Numerical modelling course

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Head of statistical counselling (since 09/2018)
@ Leibniz Institute for Farm Animal Biology, near Rostock

Trained marine biologist

10-yrs experience in numerical modelling @ IOW

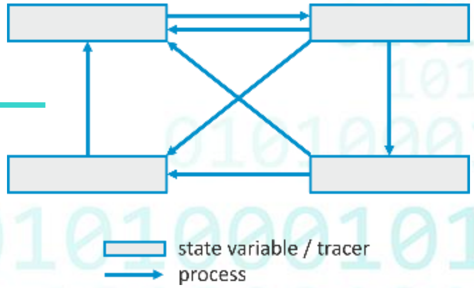
Strong statistical expertise

2-days plan

Mixture of lecture and hands-on programming

Day 1

Day 2



Run your model
Visualize results

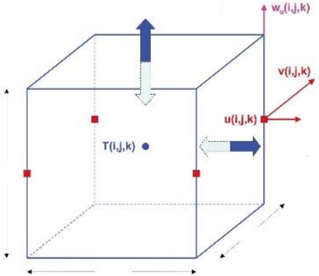
Develop your own model
Based on your own results

Introduction to CGT
First simple ready-to-use model

Lecture numerical ocean models
Examples, how models are constructed

From box models to ocean-circulation models

Contents



01 **Examples**
From box models to ocean-circulation models

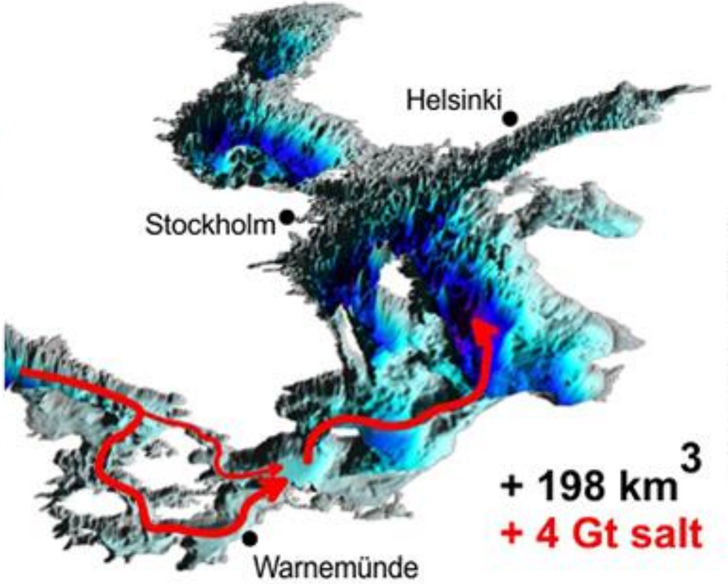
02 **How models are constructed**
Grids, physics, state variables, processes

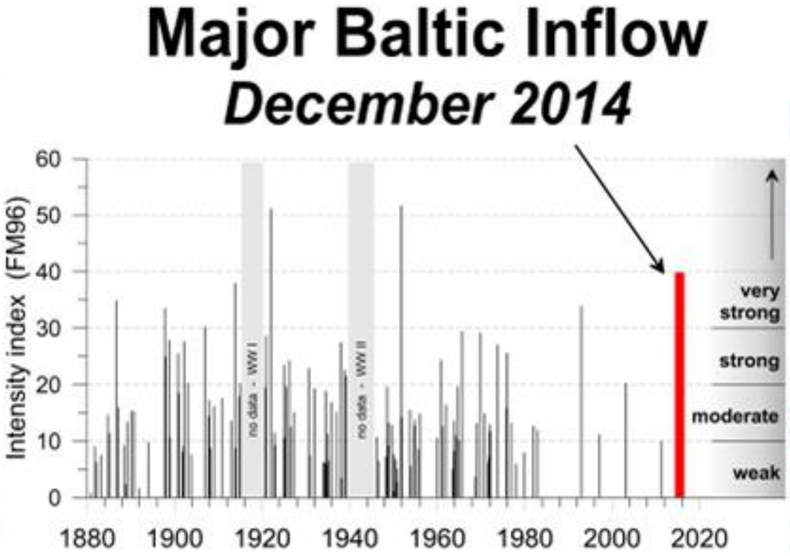
03 **Construct your first model**
KOB benthocosm – *Fucus* - *Gammarus*

04 **Code Generation Tool**
Short introduction

Examples

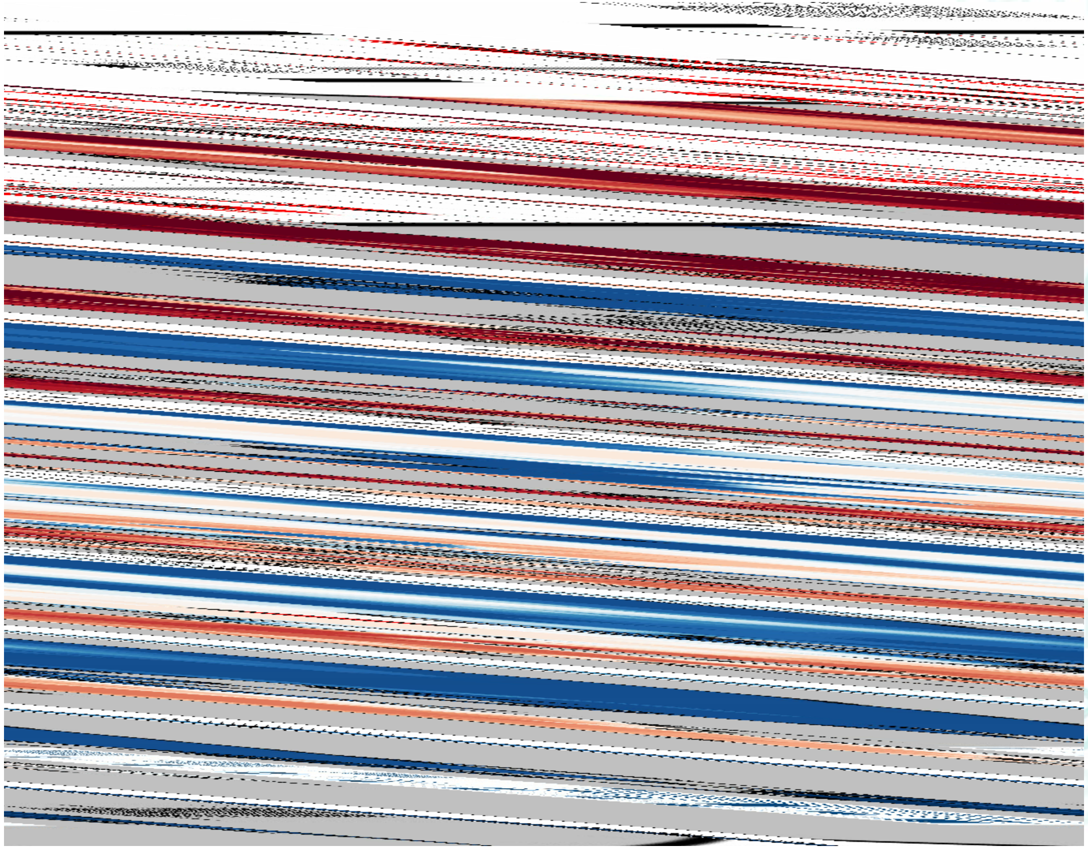
Major Baltic Inflow December 2014





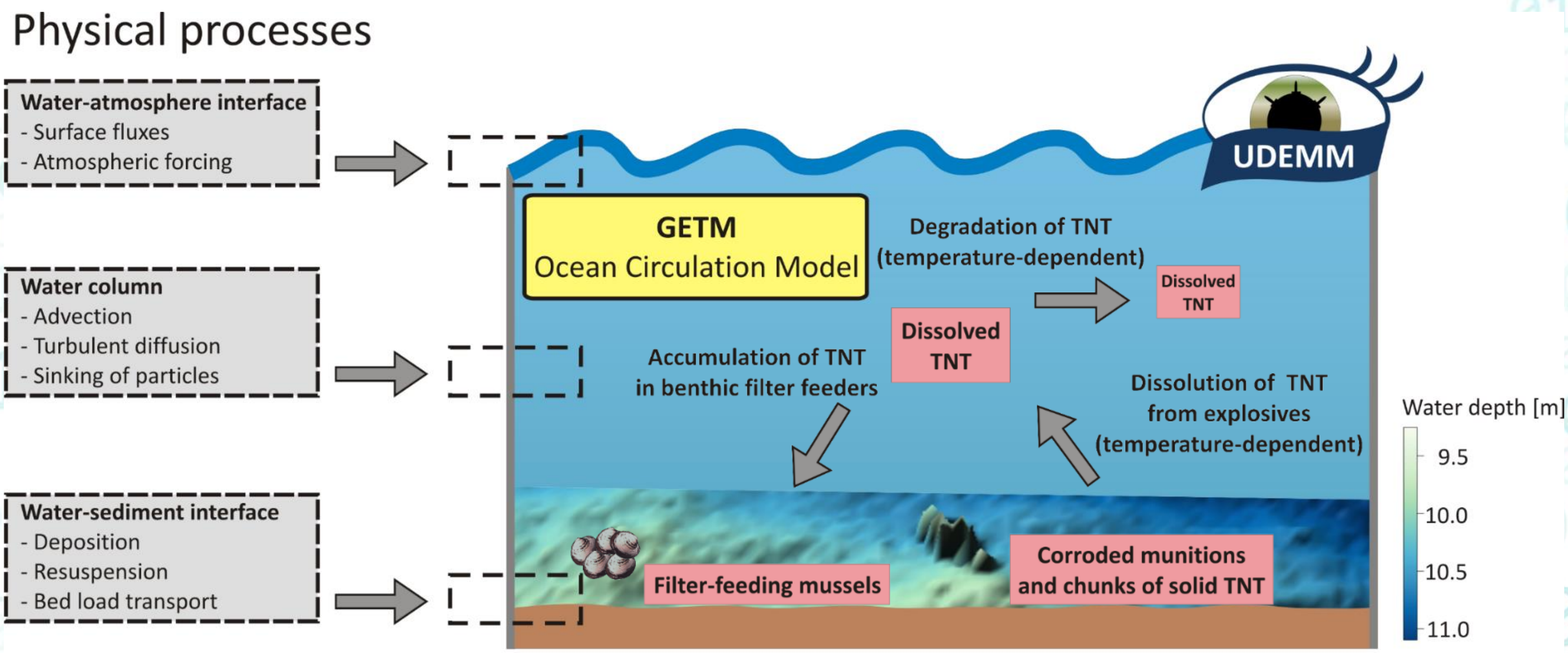
Successful simulation of Major Baltic Inflows

