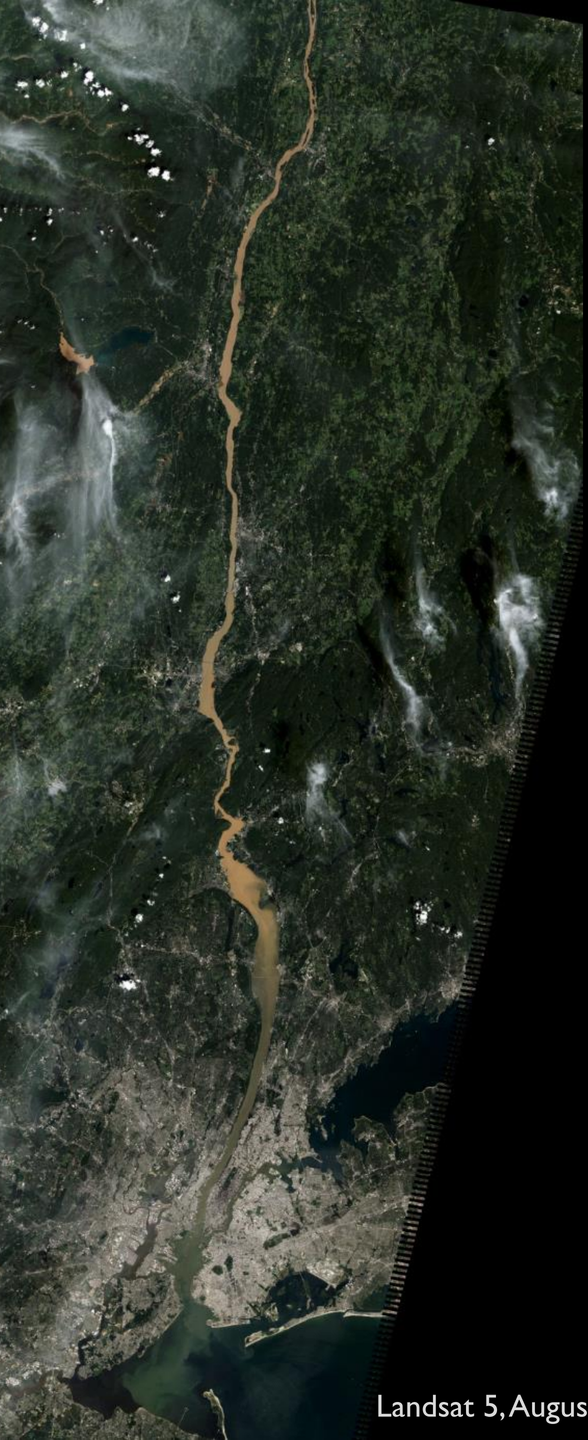


Linking Sediment Transport in the Hudson from the Tidal River to the Estuary

Or, what happened to all the mud from Irene?

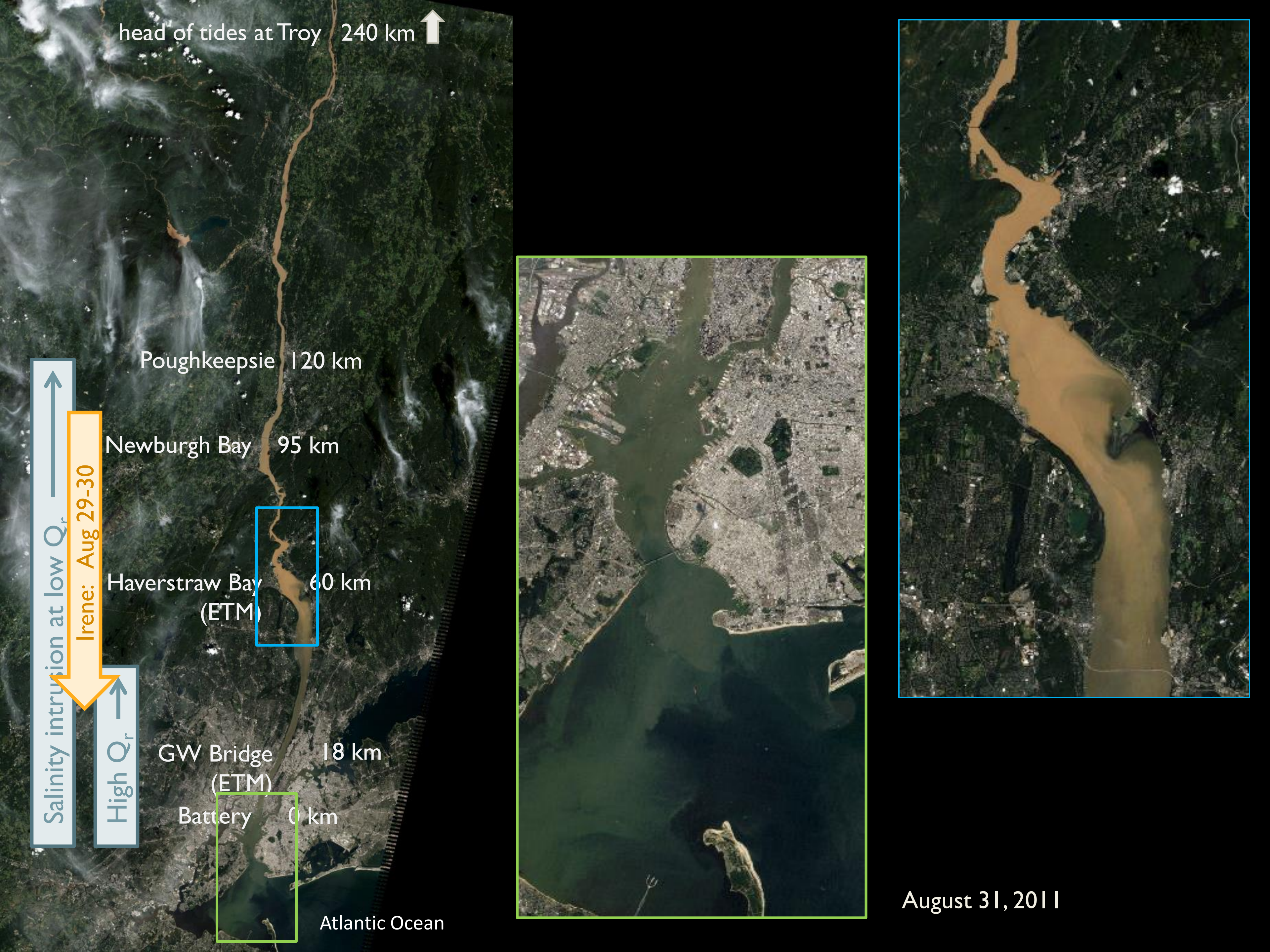
David Ralston, Rocky Geyer,
John Warner, Gary Wall

WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

USGS
science for a changing world

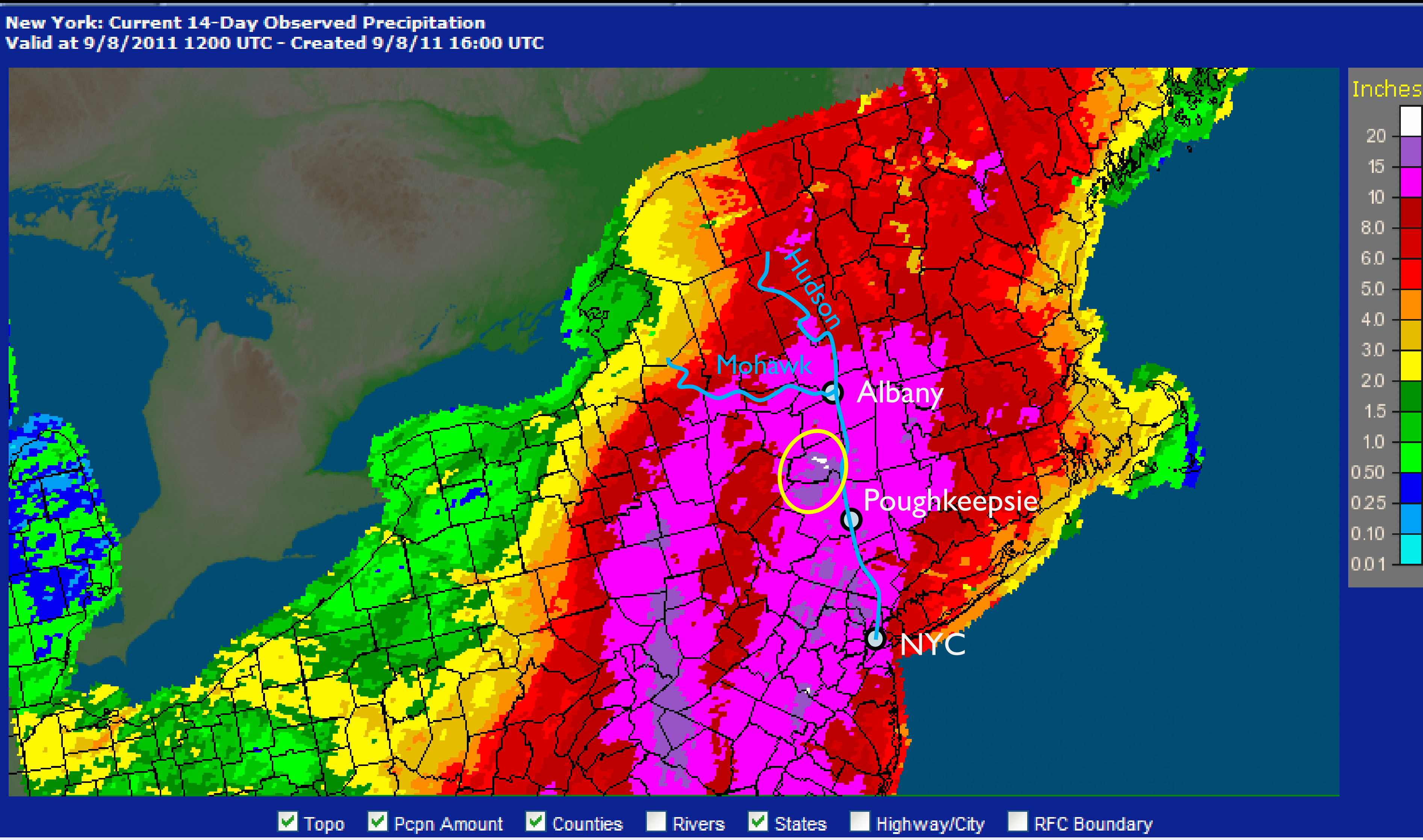
Hudson River Foundation seminar
October 2015

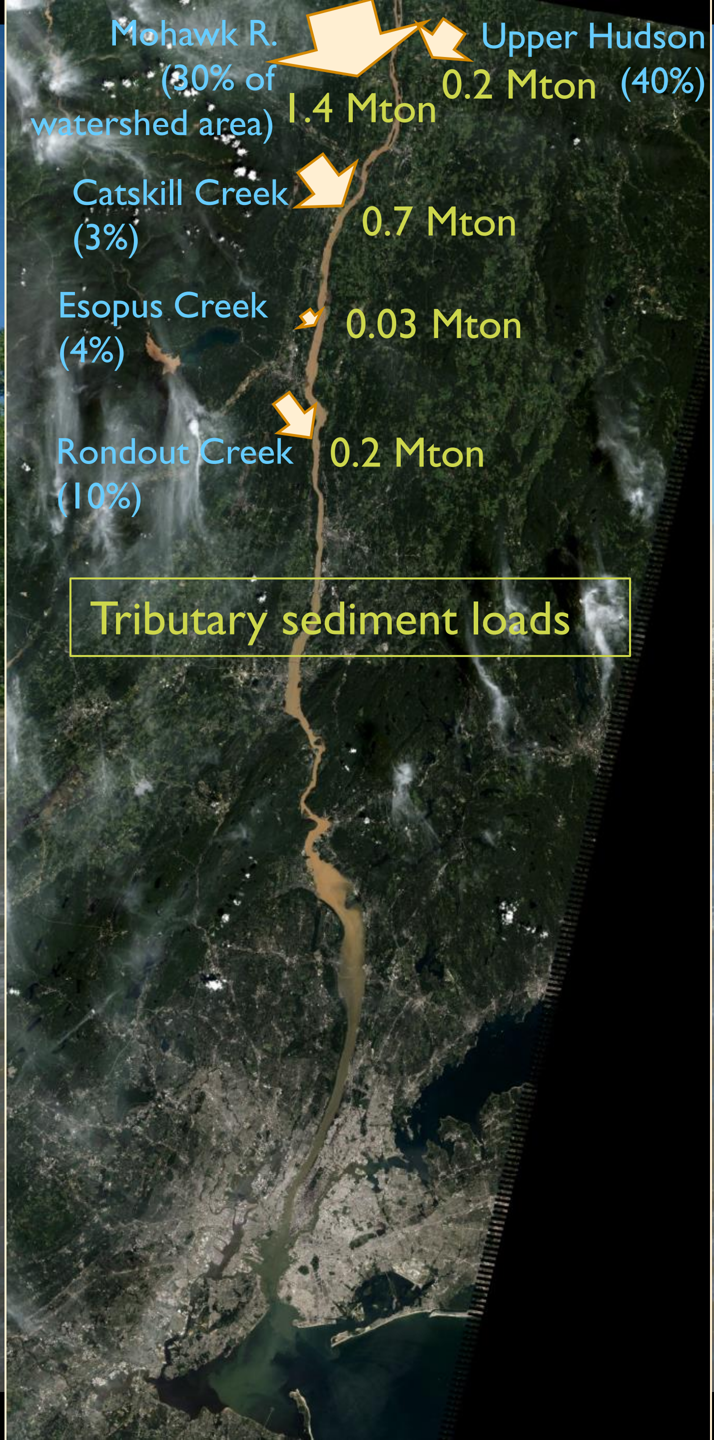
Landsat 5, August 31, 2011; credit: USGS/NASA Earth Observatory

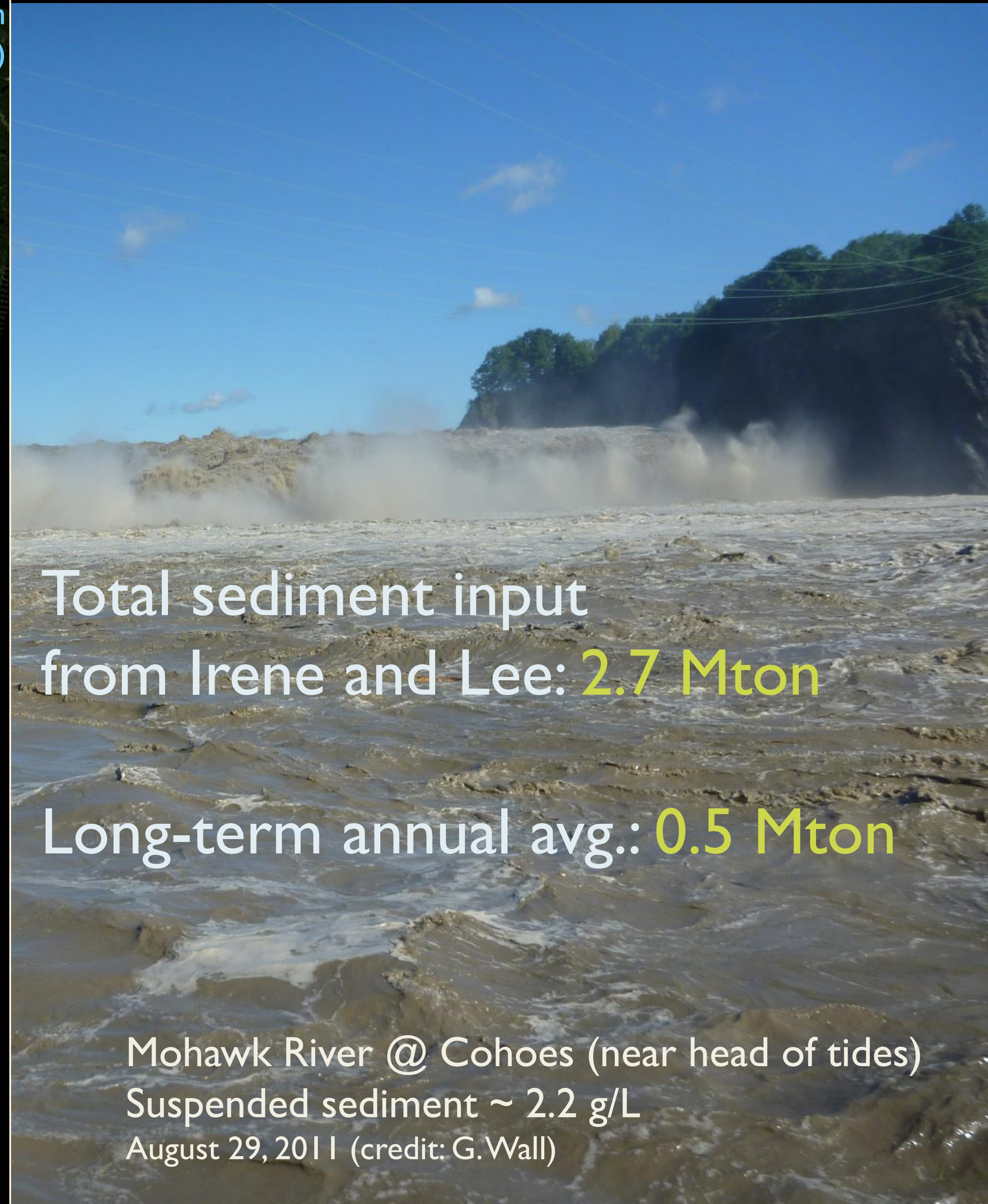

head of tides at Troy 240 km
Poughkeepsie 120 km
Newburgh Bay 95 km
Haverstraw Bay (ETM) 60 km
GW Bridge (ETM) 18 km
Battery 0 km
Atlantic Ocean
Salinity intrusion at low Q_r
Irene: Aug 29-30
High Q_r
August 31, 2011

Tropical Storms Irene and Lee

Irene (Aug 28) + Lee (Sep 7) rainfall totals (Aug 25-Sep8) [http://www.srh.noaa.gov/ridge2/RFC_Precip/]

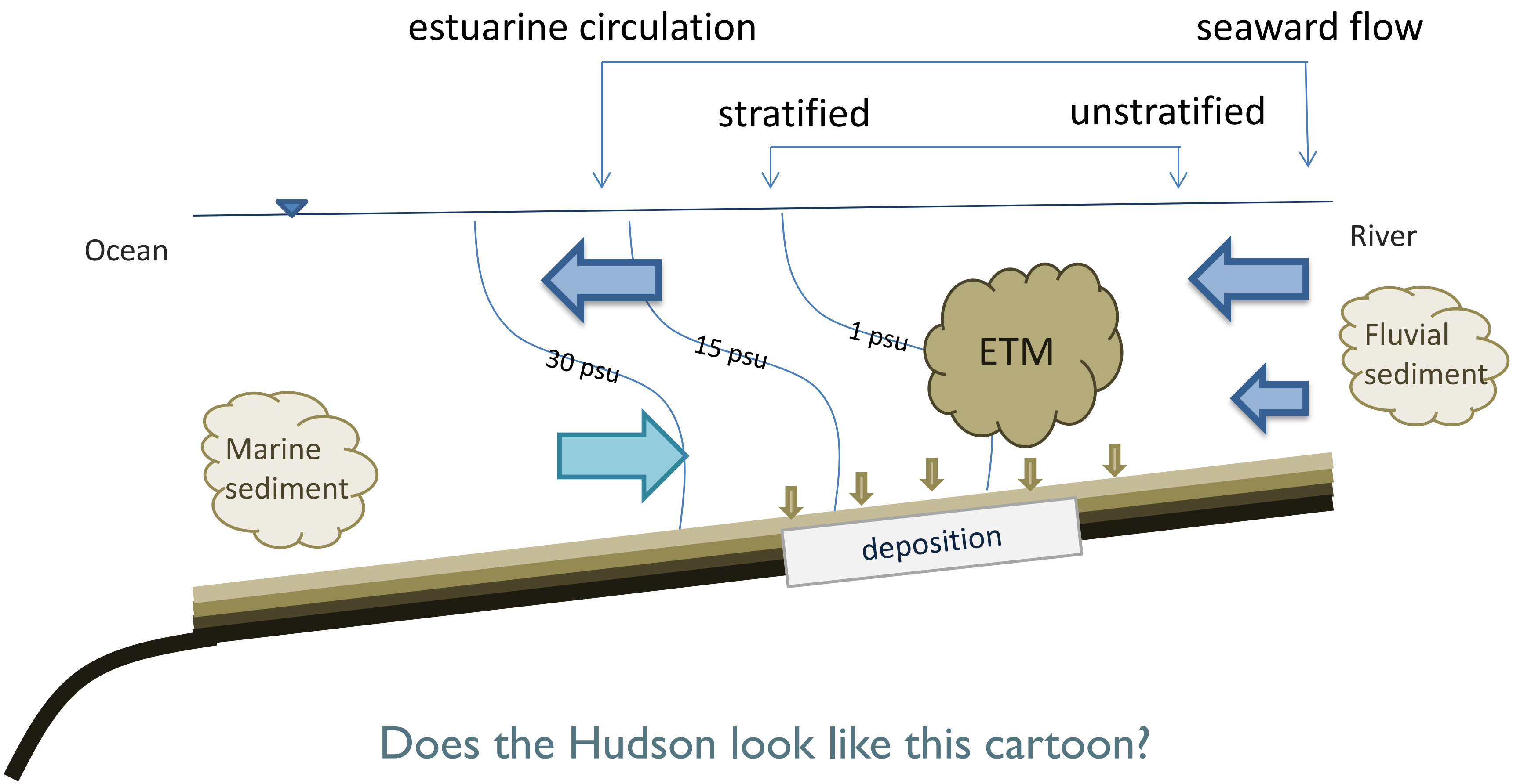



Mohawk R.
(30% of
watershed area)
1.4 Mton
Upper Hudson
0.2 Mton (40%)
Catskill Creek
(3%)
0.7 Mton
Esopus Creek
(4%)
0.03 Mton
Rondout Creek
(10%)
0.2 Mton
Tributary sediment loads


