Modelling Autotrophic Growth

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General topic : effects of light and nutrient (nitrogen) interactions on photosynthesis efficiency and production

More precisely : In deep mixed-layers, phytoplankton can experience "extended" light limitation (i.e. longer than one diel cycle)

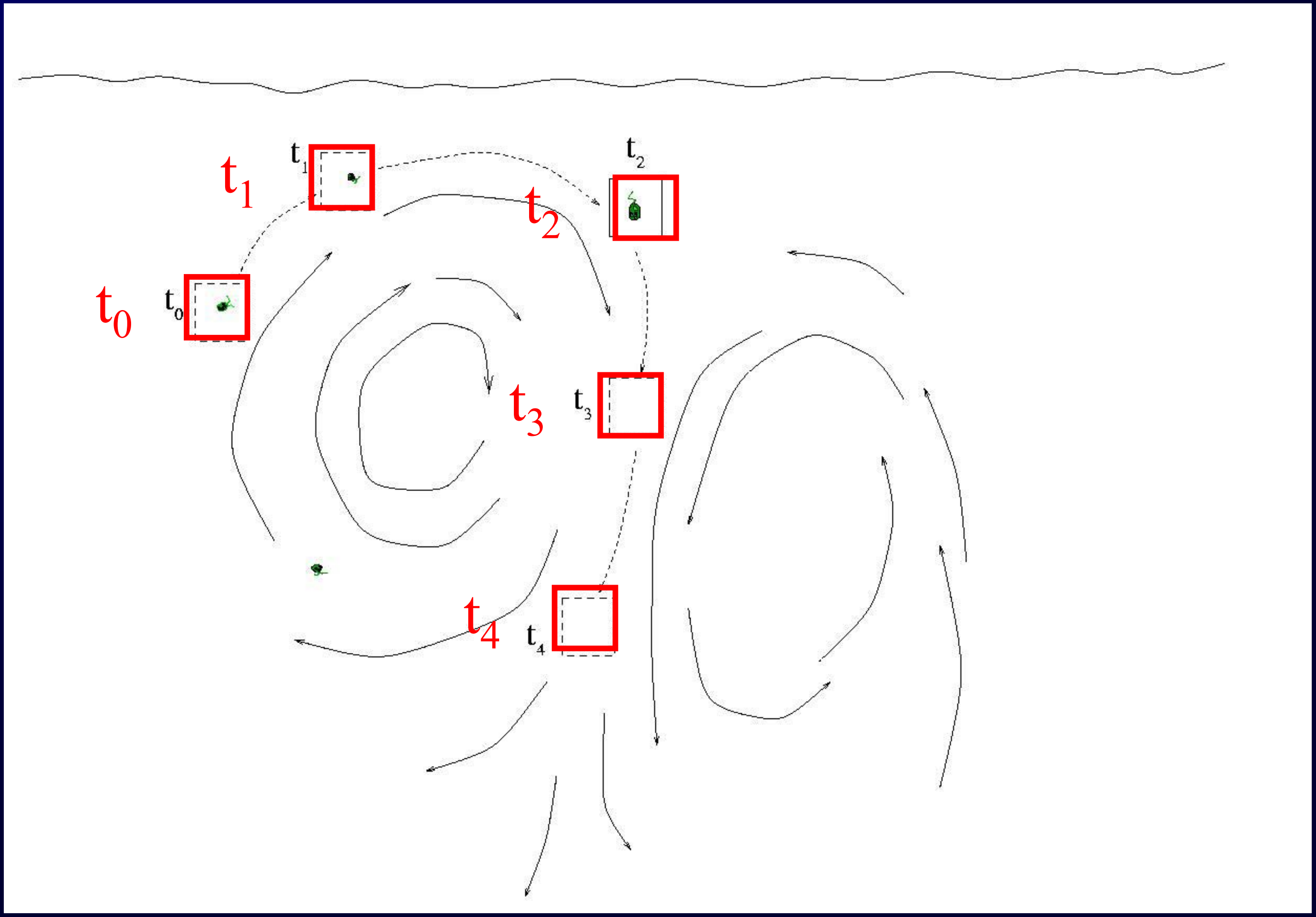
Question: How are cell division, nutrient uptake and carbon fixation affected in such conditions?

Addressing these questions in the laboratory is not easy because of the dynamical aspect of the study.

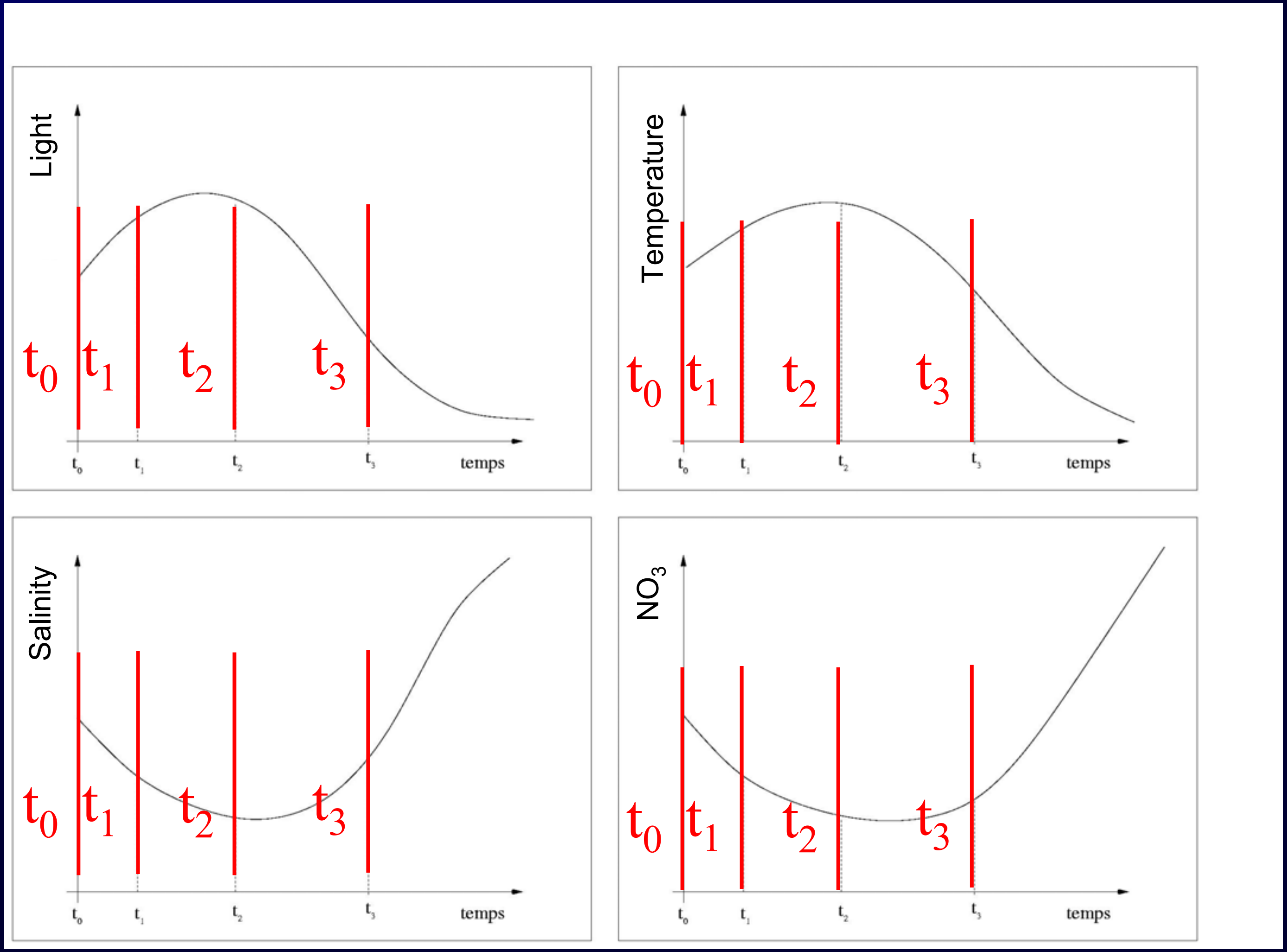
From a phenomenological point of view, one should try to understand the acclimation of a typical phytoplanktonic cell evolving in a deep mixed-layer.

- Implicitly one supposes that such a cell has a Lagrangian trajectory which can be characterized by dynamic light (and nitrogen) conditions.
- These parameters can be now reproduced within time-controlled laboratory experiments.

Lagrangian trajectory of a phytoplankton cell in the water column



How a phytoplanktonic cell sees its environment



But :

it is very difficult defining from field hydrodynamic observations or models a particular Lagrangian trajectory that could be "representative" of the deep mixed-layer dynamics.

