Mixed versus Mixing layer depth: a Bio-Argo float approach

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Introduction

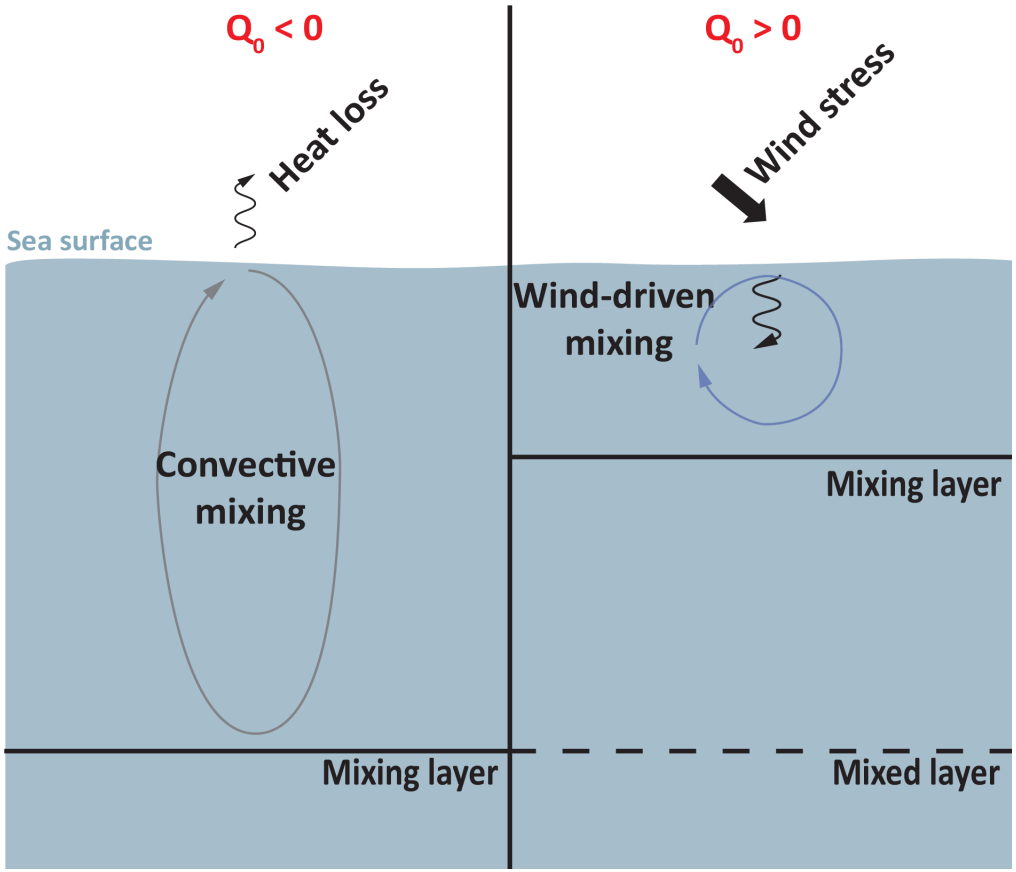
Mixed layer: '' the zone of relatively homogeneous water formed by the history of mixing ''
(Brainerd and Gregg 1995)

Mixing or turbulent layer: '' the zone in which mixing is currently active ''
(Brainerd and Gregg 1995)

Main sources of turbulence in open ocean

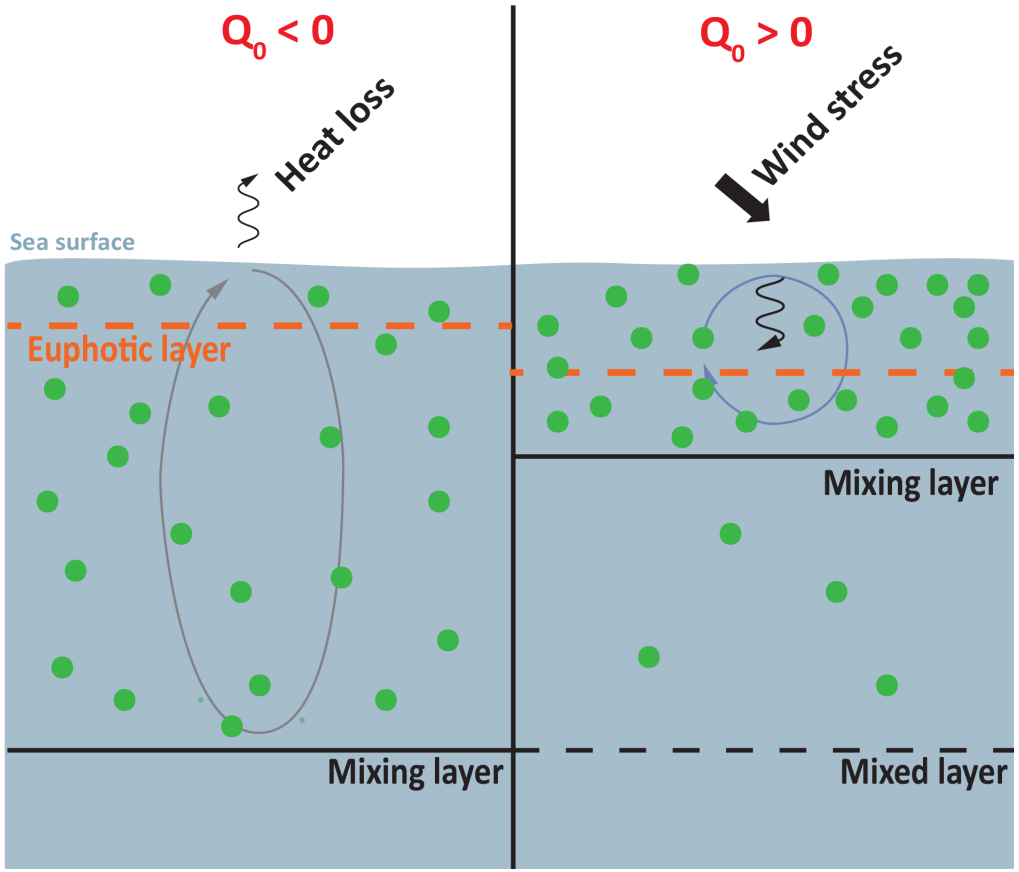
Heat loss and wind stress

- Convection : gravitational instability caused by a cooling of the ocean's surface (negative heat flux Q_0)
- Convection shuts down rapidly with small changes in stratification



Vertical distribution of phytoplankton

- Phytoplankton cells uniformly distributed over the mixing layer
- Euphotic layer : zone in which the light level allow a net phytoplankton growth
- The mixing layer is similar to a virtual euphotic layer (Backhaus et al. 2003)

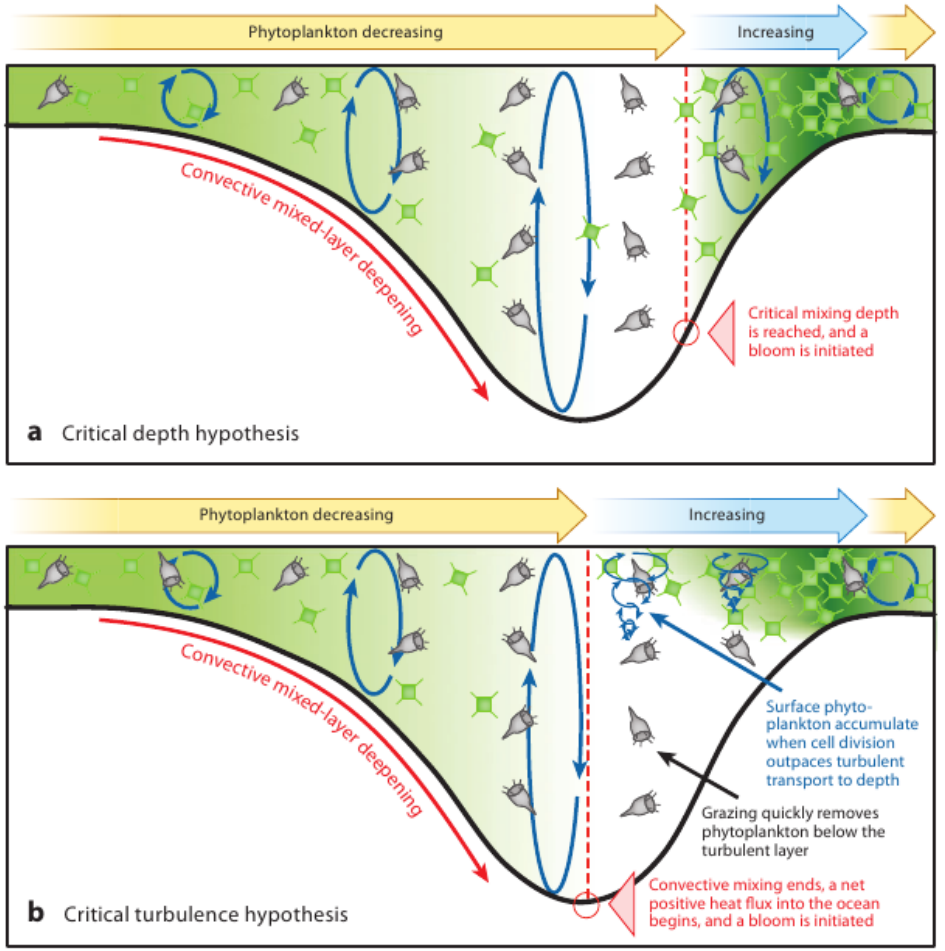


First objective

Can we use a biological indicator such as the phytoplankton biomass to estimate the mixing layer depth ?

Bloom dynamics in subpolar regions

- The mixing layer depth regulates the light availability for phytoplankton growth
- Light : critical factor for bloom initiation in subpolar regions
- **Critical depth hypothesis** : the spring shallowing of the mixed layer depth increases light availability for phytoplankton growth
  (Gran & Braarud 1935, Sverdrup 1953)
- **Critical turbulence hypothesis** : difference between the mixed layer and mixing layer depth when convection shuts down
  (Huissman et al. 1999, 2002, Chiswell 2011, Taylor & Ferrari 2011)



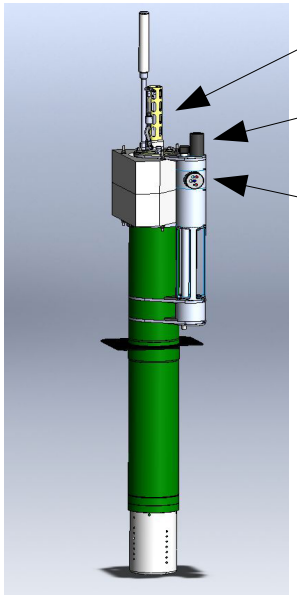
Behrenfeld 2014

Second objective

How the dynamics of the mixing layer can influence the light availability for phytoplankton growth ?

