Project information

Project title

Long-term variability and trends in the Atlantic Water inflow region (A-TWAIN)

Year

2011/2012

Project leader

Vladimir Pavlov, NPI

Participants

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- Project participants: Jørgen Berge, Frank Nilsen/The University Centre in Svalbard; Marit Reigstad/Univ. of Tromsø; Stig Falk-Petersen, Arild Sundfjord/ Norwegian Polar Institute; Vigdis Tverberg/Institute of Marine Research

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Flagship

Arctic ocean

Funding Source

Fram Centre

Summary of Results

The proposed monitoring of Atlantic Water inflow to the Arctic Ocean will increase our ability to detect effects of climate change on sea ice and biological habitat conditions in the Arctic Ocean and the coast north of Svalbard, conditions that define the possibilities for expansion of human activities in the region. The acquired database will be valuable for evaluation and improvement of coupled numerical models for ocean circulation, sea ice and ecosystems. This project will thus benefit all three activities of the flagship Arctic Ocean (shipping, petroleum and fisheries).

Background and status of knowledge The Arctic shelf seas contain some of the most biologically productive ecosystems in the world, but also play globally significant roles in heat exchange, ocean circulation, and geochemical cycling. The inflow of Atlantic water along the shelf break of Svalbard is the main gateway for transport of heat and biological energy to the Arctic Ocean. Data that have emerged over the last 15 years reveal tight linkages between physical and biological processes within and across these ecosystems, suggesting that their structure and function may be particularly sensitive to even modest changes in physical drivers.

Figure 1 . Map of study area with two suggested locations A and B for a mooring array. Depth contours are drawn with white lines: 300m, 500m, 1000m, 2000m and 3000m. Abbreviations: WSC = West Spitsbergen Current, FSB = Fram Strait Branch, BSB = Barents Sea Branch.

Large volumes of Atlantic Water (AW) enter the Arctic Ocean through the Fram Strait. This current supplies the Arctic Ocean as well as the northern part of the Barents Sea with heat, nutrients and biological energy (plankton), and will likely be an important pathway for introduction of new species in a warmer future climate. The inflow is commonly named the Fram Strait Branch (FSB) (see Figure 1), opposed to the Barents Sea Branch (BSB) that enters the Arctic Ocean in the St. Anna Through (Figure 1). The two branches have distinctly different influence on the Arctic Ocean. They split west of the Barents Sea, and while BSB loses most of its heat to the atmosphere when passing through the Barents Sea, the FSB continues along the continental shelf slope and subducts below sea ice and the Cold Halocline Layer (CHL) northwest of Spitsbergen. Both during and after subduction the heat in this water mass is a potential source for oceanic melting of sea ice.

The presence of AW in the Arctic Ocean has been known to the scientific community for a long time (Nansen, 1902). Moreover, knowledge of basic aspects of the AW inflow to the Arctic Ocean is well established. This includes the fact that in mean the AW slope current is topographically steered along the continental shelf slope (e.g. Jakobsen et.al., 2003), that anomalies in the flow can be detected as they propagate along this mean path (Polyakov et.al., 2005), and that heat from the AW is lost laterally through mesoscale activity acting on smaller scale than the mean flow, both in time and space (e.g. Nilsen et.al., 2006; Tverberg & Nøst, 2009). There is also an increasing concern in the scientific community about trends in AW characteristics (Polyakov et.al., 2004; Spielhagen et.al., 2011). The trends are obviously linked to climate change. However the understanding of forcing mechanisms behind trends and variability, as well as feedback mechanisms with sea ice and biology, still needs further development.

Monitoring of the AW slope current with current meter moorings is well established in the Fram Strait west of Svalbard. However, due to substantial recirculation in the Fram Strait area, it has been proven difficult to get reliable estimates of the AW inflow to the Arctic Ocean based on this Fram Strait array. Consequently, the volume transport of AW into the Arctic Ocean through the FSB is not known. Adding complexity to the picture, the FSB separates into two branches, one inner and shallow branch crossing the southern part of the Yermak Plateau, and an outer, deeper branch passing around the plateau (see Figure 1). Exactly where the two branches merge again, east of the plateau, is not certain. To reveal variability and trends in this inflow it is crucial to ensure that sufficiently long observation series are implemented. Except from a recently established mooring in Rijpfjorden, only sporadic and time limited mooring observations exist north of Svalbard, and several institutions plan to increase their mooring activity in this region.

