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J12.2 A WEB PRODUCT FOR HIGH FREQUENCY RADAR SURFACE CURRENT OBSERVATIONS AND TIDAL CURRENT PREDICTIONS

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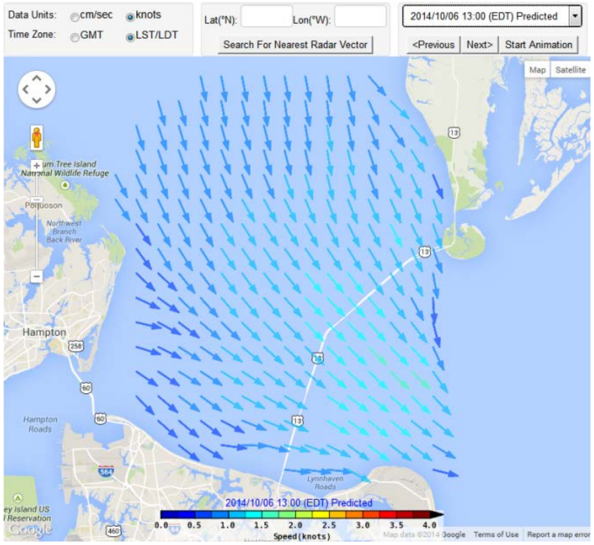
1. Introduction

Over the past couple of decades high frequency (HF) radar has become an increasingly popular way to measure ocean surface currents at near real-time (Paduan and Washburn, 2013). There are presently over 130 systems operating along U.S. coasts run by a variety of academic institutions, government and private organizations. Many of these systems receive funding and support from the NOAA-led U.S. Integrated Ocean Observing System (IOOS) through coordination with one of the eleven IOOS regional associations. IOOS also supported the creation of the HF radar National Network, a centralized access point for all near real-time HF radar data, as well as a significant amount of historic HF radar observations (Harlan et al., 2010). Despite impressive spatial coverage of HF radar observations and improved ease of access through the National Network, the use of HF radar data outside of the scientific community has remained limited. To reach new users, the NOAA Center for Operational Oceanographic Products and Services (CO-OPS) has released a new HF radar web product which provides near real-time surface current observations and tidal current predictions in select estuarine and coastal locations. This product expands the HF radar user base with benefits to marine navigation, search and rescue, oil spill response and recreational users among others.

2. Product Description

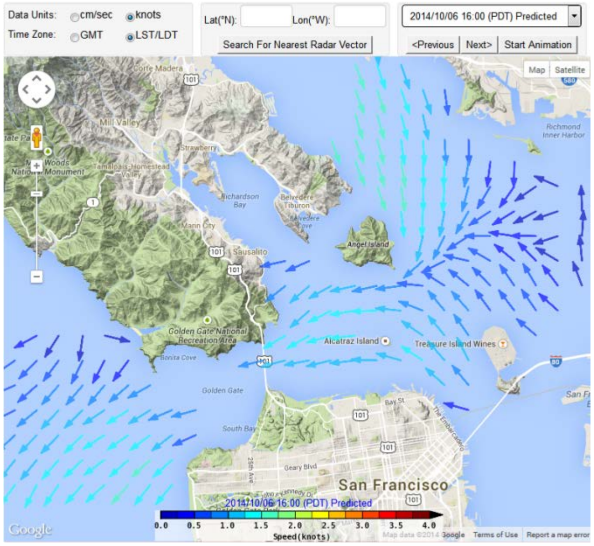
The new web product is presently available in Chesapeake Bay (Figure 1), San Francisco Bay (Figure 2) and New York Harbor (tidesandcurrents.noaa.gov/hfradar/) and provides two primary sources of information to users: near real-time HF radar surface current observations, and tidal current predictions. The hourly averaged surface current observations are provided via an interactive map and plotting interface for the most recent 48 hours at regularly spaced grid points in each domain (2 km resolution for Chesapeake Bay and 1 km resolution for San Francisco Bay and New York Harbor). The tidal current predictions are calculated based on a harmonic analysis of 1 year of observations at each grid point in the domain. The predictions are calculated each hour and are provided to users for the previous and following 48 hours.



Data Units: ○ cm/sec ● knots
Time Zone: ○ GMT ● LST/LDT
Lat(°N):
Lon(°W):
2014/10/06 13:00 (EDT) Predicted

Figure 1. The HF Radar map interface displaying surface currents data at Chesapeake Bay.

