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November 20, 2009
Japan Agency for Marine-Earth Science and Technology
Fisheries and Oceans Canada

Arctic Ocean is becoming Less Favourable for Calcifying Organisms
-Impacts of Ocean Acidification and Sea Ice Melt-

Overview

Increasing ocean acidification caused by rising anthropogenic carbon dioxide emissions combined with the drastic retreat of sea ice (sea ice melt), have turned the Canada Basin of the Arctic Ocean into waters undersaturated with aragonite(*1)-type calcium carbonate($CaCO_3$), threatening the survival of marine calcifying organisms and calcareous plankton. The findings were reported by researchers from the Arctic Ocean Climate System Research Team at the Japan Agency for Marine-Earth Science and Technology(JAMSTEC: Yasuhiro Kato, President), and the Institute of Ocean Sciences, Department of Fisheries and Oceans Canada (IOS/DFO), who jointly conducted hydrographic observations in the Pacific sector of the Arctic Ocean. The research, the first of its kind to reveal the principal cause of the aragonite undersaturation in the Arctic Ocean, will appear in the November 20, 2009 issue of journal Science, published by the American Association for the Advancement of Science.

Title	:	Aragonite Undersaturation in the Arctic Ocean: Effects of Ocean Acidification and Sea Ice Melt
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Background

The increased rate of anthropogenic carbon dioxide (CO_2) emissions is believed to be a major culprit of global warming and climate change. Approximately one third of CO_2 emissions is absorbed by the ocean; however, the increased uptake of CO_2 contributes to the acidification of the ocean, which has drawn a great deal of public attention in recent years. Carbon dioxide dissolved into the ocean pushes up the concentration of hydrogen ions (H^+), which lowers the pH and, in changing the chemical equilibrium of the inorganic carbon system, reduces the concentration of carbonate ions (CO_3^{2-}).

Such a decrease in carbonate irons would place marine calcifying organisms at risk, such as calcareous plankton, crustacean and fish. Recent simulation models predicted that an elevated atmospheric CO_2 would result in a noticeable upswing in ocean acidity in higher latitudes. Due to the undersaturation, oceans are expected to become less habitable for calcifying organisms with aragonite structures, in the Southern Ocean by 2030 and in the Northern Pacific by 2100.

Arctic sea ice has been disappearing at an alarming rate since the end of the 20th century. In this study, scientists focused on the saturation state of calcium carbonate ($CaCO_3$) in this rapidly changing Arctic ocean – whether they are at sufficient levels (supersaturated with respect to $CaCO_3$) or are in short supply (undersaturated with respect to $CaCO_3$) so that dissolution of $CaCO_3$ may commence.

The saturation state was indicated by Ω values; waters with $\Omega>1$ are supersaturated with respect to $CaCO_3$ and therefore are favourable for calcifying organisms. Whereas waters with $\Omega<1$ are undersaturated and thus endangers the organisms' survival. During the study, salinity and oxygen isotope ratio (*2) -indicators for sea ice melt- were also investigated to understand the relationships between the impact of sea ice melt and Ω values.

Summary of methods

From July 17th to August 21st, 2008, hydrographic observations aboard the CCGS Louis S. St-Laurent were conducted in the Canada Basin of the Arctic Ocean, joined by scientists from Japan, Canada and the U.S. Seawater was analyzed for total alkalinity (TA* 3), dissolved inorganic carbon (DIC*4), water temperature and salinity. The data were used to calculate Ω aragonite, a value indicating the saturation level of aragonite $CaCO_3$. The fraction of sea ice meltwater in seawater was estimated by using the oxygen isotope ratio. The results were compared with the data from the 1997 observations to investigate how the extensive melting of sea ice has changed the fraction of sea ice meltwater and Ω values in surface water.

Results and Discussions

The comparison of data between 1997 and 2008 revealed the ongoing freshening of the surface water in the Canada Basin. The oxygen isotope tracer methods indicated that a major source of this additional freshwater was meltwater from sea ice (Fig. 1). Ω aragonite dropped significantly in 2008 from the 1997 levels, suggesting the aragonite-undersaturated surface waters are spreading towards the center of the basin.

In ocean acidification in tropical or temperate waters, increased CO_2 concentrations in the atmosphere accelerate the oceanic uptake of CO_2, reducing carbonate ions (CO_3^{2-}) and lowering Ω aragonite. In the Arctic Ocean, in addition to that, sea ice melt contributes to lowering Ω values. The melting of sea ice generates large open water, which enhances air-sea gas exchange and accelerates ocean acidification.

