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

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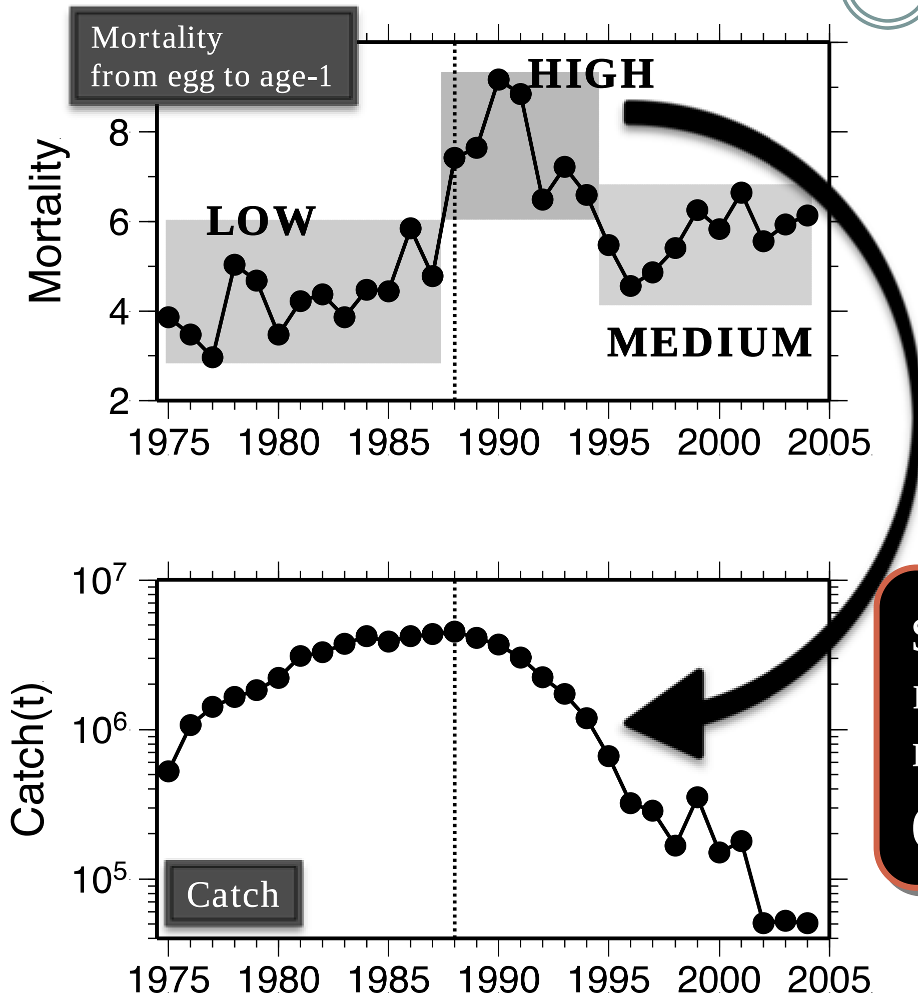
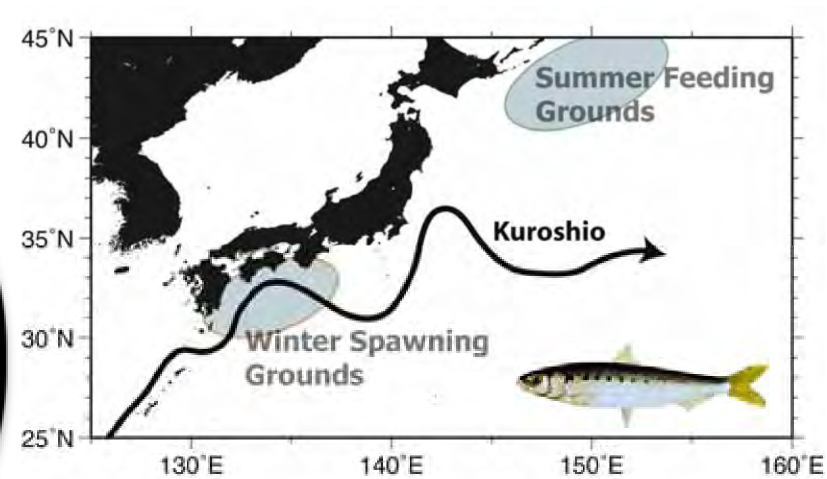
Stock collapse of Japanese sardine



