

## Project information

### Project title

Establishing the Current status of ocean acidification in the Norwegian Arctic - OAstate (ECOAN WP1)

### Year

2017

### 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)

70°N-90°N; 20°W to 35°E, Arctic Ocean/Nansen Basin, Svalbard fjords, Fram Strait, East Greenland Current, Barents Sea.

### Participants

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

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

### Flagship

Ocean Acidification

### Funding Source

Fram Centre Ocean Acidification Flagship

## Summary of Results

- Several Svalbard fjords are affected by glacial water runoff, which affects the fjord chemistry, decreasing pH and the calcium carbonate saturation state (NPI/IMR)
- Seven years of carbonate chemistry data (IMR/NPI) in Fram Strait reveals the seasonal and inter-annual variability of pH, pCO<sub>2</sub> and OA state in the Arctic outflow water in East Greenland Current. Preliminary results from the 7 years of data shows increased temperature, salinity, total dissolved inorganic carbon (DIC) and total alkalinity (AT), and decreased pH. However, this is too short time to derive a full trend analysis. 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<sub>2</sub>. Possible mechanisms for the origins of the low pH layer could be due brine transport of CO<sub>2</sub> as a result of sea-ice dynamics in the Arctic Ocean
- Unique automatic surface water/under ice pCO<sub>2</sub> measurements were obtained in 2015-2017, onboard RV Lance (NPI/IMR) in the Arctic Ocean, Fram Strait and around Svalbard. Results from pCO<sub>2</sub> data showed that the surface water was undersaturated

(below atmospheric  $p\text{CO}_2$ ) at all times, in all areas, including sea ice covered areas.

- Results from the 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 expedition were published in peer-viewed journal and presented at conferences. First winter-time  $f\text{CO}_2$  data under the ice published in the Nansen Basin/Svalbard slopes.
- Large ocean  $\text{CO}_2$  uptake in winter due to strong winds and open leads in winter ice cover (N-ICE)
- Ocean  $f\text{CO}_2$  largely decreased in spring due to large under-ice bloom (N-ICE)
- In 2016-2017, NIVA has continued development of shipboard pH and  $p\text{CO}_2$  sensors on MS Norbjørn as part of the underway FerryBox system that makes observations in the Barents Sea opening between Tromsø and Longyearbyen. The sensor data has been compared to DIC and AT measured on discrete samples taken on the FerryBox system (4x per year). Published papers on the new pH system and  $p\text{CO}_2$  data is being prepared for publications.
- Water column sampling and chemical analyses by IMR and NPI from several parts of the Arctic 2011-2017, 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.
- The  $\text{CO}_2$  sensor deployed in July 2016 in Kongsfjorden was recovered in July 2017. One-year data of  $p\text{CO}_2$  showed seasonal variability at 25 meters water depth (NPI/IMR)

Field activity:

Fram Strait expedition with RV Lance, August-September 2017

SI ARCTIC September 2017

MOSJ/KF, RV Lance, July 2017

Glacial front/TW-ICE, RV Lance and helicopter sampling, July 2017

UiT/CAGE calcifiers and OA and paleo 2017. NPI, IMR collaboration

STeP expedition in Storfjorden, collaboration with French group (B. Lansard), 2017

Kongsfjorden field work in April, May and July 2017

VanMijenfjorden seasonal ice-water field study, March-May

Barents Sea opening field work, February/May/August/November 2017

Master and PhD-students involved in the project

Several master students (UiT, UGOT, UNIS) and PhD students are involved in the project, mainly during field activity. The PhD student Y. Ericsson (UNIS) is indirectly involved in the project (M. Chierici co-advisor).

M. Chierici and A. Fransson involved in UNIS master/PhD course "Chemical oceanography" where field work and lab experiments involve the students.

For the Management

- In 2015-2017, 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 2016/2017 and MOSJ/KF 2016/2017 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.
- Variability of the carbonate chemistry due to freshwater such as glacial drainage water in Svalbard fjords. Data showed that calcium carbonate saturation, pH 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 2017.

- 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 (2011-2017) in Arctic for OA studies in the water column during Fram Strait annual cruises, MOSJ/KF, 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. Seven years of carbonate chemistry data in the Fram Strait shows variability in pH and CaCO<sub>3</sub> (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 seven years and compare with other Arctic studies, resulting in pan-Arctic studies.
- 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 of methods and the use as indicator for ocean acidification.

