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

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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

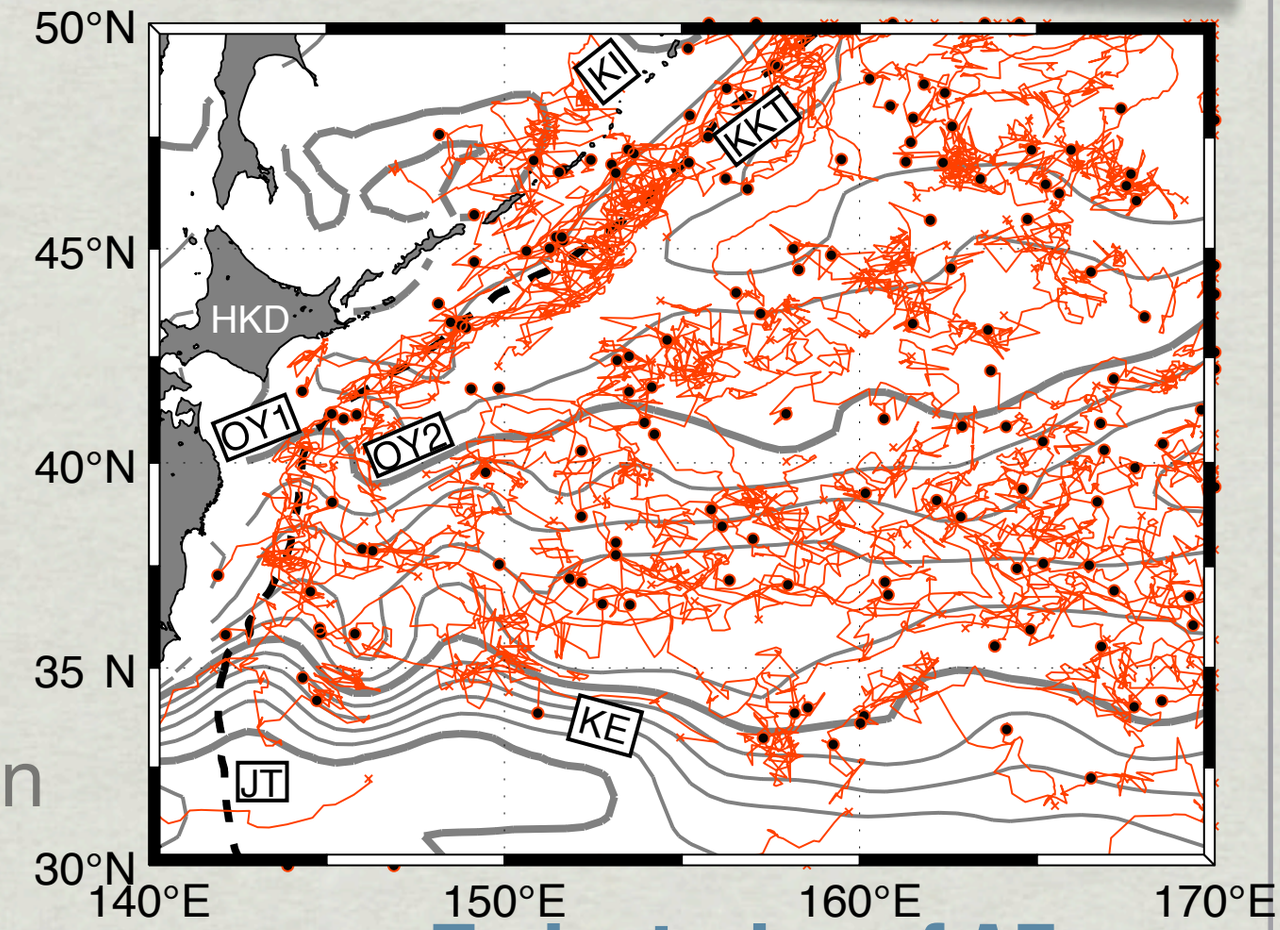
Warm anticyclonic eddy
(Kuroshio warm-core ring)

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.

