25 Years of PICES:
Celebrating the Past, Imagining the Future

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North Pacific Marine
Science Organization
2016 Annual Meeting

Recent Advances and Future Perspectives in the Understanding Mesosocale Water Dynamics in the Japan/East Sea

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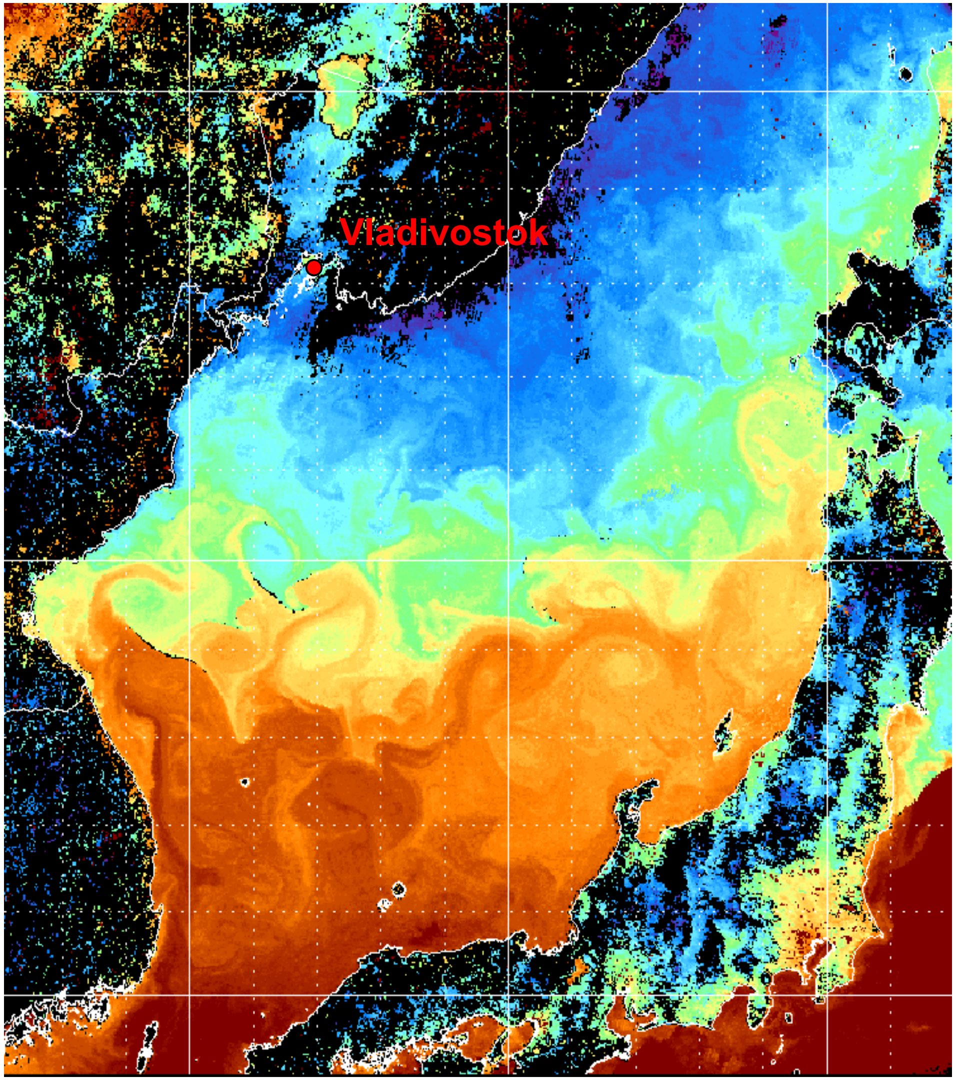
Content

Mesoscale eddies

Miniature Ocean – a model of the ocean



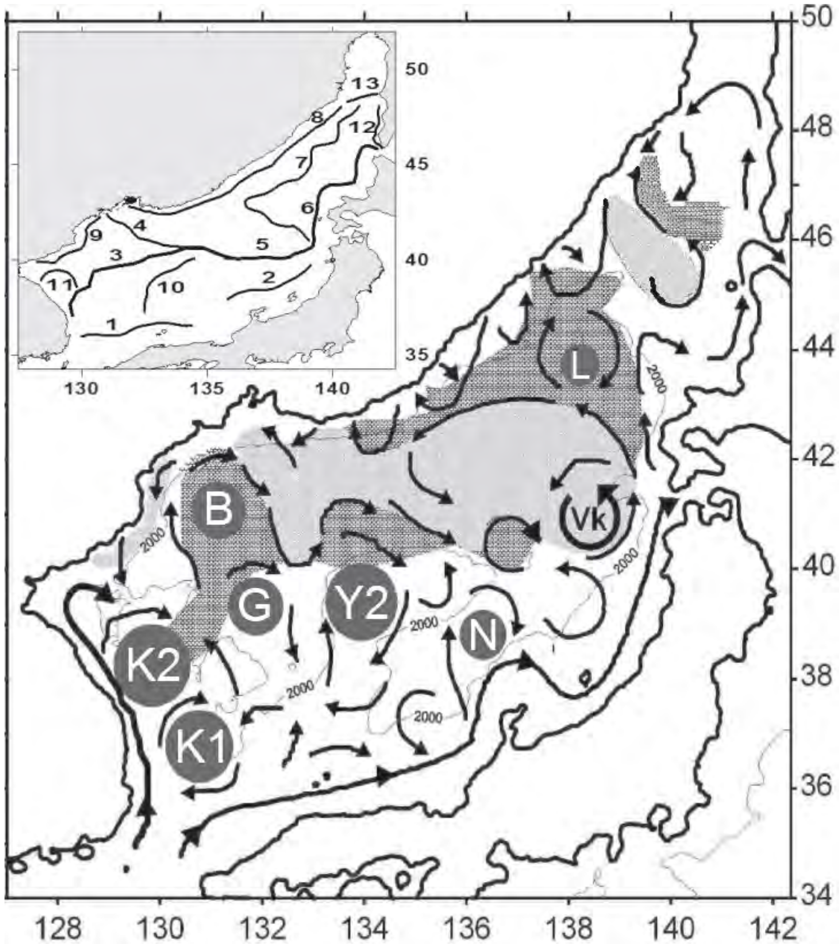
Mesoscale eddies are important component of the Japan Sea water dynamics
(e.g. Ichiye and Takano, 1988)

Strong anticyclonic eddies in the southern area
(Isoda et al., 1992; Isoda and Saitoh, 1993; Isoda, 1994; An et.al.,1994; …Gordon et al., 2002)

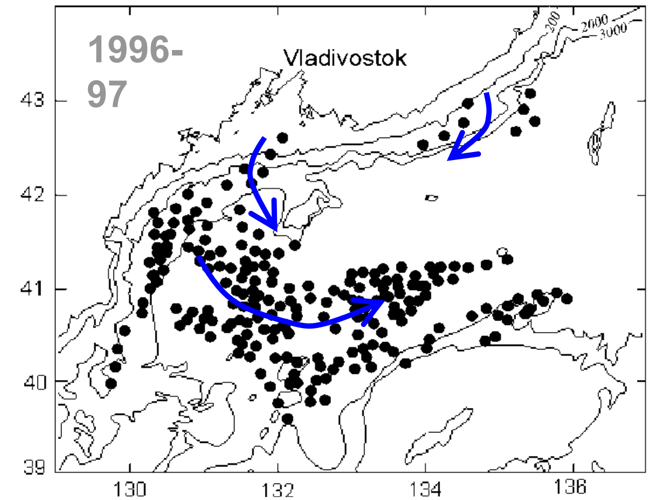
Eddies north of the subarctic front
(e.g. Sugimoto and Tameishi, 1992; Danchenkov et al., 1997; Lobanov et al., 1998)

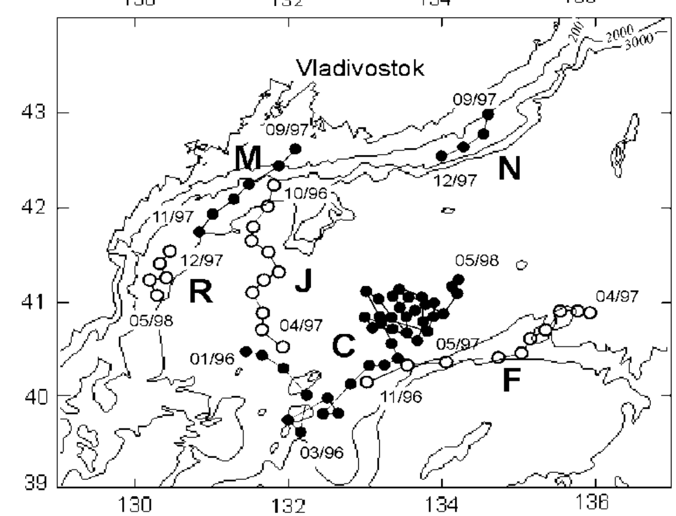
Hydrographic structure (CTD and moorings)
(Takematsu et al., 1999; Lobanov et al., 2001, 2007)

Location of Mesoscale Eddies in the JES



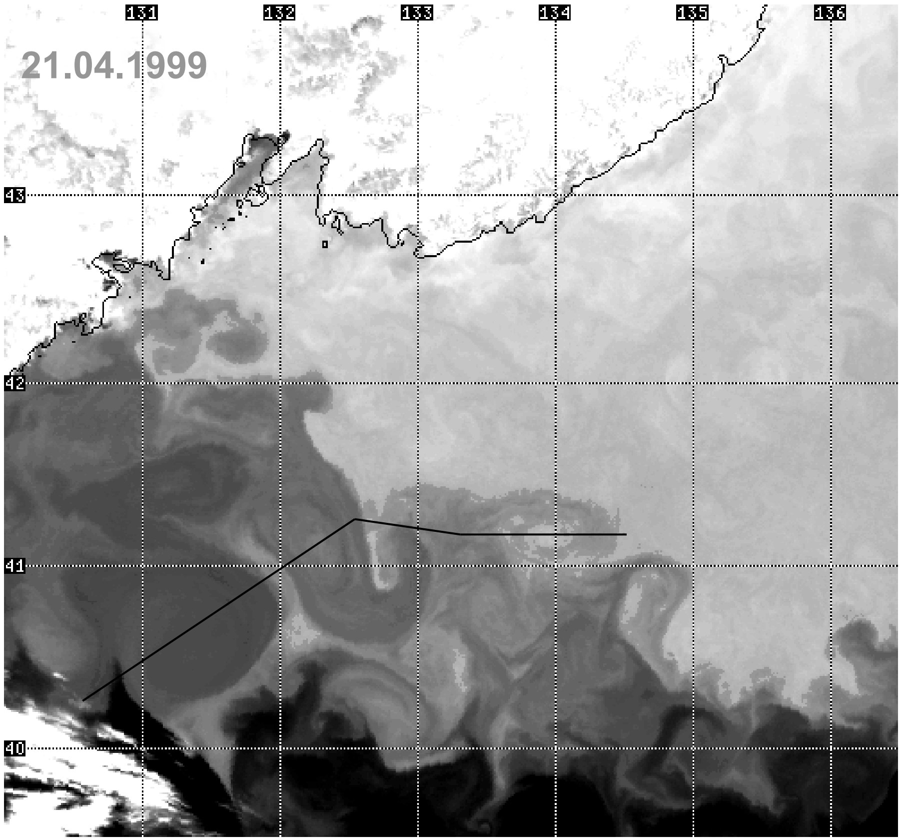
Nikitin et al., 2009

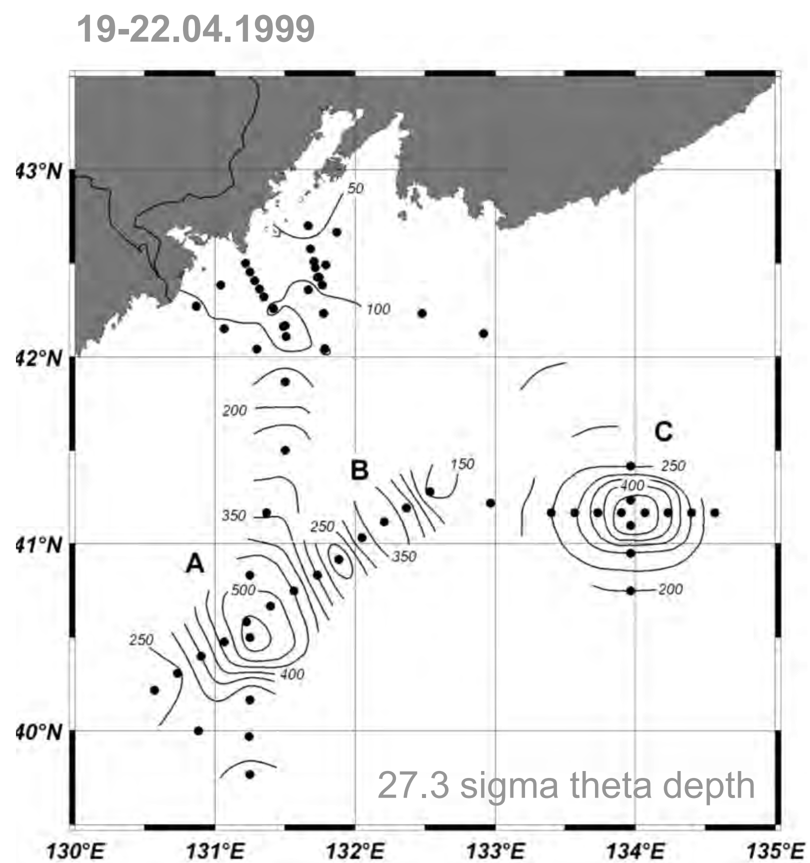




Lobanov et al., 2001, 2007

Eddies in the NW Japan Sea:
satellite controlled ship observations

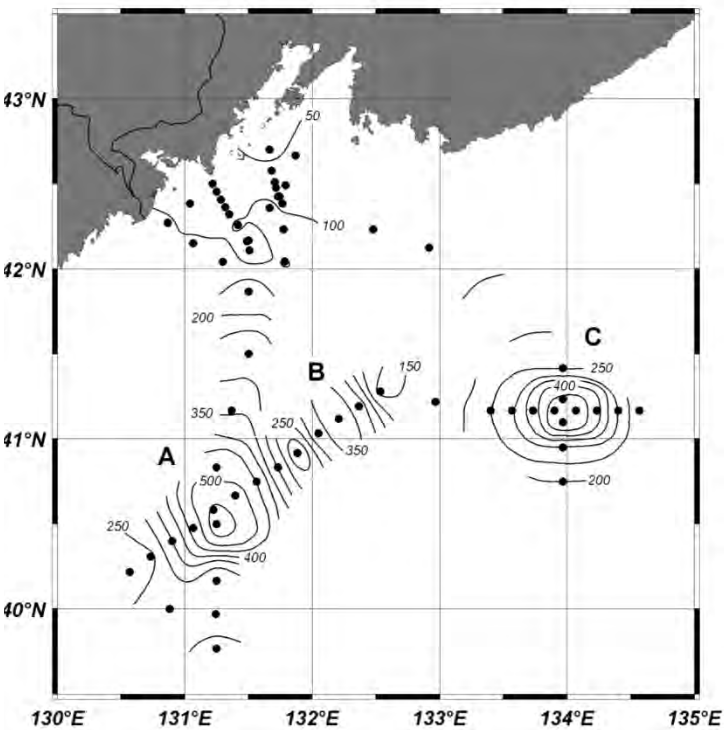


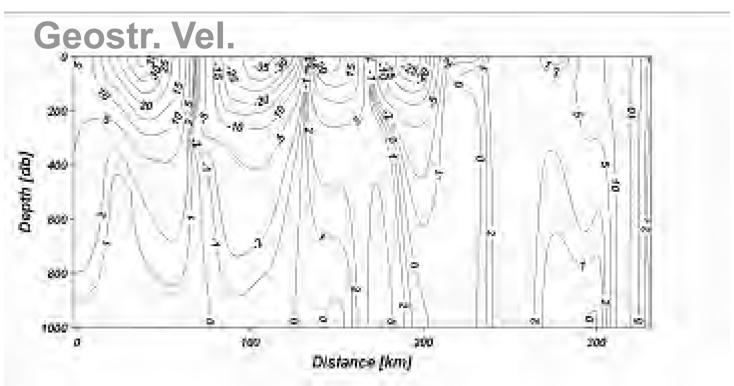


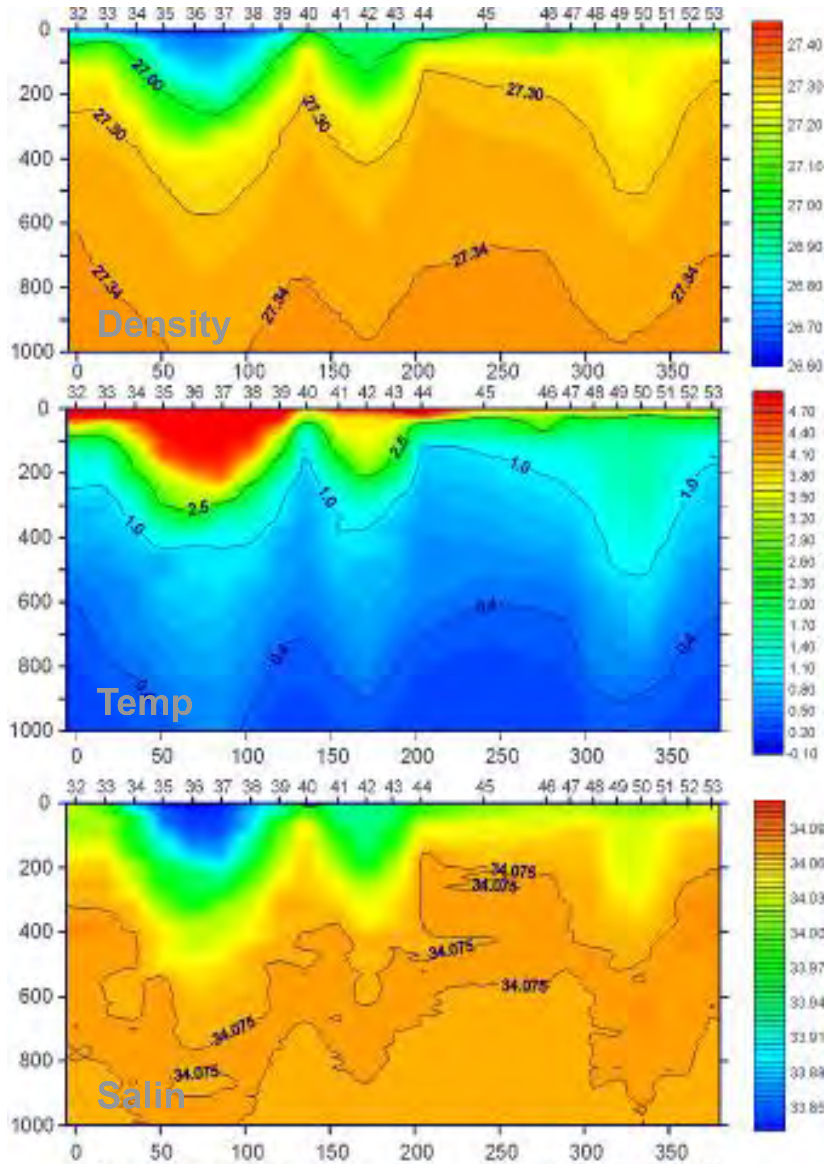
- strong dynamic features
- deep penetration
- even weak surface signature corresponds to strong eddy

Eddies in the NW Japan Sea:

vertical structure







- warm, lower salinity core; strong dynamic features, deep penetration

Modeled vertical structure of the eddy

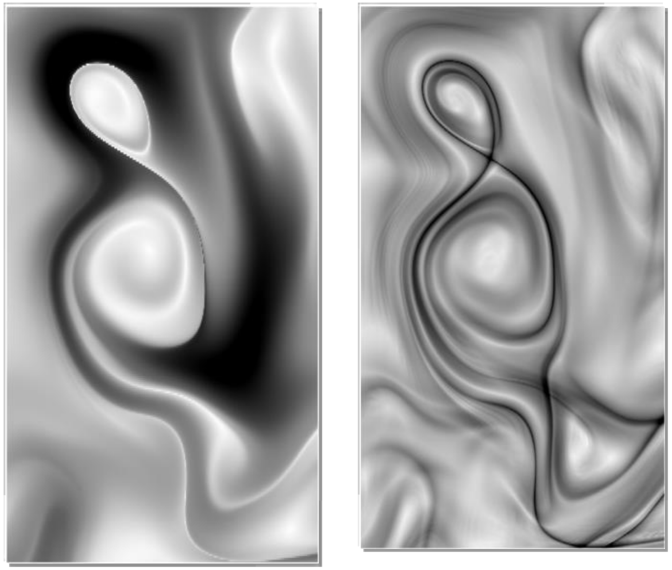


Fig. 3. Manifestations of modeled eddies on 23 July in the ninth layer on (a) the drift map (D in km) and (b) the combined Lyapunov map of forward (Kю) and backward-intime (K) FTLE with the velocity field imposed. K is in days1. ''Instantaneous'' elliptic and hyperbolic points, to be present in the area on 23 July, are indicated by circles and crosses, respectively.