Published Results/Planned Publications

#### Peer-viewed publications in 2017

Fransson A., M. Chierici, I. Skjelvan, A. Olsen, P. Assmy, A. Peterson, G. Spreen and B. Ward (2017) Effect of sea-ice and biogeochemical processes and storms on under-ice water fCO<sub>2</sub> during the winter-spring transition in the high Arctic Ocean: implications for sea-air CO<sub>2</sub> fluxes. JGR- Oceans, N-ICE

special issue, doi: 10.1002/2016JC012478.

Assmy P. M. Fernandez-Mendez, P. Duarte, A. Meyer, M. Chierici, A. Fransson, M. Granskog et al. (2017). Leads in Arctic pack ice enable early phytoplankton blooms below snow covered sea ice. Scientific Report, 7:40850, DOI: 10.1038/srep40850.

Manno C. (M. Chierici, A. Fransson) et al., Shelled pteropods in peril: assessing vulnerability in a high CO<sub>2</sub> ocean (2017). Earth Science Review, doi: 10.1016/j.earscirev.2017.04.005.

Haug, T., Bogstad, B., Chierici, M., Gjørseter, H., Hallfredsson, E., Høines, Å.S., Hoel, A.H., Ingvaldsen, R.B., Jørgensen, L.J., Knutsen, T., Loeng, H., Naustvoll, L.J., Røttingen, I., Sunnanå, K., 2017. Future harvest of living resources in the Arctic Ocean north of the Nordic and Barents Seas: a review of possibilities and constrain. Fisheries Research, 188, 38-57.

Iglikowska, A., Bełdowski, J., Chełchowski, M. Chierici, M., Kędra, M., Przytarska, J., Sowa, A., and P. Kukliński (2017)., Chemical composition of two mineralogically contrasting Arctic bivalves' shells and their relationships to environmental variables, in press, Marine Pollution Bulletin, MPB-D-16-00973R1

Thor P., A. Bailey, C. Halsband, E. Guscelli, E. Gorokhov, A. Fransson (2016) Seawater pH predicted for the year 2100 affects the metabolic response to feeding in copepodites of the Arctic copepod *Calanus Glacialis*. PLoS ONE 11(12): e0168735. doi:10.1371/journal.pone.0168735.

Yasunaka S. (M. Chierici, A. Fransson) et al Arctic Ocean CO<sub>2</sub> uptake: an improved multi-year

estimate of the air–sea CO<sub>2</sub> flux incorporating chlorophyll-a concentrations, submitted to Biogeosciences, 2017

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. CO<sub>2</sub> dynamics over young and snow-covered Arctic sea ice in winter and spring, Submitted to JGR, 2017.

Opstad, I., P. Dalpadado., A. Mangor Jensen, E. Speerfeldt., A. Fransson., M. Chierici Effects of elevated pCO<sub>2</sub> on northern krill species *Thysanoessa inermis*: survival, moulting, growth, grazing and respiration. Submitted to Journal of Plankton Research, 2017

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<sub>2</sub> fluxes and ocean acidification state in the Djimphna Sound, NE Greenland. To be submitted, 2017.

Chierici M., A. Fransson, M. Granskog et al . Ocean acidification in Arctic outflow waters. In progress 2017

#### Publications (books)

Chierici M. and A. Fransson (2017) Chemical oceanography at the edge – focus on carbonate chemistry, book chapter in Wassmann et al., At the edge, in press.

#### Publications (reports)

Chierici, M., I. Skjelvan., R. Bellerby., M.Norli., L. Lunde Fonnes., H. Lødemel Hodal., K.Y. Børshem., K. S. Lauvset., T. Johannessen., K. Sørensen., E. Yakushev. 2017. Overvåking av havforsuring i norske farvann I 2017, Rapport, Miljødirektoratet

Renner A., P. Dodd, A. Fransson. MOSJ status report: Assessment of the marine climate system around Svalbard and Jan Mayen, in review, 2017

#### Public report

Pteropod research presented in Forskning.no Havforsuring påvirker skallet til vingesneglen, (Fransson NPI/Chierici IMR)

#### Related papers

Fripiat F et al. including A. Fransson (2017). Macro-nutrient concentrations in Antarctic pack ice: overall patterns and overlooked processes, Elementa, doi.org/10.1525/elementa.217.

Torstensson A. A. Fransson, A. Wulff, K. Currie, M. Chierici (2017). Pack ice algal PSII performance is controlled by light, salinity and dissolved inorganic in the Amundsen and Ross Sea. Submitted to Scientific Report.

