Stirring and up-lifting of deep water at the entrance straits of the Sea of Okhotsk
---- *shown by data including flagged 'questionable' or 'bad'* ---

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1. *Scientific Question and Backgrounds*

Scientific Question:

"Is the Deep Water up-lifted at the Kuril Ridge?"

Backgrounds:

50yrs trend at the intermediate layer of Okhotsk Sea:

= T:↑ /S:↑ /DO:↓ at the (Nakanowatari *et al.*, 2007; Kashiwai, 2016; others);

Possible explanation:

= relative enhancement of contribution of Deep water in formation of Okhotsk Sea Intermediate water (hereafter **OkS-IntW**) (Kashiwai, 2016);

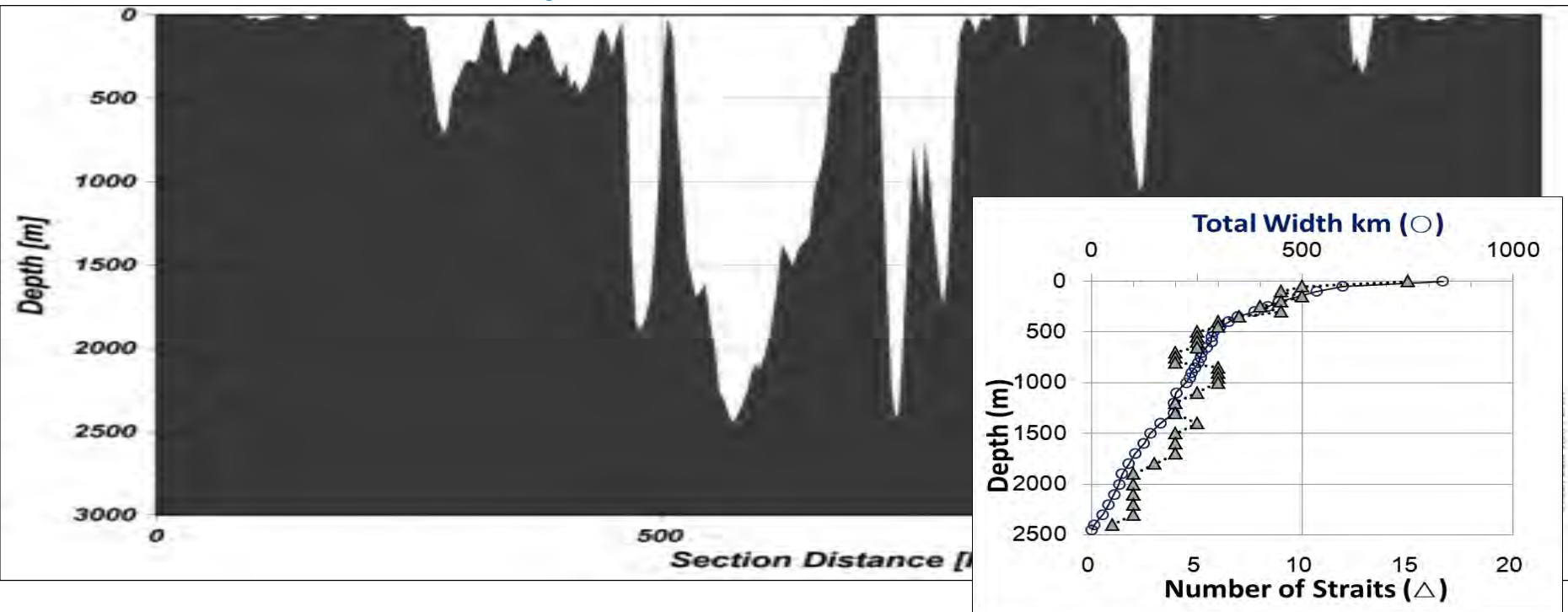**Kuril Straits:**

= many '*questionable*' data;

= possible signs of extreme events by external forcing;

2. *Approach*

- ☐ Focusing on the fact **depth of 27.1σ_0 steady at 600m**:
  - ✓ Constant not only through season but through 50yrs change.
  - ✓ Lower-limit of ventilation in the Okhotsk Sea (Wong *et al*., 1998).
  - ✓ Boundary between IntW and DpW shown by TSV-analysis.
- ☐ Focusing on **Freeland "Gap"**: (Freeland *et al*, 1998)   Eddy Carmack?
  - ✓ Sign of unique mixing process at the Kuril Ridge ;
- ☐ Positive use of **density-inversion** or **outlier data**:
  - ✓ Limited cleaning-up of data before analyses;
  - ✓ If source-water of density-inversion or outlier is not identified up to far-field, then stop further analysis on that data;
- ☐ Use **WOD13**: ∵WOA: wrong Basin-Mask; 1°mesh lost detail;
  - ✓ Bottle-data; ∵causes of apparent errors are familiar for the

3. *Depth of 27.1σ₀ :* *What is Depth 600m @ Kuril Ridge?*

# 3. $Depth\ of\ 27.1\sigma_0$:   *What is Depth 600m @ Kuril Ridge?*

Topography of the Kuril Ridge at sill section by GEBCO data.
(*Insert*): The total width and number of straits of Kuril Straits.

