Report of Working Group on *Mesoscale and Submesoscale Processes*

The first business meeting of the Working Group on *Mesoscale and Submesoscale Processes* (WG 38) was held in Vladivostok, Russia from 9:00 to 18:00 on September 23, 2017 during the PICES-2017. Ten WG members took part in this 1-day meeting, and four observers participated for part of the day (***WG 38 Endnote 1***). The meeting was co-chaired by Dr. Annalisa Bracco (USA) and Dr. Hiromichi Ueno (Japan). This report summarizes discussions at the meeting over some of the Agenda Items (***WG 38 Endnote 2***).

Participants of the first business meeting of WG 38 at PICES 2017 annual meeting at Vladivostok. Left to right: Maxim Budyansky, Sung Yong Kim, Hiromichi Ueno, Tetjana Ross, Annalisa Bracco, Elena Ustinova, Daisuke Hasegawa, Olga Trusenkova, Sergey Prants, Sachihiko Itoh.

AGENDA ITEM 2

Review and discussion of mesoscale and submesoscale processes in the North Pacific

Mesoscale processes and their impact in the North Pacific

Dr. Hiromichi Ueno reviewed mesoscale processes and their impact in the North Pacific. His talk focused on the impacts of mesoscale eddies on chlorophyll distribution. Recently, studies relating mesoscale eddies and chlorophyll at the global scale have been reviewed and six major mechanisms of mesoscale interactions have been suggested. In the PICES region there exists a rich regional variability in the response of chlorophyll to mesoscale circulations. For example, in the Gulf of Alaska, *in-situ* data indicates that the relation between eddies and chlorophyll is different among Haida, Sitka and Yakutat eddies, although they are all formed along the coast of the U.S. and Canada.

Mesoscale processes and fish migrations/fishing grounds

Dr. Elena Ustinova discussed the problems of the impact of mesoscale processes on migrations and the fishing grounds formation of saury, sardine, and mackerel in the Northwest Pacific. Positions and configurations of mesoscale and large-scale fronts determine the feeding migration patterns in June and southern migrations in autumn. The important factors are the large anticyclonic eddy east off Hokkaido

Island and the anticyclonic eddy located east off Bussol' Strait. The relatively strong northeastward "third" Kuroshio branch (or Isoguchi Jet) was found to be favorable for more intense northward migrations. Disintegration of saury and mackerel concentrations under dissipating mesoscale inhomogeneities occurs earlier in comparison with sardines aggregations due to the different feeding behavior.

Impacts of physical variability at the meso- and submeso-scales on larvae transport and marine fish

Impacts of physical variability on larval transport at meso- and submeso-scale were reviewed by Dr. Sachihiko Itoh. In his presentation the effects of meso- and submeso-scale physics on marine fish larvae were classified in terms of either larval growth and mortality, or transport and dispersal. The literature reviewed suggests that eddies, especially cyclonic ones, often became "food heaven" but can be, at the same time, "predation hell". Regarding transport/dispersal, eddies have an important role for larval retention, which has been highlighted in many papers. Since many major pelagic marine fishes have spawning ground not on strong currents such as the Kuroshio and the Gulf Stream but in the inshore side of these currents, entrainment to and detrainment from these currents are suggested to control the fate of larvae.

Observing meso/submesoscale turbulence using radar observations

Submesoscale coastal surface currents and chlorophyll concentrations at hourly and $O(1)$-km resolutions, obtained from an array of high-frequency radars and geostationary ocean color imagery in a coastal region off the east coast of Korea over a period of one year (2013), were described by Dr. Sung Yong Kim in the frequency and wavenumber domains. The low-frequency surface currents exhibit a variability broadly consistent with the regional geostrophic currents in summer more so than in winter because of the relatively weak wind conditions and shallow mixed layer depths in the warmer months. The clockwise near-inertial surface currents show onshore phase propagation and decreasing amplitudes associated with enhanced friction and reduced polarization due to the effects of the coastal boundary. The kinetic energy (KE) spectra of the surface currents in the wavenumber domain (k) become steeper at a scale of approximately 10 km from a slope of $k^{-5/3}$ found at a length scale of 2 km to slopes between k^{-2} and k^{-3}. Moreover, the KE spectra of the chlorophyll exhibit anisotropy associated with bathymetric effects and regional circulation, and their decay slopes change from $k^{-5/3}$ to k^{-1} at $O(10)$ km scales and from k^{-1} to k^{-3} at $O(1)$ km scales, which is consistent with the two-dimensional quasi-geostrophic turbulence theory. The spectral decay slopes of these KE spectra show weak seasonality, which can be interpreted with dominance of baroclinic instability in the mixed layer and the persistent and non-seasonal regional circulations.

