Tehnici de vizualizare pentru cuantificarea curgerii fluidelor de la micro la macro scari

(Image Techniques for Quantification of Micro- and Macro-Scale Fluid Flows)

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Bucuresti, 2008

Synopsis

- Imaging: oldest approach for observing flows
  - Originally for *qualitative* measurements (Leonardo da Vinci)
  - Currently enable *quantitative* measurements

→→→

- Quantitative Imaging Techniques (QIT)
  - Well-established foundations through the development of Particle Image Velocimetry (PIV), Particle Tracking Velocimetry (PTV) and Laser Induced Fluorescence (LIF)
  - increasingly popular in Hydraulic Engineering (HE) under the name Large-Scale Particle Image Velocimetry (LSPIV)
  - rapidly growing at the pace of digital revolution
  - can uniquely support observations/measurements to understanding processes and their interaction from micro- to macro-scale flows

Why QIT?

General aspects:

- **user-friendly: images as raw information**
- **fully digital → on-line data processing, remote operation**
- **rapid & continuous improvement of spatial & temporal resolutions**

Specific (hydrodynamic) aspects:

- **non-intrusive measurements (close range remote sensing)**
- **instantaneous, whole (plane, multipoint) flow velocities – most advanced measurement capabilities**
- **multiple-task technique: velocities, velocity-derived, and scalar measurements**

QIT Principles

Velocity calculation:

- **Based on the simplest velocity definition**

$$V = D/t$$

Main technique task: determine displacement (*D*) of tagged flow regions in a time-sequenced image series (*t* apart)

Scalar field measurements:

- **Based on image color or intensity (light wavelength or frequency)**

Application I: Micro-scale Flows

Particle Tracking and Particle Image Velocimetry

- Commercial hardware components: high-speed, high-resolution imaging devices, pulsed lasers, fiber optics, commercial data-acquisition software
- In house developed software for image processing (PTV and PIV)
- Experiments conducted in Japan in 2001 in open channel flows with same size suspended sediment (only) and three different concentrations :
  - NS – natural sand, $d_{50} = 0.2$ mm
  - NBS – neutrally-buoyant sand, $d_{50} = 0.2$ mm

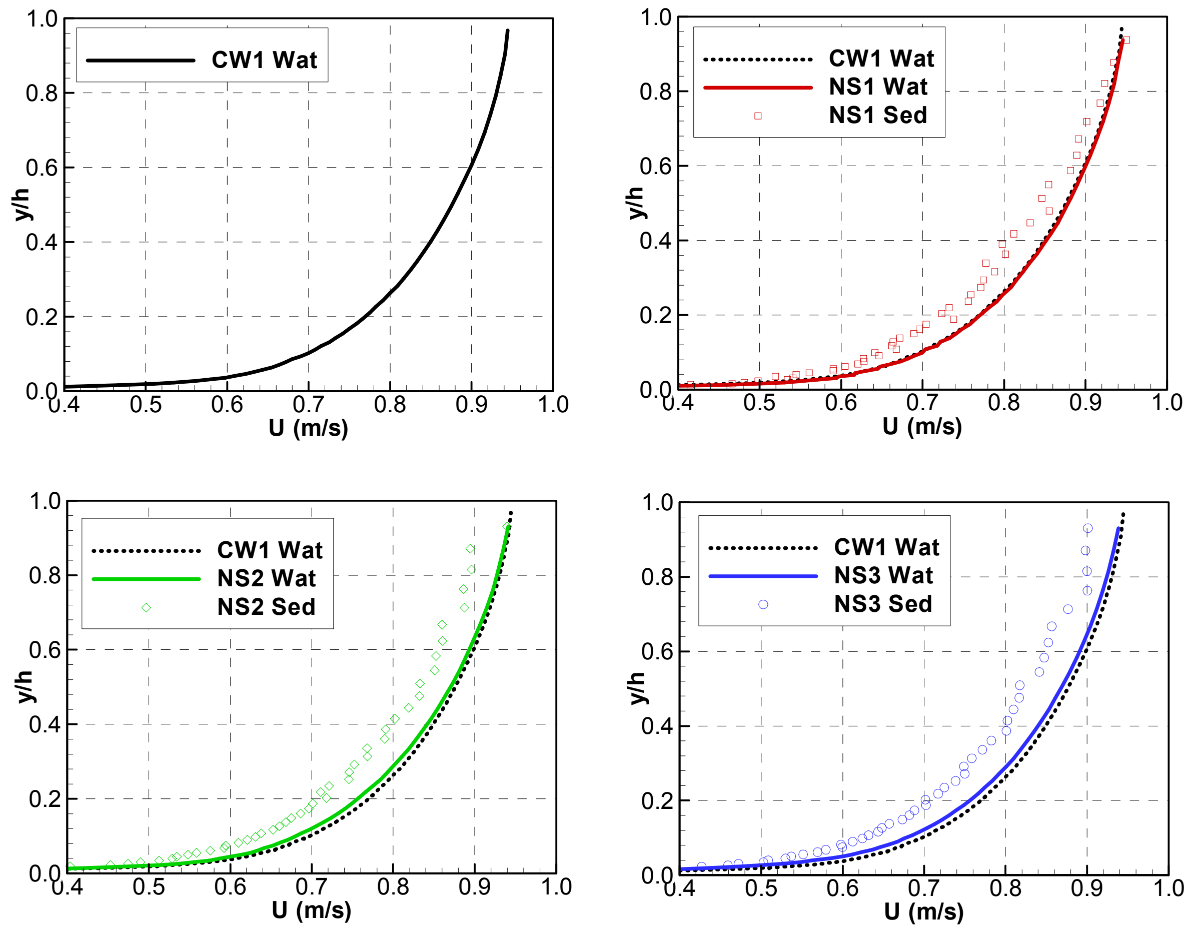
Collaborators: Ichiro Fujita, Kwonkyu Yu, Robert Ettema

Selected References:

- Muste, M., K. Yu, I. Fujita, Ettema, R. (2008). "Two-phase Flow Insights into Open-channel Flows with Suspended Particles of Different Densities," Env. Fluid Mechanics (in print)
- Muste, M., Yu, Fujital I., Ettema, R. (2005). "Traditional versus Two-phase Perspective in Turbulent Channel Flows with Suspended Sediment," Wter Resources Research 41(10)

Mean flow characteristics

NS: average streamwise sediment velocity slower up to 5 % than water (conventional time-averaging)



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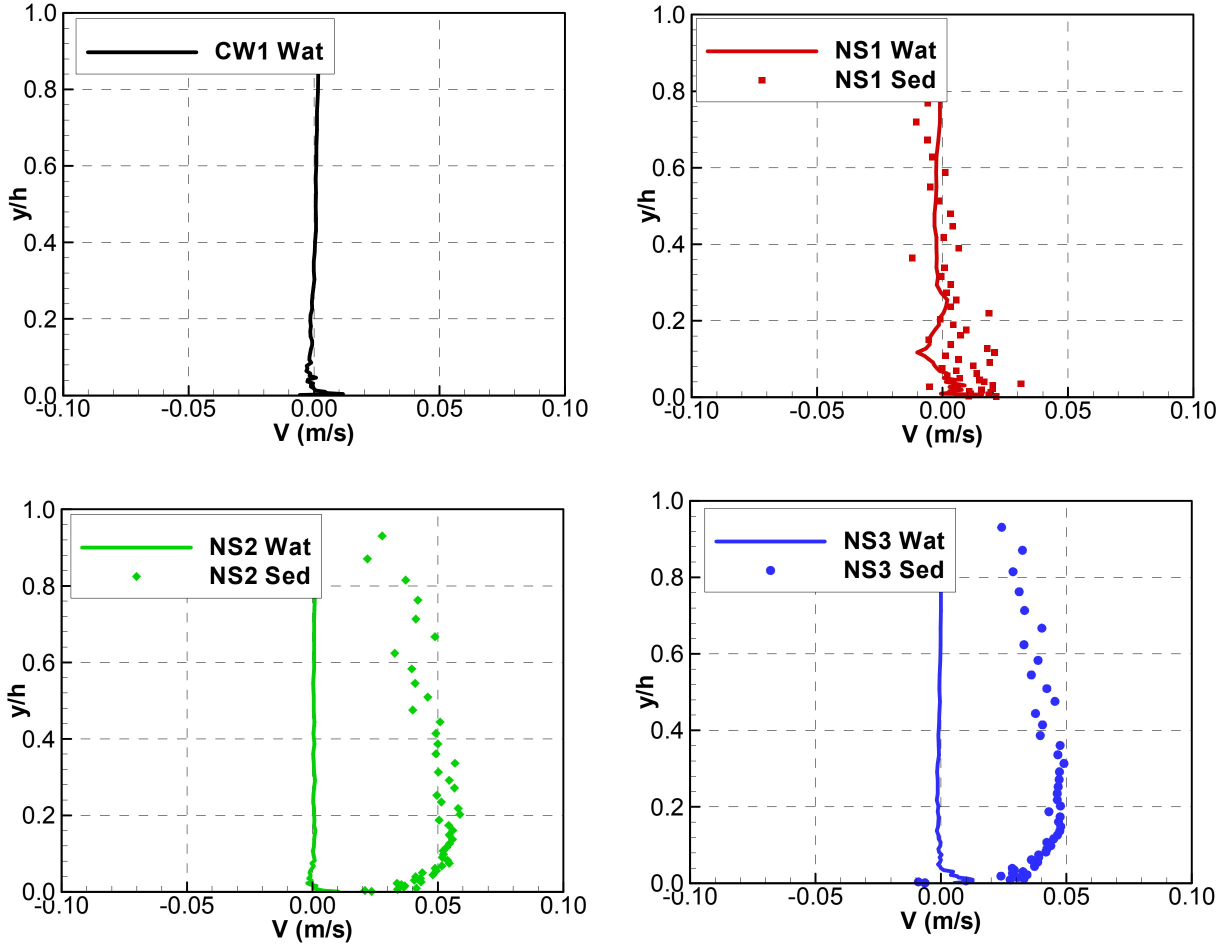
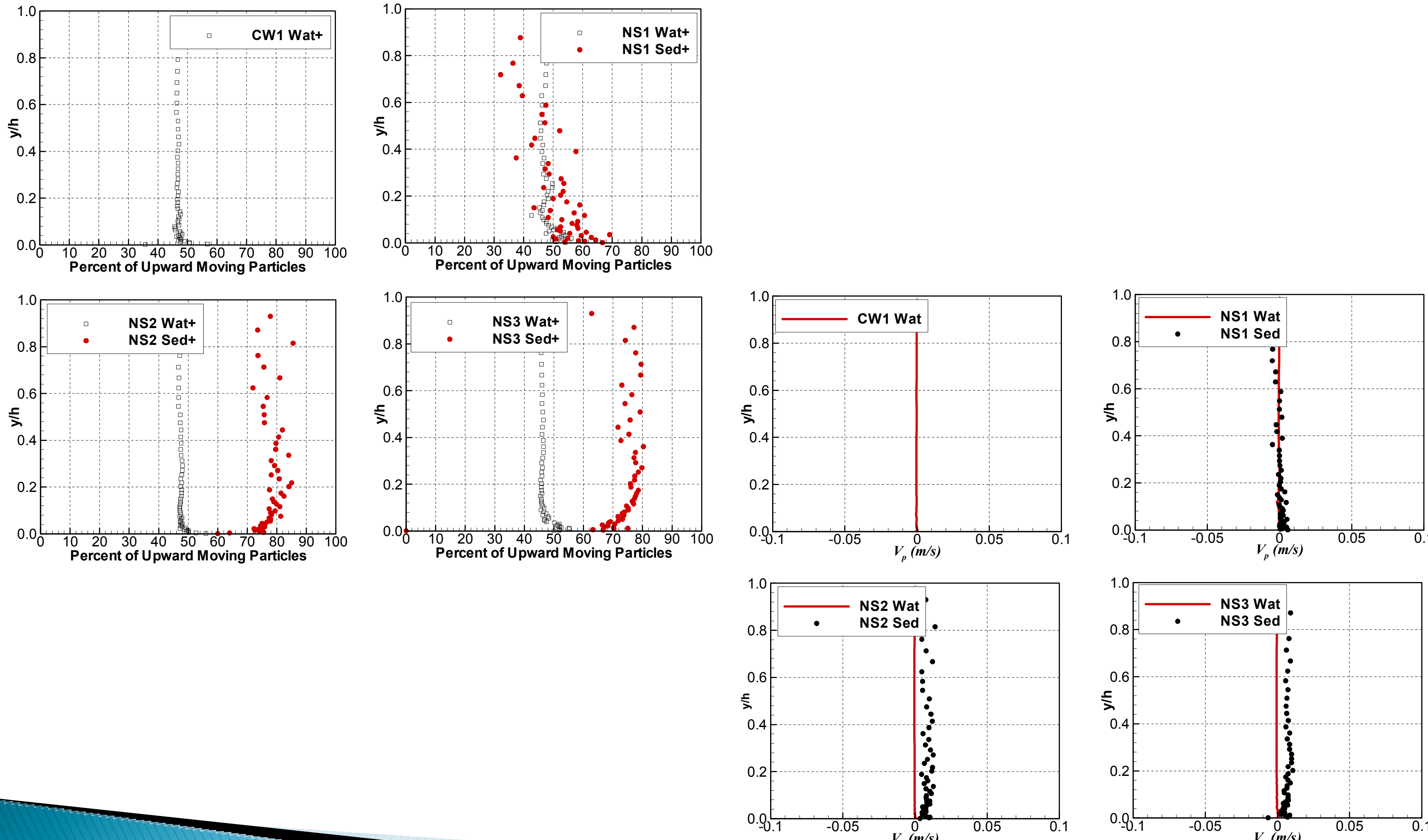
Mean flow characteristics

NS: Conventional temporal averaging on the vertical velocity samples



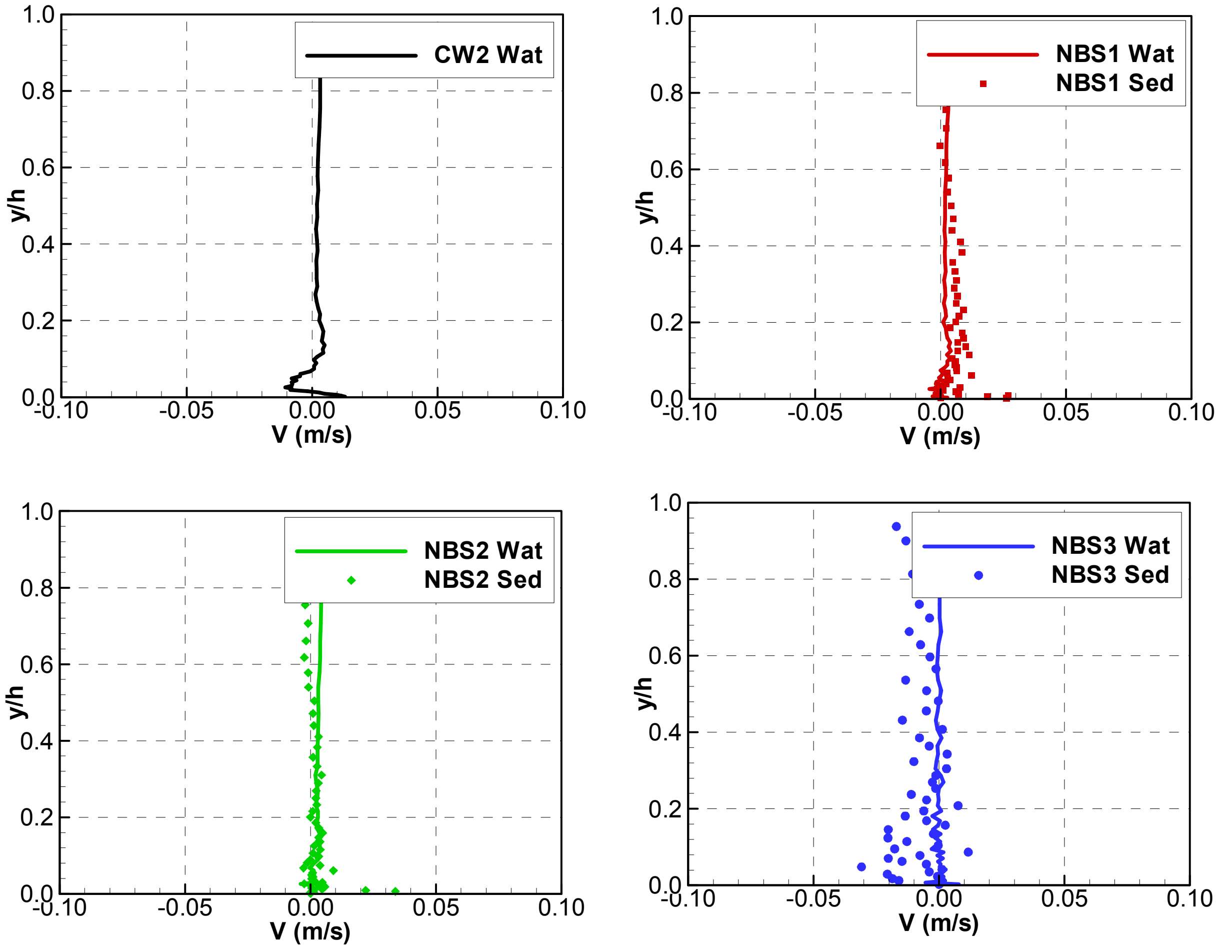
Mean flow characteristics

NS: Using McLaughlin & Tiederman's (1973) algorithm it can be proved that the vertical sediment flux is zero



