# Evaluating the Ocean Observing System: Surface Currents

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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 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.

Many researchers routinely calculate surface currents from satellite observations of wind and altimetry. As an example, geostrophic currents derived from blended satellite altimetry fields are estimated at AOML and posted daily in near-real time at http://www.aoml.noaa.gov/phod/altimetry/.
However, careful, quantified comparison with the in-situ observations has only been published for a few regions such as the Kuroshio Extension (Niiler et al., 2003). Prior to this project, no one had performed this comparison globally using non-interpolated altimetry, and the observing system had not been evaluated in this context.

## 2. ACCOMPLISHMENTS

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.

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. Each quarter, these independent measures are compared to ensure accuracy.

The FY08 quarterly report (Figure 1) presents the overall spatial coverage of surface curent 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).

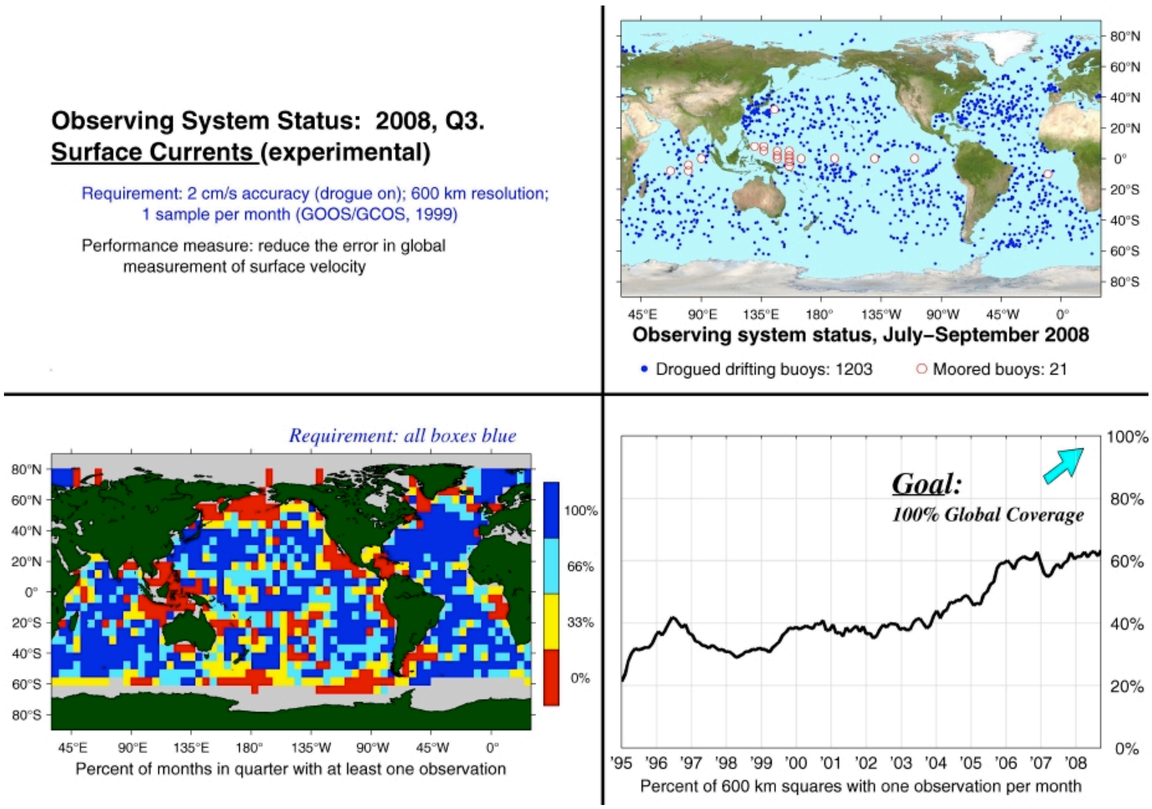


**Figure 1.** FY08 Q4 (calendar Q3) report evaluating the IOOS's performance for near surface current measurements.

The percent of 5° squares with at least one observation per month has effectively reached a plateau since early 2008, at slightly over 60%. Much of the shallow (too shallow for 15m drogued drifters) Indonesian Seas region remains unsampled, along with coastal divergent regions where drifters move rapidly away from the coast (e.g., the west coasts of Africa and South America, where drifters move into the convergent centers of the southern subtropical gyres which are heavily oversampled by the array). Regions along the ice edge of the southern ocean, and in marginal seas such as the Caribbean and Bering, are also persistent gaps in the array.

