TÉCNICO LISBOA

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Turbulence in open-channel flows over granular low-tortuosity beds

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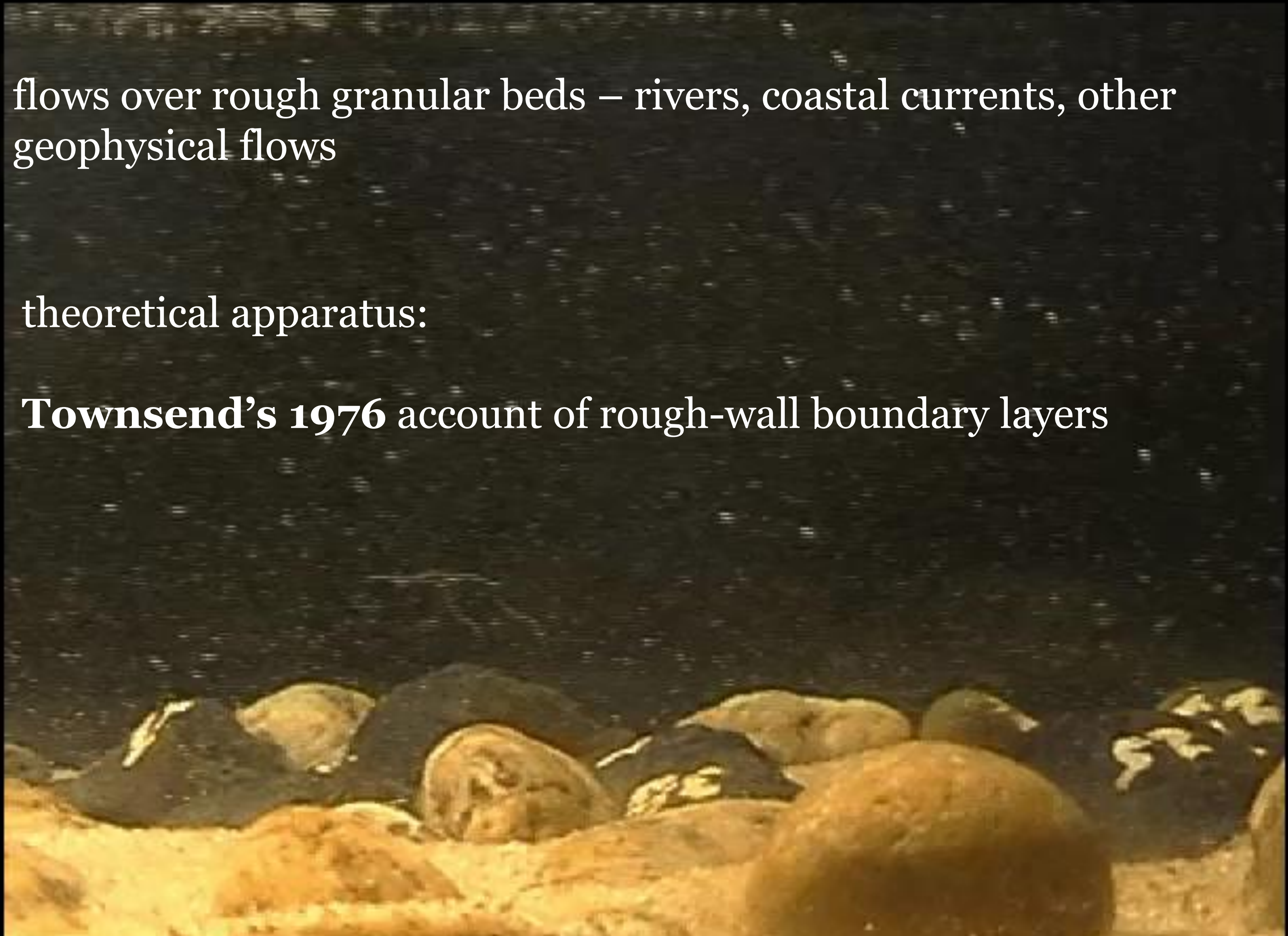
Motivation



flows over rough granular beds – rivers, coastal currents, other geophysical flows

theoretical apparatus:

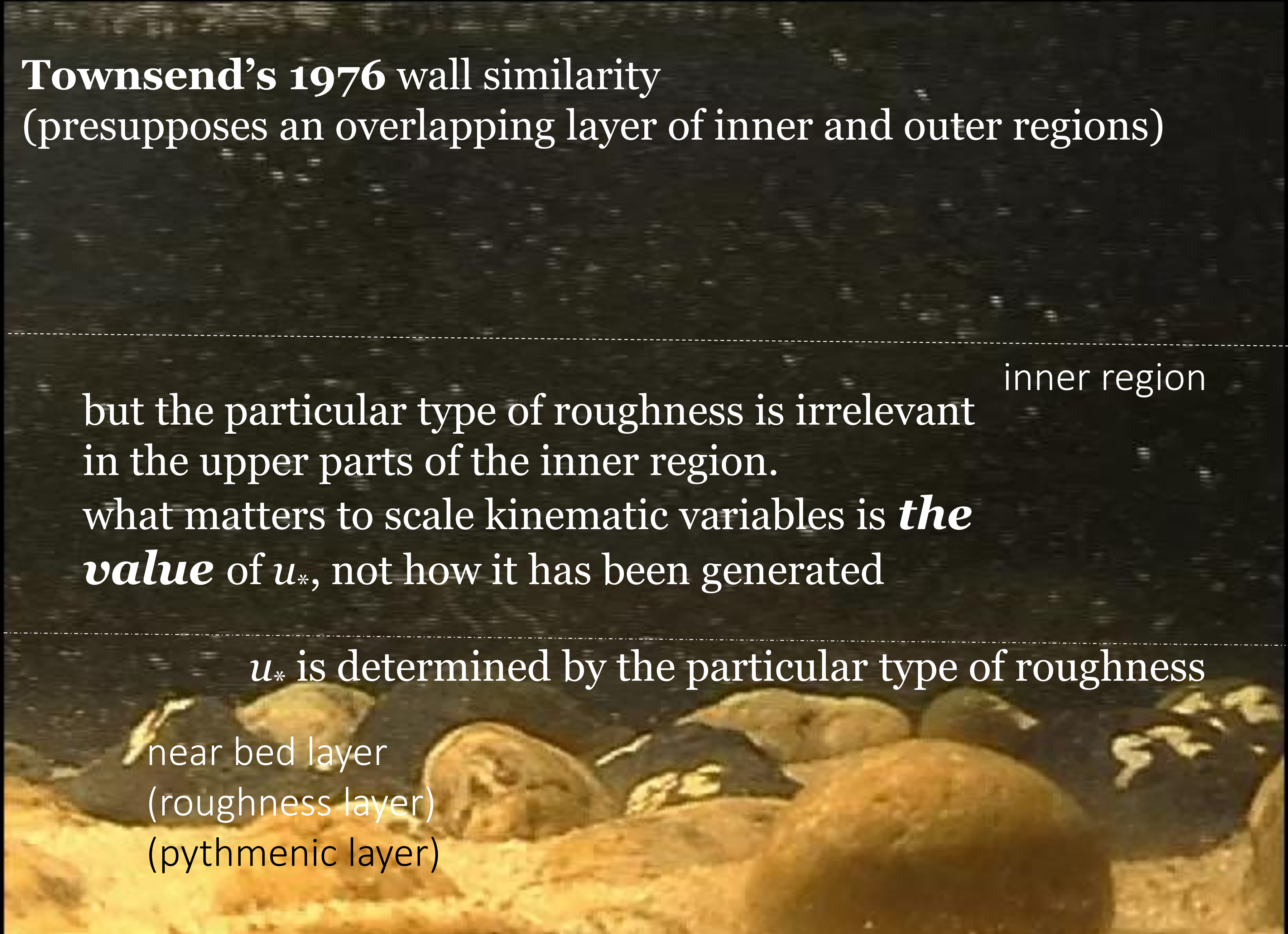
Townsend's 1976 account of rough-wall boundary layers

