Controls on the disequilibrium condition of mountain gravel-bed streams

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NSERC CRSNG

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UNIVERSITAT POLITÈCNICA DE CATALUNYA

MITACS Accelerate

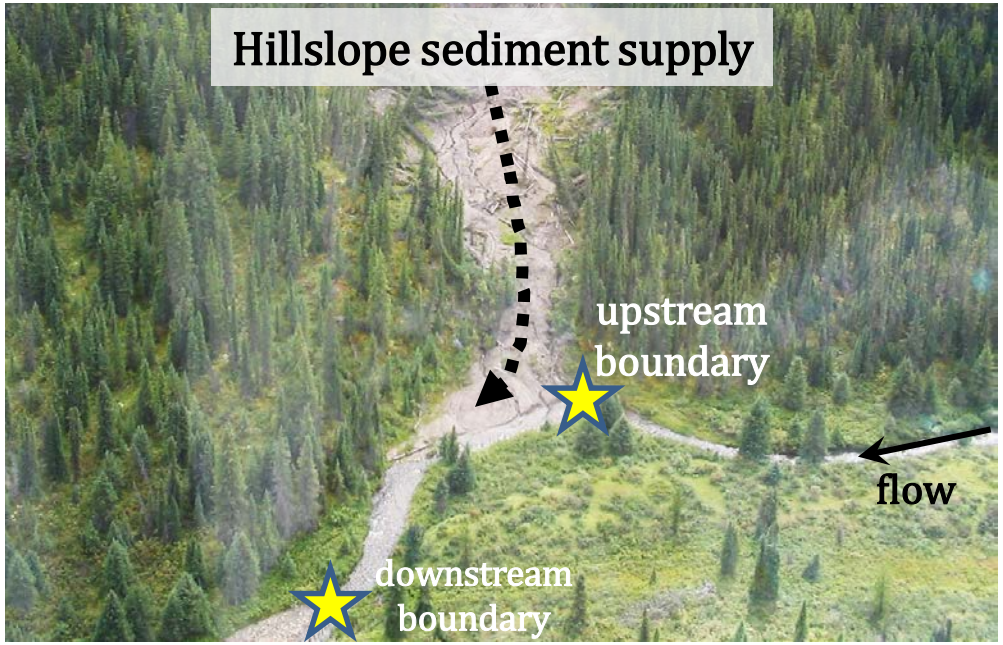
I – Motivation

Build a testable framework which quantifies disequilibrium at the reach scale

Reach

Length that scales or measures many average channel widths

Q: What happens when a river is disturbed at the reach scale?



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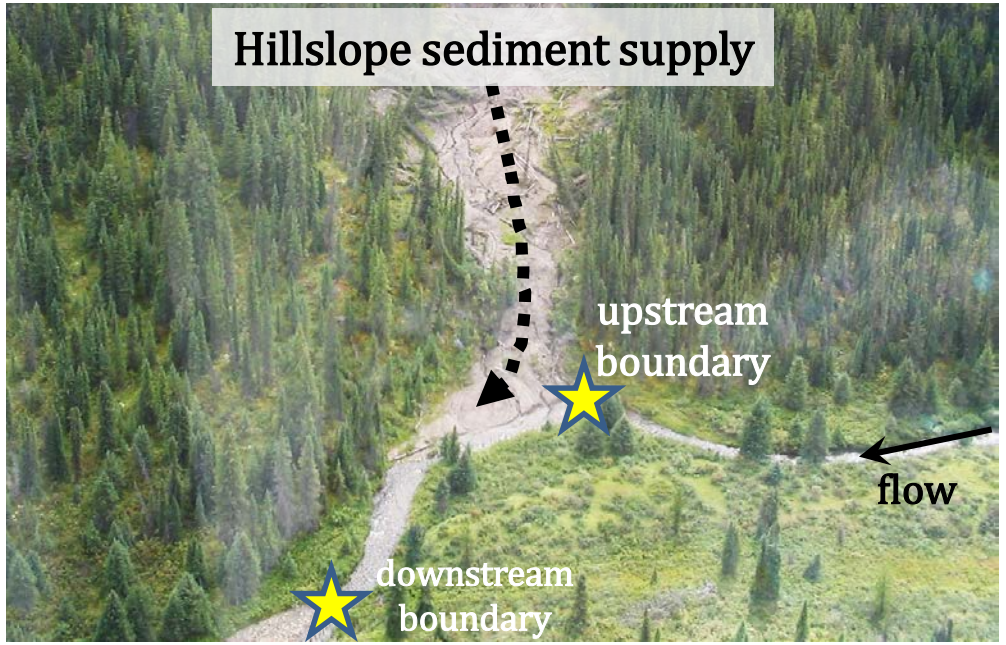
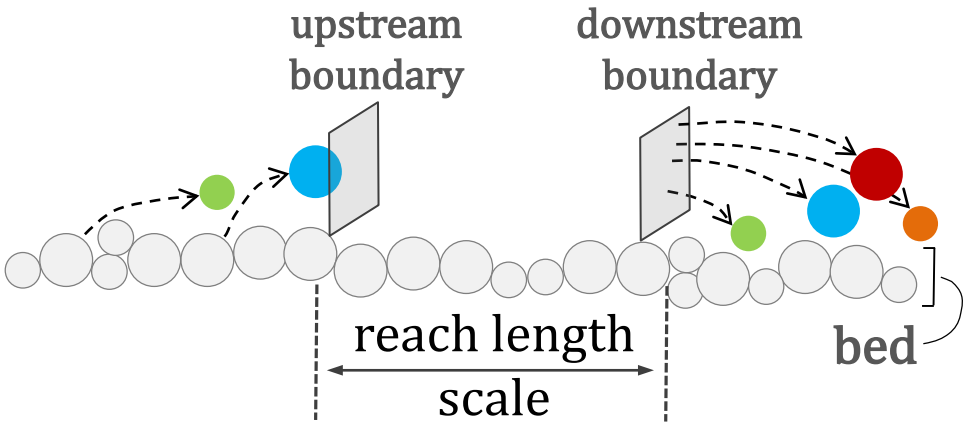
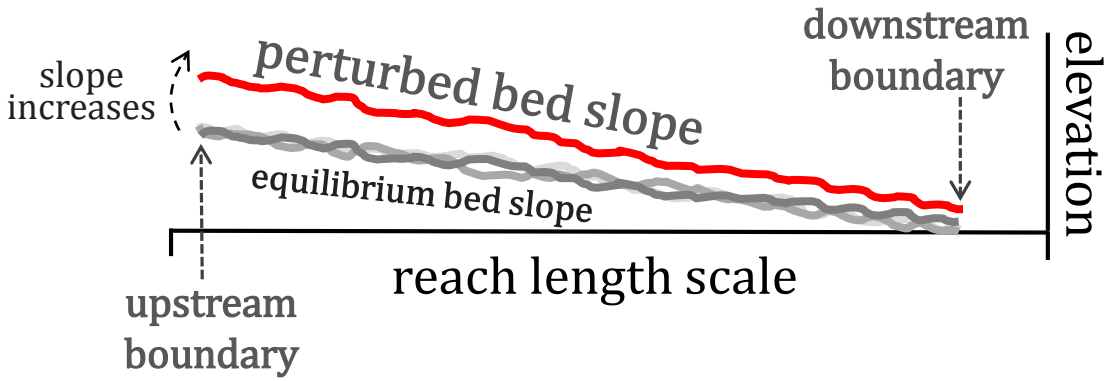


