# Title: Migration model of Japanese flying squid

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## Aim and procedure

The main purpose of this project is to introduce the follow-up development of the individual biological model (IBM) of Japanese flying squid to Environmental dynamic laboratory of CMES.

During my stay in CMES from 2018 to 2019, we finished a model simulating the early life stage (0-180 days) of Japanese flying squid in the Japan Sea. Although it was used to give a preliminary estimation of annual squid production in the situation of global warming, the model ignored the swimming ability of squid. Therefore, the model did not include the whole life cycle of squid. Consequently, the number of parent fish, spawning ability and other important process was neglected.

In this project, we expected to work on the development of IBM of Japanese flying squid to include the migration process, physiological activities and reproduction of squid from 180 - 360 days. This complements the shortcomings of the previous model. Moreover, during the visit to CMES, the migration model was expected to combine with the previous model on the computing cluster of Environmental dynamic laboratory of CMES.

The work plan includes: a seminar to introduce the migration model; the installation of the squid migration model on the computing cluster of CMES; the use of the computing cluster to simulate the whole life cycle of Japanese flying squid in the Japan Sea.

## Result

For the reason of epidemic of COVID2019, I did not visit CMES in 2020. Nevertheless, we still worked on the full life cycle IBM of Japanese flying squid.

First, we reproduced the monthly probability distribution of squid aggregation based on the working position of the squid jiggers in Japan Sea. Nighttime light data provided by Visible Infrared Imager Radiometer Suite (VIIRS 2014~2019 provided by Earth Observation Group, NOAA/NCEI) were used to obtain the monthly distribution of the fishing positions of squid jiggers in the Japan Sea.

In operation, the pixel whose brightness exceeds $400\times10^{-10}$ W cm$^{-2}$ sr$^{-1}$ is selected as the position where the jigger is working (the brightness is suggested by 日本海区水産研究所、中央水産研究所 2019 年度スルメイカ秋季発生系群の資源評価補足資料 5). Kiyofuji and Saitoh (2004) noted that the lights in the Japan Sea from the fishing of Japanese common squid is in high probability. We used 1/24° longitude and latitude resolution to mesh the brightness data, and the number of bright pixels in the grid was used as an indicator of the number (frequency) of jiggers in the region.