Motivation

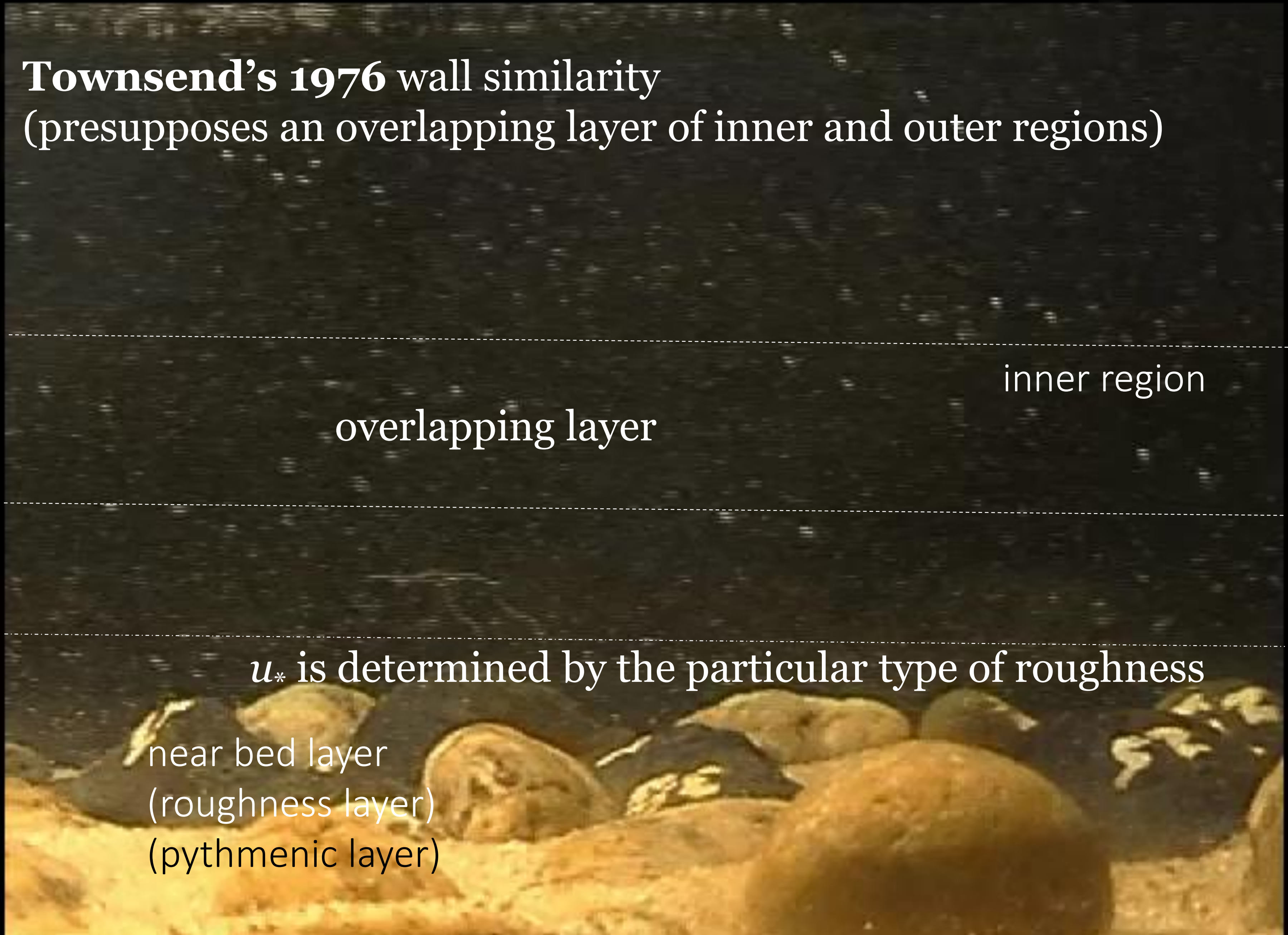
Townsend's 1976 wall similarity
(presupposes an overlapping layer of inner and outer regions)

but the particular type of roughness is irrelevant in the upper parts of the inner region.
what matters to scale kinematic variables is ***the value*** of u_*, not how it has been generated

