Part 1: Numerical Model of Estuarine Mixing

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1. The typically estuarine pattern

For a vertical profile of river, the **near surface water** flows seaward and **deeper water** flows landward, that leads to a loss of total salt in the estuary. [1]

In estuarine, the conservation of salinity is: $S_t + uS_x + wS_z = (K_h S_x)_x + (K_v S_z)_z$.

Where K_h, K_v are the horizontal and vertical exchange coefficients of momentum and salt. In the case without the change of discharge, the tides are considered to be the primary source of energy for turbulent mixing, so that these exchange coefficients represent a measure of the strength of tidal mixing and viewed as constant value.

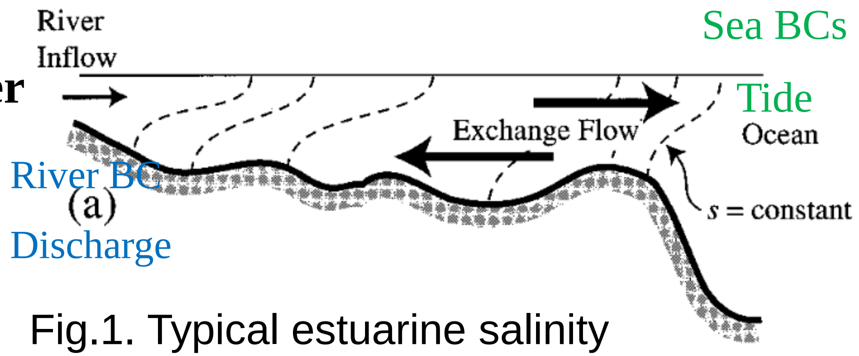

Fig.1. Typical estuarine salinity section with schematic circulation.[3]

2. Boundary conditions

Typically, river BCs are zero salinity and a parabolic velocity profile.

At the east open boundary (sea BCs), the horizontal diffusive fluxes of salt and vorticity are required to be constant, because the salt balance is maintained primarily by a dynamic balance between horizontal advection and vertical diffusion of salt. and similarly, a vorticity balance is maintained primarily by a balance between **buoyancy forces** due to horizontal density gradients and vertical diffusion of vorticity.

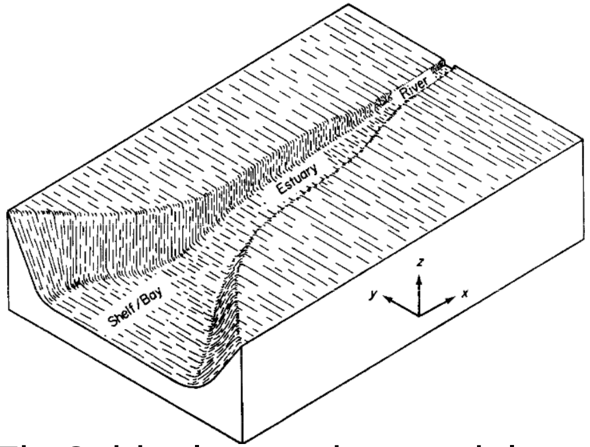

Fig.2. ideal estuarine model

3. The estuary length L and the dynamical length of the estuary L_d

The dynamical length of the estuary, L_d, roughly equivalent to the extent of salinity intrusion, with $L_d < L$. For large river flows with great discharge, L_d is small. In numerical model, ***L* is optimized to provide efficient use of the horizontal grid points**.

a) If L is too small, a smooth transition to the freshwater of the river will be prevented, since the upstream boundary will be too close to the mouth.

b) If L is too large, there will be too few grid points to resolve the dynamics close to the estuary mouth.

c) Initially, L is estimated at the beginning of a calculation and then is adjusted after a small number of iterations, if necessary.

Part 2: The estuary length *L* in model and spin-up time

1. L=10km (case 1)

For the water level at the river BCs (the western discharge boundary) in Fig.3, it can be seen that the spin-up time is about **48h**.

In Fig.4~5, the **salt wedge** [3] reaches the upstream boundary before 12h, and the salinity seems to be constant close to river BC at the surface. At T=336h, with salinity=25 PPT at depth, salinity=0 PPT at the surface, there is a discontinuous gradient in salinity. And it seems the salinity did not fully develop as insufficient L with high flow at river BC.

