Prediction of Hydrodynamics for Unidirectional Flow

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LONG-TERM GOALS

Our long term goal is to develop an understanding of the relationship between channel geometry and three-dimensional flow features in rivers. One application of such an understanding would be the prediction of channel geometry and other channel characteristics (e.g. roughness) given observations of flow velocities and/or river surface.

OBJECTIVES

Over the next biennium, our objectives involve applying previously developed methods to more challenging river geometries, and to exploit different measurement types. Hence, we would like to:

1. Assess the feasibility of determining channel depth utilizing velocity observations from drifters.
2. Assess the feasibility of determining frictional parameters (as a function of space) using remotely sensed observations of surface elevation.
3. Utilize the developed depth-inversion framework for the determination of flow depth in more complex rivers.

APPROACH

Over the last biennium, we have developed methods that allow the determination of bathymetry using information about the flow velocities. These methods rely on the use of an accurate hydrodynamic model, an initial guess for the bathymetry (often a very simple geometry), and observations of flow velocities. This methodology was first applied while utilizing observations of currents in a surf zone setting, and results of the estimated bathymetry showed significantly improved skill over the prior guess. We found that multiple observation types (e.g., current observations versus wave height observations) provided more useful information than one observation type alone (even if we accounted for differences in the number of observations). We could also pinpoint the effectiveness of any given observation in correcting the bathymetry (Wilson *et al.*, 2010).

We then applied the same methodology to the estimation of river bathymetry. Our initial bathymetric guess consisted of a simple stream-wise uniform parabolic channel. We assumed that the overall flow rate in the river was known and utilized several types of observations of river velocities. The hydrodynamic model of choice was the Regional Ocean Modeling System ROMS – a hydrostatic primitive equation model for a curvilinear boundary-following domain (Haidvogel *et al.,* 2008). We applied ROMS to several example river settings and found that it was accurate in predicting the general flow patterns including an accurate estimate for the location of a front between two counter-rotating vortex structures. Further, we found that river depth estimation was an attainable goal with multiple observation types, including surface velocities that could be obtained from radar observations and drifter-type observations of velocities (Wilson and Ozkan-Haller, 2012)

We then extended and utilized the developed methods in more challenging situations. In particular, we have applied the techniques to different types of systems (e.g. a meandering versus an anastomosing reach) with relatively sparse observations (e.g. observations from less than 10 drifters). We are assessing performance of the method and number of required observations for a successful bathymetry inversion.

WORK COMPLETED

We have so far extended the depth inversion methodology to include an iterative step to improve the resulting predictions further. We have also developed an analytical simplified model that we can use to quickly analyze dependencies on the prior bathymetry estimate and the nature of the co-variances. A publication based on this work in now in press. We subsequently moved to utilizing drifter observations from two deployments at the Kootenai River that were collected as part of ONR-funded work by PIs MacMahan and Reniers (among others).

RESULTS

In order for our bathymetry estimation technique to be successful, our numerical model has to be able to replicate river drifter tracks. We investigated the accuracy of ROMS by comparing model velocity estimates with drifter velocity observations. On the meandering reach, ROMS replicated 86 drifter tracks (~170,000 observation points) with root-mean-square velocity magnitude error of 6.6 cm/s (16% of overall average velocity) and root-mean-square directional error of 9.7° (average 0.065°). On the braided reach, ROMS replicated 47 drifter tracks (~18,000 observation points) with root-mean-square velocity magnitude error of 15 cm/s (10% of overall average velocity) and root-mean-square directional error of 4.5° (average directional error 0.013°).

The bathymetry estimation approach was successful in improving a simple prior estimate to more closely resemble the true bathymetry, and correctly detected the location and approximate magnitude of along-channel-nonuniform features (bars and pools). The success of this method indicates that drifters are sensitive enough to provide useful, extractable information about river bathymetry. On the meandering reach (Figures 1 and 2), an along-channel-uniform (parabolic cross-section) initial estimate was improved from 1.52 m to 1.11 m root-mean-square error (RMSE), and from 0.57 to 0.80 squared-correlation (R^2). On the braided reach (not shown), a sloping, rectangular channel initial estimate was improved from 1.04 m RMSE to 0.59 m RMSE, with R^2 improving from 0.06 to 0.70. These results were obtained using ten drifter deployments (i.e., ten separate trajectories covering much of the model domain), although tests with even one drifter deployment also showed skill (see Figure 3).

