On the role of flocculation, hindered settling and sediment-induced damping of turbulence in trapping sediment in estuaries, with focus on the North Passage, Yangtze Estuary

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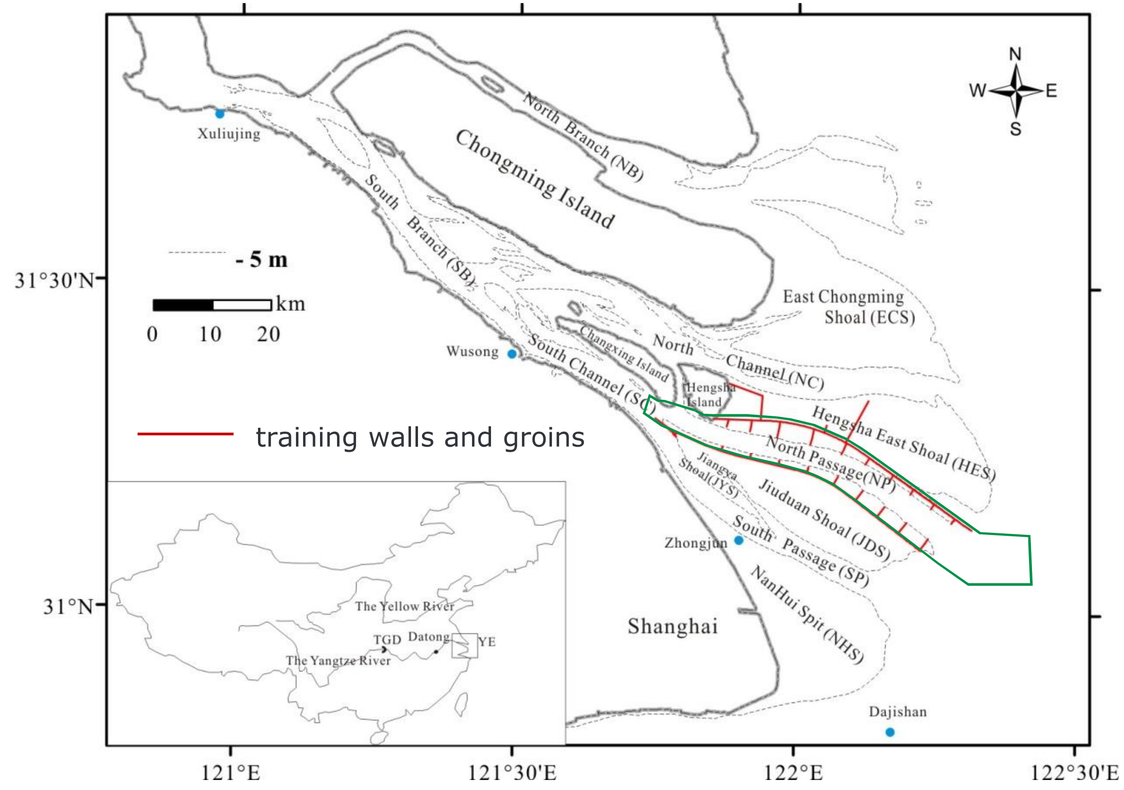
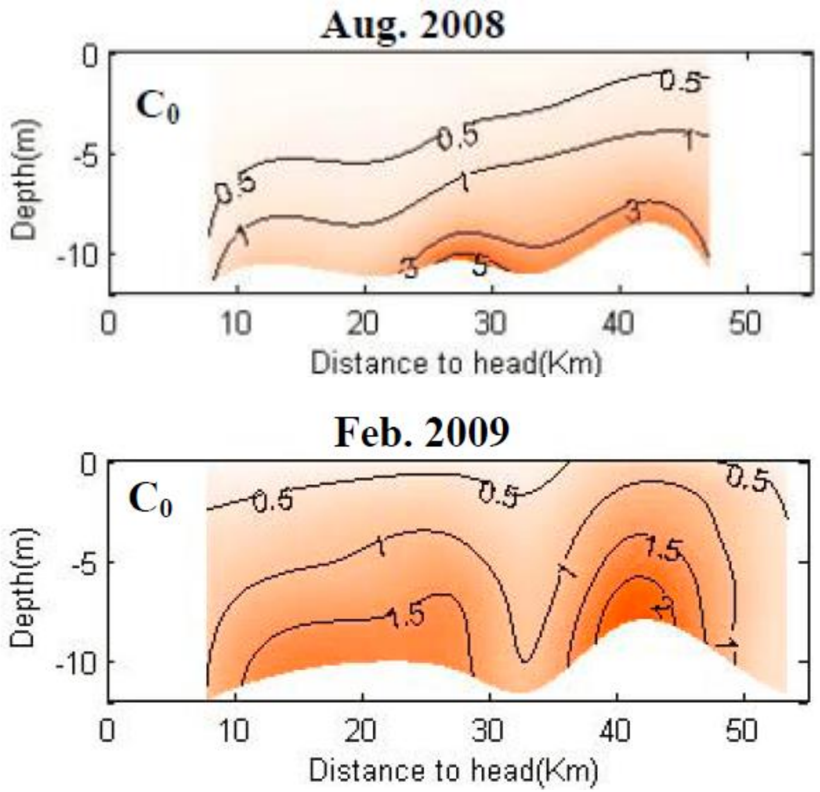
Introduction to the North Passage



Map of the Yangtze Estuary (YE)

note the trapping of sediment



Tidal mean suspended sediment concentration (SSC, kg/m^3) distribution in the North Passage (NP) (Jiang et al., 2013)

Context

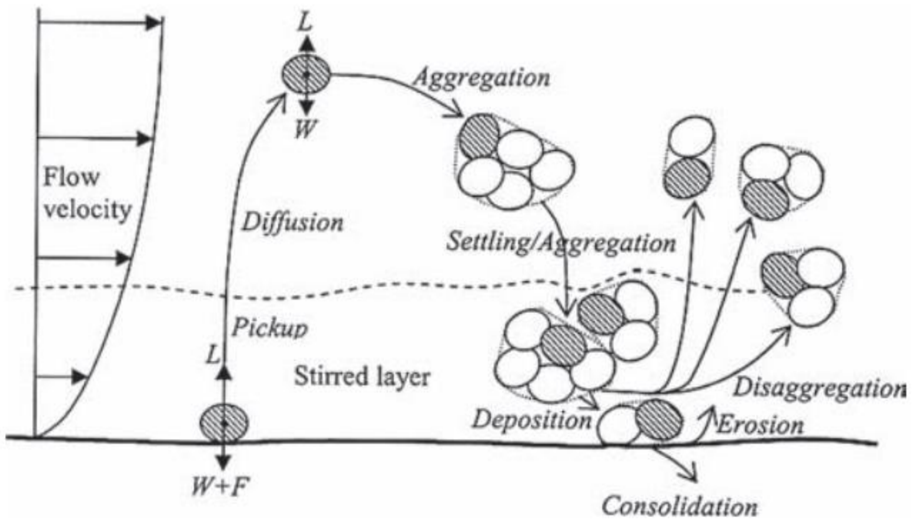
1. Research questions
2. Methodology
3. Results
4. Discussion
5. Conclusions

