

# Measurement of flow and turbulence over rough beds in a laboratory flume using acoustic Doppler velocimetry

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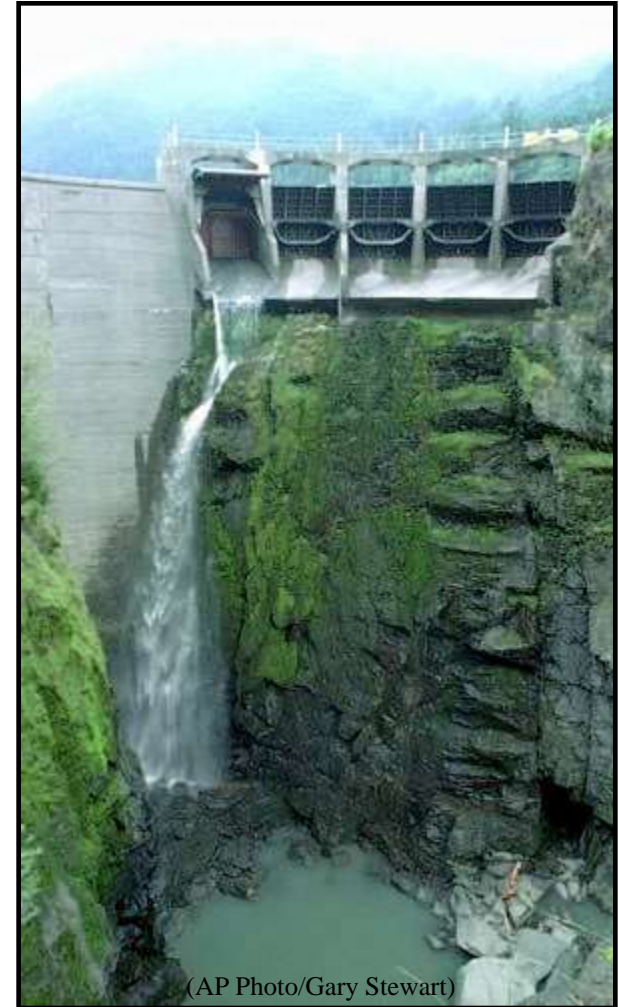
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# Motivation

- Prediction of transport rate of sand over and through immobile coarse substrate
  - Reservoir flushing and dam removal
- Quantify changes in:
  - Sand transport
  - Shear stress
  - Turbulence quantities
  - Bed configuration



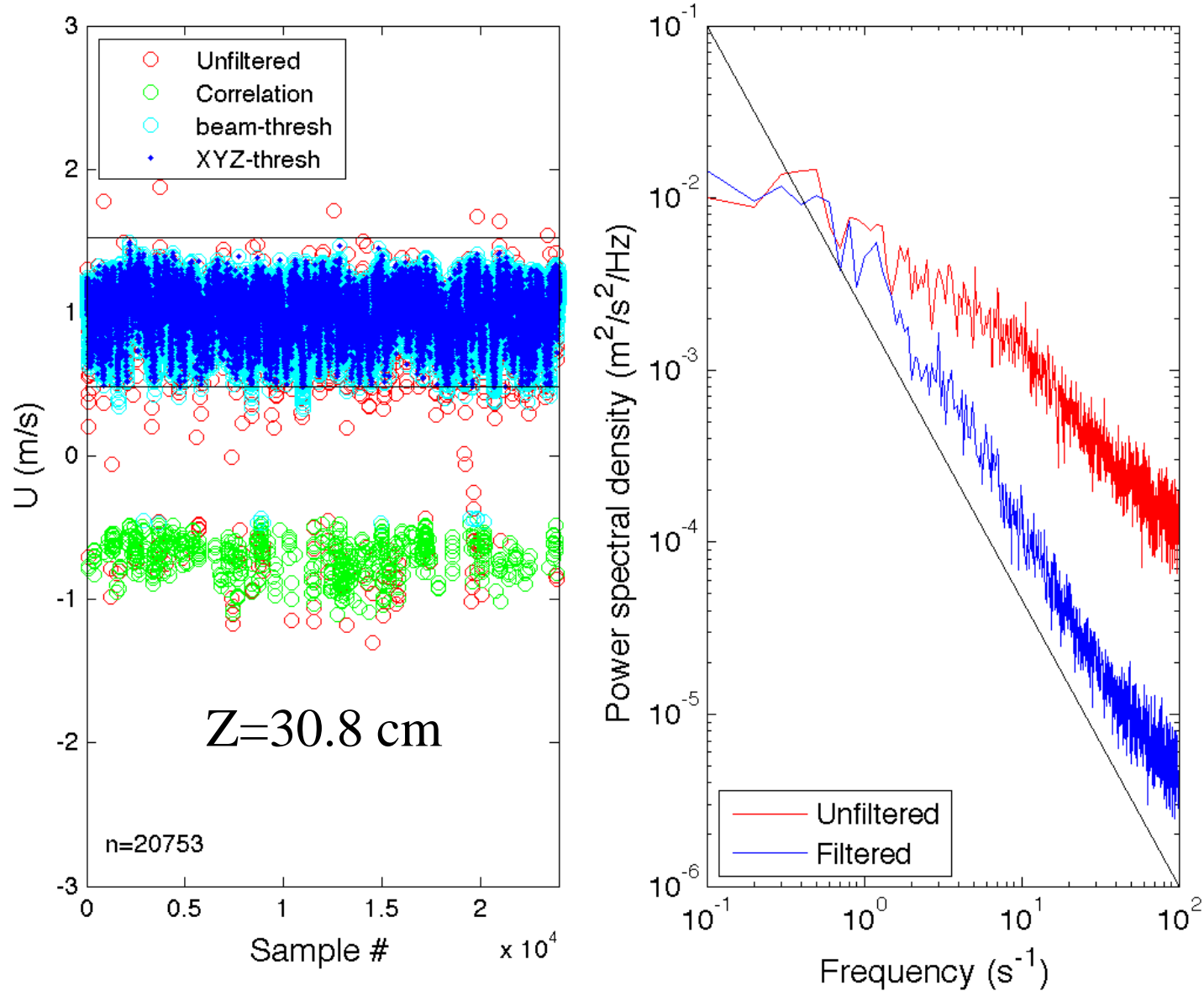
Elwha Dam

# Working with Vectrino+ data

Filtering steps:

1. Discard data points with correlation < 50%
2. Check for phase ambiguity (banded data) and discard wrapped data
3. Convert XYZ data to beam coordinates and discard data outside bounds defined by  $\pm 3.4\sigma$ , then  $\pm 3.6\sigma$
4. Convert back to XYZ coordinates and discard data outside bounds defined by  $\pm 3\sigma$ , then  $\pm 3.2\sigma$
5. Use linear interpolation to replace discarded values  
*(interpolated data are only used for spectral analysis)*

# Example of data from cobble work





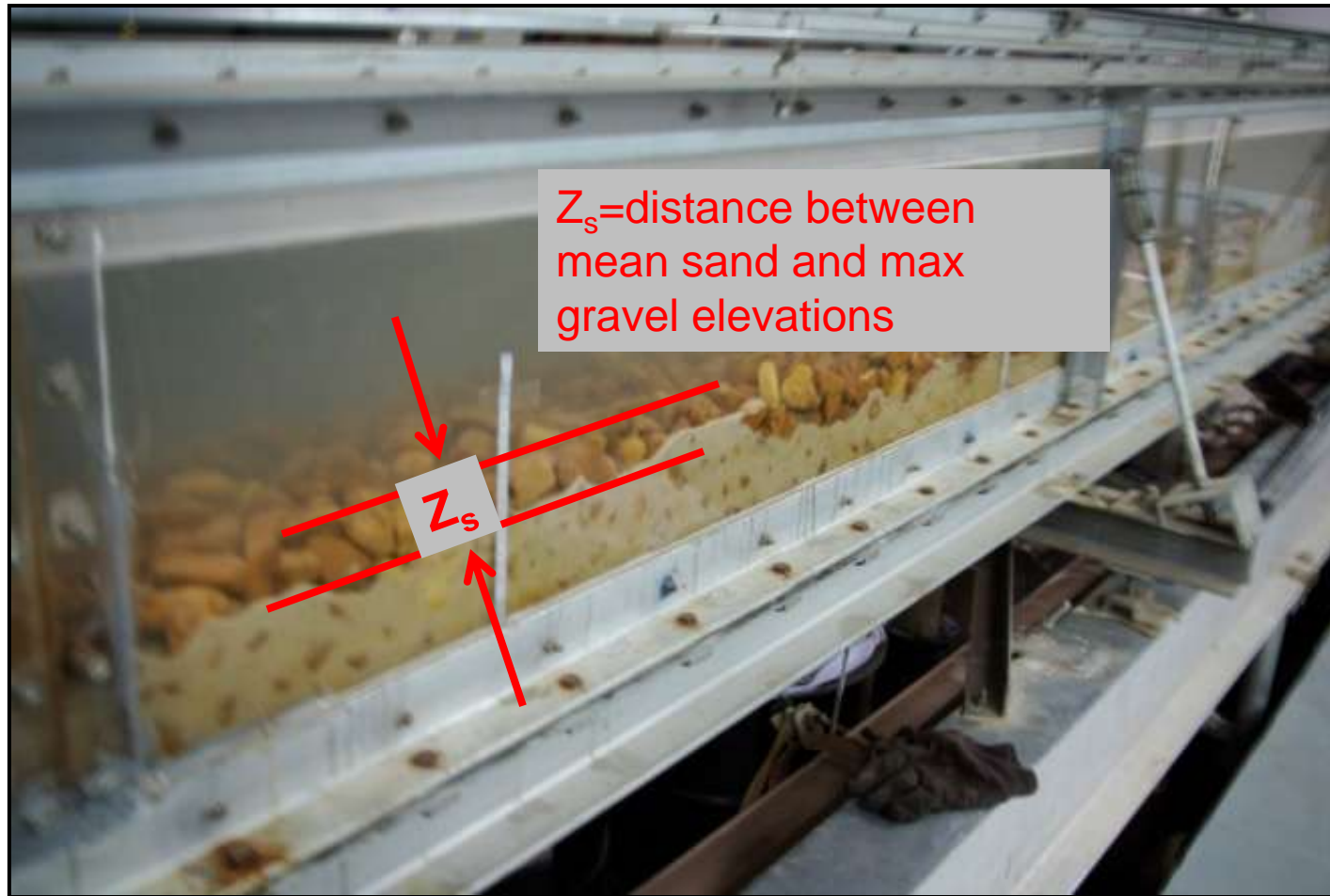
50' flume at the National Sedimentation Laboratory

Sand in gravel substrate  
(gravel  $D_{50}=35$  mm sand  $D_{50}=0.3$  mm)



# Sand in gravel substrate

(gravel  $D_{50}=35$  mm sand  $D_{50}=0.3$  mm)



