PISCES

(Pelagic Interaction Scheme for Carbon and ecosystem studies)

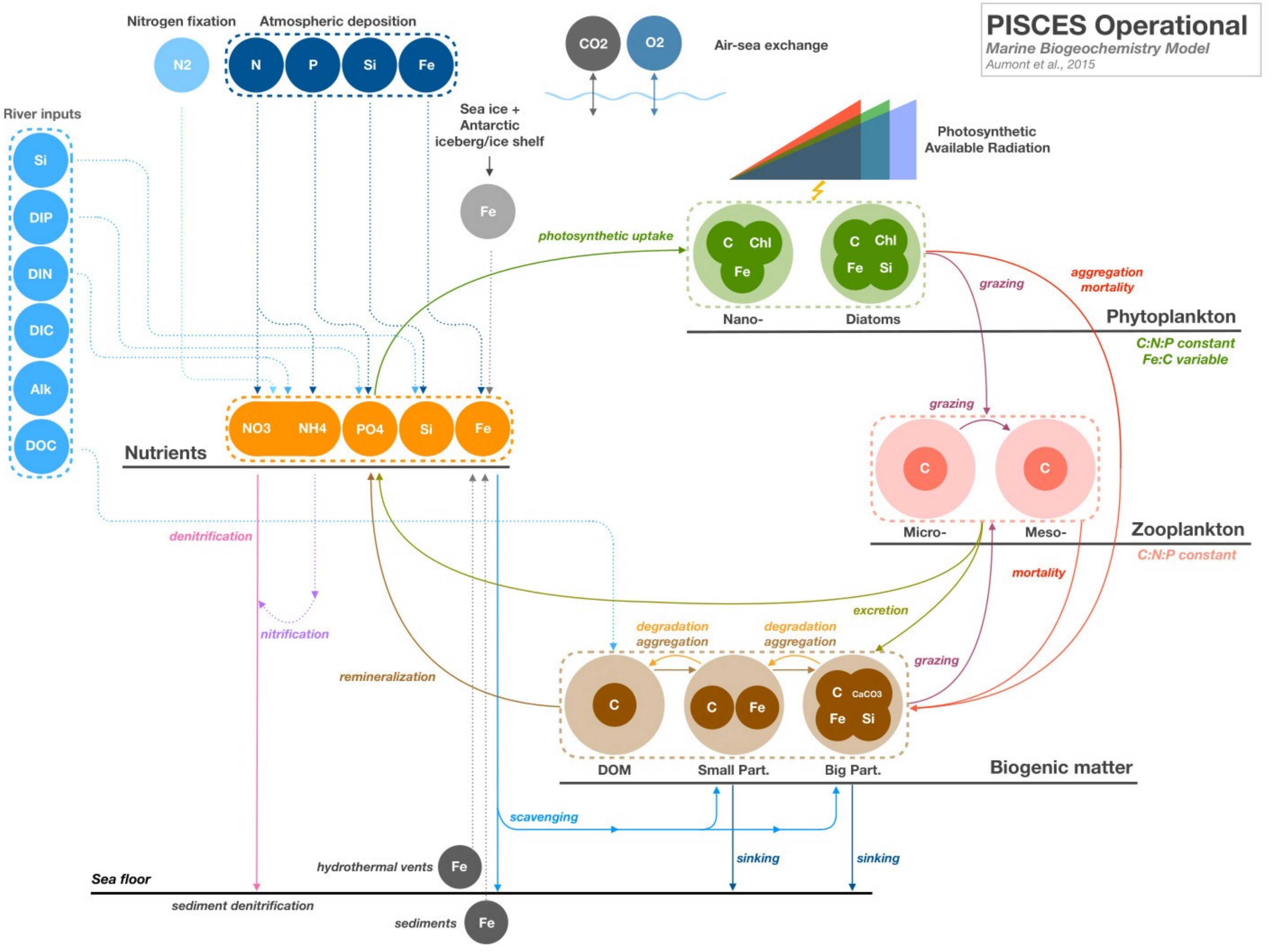
PISCES

Basic information on the model options

PISCES-std vs. PISCES-QUOTA

```
ln_p4z = .true.
```

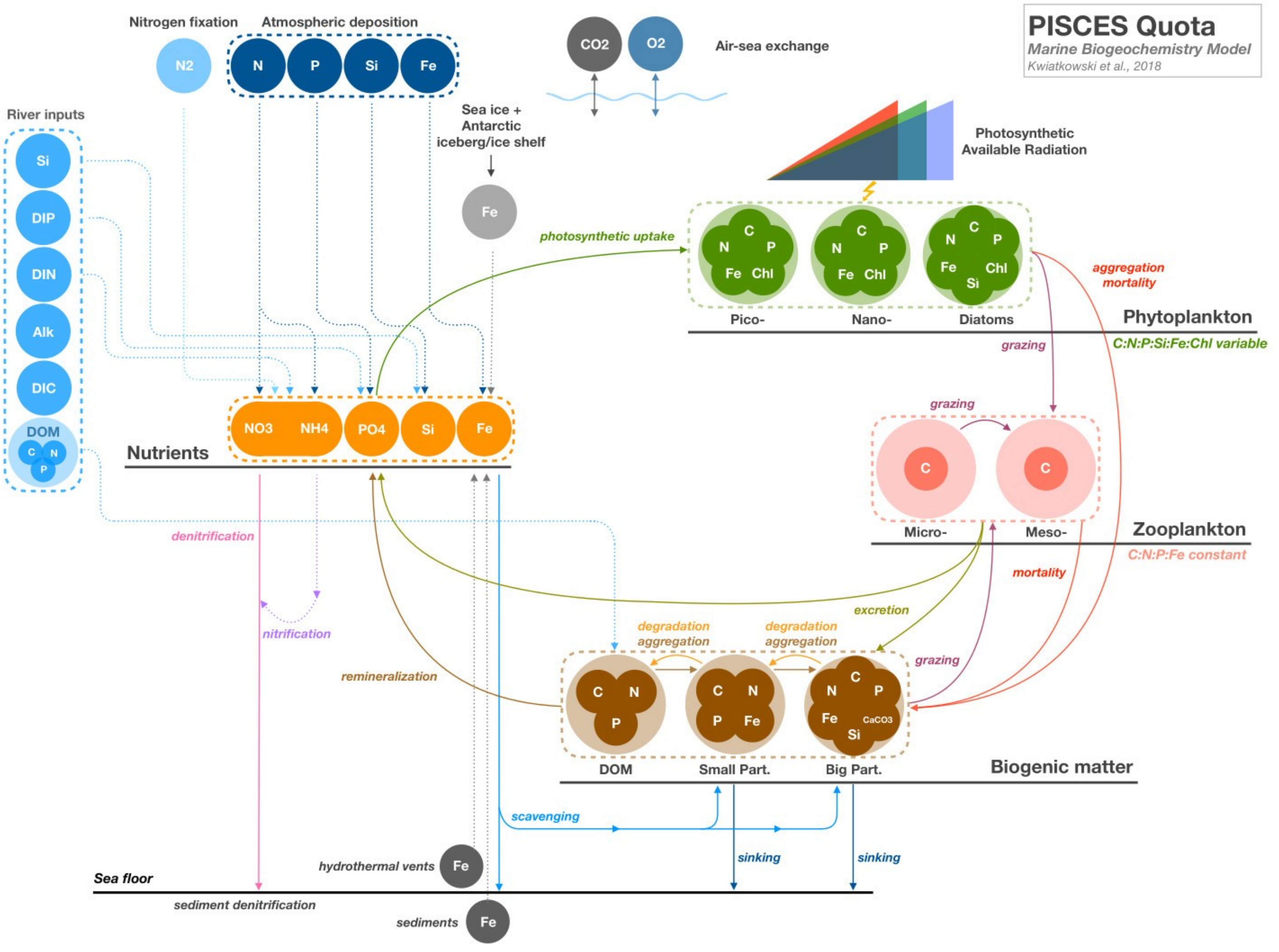
PISCES-std (24/25 tracers)



PISCES-std vs. PISCES-QUOTA

```
ln_p5z = .true.
```

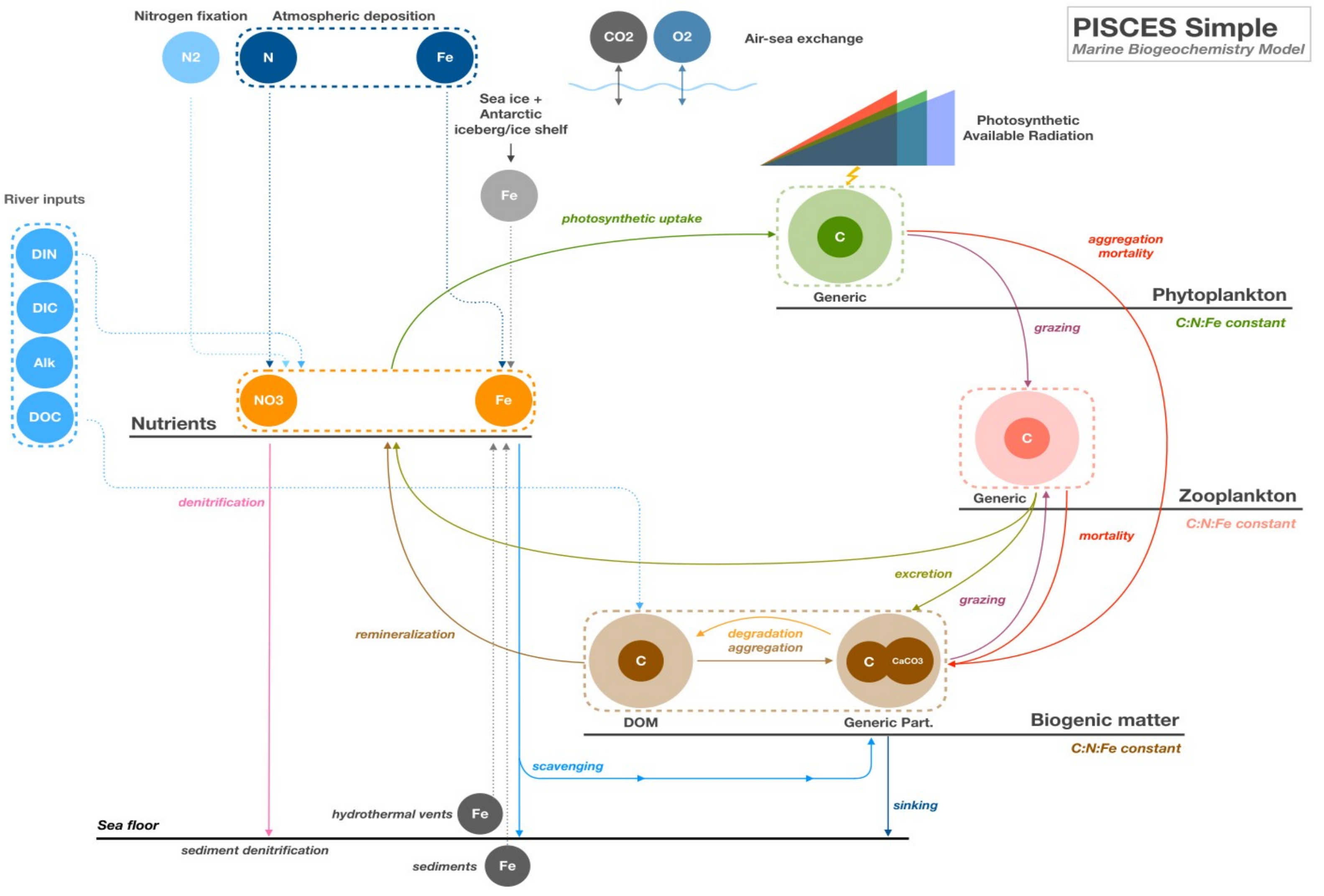
PISCES-QUOTA (39/40 tracers)



