Oceanic heat anomalies and Arctic sea-ice variability

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Summary for publication

In this deliverable we have investigated the link between the ocean heat transport and the sea ice properties (extent, thickness). Observations and climate model simulations of the last decades and in a future climate scenario have been used to explore how the variations of the sea ice cover in the Arctic can be predicted months or years in advance from the ocean surface temperature. The winter Arctic sea ice extent could be predicted with some confidence from the sea surface temperature (SST) in the northern North Atlantic several years in advance. Looking at more local scale, the ice cover can be predicted one or two years in advance in all the marginal seas of the Arctic in the Norwegian climate model, when the observed SST is imposed in the model. Regarding the prediction from seasons to seasons, the result is more contrasted and the best predictions are obtained in the Barents Sea. Prediction of the sea ice cover in this region from oceanic quantities should hold in future climate as well.

A particular attention was paid to the mechanisms controlling the regional link between sea-ice and the ocean temperature north of Svalbard, a region of the Arctic where the warm water of Atlantic origin encounters sea-ice. In this area we examined if the variations of the heat content of the ocean can be associated with variations of the volume of warm water rather than variations of the water temperature itself. Examining a one-month duration event of sea ice retreat in the 2006 winter, one of the major events in the last two decades, we could show that wind anomalies were a major driver of the sea-ice opening, contributing altogether to the offshore retreat of the sea ice edge and enhanced ice melt through upwelling of warm water to surface.

Work carried out

The link between the ocean heat transport and the sea ice properties (extent, thickness) has been analysed in two climate models, to infer the predictability of the sea ice cover at seasonal and decadal timescale. In a high-resolution coupled sea ice-ocean model, the variability of the heat content and transport associated with the Atlantic Water (AW) inflow to the western Eurasian Basin has been assessed against available observations, and processes controlling the heat transfer from the ocean to the ice have been analysed.

Predictability of the sea ice cover at seasonal and decadal timescale (UiB, NERSC)

The seasonal and decadal prediction skill of regional Arctic sea ice extent (SIE) has been assessed in the Norwegian Climate Prediction Model (NorCPM) for the time period 1960-2010. These retrospective hindcasts with NorCPM are initialized using monthly assimilation of observed sea surface temperature (SST). Building on the covariability of the sea surface temperature (SST, extracted from the Hadley Center Ice and Sea Surface Temperature datasets) along the pathway from the Gulf Stream to the Arctic, the predictability of the winter ice extent from the SST in the Gulf Stream extension (see Fig.1 for the location of the data used) has also been investigated for the period 1948-2015 (Årthun et al., 2017). Finally, ensemble simulations performed with the Coupled Earth System Model (CESM) were used to assess the evolution of the relationship between ocean heat content and sea ice in future climate.).

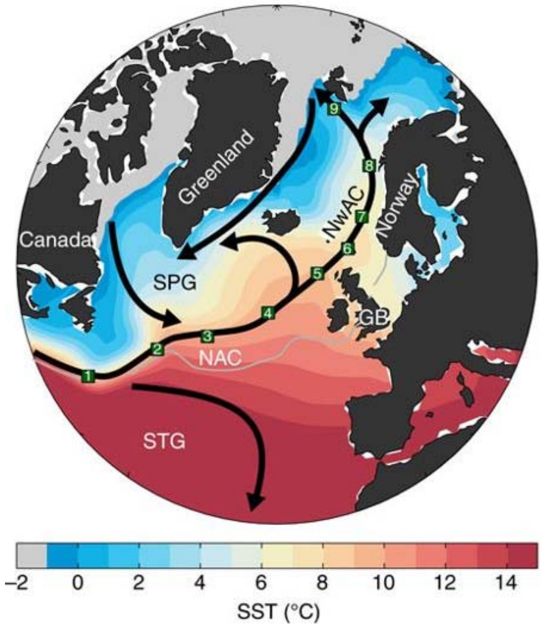

Figure 1: Climatological SST (colour) and major ocean surface currents (black arrows). Sea ice is indicated by the grey shading. SST at stations 2 and 3 (in green) are used to build a prediction model of the sea ice extent (adapted from Årthun et al., 2017).

