Present nitrogen and carbon dynamics in the Schelde estuary using a novel 1-D model

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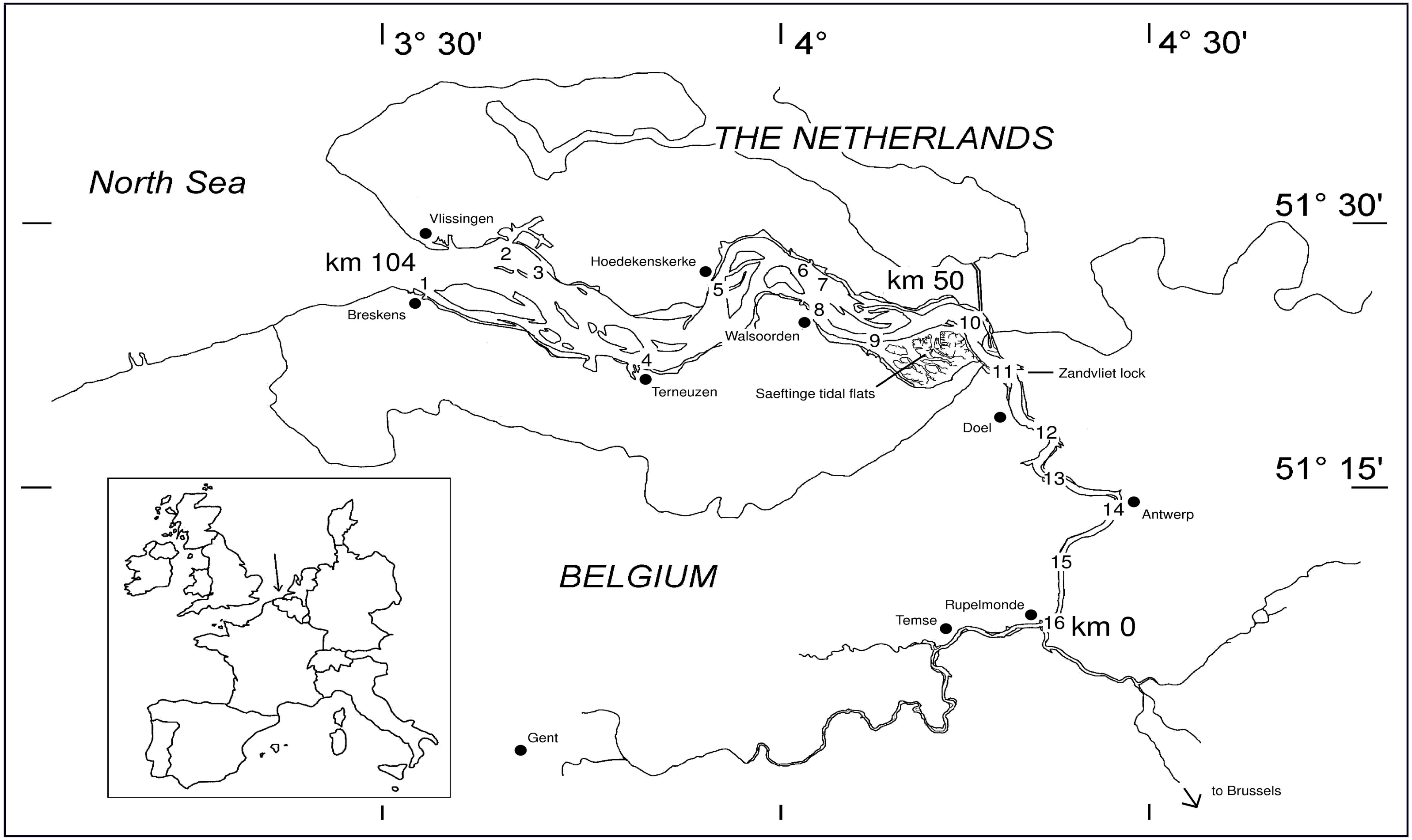
Schelde Estuary



- $Q = 100\ m^3\ s^{-1}$
- macrotidal
- $A_{cross} = 4000\ m^2$ to $75000\ m^2$
- $D = 6$ to $14\ m$
- $V = 3.6\ 10^9\ m^3$
- $A_{surf} = 338\ km^2$

Rationales for a Model

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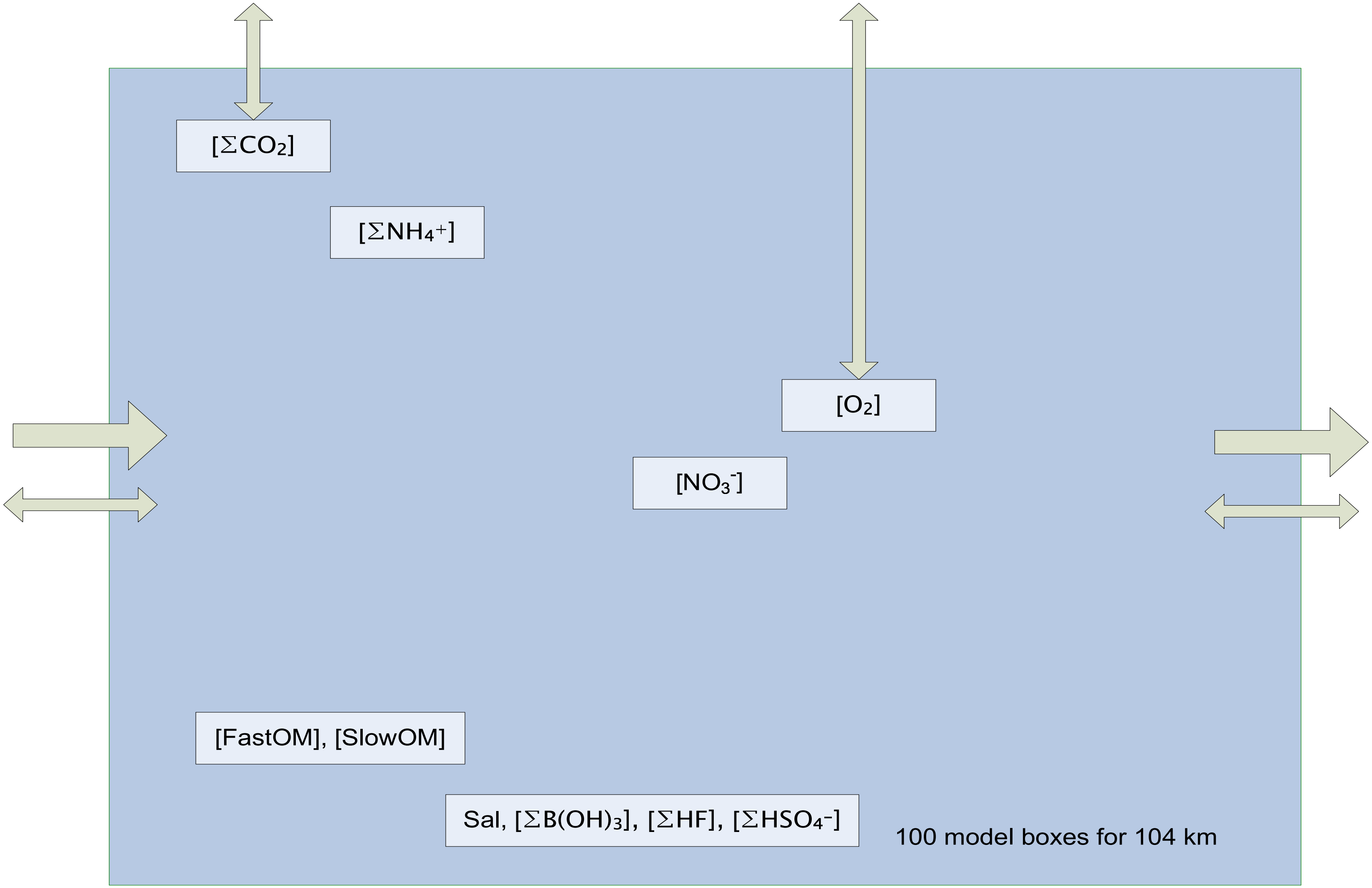
- The model should be as simple as possible but still fitting the data sufficiently to indentify the main driving processes in the rather complex ecosystem Schelde estuary.
- The model should maintain the right balance between the complexity of the representation of physical (transport) processes and biogeochemical processes.