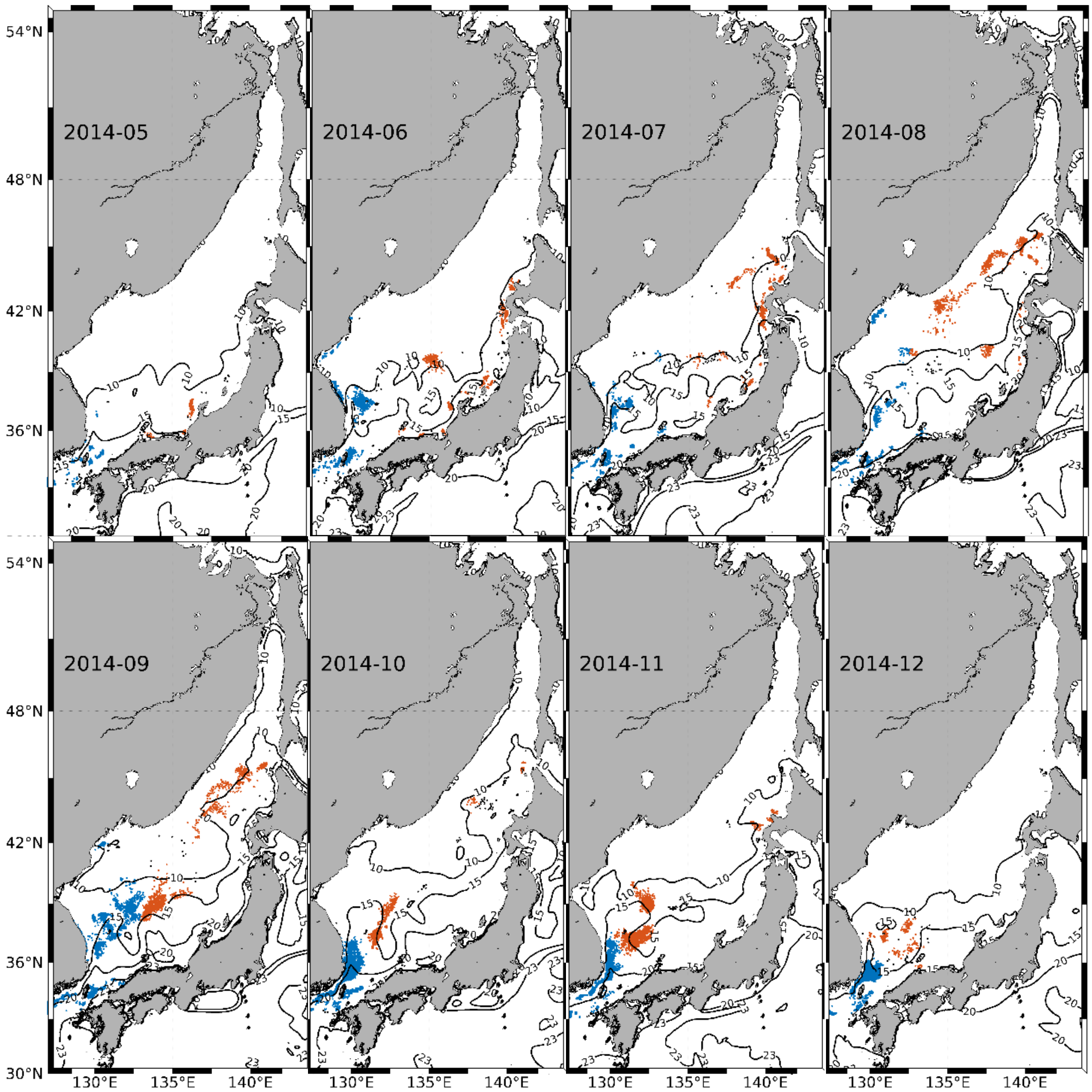


Fig. 1 The location of jiggers in May to December 2014 from VIIRS images, the blue dot denotes the jiggers fishing of peninsula group, the orange dot denotes the jiggers fishing of Tsushima group.

Figure 1 indicates the location of the jigger's brightness in May 2014 to December. Based on the speed of migration of the bright dots, we clustering dots into two groups. The dots with low speed which moves in a range less than 5° in latitude and longitude directions throughout the year is denoted by blue dots. They gathered near the coast of Korean peninsula, which is in conformity with the reported fish ground of the Korea (Choi et al., 2008, Kim et al. 2017). In some papers, Japanese flying squid living in this area was named as peninsula group (e.g., Kim et al 2015). The other group is represented by orange dots, which have a significant annual migration from north coast of Japan to the middle of Japan Sea. The trajectories of the orange dots are consistent with the migration path of Tsushima group of Japanese common squid mentioned by Kim et al (2015).

We plot the averaged positions of the two groups of bright dots respectively to sketch trajectories

(Fig.2). Overall, the jiggers went northward from June to August, and southward from September to December. For the Tsushima group, when they migrate northward, the fishing ground is distributed in the warm side of the polar front(Fig.1); When they migrate southward, the fishing ground is distributed in the cold side of the polar front (Fig.1), especially near the cold tongue where the isotherm extends southward (Fig.1, 2014-10, 2014-11). This is consistent with the result of Wang and Chen (2005).

