S7-8633

Numerically simulated migration/distribution of *Nemopilema nomurai* in the Japan Sea with temperature-based controls

Akira OKUNO[1], Tatsuro Watanabe[1], Satoshi Kitajima[1], Naoto Honda[1]

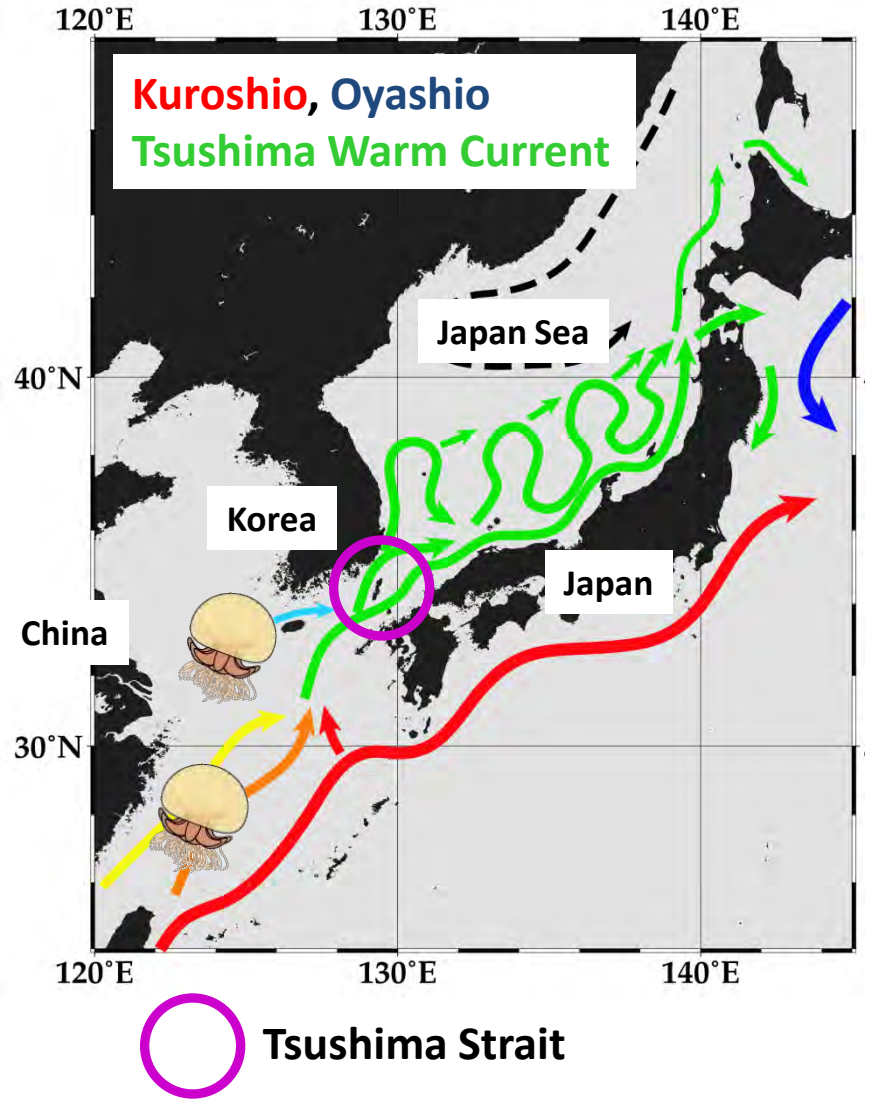
and Katsumi Takayama[2]

[1] Japan Sea National Fisheries Research Institute, Fisheries Research Agency

[2] Research Institute for Applied Mechanics, Kyushu University

PICES-2012 Annual Meeting, Hiroshima, Japan, October 12-21, 2012

Nemopilema nomurai



Nemopilema nomurai

Nomura's Jellyfish

For large individuals,

Bell diameter > 1 m

Wet weight > 100 kg

Liberation season: Spring

Needs for Jellyfish Simulation

Recently, massive blooms of *N. nomurai* frequently occurred.
2002, 2003, 2004, 2005, 2006, 2007, 2009, 2012

To avoid severe damages on fisheries in the Japan Sea, prediction of *N. nomurai* appearance is highly needed.

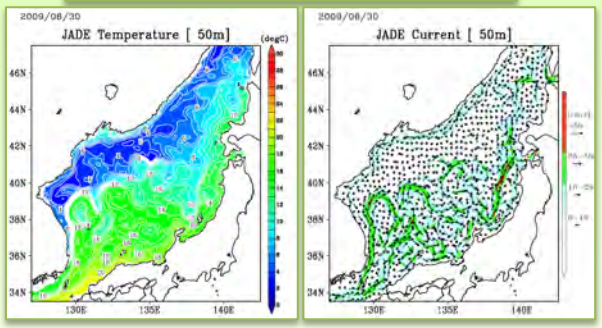
→ Numerical system for the jellyfish forecast

Jellyfish Tracking Simulator of JSNFRI

In 2009, Japan Sea National Fisheries Research Institute developed a jellyfish tracking simulator for analyses/forecasts of *Nemopilema nomurai* migration in the Japan Sea.

Operational Ocean Forecast System

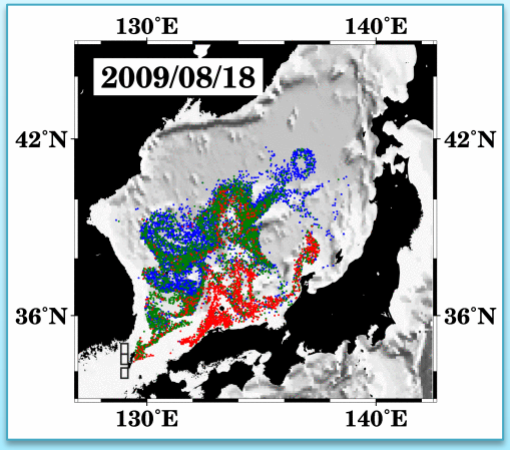
JADE (Japan sea Data assimilation Experiment)



http://jade.dc.affrc.go.jp/jade/

Hydrodynamic data

Particle Tracking Simulator



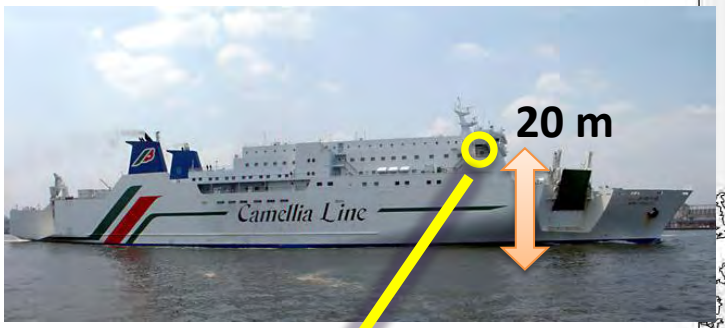
Camellia Sighting Survey & Appearance Reports from Fishermen

