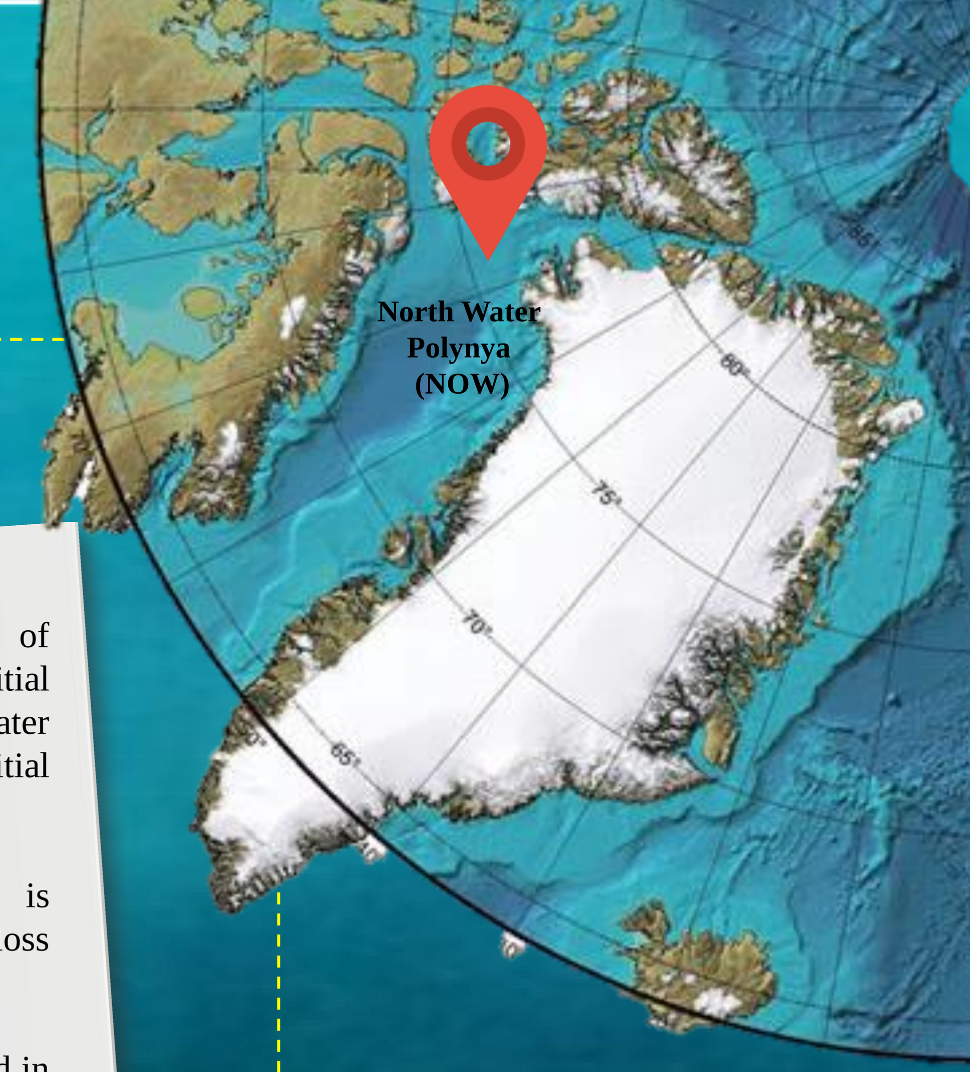
Modeling coagulation and benthic-pelagic coupling in a productive Arctic environment

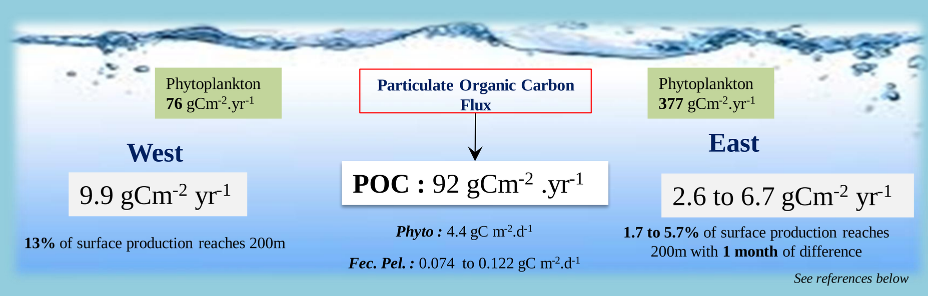


1 Context

Sedimentation of organic matter through the water column is a key process in the marine biological carbon pump (Collins et al. 2015). In general, we may consider particulate organic matter as a heterogeneous group of particles with different characteristics such as mass, volume, origin, etc. During sedimentation they further respond in various ways to biological and physical processes such as **coagulation**, fragmentation, grazing and remineralisation in addition to turbulence and advection. This will influence the quantity and quality of organic matter reaching the seabed (Boyd and Trull 2007).