u_* is determined by the particular type of roughness

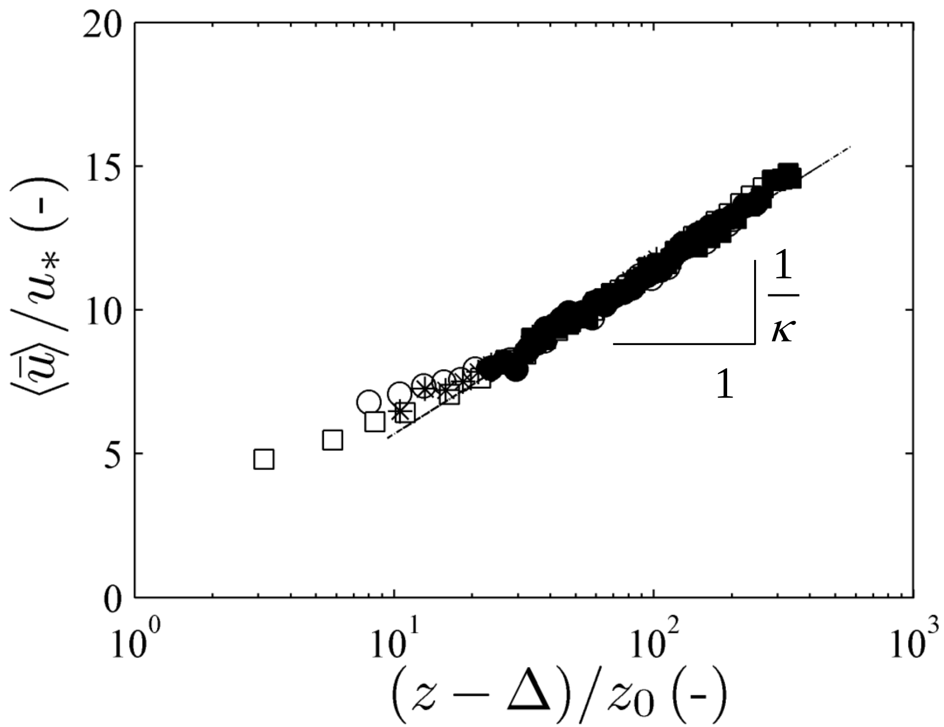


Motivation


Townsend's 1976 wall similarity
(presupposes an overlapping layer of inner and outer regions)
inner region
overlapping layer
u_* is determined by the particular type of roughness
near bed layer
(roughness layer)
(pythmenic layer)

Motivation

the wall-normal distribution of the longitudinal velocity



$$z\partial_z \{u\} = u_* A$$

A **is empirically determined;**
Re independent? universal?

$$z\partial_z \{u\} = u_* A$$

$\kappa = 1/A$ *von Kármán parameter*

Drag reducing flows: $A = 1/\kappa$ **is larger for the same normalized shear rate (lower u_*)**

Motivation

Ferreira 2015: why would the von Kármán parameter express drag reducing flows in flows over rough mobile beds?

influenced by flow anisotropy

$$\kappa \propto \frac{1}{8}\left(\frac{\ell_{0w}(z)}{z}\right)\left(\frac{u_*^2/k}{k/\overline{w'^2}} C_{2w}\right)$$

influenced by larger flow scales?

k – turbulent kinetic energy
$\overline{w'^2}$ – Wall normal turbulence intensity
ℓ_{0w} – transverse integral scale
C_{2w} – constant of transverse 2nd order structure function

Landau remark concerning C_{2w}

the Landau remark: C_2 is not flow-independent when the production range is modulated by a wide range of (roughness-influenced) scales

Motivation

Ferreira 2015: why would the von Kármán parameter express drag reducing flows in flows over rough mobile beds?

whatever the change in the structure of turbulence (very large scales and/or RS anisotropy)

there must be a cause for that change

in this work we investigate

the role of surface-hyporheic exchanges that should depend on **hydraulic conductivity** of the bed

$$\kappa \propto \frac{1}{8}\left(\frac{\ell_{0w}(z)}{z}\right)\left(\frac{u_*^2 / k}{k / \overline{w'^2}} C_{2w}\right)$$

k – turbulent kinetic energy
$\overline{w'^2}$ – Wall normal turbulence intensity
ℓ_{0w} – transverse integral scale
C_{2w} – constant of transverse 2nd order structure function

Objectives

The general objective of this work is to study the effect of the ***hydraulic conductivity*** on open-channel *turbulent flows* of viscous fluids over mobile and hydraulically rough beds of cohesionless sediment.

In particular, we:

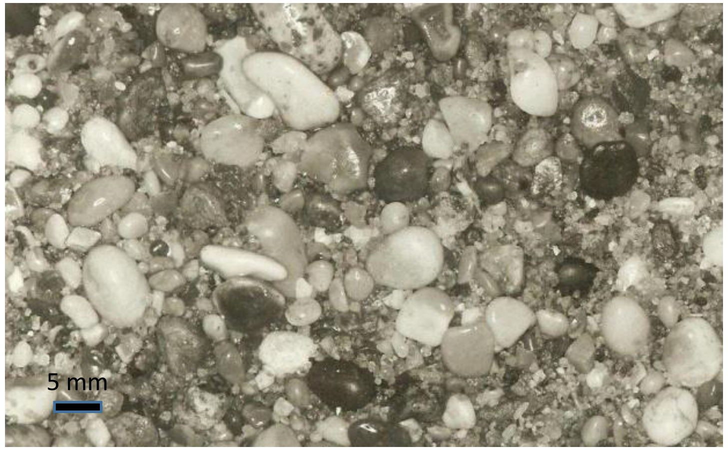
- characterize the constant of the 2^{nd} order longitudinal structure function

