Investigating the spawning migration of Japanese anchovy *Engraulis japonicus* from East China Sea to Taiwan using a coupled fish behavior-hydrodynamic model

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Japanese anchovy *Engraulis japonicus*

- Small pelagic fish distributed in Asian marginal sea
- Important fishery target species
- Link lower trophic levels to higher trophic levels

Anchovy larval fishery

- Migrate to inshore area for spawning in early spring

Anchovy larval fishery

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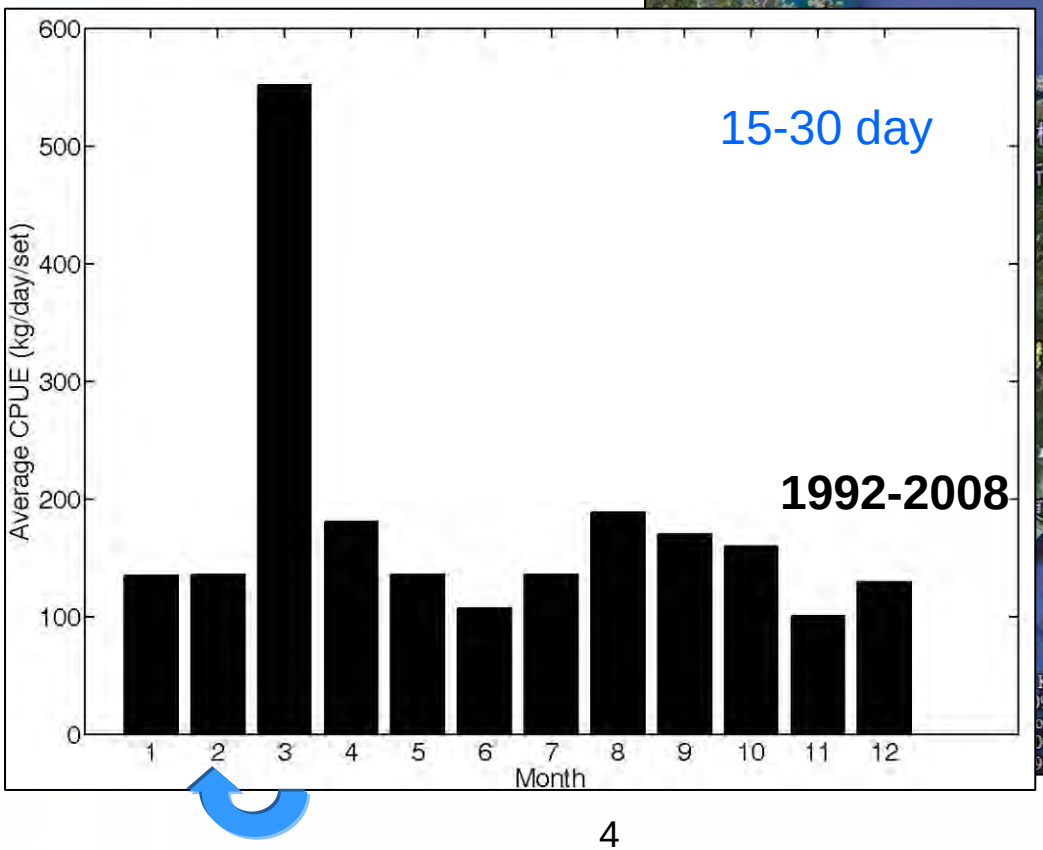
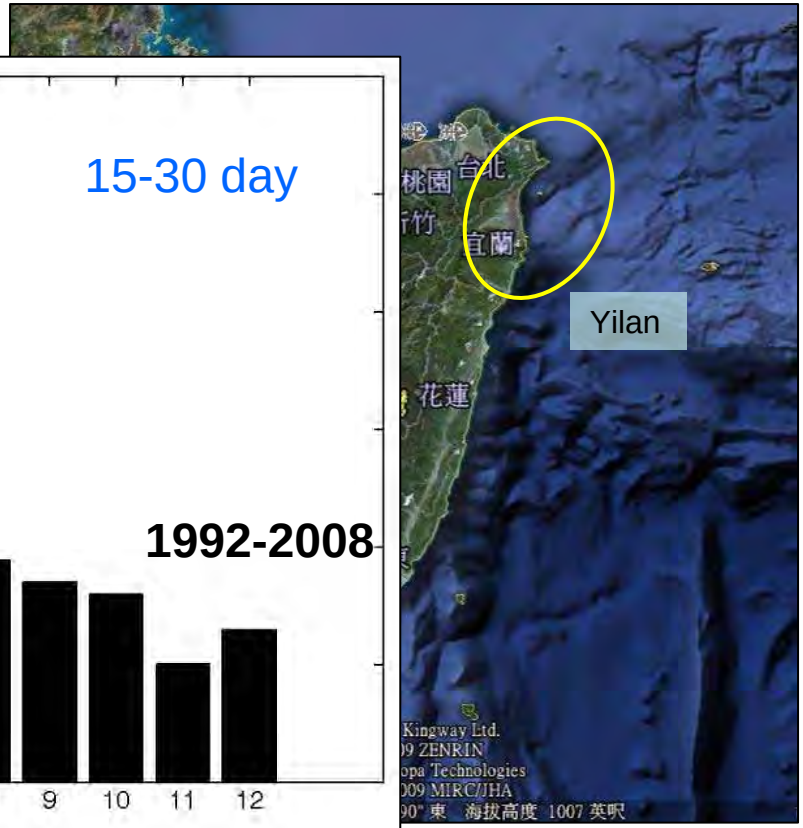
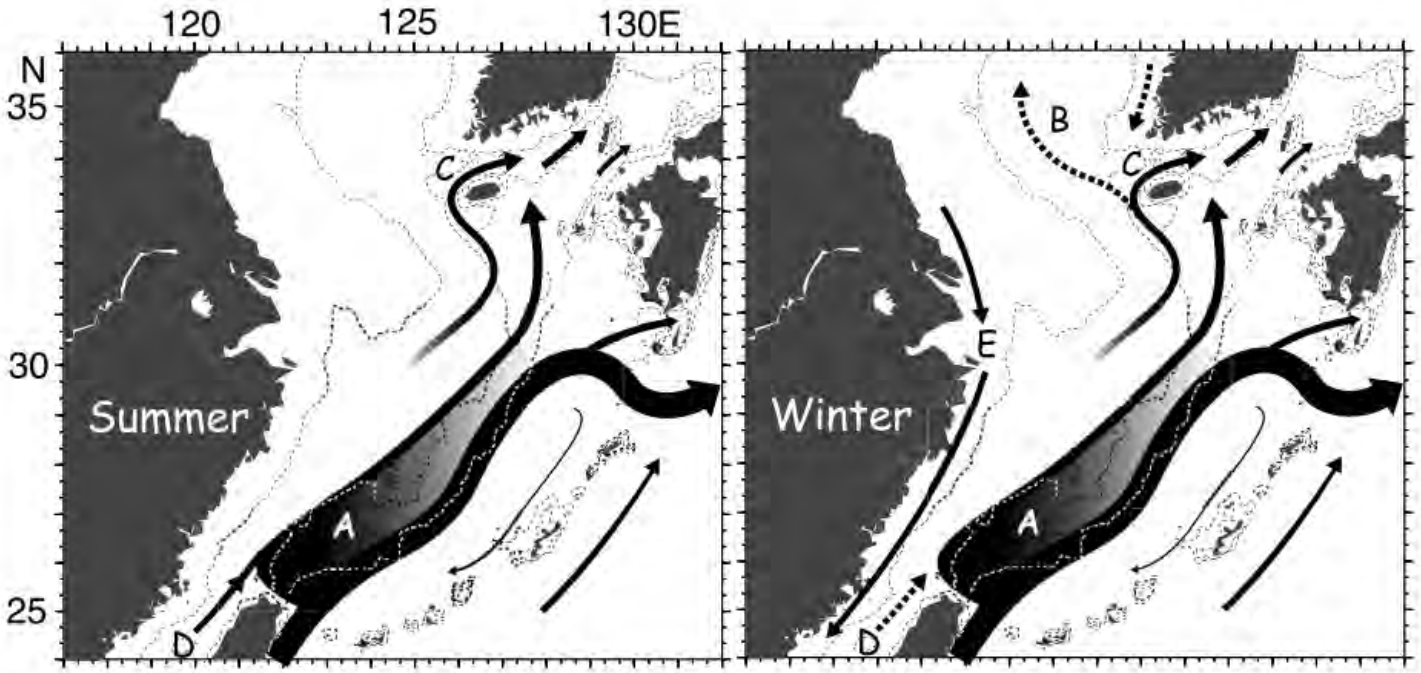