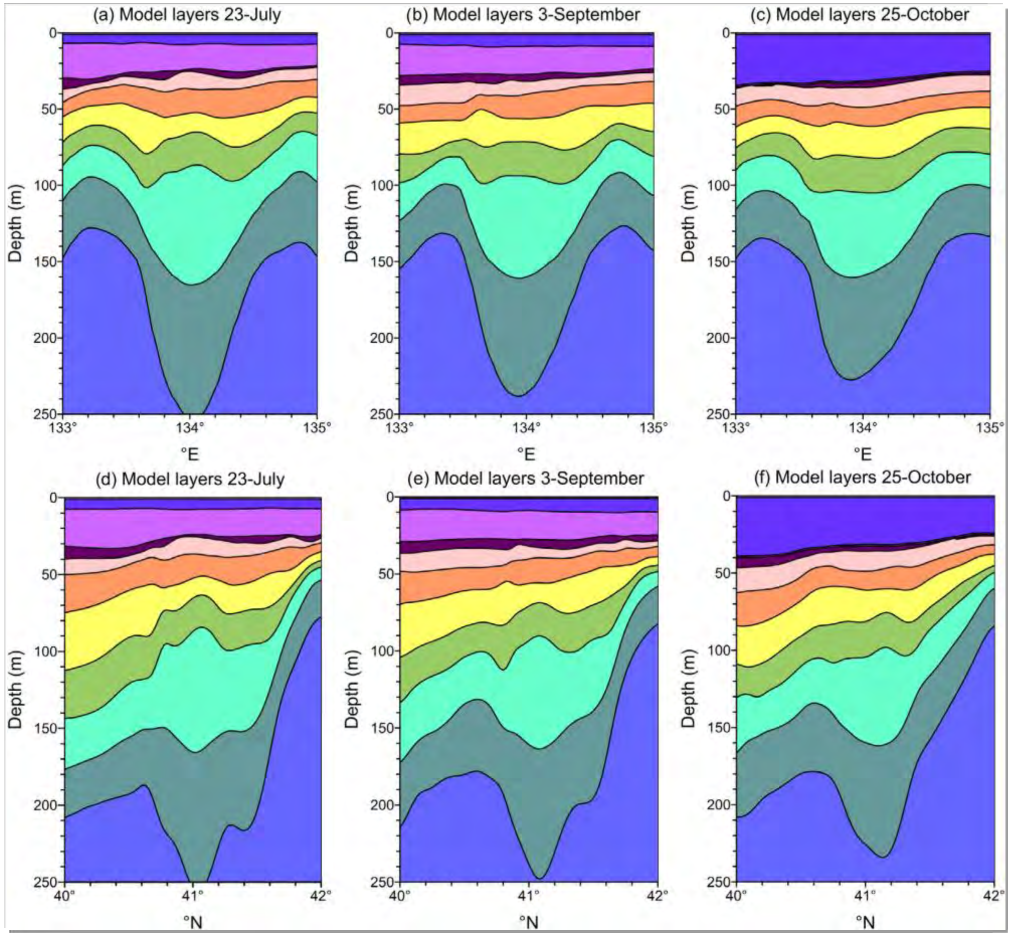
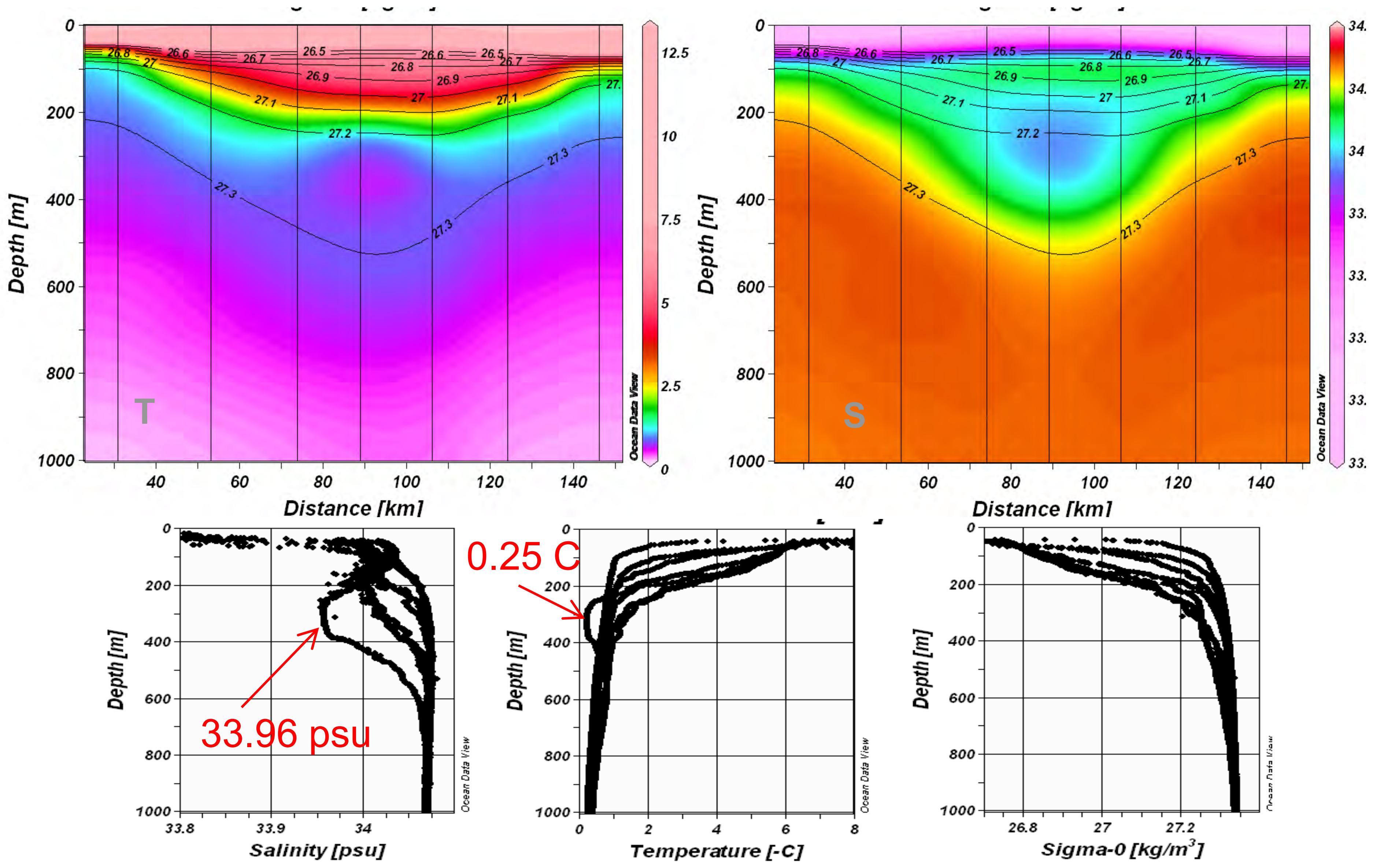


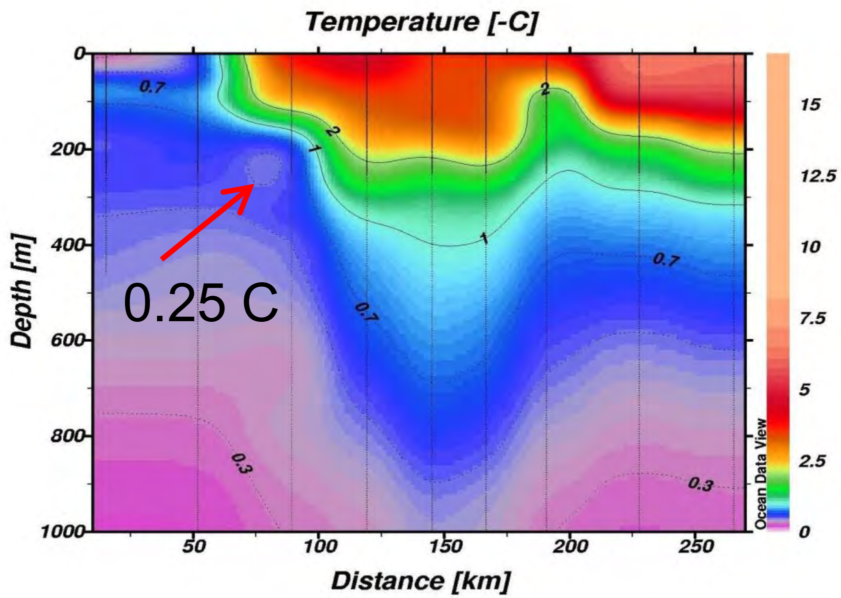
Fig. 6. Zonal (along 41N, the upper row) and meridional (along 134E, the lower row) sections of the interfaces between modeled eddy layers on 23 July, 3 September and 25 October. Each quasi-isopycnal layer is shown by its own color

Prants et al., OM, 2015

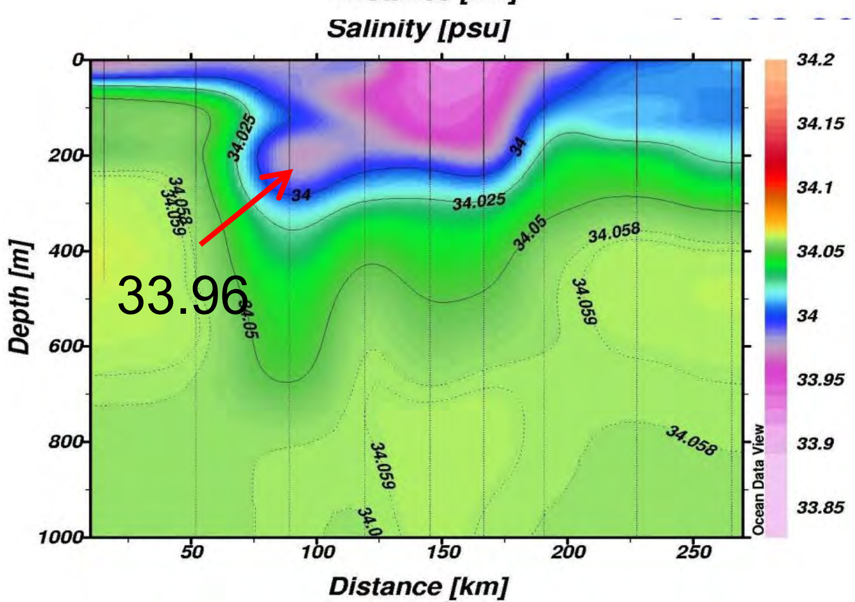
Anomalous structure of eddy core:
secondary cold and fresh core of Eddy 00A

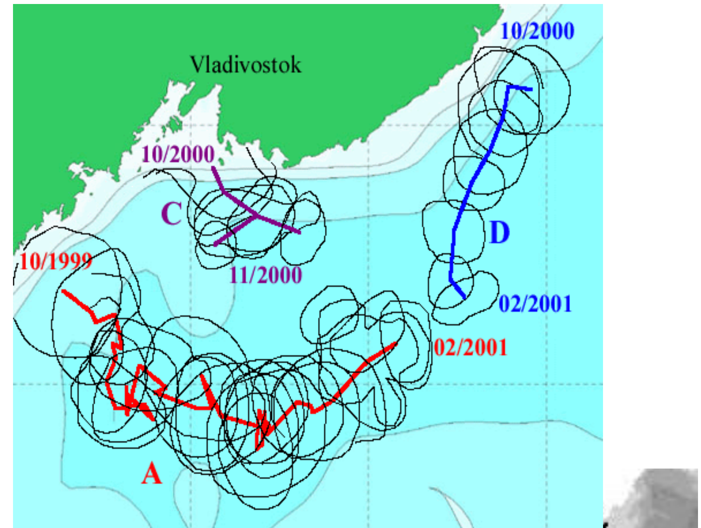


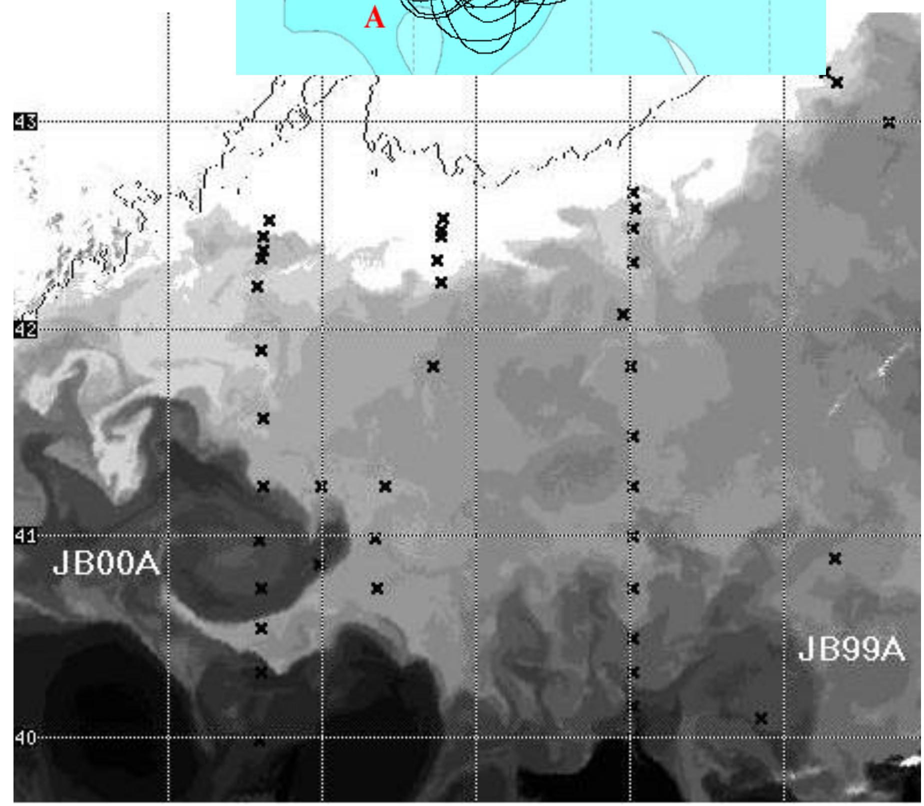
Anomalous structure of eddy 00A:
subduction of cold and fresh core in the NW in winter



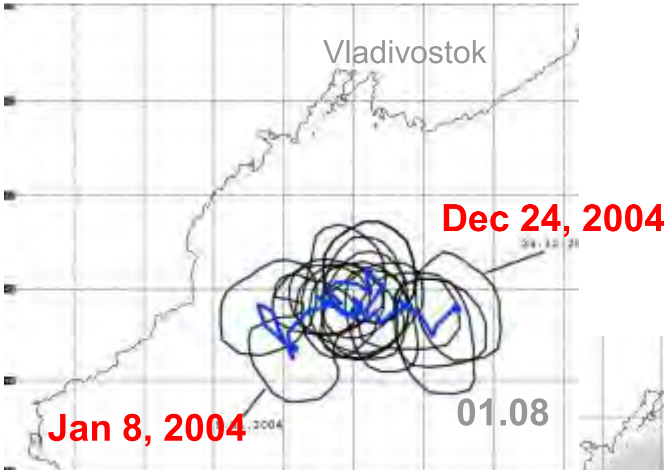
4-6.03. 2000





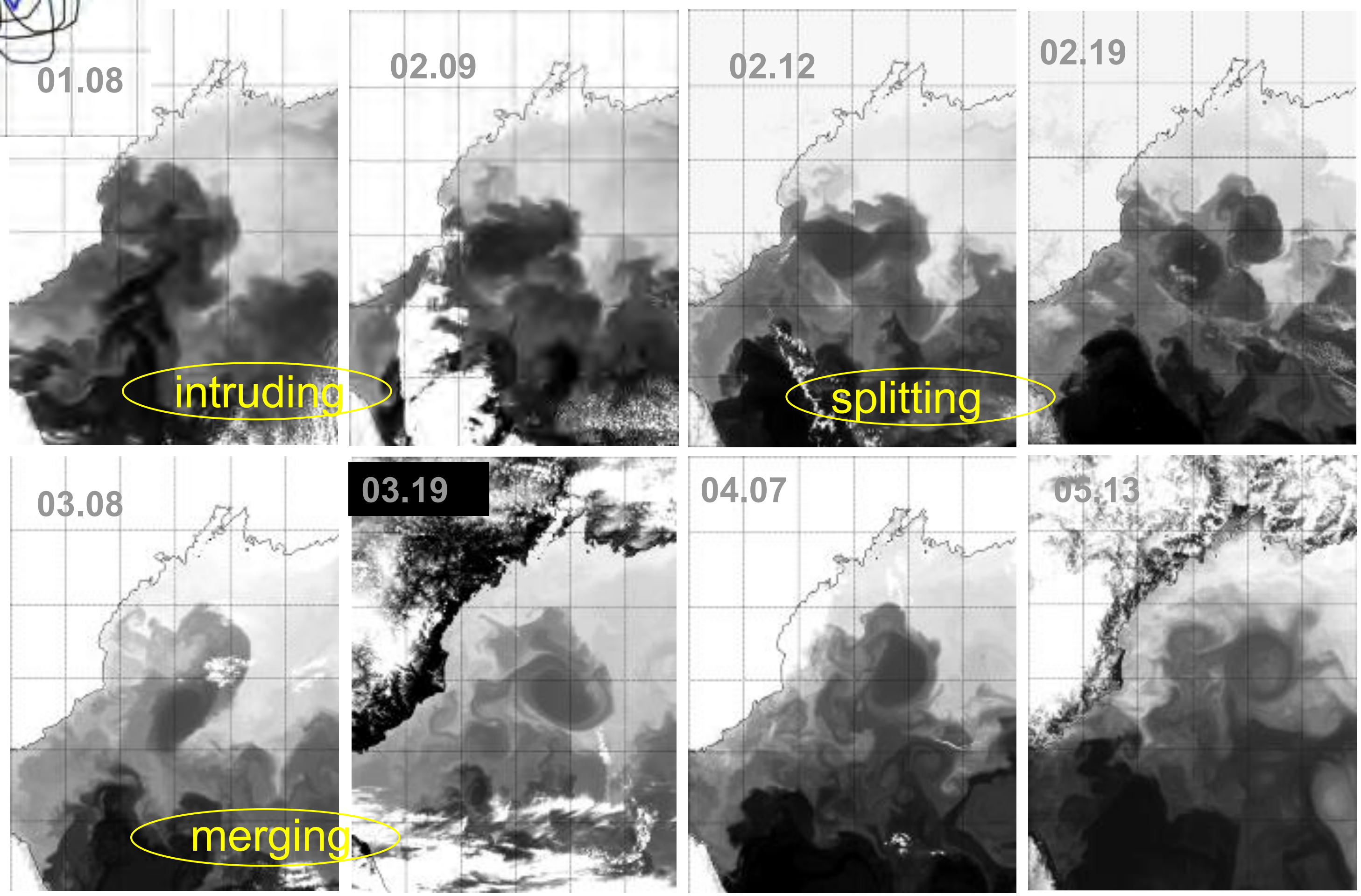


Eddy Evolution (Jan-Dec 2004)

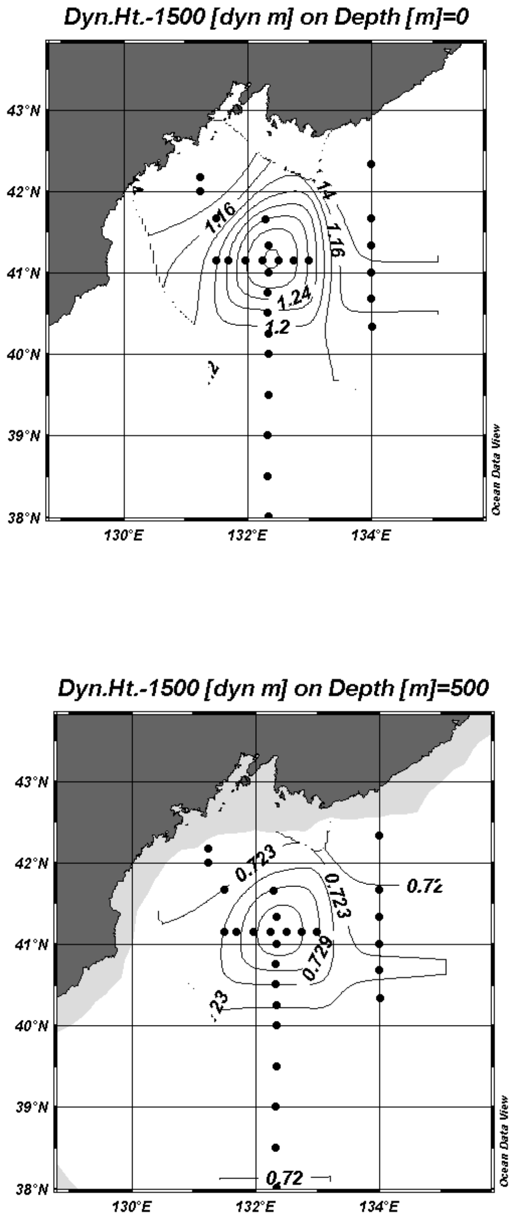


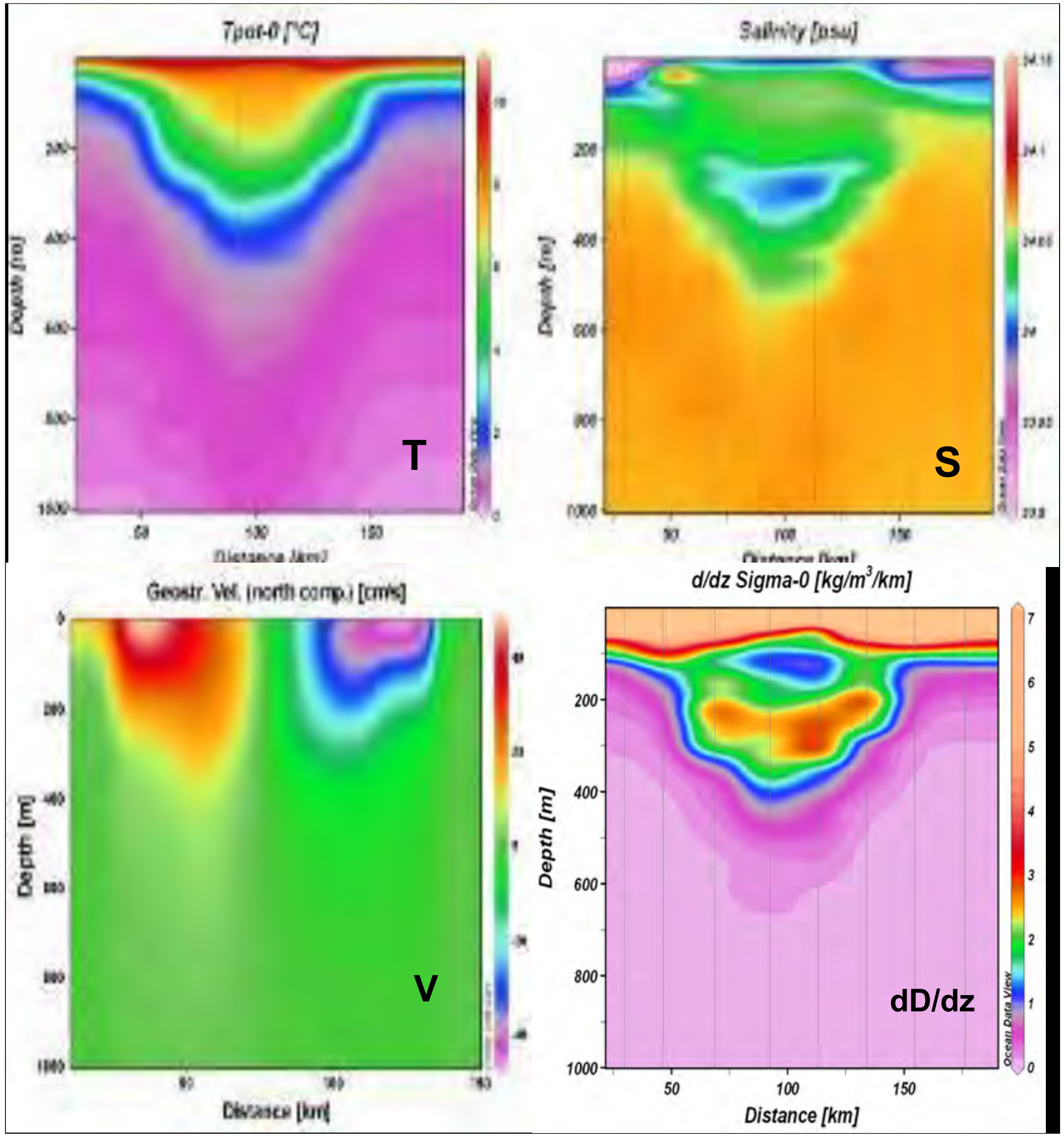
NOAA AVHRR images for 2004:

- **long-lived structure (> 1 yr)**
- **formation in the NW corner**
- **intense short term variability**
  (merging with adjacent structure, splitting etc.)



