Abstract Volume

Arctic Ocean Acidification

Bergen, Norway
6-8 May, 2013

AMAP
Arctic Monitoring and Assessment Programme

ARCTIC COUNCIL

Arctic Ocean Acidification

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Abstract Volume

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Preface

This volume comprises the abstracts of oral and poster presentations at the conference "Arctic Ocean Acidification", Bergen, Norway, 6-8 May 2013.

The conference is organized by the Arctic Monitoring and Assessment Programme (AMAP), Institute of Marine Research (IMR), Norwegian Institute for Water Research (NIVA), Scientific Committee on Oceanic Research (SCOR) and University of British Columbia (UBC).

The organizers gratefully acknowledge the countries and organizations that have sponsored the conference and/or participated in its arrangement, and welcome all participants to Bergen.

Background

The Arctic Ocean is rapidly accumulating carbon dioxide owing to perturbations in the global carbon cycle and particularly to increases in anthropogenic carbon concentrations. This is resulting in a decline in seawater pH, so-called ocean acidification. Increasing ocean acidification and warming of the ocean will cause changes in the ecological and biogeochemical coupling in the Arctic Ocean, influencing the Arctic marine ecosystem at all scales. Ocean acidification is expected to affect marine food chains and fish stocks and thus the commercial, subsistence, and recreational fisheries in the Arctic. There is a need for a better understanding of the nature and scope of these changes and of the resilience of the ecosystem to the changing carbon chemistry of the Arctic Ocean.

In addition, given the importance of the Arctic Ocean as a regulator of global climate, there is a need to understand the implications of the changing role of the Arctic on the global carbon cycle.

Over the past 20-30 years, our knowledge and understanding of the Arctic has expanded rapidly against the backdrop of concerns about climate change and pollution. The linkages between the Arctic and the rest of the world mean that Arctic science has come to play an increasingly prominent role in the public consciousness and the concerns of policy-makers. Key to these developments has been the cooperation on science in the post-Cold War era - initially between the Arctic countries and later extending to the global scientific community - that formed the basis for the establishment of internationally coordinated monitoring and assessment efforts that have provided vital information necessary for science-based decision-making.

Over the past 20 years, the Arctic Monitoring and Assessment Programme (AMAP) has played a central role in these developments. Established by the eight Arctic Countries in 1991, and now one of the groups serving the Arctic Council AMAP is charged with coordinating monitoring and performing scientific assessments of pollution and climate change issues in the circum Arctic area to document trends and effects in Arctic ecosystems and humans and identify possible actions for consideration by policy-makers.

AMAP has produced several highly-valued science based assessment reports over the years. At this conference AMAP will present the results of its new assessment of Arctic Ocean Acidification.

Session 1

Acidification in the Arctic Ocean – set the scene

Keynote 1
Presenter: Ulf Riebesell

Plankton community responses to ocean acidification: implications for food webs and biogeochemical cycling

Ulf Riebesell
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Phytoplankton forms the base of the marine food web and is the primary driver of marine elemental cycles. Our ability to predict future changes in ocean ecosystems and biogeochemistry therefore crucially depends on our understanding of the impacts of ocean acidification (OA) on planktonic organisms and communities. The information presently available suggests a great diversity in OA responses. This ranges from adverse effects on growth and calcification in some phytoplankton species to stimulated carbon and nitrogen fixation, growth and organic matter exudation in other groups of phytoplankton. These physiological responses can mediate ecological and biogeochemical impacts. For instance, changes in food quality with regard to size, stoichiometry, and fatty acid composition will affect higher trophic levels. Shifts in community composition and trophic interactions, in turn, are likely to affect elemental cycling and export fluxes. Much of our present knowledge on OA effects is based on single species experiments, with little information about possible impacts on natural communities, food webs and ecosystems. Even less is known about the potential for evolutionary adaptation to OA. In my presentation I will (1) outline the knowns and unknows in OA research on pelagic systems, (2) highlight a few surprises which occurred when taking the knowledge gained in lab experiments out into the field, (3) give examples of OA-effects on trophic interactions, and (4) discuss possible biogeochemical implications of the observed community-level responses.

Keynote 2
Presenter: Sam Dupont

The alpha and omega of ocean acidification – biological impacts on benthic organisms

Sam Dupont
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Ocean acidification due to CO_2 uptake leads to a reduction in saturation state (Ω) of seawater with respect to calcium carbonate minerals (calcite and aragonite). Because of the high CO_2 solubility of cold waters, under-saturation (Ω<1) will occur first in polar waters and become widespread in the Arctic within decades. Some Arctic regions, in particular coastal and shelf zones, have already crossed important geochemical thresholds (e.g. War<1) and have naturally high CO_2 system variability, and near-future ocean acidification will lead to a wide scale expansion of these regions. It is often assumed that under-saturation causes problems for calcification and marine calcifiers and Ω is used as a key geochemical threshold to link chemistry to biological and socio-economical responses.

However, benthic species including calcifiers are able to adapt and even thrive while acutely (e.g. upwelling areas) and chronically (e.g. deep sea vents) exposed to under-saturated seawater.

When Ω has a value less than 1, calcium carbonate dissolves. However, living organisms are not pieces of calcium carbonate and are able to calcify and maintain their skeleton structures in under-saturated conditions. (i) The process of calcification is often intracellular, coupled with efficient pH regulatory mechanisms. (ii) Most calcifying organisms rely on either bicarbonate or metabolically-produced CO_2 and their calcification is independent from seawater carbonate concentration. (iii) Skeletal structures can be internal or covered by an organic protective layer preventing from dissolution. (iv) Several modulating environmental parameters allow compensating for any increased dissolution by an increased calcification and an increase in energy acquisition. (v) A decreased net calcification is not necessarily detrimental and consequences are highly dependent on ecological interactions. As a consequence, Ω is then not the only and may not be the more important parameter to assess biological consequences of ocean acidification. Calcification is only one of the many physiological parameters impacted by ocean acidification and consequences for both calcifying and non-calcifying species can be expected.

In the Arctic, the impact of ocean acidification will become effective on a strong background of warming and, in some regions, expanding hypoxia. By exacerbating temperature and hypoxia effects ocean acidification has the potential to affect keystone and commercially important species. Data on how ocean acidification might influence benthic Arctic species are not yet available but a theoretical framework is now available.

Keynote 3
Presenter: Carol Turley

Policy and Ocean Acidification

Carol Turley

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Ocean acidification is happening now, will worsen with continued CO_2 emissions to the atmosphere and has the potential for widespread and significant effects to marine ecosystems that may also be a risk to humans and society. Scientific study of the impacts and consequences is still in its relative infancy but there has been rapid and substantial national and international investment in research in the last six years. Scientists have worked with policy makers to ensure that they are well-informed about the evidence base. In the last five years, this outreach has resulted in extraordinary uptake by policy makers and other stakeholders. Such uptake requires scientists, policy makers and stakeholders to work together to understand the broad implications of ocean acidification in order to assess the challenges of mitigating and adapting to a future high CO_2 ocean. Ocean acidification is increasing considered as a climate change, biodiversity and sustainability policy issue at nongovernmental governmental and intergovernmental levels as more and more expert reports are published. However, it is currently failing to be significantly addressed at the highest policy level, such as at the United Nations Framework Convention on Climate Change. Is this because the processes of including new scientific evidence is inherently slow, or that the climate change negotiations are already full and complex without adding ocean acidification, or that ocean acidification does not add anything new to the CO_2 targets under negotiation or that ocean acidification science is not addressing the questions that policy makers want to know?

Session 2

Chemistry

Presenter: Richard Bellerby

Arctic Ocean Acidification: Response to changes to the physical climate and biogeochemical cycling

Bellerby, Richard [1,2], **Silyakova, Anna** [2], **Slagstad, Dag** [3]

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Changes to Arctic Ocean biogeochemistry will result from a complex array of climate and chemical perturbations over the next decades. Changes to freshwater content through ice melt and continental runoff, warming of the ocean and an increasing ocean acidification through partial equilibrium with a rising anthropogenic CO_2 load will change the nature of Arctic marine carbonate chemistry. Large changes in recent carbon fluxes to the Arctic are resulting in variable regional and water mass ocean acidification. Using a regional, coupled physical-ecosystem-carbon biogeochemical model (informed at the boundaries by downscaled global earth system model) we have developed scenarios of future Arctic Ocean acidification. Sensitivity studies are explored under variable land-ocean interaction and feedbacks to ocean-acidification sensitive ecosystem responses.

Presenter: Toby Tyrrell

Seasonal cycle of $CaCO_3$ saturation state across the entrance to the Barents Sea

Toby Tyrrell, Eithne Tynan, Mariana Ribas Ribas and Eric P. Achterberg

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Ocean acidification (OA) due to anthropogenic CO_2 uptake leads to a decline in Ω, the saturation state of seawater with respect to calcium carbonate. Because of the high CO_2 solubility of cold polar waters, the onset of undersaturation ($\Omega<1$) will occur first in polar waters, and according to models is predicted to become widespread in the Arctic before it does in the Southern Ocean. Undersaturation is likely to cause problems for pelagic calcifiers such as pteropods. Winter measurements of seawater carbonate chemistry are scarce because of the poor conditions for cruises, but are important because the seasonally lowest Ω values (and hence first occurrences of undersaturation) will take place in wintertime. We report the first observations of the carbonate system of surface waters across the Atlantic entrance to the Barents Sea (mainland Norway to Svalbard) over a seasonal cycle. Data were collected on board a ship-of-opportunity (the cargo vessel *Green Frost*) supplying Svalbard. Sampling was conducted during four *Green Frost* crossings in 2010 and 2011, including one in late winter (early April), and also on summer research cruises including the 2012 Arctic cruise of the sea surface consortium of the UKOA programme. Aragonite saturation states (Ω_{Ar}) were found to be lowest in winter, at which time they decreased northwards (2.0 down to 1.8). In contrast to some other areas of the Arctic Ocean, however, no undersaturation was observed at any time of year, even in winter, probably due to somewhat lower saturation states in Pacific than in Atlantic waters at the same latitude, and only minor freshwater inputs to this study area. Analysis suggested biological production to be the most important factor driving variability in Ω_{Ar}. It is therefore predicted that if biological production becomes more intensive in a future ice-free Arctic, the amplitude of the seasonal cycle in Ω_{Ar} will also increase.

Presenter: Ingunn Skjelvan

Ocean acidification trends in the Norwegian Sea

Ingunn Skjelvan [1,2], Abdirahman Omar [1,2], and Are Olsen [1,2,3]
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The biodiversity of the Norwegian Sea is huge. This ocean area is the home of large and international important stocks of fish and sea birds, and it also houses unique cold water coral reefs. With this in mind we have assembled new data with the aim to quantify ocean acidification in terms of pH and degree of carbonate saturation of the Norwegian Sea.

Time series of oceanographic data are of vital importance for ocean acidification studies, and in this work we have used data from Ocean Weather Station M in the Norwegian Sea in addition to data from the CARINA data base. The seasonal cycle is the most striking characteristics of oceanographic parameters in our ocean areas. On top of this is an anthropogenic signal which might be hard to discover. However, today we have available both methods and data which enable us to calculate the present status of the ocean acidification, to separate anthropogenic changes from the natural variation of the carbon system, and to determine the changes in the ocean acidification since the mid 90ties.

Session 3 Chemistry

Keynote 4
Presenter: Leif G. Anderson

Changes in observed Arctic Ocean Acidification during the last decades

Leif G. Anderson
Department of Chemistry and Molecular Biology, University of Gothenburg, Sweden

High quality measurements of the carbon system parameters have been performed in the Arctic Ocean for about 20 years. These observations reveal that waters of the shelf seas with low salinity are under-saturated with respect to aragonite, an under-saturation that has been amplified in some regions by microbial decay of organic matter of mainly terrestrial origin. Under-saturated shelf bottom waters supply the halocline of mainly the Canadian Basin. The depth range of this under-saturated water is increasing with time and reaches up into the productive surface waters at some locations. Likewise are the bottom waters of the deep basins under-saturated, but no change in the depth of the saturation horizon can be detected. However, there are several indications of increasing ocean acidification at intermediate deep waters, a result of the inflowing Atlantic water carrying a substantial anthropogenic carbon dioxide concentrations. In this presentation data of increasing Arctic Ocean Acidification will be shown covering both the deep central Arctic Ocean as well as part of the Siberian shelves.