### 2.1. Evaluating potential satellite bias

Potential satellite bias error can be calculated for surface current measurements in analogy to the process for SST measurements. Satellite measurements are collected of intensity at various light frequencies, in particular infrared and microwave. A model is used to convert these measurements to surface temperatures in degrees C. Due to various biases that exist in the model, for example the influence of atmospheric dust, the resulting SST field can be significantly offset from actual SST. In-situ observations can be used to reduce this maximum bias, which varies spatially, and the resulting globally-averaged potential satellite bias error is a function of the number and distribution of the observing network.

For surface currents, models to convert satellite measurements to surface current estimates are less mature than with SST. The most developed example is NOAA's OSCAR, which includes both geostrophic and wind-driven components. However, as noted below, it is not immediately clear how to compare drifter measurements to OSCAR measurements, as differences may not necessarily be due to biases in the OSCAR model. In fact, our analysis funded by this project points to biases in the in-situ drifter measurements at high wind speeds.

For FY08, we chose to explicitly decompose drifter motion into (0) time mean, (1) geostrophic, (2) wind-driven and (3) slip components, given by time mean offsets and regression coefficients multiplying: (1) geostrophic current anomalies calculated from AVISO sea level anomaly fields using the Lagerloef et al. (1999) alogorithm, constant offsets for adjustments to the time-mean state, (2) friction velocity (proportional to the square root of the surface wind stress) and (3) wind speed at the surface. Wind stresses were derived from wind speeds using the Smith (1988) algorithm as implemented in COARE 3.0, with wind speeds from the Atlas et al. (1996, 2008) Variational Analysis Method scatterometer-based product. Drifter observations were divided into bins, with the best-fit coefficients derived via Gauss-Markov estimation. This approach requires estimating errors in the satellite-based estimates (a priori errors), and produces formal errors for the resulting ocean currents derived from satellite measurements (a posteriori errors). Maximum satellite bias can be derived from the distribution of a posteriori errors. We assume that a priori errors are dominated by errors in the geostrophic currents estimated from the AVISO product, and calculate them taking advantage of the fact that AVISO provides formal errors in the sea height anomaly that are a function of the altimetry coverage (Figure 2). We further assume that these errors are distributed over an eddy length scale, calculated as in Stammer (1999), to convert this to an error in geostrophic current. The present model results in infinite errors on the equator, an unrealistic artifact that we will address in FY09.