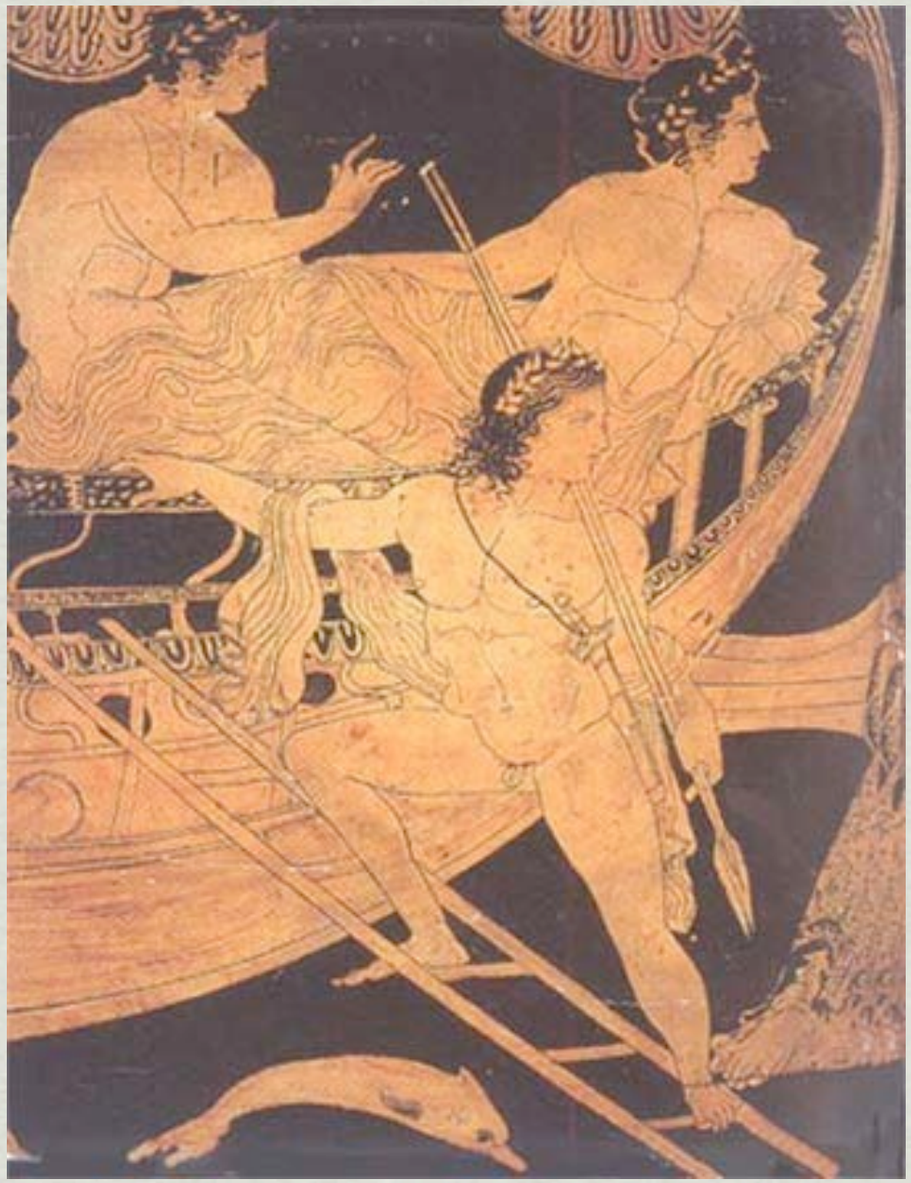
ARGO

JMA R/V

HAKUHO-MARU

Jason and Argo

1963 Film by Harryhausen



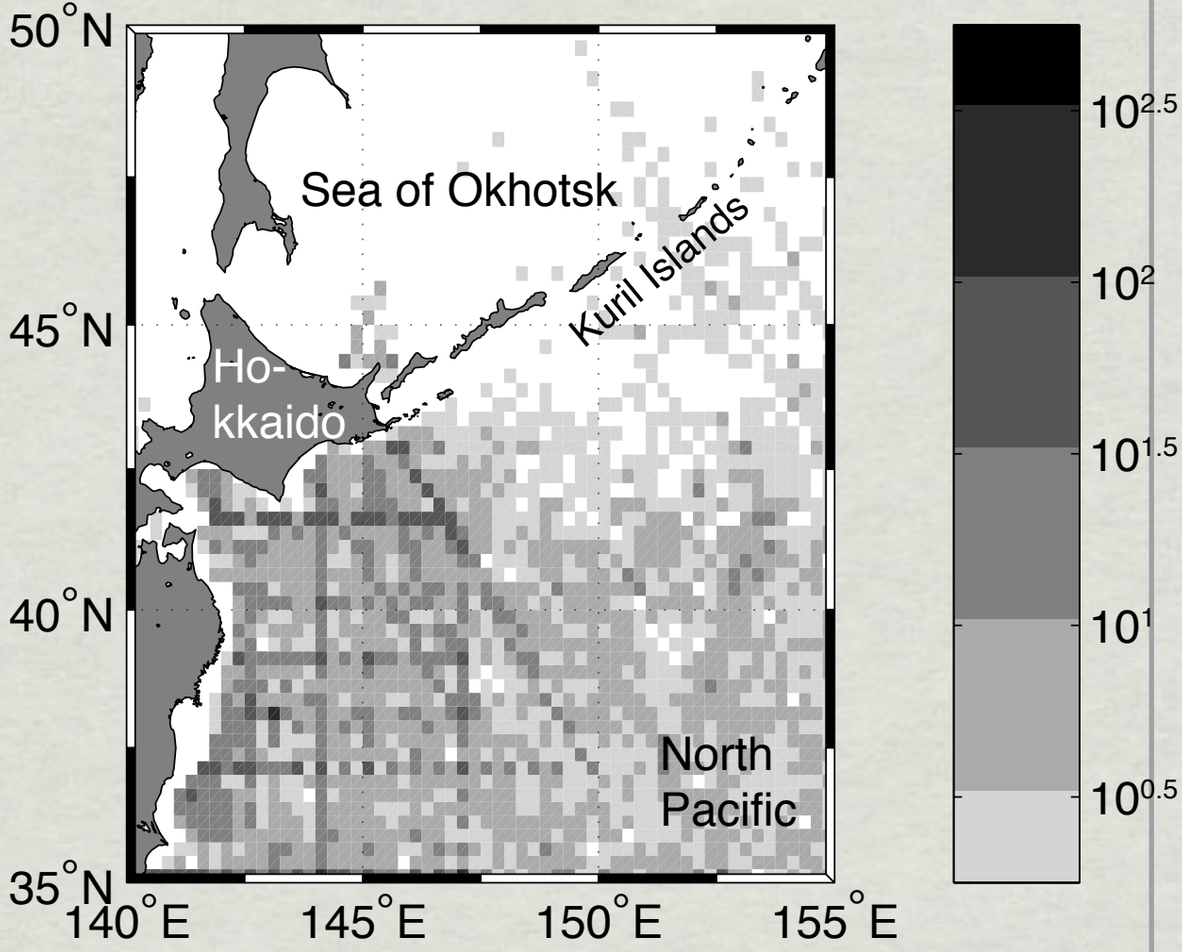
Jason and Argonauts
on their ship Argo

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