 ✓ **Composed** from **many shallow straits** and **few deep straits**;
 ✓ **Shape of the Kuril Straits** is notched weir composed of 3 slopes:
   • Beach Slope   (depth<50m);
   • Coastal Shelf Slope   (50m<depth<500m) ;
   • Shelf Slope   (500m<depth<2450m).
 ✓ **Depth 600m (27.1σ₀)** can correspond to

   • **Effective depth of mixing at shallow straits**

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4. *Freeland "Gap"*;　　　　　　*WOCE / P1W section*
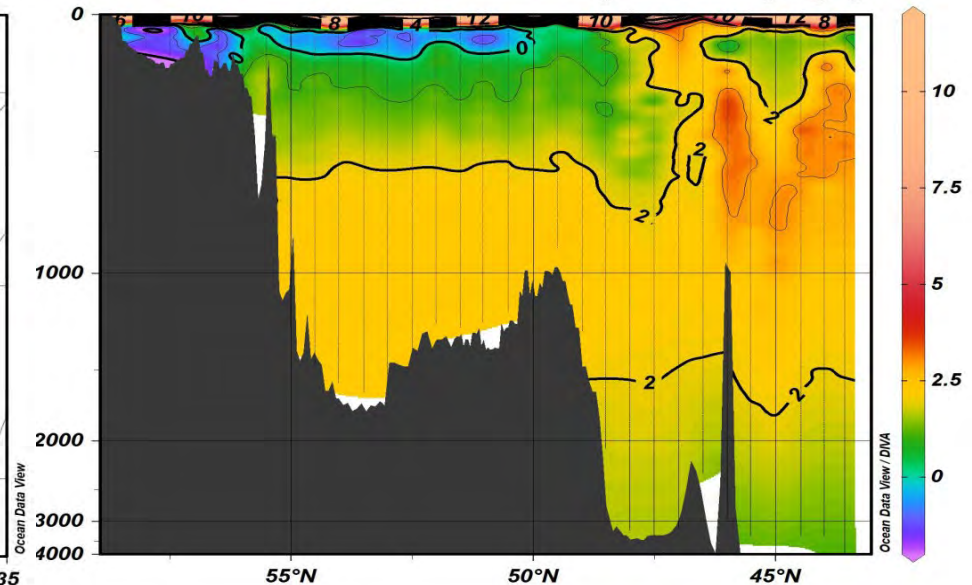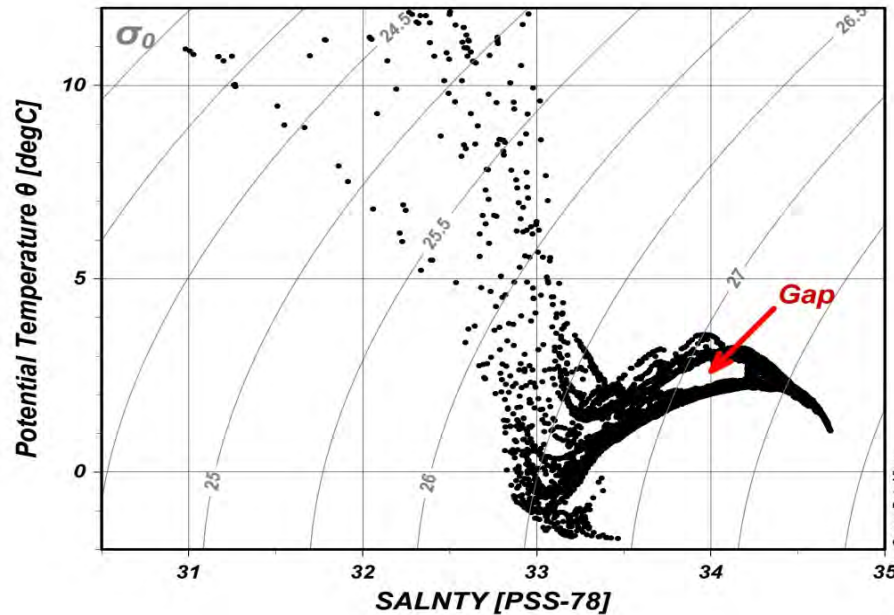
TS-diagram of P1W-section; Red arrow: "Gap" (Freeland et al, 1998)

T_{pot} section; T_{pot}max extends from the Pacific, but terminates at the Sill.

