

Project information

Keywords

ocean acidification, biogeochemical processes, sea ice, glacial water, freshwater, Arctic, Svalbard fjords

Project title

OA-1/Ocean acidification state and drivers in Arctic waters (OAstate/OAdriver)

Year

2019

Project leader

Agneta Fransson (NPI) and Melissa Chierici (IMR)

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

Kai Sørensen; Andrew King, Marit Norli (NIVA)

Helene Hodal Lødemel (IMR), Elizabeth Jones (IMR)

Mats Granskog (NPI), Ylva Ericson (NPI), Katarzyna Zamelczyk (NPI)

Flagship

Ocean Acidification

Funding Source

Fram Centre/KLD, Norway

Summary of Results

- **Time-series of chemistry data 2011-2019** from Arctic outflow waters in the Fram Strait clearly show integrated **changes in the chemistry**, pH and ocean acidification state in the Arctic Ocean due to climate change.

- Nine years of carbonate chemistry data (IMR/NPI) in Fram Strait reveals the seasonal and inter-annual variability of pH, pCO₂ and aragonite saturation in the Arctic outflow water at 50-150m in East Greenland Current. Results from the 9 years of data show increased temperature, salinity, total dissolved inorganic carbon, pCO₂ and total alkalinity, and decreased pH.

-The **lowest pH and aragonite saturation** in the Fram Strait were found in the upper halocline (50 to 150m) Arctic outflow waters (western Fram Strait), coinciding with high brine content (negative sea-ice melt) and high pCO₂. Possible mechanisms for the origins of the low pH layer could be due brine transport of CO₂ as a result of sea-ice dynamics in the Arctic Ocean and

CO₂ from Siberian rivers.

- **Continued water column sampling and chemical analyses** by IMR and NPI from several parts of the Arctic 2011-2019, 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/KF cruises, A-TWAIN section, SI Arctic, N-ICE 2015 and Nansen Legacy cruises.
- **Several Svalbard fjords are affected by glacial water runoff, which affects the fjord chemistry**, decreasing pH and the calcium carbonate saturation state (NPI/IMR).
- **Fjord ice affected by glacial water and sea-ice processes**, observed during several field campaigns in Tempelfjorden, Kongsfjorden and van Mijenfjorden, Svalbard (NPI/NIVA), manuscript in progress.
- **Combined modelling (BGC and physics) and carbonate chemistry** resulted in seasonal data for extended data set on the **variability aragonite saturation** with changes in freshwater (collaboration with WP3), work in progress.

- **Unique automatic surface water pCO₂ measurements in 2018-2019** from the new pCO₂ instrument onboard the RV Kronprins Haakon (NPI/IMR) in the Arctic Ocean, Fram Strait, around Svalbard and in the Southern Ocean (2019). Results are quality controlled, and results will be published in 2020.
- **Southern Ocean surface water pCO₂ variability** in different areas in austral autumn in the Dronning Maud Land/Kong Håkons VII hav, due to different physico-chemical processes (NPI/IMR), manuscript in progress in collaboration with the SANOCLEAN project.
- **Storms in winter affects vertical mixing, gas and heat exchange**, resulting in open leads in the ice cover and large **ocean CO₂ uptake** in winter. Storm paper published in 2019.
 - **New preliminary results from the unique winter-to-spring data of the sea-ice and under-ice water carbonate chemistry (NPI/IMR)** from north of Svalbard (80 to 83°N) from January to June 2015 during the N-ICE 2015 expedition, show that **ikaite (CaCO₂ mineral) precipitation** in the ice affects the underlying water and partly mitigate the effects of ocean acidification. New manuscript in progress.
- **NIVA has continued development and operation of shipboard pH and pCO₂ sensors on MS Norbjørn** as part of the underway FerryBox system that makes observations in the Barents Sea opening between Tromsø and Longyearbyen. **A new and improved version of the spectrophotometric pH sensor** was developed, completed, and now installed on MS Norbjørn in 2019. The improved sensor includes an improved cuvette and optics, full control and operation via a

