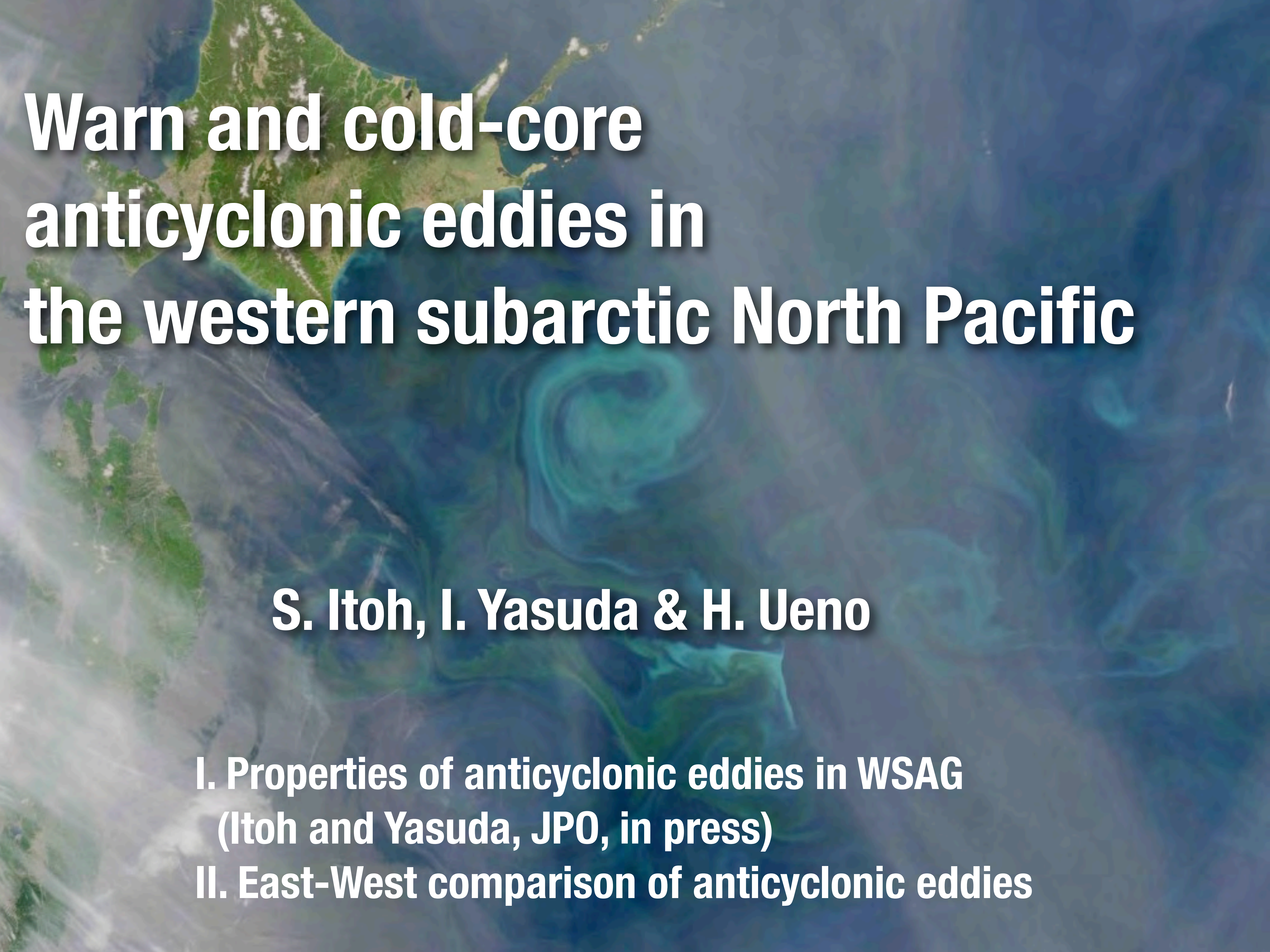
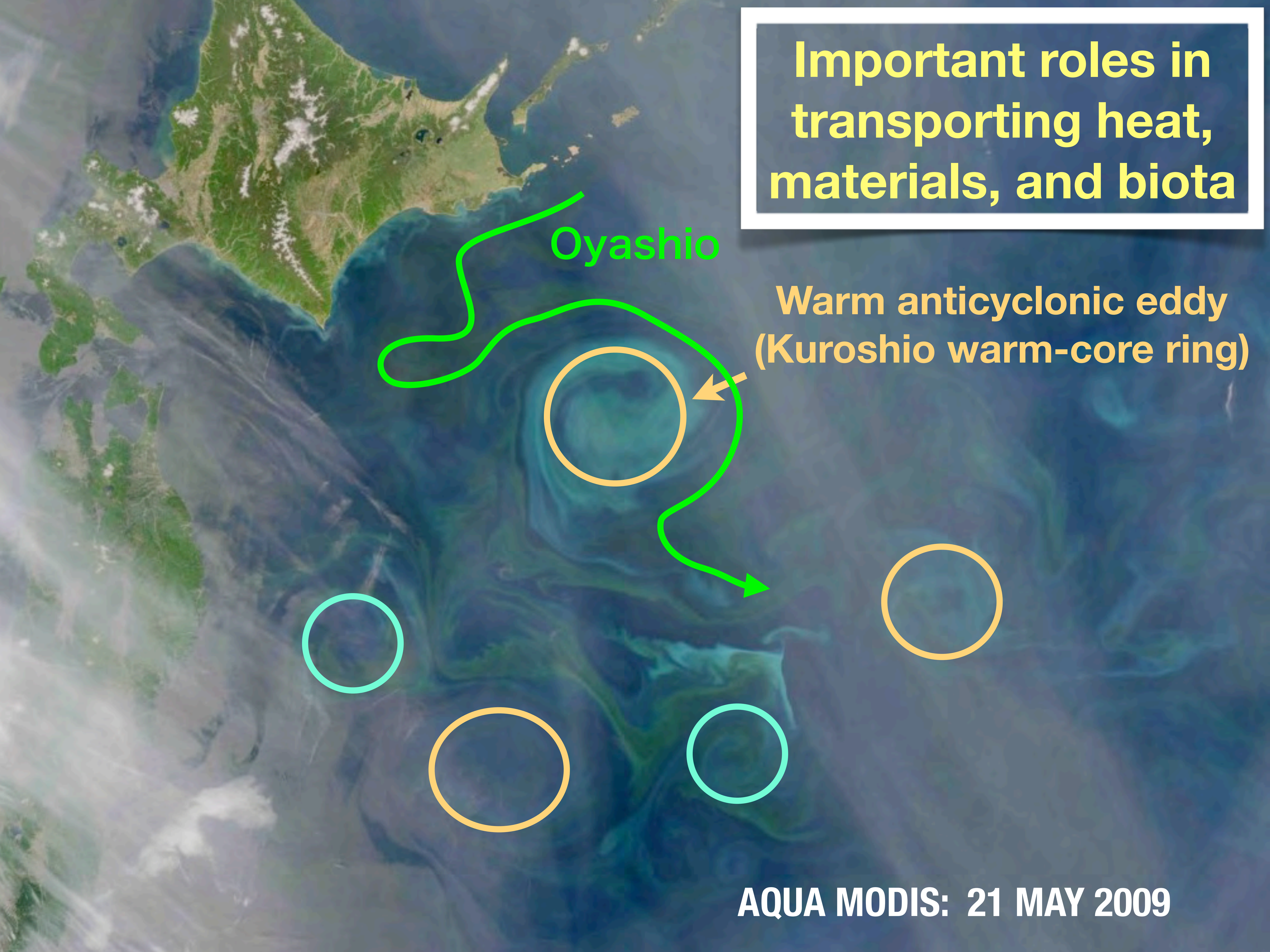