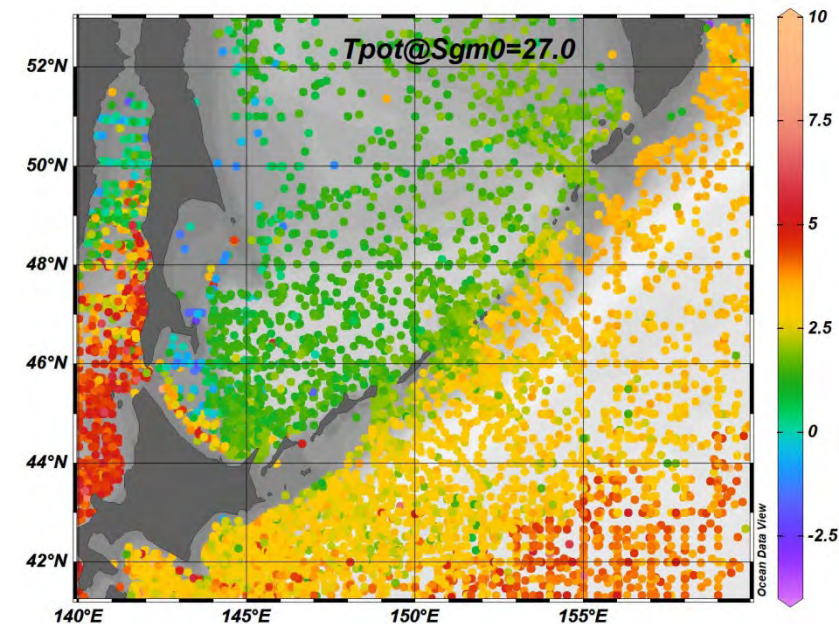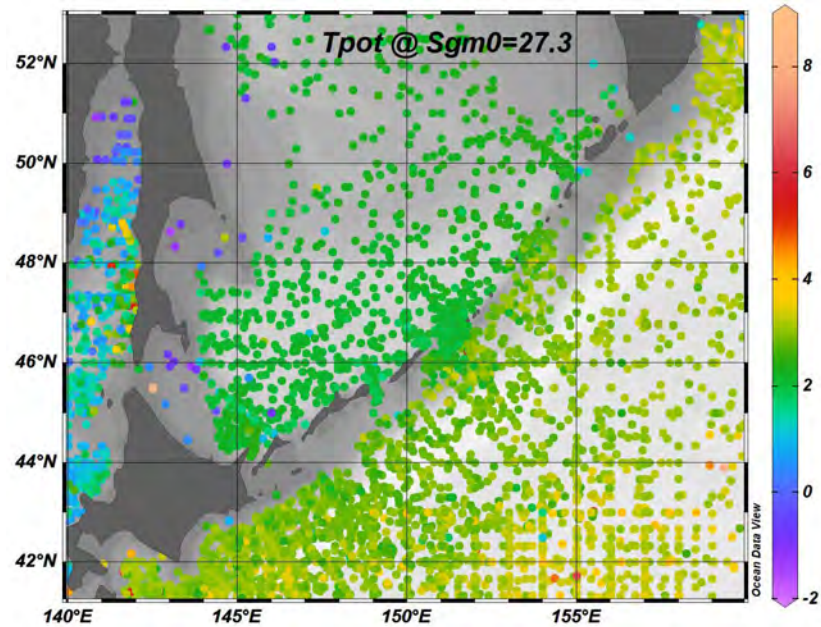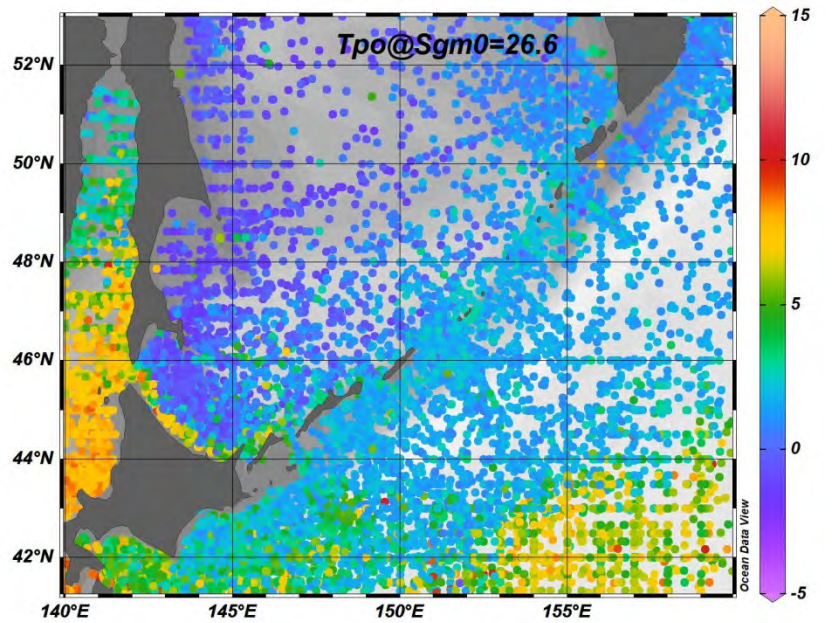**WOCE-P1W-section**, through Bussol Strait（1996/10/3-12）,

☐ **Freeland Gap = Sharp Front** formed at the sill.

　　= *Why this sharp front is kept, in spite of so strong mixing as the T_{pot}max to disappear?*

