

Project information

Keywords

Arctic Ocean acidification

Project title

Establishing the Current status of ocean acidification in the Norwegian Arctic - OAstate

Year

2016

Project leader

Agneta Fransson (NPI) and Andrew King (NIVA)

Geographical localization of the research project in decimal degrees (max 5 per project, ex. 70,662°N and 23,707°E)

83 N 19E, 79N 15W til 10E,

Participants

Melissa Chierici (IMR), Helene Hodal Lødemel (IMR)

Mats Granskog (NPI), Kai Sørensen (NIVA), Marit Norli (NIVA)

Flagship

Ocean Acidification

Funding Source

KLD, NFD and internal NIVA

Fram Centre funding/KLD is the original and in kind contribution in brackets include funding from NMD (Nærings og Fiskeridepartementet)

This is the sum for the projects OA^{STATE}, OA^{DRIVERS} and OA^{pteropod}

Summary of Results

- Inter-annual and seasonal variability of the carbonate chemistry 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.

- In 2015-2016, unique automatic surface water/under ice $p\text{CO}_2$ measurements were obtained onboard RV Lance (NPI in collaboration with IMR) in the Arctic Ocean during the N-ICE 2015 and Fram Strait 2016 expeditions. Preliminary $p\text{CO}_2$ data was undersaturated (below atmospheric $p\text{CO}_2$) in the surface water and under the sea ice at all times, in all areas.
- Unique winter-to-spring data of the carbonate chemistry from north of Svalbard (80 to 83°N) from January to June 2015 during the N-ICE 2015 drift expedition, was analysed, compiled, interpreted and presented by NPI/IMR.
- In 2016 NIVA has combined data on surface water $p\text{CO}_2$ and pH using the shipmounted sensor on different ships along the Norwegian coast into the Arctic and the Barents Sea. Published the first paper on the new pH system and worked on the $p\text{CO}_2$ data for publications.
- Water column sampling and chemical analyses by IMR and NPI from several parts of the Arctic 2011-2016, 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, A-TWAIN mooring section, SI Arctic and N-ICE 2015.
- Six years of carbonate chemistry data (NPI/IMR) in the Fram Strait shows interannual variability in the ocean acidification state (pH and CaCO_3 aragonite saturation). 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 $p\text{CO}_2$. 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
- $p\text{CO}_2$ sensor deployed in Kongsfjorden for seasonal autonomous measurements of $p\text{CO}_2$ (NPI/IMR)

Field activity:

Fram Strait, August-September 2016

SI ARCTIC September 2016

MOSJ, July 2016

UiT/CAGE calcifiers and OA and paleo April, June and July 2016. NPI, IMR collaboration

STeP expedition in Storfjorden collaboration with UiT and French research group

Kongsfjorden field work in April 2016

Master and PhD-students involved in the project

Ylva Ericson, PhD student UNIS

Elina Nystedt, MSc

Siri Ofstad, UiT

For the Management

- In 2015-2016, unique automatic surface/under ice $f\text{CO}_2$ measurements onboard RV Lance (NPI in collaboration with IMR) in the Arctic Ocean during the N-ICE 2015, Fram Strait 2016 and MOSJ 2016 expeditions from winter to spring. $f\text{CO}_2$ under the sea ice was undersaturated (below atmospheric $f\text{CO}_2$) at all times, in all areas during N-ICE2015.
- Variability of the carbonate chemistry due to freshwater such as glacial drainage water in Spitsbergen fjords. Data showed that calcium carbonate saturation and OA state decreased near the glacier front due to freshwater.

