Statistical Characteristics of East Sea Mesoscale Eddies Detected, Tracked, and Grouped Using Satellite Altimeter Data from 1993 to 2017

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Introduction (1/4)

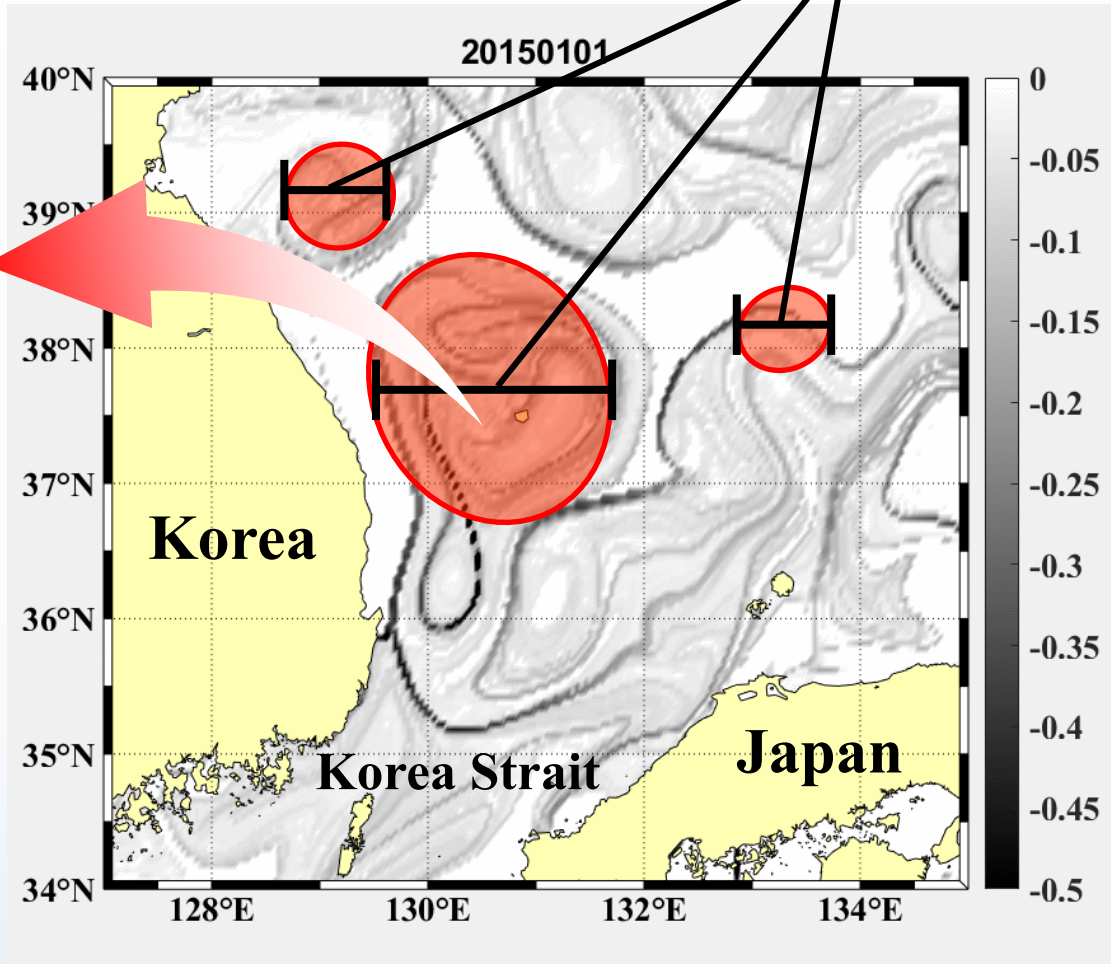
What are mesoscale eddies?

Momentum

Heat

Salt

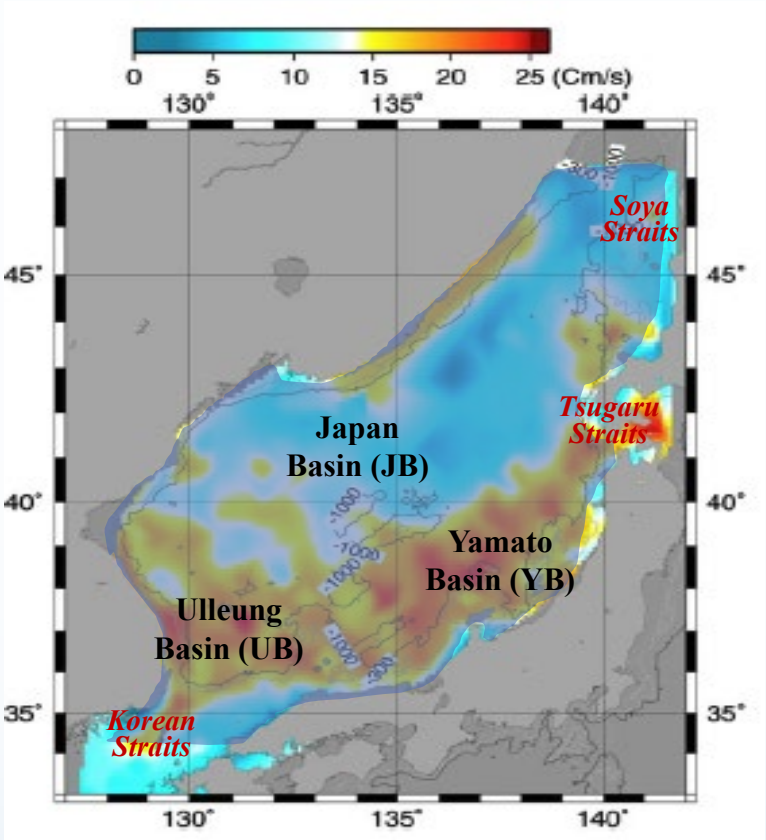
Biochemical tracers



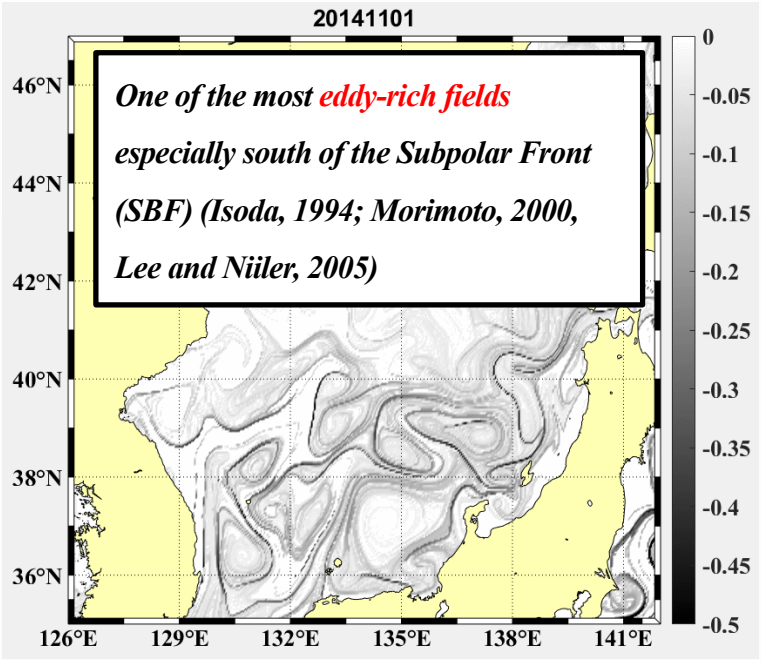
▲ FSLE (Finite Size Lyapunov Exponents) by AVISO at Ulleung Basin

