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Turbidity Currents That Co-Evolve With Channels over Lengths as Much as 1000 km: How Can they do it?*

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[2]Universita degli studi di Genova, Italy

Abstract

Here we consider the puzzle of long-runout turbidity currents and the channels they create. It is well known, through direct evidence of the flows or from the morphology that they create, that turbidity currents can run out over 1000 km in the ocean. The currents do so without dissipating themselves via the excess entrainment of ambient water. Existing layer-averaged formulations are, however, unable to capture this behavior. Here we use the formalism of a "Turbidity Current with a Roof" to show that the turbidity current partitions itself into two layers. The lower "driving layer" approaches an asymptotic behavior with invariant flow thickness, velocity profile and suspended sediment concentration profile. The upper "rarified layer" continues to entrain ambient water indefinitely, but the concentration in that layer becomes ever more dilute, and the layer ultimately has little interaction with bed morphology. This partition likely allows the driving layer to run out long distances while maintaining coherence, and to follow morphology of its own creation such as leveed subaqueous channels.

References Cited

Parker, G., Y. Fukushima, and H.M. Pantin, 1986, Self-accelerating turbidity currents: J. Fluid Mech., v. 171, p. 145-181.

Sequeiros, O.E., H. Naruse, N. Endo, M.H. Garcia, and G. Parker, 2009, Experimental study on self-accelerating turbidity currents: Journal of Geophysical Research, v. 114: C05025.

TURBIDITY CURRENTS THAT CO-EVOLVE WITH CHANNELS OVER LENGTHS AS MUCH AS 1000 KM: HOW CAN THEY DO IT?

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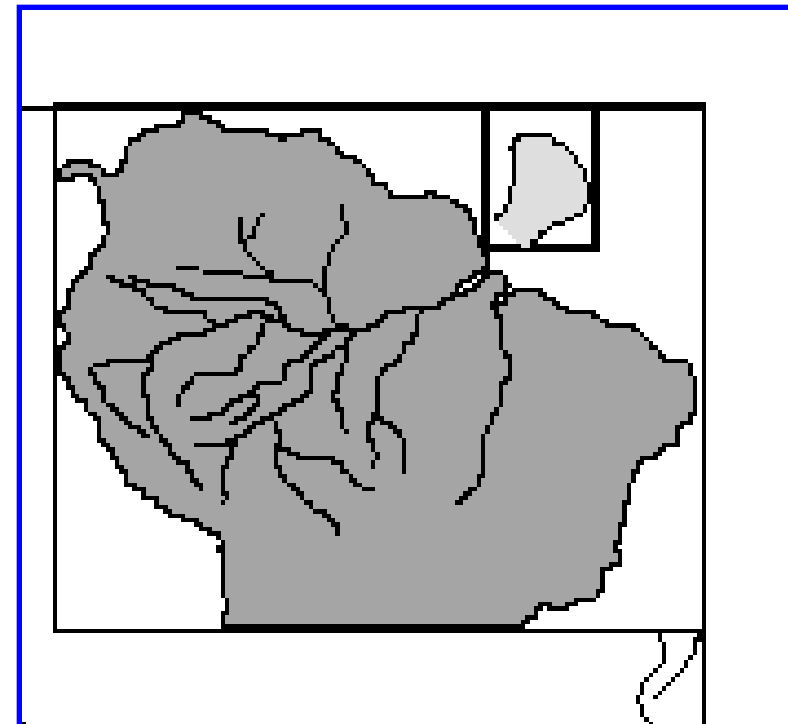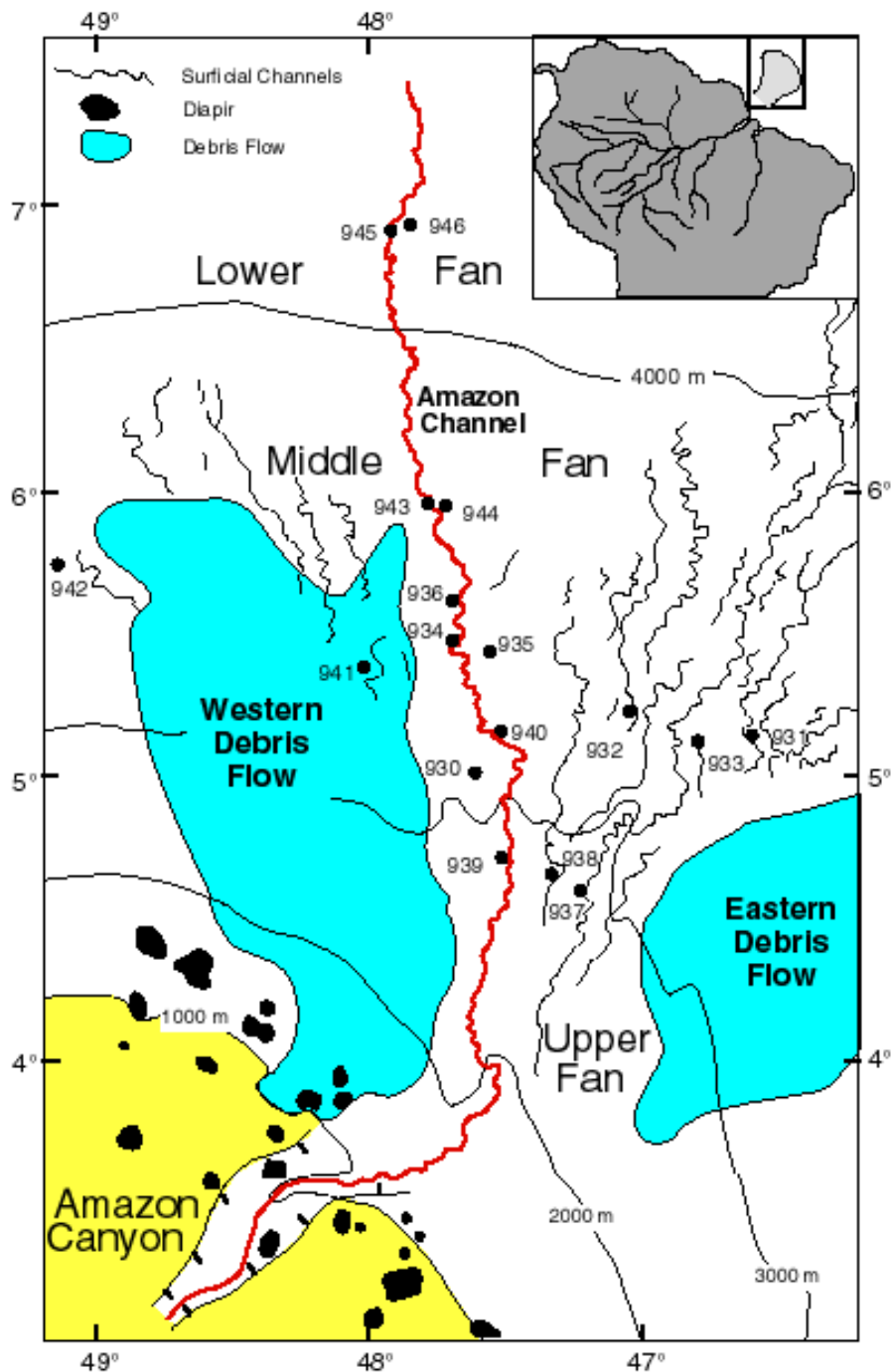**Turbidity current flushing event, Xiaolangdi Reservoir, China**
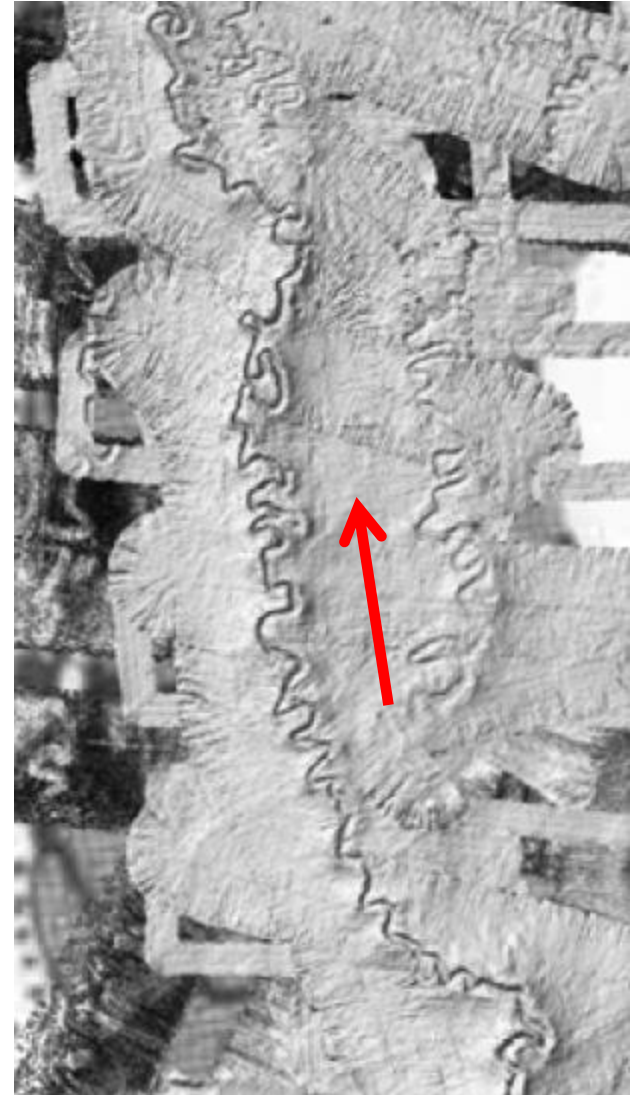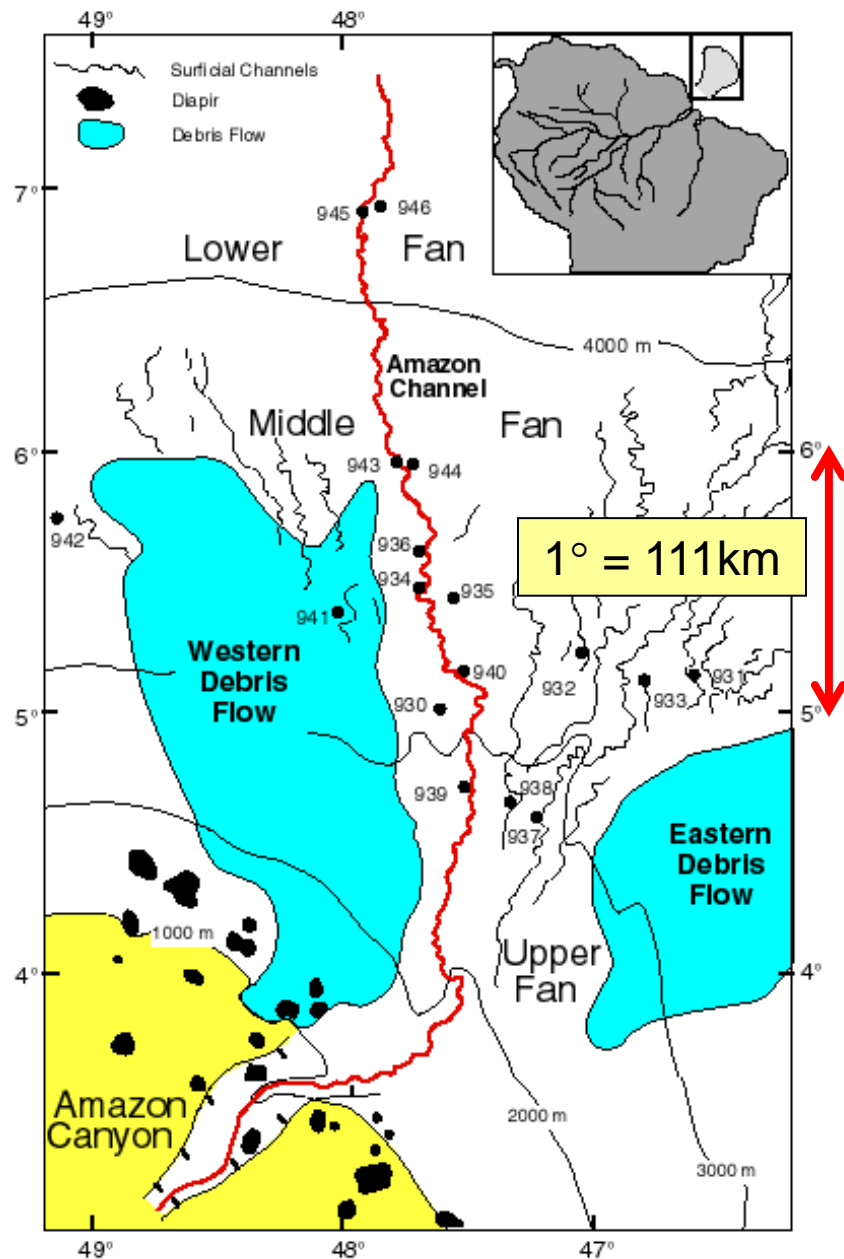
MY COAUTHORS