- Unique seasonal data of the carbonate chemistry in the water column under the sea ice, from winter to spring, north of Svalbard (between 80 and 83°N) obtained during the N-ICE 2015, processed and published in 2016.
- 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 (2011-2016) in Arctic for OA studies in the water column during Fram Strait annual cruises, MOSJ, A-TWAIN and SI-Arctic cruises continued. Winter data of the carbonate chemistry was sampled North of Svalbard in January 2014-2015 in collaboration with CarbonBridge project and N-ICE in 2015. Six years of carbonate chemistry data in the Fram Strait shows variability in pH and CaCO₃ (aragonite) saturation between the years with more river runoff and Pacific water of the Arctic outflow (to the west). 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.

- Need for writing scientific publications on Arctic data collected during the six years.
- 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 in 2016

Fransson A, M. Chierici, H. Hop, H. Findlay, S. Kristiansen, A. Wold (2016). Late winter-to- summer change in ocean acidification state in Kongsfjorden, with implications for calcifying organisms. *Polar Biol.* , 1-17, DOI:10.1007/s00300-016-1955-5 special issue on Kongsfjorden

Reggiani, E.R., A.L. King, M. Norli, P. Jaccard, K. Sørensen, R.G.J. Bellerby. (2016). FerryBox-assisted monitoring of mixed layer pH in the Norwegian Coastal Current. *Journal of Marine Systems* Volume 162, October 2016, Pages 29–36

Yasunaka S, A. Murata, E. Watanabe, C. Chierici, A. Fransson et al. (2016) Mapping of the air-sea CO₂ flux in the Arctic Ocean and adjacent seas: Basin-wide distribution and seasonal to interannual variability, *Polar Science*, 1-12, 2016

Stiasny, M. H., F. Mittermayer, F., Sswat, M., Voss, R., Jutfelt, F., Chierici, M., Puvanendran, V., Mortensen, A., Reusch, T.B.H., and C. Clemmesen., 2016 Ocean Acidification Effects on Atlantic Cod Larval Survival and Recruitment to the Fished Population doi: PONE-D-16-03859R1

Fransson A., M. Chierici, I. Skjelvan, A. Olsen, P. Assmy, A. Peterson, G. Spreen and B. Ward (2016) Under-ice water fCO₂, sea-air CO₂ fluxes and effect of storm events and an under-ice phytoplankton bloom on during the winter-spring transition in the high Arctic Ocean. submitted to JGR, N-ICE special issue

Assmy P. M. Fernandez-Mendez, P. Duarte, A. Meyer (A.Fransson) et al. (2016). Leads in Arctic pack ice enable early phytoplankton blooms below snow covered sea ice. In review, *Scientific Report*

Haug, T., Bogstad, B., Chierici, M., Gjøsæter, H., Hallfredsson, E., Høines, Å., Hoel, A.H., Ingvaldsen,

R.B., Jørgensen, L.L., Knutsen, T., Loeng, H., Naustvoll, L.J., Røttingen, I., and K. Sunnanå., Future harvest of marine biological resources on the Northeast Atlantic side of the Arctic Ocean: a review of possibilities and constraints, in review, *Frontiers in Marine Science*

Thor P., A. Bailey, C. Halsband, E. Guscchelli, E. Gorokhova, A. Fransson, Effects of future pH on the metabolic response to feeding in copepodite larvae of the Arctic copepod *Calanus glacialis*, in review, *PlosOne*

Manno C. (M. Chierici, A. Fransson) et al., Shelled pteropods in peril: assessing vulnerability in a high CO₂ ocean. In review, *Earth Science Review*, 2016.

Fransson A, M Chierici, P Dodd, M Granskog, C Stedmon, E Hansen. Feedbacks of freshwater and primary production on the carbonate system, air-sea CO₂ fluxes and ocean acidification state in the Djimphna Sound, NE Greenland. To be submitted, 2016.

Nomura D, M. A. Granskog, A. Fransson, M. Chierici, A. Silyakova, B. Delille, ,L. Cohen, S.R. Hudson, K.I. Ohshima and G.S. Dieckmann (2016) CO₂ dynamics over young and snow-covered Arctic sea ice in winter and spring submitted to *JGR N-ICE* special issue.

