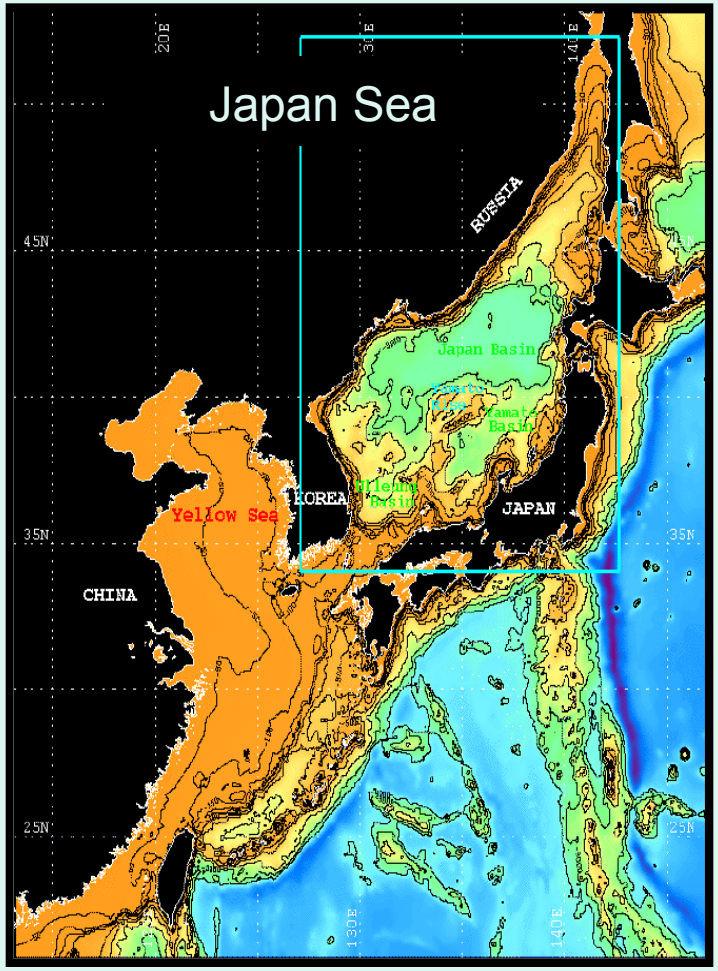
# Cascading of Dense Water along the Peter the Great Bay Slope in the northwestern Japan Sea

*V.Lobanov, A.Sergeev, I.Gorin, P.Scherbinin, A.Voronin, D.Kaplunenko, O.Popov, T.Gulenko and S.Ladychenko*

V.I.Il'ichev Pacific Oceanological Institute,
Far Eastern Branch, Russian Academy of Sciences,
Vladivostok, Russia

# Japan Sea – geographic features




- Deep semi isolated basin (>3500 m)
- Inflow of Tsushima Warm Current from the south
- Strong seasonal variations, ice formation
- Winter monsoon winds bring cold dry air mass
- Convective processes in the northern area control water mass properties
- Deep convection and fast renewal of deep water

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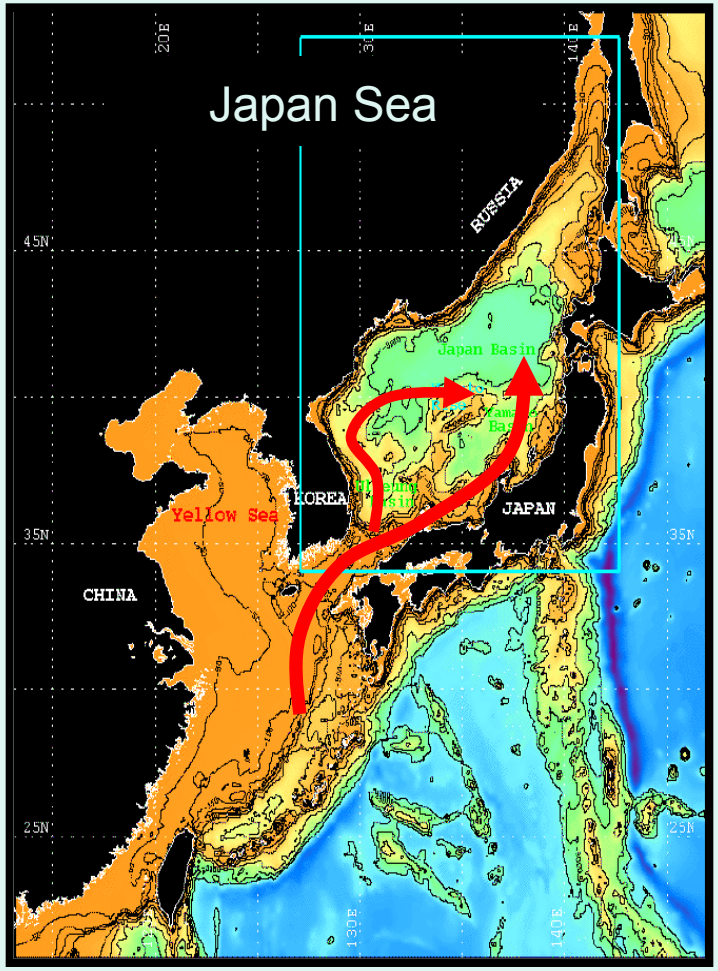


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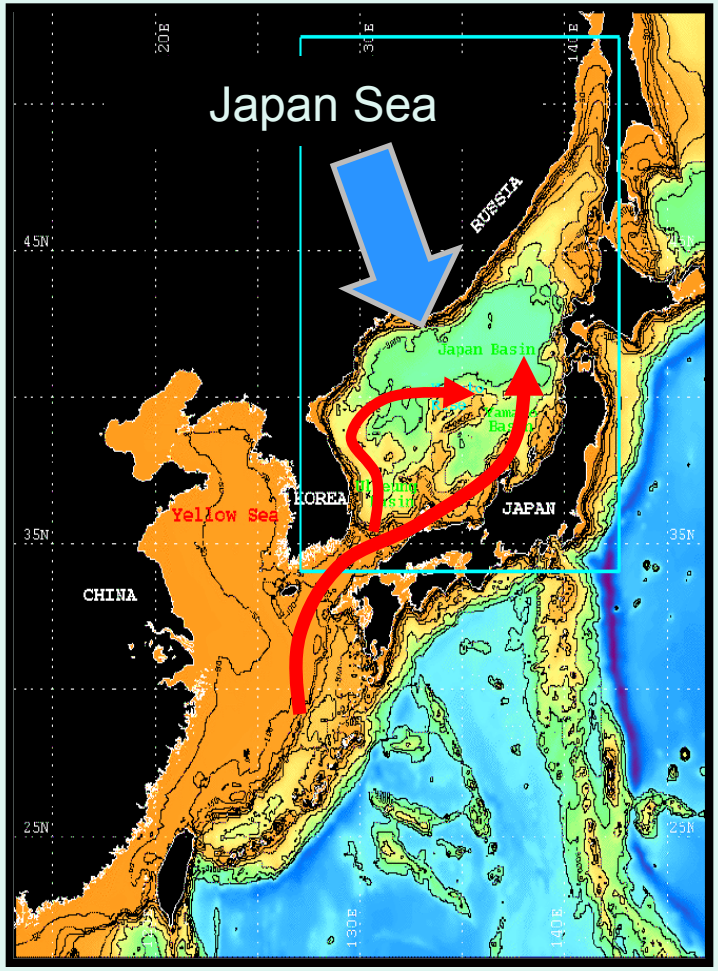


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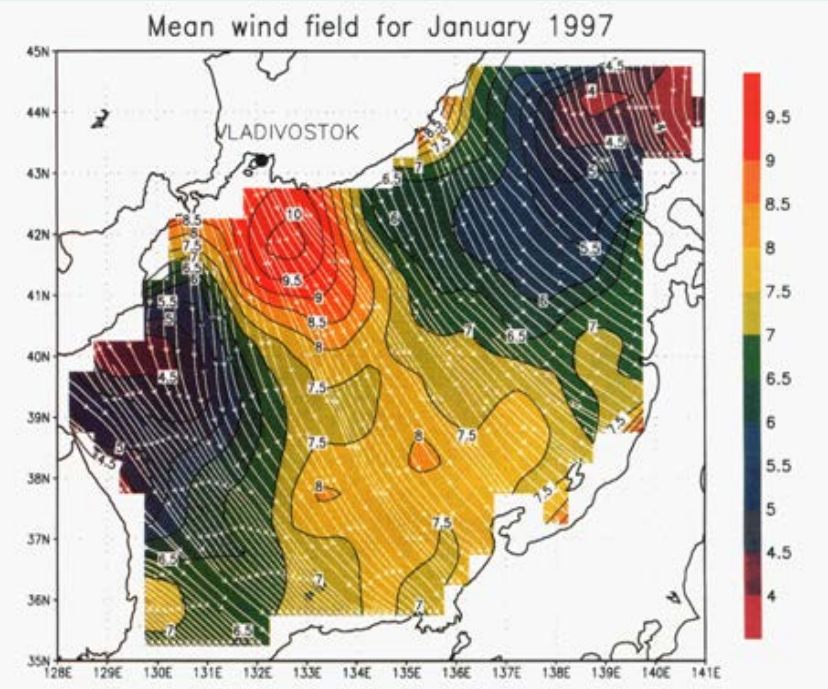
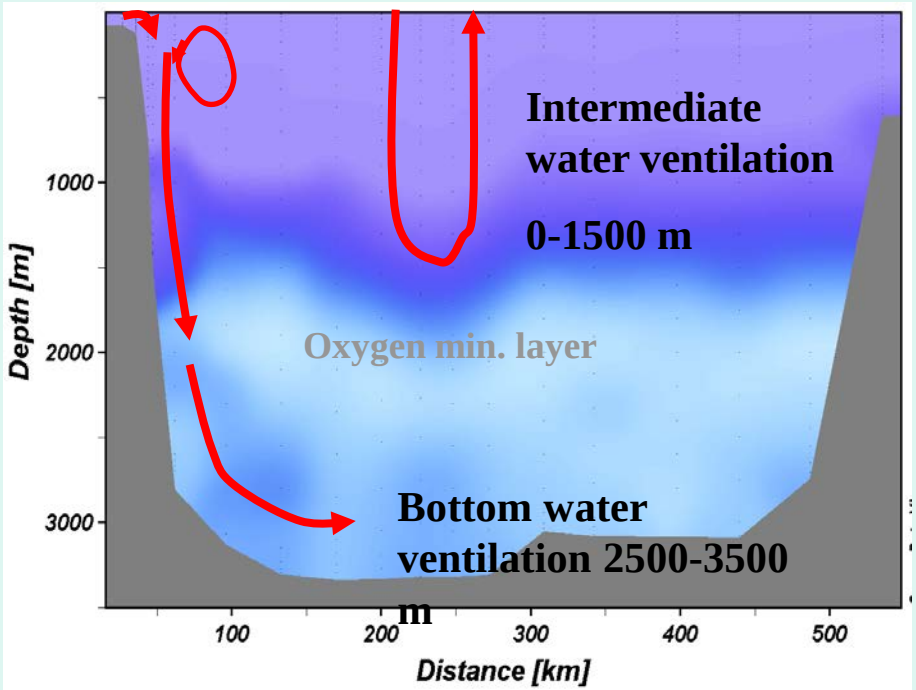
# Winter convection processes

Typical winter winds pattern
(Kawamura et al., 1999)




**Brine rejection and slope convection**

**Open sea convection**



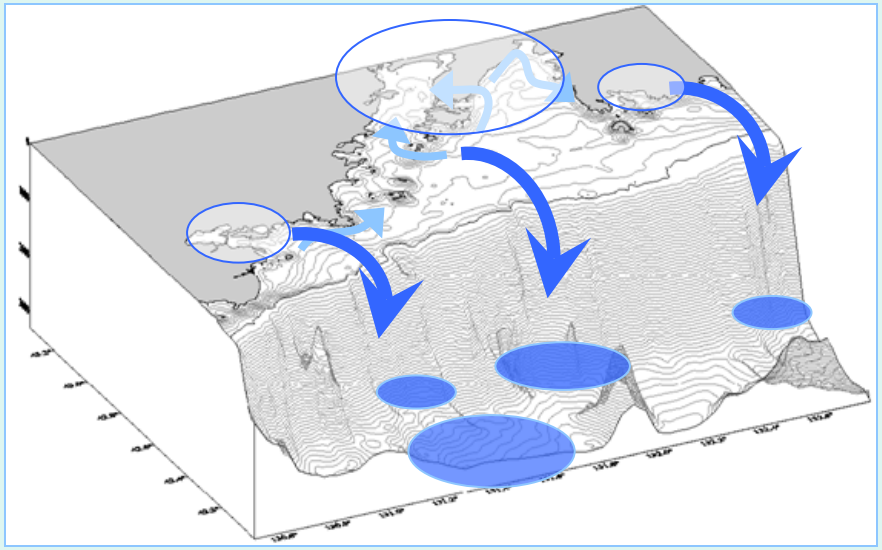

Ventilation rates - turnover time:

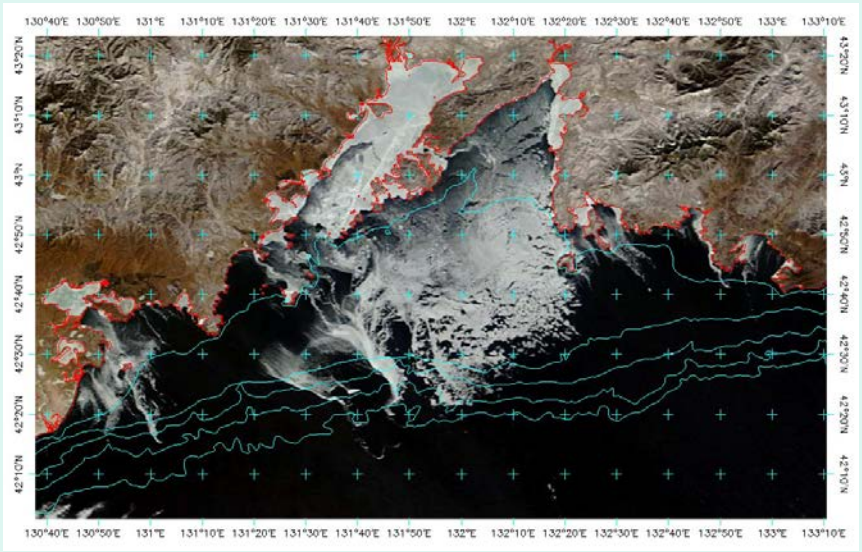
300 yr - radiocarbon (Gamo and Horibe, 1983)
300-400 yr -radium-226 (Harada and Tsunogai, 1986)

100 yr - tritium (Watanabe et al., 1991)
100 yr - radiocarbon (Kumamoto et.al, 1998)

**uncertainties indicate non permanent process of ventilation with large inter-annual variations (episodic events?)**

# Cascading in Peter the Great Bay






**- sea ice formation and brine rejection**
**- fasten (stable) ice and drifting ice**

"Cascading" is a sinking of dense waters flowing from shelf seas down the continental slope. It occurs where dense water - formed by cooling, evaporation or ice-formation with brine rejection over the shallow continental shelf - spills over the shelf edge and descends the continental slope as a near-bottom gravity current. During its descent, the plume is modified by mixing and entrainment, and detaches off the slope when reaching its neutral buoyancy level. Observed at many slope locations of the world ocean (e.g. Shapiro and Hill, 1997; Shapiro et al., 2003; Ivanov et al., 2004; Canals et al., 2006; etc.)