Total sediment input
from Irene and Lee: 2.7 Mton
Long-term annual avg.: 0.5 Mton
Mohawk River @ Cohoes (near head of tides)
Suspended sediment ~ 2.2 g/L
August 29, 2011 (credit: G. Wall)

Estuaries efficiently trap sediment

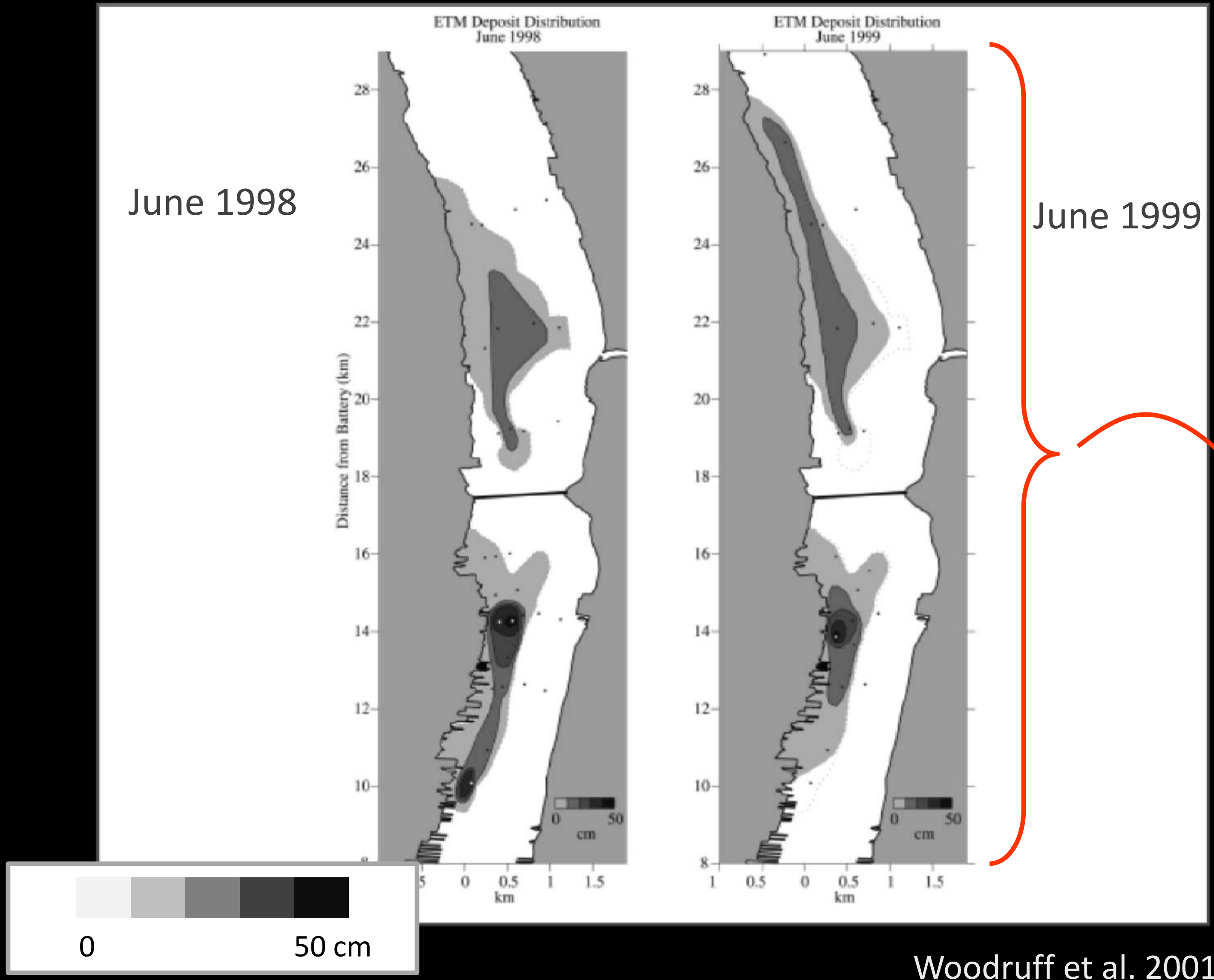
→ High sediment concentrations and deposition rates, efficient trapping

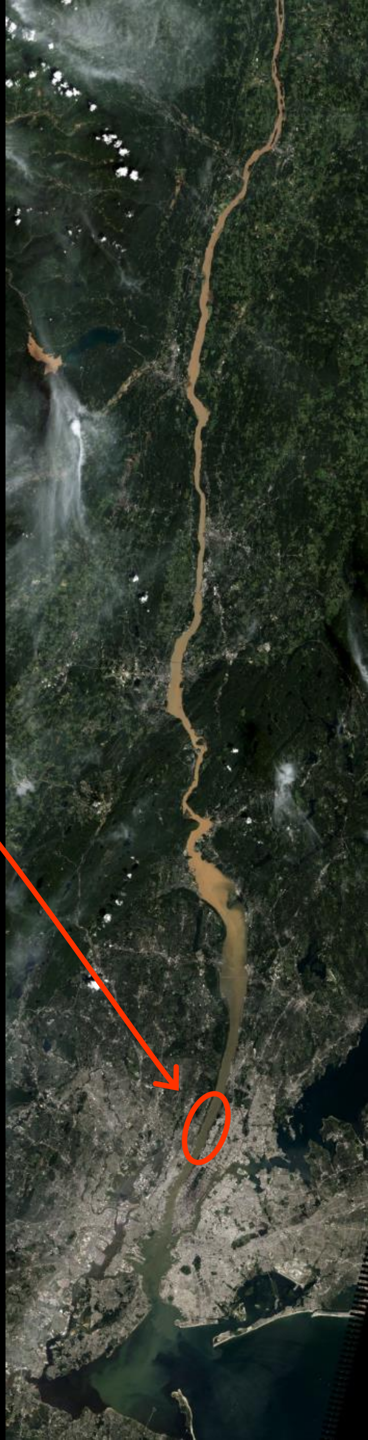


Does the Hudson look like this cartoon?

Lower Hudson ETM: near GW Bridge

high deposition rates after spring freshet

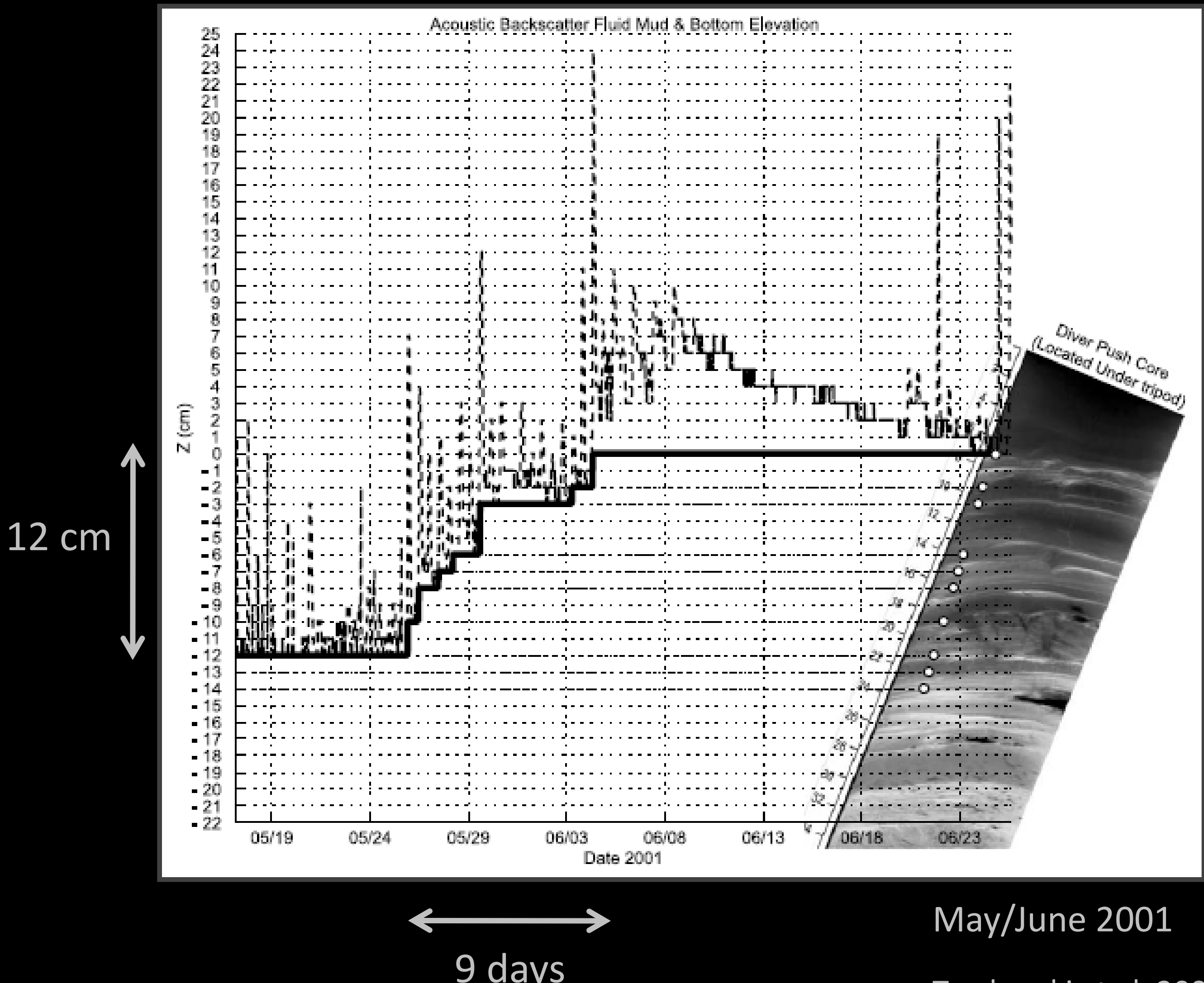




Woodruff et al. 2001

Lower Hudson ETM: near GW Bridge

high deposition rates after spring freshet



May/June 2001

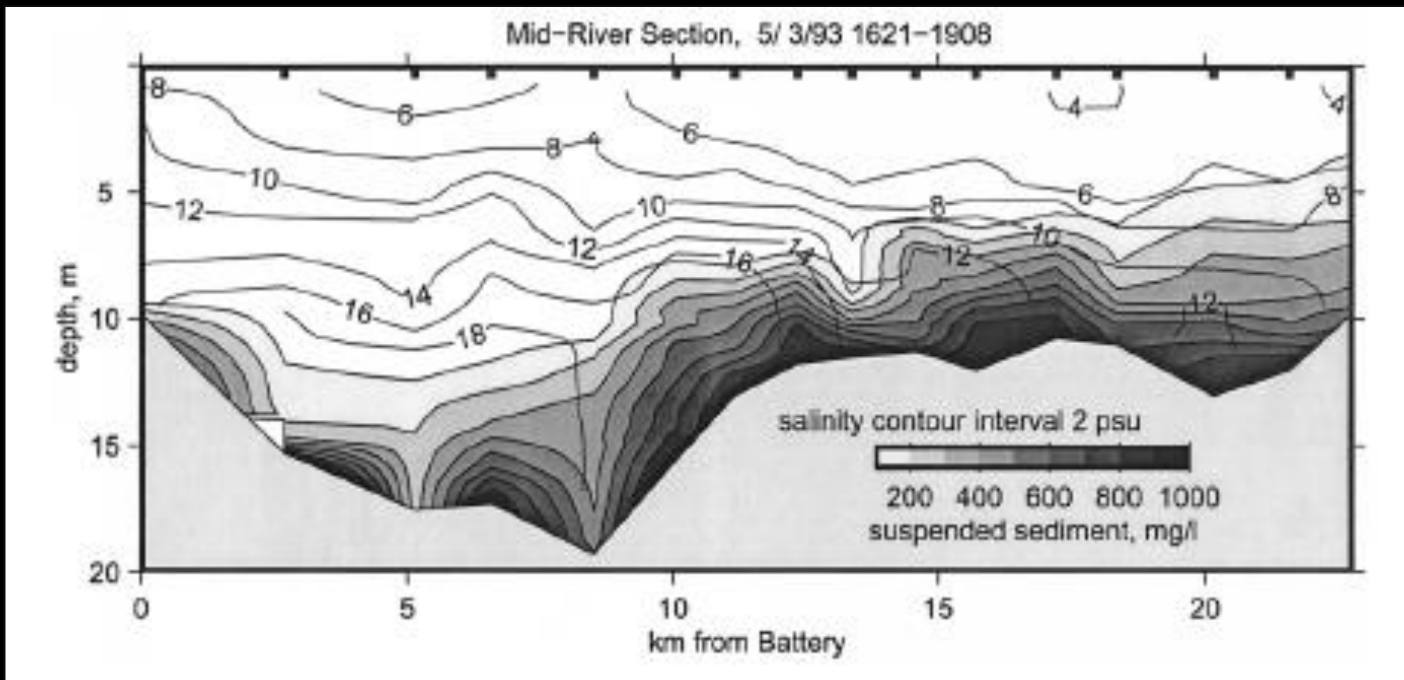
Traykovski et al. 2004

Lower Hudson ETM: near GW Bridge

high deposition rates after spring freshet

high sediment concentrations (>1 g/L)