Assessment of the variability of the heat content and transport (CNRS)

The AW is carried northward to the Arctic Ocean by the West Spitzbergen Current (Walczowski et al., 2016). A first comparison between a 1/24° coupled sea ice-ocean model and observations has been made in Fram Strait where long term observations are available (Beszczynska-Möller, et al., 2012). We additionally examined the AW distribution at two locations in the Eurasian basin, where sparser mooring and CTD data have been collected (Dmitrenko et al., 2011, Ivanov et al. 2009), and we investigated the link between the variability at these two locations, on one hand, and that observed in Fram Strait, on the other hand.

The 1/24° ice-ocean model configuration of the Arctic Ocean and the Atlantic Subpolar Gyre is based on NEMO 3.6. The model domain extends from 28°N in the Atlantic Ocean to the Bering Strait and is forced at its lateral boundaries by 5-day averaged oceanic conditions from a ¼° global simulation. In the vertical, the equations are discretized on 75 levels and the horizontal resolution is around 2.5 km in our region of interest. The atmospheric forcing fields are based on the ERA-interim reanalysis (Dee et al., 2011), with some corrections applied to precipitation (DFS5, Dussin et al., 2016) and the surface atmospheric temperature. We analyze here a simulation over the period 1995-2015 and focus our analysis on the last period of the simulation (2004-2015) when surface salinity restoring has been removed.

Mooring data from the eastern part of the Fram Strait (east of 3°W) along the 78°50'N latitude for the period 2004-2011 (doi.org/10.1594/PANGAEA.150016) have been used to characterize the AW distribution and associated transports in the strait. The data have been reduced to 5 day averages (to compare with the model data), and an objective analysis has been used to generate sections of temperature and meridional velocity. Closely separated (roughly 5 km apart on the continental slope) CTD casts collected during six summer cruises of PRV Polarstern (doi.pangaea.de/10.1594/PANGAEA.845938) were also extracted from the Pangaea database. In the Eurasian Basin, CTD casts and velocity measurements from a 2-year mooring record collected during the NABOS project have been extracted from the NABOS database (https://uaf-iarc.org/nabos/).
In Fram strait, metrics have been defined (see Milestone MS8) which best represent the AW distribution and allow for useful comparison between model and observations. These are the AW mean temperature, cross section area, heat content, volume and heat transports. Due to the shortness of the observation time series available, the comparison with the model outputs, based on correlation and wavelet analysis, mainly focused on the annual cycle. In the Eurasian Basin the assessment has been more qualitative and was based on the comparison of summer sections of temperature at two locations: across the slope at 30°E and north of the Laptev Sea. Correlations between current velocities measured at a mooring located at 30°E and the model velocities were also computed.

Processes controlling the heat transfer from ocean to the ice (CNRS, UiB)

This process analysis focuses on the region north of Svalbard, where strong ice-ocean interactions are expected to occur in winter. In this area, the winter sea ice cover indeed exhibited large negative anomalies in the early 2010s, as part of a negative trend which has been partly attributed to enhanced upward ocean heat flux (Ivanov et al., 2016). Coupled climate model simulations (considering one large ensemble, CESM-LE, RCP8.5) consistently suggest that the ocean heat transport toward the Arctic contribute to the negative trend in sea ice cover in this region, and will remain to do so through the 21st century (Årthun et al., 2019). Additionally, events of large sea ice cover opening have been reported in the recent winters (Falck-Petersen et al., 2014; Ivanov et al., 2016). However, it is not clear whether such events were also occurring in the preceding decades, nor what would have been the role of the ocean in these openings. In order to answer this question we analyzed the ASI-SSMI sea ice concentration data (Kaleschke et al., 2011) in combination with results of the aforementioned high-resolution model simulation. The satellite data were used to define an index of maximum sea ice opening for each winter. Two major openings (in 2006 and 2013) are identified over the 1992-2014 period in the model and in the observations. The 2006 event, the largest one, has been analyzed in details. Estimates of the sea ice volume budget in the simulation allowed us to distinguish the contribution of the ice transport and deformation with the respect to that of thermodynamics, in particular ocean driven sea ice melt.
Heat is carried to the Arctic, mainly through the AW inflow, but the Pacific inflow through Bering Strait is also a source of heat. This heat transport could influence the ice cover as suggested by Woodgate et al.