Rossella LUCHI

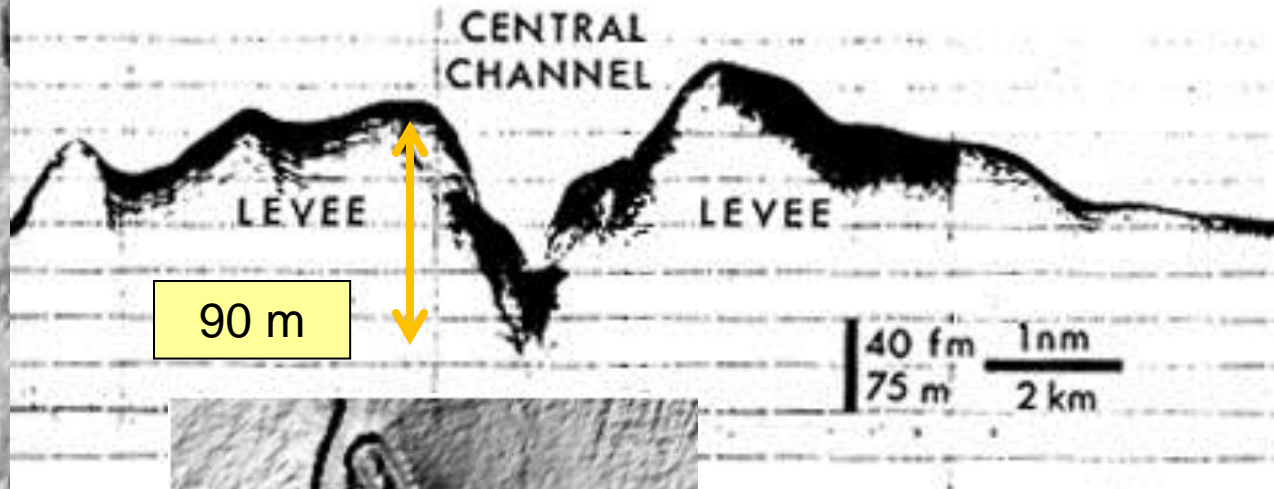
S. BALACHANDAR

The Case of the Amazon Submarine Fan
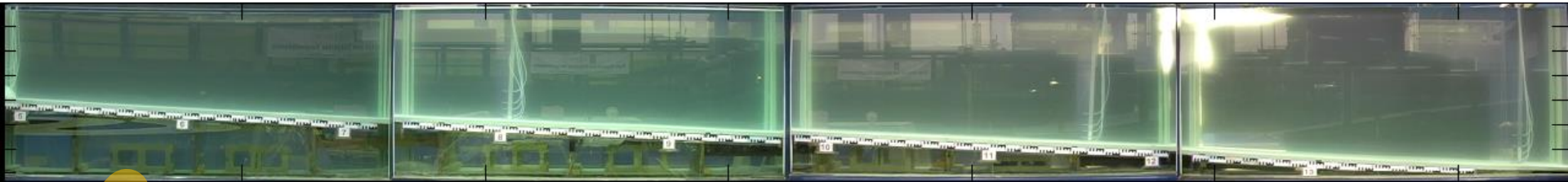
Cour. C. Pirmez

SOME CHANNELS ~> 1000 KM IN LENGTH

1° = 111km
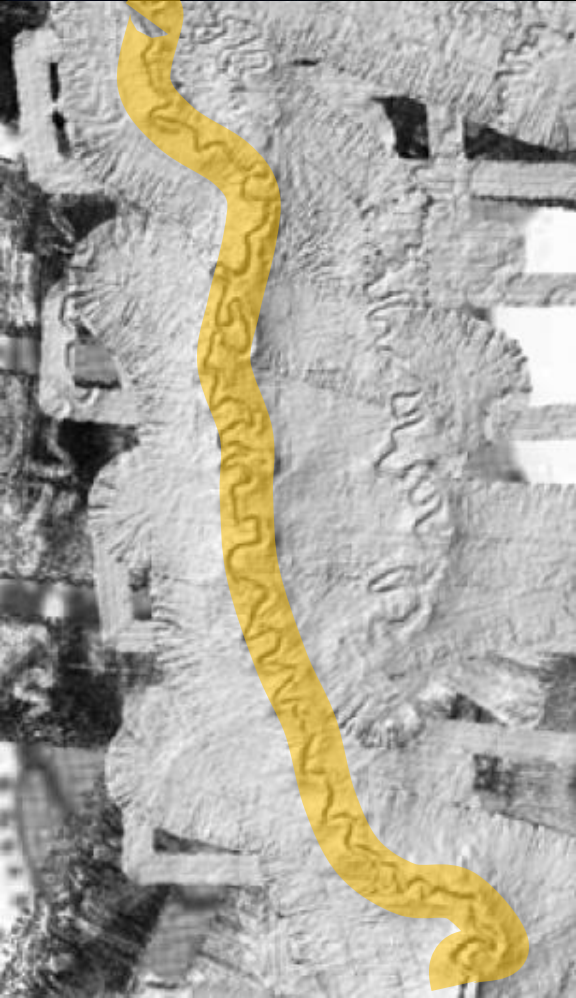
Cour. C. Pirmez

BOUNDED BY LEVEES UP TO 100 M

CENTRAL CHANNEL

LEVEE

LEVEE

90 m

40 fm   1 nm
75 m   2 km

Cour. R. Flood

Access video from page 1

Sequeiros et al. (2009)

How can such turbidity currents maintain their integrity, without getting thicker and more dilute, over such long distances?
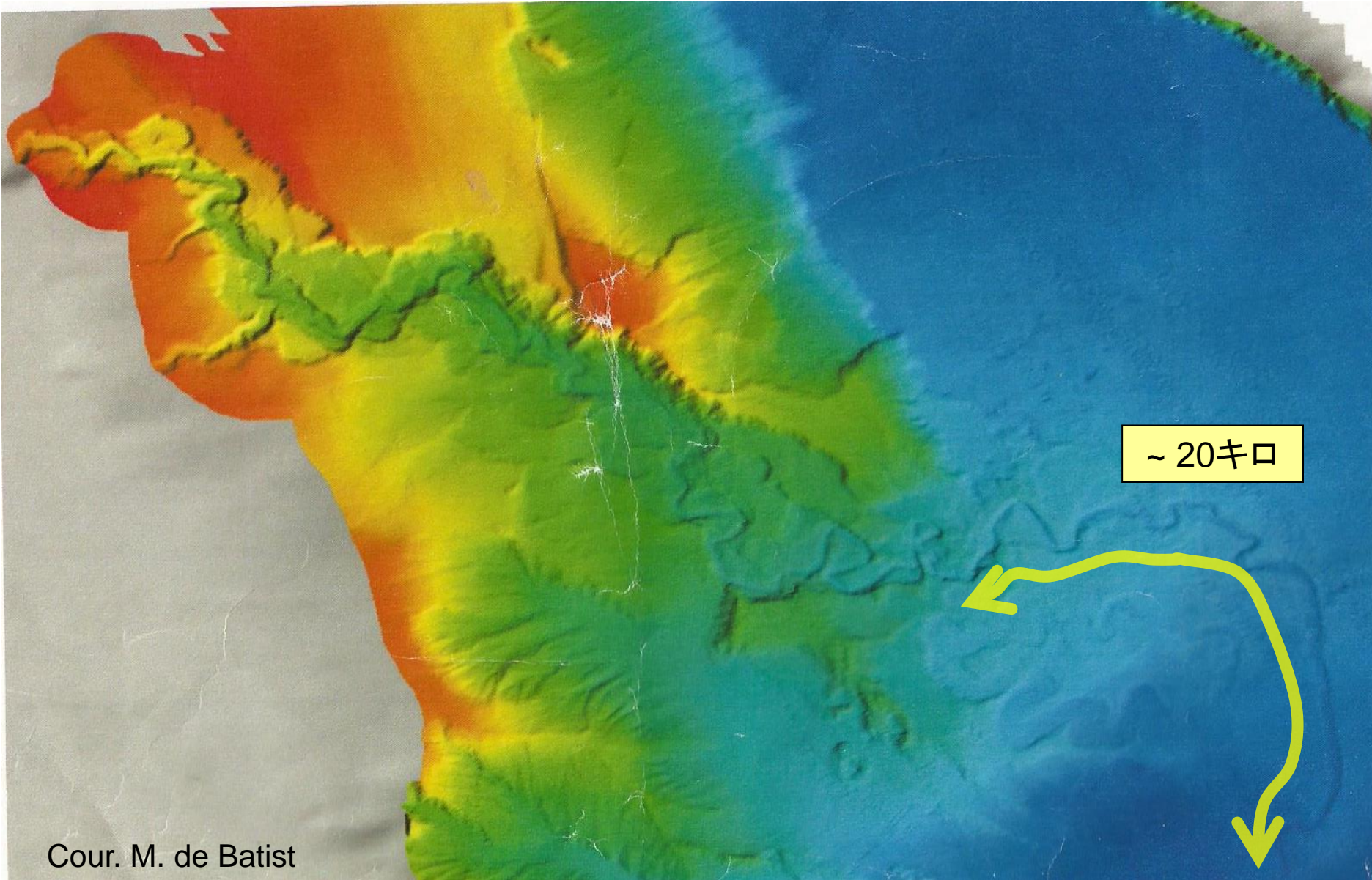
Cour. E. Flood

The case of Xiaolangdi Reservoir, China

Turbidity currents travel ~ 90 km before being vented

The Case of Freshwater Lake Baikal:
Long, levee-bounded channel created by turbidity currents

~ 20キロ

Cour. M. de Batist

The Old War Tanks
3-Equation and 4-Equation Layer-averaged Models of Parker, Fukushima and Pantin
1986

Self-accelerating turbidity currents

By GARY PARKER,

St Anthony Falls, Hydraulic Laboratory, University of Minnesota,
Minneapolis, Minnesota 55414, USA

YUSUKE FUKUSHIMA

Faculty of Engineering, Technological University of Nagaoka, Niigata, Japan

AND HENRY M. PANTIN

British Geological Survey, Keyworth, Nottingham NG12 5GG UK

THE MODELS CAN EXPLAIN SELF-ACCELERATION

$$\frac{\partial U\delta}{\partial t} + \frac{\partial U^2\delta}{\partial x} = -\frac{1}{2}Rg\frac{\partial C\delta^2}{\partial x} + RgC\delta S - C_f U^2$$

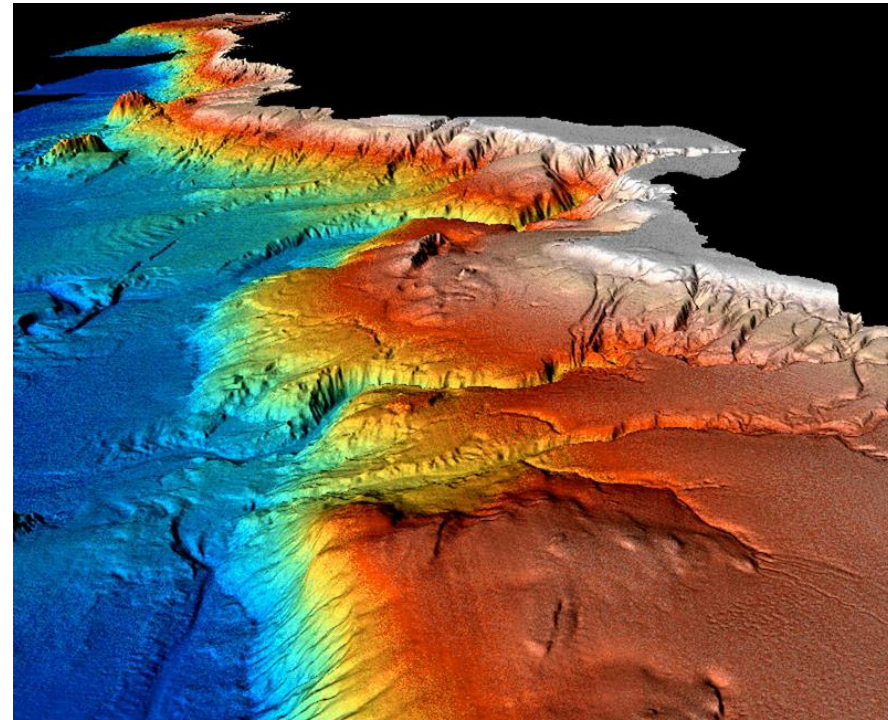$$\frac{\partial \delta}{\partial t} + \frac{\partial U\delta}{\partial x} = e_w U$$

$$\frac{\partial C\delta}{\partial t} + \frac{\partial UC\delta}{\partial x} = v_s[E_s(U) - c_b]$$

