Towards a complete study of water renewal timescales of the Scheldt Estuary

Benjamin de Brye[1], Anouk de Brauwere[1,2], Eric Deleersnijder[1,3]

1 Université catholique de Louvain (UCL), Institute of Mechanics, Materials and Civil Engineering (iMMC), G. Lemaître Centre for Earth and Climate Research (TECLIM)
2 Vrije Universiteit Brussel (VUB), Analytical and Environmental Chemistry
3 Université catholique de Louvain (UCL), Earth and Life Institute (ELI), G. Lemaître Centre for Earth and Climate Research (TECLIM)

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Renewal timescales
Definitions

To define the renewal timescales of a water parcel in an estuary, you need:

- To define the estuary
- A water parcel (location, time)

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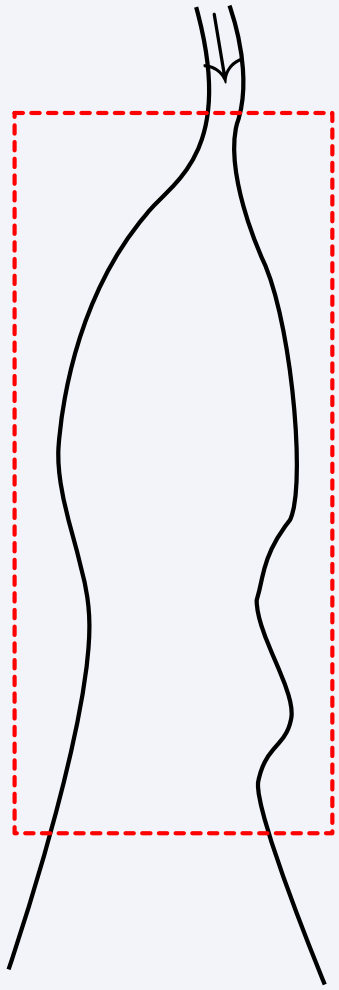

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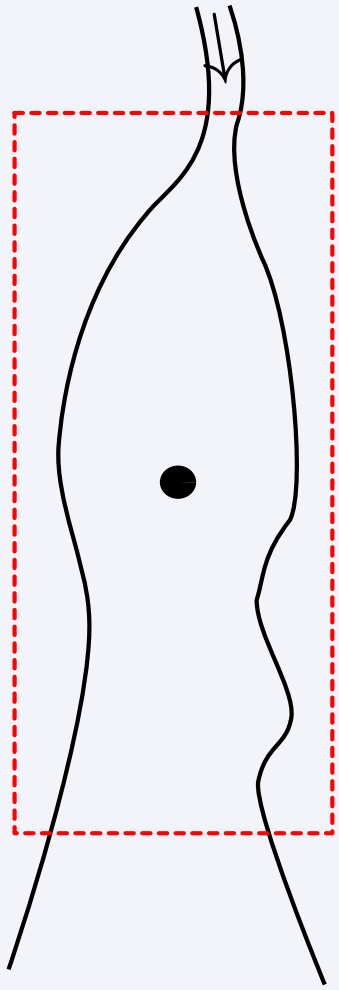

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Renewal timescales
Definitions

Age of the fresh water

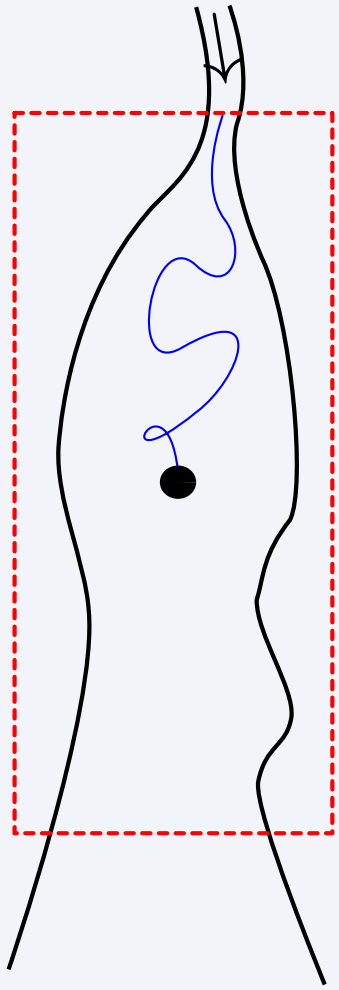
is the time elapsed since the water parcel left the upstream boundary = $t(\rightsquigarrow)$

Residence time of a water parcel

is the time taken by the water parcel to leave for the first time the estuary = $t(\rightsquigarrow)$

Exposure time of a water parcel

is the total time spent by the water parcel inside the estuary = $t(\rightsquigarrow) + t(\rightsquigarrow)$



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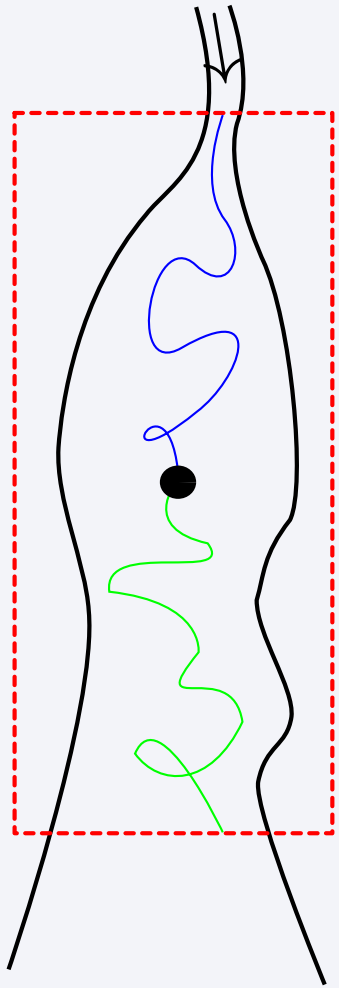

