Project information

Project title
ECOAN-WP1 Current and future ocean acidification state OA1 OASTATE
Year
2015
Project leader
Agneta Fransson (NPI) and Andrew King (NIVA)
Participants

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Flagship
Ocean Acidification
Funding Source

Fram Centre (KLD) and NFD and internal funding at participants home institutes

Summary of Results

- Inter-annual variability of the carbonate system was observed due to freshwater supply from glacial drainage water in a Spitsbergen fjord. Data (NPI/IMR) showed that calcium carbonate saturation and OA state decreased near the glacier front due to freshwater. However, carbonate ions and increased total alkalinity from the carbonate-rich bedrock mitigated parts of the negative effect on OA of freshwater. In addition, the potential for uptake of atmospheric CO_2 increased near the glacier front.

- In 2015, unique automatic surface/under ice pCO_2 measurements were obtained onboard RV Lance (NPI in collaboration with IMR and UiB) in the Arctic Ocean during the N-ICE 2015 expeditions from winter to spring. Preliminary pCO_2 data was undersaturated (below atmospheric pCO_2) under the sea ice at all times, in all areas.

- Unique winter-to-spring data of the carbonate system was sampled by NPI/IMR North of Svalbard (80 to 83°N) from January to June 2015 during the N-ICE 2015 drift expedition.

- In 2015 NIVA has newly combined data on surface water pCO_2 and pH using different ships along the Norwegian coast into the Arctic and the Barents Sea.

- Water column sampling and chemical analyses by IMR and NPI from several parts of the Arctic 2011-2015, resulted in a unique data set covering ocean acidification data and tracers for studies on the effect of freshwater on OA state, using the Fram Strait annual cruises, MOSJ cruises and along A-TWAIN mooring section continued and N-ICE 2015.

- Five years of carbonate system data (NPI/IMR) in the Fram Strait shows interannual variability in the ocean acidification state (pH and $CaCO_3$ aragonite saturation; Figure 4). In 2011, there was more river runoff and less Pacific water of the Arctic outflow (to the west) than in 2012. Both years showed brine content in the western Fram Strait. The highest brine content was observed in 2011 in the western part. The lowest pH and aragonite saturation in Fram Strait were found in the upper halocline (20 to 200m) outflow waters (to the west), coinciding with high brine content (negative sea-ice melt) and high pCO_2. Possible mechanisms for the origins of the low pH layer could be due brine transport of CO_2 as a result of sea-ice dynamics in the Arctic Ocean, coinciding with higher content of organic matter (CDOM).

Field activity:

N-ICE 2015, January to June

SI ARCTIC 19 Aug to 7 September 2015

MOSJ, 20 to 30 July 2015

UiT/CAGE calcifiers and OA and paleo April and July 2015. NPI, IMR collaboration

Svalbard fjord expedition UNIS AGF352 (educational and sampling unique data) 600 samples in West Spitsbergen fjords

Tempelfjorden field work in April. NPI, IMR, UNIS collaboration

Fram Strait (PhD student onboard), September

Mareano August (added carbonate chemistry studies in areas with new coral reefs in

For the Management

- In 2015, unique automatic surface/under ice pCO_2 measurements were obtained onboard RV Lance (NPI in collaboration with IMR and UiB) in the Arctic Ocean during the N-ICE 2015 expeditions from winter to spring. Preliminary pCO_2 data was undersaturated (below atmospheric pCO_2) under the sea ice at all times, in all areas.

- Unique seasonal data of the carbonate system in the water column under the sea ice, from winter to spring, north of Svalbard (between 80 and 83°N) was obtained during the N-ICE 2015 expedition.

- Large and successful sampling campaign in several parts of the Arctic, resulting in a unique

data set covering ocean acidification data and tracers for studies on the effect of freshwater on OA state. Time series (2011-2015) in Arctic for OA studies in the water column during Fram Strait annual cruises, MOSJ cruises and along A-TWAIN mooring section continued. Winter data of the carbonate system was sampled North of Svalbard in January 2014 in collaboration with CarbonBridge project and during N-ICE in 2015. Five years of carbonate system data in the Fram Strait shows variability in pH and $CaCO_3$ (aragonite) saturation between the two years with more river runoff and Pacific water of the Arctic outflow (to the west) and less sea-ice melt in 2012 than in 2011. Higher content of inorganic carbon in the inflow of Atlantic water in 2012. These studies direct to large interannual variability which motivates further field sampling to establish and continue the first OA time series in the Arctic.
The clear seasonal changes in the seawater carbonate chemistry from the Tromsø-Svalbard transect emphasizes the need for long time-series in order to separate a climate trend from the seasonal variation.