Mean flow characteristics

NBS: Conventional temporal averaging on the vertical velocity samples



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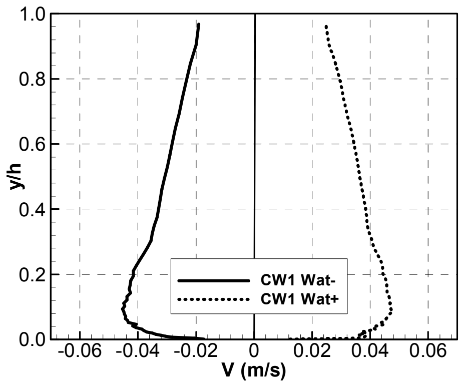
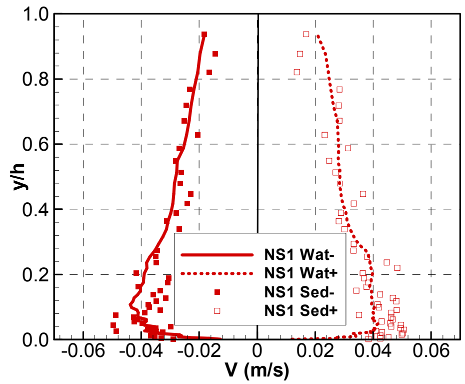
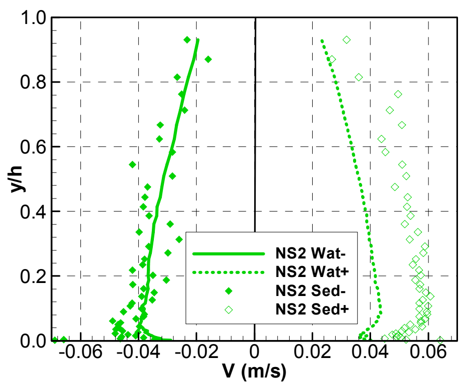
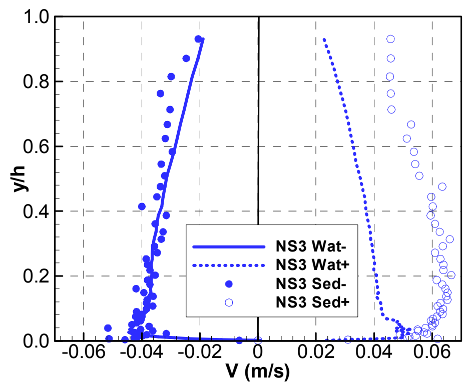
Mean flow characteristics

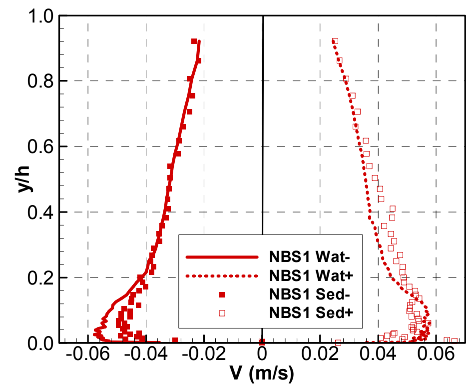


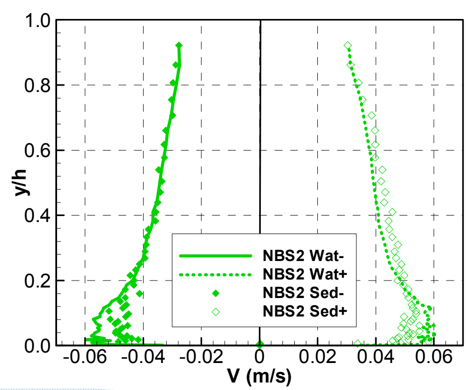


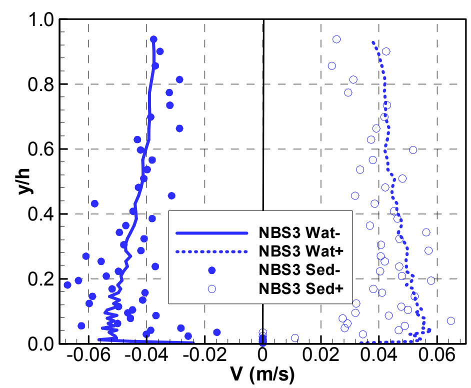
- **NS**: Particles move faster than water upward and with the water downward
- **NBS**: Particles follow closely water both upward and downward









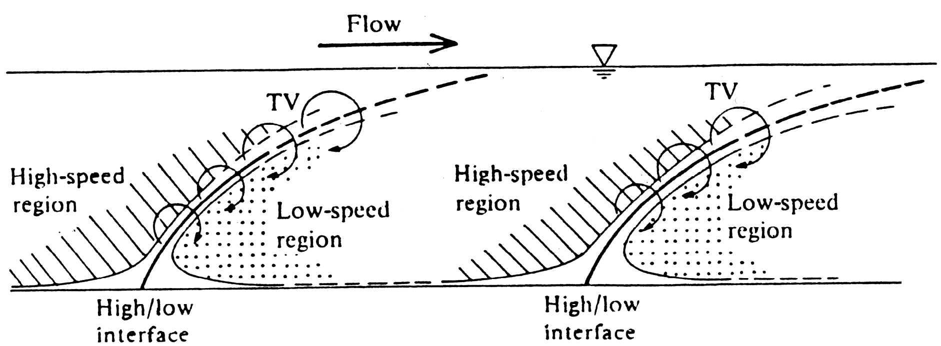


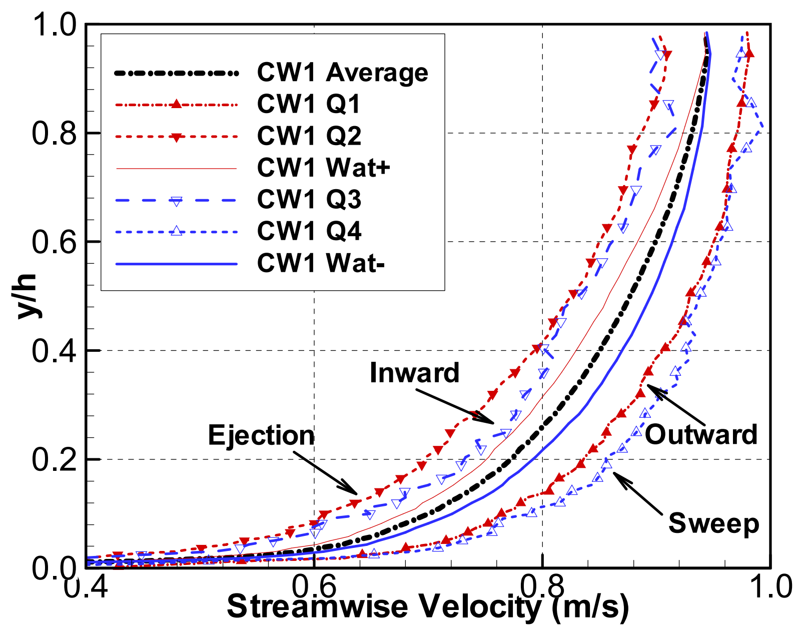
Particle–fluid interaction

- There is no velocity lag in an instantaneous interaction (violation of the non-slip condition around individual grains - Kiger & Pan; 2002)
- What is the significance of a velocity difference between water and particles (lag) in the NS average statistics?

Particle–fluid interaction

- Turbulence in OCF comprises coherent structures generated near the bed with sweeps, $u'_w > 0,\ v'_w < 0$ (quadrant four events) and ejections, $u'_w < 0,\ v'_w > 0$ (quadrant second events) being the most energetic.

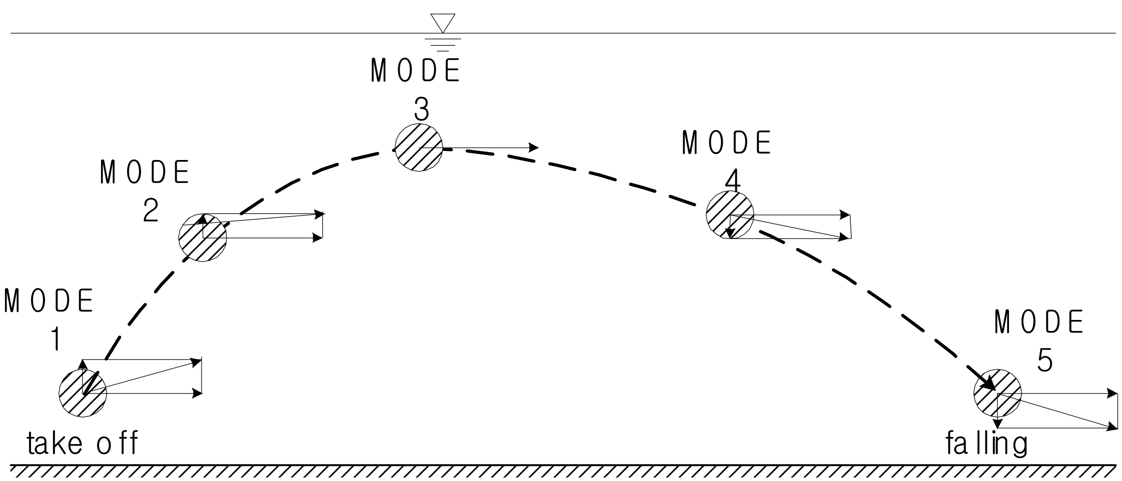




Particle-fluid interaction

- Particle-fluid interaction is taking place at two levels:
  - Micro = eddies comparable with particle size (turbulence modification)
  - Macro = larger coherent structures (deposition-entrainment)

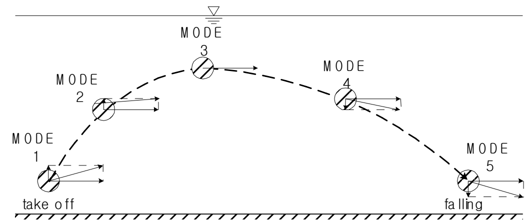
- Direct observations of the macro particle behavior reveals that heavy sediment has not a symmetrical trajectory in its suspension-deposition cycle (Abbott & Francis, 1977; Summer & Deigaard; 1981)

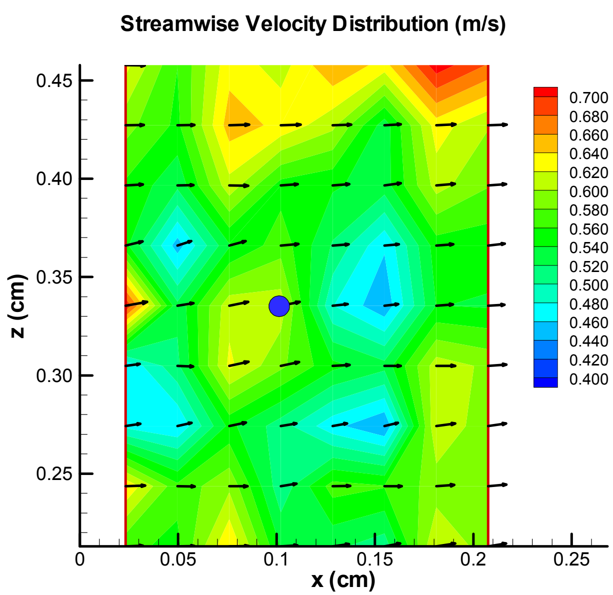


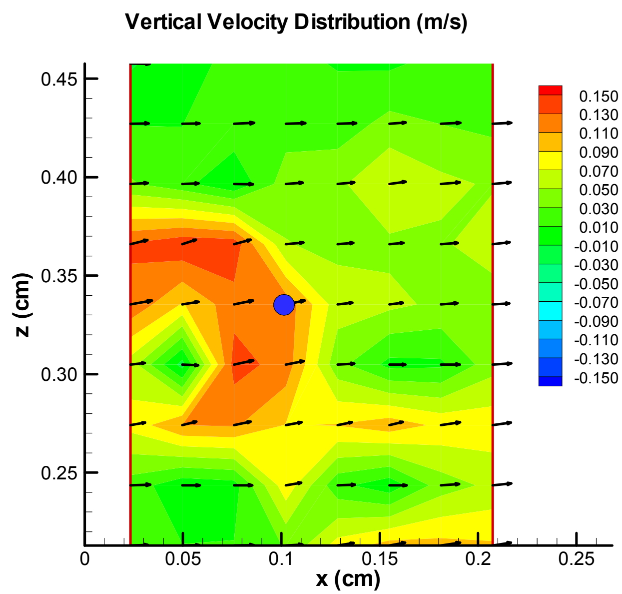
Particle–fluid interaction

NS

Mode 1 (y/h < 0.2): Magnitude of the total velocity for particle larger than water and oriented upward