How does the transformation of an organic particle will affect its sedimentation to the bottom ?

This study takes place in the scientific context of understanding the ecosystem of the North Water Polynya (NOW) in northern Baffin Bay (Canadian Arctic). There, it was found that benthic organisms feeding mainly on fresh microalgae grew significantly faster (Gaillard 2015) during a period where the surface primary production was decreasing (Bélanger et al. 2013). We hypothesize that the apparent contradiction may be resolved by putting the pelagic-to-benthic interactions in a 4D context.



2 Methods

As a first step of this project, we will use the coupled physical-biogeochemical 1-D *General Ocean Turbulence Model* (GOTM, Burchard et al. 2006) to study the effect of **coagulation** and **size modification** of the particles on the quality and quantity of organic matter reaching the seabed.

Physical model

The numerical grid resolves a 100-m deep water column with Δx=2m and Δt=2s. Salinity, temperature and nutrients were initialized by initial value with a two layer stratification. No wind where prescribed, and a constant incident photosynthetically available irradiance of 200 W/m² is prescribed at the surface.

Biological Model

- We set the biological model with 3 variables :

Two will be our **initial particles** and the third one will be the produced **marine snow**.

- The only link between our two first variables will be the possibility for them to coagulate (stick together) following the **coagulation rate equation**.
- The marine snow variable will only increase following the coagulation rate.

NEW!

Coagulation rate $= c_i \times c_j \times \beta \times \alpha_{i,j}$

$\alpha_{i,j}$ – Stickiness of the two particles (Set to 1)
β – Collision rate
$C_{i,j}$ – Concentration of the two particles

Brownian motion

$$\beta_{Br} = \frac{2}{3}\frac{kT}{\mu}\frac{(r_i + r_j)^2}{r_i \times r_j}$$

k : Boltzmann's constant ($k = 1.38 \times 10^{-23}$) (*J.°K⁻¹*)
μ: dynamic viscosity of seawater ($\mu = 1.79 \times 10^{-3}$) (*Pa.s*)
T: absolute temperature of water ($T = 274.51$) (*°K*)
r : size (radii of the two particles) *(m)*

Shear

$$\beta_{Sh} = 9.8\left(\frac{q^2}{1+2q^2}\right)\sqrt{\frac{\varepsilon}{\nu}}(r_i + r_j)^3$$

With **q** = min(ri,rj)/max(ri,rj) *(m)*
ν : kinematic viscosity of seawater ($\nu = 1.52 \times 10^{-6}$) ($m^2.s^{-1}$)
ε : average energy of dissipation rate ($\varepsilon = 8.52 \times 10^{-10}$) ($m^2.s^{-3}$)

Differential settling

$$\beta_{Ds} = \frac{1}{2}\pi\, min(r_i, r_j)^2\,|w_i - w_j|$$

w : settling velocity of the two particles ($m.s^{-1}$)

Collision rate ($m^3.s^{-1}$) $\beta = \beta_{Br} + \beta_{Sh} + \beta_{Ds}$

See references below

NEW!

Settling velocities

Up **0.001 m** Down

$$\omega_{msn} = -50 r_{msn}^{0.26} \quad (m.d^{-1})$$

$$\omega_{msn} = -160 r_{msn}^{0.57} \quad (m.d^{-1})$$

- We set settling velocities different in depth and time for our 3 variables.
- Settling velocities will vary only with the size of our particles.

See references below

NEW!

Size for particles

- Will vary randomly between 2 limiting values.

