Towards an improved benthic biogeochemistry description in ecosystem modeling: challenges and potential solutions

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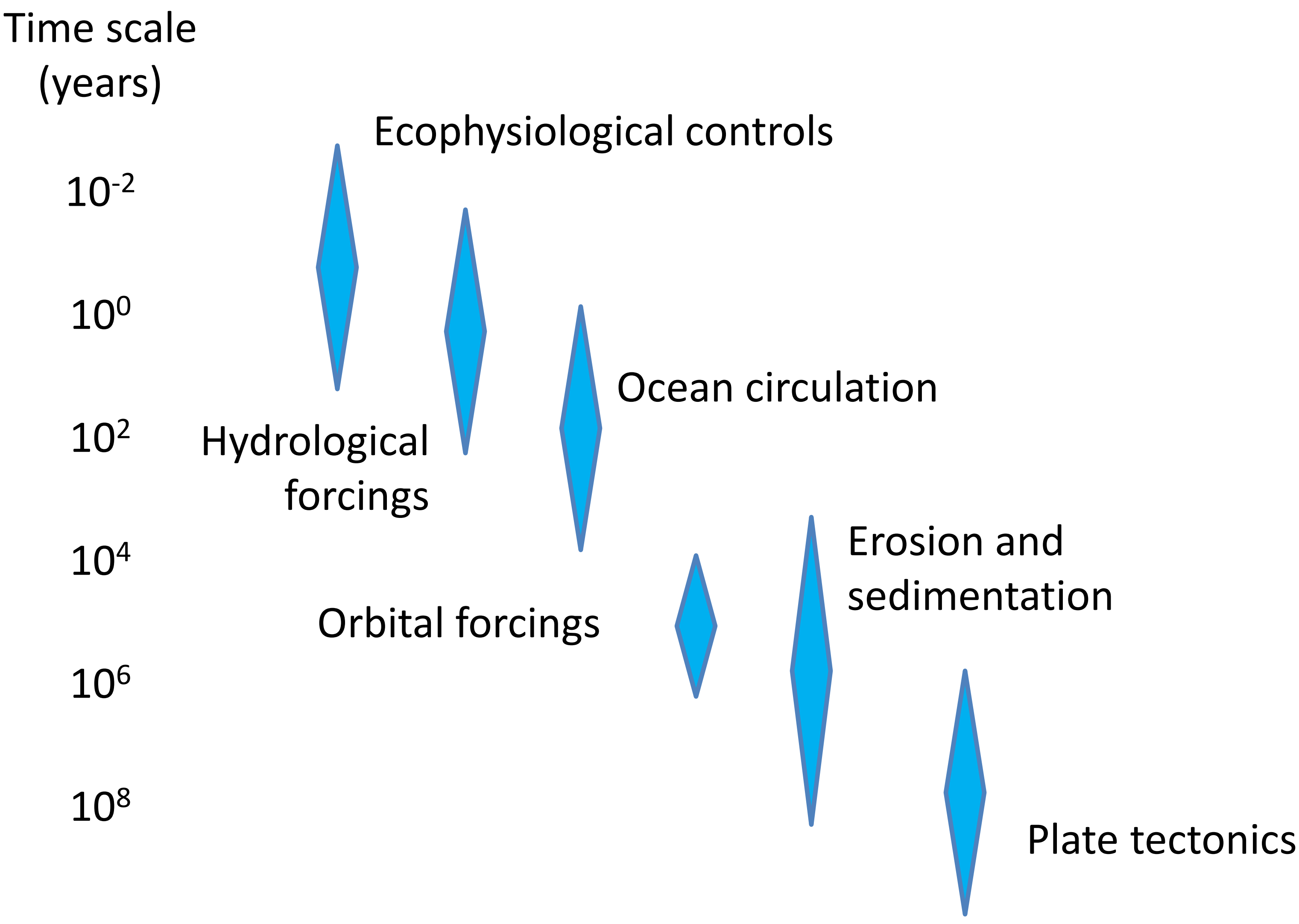
Content

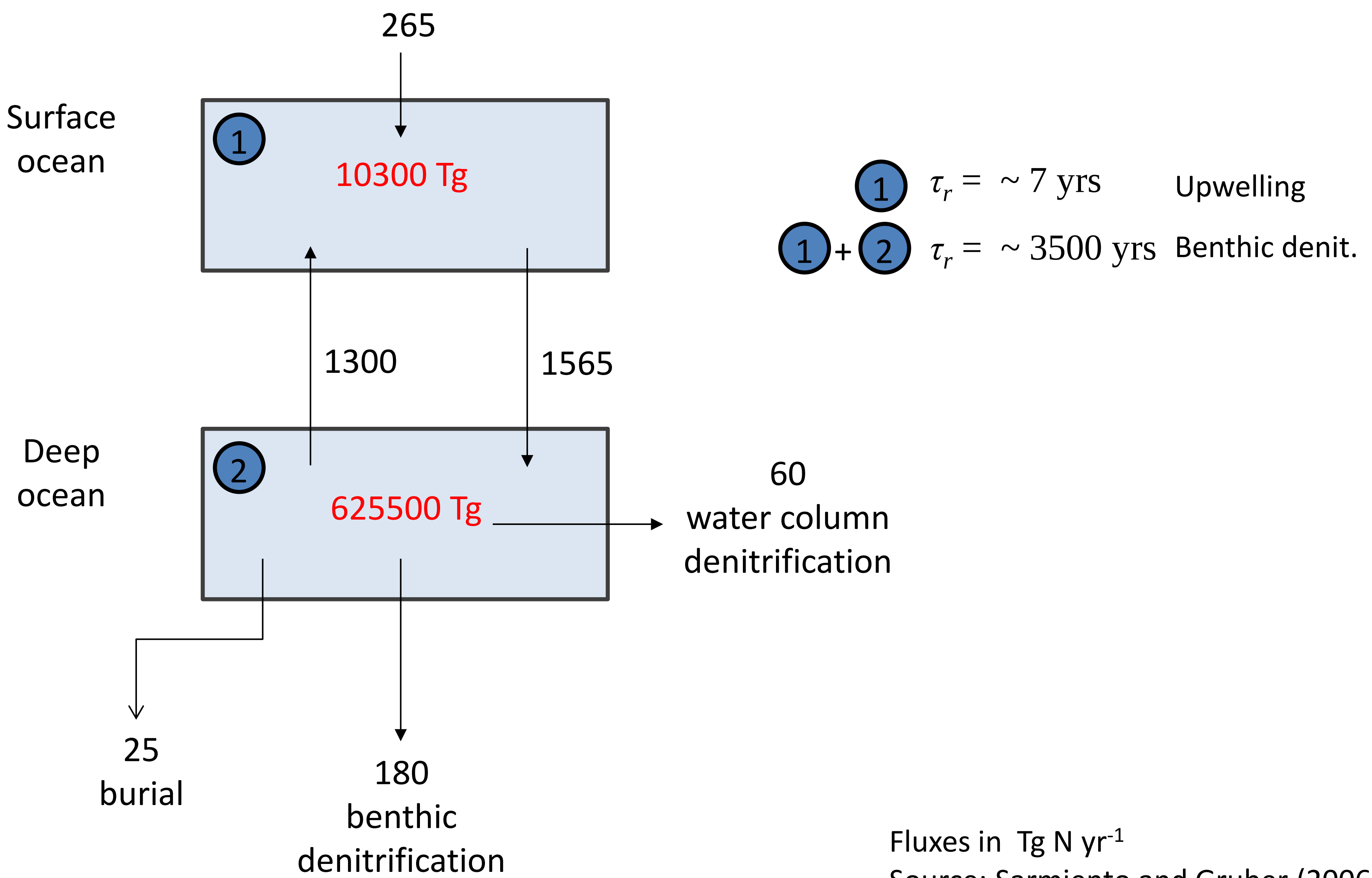
- Introduction: Overview of benthic models
- Evaluation of current approaches of benthic-pelagic coupling in Baltic Sea ecosystem models
- Major challenges