BUT, at intermediate salinities, not at salinity limit

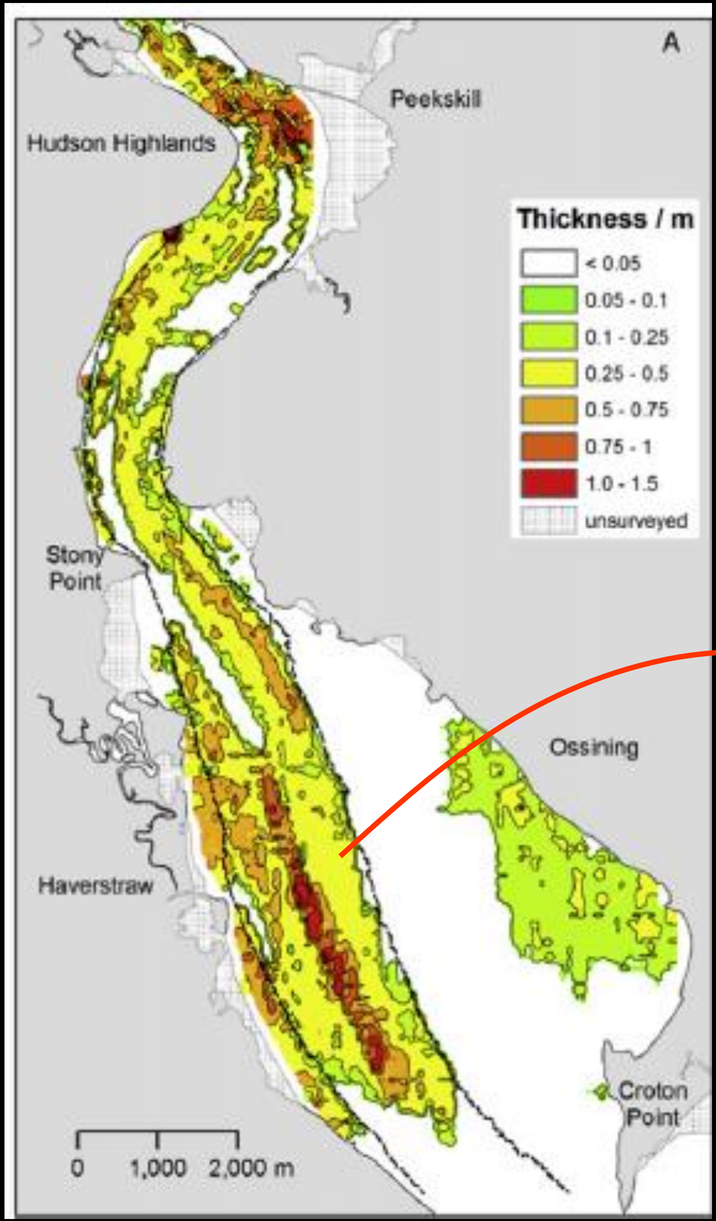


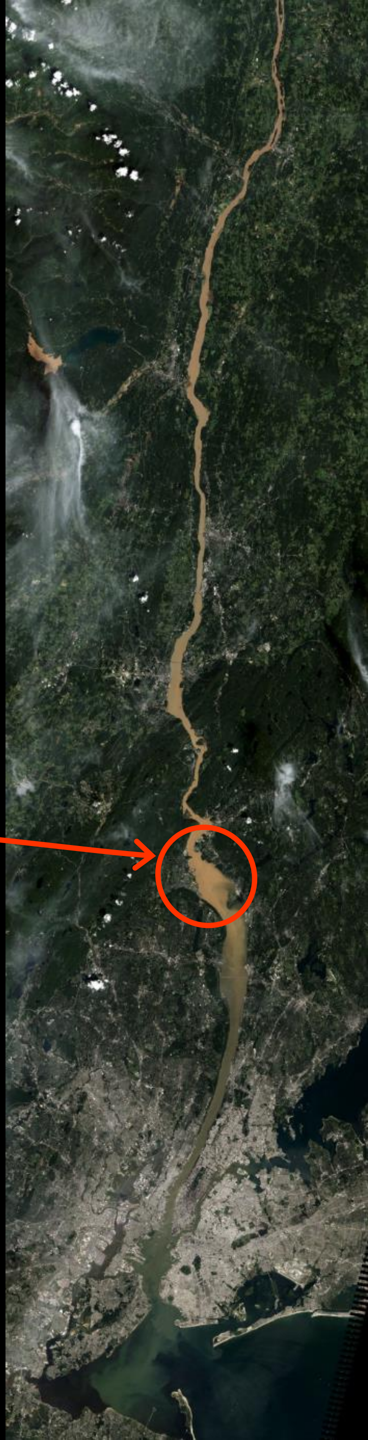
Geyer et al. 2001

Upper Hudson ETM: Haverstraw Bay

High deposition rates; frequent dredging

Often near limit of salinity intrusion



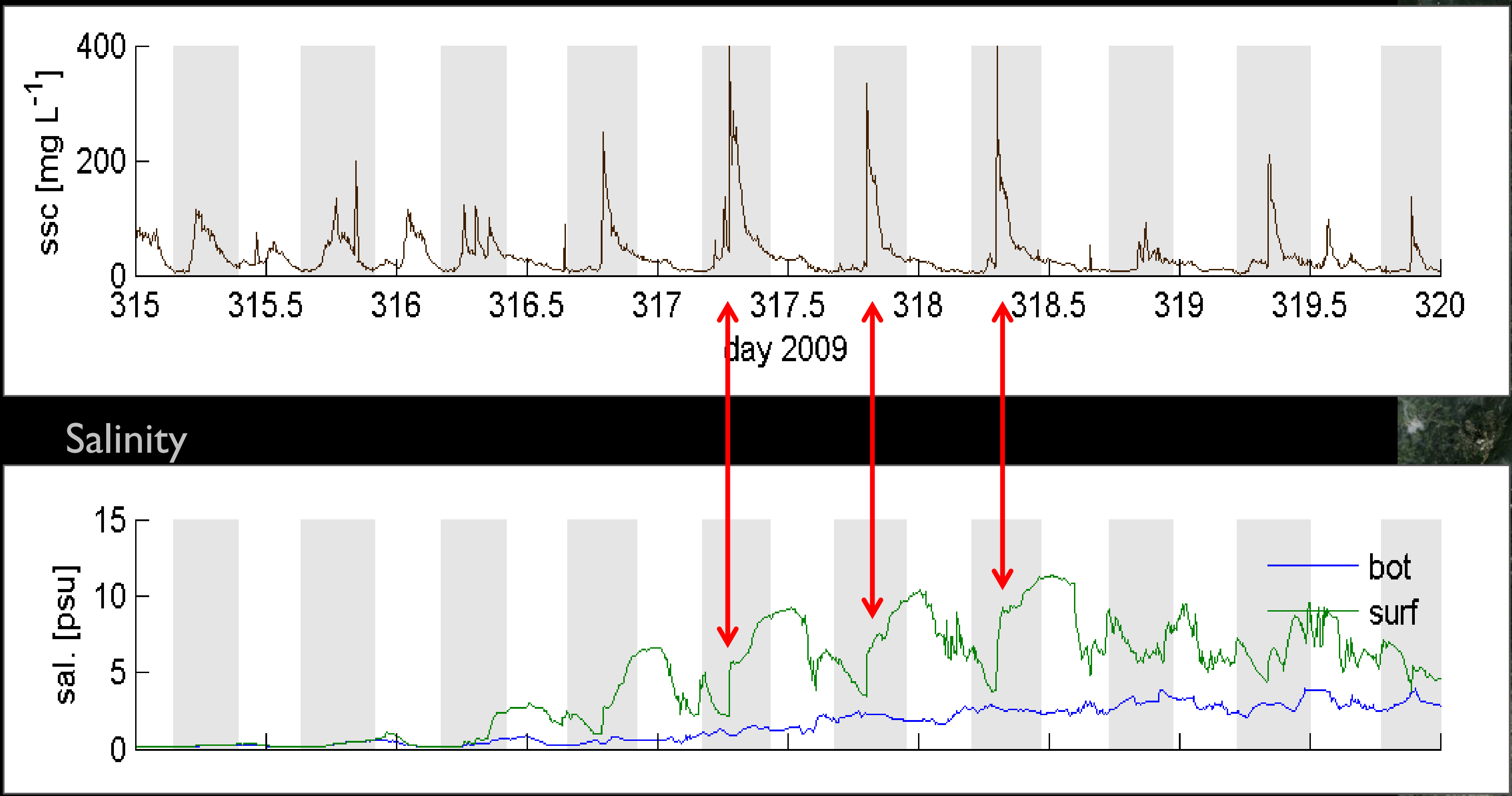


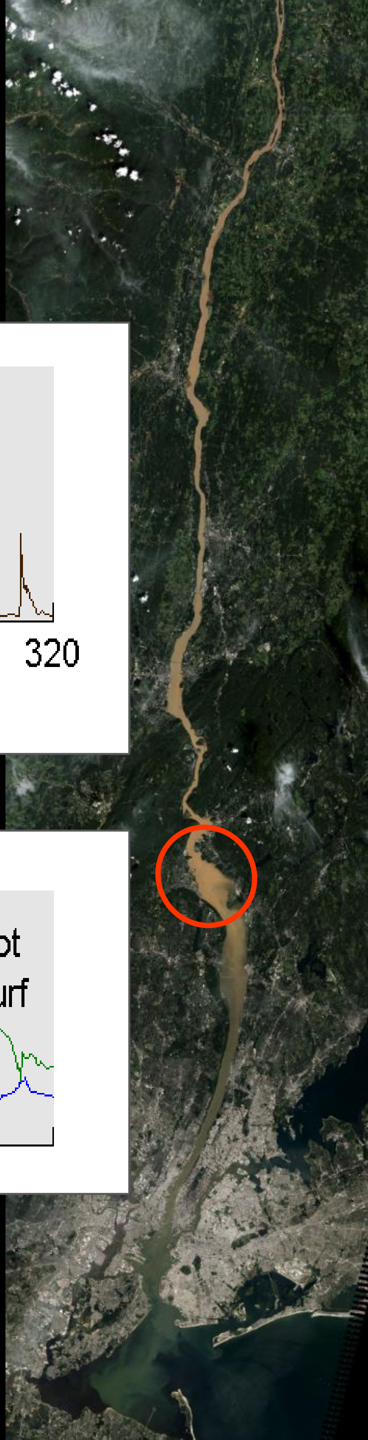
Nitsche et al., 2010

Upper Hudson ETM: Haverstraw Bay

High sediment concentrations at flood tide salinity fronts,
Ebb concentrations reduced by stratification

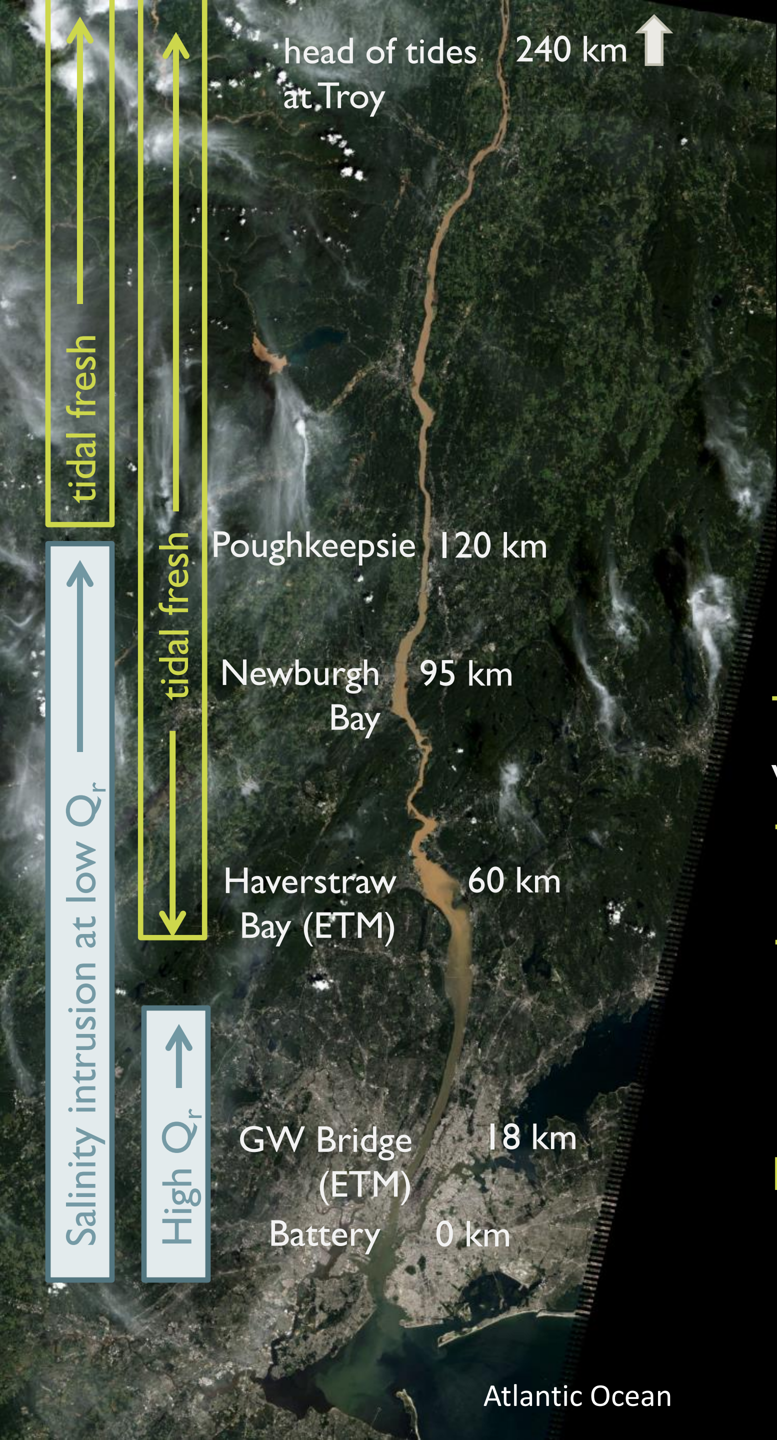
Suspended sediment concentration





Observations, Fall 2009

Ralston et al., 2012



What happens to sediment in the tidal river?

Much less studied, but important in major river systems – Amazon (600 km), Ganges-Brahamaputra, Changjiang (180-290 km), Mekong (>190 km); also Thames (160 km), CT (100 km)

Can sequester an estimated 1/3 of sediment discharge [Milliman and Farnsworth 2011]

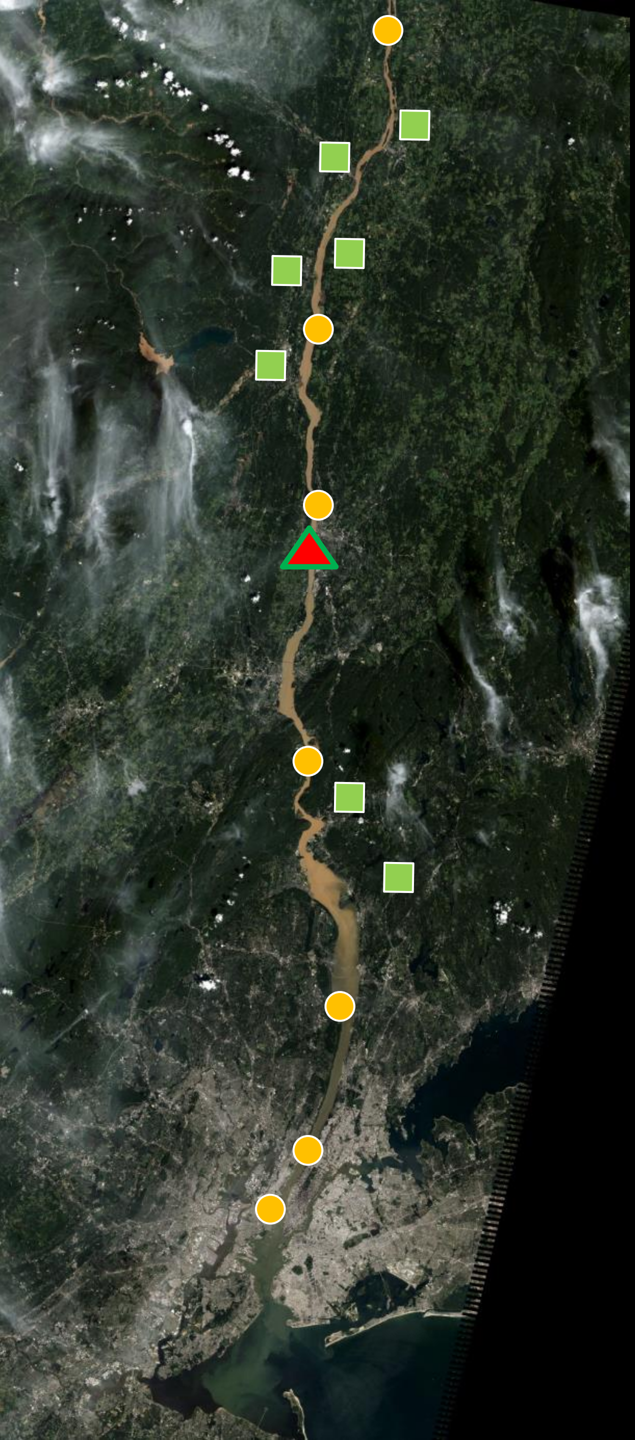
Tidal and river forcing both contribute to transport, with different time scales and amplitudes

→ Tidal velocities usually dominate, control river geometry, vary at spring/neap cycle

→ River discharge varies at event, seasonal, and interannual time scales; magnitude at times similar to tides, but unidirectional

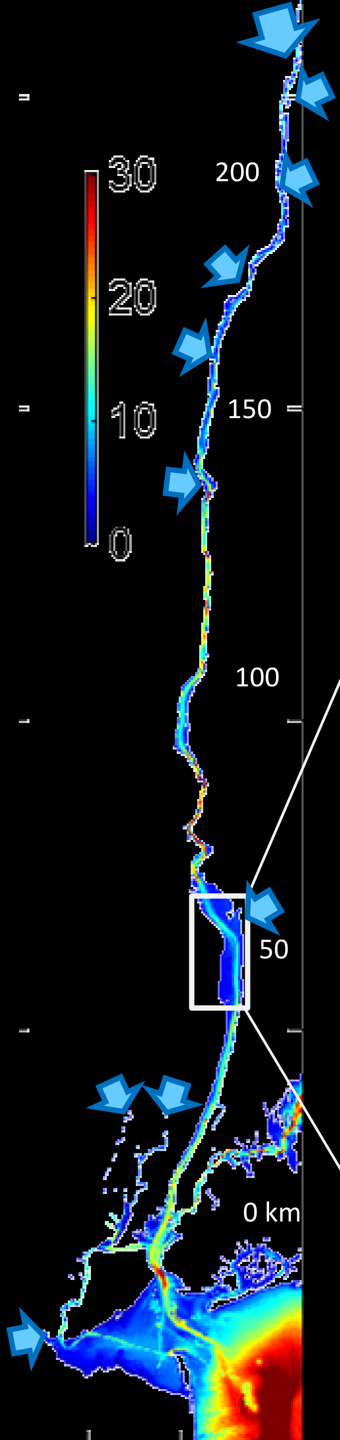
River discharge controls sediment supply

Irene/Lee observations



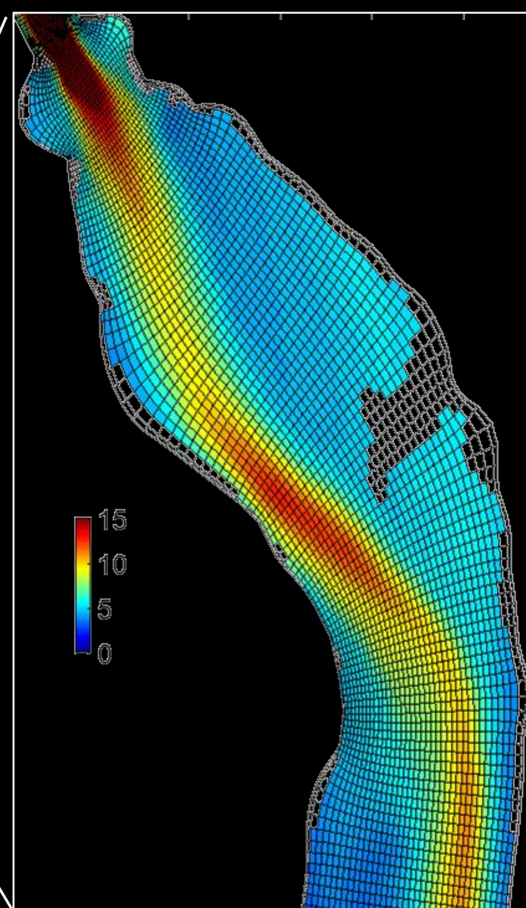
- Gaged flow & SSC (91% of watershed)
- ADCP w/ SSC calibration at Poughkeepsie
- Mix of turbidity, salinity, and water level sensors; some calibration during Irene/Lee.

Model



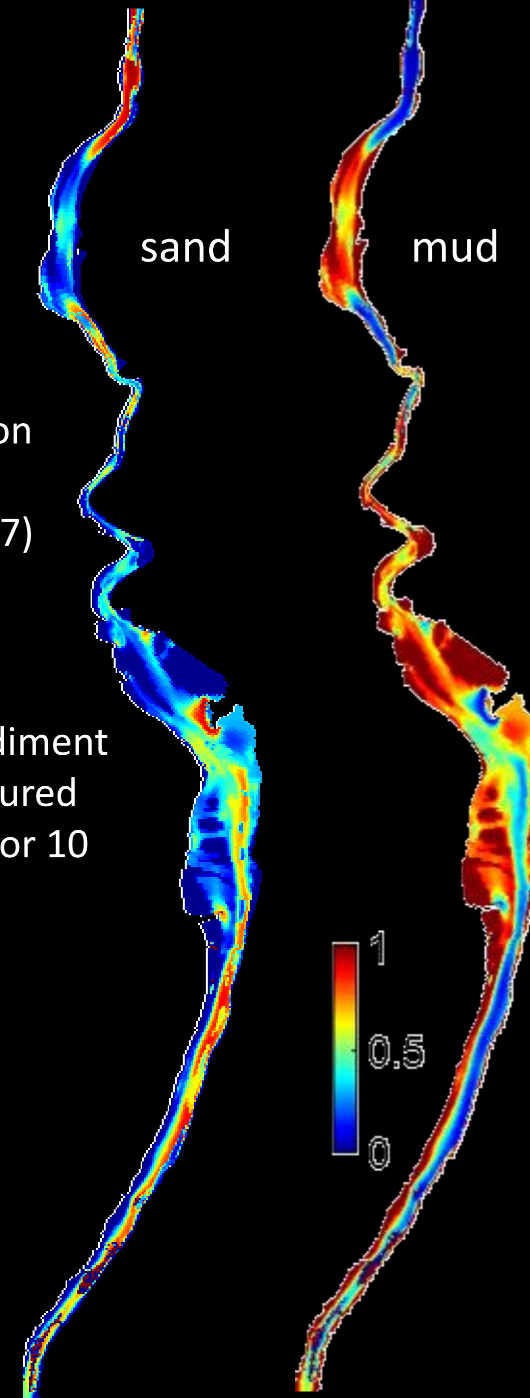
3-d Hydrodynamics (ROMS) and sediment transport (CSTMS)

Previously used in the estuary (Ralston et al. 2012)



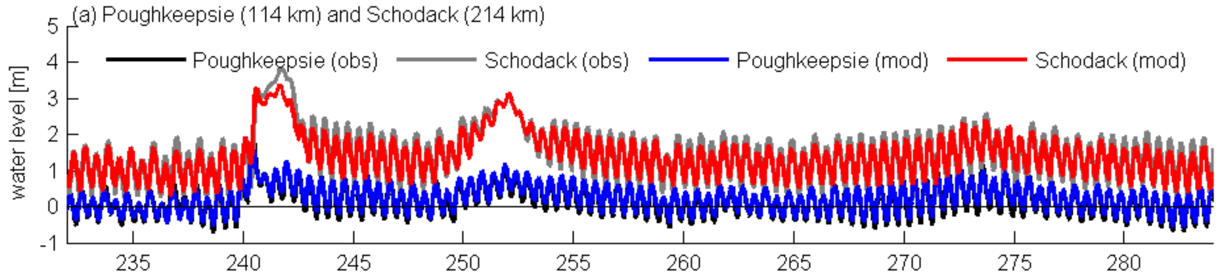
Bed initial condition from surveys (Nitsche et al. 2007)

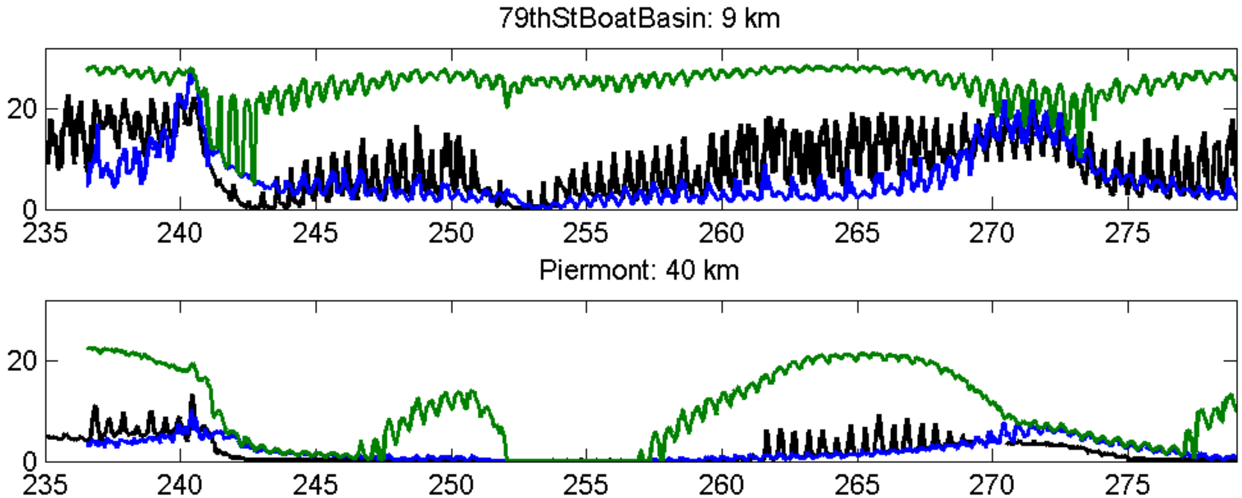
Discharge and sediment load (USGS, measured or rating curves) for 10 tributaries