# Overhead view of test section

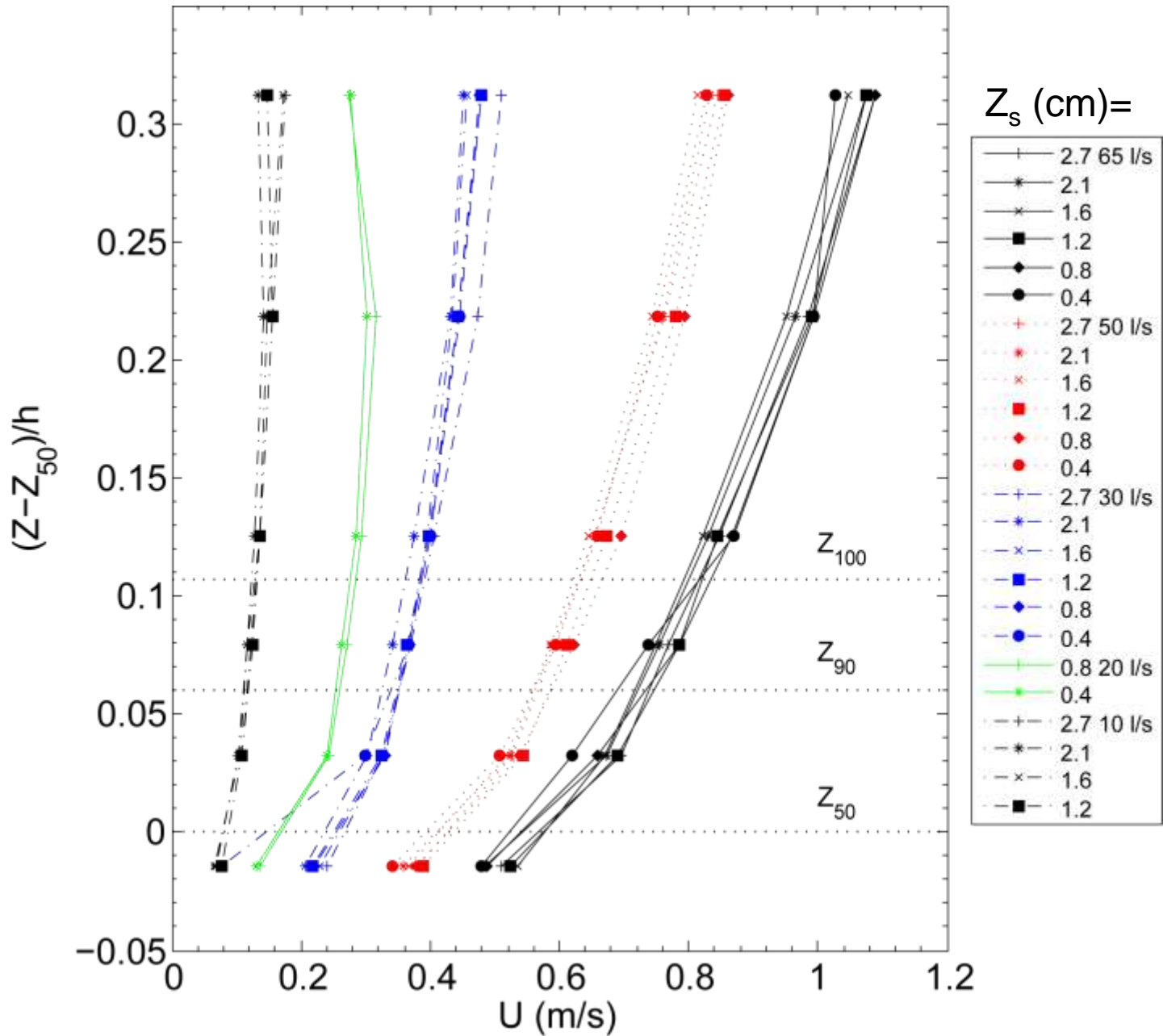
Flow direction →

42 profiles  
6 points each  
252 points  
2 minutes per point

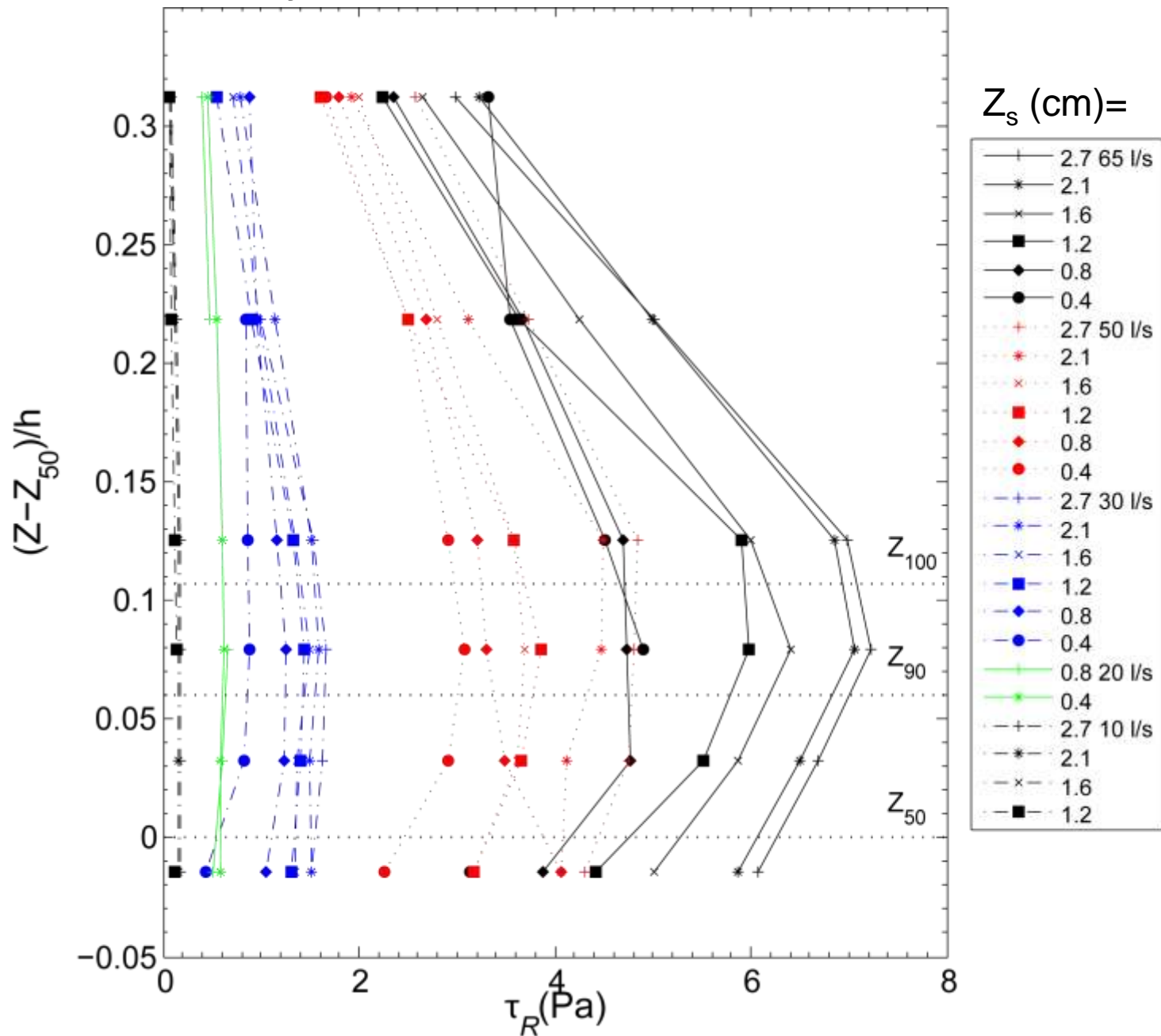


Sampled locations

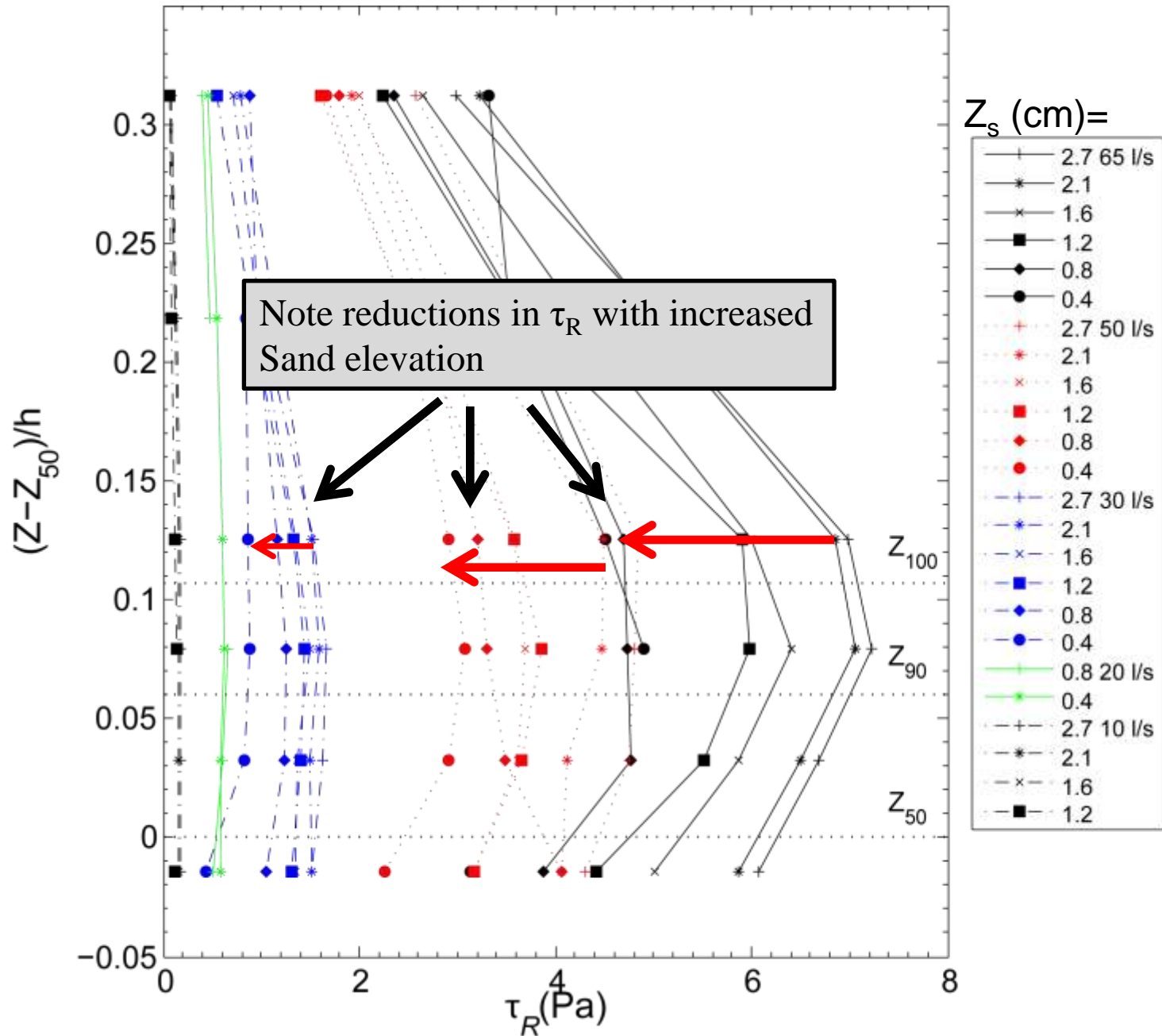
# Velocity profiles



# Reynolds shear stress



# Reynolds shear stress



# Cobble bed experiments

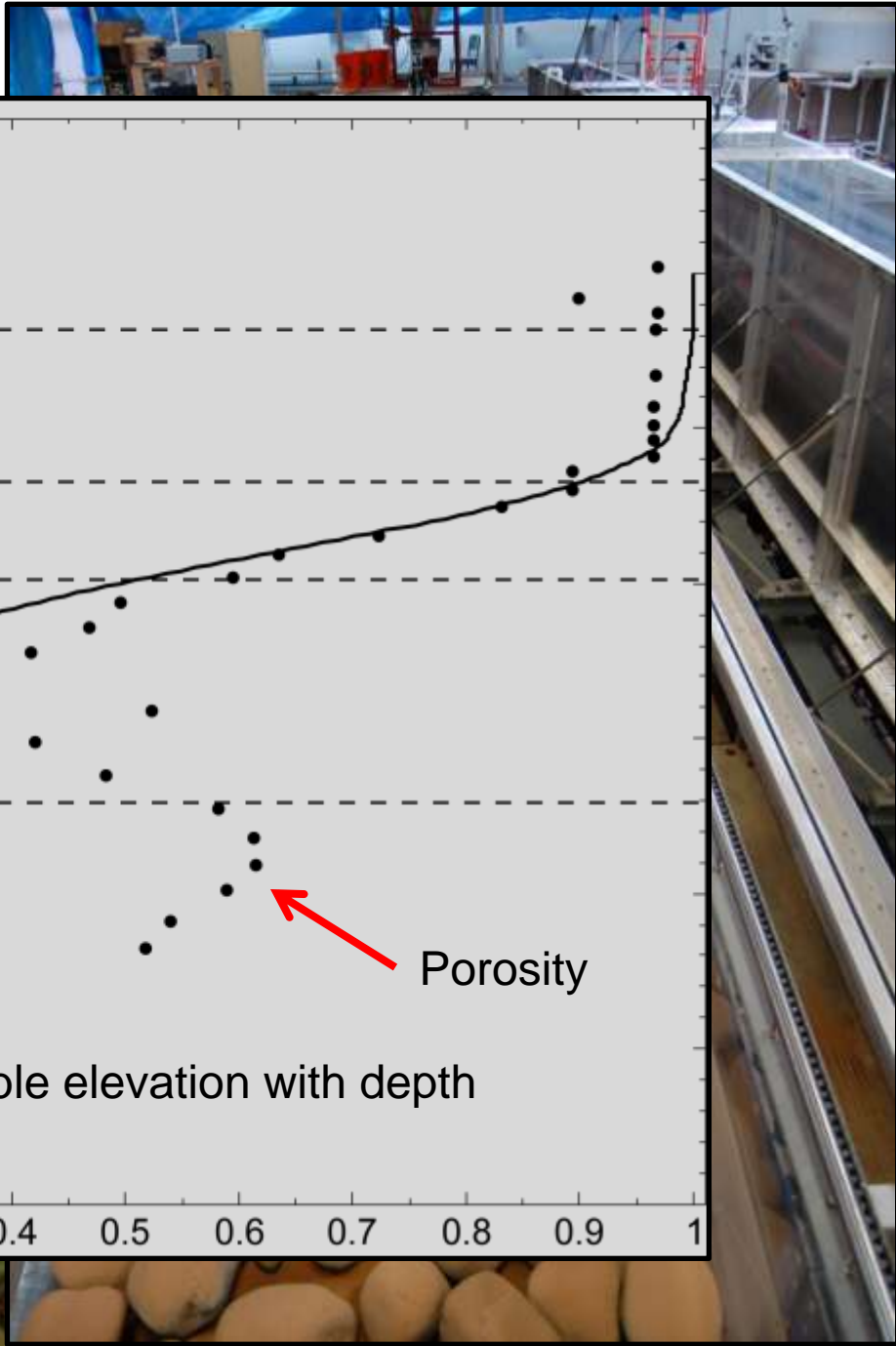