The surface current observations must traverse multiple stages of review and processing each hour prior to reaching potential users. The process begins at the instrument level, as HF radar data is collected, processed and quality controlled (QC) locally prior to being transmitted to the HF Radar National Network hosted by the University of California San Diego (UCSD) Scripps Institute of Oceanography (U.S. Integrated Ocean Observing System, 2013). At the National Network, data undergoes additional QC and processing prior to being made available for CO-OPS to access and ingest into the back-end application of the web product. At this point, additional QC is performed at CO-OPS where data points that show poor data return values (data points with less than 40% data return over the past year) are removed. The surface current speed and direction for the most recent 48 hours is then presented via the web map interface.



Data Units: ○ cm/sec ● knots

Time Zone: ○ GMT ● LST/LDT

2014/10/06 16:00 (PDT) Predicted

Figure 2. The HF Radar map interface displaying surface currents data at San Francisco Bay.

3. Harmonic Analysis of HF Radar Observations

The current predictions shown at each grid point represent the speed and direction of the tidal component of the surface current at that location. These predictions are generated from 37 harmonic constituents derived from a least squares harmonic analysis of 1 year of HF radar surface current data as detailed in Parker (2007). CO-OPS has been performing harmonic analyses on current data for decades, and publishes the nation's current predictions annually in the NOAA Tidal Current Tables and through a new online interface called NOAA Current Predictions. However, HF radar data presented a number of potential issues that required investigation to ensure confidence in the tidal current predictions.

3.1 The influence of missing data

The current measurements collected by CO-OPS from self-contained Acoustic Doppler Current Profilers (ADCPs) typically have a high degree of accuracy with very little bad or missing data (< 10% data loss). HF Radar data can have much greater amounts of data missing or removed, especially at points near the perimeter of the grid where 80% or more of data can be missing over the course of 1 year. Although the least squares harmonic analysis method can handle data gaps, studies were conducted to determine what percentage of data is needed to provide a reliable harmonic analysis result.

Utilizing 1 year of HF Radar data from Chesapeake Bay (at a grid point with only ~5% data missing) an algorithm was developed to randomly remove data points – iteratively from 5% to 99% of the data removed – and then re-run the harmonic analysis to determine the error introduced in the results. It was surprising to find that the mean error in the predicted current speed only exceeded 5 cm/s (deemed an acceptable level of error) when 87% of the data was randomly removed from the time series (Figure 3). Since missing or removed HF radar data can occur continuously for extended periods of time (days to weeks), additional testing was performed by randomly removing "chunks" of data of various lengths (ranging from 1 week to months) in addition to random points. This analysis indicated that depending on the size and number of missing "chunks", acceptable harmonic analysis results could usually be achieved after removing 60-70% of the data. Thus, it was decided that a minimum threshold of at least 40% data return must be achieved over 1 year for the tidal current predictions to be included in the web product for a given grid point.

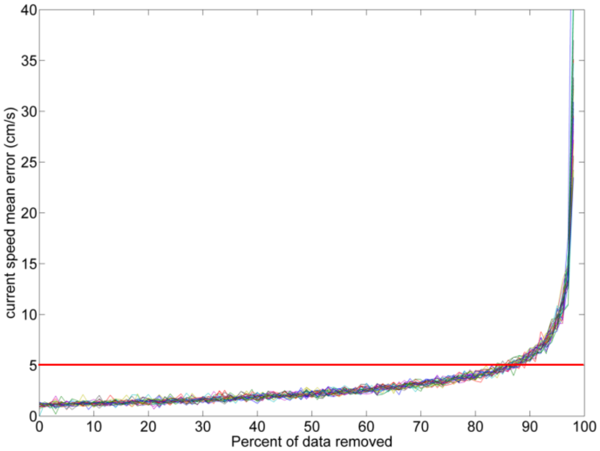


Figure 3. Plot showing the predicted current speed mean error for each simulation when a percent of random data points were removed. The red line indicates the 5 cm/s threshold deemed the maximum acceptable error.

3.2 Assessing harmonic analysis quality

Another challenge with HF radar current observations is verifying the overall performance of the harmonic analysis and the resultant tidal current predictions. How can we ensure the tidal current predictions are reasonable? Although many of the same methods for verifying an analysis from ADCP data can be used, difficulties with HF radar data lie in the large number of time series to analyze (e.g., over 240 for the lower Chesapeake Bay) and the added complexity of spatial variability in the current field. A modified set of spatial and statistical diagnostics were implemented to more easily assess performance over the large number of spatially varying current observations.

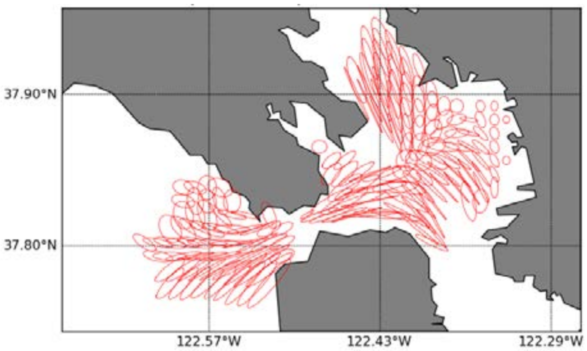


Figure 4. The M2 tidal ellipses resulting from the harmonic analysis at San Francisco Bay. Similar plots are made for the S2, N2, K1 and O1 constituents.