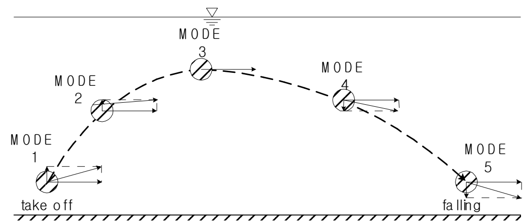


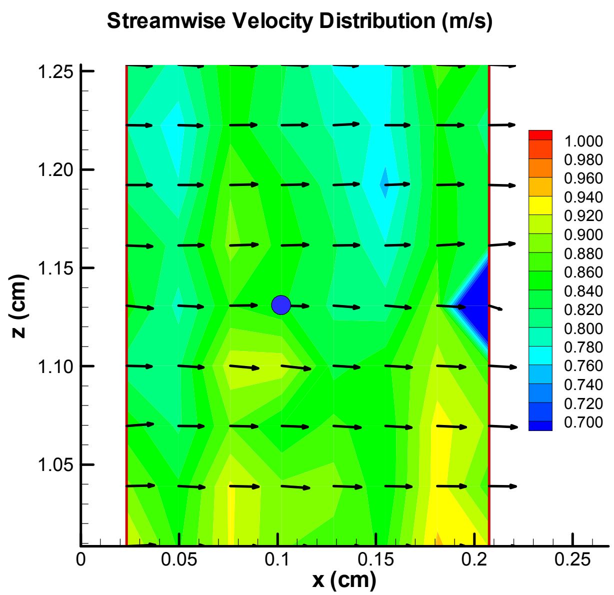


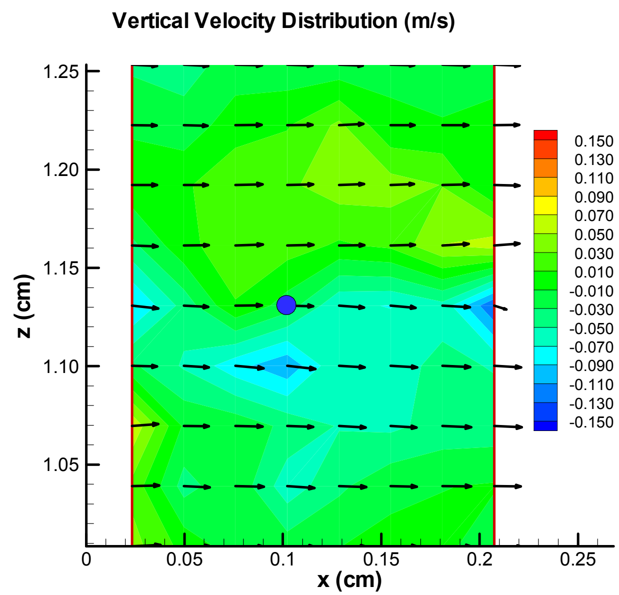
Particle–fluid interaction

NS

Mode 3 (y/h > 0.6): Magnitude of the total velocities for particles and water close and oriented horizontal



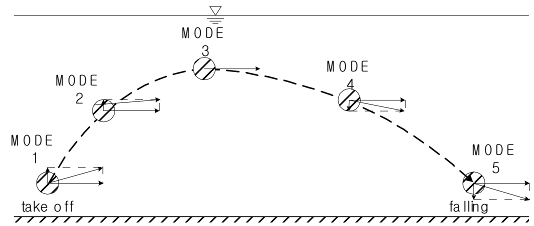


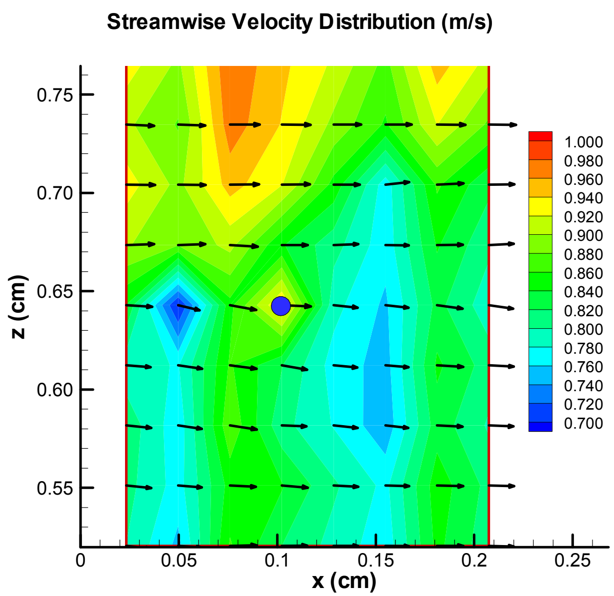


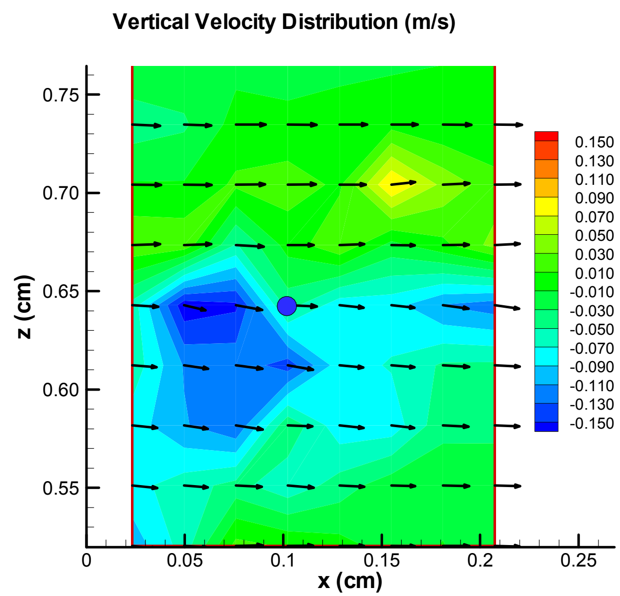
Particle–fluid interaction

NS

Mode 5 (y/h < 0.2): Magnitude of the total velocity for particles and water close and oriented downward





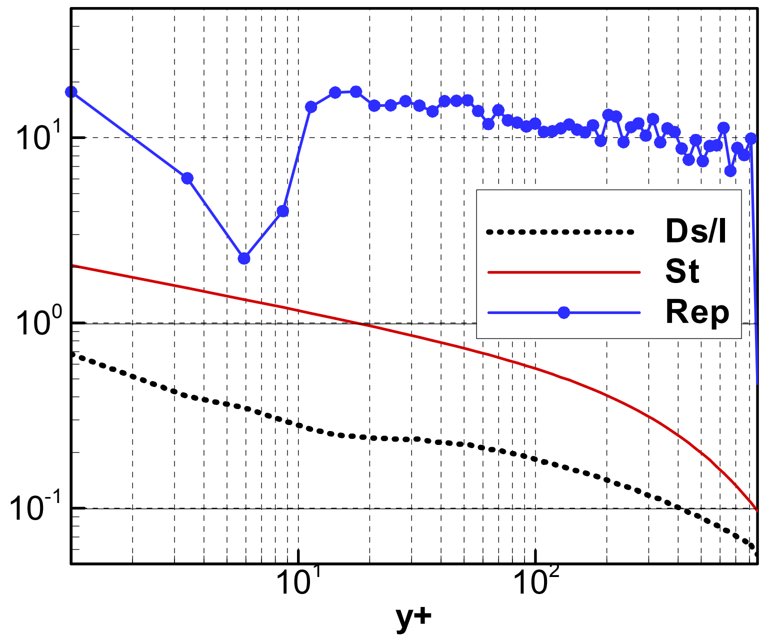


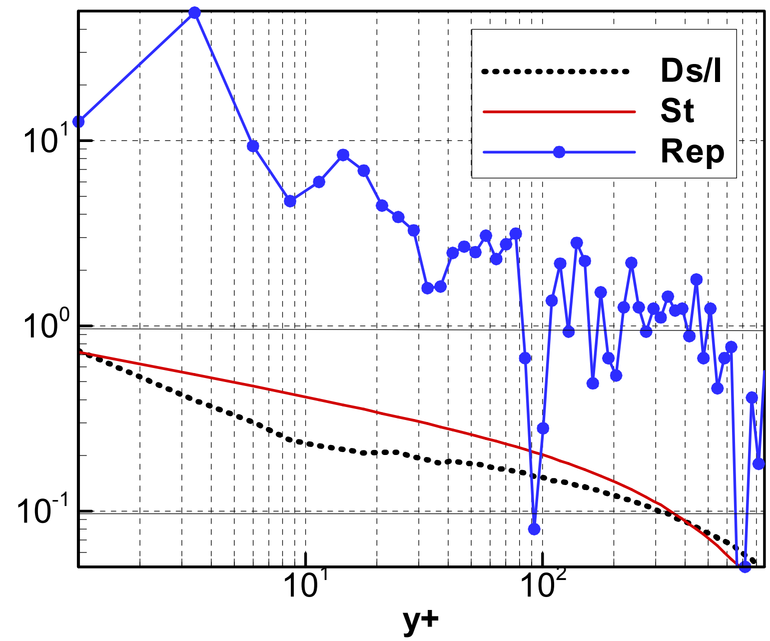
Turbulence characteristics

- Conventional parameters used to characterize turbulence changes for water

$$D_s/\lambda; \qquad St = \frac{\tau_p}{\tau_f} = \frac{D_s^2\,\rho_s}{18\nu\,\rho_w}\sqrt{\frac{\varepsilon}{15\nu}}; \qquad \mathrm{Re}_p = D_s|U_L|/\nu$$

- Not accounted: sediment concentration

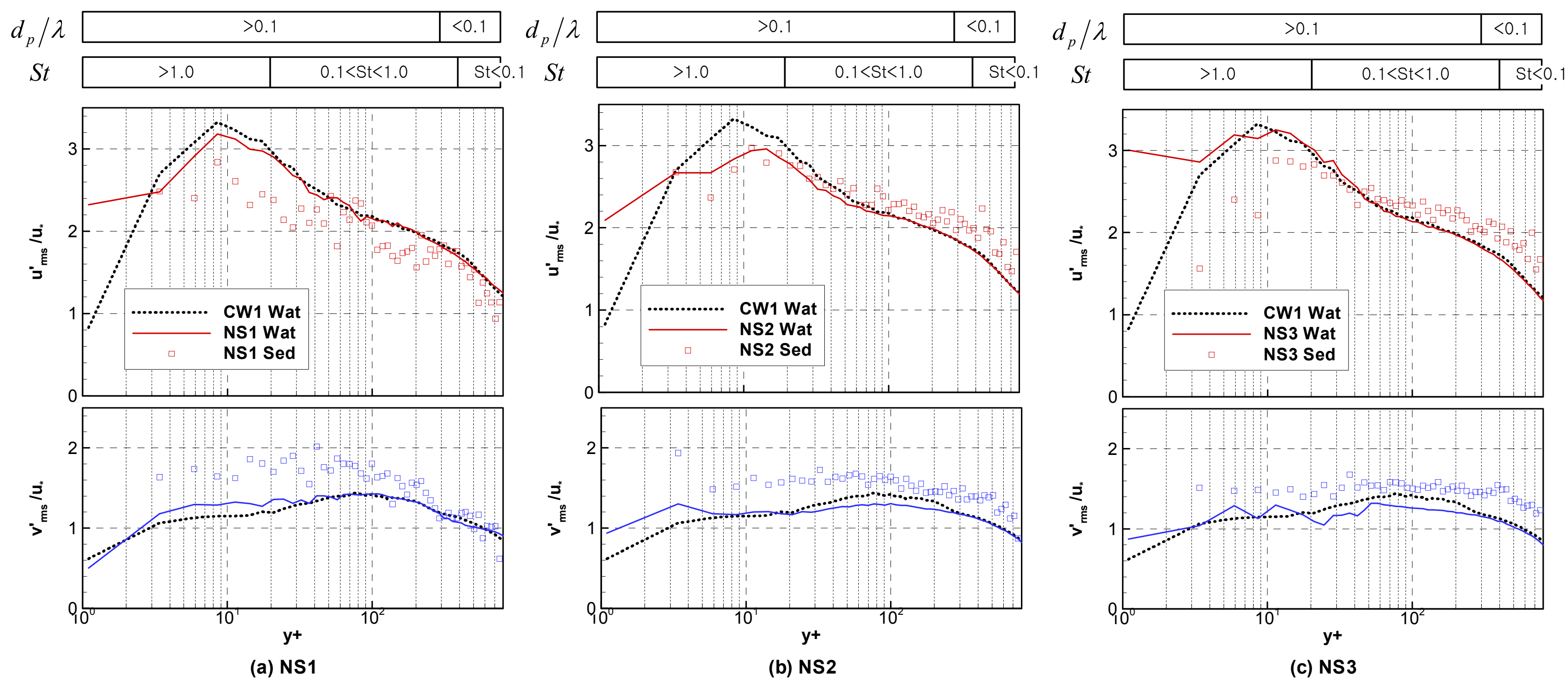




Turbulence characteristics

NS

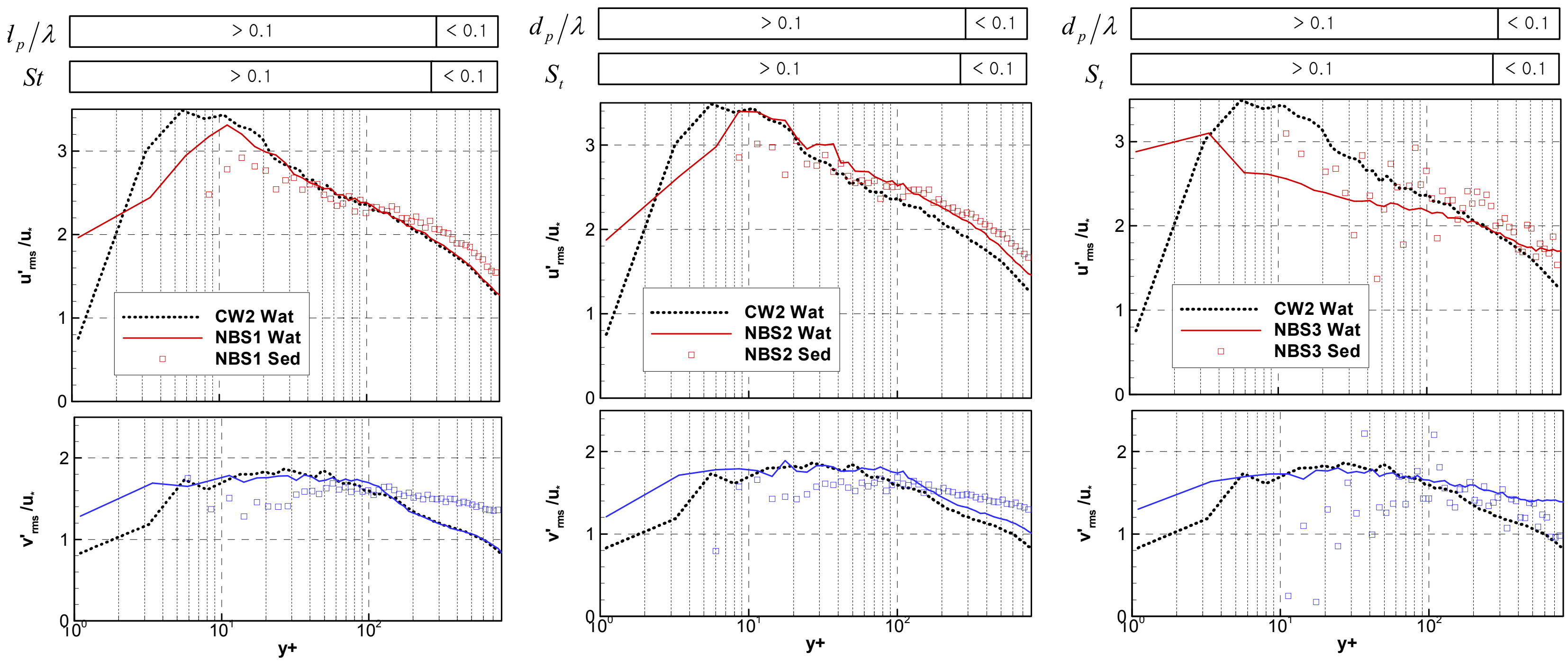
- Streamwise turbulence intensities = intricate interdependencies
- Water turbulence intensities increased near bed, unchanged in the outer layer
- Particle turbulence intensities larger than fluid (especially vertical)