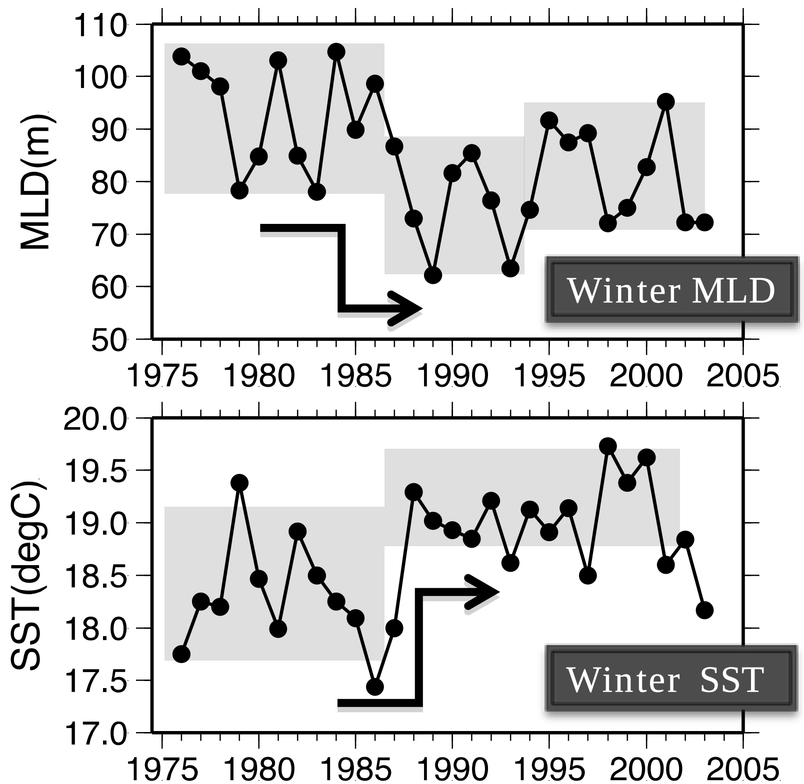


Successive high larvae mortality from 1988 to 1994 resulted in stock collapse.

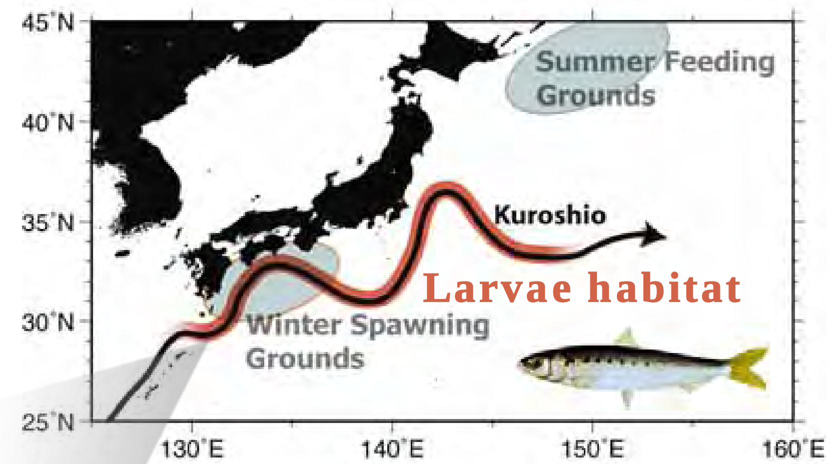
(Watanabe *et al.*, 1995)

Causes for high mortality from 1988

OGCM data near the Kuroshio jet



Shallow ML & High SST regime



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?

