Mesoscale and submesoscale dynamic structures off the Russian coast in the northwestern Japan/East Sea and their impact on chlorophyll-a concentration: satellite imagery and moored profiler measurements

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Background: the dynamically active zone in the Primorye (Liman) Current area (the northwestern Japan Sea)

Slope eddies, shelf waves, alien water intrusions with eddies, streamers, and filaments.

Advection of warm water from south and east

Satellite IR imagery (Ginzburg et al., 1998)

EKE, surface drifters (Lee, Niiler, 2005)

Satellite altimetry, AVISO, 1993-2015 (Trusenkova, 2014)
To study the dynamically active zone within the Primorye Current

_Aqualog_ moored profiler installed at the continental slope (42.5°N, 133.8°E), depth of 440 m. April 18 through October 15, 2015. Unique data for half a year with high resolution in depth and time.

(Ostrovskii et al., 2013)
27.15σ_t isopycnal depth (140±31 m) – a good indicator of pycnocline fluctuations ~ dynamic height (R > 0.9) (Trusenkova et al., 2018)

Periods: 2 – 6 days (in June), 8–12 & 20–30 days (before mid August), 110 – 130 days (the whole observation time).
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Periods: 2 – 6 days (in June), 8–12 & 20–30 days (before mid August), 110 – 130 days (the whole observation time).

T & S in the upper profiled layer (64–70 m)
T at the upper isopycnals (sigma = 27.05 – D27.15 kg/m³)

Short-lived thermohaline anomalies at the upper isopycnals (64–150 m) as indicators of alien water intrusions

What is the source of this variability?
Is it possible to identify dynamic structures?
Satellite information?
Purpose of the study

To link thermohaline anomalies from the Aqualog data to dynamic patterns observed from satellite imagery, to check the vertical extent of surface mesoscale and submesoscale features and to relate them to surface Chl-a from satellite data.
Satellite data

*Infrared imagery:* AVHRR/NOAA (1 km); VIIRS/Suomi-NPP (375 m).

*Visible imagery:* Chl-a, GOCI/COMS, 500 m

April – October 2015: frequent clouds; however, set of good images found to discuss cases of alien water intrusions.
**Aqualog data**

*Period:* April 18 through October 14, 2015.

*Upward/downward casts* 4 times a day, sampling every 0.2–1 m, from 64 m through 300 m.

**Below the seasonal pycnocline of the subarctic water structure.**

CTD measurements by SBE CTD 52-MP.

*T, S, and sigma* interpolated to 1 m depth and 6 hour intervals.

Mooring site, instruments, primary data processing and data corrections are discussed by Lazaryuk et al. (2017).

Using specially developed techniques of dynamic errors correction, T errors were decreased to 0.002 °C and S errors to 0.003 psu (WOCE standard).

Thermohaline anomalies considered (above 0.1 °C and 0.005 psu) exceed errors.
T,S scatter diagrams (mean in the upper profiled layer; 64–70 m)

Temperature increase from April to September and decrease to October, although the climatic max at 70 m is in October – November (Luchin et al., 2003).

Months:
4 for April,
5 for May,
6 for June,
7 for July,
8 for August,
9 for September,
10 for October.
Thermohaline anomalies from April 21 through May 1 (111 – 121 days of the year)

64–70 m

Mean for 111–121 days: $T_{64-70}: 1.92 \, ^\circ C$, $S_{64-70}: 33.768 \, psu$, sigma: 26.99 $kg/m^3$.

T, S, sigma jump on May 2

Anomalies down to 150 m
No such anomalies in other months.

April 21 – May 1

Temperature, °C

Salinity, psu

64–70 m

Months:

4 for April,
5 for May,
6 for June,
7 for July,
8 for August,
9 for September,
10 for October.
Cold fresh water intrusion (down to 150 m)
Cold water is blue, warm water is green, yellow & red.

The front shifts first to the west, then to the east.

No informative images between 04/24 and 05/10.
Cold water is blue, warm water is green, yellow & red.

The front shifts first to the west, then to the east.

High-resolution from Suomi/NPP

Cold water is dark, warm water is light.

Eddy moving southwestward and merging with the front.

No informative images between 04/24 and 05/10.
Wedge-like structure due to instability

Cold water is blue, warm water is green, yellow & red.

Cold water of the Primorye Current, rich in Chl-a.

Alternating cold and warm water in SST & rich and poor in Chl-a.
Large anticyclonic eddy in late May – early June

Cold water is blue, warm water is green, yellow & red.