Introduction (2/4)

Mesoscale eddies in the East Sea



▲ EKE distribution in the East Sea (Lee and Niiler, 2005)



- **Variation of mean current and water mass distribution** in the East sea (Mitchell et al.,2005; Lee and Niiler, 2010; Kim et al., 2004; Nam et al., 2016)
- **Refraction of semi-diurnal internal tides** in the eddy interior (Park and Watts, 2005; Nam and Park, 2008)
- **High primary production** at periphery of anticyclonic eddy (Lim et al., 2012)
- **Low nitrate concentrations** in the core of Ulleung Warm Eddy (Rho et al., 2010)

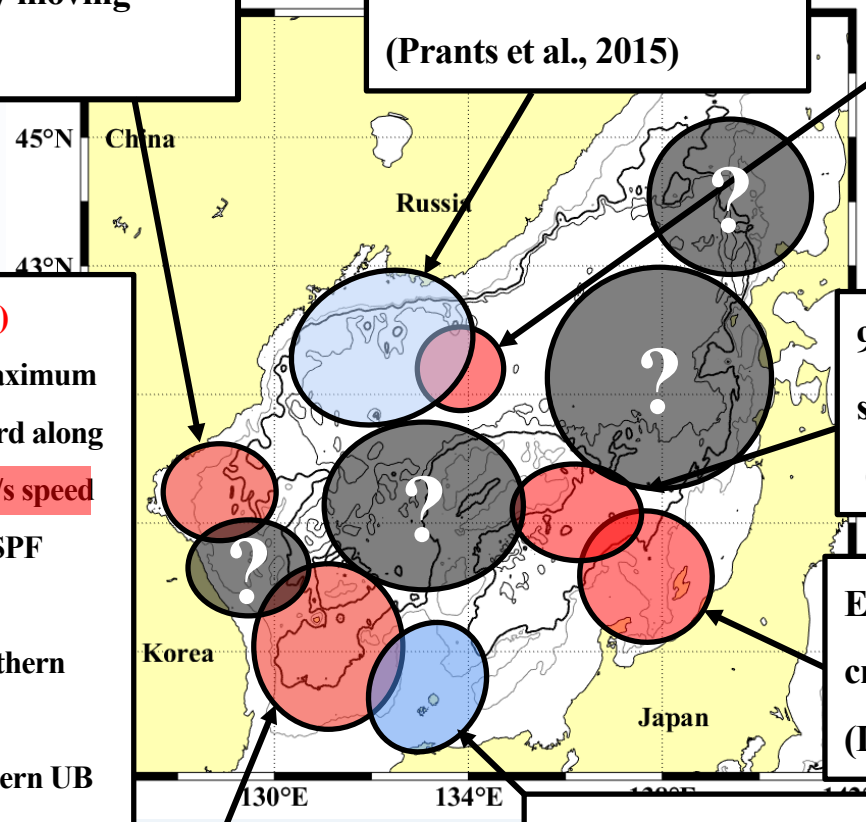
Introduction (3/4)

Previous studies about Eddy characteristics in the East Sea

3-5 months of lifetime, hardly moving (Morimoto et al., 2000)

15-25 km of mean radius (Prants et al., 2015)

35-35 km of mean radius (Takematsu et al., 1999)



- Ulleung Warm Eddies (UWE)
  - ✓ 75-85 km of mean radius, maximum depth to 310 m, northwestward along the Korean coast with 0.8 cm/s speed and northeastward near the SPF (Shin et al., 2005)
  - ✓ Northward movement at northern UB (Morimoto et al., 2000)
  - ✓ Eastward movement at southern UB with 1.8 cm/s speed (Morimoto et al., 2000)
  - ✓ Southeastward movement with 0.14 cm/s speed (Lee and Niiler, 2010)

9 months of life time, southwestward with 1 cm/s speed (Morimoto et al., 2000)

Eastward movement with 0.5-2.0 cm/s speed during about a year (Isoda, 1994)

- Dok Cold Eddies (DCE)
  - ✓ 60 km of mean radius, westward with 6-8 cm/s speed after southwestward @ 1999-2001 (Mitchell et al., 2005)
  - ✓ 99 days of lifetime, hardly moving (Lee and Niiler, 2010)

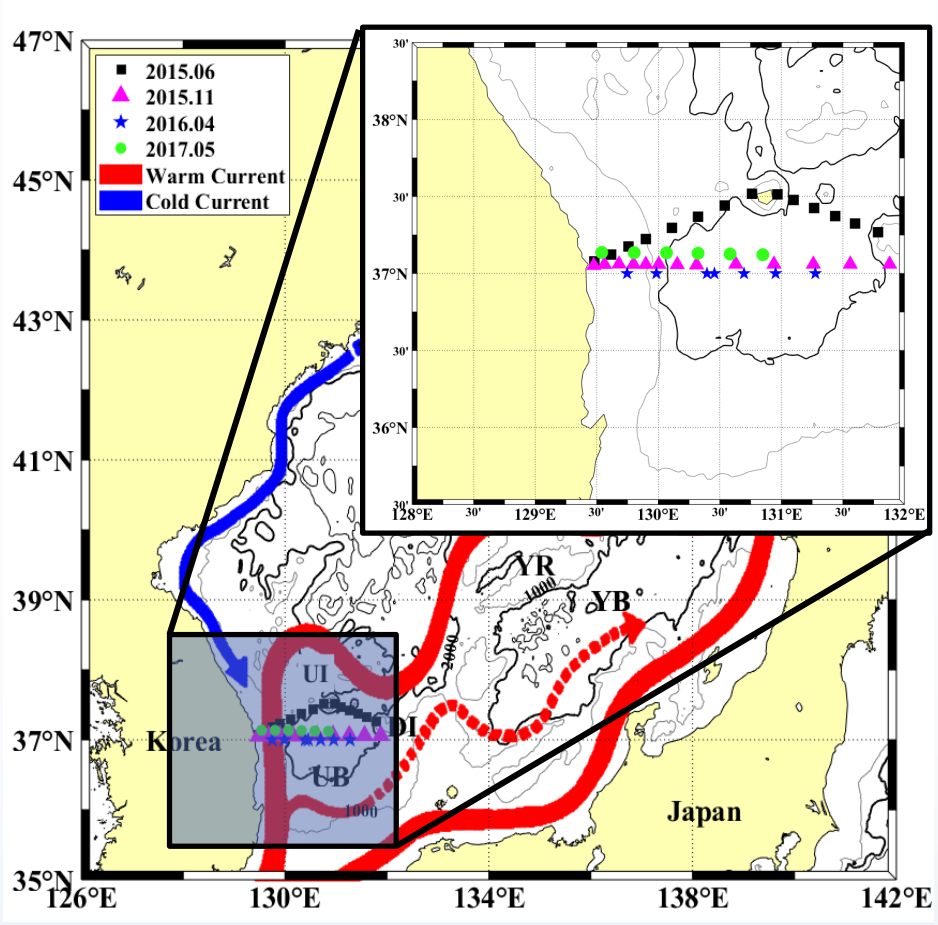
Introduction (4/4)