1 Research questions

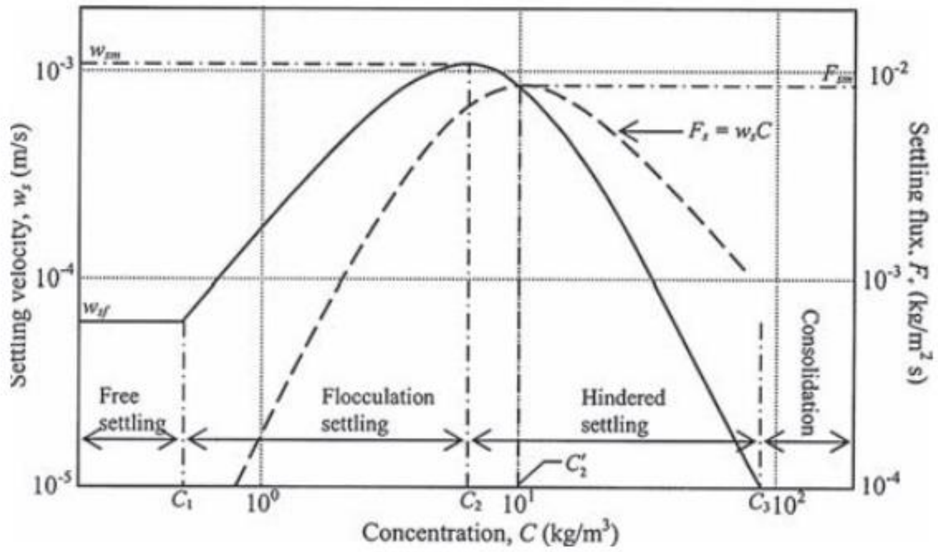
the sensitivity of location and intensity of estuarine turbidity maximum (ETM) to

1) flocculation and hindered settling of fine sediment

2) sediment-induced damping of turbulence.



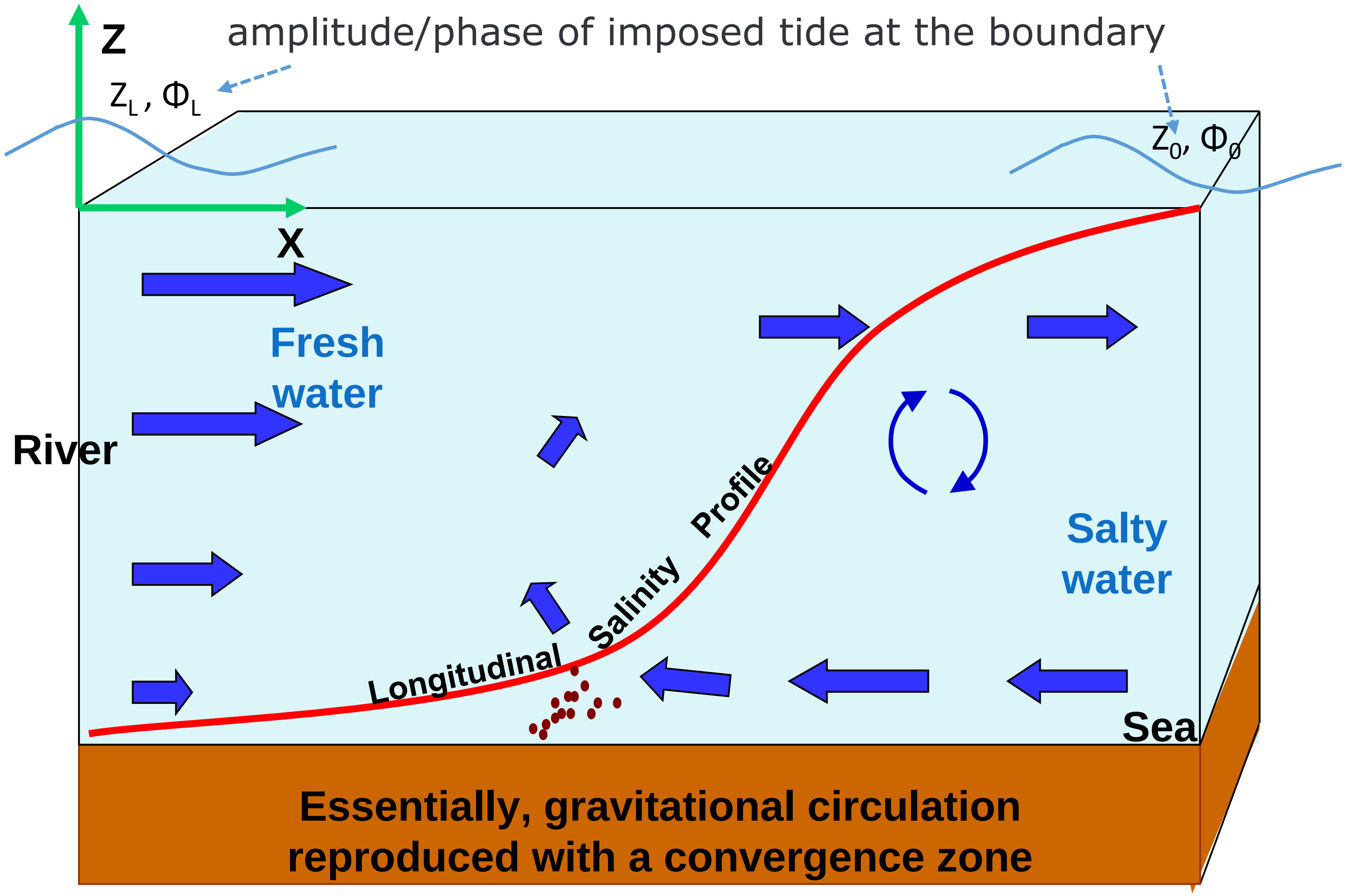
Sketch of aggregation of cohesive sediment particles or flocs (aggregation=flocculation) Mehta et al. (2008)

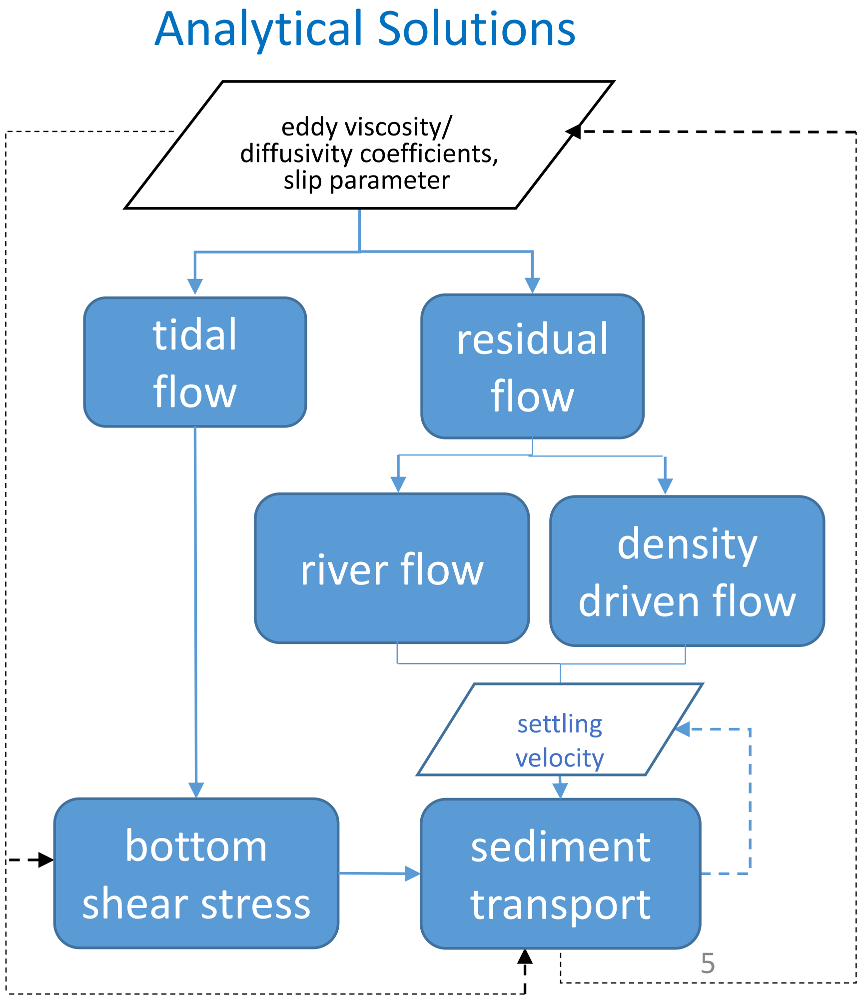


Dependence of sediment settling velocity on concentration Mehta et al. (2008)

2 Methodology

A width-averaged process-based model that describes tides, residual currents and sediment transport in an estuarine channel was developed.





