Observed Climatic and Oceanographic Variations Related to Harmful Algal Blooms: Comparisons between the Western and Eastern North Pacific

Mean Circulation
Patterns of Variability
Upper Ocean Vertical Profiles
Effects of Climate Change
(from a climate guy perspective)

Nick Bond University of Washington
Bathymetry of North Pacific Ocean
Continental shelf regions of strong tidal mixing

Shaded areas indicate shelf regions of the world with sufficiently strong tidal mixing for likelihood of significant development of shelf-sea fronts (Hunter and Sharp 1983)
Pacific winds and coastal upwelling

October-March average

April-September average
Net surface heat exchange
The NPGO index measures changes in the North Pacific gyres circulation and explains key physical-biological ocean variables.

Di Lorenzo et al., 2008
(a) Eastern Pacific El Niño (EP-ENSO)

(b) Central Pacific El Niño (CP-ENSO)

POBEX Regions
KOE: Kuroshio-Oyashio Extension
NEP: Northeast Pacific
PCCS: Peru-Chile Current System

ENSO Atmospheric Projections
Regions of North Pacific SLPa driven by ENSO teleconnection during the EP and CP El Niños.
North Pacific Ocean Modes integrate and low-pass filter forcing of Atmospheric Modes & ENSO teleconnections
Winter-spring processes during the regime of strong Aleutian Low (e.g. 1976 -)

- Aleutian Low ENHANCED
- Light availability: UP
- Spring production: UP
- Bloom timing: LATE
- Subarctic circulation: strong
- Wind stress: STRONG
- Water temp.: LOW

Changes in the Kuroshio properties occurred several years behind that of the Oyashio.

After the mid 1970s

Lower tropic level responses to the 1976 and 1988 RS:
(winter-spring processes)

Winter-spring processes during the regime of strong Polar vortex and weak Aleutian Low (e.g. 1990s)

- Polar vortex ENHANCED
- Aleutian Low weakened
- Light availability: DOWN?
- Spring production: ?
- Bloom timing: EARLY
- Subarctic circulation: weak

Changes in the Kuroshio properties occurred several years behind that of the Oyashio.

After the late 1988s

(Chiba et al, submitted, PO)
(b) North Pacific Gyre Oscillation (NPGO) (positive phase)

KOE and NPGO

Zooplankton (sign reverse)

KOE Transport Strength Index

NPGO (lead 2.5)

R = 0.62

R = 0.75

1965 1975 1985 1995

Chiba et al., 2013

M. Di Lorenzo, S. Chiba and collaborators
WP- A primary mode of NH atmospheric circulation variability
East Asian Winter Monsoon


(b) Correlation between EAWMI and surface temperature

Ha et al. (2012)
East Asian Summer Monsoon Related to Precipitation and Low-level Winds

Ha et al. (2012)
Three Concepts Related to HABs

• **Stress** – Macronutrient, micronutrient and contaminant concentrations have been linked to development of domoic acid (DA).

• **Retention** – Prolonged periods of particular conditions appear to be instrumental for toxic levels (e.g., Juan de Fuca eddy).

• **Transport** – Onshore directed flow is necessary to infect coastal locations.
Mean Upper Ocean Density Profiles: West versus East

West (35 N, 125 E)                                    East (48 N, 125 W)

August                       February                                August                 February

Depth (m)

Density

Density

Depth (m)
Warm Season (Aug 2011) Profiles in the Yellow Sea

Fu et al. (2016)
Mean Si:N Ratios in Top 60 meters during May

Greater in the coastal zone of the western North Pacific from World Ocean Atlas 2013
Near-shore circulation associated with coastal upwelling

- In coastal upwelling periods, **offshore** transport in the surface Ekman layer is balanced by **onshore** transport at depth
  - Vertical migration in coastal upwelling regions provides organisms a means for a free-ride offshore and onshore
Bottom boundary layers

• Directly adjacent to the ocean bottom, flow is retarded by friction. In large-scale, low-frequency flows, the effect of the earth’s rotation is important and results in a *bottom Ekman layer* -- analogous to the surface Ekman layer but turned upside down.

