2015 Report to the OSNAP International Oversight Committee 9.21.2015

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1. OSNAP Overview

a. Program goals

The overarching goal of the Overturning in the Subpolar North Atlantic Program (OSNAP) is to measure the full-depth mass fluxes associated with the AMOC (Atlantic Meridional Overturning Circulation), as well as meridional heat and freshwater fluxes. Funded in the summer of 2013 and deployed in the summer of 2014, this observing system is currently slated for a four-year deployment.

The specific OSNAP objectives are to:

1. Quantify the subpolar AMOC and its intra-seasonal to interannual variability via overturning metrics, including associated fluxes of heat and freshwater.

2. Determine the pathways of overflow waters in the North Atlantic subpolar gyre (NASPG) to investigate the connectivity of the deep boundary current system.

3. Relate AMOC variability to deep water mass variability and basin-scale wind forcing.

4. Determine the nature and degree of the subpolar-subtropical AMOC connectivity.

5. Determine from new OSNAP measurements the configuration of an optimally efficient long-term AMOC monitoring system in the NASPG.

The first two objectives will be met directly via the observing system, while the latter three goals will be achieved in coordination with ongoing and planned programs.

While we are aware that a four-year deployment (with possible extension to an 8-10 year record) is insufficient to make clear assessments of the AMOC's response to anthropogenic climate change, previous observations (Yashayaev et al. 2008) have suggested a high likelihood that significant interannual changes in deep convection would occur during the OSNAP measurement period, allowing an assessment of its linkage to AMOC variability. Indeed, convection during the 2014-2015 winter was the deepest and strongest since 1995 (I. Yashayaev, personal communication), creating the potential for a strong overturning signal across the OSNAP West array.

With regard to longer-term AMOC variability, OSNAP will contribute to an assessment of the critical measurements needed for a multi-decadal observing system and will provide essential ground truth to AMOC model estimates. The intent is to move toward an observing system where a few critical *in situ* observations, coupled with satellite observations and the Argo float array, provide a reliable and sustainable measure of the AMOC for decades to come.

b. Connections to other programs

A key aim of this work is to build a North Atlantic MOC observing system by integrating observations from the RAPID-MOCHA 26.5°N array and from the Nordic Seas exchange across the

Greenland-Scotland Ridge (GSR). Overflows through the Denmark Strait, across the Iceland Ridge and through Faroe Bank Channel, and the inflows west and east of Iceland and west of Scotland have been monitored for decades through research efforts in Iceland, the Faroe Islands, Norway, Denmark, Germany and Scotland. Currently, these measurements are continuing at least through 2017 as part of the European Union NACLIM (North Atlantic CLIMate) project. Also, the RAPID observing system, in place since 2004, will be in place at least until 2022. Together, OSNAP, the GSR observations and the RAPID 26°N observational systems provide a means to evaluate intergyre connectivity and to establish a long-term comprehensive observing system in the North Atlantic.

OSNAP is also connected with Ventilation, Interactions and Transports Across the Labrador Sea (VITALS; knossos.eas.ualberta.ca/vitals/), a Canadian research program designed to measure the uptake and storage of oxygen and carbon in the central Labrador Sea over several season cycles. Another connected program is the French Reykjanes Ridge Experiment (RREX; http://wwz.ifremer.fr/lpo/La-recherche/Projets-en-cours/RREX), an observational and modeling study designed to study the processes controlling the dynamical connections between the two sides of the Reykjanes Ridge.

Finally, OSNAP plans to participate in AtlantOS (www.atlantos-h2020.eu), an EU research and innovation project, whose goal is the integration of existing ocean observing activities in the Atlantic.

c. International partners and their contributions

OSNAP is an international program with contributions from seven countries, as depicted in Figures 1 and 2 and described below.