Warn and cold-core anticyclonic eddies in the western subarctic North Pacific

S. Itoh, I. Yasuda & H. Ueno

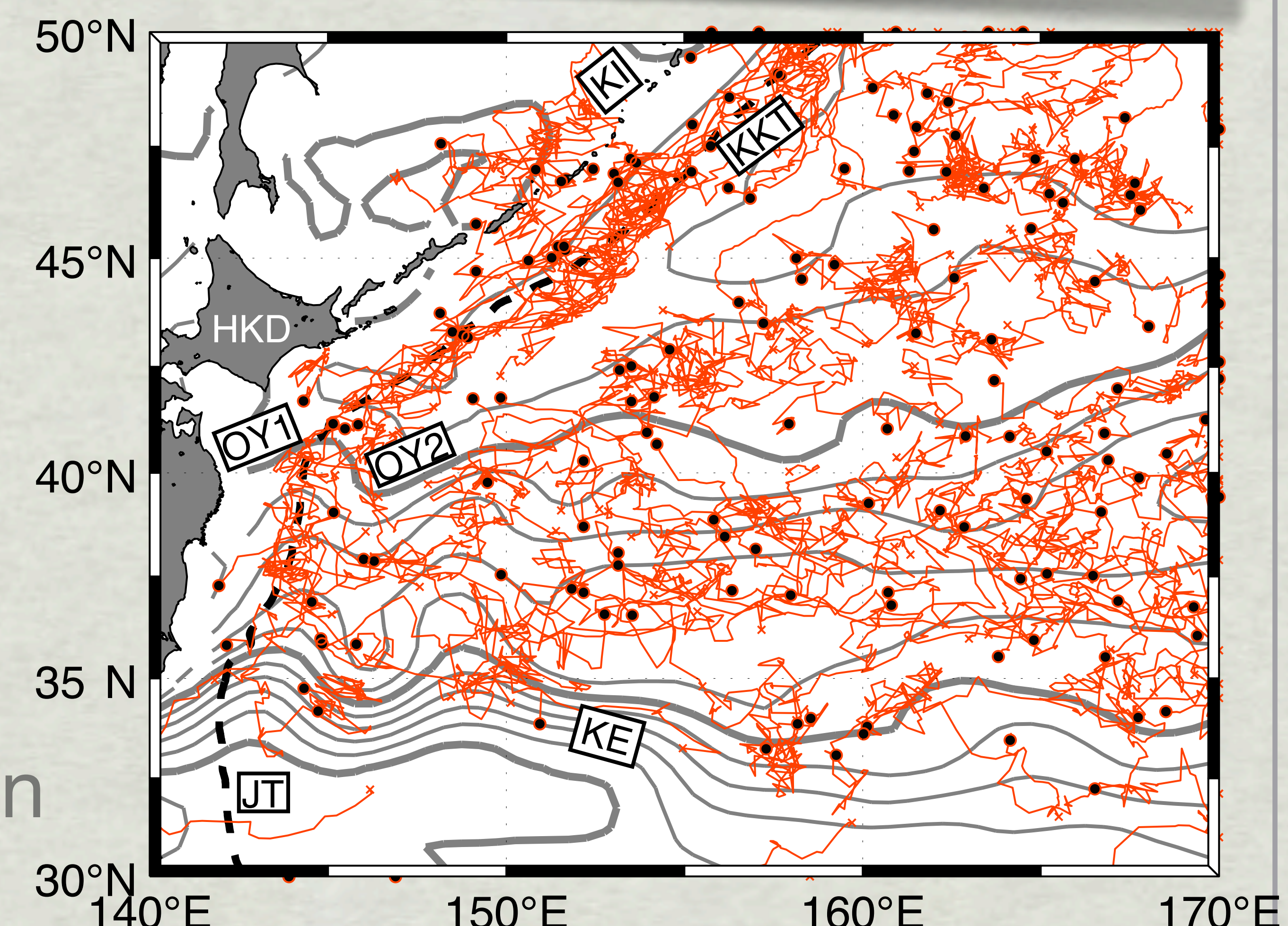
I. Properties of anticyclonic eddies in WSAG
(Itoh and Yasuda, JPO, in press)
II. East-West comparison of anticyclonic eddies


Important roles in transporting heat, materials, and biota
Oyashio
Warm anticyclonic eddy
(Kuroshio warm-core ring)
AQUA MODIS: 21 MAY 2009

Anticyclonic eddies (AEs) in the Kuroshio-Oyashio Extension region

Itoh & Yasuda (2010 JPOa):
Quantified eddy characteristics using altimetric data

- **Anticyclonic eddies (AEs)**
  - Propagate northward along the J & KK trenches
- **Problem**
  - Warm- and cold AEs (e.g. Yasuda et al. 2000) were not distinguished
  - Vertical structure information is needed to examine their roles in transporting heat & materials



Trajectories of AEs
(Itoh & Yasuda 2010)

Objective (On AEs in WSAG:)

- To clarify water mass structure of anticyclonic eddies in the western subarctic North Pacific
  - Distributions of warm and cold AEs
  - Temperature/Salinity properties

Analyses using altimeter and profile data

ERS
JASON
T/P
ETC.

