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Numerical simulation of the larval transport of snow crab *Chionoecetes opilio* in the Japan Sea

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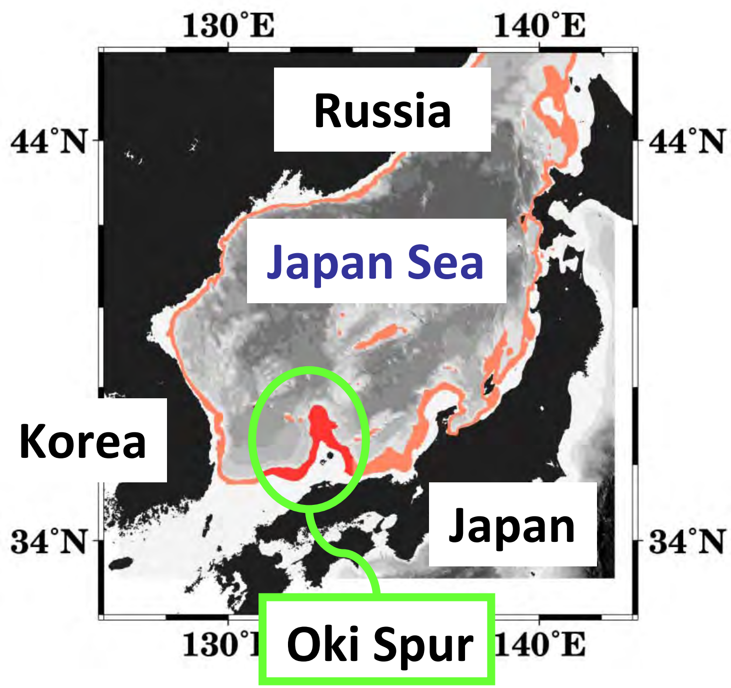
Background (1/2)

- Snow crab *Chionoecetes opilio* inhabits the Japan Sea is an important fishery resource in Japan.
- Abundance of the crab shows significant spatio-temporal variation, but the underlying mechanism is unknown.

