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Measuring the uncertainties of discharge measurements: interlaboratory experiments in hydrometry

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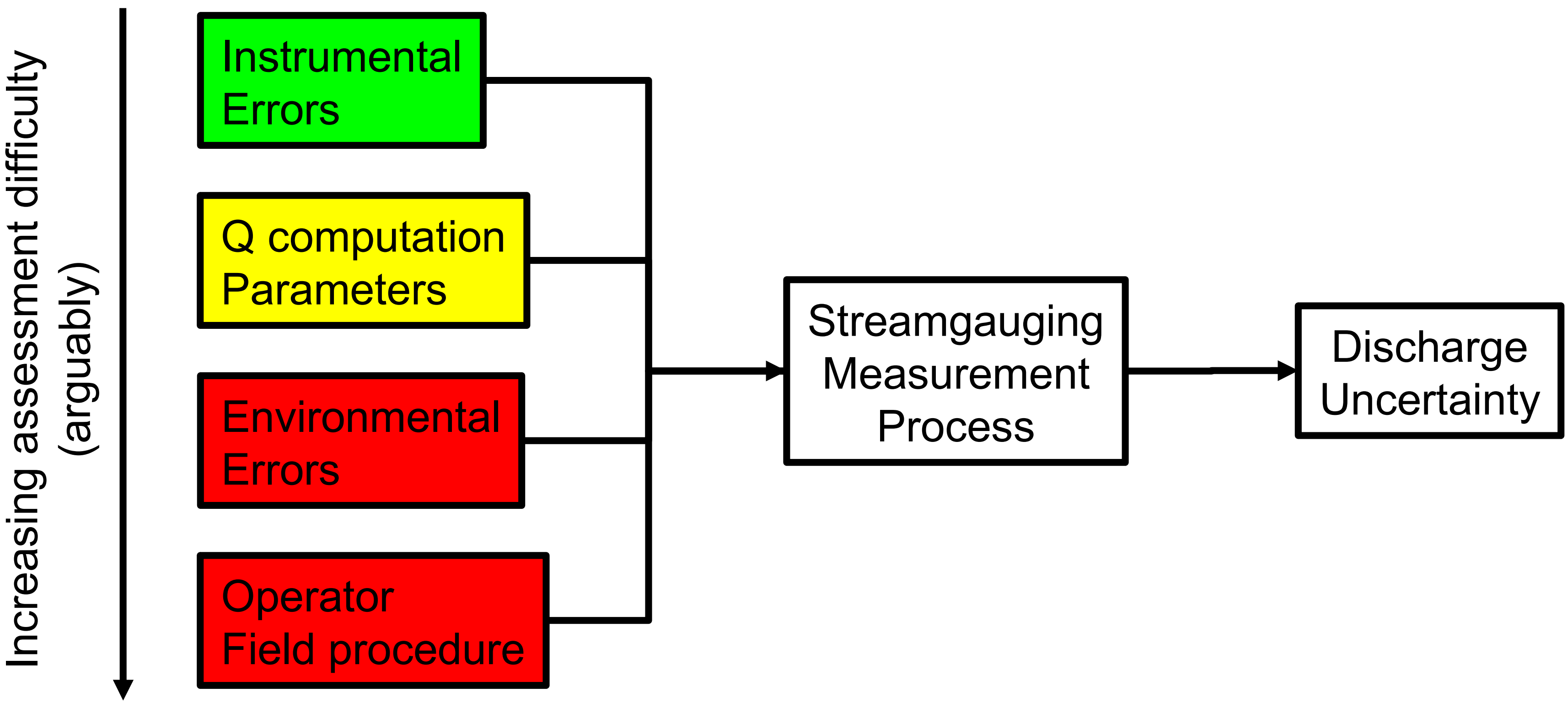
Some troubles which jeopardize uncertainty analysis in hydrometry...

- No discharge reference traceable to international standards
- Measurement process may be complex and difficult to model
- Elementary measurements are not always calibrated against standards
- The assessment of covariance terms is quite problematic
- Important uncertainty components are difficult to estimate...



Organising interlaboratory experiments in hydrometry

Requirements for uncertainty analysis

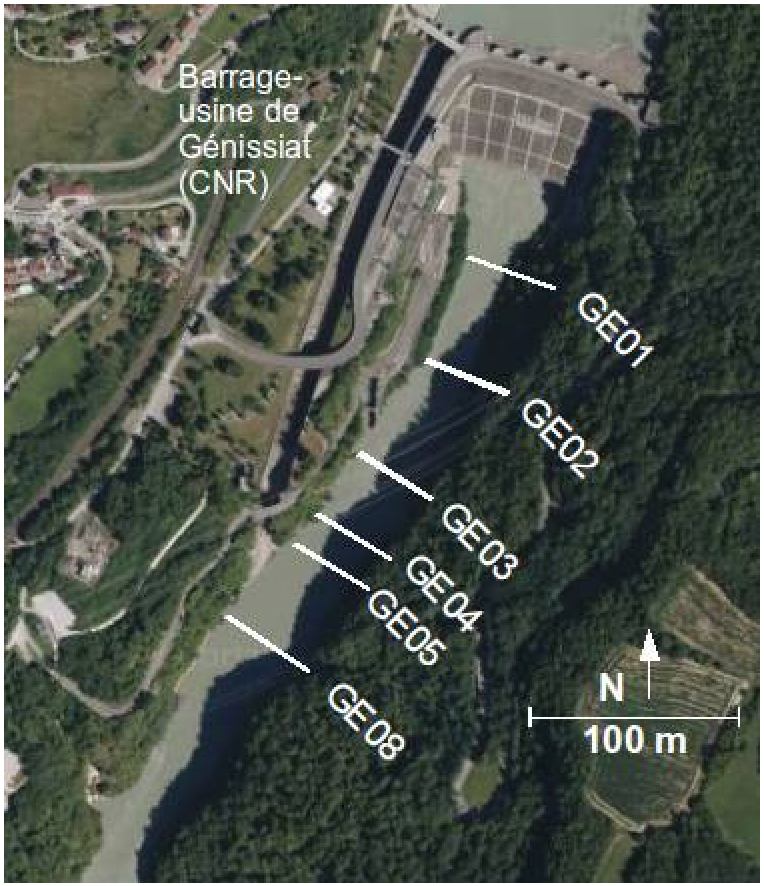
- **Constant discharge** (monitor water level and velocity fluctuations)
- **Homogeneous site**: close cross-sections, with similar conditions
- **Stable procedure**: do not change team positions, configurations, instruments (minimum 4), etc.
- **Repetition of simultaneous measurements**, approximately the same number for each instrument (minimum 2)
- Identification of **active error sources** during the experiments