(2010), for the minimum sea ice cover in summer 2007. This Pacific influence has been investigated in future climate, during the project.

Main results achieved

Predictability of the sea ice cover at seasonal and decadal timescale (UiB, NERSC)

For decadal prediction, NorCPM has skill in predicting SIE at short lead time in the Arctic as a whole and in most of the marginal seas of Pacific and Atlantic sectors. For seasonal prediction, the skill varies regionally and seasonally. The Barents Sea shows the highest skill, especially for the winter-spring target months. A statistical regression model based on the SST in Gulf Stream extension provides also a skillful prediction of the winter ice extent in the Arctic up to a decade in advance (Årthun et al., 2017). In future climate, the ocean heat transport toward the Arctic remains a good predictor of the winter Arctic sea ice, even if the relationship weakens as the Barents Sea becomes ice free (Fig.2, Årthun et al., 2019).

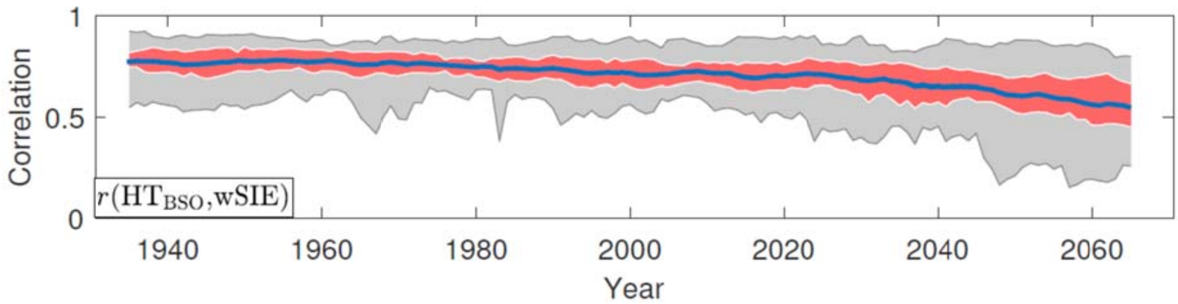

Figure 2*: Running 30-year correlations between the winter Barents Sea ice extent and the heat transport at the Barents Sea Opening from 40 members of an ensemble coupled simulation with CESM. Blue line: ensemble mean. Red shading: interquartile range. Grey shading: ensemble spread (from Årthun et al., 2019)*

Assessment of the variability of the heat content and transport (CNRS)

The heat content of the AW exhibits a clear annual cycle in the West Spitsbergen Current (WSC) (Fig.3). Separating the contribution of the mean temperature and cross-section area variations, respectively, to this annual cycle, it is possible to show that temperature variations dominate in the observations, with a variance twice larger than that associated with the area variations. The predominant impact of the temperature on the seasonal heat content is also found in the model, although to a lesser extent. This is mostly due to the underestimated seasonal contrast in the mean AW temperature in the model. Overall, the AW heat content across the Fram Strait section appears to be underestimated in the model (due to a negative bias in both the AW layer temperature and its offshore extent). Farther north, in the Eurasian Basin, a cold bias in the AW layer is still present in the model but the distribution of the AW heat agrees well with the observations.

The AW heat transport in Fram Strait is well correlated with the volume transport (both in observations and in the model) suggesting that the velocity variations are the main driver of the heat transport variability (Fig. 4). This transport is well correlated with the AW transport to the north of Svalbard, with maximum correlations occurring in phase. A maximum correlation of ~0.7 is found in the observations between the velocity in the core of AW north of Svalbard and the current in the inshore core of the WSC (Fig. 5) while a correlation of 0.78 is found in the model between the AW transport at 30°E and the WSC transport.