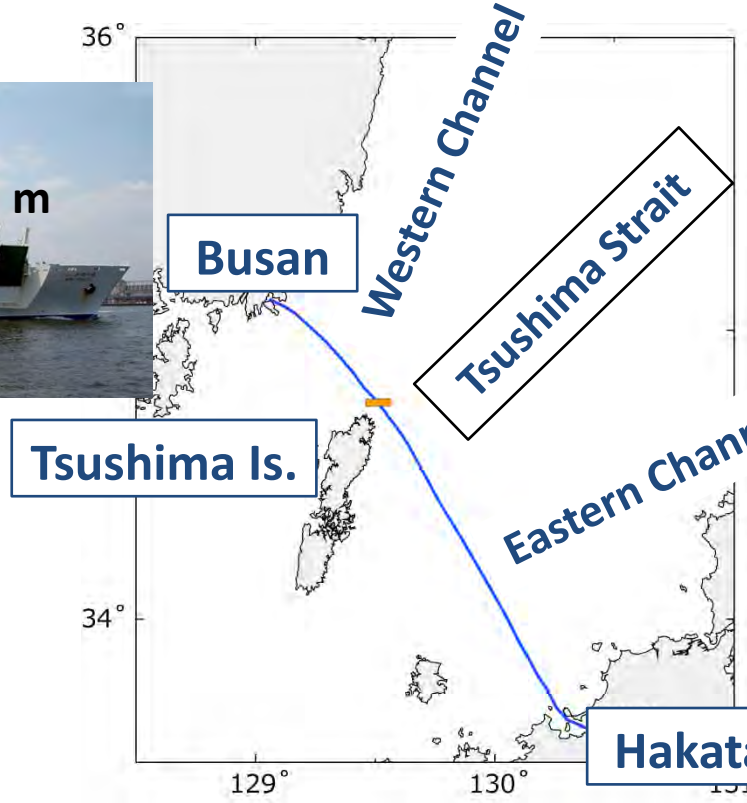
Release conditions

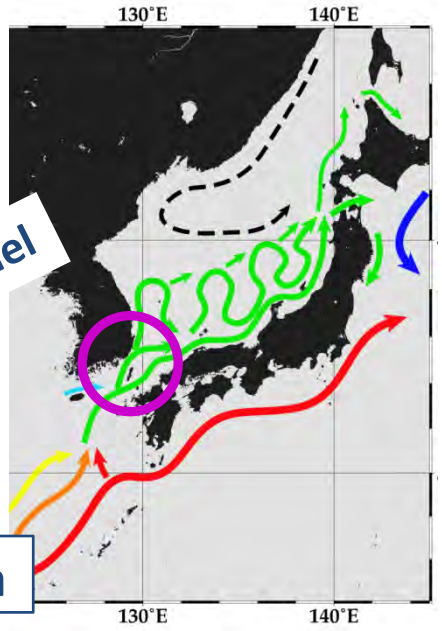
Sighting survey in the Tsushima Strait

Since 2006, regular (roughly 2-week interval) sighting surveys of *N. nomurai* are conducted every year in the jellyfish season, to monitor the inflow of the jellyfishes. → Release conditions

Ferry New Camellia







Horizontal movement of particles

Stochastic dispersion (Random walk)

The horizontal migration of *N. Nomurai* is basically passive to the oceanic velocities.

Honda *et al.* (2009) Fish. Sci. 75:947-956.

Deterministic advection by ambient oceanic velocity

$$\frac{d\boldsymbol{x}}{dt} = \boldsymbol{U} + \boldsymbol{u}_{\mathrm{R}} \longrightarrow \boldsymbol{x}(t+\Delta t) = \boldsymbol{x}(t) + \boldsymbol{U}(t)\Delta t + \Delta \boldsymbol{x}_{\mathrm{R}}$$ **Explicit Euler discretization**

$\boldsymbol{x}$: horizontal position

$\boldsymbol{U}$: ambient velocity (JADE)

Horizontal diffusivity: Smagorinsky (1963)

$$K_{\mathrm{h}} = A\,\delta x \delta y \sqrt{\left(\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)^2}$$

The random walk "step width"

$$\Delta \boldsymbol{x}_{\mathrm{R}} = (\Delta x_{\mathrm{R}},\ \Delta y_{\mathrm{R}}) = \sqrt{2K_{\mathrm{h}}\Delta t} \times (R_1, R_2)$$

$\delta x, \delta y$: Grid Spacing

R_1, R_2 : $N(0,\ 1)$ Random Numbers

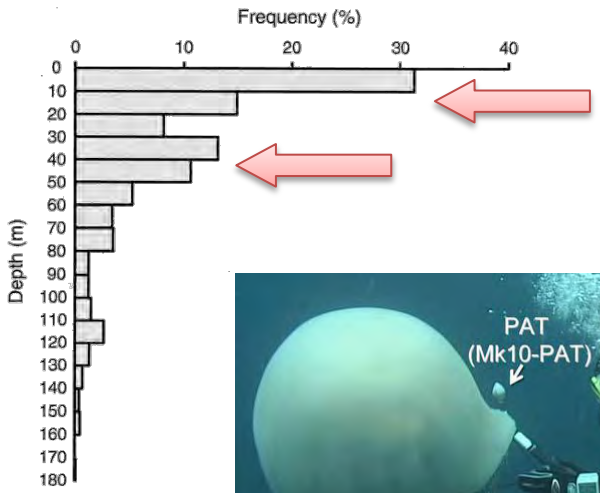
Adjustment Constant $A = 0.05$

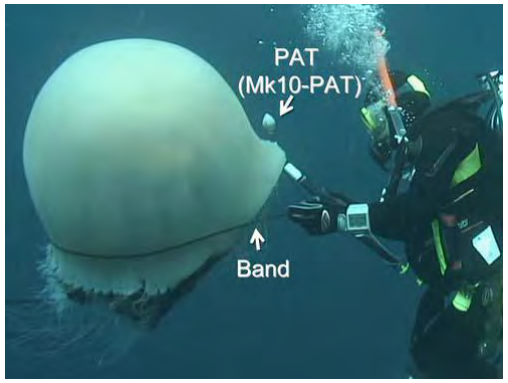
The jellyfish icon is provided by M/Y/D/S (http://animal.myds.jp/aquatic/nomuras_jellyfish/).