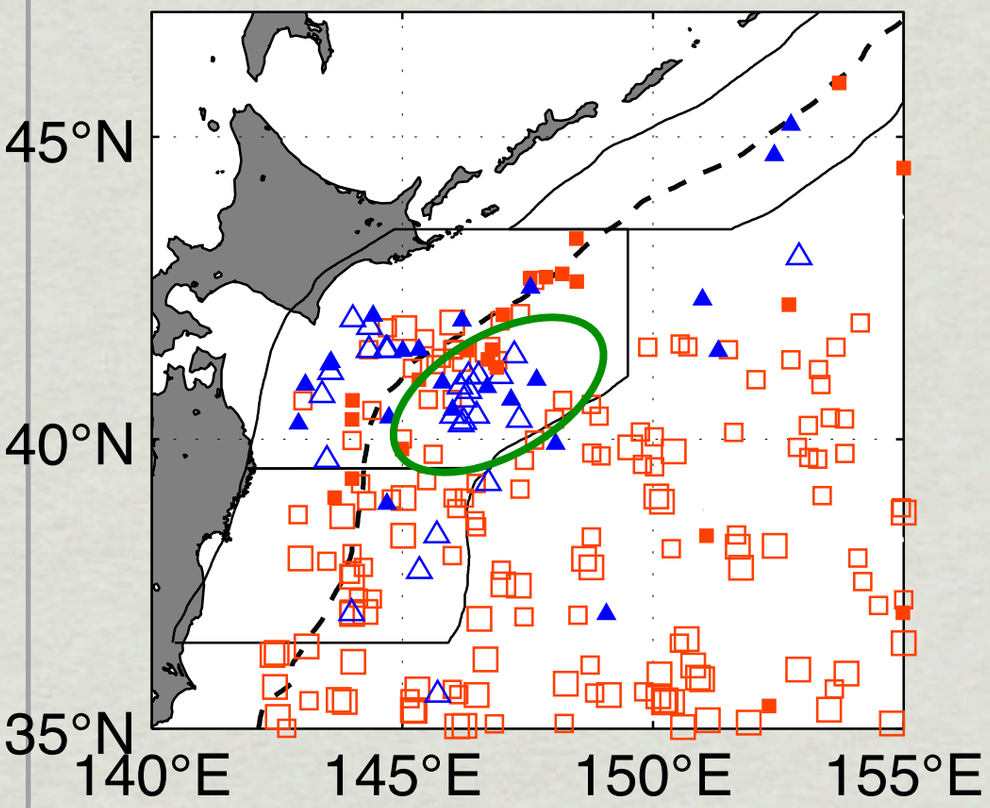


Data density of profile data

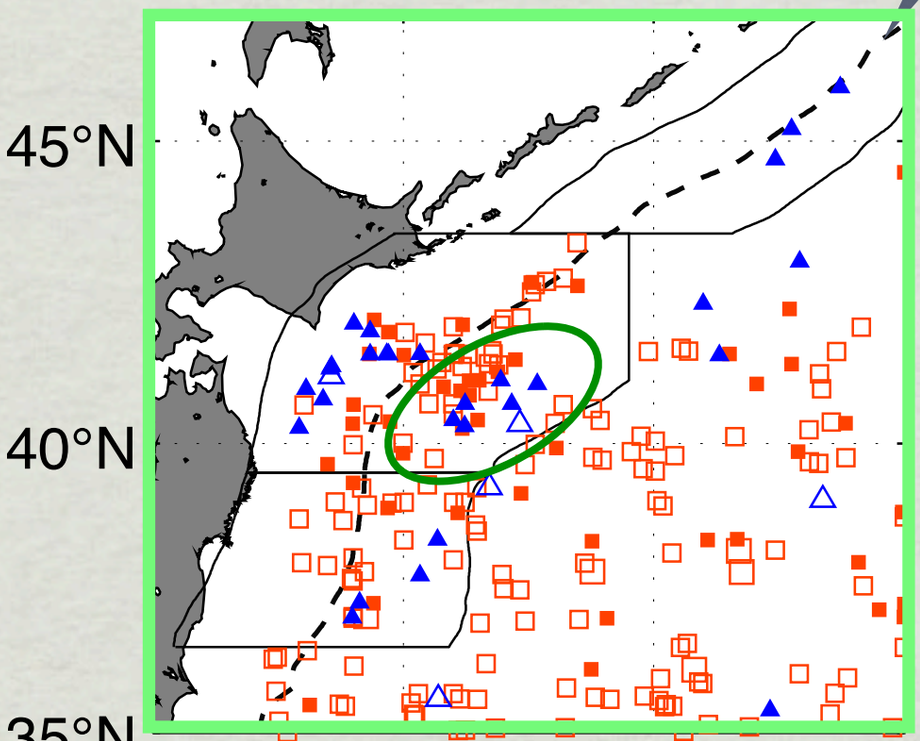
Distribution

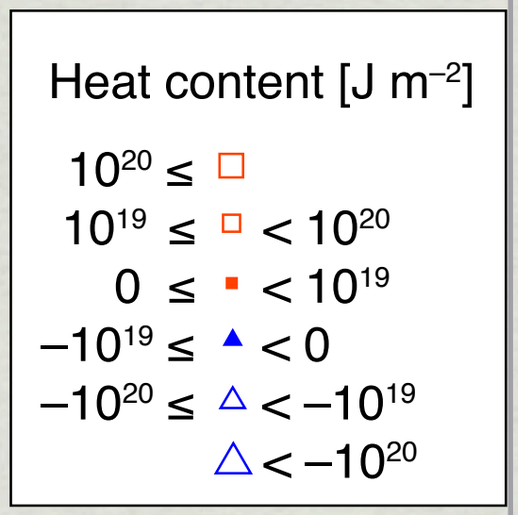
Warm eddies occupies 85%

50–800 db Heat C.



50–200 db Heat C.