Our accumulated understanding of Arctic ecosystems, ocean circulation, and atmospheric forcing provides the basis for addressing possible impacts of environmental change on key system processes. But it is only through an integrated, multidisciplinary perspective using novel approaches and modern research tools that we can assess potential system responses. We suggest installing new Arctic Sea Observatories (biophysical moorings) to address the following key questions:

The key question is : How does climate forcing impact 1) fluxes of physical properties (sea ice, current, temperature and salt) and biological energy (organic constituents, particulates and zooplankton) into the Arctic Ocean across the European Arctic gateways off Spitsbergen, and 2) what is the impact on the functioning of ecosystems in Svalbard waters?

Research questions and hypotheses A-TWAIN (long term variability and trends in the Atlantic Water Inflow region) will merge national and international initiatives to start monitoring programs north of Svalbard, into a “Kvitøya mooring transect”, preferably at location A in Figure 1. This array will be complementary to existing monitoring programs, and should be extensive enough to illuminate the key question. The scientific aim is formulated below as five scientific questions (Q1-Q5) and altogether ten hypotheses (H1-H10):

Q1: What are the characteristics of the Atlantic inflow of biological and physical energy to the Arctic Ocean?

Hypotheses:
H1: The AW inflow of physical and biological energy is larger during summer season than during winter (High temperature and biomass in summer is more important than high volume flux in winter.).
H2: Seasonal variability in AW is expected to be small compared to interannual variability.
H3: The AW core depth and cross-slope position is mainly influenced by large scale atmospheric circulation.
Q2: How is the AW inflow influencing sea ice condition?
Hypotheses:
H4: Sea ice is separated from AW by Arctic surface water, and the impact from AW on sea ice is insignificant in this region.
H5: Wind induced upwelling combined with favorable ice conditions can allow for AW to reach surface waters.
Q3: How is sea ice variability influencing the timing of biological production?
Hypotheses:
H6: The onset of biological production occurs at the same time every year, regardless of ice conditions.
H7: The relative amount and activity of zooplankton will increase as a response to the onset of primary production.
Q4: How will the inflow of AW and ice extent influence the cross slope exchange of physical and biological energy?
Hypotheses:
H8: Mesoscale eddies transport heat and salt and biological matter across the slope current.
H9: Internal wave energy is not generated by current shear over steep topography.
Q5: How large is the heat loss from AW between the Fram Strait and the Kvitøya mooring transect?
Hypothesis:
H10: The heat loss is insignificant between the two transects.
Approach A-TWAIN uses a monitoring approach to get data necessary to answer the five research questions listed in Section 3.2. Due to the subsurface nature of the Atlantic Water inflow, the direct measurements approach is the scientific method that will provide the most reliable information of the inflow. The mooring design will be appropriate to provide data of the inflow and properties relevant for sea ice and habitat conditions. The subsurface nature of the inflow, rules out for instance remote sensing. The first task, and also the ongoing prioritized task throughout the duration of the project, will be to coordinate, optimize, develop and implement a strategic mooring program that can monitor a wide range of relevant properties associated with Atlantic Water inflow along the shelf slope north of Barents Sea/Svalbard. Coordination of monitoring activity between several institutions will ensure efficient utilization of mooring instrumentation. Moreover, a wider range of parameters can be monitored if the institutions join their efforts.
Parameters ranging from physical (Q1), chemical and biological ocean properties (Q1, Q3) as well as sea ice properties (Q2, Q3) will be included in the mooring set up. Based on total mooring array design and mooring instrumentation, we need to be able to estimate cross-slope (Q4) and along-slope (Q1, Q5) volume and heat fluxes as well as related fluxes of chemical and biological parameters. The success of the project is dependent on interplay between configuration of each mooring, the configuration of the total mooring array, and the geographical location of the mooring array. The fully developed mooring array configuration will include five moorings placed in an array starting on the shelf and spread across the shelf slope with the deepest mooring anchored at bottom depth at least 1000m. These five moorings will be complemented by four WHOI moorings placed along a continuation of this line into the deep Arctic basin, with the shallowest mooring anchored at bottom depth 2000m.