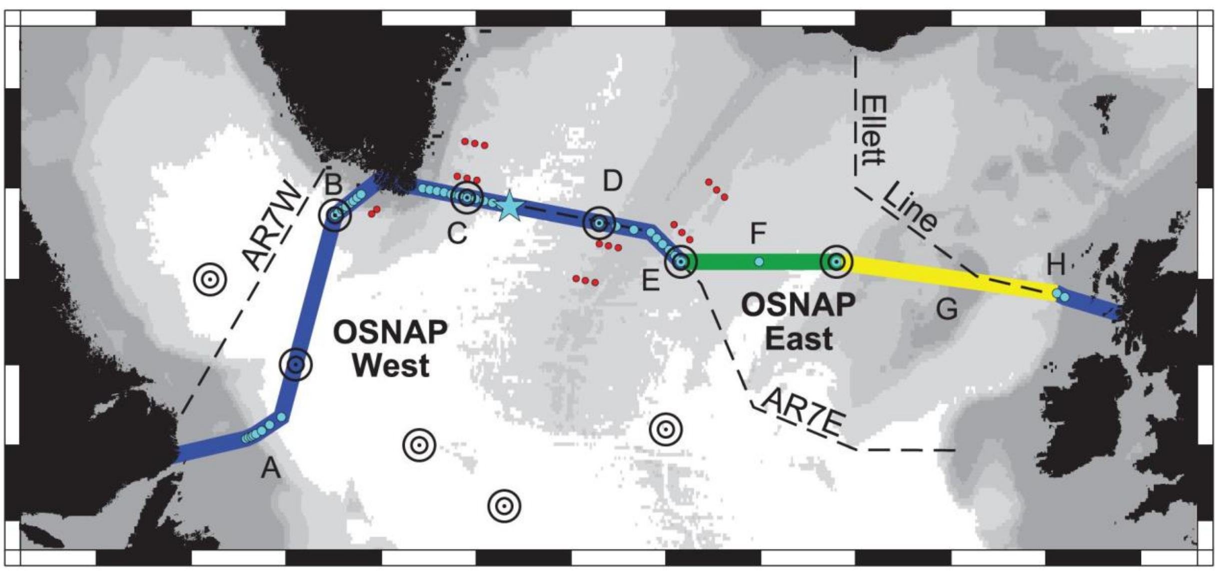


Figure 1: Schematic of OSNAP array. (A) German 53°N western boundary array and Canadian shelfbreak array; (B)US West Greenland boundary array; (C) US/UK East Greenland boundary array; (D) Netherlands western Mid-Atlantic Ridge array; (E) US eastern Mid-Atlantic Ridge array; (F) OUC (China) glider survey; (G) UK glider survey over Hatton-Rockall Bank and Rockall Trough; (H) UK Rockall Trough current array. Red dots: US float launch sites; Blue star: US OOI Irminger Sea global node; Black concentric circles: US sound sources.

