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Calibration of an acoustic pipe sensor through bedload traps in a glacierized basin

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ABSTRACT

Quantifying sediment transport in small mountain basins is of great relevance to assess the morphological and ecological dynamics of the entire channel network and to predict flood hazards. In high-elevation, glacierized basins, seasonal variability in sediment transport is dramatic, but despite the relevance of such basins in many regions worldwide, very few investigations have tried to quantify it. Since direct methods to assess bedload transport are time consuming and practically challenging at high flows, indirect surrogate methods, allowing continuous measurements over time, are highly desirable. Yet, these methods require calibration to provide reliable estimations. The present research is focused on the calibration of an acoustic pipe sensor in the recently established (Spring 2011) monitoring station in the Saldur basin, a high-elevation glacierized watershed in the Eastern Italian Alps. The acoustic pipe signal (which is amplified through 6 channels having different gains) was calibrated against samples collected over 26 sampling periods using "Bunte" bedload traps along a cross-section 12 m upstream of the pipe. Samples were collected from June to August 2011 during daily discharge fluctuations (ranging from 1.40 to 3.63 $m^3 s^{-1}$) due to snow- and glacier-melt, featuring very different bedload rates (up to 0.14 $kg\ s^{-1} m^{-1}$). In order to calibrate the pipe sensor signal, the average number of impulses was plotted against the corresponding unit bedload rates for the associated bedload sampling periods. As expected, the signal from the two most sensitive channels of the acoustic sensor resulted dampened even at low discharges, and thus could not be used for calibration and bedload assessment. Instead, power laws (R^2 from 0.76 to 0.92) relating the number of impulses per minute to unit bedload rate were obtained using channels having intermediate and low sensitivities, with higher correlations associated with the less sensitive channels.

1. Introduction

Bedload transport in small mountain basins represents a fundamental process for the dynamics and equilibrium of the whole channel network. The determination of bedload rates and volumes transported in mountain rivers has always been a major issue, key for flood hazard assessment and mitigation and now increasingly recognized for aquatic ecosystem analysis (Schwendel et al., 2010). Since the first half of the 20th Century, different instruments for bedload measurement have been developed. However, the monitoring of bedload flux in rivers is still highly challenging and subject to relevant technical problems (Gray et al., 2007). This is even more so for mountain rivers, especially during high water stages. Starting in the 1970s and 1980s, indirect methods (i.e. not directly "sampling" the transported sediment) were developed to overcome the difficulties inherent in direct bedload sampling.

In mountain rivers, which feature steep slopes, coarse and poorly-sorted sediments along with high flow velocities and turbulence, bedload transport can be measured through different methods, both direct and indirect. Direct methods include retention basins that physically trap all or most of the sediments transported through a section, providing an integral value of transport between consecutive surveys of the basin, i.e. do not provide information on transport rates unless sensors (e.g. pressure cells, distance sensors) are installed to monitor continuously the deposition process, as in the case of the Rio Cordon station (Italy, Mao et al., 2010), the Gråelva weir (Norway, Bogen and Møen, 2003), or the Pitzbach weir (Austria, Rickenmann and McArdell, 2008; Turowski and Rickenmann, 2009). Such systems are quite expensive in terms of initial installation and are feasible in relatively small streams only. Other stations for direct continuous records of bedload transport utilize different methods, as in the Erlenbach (Switzerland, Rickenmann et al., 2012), where a basket automatically moving below the crest of a check-dam catches the sediment falling into the retention basin downstream. Slot "Reid-type" traps deployed across a section are used in Japan (Mizuyama et al., 2010b) and Austria (Habersack et al., 2001), and vortex tube samplers were used for some time in the US and Italy (Hayward, 1980; Tacconi and Billi, 1987). Besides fixed instruments, which feature great advantages in terms of continuous bedload records but present high initial costs and mostly require a careful frequent maintenance, bedload can be sampled

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through portable devices as the “Helley-Smith” samplers (Emmett, 1980) or by “Bunte” bedload traps (Bunte et al., 2004, 2007), which are more suitable for coarse-bedded mountain rivers (Bunte et al., 2008). These instruments are much cheaper than permanent stations, but their deployment presents relevant difficulties at high flows and – importantly – they cannot provide continuous bedload data. Hence, the need to use indirect methods relying on different types of sensors deployed in or near the riverbed, such as vibration sensors, including piezoelectric sensors and velocimeters (Bogen and Møen, 2003; Richardson et al., 2003; Rickenmann and Fritschi, 2010; Rickenmann and McArdell, 2007) and passive acoustic sensors (Bänziger and Burch, 1990; Barton et al., 2010; Belleudy et al., 2010; Downing et al., 2003; Froehlich, 2003; Jagger and Hardisty, 1991; Krein et al., 2004; Mizuyama et al., 2003, 2010a,b; Rouse, 1994; Taniguchi et al., 1992; Thorne and Hanes, 2002). Active acoustic methods are also being effectively deployed (Habersack et al., 2010; Rennie and Church, 2010) but not in mountain streams. Other indirect methods effective in coarse-bedded streams include the assessment of cross-sectional variations coupled to particle velocities (Reimann, 1990), which nowadays can be obtained by tagging clasts with transponders (Lamarre et al., 2005; Liébault et al., 2012; Schneider et al., 2010), whereas in the past it was carried out through naturally magnetic particles (Ergenzinger and Custer, 1983; Hassan and Ergenzinger, 2005).