Model evaluation

Water level





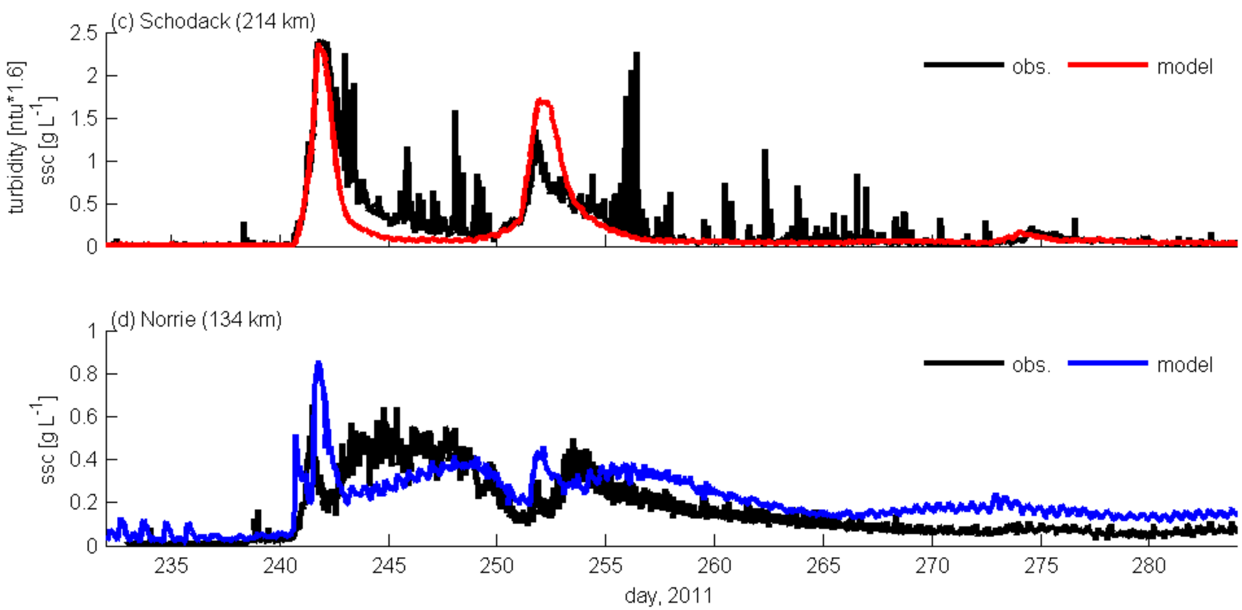
Salinity

Observed

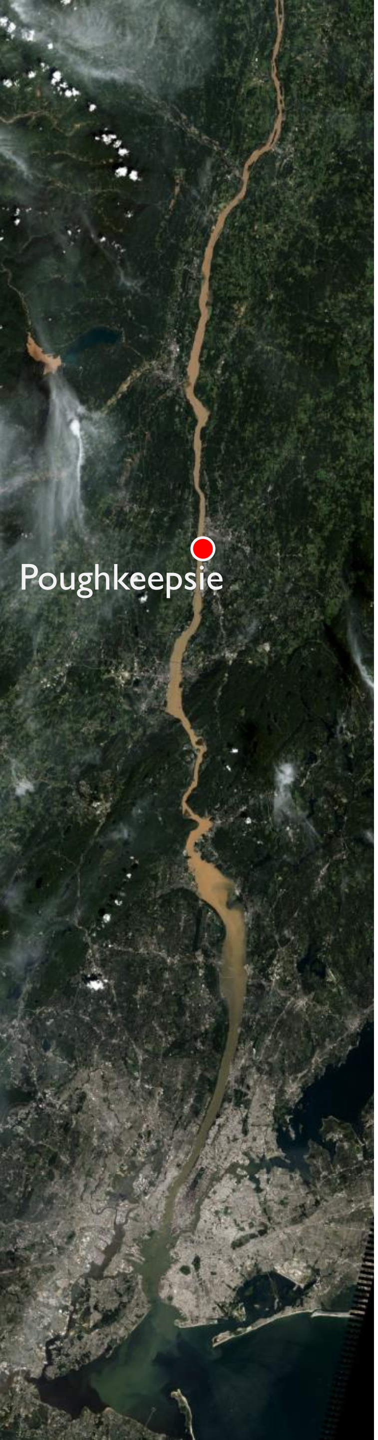
Model (surf)

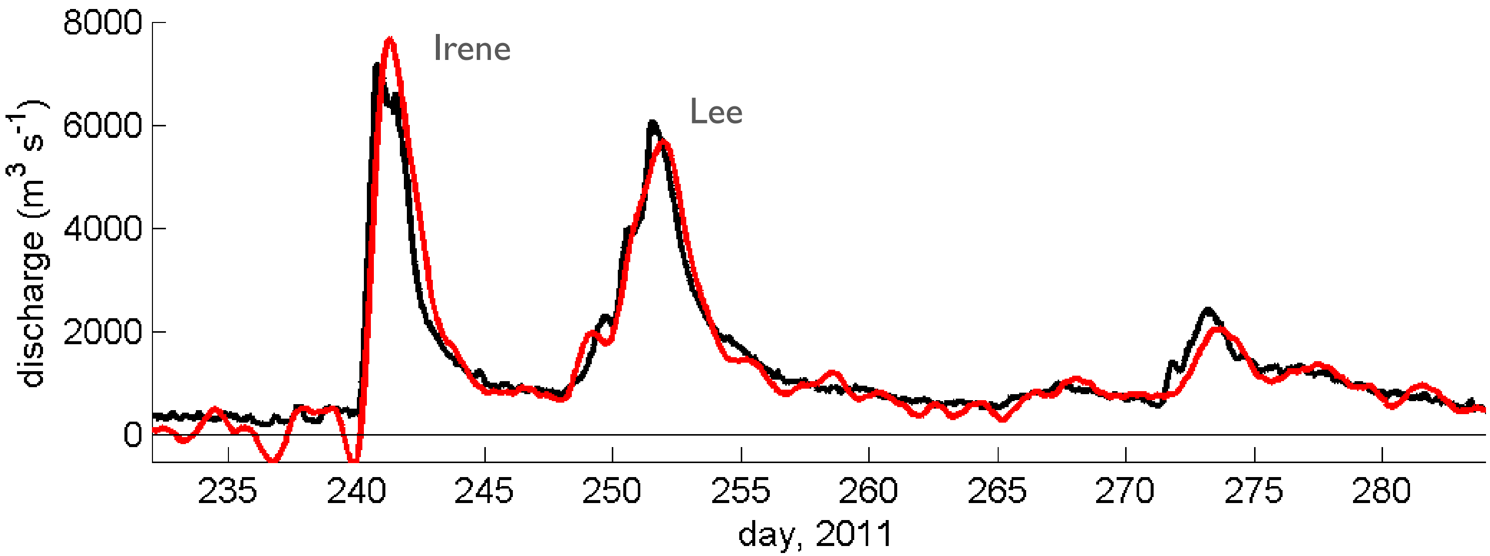
Model (bot)

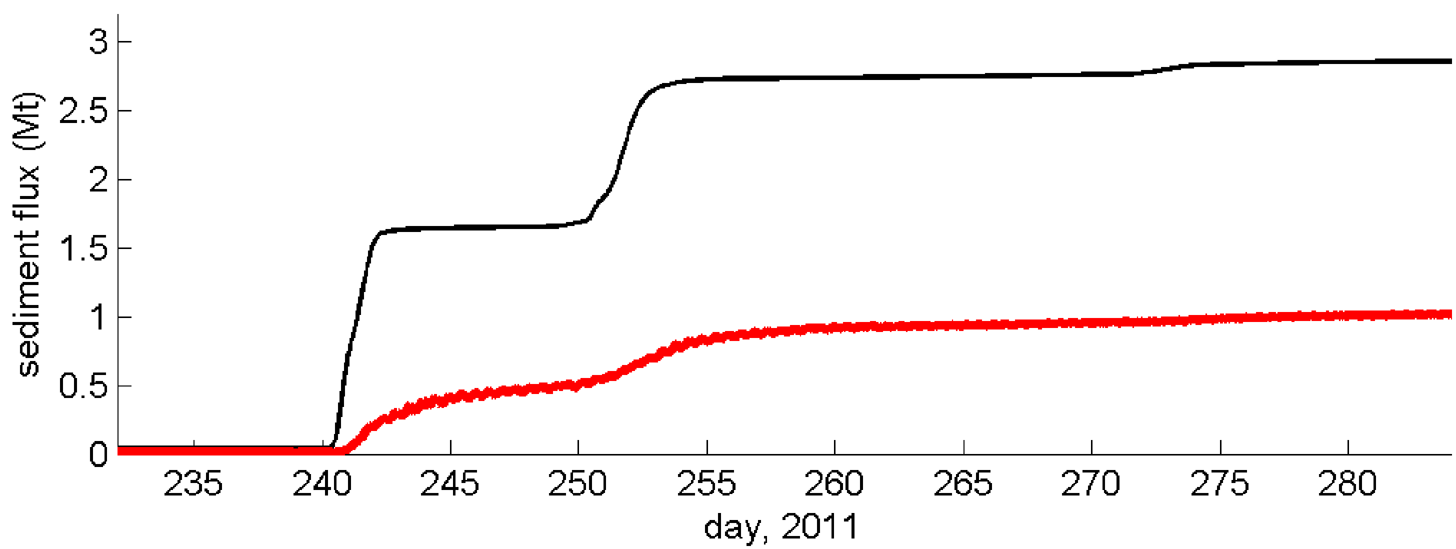
Suspended sediment



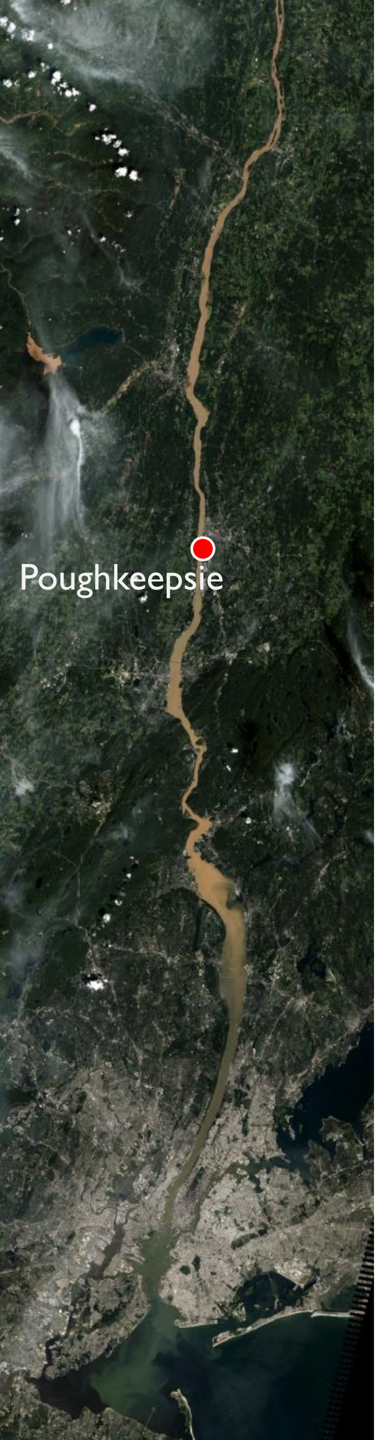
Discharge + sediment flux: observed

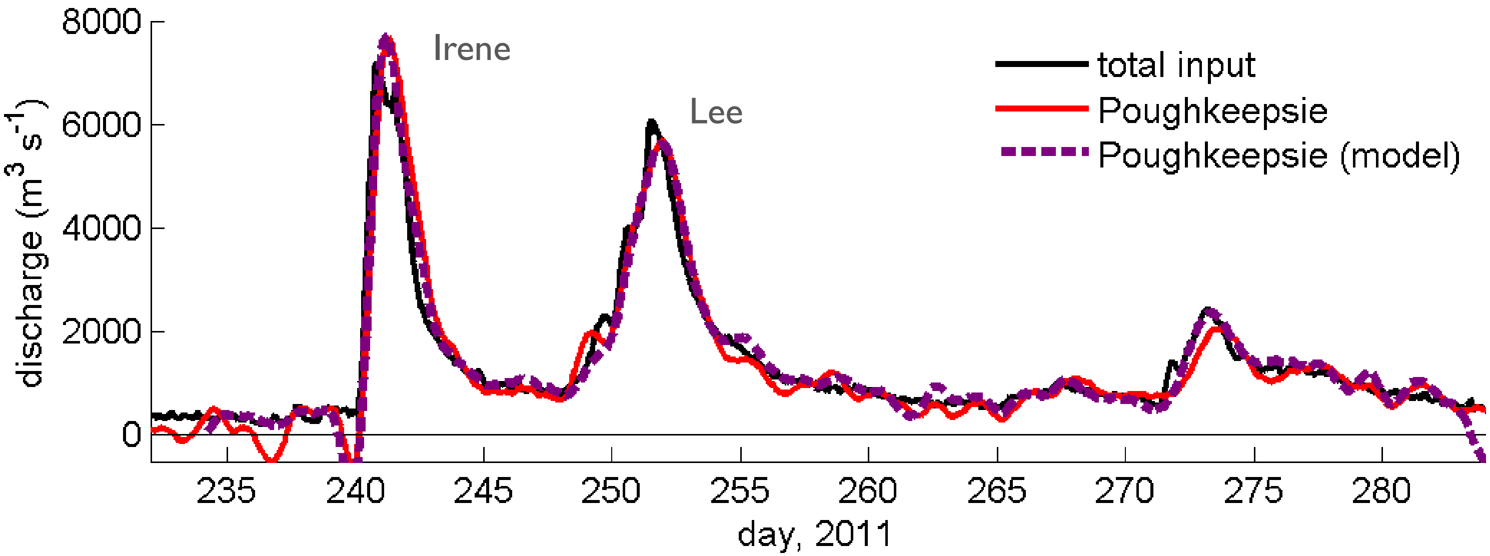


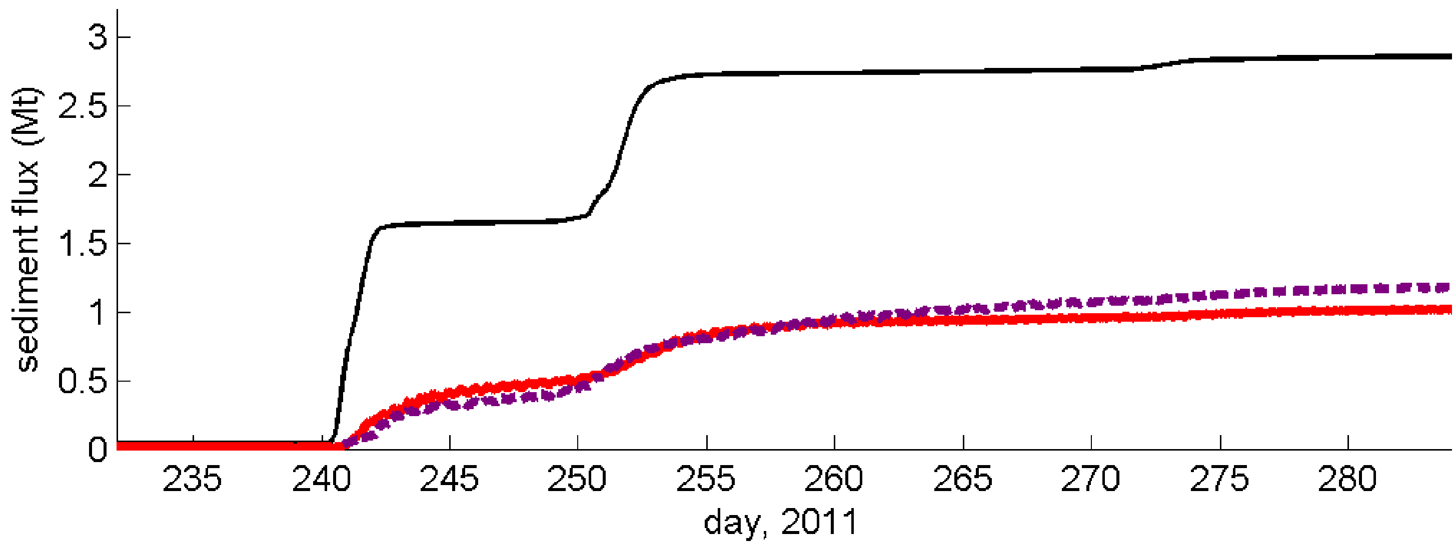




Discharge + sediment flux: observed, modeled

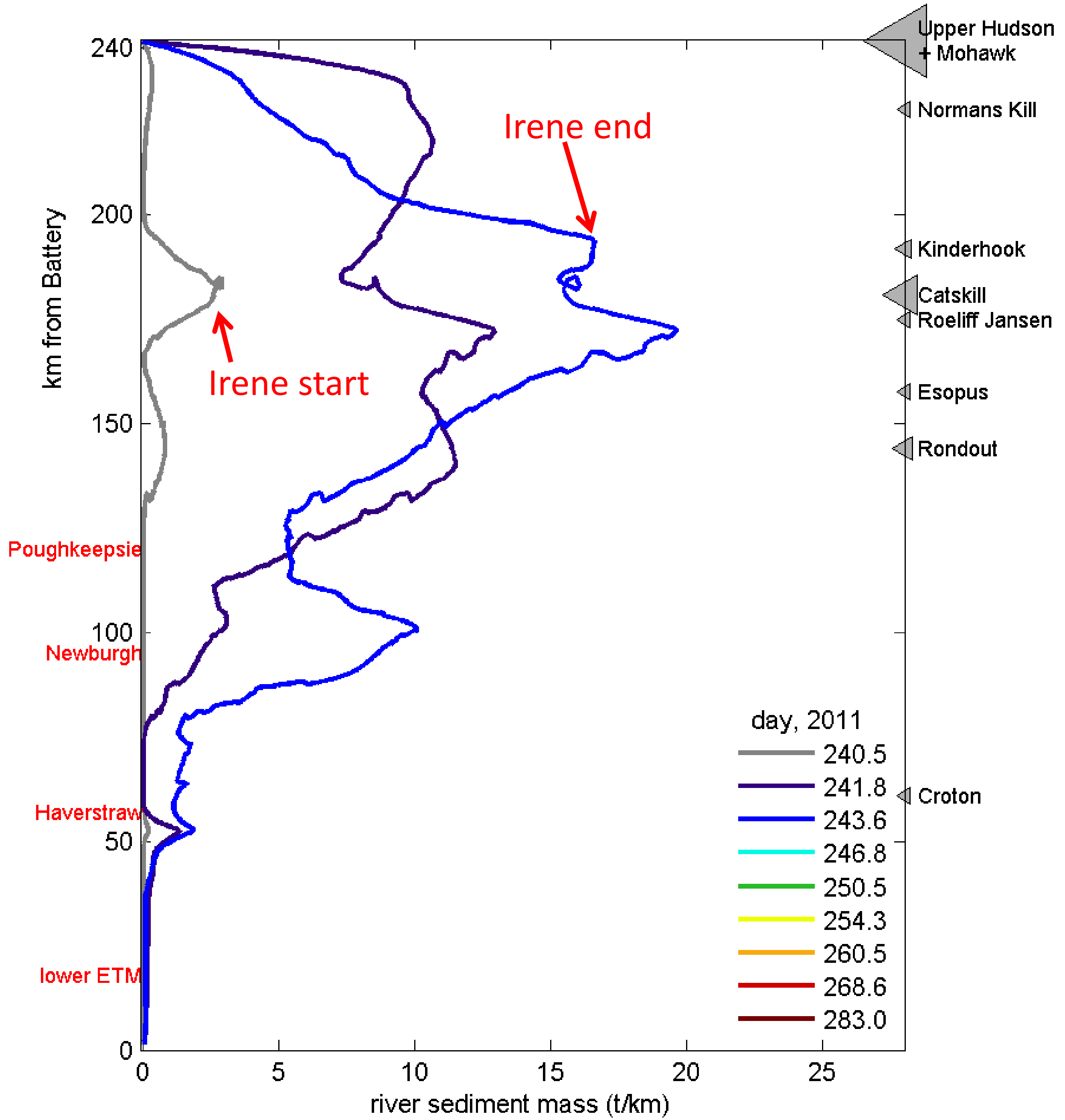






Where did the new sediment go?

