Discussion of behavior of fine sediment using ADCP

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Atsuhiro Yorozuya, Ph.D.

PWRI, Japan

Ahmad Ali Gul, Ph.D.

Former student of GRIPS, Japan

Direct quotation from my abstract

Sediment hydraulics have studied by several historical figures; e.g., H. Albert Einstein, J. F. Kennedy, M. Selim Yalin and many others, whose most of their studies have conducted in the experimental flumes. Thanks to recent technologies, varieties of the measurement were widely extended. The recent technologies here mean not only mechanical aspects (by the largest contribution by Teledyne RDI), but also data analysis (by several different researchers). With such a technology, water flow/sediment transport rate can be understood in actual river as if we conduct experimental studies. Therefore, it could be good way to verify the past achievement with the observational results, regarding bedload functions, suspended sediment load, size of bed forms, flow resistance and others. It is also good chance to improve the knowledge of the sediment hydraulics. The authors have worked for this kind with Acoustic Doppler Current Profiler (ADCP) and others. Here, authors will report the behavior of suspended sediment.

Numerical model (Current Model) as current sediment hydraulics

River bed elevation changes

$$\frac{\partial z_b}{\partial t}+\frac{1}{1-\lambda}\left(\frac{\partial \sum q_{bi}}{\partial x}+\frac{\partial \sum q_{bi}}{\partial y}+\sum E_i-\sum D_i\right)=0$$

Water flow

$$\frac{\partial h}{\partial t}+\frac{\partial uh}{\partial x}+\frac{\partial vh}{\partial y}=0$$

$$\frac{Du}{Dt}=-g\frac{\partial H}{\partial x}-\frac{\tau_b}{\rho h}$$

$$\frac{Dv}{Dt}=-g\frac{\partial H}{\partial y}-\frac{\tau_b}{\rho h}$$

$$\frac{\tau_b}{\rho}=u_*^2$$

Bedload function

$$\frac{q_{bi}}{\sqrt{sgd_i^3}}=17\,p_i\tau_{*ei}^{3/2}\left(1-\tau_{*ci}/\tau_{*i}\right)\left(1-u_{*ci}/u_*\right)$$

Shear velocity

$$u_*^2=\frac{n^2g}{h^{1/3}}\left(u^2+v^2\right)$$

or

$$u_*=\sqrt{ghI}$$

Suspended sediment and washload

$$\frac{\partial c_i h}{\partial t}+\frac{\partial r_1 u c_i h}{\partial x}+\frac{\partial r_1 v c_i h}{\partial y}=\frac{\partial}{\partial x}\left(h\varepsilon_x\frac{\partial c_i}{\partial x}\right)+\frac{\partial}{\partial y}\left(h\varepsilon_y\frac{\partial c_i}{\partial y}\right)+E_i-D_i$$

$E_i = E_{si} + E_w$ $D_i =$ This is today's discussion point

$$E_{Si}=w_{0i}C_{aei}$$

$$D_{Si}=w_{0i}C_{sbi}$$

$$C_{aei}=5.55\left(\frac{1}{2}\frac{u_*}{w_{0i}}\exp\left(-\frac{w_{0i}}{u_*}\right)\right)^{1.61}r_b \qquad C_{sbi}=\frac{C_{si}\beta_{si}}{1-\exp(-\beta_{si})}$$

$$E_w=-(1-\lambda)p\frac{\partial z_b}{\partial t}\ \text{(when}\ \frac{\partial z_b}{\partial t}<0),\quad E_w=0\ \text{(when}\ \frac{\partial z_b}{\partial t}\geq 0)$$

$D_w = w_0 c_{wb}$

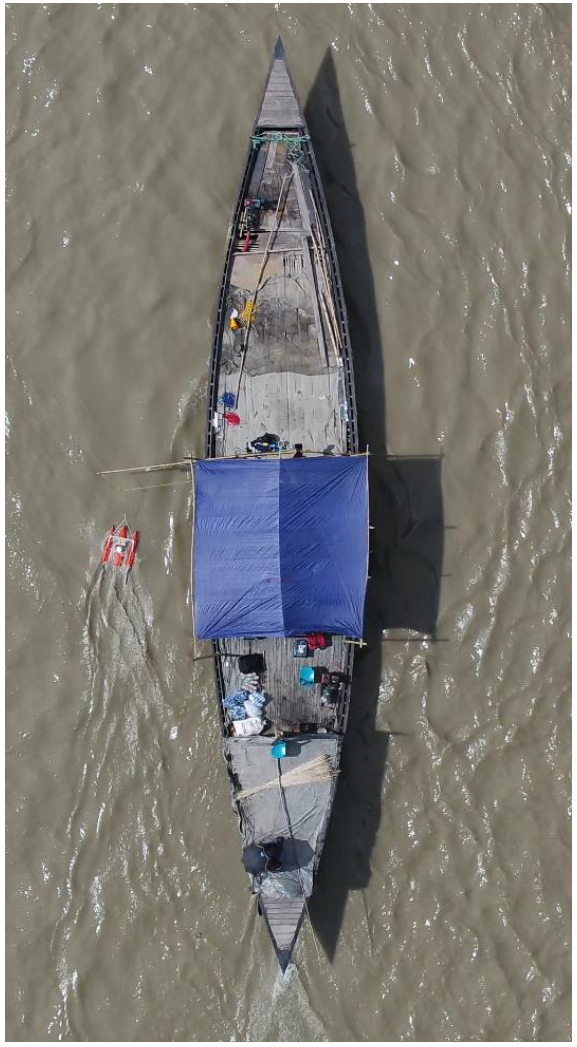
Field Measurements

Dense measurements along the direction of the flow were performed by many longitudinal passes over the target area (as described by *Yorozuya et al. 2014*)

Teledyne RDI RiverRay ADCP (600kHz)

Tethered boat mounted with ADCP and STARFIRE WDGPS

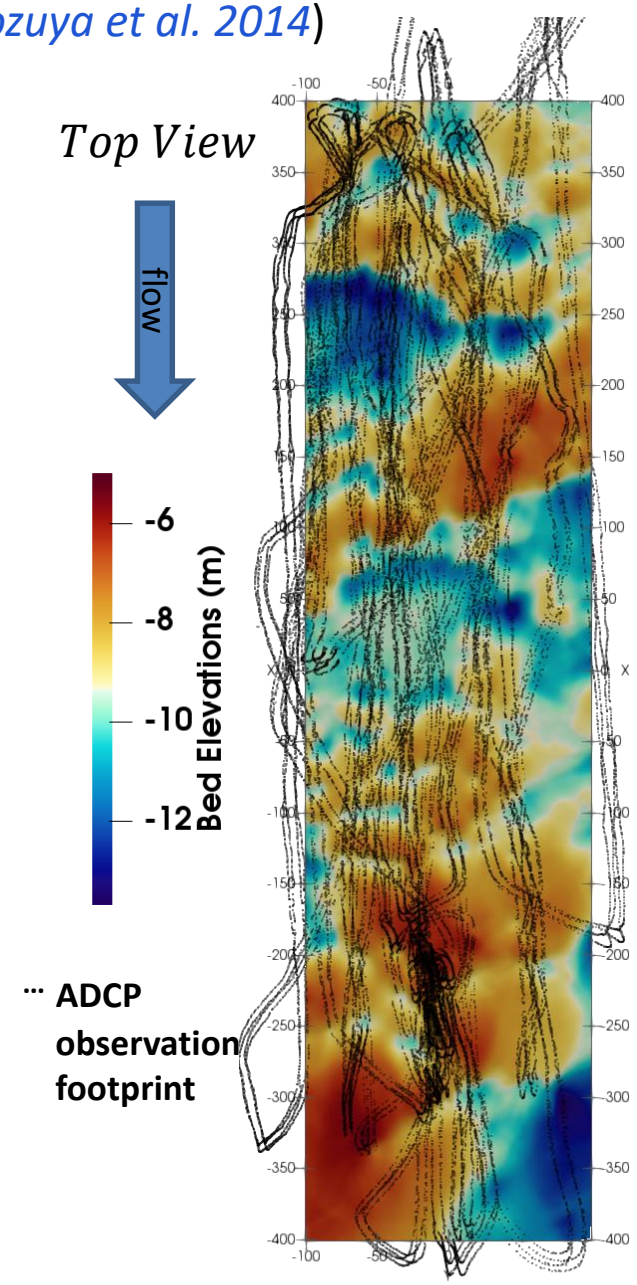
Aerial view of manned boat, tethered boat mounted with ADCP and WDGPS



