General Comments

The idea of estimating the freshwater flow through an estuarine cross-section using tidal theory and tidal analysis is not new [cf. Jay and Kulkulka, 2003], but it has only recently been presented with a careful verification and analysis of uncertainty [Moftakhari et al., 2013]. The latter authors also introduced the term "tidal discharge estimation" or TDE. As with any innovation, multiple approaches are useful, so the present contribution is a welcome addition to the field of applied tidal dynamics.

Specific Comments

a. History of TDE

The history of the idea of using tidal theory and the fluvial modification of tidal properties to estimate river discharge needs some explanation, which is not provided here. This is most simply explained using the nomenclature "forward model" (determining tidal properties from river flow) and "inverse model" (determining river flow from tidal properties). Conceptually, the key idea is that river tides are very non-stationary, and that this non-stationarity, while complicating the prediction of tides, has many dynamical uses [Jay and Kulkulka, 2003], of which TDE is only one. There is an extensive literature on river tides dating to at least WWII, and I will not attempt to review it here. Jay and Flinchem [1997] added continuous wavelet transform (CWT) methods to the tidal analyst's tool kit and provided a simple forward model that related the tidal admittance (the complex ratio of tidal amplitude and phase at any point in the river to the tidal amplitude and phase at the ocean entrance) to river flow. Kukulka and Jay [2003a,b] provided a better forward model. Jay and Kukulka [2003] then used an inverse model to hindcast river flow for the December 1964 Columbia River, USA flood. Because this flood resulted primarily from tributary inflow below the most seaward river gauge, our estimate of its flow history is the only instrumental "measurement" available, though the usual flow routing approaches have also been used. We also verified that the method worked in the Fraser River, British Columbia, Canada, though this work has not been published. Jay et al. [2006] then provided a hindcast of the history of inflow to San Francisco Bay, using the long (1858 to date) San Francisco tidal record. This is a useful step, because the inflow to San Francisco Bay through its complex delta was not gauged by the US Geological Survey until 1930. This 2006 AGU presentation also provided the first instrumental estimate of the magnitude of the great flood of January 1862, the largest in the last two centuries in San Francisco Bay. The inverse models used in these two studies added an innovation, in that they were based on a single tide gauge. When only one gauge is available, then the admittance is formed in one of two ways: (a) if the variations of a major constituent like M_2 are used, then an admittance is formed using the astronomical tidal potential; or (b) if an overtide like M_4 is used, then the ratio M_4/M_2^2 is employed as an ersatz admittance. This complex admittance can be separated into an amplitude ratio and phase difference. Tidal theory suggest that the M_4/M_2^4 ratio should be useful for low flows, while the M_2 admittance is best for high flows. Practice confirms this, at least for the Columbia River and San Francisco Bay. To minimize the impact of time errors inherent in historical tidal records we have used amplitude ratios, though Kulkulka and Jay [2003a] verified that the phase difference could also be represented by a forward model. More recently, Moftakhari et al. [2013] returned to the San Francisco

Bay case to provide a revised estimate, a formal error analysis, and a discussion of long-term hydrologic change in the system. Also, if CWT methods are used to provide an estimate with a time-scale of a few days, the ratios actually involve the D_2 and D_4 tidal species, not the M_2 and M_4 constituents. If the M_2 and M_4 constituents are resolved via a properly windowed monthly harmonic analysis (as in Moftakhari et al. [2013]), then the time scale of flow estimates is ~18 days.

b. Theoretical Foundation

The theoretical foundation of the TDE is also not explained here. It uses the tidal propagation theory for convergent channels of Jay et al. [1991]. The key assumptions are that: (a) there is no reflected wave; (b) the wave is critically convergent so that the real and imaginary part of the complex wave number are equal (i.e., the scale length for damping is the same as the inverse wave number); (c) the tidal velocity amplitude and river flow velocity are of the same order; and (d) the channel geometry does not change drastically with river flow. In practice, the last two assumptions are the most restrictive, though both can be stretched. With these assumptions it is simple to express the tidal admittance in terms of the wave number, which can then be represented using the Dronkers [1964] cubic Tschebychev polynomial. The latter allows the admittance to be expressed in terms of the river flow and tidal amplitude at the ocean entrance. The tidal range terms recognizes that the relationship between river flow and damping of the tides varies over the neap-spring cycle. This is important for hindcasting flows on the scale of days, but not for hindcasts based on windowed monthly harmonic analyses. The relationship between admittance, river and tidal range is nonlinear and cannot be exactly inverted, but approximate inversion is simple, especially when windowed monthly harmonic analyses -- this scale of time averaging allows the tidal range term to be dropped. In practice, the coefficients in the equation for TDE are fit by regression using a calibration data set. On the whole, the analysis is just as rigorous as that proposed here. In both cases, the nonlinear bedstress term is approximated, and one or more constants must be determined from data.

c. Practical Application

The approach presented here finds a closed form equation, which is an advantage for application. On the other hand, it is not obvious that the envelope tidal theory used here would work in tidal rivers where mixed tides are prominent. All three Eastern Pacific systems (the Fraser and Columbia Rivers and San Francisco Bay) we have examined have mixed tides. it is also unclear whether the present method could be used to estimate river flow variations on a scale of days, as is possible through use of the TDE method with CWT determination of tidal properties. In conclusion, any new methodology benefits from diverse approaches, and this is a useful contribution.

References

Dronkers J. J., 1964, *Tidal Computations in Rivers and Coastal Waters*, North-Holland Publishing Company, Amsterdam, 296-304.

Jay, D. A., 1991, Green's law revisited: tidal long wave propagation in channels with strong topography. *J. Geophys. Res.* 96: 20,585-20,598.

Jay, D.A., R.E. Flick, & T. Kukulka, 2006. A Long-Term San Francisco Bay Inflow Record Derived From Tides: Defining the Great Flood of 1862, GC13B-1228, Fall AGU Meeting, San Francisco.

Jay, D. A. and Flinchem, E. P., 1997, Interaction of fluctuating river flow with a barotropic tide: A test of wavelet tidal analysis methods, *J. Geophys. Res.* 102: 5705-5720.

Jay, D. A., and T. Kukulka, 2003, Revising the paradigm of tidal analysis – the uses of non-stationary data, *Ocean Dynamics* 53: 110-123.

Kukulka, T., and D. A. Jay, 2003a, Impacts of Columbia River discharge on salmonid habitat I. a non-stationary fluvial tide model, *J. Geophys. Res*. 108, 3293 doi 10.1029/2002JC001382.

Kukulka, T., and D. A. Jay, 2003b, Impacts of Columbia River discharge on salmonid habitat II. Changes in shallow-water habitat, *J. Geophys. Res*. 108, 3294 doi 10.1029/2003JC001829.

Moftakhari, H. R., D. A. Jay, S. A. Talke, T. Kukulka, and P. D. Bromirski, 2013, A Novel Approach to Flow Estimation in Tidal Rivers, Water Resour. Res., 49, doi:10.1002/wrcr.20363. *way, Port, Coastal, and Ocean Engineering*, doi:10.1061/(ASCE)WW.1943-5460.0000188.