Furthermore, as sea ice meltwater is similar to freshwater, with lower total alkalinity (TA) and dissolved inorganic carbon (DIC) levels than those of seawater or river water, the meltwater input dilutes seawater, decreases TA and CO_3^{2-} (a form of DIC)concentrations, and consequently reduces Ω aragonite. The aragonite-undersaturated waters (Ω<1)in the Canada Basin also showed lower TA levels, suggesting a strong influence of sea ice melt on the decrease of Ω.

Aragonite undersaturation (Ω<1) has been observed in waters near coasts or continental shelf breaks where upwelling or river waters have a strong influence on water profiles. The Canada Basin is the first deep basin with an extensive distribution of low Ω aragonite (Ω<1). The research revealed that the undersaturation was caused by the ocean acidification coupled with increased melting of sea ice, making this Arctic basin the first aragonite undersaturated ocean in the world.

Future perspectives

JAMSTEC researchers conducted field experiments on board the Research Vessel Mirai in the western part of the Canada Basin, from September to October 2009. Dr. Michiyo Yamamoto-Kawai, IOS/DFO researcher and associate researcher of JAMSTEC, joined this mission and confirmed that the aragonite undersaturation (Ω<1) was also spreading across the western part of the Canada Basin (Fig. 2).

Simulation models predict that the Arctic Ocean will be free of sea ice in summer by the middle of this century. The retreat of sea ice is expected to further accelerate and affect the environment in various ways. JAMSTEC research team assumes that the decrease in Ω will continue until no sea ice is left in the Arctic Ocean.

Although the possible impact of decreased Ω and aragonite-undersaturation on the ecosystem is not fully understood, laboratory experiments on marine biota in an elevated CO_2 environment show that changes in Ω would cause substantial changes in aragonite-structured Arctic organisms including Limacina helicina (the only prey of Clione limacine). Scientists anticipate how the low Ω aragonite (Ω<1) induced by ocean acidification and sea ice melt will affect the population and distribution of these organisms, and how such changes will affect the food chain and eventually the entire Arctic marine ecosystem. The surface waters of the Canada Basin are known to flow out into the Atlantic Ocean over a time span of 10 years. The changes in Ω aragonite occurring in the Canada Basin could be seen in the future Atlantic waters.

To better understand the ongoing changes in the Arctic Ocean, continued and integrated observations should be conducted to carefully analyze the impact. Such research activities will lead to an improved understanding of the Arctic climate system, and offer new insight into Arctic climate variations and corresponding ecosystem changes.

***1. Aragonite** is a relatively soluble form of calcium carbonate found in plankton and invertebrates. Coral skeleton is also made of aragonite.

***2 . Oxygen isotope ratio**
A stable isotope ratio of oxygen in water. Oxygen has three stable isotopes (^{16}O = 99.763%, ^{17}O = 0.0375%, ^{18}O = 0.1995%). Relatively heavy ^{18}O is contained more in seawater and sea ice than in rainfall and river waters. The origin of freshwater therefore can be determined by the isotope ratio.

***3. Total alkalinity (TA)**
Total alkalinity is the total electric charge to neutralize acids. In seawater, TA is expressed as a total electric charge of bicarbonate ions (HCO_3-) and carbonate ions (CO_3^{2-}).

***4. Dissolve inorganic carbon**
A term referring to inorganic carbon species in a solution. DIC species in seawater include carbon dioxide (CO_2), carbonic acid (H_2CO_3), bicarbonate ion (HCO_3-), and carbonate ion (CO_3^{2-}).