☐ *This can be a sign of unique mixing at the Kuril Ridge!*

☐ *Not shown by WOA data = wrong Basin-Mask design.*
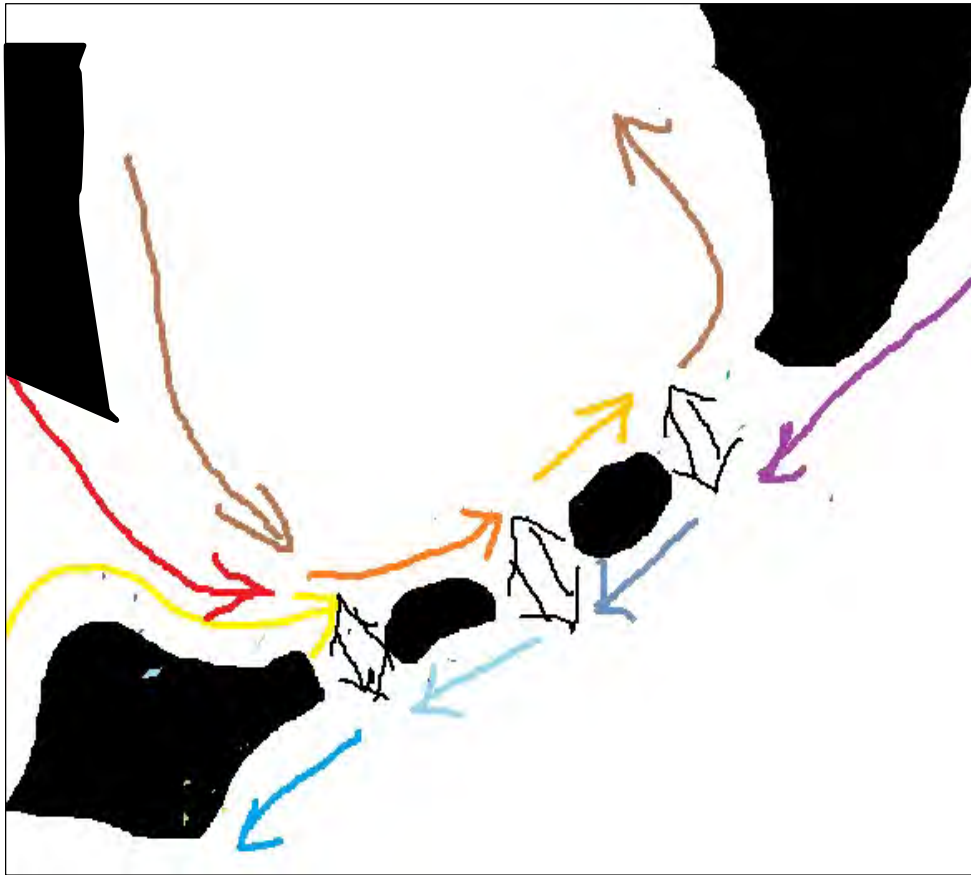
Freeland Gap from horizontal view

□ **Tpot@26.6σ_0**:   Middle of IntW;

   ✓JpnS–IntW, EskC–IntW, and EkmC–IntW.

□ **Tpot@27.0σ_0**:   Bottom of IntW;

   ✓JpnS–IntW, EskC–IntW, and EkmC–IntW.

□ **Tpot@27.3σ_0**:   Upper OkS–DpW,

   ✓ OkS–DpW, EkmC–DpW.

■ Counter Flow + Interface Mixing

   = Refreshing sharp front!

Counter Flow Mixing at Kuril Ridge

Counter flow mixing along Kuril Ridge