touchscreen and embedded Raspberry Pi, and new Python-based software and GUI. Development of a spectrophotometric carbonate ion sensor prototype (in cooperation with Horizon 2020 INTAROS) also took place in 2019, but the final version of the sensor will likely not be ready until 2020. The sensor data collected in 2019 complemented inorganic carbon (CT) and total alkalinity (AT) measured on discrete samples taken on the FerryBox system on four cruises per year that is financed by Miljødirektoratet. Continued collaboration with Dr. Claire Mahaffey at University of Liverpool on NERC UK project ArcticChange which addresses climate change effects, including ocean acidification, on the Arctic isoscape.

Master and PhD-students involved in the project

Griselda Anglada-Ortiz (PhD student, UiT); Fransson (NPI), Chierici (IMR) and Zamelczyk (NPI) are co-advisors

Margret Ogundare (PhD student, Stellenbosch University, South Africa); collaborators Fransson (NPI) and Chierici (IMR)

For the Management

- Time-series of chemistry data 2011-2019 from Arctic outflow waters in the Fram Strait clearly show integrated changes in the chemistry, pH and aragonite saturation/ocean acidification state in the Arctic Ocean due to climate change.
- In 2018-2019, unique automatic surface $f\text{CO}_2$ measurements using new CO_2 instrument onboard RV Kronprins Haakon (NPI in collaboration with IMR) in the Arctic Ocean, Fram Strait, around Svalbard and in the Southern Ocean (2019).
- 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 sea ice and water, from winter to spring, north of Svalbard (between 80 and 83°N) obtained during the N-ICE 2015, new results in

progress 2019-2010.

- 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 (2011-2019) in Arctic for OA studies in the water column during Fram Strait annual cruises, MOSJ/KF, A-TWAIN, SI-Arctic cruises continued and Nansen Legacy (AeN) cruises (2018-2019). 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. Nine years of carbonate chemistry data in the Fram Strait shows variability in pH and aragonite saturation between the years with the effect of increased river runoff in the Arctic outflow (western Fram Strait). 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 (MS Norbjørn FerryBox) 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 nine years and compare with other Arctic studies, resulting in pan-Arctic studies, such as the MOSAiC campaign 2019-2020.

- 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.

Peer-viewed publications in 2019

Armstrong, C.W., N. Foley., D. Slagstad., M. Chierici., I. Ellingsen., M. Reigstad (2019). Valuing blue carbon changes in the Arctic Ocean. *Frontiers in Marine Science*, <https://doi.org/10.3389/fmars.2019.00331>, Carbon Bridge to the Arctic special issue.

Chierici M., M. Vernet, A. Fransson, Y. Børsheim (2019) Net community production and carbon exchange from winter to summer in the Atlantic Water inflow to the Arctic Ocean. *Frontiers in Marine Science*, doi: 10.3389/fmars.2019.00528.

Ericson, Y., E. Falck., M. Chierici., A. Fransson., E. Jones and S. Kristiansen (2019). Marine CO₂ system variability in a high Arctic tidewater-glacier fjord system, Tempelfjorden, Svalbard. 2019. *Continental Shelf Research*, DOI: 10.1016/j.csr.2019.04.013.

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Ericson Y, Chierici M, Falck E, Fransson AI, Jones EM, Kristiansen S (2019). Seasonal dynamics of the marine CO₂ system in Adventfjorden, a West Spitsbergen fjord. *Polar Research*. 2019;38:3345, doi: 10.33265/polar.v38.3345.

Fransner, F., A. Fransson, C. Humborg, E. Gustafsson, L. Tedesco, R. Hordoir, and J. Nycander (2019) Remineralization rate of terrestrial DOC as inferred from CO₂ supersaturated coastal waters, *Biogeosciences*, 16, 1–17, 2019, doi.org/10.5194/bg-16-1-2019.