Materiel and methods

Bio-Argo floats

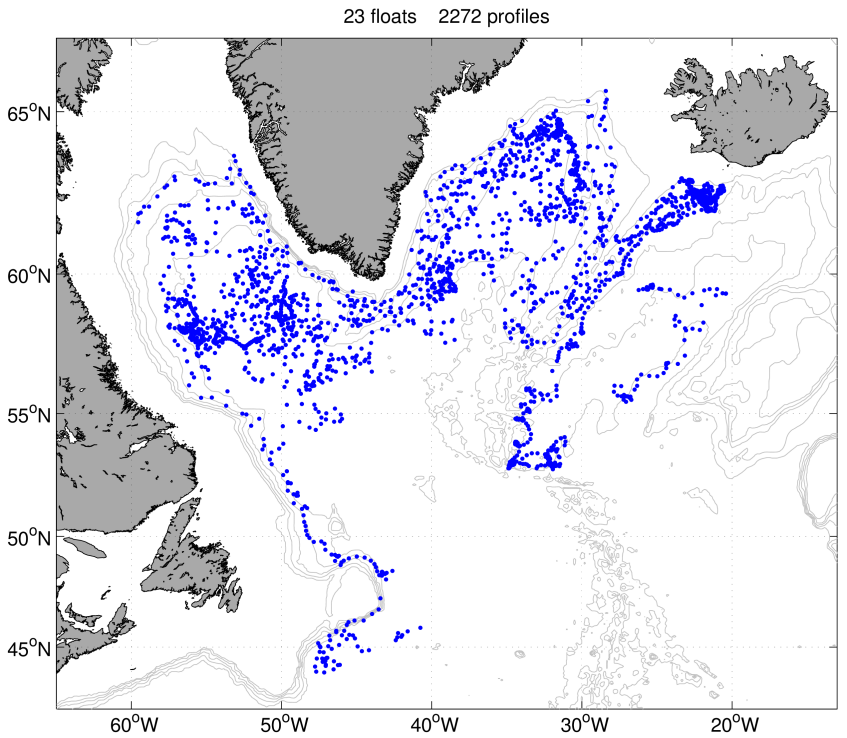


Temperature, salinity

PAR : photosynthetically available radiation

Chla, bbp, CDOM

Nitrate, Oxygen



- 23 floats deployed in the subpolar gyre (remOcean)
  → First deployment 18 april 2013 in the Iceland basin

- More than 2200 profiles (at solar noon) in the three main basins of the subpolar gyre (Iceland sea, Irminger Sea, Labrador sea)

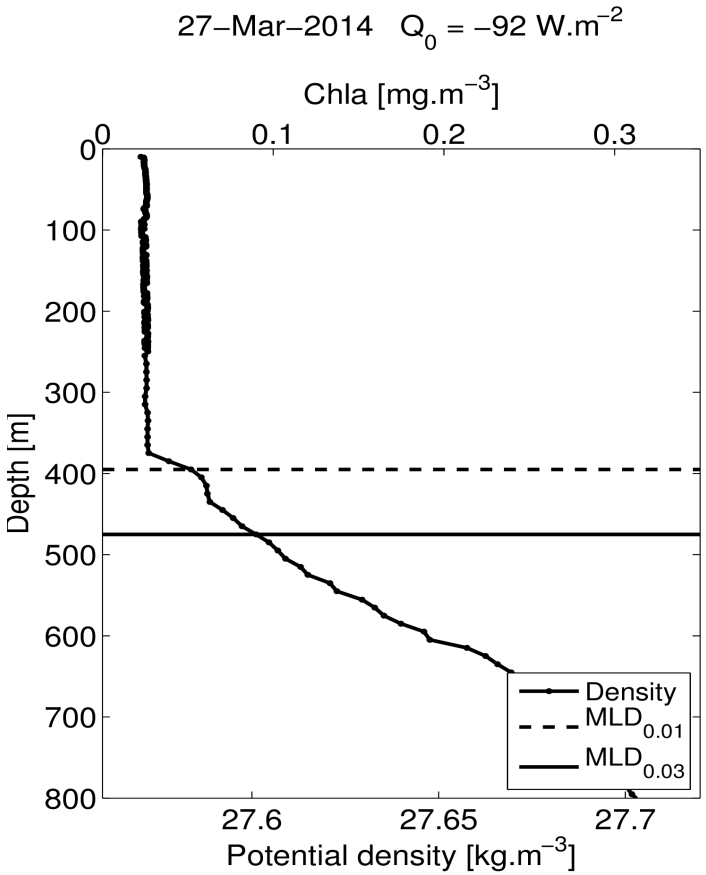
Atmospheric forcing

- **Net heat flux** (data from ECMWF, 0.25°, 24h)

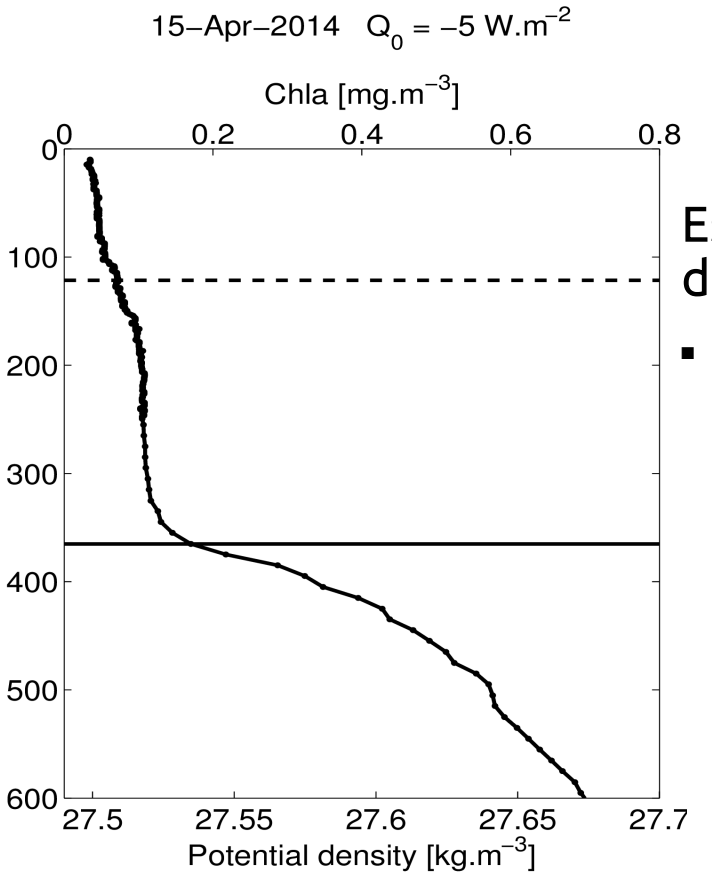
8-day average to match the phytoplankton life cycle (Ferrari et al. 2014)

Mixed and mixing layer depth estimation

$Q_0 << 0$



$Q_0 \sim 0$

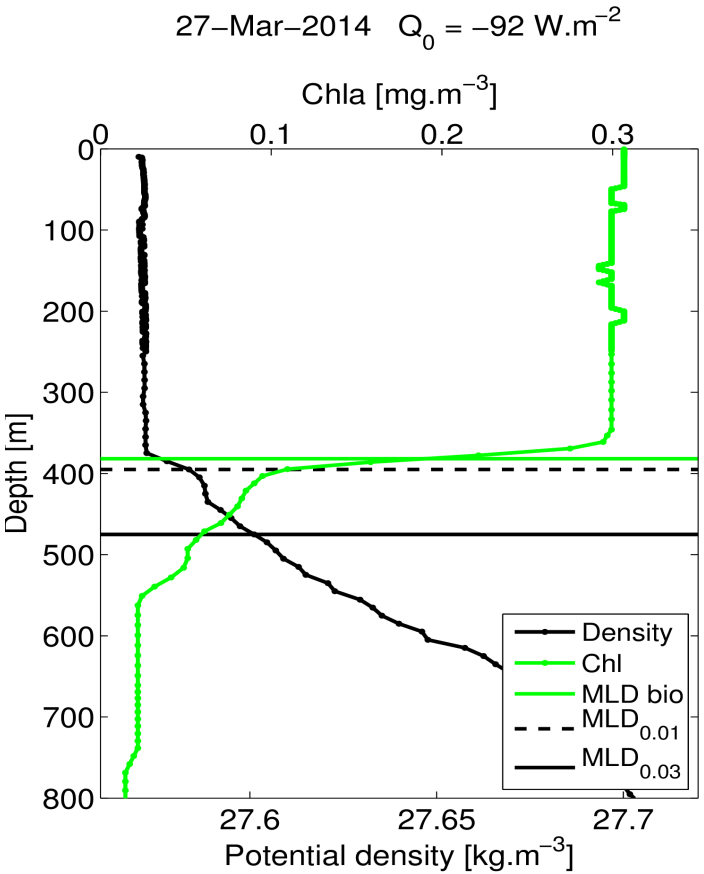


Estimation of the mixed layer depth

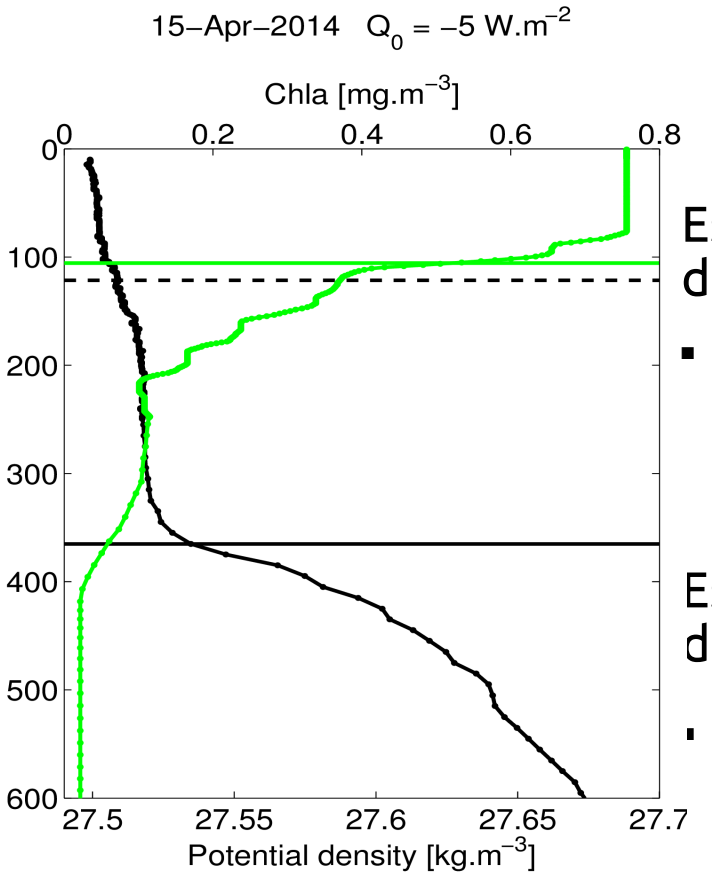
- Density criteria (MLD_{dens}) density threshold of 0.01, 0.03 kg.m^{-3}

Mixed versus mixing layer depth

$Q_0 << 0$



$Q_0 \sim 0$



Estimation of the mixed layer depth

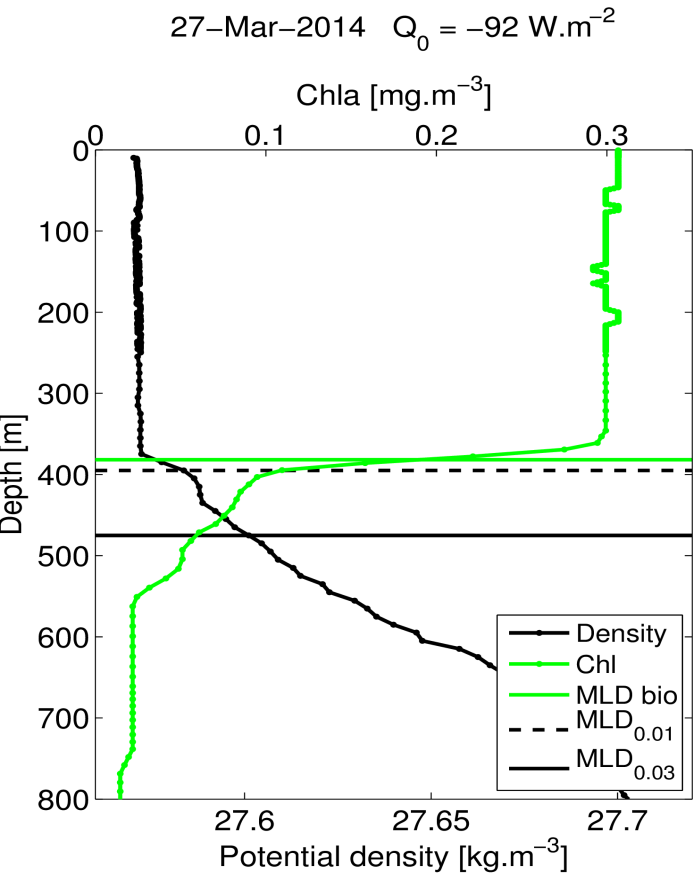
- Density criteria (MLD_{dens}) density threshold of 0.01, 0.03 kg.m^{-3}

