2.29 final project

Differences between a straight river estuary and a meandering estuary

- hydrodynamics and salinity dynamics

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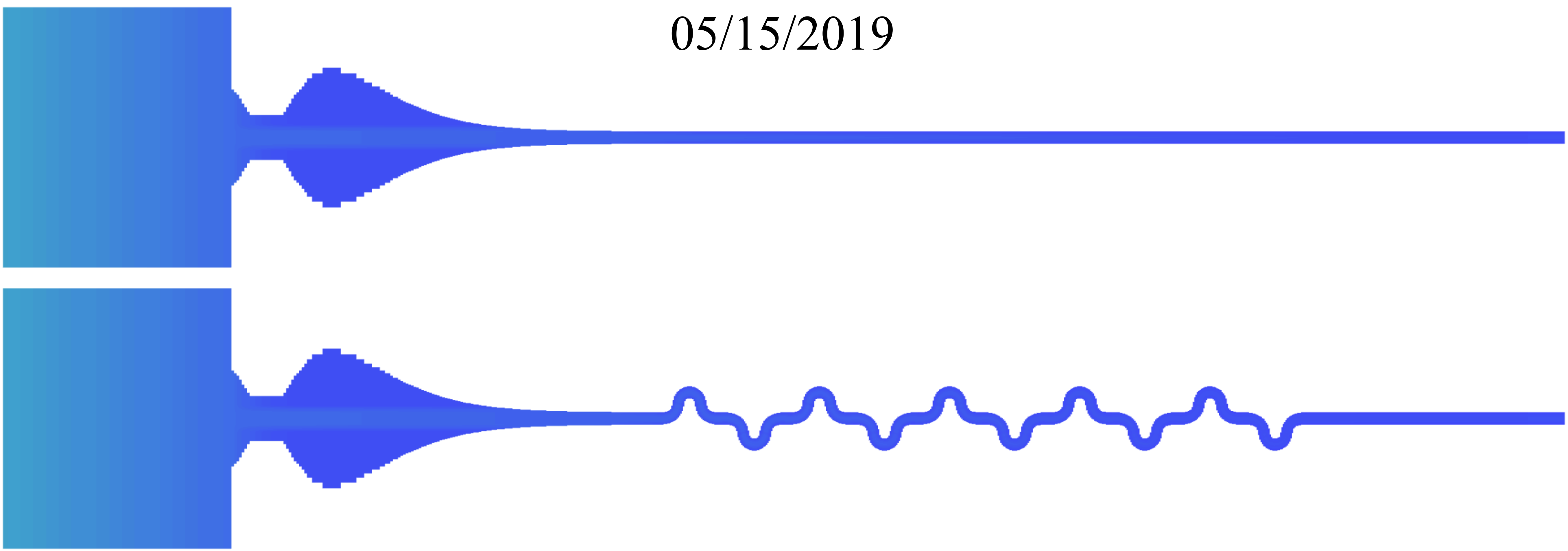


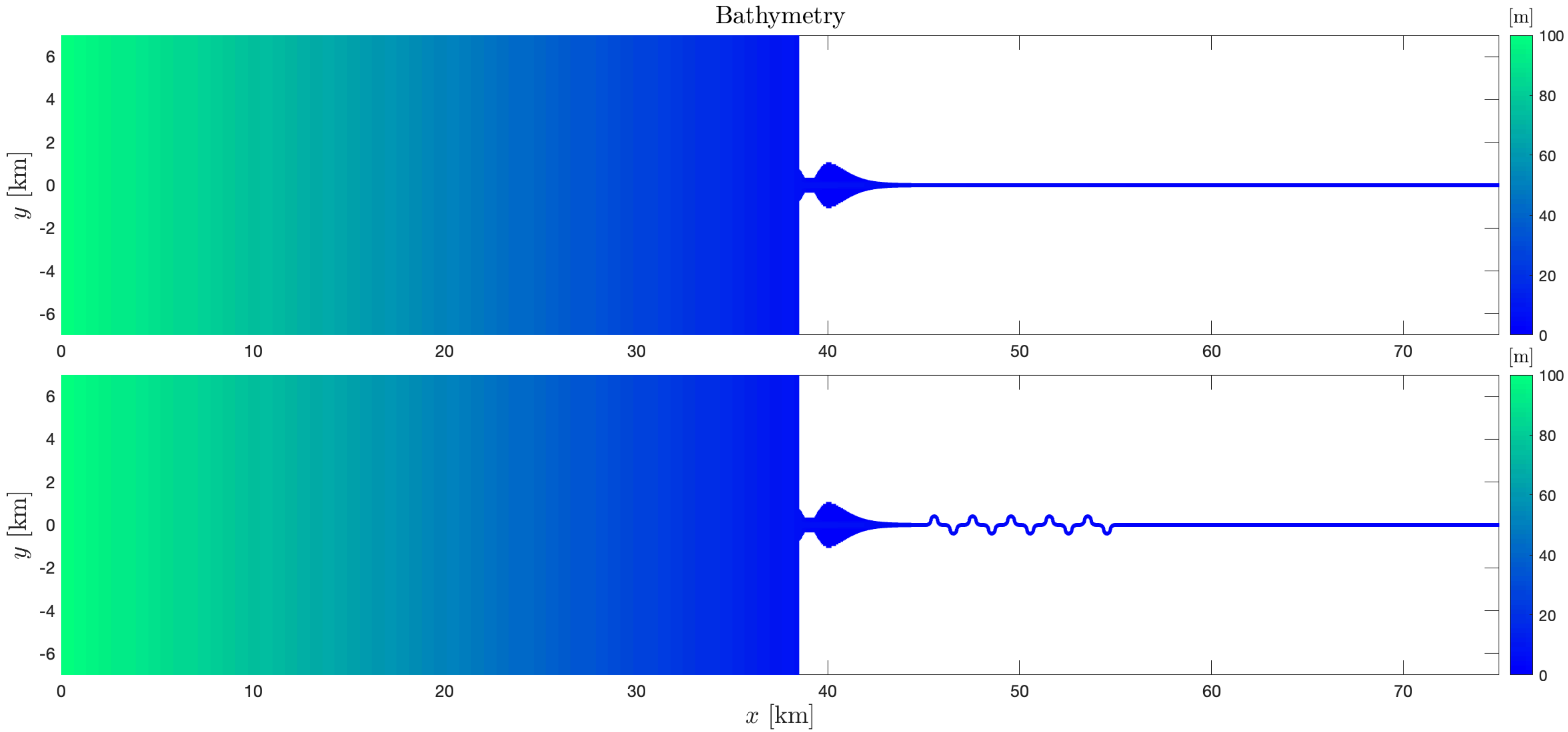
Research background

- Estuary is where a river meets the ocean; river water is mixed with seawater.
- Influenced by both river discharge and tides.
- Meandering river estuaries show different hydrodynamics, salinity dynamics and sediment transport behaviors from straight river estuaries.
- Inspired by recent observations from the North River.

A map of North River, from Google Earth.

