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Including Expert Knowledge in Finite Element Models by means of Fuzzy based Parameter Estimation

O. Krol, N. Weiss, T. Bernard & F.Sawo*

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*Fraunhofer-Institut für Informations- und Datenverarbeitung IITB
Fraunhoferstraße 1, 76131 Karlsruhe
oliver.krol@iitb.fraunhofer.de

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Eutrophication of water bodies

Eutrophication:

- Toxicity
- Hygiene conditions
- Collapse of water bodies

Aim:

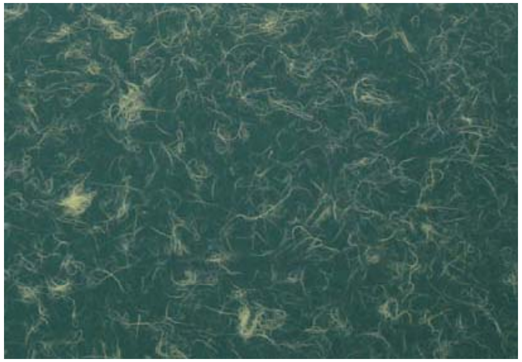
- Prediction of the development and distribution of Algea

Problem:

- Complex growth models
- Parameterization of spatially distributed models

Idea:

- Combination of FEM and Fuzzy-Methods
- Integration of expert knowledge
- Nonlinearity of biological growth



Modelling of Flow and Transport

Navier - Stokes - Equations:

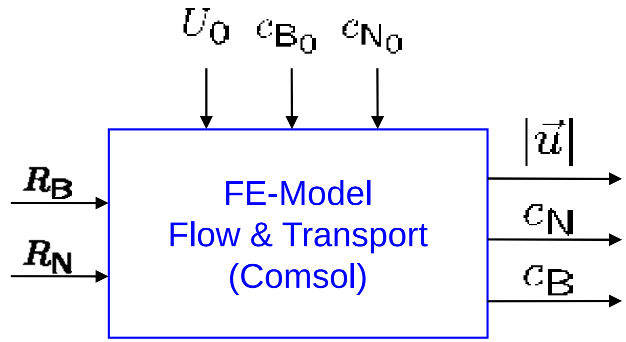
$$\frac{\partial \rho}{\partial t} + \operatorname{div}\left(\rho \vec{u}\right) = 0$$

$$\frac{\partial \vec{u}}{\partial t} + \vec{u} \cdot \operatorname{div} \vec{u} = -\frac{1}{\rho} \operatorname{grad} p + \eta \operatorname{div}\left(\operatorname{grad} \vec{u}\right)$$

Transport of nutrients and biomass:

$$\frac{\partial c_N}{\partial t} = -\vec{u} \cdot \operatorname{grad} c_N + R_N(t)$$

$$\frac{\partial c_B}{\partial t} = -\vec{u} \cdot \operatorname{grad} c_B + R_B(t)$$



Assumptions

- Neglect of dispersion and diffusion
- Neglect of 3. dimension
- Ideal units of nutrients N

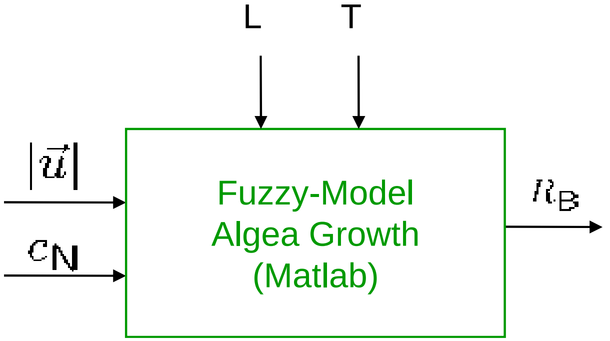
Modelling of Growth of Biomass by Fuzzy

- Flow velocity
- Distribution of nutrients
- Water temperature
- Light

Input

- Growth rate of biomass

Output



Assumptions

- u(x,t) and c_N (x,t) from FE-model
- Temperature and sunshine duration depend on geographic location and season