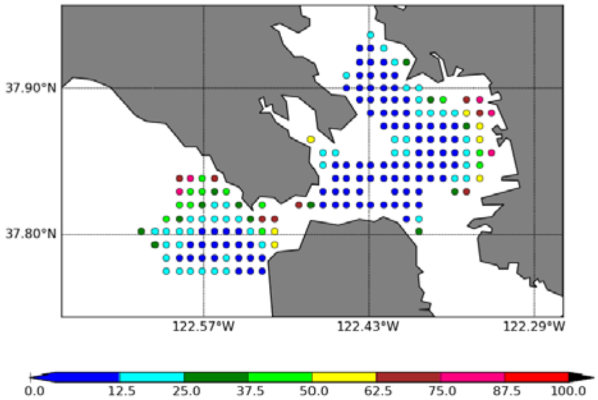


Figure 5. The percent variance of the non-tidal residual along the major axis for each grid point in San Francisco Bay resulting from the 1-year harmonic analysis.

Some examples of these new diagnostics used to quality control the results include ellipse plots of the five major tidal current harmonic constituents (Figure 4), and the fraction of the total current variance not accounted for by the tidal current predictions (Figure 5). For instance, grid points with significantly different constituent properties than their neighboring points were more closely analyzed and potentially removed. Additionally, grid points where the tidal current predictions did not account for at least 50% of the total current variance were in most cases removed since these predictions would not provide a very reliable estimate of the total currents. These and other diagnostics were utilized to identify grid points with poor harmonic analysis results, which are then excluded from the final web product.

4. Non-tidal predictions

A limitation of relying on tidal harmonics as a predictor for the current is that non-tidal influences are not included. Variability in winds, freshwater discharge, stratification or other factors can lead to significant deviation from the underlying tidal currents and thus limit the accuracy of predictions. One method to improve the accuracy of current predictions is through a statistical model that utilizes previous residual current (i.e. non-tidal current) to predict short-term residual current variability. Analyzing the residual current for six months at a grid point from Chesapeake Bay shows that residual current has some predictive skill looking forward at least 4 hours (Figure 6). This can be further quantified by an autocorrelation at this same location, which also suggests a significant correlation out to at least 4 hours lag (Figure 7).

To begin to explore what amount of improvement in the current predictions one could expect by including a statistical model of the residual current, we utilized a simple statistical approach. We calculated the total predicted current at time *t* as

$$u_{pred_t} = u_{h_t} + f_t u_{res_t},$$

where u_{res} is the residual current and *f* is a linear taper such that

$$u_{res_t} = u_{obs_0} - u_{h_0} \text{ and}$$

$$f_t = 1 - 0.25(t - 1).$$

The variable u_h is the harmonic tidal current prediction, u_{obs} is the observed current at time 0 and time *t* is a lead of 1 to 4 hours. Effectively this model is taking the residual current at the present time and adding it to future tidal current