Forcings and time scales



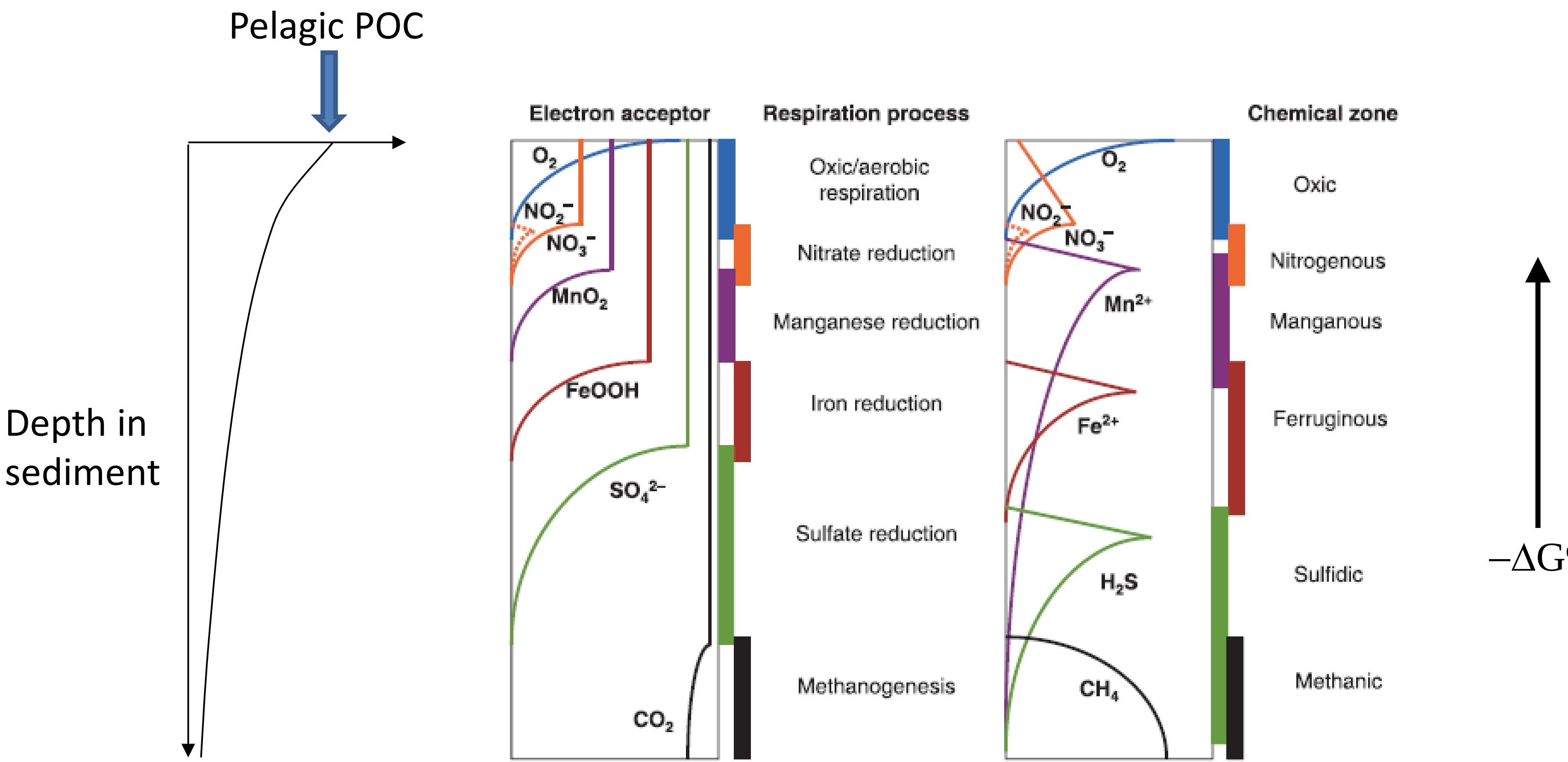
Source: Van Cappellen (2003)

Fixed N budget in the ocean



Fluxes in Tg N yr^{-1}
Source: Sarmiento and Gruber (2006)

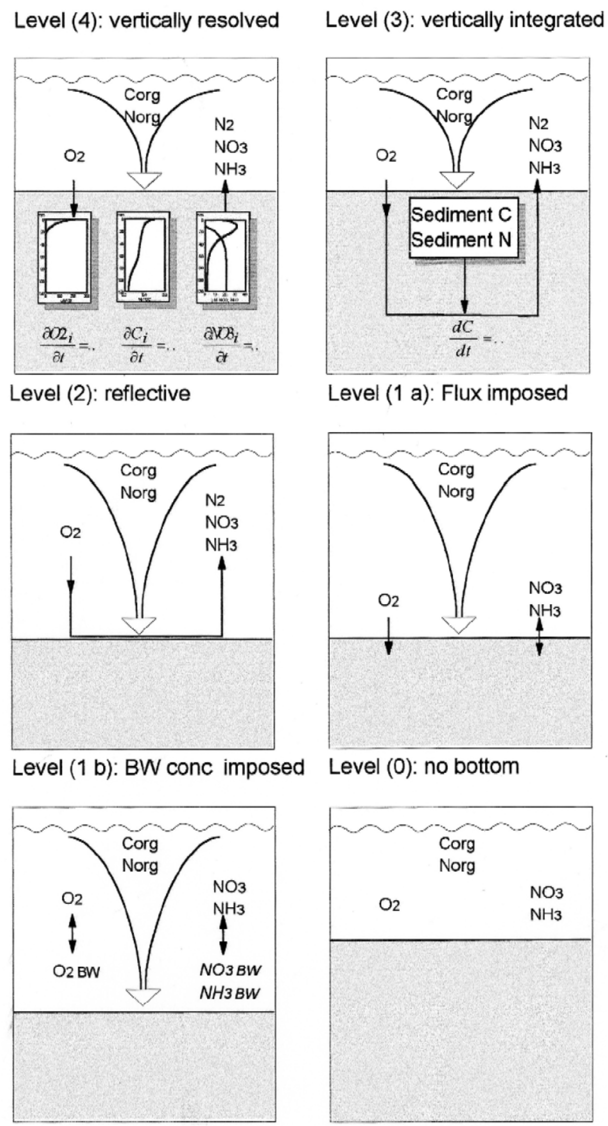
Idealized spatial structure of redox zonation in sediments



mm scale structuring

Source: Canfield and Thamdrup (2010, *Geobiology*)