ARGO

JMA R/V

HAKUHO-MARU

Jason and Argo

1963 Film by Harryhausen

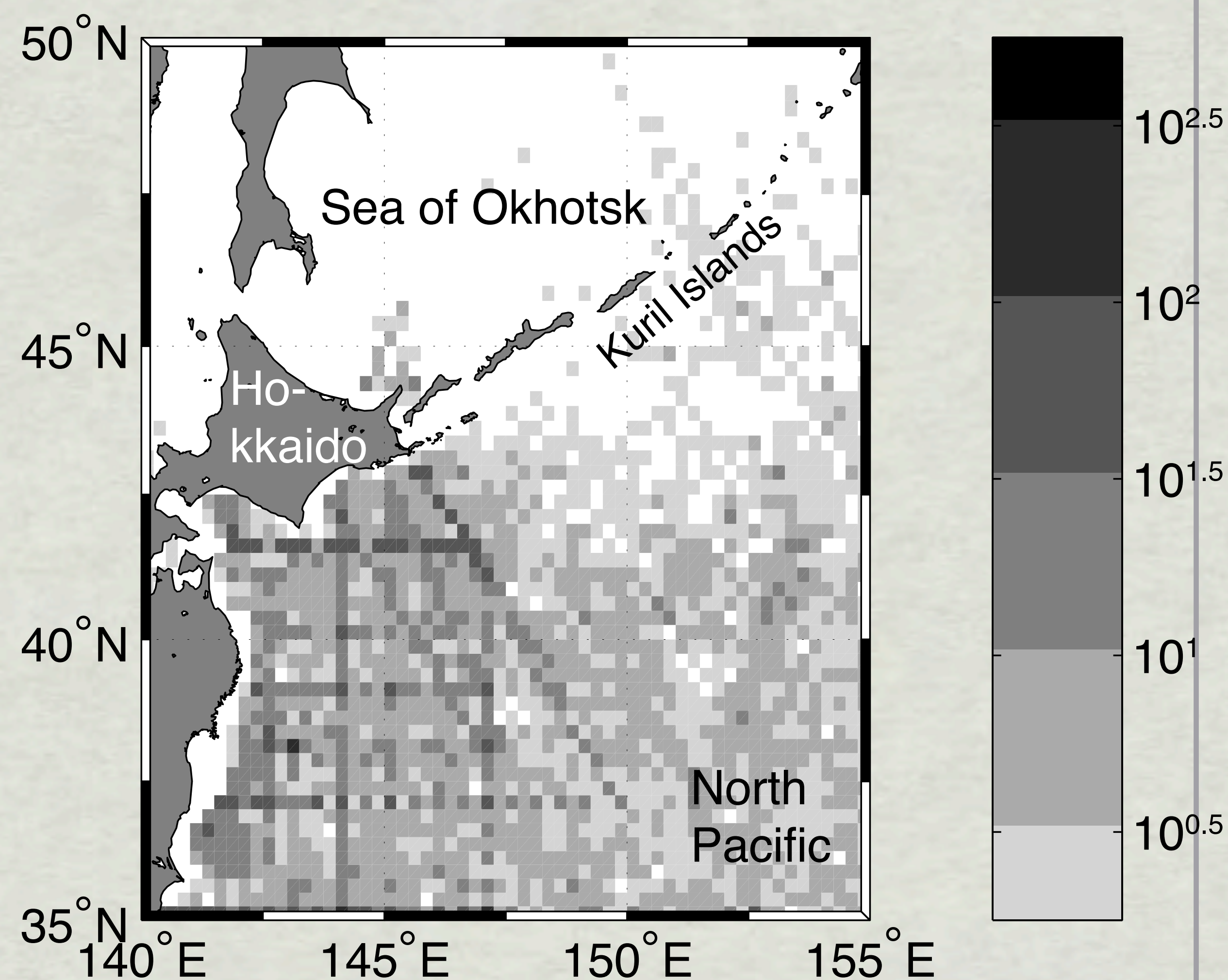
Jason and Argonauts
on their ship Argo

Present Study: another adventure

Jason, T/P, ERS, etc., with
in situ observations,
WOD05, and Argo

Data and Methods

- **Data**
  - SSH anomaly: AVISO
  - Profile data: Argo, WOD05, & observations by ourselves
- **Methods**
  - AEs are detected from SSHA
  - Profile data near the detected center of AEs are retrieved
  - Anomalous water properties from climatology (WOA01) are estimated

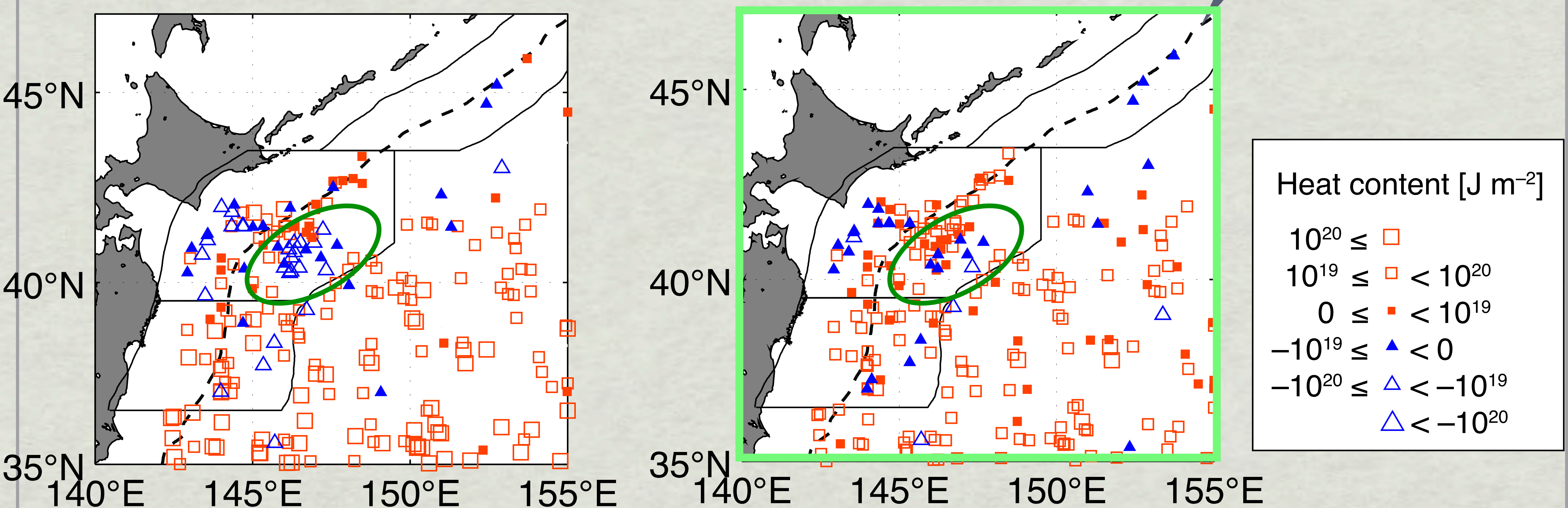


Data density of profile data

Distribution

Warm eddies occupies 85%

50–800 db Heat C. **50–200 db Heat C.**



Positive anomaly (warm eddies)

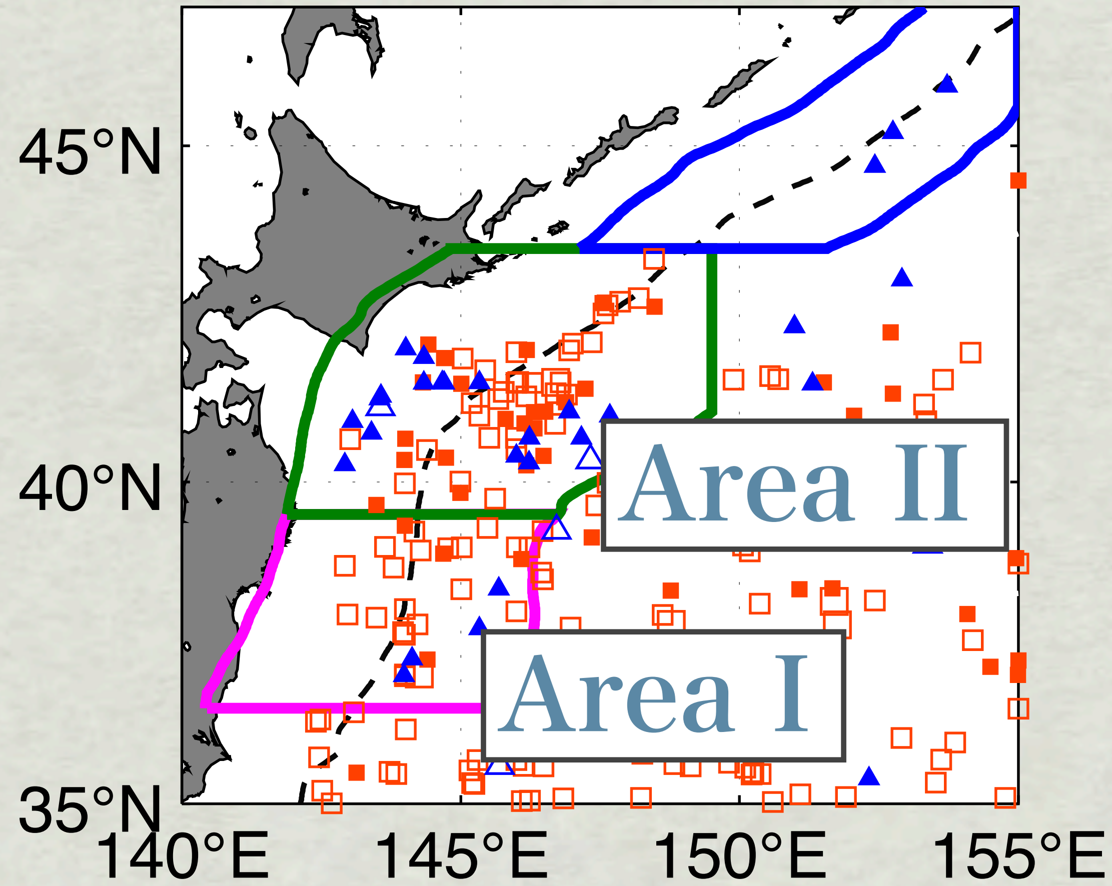
Negative anomaly (cold eddies)