Presenter: M. Yamamoto-Kawai

Distribution of $CaCO_3$ undersaturated waters in the Arctic ocean, from observation and reconstruction

M. Yamamoto-Kawai [1], W. Williams [2], F. McLaughlin [2], E. Carmack [2], S. Nishino [3] and T. Mifune [1]
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Owing to anthropogenic ocean acidification and climate change, waters potentially corrosive to aragonite-type $CaCO_3$ shells and skeletons are now found in both the surface and subsurface/bottom layers of the Chukchi Sea and Canada Basin. Time-series observations in this region show that aragonite saturation state rapidly decreased to <1 from 1990s to 2000s in surface waters due to the melting and retreat of sea ice which diluted surface water and enhanced air-sea CO_2 exchange. Observations also show that there is substantial spatial and interannual variability in the distribution of this undersaturated water. Analysis of physical and chemical properties indicate that the saturation state disposition is mainly determined by the distribution and component mixtures of water masses including freshwater from sea ice melt and rivers, and attendant processes such as warming and the formation and remineralization of organic matter. From this analysis, it is possibile to estimate a proxy saturation state from T, S and O_2 only. As the distribution of undersaturated waters in the whole Arctic Ocean is not well known due to the scarcity of observational data, we have used this approach to reconstruct the saturation state from the more abundant T, S, and O_2 data. A multi-regression analysis was applied to our observations of alkalinity and dissolved organic carbon and to T, S and O_2 (as Apparent Oxygen Utilization). By applying the obtained relationship to T, S, and O_2 data in the World Ocean Atlas we then reconstruct a saturation state in the entire Arctic Ocean. Importantly, this reconstruction identifies regions that are vulnerable to ocean acidification and provides a starting point for validation of model simulations to predict future Arctic acidification.

Presenter: Melissa Chierici

Ocean Acidification state in Arctic outflow waters in the Fram Strait

Melissa Chierici [1], **Agneta Fransson** [2], **Mats A.Granskog** [2], **Paul Dodd** [2], **Edmond Hansen** [2]

1) Institute of Marine Research and the Fram Centre, Tromsø, Norway
2) Norwegian Polar Institute, Fram Centre, Tromsø, Norway

In 2011, the Ocean Acidification Flagship at the Fram Centre established a new time-series transect for ocean acidification studies in the Fram Strait. The OA work complements ongoing monitoring of sea ice thickness and drift, ocean temperature, salinity and currents in Fram Strait. The study was expanded in 2012 and is part of an observational network investigating the carbonate system and ocean acidification state in the Arctic gateways. The motivation is to investigate the effect of a changing Arctic such as freshening, warming, sea-ice cover decline and changes in the Polar and Atlantic waters influence on the ocean acidification state and the carbon cycle. During two years, we performed extensive sampling of the water column, and determined the carbonate system parameters, nutrients, isotope tracers, and colored dissolved organic matter (CDOM). Using total alkalinity-and isotope tracer-salinity relationships we estimated the water mass composition in the water exiting the Arctic. From these data, we investigate the influence of freshwater (river runoff and sea-ice melt), Pacific water, and Atlantic water on the ocean acidification state. Lowest pH and $CaCO_3$ saturation state was found in a layer between 20 to 200 meters depth in the outflow water coinciding with high brine, CO_2 and CDOM content. In this presentation we discuss the possible mechanisms for the origins of the low pH layer.

Presenter: V.V. Ivanov

On the direction of carbon dioxide fluxes in the Arctic Ocean

I.A. Repina [1,2,3] **and V.V. Ivanov** [4]

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3) Russian State Hydrometeorological university, St. Petersburg, Russia
4) Arctic and Antarctic research institute, St.Petersburg, Russia

Uptake of carbon dioxide (CO_2) from the atmosphere leads to decrease in the pH of the World Ocean, causing acidification of the sea water. In the recent years the natural balance of CO_2 between the oceans and atmosphere is distorted because of increased import of the anthropogenic carbon. Thus, ocean acidification is driven by increased emissions of carbon dioxide in the atmosphere, and like global climate change poses a threat to the Earth ecosystems. We present observational results, which demonstrate that in the Arctic Ocean the direction of carbon dioxide fluxes at the ocean/ice/air interface may vary depending on specific conditions. These measurements were carried out in the Arctic Ocean in framework of NABOS (= Nansen and Amundsen Basins Observations System) during the IPY (2007-2009). Ship observations have revealed differences in intensity and direction of gas exchange, which depend on the characteristics of the underlying water masses. Coastal areas, strongly influenced by coastal erosion and the river input of terrestrial carbon (suspended and dissolved), are the sources of CO_2 into the atmosphere. Emission of CO_2 from the Arctic coastal zone is influenced by coastal erosion and river runoff water, which is generally low in transparency and productivity; erosion and runoff may increase as global warming continues. Eddy correlation measurements made above the open water surface of the Laptev Sea ranged between the negative (invasion) and positive (evasion) values of +1.7 mmol m^{-2} d^{-1} and –1.2 mmol m^{-2} d^{-1} Comparing the distribution of CO_2 fluxes with surface temperature and salinity shows that warmer and fresher water, which is probably a riverine plume, acts as a source of CO_2, while relatively colder and saltier water near the ice edge is a sink. Flux measurements made on one-year ice in the Laptev Sea and fast ice provide some insights onto the influence of sea ice on CO_2 exchange between atmosphere and sea ice surface. We infer that in early summer absorption of atmospheric CO_2 by ice-covered ocean dominates; this agrees with data collected using aircraft. Our measurements also suggest the important role of melt ponds and leads in gas exchange. The sea-ice melt ponds form an important spring/summer air CO_2 sink that also must be included in any Arctic regional CO_2 budget. Contrary to ponds, summer leads act as a source of CO_2, which is released to the atmosphere. Both: the direction and amount of CO_2 transfer between air and the sea during open water season may be different from transfer during freezing and thawing, or during winter when CO_2 accumulates beneath the Arctic sea-ice.

Session 4

Chemistry

Keynote 4

Presenter: Nadja Steiner

Model projections of future AOA

Nadja Steiner, James Christian

Institute of Ocean Sciences, Fisheries and Oceans Canada, Sidney, BC, Canada and
Canadian Centre for Climate Modelling and Analysis, Victoria, BC, Canada

The Canadian Aquatic Climate Change Adaptation Services Program (ACCASP) assesses regional risks and fosters research and the development of science-based tools to increase our understanding of the impacts of climate change and to integrate climate change considerations into the mainstream of decision-making in the Department of Fisheries and Oceans. Regionally and spatially limited observations show trends of enhanced ocean acidification in the Canadian Arctic. In support of ACCASP activities, several Earth System Models (ESMs) submitted to the 5th Coupled Model Intercomparison Project (CMIP5) were evaluated with respect to Arctic Ocean acidification.

Future projections under Representative Concentration Pathways 4.5 and 8.5 consistently project a reduction in surface pH from about 8.1 in the recent past to about 7.7 by the end of the 21st century, and a reduction in the saturation state of calcium carbonate minerals from about 1.2 (2.0) to about 0.6 (1.0) for aragonite (calcite) in the Canada Basin. Global timeseries of the zonal mean saturation horizon show a continuous decrease from preindustrial times to 2100 for all latitude bands except the Arctic. In the Arctic, the saturation horizon changes abruptly and consistently for all models, from depths greater than 2000 m to zero. In a large part of the Arctic ocean basins, increased CO_2 uptake and additional freshwater contributions at the surface cause the saturation state to approach undersaturation both from the ocean surface and the ocean bottom, rendering the common definition of the saturation horizon unsuitable. Below 100-300m waters remain saturated. The models vary by about 0.7 in the aragonite saturation state of the deep ocean (below 500m) with the deep saturation horizon varying between 2000m and 4000m. Waters in the European Basin follow the pattern seen in the major oceans, with the saturation horizon rising from the bottom and surface waters becoming undersaturated much later than in the rest of the Arctic. While the models' resolution and coastlines vary, affecting flows in and out of the Arctic as well as flow e.g. through the Canadian Archipelago, the main differences among models' acidification projections seem to be related to the reduction in sea-ice cover and related responses of wind mixing and stratification.

Presenter: Agneta Fransson

Sea-ice processes and glacier runoff as drivers of inorganic carbon and ocean acidification state in the Arctic Ocean

Agneta Fransson [1], Melissa Chierici [2], Daiki Nomura [1], Mats Granskog [1]

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Observations from field campaigns in Svalbard, Fram Strait and Canadian Arctic showed large regional and temporal variability in surface-water (under-ice water) carbonate system and calcium carbonate saturation (Ω). We investigated the carbonate system in sea ice, snow, brine and in the under-ice water. Part of the variability of the carbonate system and Ω in the under-ice water was explained by the impact of sea-ice processes, such as calcium carbonate ($CaCO_3$) formation, brine transport, ice melt and freezing, and glacier runoff. During sea-ice formation, carbon and other chemical substances are rejected from the ice, forming concentrated brine. In this study, brine and melt water were released to the surface water under the ice, reflected by the changes of total alkalinity in the water under the ice. In addition, $CaCO_3$ crystals were formed within the ice, changing the carbonate system and Ω in the ice and in the under-ice water.

With changing seasonal ice cover, increased summer ice melt (from sea ice and glacier ice) and river runoff in the Arctic Ocean, CO_2 fluxes, vertical carbon transport and carbonate system will be affected; increased freshwater may change the brine-carbon pump as well as dilute the carbonate system, changing the uptake of atmospheric CO_2.

In this presentation we discuss the effect of sea-ice processes and glacier runoff on the surface water during the seasons in the context of decreased ice cover.

Session 5 Biology

Keynote 5
Presenter: Howard I. Browman

Biological responses to ocean acidification

Howard I. Browman

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Ocean acidification (OA) may cause changes to Arctic marine systems at the organismal and ecological levels. At the organismal level, there will be both direct effects on physiology and behavior and indirect effects *via*, for example, trophic interactions (e.g., food availability and quality). OA will affect energy flux through food webs and material flux through changes in the vertical movement of organic and inorganic matter. Pelagic and benthic calcifiers are at greatest risk to OA. The early life stages of both invertebrates and vertebrates, particularly larval forms with limited autoregulatory capacity, will generally be more susceptible to OA. Sessile benthic organisms will in general be more susceptible to OA and will likely be excluded from some regions in which they were previously present. On the other hand, productivity of autotrophs (e.g., dinoflagellates) will likely increase as may primary productivity (as a result of higher CO_2 and temperature). Organisms inhabiting regions that have always exhibited marked fluctuations in pH and CO_2 may prove highly resilient to OA. Northward movement of some organisms – driven by warming of the oceans – may be limited by direct or indirect effects of OA. There is an almost complete lack of information on the effects of OA (in isolation or in combination with other environmental stressors) on keystone species and processes in the Arctic. Accordingly, there is an urgent need for focused research on the likely impacts of OA on a range of taxa and processes.

Presenter: H.S. Findlay

Behavioural strategies predict ocean acidification responses in Arctic copepods

Findlay H.S. [1], **Lewis C.N.** [2], **Brown K.A.** [3], **Miller L.A.** [4]

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Increased uptake of anthropogenic carbon dioxide by the oceans is rapidly changing their carbonate chemistry; a process termed Ocean Acidification (OA). In particular, OA is occurring most rapidly in the Arctic Ocean where shallow shelves already periodically experience undersaturation of aragonite, a biologically important form of calcium carbonate mineral, at depths of around 100 m. Knowledge of the seasonal and annual variability in carbonate system parameters in the Arctic Ocean is limited; hampering our understanding of the processes that contribute to OA, especially associated with continued sea ice loss. Furthermore, predicting how organisms and ecosystems respond to OA in the Arctic currently relies on studies from sub-arctic and/or ice-free systems. Copepods make up the dominant zooplankton species of Arctic waters; hence their responses to OA conditions have important implications for Arctic ecosystems. Indeed early life stages of copepods have been shown to be impacted by OA in laboratory experiments. Here we present carbonate chemistry data collected during the Catlin Arctic Survey from a late winter ice base in the Canadian high Arctic, together with results from experiments on under-ice pelagic copepod species exposed to projected future OA conditions. We highlight that understanding the *in situ* environmental conditions, together with life history strategies of these organisms, is vital to make an assessment of the vulnerability and sensitivity of Arctic species to a rapidly changing environment.

Presenter: R. Leakey

The impact of ocean acidification on the Arctic surface ocean biology: preliminary results from the UK Ocean Acidification Research Programme research cruise to the Atlantic sector of the Arctic, summer 2012.

R. Leakey [1*], E.Achterberg [2], I.Brown [3], D. Clark [3], F.Hopkins [3], M.Moore [2], V.Peck [5], A. Poulton [4], A.Rees [3], M.Ribas-Ribas [2], S.Richier [2], G.Tarling [5], E.Tynan [2], T.Tyrell [2], J.Young [6], M.Zubkov [4].