Estimation of the mixing layer depth

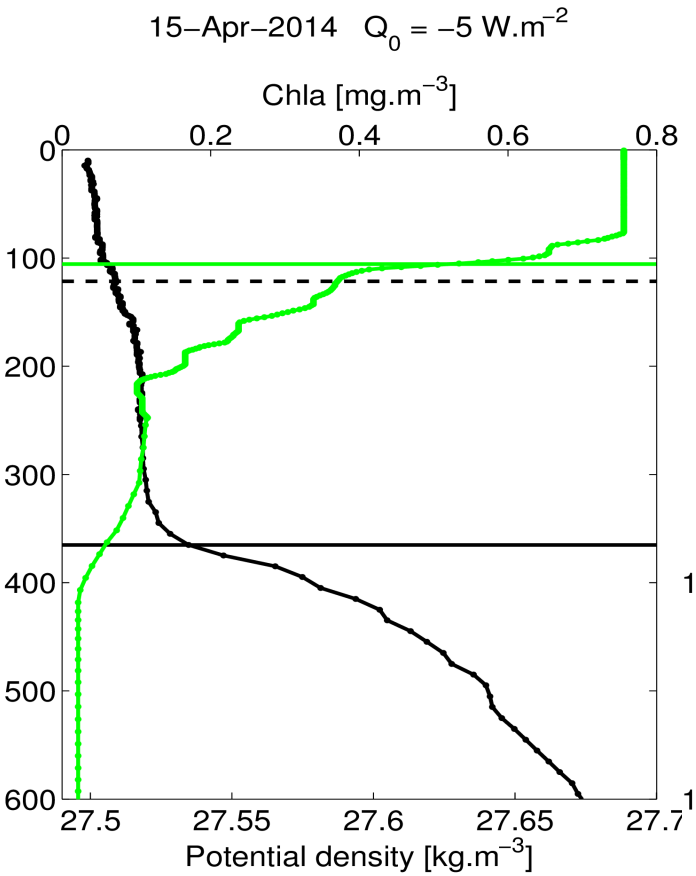
- Biological criteria (MLD_{bio}) maximum gradient of Chla

Mixed versus mixing layer depth

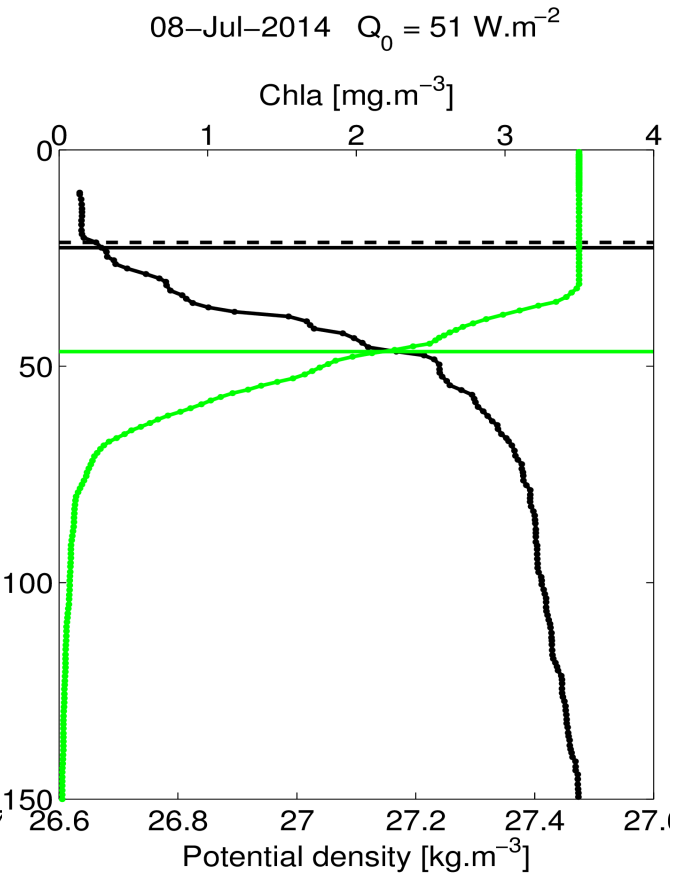
$Q_0 << 0$



$Q_0 \sim 0$



$Q_0 >> 0$



Mixed versus mixing layer depth

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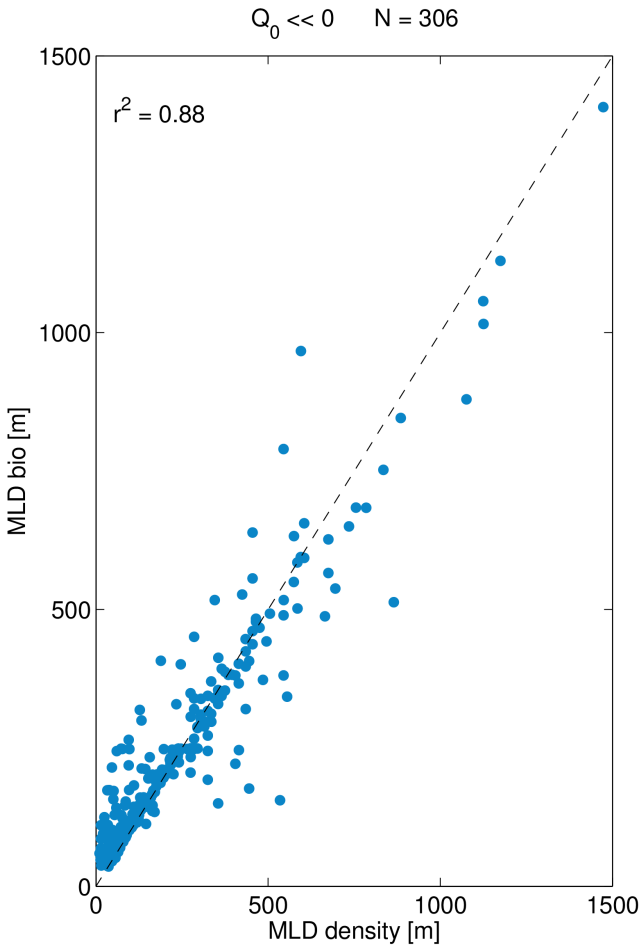

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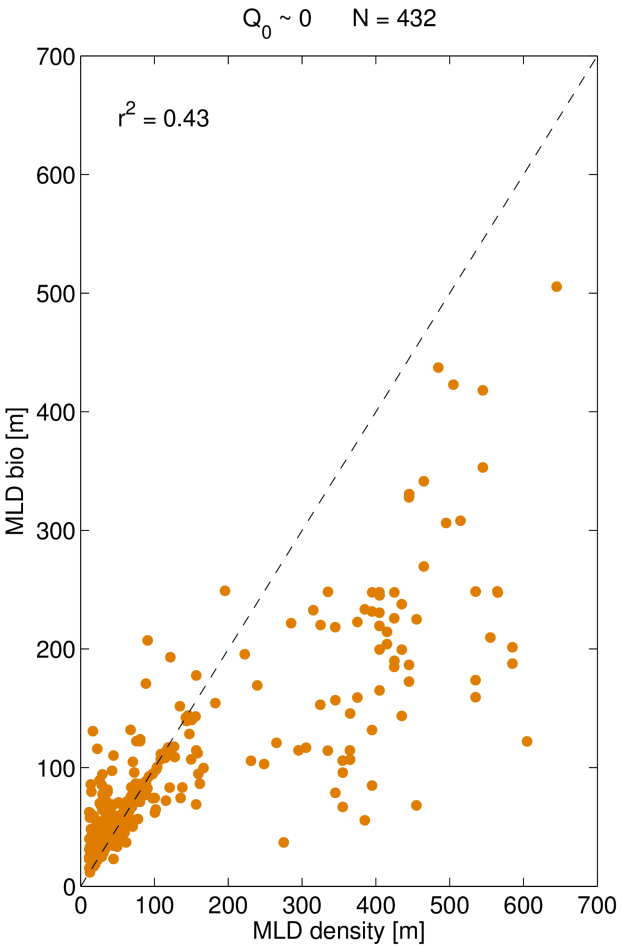
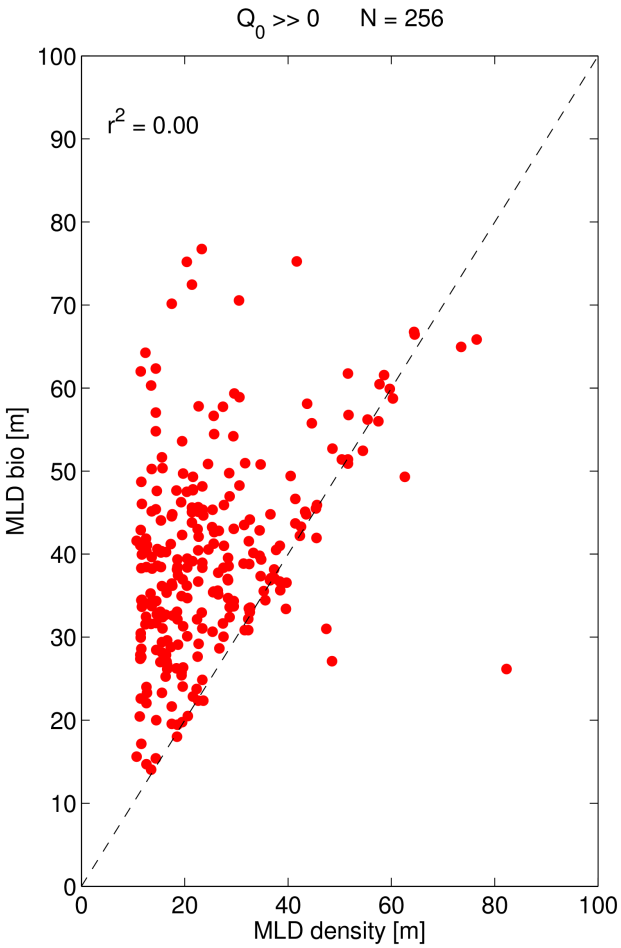