Modelling of Algea Growth

Biological submodel

Harmful Algal Blooms
Expert System

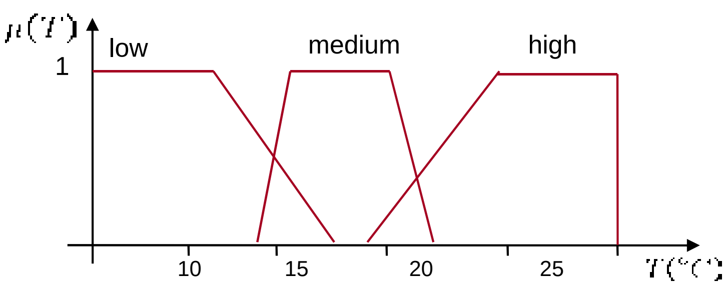
- Knowledge represented by *if-then*-rules
- Fuzzyfication of input data
- Evaluation of *if-then*-rules
- Derivation of crisp values for output variable(s)

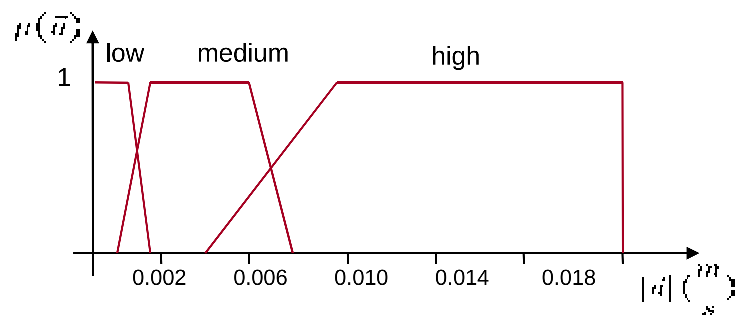
Examples

IF „Nutrients = high“ and „Temperature = high“ THEN „Growth = high“

