PTA2018 Symposium Sesseion-4: 25 April 15:00-

Numerical experiments based on a coupled physical–biochemical ocean model to study the Kuroshio-induced nutrient supply on the shelf–slope region south of Japan

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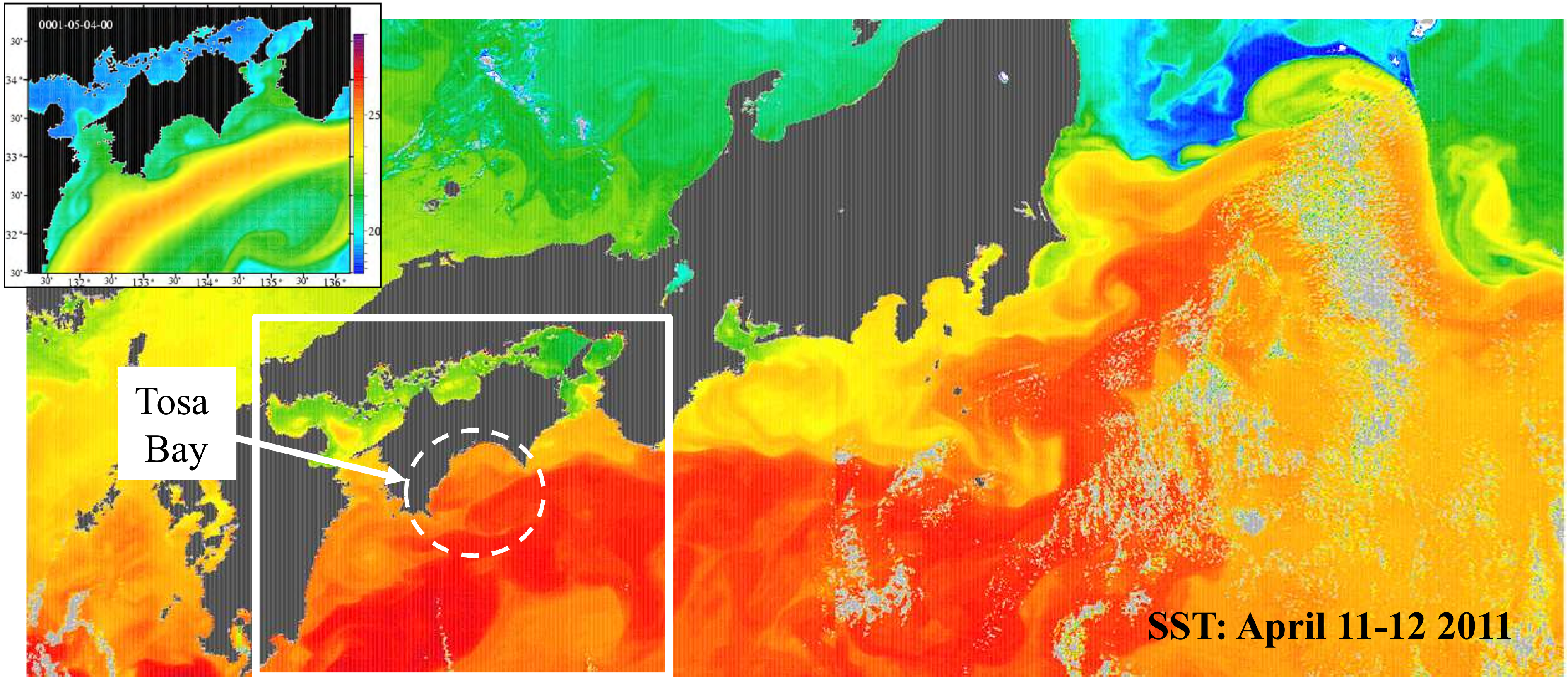


Overview

☆Numerical simulation of a coupled physical–biochemical ocean model with a grid size of 1/50˚

☆Submesoscale is defied as variations with *O(1)* day and *O(10)* km

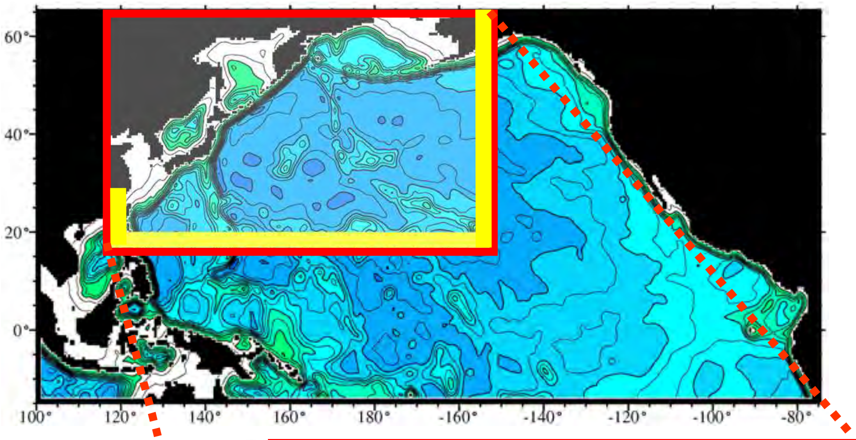
☆Shelf and slope region in Tosa Bay facing the Kuroshio

Today's main topics

1. Importance of submesoscale modeling to simulate the Kuroshio-induced nutrient supply in terms of **time-independent** structure of density and nutrient
2. Eulerian viewpoints: Reynolds decomposition
   Roles of **time-dependen**t submesoscale variations via eddy advection of nutrient
3. Lagrangian viewpoint: Particle-tracking experiment
   A submesoscale process of nutrient uplift and transport

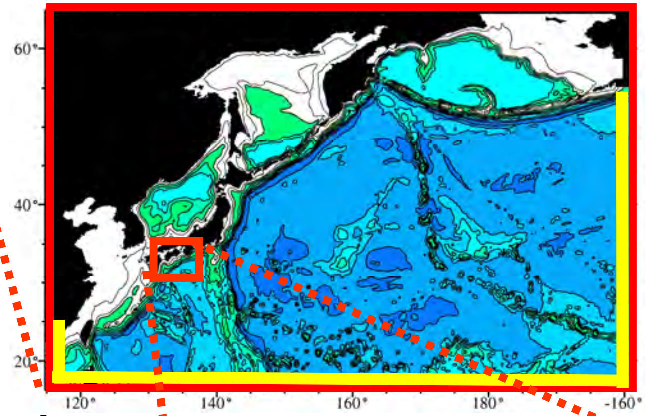
Dynamical downscaling of an online coupled ocean-NPZD model

ROMS
- Regional
- Ocean
- Modeling
- System

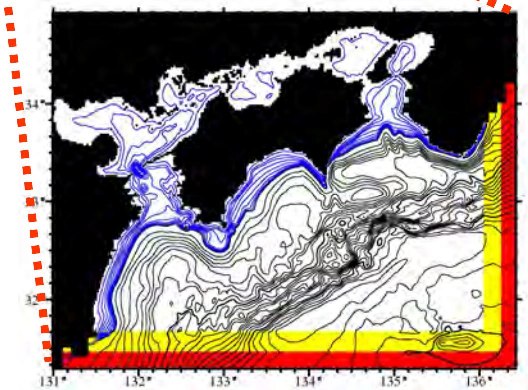


one-way nesting system

1/2°
Basin-scale
(O(10^3) km)



1/10°
Mesoscale
(O(10^2) km)



1/50°
Submesoscale
(O(10^1) km)

Forcings of 1/50°

At the sea surface
- climatological monthly mean fluxes

On the lateral boundary
- 6-hourly means from 1/10°
- + tidal oscillation

On the land-sea boundary
- monthly mean discharge & annual mean NO_3 conc.

Kuroda et al. (2013, 2014, 2017, 2018)

A simple NPDZ model coupled with ocean circulation model

Oschlies (2001), Sasai et al. (2007 & 2010)

$$sms(P) = \overline{J}(z,t,N)P - G(P)Z - \mu_P P - \mu_{pp} P^2 \quad (2)$$

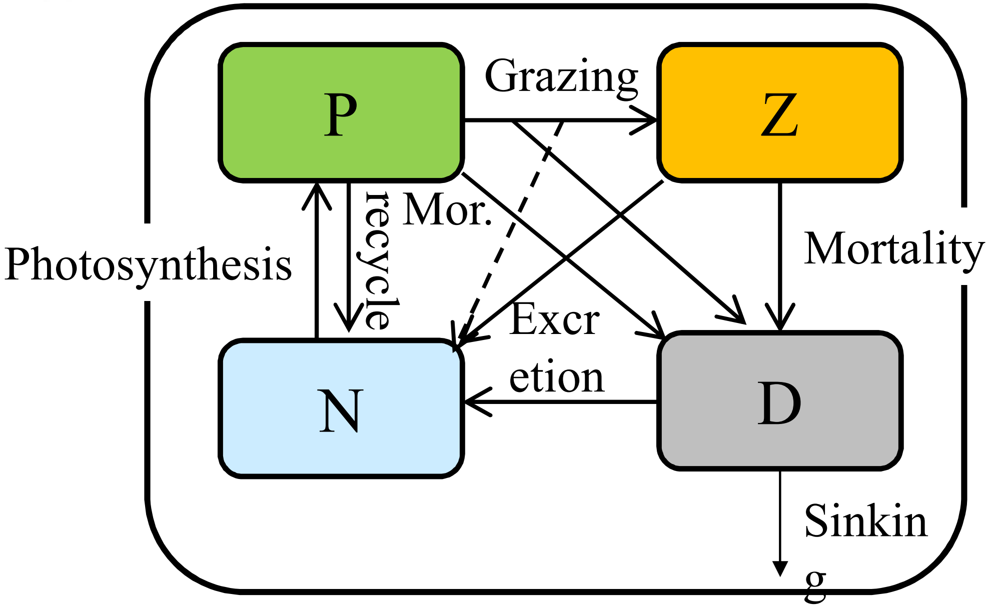
$$sms(Z) = \gamma_1 G(P)Z - \gamma_2 Z - \mu_Z Z^2 \quad (3)$$

$$sms(D) = (1-\gamma_1)G(P)Z + \mu_{pp} P^2 + \mu_z Z^2 - \mu_D D - w_S \frac{\partial D}{\partial z} \quad (4)$$