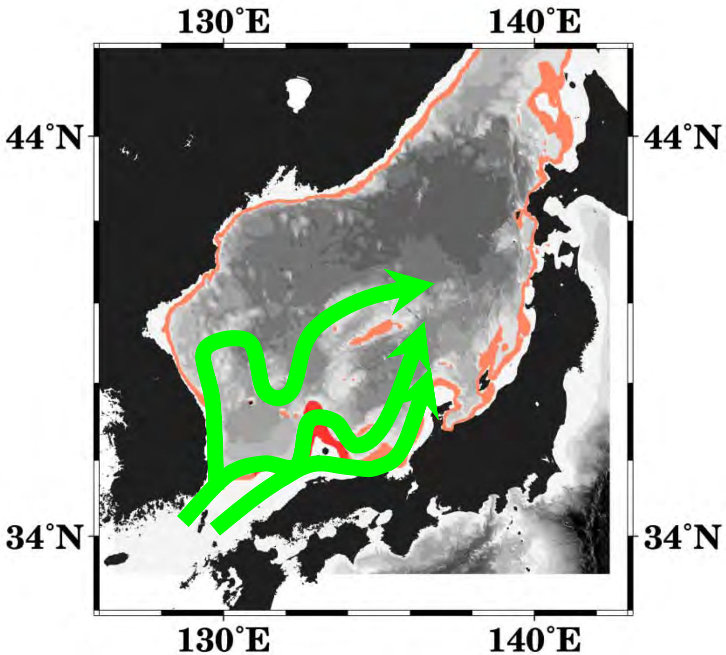


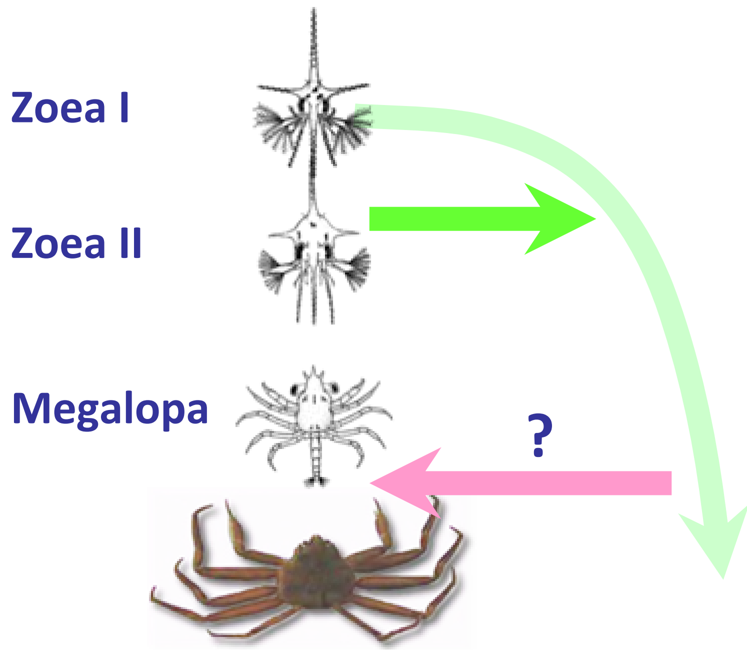
Habitat: Bottom of 200-500 m depth.

Abundant in the south western part of the Japan Sea. Esp., abundant around the Oki Spur in recent years.

Background (2/2)

- The Tsushima Warm Current flows the larvae away from the habitat.
- Thus, some return path is needed for local reproduction, and year-to-year variation of such return path may lead to the resource variation.
- So, we carried out numerical simulation to find a possible mechanism.





Particle Tracking

- **Using the horizontal oceanic velocity data due to JADE, we carried out the particle tracking simulation (cf. http://jade.dc.affrc.go.jp/jade/).**
  JADE: An operational ocean forecasting system for the Japan Sea.
  Horizontal resolution: 1/12 deg., Vertical resolution: 36 z-levels.
  We used data assimilative daily data from 1999 to 2009 (hindcast).
- **Horizontal movement: Passive to the oceanic horizontal velocity.**
  A Smagorinsky type diffusion is added as a random walk process.

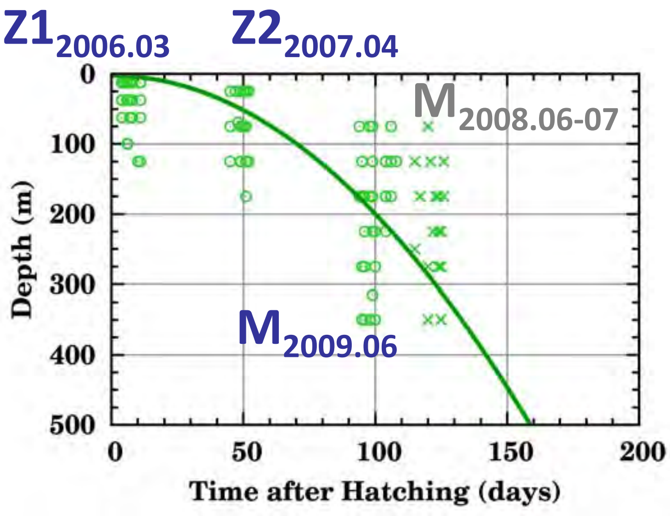
$$\boldsymbol{x}(t+\Delta t) = \boldsymbol{x}(t) + \Delta \boldsymbol{x},$$

$$\Delta \boldsymbol{x} = \int_{t}^{t+\Delta t} \boldsymbol{u} dt + \delta \boldsymbol{x}.$$

- **Vertical movement: Prescribed sinking.**
- **Output: Daily record of particle position & status.**

Duration of Larval Phase and Sinking Manner of Larvae

- **Hatching season: from Feb. to Mar.**
- **Duration: Assuming the planktonic phase of about 100 days, we tracked the particles from Feb. 01 to Jul. 31 in each year.**
- **Sinking manner: Defined based on past surveys (JSNFRI, 2006-2009).**
- **Touchdown to the bottom within 90-120 days of the tracking was counted in settlement success, otherwise counted in settlement failure.**



Assuming the date of hatch as Mar. 01, the relation between age and swimming depth was approximated by an quadratic curve.

The data in 2008 was eliminated from the fitting.