PISCES-simple vs. PISCES-STD

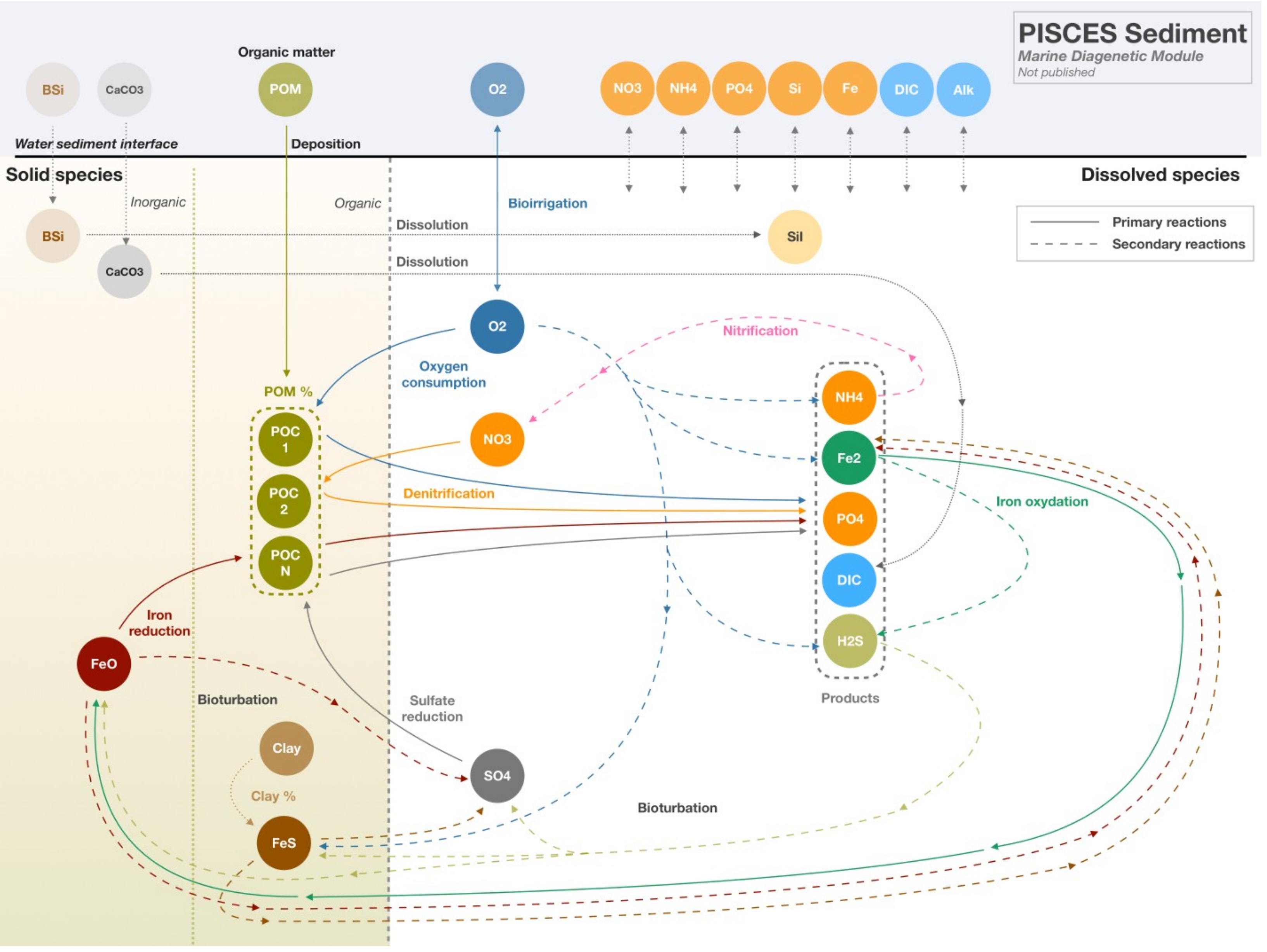
```
ln_p2z = .true.
```

PISCES-Simple (9 tracers)