These two phenomenon are not satisfied to the typical estuarine salinity section (Fig.6(a)), especially for a tide-dominated estuary open to the sea. That means the **artificial boundary effects** occur at the beginning of model and as the limitation of the estuary length L.

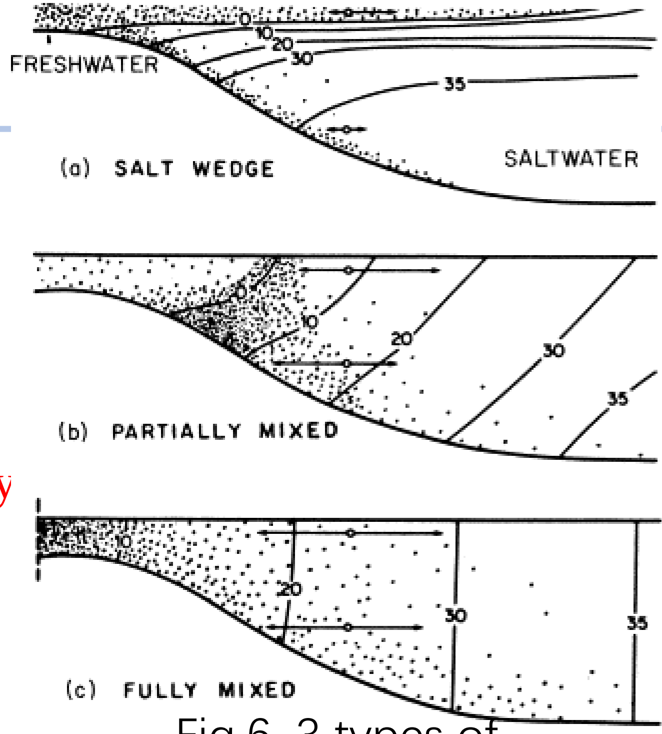

Fig.6. 3 types of estuarine circulation

The salt wedge: The competing influences of river flow and turbulent mixing in an estuary typically create a time-mean circulation with fresher outflow near the surface and saltier inflow at depth. [3]