Determinants of winter MLD/SST interannual variation near the Kuroshio jet

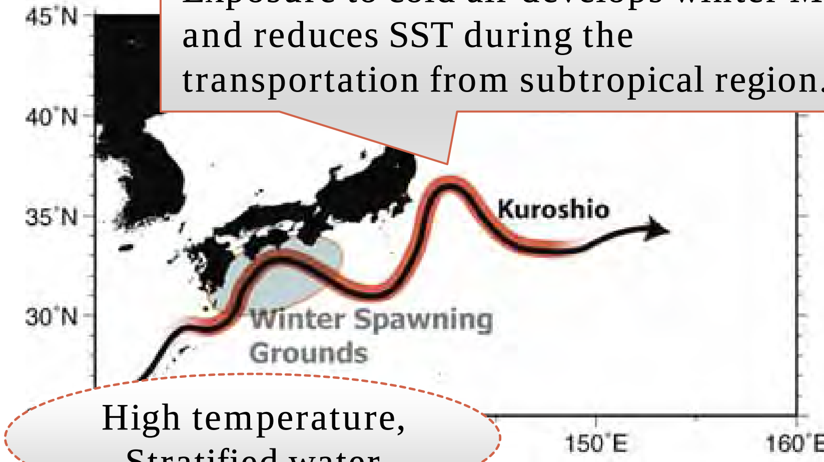
Common determinants for MLD and SST

- Surface cooling intensity
  - Net heat flux
  - Ekman heat advection

- Cooling duration time
  - Transport velocity
  - Transport path length

- Horizontal diffusion

Exposure to cold air develops winter ML and reduces SST during the transportation from subtropical region.



High temperature, Stratified water

MLD specific

- Short wave radiation in ML
- Wind stirring
- Convergence and Divergence

SST specific

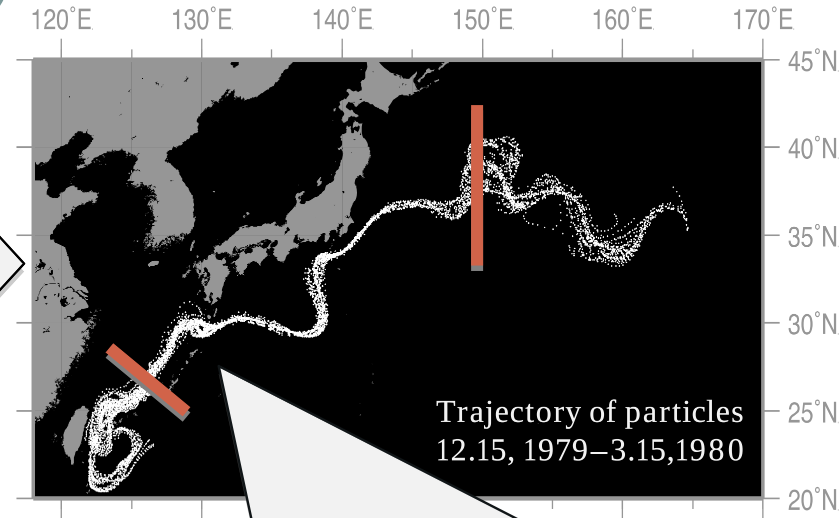
- Entrainment of cold water by ML development

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)

$$\frac{1}{2}\alpha g h_m \Delta T w_e = m_o u_*^3 + \frac{\alpha g}{\rho_o c}\int_{-h_m}^{0} q(z)\,dz - \frac{\alpha g h_m}{2\rho_o c}\left(Q_{net} + q_d\right) - m_c \frac{\alpha g h_m}{4\rho_o c}\left(\left|Q_{net}\right| - Q_{net}\right)$$

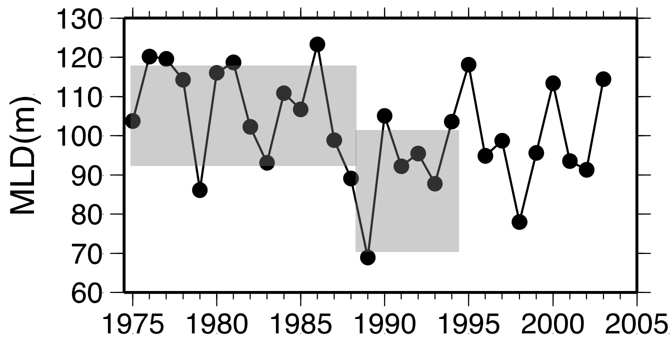
$$\frac{dh_m}{dt} = -\int_{-h_m}^{0} \nabla_H \cdot \mathbf{u}\,dz + A_h \nabla_H^2 h_m + w_e$$