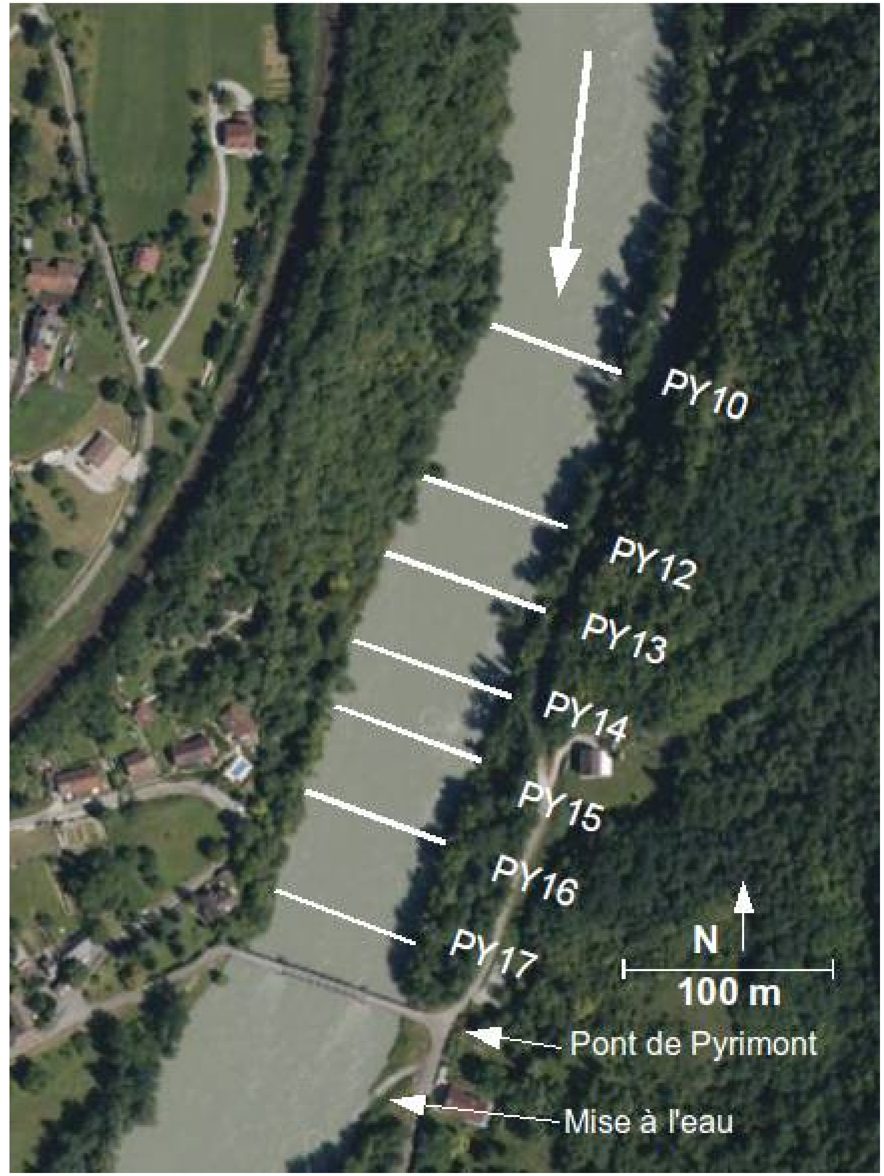
All participants are assumed to apply the same gauging technique in the same conditions with equal performances

Bonus to improve the uncertainty analysis

- Independent discharge measurement (**reference**) with assessed uncertainty
→ assess the bias of the gauging method and the ***uncertainty of the bias***
- **Ancillary measurements** and **hydraulic modelling** of the site
→ ***hydraulic conditions*** during the experiments (stage and velocity)

Example: vessel-mounted ADCP regatta (Génissiat 2010, 2012)





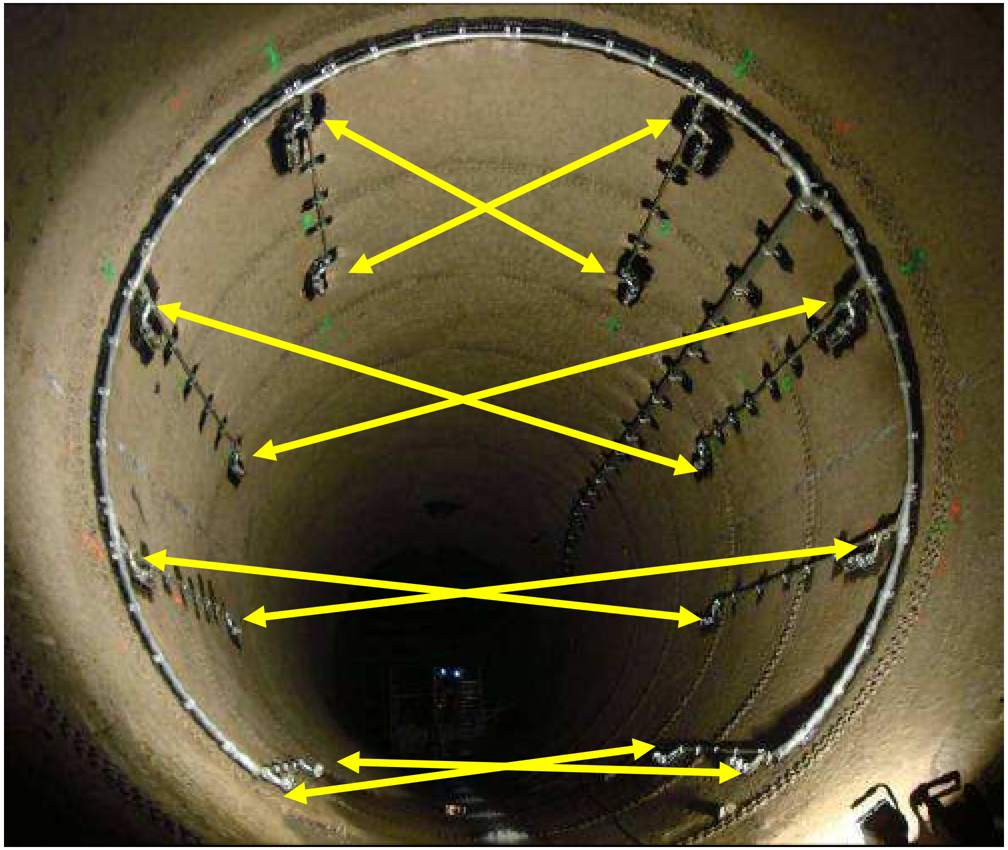
Contrasted measurement conditions:
- downstream of dam (GE site: poor)
- at Pyrimont bridge (PY site: good)