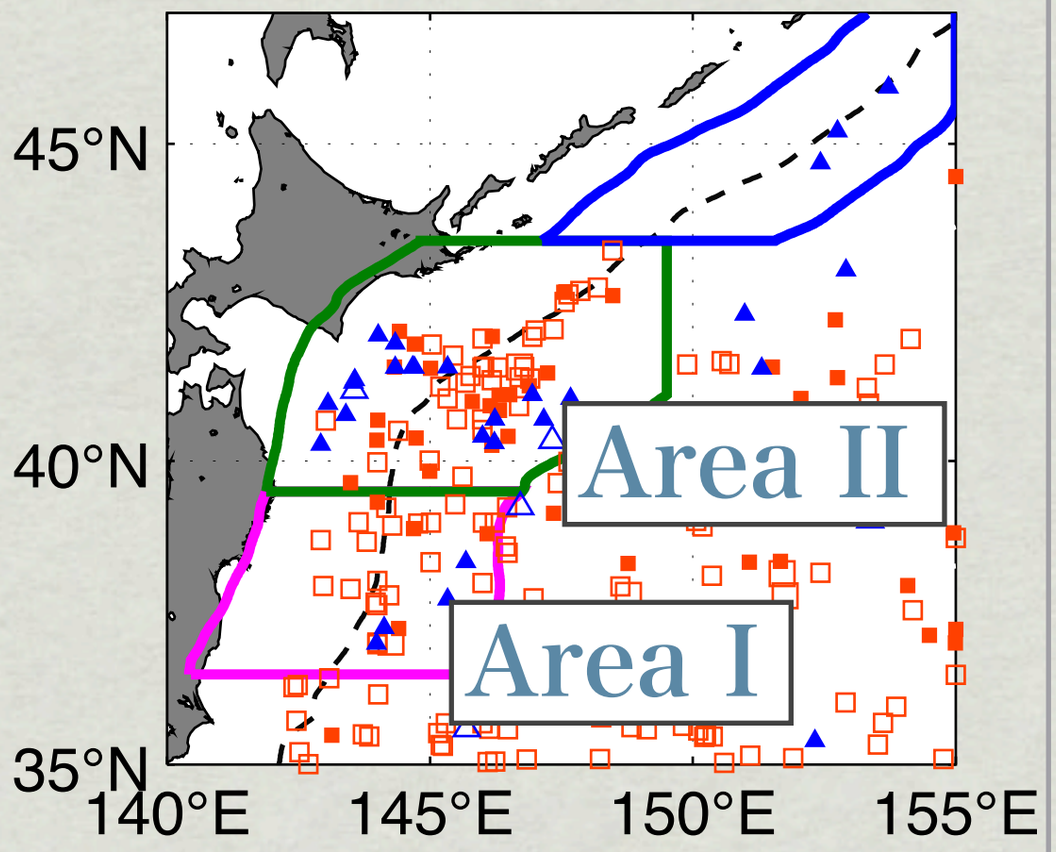


Distribution of warm and cold AEs based on heat content anomalies

Classification

Area

Area I	Between Kuroshio and Oyashio
Area II	Oyashio area

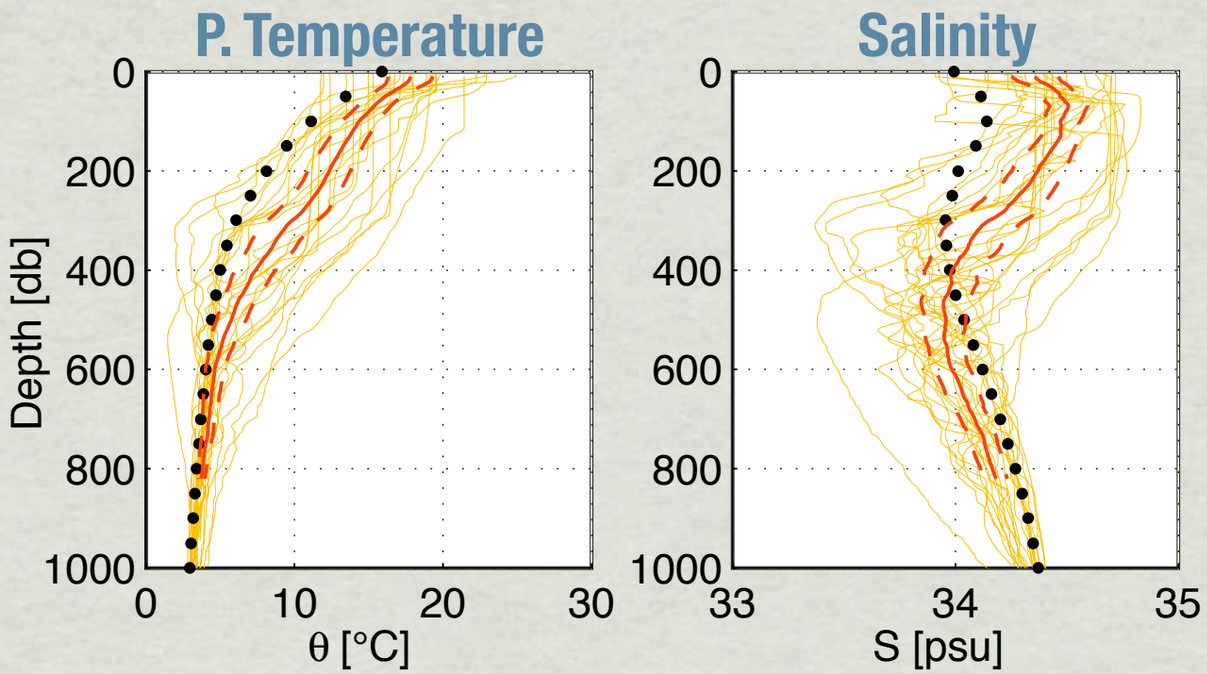


Area classification

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)