• In a bottom Ekman layer, there is frictional transport *to the left of the flow direction* in the Northern Hemisphere.
Strong poleward flowing western boundary currents and bottom Ekman layers

- These deep currents directly impinge on the continental shelf and slope -- here expect a substantial bottom Ekman layer in which the flow is upslope and toward the coast
Kuroshio Intrusion for East China Sea (ECS) and Tsushima Warm Current (TWC) Varies Seasonally

Guo et al. (2006)
The Juan de Fuca Eddy at 35 meters

Foreman et al. (2008)
Vortex driven upwelling

• While the pressure force is overbalanced, the outward moving surface waters are replaced by upwelled subsurface water from the eddy interior.

• This loss of surface water and upwelling continues until the resulting sea surface depression, and accumulation of higher-density water, in the eddy interior re-establishes a pressure gradient sufficient to balance the combined Coriolis and centrifugal forces.
Transport of toxic cells onto beaches in the Pacific NW

Hickey et al (2013)
Continental shelf regions of strong tidal mixing

Shaded areas indicate shelf regions of the world with sufficiently strong tidal mixing for likelihood of significant development of shelf-sea fronts (Hunter and Sharp 1983)
Shallow water, greener pastures

- Over large shallow banks and continental shelf regions of the ocean, organic matter can sink only to the depth of the shallow sea bottom.
  - Remineralization and redissolution of plant nutrients takes place much closer to, or even within, the photic zone
  - This is a major reason for the high rates of primary organic production typical of shallow seas
  - The sediment can also represent a source of iron in a bio-available (reduced) form
Shelf-sea fronts

- Over shallow continental shelf regions, tidal mixing may homogenize the water from surface to bottom.
- This results in surface water of greater density and bottom water of lesser density over the shelf compared with offshore waters at the same depths.
  - Onshore flows in surface and bottom waters, offshore flow at mid-depths.

<table>
<thead>
<tr>
<th>Lower density surface water</th>
<th>Mixed water</th>
<th>Higher density bottom water</th>
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Concentrated productivity in the pycnocline
Projected Change in SST (Ensemble Model Average)
Ensemble Model Average Change in 0-50 meter static stability (AMJ)

Historical (1956-2005)
Average

(2006 to 2055) –
(1956-2005)

CMIP5 ENSMN RCP8.5 anomaly (2006-2055)-(1956-2005)

0.6 1 1.4 1.8 2.2 2.6 3 3.4 3.8 4.2

0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6 2.8 3 3.2 3.4

(2006 to 2055) –
(1956 to 2005)
Changes in Nutrient Concentrations and Primary Productivity in the North Pacific

Rykaczewski and Dunne (2010)
Less ventilation of waters below the mixed layer in the North Pacific leading to higher nutrient and lower oxygen concentrations along US West Coast.
Changes in Source Waters of the Southern California Bight Based on CalCOFI Time Series

Bograd et al. (2015)
North Pacific: West vs. East Shelf
Regions

<table>
<thead>
<tr>
<th>West</th>
<th>East</th>
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<tbody>
<tr>
<td>Shelf Width</td>
<td>• Mostly narrow</td>
</tr>
<tr>
<td>Tidal Mixing</td>
<td>• Moderate</td>
</tr>
<tr>
<td>Winter Stratification</td>
<td>• Weak</td>
</tr>
<tr>
<td>Summer Stratification</td>
<td>• Moderate</td>
</tr>
<tr>
<td>Source Surface H₂O</td>
<td>• From west</td>
</tr>
<tr>
<td>Source Deep H₂O</td>
<td>• Coastal upwelling (summer)</td>
</tr>
<tr>
<td>Si:Nitrate Ratio</td>
<td>• Moderate</td>
</tr>
<tr>
<td>Iron Concentration</td>
<td>• Low (sediments)</td>
</tr>
<tr>
<td>Future Stratification</td>
<td>• Higher</td>
</tr>
<tr>
<td>Future Primary Prod.</td>
<td>• Maybe higher</td>
</tr>
<tr>
<td>Future Chemistry</td>
<td>• Lower pH, O₂</td>
</tr>
<tr>
<td></td>
<td>• ???</td>
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