Example: vessel-mounted ADCP regatta (Génissiat 2010)

Nominal discharge for each of the 6 turbines is 107 m^3/s.

The 6 dam conduits are now equipped with ultrasonic transit-time flow measuring system.

Uncertainty analysis showed that the expanded uncertainty in the mean measured discharge is likely to be less than ± 2.3%.



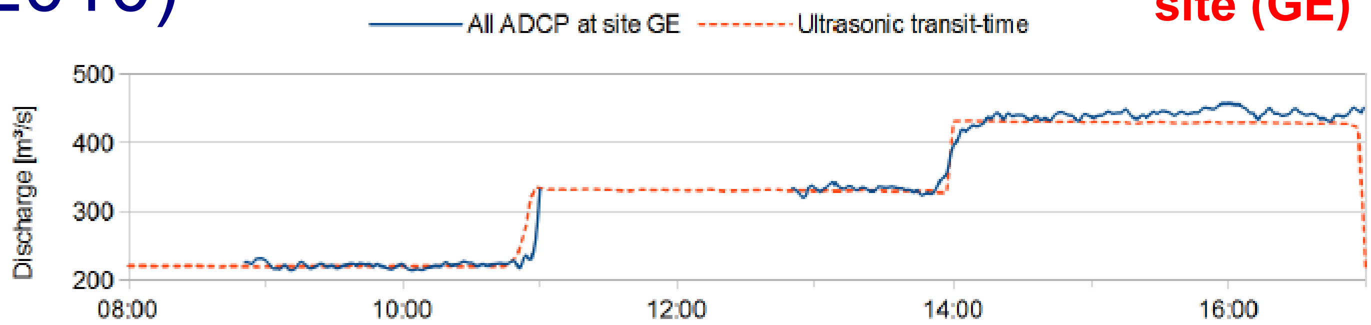
Transit-time acoustic system for monitoring discharge in a conduit of Génissiat dam (diameter = 6 metres)

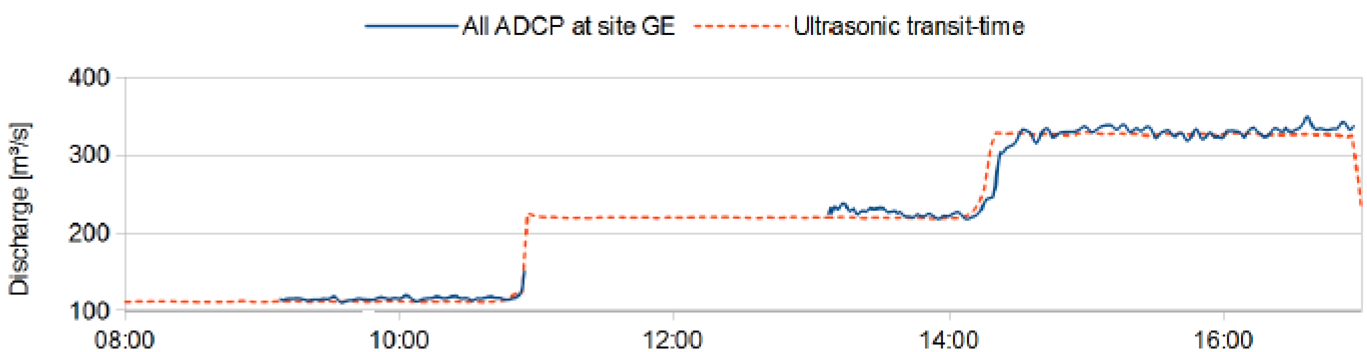
Example: vessel-mounted ADCP regatta (Génissiat 2010)

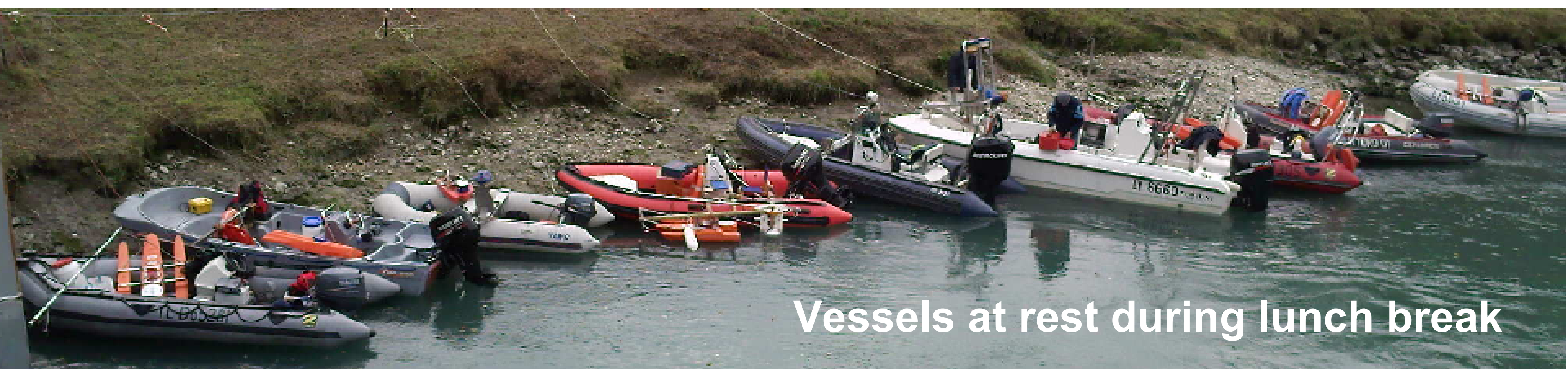
Upstream site (GE)