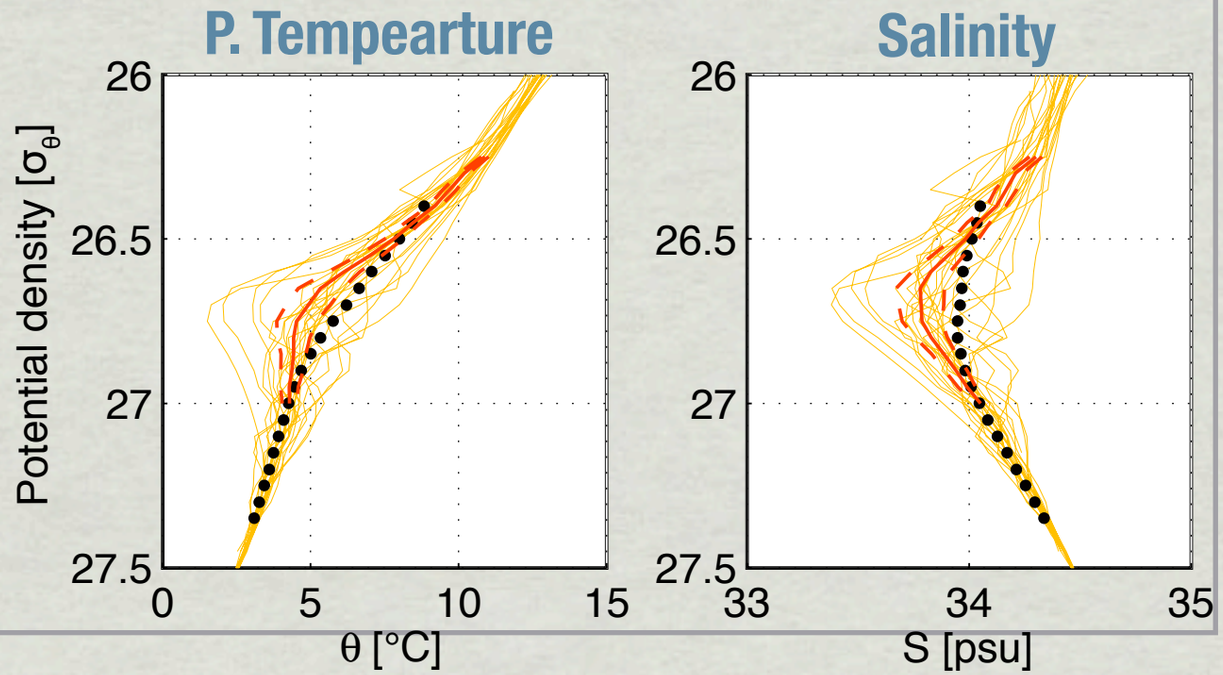
Vertical profiles （vs pressure）

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

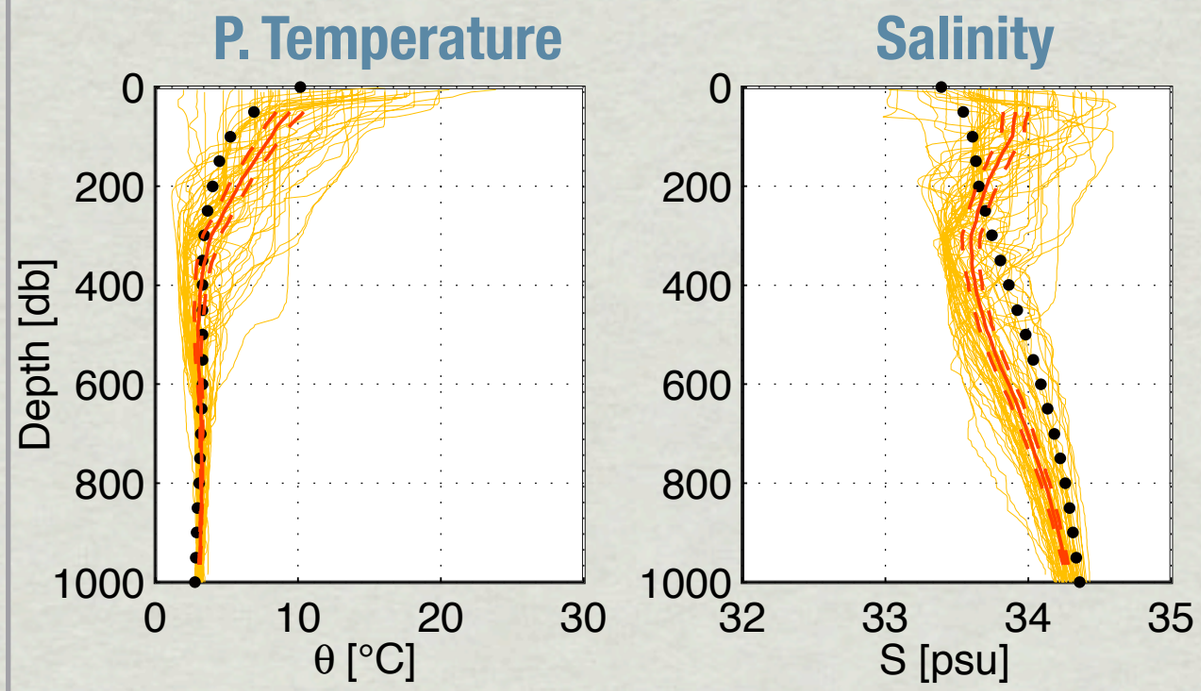
Measurements | Mean | S. E. | Climatology

- 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)



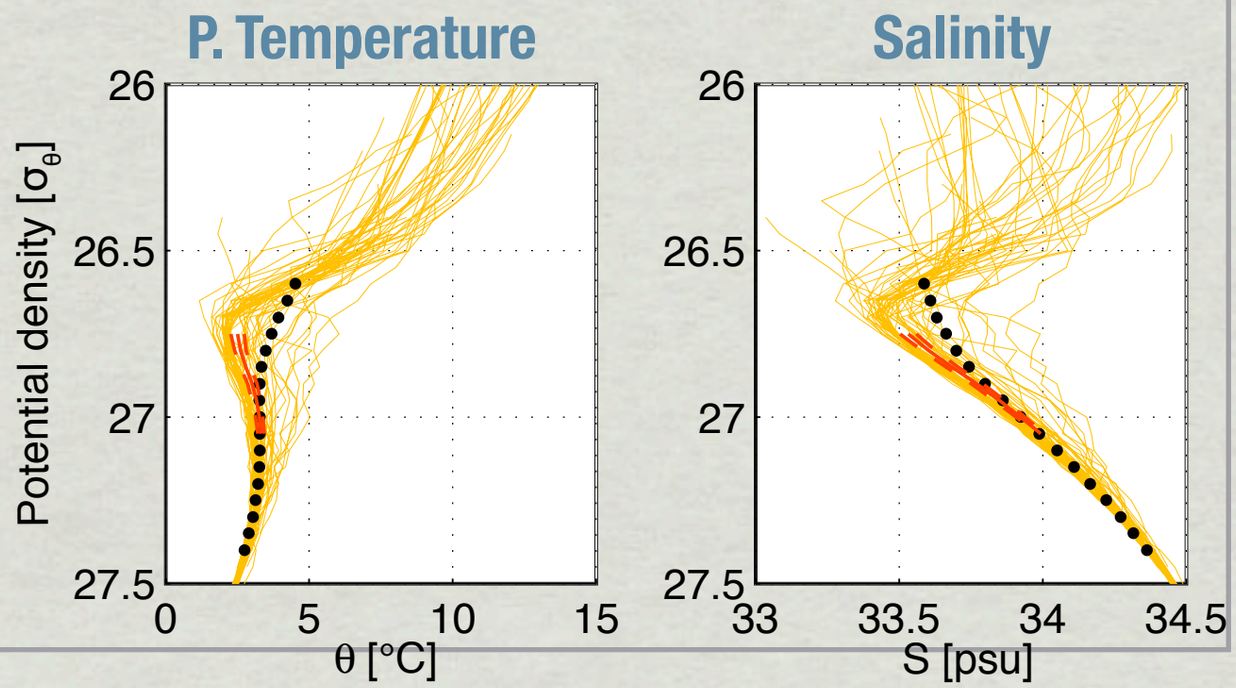
Vertical profiles （vs pressure）

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

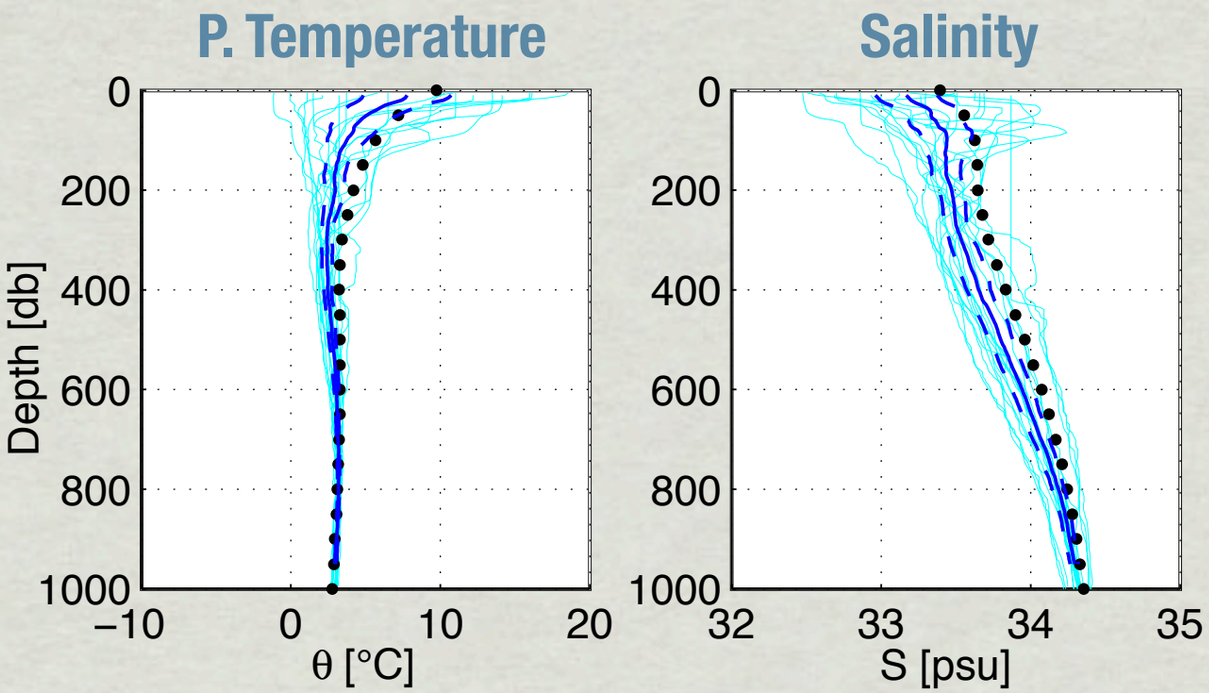
Measurements | Mean | S. E. | Climatology

