The role of the Aleutian Low Pressure System in regulating primary and export production in the North Pacific Ocean – results from a decade and half of satellite ocean color observations

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Unique features of the North Pacific Ocean

It is the world’s largest ocean basin and an important sink for atmospheric CO$_2$

As a consequence of its positive Ekman velocity, circulation is largely driven by changes in the overlying atmosphere.

Close coupling between the atmosphere, the ocean and the ecosystem of the subarctic Pacific makes it an ideal natural laboratory to observe, understand and model seasonal, interannual to decadal time scale climate variability and its consequences for carbon cycling.
The Aleutian Low Pressure System (ALPS)

Central Hypothesis

Interannual changes in the location and the strength of the ALPS have a major influence on the variability of phytoplankton primary and export production patterns, and gradients across the subarctic Pacific Ocean.
East-West gradients in the photosynthetic competency of surface phytoplankton from the North Pacific Ocean. Suzuki et al L & O (2002)
Atmospheric iron dust deposition in the Pacific Ocean. Model output data from N. Malhowald
Comparison of the Aleutian Low Pressure Region during El Niño and La Niña

January-February
Average sea-level air pressure
Mostly El Niño

January-February
Average sea-level air pressure
Mostly La Niña
MAJOR SCIENCE QUESTIONS

How does the strength and the position of the Aleutian Low impact large scale atmospheric and oceanic processes in the North Pacific Ocean?

What are the major factors responsible for the altered strength and position of the Aleutian Low Pressure region?

How do changes in atmospheric–oceanic processes impact primary and export production in the North Pacific?
Schematic show the seasonal evolution of the mixed layer ($D_M$), the compensation depth $D_c$ and the critical depth ($D_{CR}$) in the subarctic Pacific Ocean. $D_N$ indicates the depth above which nutrients are exhausted. Hypothetical distribution of those areas (dotted) in the time-depth domain within which new production is possible. Adapted from Strass and Woods (1980).
Nitrate fields generated using MODIS chl and MODIS SST

Goes et al. IEEE 1999
Goes et al., EOS 2005
Monthly composites of sea surface nitrate concentrations derived from SeaWiFS chlorophyll a and AVHRR SST for the year 2000.
Comparison of Alligator Hope ship nitrate and MODIS Terra satellite derived sea surface nitrate concentrations

Ship data courtesy Dr. Nojiri and Dr. Wong
Combined effects of errors in satellite derived SST and Chl a on nitrate estimates at three different temperatures of seawater.

Goes et al. IEEE 1999
Schematic diagram showing construction of nitrate and new production maps

Nitrate = $f(SST, Chl\ a)$

New Production = $f(\Delta N, Depth\ of\ Nitracline)$

Goes et al. GRL 2000
Table 1. Comparison of satellite estimates of new production with sediment trap POC fluxes (g C m$^{-2}$ y$^{-1}$)

<table>
<thead>
<tr>
<th>Sediment trap site</th>
<th>Satellite Estimates</th>
<th>Measured Trap Flux</th>
<th>Year</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>48° N 175° E (NOPACCS)</td>
<td>17 36 24</td>
<td>37.4*</td>
<td>1993-1994</td>
<td>Harada (NOPACCS)</td>
</tr>
<tr>
<td>41.5° N 146.5° E (W. PACIFIC)</td>
<td>31 38 53</td>
<td>54.1**</td>
<td>1983</td>
<td>Noriki &amp; Tsunogai (1986)</td>
</tr>
<tr>
<td>30° N 175° E (NOPACCS)</td>
<td>3 10 7</td>
<td>6.48</td>
<td>1993-1994</td>
<td>Harada (NOPACCS)</td>
</tr>
</tbody>
</table>

* Referenced to 100 m using formulation of Martin et al., 1987
  Referenced to 150 m using formulation of Martin et al., 1987
** Value based on sediment trap data from mid Aug. to mid Sept. 1983
Reference depths chosen to reflect maximum depths of euphotic column
Interannual variations in NO$_3$ (µM) in the North Pacific Ocean
Years of narrow low-nitrate region, mostly La Niña

Years of wide low-nitrate region, Mostly El Niño

Surface nitrate concentrations along Line P. Data and slide courtesy F. Whitney and W. Crawford, IOS Canada
Interannual variation in New Production (gC m$^{-2}$ yr$^{-1}$) in the North Pacific Ocean
New Production ($gC \ m^{-2} \ yr^{-1}$)

Jan 1998

Jan 2000
Location of shipboard data (1976-2000). All data collected by research vessels from Japan.
Interannual variation of phytoplankton biomass in the western North Pacific Ocean and relationship to the southern oscillation index
Interannual variation of winter time wind stress in relation to the MOI

(r² = 0.62, p < 0.05)
Seasonal and interannual changes in oceanographic conditions in the western North Pacific Ocean in relation to changes in the Southern Oscillation Index.
Impact of wind stress on southern limit of the Oyashio Front
Interannual variation of winter time wind stress and its effect on mixed layer depths in the western North Pacific Ocean
Relationship between the mixed layer depth and mixed layer nitrate concentrations in the western North Pacific Ocean

$r^2=0.69$ (p<0.05)
Relationship between the Monsoonal Index (MOI) and the SOI. The MOI is defined as the difference in SLP between Irkutsk (52.2° N, 104.2° E), Russia and Nemuro (43.0° N, 145.5° E), Japan
Relationship between SOI and indices describing the Aleutian Low Pressure System
SCHEMATIC DIAGRAM SHOWING CHANGES IN ATMOSPHERIC AND OCEANOGRAPHIC CONDITIONS IN THE NORTH PACIFIC OCEAN FOLLOWING AN ENSO EVENT IN THE TROPICS.
Summary

El-Nino events in the tropics have a profound impact on primary production and export production gradients across the subarctic Pacific Ocean through impacts on the location and strength of the ALPS and consequently the strength of winter monsoonal winds and winter-time convective mixing.

Over large parts of the central and eastern subarctic Pacific, phytoplankton photosynthetic competency, and hence primary production and carbon export rates are regulated by iron, whose availability could be regulated by the strength of winter-time winds.

There is an urgent need to examine rates of iron dust deposition, its solubility in seawater and bioavailability for phytoplankton.
Acknowledgments

National Aeronautical and Space Agency (NASA), USA for funding this work

Japan Meteorological Agency and Fisheries Agency of Japan for shipboard data sets

Dr. Y. Nojiri, NIES Japan and Dr. C.S.Wong, IOS, Canada for use of Trans-Pacific shipboard data sets

KORUS Committee for invitation to present this talk