Nice system of material cycle between land and sea producing fishery-rich sea

- As an example of roles of ocean, now and in our future -

Masaaki Wakatsuchi

（Institute of Low Temperature Science, HU）

Our Project

Japan-Russia-US Joint Okhotsk Sea Project (1997-2002)

International Joint Amur-Okhotsk Project (2004-2009)

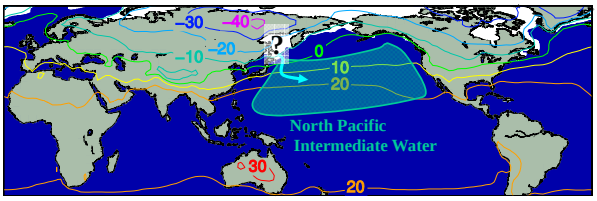
Japanese-Russian-US researchers with R/V Khromov

- Six times cruises aboard Russian R/V were performed in the Sea of Okhotsk -

The Sea of Okhotsk was shrouded in mystery!!

Geographical Environment of the Sea of Okhotsk

Sea Ice Distribution (white color) and Surface Air Temperature on February (2001)



courtesy by S. Nihashi

The Sea of Okhotsk;

- **Southernmost seasonal sea ice zone in the Northern Hemisphere**
- **Locations for the ventilation of NPIW and absorption of CO2**
- **One of the fishery-richest sea in the world**

NOAA/AVHRR 1998/02/24

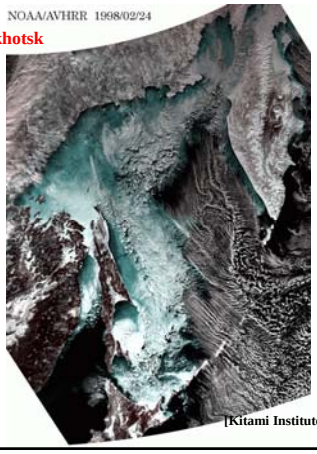
Sea ice in the Sea of Okhotsk

- Sea ice starts its generation on November, having the maximum ice extent on March, and exactly disappearing on June.

Big questions were

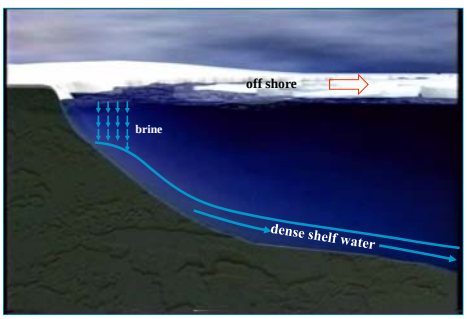
(1) Why and where sea ice forms in this sea.

(2) How sea ice is transported northward and southward.



[Kitami Institute of Technology]

Images of active sea-ice formation and brine rejection which will occur in the coastal polynya off the Siberia coast in winter



JST

Observations of Surface Water Circulation

Trajectories of 20 Argos surface drifters
（Sept. '99~Feb. '00）

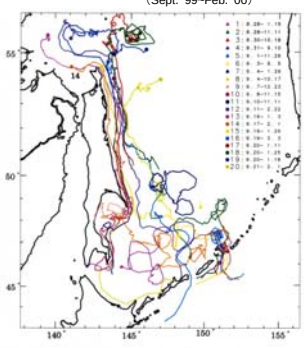


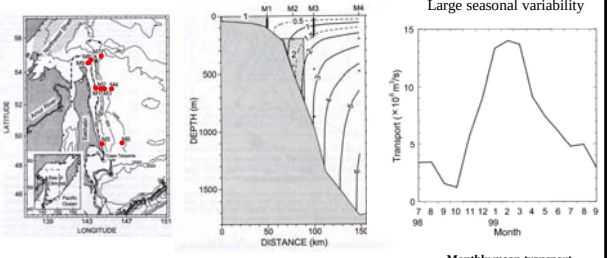
Illustration of the observed surface circulation

(Ohshima et al., JGR, 2002)

