Field survey and monitoring methods for river flow, sediment transport and river bed in mountain regions

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Outline

- Brief introduction on rivers in mountain regions
- Objective, plan and preparation of field survey
- Measured methods for river flow
- Measured methods for sediment transport
- Measured methods for river bed
- Concluding remarks

Education and Research Experience

- **Study area: Qinghai Tibet Plateau (QTP)**
- **Study field: River dynamics and fluvial processes**

Education

Sept. 2011-Jan. 2014	Tsinghua University	Ph.D.
Sept. 2008-Mar. 2011	IWHR	Eng. M.
Sept 2003-June 2007	Wuhan University	Eng. B.

Research

Nov. 2019-	Wuhan University	Associate Professor
Jan. 2016-Oct. 2019	Changsha University of S & T	Associate Professor
Feb. 2014-Feb. 2016	National University of Singapore	Research Fellow
Jan. 2014-Jan. 2016	Tsinghua University	Post-doctoral

> 30 times field experiences on QTP


Yangtze River Source


Yellow River Source


Yarlung Tsangpo Grand Canyon

2010

2011

2012


Yarlung Tsangpo Grand Canyon


Yellow River Source


Yarlung Tsangpo Source

2013

2016


Yarlung Tsangpo Canyon


Yellow River Source


Nujiang River Source

2017

2018


Yigong Tsangpo Canyon

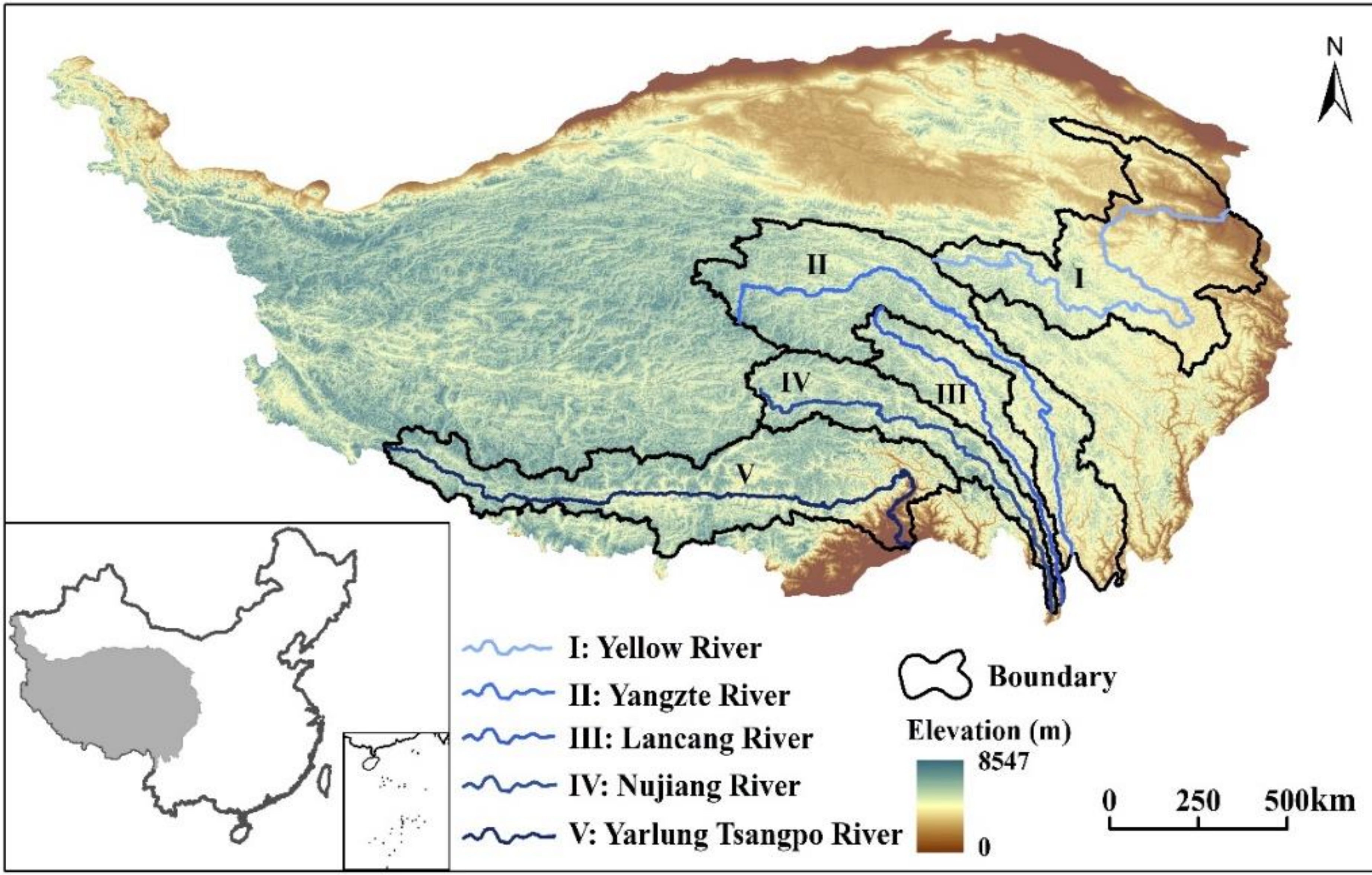
2019

2020

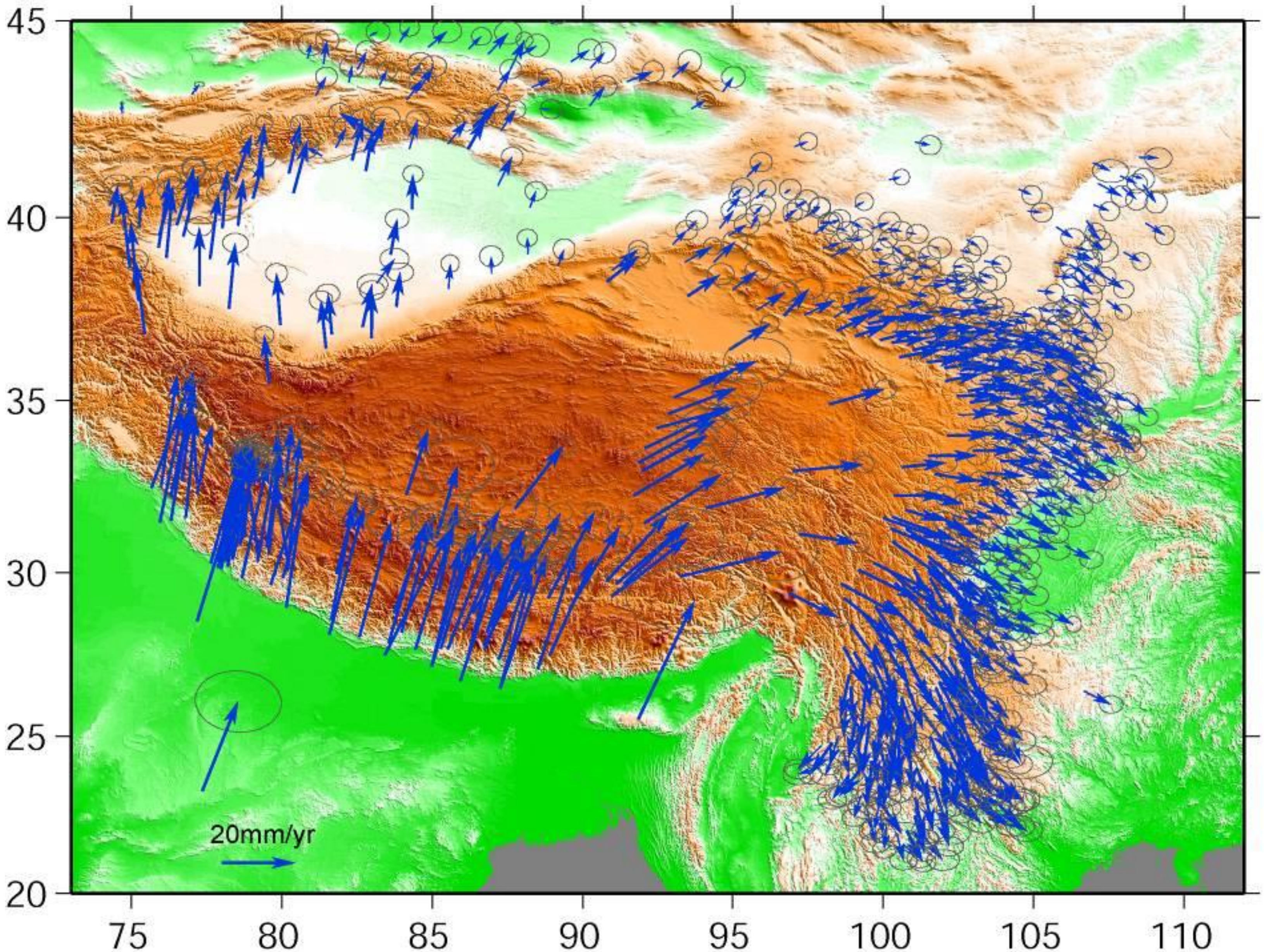

Yellow River Source


Palong Tsangpo Canyon

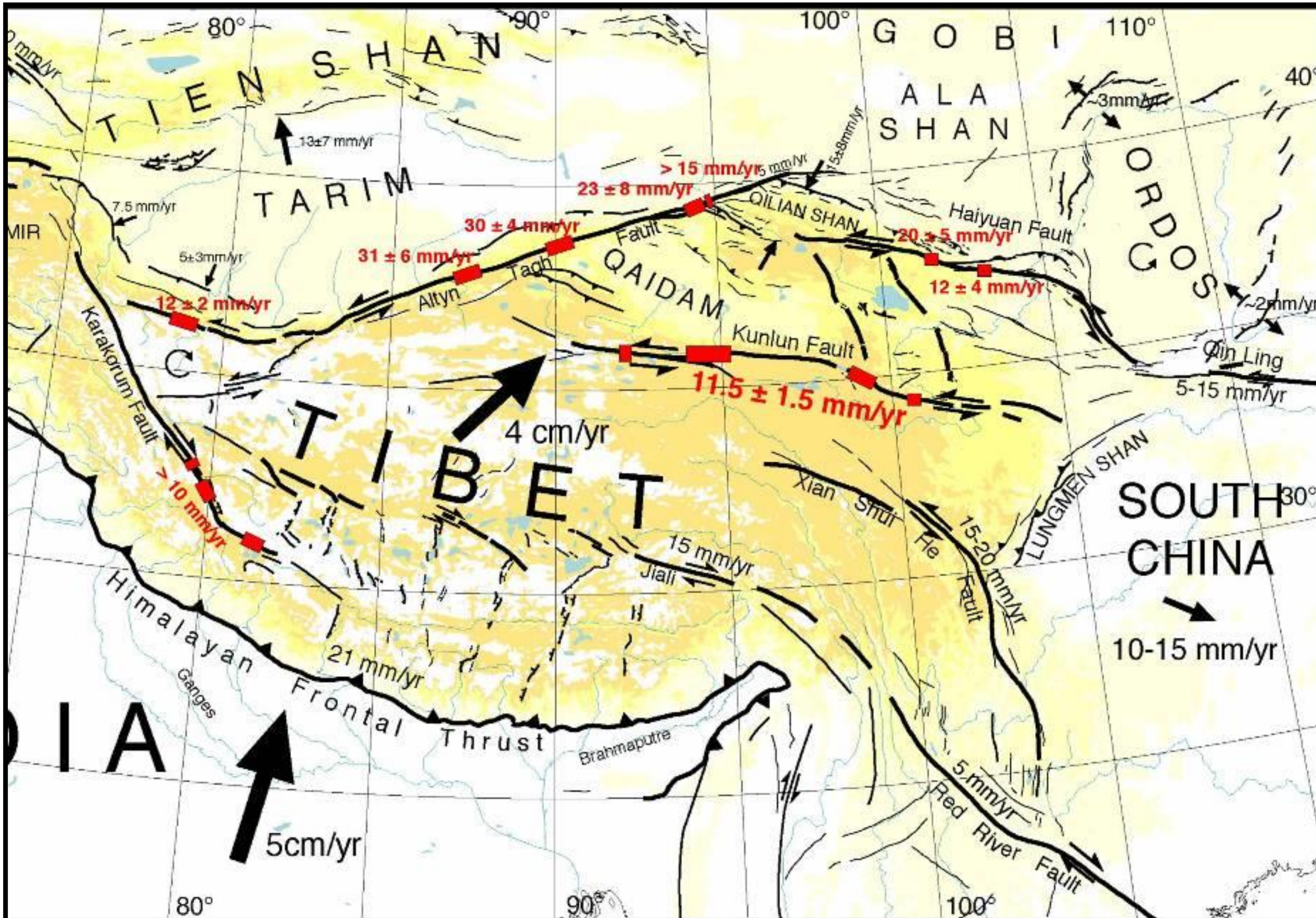
Five large river basins drain on QTP



High stress and strain accumulation on the QTP



Mean annual displacement rate on the QTP



Aim of field survey (Prof. Gary Brierley’s advices)

- **It isn’t real until it’s virtual---field survey**;
- Interpretative river: describe, explain, predict;
- An ability to relate place-based findings to general or theoretical principles;
- An intuitive eye for river pattern, form and process
- How do we obtain an ability to ‘read a river’?

Automated mapping for rivers (Prof. Gary Brierley)

- ✓ Making riverscapes real (Carbonneau et al., 2012; Wheaton et al., 2015)
- ✓ Development and use of fluvial process (Cullum et al. 2016)
- ✓ Automated reach delineation (Notebaert & Piegay, 2013)
- ✓ Habitat mapping (Wheaton et al., 2010)

☐ Management implication: "***Respect Diversity***"

Automated change detection (Prof. Gary Brierley)

- Process-based understandings of what happens where, at what rate

- Analysis of behaviour, change, range of variability

- Capacity to test equilibrium notions and magnitude-frequency relations (among many things)

- Explanation of controls and drivers … from channel processes to valley evolution … rivers are products of their valleys!

□ Management application: "*Work with Change*"

Brief introduction on rivers in mountain rivers

- **A classification of channel-reach morphology in mountain drainage basins synthesizes stream morphologies into seven distinct reach types: colluvial, bedrock, and five alluvial channel types (cascade, step pool, plane bed, pool riffle, and dune ripple).**

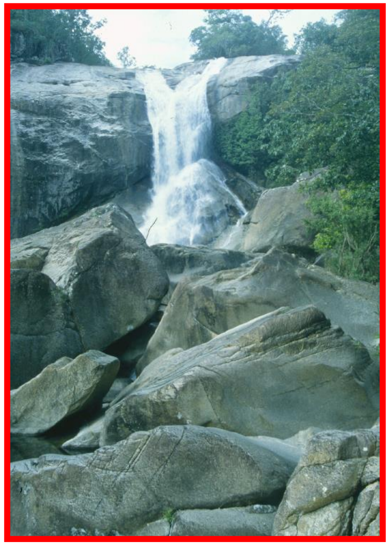
- **An incised river** is defined as a river that is experiencing bed-level lowering. From the viewpoint of geomorphological process, mountain rivers either were or are **incised rivers**.
- **Large rivers** may be incised rivers in the upper reaches, but fluvial rivers in the middle and lower reaches.

Diagnostic features of each channel type

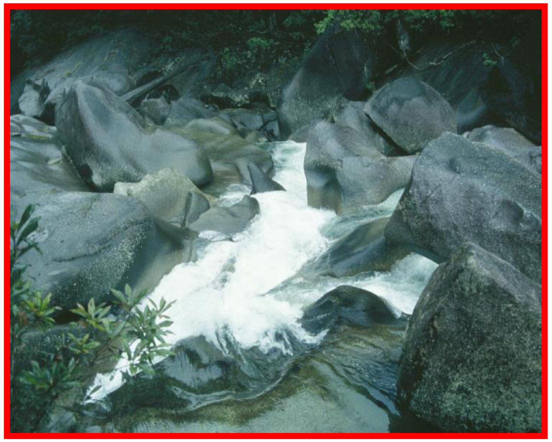
	Dune ripple	Pool riffle	Plane bed	Step pool	Cascade	Bedrock	Colluvial
Typical bed material	Sand	Gravel	Gravel-cobble	Cobble-boulder	Boulder	Rock	Variable
Bedform pattern	Multilayered	Laterally oscillatory	Featureless	Vertically oscillatory	Random	Irregular	Variable
Dominant roughness elements	Sinuosity, bedforms (dunes, ripples, bars) grains, banks	Bedforms (bars, pools), grains, sinuosity, banks	Grains, banks	Bedforms (steps, pools), grains, banks	Grains, banks	Boundaries (bed and banks)	Grains
Dominant sediment sources	Fluvial, bank failure	Fluvial, bank failure	Fluvial, bank failure, debris flows	Fluvial, hillslope, debris flows	Fluvial, hillslope, debris flows	Fluvial, hillslope, debris flows	Hillslope, debris flows
Sediment storage elements	Overbank, bedforms	Overbank, bedforms	Overbank	Bedforms	Lee and stoss sides of flow obstructions	Pockets	Bed
Typical confinement	Unconfined	Unconfined	Variable	Confined	Confined	Confined	Confined
Typical pool spacing (channel widths)	5 to 7	5 to 7	None	1 to 4	<1	Variable	Unknown

Montgomery and Buffington(1997). Channel-reach morphology in mountain drainage basins. GSA Bulletin.

Instream sculpted or erosional units



Waterfall



Cascade

Step-pool

Pool

Decreasing slope, energy and grain size continuum

Colluvial type




- Riverbed incision increased the landslide potential and resulted in the Xiaolin landslide, which was triggered by a Typhoon in 2009.

Bedrock type

Cascade type

Hukou waterfall

Jiuzhaigou waterfall

Jinzhu Tsangpo River

A cascade in Jinzhu Tsangpo in Tibetan Plateau

Step-pool type

Step-pool type in the Yarlung Tsangpo Grand Canyon

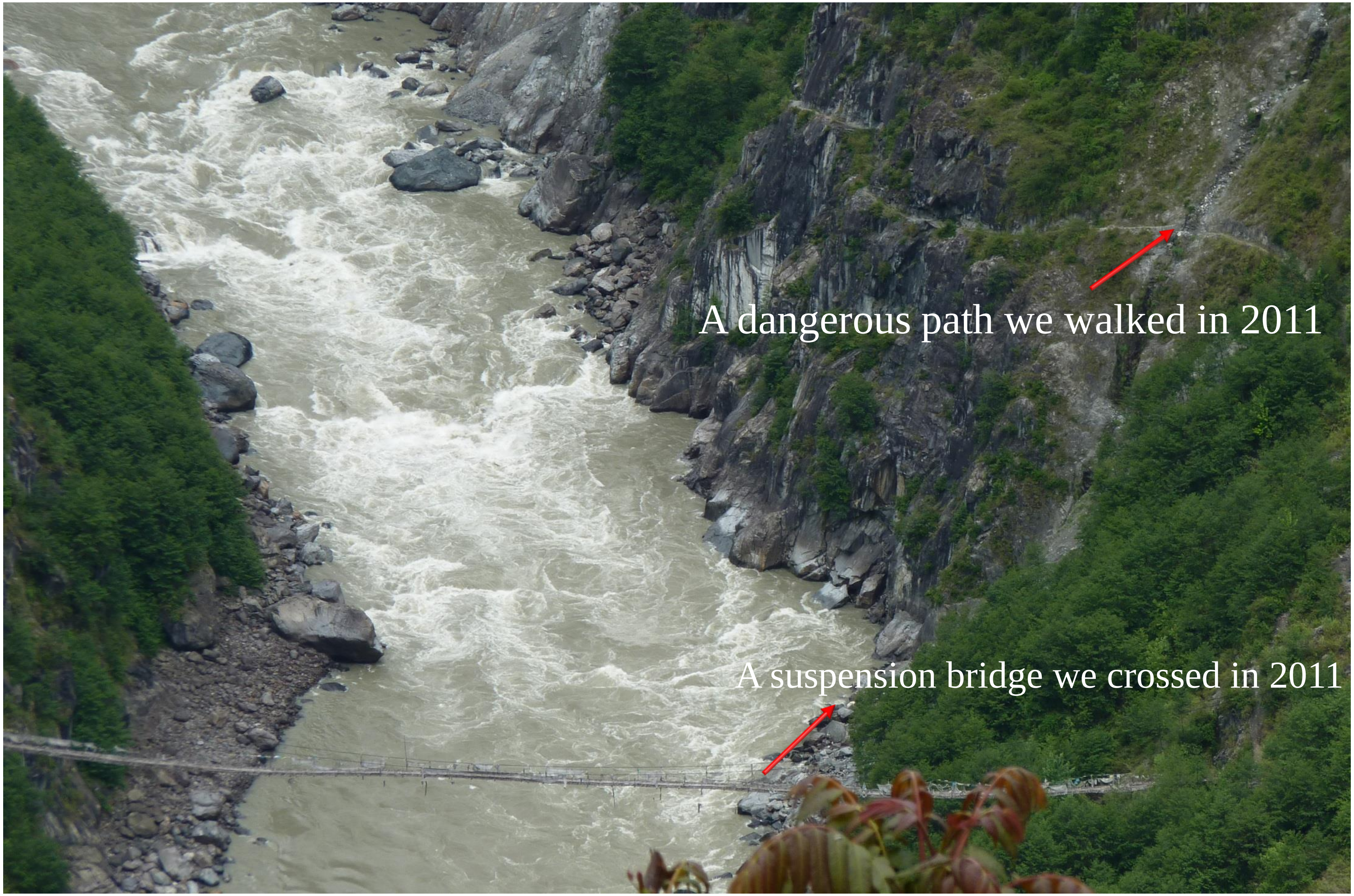
Large woody debris forms step-pool system

Large woody debris forms step-pool system

- Large woody debris mitigates incision in a tributary stream of the Yalong River in Sichuan Province, China

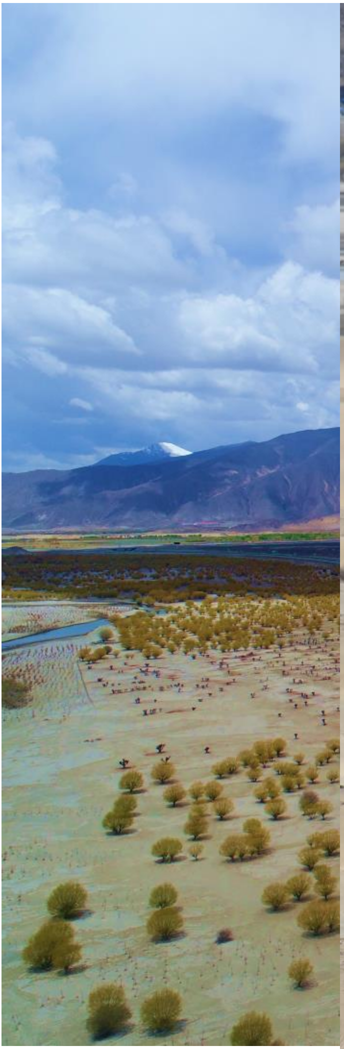
Plane bed type

Pool riffle type



Palong Tsangpo River in the Yarlung Tsangpo Grand Canyon

Dune ripple type




The middle Yurlung Tsangpo River near Naidong County

Schematic planform of five channel morphologies

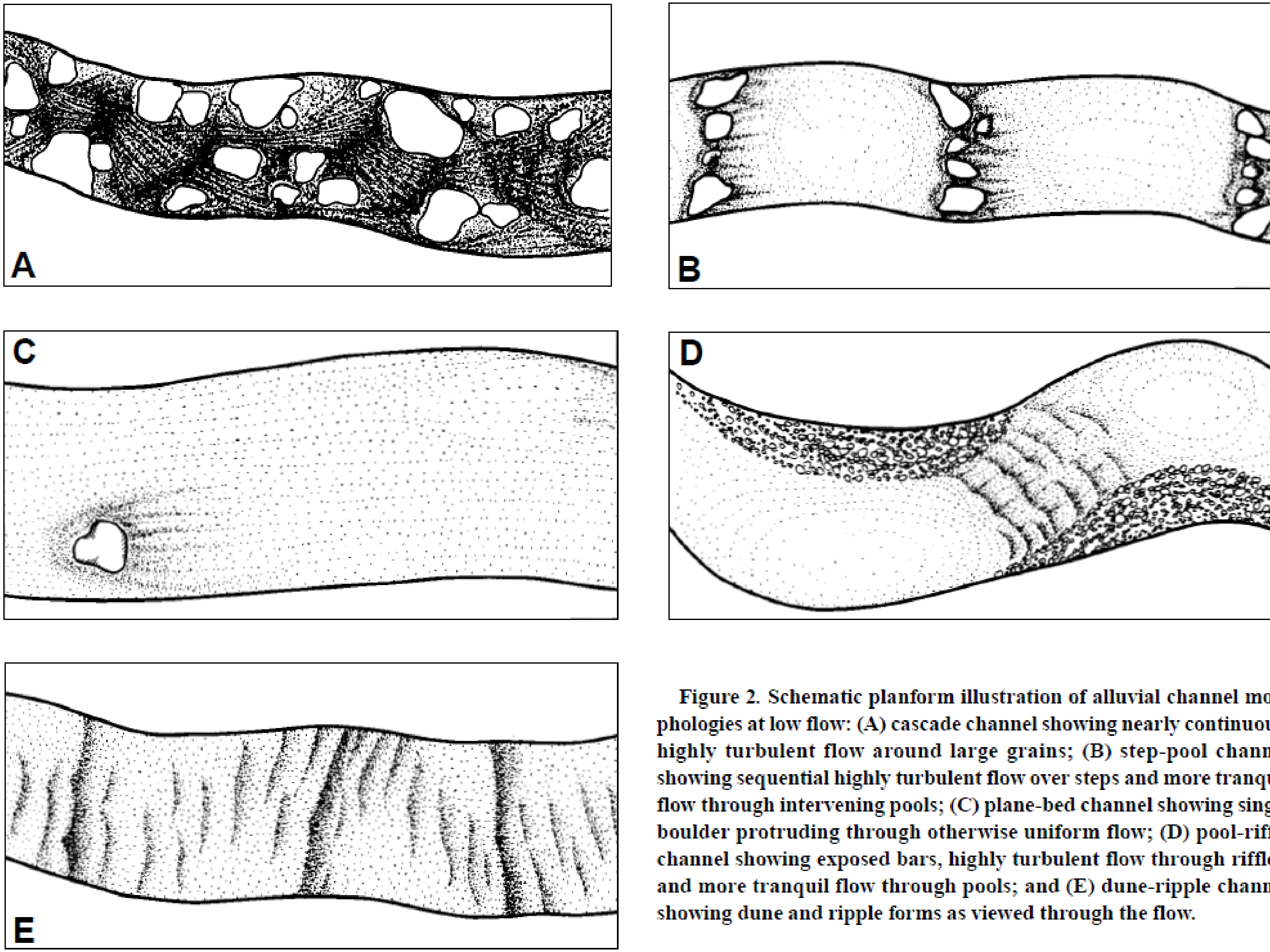


Figure 2. Schematic planform illustration of alluvial channel morphologies at low flow: (A) cascade channel showing nearly continuous, highly turbulent flow around large grains; (B) step-pool channel showing sequential highly turbulent flow over steps and more tranquil flow through intervening pools; (C) plane-bed channel showing single boulder protruding through otherwise uniform flow; (D) pool-riffle channel showing exposed bars, highly turbulent flow through riffles, and more tranquil flow through pools; and (E) dune-ripple channel showing dune and ripple forms as viewed through the flow.