To conclude :

To reconcile the facts that :

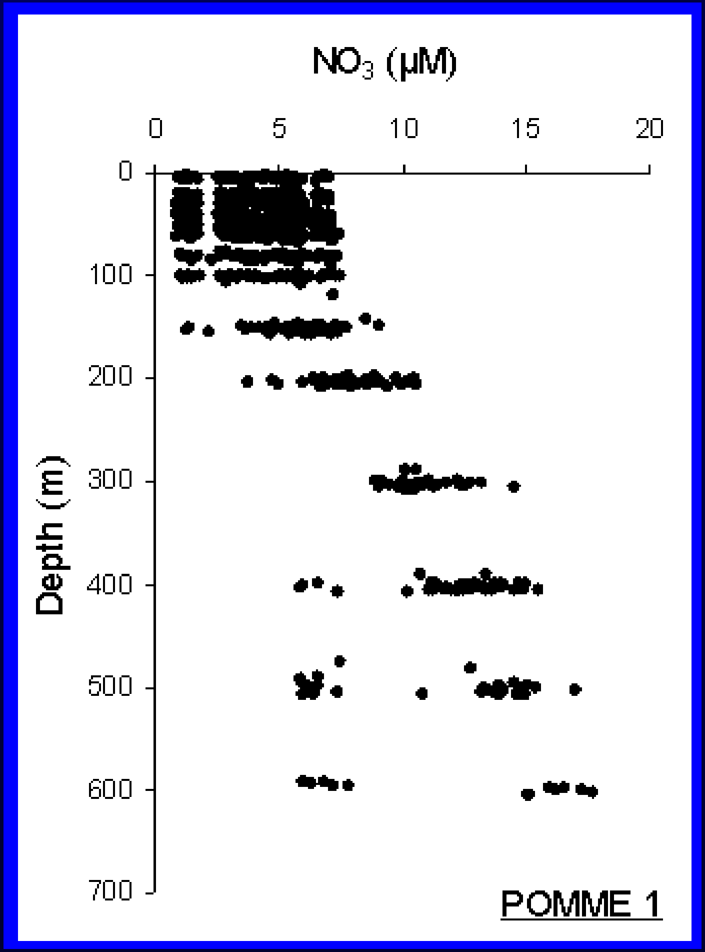
1. only limited experiments can be conducted in the laboratory and
2. there is an infinite number of Lagrangian trajectories in the water column,

we are lead to simulate "idealistic" situations in controlled experiments in order to study the effects of particular hydrodynamic regimes on photoacclimation.

Definition of the wintering autotrophic growth conditions in the mixed-layer during the POMME 1 cruise

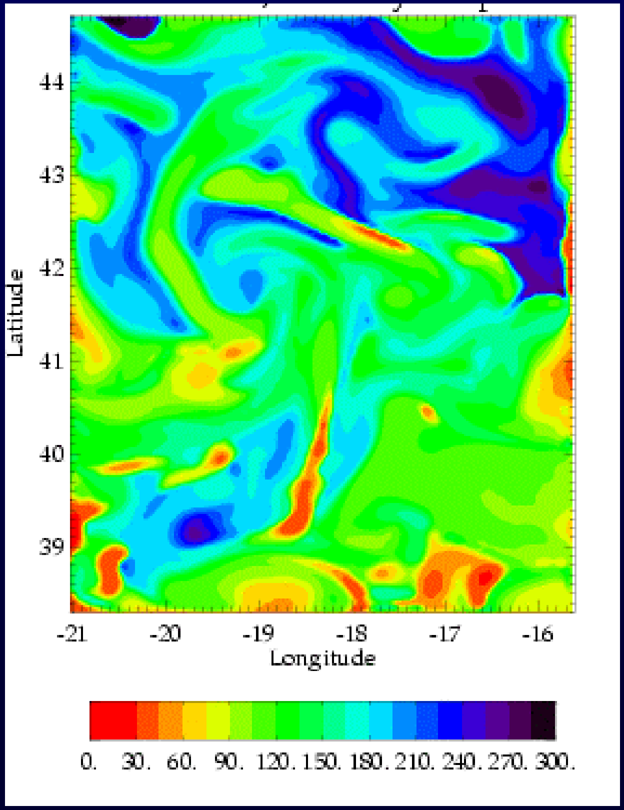
- Relatively deep mixed-layer (deeper than the euphotic zone)
- No nutrient limitation (nitrate)
- Variable temperature

Lack of NO_3 limitation



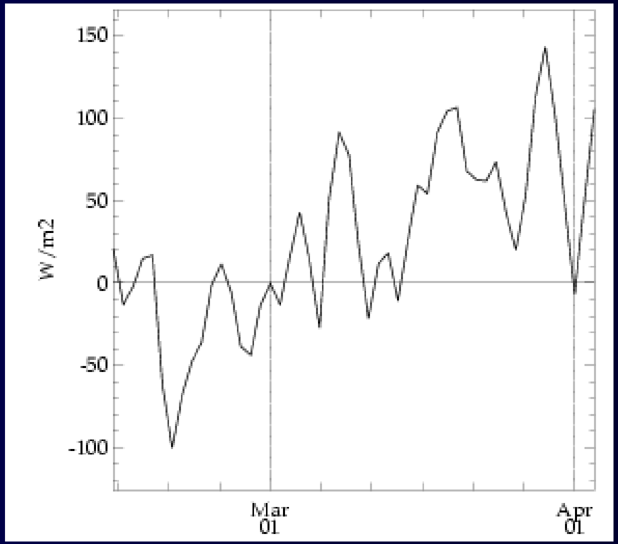
Variability of the mixed-layer depth can be inferred from the models

Regional Model POMME :
22W-16W, 38N-45N
February - March 2001

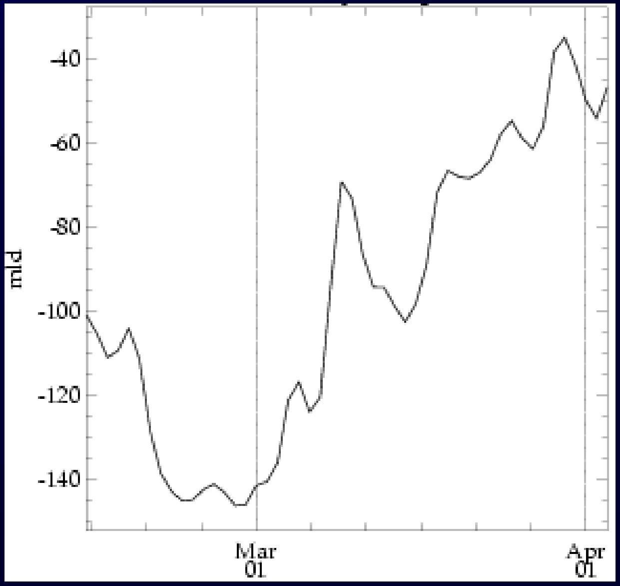


Mixed-layer depth

Net Heat Flux



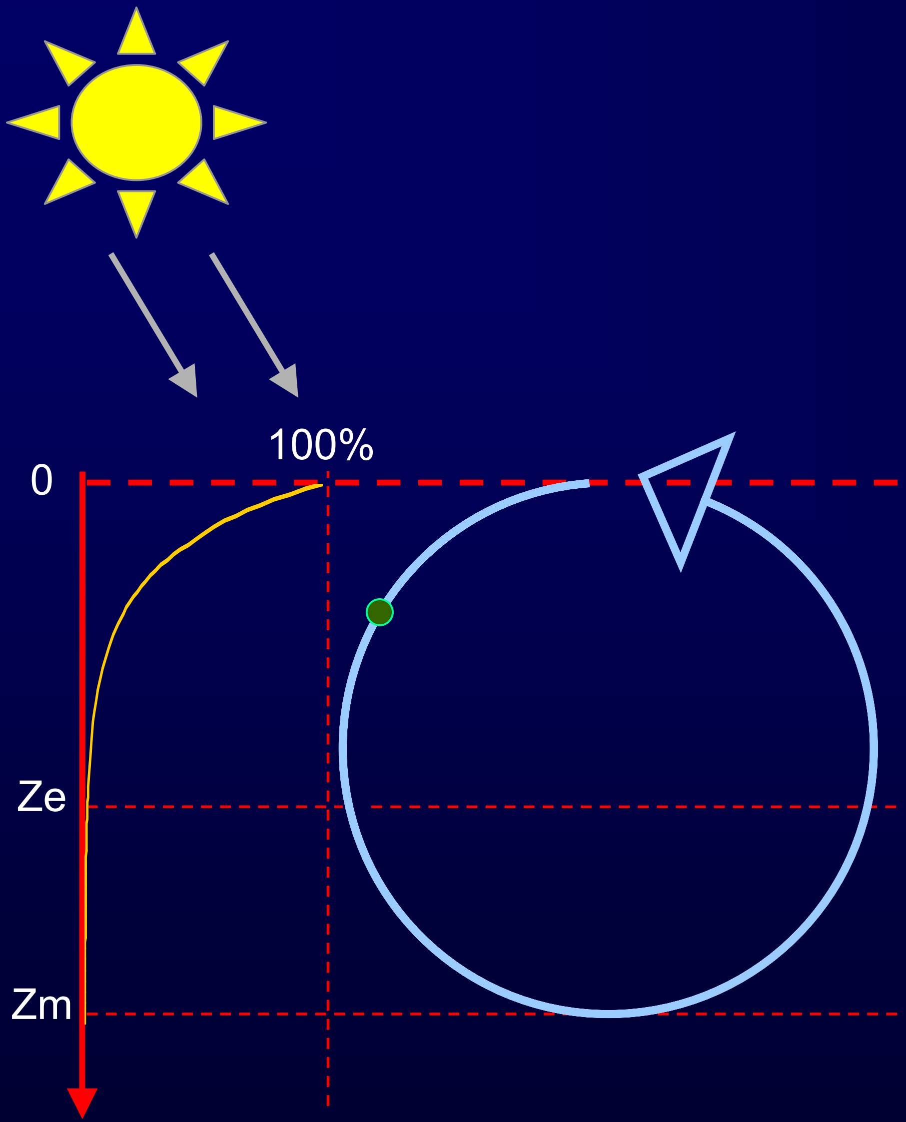
Mixed-layer depth



Light regime

- Photoperiod ≈ 13D/11L
- Sea-surface PAR at noon ≈1700 µmol quanta.m^{-2}.sec^{-1}
- Mean mixed-layer depth ≈ 144 m

- Motion of the cells in the mixed-layer ?
  - Turbulent ?
  - Convective ?

