Effect of algae on flocculation of suspended bed-sediments in a large shallow lake

consequences for ecology and sediment transport processes.

M. A. de Lucas Pardo[1,2], TUDelft & Deltares
J. C. Winterwerp[1,2], TUDelft & Deltares

SedNet, Krakow, Poland, 23-25 September 2015

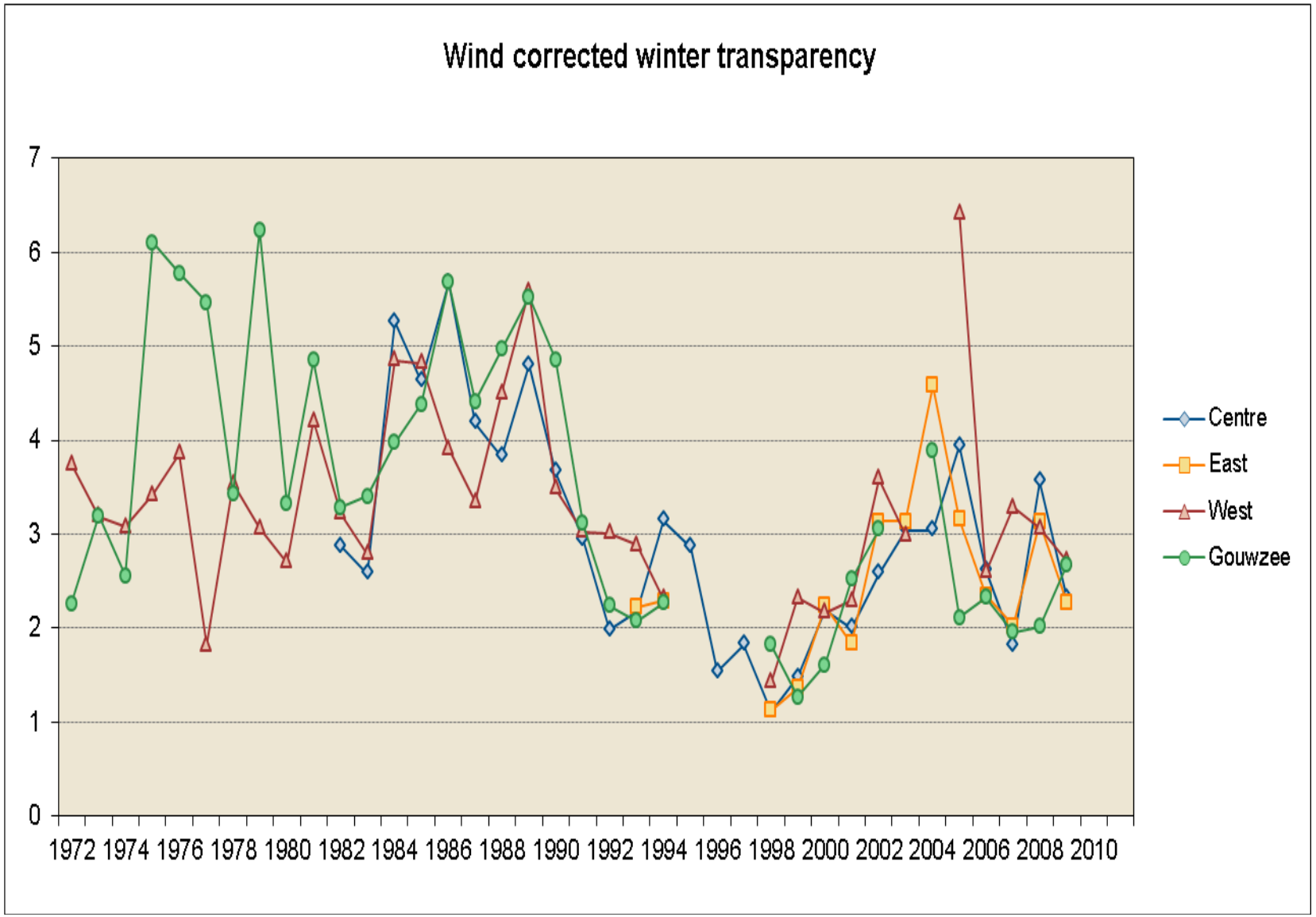
Index

- Introduction and hypotheses
- Methodology
- Small-scale flocculation experiments
  - Bed sediments
  - Blue-green algae
  - Mutual flocculation between algae and bed sediments
- Conclusions
- Relevance

Introduction and hypothesis

Study site: Markermeer

	background concentration	maximum concentration
Markermeer	30 (mg/l)	250 (mg/l)
Ketelmeer	5 (mg/l)	100 (mg/l)
Lake Balaton (Hungary)	15 (mg/l)	170 (mg/l)


Wind corrected winter transparency
7
6
5
4
3
2
1
0
1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010
Centre
East
West
Gouwzee

Introduction and hypothesis

Previous work (diatoms)

- *van Leussen 1994* diatoms enhance flocculation
- *van der Lee 2000* large aggregates during algae bloom
- *Sanford 2001* seasonal variation floc properties
- *Mikkelsen 2002* diatoms cause floc properties to vary
- *Fugate and Friedricks 2003* biological aggregation cause large particles
- *Lunau 2006* Chl *a* and size are correlated

- *Verspagen 2006* pure clay and cyanobacteria
- *Verney 2009* lab measurements, diatom bloom increase flocculation rate

Deeper into mechanism behind algae-sediments flocculation, broader range of hydrodynamics, two specific algae species

Introduction and hypothesis

Hypothesis

- **Hypothesis 1:**
  "In the ***Markermeer***, suspended sediments, mobilized form the bed, can ***flocculate***, attaining an equilibrium floc size which is a function of the turbulence level"

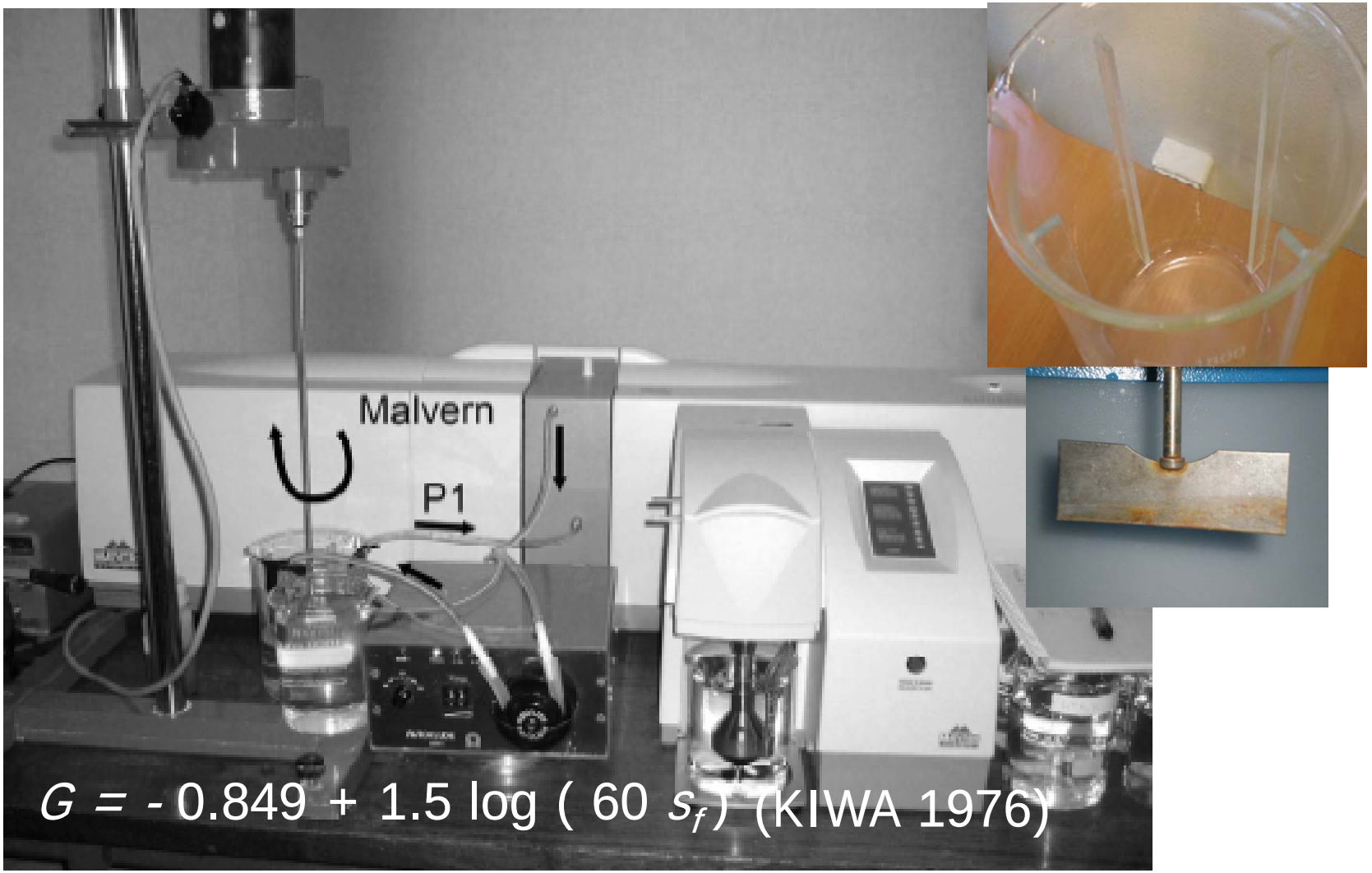
- **Hypothesis 2:**
  "***Algae*** and ***suspended sediments*** can ***flocculate***, affecting **floc properties** and **light climate** in the water column"

- **Hypothesis 3:**
  "The ***characteristics*** of the resulting organic-inorganic ***flocs*** depend on the ***type of algae*** added to the suspension.