Introduction



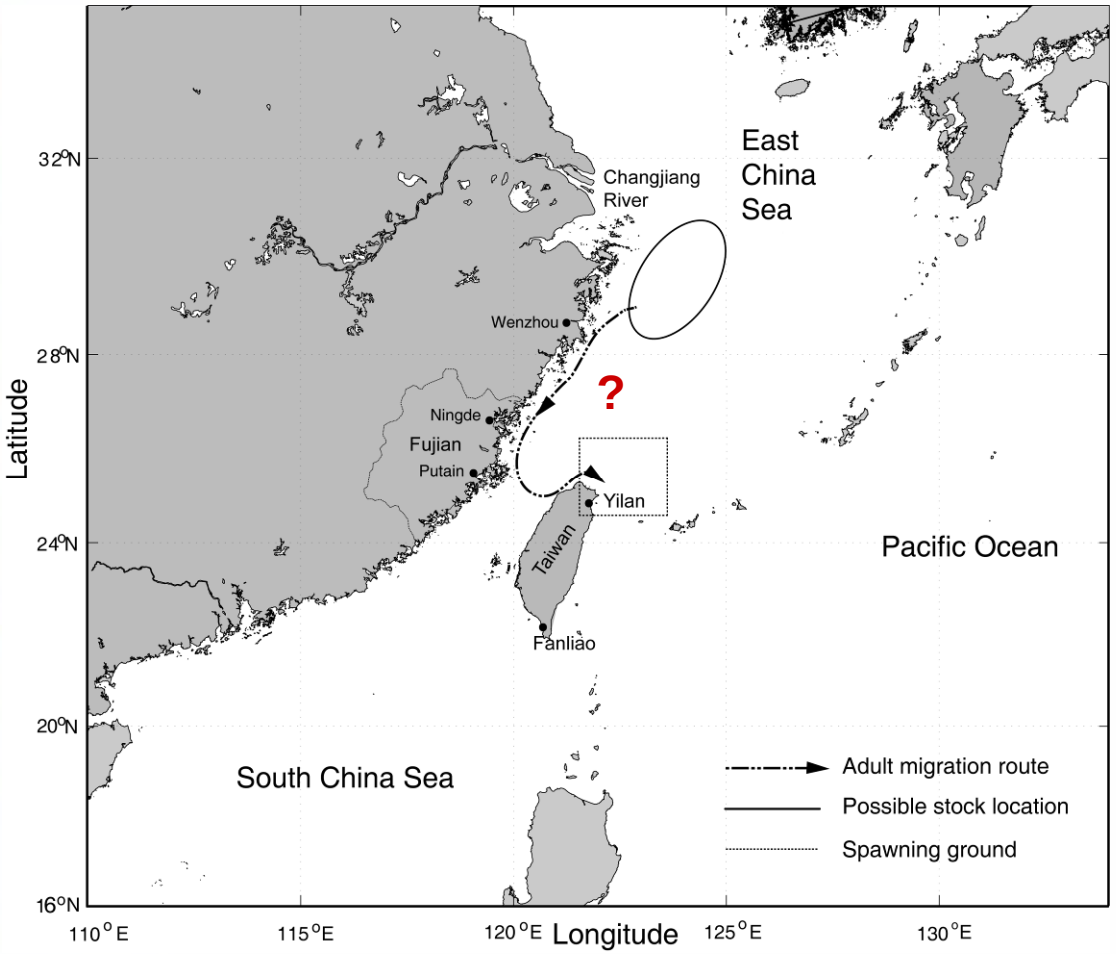
A: Kuroshio

D: Taiwan Strait Current

E: China Coastal Current

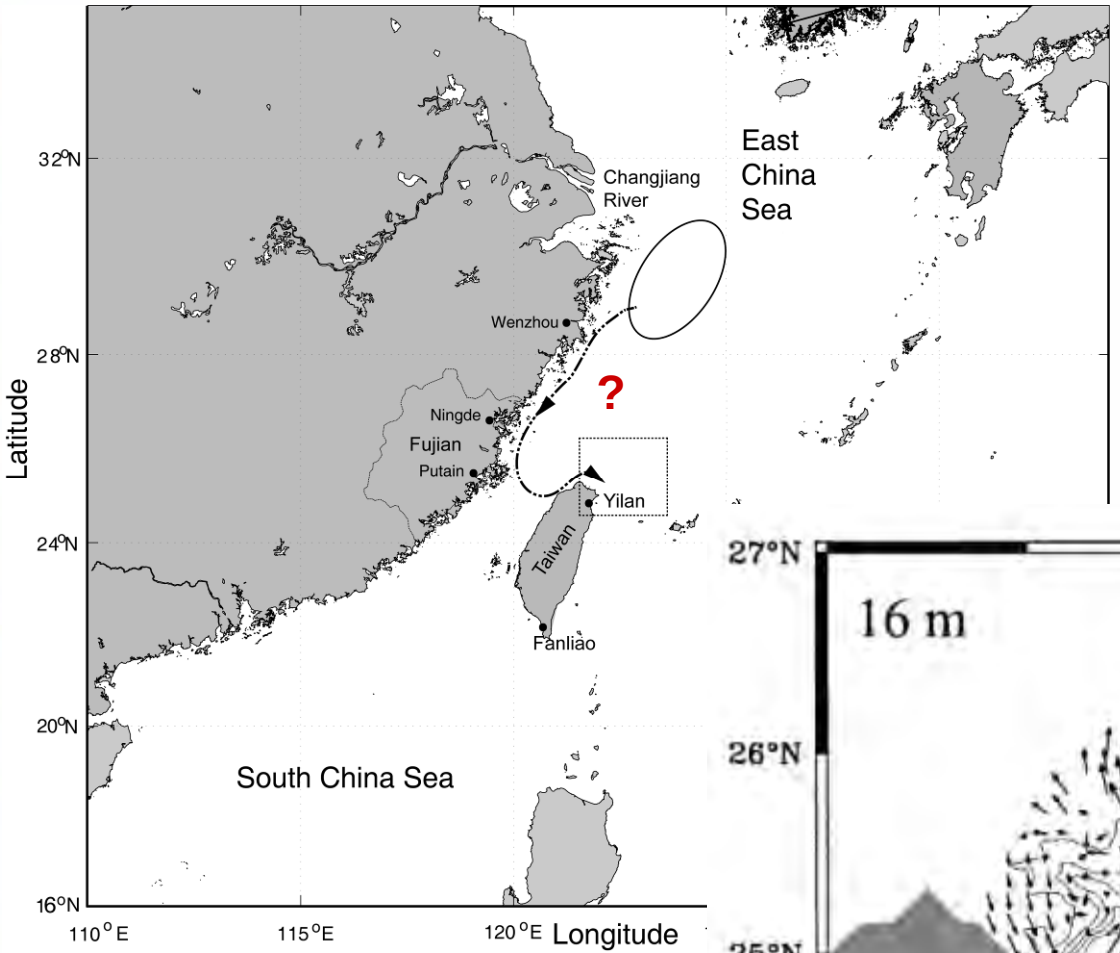
Isobe *et al*. 2008

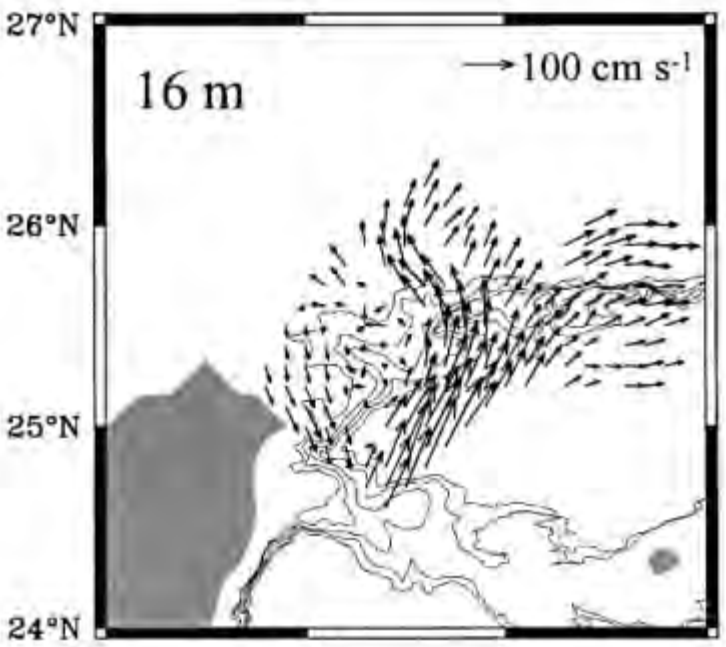
Introduction



Tang *et al.*, 2000

Introduction





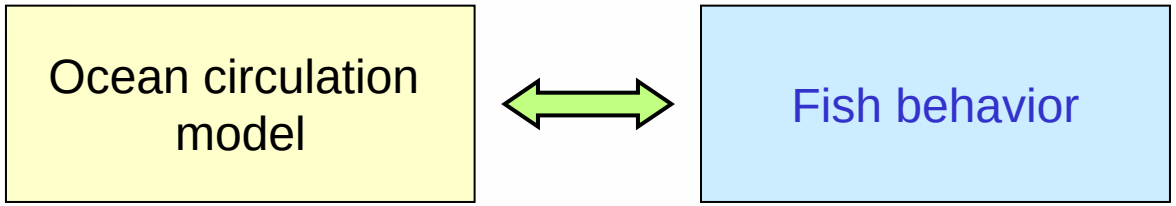
Tang *et al.*, 2000

- Success in spawning migration potentially affects larval recruitment (Cushing, 1975)
- Fishes tend to spawn at certain area where the physical environment favors the retention of egg/larvae
  - Member-Vagrant hypothesis (Sinclair, 1988)

Objectives

- Is the spawning migration of Japanese anchovy aided by China Coastal Current?
- Importance of fish swimming behavior during migration

