Effect of sea ice melting processes on phytoplankton physiology in the northern Chukchi Sea

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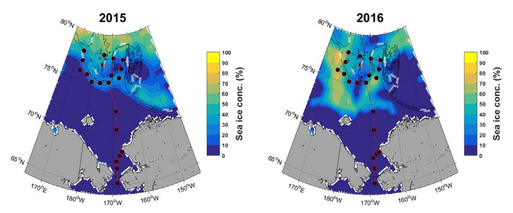
Abstract

- ***Goal:*** ***1) To understand the physiological state of phytoplankton according to the retreat of sea ice***
  2) To observe nutritional stress (nitrate) for phytoplankton growth

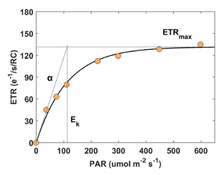
We investigated phytoplankton physiology in the northern Chukchi Sea in the late summer of 2015 and 2016 during icebreaker R/V Araon cruises. The amount of sea ice was greater in the late summer of 2016 than in 2015. Due to difference in sea ice extent, the thickness of the surface low-salinity layer was larger in 2015 than in 2016. The influence of fresh water content enhanced the stratification in the upper ocean. The stratification index calculated by the density profile was larger in 2015 than in 2016. Previous studies reported that the thickness of freshwater layer may also affect the depth of nitracline, which was closely related to depth of subsurface chlorophyll maximum (SCM), because nitrate is usually the main limiting nutrients in the Arctic Ocean. As a result, depths of nitracline and SCM in 2015 were 39±10 m and 53±6 m, which were deeper than the depths of 30±11 m and 45±10 m in 2016. There was a statistically significant correlation between freshwater content and the depth of nitracline (r=0.78, p<0.01, n=28). In physiological parameters of phytoplankton, the quantum efficiency of photochemistry in PSII (Fv/Fm = 0.43±0.09) in MLD was about 20% lower than that (0.55±0.03) in SCM, because of nitrate depletion in the surface layer. The functional absorption cross section of PSII (σ_{PSII}) in SCM depth were higher than those in MLD, indicating that the phytoplankton improved its light-harvesting capability of the photosynthetic pigments under low light condition in depth of SCM.

Methods

- **Field survey (Icebreaker R/V Araon)**
  - Period: 2015. 08. 02. ~ 20. / 2016. 08. 06. ~ 19.
- **Sea ice concentration & retreat time**
  - Data (25 × 25km) from NSIDC (http://www.nsidc.org)
  - Less than 15% sea ice conc. – Retreat time



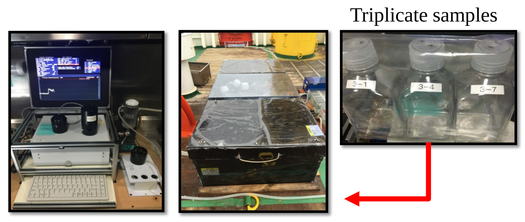
- **Phytoplankton physiology & P-E measurements**
  - Mini-FIRe (Miniaturized Fluorescence Induction & Relaxation system)
  - Samples were kept in dim light for 30 min, before being estimated.
  - We measured P-E parameter with an Actinic Light Source.



- **Nitrate enrichment experiment**
  - Samples were collected between about 10 and 20 m.
  - Triplicate treatments and 2 – 3 days incubation on deck
  - Nutrients enrichment in three conditions

① Control
② +Nitrate [5 μM]
③ +All nutrients [N (5 μM), Si (8 μM), P (1 μM), Fe (10 nM)]

Triplicate samples



Mini-FIRe Incubator on deck

Sea ice retreat time

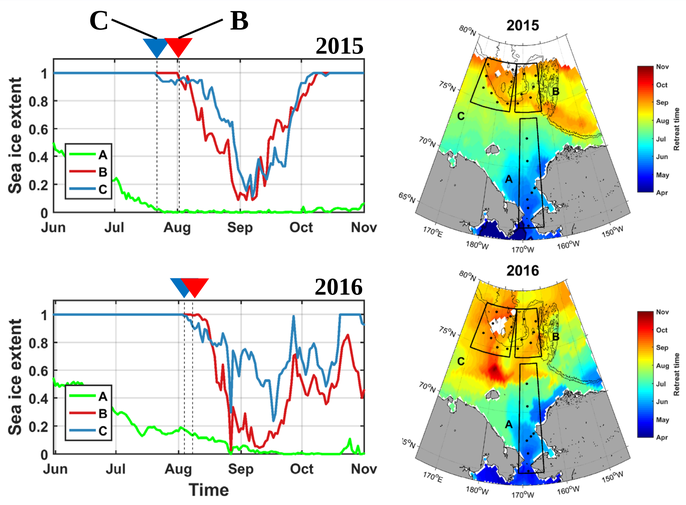
- **Difference in sea ice retreat time**