Distribution of warm and cold AEs based on heat content anomalies

Classification

- Area

Area I	Between Kuroshio and Oyashio
Area II	Oyashio area

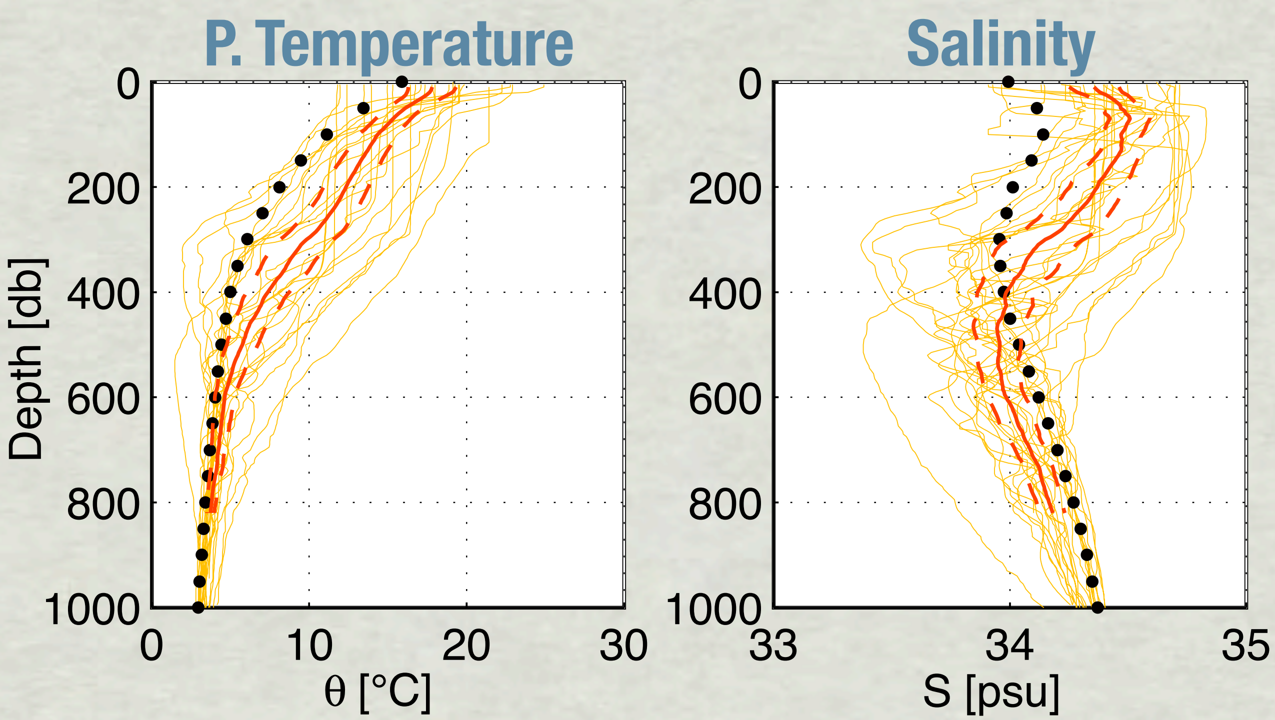


Area classification

- Groups of anticyclonic eddies

Group I	Warm eddies in Area I
Group IIw	Warm eddies in Area II
Group IIc	Cold eddies in Area II

Group I (Area between K & O)



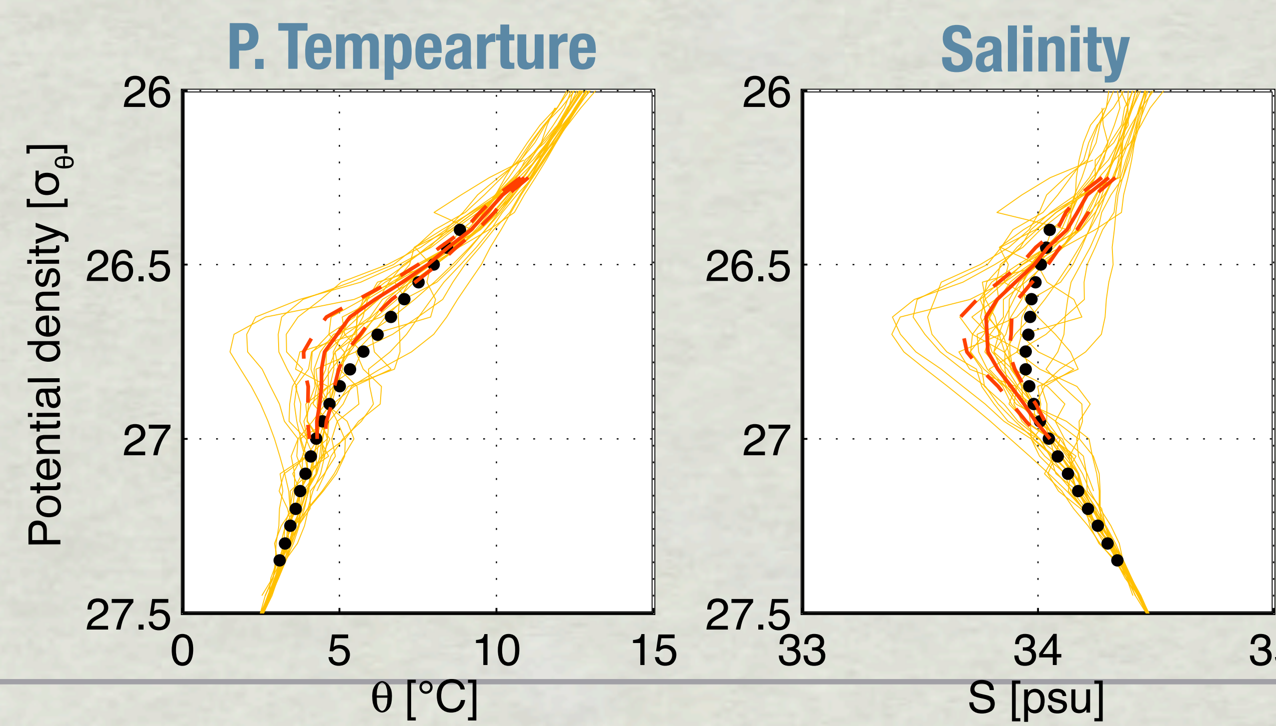
Vertical profiles (vs pressure)

- Warm & Saline anomalies above 400 m (reflecting Kuroshio properties)
- Fresh anomalies below 400 m