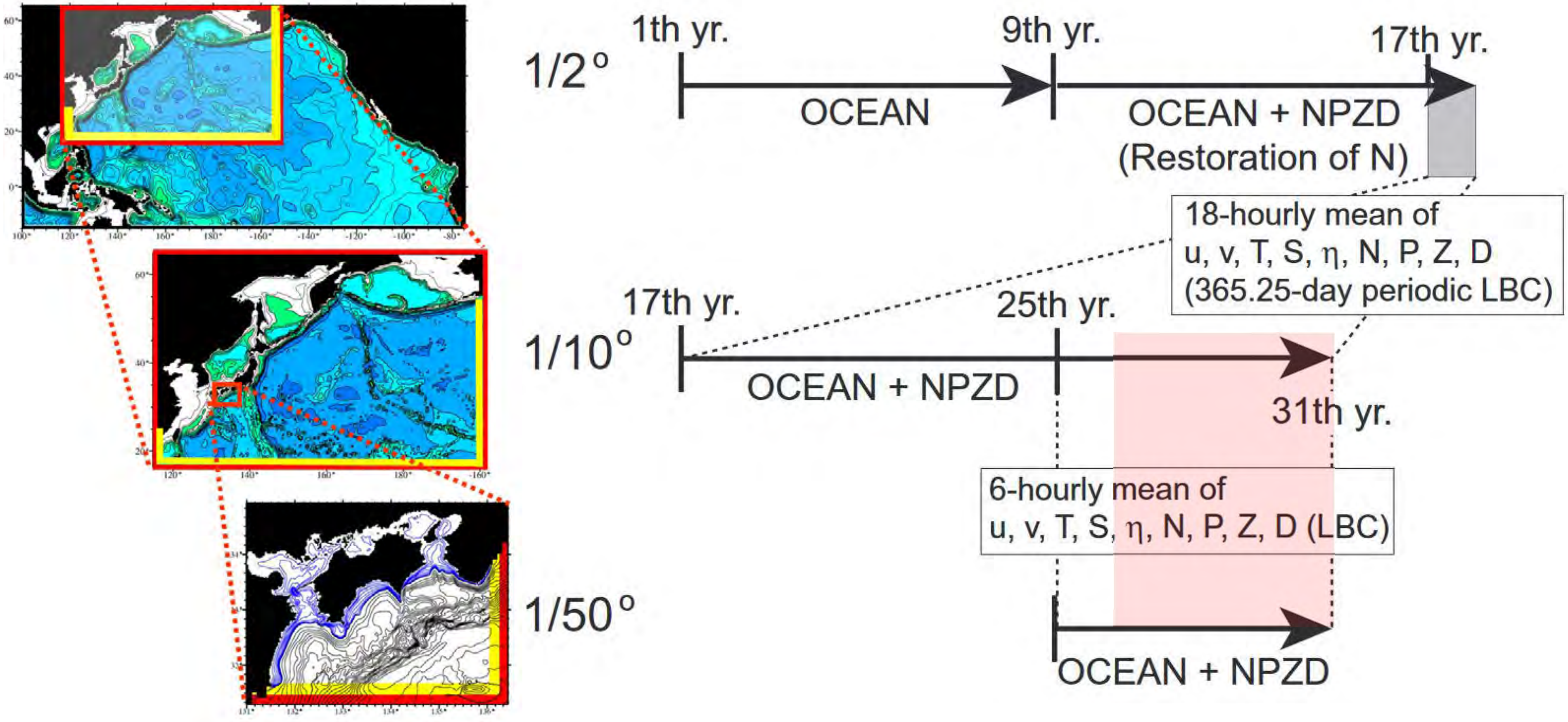
$$sms(N) = \mu_D D + \gamma_2 Z + \mu_P P - \overline{J}(z,t,N)P \quad (5)$$

Table 1 Parameters of ecosystem model

Parameter	Symbol	Value	Units
Phytoplankton (P) coefficients			
Integration method for daily growth rate		Evans and Parslow (1985)	
Half saturation constant for N uptake	k_1	0.5	mmol m^{-3}
Specific mortality/ recycling rate	μ_P	0.05	day^{-1}
Quadratic mortality rate	μ_{PP}	0.05	(mmol $m^{-3})^{-1}day^{-1}$
Zooplankton (Z) coefficients			
Assimilation efficiency	γ_1	0.75	
Maximum grazing rate	g	2.0	day^{-1}
Prey capture rate	ε	1.0	(mmol $m^{-3})^{-2}day^{-1}$
(Quadratic) mortality	μ_Z	0.20	(mmol $m^{-3})^{-1}day^{-1}$
Excretion	γ_2	0.03	day^{-1}
Detritus (D) coefficients			
Remineralization rate	μ_D	0.05	day-1
Sinking velocity	w_S	5.0	m d-1

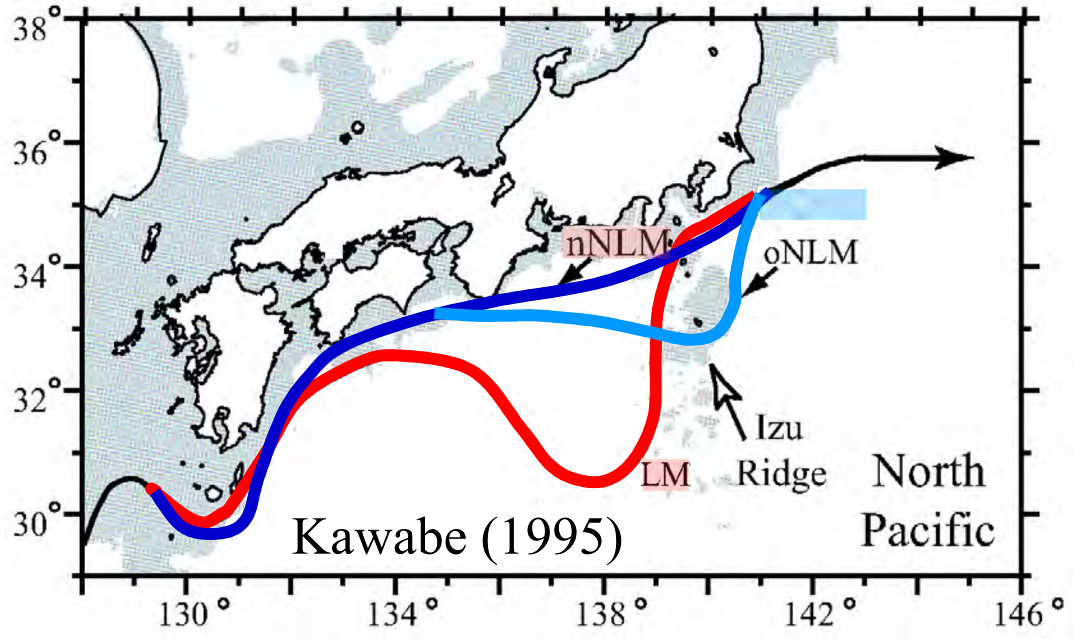


Integration time schedule



- ✪Total 30-year integration
- ✪The 1/50° model was integrated for the last 6 years
- ✪The last 5-year output was analyzed