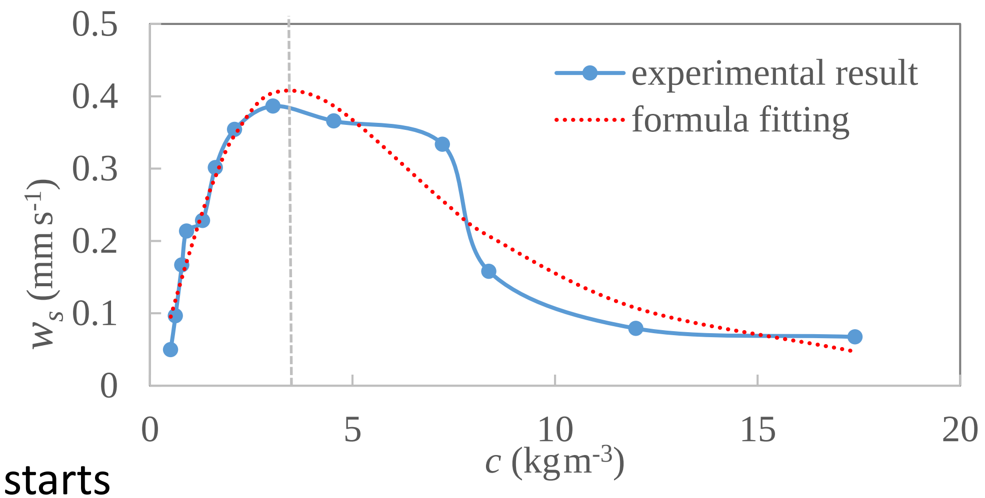
2 Methodology

Parametrization of sediment settling velocity

settling velocity assumed to be a function of subtidal near-bed sediment concentration (Wan, 2014,Mehta et al.,2008)

$$w_s = \begin{cases} w_{s0}, & c \le c_0 \\ \dfrac{\alpha \left(\frac{c}{\hat{c}}\right)^{1.1}}{\left(\frac{c}{\hat{c}}\right)^2 + c^{*2}}, & c > c_0 \end{cases}$$

$c_0 = 0.5$ kg.m^{-3}
$w_{s0} = 0.0001$ ms^{-1}
$\alpha = 0.125$ms^{-1}
$\hat{c} = 1$ kgm^{-3}
$c^* = 5.5$



w_s: settling velocity
c: bottom concentration
c_0: critical bottom concentration when flocculation process starts
w_{s0}: particle free settling velocity

2 Methodology

Parametrization of sediment-induced turbulence damping

➢ eddy viscosity coefficient (modification of Munk&Anderson, 1948)

$$A_v = \left\langle k\, u_{bed} (H+\eta) F(\overline{Ri}) \right\rangle \qquad F(\overline{Ri}) = \left(1+10\overline{Ri}\right)^{-1/2}$$

➢ eddy diffusivity coefficient (modification of Munk&Anderson, 1948)

$$K_v = \left\langle \frac{k}{\sigma_\rho} u_{bed} (H+\eta) G(\overline{Ri}) \right\rangle \qquad G(\overline{Ri}) = \left(1+3.33\overline{Ri}\right)^{-3/2}$$

k : drag coefficient, determined according to (Bowden, 1953) ,

σ_p :Prandtl-Schmidt number,

$\overline{Ri}$:depth-averaged gradient Richardson number.

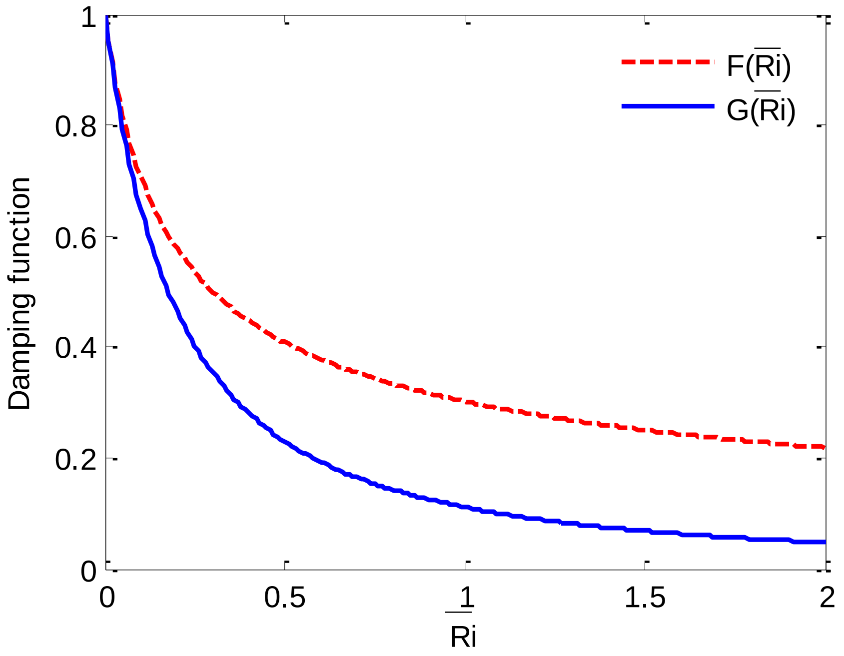
$$Ri = -\frac{g\beta_c}{\rho_0} \frac{\frac{dc}{dz}}{\left(\frac{du}{dz}\right)^2 + \left(\frac{du}{dz}\right)^2_{min}}$$

$\beta_c = 1 - \rho_0/\rho_s$,

ρ_0 : clear-water density, 1000 kg/m³

ρ_s: dry sediment density, 2650 kg/m³

$\left(\frac{du}{dz}\right)^2_{min}$: background shear



2 Methodology

Parametrization of sediment-induced turbulence damping

- bed shear stress (modification of Dijkstra et al., 2019)

$$\tau_b = s\, u_{bed}$$

slip parameter

$$s = \langle c_v c_D u_{bed} \rangle$$

c_v : drag coefficient, determined according to (Soulsby 1997)