Size for marine snow

- Its size will be modified depending on the ratio of particles (with differents size) that will compose it.
- This size will be kept in memory to be the « new size » from which we will have to add the new ratio and increase size at the next time step. Some parameters of the environment are set in our model, to be sure that the increase of size happens when we have marine snow in the water column as well as a certain concentration of particles which may compose it.

$$r_{msn}(t) = r_{msn}(t_0) + \left[\sum_{i=1}^{n}\frac{F_i(t)}{F_{tot}(t)} \times r_i(t)\right]$$

F : Flux of particules *i* coagulated *(mmol.m⁻³ .j⁻¹)*
r : size (radii of the two particles)*(m)*

Initial conditions

Concentration	30 mmol N.m⁻³	30 mmol N.m⁻³
Depth	10 m	10 m

Size	Max	200 µm	100 µm
	Min	20 µm	10 µm
Settling velocity	Max	$-1.26\ m.d^{-1}$	$-0.84\ m.d^{-1}$
	Min	$-0.34\ m.d^{-1}$	$-0.24\ m.d^{-1}$

3 Results

Fig 1: Particle concentrations (*mmol N.m⁻³*)

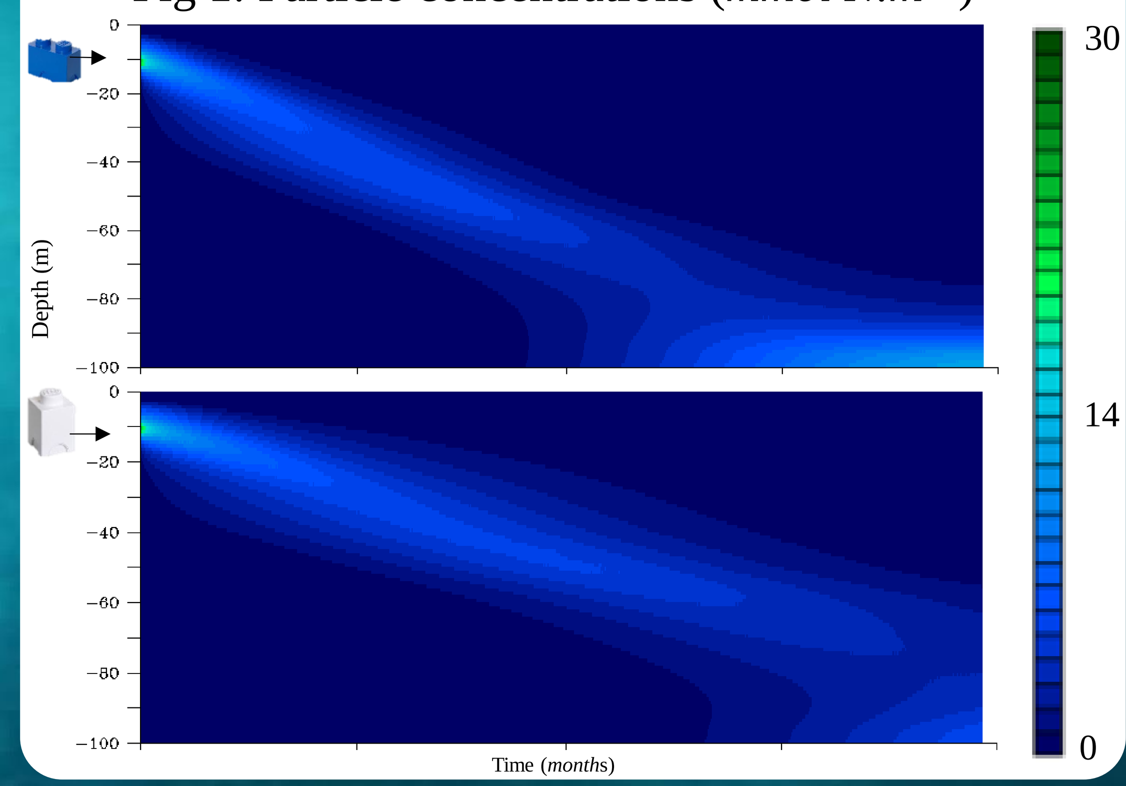
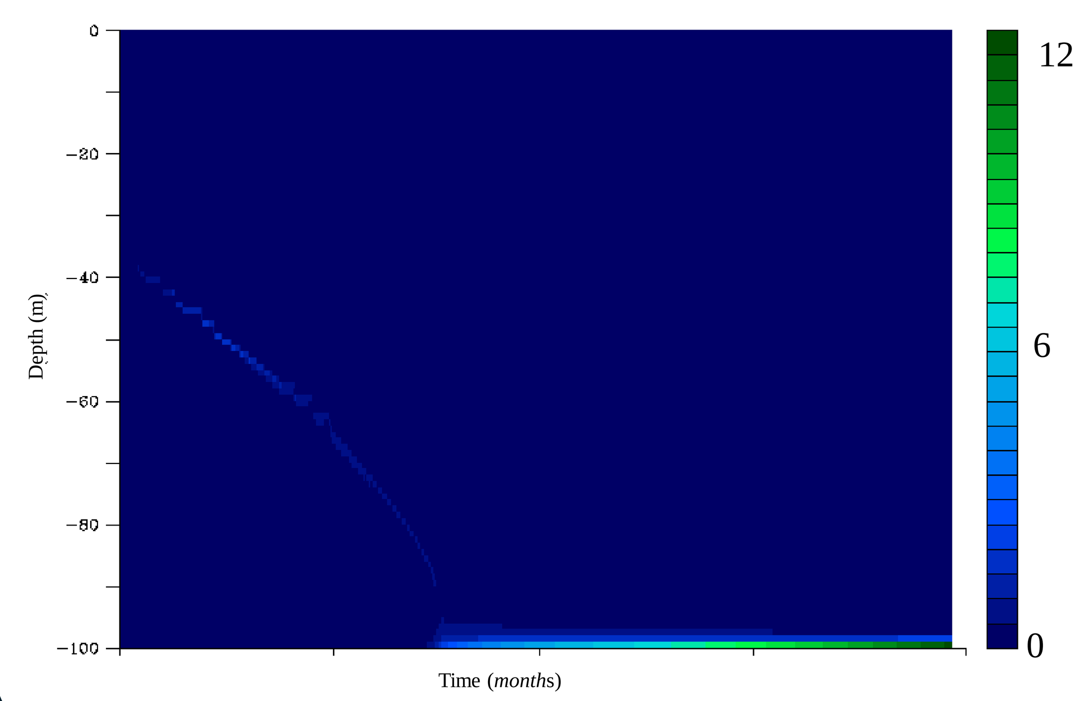