U = velocity
C = suspended sed. conc
δ = flow thickness

Ri

t = time
R = sed. Submerged spec grav ~ 1.65
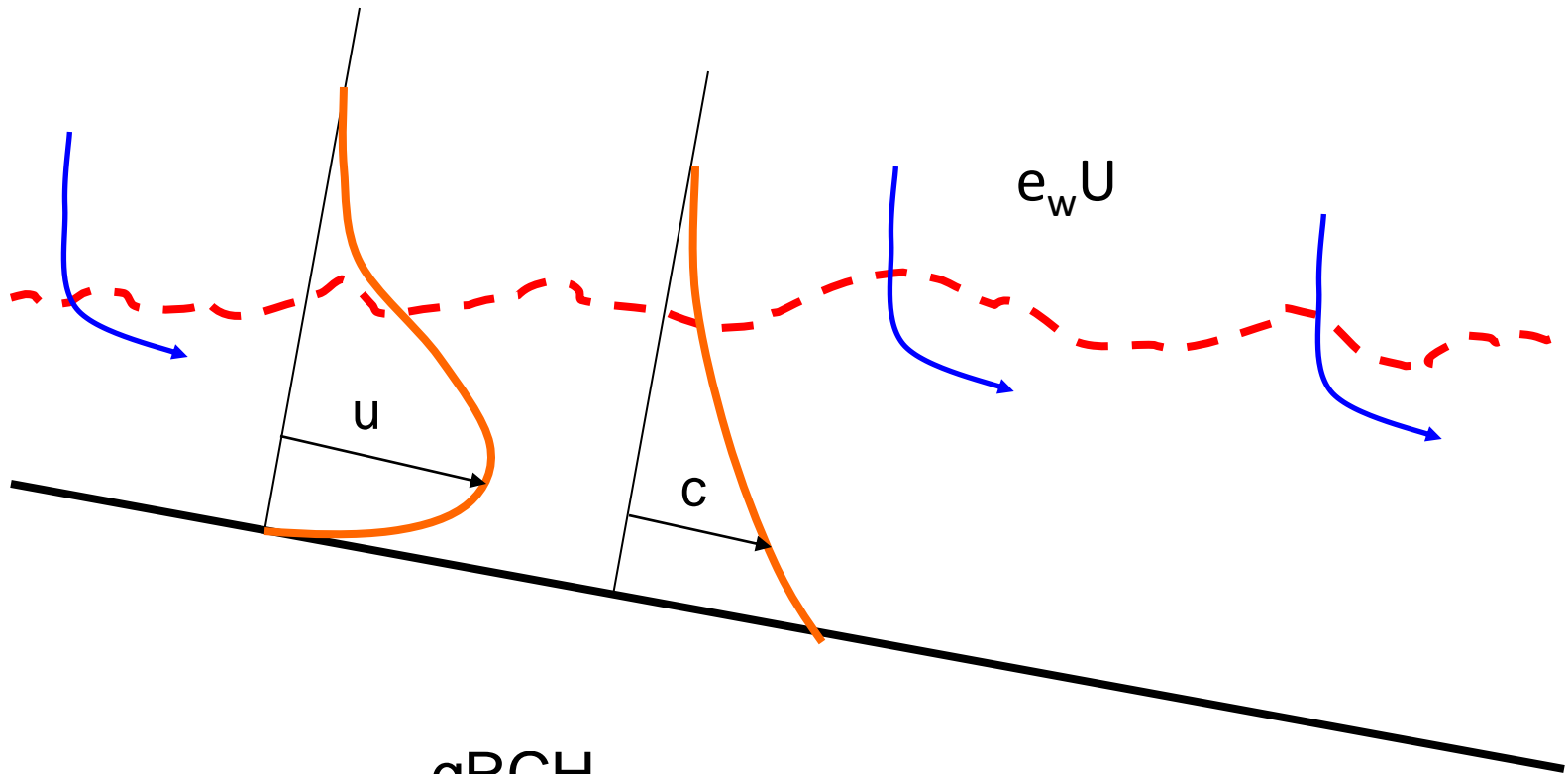v_s = sediment fall velocity
c_b = near-bed susp sed. Conc.

E_s = coefficient of entrainment of bed sed.
C_f = bed resistance coefficient
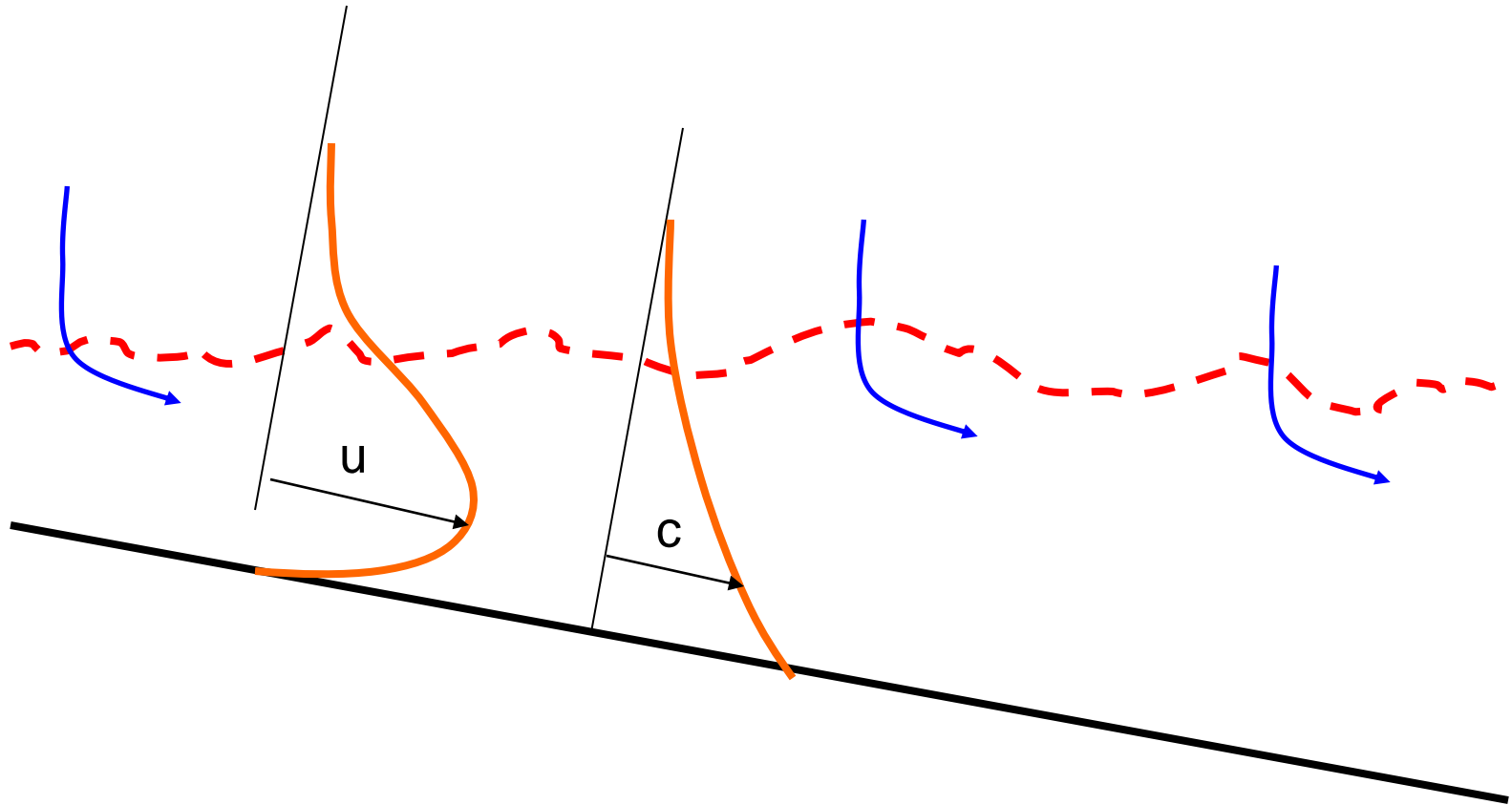e_w = coefficient of water entrainment

BUT THESE CURRENTS THICKEN AND BECOME DILUTE DUE TO AMBIENT WATER ENTRAINMENT
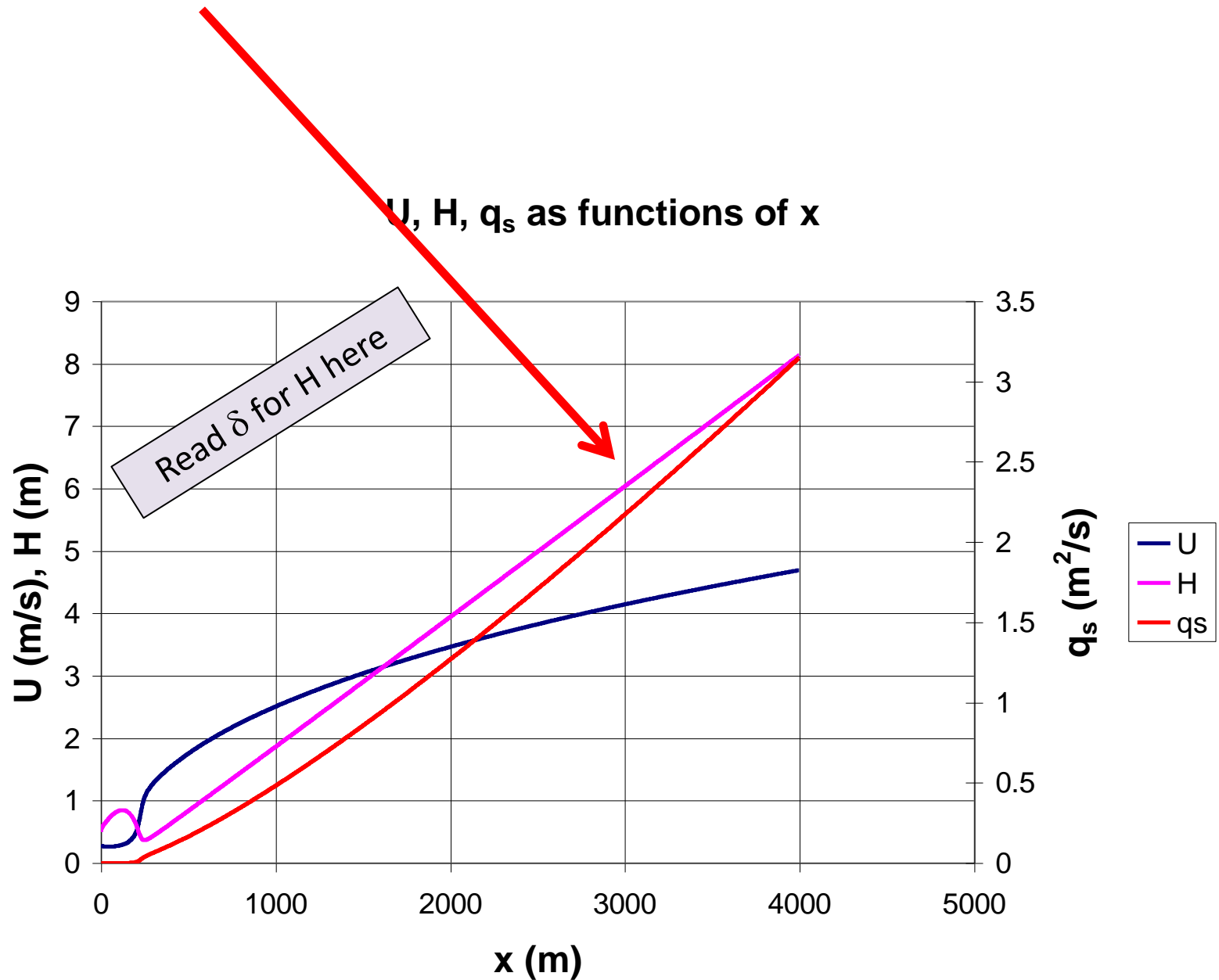
$e_w U$

u

c

$$e_w = fn(\mathbf{Ri}) \quad , \quad \mathbf{Ri} = \frac{gRCH}{U^2} \quad = \quad \text{Bulk Richardson no.}$$

WHY?

THEY ENTRAIN AMBIENT WATER RAPIDLY AND DILUTE THEMSELVES OVER SHORT DISTANCES

u

c

AND SO CANNOT RUN OUT LONG DISTANCES

U, H, q$_s$ as functions of x

Read δ for H here

U (m/s), H (m)

q_s (m^2/s)

x (m)