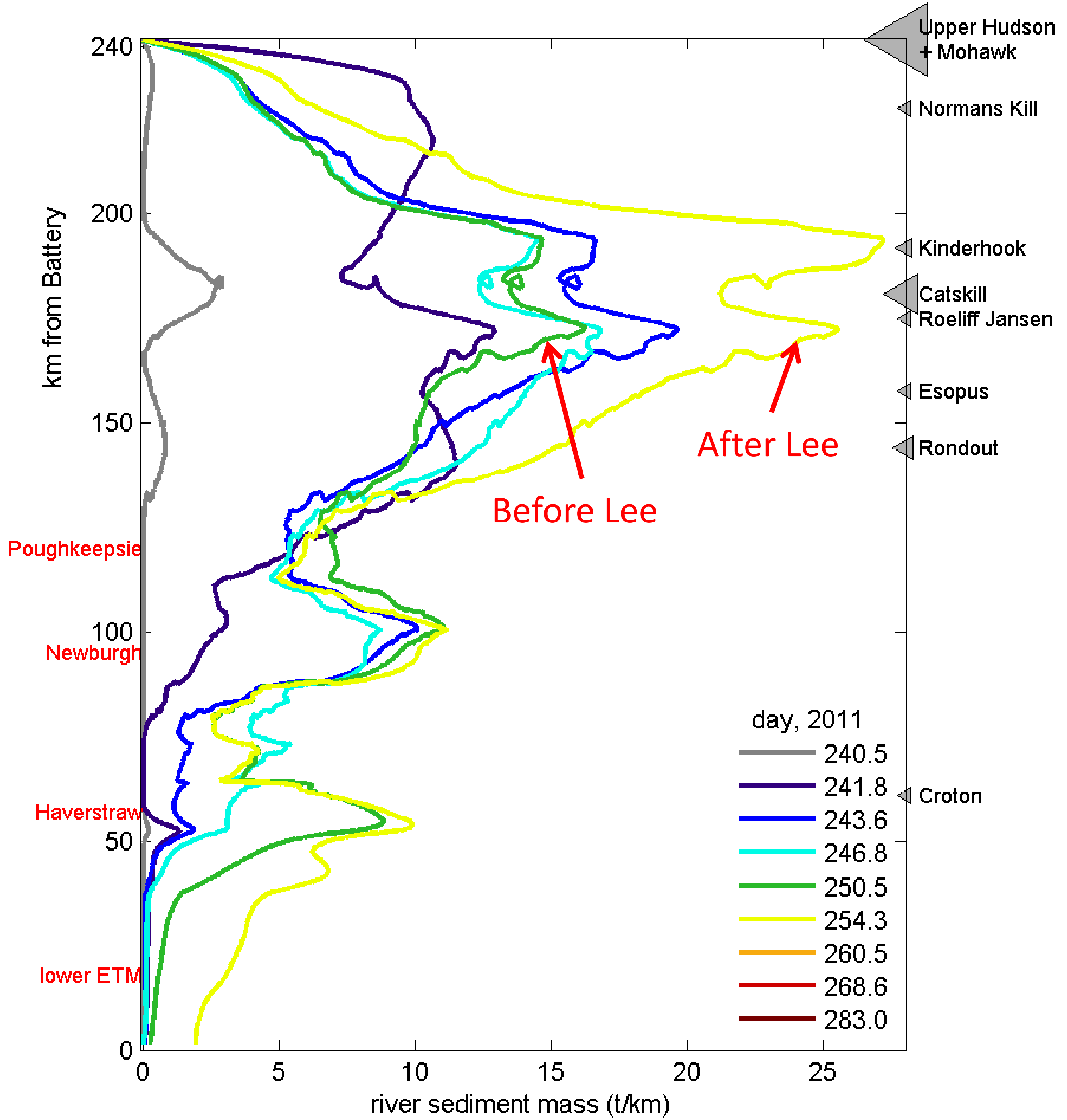
Sediment mass distributions through time



model results

Where did the new sediment go?

Sediment mass distributions through time



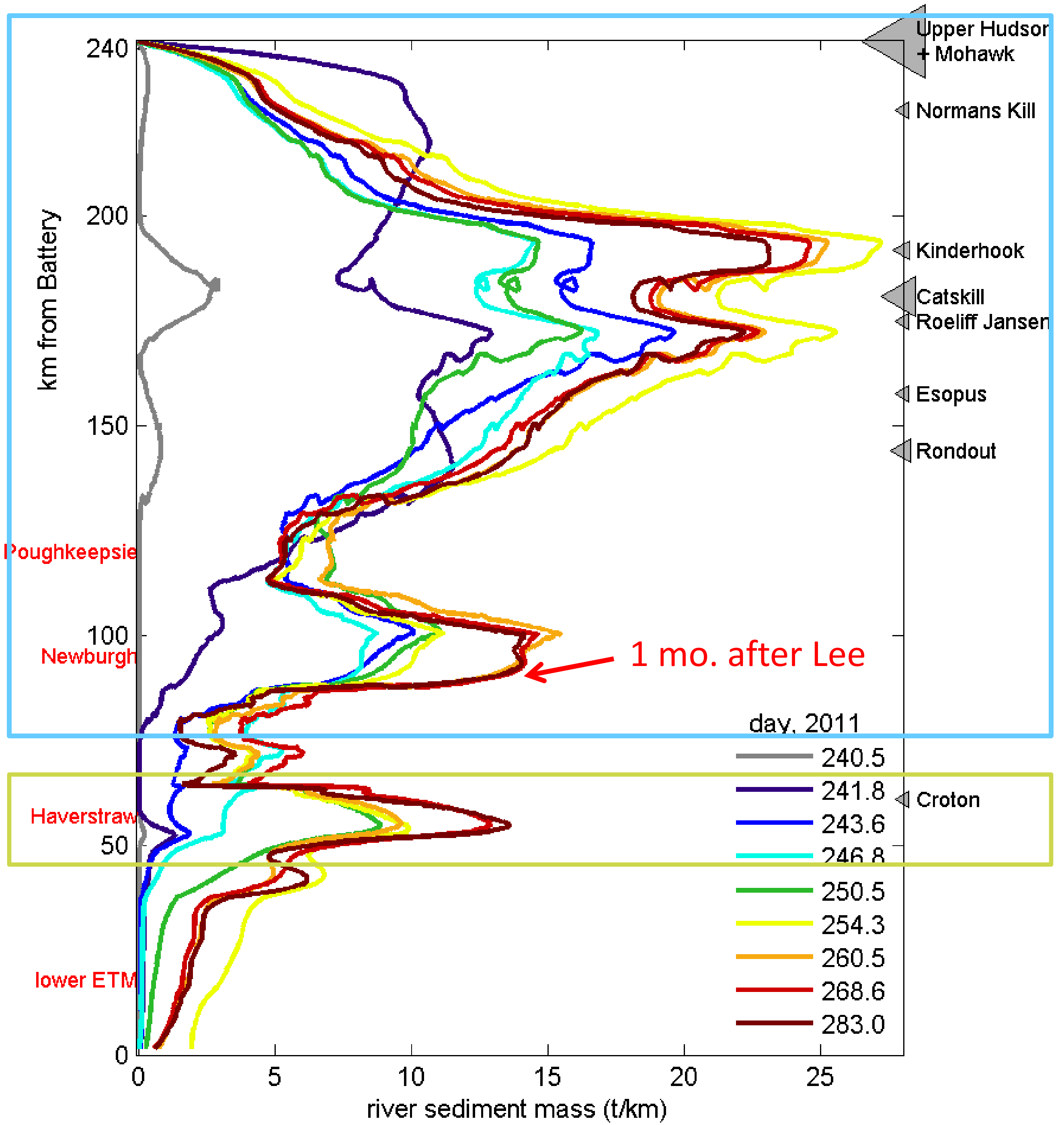
model results

Where did the new sediment go?

Sediment mass distributions through time

Fresh, tidal river

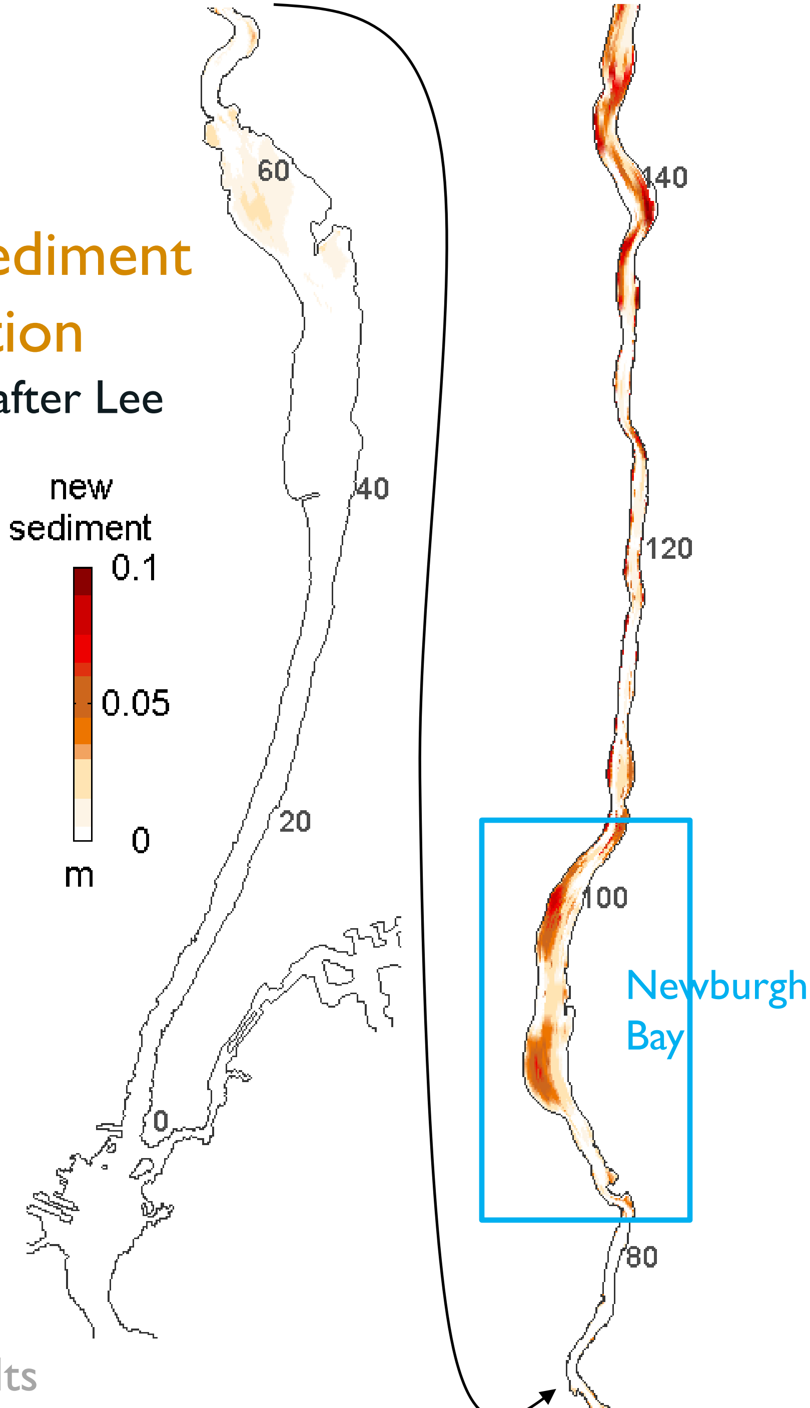
Deposition in upper ETM



model results

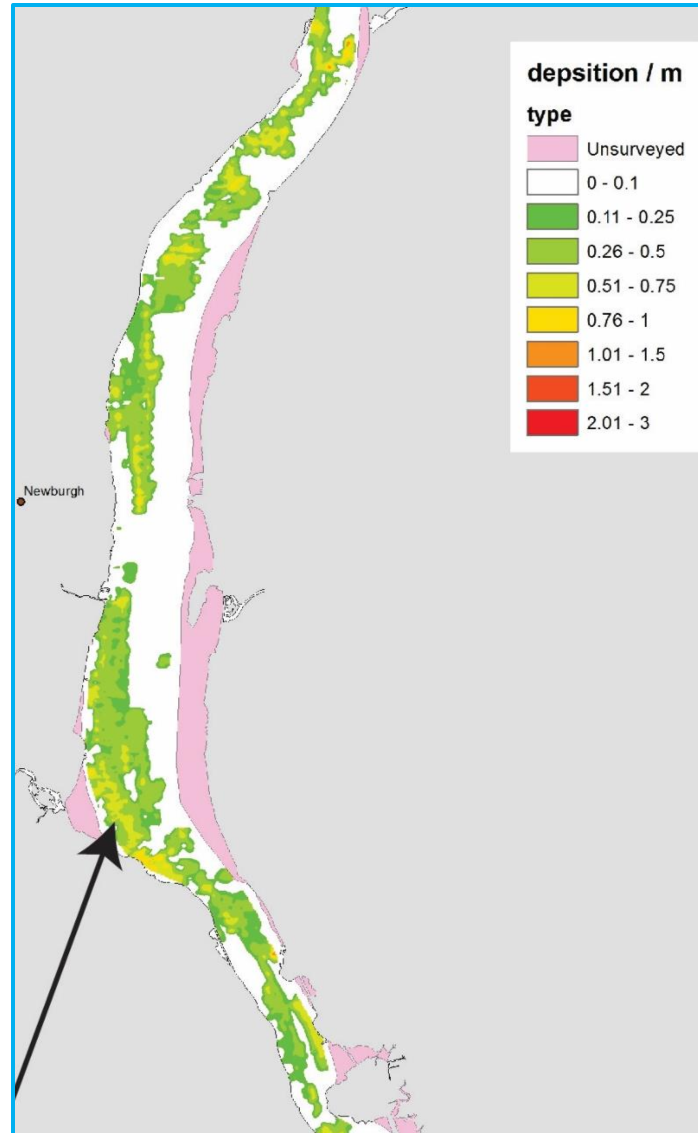
New sediment deposition

1 month after Lee

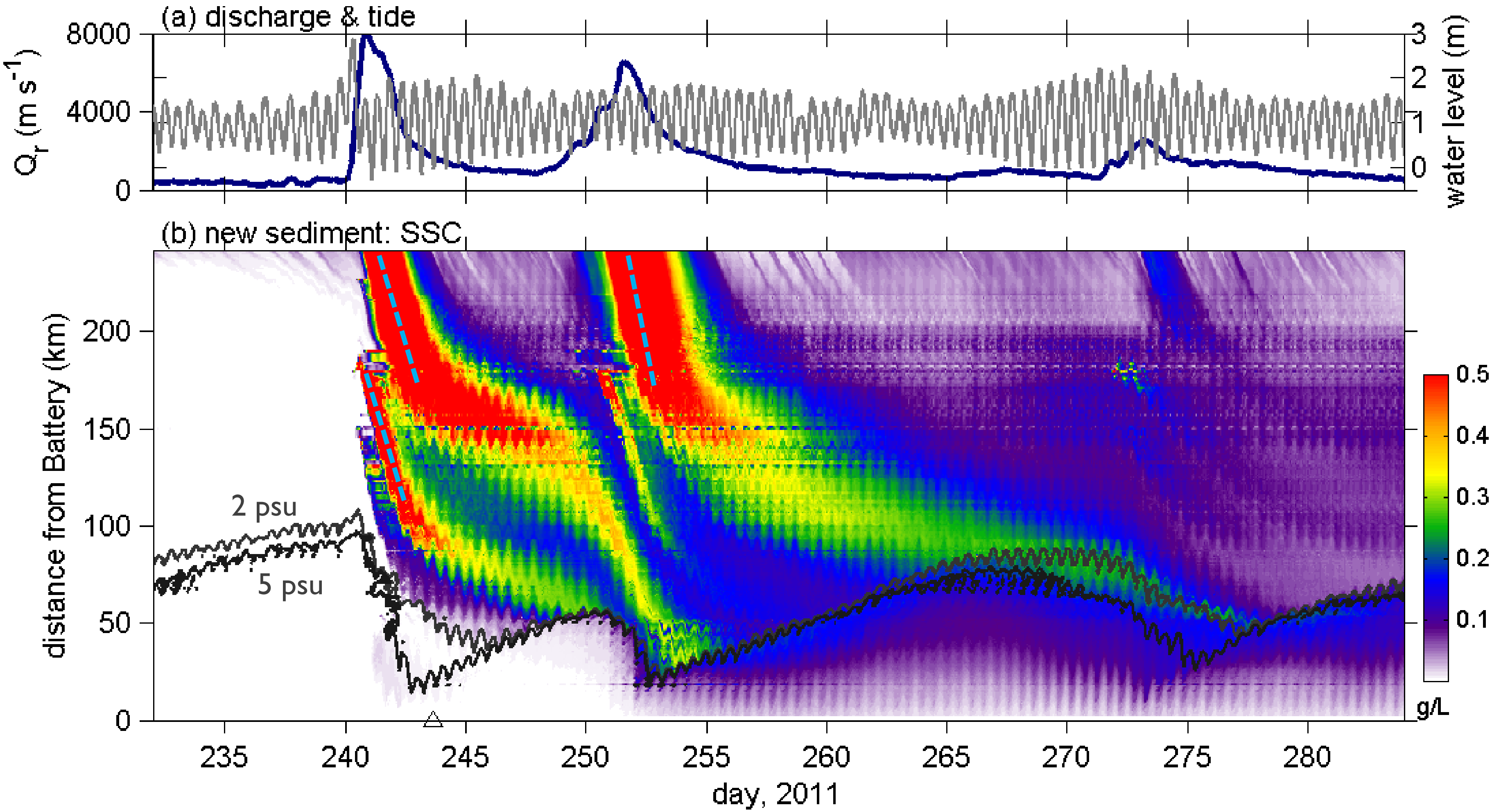


model results

Observed accumulation over past ~70 yr.
from Frank Nitsche (LDEO)



Suspended sediment – from watershed

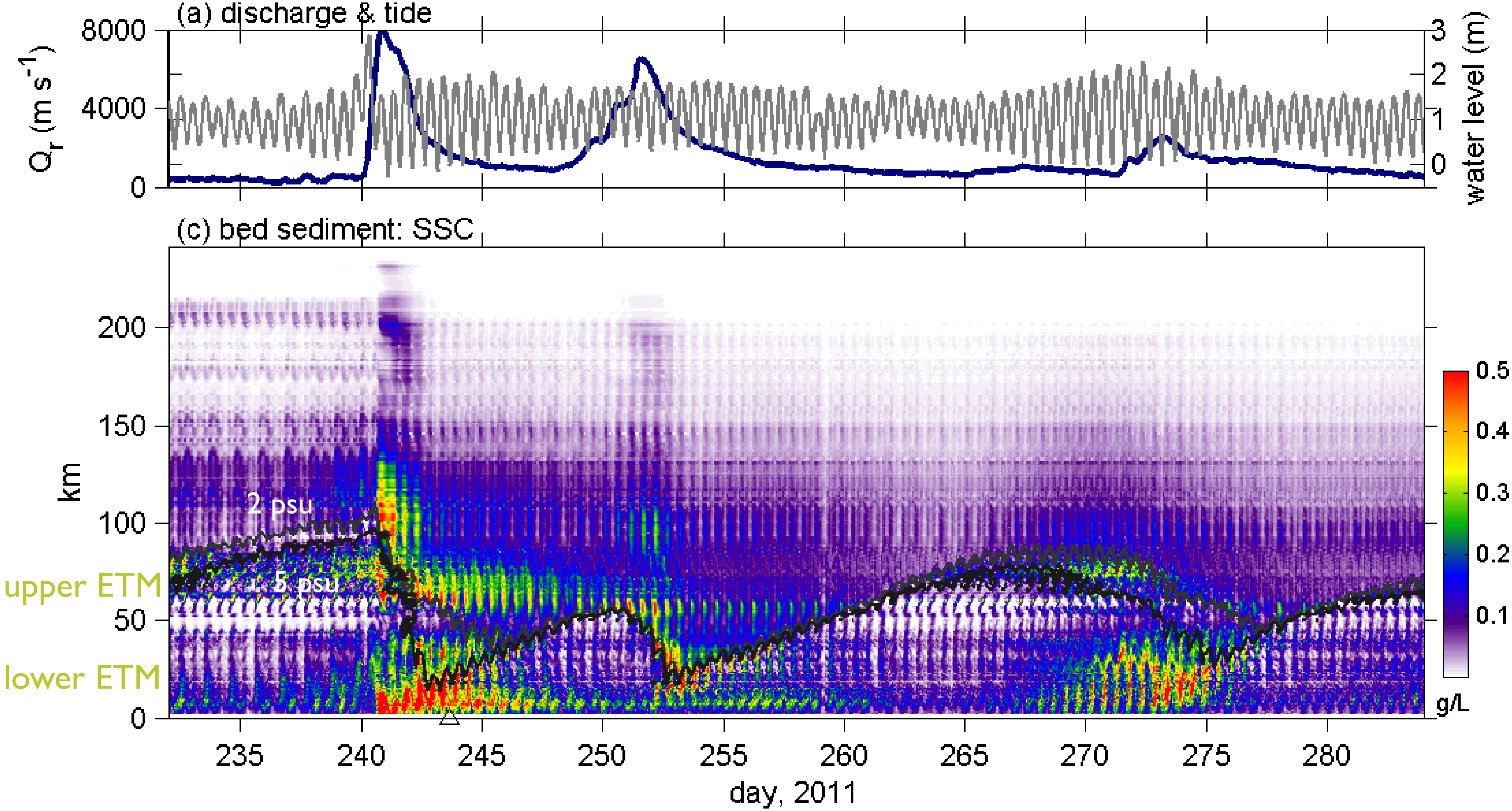


Advective length scale ~ $U_{river}\Delta t_{storm}$ ~ (0.4 m/s)(2 d) ~ 70 km

Flood pulses too short to move sediment through tidal river.