Importance of the Swimming Depth

N. nomurai **shows vigorous and complicated vertical migration, and the swimming depth is quite important in determination of the migration path.**

Observed swimming-depth frequency





Oceanic velocities vary with depth.

Direct observation using pop-up archival transmitting tags and ultrasonic pingers.

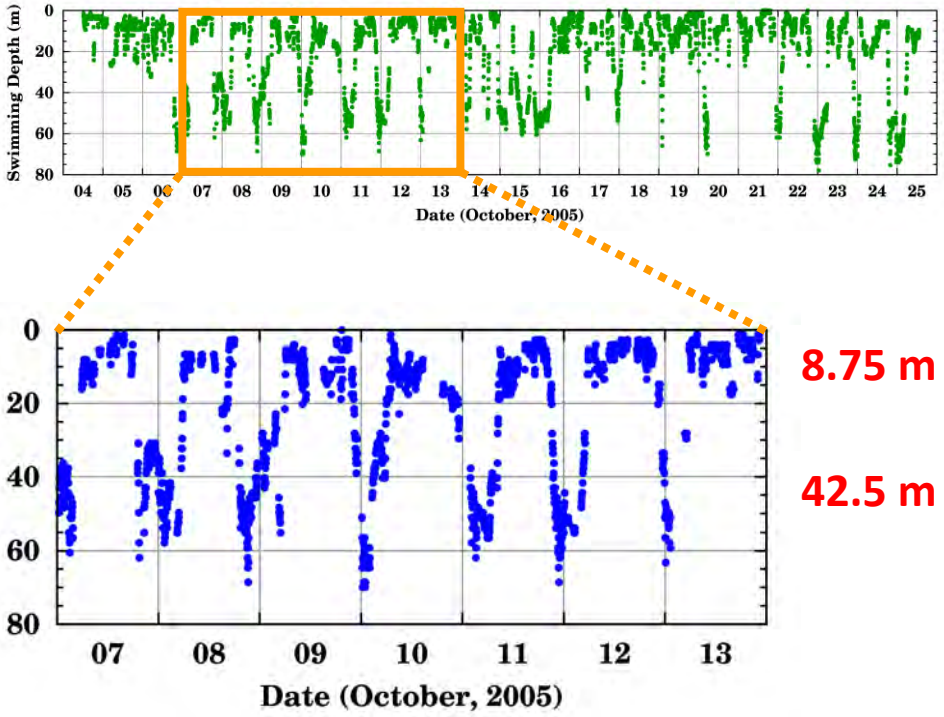
Honda *et al.* (2009) Fish. Sci. 75:947-956.

The jellyfish icon is provided by M/Y/D/S (http://animal.myds.jp/aquatic/nomuras_jellyfish/).

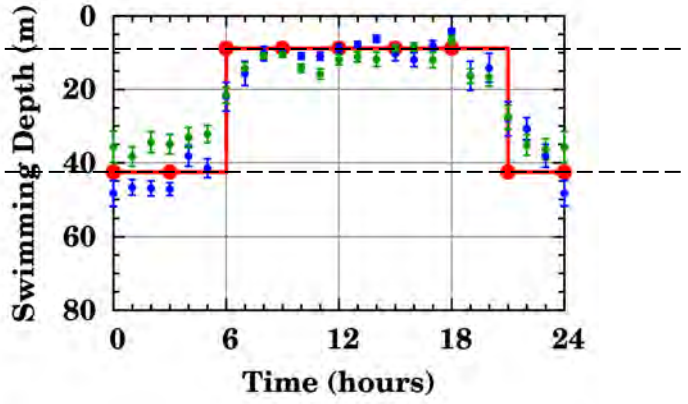
Former Scheme for the Swimming Depth

We prescribed a simplified diel vertical migration based on direct observation. Honda *et al.* (2009) Fish. Sci. 75:947-956.

A pop-up archival tag record.



Daytime: 15 hours at 8.75 m
Nighttime: 9 hours at 42.5 m

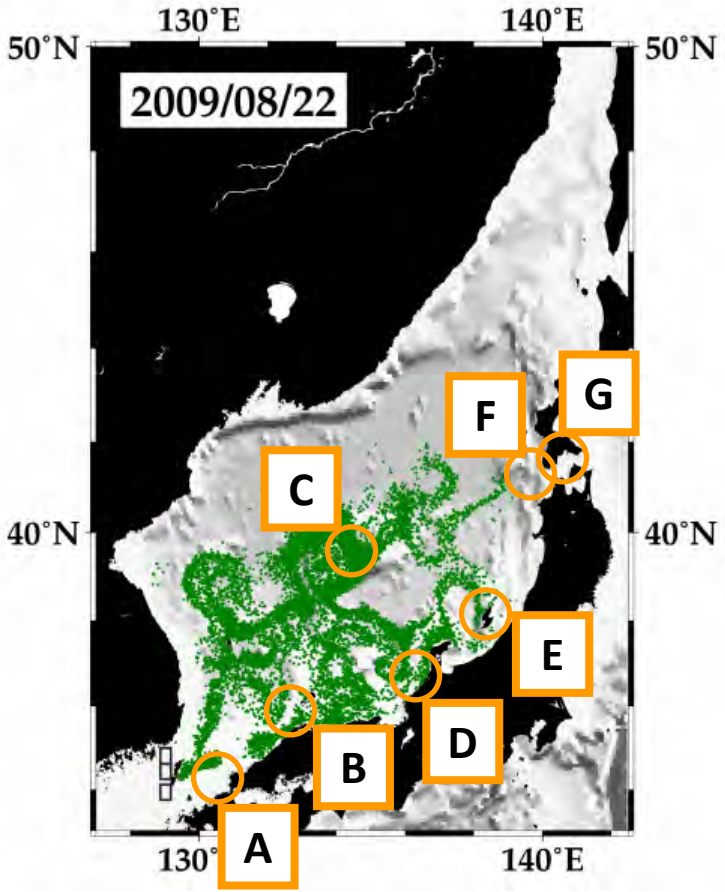


An Example of Appearance Forecast in 2009

Forecast of the jellyfish "front edge"

carried out on August 10, 2009.

