correlated with negative (positive) zonal mode events, and that these interannual NECC changes are likely driven by changes in the wind stress curl field associated with the Tropical Atlantic climate modal events.

Lumpkin, Maximenko and Pazos (2012) examined how exposed various coastlines are to the deposit of marine debris, using a statistical model derived from the trajectories and "ran aground" locations of all drifters in the GDP data base.

Lumpkin et al. (2013) described a methodology to identify drogue loss using multiple sources of information including submergence or tether strain, anomalous downwind motion, and transmission frequency anomaly. Results of this methodology were offered to the research community, and are being included in updates of the GDP's metadata files.

FY11 Meetings

PI R. Lumpkin attended the following meetings:

2012 Ocean Sciences, February 20—24, Salt Lake City, Utah; presented results from drogue detection study.

European Space Agency GlobCurrents, March 7—9, Brest, France; presented opening keynote lecture on ocean surface currents and in-situ measurements. Represented NOAA and PhOD activities in discussions on proposed GlobCurrents product.

2012 PhOD retreat, Miami FL, March 28—29; presented results from drogue detection study.

5th Workshop on the Impact of Observing Systems on Numerical Weather Forecasting, 21—25 June including one-day workshop on drifting buoys, 21 June, Sedona AZ; co-wrote report documenting value of drift sea level pressure measurements for improving numerical weather prediction.

NOAA Climate Observations Division Annual PI meeting, 25—27 June, Silver Spring MD; presented poster on results of drogue detection study.

US CLIVAR Summit, 17—20 July, Newport Beach CA; served as member of Phenomenon, Observation and Synthesis (POS) panel.

Tropical Atlantic Variability/PIRATA-17, 10—14 September; Kiel, Germany; co-chair of PIRATA Science Steering Group, session convener, two oral presentations and one poster.

2.1 Education and Outreach

R. Lumpkin gave a presentation on drifters and the Global Ocean Observing System for visiting students from Gulliver Schools, 9 November 2011, and for Miami-Dade Science Camp, 10 July 2012, and served as Technical Input Author for the National Climate Assessment Ocean and Marine Resources report, which will be published in Oceanography and Marine Biology: Annual Review in 2013.

3. Publications and Reports

3.1. Publications by Principal Investigators

The following peer-reviewed publications were authored by the PI of this project and were published in FY2012-2013:

FY2013

Submitted

Beal, L., V. Hormann, R. Lumpkin and G. R. Foltz: The surface monsoon circulation of the Arabian Sea. J. Phys. Oceanogr., submitted February 2013.

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., submitted November 2012 (in revision).

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, submitted February 2013.

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

Foltz, G. R., C. Schmid and R. Lumpkin: Seasonal cycle of the mixed layer heat budget in the northeastern tropical Atlantic Ocean. J. Climate, accepted May 2013.

Fox-Kemper, B., R. Lumpkin and F. Bryan: Lateral Transport in the Ocean. Chapter 3.5 of "Ocean Circulation and Climate (Second edition)", ed. G. Siedler, J. Church, J. Gould and S. Griffies, Academic Press (Elsevier), in press.

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., accepted February 2013.

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, doi: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, in press, doi: 10.1002/jgrc.20210.

Maximenko, N., R. Lumpkin and L. Centurioni: Ocean Surface Circulation. Chapter 4.2 of "Ocean Circulation and Climate (Second edition)", ed. G. Siedler, J. Church, J. Gould and S. Griffies, Academic Press (Elsevier), in press.

Published

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, doi: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.

FY2012

Foltz, G. R., M. J. McPhaden and R. Lumpkin, 2012: A strong Atlantic Meridional Mode event in 2009: the role of mixed layer dynamics. J. Climate, 25, 363—380, doi: 10.1175/JCLI-D-11-00150.1.

Hormann, V., R. Lumpkin and G. Foltz, 2012: Interannual North Equatorial Countercurrent Variability and its Relation to Tropical Atlantic Climate Modes. J. Geophys. Res., 117, C04035, doi:10.1029/2011JC007697.

Lumpkin R., G. Goni and K. Dohan, 2012: State of the Ocean in 2011: Surface Currents. In "State of the Climate in 2011", M. Gregg and J. Levy (eds), Bulletin of the American Meteorological Society 93 (7), S75-S78.