Figure 1 represents the dynamic of the concentration of our initial particles in the simulated water column following the initial conditions.

The decrease of concentration is related to the coagulation rate loss only.

Note: Concentrations are expressed in nitrate as it is our model currency.

Fig 2: Marine Snow concentration (*mmol N.m⁻³*)



Collision rate (*) ($m^3.s^{-1}$)

$\beta_{Br} = 3.12 \times 10^{-17}$
$\beta_{Sh} = 5.35 \times 10^{-15}$
$\beta_{Ds} = 3.54 \times 10^{-16}$
$\beta = 5.73 \times 10^{-15}$

20% of the original matter was transformed in marine snow.

- *Figure 2* represents the dynamics of marine snow as a result of both the coagulation rate among particles as well as their respective settling velocities.

Turbulence level plays a great role in the *coagulation rate*.

(*) Maximum value of size for both particles as well as value of settling velocities at 10m depth were used for the calculation.

Fig 3: Size augmentation (*m*)

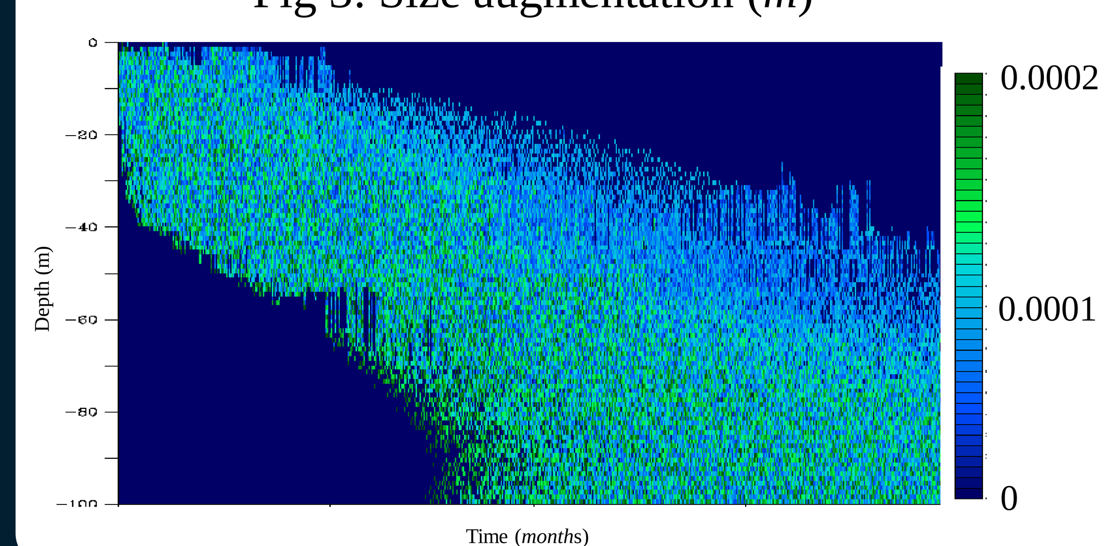


Fig 4: Final size of marine snow (*m*)