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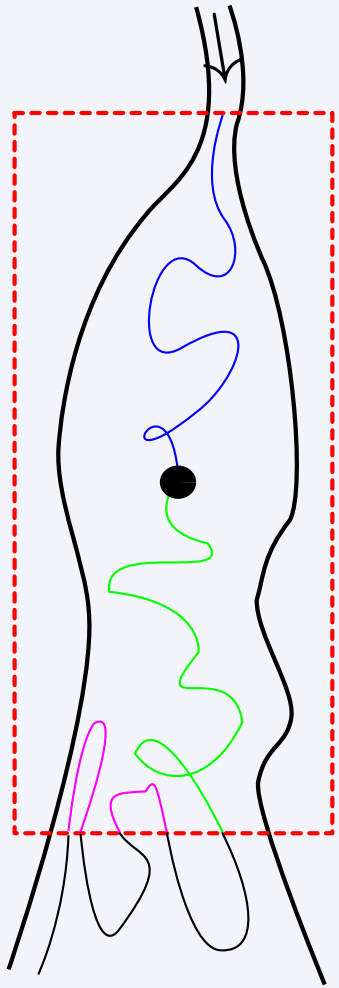

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How to compute these timescales

Residence time and exposure time

1. Lagrangian particles
   - Large numbers of particles (to cover diffusion, time and space variabilities)
2. Box division
   - Tracer initially in several boxes + forward advection-diffusion equation
   - Gives averaged residence time per box
   - Only possible for a small number of boxes
3. CART Theory (`www.climate.be/CART`)
   - One backward advection-diffusion equation

Age

1. CART Theory (`www.climate.be/CART`)
   - Two forward advection-diffusion equations

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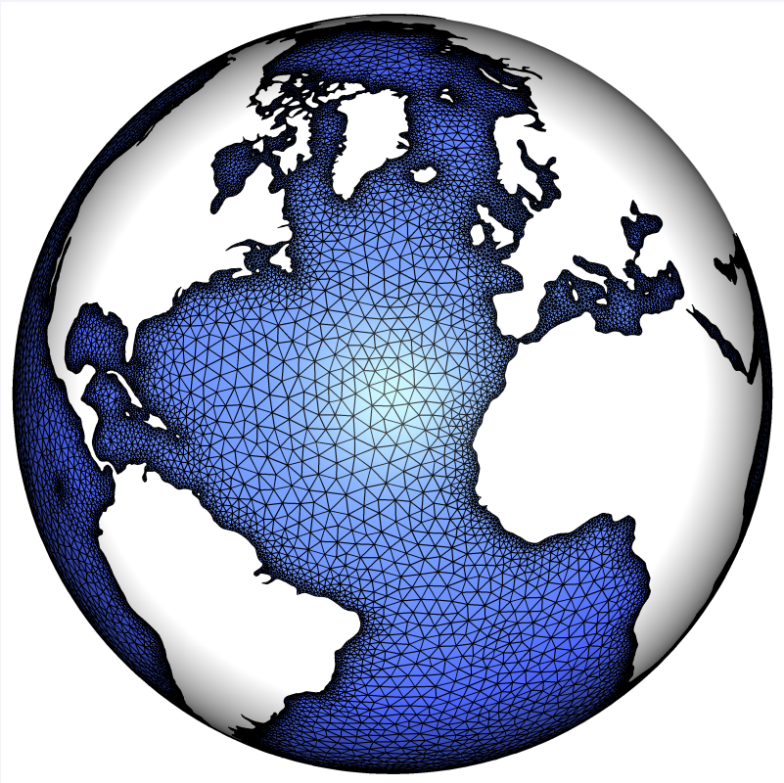
SLIM model
Overview

Second-generation Louvain-la-Neuve Ice-ocean Model (SLIM)



`http://www.climate.be/SLIM`

- Shallow water equations
- Discontinuous Galerkin Finite Element Method (DG-FEM)
- 1D, 2D and 3D models
- Fully implicit time integration
- Implicit wetting-drying
- Coupling 1D/2D

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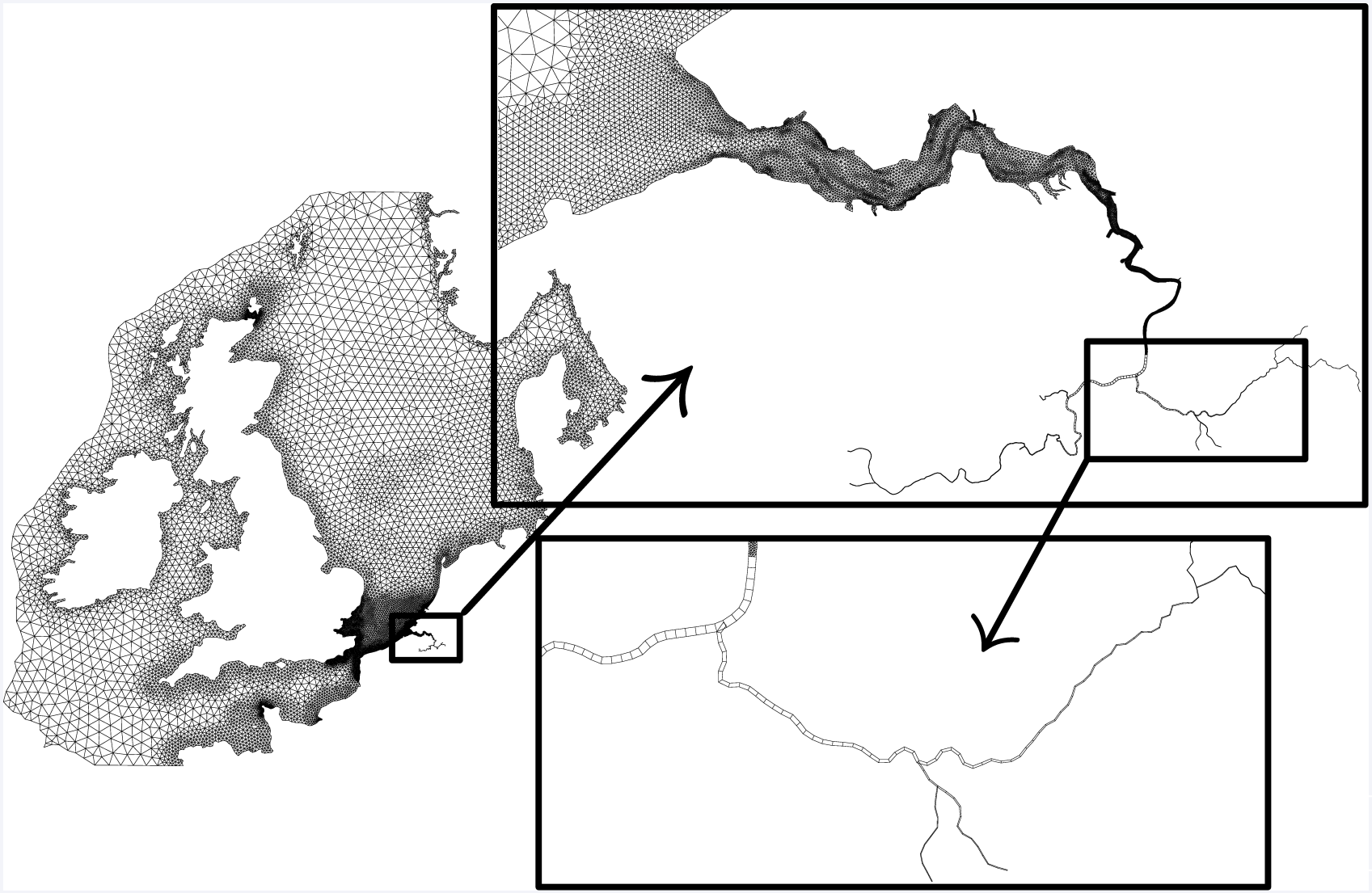
Application: the Scheldt Estuary
Multiscale model



