Nutrient transport and transformation in macrotidal estuaries of the French Atlantic coast: a modelling approach using C-GEM

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Due to the limited space in the main context, the results of small estuaries (the Somme and Vilaine) are presented in the supplement.

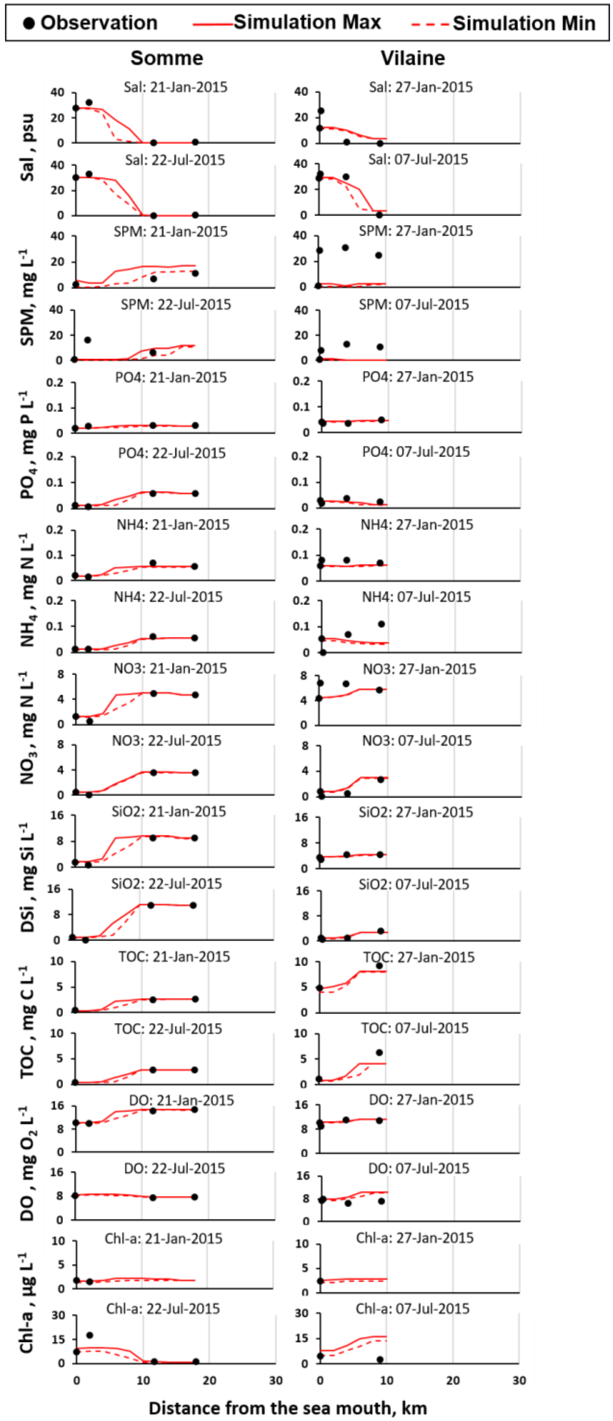

Figure S-1 Salinity (Sal), suspended particulate matter (SPM) and nutrients (PO4, NH4, NO3, DSi, TOC), dissolved oxygen (DO), chlorophyll a (Chl-a) concentrations variations along the estuaries (the Somme and Vilaine) for two selected dates (one in winter and the other one in summer). Note the different scales for the Chl-a for the estuaries.