Graham R.M., P. Itkin, A. Meyer, A. Sundfjord, G. Spreen, L. H. Smedsrud, (M. Granskog, A. Fransson) et al. (2019) Winter storms accelerate the demise of sea ice in the Atlantic sector of the Arctic Ocean, *Scientific Reports*, 9:9222 | <https://doi.org/10.1038/s41598-019-45574-5>.

Hop, H., P. Assmy, A. Wold, A. Sundfjord, M. Daase, S. Kristiansen, P. Duarte, M. A. Granskog, S. Kwasniewski, M. Gluchowska, J. Wiktor, A. Tatarek, M. Róžańska- Pluta, A. Fransson, M. Chierici, M. Vihtakari. Pelagic ecosystem characteristics across the Atlantic Waters Boundary Current from Rijpfjorden, Svalbard, to the Arctic Ocean during summer (2010-2014), *Frontiers in Marine Science*, 09 April 2019 | <https://doi.org/10.3389/fmars.2019.00181>.

Lee, C.M., S. Starkweather S., H. Eicken, M.-L.Timmermans, J. Wilkinson, S. Sandven, including A.L. King and K. Sørensen and 23 others. 2019. A framework for the development, design and implementation of a sustained Arctic Ocean Observing System. *Frontiers in Marine Science*, <https://doi.org/10.3389/fmars.2019.00451>.

Mittermayer,F.H., M.H. Stiasny., C. Clemmesen., T. Bayer., V. Puvanendran., S. Jentoft., M. Chierici & T.B.H. Reusch. 2019. Transcriptome profiling reveals exposure to predicted end-of-century ocean acidification is a stealth stressor for Atlantic cod larvae, *Scientific Reports* accepted [SREP-18-01510].

Olofsson, M., A. Torstensson., M. Karlberg., F. S. Steinhoff., J. Dinasquet., L. Riemann., M. Chierici., and A.Wulff. 2019. Limited response of a spring bloom community and inoculated filamentous cyanobacteria to elevated temperature and pCO₂, *Botanica Marina*, 62(1):3-16, <https://doi.org/10.1515/bot-2018-0005>.

Steinhoff T., (including A. Fransson) et al. (2019) Constraining the Oceanic Uptake and Fluxes of Greenhouse Gases by Building an Ocean Network of Certified Stations: The Ocean Component of the Integrated Carbon Observation System, ICOS-Oceans. *Frontiers in Marine Science*, 03 September 2019 | <https://doi.org/10.3389/fmars.2019.00544>.

Schmidt J. O., (including A. Fransson) et al. (2019) Future ocean observations to connect climate, fisheries and marine ecosystems. *Frontiers in Marine Science*. *Front. Mar. Sci.*, 13 September 2019, <https://doi.org/10.3389/fmars.2019.00550>.

In review

Ofstad Siri, Julie Meilland, Katarzyna Zamelczyk, Melissa Chierici, Agneta Fransson, Friederike Gründger, and Tine L. Rasmussen. Development, productivity and seasonality of living planktonic foraminiferal faunas and *Limacina helicina* in an area of intense methane seepage in the Barents Sea, *JGR-Biogeosciences* in review 2019.

Hopwood (Chierici, Fransson) et al. How does glacier discharge affect marine biogeochemistry and primary production in the Arctic? *Cryosphere*, in review 2019.

Lannuzel (Fransson, Chierici) et al. The future of Arctic sea-ice biogeochemistry and ice-associated

ecosystems. Submitted to Elementa, 2019

In progress

Chierici M., A. Fransson, M. Granskog et al . Ocean acidification in Arctic outflow waters. To be submitted in Dec 2019.

Fransson A, M Chierici, P Dodd, M Granskog, C Stedmon, et al. 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, 2019/2020.

Henly et al. (Fransson) et al. Nutrients variability in Antarctic fast ice. in progress.

Fransson, Chierici, Nomura, Granskog et al Sea ice and glacial water in Tempelfjorden, submit 2019/2020.

Chierici M. and A. Fransson, Barents Sea CO₂ variability 2012-2016, in progress, 2019.