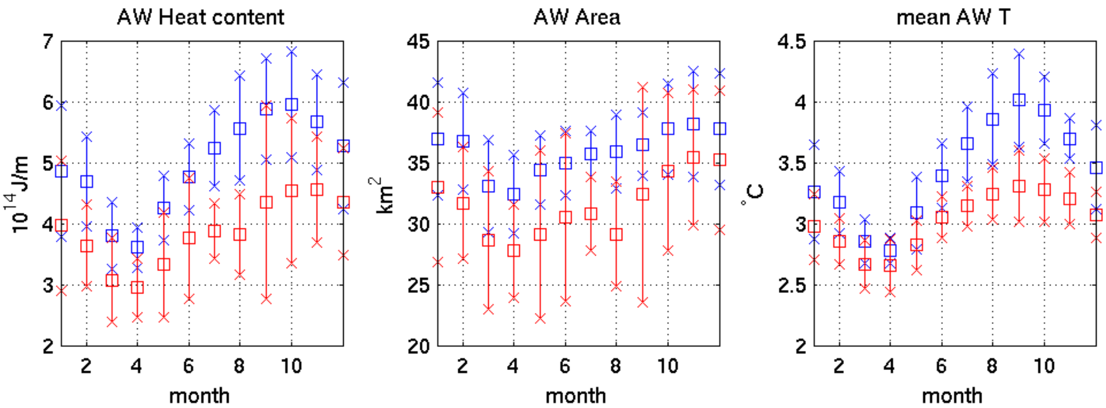

***Figure 3**: Long term mean of the monthly AW (left) heat content, (middle) area, and (right) mean temperature in the WSC, for (blue square) the mooring observations and (red square) the model, and their standard deviation (vertical bars with crosses indicating one standard deviation).*

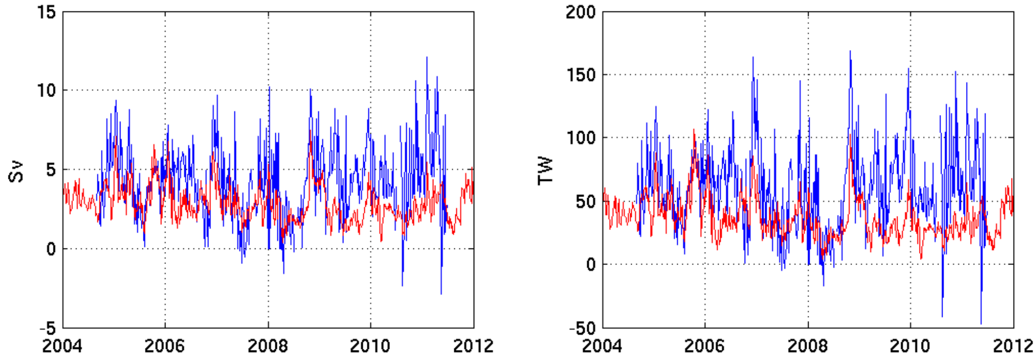

***Figure 4:** (left) AW volume and (right) heat transport through Fram Strait from (blue) the mooring observations and (red) the simulation.*

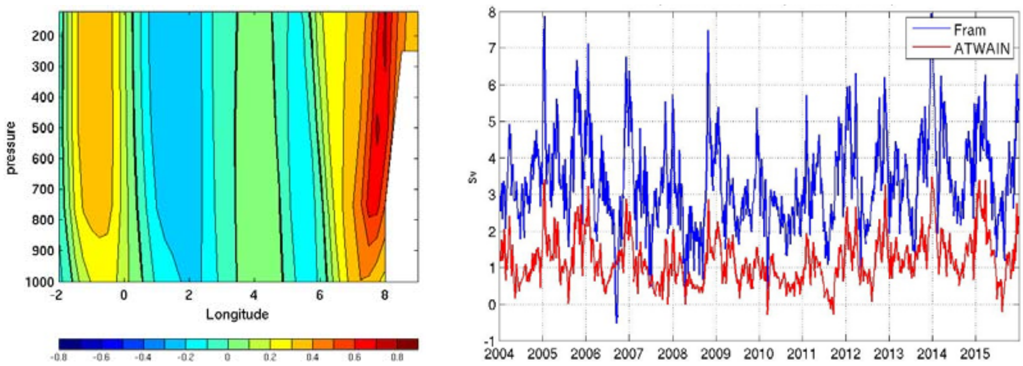

***Figure 5:** (Left) Correlation between the velocity at 200 m at the NABOS mooring at 30°E in the Eurasian Basin and the current velocity measured across the mooring network in Fram Strait. Velocities in Fram Strait lead the velocity at 30°E by 5 days. The correlations have been computed over a one-year period in 2004-2005. (Right) AW volume transport (blue) in Fram Strait and (red) at 30°E in the Eurasian Basin in the model. The correlation between the transports is 0.78 at lag 0.*