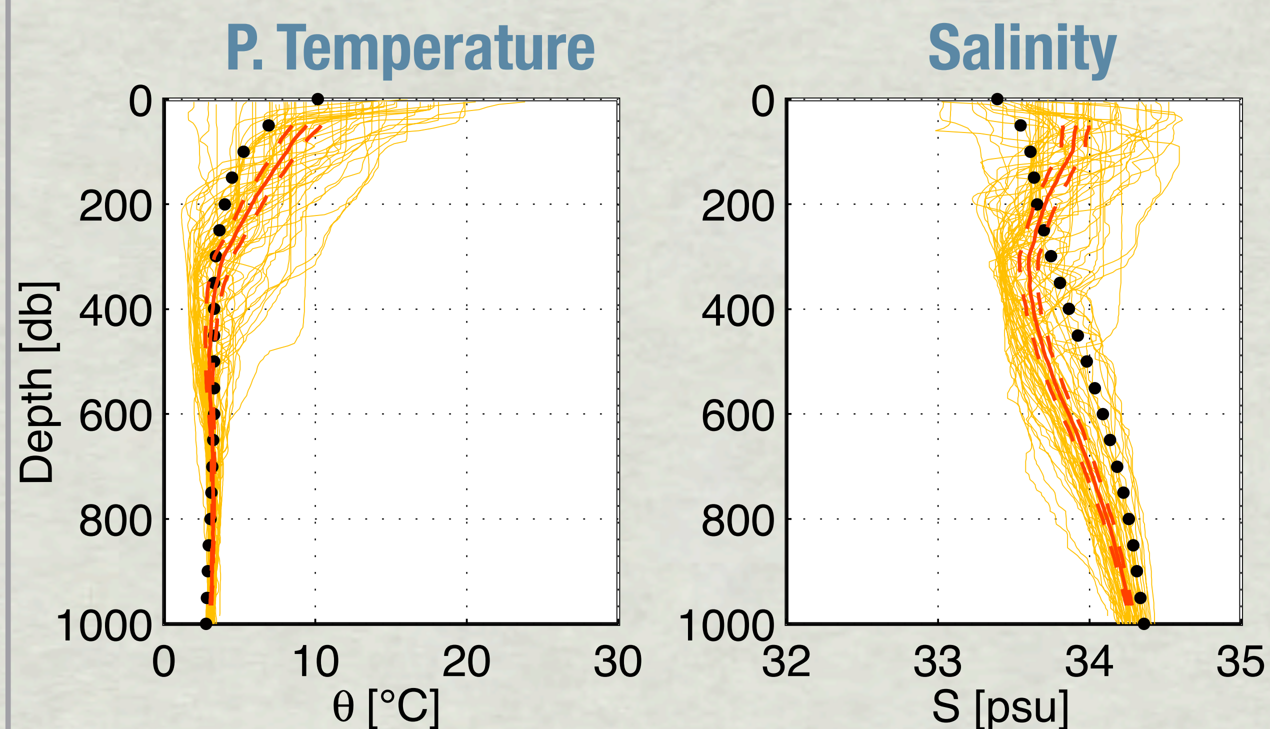
Measurements	Mean	S. E.	Climatology

- Cold and fresh anomalies around 26.6–26.8 σ_θ

Vertical profiles (vs σ_θ) (below the upper core)



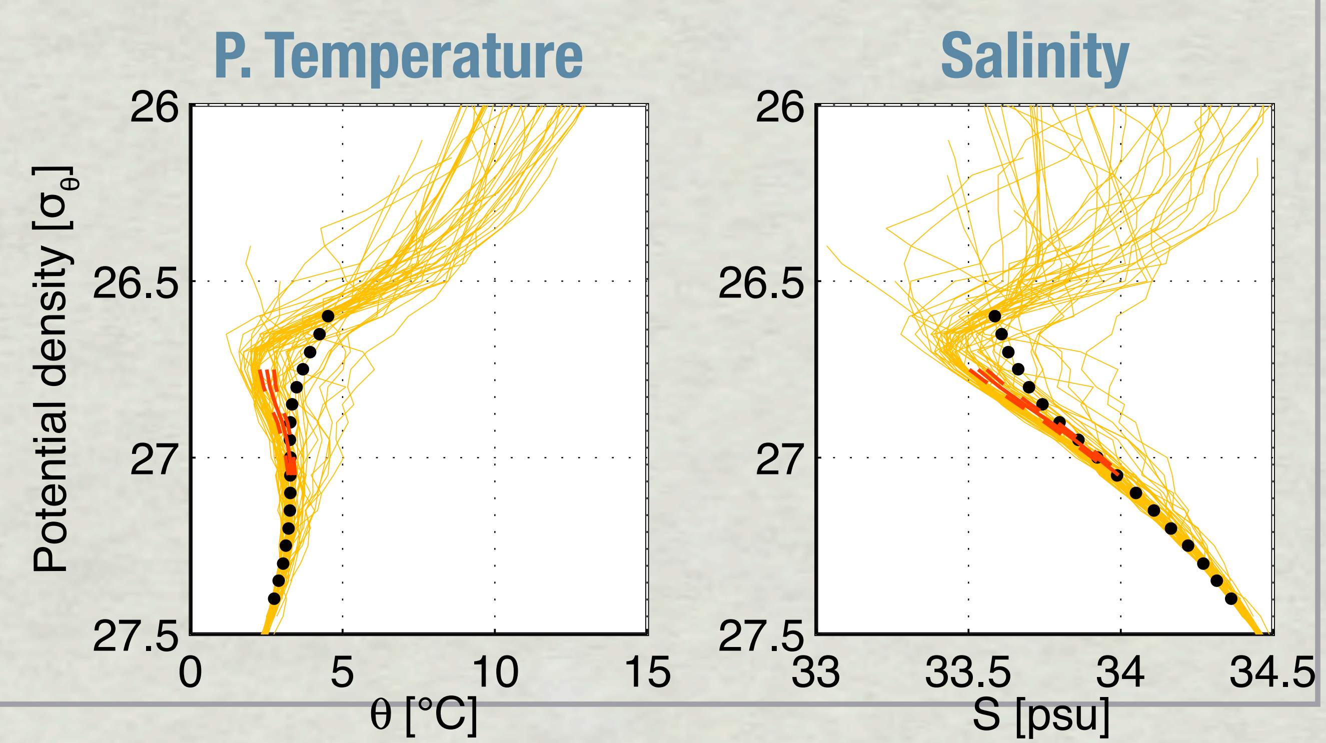
Group IIw (Warm eddies in Oyashio area)



Vertical profiles (vs pressure)

- Warm & Saline anomalies above 200 m
- Fresh anomalies below 200 m

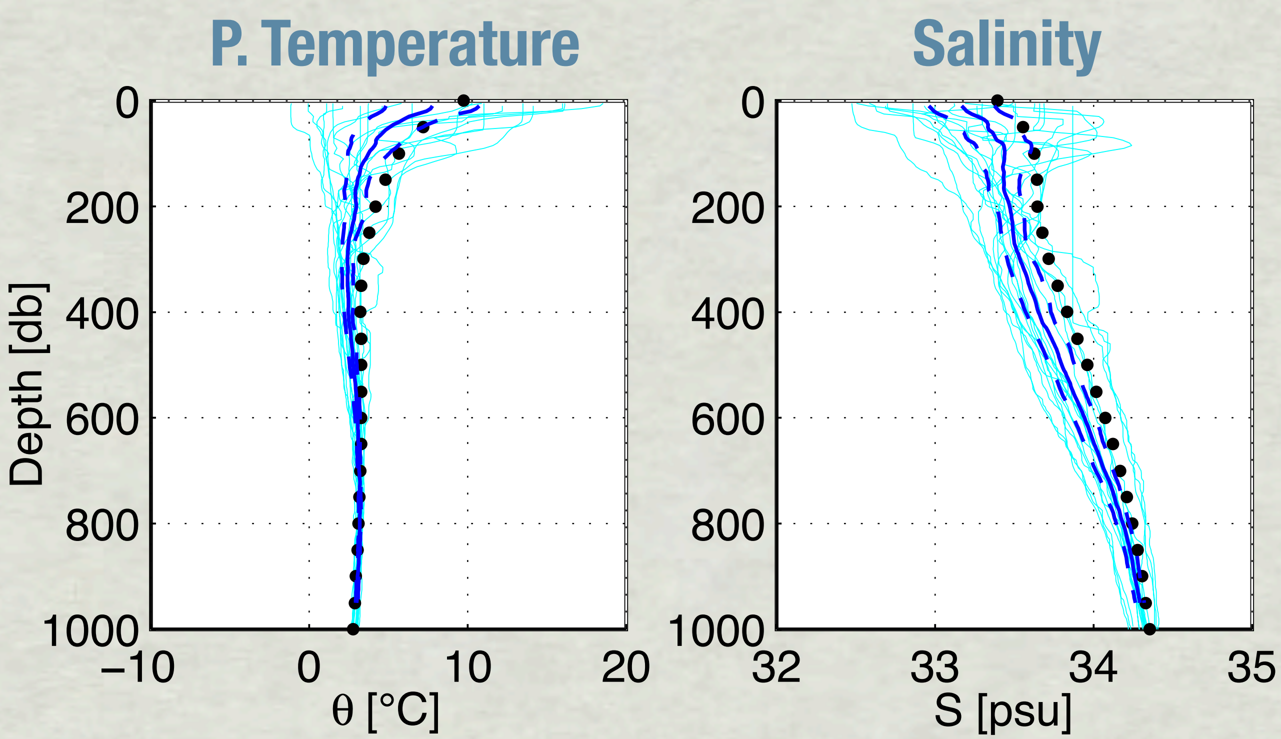
Measurements	Mean	S. E.	Climatology



- Cold and fresh anomalies around 26.6–26.8 σ_θ

Vertical profiles (vs σ_θ)