IF „Nutrients = low“ and „Temperature = high“ THEN „Growth = low“

Membership-function describing fuzzy sets

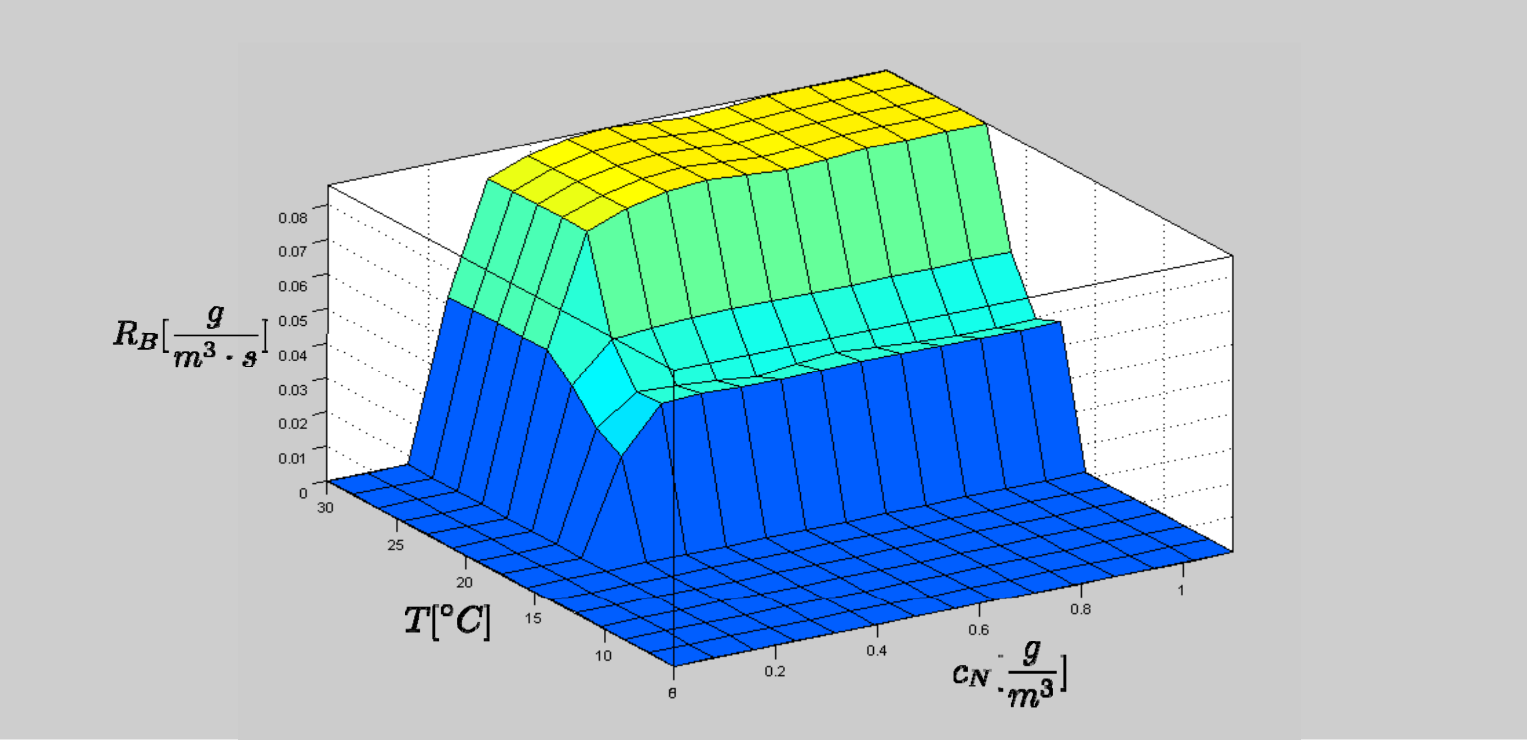




Modelling of Algea Growth

Result of Fuzzy-Modelling:

Nonlinear Look-up-table for biological growth R_B=f(T,c_N,u=const))



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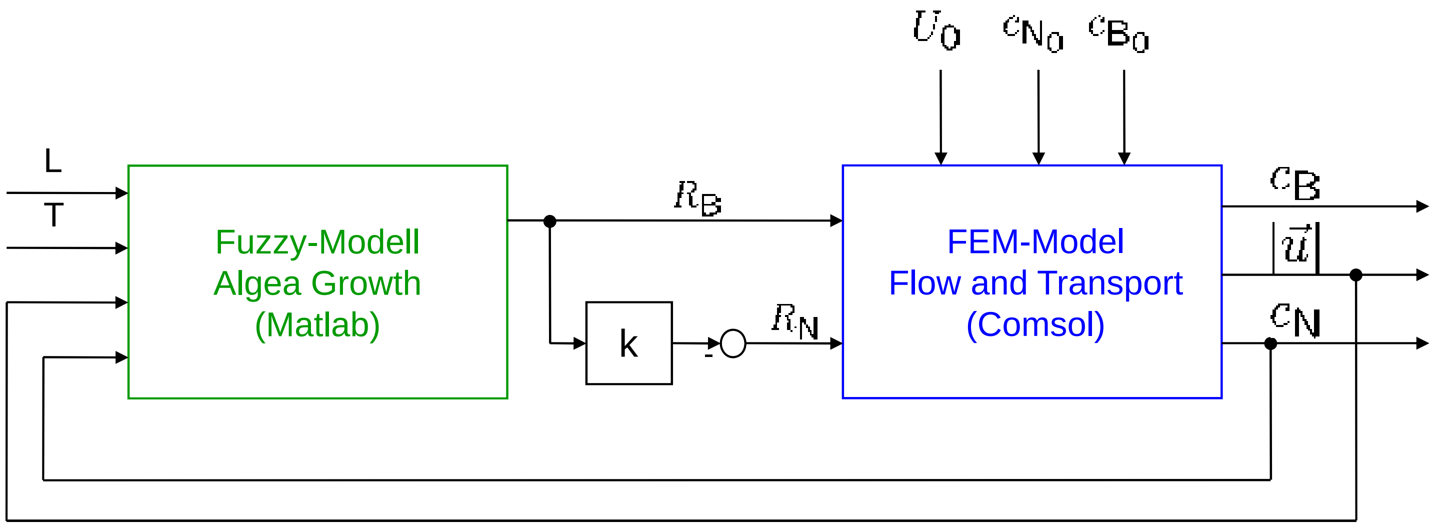
Coupling of Models