1-D Reactive-Transport Model



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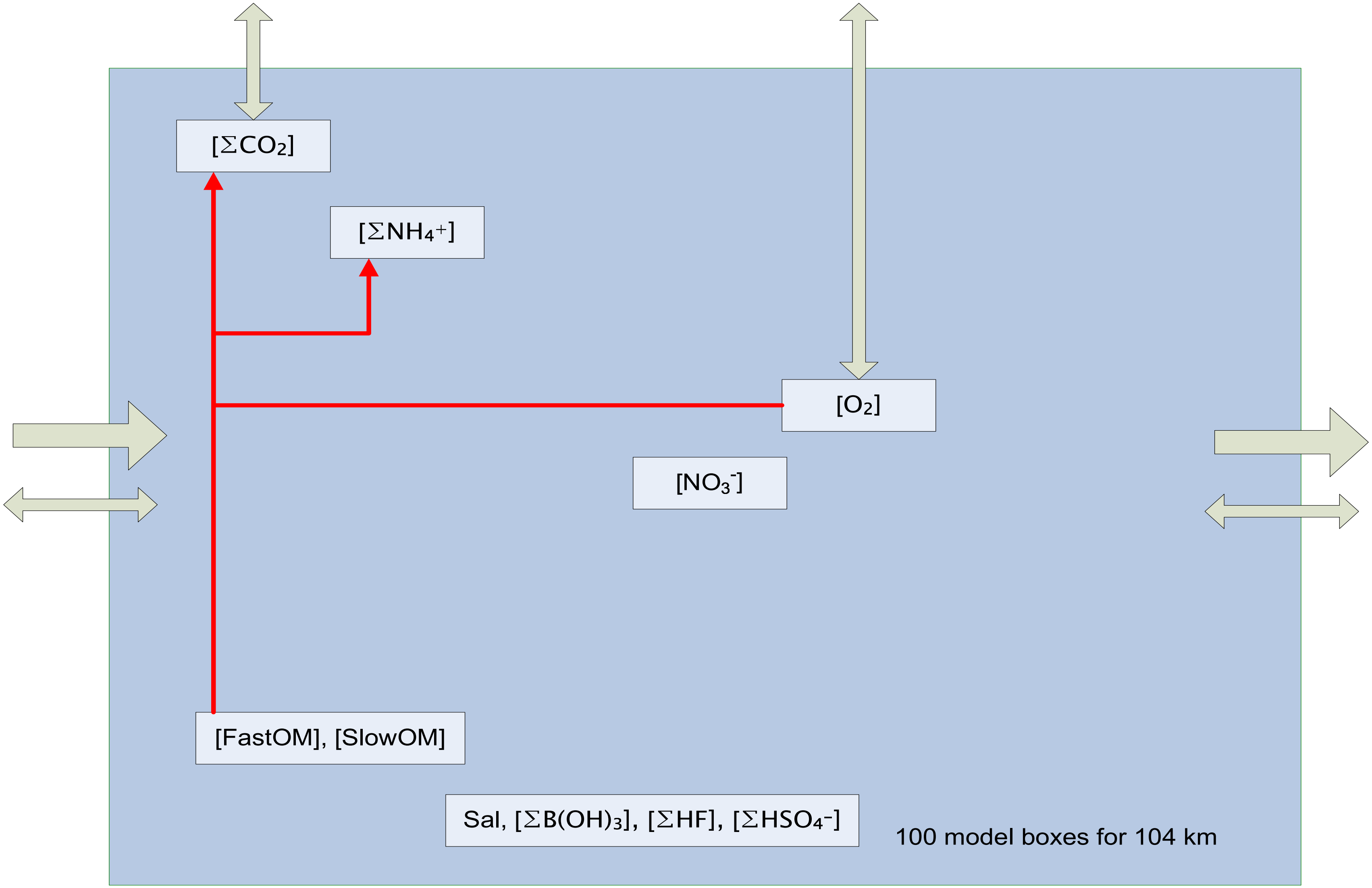

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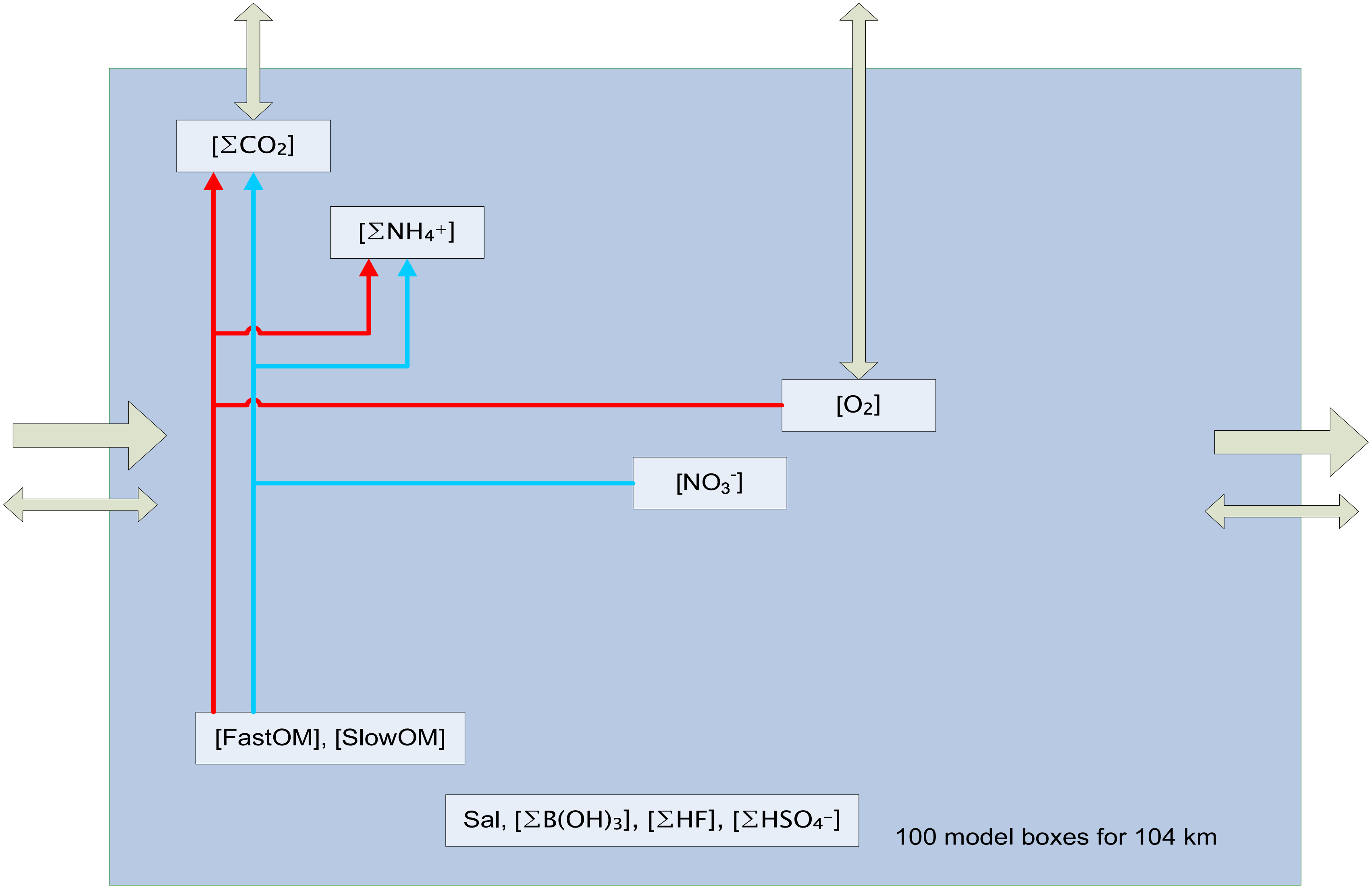

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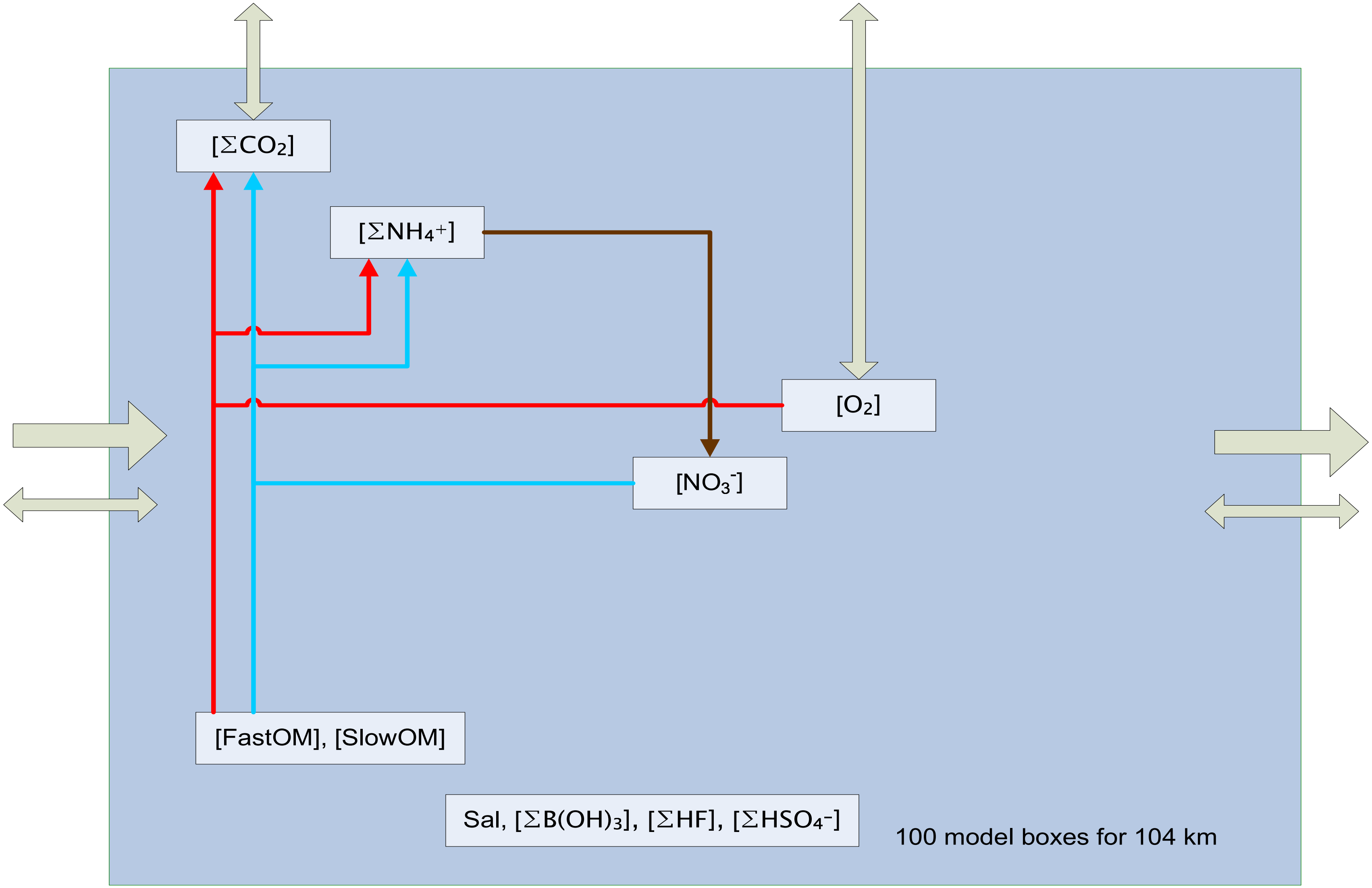