Opstad, I., P. Dalpadado., A. Mangor Jensen, E. Speerfeldt., A. Fransson., M. Chierici Effects of elevated pCO₂ on northern krill species *Thysanoessa inermis*: survival, moulting, growth, grazing and respiration. Submitted to *Journal of Plankton Research*

Iglikowska, A., Bełdowski, J., Chełchowski, M. Chierici, M., Kędra, M., Przytarska, J., Sowa, A., and P. Kukliński., Chemical composition of two mineralogically contrasting Arctic bivalves' shells and their relationships to environmental variables, accepted, Marine Pollution Bulletin, MPB-D-16-00973R1

Publications (reports)

Chierici, M., I. Skjelvan., R. Bellerby., M.Norli., L. Lunde Fønnes., H. Lødemel Hodal., K.Y. Børshem., K. S. Lauvset., T. Johannessen., K. Sørensen., E. Yakushev. 2016. Overvåking av havforsuring i norske farvann I 2015, Rapport, Miljødirektoratet

Public report

Fransson A., P. Thor, A. Bailey, M. Chierici (2016) Ocean acidification in Kongsfjorden, Fram Forum, 2016

de Steur L, P.A. Dodd, S. Gerland, M. Granskog, A. Fransson, G. Spreen, M. Chierici (2016) Highlights from the Fram Strait Arctic Outflow Observatory, Fram Forum, 2016

Related papers

Bakker DCE, (M. Chierici, A. Fransson) et al., (2016) A multi-decade record of high-quality fCO₂ data in version 3 of the Surface Ocean CO₂ Atlas (SOCAT). Earth Syst. Sci. Data. doi:10.5194/essd-2016-15, 2016

Torstensson A. A. Fransson, A. Wulff, M. Chierici (2016). Pack ice algal PSII performance is controlled by light, salinity and dissolved inorganic in the Amundsen and Ross Sea. Submitted to Scientific Report.

Fripiat F et al. including A. Fransson. Macro-nutrient concentrations in Antarctic pack ice: overall patterns and overlooked processes, Resubmitted after revisions, Elementa, 2016

Expertise/advice:

Advice “Biological effect indicators for OA - pteropods”, October 2016, Skype meeting with Miljødirektoratet

ICESWKACIDUSE, (M. Chierici)

Arctic Ocean Assessment-AMAP vs 2

ICOS (Integrated Carbon Observing System) expert meeting in Bergen, February 2016 (A. Fransson).

BEPSII expert meeting in Paris 2016 (A. Fransson presentation of N-ICE2015)

BEPSII expert meeting in Amsterdam 2016 (A. Fransson presentation)

Planned publications/in preparation

Fransson A. et al., Seasonal impact of sea-ice processes and freshwater on calcium carbonate saturation in the Svalbard fjords. In prep.

Fransson A. et al., Export of sea-ice inorganic carbon from Arctic Ocean: implication for ocean acidification. In prep.

Conferences/workshops abstracts 2016

Assmy, Chierici, Fransson, Hop, Granskog et al. Leads in Arctic pack ice enable early phytoplankton blooms below snow covered sea ice. Norske Havforskernes Forening møte, Bergen, Nov 2016

Fransson A. M. Chierici, D. Nomura, M. A. Granskog, S. Kristiansen, T. Martma, G.

Nehrke. Effect of glacial drainage water on the CO₂ system and ocean acidification state in an Arctic tidewater-glacier fjord during two contrasting years (Arctic Frontiers, Tromsø, 2016)

Fransson A., M. Chierici, M. Granskog, D. Nomura, P. Assmy, M. Fernandez-Mendez, P.