Model setup

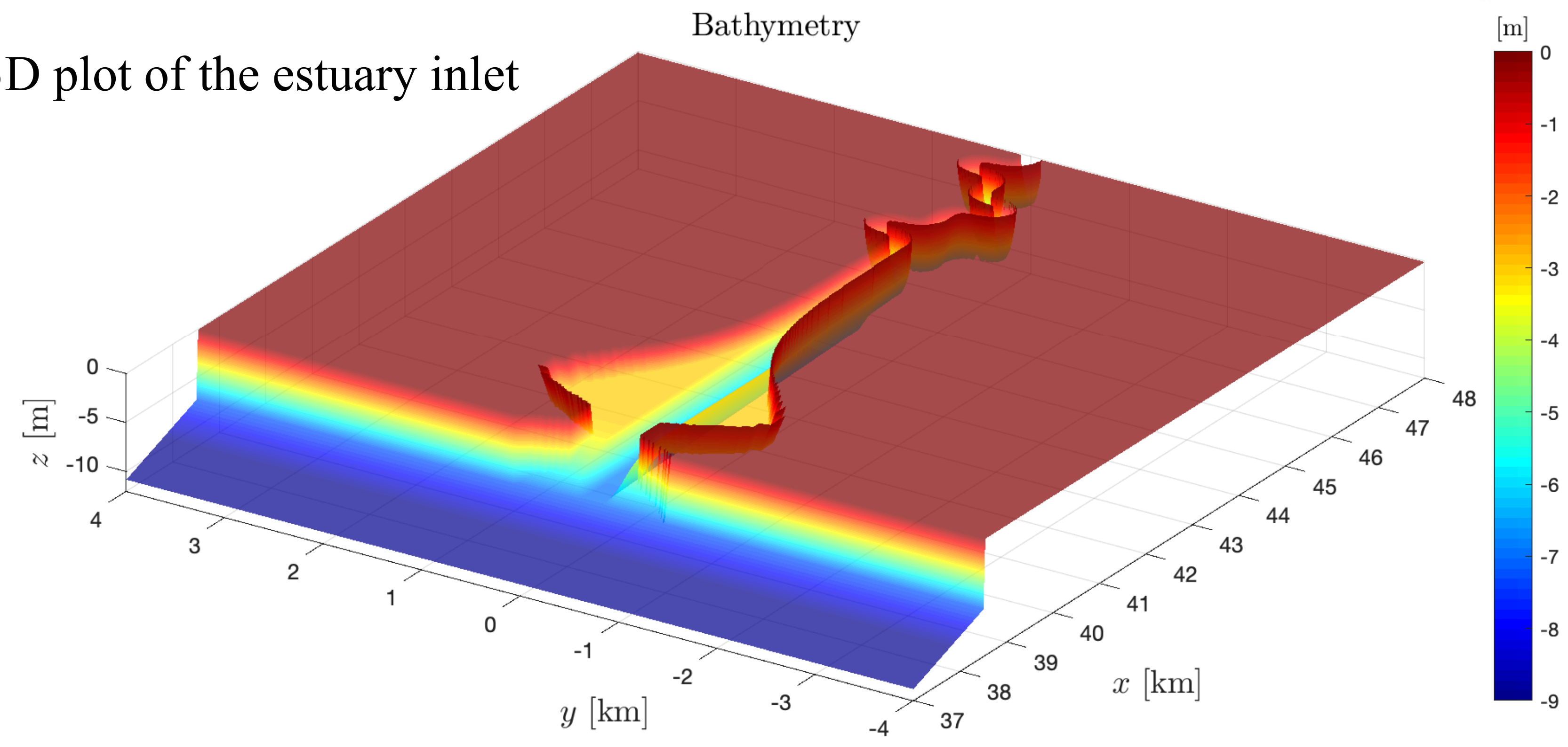
- domain: ~ 80 km by 14 km, meanders: x = 45 - 55 km
- ocean shelf, depth 7 m -100 m; tidal inlet, width 600 m; lagoon, width 2000 m; river, width 200 m, depth 3 m - 7 m.
- The Regional Ocean Modeling System (ROMS), 3D finite volume solver



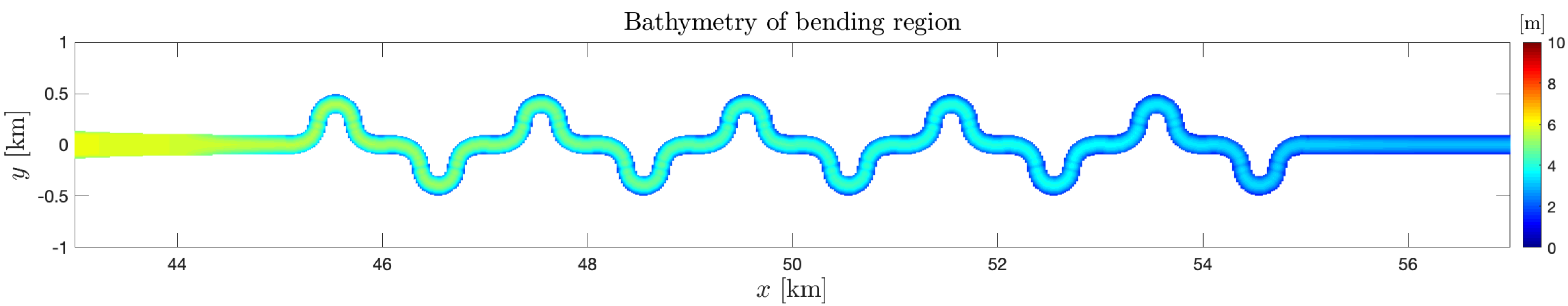
Bathymetry map of the two models

Model setup

3D plot of the estuary inlet



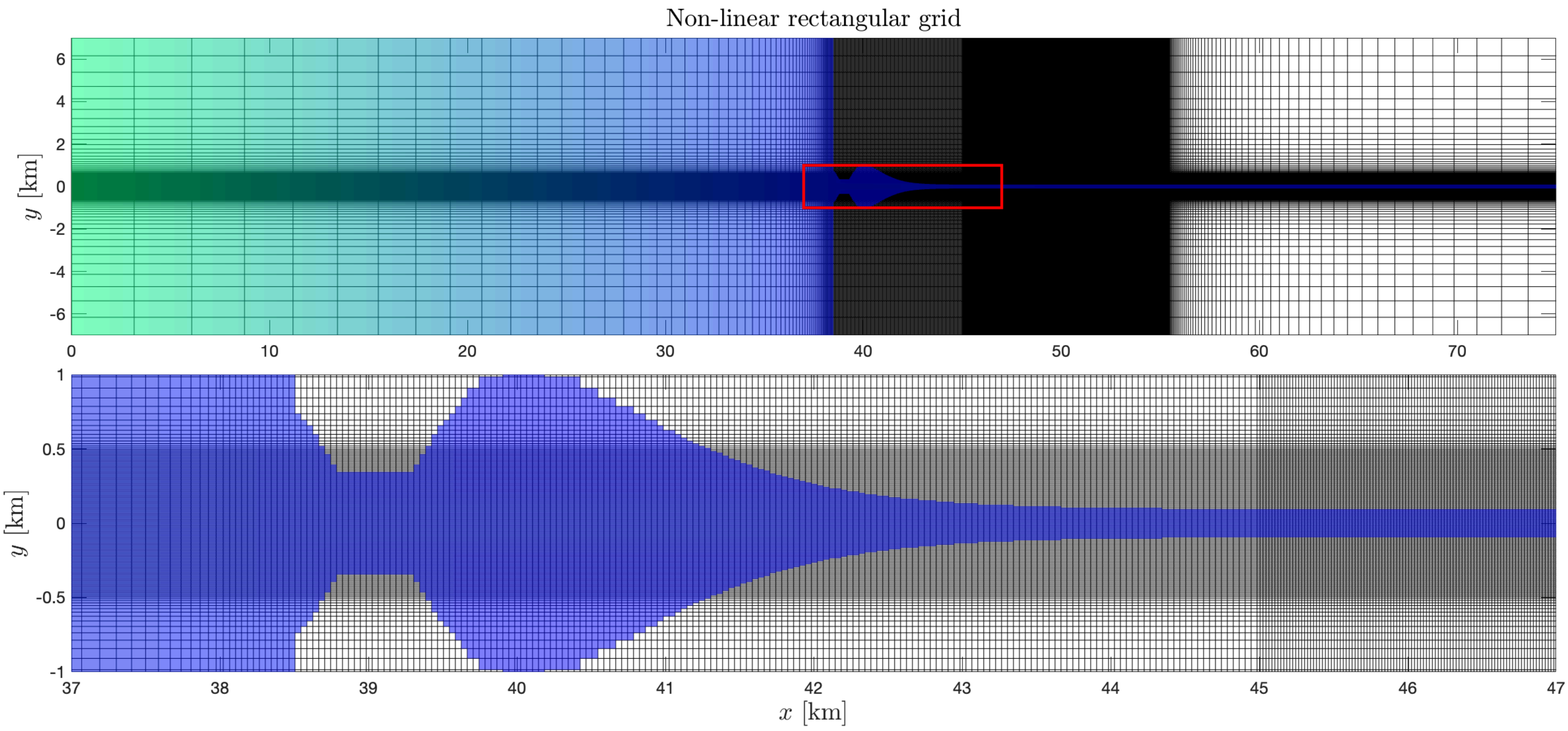
- river cross-sectional profile: parabolic profile
- geometry shape of the meandering river: $\theta = 0.9\frac{\pi}{2}A\sin^2(s)\cos(s),\ x = \int \cos\theta\ ds;\ y = \int \sin\theta\ ds$