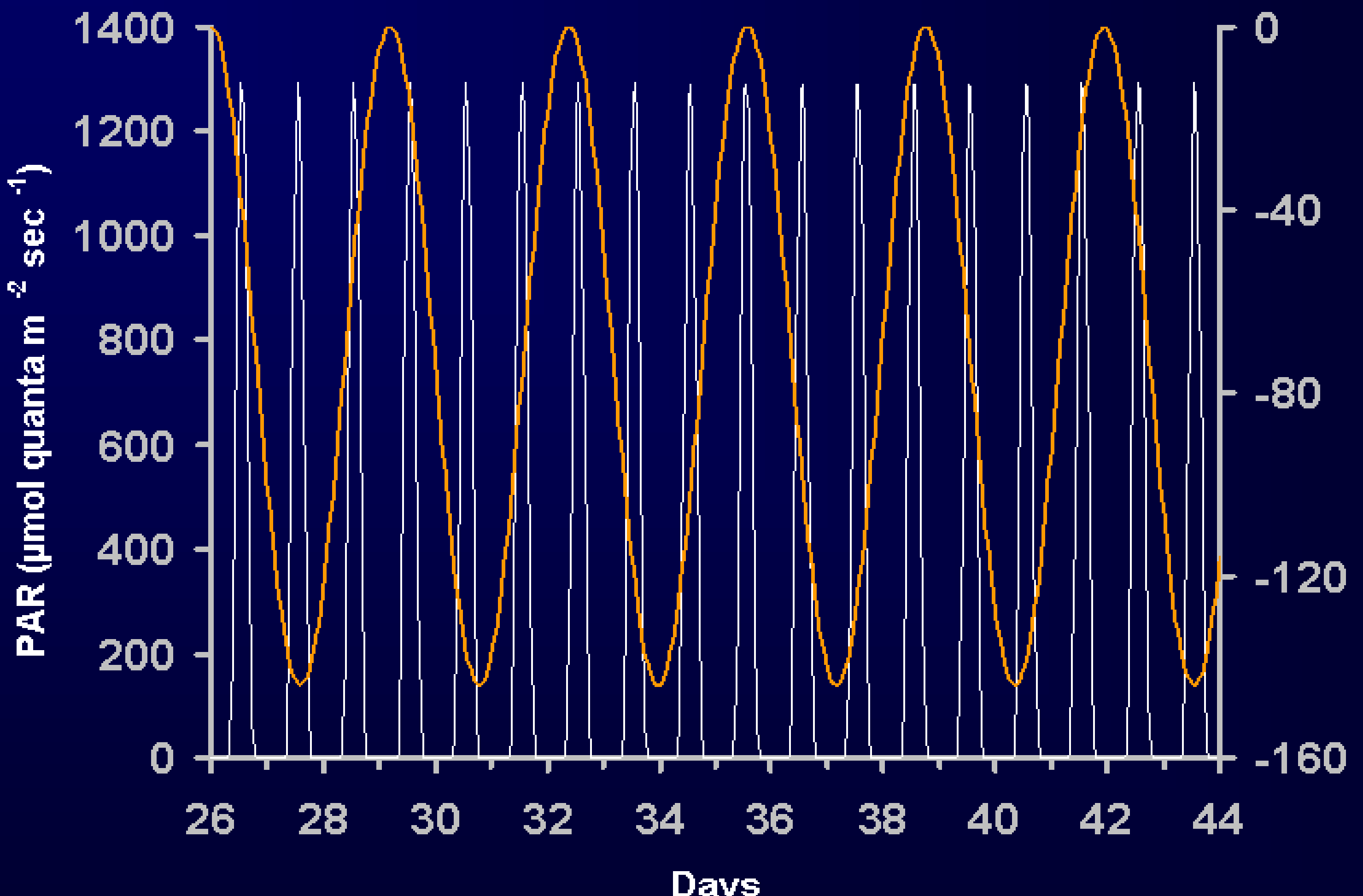


Hypotheses

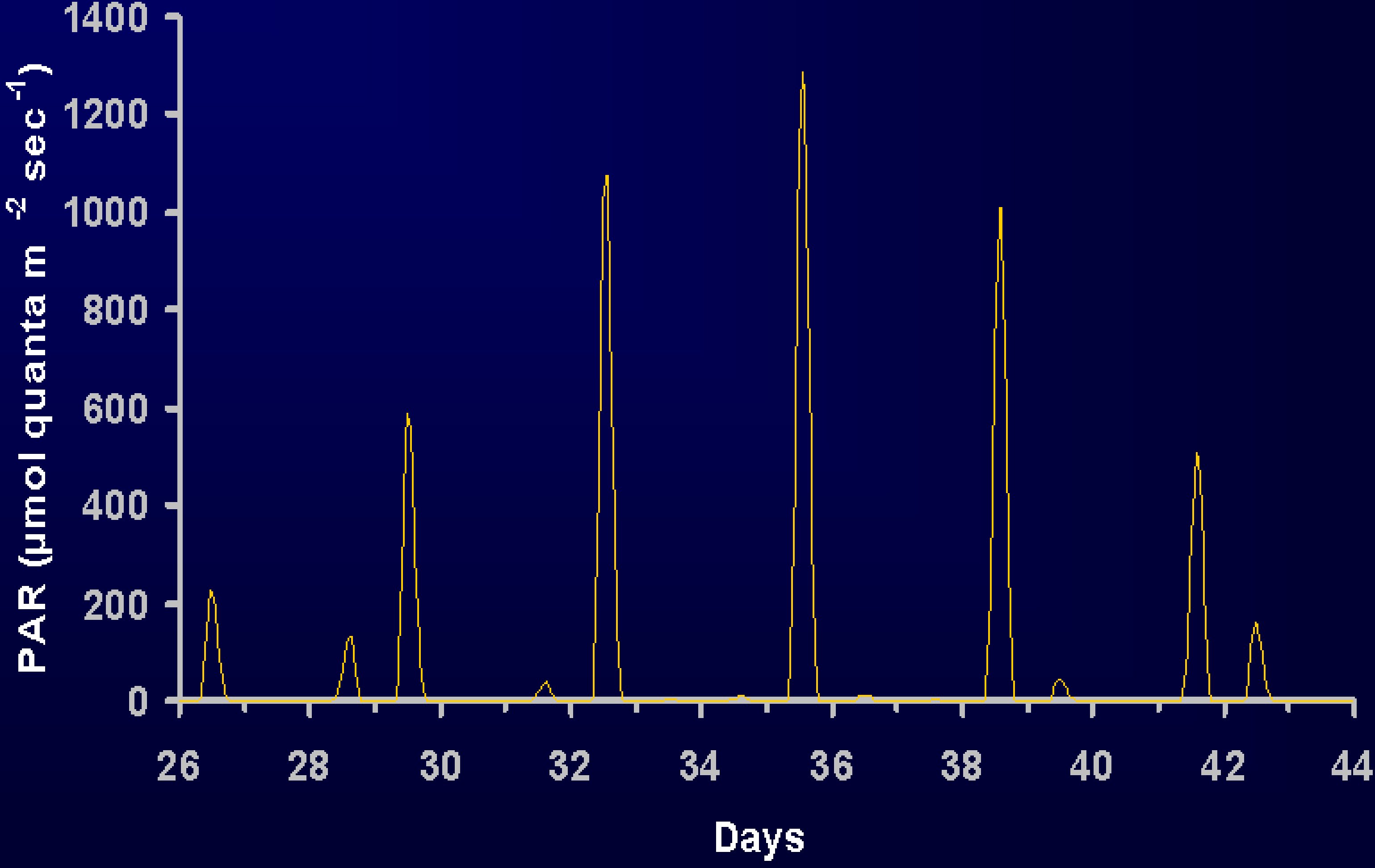
- Circular trajectory
- Vertical velocity : 100 m day^{-1}

  → 1 cycle takes 76.6 h
- Light attenuation calculated from [Chla]

