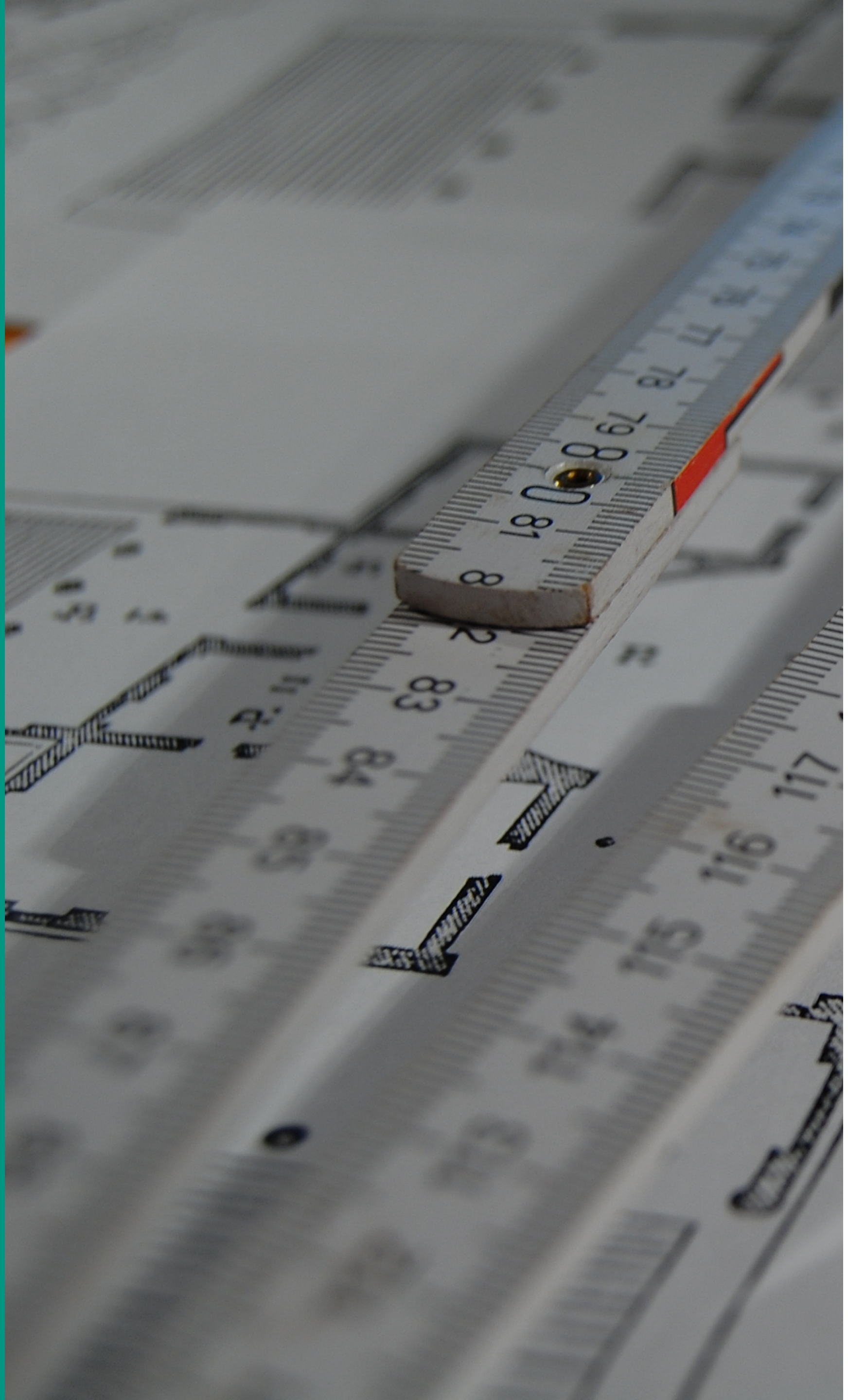
Turbulence increases sediment transport



KIT

EGU General Assembly 2025
Session GM2.7
Measuring and Modelling Geomorphic Processes Across Scales

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Institute for Water and Environment

Introduction

Problem statement:

- Fully developed flows over erodible beds [1]

$$[q_s] = f(\overline{\tau})$$

- Presence of disturbances
  Homogeneous: regular vegetation or bedforms
  Non-homogeneous: scour at hydraulic structures

$$[q_s] = f(\overline{\tau}, ?)$$

Research questions:

- What is the effect of turbulent fluctuations on sediment flowrate?
- What is the effect of turbulent fluctuations on primary variables (concentration and velocity)?