Cobbles:  $D_{50}=150$  mm

Sand:  $D_{50}=0.3$  mm

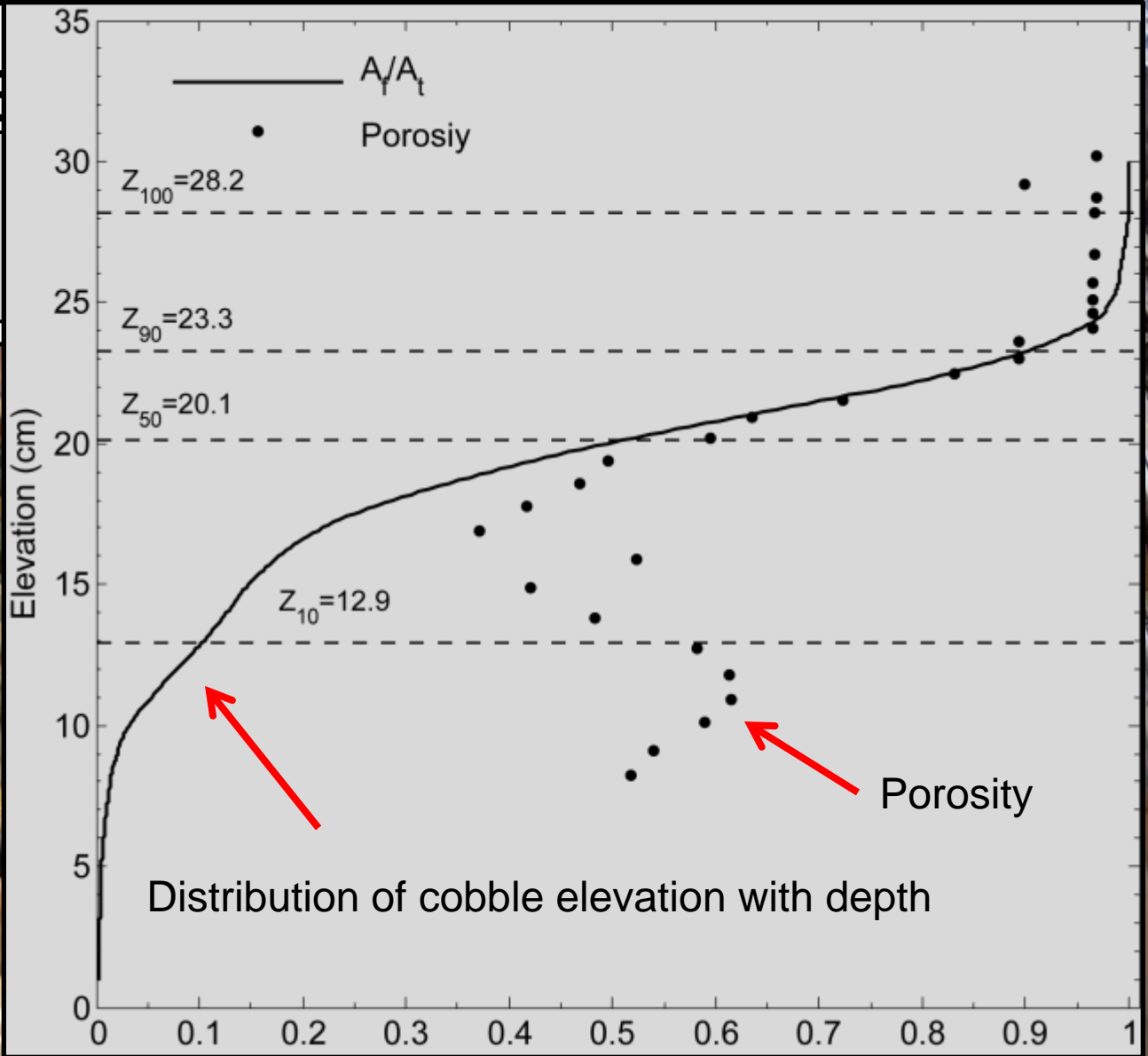


# Cobble bed

exper



Cobbles:  
Sand:



Measurement locations

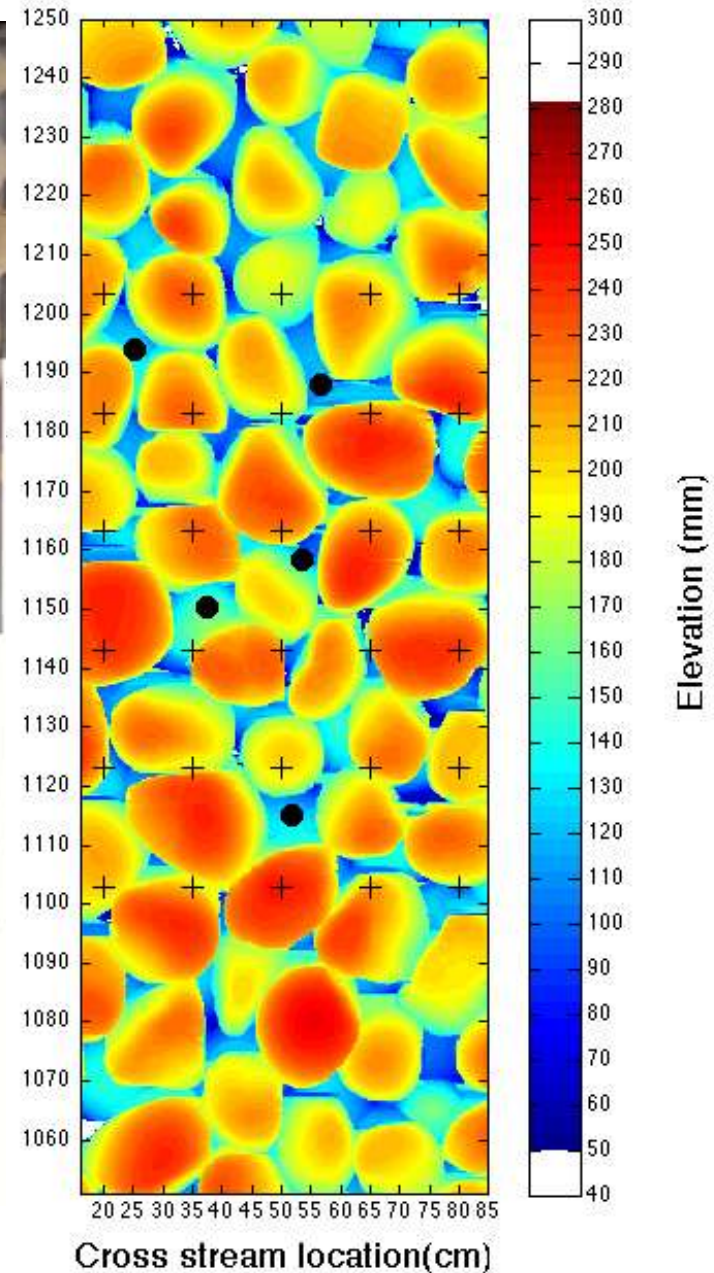
“+”=regular grid

“●”=pore

30 vertical profiles

12 pnts per profile

360 pnts total



# Fluid stress terms

Decomposition of time-varying quantity

Where:  $\bar{u}$  = temporal average

$$u = \bar{u} + u'$$

$\langle \bar{u} \rangle$  = spatial average

$\tilde{u}$  = spatial fluctuation

Decomposition of spatially varied quantity

Where:  $\bar{u}$  = temporal average

$$\bar{u} = \langle \bar{u} \rangle + \tilde{u}$$

$\langle \bar{u} \rangle$  = spatial average

$\tilde{u}$  = spatial fluctuation

Reynolds stress      Dispersive stress      Viscous stress

$$\tau = \rho \left[ -\overbrace{\langle u'w' \rangle}^{\text{Reynolds stress}} - \overbrace{\langle \tilde{u}\tilde{w} \rangle}^{\text{Dispersive stress}} + \overbrace{\frac{\nu}{\phi} \frac{d\phi \langle \bar{u} \rangle}{dz}}^{\text{Viscous stress}} \right]$$