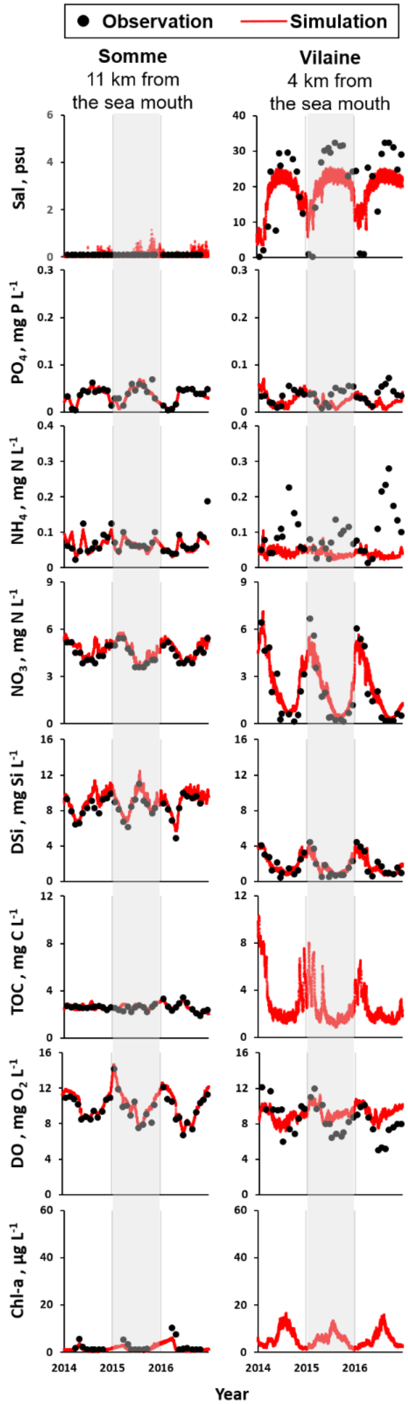

Figure S-2 Temporal variations for salinity (Sal), phosphate (PO4), ammonium (NH4), nitrate (NO3), dissolved silica (DSi), total organic carbon (TOC), dissolved oxygen (DO), and chlorophyll a (Chl-a) concentrations from 2014 to 2016 for the Somme and Vilaine estuaries at the sampling stations located about 1/2 the length of the estuary to the sea mouth. Gray columns covered the year of calibration (2015).

