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Measuring bedload in gravel-bed mountain rivers: averaging methods and sampling strategies

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Abstract

A dataset of more than 1,000 individual bedload samples coupled with hydraulic flow variables (water depth and velocity) was collected on two high mountain rivers the torrent de Saint Pierre, a proglacial gravel-bed river in the French Alps, in July 2002 and the Urumqi River, in the Chinese Tianshan mountains during summer 2005 and 2006.

Analysis of the dataset leads to question the usual section averaged sampling procedure of bedload using Helley-Smith type bedload sampler. It is shown that this procedure is inadequate to catch the full range of flow conditions. Comparison between moving averages on individual datasets and section averages furthermore show that this technique can lead to significantly different rating curves with predictions differing by more than an order of magnitude. Single point sampling is shown to be much more adequate than multiple point sampling and section averaging provided the dataset is sufficiently large.

Keywords: Braided rivers, Mountain rivers, Bedload, Sampling Procedure

1. Introduction

Understanding gravel-bed river morphodynamics implies understanding the dynamics of bedload. A significant portion of the grains composing the bed must be put into motion for it to evolve [1,2,3]. In mountain rivers it can also account for a significant portion of the mass transported [4,5]. Much of the research on gravel-bed rivers has therefore been devoted to bedload transport in relation with flow hydraulics. Still no satisfactory description of bedload dynamics has been achieved. Many transport equations have been devised both based on field or hydraulic modelling. Although some general features are accepted no relationship has gained universal acceptance because it relies too much on the dataset it was derived from [1-4,6].

Among the reasons mostly invoked are the many problems linked to field measurement. The most common devices used to sample bedload are Helley-Smith like pressure difference samplers. These samplers are commonly composed of a metal intake (square or rectangular), a flare that expends to the

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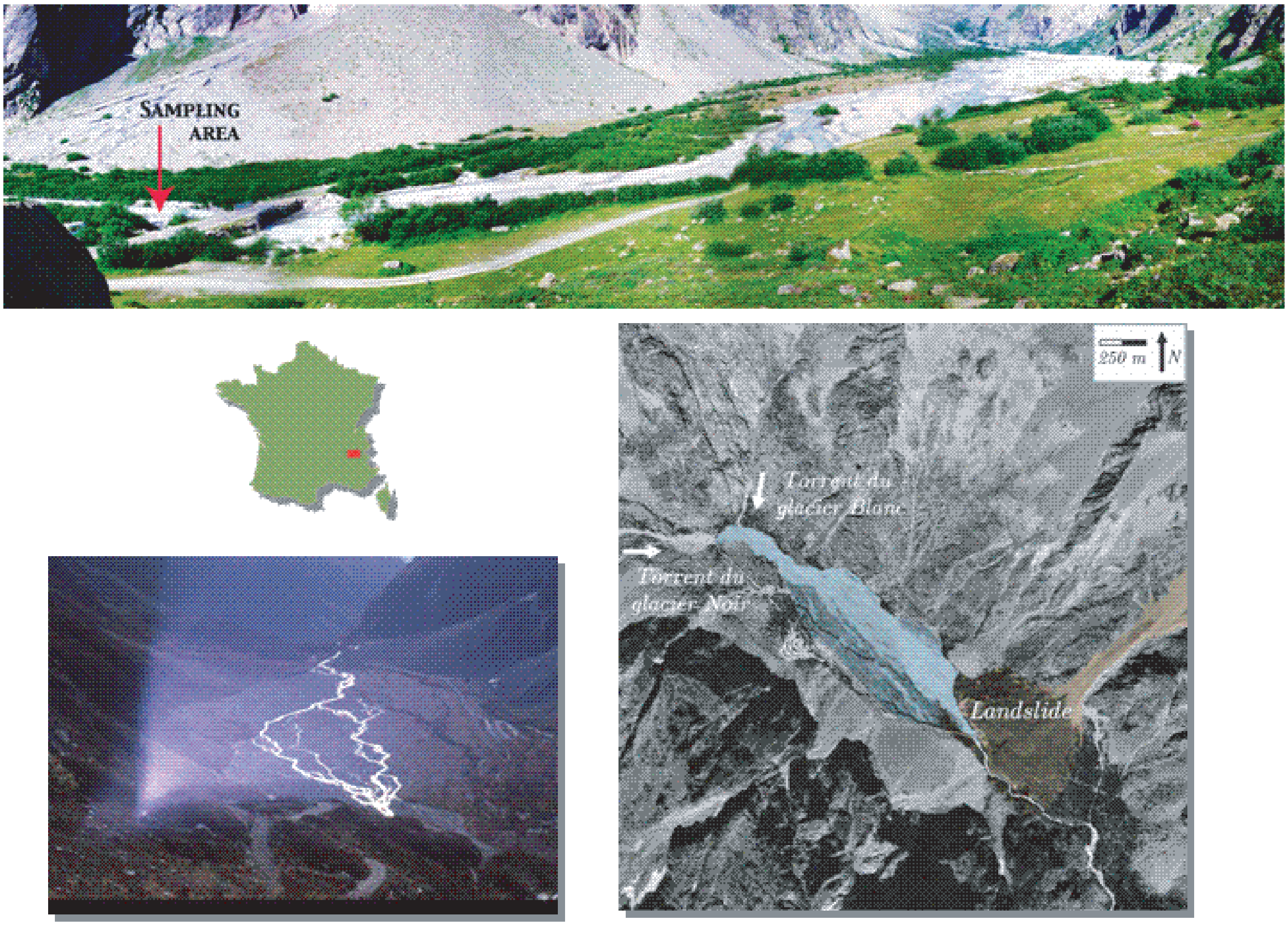


Fig. 1: Location and morphology of the Torrent de Saint-Pierre sampling site. After Meunier *et al*. 2006

back of the sampler and produces a pressure difference, and a nylon mesh. Flow and sediment enters the sampler through the intake. Velocity is reduced because of expansion due to the flare. This favors sediment settling and trapping in the nylon mesh whereas the flow passes through. Many version exist with different hydraulic efficiency and nozzle size [7]. The fluxes obtained from these samplers can vary within an order of magnitude depending on the type of sampler used. Among the many other factors that may influence the measured fluxes are the positioning of the sampler, the size distribution of the material transported, the hydraulic conditions of flow and the geometry of the bed.

Attempts were made to calibrate these samplers on hydraulic models [9]. Monitoring of bedload was performed at Saint-Anthony hydraulic labs on sand and gravel size fractions (up to 22 mm). Both pit traps and Helley-Smith bedload samplers were used and compared. Because of the physical impossibility to perform the same measurement at the same place and time using two different samplers, statistical techniques were developed in order to match both sampling techniques and compare their relative and absolute efficiency [9]. The technique developed by Hubbell [9] of the experimental runs was later questioned and a new more rigorous technique was proposed [8]. Apart from the discussion on the statistical validity of the technique devised for calibration, one problematic feature is the grain size distribution. It does not resemble that of a typical mountain gravel-bed stream. The largest gravels and cobbles were absent from the runs of Hubbel *et al*. Furthermore bed forms appeared that led Thomas and Lewis to question the relevance of the pit traps calibration [8].