[1] Being other factors constant, such as sediment gradation, shape, etc.

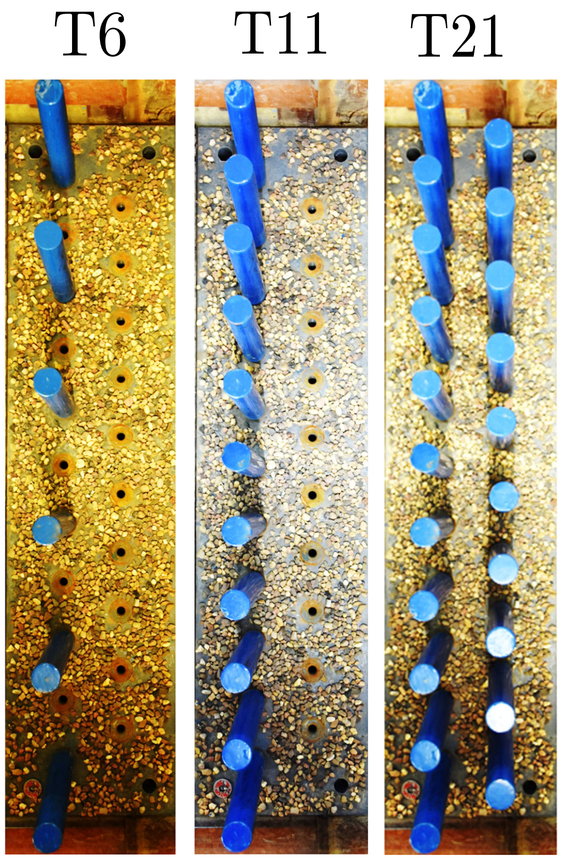
Description of the experiments

Controls

- We disturbed the flow using arrays of cylinders.
  T0 is the reference condition without cylinders.
- We tested different flowrates.

Asynchronous measurements

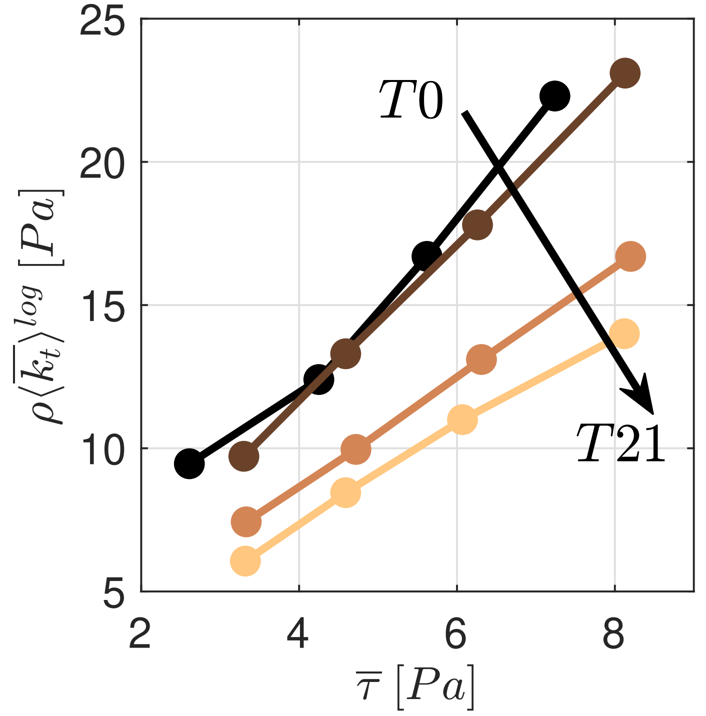
- Bedload: Particle Tracking Velocimetry
- Turbulence, Laser Doppler Anemometry
- Bed shear stress, Shear Plate