Methodology

- Small-scale flocculation experiments (Jar Test)
  - Measurements of floc size (Malvern MasterSizer): D_{50} of FSD
  - and obscuration (Malver MasterSizer)
    - Obscuration: % of either absorbed or scattered light from the laser beam in the particle sizer.
    - Obscuration is a measure of turbidity induced by suspension (we don't know equivalence with NTU or other)
    - Δnumber of fines or Δconcentration $\longrightarrow$ Δobscuration
    - Δfloc size or settling $\longrightarrow$ - Δobscuration

Methodology



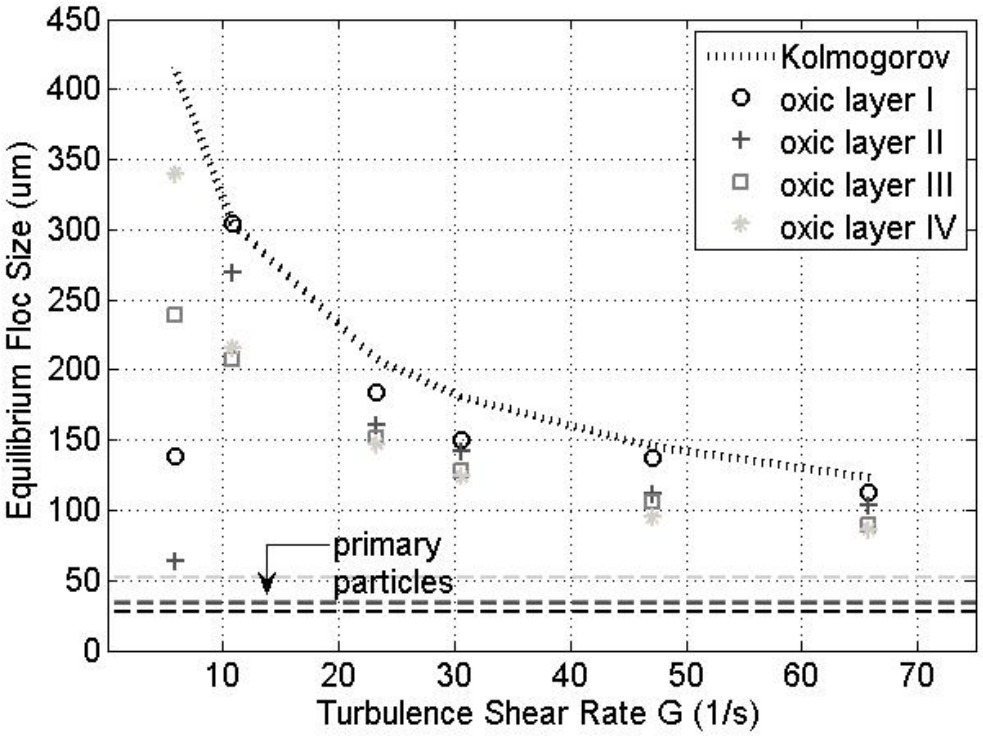
Methodology

	$G = 65\ s^{-1}$	$G = 47\ s^{-1}$	$G = 30\ s^{-1}$	$G = 23\ s^{-1}$	$G = 11\ s^{-1}$	$G = 6\ s^{-1}$
order	first	second	third	fourth	fifth	sixth
initial size of flocs	Primary particles	Equilibrium Floc Size from $G = 65\ s^{-1}$	Equilibrium Floc Size from $G = 47\ s^{-1}$	Equilibrium Floc Size from $G = 30\ s^{-1}$	Equilibrium Floc Size from $G = 23\ s^{-1}$	Equilibrium Floc Size from $G = 11\ s^{-1}$

All experiments with Markermeer filtered water (2microns), Markermeer bed-sediments, and Markermeer algae species

Results

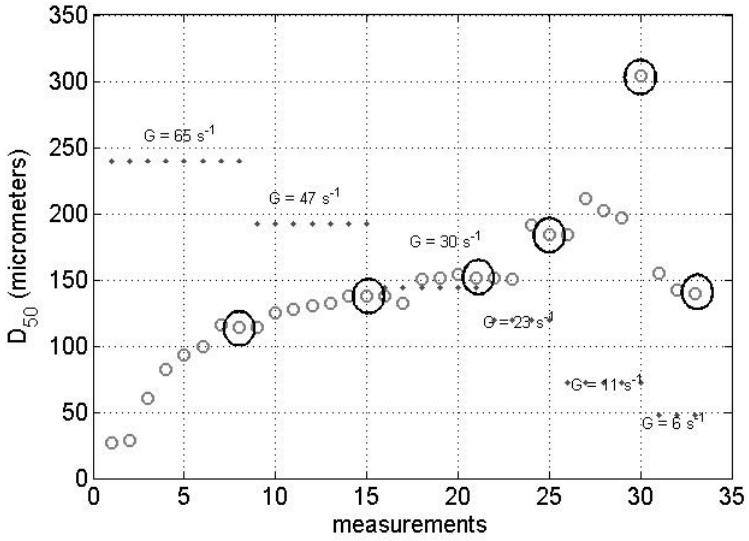
Bed sediments



	$G = 65\ s^{-1}$	$G = 47\ s^{-1}$	$G = 30\ s^{-1}$	$G = 23\ s^{-1}$	$G = 11\ s^{-1}$	$G = 6\ s^{-1}$
order	first	second	third	fourth	fifth	sixth
initial size of flocs	Primary particles	Equilibrium Floc Size from $G = 65\ s^{-1}$	Equilibrium Floc Size from $G = 47\ s^{-1}$	Equilibrium Floc Size from $G = 30\ s^{-1}$	Equilibrium Floc Size from $G = 23\ s^{-1}$	Equilibrium Floc Size from $G = 11\ s^{-1}$

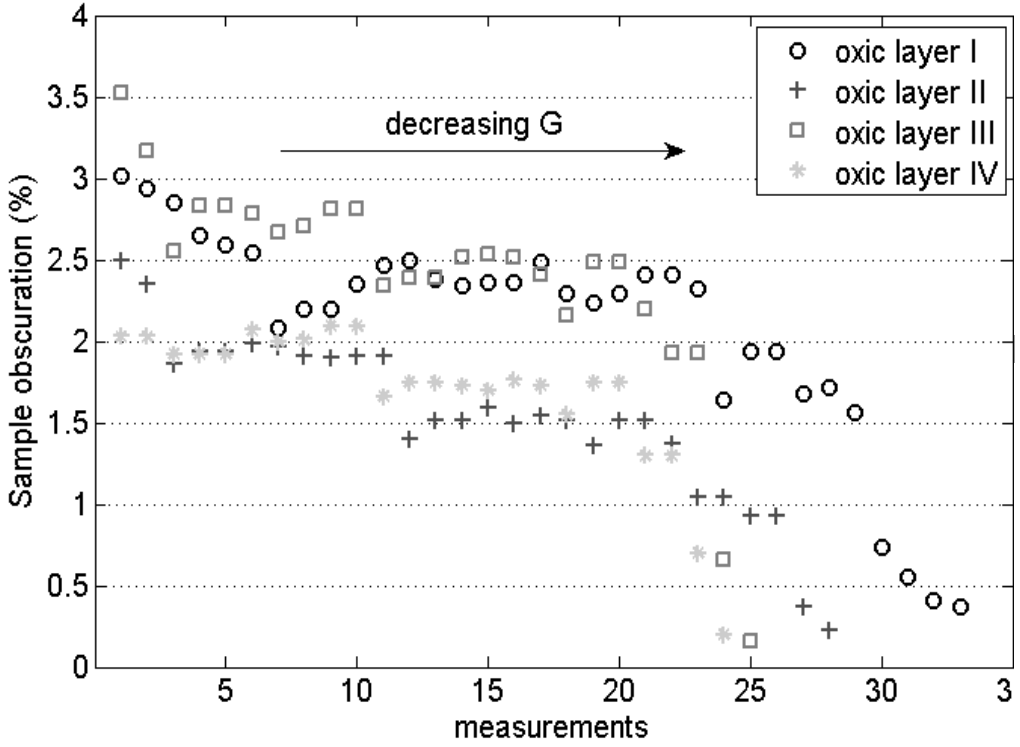
Hypothesis 1:

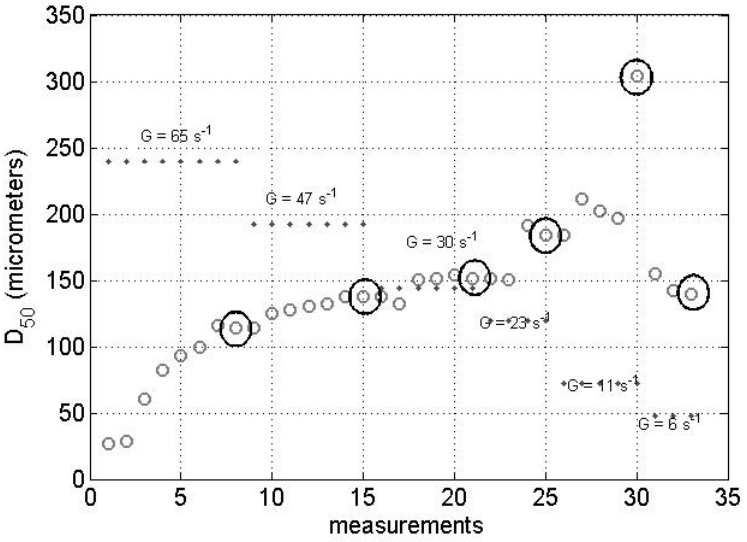
"In the ***Markermeer***, suspended sediments, mobilized form the bed, can ***flocculate***, attaining an equilibrium floc size which is a function of the turbulence level"