model results

Suspended sediment – from bed

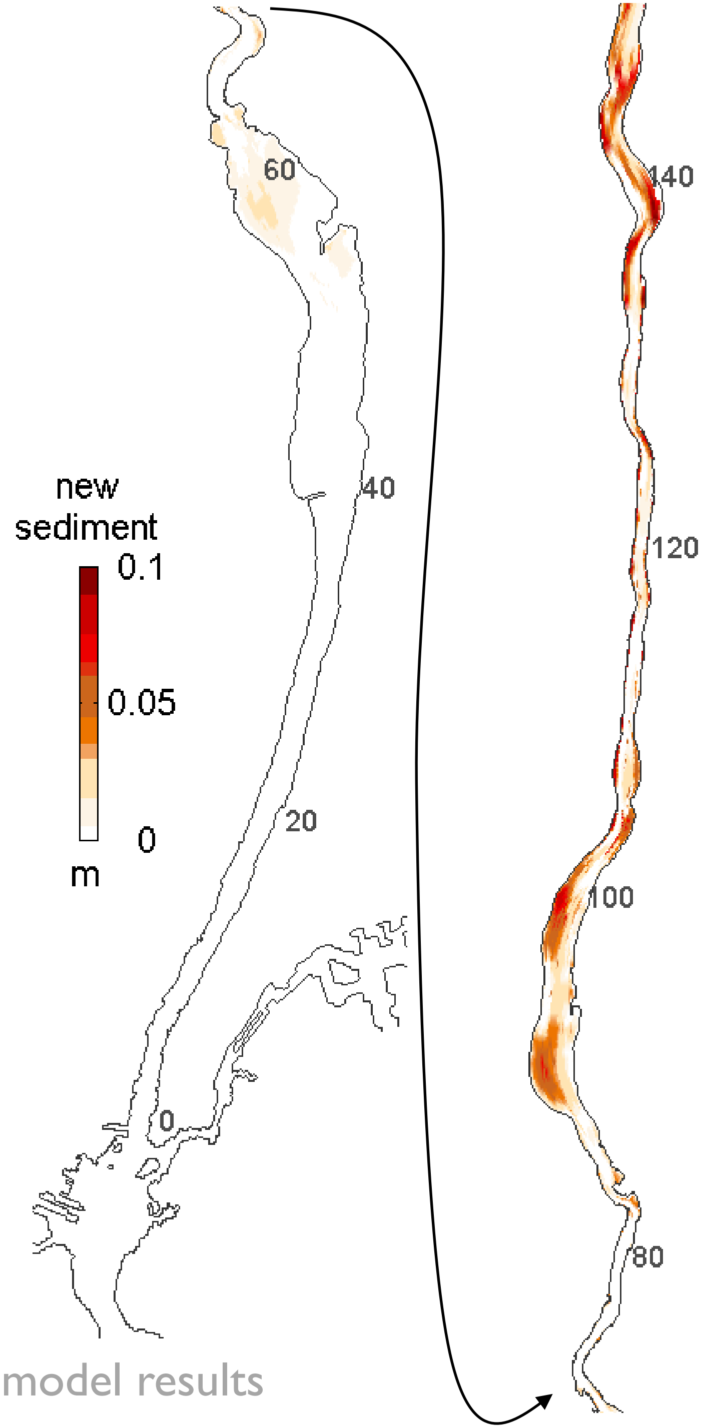


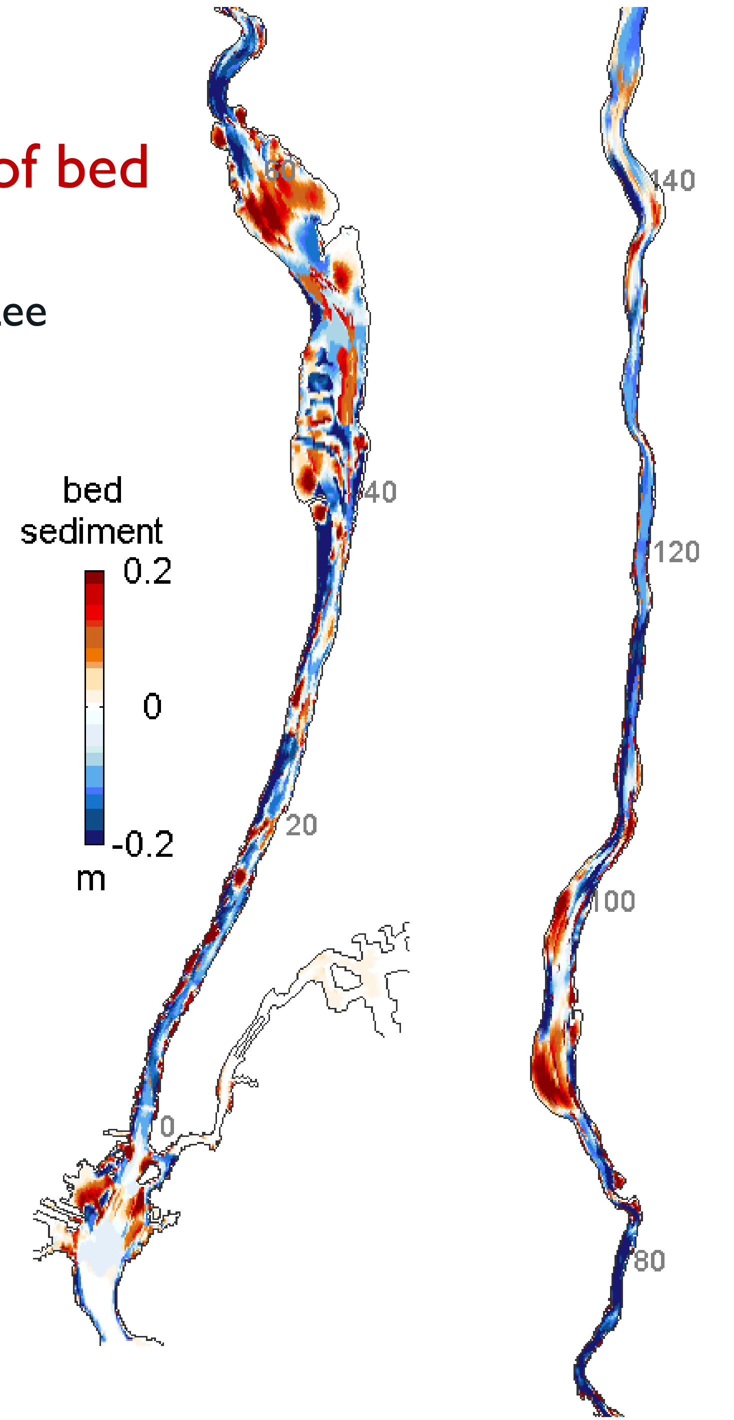
Remobilized bed sediment due to increased stress and reduced stratification dominates SSC signal in the estuary.

model results

Erosion and deposition of bed sediment

1 month after Lee

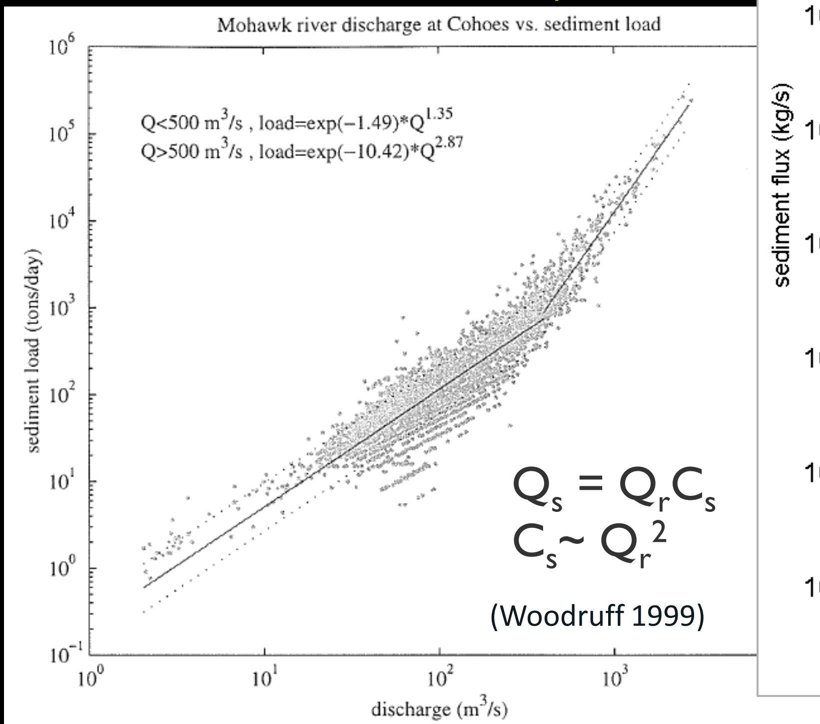




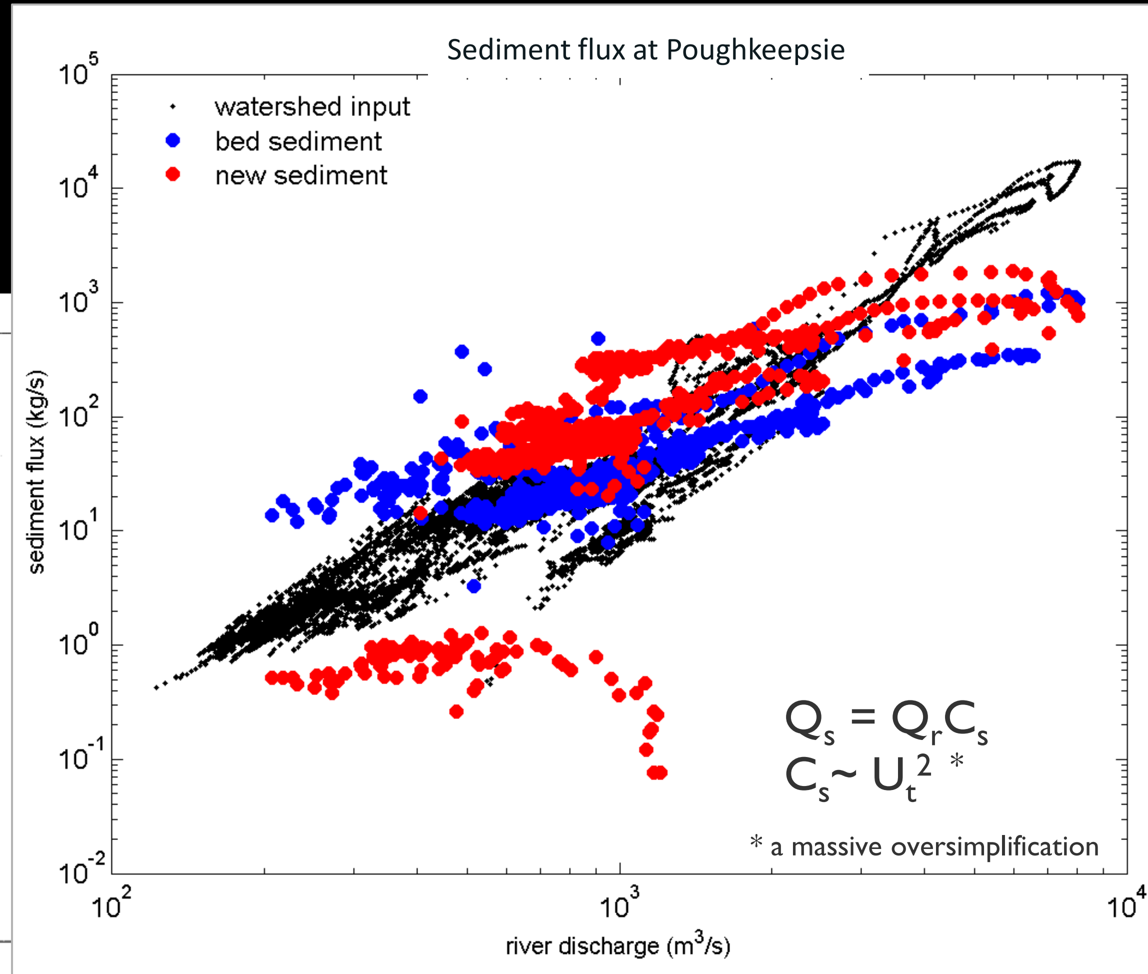
model results

Why is new sediment stuck in the tidal river?

Watershed sediment loading highly non-linear → ~ Q_r^3

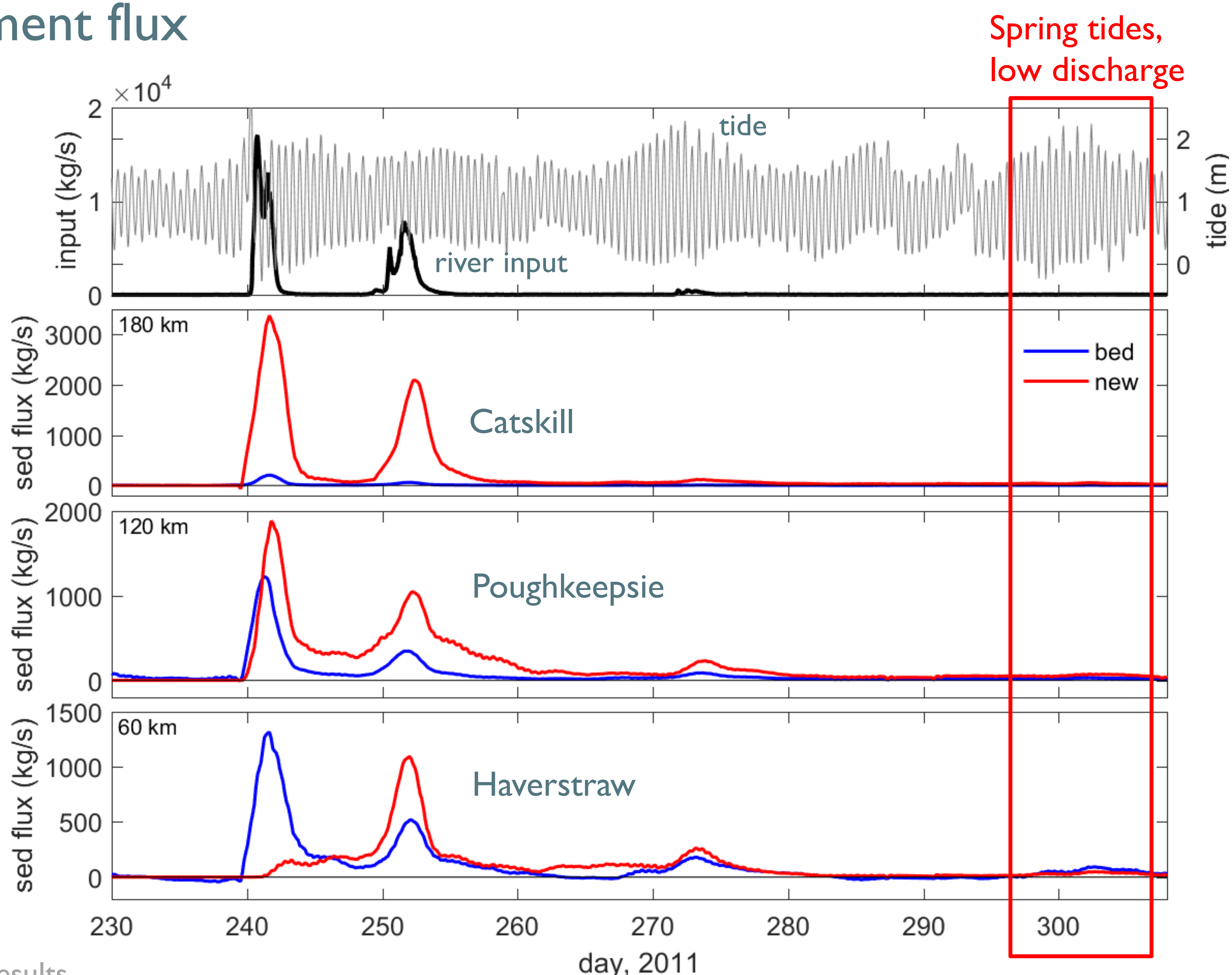


Transport in river scales linearly → ~ Q_r^1



- River provides mean flow (0.05-0.4 m/s), but tides dominate resuspension (0.5-1m/s)
- Enhanced velocity, resuspension, seaward flux during event is brief, much less than input