Fransson A. et al., Seasonal impact of sea-ice processes and freshwater on calcium carbonate saturation in the Svalbard fjords. Submit in 2020.

Publications (reports)

Jones, E., Chierici, M., I. Skjelvan, M. Norli, K. Y. Børsheim, S. K. Lauvset, H.H. Lødemel, K. Sørensen, A.L. King, T. Johannessen, (2019). Monitoring Ocean Acidification in Norwegian waters/Overvåking av havforsuring i norske farvann i 2018 Report, Norwegian Environment Agency/Miljødirektoratet, M-|2019.

Data sets in NMDC and NPI

Chierici, M and Agneta Fransson (2019). Seasonal variability of the marine CO₂ system and nutrients in the Atlantic water inflow to the Arctic Ocean in 2014. DOI: 10.21335/NMDC-154415697

<http://metadata.nmdc.no/metadata-api/landingpage/6cd1173cca04935cc95efb5c5324615d>

Fransson, A and M. Chierici. 2019. Marine CO2 system in a high- Arctic fjord Rippfjorden 2012-2014:

<https://data.npolar.no/dataset/5f7fde82-c161-45c1-8602-3fb1b54f853b>

Fransson, A and M. Chierici. 2019. Marine CO2 system in Kongsfjorden and July 2012 to 2014.

Ericson, Y., E. Falck., A. Fransson., and M. Chierici. 2019. Marine CO2 system data from Tempelfjorden, Svalbard, 2015-2017, DOI: 10.21335/NMDC-656799113

ftp://ftp.nmdc.no/nmdc/UNIS/Marine_CO2_system_data_from_Tempelfjorden_2015_to_2017.xlsx

Ericson, Y., E. Falck., and M. Chierici. 2019. Marine CO2 system data from the IsA Station, Svalbard, 2015-2017, DOI: 10.21335/NMDC-80568951

ftp://ftp.nmdc.no/nmdc/UNIS/Marine_CO2_system_data_at_the_IsA_Station_2015_to_2017.xlsx

Communicated Results

[Conferences/workshops abstracts in 2019](#)

[Main conferences](#)

Nansen Legacy annual meeting, Oslo, October/November 2019 (Chierici, Fransson, Jones, Granskog, Zamelczyk)

Svalbard Science Conference, Oslo, November 2019 (Chierici, Fransson)

OceanObs19, Honolulu, Hawaii (Sørensen, King)

ASLO, Puerto Rico (Sørensen, King)

Chierici M., M. Vernet, A. Fransson, Y. Børsheim (2019) Net community production and carbon exchange from winter to summer in the Atlantic Water inflow to the Arctic Ocean. Abstract for oral presentation at ISAR, Tokyo, 2020.

Fransson A., M. Chierici, D. Nomura, M. Granskog, E. Leu, C. Hoppe, K. Abrahamsson, S. Kristiansen. Arctic sea-ice biogeochemistry and ice-air CO₂ exchange in the coldest period in January to April, Abstract for poster for ISAR, Tokyo, 2020.

Fransson A., M. Chierici, Y. Ericsson, E. Falck, S. Kristiansen. Influence of glacial water on carbonate chemistry and biogeochemical processes in Svalbard fjords with different characteristics. Abstract and poster to ISAR, Tokyo, 2020.

Silyakova A., M. Kotovitch, B. Delille, D. Nomura, E. Damm, A. Fransson, M. Chierici, M. Granskog. Methane chemistry in the ice-covered Arctic Ocean from winter to summer time. Abstract submitted to ISAR, Tokyo 2020.

Anglada-Ortiz G., K. Zamelczyk, M. Chierici, A. Fransson, J. Meilland and T. L. Rasmussen. Planktic calcifiers in acidifying ocean: abundance distribution and carbon fluxes in the Barents Sea. Poster presentation at the Nansen Legacy annual meeting, Oslo, October 2019.

Jones E. M. Chierici, A. Fransson, H. Hodal Lødemel. Variability and drivers of ocean acidification in the Barents Sea. Poster presentation at the Nansen Legacy annual meeting, Oslo, October 2019.

