Multi-frequency acoustic inversion derived from a broad and shifting grain size distribution using “off-the-shelf” acoustic Doppler current profilers

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1 INTRODUCTION

Over the last several decades the use of “off-the-shelf” acoustic Doppler current profilers (ADCPs) has become a common tool in river and oceanic hydraulic observations. They can reliably produce velocity and discharge when calibrated. Additionally, these instruments resist fouling and deliver higher spatial and temporal resolution observations. Sedimentologist’s have become increasingly interested in their use due to the possibility of acoustically inverting the returned backscatter signal to estimate sediment concentration and mean particle size. The coupling of these sedimentological characteristics with the velocity and discharge data provides the additional advantage of obtaining an estimate of sediment flux, both total and, potentially, size specific.

Prediction of suspended sediment flux from hydraulics remains a stubbornly difficult problem, particularly for the washload component which is controlled by sediment supply from the drainage basin. Traditional methods, such as relations produced by sediment rating curves, can produce significant error (Walling, 1977), especially when hysteretic relations are present. In the Fraser River (British Columbia, Canada), where this study takes place, hysteretic rating curves occur (McLean et al. 1999a) and can contribute to inaccurate sediment load estimations.

The theory of multi-frequency acoustic inversions has been developed over the last three decades (Hay, 1991; Crawford and Hay 1993; Holdaway and Thorne, 1999; Thorne and Hardcastle, 1997; Thosteson and Hanes, 1998) and reviewed more recently (see recent reviews by Thorne and Hanes, 2002; Thorne and Hurther, 2014). These studies have primarily taken place at the small scale (meters) (Sheng and Hay, 1988; Thorne and Campbell, 1992; Thosteson and Hanes, 1998; Moate and Thorne, 2009) or in the near-shore environment where grain size distributions (GSD) are unimodal and narrow or in laboratories where the GSD is purposely constrained.

More recently, multi-frequency acoustic inversion investigations have moved into estuarine (Thorne et al., 1994) and riverine environments (Guerrero et al., 2013; Moore et al. 2012, 2013) where grain size distributions vary due to differing sources and flocculation. This has led to laboratory studies that have examined acoustic response to suspensions with different particle shape (Thorne et al., 1995a; Richards 2003; Thorne and Buckingham, 2004), mixed mineralogy (Schaafsma and Hay, 1997; Moate and Thorne, 2011, 2013), broad and bimodal size distributions (Moate and Thorne, 2009), and, more recently, flocculated aggregates (MacDonald et al., 2013; Thorne et al., 2014).

These studies have shown that acoustic signals, either through backscattering or attenuation, are significantly influenced by the median size of the particle, concentration or number of particles in suspension, shape and mineralogy of the particles in suspension, and the GSD breadth. Moate and Thorne (2009) have shown how variability in the GSD can perpetuate error through the inversion, resulting in error in both the estimated median grain diameter and/or the mass concentration.

Previous application of acoustic inversion techniques in riverine environments have assumed constant particle mineralogy and shape of the GSD, which was justified because sediment sources were partly controlled by the presence of large-scale dams that filter some of the variability in sediment size (e.g. Moore et al. 2012, 2013). Here we apply the acoustic inversion methods in a somewhat more challenging riverine environment where sediment sources vary through the annual freshet, causing changes in particle concentration, size, size distribution, minerology, [illegible] (8)

where *n(a)* is the probability distribution function (PDF) by number of particles, ρ is the particle density, mouth at the Strait of Georgia. Here, the Fraser is constrained to a single ~550 m wide channel carrying runoff from the 228,000 km^2 basin. This section provides an ideal location to measure the input of flow and sediment to the increasingly industrialized Fraser Estuary and Delta. The runoff pattern is dominated annually by the spring snowmelt in May-June initiating a freshet in late May, June and early July. The mean annual flow at Mission is 3410 m^3/s and the mean annual flood is 9790 m^3/s. McLean at al. (1999a) found that on average 17 million tonnes per year (Mt a^{-1}) of sediment moved past Mission, BC using WSC 1965-1986 data. About one third, $6.1x10^6$ Mt a^{-1}, is suspended sand and half of that (3.0 Mt a^{-1}),

where *i* and *j* are two different frequencies and are minimized between all three pairs by:

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in either underestimated or overestimated, an inverse response can occur in the estimate of concentration and particle radius. This work has presented an acoustic inversion that can account for a shifting and broad GSD by estimating the relative standard deviation, in addition to the particle radius and concentration.

The mixed implicit/explicit acoustic inversion method, similar to Thosteson and Hanes (1998), presented here provides a means to estimate both the median particle diameter and GSD standard deviation,