Okuno *et al.* (2011) PICES-2011 Annual Meeting, BIO-P-7683.



Appearance report vs. Computation

vs. Hindcast (Analysis)

A: Jul. 14	(the first appearance)
B: Jul. 21	(the first appearance)
C: Jul. 23-27	(the first appearance)

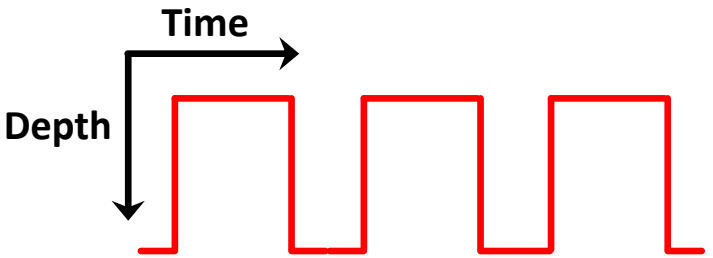
vs. Forecast

D: Aug. 12	(the first appearance)
E: Aug. 24-26	(the first appearance)
F: Aug. 31-Sep 1	(the first appearance)
G: Sep. 11-14	(enhanced outflow)

Insufficiencies of the Simulator

The simulator showed notable skill
in forecast of *N. nomurai* migration in the Japan Sea in 2009.

Okuno *et al.* (2011) PICES-2011 Annual Meeting, BIO-P-7683.



However, in the simulator,

1. **Swimming depth of *N. nomurai* was quite simplified based on the diel vertical migration.**
2. **Mortality of *N. nomurai* was not considered.**

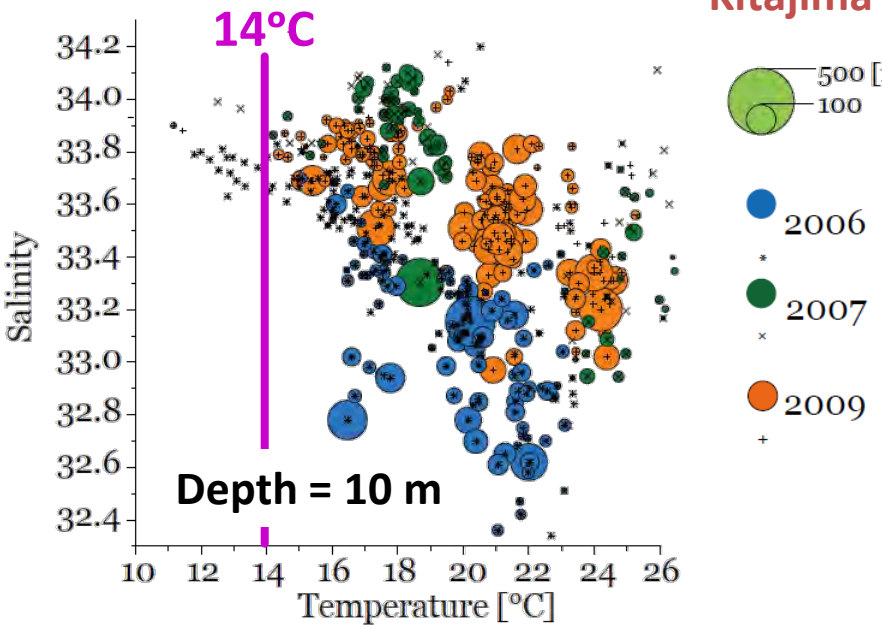
Thus, the simulator admits of improvement.

Habitat Regulation by Temperature

Recently, it is suggested that the habitat of *N. nomurai* in the Japan Sea is regulated by temperature.

Relation between salinity, temperature and *N. nomurai* abundance.

Kitajima *et al*. (2012): This meeting, Poster S7-5



The same tendency was also observed at 30 and 50 m depths.

→ Irrespective of depth.

→ Regulation by Temperature.

Modification of the Simulator

We appended temperature-based controls on:

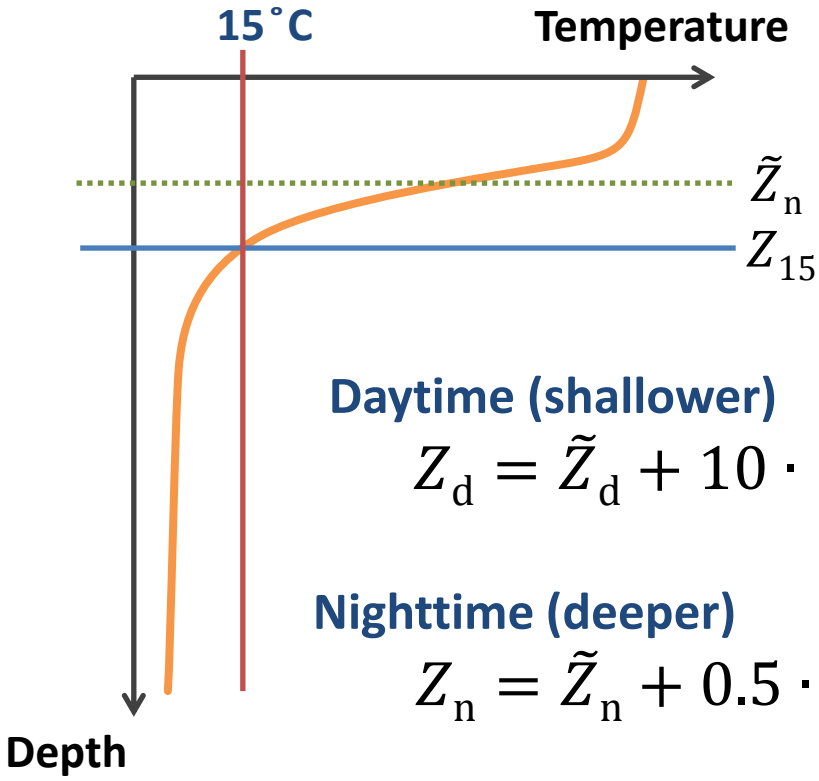
1. **Swimming depth variation**
   Assumption: The nighttime (deeper) swimming depth can be modeled in relation with 15°C depth.