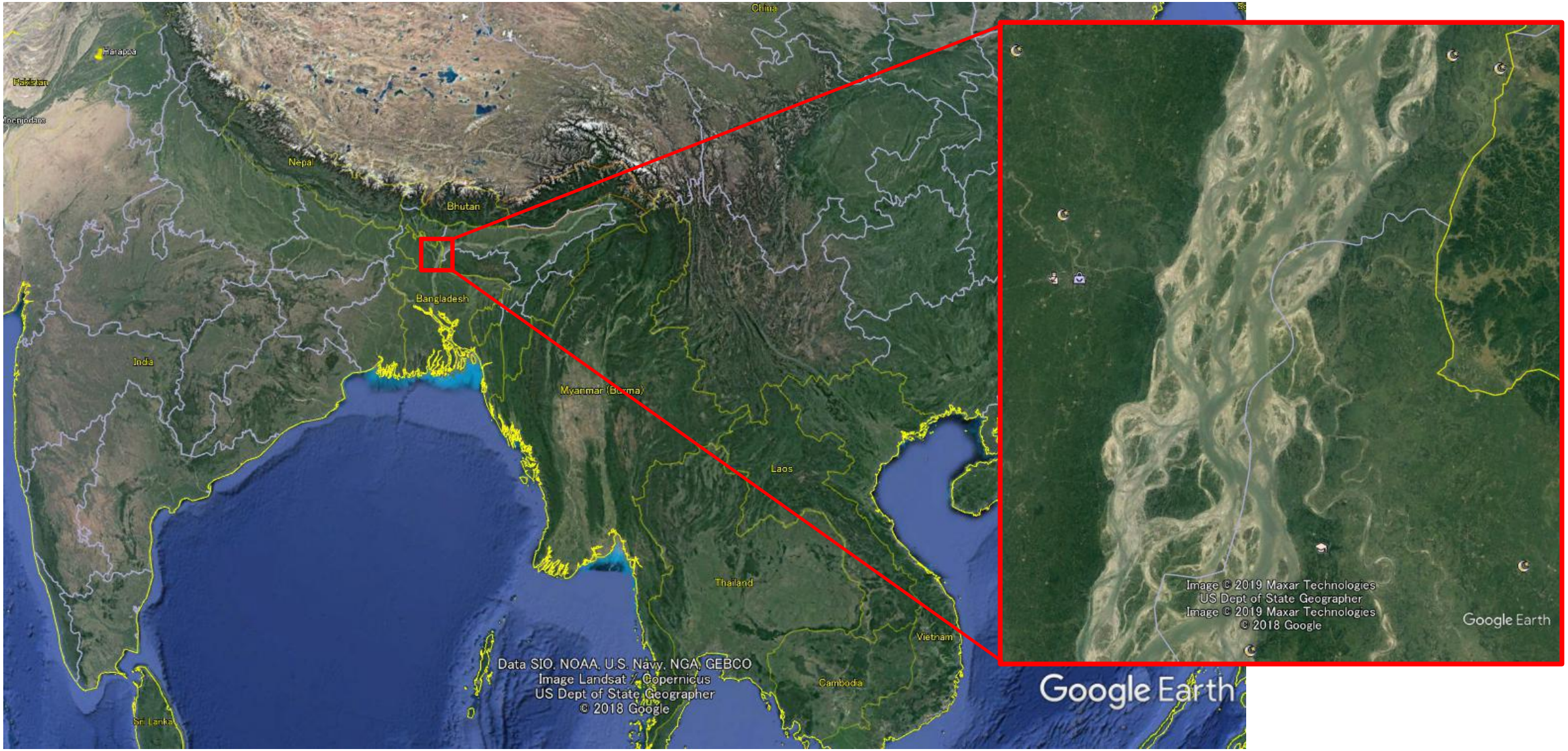
Turbidity meter

Water sampler

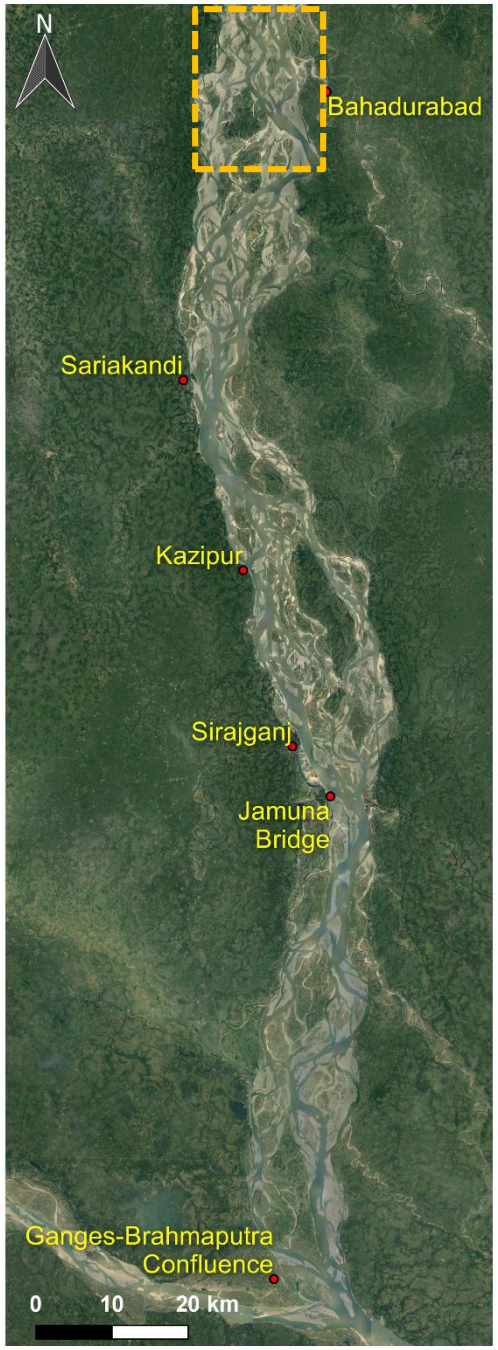
Dredge sampler

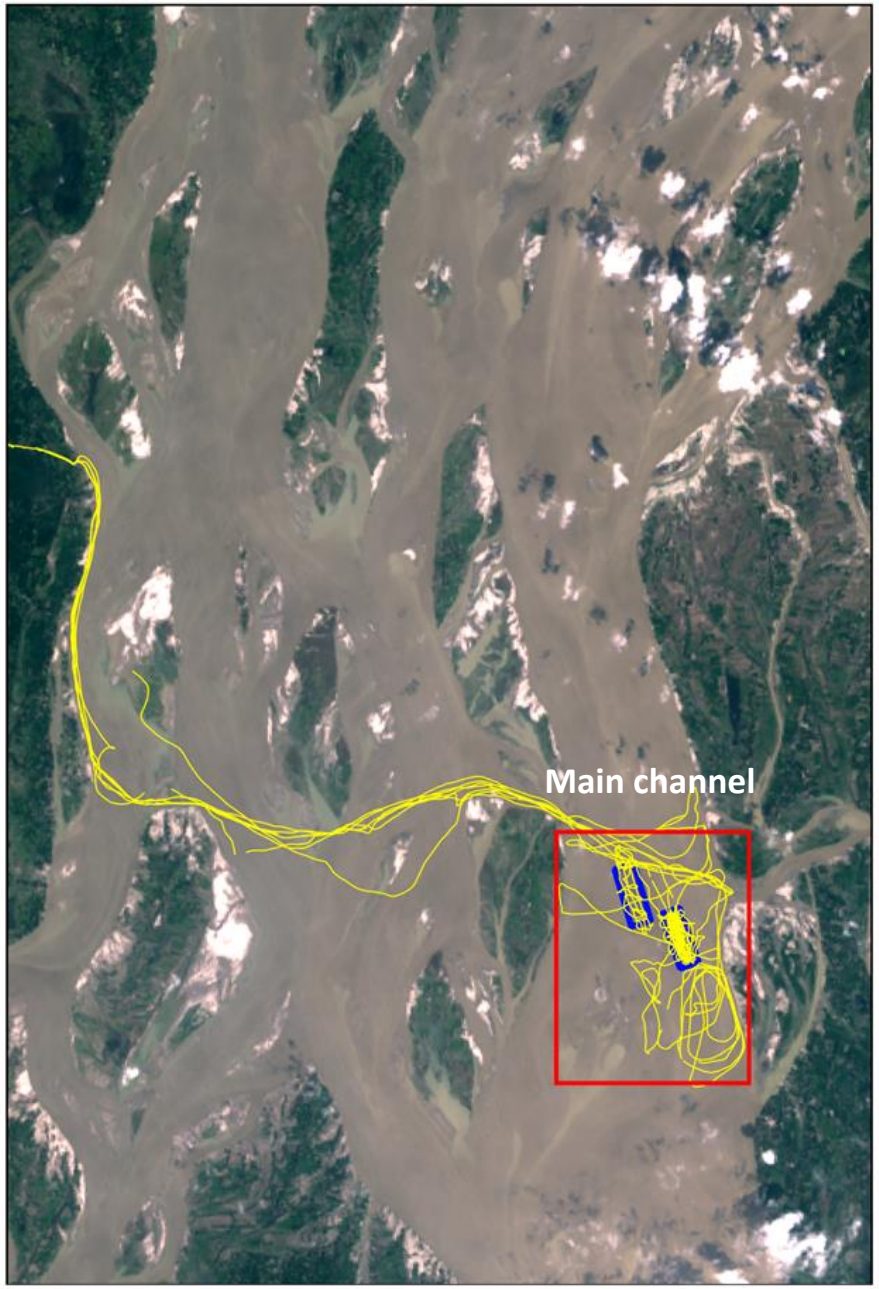


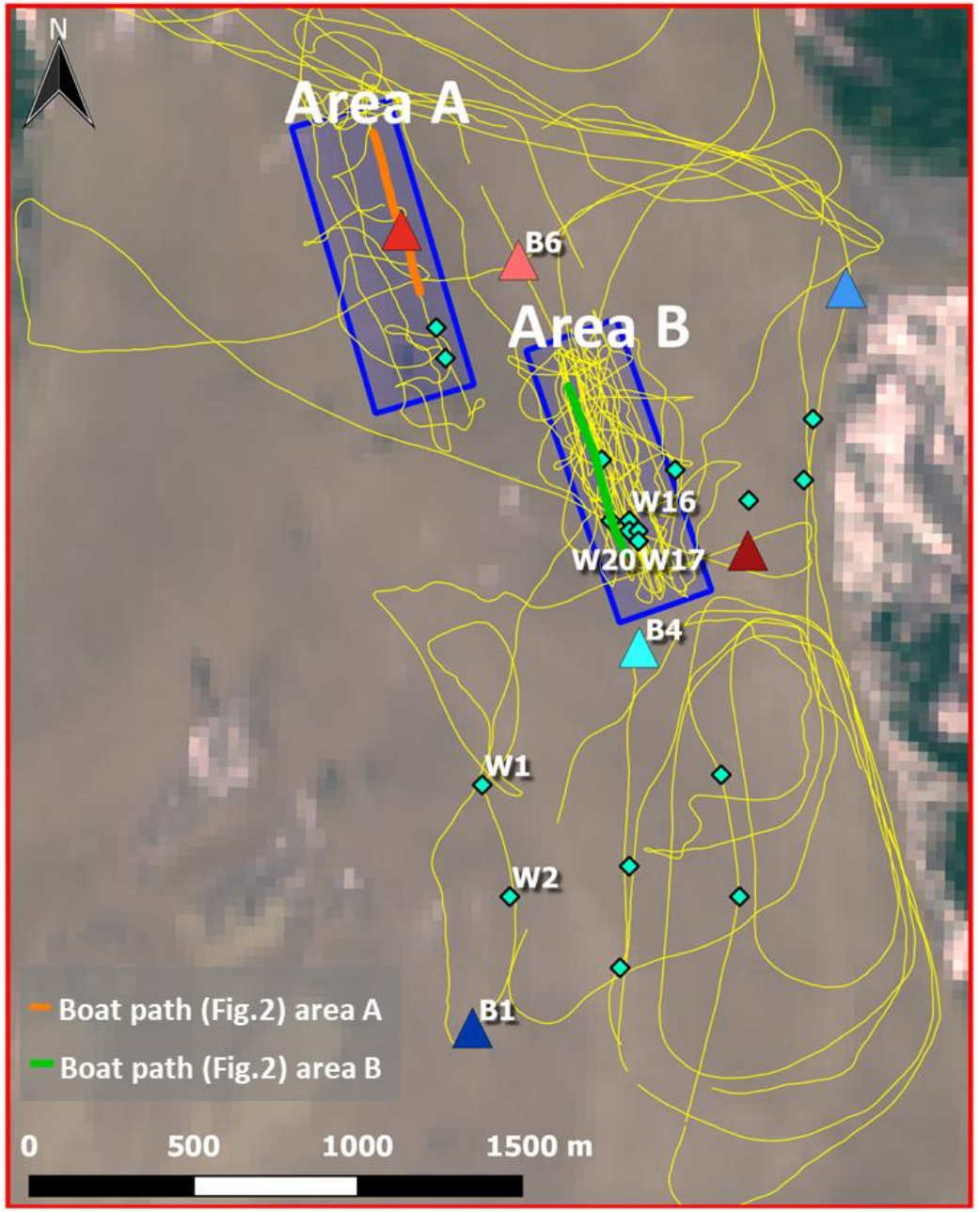
Measurement site: Brahmaputra river in Bangradesh



Field Measurements