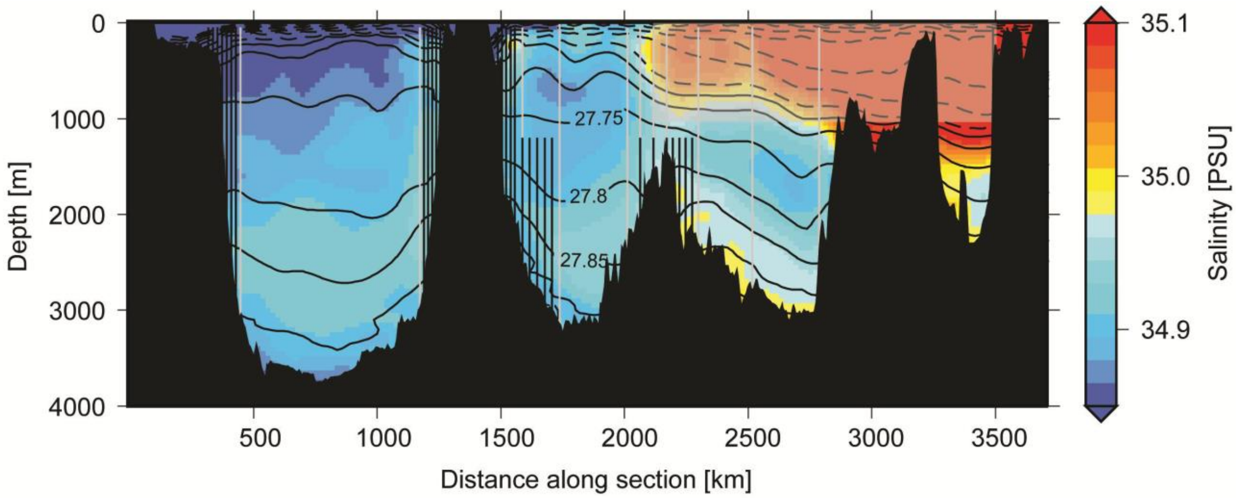


Figure 2: OSNAP array superposed on climatological salinity. Mooring locations (vertical lines) and glider domains (shaded boxes) are indicated. To reconstruct the velocity field, we are directly measuring the currents at the boundaries and the flanks of the Reykjanes Ridge and using T/S sensors and gliders to estimate the interior geostrophic velocities. Black moorings indicate where the velocity field is directly sampled. Gray moorings double as direct velocity measures and endpoints for the geostrophic regions.

Canada

The Canadian contribution to OSNAP is from Fisheries and Oceans Canada (DFO) and Memorial University. Canada supports the deployment of moorings on the 53°N line and deploys gliders on the shelf and in the Labrador Sea in support of OSNAP and the Labrador Sea gas exchange program VITALS. Canada has deployed moorings on the shelf inside the German array at 53 ^{0} N with the goal of making measurements in the Labrador Current that is centered over the shelf break. Another mooring is deployed on the inner shelf. These moorings are measuring the freshwater and heat flux in the upper water column. Glider deployments serve the purpose of measuring the alongshelf structure of the shelf-slope Labrador Current. It is intended that the Canadian moorings will be turned over each year as they are deployed in a region of intense fishing activity.

China

The Chinese contribution to OSNAP is from the Physical Oceanography Laboratory of the Ocean University of China. To provide higher spatial resolution of water properties along the eastern part of the OSNAP line Ocean University of China (OUC) and Woods Hole Oceanographic Institution (WHOI) began a collaborative effort in 2014 to collect glider-based hydrographic measurements in the eastern Iceland Basin. The gliders, first deployed on leg 1 of the OSNAP summer 2015 cruise, will provide information on energetic mesoscale processes and biogeochemical processes in this basin, as well as improve the estimate of the overturning, heat and freshwater fluxes across the OSNAP East line.

In addition to this observational effort, PIs from OUC are employing a high-resolution model, a two-layer model and a one and a half layer model to study AMOC and ocean heat content changes during the past two decades. The goal is to identify the key dynamics that control the AMOC variability on decadal time scales. Observational data will also be used in this analysis.

Germany

No official OSNAP project exists in Germany, but OSNAP aligns very well with long term observing efforts in the subpolar North Atlantic conducted at GEOMAR Helmholtz Centre for Ocean Research Kiel (53°N array), the University of Bremen (47°N array) and the University Hamburg (Denmark Strait overflow). In the Labrador Sea the 53°N array has been recognized as a central part of the OSNAP West section. The array is in part financed by GEOMAR through institutional funding in the research program "OCEANS". Moreover, the array maintenance is financed through the German RACE (Regional Atlantic Circulation and Global Change) project phase 1 (ending in 2015) and phase 2 (2016-2018). The array consists of 7 moorings of different complexity, from short (300m) moorings recording only at two depths to full depth (>3000m) moorings. Two short moorings are also added to the northern branch of the OSNAP West section and supplement the US West Greenland array.

Furthermore, Germany has, and will provide ship time for the installation and recovery of instrumentation as well as for international partnerships.

