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Discussion

Statistical analysis methods for transient flows – the dam-break case

By RUI ALEIXO, SANDRA SOARES-FRAZÃO and YVES ZECH, *J. Hydraulic Res.* 57(5), 2019, 688–701.
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Discusser:
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The Authors developed an interesting discussion on measurements in highly-unsteady transient free-surface flows. Using the dam break wave propagation on a dry bed as an example, they discussed the differences between three experimental approaches, namely single experiment, Fourier component method, sometimes called variable interval time average (VITA) method, and ensemble-averaging approach. All these approaches were previously tested for transient flow properties of breaking surges (Figure D1) by Chanson and Docherty (2012), plus the ensemble-statistics of Fourier component data. Further discussions were developed with relevance to transient sediment transport and turbulent integral scales (Khzeri & Chanson, 2015; Leng & Chanson, 2017a). In this discussion paper, the experience in transient flow measurements in surges is reviewed and a critical discussion on the suitability to laboratory and field data analyses is developed.

Extensive transient flow measurements were undertaken in positive and negative surges over the last three decades (e.g. Hornung, Willert, & Turner, 1995; Koch & Chanson, 2009; Reichstetter & Chanson, 2013). Several statistical methods were tested, from single experiment data to the ensemble statistics of Fourier component analyses (Table 1). Table 1 lists a number of relevant studies. The experience from both laboratory and field measurement data analyses suggests a number of important outcomes. A single experiment or single realization is suitable to gain information on qualitative patterns and instantaneous quantities. But it is unsuitable to derive statistical data in highly-unsteady transient flows like the leading edge of positive and negative surges, because the relevant time scale of the physical processes is often very short, i.e. less than 100 ms to 500 ms even at a prototype scale (Figure D1b). The Fourier component analysis, also called low-pass filtered or variable interval time average technique, may be better suited to positive and negative surges, provided that (a) a threshold frequency f_c can be selected based upon physically-meaningful considerations, (b) the instrumentation's sampling frequency is significantly larger than f_c, and (c) the results are not sensitive to a precise estimate of f_c. This approach was successfully applied to both laboratory and field observations (Table 1). In the laboratory, however, the repetition of the experiments and the ensemble statistics are the most reliable approach (Bradshaw, 1971), and it was successfully applied to both positive and negative surges (Chanson & Docherty, 2012; Leng & Chanson, 2015). This experimental approach requires great care to ascertain the repeatability of the experiments and the synchronization between repeated runs. These critical points are far from trivial, albeit rarely mentioned in the literature with a few exceptions (Leng, Simon, Khezri, Lubin, & Chanson, 2018). To date, a limited number of transient flow studies were successfully conducted based upon experimental ensemble statistics, e.g. Chanson and Docherty (2012), Leng and Chanson (2016, 2017a, 2017b), Wang, Leng, and Chanson (2017) (also Table 1), often because of practical technical limitations, time constraints and limited resources.

For ensemble statistics, a minimum number of repeats is critical to the data quality. A number of sensitivity analyses were performed (Table 1). In monophase flows, the results in terms of free-surface properties, longitudinal velocity and average tangential Reynolds stress were basically independent of the number of realizations for a minimum of 20 runs. In practice, a selection of 25 repeats may be a reasonable compromise, in line with earlier literature (Perry, Lim, & Chong, 1980). Figure D2 presents some results in terms of the maximum longitudinal velocity fluctuations beneath a breaking surge, with the velocity fluctuation defined as the quartile difference ($V_{75} - V_{25}$),

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(a) (b)

Figure D1 Breaking surge propagation: (a) laboratory study in a 19 m long 0.7 m wide flume – bore propagation (from left to right) against the initial flow direction; (b) field measurements in the Garonne River (France) – bore propagation background to foreground