Consistent with Kon *et al.* (2003)

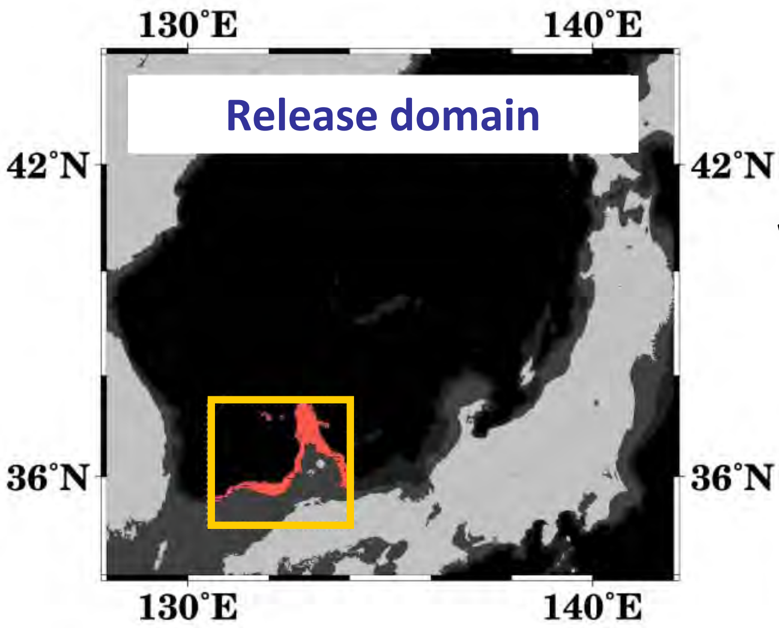
Kon *et al.* (2003): *Fish. Sci.*, 69, 1109-1115.

Release of the Particles

- The particles were released just beneath the sea surface (2.5 m depth) between the isobaths of 200 m and 400 m in the release domain.
- Hatching Season: From Feb. to Mar.

  From Feb. 01, the particles are released for 2 months (59 days).

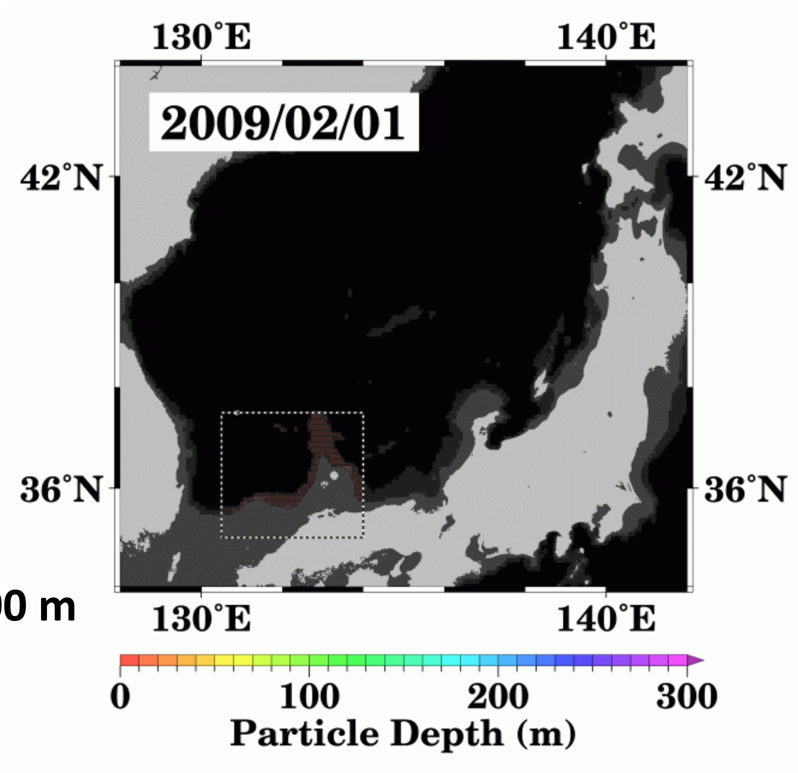
  1,178 particles per release, 1 release per day, total 69,502 particles.



With these settings, we carried out
- Yearly transport simulation (1999-2009)
- Climatological simulation
  (based on 11-year averaged daily data)

An Example of the Results: Simulated Transport in 2009

- The expected return of particles to the release domain was found.



