Variability of the phytoplankton functional types under changing winter vertical mixing in the Ulleung Basin, East Sea: A modeling study

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**Introduction**

**Previous studies and objective**

- **Vertical mixing**
  - Focus on the phenological response of total phytoplankton or primary production [Yamada et al., 2004; Kim et al., 2007, etc.]
  - Simplistic model approach: NPZD/COM9 [Onitsuka and Yabnagi, 2005]

- **Atmospheric deposition**
  - Focus on the primary production
  - Simplistic model approach: NPZD [Onitsuka et al., 2009]

- Lack of clear understanding of the interannual variability and shifts in PFTs\(^a\)

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**Objective:**

to understand the role of vertical mixing and atmospheric deposition in modulating the interannual variability of PFTs using an ERSEM\(^b\).

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\(^a\) Phytoplankton functional types

\(^b\) European Regional Seas Ecosystem Model
European Regional Seas Ecosystem Model (ERSEM; Blackford et al., 2004)
Data and Methods

Model setup

\[ I_{\text{mld}} = \frac{1}{Z_{\text{mld}}} \int_{0}^{Z_{\text{mld}}} I_0 e^{-k_e Z_{\text{mld}}} dZ \]

\[ h^{-} = h(t) \]

\[ h^{-} = 0 \]

Shallowing, \( h < 0 \)

Deepening, \( h > 0 \)

Spring: \( l_0 = \text{Surface Irradiance} \), \( I_{\text{mld}} = \text{Irradiance in MLD} \)

Summer:

Autumn:

Winter:

- Mixed layer depth
- Atmospheric deposition
- Detritus sinking
- Phytoplankton sinking

Phytoplankton
Zooplankton
Nutrient-poor water
Detritus

\[ D = \text{Diffusion for others} \]

\[ k = \text{diffusive mixing across the thermocline} \]

\[ Z_{\text{mld}} = \text{MLD} \]

\[ h^{-}(t) = \text{the rate of entrainment nutrient into MLD} \]

\[ h(t) = \text{the time rate of MLD change} \]

\[ D = \frac{k + h^{-}(t)}{Z_{\text{mld}}} \]

\[ h = \frac{dt}{dZ_{\text{mld}}} \]

\[ h^{-}(t) = \max (h(t), 0) \]
Data and Methods

Study area and data sources

- **SST** [sea surface temperature]
  - 0~MLD average (KODCa, bimonthly)

- **SSS** [sea surface salinity]
  - 0~MLD average (KODC, bimonthly)

- **MLD** [mixed layer depth]
  - Density threshold method (bimonthly, Sprintall and Tomczak, 1992)
  - Monotone cubic interpolation

- **SPAR** [surface photosynthetically active radiation]
  - Cloud cover from KMAb (daily)
  - Astronomical formula (Rosati and Miyakoda, 1988)

- **Chl** [chlorophyll a]
  - SeaWiFS & MODIS Aqua merged datac (Oc v6 algorithm, monthly)

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Korea Ocean Data Center, 104-09 (37.057°N, 130.63°E), 2001-2012

Korean Meteorological Administration, Ulleung Island (37.47°N, 130.88°E)

37.0°N, 130.6°E
Model input

- Nutrient data from KIOST survey from Nov. 2000 to Jul. 2010
Model outputs: Seasonal cycle
Model evaluation

(a) Model – Obs.

(b) Model – Obs.

(c) Model – Obs.

\[ R = 0.69, \ P < 0.001 \]
Comparison of PFT composition by observation and model

- **Winter**
  - Observation: Diatoms 76%, Flag 0%s, Pico 14%, Dino 10%
  - Model: Diatoms 76%, Flag 17%, Pico 23%, Dino 10%

- **Spring**
  - Observation: Diatoms 60%, Flag 20%, Pico 17%, Dino 3%
  - Model: Diatoms 60%, Flag 23%, Pico 39%, Dino 11%

- **Summer**
  - Observation: Diatoms 67%, Flag 21%, Pico 8%, Dino 4%
  - Model: Diatoms 67%, Flag 32%, Pico 17%, Dino 11%

- **Autumn**
  - Observation: Diatoms 25%, Flag 52%, Pico 20%, Dino 3%
  - Model: Diatoms 25%, Flag 47%, Pico 23%, Dino 11%
The effect of vertical mixing

Correlation coefficient with p-value in parantheses

MMLD = Maximum MLD
The deepest MLD: The shallowest MLD
Why do PFTs respond differently as such?

Monthly means of photosynthesis rate and annual means of nutrient uptake rates (upper panels) and monthly grazing rate of PFTs (lower panels).
(a) Relationship between Feb-Apr mean of PAR in the upper mixed layer and MMLD,
(b) Relationship between annual mean of nitrogen concentration and MMLD (red: nitrate, blue: ammonium),
(c) Relationship between annual mean of nitrate flux and MMLD,
(a) Relationship between annual mean proportion of nitrogen uptake (PFT/total) and MMLD.

(b) Relationship between annual means of nutrient limitation (equation (8) of Blackford et al., 2004) and MMLD,
(c) Relationship between Feb-Apr means of NPP and Feb-Apr means of PAR within the upper mixed layer.

(d) Relationship between Feb-Apr means of grazing rate and Feb-Apr means of NPP.
Summaries

• Diatoms preempt the early spring growth by better utilization of light and nitrate.
• Diatoms’ advantages lessen as MMLD decreases.
• Flagellates and picophytoplankton show mixed responses to increased winter vertical mixing.
  – Higher NPP and peak biomass but lower annual biomass due to increased grazing
• Dinoflagellates are always doing better with shallower MLD.
• If warming continues and winter vertical mixing decreases, the total NPP will decrease although flagellate, pico-, and dinoflagellate yearly biomass will increases.
Thanks for your kind attention!