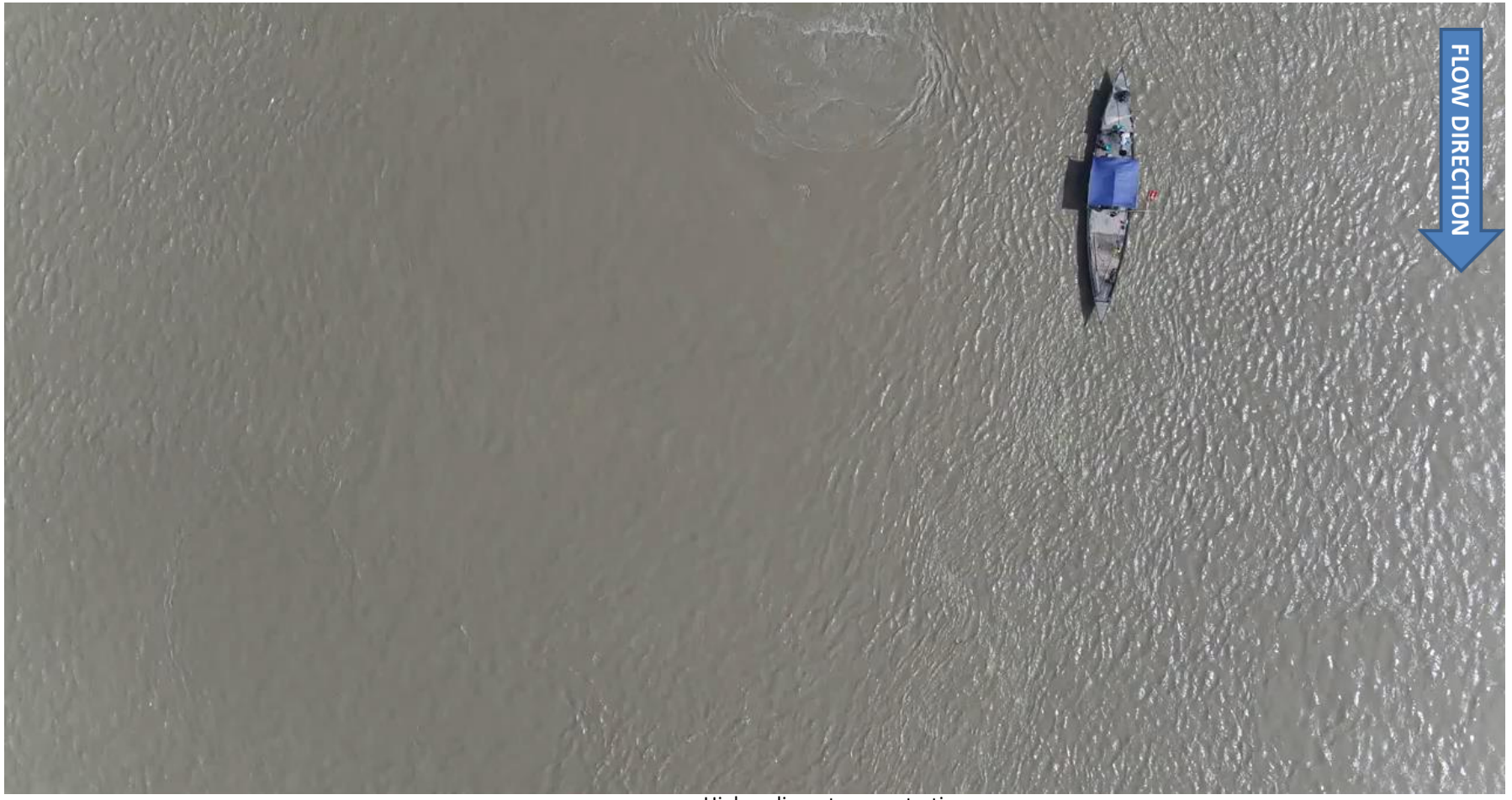




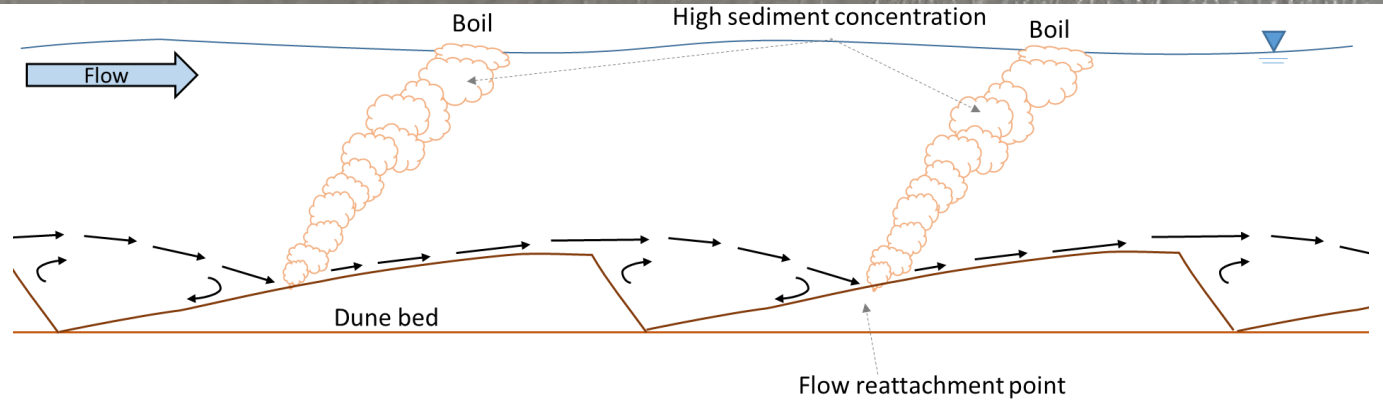
Dense Measurement Areas Boat Track Water Sample Point Bed Material Sample Point

Field Measurements

During field observations in Brahmaputra, many **boil** are observed on the water surface