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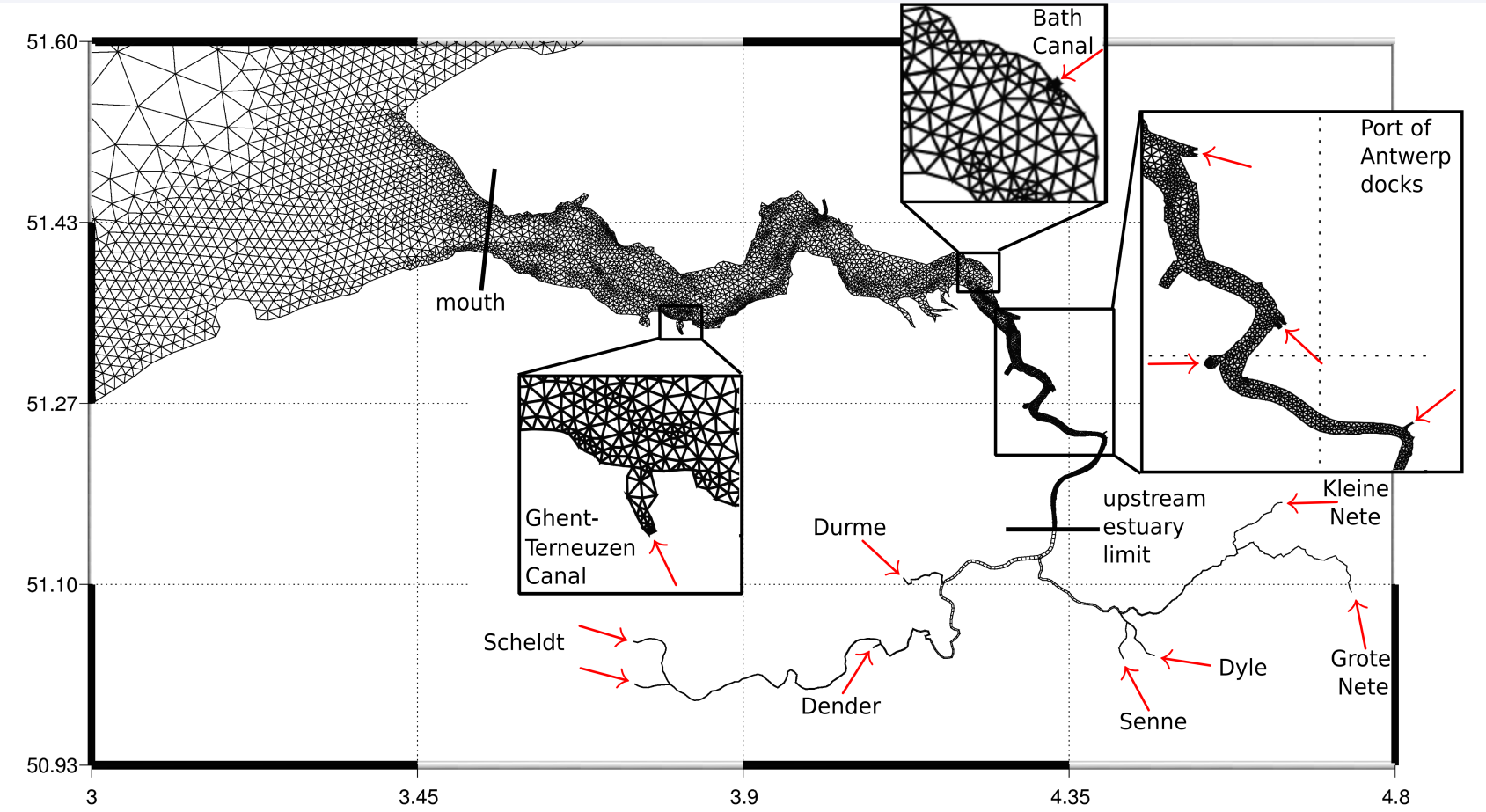
Application: the Scheldt Estuary