- 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）

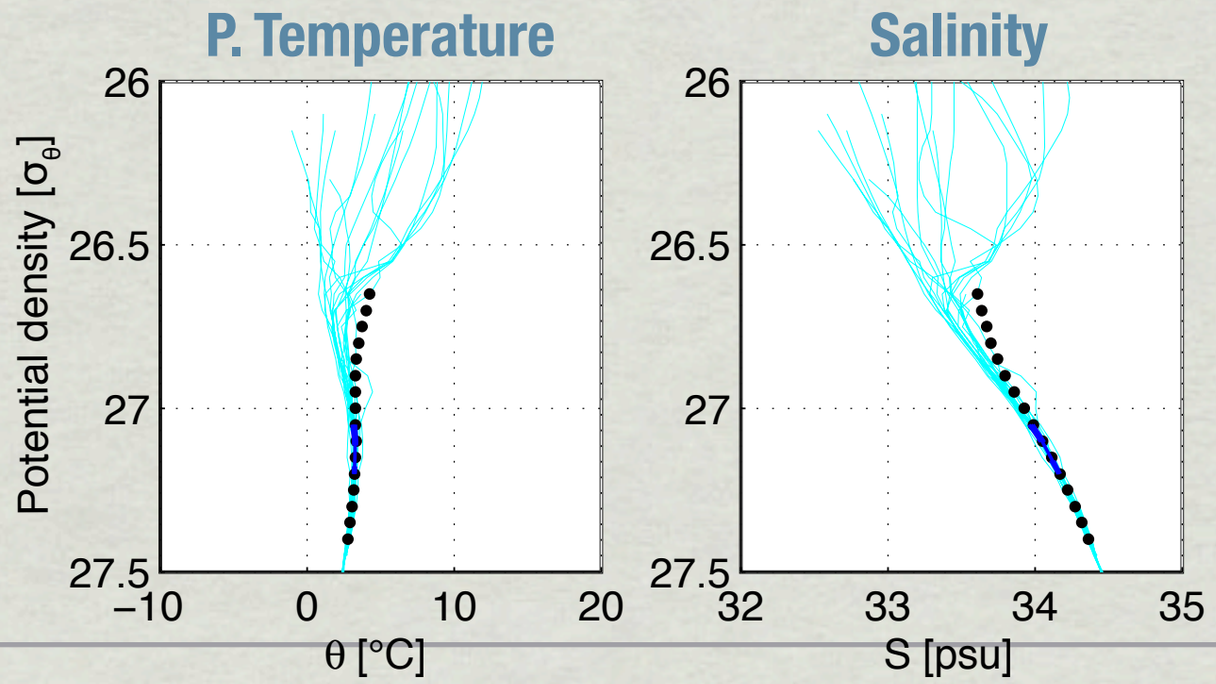
- Cold above 400 m
- Fresh anomalies from surface to 1000 m

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）

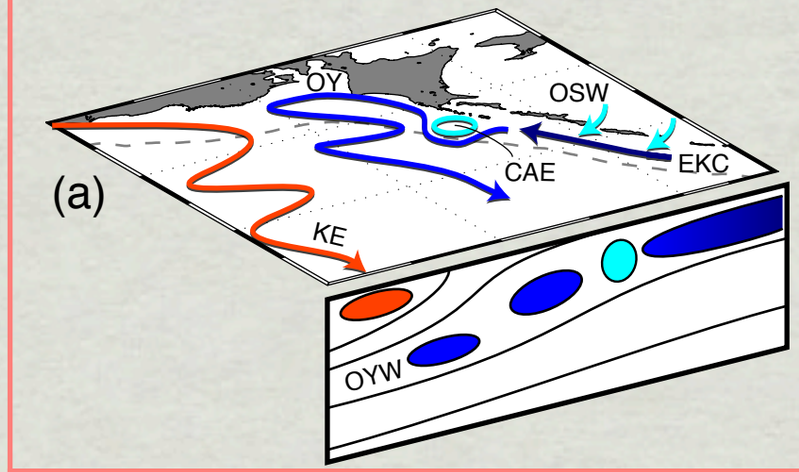


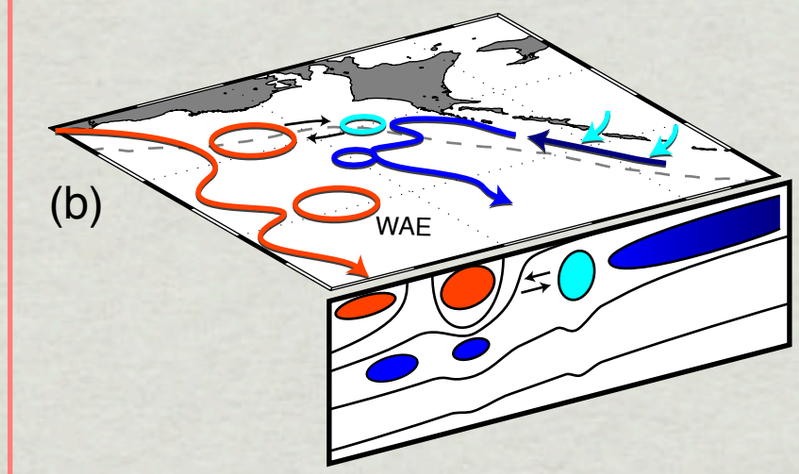
Evolution & interaction of warm & cold anticyclones