Bathymetry map of the meandering region

Non-uniform rectangular grids

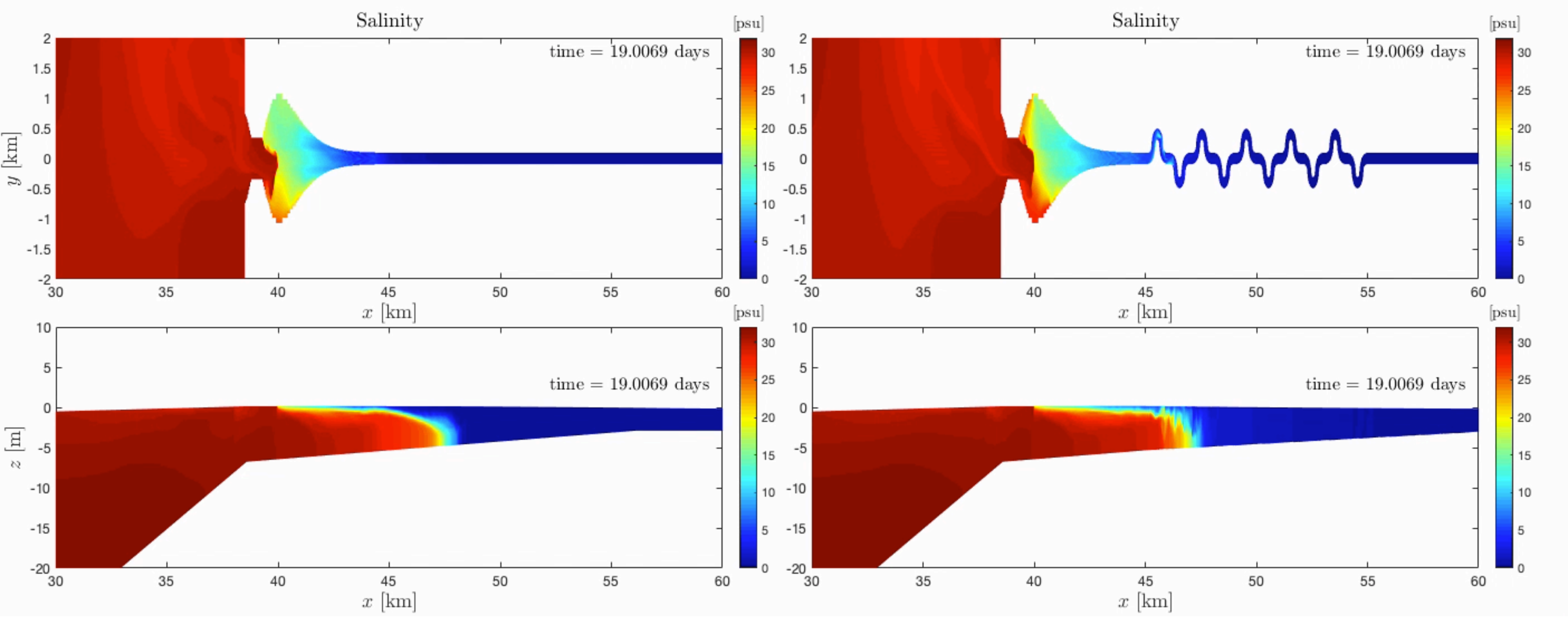
- gridsize: dy = 10 m to ~1 km; dx = 20 m to ~1 km.
- larger gradient in the estuarine region, smaller grid size $\tau_{\Delta x} \approx C \frac{\partial^{p+1} S}{\partial \xi^{p+1}} (\Delta x)^p$
- masks added to the land



Non-uniform rectangular grids used in the model

Modeling results

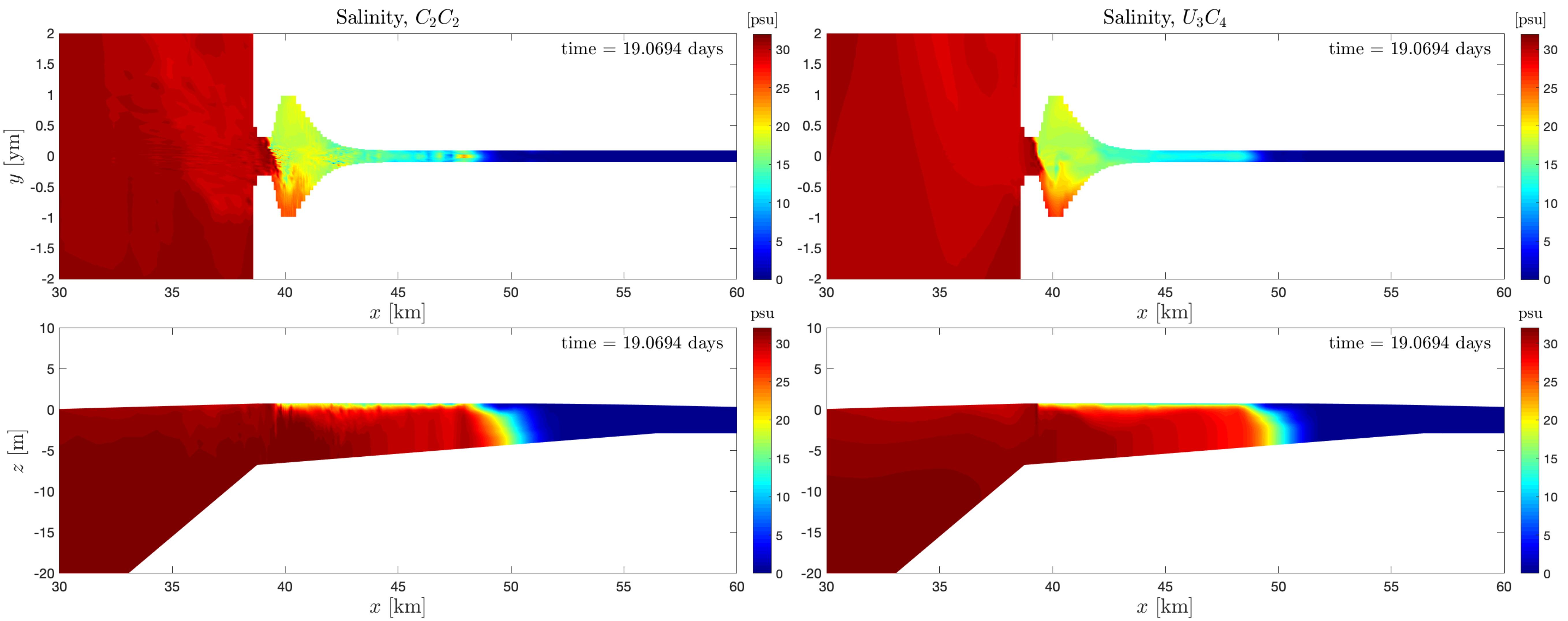
- modeling a 20-days time period, dominated by semi-diurnal tides
- semi-diurnal tides set on ocean boundaries and river discharge on the upstream boundary
- a partially mixed estuary



numerical simulation results: straight river and meandering river estuary models

Compare different advection schemes in ROMS

- C2C2: second order centered scheme for momentum and tracers
- U3C4: combination of third order upstream scheme (QUICK scheme) and forth order centered scheme for momentum and tracers
- More fluctuations in C2C2 scheme - undershoots and overshoots of tracers, especially in the presence of strong gradients
-