- contributes to ocean ventilation and water mass formation and hence ocean circulation;
- vertical flux of chemical components;
- transport of sediments, etc.

# Cascading at PGB - previous studies

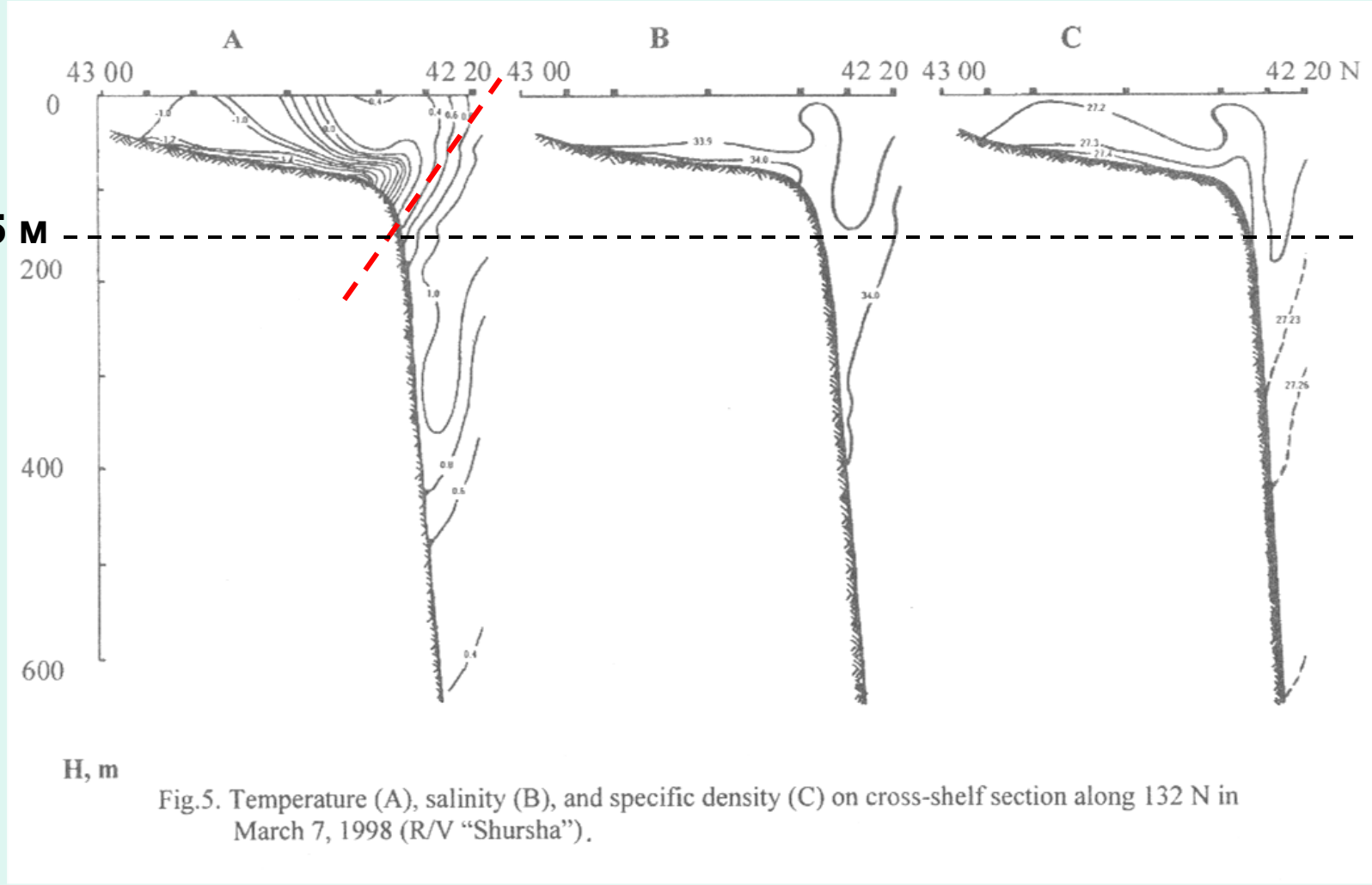
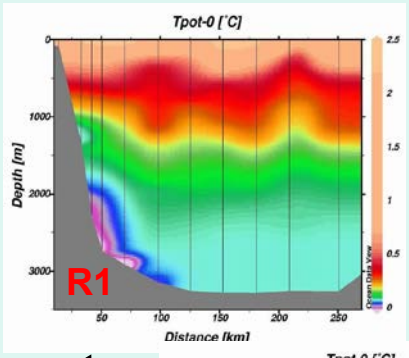
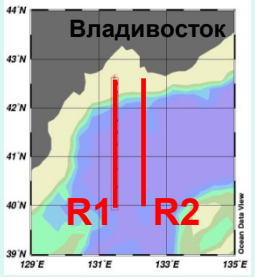



Fig.5. Temperature (A), salinity (B), and specific density (C) on cross-shelf section along 132 N in March 7, 1998 (R/V "Shursha").

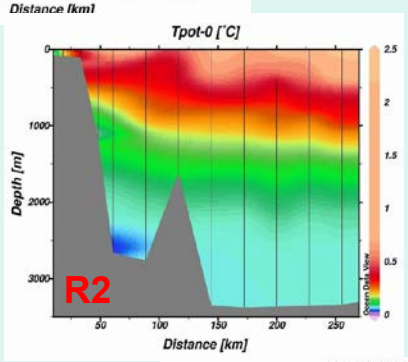
Zuenko, 1998; 2000

# Evidence of Cascading in a severely cold winter of 2001
## and Ventilation of Bottom Water



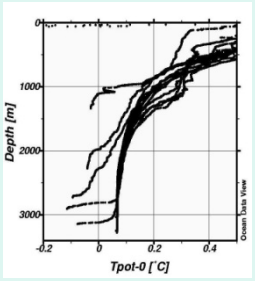



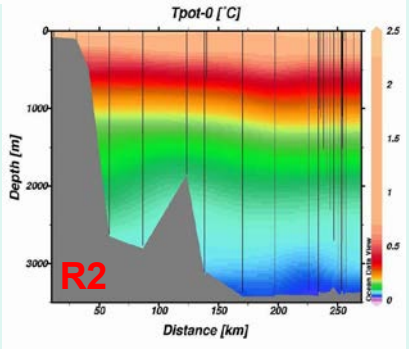

February

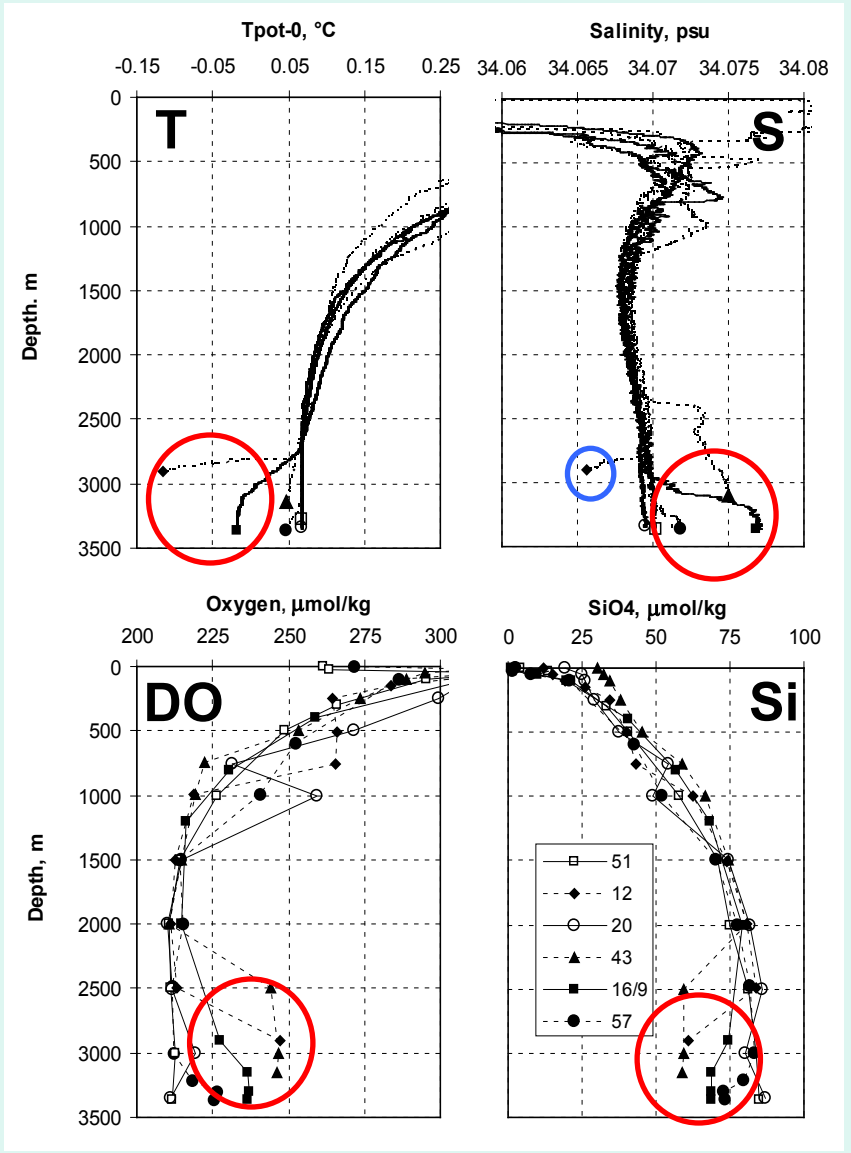



March →

April-May →



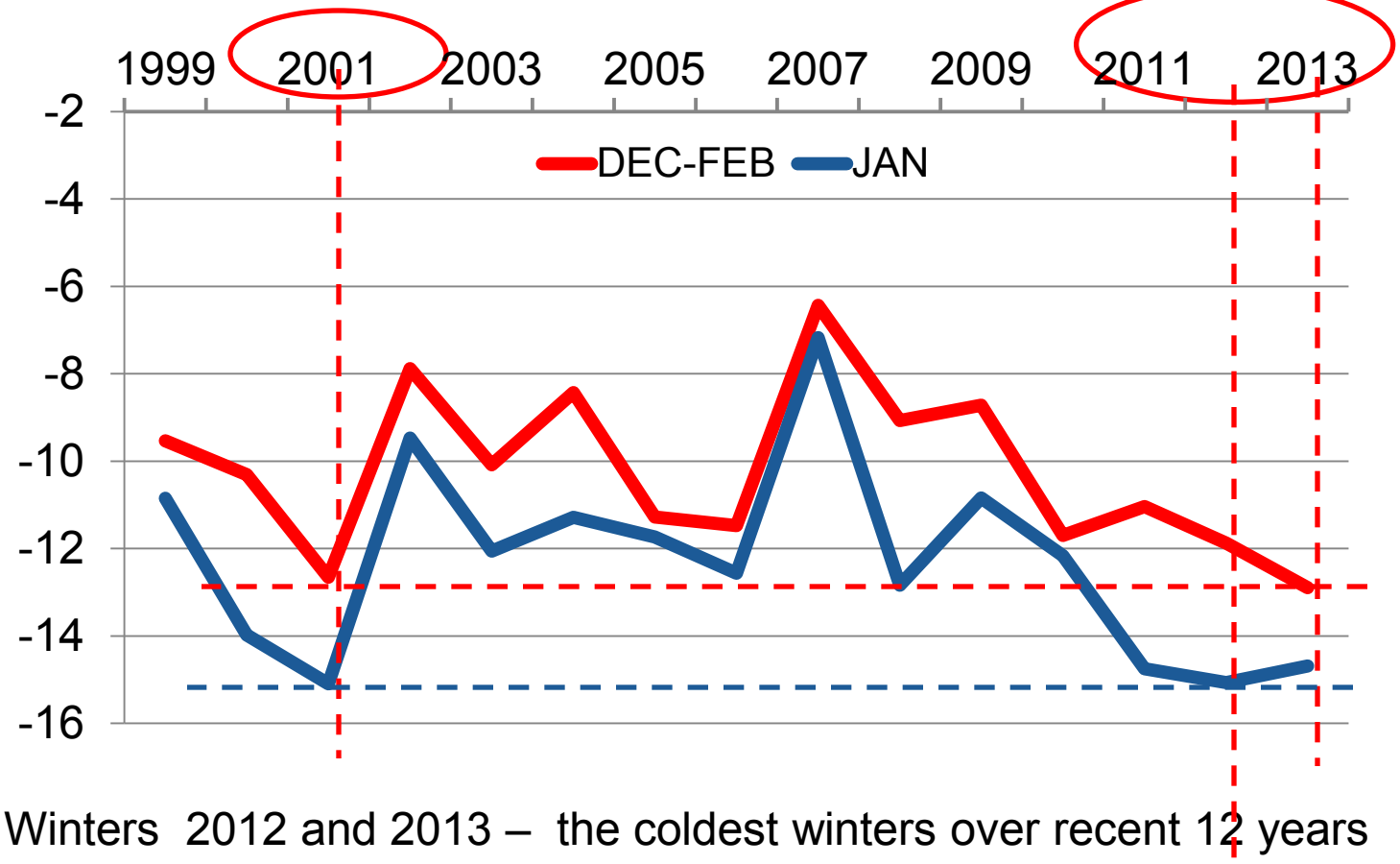




*Lobanov et al., 2002; Kim et al., 2002; Senjyu et al., 2002; Talley et al., 2003; Tsunogai et al., 2003*