Bathymetric contours:
0 (coastline), 200 and 500 m

Particle color: Swimming depth

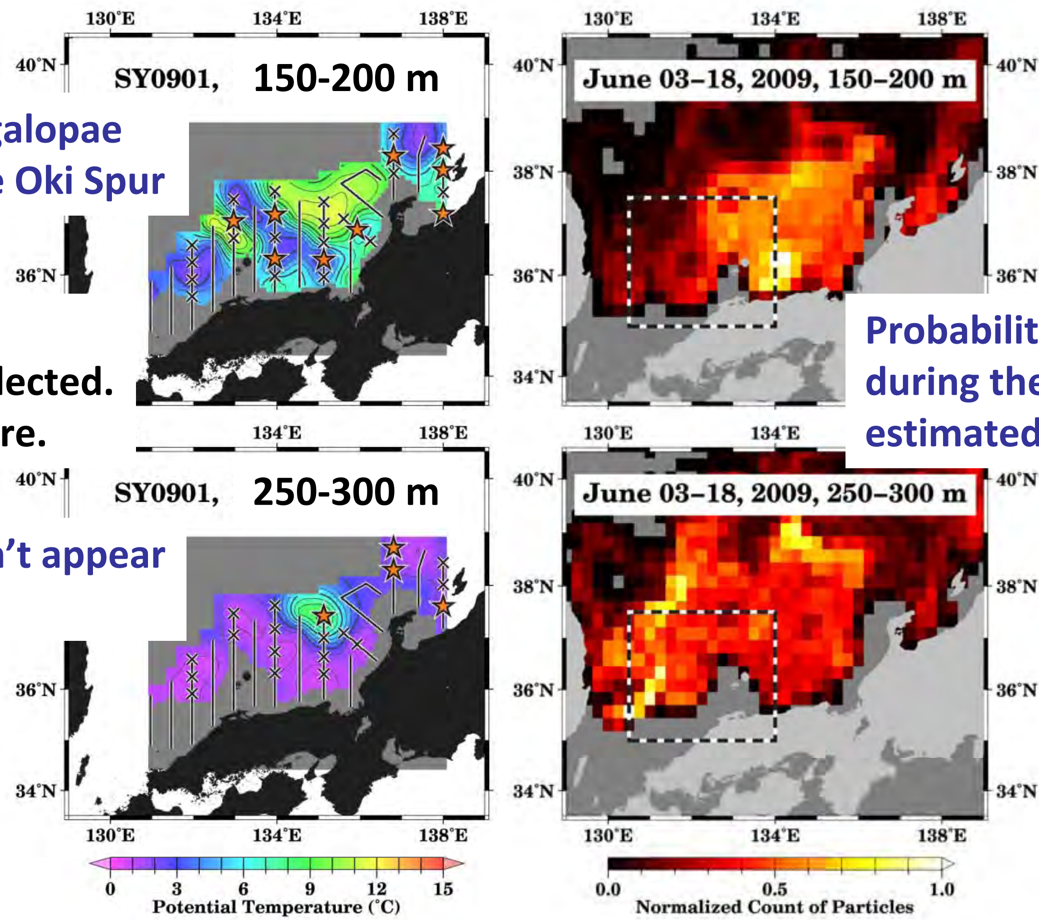
Comparison with Field Survey in 2009

- **Simulation qualitatively reproduced the surveyed megalopal distribution.**

Upper layers: Megalopae appeared near the Oki Spur

☆: Station at which megalopae were collected.
Contour: Temperature.

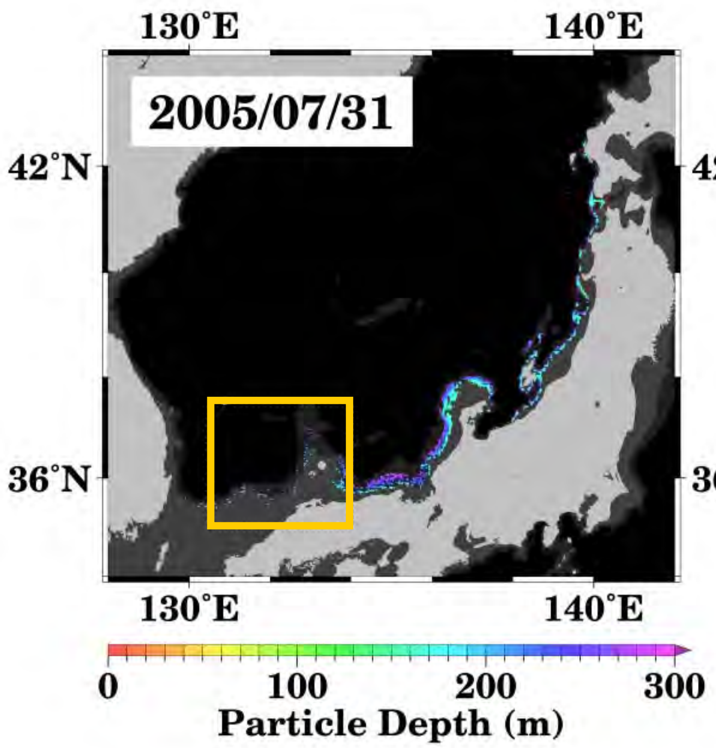
Lower layers: Didn't appear near the Oki Spur.