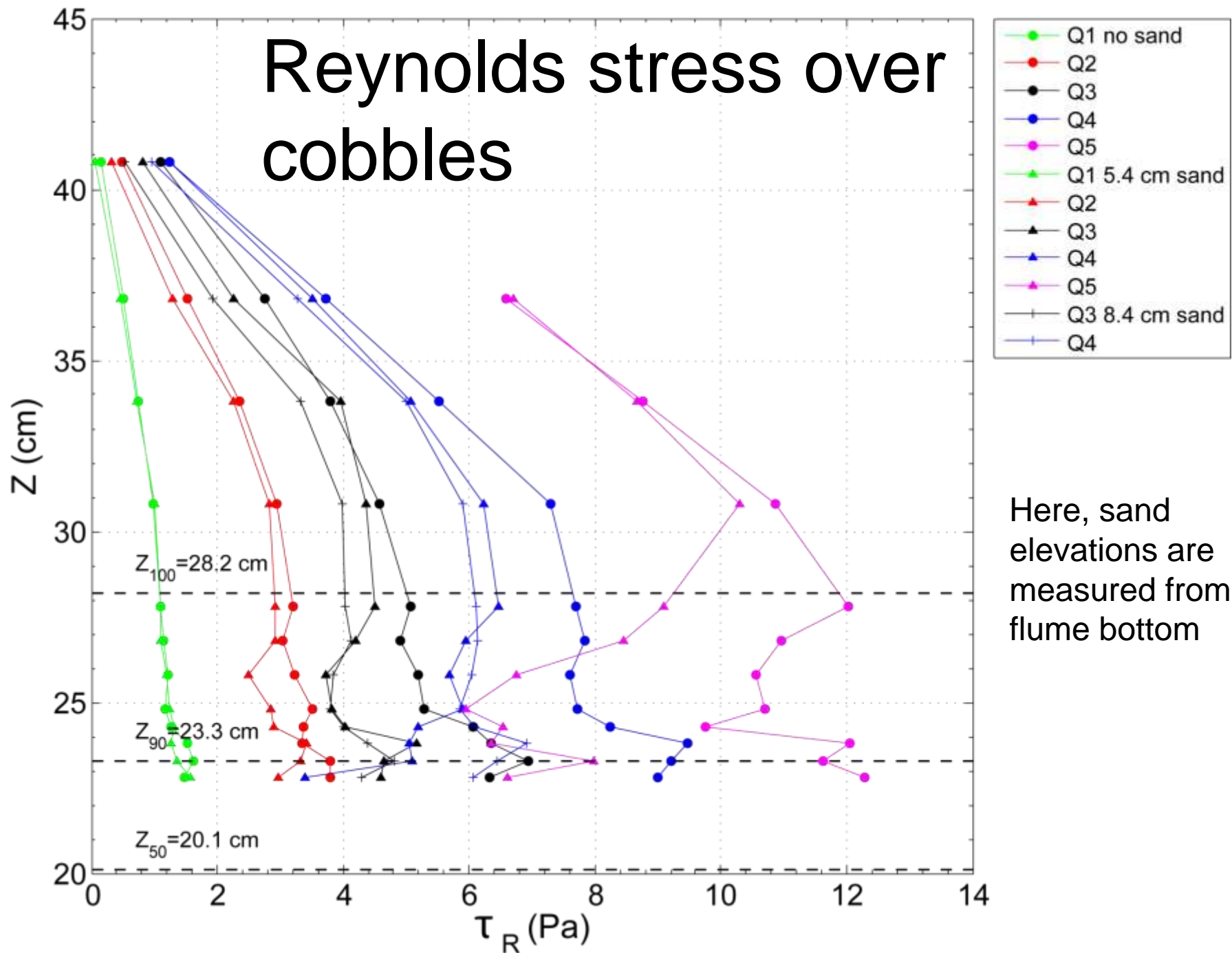
$\tau$  = total fluid stress

$\rho$  = fluid density     $\phi$  = roughness geometry function

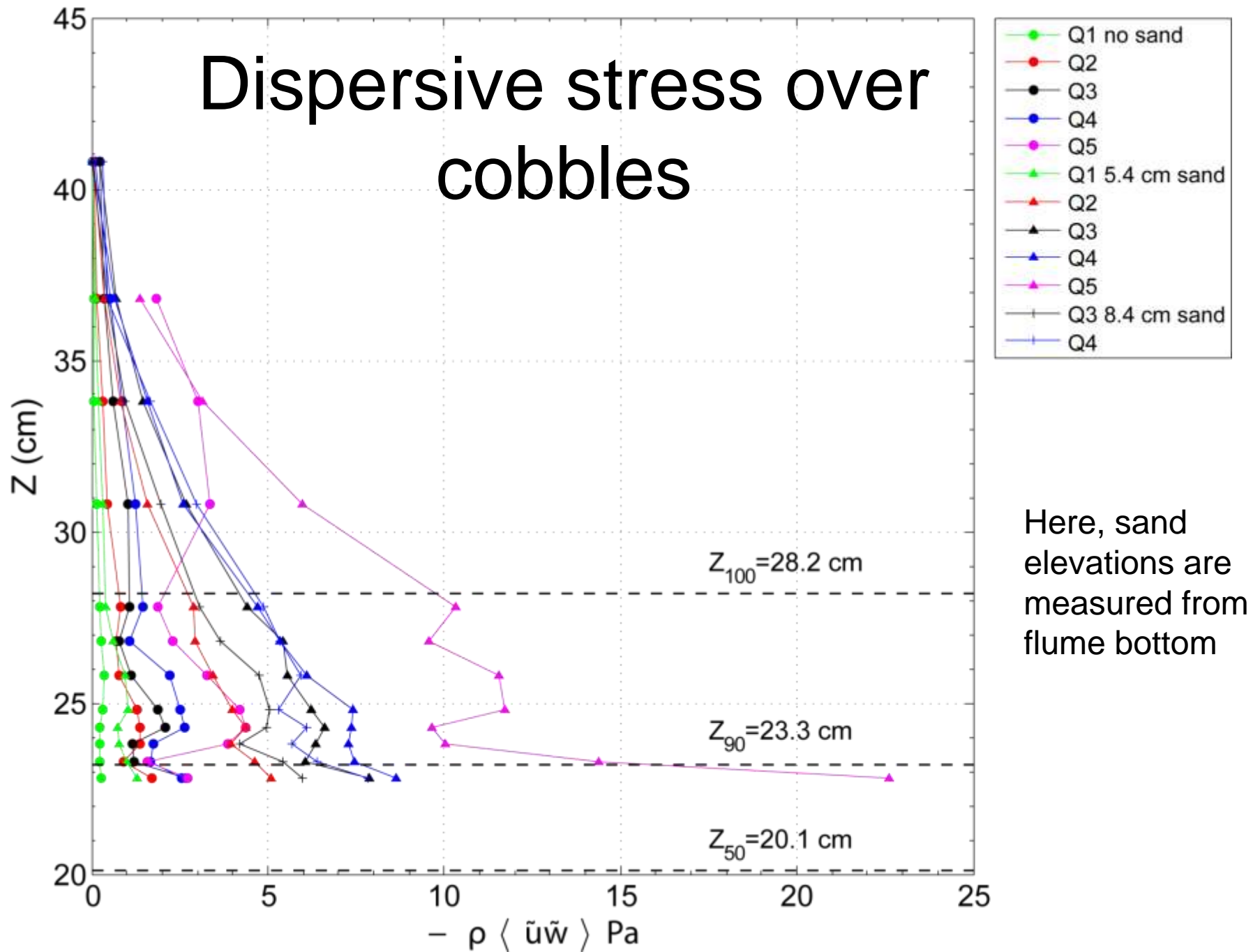
$u$  = longitudinal velocity     $w$  = vertical velocity