Montgomery and Buffington (1997)

Longitudinal profiles of five channel morphologies

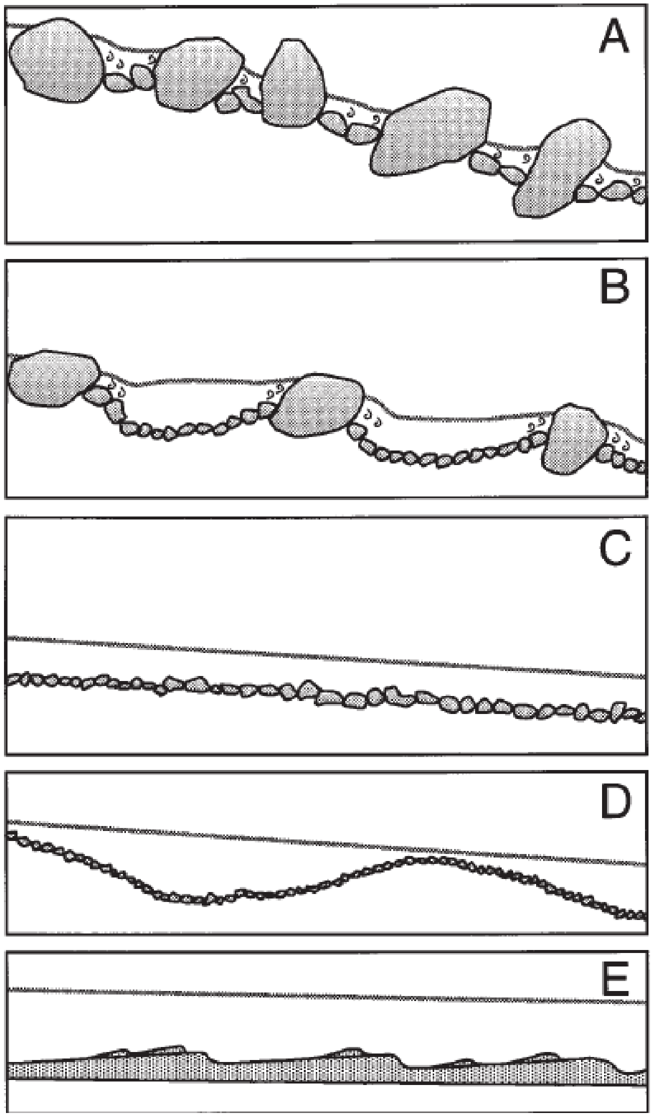
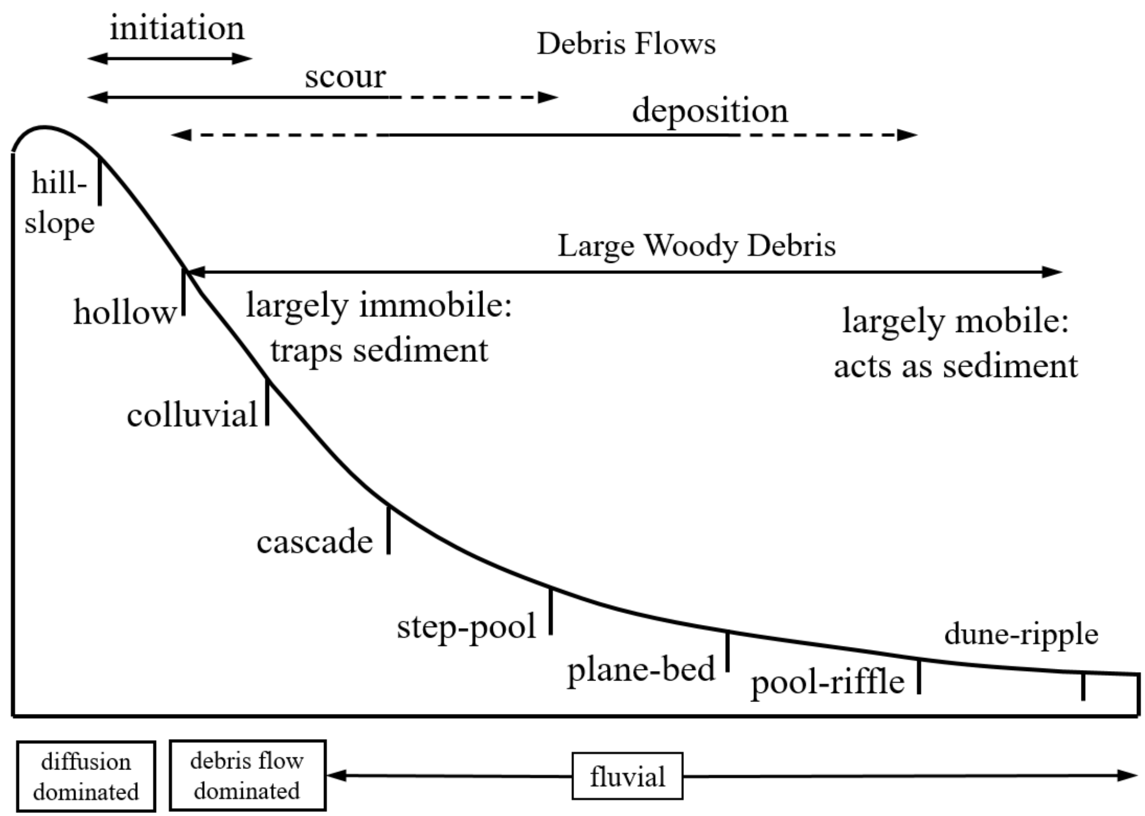


Figure 3. Schematic longitudinal profiles of alluvial channel morphologies at low flow: (A) cascade; (B) step pool; (C) plane bed; (D) pool riffle; and (E) dune ripple.

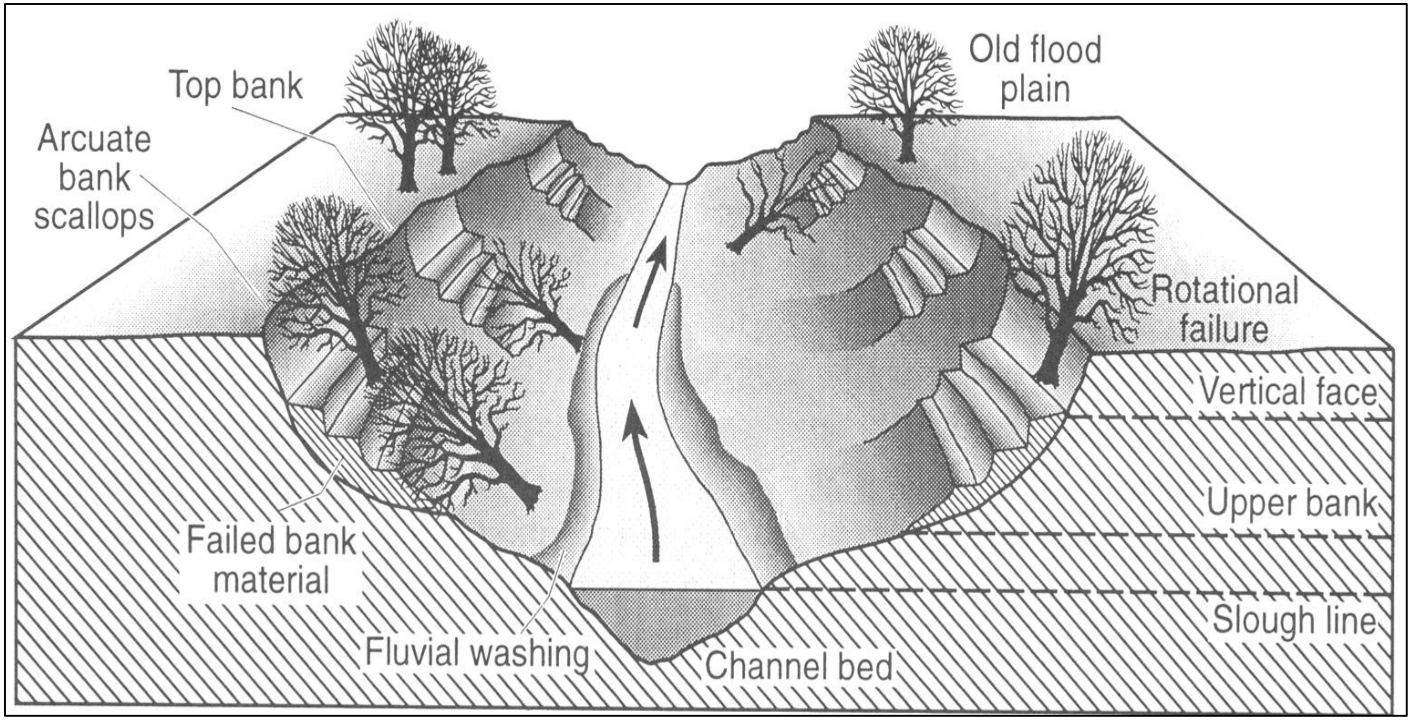


- Idealized long profile from hillslopes and unchanneled hollows downslope through the channel network showing the general distribution of alluvial channel types and controls on channel processes in mountain drainage basins.

Montgomery and Buffington (1997)

River bed incision

- The essential cause of channel incision is **high slope**, **non-equilibrated stream flow and bed roughness**.
- Development of channel incision in mountainous areas depends on the rainfall, watershed vegetation, and soil and rock compositions.
- Channel incision may cause **landslides** and **debris flows**.
- Channel incision is the key process in drainage-network development and landscape evolution



Causes of channel incision

- Geologic and geomorphic causes may require many years to develop a response (large scale), whereas **climatic and hydrologic variability**, **animal grazing**, and **human activities** can have a more immediate impact (local and small scale)**.**

Category	Causes
A. Geologic	Orogenesis, tectonic motion: A1. uplift; A2.Subsidence; A3.Faulting; A4. Lateral tilt
B. Geomorphologic	B1. Topography, high slopes; B2. Base-level lowering B3. Meander cutoffs; B4. Avulsion; B5. Lateral channel shift; B6. Cliff retreat; B7. Sediment storage (increased gradient)B8. Mass movement; B9. Groundwater sapping
C. Climatic	C1. Drier; C2. Wetter; C3. Increased intensity
D. Hydrologic	D1. Increased discharge; D2. Increased peak discharge D3. Decreased sediment load
E. Animals	E1. Grazing; E2. Tracking
F. Humans	F1. Dam construction; F2. Sediment diversion; F3. Flow diversion; F4. Urbanization; F5. Dam removal, failure; F6. Lowering lake levels; F7. Meander cutoff; F8. Underground mining; F9. Groundwater and petroleum withdrawal; F10. Gravel mining; F11. Dredging; F12. Roads, trails, ditches; F13. Channelization; F14. Flow constriction; F15. Deforestation; F16. Fire

V- and U-shape valleys

- "V"-shape valley is the diagnostic feature of incised rivers.
- **Super "V"-shape valley** has higher bank slops in the lowest part than upper part of the slope, generally higher than 35 degrees. Super "V"-shape valley indicates accelerating incision in the past centuries.
- As incision propagates to upstream tributaries, which resulted in a huge amount of incoming sediment to the stem river. The stem river may silt up and develop into a U shape valley.

Tianmo Gully, a tributary of Palong Tsangpo River in Tibet

V-shape valley (Nujiang River in Yunnan)

V-shape valley (Yarlung Tsangpo Grand Canyon)

Super “V-shape” valley of the Parlong Tsangpo River in the East Tibetan Plateau

A path on the steep slope of the Parlong Tsangpo

Bed structures

- **Bed structures** are composition of boulders and cobbles on mountain streambeds rearranged by flood flow to reach high resistance and high bed stability.

- **Step-pool system** is the most important type of bed structure in high gradient streams.

Other bed structures are

- **Ribbing structure** – middle gradient
- **Bank stones** - middle gradient
- **Star-studded boulders** – middle and low gradient
- **Cobble clusters** – middle and low gradient
- **Fire rocks-** high gradient – high gradient

Ribbing structures

- Ribbing structures in the Balan River, which is a tributary of the Songhua River in northeastern China. The ribbing structure is composed of cobbles, gravel, and some boulders

Bank stone

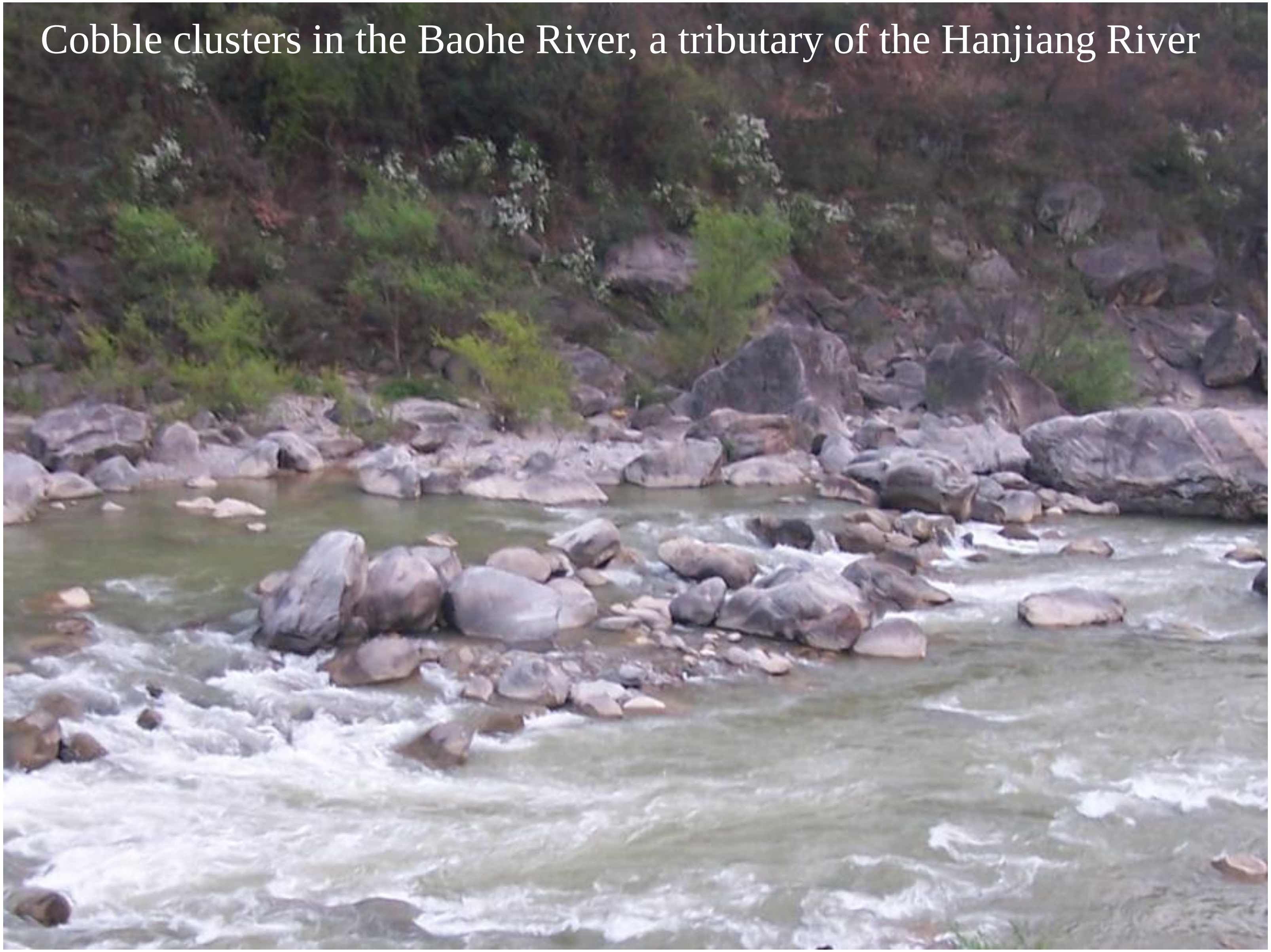
Bank stone

Bank stone structure on the Jialing River, a tributary of the Yangtze River.

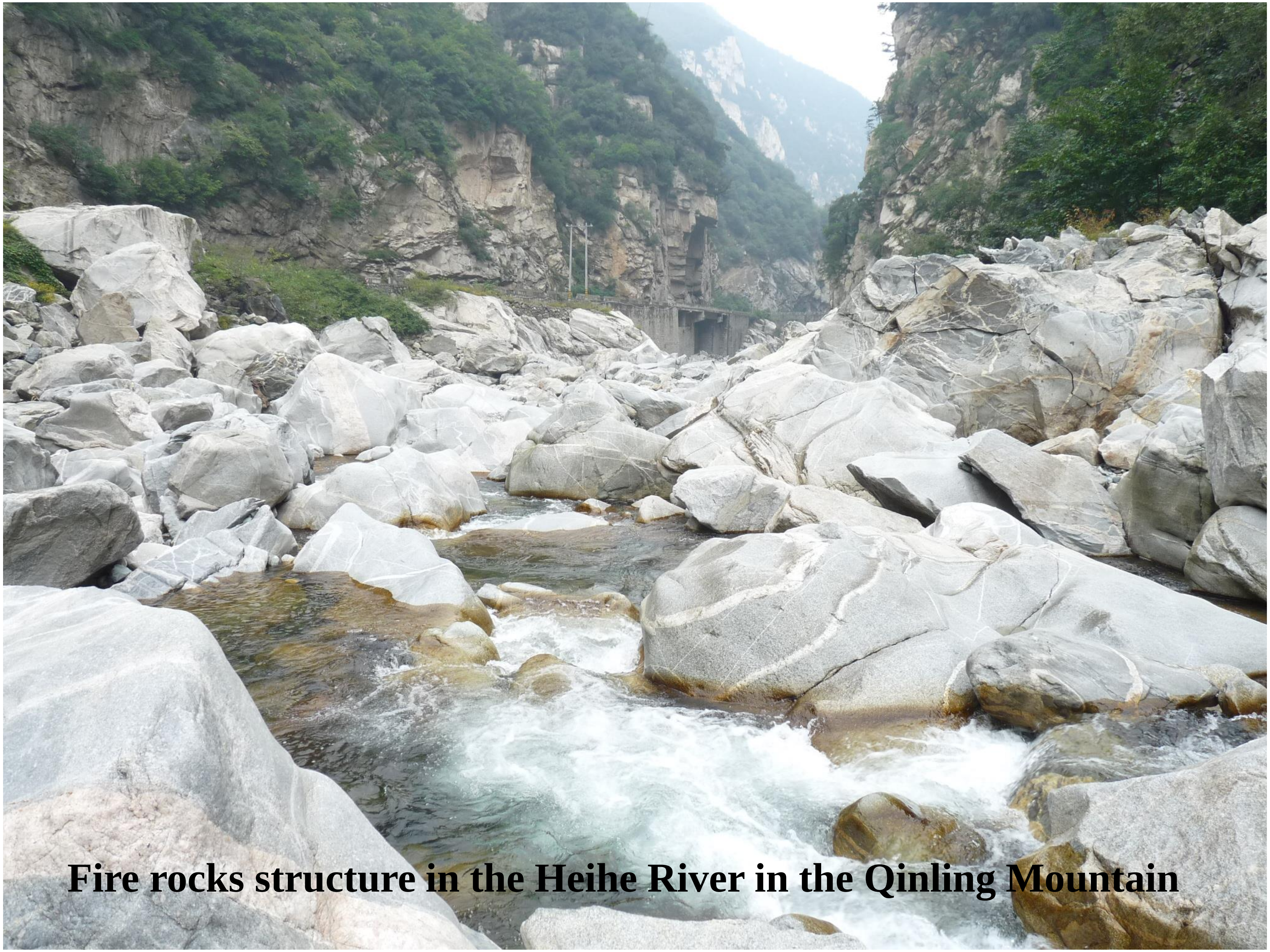
Star-studded boulders

Star-studded boulders in the Balan River in northeastern China

Cobble clusters



Fire rocks



Fire rocks structure in the Heihe River in the Qinling Mountain

A brief summary on mountain rivers

- Channel-reach morphology in mountain drainage basins are classified by seven types: colluvial, bedrock, cascade, step pool, plane bed, pool riffle, and dune ripple.

- Development of channel incision in mountainous areas depends on the rainfall, watershed vegetation, and soil and rock compositions. Channel incision is the key process in drainage-network development and landscape evolution.

- Bed structures are structures of boulders and cobbles on mountain streambeds rearranged by flood flow to reach high resistance and high bed stability.

- The step-pool system is the most important type of bed structure in high gradient streams.

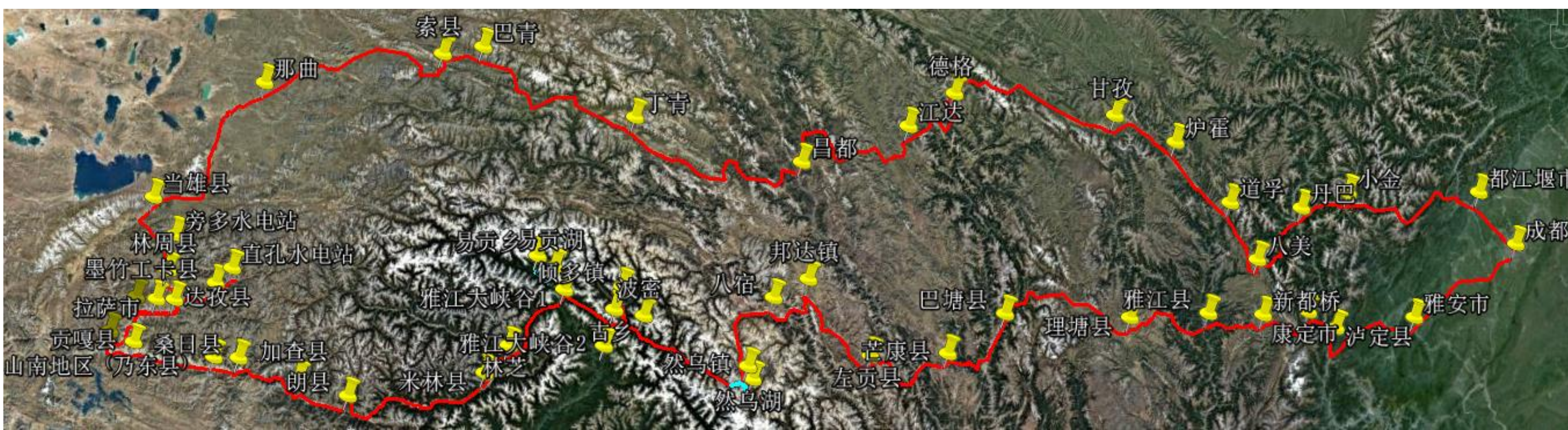
Outline

- ☐ Brief introduction on rivers in mountain regions
- ☐ **Objective, plan and preparation of field survey**
- ☐ Measured methods for river flow
- ☐ Measured methods for sediment transport
- ☐ Measured methods for river bed
- ☐ Concluding remarks

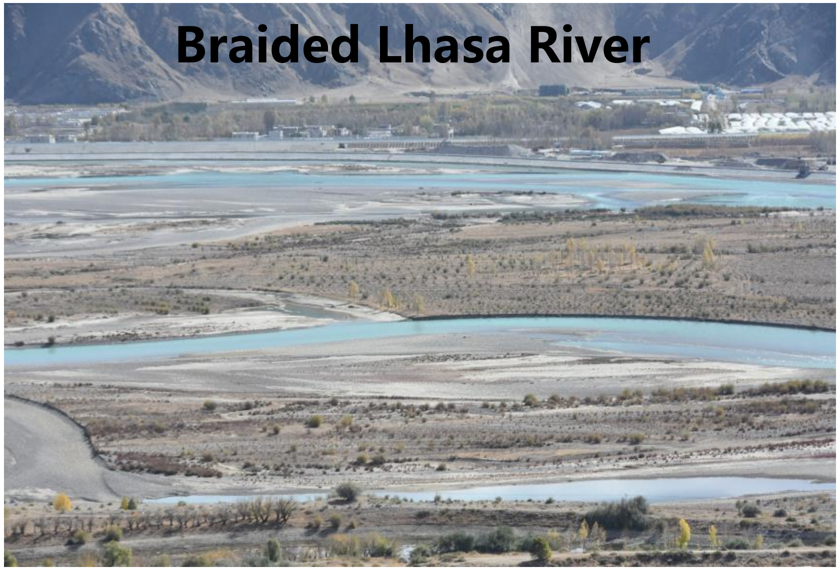
Objective, plan and preparation of field survey

- ☐ Research questions and main tasks ;
- ☐ Field route, schedule and investigation contents;
- ☐ Participants and division of various works;
- ☐ Preparations: cash, car rental, tools, instruments, medicines, insurance, weather information, etc.

A long and round trip on the QTP from Chengdu to Lhasa City in March 2017



A long and round trip on the QTP from Chengdu to Lhasa City in 2017



Outline

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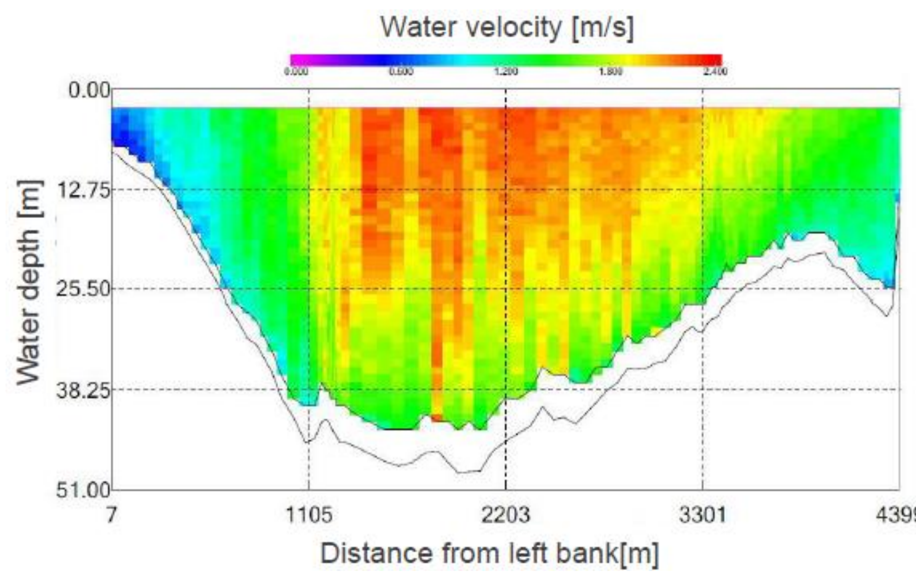
Measured methods for river flow

What is stream flow?