#### Expertise/advice:

“Biological effect indicators and OA”, Miljødirektoratet Fagdag om havforsuring, Miljødirektoratet, Oslo, 2017 (Fransson/Chierici)

Marine Protected Areas (MPA) workshop in Helsinki, Finland, 2017 (advice OA, A. Fransson)

ICOS (Integrated Carbon Observing System) expert meeting in Bergen, 2017 (A. Fransson).

BEPSII expert meeting in San Diego/La Jolla, USA 2017 (A. Fransson/m. Chierici poster presentations)

BEPSII expert meeting in Amsterdam 2017 (A. Fransson)

Planned publications/in preparation

Fransson A. et al., Seasonal impact of sea-ice processes and freshwater on calcium carbonate saturation in the Svalbard fjords. Submit in 2017

Kotowich M., B. Delille, A. Fransson, M. Chierici, M. Granskog et al. Nitrous oxide in Arctic sea ice and water from winter to spring, N-ICE. To submit to JGR 2017.

Siljakova A., M. Granskog, A. Fransson, M. Chierici et al., Seasonal variability in methane in Arctic sea ice and water, N-ICE. To submit to JGR 2017.

Hendry K.R, (A. Fransson, M. Chierici, P.A. Dodd) et al., Spatiotemporal variability of barium in Arctic sea-ice and seawater. To submit JGR 2017.

Conferences/workshops abstracts in 2017



Fransson Agneta, Melissa Chierici, Ingunn Skjelvan, Are Olsen, Philipp Assmy, Algot K. Peterson, Gunnar Spreen, Brian Ward. Effects of sea-ice and biogeochemical processes and storms on under-ice water  $f\text{CO}_2$  from winter to spring in the high Arctic Ocean: Implications for sea-air  $\text{CO}_2$  fluxes. Abstract submitted to the Ocean Science Meeting, Portland, USA, 2018.

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. Abstract submitted to the Polar2018 conference, Davvos, Switzerland, 2018.

Chierici M., A. Fransson, M. Granskog, P. Dodd et al. Ocean acidification in Arctic outflow water. Abstract submitted to the Polar2018 conference, Davvos, Switzerland, 2018.

Fransson Agneta, Melissa Chierici, Ingunn Skjelvan, Are Olsen, Philipp Assmy, Algot K. Peterson, Gunnar Spreen, Brian Ward. Effects of sea-ice and biogeochemical processes and storms on under-ice water  $f\text{CO}_2$  from winter to spring in the high Arctic Ocean: Implications for sea-air  $\text{CO}_2$  fluxes. Abstract submitted to the Polar2018 conference, Davvos, Switzerland, 2018.

Fransson Agneta, Melissa Chierici, Ingunn Skjelvan, Are Olsen, Philipp Assmy, Algot K. Peterson, Gunnar Spreen, Brian Ward. Effects of sea-ice and biogeochemical processes and storms on under-ice water  $f\text{CO}_2$  from winter to spring in the high Arctic Ocean: Implications for sea-air  $\text{CO}_2$  fluxes. Abstract submitted to the Arctic Frontier Conference, Tromsø, Norway 2018.

Fransson A. M. Chierici, H. Hop, S. Kristiansen, A. Wold. Seasonal variability of the carbonate chemistry and ocean acidification state in Kongsfjorden: Implications for calcifying organisms. Abstract accepted for the Svalbard Science Forum, Oslo, Norway 2018

Assmy P, et al. (A. Fransson) Emerging physical and biological properties in a new Arctic ice regime. Abstract submitted to the Ocean Science Meeting, Portland, USA, 2018.

Assmy P, et al. (A. Fransson) Emerging physical and biological properties in a new Arctic ice regime. Abstract submitted to the Arctic Frontier Conference, Tromsø, Norway 2018.

Chierici Melissa., Agneta Fransson, Ylva Ericsson, Eva Falck, Svein Kristiansen. Influence of glacial water on carbonate chemistry and biogeochemical processes in Svalbard fjords with different characteristics. Abstract submitted to the Arctic Frontier Conference, Tromsø, Norway 2018.

Chierici Melissa., Agneta Fransson, Ylva Ericsson, Eva Falck, Svein Kristiansen. Influence of glacial water on carbonate chemistry and biogeochemical processes in Svalbard fjords with different characteristics. Abstract submitted to the Ocean Science Meeting, Portland, USA, 2018.