$Q_0 >> 0$

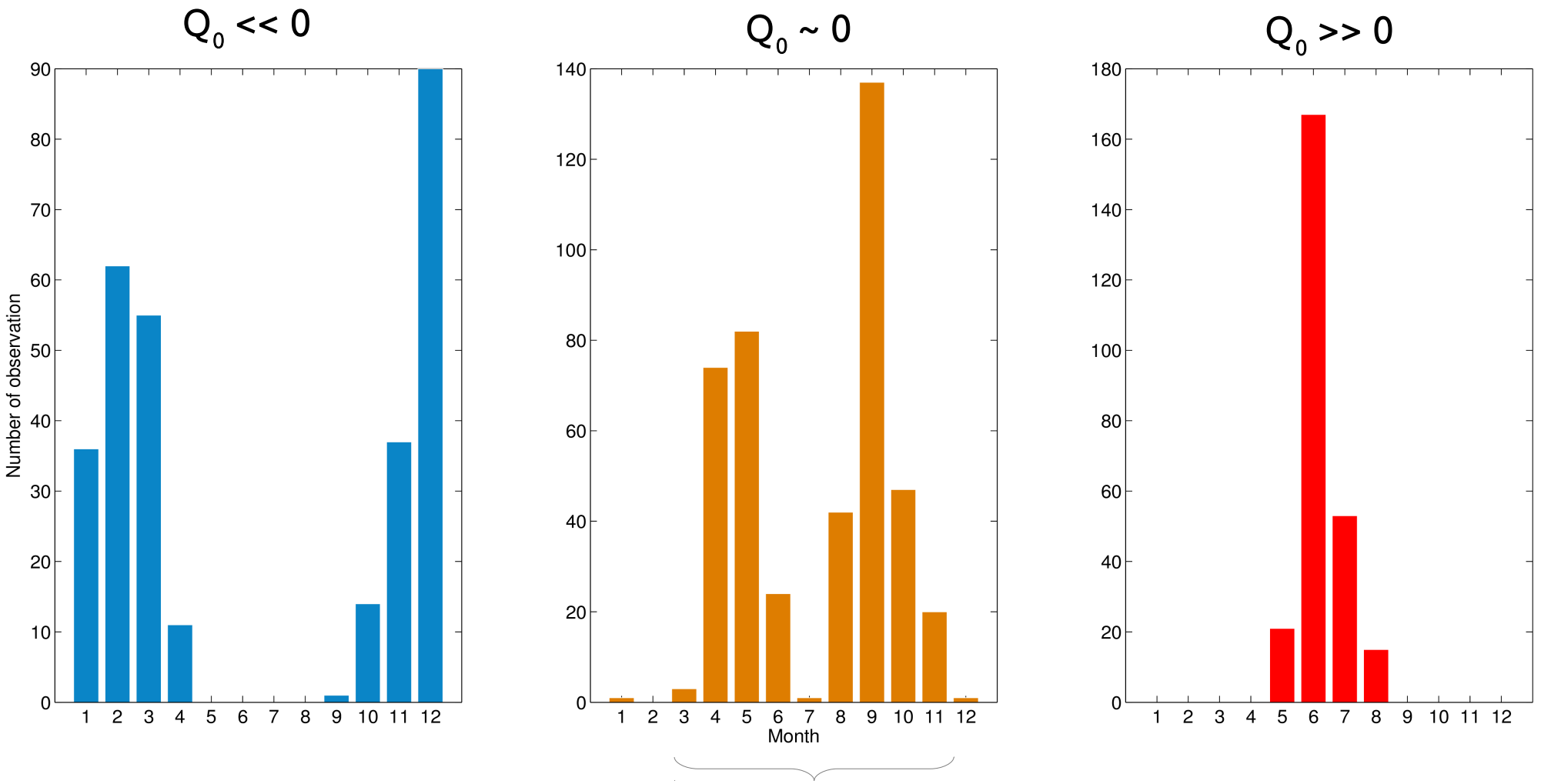


Density threshold : 0.01 $kg.m^{-3}$

0.03 $kg.m^{-3}$

0.03 $kg.m^{-3}$

Temporal distribution of the float profiles

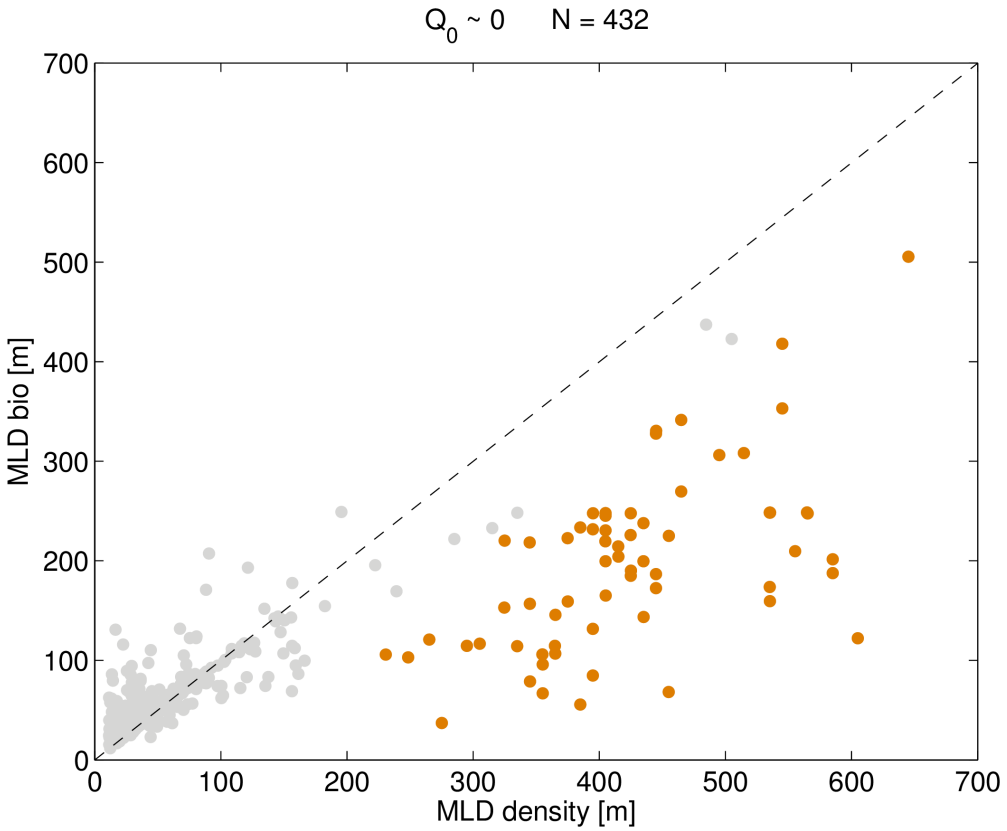


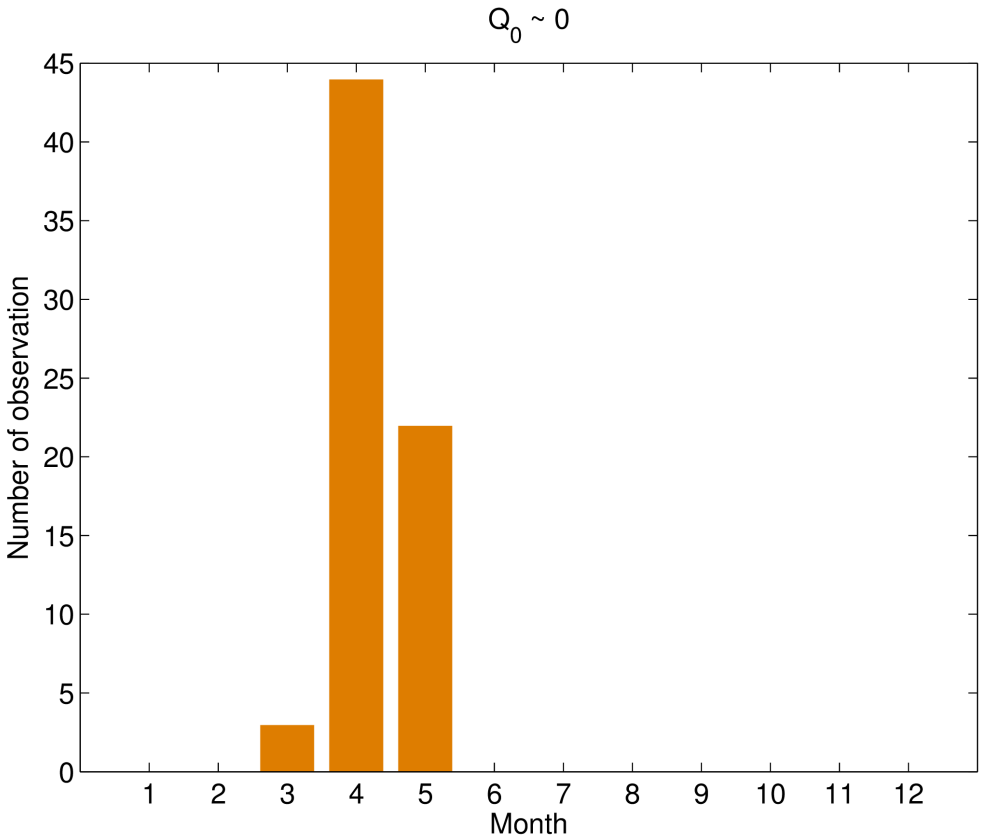
Bimodal distribution

Spring shallowing of the mixed layer

Fall deepening of the mixed layer

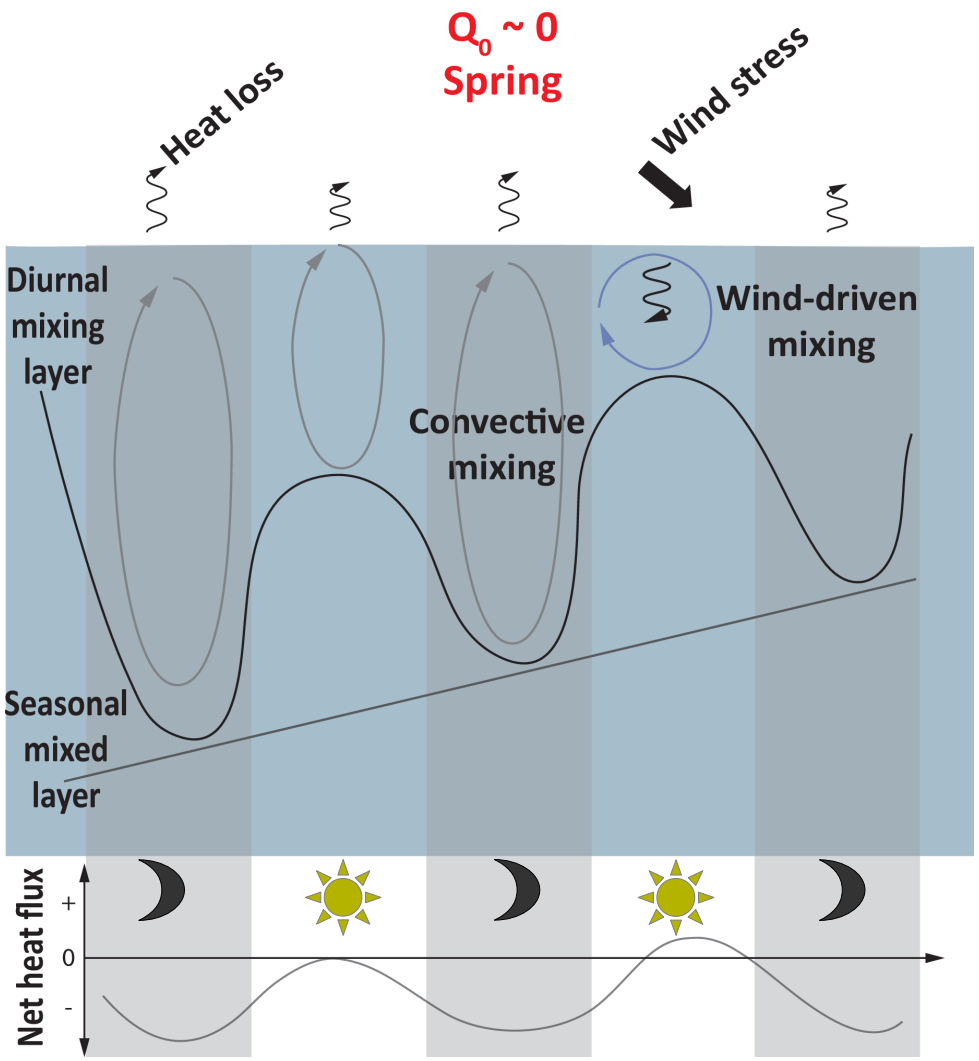
Critical period for bloom initiation





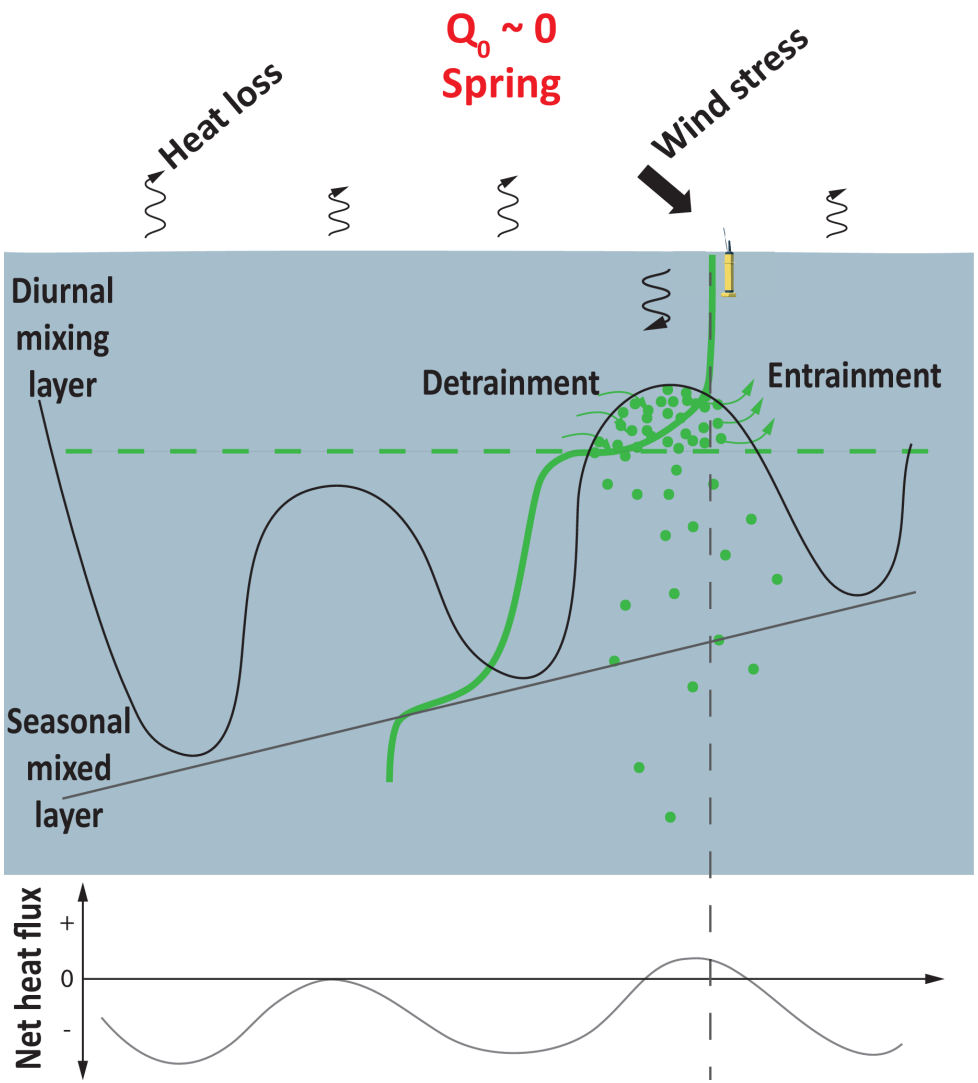
Short time scale variability of the mixing layer

Diurnal cycle



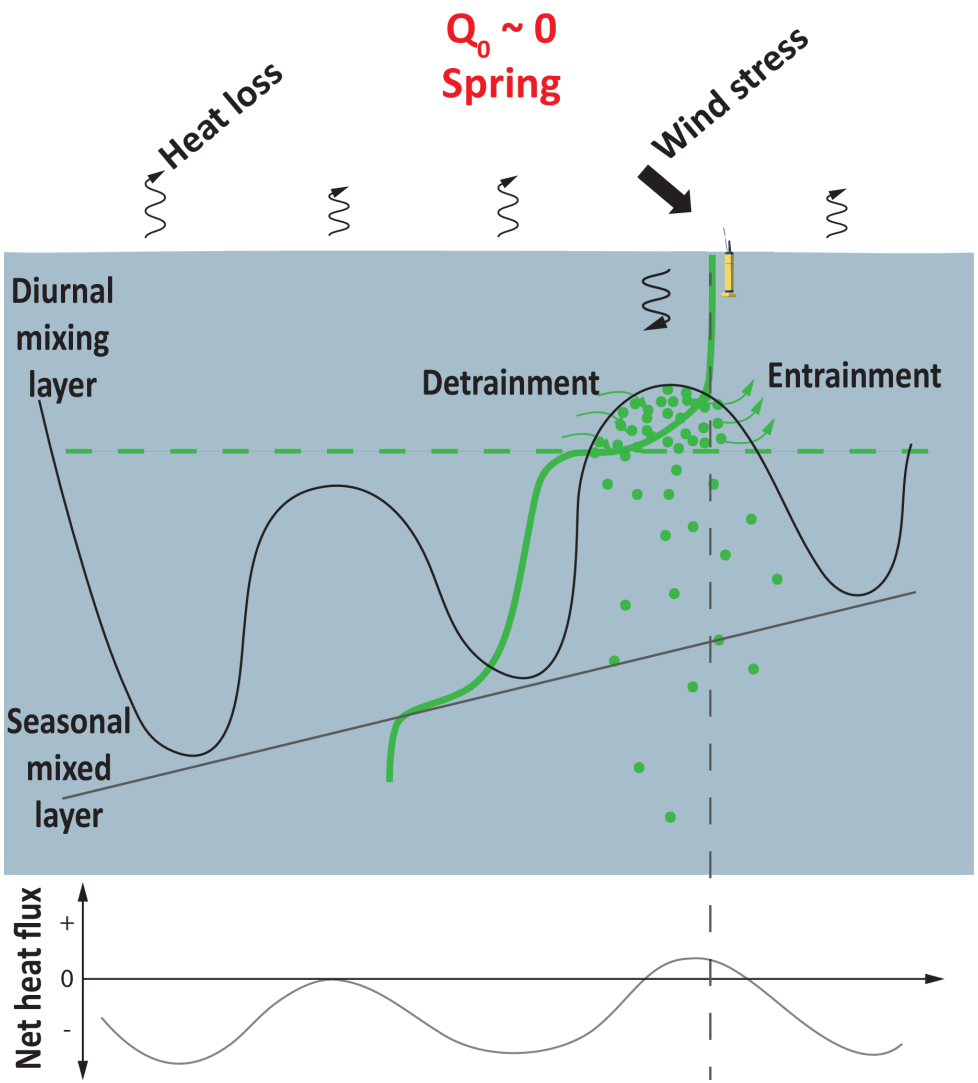
- Negative nigth-time heat flux drive deep convection
- Heat-induced stratification shuts down convection during the day