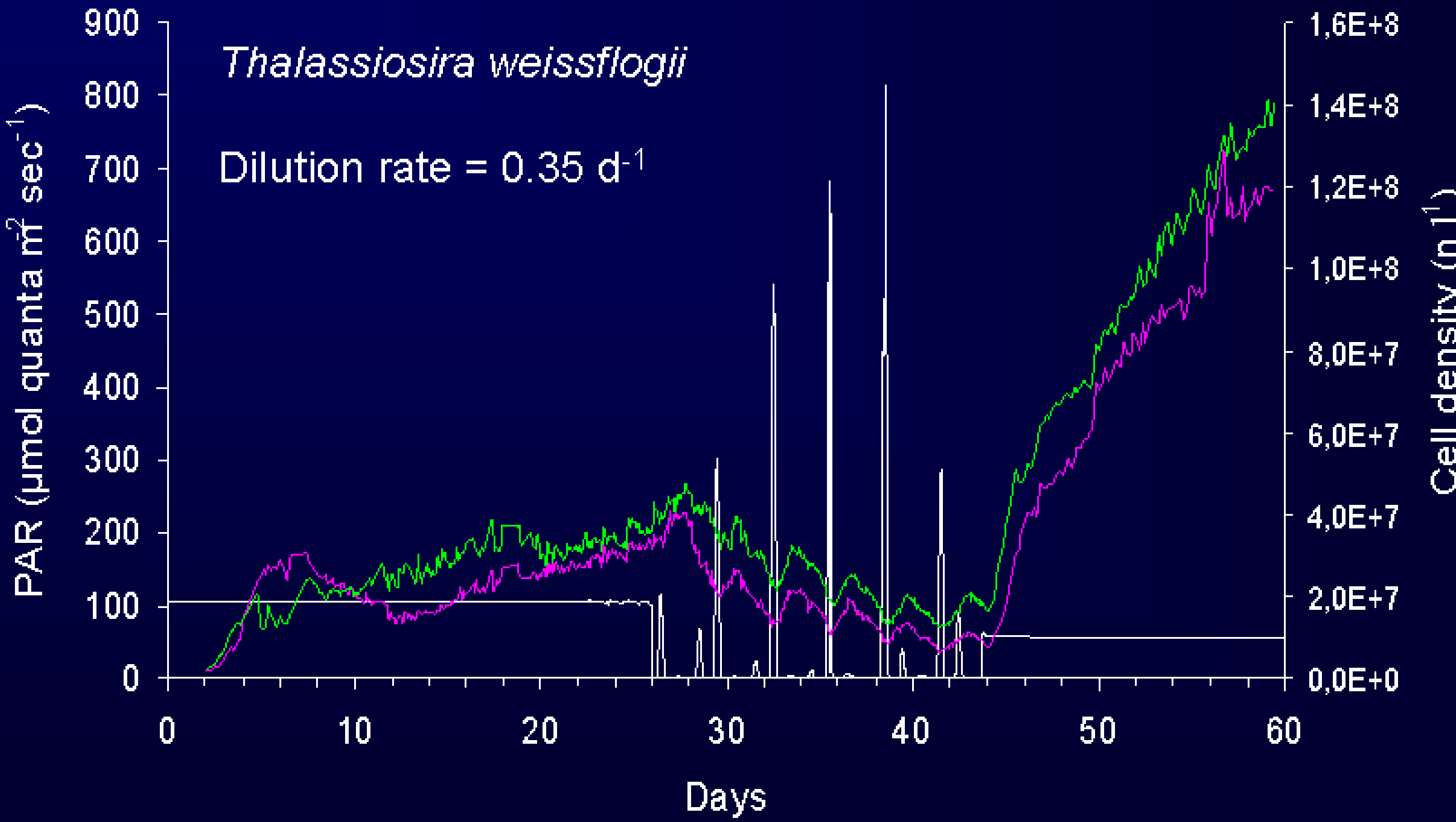
  → euphotic depth Ze = 91 m


PAR (µmol quanta m -2 sec -1)
1400
1200
1000
800
600
400
200
0
0
-40
-80
-120
-160
Depth (m)
26
28
30
32
34
36
38
40
42
44
Days