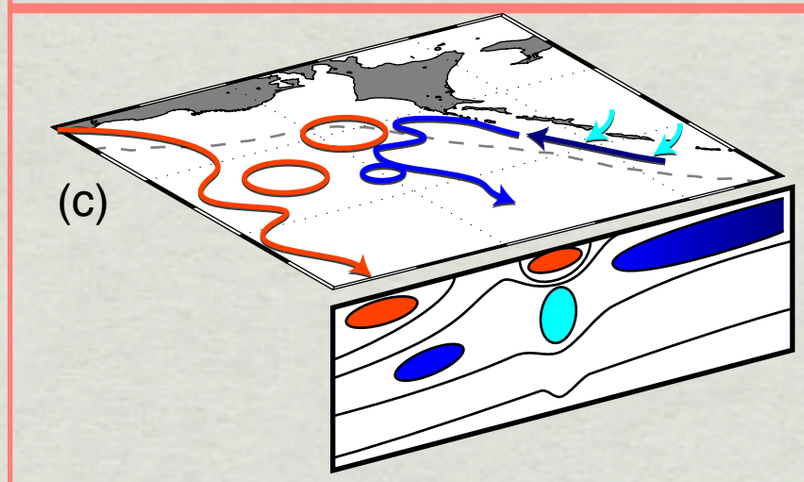
(a) Warm eddies from KE in the south,
with moderately cold Oyashio water below,
and cold eddies from Okhotsk in the north

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

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

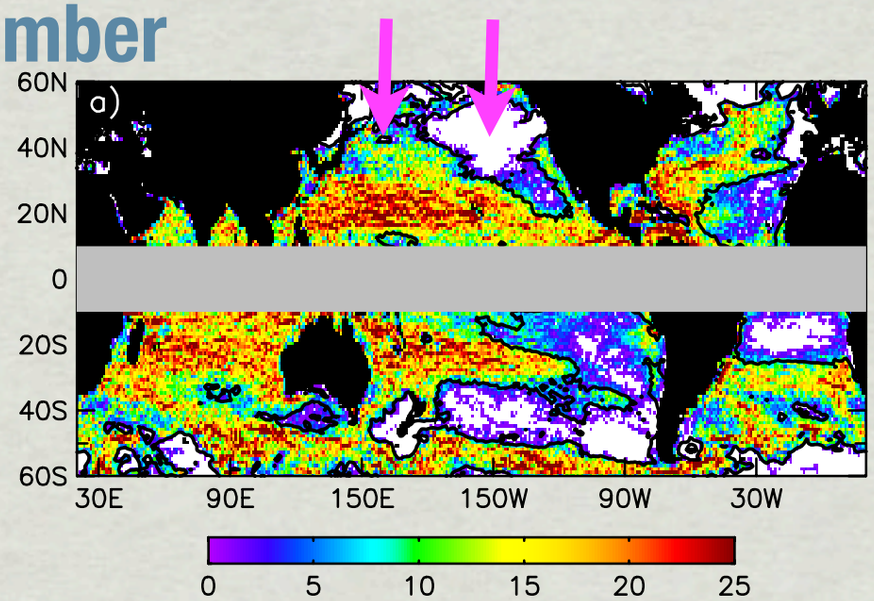




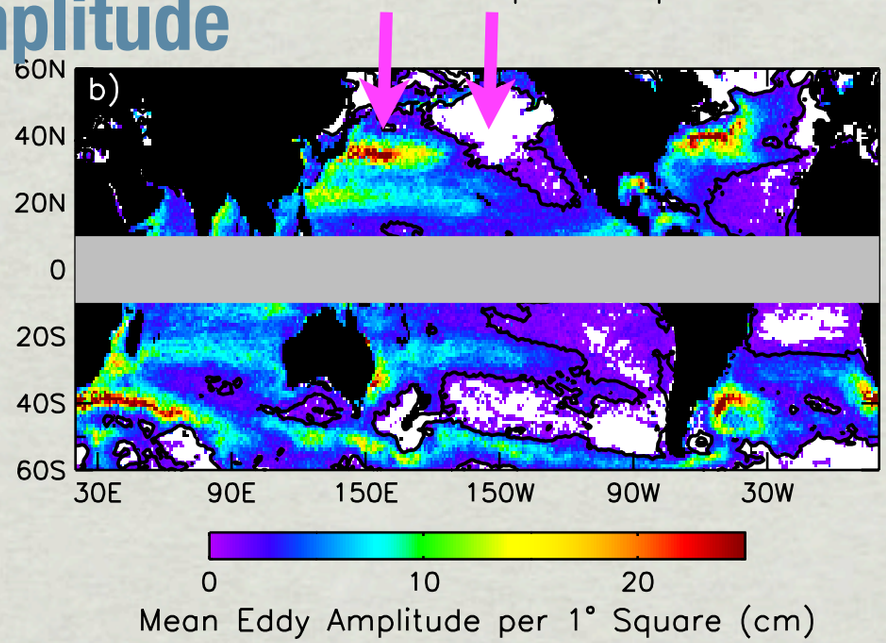


East-West comparison

Number



Amplitude



Looking into subarctic gyres of the North Pacific,

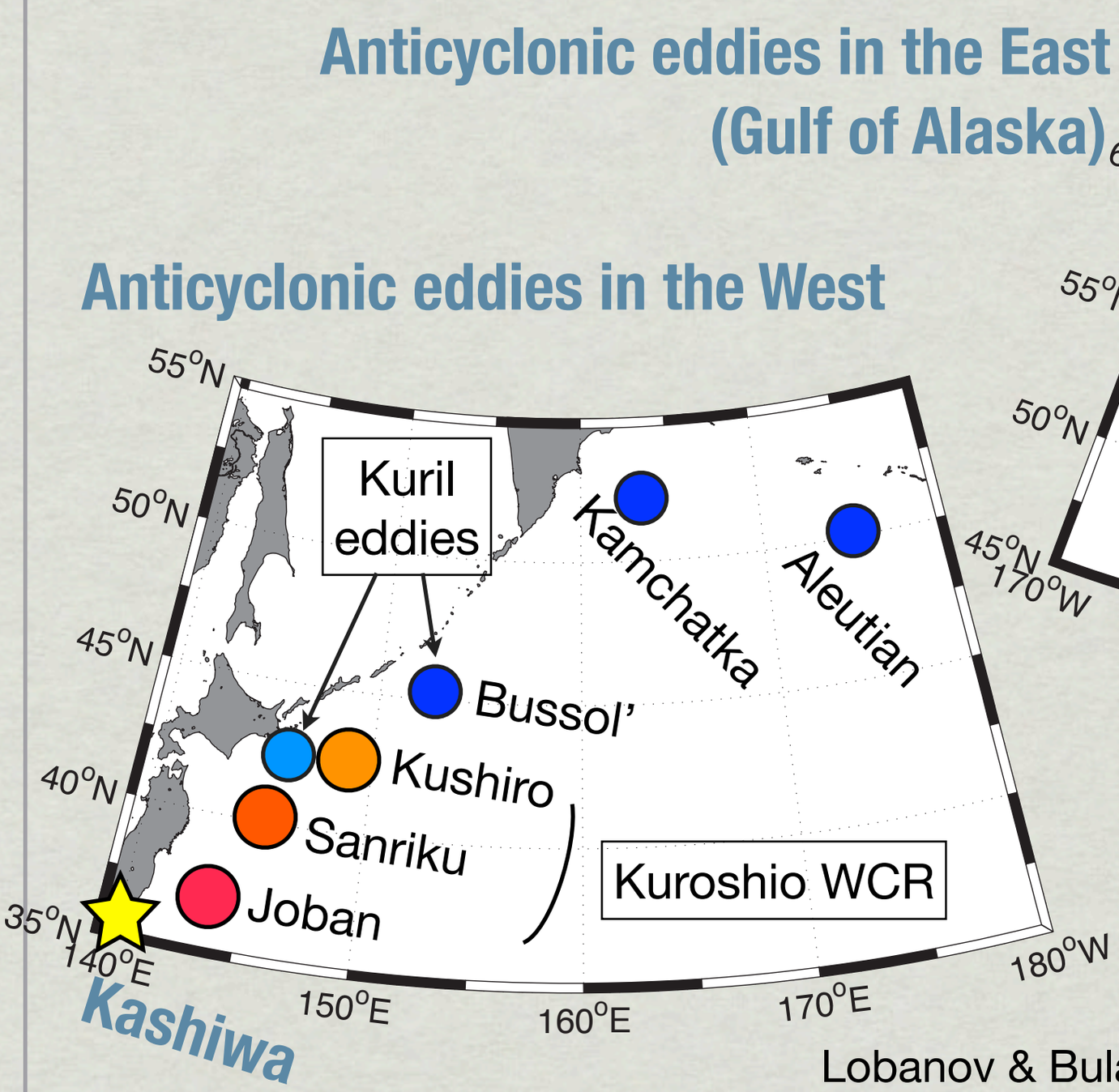
- Eddies are far richer and stronger in the west than in the east (despite the underestimation in the west; Itoh & Yasuda, 2010a)
- Eddies are detected along the coast in the east