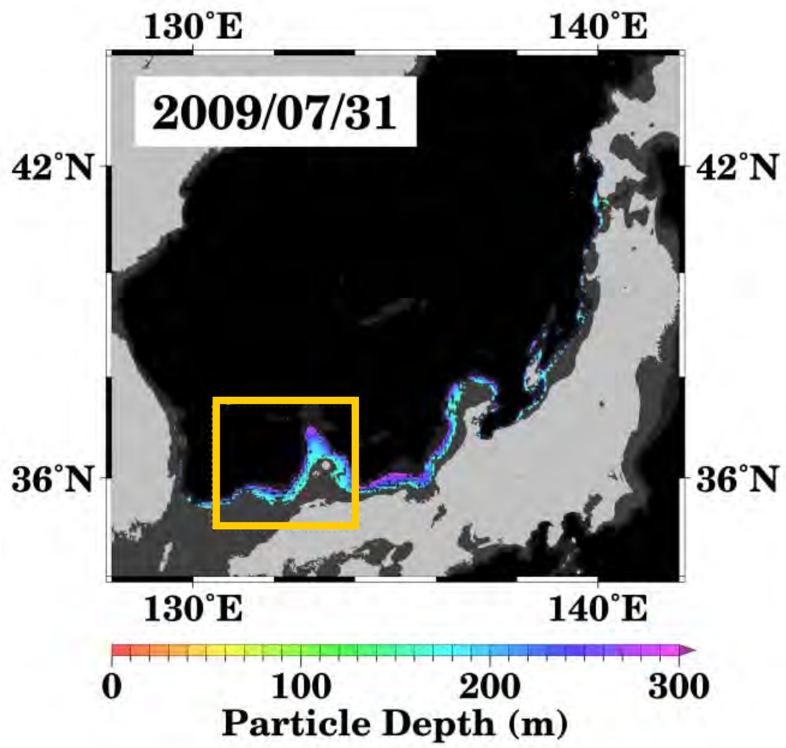


Probability of particle existence during the period of survey, estimated with 1/4 deg. bins.

Year-to-Year Variation of Settlement

- Settlement in the release domain showed year-to-year variation.
- **Climatological velocity field does not serve definite return path.**



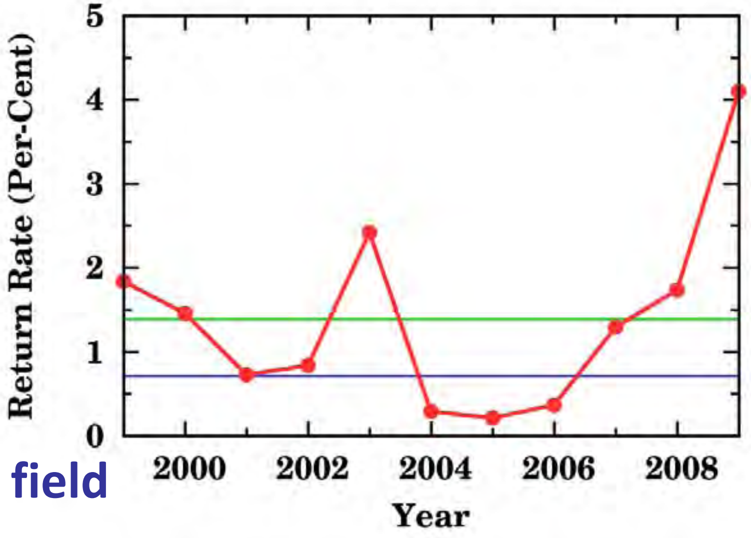


Return to Release Ratio

- **Using the number of particles settled in the release domain *n* and the total number of released particles *N*, we defined the return to release ratio $R = n / N$.**

***R*, Average *R* and *R* due to the climatological velocity**

***R* shows significant year-to-year variation.**

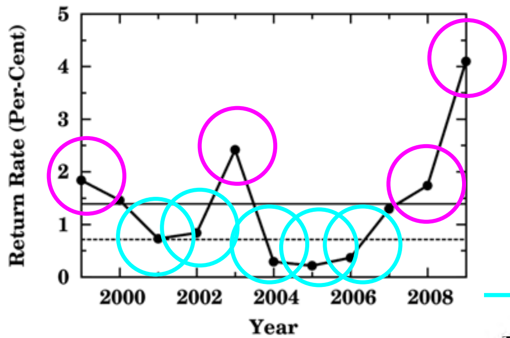


Ave. *R* is raised by the year-to-year var. of oceanic velocity field.