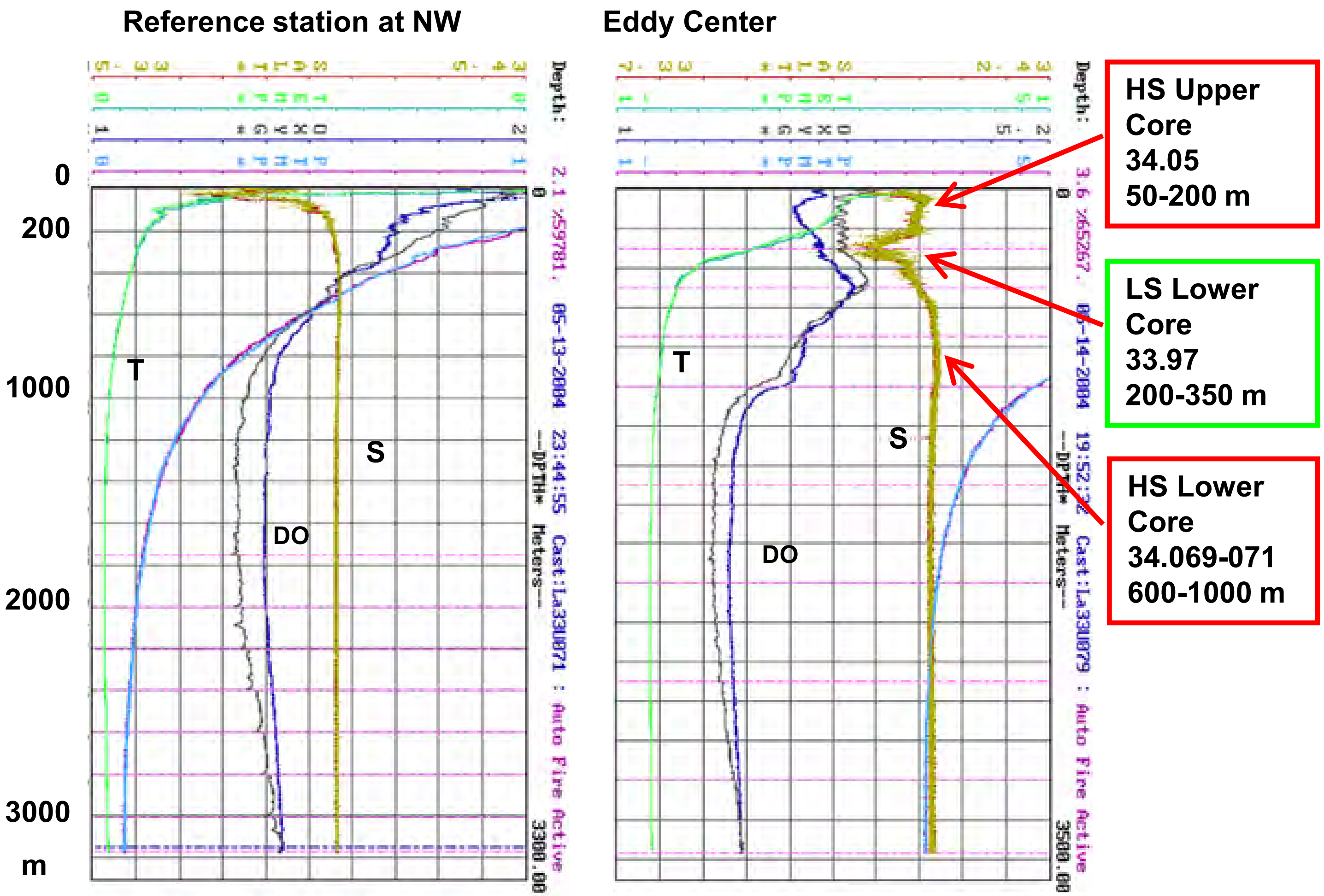
Multiple Core Hydrographic Structure





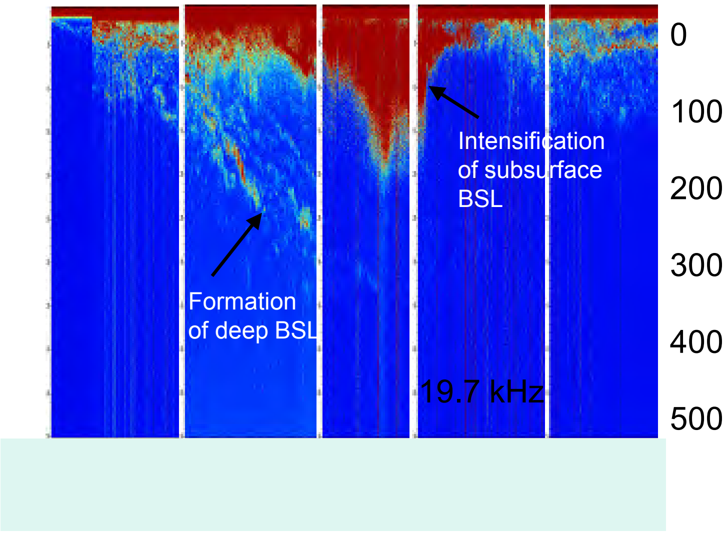
- strong dynamic feature (~45cm/s),
- multi layer core structure

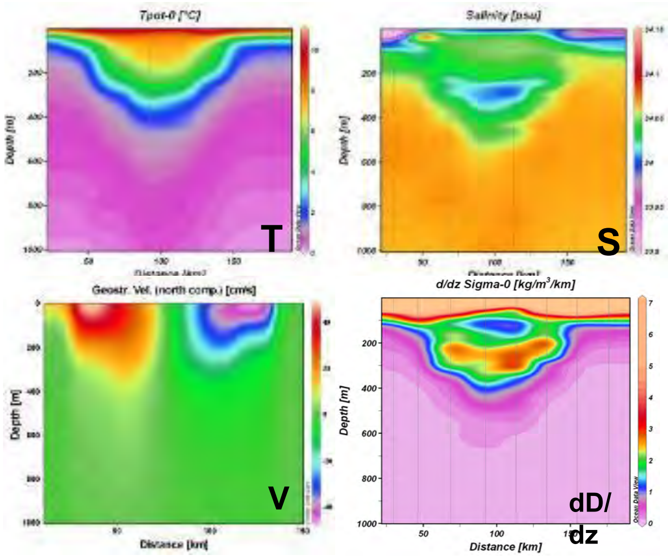
Water Masses of the Eddy Core

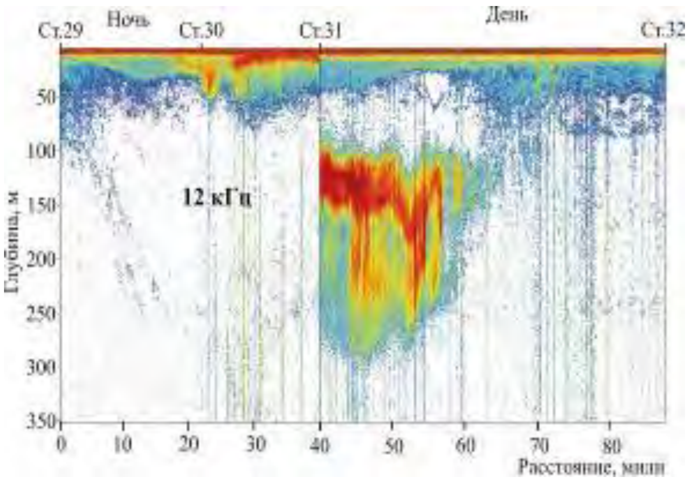


Extreme values of T, S and DO in the eddy center - formation and transport of both Low and High Salinity Intermediate Waters

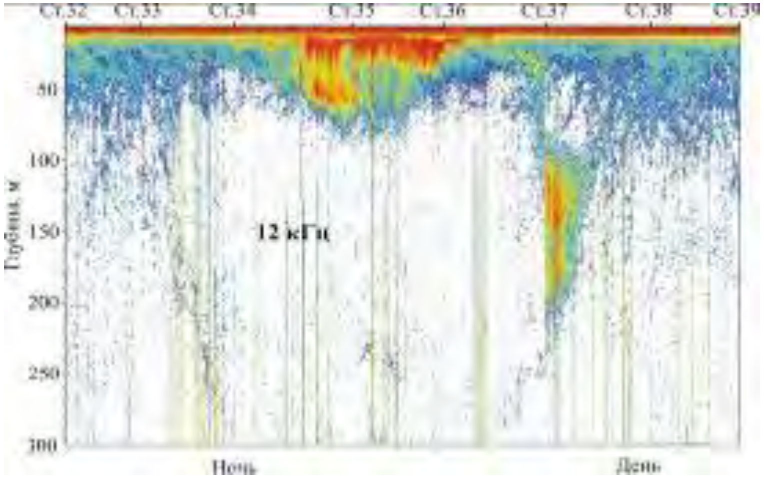
Acoustic Backscatter







Nighttime Daytime

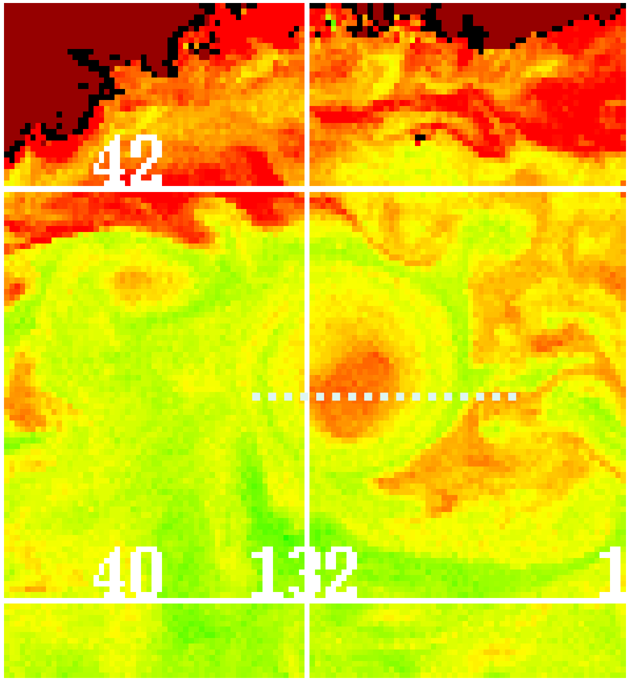


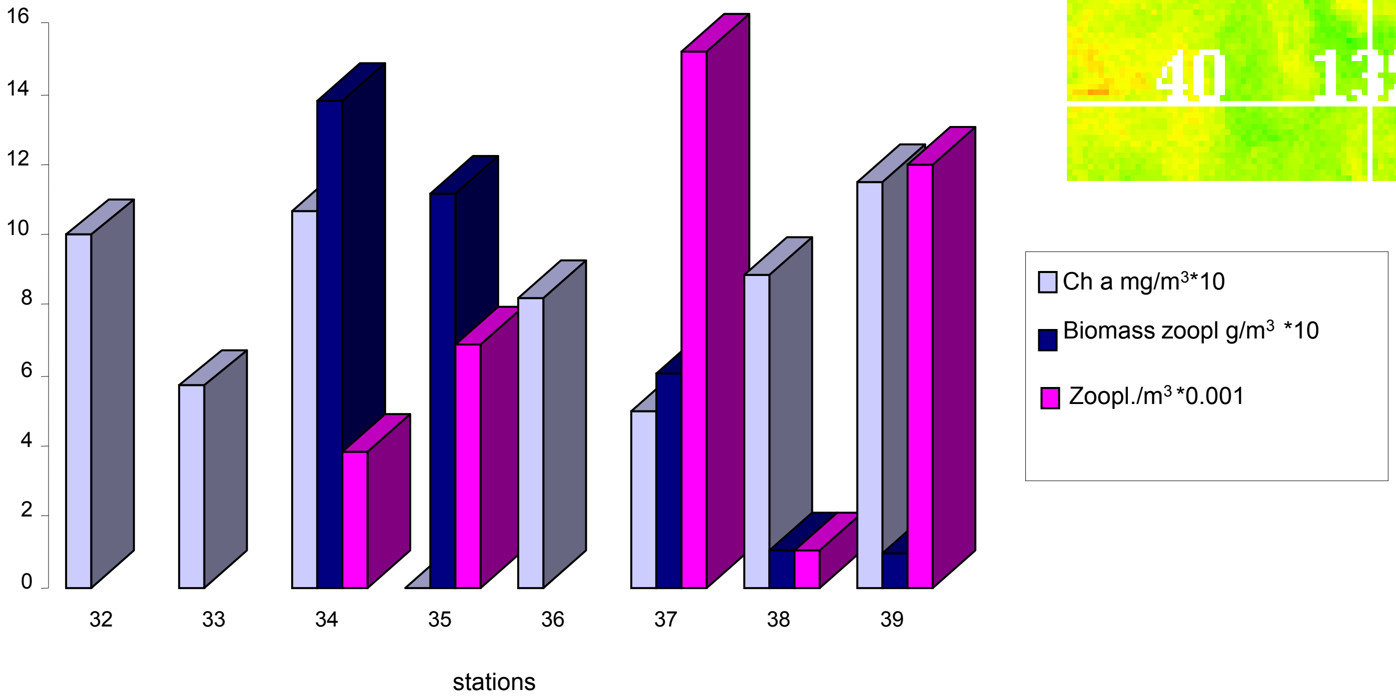
Nighttime Daytime

Biological impact of the eddies

Zooplankton

Sampling at 0-100 and 100-200 m
Max- upper layer (up to 13000 org/m3)
Copepods – 80-90%.
Max – in the eddy
No symmetry
Max biomass – min Chl *a* = grazing



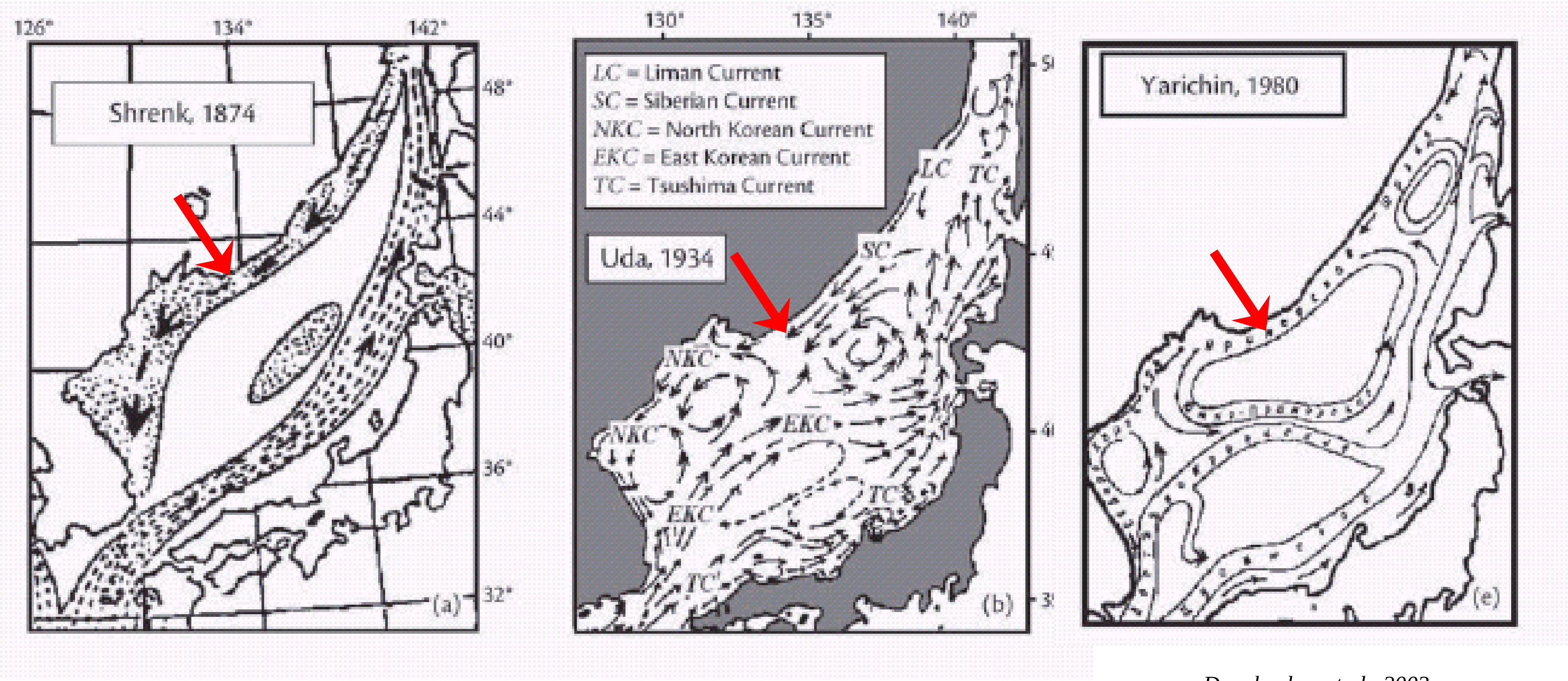


Mesocale water dynamics of Primorye Current:

- Coastal eddies
- Upwelling
- Seasonal reverse of Primorye Current

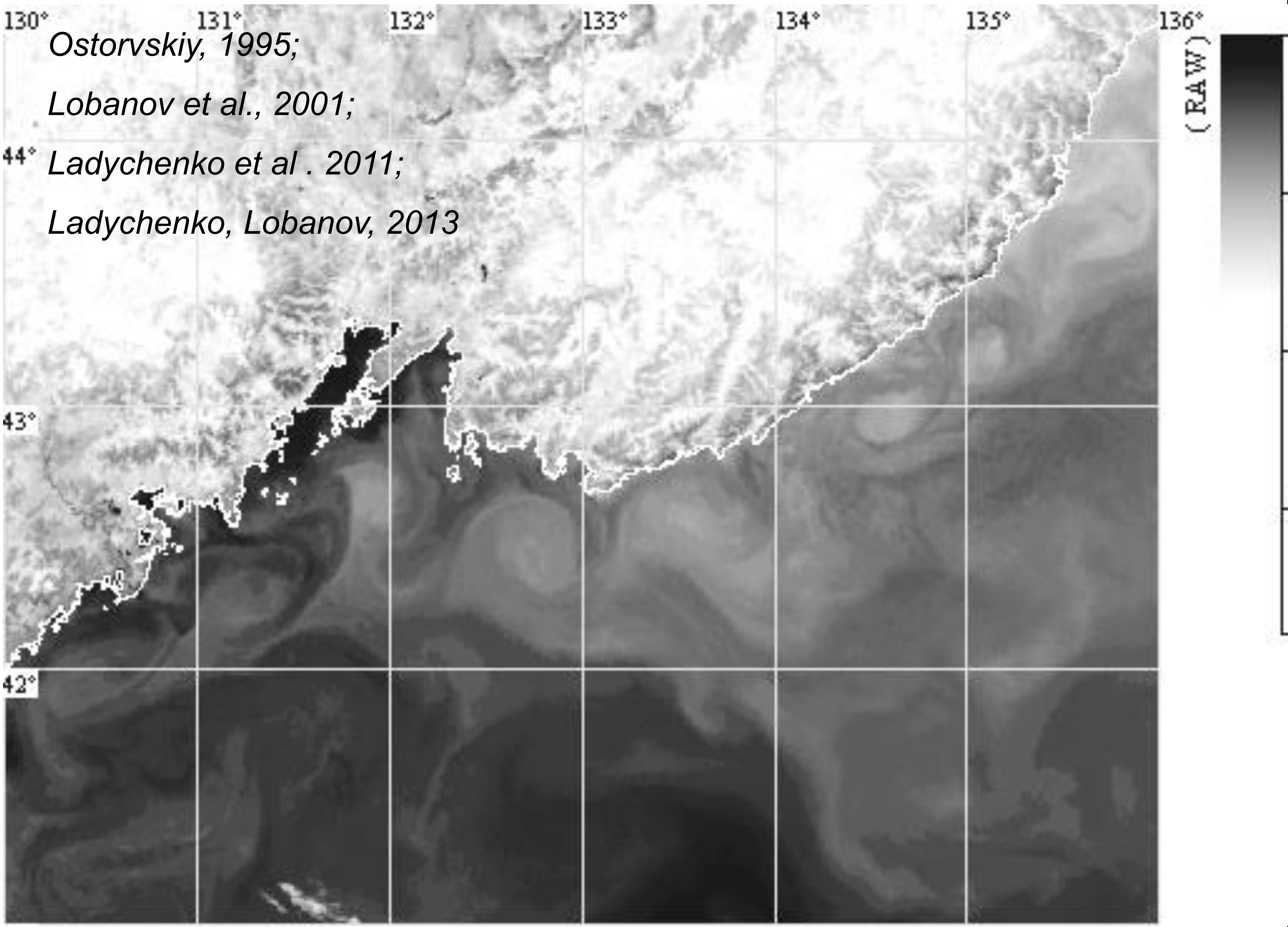
Liman Current – south westward boundary current of the Japan/East Sea

(Primorye Current, North Korean Current)

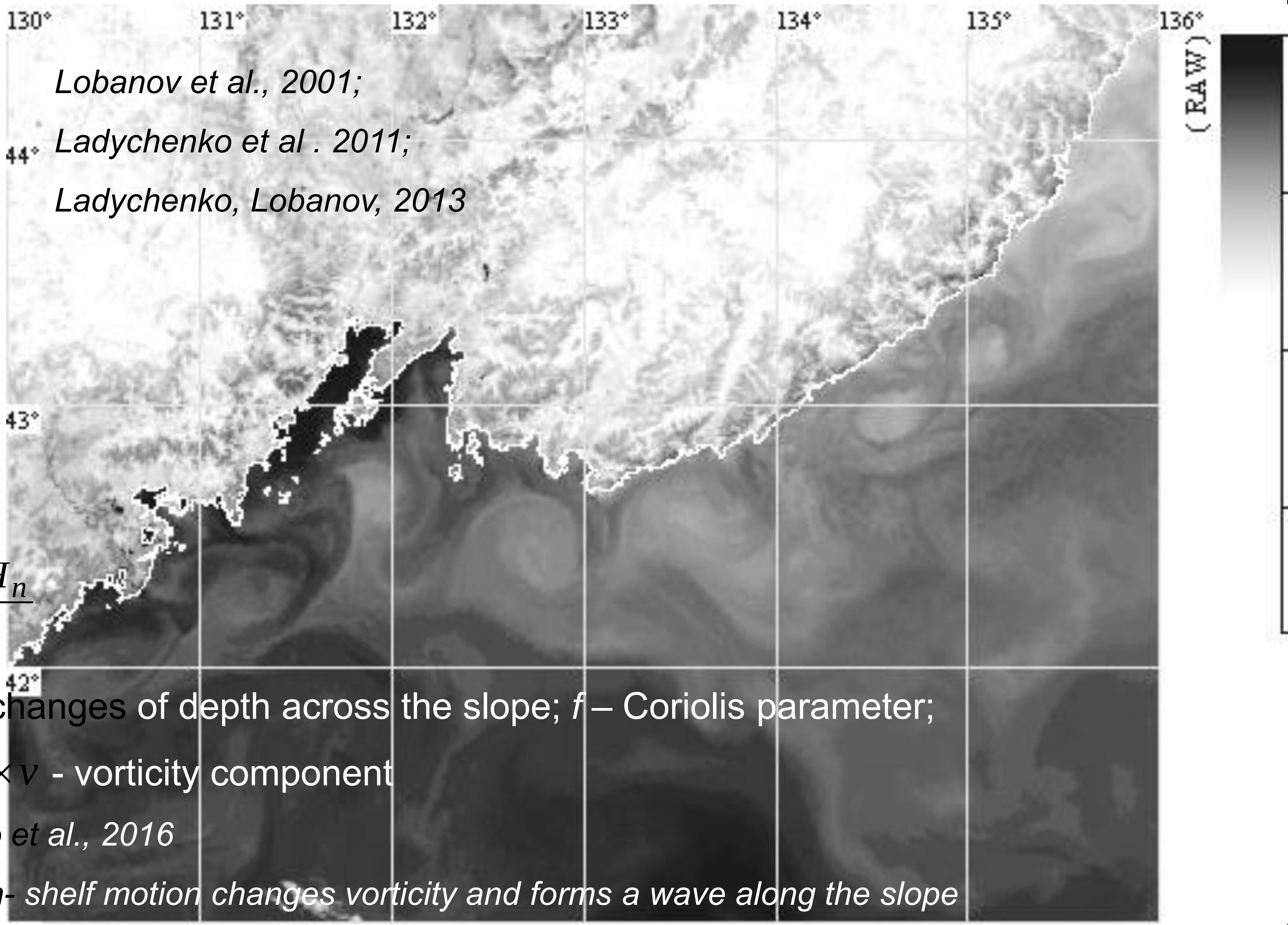


Danchenkov et al., 2003

Mesoscale Eddies along Primorye



Mesoscale Eddies along Primorye



Lobanov et al., 2001;

Ladychenko et al . 2011;

Ladychenko, Lobanov, 2013

$$\frac{\zeta}{f} = \frac{H - H_n}{H_n}$$

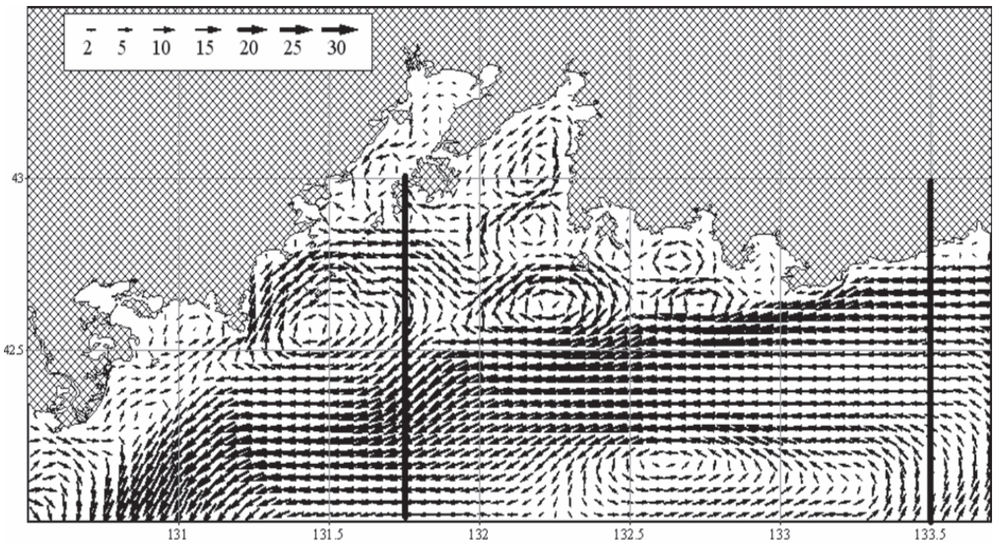
$H - H_n$ – changes of depth across the slope; f – Coriolis parameter;

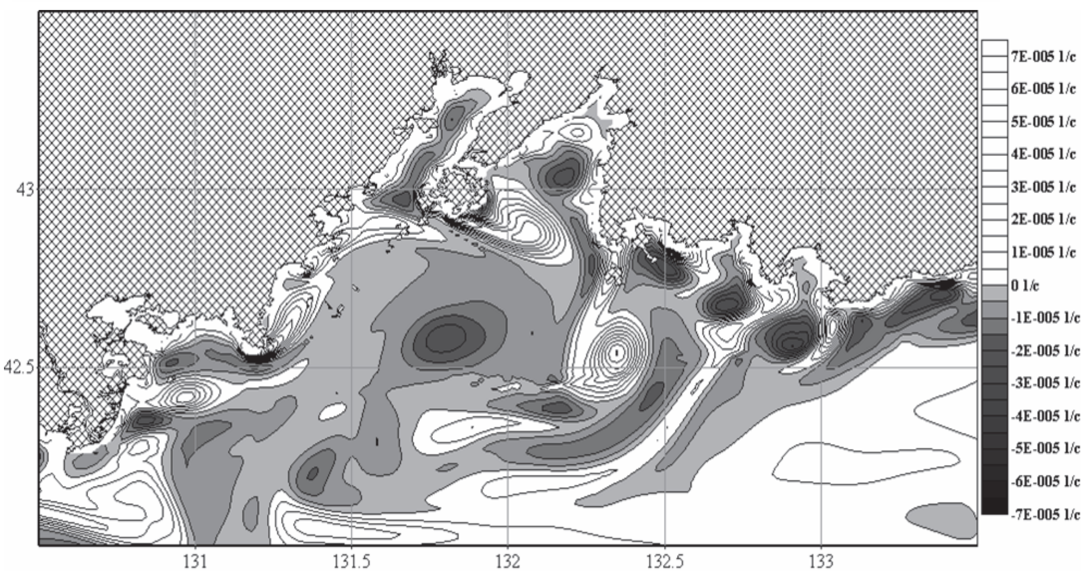
$\zeta \equiv \vec{k} \cdot \nabla \times v$ - vorticity component

Belonenko et al., 2016

off- and on- shelf motion changes vorticity and forms a wave along the slope

Modelled Primorye Slope Eddies

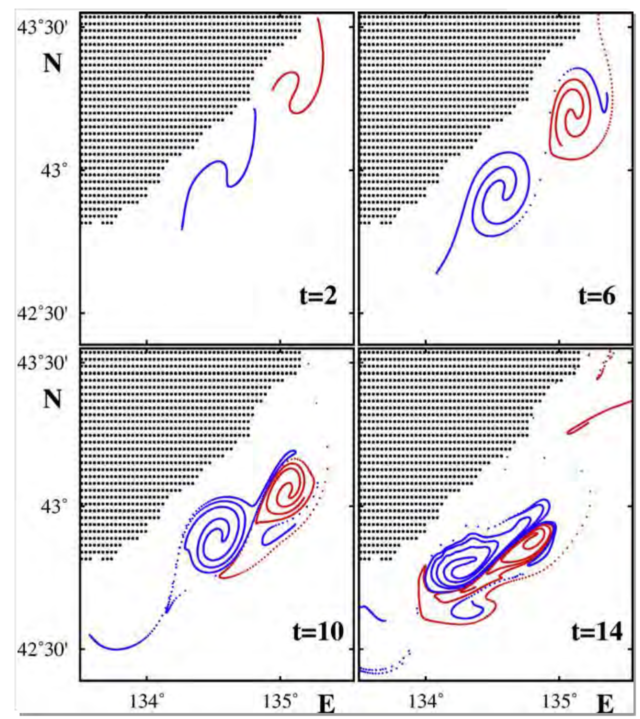




Current velocity (top) and vorticity (bottom) in the upper mixed layer by quasi-isopycnal layered model in z-coordinate system (Shapiro and Mikhailova, 2001)

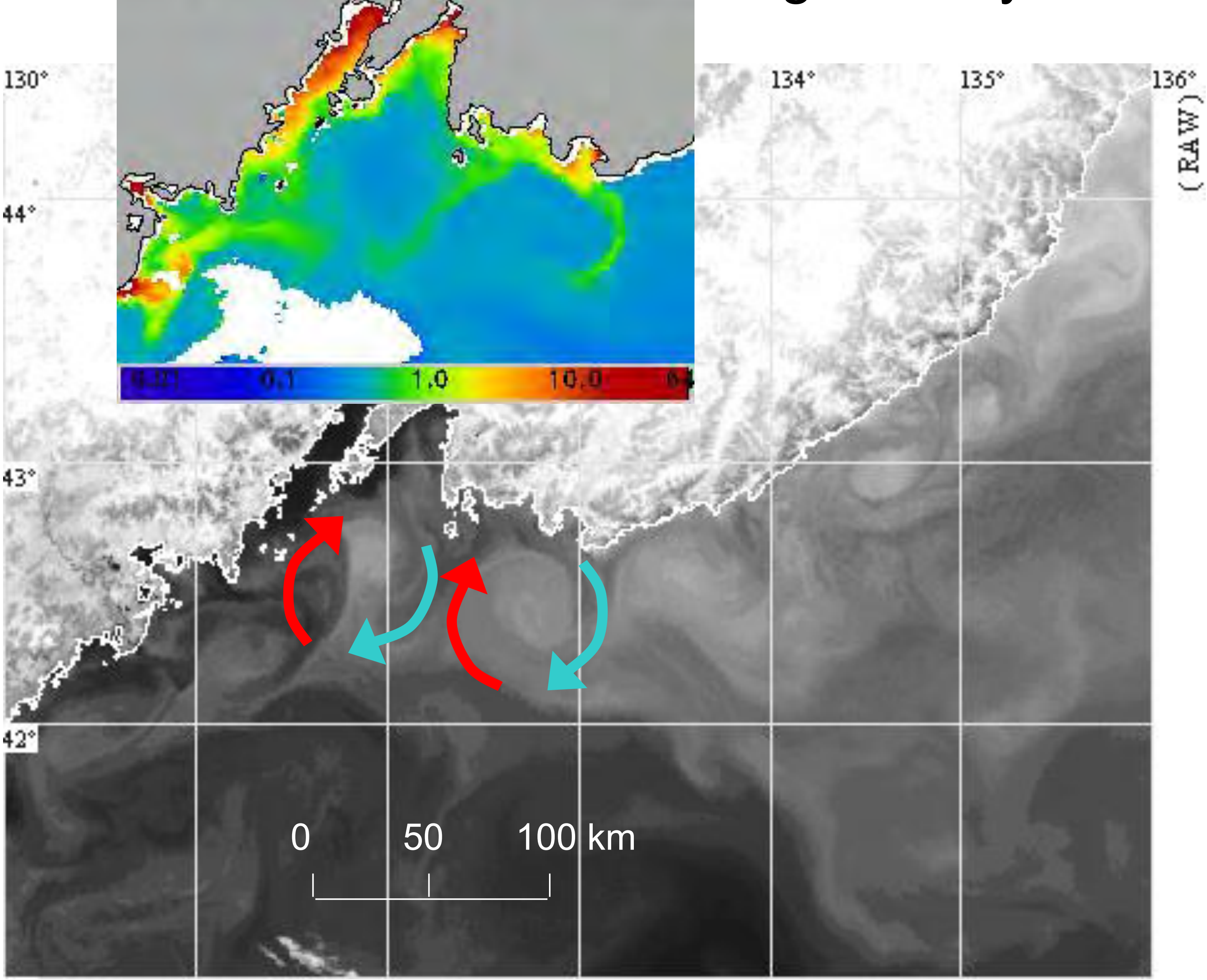
2,5 km, 10 layers

Ponomarev et al., 2011



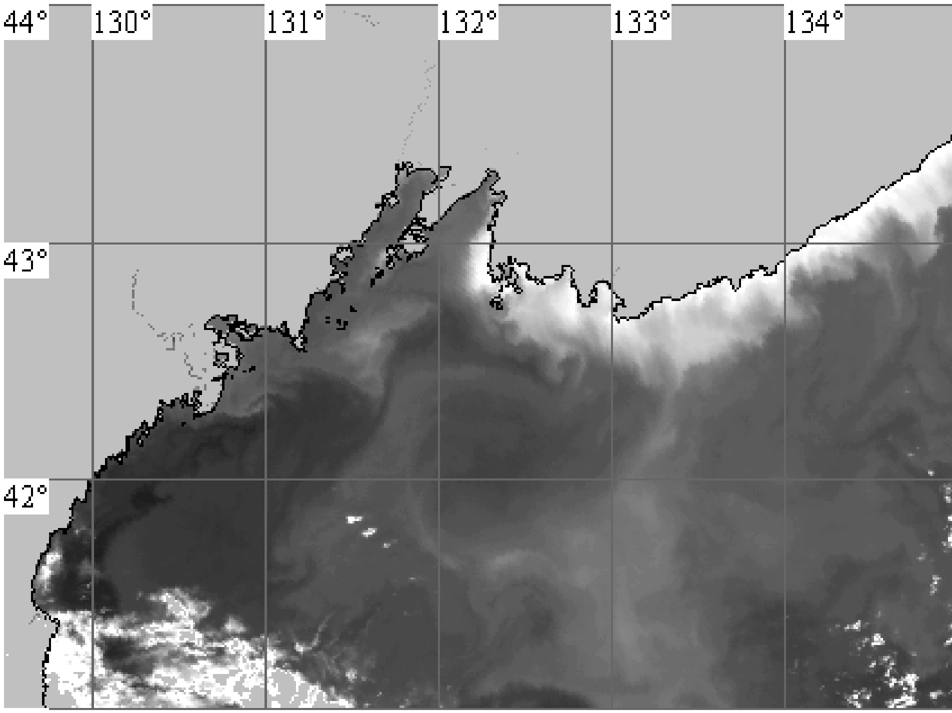
Prants et al. 2011

along Primorye

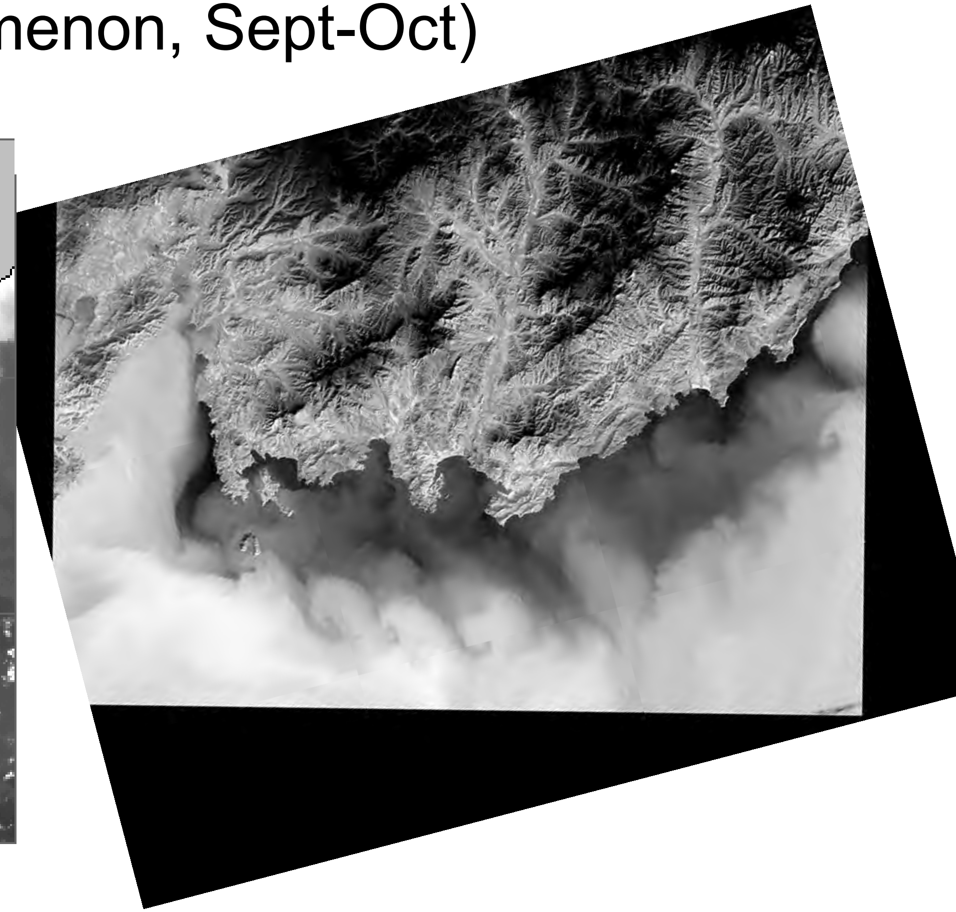


Upwelling along Primorye Coast

(seasonal phenomenon, Sept-Oct)