A highly polluted macrotidal estuary in the Netherlands and Belgium



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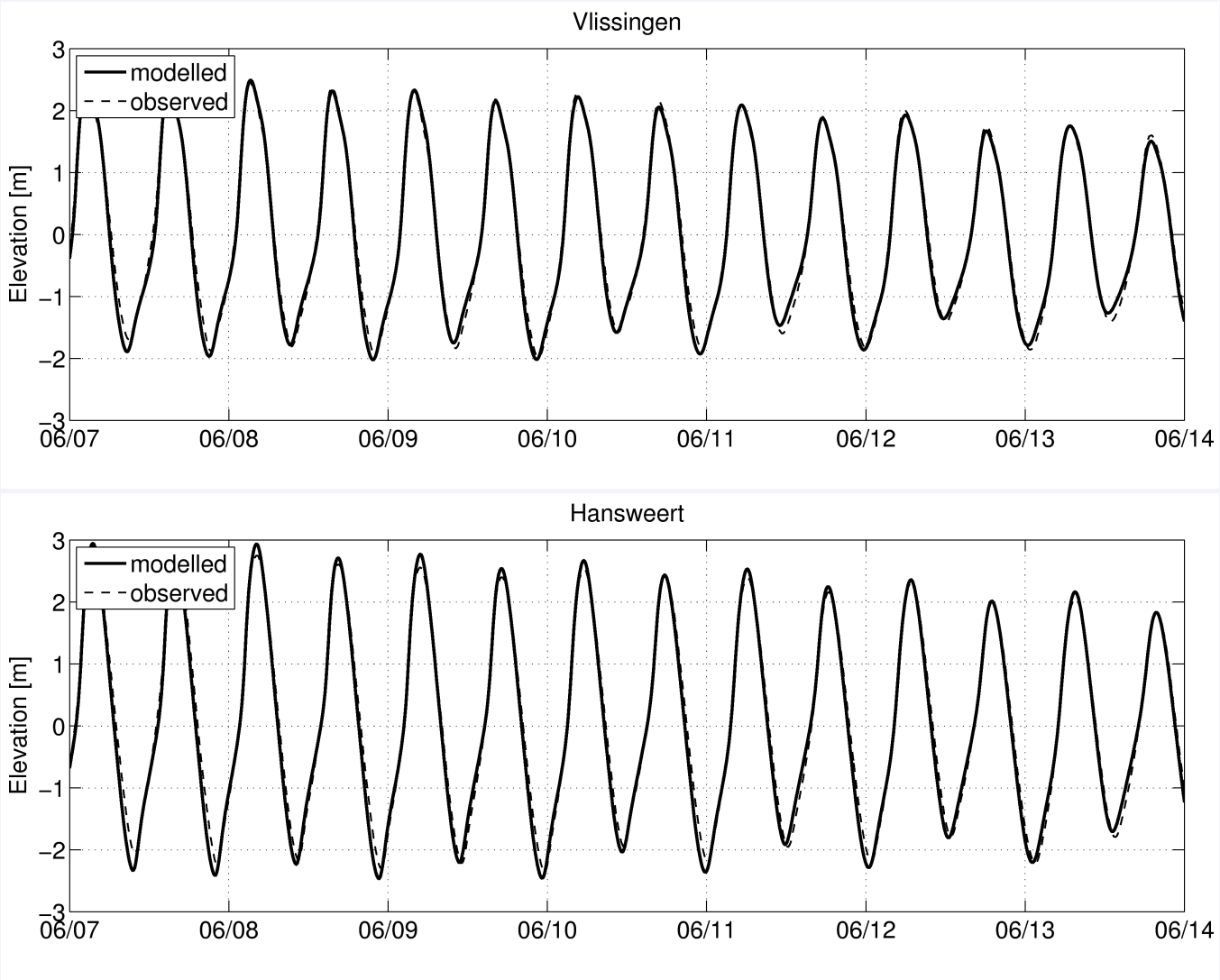
Hydrodynamics
Validation of the elevation



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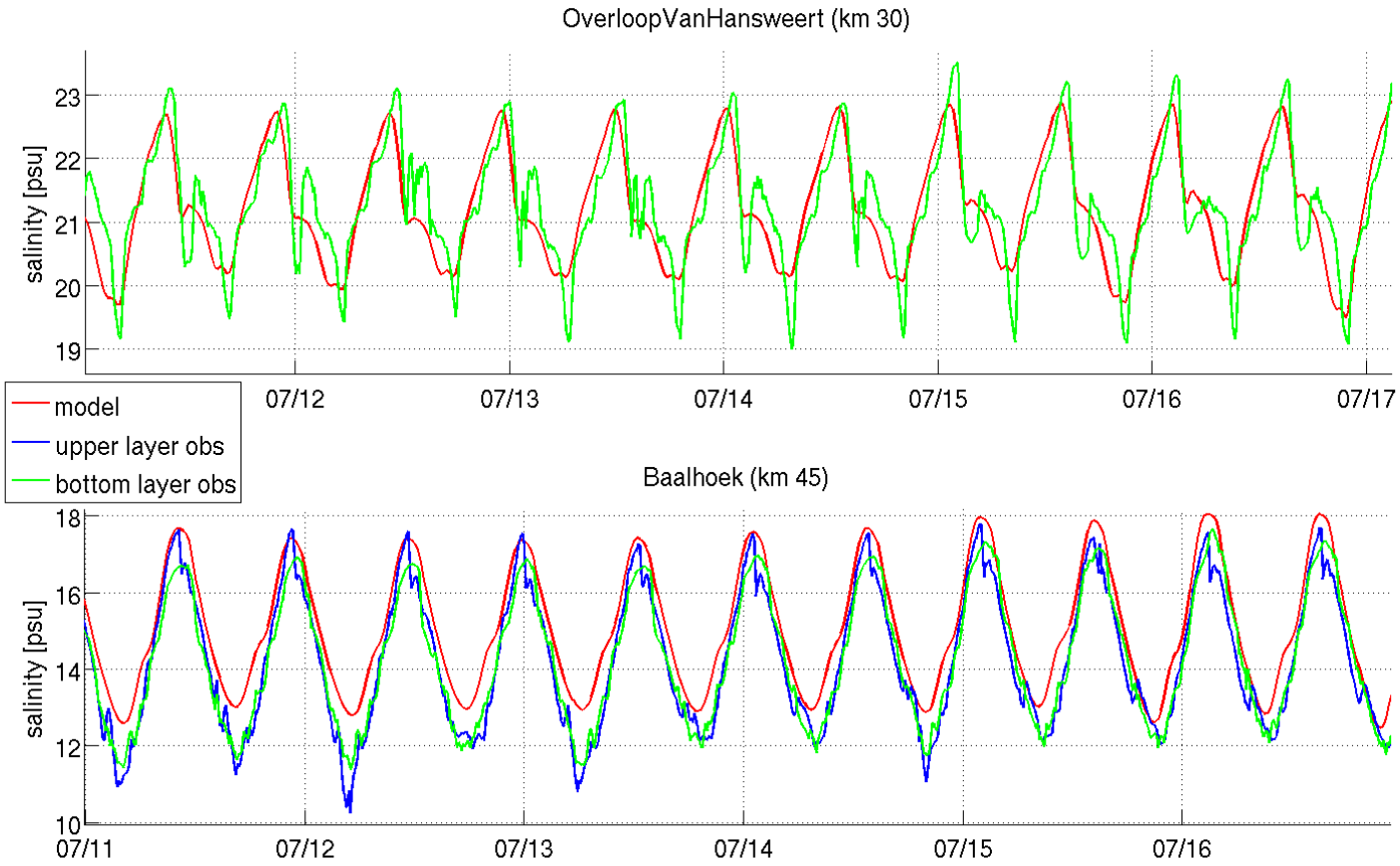
Salinity
Validation of a passive tracer