Behavior-hydrodynamic coupled model



- TIMCOM model
  - 1/8° x 1/8°
  - http://efdl.as.ntu.edu.tw/research/timcom
  - Wind-driven
  - Changjiang inflow

    0.02 SV (long-term average)
- Lagrangian particle tracking model

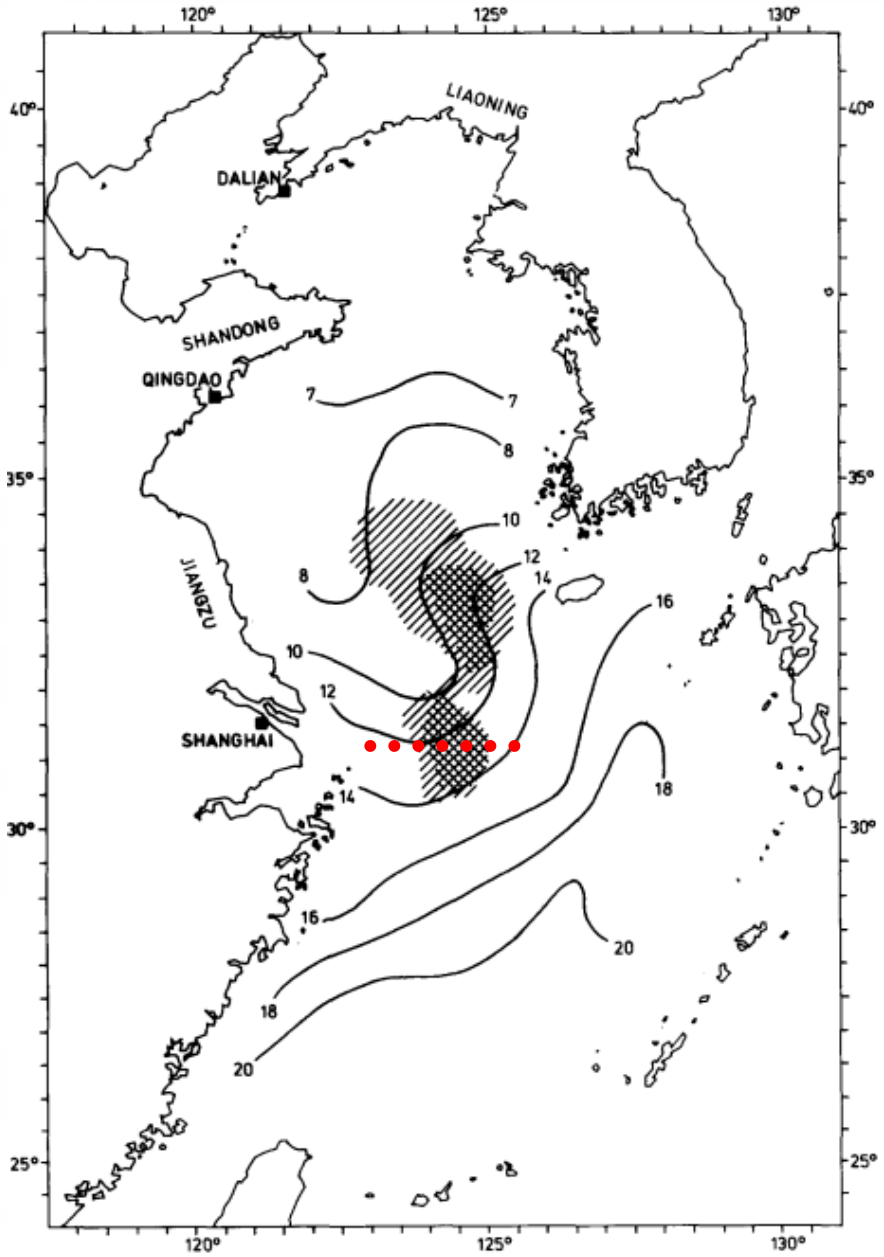


Fig. 4. Surface temperature (°C) and main distribution of anchovy in January.

Lagrangian model

- Initial location

1. 'Super-individual'
2. Depth: 12.5 m
3. Neglect vertical migration

Iversen *et al.*, 1993

Fish swimming behavior

$\boldsymbol{V}$ = 2BL = 30 cm/s

1. Swimming along with current

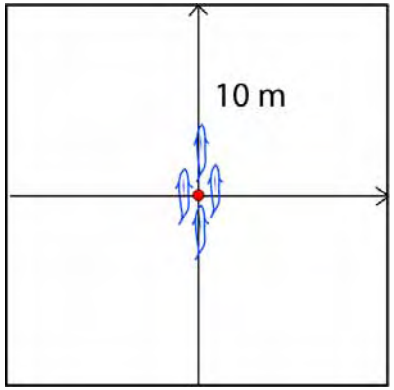
$$u_s = V \times \frac{u_c}{\sqrt{{u_c}^2 + {v_c}^2}}, v_s = V \times \frac{v_c}{\sqrt{{u_c}^2 + {v_c}^2}}$$

2. Following the temperature gradient

$$\nabla T = \frac{\partial T}{\partial x}\hat{i} + \frac{\partial T}{\partial y}\hat{j}$$

$$GM = \sqrt{(\partial T/\partial x)^2 + (\partial T/\partial y)^2}$$

$$u_s = V \times \frac{(\partial T/\partial x)}{GM}\hat{i}, v_s = V \times \frac{(\partial T/\partial y)}{GM}\hat{j}$$