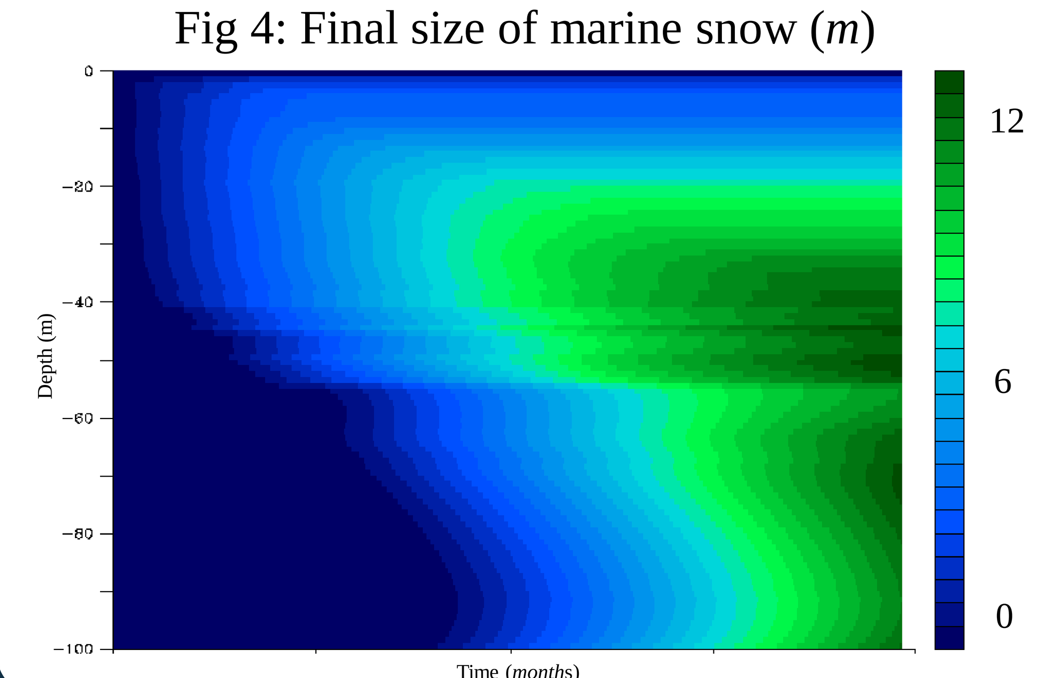
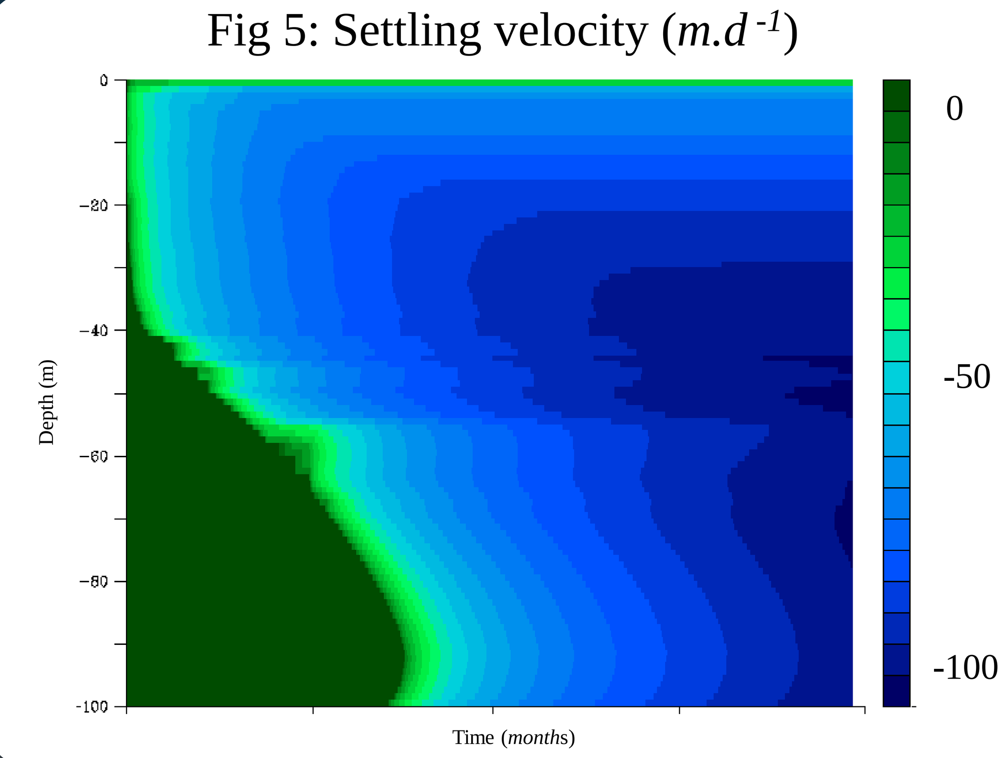