Compare different advection schemes in ROMS

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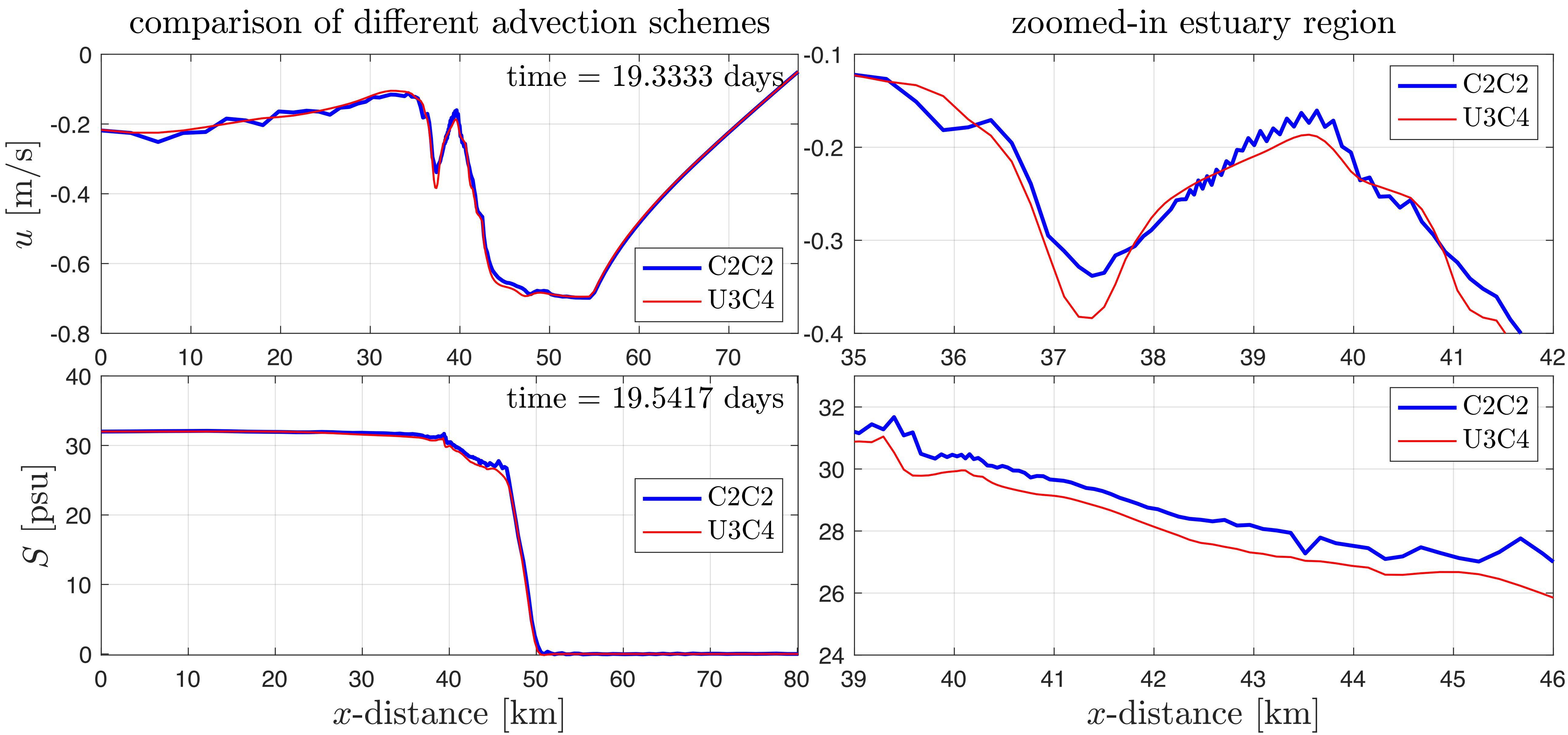

compare depth averaged velocity and surface salinity along the river centerline

large fluctuations in C2C2 scheme

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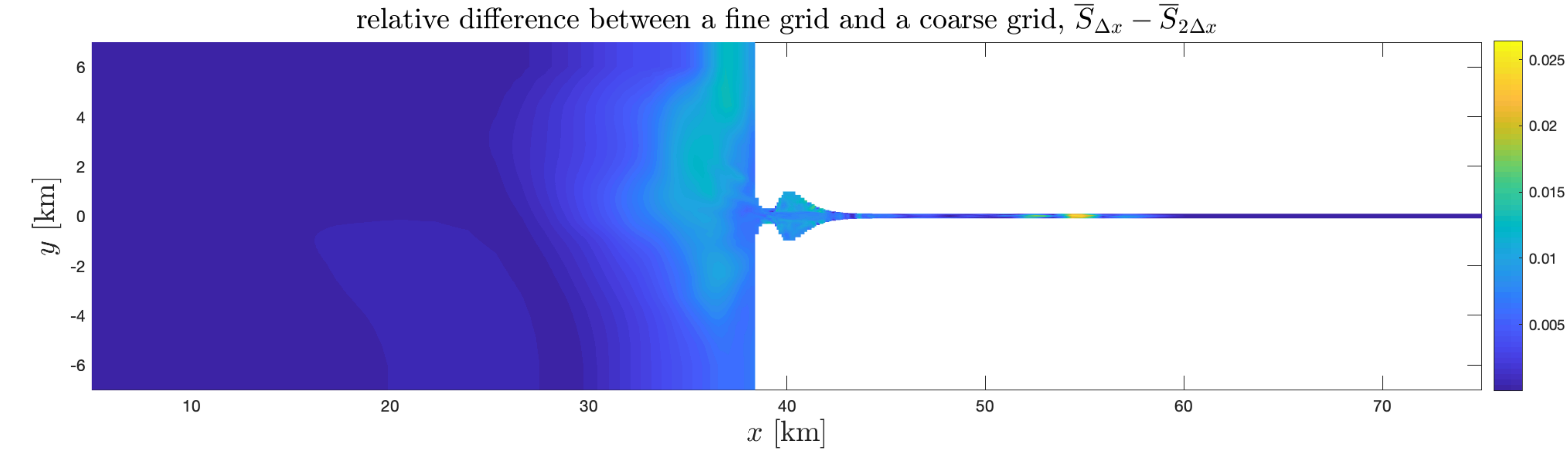
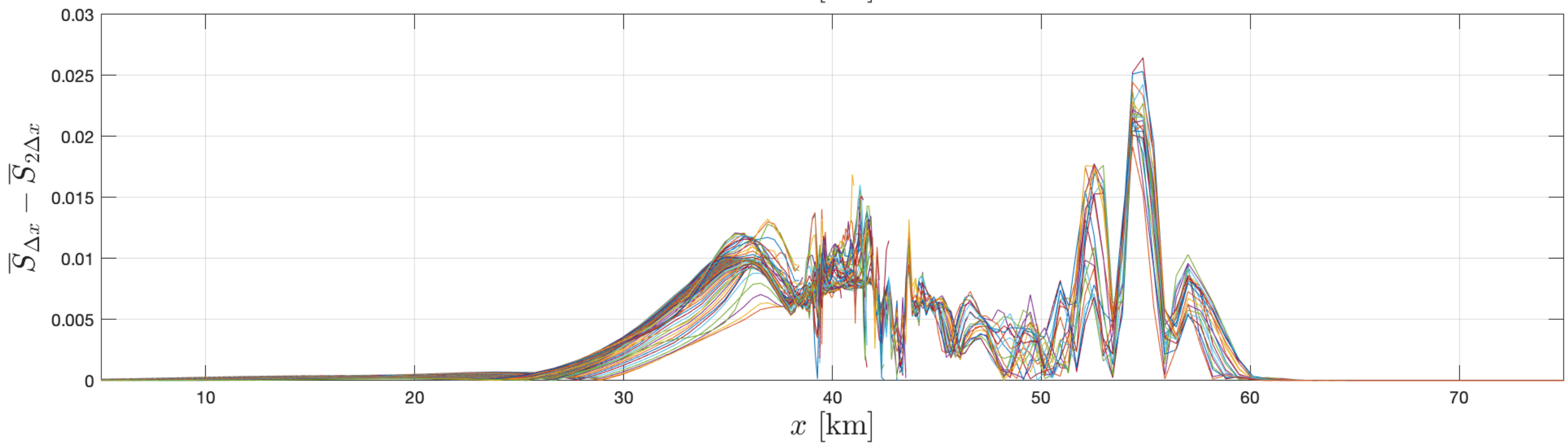
Differences between coarse/fine grids