Fransson A., M. Chierici, Y. Ericsson, E. Falck, S. Kristiansen. Influence of glacial water on carbonate chemistry and biogeochemical processes in Svalbard fjords with different characteristics. Abstract and poster at the Svalbard Science Conference, Oslo, Norway 2019.

Fransson A., M. Chierici, D. Nomura, M. Granskog, E. Leu, C. Hoppe, K. Abrahamsson, S. Kristiansen. Arctic sea-ice biogeochemistry and ice-air CO₂ exchange in the coldest period in January to April, Abstract for poster, IGS conference, August 2019, Winnipeg, Canada.

Fransson A., M. Chierici, I. Skjelvan, A. Olsen, P. Assmy, A. K. Peterson, G. Spreen, B. Ward. Effects of sea-ice and biogeochemical processes and storms on under-ice water fCO₂ from winter to spring in

the high Arctic Ocean: Implications for sea-air CO₂ fluxes. Abstract for poster, IGS conference, August 2019, Winnipeg, Canada.

Sørensen, K., A.L. King, M. Norli, D. Hjermann, T. Kristiansen, S. Marty, P. Jaccard, C. Mengeot, E. Protsenko and W. Eikrem. Use of FerryBox Ships of Opportunity systems for satellite product validation. Abstract. ASLO Aquatic Sciences Meeting, Puerto Rico, 2019.

King, A.L., H. Frigstad, M. Norli, R. Bellerby, Ø. Kaste, and K. Sørensen. DOM and nutrients from rivers to coast: Observations and experimental results. Abstract. ASLO Aquatic Sciences Meeting, Puerto Rico, 2019.

Sørensen, K., M. Norli, A.L. King, P. Jaccard, S. Marty, A. Ledang, D. Hjermann, T. Kristiansen, and W. Eikrem. Experience from the Norwegian FerryBox network in national monitoring. Abstract. 9th Ferrybox Workshop, Genoa, Italy, 2019.

Marty, S., P. Jaccard, M. Norli, A. King, and K. Sørensen. Validation of remote sensing algorithms using the Norwegian ship of opportunity network. Abstract. 9th Ferrybox Workshop, Genoa, Italy, 2019.

King, A.L., H. Frigstad, M. Norli, R., Ø. Kaste, and K. Sørensen. DOM and nutrients from rivers to coast: FerryBox observations and experimental results. Abstract. 9th Ferrybox Workshop, Genoa, Italy, 2019.

Marty, S., H. Frigstad, M. Norli, R. Bellerby, A.B. Ledang, S. Marty, K. Sørensen, and A.L. King. Coastal observations of biogeochemical cycles using FerryBox Ships of Opportunity. OceanObs'19, Honolulu, Hawaii, USA, 2019.

King, A.L., S. Marty, M. Norli, P. Jaccard, R. Bellerby, and K. Sørensen. Monitoring ocean acidification and carbon cycling on FerryBox Ships of Opportunity with underway carbonate system sensors. OceanObs'19, Honolulu, Hawaii, USA, 2019.

Chierici, M., A. Fransson, 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 in a West-Spitsbergen fjord. IASC-NAG Glacier workshop, Geilo, January 2019.

Fransson A., M. Chierici, Y. Ericsson, E. Falck, S. Kristiansen. Influence of glacial water on carbonate chemistry and biogeochemical processes in Svalbard fjords with different characteristics. Abstract IASC-NAG Glacier workshop, Geilo, January 2019.

Graham, Itkin, Granskog et al (Fransson) Storm events, N-ICE, Abstract for IGS meeting, Winnipeg, 2019.

Nomura D. et al. (A. Fransson). ECV-Ice: Measuring Essential Climate Variables in Sea Ice–SCOR

Working Group 152. Abstract BEPSII meeting, Winnipeg, Canada, 2019.

OA flagship meetings, 2019, NPI, IMR, NIVA, Akvaplan-Niva, UiT, NINA, NORUT/SALT.