Processes controlling the heat transfer from ocean to the ice (CNRS, UiB)

The ice opening index suggests that large sea ice opening occurred in the early 2000s, in 2006 and in the early 2010s (Fig. 6). The 2006 event, which emerges as the largest event and is well reproduced in the model (Fig. 7), has been analyzed in more details. This event, which started at the beginning of January and lasted about a month, with a minimum ice cover occurring on January 25, was associated with large ice divergence and concomitant sea ice melting. Winds with a strong northward component advected the ice northward leading to an offshore opening of the ice, while increased vertical mixing in response to strong winds combined with the presence of Atlantic water closer to the surface brought an increased amount of heat to the surface. Enhanced vertical ocean heat flux contributed to expand the open water area eastward. When northerly winds started to blow in February, recapping the ocean with drifting ice, the presence of warm water at the surface contributed to slow down this process. This mechanism differs from the one suggested by Ivanov et al. (2016) to explain the low ice extent in winters 2012 to 2014, which mainly stresses the role of the winter thermohaline convection and the preconditioning by low ice cover in the preceding summers.

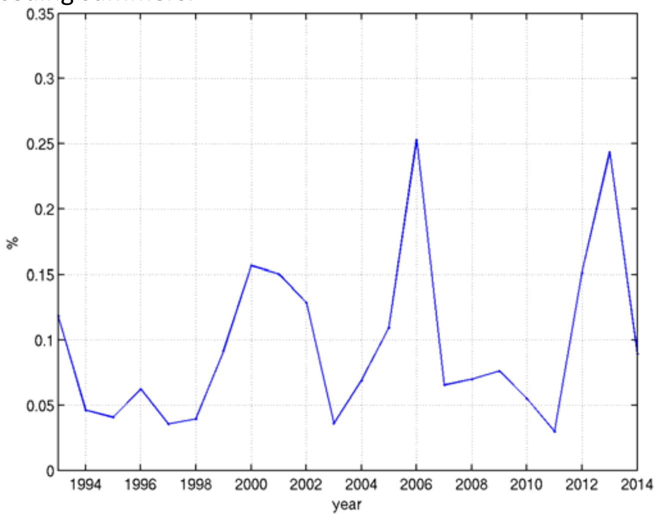

Figure 6: *Index of maximum sea ice opening computed from the ASI-SSMI dataset.*

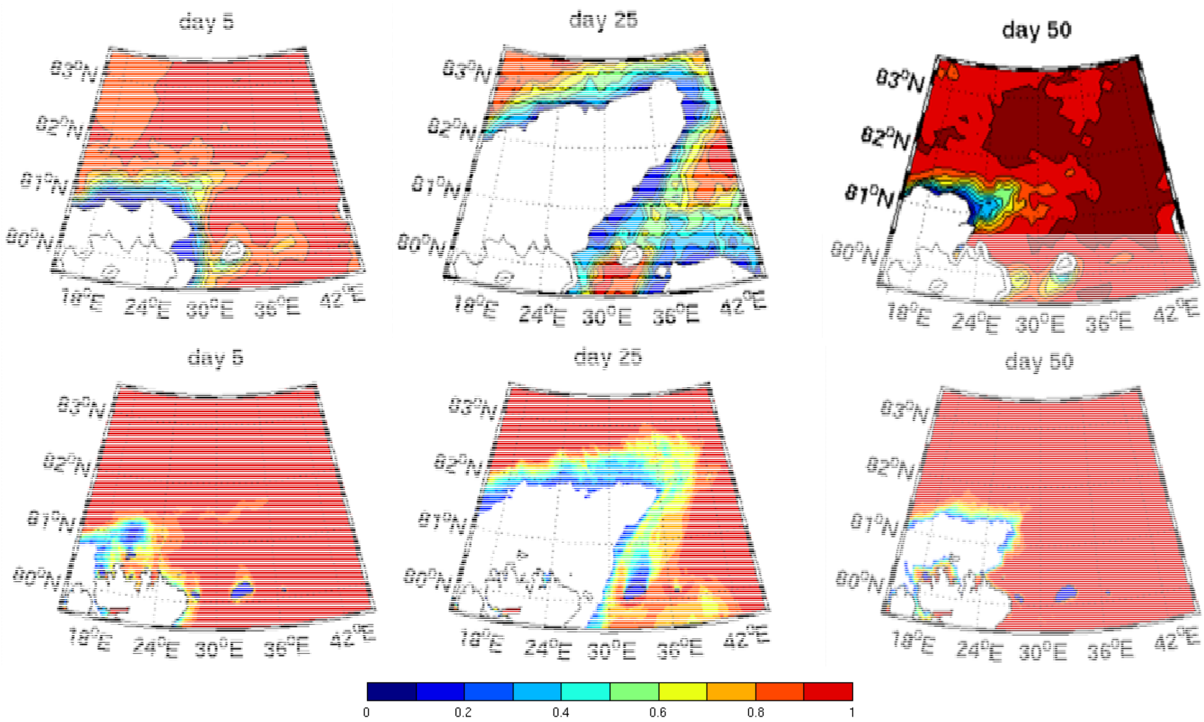

Figure 7*: 5-day average sea ice concentration, North of Svalbard, in 2006 from the (upper row) ASI-SSMI dataset and (lower row) the model.*

Although the Atlantic sector, via the Barents Sea and Fram Strait, is the main gateway for water masses exchanged with the Arctic Ocean, the Arctic sea ice cover is also influenced by the inflow of Pacific Water through the Bering Strait. There is local variability and trends associated immediately downstream of the strait, but also possibly remote decrease from relatively warm anomalies towards the Fram Strait (e.g., Zhang 2015). Analyses have also been performed within Blue-Action to contrast the Atlantic versus Pacific influence on Arctic sea ice retreat (building on Årthun et al. (2019) and the model system analyzed therein, CESM-LE). Following Onarheim et al. (2018), the synthesis of model sea ice trends in a "matrix of change" – for each Arctic regional sea and for each month of the year – suggests an Atlantic influence that progresses with time through the 21st century to reach the Laptev Sea, but with further influence being hampered by the Lomonosov Ridge. On the Pacific side of the ridge, and particularly for the second half of the 21st century, a Pacific influence is evident in retreating the sea ice extent from the Bering Strait and poleward. The analyses are part of Eldevik et al. (2019), which is presently being finalized for submission to a peer-review journal.

