Effects of environmental factors on the Arctic ocean acidification: Evaluation based on field observation and model simulation

［課程博士・論文博士共通］

博士学位論文内容要旨
Abstract

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論文題目 Title	北極海における海洋酸性化への環境因子の影響評価 ～現場観測とモデルシミュレーションから～ Effects of environmental factors on the Arctic ocean acidification: Evaluation based on field observation and model simulation		

The uptake of anthropogenic CO_2 from the atmosphere drives ocean acidification (OA) and decreases the calcium carbonate ($CaCO_3$) saturation state (Ω), which have negative impacts on marine calcifying organisms. Undersaturation of surface water with respect to aragonite-type $CaCO_3$ has been reported in many regions of the Arctic Ocean in the last two decades, which precedes other open ocean basins. Arctic Ocean and surrounding lands are undergoing rapid environmental changes, such as seawater warming, sea ice retreat, increasing in river discharge and riverine biogeochemical delivery (carbon and nutrient), and these can affect OA in the Arctic Ocean. This study aimed 1) to quantify the change in Ω and its controlling factors by analyzing observations for two decades in the Canada Basin of the Arctic Ocean, and 2) to evaluate the effect of the riverine biochemical fluxes on the carbonate properties and OA based on an ice and carbonate chemistry involved numerical model.

This dissertation consists of 5 chapters. Chapter 1 summarizes background information and current knowledge on the Arctic Ocean and ocean acidification. Data, model, and calculations used in this study are summarized in Chapter 2.

In Chapter 3, interannual variation of Ω in the surface Canada Basin from 1997 to 2018 was examined. Observational data of carbonate chemistry (dissolved inorganic carbon and alkalinity) from repeated hydrographic survey under an international collaborative project were used to calculate Ω. A rapid decrease in mean Ω for the study region occurred during 2003-2007 at a rate of -0.09 yr^{-1}, 10 times faster than other open oceans. Quantitative analysis of changes in environmental factors revealed that this rapid decrease in Ω was due to melting and retreat of sea ice, which diluted surface water and enhanced air-sea CO_2 exchange. After 2007, mean Ω did not further decrease, despite increasing atmospheric CO_2 and continued sea ice retreat. A weakened dilution effect from sea-ice melt and stabilized air-sea CO_2 disequilibrium state are the main reasons for this stabilization of Ω. The aragonite undersaturation has been observed repeatedly for more than 10 years in the Canada Basin. This means that aragonite shelled organisms in this part of the Arctic Ocean have already been living in a corrosive environment for a long time.

In Chapter 4, a Pan-Arctic Sea Ice-Ocean Model (COCO) coupled to an Arctic and North Pacific Model for Lower-trophic Marine Ecosystem with Carbonate Chemistry (Arctic NEMURO-C) was used to conduct sensitivity experiments to understand the impact of riverine biogeochemical delivery on OA (including indexes of pH, Ω) in the Arctic Ocean for the period of 1979-2018. Four experiments are conducted; 1. control (CTL), 2. with riverine carbon and nutrient fluxes (CN), 3. with riverine carbon fluxes (CAR), and 4. with riverine nutrient fluxes (NUT). Monthly climatological riverine carbon and nutrient data were obtained from the Arctic Great

Rivers Observatory (ArcticGRO) and monthly climatological freshwater fluxes known as R-ArcticNET were obtained from the Arctic Ocean Model Inter-comparison Project (AOMIP).

The simulation results in the CTL case revealed great impacts of riverine freshwater on seawater carbon system in the surface water over the coastal regions of the Arctic Ocean as well as along the Lomonosov Ridge reflecting the transport pathway of river water by the ocean current. Riverine freshwater together with sea ice meltwater diluted seawater and thus decreased Ω in the CTL case. The simulated Ω averaged for 1989-2018 was lower than 1 in most regions of the Siberian shelves. During 1989-2018, decreasing trends in Ω and pH occurred in the Arctic Ocean except for the Kara Sea and a part of the Laptev Sea, where Ω has increased since the 2000s was due to the reduced dilution effect of river water.

With input of riverine carbon and nutrient fluxes, the positive anomalies (relative to the CTL case) in Ω and pH were found. In the central part of the ocean, positive anomalies were mainly caused by riverine carbon fluxes, while effects of riverine nutrient fluxes were negligible. On the other hand, in the coastal regions, riverine nutrient fluxes accounted for ~20% of the positive anomalies in Ω and pH as a consequence of the enhanced primary production and corresponding reduction in seawater pCO_2. A major finding in the present study is that riverine carbon fluxes slowed down the OA with the increasing of riverine water during 1989-2018 in the Canada Basin, a part of the Eurasian Basin, the East Siberian Sea, and a part of the Greenland Sea. However, in the Kara Sea and coastal regions of the Laptev Sea and the Beaufort Shelf, the Ω and pH anomalies showed negative trends in the CN/CAR/NUT cases, reflecting the decreasing river water concentration in these regions. Ocean currents would have promoted river water export from these regions to nearby regions or the central Arctic Ocean. Simulations of this research indicated the major impact of riverine carbon and nutrients on the OA. This suggests that in the future the increased riverine biogeochemical fluxes due to coastal erosion or permafrost thawing would act to mitigate the OA.

Chapter 5 summarizes the results of the study and suggest necessary future works. Quantitative analysis of this study revealed that the OA in the Arctic Ocean is affected largely by the melting and retreat of sea ice, which dilutes surface water and enhances air-sea CO_2 exchange. Results of modeling simulation in this study also show the significant impacts of riverine freshwater, carbon, and nutrient fluxes on OA. Effects of the sea ice meltwater and riverine biogeochemical fluxes on the OA in the future will depend on the variation of distributions of meltwater and river water in each region, as well on biogeochemical properties in the river water. Although spatial and temporal expansion of aragonite undersaturation is expected to occur with the accumulation of anthropogenic CO_2, a decrease in freshwater content and/or an increase in carbon and nutrient in river water due to change on land would act to mitigate the OA. This study indicates the importance of understanding the Arctic Ocean as the system tightly coupled to overlying sea ice and surrounding land, to better predict future changes in carbonate chemistry and OA in this ocean.