- Discharge is the volume of water flowing through a river cross-section per unit of time

Q=Volume / Time

Q=Velocity x Area



Cross-section of the Amazon River at Itacoatiara, Brazil (2014)

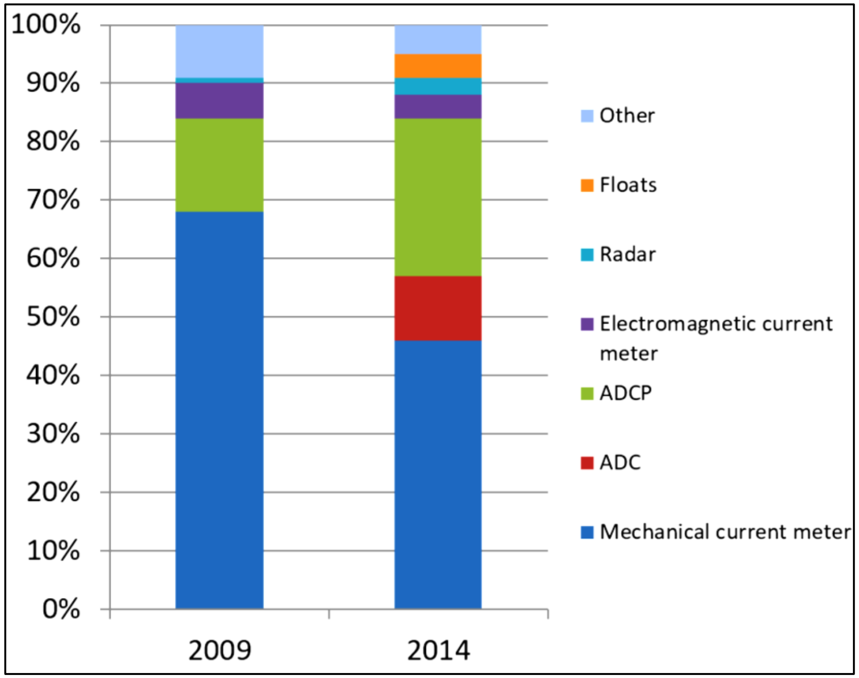
Measured methods for river flow

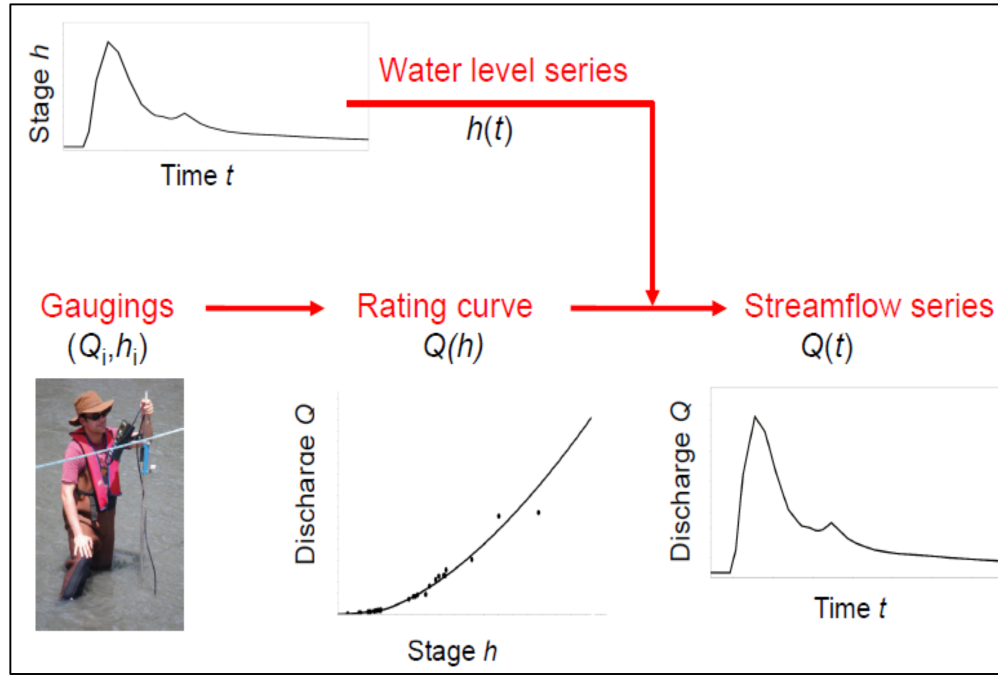
- Discharge measurements require **skilled operators**, a variety of **techniques**, **sound**, **safe** and **stable procedures**

Cited from the 4th IAHR-WMO-IAHS Training Course on Stream Gauging, 2018

New discharge measurement technologies

Obtain a rating curve

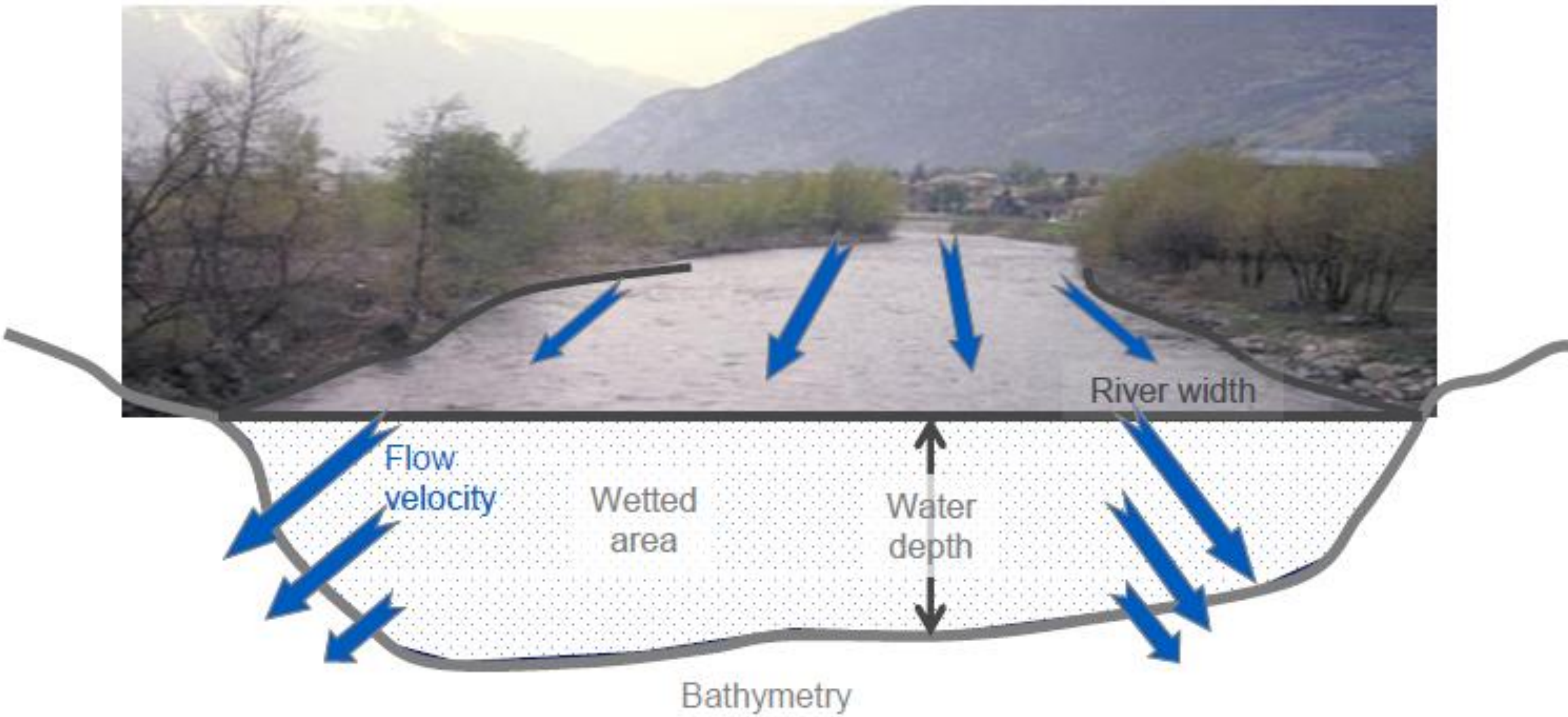




Worldwide surveyon gauging techniques used by national hydrological services, from Fulford (2016), WMO CHyProjectX

Velocity-area method using current meters

- Discharge is equal to cross sectional area X Average velocity



4th IAHR-WMO-IAHS Training Course on Stream Gauging, 2018

Velocity-area method using current meters

- Discharge is equal to cross sectional area X average velocity

□ Measure cross sectional area

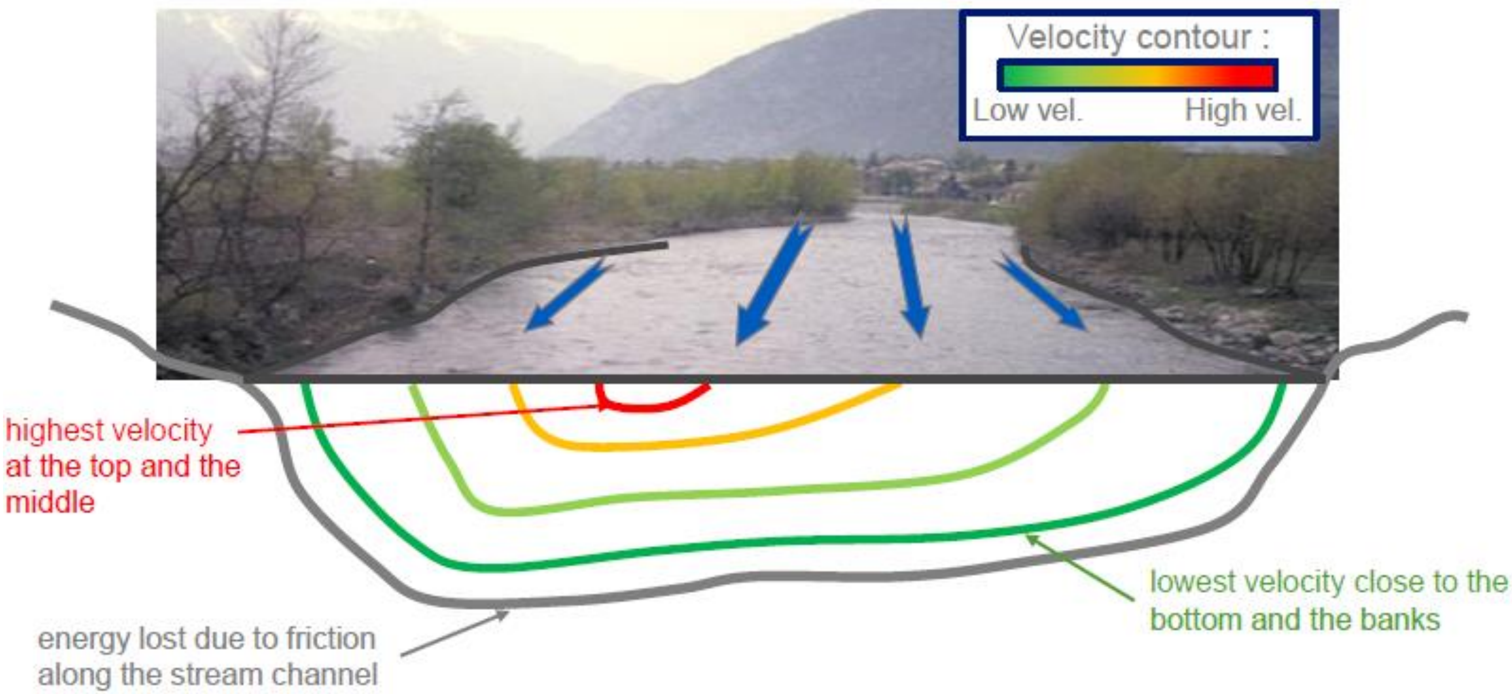
***Stream bed bathymetry**

***Sufficient bathymetric sampling to catch the shape of the wetted area**

□ Determine average velocity over the cross section

***Stream velocity varies through the stream profile**

***Sufficient sampling to determine the average velocity**



Velocity-area method using current meters

- Selection of the gauging cross-section

□ A stream reach as simple as possible

*subcritical flow

*uniform reach upstream and downstream without bridge, weir, dam, gorges

*a cross section perpendicular to the flow

□ General suggestions:

*Velocities at all points are parallel to one another and at right angles to the cross section

*curves of distribution of velocity in the section are regular in the vertical and horizontal planes;

*velocity greater than 0.15m/s; flow depth greater than 0.3m

*regular and stable streambed;

*no aquatic growth,

*small modifications of the cross section are possible

*stream modification must be limited and reversible.

Velocity-area method using current meters

- Different supports depending on the accessibility of the river

- ☐ Wading rod: section fully accessible by foot
- ☐ Gauging truck: retractable arm mounted on a truck, sounding weights
- ☐ Cableways:

*carrier cable permanently stretched across a section

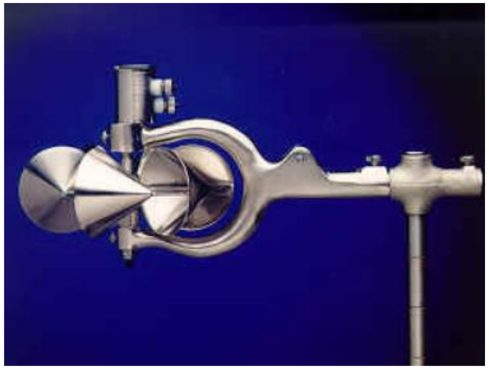
*equipped with a sounding weight or a cable car

Mechanical current meters

- Velocity by counting revolutions of rotor during a short-time period
- Two types of current meter rotors
  - Cup type with a vertical shaft
  - Propeller type with a horizontal shaft
- Contact to generate an electric pulse for indicating the revolutions of the rotor
- Can measure from 0.05 to 5m/s
- The component of velocity normal to the cross section
- Advantages: one can see when it is not working properly
- Drawbacks:

*need periodic verification of the moving parts

*susceptible to vegetation



Electromagnetic current meters

- **Principle**: water moving through a magnetic field produced an electric current; velocity of the water is proportional to the electric current
- Velocity range: 0-6m/s with accuracy of 2%

- Advantages:

*Can measure low velocities

*No moving part

*Can measure with vegetation

- Drawbacks:

*susceptible to electrical interference

4th IAHR-WMO-IAHS Training Course on Stream Gauging, 2018

FP311(Global Water)

Acoustic current meters

- **Principle**:

*Transmit acoustic signals into a water column with a frequency *f*

*Signal is backscattered by particles moving in the water

*Doppler effect-change of frequency of the backscatter signals

*Computation of radial velocity on each beam

*Computation of flow velocity

- Velocity range: 0-2m/s with accuracy of 1%
- Advantages：

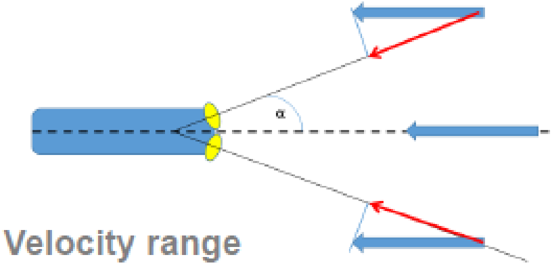
*No moving part

*2D or 3D velocity components and backward flow

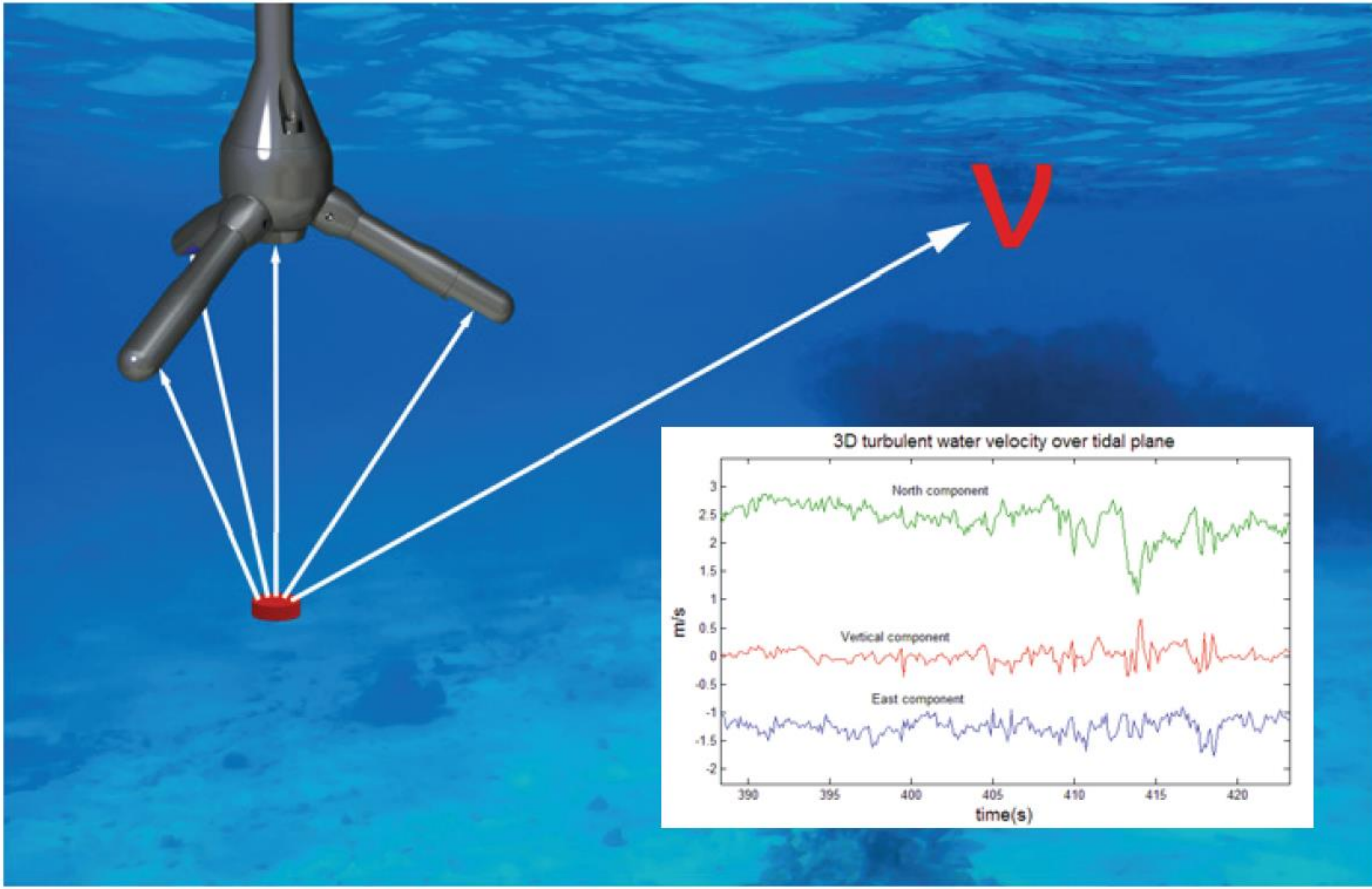
*Can measure very low velocities (2 cm/s)

- Drawbacks:

*susceptible to electrical interference



Acoustic Doppler Velocimetry (ADV)



Velocity-area method using current meters

◘ Measurement protocol:

*Temporal sampling of the velocity

- Streams: turbulent flow to average turbulent velocities
- Exposure time of at least 30s to get average velocity

(at least 100 rotations for a mechanical current meter; optimal exposure time should be evaluated for each measurement)

Table E.3 — **Percentage uncertainties in point velocity measurements due to limited exposure time**
(Standard uncertainties, level of confidence approximately 68 %)

Velocity m/s	Point in vertical: 0,2*D*, 0,4*D* or 0,6*D*				Point in vertical: 0,8*D* or 0,9*D*			
	Exposure time (min)							
	0,5	1	2	3	0,5	1	2	3
0,050	25	20	15	10	40	30	25	20
0,100	14	11	8	7	17	14	10	8
0,200	8	6	5	4	9	7	5	4
0,300	5	4	3	3	5	4	3	3
0,400	4	3	3	3	4	3	3	3
0,500	4	3	3	2	4	3	3	2
1,000	4	3	3	2	4	3	3	2
over 1,000	4	3	3	2	4	3	3	2

Velocity-area method using current meters

- Measurement protocol: measuring the stream bathymetry

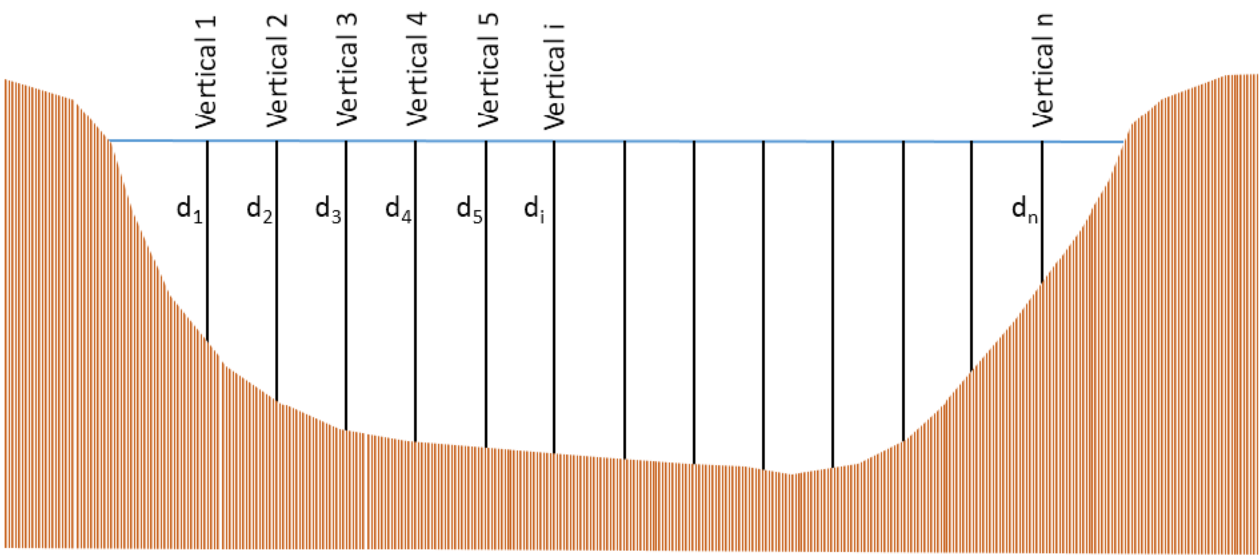
*spatial sampling of the cross section bathymetry at n verticals

(depth of each vertical d_i)

*spatial sampling of the cross-section velocity distribution at the n verticals

(velocity distribution method; reduced point method; integration method)

*depth-averaged velocity of each vertical V_i

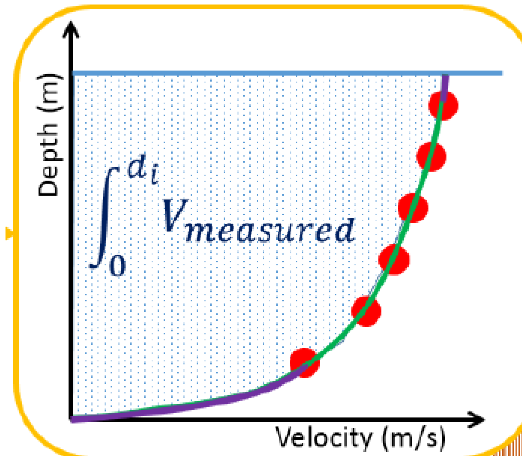


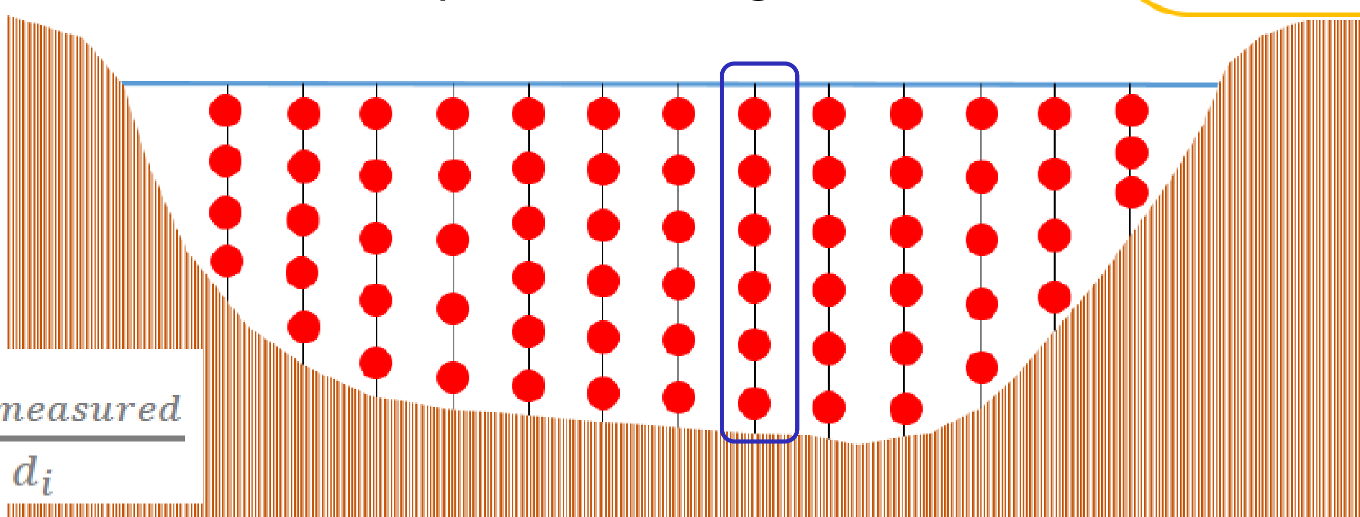
Velocity-area method using current meters

- ☐ Measurement protocol: computing depth-averaged velocity at vertical I
- ☐ Velocity distribution method

- Important number of velocity measurement points along each vertical
- Interpolation between measured velocity
- Extrapolation to the bed and the surface
- Number and spacing of the points are chosen as to

define accurately the velocity distribution in each vertical with a difference in readings between two adjacent points of not more than 20% with respect to the higher value





$$V_i = \frac{\int_0^{d_i} V_{measured}}{d_i}$$

Velocity-area method using current meters

- Measurement protocol: computing depth-averaged velocity at vertical I
- Reduced point method
- 1 to 6 velocity measurements per vertical
- Computation of Vi with algebraic formula

-1 pt method: $Vi=V_{0.6di}$

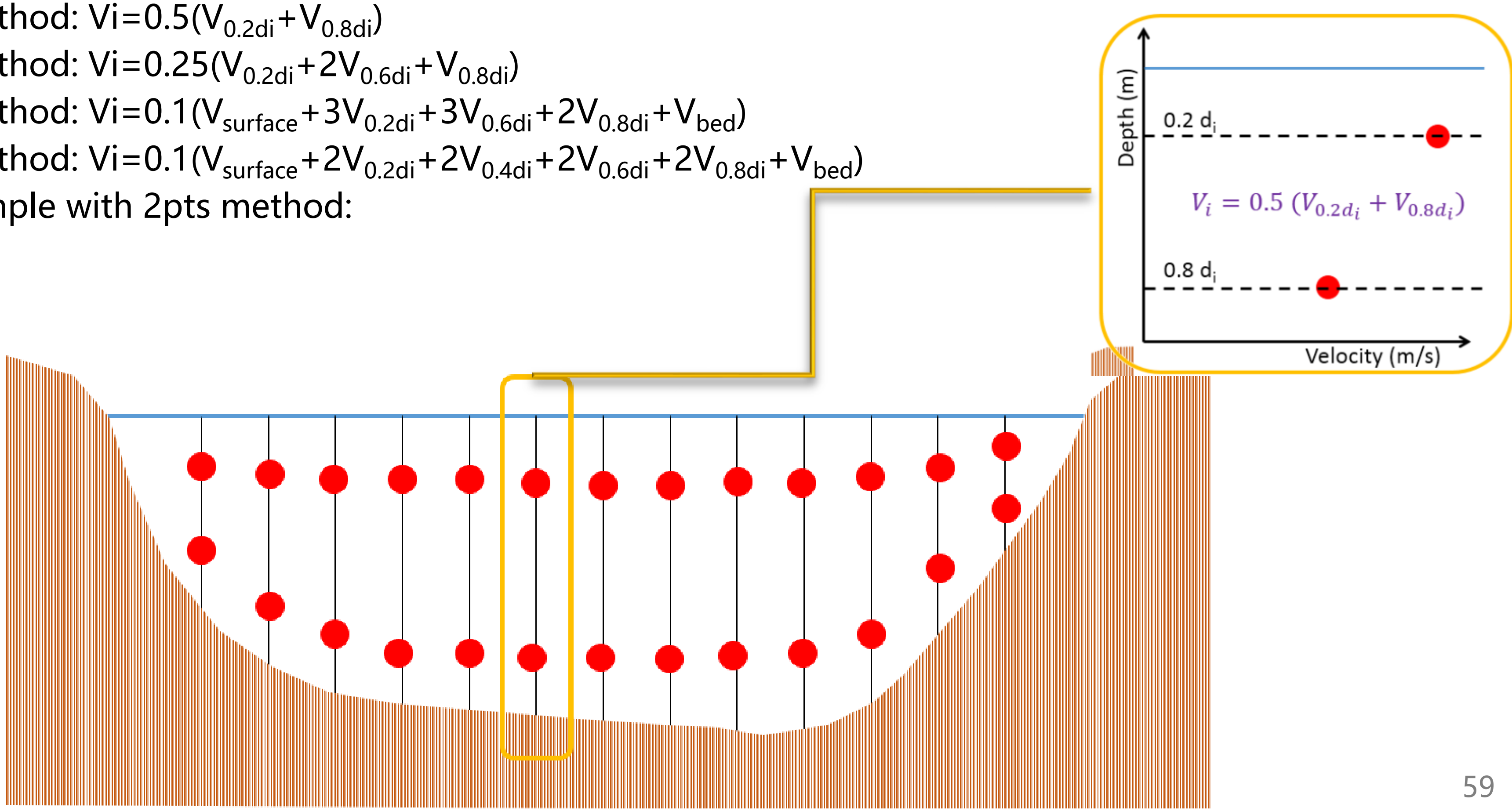
-2 pt method: $Vi=0.5(V_{0.2di}+V_{0.8di})$

-3 pt method: $Vi=0.25(V_{0.2di}+2V_{0.6di}+V_{0.8di})$

-5 pt method: $Vi=0.1(V_{surface}+3V_{0.2di}+3V_{0.6di}+2V_{0.8di}+V_{bed})$

-6 pt method: $Vi=0.1(V_{surface}+2V_{0.2di}+2V_{0.4di}+2V_{0.6di}+2V_{0.8di}+V_{bed})$

- Example with 2pts method:



Velocity-area method using current meters

- **Measurement protocol: computing depth-averaged velocity at vertical I**
- Integration method using mechanical current meters
- Current meter is lowered and raised through the entire depth at each vertical at a uniform rate
- Average number of revolutions per second is determined---depth-averaged velocity
- The speed at which the meter is lowered <5% of the flow velocity and between 0.04 and 0.10 m/s
- Two complete cycles are made in each vertical—if the results differ by more than 10 percent, the measurement is repeated.
- Restriction of use:

---depth >1 m

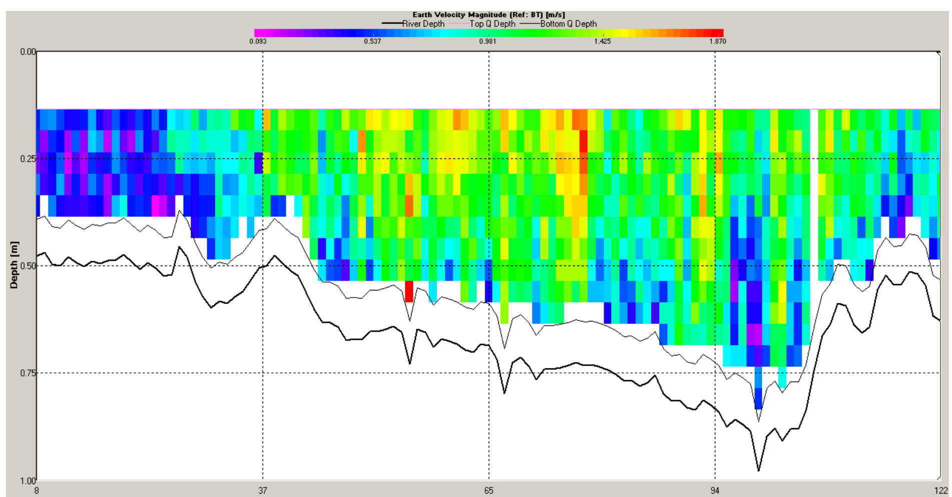
---velocities >1 m/s

- The integration method should not be used with a vertical axis current meter

Stream discharge using an ADCP (SonTek M9)

- ADCP: **Acoustic Doppler Current Profiler**
  - Ultrasonic measurement (300-3000 kHz)
  - Sonar principle to measure the river bathymetry---wetted area
  - Doppler shift to measure flow velocity

- Profiler:
  - ADCP mounted on a float, generally pointing down
  - Sending an ultrasonic acoustic wave in the water
  - Backscatter by particles in suspension in the water
  - Analyze of the Doppler shift between the transmitted and the backscatter signals

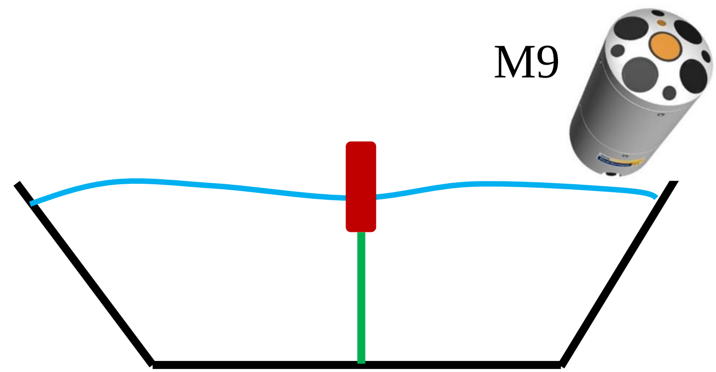


How an ADCP measures the water depth

- **Sonar principle:**

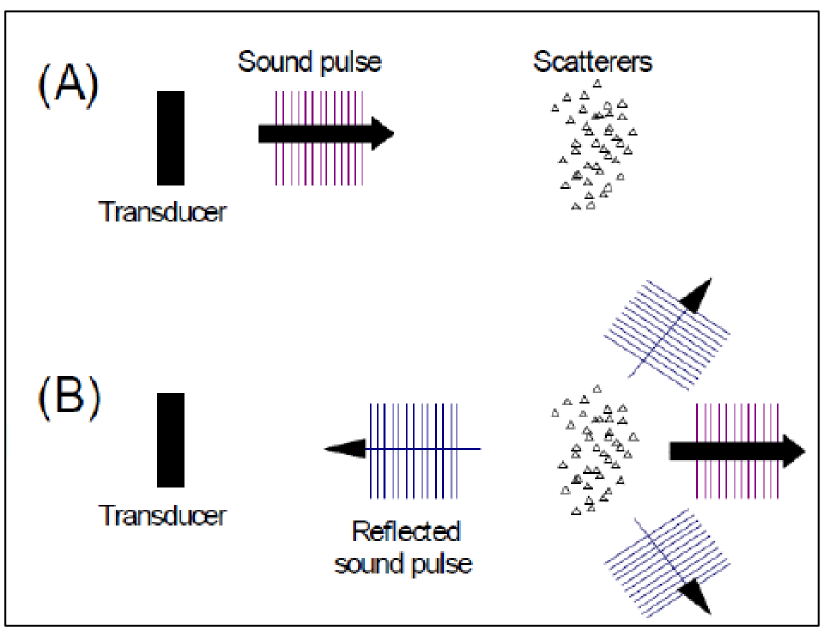
---Peak of retuned intensity when the echo hit the river bed

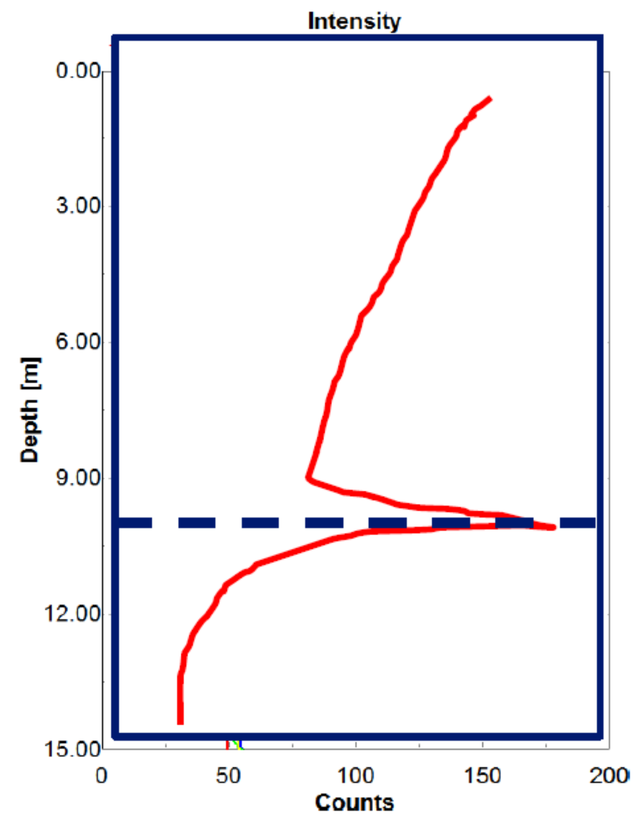
- Let postulate that the ADCP is not moving
- ADCP transmits an ultrasonic pulse in the water
- Pulse is backscattered by particles in the water
- ADCP received backscattered echo
- Analysis of Doppler shift between transmitted and backscattered pulsed---velocity of the particles



- Basic hypothesis: particles are advected by the water

---velocity of the particle=velocity of the water





How an ADCP measures the water velocity

- **Doppler shift---radial velocity**

---component of velocity in the beam axis

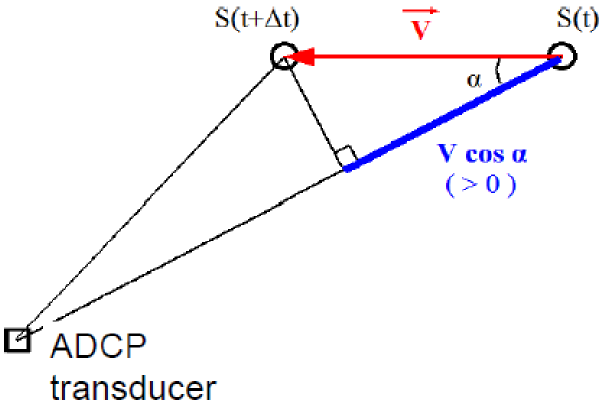
- V cosa=c $\Delta f/f_0$ with $\Delta f = f_1 - f_0$

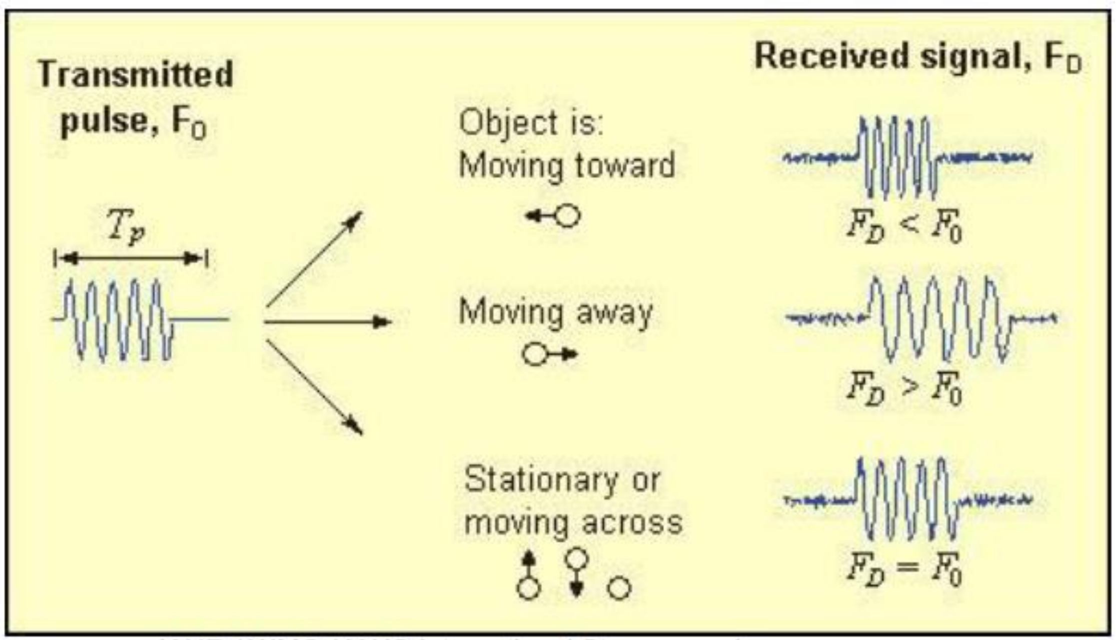
f_0 : frequency of the transmitted pulse

f_1 : frequency of the backscattered pulse

C : speed of the sound. C depends on the water temperature

--- it is crucial to measure accurately the water temperature





How an ADCP measures the water velocity

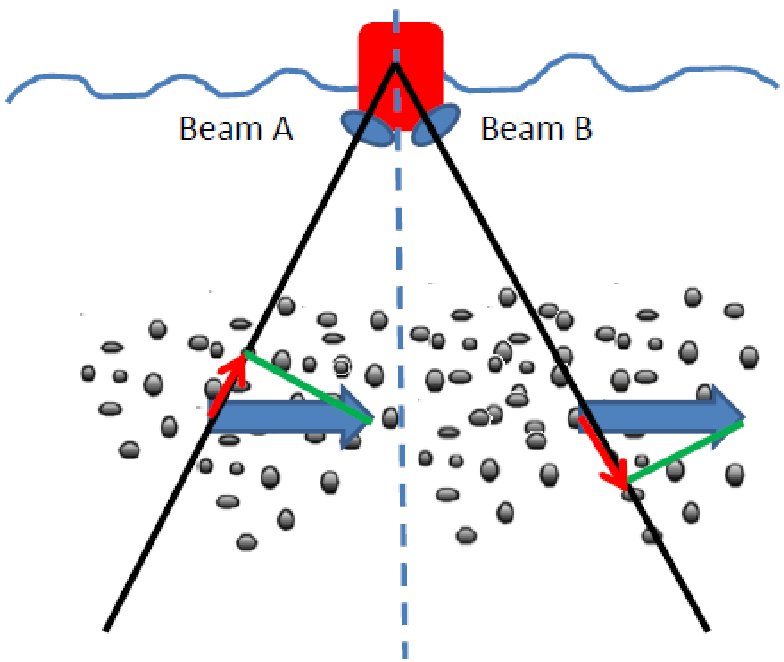
- How measuring 3D velocity components (x, y, z)
- Geometric configuration:

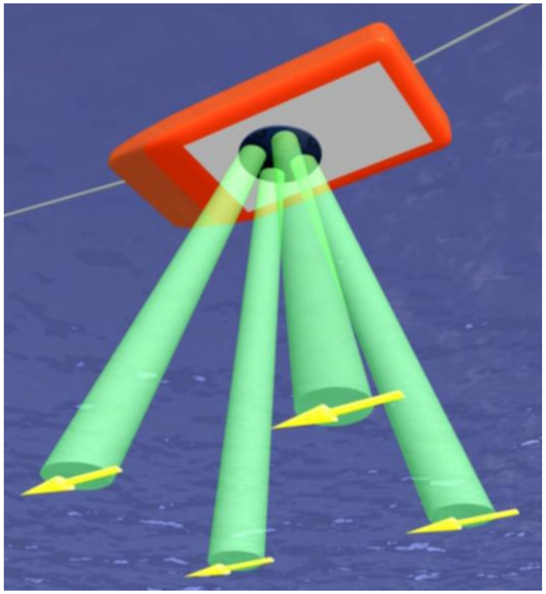
□ 2, 3, 4, divergent beams

□ Measurement of radial velocity on each beam

□ Trigonometric calculation to obtain 3D velocity

---under the assumption that the velocity is homogeneous on the 3 beams





Unmeasured areas

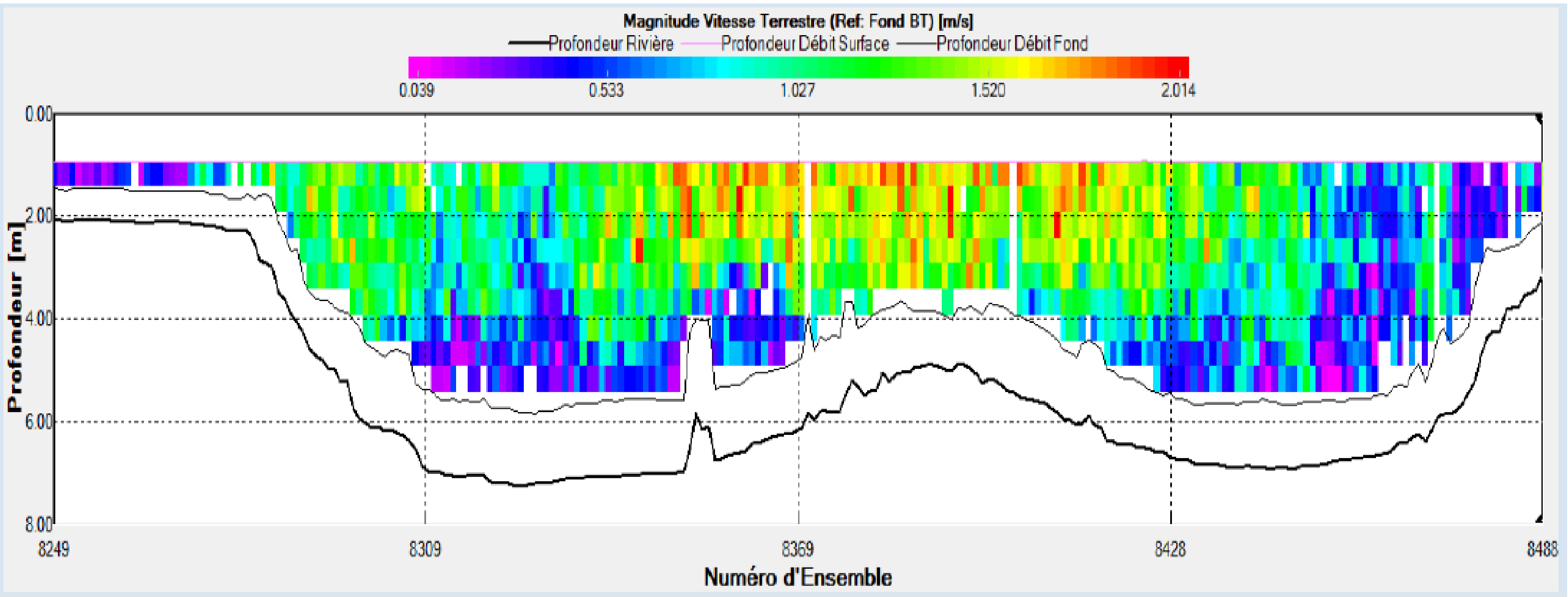
- Close to the river bed

---side-lobes hit the river bed before the main lobe

- Bad bins / bad ensembles

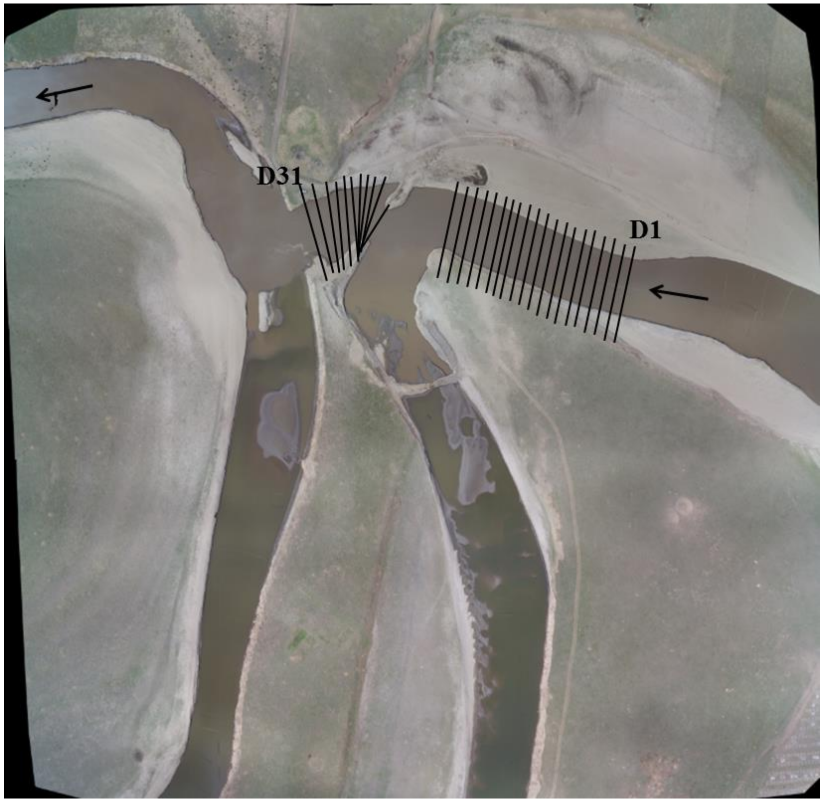
---error velocity > threshold

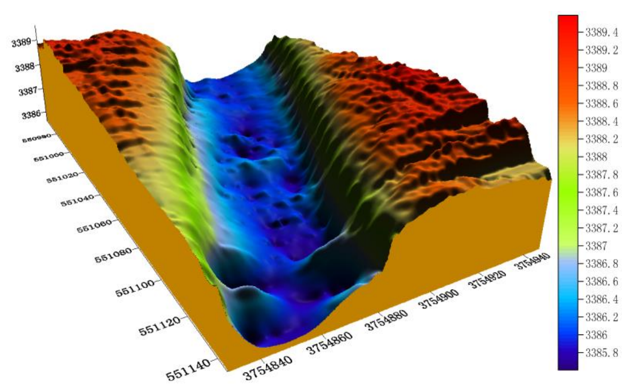
---correlation < threshold

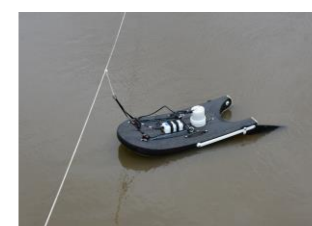


Most used ADCP

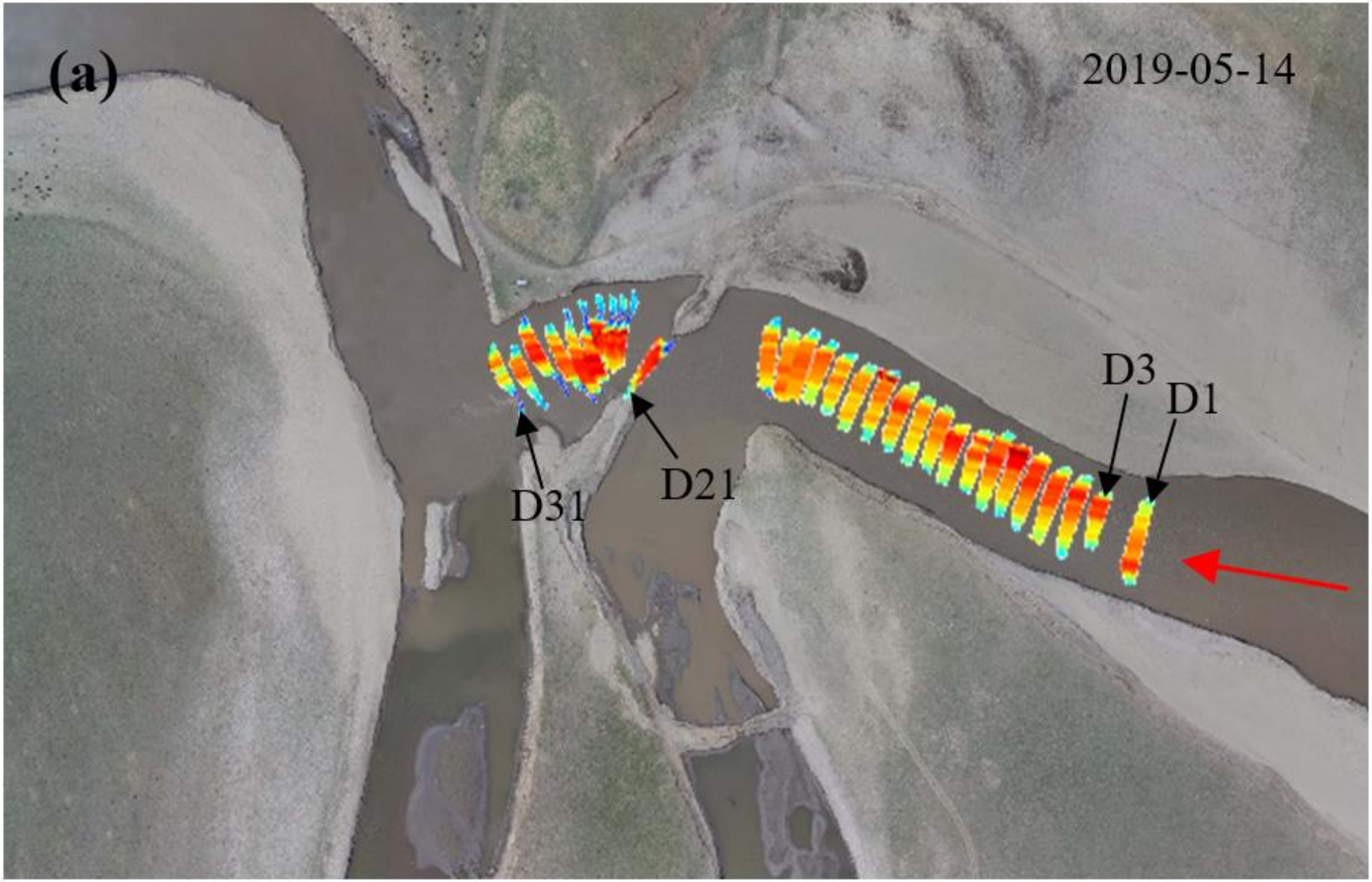
ADCP: A case in the Black River of the Yellow River Source



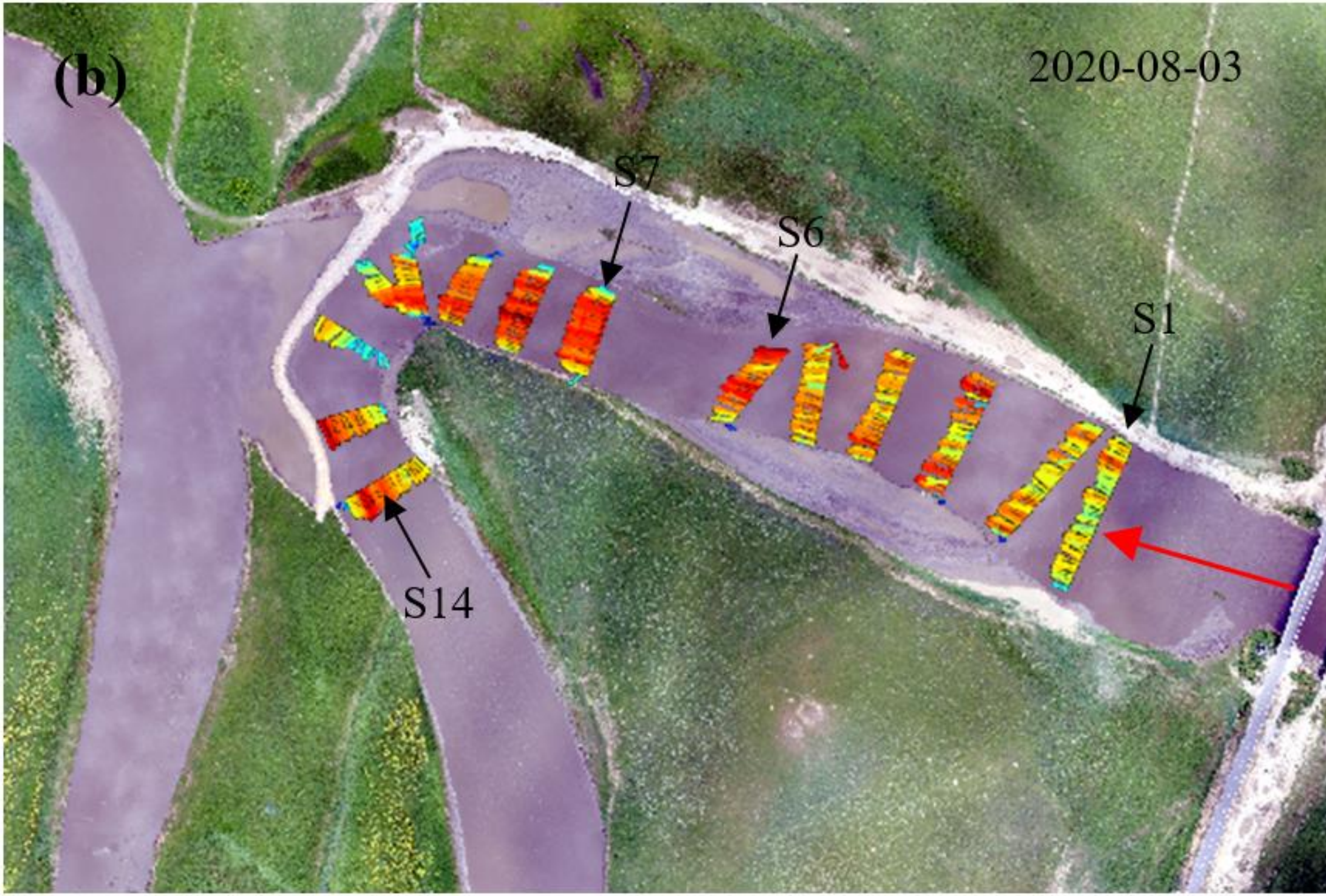




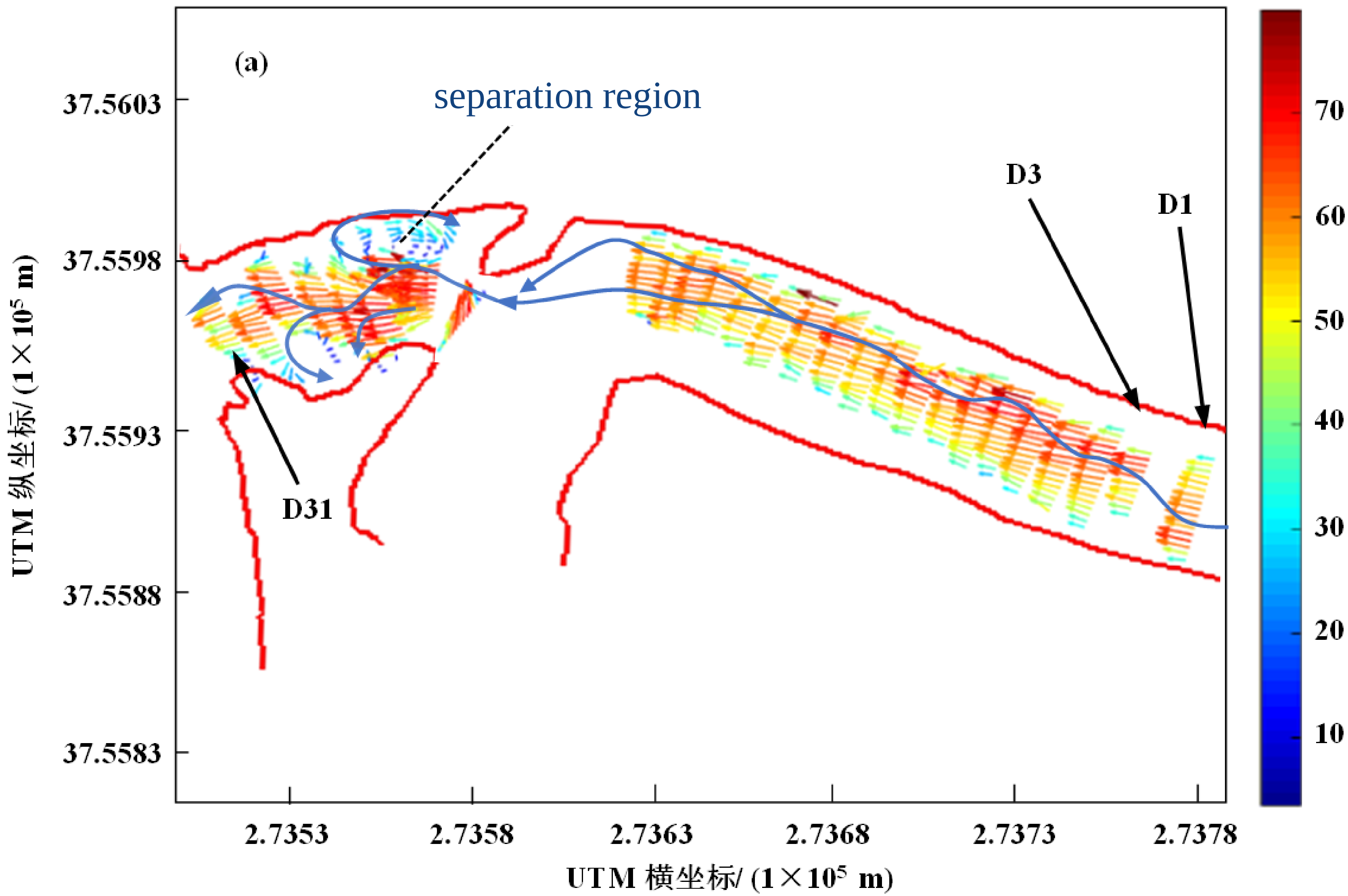
2D longitudinal velocity distribution at each cross section