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The impact of ocean acidification on Arctic surface ocean biology, ecosystems and biogeochemical cycling was investigated during a multidisciplinary research cruise to Barents, Greenland, Norwegian and North Seas during June 2012. The research was undertaken as part of the Sea Surface Research Consortium of the UK Ocean Acidification Research Programme. The high-level objectives of the cruise were to: (i) Ascertain the impact of ocean acidification on planktonic organisms (in terms of physiological impacts, morphology, population abundances and community composition); (ii) Quantify the impacts of ocean acidification on biogeochemical processes affecting the ocean carbon cycle (both directly and indirectly, such as via availability of biolimiting nutrients); (iii) Quantify the impacts of ocean acidification on the air-sea flux of climate active gases (DMS and N_2O in particular). These objectives were achieved by undertaking in-situ observations across natural carbonate chemistry gradients, and by undertaking five on-deck CO_2 perturbation incubations ("bioassays"). The cruise visited 45 stations in 33 days, encompassing wide range of environmental conditions, including temperature, sea-ice cover, carbonate chemistry, nutrients, productivity, plankton composition and biomass. An overview of the cruise including preliminary results will be presented.

Presenter: Erik Sperfeld

How will ocean acidification affect northern krill? - Experimental investigations

Authors: Erik Sperfeld, Anders Mangor-Jensen, Padmini Dalpadado
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Abstract:

Anthropogenic CO_2 emissions and the associated changes in ocean water chemistry might adversely affect marine organisms. Ocean acidification (OA) is predicted to be most pronounced in waters of high latitude, which (in combination with temperature changes) makes the Arctic ecosystem highly vulnerable to this stressor. Negative effects of OA on calcifying organisms have been reported frequently during the last decade, whereas much less is known about potential effects of OA on ecologically important pelagic crustaceans such as copepods, krill and amphipods.

In laboratory experiments, we exposed krill of the northern hemisphere to different pCO_2/pH levels in order to assess the consequences of OA on this important key species. Krill were caught near Austevoll research station (Institute of Marine research) during night using light traps, subsequently sorted and gently placed into flow through jars of an OA facility. After one week acclimation time in sea water of ambient carbon chemistry, individual krill have been kept additionally at three levels of decreased pH (i.e. increased pCO_2) for several weeks under different food supply. Results of growth/development and feeding rates for *Meganyctiphanes norvegica* or *Nyctiphanes couchii* will be presented. Longer-term experiments are intended to assess the adaptability of different krill species to changing seawater carbon chemistry, also under changing conditions of other environmental factors, such as temperature. These experiments will be the basis for collaborative OA research also on *Thysanoessa inermis* and *T. longicaudata* as more arctic related krill species.

Session 6 Biology

Presenter: Hrönn Egilsdóttir

Shoaling calcium carbonate saturation horizons and potential implications for deep sea calcifyers

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Carbon chemistry time series observations have been conducted in Iceland Sea surface and deep waters from 1994. The time series site is at 68.00°N, 12.67°W where the water depth is 1850 m. The surface pH in winter decreases at a high rate of 0.0024 yr^{-1}, and the aragonite saturation horizon, which is currently at about 1700 m, is shoaling at a rate of 4 m yr^{-1}. The deep water of the Iceland Sea is stable with respect to temperature distribution and the calcium carbonate saturation can be expressed by a function, derived by regression, relating it to pressure and time. The observed shoaling of aragonite and calcite omega values in the Iceland Sea needs to be addressed in relation to the presence of calcium carbonate forming biota. For that purpose we review species occurrence data from the benthic sampling project BIOICE, carried out from 1994 to 2004. Molluscs produce both aragonite and calcite, together in their shell, or just one of the morphotypes, and they commonly occur in benthic environments. We investigated the depth distribution of 10 commonly occurring families of bivalves and gastropods of the Iceland Sea in relation to aragonite and calcite saturation states at the sample depths.

Presenter: Ingrid C. Taban

The combined effects of ocean acidification, ocean warming and oil spill on the development, feeding and metabolism of the Northern Shrimp (Pandalus borealis) larvae

Maj Arnberg [1,2*], Piero Calosi [2], John I. Spicer [2], Ingrid C. Taban [1], Stig Westerlund [1], Renée K. Bechmann [1]

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The future ocean will suffer from the increasing pressure from several anthropogenic activities, including offshore oil drilling, ship transports and combustion of fossil fuels, the latter being considered the main cause for the ongoing global changes. These combined stressors will pose a threat to marine ecosystems. Currently, the potential effects of stressors, such as ocean acidification (OA), are mainly studied independently from each other, our understanding of the potential effects of complex interactions of multiple drives being rather limited. To improve our ability to predict the consequences that multiple stressors may have on marine life, we investigated the effect of the exposure to combined decreased pH, elevated temperature and an oil spill on the larval development of the commercially important northern shrimp *Pandalus borealis*.

In a laboratory experiment, four different scenarios were simulated: 1) Ambient (pH 8.1, 6.5 °C), 2), Ambient + oil spill (pH 8.1, 6.5 °C, oil conc. 0.5 mg L^{-1}), 3) Future (IPCC 2007 scenarios + regional scenarios)(pH 7.6, 9.5 °C), 4), Future + oil spill (pH 7.6, 9.5 °C, oil conc. 0.5 mg L^{-1}). Hatching timing and success, as well as the zoeal development, survival, feeding, respiration and growth (up to stage IV zoea) were characterised. Larvae developed 9 days faster in reaching stage IV zoea under elevated temperature, and exhibited an increase in metabolic rates and feeding rates (15-20 %). However zoea larvae were smaller in size, in terms of total length and dry mass. When exposed to the oil treatments the larvae showed reduced feeding, metabolic rates and growth, independently of exposure to OA. Furthermore oil-exposed larvae at zoea IV showed a high incident of (20%) deformities of the abdomen. Overall the treatment that combined of future climate conditions with an oil spill produced the smallest larvae with both total length and dry weight, significantly smaller than all other treatments. Based on these findings, we conclude that shrimp larvae in the future ocean could experience accelerated developmental rates, but with greater maintenance costs. And with an additional cost of reduced feeding and growth due to an oil spill, will likely make the larvae more vulnerable to accidental oil spills in the future.

Presenter: René Bechmann

Combined effects of ocean acidification, ocean warming and oil related discharges

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3) Plymouth University

Abstract: The existing literature on effects of OA on different marine organisms clearly shows that the responses are stage- and species specific. To improve the predictions about the fate of marine ecosystems in a high CO_2 world, more information about how different species in the ecosystem respond to ocean acidification (OA) and other anthropogenic and natural stressors is needed. We will present an overview of the main results from a series of experiment where key organisms in the marine ecosystem have been exposed to OA in combination with other types of anthropogenic stressors; 1) embryos, larvae and adults of Northern shrimp (*Pandalus borealis*) exposed to OA, increased temperature and an oil spill scenario; 2) early life stages of Northern Krill (*Meganycthiphanes norvegica*) exposed to increased temperature and OA; 3) embryos and larvae of the green sea urchin (*Strongylocentrotus droebachiensis)* exposed to OA and an oil spill

scenario; and 4) the cold water coral *Lophelia pertusa* exposed to OA and petroleum-related drilling mud. The experiments included single stress and combined stress treatments, and the test conditions were based on the emission scenarios for this century presented by IPCC. The aim was to find out if there were synergistic effects of combined exposure to ocean acidification and ocean warming or relevant concentrations of oil related discharges.

Presenter: Eduard Bauerfeind

Shift in species composition and abundances of pteropods in the eastern Fram Strait sampled with moored sediment traps at the AWI – HAUSGARTEN (79°/4°E) since the year 2000

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Pteropods are an important component of the zooplankton community and hence of the food web in Fram Strait. They can also contribute significantly to the vertical export of calcium carbonate in the form of aragonite. In eastern Fram Strait two species of thecosome pteropods occur, the cold water adapted *Limacina helicina* and the subarctic boreal species *Limacina retroversa*. Both species were regularly observed in our year-round-moored sediment traps in ~200-300m depth. The flux of all pteropods found in the trap samples varied from < 20 to ~ 870 specimens $m^{-2} d^{-1}$ in the years 2000-2009 being somewhat lower during the period 2000-2006. At the beginning of the time series, pteropods were dominated by the cold-water-adapted *L. helicina* whereas the subarctic boreal *L. retroversa* was only occasionally found in large quantities (>50 $m^{-2} d^{-1}$). This picture completely changed after 2005/6 when *L. retroversa* became dominant and pteropod numbers in the trap samples increased significantly. This shift occurred concomitant with a warming event in 2005/6 and persisted till the end of the study in 2009, despite a slight cooling in the upper water layer after 2007/8. Sedimentation of pteropods also showed a strong seasonality with elevated fluxes of *L. helicina* during August – November whereas numbers of *L. retroversa* usually increased during September/October with a maximum later in the season during December/January. In terms of carbonate export pteropods contributed with 11-77 % to the annual total $CaCO_3$ flux in Fram Strait with the highest share during the last years of the study and the majority of this flux occurred during sedimentation events at the end of the year. Results obtained by sediment traps installed close to the seafloor and which operated only during a part of the 9 years study showed that pteropods also arrive at the seafloor in 2500m almost simultaneously to their occurrence in the shallower traps. This indicates also that nutritious particles are provided to the deep-sea benthos during winter when production in the upper water column is shut down.

The results of our study emphasize the present day importance of pteropods for the biological - as well as the carbonate system in Fram Strait. Pteropods are highly endangered in the near future due to the effects of the increasing CO_2 concentration in the atmosphere and the associated changes of pH and temperature in the ocean.

Session 7 Socio-economy and policy

Presenter: Rashid Sumaila

Potential Economic and Social Impacts of Ocean Acidification on Arctic Fisheries

Rashid Sumaila
Fisheries Economics Research Unit, University of British Columbia, Canada

The objective of this talk is to review existing knowledge on ocean acidification's (OA) impact on social and economic aspects of Arctic fisheries, and discuss how change in ocean pH under anthropogenic CO_2 emission may present a risk to marine fisheries economics, the food security and culture of indigenous communities of the Arctic. The talk builds on the knowledge on the chemistry of OA and the biological effects of OA. The literature reports that OA is likely to affect the abundance, productivity and distribution of marine species although the magnitude and direction of changes are uncertain. This, in turn, is likely to affect the price of fish, the cost of fishing and the fisheries benefits to the indigenous populations of the Arctic. With respect to social and economic impacts there are very few studies, especially, in relation to the Arctic. Given that management and policy development to counteract the effects of OA alone is difficult because it is not easy to isolate OA effects from other anthropogenic impacts, I stress the need to strengthen marine management in general.

Presenter: Jeremy T. Mathis

Preparing for the Challenges of Ocean Acidification In The Pacific-Arctic Region

Jeremy T. Mathis[1, 2]

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New data from ship-based and moored observations, species manipulation experiments and model outputs continue to show that ocean acidification is an imminent and potentially disruptive threat for the coastal waters of the Pacific sector of the Arctic Ocean. Precipitous reductions in pH as well as the suppression of important carbonate mineral concentrations are being observed from the waterways of Gulf of Alaska to the rapidly changing coastline of the Beaufort Sea. In the last two and a half centuries, but mainly in the past fifty years, the pH of the ocean has been reduced due to the intrusion of anthropogenic CO_2 produced mainly from fossil fuel burning and changes in land use practices. This reduction in pH could have far-reaching and detrimental consequences for a number of marine species, particularly those that produce carbonate shells. With a multi-billion dollar fishing industry and a large subsistence population that relies heavily on ocean resources for the majority of their dietary protein, the Pacific-Arctic Region is particularly vulnerable to the impacts of ocean acidification. Here, newly synthesized economic data that provides the first assessment of the potential financial consequences of ocean acidification will be presented along with strategies for combating and adapting to changes brought on by a reduction in pH. These new strategies include the construction of a multi-million dollar network of moorings that will be capable of providing early warning data to stakeholders and policymakers throughout the Pacific-Arctic Region. This project provides an ideal framework for future efforts because it harnesses resources from the state government, federal and private funding agencies and non-governmental organizations. Ocean acidification is a complex problem that will require a multilateral approach to solve, but with a concerted, well-coordinated effort we can sustain the commercially important fisheries and the native subsistence lifestyle.

Presenter: Nathalie Hilmi

The socio-economic impacts of ocean acidification on recreational activities in the Arctic

Nathalie Hilmi

Centre Scientifique de Monaco and International Atomic Energy Agency

According to scientific studies, ocean acidification (OA) will impact the economic activities in the arctic. Usually, tourism is an important economic sector and a way to have foreign currencies, especially when exports and foreign direct investment decline. The objective of this presentation is to put into light the different recreational activities that are likely to be impacted by OA: ecotourism and recreational fishing. Then, we can question if the current state of knowledge permits us to conclude on a potential impact of OA on those economic activities.

