Completion Report of the Research Expedition in the Sea of Okhotsk for 2006

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1. INTRODUCTION

The Research Expedition in the Sea of Okhotsk for 2006 has been carried out in the period from 8 August to 18 September in 2006 by *R/V Professor Khromov* of Far Eastren Regional Hydrometeorological Research Institute (FERHRI), Vladivostok, Russia. This expedition was a part of a Research Project, entitled as “Human Activities in Northeastern Asia and Their Impact to the Biological Productivity in North Pacific Ocean” conducted by Research Institute of Humanity and Nature (RIHN), Kyoto, Japan.

The main purpose of this research expedition was to understand transport processes of land-derived materials, especially iron, from Amur River to the Sea of Okhotsk and Pacific Ocean and their contribution to biological productivity there. This research expedition had following subjects.

1) To clarify the vertical and horizontal distribution of iron and related substances in water masses of the Sea of Okhotsk, especially in areas of Amur River mouth, northern and eastern continental shelves of Sakhalin, and area around Bussol strait.

2) To quantify the physical processes, which transport iron and related substances from Amur River to Pacific Ocean, such as shelf tidal mixing, intermediate water formation, East Sakhalin current and water dispersion around Bussol strait.

3) To investigate the biomass and productivity of phytoplankton and heterotrophic organisms in the Sea of Okhotsk, relating to the spatial distributions of the iron, nutrients and organic matter.

4) To measure the budget and the deposition-regeneration rates of iron and related substances in the sediment on shelf, slope and basin of the western Sea of Okhotsk.

5) To monitor the optical and meteorological conditions, which govern the primary productivity, in the Sea of Okhotsk.

6) To infer the contribution of aerosol, which supply iron from atmosphere to the surface water, in the Sea of Okhotsk.

2. PROGRAM OF THE EXPEDITION AND ITS IMPLEMENTATION

2.1. CTD & LADCP observations, water chemistry and biogeochemistry

2.1.1. CTD and LADCP observations

Purpose. The purpose of CTD (Conductivity, Temperature and Depth probe) casts was to examine the water characteristics in the Sea of Okhotsk from the Sakhalin Bay

and around Sakhalin Island through the Kuril Straits (especially Bussol' Strait), in order to elucidate the influence of the Amur River water and dense shelf water on the Okhotsk Sea water-masses and on bio-chemistry in the Sea of Okhotsk and the North Pacific. The purpose of LADCP (Lowered Acoustic Doppler Current Profiler) attached to CTD frame was to measure the horizontal current profiles at the CTD casts to know horizontal currents including tidal and mean currents.

Data Acquisition. The CTD/Carousel water sampling system was used to acquire water samples and CTD data (pressure, temperature and conductivity). The CTD is Sea-Bird 911 plus system, and Seabird Carousel bottle release systems were used. The CTD/rosette held twelve 10-liter Niskin bottles with Teflon coating for iron measurements. The CTD instruments were equipped with a dissolved oxygen sensor (Sea-bird SBE43), transmissiometer (Wet lab C-Star) and altimeter (Data sonic PSA-900D). The CTD-frame was deployed via the right-side A-frame at the sites described in Figure A-1, A-2 and Table C-1 in Appendix A and C, respectively.

Water samples were drawn for dissolved oxygen and salinity at most of the CTD/rosette casts. The samples of dissolved oxygen were analyzed by Winkler method using an automated titration system with an oxidation-reduction electrode. Salinities were analyzed with a Guildline Model 8400A Autosal salinometer, using a computer interface and software. IAPSO Standard Seawater, batch P-146, served as the standard.

The LADCP is the RD-instruments 300kHz workhorse ADCP with battery case. These were attached to the CTD-frame. Velocity data relative to the LADCP sensor in the 1 second interval was obtained throughout the casts. The time, position and depth data is obtained from the GPS and the CTD, which were merged with the LADCP data to produce the absolute horizontal velocity profiles.

Data Processing. Conductivities and dissolved oxygen obtained by CTD sensors at each bottle level will be merged with the results from bottle salinity and oxygen analyses. Bottle salinity and oxygen concentrations will be calculated and compared with the CTD data. CTD performance will be monitored by means of these comparisons. Final processing of CTD data will be completed at a later date.

Preliminary velocity data from the LADCP were processed during the cruise. Some of the stations cannot be processed due to various problems. The final data will be provided at a later time.