May 30

Eddy moving to SW

May 31

June 4

June 9, NOAA

No eddy

Eddy size:
60–80 km,
translation speed:
6–9 cm/s.
Large anticyclonic eddy in late May – early June

Cold water is blue, warm water is green, yellow & red.

Eddy moving to SW

Eddy size: 60–80 km, translation speed: 6–9 cm/s.

Eddy signature in Aqualog data:
- Cool & fresh water at 60 – 100 m,
- Warm & fresh water at 150–300 m
Large anticyclonic eddy in late May – early June

Cold water is blue, warm water is green, yellow & red.

Eddy moving to SW

May 30

Eddy signature in Aqualog data:

Offshore advection of coastal water at the rear (eastern) eddy edge.

June 4

June 9, NOAA

No eddy

Cold water is dark, warm water is light.

Aqualog

Suomi/NPP
Warm and fresh coastal water
June 7–8 (158–159 days of the year)

Increased T (3.5–4.0 °C),
very low S (33.713 psu;),
sigma (26.87 kg/m³; abс. min for the whole time).

June: cluster of warm low salinity water
(down to 80 m)

64-70 m

Day of the year

Temperature, °C

Salinity, psu

Sigma, kg/m³

Temperature, °C

Salinity, psu

No such cluster

100 m
Intrusions of warm and salty water (from mid June through mid September)

S = ≥34.0 psu

S anomalies down to 150 m

34.06 psu, max for the whole time

S = 34 psu at 150 m on average

mean S, psu
Intrusions of warm and salty water (from mid June through mid September)

S anomalies down to 150 m

S ≥ 34.0 psu

34.06 psu, max for the whole time

mean S, psu
Positive T & S anomalies
(from mid June through mid September)

July - August:
T = 3.5–4.0 °C, S > 34 psu.

September:
T = 3.5–5.5 °C, S > 34 psu.

Increased T and S (> 34 psu) \( \rightarrow \) originate from the southern Sea, transformed subtropical water.
Satellite images: warm water advection towards the Russian coast (July 27 and September 4)

From the south

Cold water is blue, warm water is green, yellow & red.

From the east

Decreased Chl-a from the east.
Warm water advection towards the Russian coast

Frequent cloudy conditions in summer 2015:
no informative NOAA IR images on June 16 – July 7,
July 8 – July 26, July 28 – September 3, September 8 – October 2;
no informative Suomi/NPP IR images
on June 16 – September 3, September 8 – October;
no informative COMS visible images on June 11 – September 4.

However, an increased S (> 34.0 psu) $\rightarrow$ transformed subtropical water.

On northward advection of warm water:
Danchenkov et al., 2002; Lobanov et al., 2007;
Nikitin, Yurason, 2008.
Temperature decrease in October

September 30 – October 3 (273 – 276 days of the year): $T_{64-70}$ decreased from 4.1 to 3.1 °C; S almost not changing.

Seasonal T max: October – November (Luchin et al., 2003).
Upwelling in October

October 4

Aqualog

Cold water is blue, warm water is yellow & red.

Surface manifestation closer to the coast

COMS, Chl-a (mg/m³)

Wind upwelling?
September 30 – October 2: cyclone passage, strong wind

$\tau > 0$, SW, upwelling favorable, 
Alongshore $\tau$  
$\tau < 0$, NE, downwelling favorable
Upwelling in October

Aqualog

Surface manifestation closer to the coast

Cold water is blue, warm water is yellow & red.

April – September: strong wind was mostly downwelling favorable (easterlies).

$\tau > 0$, SW, upwelling favorable, $\tau < 0$, NE, downwelling favorable

September 30 – October 2: cyclone passage, strong wind
**Conclusion**

**T,S-indices, 64 – 70 m**

<table>
<thead>
<tr>
<th>Water mass</th>
<th>$T$ (°C)</th>
<th>$S$ (psu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primorye Current, April</td>
<td>1 – 2.5</td>
<td>33.67 – 33.85</td>
</tr>
<tr>
<td>Coastal water, June</td>
<td>3.0 – 4.0</td>
<td>33.67 – 33.82</td>
</tr>
<tr>
<td>Subtropical water, July - August</td>
<td>3.5 – 4.8</td>
<td>34.00 – 34.06</td>
</tr>
<tr>
<td>Subtropical water, September</td>
<td>3.5 – 5.5</td>
<td>34.00 – 34.06</td>
</tr>
<tr>
<td>Upwelling, late September – early October</td>
<td>2.9 – 3.3</td>
<td>33.93 – 33.95</td>
</tr>
</tbody>
</table>

Linked to dynamic structures using satellite imagery

**Thank you for your attention!**