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
Warm anticyclonic eddy (Kuroshio warm-core ring)

Important roles in transporting heat, materials, and biota
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
**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
Jason and Argo

1963 Film by Harryhausen

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 of warm and cold AEs based on heat content anomalies

50–800 db Heat C.

50–200 db Heat C.

Heat content [J m⁻²]

- $10^{20}$ ≤ □
- $10^{19}$ ≤ □ < $10^{20}$
- $0$ ≤ □ < $10^{19}$
- $-10^{19}$ ≤ △ < 0
- $-10^{20}$ ≤ △ < $-10^{19}$
- △ < $-10^{20}$

Positive anomaly (warm eddies) □ □ □
Negative anomaly (cold eddies) △ △ △ △

Warm eddies occupies 85%
Classification

Area

<table>
<thead>
<tr>
<th>Area I</th>
<th>Between Kuroshio and Oyashio</th>
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<tr>
<td>Area II</td>
<td>Oyashio area</td>
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Groups of anticyclonic eddies

<table>
<thead>
<tr>
<th>Group I</th>
<th>Warm eddies in Area I</th>
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</thead>
<tbody>
<tr>
<td>Group IIW</td>
<td>Warm eddies in Area II</td>
</tr>
<tr>
<td>Group IIc</td>
<td>Cold eddies in Area II</td>
</tr>
</tbody>
</table>
Group I (Area between K & O)

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

**Vertical profiles (vs pressure)**

- Cold and fresh anomalies around 26.6–26.8 $\sigma_\theta$

**Vertical profiles (vs $\sigma_\theta$) (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

Cold and fresh anomalies around 26.6–26.8 $\sigma_\theta$

Vertical profiles (vs $\sigma_\theta$)
Group IIc (Cold eddies in Oyashio area)

- Cold above 400 m
- Fresh anomalies from surface to 1000 m
- Cold and fresh anomalies around 26.6–26.8 $\sigma_\theta$

Similar to Okhotsk water

Vertical profiles (vs $\sigma_\theta$)

Measurements | Mean | S. E. | Climatology
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

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

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<thead>
<tr>
<th></th>
<th>West</th>
<th>East</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Core water</strong></td>
<td>Kuroshio (Upper: W/S, Lower: C/F)</td>
<td>Cold &amp; Fresh</td>
</tr>
<tr>
<td><strong>Origin</strong></td>
<td>Upper: Kuroshio</td>
<td>Okhotsk Sea</td>
</tr>
<tr>
<td></td>
<td>Lower: Okhotsk</td>
<td>Coastal water</td>
</tr>
<tr>
<td><strong>SSH amplitude</strong></td>
<td>26 (88) cm</td>
<td>11 (41) cm</td>
</tr>
<tr>
<td></td>
<td>24 (53) cm</td>
<td></td>
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<tr>
<td><strong>Core radius</strong></td>
<td>61 (99) km</td>
<td>46 (71) km</td>
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<td></td>
<td>53 (113) km</td>
<td></td>
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<tr>
<td><strong>Lifetime</strong></td>
<td>40 (167) weeks</td>
<td>32 (115) weeks</td>
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<td></td>
<td>~ 32 (131) weeks</td>
<td>~ 32 (131) weeks, ~ 5yr W of 160W</td>
</tr>
<tr>
<td><strong>Propagation</strong></td>
<td>N–NE O (1km/day)</td>
<td>S–SW O(–1km/day)</td>
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<td>W2.3 (0.4–4.5) km/day</td>
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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 \( \sigma_\theta \).
- 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