- **Limitation of previous studies**
  - Inconsistency among characteristics of same eddy groups from different studies
  - Limited to the specific regions or cases
  - No report on the long-term mean characteristics of mesoscale eddies as a whole

Objective

- To quantify the long-term (25 years) characteristics and identify groups of mesoscale eddies in the East Sea

Data



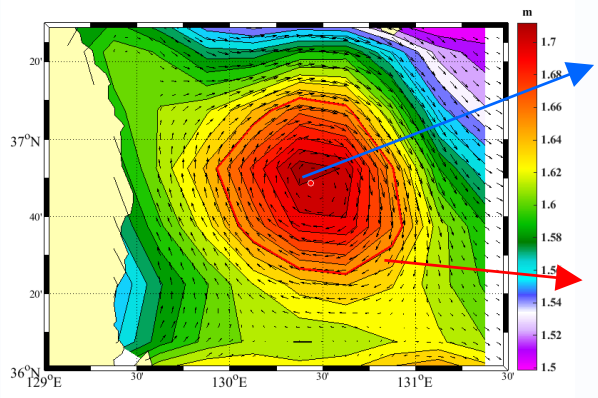
▲ **Schematics on near-surface circulation superimposed with bottom topography in the East Sea (Park et al., 2013). Each markers denote the CTD stations for four cruises.**

Data	Variables	Period	Resolution
Absolute Dynamic Topography (ADT) (CMEMS)	Sea Surface elevation	1993.01.01~ 2017.06.30	0.25 ° × 0.25°, daily
WOA 2001	Salinity, Temperature, Depth	mean	1° × 1° (horizontal), Standard depth in vertical, monthly
Cruise observation	Salinity, Temperature, Pressure	2015. 06	10~25 km (horizontal), 1 m (vertical), 2~4 hours among stations
Cruise observation	〃	2015. 11	〃
Cruise observation	〃	2016. 04	〃
Cruise observation	〃	2017. 05	〃

Methods (1/3)

Detecting

SSH based method (Chelton et al, 2011)

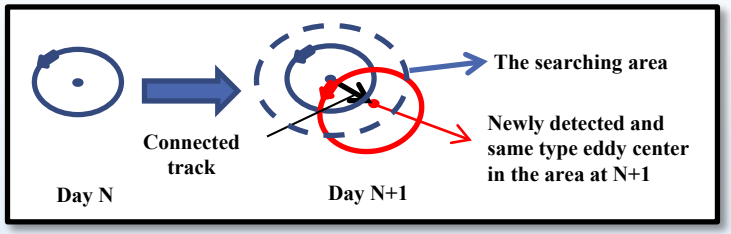


▲ Example for identified eddy (Ulleung Warm Eddy) from SSH contour (1cm interval)

Tracking

- Maximum distances that the eddies can move

  < 43 km

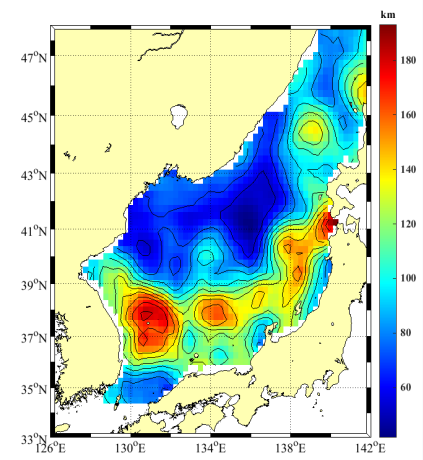


▲ Eddy tracking method

Improvement

1. Maximum size limits : Rhines scale

   (Eden et al, 2007; Theiss, 2006)



▲ Rhines scale at 01/Jan/2014
(5 × 5 grids horizontal smoothed)

2. At least, including 8 grids (minimum eddy size)
3. More than 1cm amplitudes at the eddy center
4. Lasting longer than 35 days

Methods (2/3)

◆Definitions of eddy characteristics

1. Eddy Intensity (EI, $m^2/s^2/km^2$)

- Eddy kinetic energy density inside the eddy

2. Eddy radius (R, km)

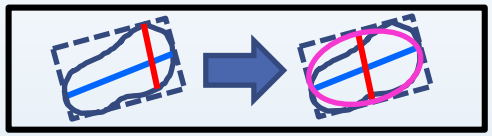
- Radius of the circle that has the same area with the eddy.