Levels of benthic-pelagic model complexity



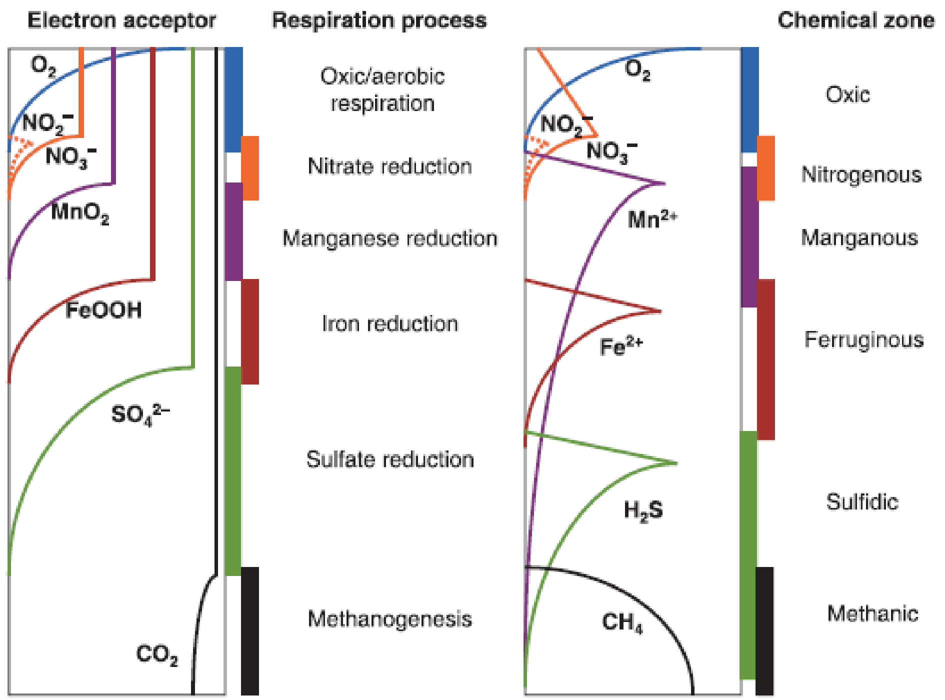
Complexity

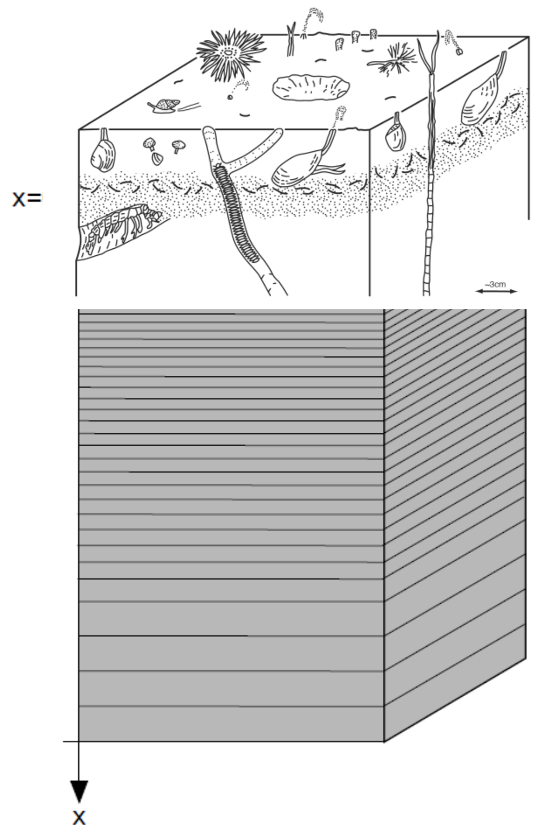
Computational efficiency

Source: Soetaert et al. (2002, *Earth Sci. Rev.*)

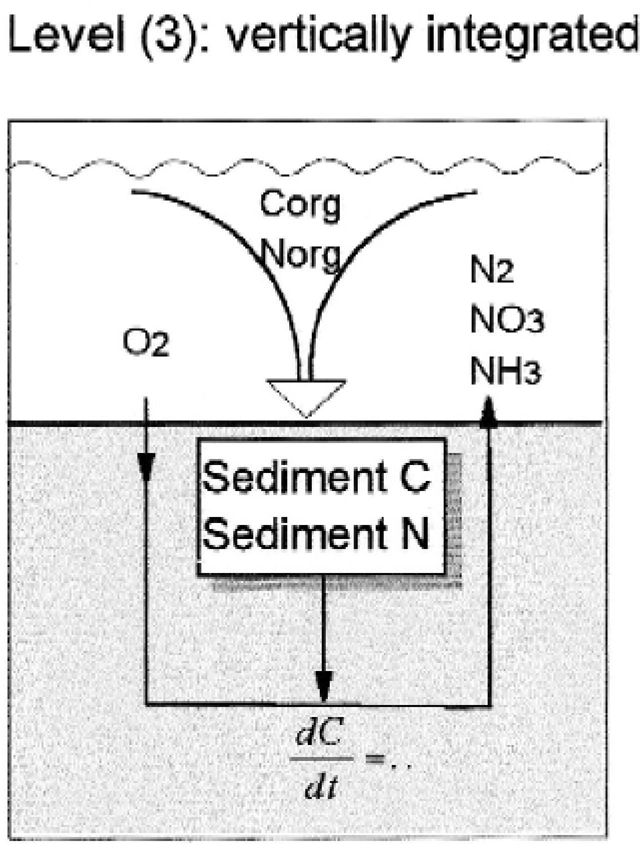
Benthic reaction-transport models, RTM (level 4)

$$\underbrace{\frac{\partial C_j}{\partial t} = -\frac{\partial F_{ADV}}{\partial x} + \frac{\partial F_{DIF}}{\partial x} + \frac{\partial F_{BIO}}{\partial x}}_{\text{transport}} + \underbrace{R_j}_{\text{reaction}} \qquad j = 1,\ldots\text{total species}$$





Transfer functions (level 3)



Black box approach for calculating solute exchange

$dC_{org}/dt = C_{deposition} - C_{degradation}$

NO_3 flux = f ($C_{degradation}$, $[NO_3]$, $[O_2]$ + “others”)

TF’s often employ the dreaded ‘O_2 switches’

Pros and cons of RTMs (level 4) and TFs (level 3)

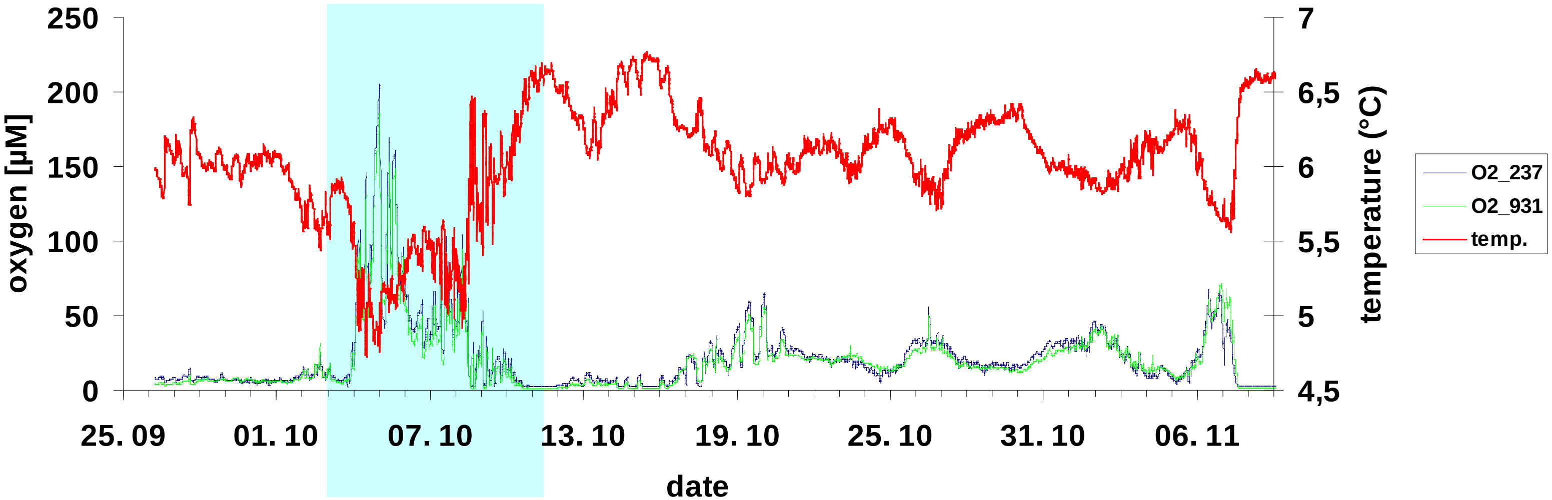
	Mass conservation	Retention capacity	Speciation of efflux	Short-term response	Parameter requirements	Data requirements	Computational demand
RTM (level 4)	Yes	Yes	Yes	Yes	High	porewater profiles fluxes	high
TF (level 3)	Yes	Yes/No	Yes/No	Yes/No	Low	fluxes	low