- ❑ **Counter Flow Mixing**
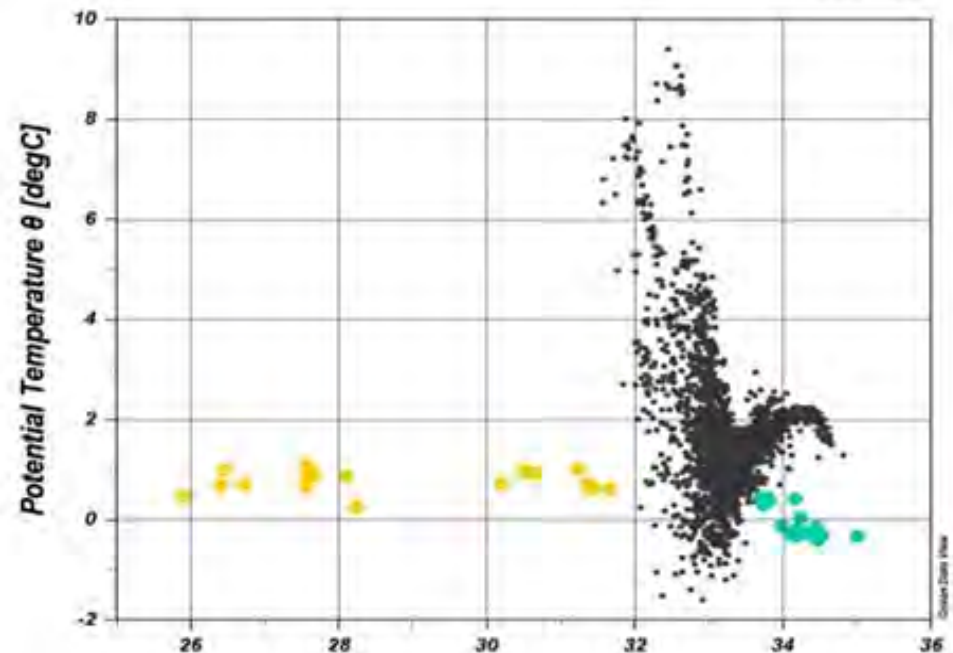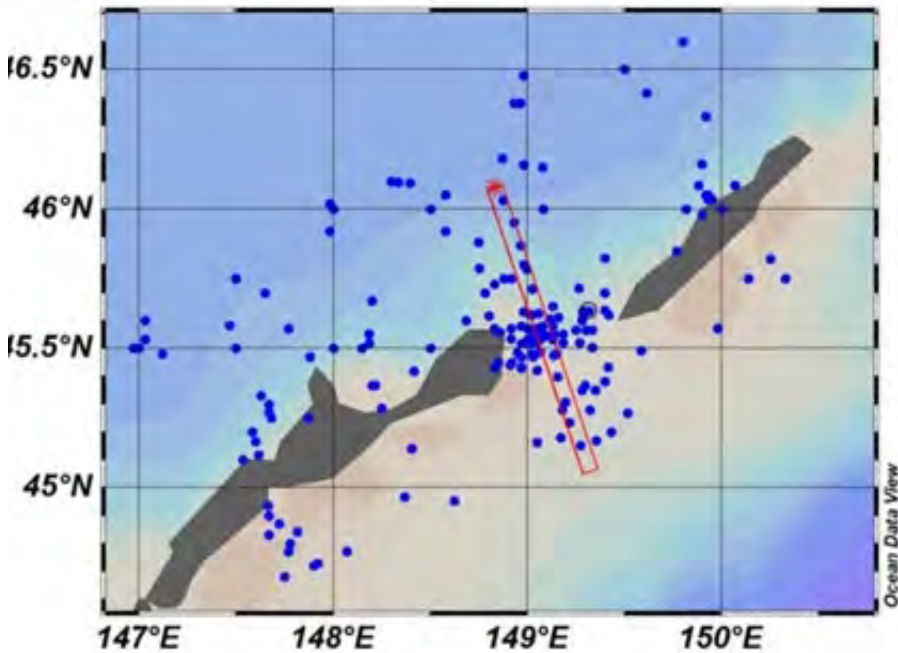 = **Mixing between opposite direction flows**
  = adopted in Counter Flow Type heat exchanger;
- ✓ Watermass of both currents are **changing toward down stream**, by result of mixing;
- ✓ The watermass **difference at interface is kept sharp**, by lateral transport of along Ridge flow;
- ✓ Relative strength of along ridge current and cross-ridge mixing can make different pattern from the case of Kuril Ridge mixing.

