Satellite-Tracked Drifter Measurements of Inertial Currents in the Gulf of Mexico

Steven P. Anderson
Neha Sharma

Horizon Marine, Inc.
15 Creek Road
Marion, MA 02728 USA

***Abstract*-Over 2200 satellite-tracked drifters have been air deployed from fixed wing aircraft into the Gulf of Mexico over the past 25 years as part of a Loop Current monitoring program. The drifters are cylinder shaped and are approximately 96 cm tall and 12 cm in diameter. They each have a 45 m tether attached to a 1.2 m diameter drogue/chute. While the drifter design allows for cost-effective monitoring of mesoscale variability, the drogue/buoy pairing is not ideal for measuring wind-driven currents since the effective drogue depth is strongly dependent on shear near the surface and at the base of the mixed layer. However, in 2002 the buoys were upgraded with GPS receivers which provided more accurate positions than standard Argos tracking. With the improved measurements, inertial current and wind-driven variability is now clearly evident in the drifter trajectories. An analysis of the data shows that near-inertial variability is strongest during June. The data also reveal that the variability is reduced over Loop Current. This is consistent with previous studies showing low near-inertial energy near regions with large gradients in mesoscale vorticity.**

I. INTRODUCTION

Inertial internal waves are known to play an important role in propagating wind energy applied to the ocean surface to shear induced mixing at the top of the oceanic thermocline and moving energy into the deep ocean. In addition to their role in oceanic mixing processes, the inertial surface oscillations have direct impact on deepwater operators who are often working at the edge of operational thresholds in the Gulf of Mexico. Yet little is known about the spatial and temporal variability of inertial currents in the Gulf of Mexico.

Inertial wave frequency is a function of both the latitude and vorticity from geostrophic currents, and inertial wave propagation is known to be affected by geostrophic shear [1]. Previous modeling and observational studies have shown that regions of large gradients in the mesoscale vorticity will coincide with areas of low near-inertial energy [2]. The mesoscale circulation in the Gulf of Mexico is dominated by the Loop Current and its associated anticyclones. Thus, one might expect that the variability of the near-inertial oscillations would be smaller near the Loop Current.

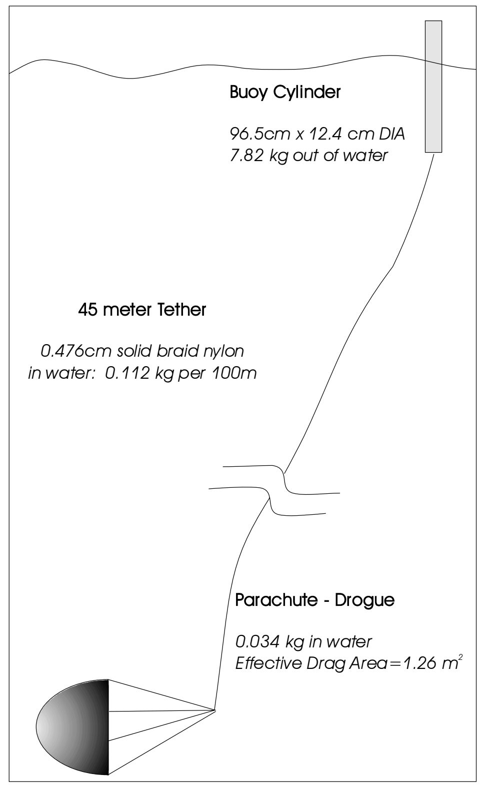

Figure 1. Far Horizon Drifter.

Satellite-tracked surface drifters have been used before to look at spatial variability of inertial oscillations. The Lagrangian drifters, unlike Eularian measurements, are not affected by Doppler shifting through background currents. In addition, the drifters provide good spatial coverage. Reference [3] used surface drifters to examine the meridional structure of inertial variability in the Pacific. Reference [4] calculated rotary velocity directly from drifter tracks to estimate tidal amplitudes and phases.

In this study, we take a preliminary look at the near-inertial (any oscillation near the local inertial frequency) variance in the Gulf of Mexico using a unique data set of air-deployed drifters.

1-4244-1486-5/08/$25.00 ©2008 IEEE

II. Measurement Program and Data Analysis

The Far Horizon Drifter (FHD) is a low-cost, air-deployable drifting buoy that was first deployed in 1985 (Figure 1). The buoy hull is cylindrical shaped 96.5 cm by 12.4 cm DIA. The parachute has an effective drag area of 1.28 m^2 and is connected to the buoy with a 45 m nylon tether. The buoy deployment package is designed to be dimensionally compatible with a standard Sonobuoy.