Turbulence characteristics

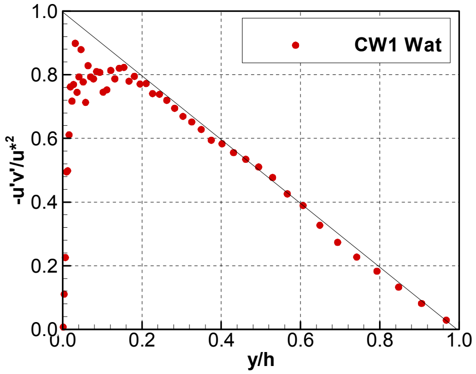
NBS

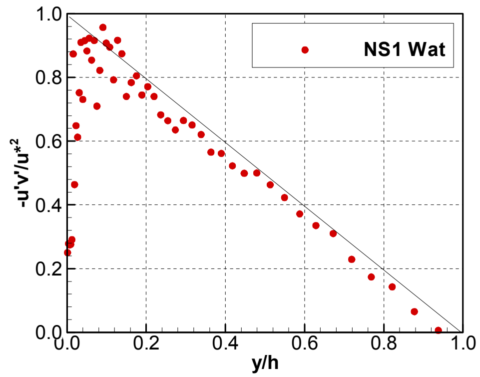
- Water turbulence intensities increased near bed
- Water turbulence intensities increased in the outer layer (more particles in this area)
- Particle turbulence intensities larger than fluid, excepting near the bed



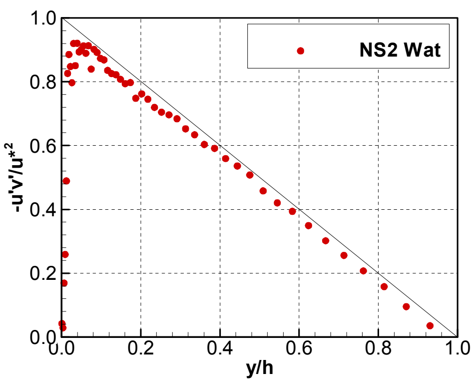
(d) NBS1 (e) NBS2 (f) NBS3

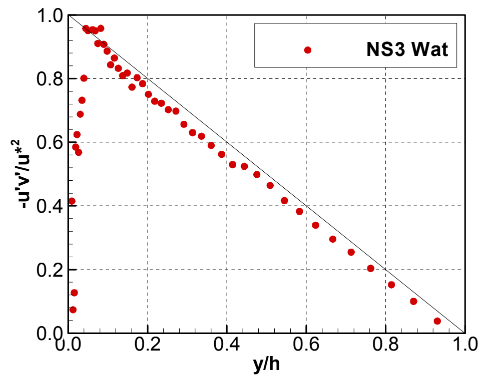
Turbulence characteristics

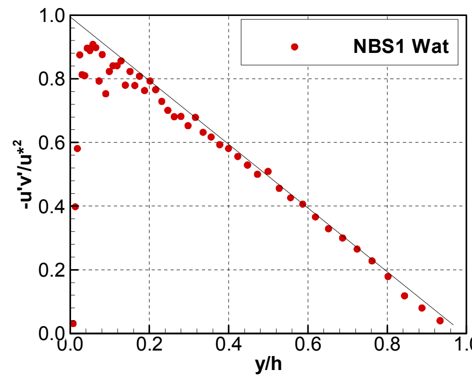


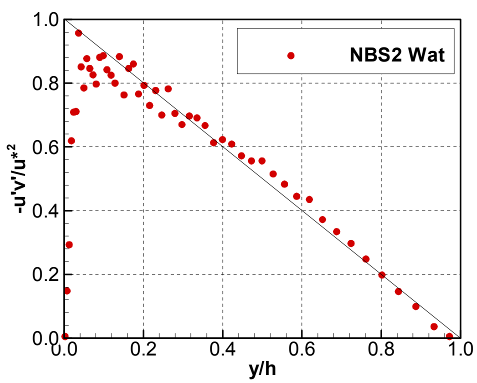


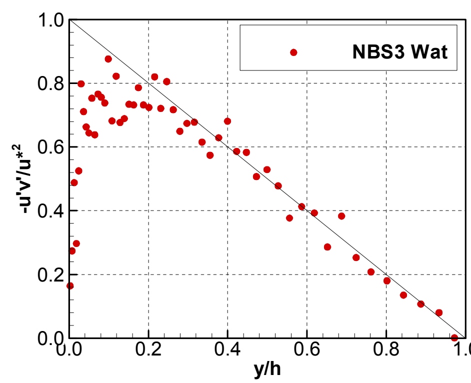
Reynolds stress not affected by sediment presence ➔ friction velocity can be reliably determined using these measurements





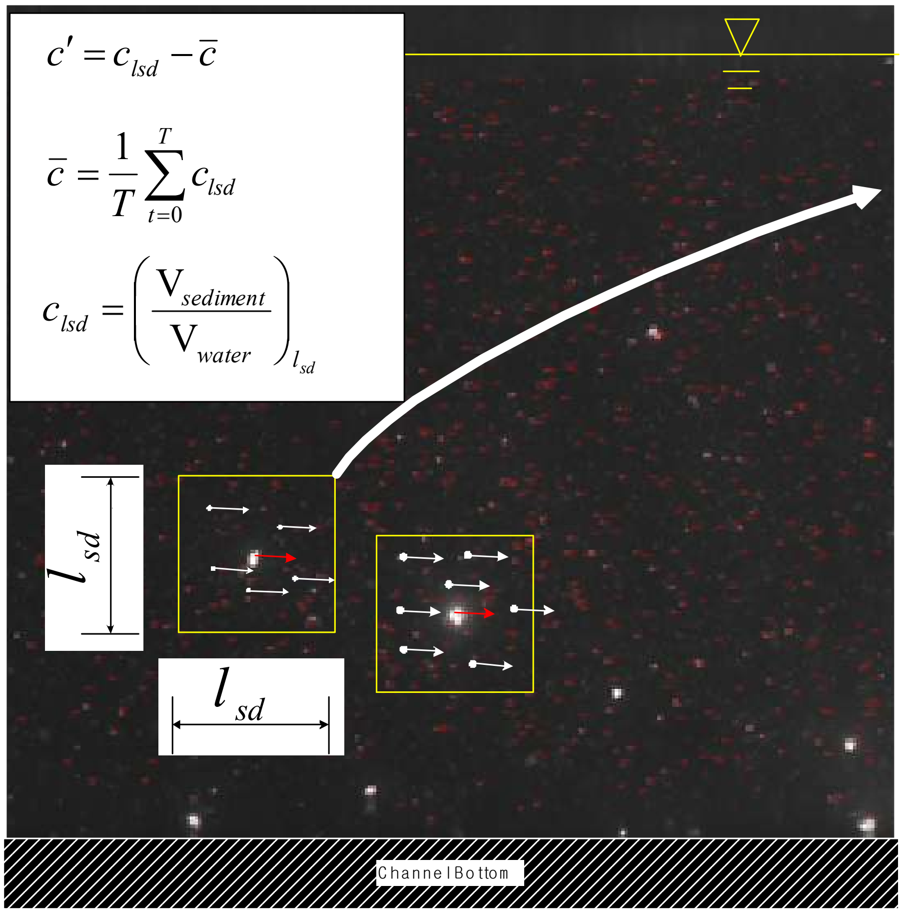


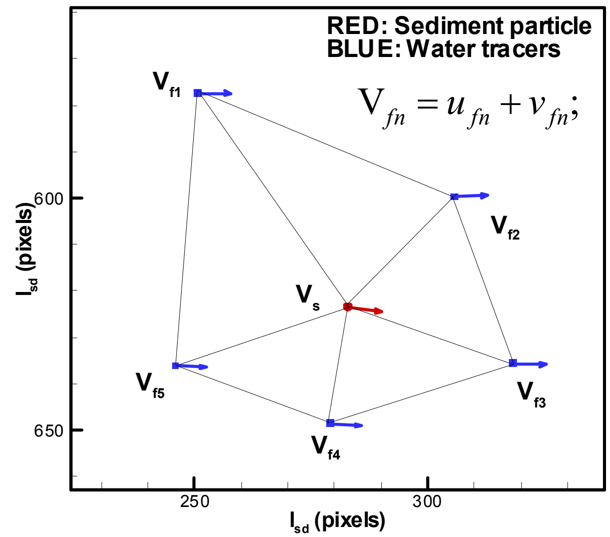




Particle-fluid interaction

- Multiple particle-fluid interaction defines the sediment diffusion coefficient





$$v'_f = v_f - \bar{v}_f; \quad \bar{v}_f = \frac{1}{T}\sum_{t=0}^{T} v_f$$

$$v_f = \frac{1}{N}\sum_{n=0}^{N} v_{f,n} \quad on \quad l_{sd} \times l_{sd}$$

Conclusion I

- Up to 5% average streamwise velocity lag for NS ➔ up to 40% reduction in suspended sediment transport (Aziz, 1996). No lag for NBS.
- Average vertical velocity (inverse) lag for NS. No lag for NBS.
- Smaller K for both NS and NBS for $C_{vol} > 10^{-4}$
- Average vertical particle velocity different from the settling velocity
- Turbulence intensities for water modified in the presence of sediment and different from those measured on the sediment particles
- Two-phase measurements promise important clarifications on the interaction between turbulence coherent structures and individual or groups of sediment particles and for formulation of improved sediment transport predictive relationships

Application II: Macro-Scale Flows

Large-Scale Particle-Image Velocimetry (LSPIV)

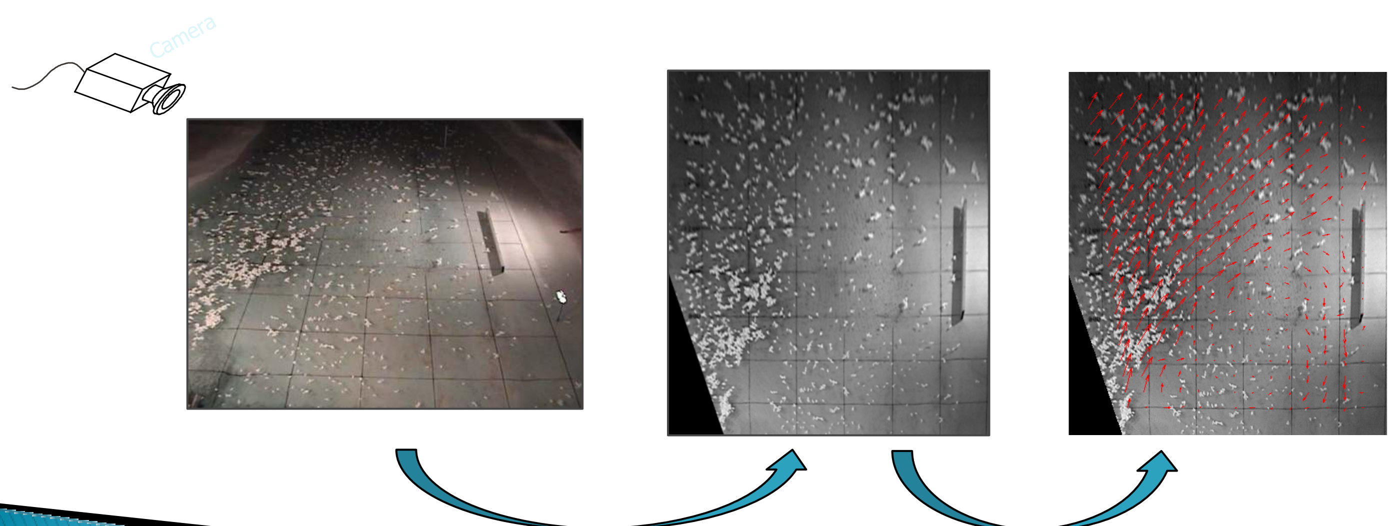
- an extension of the conventional PIV
- mostly applied for velocity measurement at the free surface of a moving water body
- Pioneered at IIHR since 1994
- identified by USGS Hydro21 committee as one of the candidate technology for remote discharge measurement in 1999

Collaborators:

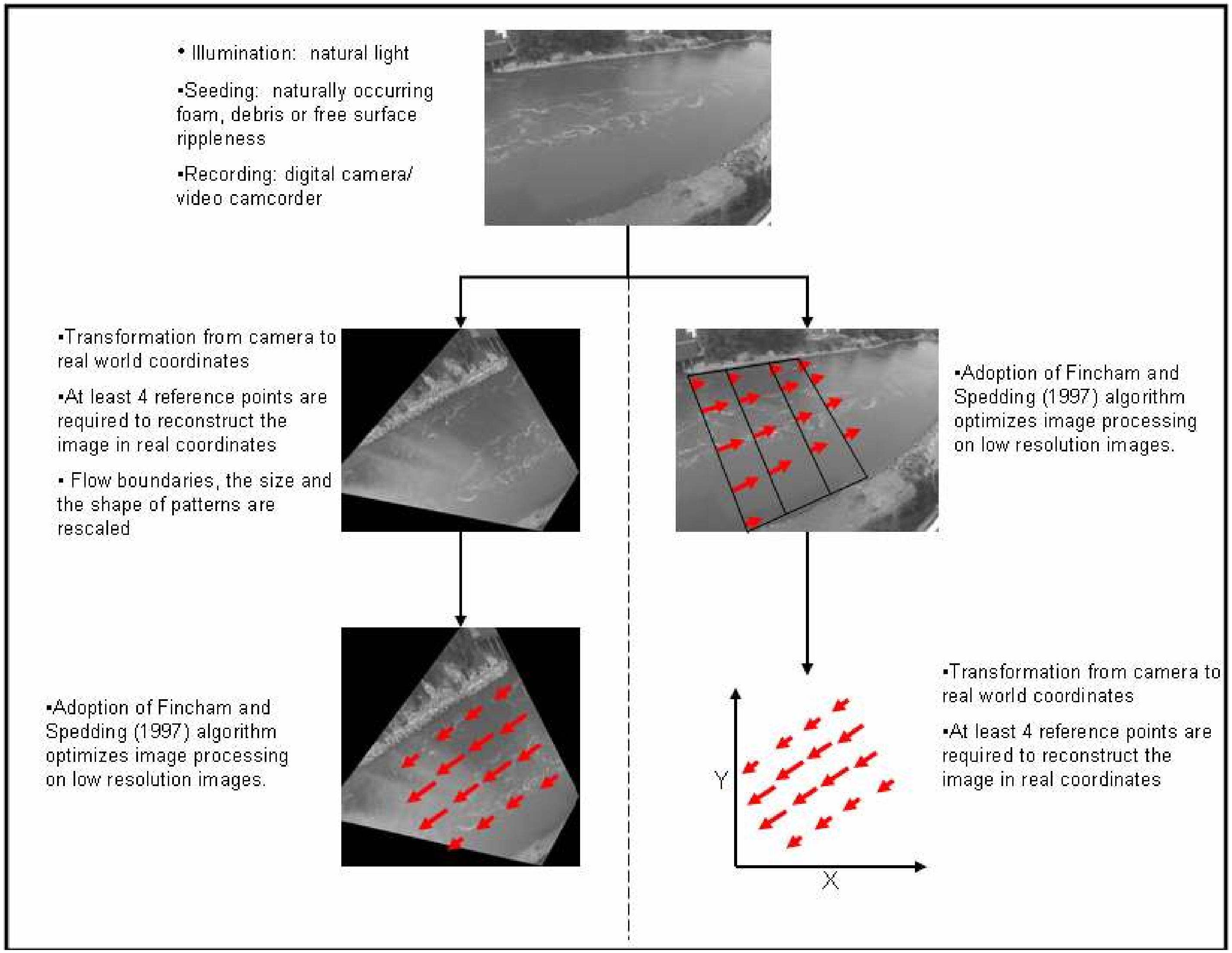
I. Fujita, A. Kruger, A. Bradley, W. Krajewski, K. Yu, G. Schone, D. Creutin, S-C Schul, Y. Kim, Z. Xiong, X. Zhongwei, H-C Ho