# Winter air temperature in Vladivostok

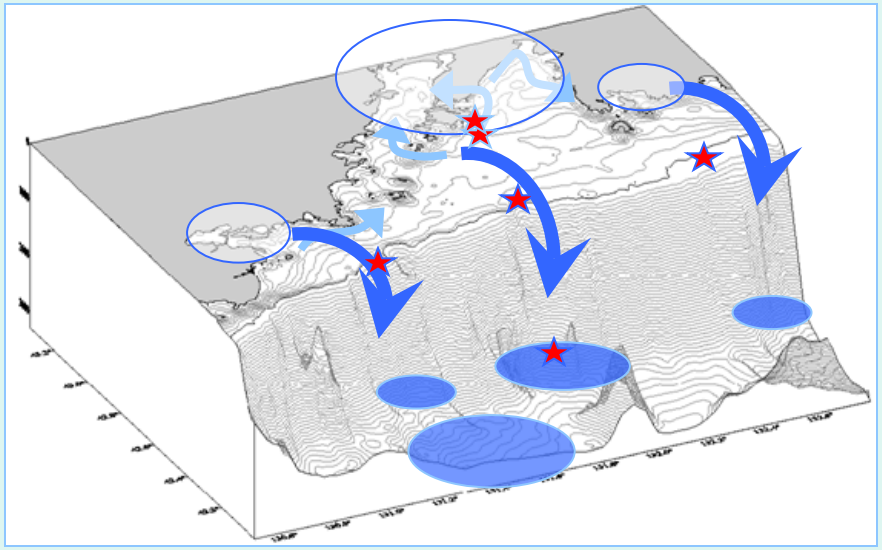
(mean January and mean Dec-Feb)

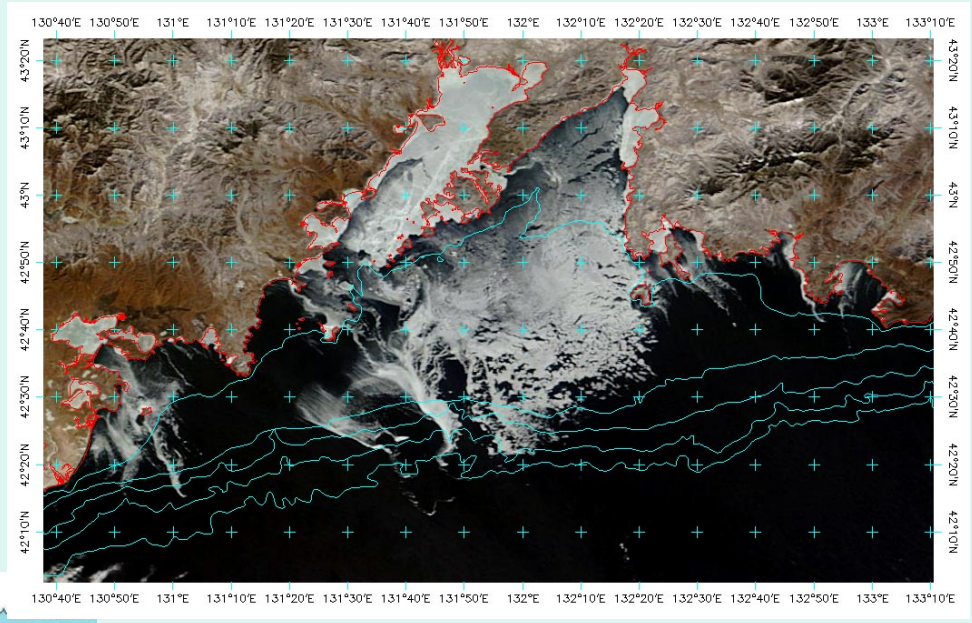


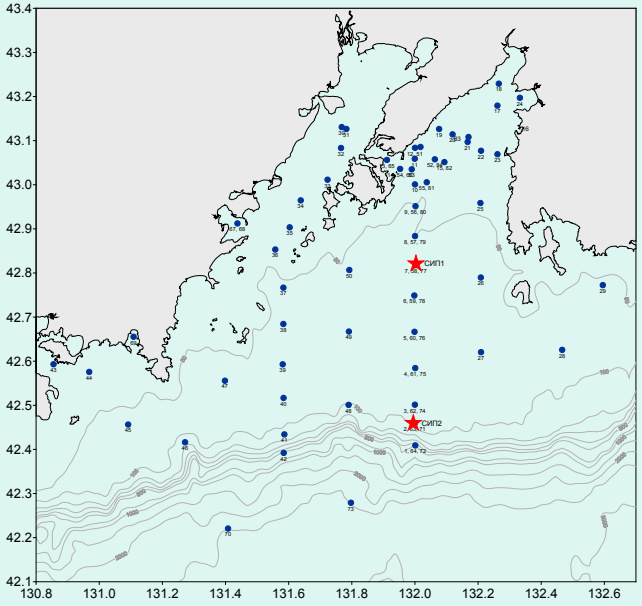

Winters 2012 and 2013 – the coldest winters over recent 12 years and second coldest January T over 35 years after 2001

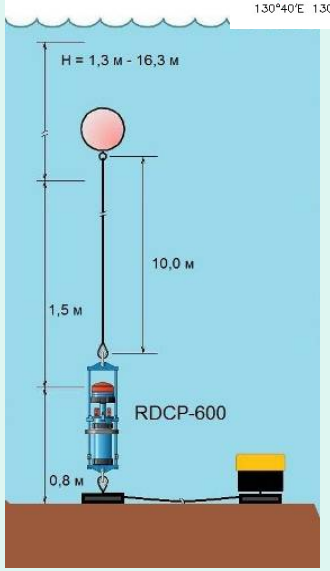
# Observations of cascading in PGB

## during cold winters 2010-2013






- CTD surveys (SBE19, SBE911, RBR-XR);

- Moorings with T, S, DO, Turb, Flu and current meters (SBE37, RBR-XR, S4, RDCP600)

# Pre-conditions for cascading

- If there is enough dense water forms on the Peter the Great Bay shelf?

- Its distribution and propagation toward the slope

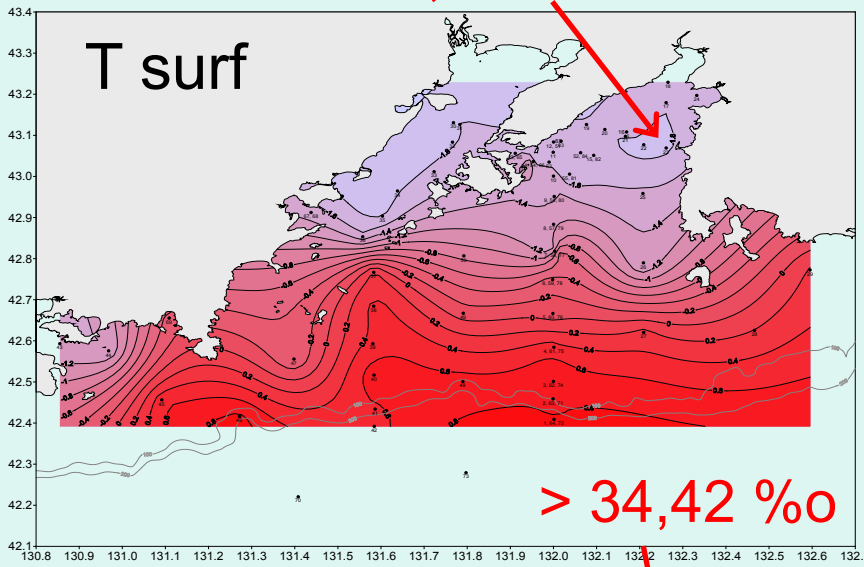
> CTD surveys

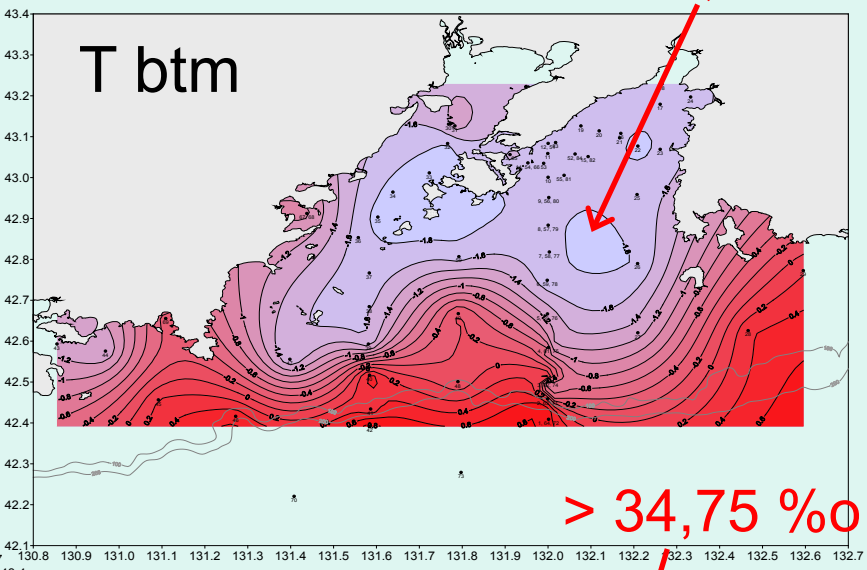
# T and S at the surface and bottom layer of Peter the Great Bay