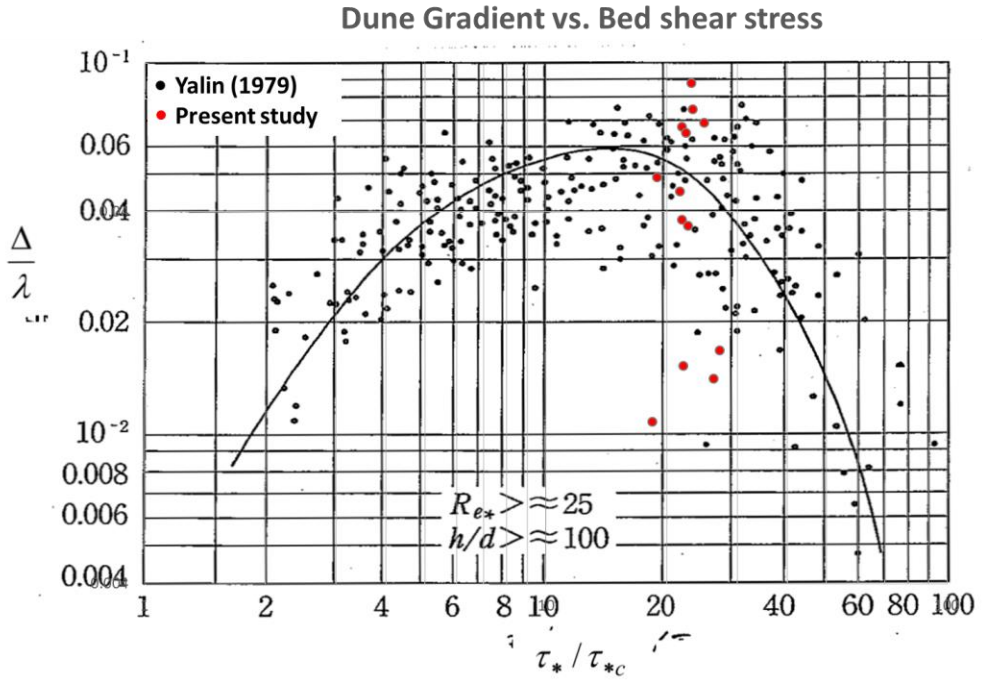
Scale – Boat length = **26m**
Boat speed
(along flow direction) = **1.1 m/s**
Boil speed = **2.6 m/s**

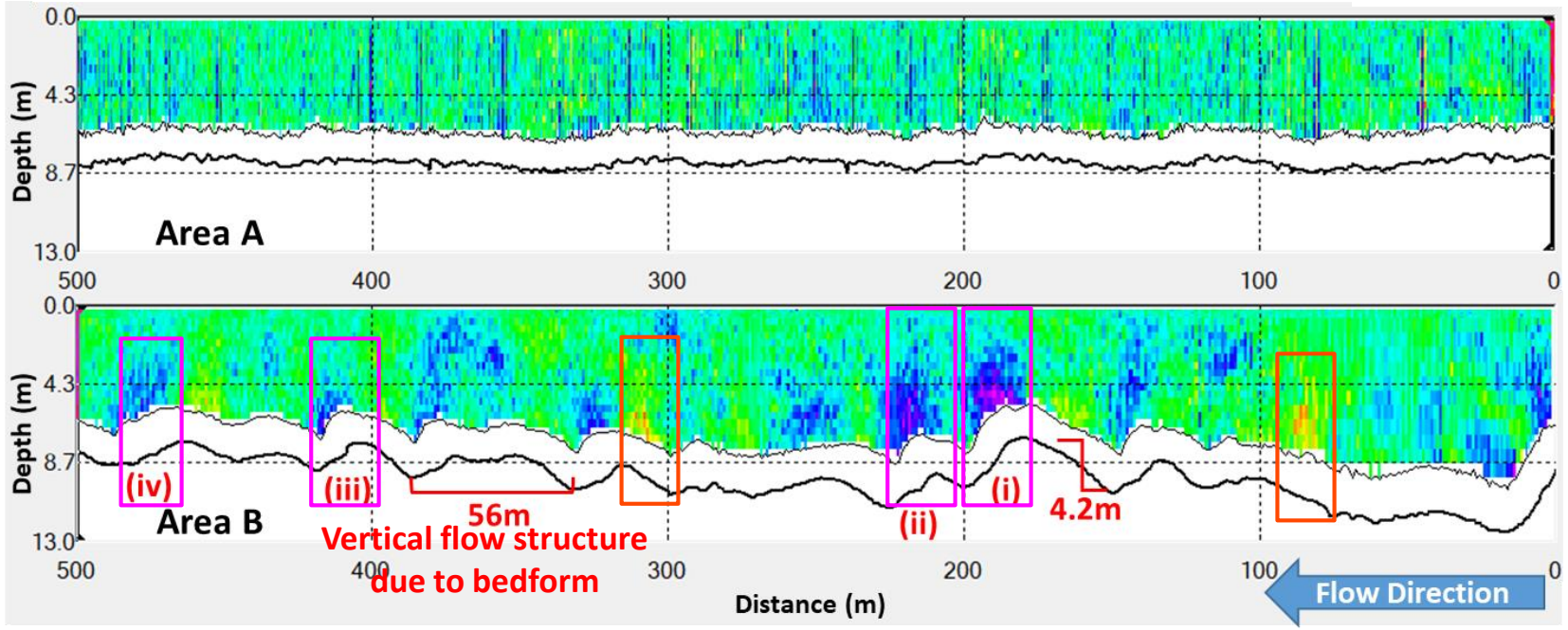


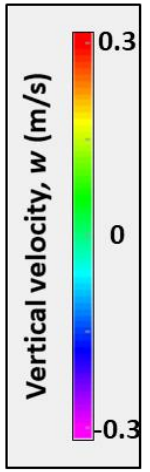
Results – Longitudinal Profile

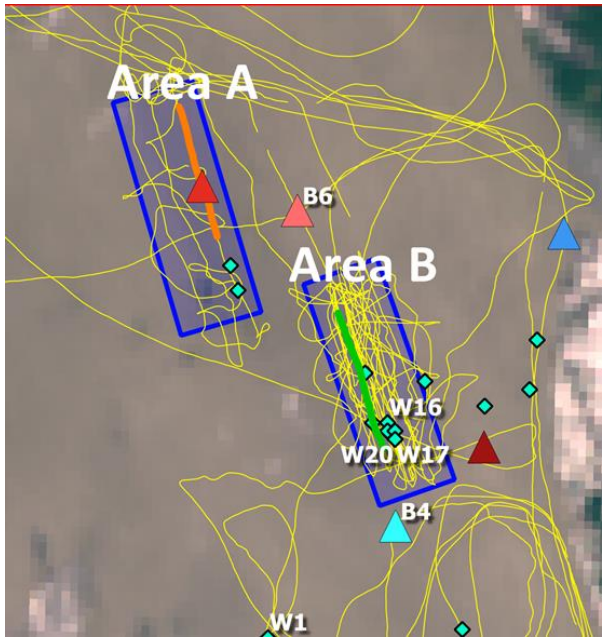
ADCP transect along the direction of flow.

- Sand wave pattern observed in Area B, flat bed observed in A
- Downward flow over the crests and upwards flow on the stoss side