- Strong diurnal variability of the mixing layer depth in spring (Woods 1980, Brainerd and Gregg 1995)
- Seasonal variability of the mixed layer depth

Rapid response of the phytoplankton in spring



- Phytoplankton cells mixed over a shallow mixing layer by day experience more light to grow
- MLD_{bio} is well adapted to this short time scale variability due to rapid response of the phytoplankton
- MLD_{bio} is a good indicator of the recent mixing layer depth, with time scale typical of phytoplankton growth

Rapid response of the phytoplankton in spring



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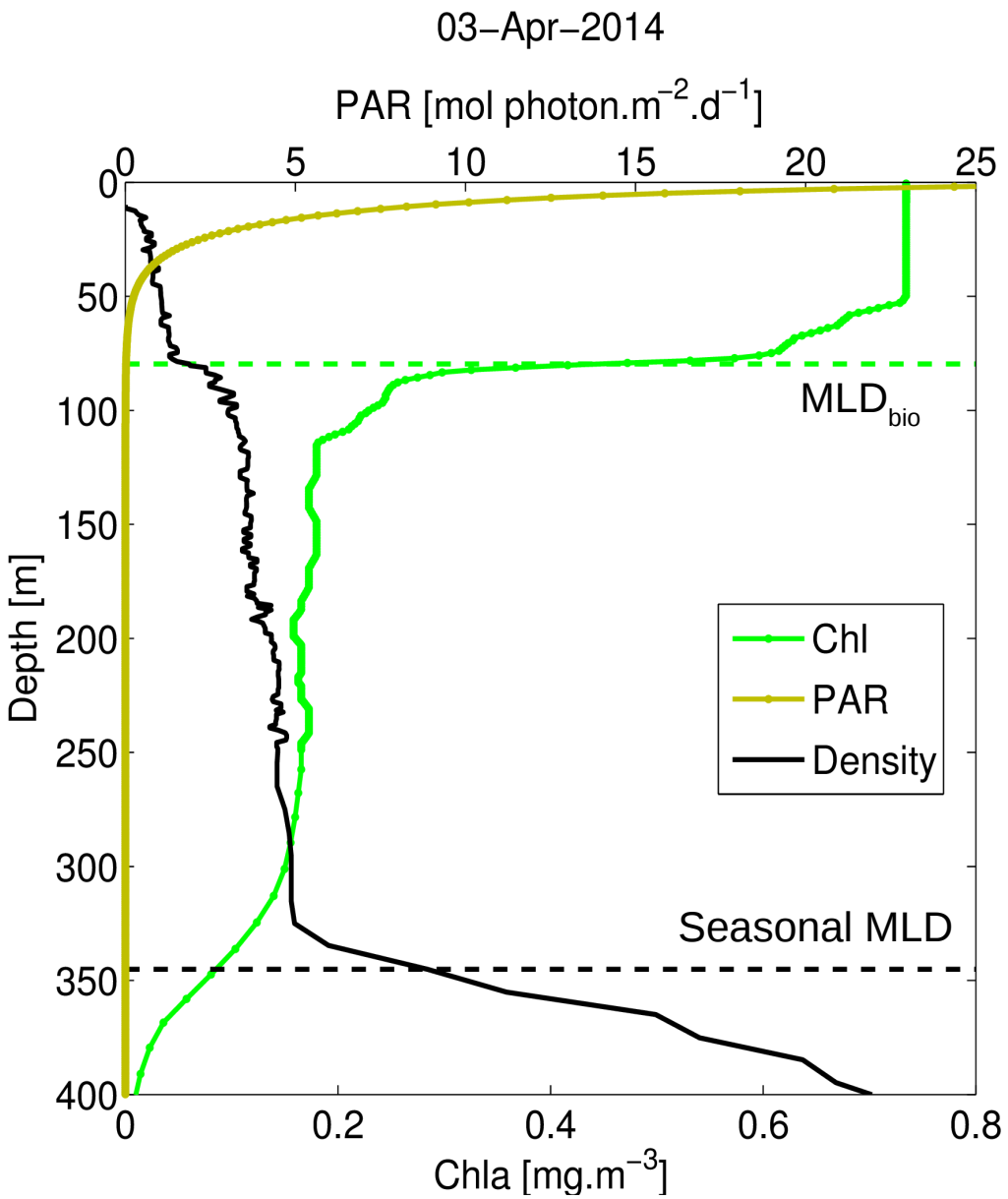
Light availability for phytoplankton growth