Physical model (GETM)



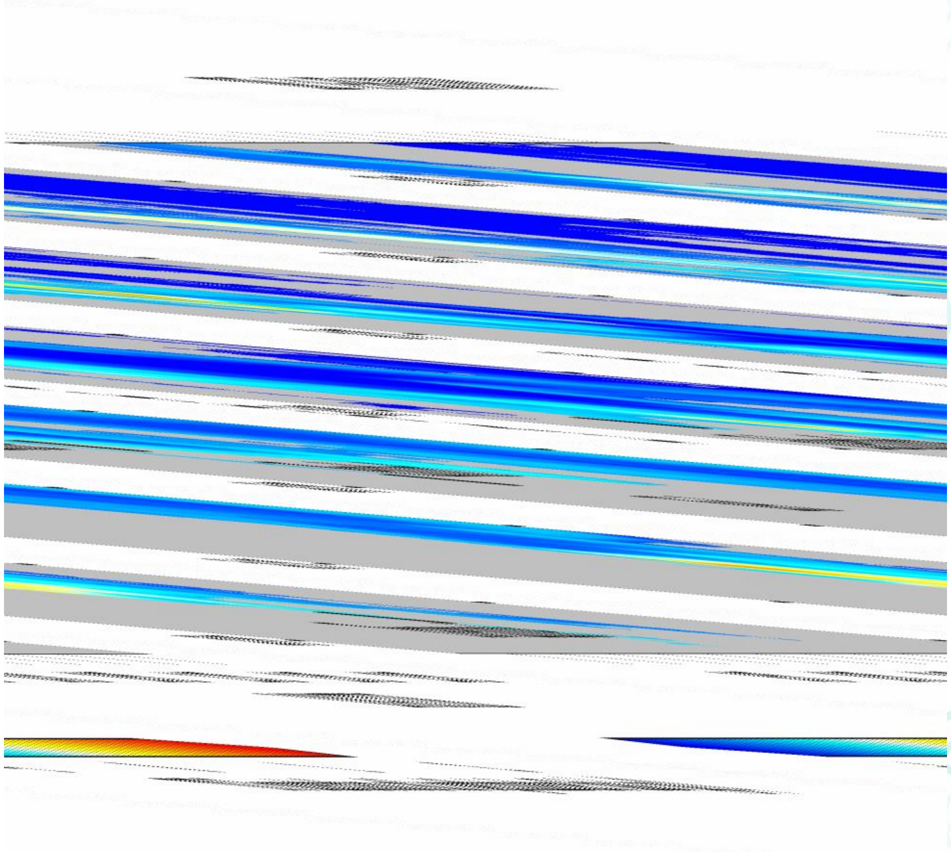
Simulating transport and fate of TNT

Coupled physical (GETM) – TNT model



Simulating transport and fate of TNT

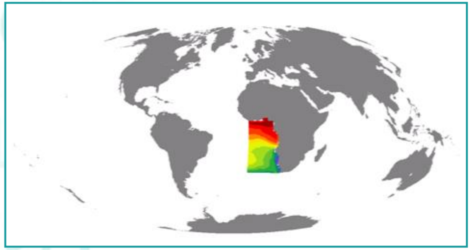
Coupled physical (GETM) – TNT model



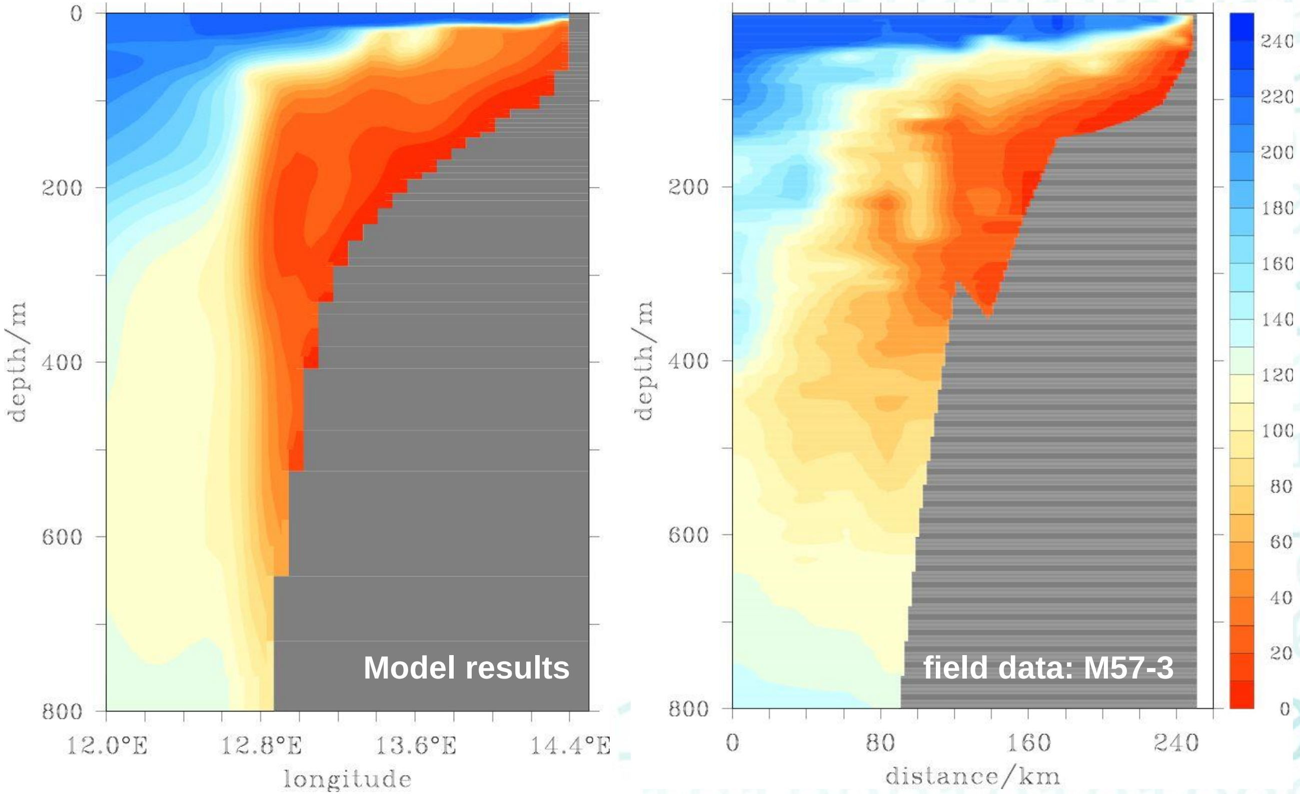
Extended oxygen minimum zones off Namibia

Coupled physical (MOM) – biogeochemical model

Hypoxic zone stretches in the near bottom water



GENUS



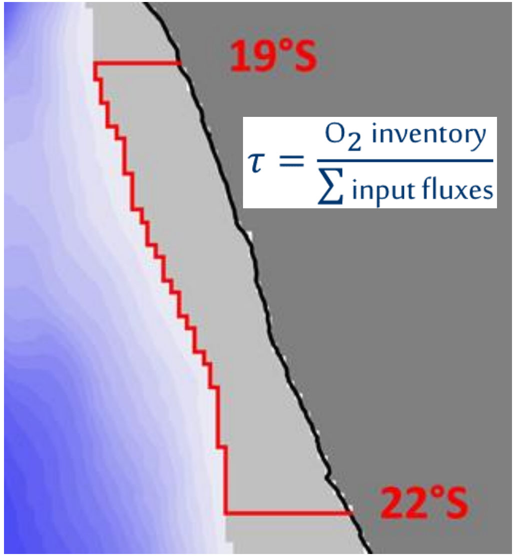
23°S in March 2003

Physical vs. biochemical residence times

Coupled physical (MOM) – biogeochemical model

Physical advection of oxygen

$$\tau_{dyn} = \frac{438.7\ \text{Gmol}}{12.6\ \frac{\text{Gmol}}{\text{day}}} = 35\ \text{days}$$