Structure and Seasonal Variability of the East Sakhalin Current

Width; 150 km

Large seasonal variability

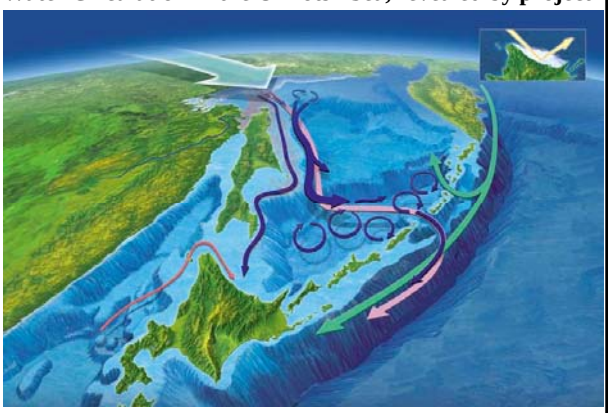


Locations of current moorings (red dots)

Annual-mean transport (×10⁶m³s⁻¹) along a vertical cross section at 53° N

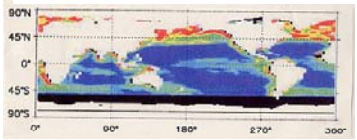
Monthly mean transport (×10⁶m³s⁻¹) at 53° N
〔Mizuta et al., 2003〕

Water Circulation in the Okhotsk Sea, revealed by project



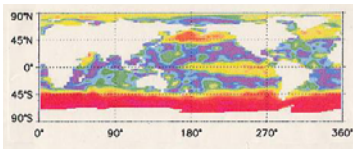
Search for the reason why Okhotsk Sea and Oyashio are fishery-rich sea

Surface distribution of chlorophyll on June



Orange color areas ; high biological productivity areas.

Spatial distribution of nutrient (NO_3) in summer



In the northwestern North Pacific, large amounts of nutrients still remains even in summer when the active blooming of phytoplankton occurs.

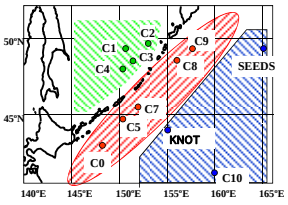
Meanwhile in the Sea of Okhotsk, almost all the nutrients are disappeared from sea.

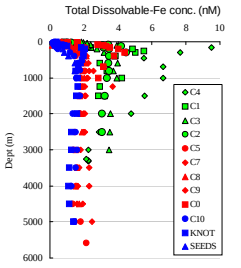
→What's happened?

Recent study shows that the excess nutrients may be due to the lack of iron.

Iron is very necessary for the photosynthesis of phytoplankton.

Spatial distribution of total dissolvable iron within sea water around the Kuril Island





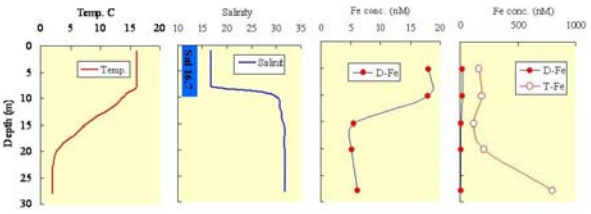
Observational Data
(Nishioka et al. 2006)

Green; the Sea of Okhotsk region
Red; the Oyashio region
Blue; the Subarctic Pacific region

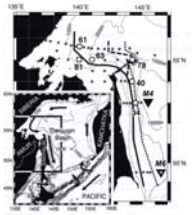
Detailed Iron Observations;

Amount of iron near the mouth of Amur River was about 1000 times larger than that in the southern Sea of Okhotsk.

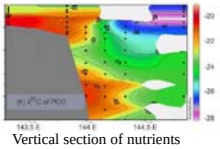
Origin of iron is Amur River!!



Iron is successfully trapped by dense shelf water!

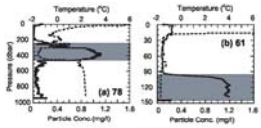


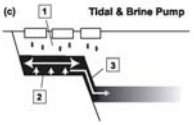
Observational sites



Vertical section of nutrients

Transport cold, turbid water through the intermediate layer





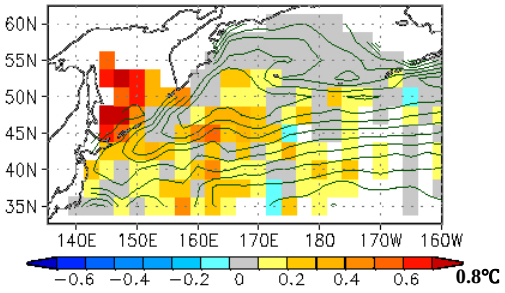
1. **Rejection of Sea-ice brine,**
2. **Tidal Mixing,**
3. **Outflow of cold & turbid water into offshore intermediate layer**