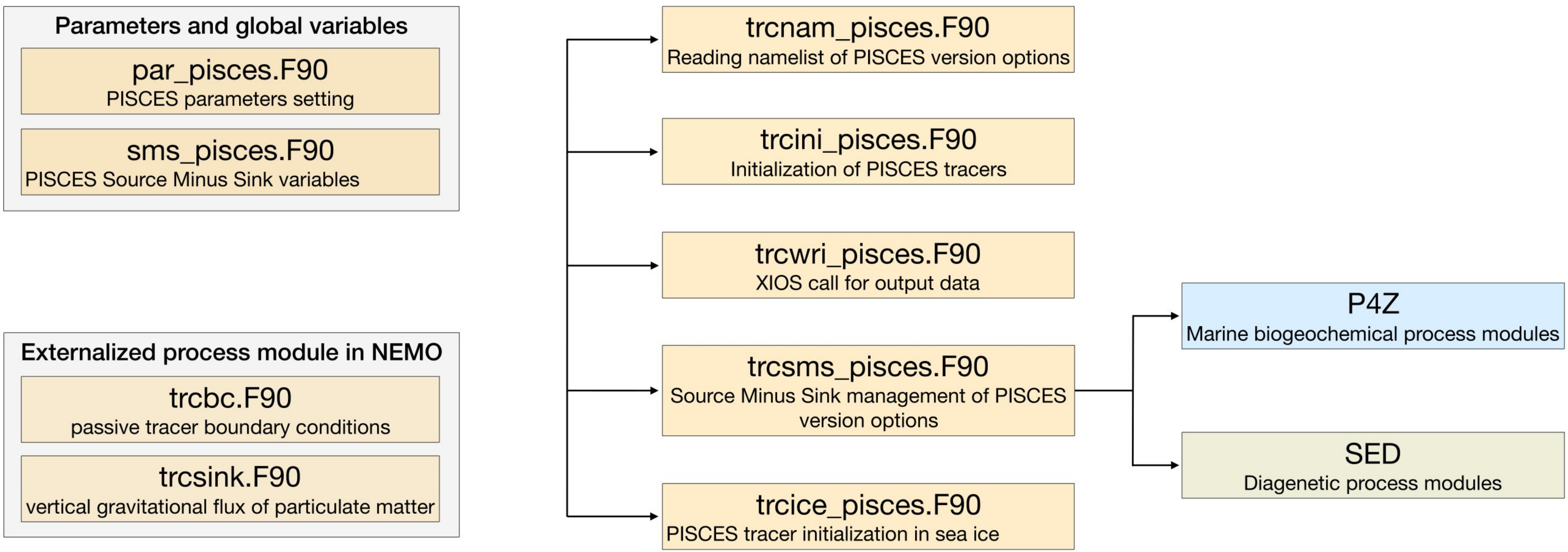


PISCES-Sediment

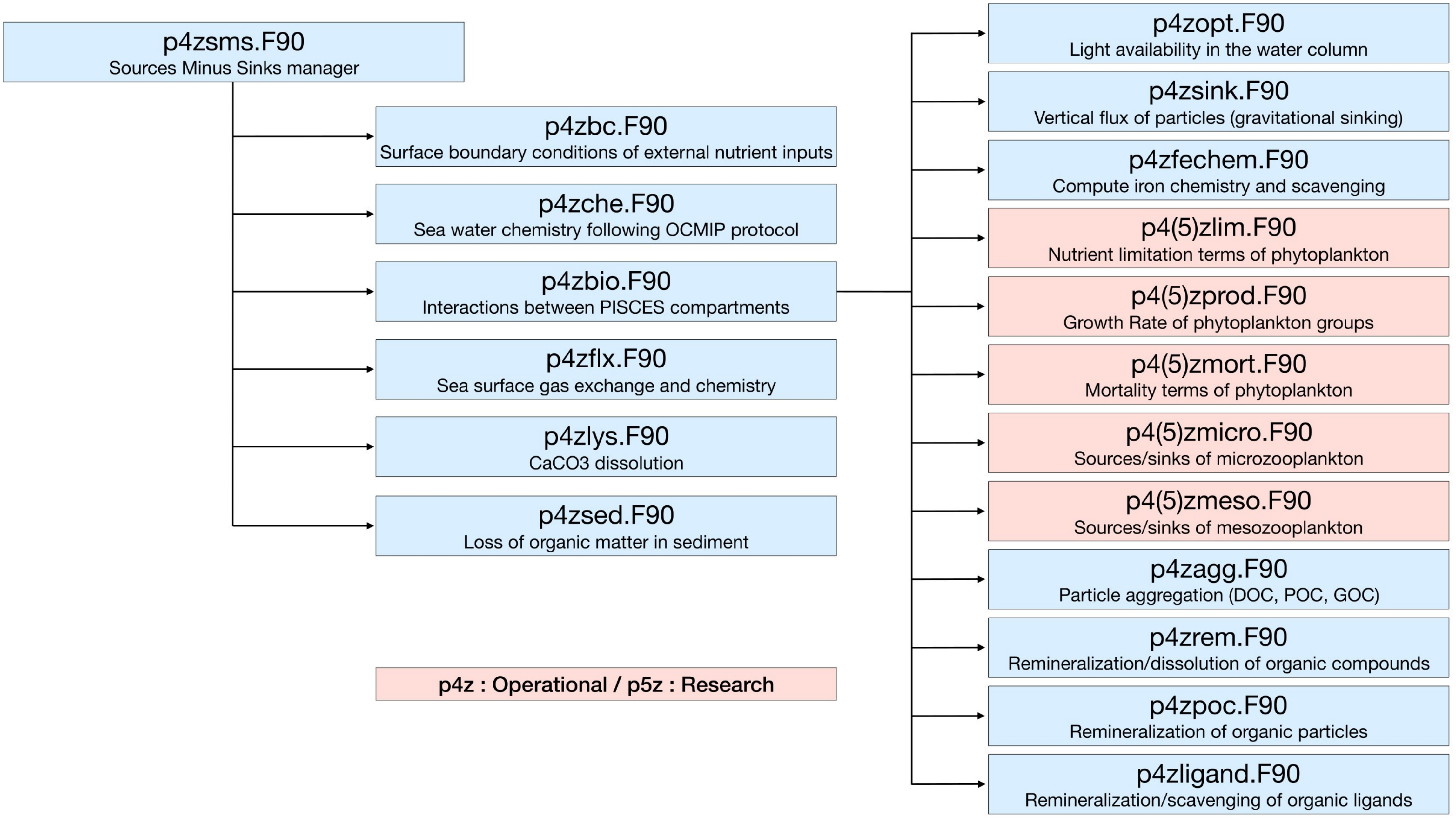
Can be used online/offline/standalone



Code structure - Main



Code structure - SMS

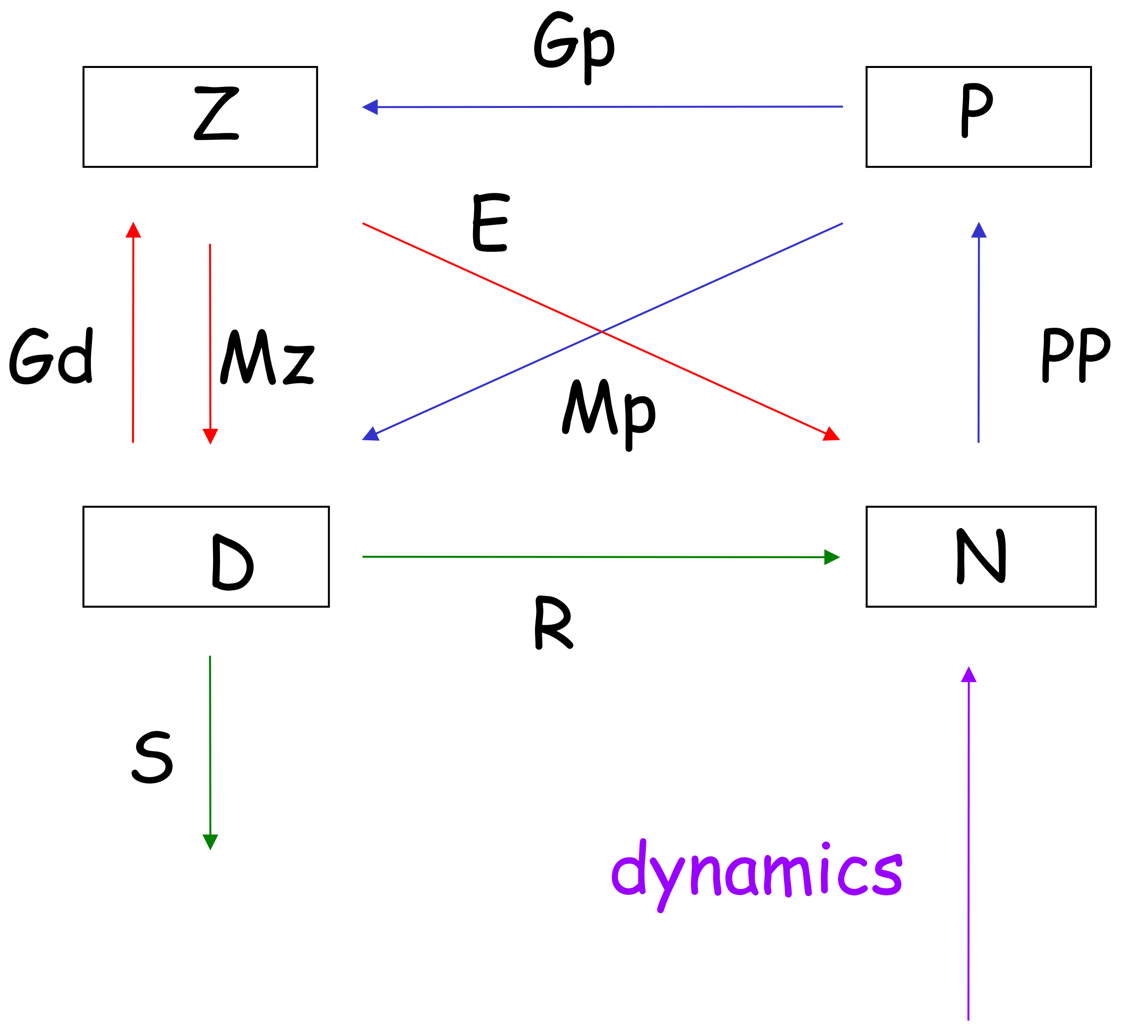


Modeling platforms

Parameterizing marine biogeochemistry

Olivier Aumont

LOCEAN



Conservation:

S(P)+S(Z)+S(D)+S(N)- P(P)-P(Z)-P(D)-P(N)= 0

(1) Phyto

S(P)=PP
P(P)=Gp+Mp

(2) Zoo

S(Z)=Gp+Gd
P(Z)=Mz+E

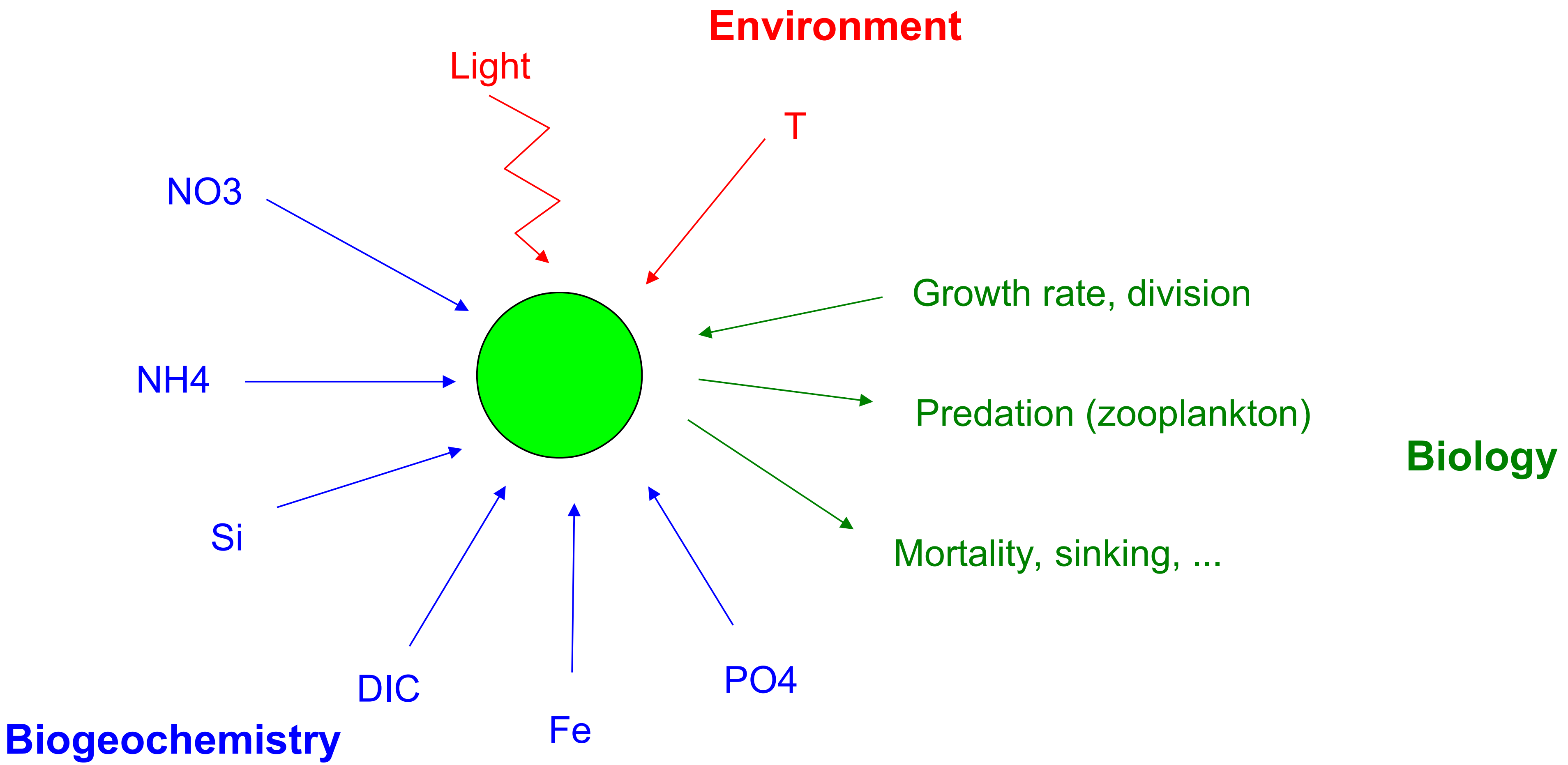
(3) Detritus

S(D)=Mz+Mp
P(D)=Gd+S+R

(4) Nutrients

S(N)=R+E
P(N)=PP

Colimitations: Background



Photosynthesis, growth rate

Photosynthesis

- Photosynthesis: Process by which autrophic organism use solar energy to produce organic matter

$106CO_2 + 16\ NO_3^- + HPO_4^{2-} + 122H_2O + 18H^+ +$ trace elements, light --> $C_{106}H_{263}O_{110}N_{16}P + 138O_2$

- The ratio between the different chemical elements is called the Redfield ratio
- The amount of organic matter produced by the photosynthesis is called Gross Primary Production

Growth rate

- Growth refers to the increase in biomass (in C units generally)

$$\mu = P^B \frac{Chl}{C} - r$$

Where r is the respiration rate

- From the growth rate, net primary production can be defined as the accumulation of organic matter