LSPIV Components

- **Illumination** - natural or artificial light
- **Seeding** - small & light for accurate flow tracing
  - large enough for efficient detection
  - various particle sizes or image brightness distributions (patterns)
- **Recording** - video systems for most HE applications
- **Image Processing** - related to seeding concentration
  - 2-D cross-correlation (most often used)



LSPIV - Approaches

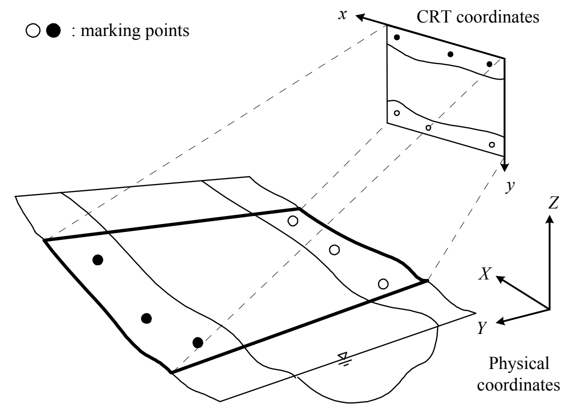


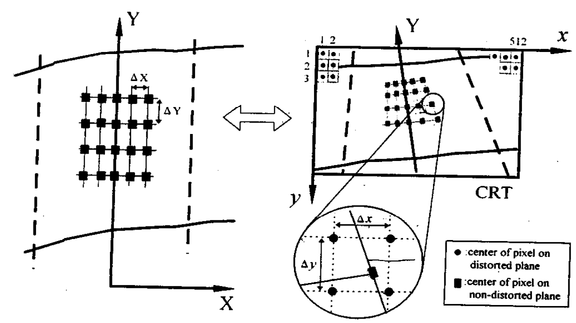
LSPIV - Image Orto-rectification

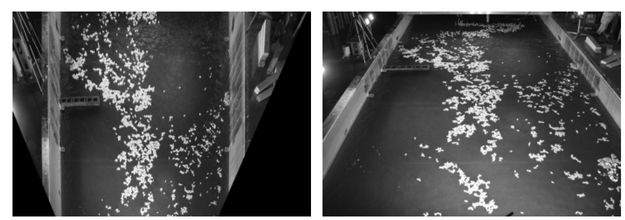
- LSPIV images : usually oblique angle
  - Introduce lens and geometrical distortion of the actual configuration of the flow
  - Remove both types of distortion using a geometrical transformation to the recorded images

- Conventional transformation
  - Surveying physical coordinates of ground reference points

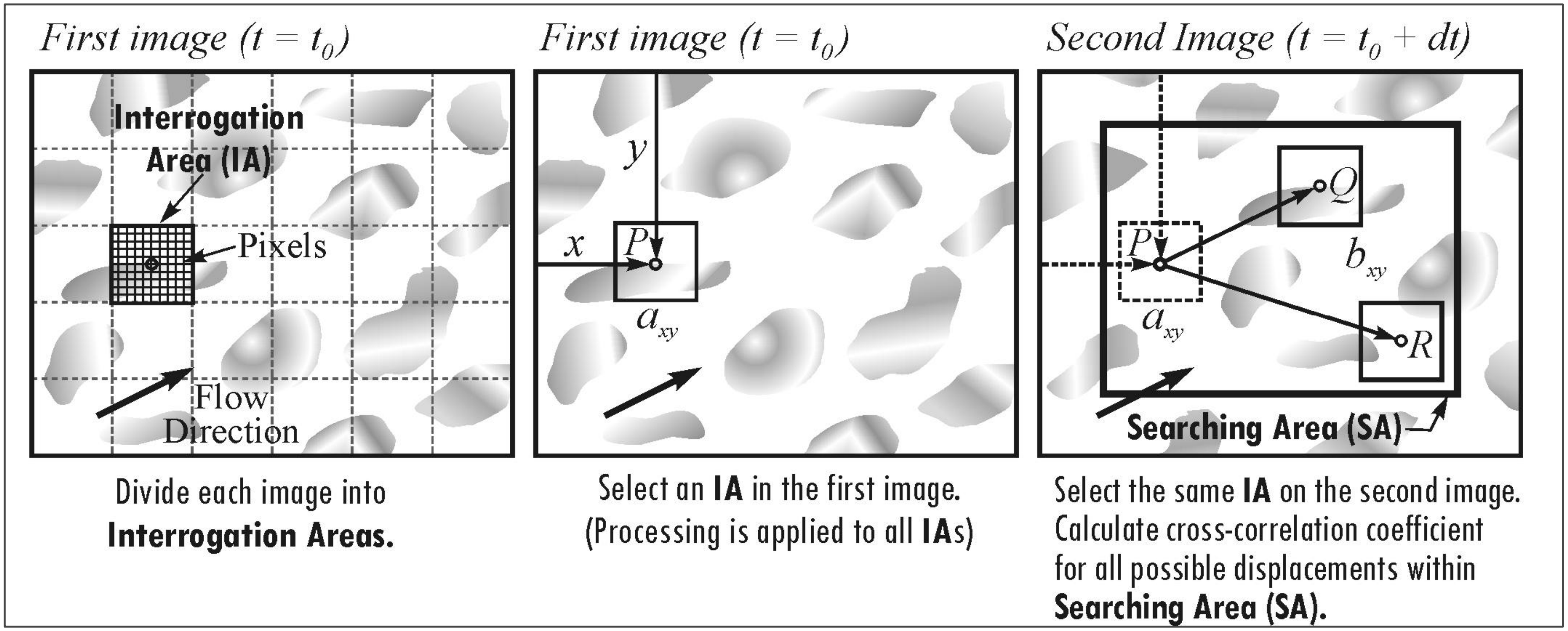
- Transformation with non-intrusive instrumentation
  - Range finder, laser total station, GPS
  - Camera model calibration method
  - Automated transformation method





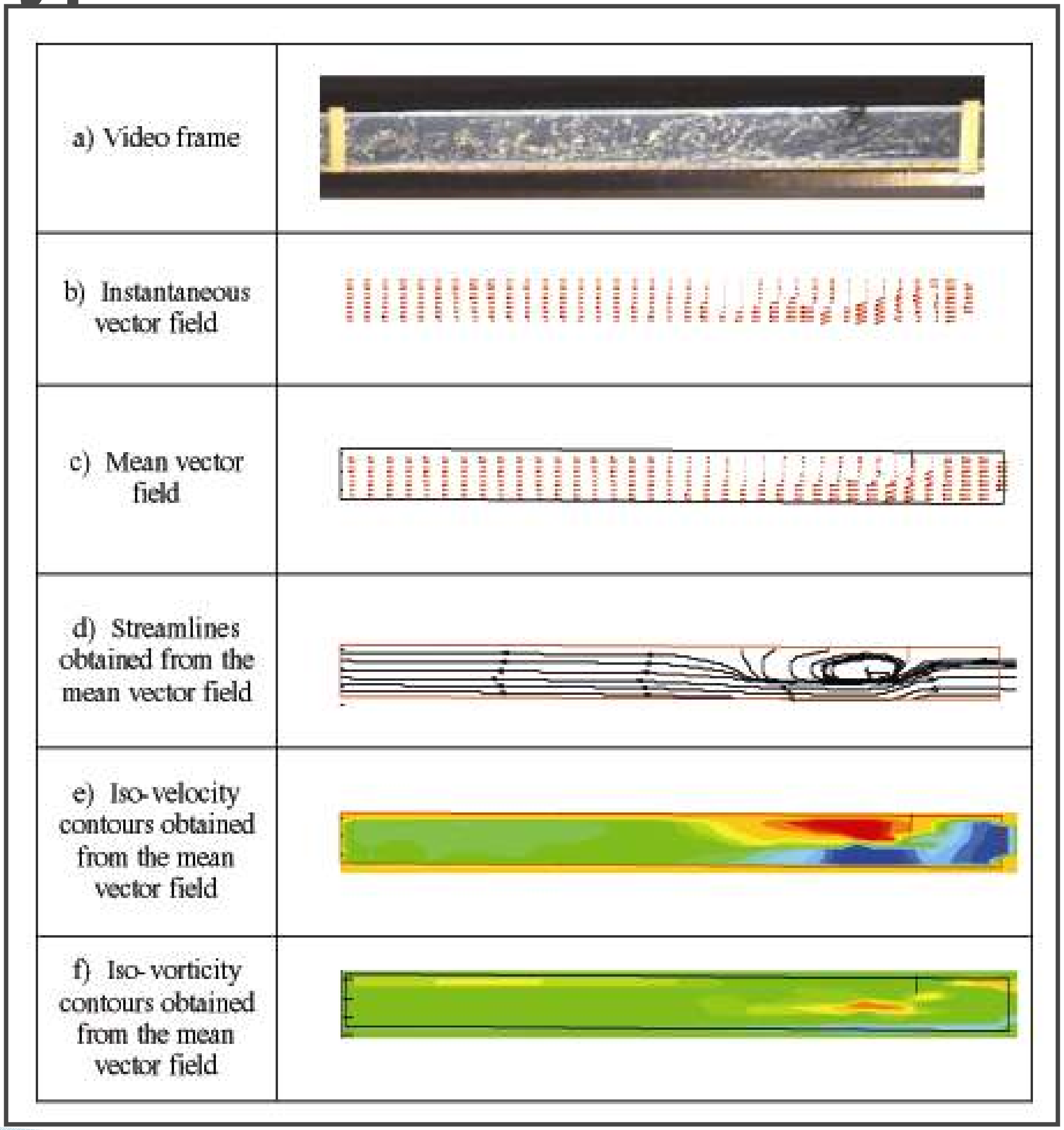


LSPIV - Image Velocimetry



- Estimate the *displacement of marked regions of the flow* by observing the images of the markers on two or a series of images
- The displacement measurements of markers between two successive images are calculated on *small regions (interrogation areas)* in the images using a statistical approach
- The velocity vector of each interrogation area is calculated by dividing the displacements by the time difference of the two successive images

LSPIV typical results



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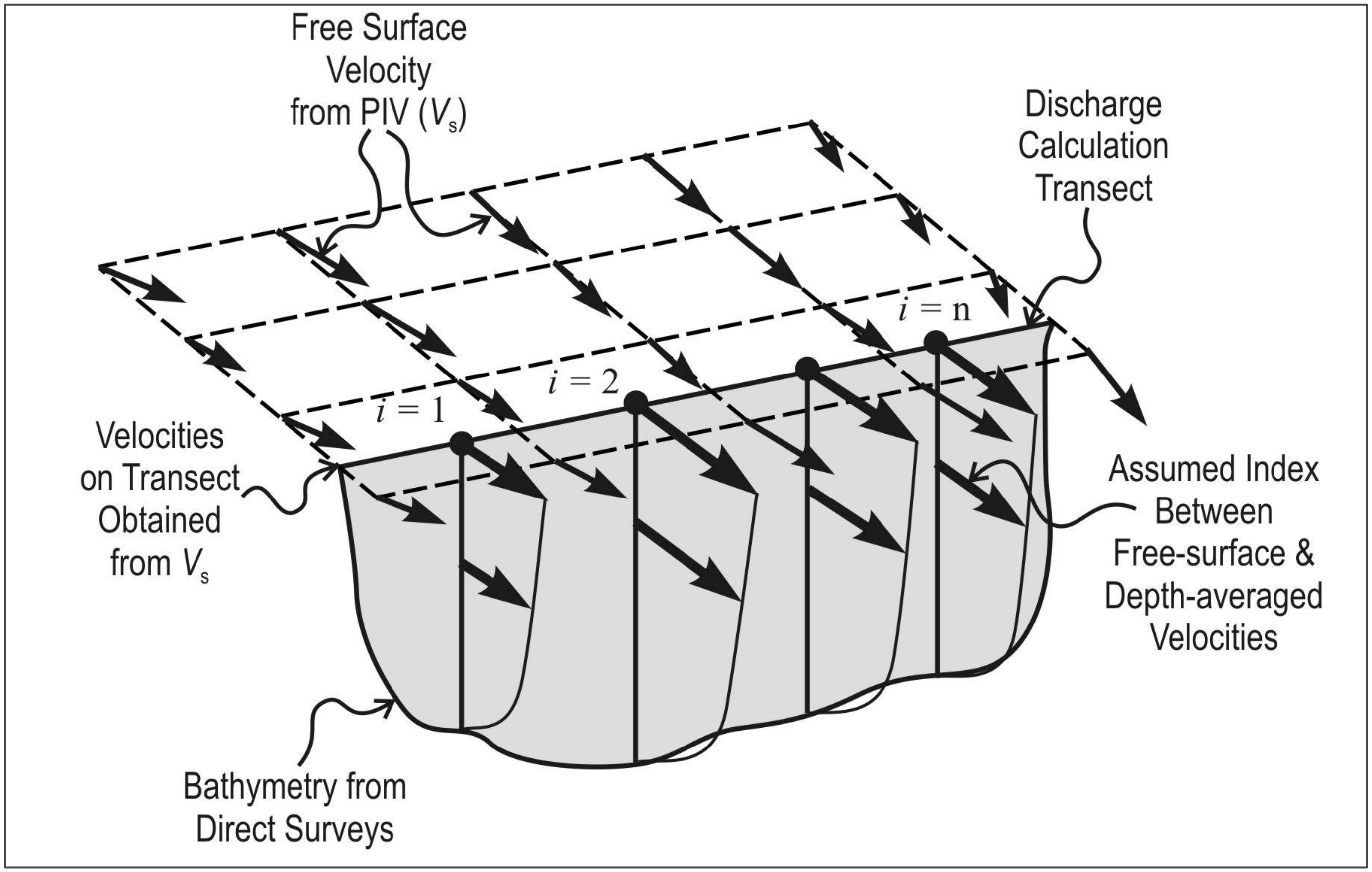
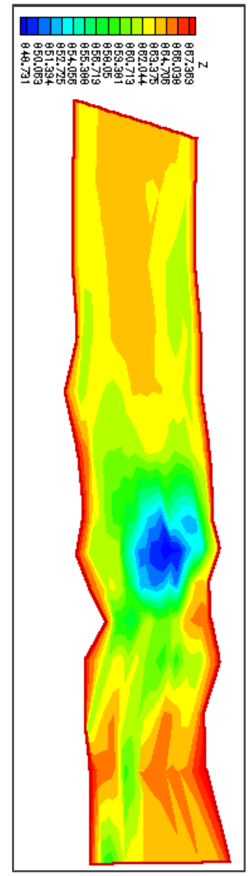
LSPIV - Typical results