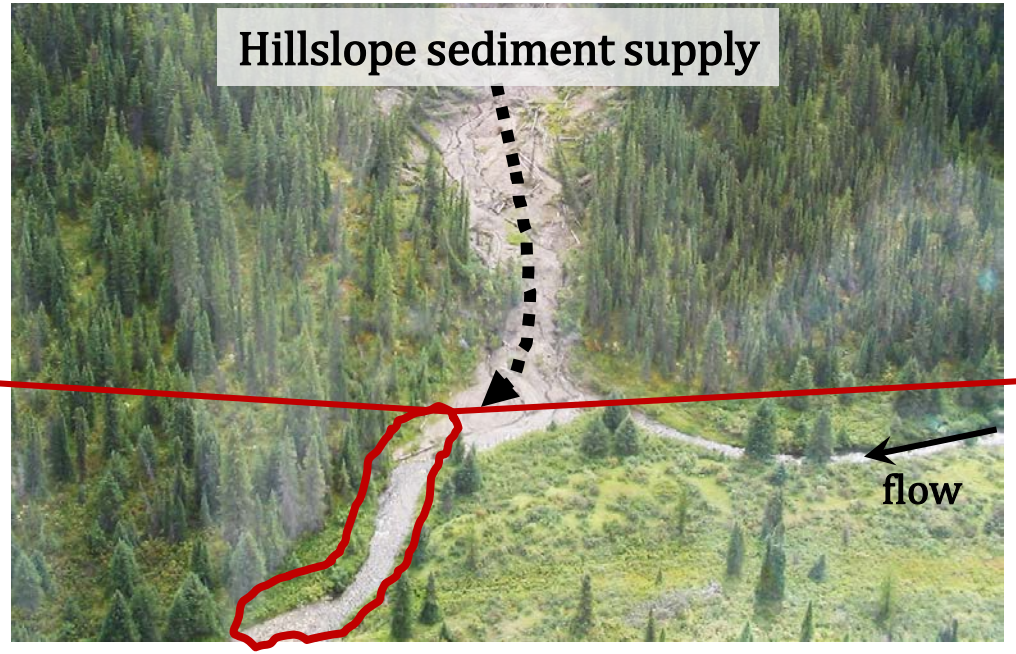
Transport Non Steady-State



Bed Profile Disequilibrium



Physical responses neglecting channel position shifting and size change



Channel Bed Erosion/Deposition

Distribution of Elevations

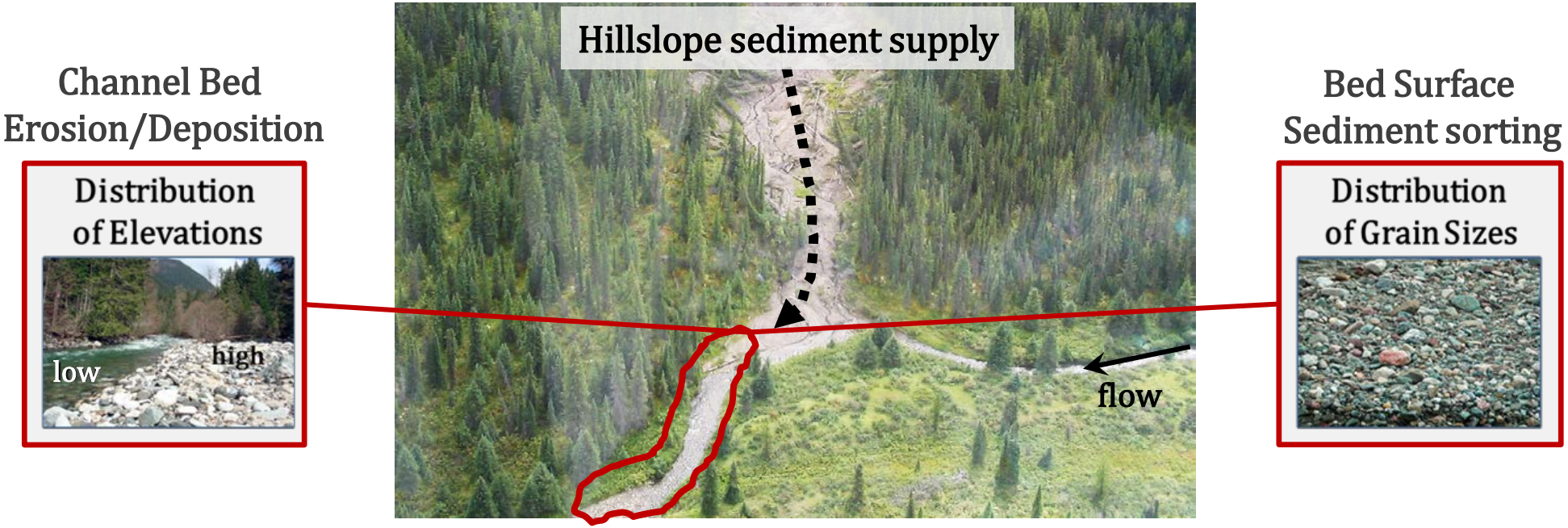
Bed Surface Sediment sorting

Distribution of Grain Sizes

Transport Non Steady-State

Bed Profile Disequilibrium

Physical responses neglecting channel position shifting and size change



Erosion/Deposition

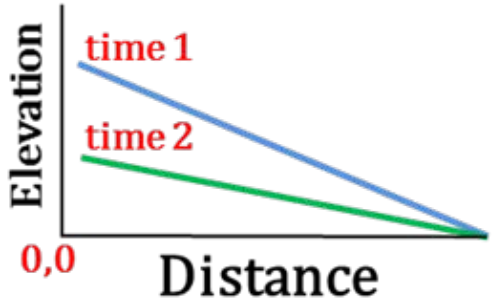
- **Local bed topography scales** momentum delivery
- **Fluid momentum delivery** is a control parameter that governs the magnitude of sediment transport

Sediment Sorting

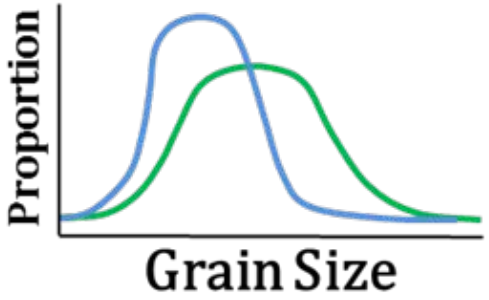
- **Sediment texture scales** the riverbed strength
- **Riverbed strength** is a control parameter that governs bed and particle responsiveness

OBJECTIVE: Use the two response processes to derive a <u>disequilibrium metric</u> for alluvial, mountain streams

Channel Bed Erosion/Deposition



Bed Surface Sediment sorting



II – Disequilibrium framework

Apply scaling theory to develop disequilibrium metric

The disequilibrium proposal

Chartrand et al., In Revision:

"…streams erode or build up their beds until **rates of bed topography and sediment sorting adjustment** are **comparable**"

Guglielmini, 1697; Howard, 1982; Ahnert, 1994; Blom et al., 2016, 2017

The disequilibrium proposal

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"…streams erode or build up their beds until **rates of bed topography and sediment sorting adjustment** are **comparable**"

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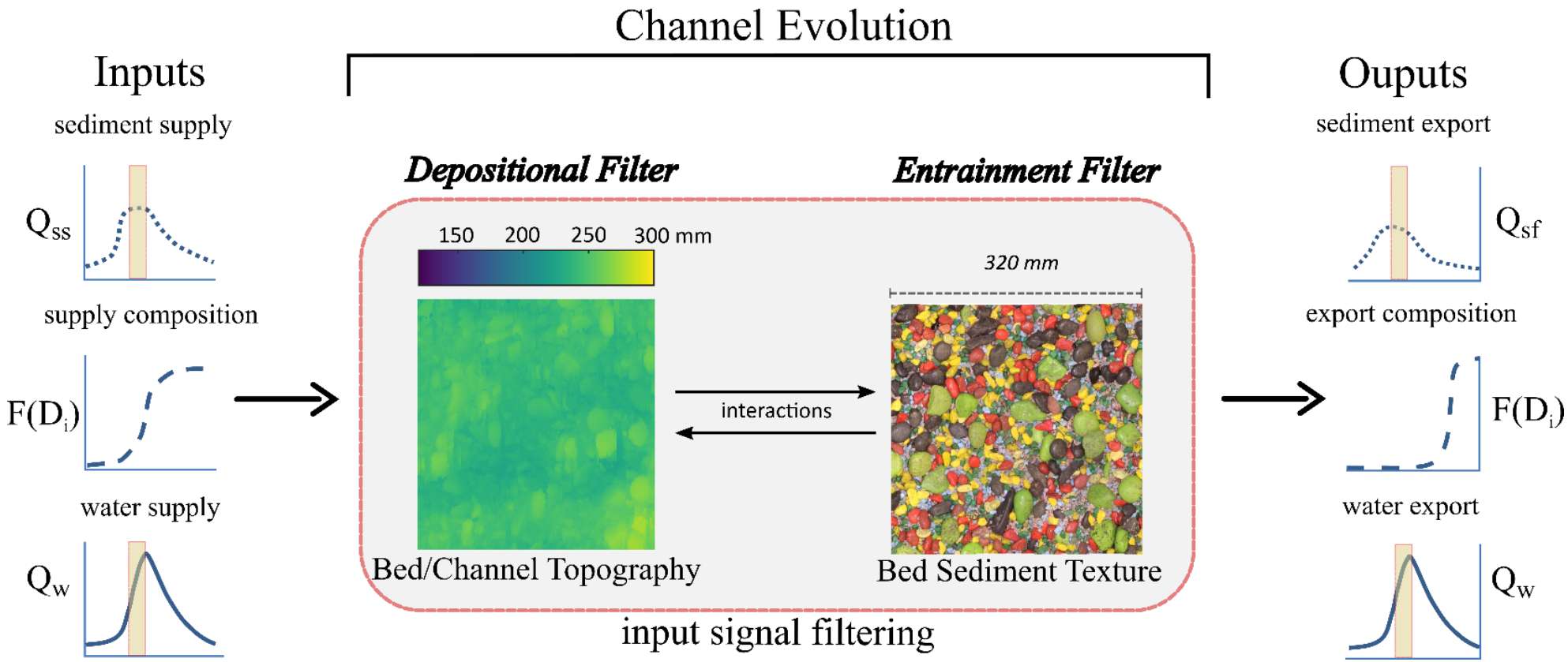
Reach Scale Equilibrium

Topographic Adjustment Rate $\approx$ Sediment Sorting Rate

Reach Scale Disequilibrium

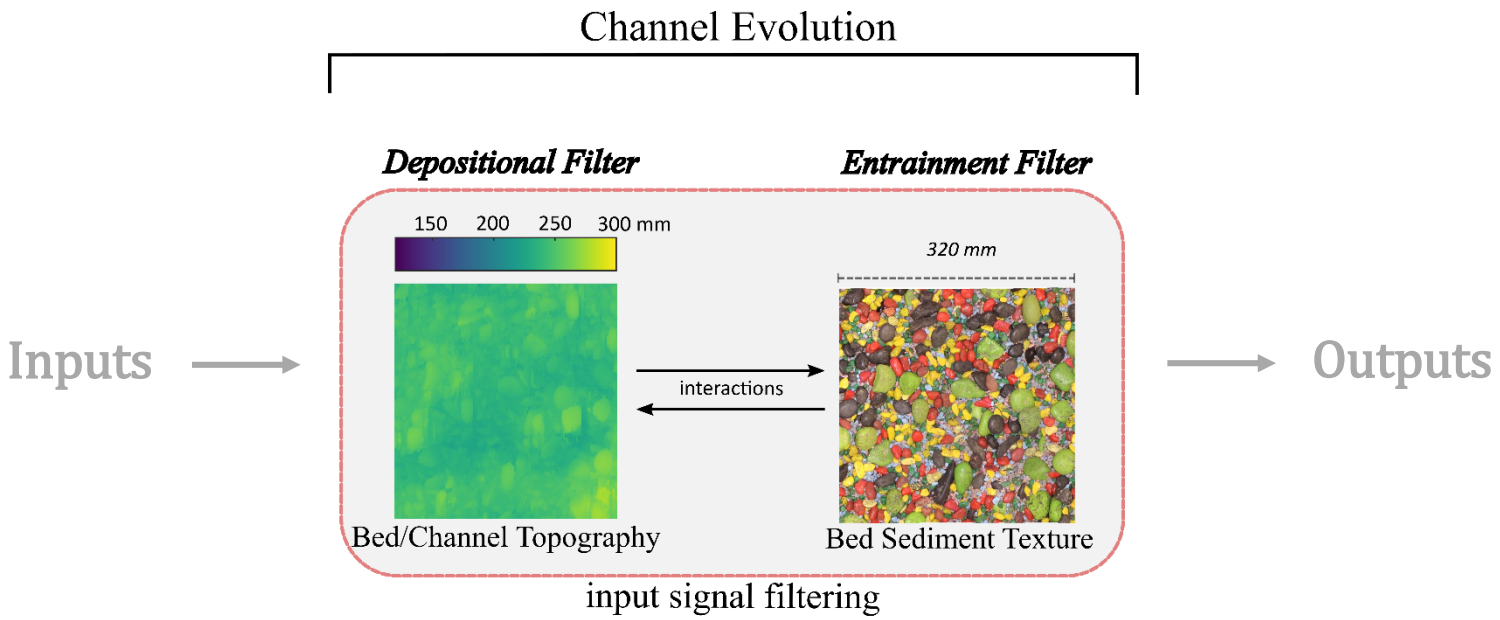
Topographic Adjustment Rate $\not\approx$ Sediment Sorting Rate