Fig 5: Settling velocity (*m.d⁻¹*)



- *Figure 3* represents the augmentation of size that will endure marine snow at each timestep depends on the particle which will compose it.

The maximum is an **augmentation of 0.0002 m** (200µm), which is the maximum size of particles that we set.

- *Figure 4* represents the cumulative augmentation size of our marine snow as a function of time and depth.

By this method we reach a value of a marine snow **size of 12 m** at the end of our simulation

- *Figure 5* represents the size-related settling velocity for marine snow.

The maximum is **100m/d.**

4

To conclude :

-Coagulation plays an important role in the transport of organic matter though the water column.

-Size plays an important role in the **coagulation rate** as well as in the **settling velocities** of particles

5

.

What we need to do :

-We need to play with the **random effect of the coagulation.**

-We need to add **fragmentation processes** to control the size of marine snow.

-And add **biological interactions** among particles.

Ultimately:
We will be able to implement this model in a 3D one in order to study the impact of **advection** and **tides** in the sedimentation of organic matter in the ocean.

6 References

Alldredge, A. L., and C. Gotschalk. 1988. Limnol. Oceanogr. **33**: 339–351.
Bélanger, S., M. Babin, and J.-E. Tremblay. 2013. Biogeosciences **10**: 4087–4101.
Boyd, P. W., and T. W. Trull. 2007. Prog. Oceanogr. **72**: 276–312.
Burchard, H., et al., 2006. J. Mar. Syst. **61**: 180–211.
Burd, A. B., and G. a Jackson. 2009. Ann. Rev. Mar. Sci. **1**: 65–90.
Burd, A. B., and G. A. Jackson. 1997. J. Geophys. Res. **102**: 545–561.
Collins, J. R., et al., 2015. Global Biogeochem. Cycles **29**: 1471–1494.
Constable, A. J., et al., 2012. Clim. Change **115**: 179–205.
Fasham, M. J., et al., 1990. J. Mar. Res. **48**: 591–639.
Gaillard, B. 2015. UQAR.
Jackson, G. A. 2001. Deep. Res. Part I Oceanogr. Res. Pap. **48**: 95–123.
Jokulsdottir, T., and D. Archer. 2015. Geosci. Model Dev. Discuss. **8**: 5931–5982.
Kajihara, M. 1971. J. Oceanogr. Soc. Japan **27**: 158–162.
Kiørboe, T., et al., 1996. J. Mar. Res. **54**: 1123–1148.
Lalande, C., et al.,2009. Geophys. Res. Lett. **36**: 1–5.
Michel, C., et al., 2002. Aquat. Microb. Ecol. **30**: 57–68.
Sampei, M., H. et al., 2004. Mar. Ecol. Prog. Ser. **278**: 17–25.
Tremblay, J.-E., and J. Gagnon. 2009., p. 73–89. *In* J.C.
Tremblay, J.-E., and W. O. Smith Jr. 2007. Elsevier Oceanogr. Ser. **74**: 239–269.
Yool, A., et al.,. 2015. J. Geophys. Res. Ocean. **120**: 7771–7790.

Thanks to my directors for their precious advice as well as ArcticNet for their authorization to attempt this meeting and have the chance to present my results.

Gwenaëlle Gremion [1]
(gwenaelle.gremion@gmail.com)
PhD candidate

I. R. Schloss [2,3], P. Archambault [4] and D. Dumont [1]

(1) Institut des Sciences de la mer, Université du Québec à Rimouski, Rimouski (Qc), Canada
(2) Instituto Antártico Argentino, Buenos Aires, Argentine,
(3) CONICET, Argentine
(4) Université Laval, Québec (Qc), Canada