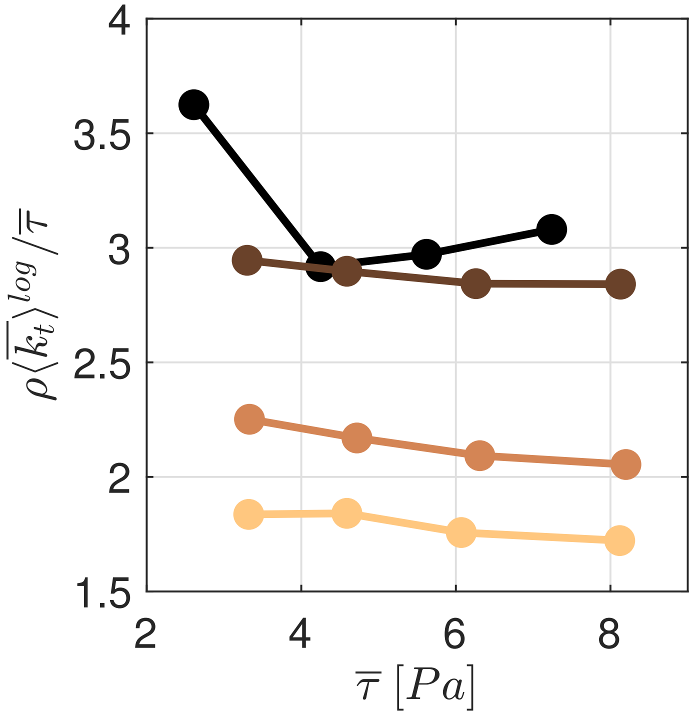
De-coupling bed shear stress and turbulence

$$q_s = f(average, fluctuations) = f\left(\overline{\tau}, \frac{\rho\langle\overline{k}_t\rangle^{log}}{\overline{\tau}}\right)$$

Disturbances: T0, T6, T11, and T21



Scaling



Independence

Proof of concept

Concentration: $\overline{\langle C \rangle}$	Velocity: $[F]$	Average flow: θ	Fluctuations: K

Separated modeling of concentration and velocity

$$[q_s] = d\overline{\langle C \rangle}\,[u_s]$$

The dimensionless counterpart of this equation is[2]:

$$[\Phi] = \overline{\langle C \rangle}\,[F]$$

Descriptive model:

$$\overline{\langle C \rangle} = a_C \cdot f_C(\theta) \cdot f_C(K)$$
$$[F] = a_F \cdot f_F(\theta) \cdot f_F(K)$$

[2]Note that: $[\Phi] = [q_s]/\sqrt{g\Delta d^3}$, $[F] = [u_s]/\sqrt{g\Delta d}$, $\Delta = (\rho_s - \rho)/\rho$, $\theta = \overline{\tau}/(\rho_s - \rho)gd$ and $K = \rho\langle \overline{k}_t \rangle^{log}/\overline{\tau}$.

Descriptive model

Concentration: $\overline{\langle C \rangle}$	Velocity: $[F]$	Average flow: θ	Fluctuations: K