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Model setup

Recycling the hydrodynamics

- **Downstream bnd**: Only the M2 tide
- **Upstream bnd**: Three constant discharges scenarios:
  - Q = mean situation
  - 2Q = winter situation
  - Q/2 = summer situation

Domain extension

- **Hydrodynamics**: sea + estuary + rivers
- **Residence time**: estuary
- **Exposure time**: sea + estuary + rivers
- **Age**: estuary

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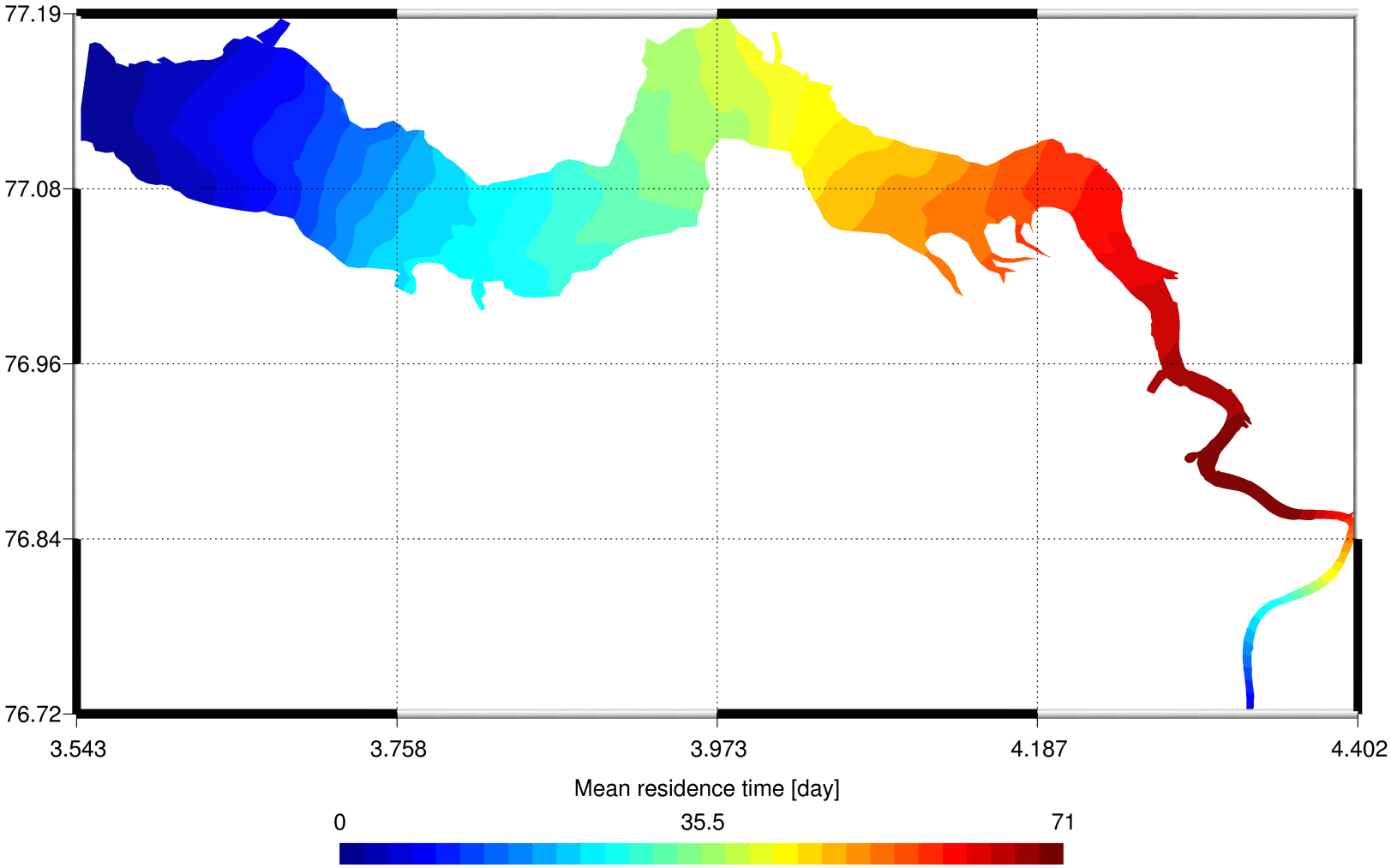
Residence time

Tidally averaged, Mean situation (Q)