- Investigations of OA state in Svalbard fjords in winter and summer and the relation to abundance and shell structure of the aragonite forming pteropod L.helicina motivate further investigations.

Published Results/Planned Publications

Peer-viewed publications

Fransson A, M Chierici, P Dodd, M Granskog, C Stedmon, E Hansen. Feedbacks of freshwater and primary production on the carbonate system, air-sea CO_2 fluxes and ocean acidification state in the Nioghalvfjerdsfjorden and Djimphna Sound, NE Greenland. Submitted.

Fransson A., M. Chierici, H. Findlay, H. Hop, S. Kristiansen, A. Wold. Seasonal of change ocean acidification state in Kongsfjorden, with implications for calcifying organisms. Submitted, 2015.

Yasunaka S, Murata A, Watanabe E, Chierici M, Fransson A, van Heuven S, Hoppema M, Ishii M,

Johannessen, Kosugi N, Lauvset S.K, Mathis J.T et al. Mapping of the air–sea CO_2 flux in the Arctic Ocean and its surrounding seas: Basin-wide distribution and seasonal to interannual variability. Submitted 2015.

Fransson A. M. Chierici, D. Nomura, M. A. Granskog, S. Kristiansen, T. Martma, G. Nehrke. Effect of glacial drainage water on the CO_2 system and ocean acidification state in an Arctic tidewater-glacier fjord during two contrasting years. Journal of Geophysical Research: Oceans DOI 10.1002/2014JC01032.

Holding, J.M., C.M. Duarte., M. Sanz-Martín., E. Mesa., J. M. Arietta., M. Chierici., I.E. Hendriks., L. S. García-Corral., A. Regaudie-de-Gioux., A. Delgado., M. Reigstad., P. Wassmann., S. Agustí. 2015. Temperature-dependence of CO2-enhanced primary production in the European Arctic Ocean, Nature Climate Change, doi:10.1038/nclimate2768

Torstensson, A., M. Hedblom., M. Mattsdotter Björk., M. Chierici., A. Wulff. 2015. Long-term acclimation to elevated pCO2 alters carbon metabolism and reduces growth in the Antarctic sea ice diatom Nitzschia lecointei, Proceedings of the Royal Society B, 282 20151513; DOI: 10.1098/rspb.2015.1513

Torstensson, A., J. Dinasquet, M. Chierici, A. Fransson, L. Riemann, A. Wulff. 2015. Physicochemical control of bacterial and protest community composition and diversity in Antarctic sea ice, Environmental Microbiology, DOI: 10.1111/1462-2920.12865

Publications (reports)

Chierici, M., I. Skjelvan., R. Bellerby., M.Norli., L. Lunde Fonnes., H. Lødemel Hodal., K.Y. Børsheim., K. S. Lauvset., T. Johannessen., K. Sørensen., E. Yakushev. 2015. Overvåking av havforsuring i norske farvann, Rapport, Miljødirektoratet

Expertise/advice:

Advice "Biological effect indicators for OA", 17 September 2015, Miljødirektoratet, Oslo

ICES-OSPAR SGOA (M. Chierici)

Manuscript in preparation

Chierici, M., A. Fransson, M. Granskog, P. Dodd, E. Hansen. The ocean acidification state and interannual variability in Fram Strait. In preparation.

Fransson A., Chierici, M., Granskog, P. Dodd, C. Stedmon, E. Hansen. Influence of freshwater Arctic Ocean outflow for the ocean acidification state. In preparation.

Dodd P., E. Hansen, M. Granskog, A. Fransson, M. Chierici, C. Stedmon, Precipitation in the Arctic Ocean outflow quantified with concurrent $\delta^{18}O$ and A_T measurements. In preparation.

Chierici et al. Variability of CO_2 flux, carbon transport and ocean acidification state in Polar waters on the East Greenland shelf.

Conference/workshop proceedings: International conferences and workshops such as

OA workshop on Calanus and socioeconomic modeling, 24 November 2015 at NORUT.

N-ICE mini works shops at NPI every week, Sept to Dec 2015. Presentation (Fransson) of gases and carbonate system.

N-ICE workshop, 17-19 November 2015, Malangen, Norway.