In alluvial mountain streams the most important feature that characterizes the bed is the friction on protruding gravels [e.g. 10,11]. These gravels are also important as the flux corresponding to the movement of one pebble can equal the flux of all other grains. Yet no information is available on the sampling efficiency of samplers with regard to large particles but the maximum size a sampler can catch. The most reliable calibration to date is that proposed by Emmett [12]. A field comparison was established on the East Fork River (Wyoming) between bedload measurements using a Helley-Smith sampler and a concrete bedload trap. The results obtained tend to show that the trapping efficiency of the sampler is more or less equivalent to that of the trap for particles up to 8 mm. Discrepancies arise above that size. As stated by Emmett [12] the poor number of samples of large size fractions that were caught both by the trap and the sampler during the experiment prevented the use of classical regression techniques to compare the efficiency of the sampler. Therefore it is not clear what value can be attributed to large size fractions measurements using bedload samplers.

Another striking feature is the very high variability of measured rates of bedload [13,14]. For given flow conditions measured rates can vary by an order of magnitude. This observation is most often related to flow turbulence [15] although it is also a common observation in non turbulent flows [16]. This variability has lead researchers to question the importance of sampling time [e.g. 17] on the fluxes measured.

Eventually the samplers' nozzle is small compared to the river width and question is often put on the reliability of punctual estimates of bedload. It is then advised to measure bedload by successively positioning the sampler at equally spaced positions on the bed. The resulting mass is divided by the total (cumulative) time of sampling and normalized to the size of the sampler [7,18].

It is then quite common in studies of bedload transport to represent and analyse bedload on an integrated basis [e.g. 7,11,17,19], rather then on a local basis [e.g. 20,21]. Although the choice between the use of individual samples or section averages of bedload more often than not depends on the availability of synchronous measurements of hydraulic variables, we hereafter question the relevance of the section averaging technique as, to our knowledge, the possibility for such a technique to induce biased rating curves for bedload transport has never been explicitly addressed. A dataset is disclosed comprising more than 1000 individual measurements of mass fluxes with hydraulic measurements of flow. This dataset was levelled on the torrent de Saint-Pierre, a small pro-glacial braided stream in the Ecrins massif (French Alps) and on the Urumqi He in the Chinese Tianshan. We present the dataset together with a description of the surface grain size and structure of the river. The sampling procedure is then analysed. Averaging procedures | especially the section averaged described above|, and sampling durations are then discussed.

2. Field Sites

2.1. The torrent de Saint-Pierre

The measurement reach has been described in [22]. The torrent de Saint-Pierre at the Pré de Madame Carle in the Ecrins massif is a typical proglacial braided stream (Fig. 1). The general morphology is that of a gravel braided stream where bars, diverging and converging channels, riffles and confluence pools can clearly be distinguished on the braid plain. All along the plain, slope averages 0.025. Surface grain size was evaluated using pebble counts. It is highly variable and depends on the bed structure sampled. Median grain size ranges between 16 and 48 mm and maximum grain size sampled ranges between 58 and 300 mm. Surface samples where collected in confluence scours and channels they initiate, on banks and bars and in riffle sections. One very significant feature is that the sand content varies from 3 % on banks and bars to about 23 % in channels and pools. All these bed structures were potentially active as they could be inundated by the flow during the rising stage. They could also evolve and even disappear. During data collection in July 2002, one of the measurements sites was destroyed during the night flood. In the morning, ropes delineating the measurements site had been buried under up to one meter of gravels and sand. In this context, differentiation between surface and subsurface structure seems difficult to establish with any confidence. As already described both experimentally and on the field [16,23,24,25], sediment transfer is a wave like mechanism. Riffles can get buried under channels and pools and vice-versa in a very short time interval. Poor differentiation could also be both related the poorly sorted nature of sediment input from the glaciers and to the hydrograph structure [26].

There is no gaging station at or near the place of measurement in the National Parc but significant flow occurs during about four months each year. Therefore the duration of sampling represents about 5 to 8 % of the flow season. Highest flows occur during July and August. Sampling occurred during this period and therefore represents about 10 to 15 percent of the peak flows. This will be of use when we analyse the data. During sampling, channel width varied between 9 and 11m. Depending on position along the section averaged flow depth varied between 8 and 20 cm whereas maximum flow depth varied between 28 and 98 cm. Hence an aspect ratio (width over depth) on order of 100 for the torrent at the measurement site.

2.2. The Urumqi He (river) upstream

The Urumqi river initiates at 3,600 m ASL from the melt of a glacier known as Glacier N 1 flowing down Tangger Peak (4,900 m ASL) on the north flank of the Eastern Tianshan range in central Asia (Fig.2a). The river flows through two steep sections separated by a flat basin where the town of Houxia and the glacial station of the Chinese Academy of science are located. The river length from its headwater to the piedmont where it enters a semi-desertic environment is on order of 60 km. The sampling site whose measurements are discussed hereafter is located in the glacial valley at an elevation of 3,300 m approximately 8 km downstream of the source. Description of the site can be found in [5]. The river flows on glacial moraines through a series of cascades and flats (see Fig.2b). The long distance profile of the valley is relatively steep (4.9 % measured on a riffle and 2.5 % on a pool section at the survey site using a WILD T2000 theodolite). The grain size of surface particles is gravel-like. Using Pebble count D_{50} of the surface samples is 21.5 mm and D_{90} is equal to 158 mm.

The river hydrology is that of a glacial stream with summer orographic precipitation. This leads to a nice and narrow bell shaped form of the hydrograph with more than two third of the water flowing during three months from June to August (Fig.2c). At the measurement site the ratio is probably higher as the river does not flow from October to April.

