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

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- A water parcel (location, time)
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is the time elapsed since the water parcel left the upstream boundary = $t(\rightarrow)$

Residence time of a water parcel
is the time taken by the water parcel to leave for the first time the estuary = $t(\rightarrow)$

Exposure time of a water parcel
is the total time spent by the water parcel inside the estuary = $t(\rightarrow) + t(\rightarrow)$
Renewal timescales

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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

   ▶ One backward advection-diffusion equation

Age

1. CART Theory ([www.climate.be/CART](http://www.climate.be/CART))
   ▶ Two forward advection-diffusion equations
How to compute these timescales

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

http://www.climate.be/SLIM
Application: the Scheldt Estuary
Multiscale model

Renewal timescales in the Scheldt Estuary
Application: the Scheldt Estuary
A highly polluted macrotidal estuary in the Netherlands and Belgium
Hydrodynamics
Validation of the elevation

Vlissingen

Hansweert

Modelled
Observed

Elevation [m]

06/07 06/08 06/09 06/10 06/11 06/12 06/13 06/14
Salinity
Validation of a passive tracer

Overloop Van Hansweert (km 30)

Baalhoek (km 45)

Salinity [psu]

07/12 07/13 07/14 07/15 07/16 07/17

model
upper layer obs
bottom layer obs

07/11 07/12 07/13 07/14 07/15 07/16

salinity [psu]

10 12 14 16 18
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)
Residence time
Longitudinal projection

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

M2 amplitude of the exposure time
Exposure time
M2 amplitude, Mean situation (Q)
Effect of the tide
Tidally-averaged exposure time, Mean situation

- 0D flushing time $\approx \frac{V}{Q} \left(1 - \frac{S_m}{S_0}\right) = \frac{2 \times 10^9 \ m^3}{120 \ m^3/s} = 190 \ days$
- The timescales are 2 times smaller with the tide
- The Stokes drift is important
Age of renewal water
Sea water + river water

Mean concentration [\(Q\)]

\(Q_{\text{river}}\) \(Q_{\text{sea}}\)

Mean age [\(\text{day}\)]

Distance to mouth [\(\text{km}\)]

\(\uparrow\) Vlissingen \(\downarrow\) Terneuzen \(\downarrow\) Hansweert \(\downarrow\) Bath \(\downarrow\) Doel \(\downarrow\) Antwerp

de Brye, de Brauwere and Deleersnijder
Renewal timescales in the Scheldt Estuary
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
More informations

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