The Netherlands

The Netherlands contribution to OSNAP is from the Royal Netherlands Institute for Sea Research (NIOZ). This contribution consists of a mooring array of 4 tall moorings between 3000 and 1400 m in the Irminger Current (IC) on the western flank of the Reykjanes Ridge. The moorings IC1 through IC4 were installed for the first time in July 2014 and capture the northward flowing Irminger Current. The subsurface moorings consist of current meters, ADCPs and SBE37 Microcats at the bottom, 1500 m, 1000 m, 750 m, 500 m and 65 m depth.

A fifth mooring (IC0), located at the western end of this array at 2940 m depth, was made possible through contributions from WHOI, RSMAS and NIOZ. This mooring extends only up to 2250 m and aims to capture the northward flowing ISOW. The Dutch mooring array in the IC is largely funded through the EU project NACLIM (www.naclim.eu). The Royal Netherlands Institute for Sea Research (NIOZ) contributed two 3-week long cruises (OSNAP East leg 1 and leg 2) during the summer of 2015 and continues to contribute marine research facilities, *e.g* moored instrumentation and personnel, to the OSNAP project.

United Kingdom

UK OSNAP is a NERC (Natural Environment Research Council) Large Grant funded for 5 years and supported by NERC National Capability funding. Partners are the National Oceanography Centre, Scottish Association for Marine Science, Oxford University and Liverpool University. The objectives of UK OSNAP are:

1. To contribute to the OSNAP array with measurements in (a) the DWBC in the Irminger Basin (5 moorings with current meters, ADCPs and microcats); (b) the Eastern Boundary (gliders and 5 moorings with current meters, ADCPs and microcats); and (c) a high quality, high resolution synoptic hydrographic section across the OSNAP line with full suite of biogeochemistry (including carbonate) at the start of the fieldwork programme (2014). This objective is led by NOC and SAMS.

2. To generate a seasonally-resolved time series of SPG circulation and isopycnal and diapyncal mixing rates and their contribution to net fluxes of heat and freshwater, from 2001, and for each of the SPG sub-basins. Led by NOC, this work will use historical records from Argo float profiles.

3. To identify the link between SPG heat storage and convergence in ocean heat transport. Led by Liverpool University, this effort will use dynamical assimilation and forward model experiments to

develop diagnostics of ocean heat content change and heat transport convergence, and to explore the link to atmospheric forcing regimes.

4. To quantify and understand the local and remote causes of the observed SPG variability using a combination of adjoint modelling at non-eddying resolution to determine sensitivities, and high-resolution eddy-permitting forward modelling to test sensitivity robustness (Oxford University)

5. To develop metrics appropriate to the SPG mass, heat and freshwater fluxes by exploring improvements to AMOC metrics via the inclusion of horizontal circulation and Ekman fluxes, and by testing using models (mentioned above), inverse solutions (mentioned above) and the OSNAP array.

United States

OSNAP is led by the United States and funded by the National Science Foundation. Participating institutions are Duke University, University of Miami and the Woods Hole Oceanographic Institution.

Iceland basin array along OSNAP East

The University of Miami's contribution to OSNAP is an array of 8 moorings across the Iceland Basin extending from the top of the Reykjanes Ridge to the edge of the Hatton Bank in the east. It is designed to capture several key elements of the NASPG circulation: (1) the DWBC along the eastern flank of the Reykjanes Ridge, composed of ISOW and its entrainment products; (2) the northward flow of upper ocean waters transported by the main branch of the NAC toward the Norwegian Seas; and (3) the southward recirculation of the Iceland basin sub-gyre of the NASPG along the eastern flank of the Reykjanes Ridge. The array consists of a basin-spanning array of four full-water column "dynamic height" moorings carrying vertical arrays of moored T/S sensors, to monitor geostrophic transports across broad segments of the Iceland Basin and a closely-spaced DWBC array along the eastern flank of the Reykjanes Ridge made up of four additional deep (>1200 m) moorings. In all, the array contains 28 current meters, 60 temperature/salinity recorders and 4 acoustic Doppler current profilers.