U
H
qs

THESE OLD WAR HORSES
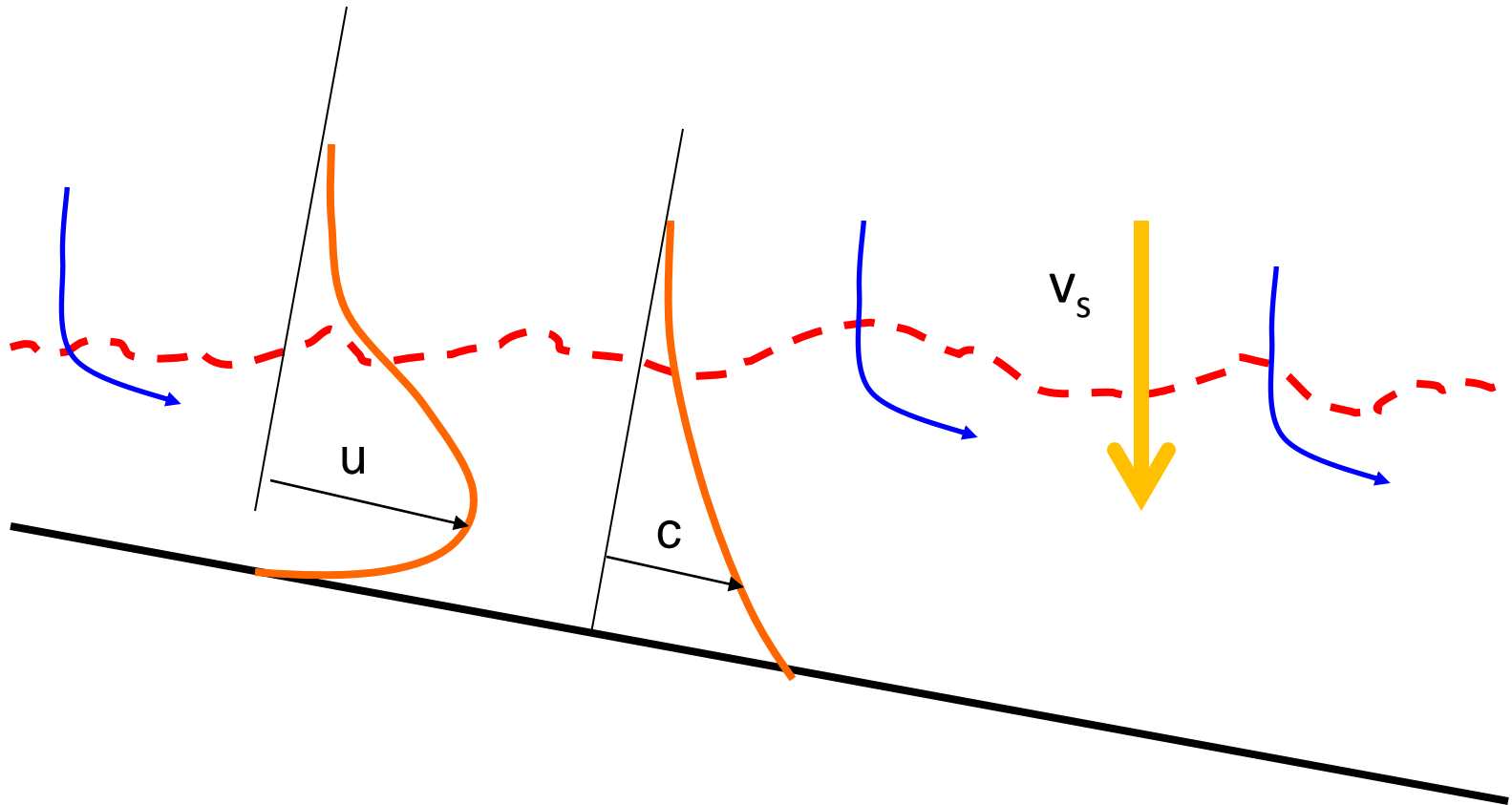

Model 3 Tank

Model 4 Tank

CAN'T GO VERY FAR

and certainly cannot explain channels from 100 to 1000 or more km long

But sediment, as opposed to dissolved salt, FIGHTS against entrainment

TIME TO RETHINK

THIS FORMULATION **NO GOOD** FOR LONG RUNOUT

J. Fluid Mech. (1986), vol. 171, pp. 145–181
Printed in Great Britain

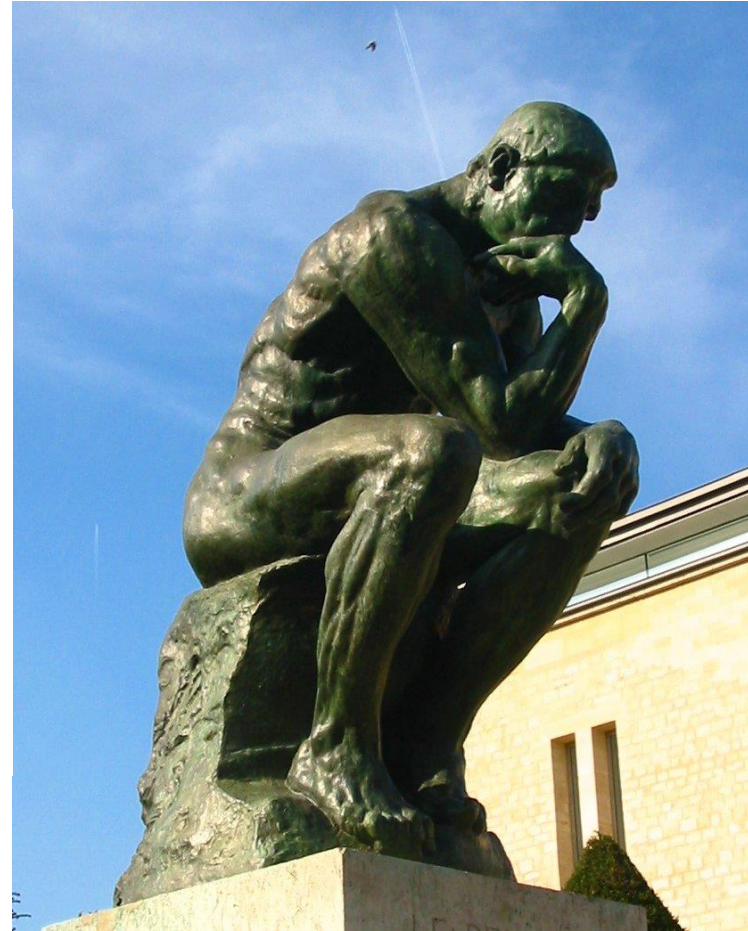## Self-accelerating turbidity currents

BY GARY PARKER,

St Anthony Falls Hydraulic Laboratory, University of Minnesota,
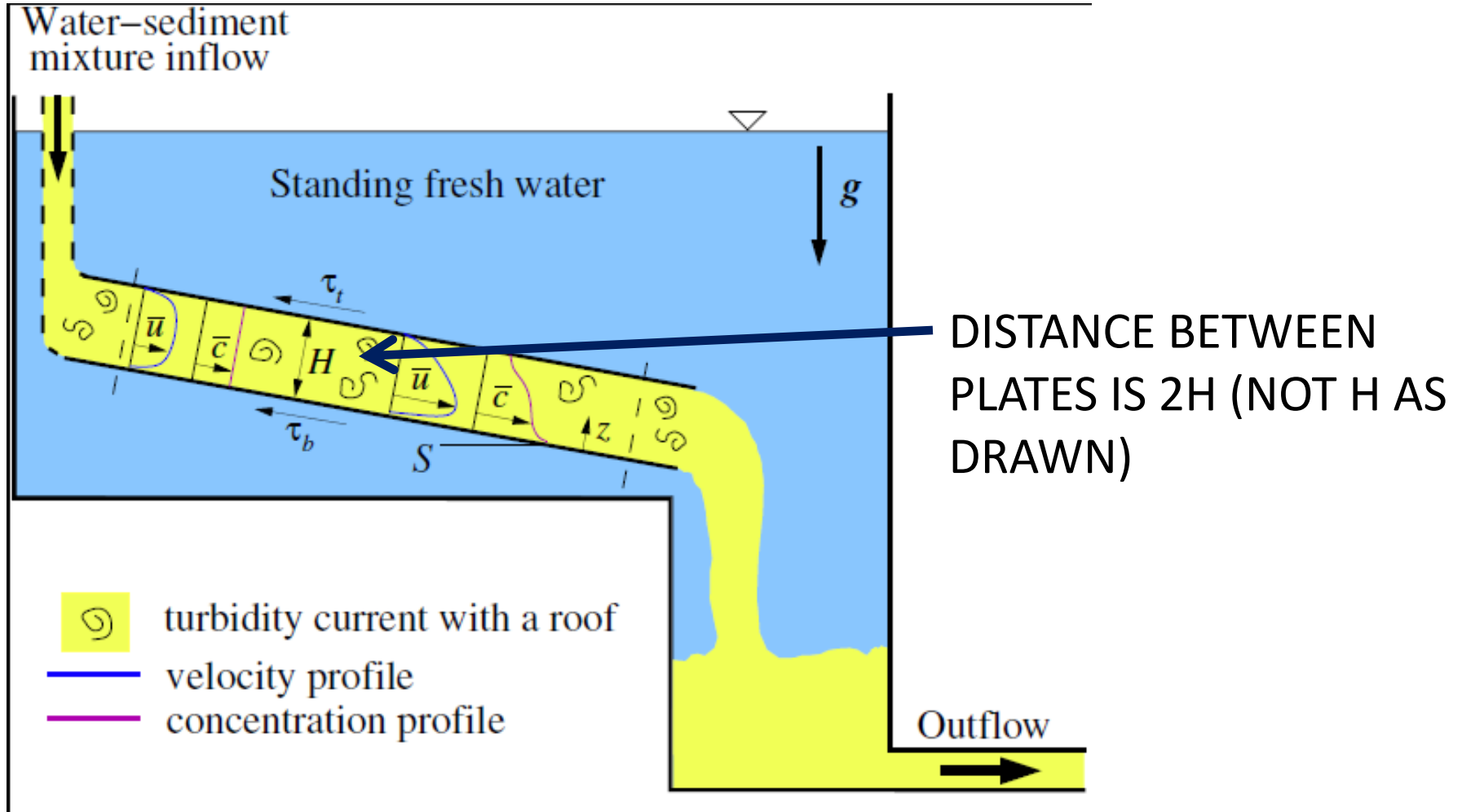Minneapolis, Minnesota 55414, USA

YUSUKE FUKUSHIMA

Faculty of Engineering, Technological University of Nagaoka, Niigata, Japan

AND HENRY M. PANTIN

British Geological Survey, Keyworth, Nottingham NG12 5GG UK

TURBIDITY CURREND WITH A ROOF UNDER BYPASS CONDITIONS

Water−sediment mixture inflow

Standing fresh water

g

τ_t

$\bar{u}$ $\bar{c}$ H $\bar{u}$ $\bar{c}$

τ_b

S

z

DISTANCE BETWEEN PLATES IS 2H (NOT H AS DRAWN)

turbidity current with a roof
velocity profile
concentration profile

Outflow

WHAT HAPPENS AS H $\rightarrow \infty$
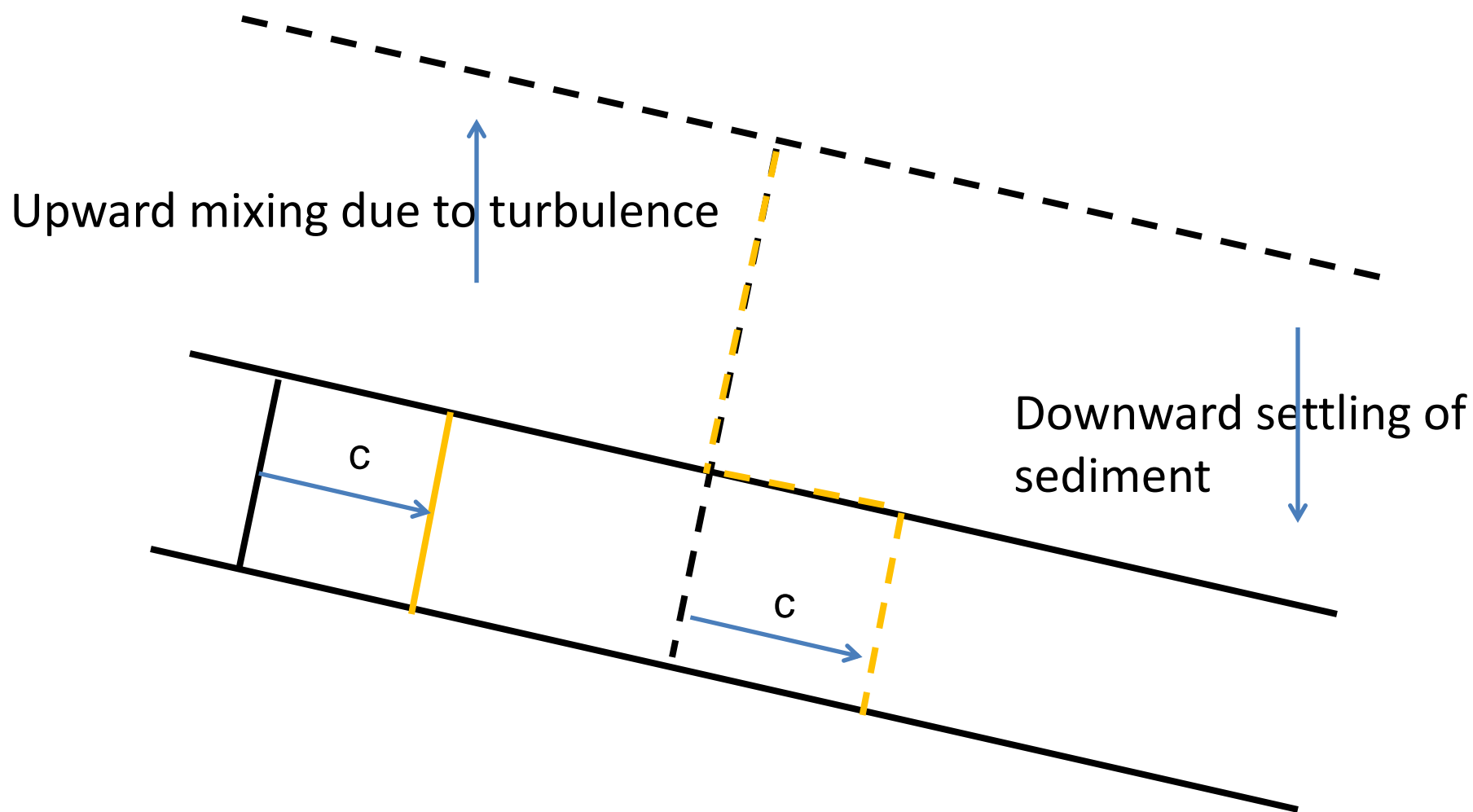
DISSOLVED SALT:
change in equilibrium concentration with gap height