27.02-16.03.2010

< -1,82 C

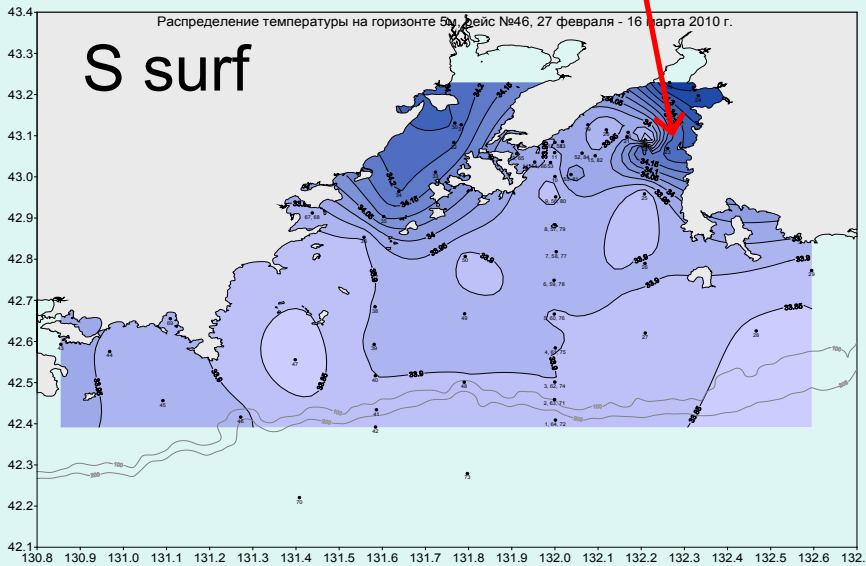
< -1,88 C

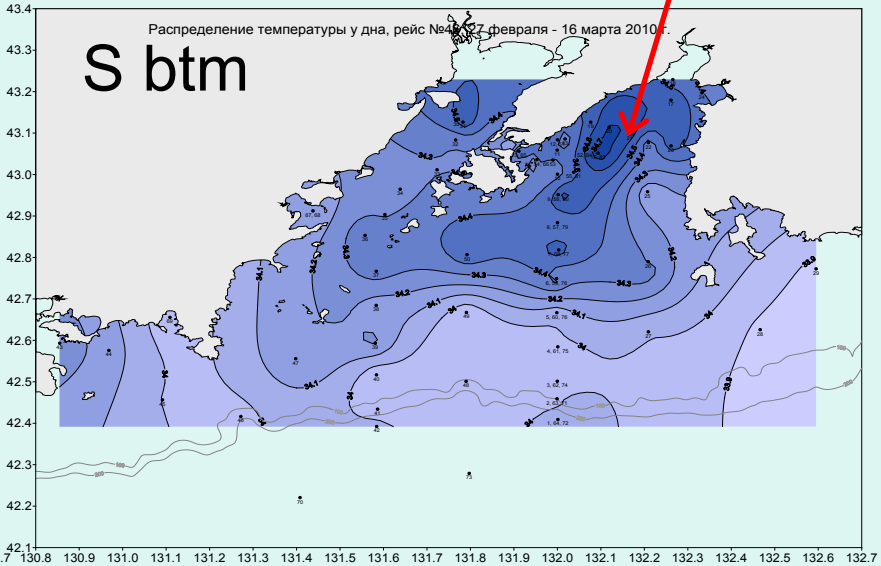



> 34,42 ‰

> 34,75 ‰

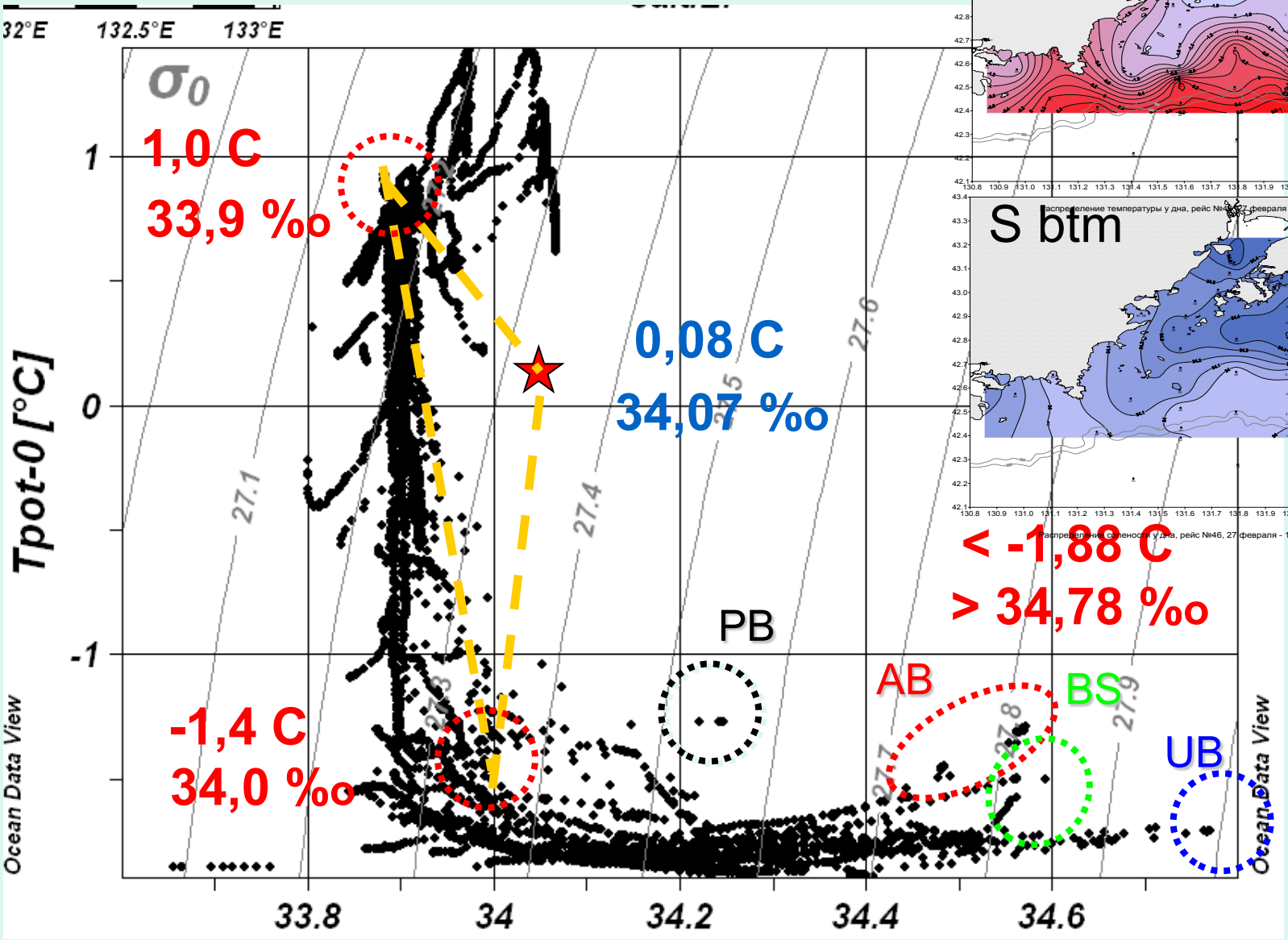


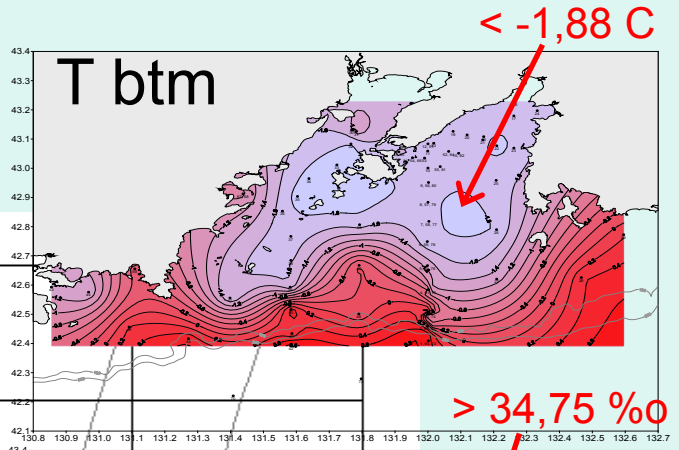




Распределение солености на горизонте 5м, рейс №46, 27 февраля - 16 марта 2010 г.

Распределение солености у дна, рейс №46, 27 февраля - 16 марта 2010 г.

# T, S diagram, Feb-March

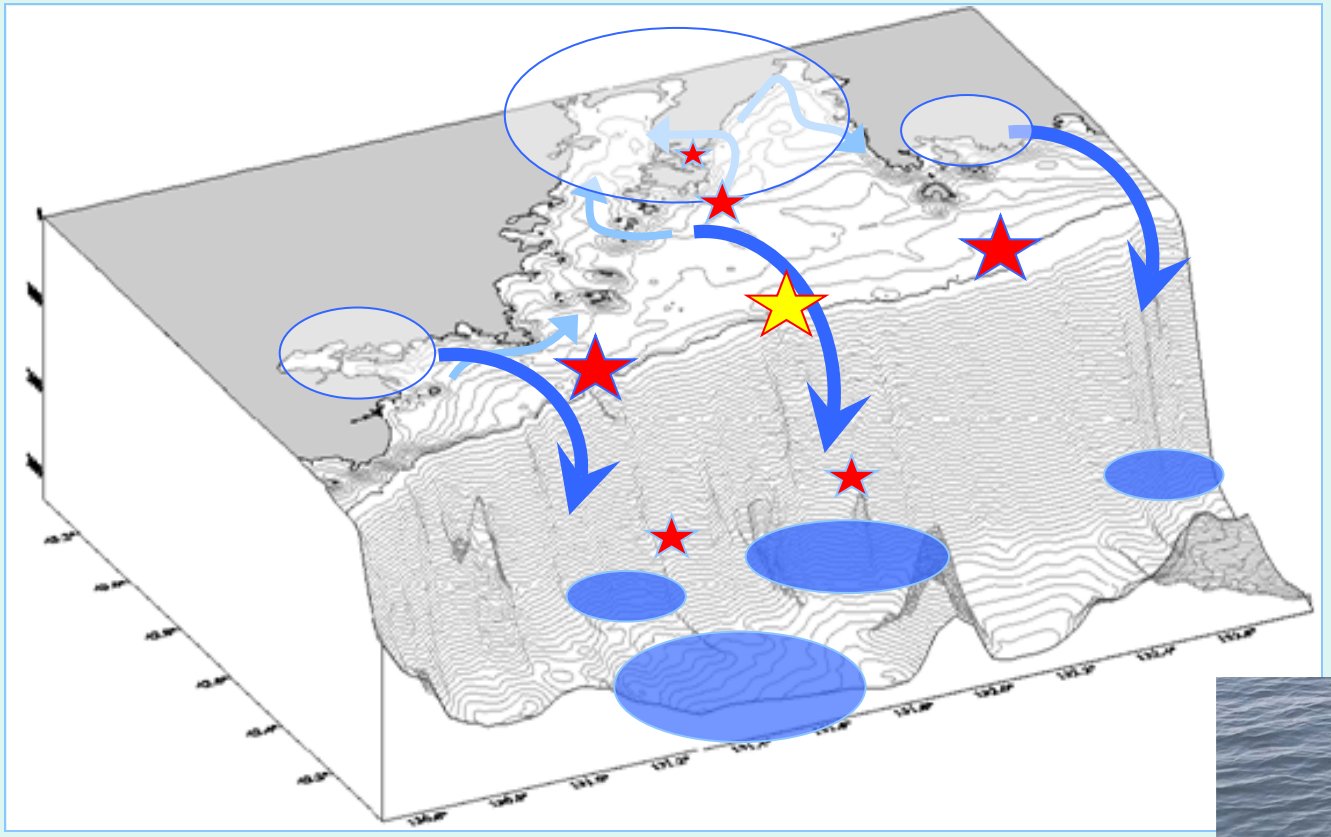


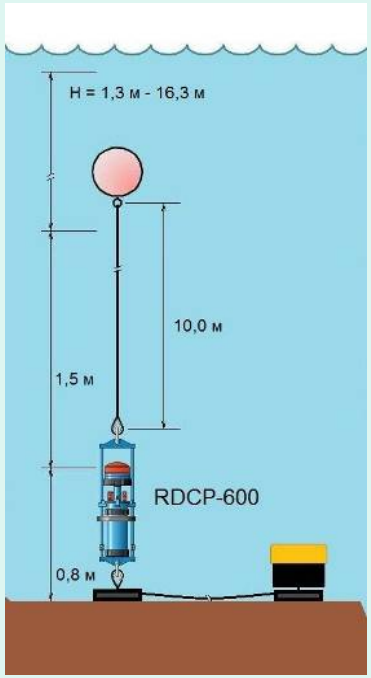



# Spatial and temporal scales of cascading

> mooring observations

# Shelf edge moorings 2011-2013

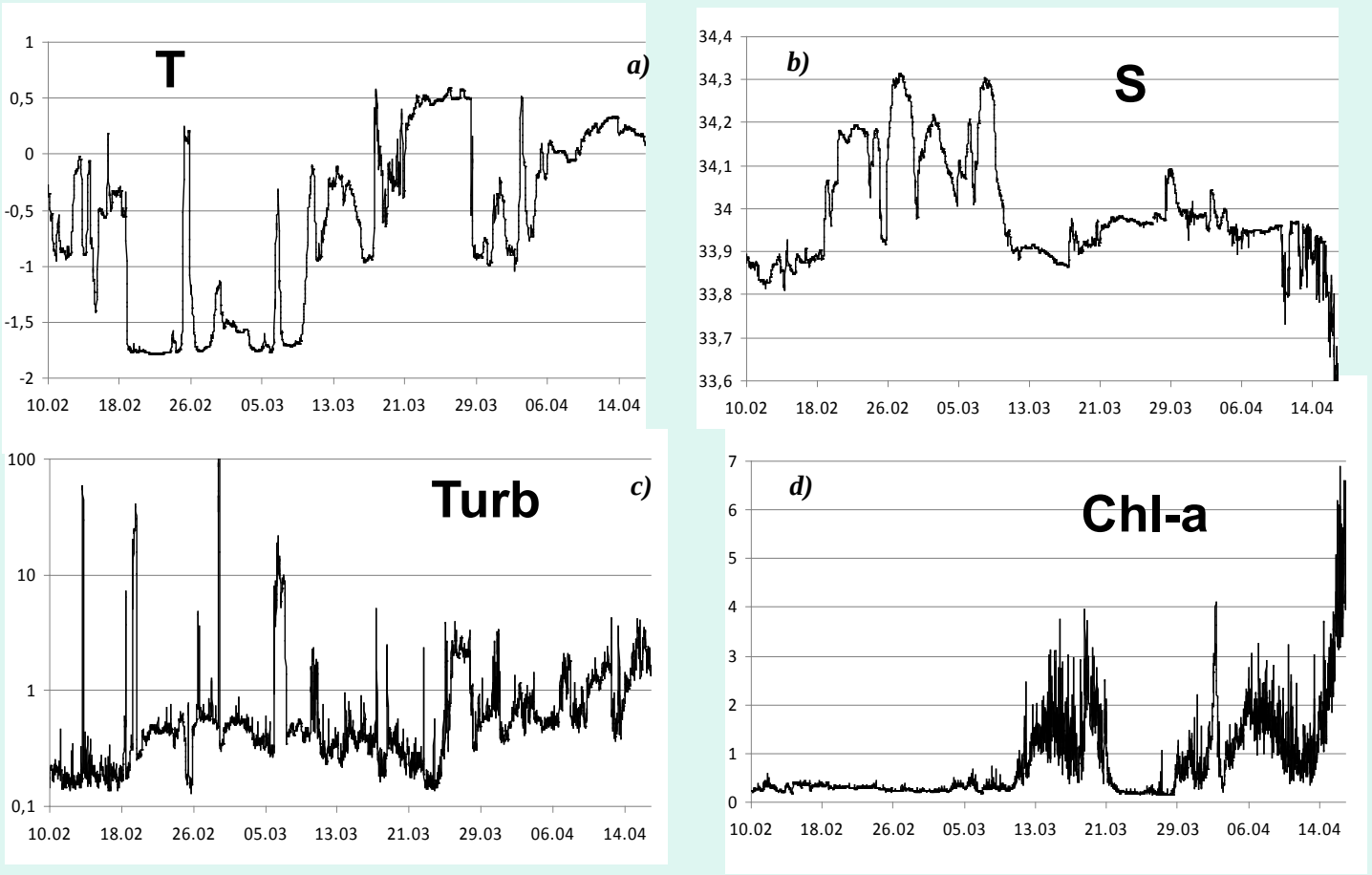





Moorings with T, S, DO, Turb, Flu and current meters (SBE37, RBR-XR, S4, Infinity EM, RDCP600, WHS300)

# Slope Convection in winter 2012

## mooring period Feb 10 – Apr 17




*Variability of water temperature (a), salinity (b), turbidity (c) and chlorophyll-a concentration (d) in the bottom layer at the shelf edge of Peter the Great Bay in the period February 10 – April 17, 2012.*

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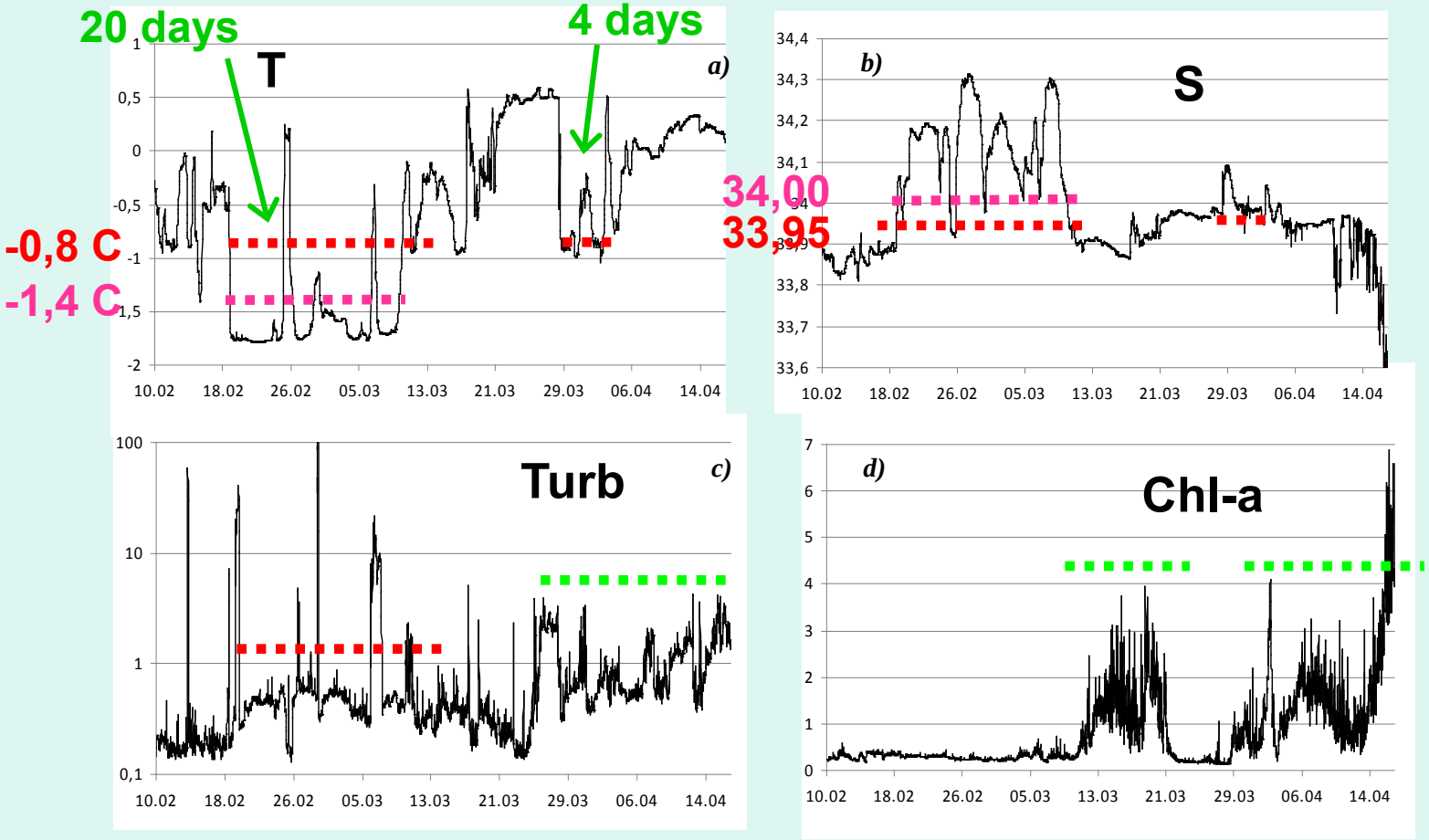