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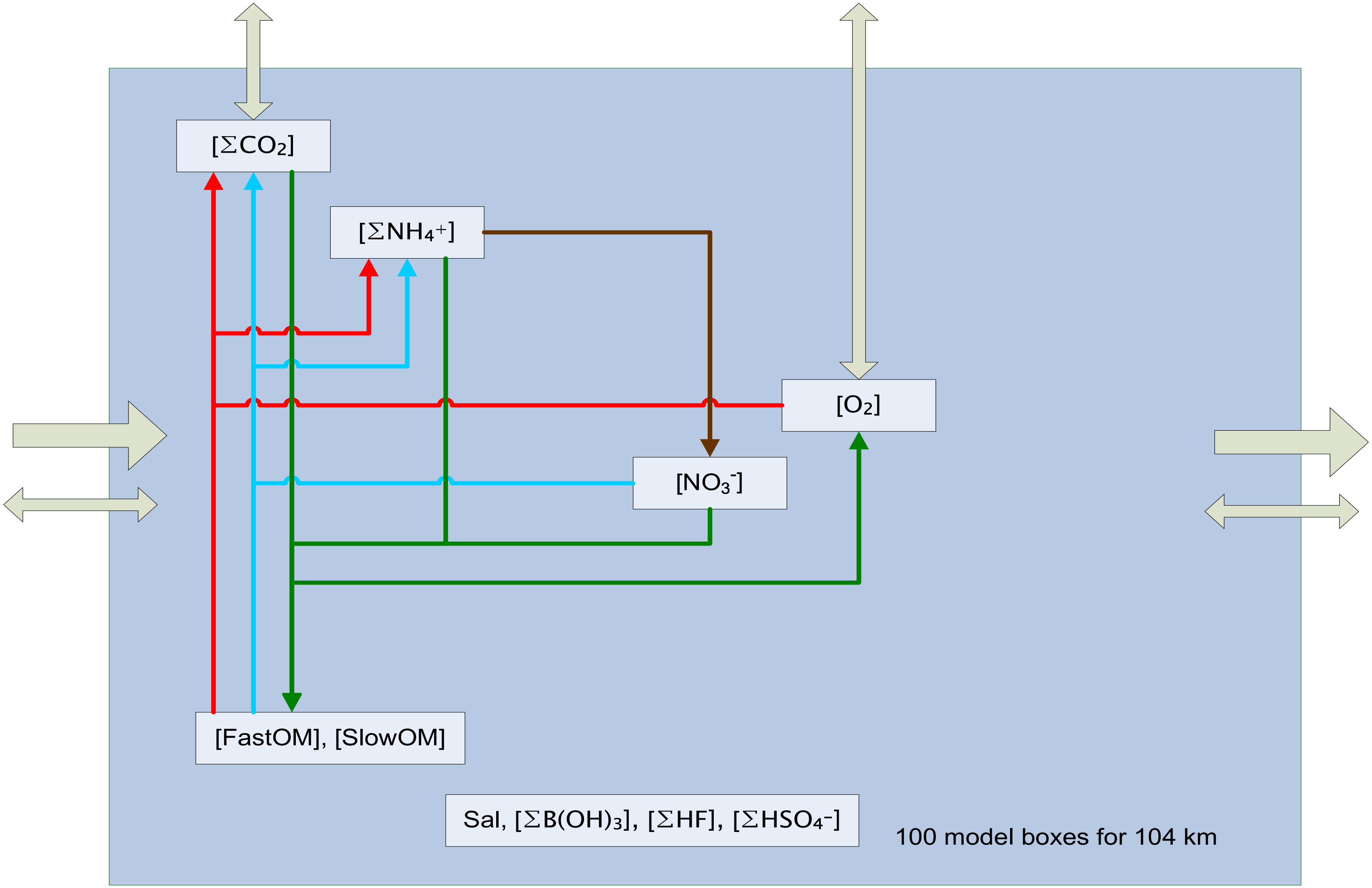

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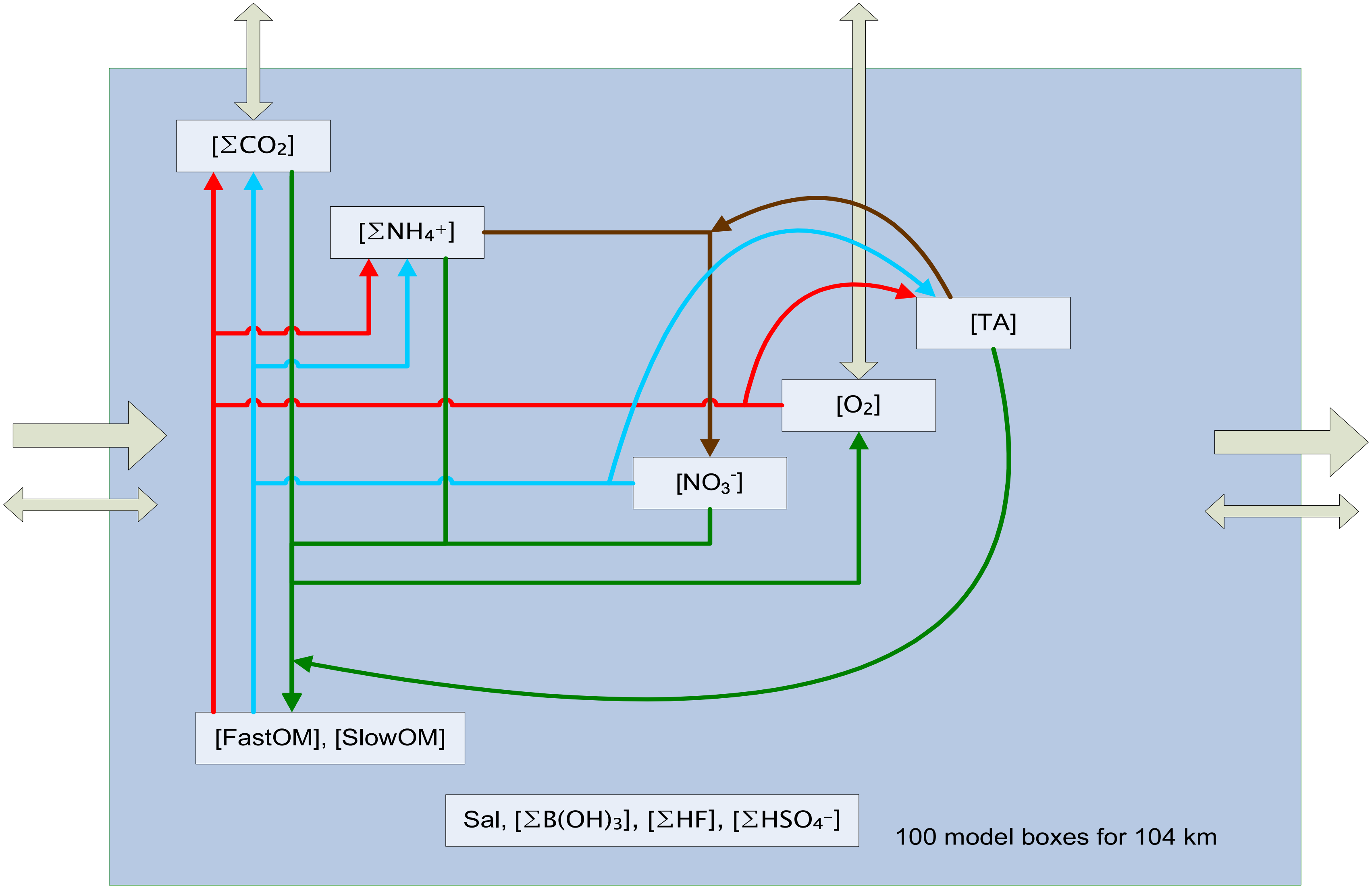

