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# Transfer of momentum from Atmosphere into the ocean via sea ice

YOSHIZAWA, Eri[1*], SHIMADA. Koji[1], MIZOBATA. Kohei[1]

[1]Graduate School of Marine Science and Technology

Recent rapid sea ice reduction (SIR) gives us an image that the Arctic climate sub-system is vulnerable to global warming. By the end of this century, IPCC AR4 climate models show that substantial warming in surface temperature occurred in the Arctic Ocean where the sea surface was covered by sea ice in late of last century. This implies the warming in the Arctic Ocean was not only caused by global warming but by some positive feedback mechanism to accelerate SIR in the Arctic climate sub-system. Current numerical models cannot predict the variation of sea ice extent and spatial pattern of sea ice retreat. To understand the fate of the Arctic sea ice will contribute to reduce the uncertainty of future prediction of global climate.

Our scientific goal is to clarify actual mechanism of catastrophic SIR and to suggest the viewpoint to improve the current models from real observational and dynamical research. A quantification of a hypothesis on ”Positive feedback mechanism (Shimada et al., 2006)” that accelerates SIR is our main stream toward the goal. This Positive feedback mechanism hypothesis consists of sequential phenomena just like as domino; (1) activations of sea ice motion (SIM) associated with SIR, (2) strengthening of upper ocean circulation (UOC), (3) upper oceanic warming, (4) less sea ice formation, (5) imbalance between sea ice melt and formation. These phenomena compose a positive feedback loop to induce further SIR. This hypothesis well explains pattern of SIR from Pacific sector, however, the conceptual idea is insufficient to improve the current climate models. Development of the qualitative and conceptual research into more quantitative and practical one is required. Here, we focus (1) and (2) among the feedback system toward quantitative understandings.

(1) Mechanism of increase in SIM associated with changes in sea ice properties; There are large discrepancies of SIM between actual data and model results. In particular, recent activations of SIM do not linearly respond to the surface winds stress. Then, we examine relationships between winds and SIM dependent on sea ice properties. Basically, SIM in the first-year ice area is much faster than that in the multi-year ice area, under almost the same strength of wind stresses. Additionally, in the area of large divergence of SIM, the efficiency of momentum transfer increases regardless of the sea ice type. In both cases, strengthening of SIM is owing to dissipations of internal stresses dependent on changes in sea ice properties and motion. Therefore, the sea ice type and divergence/convergence of SIM are useful parameter to improve parameterizations of momentum exchange between atmosphere and sea ice.

(2) Dynamics of UOC pattern and its inter-annual variation; Strength of UOC has been speculated that it linearly respond to that of Ekman pumping/suction (EP/S) caused by sea surface stresses. However, in some area there is an inconsistency between the spatial distribution of EP/S and depth of main pycnocline that is a kind of proxy of strength of UOC. This inconsistency is found in the region where bottom slope is greater than some critical value. The variation of SIM, that is the main driving force of UOC, has a power spectrum peak near annual time scale. This time scale disturbance is significant to argue the inter-annual variation of UOC. In this timescale, in the region with flat seafloor topography, an induced baroclinic structure cannot propagate due to small value of planetary beta effect. While in the region where the slope is greater than some critical value, baroclinic structures can propagate as topographic Rossby waves and the depression structure is radiated. This basic dynamics is crucial to understand the observed spatial pattern of UOC. In the flat deep Basin, UOC is identified by satellite derived surface data, but in the slope region such surface data is not sufficient to understand the actual pattern.

Keywords: Arctic Ocean, sea ice reduction, climate change, global warming