Growth rate: General background

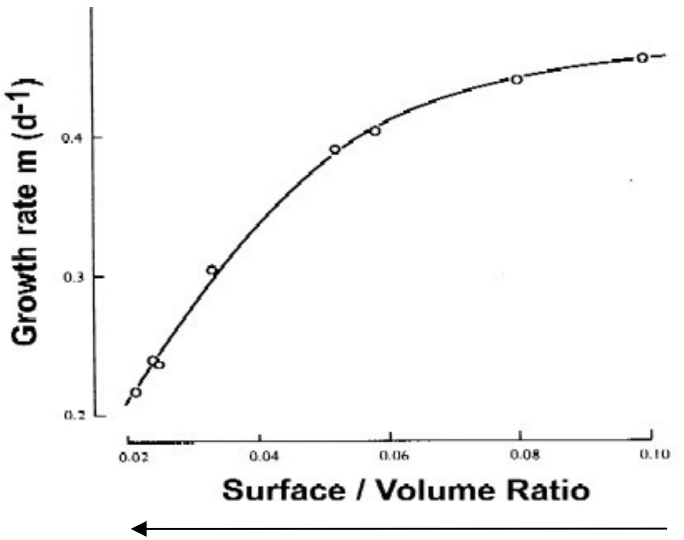
- Growth rate is a function of the environmental and biogeochemical conditions and of the species

- It can be expressed as follows:

$$\mu = g f(T)\, g(E)\, L(N)$$

temperature Light Nutrients

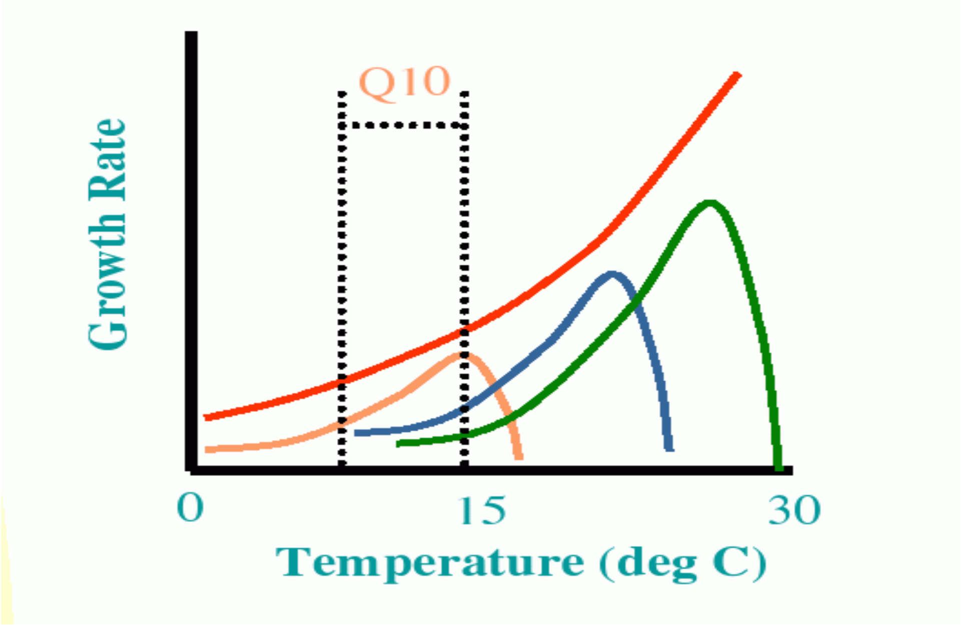
- The specific growth rate varies with species. In general, it tends to decrease with size.



size

Growth rate: Temperature

- Growth rate increases with temperature until a critical level



- A relationship for the enveloppe has been proposed for the first time by Eppley (1972) :

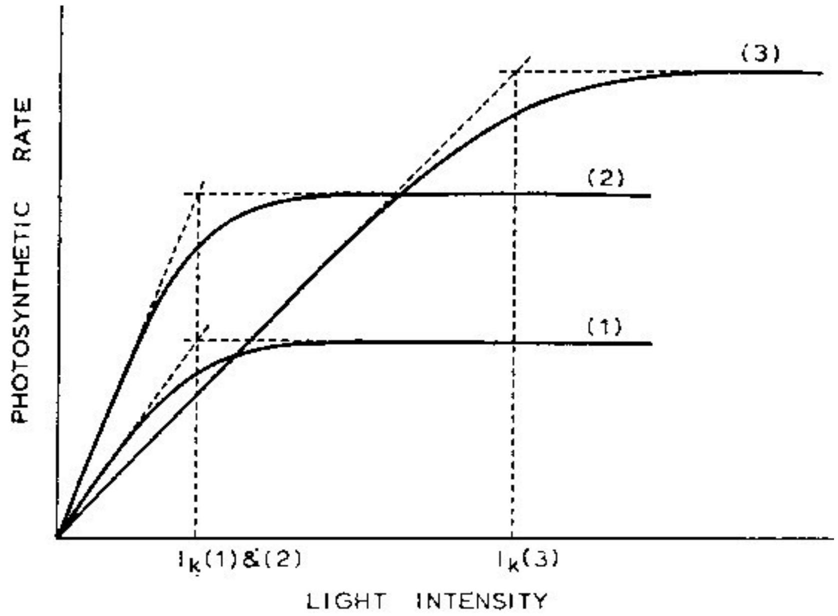
$$f(T) = 1.066^T$$

Growth rate increases by 1.9 times every 10°C (Q10).

- Since, several alternative expressions have been proposed, but Eppley's relationship remains the most commonly used one.

Growth rate: Light

- Growth rate increases with light until a maximum value at which it saturates or even decreases



α initial slope
μ_{max} maximum growth rate
$I_k = \mu_{max} / \alpha$

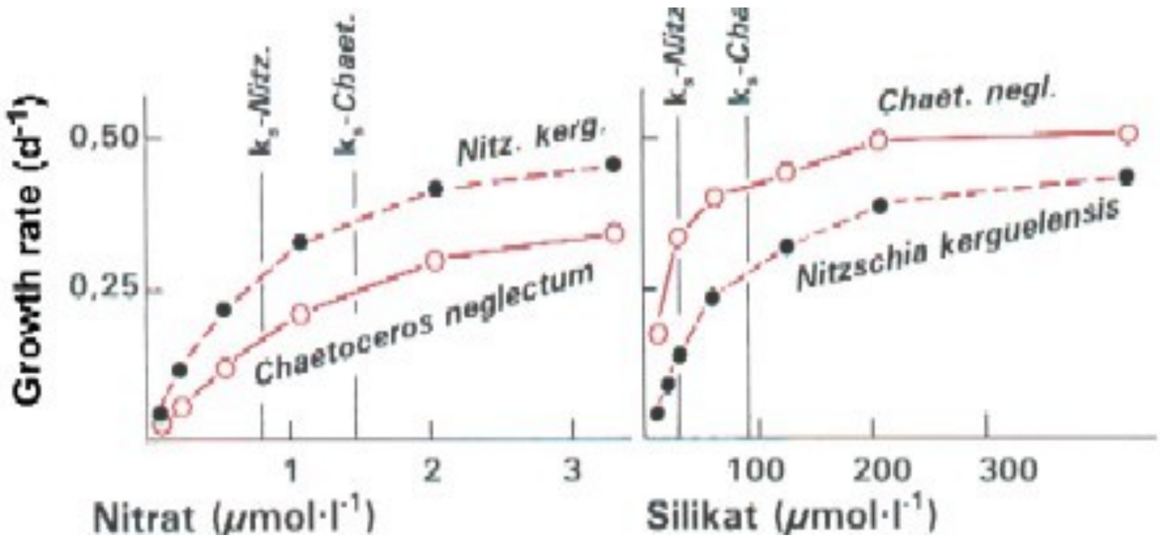
$$\mu = \mu_{max}\left(1 - \exp\left(\frac{-I}{I_k}\right)\right)$$

- I_k is extremely variable between species. For instance, in cyanobacteria, synechococcus spp have a high I_k whereas some prochlorococcus spp have very low I_k.

- I_k strongly varies with the average received light (photoacclimation)

Growth rate: Monod model (1942)

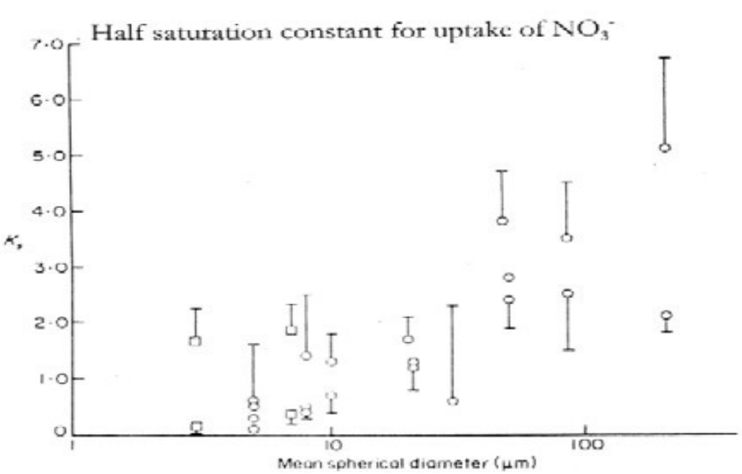
- Monod model = growth rate is a function of the external concentration of nutrients



$$\mu = \mu_{max} \frac{N}{K_N + N}$$

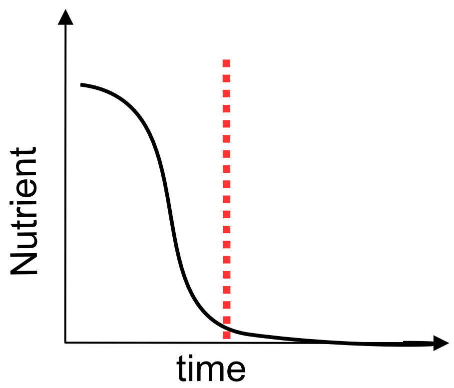
K_N : half-saturation constant

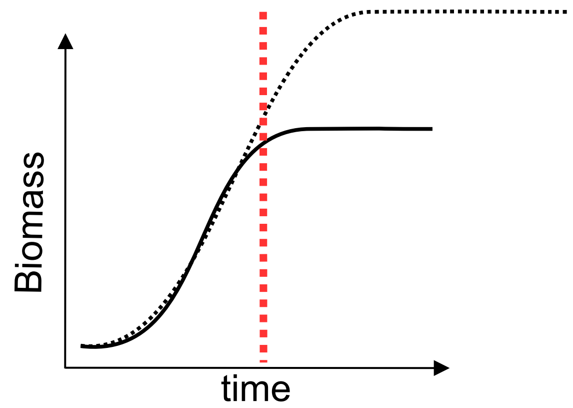
- K_N increases with size because the S/V ratio decreases. Furthermore, as a result of acclimation processes, K_N decreases with the nutrient concentration