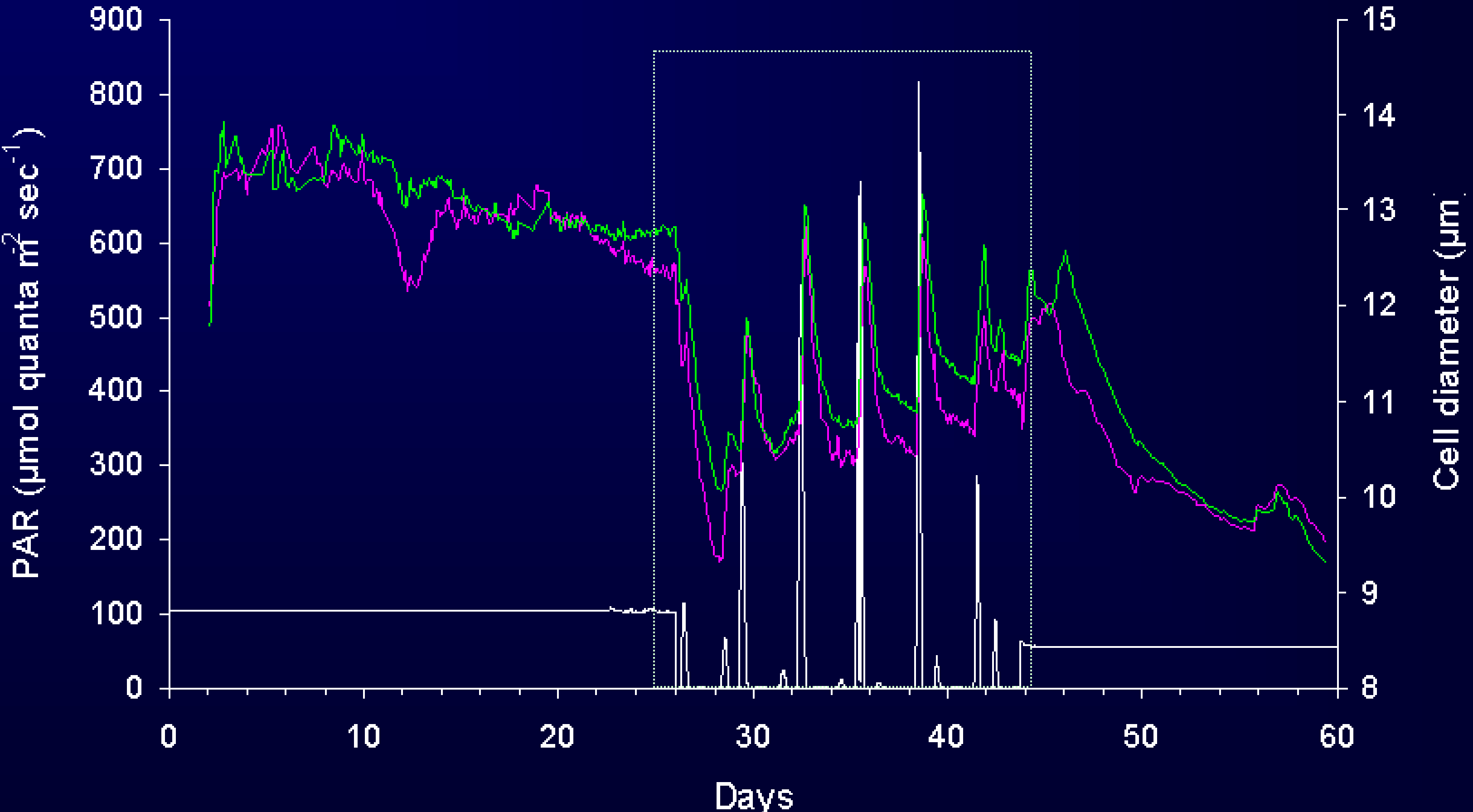
Programmed light intensity



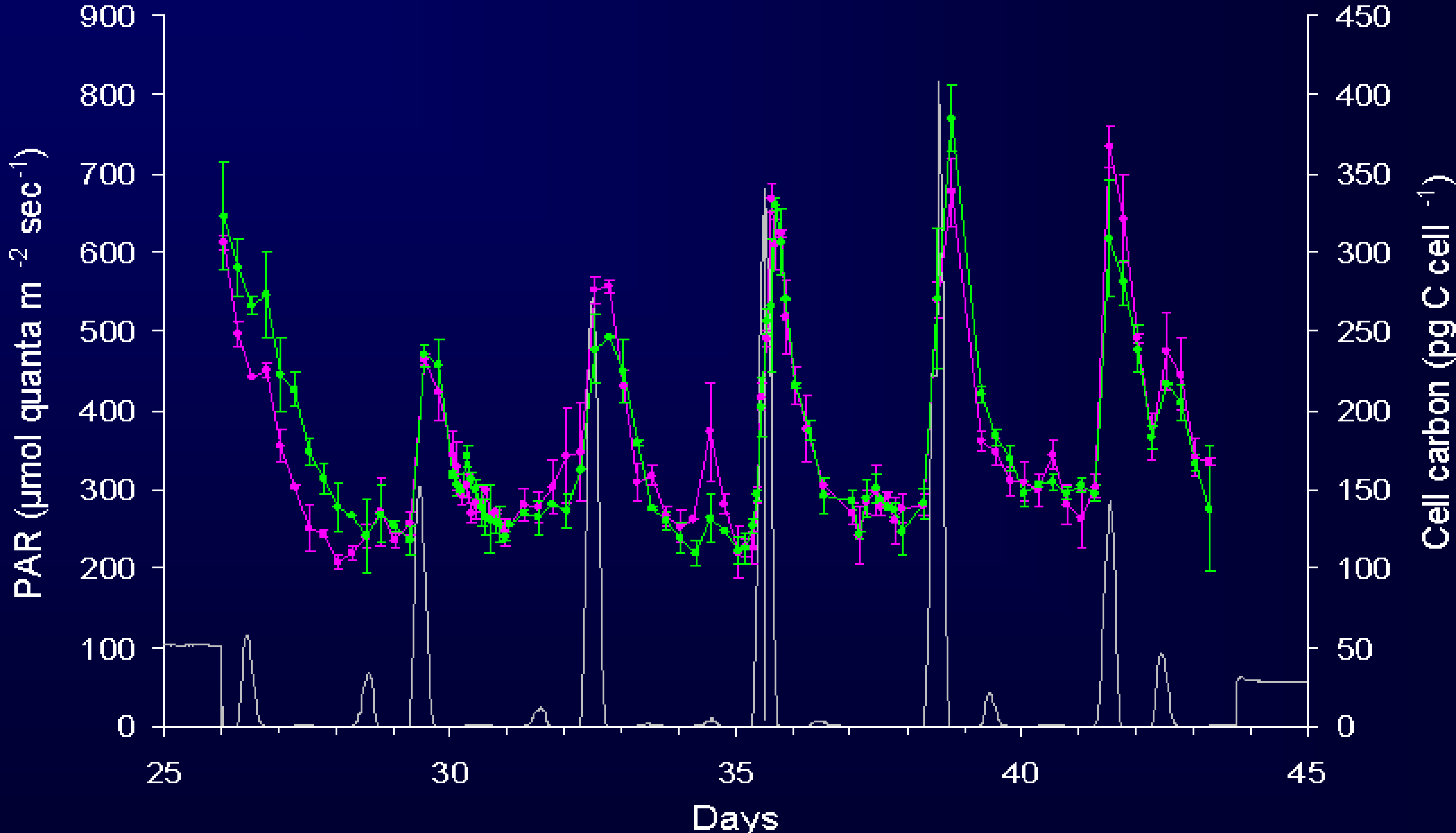
Experiment reproducibility



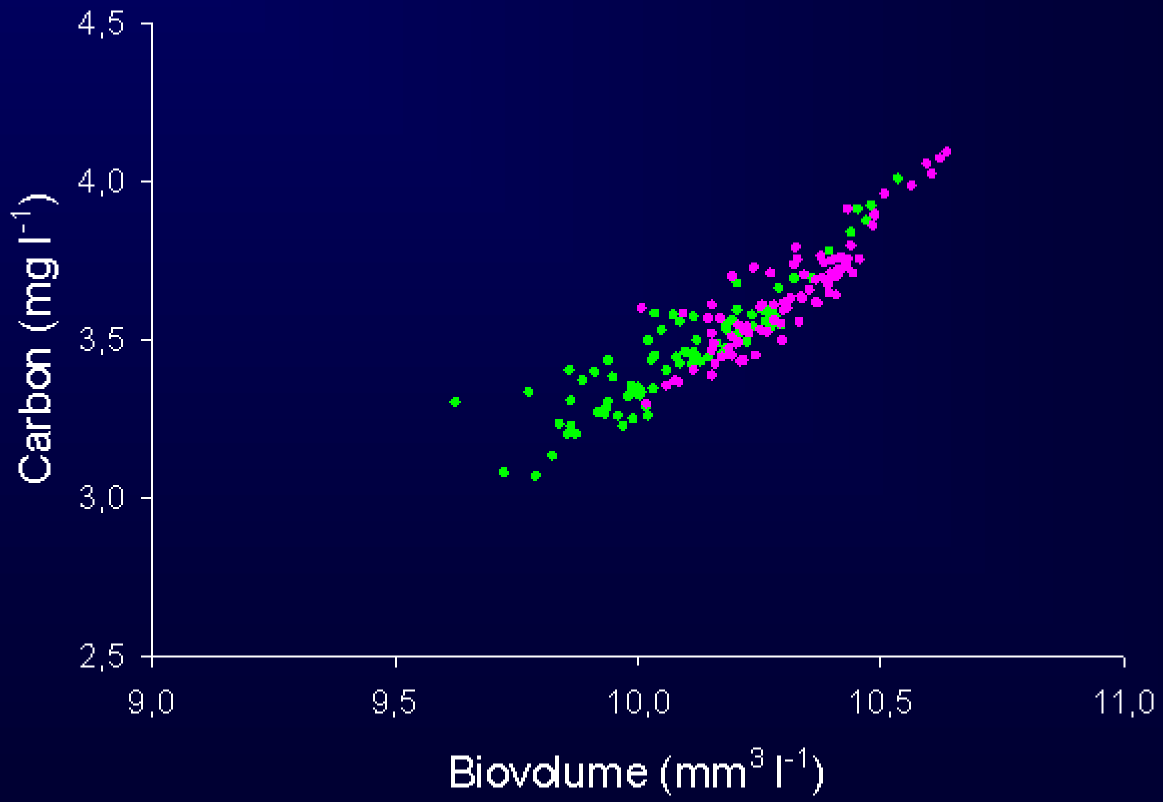