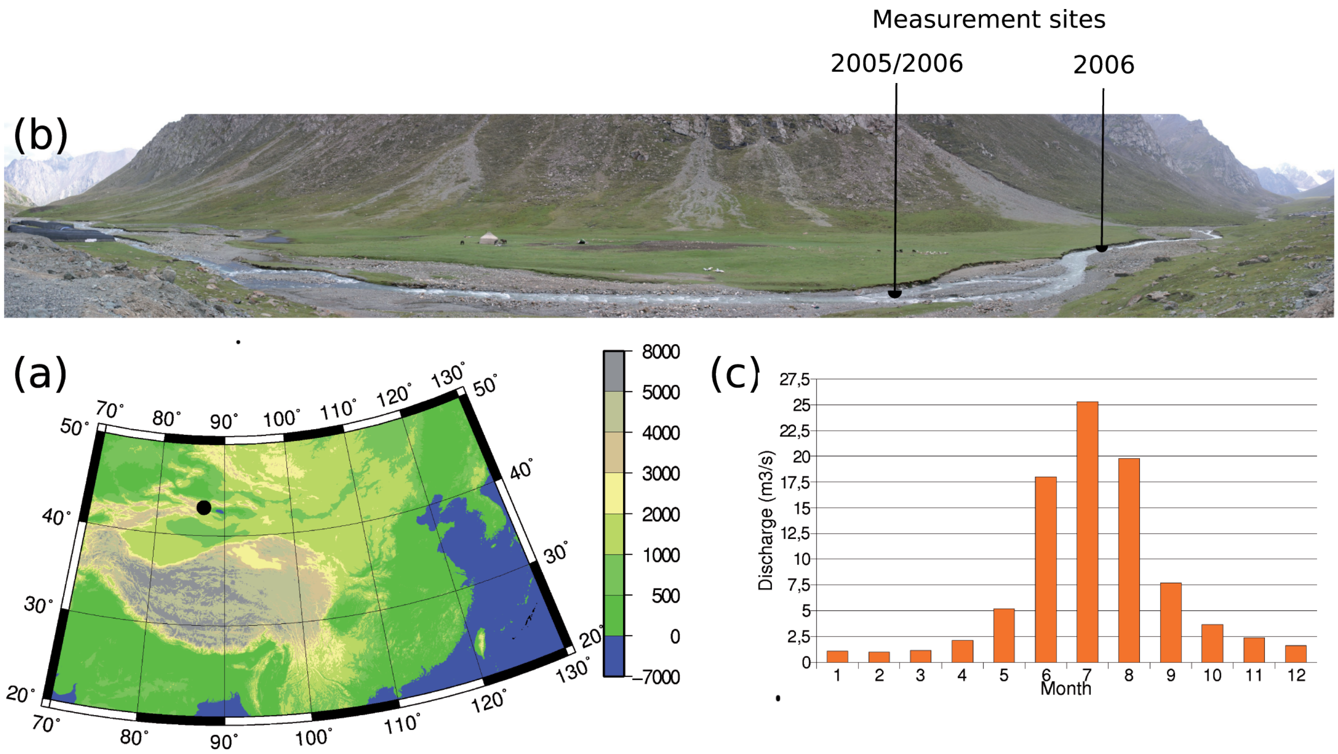


Fig. 2: Location and morphology of the Urumqi river sampling site. **(a)** Location of the Urumqi drainage. The river is part of the Tianshan range in central Asia. **(b)** Panorama of glacial valley of the Urumqi river where measurements were performed. Two sites (straight section and confluence pool) were surveyed in 2006. The confluence pool was also surveyed in 2005. **(c)** Monthly discharge 50 km downstream of the river.

Yet measurements are conducted by the Chinese Academy of science only from May to September so it is not possible to establish a correct balance. Flow regime upstream in the glacial valley is controlled by glacial snow melt and presents a diurnal oscillation like in the torrent de Saint-Pierre. Measurements performed during the summer 2005 and 2006 therefore encompass most of the flow season and give us a very good view of sediment transport dynamics in a high mountain stream.

3. Data acquisition

In the Torrent de Saint-Pierre 200 individual velocity profiles were levelled during 10 days with an OTT C2 current meter mounted on a wading rod [22]. Along each section, spacing between sampling stations was equal to one meter. At each station, a velocity profile was levelled and a bedload sample taken with a 15.2 cm (6”) entrance Helley-Smith sampler. The sampler had an expansion ratio of 3.22 and was equipped with a 250 microns mesh sampling bag. Sampling duration was 60 seconds. Each sample was retrieved dried and sieved.

The dataset of the Urumqi River is much more complete. Two flow seasons (approximately 3 months) were surveyed on a daily basis during the years 2005 and 2006 from June to August. Velocity profiles were levelled using an OTT C20 velocimeter. In 2006 up to 4 propeller could be used at the same time to measure velocity instantaneously at different position. bedload was sampled using a custom sampler. The sampler had an entrance of 30x15 cm and an expansion ratio of 1.4. The bags used are the same as those used for a conventional 6” Helley and smith sampler. In 2006 all the samples were retrieved dried and sieved. In 2005 only the samples above 100 g were sieved. In 2006 two sites were measured one in a straight section one at the outlet of a confluence pool about 200 m downstream. Only the latter was surveyed in 2005. Description of the river at the survey site can be found in [5].

The general pattern of flow and sediment transport is discussed in detail elsewhere [22]. The main features can be summarized as follow. From the data of the French Alps and hydrologic Data acquired earlier on the Urumqi He it is clear that only one velocity scale is relevant given the precision of measurements, namely the velocity averaged over the height of flow. The use of shear velocity calculated from profile fitting is precluded given both the very high variability of the flow and the non logarithmic nature of the velocity profile [5,22]. Although the flow is highly variable, it can be on average related to the flow depth by a Chézy law. This clear pattern is confirmed by the statistical distribution of Froude numbers that presents a normal distribution around a clearly defined average value. The sediment transport is mainly suspended with a minor but non negligible fraction of bedload. Solute load is of second order importance with regard to the flux involved.

3.1. Data description and note concerning data sampling

The data gathered is presented in Figure 3. The plot presented here are that of a unit bedload (g/m/s) versus a unit discharge

