

Assessment of Oceanic Anomalies of Predictive Potential



Greenland ice sheets. Credits: SAMS

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Summary for publication

Climate prediction is the challenge to forecast climatic conditions months to decades into the future with a skill and regional detail that is of practical use. *Will, for example, Arctic sea ice cover increase the next winter? Will Scandinavian hydroclimate be particularly beneficial for hydropower production? Will Southern European summers be excessively warm through the 2020s?*

To what extent such conditions are predictable in nature and to what extent predictability can be realised in operational climate forecast systems and translated to useful stakeholder information, i.e., the climate equivalent to weather forecasting, remain unknown.

It is commonly understood that predictability resides with the more inert components of the climate system and particularly—as is the focus of Blue-Action—with ocean circulation. Blue-Action has substantiated this premise by exploring observations, climate models, and reanalyses (model simulations tightly constrained by available observations).

Successful avenues of research and progress made in Blue-Action include mapping out the dominant timescales of European interannual-to-decadal climate variability, the identification of consistent and predictable variability in Atlantic-to-Arctic ocean circulation, the link of ocean variability to fluctuating climate over land and sea ice extent, and making actual climate forecasts toward 2020.

We find that winter surface air temperatures for much of continental Europe, and generally for Eastern Europe, are characterized by a 5–10 year timescale. This reflects the variable strength of the large-scale westerly winds, commonly summarized in the so-called North Atlantic Oscillation (NAO) index. The longest timescale that our observation-based record resolves is a 25–40 year fluctuation characteristic for Western Europe (Iberia and England). This we associate with more hemisphere-scale coherent temperature fluctuations, the so-called Atlantic Multidecadal Oscillation (AMO).

The winter temperature over Northwest Europe (Norway, Sweden and parts of Finland), on the other hand, is dominated by an intermediate 14-year timescale coherent with the sea surface temperature of the Norwegian Sea. Fluctuating warm and cold ocean states off the east coast of Newfoundland progress persistently with ocean circulation to and through the Norwegian Sea subsequently to face the Arctic sea ice cover. Our analyses show that this variable ocean heat arrives predictably in the Norwegian Sea and imprints on the surface air temperature carried in over Scandinavia “downwind” with the mean westerly wind with a forecast horizon of 7–10 years.

We particularly predict (from data through to 2016) that Norwegian mean temperature and precipitation will decrease, although very marginally so (and remain above 1981–2010 climatology), toward 2020. And a general mean temperature decrease was indeed observed from 2014 through to 2018 (but only slightly from 2016). Similarly, winter sea ice extent in the Atlantic sector is predicted slightly to increase (but remain below climatology). This is qualitatively reflected in the fact that Arctic March winter maximum increased – also relatively slightly – from 2017 to 2018, and then again from 2018 to 2019.

A basis for exploring climate predictability is the access to, and maintenance of, key observational time series. Blue-Action benefits from the collective effort of the scientific community in making repeated observations of the

ocean and from satellite remote sensing of the sea surface. Importantly, Blue-Action contributes observations to this effort with full-depth hydrographic and current meter measurements of the water mass exchanges at the Greenland-Scotland Ridge, the main gateway between the North Atlantic and the Arctic region—including the passage into the Norwegian Sea of the Gulf Stream’s northern limb and the cold and warm ocean states giving rise to climate predictability as alluded to above.

A priority for Blue-Action is therefore both the maintenance and consistency of these main time series of northern ocean climate, and further to deepen the understanding of the full spectrum of variability reflected at the mooring sites (predictable and otherwise). We find that at seasonal time scales, the vigour of the exchanges generally reflects that of the regional wind (broadly speaking the NAO), but that changes in so-called buoyancy forcing (heat loss and freshwater input) seems increasingly important with increasing timescales.

The current meter measurement records, initiated by several of the Blue-Action partners through the 1990s, are still too short for confidently concluding on the nature of observed variability at timescales longer than the interannual. Further progress in “taking the pulse” of the Gulf Stream’s interaction with the Arctic is therefore from an observational perspective critically dependent on the future maintenance and thus increasing temporal range covered by the Greenland-Scotland Ridge observational array.

Work carried out

The *Description of Action for D2.5 Assessment of Oceanic Anomalies of Predictive Potential* reads:

In order to enhance climate predictability provided by the ocean, the **observed thermohaline anomalies** travelling the Nordic Seas and into Arctic Ocean **will be assessed and compared** with their **representation in state-of-the-art models** and the **underlying mechanisms** will be scrutinized. Particular emphasis will be on the models’ representation of the **flow through key hydrographic sections** in the GSR, the Norwegian Sea and into the Arctic (Barents Sea Opening, Fram Strait), as well as the **air-sea interaction associated** with persistent anomalies identified accordingly – and thus including also potential **impact by and on atmospheric circulation** (D2.5).

We have **emphasized in bold** what points to work carried out and have organized this part of the report accordingly. The itemized reporting is kept concise and relatively short for work that has been published or is in the process of peer review; work still in progress is described in a little more detail.

Assessment of anomalies [Partners involved: UiB, NERSC, NORCE, NCAR]. The manifestation and degree of persistence/predictability in the propagation of thermohaline anomalies from the North Atlantic through the Nordic Seas and eventually into the Arctic proper have been assessed based on observations (Fig. 1; Årthun et al. 2017), ocean reanalyses (Asbjørnsen et al. 2019), and climate model simulations (Langehaug et al. 2019; Årthun et al. 2019).

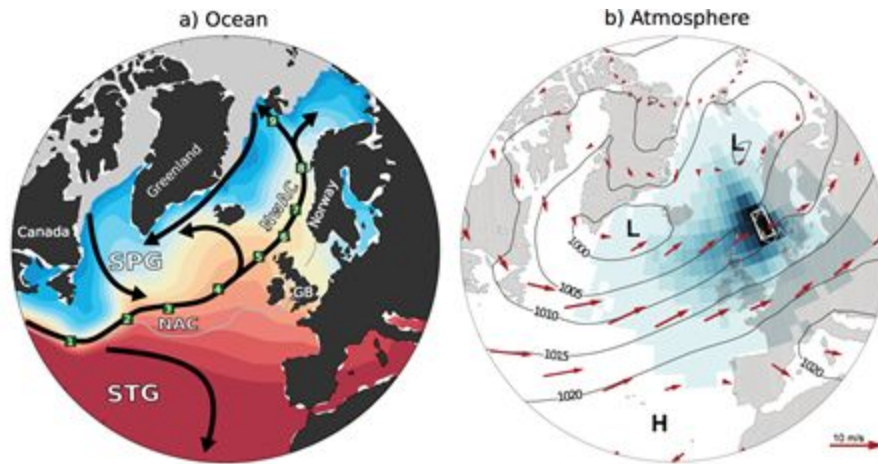


Figure 1. Dominant ocean and atmosphere circulation in the North Atlantic sector. (a) Climatological SST (colour) and major ocean surface currents (black arrows). Sea ice is indicated by the grey shading. The green squares represent the selected stations (St1–9) along the Atlantic water pathway [along which the propagation of thermohaline anomalies is considered]. The boundary between the subtropical gyre (STG) and subpolar gyre (SPG) is indicated by the time-mean zero sea surface height contour (grey line). (b) Mean winds (925 hPa; arrows) and sea level pressure (black contours) between 1998–2008 from Era-Interim reanalysis. H/L indicates high/low-pressure centers. The maritime influence on Norwegian climate is highlighted by the distribution of air (shading) in the planetary boundary layer one day before the air reaches western Norway (white box; calculated using a Lagrangian trajectory model), indicating the moisture source for downwind rainfall. [Figure and caption from Årthun et al. 2017.]