Acoustic detection of bedload by passive sensors has been studied since the 1950s (e.g., Anderson, 1976; Ivicsics, 1956; Johnson and Muir, 1969; Jonys, 1976; Richards and Milne, 1979), with the specific aim of finding out a non-perturbative technique able to keep the flow regime unaltered near the instrument and acquiring data in a continuous way. Previous research revealed the correspondence of variation ranges between bedload and acoustic pulses (Nakaya, 2008) with sound intensity generally increasing with bedload transport rate, and the frequency of the acoustic signal inversely proportional to the diameter of the moving particles (Froehlich, 2003). Nonetheless, in order to properly use an indirect method, the instrument needs to be calibrated with bedload data obtained via direct methods. At the moment, passive acoustic sensors for bedload monitoring in mountain rivers are widely used in Japan (Mizuyama et al., 2010b), whereas elsewhere – namely in Switzerland and Austria – the use of vibration sensors (i.e. velocimeters, more commonly called geophones) has been adopted (Habersack et al., 2001; Rickenmann et al., 2012).

The objective of this paper is to present an on-field calibration through portable “Bunte” bedload traps of an acoustic pipe sensor (called pipe hydrophone or pipe geophone by its Japanese developers, Mizuyama et al., 2003, 2010b), deployed in a glacierized basin (Saldur River, Italian Alps). To our knowledge, the calibration of indirect bedload sensors by means of portable bedload traps has never been carried out before, as this type of sensors has been calibrated either through slot samplers (Habersack et al., 2001; Mizuyama et al., 2010b) or by more sophisticated stations (as in the Erlenbach, Rickenmann and McArdell, 2007). Because the installation and the maintenance of slot samplers in mountain rivers – especially if snow- or glacier-fed – is neither technically easy nor cheap, the possibility of calibrating a relatively inexpensive acoustic sensor such as the pipe sensor through cheap portable traps (<500€ each) could represent an effective combination to be deployed in such rivers for a continuous bedload monitoring. The bedload sampling carried out to calibrate the acoustic pipe will be first illustrated, followed by the different calibration curves obtained. Finally, the threshold discharges and the related particle size which induces a response of the acoustic pipe will be analyzed.

2. Study area and methods

2.1. The study basin

The study area is the upper Saldur basin (Eastern Italian Alps), whose elevation range from 2150 m.a.s.l. (location of the main monitoring site, called LSG as it hosts the lower stream gauge of the monitored watershed) to 3738 m.a.s.l. (Weisskugel/Palla Bianca peak), for a total area of 18.6 km^2 (Fig. 1). The main glacier hosted in

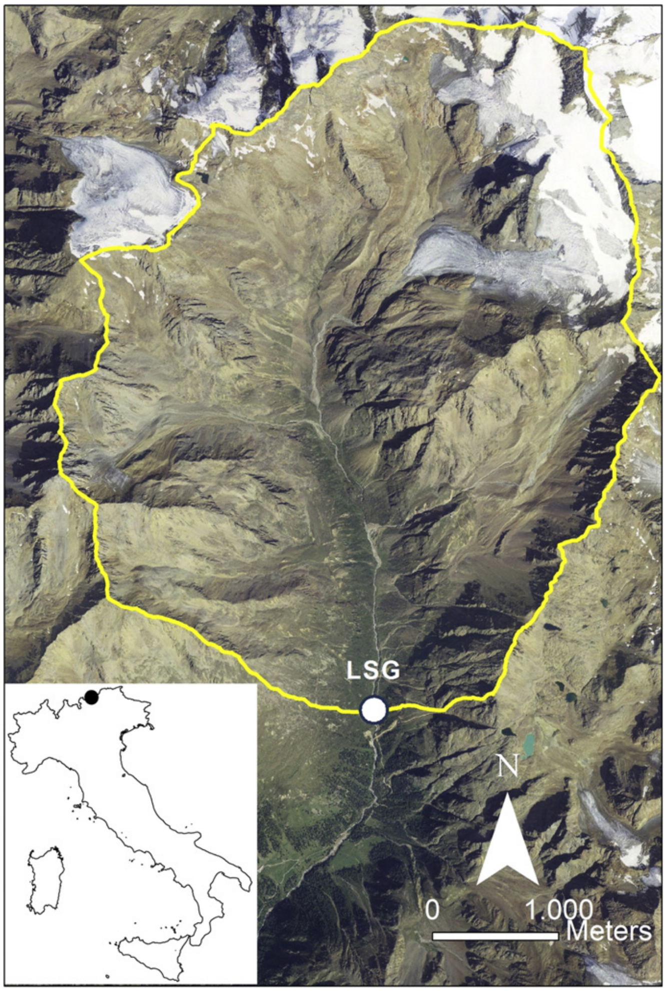

Fig. 1. Map and location of the Saldur basin, showing the position of the monitoring station (LSG). The Matsch glacier is visibile in the northern part of the catchment.

Fig. 2. Photo showing the works by the Dept. of Hydraulic Engineering of the Autonomous Province of Bolzano for the installation of the acoustic pipe in the Saldur River (section LSG, May 2011). Stream water was diverted to place a wooden log on the channel bottom, later stabilized by large rocks forming a ramp. The acoustic pipe was then fixed to the log by metal braces. A semi-circular slot – visible in the image – had been previously carved to host approximately half the diameter of the pipe.