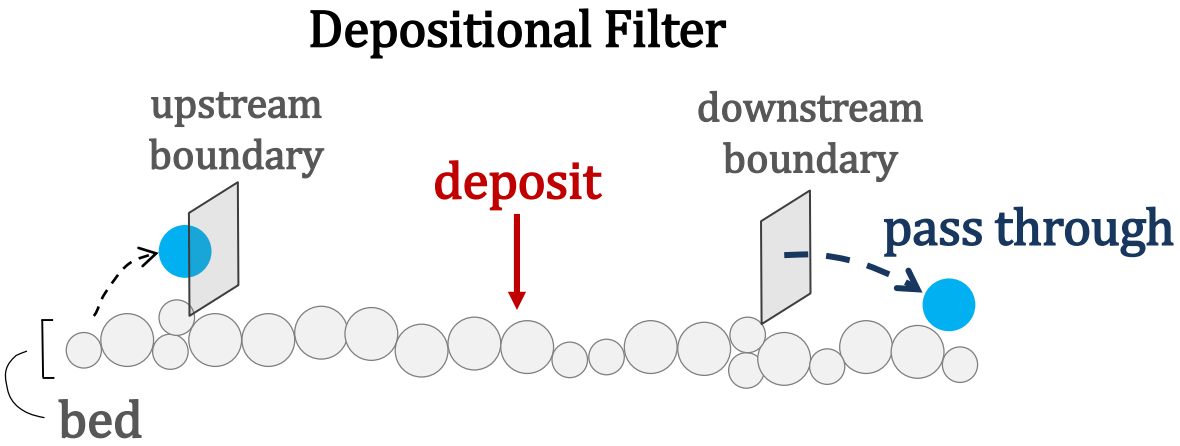
Conceptualize the disequilibrium proposal as a **filtering problem**



Modified from Chartrand et al., In Revision

Conceptualize the disequilibrium proposal as a **filtering problem**





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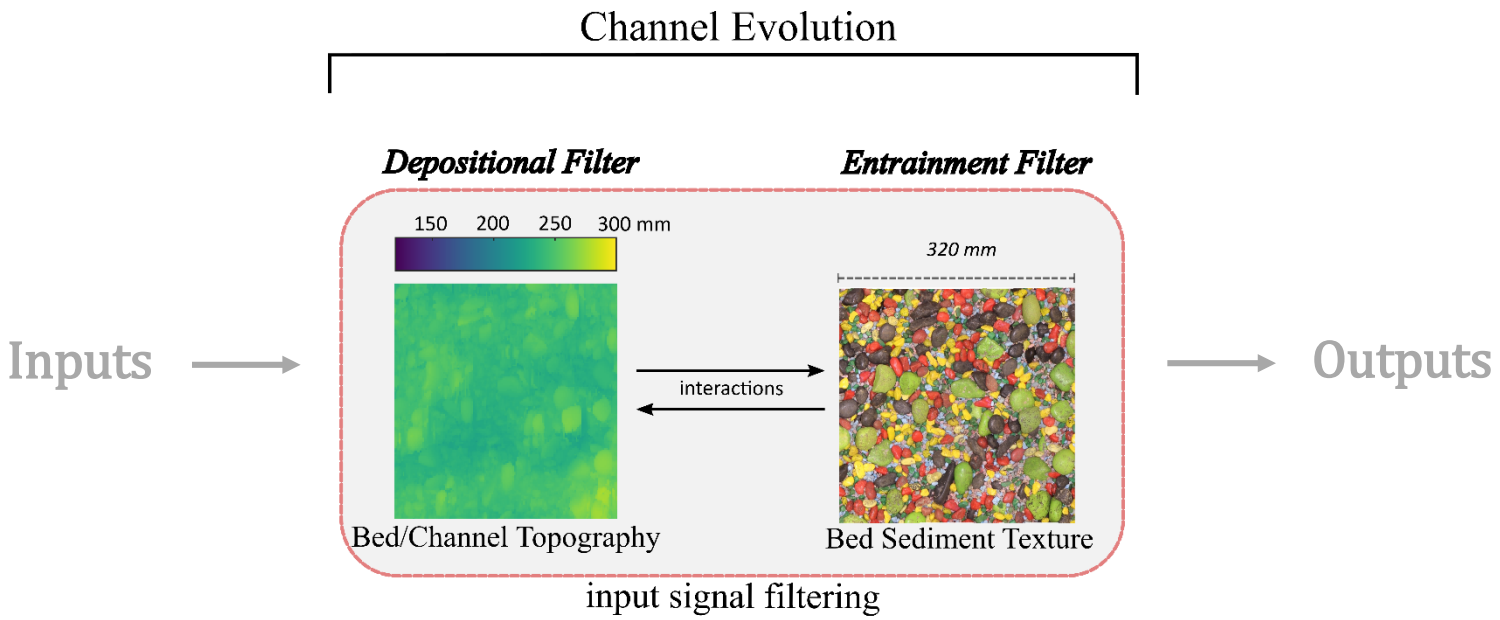
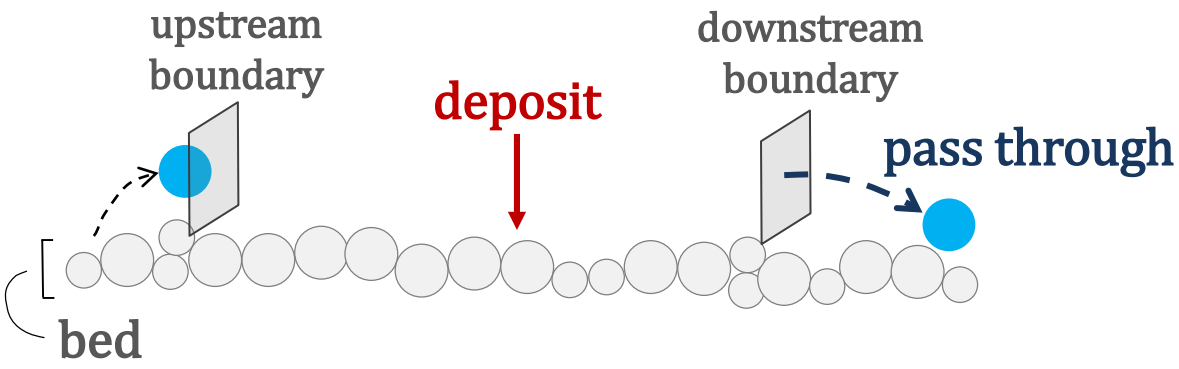
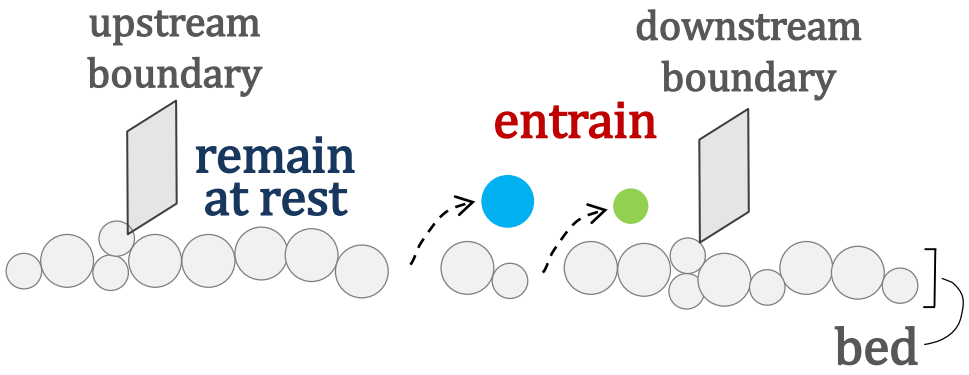


Depositional Filter



Entrainment Filter



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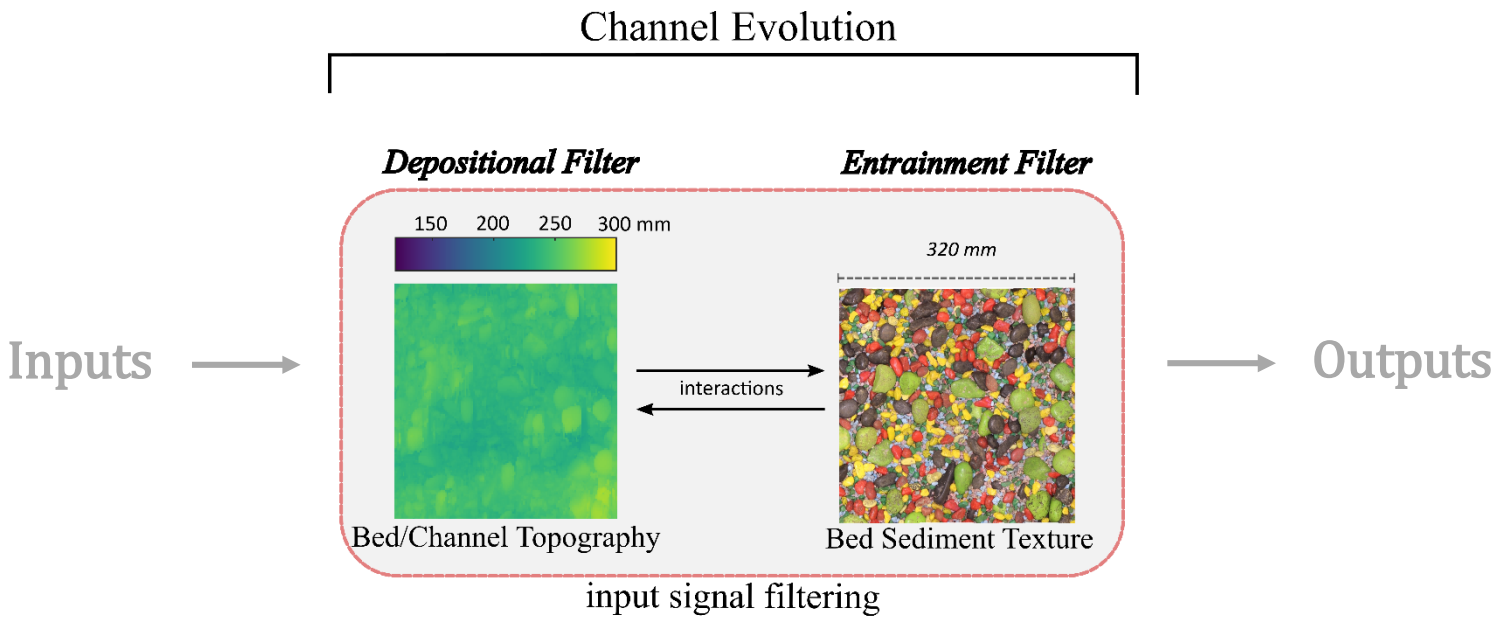