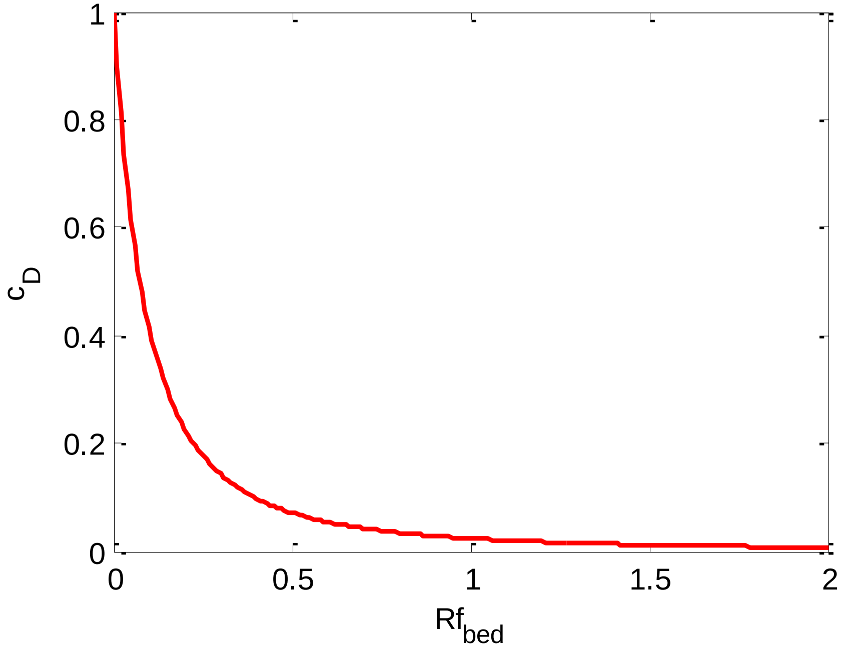
reduced-drag coefficient

$$c_D = (1 + A\langle Rf_{bed} \rangle)^{-2}$$

A: empirically determined parameter, 5.5

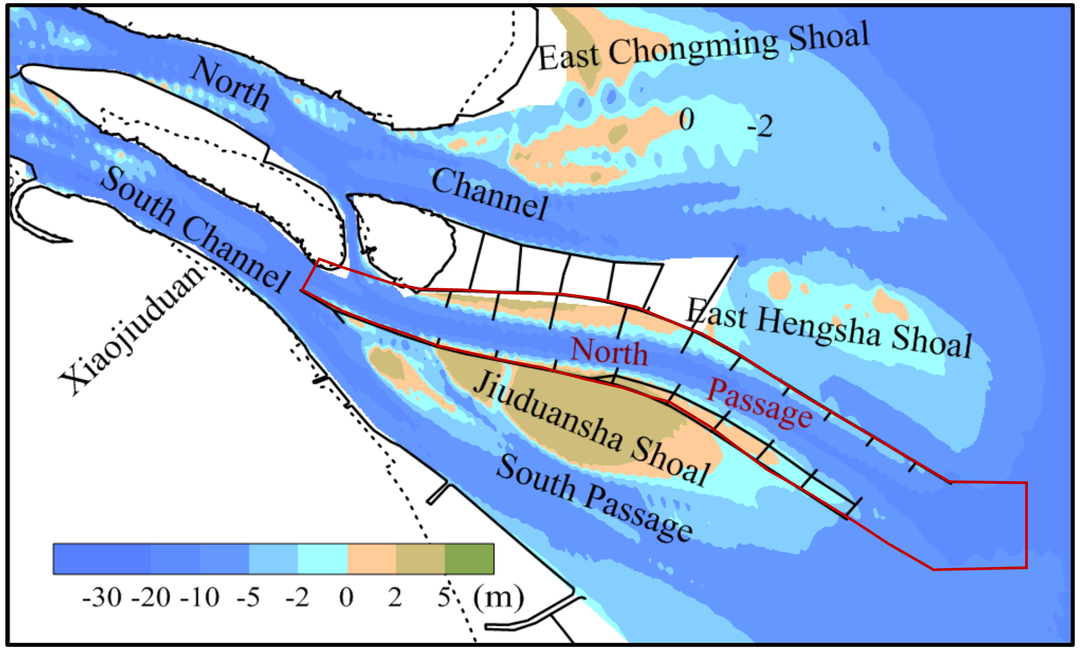
flux Richardson number near the bed

$$Rf_{bed} = \frac{K_v}{A_v} Ri_{bed}$$



2 Methodology

Application to the North Passage



Model parameters for the North Passage

parameter	description	value	
		Low C.	High C.
L	channel length	57 km	
B	channel width	5 km	
H	channel depth	12.5m	
K_h	horizontal eddy diffusivity	100m^2/s	
Q	net water transport	750m^3/s	
Z_0	M_2 tidal amplitude at seaward end	1.29m	1.6m
Z_L	M_2 tidal amplitude at riverine entrance	1.21m	1.5m
φ_L	M_2 tidal phase at landward boundary	0.873 radian	
d_s	sediment particle diameter	10 μm	
a^*	reference erosion coefficient	0.0001	0.0002

Low concentration cases

cases	flocculation	damping
L1	×	×
L2	×	√
L3	√	×
L4	√	√

High concentration cases

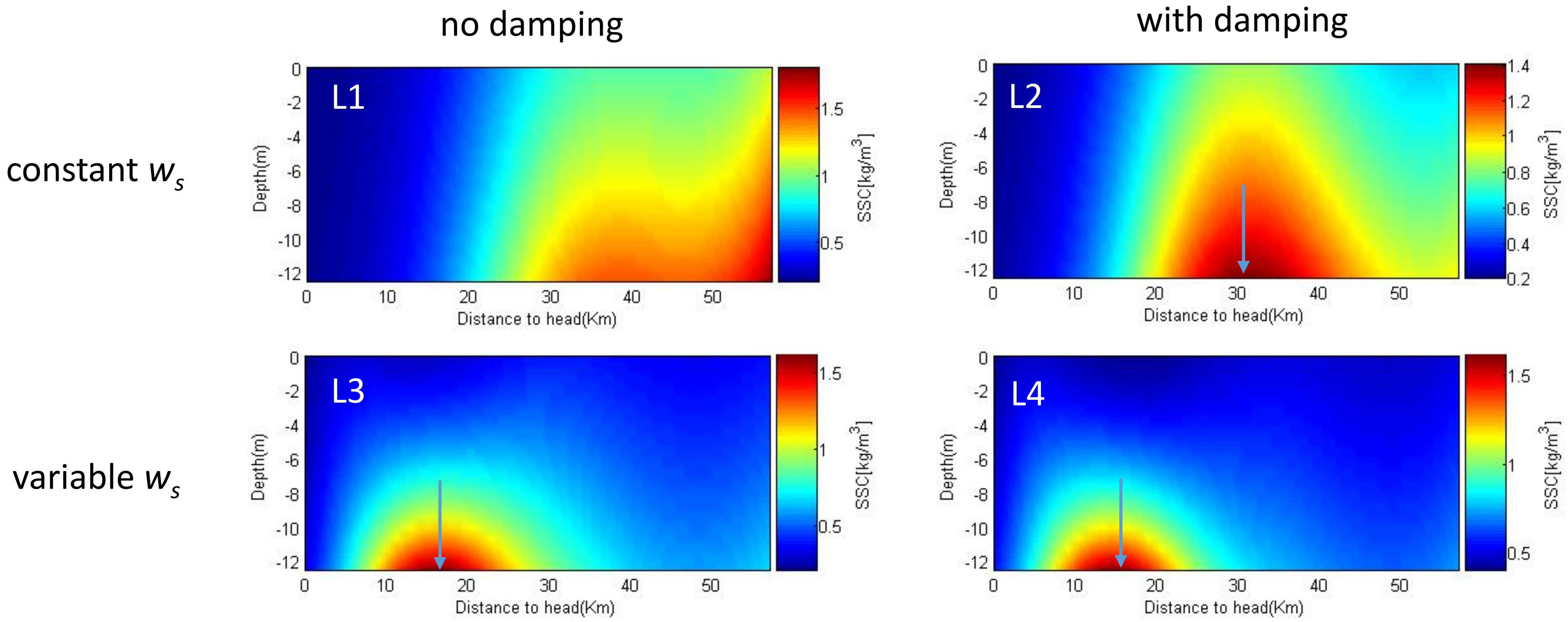
cases	hindered settling	damping
H1	×	×
H2	×	√
H3	√	×
H4	√	√

3 Results Low concentration cases

Location of $(c_b)_{max}$ (km)

Maximum bottom concentration (kg/m³)

cases	flocculation	damping	ETM	$(c_b)_{max}$	$x_{(cb)max}$
L1	×	×	×	-	-
L2	×	√	√	1.55	31.4
L3	√	×	√	1.7	16
L4	√	√	√	1.7	14.8