PAR_{ML} : mean daily-integrated PAR over the mixed or mixing layer

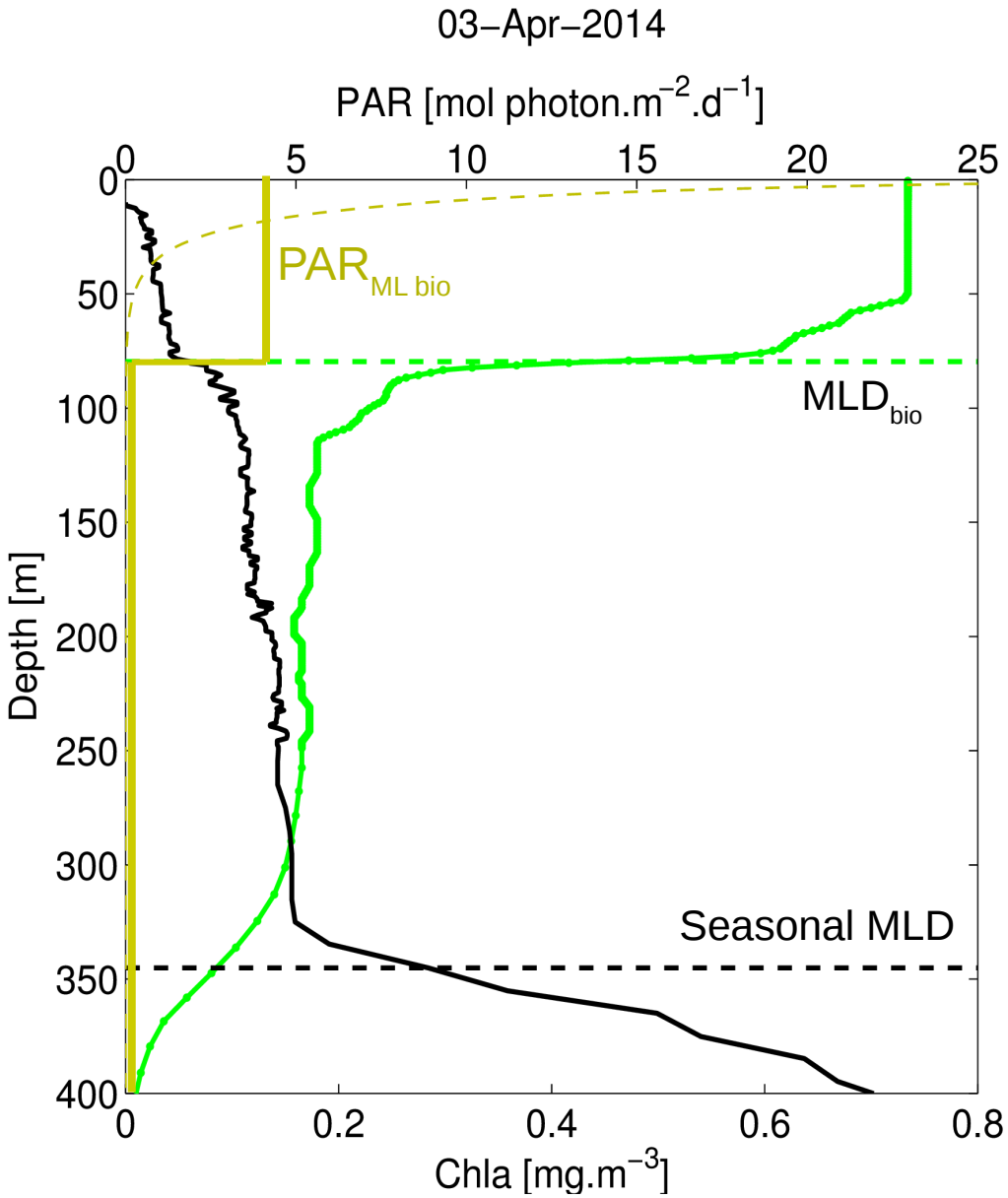


Hypothesis

- Each phytoplankton cells mixed over the MLD_{bio} experience in average the same amount of light during the day

Light availability for phytoplankton growth

PAR_{ML} : mean daily-integrated PAR over the mixed or mixing layer

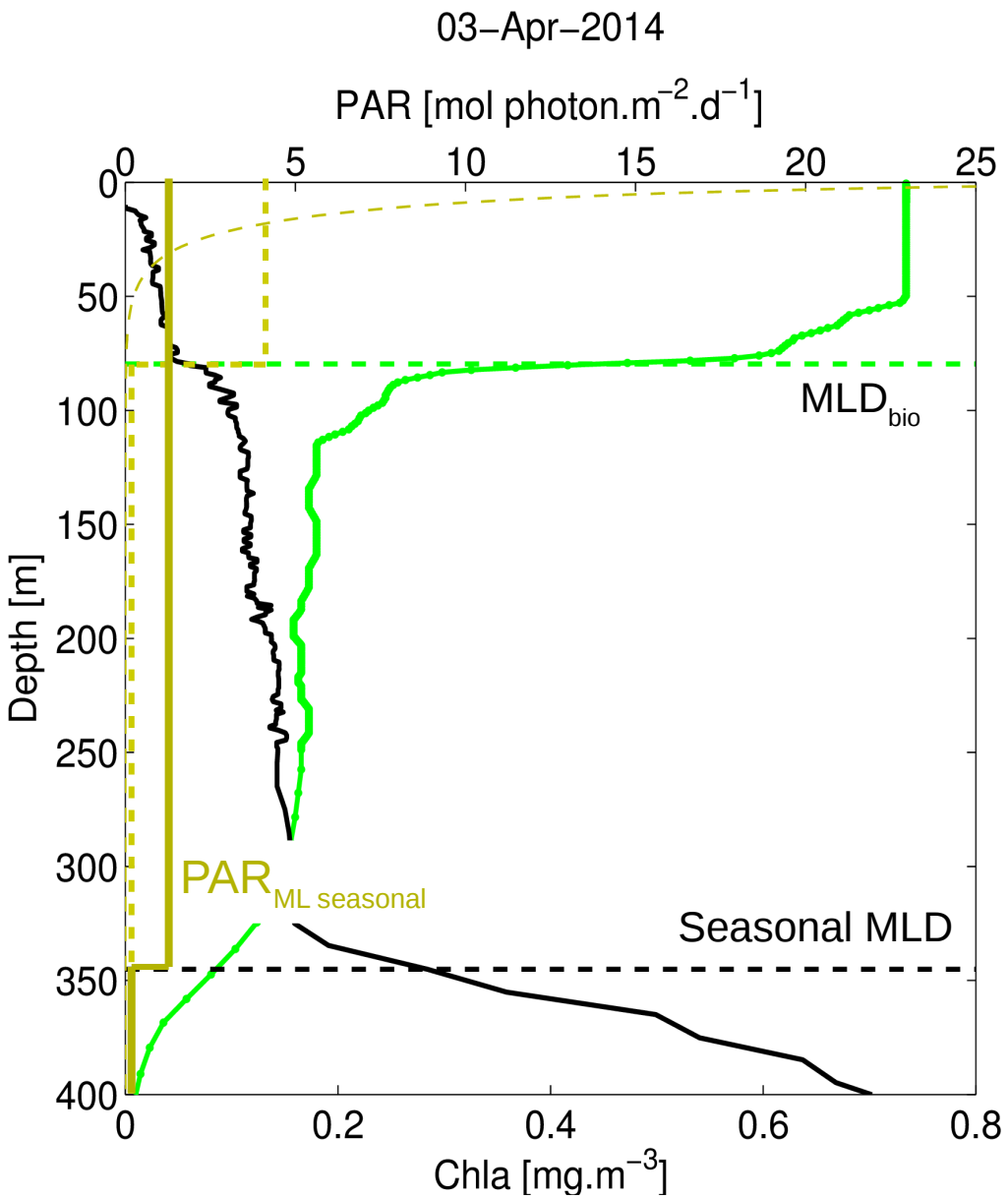


Light availability over the mixing layer

- $PAR_{ML\ bio}$ = 4.6 mol photon.m^{-2}.d^{-1}

Light availability for phytoplankton growth

PAR_{ML} : mean daily-integrated PAR over the mixed or mixing layer



Light availability over the diurnal mixing layer

- $PAR_{ML\ bio}$ = 4.6 mol photon.m^{-2}.d^{-1}

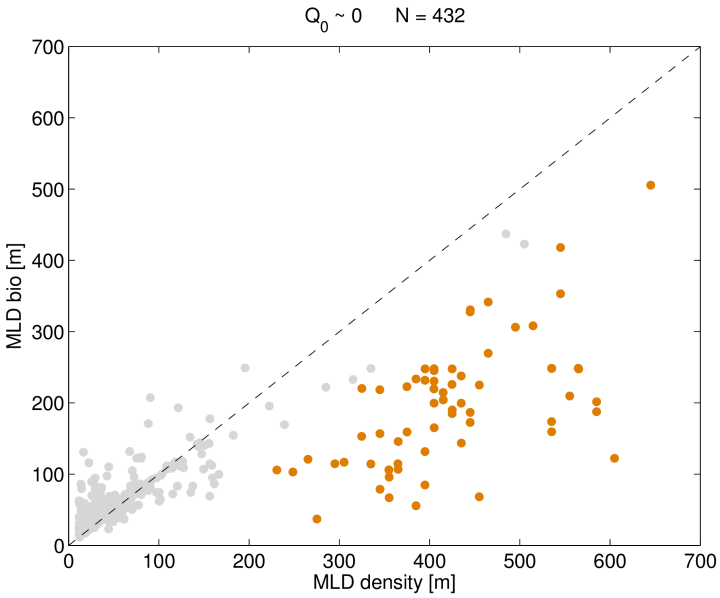
Light availability over the seasonal mixed layer

- $PAR_{ML\ seasonal}$ = 1.2 mol photon.m^{-2}.d^{-1}

Influence of the diurnal cycle on the light availability

On 69 spring profiles

→ mean underestimation of 57 % of the light availability for phytoplankton growth by ignoring the diurnal cycle of the mixing layer depth



- Diurnal cycle is already included in several circulation models focusing on atmosphere-ocean coupling (Bernie et al. 2007, 2008)
- The short time scale variability seems to affect the long term behaviour of the system
- Considering short time scale variability, such as diurnal cycle of the mixing layer depth is essential to understand the bloom dynamics