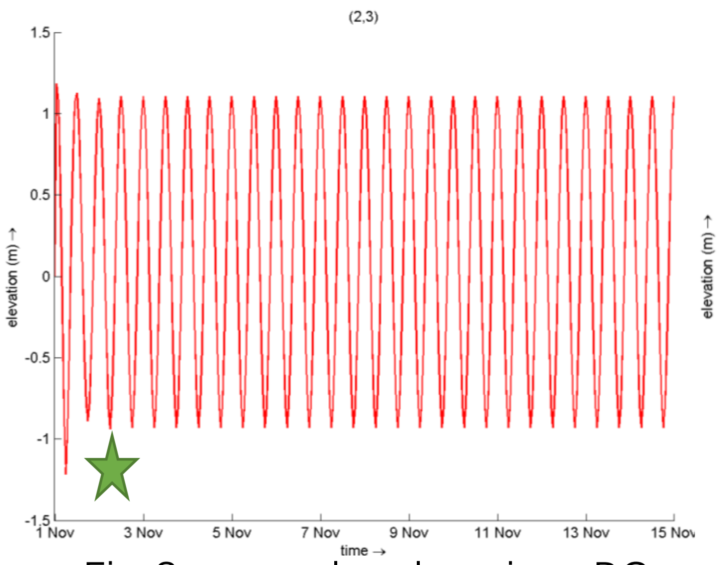

Fig.3. water level at river BC

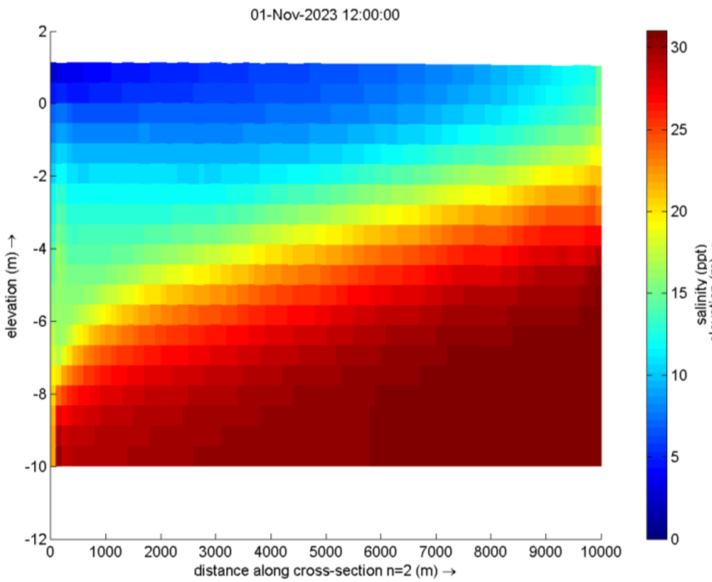

Fig.4. T=12h

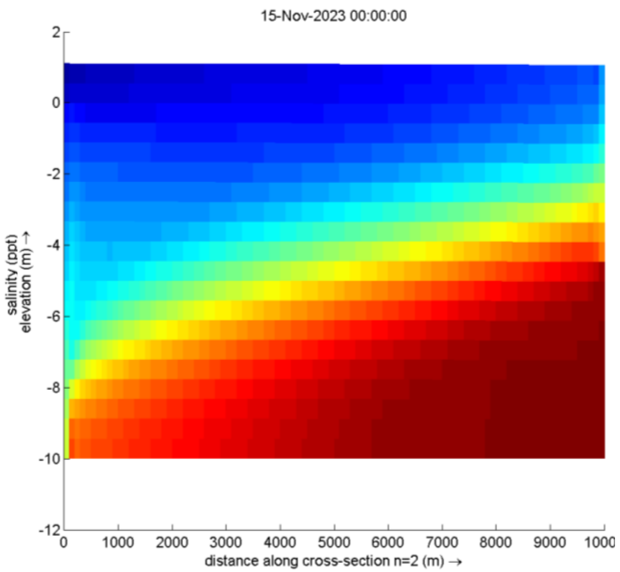

Fig.5. T=336h

Part 2: The estuary length *L* in model and spin-up time

2. L=20km (case 2)

In Fig.7, it can be seen that the spin-up time is about **72h**, that is longer than L=10km. From Fig.8~10, compared salinity at the same time, it can be seen that the more obvious artificial boundary effect occurring at the beginning and the zero PPT point is not incoherent at river BC. However, compared to Fig.5, $\boldsymbol{L_d}$ is greater than 10km at T=336h, and the partially mixed type of estuary(Fig.6(b)) appears, where there is a modest mixing zone between the fresh and salt water masses with isohalines inclined.

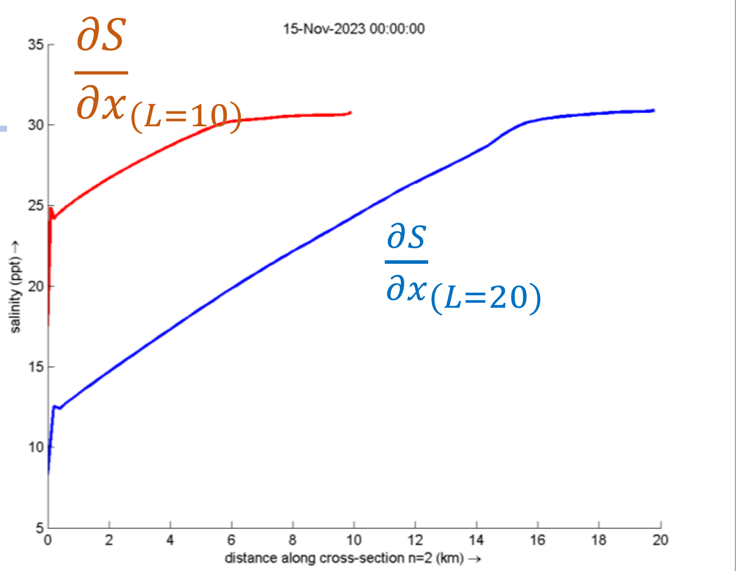

Fig.11. salinity at the river BC

- To avoid artificial open boundary effects, for a large discharge river BC, the estuary length L should be longer.
- When the **salt wedge** occurs at the beginning, artificial open boundary effects usually cannot be avoided.