Flow Discharge



LSPIV implementation: Laboratory

Flow distribution in large-scale models



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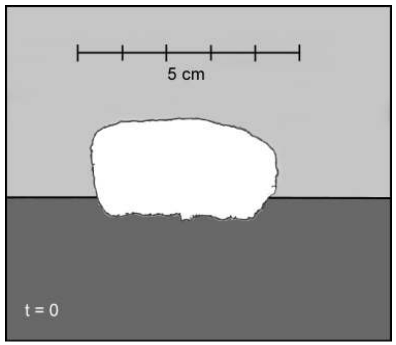
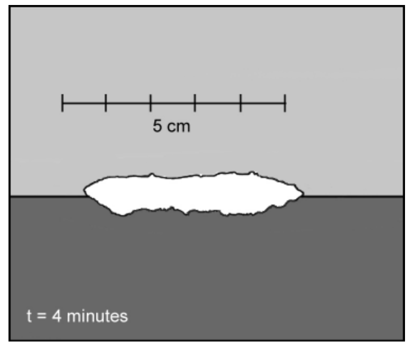
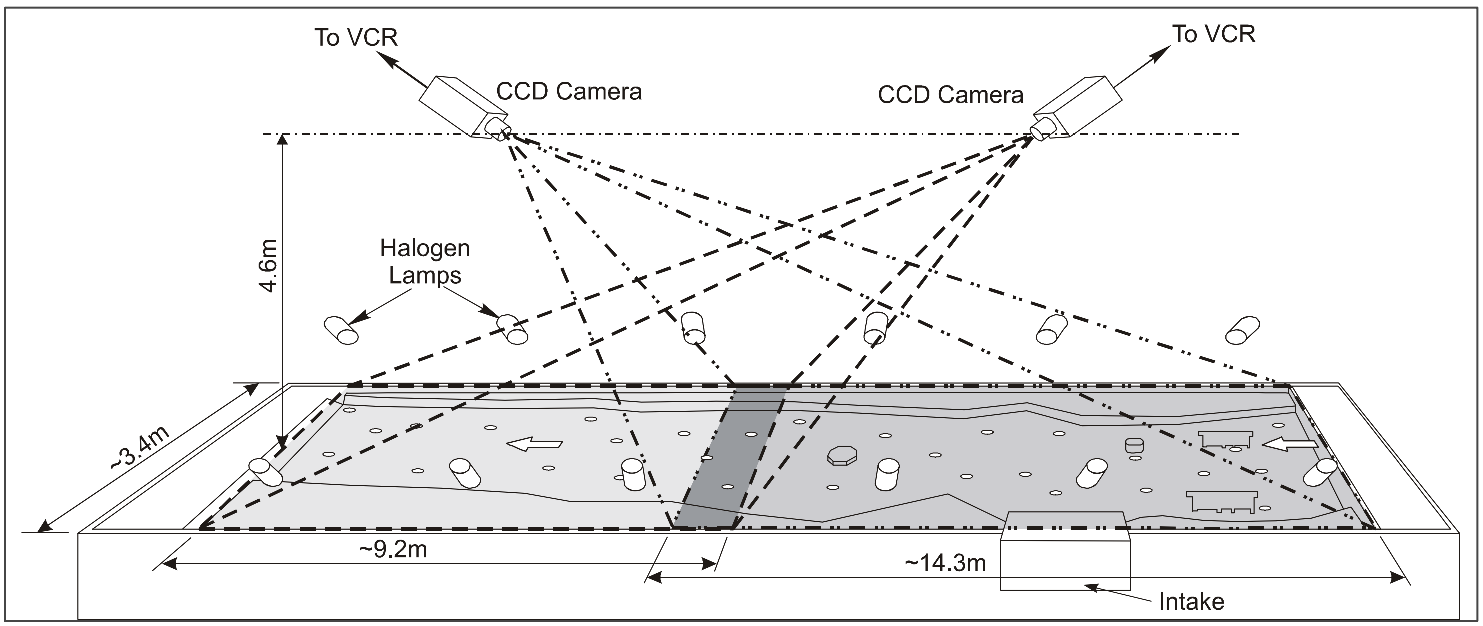
LSPIV implementation: Laboratory

Flow distribution in large-scale models

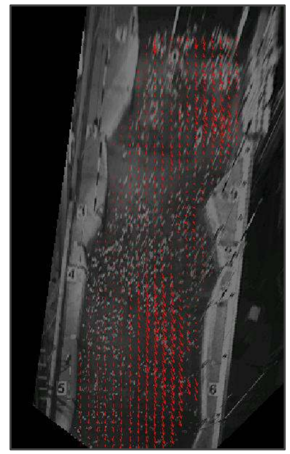


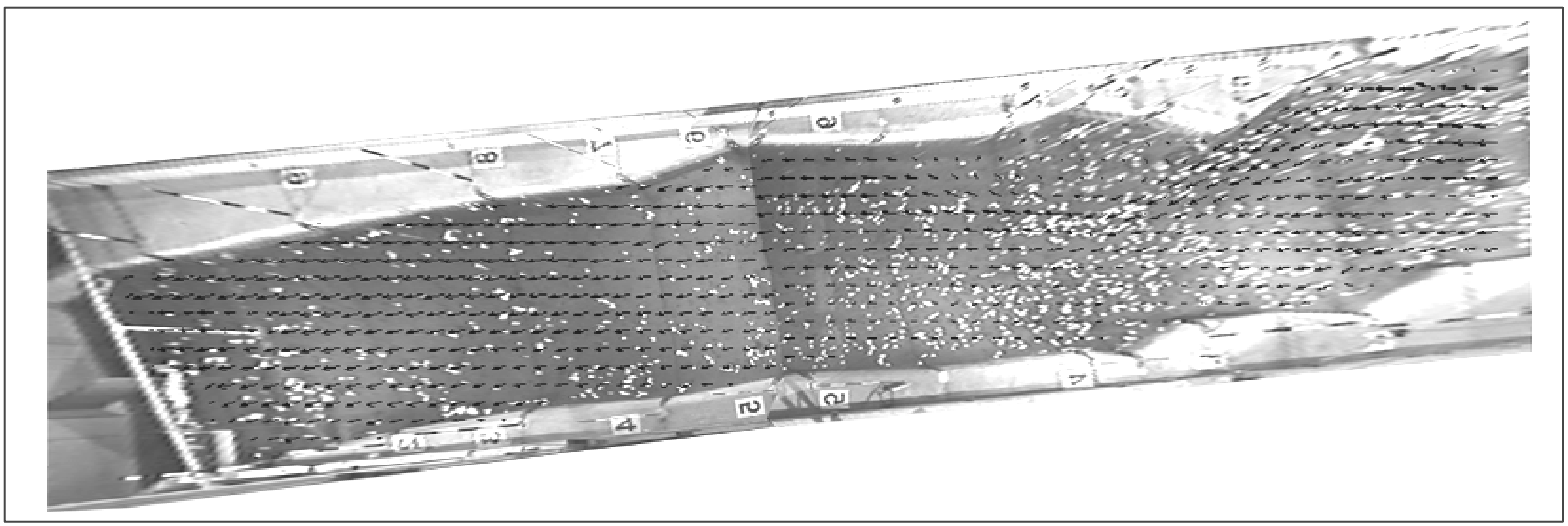




LSPIV implementation: Laboratory

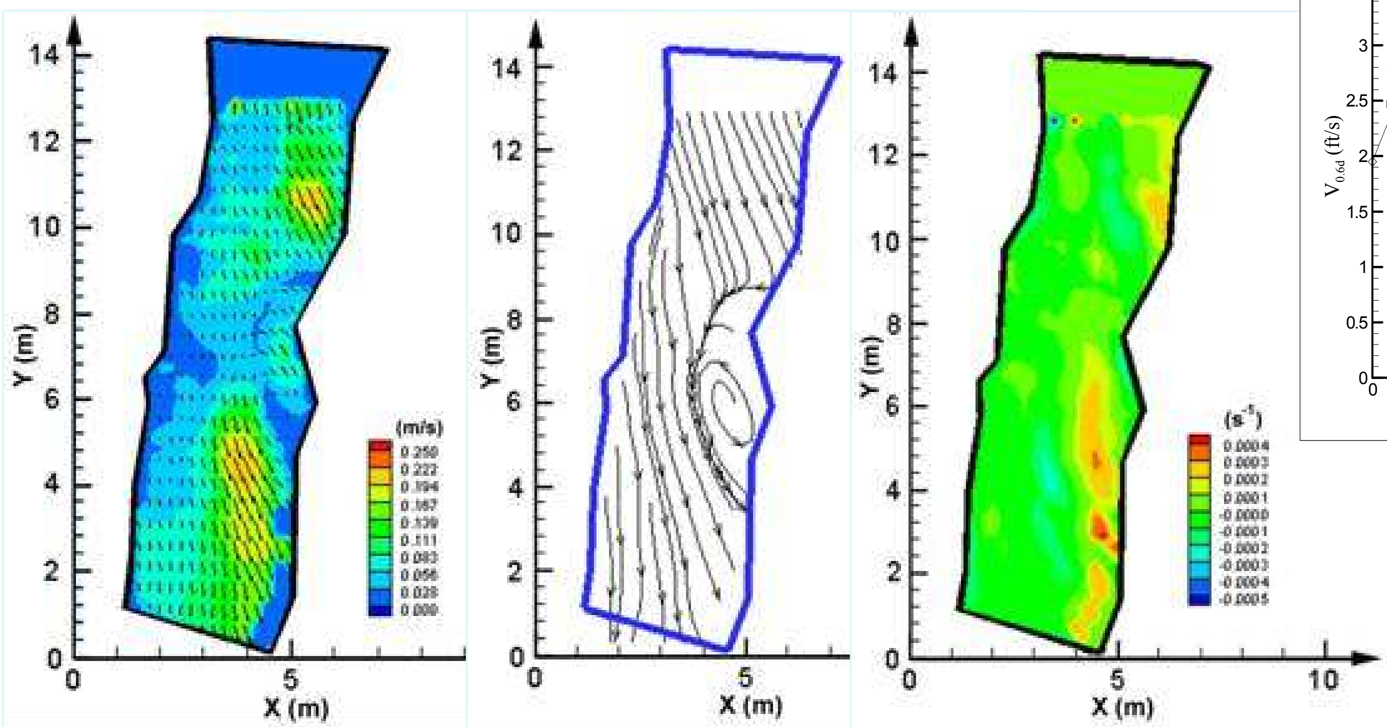
Flow distribution in large-scale models

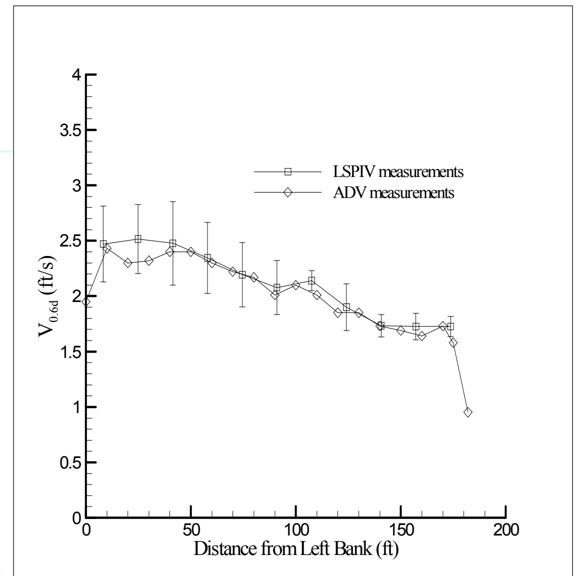




LSPIV implementation: Laboratory

Flow distribution in large-scale models





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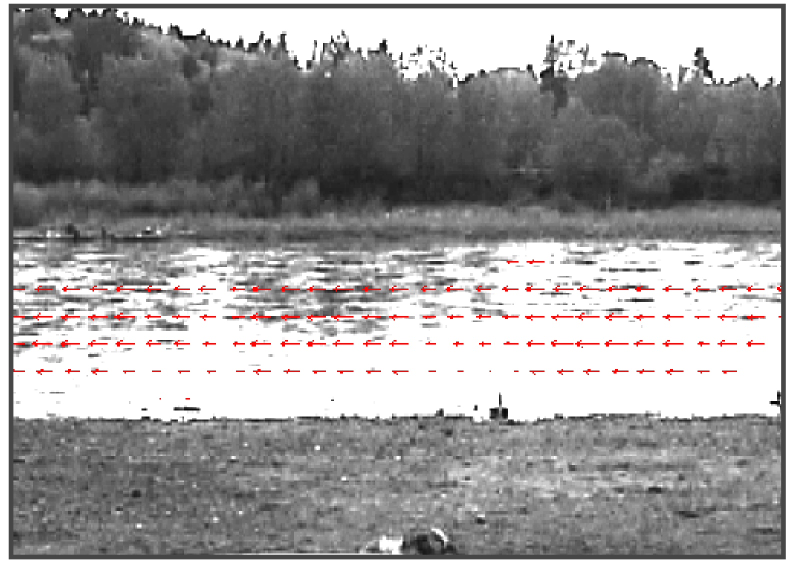
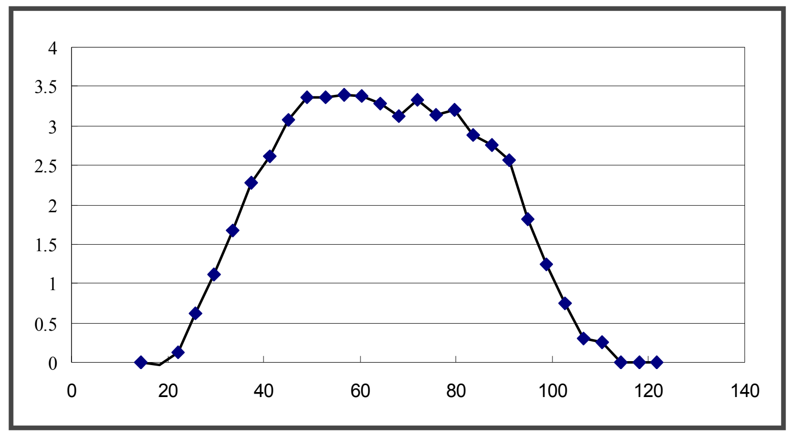
LSPIV implementation: Field

Stream velocity





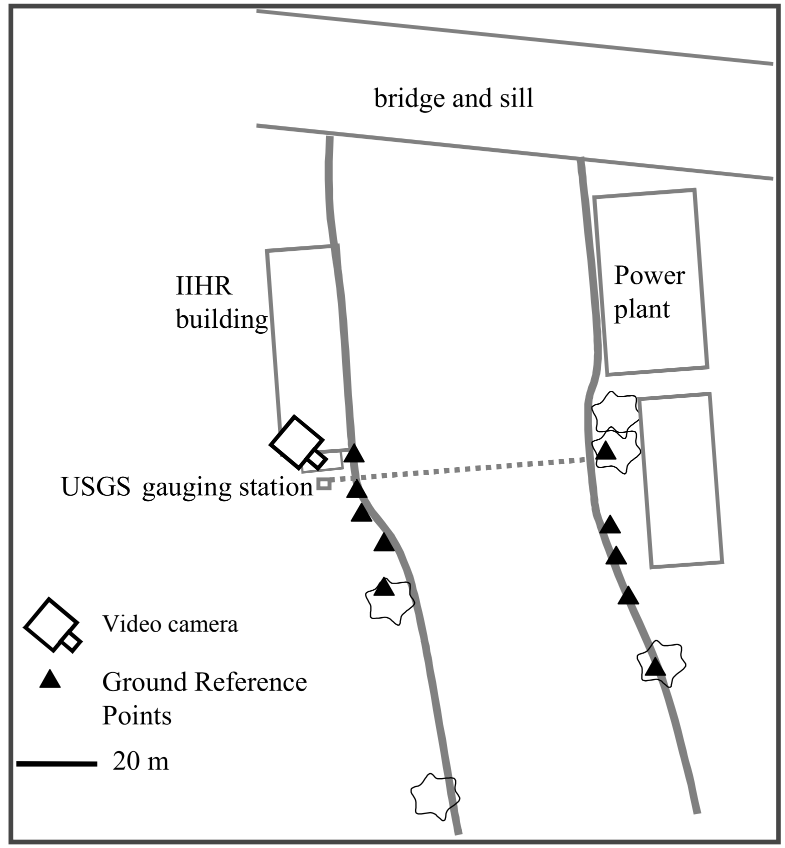
LSPIV implementation: Field

River discharge Measurements

(LSPIV measurements in conjunction with bathymetry information)

Iowa River

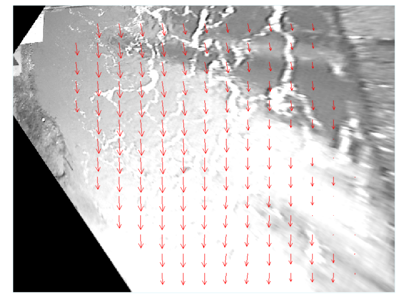
- **Flow imaged area: ~ 3,500 m²**
- **Velocity range: 0 – 3 m/s**
- **Seeding: natural foam**
- **comparison with USGS measured discharges shows good agreement for 10 individual measurements conducted over three weeks**