Parameterized

Temporal variability in East Gotland

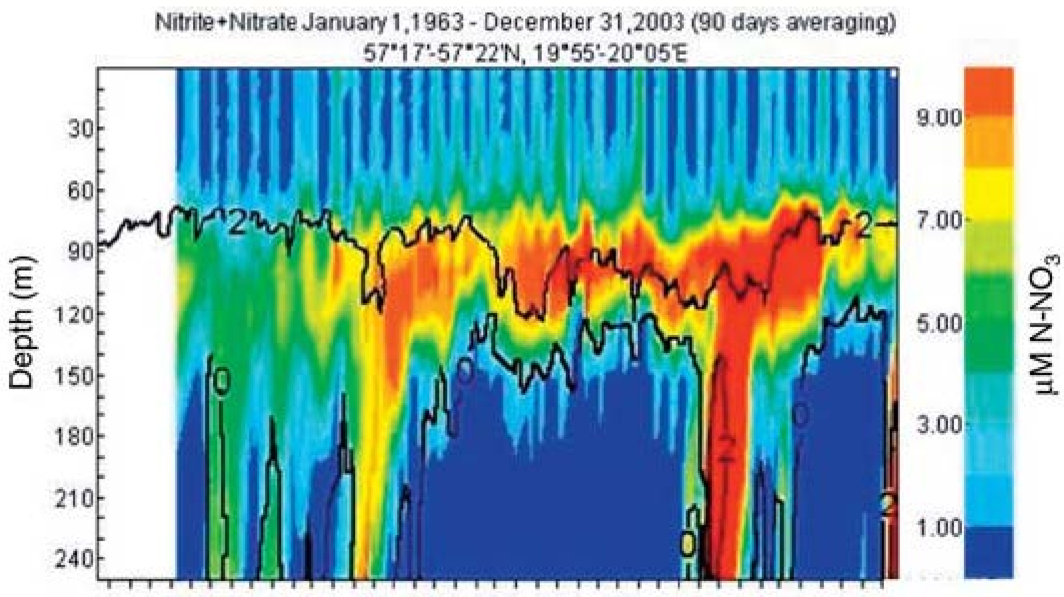
Oxygen (μM)

Source: S. Sommer *unpub.*

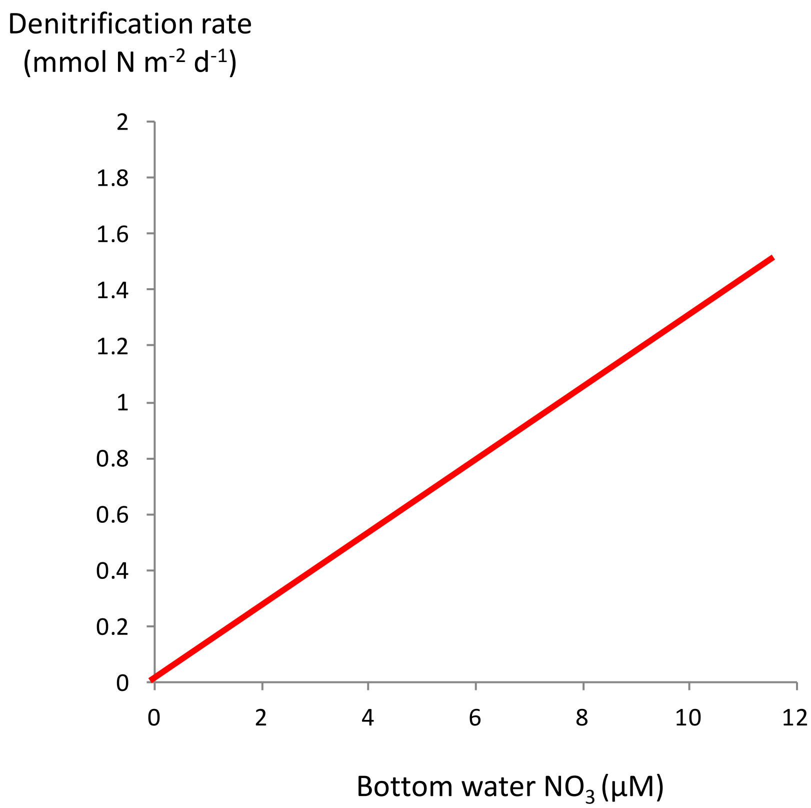


Nitrate (μM)

Source: Vahtera et al. (2007, *Ambio*)