Coupling of Submodels

$$R_N = -k \cdot R_B$$ → 1 Unit of biomass requires k units of nutrients

Complete Model



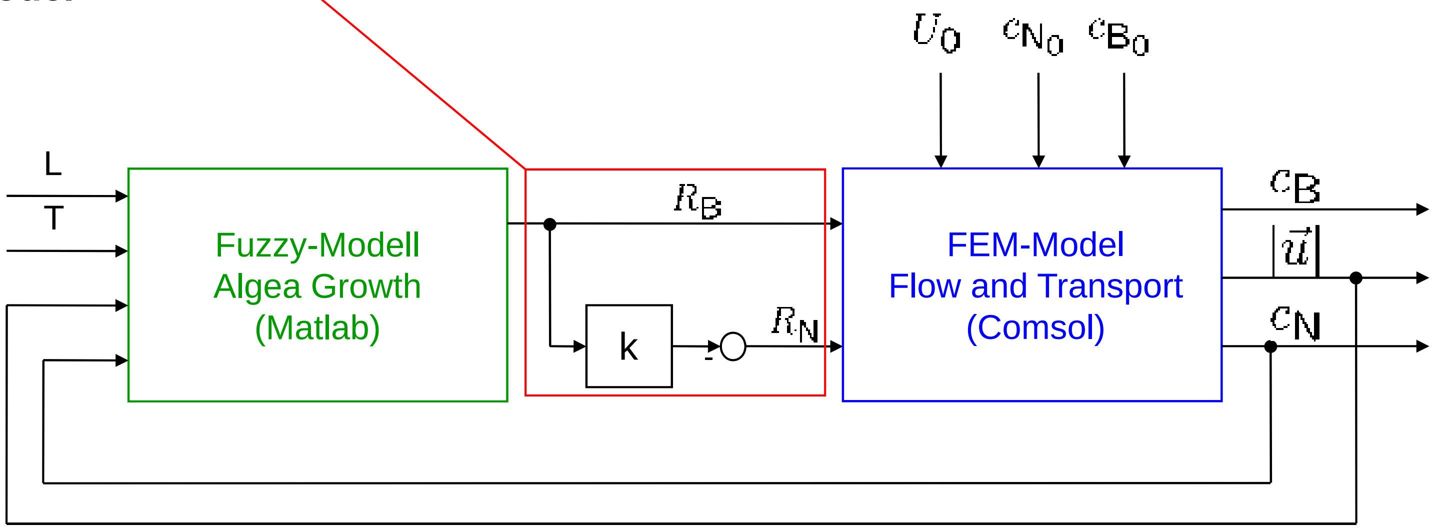
Coupling of Models

Coupling of Submodels

$$\boxed{R_N = -k \cdot R_B}$$

→ 1 Unit of biomass requires k units of nutrients

Complete Model



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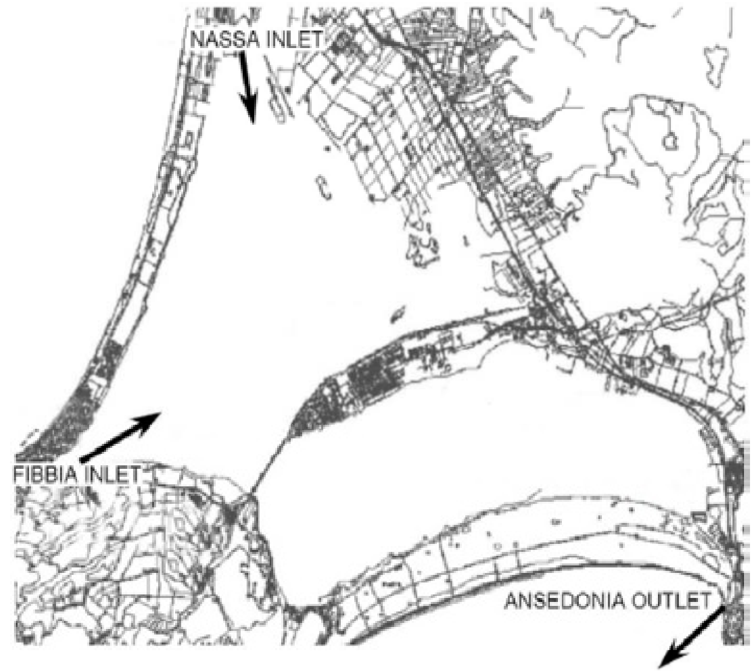
Simulation Results