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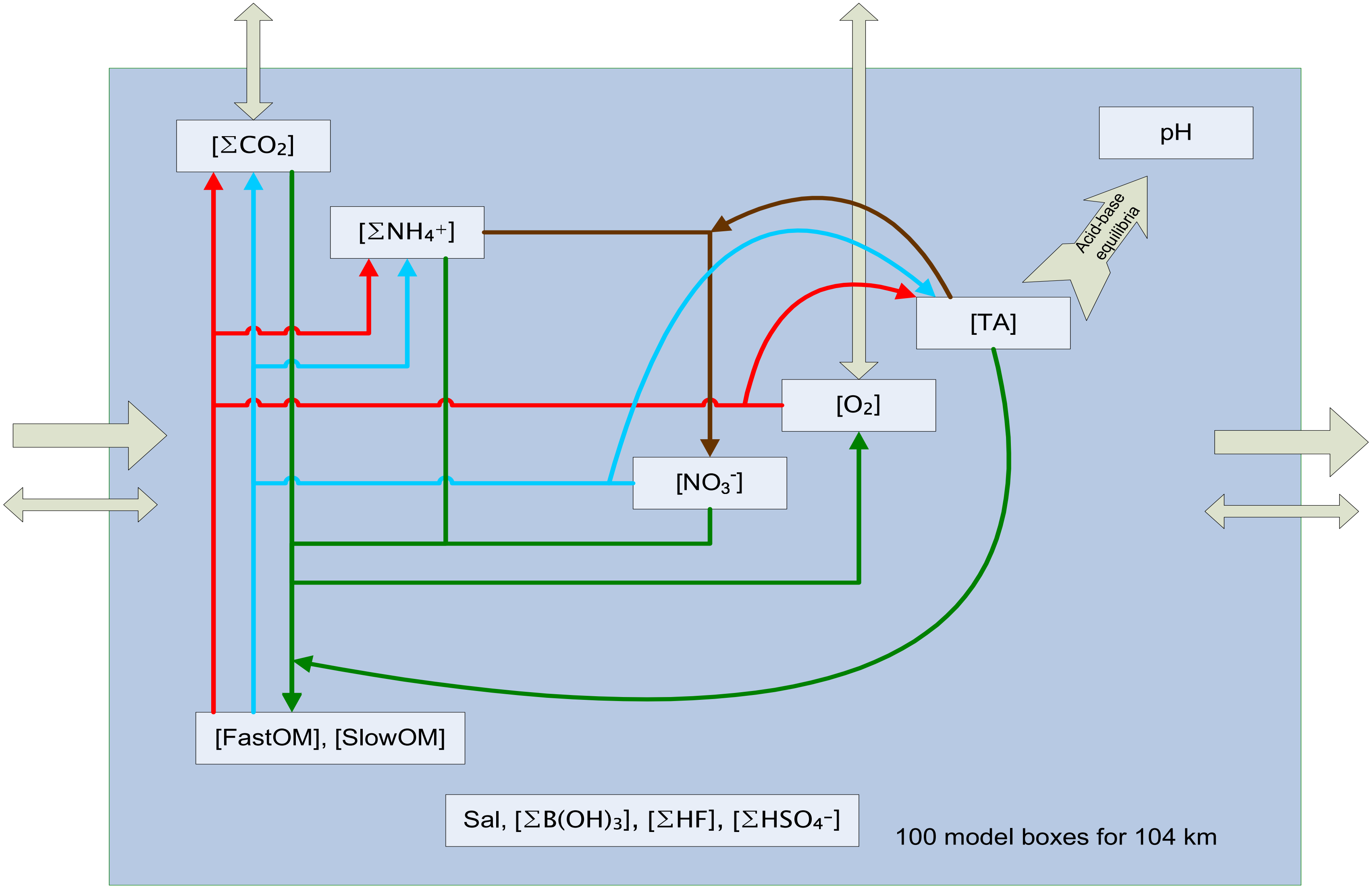


1-D Reactive-Transport Model

$$\frac{d[\mathrm{FastOM}]}{dt} = \mathbf{Tr}_{\mathrm{FastOM}} - \mathbf{R}_{OxFastOM} - \mathbf{R}_{DenFastOM} + \mathbf{R}_{PP}$$

$$\frac{d[\mathrm{SlowOM}]}{dt} = \mathbf{Tr}_{\mathrm{SlowOM}} - \mathbf{R}_{OxSlowOM} - \mathbf{R}_{DenSlowOM}$$

$$\frac{d[\mathrm{DOC}]}{dt} = \mathbf{Tr}_{\mathrm{DOC}}$$

$$\frac{d[\mathrm{O_2}]}{dt} = \mathbf{Tr}_{\mathrm{O_2}} + \mathbf{E}_{\mathrm{O_2}} - \mathbf{R}_{OxCarb} - 2 \cdot \mathbf{R}_{Nit} + (2 - 2 \cdot p^{PP}_{\mathrm{NH_4^+}}) \cdot \mathbf{R}_{PP} + \mathbf{R}_{PPCarb}$$

$$\frac{d[\mathrm{NO_3^-}]}{dt} = \mathbf{Tr}_{\mathrm{NO_3^-}} - 0.8 \cdot \mathbf{R}_{DenCarb} + \mathbf{R}_{Nit} - (1 - p^{PP}_{\mathrm{NH_4^+}}) \cdot \mathbf{R}_{PP}$$

$$\frac{d[\mathrm{S}]}{dt} = \mathbf{Tr}_{\mathrm{S}}$$

$$\frac{d[\sum \mathrm{CO_2}]}{dt} = \mathbf{Tr}_{\sum \mathrm{CO_2}} + \mathbf{E}_{\mathrm{CO_2}} + \mathbf{R}_{OxCarb} + \mathbf{R}_{DenCarb} - \mathbf{R}_{PPCarb}$$

$$\frac{d[\sum \mathrm{NH_4^+}]}{dt} = \mathbf{Tr}_{\sum \mathrm{NH_3}} + \mathbf{R}_{Ox} + \mathbf{R}_{Den} - \mathbf{R}_{Nit} - p^{PP}_{\mathrm{NH_4^+}} \cdot \mathbf{R}_{PP}$$

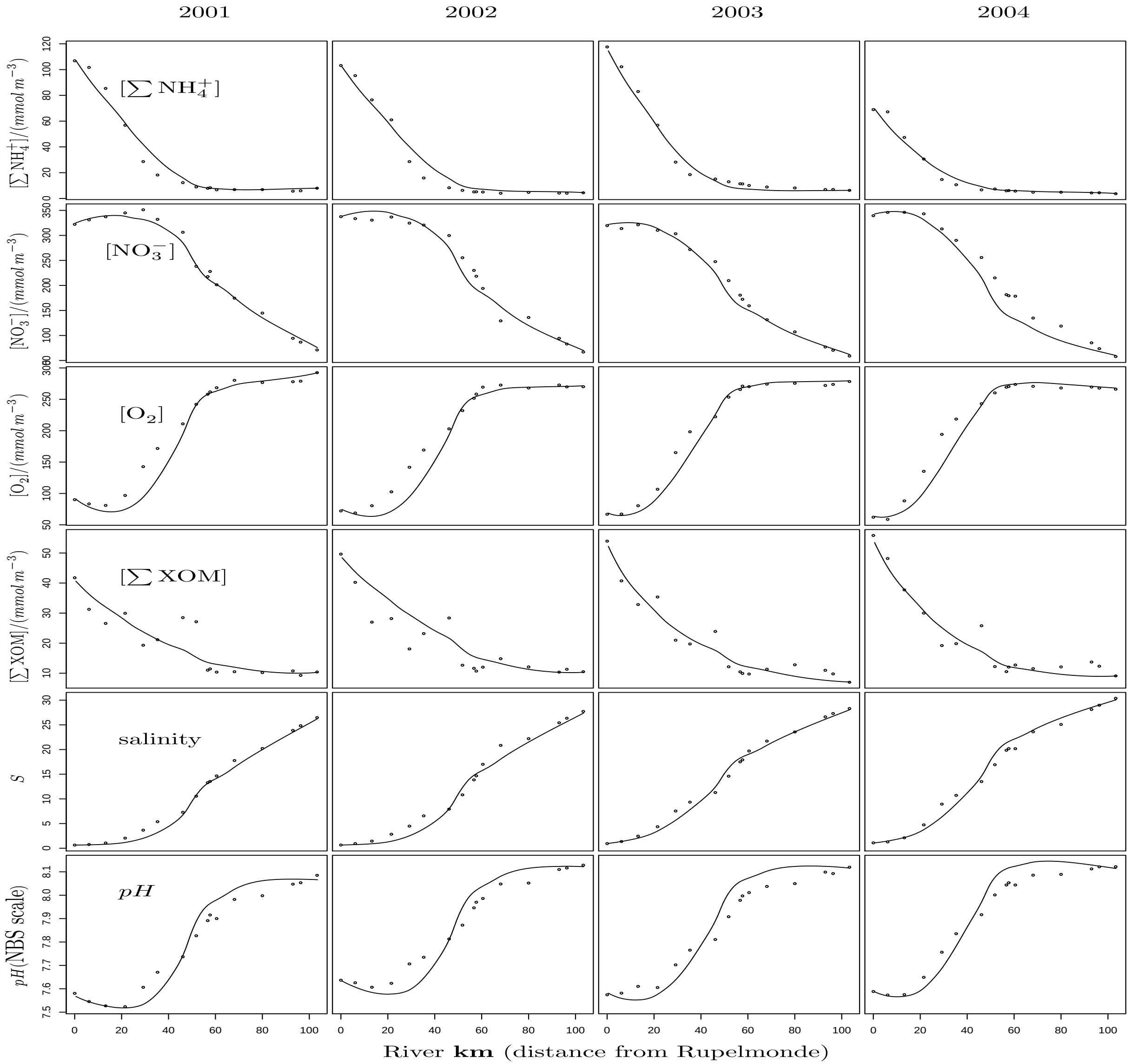
$$\frac{d[\sum \mathrm{HSO_4^-}]}{dt} = \mathbf{Tr}_{\sum \mathrm{HSO_4^-}}$$