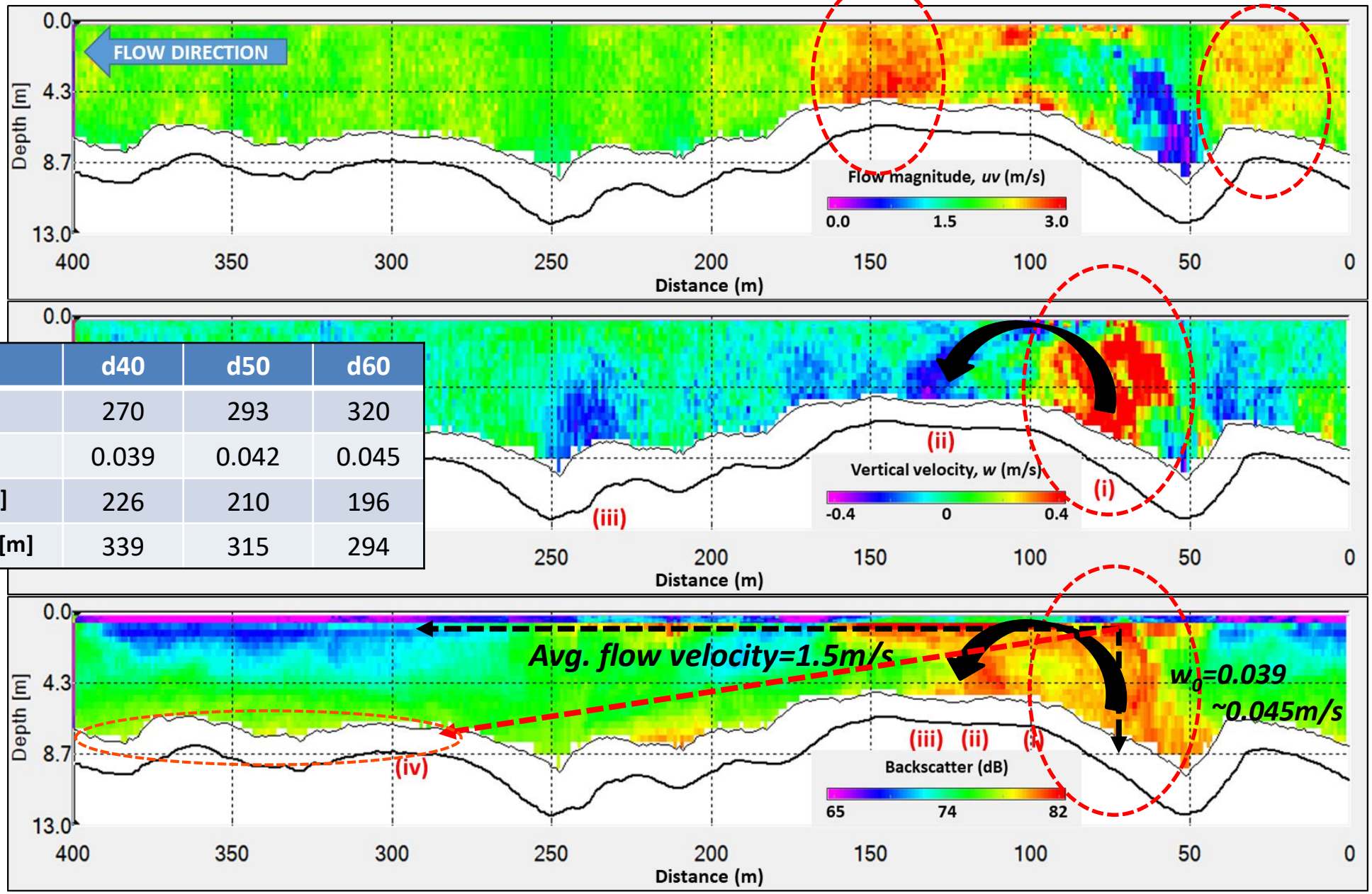






Results – Longitudinal Profile

Observation of Boil of First Kind (Nakagawa & Nezu, 1993) by the ADCP



	d40	d50	d60
Particle size [μm]	270	293	320
Fall velocity [m/s]	0.039	0.042	0.045
Time taken to fall from surface to bed [s]	226	210	196
Est. travel distance at avg. flow velocity [m]	339	315	294

6. Analysis of Field Measurement dataset – Grain Size Distributions

- To obtain **spatial distribution** of **suspended sediment** and **wash load concentration** (hereafter mentioned as Sediment Concentrations, SC), Acoustic Backscatter data from the dense measurements was tuned up using turbidity data (*Okada et al. 2016, Wood et al, 2012*) shown in **Eq. 1**.
- Similarly, turbidity and Sediment Concentrations (SC, mg/L) relation is created implying sampled bed material under laboratory conditions, shown in **Eq. 2**.

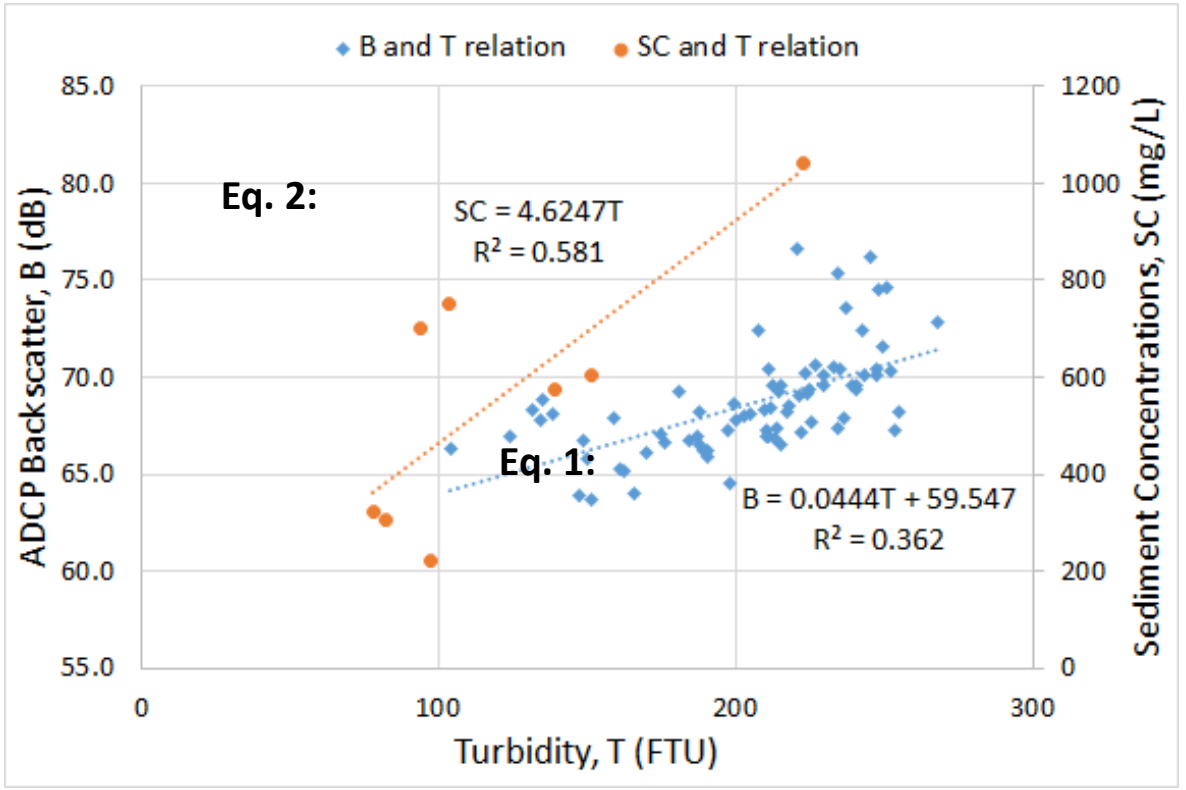
ADCP Backscatter (dB)

Eq. 1

Turbidity (FTU)

Eq. 2

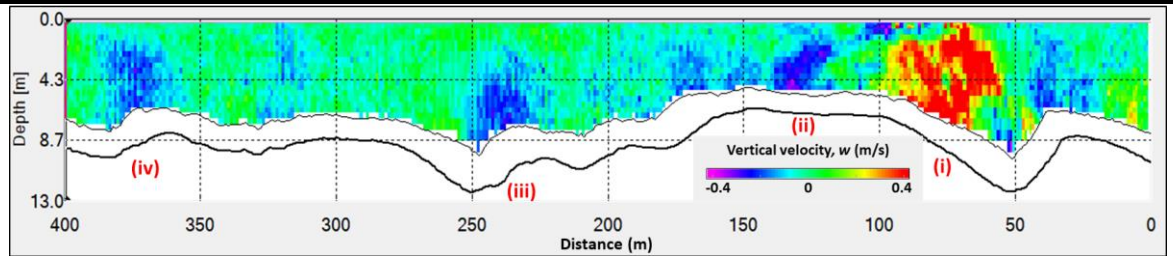
Sediment Concentrations (mg/l)

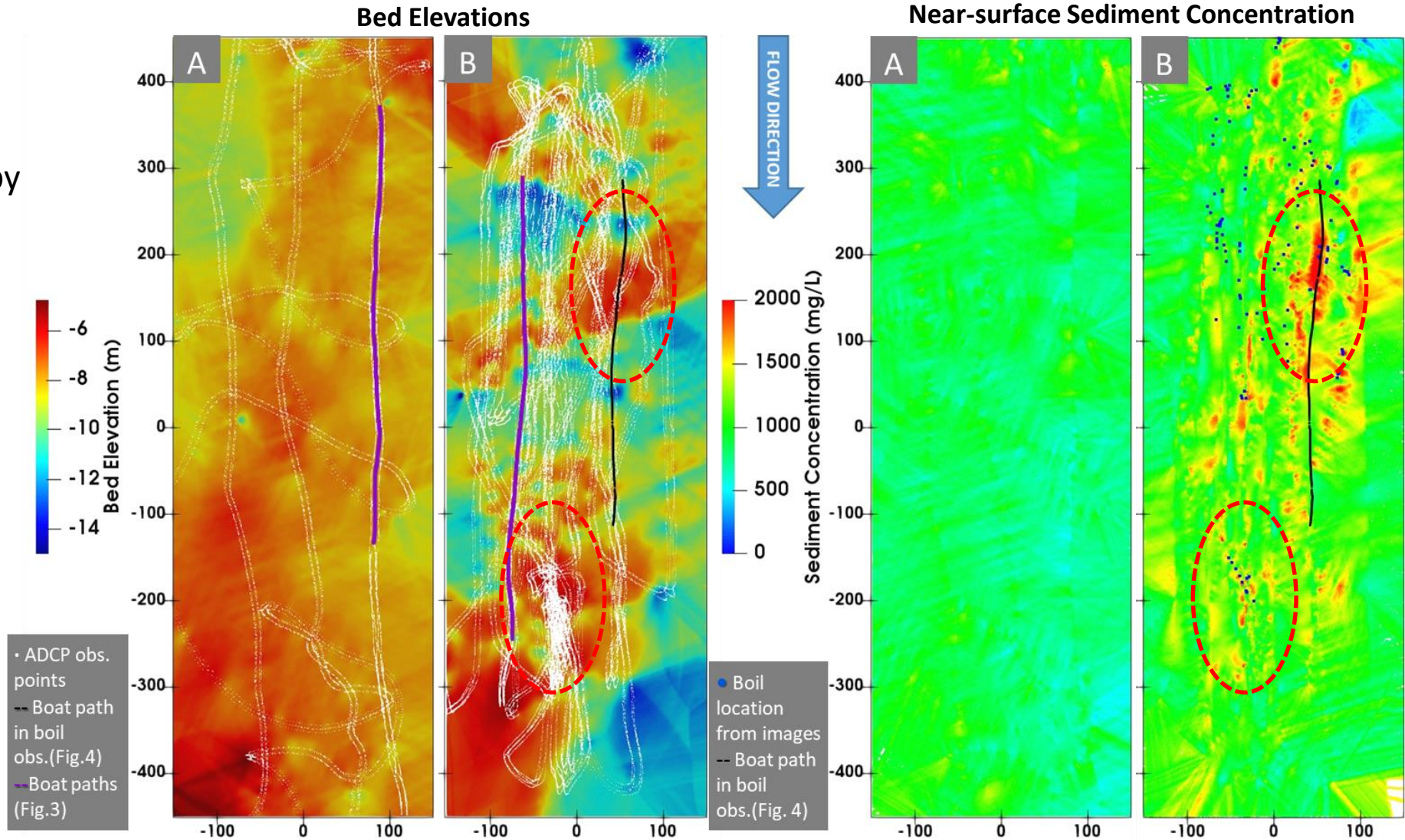


This kind of process can be conducted by **Visual ADCP tools** produced by Hydro Systems Development, Inc.