OSNAP float program

WHOI and Duke are contributing to OSNAP through a study of the overflow water pathways in the subpolar North Atlantic in order to determine the degree of connectivity of the deep boundary currents. Forty acoustically-tracked RAFOS floats are being deployed in the paths of Iceland-Scotland Overflow Water (ISOW) and Denmark Strait Overflow Water (DSOW) in 2014, in 2015 and in 2016 at depths between 1800 and 2800 m. They will be tracked using an array of 10 RAFOS sound sources and collect position, temperature and pressure measurements once per day for two years. Complementing this observational effort is a modeling effort focused on simulating Lagrangian pathways for the overflow waters, as well as investigating the subpolar to subtropical export of the overflow waters and Labrador Sea Water. The overall goal of the modeling study is to understand what mechanism controls the interannual variability in the export of subpolar waters into the subtropical region.

East Greenland array along OSNAP East

WHOI is also contributing via the deployment of seven moorings across the East Greenland and Irminger Currents off of SE Greenland in conjunction with the UK moorings sampling the DWBC. This OSNAP deployment, in the summer of 2014, was coordinated with the Ocean Observatories Initiative (OOI) deployment of the Irminger Sea node, which included additional sampling of properties and currents at depth. The WHOI East moorings will be recovered and re-deployed in the summer of 2016.

West Greenland array along OSNAP West

WHOI is also responsible for the mooring array across the West Greenland shelf and slope that is part of the OSNAP-West line. The array is designed to measure the West Greenland Current, Irminger Current and Deep Western Boundary Current. There are 8 US moorings on the line: three tripods on the shelf and five tall moorings on the continental slope. The instrumentation consists of point hydrographic measurements (MicroCats), point velocity measurements (Aquadopps) and profiling velocity measurements (ADCPs). In addition to this, GEOMAR contributed two short moorings on the seaward end of the array to provide additional coverage of the near-bottom component of the Deep Western Boundary Current.

Calculation, delivery of OSNAP products and assessment of OSNAP legacy

Duke is responsible for the calculation and delivery of the OSNAP products (see section 3a). Susan Lozier will work with all OSNAP PIs responsible for observational measurements to assure the timely delivery of OSNAP products to the community. Please see the OSNAP Data Management Plan for further information on data collection, policy and dissemination.

Duke is also responsible for a study of which instruments/arrays are critical for the overturning measures so that plans can be made for key sustained measurements of the subpolar AMOC. Initially this work will use model data in order to have proven methodology once the OSNAP array data becomes available. A goal of this work will be to design a cost-effective monitoring of the subpolar AMOC.

d. OSNAP organization

Steering committee

The purpose of the OSNAP steering committee is to provide guidance and oversight to the program as a whole. Each participating country has one representative. The specific goals of the steering committee are to:

1. Facilitate project communication and collaborations
2. Provide oversight of OSNAP data management and sharing
3. Coordinate timing and agendas of both national and international meetings
4. Interface with the international project oversight committee.

All members serve three years. The committee meets quarterly via teleconference at national or international meetings as the opportunity arises. The current steering committee members are: Canada: Brad DeYoung; China: Xioapei Lin; Germany: Johannes Karstensen; The Netherlands: Laura de Steur; United Kingdom: Penny Holliday; United States: Susan Lozier (chair)

OSNAP International Project Oversight committee

The overall purpose of the OSNAP International Project Oversight Committee (IPOC) is to provide an independent assessment of progress toward OSNAP program goals. The IPOC, whose membership is drawn from the international oceanographic community, will provide that assessment to the OSNAP Steering Committee on an annual basis. The OSNAP Steering Committee has the responsibility for the response to the assessment.