$$\frac{d[\sum \mathrm{B(OH)_3}]}{dt} = \mathbf{Tr}_{\sum \mathrm{B(OH)_3}}$$

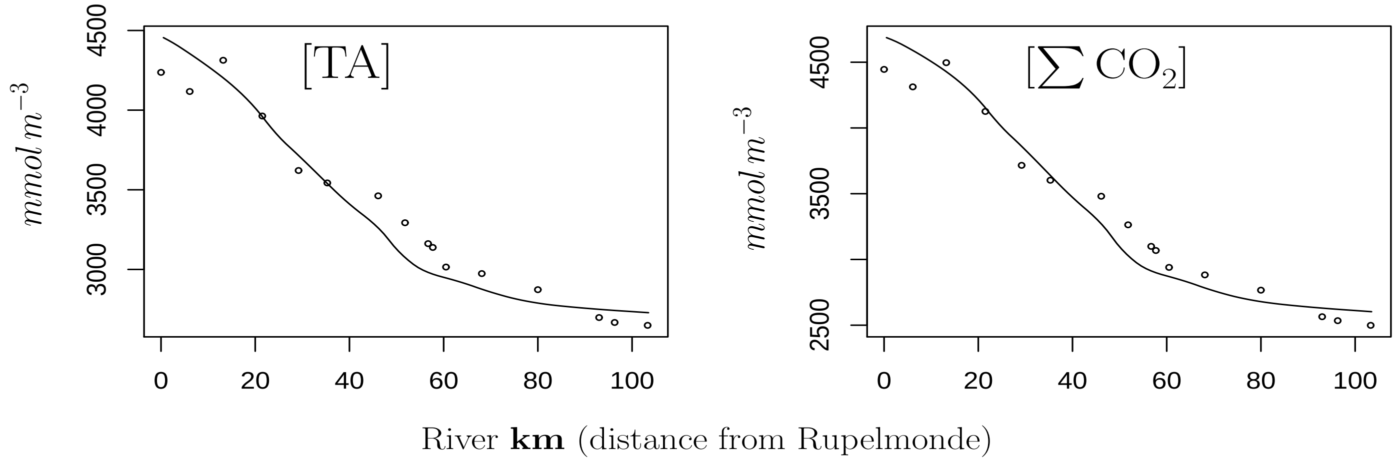
$$\frac{d[\sum \mathrm{HF}]}{dt} = \mathbf{Tr}_{\sum \mathrm{HF}}$$

$$\frac{d[\mathrm{TA}]}{dt} = \mathbf{Tr}_{\mathrm{TA}} + \mathbf{R}_{Ox} + 0.8 \cdot \mathbf{R}_{DenCarb} + \mathbf{R}_{Den} - 2 \cdot \mathbf{R}_{Nit} - (2 \cdot p^{PP}_{\mathrm{NH_4^+}} - 1) \cdot \mathbf{R}_{PP}$$

Model Fit (yearly avg. longitudinal profiles)



(NIOO monitoring data)



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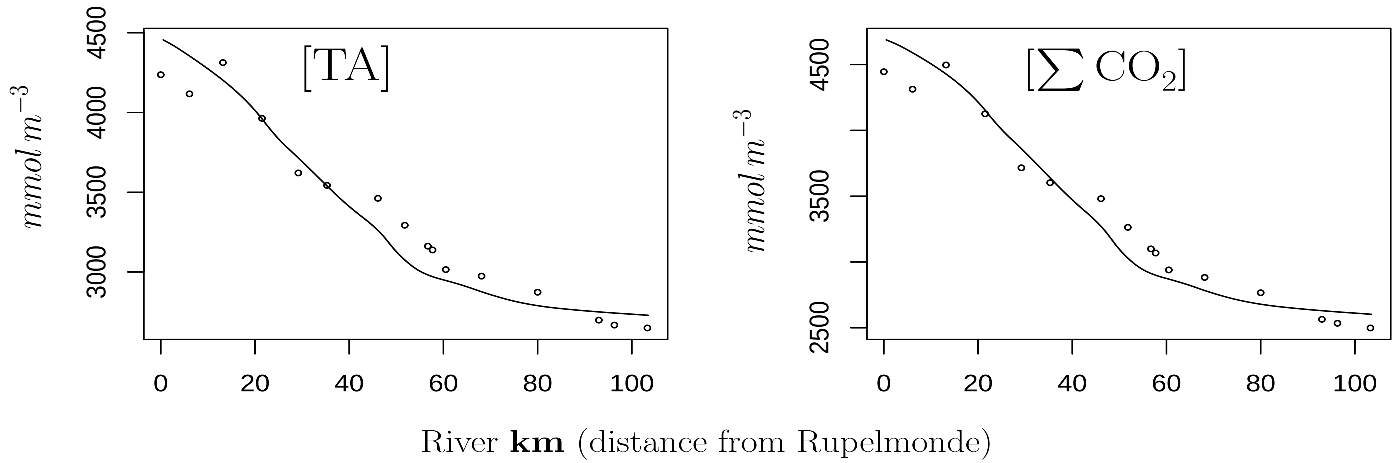

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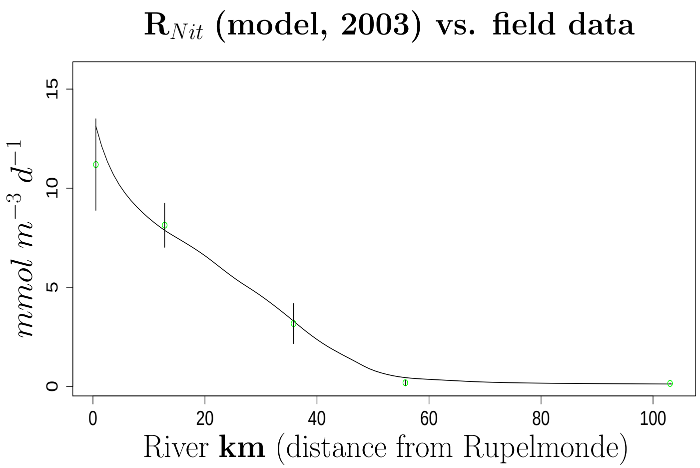

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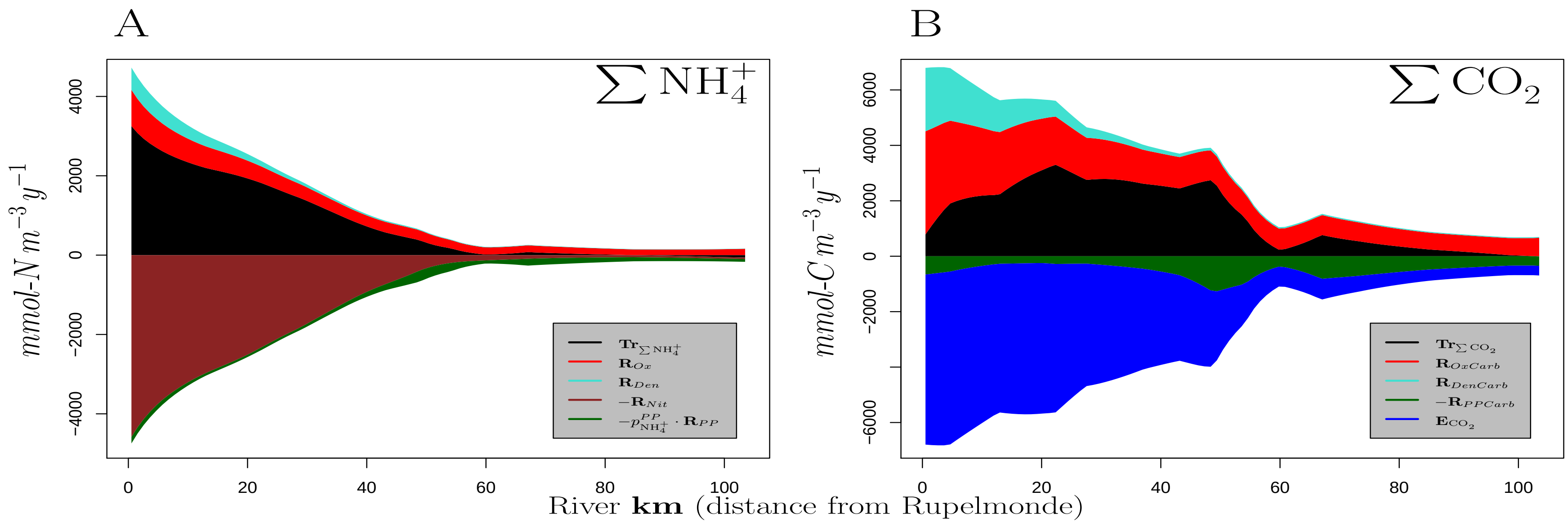
Longitudinal profiles