- Univariate modelling

$$\overline{\langle C \rangle} = a_C \cdot f_C(\theta)$$

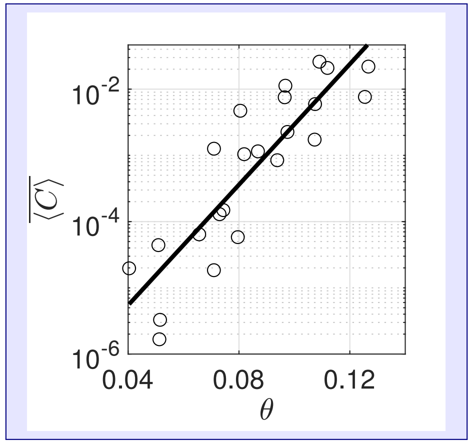
$$[F] = a_F \cdot f_F(\theta)$$

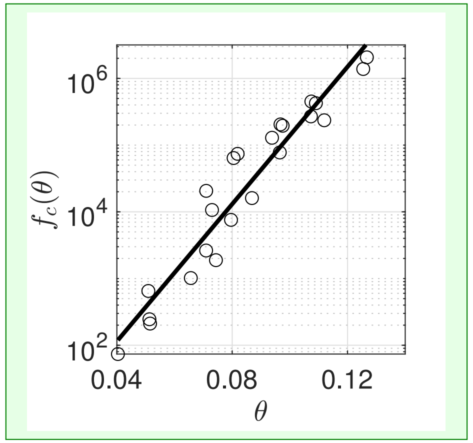
- Bivariate modelling for concentration

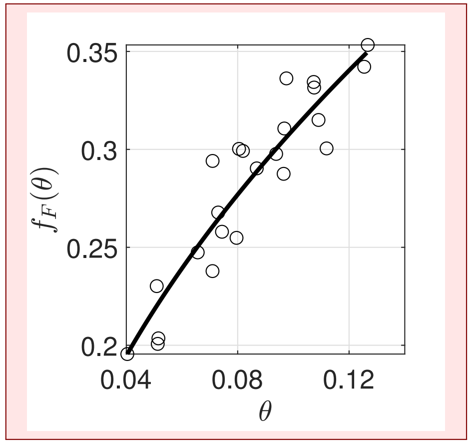
$$\overline{\langle C \rangle} = a_C \cdot f_C(\theta) \cdot f_C(K)$$

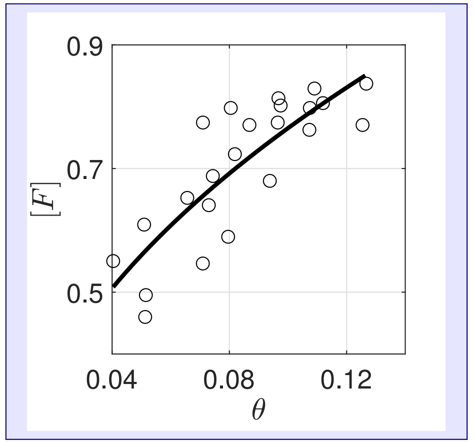
- Bivariate modelling for velocity

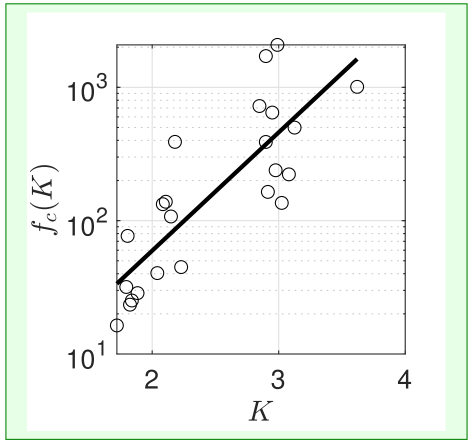
$$[F] = a_F \cdot f_F(\theta) \cdot f_F(K)$$

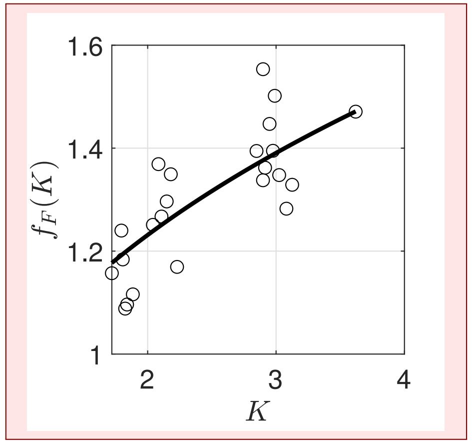












Argument

Concentration: $\overline{\langle C \rangle}$	Velocity: $[F]$	Average flow: θ	Fluctuations: K