Upward mixing due to turbulence

c

c
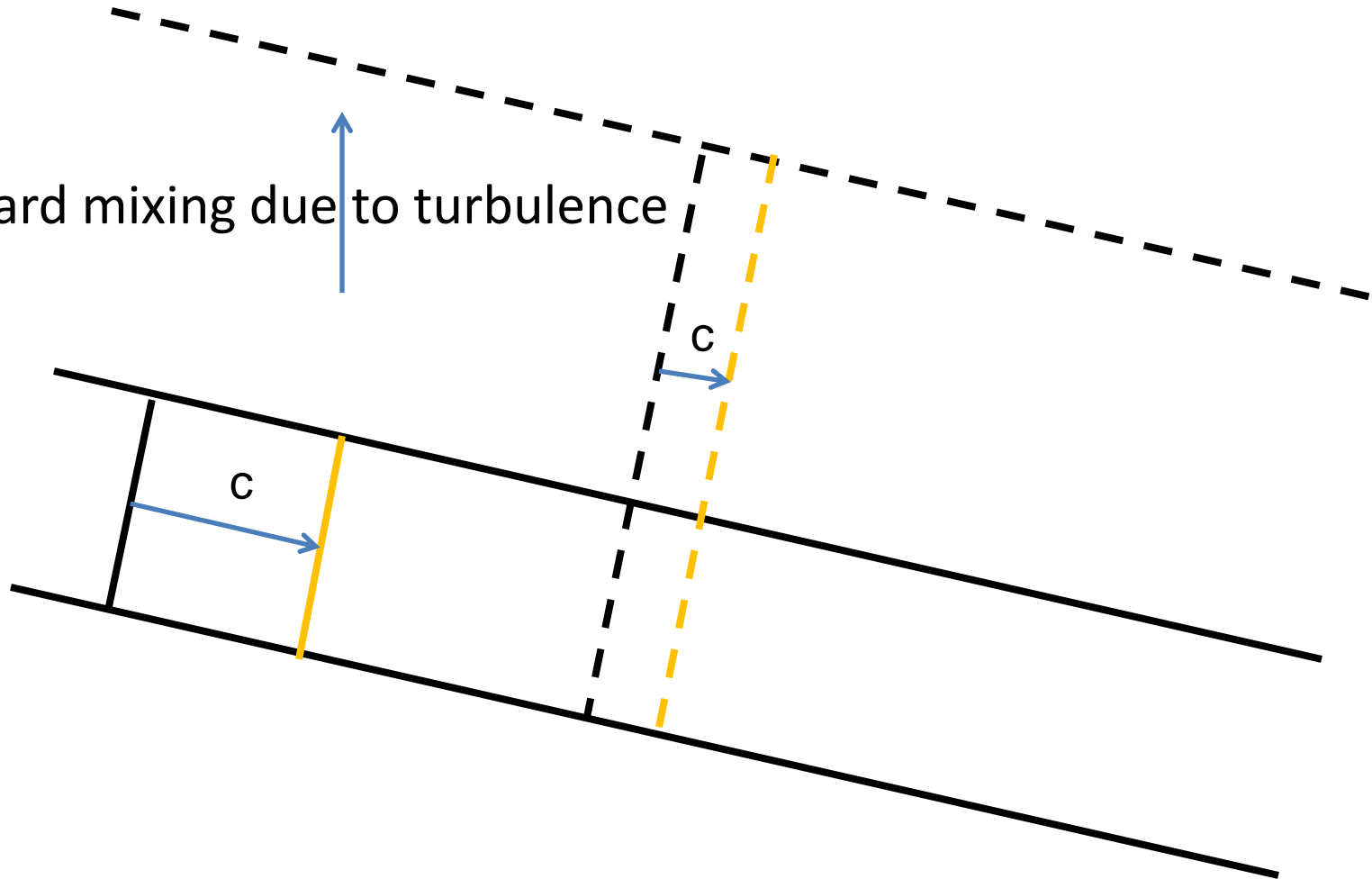
SUSPENDED SEDIMENT: FALL VELOCITY FIGHTS WITH TURBULENCE, PREVENTS UNLIMITED UPWARD MIXING

Maybe????

Upward mixing due to turbulence

Downward settling of sediment

c

c

A BETTER MODEL THAT RESOLVES VERTICAL STRUCTURE (k-ε)

The governing equations are made dimensionless with:

Length scale L^* such that $H^* = nL^*$
Average shear stress $u_* = \frac{u_{*T} + u_{*B}}{2} = \sqrt{RgSCnL^*}\ u_{*B}$ with u_{*T} and u_{*B} the shear velocity at the top and at the bottom
Average concentration C

Momentum balance

$\frac{\partial u}{\partial t} = \frac{\partial}{\partial z}\left[\left(\frac{1}{Re_\tau} + \nu_T\right)\frac{\partial u}{\partial z}\right] + c$

We are looking for the steady solution

C is the average concentration
'tilde c' is the local value concentration
c is the 'tilde c' divided by average concentration C

* means dimensional variable
S slope
$R = \frac{\rho_s - \rho_s}{\rho_a}$

Mass balance

$\frac{\partial c}{\partial t} = \frac{\partial}{\partial z}\left[\left(\frac{1}{S_c Re_\tau} + \nu_{Tc}\right)\frac{\partial c}{\partial z}\right] + \frac{\partial v_s c}{\partial z}$

2 H

Hp: no entrainment
$\int_0^{2H^*} \tilde{c}\, dz^* = 2H^* C = L^*$

Turbulence e~~~

OK, LOTS OF EQUATIONS

$\frac{\partial k}{\partial t} = \frac{\partial}{\partial z}\left[\left(\frac{\nu_T}{\sigma_k} + \frac{1}{Re_\tau}\right)\frac{\partial k}{\partial z}\right] + \nu_T\left(\frac{\partial u}{\partial z}\right)^2 - \varepsilon + Ri_\tau \nu_{Tc}\frac{\partial c}{\partial z}$

Formulation for k-e model
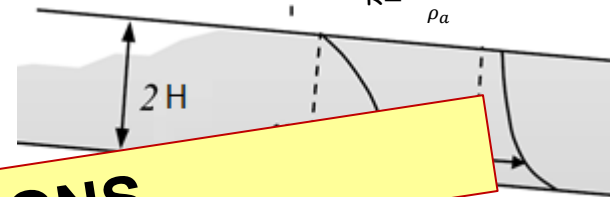(MY model is also implemented)

Energy dissipation

$\frac{\partial \varepsilon}{\partial t} = \frac{\partial}{\partial z}\left[\left(\frac{\nu_T}{\sigma_\varepsilon} + \frac{1}{Re_\tau}\right)\frac{\partial \varepsilon}{\partial z}\right] + c_{\varepsilon 1}\frac{\varepsilon}{k}\left\{\left(\nu_T\left(\frac{\partial u}{\partial z}\right)^2 + c_{\varepsilon 3}Ri_\tau \nu_{Tc}\frac{\partial c}{\partial z}\right)\right\} - c_{\varepsilon 2}\frac{\varepsilon^2}{k}$

$Ri_\tau = \frac{RgCnL^*}{u_*^2} = \frac{RgCH^*}{u_*^2}$ $Re_\tau = \frac{u_* L^*}{\nu}$
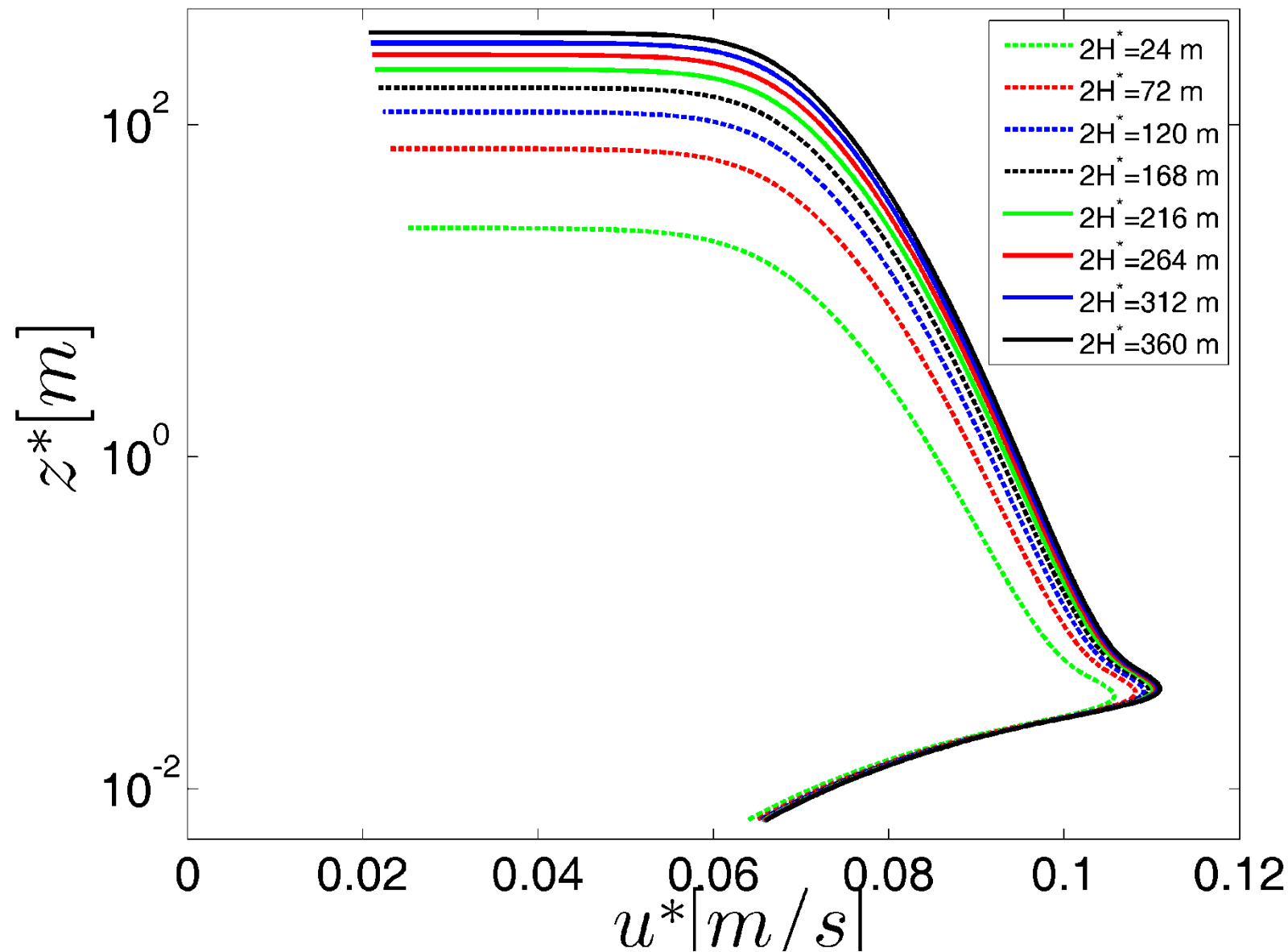
Formulation for k-e model
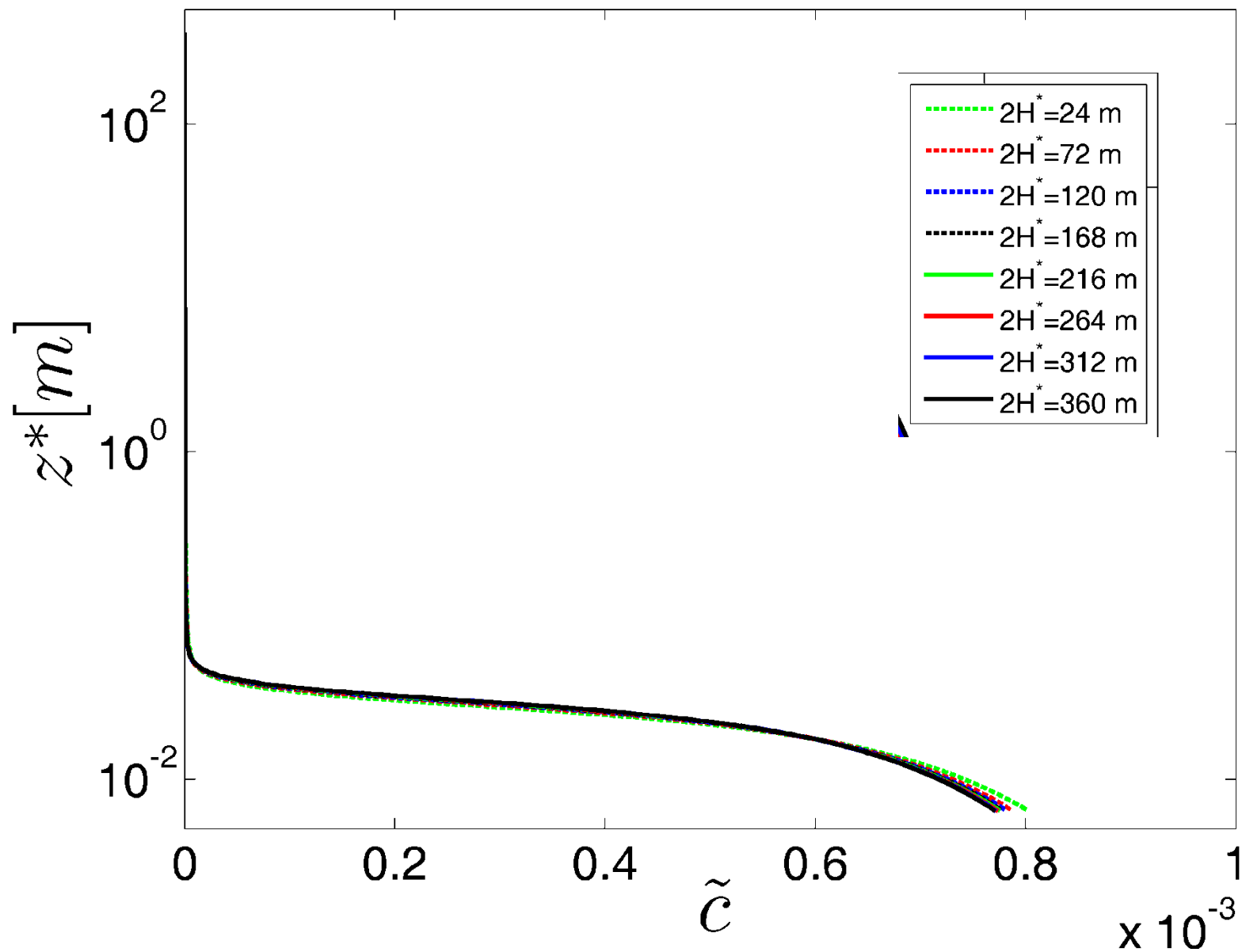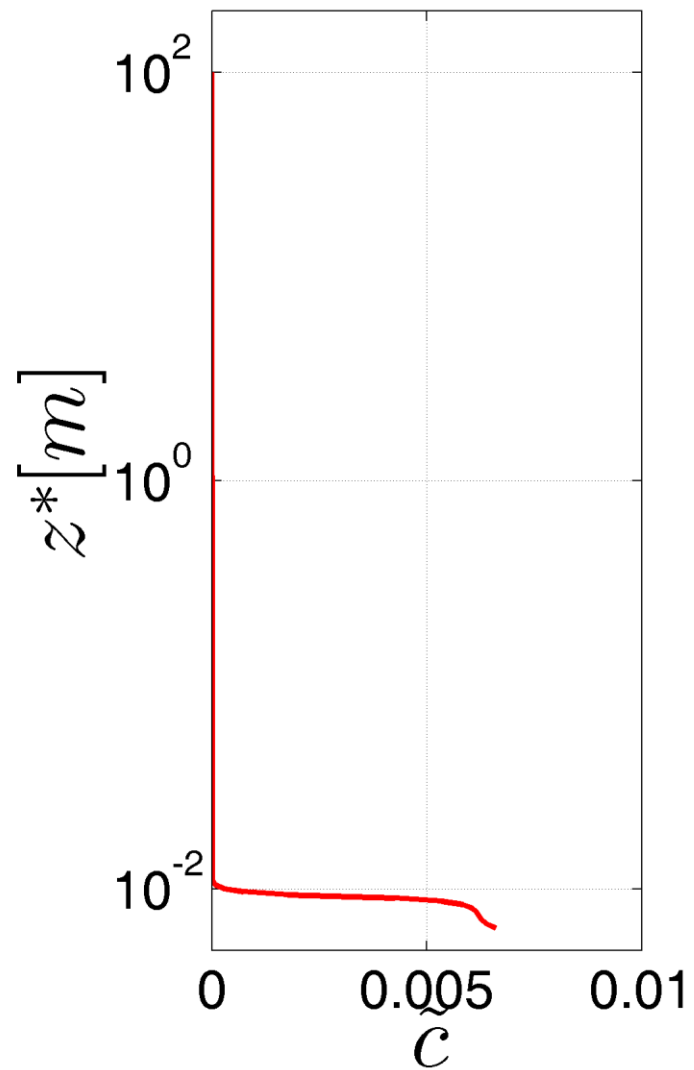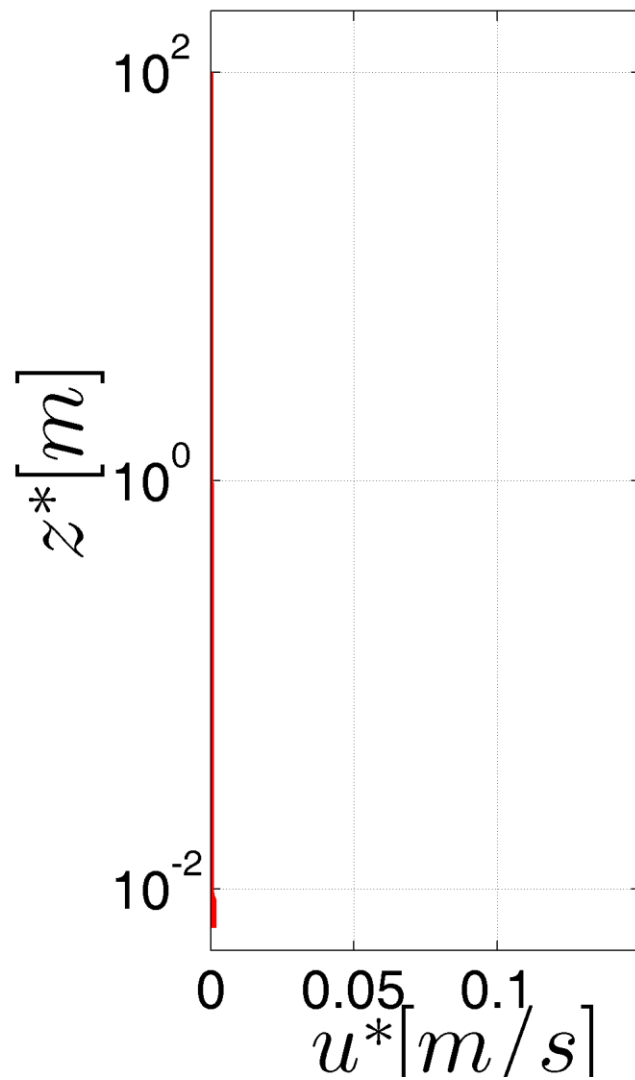(MY model is also implemented)