$$\overline{S}^e = \overline{S}_{\Delta x} + \epsilon_{\Delta x} \qquad \overline{S}^e = \overline{S}_{2\Delta x} + \epsilon_{2\Delta x}$$

$$|\overline{S}_{\Delta x} - \overline{S}_{2\Delta x}| = |\epsilon_{\Delta x} - \epsilon_{2\Delta x}| \approx |\beta_1(\Delta x)^p - \beta_2(2\Delta x)^p| \approx \left| C \frac{\partial^{p+1} S}{\partial \xi^{p+1}} (\Delta x)^p \right|$$



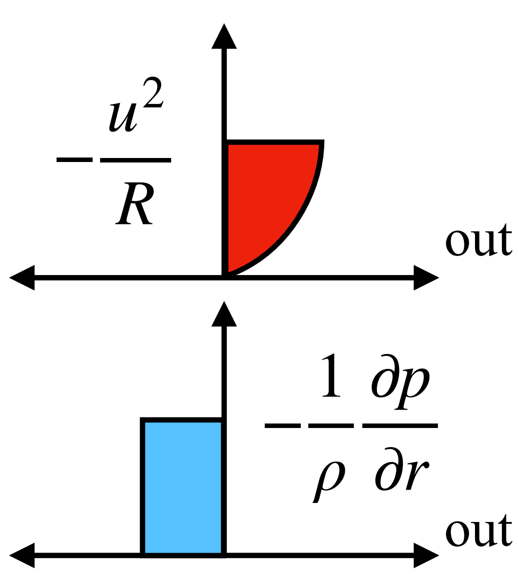


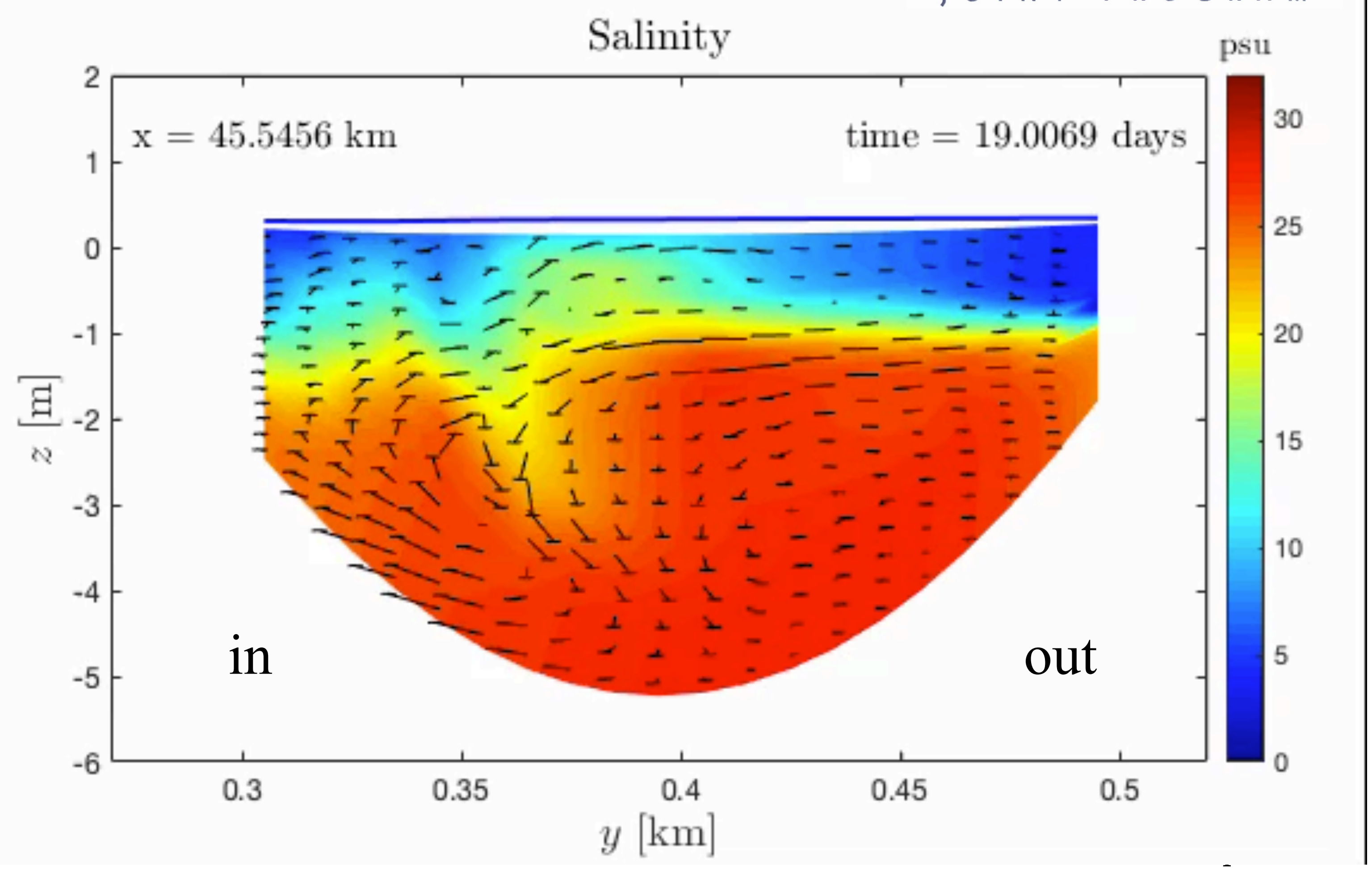
generally the non-uniform grid is distributed reasonably; we may need to refine the grid at x = 55 km