3 stable discharge time slots for each of the 2 days

→ 6 experiments (6 discharge levels)





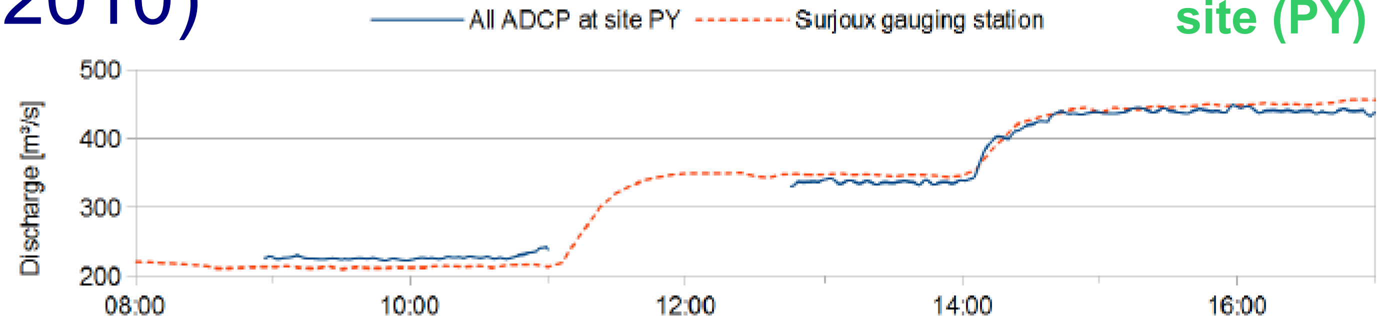


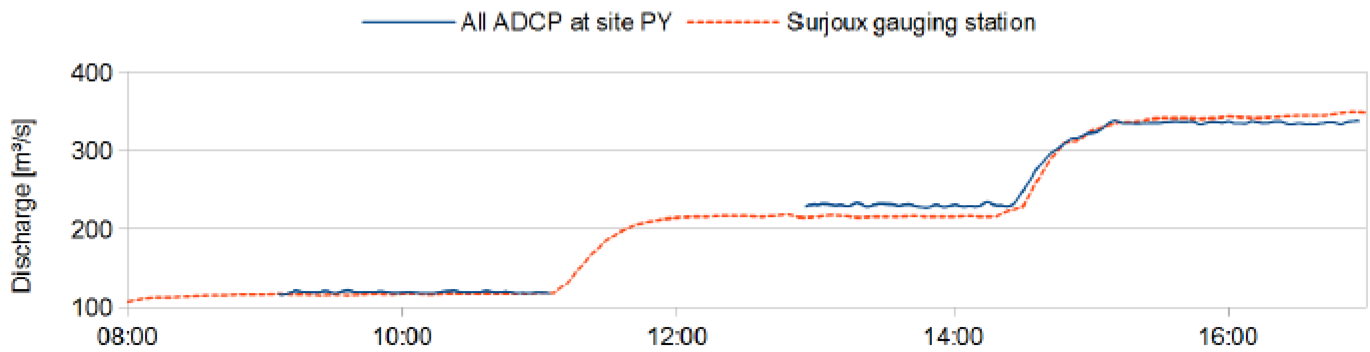
Example: vessel-mounted ADCP regatta (Génissiat 2010)

Downstream site (PY)