Experiment reproducibility



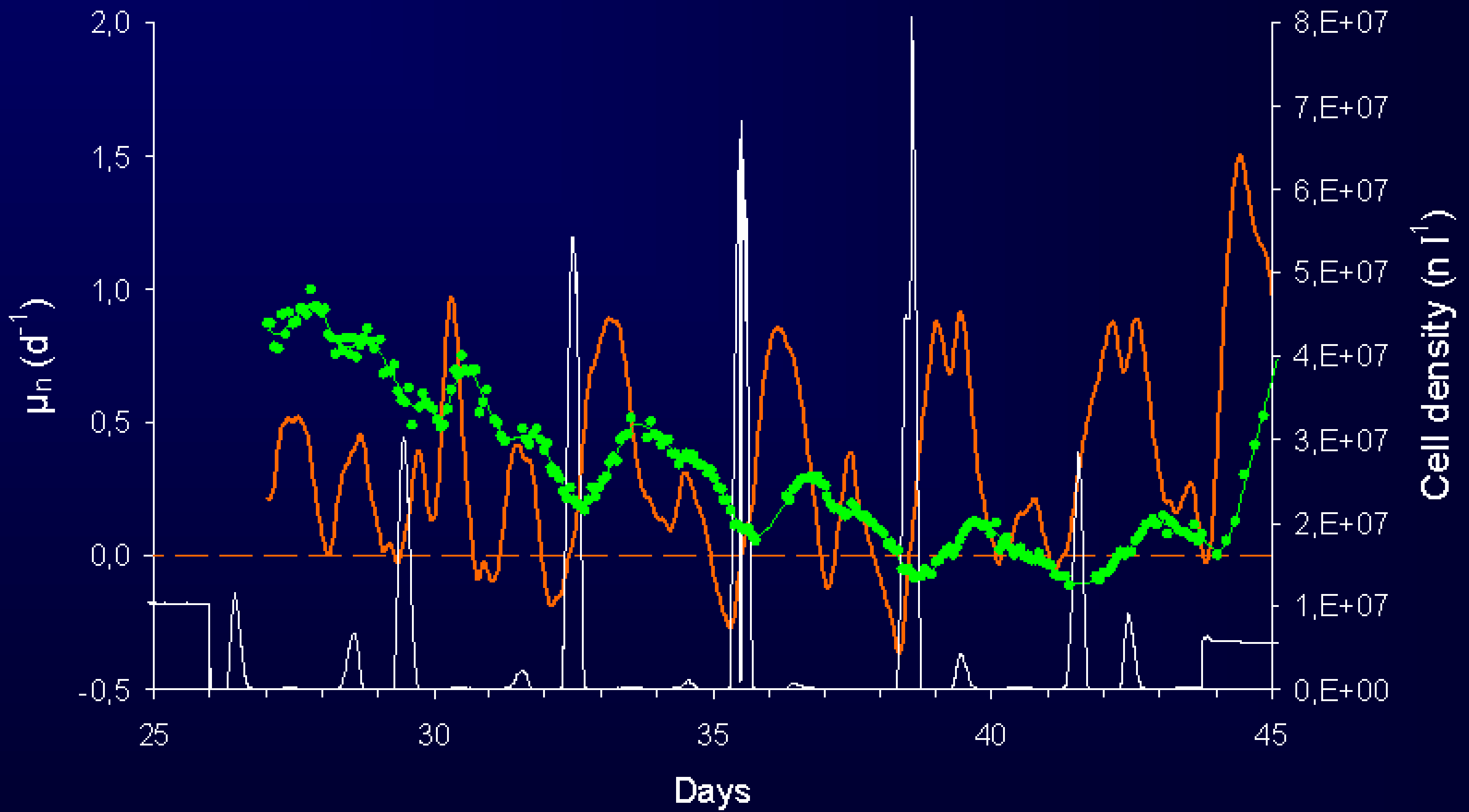
Experiment reproducibility



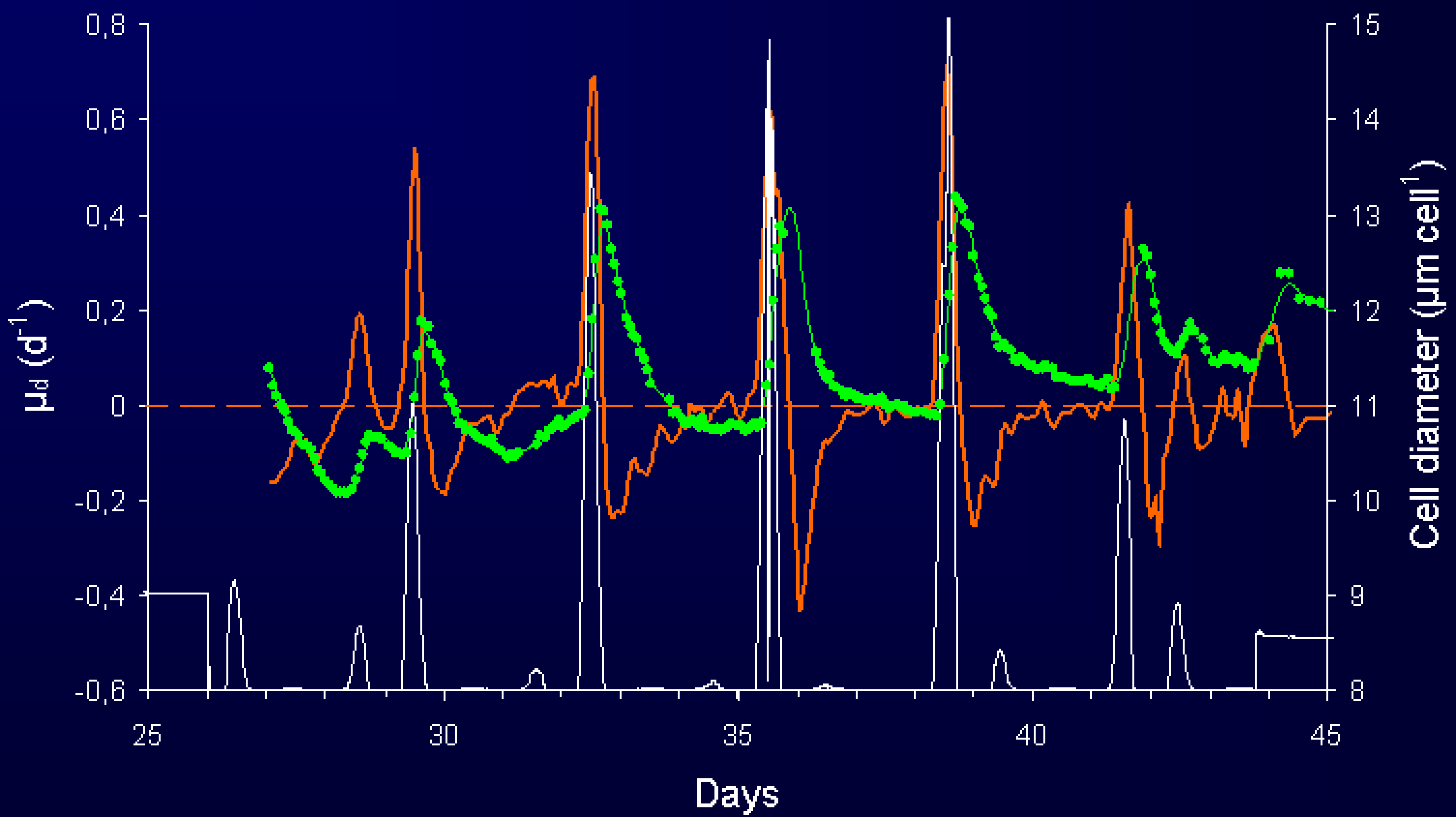
Biovolume is a good proxi of particulate carbon