2.1.2. Water Chemistry and Biogeochemistry

Purpose. The most important goal of this cruise is to grasp direct evidences of the tight connections between land and ocean ecosystems through material transports via river and shelf systems. Main targets are riverine iron and related substances, which are dissolved and/or suspended in the water of the Sea of Okhotsk, and their impacts on biological productivity there. In order to clarify the spatial distributions of iron and related substances and its influences to biological productivity, water samplings were performed from the areas near Amur River mouth to Pacific Ocean.

Water Samplings and Sample Treatments. Waters were collected during most of the CTD casts listed in Table C-1 of Appendix C. In addition, surface water was continuously analyzed for some parameters using underway waters supplied from engine room. Water samples were distributed into various sizes of bottles at once for on-board and/or on-shore analyses. Some were then filtrated, and some were utilized to ^{13}C-incubation for primary productivity measurements on board. The incubated waters were finally filtrated, and filters were frozen for further ^{13}C analyses on shore.

Water Analyses. The distributed waters and filter samples are to be measured on the following list of chemical and biogeochemical parameters. Some of them have been analyzed on board, and the rests are to be analyzed on shore. The data analyzed on board have been already compiled in a separate data file, except for the total alkalinity and pH, monitored using underway water, which requires recalculation by comparison with the on-shore measurement of total alkalinity.

Substance	Number of water samples *	Analytical Method or Instrument	Measurement Remarks
Basic properties			
Salinity	All	Guildline Auto-Sal	On board
Dissolved Oxygen	All	Winkler method (Titrated by Oxidation –Reduction Electrode)	On board
Nutrients	All	Continuous Flow type of Auto Analyzer	On shore

Biogeochemical parameters			
Iron (dissolved and total)	All	Chemiluminescence method (Kimoto-Denshi, EN-701)	On shore (partly on board)
Barium	About 50%	ICP-MS	On shore
Chlorophyll a	All, but only shallow layer	Fluorescence Spectrophotometer (Turner, 10-AU)	On board
Suspended matter	About 50%	X-rays Diffraction method	On shore
Chromo-Dissolved Organic Matter	Almost all	3D-fluorescence method	On shore
Carbon chemistry			
Dissolved inorganic carbon	About 60%	CO_2 coulometer	On shore
Total Alkalinity	About 60%	Radiometer PHM93	On shore
Total Alkalinity	(Underway)	Spectrophotometer	On board
pH	(Underway)	Spectrophotometer	On board
Dissolved Organic Carbon	Almost all	High Temperature Combustion method	On shore
Incubation study			
Primary Production	About 30%	^{13}C-inculation method, (mass spectrometer)	On shore

* “Number of water samples” indicates how much % of water samples collected by CTD/carousel systems were applied for the analyses of the corresponding substances.

2.2. Shear probe observations

Purpose. Around the Kuril Islands in the Okhotsk Sea, tidal currents are strong and the vertical mixing is expected to be large and to contribute to the material circulation and resulting biological activity as well as the physical processes. However the mixing activity has not been directly measured. Measurements of turbulence and microstructure were performed aound the Bussol' Strait and Urup Islands. The modification process of dense shelf water around the northwestern shelf due to vertical mixing was also examined by the profiler data.

Instruments and observation. A real time system of VMP2000 (Vertical Microstructure Profiler for 2000m casts) manufactured in Rockland Scientific Service (Victoria Canada) was used with the hydraulic motor, winch and line puller system. The fish deploys and recoveries were from the stern using A-frame and capstan at the site listed in Table C-2 of Appendix C. During the profiling, the ship moved as slowly as possible against the surface currents or winds in order the ship to be away from the cable and to avoid the cable cut by ship propeller. The motor (380V, 50Hz 3-phase) was broken in the midway at Sta. Bussol-2. The spare motor of 220V 60Hz was replaced and used from Sta. Bussol-3 to G2.

Data acquisition and processing. Shear probe, micro-temperature probe and acceleration data were obtained in 512Hz, and the pressure and Sea-Bird temperature and conductivity were obtained in 64Hz. These were used to obtain the turbulent kinetic energy dissipation rate during 2 seconds from velocity shear spectra. Very preliminary data of diapycnal mixing coefficients of density in the interval of 1dbar were processed during the cruise. But the careful treatments are necessary to make final data because the probes are quite sensitive and the Sea-Bird sensors had troubles with water invasion and also because the data is frequently influenced by various matters. The final data will be provided at a later time.