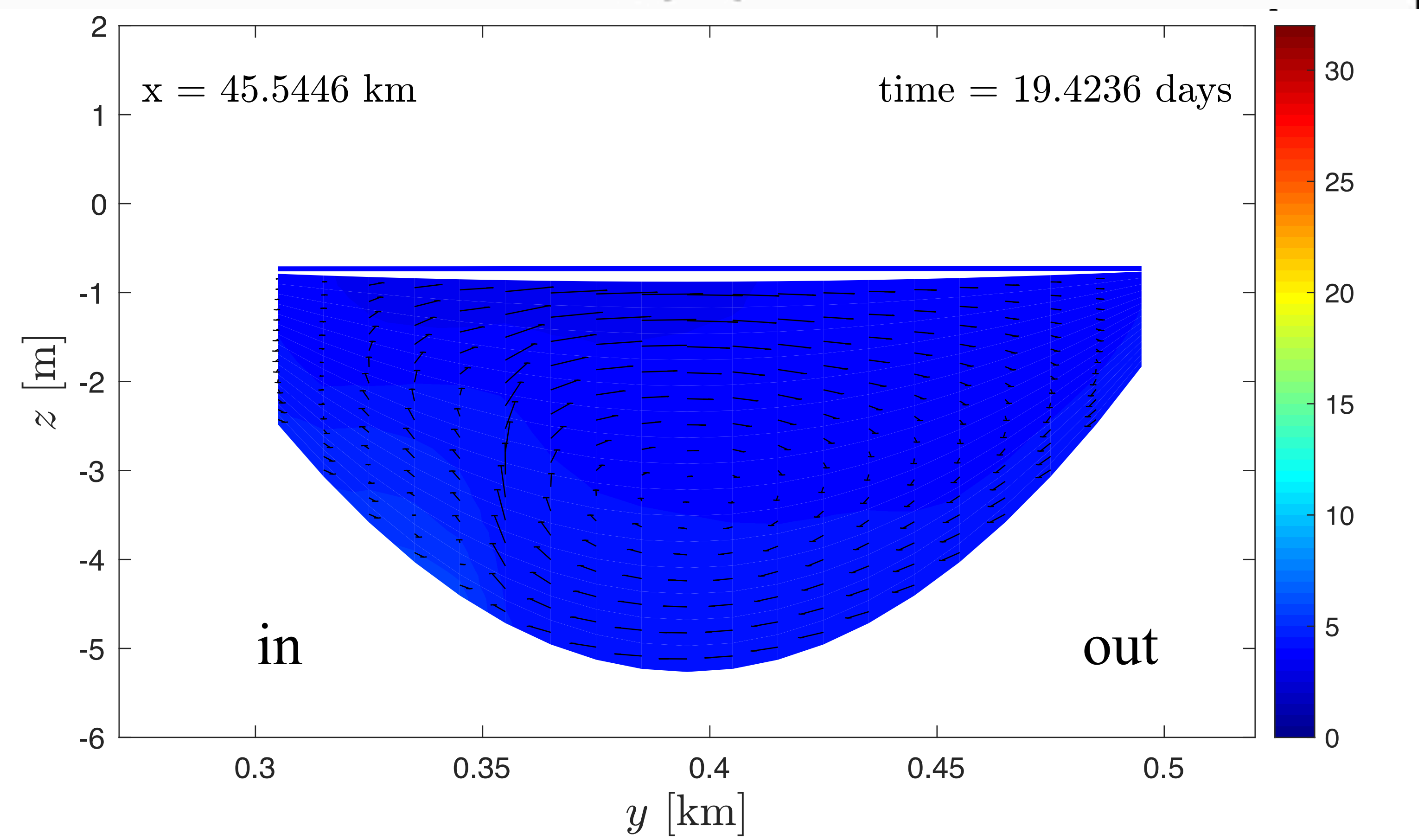
Hydrodynamics

- cross-sectional circulation
  - barotropic: normal secondary circulation, water level gradient
  - baroclinic: density driven circulation
- stronger cross-sectional circulation in the meandering river

transverse momentum balance







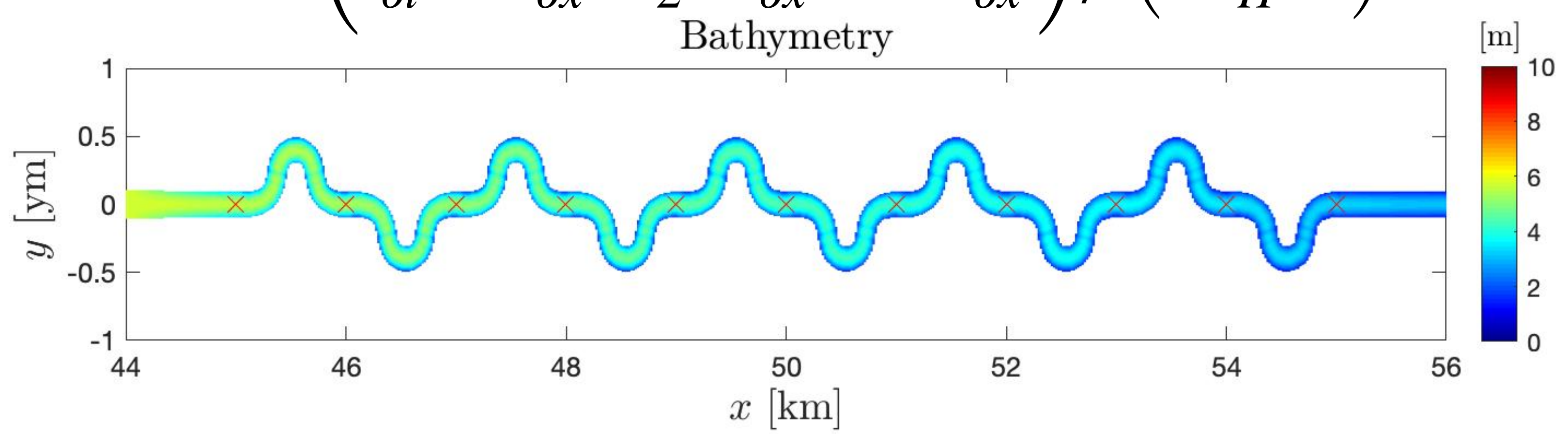
Hydrodynamics

- drag coefficient
  - along river momentum balance, depth averaged

$$\frac{\partial \bar{u}}{\partial t} + \bar{u}\frac{\partial \bar{u}}{\partial x} = -g\frac{\partial \eta}{\partial x} - \frac{1}{2}\beta g \frac{\partial \bar{S}}{\partial x} H - C_D \frac{\bar{u}|\bar{u}|}{H}$$

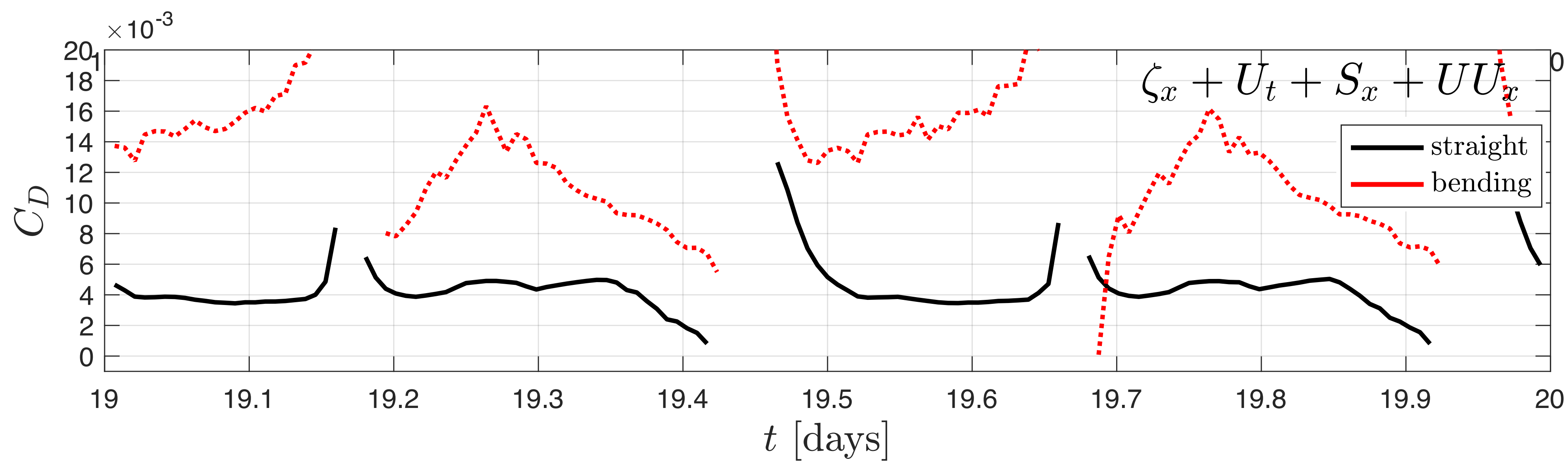
  - drag coefficient computed at a large scale (using same formula as observations)

$$C_D = \left(\frac{\partial U}{\partial t} + g\frac{\partial \eta}{\partial x} + \frac{1}{2}\beta g \frac{\partial \bar{S}}{\partial x} H + U\frac{\partial U}{\partial x}\right) \Big/ \left(\frac{-U|U|}{H}\right)$$