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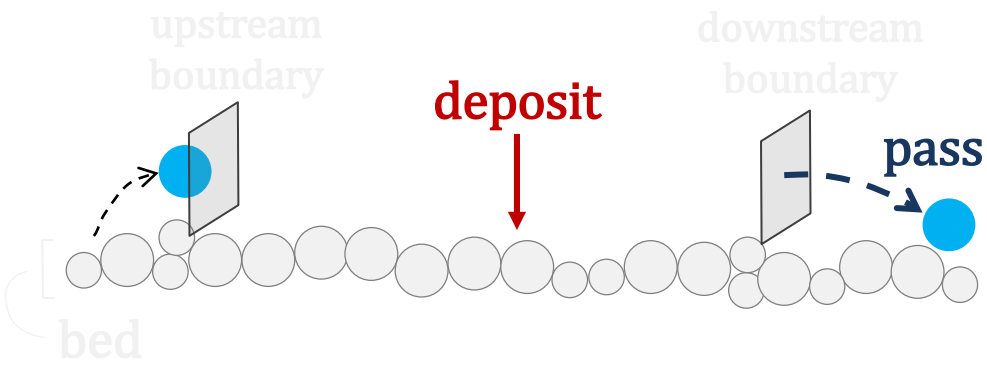

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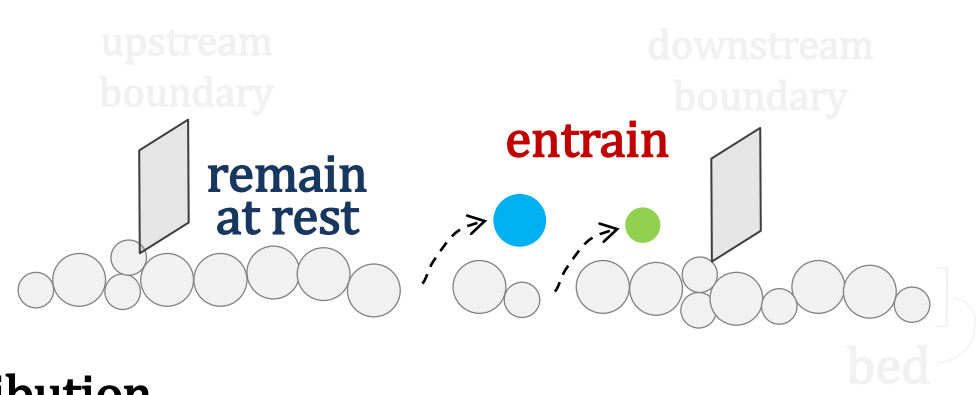

Interactions
Modify the Surface Distribution

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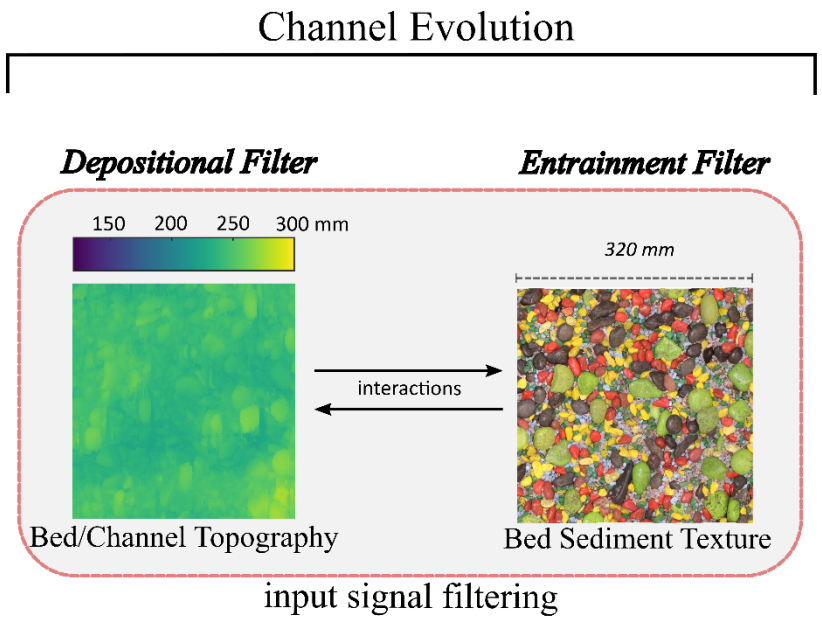
Derive expressions for the filters and interactions between the filters



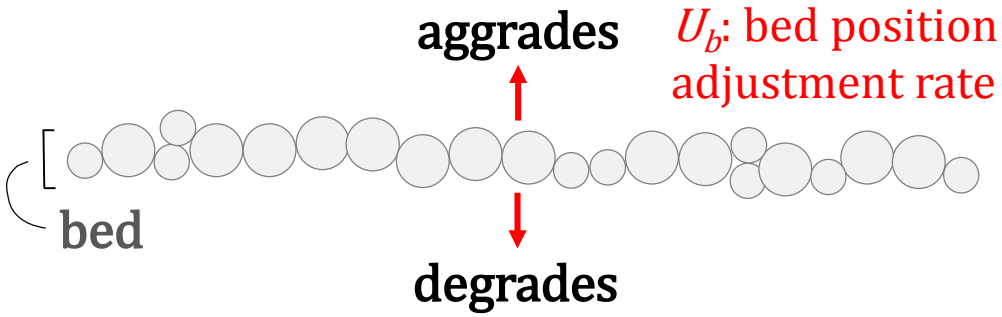
1. 1D form of **Exner** (bed topography) and the **Hirano** (sediment sorting) equations.
2. Simplify and nondimensionalize the equations
3. Organize all dimensional terms to form coefficients

Derive expressions for the filters and interactions between the filters

EXNER

N_t: topographic response number

$$N_t \approx -\epsilon U_b$$



Modified from Chartrand et al., In Revision

Derive expressions for the filters and interactions between the filters

Erosion/Deposition

N_t: topographic response number

$$N_t \approx -\epsilon U_b$$

aggrades

U_b: bed position adjustment rate

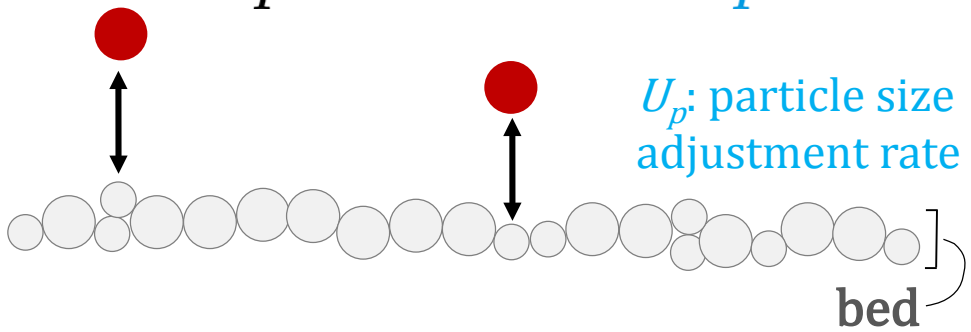
bed

degrades

HIRANO

N_p: particle response number

$$N_p \approx -\epsilon \delta_2 U_p$$



Modified from Chartrand et al., In Revision

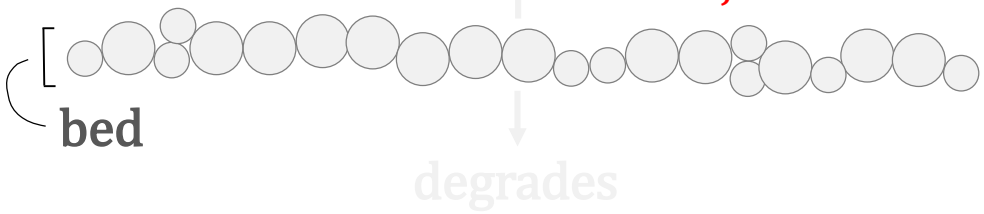
Disequilibrium Metric Proposal

EXNER

N_t: topographic response number

$$N_t \approx -\epsilon U_b$$

U_b: bed position adjustment rate

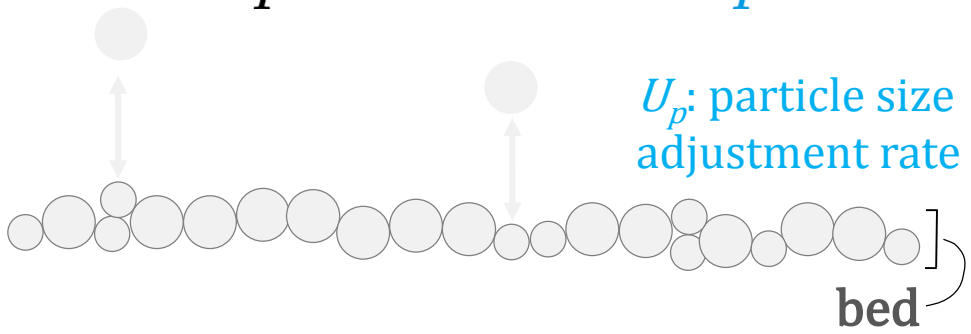


HIRANO

N_p: particle response number

$$N_p \approx -\epsilon \delta_2 U_p$$

U_p: particle size adjustment rate



N_e: channel response number(s)

Disequilibrium metric for alluvial mountain streams

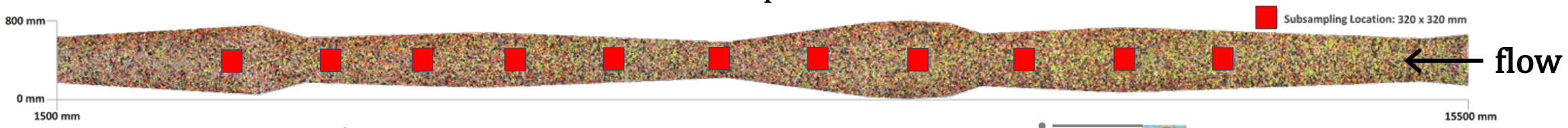
$$N_e(t) = \left(\frac{N_t}{N_p}\right) = \left|\left(\frac{1}{\delta_2}\right)\frac{U_b}{U_p}\right|$$