(Nakatsuka et al., 2004)

Next problem;

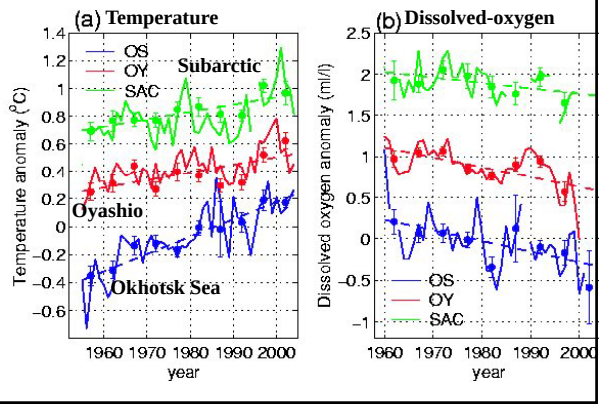
What is the effect of global warming on this system?

Warming of intermediate waters (200 – 1000 m) in the North Pacific during the past 50 years

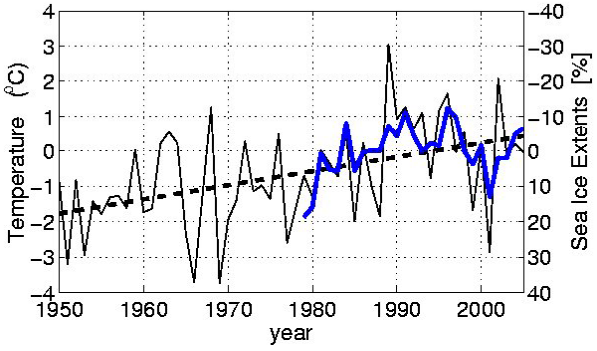


(Nakanowatari et al., GRL, 2007)

Interannual variability of (a) Temperature and (b) Dissolved-oxygen of intermediate waters in the Okhotsk Sea, Oyashio and Subarctic



Interannual variability of air temperature (black) & sea ice extent (blue) in the Sea of Okhotsk



Trends of warming and oxygen-decrease for intermediate waters in the Sea of Okhotsk and western North Pacific during past 50 years were observed.

This suggests the weakening of the intermediate water circulation, probably because of the decrease of sea-ice formation due to the global warming.

The weakening of the intermediate water circulation may cause the drop-down of primary productivity in this region, because of the lack of iron.

Its evidence has already been observed in the Oyashio region!!

Time series of Ch for mixed layer in the Oyashio

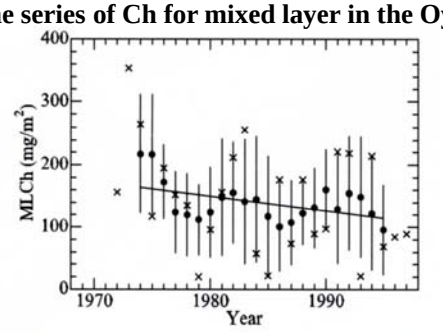
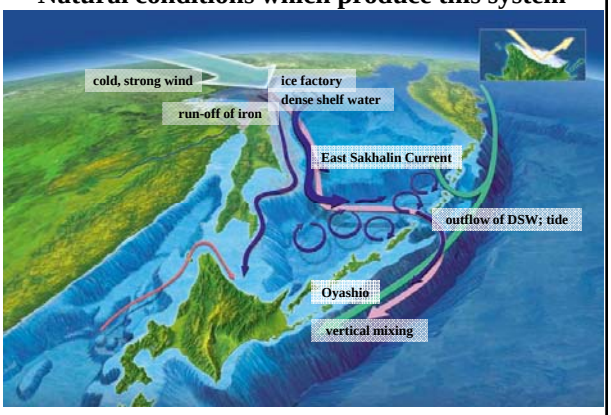


Figure 3. Time series of MLCh (pluses) and their 5-y running mean (circles). Error bar represents 1SD of each 5-y average. Regression line of 5-y running mean (solid line) is: MLCh = −2.35 ± 1.22 y + 4796.1 (r = 0.47).