Anomalies have been identified by constructing and analysing hydrographic time series—both at virtual and standard hydrographic sections—along representative ocean pathways considering interannual and low-pass (typically pentadal) variability. The resulting variability and coherence were compared using, e.g., power spectra and spatial maps of lagged correlation/regression; and the nature and degree of persistent propagation were identified objectively using complex principal component (CPC; Fig. 2) analysis (e.g., Årthun et al. 2017; Langehaug et al. 2019).

When a complete and internally consistent data set is available for analyses, e.g., using the ECCOv4 Ocean State Estimate (Asbjørnsen et al. 2019), analyses are extended also to scrutinizing anomalies based on first principles (conservation of volume, heat and salt). Asbjørnsen et al. (2019) assess the oceanic transports and ocean-atmosphere fluxes constraining the heat content of the Norwegian Sea accordingly, after first having compared ECCOv4 relatively favourably with observed variability at standard regional hydrographic sections.

Representation in models [Partners involved: UiB, NERSC, HAV, NORCE, NCAR]. The representation of anomalous hydrography and ocean circulation has been assessed in a suite of global climate models (CMIP5 repository; Heuzé and Årthun 2019), in a large ensemble simulation of one climate model (CESM-LE; Årthun et al. 2019), and in two versions of the Norwegian Earth System Model (NorESM) subject to prescribed atmospheric forcing (Langehaug et al. 2019).

The methodology for assessing anomalies described above (e.g., power spectra, regression maps, CPC analyses) has generally been used for model evaluation against observations and model-model intercomparison. Basic comparison of climatological features, e.g., the magnitude of mean water mass exchange across the Greenland-Scotland Ridge, is also performed (Heuzé and Årthun 2019).

In addition, considering anomalous flow from the Arctic back to the North Atlantic, the high resolution ocean-only model NEMO has been evaluated against observed variance of overflow through the Faroe Bank Channel (Chafik et al., in prep).

Underlying mechanisms [Partners involved: UiB, NERSC, NORCE]. Broadly, two classes of mechanisms have been assessed.

1. The poleward progression of oceanic anomalies, e.g., to what extent is it intrinsic ocean circulation, and to what extent is it the atmosphere imprinting a seemingly advective signal on the surface ocean (Årthun et al. 2017; Langehaug et al. 2019; Asbjørnsen et al. 2019).
2. How the anomalous state of the ocean translates into climate variability over land (Kolstad and Årthun 2018; Årthun et al. 2018), and Arctic sea ice extent (Årthun et al. 2017, 2019; cf. D2.6 “Oceanic heat anomalies and Arctic sea-ice variability”¹).

The assessment of “an oceanic advective signal vs atmospheric imprint” (class #1) was performed according to the statistical methods described above (e.g., power spectra, regression maps, CPC analyses) but also importantly by comparing with the accompanying anomalous circulation of salt and radioactive isotopes (Årthun et al. 2017) which are more conservative tracers of ocean advection than SST/heat. In the case of reanalysis or model simulations, there is also more direct analysis done based on first principles, e.g., explicitly diagnosing the contributions of ocean advection and atmospheric heat flux in anomalous Norwegian Sea heat content (Asbjørnsen et al. 2019).

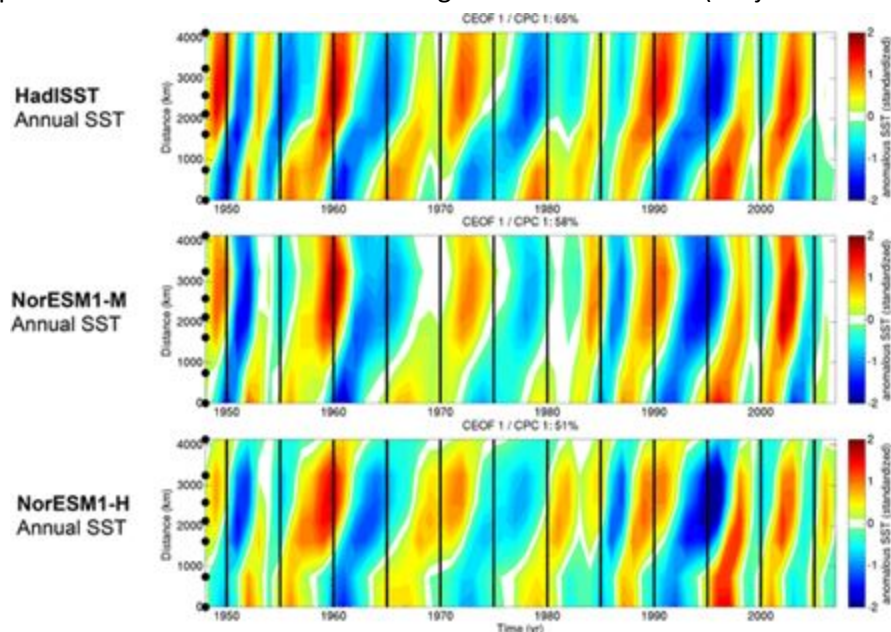


Figure 2. Observation-based and modelled SST anomalies. The poleward progression (vertical axis) of SST anomalies as a function of time from CPC analyses for HadISST (top panel) and a medium (middle) and relatively high resolution version (bottom) of the NorESM1. [Figure from Langehaug et al. 2019.]

The associated climate variability over land (class #2) is assessed in Årthun et al. (2017, 2018b). In Årthun et al. (2017), the assessment is relatively basic. The degree of common time scales and co-variance between selected time series in the ocean (Norwegian Sea) and over land (Norwegian surface air temperature, SAT, and precipitation; Central England Temperature) is identified, and retrospective predictability is quantified from regressional relations.

¹ Available in Zenodo: <https://www.zenodo.org/communities/blue-actionh2020>

The underlying assumption is that anomalous ocean heat can be carried over land by the mean westerlies. This assumption is put to test by Årthun et al. (2018b) using a dynamical analysis – the “constructed circulation analog” method – with data provided by a relatively novel coupled climate reanalysis (CERA-20C of the ECMWF).

Key hydrographic sections [Partners involved: HAV, NORCE, UiB, NERSC]. Available observations from key sections of poleward ocean heat transport, e.g., the Greenland-Scotland Ridge and the Barents Opening, are included either in the progression of oceanic anomalies (e.g., Årthun et al. 2017), or as evaluation of reanalysis or model data (e.g., Asbjørnsen et al. 2019; Årthun et al. 2019). Furthermore, the current meter measurements at all available gateways were synthesized and combined into a consistent total volume budget for the mean balance and eventual trends of Arctic Mediterranean exchanges, uncertainties included (Østerhus et al. 2019).

The Greenland-Scotland Ridge is a particular focal point of Arctic-Atlantic exchanges and of the Blue-Action project. During the project period, monitoring the volume transport and transports of heat (relative to 0°C) and salt of the strongest Atlantic inflow branch, which enters the Nordic Seas between Iceland and the Faroes and continues in the Faroe Current has been sustained. This has been carried out by regular CTD cruises and current measuring (ADCP) deployments funded by the Danish National project FARMON. To enhance the sustainability of the monitoring system, a major effort has been to evaluate and calibrate remote sensing (especially satellite altimetry) data in order to determine the minimum necessary component of (resource-demanding) in situ observations in the future monitoring system (Hansen et al., 2019).

For the distribution of heat downstream, including associated predictability—and also for general model evaluation, a main unknown has been how large a portion of the Faroe Current flows towards the Faroe-Shetland Channel, and joins the slope current towards the Barents Sea and the Arctic Ocean, and how much continues in a deeper branch heading for the Norwegian Sea interior (Hátún etl., in prep).



Figure 3. Deployment of mooring in the Faroe Current. Final control and verification of mooring details (left) prior to deployment of ADCP mooring (right).