3. Eddy amplitude (H, m)

- ADT difference between eddy center and boundary

4. Eddy ellipticity (e)

- $0 < e < 1$



▲ Eddy ellipticity identification

5. Eddy lifetime (L, $days$)

- Days from generation to decay

6. Eddy Kinetic Energy (EKE, $TJ = 10^{12}J$)

- $EKE(J) = \frac{1}{2}\rho_0\sqrt{u'^2 + v'^2}$, Sum of EKE inside the eddy

7. Available Potential Energy (APE, $TJ = 10^{12}J$)

- $APE(J) = \frac{g^2\rho'^2}{2\rho_0 N^2}$, Sum of APE inside the eddy

- Regression equation from 4 cruise observation

$$APE(TJ) = 168 \times Amplitude(cm)$$

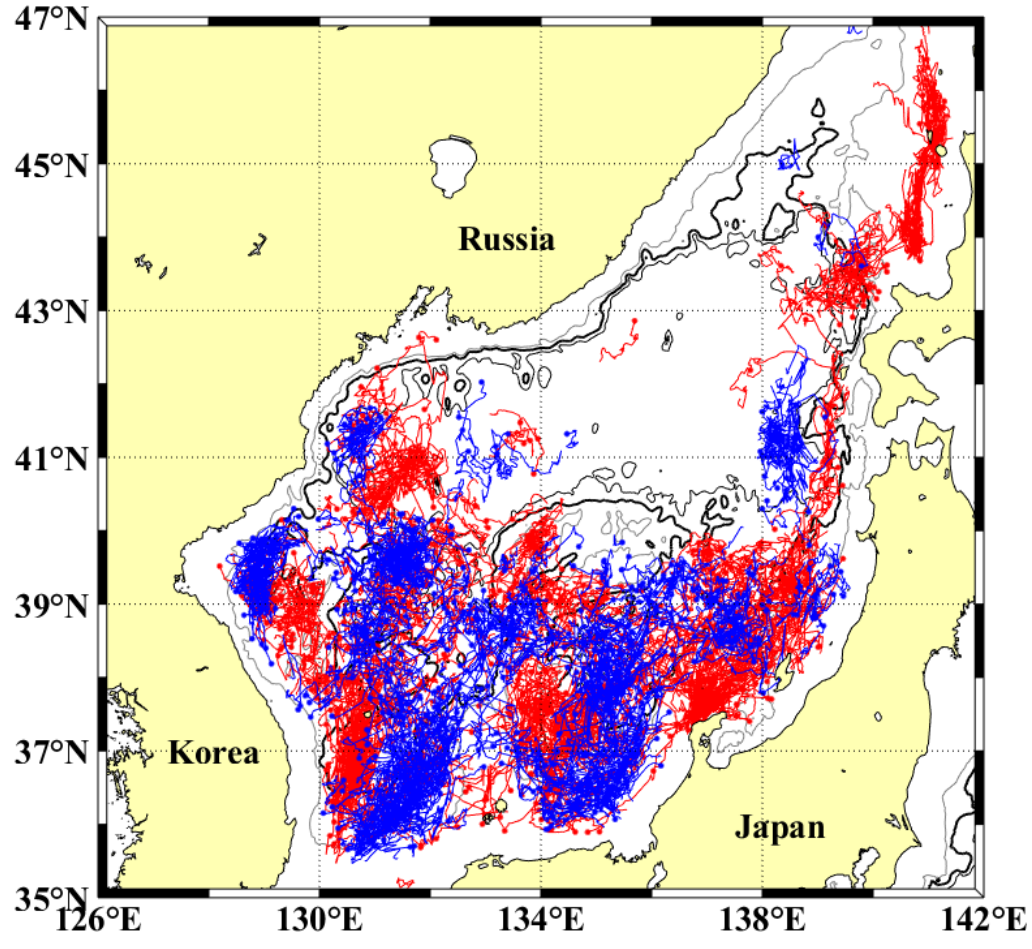
8. Movement direction (d)

- The direction of decaying point relative to the generation point

9. Movement distance (D, km)

- Distance between generation and decaying points

Methods (3/3): group categorization



▲ Total anticyclonic (red) and cyclonic (blue) eddy generation points and tracks in 25 years.

1. Rotation direction
2. Generation locations
3. Activation locations
4. movement directions

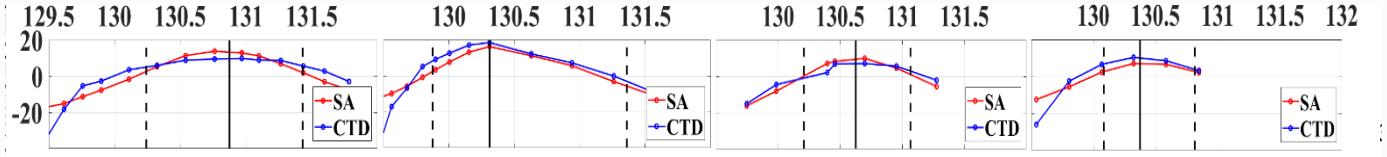
❖ At least, 10 eddy tracks have to be included in each group

Results (1/5)

◆ Comparison between cruise observation and eddy detection results

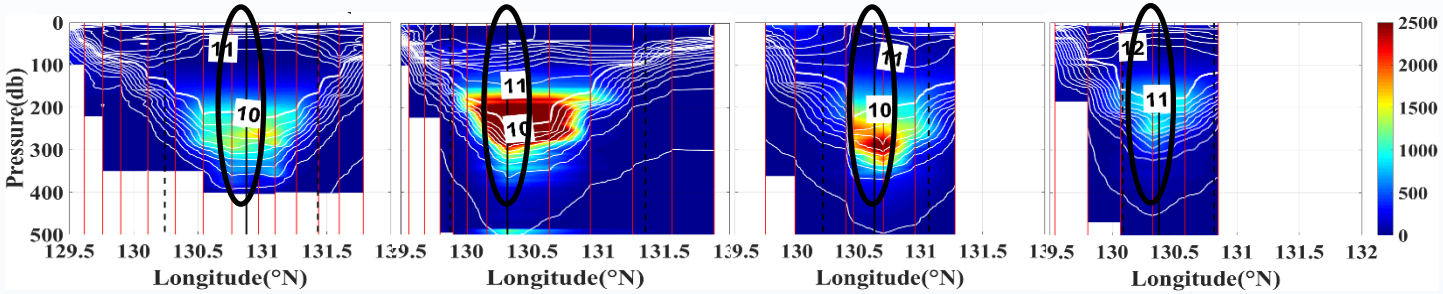
➢ Sea Level Elevation (cm)

Jun. 2015 | Nov. 2015 | Apr. 2016 | May 2017

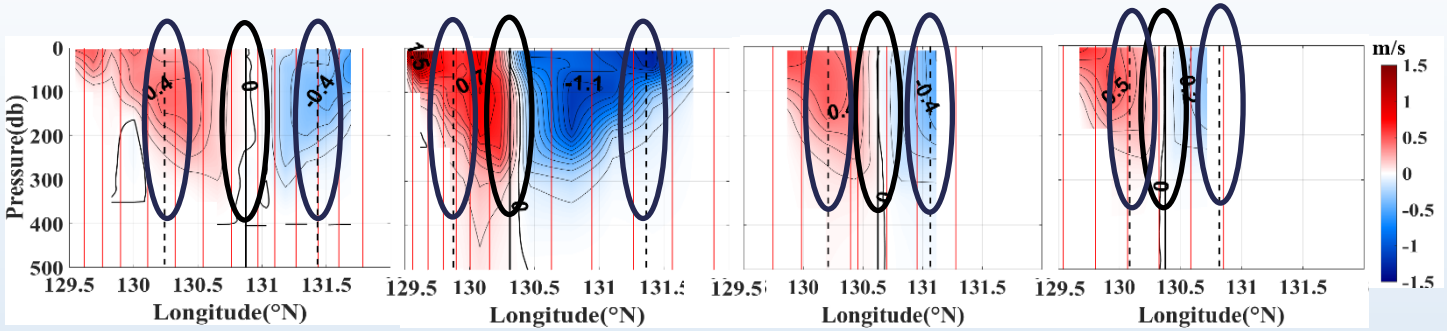


Satellite Altimetry
CTD observation
Eddy Core
Eddy boundary

➢ Temperature (℃) and Available Potential Energy (J/m³)