Modified from Chartrand et al., In Revision

III – Framework testing and extension

Testing with experimental data at the local scale

Overhead view of experimental channel

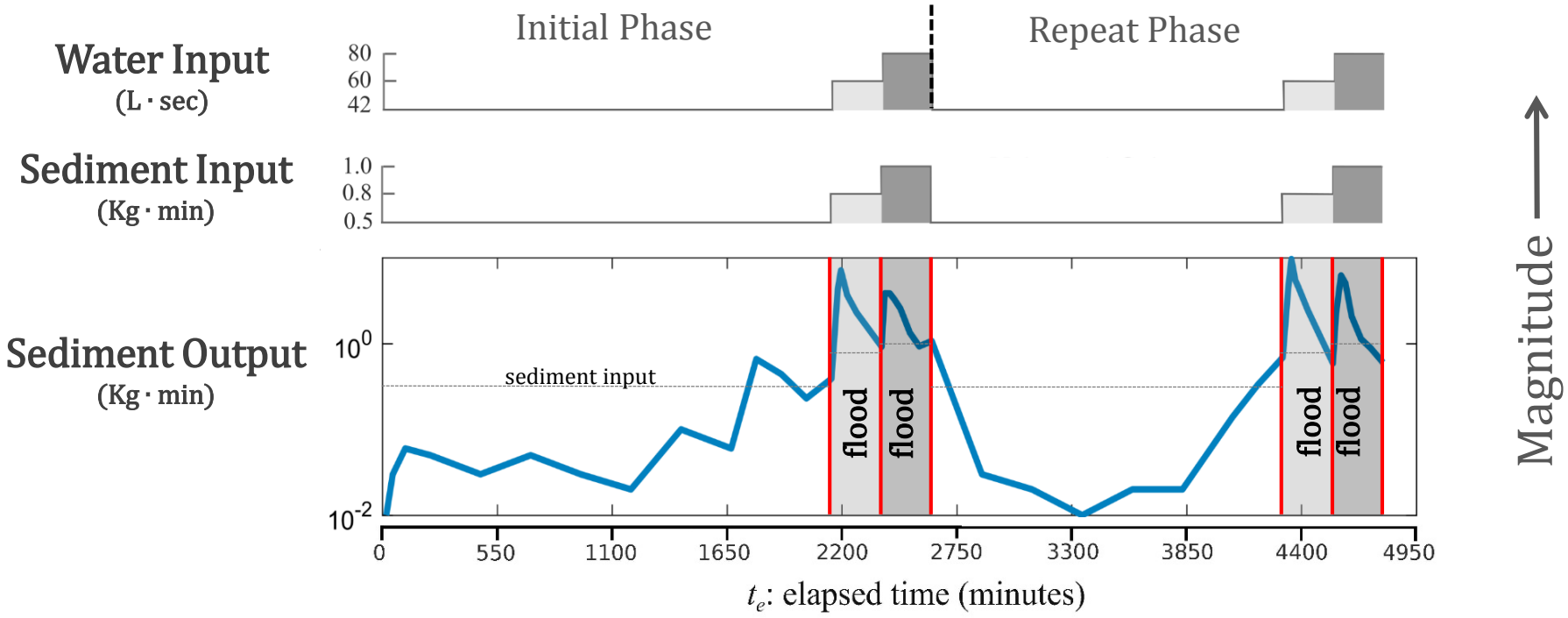


GSD: 0.5 – 32 mm

1 meter

Mira scale

Modified from Chartrand et al., In Revision



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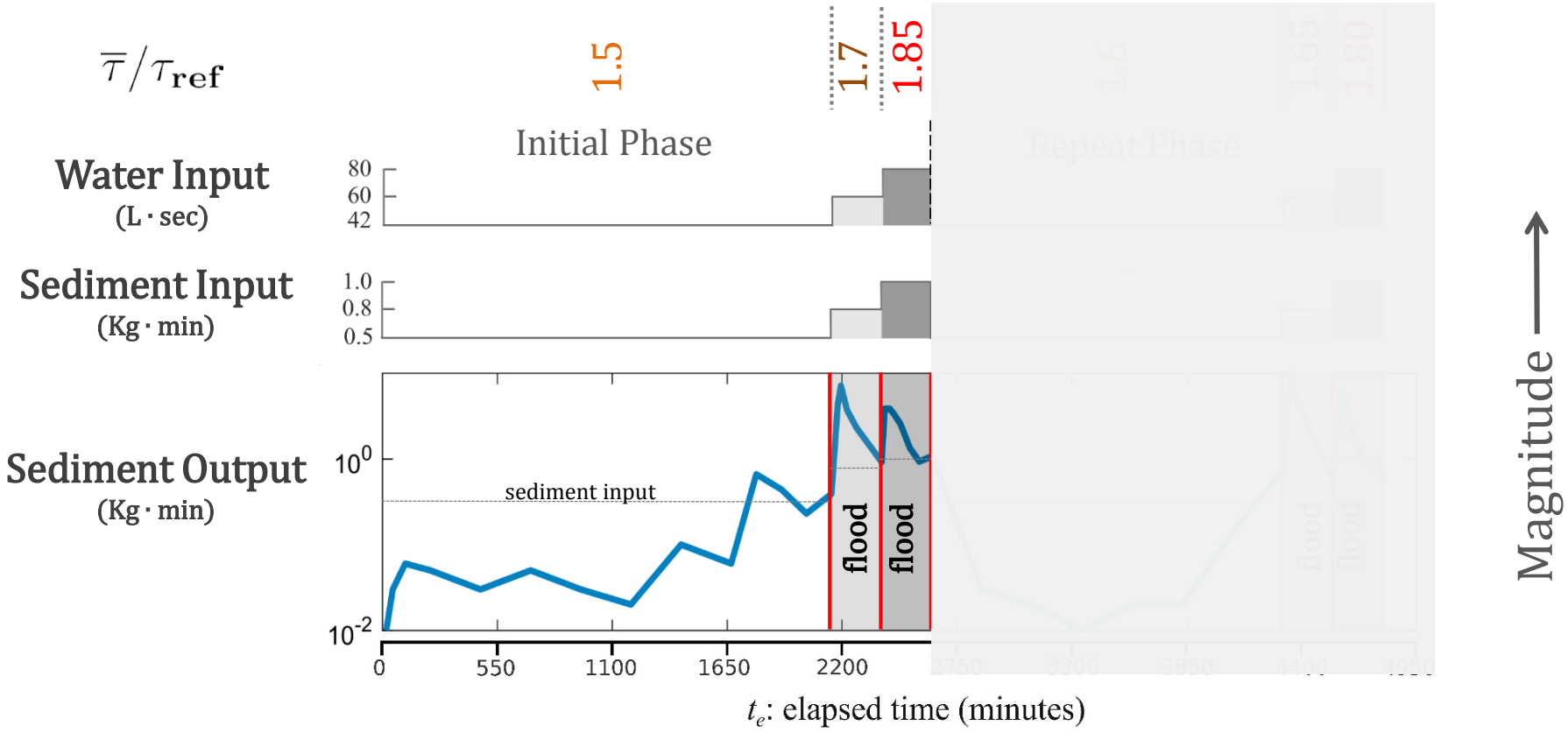

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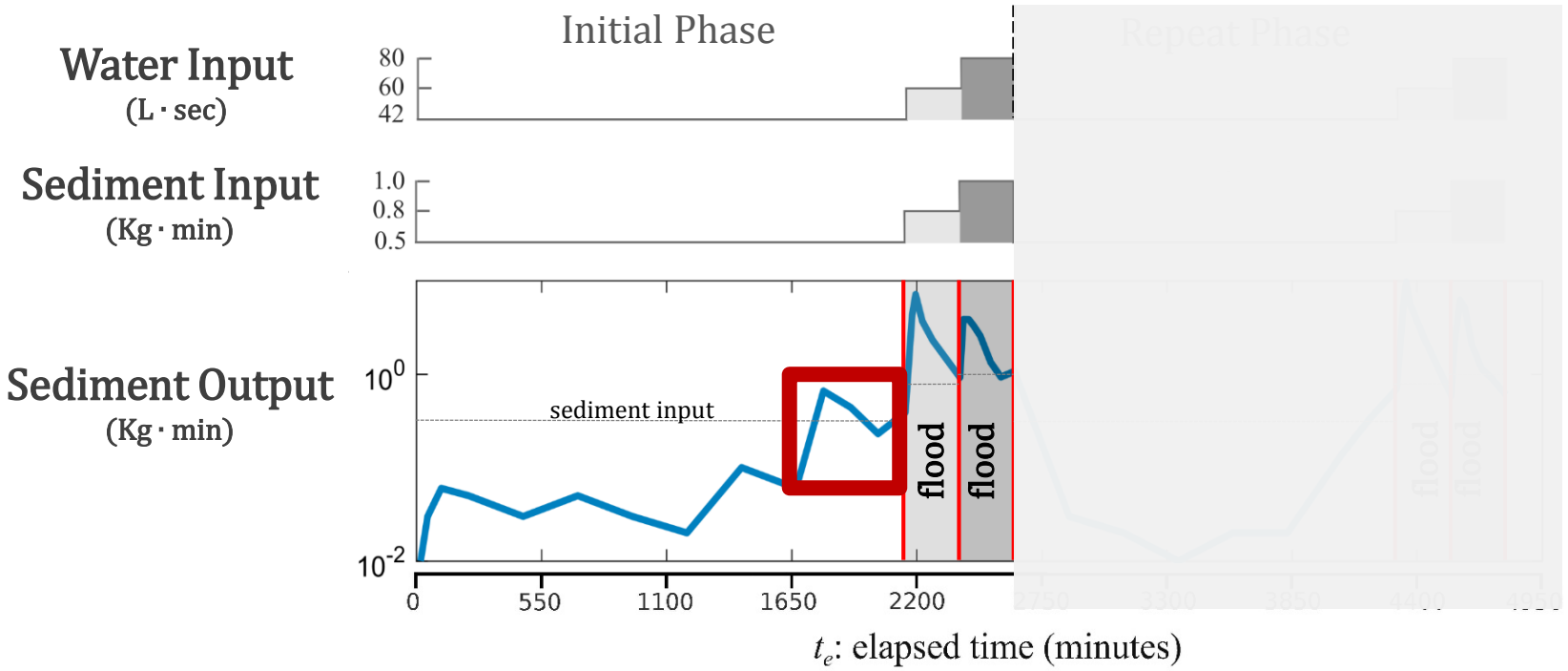
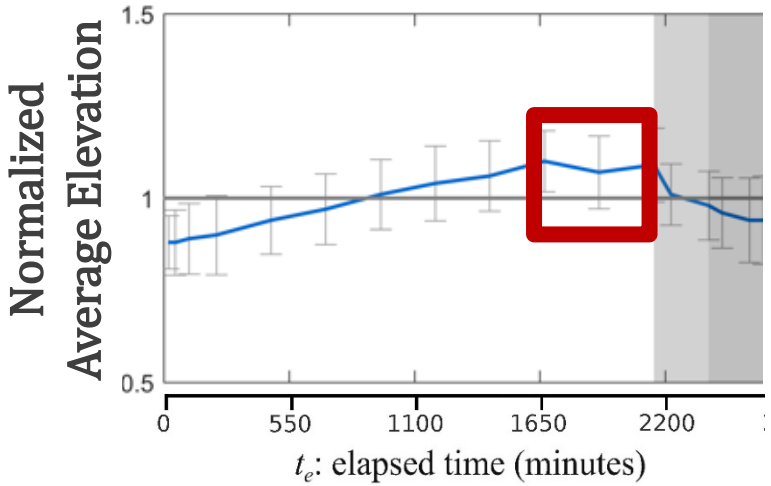
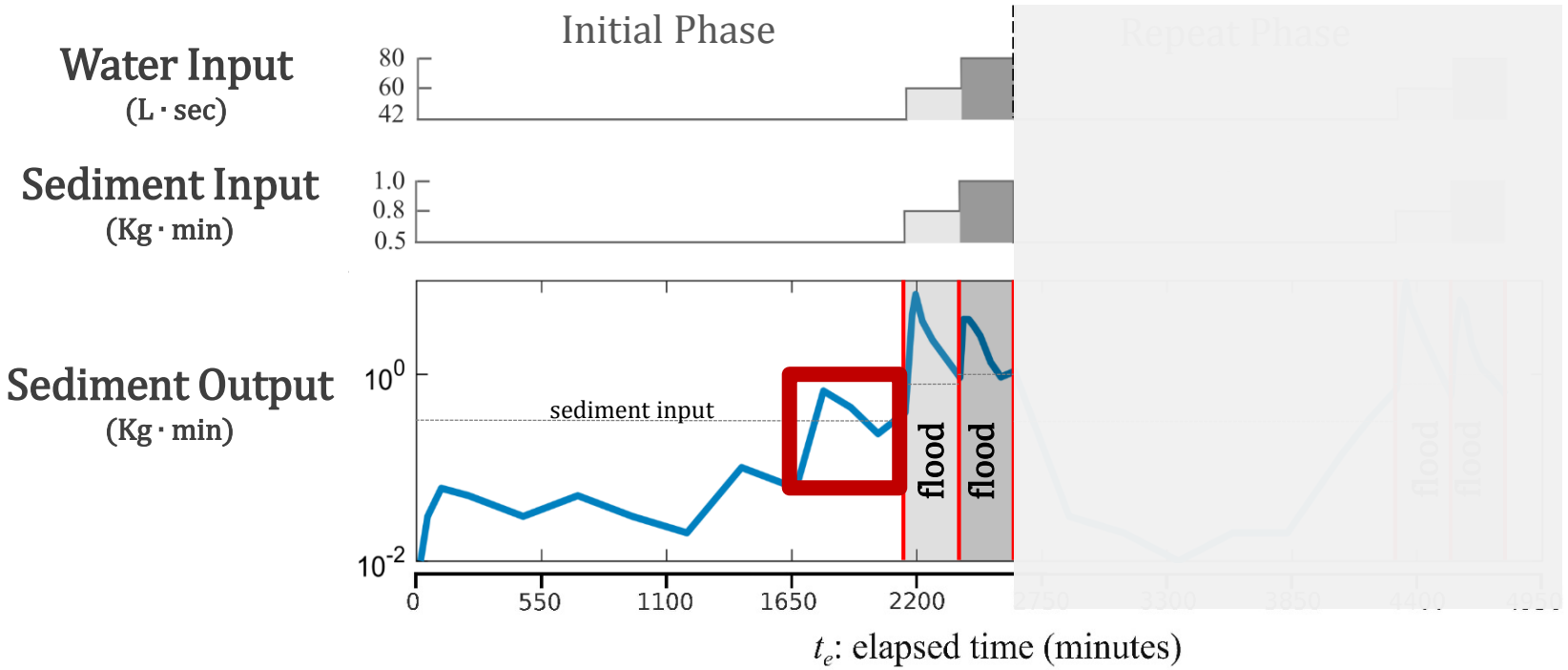