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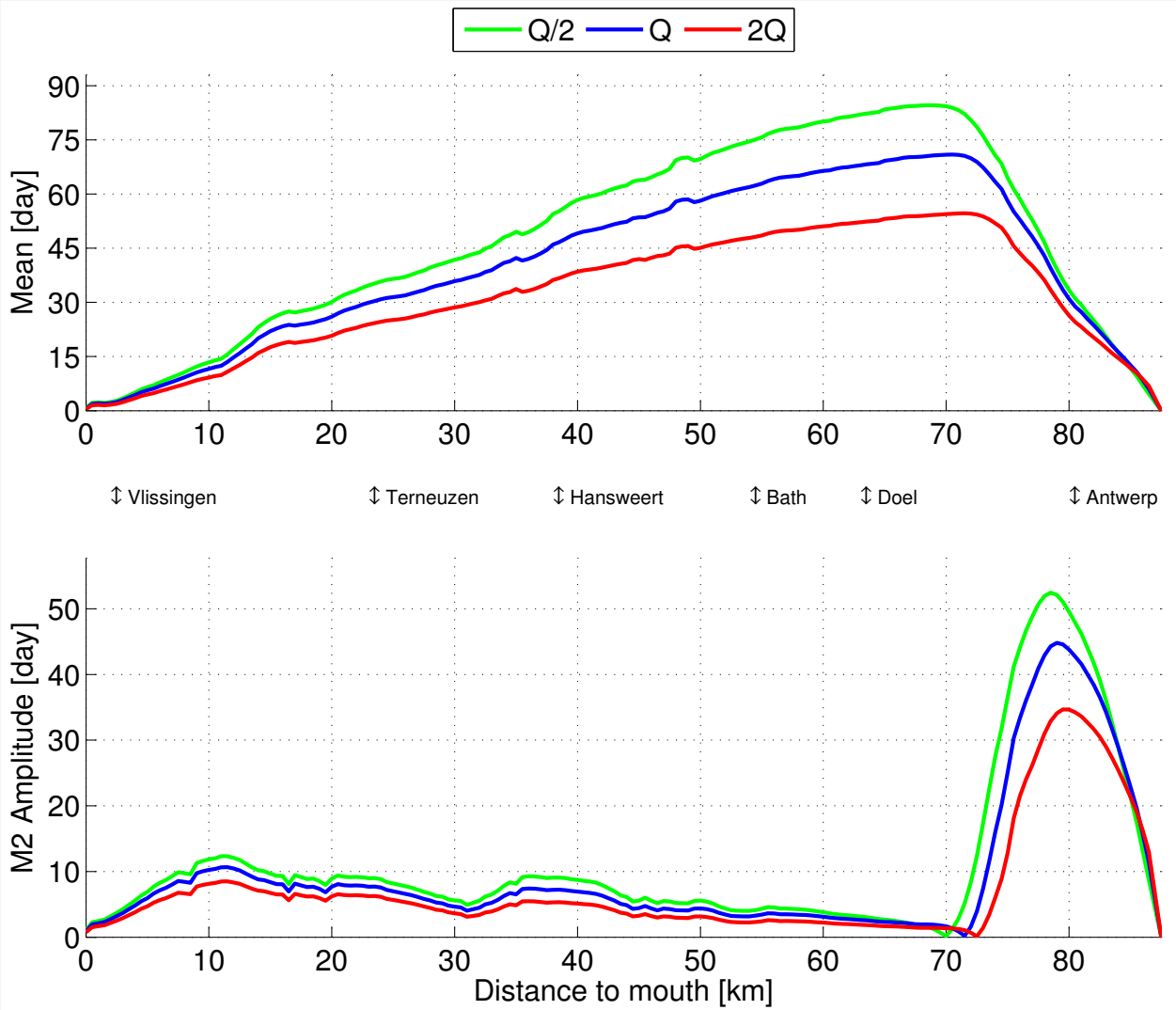
Residence time
Longitudinal projection



- Tidally-averaged residence time
- M2 amplitude of the residence time

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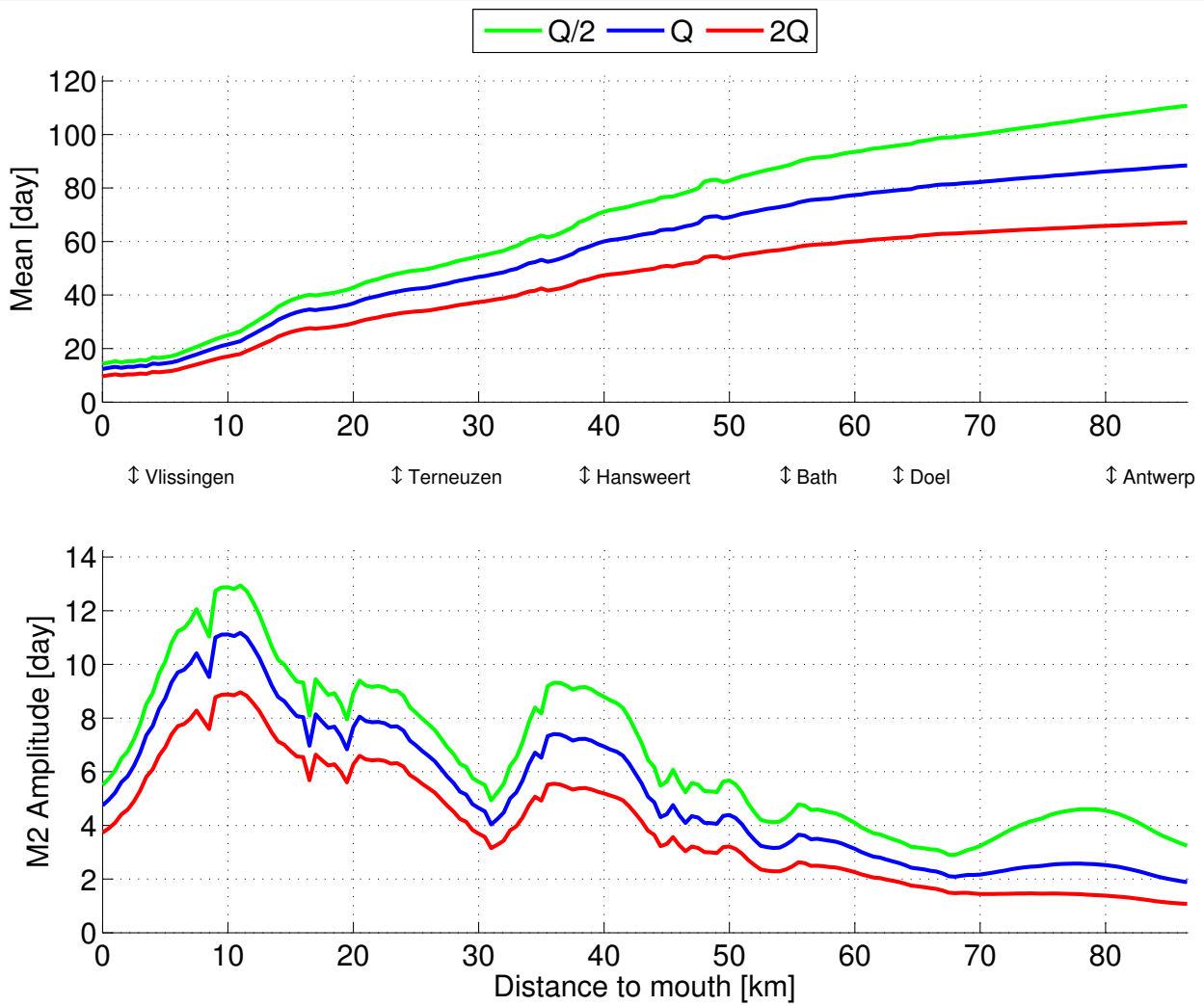
Exposure time
Longitudinal projection