Dodd, A. Meyer, A. Rösel, A. Silyakova, H. Steen. Winter-to-spring evolution of Arctic

Ocean acidification state in under-ice water and effect of sea-ice dynamics during N-ICE2015 ice drift project, (OA Ocean in High CO₂ world, Hobart, 2016)

Chierici, M., Fransson, et al., Advancement of OA monitoring in AO and Norwegian waters, 4th Ocean in a high CO₂-world, 2-7th of May 2016, Hobart, AUS oral presentation

Chierici., M., A. Fransson, H. Hop., A. Wold., H. Findlay., 2016. Seasonal variability of OA state and implications for calcifiers in Kongsfjorden, oral presentation 4th Ocean in a high CO₂-world, 2-7th of May 2016, Hobart, AUS oral presentation

Fransson A. M. Chierici, D. Nomura, M. A. Granskog, S. Kristiansen, T. Martma, G.

Nehrke. Wintertime sea-ice carbonate system and influence of sea-ice processes and glacial freshwater discharge during two contrasting years in a West-Spitsbergen fjord. (ESSAS, March, Yokohama, Japan + Goldschmidt, Yokohama, Japan, June 2016)

Granskog MA., P. Assmy, P. Duarte, M. Fernandez-Mendez, A. Fransson, H. Kauko, L.M.Olsen, M. Chierici, D. Nomura, C. J. Mundy, H. Steen. Observations of Arctic sea ice and ocean biogeochemistry in the new thinner ice era: the N-ICE2015 drift ice expedition (N- ICE biogeochemistry Goldschmidt, June, Japan 2016)

Assmy, P., A. Fransson., M. Chierici., A. Wold., H. Hop., et al., Phytoplankton spring bloom beneath heavily snow-covered arctic sea ice during the N-ICE2015. 2016. Abstract accepted in Session CR5.4/OS1.24 Marginal ice zone processes, EGU2016-17254

Dodd, P., A., Fransson., M. Chierici., M. Granskog., C. Stedmon et al., Changes in the Composition of the Fram Strait Freshwater Outflow. 2016. abstract accepted in Session IE4.3/OS1.2 Changes in the Arctic Ocean and Sea Ice System: Observations, Models and Perspectives EGU2016-14193

Yasunaka, S., Akihiko Murata., Eiji Watanabe., Melissa Chierici., Agneta Fransson., Steven van Heuven., Mario Hoppema., Masao Ishii., Truls Johannessen., Naohiro Kosugi., Siv K. Lauvset., Jeremy T. Mathis., Shigeto Nishino., Abdirahman M. Omar., Are Olsen.,

Daisuke Sasano., Taro Takahashi., Rik Wanninkhof. 2016. Mapping of the air–sea CO₂ flux in the Arctic Ocean and its surrounding seas: Basin-wide distribution and seasonal to interannual variability, abstract for the NIPR Polar Symposium, GRENE-Arctic project, 3-4 March 2016, Tokyo, Japan.

Hoppe, C.J.M., L. Wischnewski, M. Nielsdóttir, E. Leu, I. Salter, D. Scholz, A C Kvenvik,

M. Chierici, A. Fransson, and B. Rost. Carbonate Chemistry measurements in the Arctic– activities by FRAM and FAABulous. 2016. Poster for the “Ocean Carbonate chemistry measurements workshop, Southampton, UK, 3-5 February 2016.

OA flagship meetings, 27 March, 30 Oct. 2016, NPI, IMR, NIVA, Akvaplan-Niva, UiT, NINA, NORUT.

Fram Dagen, 4 posters, 10th November 2016, Tromsø

N-ICE mini works shops at NPI every week, Sept to Dec 2016.

N-ICE workshop, November 2016, Tromsø, Norway.

Norske havforskermøte, November 2016, Bergen, Norway (oral presentation Assmy et al)

ICOS expert meeting in Bergen (A. Fransson)

BEPSII expert meeting in Paris (A. Fransson presentation)

BEPSII expert meeting in Amsterdam (A. Fransson presentation)

Time series workshop, CAGE and UiT, Tromsø, 10-11th Nov 2016.