Group IIc (Cold eddies in Oyashio area)



Vertical profiles (vs pressure)

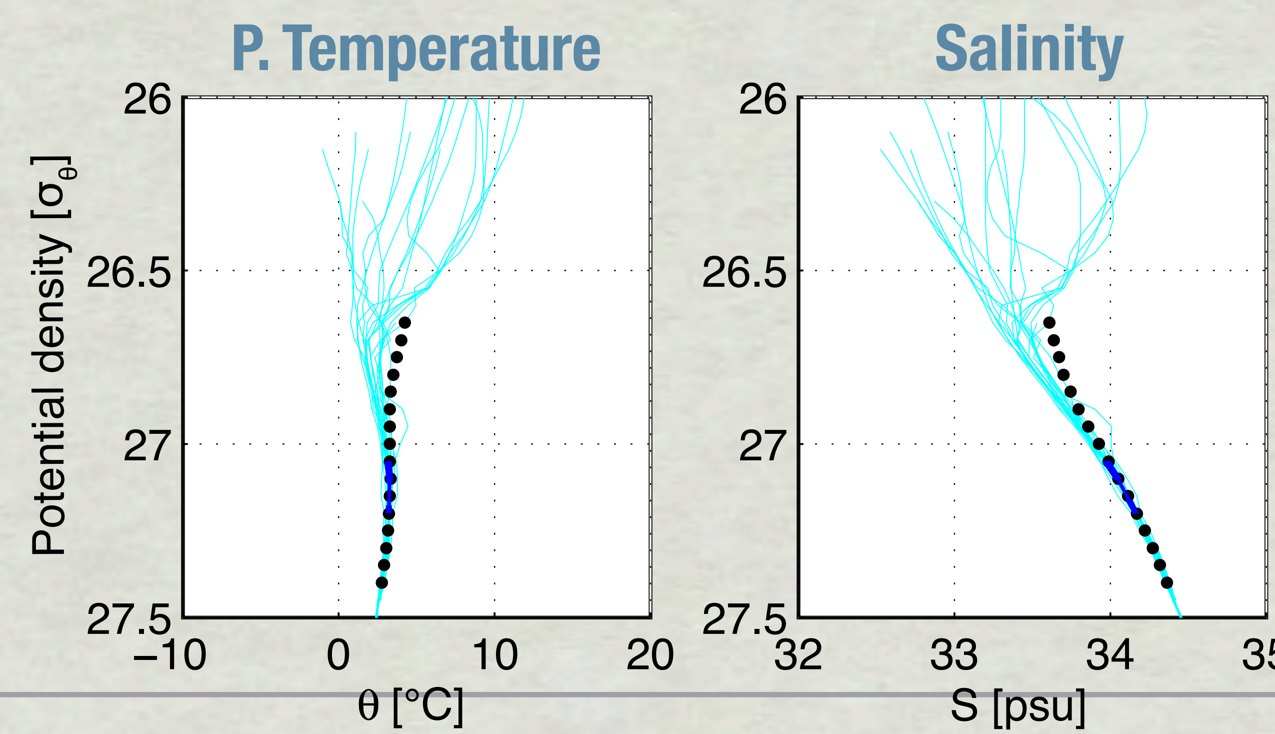
- Cold above 400 m
- Fresh anomalies from surface to 1000 m

Measurements	Mean	S. E.	Climatology

- Cold and fresh anomalies around 26.6–26.8 σ_θ

Similar to Okhotsk water

Vertical profiles (vs σ_θ)

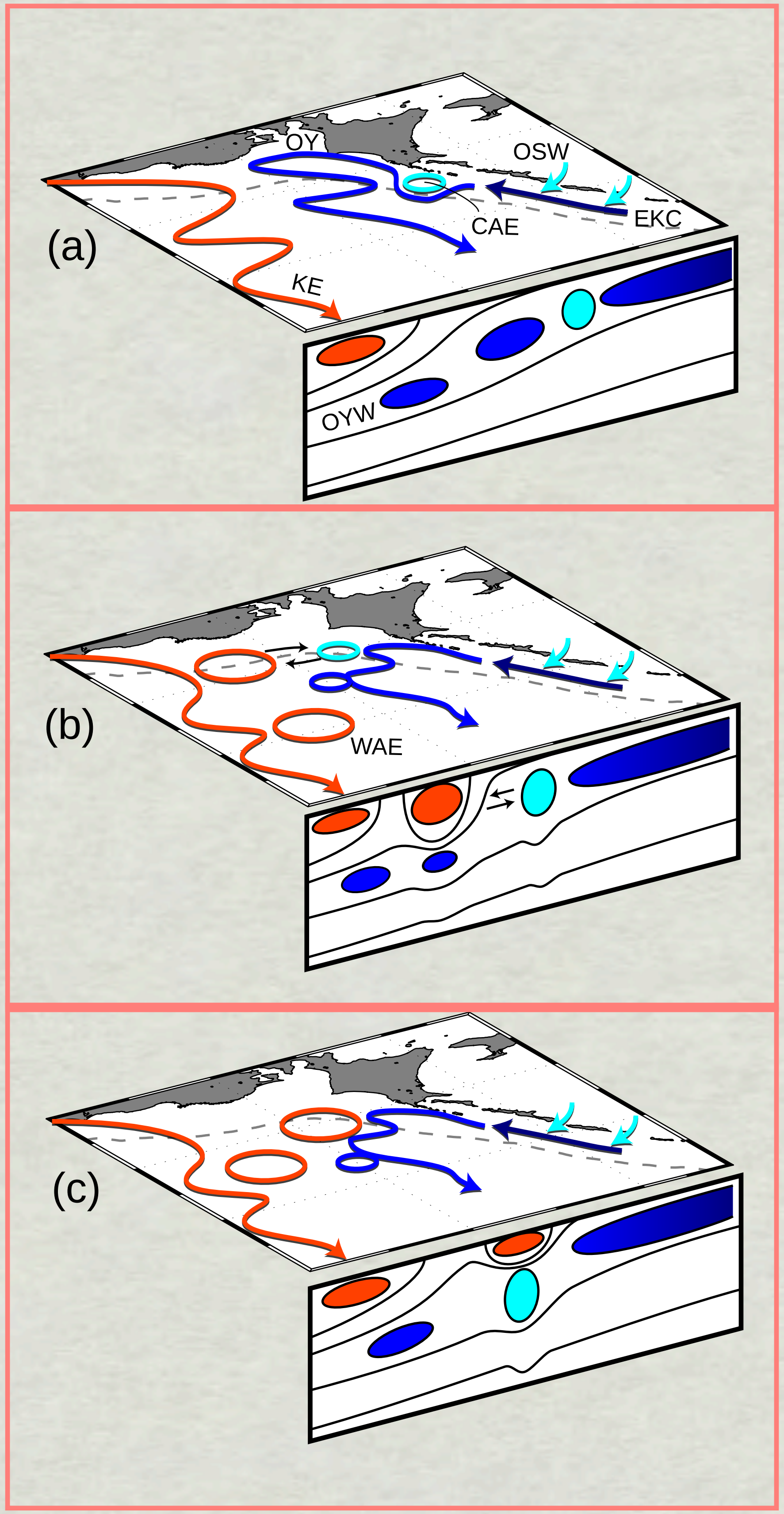


Evolution & interaction of warm & cold anticyclones

(a) Warm eddies from KE in the south, with moderately cold Oyashio water below, and cold eddies from Okhotsk in the north