In June 2017, two Acoustic Doppler Current Profiler (ADCP; Fig. 3) moorings (funded by FARMON) on the Faroese side of the Faroe-Shetland Channel just south of the entrance in order to observe the bifurcation of the Faroe Current

were deployed. These instruments were recovered in May 2018 and the data have been analysed within the FARMON and Blue-Action projects. The ADCP observations have been compared with satellite altimetry data, available surface drifter data and vessel mounted ADCP data and XBT data from the high seas ferry M/F Norrøna. The aim is to develop algorithms that will allow monitoring of the bifurcation by satellite altimetry (Hátún et al., in prep.). Hansen et al. (2017) analysed available in situ and satellite altimetry data in order to trace the further pathway of the bifurcated waters.

The well-constrained exchange of the Faroe Bank Channel (FBC) has also been further scrutinized as part of Blue-Action by combining observational data and altimetry, the latter specifically to identify the link between FBC overflow transport and the sea surface height in the southwest Norwegian Sea (Chafik et al., in prep).

Bringedal et al. (2018) synthesized all available current meter time series at the Greenland-Scotland Ridge distinguishing seasonal and interannual variability, assessing co-variance of the branches of in- and outflow in terms of anomalous horizontal and overturning ocean circulation. Modes and timescales of observed exchange were related to forcing patterns and variance of reanalysis wind and to theory also accounting for buoyancy forcing.

Air-sea interaction [Partners involved: UiB, NORCE]. Air-sea interaction, and in our case the interaction associated with persistent oceanic anomalies, can only be directly assessed in model or reanalysis-like data (at least for the observational data considered in D2.5). This was part of the Norwegian Sea heat budget analysis of Asbjørnsen et al. (2019) based on first principles to detail the relative role of the net air-sea heat flux in explaining the changing heat content of the Norwegian Sea (according to the ECCOv4 ocean state estimate). Årthun et al. (2018b), using coupled climate reanalysis, relate by regression “upwind” oceanic turbulent heat fluxes to the variable winter SAT over Europe.

Atmospheric circulation [Partners involved: UiB, HAV, NORCE]. The ocean and atmosphere are a fundamentally coupled component of the climate system. On one hand, for the anomalous state of the ocean to imprint on the climate over land it must first imprint on the atmosphere. And on the other hand, the mean and variable state of the atmosphere drives ocean circulation.

The variable state of the atmosphere, typically in terms of sea level pressure (SLP), has been related to the manifestation of thermohaline anomalies (Årthun et al. 2017), and to variable oceanic pathways and their strength (Årthun et al. 2019). Emphasis has been on documenting the eventual independence of oceanic variance – subsequently reflected over land – from that intrinsic to the dominant regional atmospheric teleconnection pattern, the NAO (Årthun et al. 2017, 2018b).

From the perspective of continental climate, Årthun et al. (2018b) have by means of combined dynamical and statistical analysis diagnosed the nature of spatial variability in European winter SAT to sort out what projects on variable atmospheric circulation (“dynamical” anomalies in the nomenclature of the analysis), e.g., the NAO, and what does not (“thermodynamic”) and thus can be traced back to an oceanic source “upwind”.

For the evolving heat content of the Norwegian Sea, Asbjørnsen et al. (2019) specifically assess the influence of local wind forcing thus disentangling the Ekman transport contribution to ocean advection. The atmospheric forcing of Greenland-Scotland Ridge exchanges have been assessed by relating atmospheric reanalysis, typically using regression, with observed current meter observations (Bringedal et al. 2018) and observed hydrography (Kristiansen et al. 2019).

Main results achieved

The organization of this part of the report is consistent with that of “Work carried out” above. The itemized reporting is kept concise and relatively short for results that has been published or is in the process of peer review; work still in progress is described a little more in detail.

Assessment of anomalies [Partners involved: UiB, NERSC, NORCE, NCAR]. Årthun et al. (2017) find that North Atlantic sea surface temperature (SST) anomalies progress persistently and predictably along the Gulf Stream’s poleward extension—the North Atlantic Current—and its partial continuation with the Norwegian Atlantic Current, through to facing Arctic sea ice in the Svalbard region (Barents Sea and Fram Strait). For multiannual variance (using a 5-year low-pass filter), we find that the leading mode of SST propagation explains 55% of the total SST variance and is characterized by a 14-year cycle. The propagation of SST is generally found to be accompanied by a consistent and coherent propagation of anomalous salinity.

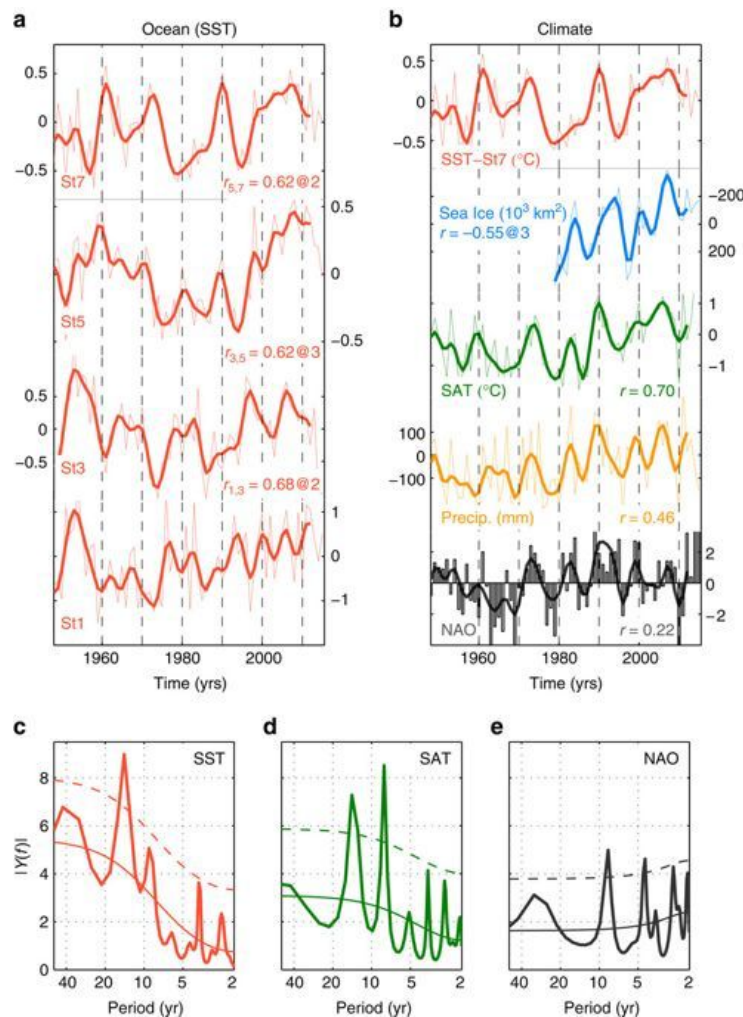


Figure 4. Oceanic anomalies of predictive potential. (a) Observed SST anomalies (°C) from the subpolar North Atlantic and Nordic Seas (increasing station number going downstream, cf. Fig. 1). Lagged correlations between low-passed and detrended time series are shown. (b) Time series of observed winter-spring Nordic Seas SST (St7), winter Arctic sea ice extent, annual Norwegian SAT and precipitation, and the annual NAO index. Correlations between low-pass filtered SST and other time series are given. In (a) and (b) thick lines show low-pass filtered data (Methods). All anomalies are relative to 1981–2010 climatology. (c–e) Power spectra, estimated by the maximum entropy method, for Nordic Seas SST (St7), Norwegian SAT, and the NAO index

based on unfiltered data from 1948 to 2015. Thin solid lines are the theoretical red noise spectrum computed by fitting a first order autoregressive process with a 95% confidence interval (thin dashed lines) around the red noise. [Figure and caption from Årthun et al. 2017]

In particular, Årthun et al. (2017) find that Norwegian Sea SST can be explained by upstream conditions in the subpolar North Atlantic off North America with a forecast horizon of 7 years, with warm/cold anomalies subsequently reflected in the decreasing/increasing Arctic winter sea ice extent 3 years later (relative to the decreasing long-term trend). The predictive potential is further documented by the covariance (50%) between Norwegian Sea SST and the mean surface air temperature (SAT) over Norway, including sharing the same 14-year time scale (Fig. 4). A weaker potential predictive influence was also inferred for precipitation over Norway (likely via precipitation linked to SAT as, in a maritime climate, warm air is generally moist) and for Central England Temperature (which finds its oceanic influence in multidecadal basin-scale variability, cf. Årthun et al. 2018b).