The FHD works well for its designed purpose of tracking mesoscale oceanic features as part of the Eddy Watch[sm] program. The drogue to buoy drag ratio is 60 to 1 which allows for limited wind slippage. However, effective drogue depth is a strong function of near-surface shear. For example, the drogue depth will rise to 20 m if there is a 20 cm s^{-1} shear between the surface and 20 m. Since the near-surface shear is not known, the effective measurement depth at any given time is also unknown. This uncertainty limits the usefulness in using this drifter to study mixed layer response to wind forcing.

From 1985 until 2002 standard Argos positioning was used to track the FHD. The Argos positioning in the Gulf of Mexico often had gaps for 8 to 10 hours between groups of position retrievals. This provided adequate coverage for mesoscale features, but inertial currents could not be fully resolved.

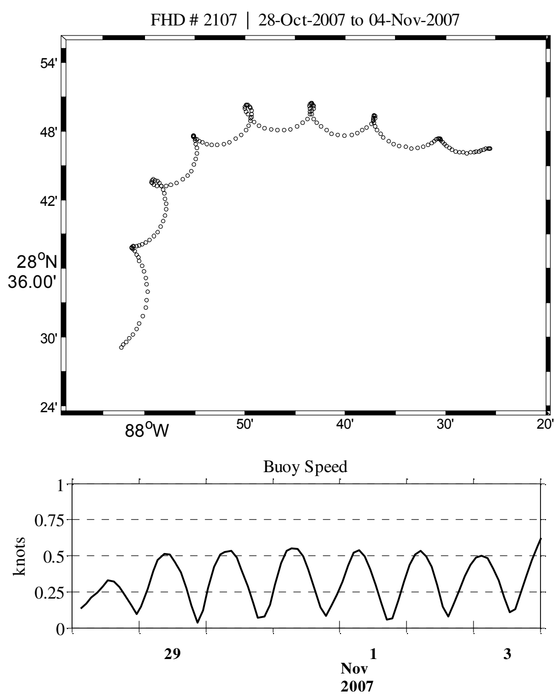

Figure 2. Example trajectory of a GPS-enabled FHD.
The top figure shows the retrieved positions every hour for seven days and the bottom figure shows the derived speed. The clockwise near-inertial orbits can clearly be seen in both the speed and trajectory.

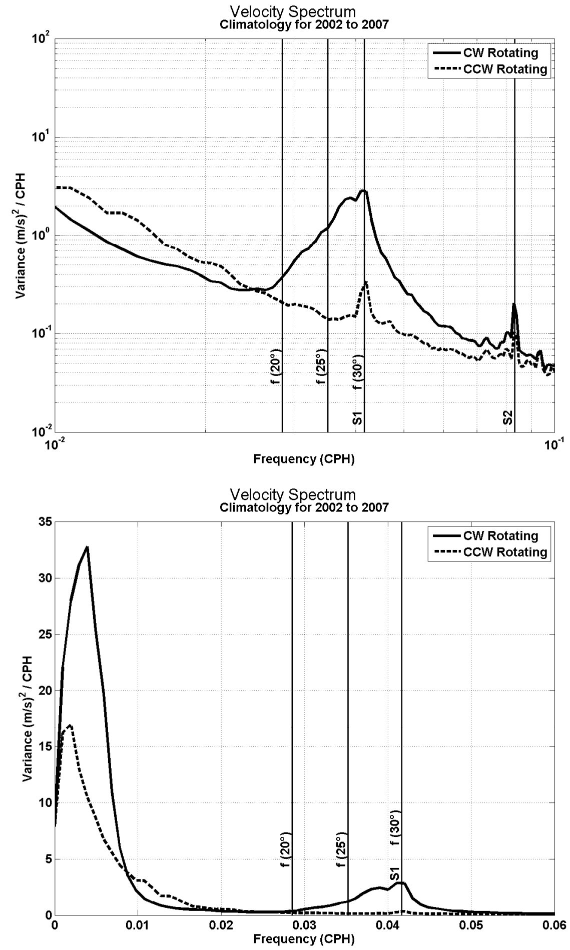

Figure 3. Rotary Velocity Spectra from FHD tracks.
The solid line and dashed lines show the clockwise (CW) and counterclockwise (CCW) rotating energy respectively. The frequency of the solar tidal components S1 and S2 are indicated as are the inertial frequencies at latitudes of 20°, 25° and 30°. The top figure shows the near-inertial frequency band on a log-long graph. The bottom figure shows the same data on a linear graph.