Session 8

Technical aspects

Presenter: Jamie Griffith

Autonomous Ocean Acidification Survey Utilizing the Wave Glider

Jamie Griffith [1] and Stephan Howden [2]

1) Liquid Robotics
2) University of Southern Mississippi

The Wave Glider (WG) is an Unmanned Surface Vehicle (USV) that harnesses mechanical energy from waves and electrical energy from solar cells to power a configurable panel of scientific instruments. In partnership with the University of Southern Mississippi, the Gulf of Mexico Coastal Ocean Observing System (GCOOS) and the Northern Gulf Institute, Liquid Robotics deployed a Wave Glider in the northern Gulf of Mexico to monitor pCO_2 levels. The system was outfitted with a CO_2 air--sea interface system, a CTD+dO, a pH sensor, a weather station, and a water speed sensor. The vehicle was deployed near the Central Gulf of Mexico Ocean Observing System (CenGOOS) buoy site at the 20m isobath in the northwest corner of the Mississippi Bight in early October of 2012 and directed along a path near the Mississippi Balize Delta defined by the July 2012 GOMEC--II trials ship route. The purpose of the mission was to assess the ability to support the monitoring goals of NOAA's Ocean and Great Lakes Acidification Research Implementation Plan, the interagency North American Carbon Program (NACP), and the Integrated Ocean Observing System (IOOS) through the autonomous collection of CO_2 using a Wave Glider. This study also demonstrated the ability to use the Wave Glider as an effective mobile tool for gathering a suite of in--situ observations typically collected with fixed buoys, and how the real--time data stream could effectively be integrated into GCOOS Data Portal and made readily available for coastal resource decision makers.

Presenter: Philip McGillivary

Use of Multiple Autonomous Systems to Improve Arctic Ocean Acidification Data Collection

Philip McGillivary [1], Francisco Chavez [2], Francois Leroy [3], Vicky Fabry [4],

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3) Liquid Robotics, Inc., Sunnyvale, CA
4) Cal State San Marcos, San Marcos, CA

Collection of data on ocean acidification in the arctic requires sampling over temporal and spatial scales beyond the limitations of manned platforms. Improved environmental monitoring of ocean acidification can be accomplished using autonomous vehicles, including autonomous underwater vehicles (AUVs), autonomous surface vehicles (ASVs), and autonomous (or unmanned) aerial vehicles (UAS). Data collection from such autonomous vehicles can be optimized by use of multiple autonomous vehicle systems communicating and interacting to autonomously execute adaptive anomaly mapping. Such a system of data collection platforms can be used to study critical ecosystem components in the Arctic Ocean, including air-sea flux dynamics at shelf breaks, ice-edges, in areas of river or glacier melt freshwater runoff, and at coastal polynyas.

We present data on a compact ocean acidification monitoring system incorporated into a wave-powered ASV, the WaveGlider (WG). Propulsion of WGs is via wave energy, permitting onboard power systems to support sensor and communication systems. Real-time data communication via satellite allows data forwarding to operators. The WG OA sampling system has proven successful for periods of months. It can be deployed using pre-programmed survey tracks, as well as having the option of employing adaptive sampling software for anomaly mapping, while including software to maintain on-demand human-in-the-loop operation. ASVs have been demonstrated with sensors to provide marine meteorological data (eg wind speed and direction, as well as sea state), and can be equipped with sensors for atmospheric CO2 sampling.

Additionally, the ASVs can act as data nodes for AUV measurements of ocean acidification and other data collected beneath the surface or under-ice. The ASV can then transmit this data to nearby ships or UAS using wireless communications equipment, or to shore via satellite communication links. Any given ASV can also coordinate sampling with UAS. For example, the more rapid spatial airborne sampling capability of the UAS can be used to direct the ASV and AUVs to anomaly locations for sampling, thereby optimizing time and power response capabilities of these platforms for data collection. Moreover, sampling can include not only individual UAS, but studies using multiple vertically "stacked" UAS for measuring air-sea fluxes of heat, momentum, as well as air-sea gas fluxes including CO_2, methane and other gases (e.g. DHS, bromine) are also possible. The use of autonomous sampling platforms can significantly and cost-effectively extend spatial and temporal data collection beyond the limitations of other OA monitoring capabilities.

A number of important Arctic Ocean ecosystems are currently under-sampled. Many arctic coastal areas have been identified as of special scientific and environmental significance. However these are often in very remote locations, and there is limited capability to monitor these critical arctic ecosystems to monitor the effects of climate change and ocean acidification on ecosystem biogeochemical cycling and population effects. We know that ocean acidification will potentially affect key zooplankton species with carbonate components such as pteropods, which are a critical food source for many arctic species. Further there is concern about monitoring ocean acidification effects in the ocean on the deposition of bones and long-term survival of juvenile fish for at least some arctic fish species based on laboratory studies. Sustained field data collection on ocean acidification in critical habitats over large spatial areas and time must be obtained and combined with complementary data on zooplankton and meroplantkon. In many cases critical habitat for these species is in ice-edge areas poorly sampled by manned platforms. By using autonomous systems with ocean acidification sensors coupled with sensor arrays (such as ADCPs and cameras) to monitor zooplankton and meroplankton abundance data can better be obtained to understand the relationship of climate change to critical biological populations. Arctic river outflows are critical habitats for many arctic fish species, and studies in these areas as well as areas of glacier melt are a priority to provide needed data on climate effects on ecosystem biology in the Arctic Ocean.

In summary pilot studies which can incorporate multiple underwater, surface and airborne autonomous systems in the arctic for study of critical habitats, such as polynyas, should be a priority to demonstrate improved data collection and analysis of climate dynamic effects on ocean acidification. We have demonstrated that the tools for such sampling are now available.

Session 9

Chemistry

Presenter: Peter Croot

Sensitivity of trace metal biogeochemical cycles to ocean acidification in the Arctic: An assessment of our current state of knowledge

Peter Croot

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The impact of ocean acidification (OA) on the biogeochemical cycling of trace metals is still relatively unknown. While it is possible to directly calculate the distribution at equilibrium of inorganic metal species as a function of the pH and carbonate concentration of seawater, there are two main limitations to this approach; (1) There is very little data available for the water temperatures encountered in the Arctic as most data is for 25° C, (2) for many elements the speciation is dominated by organic complexes for which we do not have data on the influence of pH. Furthermore pH induced changes in metal speciation can also lead to small but significant changes in the redox behavior of elements like Fe and Cu which may alter their kinetic lability and overall bioavailability to organisms. Contrastingly OA is not expected to alter Mn speciation significantly, as it is already dominated by the free metal ion, as it forms weak organic complexes. However Mn concentrations may increase in the Arctic due to increases in fluvial inputs and release from shelf sediments, in part unrelated to direct OA effects.

In this presentation I will summarize the current state of knowledge on trace metal cycling in the Arctic, based on an overview of published research in this region, and link this to recent laboratory and modeling work on ocean acidification in an attempt to identify the most sensitive elements and processes in the Arctic. Particular emphasis will be placed on the impact of OA on Fe and Mn cycling in the context of other climate change drivers in the Arctic.

Presenter: Irina I. Pipko

Features of the carbonate system dynamics in the shelf waters of the eastern Laptev Sea

Irina I. Pipko [1], Svetlana P. Pugach [1], Anatoly N. Salyuk [1], Igor P. Semiletov [1,2]

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The Arctic Ocean is one of the most sensitive regions in its response to global climate changes. The Arctic Ocean is small (only ~4% of the entire World Ocean), but it receives about 10 % of the global riverine discharge, which has accelerated in the last decades, and it is surrounded by permafrost, which is degrading at an increasing rate under conditions of warming. Thaw and release of organic carbon from the Arctic permafrost is postulated to be one of the most powerful mechanisms causing a net redistribution of carbon from land and ocean to the atmosphere. This is of particular interest in the context of the ocean acidification.

Arctic shelf seas are among the most active biogeochemical marine environments and the Laptev Sea is a prime example. It is strongly influenced by the freshwater input and receives a substantial amount of the terrestrial organic matter both from rivers and from coastal erosion. So, the eastern Laptev Sea shelf region is exposed to the conditions of low aragonite saturation state during a warm season but the extent of its evolution is largely unknown. We examined the spatial and interannual dynamics of the carbonate system in the shelf waters of the eastern Laptev Sea from data collected in our multiyear expeditions. The characteristic features of the carbonate parameters dynamics in the inner, middle, and outer shelf waters were determined. The data demonstrated significant heterogeneity in the carbonate system across the entire domain. The inner and middle shelves of the Laptev Sea are a source of the carbon dioxide into the atmosphere whereas an outer shelf is a CO_2 sink over the late summer/fall period. The southeastern Laptev Sea is a naturally acidified marine environment and exhibits very low values of $pH_{in\ situ}$ (as low as 7.24, total scale). It was found that a significant part of the eastern Laptev Sea surface waters was strongly undersaturated with respect to aragonite, a relatively soluble form of the calcium carbonate. Undersaturation was identified in a whole water column of the inner and middle shelves, in some areas the saturation state of aragonite dropped to 0.1-0.2.

Our investigations indicate that the interannual dynamics of carbonate system parameters in the eastern Laptev Sea is strongly depending on the atmospheric circulation regime, on the volume of riverine discharge, on the intensity of sea ice retreat and coastal erosion processes. Thus, we can suggest that in the nearest future the saturation state of the calcium carbonate in the Laptev Sea will decrease with the Arctic amplification of climate warming. Further all-seasons investigations are necessary for better assessment of the carbonate system response and feedback to rapid climate changes and its consequences for the marine ecosystem in this unique region of the Arctic Ocean.

Presenter: Kumiko Azetsu-Scott

Ocean Acidification in Hudson Bay System: influence of high fluvial input and ice formation

Kumiko Azetsu-Scott [1], Michel Starr [2], Zhi-Ping Mei [3] and Mats Granskog [4]

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Hudson Bay system (HBS) is a shallow inland sea in the southern margin of Arctic including Hudson Strait, Foxe Basin, James Bay and Hudson Bay. HBS is covered by seasonal sea ice 8-9 month of the year with a large fluvial input. Water mass characteristics and circulation in HBS are strongly influenced by freshwater dynamics. Freshwater dynamics are also important controlling factors for the carbon system in the HBS. A study in HBS provides not only a local ocean acidification condition, but an insight into the influence of rapidly changing hydrological cycle to ocean acidification in the Arctic.

An extensive study in HBS was conducted from August to October in 2005 by the programs MERICA and ArcticNet, measuring dissolved inorganic carbon (DIC), total alkalinity and oxygen isotope composition. Oxygen isotope composition ($\delta^{18}O$) was used to identify the freshwater sources including sea ice melt water and meteoric water (precipitation and river or glacier runoff). From DIC and alkalinity, pH (in total scale pH_{total}) and saturation state of seawater with respect to calcite (Ω_{cal}) and aragonite (Ω_{arg}) were calculated.

Highest DIC concentrations (>2300 µmol/kg) were observed at the central part of HBS bottom water (175m deep) with pH_{total} of 7.49 and Ω_{arg} of 0.37. The Ω_{arg} distribution in surface water (<10m) reflected river runoff distribution with lower Ω_{arg} (<1.2) along the coastal regions, especially in the eastern Hudson Bay. The Ω_{arg} was higher (>1.75) along northern Hudson Strait where offshore water with high salinity flows from Baffin Bay. The saturation horizon for aragonite was less than 5m deep in the coastal area of Hudson Bay where salinity ranged from 25-27, whereas in central Hudson Bay it was around 50m with an east-west gradient, with shoaling to the east. The river water fraction in freshwater showed a strong negative correlation with Ω_{arg}, while sea ice meltwater fraction was small during the study and didn't show a clear relationship with Ω_{arg}.

Presenter: Evgeniy Yakushev

Modeling of carbonate system parameters sediment-water fluxes in changeable redox conditions

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Climate Change affects oxygen depletion and leads to spreading of the bottom areas with hypoxic and anoxic conditions. This work aimed in estimation of a potential role of changes of redox conditions at the sediment –water interface on the fluxes of carbon. We use a 1-dimensional C-N-P-Si-O-S-Mn-Fe vertical transport-reaction model describing both the sediments and bottom boundary layers coupled with biogeochemical block simulating changeable redox conditions, and the carbonate system processes block. A biogeochemical block is based on ROLM (RedOx Layer Model), that was constructed to simulate basic features of the water column biogeochemical structure changes in oxic, anoxic and changeable conditions (Yakushev et al., 2007). Organic matter formation and decay, reduction and oxidation of species of nitrogen, sulfur, manganese, iron, and the transformation of phosphorus species are parameterized in the model. ROLM was applied for the description of the water column oxic/anoxic interface structure in the Black and Baltic Seas and the fjords. In this study we additionally parameterized transformation of Si and C.

