Phytoplankton production changes driven by physical forcing in the western Arctic Ocean

Mi Sun Yun and Sang Heon Lee*

Department of Oceanography, Pusan National University
Introduction

Changes in Arctic sea ice cover

- Decreasing trend in summer sea ice cover
- Reductions in sea ice thickness

Krishfield et al. (2013)
Introduction

The largest sea ice loss in the western Arctic Ocean

Arrigo and Dijken (2011)
Introduction

Arctic Ocean surface warming and freshening

Steele et al. (2008)

Yamamoto-Kawai et al. (2009)
Introduction

Changes in Arctic physical environments

▲ A strong Beaufort Gyre

Nishino et al. 2013

► Frequent of occurrence eddies

Krishfield et al. (2013)

▲ Accumulation of surface freshwater within the Beaufort Gyre

Anticyclonic eddies

Spall et al. 2008
Introduction

Impacts of recent environmental changes on the phytoplankton

Arrigo and Dijken, (2011)

Li et al. (2009)

Exceptional dominance of the colonial form of *Phaeocystis pouchetii*
Research Questions

Given ongoing environmental changes in the Arctic Ocean….

• How has primary production of phytoplankton changed driven by physical forcing?
  - Effects of freshwater inputs
  - Influence of eddies

http://www.awi.de/de/forschung/fachbereiche/biowissenschaft/en/polare_biolosgische_
Materials and methods

Water samples from different light depths

Light Depth

100 %  50 %  30 %  12 %  5 %  1 %

$^{15}\text{NO}_3 +^{13}\text{C}$

$^{15}\text{NH}_4 +^{13}\text{C}$
Materials and methods

In-situ Incubations & analysis

Incubation ➔ Filtering ➔ Analysis
Results and Discussion

Comparison of recent primary production

2nd RUSALCA cruise (in 2009)

1st RUSALCA cruise (in 2004)

Yun et al. (2014)

Average ± S.D.: 17.03 ± 16.18 mg C m\(^{-2}\) h\(^{-1}\)

Lee et al. (2007)

Average ± S.D.: 46.7 ± 60.0 mg C m\(^{-2}\) h\(^{-1}\)
Results and Discussion

A comparison of environmental factors in 2009 and 2004
### Results and Discussion