Application to Orbetello Sea

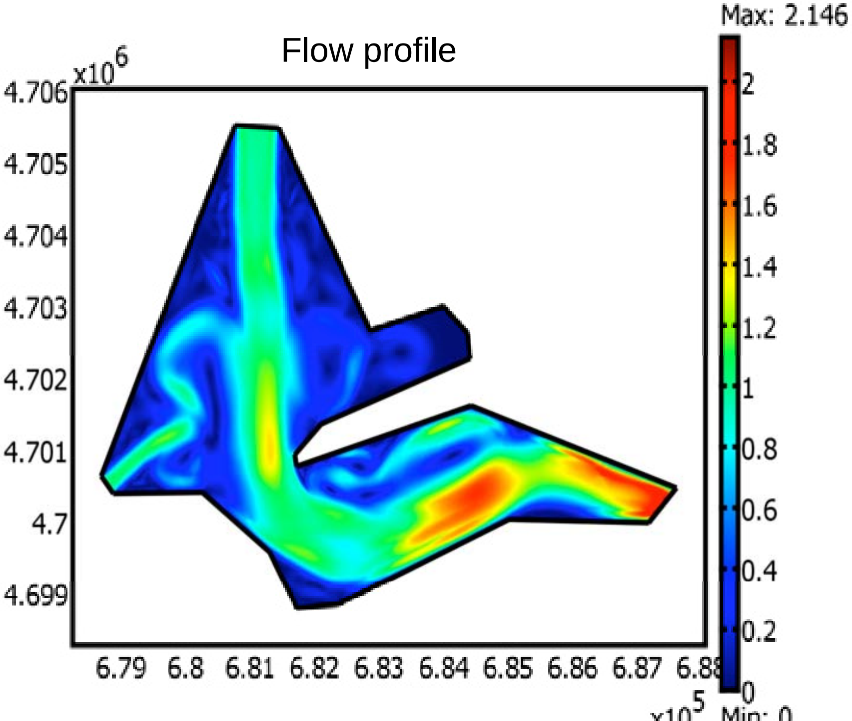


- Water body of about 27 km^2 at western coast of Italy
- 2 inflows and 1 outflow
- Strong Eutrophication due to intense agriculture and fish farming