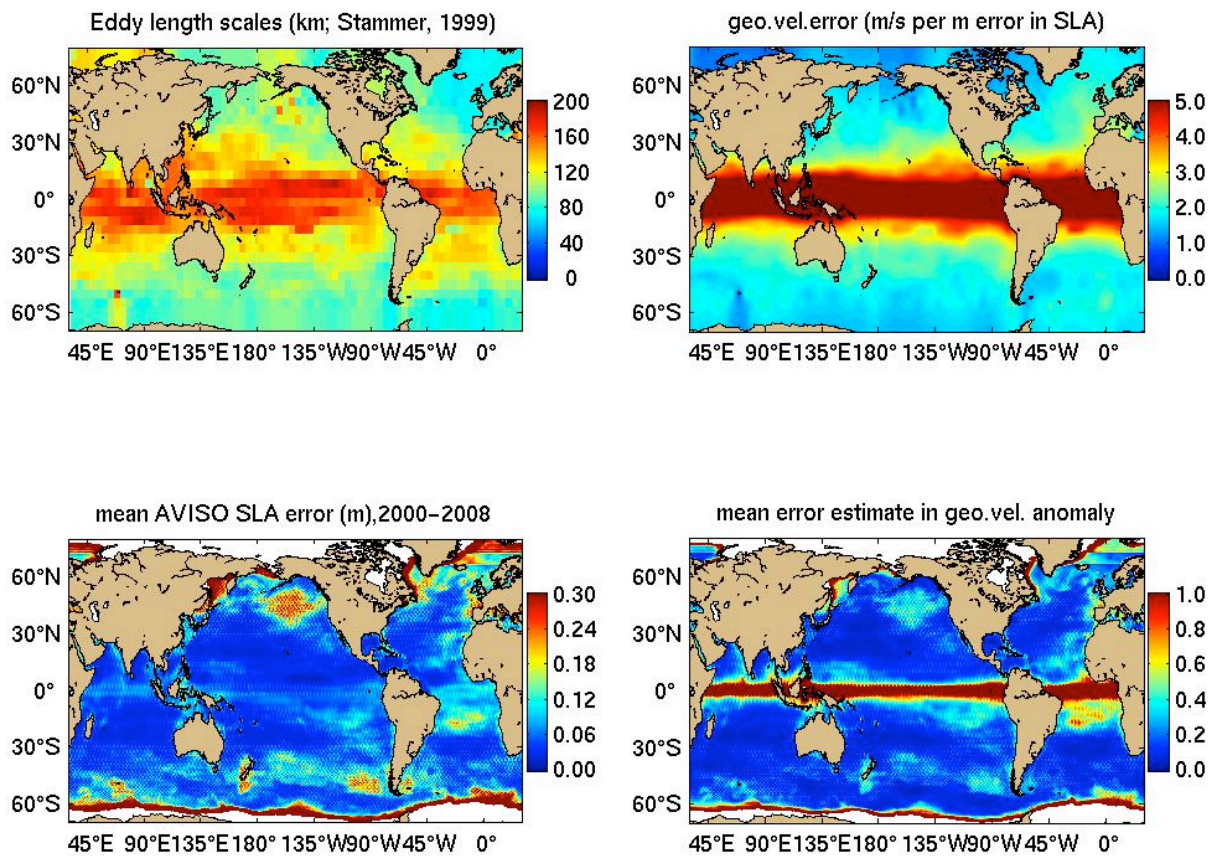


**Figure 2.** Eddy length scales (top left) and resulting error in geostrophic velocity anomaly (top right) in m/s, for a 1m error in sea height. The actual time-mean distribution of altimetric sea level anomaly, provided by AVISO, is shown in the bottom left panel. Resulting time-mean errors in satellite-derived geostrophic velocity anomaly is shown in bottom right.

As reported in last year's progress report, our previous work had focused on removing the Ekman component of drifter movement using the Ralph and Niiler (1999) parameterization (herafter RN99). The remaining motion, lowpassed to remove tides and inertial oscillations, was treated as dominated by geostrophic motion and compared to altimetry-based calculations. With our new approach, simultaneously decomposing the motion into wind and geostrophic components, we permit significant variations from the RN99 parameterization. For most of the globe, we find that RN99 works well. However, we find that the wind-driven component in some regions, particularly the Southern Ocean, exceeds the estimate that would be provided by RN99 (Figure 3).