- Tidally-averaged exposure time
- M2 amplitude of the exposure time

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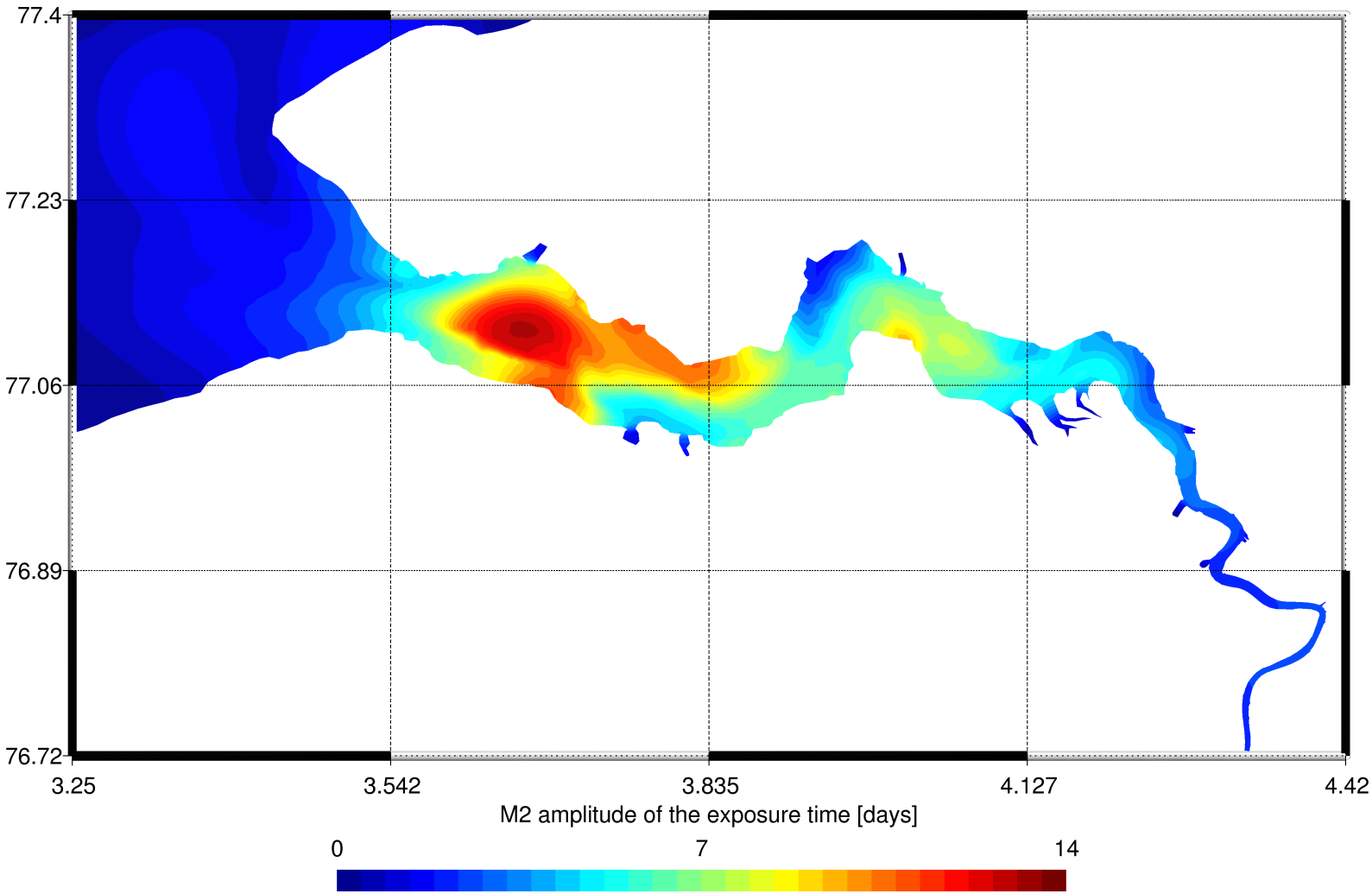
Exposure time
M2 amplitude, Mean situation (Q)



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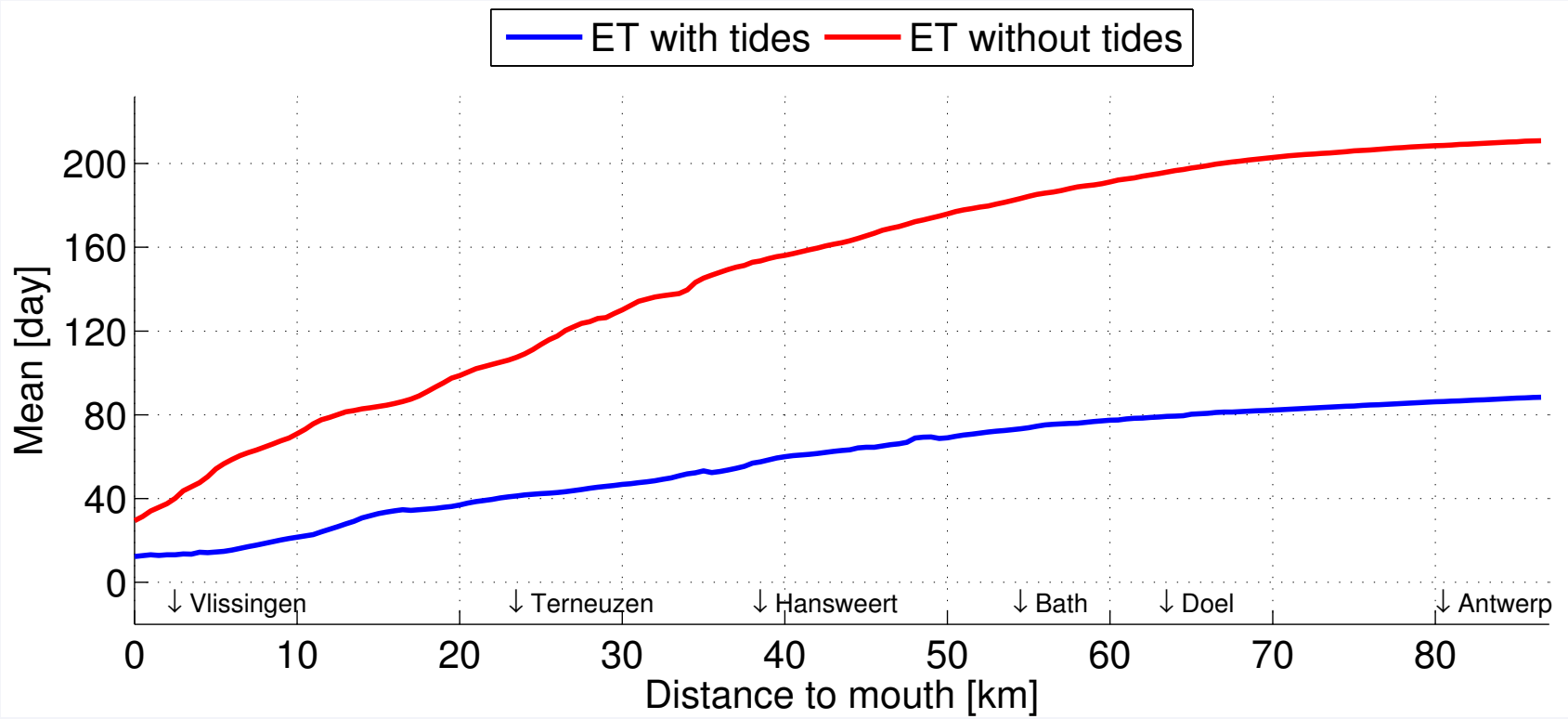
Effect of the tide