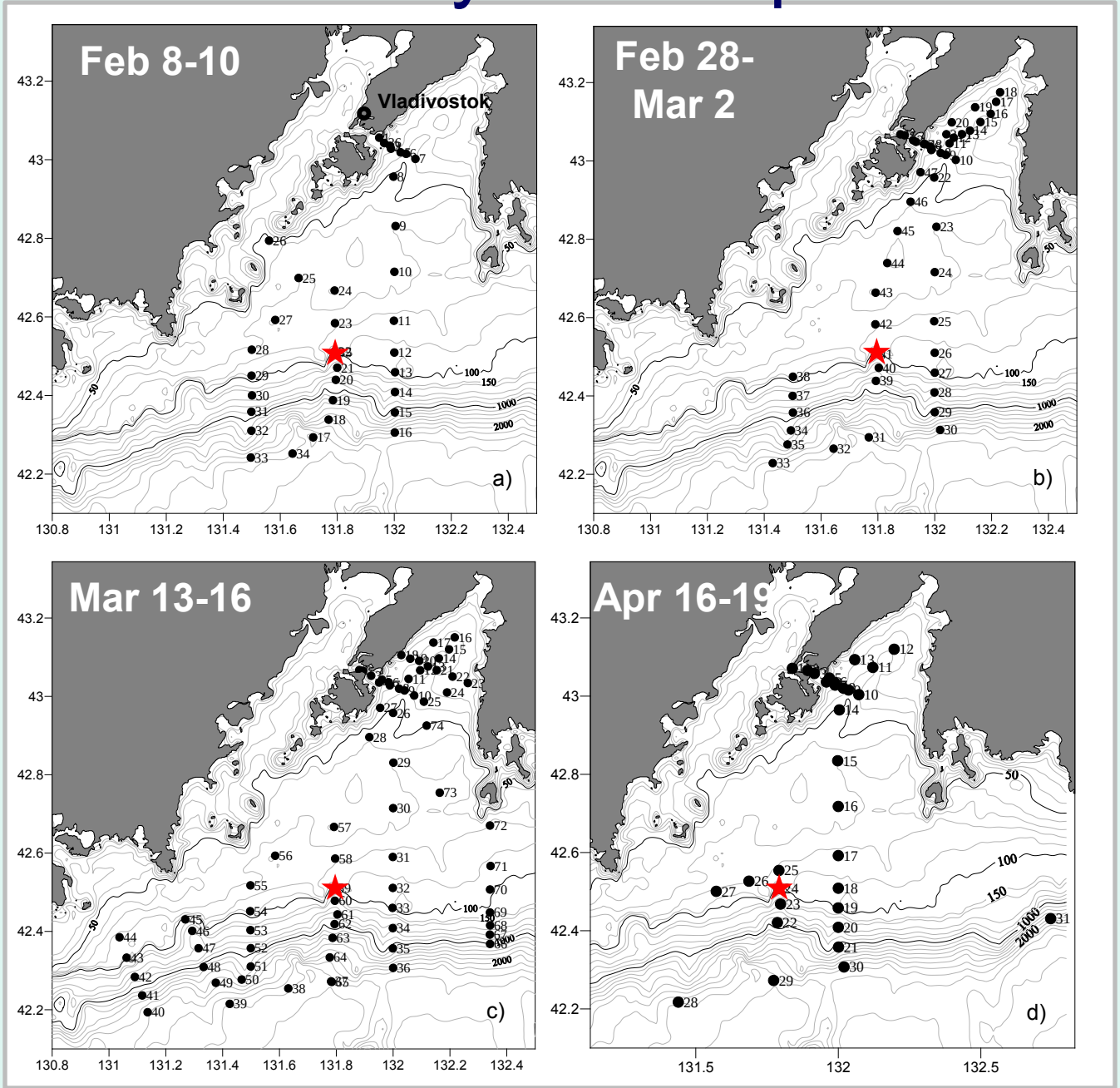

**Sigma theta > 27.33 – Feb 19-Mar 10 and Mar 28-30**

*Variability of water temperature (a), salinity (b), turbidity (c) and chlorophyll-a concentration (d) in the bottom layer at the shelf edge of Peter the Great Bay in the period February 10 – April 17, 2012.*

# Deep penetration of cascading water

> 4 CTD surveys in 2012

# CTD surveys Feb-Apr 2012



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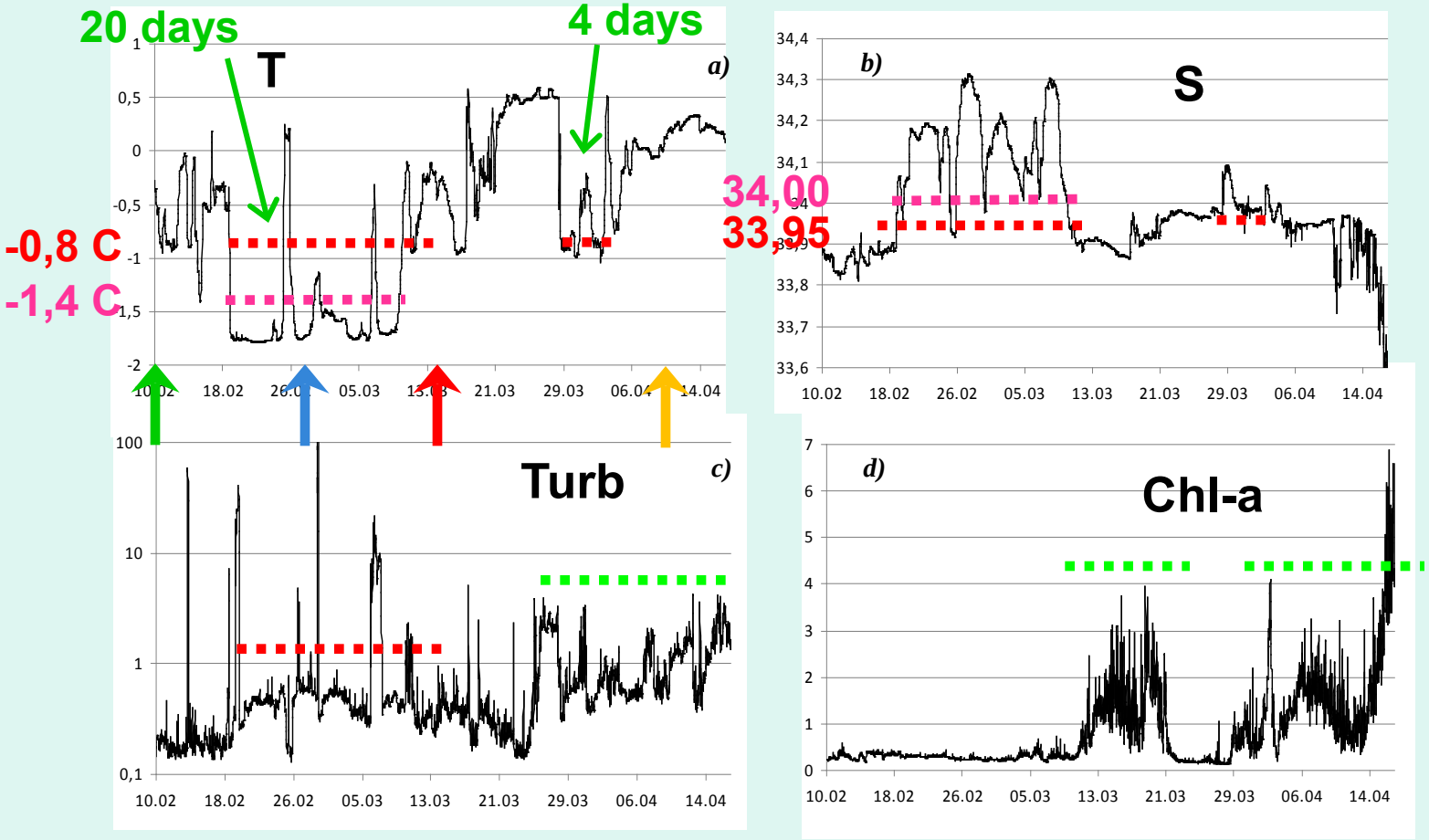
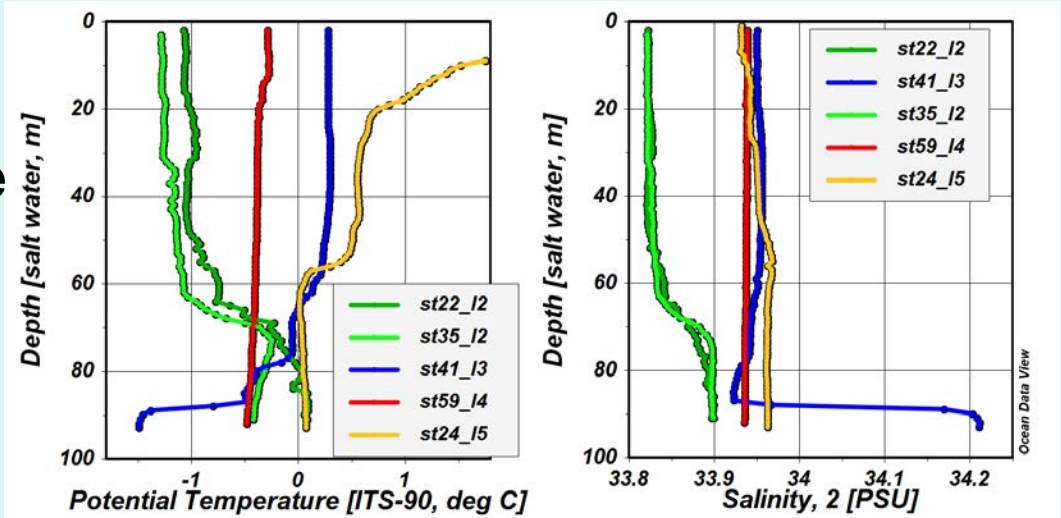



**Sigma theta > 27.33 – Feb 19-Mar 10 and Mar 28-30**

**CTD: ___ Feb 08, ___ Mar 01, ___ Mar 15, ___ Apr 17**

# Dense water approaches the shelf edge, 2012

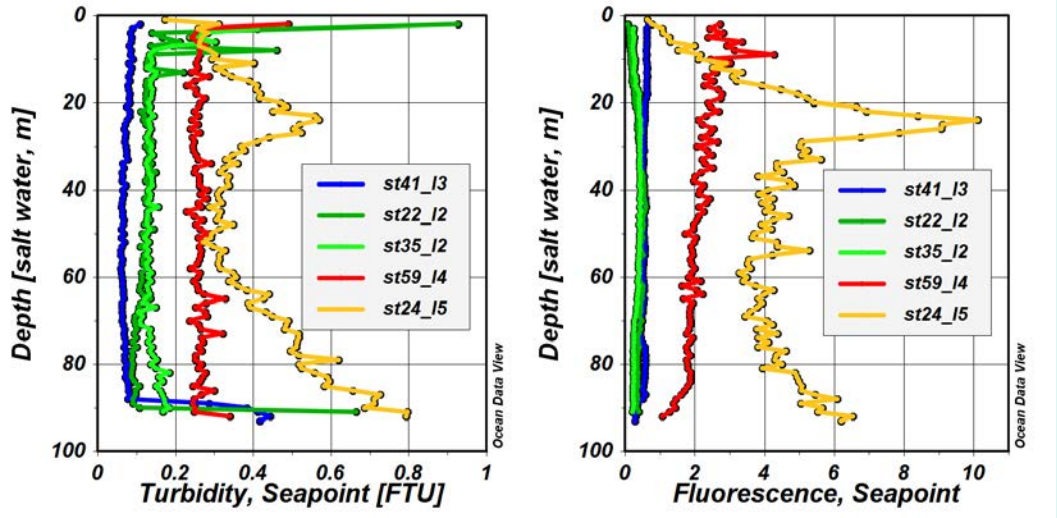
Temperature




Salinity




Turbidity

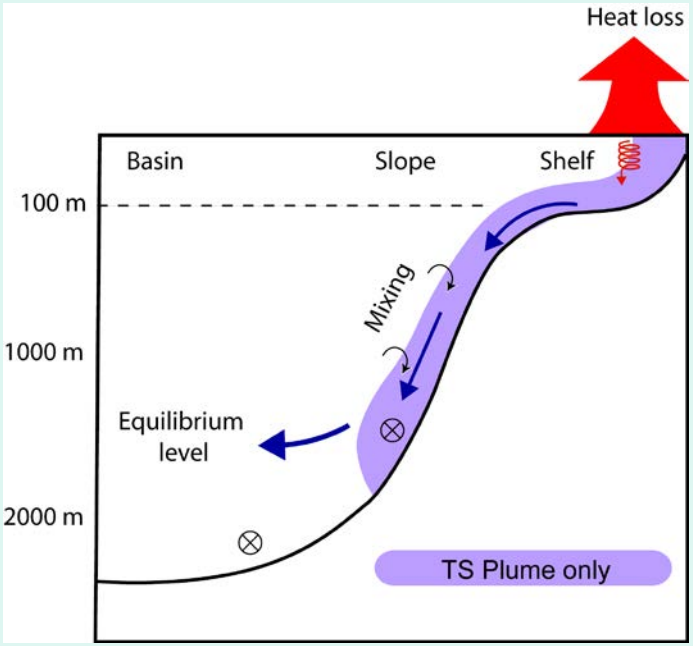


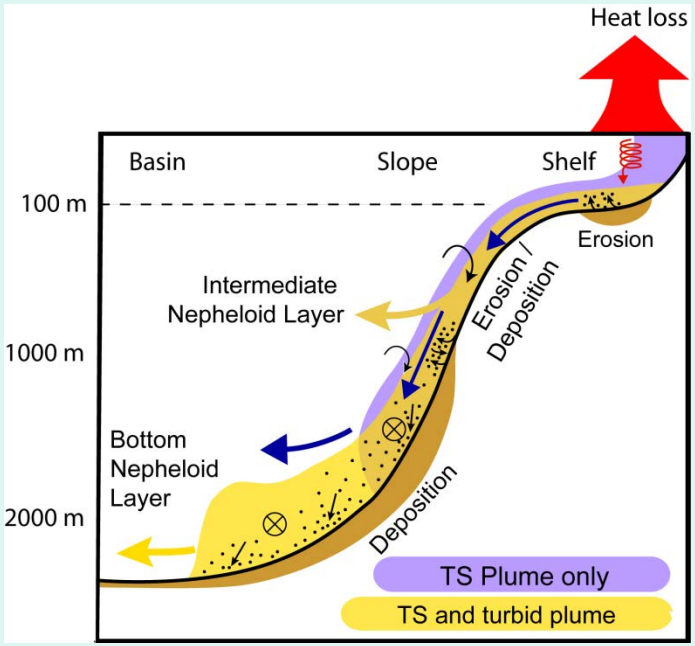

Chl-a




**Feb 08, Mar 01, Mar 15, Apr 17**

# Cascading along continental slope




(Adapted from Fohrmann et al, 1998 and DeMadron et al., 2012)