Climatological velocity field does not serve high *R*.

Factor 1: Path Variation of the Tsushima Warm Current

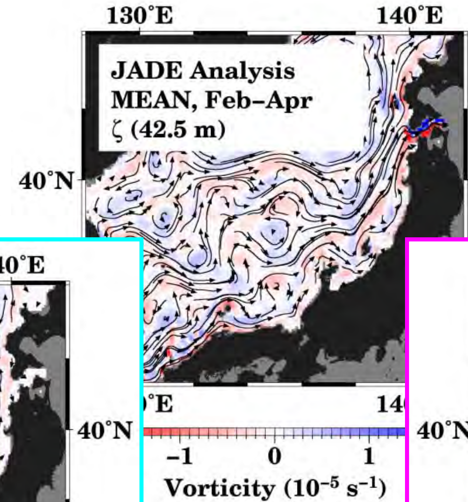
- **Path of the Tsushima Warm Current** **during the zoeal season (Feb.-Apr.) shows phase shift between the along-shore path and meandering path.**



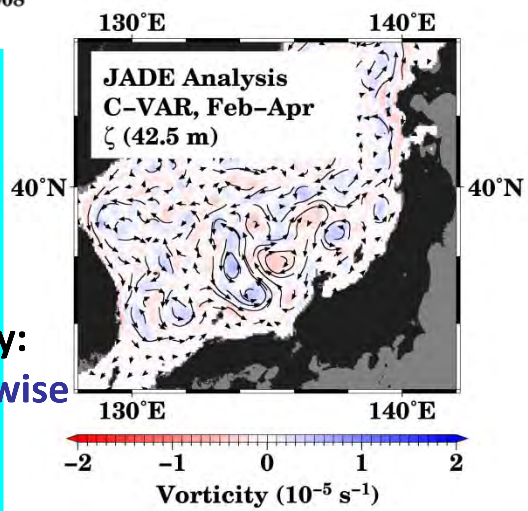
Define 2 groups of years based on *R*.

Color denotes the vorticity:
Clockwise, Counter-Clockwise

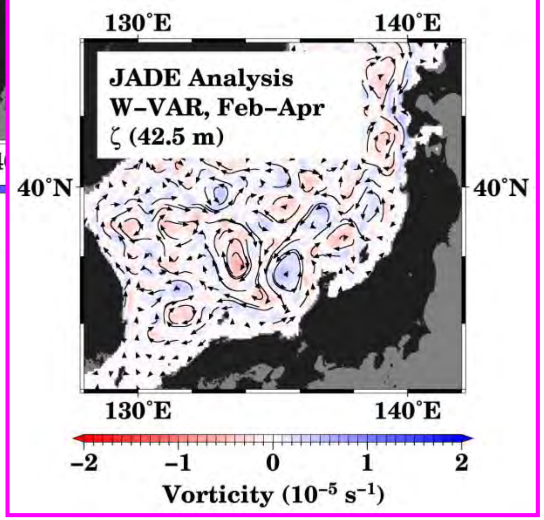
Climatology (11-year Ave.)



Along-shore
(01, 02, 04, 05, 06)