Limitation of the Monod model

- Measured & works best under relatively steady nutrients (or slow change)
- Growth stops when nutrients fall to 0

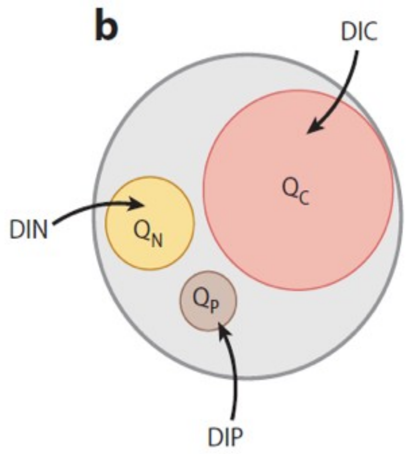




- Assumes constant stoichiometry
- No luxury uptake of transiently elevated nutrients
- Can be difficult to estimate $\boldsymbol{K_N}$

Growth rate: Droop model (1968)

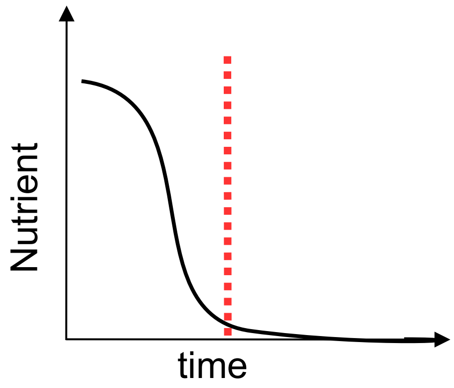
- Droop model = growth rate is a function of the internal pool of nutrients (quota)
- The internal pool (quota) is a function of the external concentrations of N

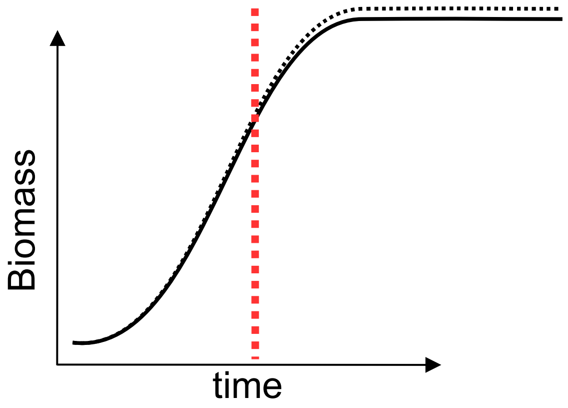


$$\text{growth} = \mu_\infty \left(1 - \frac{Q_{\min}}{Q} \right)$$

$$V = V_{max} \frac{N}{K_N + N}$$

- Generally works better, more physiologically grounded, more general





Growth rate: multi-nutrients

- Currently, there is no clear consensus on the law which drives growth rate with multiple nutrients. 2 different laws are generally used:
  - The multiplicative law:

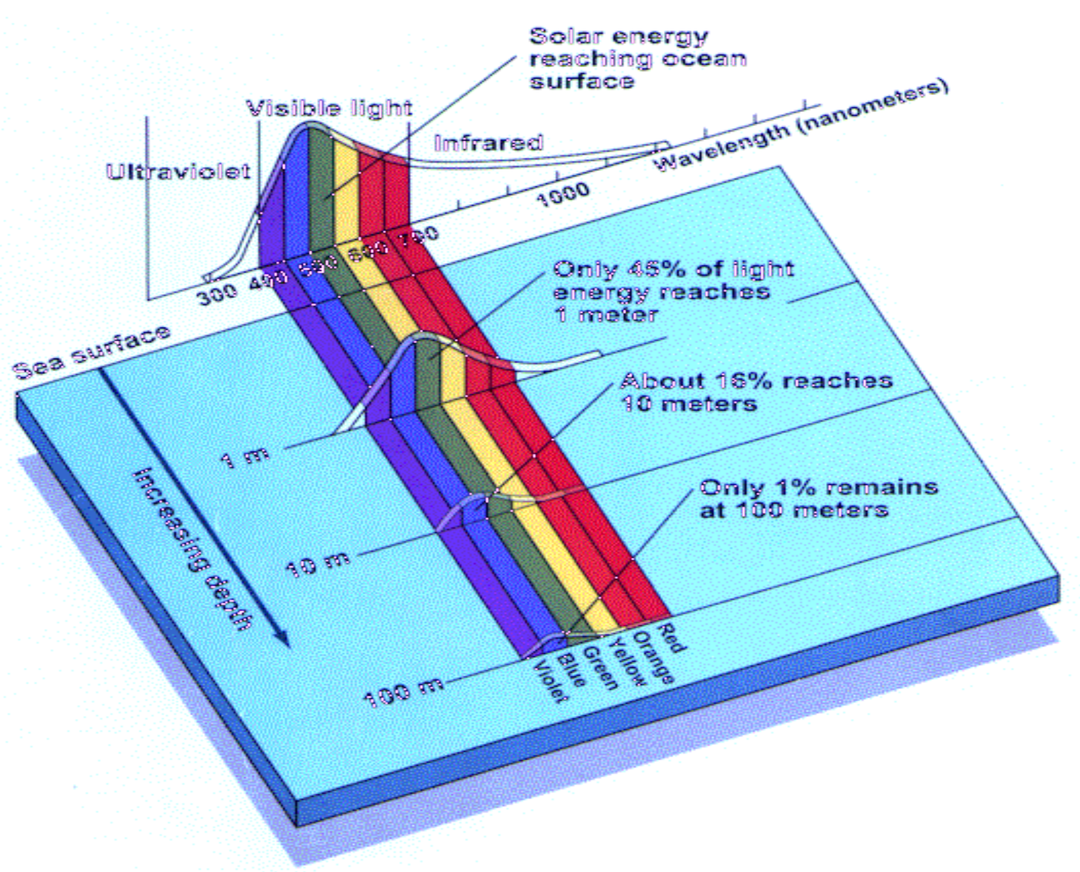
$$\mu = \mu_{max} \frac{N_1}{K_{N_1} + N_1} \frac{N_2}{K_{N_2} + N_2} * \ldots$$

  - The law of the minimum or Liebig's law (1840) :

$$\mu = \mu_{max} \min\left(\frac{N_1}{K_{N_1} + N_1}, \frac{N_2}{K_{N_2} + N_2}, \ldots\right)$$

- Many other laws do exist but they are not commonly used.

Light in the ocean



- Light decreases with depth as (Loi de Beer): $I(z) = I(0)\,e^{-kz}$

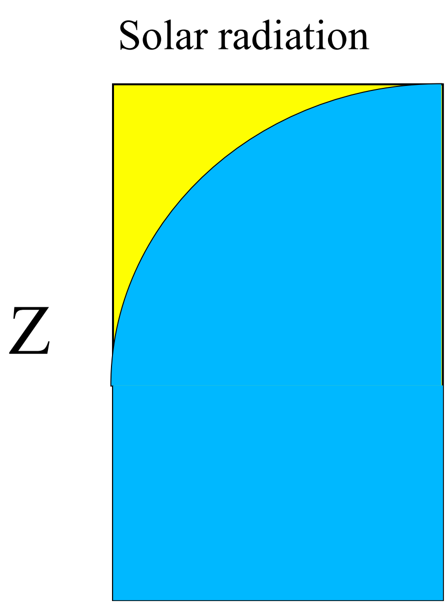
- In pure water, the attenuation length is 37m. for a chlorophyll concentation of 0.2 mg Chla/m^3, its value is about 20m.

- Blue light penetrates much deeper than red light which remains trapped in the top 10 to 20m of the ocean.