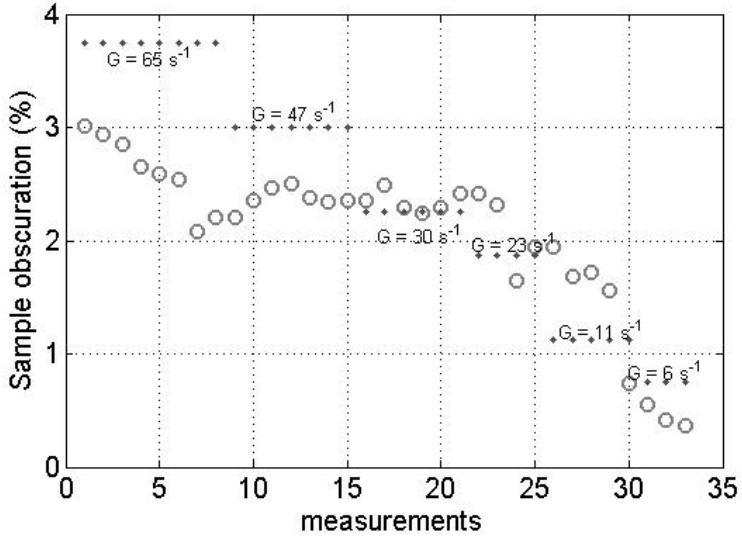


Results

Bed sediments

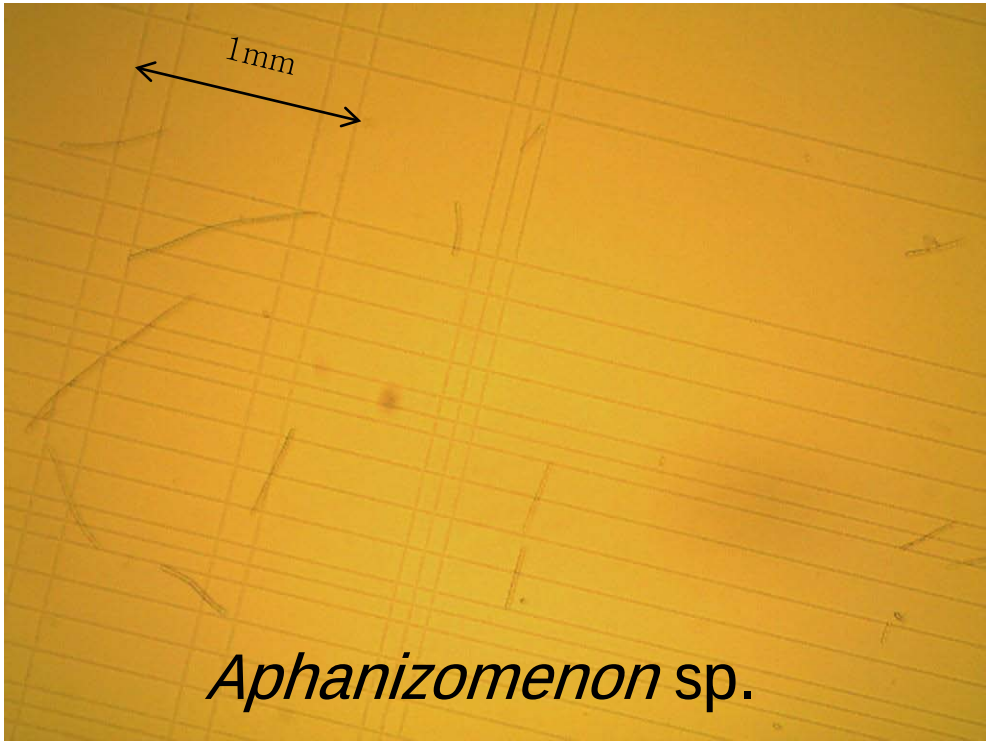






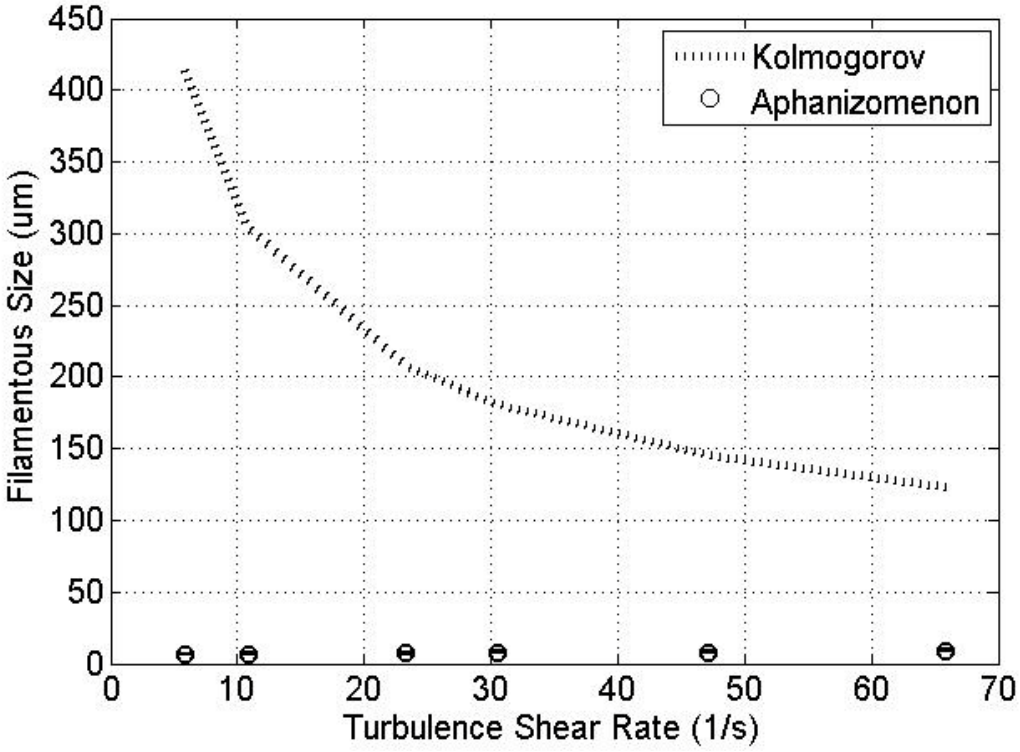
Results

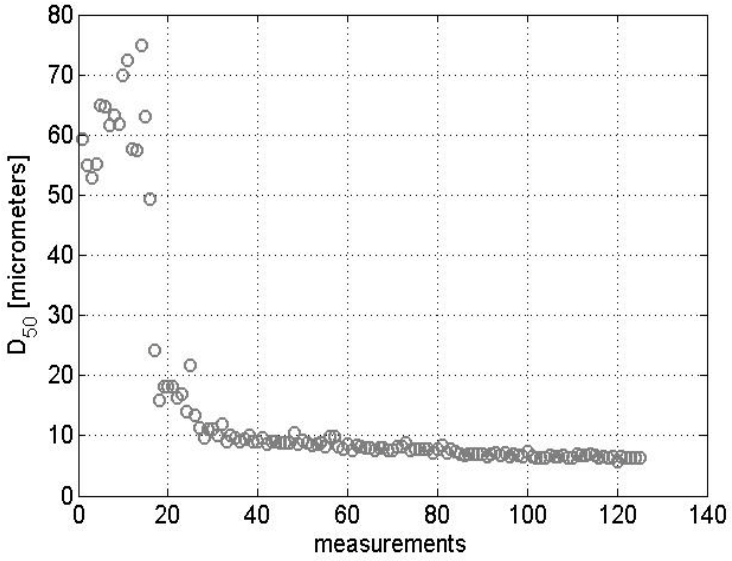
Behaviour of algae



Results

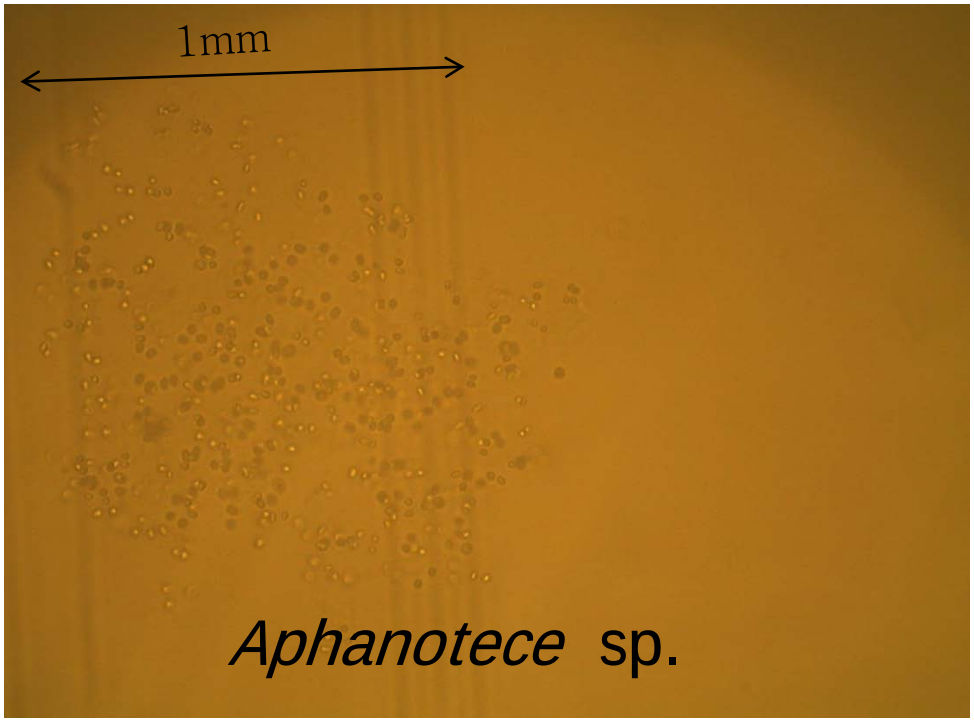
Behaviour of algae





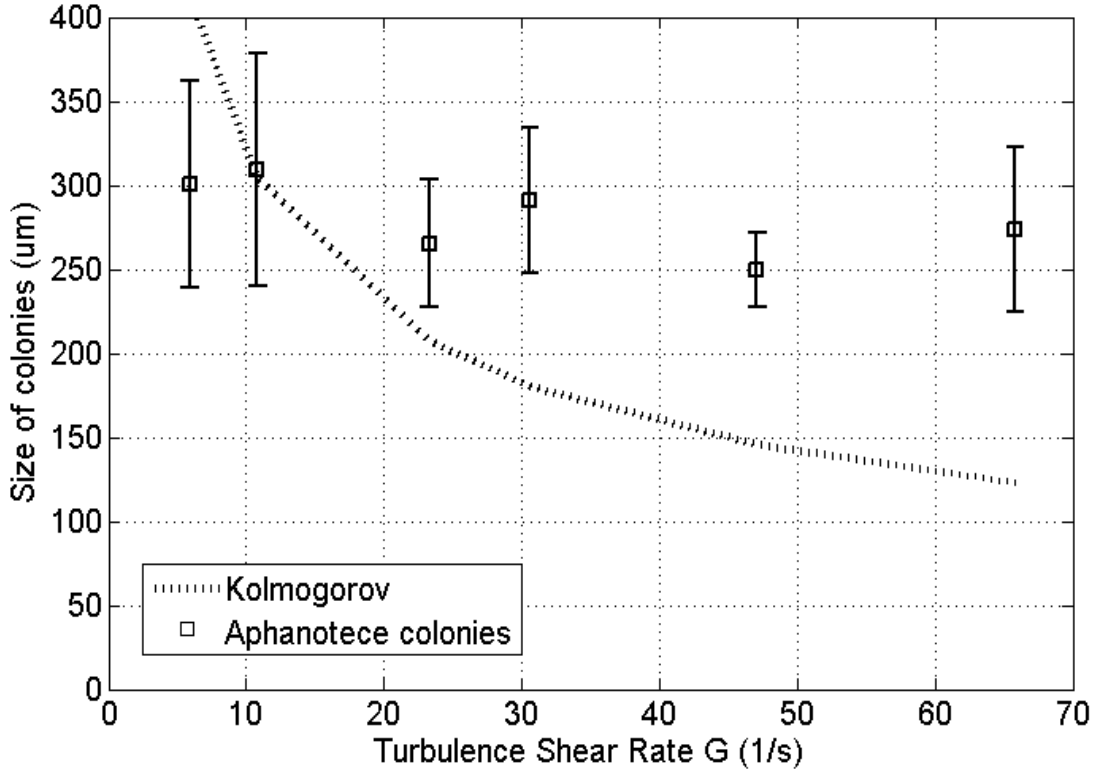
Results

Behaviour of algae



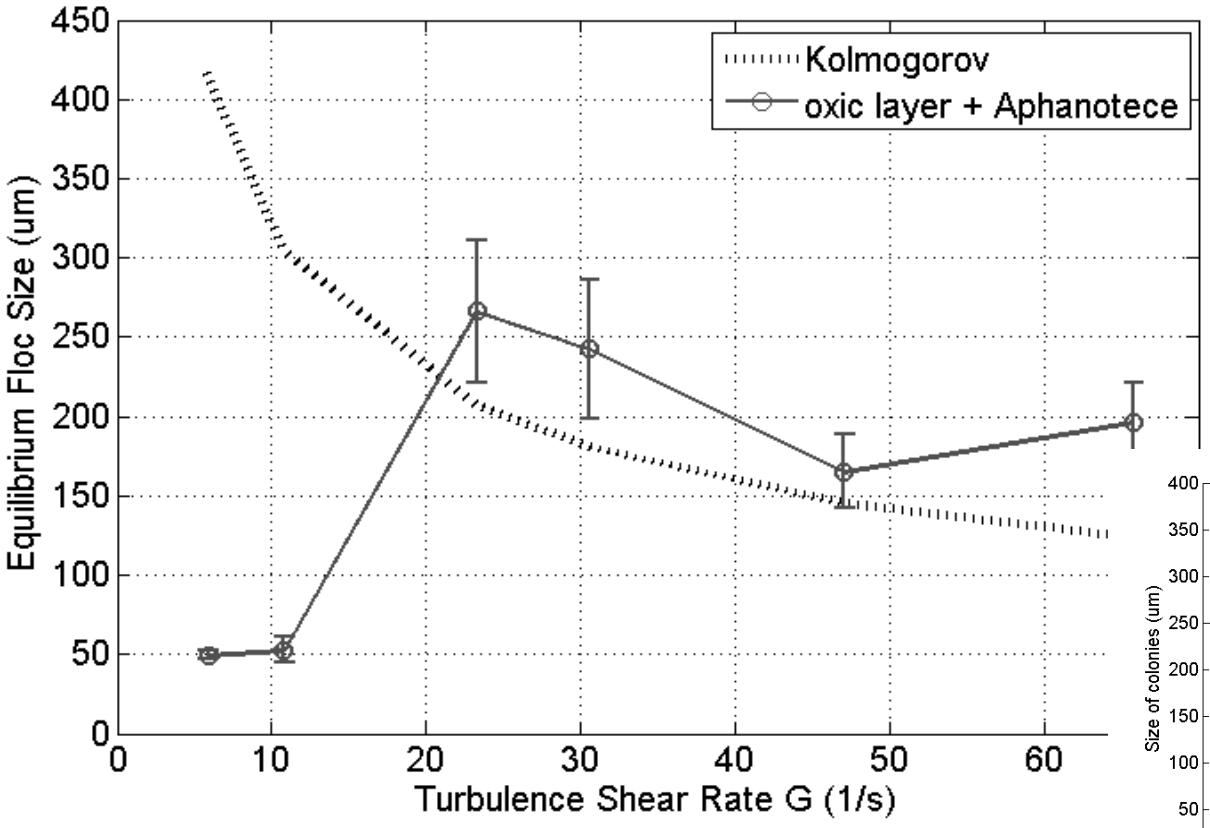