The manifestation of anomalous conditions in the Norwegian Sea was further assessed in Asbjørnsen et al. (2019). The dominant source of variability was found to be ocean advection, broadly consistent with the above but with the variable heat transport mostly related to changing volume transport. Furthermore, the active influence of regional air-sea heat fluxes was found to contribute to substantial additional interannual variance.

Representation in models [Partners involved: UiB, NERSC, HAV, NORCE, NCAR]. The observation-based documentation of propagating oceanographic anomalies guided the subsequent evaluation of anomalies in two versions of the Norwegian Earth System Model (NorESM; low vs higher horizontal spatial resolution) that were subject to prescribed atmospheric forcing (Langehaug et al. 2019). The SST propagation is qualitatively represented in these two model versions, but by no means perfectly simulated. There is not in every aspect a clear-cut distinction between the low-resolution and the high-resolution versions in performance. However, the higher resolution version is generally found to be the more accurate, both in terms of simulated inflowing anomalies from the North Atlantic to the Norwegian Sea and its relation to the structure and strength of the Subpolar Gyre. Langehaug et al. (2019) promote—and emphasize the need—further to assess the representation of these (and other) oceanographic anomalies of predictive potential in a broader suite of models (both forced and coupled).

A so-called “ocean state estimate”, as utilized by Asbjørnsen et al. (2019; in their case ECCOv4), is both a model simulation and observation-based; the simulation is consistently being constrained by observations or data products derived thereof. Asbjørnsen et al. (2019) provide evidence that the ECCOv4 – a complete and internally consistent data set – is both a realistic representation of and useful for assessing the state of the Nordic Seas, in their case specifically relating to poleward ocean heat transport and changing ocean heat content. A prime source for evaluating ECCOv4 realism prior to analyses was the generally favourable (but not perfect) comparison with repeated hydrographic sections at the Faroe-Shetland Channel and the Barents Sea Opening.

Similarly, reanalysis data products are now also available for the coupled air-ocean-sea ice system, and one such product (CERA-20C of the ECMWF) was used for the mechanistic analysis of cause-and-effect in variable and possibly predictable winter temperatures over Europe (Årthun et al. 2018b). The coupled reanalysis was in particular found to be consistent in the representation—importantly including characteristic time scales—of Norwegian Sea SST and surface air temperature observed over Scandinavia.

Heuzé and Årthun (2019) present the first multi-model assessment of the poleward ocean heat transport with the three main inflows to the Nordic Seas, using 23 state-of-the-art global climate models that participated in the Climate Model Intercomparison Project phase 5 (CMIP5). The majority of CMIP5 models have weaker poleward heat

transports than observed in the Denmark Strait and across the Iceland-Faroe Ridge. In contrast, in the Faroe-Shetland Channel, the majority of models have stronger transport than reported in observations. Discrepancies depend on the inflow branch considered. In Denmark Strait, model resolution is key, with high resolution being associated with strong transport, and low resolution and/or a too narrow strait with weak heat transport. In the Faroe-Scotland channel the linear relationship between resolution and heat transport is only valid for models coarser than 1°, whereas the resolution has no significant impact on the inflow across the Iceland-Faroe ridge. The representation of atmospheric dynamics, and in particular the relative location of the low/high pressure systems in the North Atlantic, are also crucial. Models with too weak heat transports have their Iceland-low pressure center shifted towards the central Atlantic, thus shifting the wind stress that controls the inflow.

Årthun et al. (2019) assess the temperature, volume- and heat transport through the Barents Sea Opening in the CESM large ensemble. Compared with observations the heat transport into the Barents Sea is underestimated as a result of lower temperatures than observed. The lower temperatures are furthermore reflected in an overestimated sea ice cover, especially during recent decades. The model nevertheless represents well present-day ice-ocean interaction in the Barents Sea, quantified as the sensitivity of simulated sea ice extent to interannual heat transport variations.

Underlying mechanisms [Partners involved: UiB, NERSC, NORCE]. We generally corroborate that “anomalies of predictive potential” are indeed intrinsic to Subpolar-to-Arctic ocean circulation (Årthun et al. 2017; Langehaug et al. 2019; Asbjørnsen et al. 2019). There is nevertheless a relatively broad literature that explains similar anomalous ocean heat, and particularly SST, from atmospheric forcing (see Årthun et al. 2017 for a brief discussion and relevant references). However, our inference that the propagating anomalies are not the atmosphere imprinting on the ocean surface is supported by two additional lines of independent evidence. First, there is a consistent pattern of propagation and persistence in accompanying subsurface salinity anomalies; second, radioactive tracers are observed to travel from release sites in France and the UK to and through the Norwegian Sea having consistent characteristics (Årthun et al. 2017). This does not exclude the possibility that the atmosphere is also contributing to the anomalies’ manifestation, although this process is secondary in magnitude as the bulk of the heat is carried by the ocean. The analysis of Asbjørnsen et al. (2019) of the ocean state estimate ECCOV4, shows that air-sea heat flux—although of lesser physical magnitude—contributes variance explained to the Norwegian Sea heat budget similar to that associated with ocean advection.

The poleward reach of warm ocean circulation anomalies is found to restrict the Arctic winter sea ice extent in the Atlantic sector (Fram Strait and Barents Sea; Årthun et al. 2017, 2018a, 2019, cf. D2.6 “Oceanic heat anomalies and Arctic sea-ice variability” deliverable report for on the specific topic of sea ice). This predictable ice-free Atlantic domain is what defines the possible habitat for Barents Sea cod: this physical constraint “capture[s] well multi-year to decadal variations in cod stock biomass”, with variance explained exceeding 60% considering retrospective predictions (Årthun et al. 2018a). Prediction errors are particularly associated with harvest rates and additional unexplained variance intrinsic to the marine ecosystem that is not accounted for only considering hydrography.

We readily admit that in nature, it is generally not a case of anomalies strictly being either of oceanographic or of atmospheric origin. And the inference for a specific case will always be somewhat dependent on the premise for the analysis done. Hydrographic anomalies truly imbedded in ocean circulation can have a source upstream or back in time rooted in the atmosphere; the pathway of ocean circulation considered can very well be sustained or vary from atmospheric forcing. The further pursuit of the origin and maintenance of the oceanic anomalies addressed here will remain a priority in our present and future research, both as a fundamental quest for understanding coupled

air-ocean-ice climate-scale interactions in the Atlantic-Arctic sector and for the practical realisation of eventual climate predictability.

Key hydrographic sections [Partners involved: HAV, NORCE, UiB, NERSC]

Time series of volume transport through the key hydrographic sections over the GSR have been included into a recent synthesis supported by Blue-Action of all the observed exchanges between the Arctic Mediterranean and its neighbouring oceans (Østerhus et al., 2019). The synthesis emphasizes the key role of the Atlantic inflow across the GSR for the marine Arctic. The total Atlantic inflow has a seasonal variation on the order of 1 Sv with maximum inflow in early winter, which mainly derives from the inflow through the Faroe-Shetland Channel. Although considerably stronger on the average, the inflow between Iceland and Faroes has a much weaker seasonal signal (Østerhus et al. 2019; Bringedal et al. 2018).