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

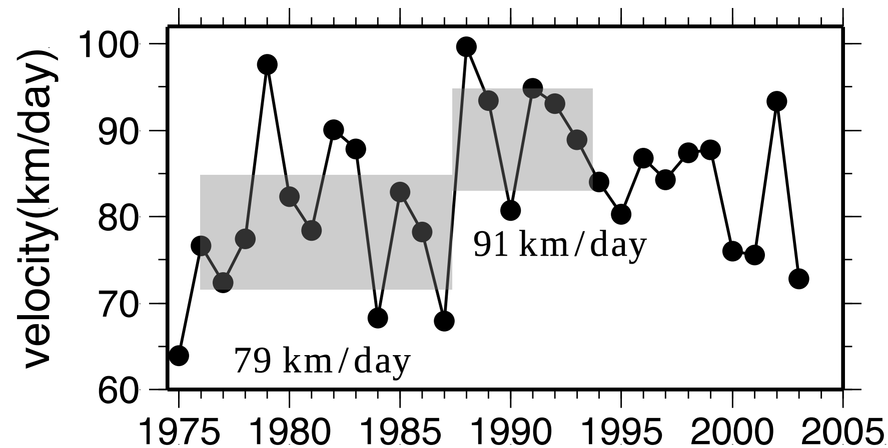
BMLM can estimate contribution of each determinant

Contribution of determinants to the regime shift

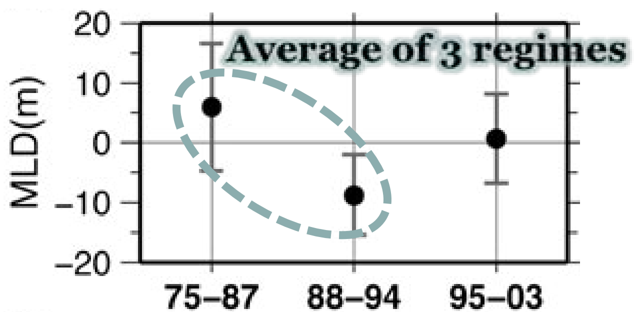
e.g. Estimation of the Kuroshio velocity regime shift impact on ML shoaling