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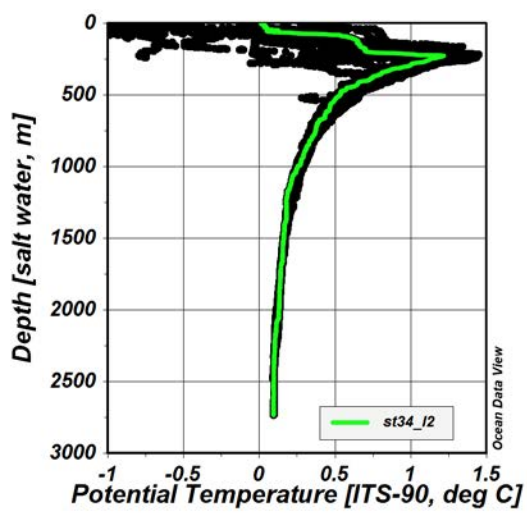
- contributes to ocean ventilation and water mass formation and hence ocean circulation;
- vertical flux of chemical components;
- transport of sediments, etc.

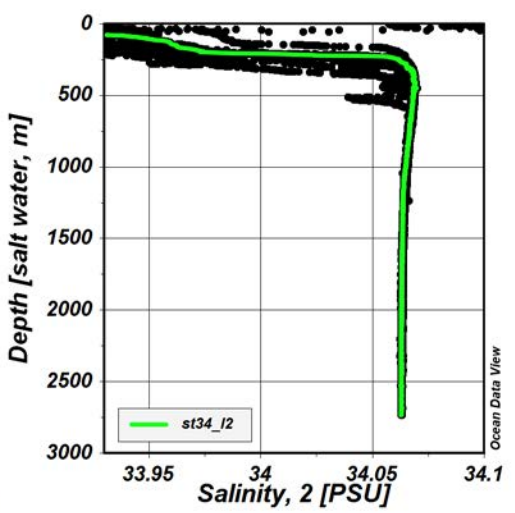
# Cascading at Peter the Great Bay, 2012:

## February 8

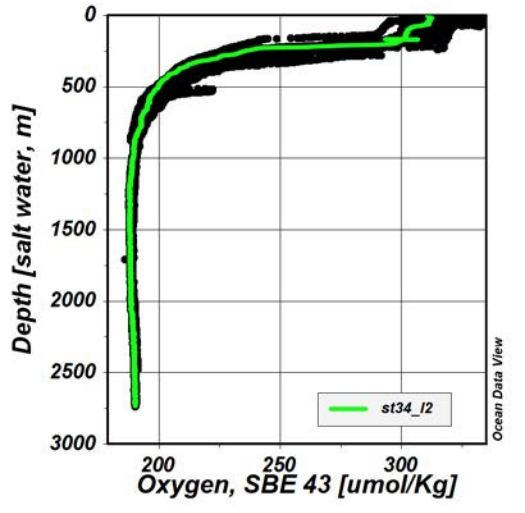
T



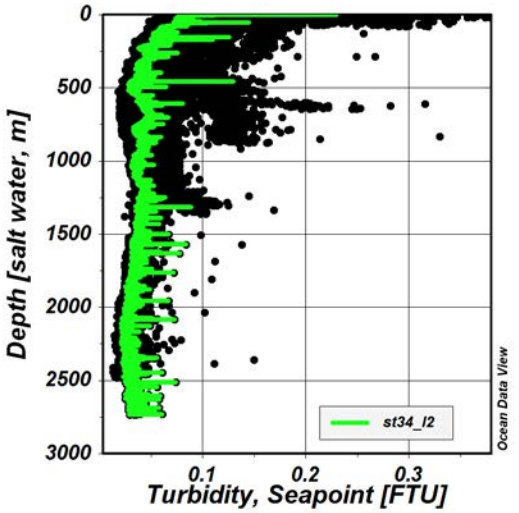

S




DO



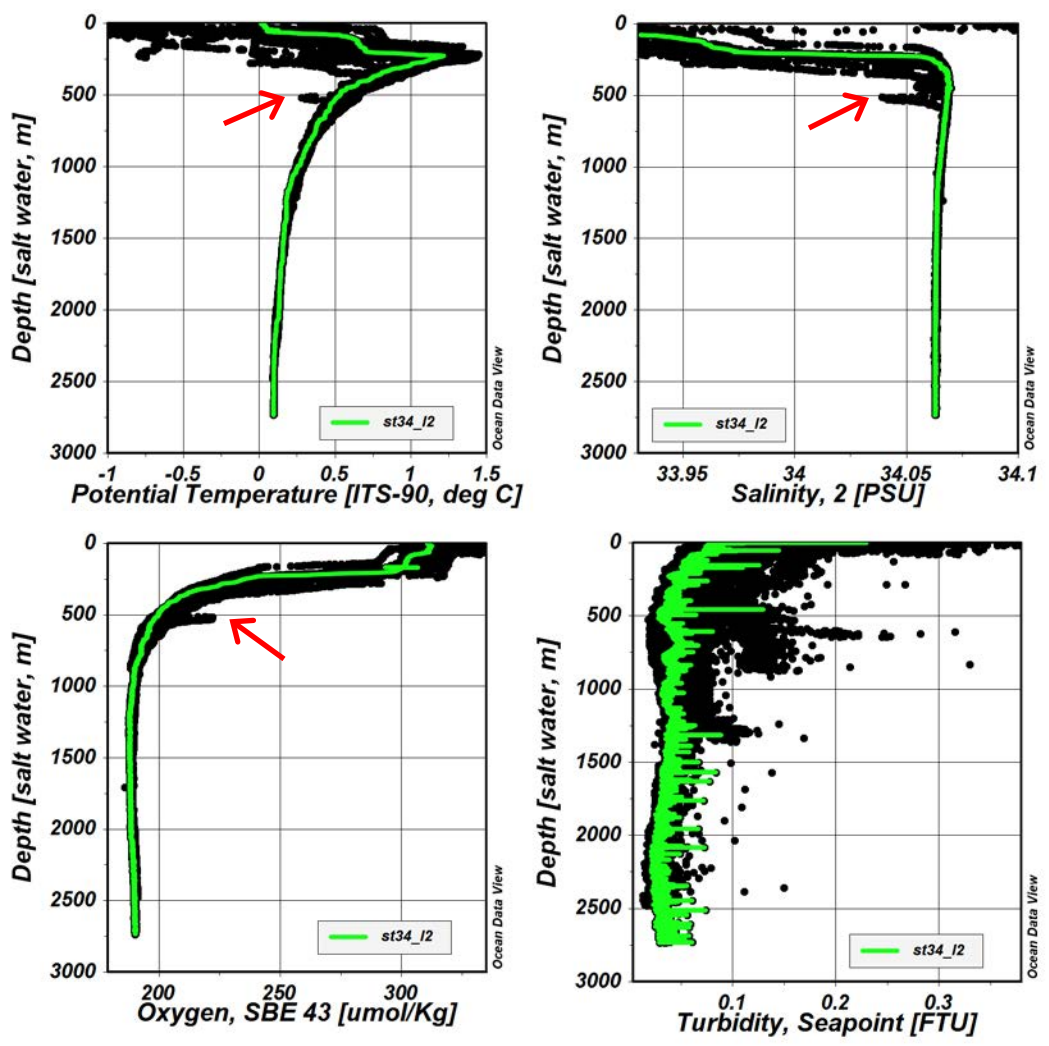

Turb



# Cascading at Peter the Great Bay, 2012:

## February 8

T




S

DO

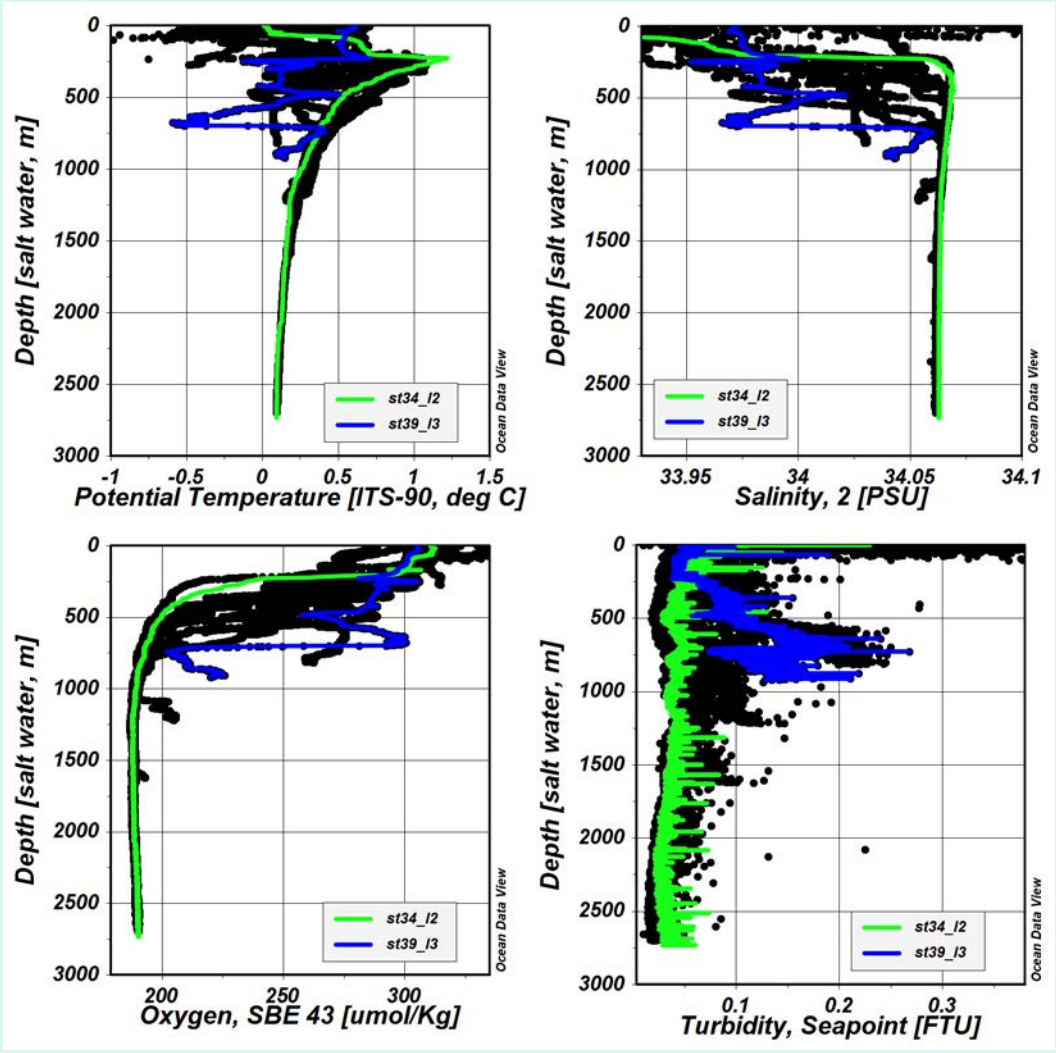
Turb

**- Intrusions of colder, less saline, higher in DO water around 550 m, 50 m thick**

# Cascading at Peter the Great Bay, 2012:

## March 1

T




S

DO

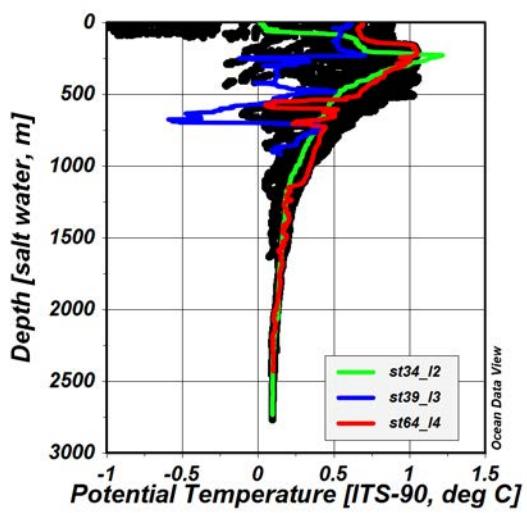
Turb

**- Many intrusions down to 1200 m**

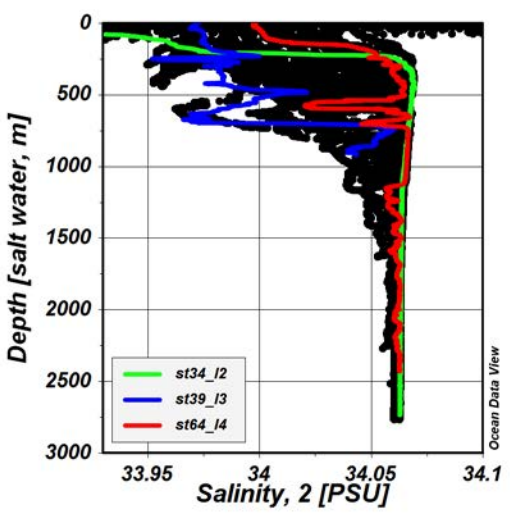
# Cascading at Peter the Great Bay, 2012:

## March 15

T




S

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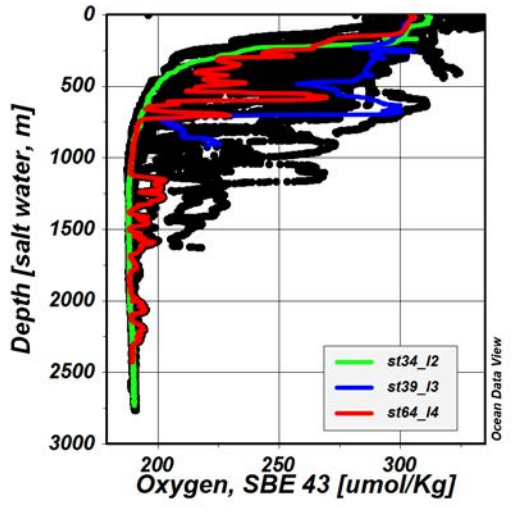
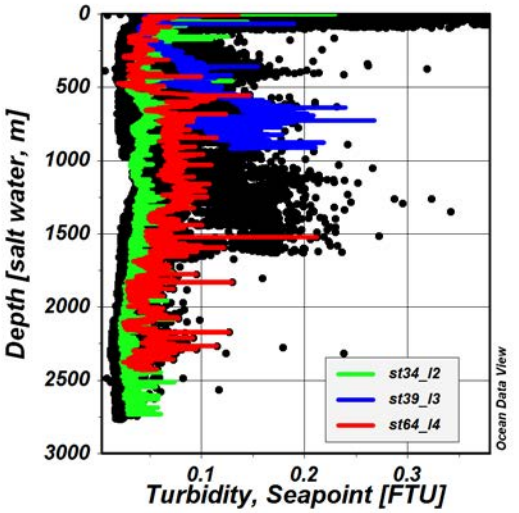



Turb

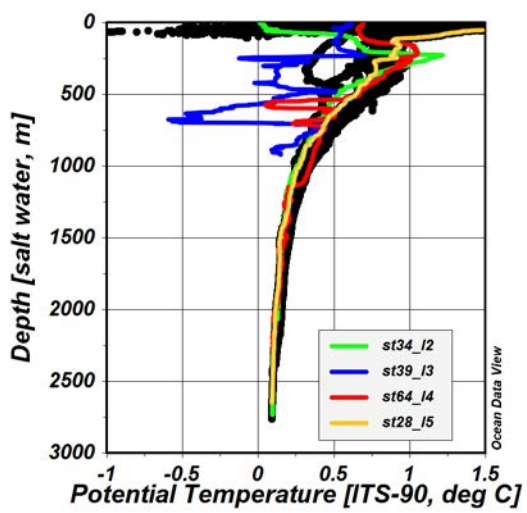



**- More intrusions down to 2200 m**

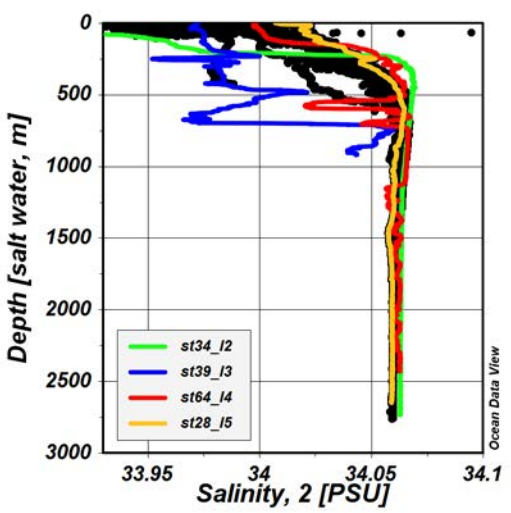
# Cascading at Peter the Great Bay, 2012:

## April 17

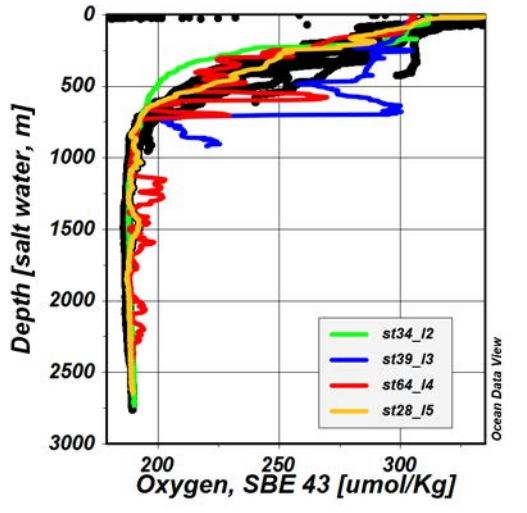
T



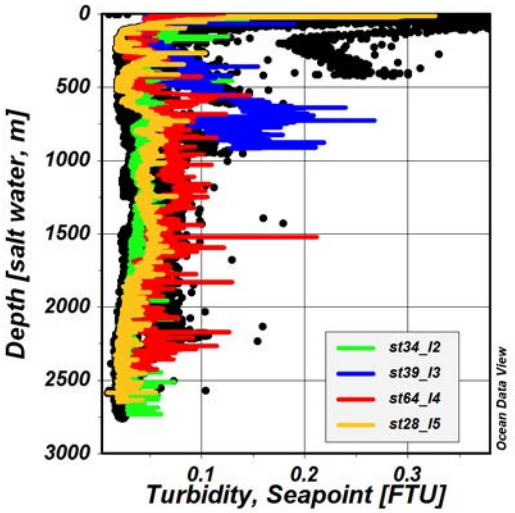

S




DO




Turb

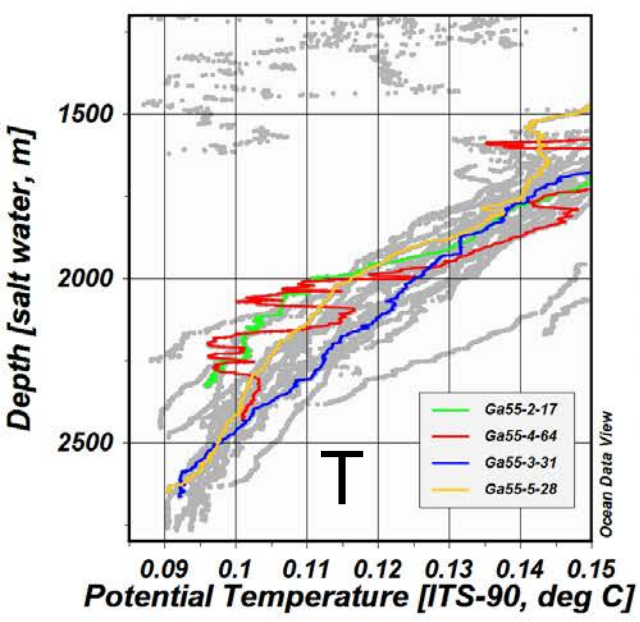


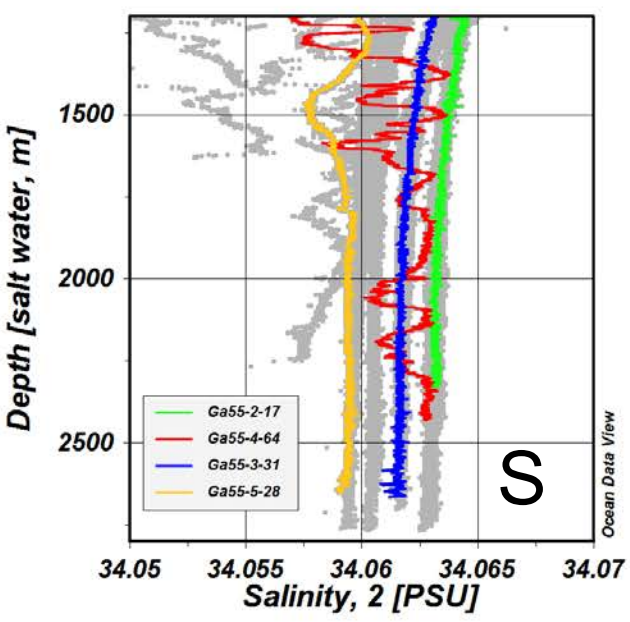

**- Less intrusions in upper layer, some intrusions below 1000 m**

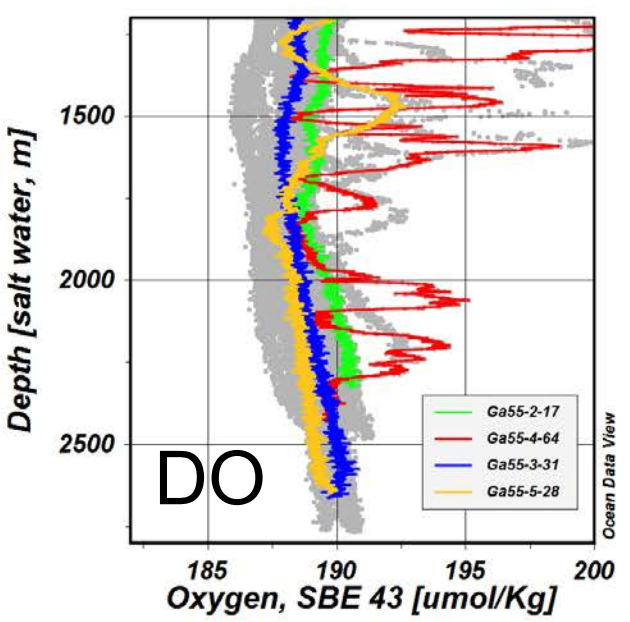
# Deep penetration of cascading, 2012

All profiles over the slope during Feb-April 2012

**___ Feb 08, ___ Mar 01, ___ Mar 15, ___ Apr 17**



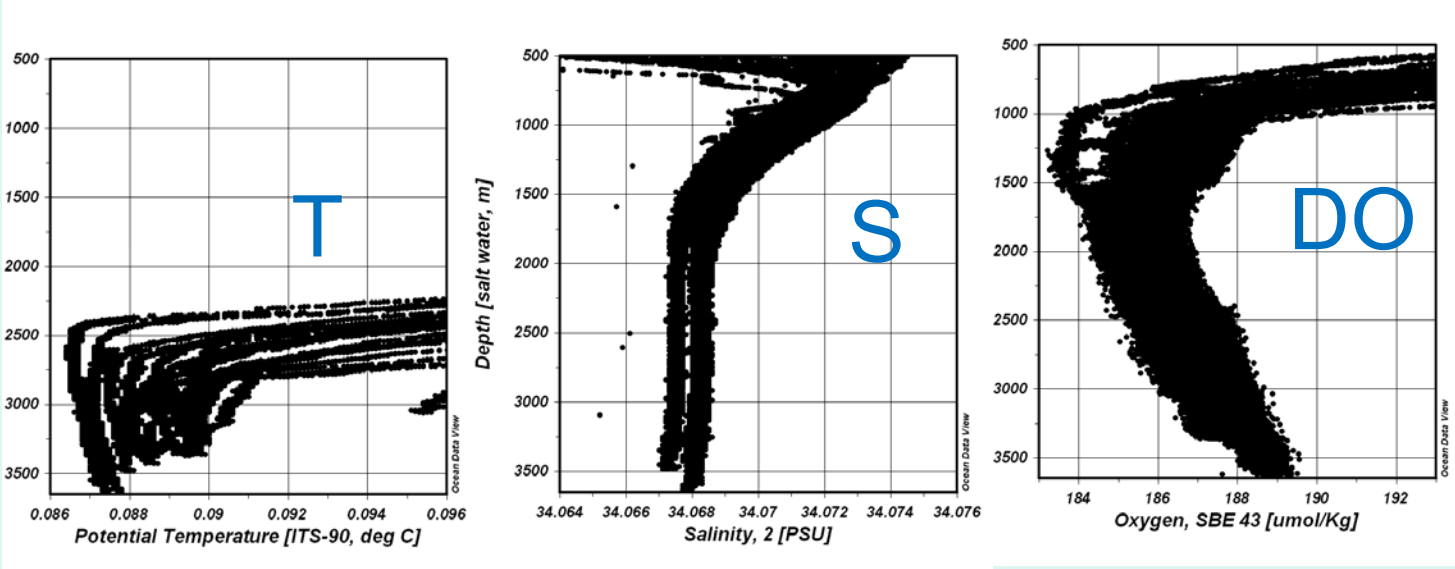

**- Intrusions of colder, fresher, higher in DO and turbidity water of 50-500 m thick,**

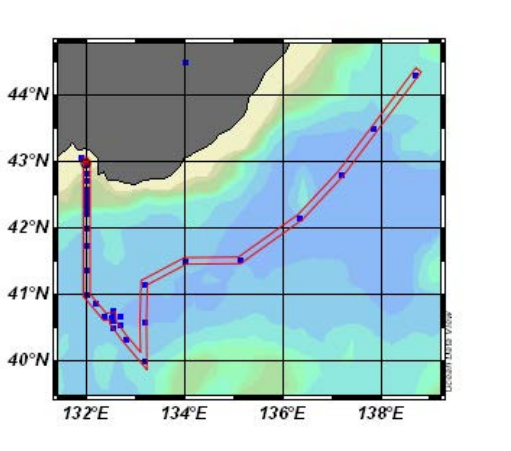
**- down to deep and bottom layers (2000-2500 m)**