2. **Mortality**
   Assumption: *N. nomurai* can not survive in waters cooler than 14°C.

Briefly, the habitat of *N. nomurai* in the Japan Sea is regulated by temperature around 14°C.

Modified Scheme for the Swimming Depth

The nighttime (deeper) staying depth is controlled in relation with the depth of 15°C isothermal surface, and moderate variance is given to the two staying depths.



$N(0,1)$: Normal random number

Daytime (shallower)

$$Z_d = \tilde{Z}_d + 10 \cdot |N(0,1)|, \quad \tilde{Z}_d = 2.5 \text{ m}$$

Nighttime (deeper)

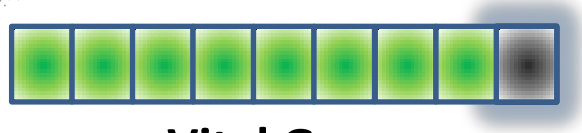
$$Z_n = \tilde{Z}_n + 0.5 \cdot (\tilde{Z}_n - Z_{15}) \cdot |N(0,1)|, \quad \tilde{Z}_n = 35 \text{ m}$$

Implementation of Mortality

On each integration step,
vitality of each simulated jellyfish was examined.

Temperature < 14°C

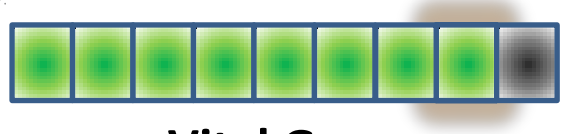
Loses vitality



Vital Gage

Temperature ≥ 14°C

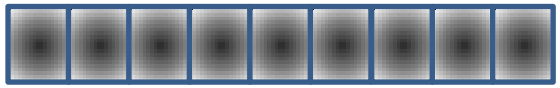
Regains vitality



Vital Gage

Dead

Capacity = 3 days (24 boxes)

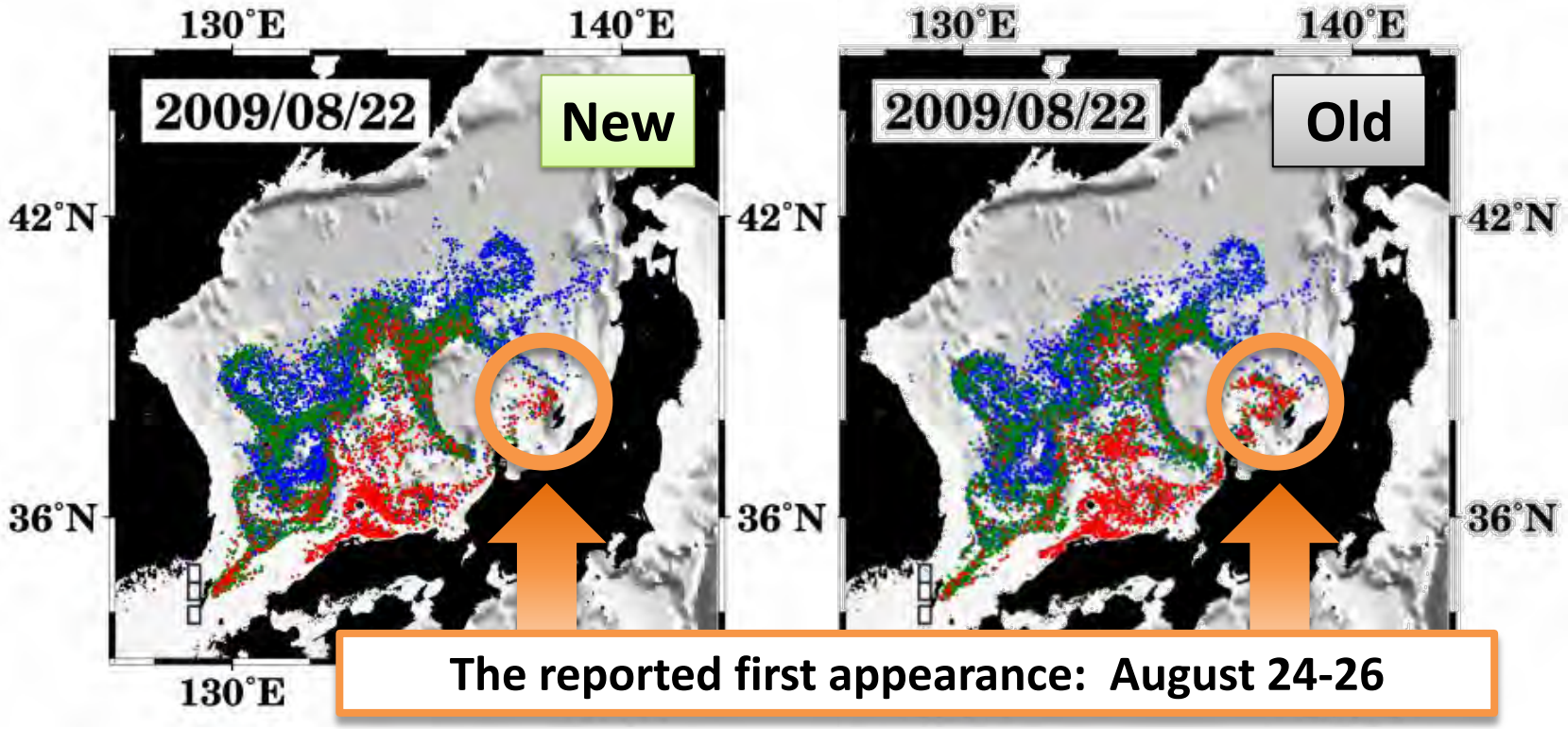


Impact on Appearance Forecast

The modification had little impact on appearance forecast.

