Impacts of climatic regime shift on Japanese sardine stock collapse

1, Haruka nishikawa
2 Ichiro Yasuda
2 Sachihiko Itoh
1 Yoshikazu Sasai
1 Hideharu Sasaki

1 Japan Agency for Marine-Earth Science and Technology
2 atmosphere and Ocean research institute, the university of Tokyo
Stock collapse of Japanese sardine

Successive high larvae mortality from 1988 to 1994 resulted in stock collapse. (Watanabe et al., 1995)
Causes for high mortality from 1988

OGCM data near the Kuroshio jet

**From 1988, Near the Kuroshio jet...**
- Shallow winter mixed layer reduced forage
- Too high temperature delayed growth
  
  (Nishikawa et al., 2011, FO)

**Why winter MLD/SST regime shift occurred in 1988 near the Kuroshio jet?**

Shallow ML & High SST regime
Determinants of winter MLD/SST interannual variation near the Kuroshio jet

**Common determinants for MLD and SST**
- Surface cooling intensity
  - Net heat flux
  - Ekman heat advection
- Cooling duration time
  - Transport velocity
  - Transport path length
- Horizontal diffusion

**MLD specific**
- Short wave radiation in ML
- Wind stirring
- Convergence and Divergence

**SST specific**
- Entrainment of cold water by ML development

Exposure to cold air develops winter ML and reduces SST during the transportation from subtropical region.
BMLM applies to particle tracking experiments

Particle tracking experiments by using velocity data from OGCM

OGCM (OFES, Masumoto et al., 2004)
- 0.1° × 0.1°, horizontally
- Atmospheric variables are from NCEP/NCAR reanalysis

Particle tracking experiments
- Particles are released at Dec. 15, 1974–2003
- From Subtropic (25.5°N) to Kuroshio Extension (150°E)

Apply the bulk mixed layer model to transported particles

Expression of Entrainment velocity ($W_e$), MLD ($h_m$) and SST ($T_m$) by BMLM (Qiu and Kelly, 1993)

\[
\frac{1}{2} \alpha gh_m \Delta Tw_e = m_o u_3^3 + \frac{\alpha g}{\rho_o c} \int_{-h_m}^0 q(z) dz - \frac{\alpha gh_m}{2 \rho_o c} (Q_{net} + q_d) - m_c \frac{\alpha gh_m}{4 \rho_o c} (|Q_{net} - Q_{net})
\]

\[
\frac{dh_m}{dt} = -\int_{-h_m}^0 \nabla H \cdot u dz + A_h \nabla^2 h_m + w_e
\]

\[
h_m \frac{dT_m}{dt} = A_h h_m \nabla^2 T_m + \frac{1}{\rho_o c} (Q_{net} - q_d) - \Delta T (w_e + A_h \nabla^2 h_m)
\]

BMLM can estimate contribution of each determinant
Contribution of determinants to the regime shift

e.g. Estimation of the Kuroshio velocity regime shift impact on ML shoaling


BMLM estimates; Decrease of entrainment during the transportation caused 17 m of ML shoaling

Kuroshio transport velocity acceleration caused 9 m ML shoaling

Accumulated entrainment is further divided into some components (Heat flux, etc.)
Causes for ML shoaling from 1988

How many meters was decreased by each determinant

Net surface heat flux intensity

Transport velocity

<table>
<thead>
<tr>
<th>contribution</th>
<th>4.7 %</th>
<th>Transport path length</th>
<th>10.2 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind stirring</td>
<td></td>
<td>Transport velocity</td>
<td>60.5 %</td>
</tr>
<tr>
<td>Short wave radiation</td>
<td>-4.7 %</td>
<td>Divergence</td>
<td>-7.4 %</td>
</tr>
<tr>
<td>Cooling by Ekman transport</td>
<td>8.1 %</td>
<td>Horizontal diffusion</td>
<td>-8.2 %</td>
</tr>
<tr>
<td>Surface heat flux</td>
<td>38.1 %</td>
<td></td>
<td></td>
</tr>
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</table>
Causes for ML shoaling from 1988

- **Kuroshio intensification**
- **Surface cooling weakening**
- How many meters was decreased by each determinant
- Shortens cooling duration time

**Results**

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Causes for SST rise from 1988

- **Shallow ML from 1988 induces cooling**
- **Surface cooling weakening**
- **Kuroshio intensification**

How many degrees was increased by each component

**Results Table**

<table>
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<tr>
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<tr>
<td>Cooling by Ekman transport</td>
<td>10.7 %</td>
</tr>
<tr>
<td>Surface heat flux</td>
<td>50.7 %</td>
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<tr>
<td>Transport path length</td>
<td>13.3 %</td>
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<tr>
<td>Transport velocity</td>
<td>77.3 %</td>
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<tr>
<td>Entrainment velocity</td>
<td>13.3 %</td>
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<tr>
<td>Horizontal diffusion</td>
<td>0.0 %</td>
</tr>
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</table>
MLD/SST regime shift near the Kuroshio jet

Surface cooling became weak

Kuroshio is accelerated
Water was not exposed to cooling for so long

Winter ML turned to be shallow and SST turned to be high around the sardine larvae feeding grounds

Bad condition for sardine larvae
Predictability for Sardine stock collapse

Anomaly of surface horizontal velocity, from 1986 to 1988 near the Kuroshio jet

Signal of Kuroshio intensification was shown 2 years ago

SSH anomaly that induces Kuroshio intensification arises in the Central Pacific and propagates as Rossby waves (Nonaka et al., 2006, 2011)

Sardine stock collapse can be predicted by sign of environmental regime shift