In 2002 the FHD transmitters were upgraded and a GPS receiver was installed. This upgrade allowed for a GPS position retrieval every hour. As a result of the improved temporal resolution, the near-inertial oscillations became very clear in the buoy trajectories (Figure 2). These oscillations have typical peak-to-trough amplitudes of 0.5 m s^{-1} and orbits dominated by clockwise rotation.

Approximately 800 GPS-equipped FHDs were deployed between January 2002 and December 2007. Not every hourly position was received from every buoy due to various factors including weather and satellite coverage, but on average the buoys return approximately 20 positions per day. The data are interpolated to every two hours prior to analysis and simple first differencing is used to calculate velocity. Data gaps that are longer than 8 hours, and data outside the Gulf of Mexico are flagged and excluded from analysis presented here.

The rotary velocity spectrum (Figure 3) are calculated using 512-point (~40 days) segments with linear trend removal and a Hanning taper. The Gulf of Mexico spans latitudes 18° to 30°N, and all data have been lumped together to create these averaged spectrum. The clockwise (CW) rotating energy shows increasing variance starting at a frequency of 0.028 cycles per hour (CPH) (~35 hour period) corresponding to the inertial frequency at 20°N and reaching a peak at 0.083 CPH (~24 hour period) which is both the diurnal solar tidal component, S1, and the inertial frequency at 30°N. Above S1, the CW variance decreases but remains above the counterclockwise (CCW) variance out to 0.1 CPH. The CCW spectrum decays roughly as f^{-2} with a tidal peak at S1 and a secondary peak at S2.

At frequencies below 0.01 CPH, the CW spectrum shows increasing variance again with a peak near 0.004 CPH. This peak corresponds to anticyclonic mesoscale features such as Loop Current eddies that have a typical rotation period of 10 days. This frequency band contains most of the observed total variance.

In the next step of our analysis, we defined the near-inertial band as extending from 0.03 to 0.05 CPH. Each trajectory was broken down into 32-point (~2.6 days) overlapping segments centered on each day. FFT was applied to each segment, and the inertial band CW and CCW variance was calculated for that day. This provided the daily inertial variance for each day and was repeated for each buoy. This resulted in a database of daily inertial variance and positions that is used in the following analysis.

III. Results

The seasonal climatology of inertial variance was calculated directly from the database of FHD near-inertial variance (Figure 4). The average variance for each month was calculated using only data north of 25°N in the Gulf of Mexico from 2002 through the end of 2007.

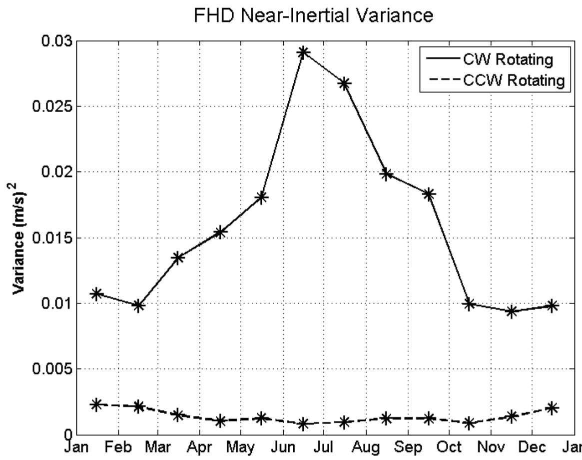

Figure 4. Seasonal Climatology of FHD Near-Inertial Variance. The monthly average variance includes data north of 25°N in the Gulf of Mexico from 2002 through 2007. The CW and CCW variance are shown by the solid and dashed lines respectively.

The lowest near-inertial variance is found from October through February. The variance increases in March and peaks in June then the variance decreases until October. The CW variance in the summer months is 2.5 times the variance in the winter months.

The season cycle in near-inertial variance is in phase with the seasonal cycle in the thermocline and mixed layer depth. The variance is largest when the mixed layer is shallowest. However, the seasonal wind forcing has a maximum during the winter months. Some mixed layer modeling may help explain the parameters governing the seasonal cycle. Curiously, the CCW variance decreases in the summer months and increases slightly in the winter months. The implication of this is uncertain.