Initial Phase
Repeat Phase
Water Input
(L · sec)
80
60
42
Sediment Input
(Kg · min)
1.0
0.8
0.5
Sediment Output
(Kg · min)
10^0
10^{-2}
sediment input
flood
flood
0
550
1100
1650
2200
t_e: elapsed time (minutes)
Magnitude


Normalized
Average Elevation
1.5
1
0.5
0
550
1100
1650
2200
t_e: elapsed time (minutes)


Initial Phase
Repeat Phase
Water Input
(L · sec)
80
60
42
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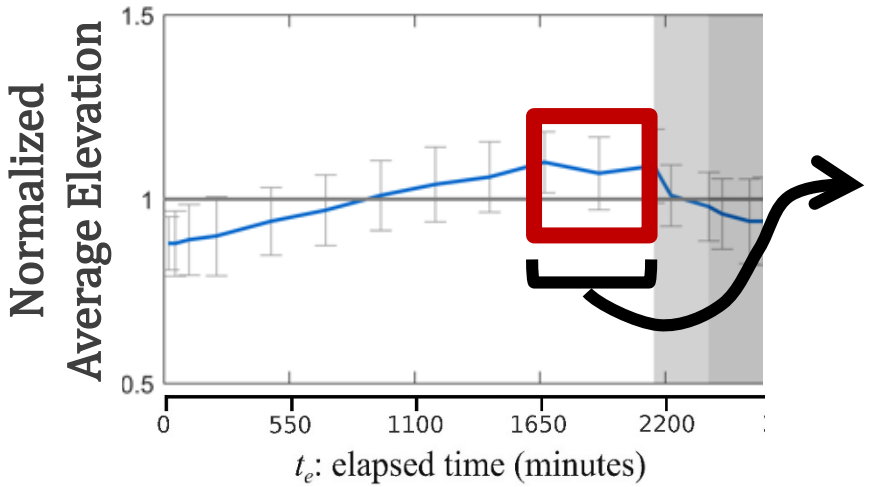
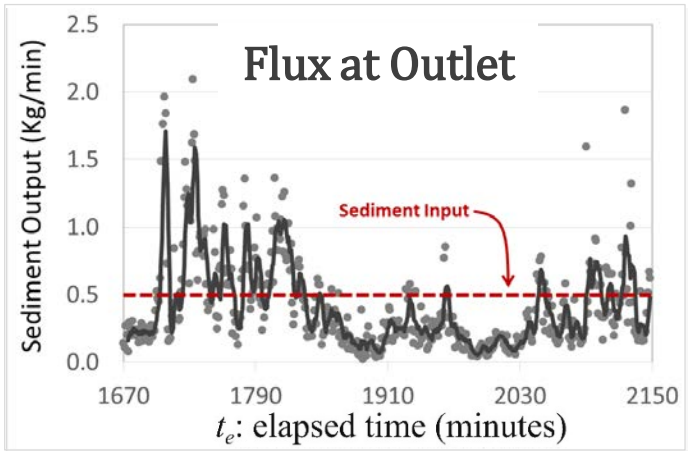
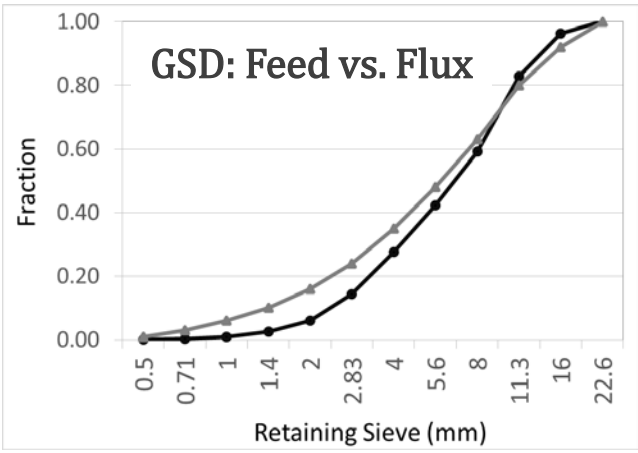
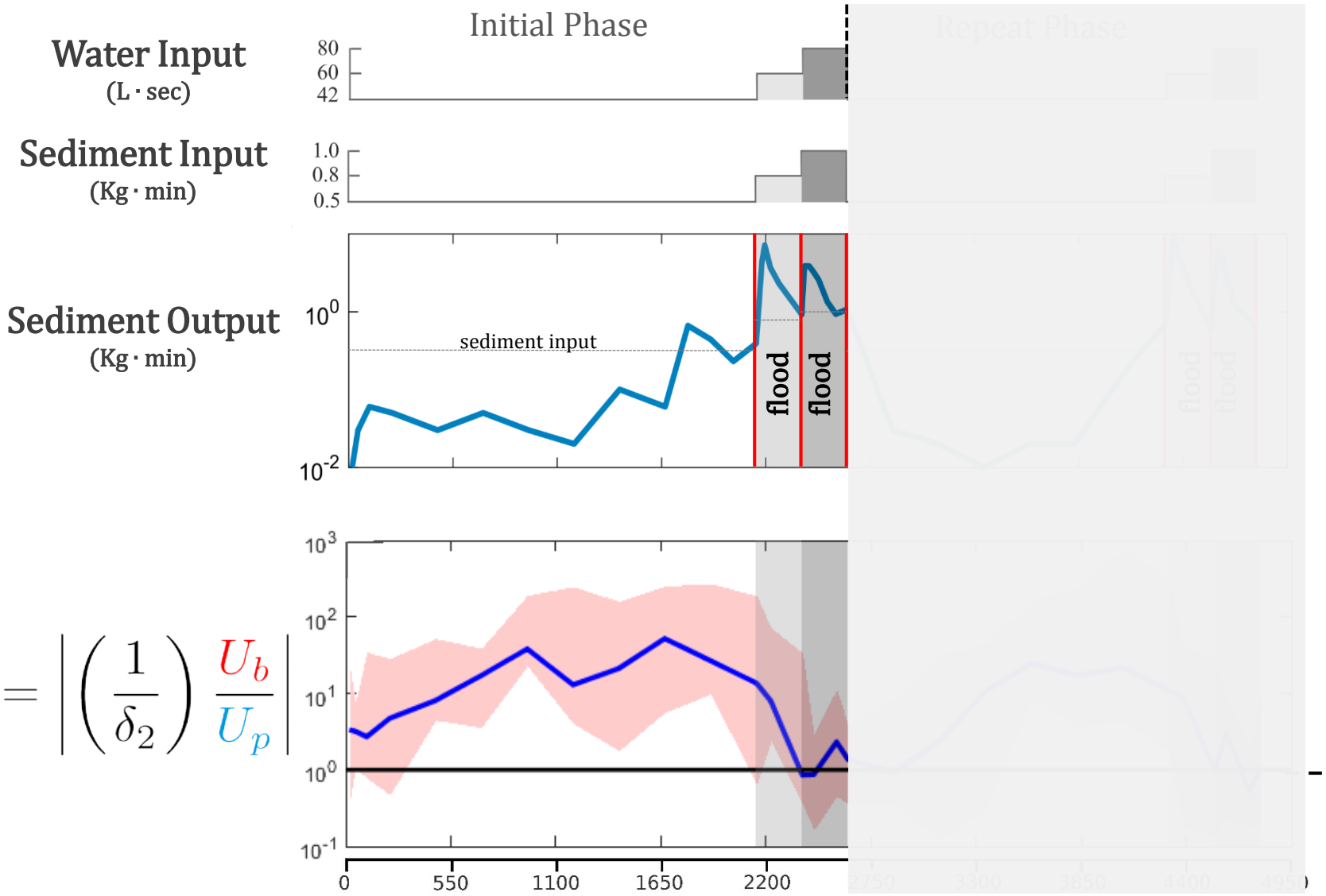