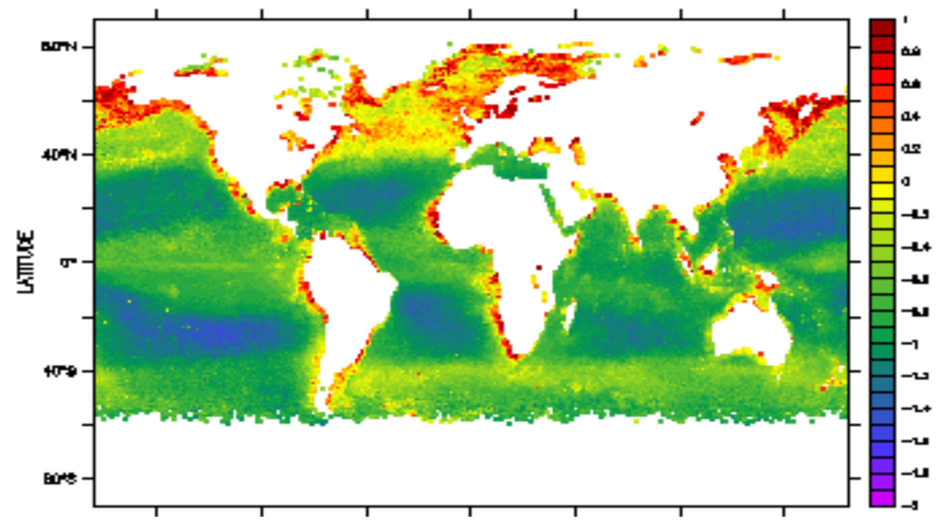
Light in the ocean

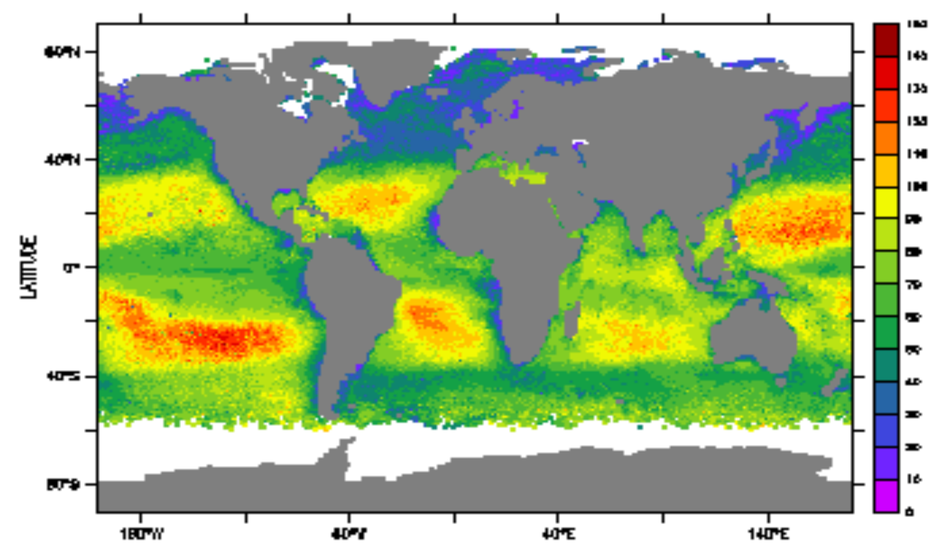
Euphotic zone

$I > 1\% \; I_o$



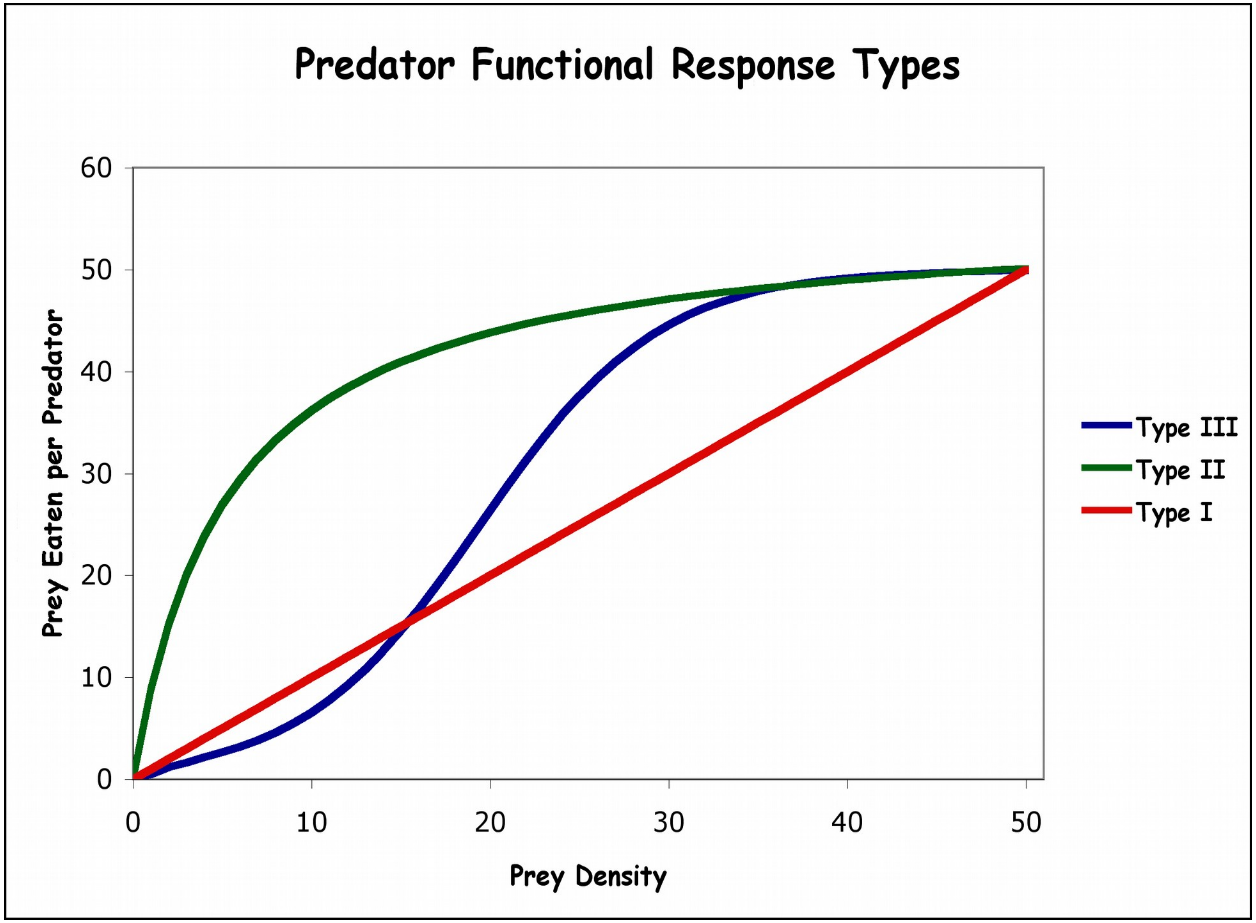
Chlorophyll





Euphotic depth

Predation by zooplankton



- Holling Type I

$$G_p = gP$$

- Holling Type II

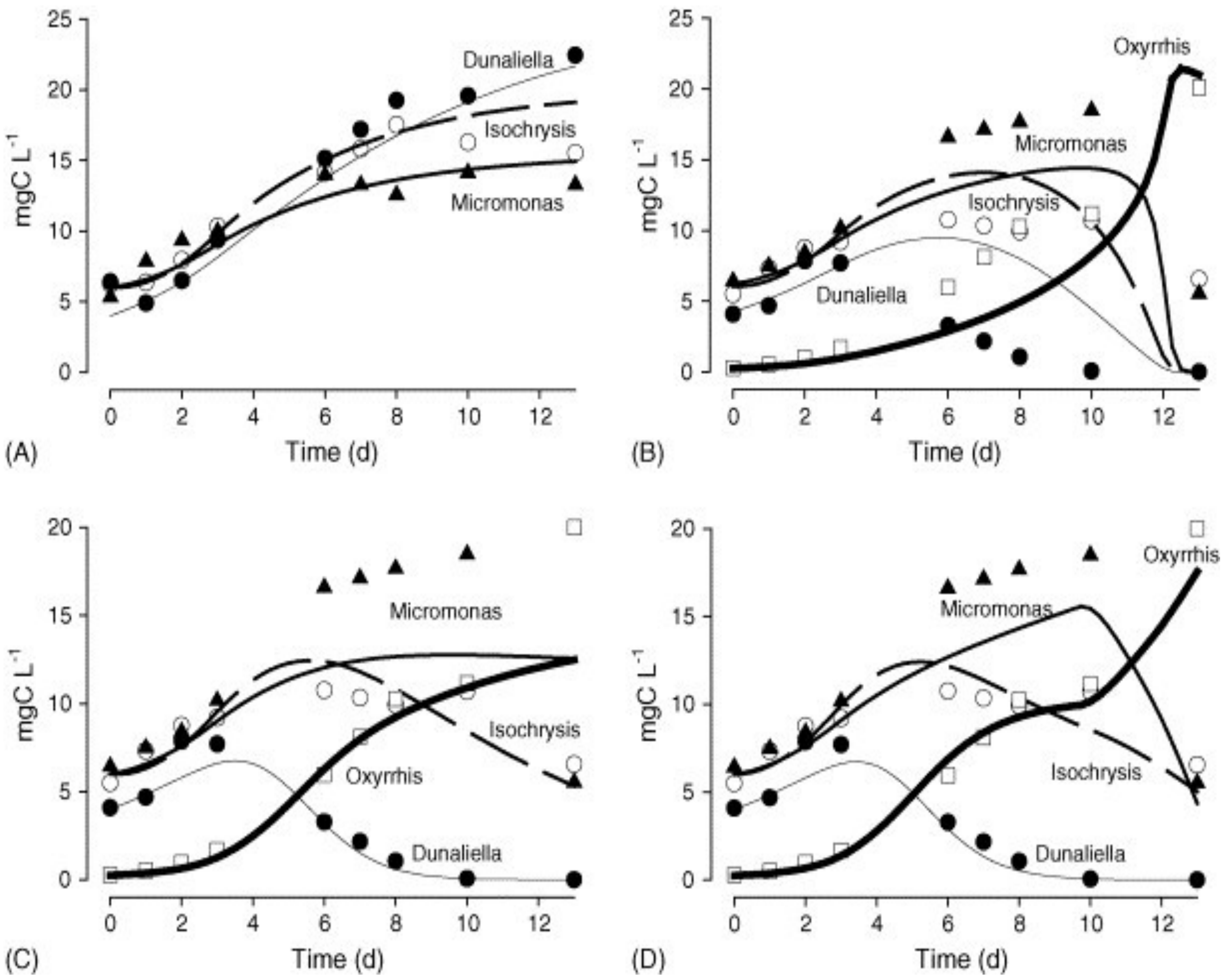
$$G_p = g\frac{P}{K_z + P}Z$$

- Holling Type III

$$G_p = g\frac{P^2}{K_z^2 + P^2}Z$$

Predation on several preys

Very complex to properly model!



Mitra et al., 2006

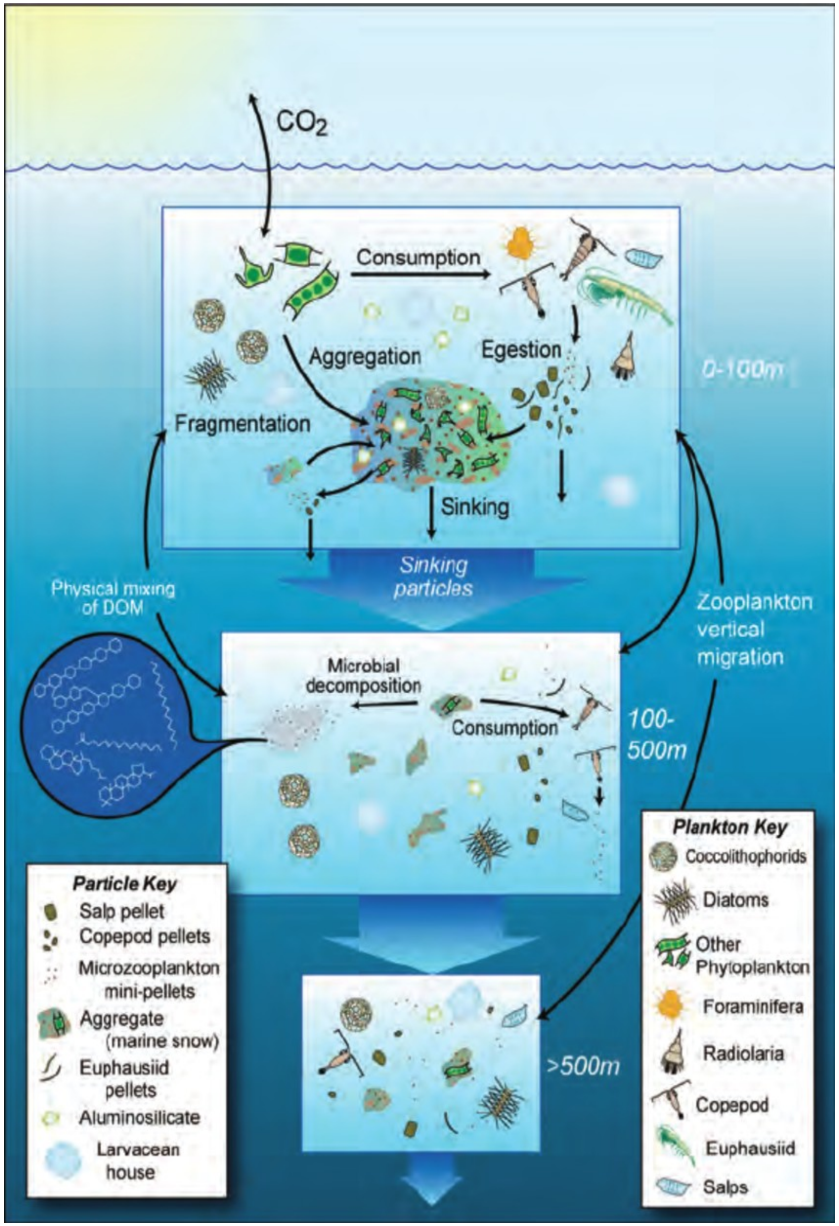
Mortality in models

- Mortality in models does not necessarily represent senescence. It may model :
  - senescence
  - viral attacks
  - aggregation/sinking
  - predation by unresolved higher trophic levels