On longer time scales, the total Atlantic inflow and outflow/overflow across the GSR has remained remarkably stable during the two decades of monitoring (Fig. 5). There may have been an increase in transport during the last years of the 20th century, although not statistically significant. Any weakening of the total inflow through the two decades can, however, be excluded. This finding is strengthened by the stable transport of the two main overflow branches that return most of the Atlantic inflow back to the Atlantic Ocean (Østerhus et al., 2019). Although the Atlantic inflow and the outflow/overflow is an integral part of the AMOC, the reported weakening of the AMOC during this period (e.g., Smeed et al., 2018) has not affected the volume transport of Atlantic inflow to the Arctic Mediterranean (Østerhus et al., 2019).

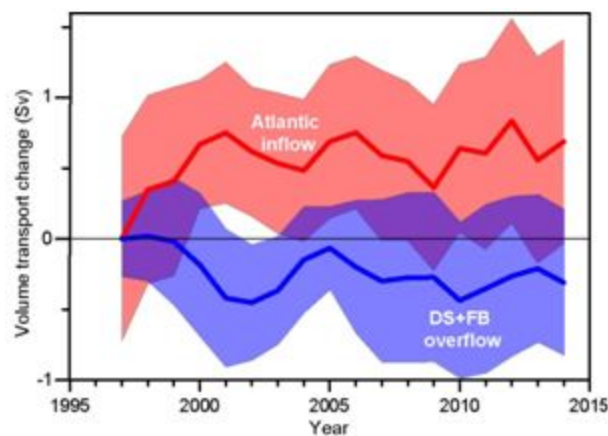


Figure 5. Anomalous Atlantic inflow and dense overflow. Low-passed (3-year running mean) volume transport change (from the value in 1997) of the sum of the four Atlantic inflow branches (thick red line) and the sum of the two main overflow branches (thick blue line). All changes are shown as positive into the Arctic Mediterranean. The coloured areas represent the 95 % confidence interval [figure from Østerhus et al., 2019].

For the strongest inflow branch, the Faroe Current, transport time series have been updated to May 2018 and for this branch there is indications of a long-term increasing trend (Fig. 6). Indeed, 2017 was the year with highest volume transport in the 25 year long series. Note, however, that the 95%-confidence interval of the the trend estimate ($0.012 \pm 0.013 \text{ Sv yr}^{-1}$) does include the null-hypothesis of no trend, if barely. For heat transport, inter-annual variations are governed by the variations in volume transport (Fig. 6), but the long-term increase in temperature (Fig. 7) has added to the increasing trend in volume transport so that the overall increasing trend for the 25 year series of heat transport ($0.70 \pm 0.46 \text{ TW yr}^{-1}$) is significant at the 95% confidence level.

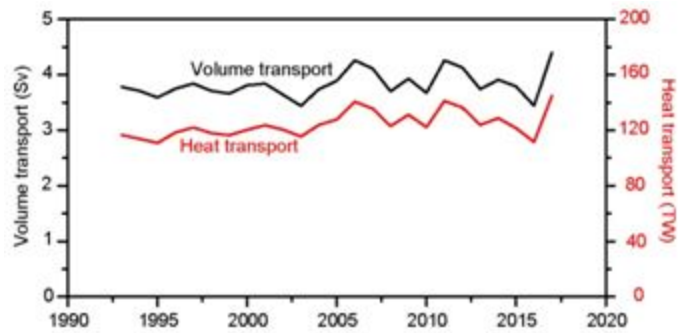


Figure 6. Observed Faroe Current Transports. Annually averaged transport of volume (black) and heat relative to 0°C (which is close to the average temperature of water returning from the Arctic Mediterranean, red). Updated from Hansen et al. (2015).

Around 70% of the total Atlantic inflow is converted to dense water and leaves the Arctic Mediterranean as overflow (Østerhus et al., 2019), which underscores the importance of the overflow in maintaining a stable Atlantic inflow (Hansen et al., 2010). Since the salinity of the inflowing Atlantic water determines the density that it can achieve by cooling, the observed freshening of the inflow (Fig. 7) is a warning signal that needs following up. This freshening is caused by a severe freshening of the subpolar North Atlantic (Holliday et al., in review). Associated with this freshening, there has been a change in the hydrographic character of the inflow. Up to 2016, changes in temperature and salinity have generally been parallel, but since then they have diverged (Fig. 7).

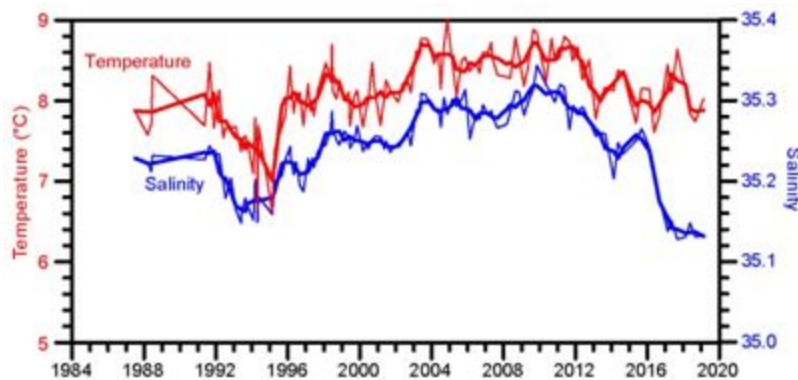


Figure 7. Atlantic inflow hydrography (Faroe Current). Deseasonalised salinity (blue) and temperature (red) in the Atlantic water core of the Faroe Current. Thin lines are values from individual cruises and thick lines are 1-year running means. Updated from Larsen et al. (2012).

The main result in Hátún et al (In Prep) is that a part of the inter-annual and seasonal wind-driven variability observed in the Norwegian Atlantic Slope Current is caused by a variable contribution from the Faroe Current. This means that within the Nordic Seas, interaction between the Atlantic inflows via the Iceland-Faroe gap and the Faroe-Shetland Channel, respectively, must be assessed to progress in estimates of the Atlantic heat transport through to the high Arctic. Furthermore, analyses of deep current observations acquired by HAV show that the Faroe Bank Channel overflow feeds from several sources. The good correspondence between these observations and results from a high resolution ocean-only model (NEMO) verify that the source waters for the overflow are variable and geographically distributed, suggesting a net stabilizing role of this “flexible” dense-water reservoir (Chafik et al., in prep) – corroborating the main conclusion of the synthesis by Østerhus et al. (2019) that the exchanges between the Arctic Mediterranean and the Atlantic Ocean—particularly in terms of volume transport—have been remarkably stable over the last two decades.

Bringedal et al. (2018) further scrutinized the observed variability at the Greenland-Scotland Ridge (three branches of Atlantic inflow and two branches of dense overflow). For seasonal to interannual timescales, wind-forcing and a horizontal barotropic-like circulation is found to carry the observed variance. An influence of the wind remains, but buoyancy forcing within the Nordic Seas and vertical overturning circulation from inflow to overflow are suggested to be of increasing importance the longer the timescale considered (inference on this aspect will presumably be better constrained as the observations are maintained into the future extending the present 20 yr record).

Considering the further evolution through the 21st century, Årthun et al. (2019) find in their analyses of a large-ensemble climate model simulation (CESM-LE, RCP8.5) that AMOC will weaken under continued global warming (in line with the general finding from the CMIP5 suite of models), but that Arctic-Atlantic exchanges, e.g., providing more heat to a retreating Arctic winter sea ice cover, will strengthen. However, the further downstream branch into the Barents Sea will provide more heat to the Arctic from persistently warming, but its volume transport is projected to weaken.