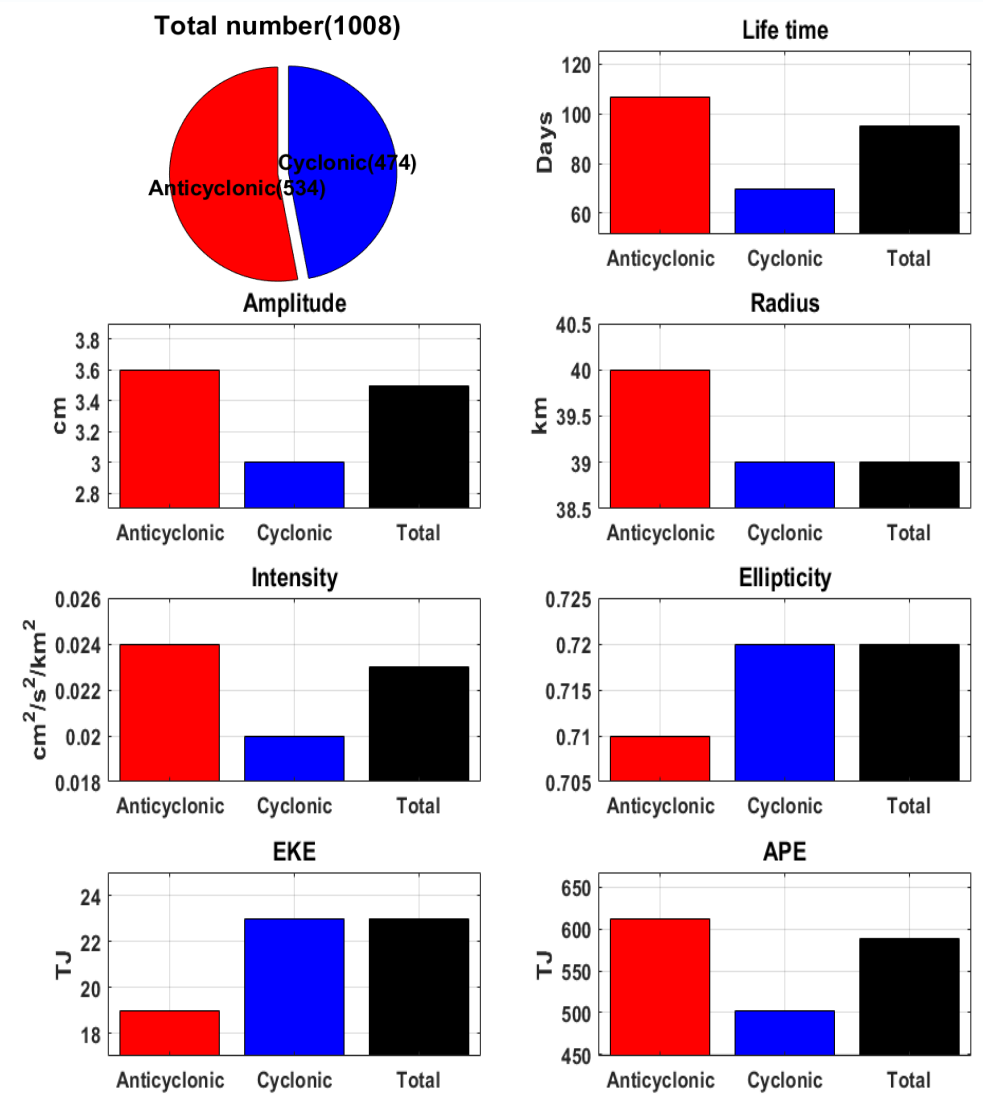


➢ Geostrophic velocity (m/s)