- Numerous formulations exist but the two most common expressions are:

$$M = m_p P \qquad\qquad M = m_p P^2$$

Representing particles in models



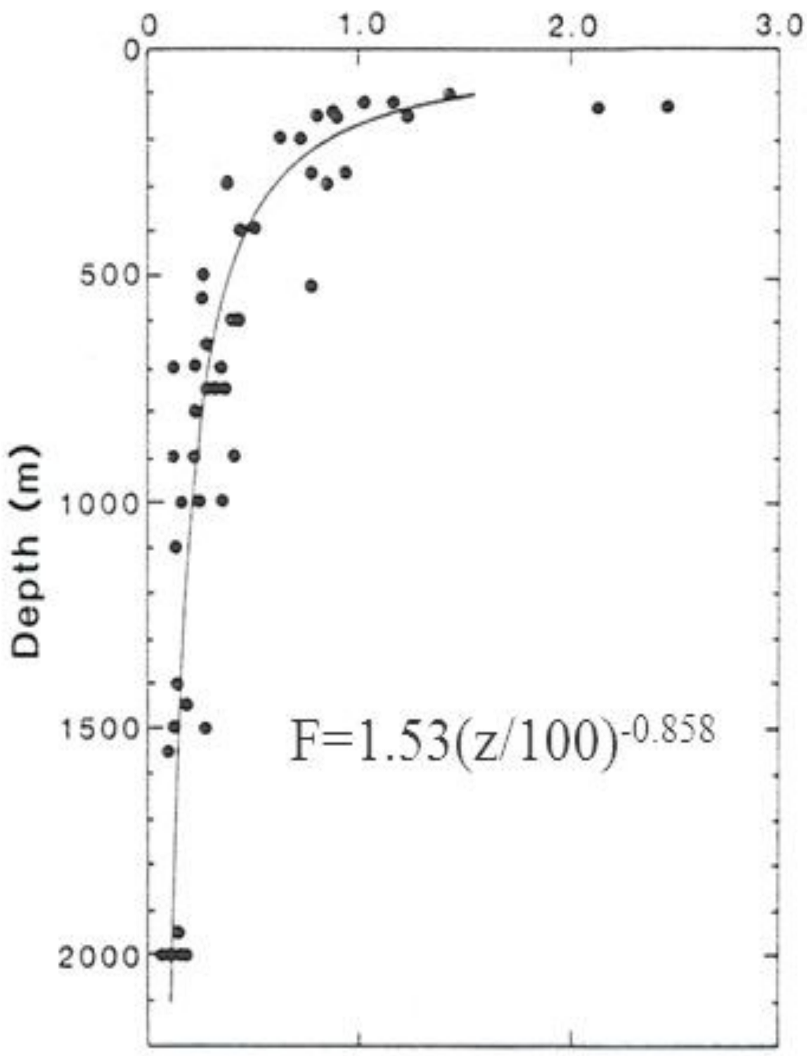
Representing particles in models: POC

- If bacterial degradation and sinking are the only active processes

$$\frac{\partial D}{\partial t} = \underbrace{-\lambda D}_{\text{Remineralization}} - \overbrace{\frac{\partial vD}{\partial z}}^{\text{Sinking}}$$

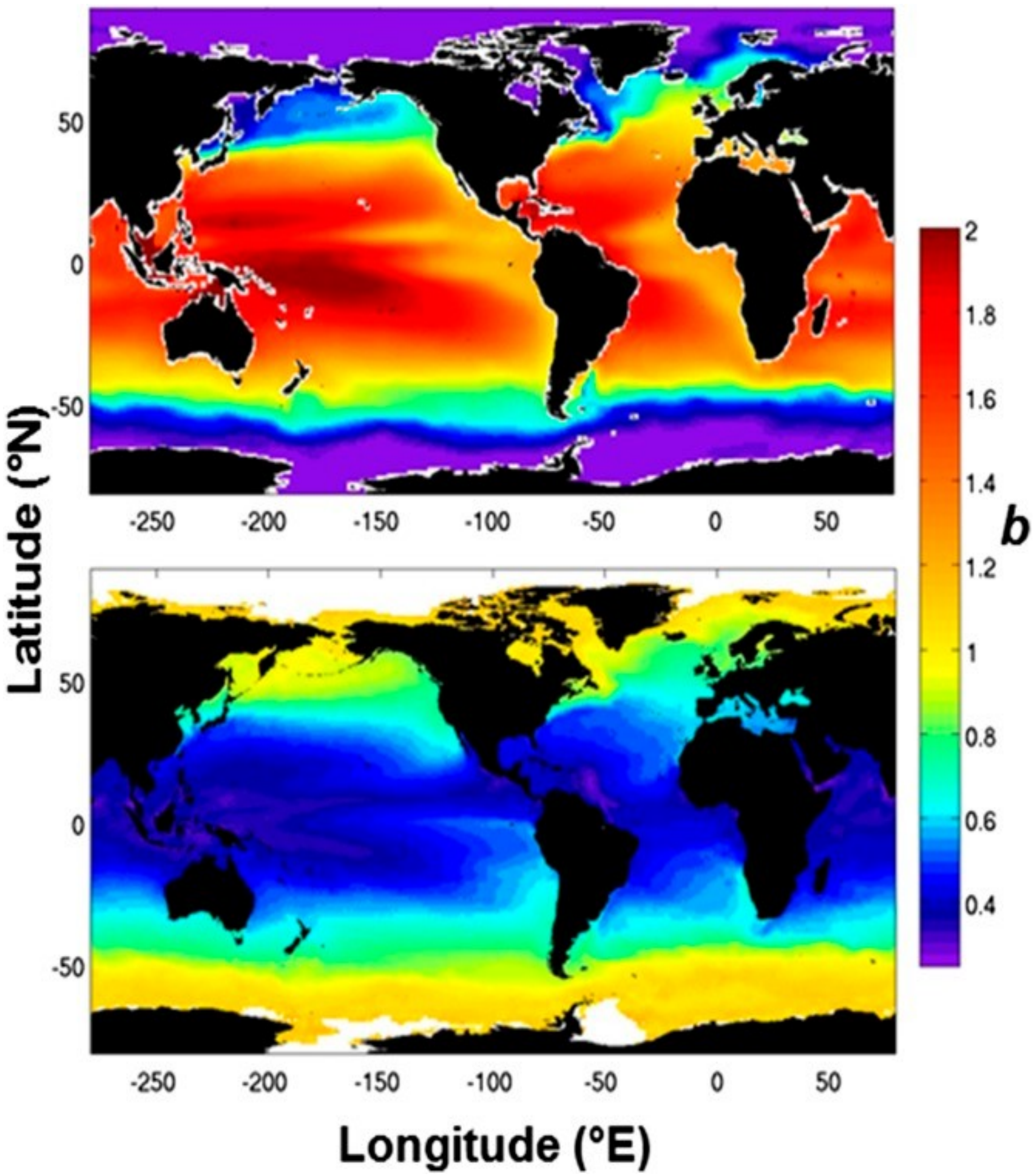
- Specific cases :
  - If v and λ are constant : $$F = vD = F(\tilde{z})\, e^{-\frac{\lambda}{v}(z-\tilde{z})}$$
  - If λ is constant and v = Az $$F = vD = F(\tilde{z})\left(\frac{z}{\tilde{z}}\right)^{(-b)}$$ where $$b = \frac{\lambda + A}{A}$$

Observed fluxes vs. modeled fluxes



Fluxes seem to be well approximated by a power law function

But far from being that simple



From Marsay et al. (2015)

A simple set of 4 equations

$$(S-P)(P)=\mu_{max} L_{NUT} L_I P - g\frac{pP}{K_z+pP+(1-p)D} Z - m_p P$$

$$(S-P)(Z)=ga\frac{pP+(1-p)D}{K_z+pP+(1-p)D} Z - m_z Z^2$$

$$(S-P)(D)=g(1-a)\frac{pP+(1-p)D}{K_z+pP+(1-p)D} Z + m_z Z^2 + m_p P$$

$$-g\frac{(1-p)D}{K_z+pP+(1-p)D} Z - v\frac{\partial}{\partial z} D - t_d D$$

$$(S-P)(N)=-m_{\max} L_{NUT} L_I P + t_d D$$

Non-linear equations

Parameters needed to constrain the model

$\mu_{\max}, K_N, K_I, m_p$ phytoplancton

g, K_z, p, a, m_z zooplancton

v, t_d détritus

Difficult estimation

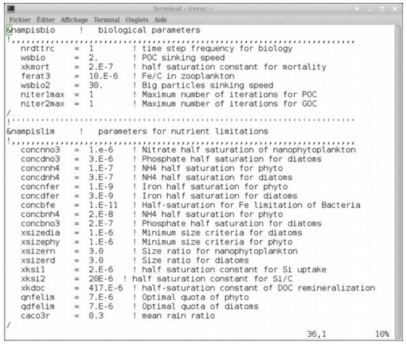
- lab experiments, species dependant, equilibrium state
- large variability: non constant
- agregate many processeses
- inverse methods (data assimilation)
- empirical estimation