points used for computing drag coefficient

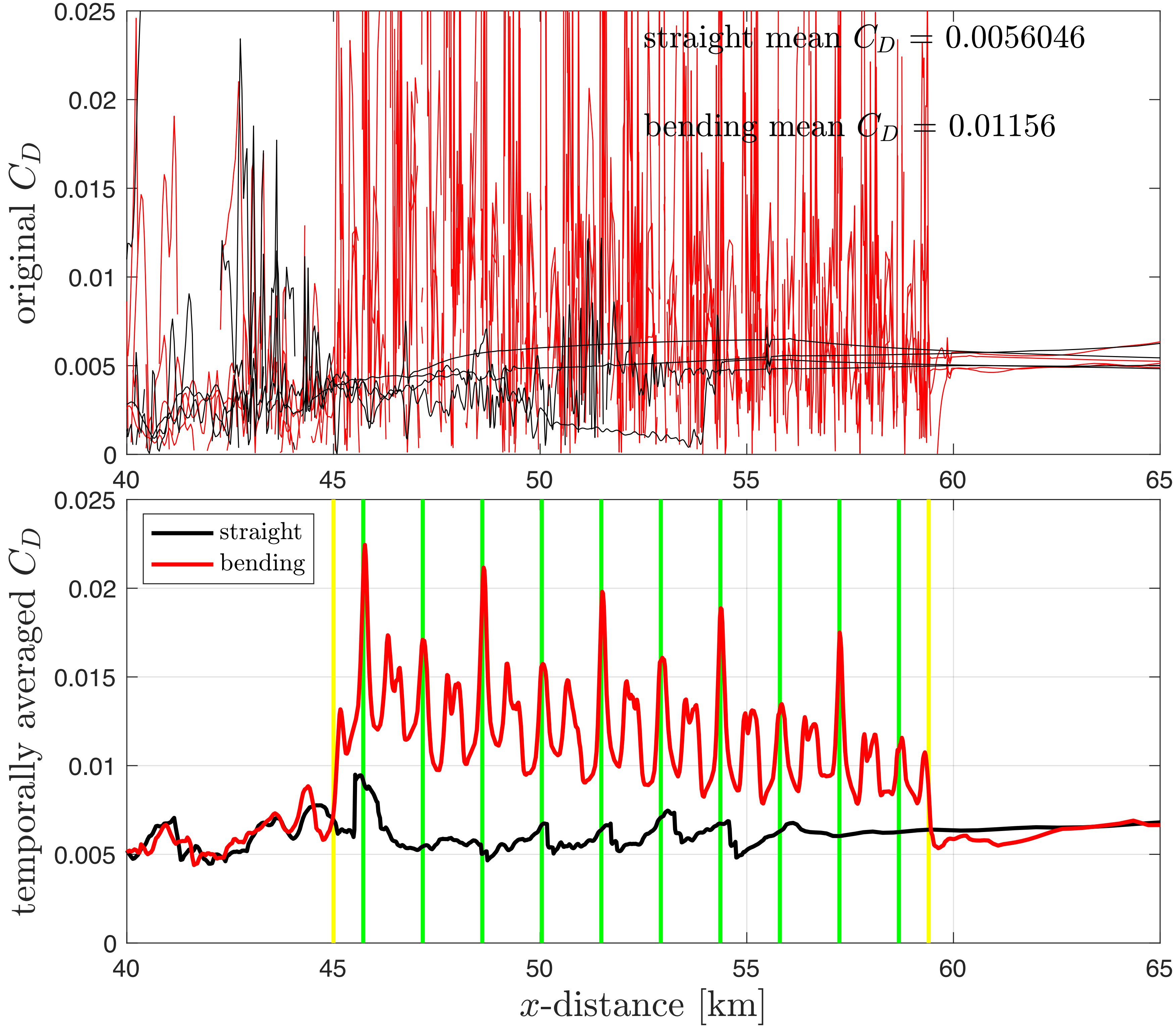
  - consistent with observations, 0.008 - 0.020 v.s. 0.003, by Wouter Kranenburg



drag coefficient computed by numerical results

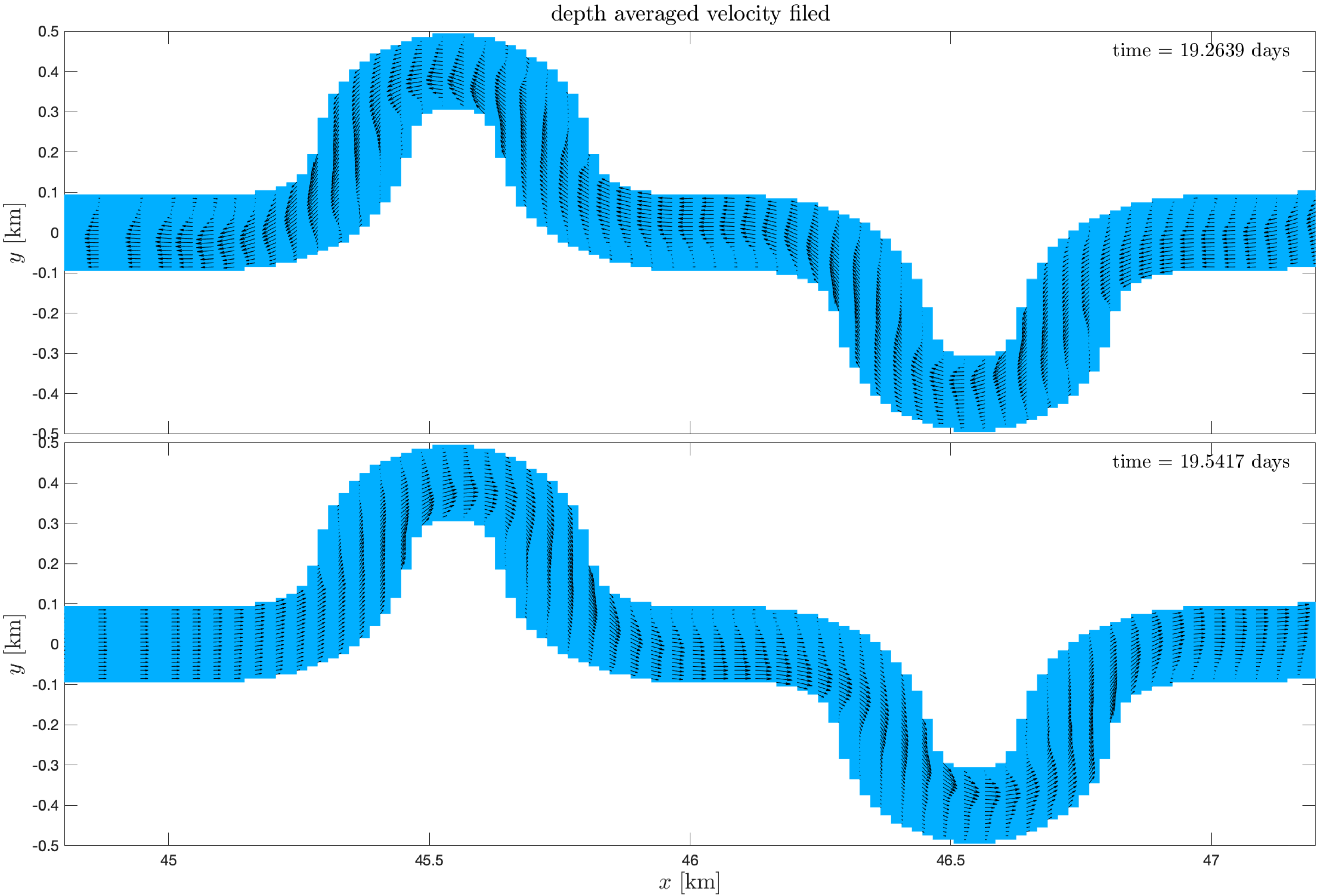
Hydrodynamics

- drag coefficient
  - larger drag coefficient in the meandering river, especially at the river bends