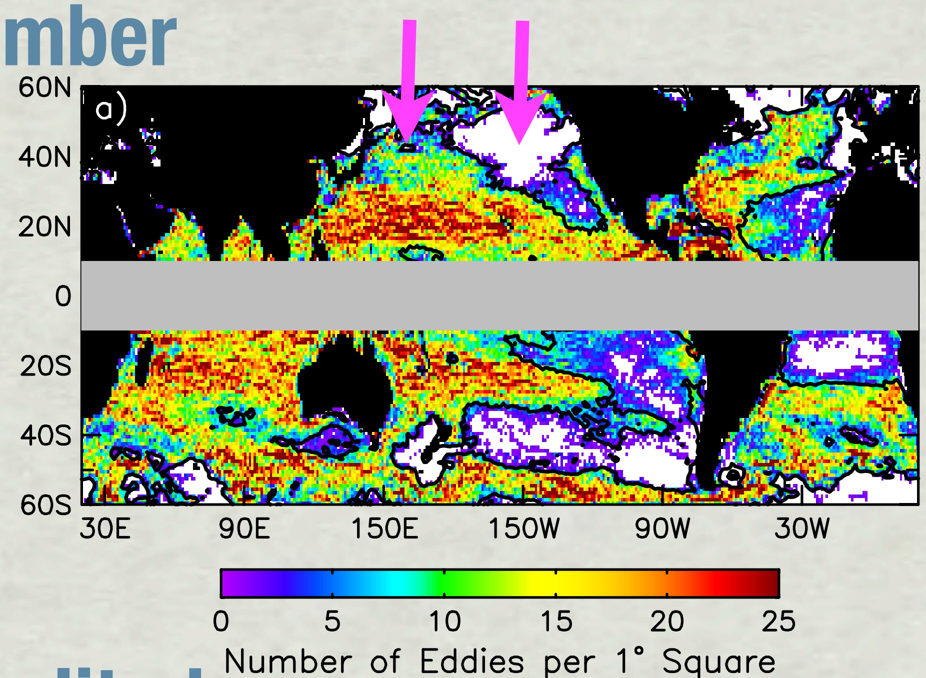
(b) A warm eddy propagates northward to interact with a cold eddy

(c) The two eddies are coupled: the process called "Alignment" (Polvani, 1991)

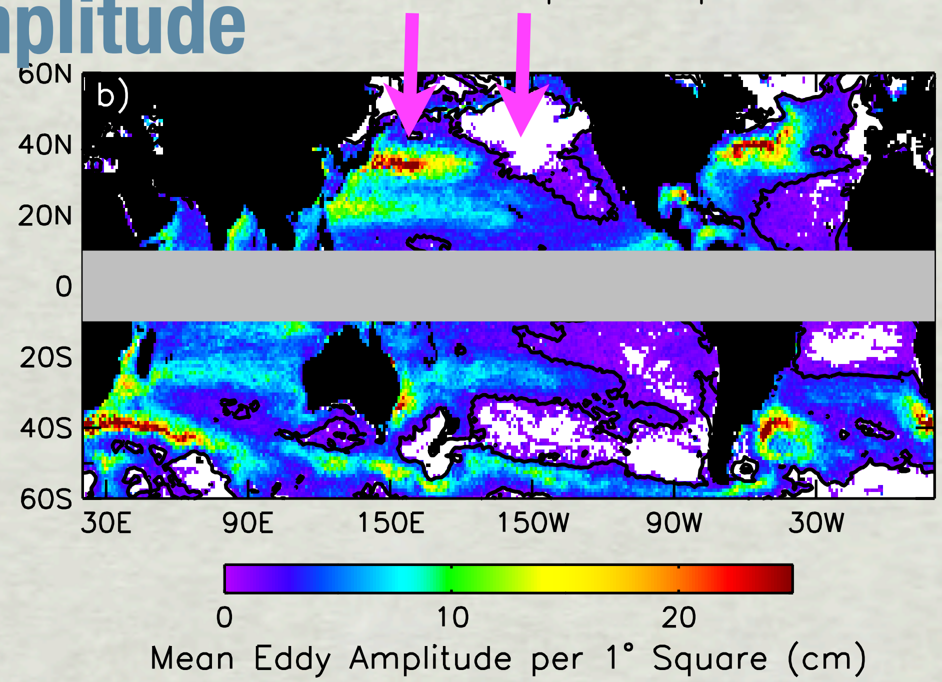


East-West comparison

Number



Amplitude



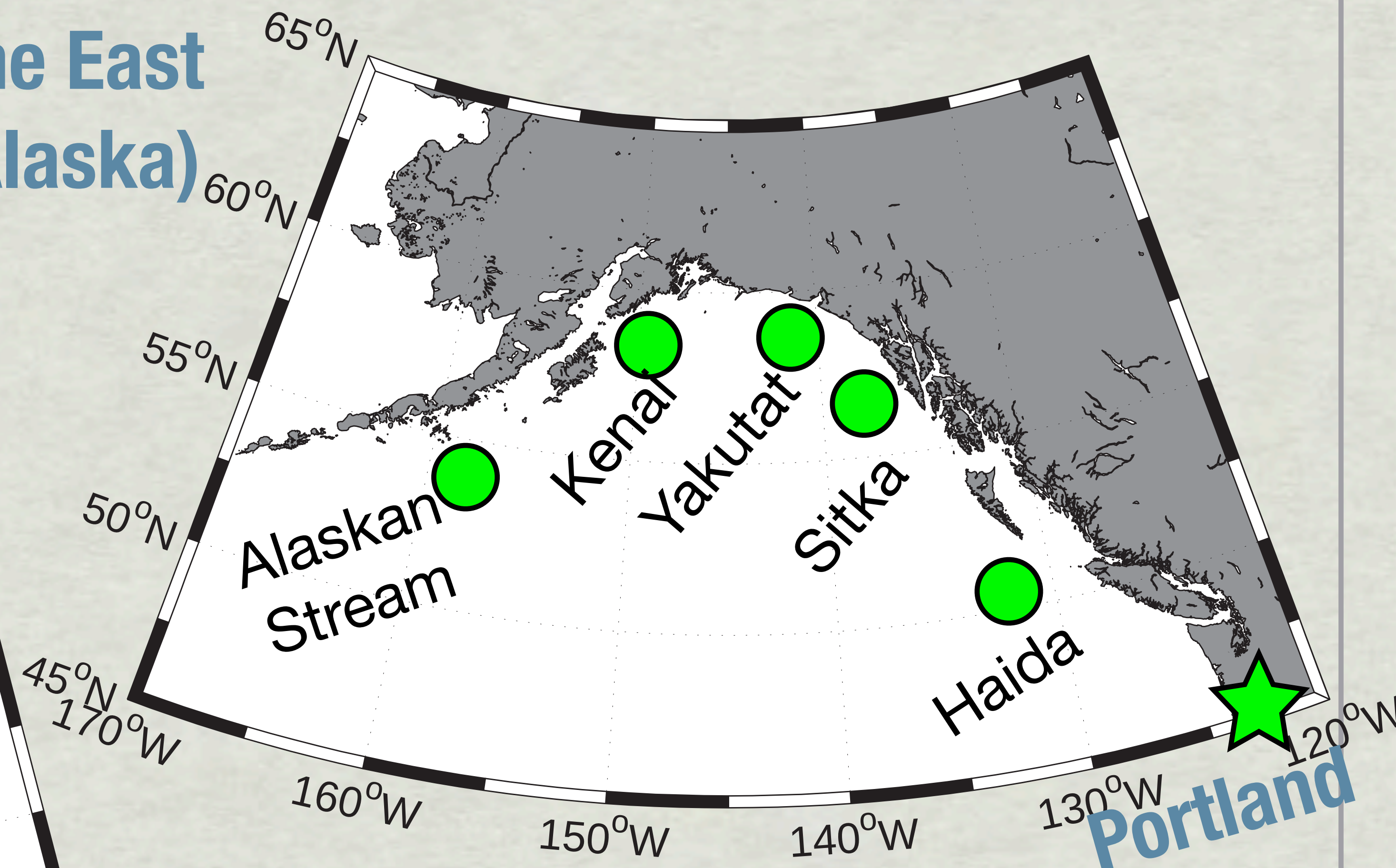
Looking into subarctic gyres of the North Pacific,