$\nu$  = kinematic viscosity

# Reynolds stress over cobbles

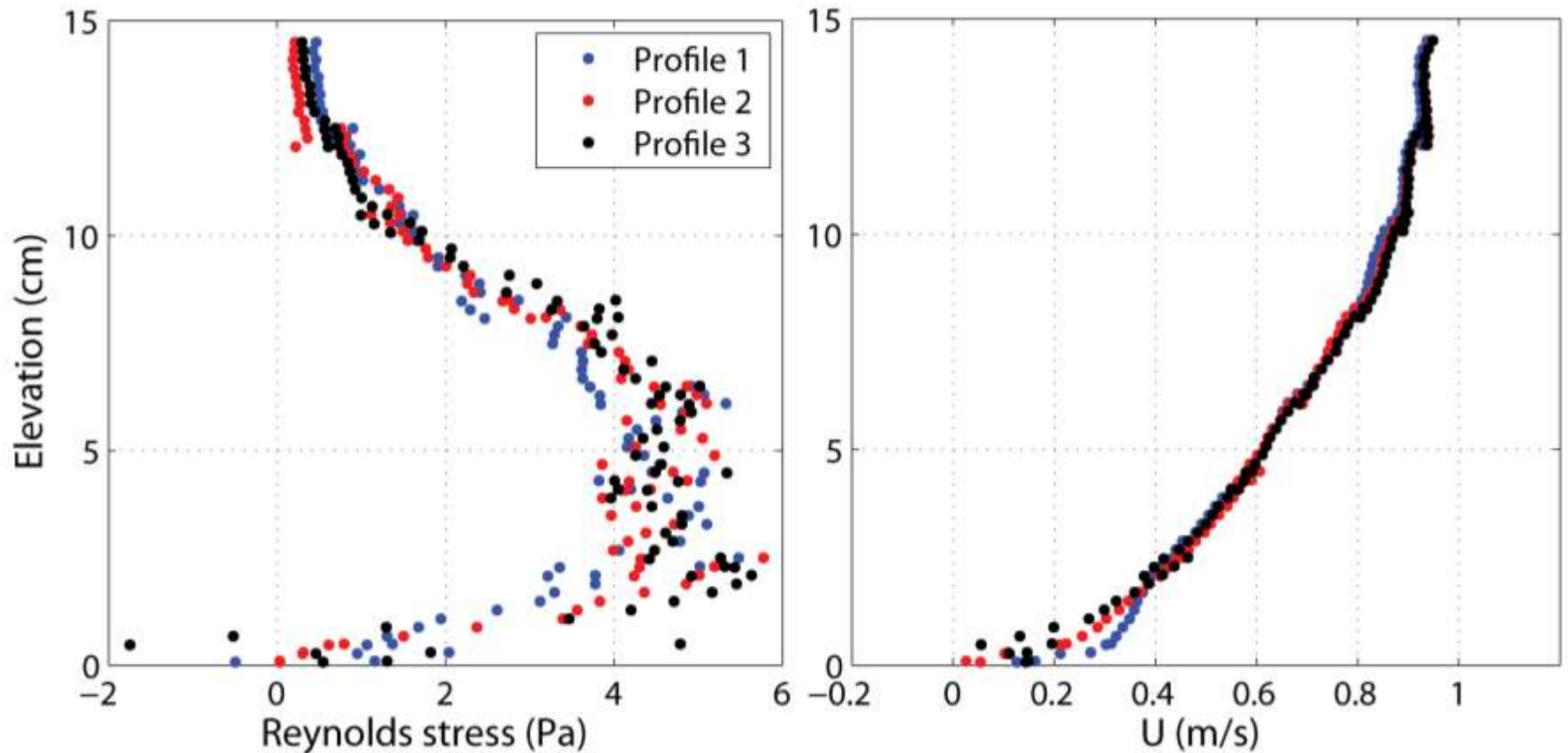


# Dispersive stress over cobbles



Here, sand elevations are measured from flume bottom

# Vectrino II data



Data collected over 35 mm gravel

Lowest points are at approximately the median gravel elevation ( $Z_{50}$ )

# Conclusions

- We are successfully using Vectrino velocimeters in a variety of challenging environments
- Data processing requires extra care in experiments that involve rough beds
- The Vectrino II opens up many possibilities, but also represents some new challenges with data processing

A wide river flows through a lush green forest. The water is a mix of brown and blue, with some white foam visible in the distance. The banks are lined with dense green trees and bushes. The sky is blue with scattered white clouds. The word "Questions?" is written in large black font in the upper right quadrant of the image.

Questions?