Large nutrient variation in the North Pacific Transitional Area

Sayaka Yasunaka (JAMSTEC, Japan)

with Yukihiro Nojiri (NIES & Hirosaki Univ., Japan)
Tsuneo Ono (FRA, Japan)
Frank Whitney (IOS, Canada)
Shin-ichiro Nakaoka (NIES, Japan)

1. Ship-of-opportunity nutrient observation
2. Gridded products
3. Seasonal change & biological production
4. Decadal to long-term variability
Ship-of-opportunity sampling for nutrients

- IOS and NIES have carried out ship-of-opportunity nutrient sampling.

- Surface water samples were manually collected from the seawater lines installed for pCO₂ observation, routinely at 2 or 3 samples per day.

- Sampled nutrient tubes were stored frozen, then analyzed by colorimetric techniques in the onshore laboratories.

- Ship-of-opportunity nutrient sampling improved data coverage of bottle samplings by the research vessels.

Wong et al. (2002); Whitney (2011); Yasunaka et al. (2014)
Nutrient sampling at ocean surface

Number of Nutrient Sampling (1961-2012)

(a) Phosphate

(b) Nitrate

(c) Silicate

WOD NIES IOS PACIFICA
JAMSTEC monitor Line-p

Yasunaka et al. (2016)
**Self organizing map (SOM)** can empirically induce the relationship between parameters without any a-priori assumptions of regression functions and divided areas.

### 1. Training

<table>
<thead>
<tr>
<th>Data</th>
<th>Initial Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SST</td>
<td>29.3</td>
</tr>
<tr>
<td>SSS</td>
<td>34.2</td>
</tr>
<tr>
<td>CHL</td>
<td>0.06</td>
</tr>
<tr>
<td>MLD</td>
<td>37.7</td>
</tr>
<tr>
<td>LAT</td>
<td>15.5</td>
</tr>
<tr>
<td>LON</td>
<td>129.4</td>
</tr>
<tr>
<td>NO3</td>
<td>NaN</td>
</tr>
</tbody>
</table>

### 2. Labeling

Nutrient Obs

### 3. Mapping
Mapping 1: SOM technique (2001/01–2010/12)

(a) Phosphate

(b) Nitrate

(c) Silicate

http://soop.jp
Mapping 2: Optimal interpolation (1961/01–2012/12)

Number of Nutrient Sampling (1961-2012)

Correlation scale:
  - Zonal: 23°
  - Meridional: 20°
  - Temporal: 3-month

SN ratio: 1.5

Interpolation error $^2 < 0.7$

Yasunaka et al. (2016)
Seasonal change

Yasunaka et al. (2013; 2014a)
Concentrations are high in the subarctic, low in the subtropics.

Max: Mar
Min: Aug-Oct

Amplitudes are large in the subarctic, small in the subtropics.

Yasunaka et al. (2014b)
### Seasonal drawdown

#### Mar-Aug

- **1**: Large drawdown
- **2**: Nutrient drawdown \( \sim 0 \)
- **3**: DIC drawdown > 0
- **4**: Diatom
- **5**: Labile DOP/DIP using microbes

<table>
<thead>
<tr>
<th></th>
<th>( \Delta nP )</th>
<th>( \Delta nN )</th>
<th>( \Delta nSi )</th>
<th>( \Delta nC )</th>
<th>( \Delta nN/\Delta nP )</th>
<th>( \Delta nSi/\Delta nP )</th>
<th>( \Delta nC/\Delta nP )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.70</td>
<td>12.98</td>
<td>23.85</td>
<td>84.2</td>
<td>*1 18.5</td>
<td>34.1</td>
<td>120.0</td>
</tr>
<tr>
<td>B</td>
<td>0.53</td>
<td>9.36</td>
<td>13.90</td>
<td>78.8</td>
<td>17.7</td>
<td>26.0</td>
<td>148.7</td>
</tr>
<tr>
<td>C</td>
<td>0.40</td>
<td>7.28</td>
<td>7.02</td>
<td>55.6</td>
<td>18.2</td>
<td>17.6</td>
<td>139.0</td>
</tr>
<tr>
<td>D</td>
<td>0.30</td>
<td>4.96</td>
<td>3.34</td>
<td>41.0</td>
<td>16.5</td>
<td>11.1</td>
<td>136.0</td>
</tr>
<tr>
<td>E</td>
<td>0.79</td>
<td>11.31</td>
<td>16.30</td>
<td>113.8</td>
<td>*1 14.3</td>
<td>*3 20.6</td>
<td>144.1</td>
</tr>
<tr>
<td>F</td>
<td>0.45</td>
<td>6.28</td>
<td>7.88</td>
<td>90.1</td>
<td>14.0</td>
<td>17.5</td>
<td>200.2</td>
</tr>
<tr>
<td>G</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>H</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>*2 27.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>I</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>16.7</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Notes:**
- \( \Delta nP \): Nitrogen drawdown
- \( \Delta nN \): Nitrogen drawdown
- \( \Delta nSi \): Silicon drawdown
- \( \Delta nC \): Carbon drawdown
- \( \Delta nN/\Delta nP \), \( \Delta nSi/\Delta nP \), \( \Delta nC/\Delta nP \): Ratios of drawdowns.
Relation to biological production