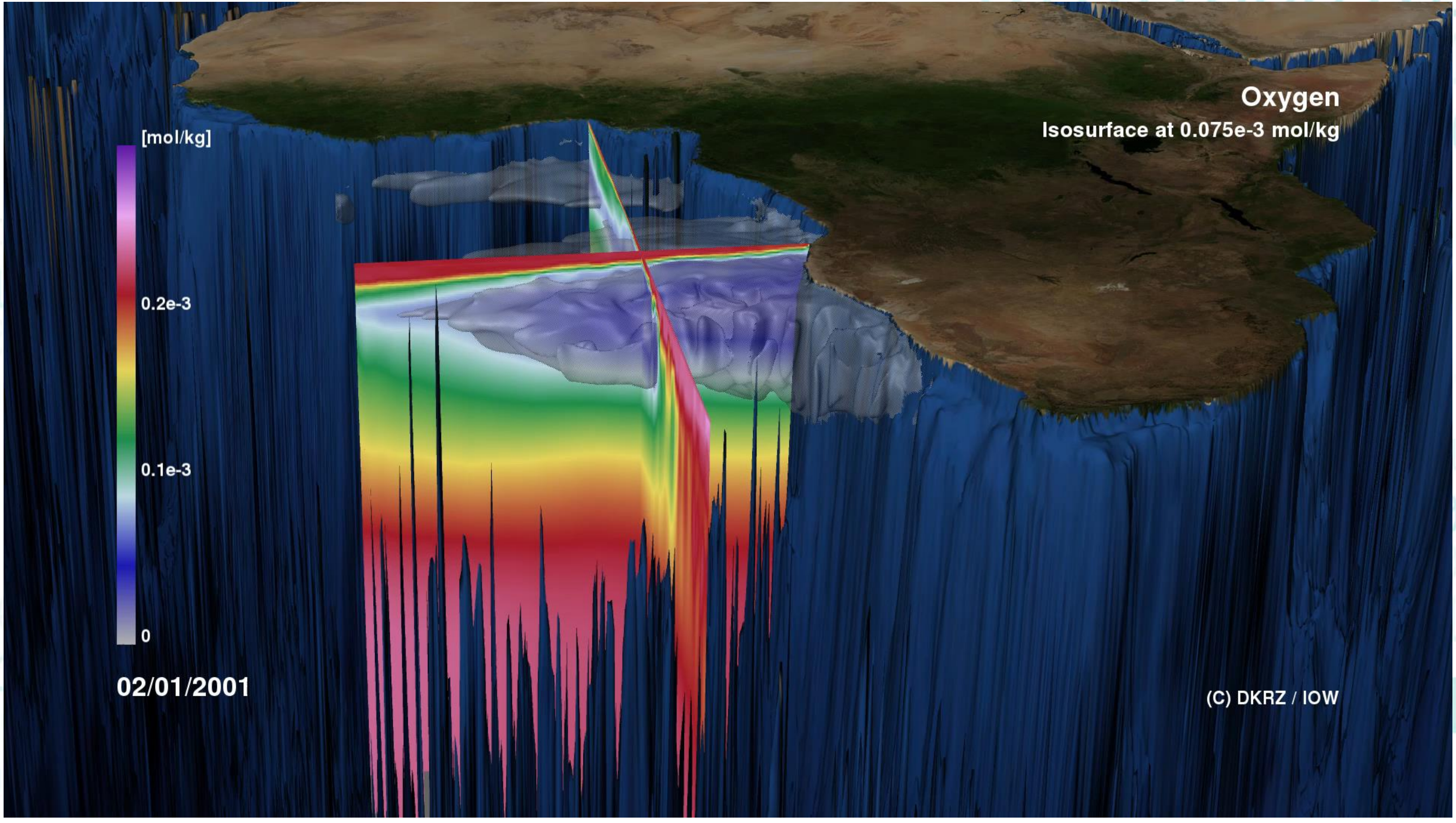


Biogeochemical oxygen consumption

$$\tau_{bio} = \frac{438.7\ \text{Gmol}}{1.8\ \frac{\text{Gmol}}{\text{day}}} = 244\ \text{days}$$

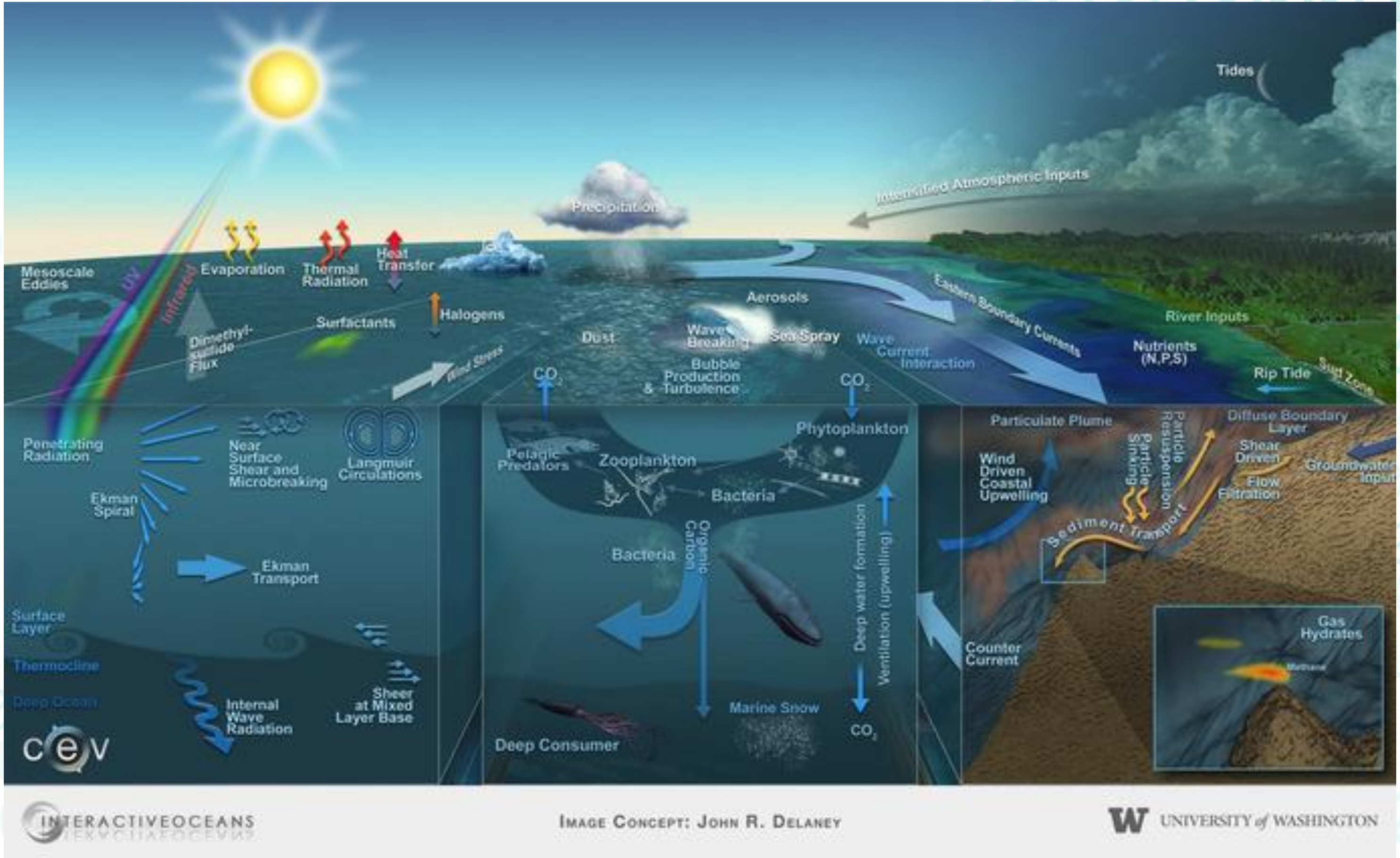
Low oxygen water on the continental shelf off Namibia is driven by ph ysical advection (from the north) and only modified through local bio geochemical oxygen consumption.