# What has happened then….?

> Japan Basin CTD surveys in June 2012

# T, S, DO profiles for deep Japan Basin, June 2012

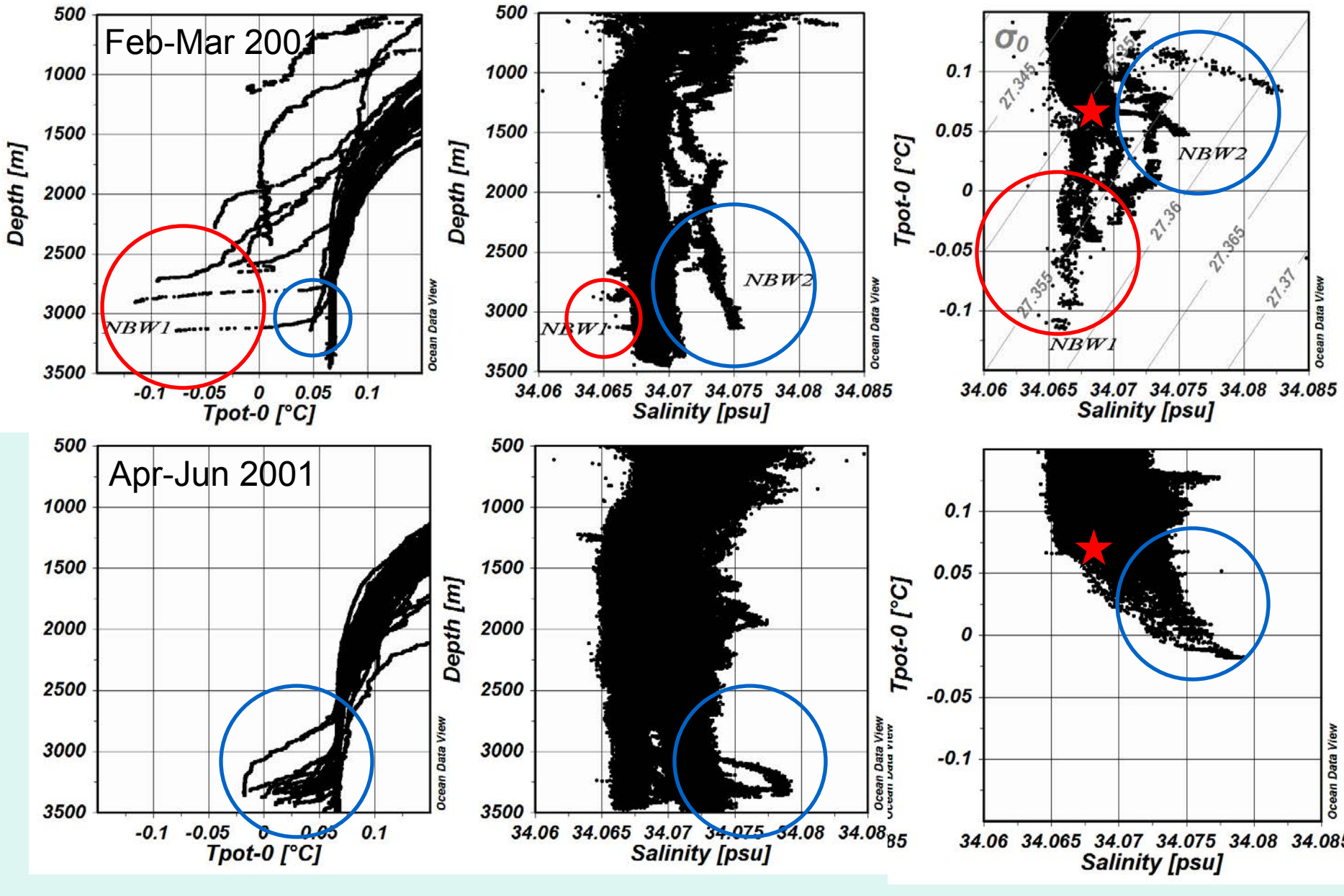


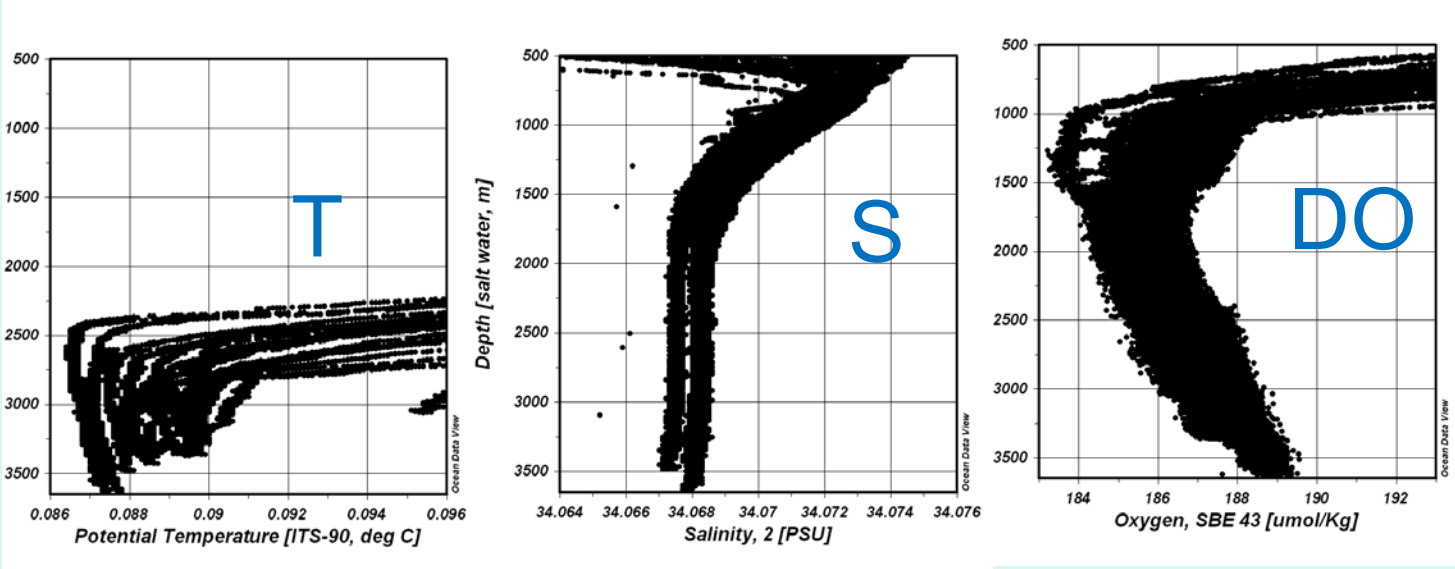

**– no ventilation signal**

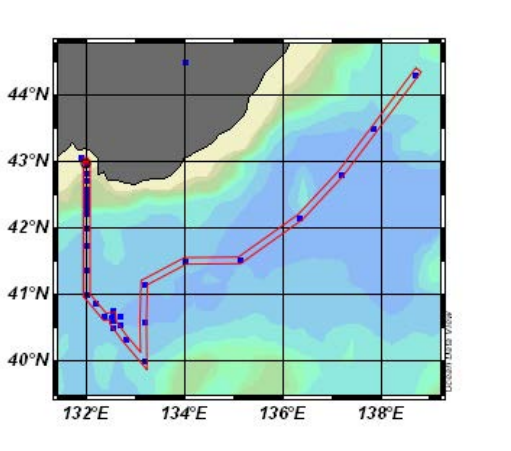
# Bottom Water Ventilation: Feb-Apr 2001

Tpot S T,S



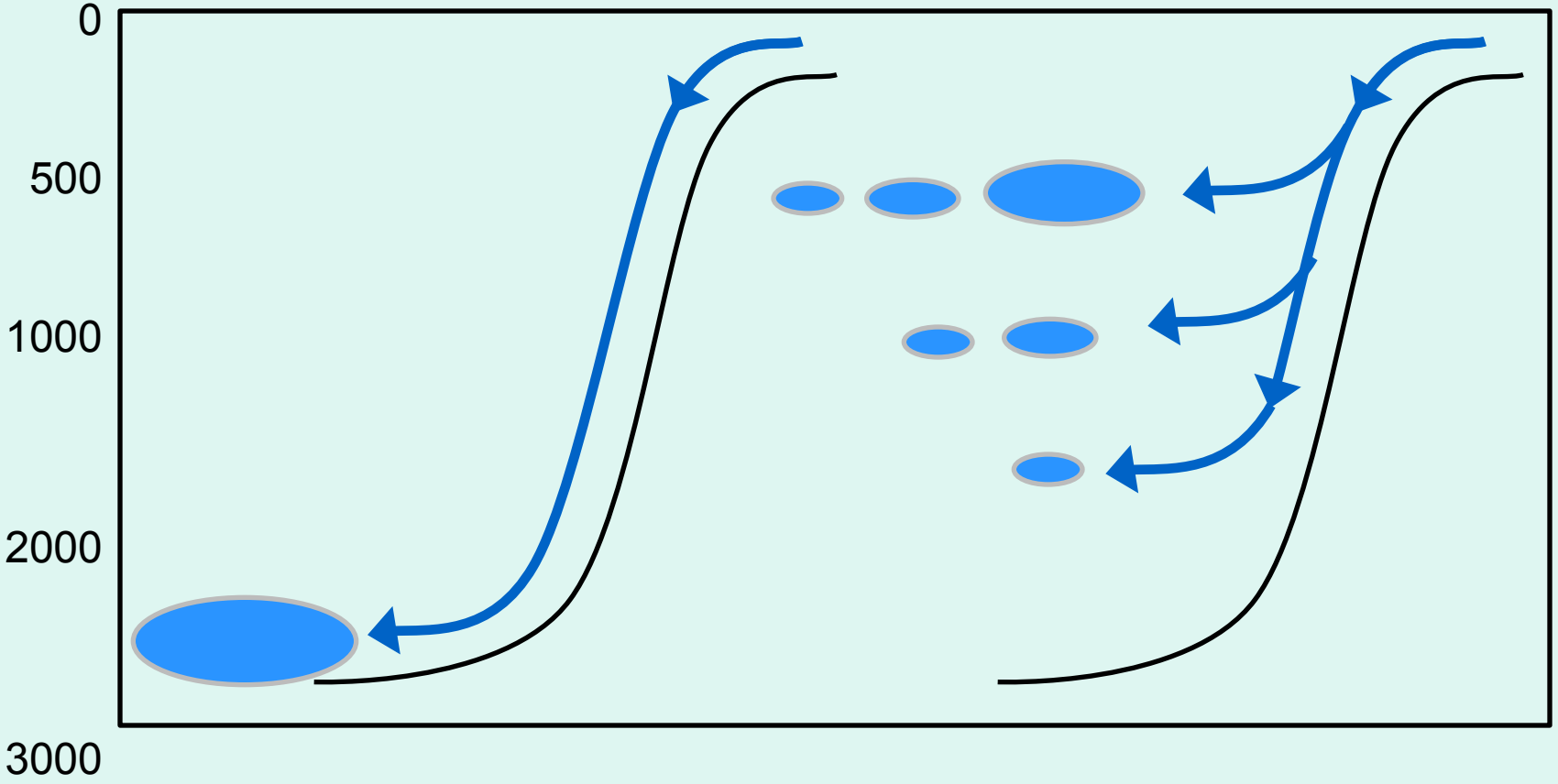
# T, S, DO profiles for deep Japan Basin, June 2012



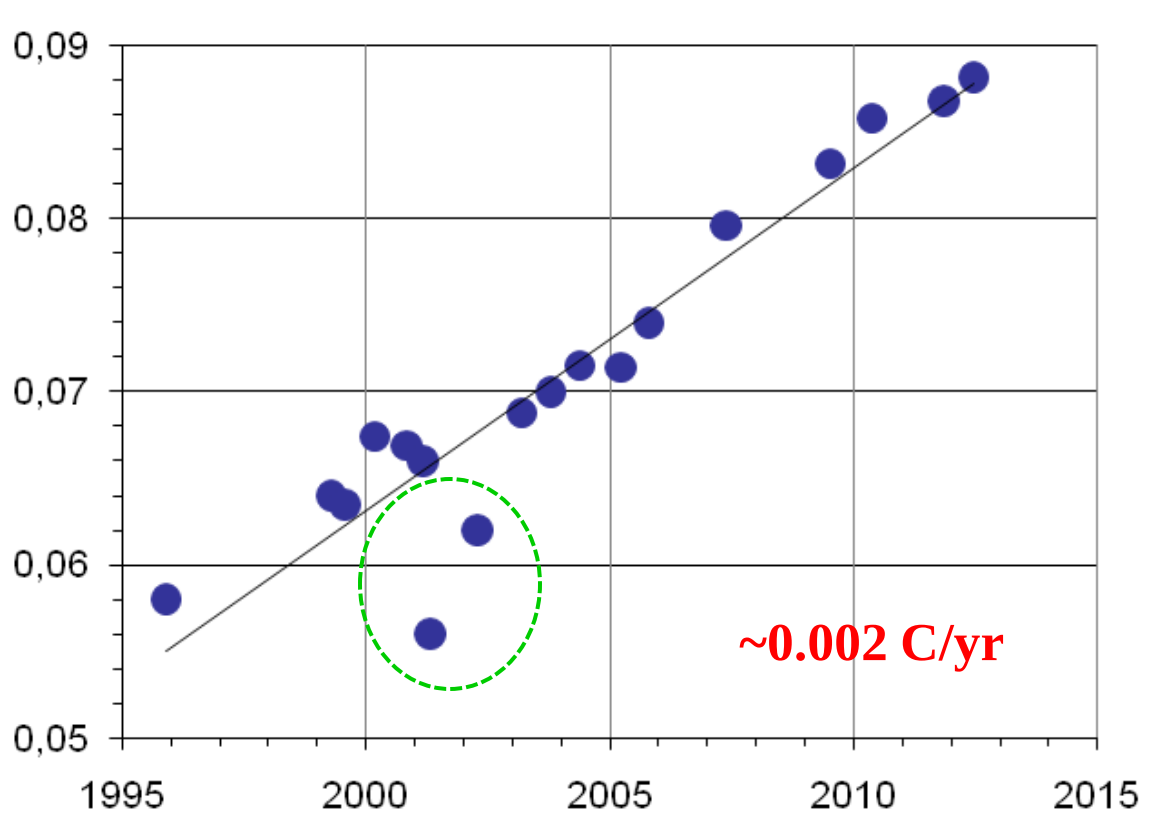




**– no ventilation signal**

# Different Ventilation Regimes



# Warming trend of bottom water temperature (ºC) in deep Japan Basin during 1995-2013




Increasing trend of bottom water temperature (2500-3600 m) in Japan Basin during 1995-2012 associated with decreasing of ventilation. Deep ventilation event was observed in severely cold winter 2001.

# Conclusion:

- Peter the Great Bay shelf has good preconditions for dense water formation enough for cascading;

- during cold winters of 2001 and 2012 a cascading of dense water down the slope was observed in Peter the Great Bay and probably it could happen in 2010 and 2011;

- even in 2012 cascading was observed down to > 2500 m. However this injection of new water does not resulted in any noticeable changes of deep and bottom waters.

# Thank you!