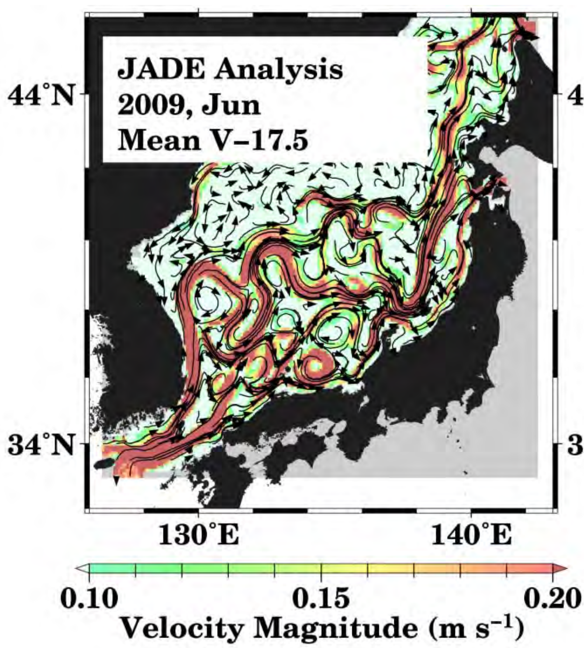


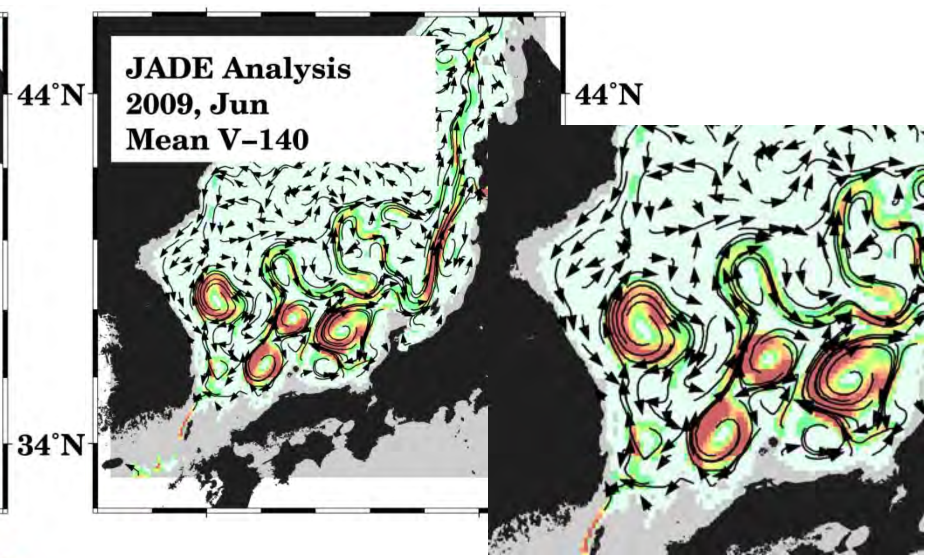
Meandering
(99, 03, 08, 09)



Subsurface Counter Current beneath the Tsushima Warm Current

- From early summer to autumn, clockwise gyres are formed beneath the Tsushima Warm Current.
- The southern flanks of the gyres are recognized as counter current (flows opposite to the surface current) over the shelf slope.



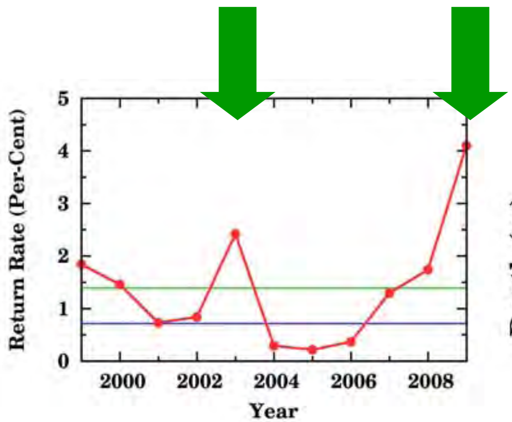


The most intensified level: About 150 m.