Seasonality of submesoscale dynamics, coastal implications and modeling techniques

Dr. Annalisa Bracco reviewed current understanding of the seasonality of submesoscale circulations at horizontal scale of ~1–10 km in coastal systems characterized by the presence/absence of freshwater fluxes from river run-off. She presented results obtained using the Regional Ocean Modeling System (ROMS) run at 1 horizontal resolution in various configurations for a region strongly impacted by riverine inflows and showed quantifications of the impacts of submesoscale circulations on Lagrangian transport in different seasons. Model results indicate that submesoscale frontogenesis is strongly modulated by the freshwater fluxes, while mixed-layer instabilities are effectively controlled by the available potential energy of the mixed-layer.

Lagrangian maps as a new tool to simulate transport processes in the ocean

Dr. Sergey Prants introduced to the audience Lagrangian methods, that are actively used in simulation of large-scale transport and mixing in the ocean. Their usefulness has increased thanked to the tremendous progress in satellite monitoring and in advanced technology of satellite-tracked buoys and drifters providing continuous, near real-time and global data at high space resolution. The combination of these data with outputs of high-resolution global and regional numerical models of ocean circulation and ideas and methods from dynamical systems and chaos theory, enables to simulate and analyze transport and mixing in the ocean at sub- and mesoscale. Dr. Prants presented a methodology for computing and

analyzing different kinds of Lagrangian maps for a large number of synthetic tracers advected by altimetry-derived and numerically-generated velocity fields. A number of examples were used to demonstrate the effectiveness of the tool to analyze the evolution of mesoscale eddies, to estimate a risk of contamination of specified eddies by Fukushima-derived radionuclides and to identify Lagrangian fronts favorable for fishing in the Asian marginal seas and the North Western Pacific.

Line P monitoring program

Dr. Tetjana Ross contributed a short presentation highlighting the extensive work on submeso/meso scale features and dynamics from the Line P monitoring program, including recent work evaluating quasi-geostrophic theories using ADCP transects and anomalous carbon to chlorophyll ratios in the vicinity of eddies.

AGENDA ITEM 3

Objectives of the WG, pathways forward, membership, publications and future activities

After the presentations, members discussed the objectives of the WG, pathways forward, membership, publications and future activities, based on terms of reference of the WG (***WG 38 Endnote 3***). The WG decided to focus activities on the investigation of seasonal to interannual changes in mesoscale and submesoscale circulations in the North Pacific using model outputs and observations. A synthesis of the interactions of these circulations with the marine ecosystem will be developed. One promising line of inquiry will involve providing a regional characterization of the mesoscale and submesoscale impacts by exploring how the seasonal cycle jointly with mesoscale and submesoscale dynamics influence the biogeochemical response at different time scales. This synthesis work will constitute a baseline against which to compare future climate scenarios that may include differential warming at various latitudes and shifting of species distributions. Based on this discussion, the WG decided to submit a 1-day topic session proposal for PICES 2018 Annual Meeting in Yokohama (***WG 38 Endnote 4***).

The WG identified the need for two or possibly three members with a modeling focus that will cover both the physical and the biogeochemical realm. Least represented countries at the moment are Canada and USA and this information will be considered in the discussion of potential nominations. WG members were asked to provide suggestions to the Co-Chairs for targeted nominations within the next two months.

The WG plans to publish a synthesis review paper with a regional characterization of mesoscale and submesoscale processes and their impact on marine ecosystem in the North Pacific, focusing on seasonal to interannual variation. Concrete targets and lead authors will be discussed after new WG members are determined.