SOME RESULTS

1. The flow decomposes into an inner (near-bed) and outer layer

2. The inner layer can reach an asymptotic state independent of gap height

3. ~ 90 percent of the sediment is trapped in the inner layer

4. It is the inner layer that drives the current

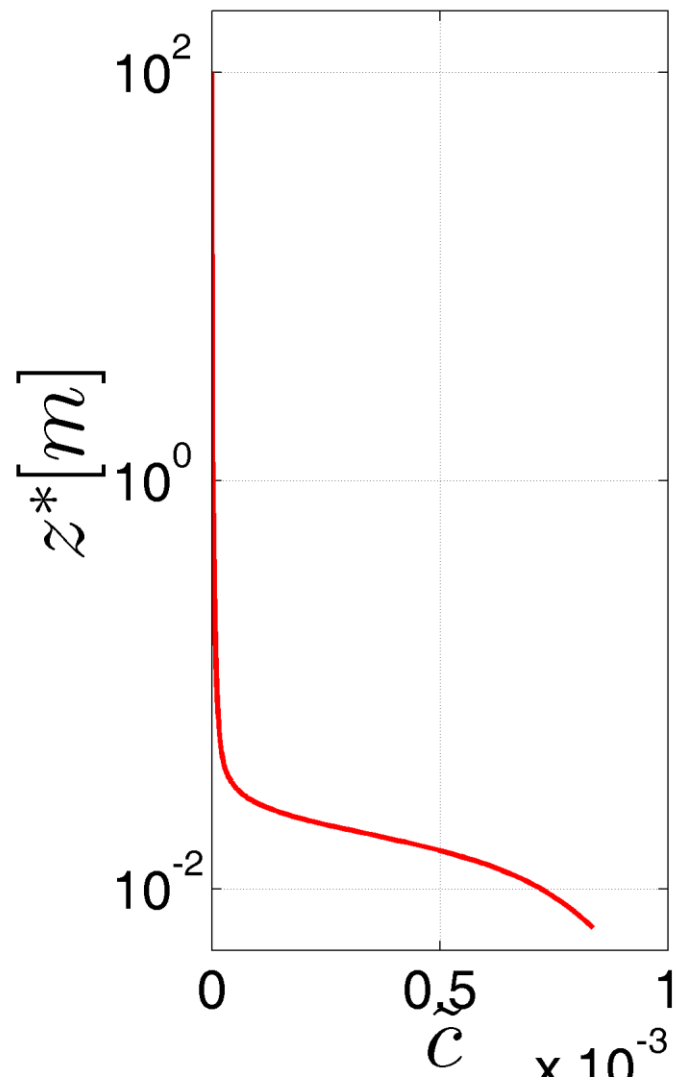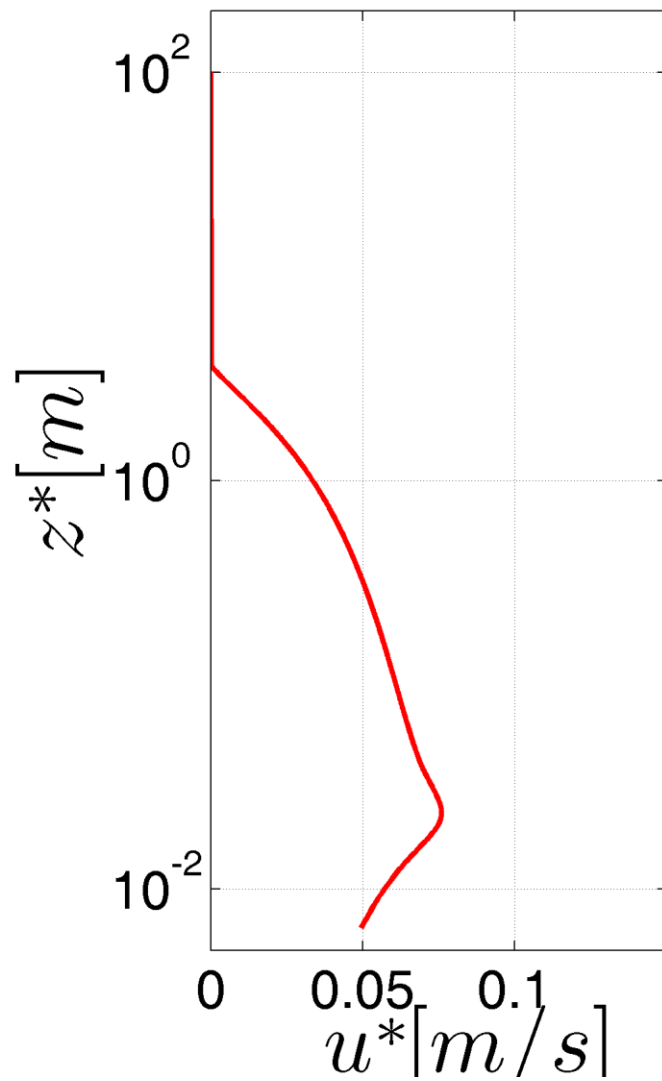**5. The outer layer gets thicker and more dilute as the gap height grows**
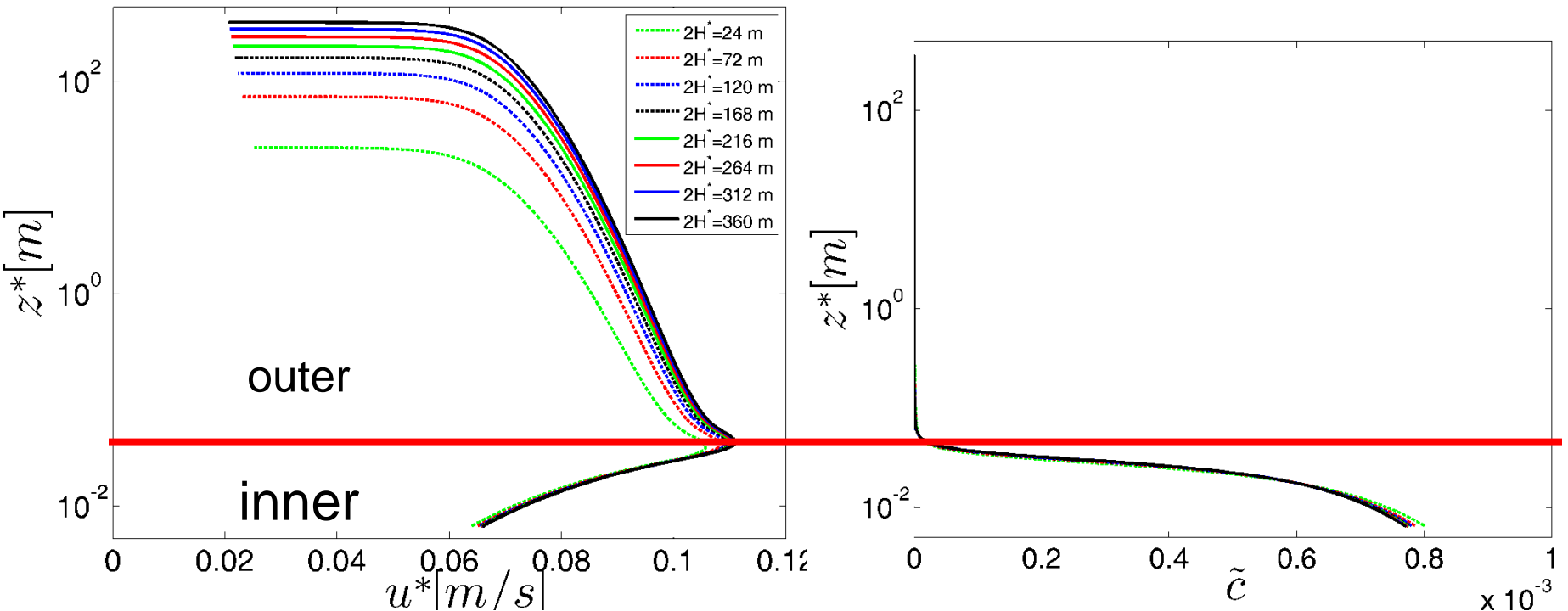
VELOCITY PROFILES