→ **The simplification in the former simulator was adequate.**

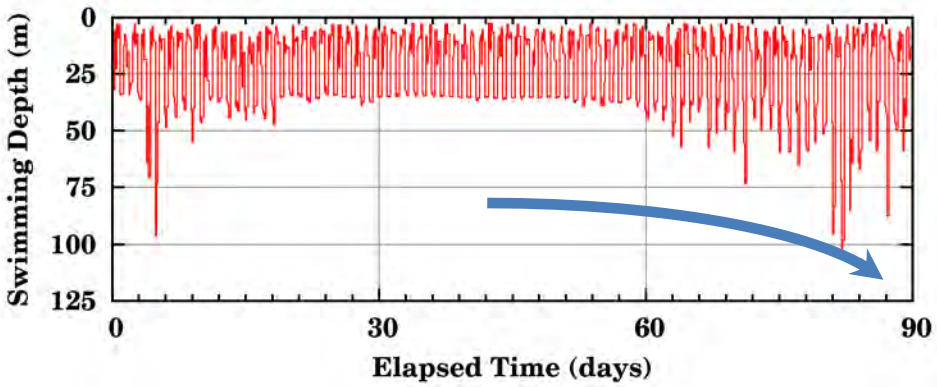
Hindcast tests for appearance forecast
with 3 release domains at the Tsushima Strait.



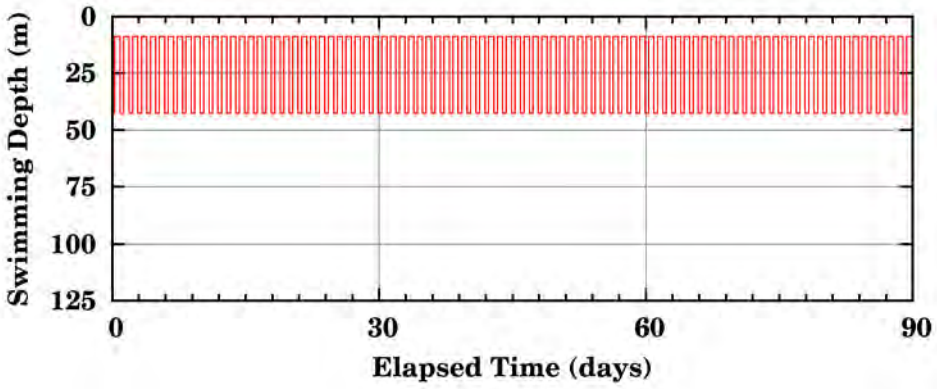
Time Series of the Swimming Depth

The modified simulator represented more realistic vertical trajectory of the jellyfish.

New



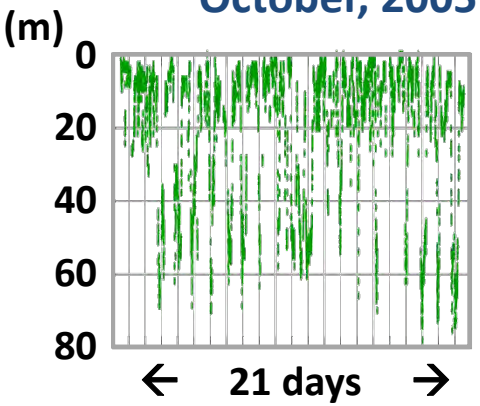
Old



Seasonal enhancement of the surface mixing and/or deepening of the 15°C depth.

Obs.

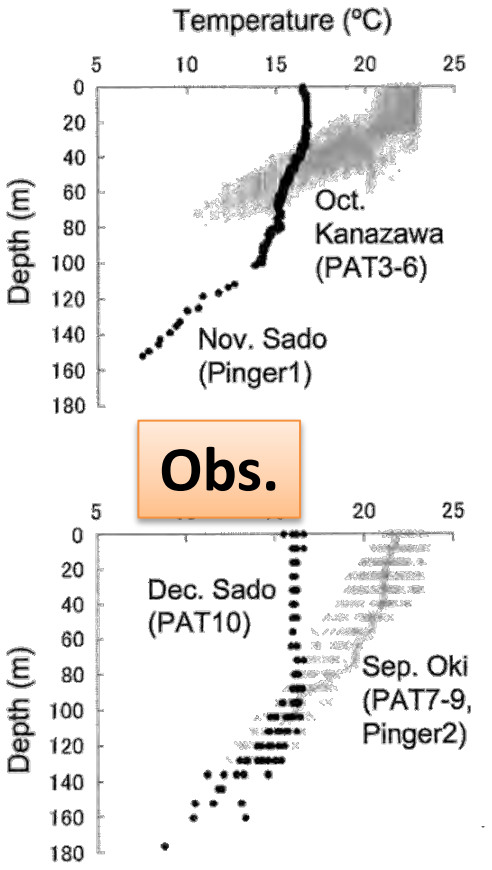
October, 2005



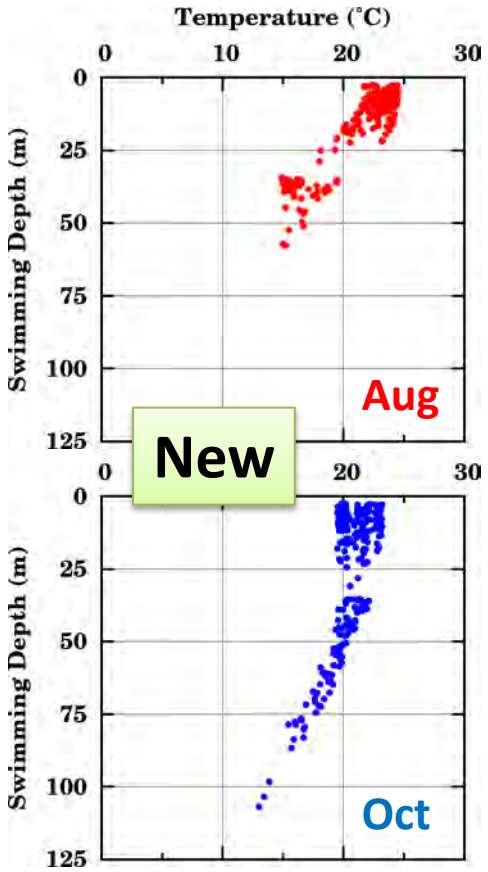
Honda *et al.* (2009)