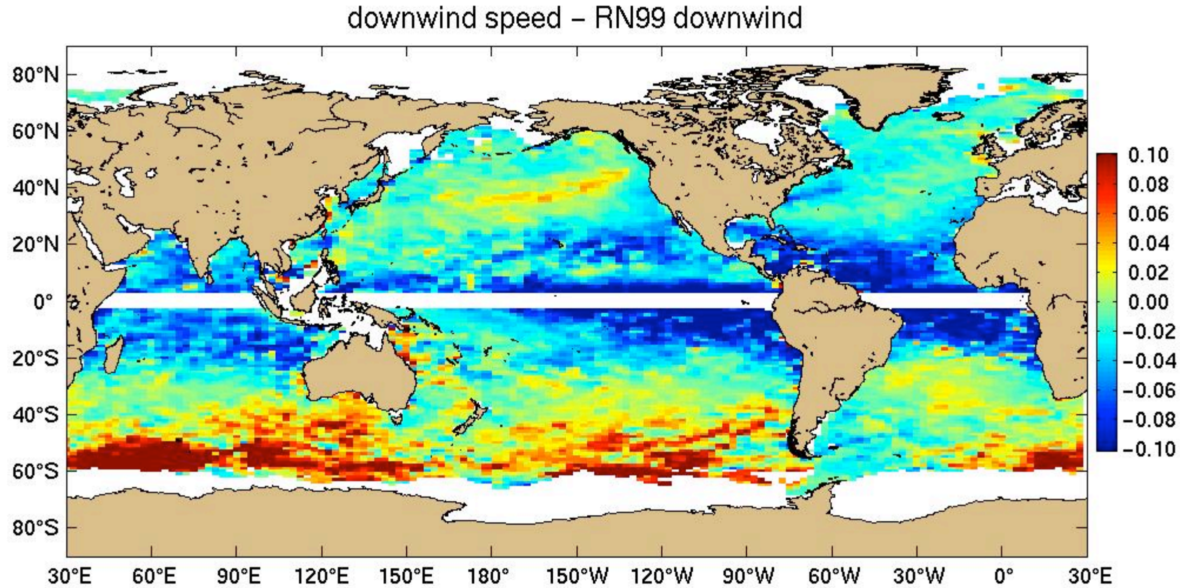


**Figure 3.** Difference (m/s) between the magnitude of the wind-driven component of drifter motion derived in our study and the RN99 result, calculated from the same wind field. The magnitude of the downwind component is shown; crosswind results are not significantly different. We find values 10-20 cm/s faster velocities in large subsections of the Southern Ocean. Negative results at low latitudes are due to the overly large a priori errors assigned in our Gauss Markov fit.

This result suggests that wind driven drifter motion significantly exceeds the RN99 estimate in regions with strong winds and waves, and will be a major focus of our work in FY09. Assessing what this motion is, and properly parameterizing it, will greatly increase the value of the drifter velocity data in data assimilation efforts.

Preliminary estimates of the potential satellite bias were presented by R. Lumpkin at this year's OCO annual workshop. They were derived by taking the distribution of a posteriori errors in the Gauss Markov model (Figure 4, left) and reducing those errors to the bias in the in-situ measurements where such measurements exist (Figure 4, right), with an assumed Gaussian distribution with width set by the eddy length scale (Figure 2, top right). Undrogued drifters are included in this estimate, with the larger slip used when assessing their bias error. For this "model" of surface currents from satellite observations, the maximum globally averaged satellite bias error is 15 cm/s. The current configuration of the IOOS has reduced the potential satellite bias error to 8.8 cm/s. We stress that these results are highly sensitive to the model as well as the configuration of the observing network, and smaller values may result from a better model… such as, perhaps, the OSCAR model. Testing this hypothesis hinges upon improving our parameterization of wind-driven motion, the focus of this study for FY09.

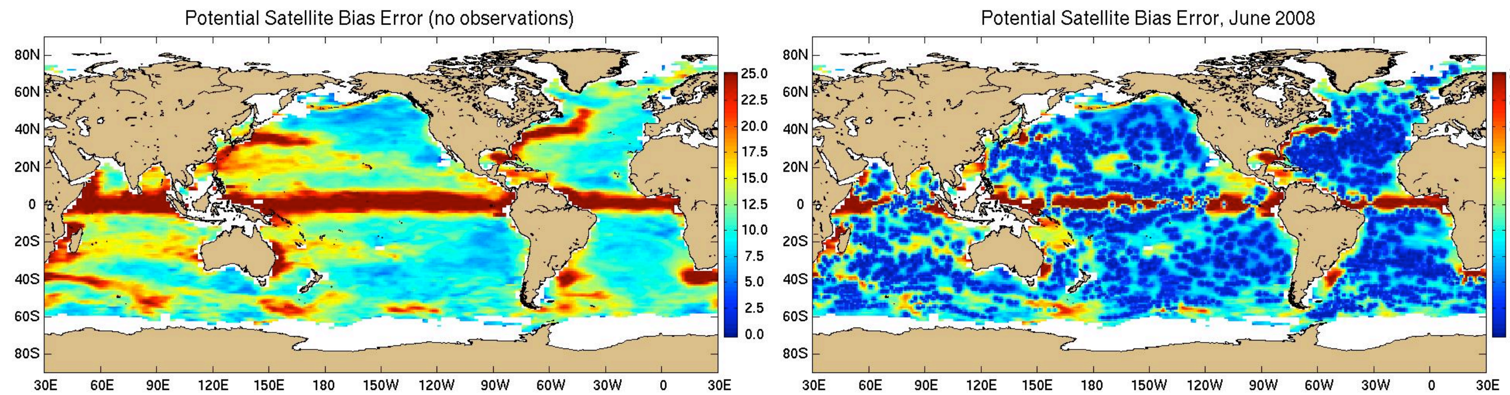


**Figure 4.** Distribution of satellite bias error (cm/s) with no observations for calibration (left), and distribution given the configuration of the drifter and moored buoy array in June 2008 (right).