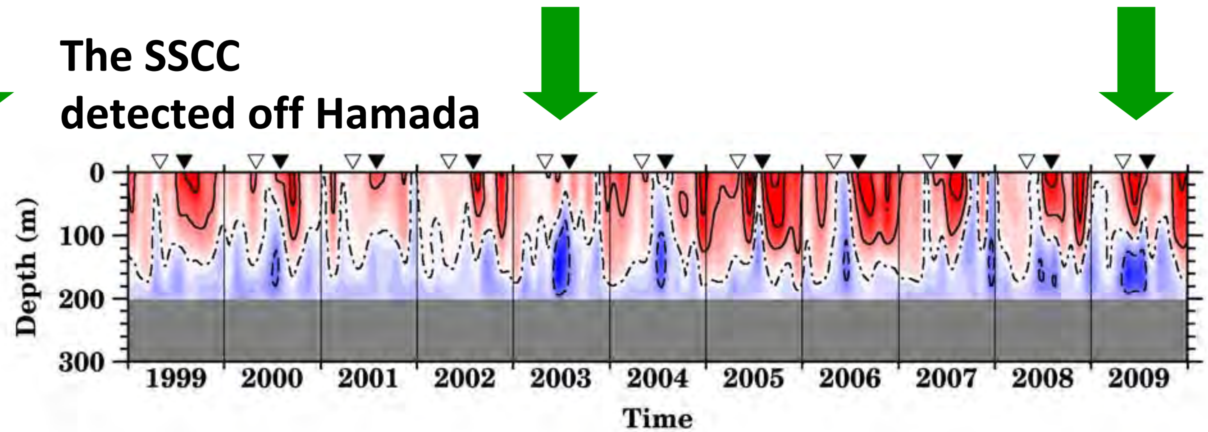
Factor 2: Subsurface Counter Current

▽ → ▼

- **During the expected settlement periods in 2003 and 2009, relatively strong counter current was detected off Hamada.**



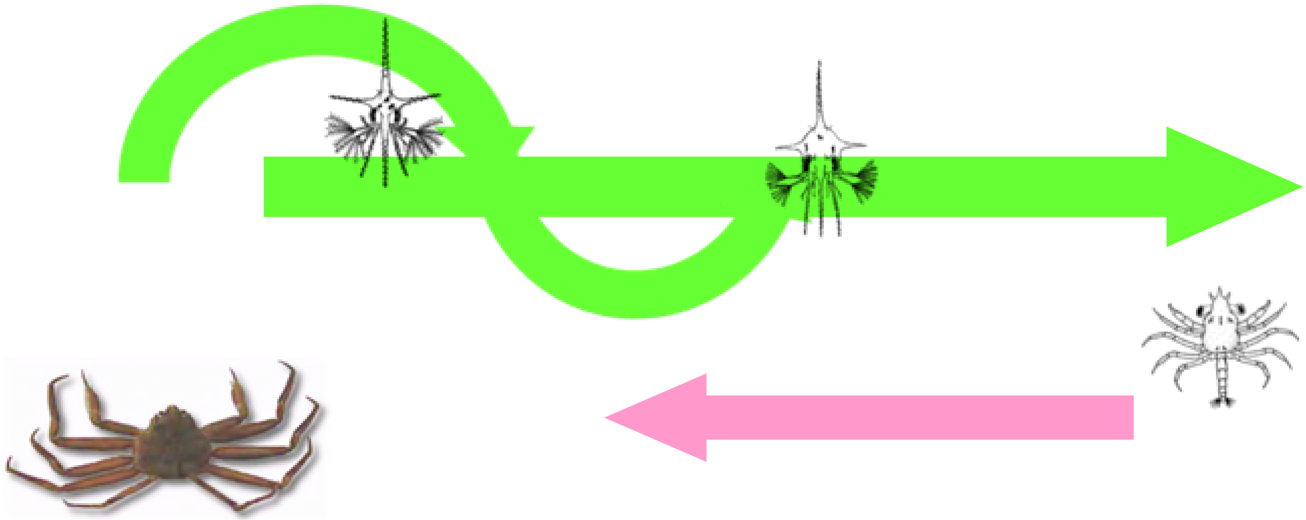
The SSCC detected off Hamada



Bathystrophic velocity, C.I. 10 cm/s, blue color denotes the counter current.

The SSCC can make the larval return more effective in relation with the path variation of the TWC.

Concluding Remarks (1/2)



- **We can expect a scenario as follows.**

  In a year of meandering path phase of the TWC, the surface transport above the hatching ground should become stagnant. Thus, relatively large amount of larvae can remain in the vicinity of the hatching ground. In such a year, the SSCC may cause effective return of larvae (and settlement of the 1st crabs) to the crab habitat.

Concluding Remarks (2/2)

- We proposed a physical mechanism which consists of two factors, and may be related to the resource variation of Japanese snow crab.
- However, the direct comparison between the fishery record of the crab and the present simulation is difficult.
- We need further development (model) and investigation (crab).

1. The ocean model (JADE) is reliable for the surface velocity field, but still insufficient in deeper layers (even with data assimilation).
2. The model data is too short (only 11-year data are now available).
3. We can distinguish year classes of the crab using carapace width, but the hatch year of each class can't be determined.
   ← The molting interval is unknown!