Session 10

Biology

Presenter: E.M. Hevrøy

Environmental challenges of ocean acidification on energy metabolism, buffer capacity and transcriptional responses in Northeast Atlantic mackerel (*Scomber scombrus L.*)

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Atlantic mackerel was challenged with reduced temperature and pH in a controlled tank experiment. The temperature was reduced weekly from 13.5°C to 4°C, with a graduate reduction of 2°C each week. The fish were kept in two groups with pH 7.8 (normal) and pH 7.4, the latter mimicking ocean acidification. Analysis of basic amino acids showed significantly increased levels of taurine, an important buffer component of the muscle, in mackerel kept at 7.4 pH. Further data on fat storage and energy metabolism hormone data will be presented. Because of the lack of sequence information for this ecologically and commercial important North Atlantic species, we decided to sequence the transcriptome for downstream gene expression analysis. RNA was extracted from muscle and liver, and a mixed sample of pooled RNA was used to sequence the transcriptome. Using Illumina technology, we sequenced about 58 million reads. The reads were assembled and mapped against the Unigene database, creating unique 57,899 Unigene-mapped contigs with an average length of 569 nt, as well as 49,260 singletons, assumed to cover most of the transcriptome. Key components of the insulin-like growth system and the oxidative stress response will be targeted for RT-qPCR analysis to understand the basic mechanisms of catabolism and oxidation.

Presenter: Piotr Kukliński

Mineralogical properties of marine invertebrates skeletons and their significance in ocean acidification

Piotr Kukliński [1,2], Tomasz Borszcz [1], Paul D. Taylor [2]

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Ocean acidification (OA) and warming (OW) acting synergistically are believed to have negative impacts on marine ecosystems. A growing body of evidence suggests that OA alters carbonate biomineralization in a variety of marine animals and plants. The solubility of calcite increases with increase in mol% $MgCO_3$, to the extent that calcite containing a high proportion of $MgCO_3$ is even more soluble than aragonite, the other common calcium carbonate biomineral. With respect to carbonate minerals, seawater saturation state is lower in polar than in temperate and tropical latitudes because calcium carbonate is more soluble in cold water. It is also recognized that pH and CO_2 levels also change with water depth. In presented study we evaluate and discuss the potential vulnerability of Arctic marine benthic communities to OA and OW using the carbonate skeletons of bryozoans as a model. Bryozoans are major carbonate-producers in some ancient and Recent benthic environments, including parts of the Arctic Ocean. Seventy-six species of bryozoans from within the Arctic Circle have been studied using XRD to determine their carbonate mineralogies and the Mg contents of the calcite. The majority of species were found to be calcitic, only four having bimineralic skeletons that combined calcite and aragonite, and none being entirely aragonitic. In almost all species the calcite was of the low- (<4 Mol% $MgCO_3$) or intermediate-Mg (4-11.99 Mol% $MgCO_3$) varieties. Previous regional studies of bryozoan biomineralogy have found higher proportions of bimineralic and/or aragonitic species in New Zealand and the Mediterranean, with a greater number of calcitic species employing intermediate- and high-Mg calcite. The Antarctic bryozoan fauna, however, has a similar mineralogical composition to the Arctic. The lesser solubility of low-Mg calcite compared to both Mg calcite and aragonite in cold polar waters is most likely responsible for this latitudinal pattern. However, it is unknown to what extent environmental factors drive the pattern directly through eliciting an ecophenotypic response from the bryozoans concerned or the pattern reflects genetic adaptations by particular bryozoan clades.

Magnesium often substitutes for Ca in the calcite skeletons of marine invertebrates, influencing their solubility, yet the spatio-environmental distribution of Mg in marine invertebrates has seldom been studied. As pH decreases with water depth, it can be predicted that levels of Mg in calcite skeletons should also decrease to counteract dissolution. Data on magnesium content and depth in Arctic bryozoans is here used to test this prediction. Analyses are based on a uniform dataset spanning more than 200 m of coastal depths. No significant relationship was found between depth and Mg content but this value did vary more strongly in bryozoan skeletons from deeper than shallower water. These findings contrast with previously published results using crinoids and suggest that OA and OW may have a less dramatic impact on the studied bryozoans than is generally assumed.

Presenter: Katarzyna Zamelczyk

Past and present water chemistry changes: planktic foraminifera in the Fram Strait (preliminary results and plans)

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Planktonic foraminifera that live in the upper 200 m of the water column constitute a major group of calcareous species of the marine microplankton in the Fram Strait. Their calcareous shells are highly sensitive to varying sea surface conditions, changes in carbonate chemistry and preservation in sedimentary records. This sensitivity makes them one of the most important objects of investigation of past changes in ocean chemistry, climate and circulation.

The main objective of our study is to reconstruct and to quantify planktonic foraminiferal response to changes in surface ocean chemistry due to shifts in concentration of atmospheric CO_2 from the past 30,000 years to the present day in the Fram Strait.

The Fram Strait is the most important oceanographic opening to the central Arctic Ocean where the major water transport takes place. The eastern Fram Strait is occupied by warm and saline Atlantic waters, whereas the western Fram Strait is dominated by cold and fresher Polar water and sea-ice. The two different water masses generate two oceanic fronts, the Polar and the Arctic front, characterized by high primary production and elevated abundances of planktonic foraminifera.

In addition to water column samples taken with plankton net (VP2, 90µm mesh size), surface sediment samples and sediment cores were collected during two cruises along the Atlantic water flow and along a E-W transect at 78°N in the central Fram Strait in 2012. The distribution patterns of fossil and living planktonic foraminifera from plankton net and sediment surface samples show strong variability.

A range of new and well established proxies reflecting sea water chemistry will be analyzed on material from all retrieved samples and annually moored sediment trap samples from 2011 and 2012. The analysis will be focused on two species of planktic foraminifera (*Neogloboquadrina pachyderma* and *Turborotalita quinqueloba*). Shell weight, degree of fragmentation and measurements of degree of dissolution based on SEM images will be used to establish the state of dissolution. Boron isotopes (a proxy for pH), carbon and oxygen isotopes as well as B/Ca ratios (a proxy for carbonate ion concentration), and Mg/Ca ratios will be measured within the same samples to obtain the profile of chemistry changes in the water column in the study area.

Presenter: Sissel Andersen

Early development of the scallop *Pecten maximus* L. veligers at increasing CO_2-concentration

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Introduction

An ongoing research project at the Institute of Marine Research in Norway is looking at possible effects of increasing CO_2-concentration in the ocean (ocean acidification, OA) on early shell formation and veliger larvae development of scallops (Mollusca, Bivalvia). Experiments have so far been carried out with a temperate species; the great scallop *Pecten maximus* L. Future experiments will include the arctic Iceland scallop (*Chlamys islandica*, O.F. Müller 1776).

Ocean acidification scenarios were produced by adding CO_2-gas to seawater. An acid stock solution of pH 5.8 was diluted to give four different pH levels each with four replicate flow-through 40 liters exposure tanks.

Material and methods

Local scallop broodstock was conditioned in a hatchery for 8 weeks (Jan-Mar) and spawning induced by an increase in temperature. Eggs were cross fertilized with sperm from 2-3 individuals and when cell division was observed embryos were incubated in the exposure tanks at a stocking density of 13 ml^{-1}. The tanks were stagnant over night, and then flow was adjusted to 10-15 L $h^{-1}d^{-1}$. Embryos and larvae were exposed to the different pH levels for seven days at 15.6 °C. Temperature was recorded using a logger set to read hourly values, pH was measured daily and alkalinity was analyzed twice during the experiment. No feed was added during the seven days experiment.

Samples of larvae were taken 1, 2 and 6 days after fertilization, and all larvae were collected after seven days when the experiment was terminated. The larvae were preserved in formalin and stored in ethanol for later observations of shell size and deformities using an Olympus BX60 microscope connected with a Canon 5D MARK II camera.

Results

OA affected both shell growth and survival negatively after seven days. Growth was reduced with 5-10 % when pCO_2 increased from ambient 477 ppm to 1627 ppm, and survival based on egg number was reduced from 40.4 % in the ambient group to 10.7 % in the highest pCO_2-group.

Larvae/embryos stained with calcein one day after fertilization and for 20 hours, showed fluorescence in the newly formed shell area indicating calcification of the shell already at the trochophore stage. This may explain the observed shell hinge deformities at elevated pCO_2-levels in trochophore larvae after only two days. Both shell hinge and edge deformities were observed in veliger larvae after seven days at elevated pCO_2-levels. Hinge deformities appeared to be more related to OA than edge deformities.

Poster presentations

Poster 1
Presenter: E.M. Foekema

Community response to elevated CO_2 concentrations tested in outdoor marine mesocosms

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Outdoor benthic mesocosms with a volume of approximately 4000 L, were applied to determine the response of a marine benthic community to elevated CO2 concentrations in order to test the response of a marine ecosystem to unintended CO2 release form sub-seabed storage. Three duplicated exposure conditions were created by bubbling the water column with a mixture of compressed air and CO_2 for a 69 day period. CO2 induced acidification resulted in average pH levels of 8.0, 7.5 and 6.8 respectively, against 8.3 in the controls. The addition of CO_2 stimulated phytoplankton production, leading to increased zooplankton density and indications of increased growth of mussels. Negative effects were observed, at least at the highest treatment level, on sessile algae, a specific copepod species, sponges, mudshrimps and polychaete worms. In the highest treatment level mollusc shells suffered from erosion, but survival and growth of adults was not negatively affected. The reproduction success of bivalves formed the most sensitive endpoint, resulting in almost complete absence of juveniles in the medium and high treatment levels.

Poster 2
Presenter: Alexander Polukhin

Long-term dynamics of pH and total alkalinity in the Kara Sea

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Shirshov Institute of Oceanology RAS, Moscow

The Kara Sea is a unique object of the hydrosphere for oceanologists. A variety of hydrological, hydrochemical and meteorological processes create a vast field for research activities. Based on field work conducted by Shirshov Institute of Oceanology (SIO RAS) from 1993 to 2011, the dynamics of pH and total alkalinity for several areas of the Kara Sea, including the Ob Inlet and the Yenisei Bay, was investigated. It is not possible to identify a trend in the variability of selected parameters for the sea. At the same time, for each district interannual changes of pH and total alkalinity have specific traits. This is due to variety of climatic factors operating on the area, and possibly to changes in river runoff and chemical composition of river water flowing into the Kara Sea.

Poster 3
Presenter: Jon Olafsson

Rapid acidification of the Iceland Sea

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The Iceland Sea is the smallest, 406000 km^2, and the shallowest, mean depth 1026 m, part of the Nordic Seas. The other parts are the Greenland Sea and the Norwegian Sea. Cold Arctic Water prevails in the Iceland Sea and the deep-water which supplies the Denmark Strait and the Iceland-Faroe overflows is an important source of North Atlantic Deep Water. Carbon chemistry time series observations of pCO_2 and total CO_2 concentration have been conducted at quarterly intervals in Iceland Sea surface waters from 1985 and from 1994 for the whole water column. The time series site is at 68.00°N, 12.67°W where the water depth is 1850 m. These observations have revealed that surface pH in winter decreases at a high rate of 0.0024 yr^{-1}, and that the aragonite saturation horizon which is currently at about 1700 m is shoaling at a rate of 4 m yr^{-1} (Olafsson, Olafsdottir et al. 2009). The shoaling rate of the aragonite saturation field accelerates with decreasing depth and is up to 4 times higher at the 400 m level. We will examine the Iceland Sea carbon chemistry changes in light of hydrography and other regional variability.

Olafsson, J., S. R. Olafsdottir, et al. (2009). "Rate of Iceland Sea acidification from time series measurements." Biogeosciences 6: 2661-2668.

Poster 4
Presenter: Solveig R. Olafsdottir

Carbon Chemistry variability within the Iceland Sea

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2) Faculty of Earth Sciences, University of Iceland, Askja, IS 107, Reykjavik, Iceland

The Iceland Sea is one of the Nordic Seas. It lies north of Iceland, east of Greenland and south of the island Jan Mayen. To the east it meets the Norwegian Sea. The hydrographic conditions in the Iceland Sea are governed by Arctic influences with the cold Polar Water of the East Greenland Current to the west and with a deep basin filled with Arctic-, and Arctic Intermediate Water. Investigations on the ecology of the Iceland Sea were conducted by the Marine Research Institute, Iceland, in 2006 to 2008. Biogeochemical data were collected on 8 cruises covering all seasons. The observations included the partial pressure of dissolved carbon dioxide, pCO_2, and total dissolved inorganic carbon dioxide, TCO_2. The pH and the saturation state of calcium carbonate were calculated. We investigate the distribution of carbon chemistry variables in relation to hydrographic properties on two sections. A section from NE-Iceland to Jan Mayen across the Iceland Sea cyclonic gyre and an EW-section at 69°N across the Kolbeinsey Ridge which separates a shallower western basin from the eastern basin. The Iceland Sea time series station (IS-ts) which records the long term ocean acidification is on the Iceland - Jan Mayen section. The 2006 -2008 data provide insight on the regional representation of the time series results.