6. Analysis of Field Measurement dataset – Bed form and Boil

- Patches of high sediment concentration observed in area B, which is caused by boil
  - Concentration suddenly decrease downstream
- The location of boil observation by the ADCP and geo-tagged photographs, can be correlated with the bedform





6. Analysis of Field Measurement dataset – Current model

Current model for very fine sediment (<100µm) :

$E_w = -(1-\lambda)p\frac{\partial z_b}{\partial t}$ (when $\frac{\partial z_b}{\partial t} < 0$),

$E_w = 0$ (when $\frac{\partial z_b}{\partial t} \geq 0$)

$D_w = w_0 c_{wb}$

Treat it as vertical distribution saying as C_W

Current model for fine sediment (>100µm) :

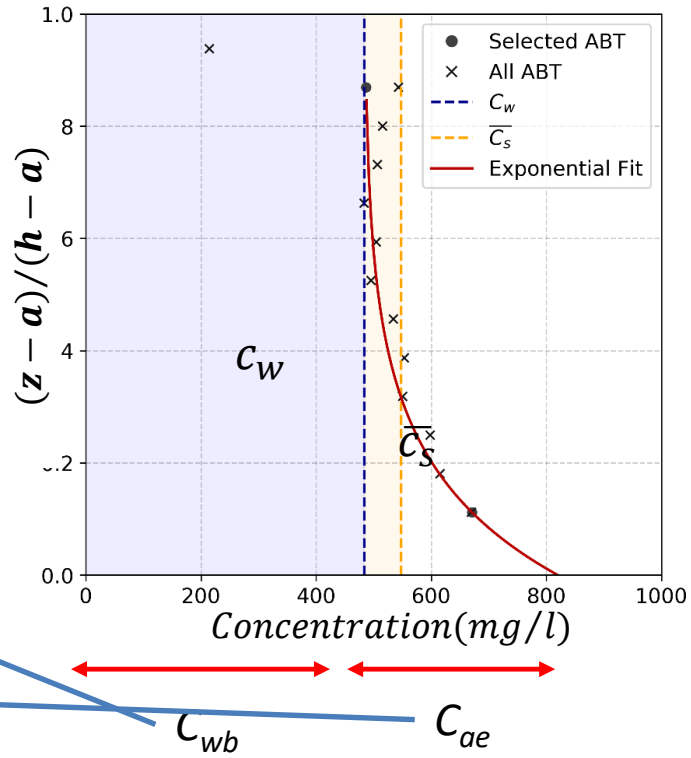
Rouse (1937):

$$\frac{c_i(z)}{c_{ai}} = \left[\frac{h-z}{z}.\frac{a}{h-a}\right]^{z_{*i}}, where: \; z_{*i} = \frac{w_{0i}}{Ku_*}$$

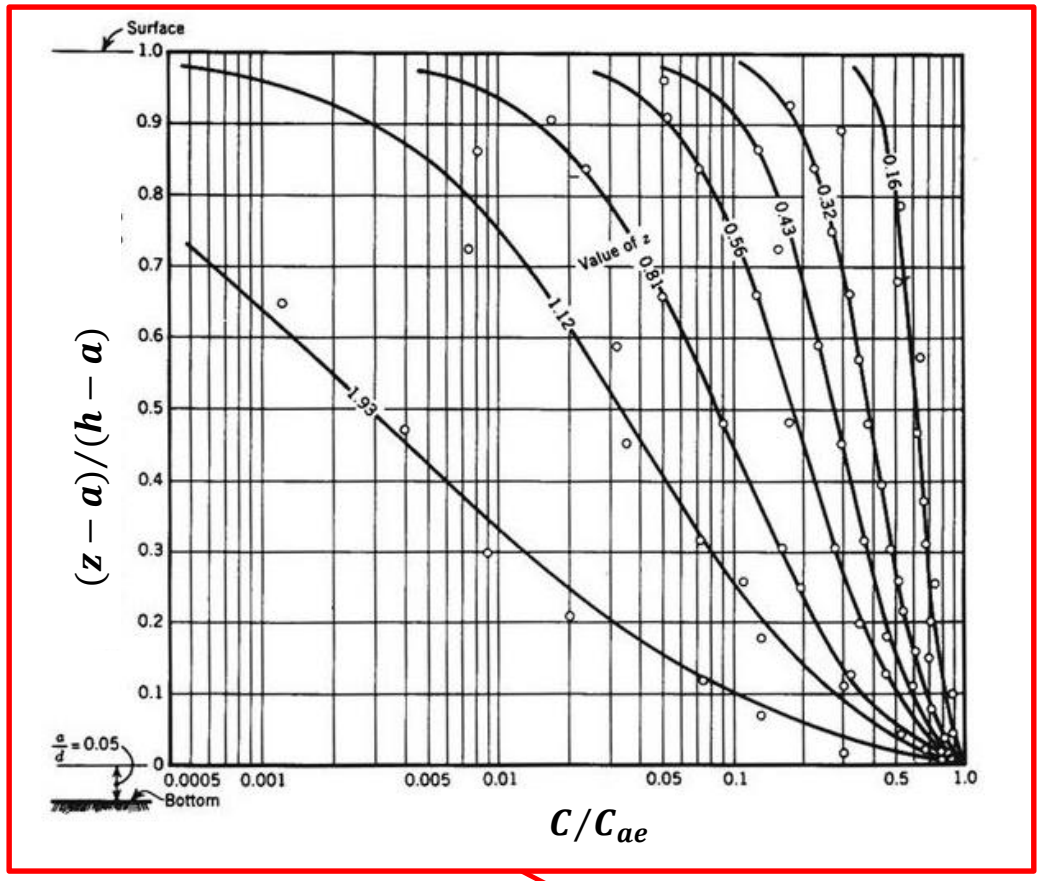
Treat it as vertical distribution saying as C_W