Models comparison			Performance ε		
$\overline{\langle C \rangle}(\theta)$	$\to$	$\overline{\langle C \rangle}(\theta, K)$	1.36	$\to$	0.81
$[F](\theta)$	$\to$	$[F](\theta, K)$	0.10	$\to$	0.06
$[\Phi](\theta)$	$\to$	$[\Phi](\theta, K)$	1.45	$\to$	0.85
$\overline{\langle C \rangle}(\theta)[F](\theta)$	$\to$	$\overline{\langle C \rangle}(\theta, K)[F](\theta)$	1.45	$\to$	0.86
$\overline{\langle C \rangle}(\theta)[F](\theta, K)$	$\to$	$\overline{\langle C \rangle}(\theta, K)[F](\theta, K)$	1.40	$\to$	0.85
$\overline{\langle C \rangle}(\theta)[F](\theta)$	$\to$	$\overline{\langle C \rangle}(\theta)[F](\theta, K)$	1.45	$\to$	1.40
$\overline{\langle C \rangle}(\theta, K)[F](\theta)$	$\to$	$\overline{\langle C \rangle}(\theta, K)[F](\theta, K)$	0.86	$\to$	0.85

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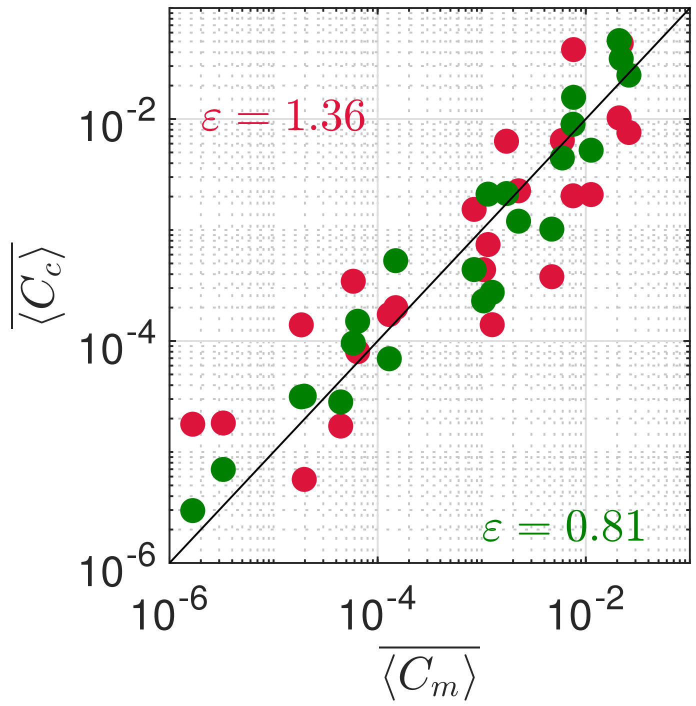
[3] Logarithmic root mean square error: $\varepsilon^2 = \sum_{i=1}^{N} (\log X_m - \log X_c)^2 / N$

Results

Concentration: $\overline{\langle C \rangle}$ | Velocity: $[F]$ | Average flow: θ | Fluctuations: K

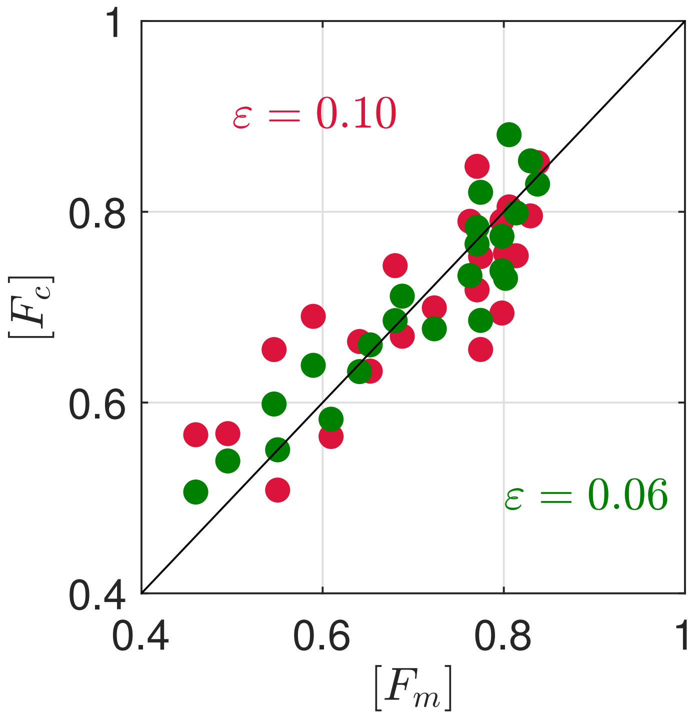
$$\overline{\langle C \rangle} = a_C \cdot f_C(\theta)$$