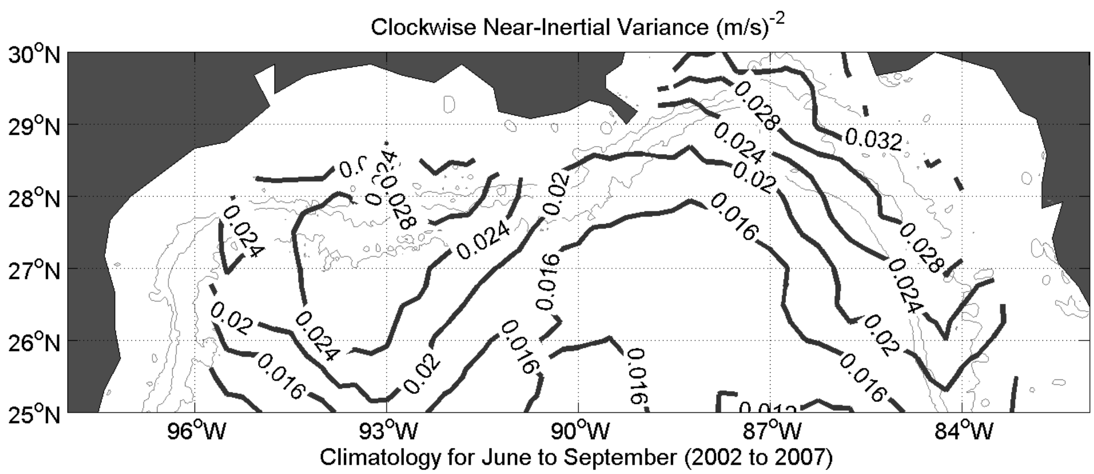

Figure 5. Summer Spatial Distribution FHD CW Near-Inertial Variance. Contour plot of CW near-inertial variance for June to September.

The summertime spatial variability is shown in Figure 5. This shows the CW near-inertial variance averaged during the summer months when the variance is largest. The largest near-inertial variance is found along the shelf-slope in the northeastern Gulf near DeSoto Canyon.

The lowest variance is found in a region east of 90°W and south of 28°N. This region is often occupied by the Loop Current and Loop Current eddies. Near-inertial variance is higher to the west of 90°W and peaks near 93°W and 27°N. Here the variance is 50% larger than the Loop Current region. This pattern is consistent with previous work [2] showing that regions of large gradients in mesoscale vorticity typically have low near-inertial variance.

IV. Conclusions

Near-inertial oscillations in the Gulf of Mexico have periods ranging from 24 to 35 hours. The drifter-drogue design is clearly not ideal for studying wind-driven mixed layer dynamics. However, when equipped with a GPS-enabled transmitter, the FHD can resolve these motions as well as tidal oscillations in the Gulf of Mexico.

While the mesoscale features associated with the Loop Current contain most of the velocity variance seen in the drifter trajectories, the near-inertial band has the most variance on time scales shorter than three days.

The near-inertial band, as defined for the northern Gulf of Mexico as frequencies 0.03 to 0.05 CPH, is dominated by CW rotating oscillations. The CW rotating near-inertial variance has a maximum during the summer months and a minimum during the winter months. The CW near-inertial variance is lower over the eastern Gulf of Mexico where the Loop Current is prevalent.

So, despite the short comings of the drifter design, the trajectories can provide some insight into the character of near-inertial oscillations. Questions will always remain as to what measurement depth the drifter velocities represent and, to some extent, this uncertainly will obscure the results. However, given the large volume of data already collected, the data may provide a unique resource for a more in-depth study of near-inertial oscillations in the Gulf of Mexico.

Certainly, further work is required to fully understand these results. Some mixed layer modeling might help understand the phasing of the seasonal cycle. Additional work is also required to better understand the relationship between inertial waves and the Loop Current. It would also be informative to look at the buoy's near-inertial response to specific storm events.

Acknowledgment

The authors thank P. Coholan, C. Cyr, J. Feeney, N. Nadler, and J. Wingenroth for their contributions in developing and deploying the Far Horizon Drifters as part of the Eddy Watch^sm program.

References

[1] E. Kunze, "Near-Inertial Wave Propagation in Geostrophic Shear." *Journal of Physical Oceanography*, vol. 15, pp. 544-565, 1985.

[2] P.M. Poulain, D. S. Luther, and W. C. Patzert, "Deriving Inertial Wave Characteristics from Surface Drifter Velocities: Frequency Variability in the Tropical Pacific," J. G. R., vol. 97, no. C11, pp. 17947-17959, 1992.

[3] P. van Meurs, "Interactions between Near-Inertial Mixed Layer Currents and the Mesoscale: The Importance of Spatial Variabilities in the Vorticity Field," *Journal of Physical Oceanography*, vol. 28, pp. 1363-1388, 1998.

[4] W. R. Crawford, J. Y. Chernaiwsky and M. G. G. Foreman, "Rotary Spectra from Short Drifter Tracks," *Journal of Atmos. and Oceanic Technology*, vol.15, pp 731-740, 1998.