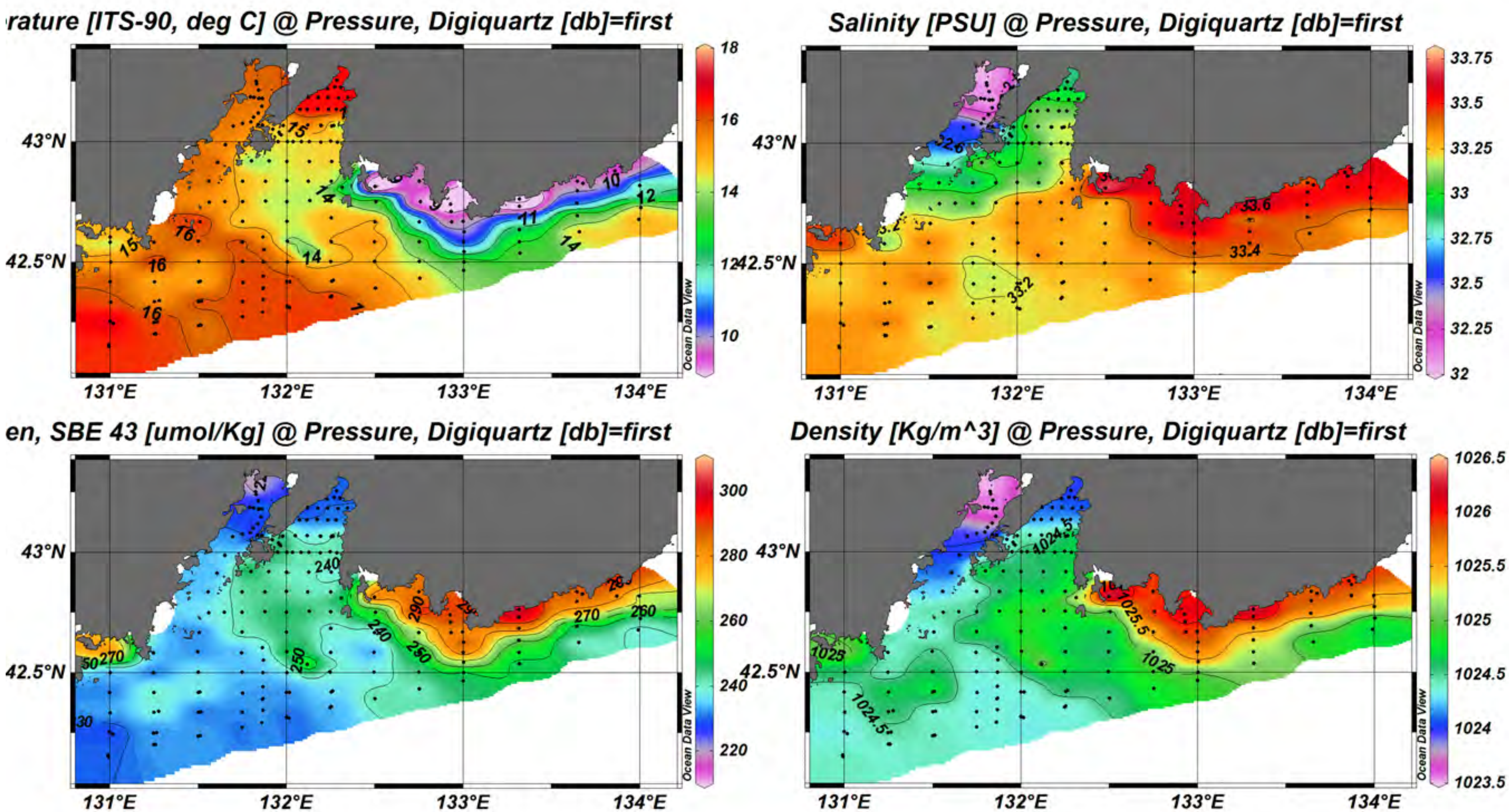


NOAA-IR-2016-10-20



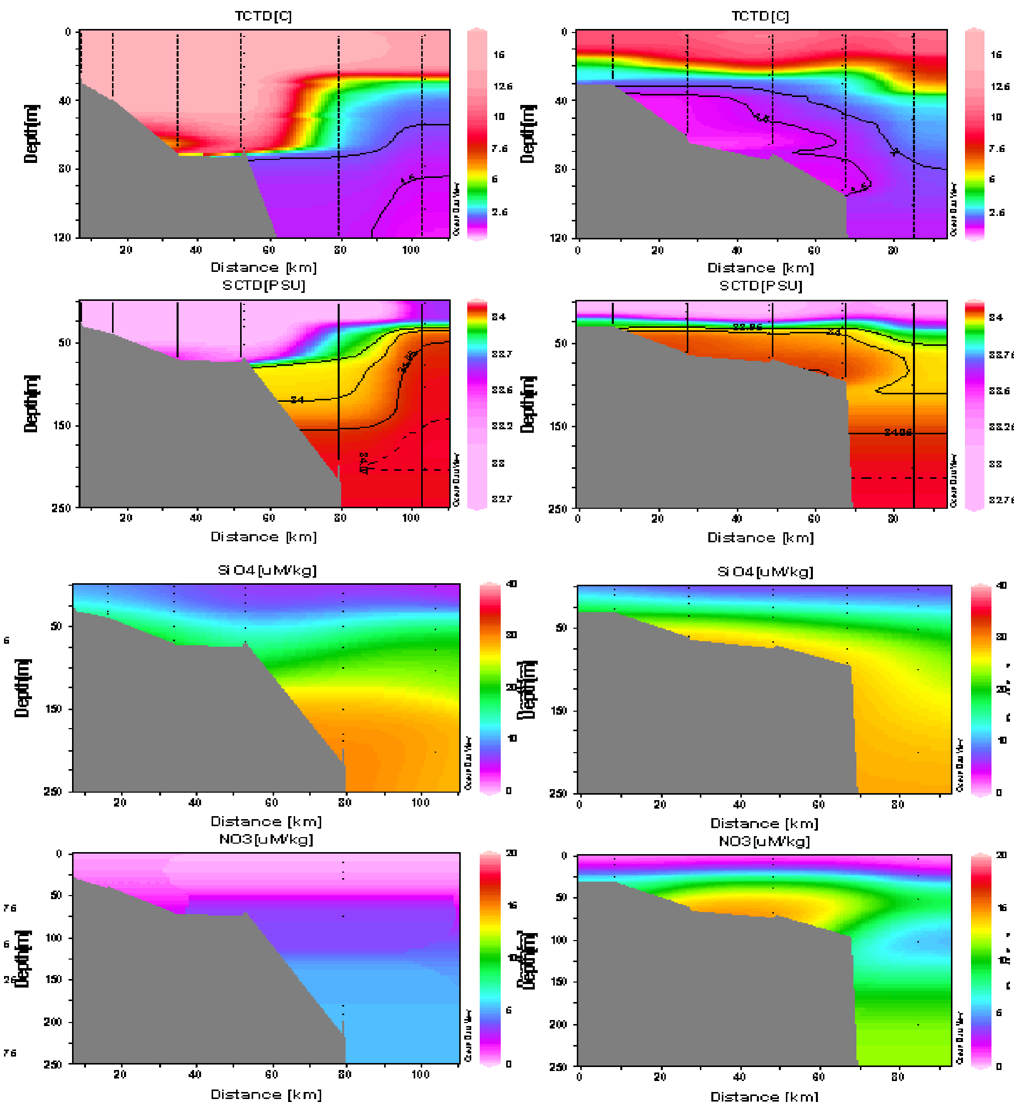
L8-IR-2016-10-21

Surface distribution of T, S, Sigma 0 and DO



Changes in water mass structure and stratification by upwelling and eddy advection

S1



before after

$\Delta T, ^oC$	S1	S3
10 m	3.5	5.2
50 m	9.6	0.5

<u>Intrusion area, wide shelf:</u>

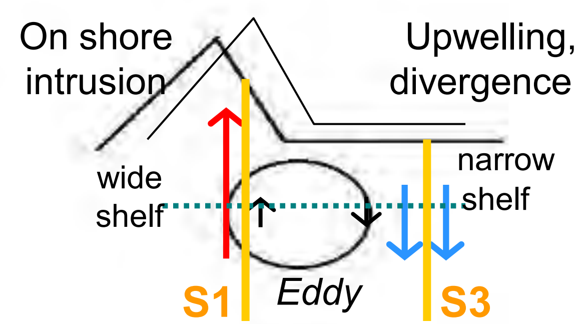
-Initially: well mixed

-Nutrients supply

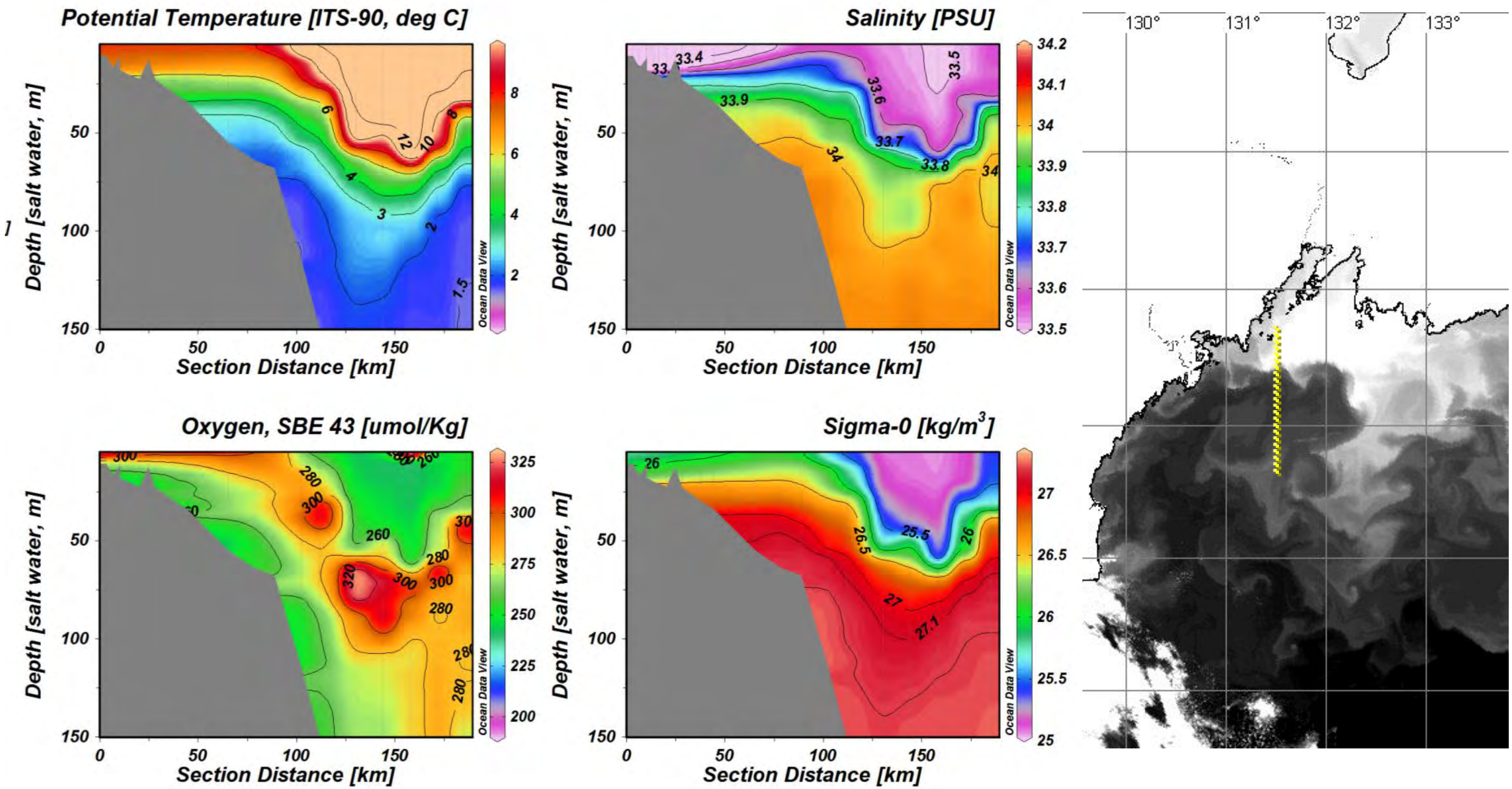
-Uplift of picnocline

-Convective mixing - upper lr.

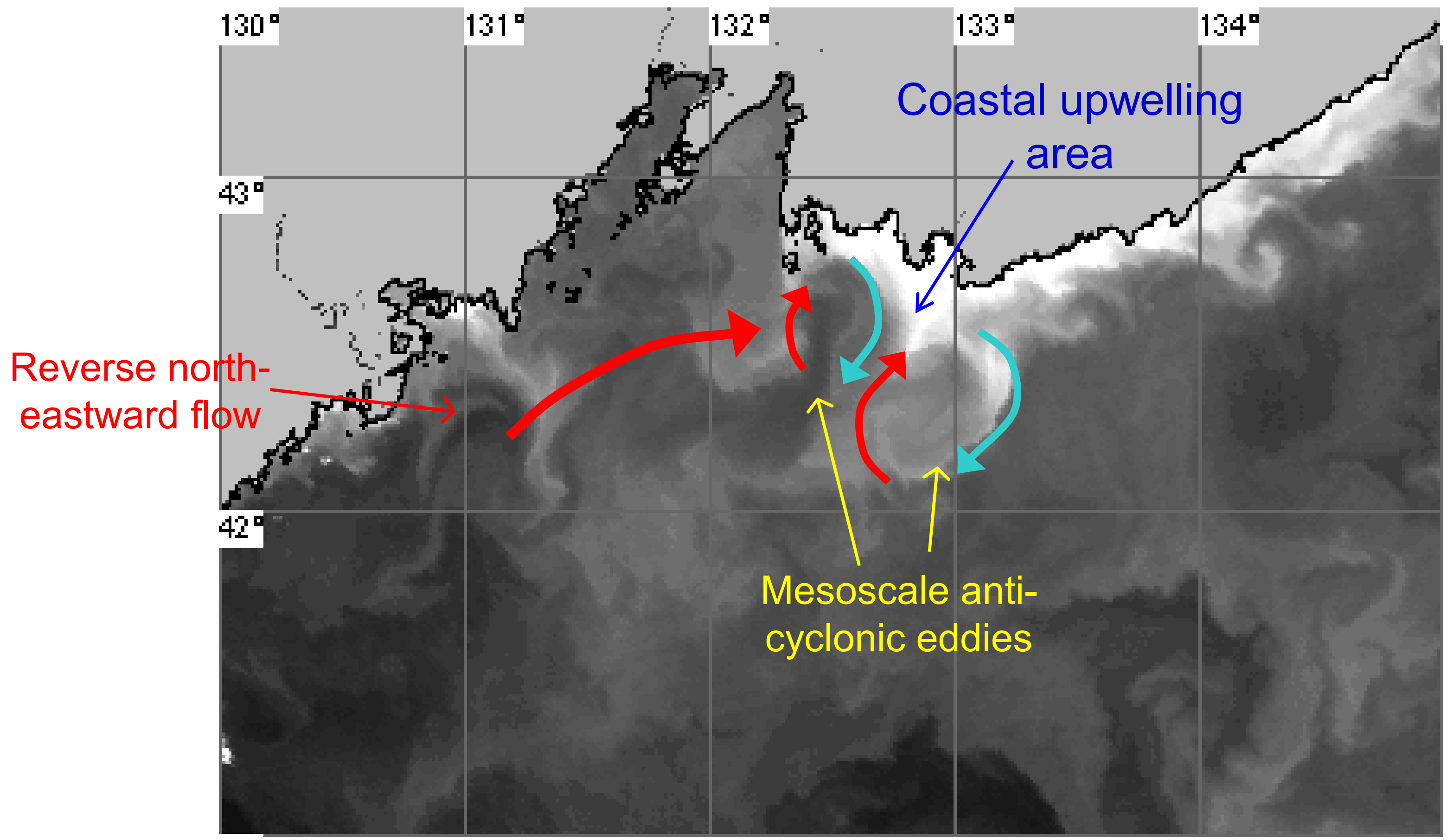
-Decrease MLD



Vertical structure of Primorye Eddy

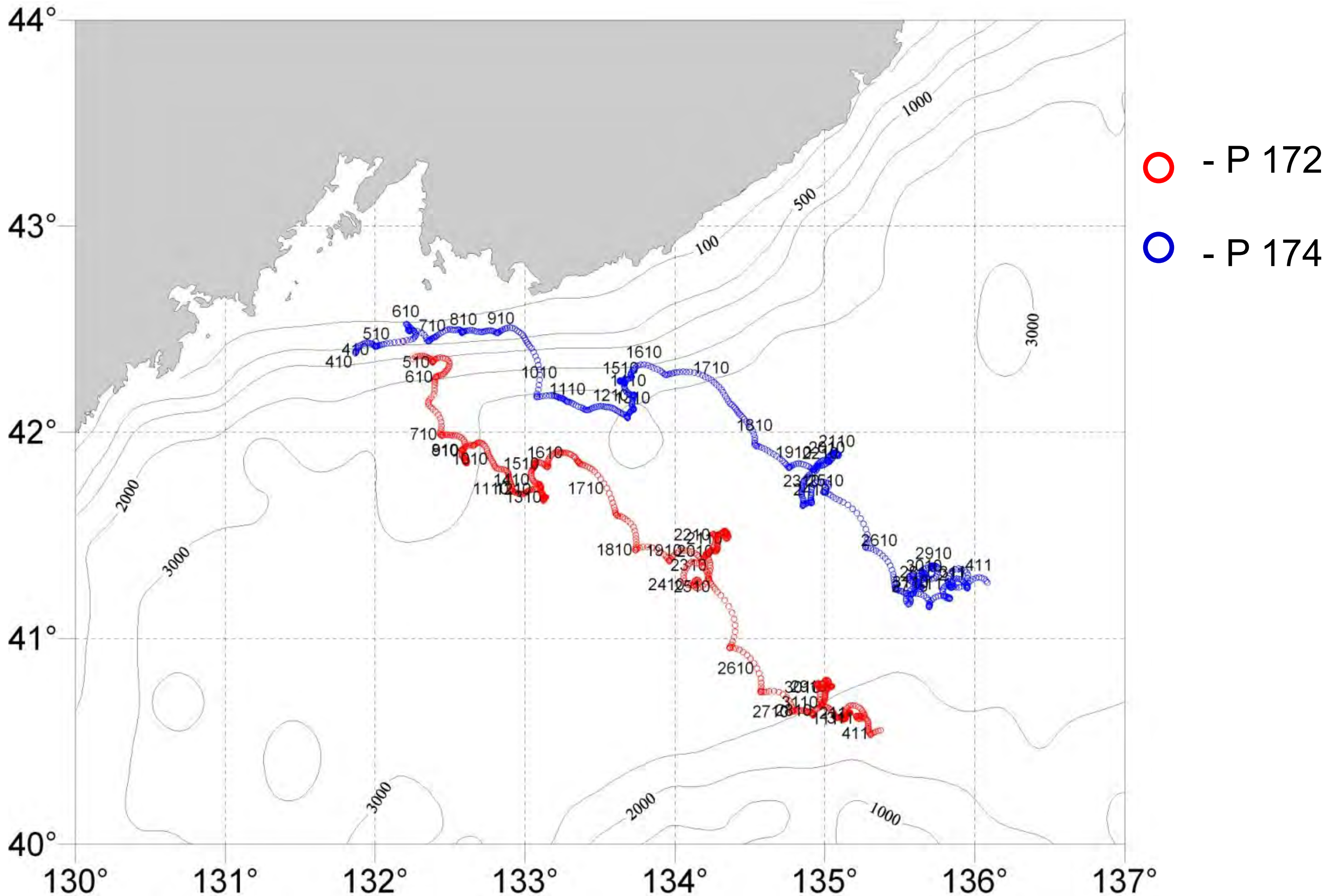


Reverse flow in the NW Japan Sea on satellite infrared images, October 7, 2011



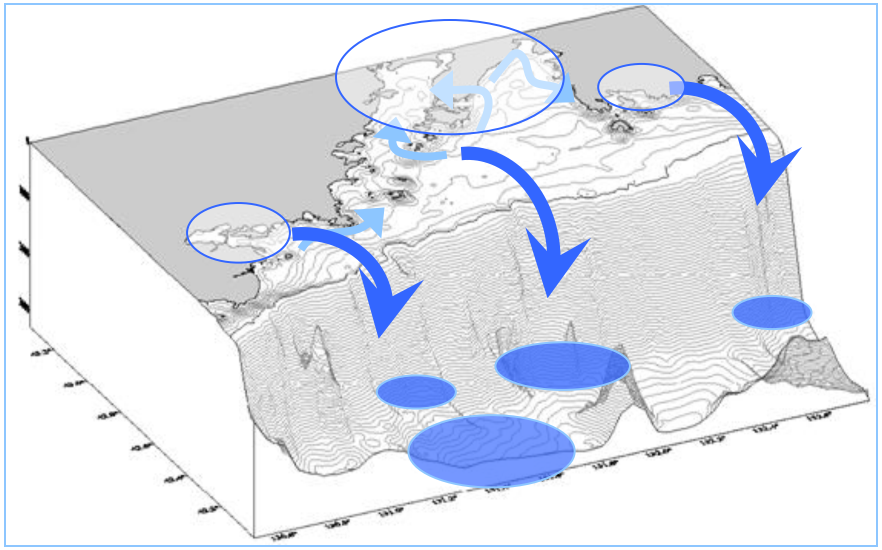
Reverse flow- surface drifters trajectories