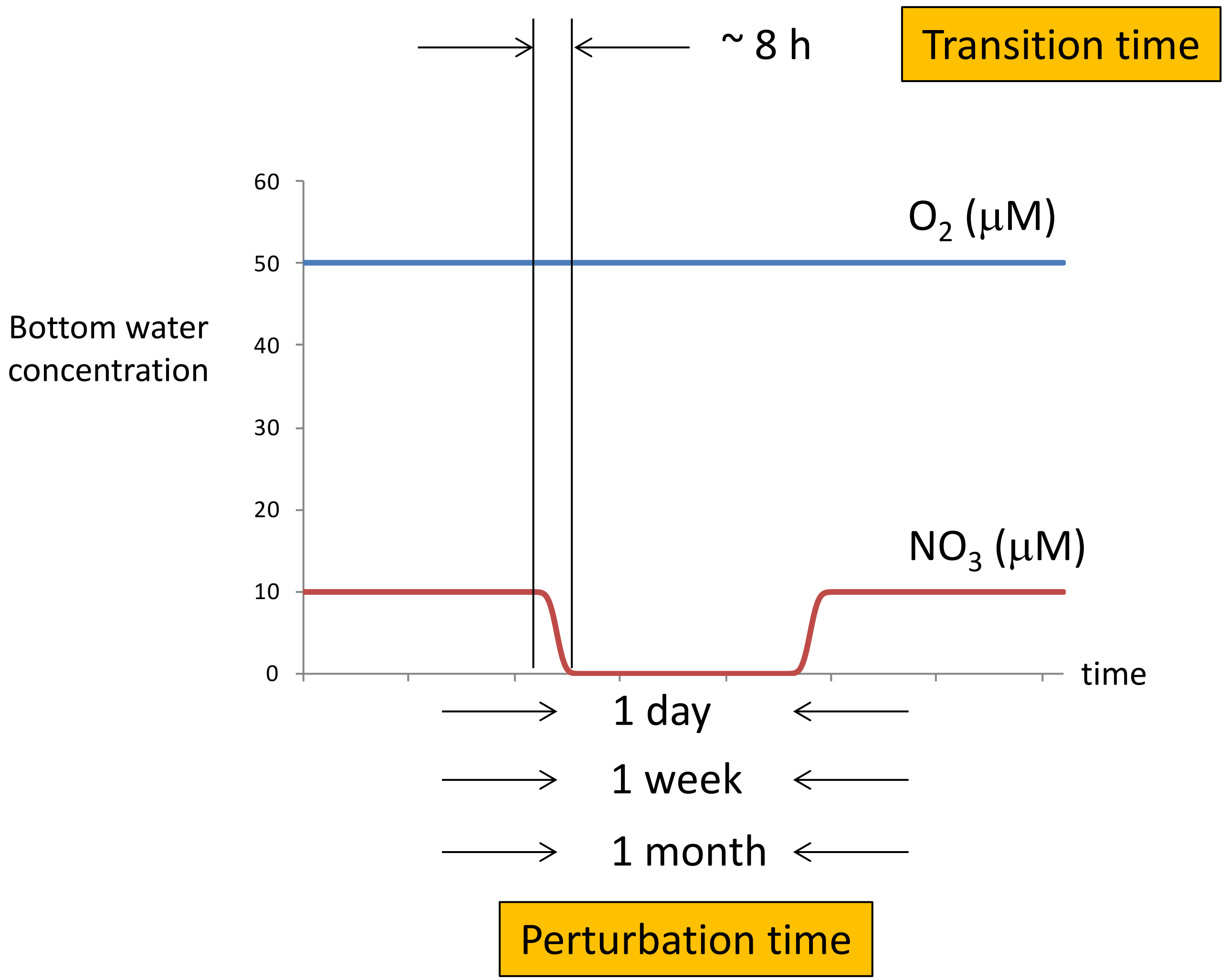


Steady state denitrification versus bottom water nitrate predicted by a level 4 model (RTM)

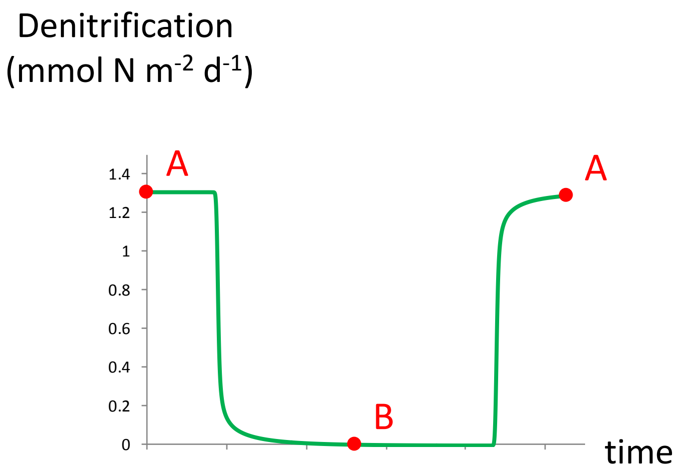


Very simple approach
→ simple result

Hypothetical variability in bottom water nitrate



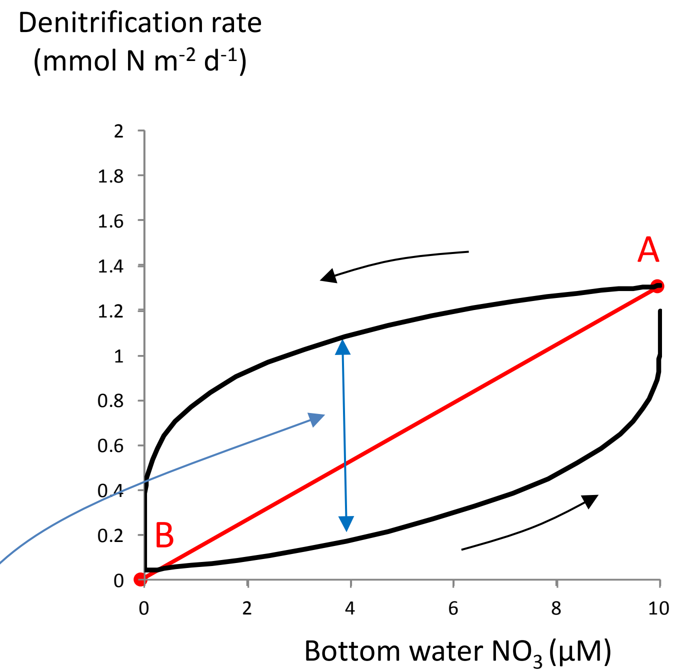
Response of (complex) level 4 model to temporal variability