$E_{Si} = w_{0i} C_{aei}$

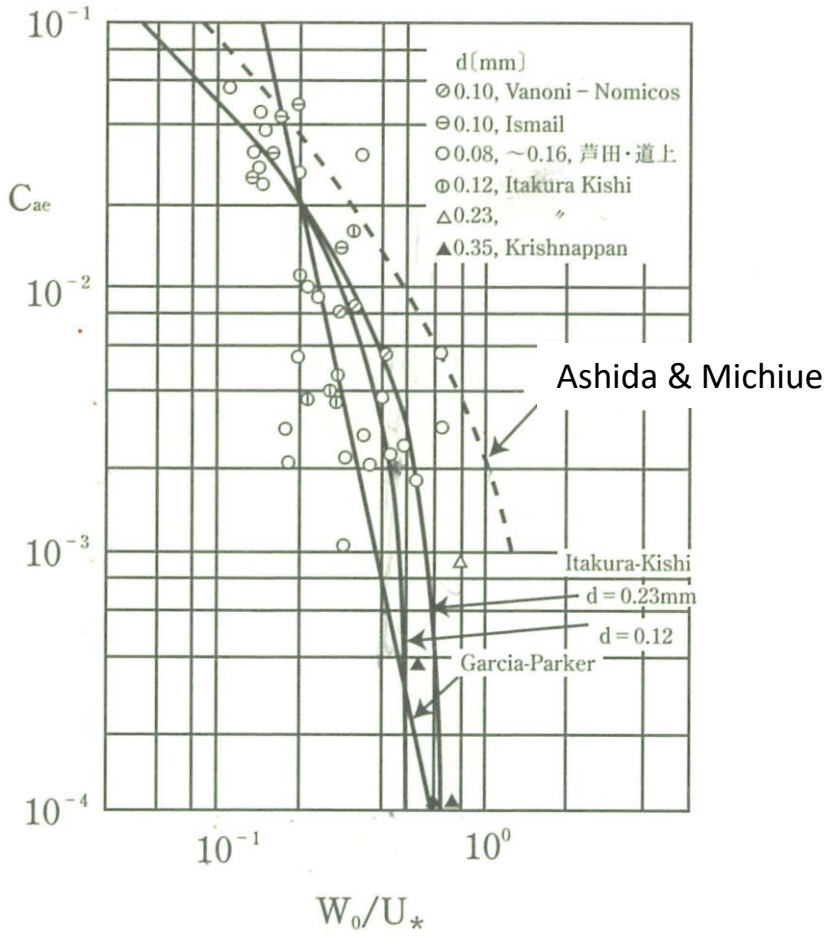
$D_{Si} = w_{0i} C_{sbi}$



Vertical profile of suspended sediment



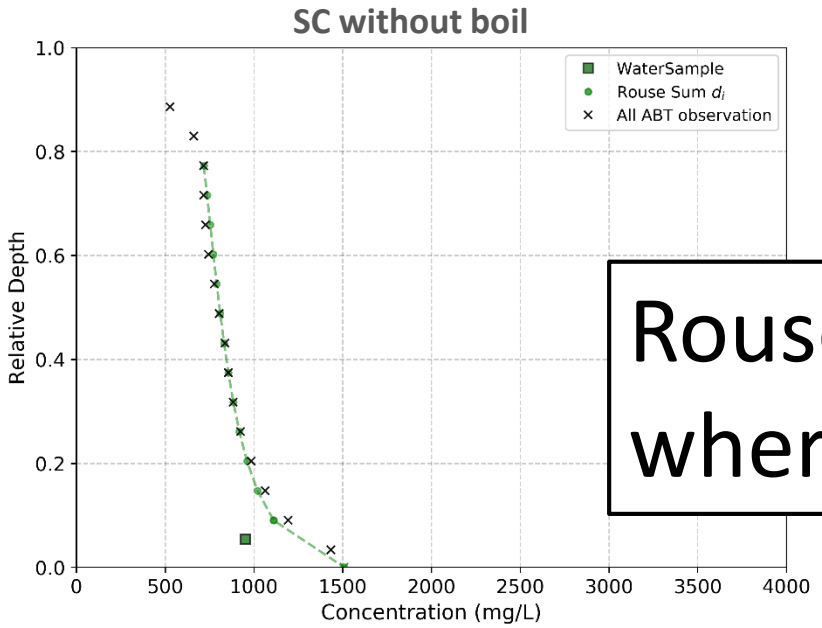
$$\frac{c_i(z)}{c_{aei}} = \left[\frac{h-z}{z}\cdot\frac{a}{h-a}\right]^{z_{*i}} \qquad z_{*i} = \frac{w_{0i}}{Ku_*}$$

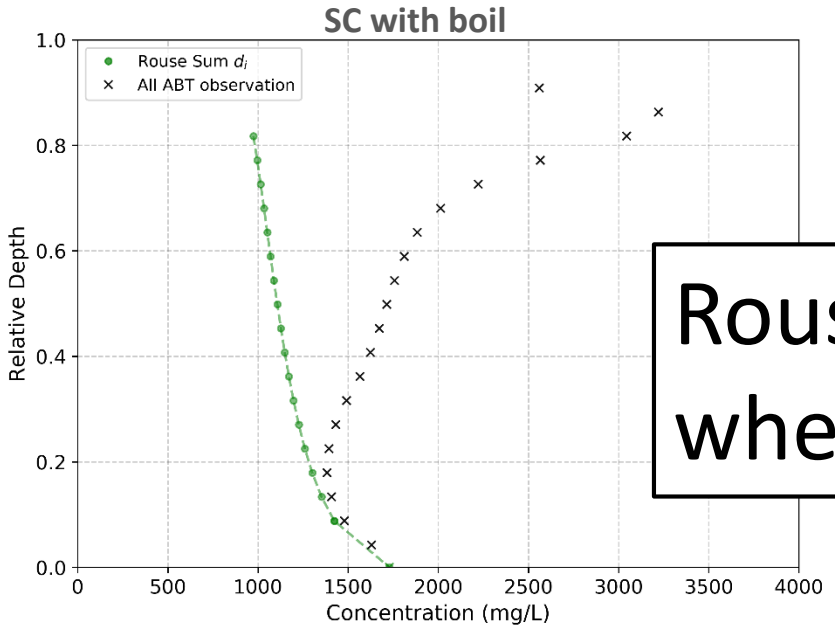


Equilibrium Concentration near the bed

6. Analysis of Field Measurement dataset – Bed form and Boil

Area	Bed Material (d50, μm)	Avg. Depth (m)	Avg. u_* ($u_*=\sqrt{gRI}$)	w_0/u_*	τ_*	R/d	C_{ae} (mg/L)	Avg. Velocity (m/s)	Bedload disch. (q_b, $m^2/s/m$)	Suspended Load disch. (q_s, $m^2/s/m$)	Wash Load disch. (q_w, $m^2/s/m$)
A	273	7.97	0.074	0.52	1.19	27500	7.98	1.22	5.83×10^{-5}	1.05×10^{-8}	3.6×10^{-3}
B	293	9.35	0.082	0.51	1.4	32200	8.19	1.77	9.74×10^{-5}	1.65×10^{-8}	6.2×10^{-3}



