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］

博士学位論文要約
Summary

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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		

[Background and Aims]

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. Due to lack of long-term observational data, the decadal variation of OA and the effects of environmental factors on OA is still unclear. This dissertation used both observational data and model simulation 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 biogeochemical fluxes on the carbonate properties and OA based on an ice and carbonate chemistry involved numerical model.

[Data and Method]

The observational data used in this dissertation is the longest observational record in the Canada Basin, Arctic Ocean that covers 2 decades, which was obtained from repeated hydrographic survey under an international collaborative project. Quantitative analysis was used to reveal the interannual variation and long-term trend of Ω, a deconvolution calculation was used to estimated contribution of different factors to the trend of Ω, including atmospheric pCO_2 increase, air-sea disequilibrium state changing, seawater temperature variation, and dilution from sea ice melting.

To understand the effect of riverine biogeochemical fluxes on OA (including indexes of pH, Ω), a high resolution and real-like model that has improved initial data for carbonate parameter and riverine fluxes derived from observational data was used for sensitivity experiments in the Arctic Ocean for the period of 1979-2018. The model is coupled by a Pan-Arctic Sea Ice-Ocean Model (COCO) and an Arctic and North Pacific Model for Lower-trophic Marine Ecosystem with Carbonate Chemistry (Arctic NEMURO-C). 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).

[Results and Discussion]

Observation dataset showed 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.

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.

With input of riverine carbon and nutrient fluxes, the positive anomalies (relative to the CTL case) in Ω and pH were found. Processes affecting interannual and seasonal variations of anomalies were found to be river water distribution, sea ice melting, primary production, and warming/cooling of seawater. Results 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.

[Conclusions]

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 CO2, 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 the ocean.