2.3. Sediment Coring

Purpose. Although the dissolve iron discharged from Amur River has a large potential to activate primary productivity in the Sea of Okhotsk, it is well-known that most of dissolved iron in river water flocculates and settles down to sediment surface in the contact zone of fresh water and sea water. Therefore, it is very important to estimate

how much % of dissolved iron is actually removed from the water mass near Amur River mouth and understand the fate of precipitated iron on the shelf. Because shelf sediments are usually anoxic due to heavy supply of organic matter, most of precipitated iron can be dissolved and released again from the sediment. Strong tidal current and dense water formation due to brine rejection during winter sea-ice formation may also support the transport of the labile iron from shelf to open ocean. In order to estimate of the budget and flux of labile iron on the shelf sediment, surface sediments and sediment cores were collected on the shelf and slope areas for analyses of iron and related chemical compounds.

Sediment Samplings. Three types of sediment samplers (Smith-Macintyre Type of Grab Sampler, "Ashura" type of Multiple Corer and a Gravity Corer) were applied in this research expedition. Surface sediments were collected using the Grab Sampler at many sites on the shelf and slope areas as described in Table C-3 of Appendix C and Figure A-1 of Appendix A. However, good sediment cores could not be obtained at most of the shelf sites, except for Line-B and F, due to the inadequate sediment conditions for coring such as sand or gravels and the unidentified mechanical trouble in the Gravity Corer.

Sample Treatments. Surface sediments collected by the grab sampler were stored in refrigerator. In cases that sediment cores were successfully collected, two of the three cores collected simultaneously by the multiple corer were sliced at 1cm or 2cm intervals on board and stored in freezer. The rest one core was sliced in a closed box, which is full of N_2 gases, and squeezed to extract pore water in the anoxic condition.

Chemical Analyses. The extracted pore waters and the sliced and surface sediments are to be analyzed for concentrations of iron and related inorganic and organic elements at on-shore laboratories using ICP-AES and an elemental analyzer. For sediment cores, ^{210}Pb concentrations are to be profiled vertically in order to determine sedimentation rates and calculate the flux of iron and related substances through the sediment-water interface.

2.4. Plankton Net Samplings

Purpose. The Sea of Okhotsk is an unique marginal sea, semi-enclosed from the North Pacific, fast-ice formation at relatively low latitude, and mega-river discharge,

and is considered to have ecological influence to the Oyashio current and subarctic North pacific ecosystems by the water exchange through the limited number of straits. Moreover, preliminary surveys of zooplankton showed that life histories of dominant zooplankton are different from those of Oyashio current and eastern subarctic Pacific (Tsuda unpublished).The goal of this study is to show the geographical and vertical distribution of major zooplankton species in late summer season.

Instruments. Two types of plankton nets were used. One is Norpac net (mouth opening; 0.16 m^2, net-length; 180 cm; mesh opening; 0.1 mm) was vertically towed from 30 and 150 m-depth to surface. When the bottom depth was shallower than 150 m, the net was towed from the near-bottom to the surface. Filtered water volume was estimated with a flow meter (Rigosha Co Ltd) attached to the mouth of the net. Another net is VMPS (Vertical Multilayer Plankton Sampler, Tsurumi-Seiki Co Ltd: mouth opening; 0.25 m^2, net-length; 180 cm; mesh opening; 0.33 mm). The VMPS equipped four nets which were remotely closed and opened at the designated depth from the ship. The all samples were preserved with 5 % buffered formalin sea water (5%).

Observations. The Norpac net and VMPS were towed at 35 and 7 stations, respectively (listed in Table C-4 of Appendix C).

Expected Outputs. Plankton samples are to be applied to following analyses on shore. 1. Settling volume of the all samples, 2. Vertical distribution of Neocalanus spp. (VMPS samples), 3. Community composition of Norpac net samples

2.5. Optical Observations

Purpose. To clear the optical properties in this study area, the absorbance of phytoplankton, particles and colored dissolved organic matter (CDOM), which called inherent optical properties of sea water, were investigated. In addition, the apparent optical properties were measured using in water spectra radiometers, and compared with each optical characteristics of sea water.

Instruments. Three types of instruments were used for optical measurements in this research expedition, as follows.

1) MER2040/2041 in water radiance measurements. The underwater downward irradiance and upward radiance were measured using MER2040 (Biospherical Inc.)

instrument. The measurements were carried out from the sea surface to 70m depth at satellite over passing time (from 9 am to 4 pm local time). The incident solar spectral irradiance was measured using deck unit of MER2041 (Biospherical Inc.), located in upper deck. The spectral channels of MERs are the wavelength of 412, 443, 465, 490, 510, 520, 555, 565, 625, 665, 670 and 683nm. Those channels were corresponding Sea-viewing Wide Field-of-view Sensor (SeaWiFS) channels. The measurement stations are listed in the Table C-5 of Appendix C.