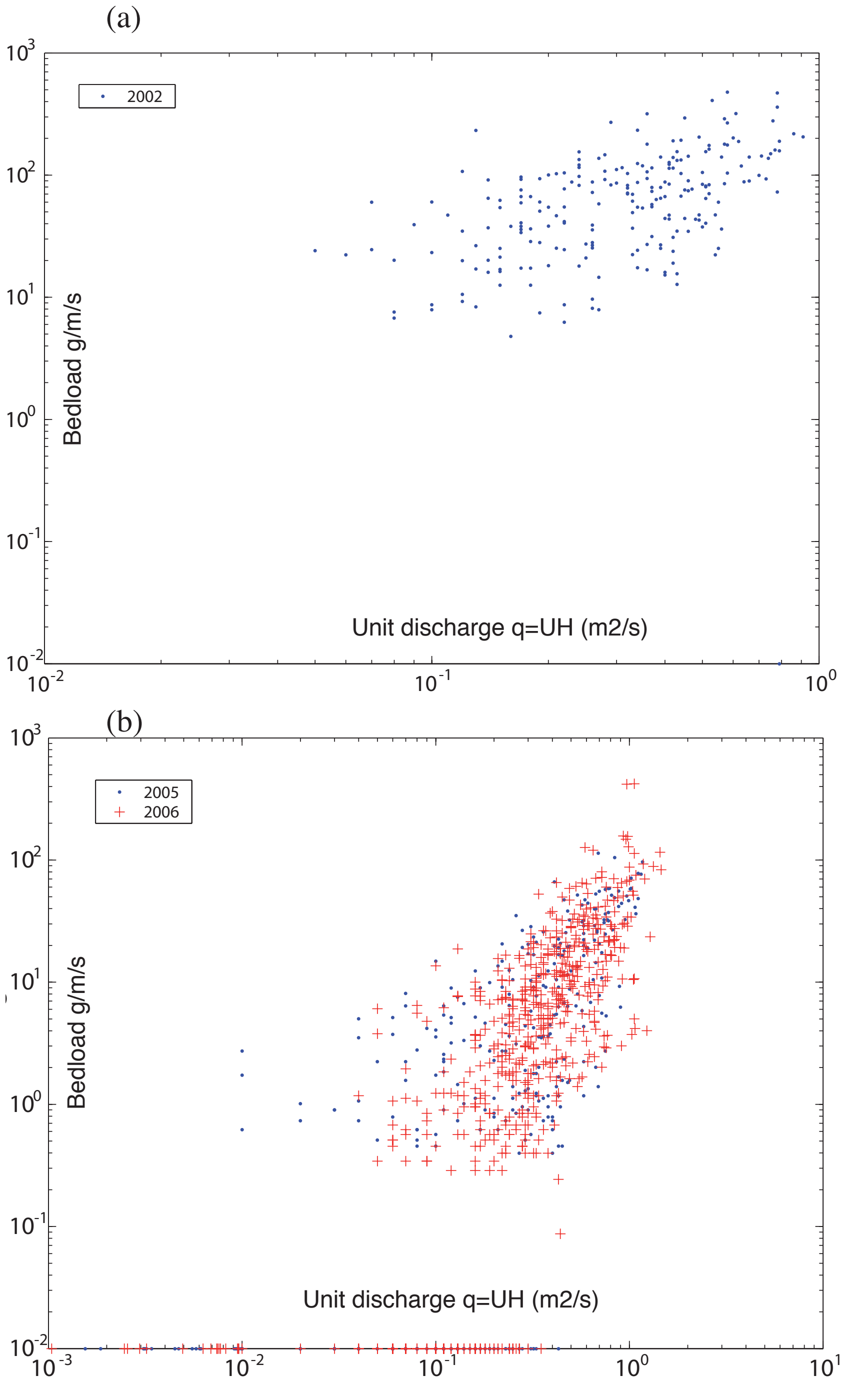


Fig. 3: Individual catches of bedload (g/m/s) as a function of unit discharge (m^2/s) derived from velocity profiles. Zero catches are represented arbitrarily at the 10^{-2}g/m/s in this loglog plot so that they can be represented and analysed. **(a)** Torrent de Saint-Pierre 2002 data, **(b)** Urumqi river 2005 (dots) and 2006 (crosses) data.

(q = *UH* in m^2/s) obtained from velocity profiling of the river flow (here U is the average velocity in m/s and *H* is the average depth of flow in m). Numerous values are plotted at 0.01 g/m/s. These values are in fact zero fluxes. the use of a unit discharge is arbitrary and it is not the purpose of this paper to derive any new bedload relationship or to discuss previous ones. Nevertheless let us note that under normal flow conditions

$$qS = UHS \sim U^3 \sim \tau_b^{3/2}$$

where *S* is the bed slope, and τ_b the bottom shear stress. As most formulas described in the literature define the flux of bedload as a function of $\tau_b^{3/2}$ data should then locally be a function of unit discharge.

The two datasets of the Urumqi river collapse very well. As the two years were similar in discharge and weather it is an infrequent example of reproducible field experiment. Also note that the data for 2006 was levelled at two different sites yet no different trends are noticeable.

A significant difference with classical procedure was that we decided to keep each individual sample at each station.

There are several reasons for this.

(1) This allowed us to analyse variations of sampling with position along the section.

(2) This provided the exact "raw signal" measured by a bedload sampler with all its statistical variability in order to address the problem of sampling procedure and averaging.

(3) All transport laws are basically local in their definition and often in their derivation. They should therefore be tested against single measurements.

(4) As the samples were dried and sieved later in the laboratory this sampling procedure enables to assess the significance of sampling for each size fraction.

4. Results and Analysis

4.1. Data scatter and averaging procedures

Although clear trend can be seen on the datasets discussed here, individual bedload samples present a well known high variability [13,14]. It is then common to smooth the dataset in order to define clear trends and correlations between bedload and fluid flow variables. There are several ways to smooth datasets such as those depicted in Fig. 3. Moving averages can be made according to a fixed number of data point or to a fixed value of one of the parameters.

In fact a common procedure recommended can be called section averaging. This consists of averaging the samples gathered along each individual cross section. This latter method has two advantages. First, it can be made directly on the field by positioning the sampler at different positions for the same period of time and gathering the final composite sample that represents an integral over the sampling positions. Second, section averaging gives access to the average value of the flux that passes through the section at a given time. For people interested in mass balance studies section averages therefore seems to be the relevant method to apply. We hereafter