Benguel Upwelling System

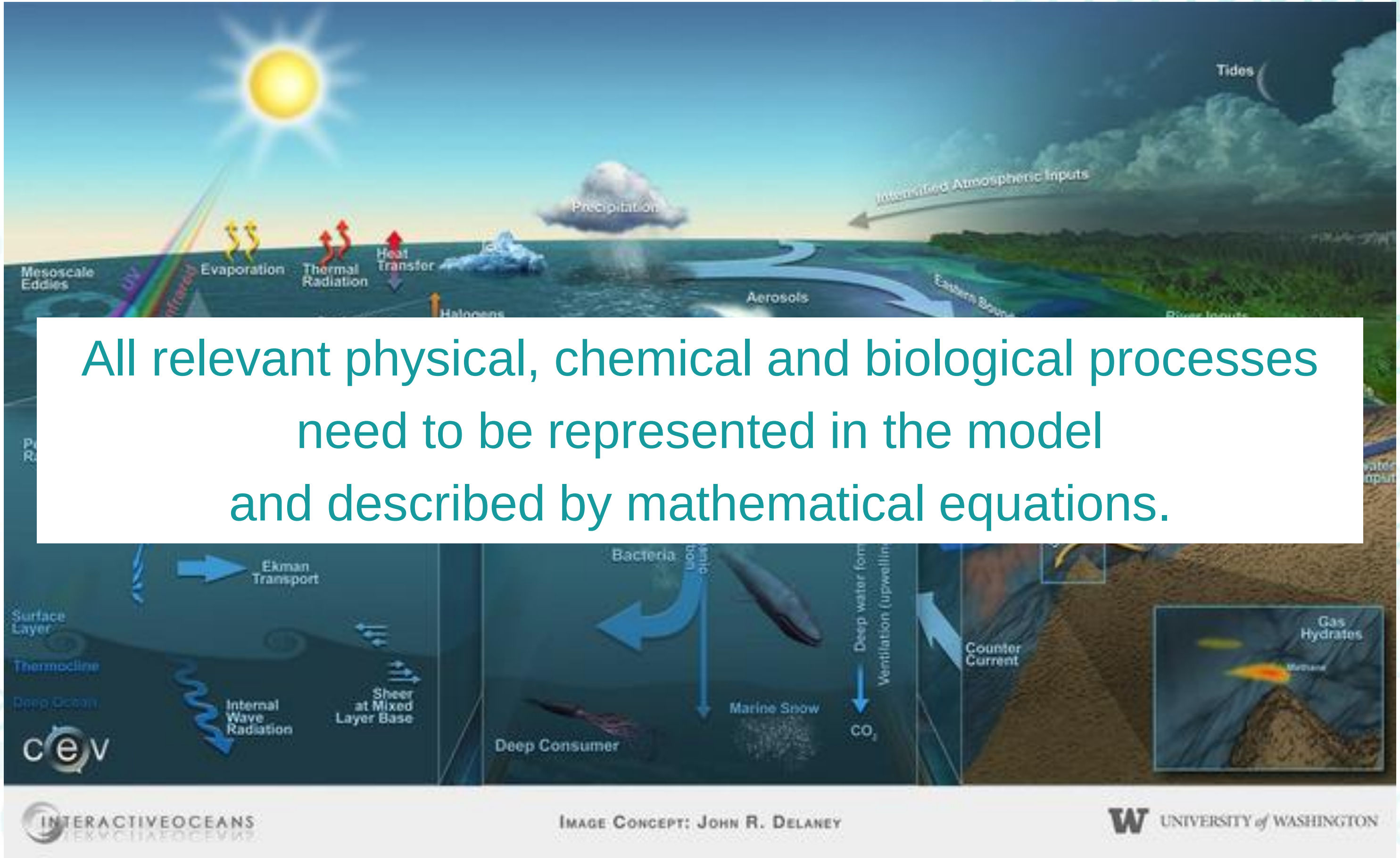


How numerical models are constructed

The ecosystem is very complex…

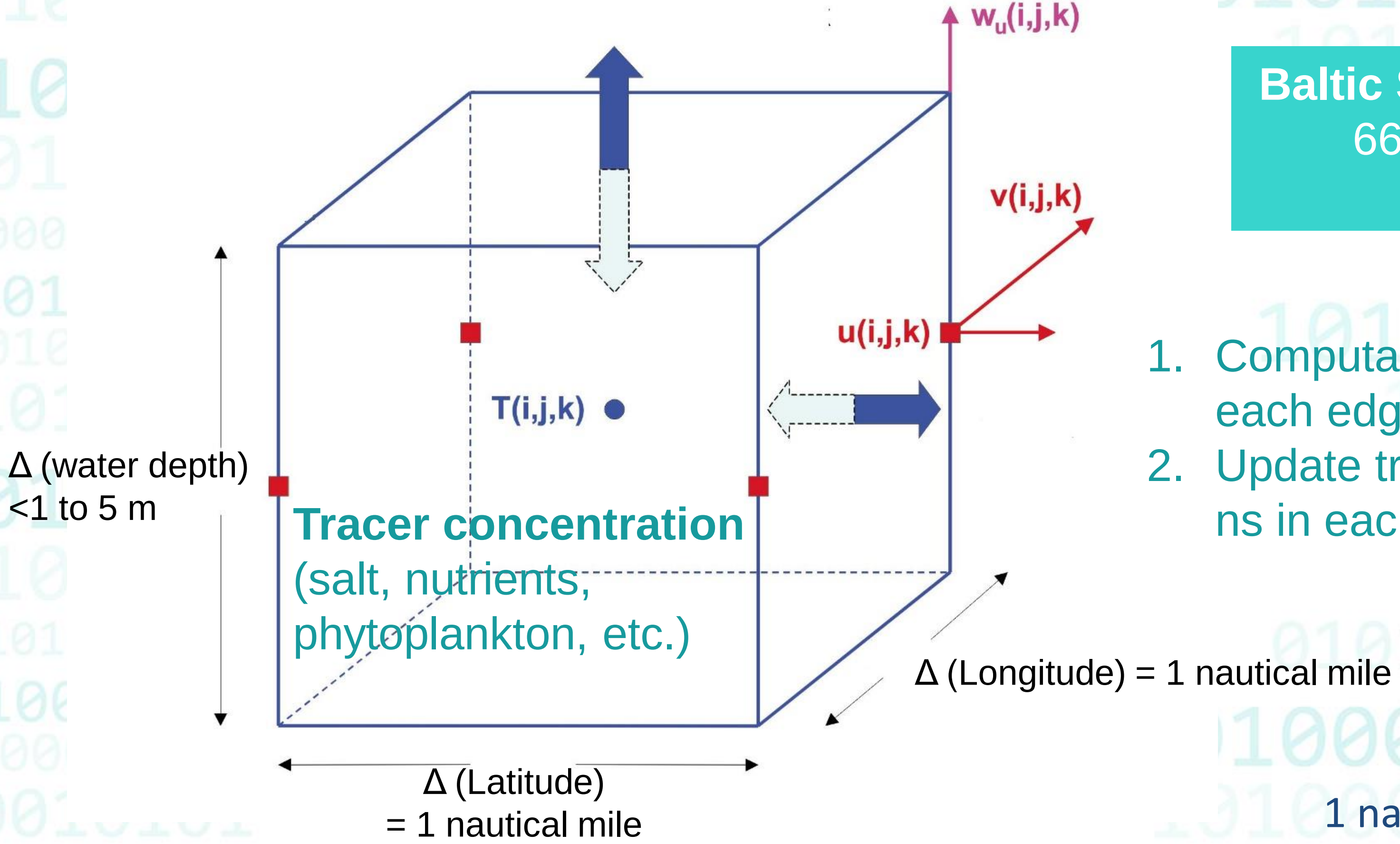


Implementing the important processes



All relevant physical, chemical and biological processes
need to be represented in the model
and described by mathematical equations.