Legend:
- $2H^* = 24$ m
- $2H^* = 72$ m
- $2H^* = 120$ m
- $2H^* = 168$ m
- $2H^* = 216$ m
- $2H^* = 264$ m
- $2H^* = 312$ m
- $2H^* = 360$ m

x-axis: $u^* [m/s]$

y-axis: $z^* [m]$

CONCENTRATION PROFILES

Legend:
- $2H^* = 24$ m
- $2H^* = 72$ m
- $2H^* = 120$ m
- $2H^* = 168$ m
- $2H^* = 216$ m
- $2H^* = 264$ m
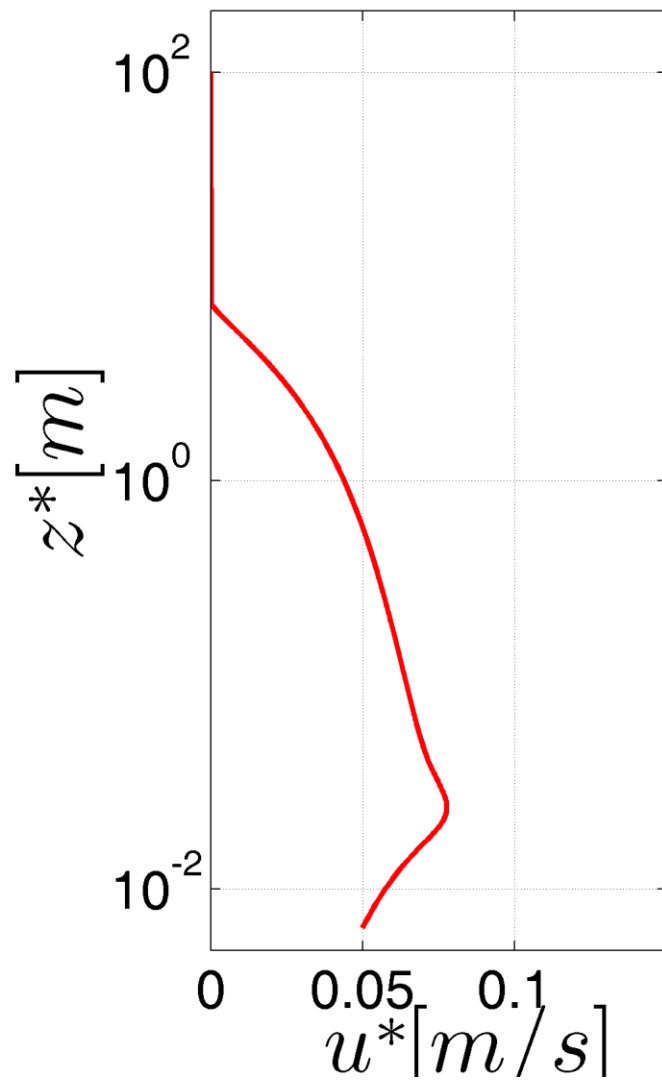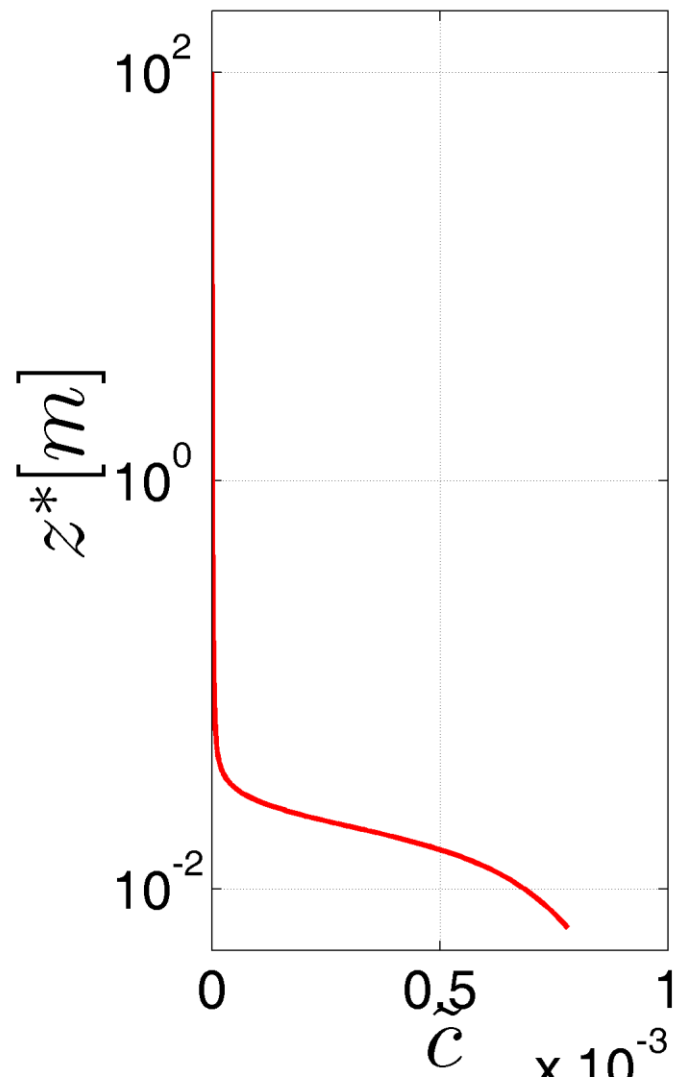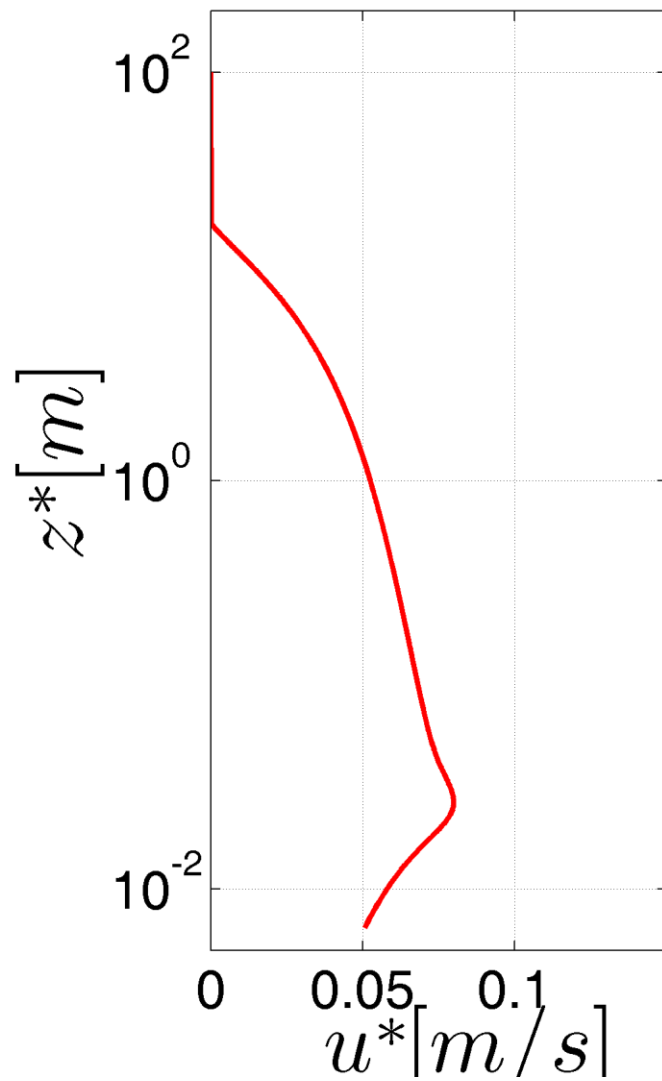- $2H^* = 312$ m
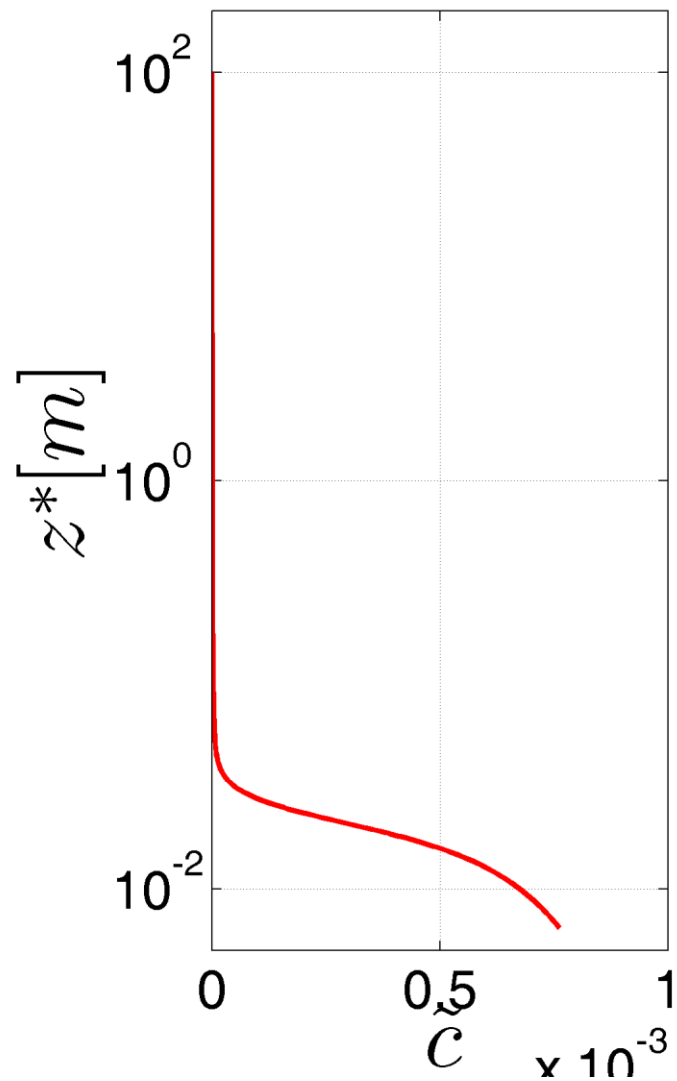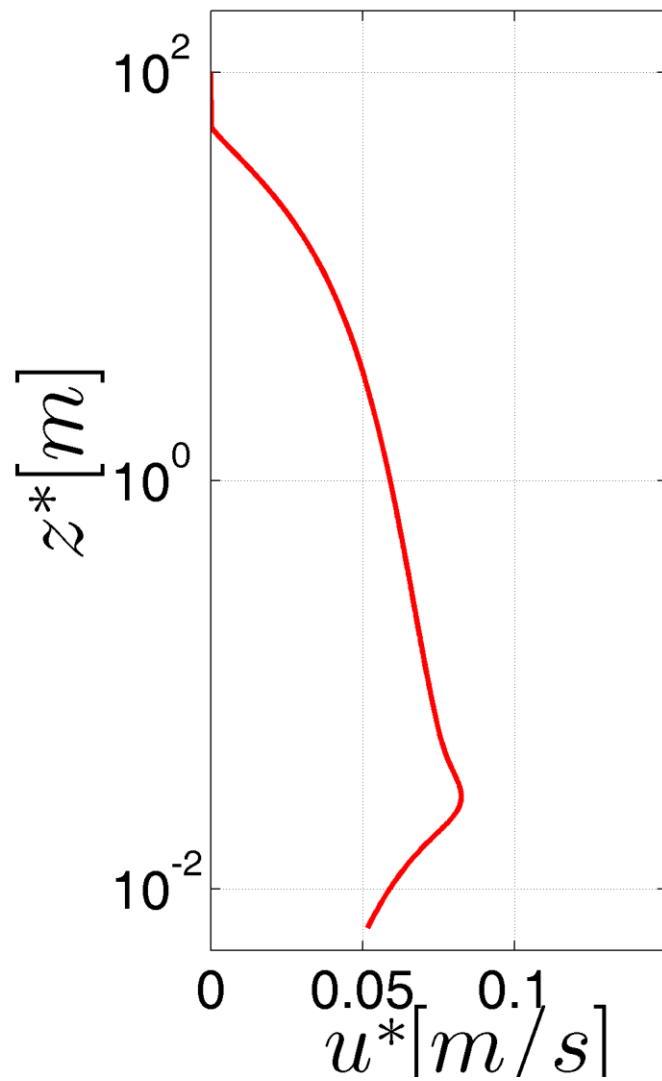- $2H^* = 360$ m

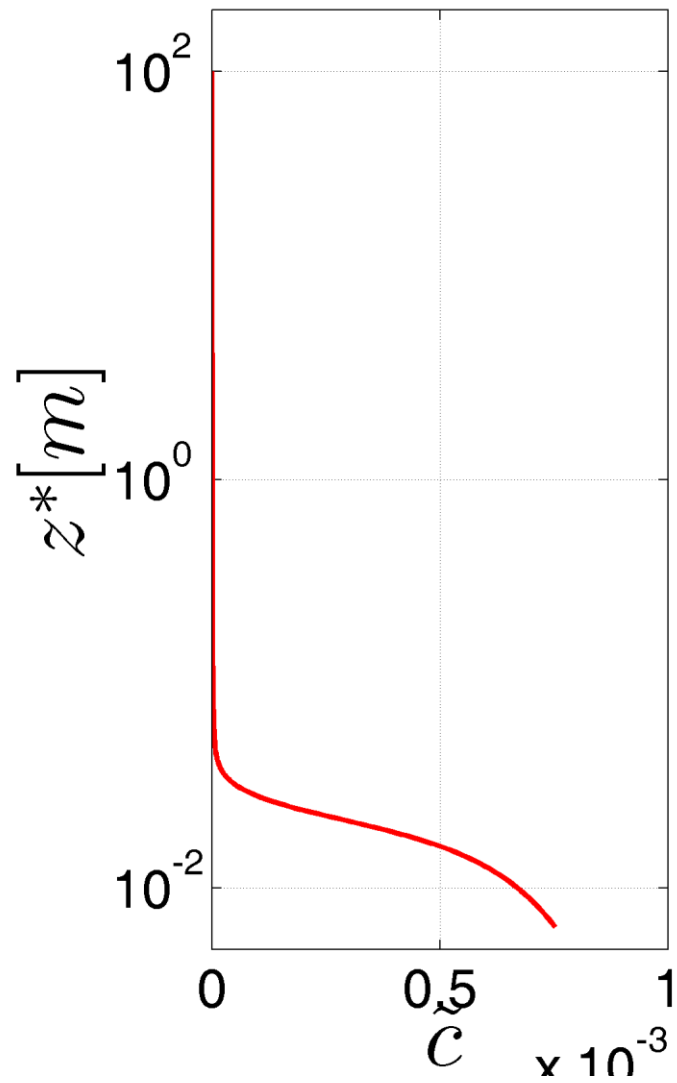y-axis: $z^* [m]$

x-axis: $\tilde{c}$ ($\times 10^{-3}$)