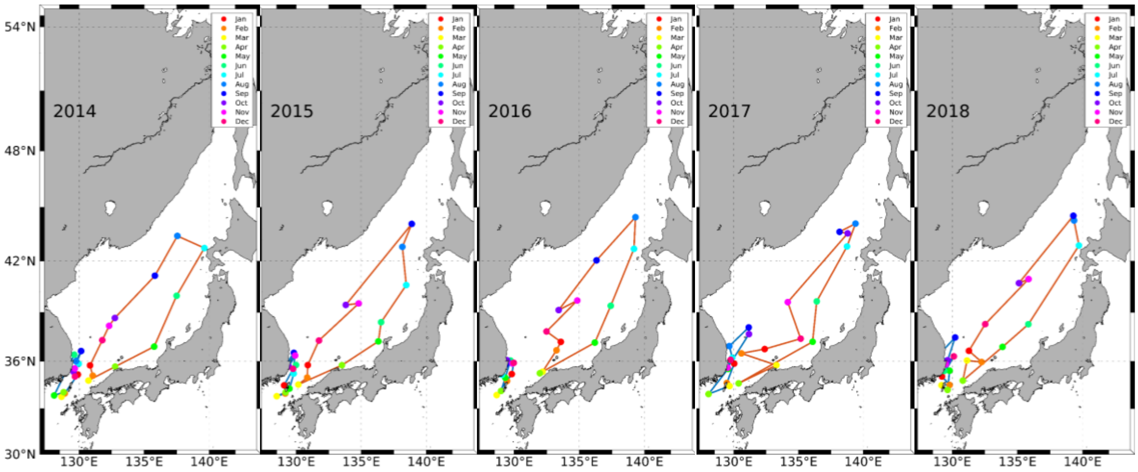


Fig. 2 Averaged migration path of Peninsula group (blue line) and Tsushima group (orange line). We use different color to mark the average position in different month.

Secondly, we build a simple migration model to simulate the migration around the polar front.

In the model, we assume that Japanese flying squid has the sensing of water temperature, and they can feel the temperature gradient of the region, through the memory of temperature and a random swim in small range. Based on this assumption, the squid's migration behavior can be simplified as a circle around the region with the largest temperature gradient (polar front). In order to complete the circle, squid changes the migrate direction in different life stages. According to the principle of simplification, we assume that the angle between the direction of migration and the water temperature gradient is a linear function of the growth stage (represented by age). In this way, 3 parameters, the migration velocity, the angular velocity of migration direction and the initial angle at the beginning of the migration swimming, can describe the orientation mechanism of migration. Although, it is a phenomenological model, the migration characteristics of "around the front" can be simulated.

The model reproduces the characteristics of the squid's anticlockwise migration around the polar front area (Fig.3). The adult squid in our model swims into the feeding ground in August and returns to the spawning ground from the feeding ground from September to December. Moreover, the monthly distribution of fish in our IBM is consistent with the fishing light observed by satellite.

Bases on above results, we are preparing a manuscript and will submit it to a journal named *Remote Sensing*(IF=4.509) next month.