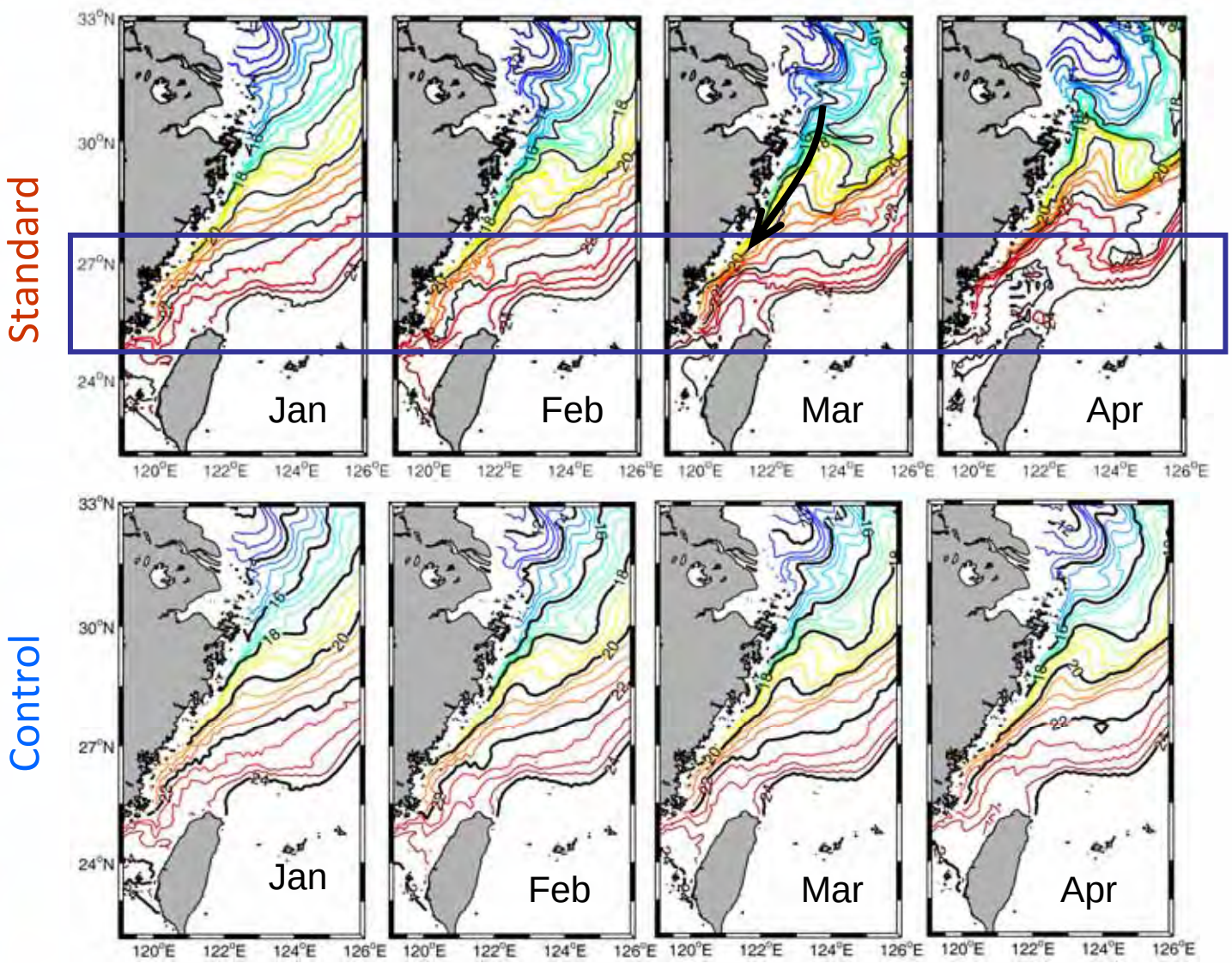


Scenarios

	0	1	2
Control*	0a	1a	2a
Standard+	0b	1b	2b

*w/o river inflow **(a)**
+w/ river inflow **(b)**

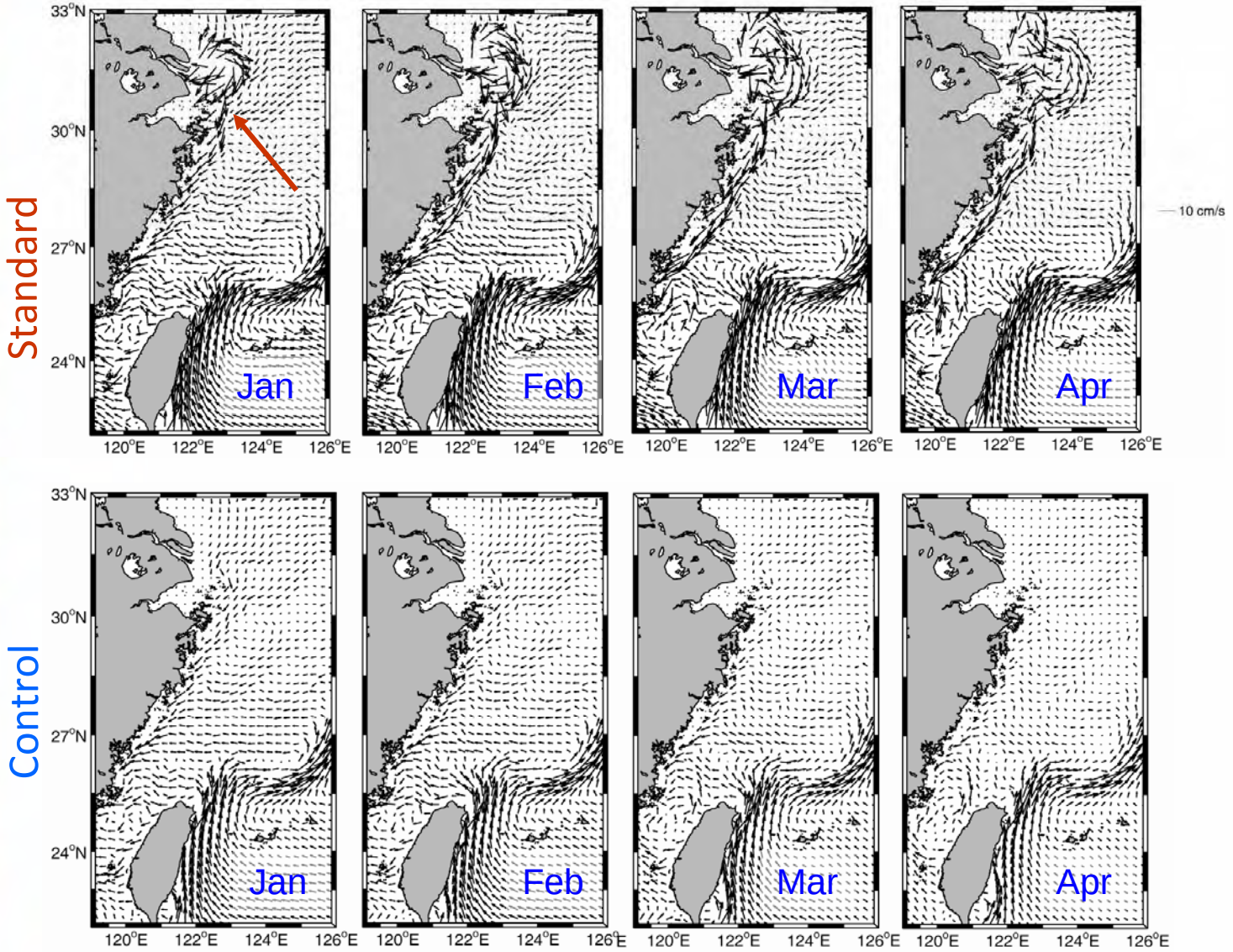
0. **Passive**
1. **Swimming along w/ current**
2. **Stepwise:**
   (1) *swimming along w/ current* and then
   (2) *following temperature gradient*
   when sensing optimal spawning temperature (22 °C) within 10m