Stable paths of the Kuroshio

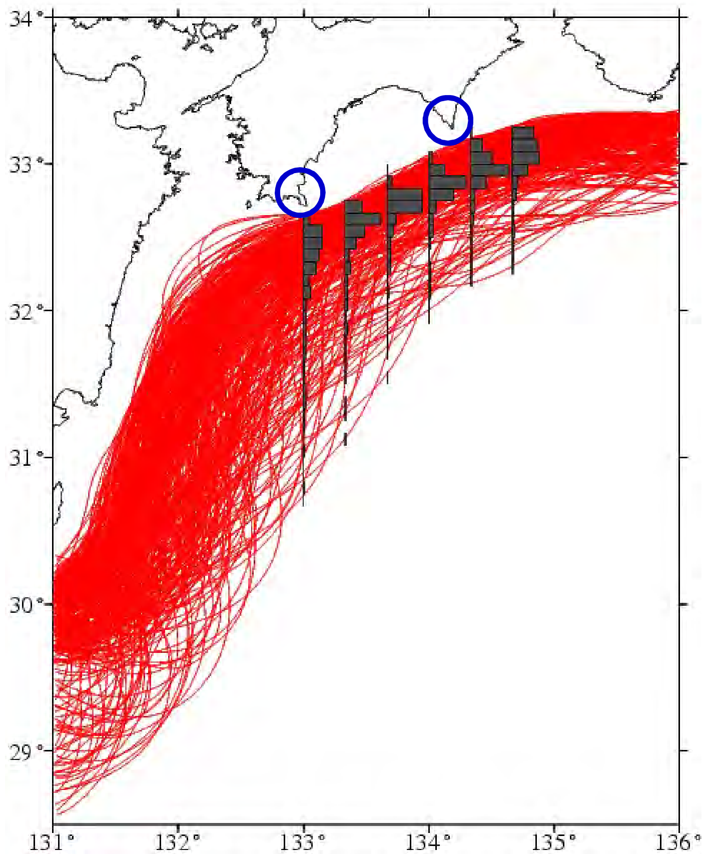


LM:
Large
Meander

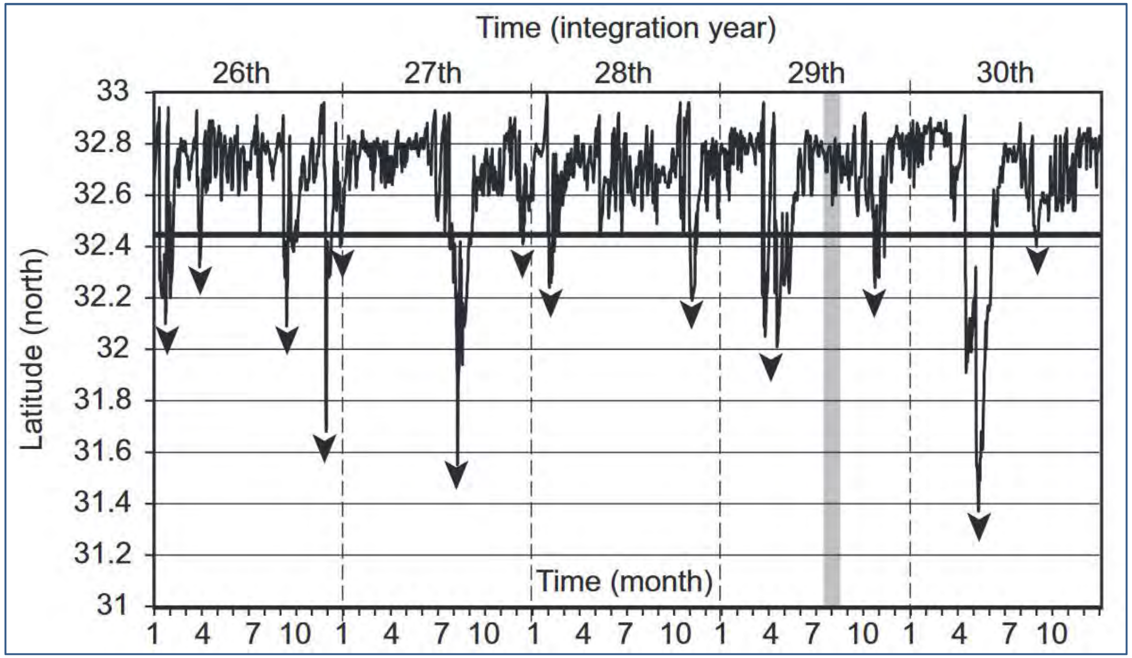
NLM:
Non
Large
Meander

✪ Only the NLM path was simulated during our analyzed period (26~30th year)

The simulated Kuroshio axis



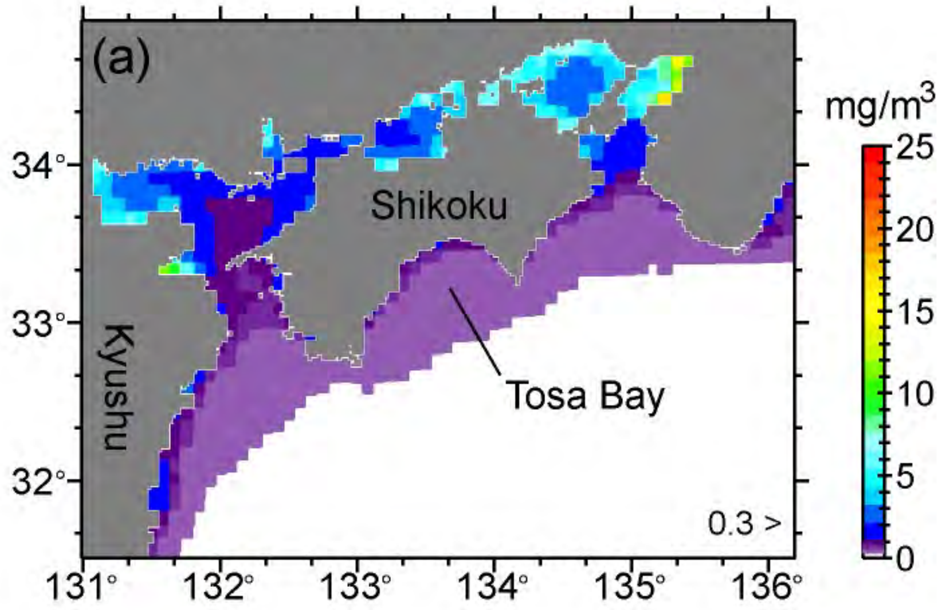
The simulated Kuroshio-axis position averaged form two capes ○ (left figure)



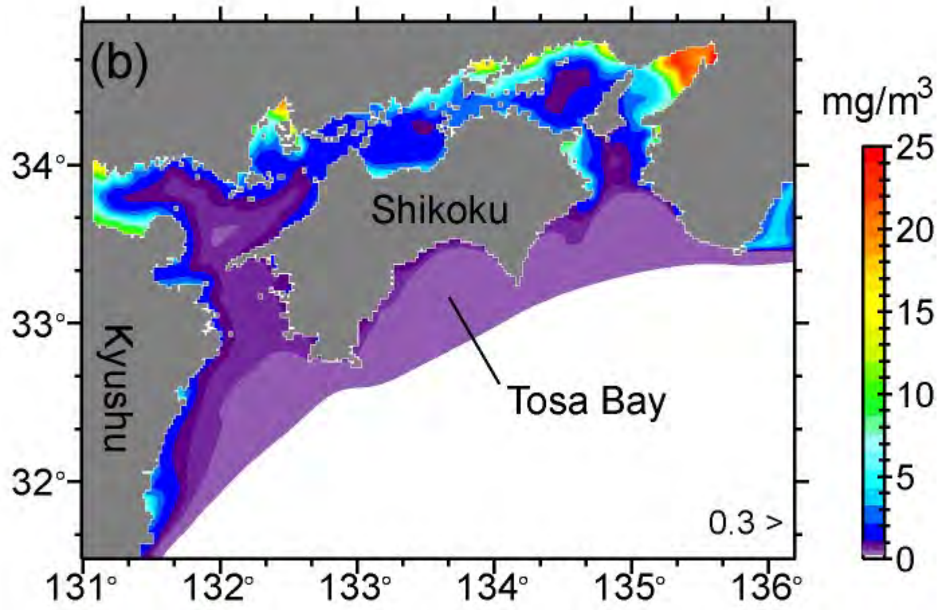
✪ During the analyzed period, the Kuroshio axis variations are characterized by onshore and offshore movement south of Tosa Bay, which is related to an eastward propagation of **mesoscale** small meander. (frequency: a few times per year)

Annual mean Chl-*a* concentrations at the sea surface

About 10-year mean MODIS/ Aqua

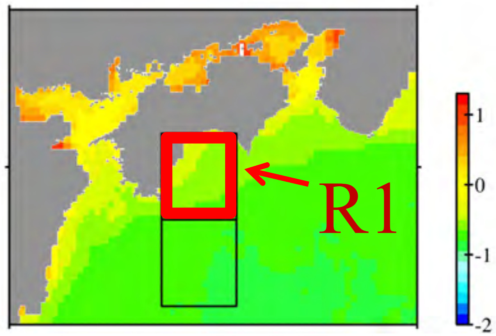


5-year mean 1/50° model



Today's main topic 1

Importance of submesoscale modeling to simulate the Kuroshio-induced nutrient supply in terms of **time-independent** structure of density and nutrient