Evaluation of a model

Experiments in controled environments

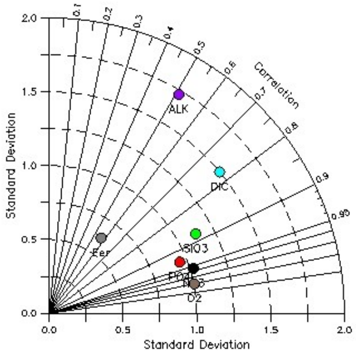
Observations

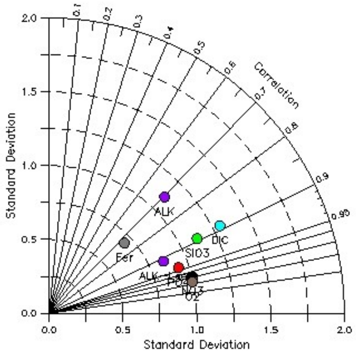
Tuning the models



```
&nampisbio     !   biological parameters
!,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
   nrdttrc    =  1        ! time step frequency for biology
   wsbio      =  2.       ! POC sinking speed
   xkmort     =  2.E-7    ! half saturation constant for mortality
   ferat3     =  10.E-6   ! Fe/C in zooplankton
   wsbio2     =  30.      ! Big particles sinking speed
   niter1max  =  1        ! Maximum number of iterations for POC
   niter2max  =  1        ! Maximum number of iterations for GOC
/
!''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
&nampislim     !   parameters for nutrient limitations
!,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,
   concnno3   =  1.e-6    ! Nitrate half saturation of nanophytoplankton
   concdno3   =  3.E-6    ! Phosphate half saturation for diatoms
   concnnh4   =  1.E-7    ! NH4 half saturation for phyto
   concdnh4   =  3.E-7    ! NH4 half saturation for diatoms
   concnfer   =  1.E-9    ! Iron half saturation for phyto
   concdfer   =  3.E-9    ! Iron half saturation for diatoms
   concbfe    =  1.E-11   ! Half-saturation for Fe limitation of Bacteria
   concbnh4   =  2.E-8    ! NH4 half saturation for phyto
   concbno3   =  2.E-7    ! Phosphate half saturation for diatoms
   xsizedia   =  1.E-6    ! Minimum size criteria for diatoms
   xsizephy   =  1.E-6    ! Minimum size criteria for phyto
   xsizern    =  3.0      ! Size ratio for nanophytoplankton
   xsizerd    =  3.0      ! Size ratio for diatoms
   xksi1      =  2.E-6    ! half saturation constant for Si uptake
   xksi2      =  20E-6  ! half saturation constant for Si/C
   xkdoc      =  417.E-6  ! half-saturation constant of DOC remineralization
   qnfelim    =  7.E-6    ! Optimal quota of phyto
   qdfelim    =  7.E-6    ! Optimal quota of diatoms
   caco3r     =  0.3      ! mean rain ratio
/
                                                        36,1          10%
```

10, 20, 100x, ...



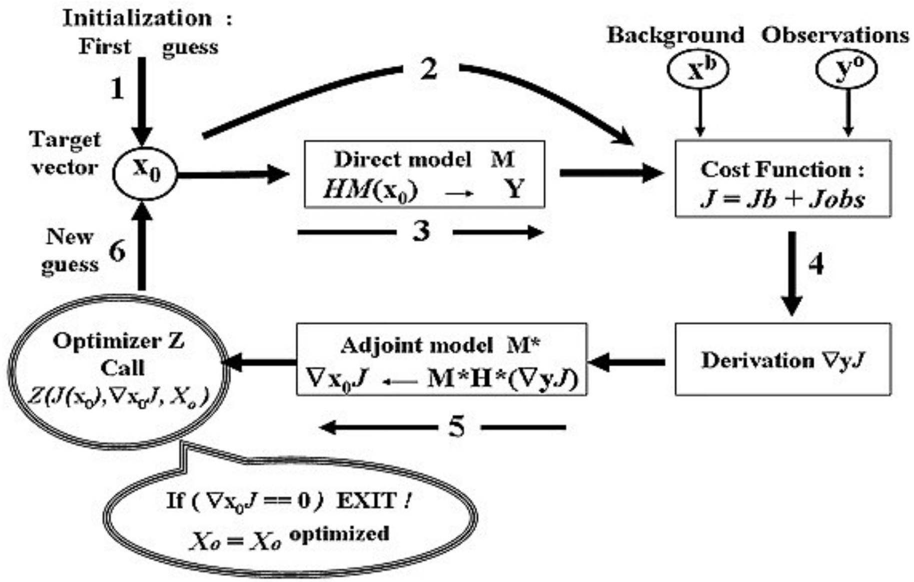


- Can be very painful
- The more complex the model is, the more difficult it is

We learn a lot on the model dynamics/behavior

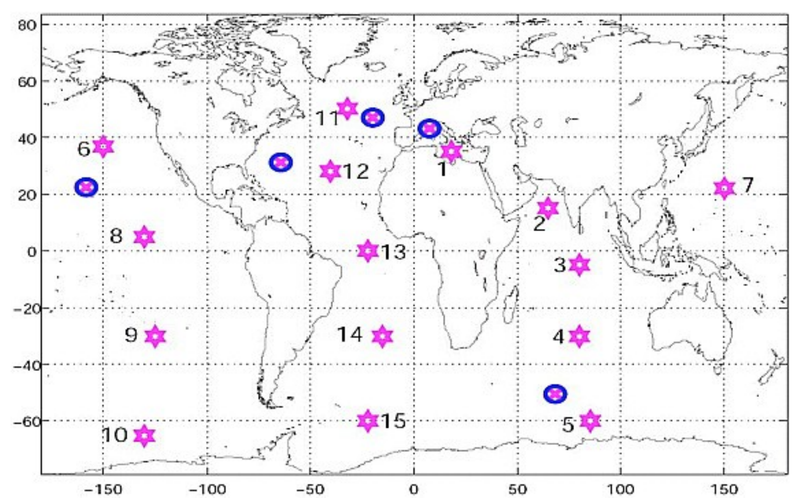
Optimizing the parameters : Assimilation

- Variational assimilation



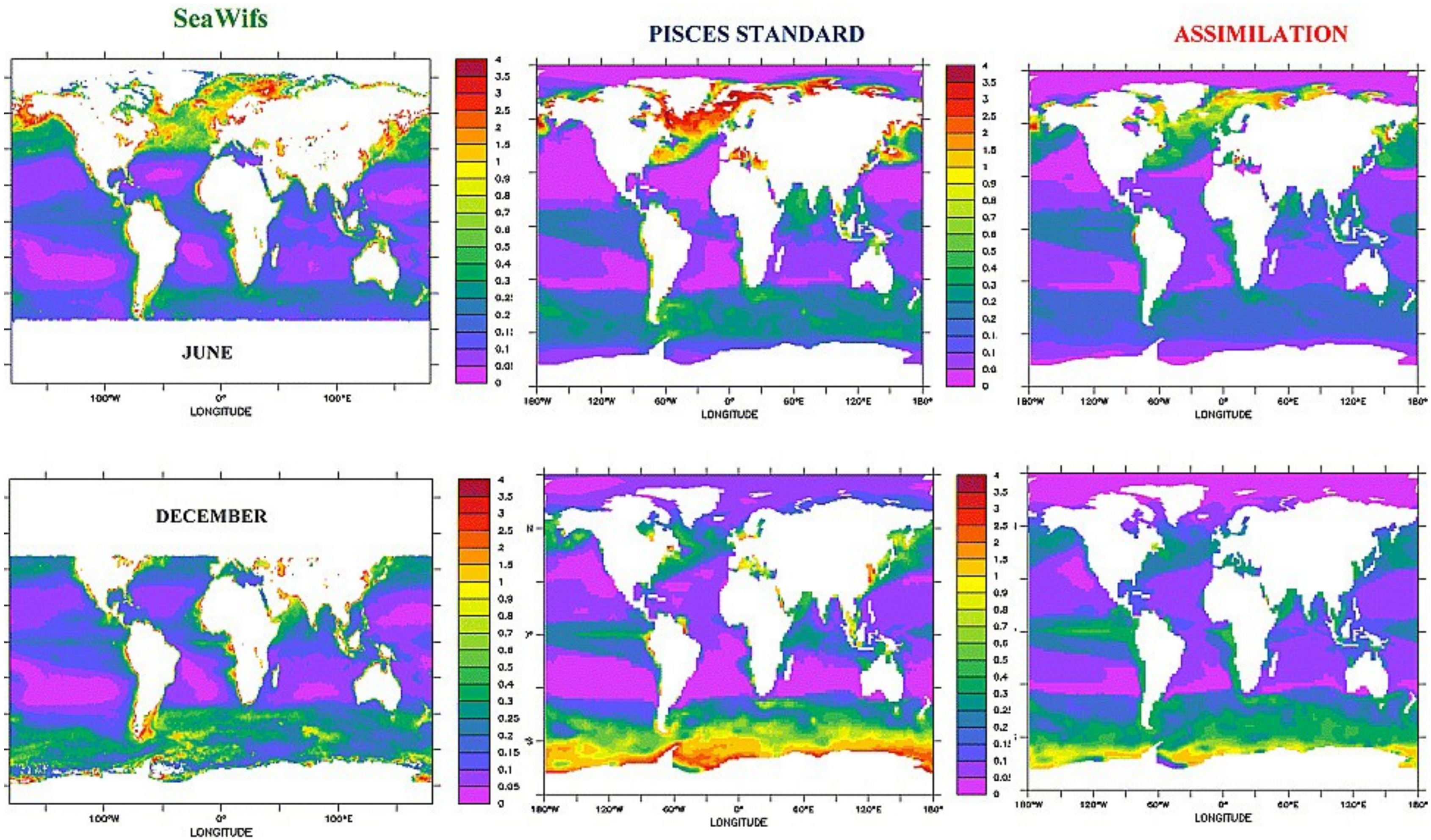
- Example: Simultaneous assimilation at 5 1-D stations: Chla, NO3, POC et Si

45 optimized parameters



Kane et al., 2011

Optimizing parameters



Kane et al., 2011

- Can be difficult (not the universal cure) !
  - Are stations representative of the system?
  - What should be done with non assimilated variables?
  - Some parameters may not be well constrained by available data

Models Intercomparison Projects (MIPs)

Motivation of these exercises

- Evaluate and intercompare the participating models
- Identify the converging and diverging behaviors and stimulate the model developments
- Estimate the uncertainties, for instance in projections

Ocean biogeochemistry: 1st exercise started in 1995

- 4 participating groups : IPSL, GFDL, MPIM, Hadley

Since, many projects have been organized:

- Carbon cycle (ocean models only) : OCMIP-2, OCMIP-3, OMIP
- Iron cycle : FeMIP
- Carbon cycle (Earth System Models) : CMIP, C4MIP
- Marine ecosystems : FISHMIP