Macroscopic properties of granular beds

Two databases in a similar flume:

- •Under same range of values of Shield parameters
- •In the mobile bed cases, under equilibrium transport conditions
- •In all cases, under uniform flow conditions
- •approximately the same d_{84}
- •Different porosity (n), tortuosity (T), permeability (k) and **hydraulic conductivity** (K))

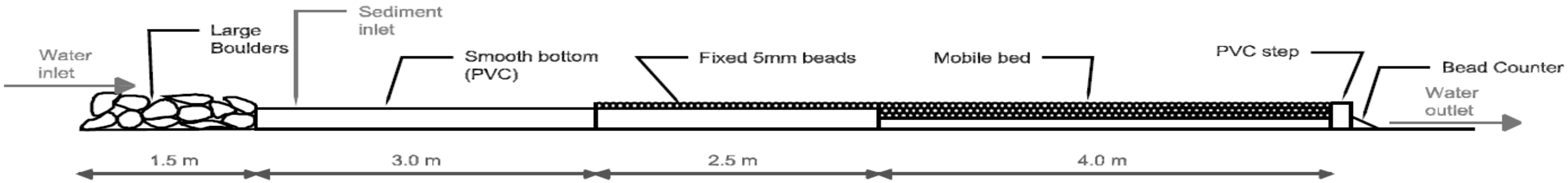
Tests	High conductivity bed (lattice-arranged)	**High conductivity bed (random)**	Low conductivity bed (Existing database)
d_{84} (mm)	4.97	4.97	5.40
ρ (kg/m^3)	2607	2607	2590
n (-)	0.325	0.369	0.301
T (-)	0.88	1.34	9.96
k (m^2)	3.E-08	5.E-09	3.E-10
K (m/s)	3.E-01	6.E-02	4.E-03



- Introduction
  - Motivation
  - Objectives
- **Experimental facilities & procedures**
  - **The Laboratory**
  - Flow characrterzation
  - Macroscopic porperties
- Methodology
  - Data treatment
  - Methods of calculation
- Results and discussion
- Conclusions and future work
- Acknowledgement

The Laboratory

Flume at the Laboratory of Hydraulics Environment of Instituto Superior Técnico, Lisbon



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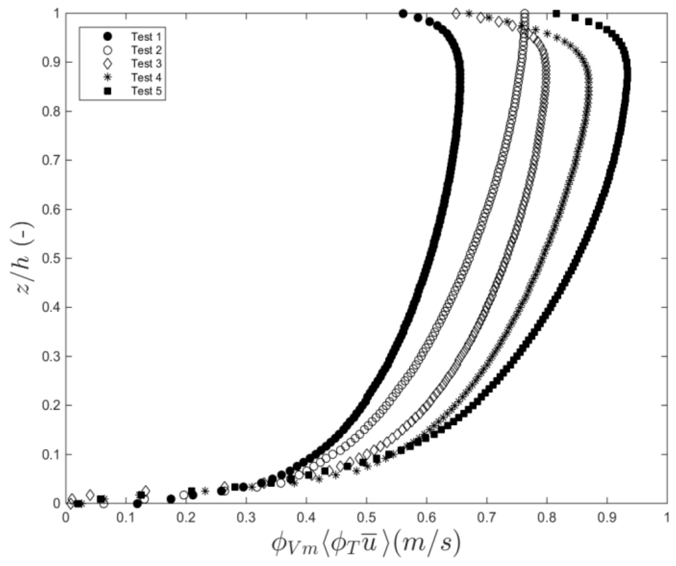
Flow characterization: Lattice arrangement