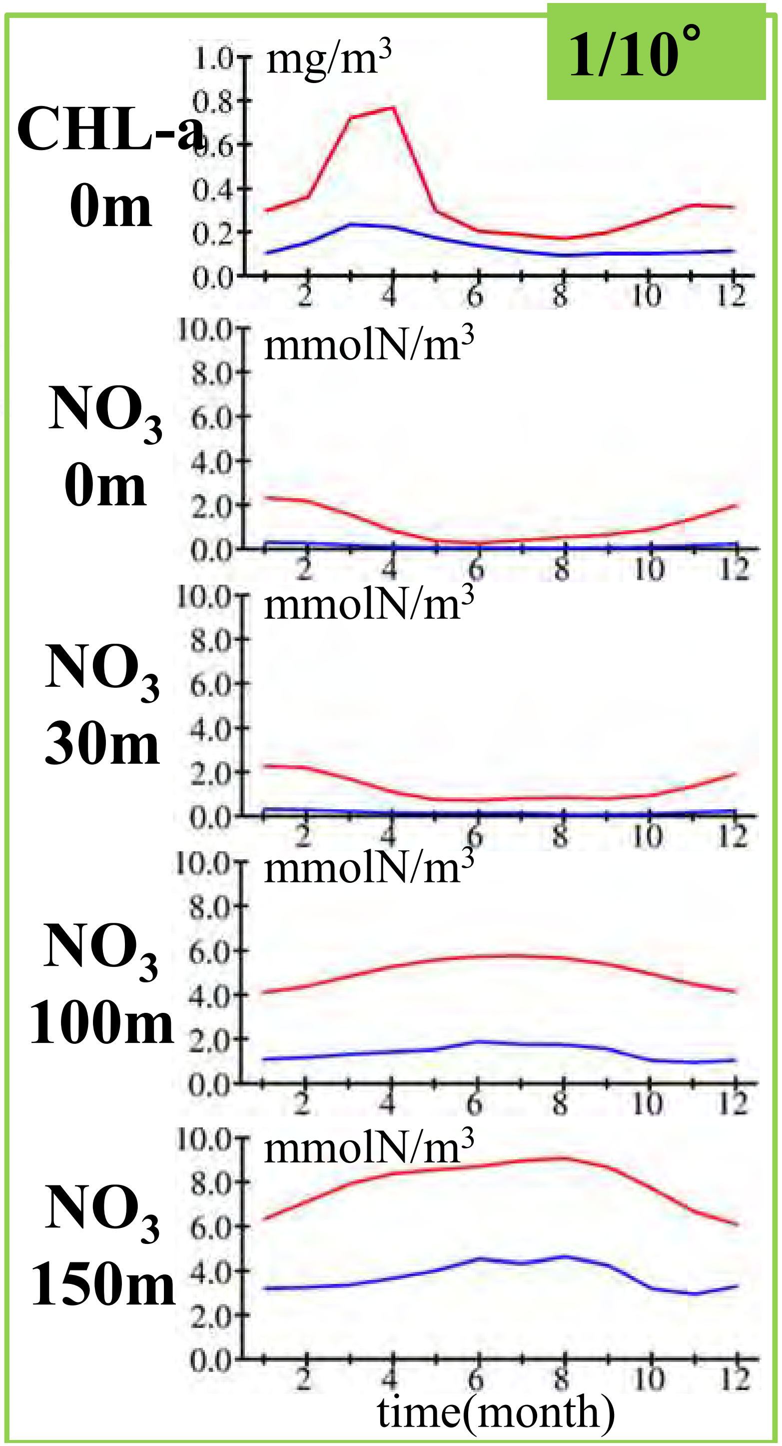


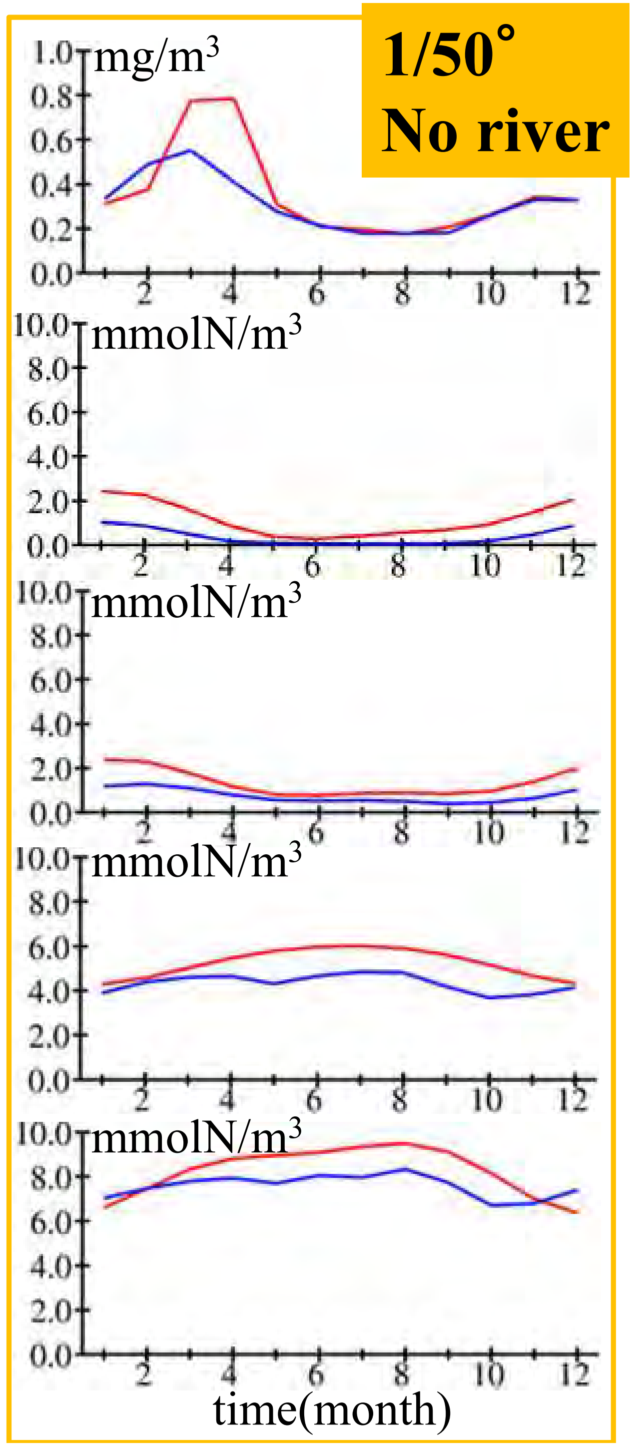
In Region R1
(Tosa Bay)

monthly mean
time series

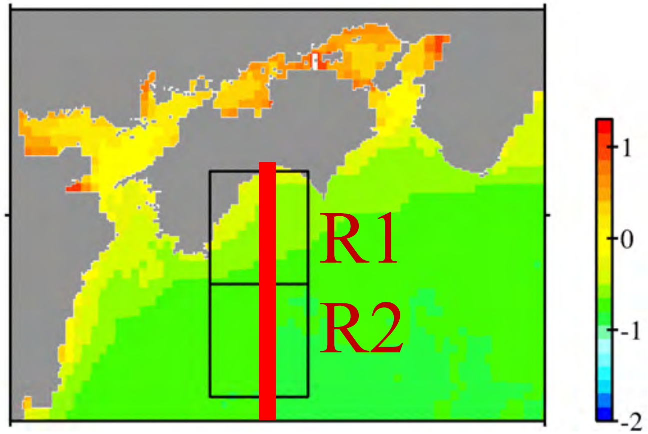
Observation

Model





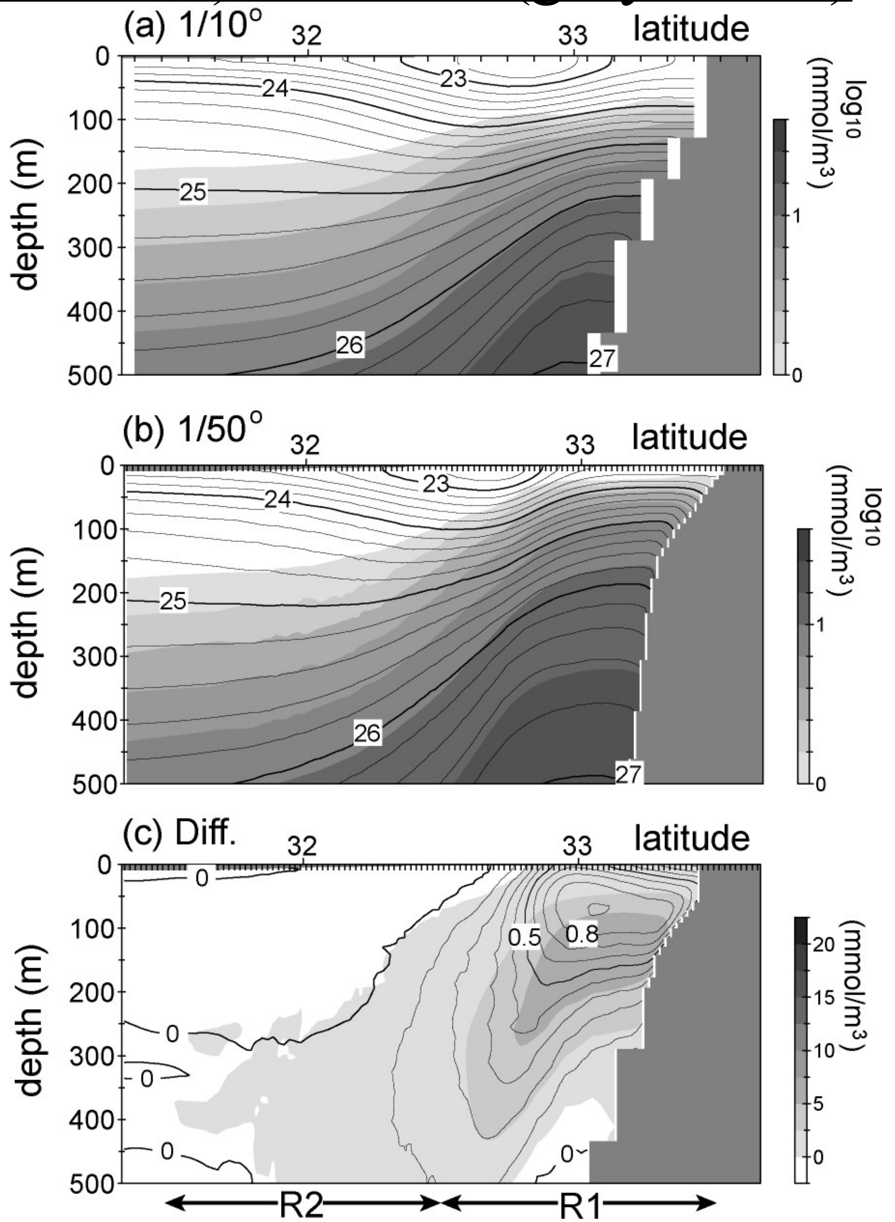
Meridional section along the red line of 5-year mean simulated density (contour) and NO_3 (gray shade)