Another somewhat surprising finding, is that even though interannual to decadal thermohaline anomalies are observed robustly to progress from the Subpolar Gyre region into the Norwegian Sea (e.g., Årthun et al. 2017), Asbjørnsen et al. (2019) find that the local communication across the ridge is somewhat intermittent and thus not very pronounced in “low-pass” properties when considering the ECCOv4 ocean state estimate. In this data, the connection is more robust considering unfiltered (monthly) timeseries.

Relatedly, how variable flow strength interplays with the progression of warm and cold ocean states from the North Atlantic to the Arctic across the ridge, and thus how the flow strength sustains (or obscures) northern climate predictability, remains unknown and a main research question in need of resolution.

Air-sea interaction [Partners involved: UiB, NORCE]. Air-sea interaction between anomalous ocean heat or SST, implicit to much of the above observation-based inference, was explicitly assessed in Årthun et al. (2018b) and Asbjørnsen et al. (2019) as they had at their disposal sufficiently complete and self-consistent data sets (coupled reanalysis and an ocean state estimate, respectively). As already summarized above, Asbjørnsen et al. (2019) find anomalous air-sea heat flux relatively marginal in magnitude compared to the anomalous heat contributed to the Norwegian Sea by ocean circulation, but the two contribute similarly in terms of variance explained. Directly related to ocean predictability communicated over land, Årthun et al. (2018b) find that the ~14 yr oceanic mode reflected in Scandinavian winter temperature is associated with the mean westerlies and in-phase heat loss from the Norwegian Sea to the atmosphere (Fig. 8).

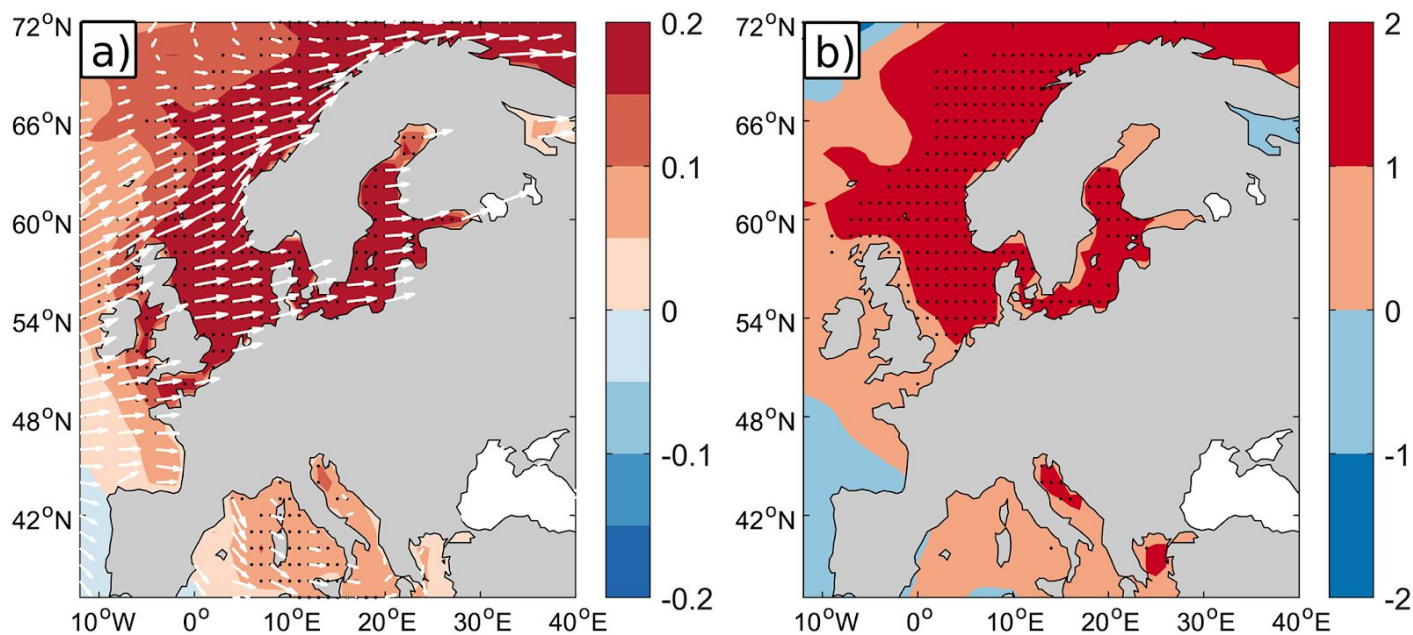


Figure 8. SST, mean westerlies, and ocean heat loss reflected over land. (a) Sea surface temperature (SST) variability associated with so-called “thermodynamic” surface air temperature (SAT) in northern Europe (cf. the “Work carried out” section), calculated by linear regression (unit: °C/°C). The white arrows show the mean surface winds over the ocean (925 hPa). **(b)** Surface turbulent heat fluxes regressed onto the annual rate of change of thermodynamic SAT in northern Europe (unit: Wm⁻²/Δ°C). Heat fluxes out of the ocean are defined as positive. Dots indicate correlations significant at the 95% confidence level according to a random phase test. [Figure and caption from Årthun et al. (2018b)]

Atmospheric circulation [Partners involved: UIB, HAV, NORCE]

A main priority for Blue-Action and D2.5 has been to document eventual predictability over land related to the poleward propagating thermohaline anomalies with the North Atlantic Current/Norwegian Atlantic Current. And, indeed, Årthun et al. (2017) find Norwegian Sea SST reflected (primarily) in mean SAT over Norway, literally downwind of the anomalous ocean state. This is documented in how the SST regresses on spatial maps of SAT and sea level pressure (SLP); it is particularly shown that the oceanic variance reflected over land is *independent* of that associated with the variable strength of the westerlies, the NAO, which is the main source of variance rooted in the atmosphere.

The above is corroborated by Årthun et al. (2018b) applying the “constructed circulation analogs” methodology to the complete data set of a coupled reanalysis. Winter temperatures of Scandinavia are primarily related to the propagating ocean anomalies of ~14 yr timescale, communicated over land by the mean wind; temperatures over continental and eastern Europe primarily relate to NAO, the variable interannual wind of ~8 yr timescale; and temperatures over Iberia and UK again relate to the ocean with the mean westerlies, but then at a multidecadal timescale, i.e., so-called Atlantic Multidecadal Variability (AMV) to the extent that it is resolved by 110 yr long data set.

Considering seasonal time scales, Kolstad and Årthun (2018) show that fall SST anomalies in the Norwegian and Barents seas have the potential to predict wintertime SAT anomalies in Europe. Norwegian Sea SST anomalies in spring are also significant predictors of European SAT anomalies in summer. The analysis suggests that Barents Sea SST anomalies in fall causes NAO anomalies in winter, which then again causes SAT anomalies over western Europe during the same season. However, the strength of this link and, hence, the potential for prediction has not been stationary in time and highlights that the physical relationships that form the basis of statistical prediction models should continuously be reassessed.

In the projected ensemble-mean evolution reflecting the external forcing under continued global warming (RCP8.5), Årthun et al. (2019) find that the exchanges between the Subpolar North Atlantic and the Nordic Seas will strengthen due to lower SLP in the Nordic Seas region, in spite of an AMOC weakening. The downstream branch entering the Arctic through the Barents Sea is weakening from projected change in local winds. Asbjørnsen et al. (2019) find that Ekman transport adds magnitude to the general ocean heat transport, and Bringedal et al. (2018) relate the seasonal-to-interannual coherence of Greenland-Scotland Ridge water-mass exchange to regional sea level pressure and wind stress curl associated with NAO-like variance.