Standard
Control
Jan
Feb
Mar
Apr
33°N
30°N
27°N
24°N
120°E
122°E
124°E
126°E

Introduction

Model description

Result



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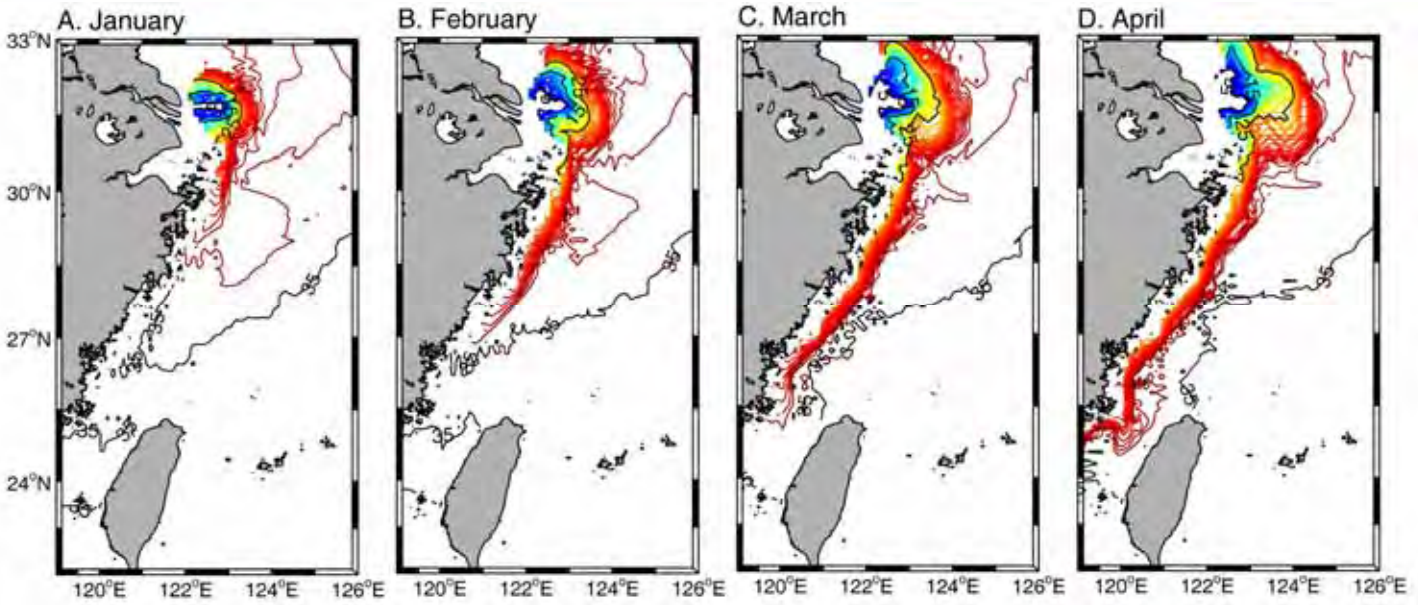
Salinity