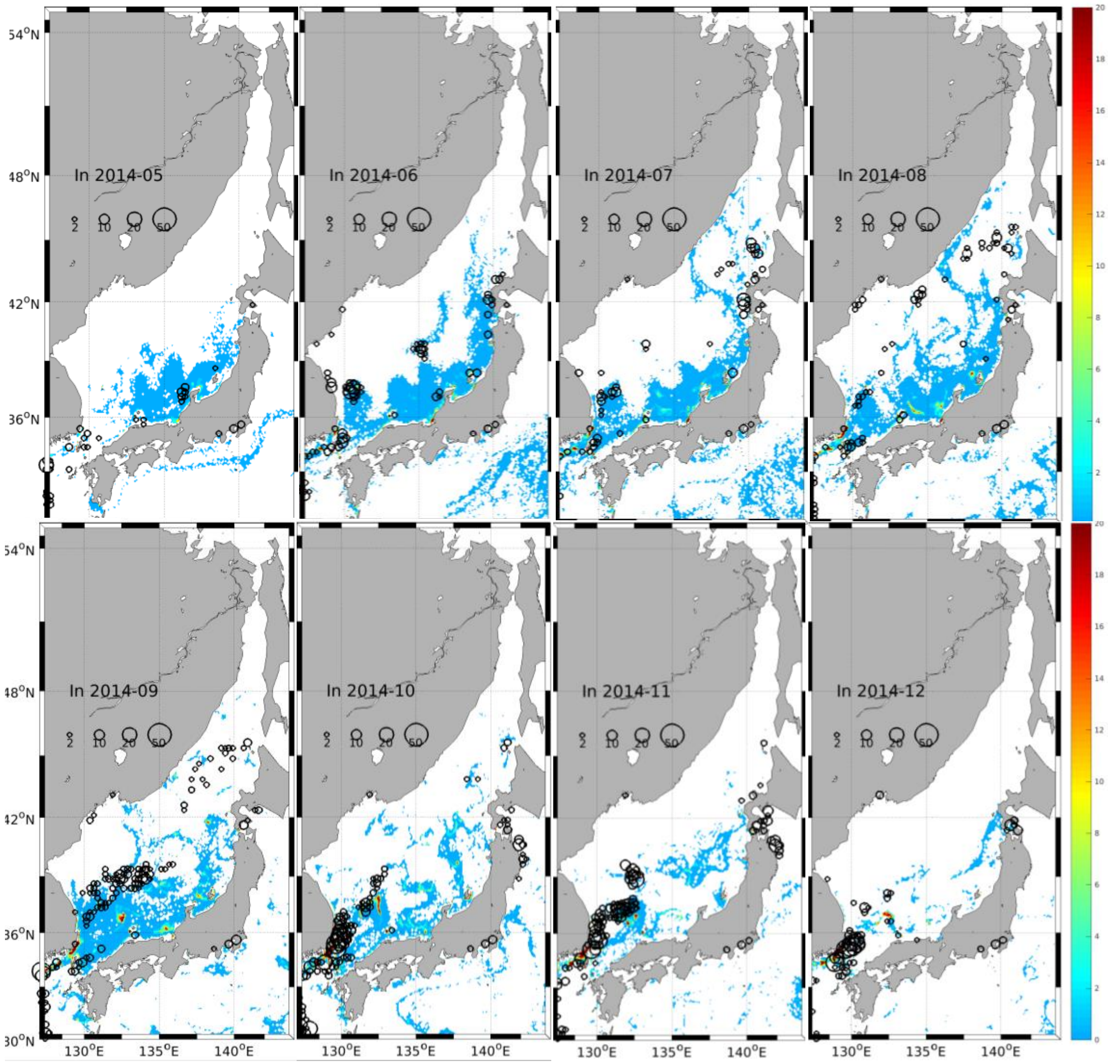


Fig. 3 The results of the IBM are compared with satellite observation. The color represents the result of the IBM, which denotes the number of particles in the grid. The size of each grid is 1/24° in longitude × 1/24°in latitude. The circle represents the number of light spots on the VIIRS image that meet the brightness requirement of working jigger. The radius of the circle denotes the number of light spots in the grid with the size 1/4°in longitude × 1/4°in latitude.

Reference:

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## Publication presentation

The results of previous research on early life stage of Japanese flying squid are summarized in the paper "response of the Japanese flying squid (*Todarodes pacificus*) in the Japanese sea to future climate warming scenarios", which has been published in March 2020.

New manuscript "Numerical simulation of migration behavior of Japanese flying squid (*Todarodes pacificus*) in the Sea of Japan" is under writing

## Perspectives in future

Based on the new developed models, we plan to study on the relationship between migration path and reproduction success rate of Japanese flying squid in the future. We notice that the resource regeneration rate of Japanese flying squid has a great interannual change. We did not read any discussion on the mechanism of such changes. We notice that the suitable spawning area of Japanese flying squid tend to be fragmented with the increase of water temperature. We want to try to use the migration models to discuss whether the fragmentation of spawning grounds will increase the difficulty of migrating to spawning grounds.

In the aspect of model, we expect to use reinforcement learning algorithm (RL) to further improve the migration model. Bring more variables, such as Chlorophyll concentration, upwelling intensity and zooplankton abundance, into the model, to deduce the optimal orientational strategy of squid in the feeding and spawning migration.

I hope to have the opportunity to visit CMEs in the near future and introduce the new achievements to CMES colleagues.