Progress beyond the state of the art

Successful and observation-based avenues of research and progress made in Blue-Action include mapping out the dominant timescales of European interannual-to-decadal climate variability, the identification of consistent and predictable variability in Atlantic-to-Arctic ocean circulation, the link of ocean variability to fluctuating climate over land and sea ice extent, and making actual climate forecasts toward 2020.

The observation-based “benchmarking” has been extended to – and thereby evaluating – the use of ocean state estimates and coupled climate reanalyses. We foresee a next stage where the benchmarks and predictability proven from observations will be key for the evaluation and further improvement of numerical climate prediction models, the basis for eventual future operational (and skilful) climate prediction similar to present weather forecasting.

Impact

How has this work contributed to the expected impacts of Blue-Action?

The outcomes of this deliverable contribute to an integrated understanding of low-latitude drivers of Arctic change, and, hence, to an improved capacity to predict climate of the Northern Hemisphere. Based on observations and model simulations, the work has identified climate variables and regions of high potential predictability, and established the underlying mechanisms. The assessment of Arctic predictability also includes marine fisheries, which could help to improve stakeholders’ capacity to adapt to climate variability and change.

The predictable relationships identified in this deliverable provide mechanistic benchmarks for climate prediction models, which will improve the capacity of these models to represent Arctic climate change and associated predictability (WP4).

The work performed has contributed to development of new data products by combining in-situ measurements from the Faroe Current bifurcation monitoring system with satellites Earth Observations. These products may be used by the modelling community in order to enhance the predictive capacity of climate models. The analysis of these data provides a better estimate of ocean heat anomaly propagation towards the Arctic.

The work performed in this deliverable contributed to the Blue-Action first policy briefing (D8.11²).

Lessons learned and links built

- The work carried out in this deliverable links to Blue-Action deliverables D2.1 “Model-observation and reanalyses comparison at key locations for heat transport to the Arctic”, D2.2 “Seasonal to decadal variability of the subpolar gyre” and D2.3 “Processes and flow over the Iceland-Faroe Ridge”. These deliverables are in preparation and will be published in December 2019. Final versions will be available in Zenodo: <https://zenodo.org/communities/blue-actionh2020>
- Contributed to the Science-Policy breakfast discussion "The slowing Gulf Stream? What we know and potential impacts" held at the European Parliament on 4 September 2018 together with H2020 AtlantOS on invitation of the European Parliament Intergroup Seas, Rivers, Islands & Coastal Areas (Searica). The policy briefing document is available in Zenodo: <https://zenodo.org/record/1409470>
- Joint ASOF/Blue-Action workshop on Arctic-Subarctic Ocean Fluxes in Copenhagen April 2019: <http://www.blue-action.eu/index.php?id=5019>
- Key European-US partners of both ASOF and Blue-Action came together for the Arctic-Nordic Seas synthesis of ocean gateway exchanges of Østerhus et al. (2019)
- Blue-Action (including D2.5 scientists Olsen, Årthun, Eldevik) contributes to the upcoming *Workshop on Climate Prediction in the Atlantic-Arctic sector* jointly organised by the Bjerknes Climate Prediction Unit and the EU Modelling Cluster on 5-7th June 2019, Bergen (NO). The EU Modelling cluster is collecting a number of H2020 projects: Blue-Action, APPLICATE, PRIMAVERA, CRESCENDO and others H2020 and Norwegian-funded projects working on modelling topics: <http://www.blue-action.eu/index.php?id=4229> Outcomes of this specific workshop will feed the D6.2 deliverable of Blue-Action “Second Joint workshop to (re)formulate open research questions of joint interest (2nd Modelling Workshop and ASOF meeting)”

Contribution to the top level objectives of Blue-Action

This deliverable contributes to the achievement of the following objectives and specific goals indicated in the Description of the Action, part B, Section 1.1: <http://blue-action.eu/index.php?id=4019>

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

The potential for climate predictability based on the propagation of ocean heat anomalies from the North Atlantic through the Nordic Seas and eventually into the Arctic proper have been assessed based on observations, ocean reanalyses, and climate model simulations. It has been shown that the Arctic winter sea ice cover and temperature over northwestern Europe can be predicted several years in advance based on the state of the ocean. Skillful climate based multi-year predictions have also been demonstrated Northeast Arctic cod.

² Olsen, Steffen, Årthun, Marius, Eldevik, Tor, Fritz, Jan-Stefan, Larsen, Karin, Miller, Ræanne, ... Oltmanns, Marilena. (2018, September 3). The Slowing Gulf Stream? What we know and potential impacts (Policy Brief) (Version 4 September 2018). Zenodo. <http://doi.org/10.5281/zenodo.1408097>

Objective 4 Improving the description of key processes controlling the impact of the polar amplification of global warming in prediction systems

By assessment of the variable contribution of the Faroe Current to the Norwegian Atlantic Slope Current, which acts to improve estimates of ocean heat fluxes to the high Arctic.

The mechanisms and predictable relationships identified in observations provide benchmarks against which dynamical prediction systems can be compared and improved. Major shortcomings in the representation of poleward ocean heat transport in global climate models (CMIP5) have also identified. Multi-model assessments and the identification of across-model similarities and differences are important in order to improve climate models. The large spread in modelled poleward ocean heat transport highlights the uncertainty in future projections of ocean heat transport and associated climate impacts.

Objective 5 Optimizing observational systems for predictions

HAV has continued its efforts to optimize the monitoring system for the Faroe Current and has added a component monitoring the bifurcation of this current into the Faroe-Shetland Channel and the easternmost branch of the pole-ward oceanic heat transport.

Objective 7 Fostering the capacity of key stakeholders to adapt and respond to climate change and boosting their economic growth

Skillful multi-year predictions of the commercially valuable Barents Sea cod stock demonstrate the potential for ecosystem-based fisheries management. Integrating the identified relationship between upstream climate variability and cod stock into management frameworks could enable the possibility of better fisheries management advice on a longer time scale than today.

Objective 8 Transferring knowledge to a wide range of interested key stakeholders

To policy makers: Blue-Action contributed preparation, context and introductions to the Blue-Action Science-Policy breakfast discussion "The slowing Gulf Stream? What we know and potential impacts", European Parliament, 4 September 2018 together with AtlantOS with inputs from Steffen M. Olsen (DMI), Tor Eldevik (UiB), Ben Moat (UKRI-NOC), Karin Margretha Larsen (HAV), Marius Årthun (UiB) and Marilena Oltmanns (GEOMAR).

To policy makers: Steffen Olsen (DMI) and Tor Eldevik (UiB) were part of their respective national delegations at the Arctic Science Ministerial (ASM2) in Berlin, Germany, 25 October 2018.

To policy and decision makers: Tor Eldevik (UiB, EASAC working group leader) and Gerard McCarthy (NUIM) are part of the newly established (May 27 2019) working group for the planned EASAC (European Academies Science Advisory Council) report "Changes in Ocean Circulation and Consequences for European Coastal Regions".

To policy and decision makers: Marius Årthun (UiB) contributed to the Nordic Workshop on Ocean and Climate, hosted by the Norwegian Environmental Agency in Oslo, Norway, 14 May 2019.

To policy and decision makers: Marius Årthun (UiB) contributed to the European Climate Research Alliance (ECRA) general assembly in Brussels, Belgium, 28 February 2019.