$$\overline{\langle C \rangle} = a_C \cdot f_C(\theta) \cdot f_C(K)$$



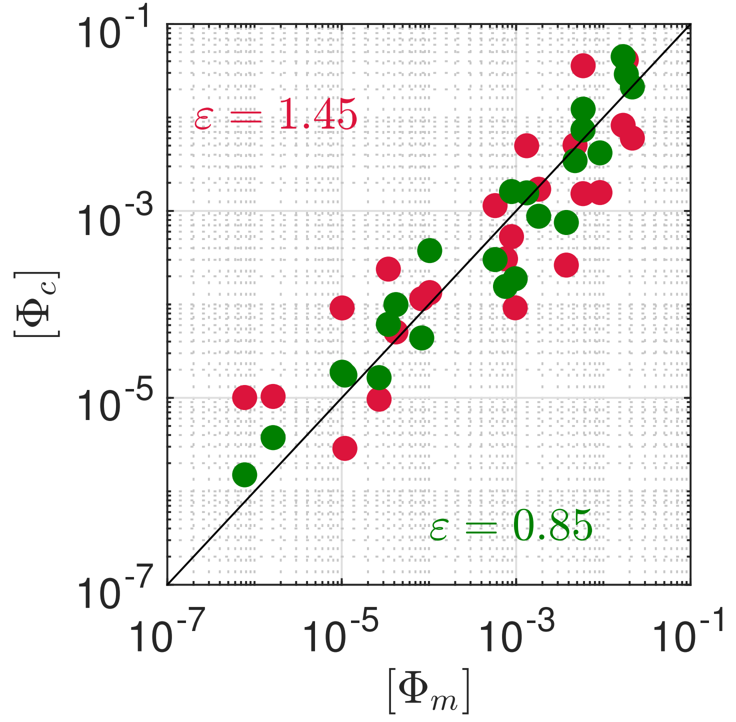
$$[F] = a_F \cdot f_F(\theta)$$

$$[F] = a_F \cdot f_F(\theta) \cdot f_F(K)$$



$$[\Phi] = \overline{\langle C \rangle}(\theta) \cdot [F](\theta)$$

$$[\Phi] = \overline{\langle C \rangle}(\theta, K) \cdot [F](\theta, K)$$

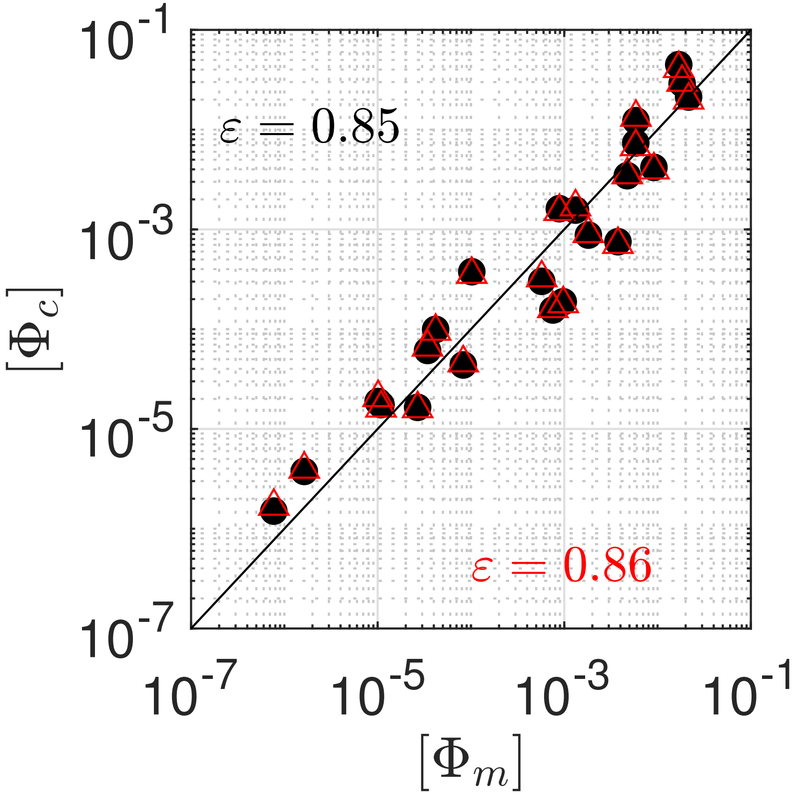


Results: separated modeling of sediment flowrate

Concentration: $\overline{\langle C \rangle}$	Velocity: $[F]$	Average flow: θ	Fluctuations: K

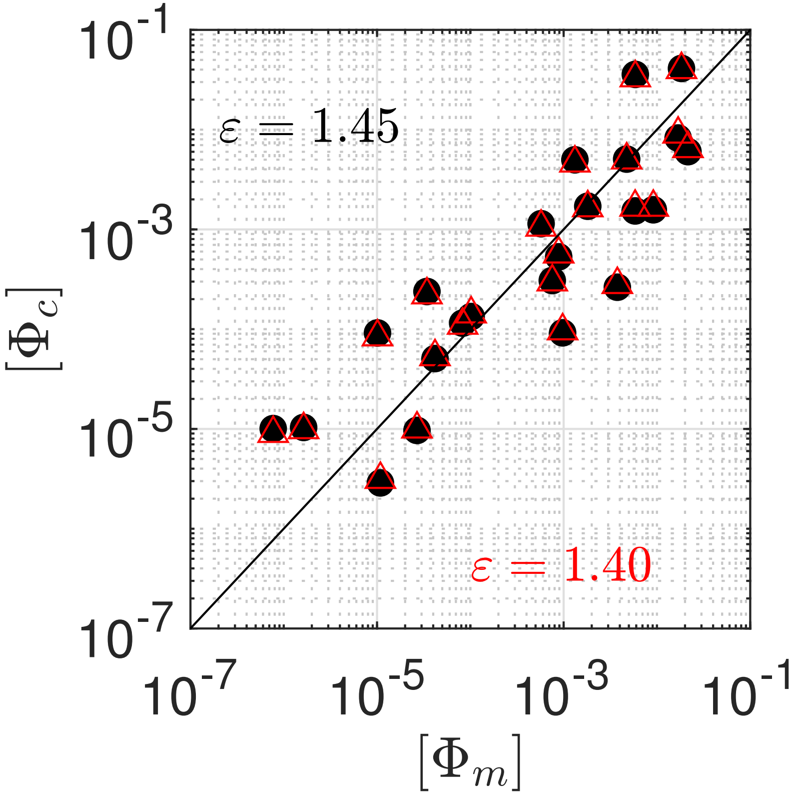
$[\Phi] = \overline{\langle C \rangle}(\theta, K) \cdot [F](\theta, K)$

$[\Phi] = \overline{\langle C \rangle}(\theta, K) \cdot [F](\theta)$



$[\Phi] = \overline{\langle C \rangle}(\theta) \cdot [F](\theta)$

$[\Phi] = \overline{\langle C \rangle}(\theta) \cdot [F](\theta, K)$



Conclusions

(1)

What is the effect of turbulent fluctuations on sediment flowrate?

For a given bed shear stress, if turbulent fluctuations increase, the sediment flowrate increases.

(2)

What is the effect of turbulent fluctuations on primary variables (concentration and velocity)?

- Including the effect of turbulence improves the performance of concentration and velocity modeling.
- For sediment flowrate modeling, the effect of turbulent fluctuations on velocity is a second-order effect w.r.t its effect on concentration.

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