Communicated Results

Conferences/workshops 2016

ESSAS 1 poster, March, Yokohama, Japan

The 4th Ocean in a High CO₂ World, 1 poster (Fransson) and 2 oral (Chierici), 2-6th May, Hobart, Tasmania 2016

Goldschmidt poster (Fransson) and oral (Granskog) Yokohama, Japan, June 2016

Fram Dagen (4 poster presentations)

N-ICE workshop, November 2016, Tromsø, Norway

Open section meeting presentation (Fransson) October 2016

N-ICE mini workshops, NPI, every week, Sept to Dec 2016

Norske havforsker møte, November 2016, Bergen, Norway (oral presentation Assmy et al)

Arctic Frontier (poster Fransson), January 2016

BEPSII meeting in Paris (Fransson presentation)

BEPSII meeting in Amsterdam (Fransson presentation)

ICOS (Fransson)

Fransson A., P. Thor, A. Bailey, M. Chierici (2016) Ocean acidification in Kongsfjorden, Fram Forum, 2016

de Steur L, P.A. Dodd, S. Gerland, M. Granskog, A. Fransson, G. Spreen, M. Chierici (2016) Highlights from the Fram Strait Arctic Outflow Observatory, Fram Forum, 2016

Global Ocean Acidification Network-GOA-ON, Hobart, 8-10th May 2016, Australia

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 chemistry and ocean acidification were added from 2011. Only positive aspects. Unique possibility to understand the underlying mechanisms if this work can continue.

During N-ICE2015 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, SI-Arctic 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, Germany and IOPAN, Poland)

Methane in seawater (AWI)

Budget in accordance to results

The project funding has been fundamental to implement this project. It supports the hiring of A. Fransson (project PI), and partly supports the high costs associated with Arctic field work and extensive sample analysis required in the work. Part of the field expenses are covered with in-kind contribution and not taken into account here. It has also supported to acquire

state-of-the-art instrument that are needed for measurements outside the time in the field. However, the funds have to be supplemented by significant external and in-kind contributions (IMR, NPI, NIVA) for successfulness.

Fram Centre funding boosted joint effort to continue the 1st Arctic time-series sections north of Svalbard with other Flagship and between institutes/universities.

Fram Centre funds have supported:

Salary to A. Fransson (Project PI – 6 months)

Salary for M. Chierici (IMR) and Helene H Lødemel (IMR)

Field work and travel to cruises/workshops/conferences

Chemical analyses

Field equipment (partly)

Supported attendance to conference and workshops and advisory committees.

Could results from the project be subject for any commercial utilization

No

Conclusions

- In 2015-2016, unique automatic surface/under ice $f\text{CO}_2$ measurements onboard RV Lance (NPI in collaboration with IMR) in the Arctic Ocean during the N-ICE 2015, Fram Strait 2016 and MOSJ 2016 expeditions from winter to spring. $f\text{CO}_2$ under the sea ice was undersaturated (below atmospheric $f\text{CO}_2$) at all times, in all areas during N-ICE2015.
- Continuation of the inter-annual study of the physical and chemical properties of water

masses, and outflow of Arctic water in the Fram Strait. Add chemical sensors such as CO₂ and pH sensors on the moorings in future (Fram Strait/NPI and Svalbard fjords/NPI-IMR, MOSJ/NPI and SI-Arctic/IMR).

- CAGE (UiT) collaboration on historical carbonate chemistry and palaeoceanography in Nordic seas

- New chemical sensors such as CO₂ sensors to put on moorings are needed to obtain information on the seasonal variability of the carbonate system and ocean acidification.
- New CO₂ sensor was deployed in Kongsfjorden in 2016 for autonomous measurements
- The new pCO₂ and pH sensors that has been developed have been implemented and in operation along with the Ferrybox system on MS Norbjørn.
- Successful measurements of surface water fCO₂ during all seasons using automated fCO₂ instrument installed on RV Lance, 2014-2016