Normalized
Average Elevation
1.5
1
0.5
0
550
1100
1650
2200
t_e: elapsed time (minutes)


Flux at Outlet
Sediment Output (Kg/min)
2.5
2.0
1.5
1.0
0.5
0.0
Sediment Input
1670
1790
1910
2030
2150
t_e: elapsed time (minutes)


GSD: Feed vs. Flux
Fraction
1.00
0.80
0.60
0.40
0.20
0.00
0.5
0.71
1
1.4
2
2.83
4
5.6
8
11.3
16
22.6
Retaining Sieve (mm)

Test of the disequilibrium metric with experimental data



$$N_e = \left| \left(\frac{1}{\delta_2} \right) \frac{U_b}{U_p} \right|$$

Magnitude

topographic response wins

$N_e = 1$

particle response wins

Modified from Chartrand et al., In Revision

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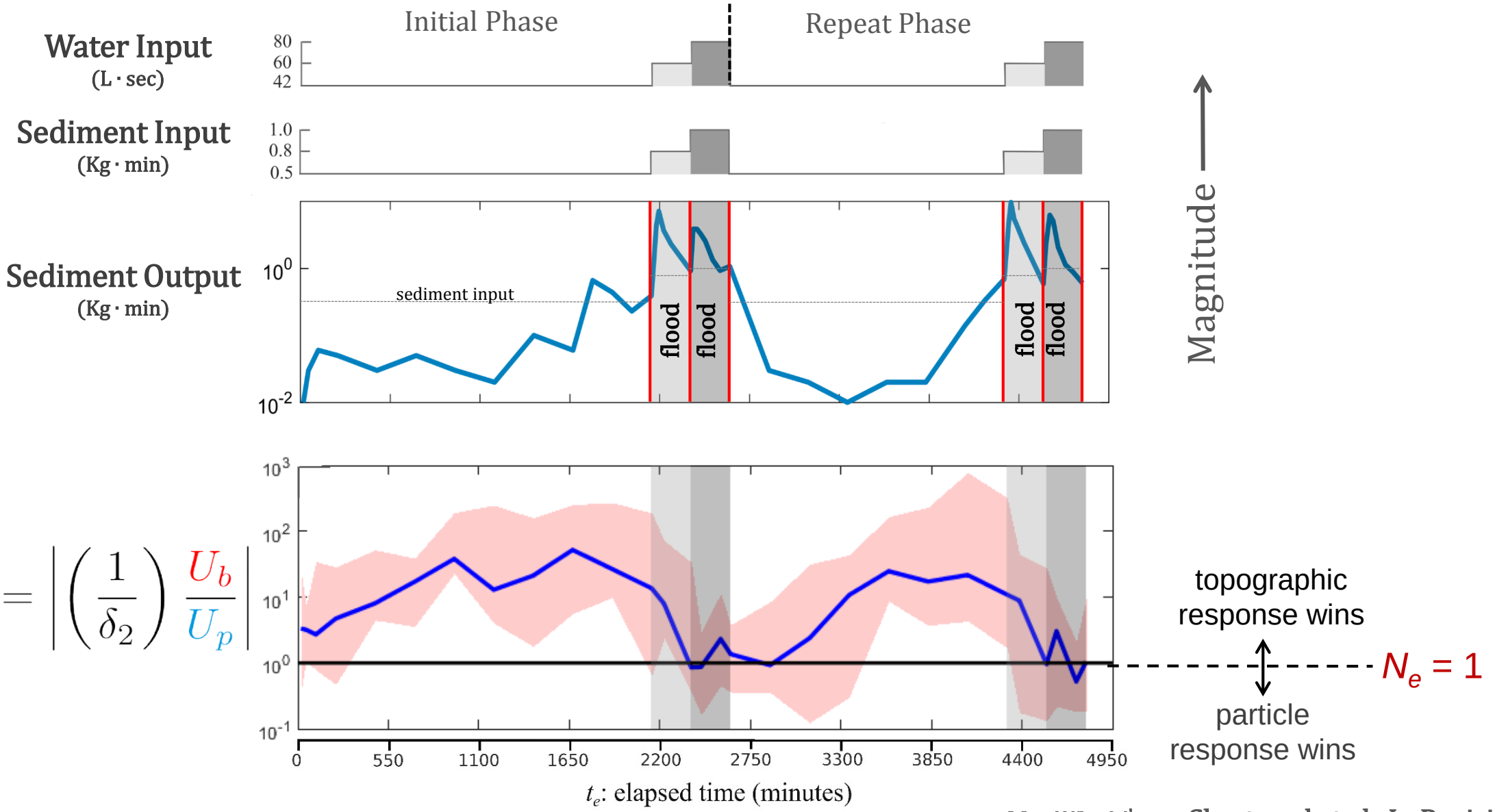

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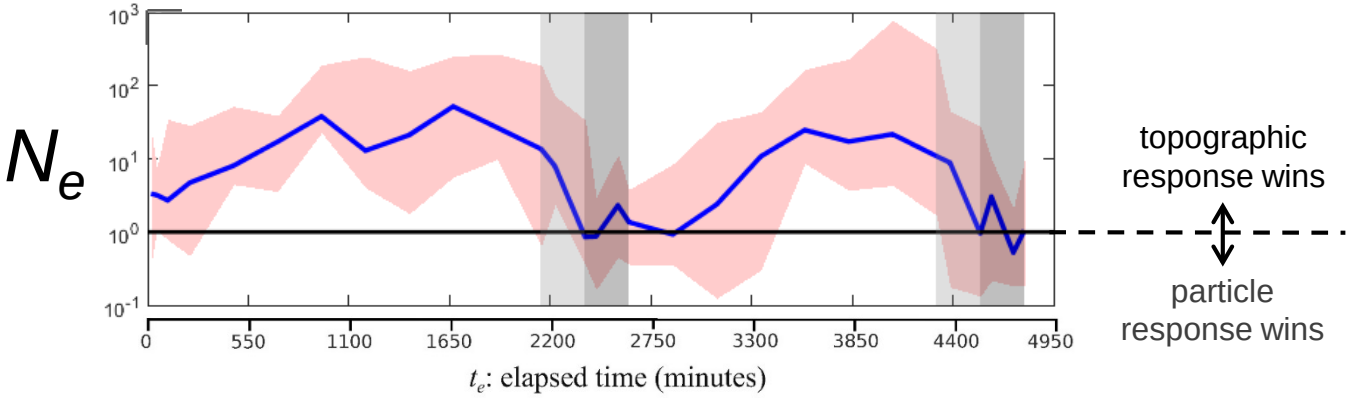
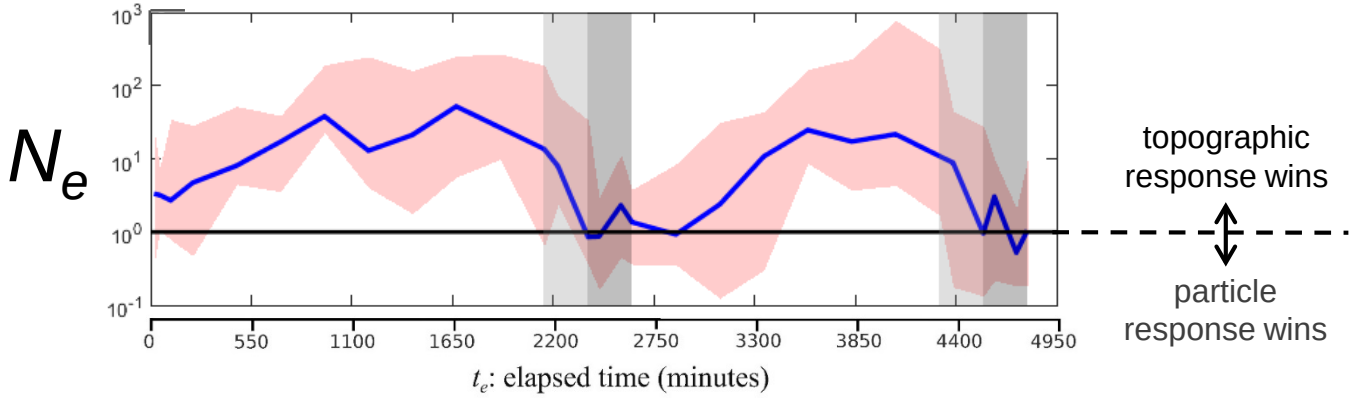


Summary Points

1. Disequilibrium metric a function of two competing adjustment rates: U_b and U_p
2. Readily measure data needed to calculate disequilibrium – NEED MORE TESTING
3. Timescale of disequilibrium adjustment is a function of sediment mobility



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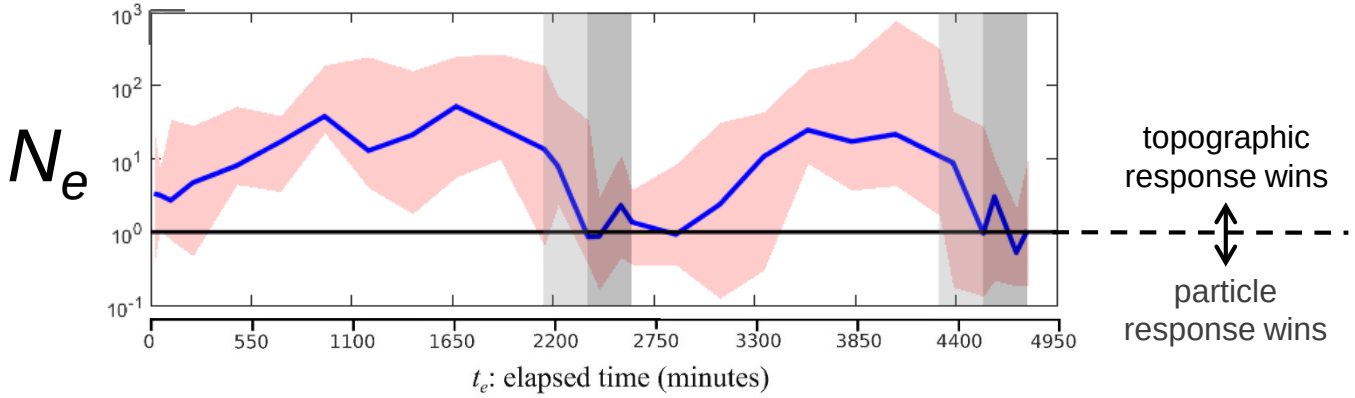
Looking Ahead and an Open Question

A. Framework can be scaled up to the drainage basin to evaluate larger scale conditions

B. Can the equilibrium metric better define the dynamic equilibrium regime?

C. Is there a regime for which grain size adjustment is consistently dominant?



Summary Points

1. Disequilibrium metric a function of two competing adjustment rates: U_b and U_p
2. Readily measu… …ORE TESTING
3. Timescale of d… …obility

Disequilibrium Reigns?