Itkin (Fransson, Chierici, Granskog) et al. Impact of winter storms in a thinner Arctic sea-ice regime, Abstract submitted to Ocean Science meeting, 2018.

Itkin (Fransson, Chierici, Granskog) et al. Impact of winter storms in a thinner Arctic sea-ice regime, Abstract submitted to Arctic Frontier, 2018. Oral presentation.

Ericson Ylva, Falck Eva, Chierici Melissa, Fransson Agneta. Temporal variability in surface water pCO<sub>2</sub> in Adventfjorden (West Spitsbergen): physical and biogeochemical drivers. Abstract submitted to the Arctic Frontier Conference, Tromsø, Norway 2018.

Ericson Ylva, Falck Eva, Chierici Melissa, Fransson Agneta. Temporal variability in surface water pCO<sub>2</sub> in Adventfjorden (West Spitsbergen): physical and biogeochemical drivers. Abstract submitted to the Ocean Science Meeting, Portland, USA, 2018.

Nomura D. et al. (A. Fransson). ECV-Ice: Measuring Essential Climate Variables in Sea Ice–SCOR Working Group 152. Abstract submitted to ASAR conference, Tokyo, Japan, 2018.

Nomura D. et al. (A. Fransson). ECV-Ice: Measuring Essential Climate Variables in Sea Ice–SCOR Working Group 152. Abstract submitted to Ocean Science meeting, 2018.

Silyakova A., M. Kotovitch, B. Delille, D. Nomura, A. Fransson, M. Chierici, M. Granskog. Methane chemistry in the ice covered Arctic Ocean from winter to summer time. Abstract submitted to the Ocean Science Meeting, Portland, USA, 2018.

Fransson A. Sea-ice carbonate chemistry and influence of biogeochemical processes and glacial water in Spitsbergen fjords. ESSAS conference, Tromsø, Norway, 2017, oral, invited

Fransson A., M. Chierici, M. P. Assmy, P. Dodd, M. Fernandez-Mendez, M. Granskog, A. Meyer, D. Nomura, A. Rösel, A. Silyakova, H. Steen. Winter-to-spring evolution of Arctic Ocean acidification state in under-ice water and effect of sea-ice processes during N-ICE2015 ice drift project. Abstract to ESSAS, Tromsø, Norway, 2017.

Fransson A. M. Chierici, H. Hop, S. Kristiansen, A. Wold. Seasonal variability of the carbonate chemistry and ocean acidification state in Kongsfjorden: Implications for calcifying organisms. Abstract to ESSAS, Tromsø, Norway 2017.

Fransson A., M. Chierici, M. P. Assmy, P. Dodd, M. Fernandez-Mendez, M. Granskog, A. Meyer, D. Nomura, A. Rösel, A. Silyakova, H. Steen. Winter-to-spring evolution of Arctic Ocean acidification state in under-ice water and effect of sea-ice processes during N-ICE2015 ice drift project. Abstract to the Gordon Ocean Research Conference, Ventura, USA, May, 2017.

Chierici M. Fransson A., H. Hop, S. Kristiansen, A. Wold. Late-winter to summer change of the carbonate chemistry and ocean acidification state in Kongsfjorden: Implications for calcifying organisms. Abstract to the Gordon Ocean Research Conference, Ventura, USA, May, 2017.

Fransson A., M. Chierici, M. P. Assmy, P. Dodd, M. Fernandez-Mendez, M. Granskog, A. Meyer, D. Nomura, A. Rösel, A. Silyakova, H. Steen. Winter-to-spring evolution of Arctic Ocean acidification state in under-ice water and effect of sea-ice processes during N-ICE2015 ice drift project. Abstract to Arctic Frontier 2017.

Fransson A. M. Chierici, H. Hop, S. Kristiansen, A. Wold. Seasonal variability of the carbonate chemistry and ocean acidification state in Kongsfjorden: Implications for calcifying organisms. Abstract to the Arctic Frontier, Tromsø, Norway 2017.