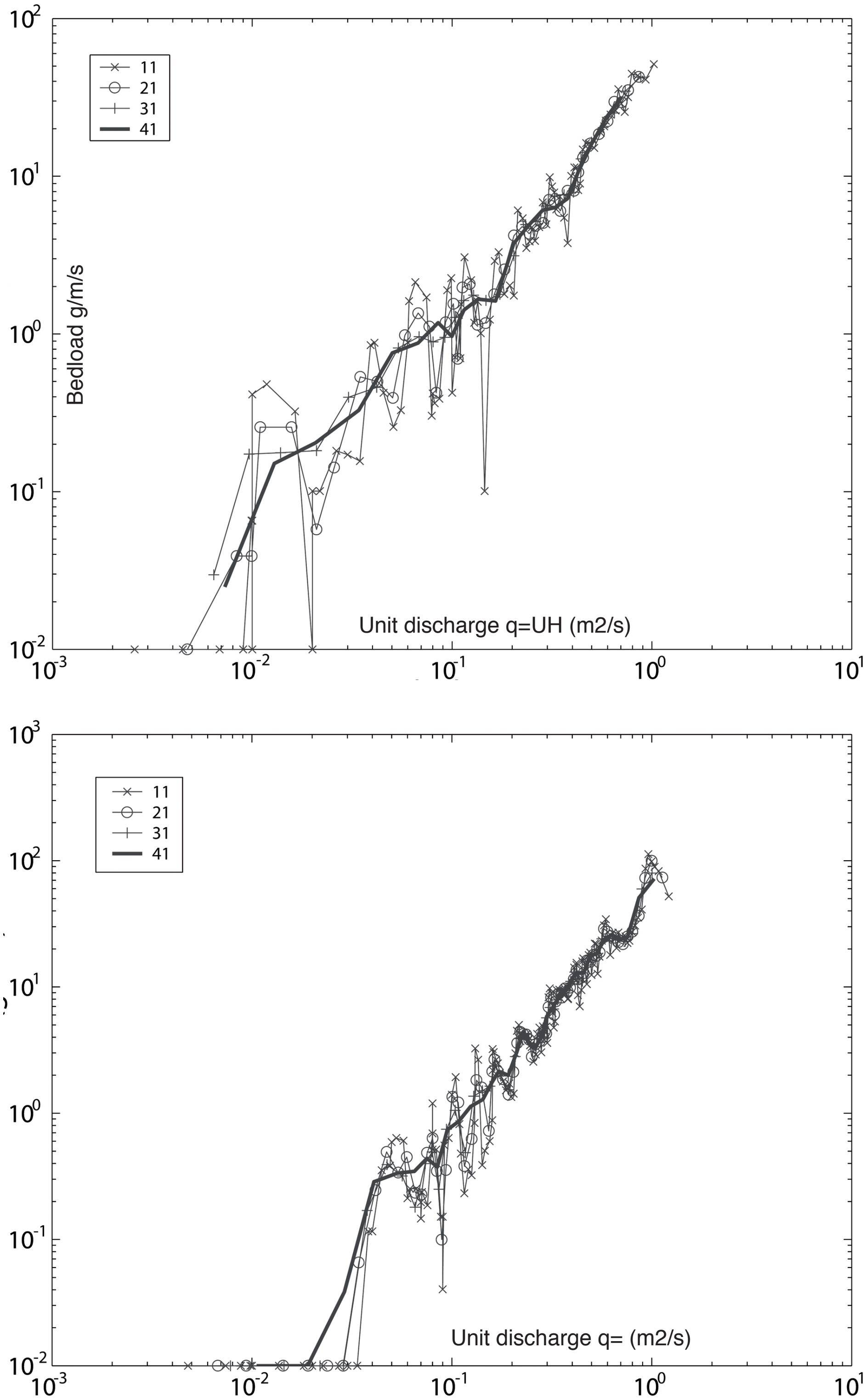


Fig. 4: Moving averages of individual measurements in the Urumqi river for different values of the averaging window. Nul values are plotted as 0.01 g/m/s bedload.

does not drastically affect the result. Variability is observed for low values of bedload flux and unit discharge because the number of zero values measures with the bedload samplers rise and non zero values have a stronger influence on the resulting average. Zero fluxes are reported here as 0.01 g/m/s for information. It can also be seen that the resulting averaged dataset expends over about two decades in unit discharge and almost three decades in bedload flux. The resulting curve seems to disclose a clear scaling relationship between the two variables. Moving averages can also be made over fixed unit discharge increments. Figure 5 shows the comparison between both averaging procedure, fixed number (41) of points or fixed interval in unit discharge (here 0.1 m^2/s interval), for the Urumqi river. It is clear the both averaging procedures are very similar and that the resulting averages collapse well. In all above mentioned averaging procedure, the ordering variable was chosen to be the unit discharge. The reason for this is that velocity propellers are well calibrated instruments with a low uncertainty (on order of 5 % for the OTT C20, less for the C2 velocimeters). Measurements are much more precise then bedload sampling using hand held Helley-Smith samplers. Scattering in unit discharge does then, and with a good level of confidence represent natural scattering due to physical conditions and not due to measurement uncertainties. On the contrary scattering in bedload measurements may in a non negligible proportion reflect measurement uncertainties. It should therefore not be used as the parameter over which averaging windows are defined. This procedure has already been used by [21] (2006) to reduce the scatter in their dataset.

question this idea but first we will go into some detail into other averaging procedures.

Figure 4 represents moving or slide averages calculated over fixed numbers of points N_{win}. Each average overlaps with the two neighbours by N_{win}=2. It can be seen for the datasets considered that the number of points (from 11 to 41)

4.2. Relevance of the section averaging procedure

It is conventionally suggested that representative samples of bedload consist of section averages [7,11,12,18,27,28]. The sampler is positioned successively at several equally spaced positions and left for the same duration. Once all positions (usually around 10 see [7] for a discussion), have been levelled the sampler is retrieved and the sample weighted. Only few studies do not follow this procedure and prefer to both collect and analyse individual samples of bedload [20,21]. When fractional transport is analysed the sample is dried and sieved in the laboratory. The composite sample obtained is transformed into a flux by dividing the mass caught by the total sampling time. This way of sampling is currently assumed to be more representative of bedload transport because it "averages" spatial fluctuations over the section.

We tested the relevance of averaging samples over the section by producing composite samples for each section from the individual samples taken at equally spaced positions. We then compared the sediment flux per unit width for section averages, for individual samples and moving averages made over the individual samples. The result is shown in Figure 6. Although section averages exhibit a smaller dispersion in mass flux, they present two major drawbacks compared to individual samples.

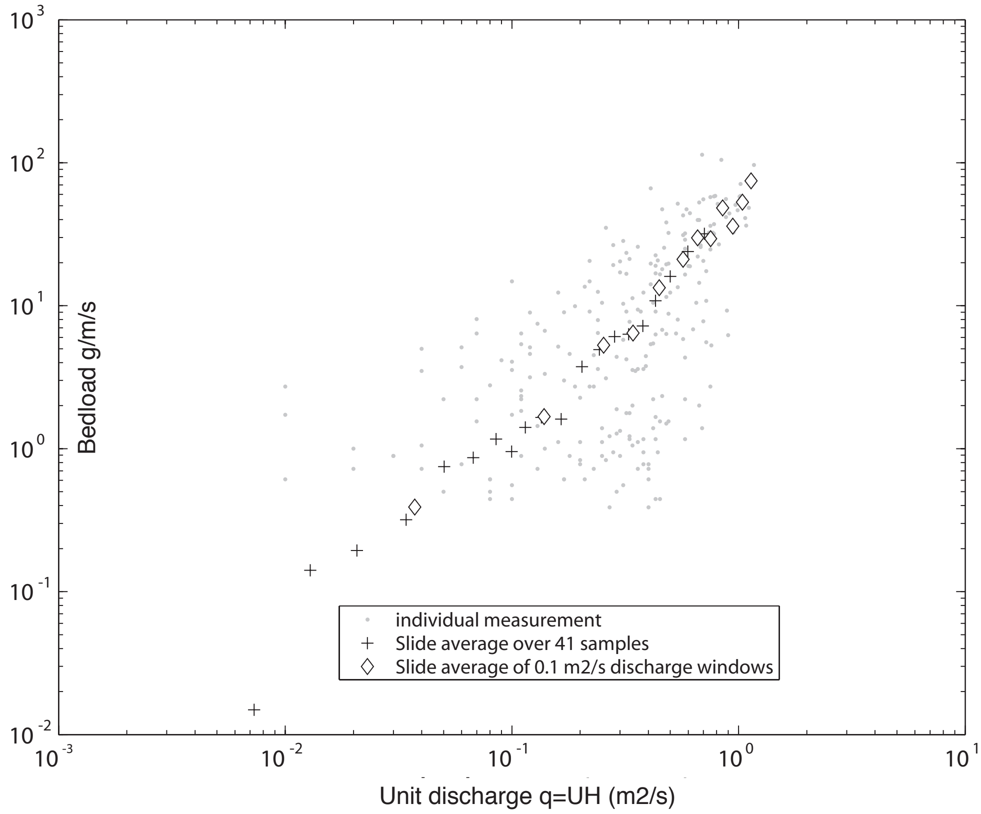


Fig. 5: Comparison between moving averages calculated over a fixed number of data points (41) and moving averages calculated by unit discharge intervals (here m²/s). In grey individual data points

First, the number of samples is much less (approximately ten times less in both cases). This renders statistical analysis difficult to perform compared to the 200 to 700 individual point samples gathered during each of the three surveys. In particular it is for example totally impossible to perform running-averages for the section averages of the torrent de Saint-Pierre the "worst" dataset of our study. For the Urumqi river moving averages on the already section averaged data would lead to very different signals compared to moving averages performed on individual bedload catches. Second The span in sediment flux values (Y-axis) and even more in unit discharge values (X-axis) are drastically reduced.