1/10°

1/50° No river

Difference (1/50° minus 1/10°)

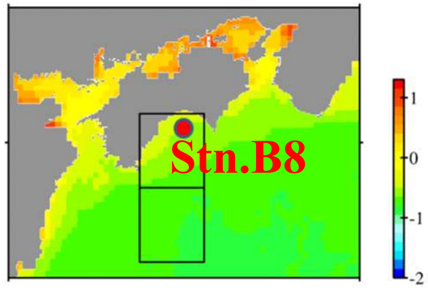


Today's main topic 2

Eulerian viewpoints:

Roles of **time-dependen**t submesoscale variations
via eddy advection of nutrient

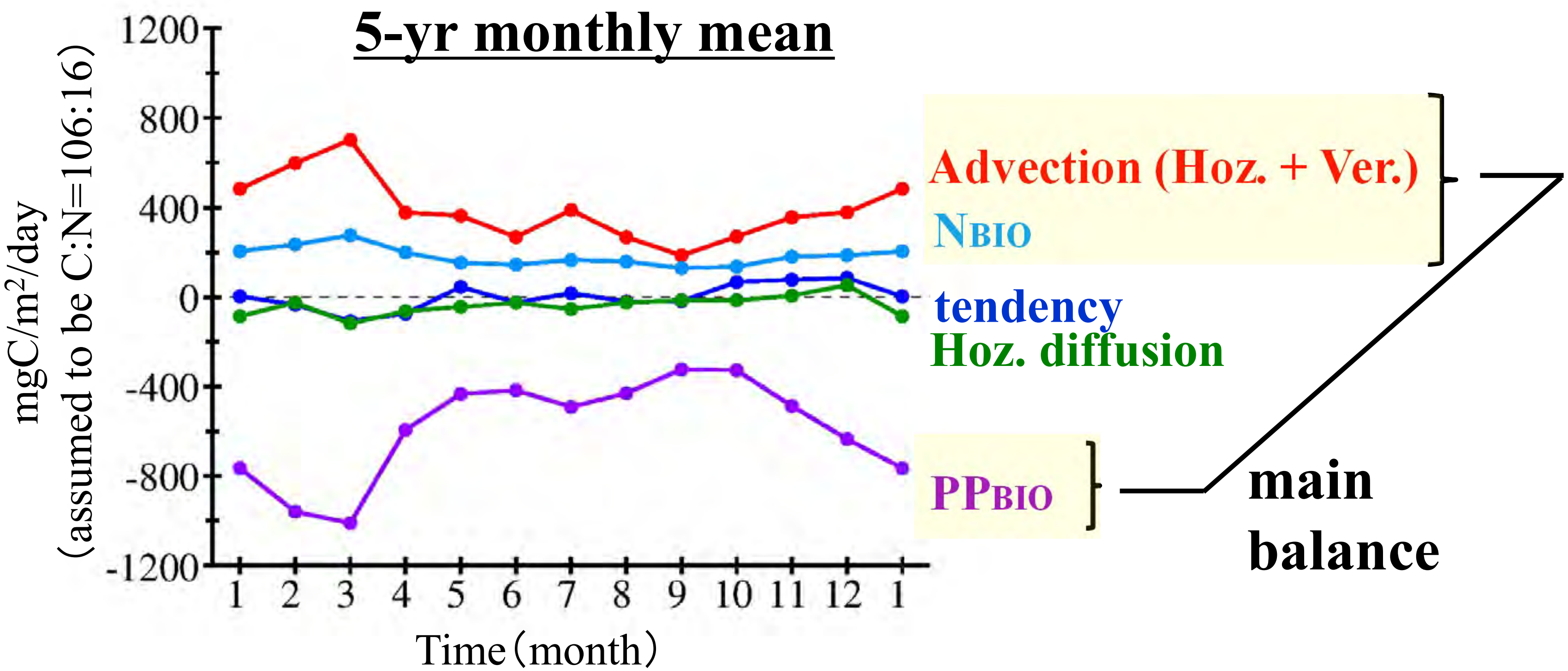
Term balance of NO3 eq. in euphotic zone (0-50 m) at Stn. B8 on the shelf



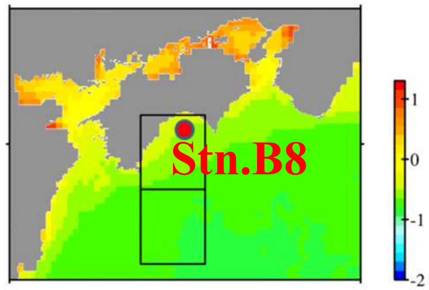
Physical processes | Biological Processes

$$\int \frac{\partial NO_3}{\partial t} dz = \int \left(\mathrm{Hadv} + \mathrm{Vadv} + \mathrm{Hdif} + \mathrm{Vdif} - PP_{BIO} + N_{BIO} \right) dz$$

Primary Production



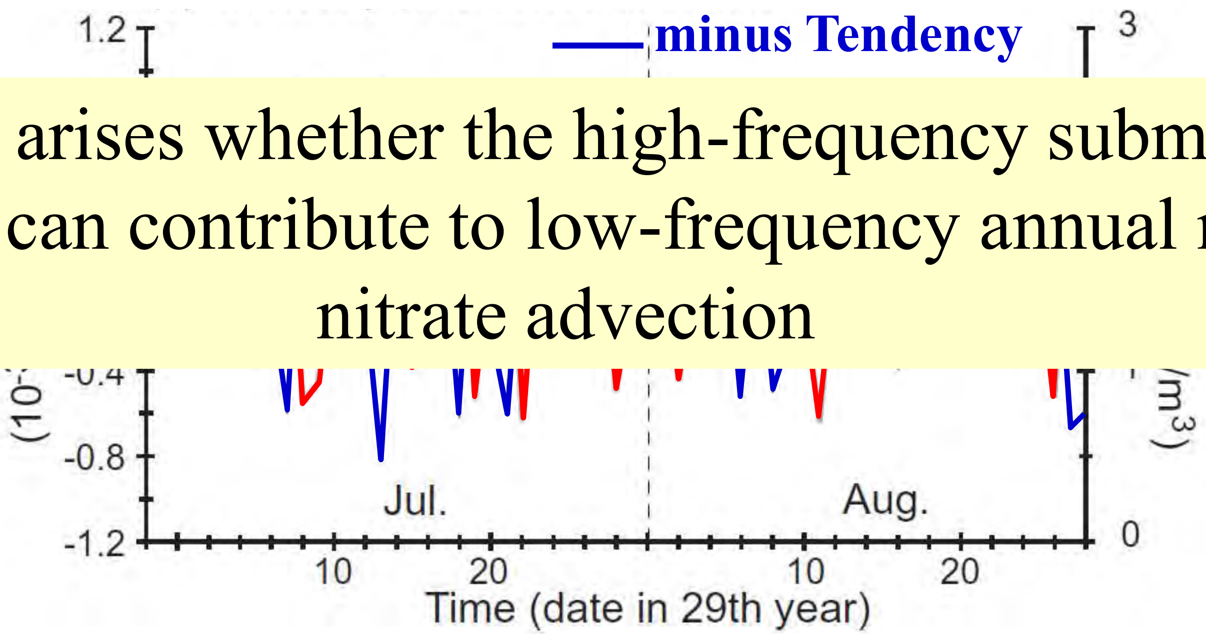
Term balance of NO_3 eq. in euphotic zone (0-50 m) at Stn. B8 on the shelf



Tendency ~ **Advection**

$$\int \frac{\partial NO_3}{\partial t} dz = \int \left(\text{Hadv} + \text{Vadv} + \text{Hdif} + \text{Vdif} - \text{PP}_{\text{BIO}} + \text{N}_{\text{BIO}} \right) dz$$

12-hourly mean time series for 2 months



A question arises whether the high-frequency submesoscale variations can contribute to low-frequency annual mean of nitrate advection

