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

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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.

As part of this project we are extending and utilizing the developed methods in more challenging situations. In particular, we are improving the inversion results by emaplying an iterative scheme. We would also like to assess whether or not the inversion technique is useful with different sets of observations, such as drifter observations as well as previously unexploited observations of the river surface. Finally, we would like to move to the more challenging environment of a river with multiple parallel channels.

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. We have applied the inversion method to a larger reach of the Snohomish River, and have also moved on to depth inversion for the Kootenai River in Idaho.

RESULTS

Application of the depth inversion methodology to a 2.5km reach of the Snohomish River is shown in Figure 1. The prior bathymetry was assumed to be constant over the entire reach. The covariances are estimated by assembling an ensemble of perturbed bathymetries with de-correlation length scales of 100m in the along-stream direction and 50m in the across-stream direction. The prior standard deviation of the perturbations is 0.75m. The "measurements" were synthetic observations distributed over the reach with a resolution similar to remote sensing observations of surface velocities (nominally 20m along-stream and 10m across-stream. A 1 cm/s random noise is assumed. The case shown here corresponds to a flow rate of 15 m^3/s. The iteration is carried out by computing a posterior bathymetry first and then assuming that this corresponds to a prior bathymetry and assembling a new set of perturbed ensemble members. The iteration improves the results markedly. This result is typical of situations where the prior bathymetry and corresponding circulation are very different from the actual bathymetric state. In such cases, a forward model run over the posterior estimate of the bathymetry is not similar to the posterior velocity estimate. This latter information can be used to indicate whether or not iteration is useful for a given case.

Next, we analyzed the effects of using different sampling methods (See Figure 2). We find that along-stream velocities contain more useful information than across-stream velocities. Under-sampling causes only local corrections near the sampled locations. In contrast, drifter sampling methods show promising results. The methodology is currently being applied to the Kootenai River, ID. The flow rate in this river is constrained and constant from day-to-day due to the presence of an upstream dam. Preliminary results using synthetic drifters for this river show results similar to the Snohomish River estimates. Drifter observations are available during several deployments in a meandering reach of the Kootenai River and are being employed here.

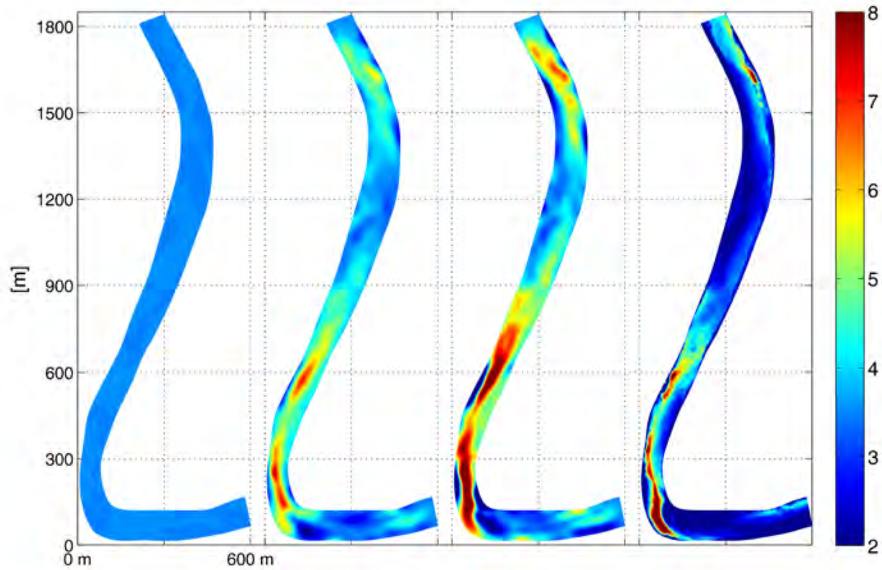

Figure 1: Prior bathymetry estimate (leftmost panel), posterior bathymetry after the first depth inversion estimate (second panel), after a subsequent iteration (third panel), and true measured bathymetry (rightmost panel).

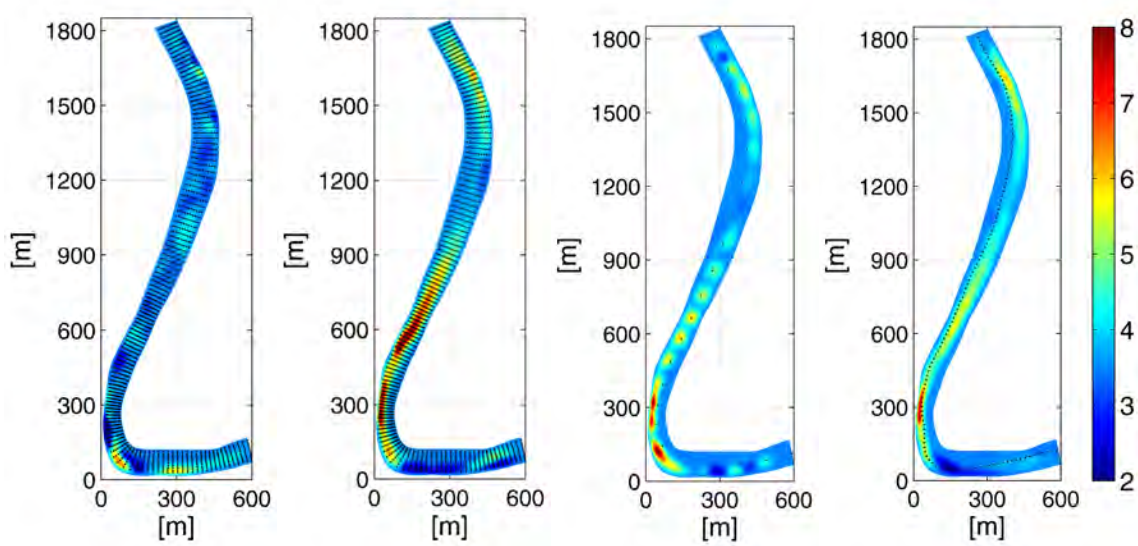

Figure 2: Bathymetry estimates using only across-stream velocity information (leftmost panel), only along-stream information (second panel), point observations (third panel), and drifter observations (rightmost panel).

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.

RELATED PROJECTS

The data that the COHSTREX MURI group obtained on the Snohomish River is being 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 Holland 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.

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PUBLICATIONS

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