Results

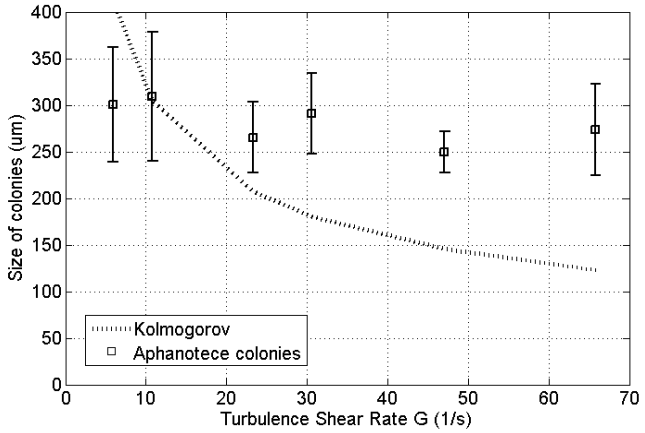
Behaviour of algae



Results

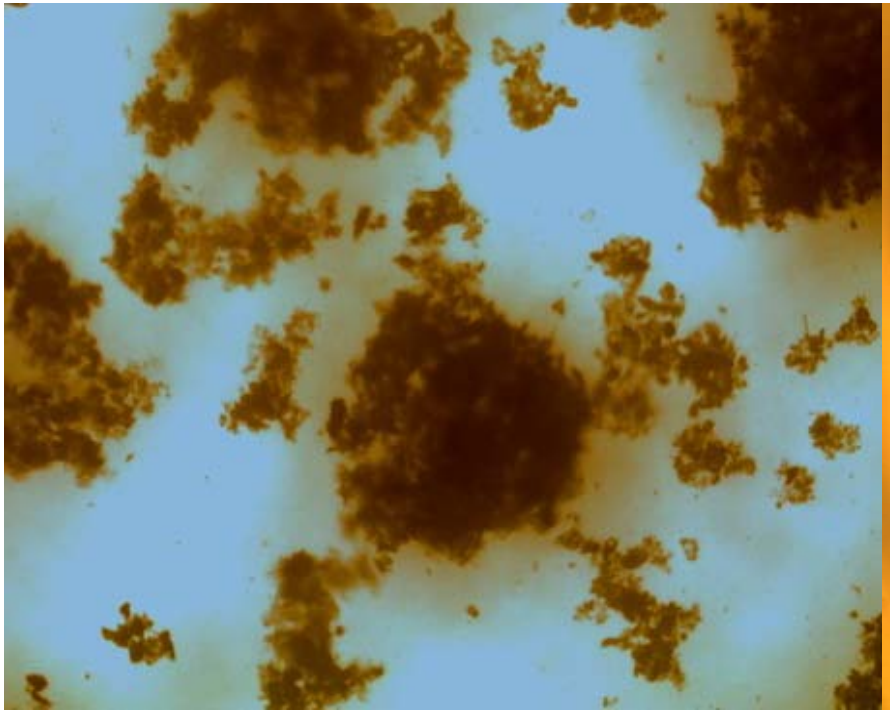
Aphanotece and bed sediments

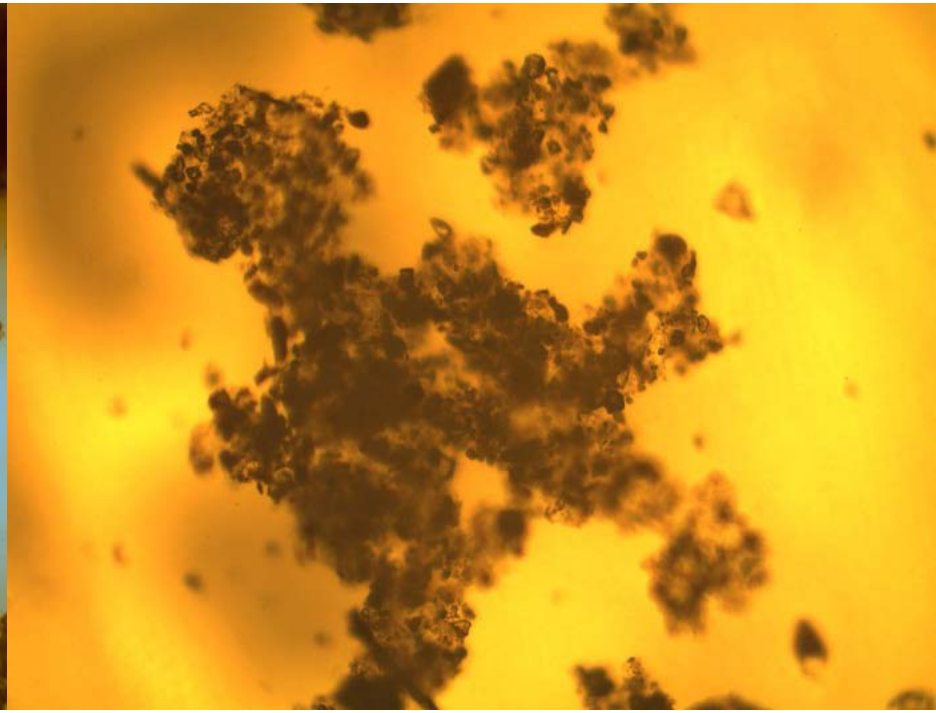




Results

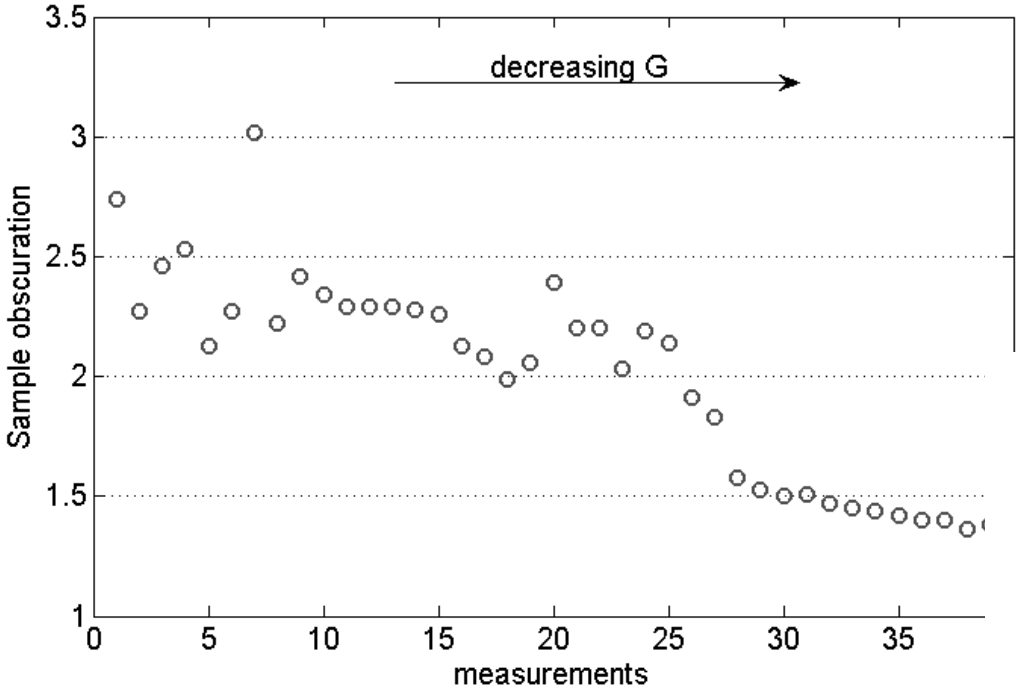
Aphanotece and bed sediments

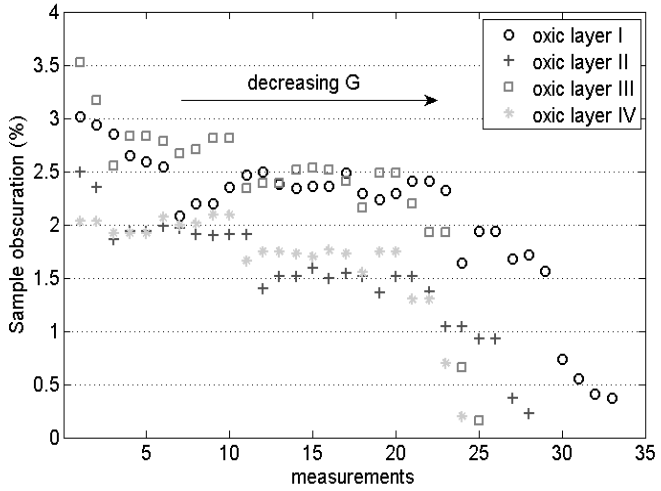




Results

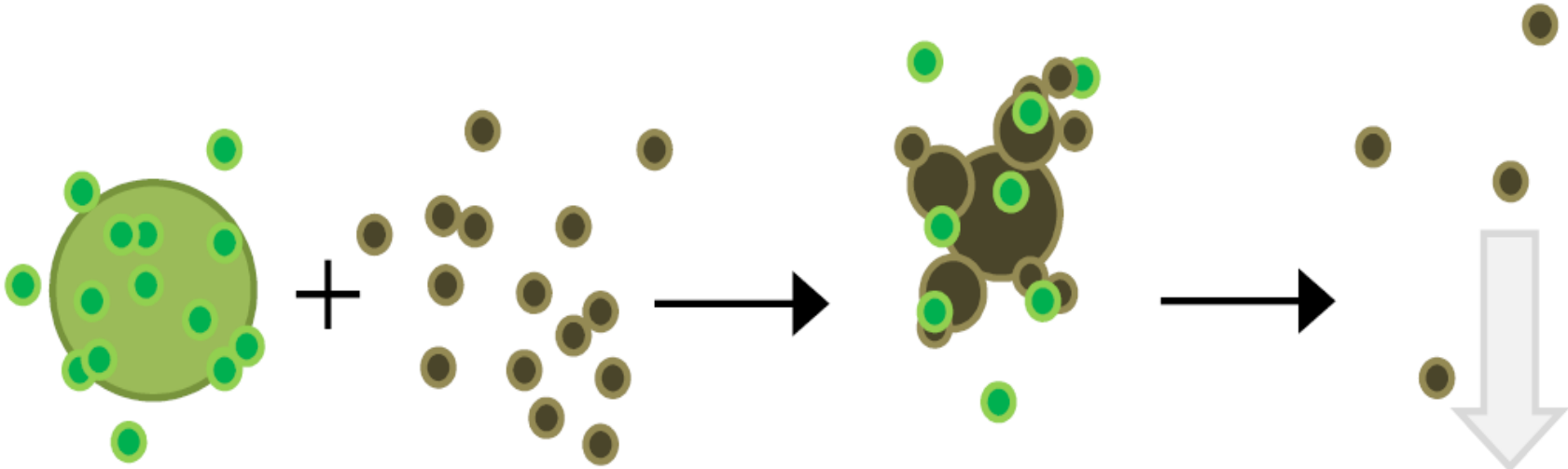
Aphanotece and bed sediments