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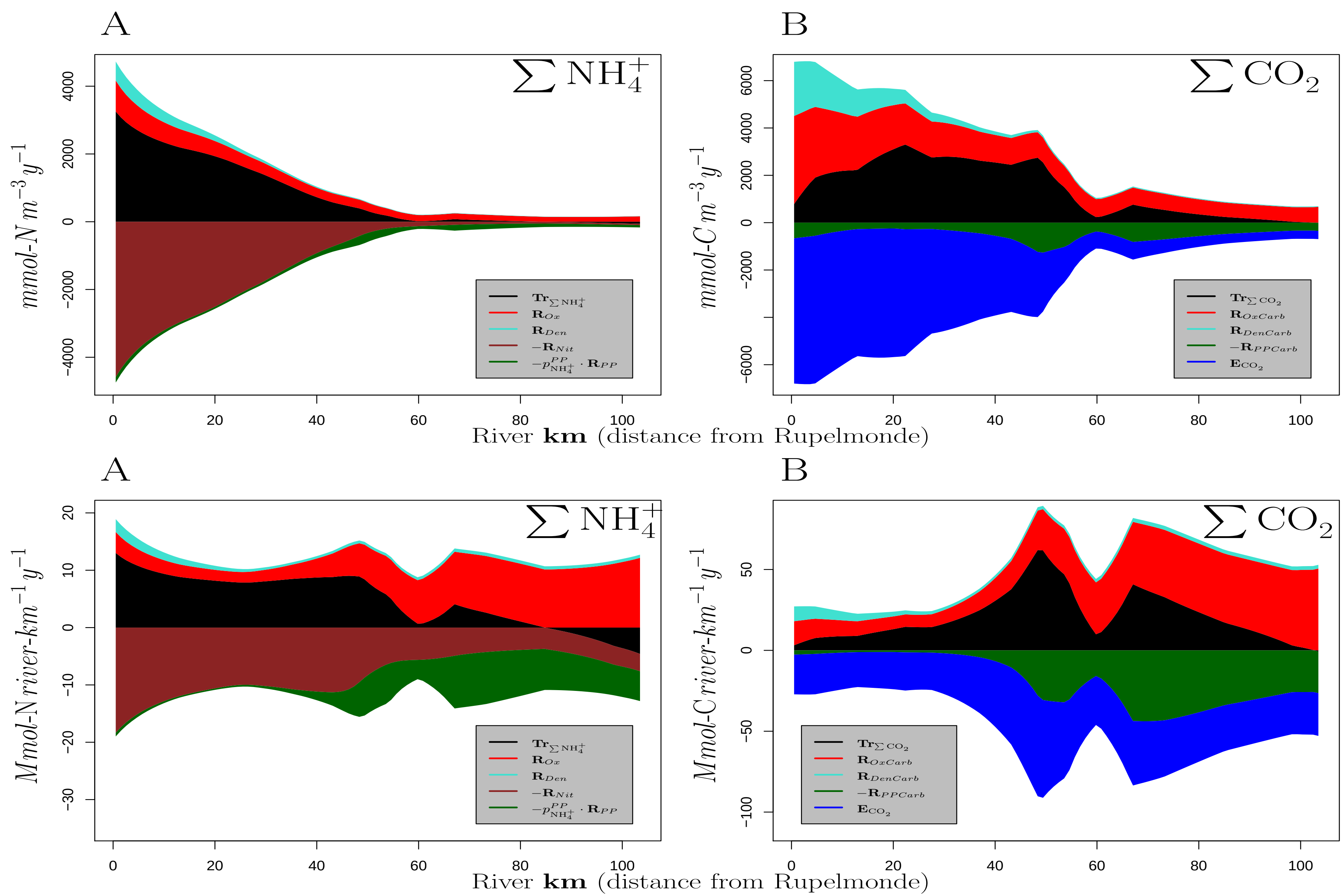
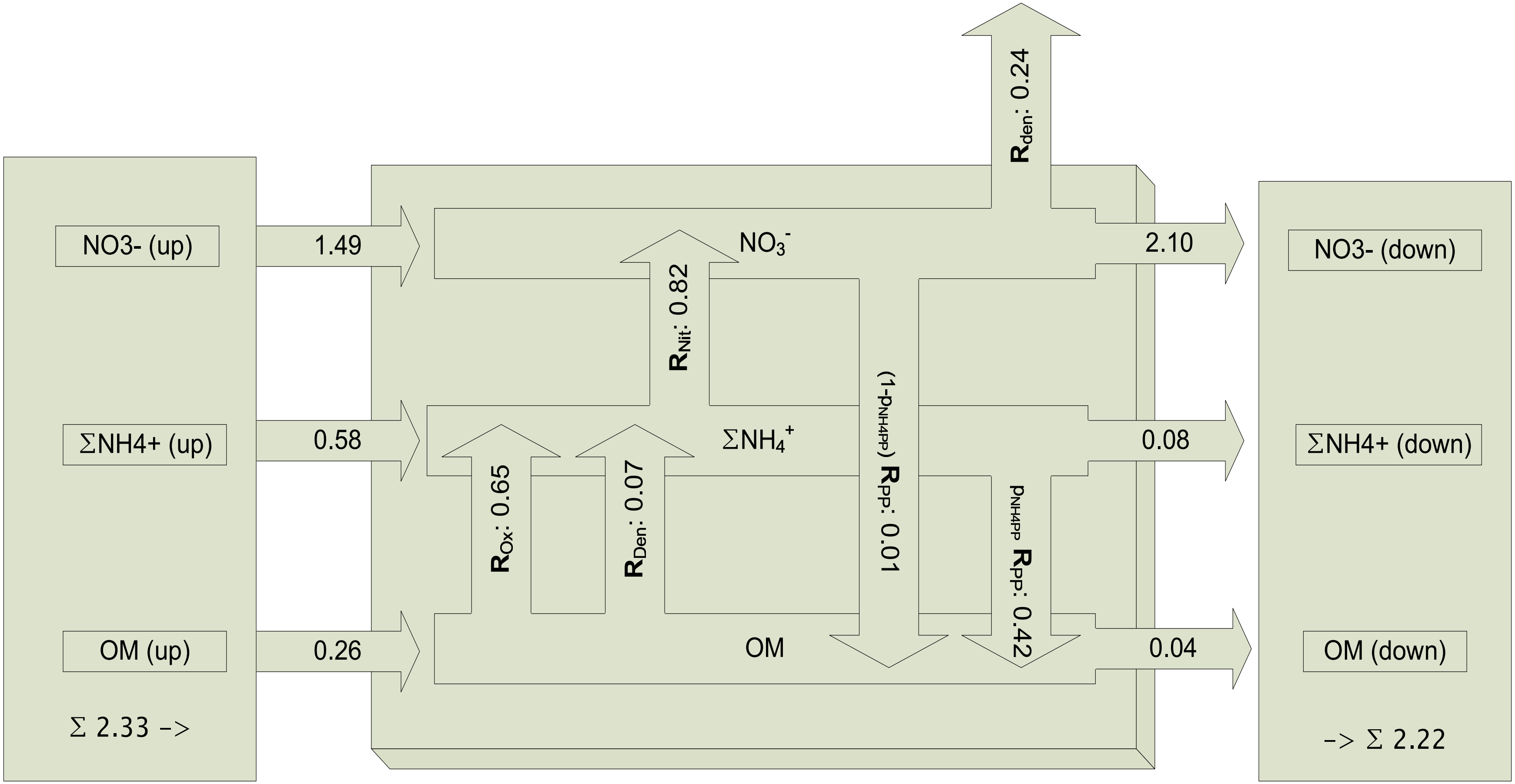


Nitrogen Budget $(Gmol\ year^{-1})$



- Nitrification

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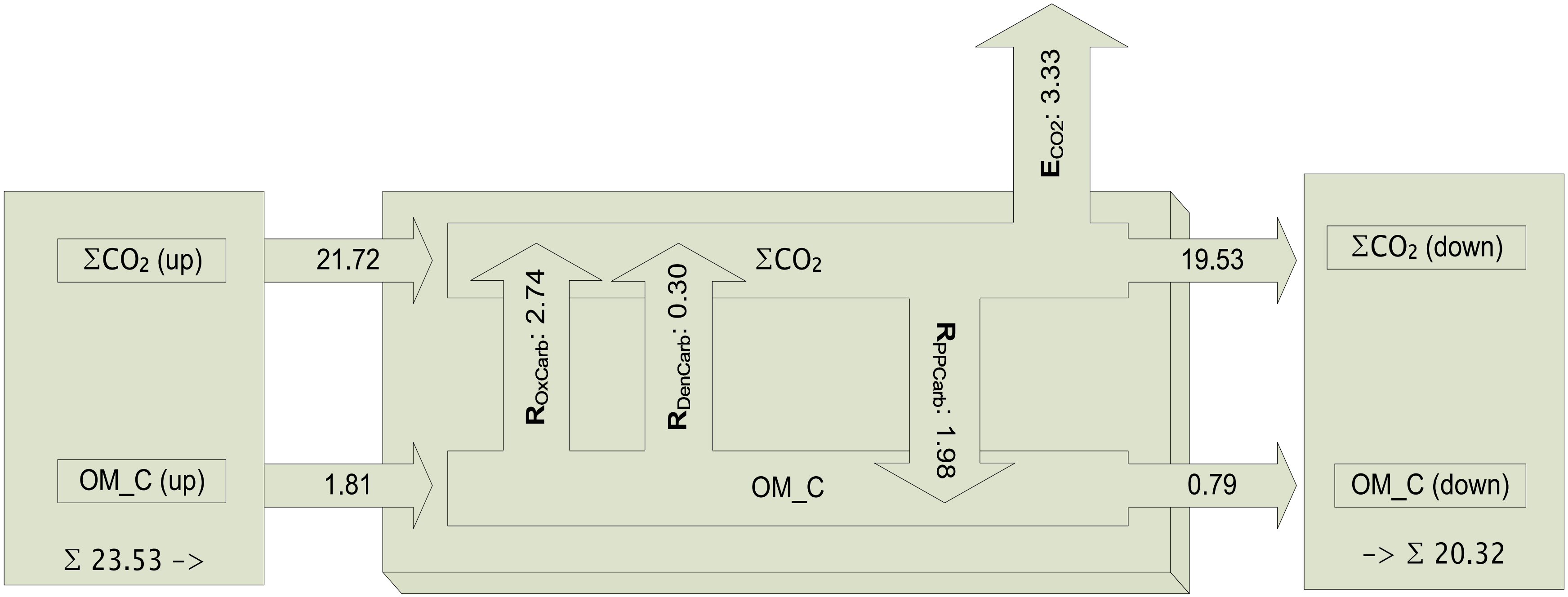
decade	′70	′80	′00
Gmol N y^{-1} imported into the Schelde	3.7	4.7	2.5
% of total N lost to the atmosphere	40	23	10
Gmol N y^{-1} exported to the North Sea	1.9	3.6	2.4

Carbon Budget $(Gmol\ year^{-1})$



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- However, there are large uncertainties associated with CO_2 degassing estimations.

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- Uncertainties in estuarine surface area estimations
- Former overestimations of piston velocities
- Employment of estimation techniques not relying on a mechanistic model with rigorous mass budgeting

Summary

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- Nitrification peaked in the ’80 due to a shift from oxygen limitation to ammonium limitation.
- Denitrification continuously decreased, reducing the N filtering capacity of the estuary. This means that the N export to North sea is higher in the ’00 than in the ’70 although the N input into the estuary almost halved.
- CO_2 degassing from the estuary decreased since the ’90, however there are severe uncertainties associated with CO_2 degassing estimates.