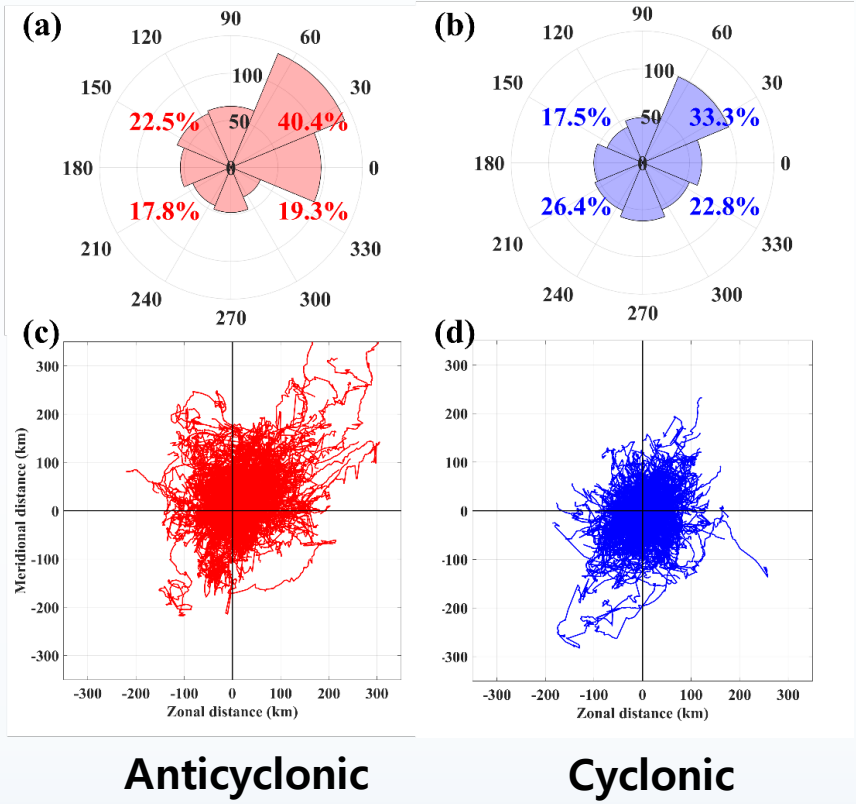


Results (2/5): mean characteristics

❖ Mean eddy characteristics

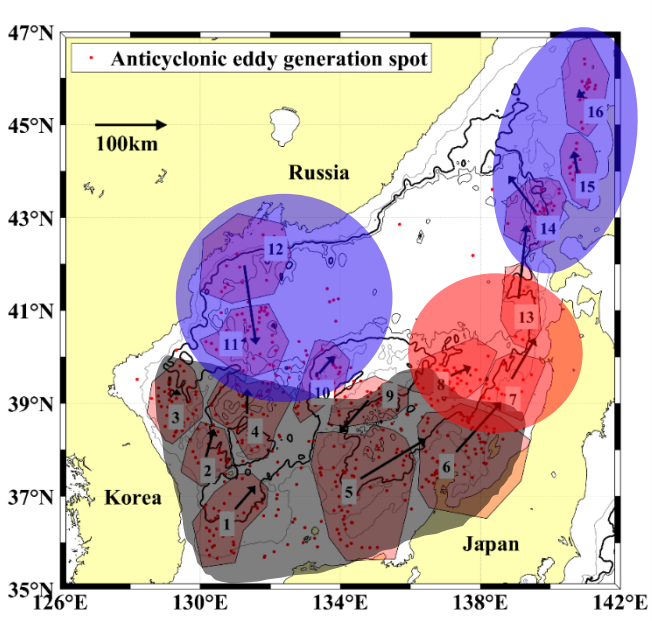


✓ **Movement characteristics**

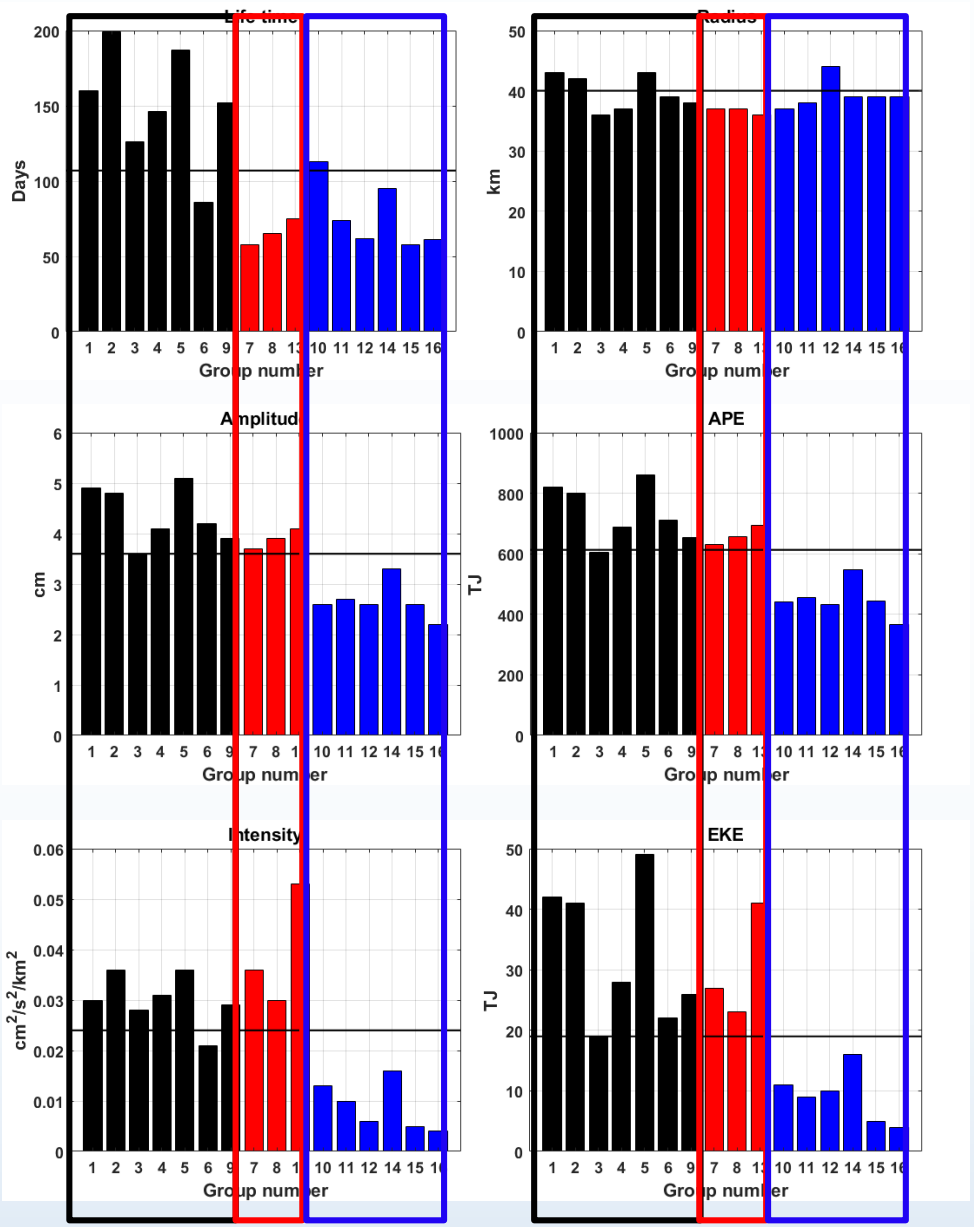


Results (4/5): group characteristics (1)

- **Anticyclonic eddy groups**

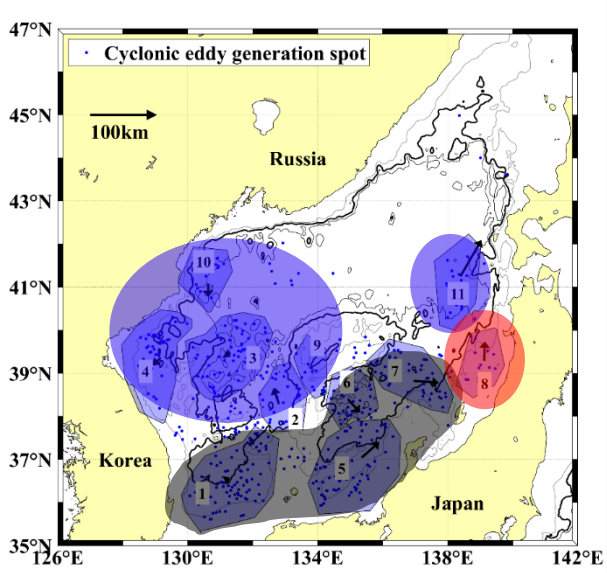


1	Ulleung Warm Eddies	9	Southern Yamato Rise Warm Eddies
2	Northern Ulleung Basin Warm Eddies	10	Western Yamato Rise Warm Eddies
3	Wonsan Warm Eddies	11	Western Japan Basin Warm Eddies
4	Subpolar Frontal Warm Eddies	12	Western Japan Basin Coastal Warm Eddies
5	Oki Warm Eddies	13	Eastern Japan Basin Coastal Warm Eddies
6	Noto Warm Eddies	14	South Hokkaido Warm Eddies
7	Yamato Coastal Warm Eddies	15	Middle Hokkaido Warm Eddies
8	Central Yamato Warm Eddies	16	North Hokkaido Warm Eddies