A. January
B. February
C. March
D. April
33°N
30°N
27°N
24°N
120°E
122°E
124°E
126°E

Introduction

Model description

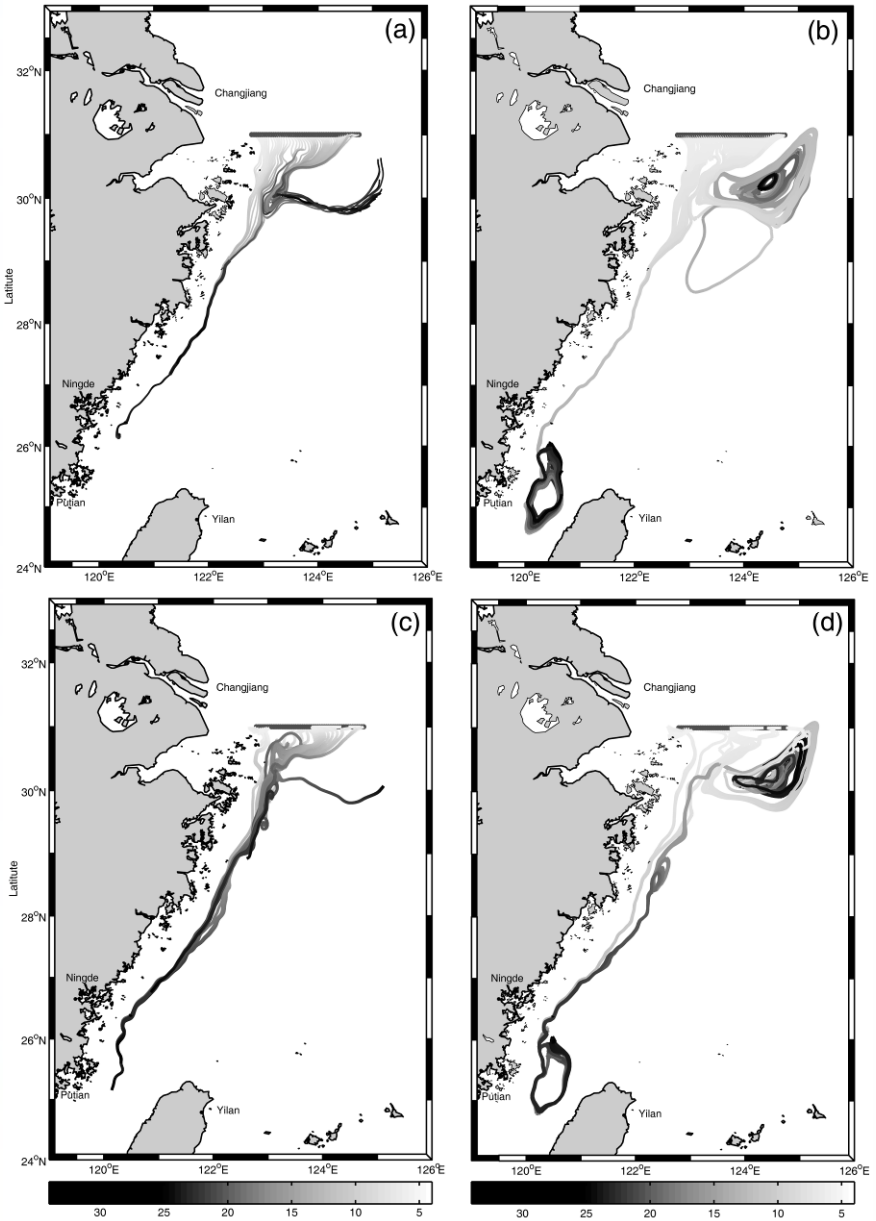
Result

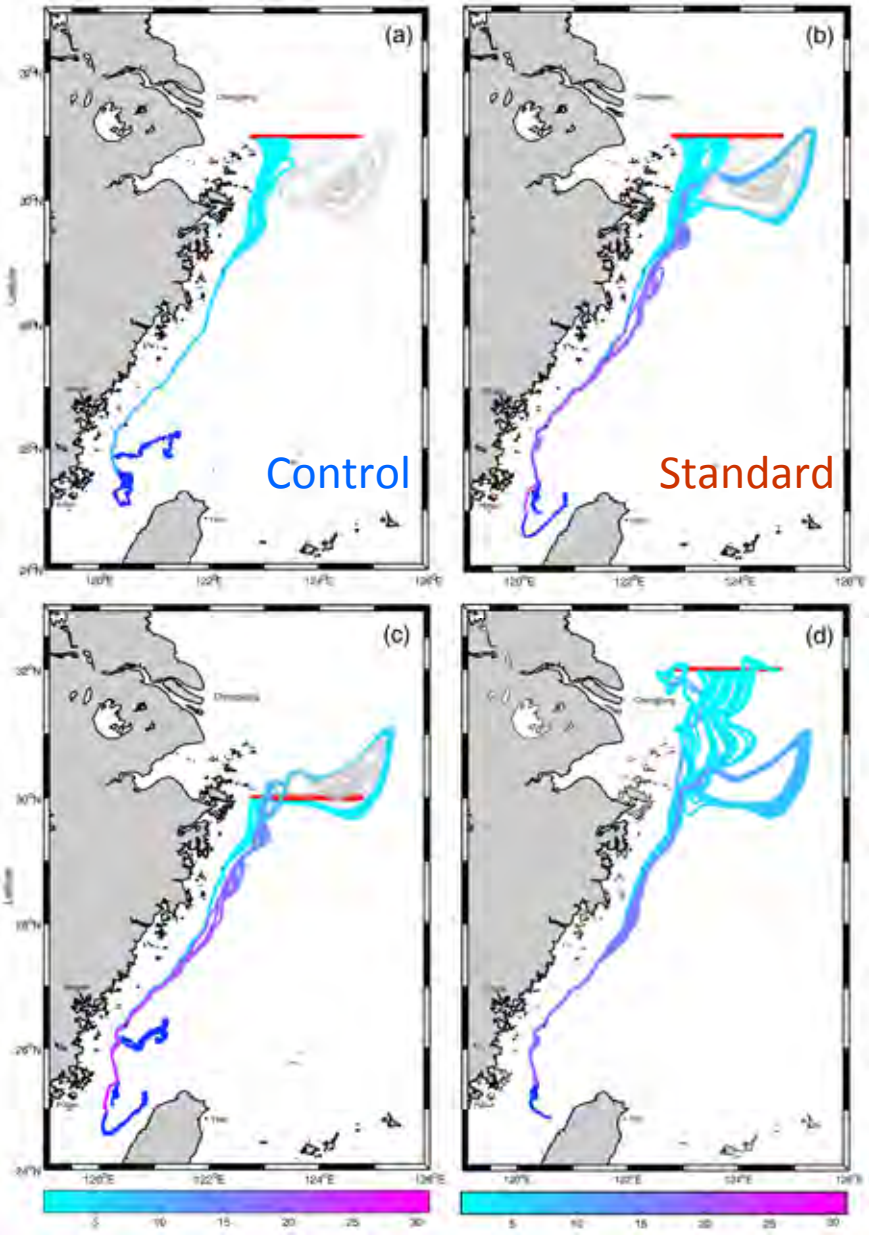
0. Passive

1. Along with current

Control

Standard





2. Step-wise

(a) Control
(b) Standard
(c) Initial location 30 °N
(d) Initial location 32 °N

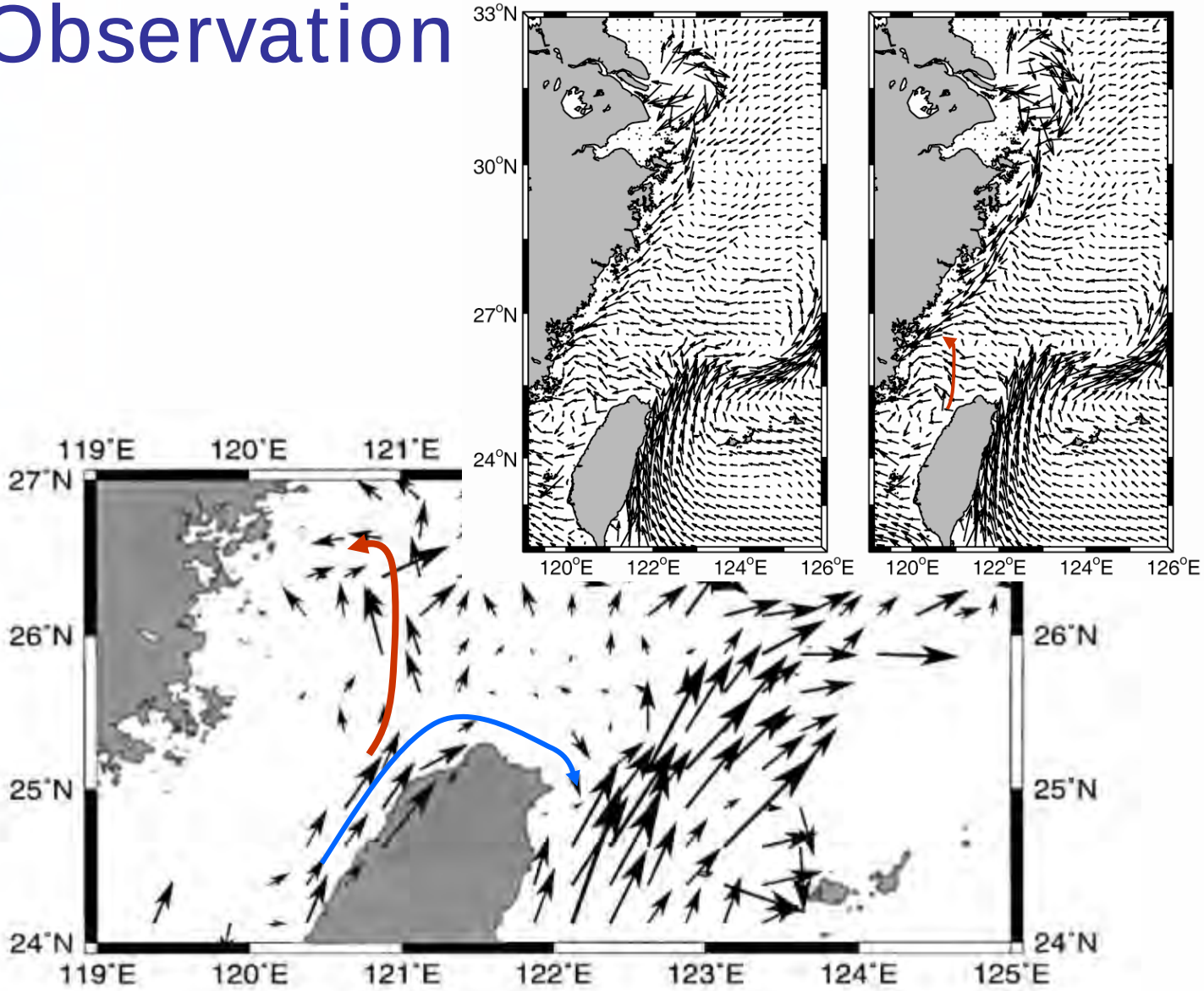
- Spawning migration of Japanese anchovy is aided by local circulation (CCC), but the swimming behavior (*velocity*, *orientation*) of fish is also very important

- The simulation results are in good agreement with the existing adult anchovy fishery along the coast of China
  - In Fujian, fishing season of the overwinter group starts from February
  - The stock only remain for a few days

- However, none of the tracers arrived at the known spawning ground (Yilan) in simulations
  - Coupled model may need some improvements (e.g. tidal forcing?)
  - Difficulties in physical modeling at coastal area

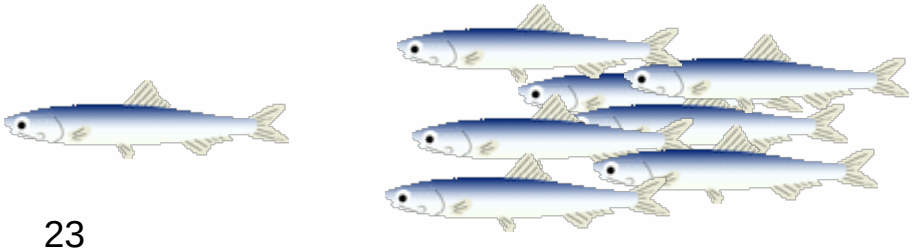
Observation

Model



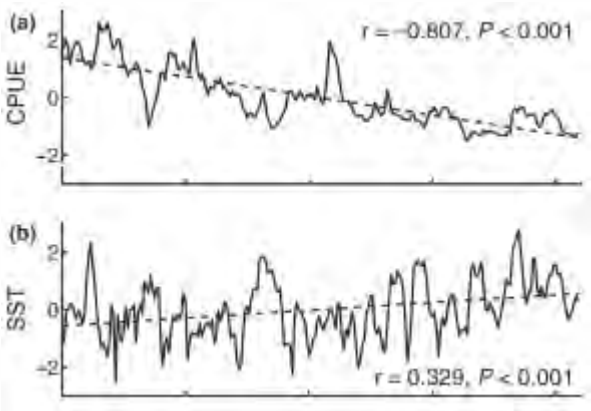
Tang *et al.*, 2000

- However, none of the tracers arrived at the known spawning ground (Yilan) in simulations
  - Coupled model may need some improvements
  - Difficulties in physical modeling at coastal area
  - Little is known about the behavior of Japanese anchovy adult, not to mention the schooling



Fluctuation of anchovy population

- Climate change
  - Japan (Takasuka et al., 2007)
  - …Less so in Taiwan (Hsieh et al., 2009)
- Changjiang discharge



Influence of Changjiang discharge

- Weakened CCC caused by low river discharge in winter may reduce the amount of anchovy arrived at the southern spawning grounds

- Reduced discharge may also induce ecosystem changes unfavorable for the adult spawning group

- Coupled fish behavior-hydrodynamic model for better understanding the influence of different environmental and behavioral scenarios
- Spawning migration of Japanese anchovy is aided by local circulation (CCC), but the swimming behavior (*velocity*, *orientation*) of fish is also very important
- As the TGD completed in 2005, the reduced Changjiang discharge and nutrient input may continue to affect the Japanese anchovy population
- Little is known about the spawning stock, therefore, the ecological studies using fishery independent data are necessary for a better understanding of the population fluctuation in Japanese anchovy