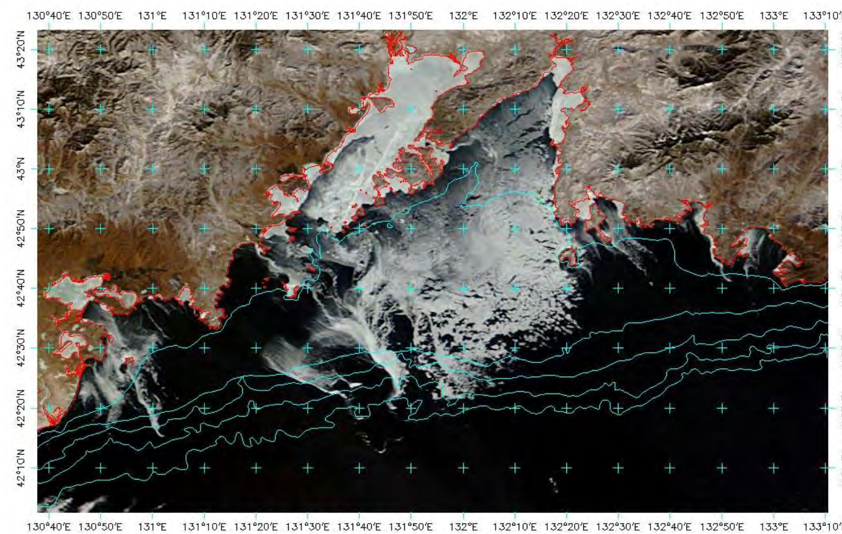
October 4 – November 4, 2011



Slope Convection (Cascading)

Cascading in the 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

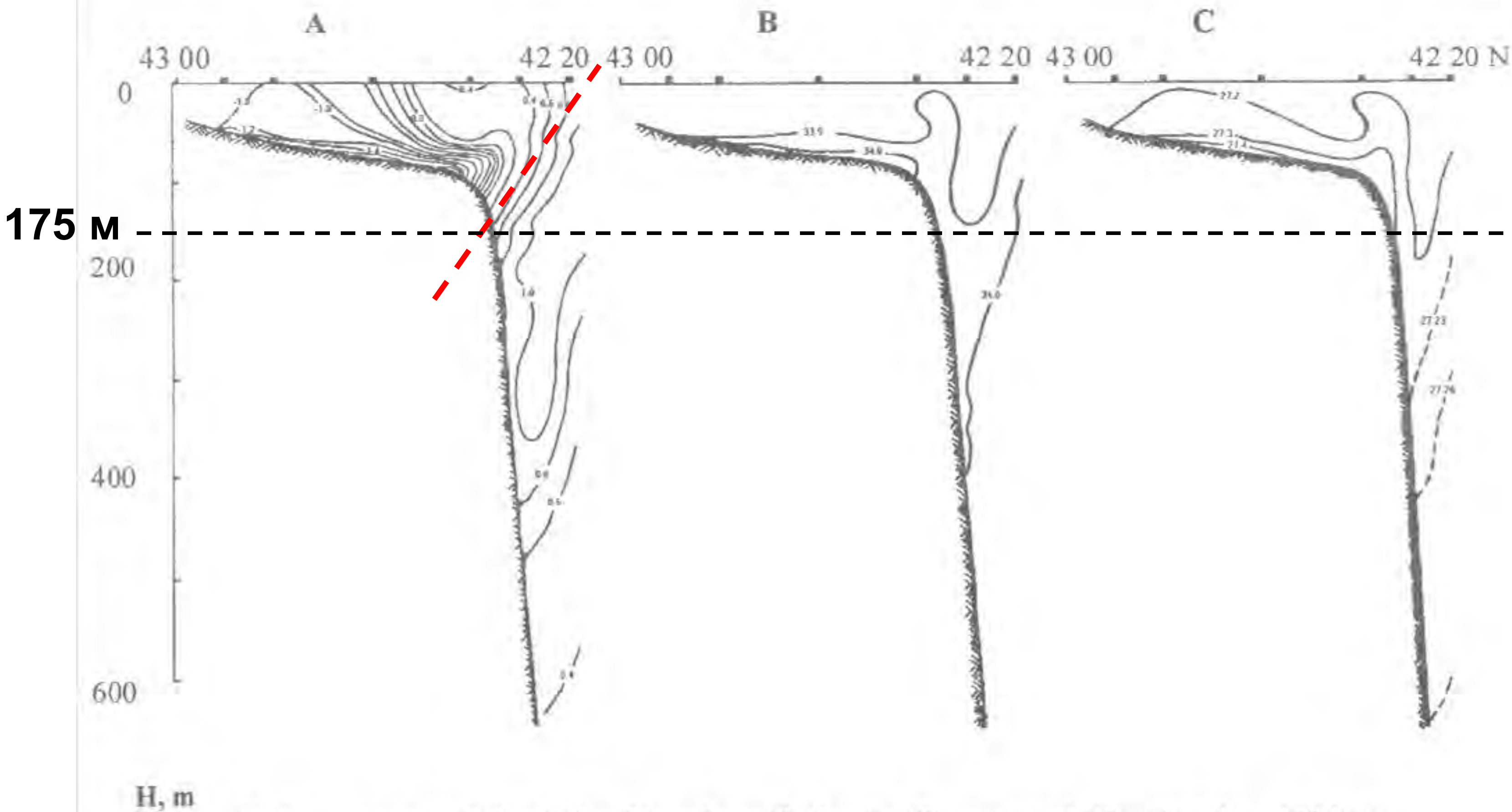
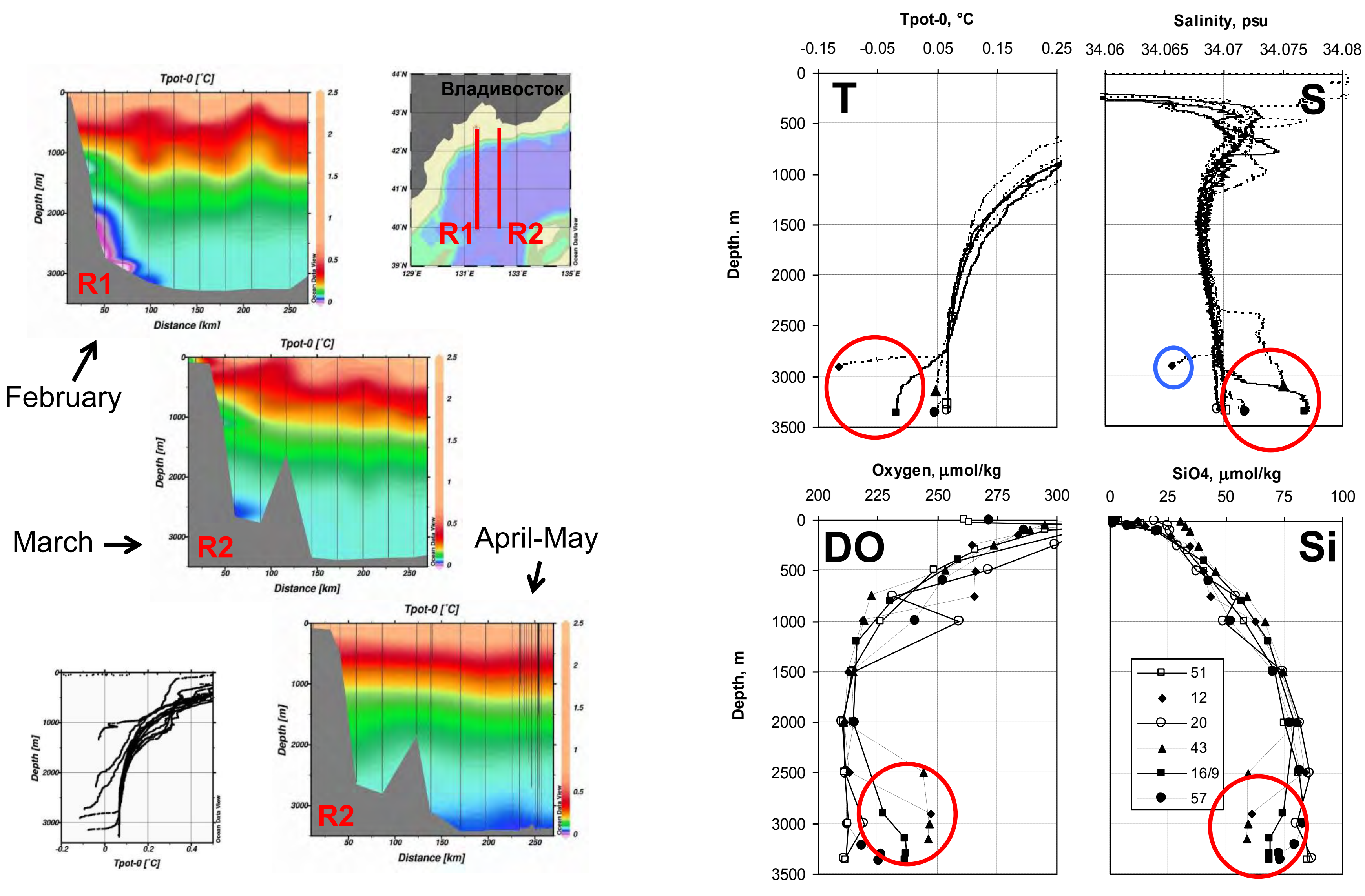


Fig.5. Temperature (A), salinity (B), and specific density (C) on cross-shelf section along 132 N in March 7, 1998 (R/V "Shursha").

Zuenko, 1998; 2000

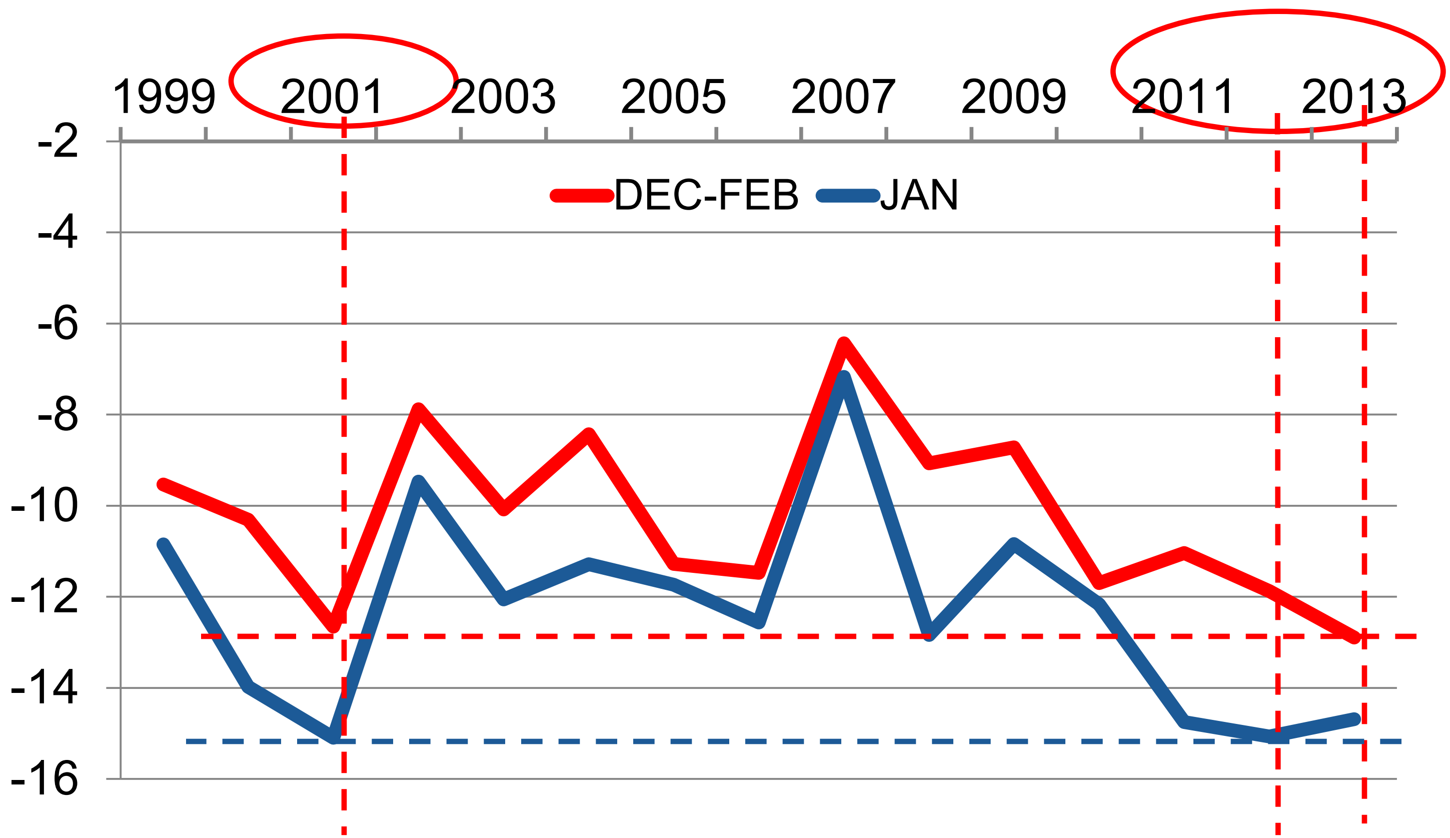
Evidence of Cascading in a severely cold winter of 2001 and Ventilation of Bottom Water



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

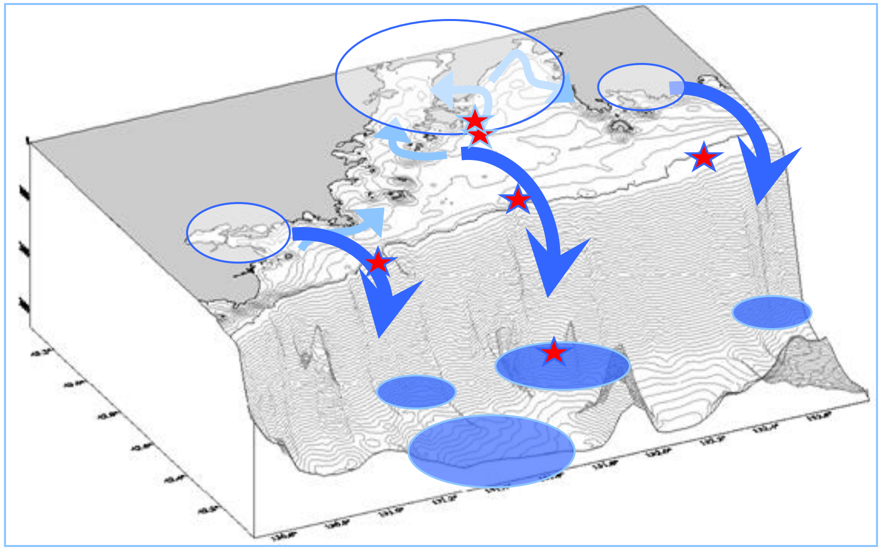
(mean January and mean Dec-Feb)

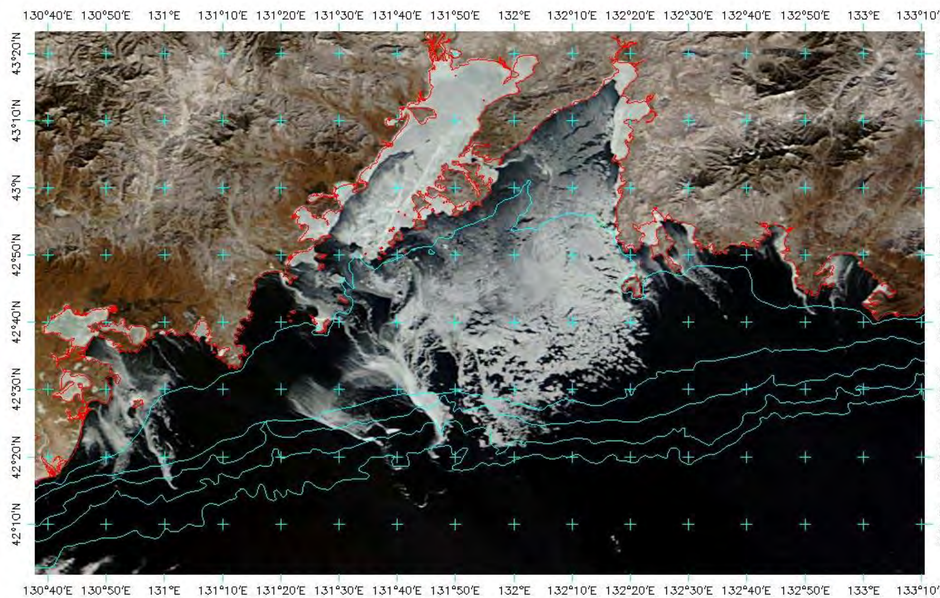


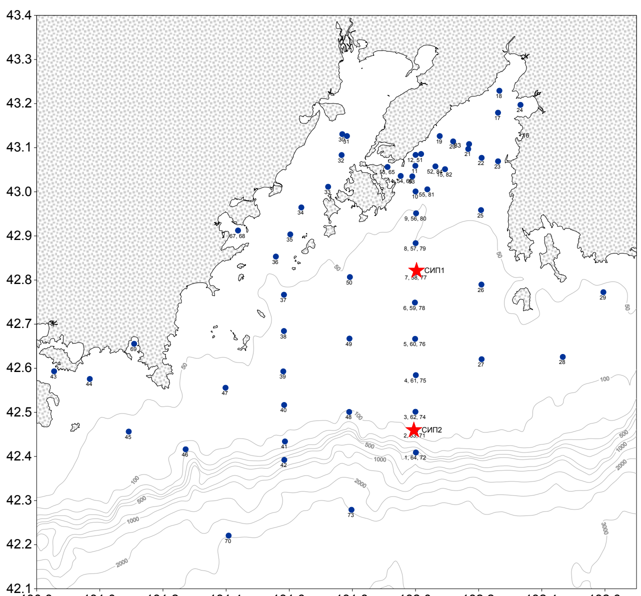
Winters 2012 and 2013 – the coldest winters over recent 12 years and second coldest January T over 35 years after 2001

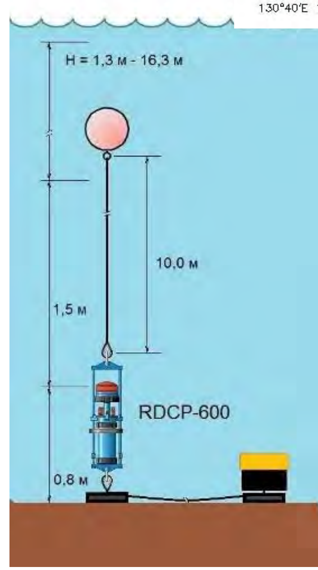
Study of Slope Convection in Peter the Great Bay

during cold winters 2011-2014 гг.







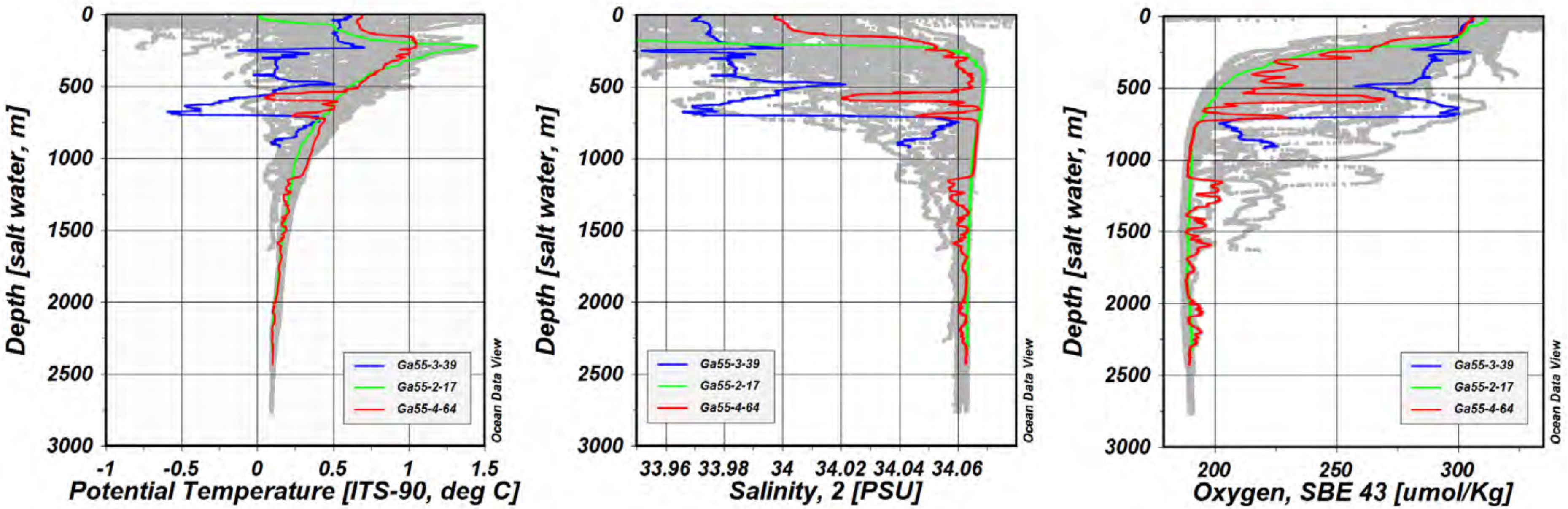


- CTD surveys (SBE19, SBE911, RBR-XR);

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

нций экспедиции ТОИ ДВО РАН на НИС "Профессор Гагаринский", рейс №46, 27 февраля - 16 марта 2010 г.