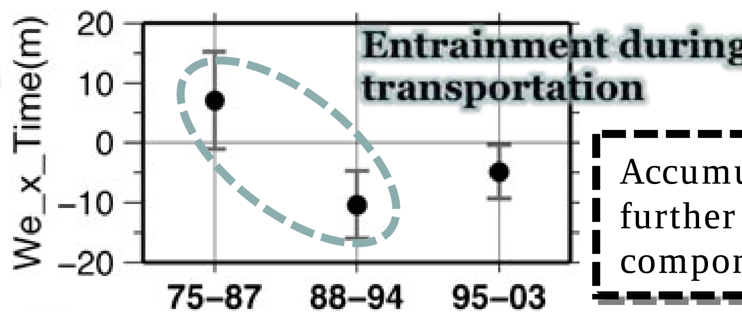


Period-average MLD decreased 14 m from 1975–1987 to 1988–1994



Kuroshio transport velocity acceleration caused 9 m ML shoaling

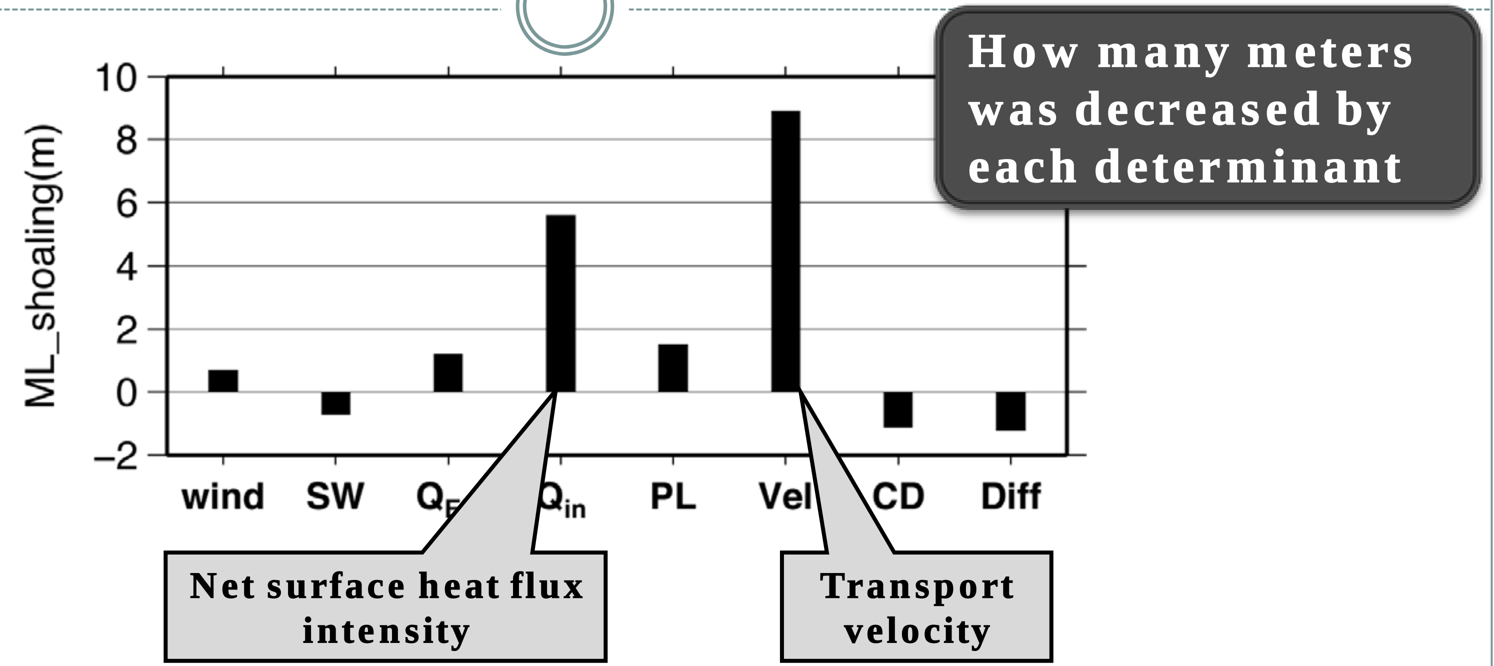