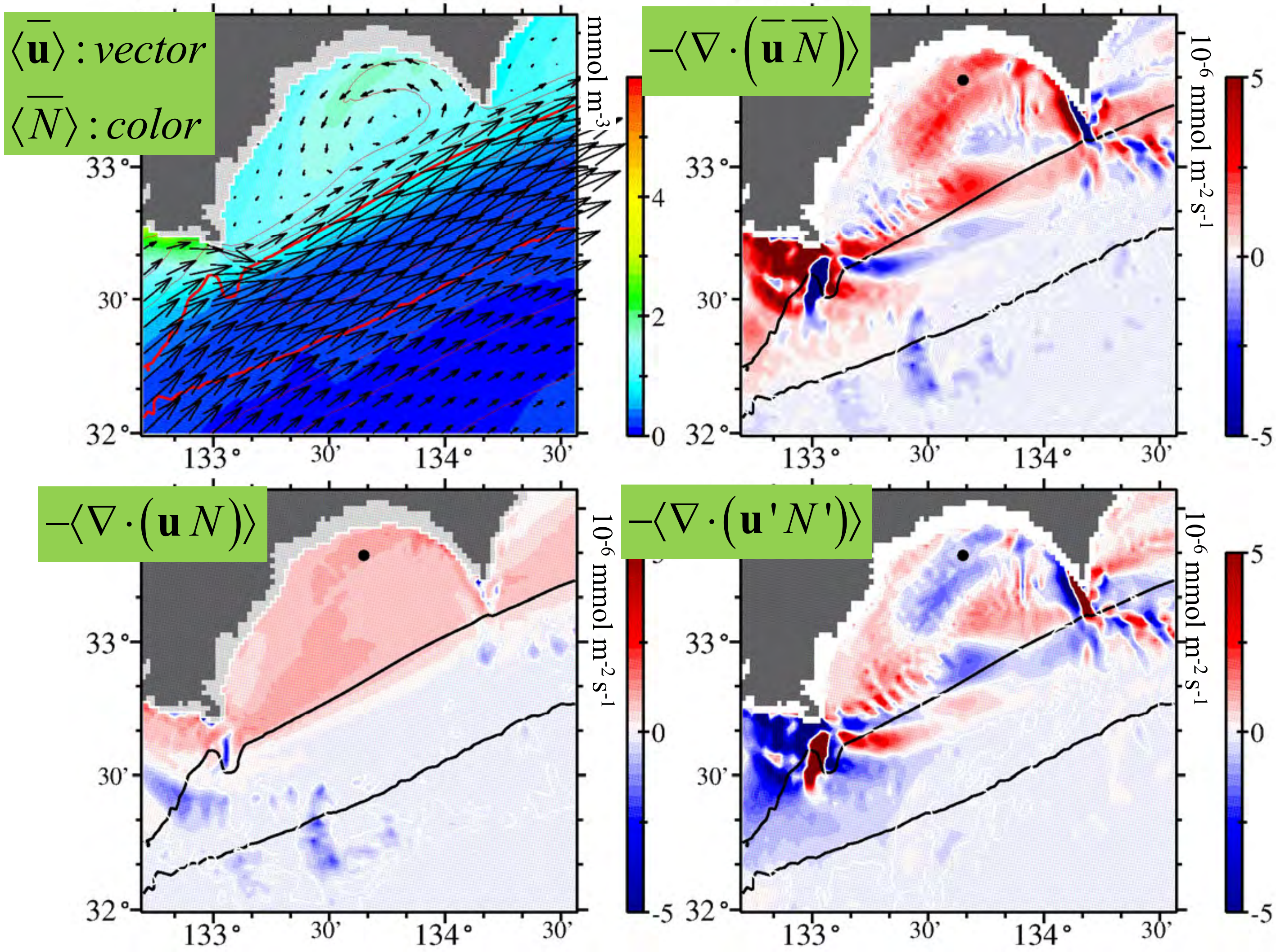
Reynolds decomposition of nitrate advection

$$\left.\begin{aligned}\mathbf{u} &= \overline{\mathbf{u}} + \mathbf{u}' \\ N &= \overline{N} + N'\end{aligned}\right\}$$

$$-\langle \nabla \cdot (\mathbf{u} N) \rangle = -\langle \nabla \cdot (\overline{\mathbf{u}}\,\overline{N}) \rangle - \langle \nabla \cdot (\mathbf{u}' N') \rangle$$

$\langle\ \rangle$: 0-50m mean &5-year mean

Monthly mean : Seasonal plus mesoscale variation

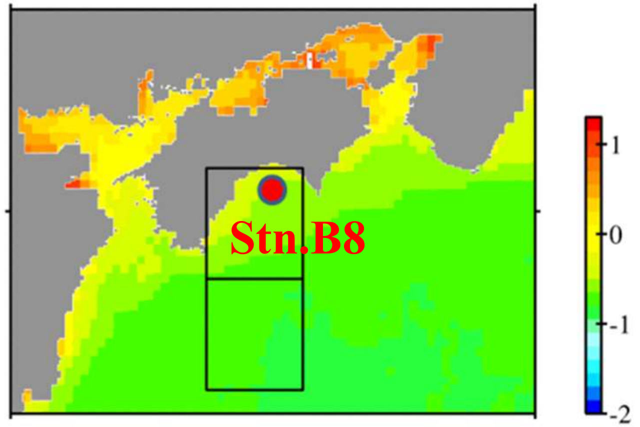


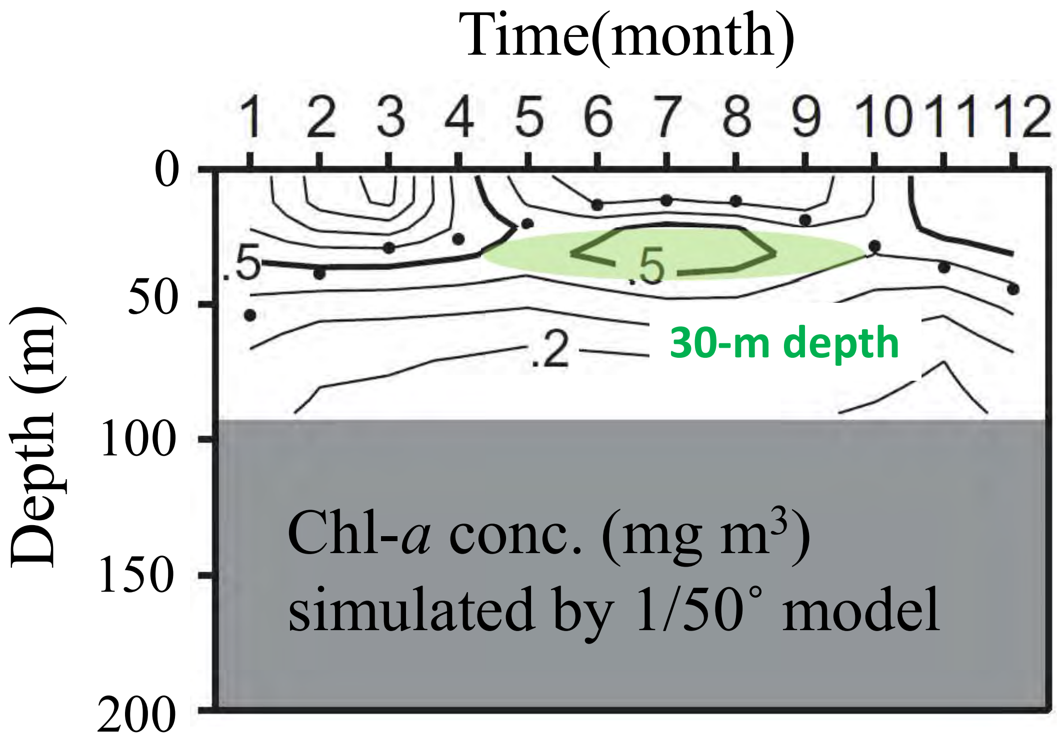
Today's main topic 3

Lagrangian viewpoint:

A submesoscale process of nitrate uplift and transport into Tasa Bay, where it is used for photosynthesis

The subsurface Chl-a/primary production max. in summer



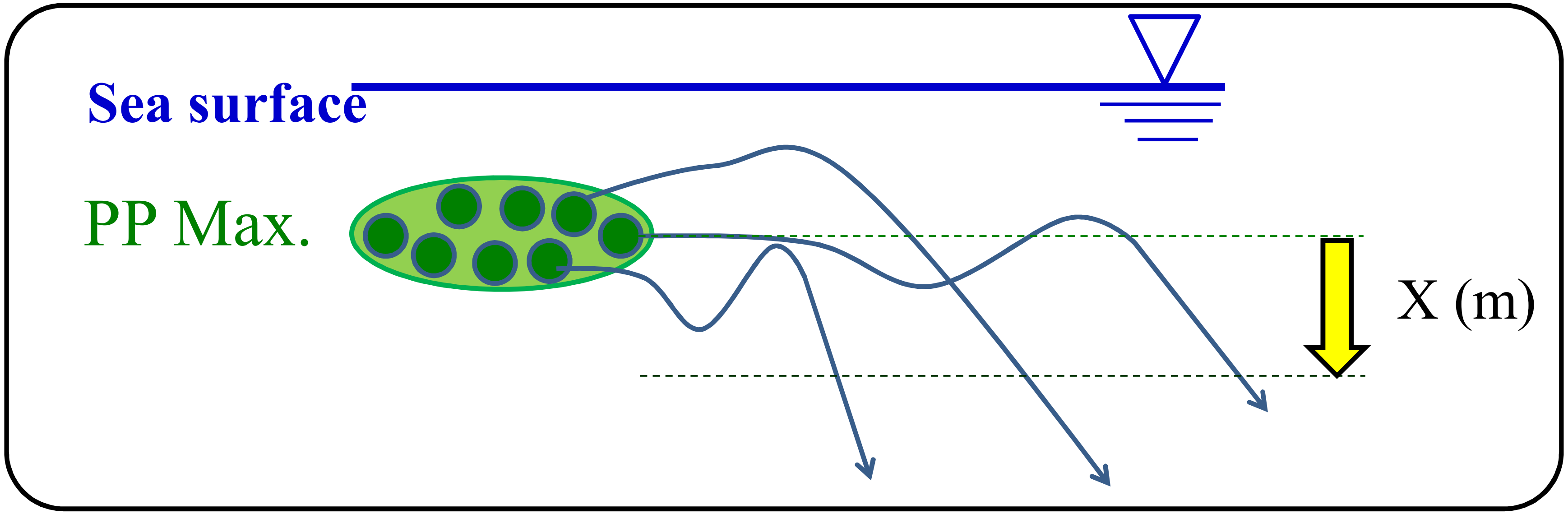


✪ During summer, the subsurface maxima of Chl-*a* and primary production ("PP") are observed and simulated on the shelf and slope.

Question

Where is the nitrate uplifted and supplied to the subsurface in Tosa Bay?