The primary focus of the IPOC assessment will be an evaluation of progress on the international OSNAP program goals. Additionally, the IPOC assessment will provide advice on effective communication within the OSNAP scientific community, to the broader oceanographic community and to the public in general. Advice will also be sought on the coordination of OSNAP activities, management and dissemination of OSNAP data, timely publication of scientific results and on the strategic direction of the program. Finally, the IPOC will provide advice on the extent to which OSNAP effectively engages with other North Atlantic observational programs.

Current IPOC members are: Kevin Speer (Chair), Florida State University; Patrick Heimbach, Massachusetts Institute of Technology; Monika Rhein, University of Bremen; Sabrina Speich, Ecole Normale Supérieure; and Richard Wood, Met Office Hadley Centre.

Additionally, UK OSNAP is reviewed by the RAPID-OSNAP Programme Advisory Group, which has a UK-specific role that is similar in scope to the International Oversight Committee.

2. Progress to date

Canada

The first dedicated cruise was on the CCGS Hudson in the summer of 2014; three moorings were deployed along the shelf slope of the 53°N line. These three moorings include RDI ADCPs, Seabird MicroCats, Aanderaa current meters and temperature sensors. The locations are indicated in the table below. At two of the moorings (C1 and C2) both a short and a tall mooring were deployed. Details of the mooring deployments can be found in the cruise report that will be available from the OSNAP web site.

Table 1. Canadian moorings

Mooring	Mooring #	Latitude (DD)	Longitude (DD)	Depth (m)
C3	1874	51.70	52.82	807
C2	1882	51.85	52.76	345
C2	1873	51.85	52.76	345
C1	1872	52.10	52.67	306
C1	1881	52.09	52.67	306

Three Teledyne Webb Slocum gliders were deployed on this cruise very near the mooring line. Two of the gliders could reach 1000m, one was limited to 100m depth. These gliders operated for almost one month, crossing back and forth across the shelf break front. Results from this study have been presented at the 2015 national science meeting of the Canadian Meteorological and Oceanographic Society (CMOS) in British Columbia.

Two of the moorings deployed in 2014 – C1 and C3 – were turned over on the CCGS Hudson cruise that took place in May 2015. No initial problems with instruments have been discovered and preliminary data processing is underway. The C2 mooring was not turned over because of lack of time. It is planned to turn over the C2 mooring in May 2016.

China

In the summer of 2014, three participants from OUC joined cruise Kn221-03 and assisted the mooring group from WHOI and SAMS in mooring preparation, instrument maintenance and mooring deployment. This cruise was the first observational experience for OUC scientists in the North Atlantic.

In the past year, a joint team of technical staff, faculty and post-docs from OUC and WHOI has made the following progress: 1) Purchase of two long-endurance 1000-m G2 Slocum gliders; 2) Pre-deployment ballasting, simulation and field testing at WHOI; 3) Deployment of the first glider on the OSNAP-East line during cruise PE399 on the R/V Pelagia in June 2015. The glider is repeatedly transiting between OSNAP-East moorings M3 and M4 (deployed by W. Johns at RSMAS). 4) The glider has now been running for over 70 days, during which four sections (including 200 profiles) have been executed. The data being sampled include pressure, temperature, salinity, dissolved oxygen, CDOM, chlorophyll, backscatter and irrradiance.

These data will provide valuable high-resolution information regarding the energetic mesoscale variability between M3 and M4. In addition to contributing to flux estimates these glider observations, taken in the same area as the North Atlantic Bloom experiment, will be used to investigate seasonal changes in the relationship between physical and biogeochemical processes. The glider will continue operation until the end of November 2015, at which point it will be sent most likely to Reykjavik, Iceland for recovery in December or early January. When recovering the first glider, the second one will be deployed to continue the mission. The second glider has been delivered to WHOI and its ballasting and pre-deployment testing will be conducted before December. The table below shows the sensors on the glider.