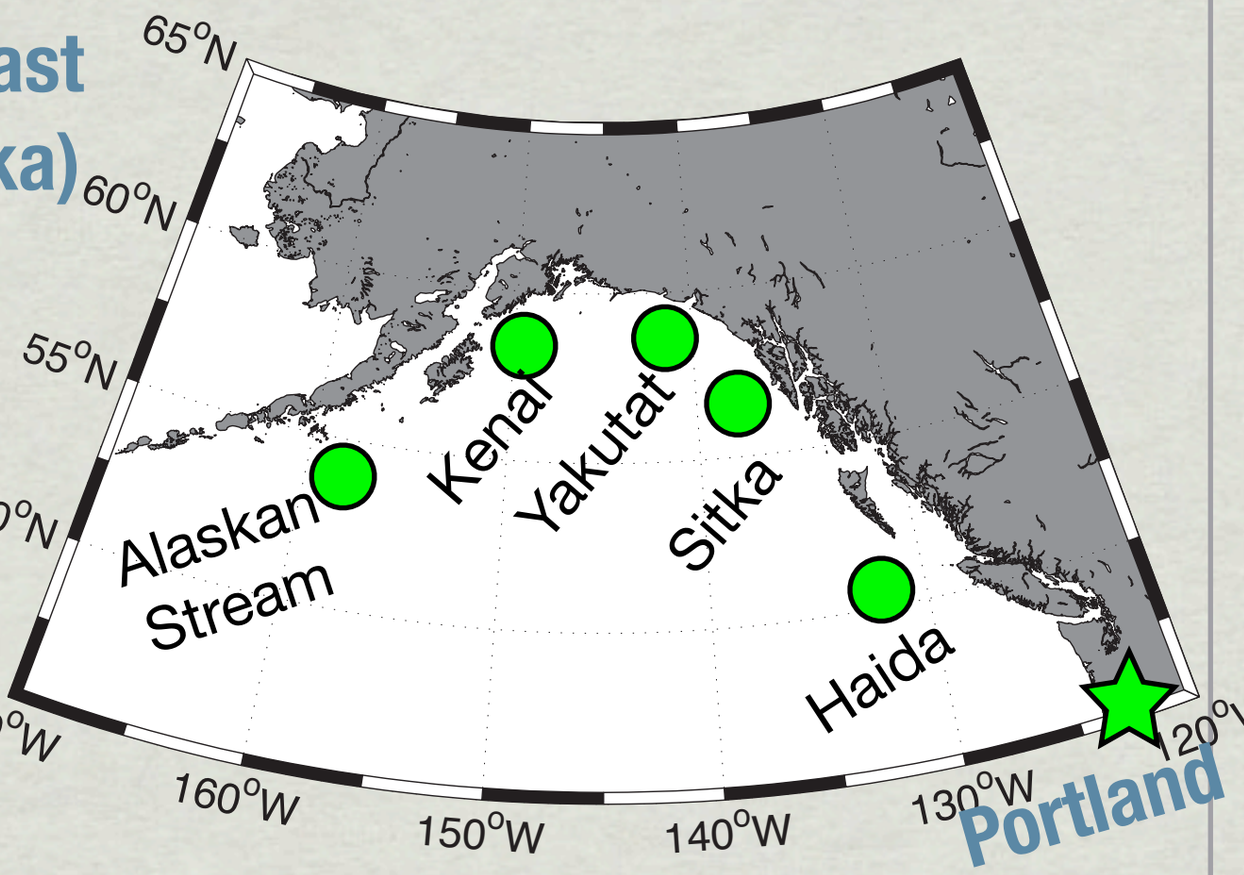
From Chelton et al. (2007) (both cyclones and Anticyclones)

Anticyclonic eddies

Anticyclonic eddies in the East (Gulf of Alaska)

Anticyclonic eddies in the West





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

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

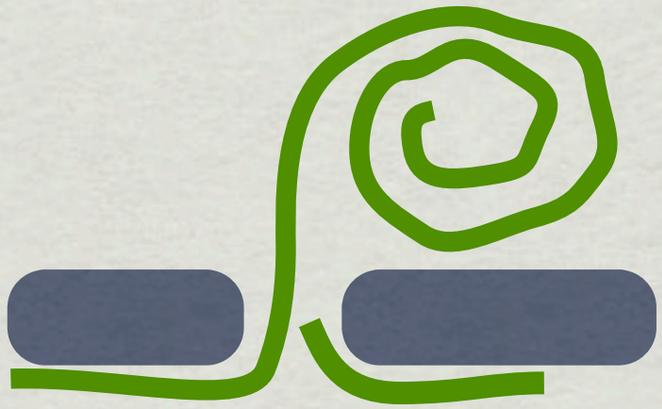
Kuroshio WCR (upper core)

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