Results

Aphanotece and bed sediments



Aphanotece colonies

Inorganic sediments (primary particles)

Organic-inorganic floc: grows as G decreases

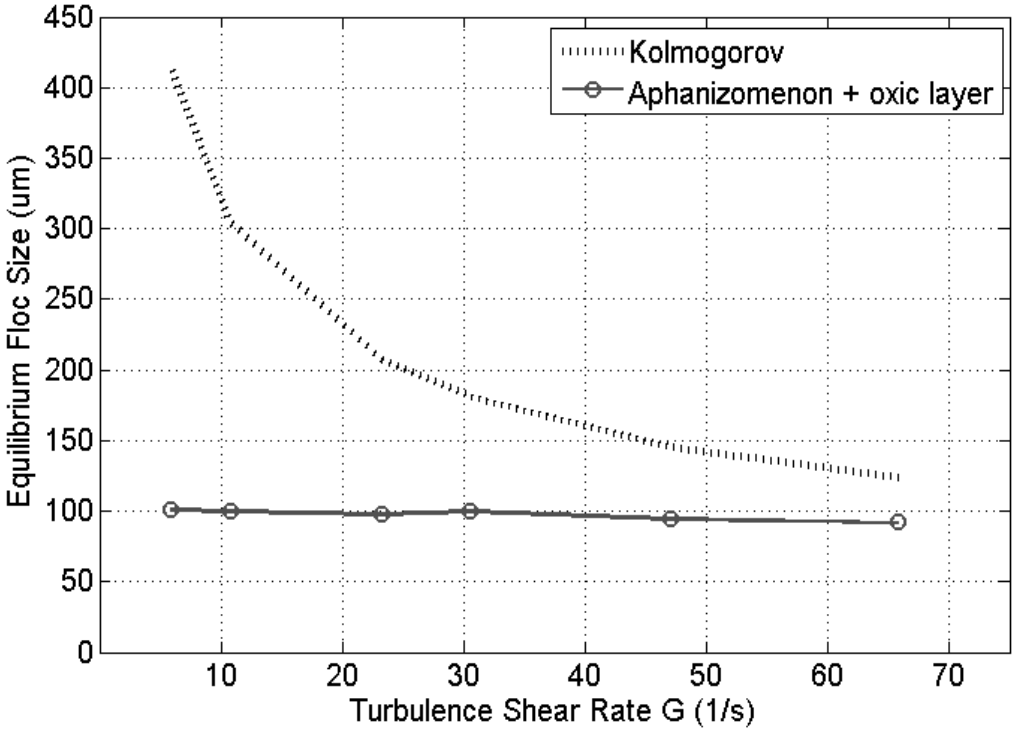
These flocs continue growing until settling, with only few inorganic fines left in the water column

Hypothesis 2 (partly):

"***Algae*** and ***suspended sediments*** can ***flocculate***, affecting floc properties"