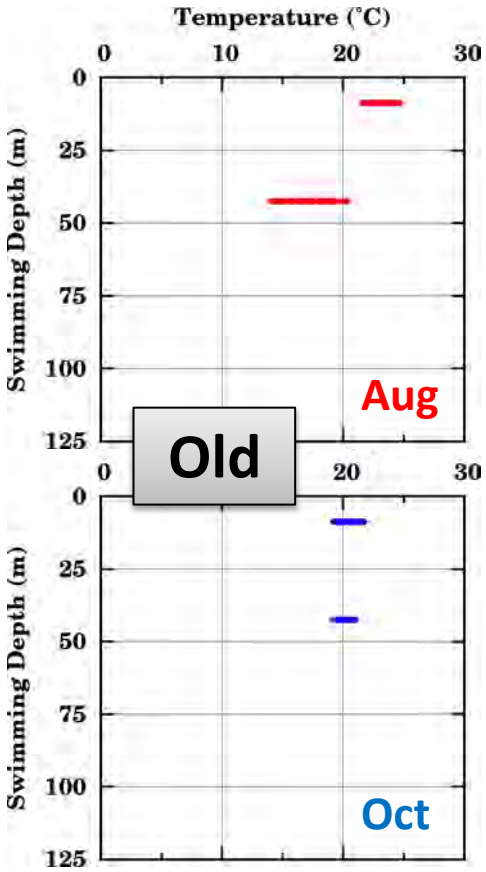
Swimming Depth vs. Temperature

The modified simulator represented more realistic relation between the swimming depth and Lagrangian temperature.



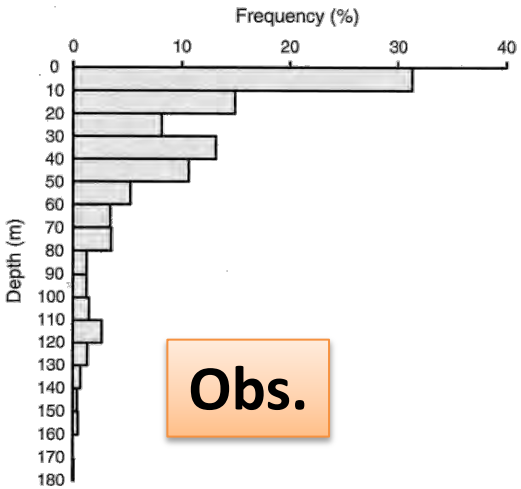
Honda *et al.* (2009)





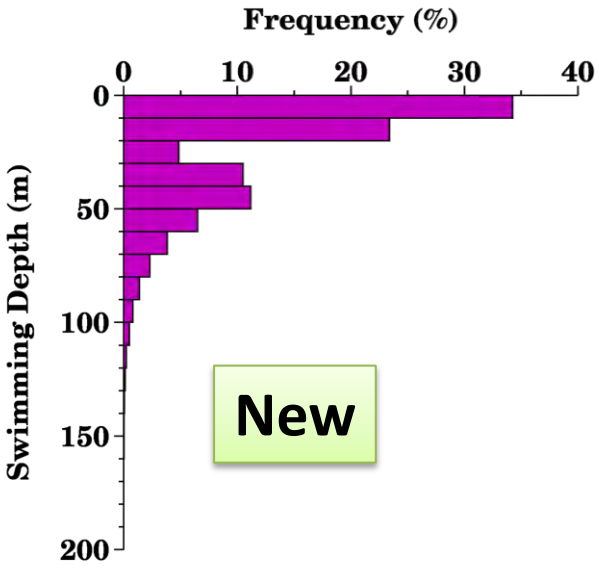
Frequency of the Swimming Depth

With the modified scheme, simulation expressed more realistic variation of the swimming depth of the jellyfish.

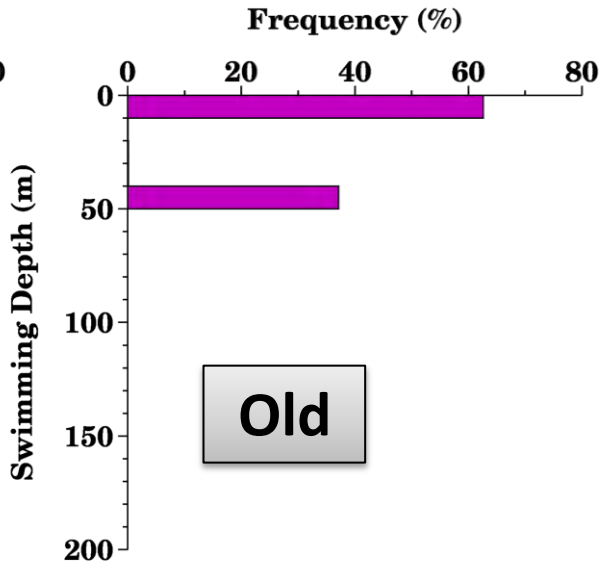


Honda *et al.* (2009)