➢ Early sea ice retreat time by region

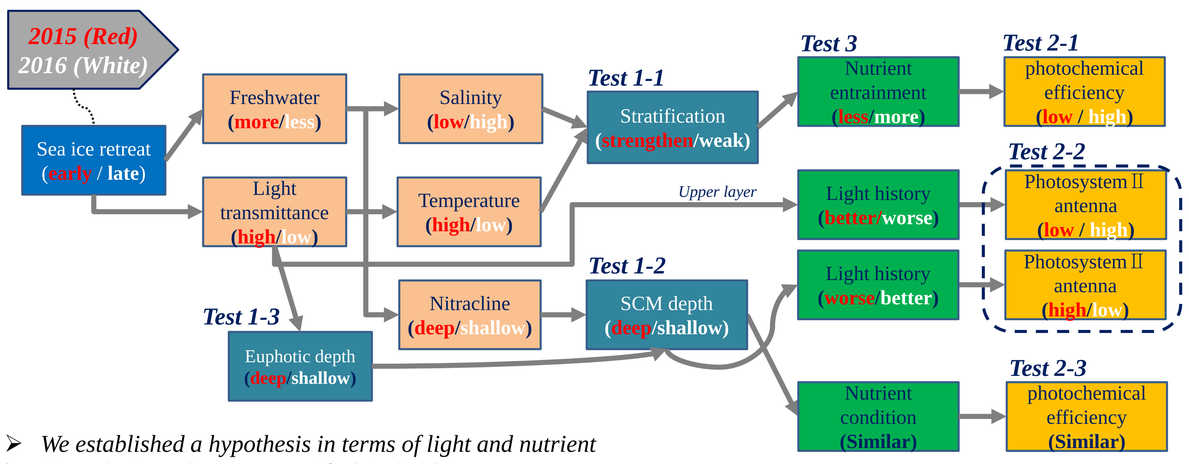
① A region in 2016

② B & C regions in 2015

	Retreat time (month/day)		Difference (days)
Region	2015	2016	2015-2016
A	5/4	4/27 (early)	+ 9
B	8/2 (early)	8/12	- 10
C	7/22 (early)	8/4	-13



- **Hypothesis: sea ice melting process for comparison between 2015 and 2016**



➢ *We established a hypothesis in terms of light and nutrient*
➢ *Next, the hypothesis was verified in the three tests*

Conclusion

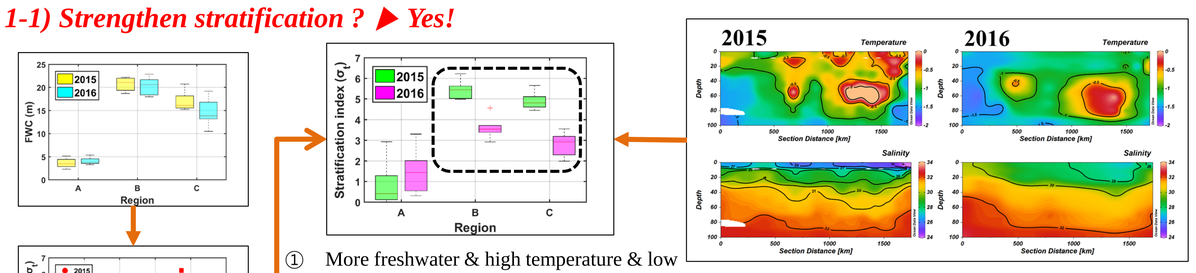
- Although more freshwater caused by earlier sea ice retreat enhanced stratification, it was not related to photochemical efficiency. On the contrary, temperature had good relationship with photochemical efficiency.
- Like previous studies, this study confirmed that freshwater affected the SCM depth. The photochemical efficiency was high and the light harvesting capacity was improved as the SCM was deepened.

- In both years, Nitrate was depleted in the northern Chukchi Sea. Therefore, low photochemical efficiency was shown in the upper layer.
- Through the photosynthetic parameter from P-E curves, phytoplankton was generally adapted to very low light ($E_k \leq 100$).