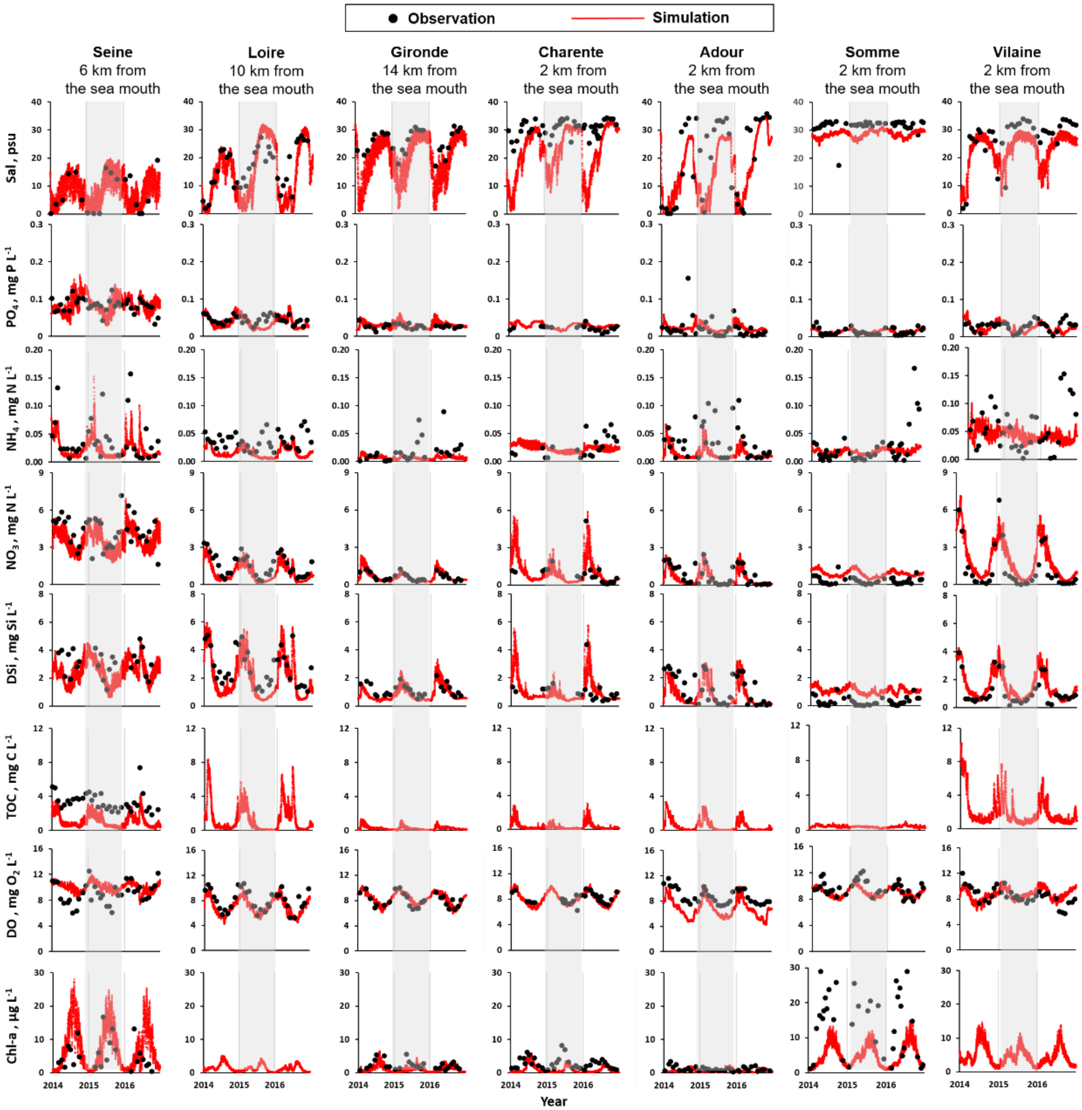

Figure S-3 Temporal variations for salinity (Sal), phosphate (PO4), ammonium (NH4), nitrate (NO3), dissolved silica (DSi), total organic carbon (TOC), dissolved oxygen (DO), and chlorophyll a (Chl-a) concentrations from 2014 to 2016 at the sampling stations located closest to the sea mouth. Gray columns covered the year of calibration (2015).

Table S-1 Biological formulations and stoichiometric equations used in the C-GEM biogeochemical reaction network. Tabs and T denote the absolute and the Celsius temperature, respectively, H is the water depth, S is the Salinity of the water and U and U_{wind} are the current velocity and the wind speed at 10 meters above the surface, respectively. (a) Vanderborght et al., 2007; (b) this study ; (c) Arndt et al., 2009; (d) Gamier et al., 1995. *If PHY=diatoms, nlim needs to account for the silica limitation for the phytoplankton growth

Gross Primary Production [a]	$GPP = P_{\max}^{B} \cdot nlim \cdot PHY \cdot \int_{H}^{0} 1-\exp\left(-\frac{\alpha}{P_{\max}^{B}} \cdot I(0) \cdot \exp(-K_D \cdot H)\right) dz$
Net Primary Production [a]	$NPP = \frac{GPP}{H} \cdot (1-k_{excr}) \cdot (1-k_{growth}) - k_{maint} \cdot PHY$
Phytoplankton mortality [a]	$phy\_death = k_{mort}(T) \cdot PHY$
Phytoplankton burial [b]	$phy\_burial = vPHY/H \cdot PHY$
Aerobic degradation [a]	$Aer\_deg = k_{ox} \cdot f_{het}(T_{abs}) \cdot \frac{TOC}{TOC+K_{TOC}} \cdot \frac{O_2}{O_2+K_{O_2}}$
Organic Mater burial [b]	$TOC\_burial = vTOC / H \cdot POC$
Denitrification [a]	$Denit = k_{denit} \cdot f_{het}(T_{abs}) \cdot \frac{TOC}{TOC+K_{TOC}} \cdot \frac{NO_3}{NO_3+K_{NO_3}} \cdot \frac{K_{in,O_2}}{O_2+K_{in,O_2}}$
Nitrification [a]	$Nit = k_{nit} \cdot f_{nit}(T_{abs}) \cdot \frac{NH_4}{NH_4+K_{NH_4}} \cdot \frac{O_2}{O_2+K_{O_2}}$
Oxygen air exchange [a]	$O_{2,ex} = \frac{vp}{H} \cdot (O_{2,sat} - O_2)$
Maximum photosynthesis rate [c]	$P_{max}^{B} = \frac{1}{\theta} \cdot exp(0.33 + 0.102 \cdot T)$
Nutrients limitation for phytoplankton growth [d], *	$nlim = \frac{NO_3+NH_4}{NO_3+NH_4+K_N} \cdot \frac{PO_4}{PO_4+K_{PO_4}}$