Conclusion

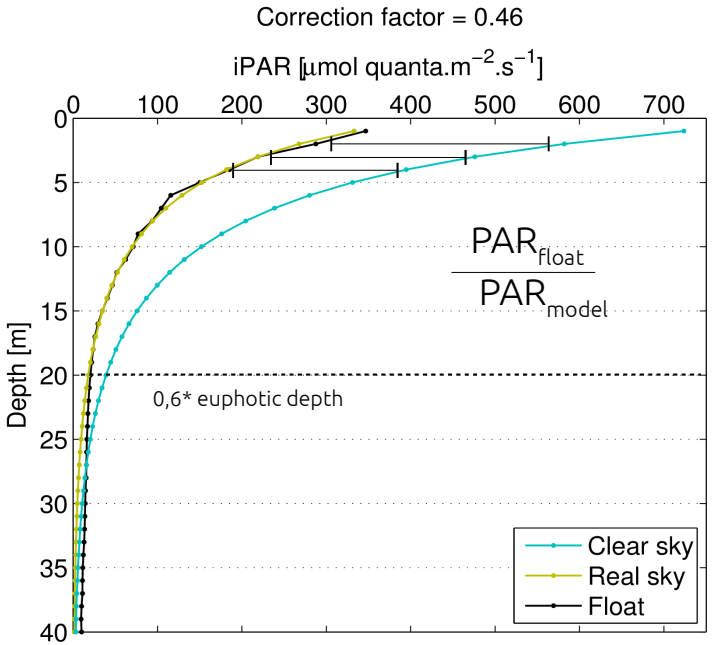
- MLD_{bio} is a good indicator of the recent mixed layer depth, with a short time scale, typical of phytoplankton growth

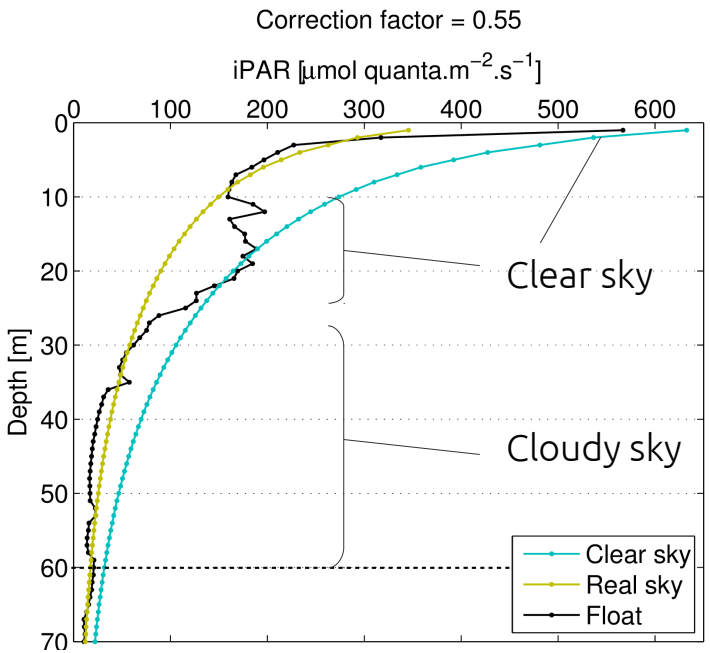
- Diurnal variability of the mixing layer could have a strong influence on the light availability for phytoplankton growth

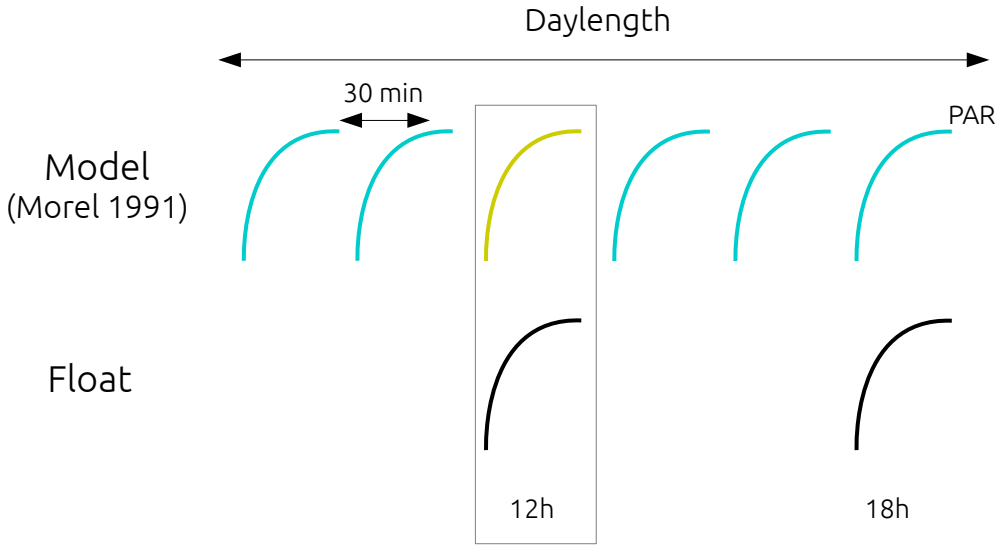
- Differentiate the mixing from the mixed layer depth is essential to understand the bloom dynamics

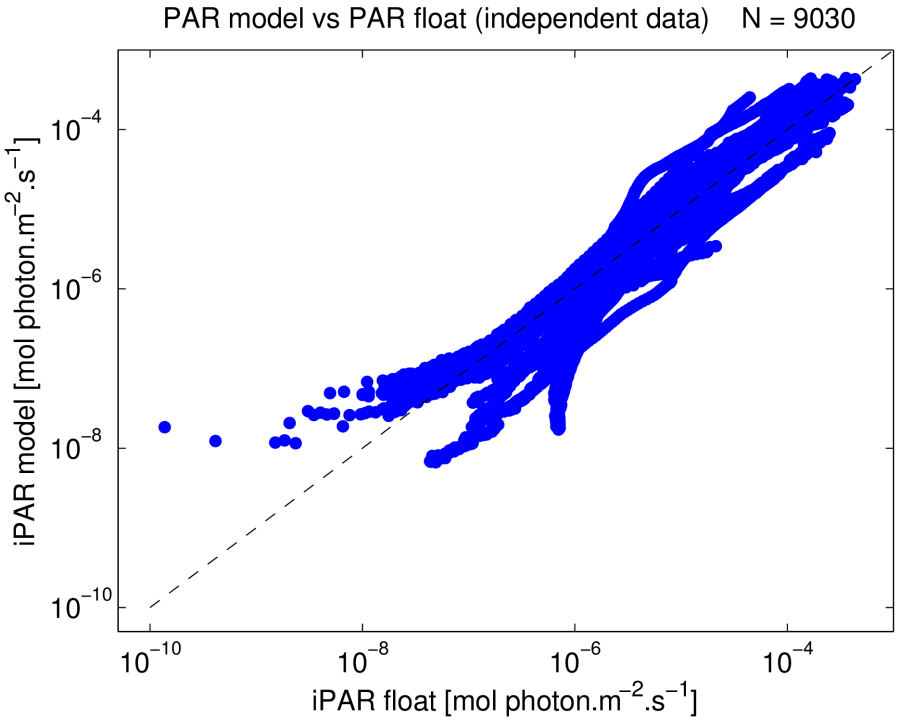
Thank you for your attention!