5. *Density Inversion at Friza Str.*   *Time change Obsv,(1988)*

Sgm0

dSgm0/dz

R/V A.A. Vinogredov / 8 June 1988

Stn 7079872
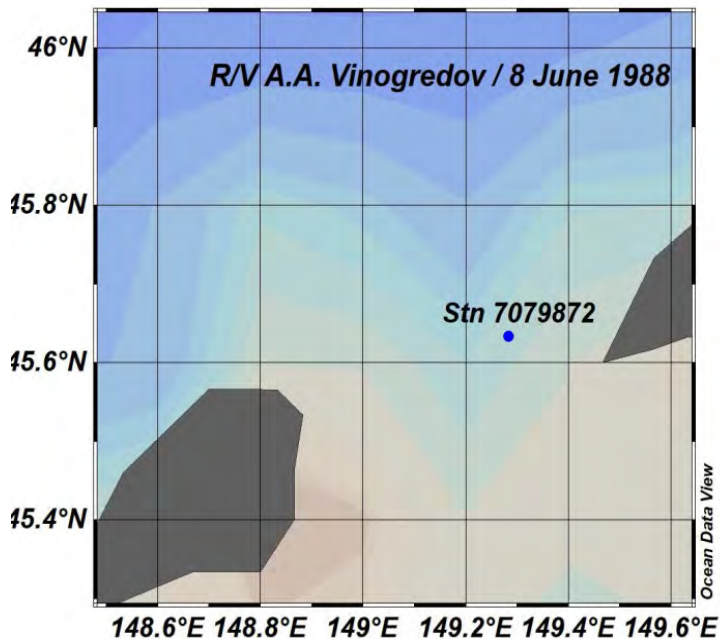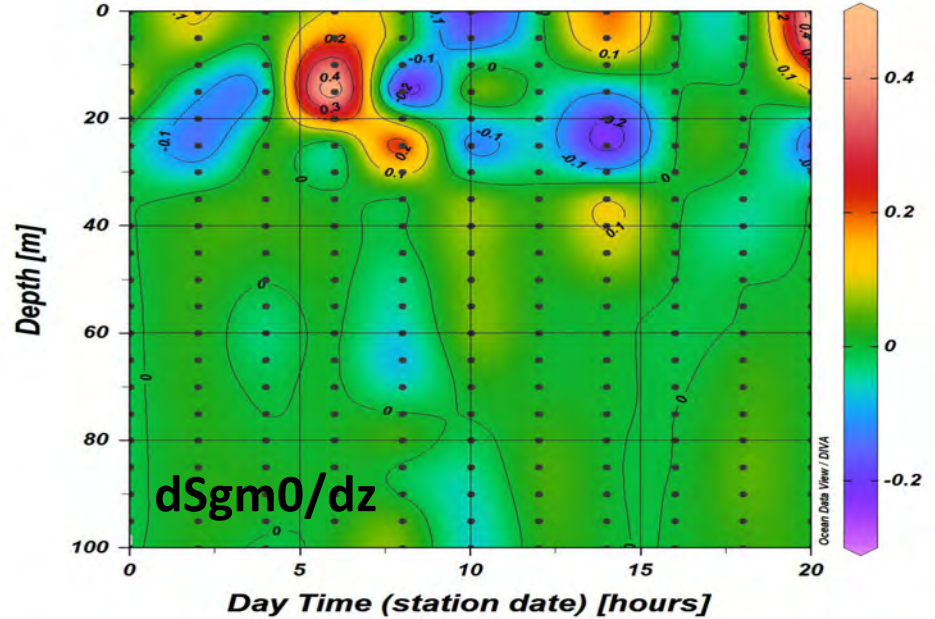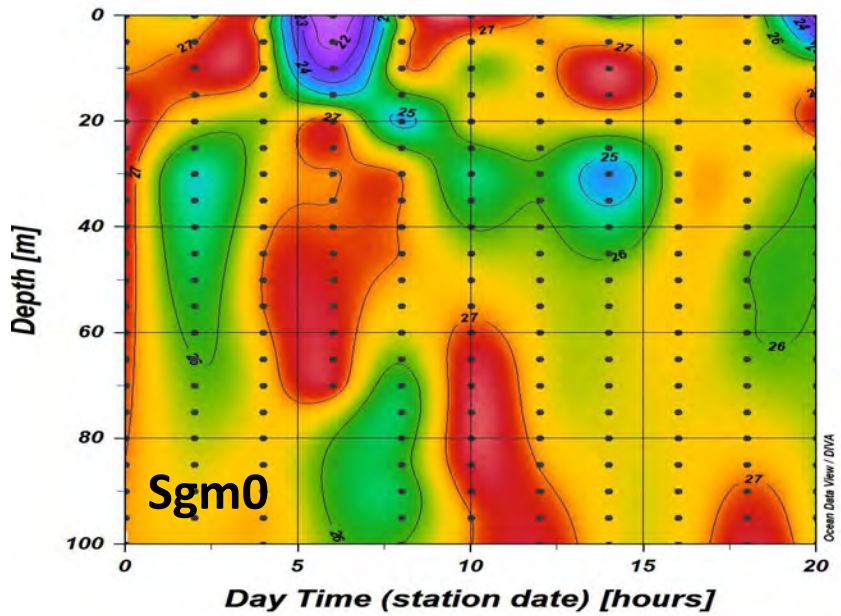
- ☐ (Bottom Left) Station of **Time change Obs.;**
- ☐ (Top Left) Time change of σ_0 **Profile**
  - ✓ **Water of $\sigma_0 \geq 27.0$** appear in the surface layer of **depth ≤ 20m** associated with low density of green patch;
- ☐ (Top Right) Time change of **$d\sigma_0/dz$ profile** :
  - ✓ **Strong density inversions** appear mainly in **depth≤25m** :