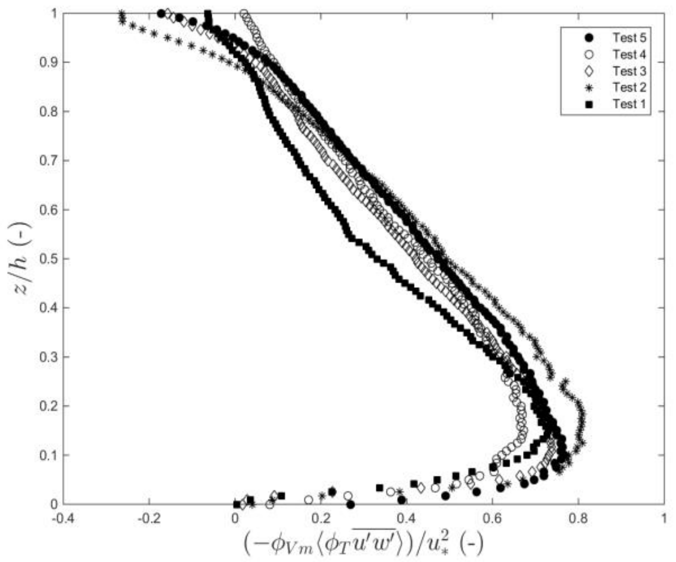
Mean flow variables characterizing the experimental tests

Tests	Q (l/s)	slope (-)	h_u (m)	U (m/s)	R_h (m)	$\tau_0^{(1)}$ (N/m^2)	$u_*^{(1)}$	bead rate	$\tau_0^{(2)}$ (N/m^2)	$u_*^{(2)}$
1	14.98	0.00317	0.0714	0.518	0.0528	1.639	0.041	0.00	1.603	0.040
2	15.90	0.00404	0.0703	0.559	0.0522	2.067	0.046	0.33	2.180	0.047
3	16.67	0.00456	0.0684	0.068	0.0511	2.287	0.048	6.23	2.187	0.047
4	20.83	0.00623	0.0744	0.691	0.0544	3.325	0.058	21.12	3.080	0.056
5	21.35	0.00714	0.0696	0.757	0.0518	3.628	0.060	28.72	3.223	0.057