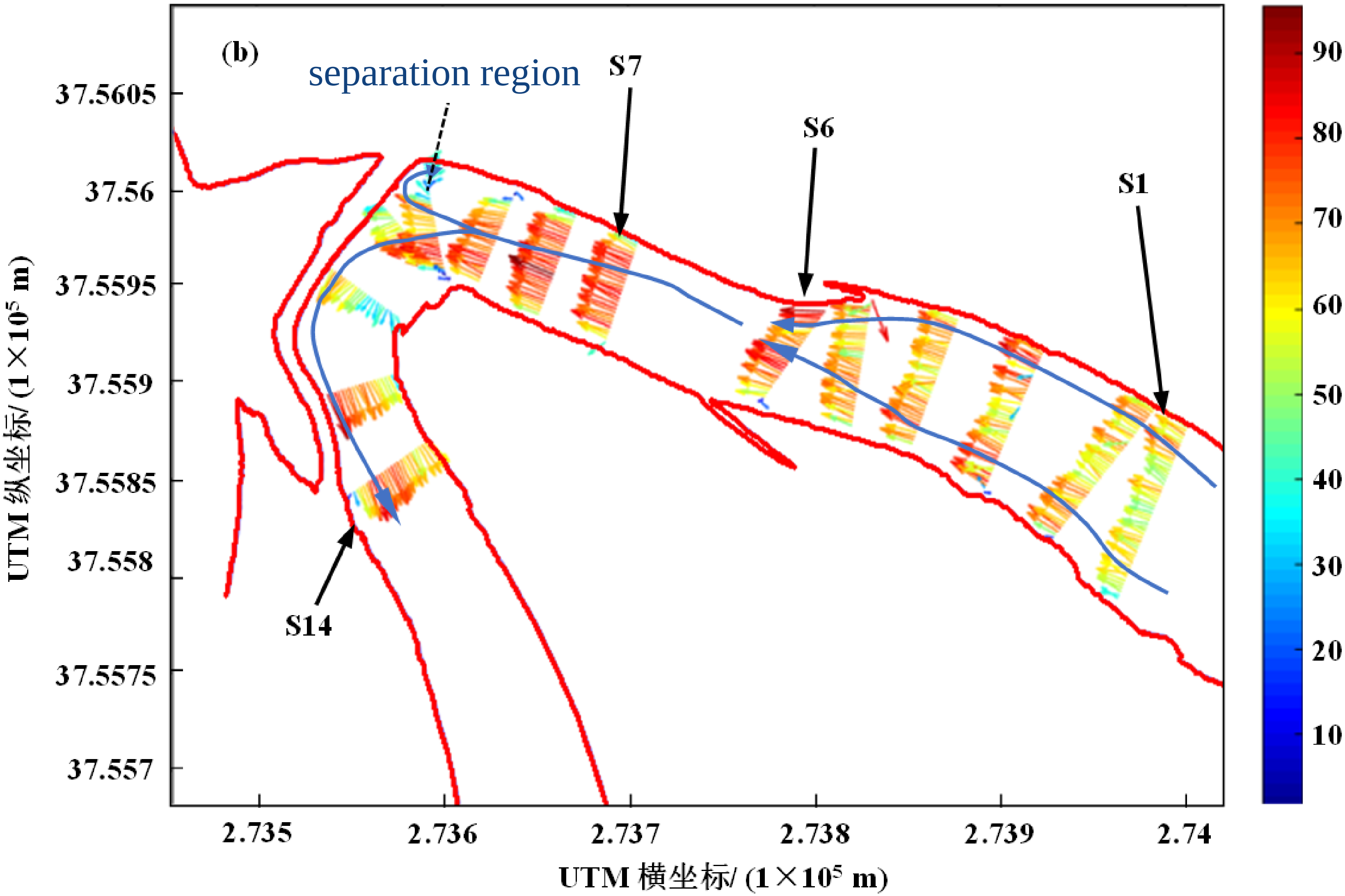
2D longitudinal velocity distribution at each cross section



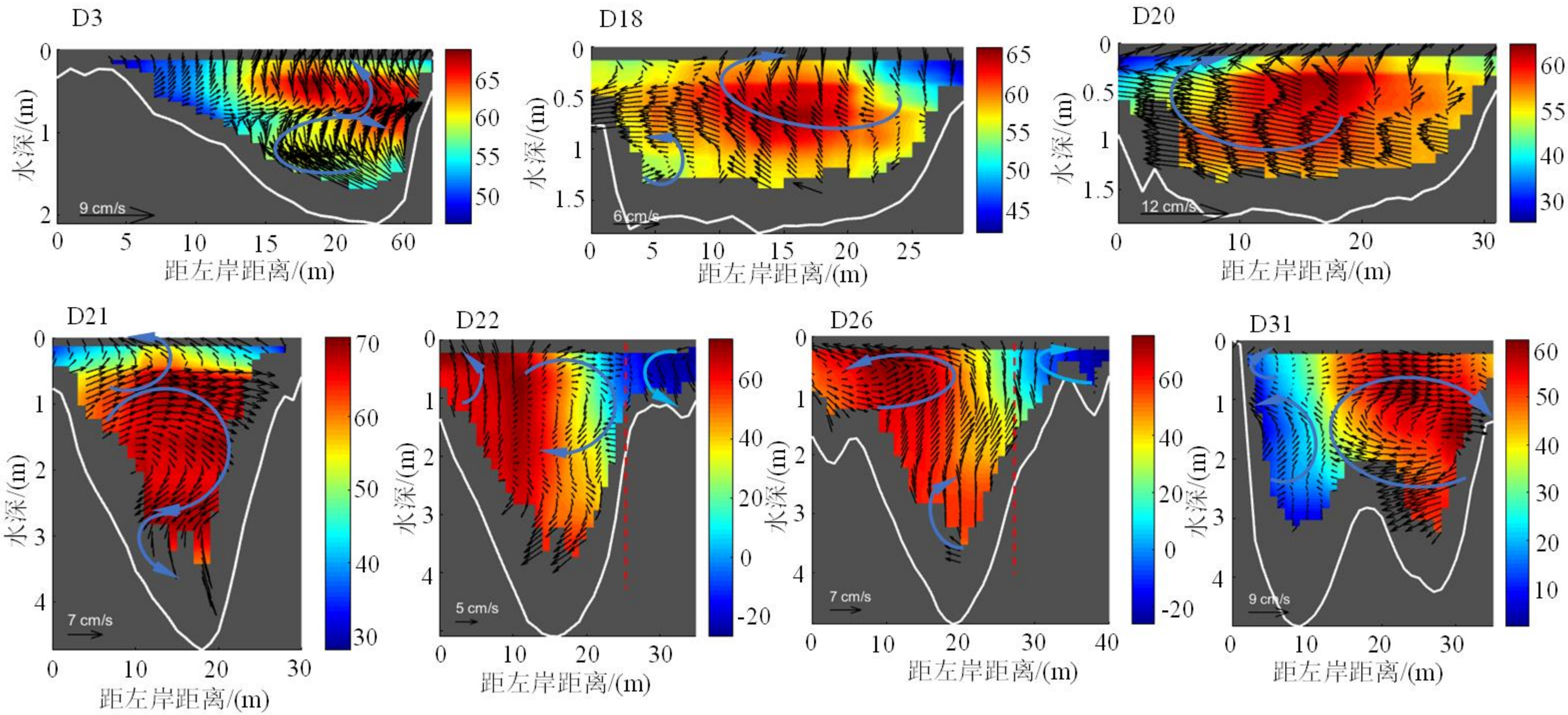
Depth-average velocity vector after neck cutoff (unit: $cm \cdot s^{-1}$)



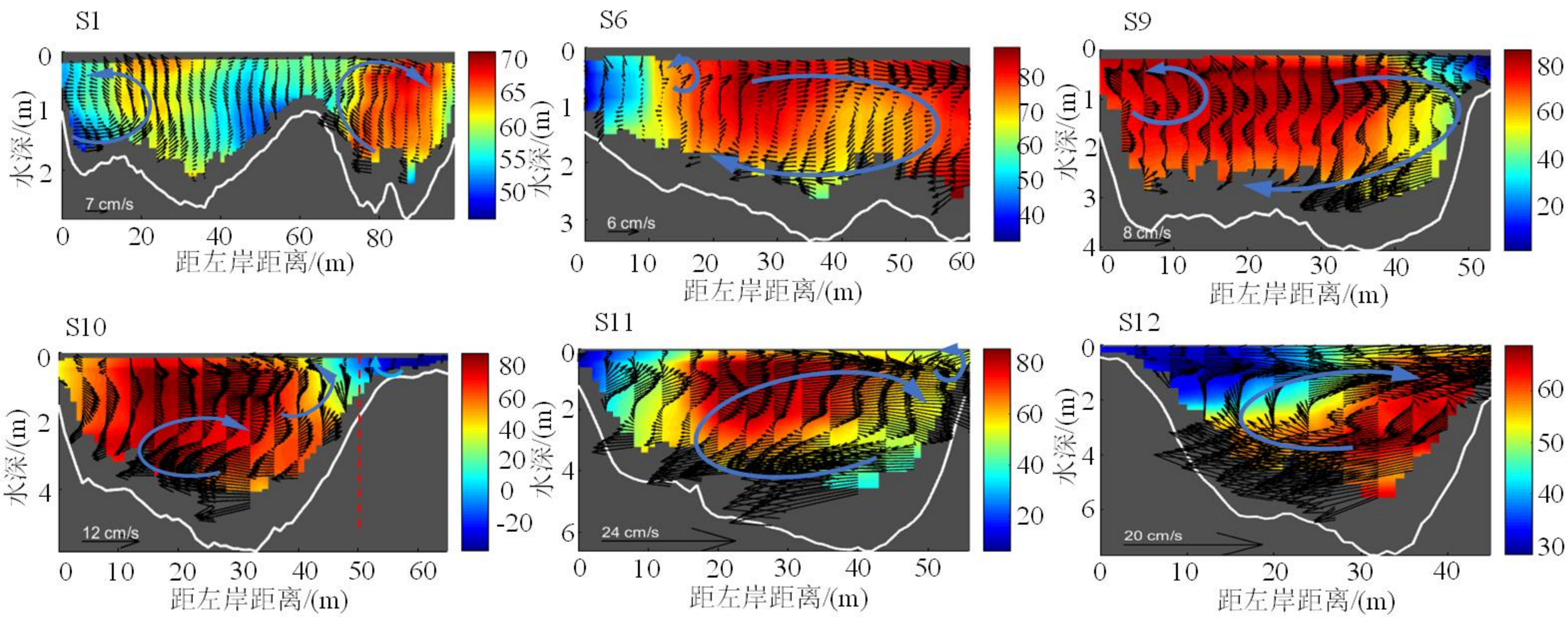
Depth-average velocity vector after neck cutoff (unit: $cm \cdot s^{-1}$)



Mainstream and secondary flow velocity distribution in 7 sections in 2019



Mainstream and secondary flow velocity distribution in 6 sections in 2020



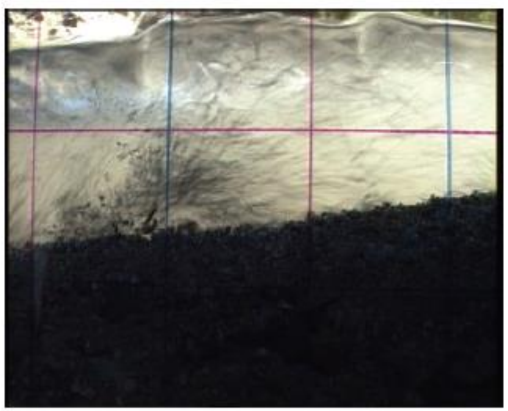
1 minute break

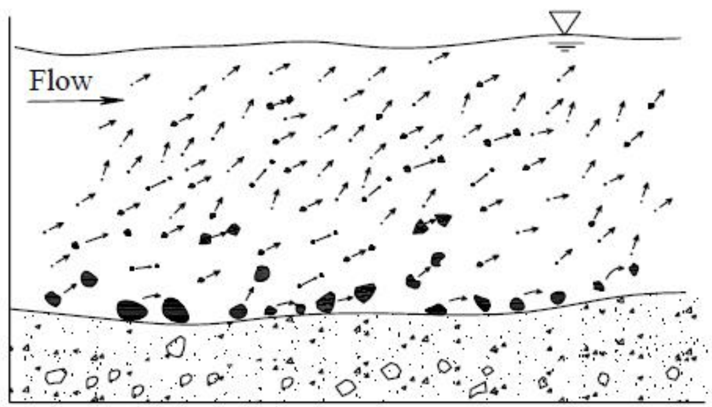
Outline

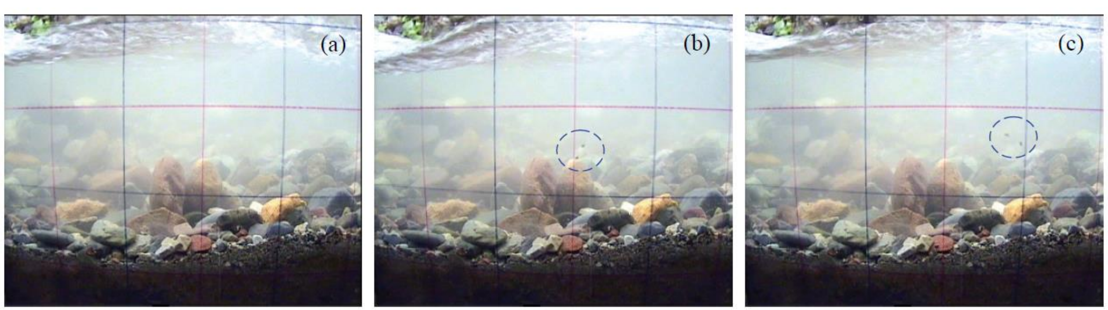
- Brief introduction on rivers in mountain regions
- Objective, plan and preparation of field survey
- Measured methods for river flow
- **Measured methods for sediment transport**
- Measured methods for river bed
- Concluding remarks

Measured methods for sediment transport

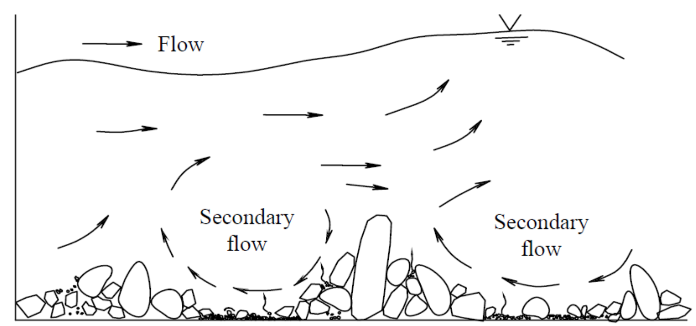
- Basin characteristics of sediment transport in mountain rivers
- Suspended load may be neglected;
- Bed load dominates riverbed processes;
- Patterns of particles motion: **rolling, sliding, saltation**
- Substrate consists mainly of cobbles and gravel





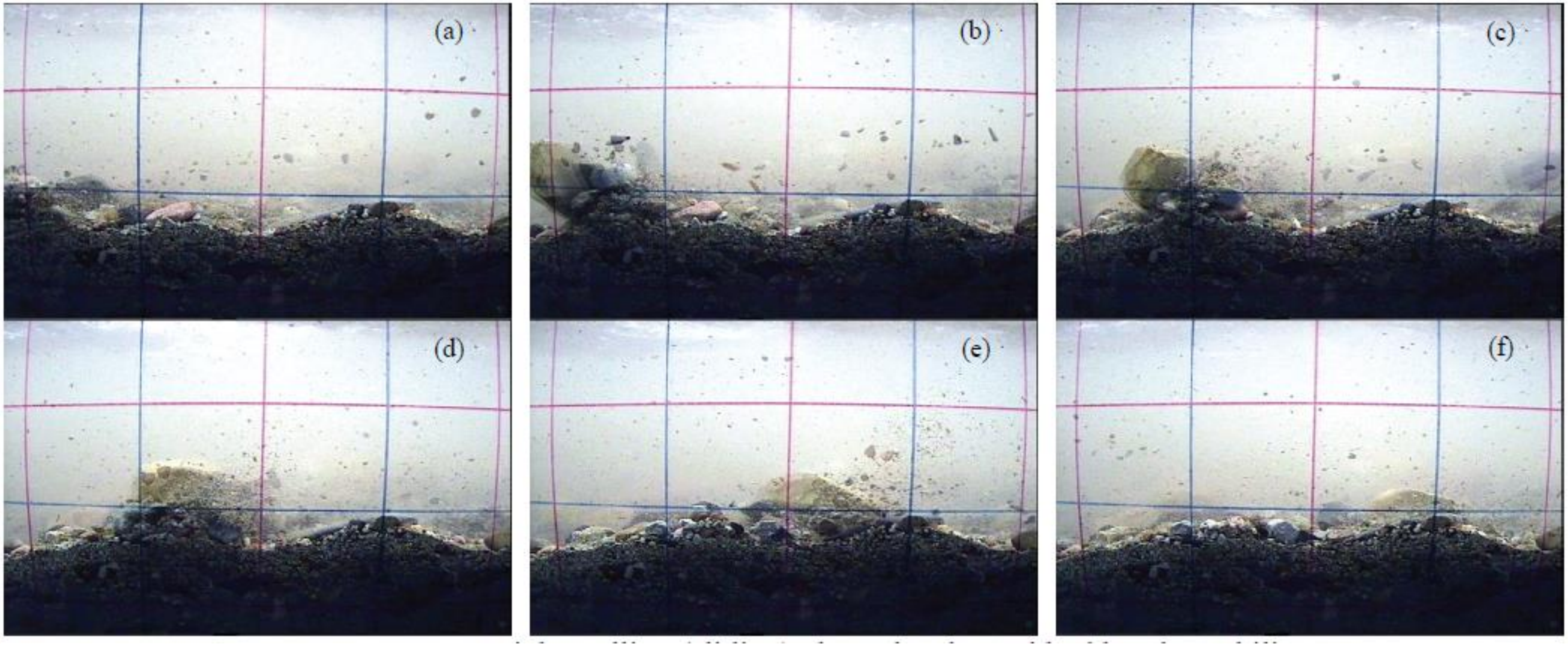


Yu et al., 2012. IJSR



Measured methods for sediment transport

- ☐ Basin characteristics of sediment transport in mountain rivers
- Suspended load may be neglected;
- Bed load dominates riverbed processes;
- Patterns of particles motion: **rolling, sliding, saltation**
- Substrate consists mainly of cobbles, gravel, and coarse sand



Yu et al., 2012. IJSR

Comparison of characteristics of different bedload-sampling technologies

Bedload-Sampling Technology	Stream Type	Requires Wading or Retrieval During High Flows	Physical Sample Obtained for Sieving	High Percentage of Channel Width Sampled	Large Opening Relative to Grain Size	Relatively Long Sampling Duration	Stream Excavation Required	Relative Ease of Use	Disruptive to Flow Fields	Status of Development	Potential Use as Calibration Standard
1. **Instream Installations**											
Birkbeck sampler[1] (weighable pit trap)	narrow gravel bed channel	no	no, automatically weighs mass in stream	typically not; depends on slot width	depends on slot width	continuous	yes	easy	may change with fill level	additional testing and modifications	high
Vortex sampler[2]	gravel bed channel	no	yes	yes	yes	continuous	yes	depends on flow conditions	depends on experimental setup	additional testing and modifications	high
Pit traps, unweighable[3]	gravel bed channel	yes	yes	typically not	possibly	possibly	yes, small scale	depends on flow conditions	slightly	additional testing	probably not
Net-frame sampler[4]	gravel bed channel	possibly	yes	yes	yes	yes	depends on experimental setup	can be difficult	depends on experimental setup	completed	possible
Sediment detention basins/weir ponds[5]	sand-gravel bed channels	no	periodically	yes	yes	yes	yes	relatively easy	no	completed	high

Comparison of characteristics of different bedload-sampling technologies

Bedload-Sampling Technology	Stream Type	Requires Wading or Retrieval During High Flows	Physical Sample Obtained for Sieving	High Percentage of Channel Width Sampled	Large Opening Relative to Grain Size	Relatively Long Sampling Duration	Stream Excavation Required	Relative Ease of Use	Disruptive to Flow Fields	Status of Development	Potential Use as Calibration Standard
2. Portable/physical devices											
Pressure-difference samplers (small openings)[6]	sand-gravel bed channel	yes	yes	no	no	no	no	depends on flow conditions	slightly	additional verification	additional verification needed
Pressure-difference samplers (large openings)[7]	gravel bed channel	yes	yes	no	yes	no	no	depends on flow conditions	highly	additional verification	additional verification needed
Baskets (suspended or instream)[8]	gravel bed channel	yes	yes	depends on design	depends on design	yes	no	depends on flow conditions	depends on experimental setup	completed	moderate
Bedload traps[9]	gravel bed channel	yes	yes	depends on number of traps deployed	yes	yes	minor	depends on flow conditions	slightly	completed: testing of modifications	moderate, with additional verification
Tracer particles (painted, magnetic, signal emitting rocks)[10]	gravel bed channel	possibly	no	depends on tracer placement	N/A	yes	no	easy	no	additional verification	low
Scour chains; scour monitor; scour core[11]	sand-gravel bed channel	possibly	no	no	N/A	yes	yes	easy	no	completed	low
Bedload collector (Streamside Systems)[12]	sand-gravel bed channel	no	yes	depends on number and size of devices deployed	depends on design of device	yes	yes	operation is easy once installed	unknown	needs verification	needs to be tested

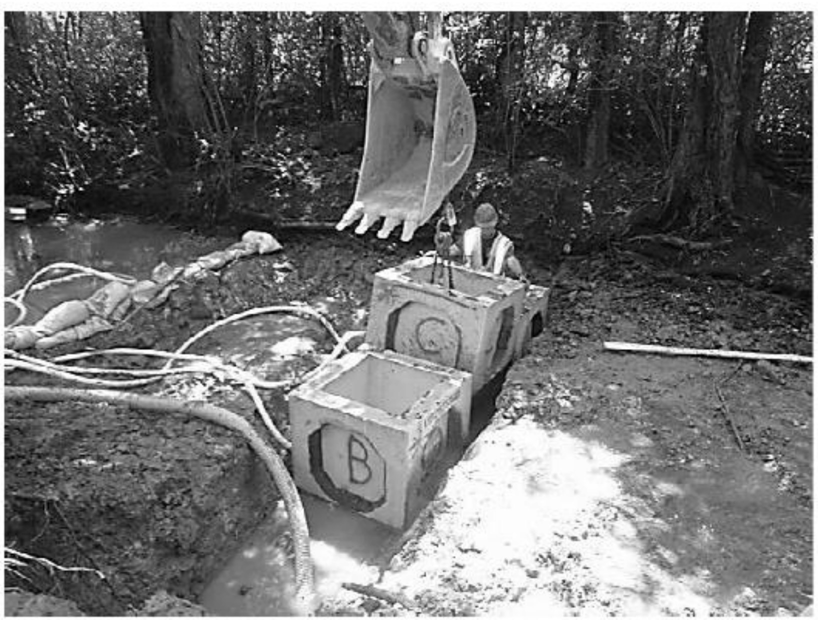
Comparison of characteristics of different bedload-sampling technologies

3. Surrogate Technologies

ADCP – acoustic Doppler current profiler[13]	sand bed rivers, experimental in larger gravel bed channels	no	no	yes	N/A	continuous	no	logistics and data reduction are complex	no	moderate (sand systems) early (gravel systems)	additional verification for gravel bed systems
Hydrophones (active and passive acoustic sensor)[14]	gravel bed channel	no	no	depends on deployment	N/A	continuous	possibly	easy	no	early	additional development needed
Gravel impact sensor[15]	gravel bed channel	yes, for hand-held model	no	not as currently designed	N/A	continuous	yes for instream model	easy under many conditions	in fast flow	early	additional development needed
Magnetic Tracers[16]	gravel bed with naturally magnetic particles	no	no	yes	N/A	continuous	yes	relatively easy	depends on experimental setup	additional testing	possible at appropriate locations
Magnetic sensors[17]	gravel bed channel	no	no	yes	N/A	continuous	yes	easy under many conditions	minor; flush with stream bottom	early	additional verification needed
Topographic differ-encing[18]	sand-gravel bed channel	no	no	yes	N/A	episodically or continuous	no	easy	no	early?	additional verification for gravel bed systems
Sonar-measured debris basin[19]	gravel bed channel	no	no	yes	N/A	continuous	with debris basin installation	easy under many conditions	N/A	early	high
Underwater video cameras[20]	relatively clear flow	used from bridges or boats	no	no	N/A	continuous	no	easy under right lighting conditions	slightly	early	additional verification needed

1. Pit trap for bed load

- A bedload monitoring station includes four Birkbeck-type pit traps (Reid et al. 1980), extending perpendicular to flow across the channel bottom in series.
- The bedload traps consist of a reinforced concrete vault and a stainless steel loading box insert resting on four submersible load cells.
- The total collection volume of each trap was 1.6 m^3.
- The four load cells in each vault were individually connected to a Campbell data logger (Model #CR1000) mounted on an instrument panel adjacent to the channel.
- Water level loggers were located 11 m and 27 m upstream and downstream respectively. They were time synchronized with the data logger at the bedload station and were tied to an established datum on the greenway adjacent to the site.