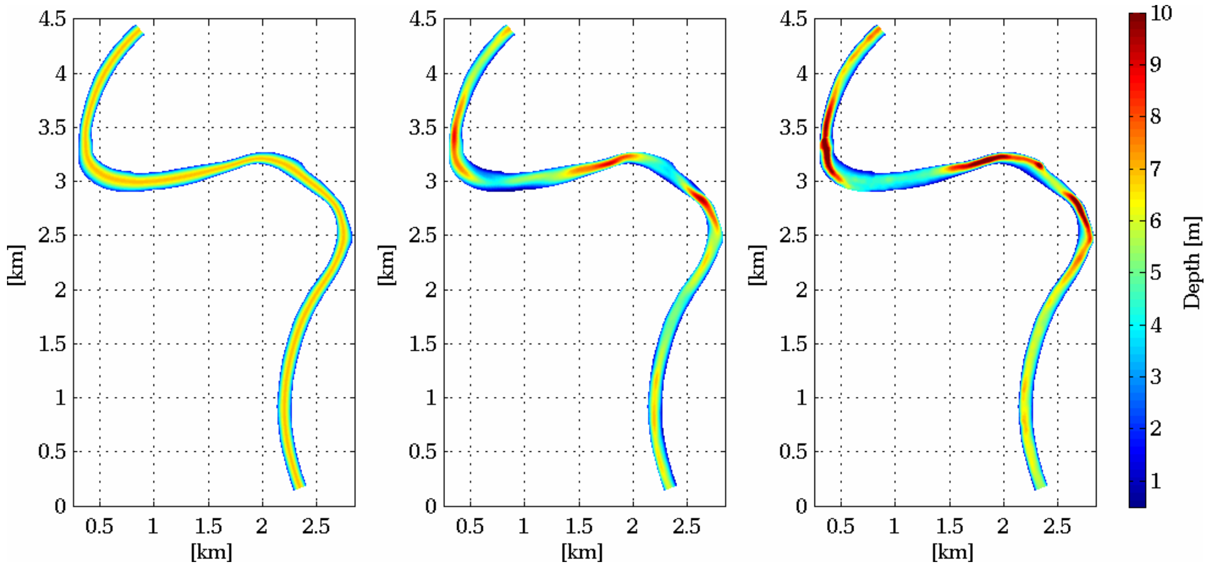

Figure 1: Prior bathymetry estimate (leftmost panel), posterior bathymetry after the assimilation of 10 drifter tracks (middle panel), and true measured bathymetry (right panel).