3 stable discharge time slots for each of the 2 days

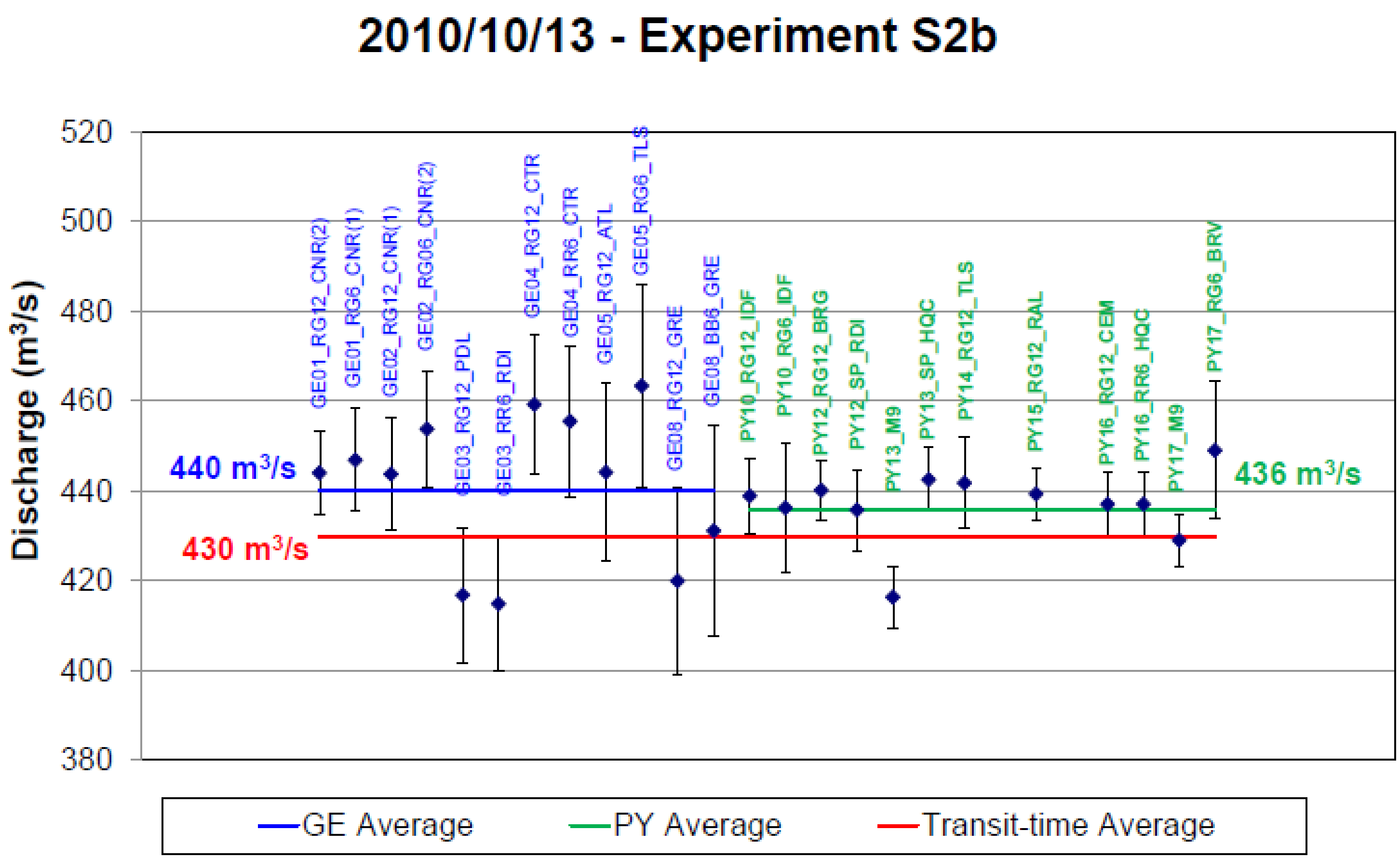
→ 6 experiments (6 discharge levels)





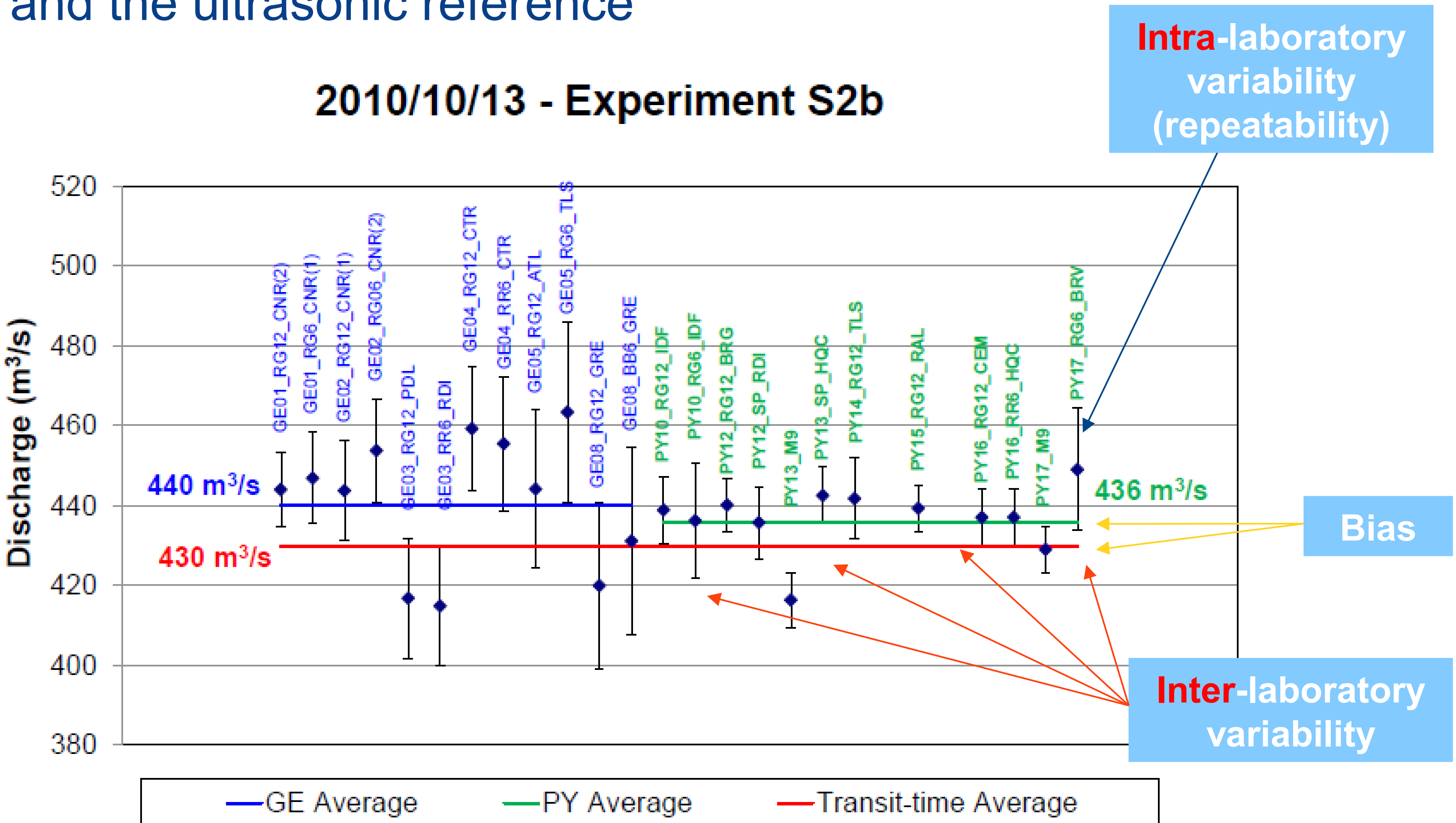
Example: vessel-mounted ADCP regatta (Génissiat 2010)

Individual results of 1 experiment with the two site-averages and the ultrasonic reference