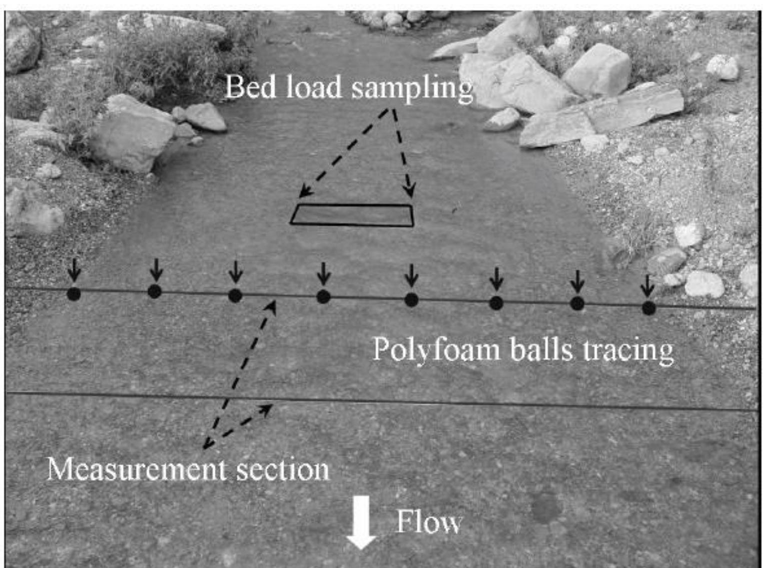
2. Double-box bed load sampler

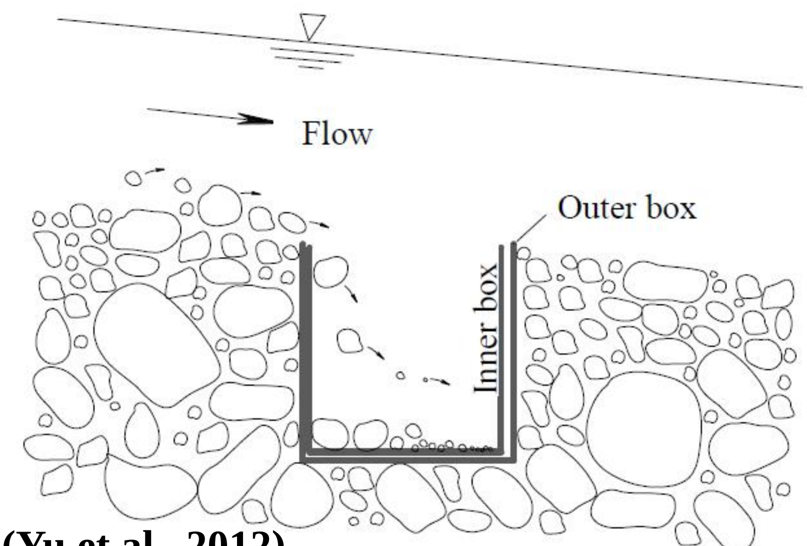
- The inner box was put into the outer box. The inner box was lifted out from the outer box when the inner box was nearly full of sediment.
- The time it took the inner box to fill with sediment was recorded. After the inner box was lifted, the wet weight of collected bed load sediment was measured.
- The sediment collected was sent to the laboratory to determine the bed load transport rate and the size distribution.

✓ The collected sediment was thoroughly and evenly mixed before the wet weight of the representative bed load measurement was taken;

✓ The sample sediment was dried, weighed, and sieved in the laboratory to attain the size distribution;

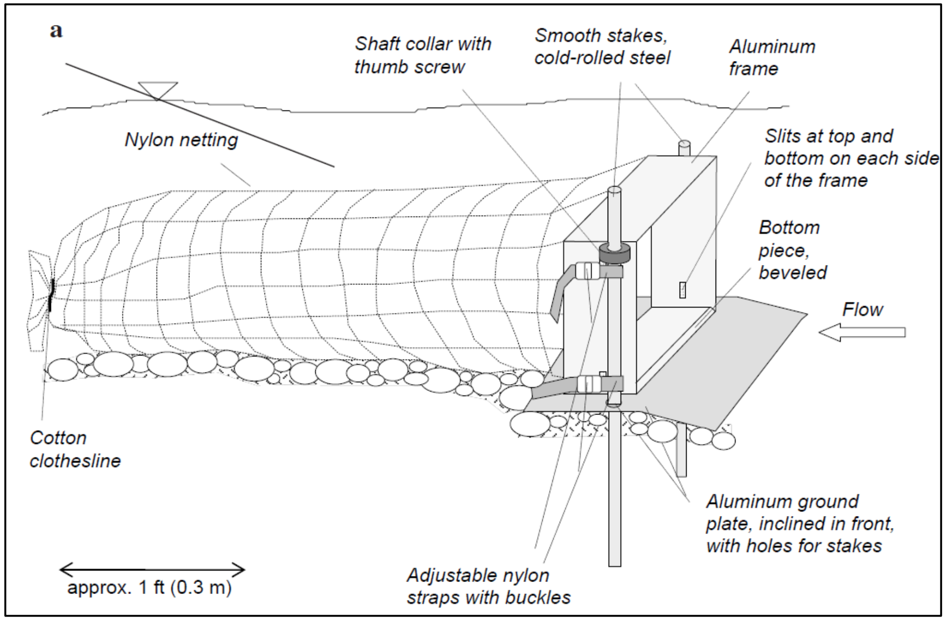
✓ The weight and diameter of the largest five particles of each bed load sample were measured.

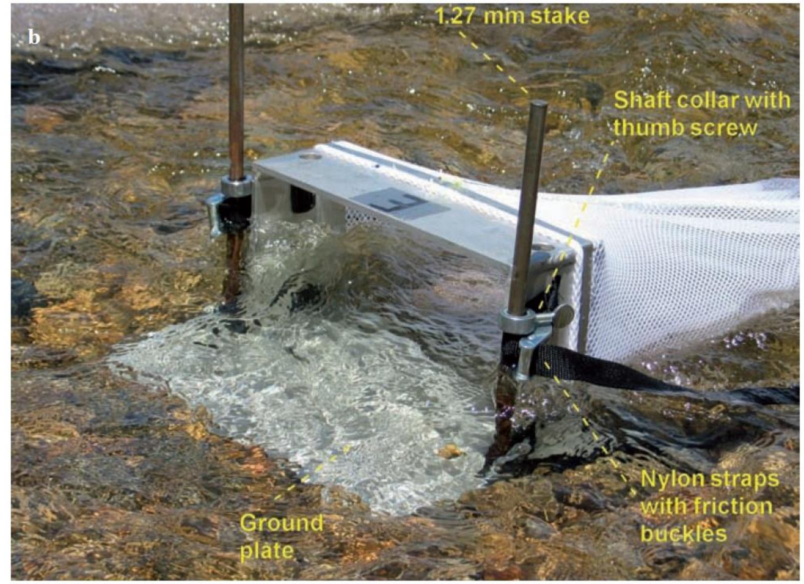




(Yu et al., 2012)

3. Bed load trap





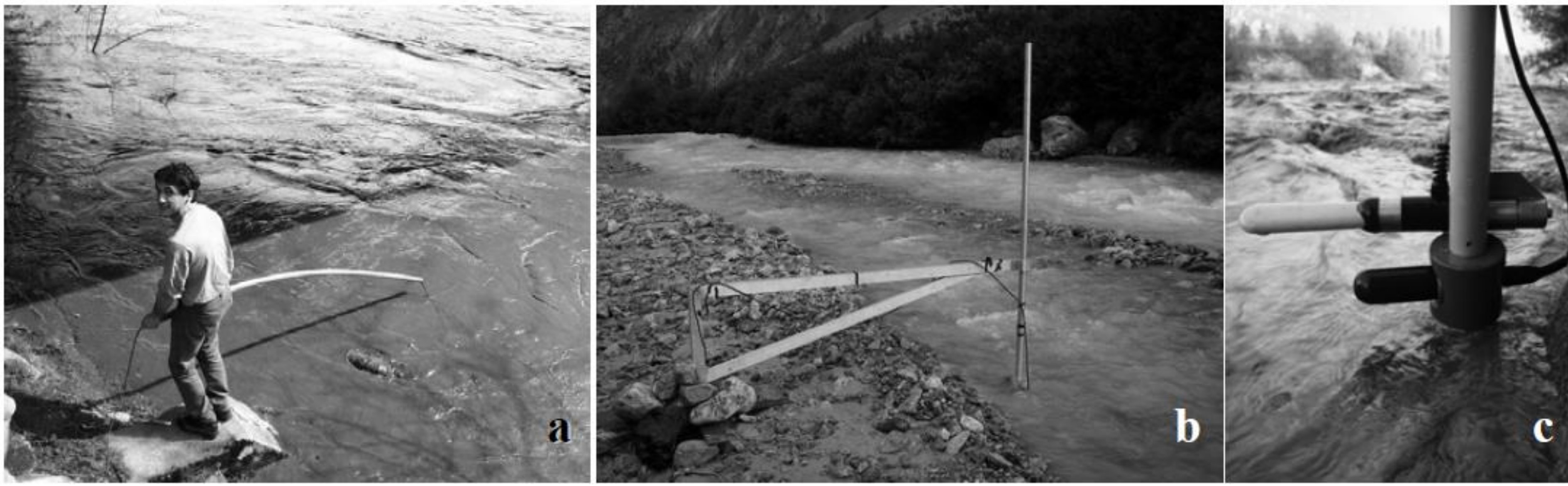
- A photograph of a bedload trap installed on a ground plate in a stream channel ready for sampling.
- The metal stakes hold the trap in place to the stream bottom and the nylon straps and shaft collars secure the trap to the ground plate.
- The trailing 3.5 mm fishnet serves to trap sediment particles. The trap can be left in place during the entire sampling period without disturbing the stream bottom.

3. Bed load trap

Six bedload traps installed in the stream are emptied at 80% of bankfull flow

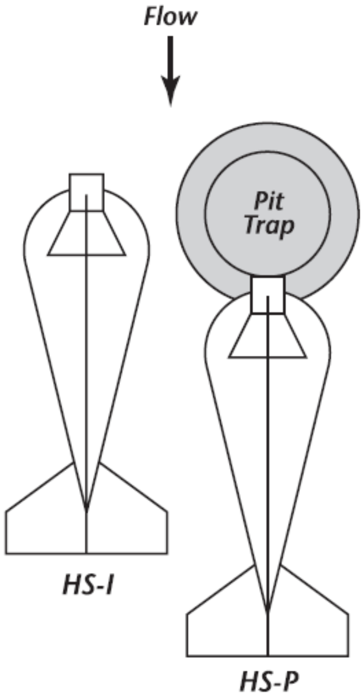
Emptying of bedload trap from a foot bridge

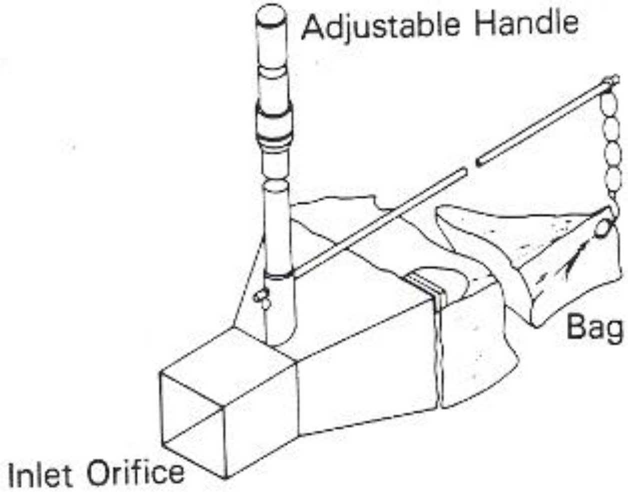
4. Hydrophone

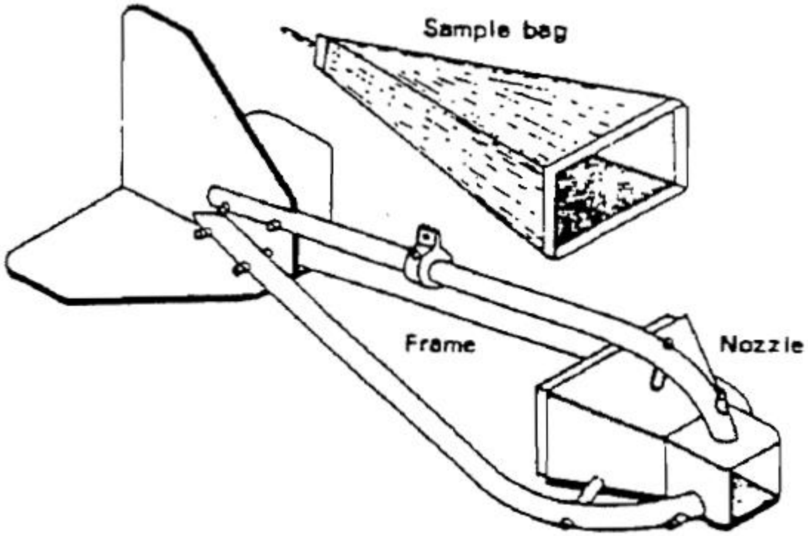


- Fig. 1a: The hydrophone hanging at the extremity of a rod
- Fig. 1b: The hydrophone held by a fixed frame
- Fig. 1c: The hydrophone on the frame before immersion. An electromagnetic flow sensor is used.

5. Helley-Smith sampler







6. Acoustic gravel-transport sensor

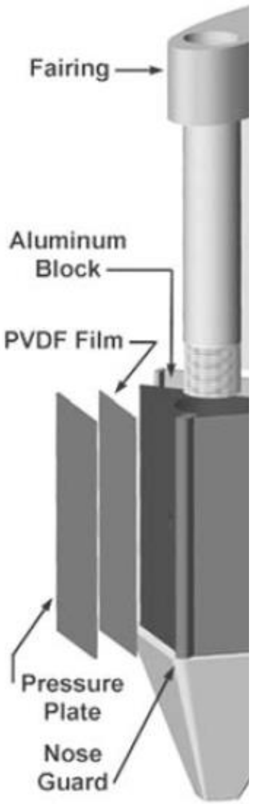


Fig. 1 Exploded v
stream survey.

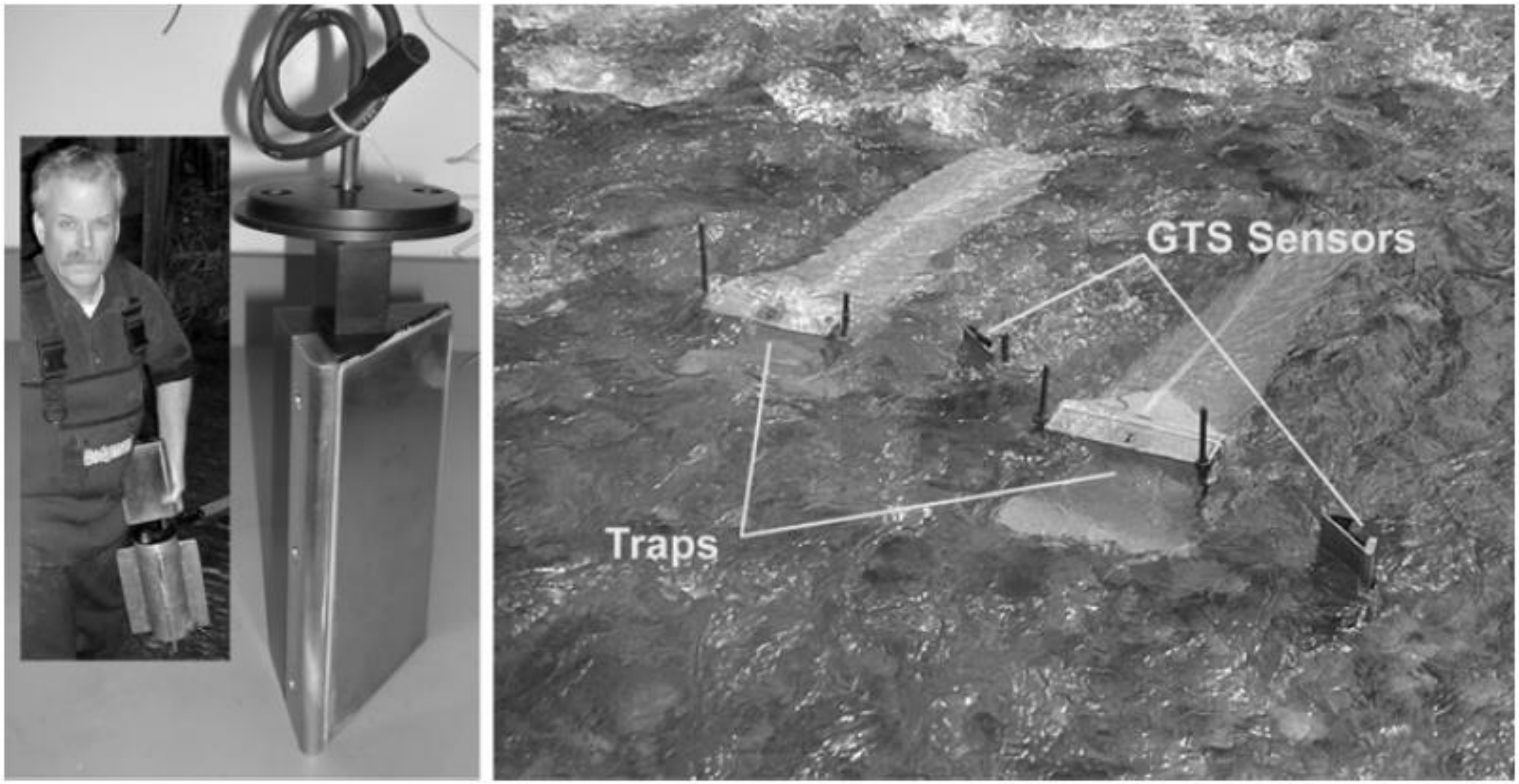
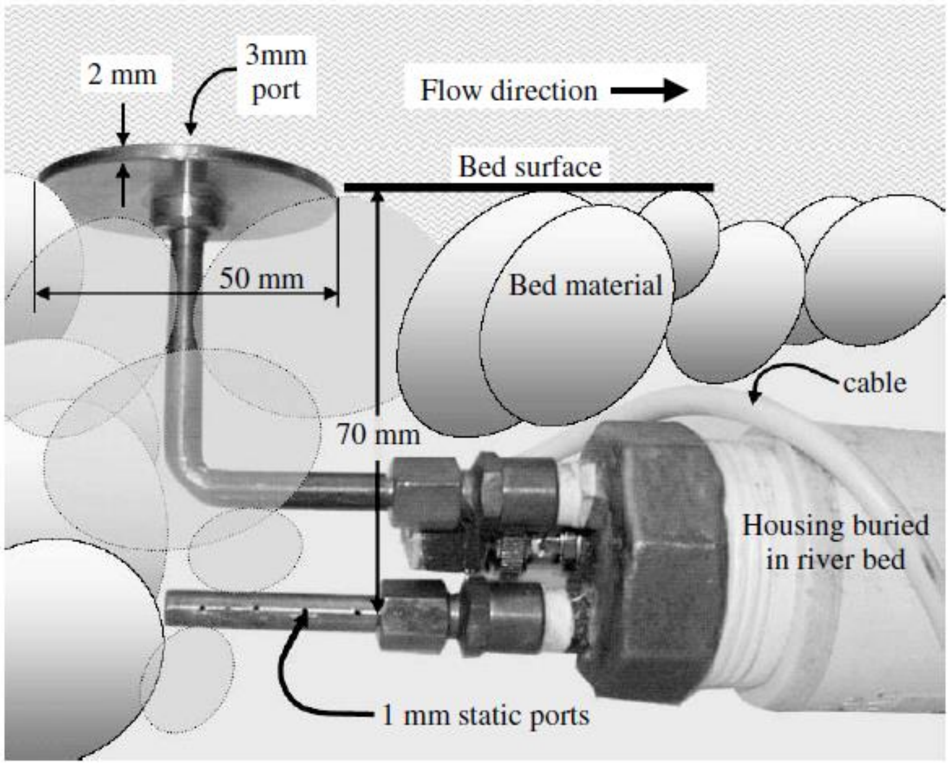


Fig. 2 Photographs of GTS-II transducer, anchor assembly (insert) and sensors deployed with bedload traps in Little Granite Creek.

7. Differential pressure sensor

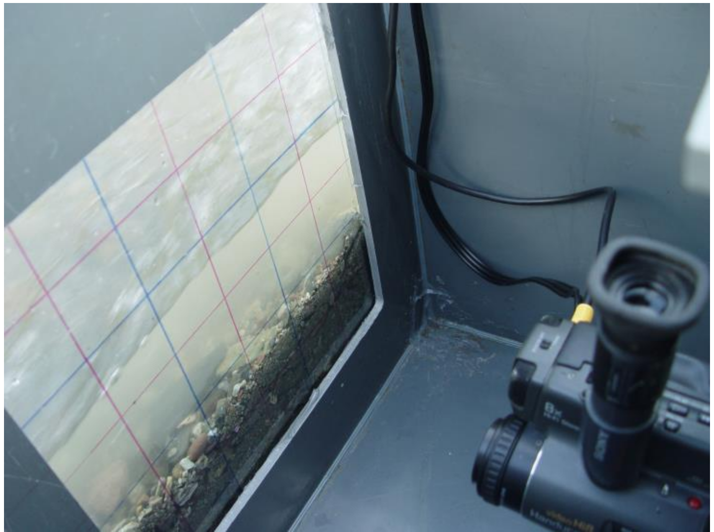


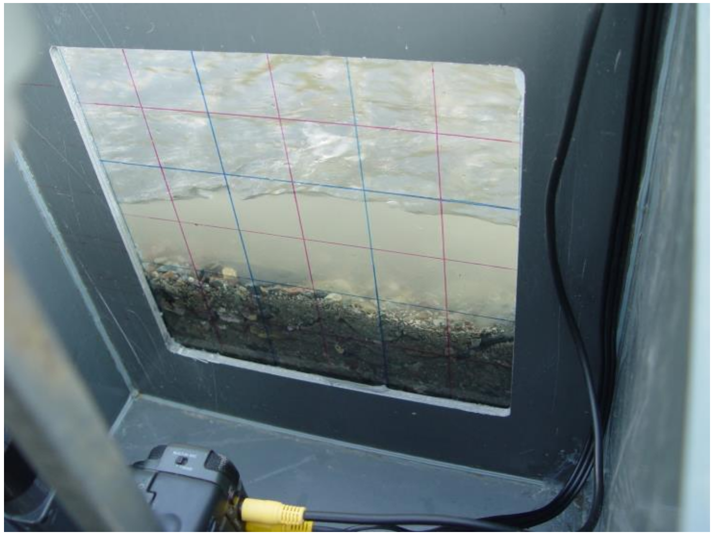
Schematic section through a gravel riverbed showing the buried instrument for measuring differential pressures in the bed surface layer (Smart and Habersack 2007)

- A differential pressure sensor, similar to those used in the Pitot tube, was buried with one port 70mm below the bed surface and the other flush with the bed surface.
- The upper port was situated in the middle of a 50mm diameter flat circular plate to avoid any local, form-induced pressure variations.
- The flat plate was situated level with the tops of bed roughness elements and bed particles were packed beneath the plate in an attempt to reproduce local bed conditions.
- Because a flat plate surrounded the upper port, the instrument recorded uplift (and downdraft) pressures being advected by the overlying flow, not pressures being generated by the (arbitrary) streamline curvature over a specific particle as is assumed in many lift and drag models.

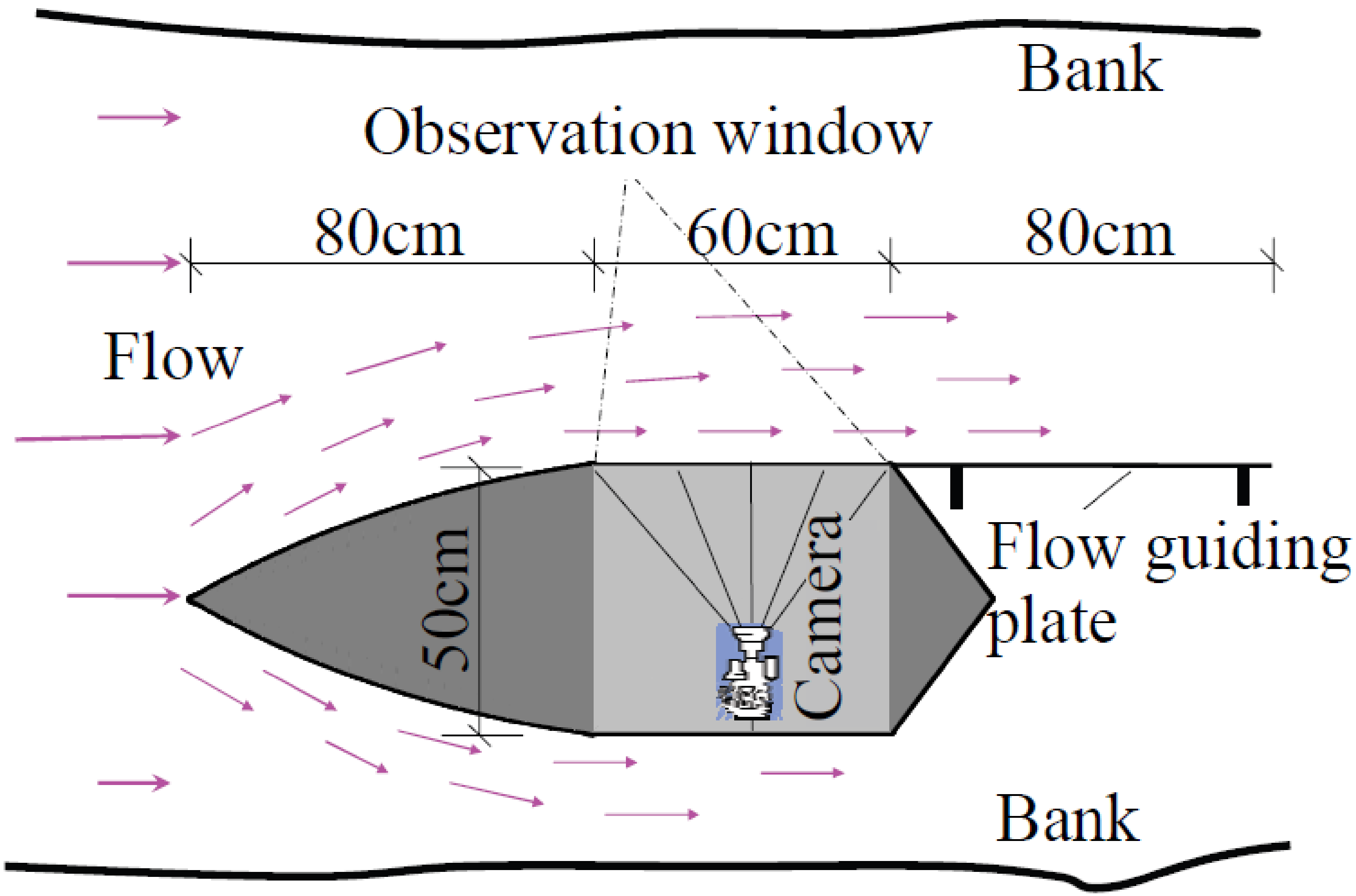
8. Bed load motion observation system using camera

(Yu et al., 2013)





8. Bed load motion observation system using camera



(Yu et al., 2013)

Outline

- ☐ Brief introduction on rivers in mountain regions
- ☐ Objective, plan and preparation of field survey
- ☐ Measured methods for river flow
- ☐ Measured methods for sediment transport
- ☐ **Measured methods for river bed**
- ☐ Concluding remarks