### 2.2. Evaluating drifter-satellite correlations

As stated in our FY08 work plan, we completed a first global analysis of satellite- and drifter-derived geostrophic velocities for a number of purposes, including assessing errors in satellite-derived velocities from gridded altimetry and assessing potential biases in the observations. We calculated correlations between geostrophic velocity anomalies derived from satellite-altimetry and drifters. High correlation between both estimates of geostrophic velocity anomalies were identified in regions of high variability, such as western boundary currents and the Antarctic Circumpolar Current. Further analysis of the correlations indicates that the geostrophic velocities obtained from alongtrack altimetry observations always overestimate the drifter-derived low passed geostrophic velocities (Figure 5). This overestimation can be also observed in the Eddy Kinetic Energy (EKE) fields derived from each of these platforms. The EKE computed from alongtrack altimetry is usually larger than that computed from low passed drifter data; this is the opposite of what is found when comparing EKE from gridded altimetry to drifters. Differences could be attributed to ageostrophic motions not included in the altimetry velocity estimates, but seen in the drifter observations. Alternatively, the source for this discrepancy could be the low-pass filtering of the drifter observations intended to remove inertial and tidal motion. More generally, these differences indicate a mismatch between the spatial scales filtered from the alongtrack altimetry and the time scales filtered from the drifter trajectories.

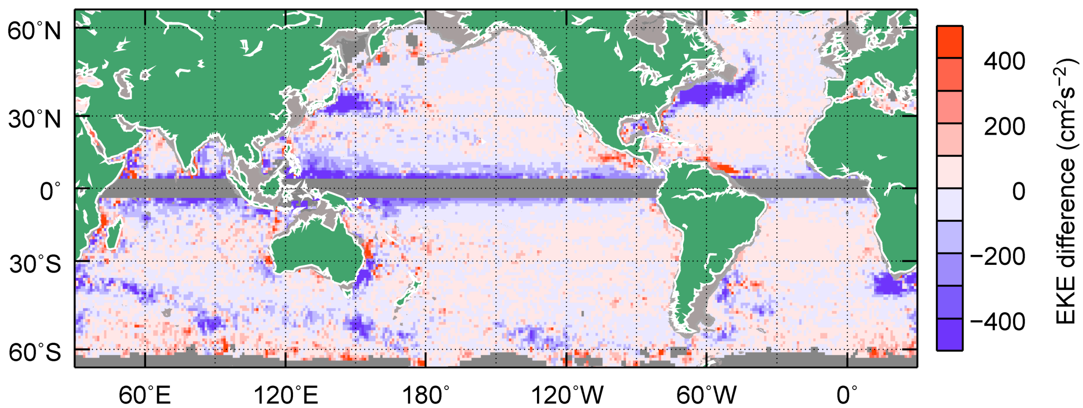


**Figure 5.** Difference between EKE derived from 5-day lowpass filtered Ekman-removed velocity anomalies derived from drifter data and geostrophic velocity anomalies derived from along-track altimetry data.

The PIs of this project, Lumpkin and Goni, also contribute the "Surface Currents" section for the State of the Ocean report using results generated in this study (Lumpkin and Goni, 2008).

## 3. PUBLICATIONS AND REPORTS

Lumpkin, R. and G. Goni, 2008: State of the Ocean in 2007: Surface Currents. In "State of the Climate in 2007", *Bulletin of the American Meteorological Society*, **89**, in press.

Lumpkin, R. and S. L. Garzoli, 2008: Interannual to Decadal Variability in the South-western Atlantic's Surface Circulation. *Geophys. Res. Lett.*, submitted.

Zhang, H.-M., R.W. Reynolds, R. Lumpkin, R. Molinari, K. Arzayus, M. Johnson, and T.M. Smith, 2008: An Integrated Global Ocean Observing System for Sea Surface Temperature Using Satellites and In situ Data: Research-to-Operations. *Bulletin of the American Meteorological Society*, in press.

## 4. CONFERENCES

Di Nezio, P. N., G. J. Goni, and R. Lumpkin, 2008: Global Comparison of Surface Currents derived from Drifter and Altimetry Observations. *ASLO Ocean Sciences Meeting 2008.*