Example: vessel-mounted ADCP regatta (Génissiat 2010)

Individual results of 1 experiment with the two site-averages and the ultrasonic reference



Analysis of interlaboratory experiments

Consider Q_i , the instantaneous discharge measured by team #i during a stable discharge time slot:

$$Q_i = \underbrace{Q_{true} + B_m}_{\approx Q_{mean}} + B_i + \varepsilon_i$$

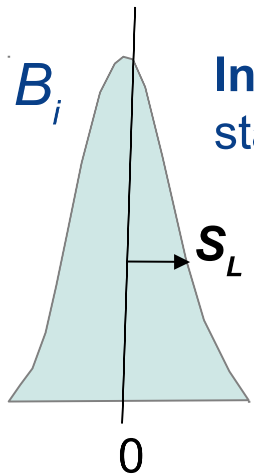
with :

- Q_{true} true discharge value (unknown)
- B_m bias associated with the measurement method
- Q_{mean} average of all discharge values (*n* repeated measurements for each of the *p* teams over the test)
- B_i bias related to team *i*
- ε_i random error

Analysis of interlaboratory experiments

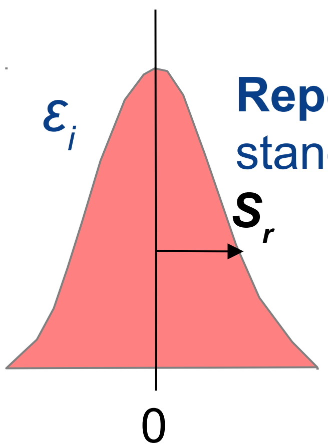
$$Q_i = Q_{mean} + B_i + \varepsilon_i$$

B_i



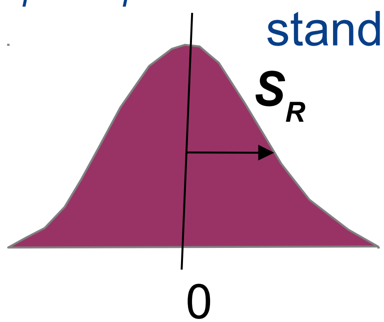
Interlaboratory
standard deviation

ε_i



Repeatability
standard deviation

$B_i + \varepsilon_i$

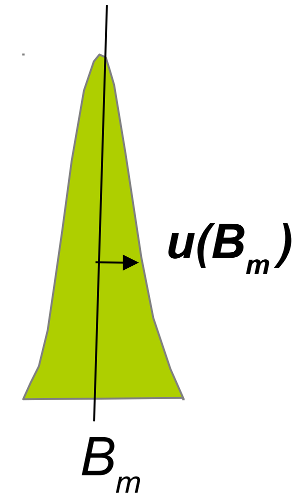


Reproducibility
standard deviation

$$S_R = \sqrt{S_r^2 + S_L^2}$$

Analysis of interlaboratory experiments

How to estimate the uncertainty u_m
related to the gauging method bias B_m?



1) Numerical estimation:
- Sensitivity tests on fixed parameters and assumptions
- Numerical simulation or additional measurements of the flow
- Propagation of uncertainties related to systematic effects

2) Comparison to reference discharge value Q_{ref} with uncertainty u_{ref}

$$B_m = Q_{mean} - Q_{\mathrm{ref}}$$

$$u\left(B_m\right) = \sqrt{\frac{s_r^2}{np} + \frac{s_L^2}{p} + u_{ref}^2}$$

with n the number of repeated measurements for each of the p teams

Analysis of interlaboratory experiments

ISO standards provide procedures for computing estimates s_r and s_L from the comparison test results, and for assessing the expanded uncertainty U at 95% level of confidence:

$$U\left(Q^{1,1}\right) = 2s_R = 2\sqrt{s_r^2 + s_L^2 + u_m^2}$$

with :

$Q^{1,1}$ discharge measurement from 1 transect for 1 ADCP
s_r repeatability standard deviation (estimate)
s_L interlaboratory standard deviation (estimate)
s_R reproducibility standard deviation (estimate)
u_m standard uncertainty related to the gauging method bias

Analysis of interlaboratory experiments

In case the discharge measurement, $Q^{N,P}$, is actually the average of N repeated gaugings for each of P instruments:

$$U\left(Q^{N,P}\right)=2\sqrt{\frac{s_r^2}{NP}+\frac{s_L^2}{P}+u_m^2}$$

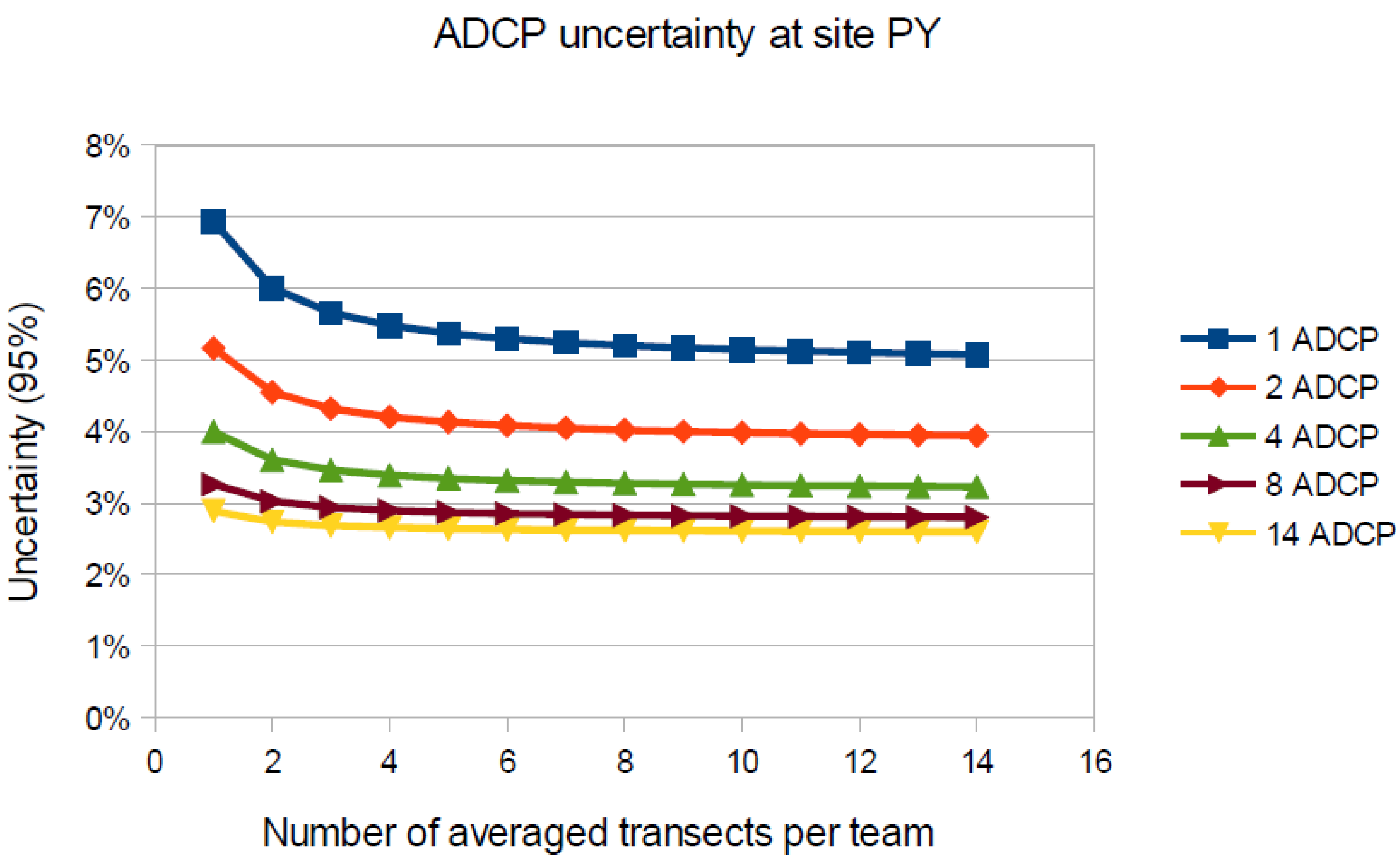
Example: a gauging conducted with an ADCP (P = 1) is usually the mean of N = 4 to 6 successive transects.

In particular cases, several (P) instruments or cross-sections may be used and their results may be averaged altogether.

Expressing uncertainty results

ADCP regatta downstream of Génissiat dam (2010)

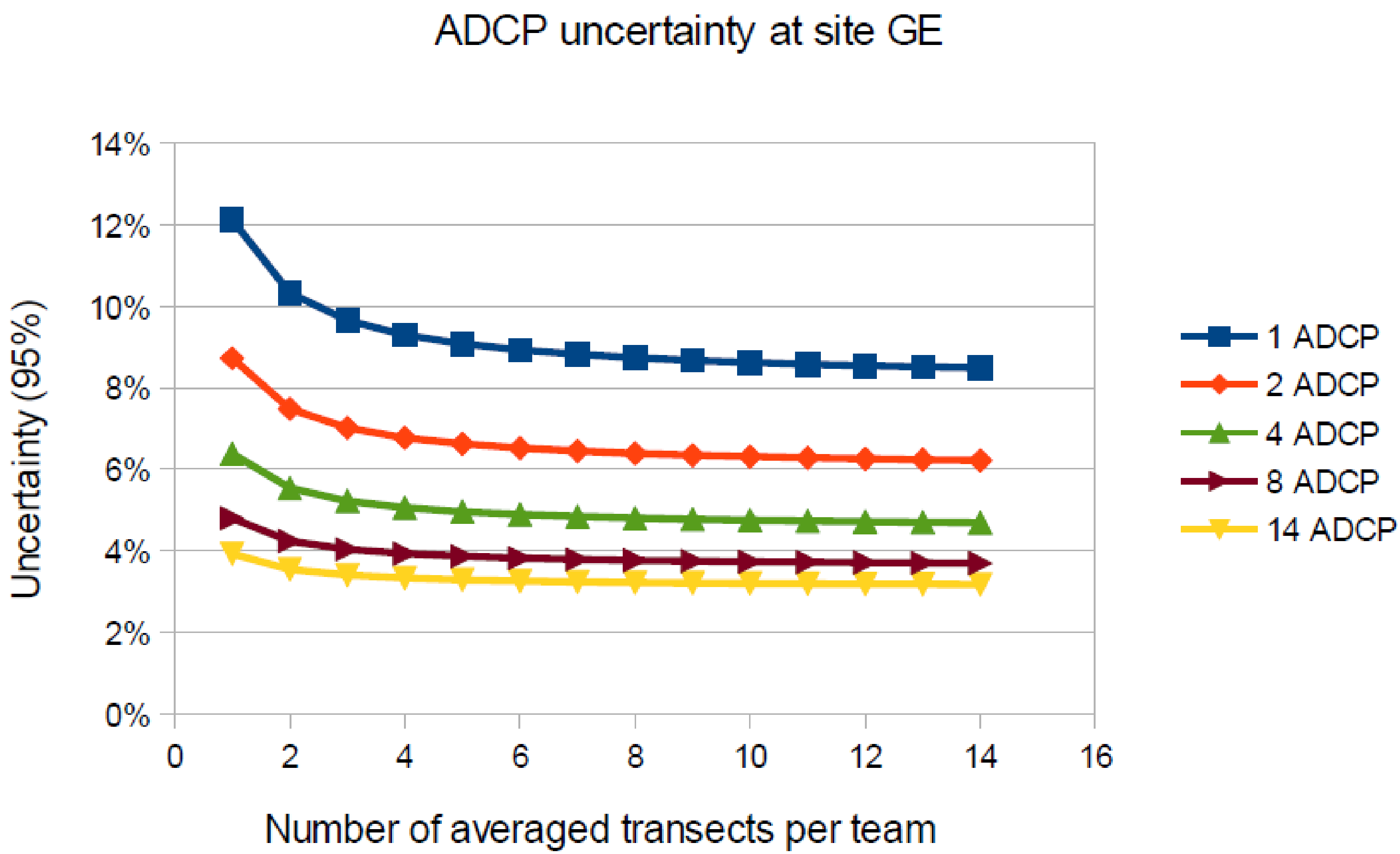
site PY: s_r = 2.4%, s_L = 2.2% (from interlaboratory analysis)
u_m = 1.25% (from sensitivity analysis)