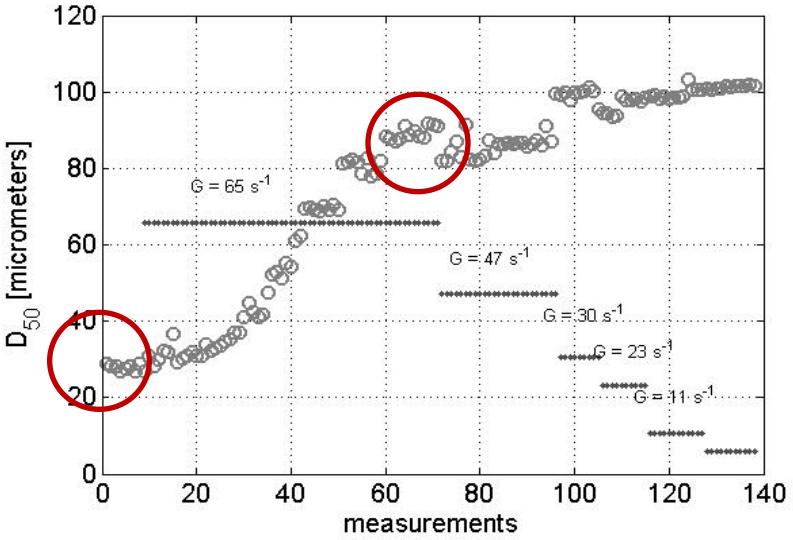
Results

Aphanizomenon and bed sediments



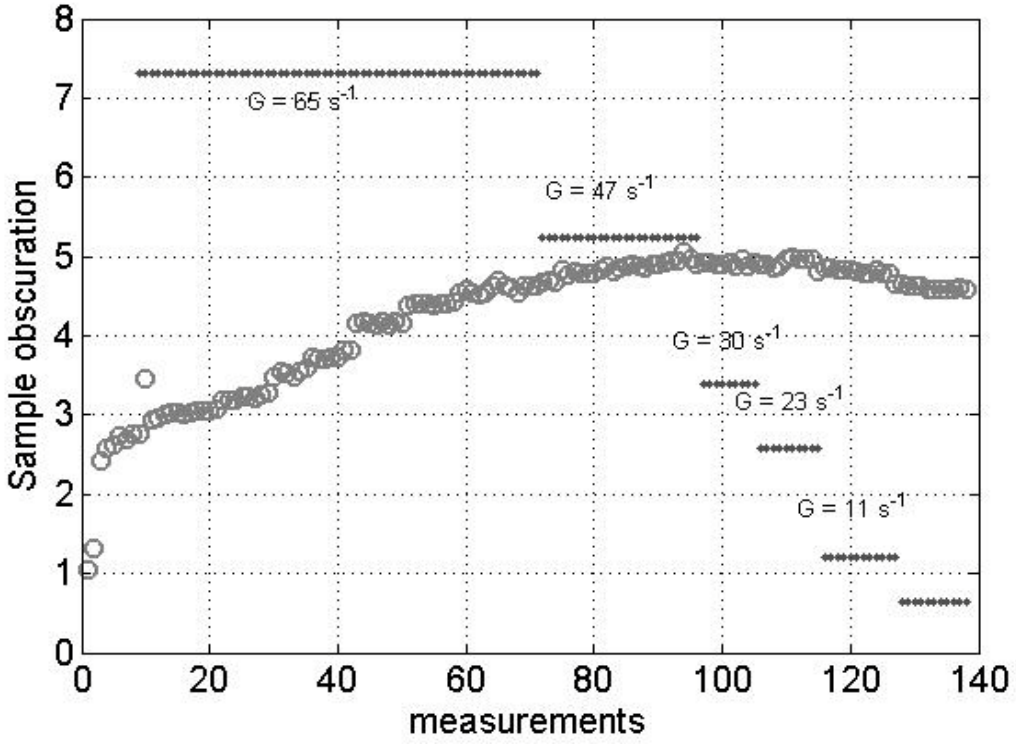
$5 \cdot 10^3$ filaments/ml
$12.5 \cdot 10^3$ flocs/ml

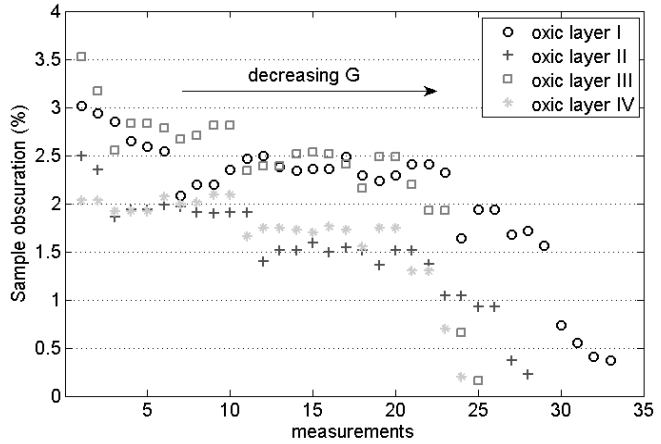
$4 \cdot 10^3$ filaments/ml
$0.5 \cdot 10^3$ floc/ml