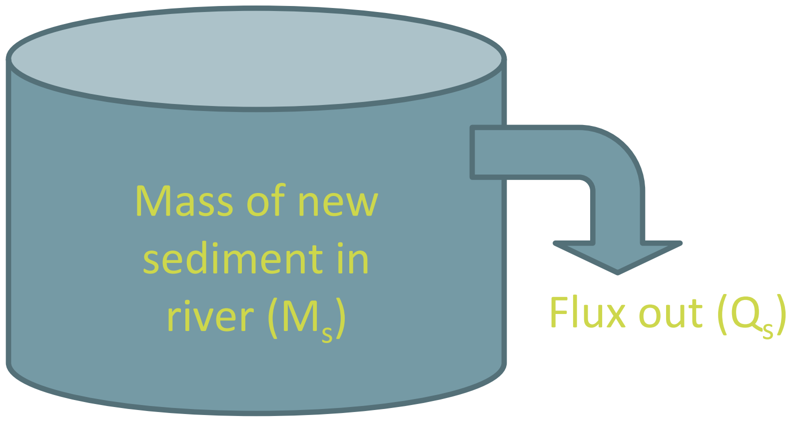
Sediment flux



model results

Transport time scale: T ~ M_s/Q_s

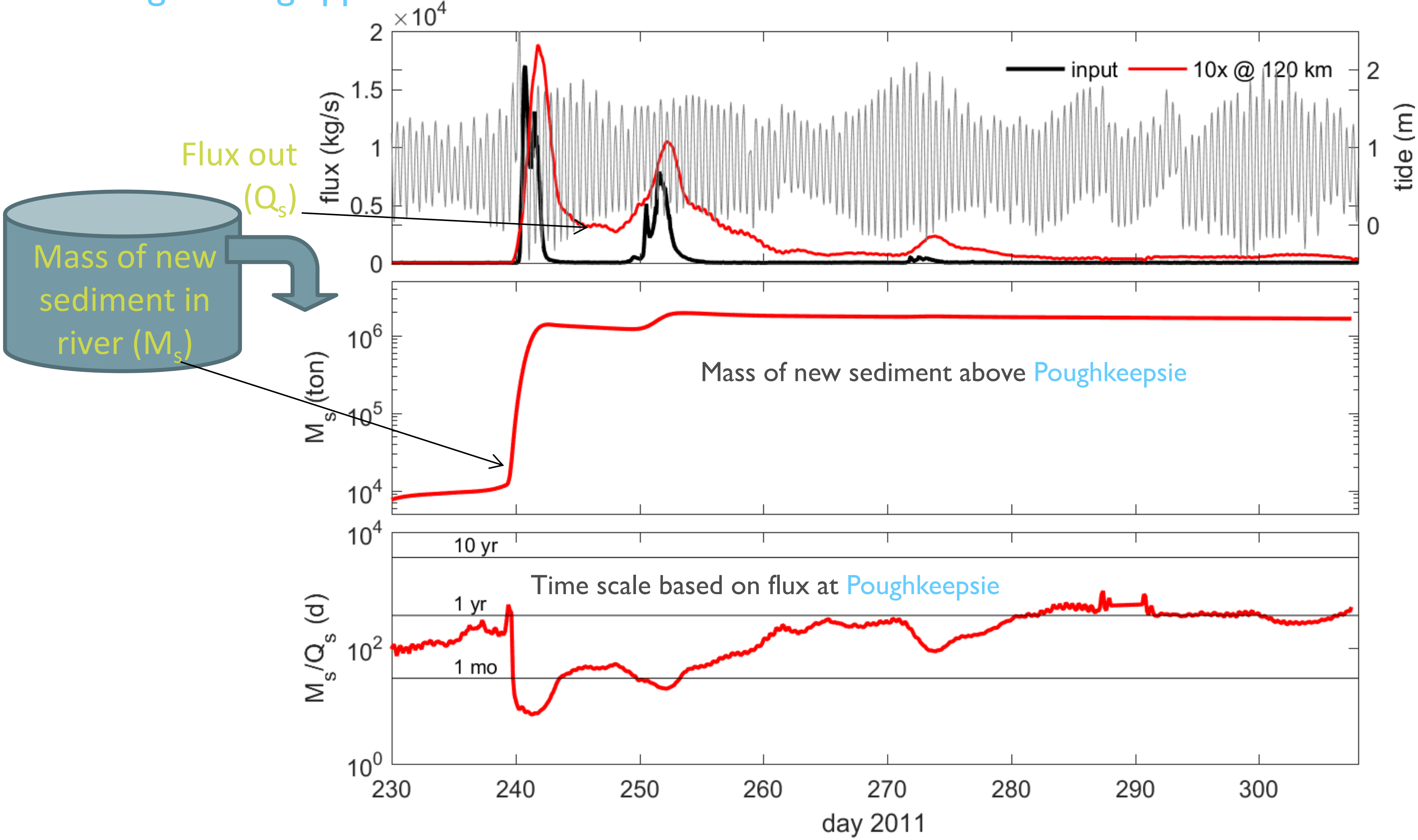
An engineering approach



Transport time scale: $T \sim M_s/Q_s$

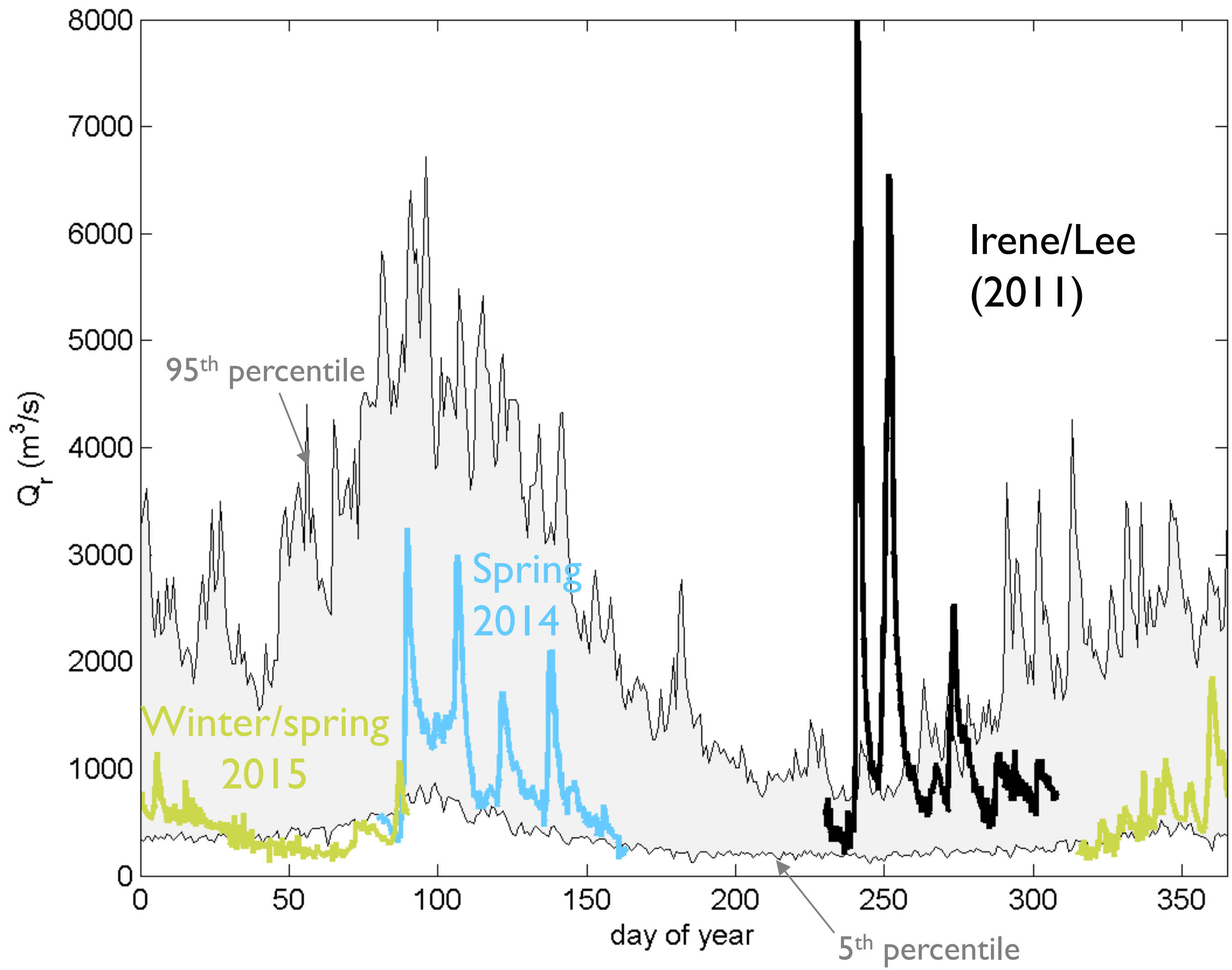
An engineering approach

Ignores changes in erodibility, settling velocity; sequestering → model uncertainty increases w/ time

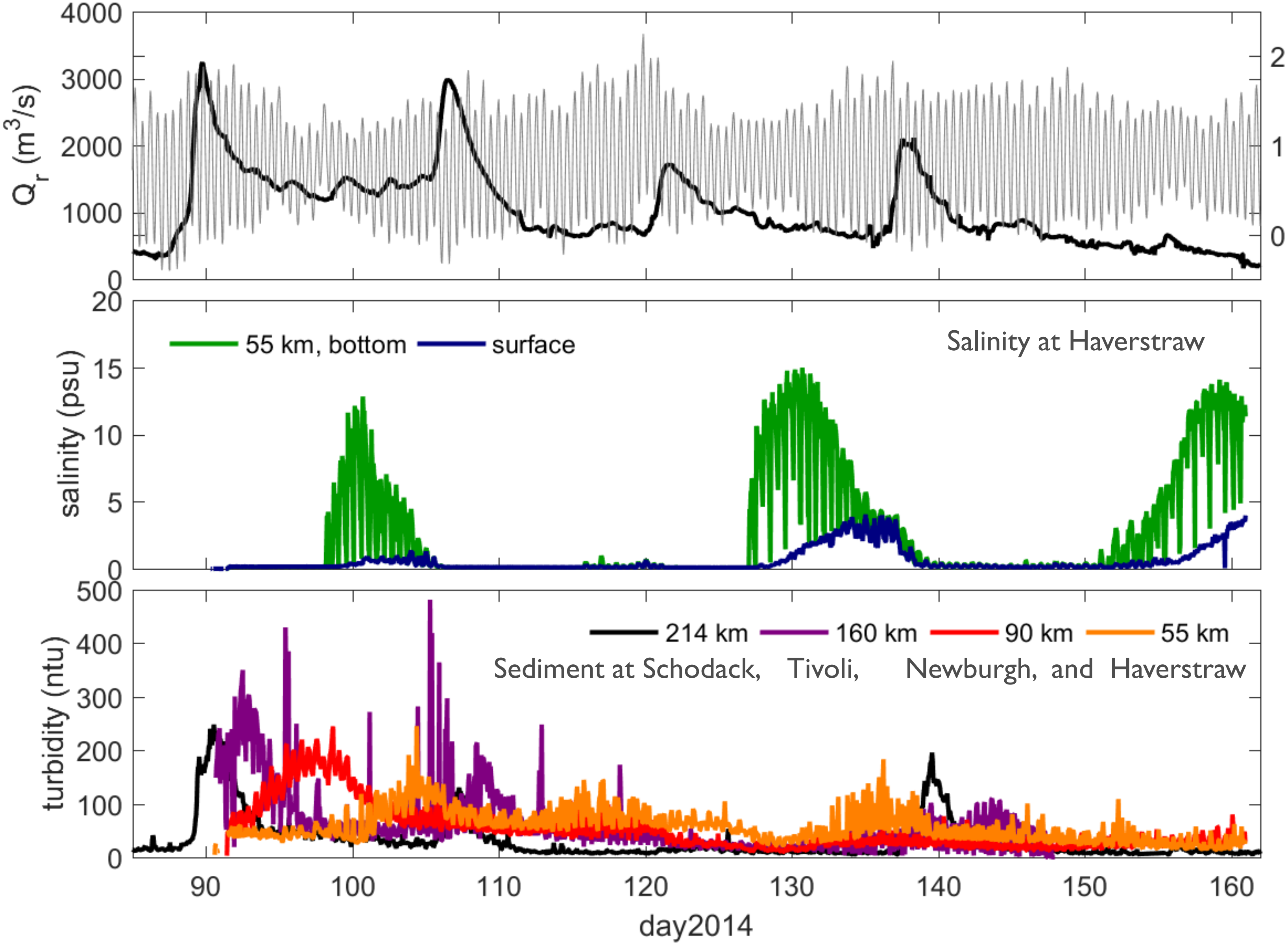


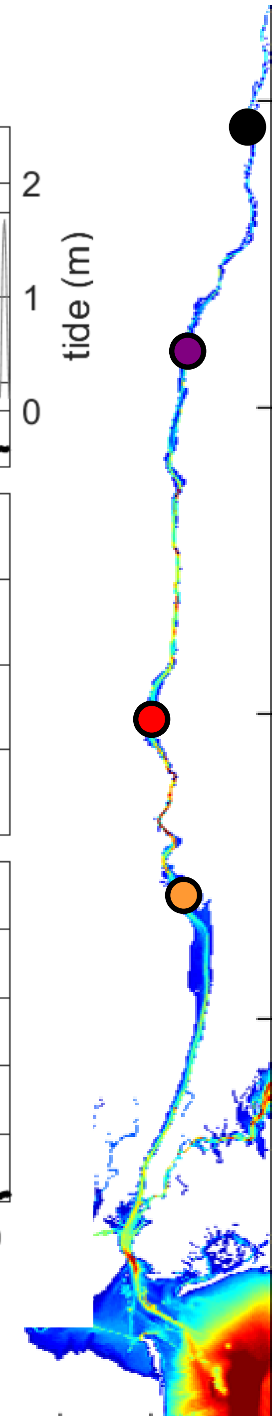
model results

Effect of discharge?