12 individuals



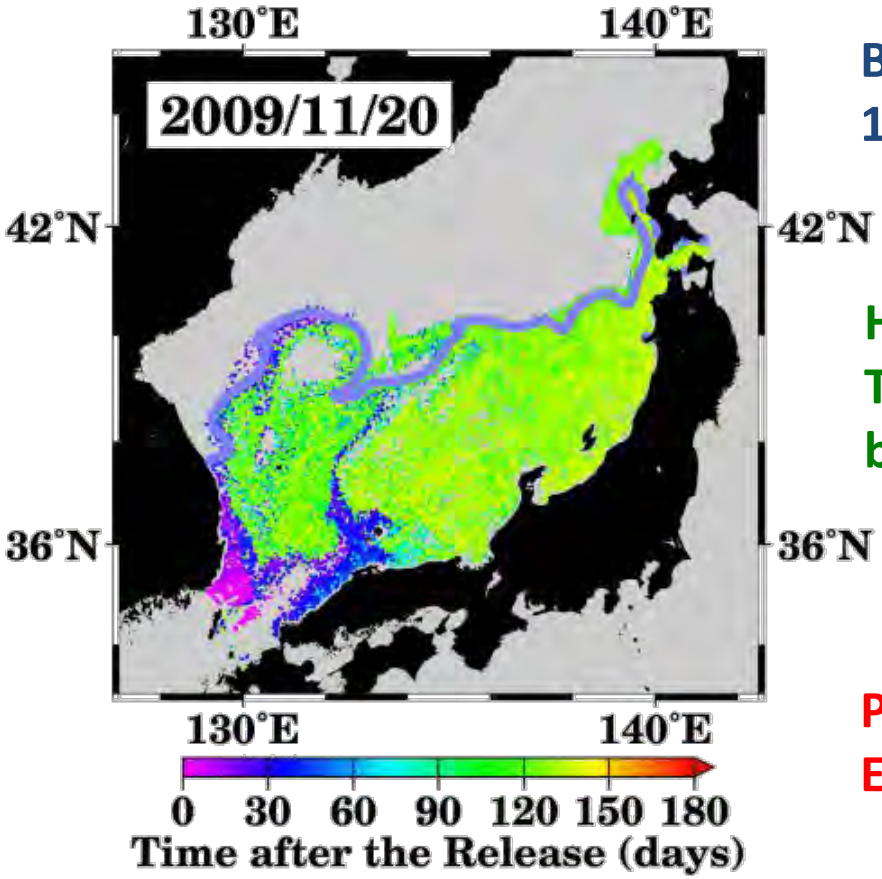
N = 16,617,727
14,108 individuals



N = 16,110,990
13,558 individuals

Seasonal Shrinkage of *N. nomurai* Distribution

The modified simulator successfully depicted the seasonal shrinkage of *N. nomurai* distribution in the Japan Sea.



Blue contour:
14°C isotherm at 8.75 m depth.

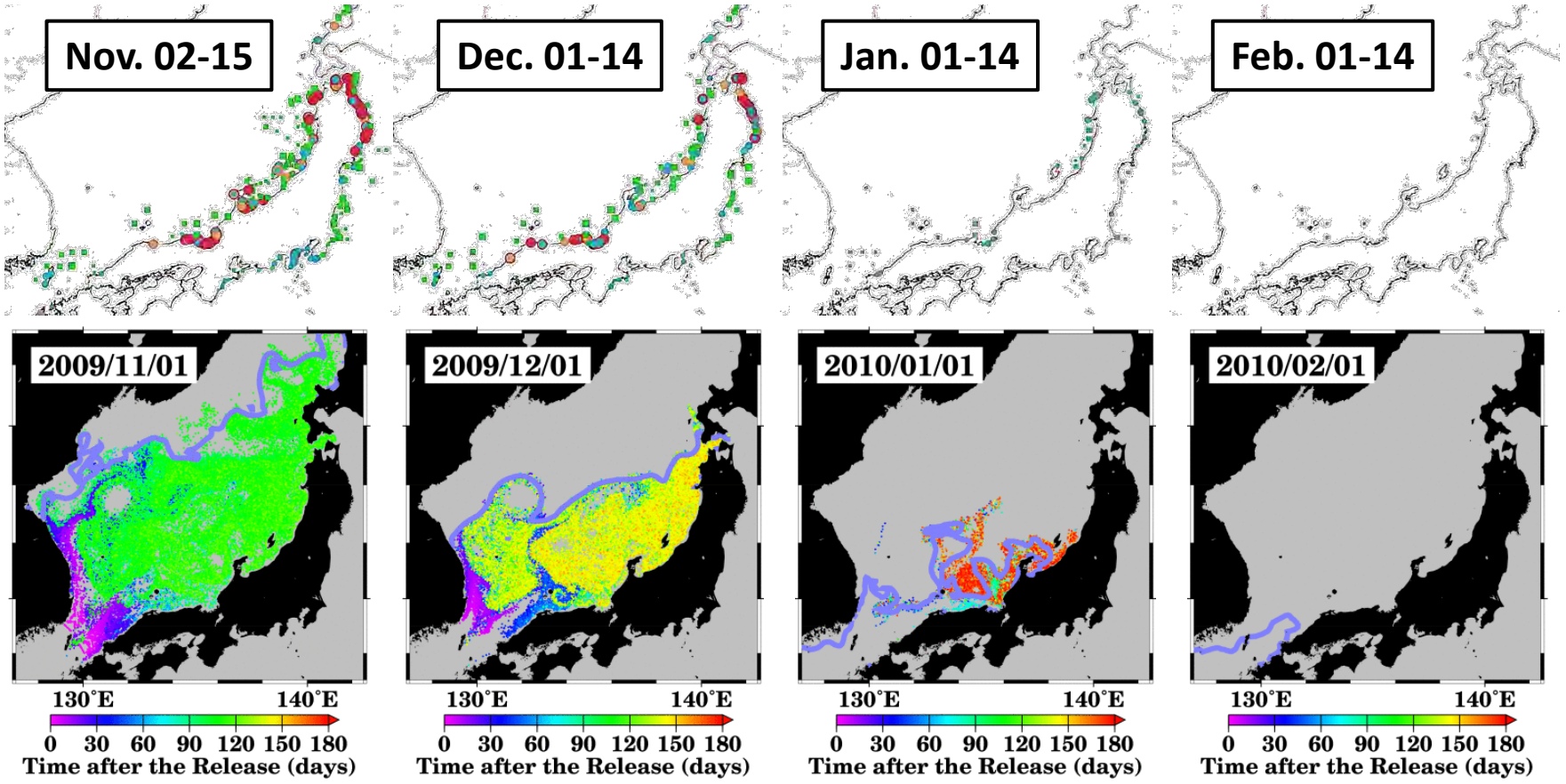
Hindcast test for distributional analysis.
The particles were continuously released based on the Camellia sighting survey.

Particle color:
Elapsed time after the release in days.

Correspondence with Appearance Reports

The simulated distribution moderately corresponded with the assembled appearance reports from fishermen.

Assembled and released by JAFIC (2009-2010)



Summary (1/2)

The jellyfish tracking simulator of JSNFRI was modified by two temperature-based controls.

1. **Swimming depth variation**
2. **Mortality**

The modified simulator represented spatiotemporal variation of the swimming depth and Lagrangian temperature more realistically than the former simulator, though the modification had little impact on forecast of *N. nomurai* migration.

Moreover, the modified simulator successfully depicted the seasonal shrinkage of *N. nomurai* distribution in the Japan Sea.

Summary (2/2)

The simulator includes a lot of unknown factors, that is,

amplitudes* and *reference depths

in the model of staying-depth variation,

***capacity* of the *vital gage*, etc.**

Hence,
the modified simulator presented today is just a prototype.

We still need more detailed information about behavior and physiology of *N. nomurai,* for more precise simulation of *N. nomurai* migration and reduction of fisheries damages.