Gridding the ocean basin



Baltic Sea 1 nm set-up
666 x 732 x 77
grid cells

1. Computation of fluxes on each edge of the grid
2. Update tracer concentrations in each cell

1 nautical mile ≈ 1.85 km

A physical circulation model

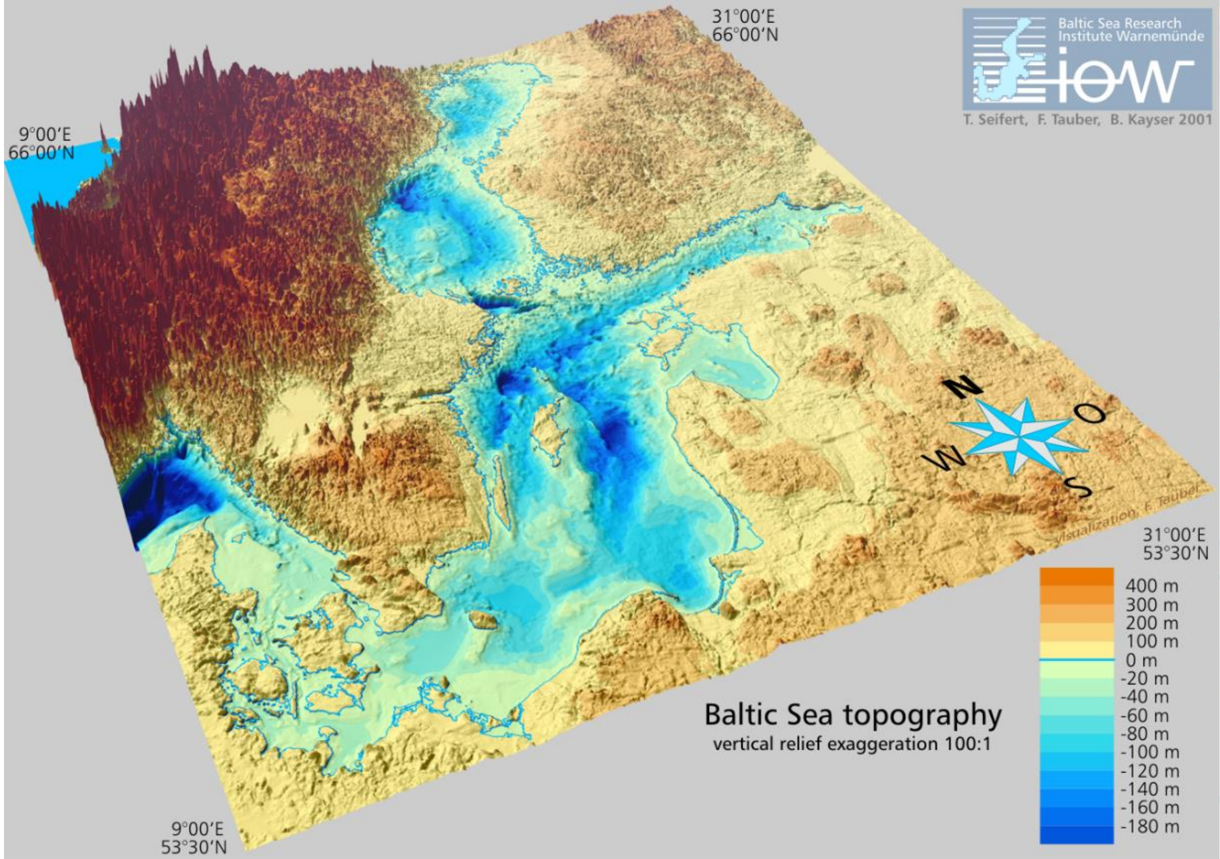
Physical model

- Thermo- & hydrodynamic equations of the ocean
- *e.g.*, MOM, GETM, ROMS

GETM

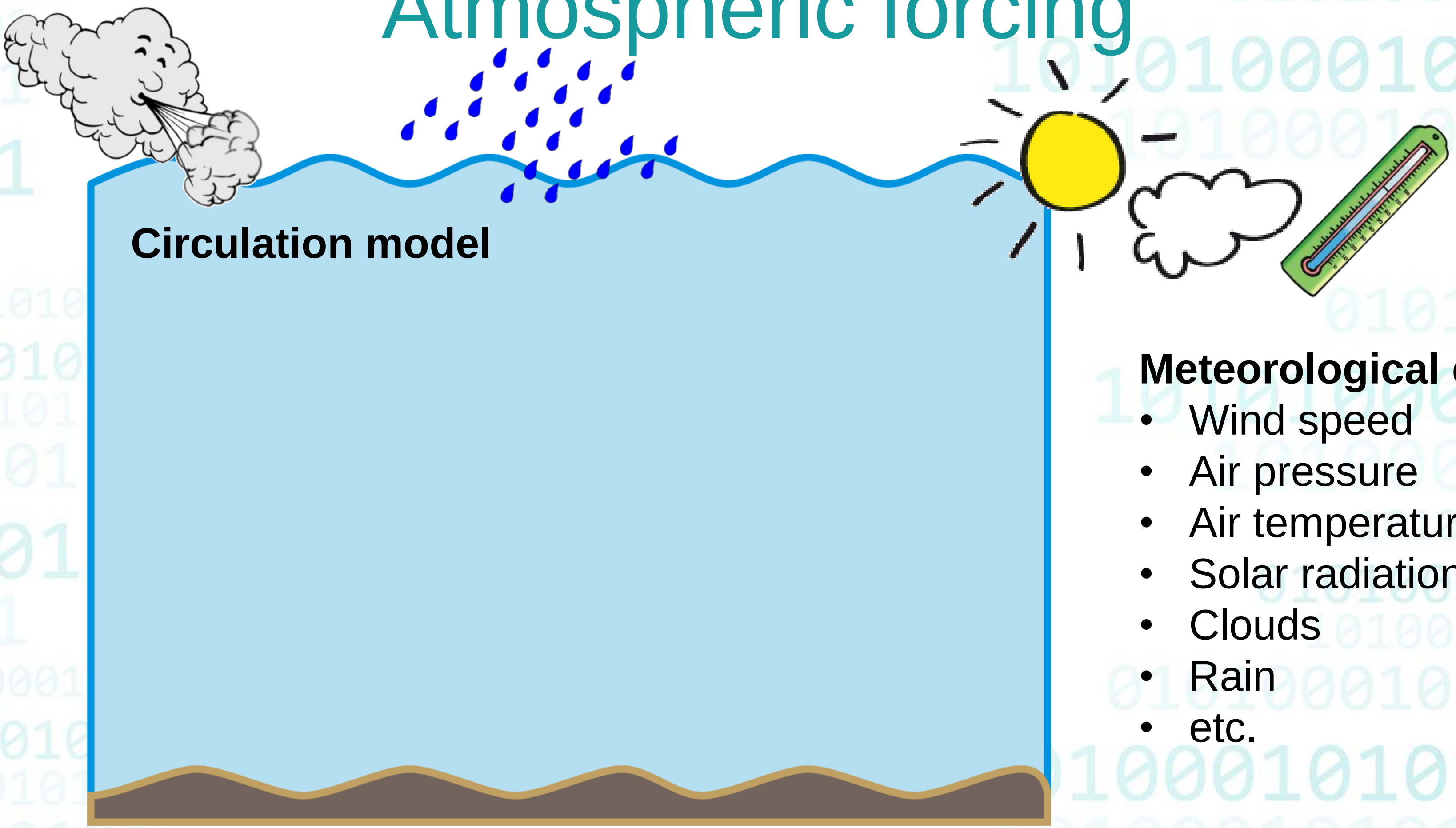
General Estuarine T
ransport Model

Bathymetry



31°00'E
66°00'N
9°00'E
66°00'N
Baltic Sea Research Institute Warnemünde
iow
T. Seifert, F. Tauber, B. Kayser 2001
N
O
W
S
31°00'E
53°30'N
400 m
300 m
200 m
100 m
0 m
-20 m
-40 m
-60 m
-80 m
-100 m
-120 m
-140 m
-160 m
-180 m
Baltic Sea topography
vertical relief exaggeration 100:1
9°00'E
53°30'N

Atmospheric forcing

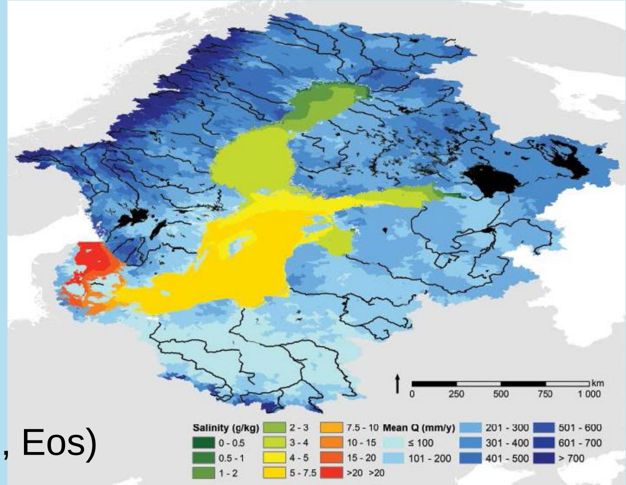


Meteorological data

- Wind speed
- Air pressure
- Air temperature
- Solar radiation
- Clouds
- Rain
- etc.

Atmospheric and river input

Circulation model

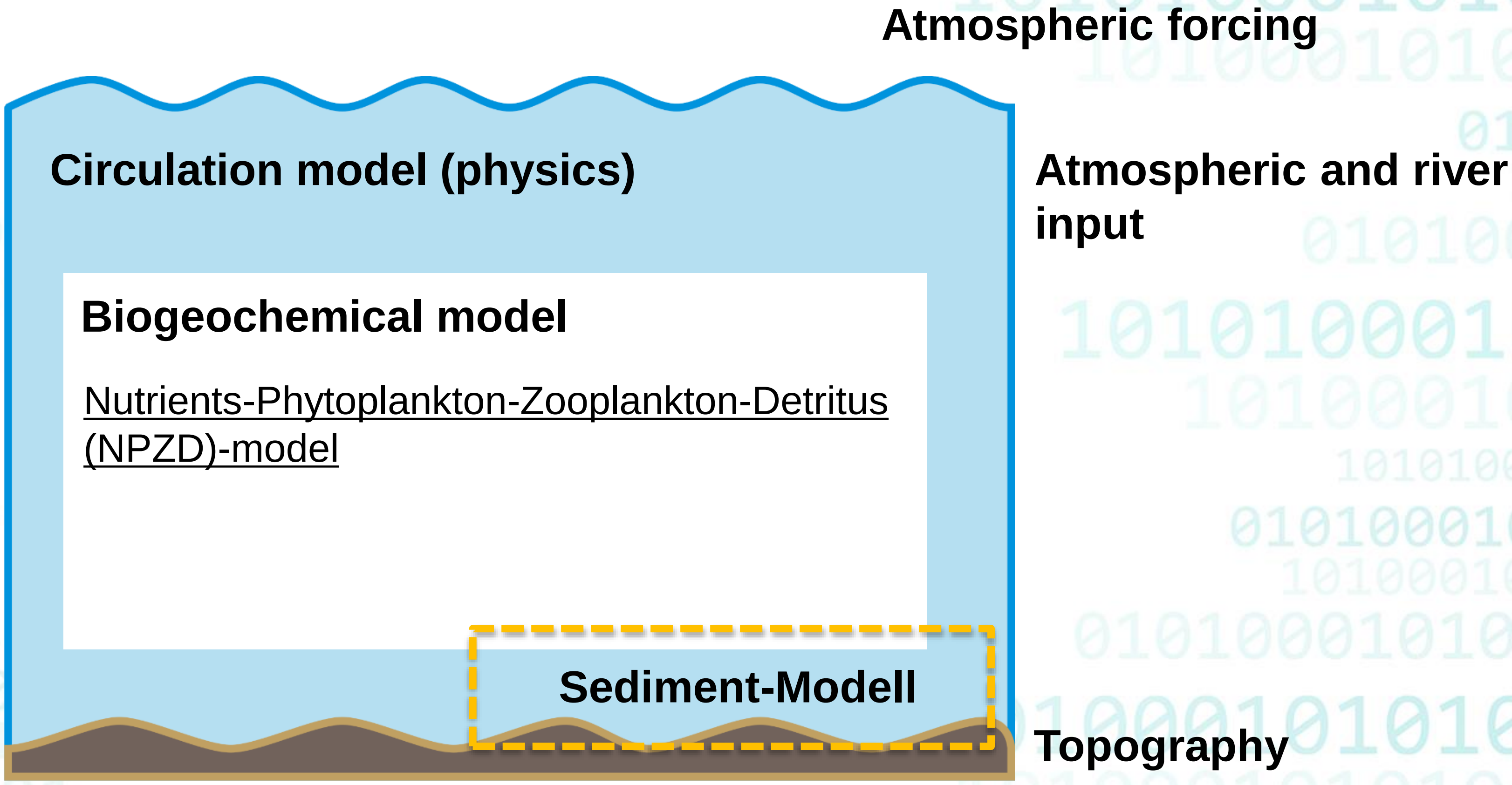


Meier et al. (2014, Eos)

River input:
≈ 480 km^3/year

Nutrient input:
- Nitrate
- Ammonium
- Phosphate

Coupled physical-biochemical model

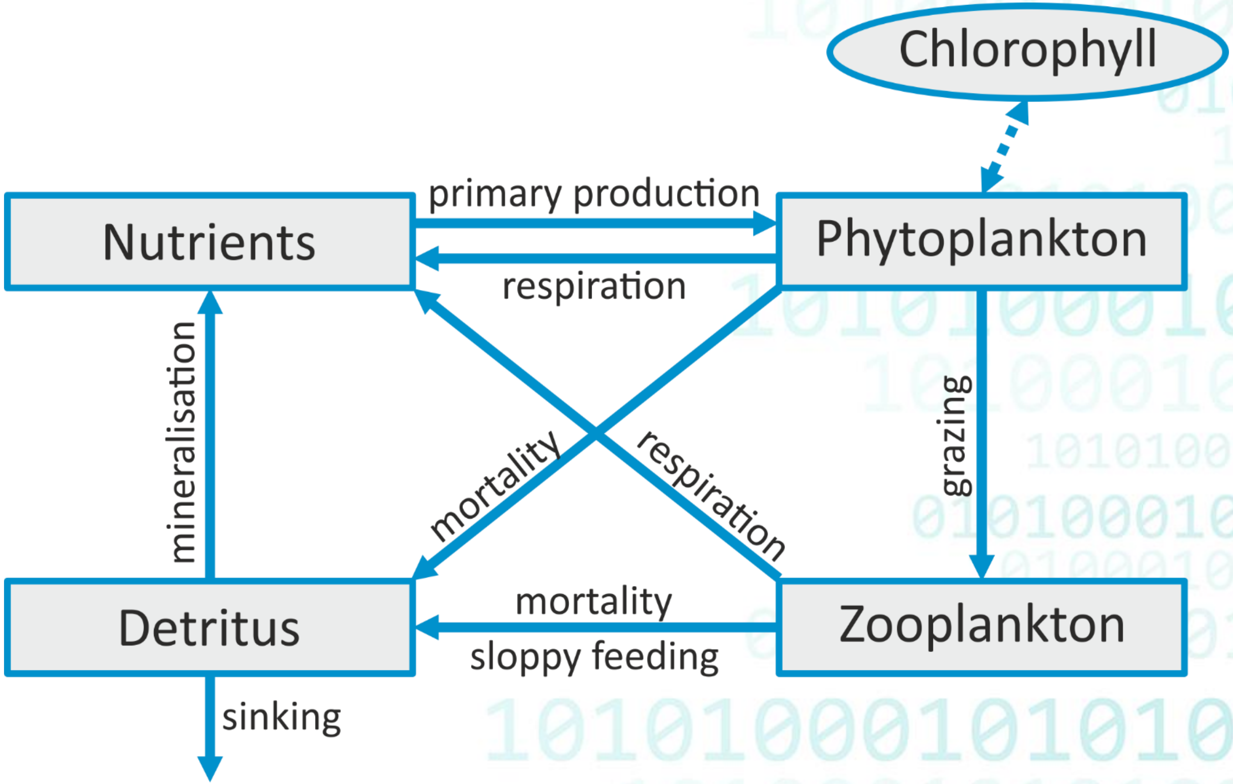


State variables and processes

„NPZD“ model named for and characterized by ist state variables

State variables are concentrations (in a common currency) that depend on space and time