- Eddies are far richer and stronger in the west than in the east (despite the underestimation in the west; Itoh & Yasuda, 2010a)
- Eddies are detected along the coast in the east

From Chelton et al. (2007) (both cyclones and Anticyclones)

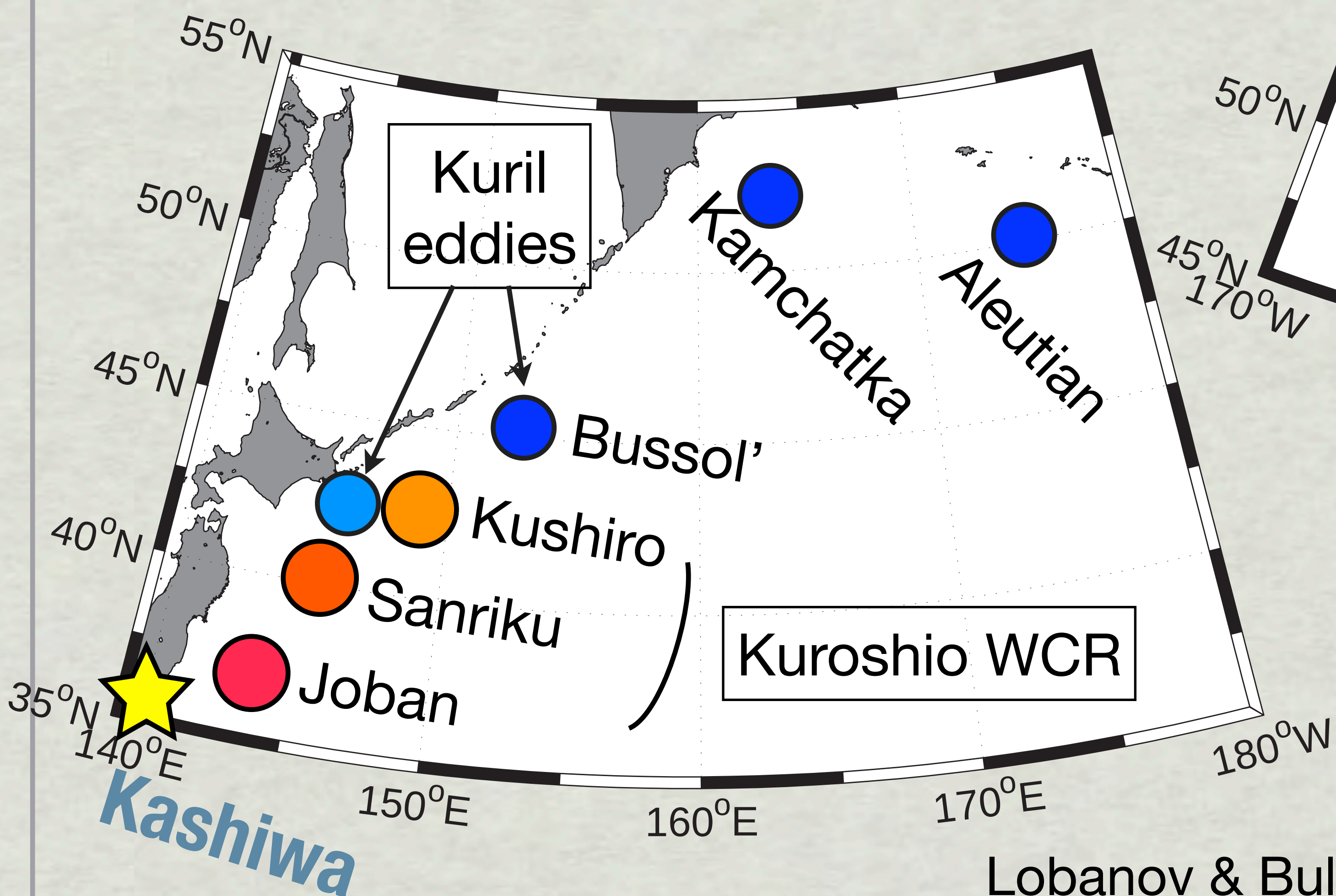
Anticyclonic eddies

Anticyclonic eddies in the East (Gulf of Alaska)



Crawford, 2005; Ladd et al., 2005; Henson & Thomas, 2008; Ueno et al., 2009; Rovegno et al., 2009

Anticyclonic eddies in the West



Lobanov & Bulatov, 1993; Yasuda et al., 2000; Rogachev, 2000; Rogachev et al., 2007; Itoh & Yasuda, 2010a,b

Properties

Mean (maximum) value

	West		East
	Kuroshio	Kuril	Haida / Sitka / Yakutat / Kenai / AS
Core water	Upper: W/S Lower: C/F	Cold & Fresh	Fresh (warm/cold)
Origin	Upper: Kuroshio Lower: Okhotsk	Okhotsk Sea	Coastal water
SSH amplitude	26 (88) cm >>	11 (41) cm <	24 (53) cm
Core radius	61 (99) km >>	46 (71) km <	53 (113) km
Lifetime	40 (167) weeks >>	32 (115) weeks ~	32 (131) weeks ~ 5yr W of 160W
Propagation	N–NE O (1km/day)	S–SW O(–1km/day)	W2.3 (0.4–4.5) km/day

Crawford, 2005; Henson & Thomas, 2008; Ueno et al., 2009;
Rovegno et al., 2009; Itoh & Yasuda 2010 a, b

Formation processes

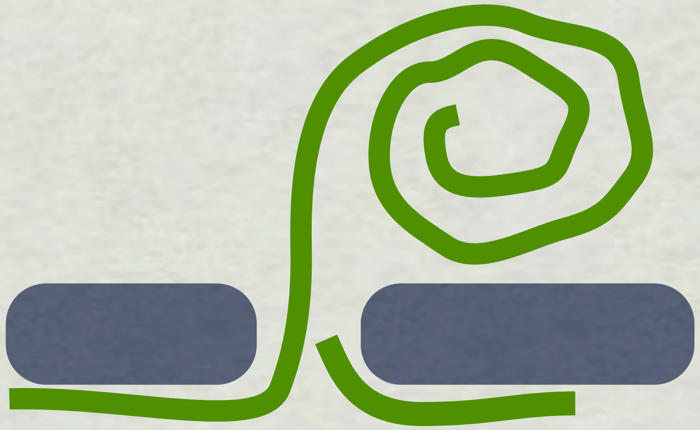
Kuroshio WCR (upper core)

Shed from a wind-driven gyre (**wind-driven**)

Transport subtropical water northward (with iron rich? water in the intermediate layer)

GOA Eddies Kuril Eddies

Originated from well-mixed coastal water (**density-driven**)



Transport iron-rich coastal water offshore

Crawford, 2005; Di Lorenzo et al., 2005; Johnson et al., 2005; Ladd et al., 2005; Rovegeno et al., 2009

Summary

- Warm and cold anticyclonic eddies in WSAG
  - 85% of AEs have a warm core in the upper layer
  - The warm eddies have a cold/fresh lower core in the intermediate layer of 26.6–26.8 σ_θ.
  - Alignment of Kuroshio WCR & Kuril eddies?
- East-west comparison
  - Richer in west than east
  - Similarities in properties & formation processes between Kuril eddies and GOA eddies