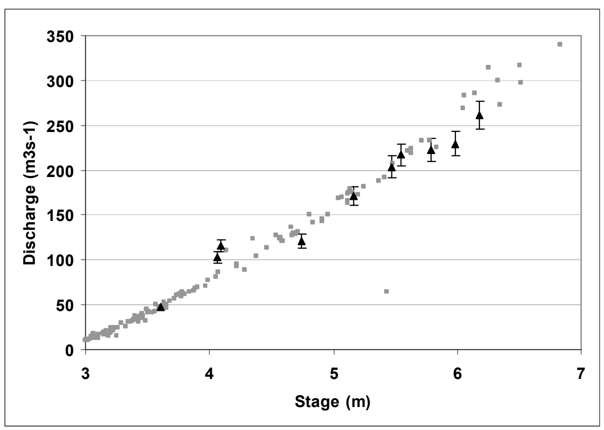


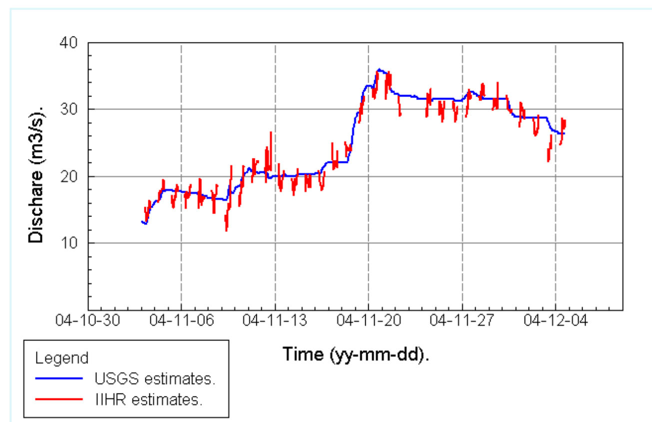
LSPIV implementation: Field

River discharge measurements:

(calibration results and real-time measurements (http://far.iihr.uiowa.edu/PIV_WebPage_Index.htm)







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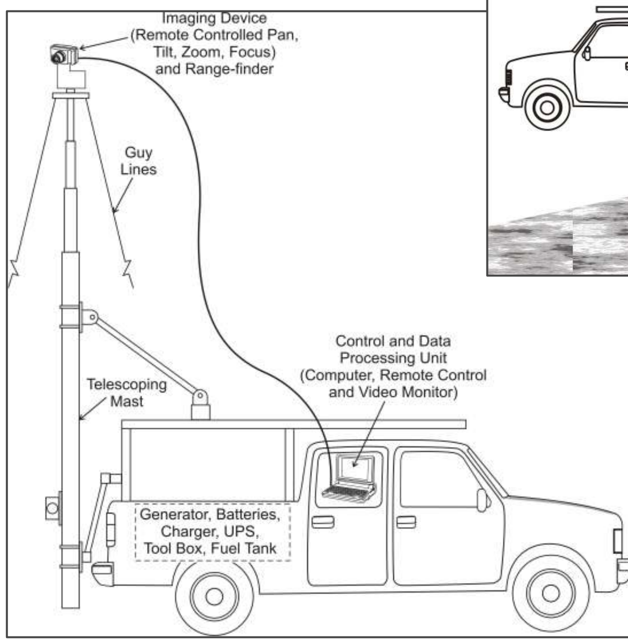
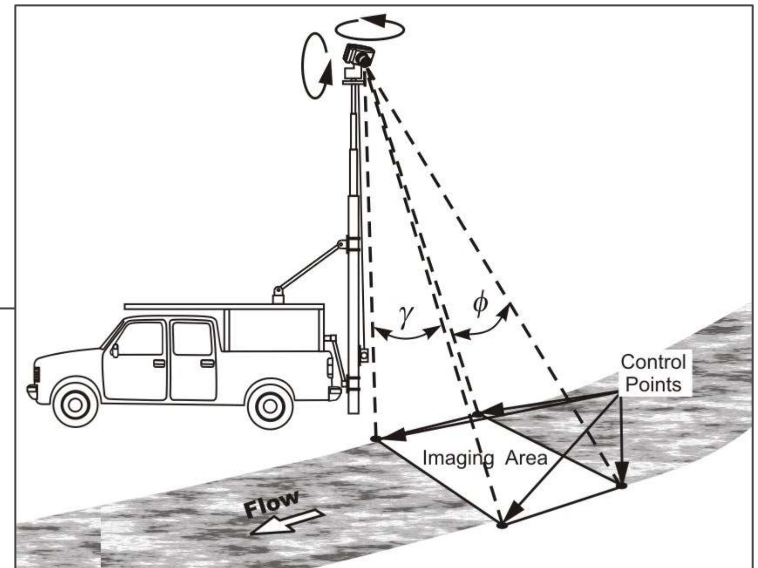
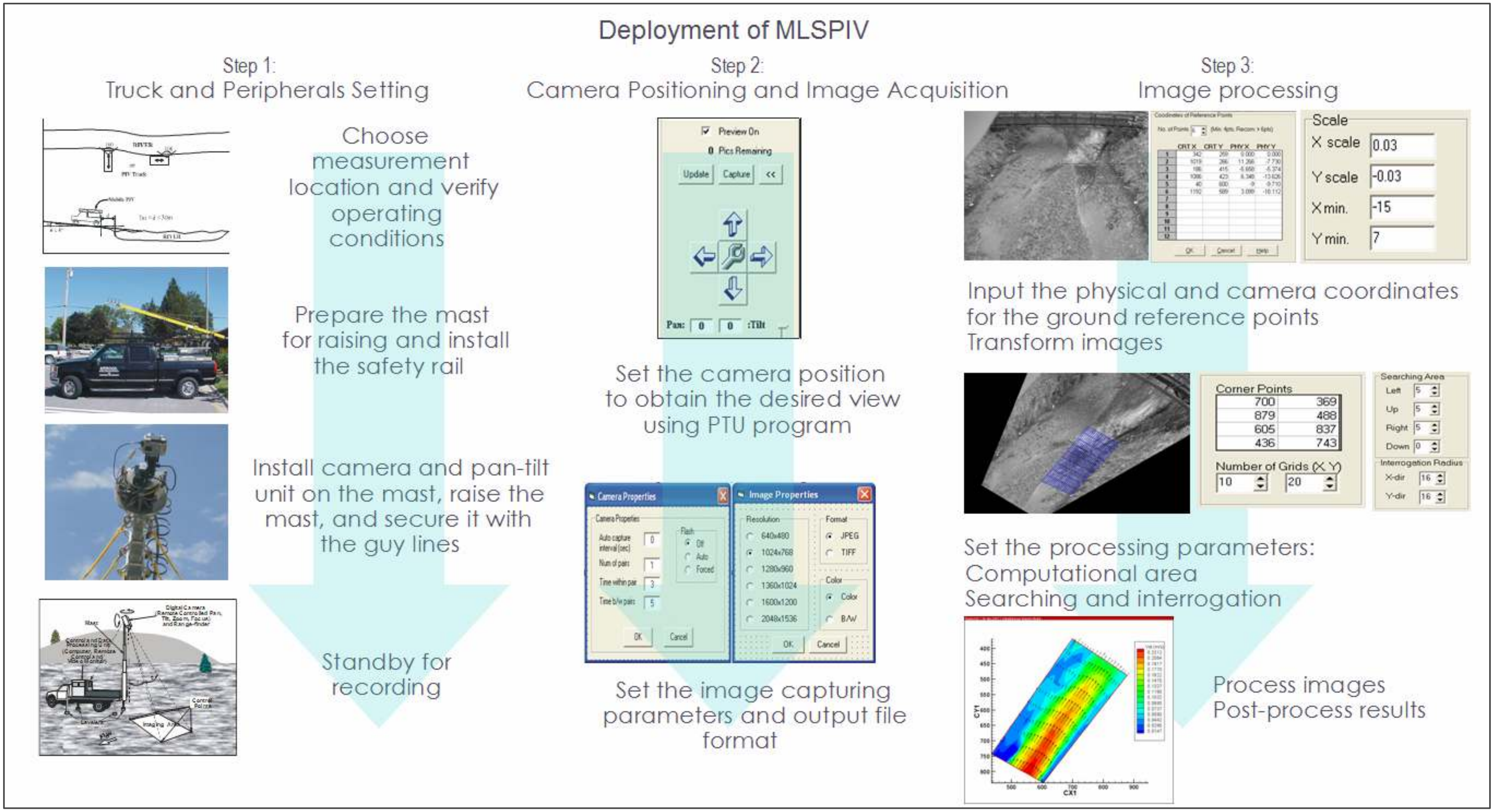
LSPIV implementation: Field

Real-time LSPIV unit for investigating stream processes



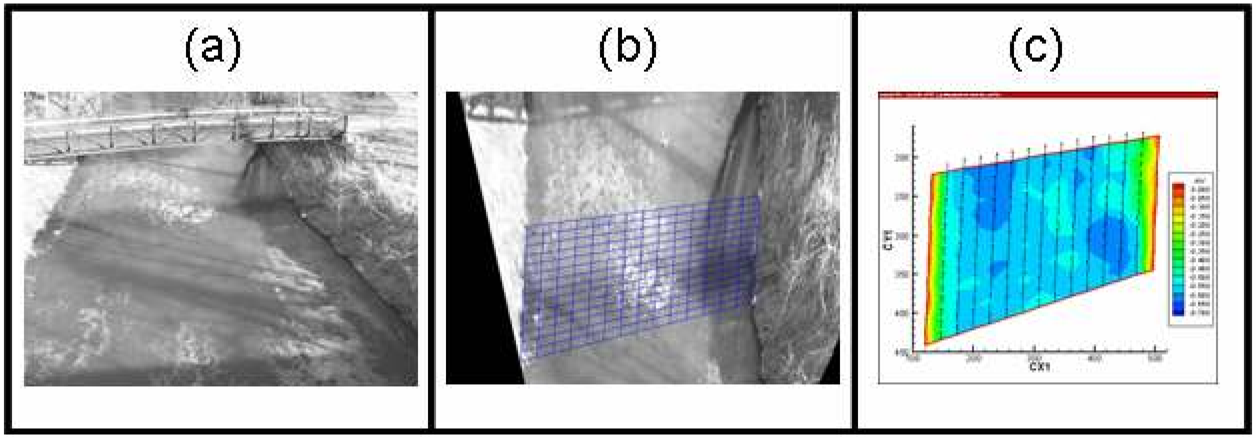


LSPIV implementation: Field



LSPIV implementation: Field

Real-time LSPIV – instrument inter-comparison



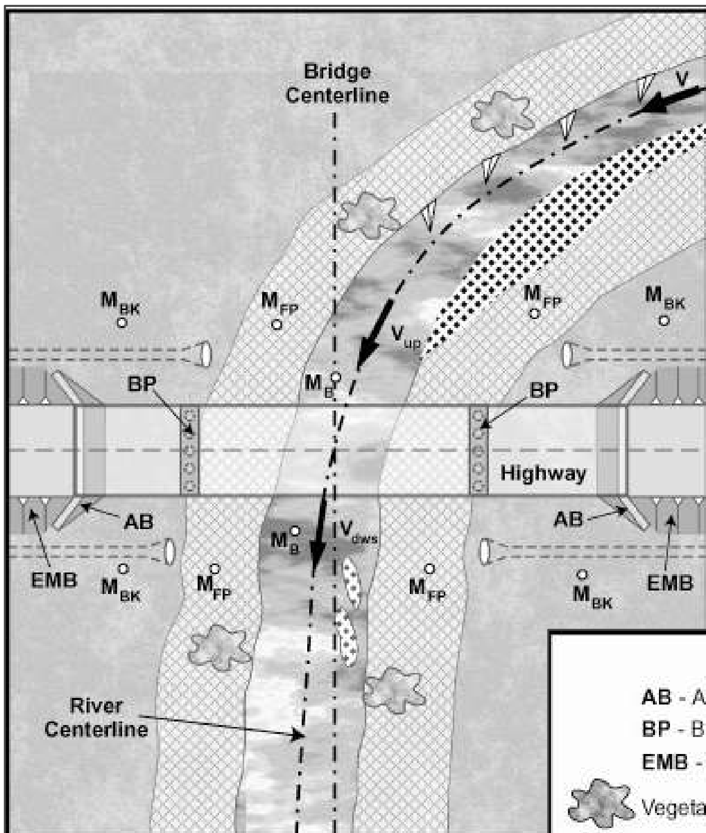
	USGS	StreamPro ADCP	MLSPIV
Discharge (m^3/s)	5.2	4.9	5.0
Error (%)	Reference	-5.5	-3.5

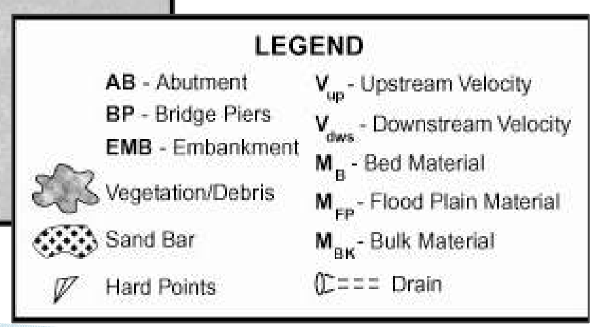
Current LSPIV research

- **Digital mapping using LSPIV**
- **Controlled Surface Wave Image Velocimetry**

Current LSPIV research

Digital Mapping: developed to reduce the time & effort required to to obtain consistent, reliable information on bridge waterways





Waterway = bridged stream + banks + abutments + local obstructions

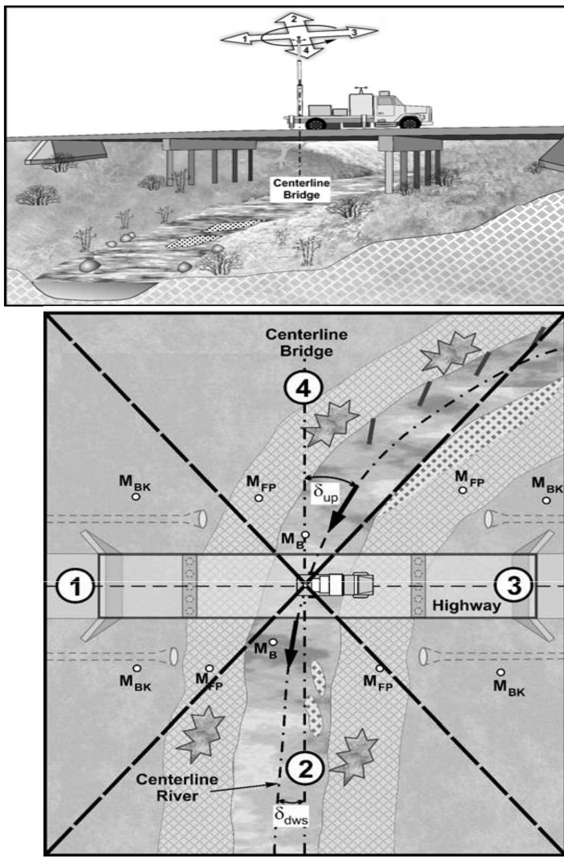
Scour monitoring:

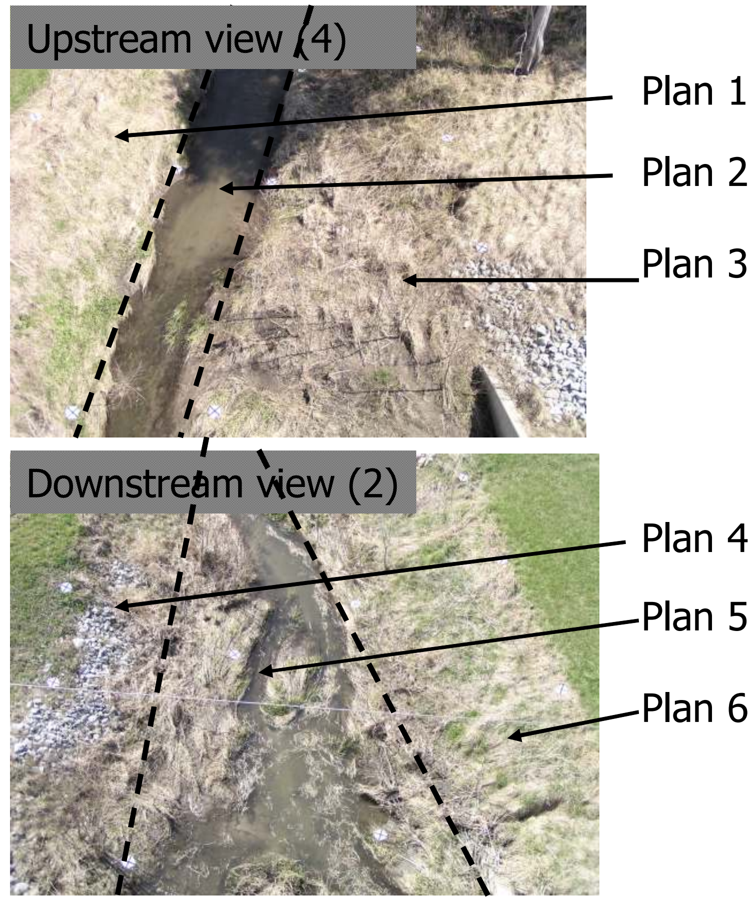
- Frequent inspections
- Checking for waterway changes
- Tracking of temporal changes

Image-based quantitative mapping

Current LSPIV research

Digital Mapping: System configuration and data acquisition



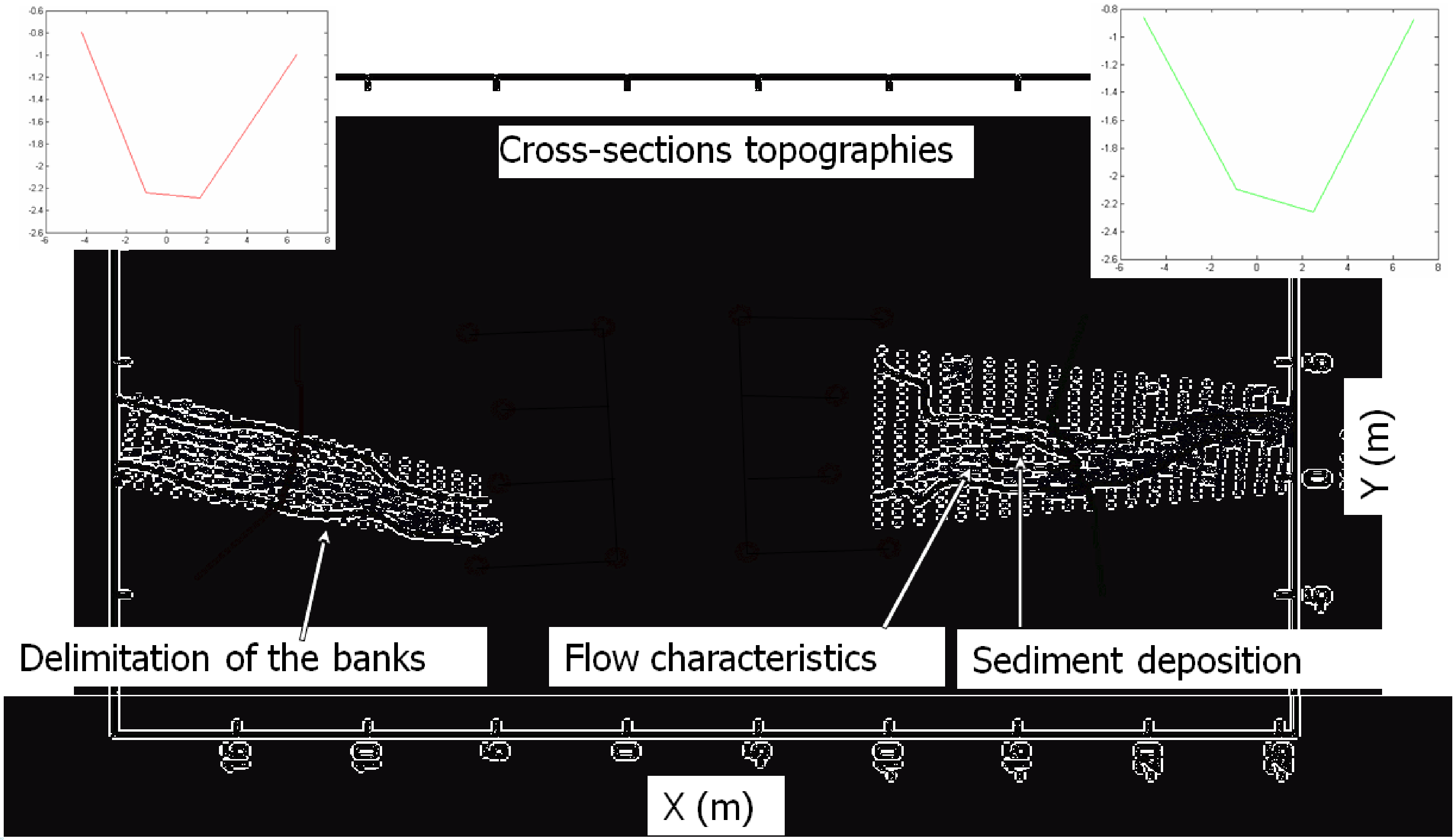


Current LSPIV research

Digital Mapping: Outcomes = orto-rectified images of the bridge vicinity + LSPIV flow surface measurement

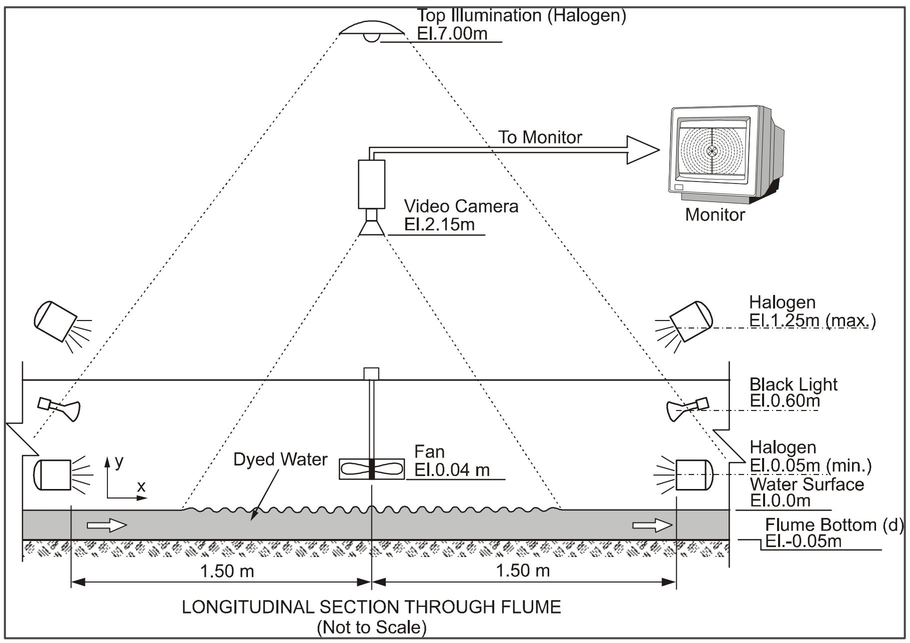
Current LSPIV research

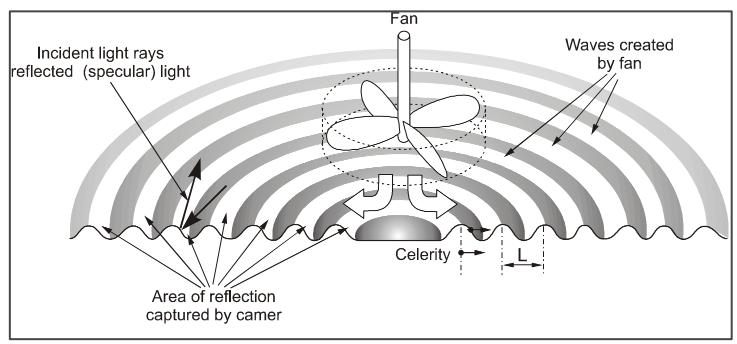
Digital Mapping: Tool for long-term tracking of the bridge waterways



Current LSPIV research

Controlled Surface Wave Image Velocimetry (CSWIV)





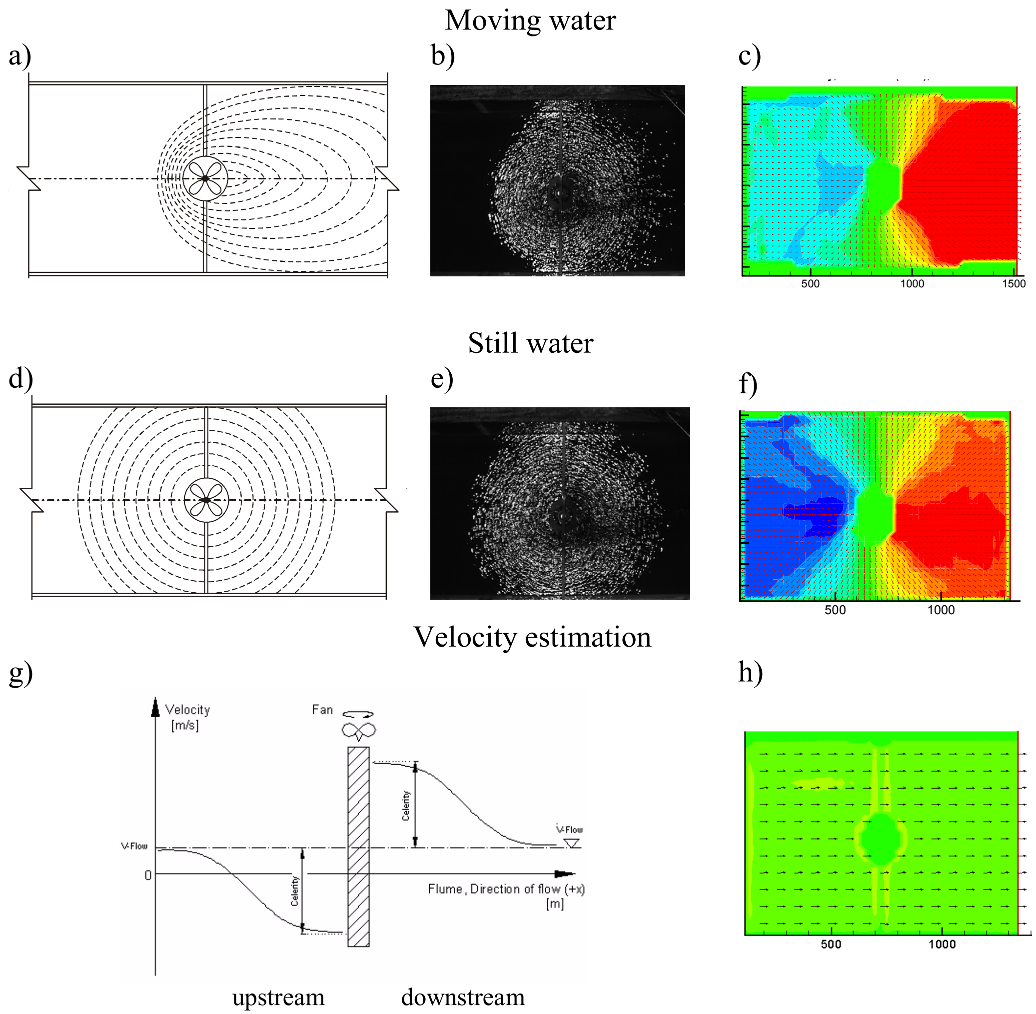
Current LSPIV research

CSWIV

-controlled disturbance produced at the free surface creates a moving pattern (a,b,c,d)

- image velocimetry applied to the moving pattern provides vector field (c,f)

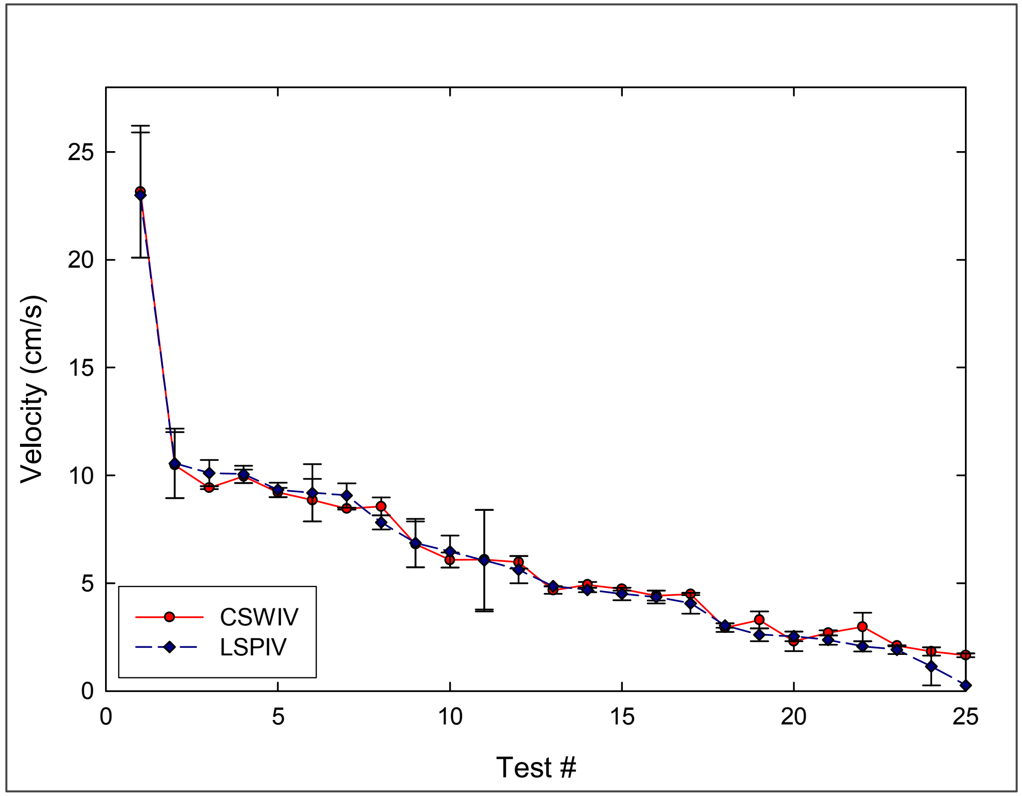
-subtraction of the velocity field upstream-downstream the disturbance provides the underlying flow velocity (g)



Current LSPIV research

CSWIV

Adequate for shallow, very low velocity flows (wetlands, runoff)



Conclusion II

- Proof of concepts and detailed tests reveal the maturity and feasibility of LSPIV for investigation of laboratory and field flows under a wide variety of conditions

- LSPIV can benefit measurements in special situations:
  - Floods
  - Streams where boats cannot be deployed (e.g., shallow)
  - Ungaged basins (using the mobile LSPIV unit)
  - Very low velocity flows (e.g., wetlands)
  - Ecohabitat restoration (bank stability & erosion)
  - Stream-hydraulic structure interaction (bridge scour)
  - Estimation of ice and debris transport rates

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