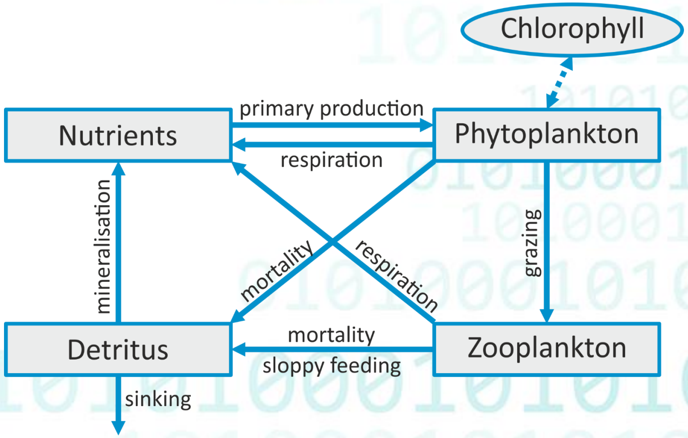
Processes link the state variables



Mathematical formulation

- **Mass conservation**, i.e. mass in kilograms of e.g. nitrogen in the system („nothing can disappear“)
- Concentration (kg m^{-3}) of **state variable C** is mass per unit volume
- **Source** for one state variable will be **sink** for another

$$\frac{\partial[C]}{\partial t} = sources - sinks$$



Rate of change…

- Rate of change of **nutrients** = -uptake + mineralisation + input
- Rate of change of **algae** = uptake – grazing – mortality – respiration
- Rate of change of **grazers** = growth – mortality – sloppy feeding – excretion
- Rate of change of **detritus** = mineralisation + mortality (algae)
  + mortality (grazers) + excretion (grazers)

Coupling to physical processes

Advection-diffusion-equation:

$$\frac{\partial[C]}{\partial t} + \nabla \cdot \vec{v}\mathrm{C} - \mathrm{D}\Delta C = gain(C) - loss(C)$$

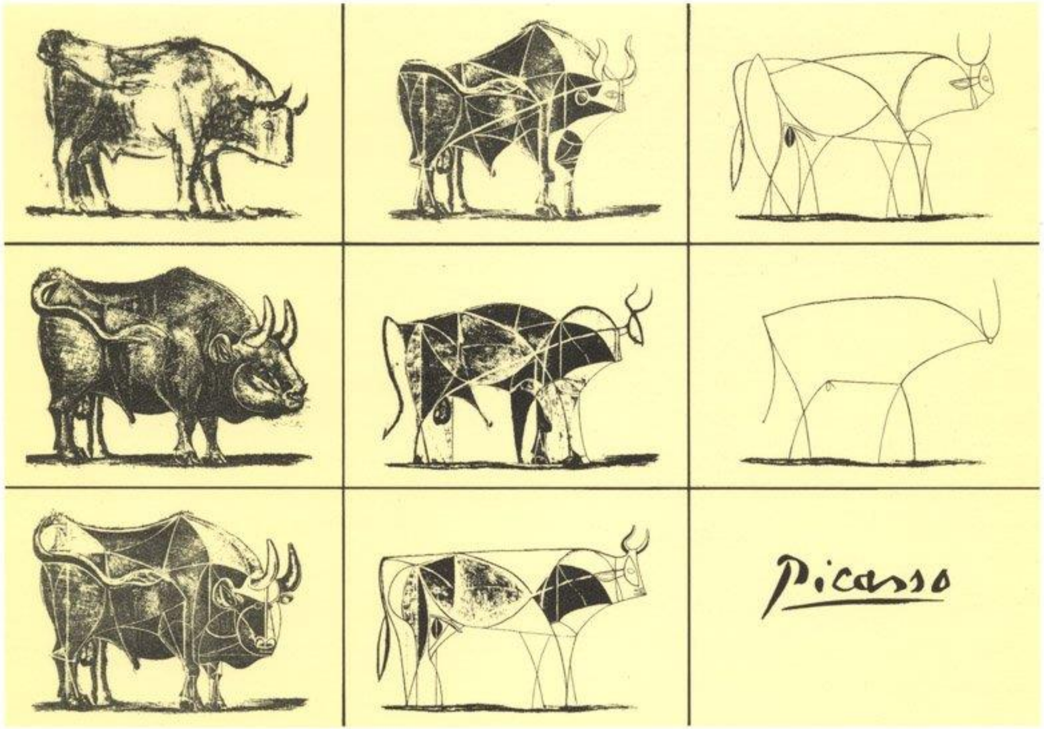
Advection
(velocity field in x, y, z direction)

Diffusion

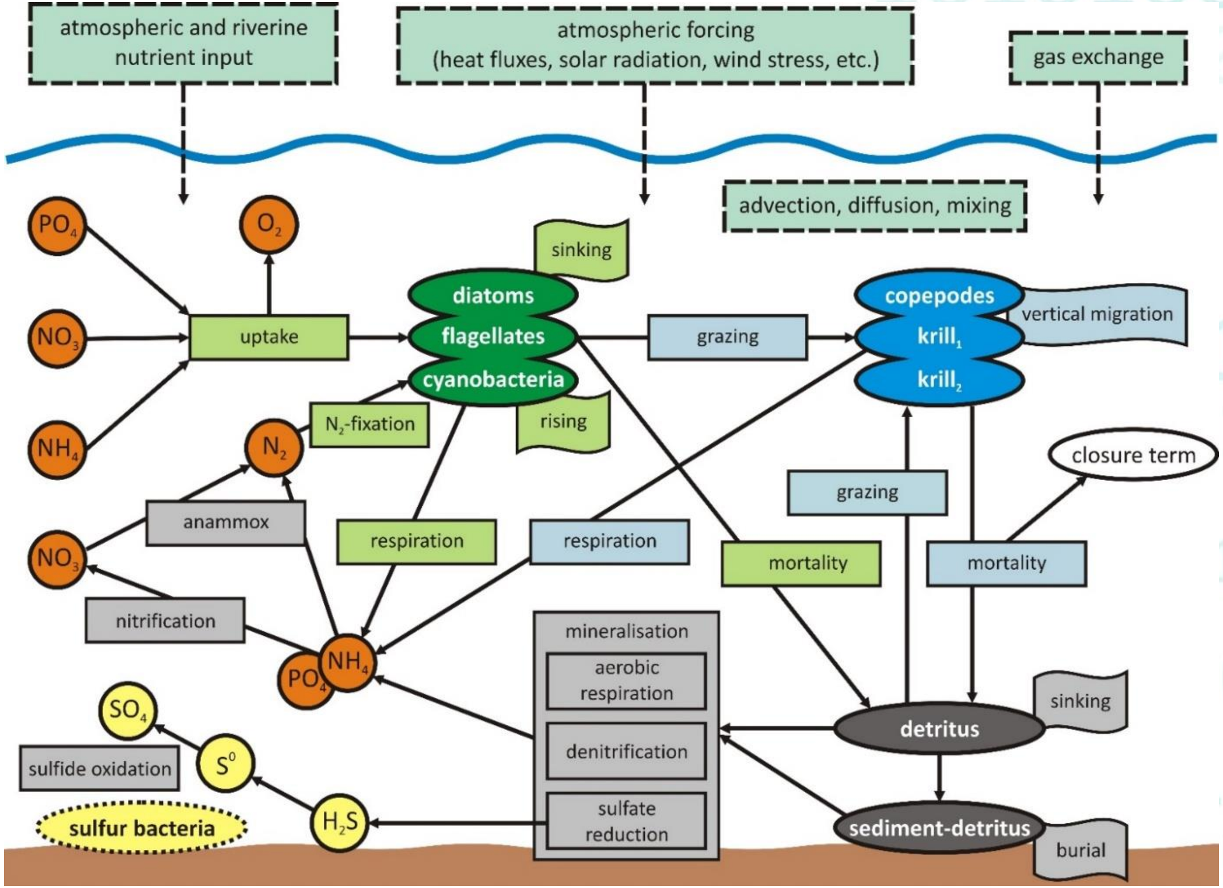
Biological dynamics

C is the consentration of any biological state variable

Make models as simple as possible - but as complex as necessary !