Poster 5
Presenter: Marit Norli

Studying the surface Arctic ocean acidification state using ships of opportunity

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Increasing partial pressure of CO_2 (pCO_2) in the atmosphere is interconnected with the pCO_2 in the surface layer of the ocean. This leads to increased acidity of the seawater, expressed by a reduced pH (Caldeira and Wickett 2003, Raven et al. 2005). An increased concentration of dissolved CO_2 in the seawater also implies reduced concentration of carbonate ions. This has consequences for the calcium carbonate saturation state of the seawater.

Estimating the ocean acidification using observations can be challenging because inter-annual changes of pH are superposed with large temporal (daily and seasonal) variability and spatial variability (for example at the frontal zones). Besides this, the commonly applied potentiometric technique has a very poor precision and accuracy (>0.02) compared with the observed trends, that makes it difficult to compare data from different sources. Also, the Arctic Ocean acidification is challenging to study because of poor data availability, especially for the winter season.

Fig. 1: Transect between Tromsø and Longyearbyen from which we will present our results of the carbonate system parameters.

During 3 years and 13 cruises (2010-2012), the carbonate system parameters were obtained at the transect between Tromsø and Longyearbyen (fig.1), onboard a Ferrybox equipped SOOP vessel MS "Norbjørn". This work are performed as a part of the Klif Ocean Acidification program as well as the FRAM center Ocean Acidification Flagship and NIVA internal projects. This work aimed to study the seasonal and interannual changes of the carbonate system (pH, pCO_2, aragonite saturation) in response to seasonal and climatic forcing. The transect covers different types of water in the connection between the Norwegian Sea and the Barents Sea.

The measurements of pH were made onboard while samples for alkalinity (At) and TIC (Ct) were measured at NIVAs Laboratories in Oslo. The measurements of pH with potentiometric (pH-P) and spectrophotometric techniques (pH-S) was taken in parallell, as recommended for the ocean acidification studies (Dickson et al. 2007, Dickson 2010). pH-P and pH-S operate with different pH scales: NBS(NIST, IUPAC) scale for pH-P and total scale for pH-S. The total scale defines pH in terms of the sum of the concentrations of free hydrogen ion and HSO^{4-} (Dickson 2010).

The measurements of alkalinity and TIC performed with a techniques described in (Dickson et al. 2007). Carbonate system parameters (value of pCO_2, concentrations of bicarbonate and carbonate ions and the aragonite saturation) were calculated with co2sys_ver14.xls tool (http://www.ecy.wa.gov/programs/eap/models.html).

The installed Norwegian Institute for Water Research (NIVA) Ferrybox system allows to perform continues measurements of temperature, salinity, turbidity, fluorescence, dissolved oxygen and chlorophyll a fluorescence. An intake of water at the ship is positioned at about 4 m depth and the water is pumped through the sensors measurements compartments. The system is equipped also with a refrigerated 24 X 1 liters sampler allowing automatic sampling in the chosen positions. The Ferrybox results of measurements are available within 1-2 days after downloading data in Tromsø and at Svalbard (www.ferrybox.no). On this ships of opportunity transect new installation of autonomous pCO_2 and photometric pH will be installed in 2013.

Results of observations completed at a transect Tromso-Longyearbyen, show variations of pH in the central Barents Sea about 0.2, i.e. 7.94-7.99 in February and 8.04-8.16 in August. A minimum pH-S value in the surface water (7.91, pH total scale) was observed in winter near Tromsø, the highest one (8.23) was found in May near the Spitsbergen coast. The results allowed us to demonstrate that the upper layer water pCO_2 varies from 480 ppm in winter to minimum values of 280 ppm during the organic matter production period. Therefore summer invasion of CO_2 should be replaced by winter evasion. The results can be helpful for planning expeditions and for analyzes of archived field data, as well as for elaborating the interannual and multidecadal changes models.

In this poster we will present our data from the period 2010-2012 from this transect. pH-S for cruises from 2010 – 2012 is shown in fig. 2.

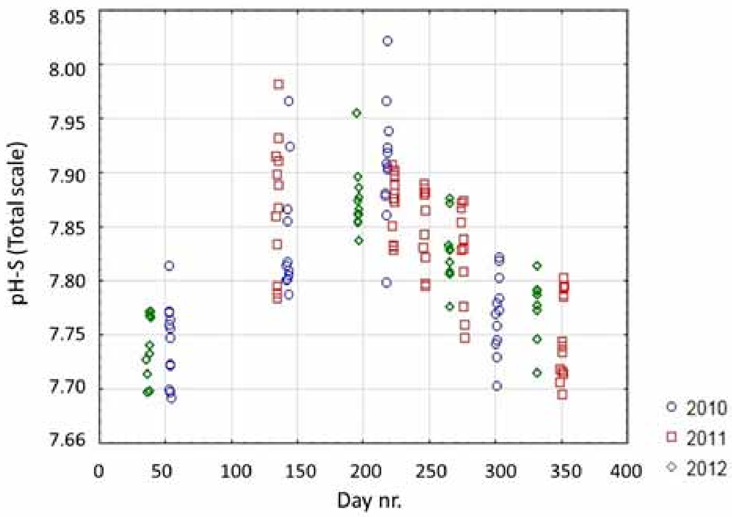

Fig. 2: pH measured at the transect Tromsø – Longyearbyen during the years 2010-2012.

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Poster 6
Presenter: Lisa A. Miller

Changes in the marine carbonate system of western Canadian Arctic: Patterns in a rescued data set

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A recently recovered and compiled set of inorganic carbon data collected in the Canadian Arctic since the 1970s has revealed substantial change, as well as variability, in the carbonate system of the Beaufort Sea and Canada Basin. While the role of this area as a net atmospheric carbon sink has been confirmed, high pCO_2 values in the upper halocline underscore the potential for CO_2 outgassing with increasing upwelling as sea ice retreats. In addition, increasing total inorganic carbon and decreasing alkalinity throughout the water column are decreasing $CaCO_3$ saturation states, and waters undersaturated in aragonite are now occurring regularly both in deep waters and in the upper halocline.

Poster 7
Presenter: Mamaeva E.V.

Study of biodiversity of total microbial community of sediments in Kara Sea shelf, Yenisey Bay and Gydan Bay

Mamaeva E.V.

LIN SB RAS, Irkutsk, Russia

Eurasian Arctic shelf is the largest shelf worldwide, the interest toward its study increases year by year. Due to exploration and development of hydrocarbon mines in Arctic basin, the studies of the participation of microbial communities in biogeochemical processes of Arctic seas ecosystems becomes of great importance.

The Kara Sea is a region with a harsh climate and a complex hydrological regime, deposits of oil and gas are found and developed in its subsoils. The territory of Kara Sea and of adjacent Yenisey Bay is crossed by Northern Sea Route which is of interest as an alternative itinerary of oil and gas transportation from Russian Arctic to other countries.

In autumn of 2009, studies of bottom sediments at 15 stations on the shelf of Kara Sea, Yenisey and Gydan Bays were performed during an expedition on board of the ship "Soviet Arctic". To study the biodiversity of microbial communities in bottom sediments using methods of molecular biology, we selected 8 stations with different mineralization of pore waters (from 0.1 to 31.7 g/l).

Due to studies using sequencing method by Senger of fragments of 16S rRNA genes in sediments of 5 stations, we revealed representatives of 13 phyla of *Bacteria* and *Archaea*. It is found out that in sediments with low mineralization (0.1 g/l), major part of representatives belongs to classes γ- and β- *Proteobacteria* playing an important role in carbon and nitrogen cycles within sub-Arctic deposits, able to acidify ammonium up to nitrite and to participate in sewage purification. In sediments with middle mineralization (8.1-8.9 g/l) bacteria of the class γ- *Proteobacteria*, as well as chemotrophic δ- *Proteobacteria* having a high level of similarity with unculturable sequences of microorganisms from freshwater and soil ecosystem dominated. In sediments with high mineralization (22.9-31.7 g/l), sequences of microorganisms characteristic for marine ecosystems dominated, major part of them manifested a high similarity with bacteria of the class γ-*Proteobacteria*. Nucleotide sequences of microorganisms of the phylum *Actinobacteria* were found in all the samples of total DNA and had a high level of similarity with bacteria of the genus *Rhodococcus* able to acidify high-molecular n-alkanes and organochlorine compounds.

The comparison of microbial communities of the areas studied has shown a high similarity level by diversity of taxonomic groups with other cold-water areas of Arctic and Antarctic.

The use of method of pyrosequencing of variable sites V1-V3 of 16S rRNA gene in this study allowed to characterize more thoroughly microbial communities of sediments (up to 34 phyla), to identify both dominant organisms and minor community compounds which can, however, play an important ecological role. Among microorganisms, besides ones revealed before, the representatives of *Verrucomicrobia* dominated by their abundance; they are widely distributed in soil, fresh water and are able to acidify methane at extremely low values of pH.

In sediments, in the areas of the shelf and Yenisey Bay, the representatives of the phylum *Crenarchaeota*, groups MG1 and MCG dominated among *Archaea*. Culturable organisms of the group MG1 are aerobic autotrophs acidifying ammonium up to nitrite, the group MCG is widely distributed in marine sediments. Only at one station, we have identified representatives of the phylum *Euryarchaeota* of an Archaea of the genus *Methanosaeta* (4.9%) participating in aceticlastic methanogenesis.

We have to notice that we revealed in natural microbial communities of sediments sequences of bacteria having a high similarity level with sequences of microorganisms revealed from areas polluted with hydrocarbons and heavy metals. To confirm the ability of microorganisms to participate in the acidification of different hydrocarbons, we have tested samples of total DNA for the presence of functional genes (*pmoA* and *alk*-3B) responsible for the degradation of methane and n-alkanes. Molecular biological analysis has allowed to obtain nucleotide sequences of fragments of the gene *pmoA* similar to unculturable representatives of aerobic methanotrophs from cold water sediments of Baltic Sea and Lake Baikal.

We have thus obtained a background, practically non-transformed pattern of the state of unpolluted Kara ecosystem which may be a background database at monitoring studies due to start of exploration of hydrocarbon raw material at marine shelf of Kara Sea.

The work is performed within the program of RAS Presidium, Project 20.7.

Poster 8
Presenter: Stefan Koenigstein

Advancing towards an end-to-end model of the impacts of ocean acidification and warming on Arctic Ocean ecosystem services: from effects on individual organisms to stakeholder integration

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The Arctic Ocean is expected to be among the first marine areas to be impacted by ocean acidification and warming (OAW), and while effects on individual organisms and potential shifts in species distribution have been identified, the overall impacts on ecosystems and the consequences for human societies are far from clear (Blackford, 2010; Fabry et al. 2008). Minor fluctuations in basic physical parameters can trigger dramatic and unexpected regime shifts in marine ecosystems (Hsieh et al. 2005), but impacts will be buffered by individual stress tolerance capacities and evolutionary adaptation of marine organisms.

In the Norwegian Sea and Barents Sea, potential impacts on ecosystem services include declining fisheries yield because of stock range shifts, decrease in carbon storage capacity caused by changes in primary production under a changing food web structure, loss of biodiversity caused by elevated physiological stress to marine organisms, and negative effects for the tourism sector by the change in abundance of whales and other top predators (Armstrong et al. 2012; Beaugrand & Kirby 2010; Cheung et al. 2010; Denman et al. 2011). These impacts on human societies can be mitigated by socio-economic adaptation and changes in ecosystem service use.

To advance our ecological understanding, improve projections about the adaptive capacity of the ecosystem and develop better management strategies, it is necessary to integrate experimental data into modeling studies and improve the assessment of uncertainty, adaptation, feedbacks and biogeographic shifts of species (Blackford 2010; Denman et al. 2011).

We present the concept of our ongoing work within the project BIOACID phase 2, combining ecological modeling with stakeholder participation to assess the impacts of OAW and corresponding adaptation options of the social-ecological system. We aim to reduce uncertainties about the effects of OAW across biological levels, by going beyond correlative studies and using mechanistic process knowledge from individual physiology and population ecology (Pörtner & Farrell 2008). Furthermore, expert knowledge and stakeholder input will be used to couple quantitative indicators to potential impacts on the provision of ecosystem services, especially fisheries yields.