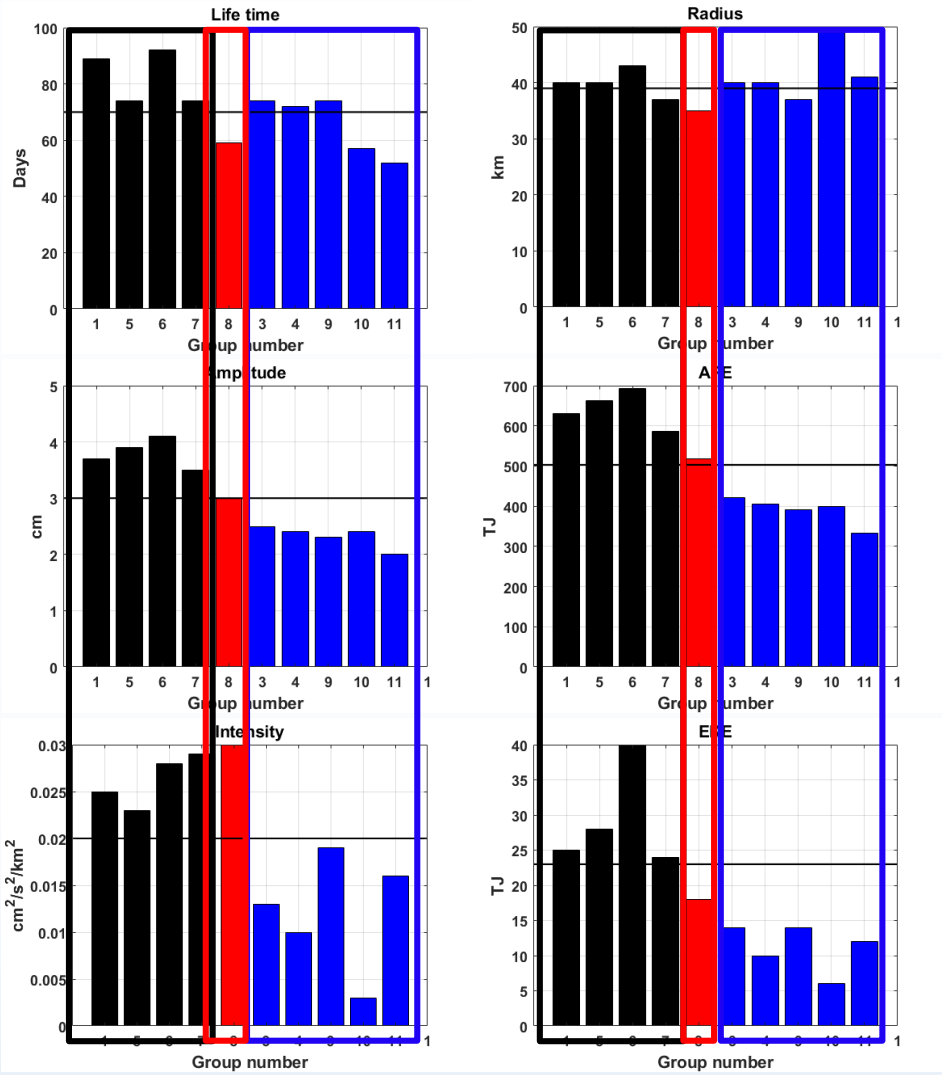


Results (5/5): group characteristics (2)

- **Cyclonic eddy groups**



1	Dok Cold Eddies	7	Central Yamato Basin Cold Eddies
2	Southern Subpolar Frontal Cold Eddies	8	Eastern Yamato Basin Coastal Cold Eddies
3	Northern Subpolar Frontal Cold Eddies	9	Western Yamato Rise Cold Eddies
4	Wonsan Cold Eddies	10	Western Japan Basin Cold Eddies
5	Southern Yamato Basin Cold Eddies	11	Eastern Japan Basin Cold Eddies
6	Southern Yamato Rise Cold Eddies		

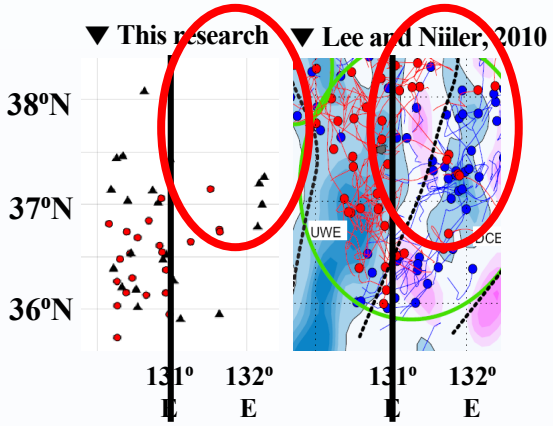


Discussions (1/3)

1. Comparison with previous studies (movement characteristics)

➢ Ulleung Warm Eddy group

	This research	Shin et al., 2005	Lee and Niiler, 2010
Speed	*0.9 cm/s*	*0.8 cm/s*	*0.14 cm/s*
Direction	*NE*	*NW→NE*	*SE*



➢ Dok Cold Eddy group

	This research	Mitchell et al., 2005
Direction	*NE (SW→NE)*	*SW(1999.06- 11) →W(1999.11-12)*

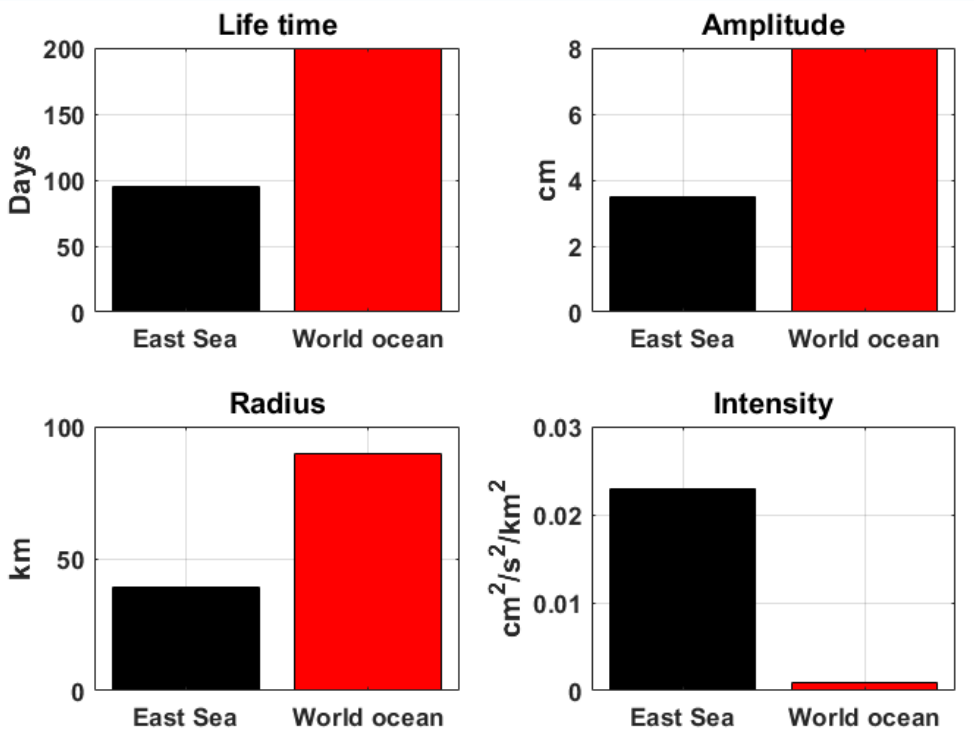
This research	Mitchell et al., 2005
1993. 01 ~ 2017. 06	*1999.06 ~ 1999.12*