→ 1 day ←

→ 1 week ←

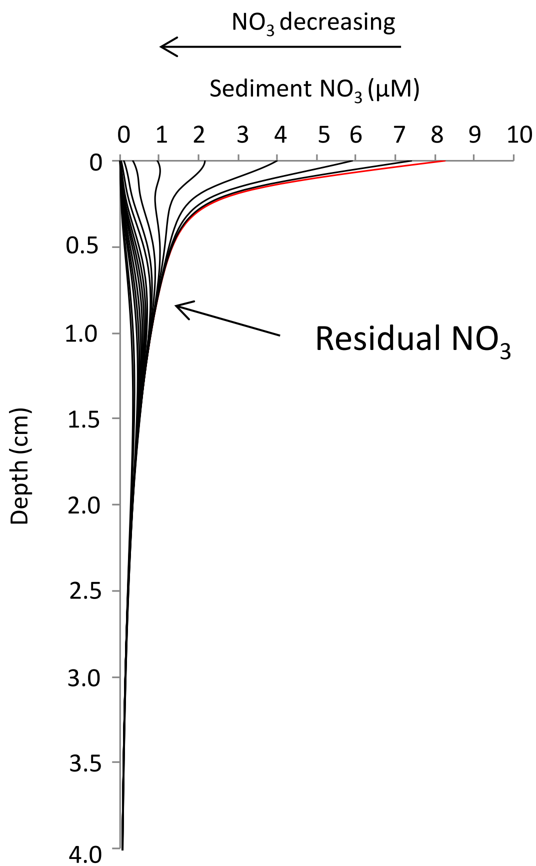
→ 1 month ←

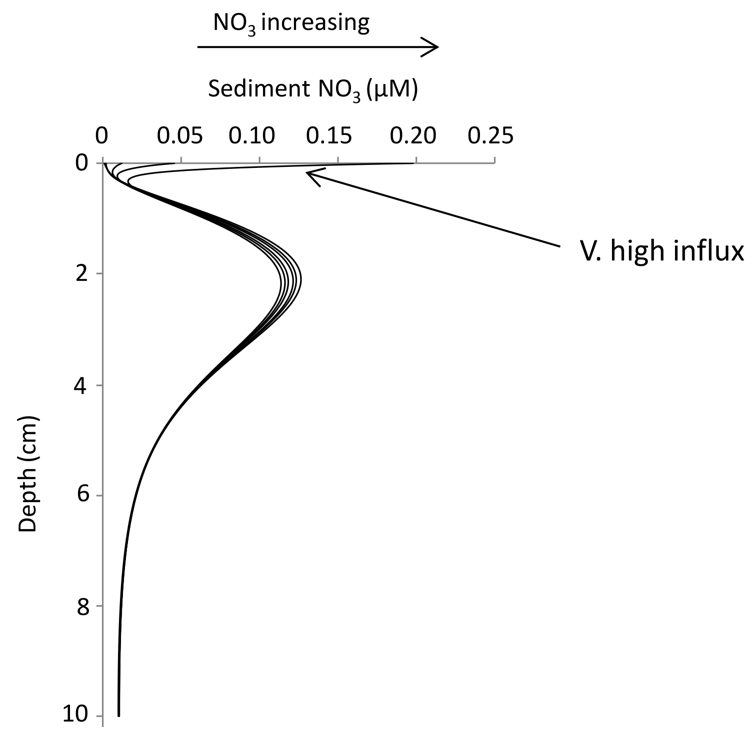


Same result regardless of perturbation time

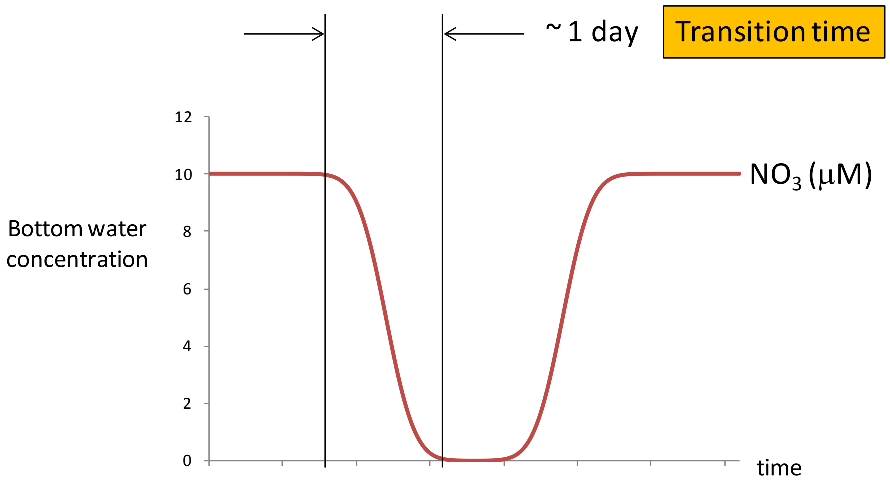
Large potential error in predicted rates

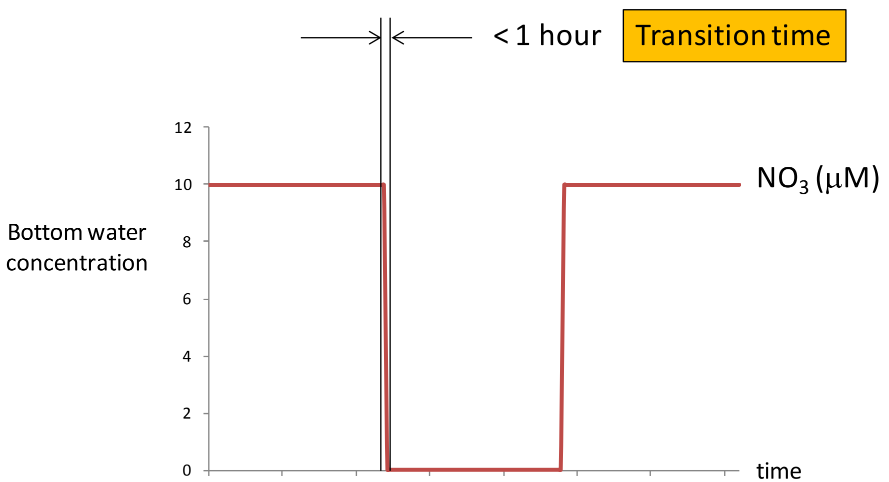
Porewater transients



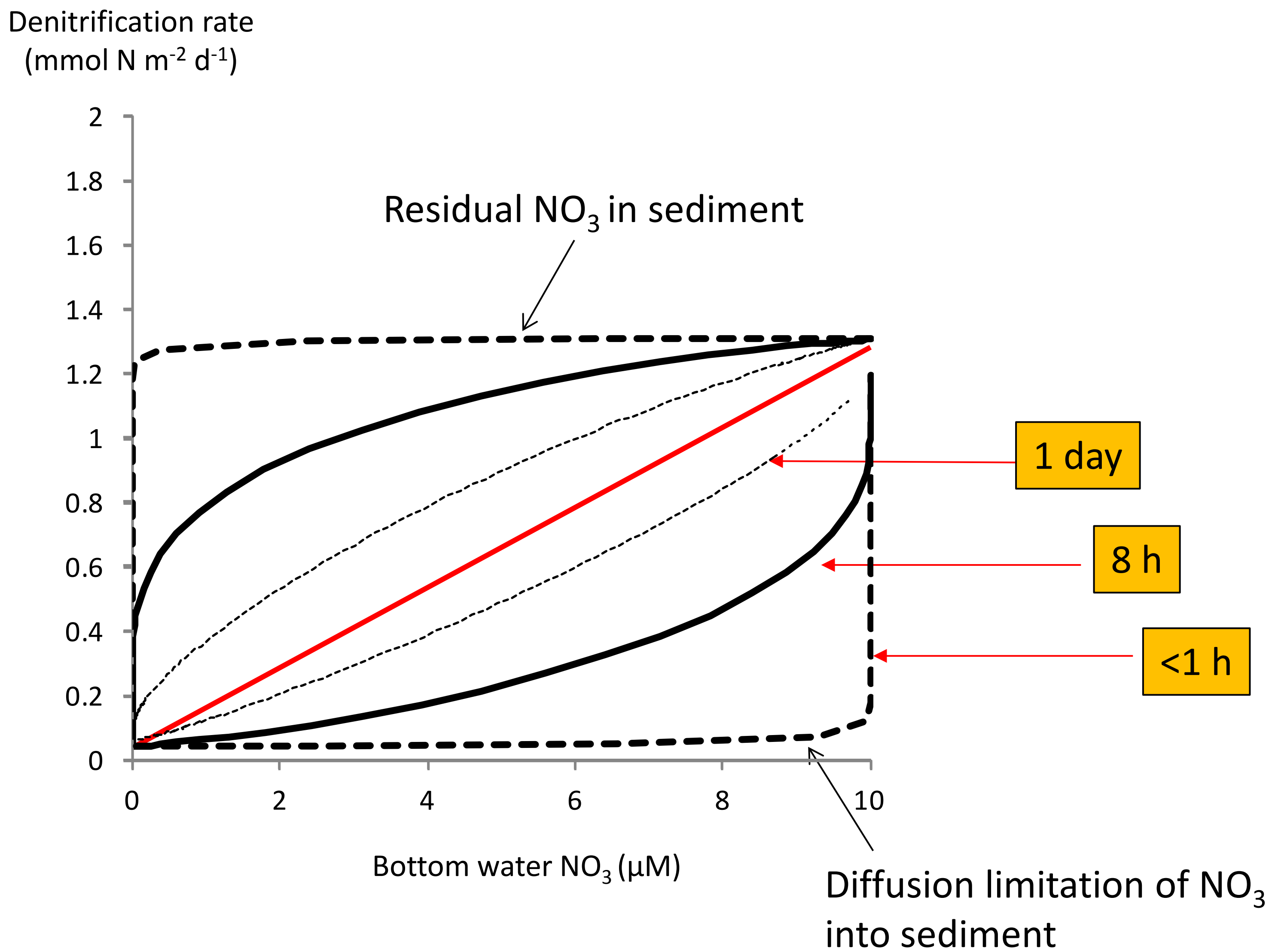


Longer and shorter transition times



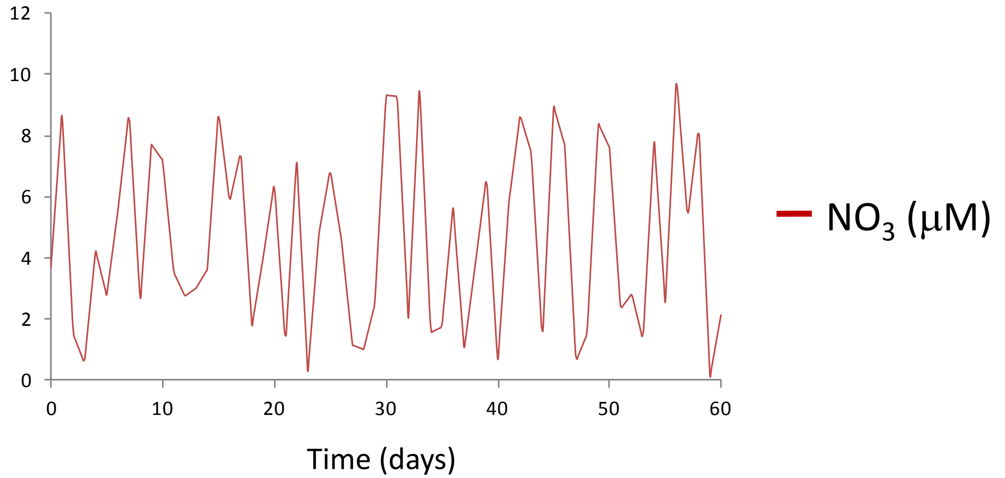


Apparent breakdown of level 3 approaches?