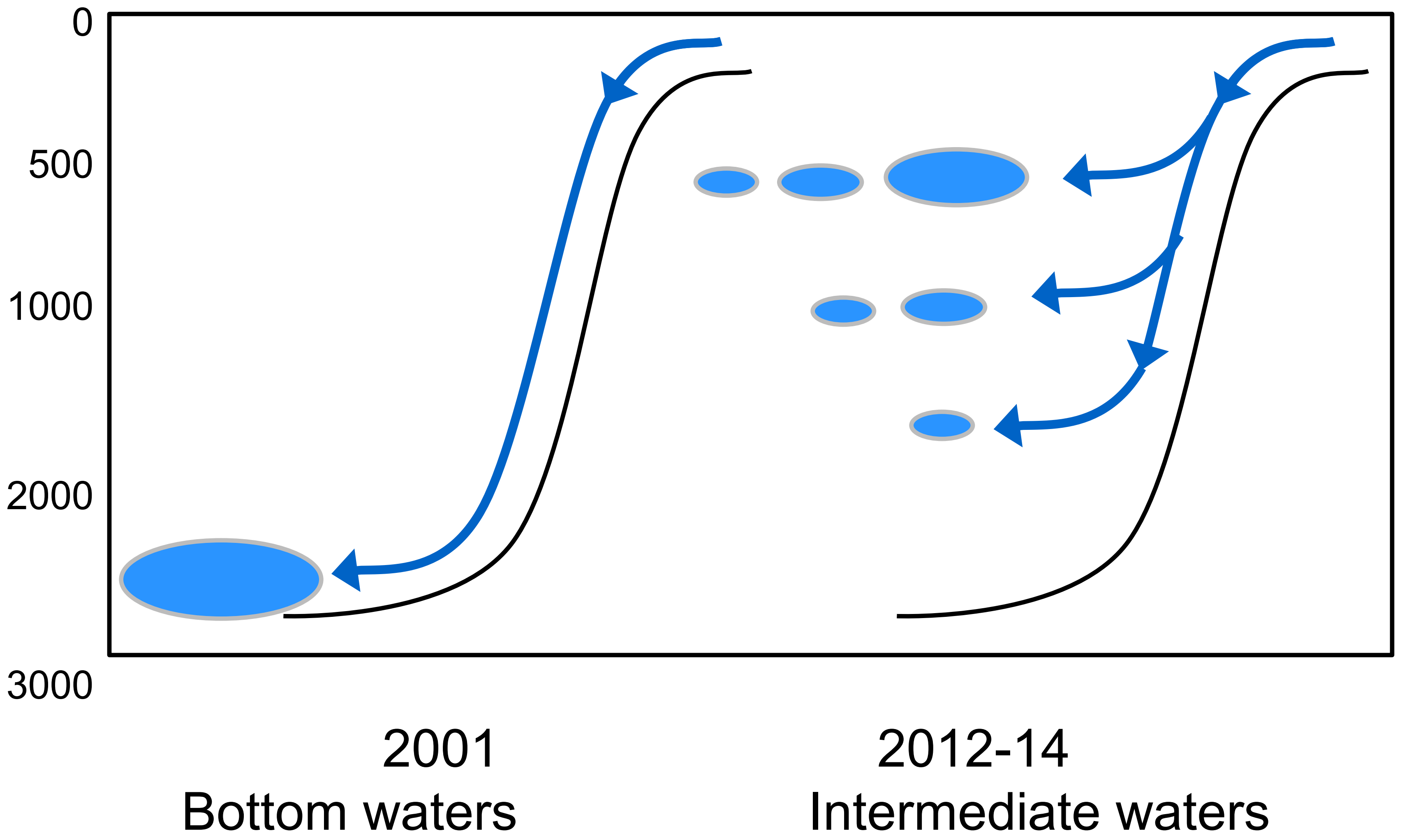
Slope convection off Peter the Great Bay, 2012



All profiles over the slope during Feb-April 2012

___ Feb 08, ___ Mar 01, ___ Mar 15

Different Ventilation Regimes



Peter the Great Bay Slope Convection Model

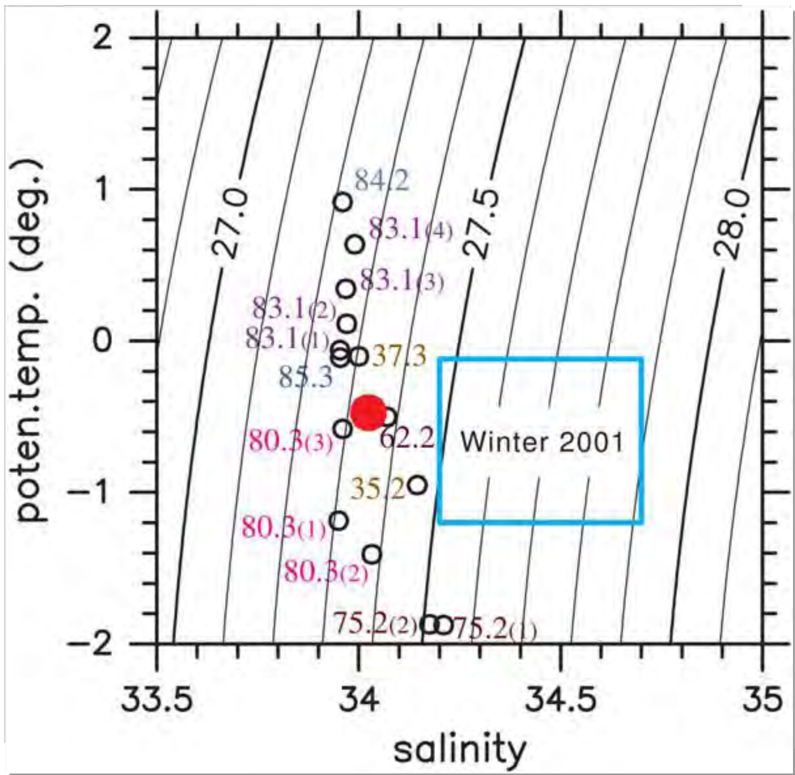


Figure 2. TS diagram of the near-bottom shelf water in Peter the Great Bay. Solid lines indicate potential density rh. The area within the blue rectangle indicates the ranges in Winter 2001 [Lobanov et al., 2002; Talley et al., 2003]: potential temperature of 21.2 to 20.12C and salinity of 34.2–34.7. Open circles indicate values derived from WOD05, and the solid red circle indicates their mean value. Subscripts on the open circles denote years and months of observation, and parentheses with numbers indicate plural casts within the month.

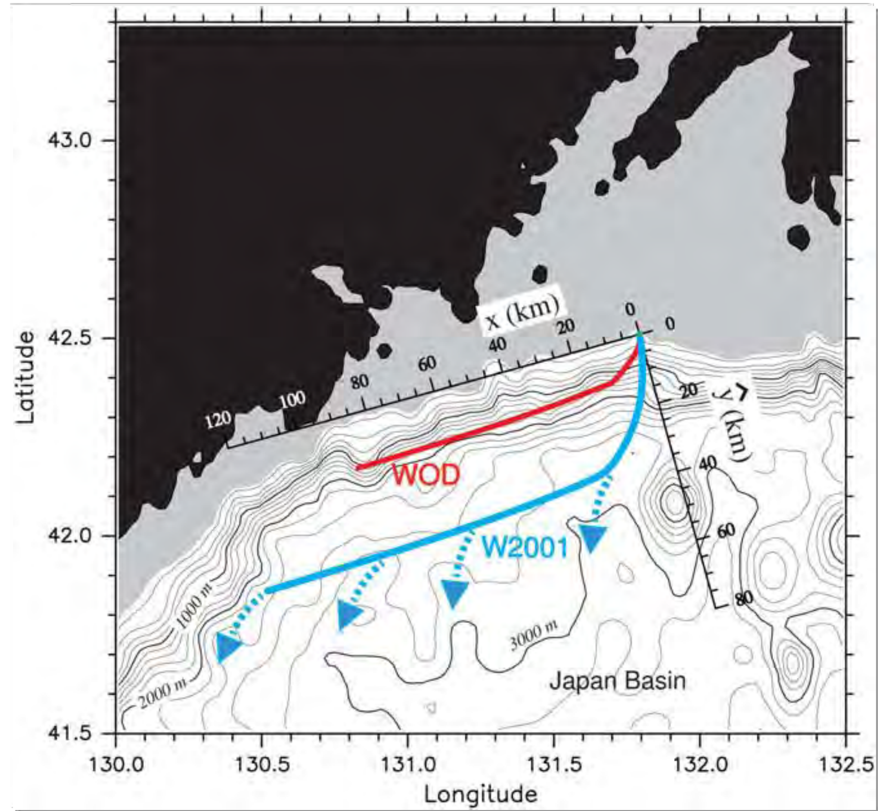
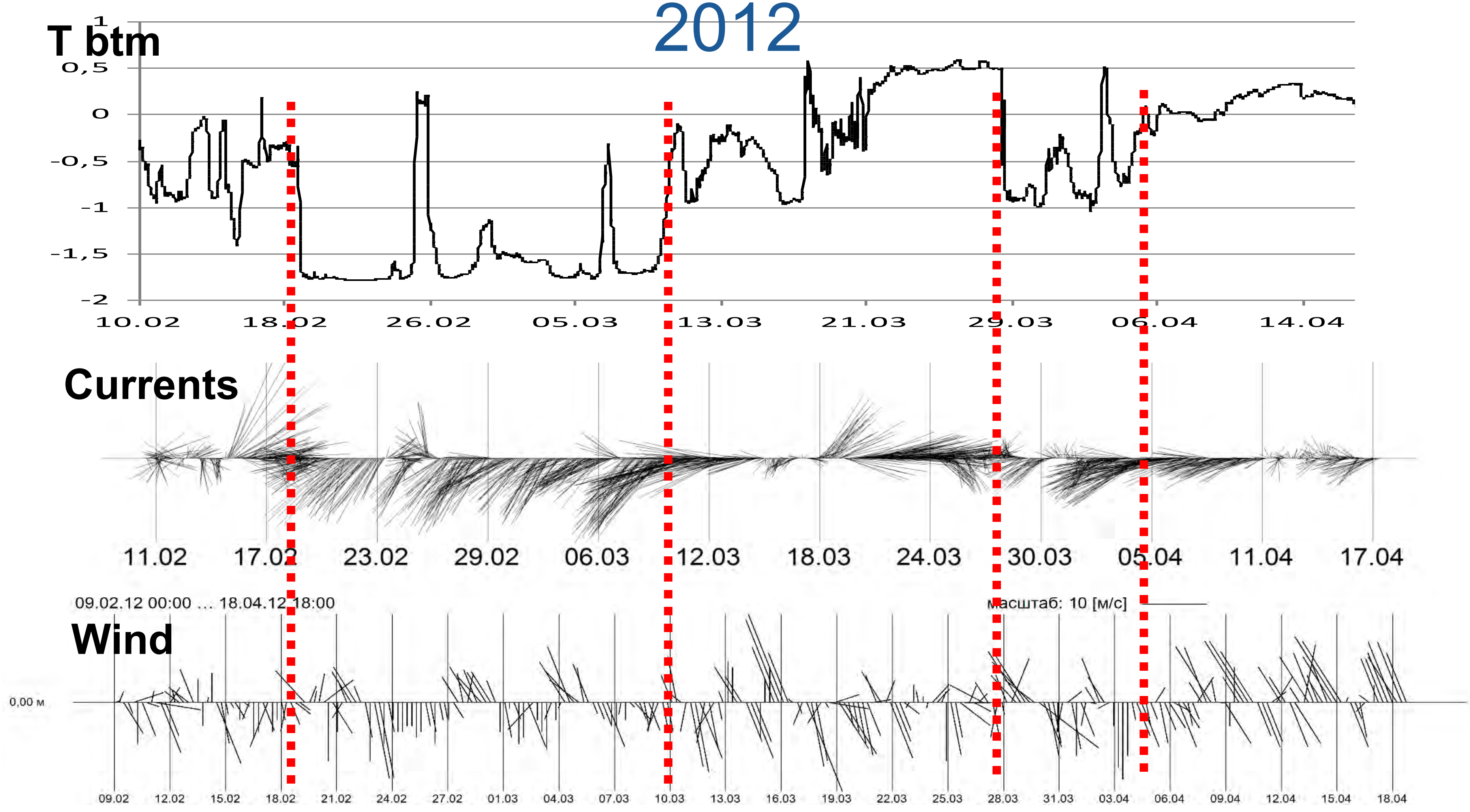


Figure 14. The stream paths (axes) of the average shelf waters (a portion of Figure 4) superposed on the actual topography around PGB. Blue and red lines indicate the paths of the average shelf waters of Winter 2001 (“W2001”) and WOD05 (labeled “WOD”), respectively. Contour lines indicate water depth at intervals of 200 m, and the continental shelf shallower than 150 m is indicated by the shaded area.

K.Tanaka, JGR, 2014

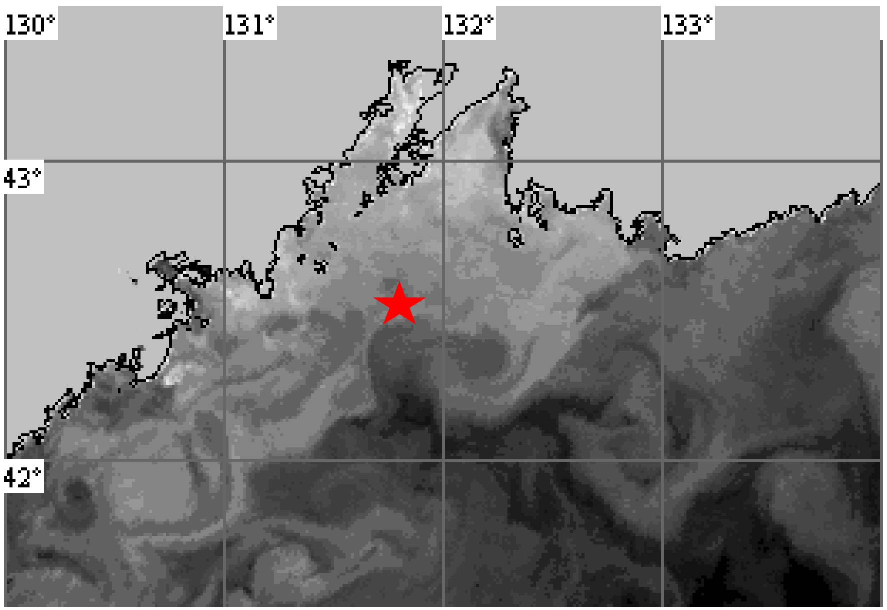
Bottom Currents and Wind, Feb 11- Apr 17, 2012



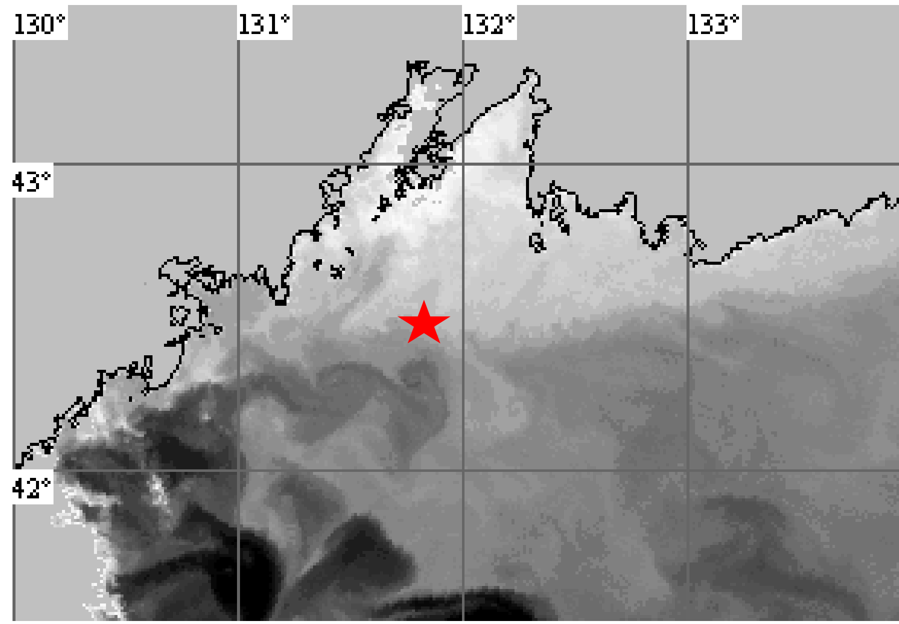
-not much coincidence with wind,
- mesoscale water dynamics over the slope is important

Mesoscale Water Dynamics over the Slope

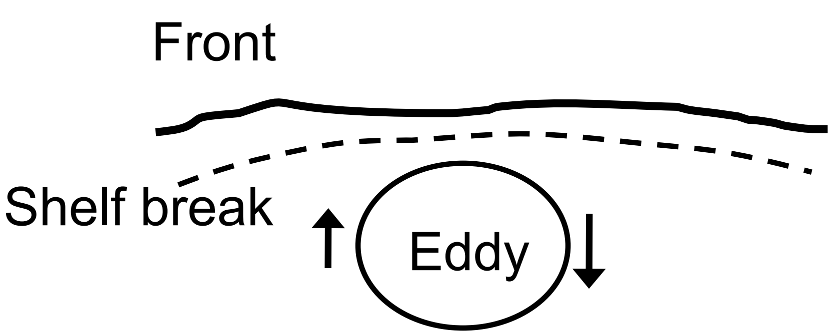
NOAA AVHRR satellite infrared images

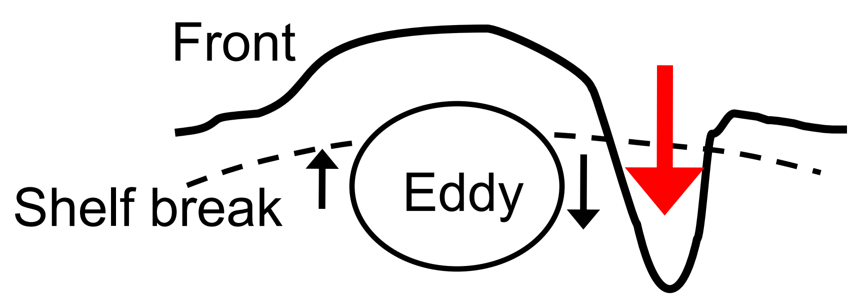


April 2, 2011

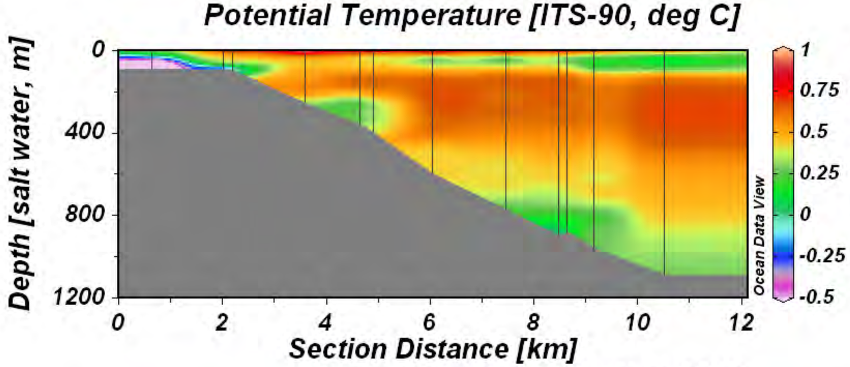


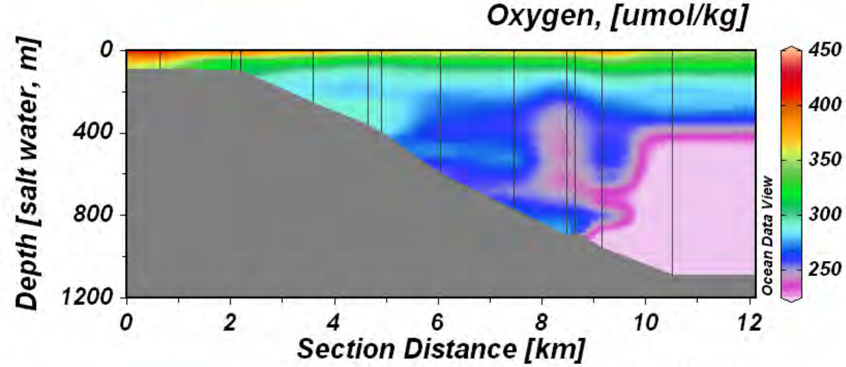
April 4, 2012

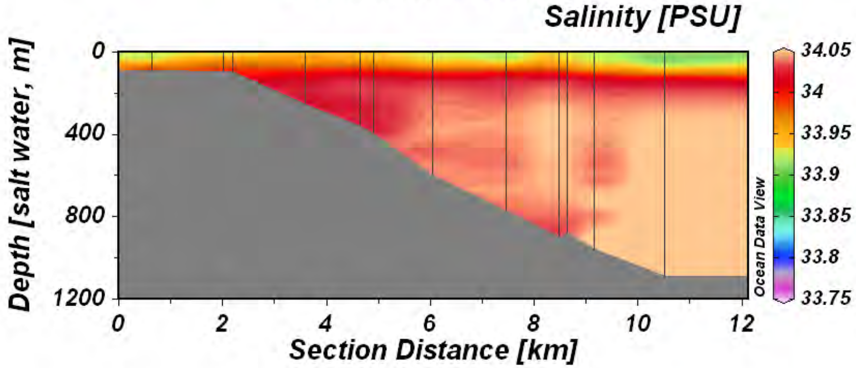


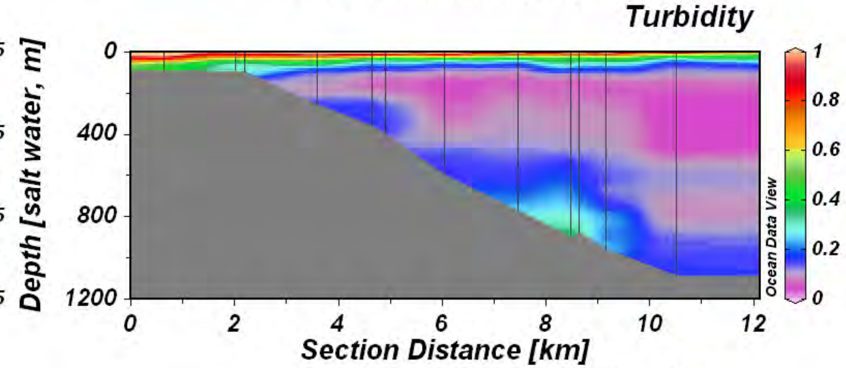


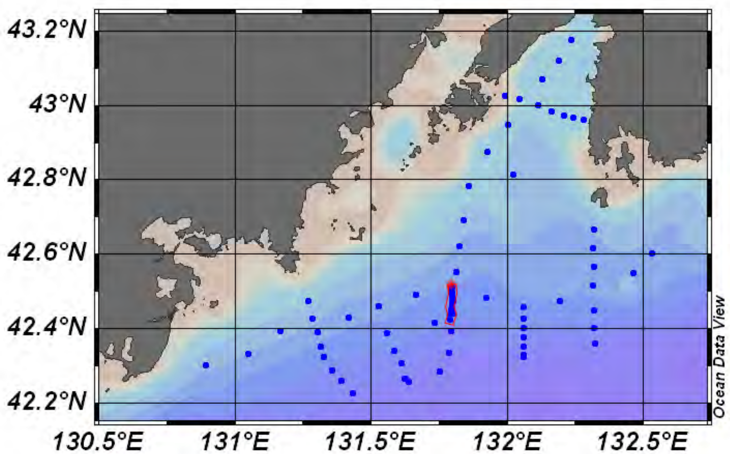
Cascading plume at PGB slope, 3-5.04.2013