- ✓ Patch of **σ_0 min**:　　　1.4 ℃/ 25.7 psu　–　1.4 ℃ / 31.8 psu
　　　　　　　　　　　　0.0 ℃ / 25.7 psu　–　0.0 ℃ / 31.8 psu
- ✓ Patch of **σ_0 max**:　　0.52 ℃ / 33.63 psu　–　0.52 ℃ / 32.25 psu
　　　　　　　　　　- 0.66 ℃ / 33.63 psu　–　-0.66 ℃ / 35.25 psu

☐ **Source-waters of Inversions** are **not found in Near-Field**!

　　　Possible reason for missing ➡ Coarse data interval near bottom
　　　　　　　　　　　　➡ Transported in narrow band

■ *Results of Counter-Flow-Mixing*

Source of Friza Str. Inversions: Far-field
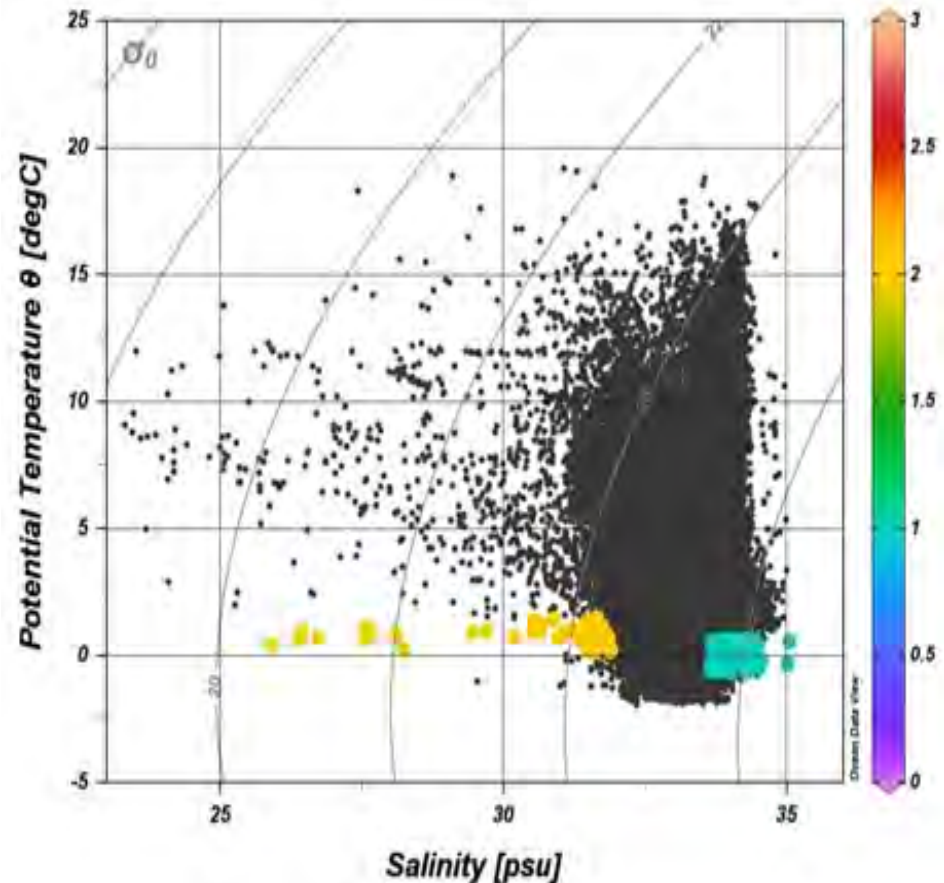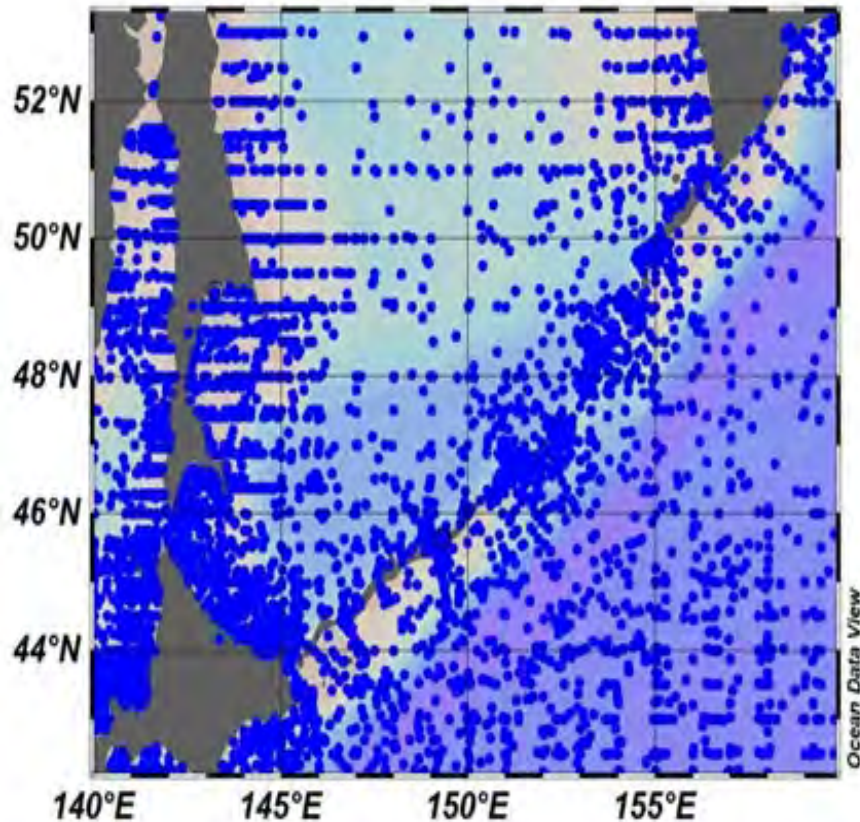
☐ Data of the **Far-Field** of Friza Strait and its TS-diagram