Running averages over individual samples permit a rather clear and direct trend to show out, trend from which a rating curve can be derived. As the span in discharge is much less the fit for section averages can be expected to be both significantly different and highly variable as it is a common practice to fit data "by eye". Eventually one may ask whether the section average technique might prove relevant for dataset with a "higher" variability. The answer there again is clearly no. First although the datasets of China are exceptional (in the sense that they span a large range of values for both unit discharge and bedload flux and that two successive years reproduce very nicely the same trends), the variability is high (as usual) and can reach two orders of magnitude. Second as already stated above the torrent de Saint-Pierre can be seen as the "poorman's" dataset in this study. The same variability in bedload for a smaller range of values and a much smaller dataset (more than 3 times less). Yet the results are the same for all the datasets (Figs. 6 and 7) and unambiguously show the strong bias induced by section averaging compared to raw data or moving averages.

This can be easily understood from Figure 8. As the velocity and depth of the stream varies significantly along the section, so does even more the discharge per unit width. Individual measurements catch these fluctuations. Section averages smooth out the fluctuations thereby reducing the potential richness of the dataset. Fig. 6 also shows that section averaging leads one to average measurements that correspond to very different flow and sediment transport conditions. The physical significance of such a way of proceeding seems not clear to us. Running averages on individual data on the contrary have a clear physical significance as they represent averages of measurements that correspond to comparable conditions of flow and sediment transport. They are just a classical way to average over the inherent variability of sediment transport dynamics.

As an example, both moving averaged datasets and section averaged datasets were fitted using power law curves. The resulting lines on a loglog plot are shown together with the data. It is clear that the predictions rapidly diverge significantly. This divergence can be more than an order of magnitude for the Urumqi river. For the Torrent de Saint-Pierre curve fitting using the available data set has no sense.

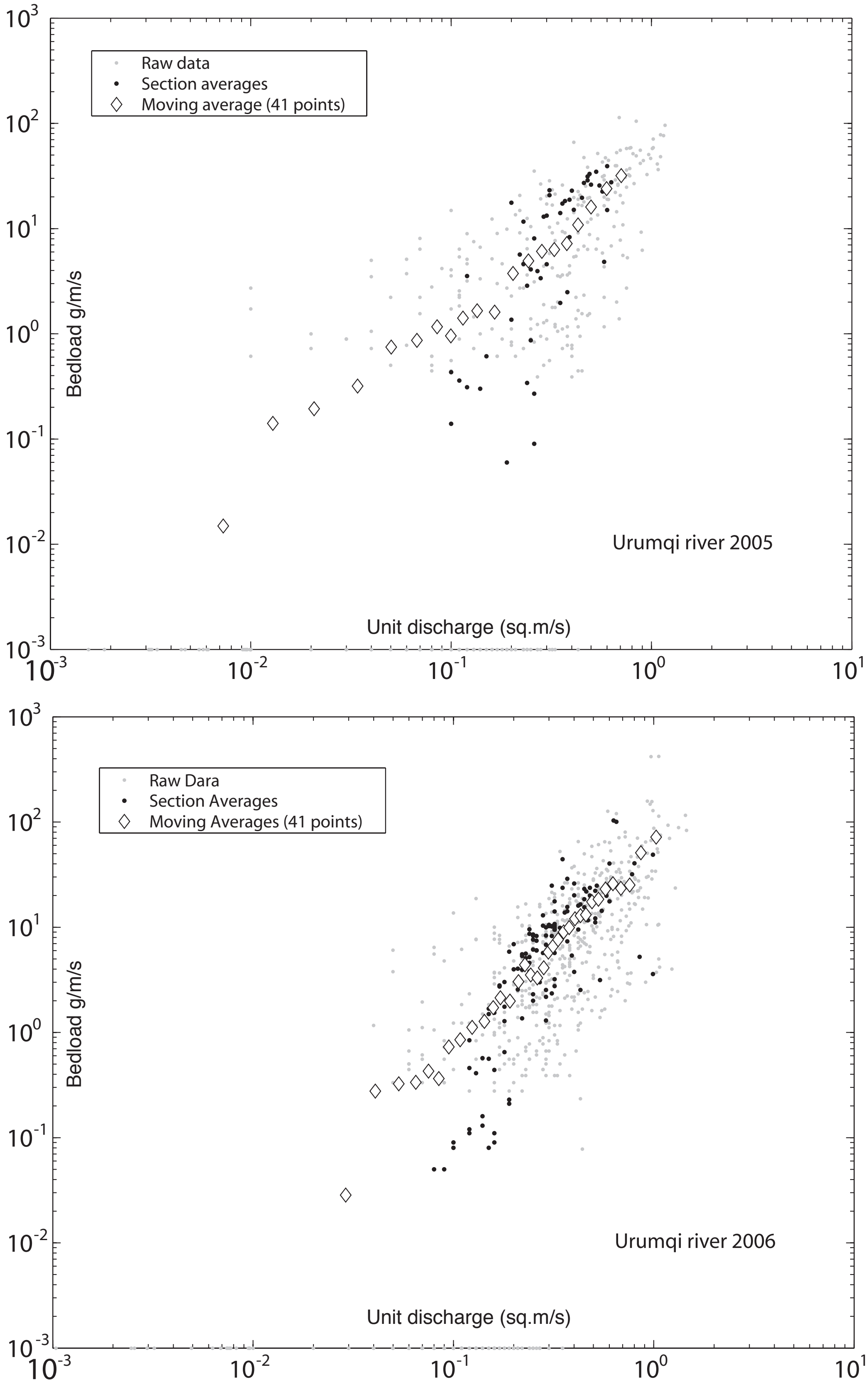
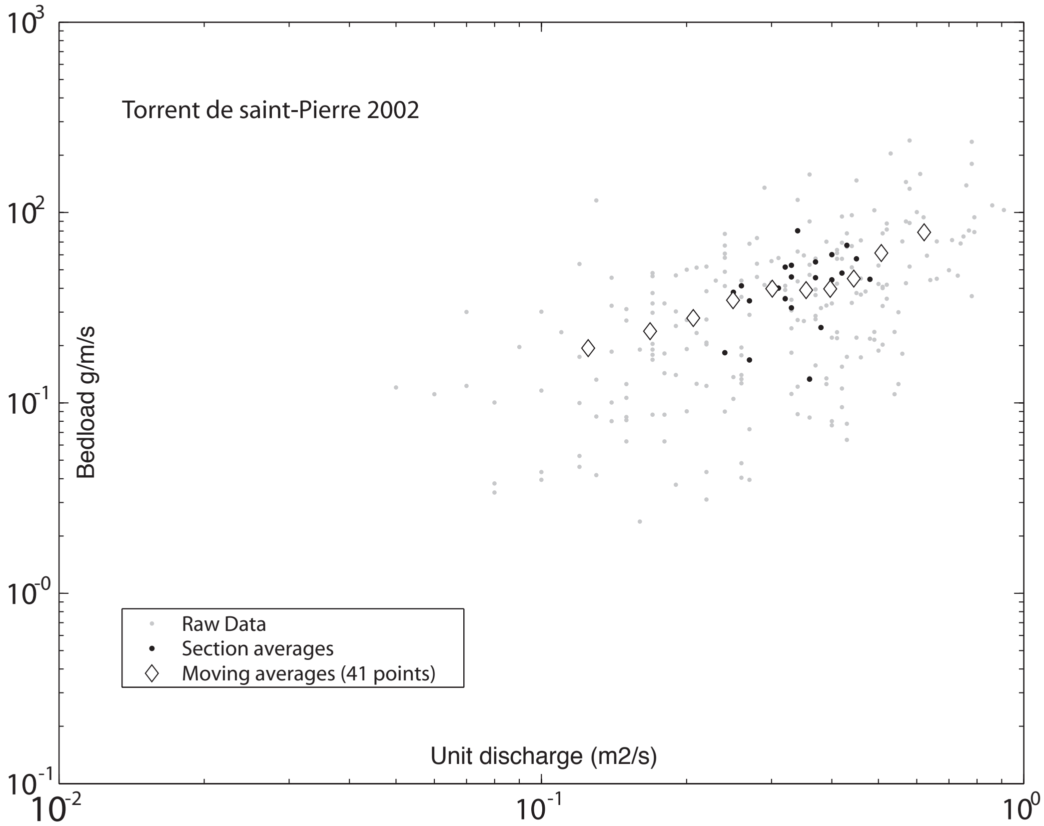