Mooring configuration
Each mooring should contain:

- Several instruments to monitor basic water properties like temperature and salinity (H1-H5, H8, H10). Temperature and conductivity sensors (CTDs) evenly spread in the whole water column are ideal for this purpose. This is to reveal the vertical distribution of water masses and which type of water mass is advected by the current at each water level (H1-H5, H8, H10).
- Instruments to monitor basic biological properties like nitrate, Chl-a and light (H1, H6). These will be placed at the shallowest cluster of instrumentation (50m). The aim is first of all to detect the onset of primary production (H6). Ideally these sensors should be placed shallower, in the euphotic zone. However danger of deep ice keels passing the mooring forces the placing of the sensors to be at 50m the shallowest.
- Supplementary to remote sensing sea ice cover data, monitoring of the sea ice thickness (H4, H5, H6, H8) with an IPS ice sonar placed at 50m. The IPS measures the distance to the surface or the underside of the sea ice.
- Current measurements of the upper 100m of the water column, monitored by an Acoustic current profiler (ADCP 300 kHz) that can be used to detect zooplankton (H7) in addition to current. The ADCP will be placed at 100m measuring upwards, returning data on the vertical current structure, which will be used to calculated volume flux and in turn other fluxes (H1, H2, H3, H4, H5, H8, H9, H10). Backscatter data from the instrument will be used to indicate amount of zooplankton in the water column (H7).
- Current measurements in the expected core of AW, monitored by a second type of Acoustic current profiler (ADCP 150kHz), place at 300m, measuring upwards (H1, H2, H3, H4, H5, H8, H9, H10)). This frequency has a longer range (up to 200m), however cannot be used to detect zooplankton.
- Depending on bottom depth, additional single point current meters will be placed at selected depths in order to resolve the current profile and related volume flux in the deep part of the water column (H1, H2, H3, H8, H9, H10).
- At the bottom, a pressure sensor can be used as an alternative method to approximately estimate tides and depth integrated volume flux (H1, H2, H10).
- Acoustic releases and other items necessary to ensure mooring integrity over time.

The list of sensors and automatic sampling devices for physical, chemical and biological measurements may be expanded or adjusted later as budgets allow. Sampling interval should be 1 hour the resolve tide and diurnal variation, as well as mesoscale eddy activities (H8, H9). Small scale turbulence is not likely to be measured in such a long term mooring set up.

Mooring array configuration: Detection of long-term variability and trends (H2, H3) requires long time series. Moreover, the ability to capture transports of properties requires resolution in space as well. Consequently, to be able to identify transports and other characteristics of the Atlantic Water inflow, a mooring design that takes into account both aspects, resolution in space as well as long duration of monitoring is required. During the present project, increasing knowledge of the inflow, based on preliminary analysis of monitored data, will be utilized to gradually develop an optimal mooring design that captures the inflow transport of the most relevant identities (physical and biological). The mooring array design will be developed and revised every year based on new updated knowledge of the AW slope current structure. Figure 2 , right panel illustrates a design containing three Norwegian moorings supplemented by the four US, WHOI moorings. A fully developed mooring design is planned to include five Norwegian moorings. Such a design will give information on the vertical and cross-slope position and extent of the AW core (H3), and can give information on the spreading of AW away from the slope current (H8, H9), both towards the shelf and towards the central deep basin in the Arctic Ocean.

Figure 2 . Mooring array configuration suggested in a WHOI proposal. Schematic diagram shows the inferred circulation of Atlantic Water (AW) in the Arctic Ocean based mainly on water mass analyses from hydrographic data (left panel). The proposed mooring array is designed to measure the AW downstream of Fram Strait. The location of the mooring array operated by IMR in the Barents Sea is also shown. The right panel shows a vertical view of the proposed mooring array. This configuration of instruments will provide multiple vertical sections of hydrographic properties and velocity per day, resulting in the first high-resolution description of the primary boundary current of the Arctic Ocean. The salinity (color) and potential density (contours, referenced to the surface, kgm $^{-3}$) are from a shipboard section through the current occupied in 2001 (Cokelet et al., 2008).