NO INFLUENCE OF TOP PLATE

NO INFLUENCE OF TOP PLATE

NO INFLUENCE OF TOP PLATE
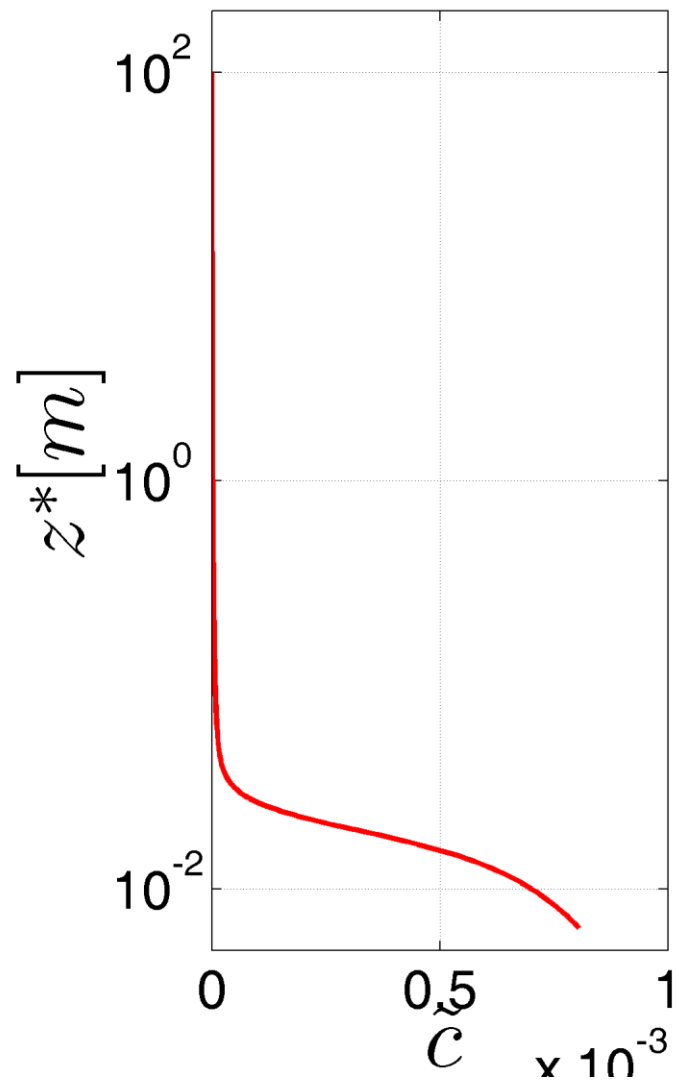
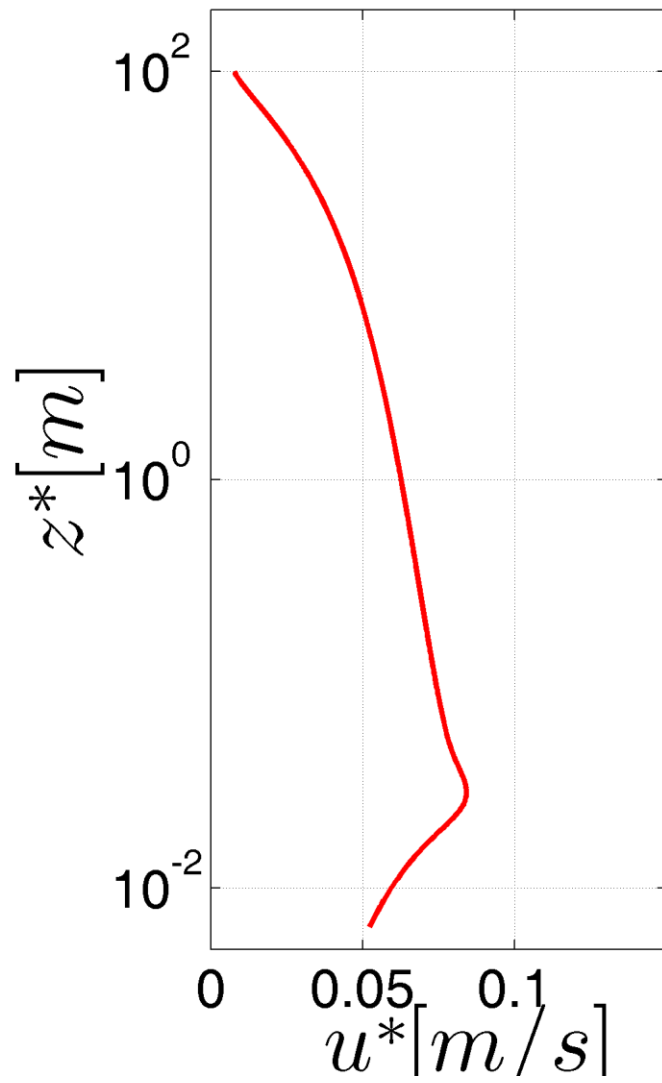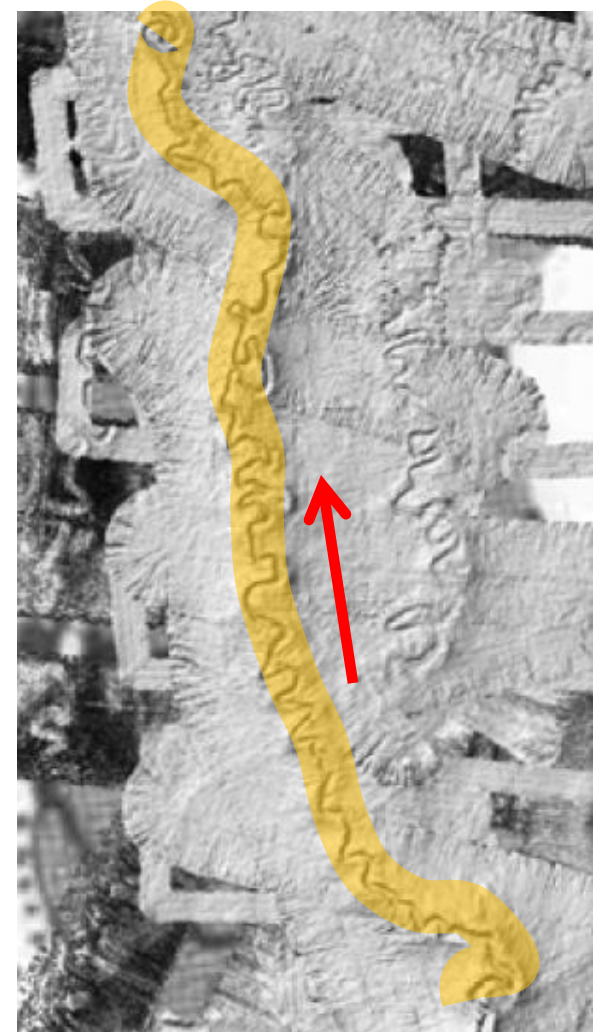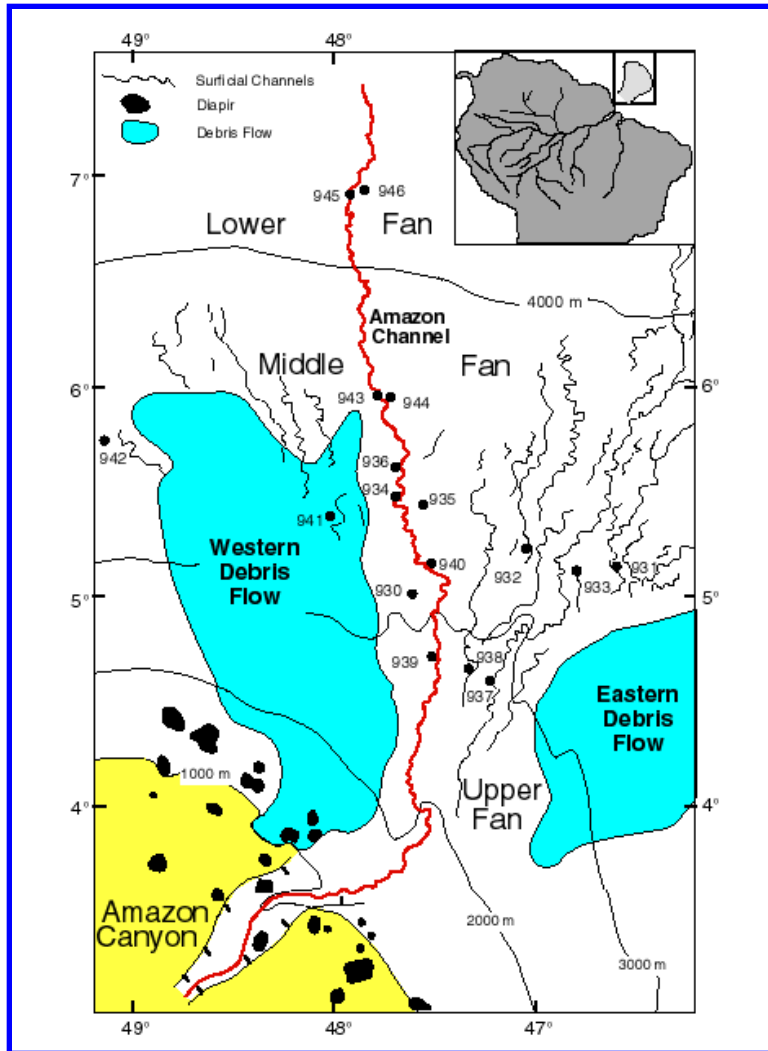# NO INFLUENCE OF TOP PLATE

NO INFLUENCE OF TOP PLATE

FINALLY FEEL INFLUENCE OF TOP PLATE

SOME IMPLICATIONS

1. LEVEE HEIGHT MAY BE CONTROLLED BY THE HEIGHT OF THE INNER LAYER

2. ONCE LEVEES ARE CONSTRUCTED, THE CURRENT COULD RUN OUT "INFINITELY FAR" ON A CONSTANT BED SLOPE

3. THE LENGTH OF THE CHANNEL AT ANY GIVEN TIME SHOULD BE PRIMARILY CONTROLLED BY THE AVAILABILITY OF MUD

4. THE NEW THEORY DOESN'T GIVE A DAMN IF THE INNER FLOW IS FROUDE-SUBCRITICAL OR NOT

u
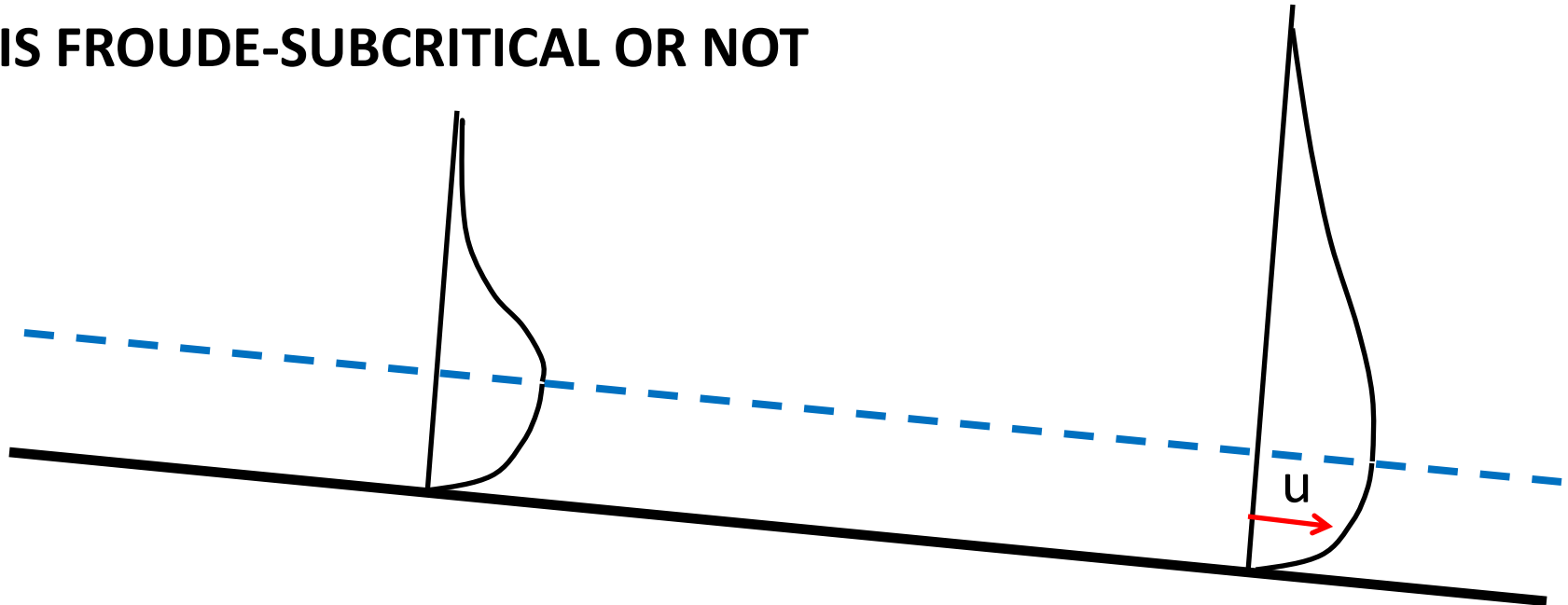
THE FUTURE

AFTER ENOUGH EXPLORATION OF PARAMETER SPACE:

Minimum:

LAYER-INTEGRATED 6-EQUATION MODEL

INNER LAYER: momentum, water mass, sediment mass balance

OUTER LAYER: momentum, water mass, sediment mass balance