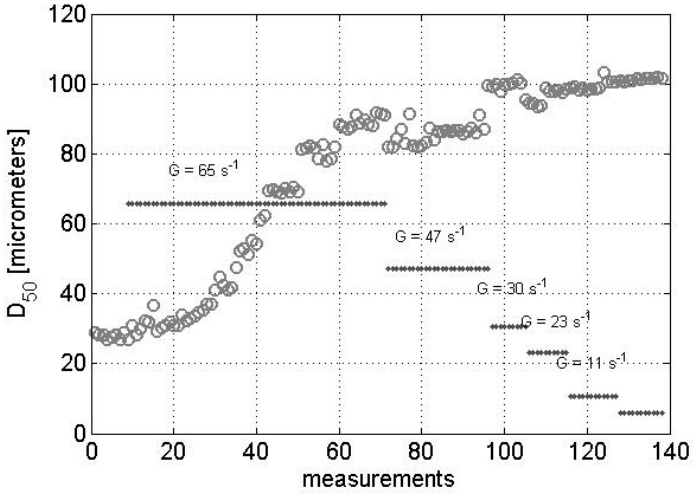


Results

Aphanizomenon and bed sediments

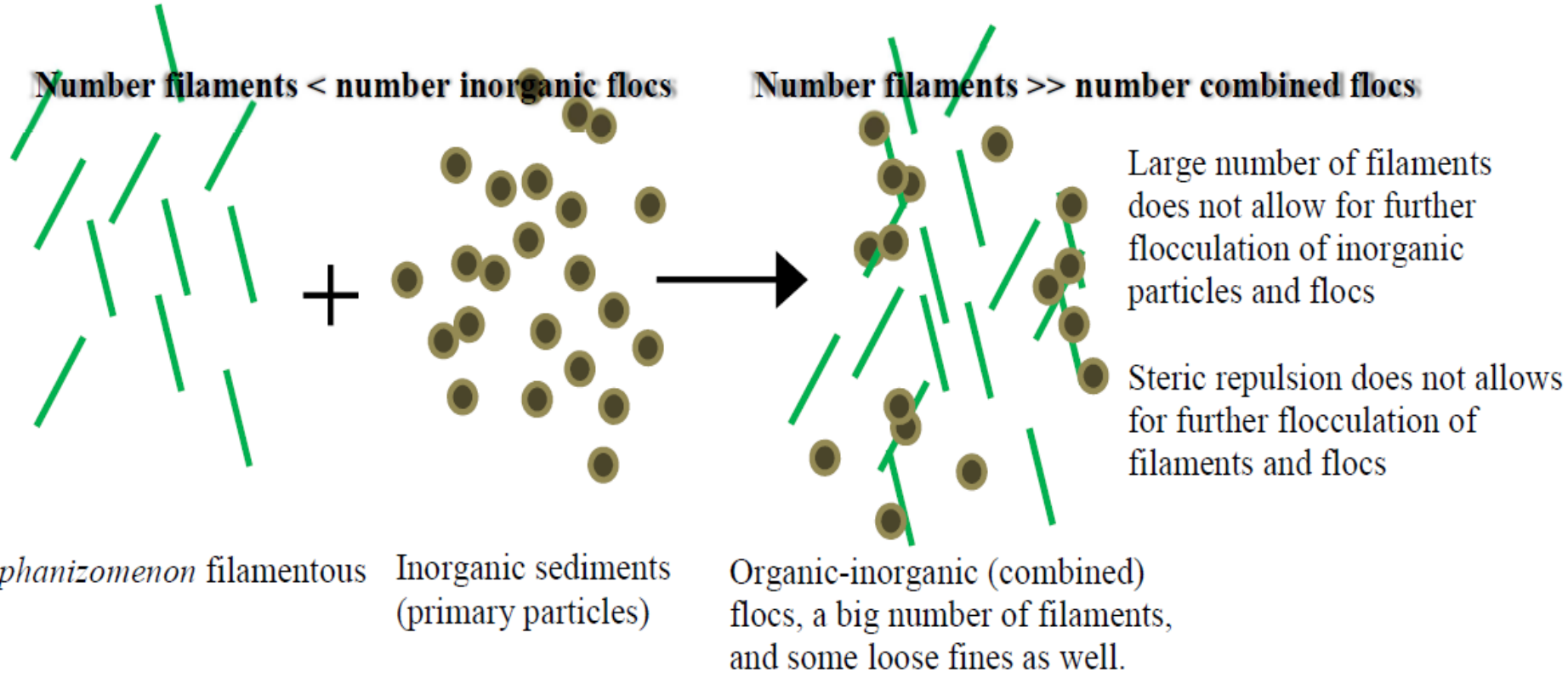




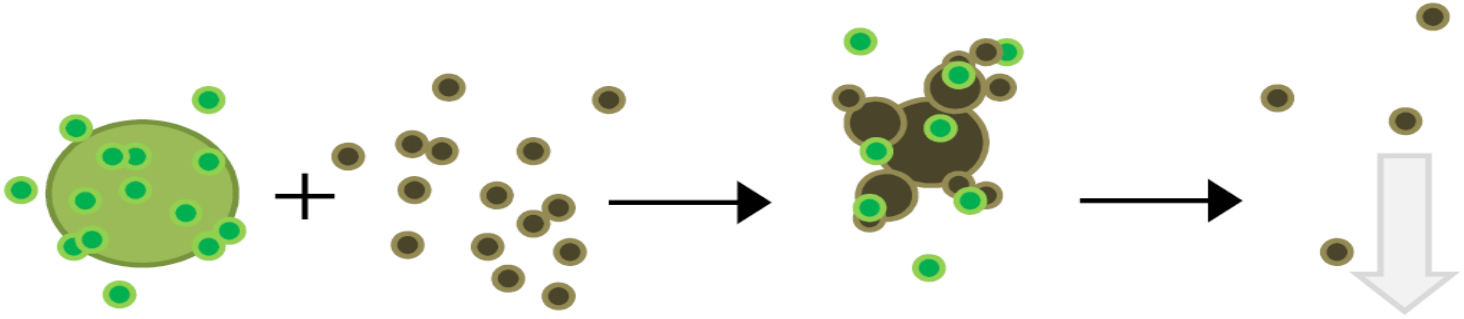


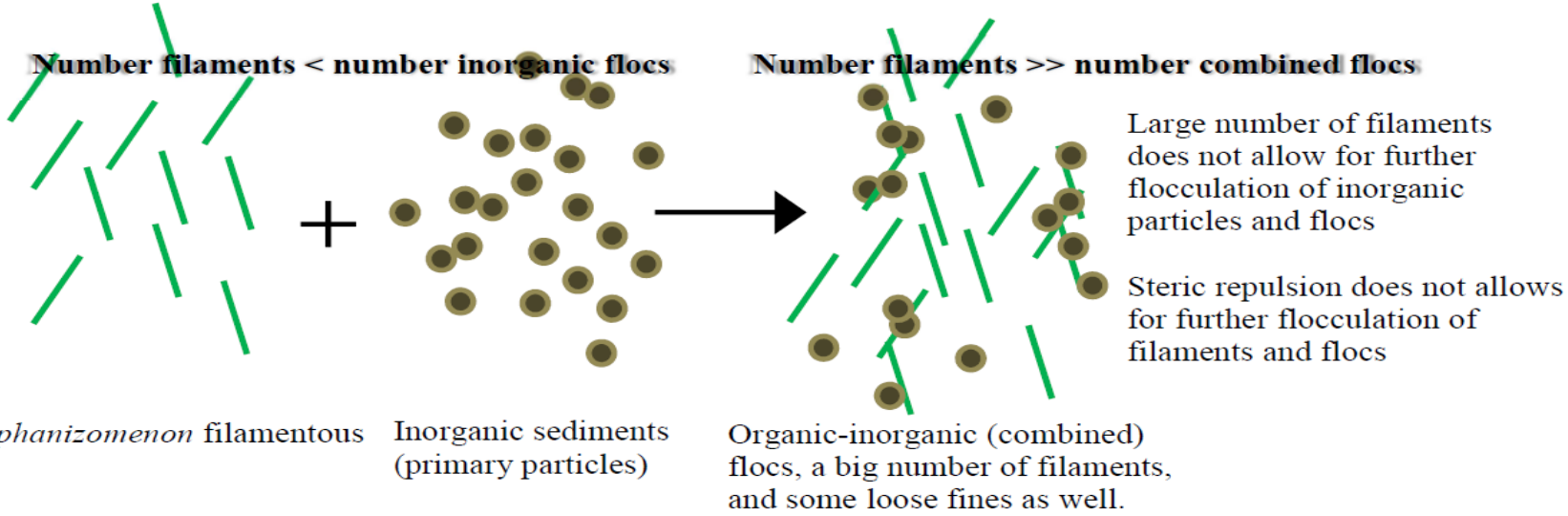
Results

Aphanizomenon and bed sediments



Decrease of 1000 filaments after final counting





Hypothesis 3: "The ***characteristics*** of the resulting organic-inorganic ***flocs*** depend on the ***type of algae*** added to the suspension.

Hypothesis 2 (partly): "***Algae*** and ***suspended sediments*** can ***flocculate***, affecting light climate in the water column"

Conclusions

- "In the ***Markermeer***, suspended sediments, mobilized form the bed, can ***flocculate***, attaining an equilibrium floc size which is a function of the turbulence level"

- "***Algae*** and ***suspended sediments*** can ***flocculate***, affecting floc properties and light climate in the water column"

- "The ***characteristics*** of the resulting organic-inorganic ***flocs*** depend on the ***type of algae*** added to the suspension.

Relevance

- This suggests that light climate is affected by mutual flocculation with algae. We suggest to consider this processes when studying historic turbidity trends.
- Ecology: Mussels and Daphnia filter algae to eat: aggregation with bed sediments makes it more difficult (maximum particle size that an animal can filter). Alteration in food chain.
- Chl *a* is not enough! Algae morphology (and surface charge properties?)
- Do algae always promote macroflocs? Not our filaments at field concentration

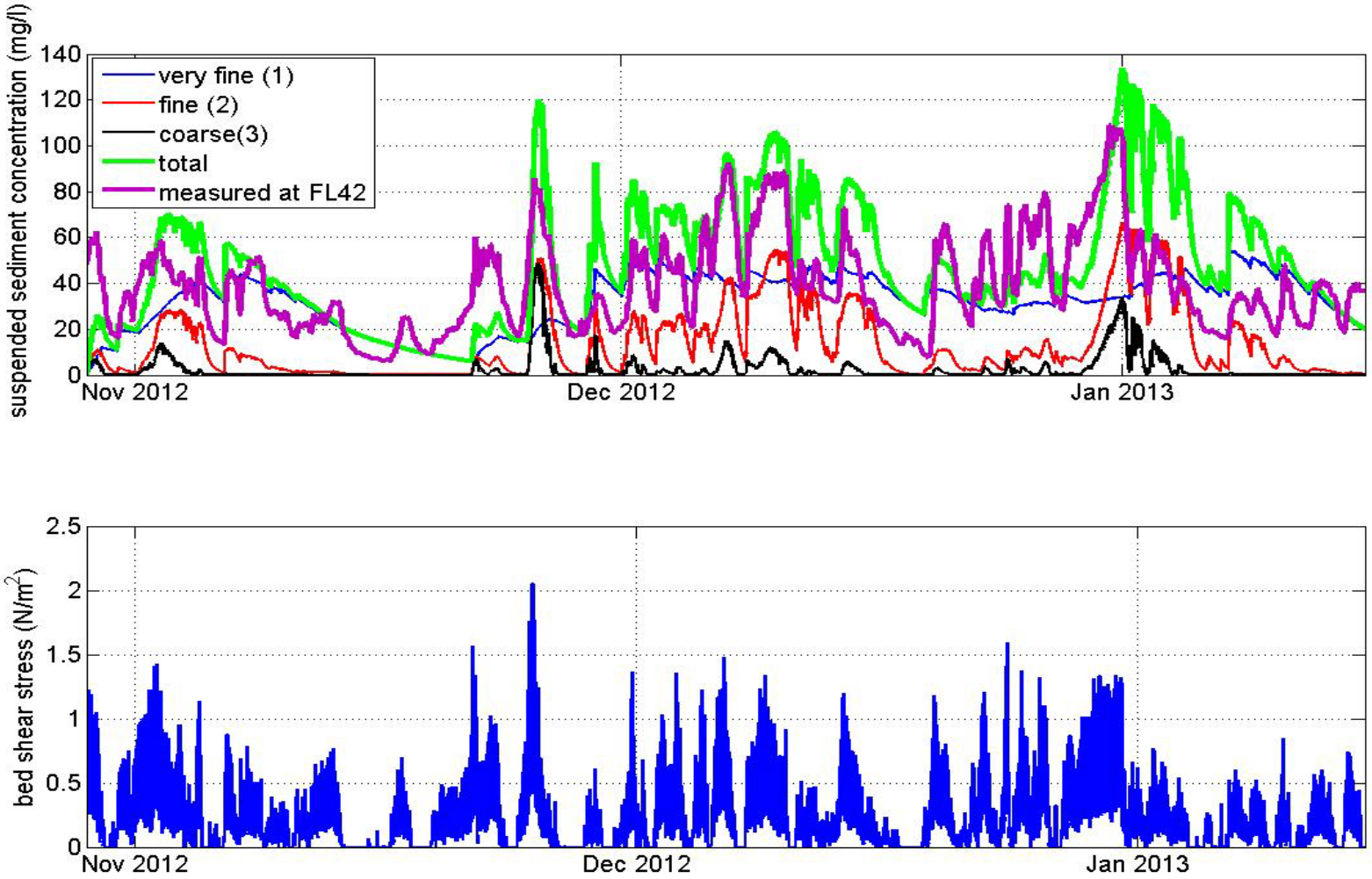
Thank you for your attention

- Any questions???

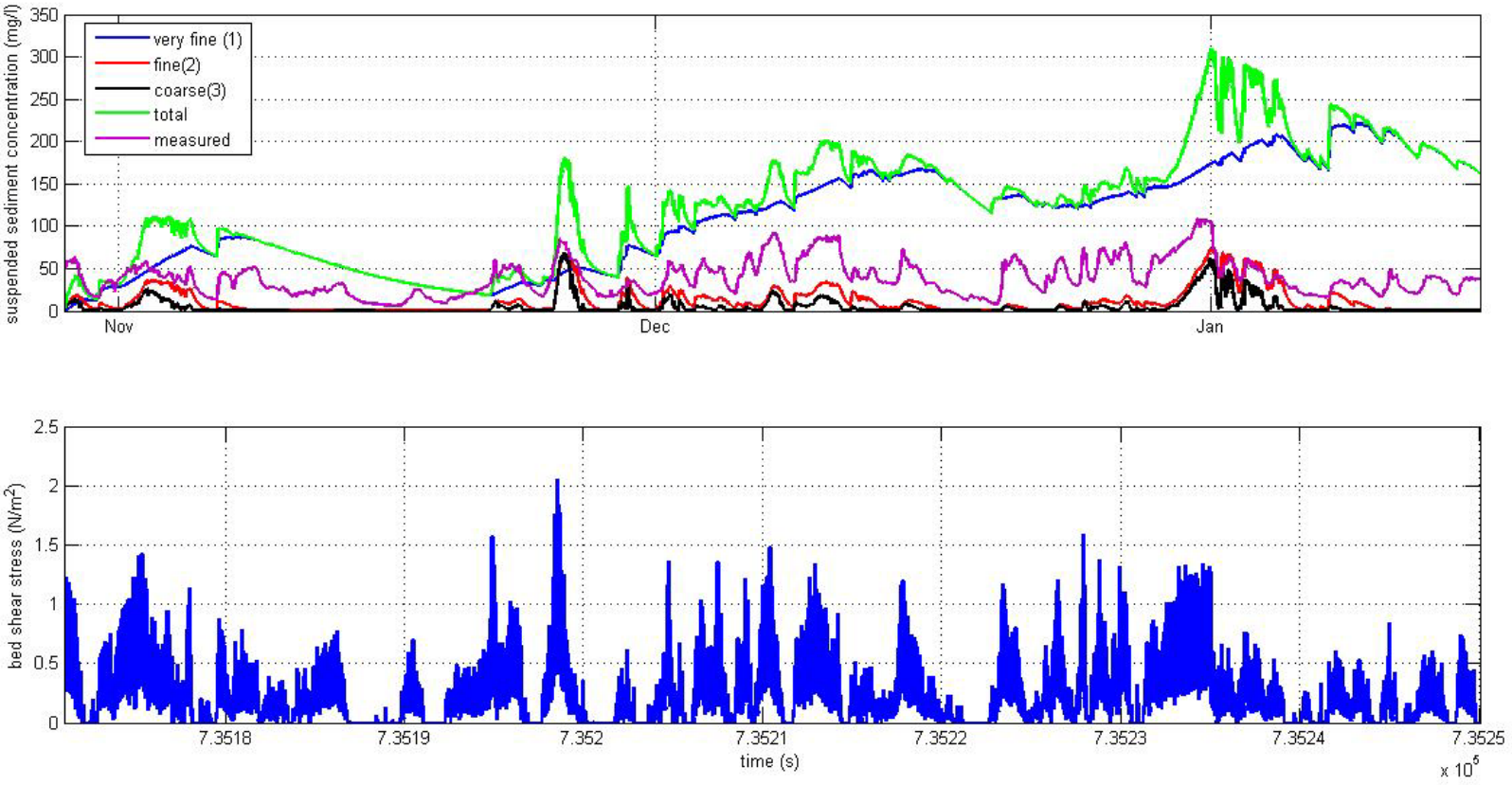
M. A. de Lucas Pardo[1,2], TUDelft & Deltares *miguel.delucaspardo@deltares.nl*