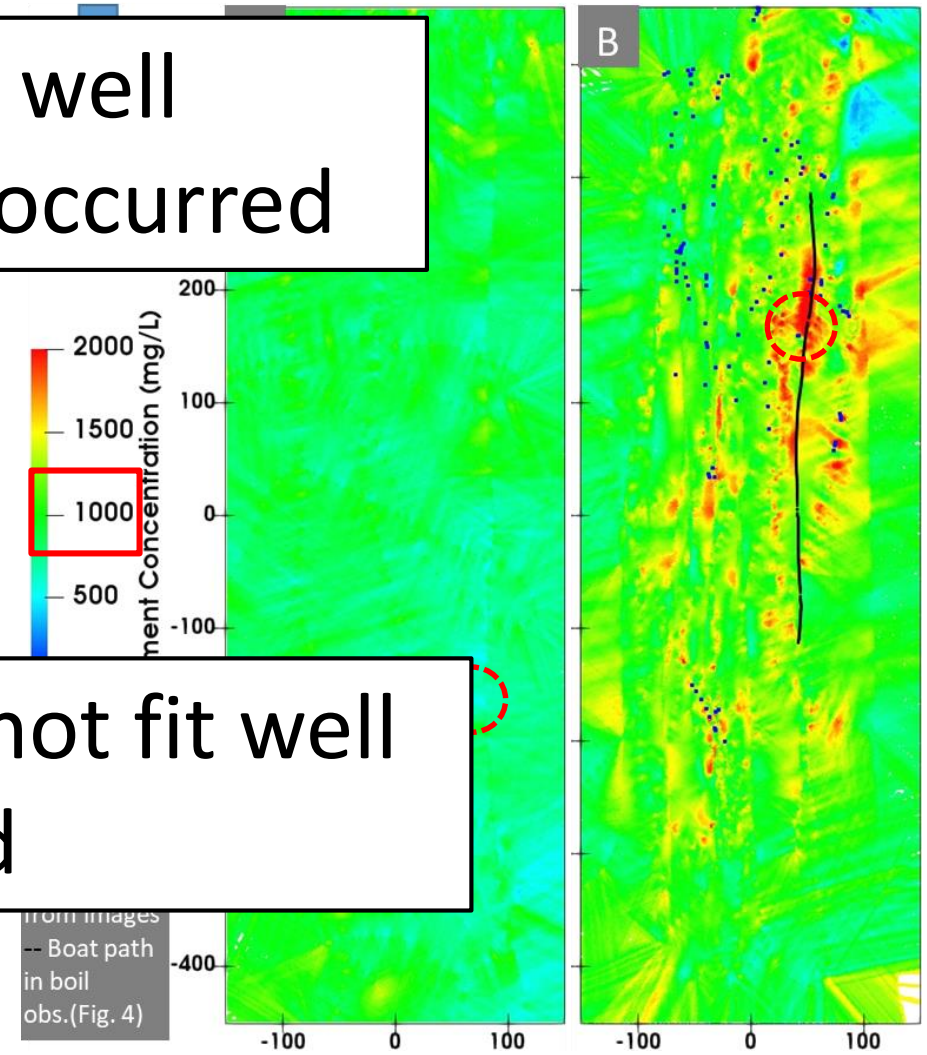


Rouse profile fit very well where boil does not occurred

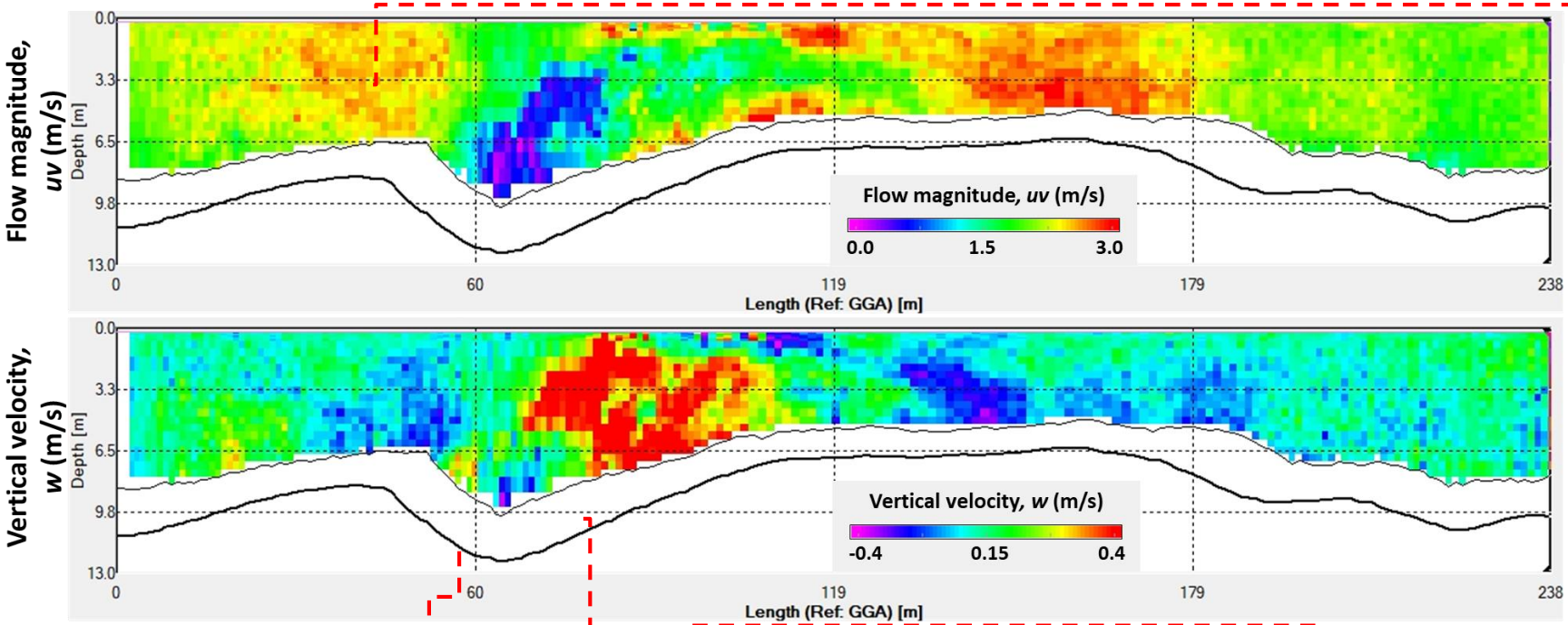
$$\frac{c_i(z)}{c_{ai}} = \left[\frac{h-z}{z} \cdot \frac{a}{h-a}\right]^{z_{*i}}$$

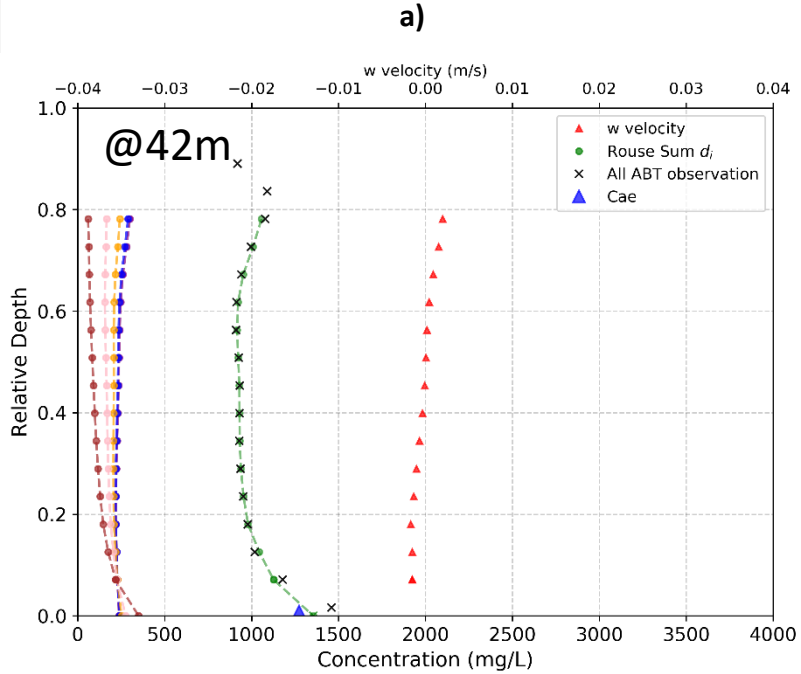
$$z_{*i} = \frac{w_{0i}}{K u_*}$$

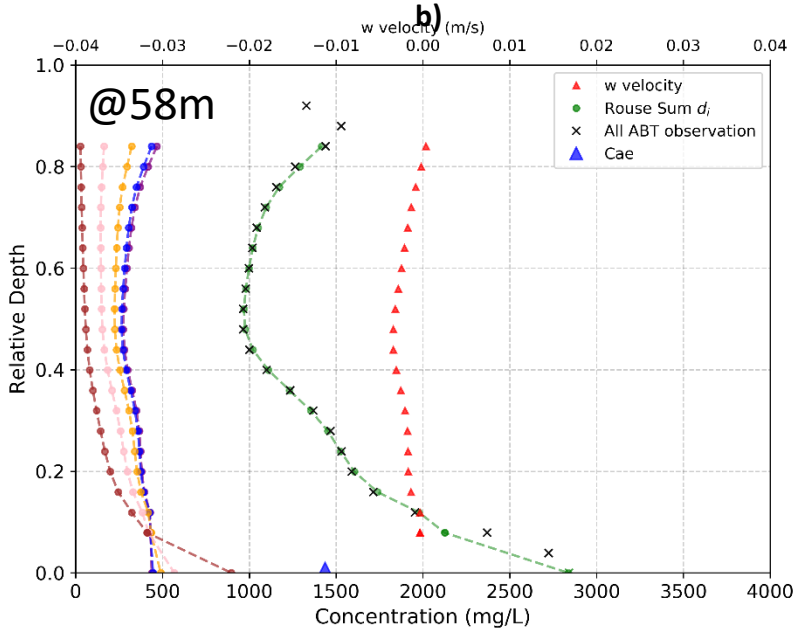
Rouse profile does not fit well where boil occurred

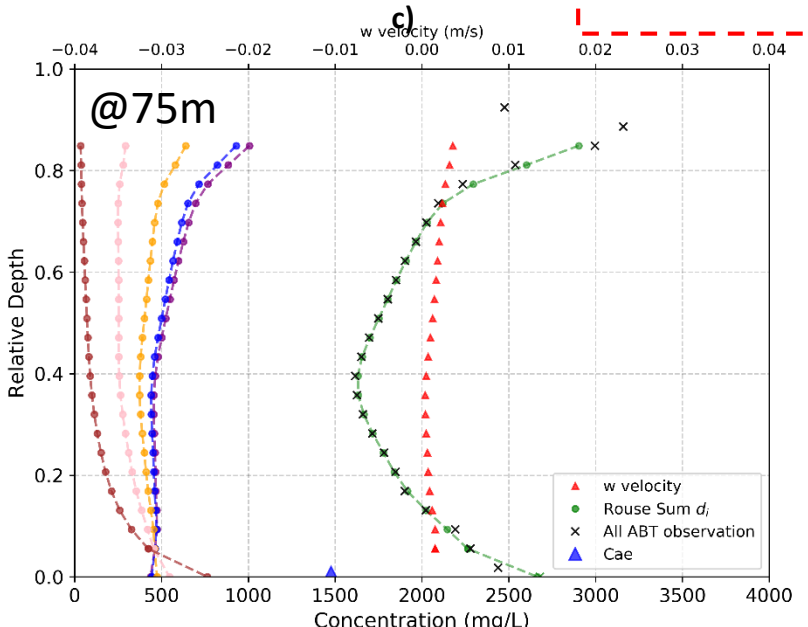


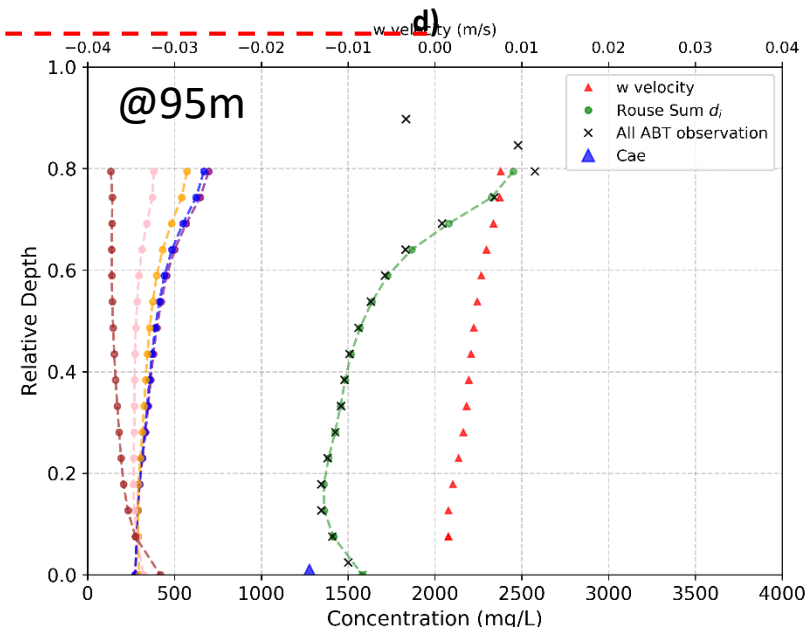
6. Analysis of Field Measurement dataset – Observation of boil











7. Summary of this presentation

1. *Current model of numerical simulation was introduced.*
2. *Boil phenomena was observed by ADCP in Brahmaputra river*
3. *Flow structure by ADCP with/without boil were explained.*
4. *Rouse Distribution was well verified conditionally.*
5. *C_{ae} for fine sediment was proposed.*
6. *Washload should be better to be tread as suspended sediment load.*
7. *Vertical distribution of fine sediment were introduced.*
8. *Currently, the modeling of Cae with occurrence of boil are working*