Fig. 6: Comparison between individual measurements of bedload (grey \raw data" points), section averages (black points), and moving averages done over the raw dataset. **(a)** and **(b)** Urumqi river samples, **(c)** Torrent de saint-Pierre sample.

Given the quality of existing datasets, averaging procedures are useful tools to get a signal out of what often look like a noisy trend. The question then arise on what kind of averaging you are willing to perform. Making a given kind of averaging on a reliable dataset is the only way to assess the relevance of the method. hence the present study. Our measurements both in France and in China therefore unambiguously demonstrate that section averaged sampling should be precluded because it drastically reduces both discharge and transport spanning without bringing effective lowering in data scattering. It should also be precluded because the variations of flow and sediment transport along the section can be large and the physical meaning of section averaging has not yet been demonstrated. On the contrary local averaging of physical variables is a common procedure used to smooth out variability linked with data acquisition. Individual collection of sediment transport is therefore much more alike to bring meaningful datasets that span the whole range of flows and transport, hence useful ones. The fact that results obtained here are good with moving averages validates their use.

4.3. Survey duration

We here add a few lines to the remarks made above on the necessity for any dataset to span the whole range of flow and transport conditions. Making both bedload sampling and velocity profiling most often implies a permanent presence of an experimentalist. In many cases it is not possible to spend months at a given place to measure daily transport and hydraulics and



yet no system has been devised that could do such a survey on a automated basis. We here try to answer two questions : how does the data set differ if the period of sampling is one, two or three weeks ? Is there an acceptable threshold above which the survey catches the essence of the dynamics ? We used the Survey made on the Urumqi river during the year 2006 as an example. The survey duration was 66 days long a duration that corresponds to about 2/3 of the period over which bedload can be seen moving. The survey is centred on the month of July where the highest flows are usually recorded. From this dataset we extracted all the contiguous 7-day to 35-day periods of survey that could be done. For each survey period all the bedload samples and velocity profiles were combined and the non zero bedload rates were adjusted to unit discharge through a simple power law fit of the form

$$q_b = aq^b$$

where q_b is bedload per unit width, q is unit discharge and a and b are the coefficients of the power law. Average and standard deviations were then calculated for each n-day ensemble. Table 1 shows the result.

On average the values of the coefficient do not vary very much. This is expected because averaging was performed over all the possible contiguous n-day periods. Hence all the entire 2006 sampling period is included in the average. The interesting variable here is the standard deviation that reflects the variability of the coefficients depending on the duration of sampling and position in time for the sampling series (say beginning of June or middle of August).

As we hypothesized the variability of the coefficients is strongly related to sampling duration. The constant a varies from about 42 % for a 7-day survey to about 11 % for a 21 day survey and 2 % for larger durations. The power low exponent b varies from about 23 % to about 9 % for a 21 day period and 3 % for a 35 day period. This means that variability in these two coefficients can, within a 95 % confidence interval, be up to 84 and 46 % respectively for a 7-day survey. If we consider two experimentalists making independent 14 days survey of the same river, they may reasonably end up with rating curves of the form $q_b = 20q^{1:2}$ and $q_b = 40q^{1:6}$.

Several conclusions can be drawn from this. First It is obvious that long duration surveys are most able to catch the dynamics of bedload transport. In the case of the Urumqi river a 21 days period that gives reasonable results corresponds to about 20 % of the total duration of bedload movement

Number of days	$\bar{a}$	σ_a	$\sigma_a/\bar{a}$ (%)	$\bar{b}$	σ_b	$\sigma_b/\bar{b}$ (%)	Number of subsets
7	27.80	11.68	42	1.40	0.32	25	59
14	28.07	7.04	25	1.43	0.21	15	52
21	26.64	3.00	11	1.41	0.13	9	45
28	26.95	2.73	10	1.41	0.09	6	38
35	27.18	1.71	6	1.42	0.04	3	31
66	26.90			1.48			1

Table 1 : Average values and standard deviations of power law fits on non zero data caught with the Helley-Smith sampler during different sampling durations. Original dataset from 2006 on Urumqi river.