#### A correlation analysis

<table>
<thead>
<tr>
<th></th>
<th>Surface Temperature</th>
<th>Bottom Temperature</th>
<th>Surface Salinity</th>
<th>Bottom Salinity</th>
<th>Surface Density</th>
<th>Bottom Density</th>
<th>Zₑₑ</th>
<th>Zₘₘ</th>
<th>SI</th>
<th>SFL</th>
<th>NO₃</th>
<th>NH₄</th>
<th>Chlorophyll a</th>
<th>Carbon Production rate</th>
<th>Nitrate Production rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Temperature</td>
<td>0.611**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom Temperature</td>
<td>0.735**</td>
<td>0.398</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface Salinity</td>
<td></td>
<td>0.466*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom Salinity</td>
<td>-0.236</td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface Density</td>
<td>0.692**</td>
<td>0.364</td>
<td>0.998**</td>
<td>0.033</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom Density</td>
<td>-0.600**</td>
<td>-0.281</td>
<td>-0.215</td>
<td>0.942**</td>
<td>-0.185</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zₑₑ</td>
<td>-0.854**</td>
<td>-0.577**</td>
<td>-0.517**</td>
<td>0.684**</td>
<td>-0.479**</td>
<td>0.796**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zₘₘ</td>
<td>0.223</td>
<td>0.046</td>
<td>0.045</td>
<td>-0.128</td>
<td>0.023</td>
<td>-0.016</td>
<td>-0.075</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SI</td>
<td>-0.826**</td>
<td>-0.535*</td>
<td>-0.894**</td>
<td>0.369</td>
<td>-0.879**</td>
<td>0.480*</td>
<td>0.691**</td>
<td>-0.184</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SFL</td>
<td>-0.248</td>
<td>0.153</td>
<td>-0.648**</td>
<td>-0.028</td>
<td>-0.678**</td>
<td>0.196</td>
<td>0.263</td>
<td>0.378</td>
<td>0.470*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NO₃</td>
<td>-0.534*</td>
<td>-0.385</td>
<td>-0.139</td>
<td>0.351</td>
<td>-0.100</td>
<td>0.303</td>
<td>0.622**</td>
<td>-0.324</td>
<td>0.312</td>
<td>-0.179</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH₄</td>
<td>-0.261</td>
<td>-0.040</td>
<td>0.060</td>
<td>0.566*</td>
<td>0.080</td>
<td>0.566*</td>
<td>0.447</td>
<td>-0.072</td>
<td>0.116</td>
<td>-0.041</td>
<td>0.434</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorophyll a</td>
<td>0.304</td>
<td>0.087</td>
<td>0.536*</td>
<td>0.037</td>
<td>0.547*</td>
<td>-0.093</td>
<td>-0.182</td>
<td>0.173</td>
<td>-0.460*</td>
<td>-0.520*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon Production</td>
<td>0.387</td>
<td>0.244</td>
<td>0.587**</td>
<td>-0.032</td>
<td>0.595**</td>
<td>-0.168</td>
<td>-0.306</td>
<td>0.115</td>
<td>-0.552*</td>
<td>-0.515*</td>
<td>-0.047</td>
<td>-0.107</td>
<td>0.795**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate</td>
<td>0.042</td>
<td>-0.326</td>
<td>0.345</td>
<td>0.203</td>
<td>0.363</td>
<td>0.104</td>
<td>0.170</td>
<td>-0.178</td>
<td>-0.174</td>
<td>-0.449</td>
<td>0.545*</td>
<td>0.541*</td>
<td>-0.091</td>
<td>-0.081</td>
<td>-0.081</td>
</tr>
</tbody>
</table>

- Chlorophyll a concentration and primary production were negatively affected by SI (Stratification Index) and SFL (Surface Freshwater Layer)
The utilization of different nitrogen source

- **The relative preference index (RPI)**: McCarthy et al. (1977)
- $\text{RPI}_{\text{NO}_3} > 1 = \text{NO}_3^- \text{ preference, } < 1 = \text{NO}_3^- \text{ rejection, or NH}_4^+ \text{ preference)}$

Results and Discussion

![Graphs showing RPI (NO3) vs NO3+NH4 conc for 2004 and 2009.]

- **2004**
- **2009**
Results and Discussion

Phytoplankton biomass

2004

Small (19.7%)
Medium (11.1%)
Large (69.2%)

2009

Small (35.2%)
Medium (23.2%)
Large (41.6%)

Small size phytoplankton increased!
Results and Discussion

Exceptionally high regional phytoplankton biomass

Chlorophyll $a$ concentrations [$\mu$g/l] (color) and temperature [$^\circ$C] (contours)

Anticyclonic warm-core eddies

Geostrophic velocity [cm/s]
Warm-core eddy caused more nitrate upward flux!
Results and Discussion

The effects of warm-core eddy on the phytoplankton biomass

Chlorophyll $\alpha$ concentrations [µg/l] (color) and temperature [$^\circ$C] (contours)

High contribution of large phytoplankton
Warm-core eddies could lead to a significant increase in new production in the region.
Given ongoing sea ice decline in the Arctic Ocean:

- **Effect of the freshwater inputs**
  - Primary production were considerably reduced
    - Higher freshwater accumulation → Increased stratification
  - Smaller size phytoplankton have increased

- **Regional influence of warm-core eddies**
  - An important role in the nitrate supply
  - A significant increase in primary/new production in the region.

- Therefore, the effects of physical forcing events (such as freshwater input and eddy) on the primary production need to be more examined to better understand changes of primary production under ongoing environmental changes in the Arctic Ocean.
Thank you for your attention.