Arctic Frontiers, Tromsø 2015-11-30

Gordon Research Conference GRC Polar Marine Sciences, Il Ciocco, Italy (posters: Tempelfjorden + 79N fjord/Djimphna), 24 March 2015,

FRAM Science Days, 10-11 th Nov 2015 FRAM Science Days (main organizer + contributed w 2 poster presentations)

Synoptic Arctic Survey (SAS) workshop, 22-26 June 2015, Norwegian embassy, Washington DC, USA (NPI and IMR contributed, UiB organized)

IGS International Symposium on Ocean-Ice sheet Interaction, Cambridge, August 2015 (Fransson, 2 posters)

Norske havforskermøte, October 2015, Bodø, Norway (2 poster presentations)

Telephone conference with UiT/CAGE about pteropod and water-chemistry sampling, 26 November 2015

Meeting UiT/CAGE /T. Rasmussen, K. Zamelyak) about collaborational project on ocean acidification state and pteropods, 4 December 2015

<u>Conference abstracts 2015:</u>

Fransson A, Chierici M, Nomura D, Granskog MA, Kristiansen S, Martma T, Nehrke G. Effect of glacial drainage water on the CO_2 system and ocean acidification state in an Arctic tidewater-glacier fjord during two contrasting years. Abstract for poster presentation at GRC conference, Italy, March, 2015

Fransson A, Chierici M, Nomura D, Granskog MA, Kristiansen S, Martma T, Nehrke G. Effect of glacial drainage water on the CO_2 system and ocean acidification state in an Arctic tidewater-glacier fjord during two contrasting years. Abstract for poster presentation at FRAM Science days, Tromsø,

November 2015

Fransson A, Chierici M, Nomura D, Granskog MA, Kristiansen S, Martma T, Nehrke G. Effect of glacial drainage water on the CO_2 system and ocean acidification state in an Arctic tidewater-glacier fjord during two contrasting years. Abstract for poster presentation at IGS Ocean-Ice sheet Interaction, Cambridge, UK, August 2015

Fransson A, Chierici M, Dodd P, Granskog MA, Stedmon C, Hansen E. Feedbacks of glacial water and primary production on the carbonate system and ocean acidification state in the Djimphna Sound fjord system, NE Greenland. Abstract for poster presentation at IGS Ocean-Ice sheet Interaction, Cambridge, UK, August 2015

Fransson A, Chierici M, Dodd P, Granskog MA, Stedmon C, Hansen E. Feedbacks of glacial water and primary production on the carbonate system and ocean acidification state in the Djimphna Sound fjord system, NE Greenland. Abstract for poster presentation at FRAM Science days, Tromsø, November 2015

Fransson A, Chierici M, Dodd P, Granskog MA, Stedmon C, Hansen E. Feedbacks of glacial water and primary production on the carbonate system and ocean acidification state in the Djimphna Sound fjord system, NE Greenland. Abstract for poster presentation at Norske Havforskermøte, October 2015

Nomura D, B. Delille, G.S. Dieckmann, M.A. Granskog, J.-L. Tison, K.M. Meiners, A. Fransson, K.I. Ohshima, T. Tamura. Mid-winter surveys of sea ice biogeochemistry in polar oceans. Abstract for

Goldschmidt Conference, Prague, August 2015

Chierici M, Fransson A, Dodd P, Granskog MA, Stedmon C, Hansen E. Influence of glacial water and primary production on the carbonate system and ocean acidification state in the NE Greenland fjord system. Abstract for poster presentation at GRC Polar Marine Sciences, Il Ciocco, Italy, March 2015

GRC conference, Italy, March, 2015

IGS Cambridge, UK, August 2015

FRAM Science Days, Tromsø, Norway 2015

Authors/presenter: Agneta Fransson, Melissa Chierici, Daiki Nomura, Mats A. Granskog, Svein Kristiansen, Tõnu Martma, Gernot Nerkhe

Title: Effect of glacial drainage water on the CO_2 system and ocean acidification state in an Arctic tidewater-glacier fjord during two contrasting years.

In order to investigate the effect of glacial water on the CO2 system in the fjord, we studied the variability of the total alkalinity (AT), total dissolved inorganic carbon (CT), dissolved inorganic nutrients, oxygen isotopic ratio (□18O), and freshwater fractions from the glacier front to the outer Tempelfjorden on Spitsbergen in winter 2012 (January, March and April) and 2013 (April) and summer/fall 2013 (September). The two contrasting years clearly showed that the influence of freshwater, mixing and haline convection affected the chemical and physical characteristics of the fjord. The seasonal variability showed the lowest calcium carbonate saturation state (□) and pH values in March 2012 coinciding with the highest freshwater fractions. The highest □ and pH were found in September 2013, mostly due to CO2 uptake during primary production. Overall, we found that increased freshwater supply decreased □, pH and AT. On the other hand, we observed higher AT relative to salinity in the freshwater end-member in the mild and rainy winter of 2012 (1142 µmol kg-1) compared to AT in 2013 (526 µmol kg-1). Observations of calcite and dolomite crystals in the glacial ice suggested supply of carbonate-rich glacial drainage water to the fjord. This implies that winters with a large amount of glacial drainage water partly provide a lessening of further ocean acidification, which will also affect the air-sea CO2 exchange.