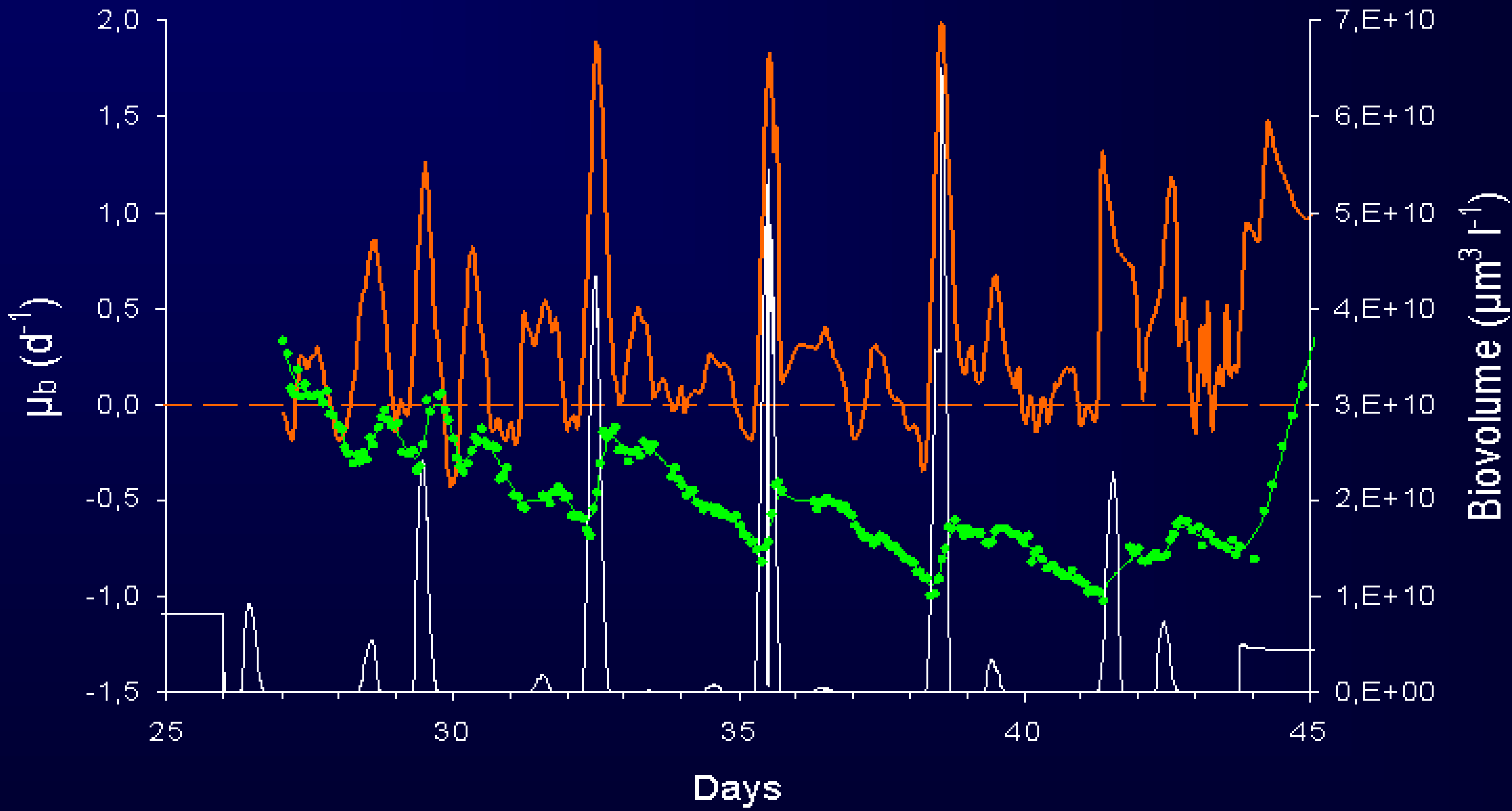
Cell division rate



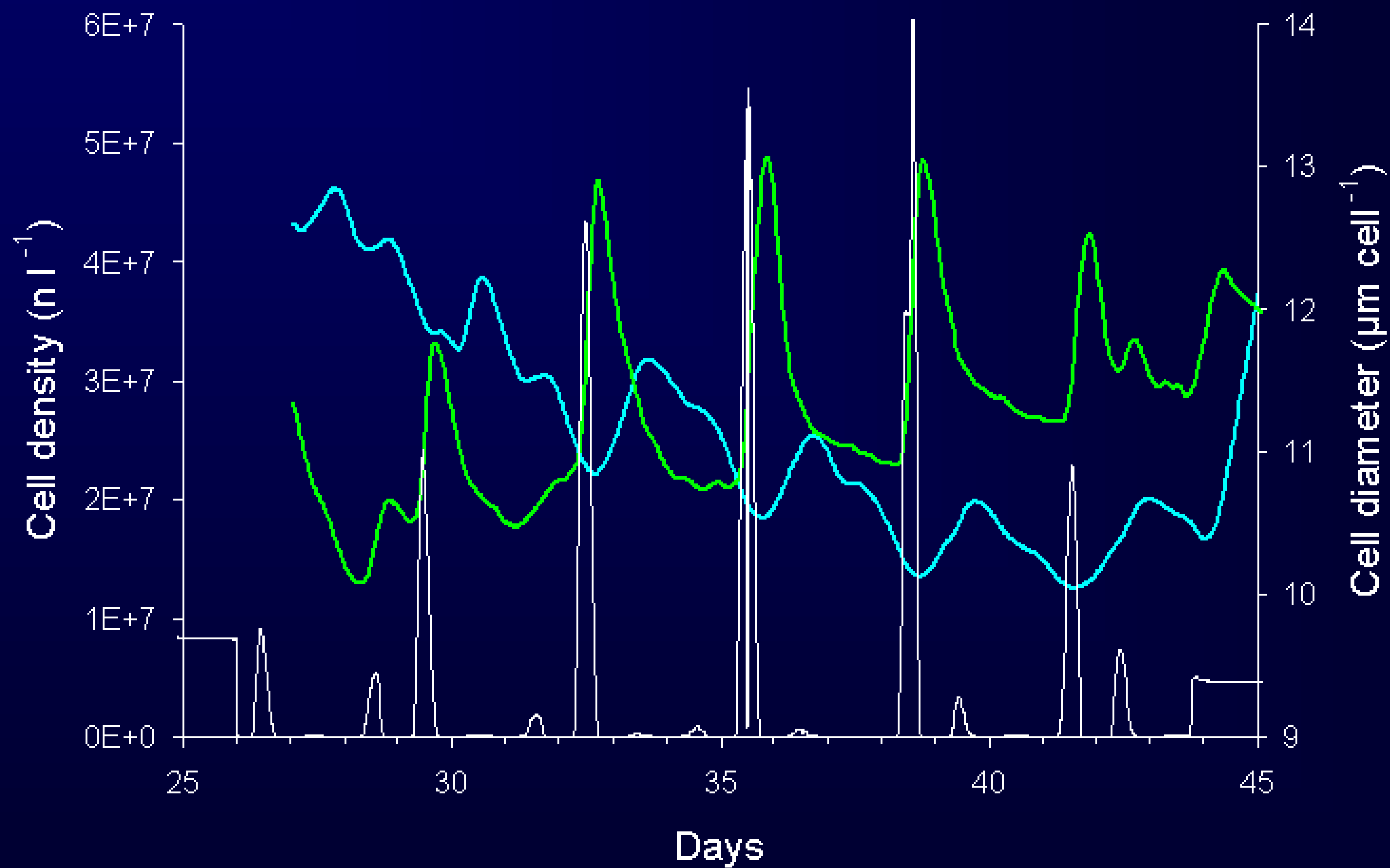
Cell size variation



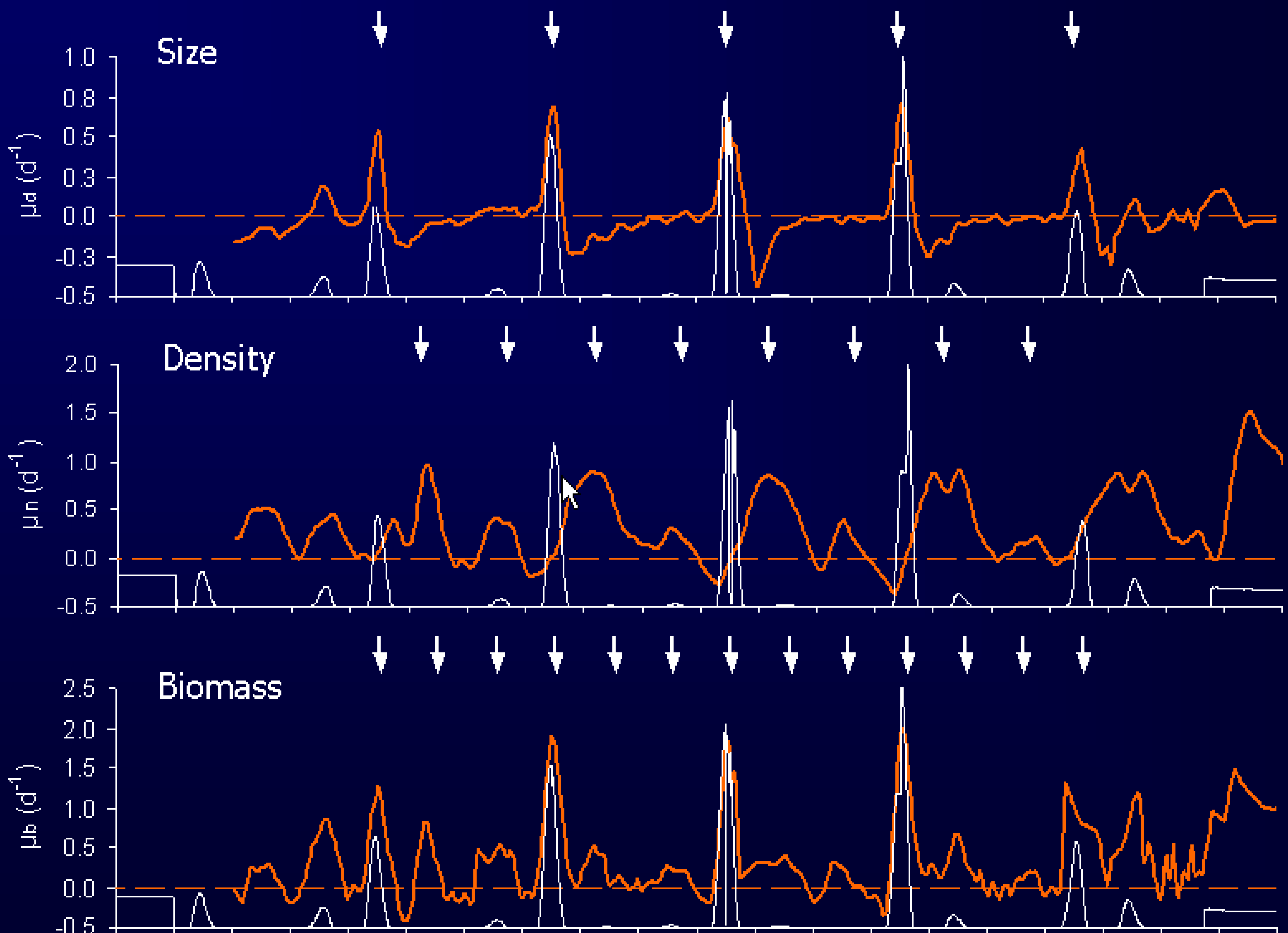
Biomass variation



The cell population is partially synchronized by the light regime



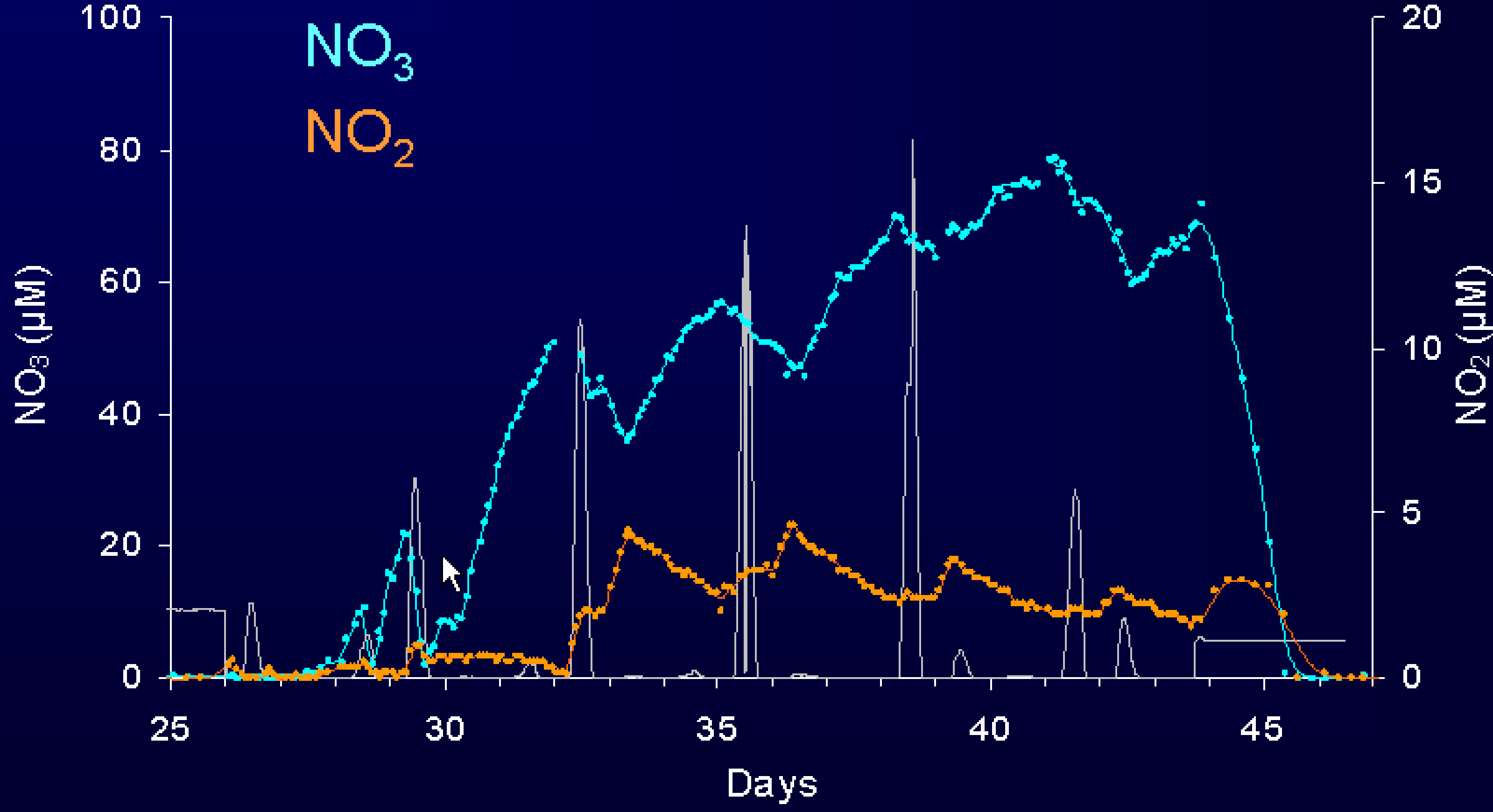
Specific variations

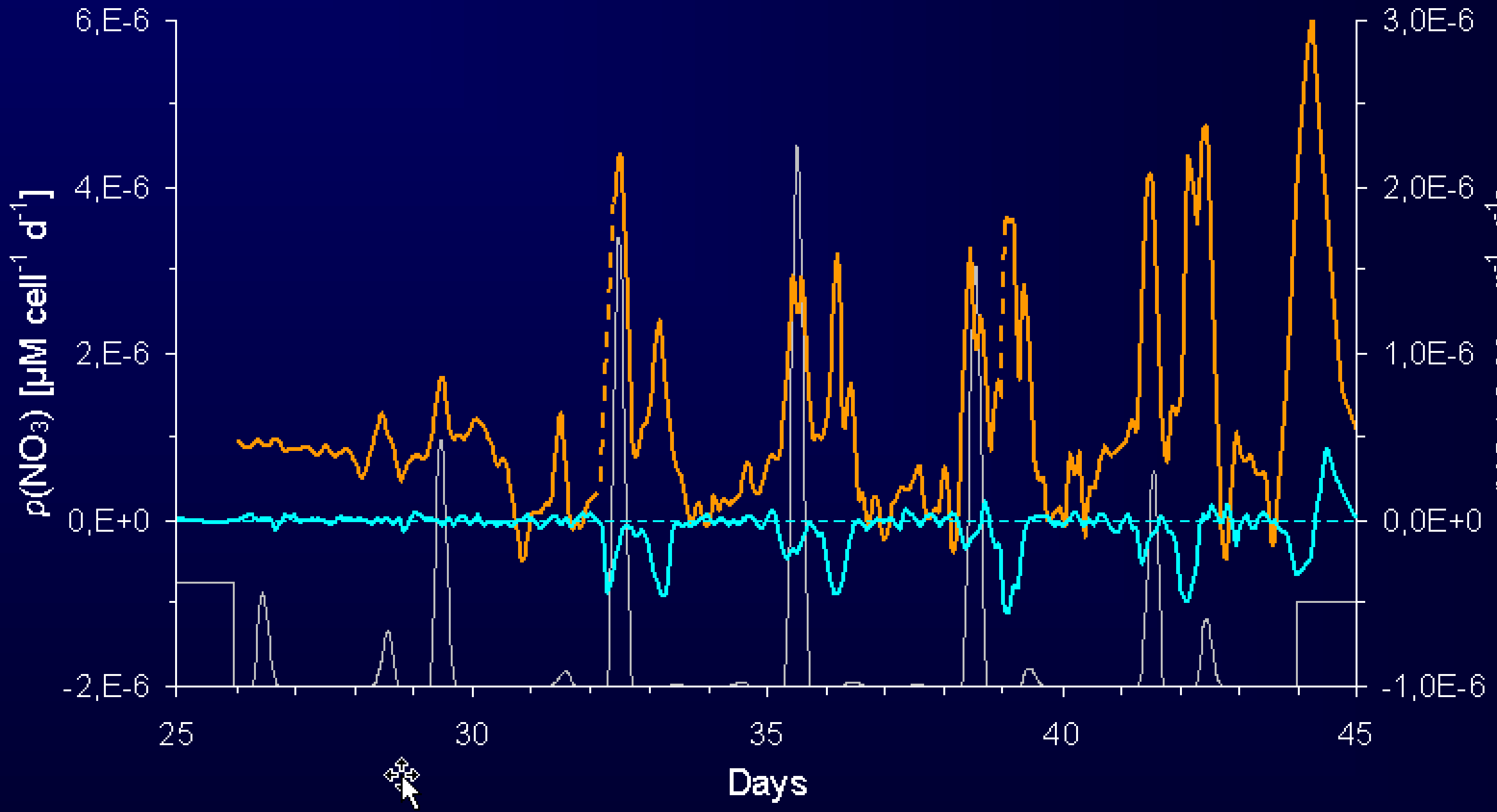


Observations

- Cell division predominantly occurs during the dark phases which follow light episodes.
- But cell division also occurs even in the absence of a significant light episode : evidence for an internal cell clock ?
- Increase in cell volume is strictly restricted to the light phases (somatic growth) and is related to the amplitude of the light episode.
- Decrease in cell size, concomitant with an increase in cell number, is due to the cell division process.
- Production of biomass occurs predominantly during the light phase, but a significant production also occurs in the dark.
- Cell division and somatic growth are not simultaneous : population is partly synchronized.

NO_3 not completely absorbed
NO_2 excretion

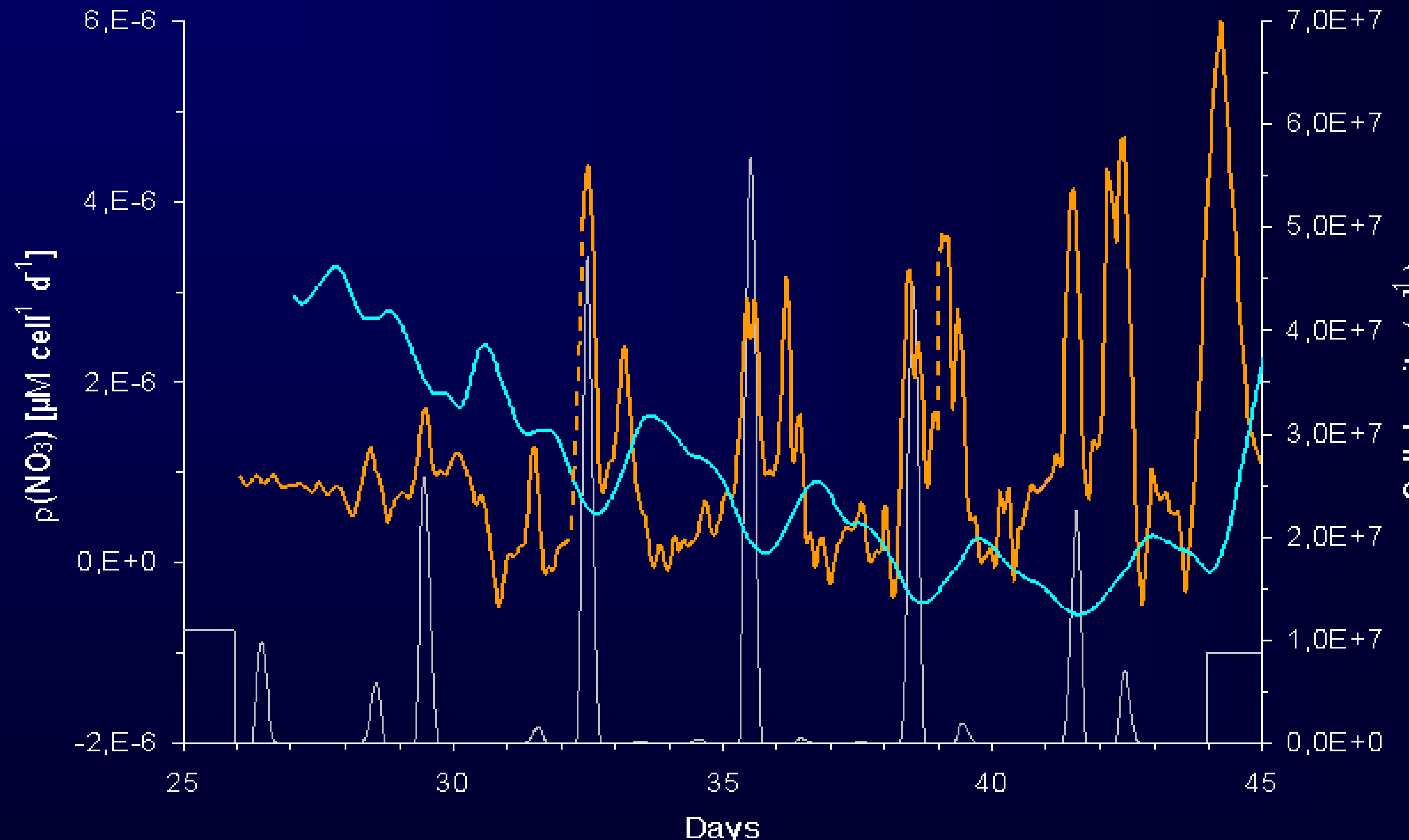




6,E-6
4,E-6
2,E-6
0,E+0
-2,E-6
p(NO3) [µM cell-1 d-1]
3,0E-6
2,0E-6
1,0E-6
0,0E+0
-1,0E-6
p(NO2) [µM cell-1 d-1]
25
30
35
40
45
Days

Observations

- The ability to take up NO_3 is tightly coupled with exposure to light.
- The release of NO_2 observed during NO_3 absorption reflects a relative inefficiency to assimilate inorganic nitrogen after exposure to darkness (insufficient reducing power provided by photosynthesis ?).
- After exposure to light, absorption of NO_3 (and excretion of NO_2) is transiently stopped before recovering in the dark for several hours.



6,E-6
4,E-6
2,E-6
0,E+0
-2,E-6
ρ(NO3) [µM cell-1 d-1]
7,0E+7
6,0E+7
5,0E+7
4,0E+7
3,0E+7
2,0E+7
1,0E+7
0,0E+0
Cell density (n l-1)
25
30
35
40
45
Days

Observations