- As the mixing decreases during increasing L, the estuary adjusts toward that new equilibrium and L_d tends to decrease.[2]

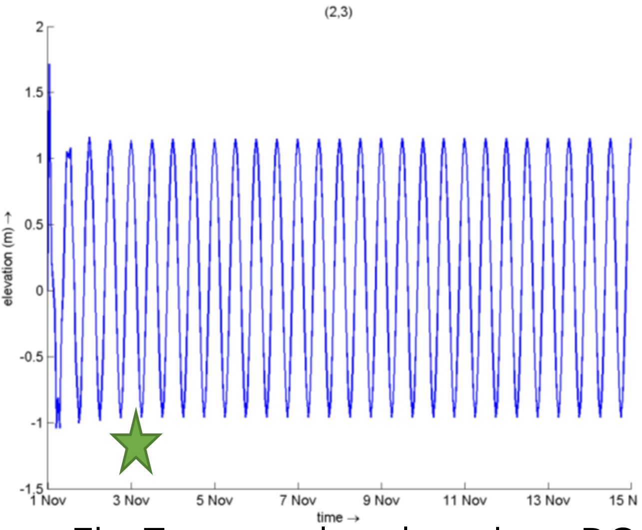

Fig.7. water level at river BC

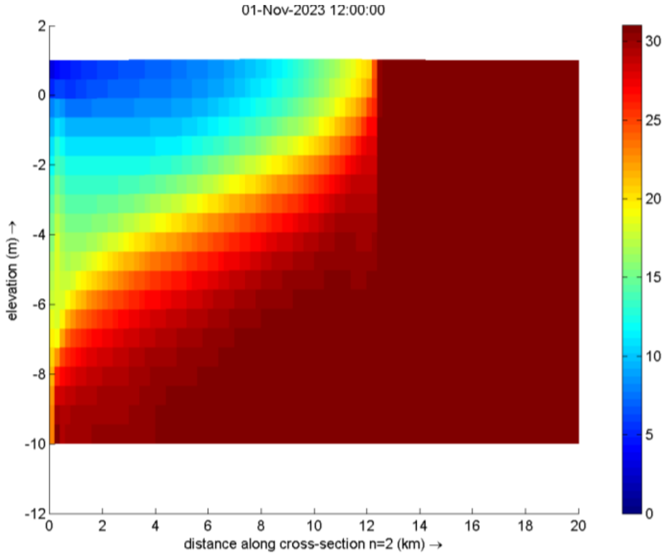

Fig.8. T=12h

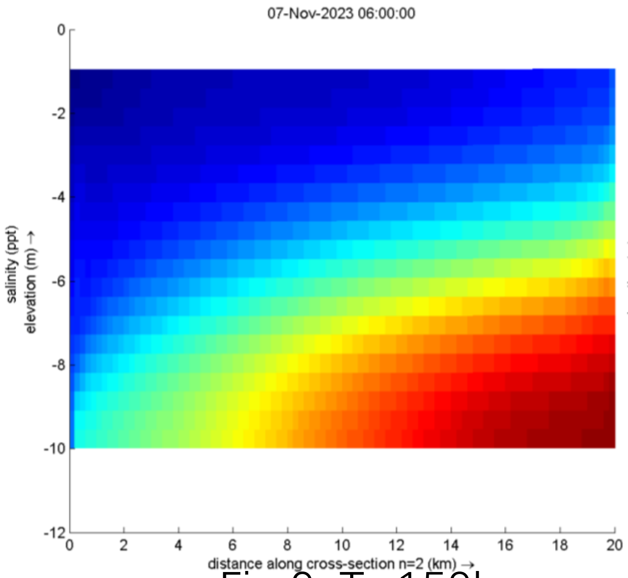

Fig.9. T=150h

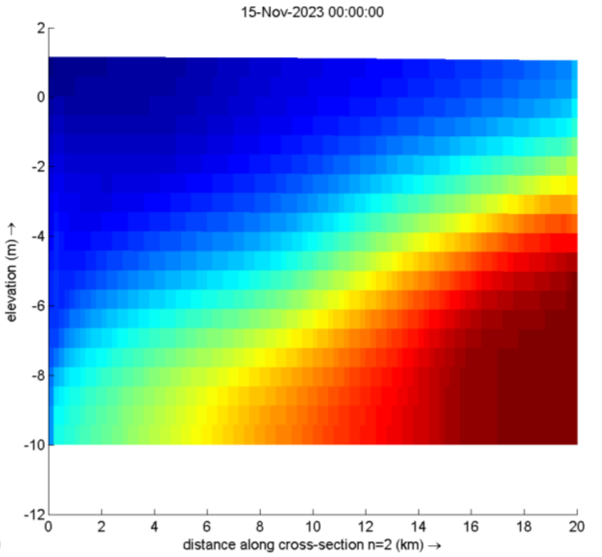

Fig.10. T=336h

Part 3: Thatcher-Harleman Time Lag

1. Intro

In DELFT3D user manual, the Thatcher-Harleman Time Lag is a return time for concentrations from their value at outflow to their value specified by the boundary condition at inflow.

For 3D simulations you can specify different values at the surface and at the bottom to represent the influence of stratification and the different flow conditions above and below the interface. At the sea-side boundary a common problem for numerical models of estuarine areas is encountered when the boundary conditions for a constituent are to be prescribed. In a physical (unbounded) world, **the inflowing water mass immediately after low water slack originates from the outflowing water mass a moment earlier.** Consequently, the concentration of the inflowing water is commonly not equal to the concentration C_{max} which has been prescribed along this open boundary. It will take some time before the concentration along this open boundary reaches the C_{max} value. In numerical models, this time lag (return time) is often modelled by means of a "Thatcher-Harleman" boundary condition (Thatcher and Harleman, 1972).

The return time depends on the flow conditions outside the estuary. If there is a strong circulation **the return time is short**.

The return time must be **specified** for each open boundary section, one for the top layer and the other for the bottom layer. The return times for the layers in between will be determined through a linear interpolation of these two values. Simplified, we choose the same TH value (0, 720, 2880 (min)) at the surface and bottom.

- Compared with L=20km, the case with L=10km means a **stronger mixing circulation**.
- In theory, that means in case 1 with the same TH time, the **salt wedge** occurring will need less simulation time.

Part 3: Thatcher-Harleman Time Lag

CASE 1(L=10km)