Discussion in WG business meeting included opportunities for collaboration with WG 35 (*Third North Pacific Ecosystem Status Report*) and the CLIVAR Ocean Modeling Development panel for the analysis of high resolution hindcast simulations.

WG 38 Endnote 1

WG 38 participation list

Members

Annalisa Bracco (USA, Co-Chair)
Maxim V. Budyansky (Russia)
Daisuke Hasegawa (Japan)
Sachihiko Itoh (Japan)
Sung Yong Kim (Korea)
Sergey Prants (Russia)
Olga O. Trusenkova (Russia)
Tetjana Ross (Canada)
Hiromichi Ueno (Japan, Co-Chair)
Elena I. Ustinova (Russia)

Members unable to attend

China: Xiaopei Lin, Bin Xiao, Dongfeng Xu
Korea: Young-Gyu Park
USA: Carol Ladd

Observers

Xindong Pan (China)
Lian Peng (China)
Hiroaki Saito (Science Board Chair)
Robert M. Suryan (USA)

WG 38 Endnote 2

WG 38 meeting agenda

1. Welcome and Introduction. Goals of the day (Annalisa Bracco & Hiromichi Ueno)

2. Review and discussion of mesoscale and submesoscale processes in the North Pacific
   - *2.1* Mesoscale processes and their impact in the North Pacific (Hiromichi Ueno)
   - *2.2* Mesoscale processes and fish-migrations/fishing-grounds (Elena Ustinova)
   - *2.3* Impacts of physical variability at the meso- and submeso-scales on larvae transport and marine fish (Sachihiko Itoh)
   - *2.4* Observing meso/submesoscale turbulence using radar observations (Sung Yong Kim)
   - *2.5* Seasonality of submesoscale dynamics, coastal implications and modeling techniques (Annalisa Bracco)

3. Discussion of objectives of the WG, pathways forward, membership, publications, future activities

WG 38 Endnote 3

WG 38 Terms of Reference

1. Review and document the current understanding of meso-/submeso-scale processes and their impact in the North Pacific.
2. Summarize the detection, observation and modeling methods of meso-/submeso-scale processes.
3. Classify meso-/submeso-scale features, and identify their spatio-temporal variations.
4. Compare the impacts of meso-/submeso-scale processes on heat/material transport and marine ecosystems between areas in the PICES region.
5. Convene a session or workshop on meso-/submeso-scale processes at PICES Annual Meetings.
6. Publish a final report summarizing results.

WG 38 Endnote 4

Proposal for Topic Session on
***"Seasonal to interannual variations of meso-/submeso-scale processes in different areas of the North Pacific and regional characterization of the ecosystem response"* at PICES-2018**

Duration: 1 day

Co-Convenors: Annalisa Bracco (USA), Sachihiko Itoh (Japan), Elena Ustinova (Russia)

Invited Speakers: TBD

Recent observations and model simulations suggest that the ocean currents and biogeochemistry at and near the ocean surface undergo prominent seasonal variability at the submesoscales (scales of 0.1 – 10 km). The submesoscale seasonal variability is function of the ratio of lateral to vertical density gradients and, in the open ocean, depends primarily on the mesoscale activity of the flow. Consequently, in the open ocean numerous submesoscale cyclonic eddies can form in winter and the vorticity distributions are skewed towards positive values typical of cyclonic structures. This skewness is highly reduced from spring to fall. In coastal areas, on the other hand, density gradients can be forced not only by mesoscale circulations but also by freshwater fluxes from rivers or melting glaciers, resulting in a seasonal cycle that may differ significantly from region to region, and in an interannual variability controlled in part by hydrological and cryospheric processes. Implications of such variability for the ocean biogeochemistry and nutrient distributions are poorly understood.

This session aims at characterizing the variability of mesoscale and submesoscale circulations and its linkages with the marine ecosystem in the PICES region at seasonal-to-interannual scales. We welcome as well contributions about future changes in mesoscale variability or in mixed-layer depth and its buoyancy, and therefore in submesoscale variability, in warming climate scenarios.