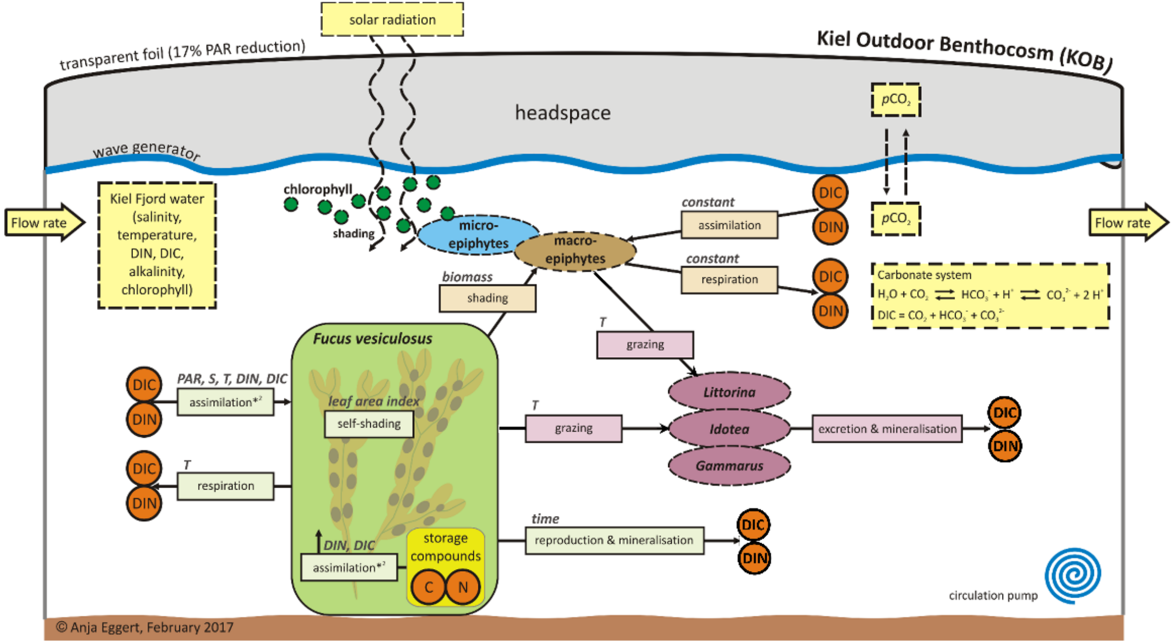


Biochemical model coupled to 3D regional model



Fucus box model

0D box model



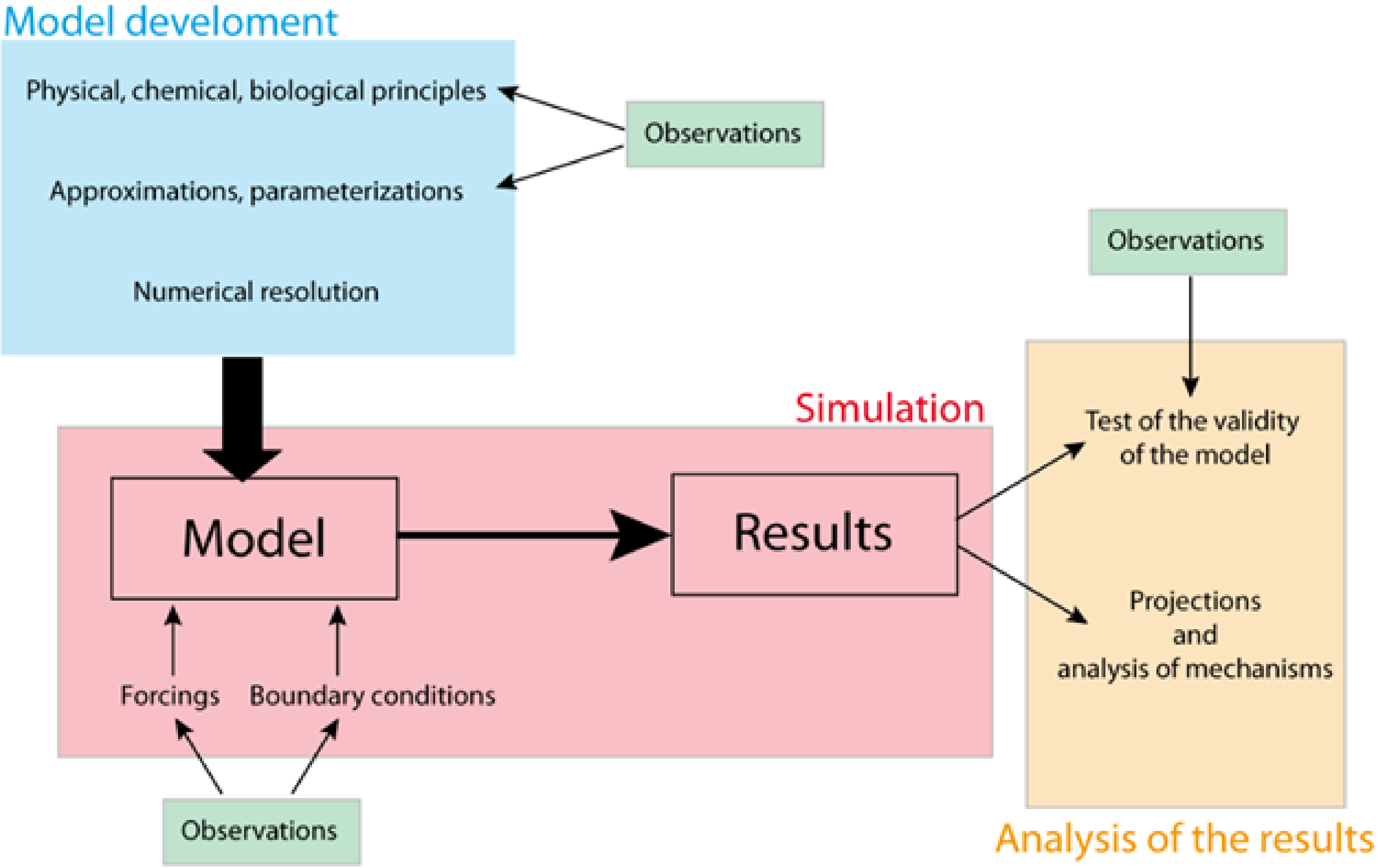
forcing — “atmospheric and hydrographic forcing”

prescribed — “prescribed biological variables”

state variable — “explicitly modelled variable“

process — “explicitly modelled process“

Why do we need observations?



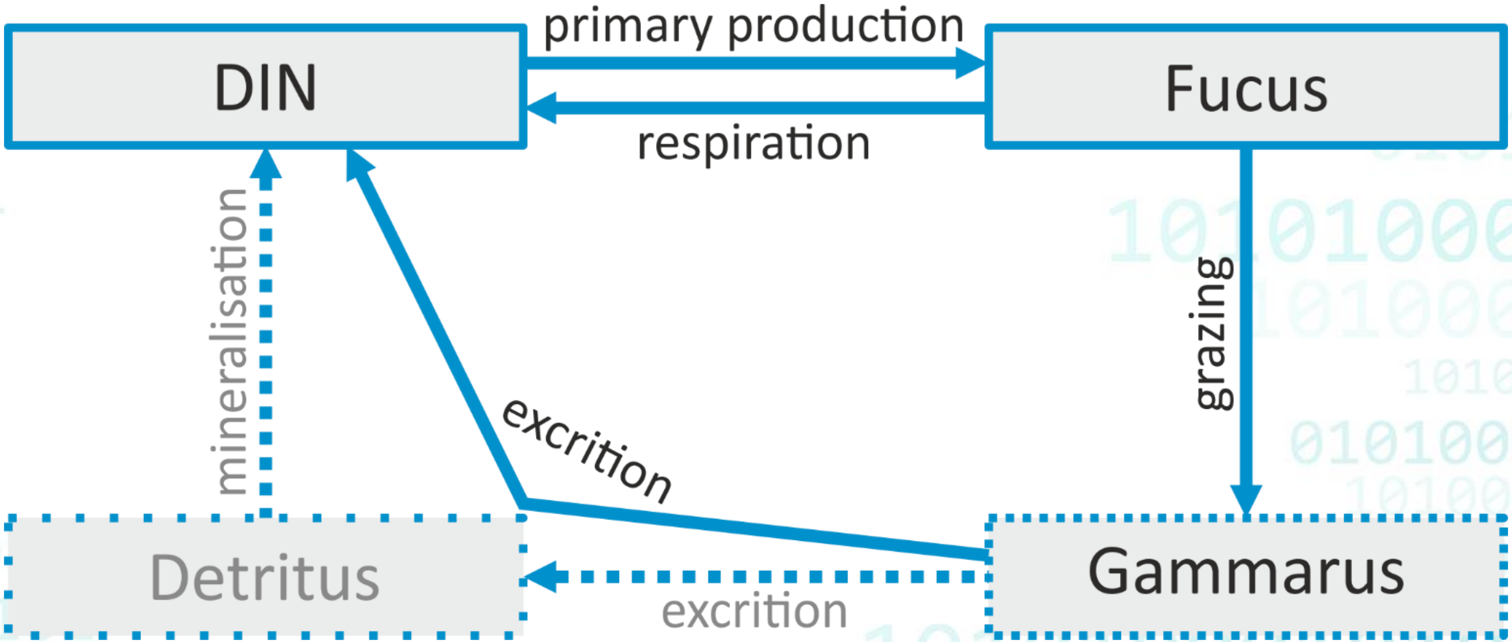
Construct a simple model

Steps in constructing a model

1. Identify the scientific problem
2. Determine relevant state variables and processes
3. Develop mathematical formulation
4. Provide forcing, initial conditions, boundary conditions etc.
5. Numerical implementation,