2) Eco-VSF3 scattering radiation meter observations. The scattering radiation was measured using Eco-VSF3 (Wet Labs) instruments. The angular distribution of scattered radiation in the backward hemisphere is important in the interpretation of remote sensing measurements. This instrument measures the optical scattering at three distinct angles: 100, 125 and 150 degrees, at three wavelengths, thus providing the shape of the volume scattering function throughout its angular domain. The measurement stations are listed in the Table C-5 of Appendix C.

3) TriOS/RAMSES hyperspectral radiometer observations. The solar radiance and upward water irradiance were measured by TriOS/RAMSES spectrophotometers. The spectra channel was 300 to 1000 nm in 1nm interval. The TriOS/RAMSES was equipped to a drifting buoy and the TriOS buoy observations were carried out with MER2040 in water optical measurements. The measurement stations are listed in the Table C-5 of Appendix C.

Data list. Following data were obtained during this research expedition.

1. *MER2040/2041 observation.* Microsoft excel csv format data in each station
2. *Eco-VSF3 observation.* Text format data in each station
3. *Drifter buoy TriOS observation.* Text format data in each station (water leaving radiance (L) and solar irradiance (E))

2.6. Air Soundings

Purpose. In summer season, the Sea of Okhotsk is often covered by a persistent high pressure field, so called as “Okhotsk-High”. “Okhotsk-High” usually creates low cloud system on the sea surface, which reduces the solar radiation necessary for phytoplankton growth and affects the biological productivity there. In spite of its importance, “Okhotsk-High” has seldom been observed directly until now. In this research expedition, radiosonde observations were carried out during the period from 16 August to 31 August for following two purposes. (1) To solve the structure of

anticyclone above the sea of Okhotsk, that is “Okhotsk - High”. (2) To solve the thermodynamic structure of low cloud system, especially stratus, stratocumulus etc., which frequently accompanies “Okhotsk – High”.

Instruments. The observation were carried out using the “Radiosonde Observation MW31 Sounding System (Vaisala Oyj, Finland)”. The MW31 sounding system consists of MW31 sounding soft ware “DigiCORA III” and PC computer system, which is connected to Ground Check “GC-25” (Radiosonde sensor reconditioning tool), Receiver “SPS311”, UHF Telemetry Antenna and GPS Antenna via cable.

Observation Condition. Totally, 63 times of radiosonde observations were conducted during the cruise. The observational and meteorological conditions at each operation are listed in Table C-6 of Appendix C.

2.7. Aerosol Samplings

Purpose. In general, land-derived iron is believed to be supplied to ocean surface via atmosphere by aerosol. Because the Sea of Okhotsk is located on the eastern end of Eurasia continent, huge amount of aerosol containing iron must be supplied to this area by the strong westerly. In order to estimate the relative importance of the iron from Amur River, it is necessary to monitor and quantify the iron load from atmosphere in the Sea of Okhotsk Therefore, aerosol samplings were conducted in this research expedition.

Observation. Aerosol samples were collected with a High Volume Sampler during the cruise (Aug. 13 – Sep. 13). Wind direction was continually monitored and the sampler was turned off if there was any risk of contamination by exhaust from the ship’s stack. The sample collection period was every 12 hours (07:00-19:00, 19:00-07:00), and samples were collected on the 90 mm Teflon filter. Sampling log is shown in the Table C-7 of Appendix C.

Sample analyses. Teflon filters with collected aerosol samples are to be used for analyzing major ions (Na^+, Ca^{2+}, SO_4^{2-}, NO_3^-) and trace metals (Fe, Al) at on-shore laboratory. Soluble major ions and trace metals are to be extracted from the filters and analyzed by ion chromatography and ICP-AES.

3. CONCLUDING REMARKS

In general, the program of this expedition was successfully completed with the combined efforts of Russian, Japanese and United State specialists. In particular, it is notable that clean water samplings were successfully performed on *R/V Professor Khromov* in this expedition. The quality of collected waters was continuously monitored during the cruise by on-board analyses of trace amount of iron, and apparent contaminations of iron from the vessel itself have never been identified. This success is greatly owing to Russian efforts to clean up the vessel before the cruise and Japanese carefulness to avoid any kind of contaminations at all procedures during the samplings of water.

All the primary and secondary data collected during the cruise will be shared according to the mutually agreed schedule.

4. ACKNOWLEDGEMENTS

This expedition was successfully completed with the effort and patience of many peoples, and with the good weather condition throughout the cruise. We would like deeply to appreciate Captain Alexander D’YACHENKO of the *R/V Professor Khromov* and his fine crews for their outstanding works during this cruise; without them, none of this expedition would have been possible.