Light extinction coefficient [a]	$K_D = K_{D1} + K_{D2} \cdot SPM$
Piston velocity [a]	$vp = k_{flow} + k_{wind}$
Temperature dependences for biogeochemical processes [c]	$f_{het}(T_{abs}) = 2.75^{\left(\frac{T_{abs}-278}{10}\right)}$; $f_{nit}(T_{abs}) = 5^{\left(\frac{T_{abs}-278}{10}\right)}$
Current component for *vp* [a]	$k_{flow} = \sqrt{\frac{U \cdot D_{O_2}(T_{abs})}{H}}$
Wind component for *vp* [a]	$k_{wind} = \frac{1}{3.6 \cdot 10^5} \cdot 0.31 \cdot U^2_{wind,10m} \cdot \sqrt{\frac{Sc(T,S)}{660}}$
Switch between NH_4 and NO_3 utilization [a]	$f_{NH_4} = \frac{NH_4}{10 + NH_4}$

$$dPHY / dt = NPP - phy\_death - phy\_burial$$

$$ddSi/dt = -redsi \cdot NPP$$

$$dTOC / dt = -Aer\_deg - Denit + phy\_death - TOC\_burial$$

$$dNO_3/dt = -94.4/106 \cdot Denit - redn \cdot (1 - f_{NH_4}) \cdot NPP + Nitr$$

$$dNH_4/dt = redn \cdot (R - f_{NH_4} \cdot NPP) - Nitr$$

$$dO_2/dt = -Aer\_deg + f_{NH_4} \cdot NPP + 138/106 \cdot (1 - f_{NH_4}) \cdot NPP - 2 \cdot Nitr + O_{2,ex}$$

$$dPO_4/dt = redp \cdot (Aer\_deg + Denit - NPP)$$

By using the outputs (reaction process rates, μmol L^{-1} d^{-1}) from the model, we were able to calculate the related process fluxes (ton C, Si or N d^{-1}) at each grid over three years. Then integrating the mean annual process fluxes along the estuary allowed us to evaluate the process fluxes in the each of the estuary systems which are the values presented in Table S-2.

Table S-2 Mean daily process fluxes (2014-2016) of the estuaries studied, and percentages (%) of the reaction process with respect to the total import fluxes from upstream.

Estuary	Variable	Reaction Process	Process Flux	% of Import Flux
Seine	TOC (ton C d^{-1})	Organic Matter Degradation	-60.7	-39%
	Si (ton Si d^{-1})	Net Primary Production	-19.2	-13%
	NO_3 (ton N d^{-1})	Denitrification	-15.0	-6%
Loire	TOC (ton C d^{-1})	Organic Matter Degradation	-153.7	-36%
	Si (ton Si d^{-1})	Net Primary Production	-11.3	-3%
	NO_3 (ton N d^{-1})	Denitrification	-39.9	-14%
Gironde	TOC (ton C d^{-1})	Organic Matter Degradation	-203.1	-98%
	Si (ton Si d^{-1})	Net Primary Production	-39.8	-16%
	NO_3 (ton N d^{-1})	Denitrification	-43.2	-26%
Charente	TOC (ton C d^{-1})	Organic Matter Degradation	-4.4	-24%
	Si (ton Si d^{-1})	Net Primary Production	-0.7	-2%
	NO_3 (ton N d^{-1})	Denitrification	-1.0	-3%
Adour	TOC (ton C d^{-1})	Organic Matter Degradation	-20.1	-33%
	Si (ton Si d^{-1})	Net Primary Production	-0.4	-1%
	NO_3 (ton N d^{-1})	Denitrification	-4.6	-8%
Somme	TOC (ton C d^{-1})	Organic Matter Degradation	-2.2	-29%
	Si (ton Si d^{-1})	Net Primary Production	-3.2	-12%
	NO_3 (ton N d^{-1})	Denitrification	-0.5	-3%
Vilaine	TOC (ton C d^{-1})	Organic Matter Degradation	-9	-10%
	Si (ton Si d^{-1})	Net Primary Production	-3.4	-8%
	NO_3 (ton N d^{-1})	Denitrification	-2.0	-3%

Reference:

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