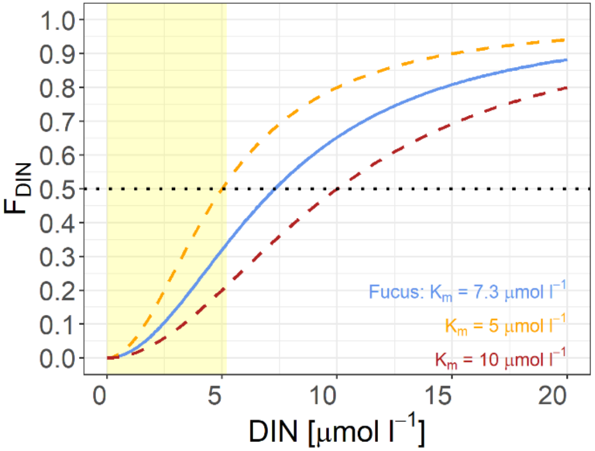
State variables and processes

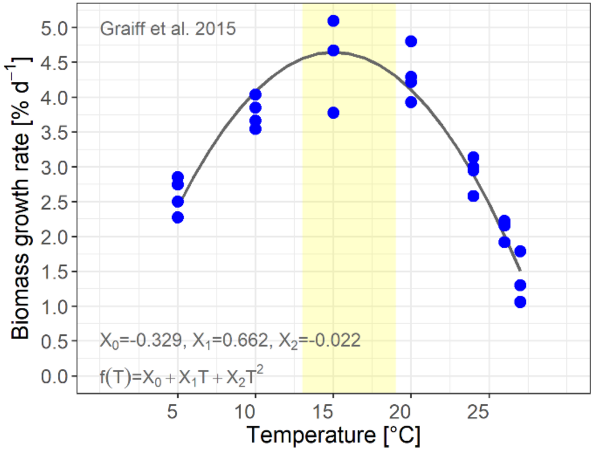
Structure of the KOB benthocosm model

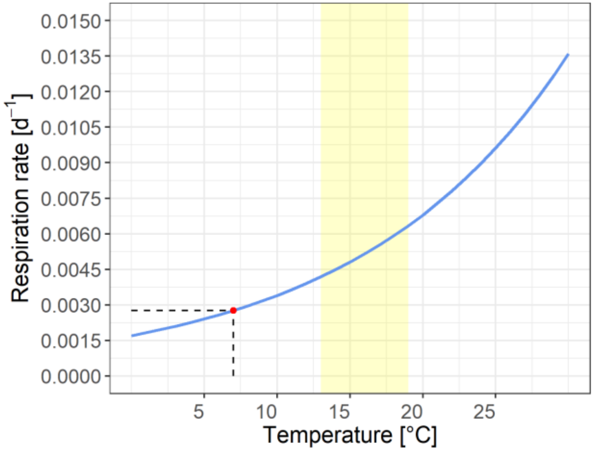


Mathematical forumations

Used mathematical functions

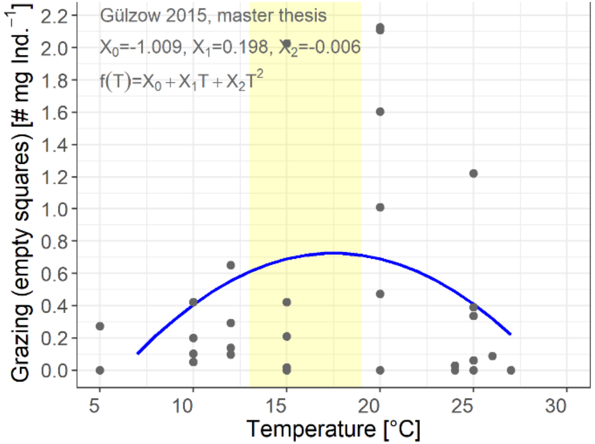






$$\mathrm{resp}_{\mathrm{fuc}}=\mathrm{r}_0 \cdot \exp^{(q_{10} \cdot \mathrm{temp})}$$

$$F_{DIN} = \frac{DIN^2}{{K_m}^2 + DIN^2}$$



$$F_T=X_0+X_1T+X_2T^2$$

It’s not magic –
it’s equations

Forcing data

Check available time series

German Weather Service (DWD)
downward short-wave radiation, conversion to PAR
3-hourly data

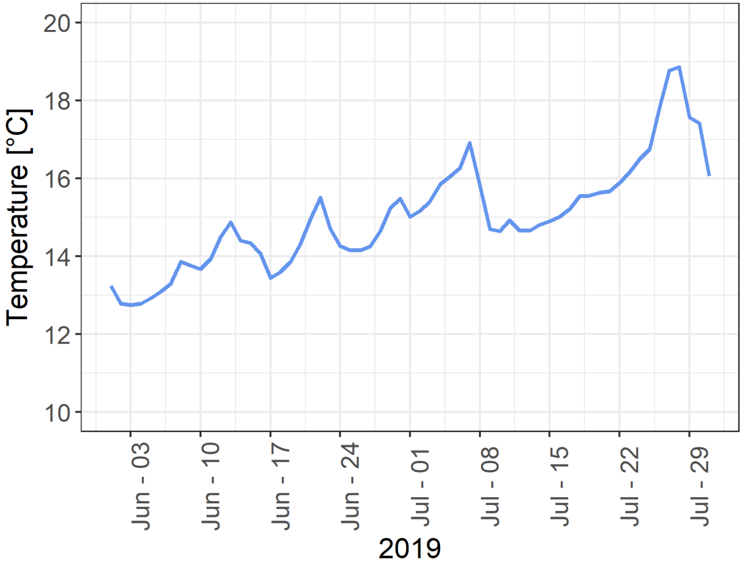
Landesamt für Landwirtschaft, Umwelt und ländliche Räume Schleswig-Holstein (LLUR)
Inner Kiel Fjord, station OM225103 (10.1646°E, 54.3539°N) between Mönkeberg and Wik
temperature, salinity, DIN [mg l^{-1}], chlorophyll [µg l^{-1}], Secchi depth
approx. monthly data

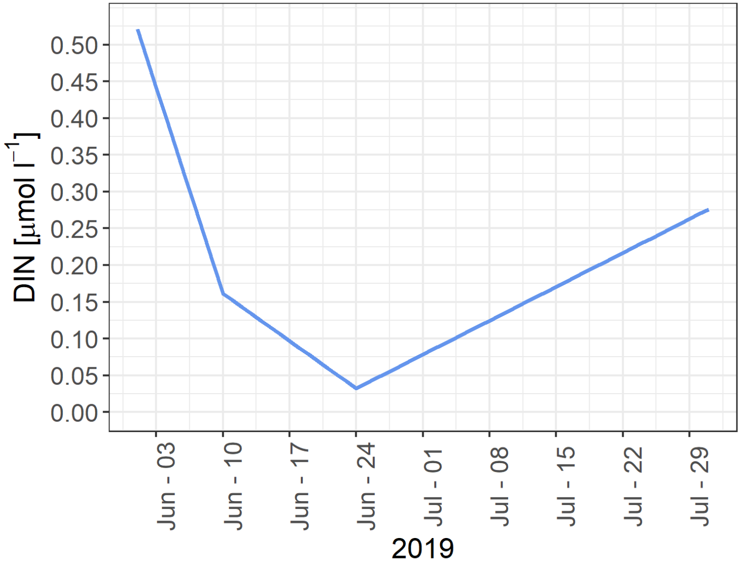
Federal Maritime and Hydrographic Agency, Bundesamt für Seeschifffahrt und Hydrographie (BSH)
MARNET station Kiel Lighthouse (10.267°E, 54.5°N)
temperature, salinity
hourly data

BIOACID measurements in Kiel Fjord
Temperature, pH
TA, DIC, pCO_2, PO_4, NO_x
every three to four days during KOB experimental period

Model results GETM
physical model (spatial resolution 600 m) coupled with biogeochemical model (ERGOM)
temperature, salinity, chlorophyll, NO_3, NH_4, PO_4, PAR (in the water)
daily data (could be more, if required)

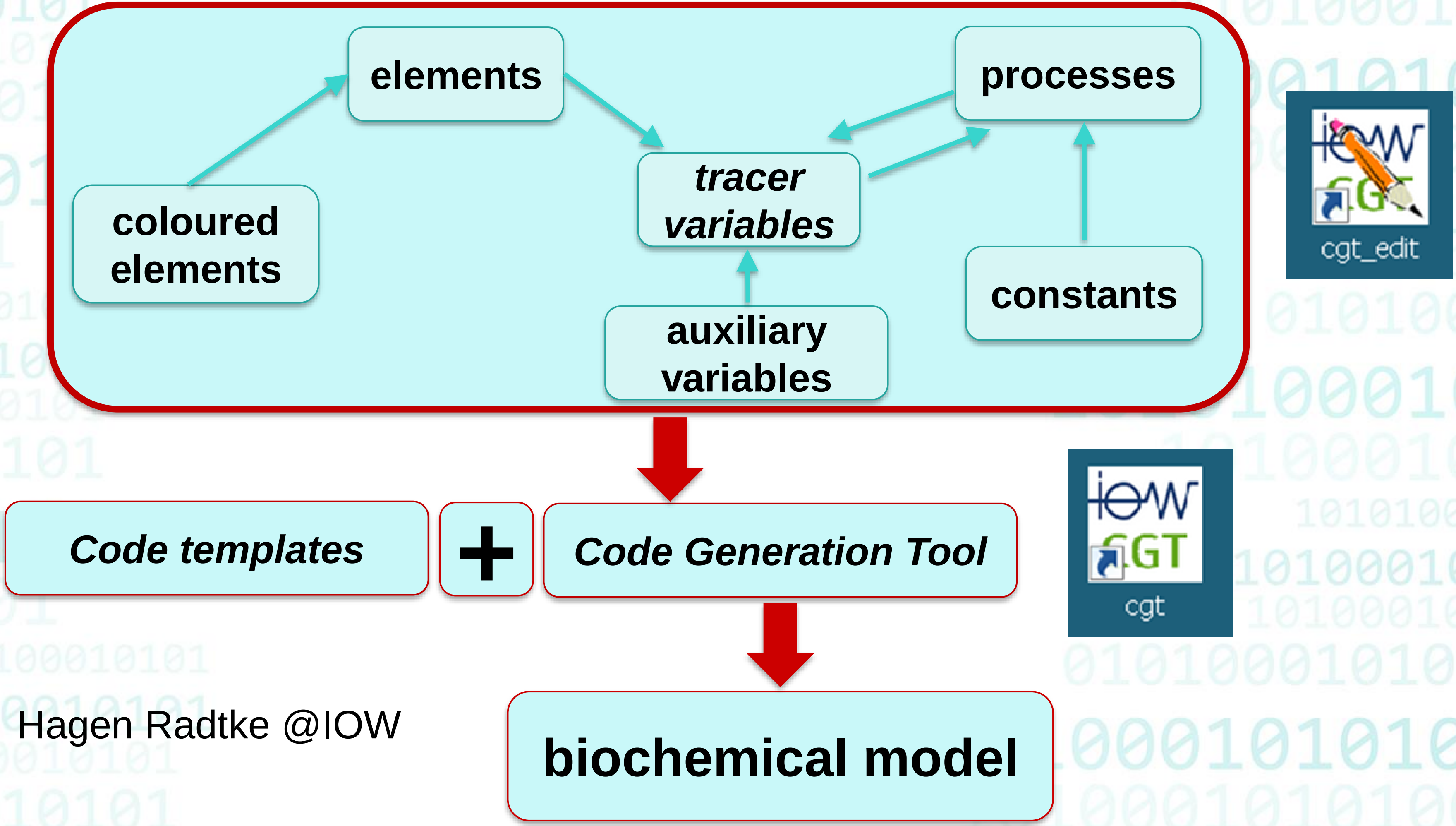
Forcing data of KOB model





BIOACID measurements in Kiel Fjord

Code Generation Tool



Hagen Radtke @IOW

elements

processes

coloured elements

tracer variables

constants

auxiliary variables

Code templates + *Code Generation Tool*

cgt_edit

cgt

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biogeochemical model + **Hydrodynamic model** 3D, 1D, 0D…

Translating program code in machine language

Compiler

.f90

Coupled model