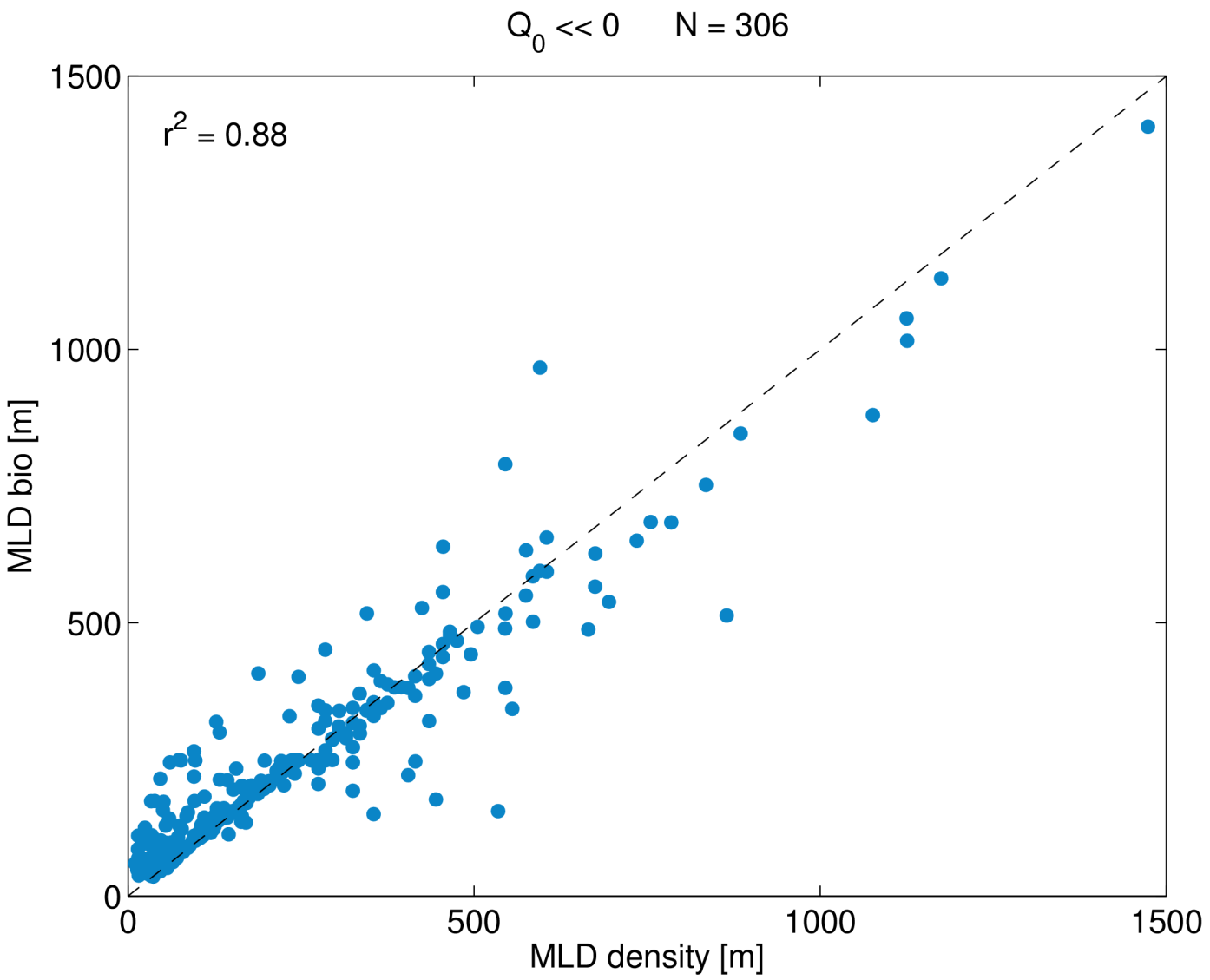
PAR model

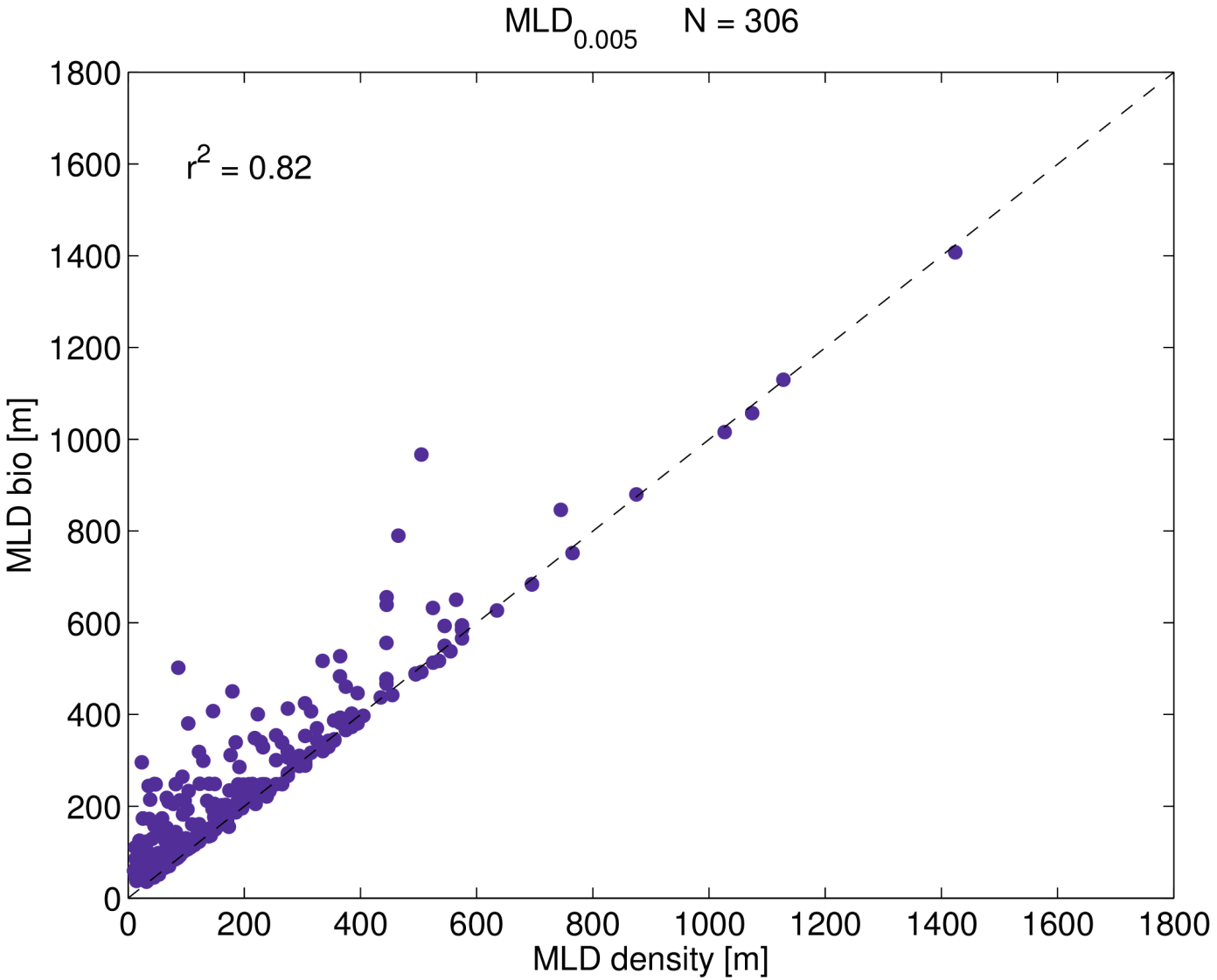

Correction factor = 0.46
iPAR [µmol quanta.m^{-2}.s^{-1}]
Depth [m]
$\frac{PAR_{float}}{PAR_{model}}$
0,6* euphotic depth
Clear sky
Real sky
Float

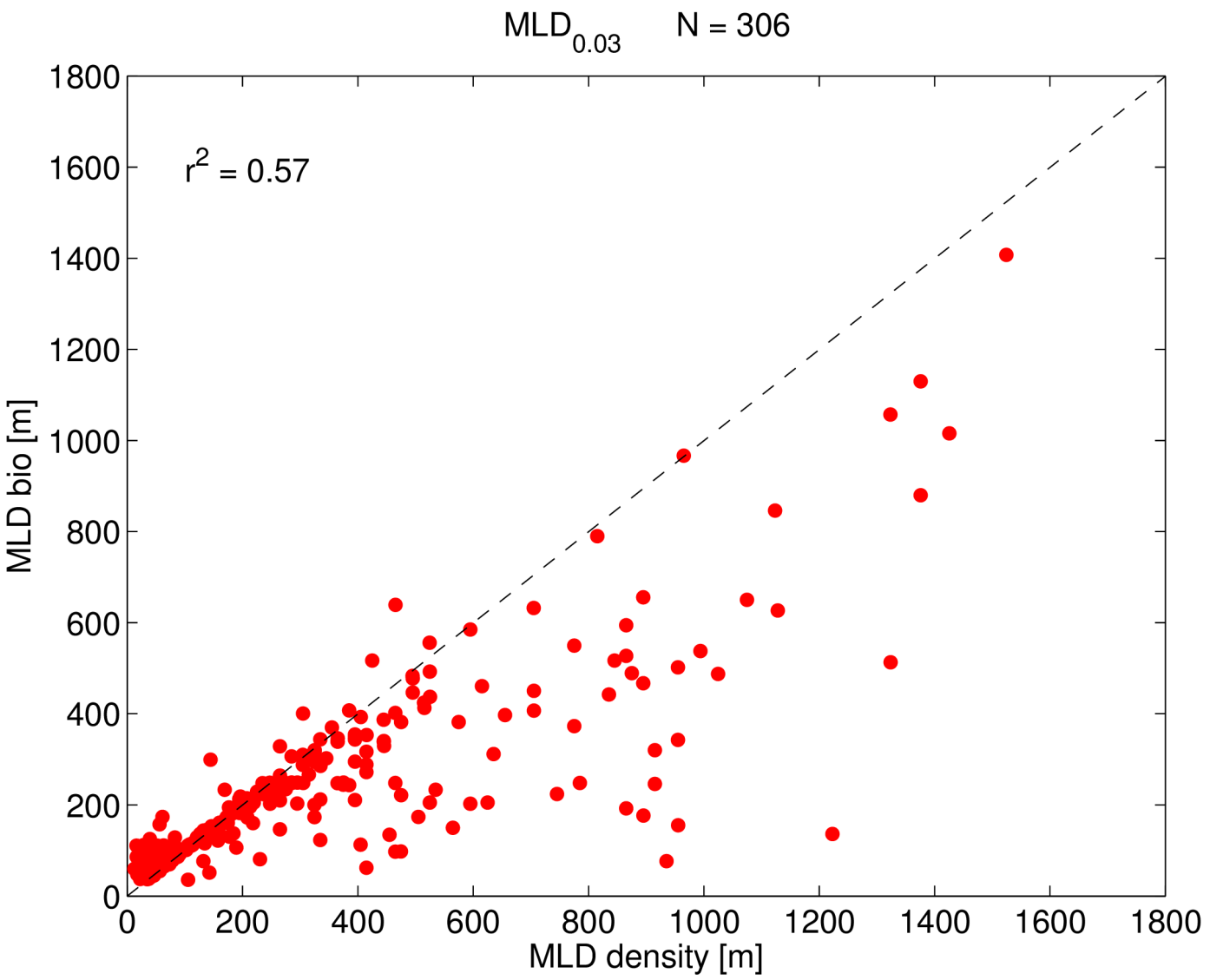

Correction factor = 0.55
iPAR [µmol quanta.m^{-2}.s^{-1}]
Depth [m]
Clear sky
Cloudy sky
Clear sky
Real sky
Float

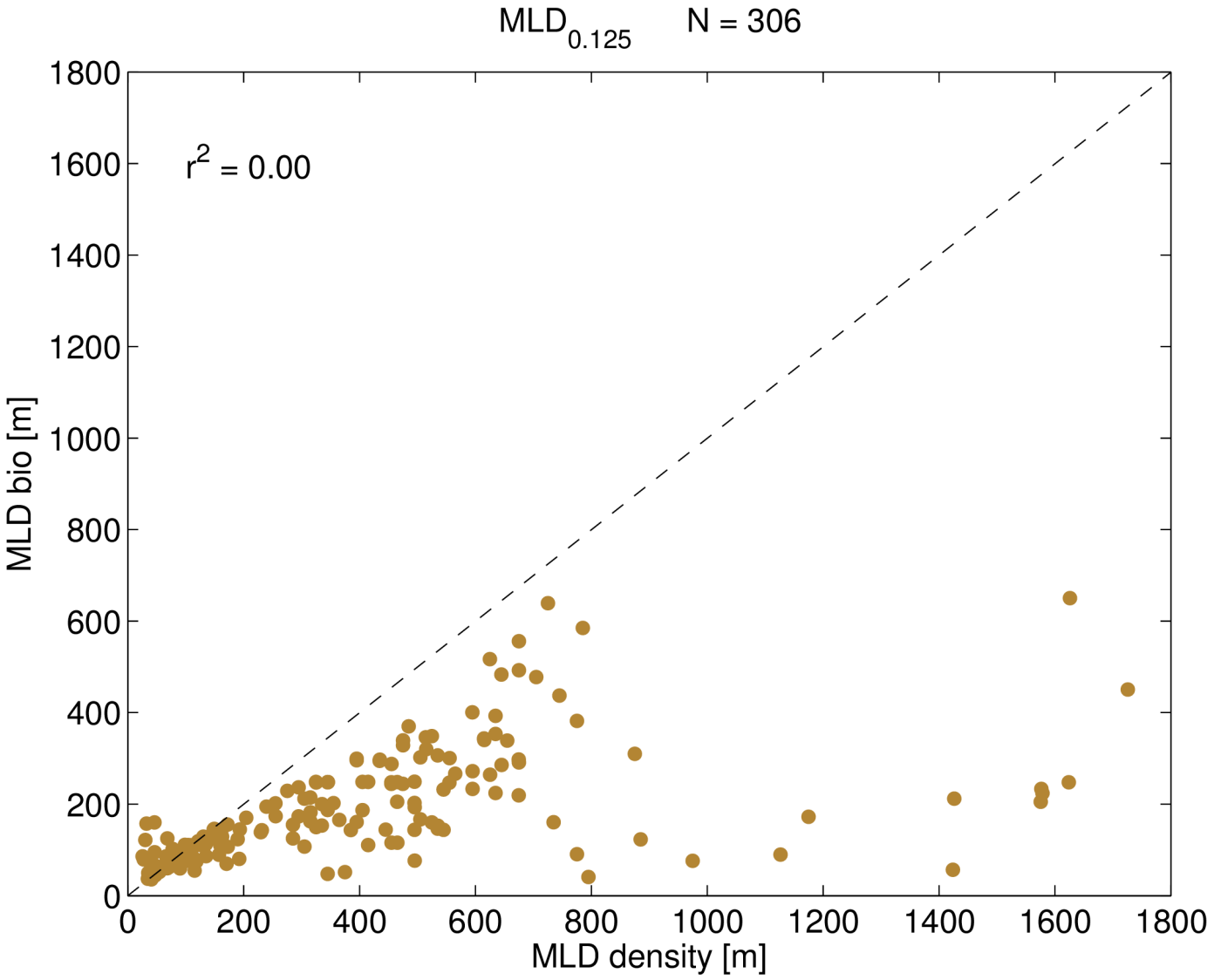

Daylength
30 min
Model
(Morel 1991)
PAR
Float
12h
18h


PAR model vs PAR float (independent data) N = 9030
iPAR model [mol photon.m^{-2}.s^{-1}]
iPAR float [mol photon.m^{-2}.s^{-1}]


Q_0 << 0 N = 306
r^2 = 0.88
MLD bio [m]
MLD density [m]
0
500
1000
1500


MLD0.005 N = 306
r2 = 0.82
MLD bio [m]
MLD density [m]
0
200
400
600
800
1000
1200
1400
1600
1800


MLD0.03 N = 306
r2 = 0.57
MLD bio [m]
MLD density [m]
0
200
400
600
800
1000
1200
1400
1600
1800


MLD0.125 N = 306
r2 = 0.00
MLD bio [m]
MLD density [m]
0
200
400
600
800
1000
1200
1400
1600
1800