Geographical location The mooring array should be located east of the merging between the shallow and deep branches crossing/rounding the Yermak plateau. Two locations are suggested in Figure 1. Location B is the feasible location for a desired expansion of a bio/physical mooring program in Rijpfjorden, a fjord on the northern side of Nordaustlandet (east of Spitsbergen). Location A is selected on physical grounds as the first location along the path where the FSB is known to flow along smooth bathymetry and is likely to be free of recirculation.This also coincides with the location of a mooring collecting data during 1.5 year 2004/2006, which was deployed with a joint effort of NPI and IARC (Ivanov et.al, 2009). This is the only mooring time series existing from the shelf slope in the region north of Svalbard. Location A will have priority for the shelf slope mooring array, but in case of difficult sea ice conditions during survey the moorings may be deployed at location B.

Milestones and deliverables Due to the novel nature of data collection in the Kvitøya transect, the research questions Q1-Q5 can only be addressed after successful recovery of the first moorings. At the earliest this will happen in September 2013. Before this date, the main focus will have to be on designing moorings and mooring array, designing scientific cruise plan for each cruise, and not at least optimize the chance of being able to accomplish successful deployments and retrievals of all moorings each year. Sea ice conditions may make ship operations very difficult, and makes it crucial that we have a ship available that is suitable for operations in the ice. Important milestones and deliverables are listed in the table below, not including two project meetings each year, to ensure good preparations for the field operations and to optimize data processing and usage.

Offshore and ship operations It should be noted that there is some inherent risk and uncertainty in any deployment of equipment offshore for long periods. Severe ice conditions can impede deployment and/or recovery of one or more moorings in a given year. Potential impacts of this are reduced by using mooring equipment of high quality, with all components designed for deployments of at least two years. To reduce the accompanying risk of data loss, battery capacities and user selectable sampling intervals will be chosen to maximize the measurement periods of all instruments, to the extent possible without compromising temporal data resolution. There is also risk of mooring loss due to trawling activities and ice berg drift. The latter risk is reduced by having the top of the moorings positioned deeper than ~50 m. If moorings are caught by fishing vessels we can increase the chance of them being returned by proper labeling of all parts and possibly also by use of ARGOS transmitters. WHOI depend on ship time allocated by A-TWAIN for deployment and retrieval of their four moorings. Ship time will be applied for both at NPI (R/V Lance), IMR (R/V Helmer Hansen) and the Norwegian national coast guard (K/V Svalbard). A detailed cruise plan will be made when ship and ship time is decided.

National collaboration The project meetings will strengthen the network between institutions that currently hold the highest national competence on Arctic Ocean mooring observatories. The national institutions involved are NPI, IMR, UNIS and UiT. In addition to personnel, these institutes can all contribute with ship time for mooring surveys as well as complementary observational data from the nearby and upstream regions of the Kvitøya transect. The bio/physical mooring observatory in Rijpfjorden (Nordaustlandet) will serve as a supplementary shelf site for A-TWAIN, and will get economical support from the A-TWAIN budget. Each institute will contribute to the project with complementary mooring equipment. We will also have close collaborations with other Fram Centre Flagship projects, in particular. 'Mesocale modeling of Ice, Ocean and Ecology of the Arctic Ocean' (Arctic Ocean flagship) and 'Establishing the Current Status of Ocean Acidification in the Norwegian Arctic' (Ocean Acidification flagship).

International collaboration There will be close international collaboration with WHOI (Woods Hole Oceanographic Institution, US), who will contribute with four moorings in the deep part of the Kvitøya transect. WHOI depend on ship time from A-TWAIN to be able to deploy and recover their moorings. After the original application was submitted in 2011, we now have commitment also from Institute of Oceanology, Poland, to participate with instrumentation and personnel for the same project goals. We will also cooperate with other relevant international institutes/networks with interest and plans for this region, primarily NABOS (Nansen and Amundsen Basins Observational Systems), APL (The John Hopkins University, Applied Physics Laboratory, US), AWI (Alfred Wegener Inst., Germany), IARC (International Arctic Research Center, University of Alaska, Fairbanks, US) and SAMS (Scottish Association for Marine Science, UK).