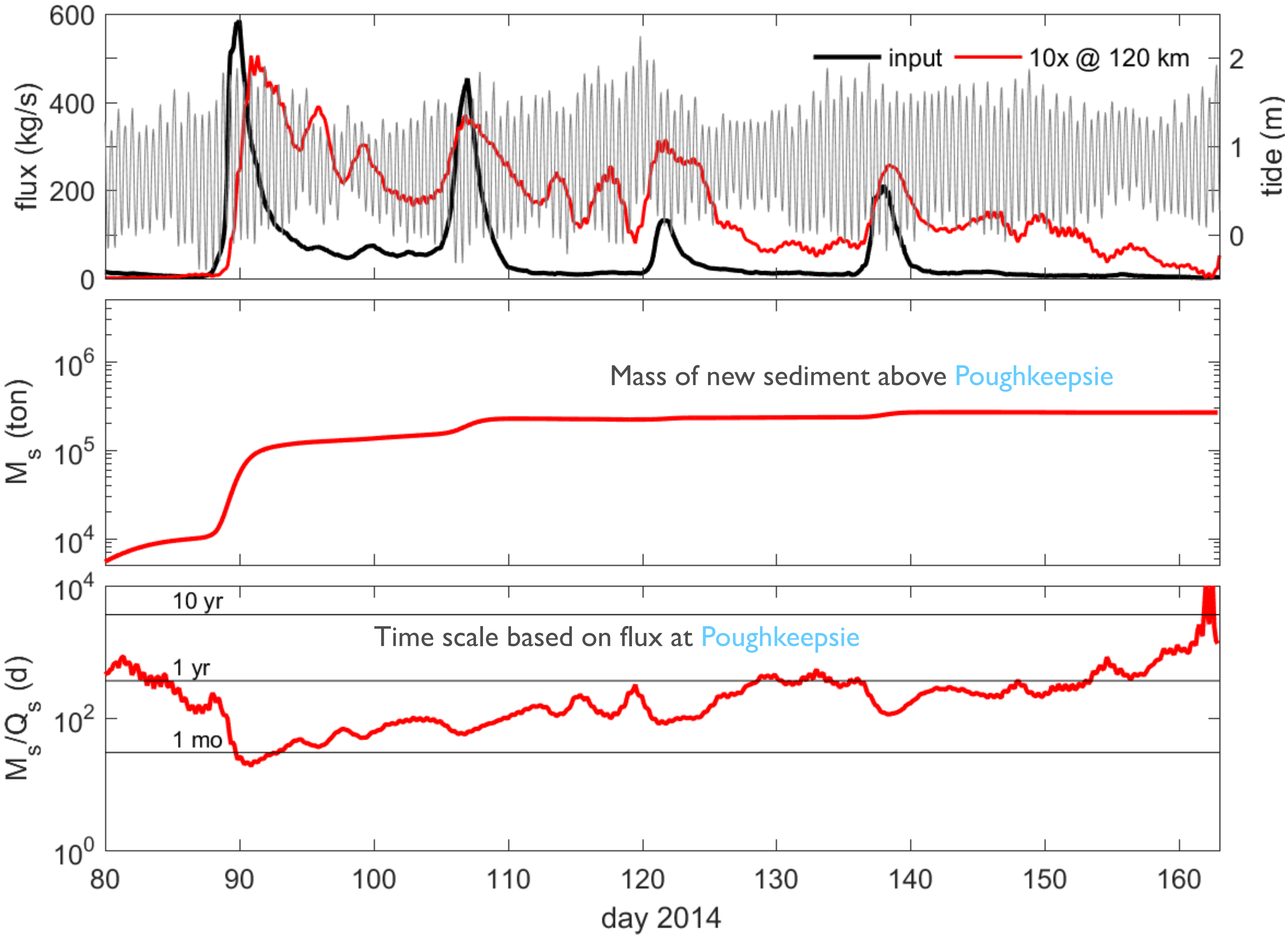
Spring 2014 – typical freshet





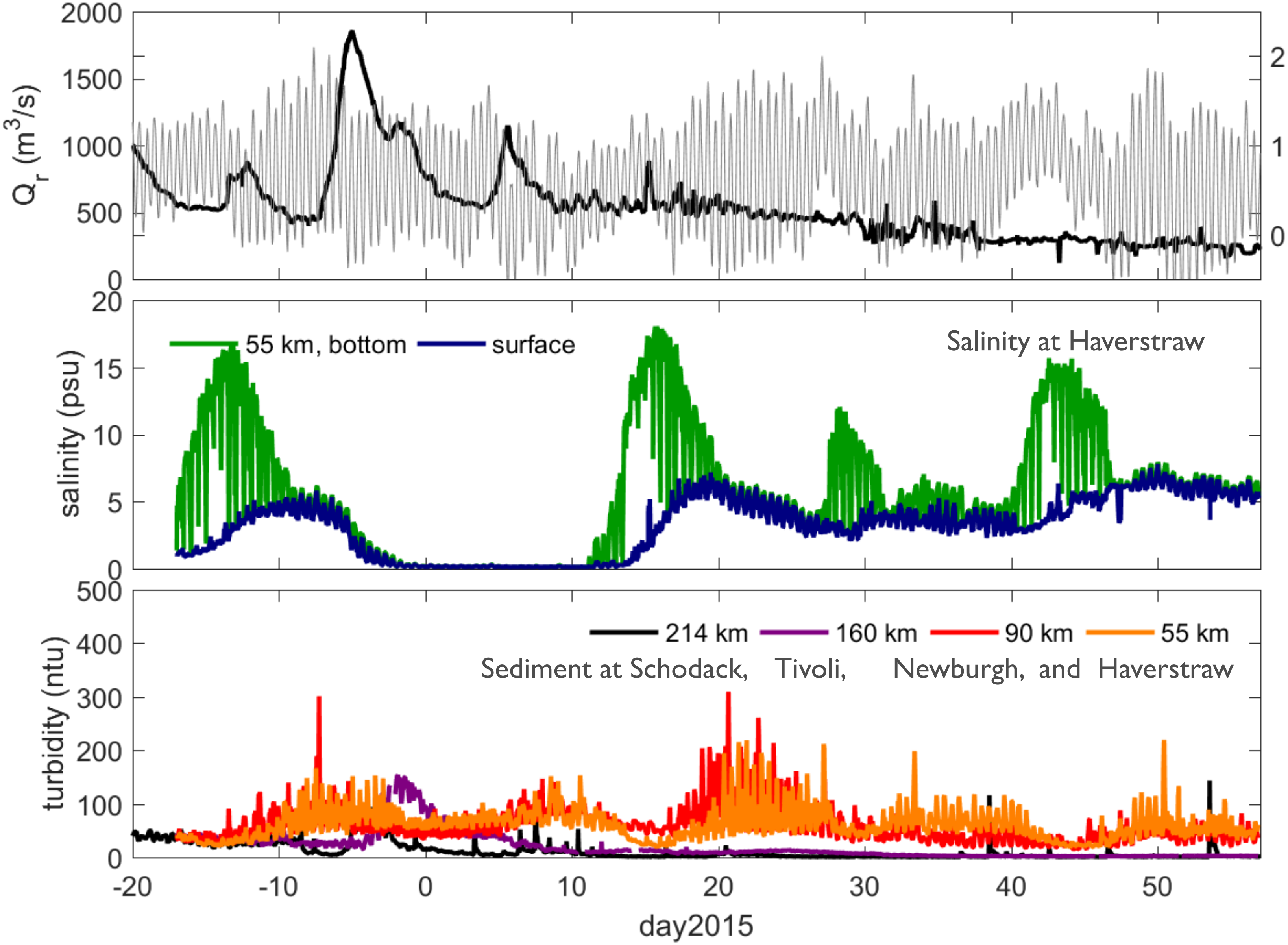
observations

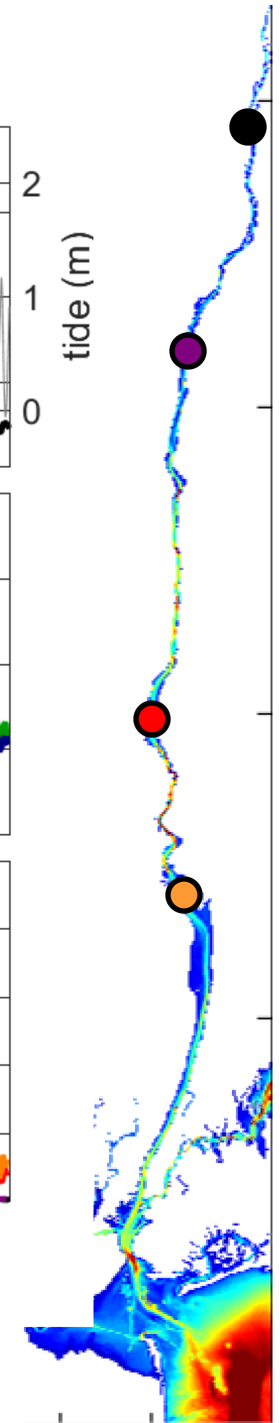
Spring 2014 – typical freshet



model results

Winter/spring 2015 – below average discharge





observations

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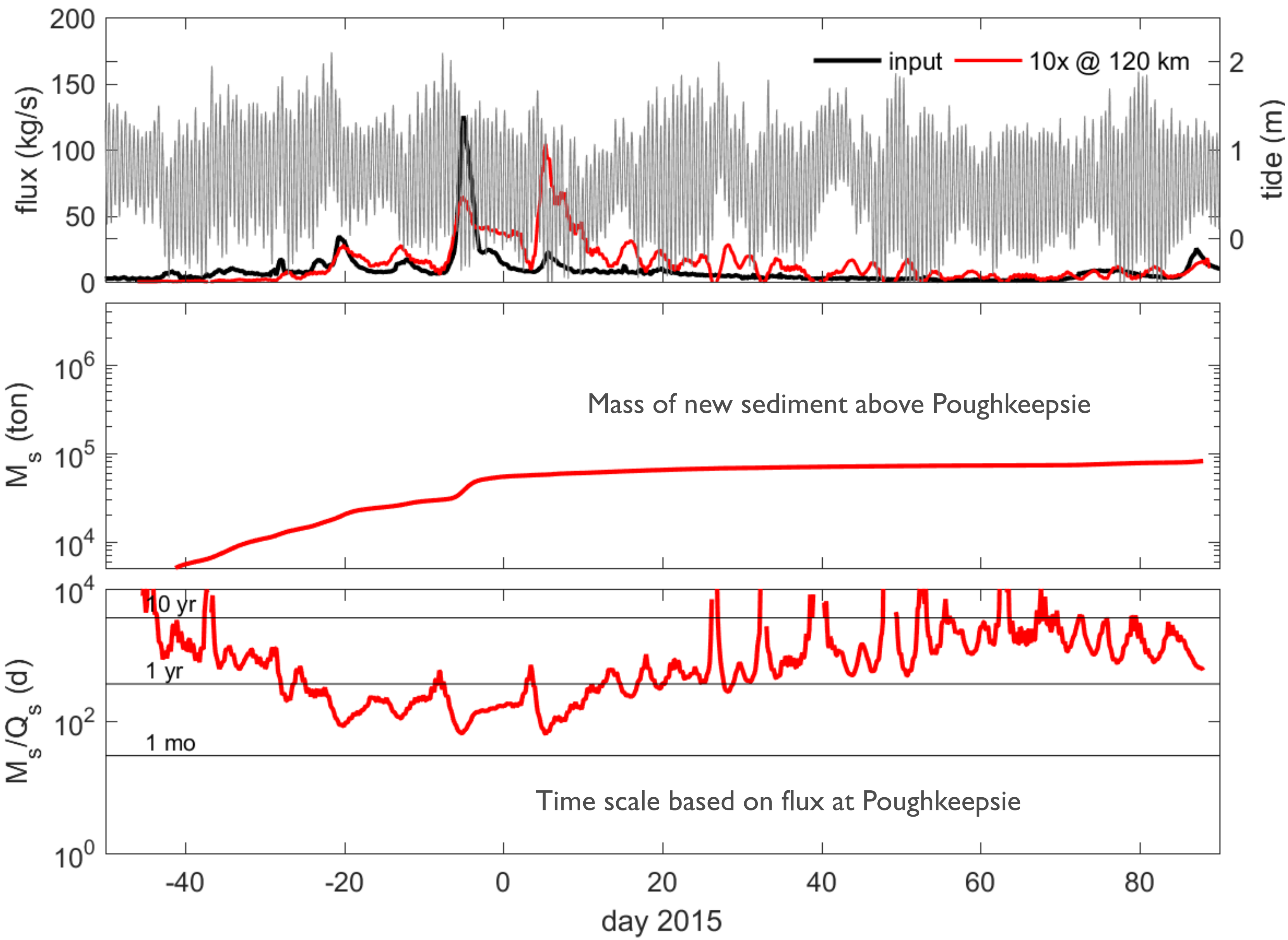
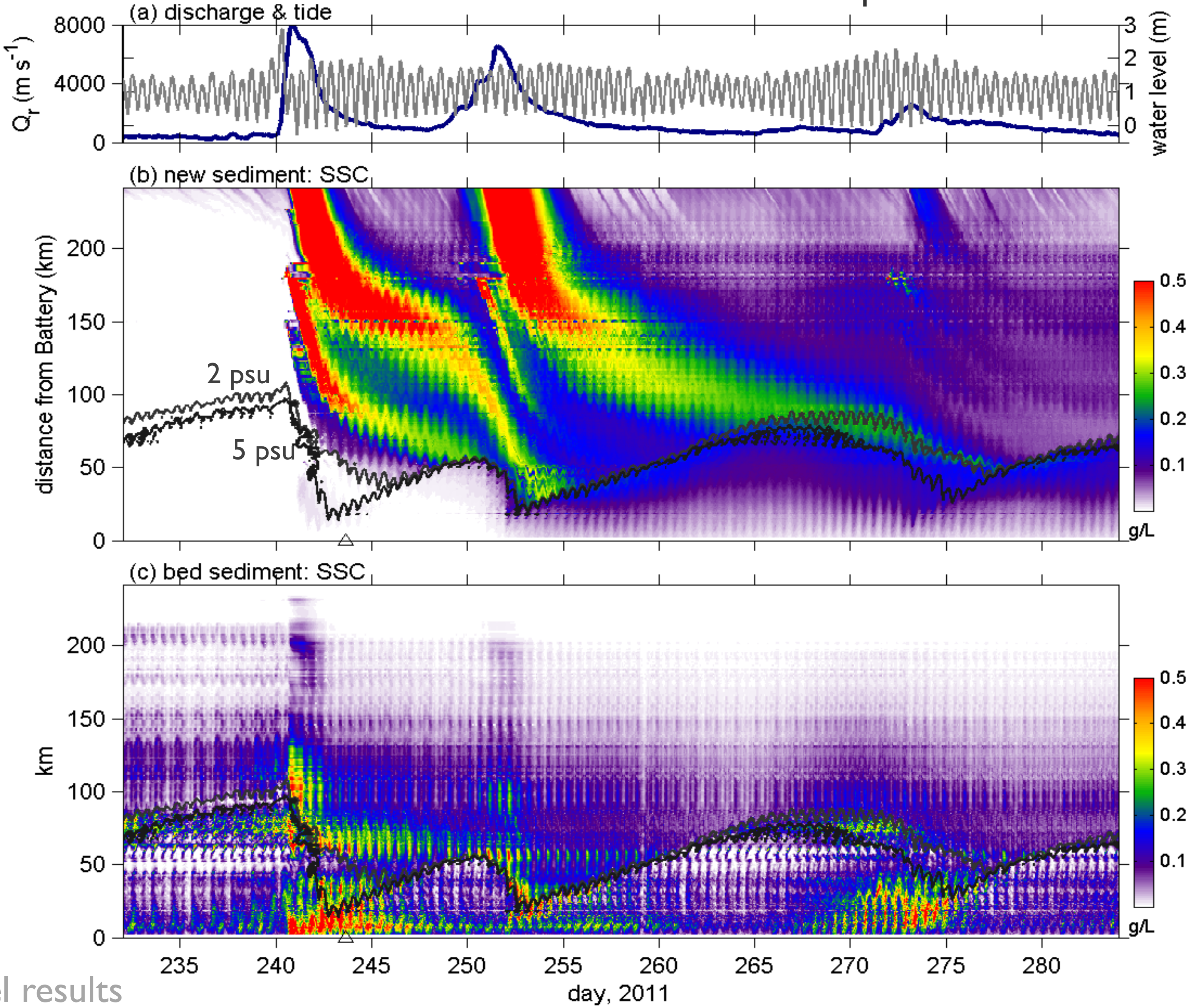


model results

Transport during event depends on salinity intrusion

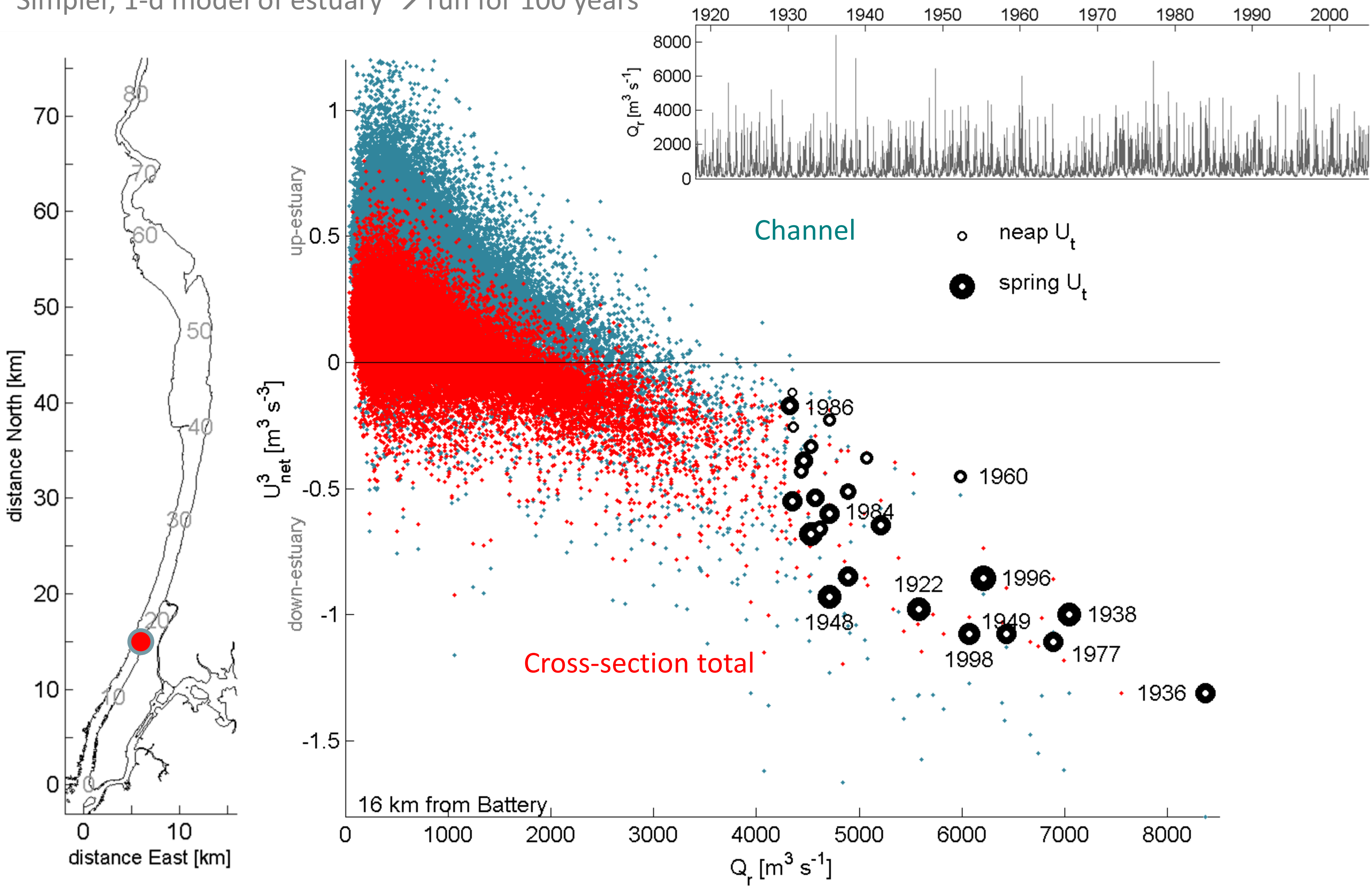
Storm duration << estuarine response time scale



model results

Sediment transport capacity in the estuary

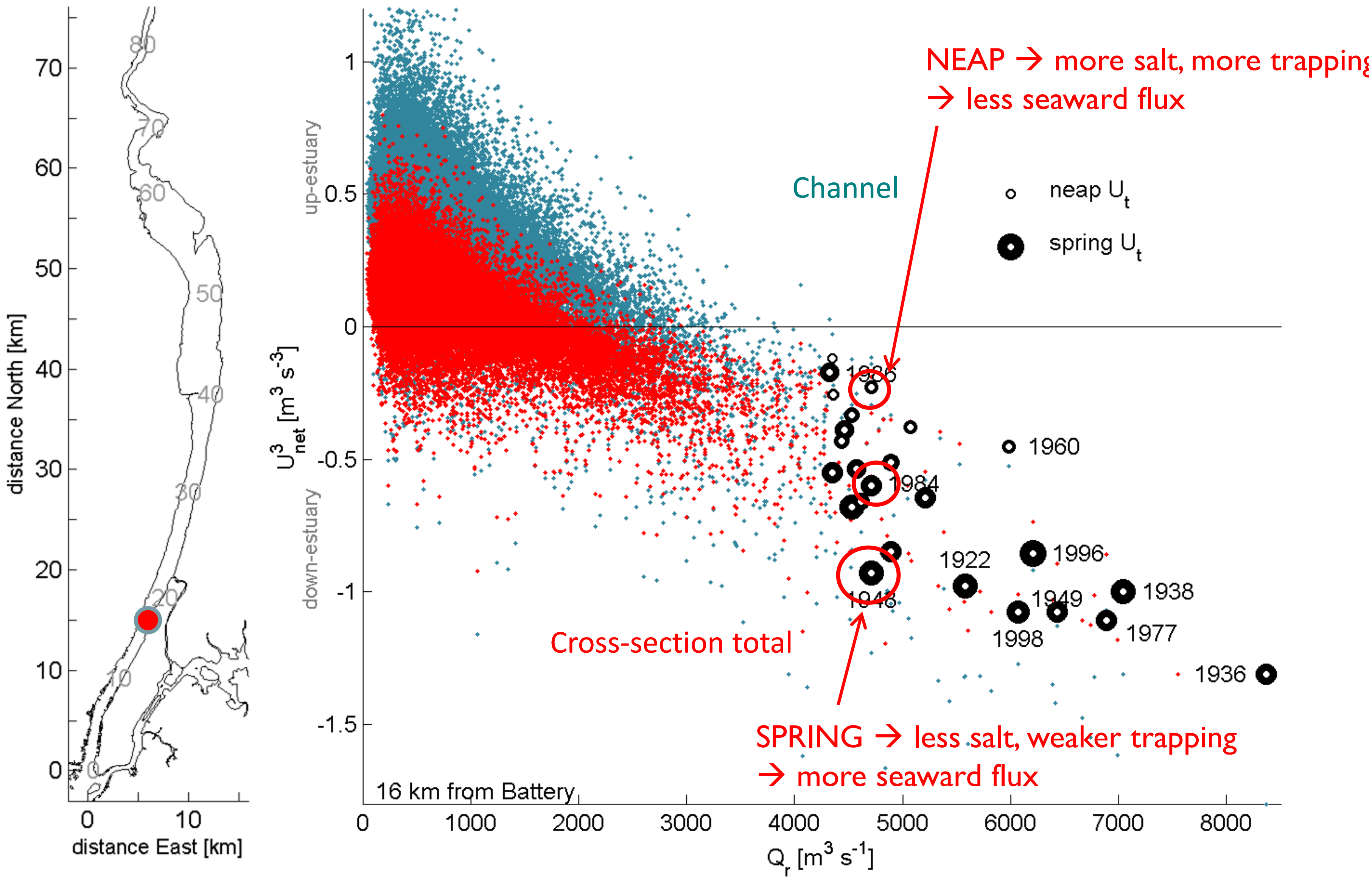
Simpler, 1-d model of estuary → run for 100 years



different model results

Sediment transport capacity in the estuary

Simpler, 1-d model of estuary → run for 100 years



different model results

Summary

Sediment load from extreme events greatly exceeds near-term transport capacity

→ Watershed input scales as Q_r^3, transport as Q_r

→ New sediment trapped in tidal river (~80%)

In estuary, bed remobilization due to reduced stratification, increased stress dominates

→ Potential to reintroduce sequestered contaminants

→ Depends on spring/neap phasing, event duration

Sediment residence times may be much longer, more variable than thought

→ Previously, focus on annual freshet cycle

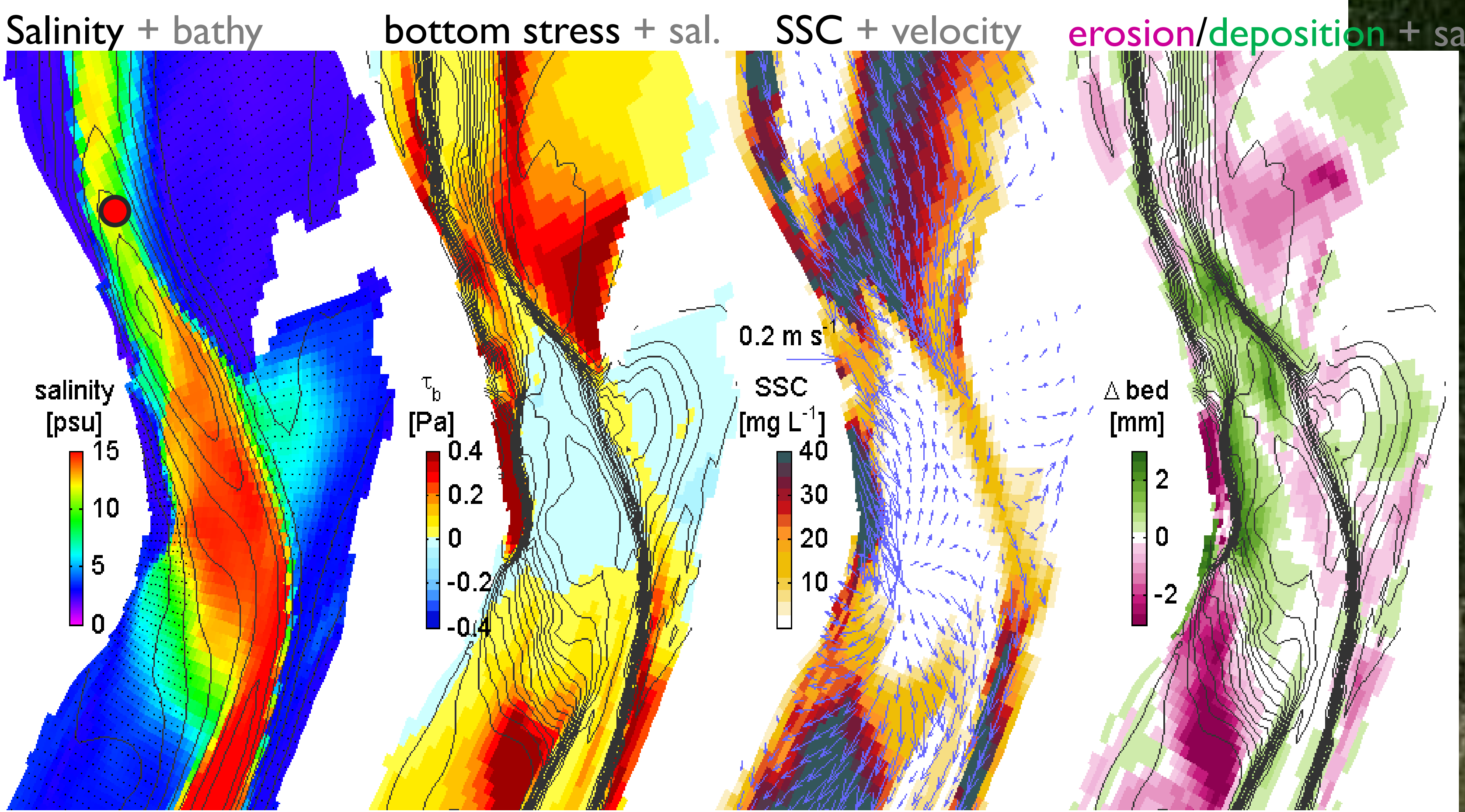
→ Slower export of terrigenous material to the coastal ocean?

→ Physics hard to constrain, use geochemistry

HUDSON RIVER FOUNDATION

NSF

Salinity front sediment trapping: Haverstraw Bay

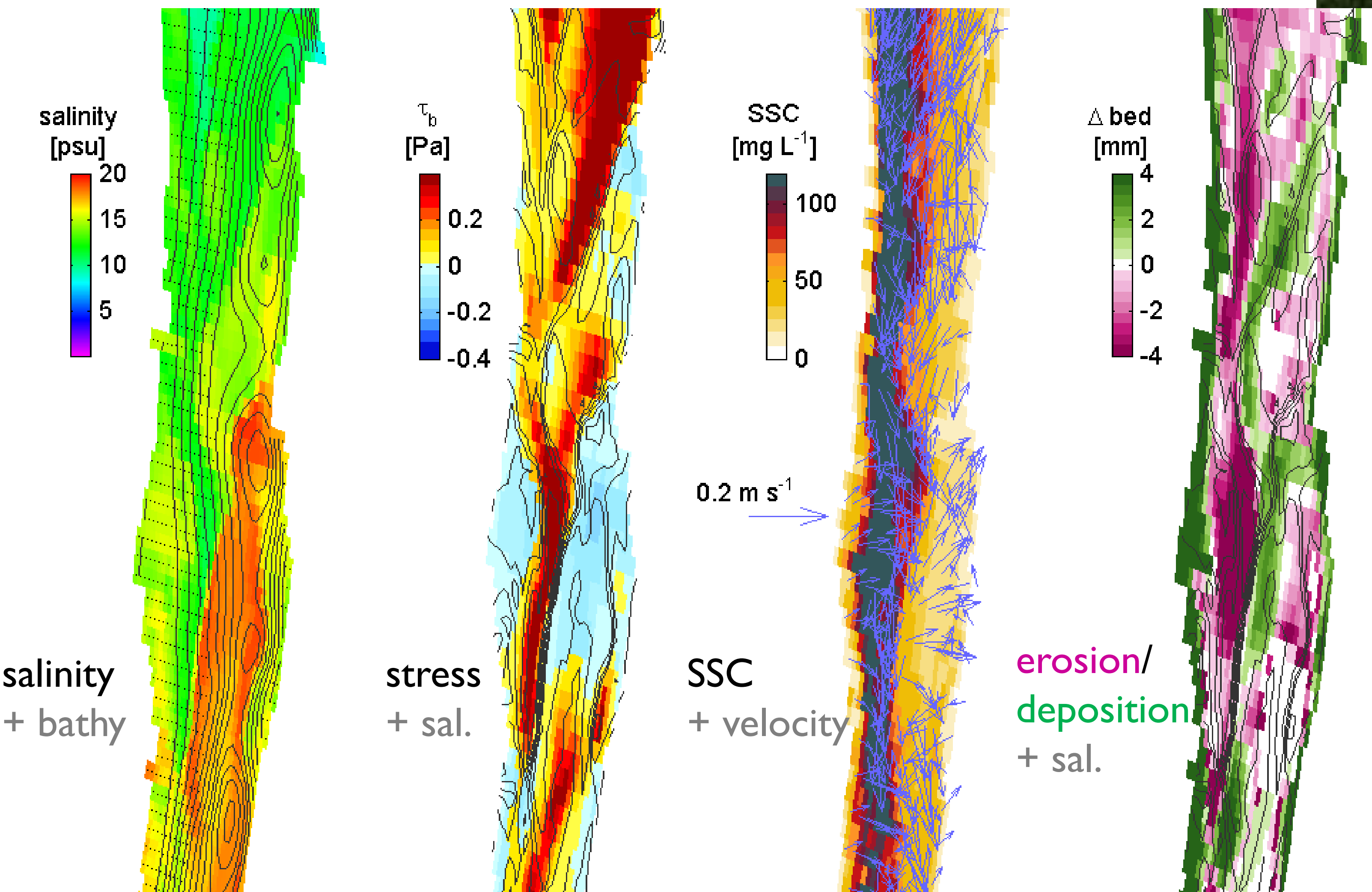


Slack before flood

Net over 1 tidal cycle

model results, Fall 2009

Salinity front sediment trapping: GW Bridge



Slack before flood

Net over 1 tidal cycle

model results, Fall 2009