Accumulated entrainment is further divided into some components (Heat flux, etc.)

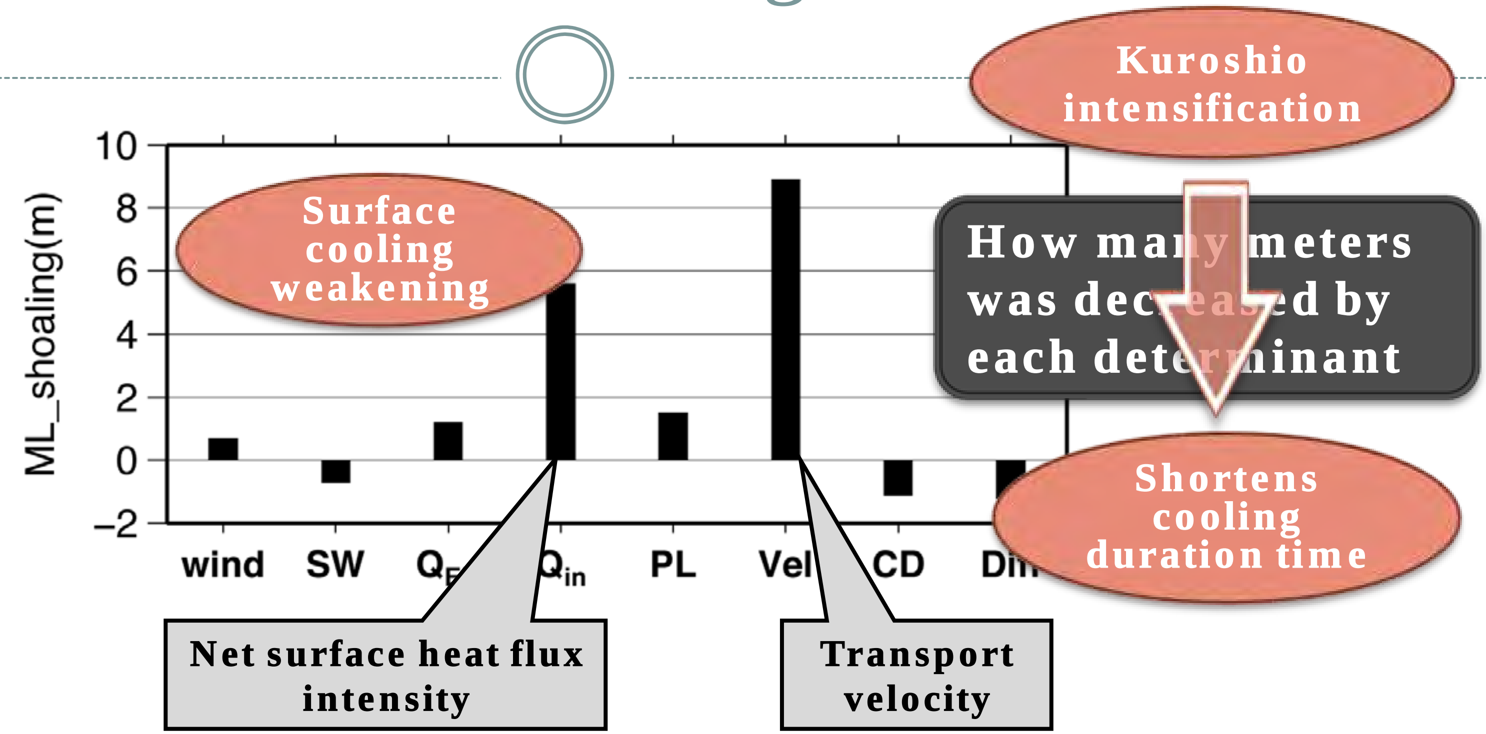
BMLM estimates;
Decrease of entrainment during the transportation caused 17 m of ML shoaling