Along-channel SSC distribution in the NP in different cases

3 Results **Low concentration cases**

- Effects of flocculation of fine sediment

cases	flocculation	damping	ETM	$(c_b)_{max}$	$x_{(cb)max}$
L2	×	√	√	1.55	31.4
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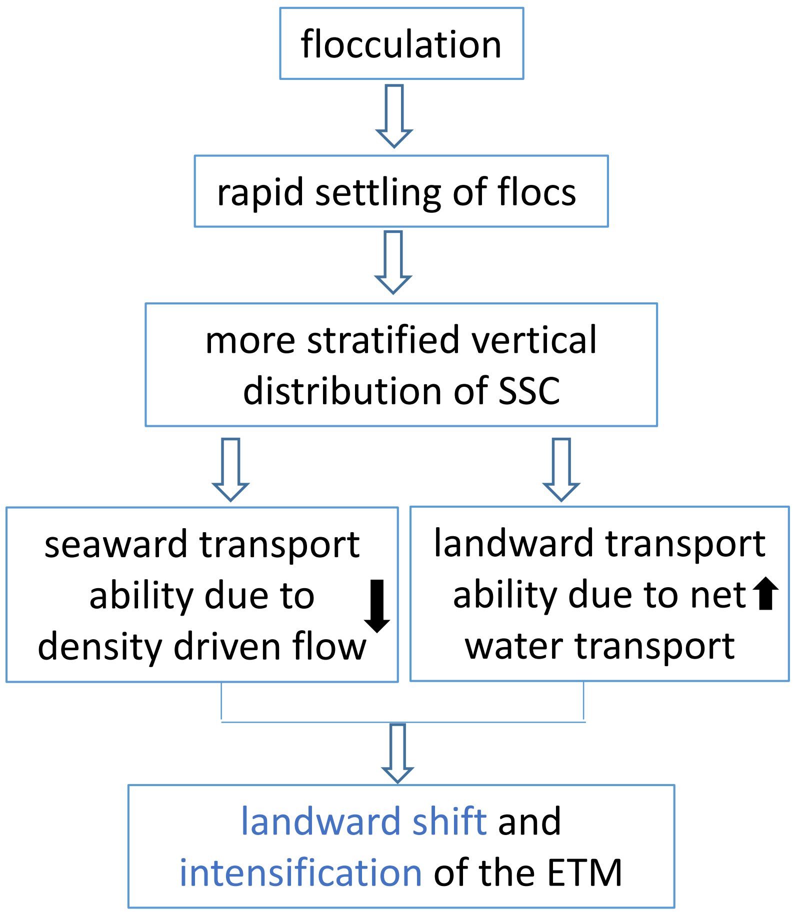
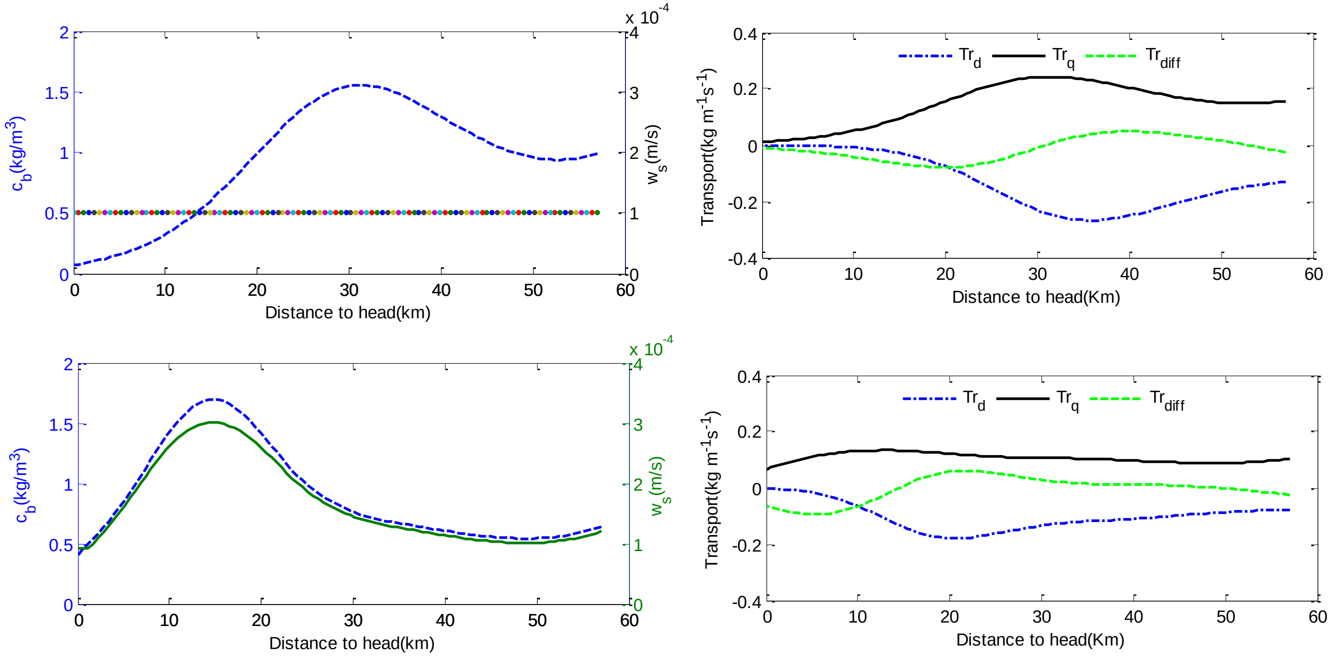


Constant w_s (L2)

Variable w_s (L4)

Bottom concentration & settling velocity

Net sediment transport
('+' seaward transport, '-' landward transport)



Tr_d: net sediment transport due to density driven flow
Tr_q: net sediment transport due to net water transport
Tr_{diff}: net sediment transport due to diffusion