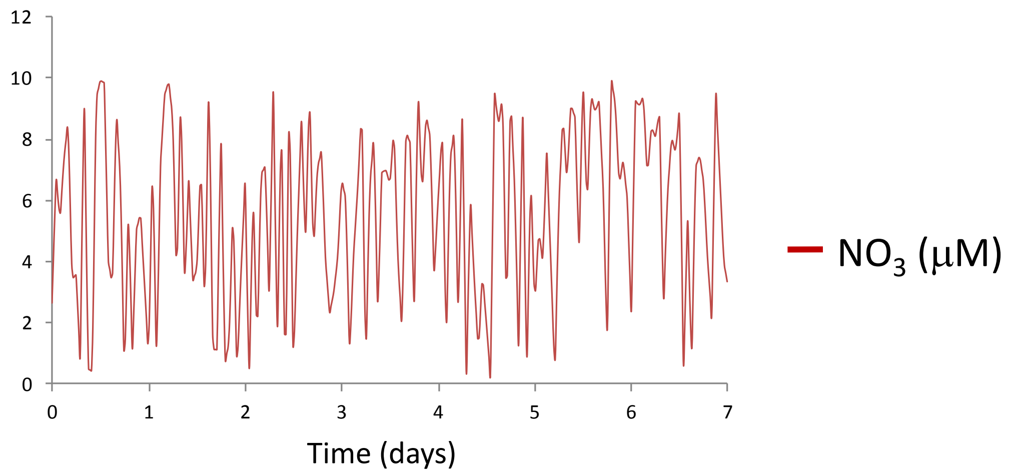


Random bottom water variability

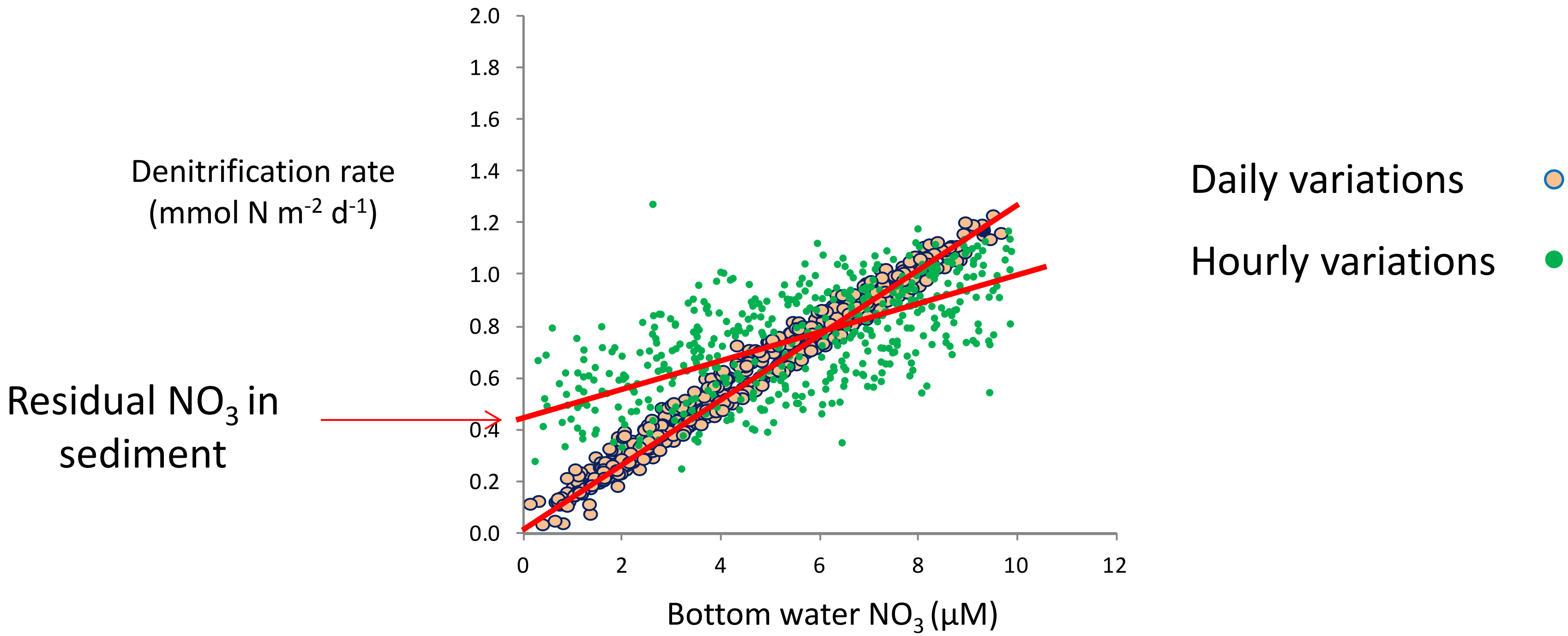
Random daily variations



Random hourly variations



Greater uncertainty as the frequency of bottom water variability increases



Much lower range in denitrification under variable conditions

Major challenges

1. Improved capacity of vertically-integrated models (level 3) to predict seasonal and episodic variability in nutrient fluxes. Need for rigorous testing based on observed dynamic variability.

2. Very simple example for N (changes in C flux and O_2 also relevant). P probably even more complex.

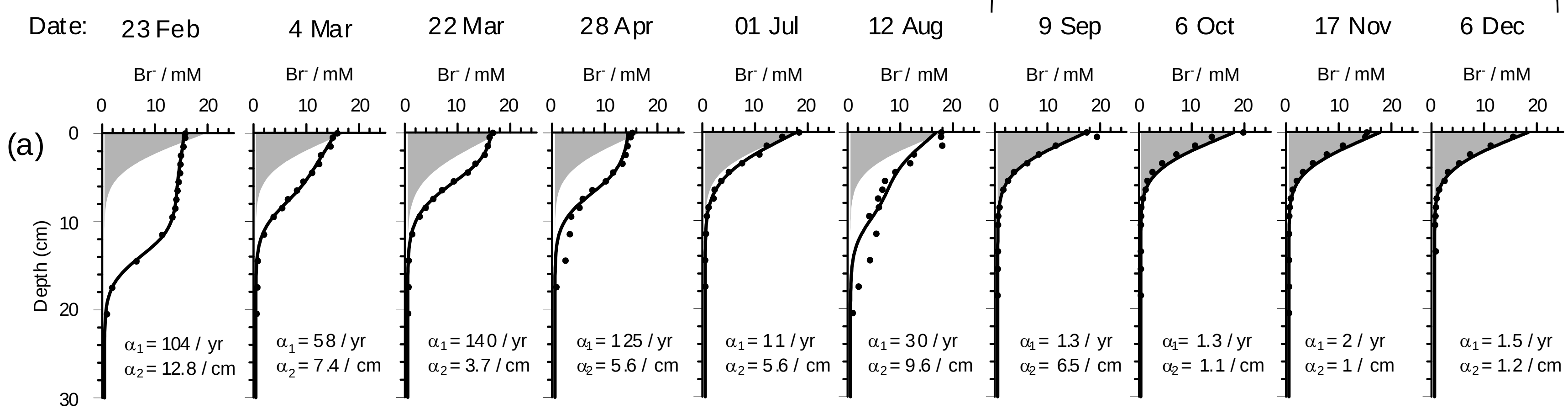
3. Proper consideration of grain size and sediment accumulation rates