❖ *Freshwater input promotes water column stratification, which affects nutrient fluxes to the euphotic zone and hence phytoplankton physiology.*
❖ *Our analysis revealed that Arctic ecosystem are severely nitrogen limited in late summer.*

Test 1: More freshwater induced by early sea ice retreat can make …

1-1) Strengthen stratification ? ▶ Yes!

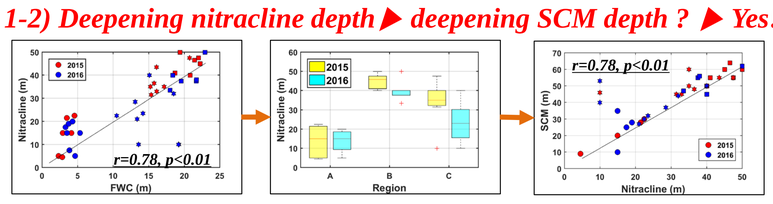


① More freshwater & high temperature & low salinity ▶ Strengthen stratification in 2015 (B, C regions)
② Strengthen stratification in the upper layer ▶ inhibits the entrainment of nutrients from the bottom waters
③ Water temperature ▶ more influence on stratification (B region)

2015 vs2016

Region	A	B	C
FWC (m)	3.6 < 4.1	20.8 ≒ 20.4	17.0 > 14.7
Temp. (℃)	6.6 ≒ 6.6	-0.6 > -1.2	-0.7 > -1.3
Salinity (‰)	31.5 < 30.9	25.5 < 27.7	26.4 < 29.1

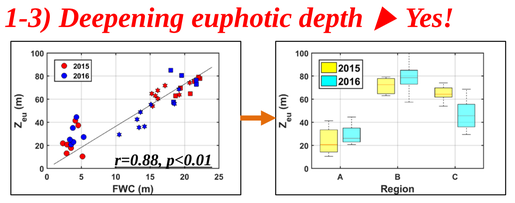
1-2) Deepening nitracline depth ▶ deepening SCM depth ? ▶ Yes!



2015 vs 2016

Region	A	B	C
Nitracline (m)	13.9 < 14.1	45.0 > 39.4	34.0 > 23.4
SCM (m)	21.8 < 24.5	57.3 > 53.3	50.5 > 39.1
Zeu (m)	23.3 ≒ 23.3	71.7 < 79.2	65.0 > 46.7

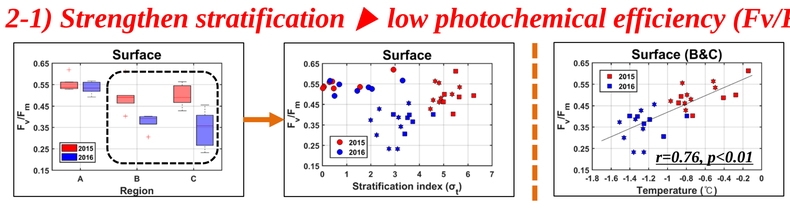
1-3) Deepening euphotic depth ▶ Yes!



① Relationship between freshwater and nitracline depth ▶ controlling the depth of SCM
② Early sea ice retreat & More freshwater (less dense) ▶ decrease water reflectance ▶ deepening euphotic depth (C region)
③ Due to some extreme values ▶More deeply euphotic depth in 2016 (B region)

Test 2: What about photochemical parameter in 2015 and 2016?

2-1) Strengthen stratification ▶ low photochemical efficiency (Fv/Fm) in the upper layer ? ▶ No!

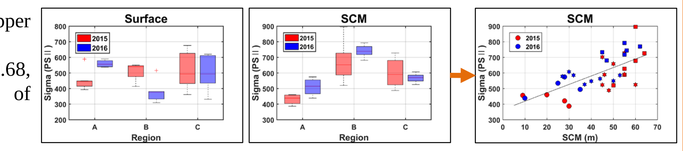


Surface	2015 vs 2016 (unit: μmol L^{-1})		
Region	NO3+NO2	Si	P
A	2.7>0.01	11.8>4.2	0.68>0.40
B	0.1≒0.20	1.36<1.7	0.53≒0.56
C	0.1≒0.1	2.0>0.2	0.57≒0.63