J. C. Winterwerp[1,2], TUDelft & Deltares

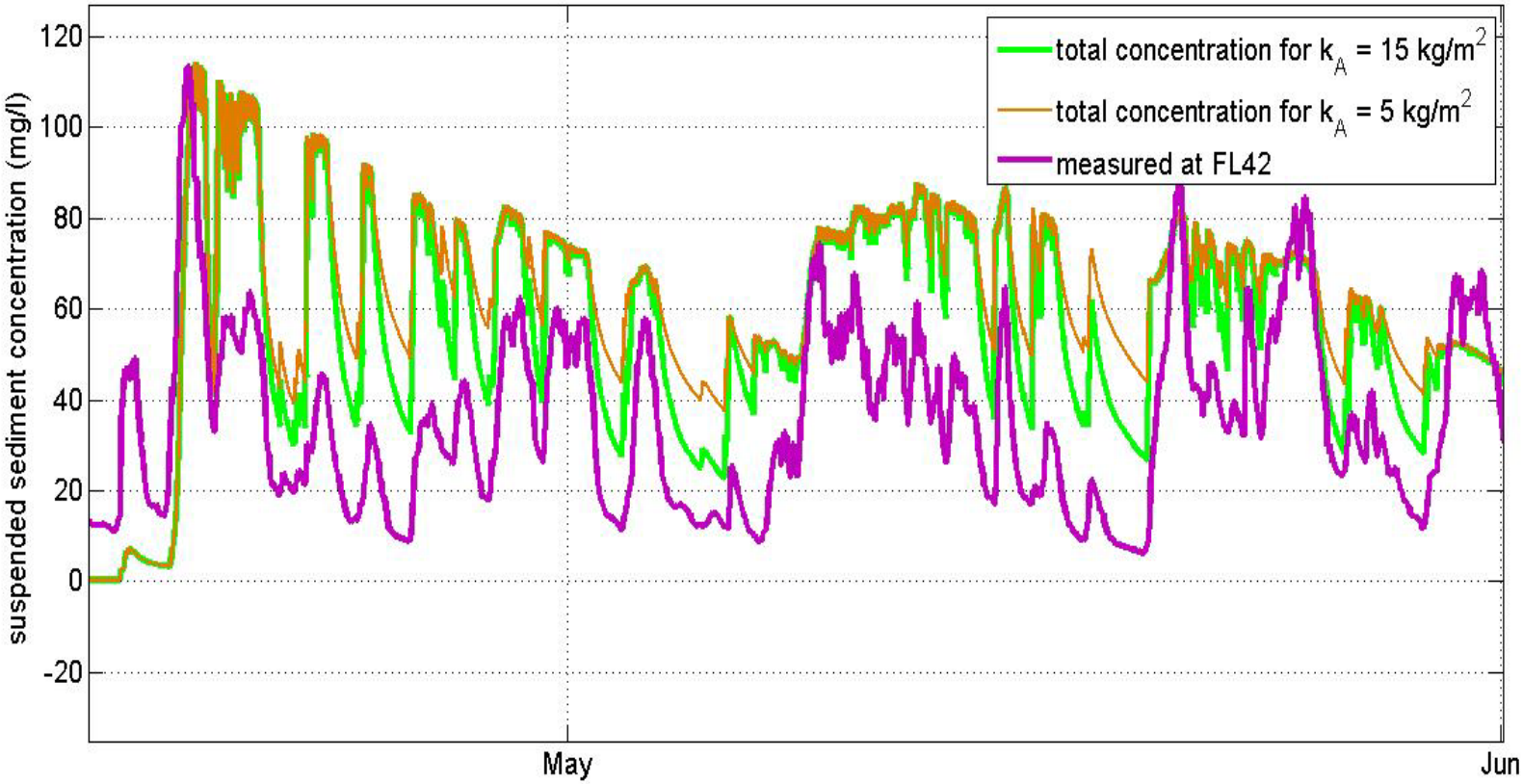
Relevance

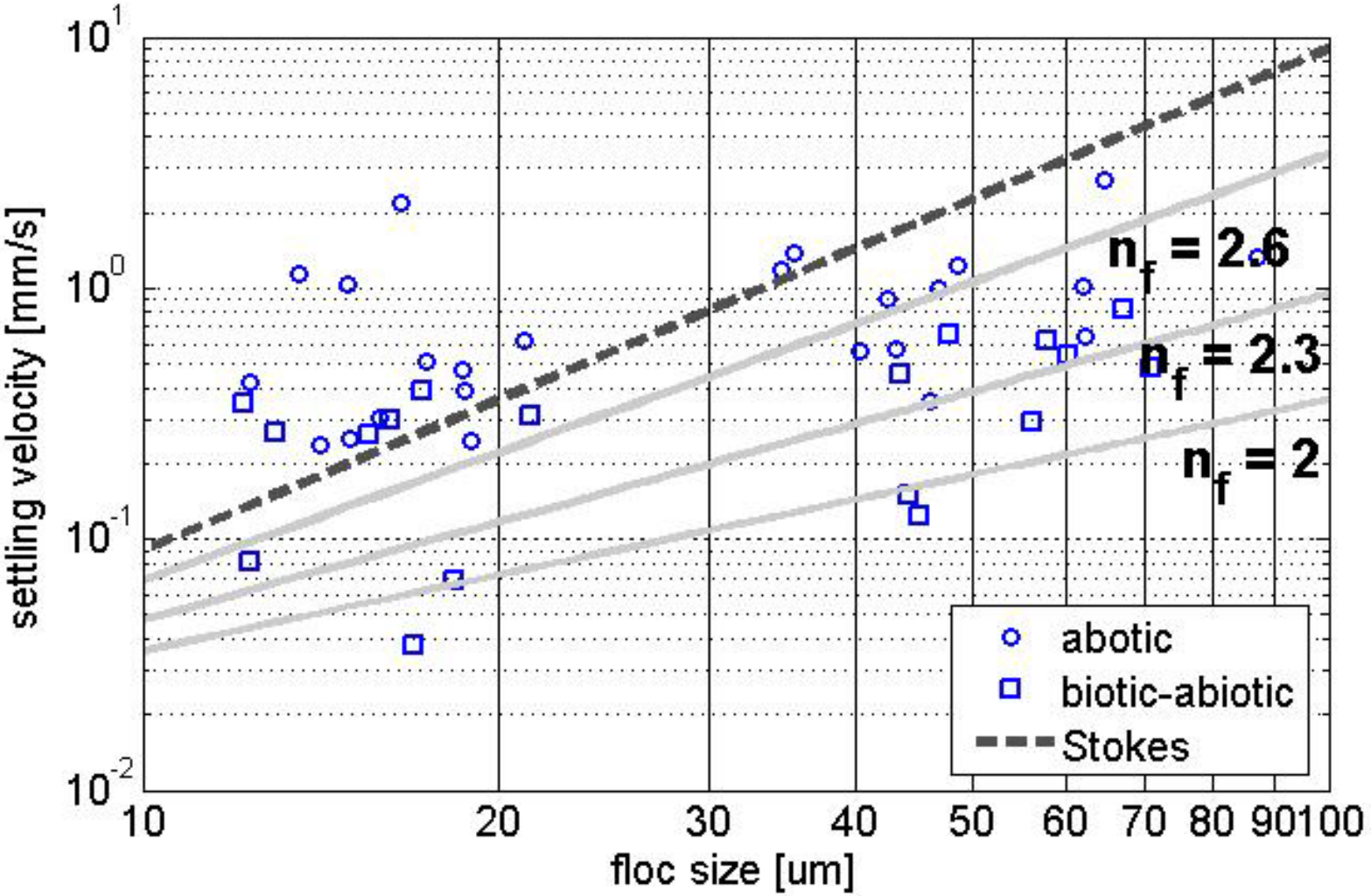

suspended sediment concentration (mg/l)
very fine (1)
fine (2)
coarse(3)
total
measured at FL42
Nov 2012
Dec 2012
Jan 2013
bed shear stress (N/m2)
Nov 2012
Dec 2012
Jan 2013

Relevance


very fine (1)
fine(2)
coarse(3)
total
measured
suspended sediment concentration (mg/l)
0
50
100
150
200
250
300
350
Nov
Dec
Jan
bed shear stress (N/m2)
0
0.5
1
1.5
2
2.5
7.3518
7.3519
7.352
7.3521
7.3522
7.3523
7.3524
7.3525
time (s)
x 10^5

Relevance


suspended sediment concentration (mg/l)
120
100
80
60
40
20
0
-20
May
Jun
total concentration for k_A = 15 kg/m^2
total concentration for k_A = 5 kg/m^2
measured at FL42


settling velocity [mm/s]
floc size [um]
10^{1}
10^{0}
10^{-1}
10^{-2}
10
20
30
40
50
60
70
80
90
100
$n_f = 2.6$
$n_f = 2.3$
$n_f = 2$
abotic
biotic-abiotic
Stokes