- Net Community Production (NCP)

\[
\text{NCP}[m - m+1] = \text{MLD}[m+1] \times (n\text{DIC}[m] - n\text{DIC}[m+1]) - \frac{(\text{Flux}[m] + \text{Flux}[m+1])}{2}
\]

by Lee (2001)

• NCP ~ 20-30% of NPP

Yasunaka et al. (2013)
Decadal & long-term variability

Yasunaka et al. (2016)

(a) PDO index / NPGO index / Trend

- PDO•NPGO
  ← Entrainment + Ekman advection
- Trend (P•Si) ← Shallowing MLD
- Trend (N) ← MLD + Atmospheric deposition?

(b) Phosphate

(c) Nitrate

(d) Silicate
Decadal & long-term variability

Yasunaka et al. (2016)

(b) Phosphate

(e) Surface density

(f) Surface wind

PDO • NPGO

← Entrainment + Ekman advection
P: $-0.012 \pm 0.005 \, \mu\text{mol/l/dec}$
N: $-0.001 \pm 0.013 \, \mu\text{mol/l/dec}$
Si: $-0.38 \pm 0.13 \, \mu\text{mol/l/dec}$

Long-term trend

Global warming
→ Shallowing mixed layer
→ Reduction of entrained nutrient
Observed trend
P: $-0.012 \pm 0.005 \, \mu\text{mol/l/dec}$
N: $-0.001 \pm 0.013 \, \mu\text{mol/l/dec}$
Si: $-0.38 \pm 0.13 \, \mu\text{mol/l/dec}$

Entrainment effect
P: $-0.014 \pm 0.006 \, \mu\text{mol/l/dec}$
N: $-0.19 \pm 0.09 \, \mu\text{mol/l/dec}$
Si: $-0.45 \pm 0.21 \, \mu\text{mol/l/dec}$

P and Si trend $\leftarrow$ shallowing MLD

- Global anthropogenic N depositions:
  54 TgN/yr (Duce et al. 2008 and references therein)

$\rightarrow$ If it is uniformly distributed in the upper 500 m of the ocean, it increases the N concentration by 0.2 $\mu\text{mol/l/dec}$.

N trend $\leftarrow$ shallowing MLD + anthropogenic N depositions
18.6-yr cycle

Moon orbit changes the inclination with the 18.6-yr, which generates the 18.6-yr modulation of tidal mixing.

Positive response around Aleutian and Kuril Islands
- high nutrient water to the surface
- strong vertical mixing
- strong 18.6-yr oscillation of tidal energy dissipation rate

OMIX web site

18.6-yr diurnal cycle
Other observations

- **Nitrate continuous observation by optical sensor**
  JAMSTEC R/V Mirai 2014-

- **Biogeochemical Argo**

I hope various observations are continued, and data are archived in a user-friendly form.
SOOP observations improved data coverage of the traditional datasets (i.e. bottle sampling by the research vessels).

Nutrient data accumulation enable us to understand large-scale variability of nutrients.

Large seasonal drawdown and decadal-scale variation were found in the North Pacific Transitional Area.

Continued observations and data archiving are desired.

References:
Yasunaka et al. (2014b) North Pacific dissolved inorganic carbon variations related to the Pacific Decadal Oscillation, GRL 41,1005-1011.
Estimate of entrainment reduction


2. Convert the surface ρ-trend into a long-term trend of MLD by using the climatological ρ-profiles during summer at the climatological MLD in winter. → 2.3 ± 0.9 m decade⁻¹

3. Assuming that annual new production is constant (c), determine the winter nutrient concentration at year i+1 \( (n_{i+1,w}) \) from the winter nutrient concentration at year i \( (n_i^w) \), the winter mixed layer depth \( (h_{i+1,w}) \), and summer euphotic zone depth \( (h_s) \):

\[
n_{i+1,w} = \frac{(n_i^w - c) h_a + [a + b (h_a + h_{i+1,w})/2](h_{i+1,w} - h_a)}{h_{i+1,w}}
\]

by Freeland et al. (1997).

4. Integrate this equation over 52 years.