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

Nehrke. Effect of glacial drainage water on the CO<sub>2</sub> system and ocean acidification state in an Arctic tidewater-glacier fjord during two contrasting years (Arctic Frontiers, Tromsø, 2017)

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, (poster at Gordon Research Conference, Marine Science, Ventura, USA, 2017)

Chierici, M., Fransson, et al., Advancement of OA monitoring in AO and Norwegian waters, (poster at Gordon Research Conference, Marine Science, Ventura, USA, 2017)

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. (Gordon Research Conference, Marine Science, Ventura, USA, 2017)

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 (2017)

King A.L., Norli, M., Ledang, A.B., Jaccard, P., Reggiani, E., Marty, S., Bellerby, R.G.J., Golmen, L., Sørensen, K. Current and emerging in situ biogeochemical observations using the FerryBox platform in Subarctic and Arctic Norwegian Waters. (8<sup>th</sup> EuroGOOS International Conference, Bergen, Norway, 2017)

Norli, M., King, A.L., Reggiani, E., Yakushev, E., Jaccard, P., Bellerby, R.G.J., Sørensen, K. Monitoring Ocean Acidification using FerryBox. (8<sup>th</sup> FerryBox workshop, Oslo, Norway, 2017)

King, A.L., Norli, M., Jaccard, P., Sørensen, K. Status of FerryBox lines in Norway and beyond. (8<sup>th</sup> FerryBox workshop, Oslo, Norway, 2017)

Kristiansen, T., Sørensen, K., King, A.L. Automated ocean observations from FerryBoxes. (Developing Arctic Observing Systems – the role of Norwegian institutions, Oslo, Norway, 2017)

Sørensen K., et al. Ocean acidification research at NIVA: observations, modeling, and experimentation. (Miljødirektoratet Fagdag om havforsuring, Oslo, Norway, 2017)

King A.L., et al. Ocean acidification SIS (OASIS): 2013-2016 Results and findings. (NIVA SIS Day, Oslo, Norway, 2017)

OA flagship meetings, 2017, NPI, IMR, NIVA, Akvaplan-Niva, UiT, NINA, NORUT.

N-ICE mini works shops at NPI every week, Jan to Dec 2017.

N-ICE workshop, November 2017, Tromsø, Norway.

ICOS expert meeting in Bergen, and skype meetings, 2017 (A. Fransson)

BEPSII expert meeting in San Diego/La Jolla (A. Fransson and M. Chierici, poster presentations), 2017

BEPSII expert meeting in Amsterdam, 2017 (A. Fransson presentation)

Communicated Results

Conferences/workshops 2017 (see publications and abstracts above)

ESSAS posters and oral presentation (A. Fransson invited), June, Tromsø, Norway

Gordon Research Conference, Marine Science, Ventura, USA, poster presentations (Fransson and Chierici)

N-ICE workshop, November 2017, Tromsø, Norway

Open section meeting presentation (Fransson), 2017

Arctic Frontier (poster Fransson), January 2017

BEPSII meeting in San Diego, 2017 (Fransson and Chierici poster presentations)

BEPSII meeting in Amsterdam, 2017 (Fransson presentation)

ICOS meetings, 2017 (Fransson)

8<sup>th</sup> EuroGOOS International Conference in Bergen, Norway, October 2017 (King)

8<sup>th</sup> FerryBox workshop, Oslo, Norway, October 2017 (King, Sørensen, Norli)

Developing Arctic Observing Systems – the role of Norwegian institutions, Oslo, Norway, November 2017 (Kristiansen, Sørensen, King)

Miljødirektoratet Fagdag om havforsuring, Oslo, Norway, September 2017 (Sørensen)

NIVA SIS Day, Oslo, Norway, September 2017 (King)

#### 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, the annual Fram Strait and MOSJ/KF expeditions, 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<sub>3</sub> 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/KF, SI-Arctic and N-ICE expeditions on zooplankton and phytoplankton in comparison to OAstate.

Crystal structures and CaCO<sub>3</sub> 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 partly 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 1<sup>st</sup> 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 – 8 months including OA drivers)

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

Salary for M. Norli (NIVA) and A. King (NIVA)

Field work and travel to cruises/workshops/conferences

Chemical analyses

Supported attendance to conference and workshops and advisory committees.

Could results from the project be subject for any commercial utilization

No

Conclusions

**a) Indicate future research and/or perspectives which the project results have led to**

- 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 CO<sub>2</sub> 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 and Barents Sea

**b) List and describe new methods or techniques that have been developed during the project or that the project has revealed a need for**

- Additional chemical sensors such as CO<sub>2</sub> sensors to put on moorings are needed to obtain information on the seasonal variability of the carbonate system and ocean acidification.
- CO<sub>2</sub> sensor was deployed in Kongsfjorden in July 2016 for autonomous seasonal measurements, and recovered in July 2017
- The pCO<sub>2</sub> 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 fCO<sub>2</sub> during all seasons using automated fCO<sub>2</sub> instrument installed on RV Lance, 2015-2017