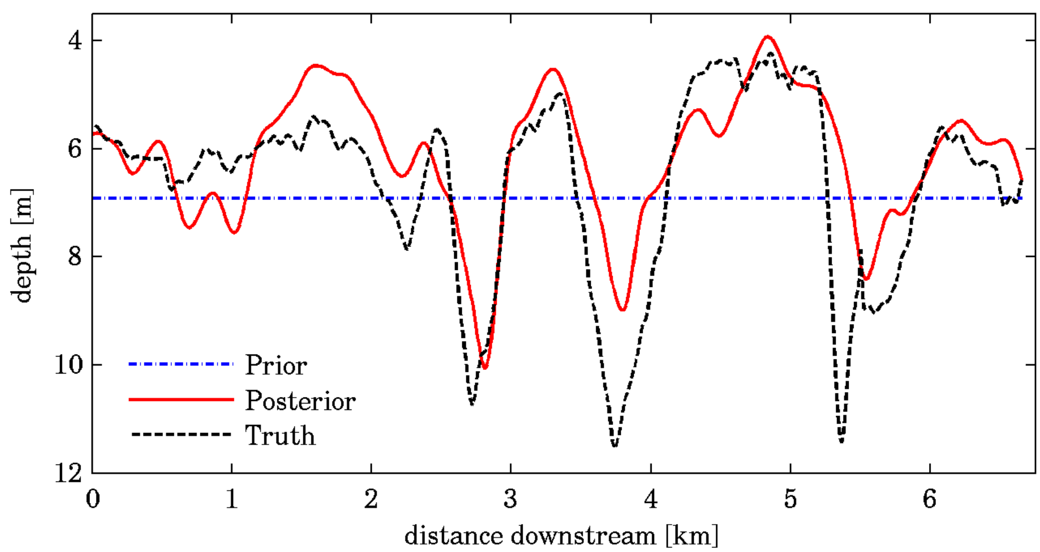

Figure 2: Centerline bathymetry for prior (blue), posterior (red) and truth (black).

The method was found to be only weakly sensitive over a broad range of various parameters (localization length scale, ensemble size, observation error/uncertainty), indicating that it is robust to the choice of those parameters. That is, the method is capable of achieving good results without significant "tuning." Errors were somewhat increased if the ensemble size was small (fewer than 100-150 members), if localization was not used or was too excessive (less than 100 m localization length scale), or if the observational error estimate was unreasonably large or small. However, even in those cases the RMSE of the posterior bathymetry was still less than that of the prior, and in that sense the method can still be considered skillful.

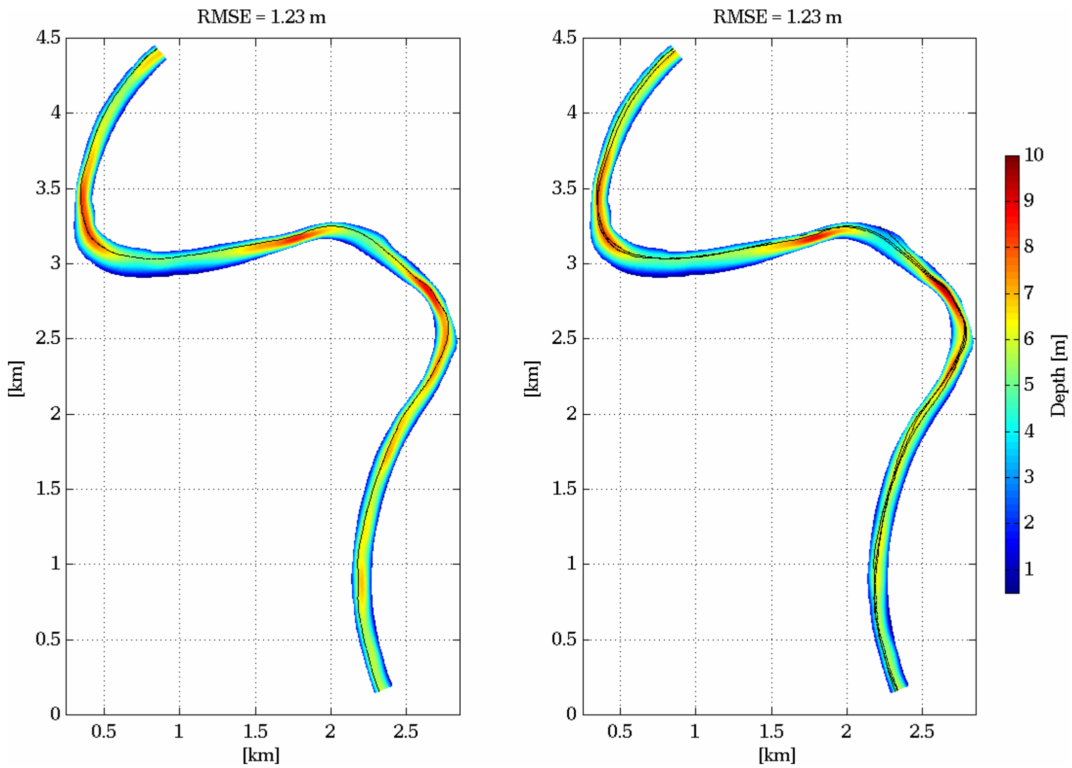

Figure 3: Posterior bathymetry for meandering reach (left panel) using only one drifter observations and (right panel) three drifter observations. The drifter tracks are shown as black lines. The RMSE-values are noted above each panel and indicate improvement in bathymetry estimation even with only one drifter track.