➢ Oki warm eddies group

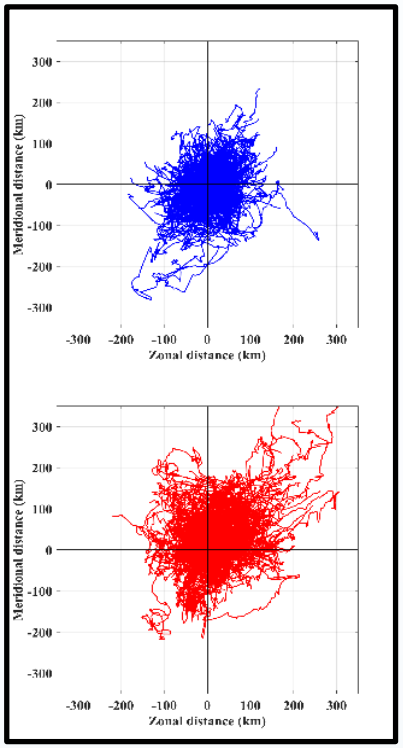
	This research	Isoda (1994)
Speed	*0.6-2.2 cm/s*	*0.5-2.0 cm/s*
Direction	*NE*	*E*

Discussions (2/3)

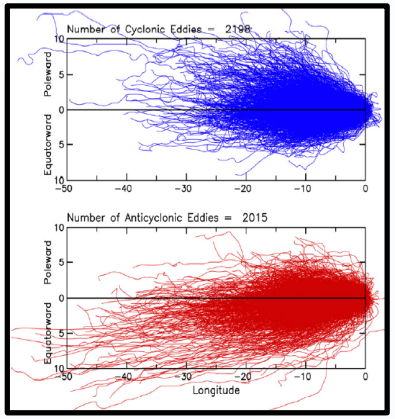
2. Comparison with global ocean mean



Movement characteristics



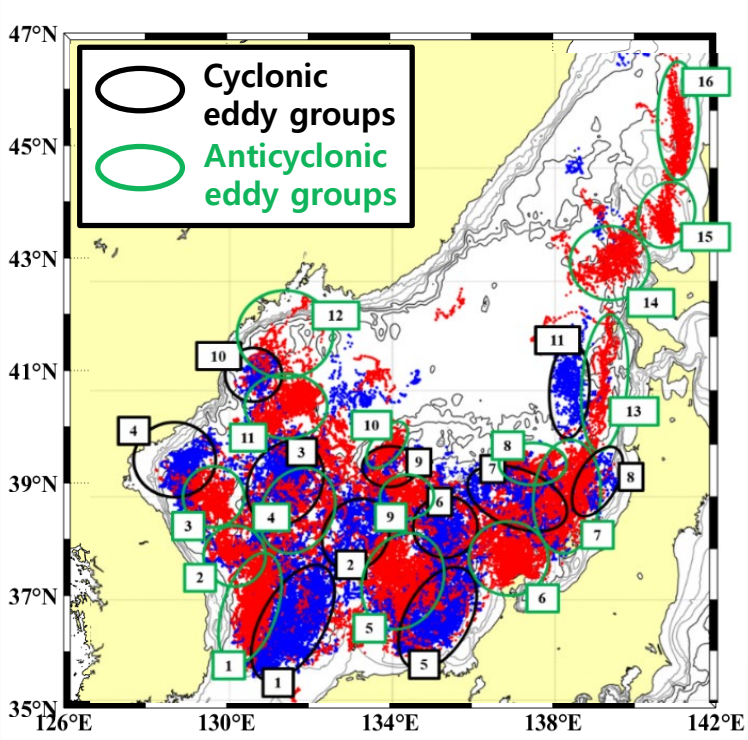
East Sea



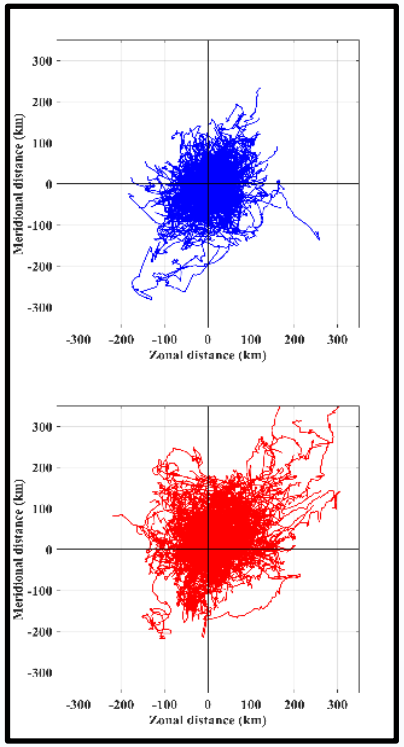
World ocean (Chelton et al, 2011)

- Mesoscale eddies in the East Sea : shorter life time, lower amplitude, smaller radius, and stronger intensity than world ocean cases
- Movement characteristics of mesoscale eddies in the East Sea are quite different for that in world ocean.

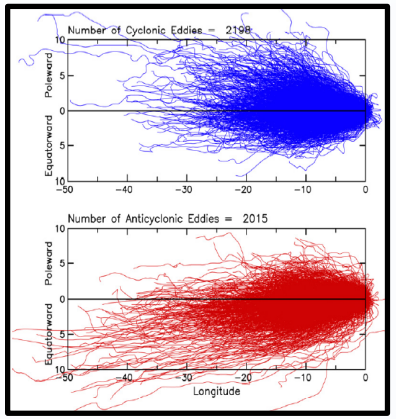
Summary and Future works



East Sea



World ocean



- Why are the properties of eddy groups at southern part of the East Sea higher than the other groups?
- Why are their movement patterns different with global ocean mean?
- How do these eddy characteristics affect to transport biochemical tracers or energetics in the East Sea?

Thank you