IGS Cambridge, UK, August 2015

FRAM Science Days, Tromsø, Norway 2015

Norske Havforskermøte, Oct 2015

Authors: Fransson A, Chierici M, Dodd P, Granskog MA, Stedmon C, Hansen E.

Title: Feedbacks of glacial water and primary production on the carbonate system and ocean acidification state in the Djimphna Sound fjord system, NE Greenland.

We investigated the processes affecting the carbonate system and the ocean acidification (OA) state (i.e. pH and calcium carbonate saturation,□) in summer 2012 in the Dijmphna Sound and Nioghalvfjerdsfjorden (79°N). This fjord system is located in one of the main outlets of the large northeast Greenland ice stream, which feeds melt water from the Greenland Ice Sheet (GrIS) to the fjord and adjacent east Greenland shelf. The tracer relationships between salinity, total alkalinity (AT) and oxygen isotopic ratios (δ18O), indicate three layers in the fjord system and the adjacent shelf; a fresh surface water, cold waters originate from the Arctic (Polar water) and warm and salty water from modified Atlantic water. We found that biological CO2 uptake and freshwater addition were major drivers for the variability of the carbonate system and ocean acidification state in the surface waters. In the upper 10 meters, freshening due to glacial water contributed with decreased ΩAr between 0.2 to 0.4 whereas CO2 uptake due to phytoplankton production resulted in an increase of about 0.35 extending from the glacier front to the central part of the fjord system. The increase in Ωdue to biological CO2 uptake thus alleviates/mitigate some of the □ decrease due to increased freshwater supply, which has implications for the effect of the observed freshening of the Arctic Ocean and changes in the processes affecting Arctic biological primary production.

Communicated Results

Conference contributions see previous chapter

Chierici, M, Monitoring OA in Norwegian and Arctic waters, oral presentation at IMR Annual Meeting 4-8 January 2015, Bergen, Norway

Workshops

N-ICE workshop, Malangen, Norway

FRAM Science Days, Tromsø, Norway

Public/Media presentations

Chierici, M. Ocean Acidification and effects in Northern waters, Oral presentation for Chinese media delegation, Fram Centre, 21 Sept, 2015

Data base

Provided data for the data bases SOCAT, GLODAP and MOSJ, NMD, CDIAC

Interdisciplinary Cooperation

The inter-disciplinary cooperation between chemical, biologists and physical oceanographers offers a wide range of knowledge and contribution to the project, especially regarding the study of the water masses and Arctic outflow in Fram Strait**.** The carbonate system and ocean acidification part are added from 2011. Only positive aspects. Unique possibility to understand the underlying mechanisms if this work can continue.

During N-ICE 2015 expedition, widely inter-disciplinary collaboration between chemical and physical oceanographers and biologists offers a wide range of knowledge and contribution to the project. The project also offers highly international and national collaboration.

Collaboration with biologists, paleoceanographers and marine geologists on an expedition organized by the University of Tromsø on historical records of carbonate system and the evolution of $CaCO_3$ forming organisms. Collaboration with Prof. Tine Rasmussen at University of Tromsø- the Arctic

university (UiT/CAGE).

Disciplines involved in the project

Physical oceanography (water column studies such as stratification, water mass, freshwater)

Chemical oceanography (carbonate system and OA state in water column)

Marine Geology (isotopic ratios in calcifying organisms, pH and climate records)

We have collaboration with biological oceanographers for nutrients availability in the water column and as tracers (UiT).

Collaboration with biologists (e.g. NPI) on MOSJ and N-ICE expeditions on zooplankton and phytoplankton in comparison to OAstate.

Crystal structures and $CaCO_3$ minerals in sea ice and water column (AWI)

Methane in seawater (AWI)

Budget in accordance to results

The project has been successfull in producing both peer review publications and new unique data in the Arctic Ocean. I 2015 we extended collaboration both nationally and internationally. The project could not be accomplished satifactory without Fram Centre funding. The project rely on significant in-kind contributions and use of infrastructure such as ships and research platforms (field stations and laboratories).

Could results from the project be subject for any commercial utilization

No

Conclusions

Interannual vribaility in the carbonate chemistry is likely larger than anticipated

Freshwater supply has large impact on progressing ocean acidification

Polar waters lowest aragonite satiration state and lowest pH

Unique winter to sping data on under ice pCO2 and OA state was obtained during N-ICE