Backward-in-time particle-tracking
to specify where nitrate used for photosynthesis in Tosa Bay is uplifted



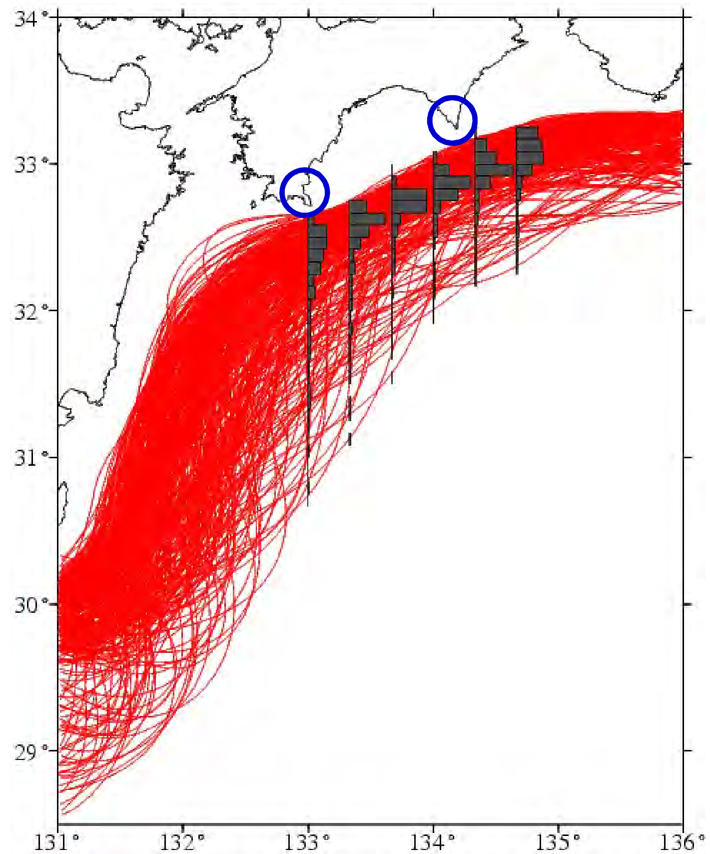
Backward PT experiment

$$\begin{cases} x_{n+1} = x_n - u_{\text{model}}\delta t \\ y_{n+1} = y_n - v_{\text{model}}\delta t \\ z_{n+1} = z_n - w_{\text{model}}\delta t \end{cases}$$

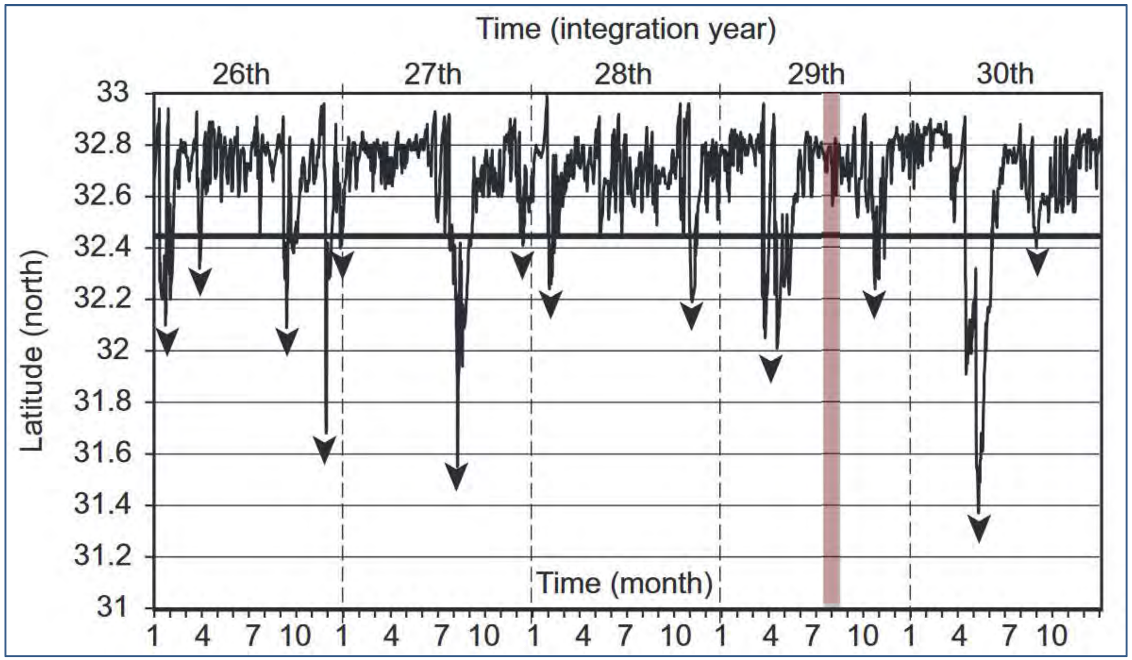
Model output: 1.2-hourly mean

We estimated
where a particle descended to X (m)
from an initial depth with the PP max

The simulated Kuroshio axis



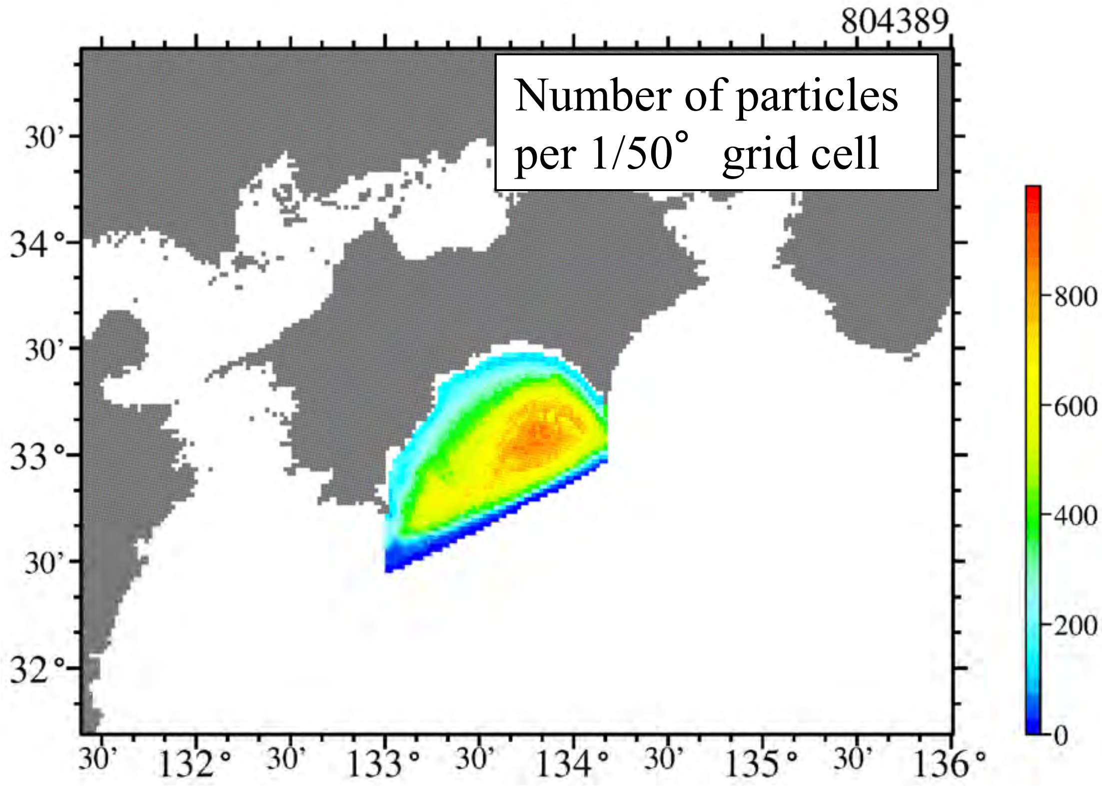
The simulated Kuroshio-axis position averaged form two capes ○ (left figure)

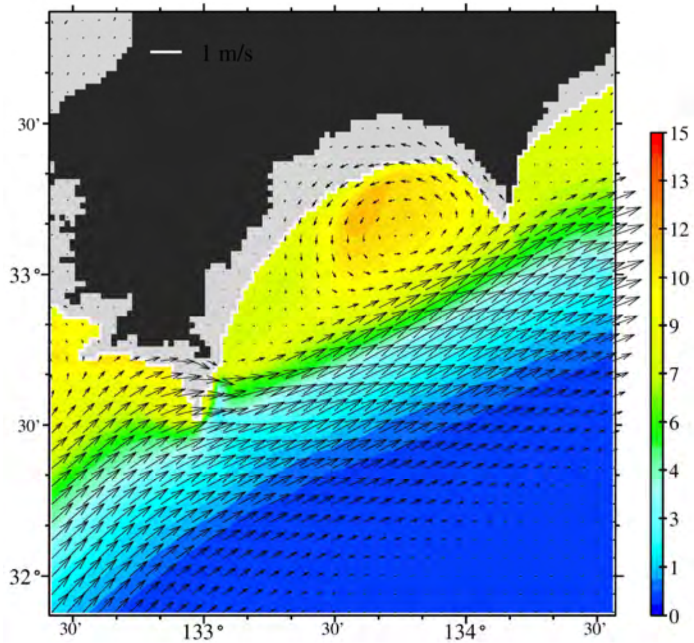


✪ The particle-tracking experiments are conducted during summertime in the 29th year, when the Kuroshio stably takes a nearshore path.