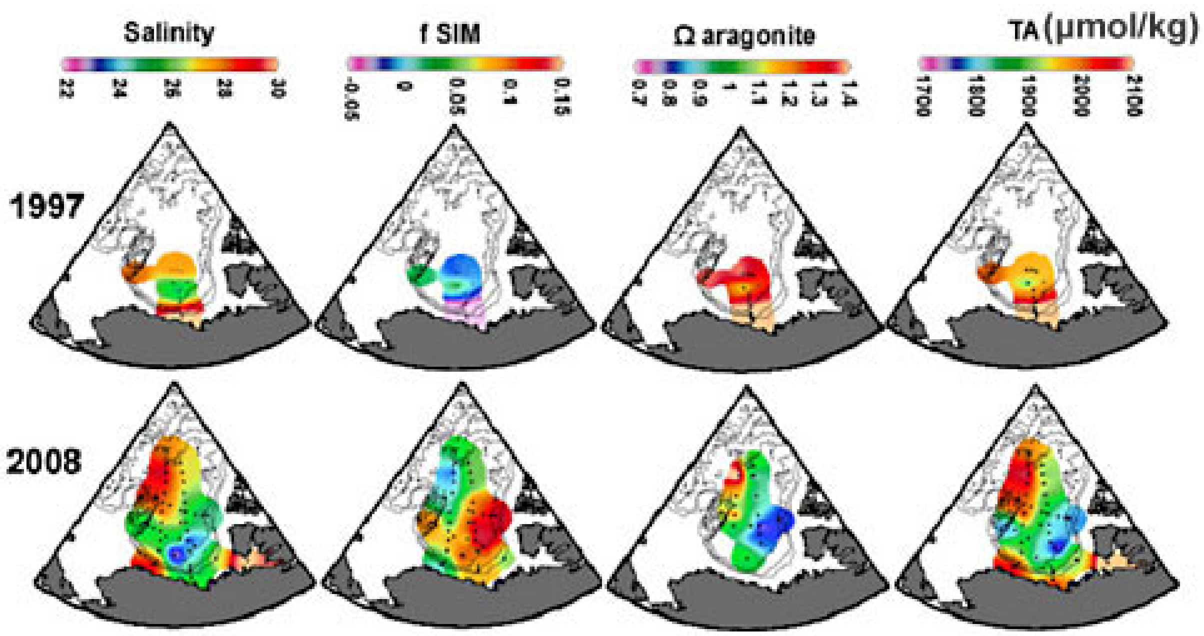

Fig. 1. Distributions of salinity, fraction of sea ice meltwater (f SIM), Ω aragonite, and TA in surface water (0 - 20 m) in the Canada Basin of the Arctic Ocean. The upper panels show the results from the data of 1997, and the lower panels show the results from the data of 2008. Gray contour lines indicate isobaths of 1000, 2000, and 3000 m. The figure illustrates the increase in f SIM, and the decrease in salinity, TA and Ω aragonite (from supersaturation to undersaturation).

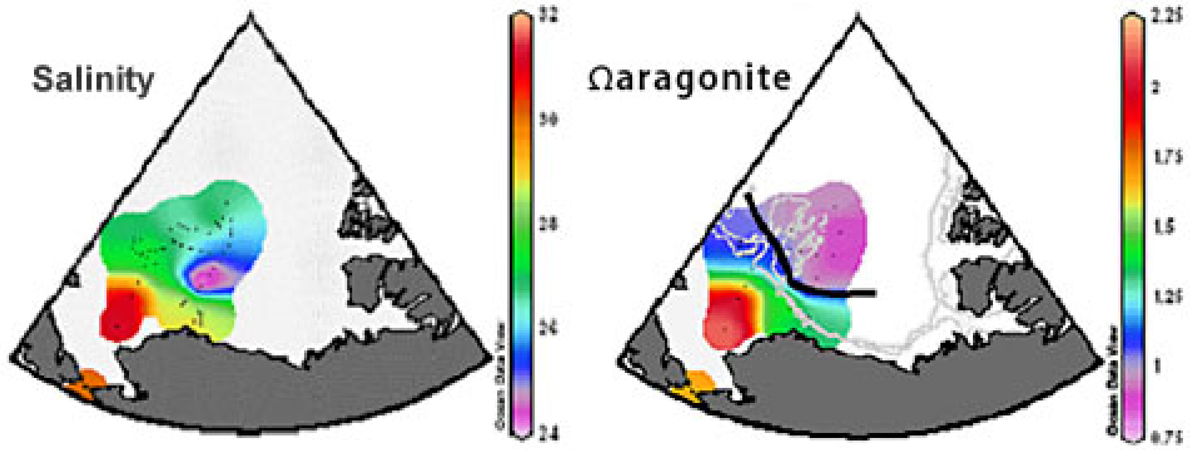

Fig. 2. Surface distributions of salinity and Ωaragonite observed in the 2009 Arctic Ocean cruise by R/V Mirai. The black dots show observation stations and the thick black line shows the aragonite saturation level Ω=1. Decreases in salinity and Ωaragonite are observed in the western Canada Basin.

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