Looking Ahead and an Open Question

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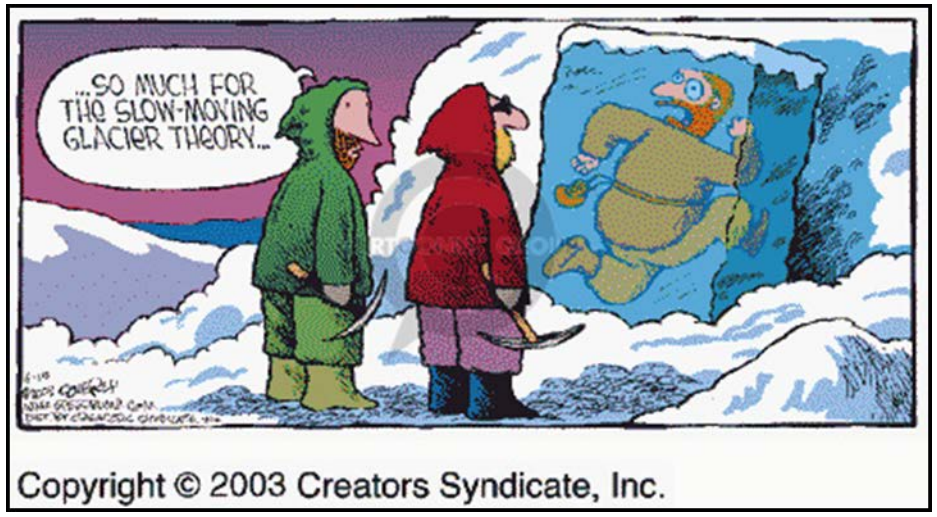
B. Can the equilibrium metric better define the dynamic equilibrium regime?

C. Is there a regime for which grain size adjustment is consistently dominant?

Questions



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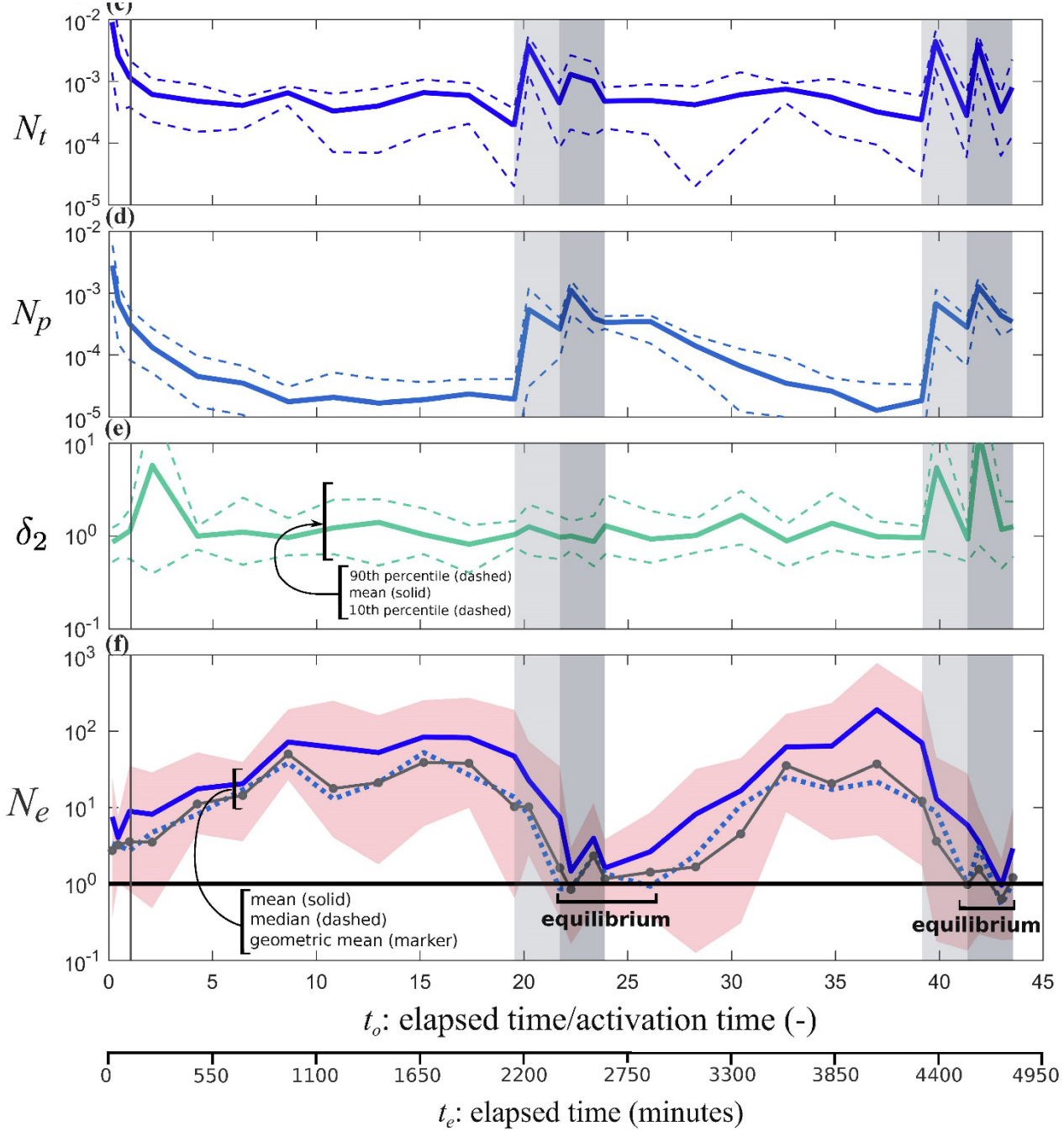
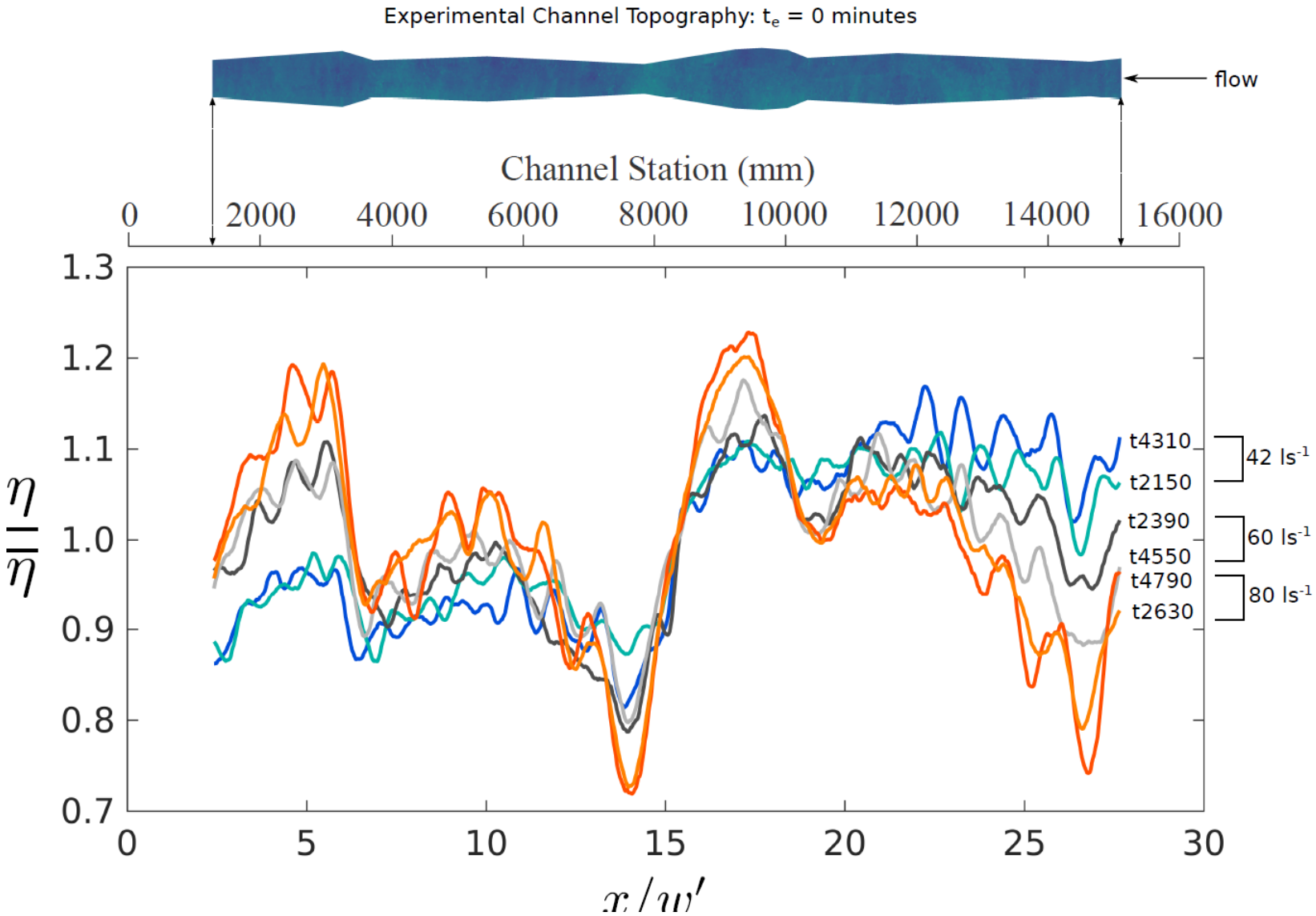

(c)
N_t
(d)
N_p
(e)
δ_2
90th percentile (dashed)
mean (solid)
10th percentile (dashed)
(f)
N_e
mean (solid)
median (dashed)
geometric mean (marker)
equilibrium
equilibrium
t_o: elapsed time/activation time (-)
t_e: elapsed time (minutes)


Experimental Channel Topography: t_e = 0 minutes
flow
Channel Station (mm)
0
2000
4000
6000
8000
10000
12000
14000
16000
$\frac{\eta}{\overline{\eta}}$
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0
5
10
15
20
25
30
x/w'
t4310
t2150
t2390
t4550
t4790
t2630
42 ls^{-1}
60 ls^{-1}
80 ls^{-1}