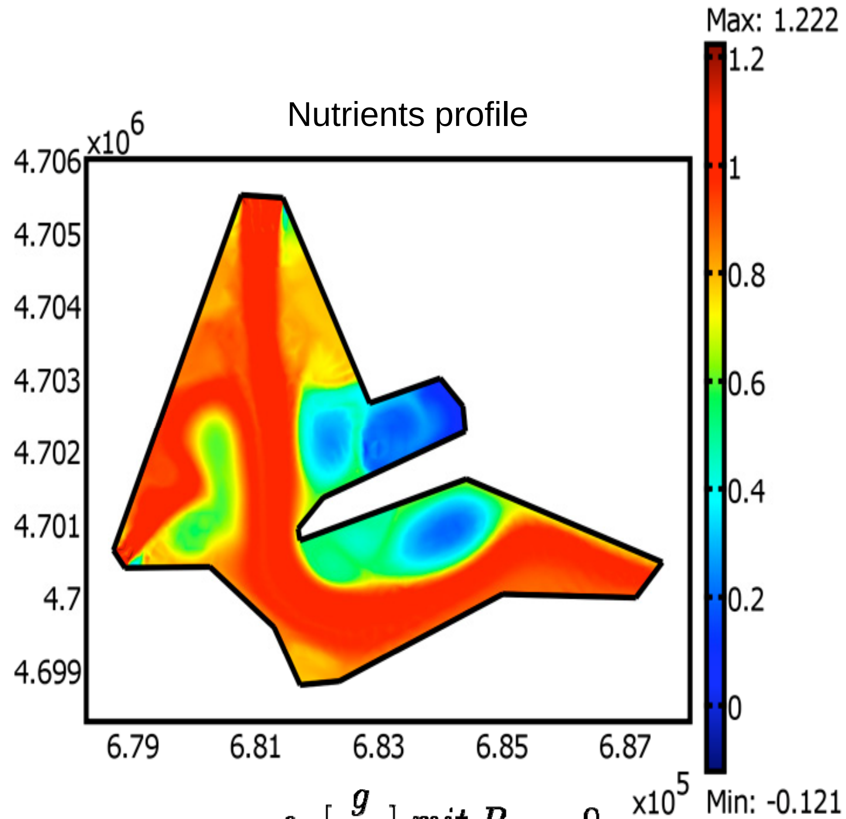
Simulation Results

FE-Model: No Biological Growth

Profile of Flow and Nutrients after 1h



$|\vec{u}|\ [\frac{m}{s}]$



$c_N[\frac{g}{m^3}]\ mit\ R_N = 0$

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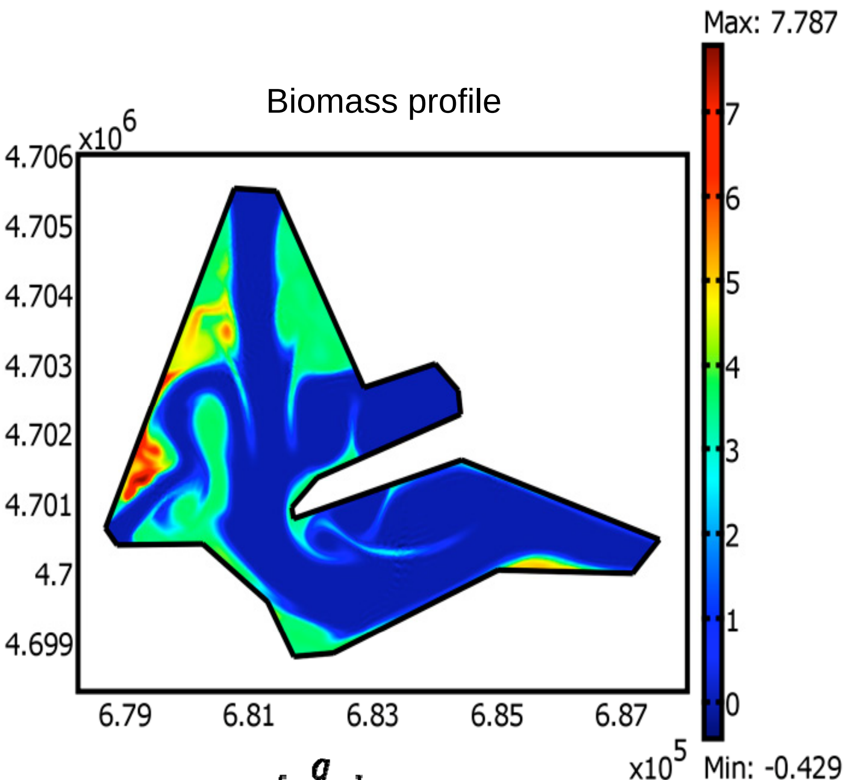
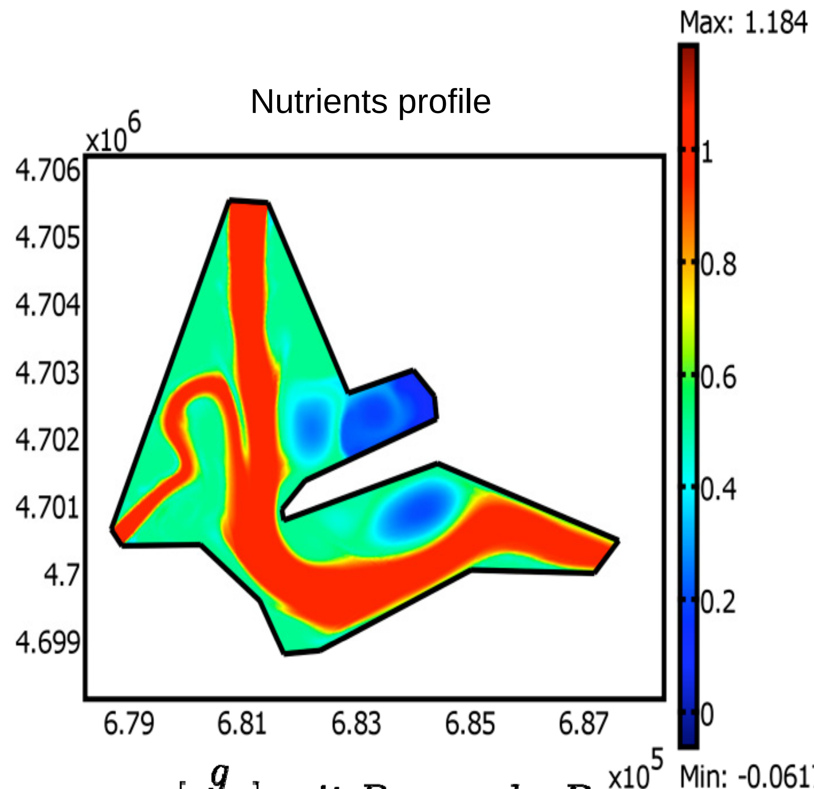
Complete Model

Profile of Biomass and Nutrients after 1h and k= -10



$c_B[\frac{g}{m^3}]$



$c_N[\frac{g}{m^3}]\ mit\ R_N = -k \cdot R_B$

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Summary

Problem in spatially distributed transient models

- Complex models for biological growth
- Requirement of big number of parameters
- Computing time

Solution Concept

- Mathematically exact description “as far as possible”
- Qualititative uncertainties described by Fuzzy-models
- Direct incoporation of expert knowledge
- Nonlinearities

Literature

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