Progress beyond the state of the art

We show that the assimilation of SST is helpful to improve the regional SIE prediction skill on both seasonal and decadal time scale. North of Svalbard, the large decrease of winter ice cover in the early 2010s was already documented (Ivanov et al., 2016) but earlier events such as the 2006 event had not been reported nor their causes documented. In particular, we suggest a different mechanism (mainly based on the wind influence) for the 2006 opening from those which have been proposed for the early 2010 s events. The difference is partly due to the different background mean state of the sea ice in the

2000's when the sea ice cover north of Svalbard in winter used to extend much farther south than in the present decade.
It is also found – on the background of a consistently decreasing sea ice cover long-term trend with increased global warming – that the probability for periods of local increase in sea ice cover is still substantial (10–50%) in the near-term future (2031–2040), but increasingly unlikely the further into the future and the longer the time period considered.

Impact

This deliverable provides a better understanding of Arctic-lower latitude ocean linkages.

We show that climate models exhibits significant skill in predicting winter sea ice extent variations in the Atlantic Sector at seasonal and decadal timescales. This skill is mainly due to the relationship between ice extent and Atlantic heat transport. In the future, the heat transport remains a good predictor of winter sea ice extent. Some processes controlling how the heat can be transferred from the Atlantic Water layer to the surface to melt the ice are also described.

Lessons learned and Links built

Links have been built with the INTAROS project which will lead to the analysis of the influence of the ocean on sea-ice using in-situ observations collected during INTAROS and a high-resolution model simulation performed in the Blue-Action project.

Contribution to the top level objectives of Blue-Action

This deliverable contributes to the following objective:

Objective 2 Enhancing the predictive capacity beyond seasons in the Arctic and the Northern Hemisphere

We show that the assimilation of SST in the Norwegian Climate Prediction Model is helpful to improve the regional sea ice extent prediction skill on both seasonal and decadal time scale. A statistical regression model based on SST of the Gulf Stream extension provides also skillful prediction of the winter sea ice extent up to decade in advance.