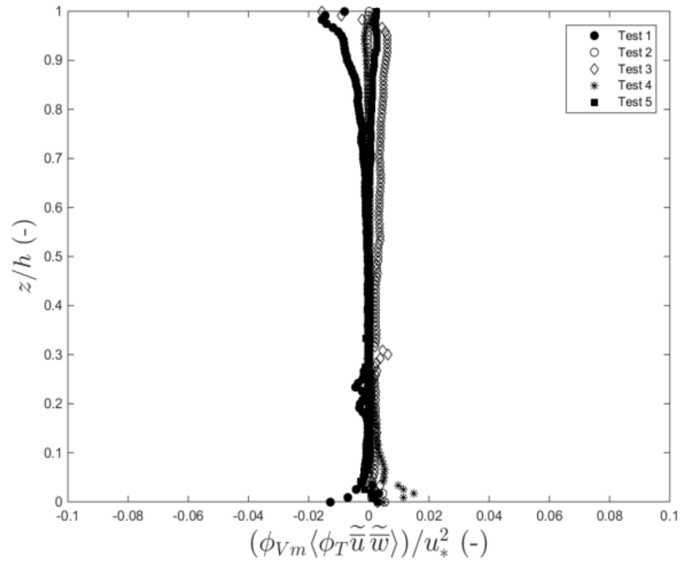
Mean flow



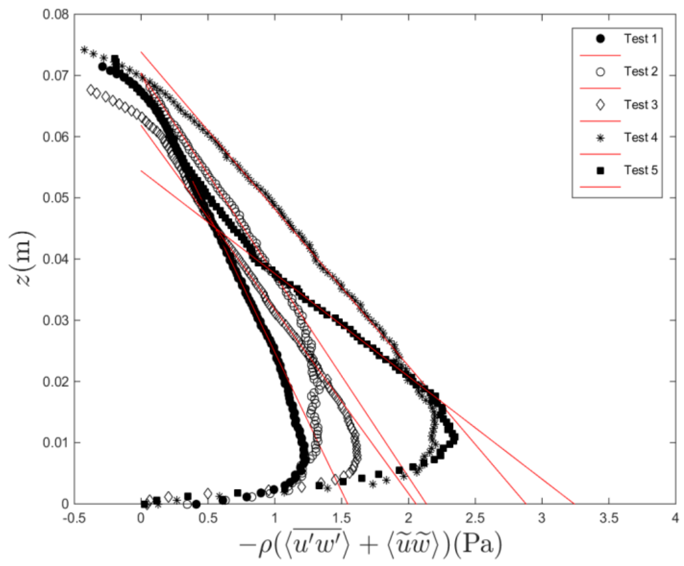
DA-longitudinal velocities



Reynolds shear stresses

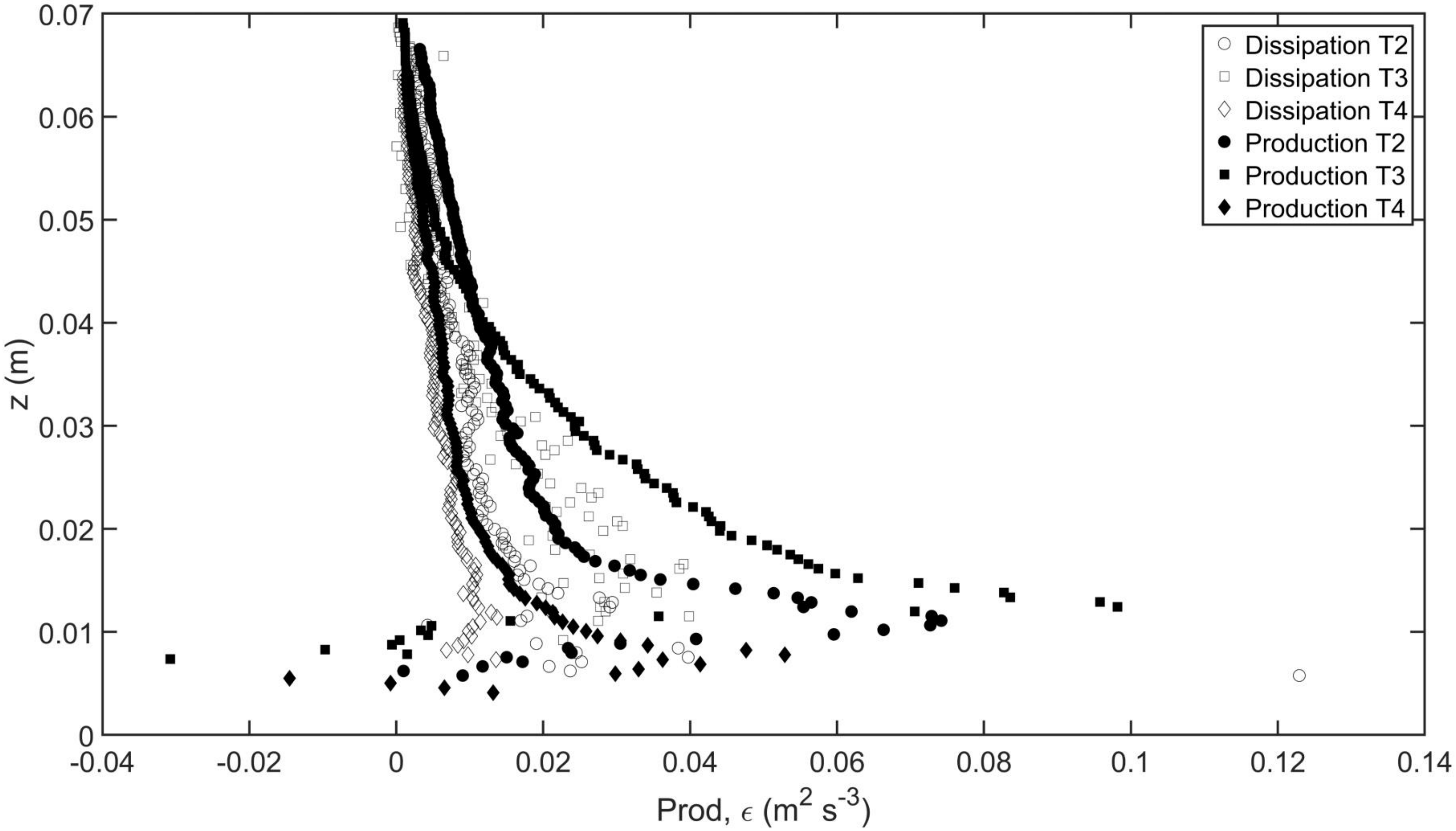


Form-induced shear stresses



Bed-shear stresses

Results and discussion



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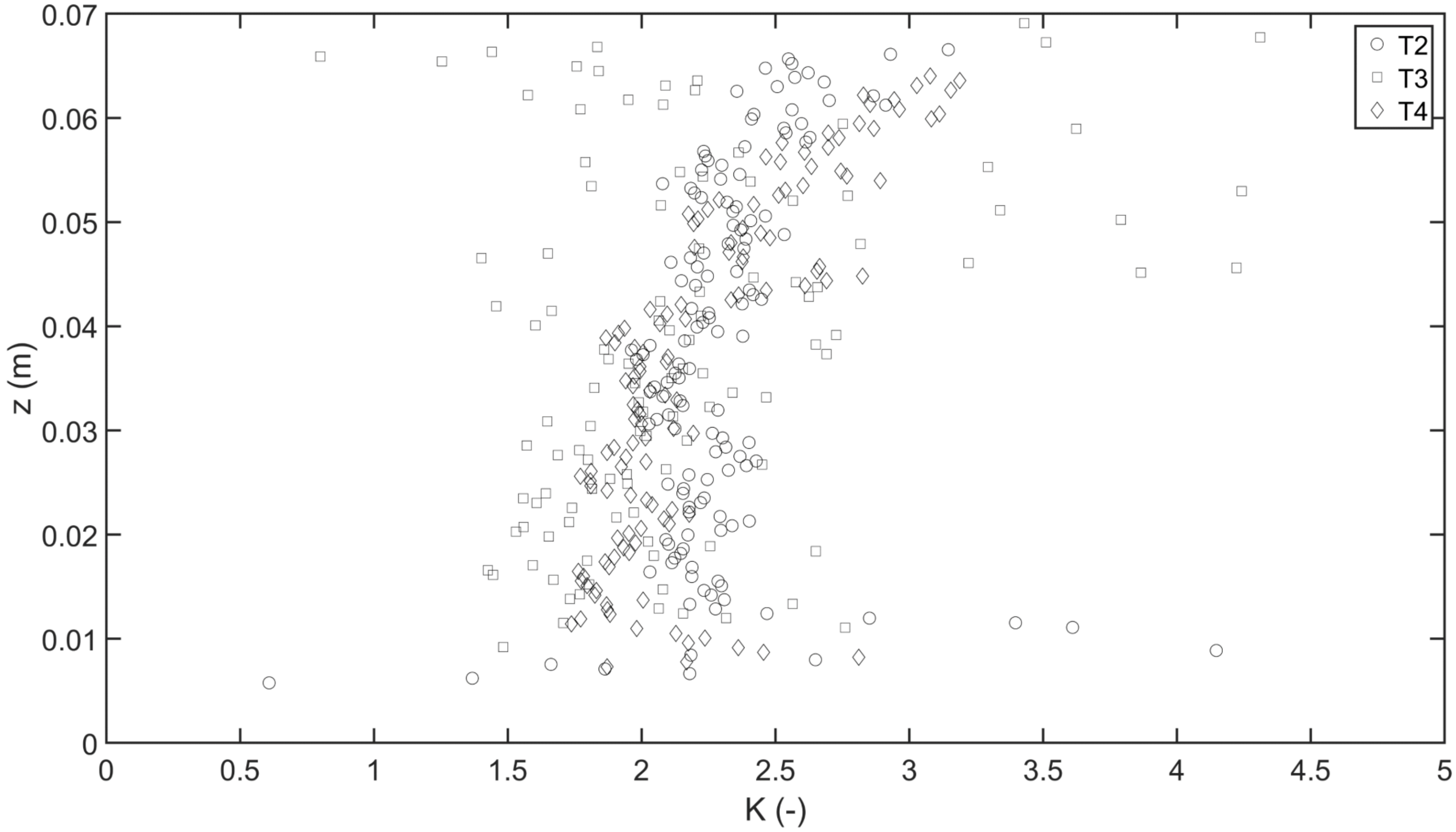
Results and discussion



Conclusion, Impact

The main findings can be summarized as follows:

i) The coefficient of the second order structure function seems to be well described by the classic value 2.17 throughout the flow depth except in the roughness layer where homogeneity conditions are not valid

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Conclusion, Impact

The main findings :

iv. So flows over high conductivity beds appear drag-reducing even if *geometric* roughness parameters do not change appreciably.

v. Within the high conductivity case, higher tortuosity leads to different results – lower value of VK constant, lower overall roughness.

Impact

i) Modellers need to incorporate properties of near-bed turbulence in their wall functions

ii) Sheds light on why simple granular beds are more mobile – forces on the bed particles (scale with U^2) are larger in high conductivity beds for the same u_*.

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