3 Results **Low concentration cases**

- Effects of sediment-induced damping of turbulence

cases	flocculation	damping	ETM	$(c_b)_{max}$	$x_{(cb)max}$
L3	√	×	√	1.7	16
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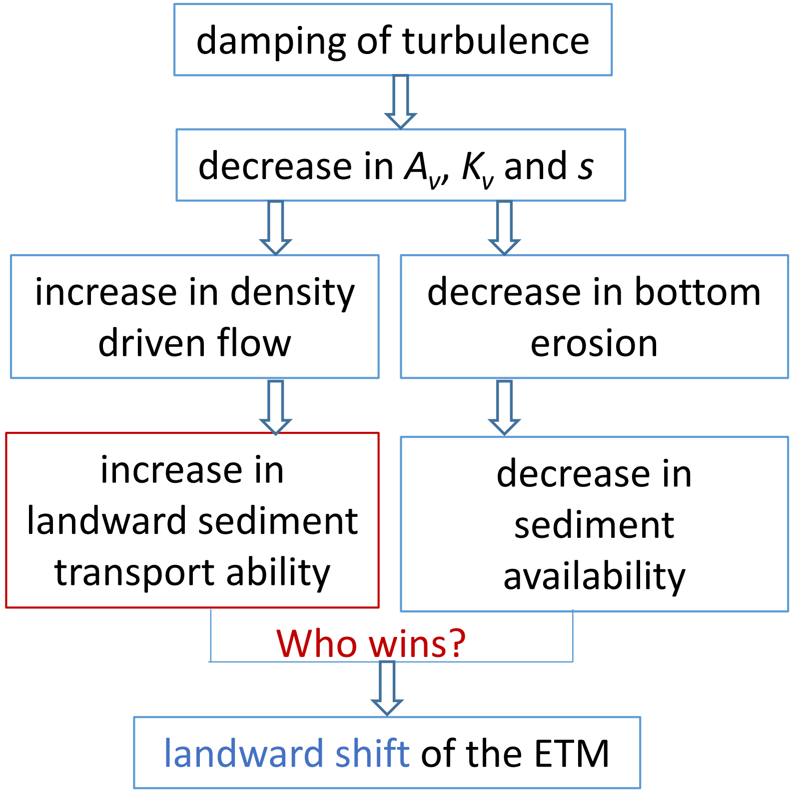
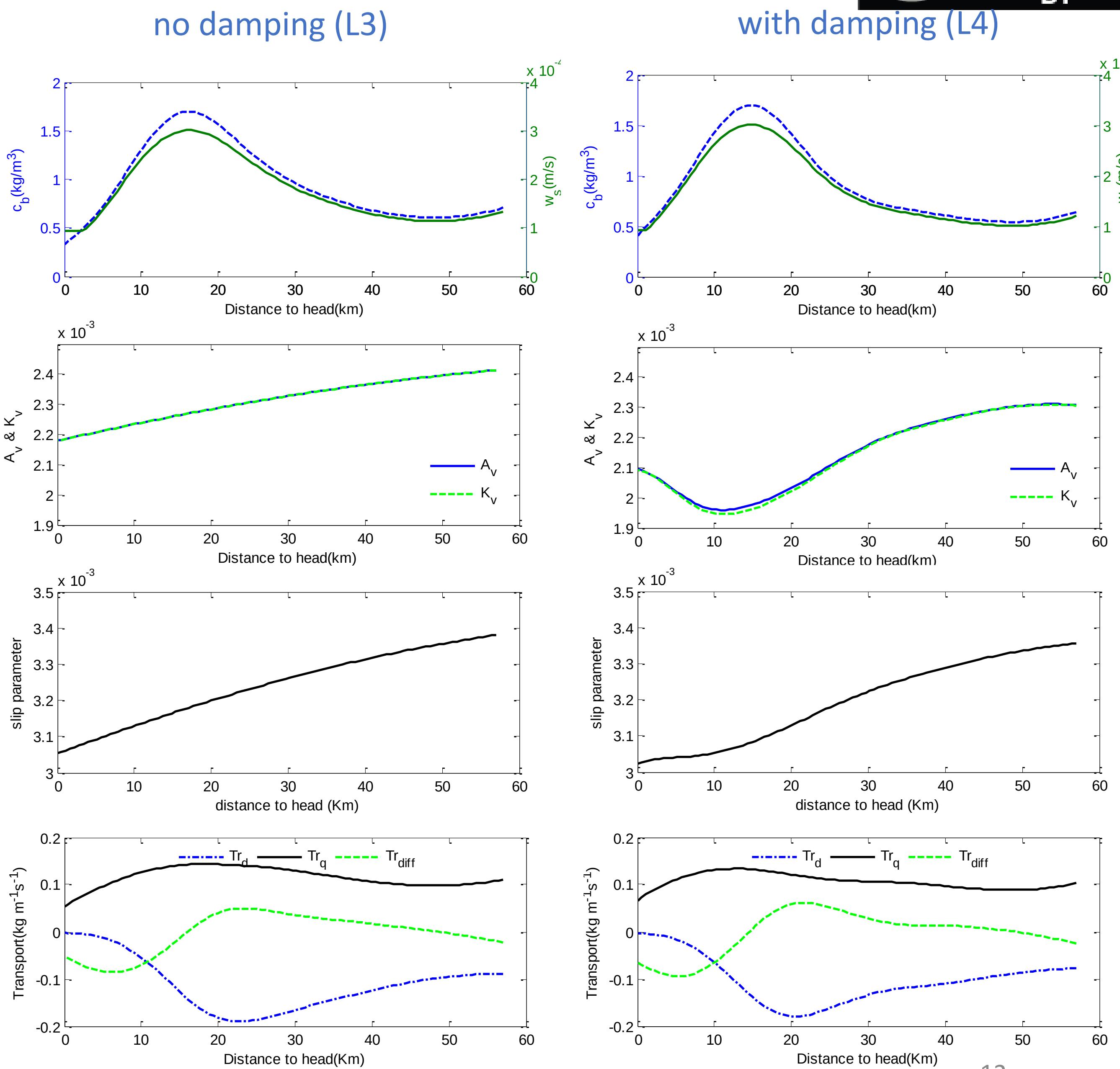




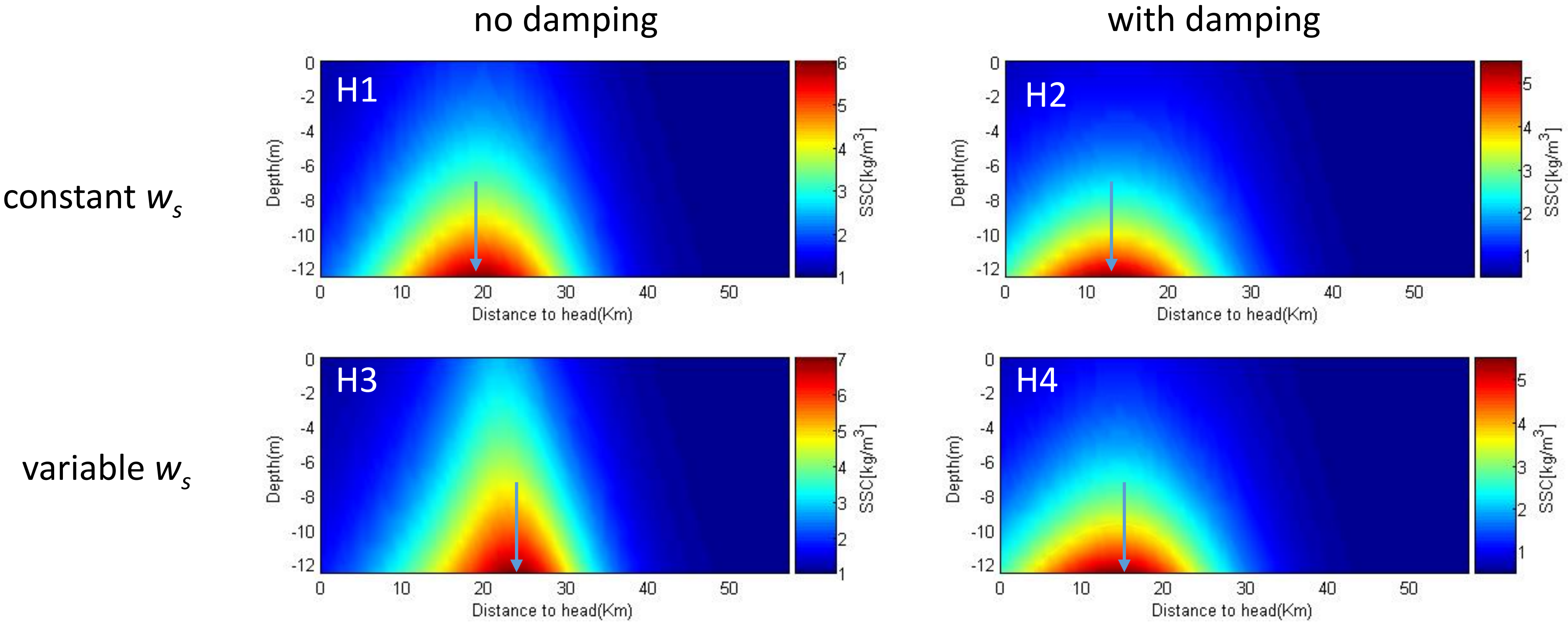
3 Results

High concentration cases

Maximum bottom concentration (kg/m^3)

Location of $(c_b)_{max}$ (km)