Causes for ML shoaling from 1988



	contribution		contribution
Wind stirring	4.7 %	Transport path length	10.2 %
Short wave radiation	-4.7 %	Transport velocity	60.5 %
Cooling by Ekman transport	8.1 %	Divergence	-7.4 %
Surface heat flux	38.1 %	Horizontal diffusion	-8.2 %

Causes for ML shoaling from 1988



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Causes for SST rise from 1988

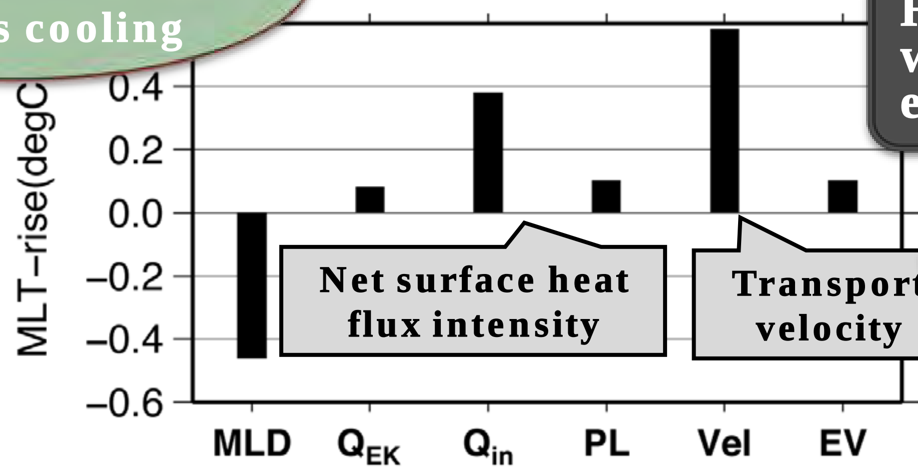
Shallow ML from 1988 induces cooling

Surface cooling weakening

Kuroshio intensification

How many degrees was increased by each component

Shortens cooling duration time

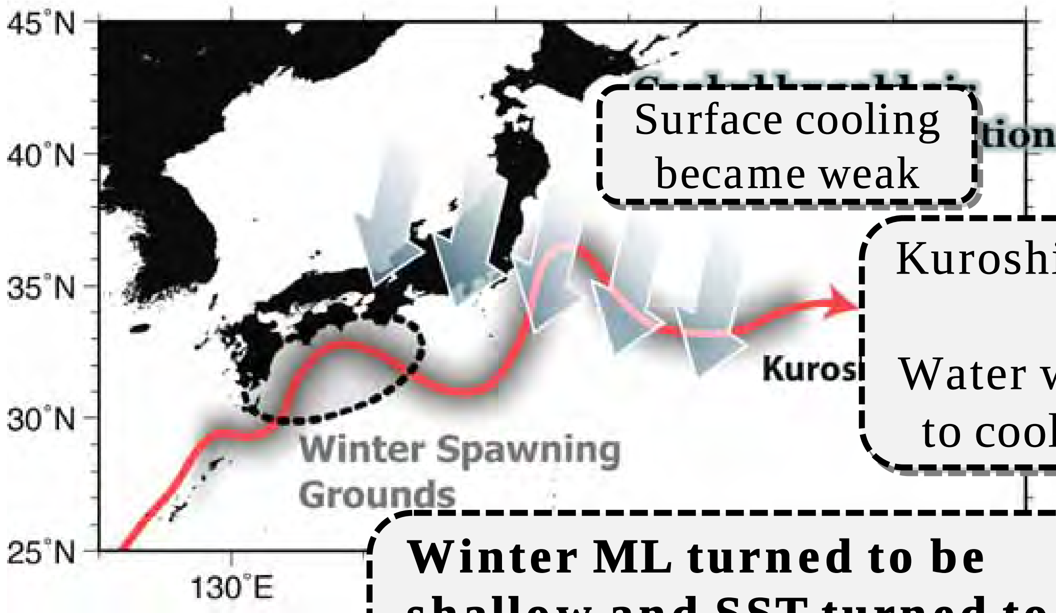


Net surface heat flux intensity

Transport velocity

	contribution		contribution
MLD	-61.3 %	Transport velocity	77.3 %
Cooling by Ekman transport	10.7 %	Entrainment velocity	13.3 %
Surface heat flux	50.7 %	Horizontal diffusion	0.0 %
Transport path length	13.3 %		

MLD/SST regime shift near the Kuroshio jet



Surface cooling became weak

Kuroshio is accelerated

▼

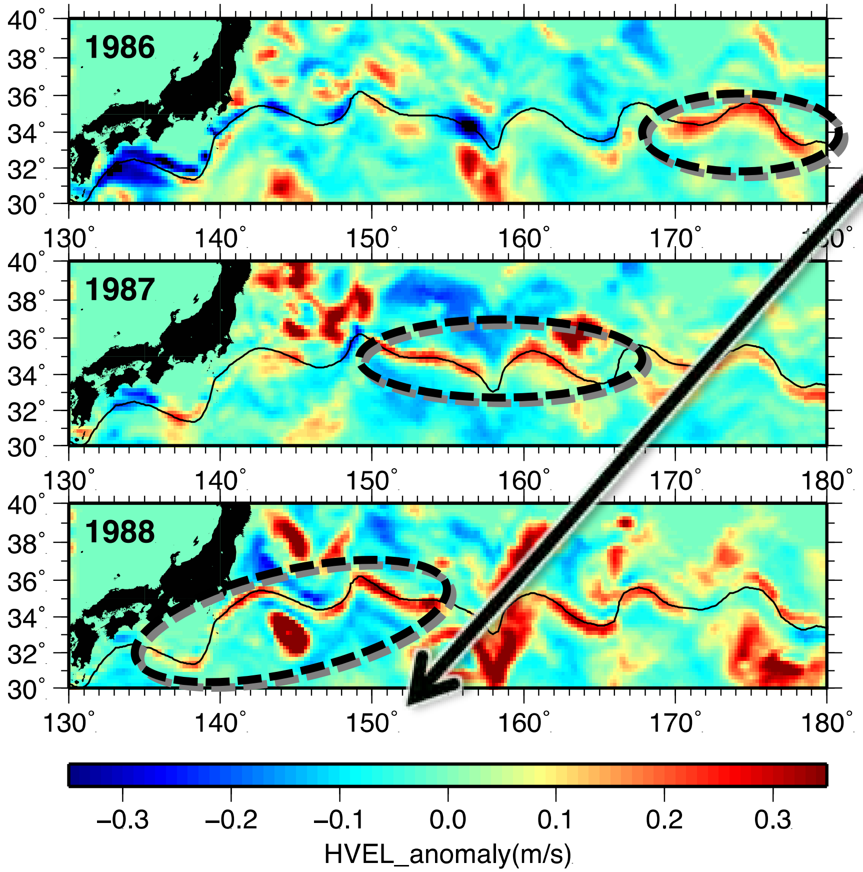
Water was not exposed to cooling for so long

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