New methods for riverbed topography





Emerging approaches to acquiring high-resolution topography

Remotely Sensed or Aerial Surveys

- Spectral-Depth Correlation
- Structure From Motion
- LiDaR
- Photogrammetry

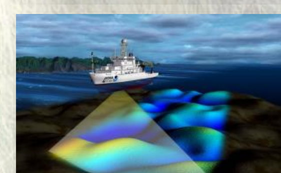
Ground-Based Surveys

- Total Station Surveys
- GPS
- Terrestrial Laser Scanning

Slide provided by Dr. Joe Wheaton

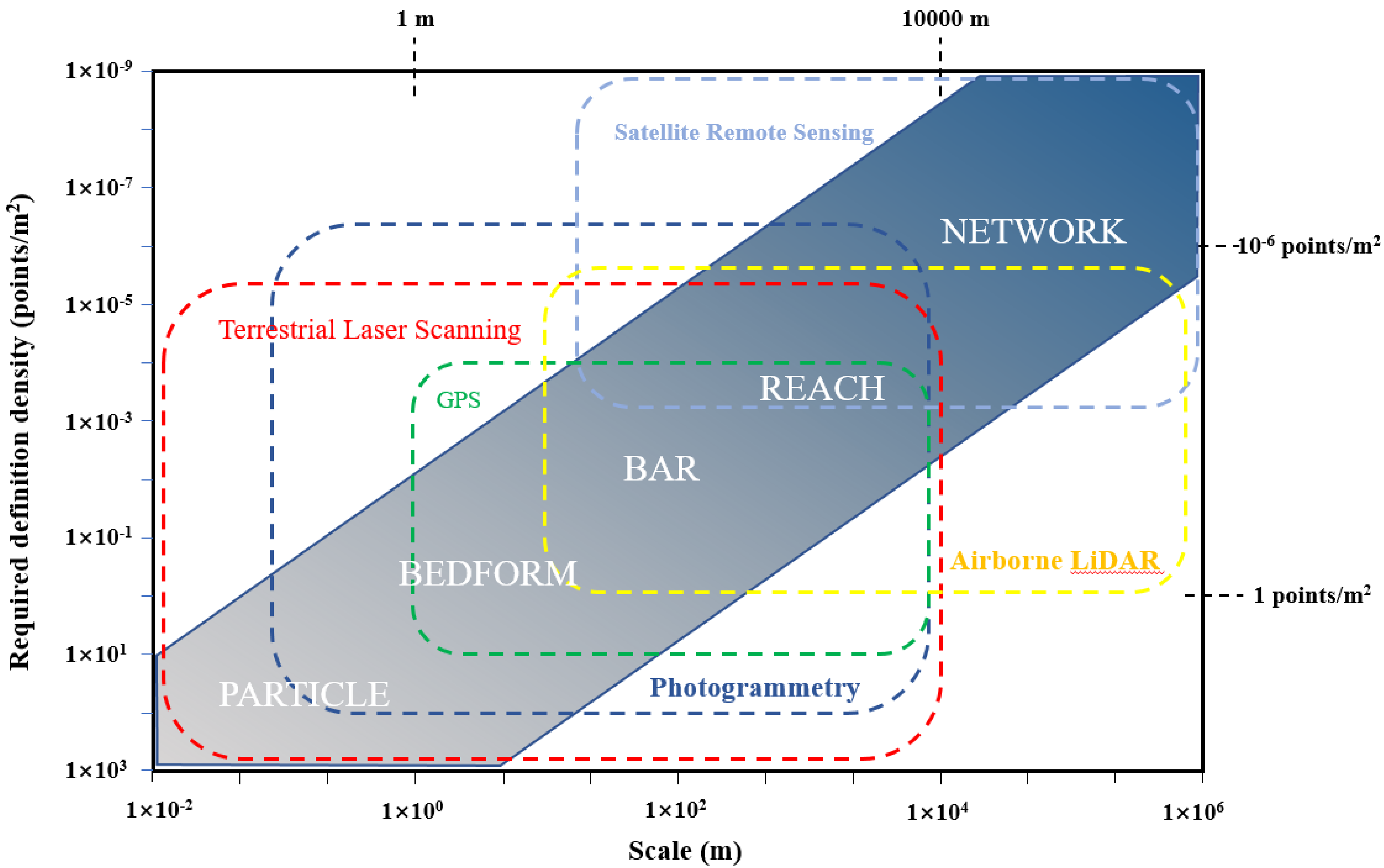
Boat-Based Bathymetry Surveys

- Multibeam Sonar
- Singlebeam Sonar



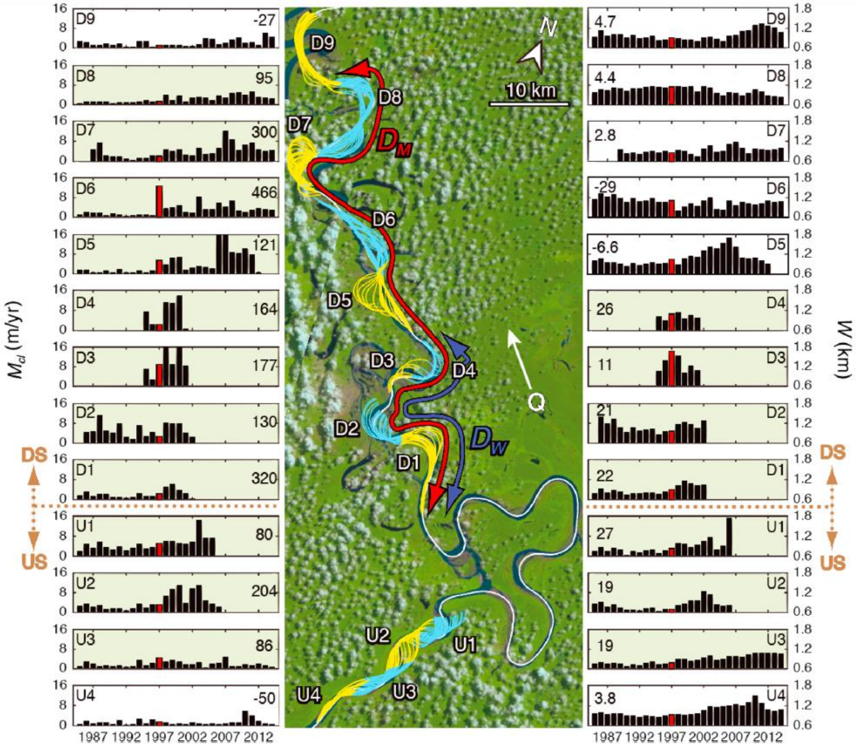


Spatial scale and point cloud density in different methods

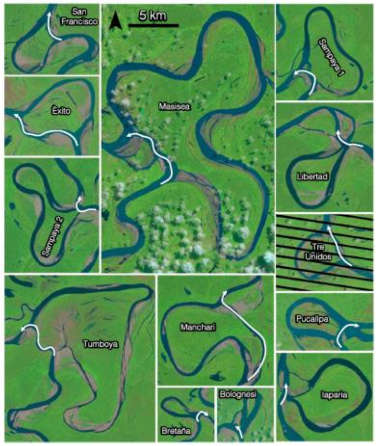


1. Multisource, long-term, hyper-spectral satellite imagery

- Remote Sensing Image: recording of various objects electromagnetic wave size film or photos, mainly divided into aerial photographs and satellite photos.
- According to the geometric and physical properties of the image, the quality and quantity characteristics of the object or phenomenon and their relationship are analyzed and revealed synthetically, and then the occurrence and development process and distribution law of the object or phenomenon are studied.
- Spatial resolution: 30m、10m、2m、0.8m、0.5m、0.3m



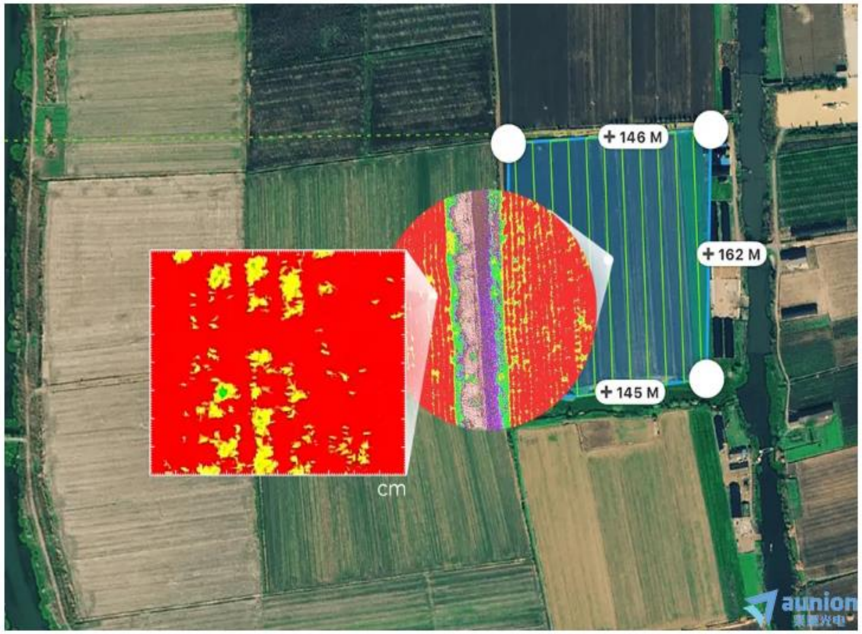
Schwenk and Foufoula-Georgiou, 2016,GRL

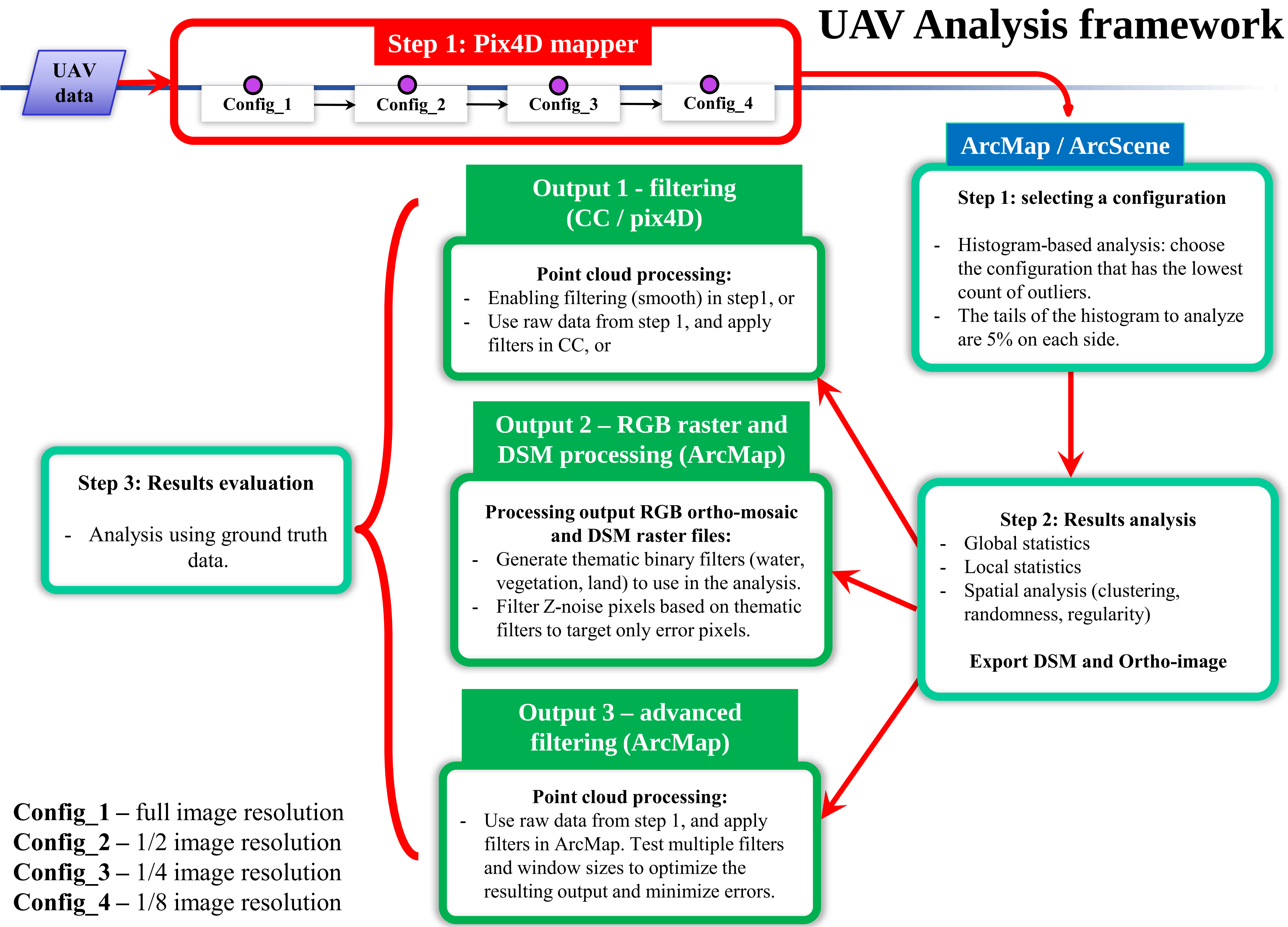


2. Unmanned Aerial Vehicle survey

- DJI UAV+RTK low altitude aerial survey has been widely used in river landscape, surface flow field and river topographic observation.

- Use Pix4D mapper, Cloud Compare, ArcMap software to generate point cloud, noise processing of DEM data, high precision data, sub-meter resolution.




UAV Analysis framework
UAV data
Step 1: Pix4D mapper
Config_1
Config_2
Config_3
Config_4
ArcMap / ArcScene
Step 1: selecting a configuration
- Histogram-based analysis: choose the configuration that has the lowest count of outliers.
- The tails of the histogram to analyze are 5% on each side.
Output 1 - filtering (CC / pix4D)
Point cloud processing:
- Enabling filtering (smooth) in step1, or
- Use raw data from step 1, and apply filters in CC, or
Output 2 – RGB raster and DSM processing (ArcMap)
Processing output RGB ortho-mosaic and DSM raster files:
- Generate thematic binary filters (water, vegetation, land) to use in the analysis.
- Filter Z-noise pixels based on thematic filters to target only error pixels.
Step 2: Results analysis
- Global statistics
- Local statistics
- Spatial analysis (clustering, randomness, regularity)
Export DSM and Ortho-image
Step 3: Results evaluation
- Analysis using ground truth data.
Output 3 – advanced filtering (ArcMap)
Point cloud processing:
- Use raw data from step 1, and apply filters in ArcMap. Test multiple filters and window sizes to optimize the resulting output and minimize errors.
Config_1 – full image resolution
Config_2 – 1/2 image resolution
Config_3 – 1/4 image resolution
Config_4 – 1/8 image resolution

Step 1: selecting a configuration

Config_1

Summary options:

- Key-points image scale: **Full**
- **Point cloud densification:**
  - ❖ Image scale: multiscale **1** (**original** image size – slow)
  - ❖ Point density: **optimal**
- **DSM & Orthomosaic:**
  - ❖ Noise filter – Smooth: **NO**

Summary results:

- **Number of 3D densified points:** **87,718,792**
- **Average density (per m³):** **109.96**
- **Processing time:**
  - ❖ PC densification: 8h:50m
  - ❖ 3D mesh: 5h59m
  - ❖ DSM generation: 9h10m
  - ❖ Orthomosaic: 1h15m

Config_2

Summary options:

- Key-points image scale: **Full**
- **Point cloud densification:**
  - ❖ Image scale: multiscale **1/2** (**half** image size – slow)
  - ❖ Point density: **optimal**
- **DSM & Orthomosaic:**
  - ❖ Noise filter – Smooth: **NO**

Summary results:

- **Number of 3D densified points:** **21,218,240**
- **Average density (per m³):** **31.92**
- **Processing time:**
  - ❖ PC densification: 1h:47m
  - ❖ 3D mesh: 21m
  - ❖ DSM generation: 1h9m
  - ❖ Orthomosaic: 59m

Config_3

Summary options:

- Key-points image scale: **Full**
- **Point cloud densification:**
  - ❖ Image scale: multiscale **1/4** (**quarter** image size – slow)
  - ❖ Point density: **optimal**
- **DSM & Orthomosaic:**
  - ❖ Noise filter – Smooth: **NO**

Summary results:

- **Number of 3D densified points:** **5,060,166**
- **Average density (per m³):** **9.25**
- **Processing time:**
  - ❖ PC densification: 28m
  - ❖ 3D mesh: 12m
  - ❖ DSM generation: 31.m
  - ❖ Orthomosaic: 1h0m

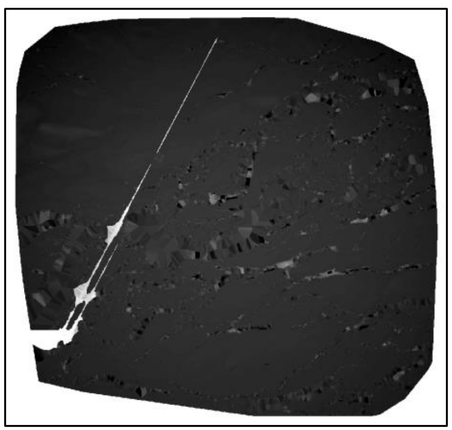
Config_4

Summary options:

- Key-points image scale: **Full**
- **Point cloud densification:**
  - ❖ Image scale: multiscale **1/8** (**eighth** image size – slow)
  - ❖ Point density: **optimal**
- **DSM & Orthomosaic:**
  - ❖ Noise filter – Smooth: **NO**

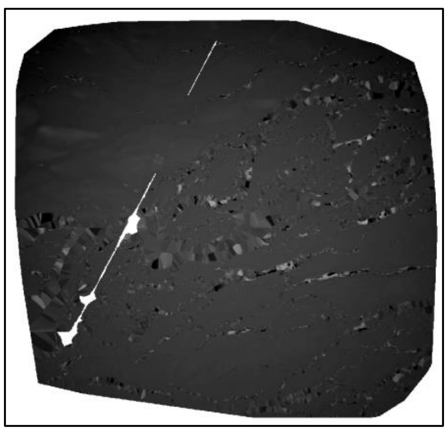
Summary results:

- **Number of 3D densified points:** **1,234,056**
- **Average density (per m³):** **2.99**
- **Processing time:**
  - ❖ PC densification: 13m
  - ❖ 3D mesh: 11m
  - ❖ DSM generation: 24.m
  - ❖ Orthomosaic: 1h0m



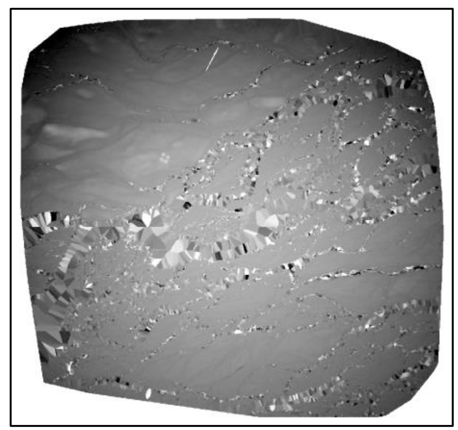
Statistics

min:	4710.99	mean:	4722.15
max:	4764.65	std. deviation:	3.21



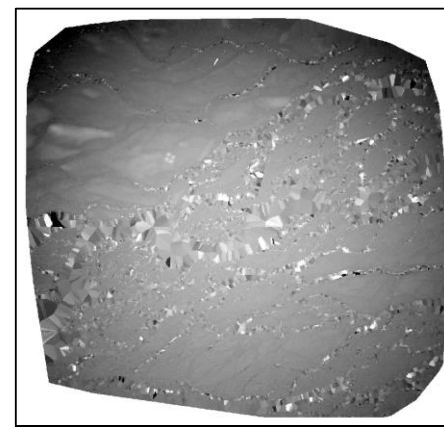
Statistics

min:	4713.02	mean:	4721.99
max:	4757.14	std. deviation:	2.29



Statistics

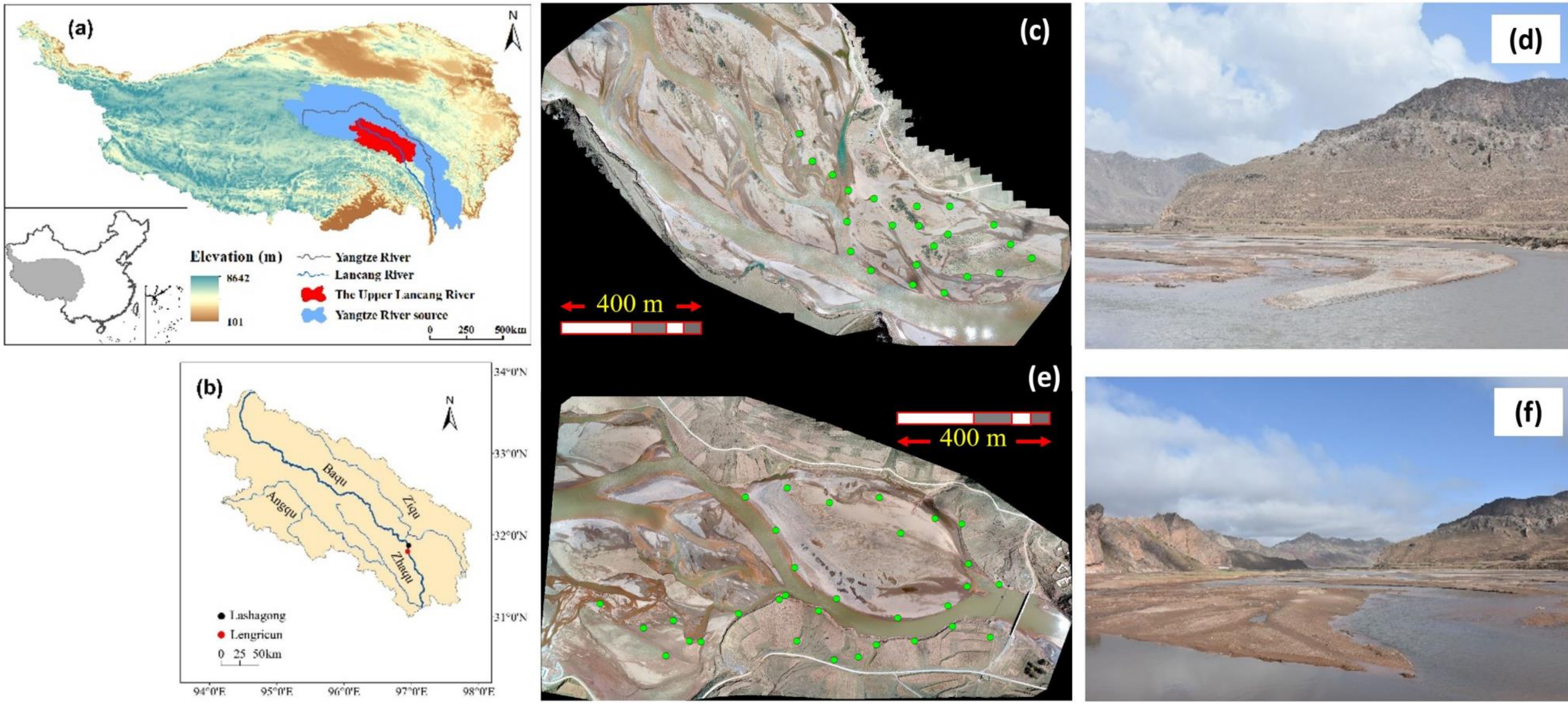
min:	4711.93	mean:	4721.86
max:	4740.15	std. deviation:	1.38

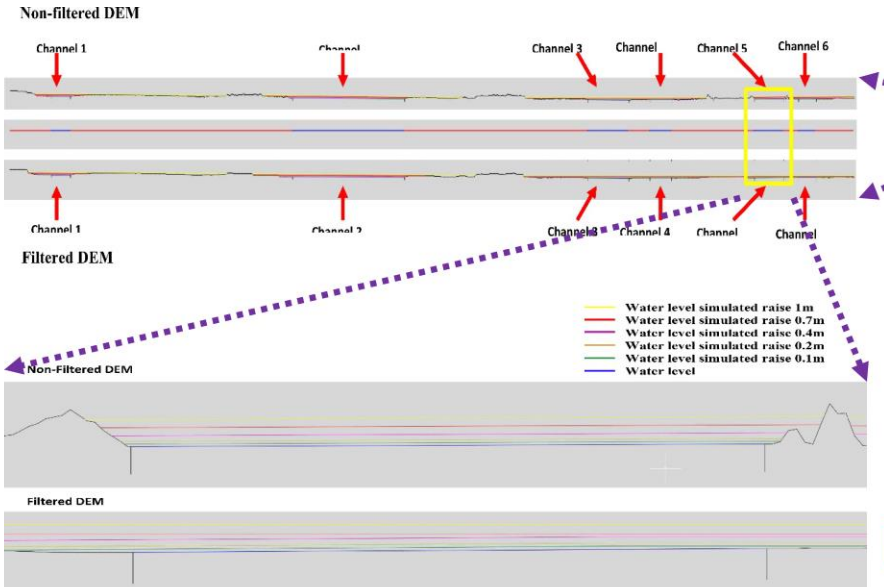


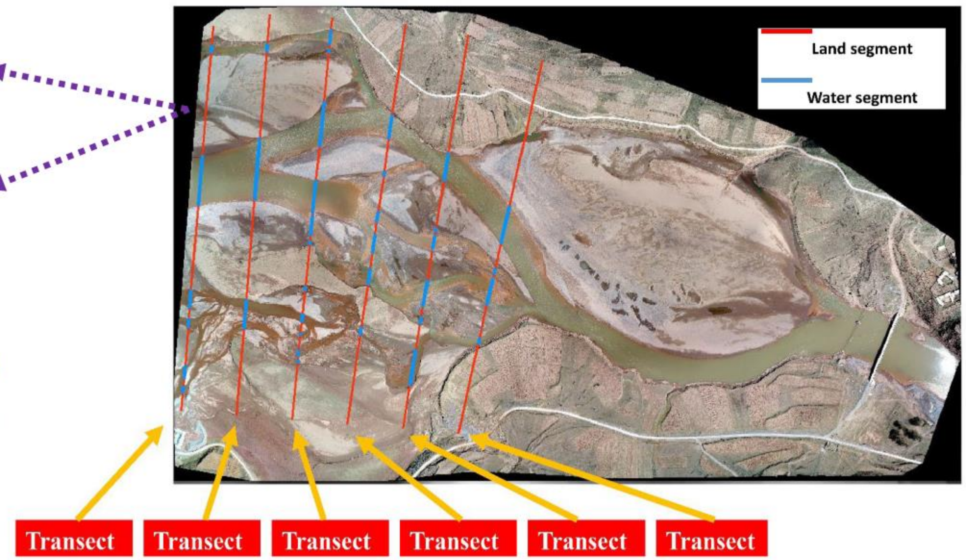
Statistics

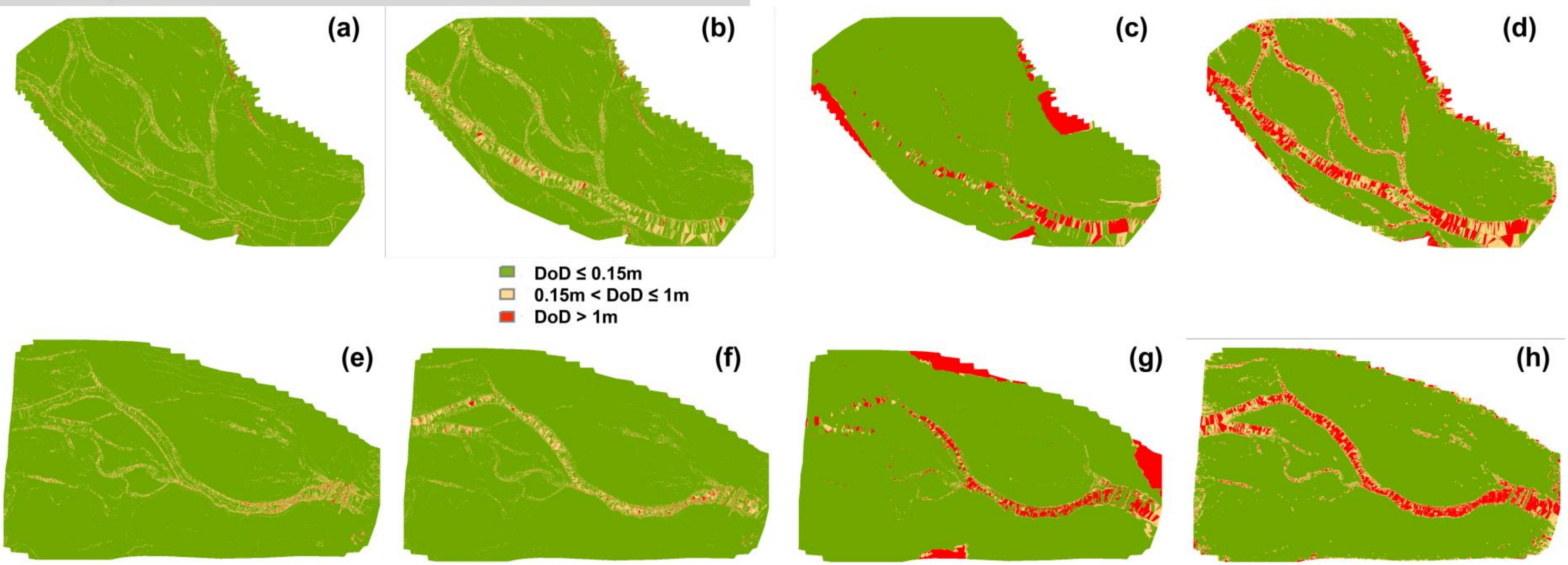
min:	4711.81	mean:	4721.86
max:	4739.48	std. deviation:	1.32

A UAV survey case study in the Upper Lancang River




Non-filtered DEM
Channel 1
Channel 3
Channel
Channel 5
Channel 6
Channel 1
Channel 4
Channel
Filtered DEM
Water level simulated raise 1m
Water level simulated raise 0.7m
Water level simulated raise 0.4m
Water level simulated raise 0.2m
Water level simulated raise 0.1m
Water level
Non-Filtered DEM
Filtered DEM


Land segment
Water segment
Transect
Transect
Transect
Transect
Transect
Transect

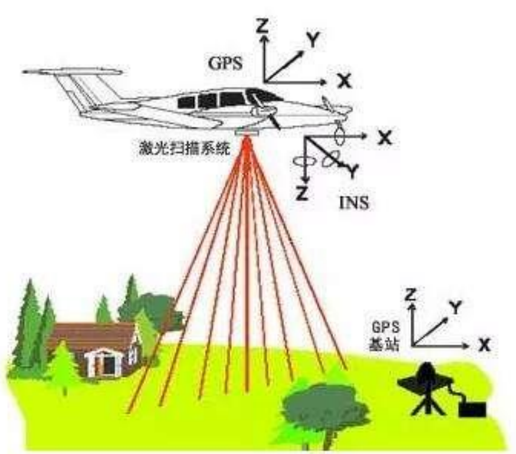

(a)
(b)
(c)
(d)
DoD ≤ 0.15m
0.15m < DoD ≤ 1m
DoD > 1m
(e)
(f)
(g)
(h)

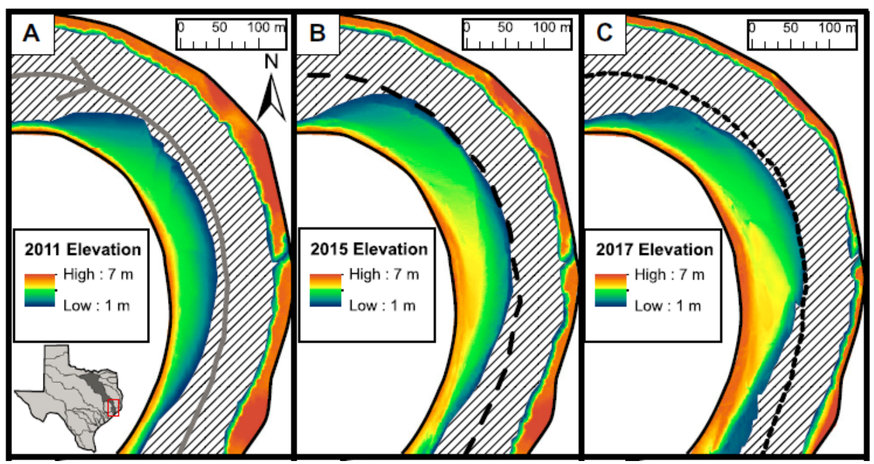
3. LiADR application

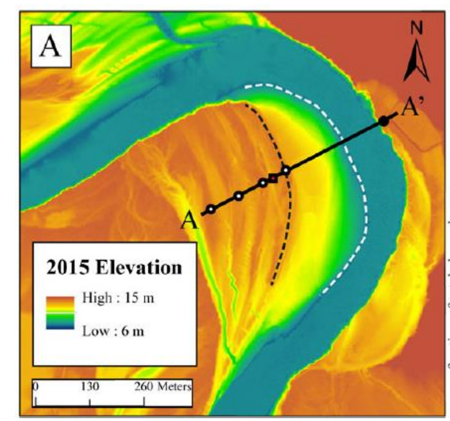
- A system which integrates laser, global positioning system (GPS) and inertial navigation system (INS) to obtain point cloud data and generate accurate digital 3D model

- The most basic working principle of lidar is that the radar transmitting system sends a signal, which is collected by the receiving system after the target is reflected, and the distance of the target is determined by measuring the running time of the reflected light. The radial velocity of the target can be determined by the Doppler shift of the reflected light, or two or more distances can be measured, and the velocity can be obtained by calculating the rate of change.