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Dissemination and exploitation of Blue-Action results

Dissemination activities

Type of dissemination activity	Name of the scientist (institution), title of the presentation, event	Place and date of the event	Type of Audience	Estimated number of persons reached	Link to Zenodo upload
Participation to a workshop	Bogi Hansen (HAV), Presentation “Atlantic water flow and heat transport between Iceland and Scotland” at ICES WGOH meeting	Tórshavn (FO), 4-6 April 2017	Scientific Community (higher education, Research)	20	https://doi.org/10.5281/zenodo.2671766
Participation to a conference	Hjalmar Hátún (HAV), Presentation “Selected short-stories from Icelandic waters” at Biology Conference	Reykjavik (IS), 26-28 October 2017	Scientific Community (higher education, Research)	500	https://doi.org/10.5281/zenodo.1295411
Participation to a conference	Tor Eldevik (UiB); “On observed northern climate change and predictability”, invited at the ACSIS - OSNAP - RAPID Joint Science Meeting	Oxford (UK), 19-21 September 2017	Scientific Community (higher education, Research)	100	https://www.zenodo.org/record/1293305
Participation to a conference	Tor Eldevik (UiB), “Skillful prediction of northern climate provided by the	Oslo (No), 7 November 2017	Scientific Community (higher	300	https://www.zenodo.org/record/1292502

	ocean”, invited; Research Council of Norway, Svalbard Science Conference 2017		education, Research)		
Participation in activities organised jointly with other H2020 project	Tor Eldevik (UiB), Presentation “The Gulf Stream and Climate”; SEARICA Science-Policy breakfast discussion, European Parliament	Brussels (Be), 4 September 2018	Policy makers	20	https://zenodo.org/record/140947
Participation to a workshop	Tor Eldevik (UiB), Presentation “How Atlantic heat makes Arctic sea ice retreat”; ASOF workshop	Copenhagen (Dk), 25 April 2019	Scientific Community (higher education, Research)	50	https://zenodo.org/record/3235663
Participation in activities organised jointly with other H2020 projects	Marius Årthun (UiB) Presentation "Blue-Action: Quantify the role of a changing Arctic in predictive capability of weather and climate of the Northern Hemisphere" at the ECRA general assembly	Brussels (BE), 28 February 2019	Scientific community and policy makers	50	http://doi.org/10.5281/zenodo.2585603
Participation to a conference	Marius Årthun (UiB), Presentation "The role of Atlantic heat transport in future Arctic winter sea ice loss" at EGU 2019	Vienna (AT), 7-12 April 2019	Scientific community	100	https://doi.org/10.5281/zenodo.3060257
Participation to conference	Marius Årthun (UiB) Presentation “The role of Atlantic heat transport in future Arctic winter sea ice loss” at the Advanced Climate Dynamics Course 10 year anniversary conference	Rondane (NO), 25 March 2019	Scientific Community (higher education, Research)	50	https://doi.org/10.5281/zenodo.3060612
Participation to a conference	Helene R. Langehaug (NERSC) Presentation “Thermohaline variability along the Atlantic Water pathway in the forced Norwegian Earth System Model” at the ACSIS - OSNAP - RAPID Joint Science Meeting	Oxford (UK), 19-21 September 2017	Scientific Community (higher education, Research)	100	https://zenodo.org/record/3236143#.XPEBSy2B1TY
Participation to an event	Helene R. Langehaug (NERSC), invited presentation: “Mechanisms	Norheimsund (NO), 5 July, 2018	Scientific Community (higher	30-40	https://zenodo.org/record/3236162#.XPEEcy2B1TY

	that give rise to predictability in the North Atlantic – Nordic Seas”; Summer School on ‘Climate Teleconnections and Predictions: Past, Present and Future’		education, Research)		
Participation to an event	Helene R. Langehaug (NERSC) Presentation “Predictive skill along the extension of the North Atlantic Current in the Norwegian Climate Prediction Model” (poster); Getaway for the Bjerknes Centre for Climate Research	Geilo (NO), 10-12 January, 2018	Scientific Community (higher education, Research)	130	https://www.zenodo.org/record/1292950#.XPEIei2B1TY

Peer reviewed articles

These are the publications acknowledging Blue-Action already published.

Title	Authors	Publication	DOI	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
Arctic Mediterranean exchanges: a consistent volume budget and trends in transports from two decades of observations	Østerhus, S., Woodgate, R., Valdimarsson, H., Turrell, B., de Steur, L., Quadfasel, D., Olsen, S. M., Moritz, M., Lee, C. M., Larsen, K. M. H., Jónsson, S., Johnson, C., Jochumsen, K., Hansen, B., Curry, B., Cunningham, S., and B. Berx	Ocean Science	https://doi.org/10.5194/os-15-379-2019	Yes	See form C of the partner organisation.	Published 12 April 2019	Yes, this is an Open Access journal	//	//

Structure and forcing of observed exchanges across the Greenland-Scotland Ridge	Bringedal, C., Eldevik, T., Skagseth, Ø., Spall, M.A., and Østerhus, S.	Journal of Climate	https://doi.org/10.1175/JCLI-D-17-0889.1	Yes	See form C of the partner organisation.	Published 19 November 2018	Yes	//	//
Atlantic water flow through the Faroese Channels	Hansen, B., Poulsen, T., Larsen, K.M.H., Hátún, H., Østerhus, S., Darelus, E., Berx, B., Quadfasel, D., Jochumsen, K.	Ocean Science	https://doi.org/10.5194/os-13-873-2017	Yes	See form C of the partner organisation.	Published 13 November 2017	Yes, this is an Open Access journal	//	//
Variability along the Atlantic water pathway in the forced Norwegian Earth System Model	Langehaug, HR, Sandø, AB, Årthun, M, Ilıcak, M	Climate Dynamics	https://doi.org/10.1007/s00382-018-4184-5	Yes	See form C of the partner organisation.	Published January 2019	Yes, this is an Open Access journal		

Peer reviewed articles accepted

Kristiansen, I., Hátún, H., Petursdottir, H., Gislason, A., Broms, C., Melle, W., Jacobsen, J.A., Eliassen, S.K., Gaard, E., Decreased influx of Calanus spp. into the south-western Norwegian Sea since 2003., *Deep Sea Res.*

Peer reviewed articles in review

Holliday, N. P., M. Bersch, B. Berx, L. Chafik, S. Cunningham, H. Hátún, W. Johns, S. A. Josey, K. M. H. Larsen, S. Mulet, M. Oltmanns, G. Reverdin, T. Rossby, V. Thierry, H. Valdimarsson, I. Yashayaev, Ocean circulation changes cause the largest freshening event for 120 years in Subpolar North Atlantic, *Nature Communications*

Peer reviewed articles in preparation

Hátún, H., Larsen, K.M.H., Hansen, B., Chafik, L. .The Southern Faroe Current

Chafik, L., Hátún, H., Hansen, B., Skagseth, O., Herbaut, C., and Larsen, K. M. H., An eastern source for the Faroe Bank Overflow

Other publications

Eldevik, T, L.H. Smedsrud, C. Li, M. Årthun, E. Madonna, and L. Svendsen, 2019: The Arctic Mediterranean. In *Interacting Climates of Ocean Basins: Observations, Mechanisms, Predictability, and Impacts*, C.R. Mechoso, Ed., Cambridge University Press, in review.

Yu, J.-Y., E. Campos, Y. Du, T. Eldevik, S.T. Gille, T. Losada, M.J. McPhaden, and L.H. Smedsrud, 2019: Variability of the oceans. In *Interacting Climates of Ocean Basins: Observations, Mechanisms, Predictability, and Impacts*, C.R. Mechoso, Ed., Cambridge University Press, in review.

Uptake by the targeted audiences

As indicated in the Description of the Action, the audience for this deliverable is The general public (PU) is and is made available to the world via [CORDIS](#).

This is how we are going to ensure the uptake of the deliverables by the targeted audiences:

We are going to make results available to the scientific community through participation in workshops and conferences.

The next one on our plan is the Workshop on Climate Prediction in the Atlantic-Arctic sector jointly organised by the Bjerknes Climate Prediction Unit and the EU Modelling Cluster on 5-7th June 2019, Bergen (NO).

Participation to other events for sharing results with the scientific community and other target audiences are planned after the summer break.