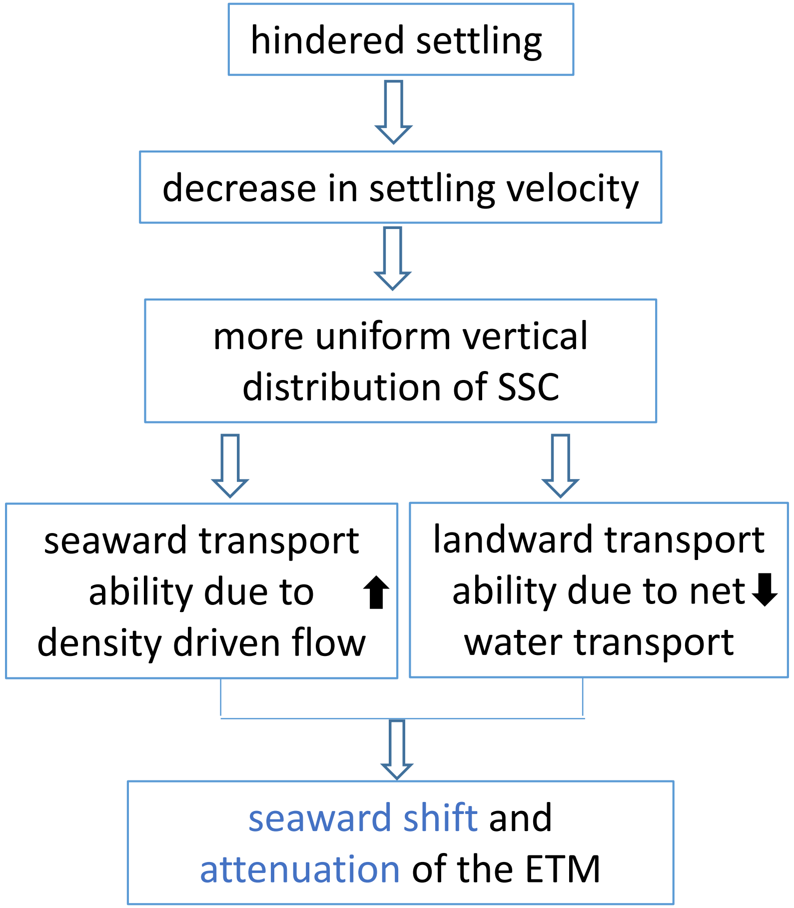
cases	damping	hindered settling	ETM	$(c_b)_{max}$	$x_{(cb)max}$
H1	×	×	×	6.7	19.4
H2	√	×	√	5.9	13.1
H3	×	√	√	7.3	23.9
H4	√	√	√	5.7	14.3



Along-channel SSC distribution in the NP in different cases

3 Results **High concentration cases**

- Effects of hindered settling of fine sediment



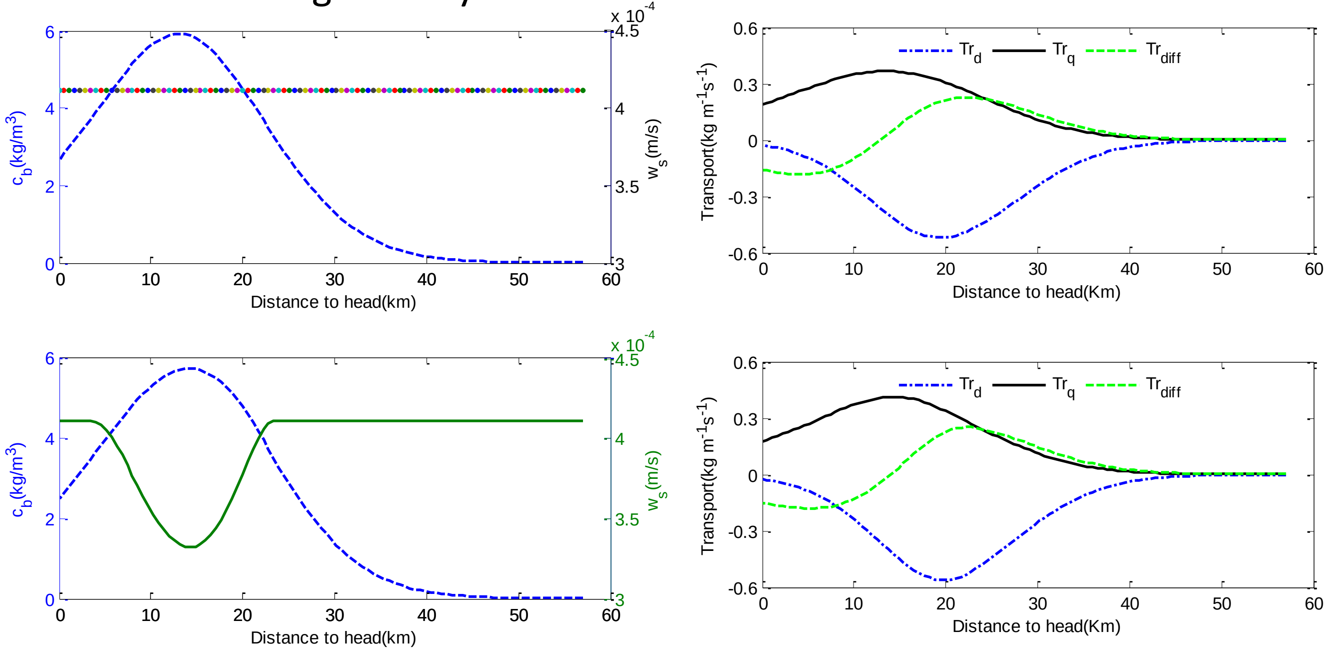
cases	damping	hindered settling	ETM	$(c_b)_{max}$	$x_{(cb)max}$
H2	√	×	√	5.9	13.1
H4	√	√	√	5.7	14.3

Bottom concentration & settling velocity

Net sediment transport
('+' seaward transport, '-' landward transport)

Constant w_s (H2)

Variable w_s (H4)



Tr_d: net sediment transport due to density driven flow
Tr_q: net sediment transport due to net water transport
Tr_{diff}: net sediment transport due to diffusion