- **Spatial resolution = 1m， vertical accuracy = 0.1m.**



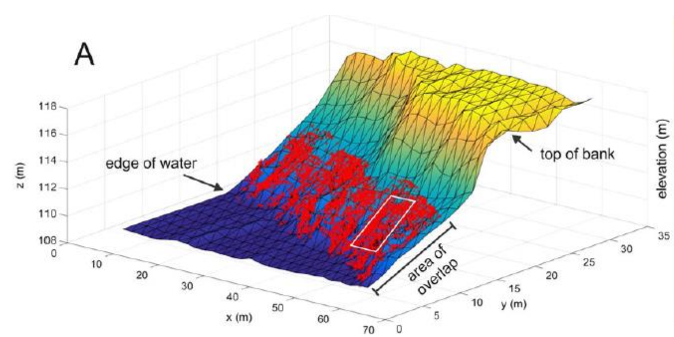




Mason and Mohrig, 2019, Geology

4. Terrestrial laser scanning

- A detection 3D laser scanning system is mainly composed of 3D laser scanner, computer, power supply system, support and system supporting software.
- The 3D laser scanner, as the main component of the 3D laser scanning system, is composed of laser emitter, receiver, time counter, motor controlled rotatable filter, control circuit board, microcomputer, CCD machine and software. It is a technological revolution in the field of surveying and mapping after GPS technology.
- It breaks through the traditional single point measurement method and has the unique advantages of high efficiency and high precision. Three-dimensional laser scanning technology can provide three-dimensional point cloud data on the surface of scanning objects, so it can be used to obtain high precision and high resolution digital terrain model.

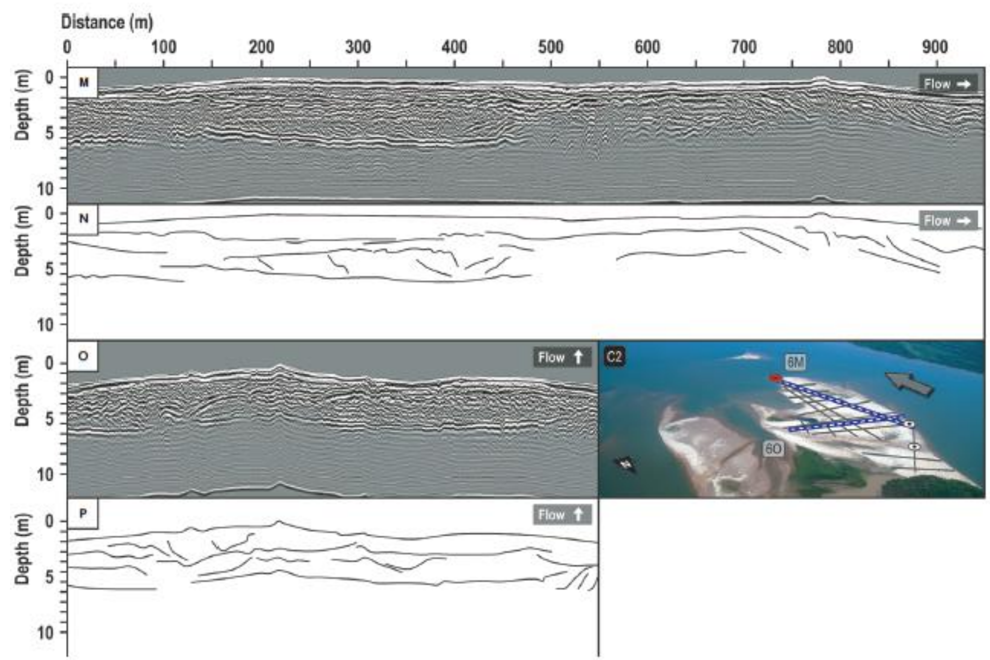


Konsoer et al., 2017,ESPL

5. Ground Penetrating Radar

- An effective means of detecting underground targets, it is a non-destructive detection technology, which has the advantages of fast detection speed, continuous detection process, high resolution, convenient and flexible operation and low detection cost. It is mainly used in sedimentology, archaeology, mineral exploration, disaster geological survey, geotechnical engineering survey, engineering quality inspection, building structure inspection.

- Ground penetrating radar(GPR) is a geophysical method that uses antenna to transmit and receive high frequency electromagnetic wave to detect the material characteristics and distribution law inside the medium.



Reesink et al., 2014, Sedimentology

A case study using GRP to measure the thickness of gravel layer

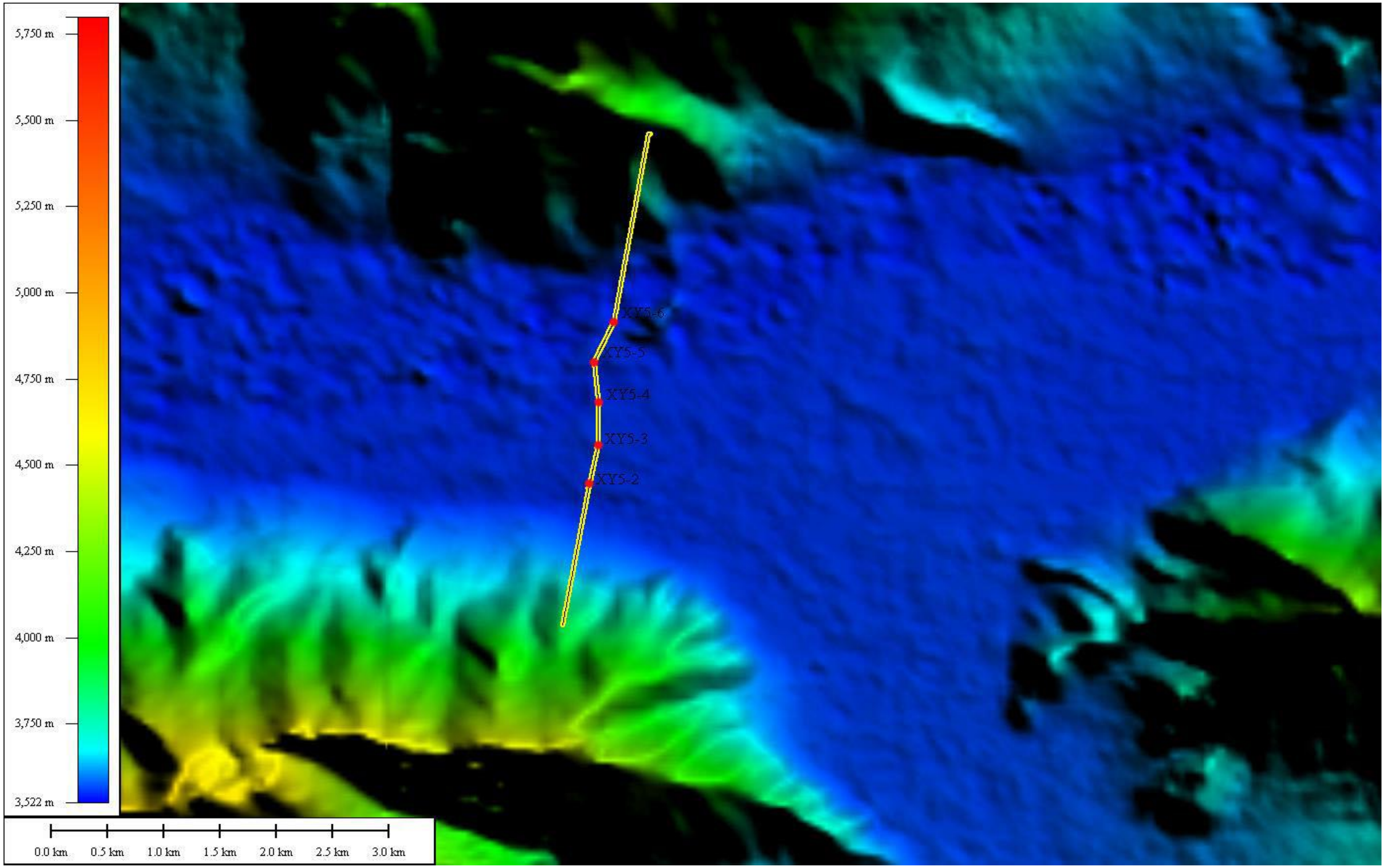

Gravel mining site

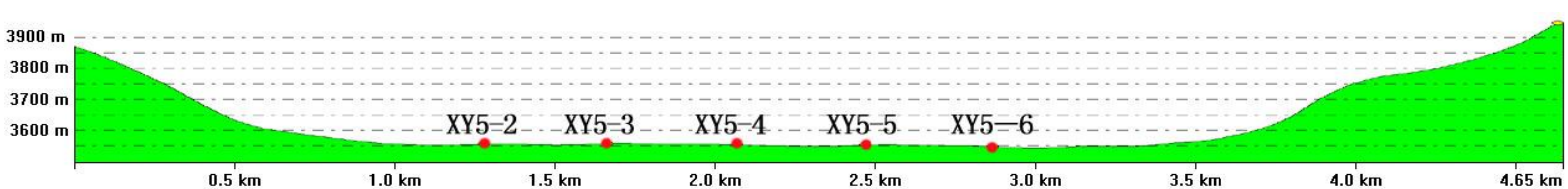

Field survey in 2011-2012

- A huge amount of gravel bed load deposited in the upstream section of the **middle Yarlung Tsangpo River in Tibetan Plateau**.

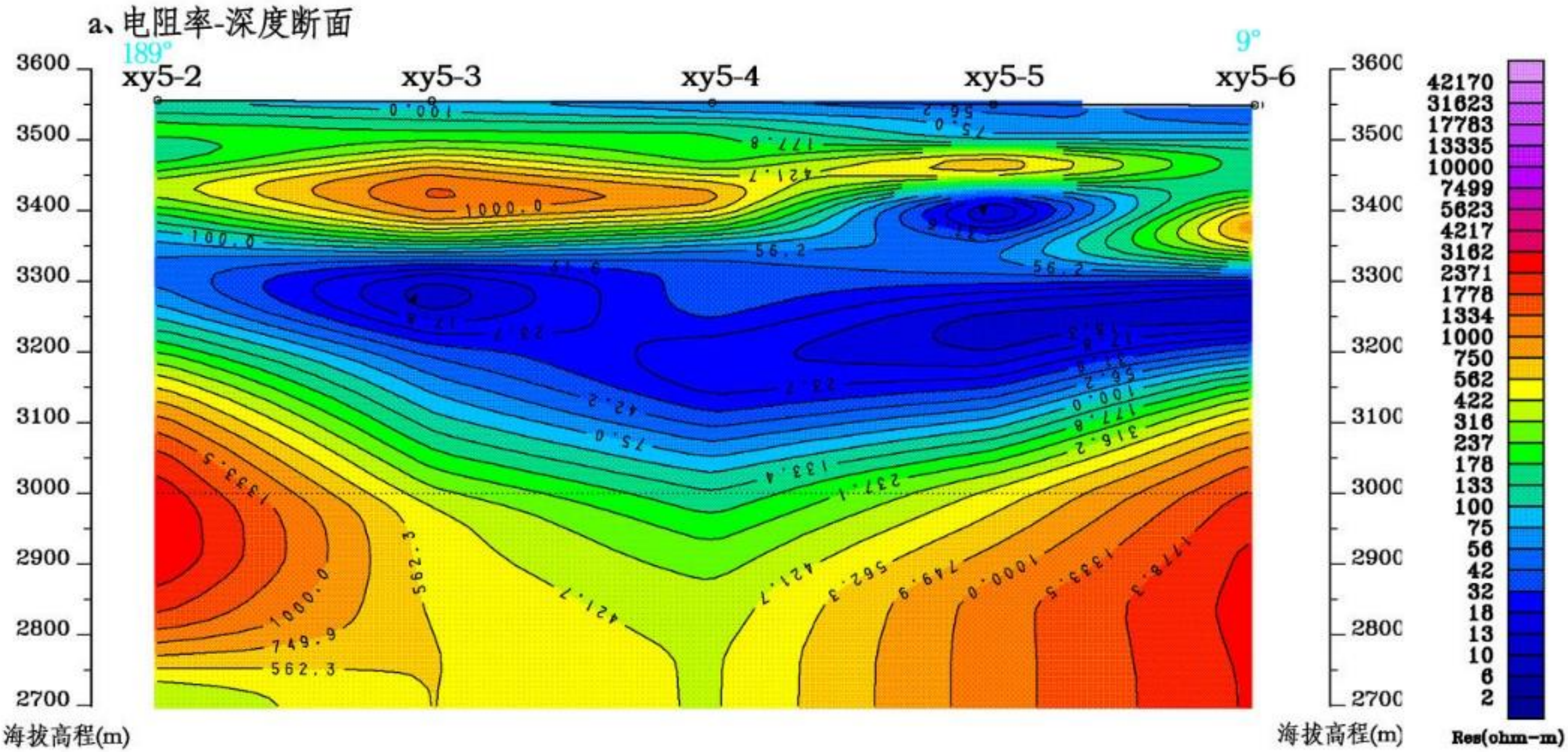
- How much is the thickness of gravel deposition?

Resistivity-depth along a cross section in the middle Yarlung Tsangpo

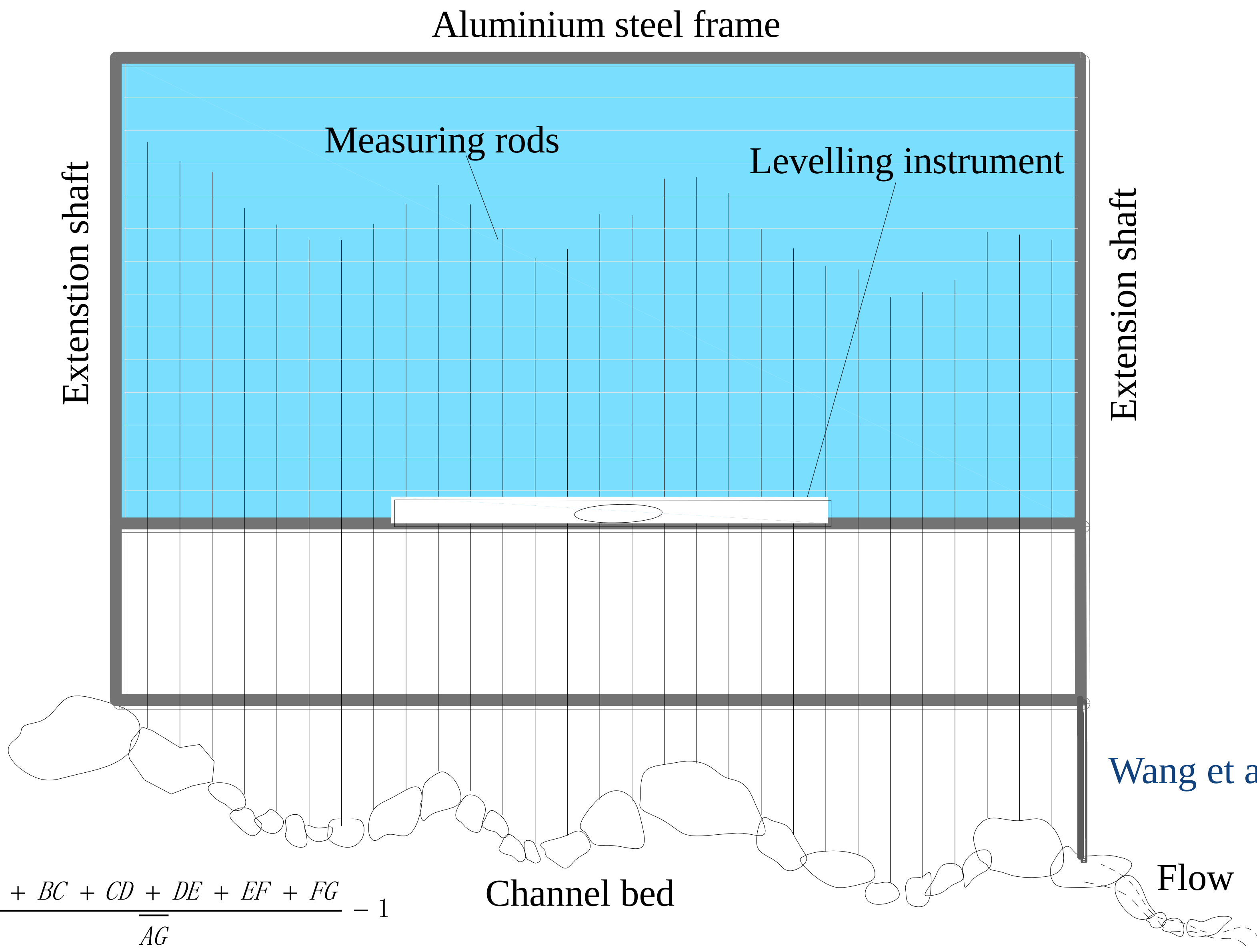




Resistivity-depth along a cross section

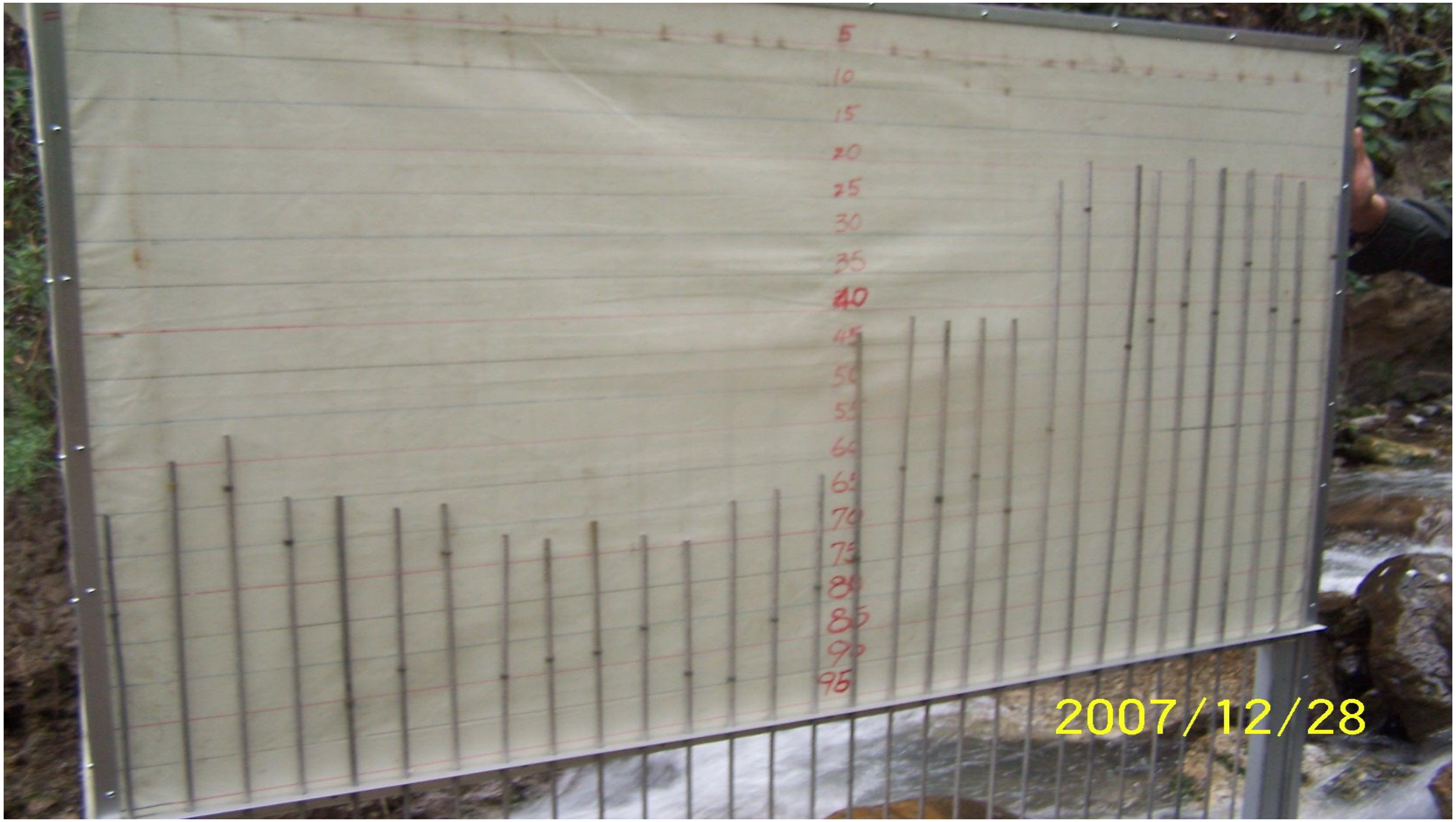


6. Framed bent for measuring bed structure



Wang et al., 2007

$$S_P = \frac{AB + BC + CD + DE + EF + FG}{\overline{AG}} - 1$$



$$S_P = \frac{\sum_{i=1}^{m}\sqrt{(R_{i+1}-R_i)^2+5^2}}{\sqrt{[5(m-1)]^2+(R_m-R_1)^2}} - 1$$

A case study in the Yigong Tsangpo River in the lower Yarlung Tsangpo River

Outline

- Brief introduction on rivers in mountain regions
- Objective, plan and preparation of field survey
- Measured methods for river flow
- Measured methods for sediment transport
- Measured methods for river bed
- **Concluding remarks**

Concluding remarks

- It is essential to understand basic concepts on pattern, form and process of river morphology in mountain regions.
- The prerequisite of field survey and measurement is to develop feasible objectives, detailed plans and adequate preparation.
- The selection of a suitable velocity meter should be considered according to the requirements of water depth, channel width and observation accuracy.
- The main difficulty of sediment transport observation is the strong movement of bed load transport in flood periods. Moreover the sampling process has large errors and low repeatability using various samplers.
- Emerging approaches to acquire high-resolution topography using remotely sensed or aerial surveys, ground-based surveys, boat-based bathymetry surveys.

Acknowledgements

- **My supervisor, Prof. Zhaoyin Wang,** led and guided field survey in mountain rivers in Qinghai-Tibet Plateau and provided many photos and his book.
- **Prof. Gary Brierley** provided many ideas and photos.
- Many materials cited from 4th IAHR-WMO-IAHS Training Course on Stream Gauging in September 2018 (Dr. Jerome Le Coz, Alexandre Hauet et al.)

- Bunte K, Abt, S. R., Phtyondy J. P., Swingle K. W., 2008. A comparison of coarse bedload transport measured with bedload traps and Helley-Smith Samplers. Geodinamica Acta, 21, 53-66.
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- …….

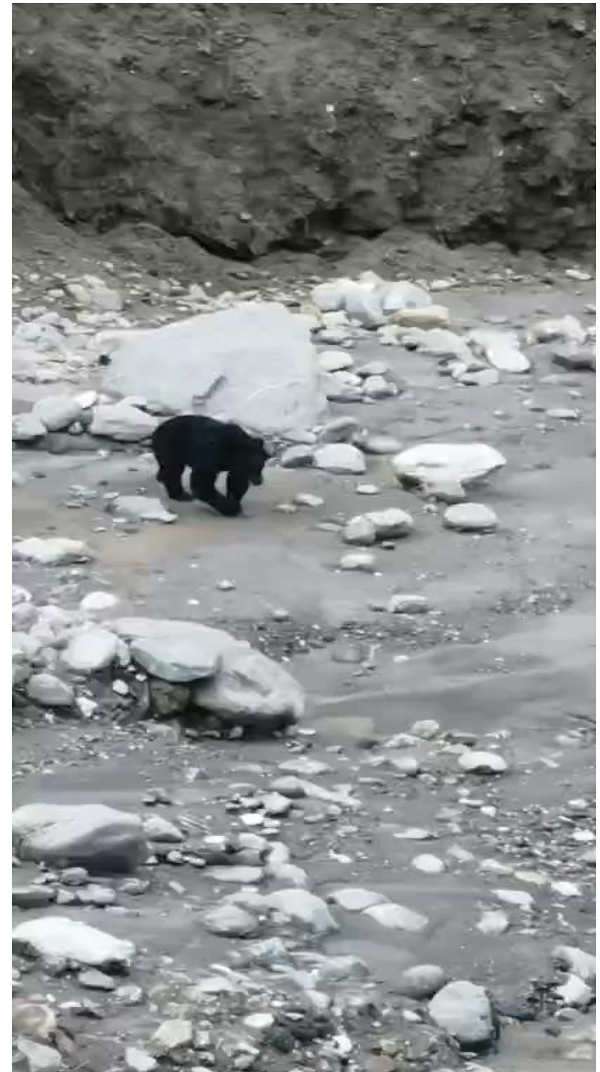
Thanks for this kind invitation from Prof. Cheng Liu.

Appendix : Brief introduction of wild animals in the QTP

Tibetan Beaver swimming in Cuoka River, a tributary Yigong Tsangpo River (Dec. 2020)

Tibetan Beaver swimming in the Cuoka River in December 2020

Tibetan Black Bear (Yarlung Tsangpo Grand Canyon in Sept. 2020)



Wild Tibetan donkeys (Yangtze River Source in July 2019)

Tibetan Antelopes (Yangtze River Source in July 2019)

Tibetan Wolf (Yangtze River Source in July 2019)

Two Tibetan Yaks (Yellow River Source in June 2019)

Tibetan Fox (Yellow River Source in June 2012)

Tibetan Vulture (Yellow River Source in June 2018)

Tibetan Camel (Karakorum Mountains in November 2017)

Thank you for attention!

Q&A

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