- The transient inhibition of NO_3 absorption is systematically observed at the end of light episodes, i.e. when cells start to divide.
- When cell division is triggered by a light episode, a significant part of the population is synchronized (i.e. cells are in the same cycle position).
- It can be suggested that the NO_3 absorption capacity of a single cell depends on its position in its cycle, since growth and division cannot be simultaneous.
- The detection of a cell's inability to take up NO_3 at mitosis becomes facilitated in a partially synchronized large population.

Conclusions

- Strong dependency of nutrient assimilation capacity on photosynthesis, and more precisely on reducing power accumulated during exposure to light.
- In deep mixed-layers where NO_3 is not limiting, the nutrient assimilation can still be limited due to insufficient light exposure.
- Cell cycle also interferes with the nutrient assimilation through the effect of light on the population synchronization.

Advantages of controlled experiments

Controlled "long-term" experiments in open cultures allow :

- highlighting the adaptation processes of phytoplankton within a a variety of dynamical environments (for example deep mixed-layers).
- studying the coupling of different limiting factors in the context of their respective variability, and assessing the effect of their concomitancy on the resulting growth rate.
- appreciating the global effects of a partially synchronized population which reflects the dynamics of a single cell.
- producing accurate and sufficient data useful to validate dynamic models.

Questions

- How to link such experimental results with the modelling of autotrophic growth in the water column?
- Is it really necessary to associate a model of the cell cycle with existing models of photoacclimation?
- What kind of experiments should be designed in the future?