Thank you for your attention!

A.F. Hofmann, K. Soetaert, and J.J. Middelburg: **Present nitrogen and carbon dynamics in the Schelde estuary using a novel 1-D model**, in review for BG

A.F. Hofmann, K. Soetaert, and J.J. Middelburg: **Nitrogen and carbon dynamics in the Scheldt estuary at the beginning of the 21st century - a modelling study**, BGD, 5, 83-161, 2008

Kinetic Reactions

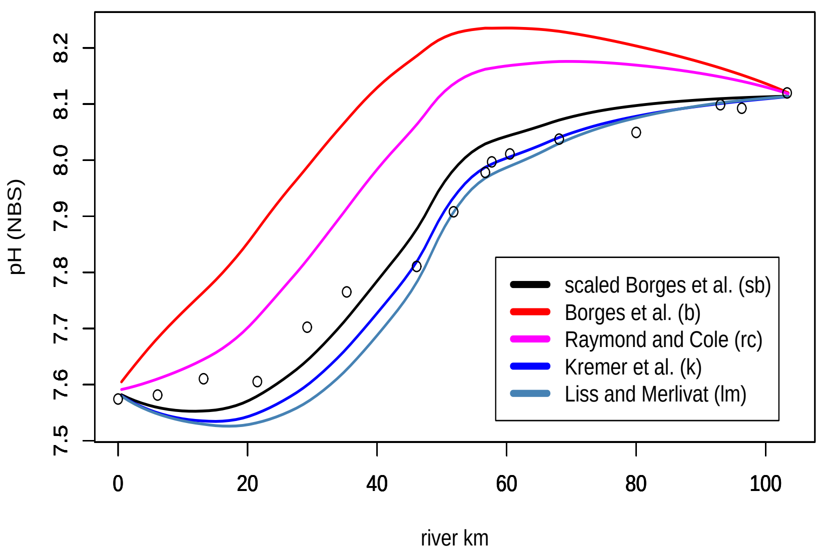
$$\mathbf{R}_{Ox}: \quad (CH_2O)_\gamma(NH_3) + \gamma O_2 \longrightarrow NH_3 + \gamma CO_2 + \gamma H_2O$$

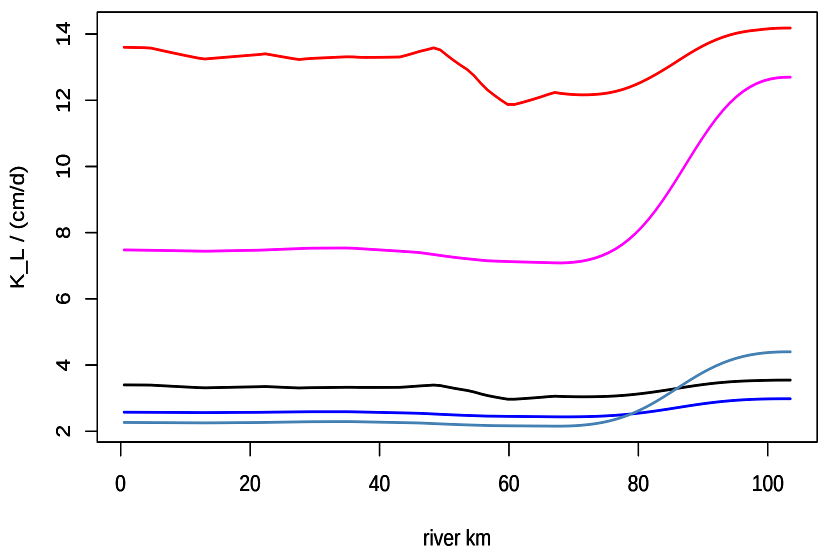
$$\mathbf{R}_{Den}: \quad (CH_2O)_\gamma(NH_3) + 0.8\gamma NO_3^- + 0.8\gamma H^+ \longrightarrow NH_3 + \gamma CO_2 + 0.4\gamma N_2 \uparrow + 1.4\gamma\ H_2O$$

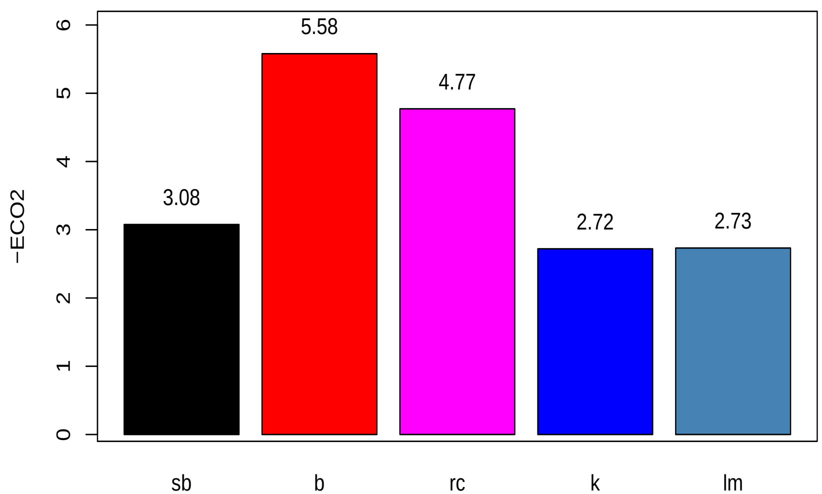
$$\mathbf{R}_{Nit}: \quad NH_3 + 2\ O_2 \longrightarrow NO_3^- + H_2O + H^+$$

$$\mathbf{R}_{PP}: \quad p^{PP}_{NH_4^+} NH_4^+ + \left(1 - p^{PP}_{NH_4^+}\right) NO_3^- + \gamma CO_2 + \left(1 + \gamma - p^{PP}_{NH_4^+}\right) H_2O \longrightarrow (CH_2O)_\gamma (NH_3) + \left(2 + \gamma - 2p^{PP}_{NH_4^+}\right) O_2 + \left(2p^{PP}_{NH_4^+} - 1\right) H^+$$

Variable Piston Velocity







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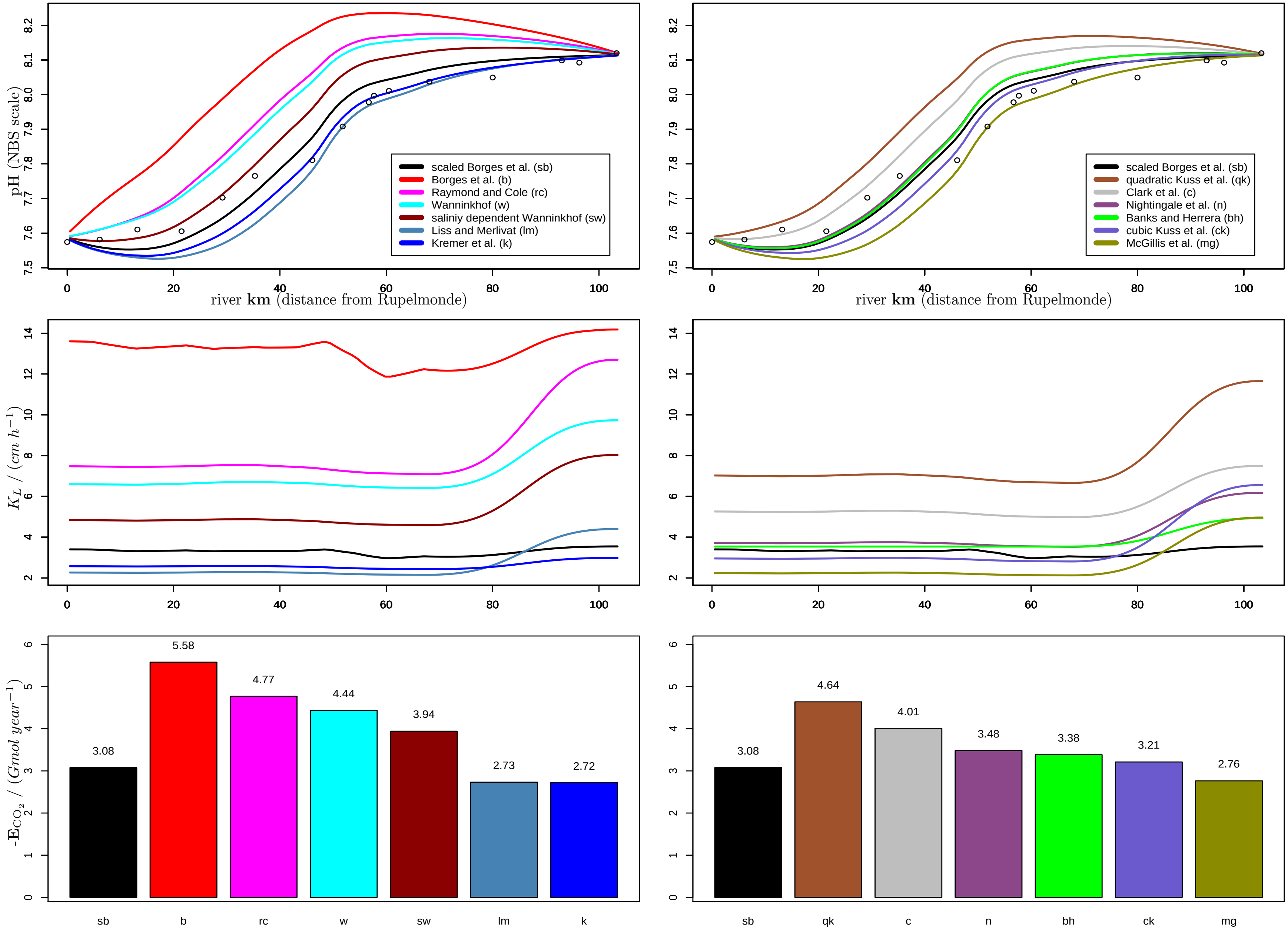