Tidally-averaged exposure time, Mean situation



- 0D flushing time $= \frac{V}{Q}\left(1 - \frac{S_m}{S_0}\right) = \frac{2\times10^9\ \mathrm{m}^3}{120\ \mathrm{m}^3/\mathrm{s}} = 190$ days
- The timescales are 2 times smaller with the tide
- The Stokes drift is important

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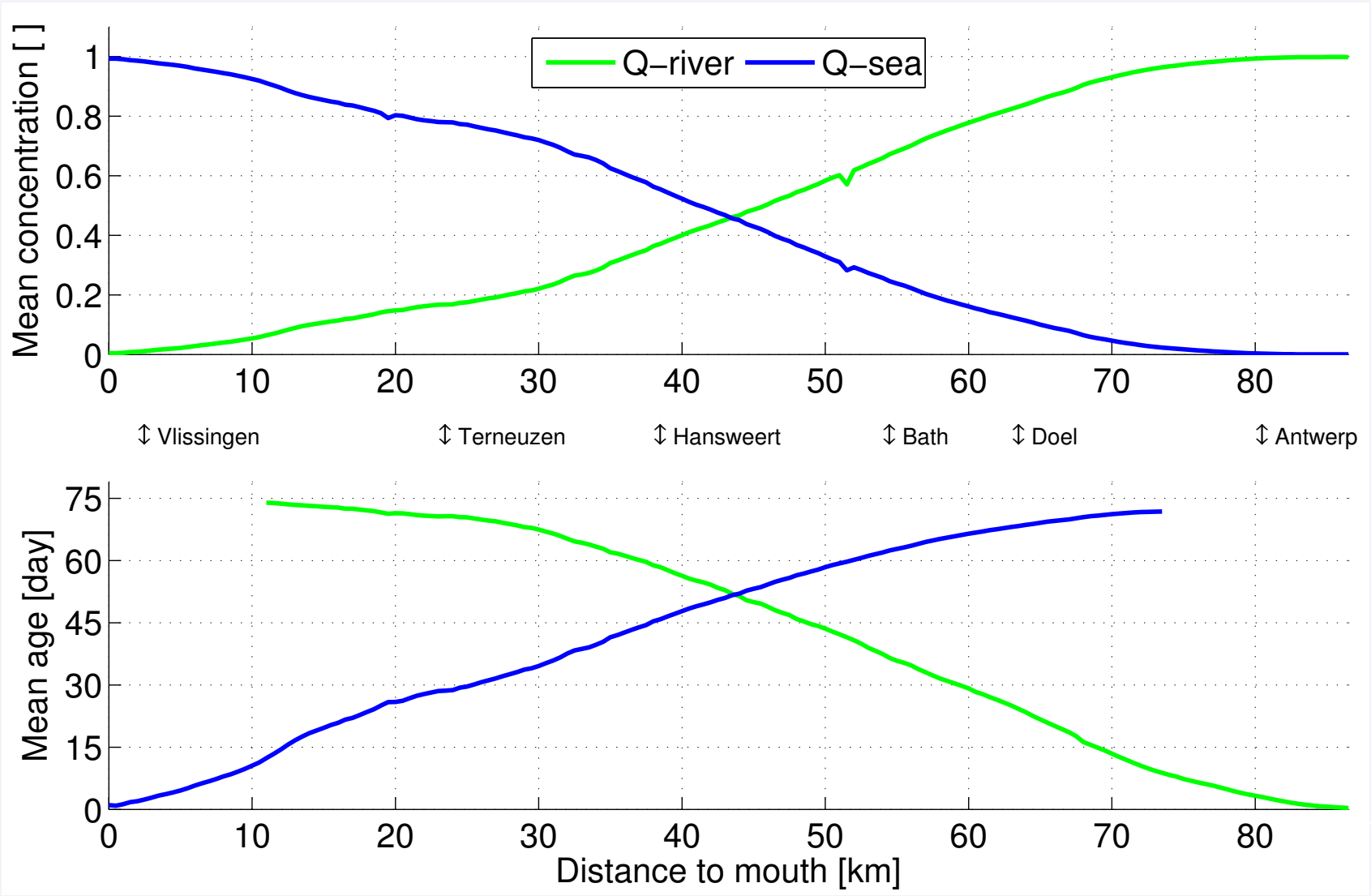
Age of renewal water

Sea water + river water



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Conclusion

- Age and residence time are complementary
- Zero-D approximations overestimate the timescales
- When the tide is neglected, the timescales increase by a factor of 2
- The residence time/exposure time depends on when the particle is released (high tide/low tide)
- The difference can reach 20 days at 10 km from the mouth
- **It is necessary to resolve the tide**

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More informations

- www.climate.be/SLIM
- www.climate.be/CART
- www.climate.be/TIMOTHY

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