Particle-tracking from 15 Jul. to 15 Aug. in the 29th year

1. Initial conditions were updated every 12 hours



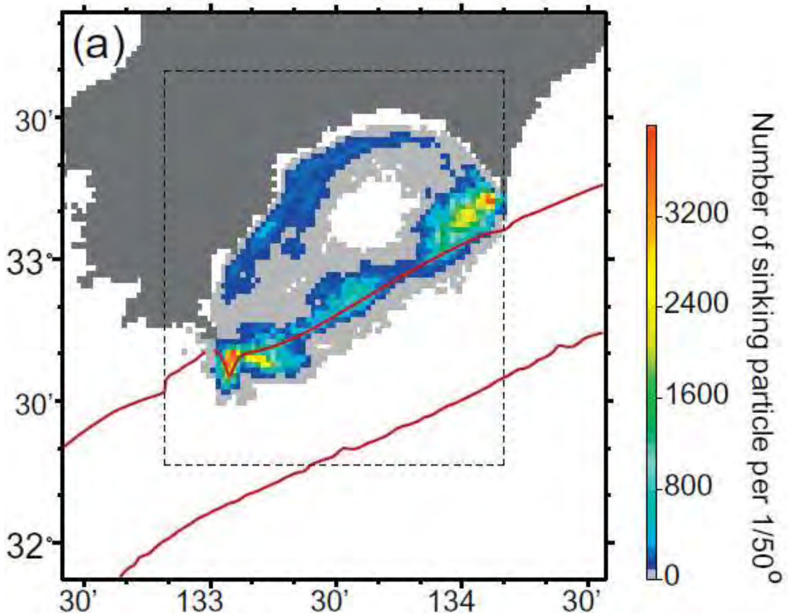


2. 6 days particle-tracking backward-in-time

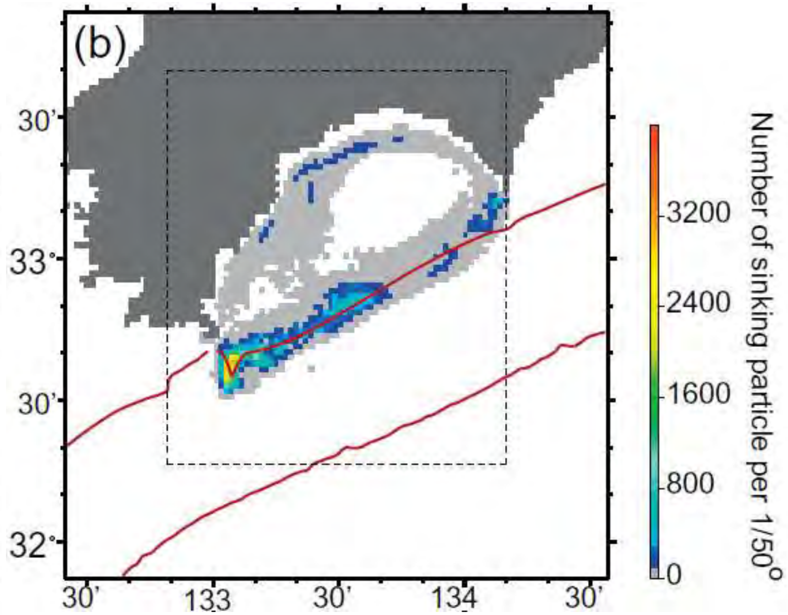
Particle-tracking from 15 Jul. to 15 Aug. in the 29th year

Q. Where did particles descend?

10 m
from the initial depth
with PP-max layer



20 m
from the initial depth
with PP-max layer

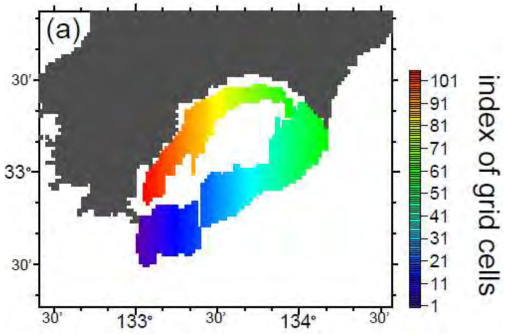


※Nitrate is frequently uplifted along the Kuroshio front, advected horizontally into the bay, and used for photosynthesis

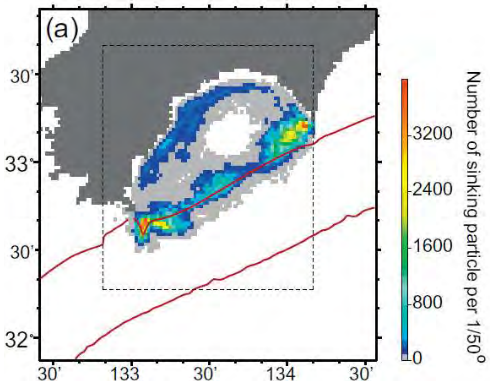
Hovmöller diagram of w and |w| at the depth of 40 m along particle descending area

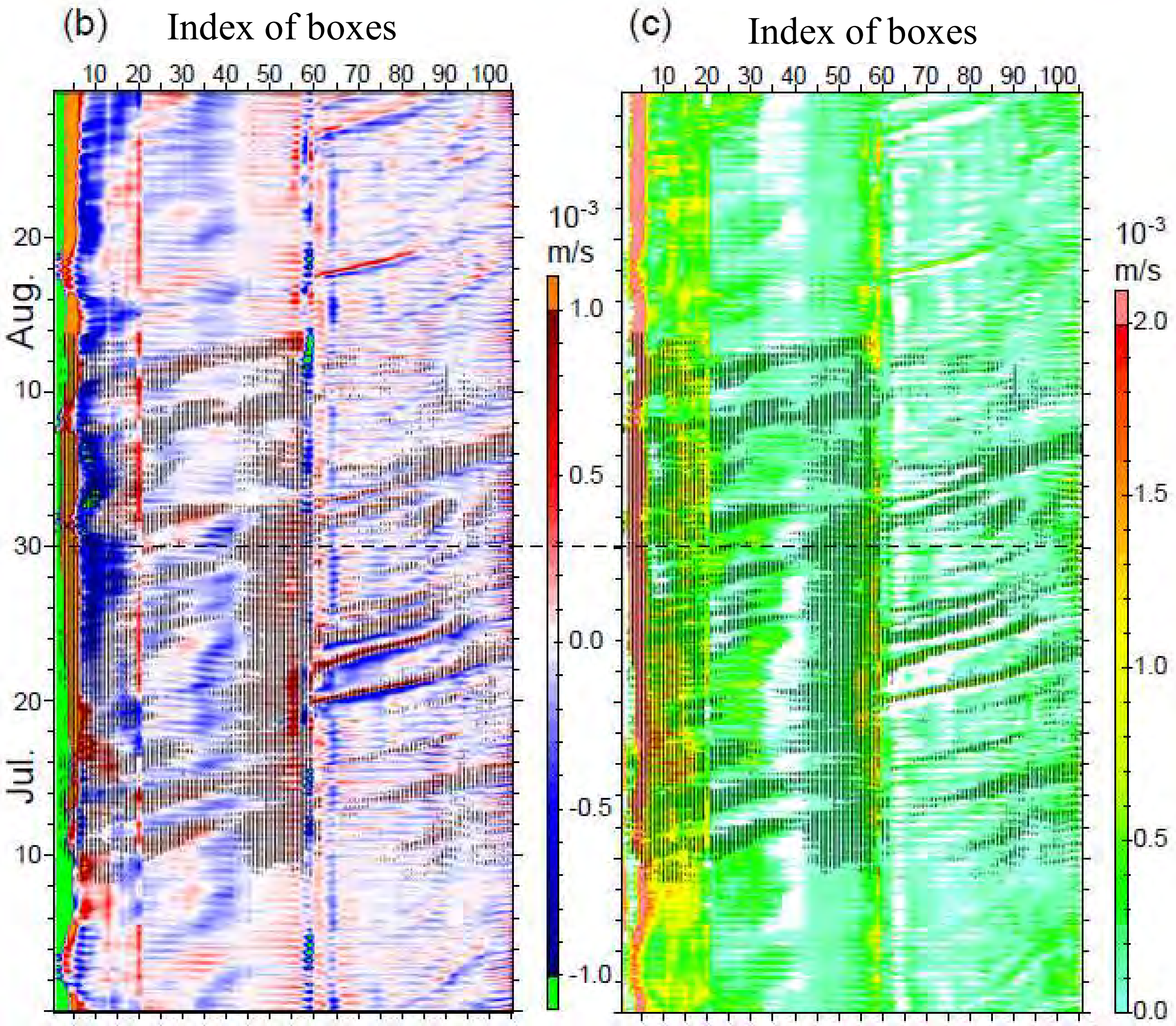
Box-averaged w at 40-m depth

Box-averaged |w| at 40-m depth



Boxes of 1 to 105 are defined on the basis of area where many particles > 100/grids descended to 10 m from the initial position





○ : where particles descended to 10,20,30m from the initial position

Conclusions

1. Importance of submesoscale modeling to simulate the Kuroshio-induced nutrient supply in terms of **time-independent** structure of density and nutrient
2. Eulerian viewpoints: Reynolds decomposition
   Roles of **time-dependent** submesoscale variations via eddy advection of nutrient are spatially different
   : supply of nitrate or removal of nitrate
3. Lagrangian viewpoint: Particle tracking
   In summer when the Kuroshio takes a nearshore path, an intermittent uplift of nutrient was frequently generated near the Kuroshio fronts, transported into the bay and used for photosynthesis in the subsurface (PP-max layer)

Thank you very much!
Muchas gracias!

Details are seen in our published paper

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