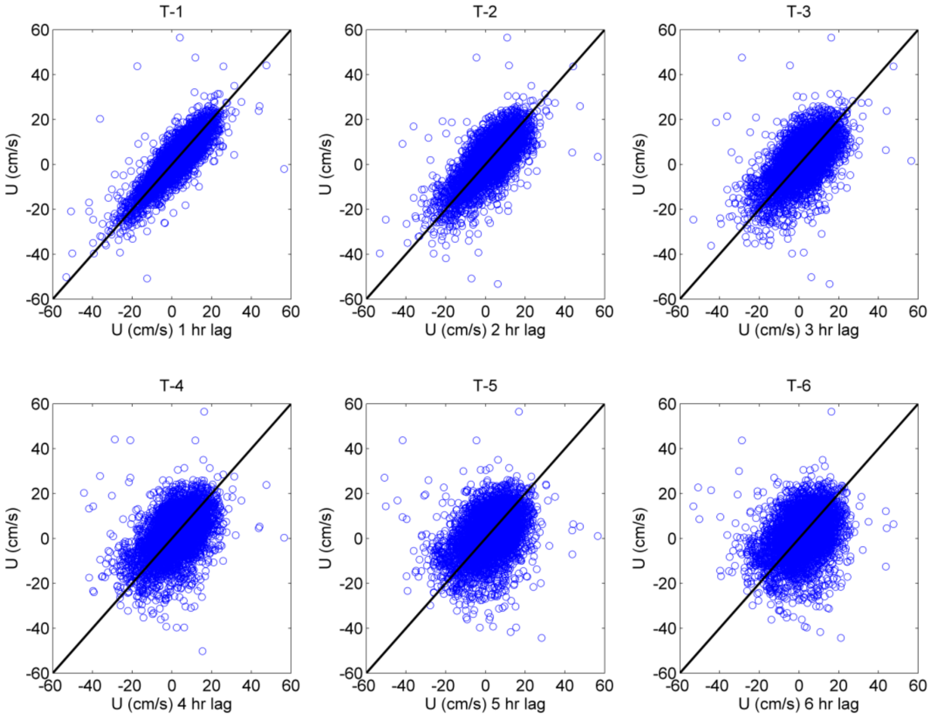


Figure 6. Example from one grid location at Chesapeake Bay of the previous residual current as a predictor of future residual current for up to 6 hours lag. Each plot shows the *u* component of the residual velocity on the x-axis with some lag and the present hour *u* component of the residual on the y-axis. The black line indicates the one-to-one line.

predictions with a linear taper down to 0 at *t* = 5 hours. Testing this approach on 3 months of independent data (i.e. outside of the initial 1-year harmonic analysis period) at a point in Chesapeake Bay shows promising results (Table 1). The 1-hour combined prediction (statistical + tide) improves dramatically over the tidal prediction alone. The residual energy is reduced by over 17% and the RMS error in the current speed is nearly cut in half. The improvement decreases slightly out to 4 hours, however this suggests that even a simple statistical prediction model can improve results significantly. Further analysis is needed before any statistical approach can be considered for the operational product and this simplified approach will first need to be assessed over all three of our web product locations before greater model complexity is investigated. However, it is expected that a more complex statistical model can likely further increase accuracy and possibly enable the model to be applied beyond 4 hours into the future.

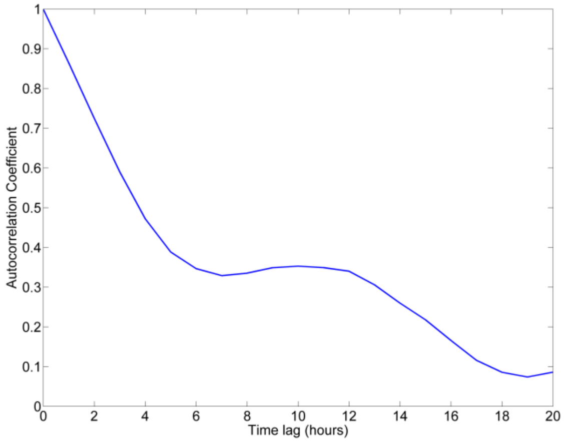


Figure 7. The normalized autocorrelation of the u component of the residual current over six months at the same grid point in Chesapeake Bay as Figure 6.

5. Future work

By leveraging our tidal current and harmonic analysis expertise, as well as the HF radar data centralization and standardization provided by IOOS, the new surface current web product described here is now available on the CO-OPS web site. However, the product release does not signify the end of development, but rather the beginning.

Table 1. The accuracy of the tidal current predictions alone compared to the combined tidal current and statistical model prediction for 3-months at one location at Chesapeake Bay.

	Tidal Prediction	**Tidal prediction + Statistical Model**			
		1 hr	**2 hr**	**3 hr**	**4 hr**
% Residual	23.3%	6.1%	11.9%	17.0%	20.7%
RMSE (cm/s)	15.2	7.8	11.7	14.0	15.0

In concert with the release, a robust outreach and communications effort has begun to solicit feedback regarding expansion of the product to additional locations and new technical enhancements. Expansion of the product to additional locations can be accomplished with only moderate effort for pre-existing HF radar deployments. Potential expansions in the near-term will focus on regions with significant tidal currents which could include Long Island Sound, Delaware Bay and southern California, depending on stakeholder interest and requirements. Opportunities for expansion into additional areas of significance for marine navigation could be further increased by the establishment of additional “inward” facing or estuarine based HF radar deployments.

Technical enhancements being considered include adding a nautical chart map layer, customizing or simplifying product visualization for specific navigation users, and showing multiple HF radar data resolutions on the same map (e.g. 2 km, 1 km, and 500 m resolutions for San Francisco Bay). We will also continue to investigate the inclusion of a statistical model to provide a short-term prediction of the non-tidal residual current. More complex statistical models and accounting for spatial correlation can likely improve upon our initial results. In addition, there are ongoing efforts to explore how to integrate the HF radar product and the CO-OPS hydrodynamic Operational Forecast System (OFS) models. This integration may include assimilation of HF radar data to improve OFS forecasts, data comparisons to inform QC, and joint product visualization to maximize benefit to end users.

6. Acknowledgments

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7. References

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