Lumpkin, R., N. Maximenko and M. Pazos, 2012: Evaluating where and why drifters die. J. Atmos. Ocean. Techn., 29 (2), 300—308,doi: 10.1175/JTECH-D-11-00100.1.

Perez, R. C., R. Lumpkin, W. E. Johns, G. R. Foltz and V. Hormann, 2012: Interannual variations of Atlantic tropical instability waves. J. Geophys. Res., 117, C03011, doi: 10.1029/2011JC007584.

3.2. Other Relevant Publications

Publications in 2012 using Global Drifter Program data not authored or coauthored by Surface Drifter Program principal investigators include:

Castro, S. L., G. A. Wick, and W. J. Emery, 2012: Evaluation of the relative performance of sea surface temperature measurements from different types of drifting and moored buoys using satellite-derived reference products, *Journal of Geophysical Research-Oceans*, **117**.

Guo, J. S., X. Y. Chen, J. Sprintall, B. H. Guo, F. L. Qiao, and Y. L. Yuan , 2012: Surface inflow into the South China Sea through the Luzon Strait in winter, *Chinese Journal of Oceanology and Limnology*, **30**(1), 163-168.

Haza, A. C., T. M. Ozgokmen, A. Griffa, Z. D. Garraffo, and L. Piterbarg , 2012: Parameterization of particle transport at submesoscales in the Gulf Stream region using Lagrangian subgridscale models, *Ocean Modelling*, **42**, 31-49.

Heinloo, J., A. Toompuu and M.-J. Lilover , 2012: Gyration effect of the large-scale turbulence in the upper ocean, *Environmental Fluid Mechanics*, **6**(4), doi:10.1007/s10652-012-9247-2.

Hobbs, W. R., and J. K. Willis , 2012: Midlatitude North Atlantic heat transport: A time series based on satellite and drifter data, *Journal of Geophysical Research-Oceans*, **117**.

Hristova, H. G., and W. S. Kessler, 2012: Surface Circulation in the Solomon Sea Derived from Lagrangian Drifter Observations, *Journal of Physical Oceanography*, **42**(3), 448-458.

Kartadikaria, A. R., Y. Miyazawa, K. Nadaoka, and A. Watanabe , 2012: Existence of eddies at crossroad of the Indonesian seas, *Ocean Dynamics*, **62**(1), 31-44.

Maximenko, N., J. Hafner, and P. Niiler , 2012: Pathways of marine debris derived from trajectories of Lagrangian drifters, *Marine Pollution Bulletin*, **65**(1-3), 51-62.

Monzon-Arguello, C., F. DellAmico, P.Moriniere, A. Maro, L. F. Lopez-Jurado, Graeme C. Hays, Rebecca Scott, Robert Marsh and Patricia L. M. Lee , 2012: Lost at sea: genetic, oceanographic and meteorological evidence for storm-forced dispersal, *J. R. Soc. Interface*, doi:10.1098/rsif.2011.0788.

Piecuch, C. G. and T. A. Rynearson , 2012: Quantifying dispersion and connectivity of surface waters using observational Lagrangian measurements. *J. Atmos. Oceanic Technolog*., **29** (8), 1127–1138, doi:10.1175/JTECH-D-11-00172.1.

Renner, A. H. H., S. E. Thorpe, K. J. Heywood, E. J. Murphy, J. L. Watkins, and M. P. Meredith , 2012: Advective pathways near the tip of the Antarctic Peninsula: Trends, variability and ecosystem implications, *Deep-Sea Research Part I-Oceanographic Research Papers*, **63**, 91-101.

Reverdin, G., S. Morisset, J. Boutin, and N. Martin , 2012: Rain-induced variability of near sea-surface T and S from drifter data, *J. Geophysical Research-Oceans*, **117**.

Volkov, D. L., and M. I. Pujol , 2012: Quality assessment of a satellite altimetry data product in the Nordic, Barents, and Kara seas, *Journal of Geophysical Research-Oceans*, **117**.

Wang, G. H., D. X. Wang, and T. J. Zhou , 2012: Upper layer circulation in the Luzon Strait, *Aquatic Ecosystem Health & Management*, **15**(1), 39-45.

Zedler, S. E., G. Kanschat, R. Korty, and I. Hoteit , 2012: A new approach for the determination of the drag coefficient from the upper ocean response to a tropical cyclone: a feasibility study, *J. Oceanography*, **68**(2), 227-241.