(Ono et al., 2001)

Natural conditions which produce this system



All the following natural conditions;

(1) cold, strong northwesterly wind,
(2) ice factory and dense shelf water (DSW) production,
(3) run-off of irons and nutrients from Amur River,
(4) East Sakhalin Current,
(5) outflow of DSW with irons and nutrients to the North Pacific, having intensive, tidal-mixing in Kuril Straits,
(6) upward transport of irons and nutrients through the vertical mixing in the Oyashio region in winter, and
(7) subarctic water circulation system in the North Pacific,

are greatly required for the maintenance of this system.

Summary

(1)We should hold this nice system of earth environment which is made by nature.

For the purpose, therefore,

(2) the continuous monitoring of the effects of "anthropogenic" global warming on the material cycle system connecting the Eurasian continent, the Sea of Okhotsk and North Pacific, and the development of precise prediction modeling are greatly required for our future.

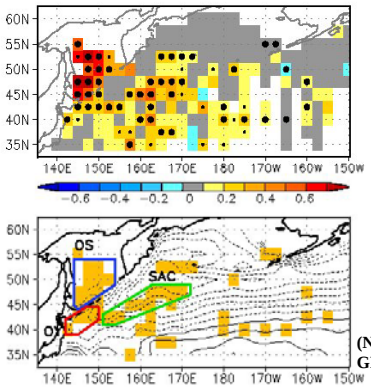
Our observations revealed the existence of a nice system of material cycle;

(1)the run-off of iron and nutrient from the Amur River is successfully trapped in cold, dense shelf water (DSW) accompanied with sea-ice formation,

(2)they are transported southward through the East Sakhalin Current.

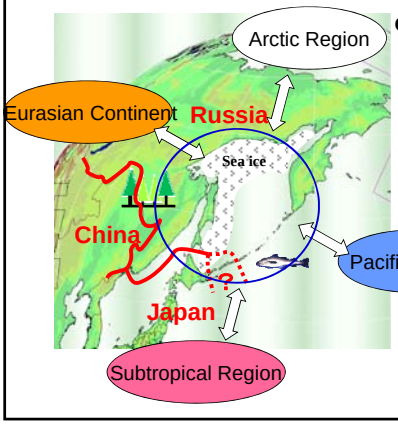
=>this system may produce this region as one of fishery-richest sea in the world.

Warming of intermediate waters (200 – 1000 m) in the North Pacific during the past 50 years



(Nakanowatari et al., GRL, 2007)

Geographical Feature of the Sea of Okhotsk

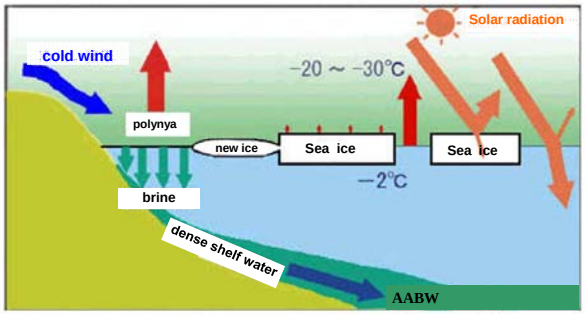


Contact Points between

1. **Cold and warm air**
   →Lowest latitude Seasonal Sea Ice Zone
2. **land and sea**
   →Rich ecological system

Pan-Okhotsk is located in crossroads between many interactions

Processes for AABW formation



(2) Contribution of ocean circulation with the sea ice formation to the maintenance of "rich" fishery resources

As an example of this contribution, I would like to introduce the observational results of our project that there exists a nice system of material cycle connecting land and sea in the Sea of Okhotsk and the surrounding environment.

My Laboratory Experiment on Brine (High-Salinity Water) Rejection from Growing Sea Ice (1974)

Abrupt reduction of Arctic sea ice extent (Sept. 07)

National Snow and Ice Date Center, Boulder, CO

The abrupt reduction of Arctic sea ice extent due to recent "anthropogenic" global warming may cause the slow-down ocean circulation and result in the unknown, earth environmental change.

(1) Contribution of ocean circulation to "the calm earth environment"

The calm earth environmental system is held by steady, global ocean circulation which transports heat and materials to the entire world ocean.

And "Polar Ocean" plays an important role as an engine of the global ocean circulation.