Management: The project will be lead from Tromsø by NPI (Dr Vladimir Pavlov) and IMR (Dr Randi Ingvaldsen). Additional main participants are listed in Section 1.3 and cover biological competence (Stig Falk Petersen, Jørgen Berge and Marit Reigstad) and competence within physical oceanography (Vladimir Pavlov, Vigdis Tverberg, Arild Sundfjord and Frank Nilsen). The achieved data base will be developed in agreement with Fram Centre standards.

Strategic relevance The aim of the project is to provide a quantitative observationally based assessment of Atlantic water inflow, heat and salt fluxes and water mass transformations in the Eurasian Basin of the Arctic Ocean.Its goals and objectives fit well into the overall scientific strategies of the Norwegian and international organizations that will collaborate in project. The aim of the research at IMR is to help ensure that Norway's marine resources are harvested in a sustainable way, through monitoring of and research in the fields ecosystem and climate change. The proposed project comprehends all these aspect, as it aim for long-term monitoring of both climatic and ecosystem related parameters. The project also fits well with NPI's mandate of research, monitoring and management of Norwegian Arctic areas. It will enhance existing programs like MOSJ and the ICE Centre in a very good manner.

Relevance and benefit to society Climate change is a big challenge to society, and preparation of new national and international strategies for society to adapt to these changes depend on the ability to make realistic future climate scenarios. The suggested activities will add new knowledge about the response of the Arctic Ocean to climate change in the form of; retreat of sea ice, sea level rise changes, biodiversity impacts caused by e.g. changes in nutrient supply, temperature and salinity and changes in fish migration pattern caused by shifts in plankton species. Also, we can contribute to the understanding of the important role that the changes in heat and salt fluxes between Atlantic and Arctic oceans plays in relation to issues important to Arctic society, including climate change. The results obtained during the implementation of the project can be used for long-term planning of marine operations such as navigation, oil and gas exploration and commercial fishing.

Environmental impact There are no specific environmental impacts from the research.

Education Data collected in the project will be used in courses and in Master's and PhD thesis work at UNIS and Univ. of Tromsø, and possibly at IMR and NPI. Existing courses at UNIS and Univ. of Tromsø are well suited for the purposes of the projects.

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Published Results/Planned Publications

Project results will be published in peer reviewed journals like Journal of Geophysical Research (impact factor 3.08), Journal of Physical Oceanography (impact factor 2.38), Deep Sea Research (impact factor 2.59), Polar Research (impact factor 0.77), Marine Ecology Progress Series (impact factor 2.52), Progress in Oceanography (impact factor 3.58) and Polar Biology (impact factor 0.58).

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Communicated Results

Users of the data base that will be gathered during the project are researchers in the institutions involved in the project, including international collaborators. Subsequently the data will be made generally available for the international scientific community in agreement with Fram Centre and SIOS database policy. The data will provide extremely valid background data for more extensive biological process studies that can be complementary to the observing sites. That will enable a far better understanding of the longer term biological dynamics and seasonality compared to snap-shot process studies conducted at present.

Interdisciplinary Cooperation

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Budget in accordance to results

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Could results from the project be subject for any commercial utilization

No

If Yes

Conclusions

Inflowing AW characteristics, ice conditions and key chemical and ecosystem parameters will be measured by a long-term array of moored instruments covering the shelf, slope, and part of the interior basin north of Svalbard. The approach will be in cooperation with international institutes. The obtained data will increase our understanding of the seasonal and inter-annual variability of the heat and freshwater fluxes into the Arctic Ocean as well as ice drift in the surface layer. They can also be used for intermediate time-scale (months to years) ocean and ice forecasting. In addition to heat and nutrients, the inflow of AW can possibly also bring new species to the system. Hence, the instrumentation will cover basic chemical, biological and ice parameters (upward looking sonars) in addition to standard oceanographic sensors. Data collected by the project will be done by joint Fram Centre infrastructure and field work, and will be made available for the partners of the Fram Centre (and the wider science community). Doing this the Fram Centre will provide a service to all partners that is too expensive for individual partners to run alone.