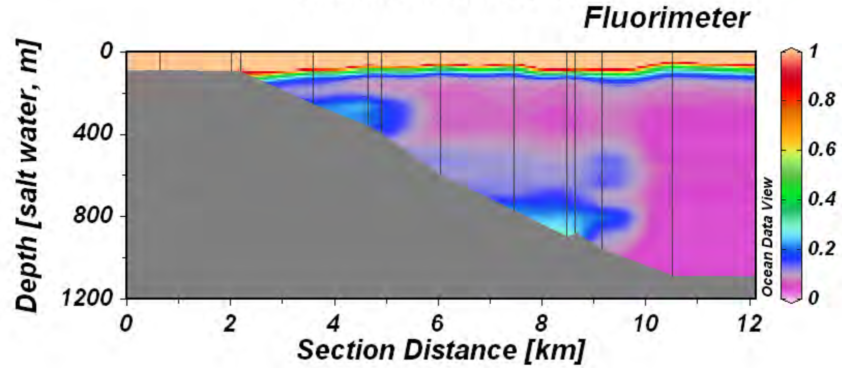




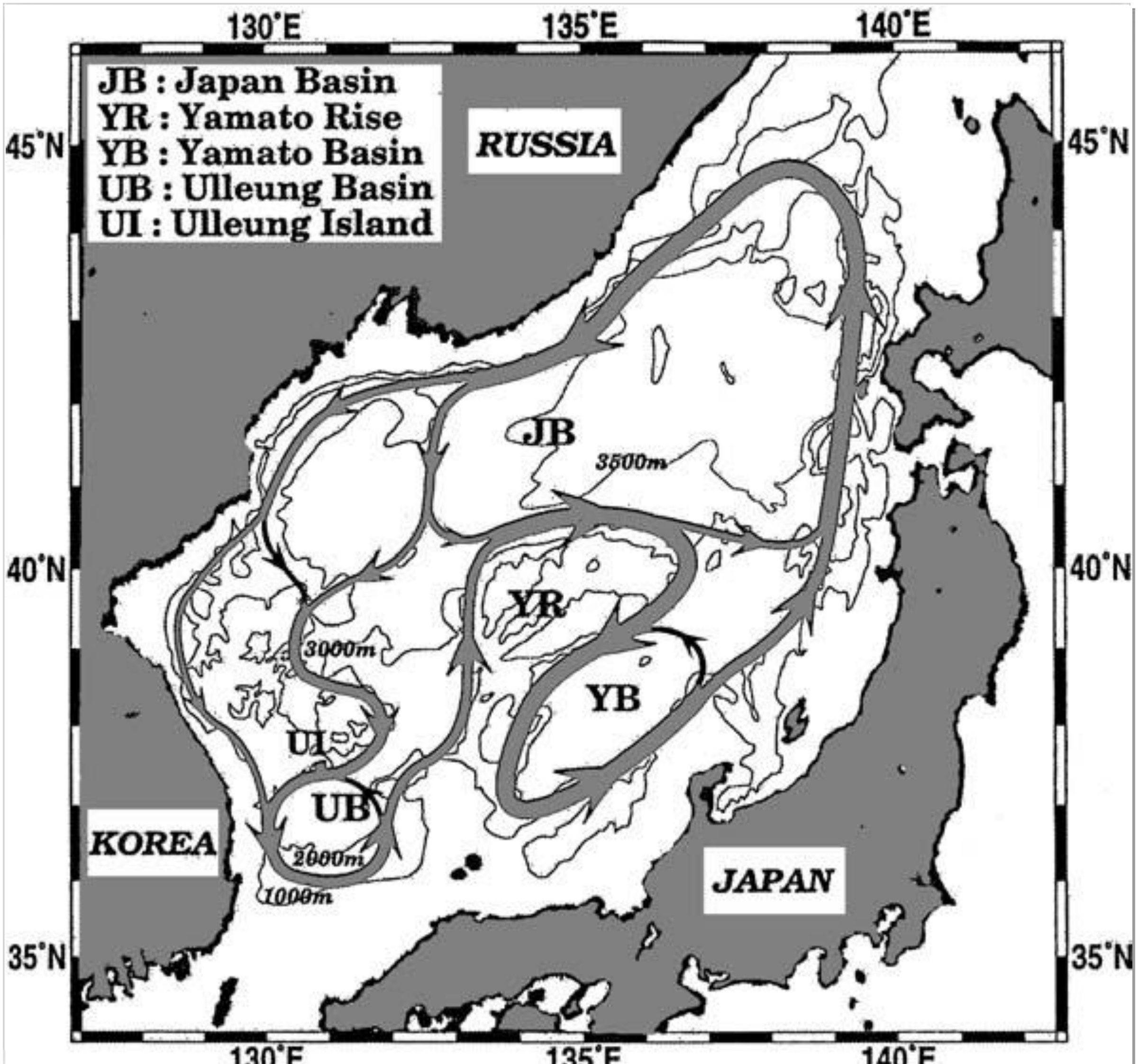








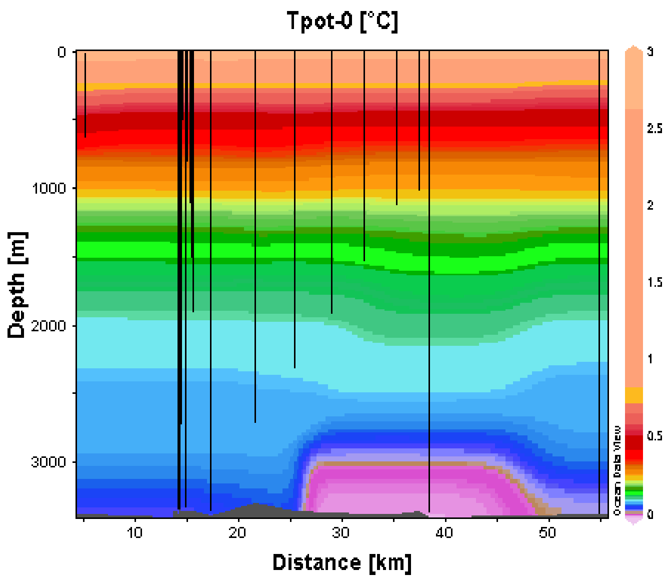
Basin scale processes go through mesoscale

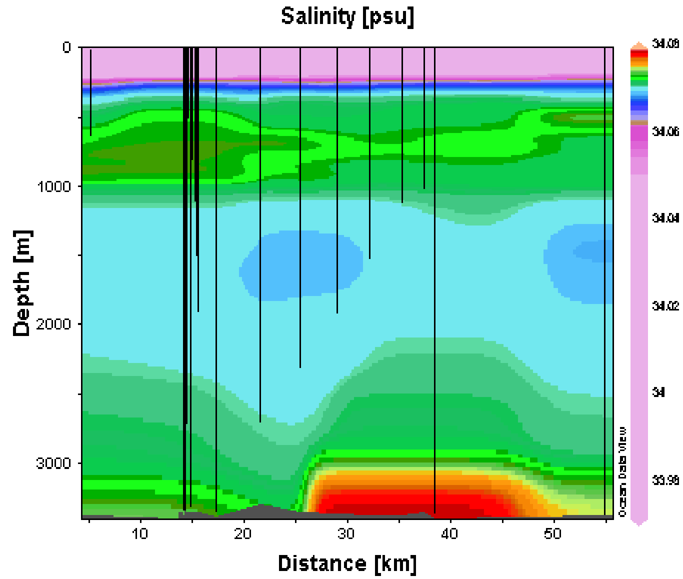


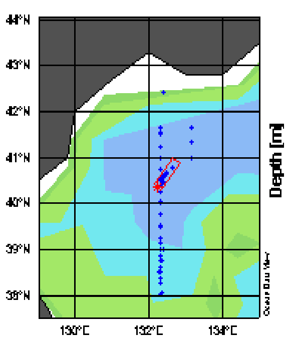
Senjyu et al., 2005

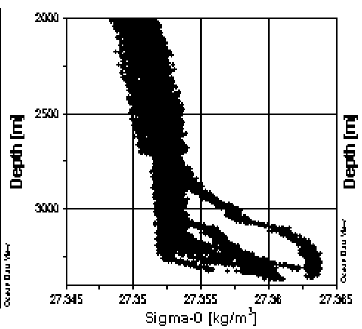
Patchiness of NBW Layer

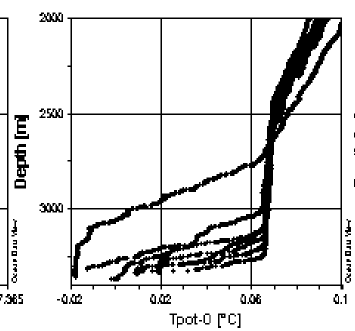
Dome of New Bottom Water around st. 16/9 in April 2001 (600 m thick, 10 miles long)

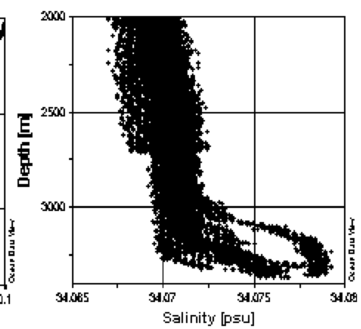










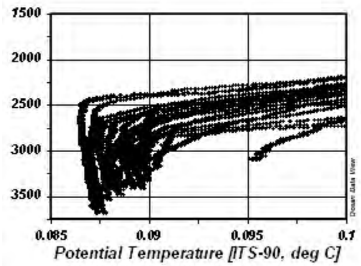


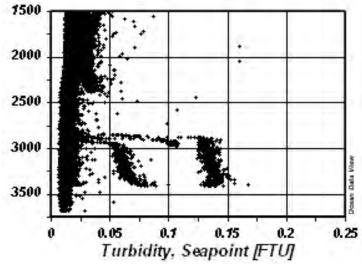
Spatial and temporal variability of New Bottom Water Layer:

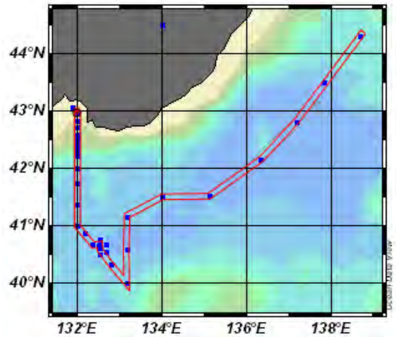
1. Strong signal at the western part of Japan Basin and weak in the eastern
2. No signal at some stations in the central part
3. Different characteristics of NBW in a order of 10 km distance
4. Different characteristics at the same locations between February, April and June cruises.

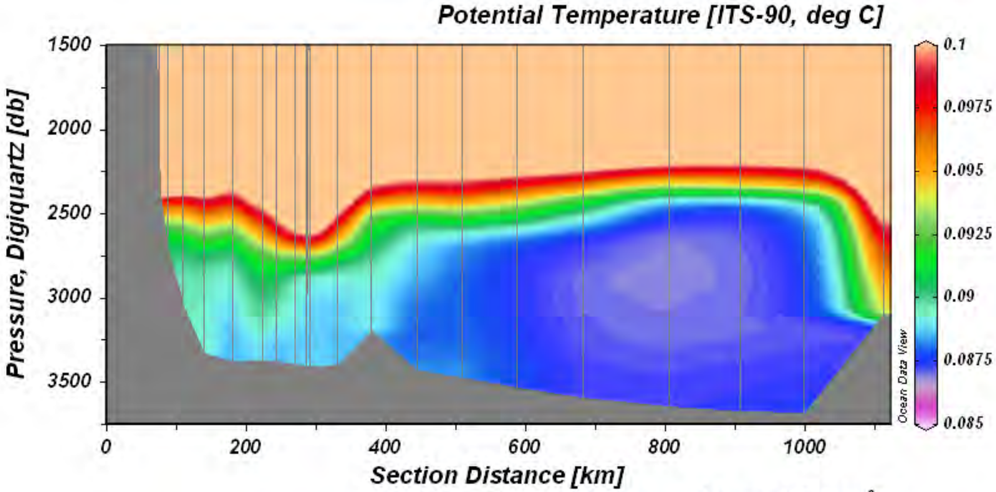
Temporal and spatial variability of NBW layer suggest different sources of its formation

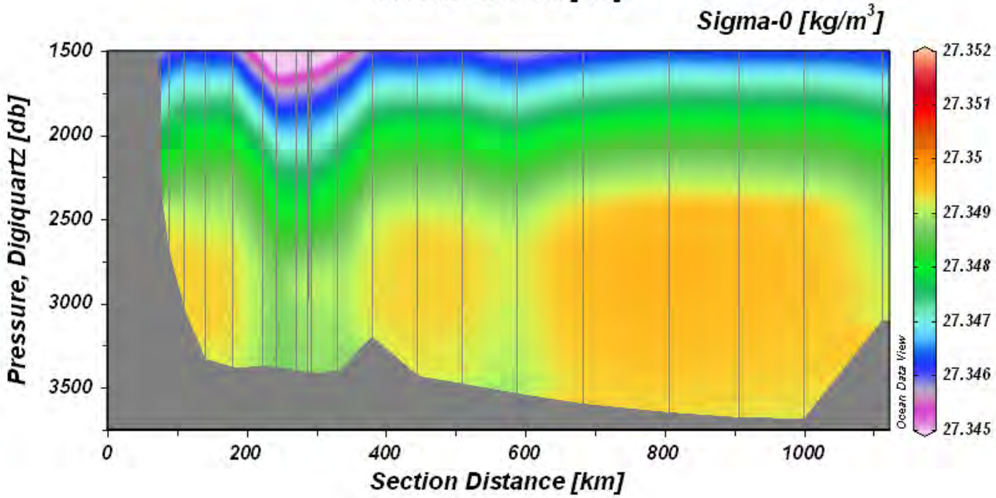
Turbid water in the bottom layer western Japan Basin, 2012-06







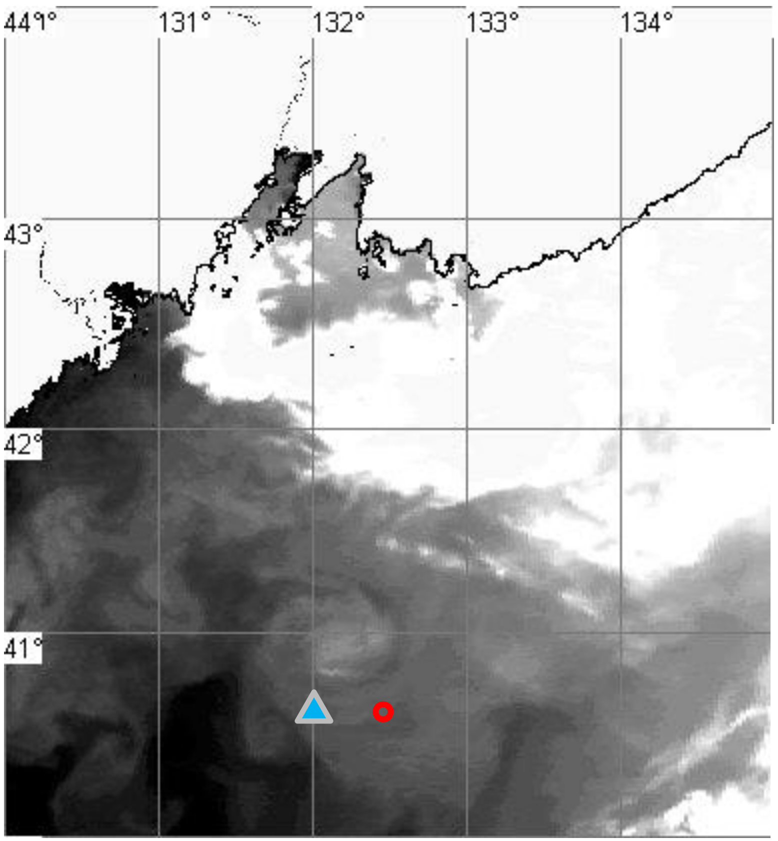


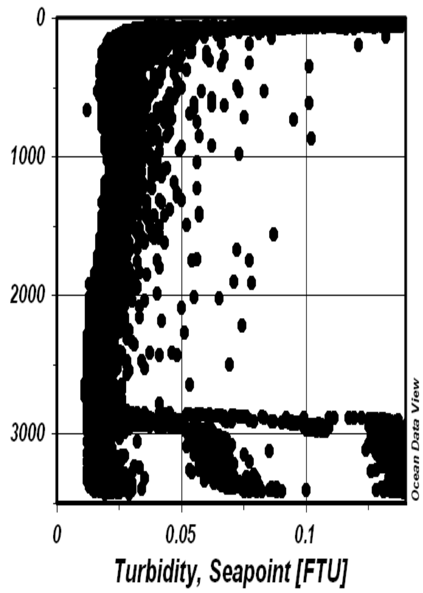


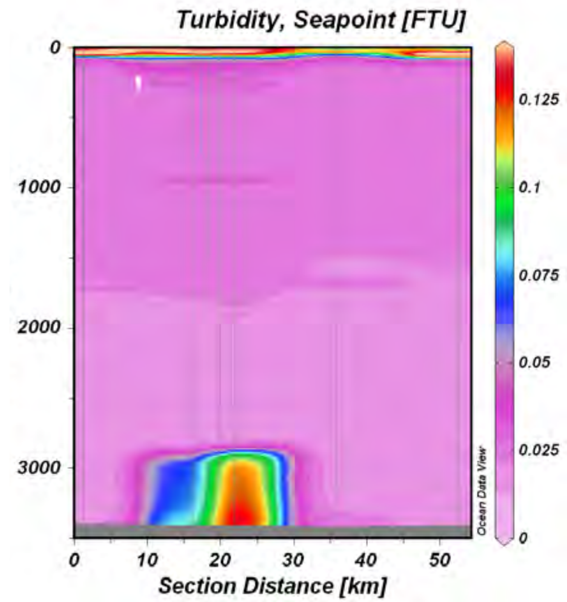
Turbid water in the bottom layer western Japan Basin, 2012-06

(h = 500 m, L ~ 10 miles)

- локальные геодинамические процессы;
- результат зимней склоновой конвекции;
- взаимодействие вихря с подводной возвышенностью







Conclusion

Mesoscale water dynamics is important element of the JES circulation that impact on water mass formation and exosystem

- Large mesoscale eddies
- Slope eddies along northern coast of the sea
- Upwelling off Primorye coast
- Slope convection, patchiness of cascading plumes
- Advection of deep and bottom water by mesoscale processes

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2016 Annual Meeting

CREAMS
(1993-1998)

PICES WG-10 CREAMS-II (1998-2001)

AP-CREAMS (2005 -)

Acknowledgements

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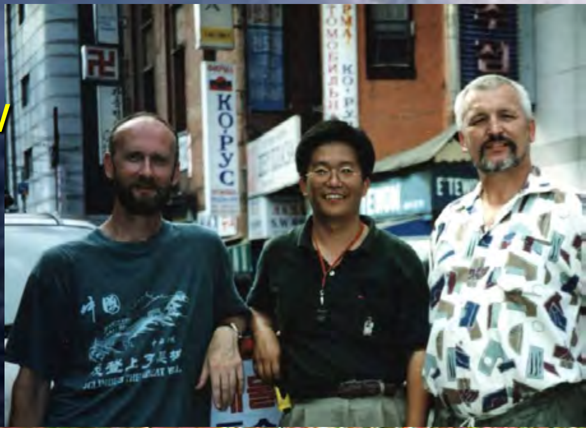
POI and FREHRI technicians and crew of r/v *Akademik M.A.Lavrentyev, Prof. Gagarinsky, Ak. Oparin, Prof. Khormov, Pavel Gordienko*



Thank you!