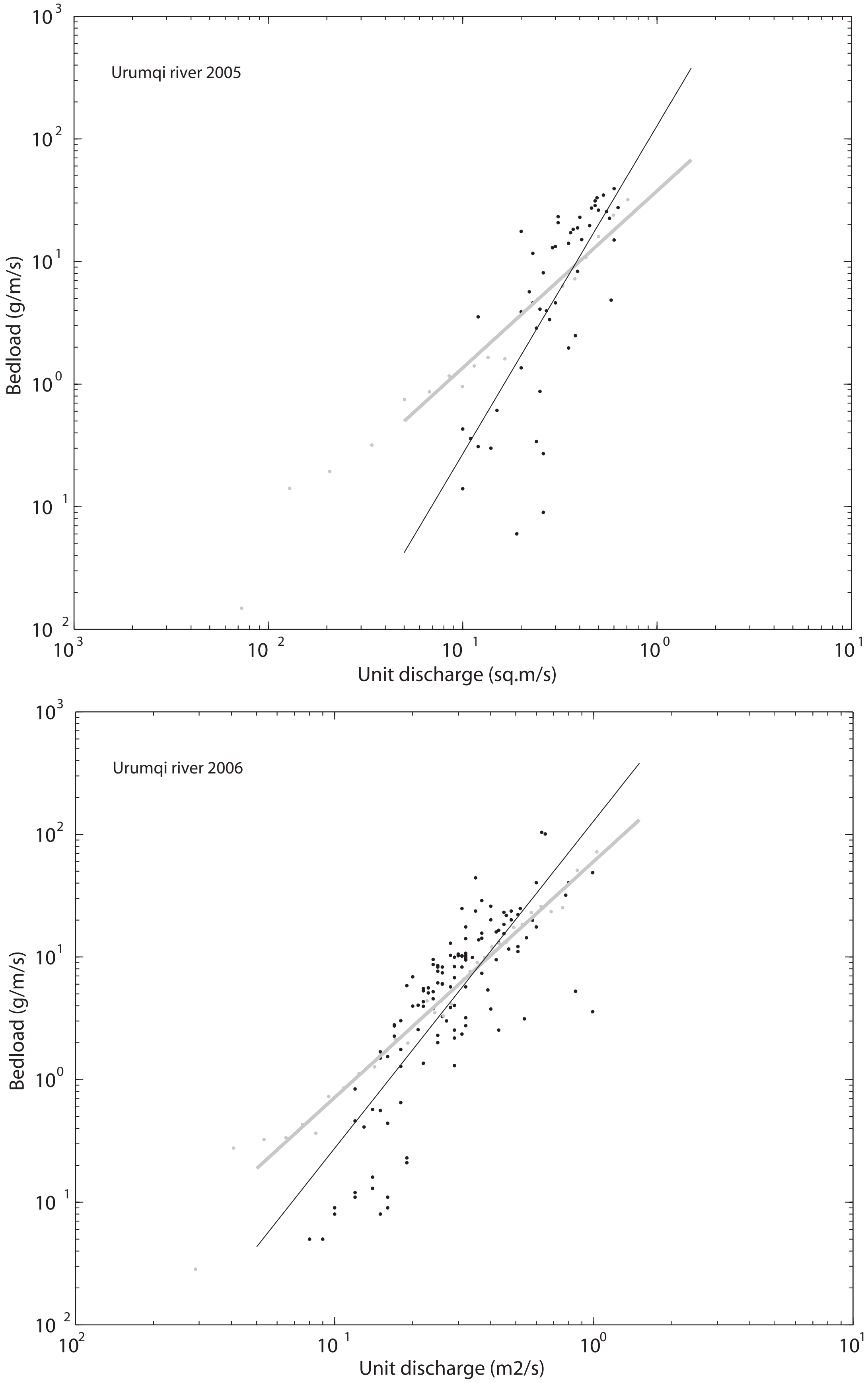


Fig. 7: Comparison between power law _tting of moving averages (gray points and line), and section averages (black points and line), of the same datasets.**(a)** and **(b)** Urumqi river samples, **(c)** Torrent de saint-Pierre sample.

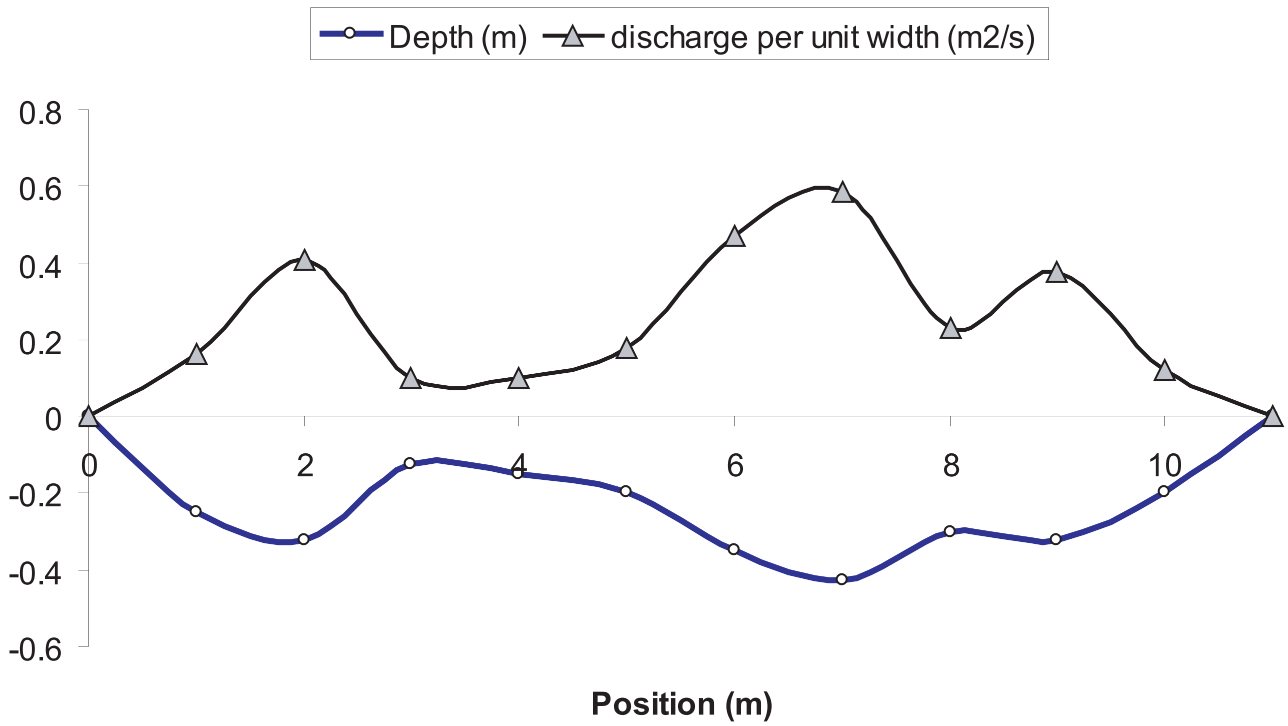


Fig. 8: Cross section of Torrent de Saint Pierre at sampling site. Flow depth is shown together with discharge per unit width.

(about three months). Second it is useless to think that even a relatively long lasting bedload survey using Helley-Smith type samplers can lead to precise predictive rating curves. The inherent uncertainty linked to bedload movement precludes this. Third, as shown above, it is probably possible to fit the same dataset with quite "different" transport laws. This probably explains, at least in part, the reason why no bedload transport relationship has really shown out of the crowd.

5. Summary and Conclusions

Much remains to be done to understand the dynamics of particle movement in gravel-bed systems. One of the essential steps is to produce reliable datasets that can be useful both for prediction and management. In order to do this reliable estimates of bedload fractions are needed that can be coupled with flow hydraulics. Our dataset from the torrent de Saint-Pierre and the Urumqi river is a step towards such achievement because it brings some useful insight into the way we measure and the way we should measure. It is now clear to us that section averaged sampling of bedload is some sort of a fall-back solution that should be precluded if measurement of both velocity profiles and sediment transport are possible. Individual sampling, although problematic on its own, bears much more information on the flux and on the uncertainties linked to its determination. Eventually the dataset from China shows that, for a single daily series of measurements (gaging and sampling on one section), at least 20 % of the effective periods where bedload moves must be sampled in order that the measurement be representative of the dynamics of sediment transport. According to our experience and to previous work further analysis has to be performed both on the statistical description of bedload, on its reliability for large size classes and on the movement of fractions.

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