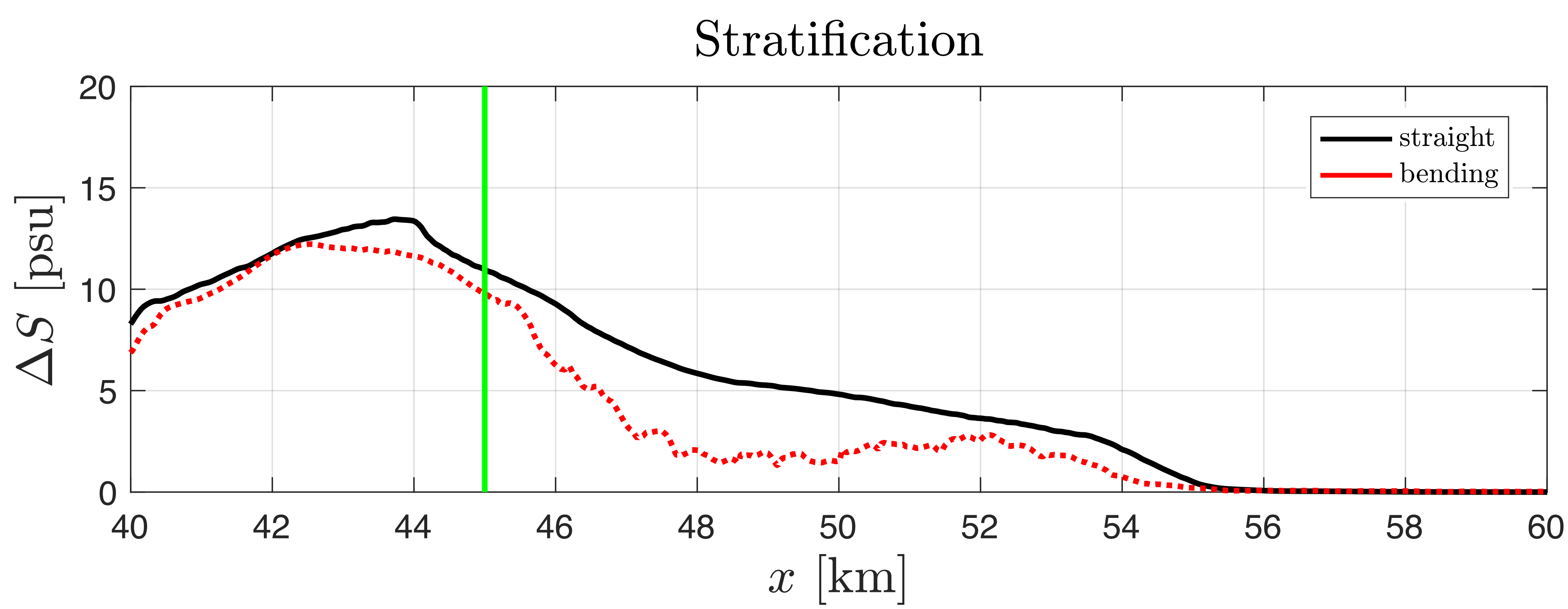
drag coefficient computed by numerical results why meandering river has larger drag coefficient?

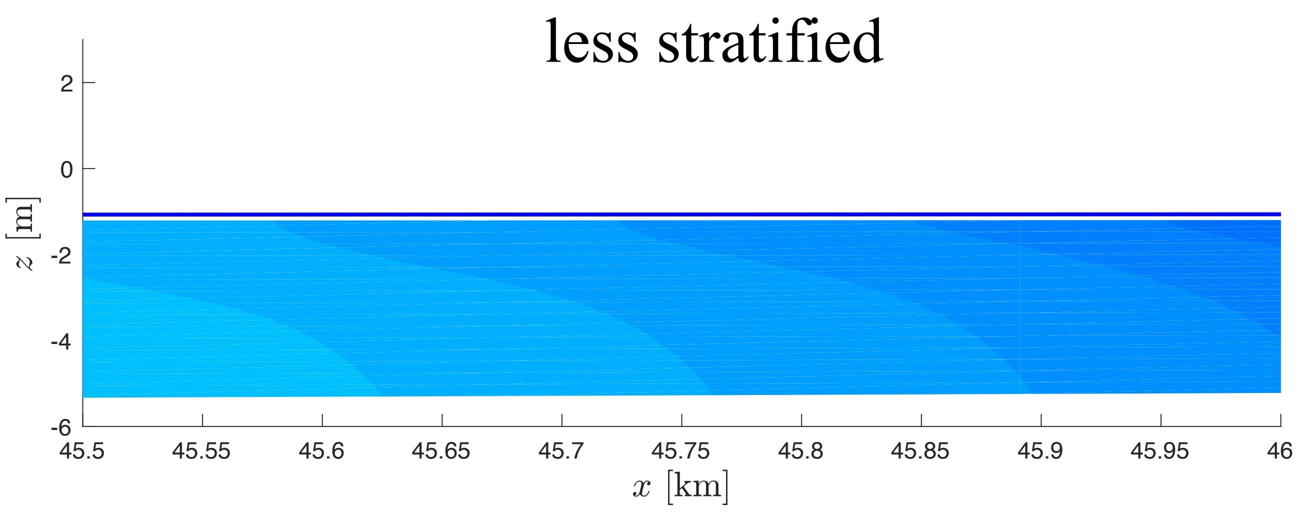
- horizontal velocity profile $\frac{\partial u}{\partial y} = 0$
- flow separation

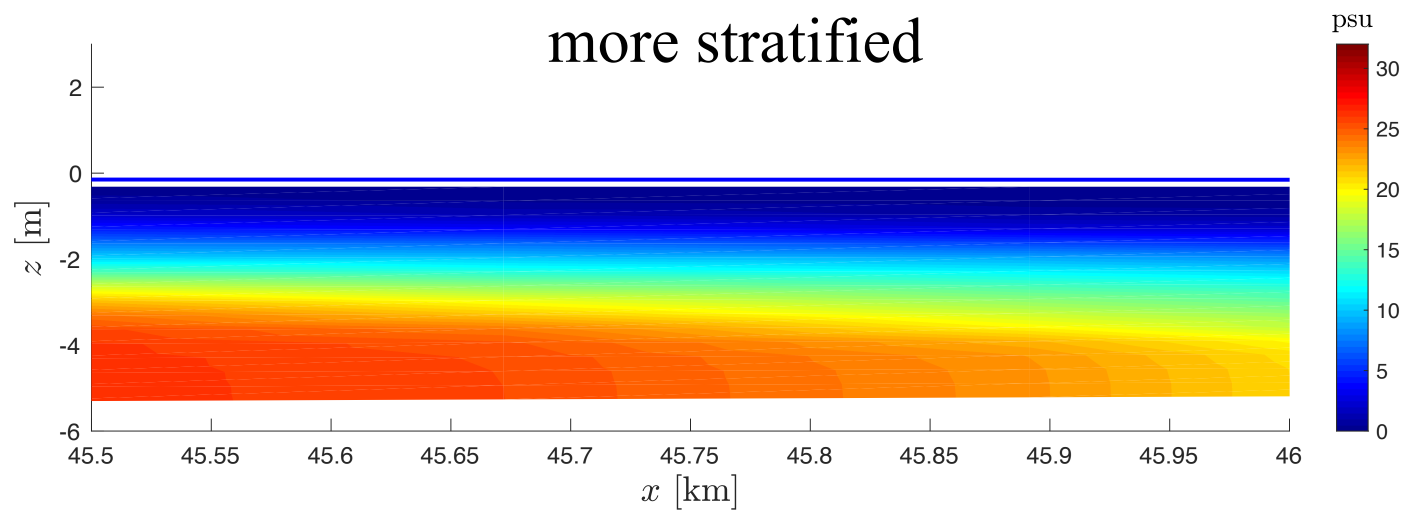


Salinity dynamics

- stratification
  - meandering river is less stratified
  - related to stronger cross-sectional circulation







summary

model setup
- non-uniform grids

numerical scheme comparison

hydrodynamics
- stronger cross-sectional circulation in a meandering river estuary
- larger drag coefficient in a meandering river
  - consistent with observations
  - flow separation

salinity dynamics
- weaker stratification in the meandering river estuary
  - related to cross-sectional circulation
- tidal dispersion

Acknowledgement

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Thank you!

Supplementary slides

tidal dispersion at the first bend