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Dissemination and exploitation of Blue-Action results

Dissemination activities

Type of dissemination activity	Title	Place and dates	Estimated budget	Type of Audience	Estimated number of persons reached	Link to Zenodo upload
Participation to a workshop	Marie-Noelle-Houssais (CNRS) Presentation at the conference" Sea-ice in the earth system: a multidisciplinary perspective". Title of the presentation: "A mechanism for winter sea-ice opening to the north of Svalbard"	Brest (FR), 4-6 June 2019	See the form C of the partner involved.	Scientific Community (higher education, Research)	>40	https://www.zenodo.org/communities/blue-actionh2020
Participation to a conference	Marie-Noëlle Houssais (CNRS) presenting a poster at the Arctic Science Summit Week: "The West Spitzbergen Current in Fram Strait: insight from a model-observation analysis"	Arkhangelsk (RU), 22-30 May 2019	See the form C of the partner involved.	Scientific Community (higher education, Research)	>100	https://zenodo.org/record/3161312#.XOWOObh9FOc
Participation to a workshop	Tor Eldevik (UIB) Presentation at the ASOF/Blue-Action meeting on " How Atlantic heat makes Arctic ice retreat".	Copenhagen, (DK), 24-26 April 2019	See the form C of the partner involved.	Scientific Community (higher education, Research)	>40	https://www.zenodo.org/communities/blue-actionh2020
Participation to a workshop	Christophe Herbaut (CNRS) giving an oral presentation at the ASOF/Blue-Action meeting on " A mechanism of winter sea-ice opening north of Svalbard.	Copenhagen, (DK), 24-26 April 2019	See the form C of the partner involved.	Scientific Community (higher education, Research)	>40	https://zenodo.org/record/3066826#.XOOl5Lh9FOd
Participation to a conference	Marius Årthun (UIB) presenting at the EGU "The role of Atlantic heat transport in future Arctic winter sea ice loss".	Vienna (AT), 7-12 April, 2019	See the form C of the partner involved.	Scientific Community (higher education, Research)	>500	https://doi.org/10.5281/zenodo.3060257
Other	Yiguo Wang (NERSC) presenting a poster at EGU: "Seasonal-to-decadal climate prediction with the Norwegian Climate Prediction Model"	Vienna (AT) 7-12 April 2019	See the form C of the partner involved.	Scientific Community (higher education, Research)	>500	https://doi.org/10.5281/zenodo.3066859
Participation to	Marius Årthun (UIB) presenting at the	Rondane (NO), 25-28 March	See the form C	Scientific Community		https://doi.org/10.5281/zenodo.3060612

conference conference	Advanced Climate Dynamics Course 10 year anniversary conference "The role of Atlantic heat transport in future Arctic winter sea ice loss"	2019	of the partner involved .	(higher education, Research)		

Peer reviewed articles

Title	Authors	Publication	DOI (if available)	Is Blue-Action correctly acknowledged?	How much did you pay for the publication?	Status?	Open Access granted	Comments on embargo time imposed by the publisher	If in Green OA, provide the link where this publication can be found
Skillful prediction of northern climate provided by ocean	Årthun, M., T. Eldevik, E. Viste, H. Drange, T. Furevik, H.L. Johnson, and N.S. Keenlyside	Nature Communications	DOI:10.1038/ncomms15875	yes	See the form C of the partners involved.	Published on 20 June 2017	Yes	None	//
The role of Atlantic heat transport in future Arctic winter sea ice loss	Årthun, M., T. Eldevik, and L.H. Smedsrud	Journal of Climate	DOI:10.1175/JCLI-D-18-0750.1	Yes	Paid by another project	Published on 14 May 2019	Yes	12 months	//

Publications in preparation

C. Herbaut, M.-N. Houssais, A.-C. Blaizot, A mechanism of winter sea ice opening north of Svalbard, Journal of Geosphysical Research: Oceans

Other publications

Blue-Action Milestone: MS8: Assessment of heat transport and distribution in the high Arctic in eddy resolving model by Herbaut, C. Houssais, M.-N.; Blaizot, A.-C, https://www.zenodo.org/record/2682406#.XNwhfpw69D8