（**Yellow-Patch** : Patch of σ_0 min, **Green-Patch:** Patch of σ_0 max）

✓ Patches of source waters are almost overlapping with the data cloud of Far field.
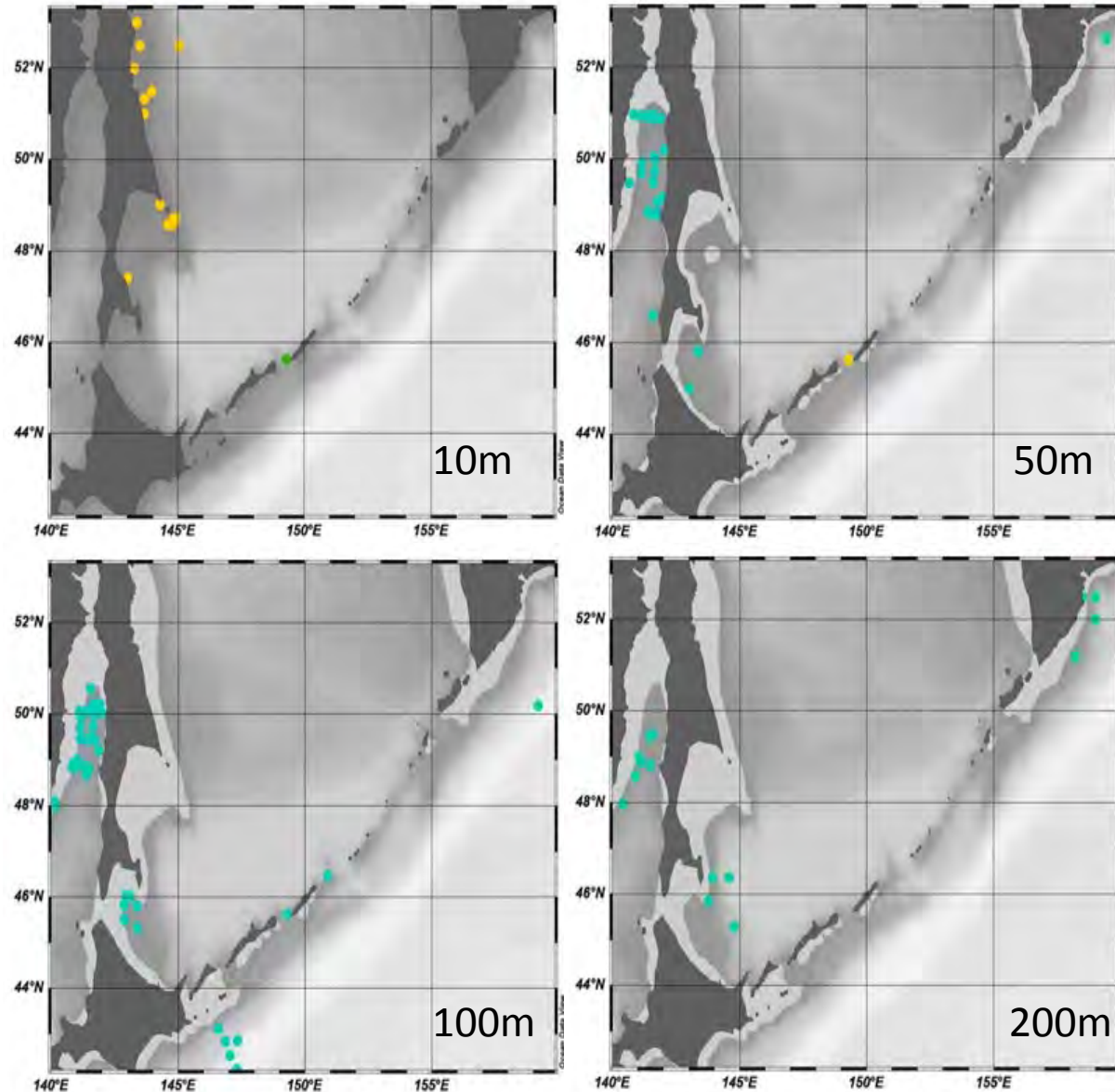
- ☐ σ_0 min (🟡):
  - ✓ **E-Sakhalin** 10m;
  - ✓ Friza Str. 50m
  - = **OkS- Dicothermal W**.
- ☐ σ_0 max (🟢):
  - ✓ **W-Sakhalin** 50m;
  - ✓ S-Sakhalin
        50 – 100m
  - ✓ **E-Kamchatka**
        500 – 200m
  - ✓ Friza Str. 100m
  - ✓ Urup Str. 100m
  - ✓ Off S–Kuril Isl. 100m
  - = **JpnS-IntW**

6. *Up-lifting of deep water at Kuril Straits*
Watermass composition of Kuril Strait water (%) by WOD13

0-1000m		0-200	200-400	400-600	600-800	800-1000
Winter	SfW	13.78	0.87	0.16	0.00	0.00
	IntW	84.72	93.43	72.97	31.73	5.39
	DpW	2.15	5.70	26.87	68.27	94.61
Spring	SfW	64.87	9.77	1.08	0.09	0.00
	IntW	34.67	87.36	79.84	26.18	0.77
	DpW	0.46	2.87	19.08	73.73	99.23
Summer	SfW	27.53	0.42	0.07	0.00	0.00
	IntW	72.52	97.33	77.69	17.78	1.50
	DpW	0.25	2.24	22.24	82.22	98.50
Autumn	SfW	34.01	0.47	0.00	0.00	0.00
	IntW	65.10	94.52	76.78	21.60	2.08
	DpW	0.88	5.01	23.22	78.40	97.92

- ☐ SfW reach 27.1 σ_0 during winter-spring;
- ☐ DpW is up-lifted beyond 600m (in winter), up to surface 0 – 200m:
  = 27.1 σ_0 is the limit of ventilation for Kuril Water;
- ☐ 27.1 σ_0 is the boundary of IntW and DpW, at 600m;
- ☐ Mixing of IntW and DpW occurs beyond 600m(27.1 σ_0);

8. Summary

☐ **Density Inversions** at the Kuril Straits:
- ✓ Source waters of Density Inversions come from far field:
  - = e.g. σ_0 min water = EskC-IntW; σ_0 max water = JpnS-IntW
- ✓ Ventilation limit of OkS-W 27.1σ_0, can be reflection of ventilation of JpnS-IntW.

☐ **Freeland "Gap"** is a sign of Counter-Flow-Mixing at the Kuril Ridge:
- ✓ Results of mixing at the Straits are conveyed by along ridge flows of opposite direction, and sharp front at interface is kept;
- ✓ Along ridge flow conveys source waters from far-field to the Straits, and forms Density Inversions;

☐ **Deep Water is** up-lifted at Kuril Ridge.
- ✓ DpW can contribute in formation of IntW;
- ✓ Mixing of IntW and DpW occurs beyond 27.1σ_0(600m);
- ✓ Ventilation of Kuril Ridge Water reach down to 27.1σ_0(600m)

☐ **Inferable results** : the **Counter-Flow-Mixing** at the Kuril Ridge**;**
- ✓ can amplify 18. 6-yrs signal, because the flows around the are driven by diurnal tide, it is highly possible that;
- ✓ can transfer changes of Subarctic Circulation into the Okhotsk Sea,