Expressing uncertainty results

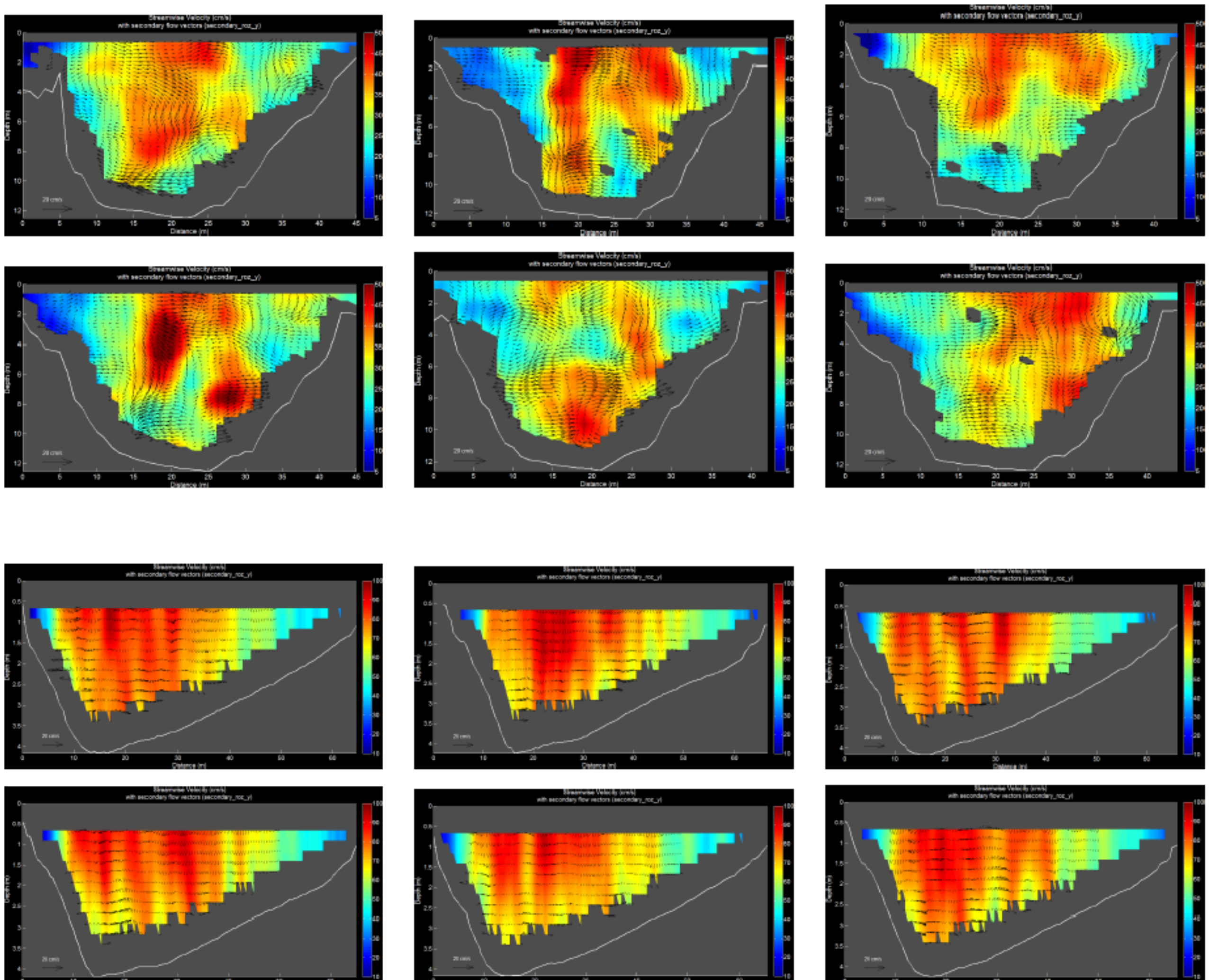
ADCP regatta downstream of Génissiat dam (2010)

site GE: $s_r = 4.5\%$, $s_L = 3.9\%$ (from interlaboratory analysis)
$u_m = 1.25\%$ (from sensitivity analysis)



Interpreting site-specific uncertainty results

Pulsating turbulent flow structures appear at upstream GE site...



… due to the not fully developed turbulent flow near the outlets of the powerplant turbines

Processed with VMT (Parsons et al., 2013)

Main conclusions on hydrometric interlaboratory experiments

From our experience of ADCP and current-meter experiments

- Provides with the uncertainty of streamgauging techniques in given conditions
- Valuable uncertainty outputs, in accordance with existing standards
- References are uncertain: bias estimate is usually lower than its uncertainty
- The uncertainty of the uncertainty results can be estimated
- Site effects were significant for ADCP at Génissiat, not for current-meters in small streams (results were too uncertain)
- Expanded uncertainties (within the 95% probability interval) were:
  - ±5% to ±10% for ADCPs in good or poor conditions [$U(U_Q)$=±25%]
  - ±10% to ±15% for currentmeters in shallow creeks [$U(U_Q)$=±40%]
- **Perspectives :**
  - **Define metrics and descriptors of the measurement conditions**
  - **Standardize methods and formats**
  - **Share results in databases and re-analyze them**

J. Le Coz, B. Blanquart, K. Pobanz, G. Dramais, G. Pierrefeu, A. Hauet, A. Despax, *Estimating the uncertainty of streamgauging techniques using field interlaboratory experiments*, **Journal of Hydraulic Engineering** (submitted Dec 2014)

Thanks for your attention!

See poster on interlaboratory experiments

Monday R1-R14
D. Besson et al.