In summary, we found that a depth averaged configuration of the ocean circulation model, ROMS, is capable of accurately replicating drifter observations, that surface velocity observations provide valuable, extractable information about river depth, and that our bathymetry estimation method is quite successful and only weakly sensitive to the evaluated parameters.

Application of the new method to the more complex domain of a tidal inlet shows much promise (see Figure 4). Using observations from only 4 SWIFT drifter deployments from the New River Inlet experiment in 2012, we can start to get a definition of the deeper channel inside of the inlet, the two distinct channels at the mouth, and the shoals on either side and between the two channels (see Figure 4). This resulting bathymetry estimate can be further refined using remotely-sensed observations of the incident waves (from X-band radar) outside the mouth, and SAR-generated surface currents inside the inlet. Such simulations using multiple observation techniques are the subject of the ONR MURI DARLA, and results are shown in that report.

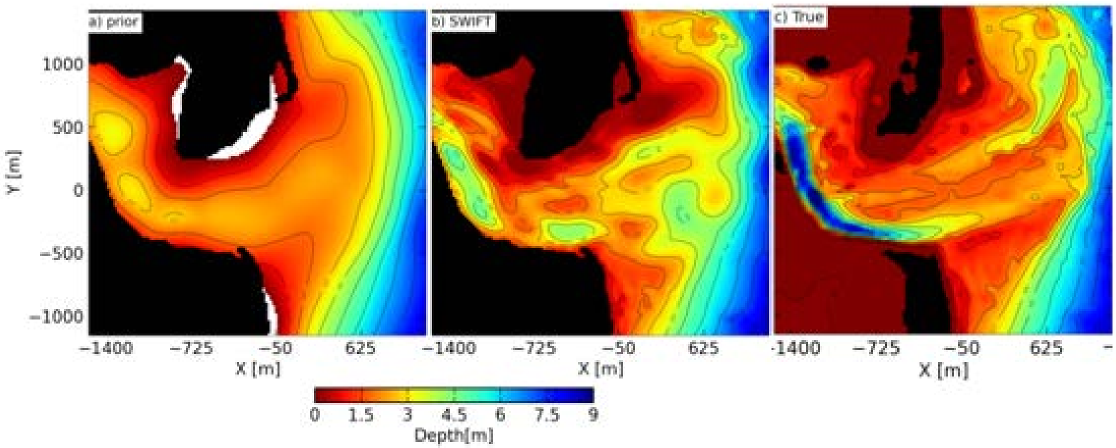

Figure 4: Prior first guess bathymetry (left panel), estimated bathymetry using only drifter observations (middle panel) and true bathymetry (right panel). The deeper channel inside the inlet, the two diverging channels at the mouth, and the shoals to either side and between the two channels are beginning to be defined once drifter observations are assimilated.

IMPACT/APPLICATIONS

As part of this study we are developing methods to estimate the depth of river channels given information about the flow velocities in the river. The potential application of this work is primarily related to problems related to navigation up river channels. Other applications involve the specification of river discharge given remote or drifter observations.

RELATED PROJECTS

The data that the COHSTREX MURI group obtained on the Snohomish River has been utilized here to validate the numerical model and aid in the assessment of depth inversion techniques. Data gathered on the Kootenai River, ID by groups led by MacMahan and Reniers is also utilized. Finally, the methods developed and tested herein are also applied to surf zone and navigational inlet situations as part of the ONR-MURI project DARLA. The SWIFT drifter observations shown herein were gathered as part of DARLA by Thomson.

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PUBLICATIONS

Wilson, G., H.T. Özkan-Haller and R.A. Holman, Data assimilation and bathymetric inversion in 2DH surf zone model, *J. Geophys. Res.,* 115, C12057, doi:10.1029/2010JC006286.

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