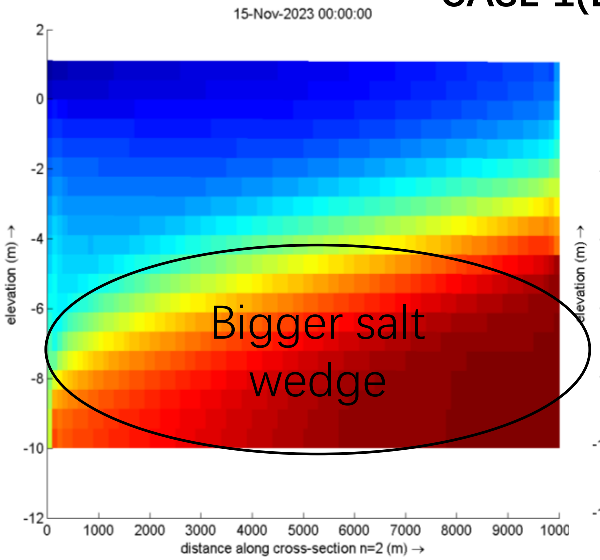

Fig.12. T=336h, TH=0min

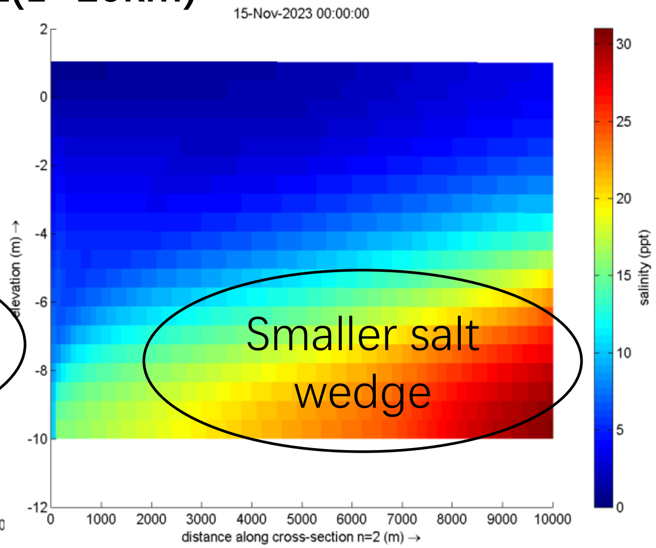

Fig.13. T=336h, TH=720min

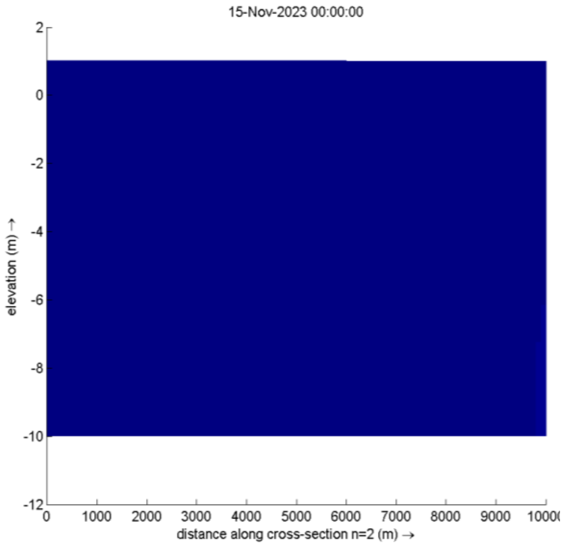

Fig.14. T=336h,TH=2880min

2. Results and discussion

Compared Fig.12 and Fig,13, or Fig.15 and Fig.16, it can be seen that within the same simulation time, the degree and range of the salt wedge intrusion decreases with increasing TH time.

CASE 2(L=20km)

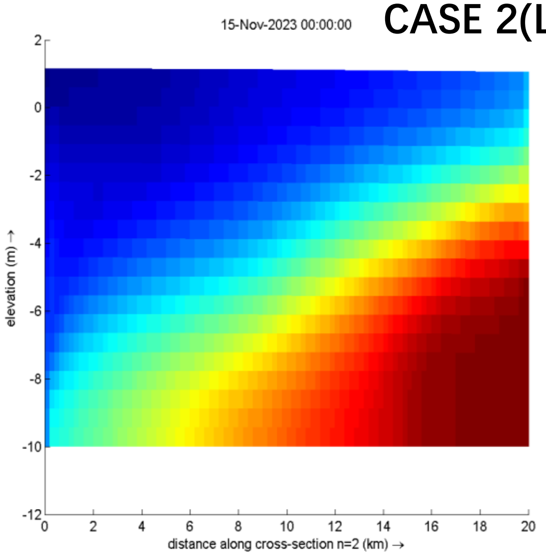

Fig.15. T=336h, TH=0min

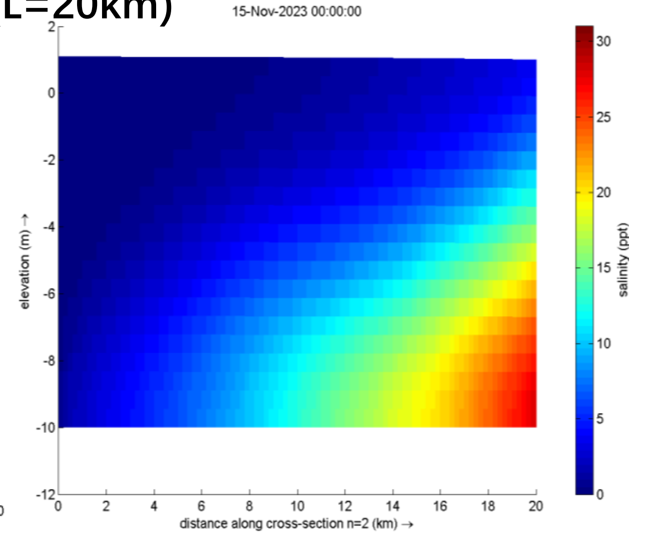

Fig.16. T=336h, TH=720min