3 Results High concentration cases

- Effects of sediment-induced damping of turbulence

cases	damping	flocculation	ETM	$(c_b)_{max}$	$x_{(cb)max}$
H3	×	√	√	7.3	23.9
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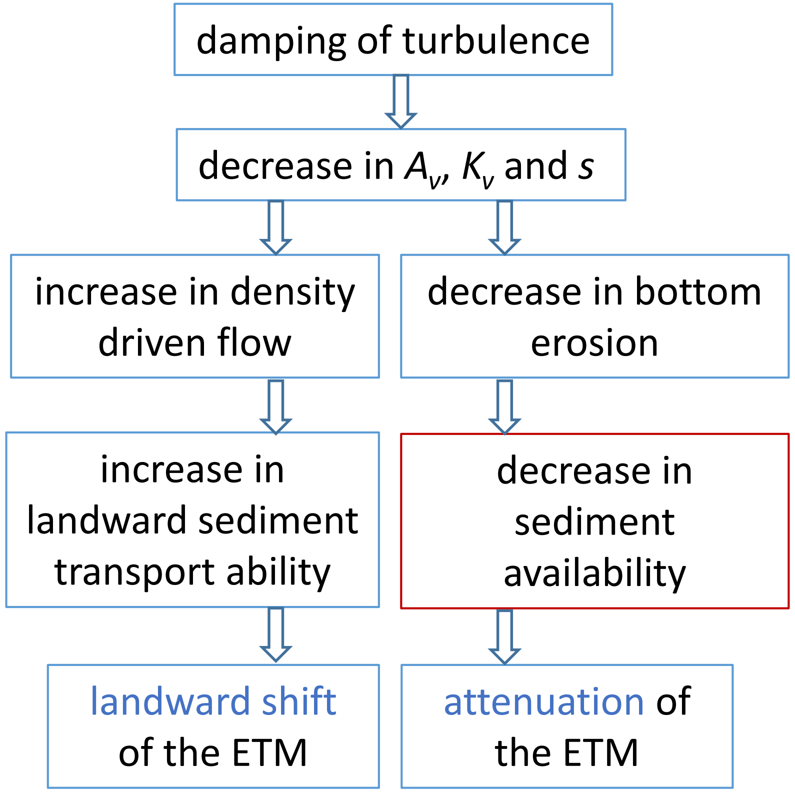
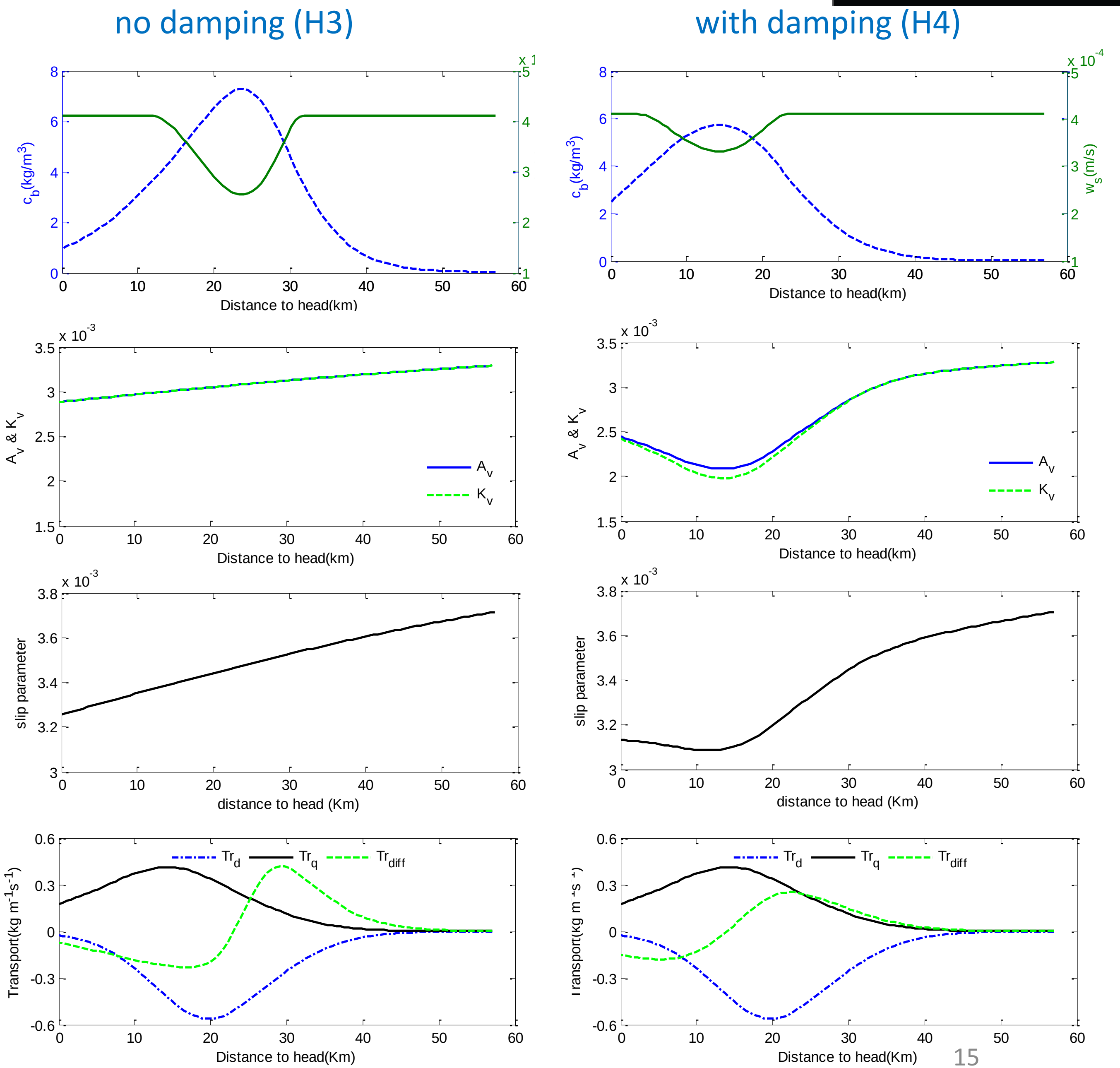




4 Discussion

- Key point:

  Study on sensitivity of location and intensity of ETM to flocculation and hindered settling of fine sediment as well as sediment-induced damping of turbulence by applying a process-based 2D model to the North Passage, Yangtze Estuary.

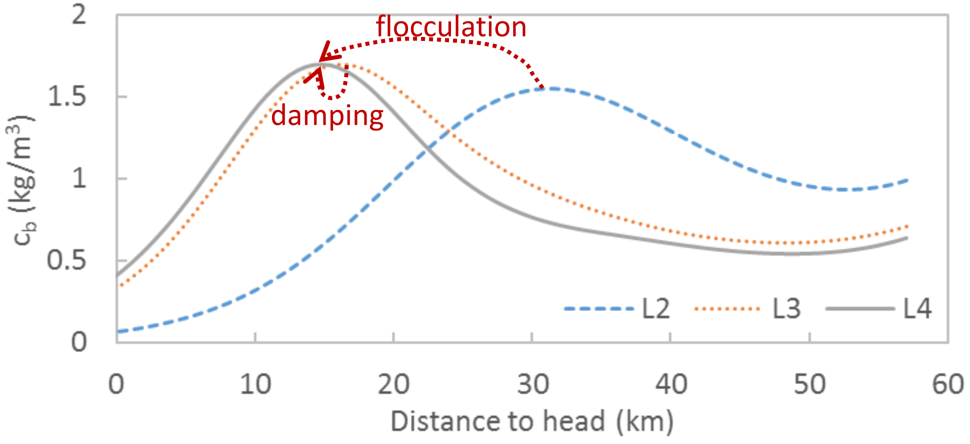
- Results compare well with other studies (Van Maren et al, 2015; Winterwerp et al., 2013), that flocculation and sediment-induced damping are important for sediment trapping in the North Passage. Hindered settling, which is significant for hyperturbid estuaries (Dijkstra et al,2018,2019), doesn't have much effect in the North Passage, which has tidal mean concentration lower than 10 kg/m^3 during calm weather.

- Model limitations:

  Only accounts for sediment transport due to gravitational circulation and turbulent diffusion. Tidal pumping, tidal straining, tidal rectification, lateral processes a.o. not taken into account.

4 Conclusions

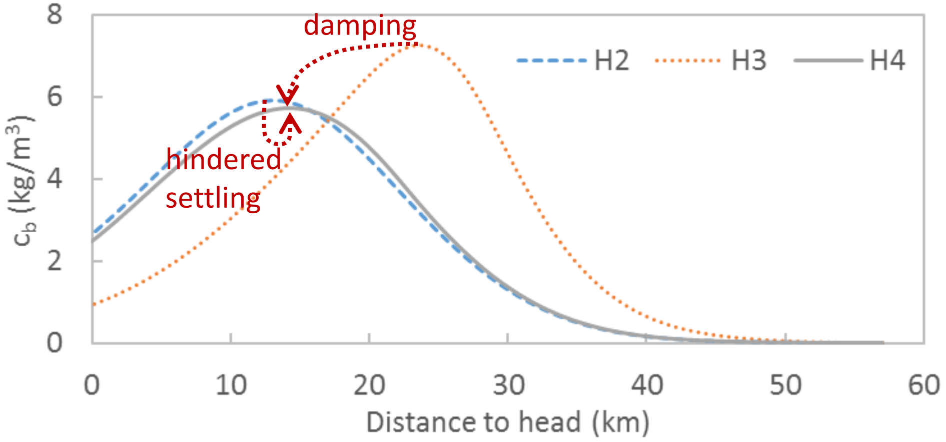
Flocculation regime



flocculation ⇒ landward shift and intensification of the ETM

sediment-induced damping of turbulence ⇒ landward shift of the ETM

Hindered settling regime



hindered settling ⇒ seaward shift and attenuation of the ETM

sediment-induced damping of turbulence ⇒ landward shift and attenuation of the ETM

Thanks for your attention!

Feedback is appreciated!