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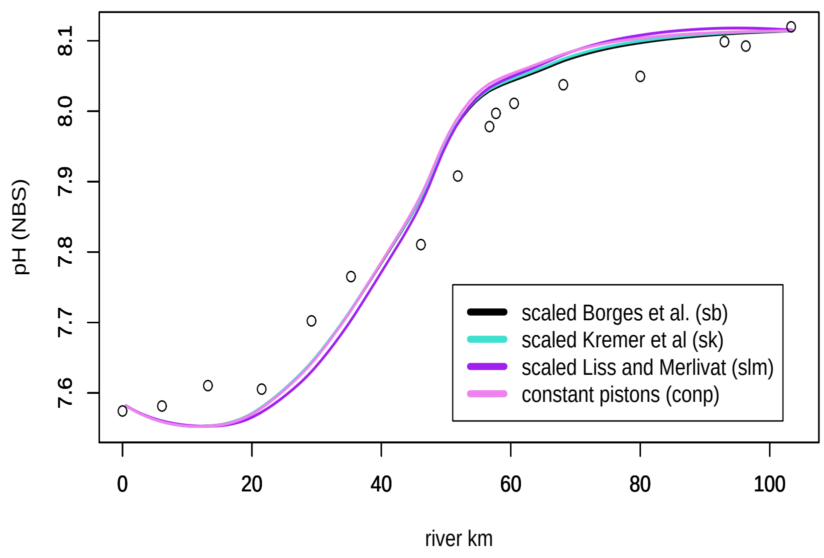
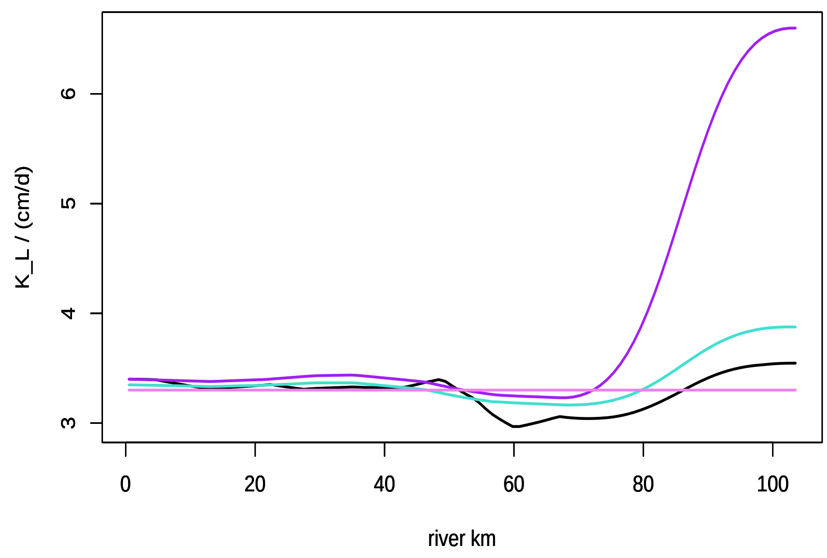
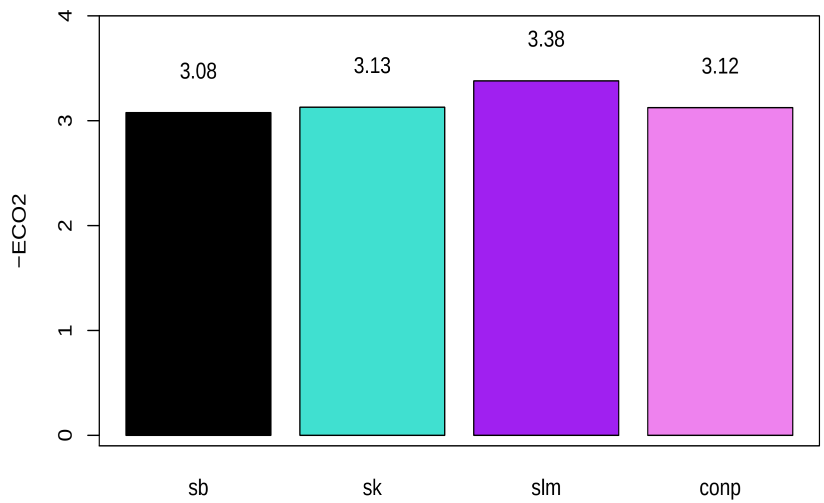




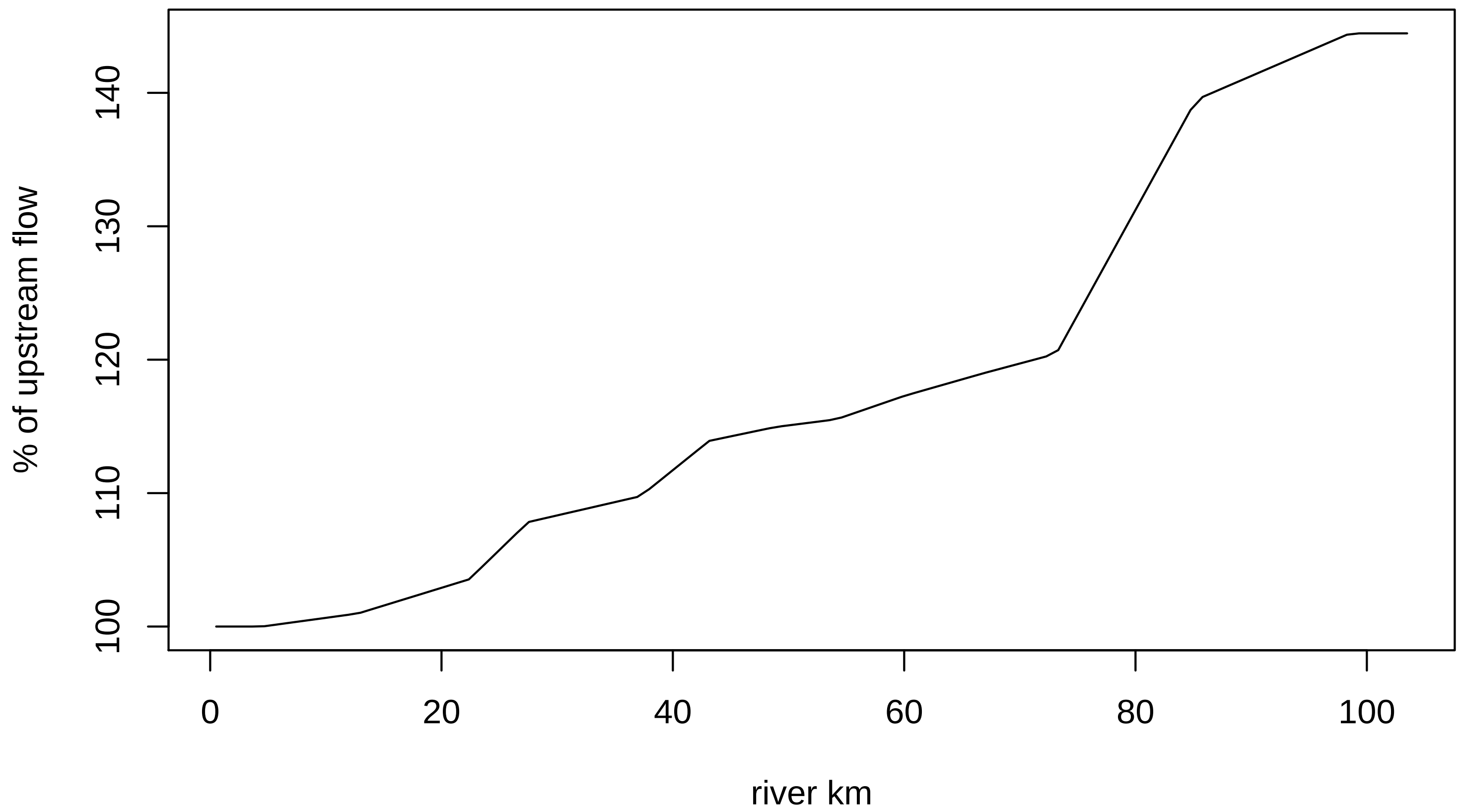


Scalefactors:

Borges et al. (2004)	0.25
Kremer et al. (2003)	1.30
Liss and Merlivat (1986)	1.50

Constant K_L: 3.3 $cm\ h^{-1}$

Advective flow increase



(calculated according to data from the SAWES model (van Gils et al., 1993; Holland, 1991))

Transport Formulation

$$\mathbf{Tr}_{\mathrm{C}} = \left.\frac{\partial[\mathrm{C}]}{\partial t}\right|_{\text{Adv-Disp}} = \frac{1}{A}\left(\frac{\partial}{\partial x}\left(E\;A\;\frac{\partial[\mathrm{C}]}{\partial x}\right) - \frac{\partial}{\partial x}\left(Q\;[\mathrm{C}]\right)\right)$$

discretised to

$$\mathbf{Tr}_{\mathrm{C}}\Big|_i \approx \Big(E'_{i-1,i}\;\left([\mathrm{C}]_{i-1} - [\mathrm{C}]_i\right) - E'_{i,i+1}\;\left([\mathrm{C}]_i - [\mathrm{C}]_{i+1}\right)$$
$$+ Q_{i-1,i}\;[\mathrm{C}]_{i-1} - Q_{i,i+1}\;[\mathrm{C}]_i\Big)\;\cdot\;V_i^{-1}$$

with

$$E'_{i-1,i} = E_{i-1,i}\;A_{i-1,i}\;\left(\Delta x_{i-1,i}\right)^{-1}$$

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