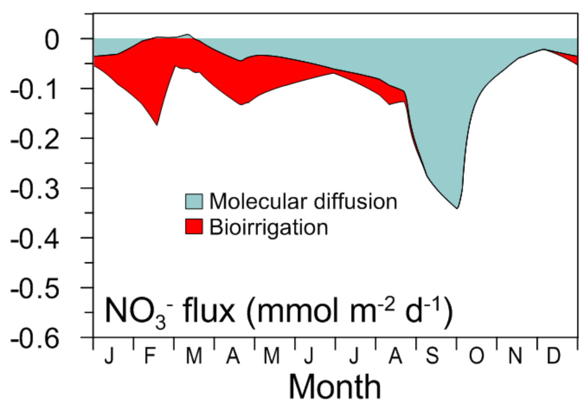
4. Reaction-transport models are powerful tools, but not transferable. Baltic Sea is very heterogeneous – many parameters required.

5. All models suffer from 'biological uncertainty'. This may be the largest source of uncertainty and is likely to be a major headache for improving predictive power of Baltic Sea benthic models.

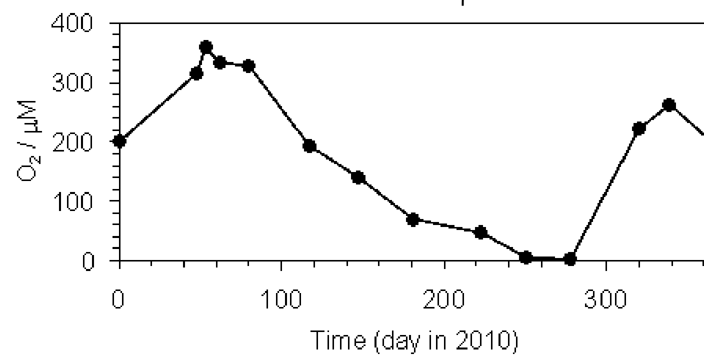
Ex situ bioirrigation experiments in SW Baltic Sea

Macrofauna absent, no irrigation





Macrofauna absent



Source: Dale et al. (2013, *Biogeosciences*)

Potential solutions

Model development in parallel with experimental observations

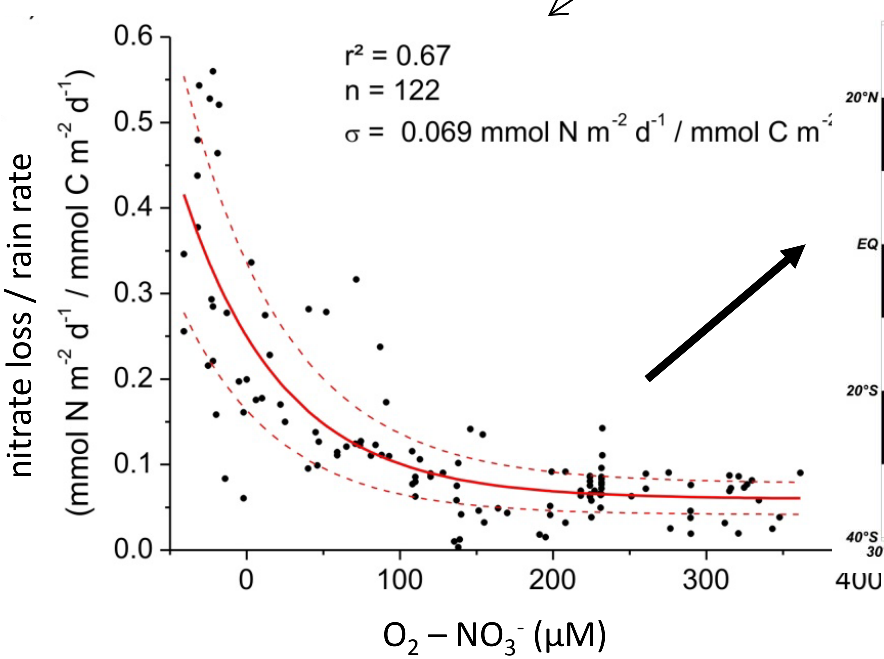
<u>Level 4 (RTMs):</u>

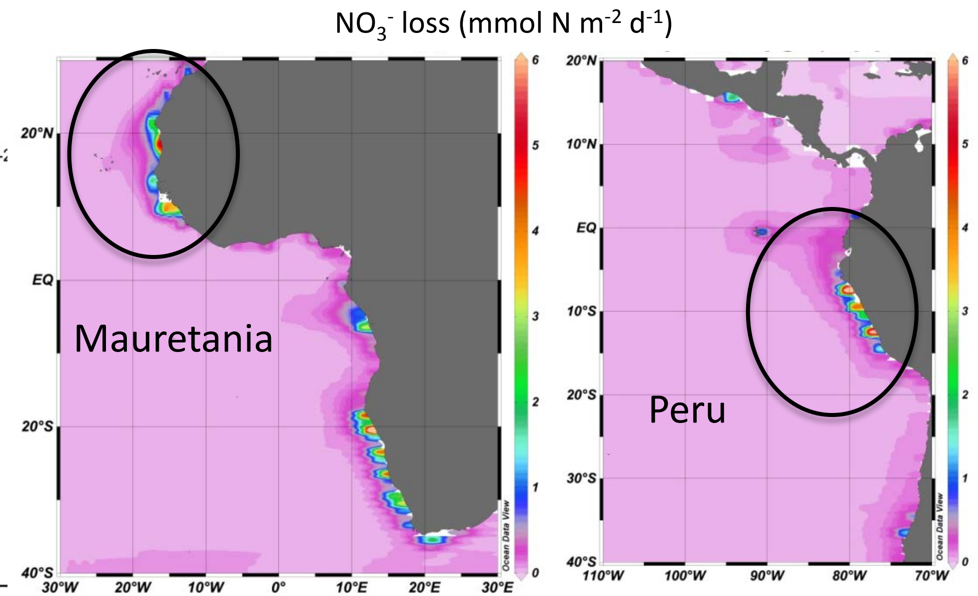
→Carefully calibrated models at target sites (grain size, bacteria, POC content etc)
→Obtain key parameters (→use in level 3 models), or
→Generation of level 3 models from RTMs
→Use RTM to estimate uncertainty in level 3 models
→More comparisons with measured fluxes

On example of developing a robust TF for denitrification
(another example would be through the use of meta-model analysis)

$$\text{Den} = (a + b \times c^{\,O_2 - NO_3}) \times \text{POC rain rate}$$

<u>Empirically derived</u>





Global benthic denitrification: 153 – 196 Tg N yr^{-1}

Previous estimates: 88 – 1960 Tg N yr^{-1}

Source: (Bohlen et al., 2012, *Glob. Biogeochem. Cy.*).