Table 1 Transient flow measurements in positive and negative surges

Reference	Experiment	Measurements	Statistical method
Positive surges			
Docherty and Chanson (2012)	Breaking surge (laboratory)	Velocity, velocity fluctuations, Reynolds stresses	Single experiment
			Fourier component method (1 run)[a]
			Ensemble-averaging (20 runs)
			Fourier component method (20 runs)
Keevil et al. (2015)	Field experiment (Garonne River)	Velocity, velocity fluctuations, Reynolds stresses, SSC	Fourier component method (1 run)[a]
Khzeri and Chanson (2015)	Breaking surge (laboratory)	Velocity, velocity fluctuations, sediment sheet flow	Single experiment
			Ensemble-averaging (40 runs)
Leng and Chanson (2017b)	Undular and breaking surges (laboratory)	Velocity, velocity fluctuations, Reynolds stresses, integral turbulent scales	Single experiment
			Ensemble-averaging (25 & 50 runs)[b]
Leng, Chanson, and Reungoat (2018)	Field experiment (Garonne River)	Velocity, velocity fluctuations, Reynolds stresses, SSC, turbulent events	Fourier component method (1 run)[a]
			Turbulent event threshold technique
Negative surges			
Reichstetter and Chanson (2013)	Negative surge (laboratory, smooth bed)	Velocity, velocity fluctuations, Reynolds stresses	Single experiment
			Ensemble-averaging (25 runs)
Leng and Chanson (2015)	Negative surge (laboratory. smooth and rough bed)	Velocity, velocity fluctuations, Reynolds stresses	Single experiment
			Ensemble-averaging (25 runs)[b]

Notes: [a] sensitivity analysis in terms of cut-off frequency; [b] sensitivity analysis in terms of the number of repeats.

at three vertical elevations z. It is important to stress that any sensitivity analysis must be closely linked to the selection of the tested parameter, e.g. velocity, velocity fluctuation, turbulent Reynolds stress, integral turbulent scales (Leng & Chanson, 2015, 2017b). A larger number of experimental repeats might be required with more advanced parameters, e.g. triple correlations, extreme pressure values, and air–water flow characteristics. In most cases, the number of realizations is much smaller than the number of data samples used in traditional steady turbulent flow analyses (Karlsson & Johansson, 1986; Krogstad, Andersson, Bakken, & Ashrafian, 2005). The instantaneous ensemble data are best analysed in terms of instantaneous median, quartile and percentile of the data ensemble, which are robust parameters insensitive to the presence of outliers. Such a data analysis may include unsteady turbulent burst detection (Shi, Leng, & Chanson, 2019). By contrast, ensemble averaged properties, including root mean square errors, are not robust estimators because they may be biased by outliers and extreme values within small data samples. More generally, the ensemble "averaging" approach should be avoided in nonlinear physical systems.