A refined model of the analysis of OAW effects will integrate direct impacts of multiple stressors (increasing temperature, acidification, hypoxia) on fish stock recruitment (Pörtner 2010), using data of extensive laboratory and mesocosm experiments on physiological processes, being conducted with Atlantic cod and Polar cod within BIOACID 2. Spatial and temporal factors of habitat suitability and seasonal cycles as well as adaptation on the population level will be investigated by upscaling these physiological processes in an Individual-Based Model (IBM), projecting changes in cod populations, species interactions and distribution range shifts (Grimm 2005). Changes in primary production and food web interactions will be incorporated by coupling to physical ocean system models and models for lower trophic levels being parameterized within BIOACID2.

The impacts on societies will be evaluated by developing the model in interchange with external experts and stakeholder groups with socio-economic interests in the Norwegian and Barents Seas (fishing associations, governmental agencies, environmental organizations, research institutes, tourism sector, and others). This input is obtained by interviews, workshops and web surveys and serves to identify potentially affected processes and ecosystem services, evaluate their societal and economic relevance and inform all relevant stakeholders about the expected changes, including the level of uncertainty in their assessment.

Our approach will increase the understanding about the links between climate change scenarios and their socio-economic relevance and help to improve the communication of the impacts of ocean warming and acidification on fisheries and other ecosystem services. We strive to fill gaps between different existing models and advance towards an end-to-end ecosystem model which integrates knowledge on many levels and can be used to guide management decisions in an ecosystem-based approach (FAO 2007; Fulton 2010). By increasing the knowledge about the adaptive capacity in the ecosystem and employing the adaptive capacity of the socio-economic system, both can be combined to improve the resilience of the social-ecological system, develop realistic management strategies and enable a multi-level governance approach (Hughes et al. 2005).

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Poster 9

Presenter: M. Blais

Towards a green oasis in the Arctic Ocean? Trends in phytoplankton biomass and production over the Canadian Arctic Ocean

M. Blais, M. Gosselin and D. Dumont

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Due to global warming, the Arctic Ocean is currently experiencing an increase in both the extent of open water and the duration of the open water season. Using remote sensing, Arrigo & van Dijken (2011) showed that total annual primary production from 1998 to 2009 decreased in the Greenland Sea and increased in the Kara, Siberian and Chukchi sectors of the Arctic Ocean. No significant trends in net primary production were detected for Beaufort Sea and Baffin Bay. Field measurements conducted during the ArcticNet program allowed us to determine directly if any changes occurred in these two sectors, as well as in the Canadian Arctic Archipelago (CAA), a region not studied by Arrigo & van Dijken. Phytoplankton biomass and production in the euphotic zone were measured in Beaufort Sea during falls 2006-2011, in the CAA during late summers 2005-2011 and falls 2006-2011 and in Baffin Bay from 1999-2011. Phytoplankton chlorophyll *a* (chl *a*) biomass was measured by the fluorometric method while primary production was estimated from C-14 uptake during *in situ* simulated incubations.

In Beaufort Sea, chl *a* biomass and primary production did not exhibit year-to-year trends but were generally twice as high in the Amundsen Gulf (32 ± 20 mg chl *a* m^{-2} and 110 ± 68 mg C $m^{-2}d^{-1}$) compared with western Beaufort Sea (14 ± 11 mg chl *a* m^{-2} and 60 mg C m^{-2}). In summer 2011, the mean biomass over the CAA (140 mg chl *a* m^{-2}) was 7 times higher than in 2005 with highest values in the western sector of the CAA (i.e. Dease, Victoria and Franklin Straits). There was also a change in the size-structure since phytoplankton biomass was largely dominated by small cells (0.7-5 µm) in the western sector of CAA in 2005 and by large cells (> 5 µm) in 2011. In addition, mean primary production increased from 300 mg C m^{-2} d^{-1} in 2005 to 640 mg C m^{-2} d^{-1} in 2011. During fall, there was no year-to-year trend in the biomass throughout the CAA, but western Lancaster Sound peaked in 2011, with a maximum biomass value of 153 mg chl *a* m^{-2} and a production of 145 mg C m^{-2} d^{-1}. There was a drastic decrease in phytoplankton biomass on the Greenland side of the Baffin Bay polynya from 1999 to 2011. Average biomass diminished > 3 times from 1999 (104 ± 58 mg chl *a* m^{-2}) to 2010 (30 ± 19 mg chl *a* m^{-2}) and primary production decreased by about 4 times from 1999 (200 mg C m^{-2} d^{-1}) to 2010 (45 mg C m^{-2} d^{-1}). These results indicate that the production, biomass and size-structure of the phytoplankton community of the Canadian Arctic Ocean are changing rapidly but it seems that trends vary according to the region studied. Reasons behind this lack of uniformity throughout the Canadian Arctic Ocean will be investigated and discussed in this poster.

Poster 10
Presenter: EB Jewett

Ocean Acidification Impacts in the Arctic: Role of the NOAA OA Program

EB Jewett and JT Mathis
National Oceanographic and Atmospheric Administration

The combined effects of global climate change and ocean acidification on many ecosystems are being explored but overall less is known about the potential effects in the Arctic than other more accessible parts of the globe. The US, like other countries, has a strong interest in understanding the ramifications of these changes for marine food webs, commercial fisheries, protected species and human communities. It is imperative that countries work together to track the changing chemistry of the ocean and the impacts of that change. NOAA is deploying both fixed and underway OA observing systems in the Arctic including an upcoming deployment north of Iceland, in partnership with University of Iceland scientists, and several new moorings around the coast of Alaska. NOAA is leading efforts to coordinate ocean acidification observing in international and coastal waters. An important organizational meeting was held in June 2012 in Seattle which established some basic international ocean acidification observing requirements. Beyond ocean observing, NOAA is also involved in linking knowledge about the changing ocean chemistry to impacts on the living ecosystem. To this end, NOAA is using observing data to establish experimental conditions for laboratory research on the impacts of OA on arctic species including king crab, Walleye Pollock and Cod. A goal of this research is to use the experimental results to parameterize ecological forecasting models which are driven by high resolution biogeochemical models.

Poster 11
Presenter: Findlay H.S.

Effects of ocean acidification on late winter under-ice bacterial communities in the high Arctic

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The Polar Oceans naturally are sinks to CO_2 because CO_2 is more soluble in cold water. The Arctic Ocean is believed to be additionally at risk to accelerated ocean acidification because of the freshwater influence from sea ice and through river inputs. There is already evidence of low pH and undersaturated conditions in some areas of the Arctic Ocean, and during winter, microbial respiration acts to further elevate CO_2 in the surface waters under sea ice. Microbial processes are crucial for biogeochemical cycling and functioning of marine ecosystems. On a seasonal cycle, the addition or removal of CO_2 by microbes contributes significantly to the mediation of ocean acidification with respect to the ambient conditions, which can have implications for the timing and rate of acidification. To-date there are only ice-free or sub-Arctic OA experiments on microbial communities, with previous studies hinting at shifts in taxa dominance and/or diversity. In April 2010, the Catlin Arctic Survey provided an opportunity to conduct *in situ*, under-ice, ocean acidification experiments during late winter. Marine bacterial communities were collected from seawater under the sea ice off Elleff Ringnes Island, and were exposed to three pH treatments (8.1, 7.7 and 7.3) for 6 days. The taxonomy and biodiversity of communities from free (<3 µm) and particle-associated (>3 µm) fractions were investigated using amplicon tag high-throughput Illumina sequencing of a hypervariable region of the small ribosomal subunit (16S) gene. Here we discuss the effects of ocean acidification on shifts in community structure of under-ice Arctic water column bacteria, as well as changes in phylogenetic taxa dominance and diversity.

Poster 12
Presenter: Knut Yngve Børsheim

Diatom and flagellate responses to increasing pCO_2

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Phytoplankton was cultured at four different carefully controlled pCO_2 scenarios and otherwise identical conditions. Preliminary experiments showed that the growth rate of the diatom *Skeletonema costatum* showed a positive response to a slight elevation in pCO_2, but when pCO_2 was higher than 800 µatm, growth rates decreased drastically. Similar experiments using the naked flagellate *Rhodomonas balticum* showed that growth rate was reduced by increasing pCO_2 in all scenarios tested.

Poster 13
Presenter: Carin Andersson

Late Holocene size normalized foraminiferal shell weights from the eastern Norwegian Sea

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Anthropogenic carbon dioxide accumulation has lowered the calcium ion concentration and pH in the ocean. Published records of foraminiferal shell weight across glacial-interglacial transitions (Barker and Elderfield, 2002) suggest that the decrease in carbonate ion concentration going from the Last Glacial Maximum into the Holocene resulted in a decrease in foraminiferal shell weight. Recent studies suggest shell thinning and reduced calcification in modern foraminiferal specimens compared to shell weights recorded in older, Holocene sediments (de Moel et al., 2009; Moy et al., 2009). Here we investigate changes in foraminiferal shell weight over the past 200 years in two multicores (GS06-144-22 MC, 921 meter water depth, and HM01-128-04, 845 meter water depth) from the eastern Norwegian Sea. Specimens of the planktic foraminifer *Globigerina bulloides* in the size fractions 250-300 µm (both sites) and >150 µm (shallower site), where weighed and measured. The measured size normalized foraminiferal shell weights are relatively stable with little variability from the base of the two records until the early 20th century. At the deeper site, GS06-144-22 MC, the variability of the shell weight record increases between approximately 1910 AD til the top of the record, around 2005 AD, at the same time displaying a few samples with significantly lower shell weights compared to the earlier parts of the record. However, the average number of specimens decreases towards the top of the records, suggesting that the low number of specimens weighed in these samples introduces significant uncertainties to the shell weights measured at the top of the section. At the shallower site (HM01-128-04) specimens of planktic foraminifers from the size fraction >150 µm, display a trend of decreasing shell weight during the Industrial Era. This implies reduced calcification and/or dissolution at sediment-water interface possibly related to anthropogenic ocean acidification.

Poster 14
Presenter: Mikko Vihtakari

Ocean acidification may drive natural selection in marine bivalves

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Fertilization is an important and complex process in broadcast spawners, and its success depends on gametes being released into an environment favourable for the gametes to remain viable, meet, and fertilize. Fertilization depends not only on egg and sperm concentration, but also on sperm swimming speed, which affects the gamete encounter rate. Increased sperm swimming speed comes at the cost of reduced longevity, as germ cells have low energy reserves and low homeostatic control mechanisms. Changes in the physical environment, such as reduced pH, which may influence cellular and sub-cellular processes, are therefore expected to influence the fertilization process.

We tested the effect of increased pCO_2 on sperm motility and longevity of the mussel *Mytilus galloprovincialis*. Results showed a negative effect in response ratio (RR) of pCO_2 on sperm swimming speed (mean = 70%; 95% CI 58 – 87%) and sperm motility (mean = 74%; 61 – 88%) for a pH decrease of 0.2 units. We observed considerable variation in sperm quality among individuals in response to reduced pH, ranging from no response to a 47 % reduction in sperm swimming speed and 62 % reduction in sperm motility. The reduction in sperm motility was instantaneous with an increased negative effect within 10 h from fertilization, after which some individuals showed higher sperm motility in high pCO_2 treatment, but constantly lower sperm swimming speeds. A small proportion of sperm cells remained motile up to 45 h after spawning. Average motility after 25 hours was 19 % and 11 % for control and high pCO_2 treatments, respectively.

These results suggest that the sensitivity to OA is variable in *M. galloprovincialis*, and that variability increases with reduction in pH. As sperm quality is an important driver of fertilization, we predict that selection by OA will favour fertilization by sperm that are more OA-resistant, and, hence, that populations may be able to adapt to near-future OA, but with a potential reduction in genetic variability in the population.

Poster 15
Presenter: Maria C Williams

The pelagic record of ocean acidification

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The current rise in atmospheric pCO_2 and its subsequent dissolution in seawater is reducing the pH and $[CO_3^{2-}]$ of the oceans. Anthropogenic ocean acidification is widely expected to affect the ability of marine calcifying organisms to precipitate their $CaCO_3$ exoskeletons, though species-specific responses are documented. The aim of this study is to determine whether historical changes in seawater $[CO_3^{2-}]$ and pH since the beginning of industrialisation have already had discernible impacts on two groups of calcifying plankton: the coccolithophores and foraminifers in high latitude environments. We aim to document trends in both plankton groups at the same location to improve our understanding of response to ocean acidification in different species and morphotypes of plankton.