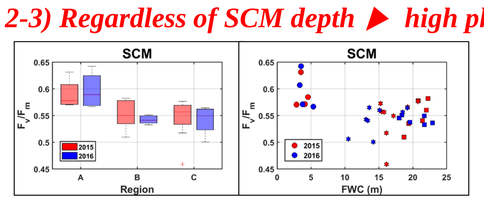
① Fv/Fm values by region: 0.55±0.03 (A region) > 0.43±0.07 (B & C regions) ▶ could be nutrient limitation (B, C regions)
② Fv/Fm values by year (B, C regions): [0.49±0.07 / 0.50±0.05 (2015)] > [0.38±0.04 / 0.34±0.09 (2016)] ▶ Why?
③ No correlation between stratification index and Fv/Fm values ▶ presumably nitrate depletion (<0.1 μmol L^{-1}) in both years
④ But, the good correlation between water temperature and Fv/Fm values (r=0.76, p<0.01) ▶Temperature has greater impact on Fv/Fm values

2-2) Light history ▶ Controlling photosystem Ⅱ antenna ($\sigma_{PS\,II}$)? ▶ No (Surface) / Yes (SCM)

① No significant difference between 2015 and 2016 in the upper layer
② Good correlation between $\sigma_{PS\,II}$ and SCM depth (r=0.68, p<0.01) ▶ Improved light-harvesting capability of photosynthetic pigments



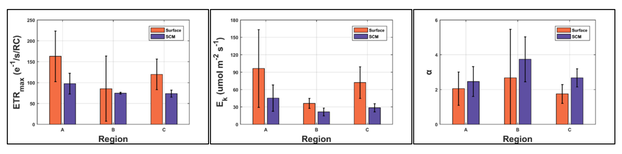
2-3) Regardless of SCM depth ▶ high photochemical efficiency (Fv/Fm) at SCM ? ▶ Yes!



① Fv/Fm values by region: 0.59±0.03 (A region) > 0.54±0.02 (B, C regions)
② High Fv/Fm values (0.56±0.03) in all regions ▶ no nutrient limitation
③ Regardless of freshwater, the Fv/Fm values always showed a high value

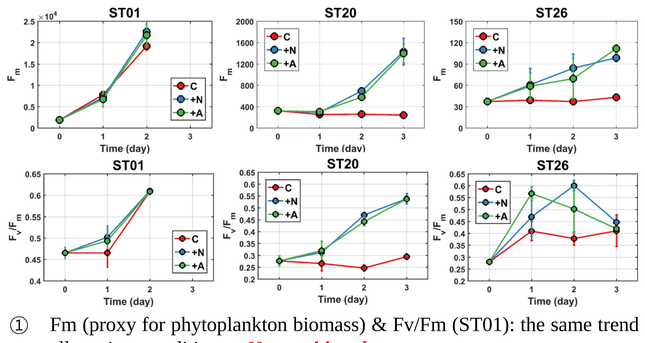
❖ ***P-E parameter in 2016***

① Low saturating light intensity (E_k) ▶ Low maximum photosynthetic rate (ETR_{max}) & High light capturing ability (α) (B, C regions)
② Low light condition in SCM ▶ Low E_k & High α & Low ETR_{max}



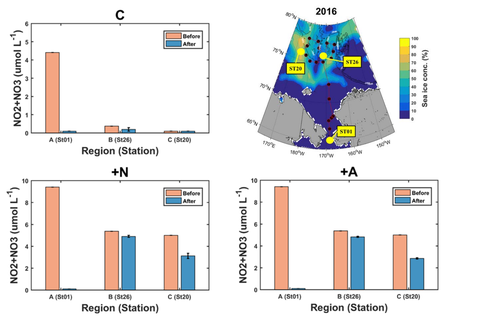
Test 3: Nutritional (nitrate) stress in the upper layer?

1) Nitrate limitation in the upper layer? ▶ Yes!



① Fm (proxy for phytoplankton biomass) & Fv/Fm (ST01): the same trend in all nutrient conditions – ***No nutritional stress***
② Fm & Fv/Fm (ST20): increasing trend under +N, +A conditions – ***Nutritional stress***
③ Fm & Fv/Fm (ST26): Fm - increasing trend, but Fv/Fm –No clear tendency

❖ ***Nitrate concentration in all condition (before / after)***



➢ ST01: In all nutrient conditions, nitrate was consumed.
➢ ST20: Nitrate decreased by about 40 – 50%
➢ ST26: No change in nitrate concentration.