ICOS expert meeting in Bergen, October, and skype meetings, 2019 (A. Fransson/M. Chierici)

BEPSII expert meeting in Winnipeg (A. Fransson), June 2019

Public report/outreach

Katz, C., Why Rising acidification poses a special peril for warming Arctic waters, Yale Environment 360, 24 October 2019, with contributions from Agneta Fransson NPI and Melissa Chierici IMR.

Social media (Ocean and sea ice, NPI) on ocean acidification from Southern Ocean expedition (NPI), 2019.

Norwegian Polar Institute social media on RV Kronprins Haakon expedition to Antarctica (NPI/Fransson and IMR/Chierici participants).

Nordlys, 2019, Antarctic expedition to Dronning Maud Land with RV Kronprins Haakon (NPI/Fransson participants).

Social media (Oceans and sea ice, NPI/Fransson) about ocean acidification and *Limacina helicina*, 2019.

Social media (Oceans and sea ice, NPI/Fransson) on glacial water in Svalbard fjords and effects on chemistry, 2019.

Social media about MOSAiC expedition to the Arctic Ocean, 2019 (NPI, IMR participants).

In addition, the OA state and OA Flagship have been involved in public presentations, school visits, interviews, radio, blogs, webinars and popular articles in newspapers and social media. The OA state and OA Flagship have contributed with photos, films and other material for the science days and other forums.

Expertise/advice:

-IGC-OA (ICES/OSPAR (M. Chierici)

-ICES-Marine Chemistry Working Group, MCWG (M. Chierici),

-ICOS (Integrated Carbon Observing System) expert meeting in Bergen, 2019 (Fransson, Chierici, Ericson).

-GOA-ON Arctic hub lead 2019 (Fransson, Chierici)

-BEPSII expert meeting in Winnipeg, Canada, 2019 (Fransson)

-Biogeochemistry of Sea Ice (BEPSII-ECV) SCOR Forum (A. Fransson, M. Chierici)

-Several contributions to OceanObs19 white papers on ocean and climate change (A. Fransson, M. Chierici)

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 Nansen Legacy (AeN) cruises and workshops, we work interdisciplinary, 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 expeditions 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), also within AeN.

Collaboration with Helen Findlay at Plymouth Marine Laboratory, UK, in Kongsfjorden.

Collaboration with Claire Mahaffey at University of Liverpool on NERC UK project ArcticChange.

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)

Marine biology (zooplankton/pteropod sampling)

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_3 minerals in sea ice and water column (AWI, Germany and IOPAN, Poland),

Shell density analyses collaboration with scientists in Japan (JAMSTEC)

Methane in seawater (AWI and UiT/CAGE)

Marine CO₂ system in the Southern Ocean (Stellenbosch University, South Africa)

Budget in accordance to results

The project funding has been fundamental to implement this project. It partly supports the hiring of a postdoc and a research assistant at NPI, and 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 and in Fram Strait with other Flagship and between institutes/universities.

Fram Centre funds have supported:

Salary for postdoc Ylva Ericson at NPI

Salary for research assistant Katarzyna Zamelczyk at NPI

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

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

- Time-series of chemistry data 2011-2019 from Arctic outflow waters in the Fram Strait clearly show integrated changes in the chemistry, pH and ocean acidification state in the Arctic Ocean due to climate change. Need for more years data to perform trend analysis.
- 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-KF/NPI and SI-Arctic/IMR).
- CAGE (UiT) collaboration on historical carbonate chemistry and palaeoceanography in Nordic seas and Barents Sea, collaboration with AeN project.

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 CO₂ sensors to put on moorings are needed to obtain information on the seasonal variability of the carbonate system and ocean acidification.
- CO₂ sensors have been added on moorings in Kongfjorden, 2019
- The 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 $f\text{CO}_2$ using automated $f\text{CO}_2$ instrument installed on RV Kronprins Haakon in 2018-2019
- Added chemical sensors for pH and oxygen on mooring in Barents Sea to study variability during a full year.