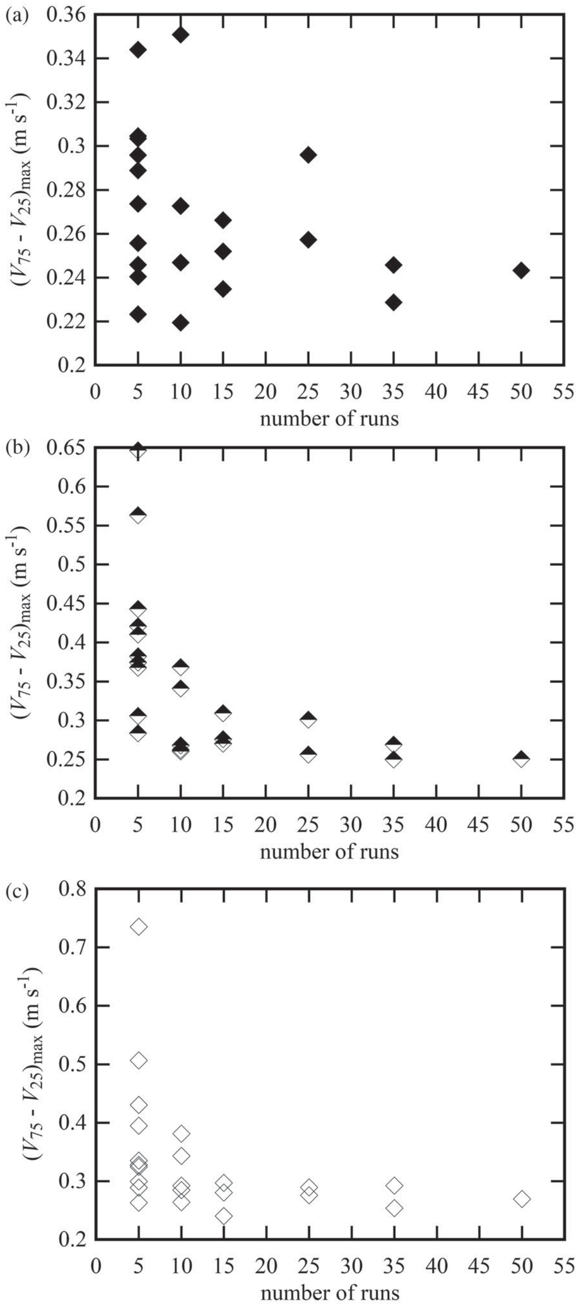

Figure D2 Sensitivity analysis in terms of maximum longitudinal velocity fluctuations beneath a breaking surge, presenting ensemble-averaged data as functions of the number of realizations (data: Leng & Chanson, 2016) – maximum number of realizations: 50. (a) $z = 0.043$ m. (b) $z = 0.028$ m. (c) $z = 0.018$ m

While an ensemble approach is the best methodology in the laboratory under well-controlled experimental conditions, field measurements in transient flows are unlikely to be repeatable in most situations. A Fourier component may therefore be the most appropriate statistical analysis, as shown by the field observations in the tidal bores of the Garonne and Sélune Rivers (Keevil, Chanson, & Reungoat, 2015; Reungoat, Lubin, Leng, & Chanson, 2018).

In summary, the Authors did well to show that the statistical analyses of transient flows are not trivial. Past studies in positive and negative surges bring relevant information and insights. In the laboratory, the ensemble statistics deliver a broader range of detailed turbulent properties, although the minimum number of repeats must be carefully assessed and linked to the measured parameter(s), and the repeatability and synchronization between repeated experiments are critical. In the field, the Fourier component approach is often best suited, because experiments can rarely be repeated under well-controlled situations.

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Closure to "Statistical analysis methods for transient flows – the dambreak case" by RUI ALEIXO, SANDRA SOARES-FRAZÃO and YVES ZECH, *J. Hydraulic Res.*, 57(5), 2019, 688–701. https://doi.org/10.1080/00221686.2018.1516700

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The author would like to express his thanks to Prof. Chanson for starting the discussion and for providing results from other well-known transient cases, that allow for a broader view of the problem.

It is never too much to stress the importance of assessing the repeatability of a phenomenon by performing the same experiment several times in the exact same conditions. This is often a problem, since sometimes an experiment cannot be physically repeated (e.g. field measurements or destructive test), or because repeating the same experiment several times is expensive. It must also be mentioned that repeating an experiment is important to determine the type A uncertainties (GUM, 2008; Muste et al., 2017; VIM, 2012).

When repeating the same experiment is possible, the number of repetitions must be assessed, namely by using some pre-established criterion, for example, the convergence of a given parameter such as the mean values. Several expressions for this can be found in literature, namely, Yanta and Smith (1973), Hitching and Lewis (1999) and Durst et al. (1996). These expressions, obtained for stationary flows, lead usually to a number of samples of hundreds to thousands, which is often not practical for transient cases even in a laboratorial environment. The suggestion made by the Discusser of 25 repetitions seems a good compromise, provided there is some degree of convergence of the variable of interest (mean velocity, Reynolds stresses, etc.), a fact also recognized by the Discusser.

As the Discusser mentions, the ensemble average properties can be biased due to outliers. However, when processing the data, an outlier detection test should be considered to prevent discarding meaningful data. As seen in Aleixo et al. (2019), the Fourier method can also be used to smooth the measured data. It is therefore possible to apply the Fourier method to each measured run of an ensemble, and then compute the ensemble statistics on the obtained Fourier series.

Often, acoustic methods, such as ADV and acoustic profilers, are used in measuring transient variables (e.g. Chanson & Docherty, 2012; Leng & Chanson, 2017). These instruments provide for a time series of velocity in a point or in a profile. When using optical techniques that rely on tracer tracking, like particle tracking velocimetry, whose distribution in the fluid is random, repeating an experiment may provide a way to complete the dataset, as from each repetition it is