The focus of the study is a Holocene marine sediment core from the Erik Drift in the sub-polar North Atlantic and a multicore from Ormen Lange off the Norwegian coast dated to the 1700s. $^{230}Th_{xs}$ was measured to identify changes in sediment drift as a result of regional dynamic bottom water currents and hence redeposition of the coccolithophores and alteration of their historical record of calcification. Lateral sediment transport of fine sediments can be determined by normalising the activity of ^{230}Th in the sediments to its production rate in the water column. We present down core analysis of planktic foraminiferal size-normalised weights for both the industrial record and the natural variability throughout the Holocene.

Poster 16
Presenter: V. Sh. Shagapov

The mathematical model of process migration of the gas bubble accompanied by formation and dissociation of hydrate in the conditions of the World Ocean

V. Sh. Shagapov, A.S. Chiglintseva, A.A. Rusinov, B.I. Tazetdinov
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In the modern world there was the new problem connected with technogenic catastrophes - leakage of gas from wells in sea depths. Recent accident testifies to it in the Gulf of Mexico which led to serious ecological consequences. For elimination of similar accidents, the various oil and gas companies, and also leading scientists offered ideas, many of which didn't bring desirable result.

In this work the technological scheme and the corresponding mathematical model of process of formation of hydrate on a surface of metane bubbles which will allow to eliminate such accidents is offered. The course of rising of metane bubble to an ocean surface in areas of accidents, depending on depth, termobarichesky conditions for formation and dissociation of hydrate on a bubble surface is established [1, 2].

According to the technological scheme, to a place of leakage of gas, the metal design having a form of the cylinder in which there is a system of aluminum grids for collecting bubbles of hydrates falls and as a result will lead to full closing of a place of leakage of gas.

On the other hand, daily emissions of methane from a seabed, make a negative contribution to environment. For example, migration of metane bubble to a surface of the ocean is accompanied at first by formation of hydrate on a bubble, and at its further rising from depths less than 300 meters - dissociation of hydrate shell [2]. Further it leads to emission of methane in the atmosphere which makes an essential contribution to global warming.

In this work the constructed theory of process of migration of gas bubble in the conditions of formation and dissociation of hydrate will allow to solve effectively a problem of elimination of spontaneous emissions of methane from natural submarine sources, and also - areas of leakage of gas from submarine wells and pipelines.

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Poster 17
Presenter: Andrew S. Mount

Cellular Biomineralization and The Pacific Oyster Genome: Carbonate considerations and Shell Formation

Andrew S. Mount
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To fully understand and appreciate the consequences of ocean acidification to shell forming mollusks, a realistic cellular and molecular biology understanding about how these organisms actually construct their shells is necessary. With the advent of the Pacific oyster *Crassostrea gigas* genome it is now possible to do such investigations. Our previous work has shown that there are specialized cells that produce calcium carbonate crystals through an intracellular mechanism, a fact that was recently confirmed with the publication of the genomic study. This is a highly significant as it represents a major shift towards intracellular compartmentation of biomineralization, and away from an extracellular model in which the organism is dependent upon the provision of exogenous carbonate from an acidifying marine environment. The cellular implications of intracellular carbonate driven biomineralization will be discussed.

Poster 18
Presenter: Oleg M. Pokrovsky

A coherency between slow oscillations in the marine biota concentration in Bering Sea and the North Pacific SST

Oleg M. Pokrovsky
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The aim of this study was to investigate physical and chemical mechanisms, which explain an impact of changes occurred in the climate system on the marina biota included the fishery, and the biomass zooplankton. Another issue is related to investigation of corresponding causal links in the North Pacific subarctic area. The sea surface temperature (SST) series in the North Pacific described by the Pacific Decadal Oscillation (PDO) have been analyzed for last century. It was shown that there is a close coherency between PDO and the ice extent time series in Chukchi Sea by means of new decadal smoothing technique and cross-wavelet spectrum analysis. The 60-70 year oscillation components were revealed in both series. Similar comparison was carried out for the SST and ice extent series in eastern part of Bering Sea. Previous research (Mantua et al. 1997) has shown that salmon runs in Alaska tend to be out of phase and that these fluctuations are linked to climate cycles. In particular, the PDO played important role in dramatic shifts in the climate of the North Pacific around 1949 and 1976, with accompanying re-organizations of the marine ecosystem (Bond et al, 2003). All marina ecosystem data were acquired from the site of PMEL-NOAA. Interannual-interdecadal variations in zooplankton biomass, chlorophyll concentration and physical environment in the Bering Sea were investigated. It was confirmed that warmer temperatures over the shelf would result in northward shift of shelf ecosystems in eastern part of Bering Sea. In particular, the ice extent influences on the timing of the phytoplankton bloom. Analysis of zooplankton biomass series for 1965-97 shown that there is also its evident coherency to the SST regimes in the North Pacific. Delayed influence of the El-Nino inter-annual oscillations on the zooplankton biomass was found. Decreasing of the seal populations in St. Pauli and St. George islands since the middle of the seventies might be explained by strong shift in the PDO series. Statistical analysis of above linkages permitted to evaluate corresponding significance levels and confidential interval values, which might be useful for further modeling studies.

Poster 19
Presenter: Are Olsen

Global carbon datasets for OA research

Are Olsen [1,2], Robert M. Key [3], Dorothee Bakker [4], Benjamin Pfeil [1,2], Toste Tanhua [5], Steven Hankin [6], Siv K. Lauvset [1,2], Mario Hoppema [7], Maciej Telszewski [8], Masao Ishii [9], Alexander Kozyr [10], Christopher Sabine [6], Reiner Steinfeldt [11], Emil Jeansson [12,2], Sara Jutterström [14] and all other SOCAT and GLODAPv2 contributors

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In response to the emerging challenges following the changes of ocean chemistry due to its uptake of anthropogenic carbon (aka Ocean Acidification), increased access to observations of marine inorganic carbon chemistry and its variations and trends are called for by scientists, stakeholders and policymakers worldwide. Two major synthesis efforts by the global ocean carbon community as organized through IOCCP, SOLAS and IMBER are already in place. These aim to assemble and distribute such data for the entire global ocean on a routine basis. The

Surface CO_2 Atlas (SOCAT, Pfeil et al., 2013) project assembled and released a near-complete set of surface ocean CO_2 partial pressure (pCO_2) data in 2011. It holds 6.3 million quality controlled surface CO_2 data from the global oceans and coastal seas, spanning four decades. Version 2 of SOCAT, which extends SOCAT by 4 years will be released at the International Carbon Dioxide Conference, which will take place in June 2013, and will contain some 10 million pCO_2 data. Plans for version 3 is already in place.

GLODAPv2 is the follow-up version of the Global Ocean Data Analysis Project, which released its seminal data product in 2004 (Key et al., 2004), and will include the data in the subsequent CARINA (Tanhua et al., 2010) and PACIFICA data products, in addition to data from approximately 100 new cruises. This product focus on interior ocean carbon and will contain the data collected at approximately 600 cruises from the early '70s until 2012. It is the intention of the community to let GLODAP evolve into a routine effort releasing updated data products at a regular schedule in the future.

Here we will present the database contents, the assembly and QC procedures and discuss their usefulness for OA research.

Poster 20
Presenter: JIANG Fan

Arctic climate change and Arctic standard

WU Aina, GAO Zhanke, JIANG Fan
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The Arctic climate change is considered one of the most sensitive in the world. Global warming is intensifying in 21st century, polar ice is melting rapidly, the Arctic has been changed to anther climate, which will cause a direct impact on the other parts of the northern hemisphere and also some indirect effects to the whole world. Global warming, environment of the polar and global change are facing new and significant changes and uncertainty, the rapid changes in the Arctic has significant impact on our climate and environment already, and may make the future of our industrial and agricultural production and the sustainable development of national economy faced with new and greater impact. So increase comprehensive survey of the Arctic to the environment and global change research, and effectively improve our ability to address climate change demand immediate attention. Therefore, we should use plan and step by step to master the Arctic environment thorough comprehensive survey and evaluation of the Arctic sea. And also get the first-hand information about the Arctic environment changes and their responses to global change and feedback, reveals the Arctic in the global climate environmental change in the status and role in enhancing our capacity to address climate change, and explore the Arctic and environmental protection measures to safeguard the interests and achieve the sustainable development of the cause of China's polar regions to enhance the level of polar research, polar scientific expedition to meet national strategic planning for the future of the bipolar the region's strategic needs. However, all these efforts need to carry out the standard norms and guidance.

Strengthen the standard of comprehensive survey of the Arctic environment and technical regulations, mainly focus on the marine seabed sediment investigation and evaluation, inspection and evaluation of marine geophysics, marine chemistry and carbon flux inspection and evaluation of marine biological and ecological survey and evaluation, and through the Arctic the standard-setting comprehensive scientific investigation, in order to provide a basis and technical specifications for comprehensive survey of the Arctic environment to meet the demand for comprehensive survey of the Arctic environment. And improve inspection efficiency and technical level, guide, regulate, promote and protect the comprehensive survey work on Arctic environment.

Poster 21
Presenter: Isabel Seifert

Economic consequences of ocean acidification – estimates for Norway

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Ocean acidification is expected to change the chemical and biological conditions in the oceans. This will also have an impact on ecosystem goods and services, provided by the oceans and exploited by humans. The aim of this paper is to assess and quantify the economic impacts of ocean acidification in Norway on a time scale of 100 years. An assemblage of data on biological and chemical effects is used to design impact scenarios, but points also out the current knowledge gaps. For the provisioning service of "fisheries and aquaculture" a market-based approach and for the regulating service of "carbon storage" a damage-cost approach are used to estimate the economic consequences. Depending on the used data and the economic settings as e.g. discount rate we estimated for fisheries and aquaculture negative as well as positive effects in the range of several Million NOK (2010). For carbon storage by the Norwegian sea the estimated negative impacts are one order of magnitude higher than for fisheries and aquaculture. Beside these results, the study highlights again the urgent need for further interdisciplinary research in the field of ocean acidification.

Poster 22
Presenter: Lisa L. Robbins

Comparison of aragonite saturation states, air-sea CO_2 fluxes, and relation to sea-ice cover in different ecosystems in the Canada Basin

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Models project that the Arctic Ocean will become undersaturated with respect to carbonate minerals such as aragonite ($CaCO_3$) in the next decade. Recent field results indicate parts of the Arctic Ocean are already undersaturated in late summer months when ice melt is at its greatest extent. Causal factors of this undersaturation in the Arctic Ocean have recently been explored and likely involve feedbacks with environmental changes in the region, such as increasing atmospheric pCO_2, changes in surface temperature, increased freshwater inputs from terrestrial runoff and reduction of the extent, thickness, and duration of sea-ice cover. Arctic Ocean marine ecosystems and associated organisms are projected to respond to these rapidly changing conditions.

In order to establish a baseline that fills critical information gaps concerning saturation state and the variability of Arctic carbon flux, during August and September of 2010, 2011 and 2013 we collected high-resolution measurements of pCO_2, pH, total dissolved inorganic carbon (DIC), total alkalinity (TA), and carbonate ($[CO_3^{-2}]$) from the Canada Basin, up to 88.45'N. We supplemented carbonate chemical data with ecosystem-wide stable oxygen isotope data and biological data to demonstrate the effects of increased freshwater content derived predominantly from sea-ice melt (f_{SIM}). These data document dramatic differences in aragonite undersaturation and pCO_2 over the different surface waters of the Canada and Makarov Basins in the Western Arctic Ocean. Within the basin, the increased freshwater from multiyear sea ice melt reduces dissolved calcium and carbonate concentrations and thereby decreases aragonite saturation states.

The fraction of sea ice melt in surface water at the most northern extent of our study sites, Makarov Basin and Sever Spur regions (on the eastern side of the Canada Basin), was significantly lower (f_{SIM}: 0.031 and 0.080, respectively) than at the southern stations in the Beaufort Sea (f_{SIM}: 0.094) and Canada Basin (f_{SIM}: 0.110). Concomitantly, there were significant differences in aragonite saturation states ($\Omega_{aragonite}$) between the Makarov Basin (median $\Omega_{aragonite}$: 1.61) and Sever Spur (median: $\Omega_{aragonite}$ 1.51) regions and Beaufort Sea (median $\Omega_{aragonite}$: 1.28) and Canada Basin (median: $\Omega_{aragonite}$ 1.09). The sea ice melt water had significant negative correlations with net productivity of photoautotrophic or heterotrophic communities, as measured by Chl-*a* and bacterial productivity, respectively. Comparison of the three years of high-spatial-resolution carbon and oxygen isotopic data with data from the Western Arctic obtained at a similar time of year (August) in 1997 shows a significant decline in saturation state over the fifteen year time span.

High-resolution data facilitate more accurate modeling of future undersaturation trends in areas such as the Makarov Basin where summer ice-free conditions are predicted in the near term. While the effects attributed to multi-year sea-ice melt may diminish, increased runoff and direct precipitation may cause the observed trends to continue.

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