Table2. OUC and WHOI Glider sensors

	SENSOR	SERIAL#	QUANTITY	SUPPLIER
1	Slocum Payload CTD	9242	1	SEABIRD
2	Oxygen Optode 4831	356	1	AANDERAA
3	FLBBCDSLC	3775	1	WETLABS
4	OCR-504	0361	1	SATLANTIC

OUC has also been contributing on the analysis and modeling front. Three high resolution ($1/12^0$) HYCOM experiments from 1993 to 2012 have been run: a control run, a wind forcing run (with climatological buoyancy forcing) and a buoyancy forcing run (with climatological wind forcing). Parallel simulations with a 2½ -layer model, forced by the same winds from 1993 to 2012, have also been finished. Preliminary analysis shows that AMOC and OHC changes in the Atlantic Ocean over the past two decades are mainly controlled by the wind forcing.

Germany

The 53°N array was installed successfully in August 2014 via cruise MSM40.

Netherlands

The Dutch mooring array in the Irminger Current (IC) was installed in 2014. It was serviced in 2015 and will be serviced again in 2016, and finally recovered in 2018. CTD stations, dissolved oxygen measurements and LADCP data was obtained during the OSNAP East leg 2 cruise in July 2015. From August 2015 onwards, the first year-long IC mooring data will be processed and analyzed jointly by L. de Steur (NIOZ) and F. de Jong (NIOZ/Duke) to estimate the volume and heat transport of the IC, and variability observed during the first year deployment.

United Kingdom

The UK Eastern Boundary Array

The moorings were deployed from the Knorr cruise KN221-2 (PS Johns) in July 2014. A fifth mooring was deployed in October 2014 from RRS Discovery. These moorings will be serviced annually through OSNAP; they were recovered and redeployed in June 2015 on a RV Pelagia cruise led by Stuart Cunningham.

Glider surveys of the Rockall-Hatton Basin began in July 2014; to date there have been 9 glider sections in the Hatton-Rockall Basin and 4 in the Rockall Trough. SAMS staff are developing glider data quality control and methods to improve data processing (specifically the conductivity cell thermal inertia effect on salinity). Glider energy usage is approximately 25% higher than predicted due to vigorous eddy activity at the western end of the glider transect.

The UK Deep Western Boundary Array

The array will quantify the mean and variability of the volume, heat and salinity transport of the dense northern overflow waters. It is part of a broad array that also encompasses the East Greenland Current and Coastal Current and two of the OOI flanking moorings instrumented at depth. The DWBC array was deployed in 2014 by WHOI and SAMS technicians on the cruise R/V Knorr KN-221-3 led by Bob Pickart (WHOI) in August 2014. The DWBC was serviced by the RV Pelagia in July 2015, a cruise led by Laura de Steur.

The 2014 OSNAP CTD and carbon section

A high resolution synoptic CTD and carbonate chemistry section along the OSNAP line was completed in summer 2014. The data are being analysed to generate a detailed view of the velocity, transport and heat fluxes (and carbon inventory) of the SPG at the start of the OSNAP measurement programme. The UK mooring data will be analysed to examine the context of the synoptic section in light of observed variability in the deep western boundary current and eastern boundary array, along with other OSNAP data available after the first year of observations.

Seasonal estimates of the subpolar gyre circulation and mixing

We have been working on setting up the Tracer Contour Inverse Method (TCIM) for use with Argo, to validate it and to apply it to the North Atlantic subpolar gyre in order to generate the initial handful of estimates of circulation and mixing. A key feature of TCIM is that it provides estimates of vertical profiles of diffusivity, in addition to circulation, hence is of interest for constraining the transfer of heat, freshwater and tracers. Additionally, it is constructed in neutral density coordinates, so is naturally compatible with Argo. TCIM contains the familiar Bernoulli and Box inverse methods as special cases. The Tracer Contour Inverse Method has been applied to a gridded, seasonal Argo climatological analysis for a subpolar region and plausible seasonal estimates of isopycnal and vertical diffusivity, as well as circulation were derived for the region. However, it is clear that further detailed validation of TCIM is needed in order to fully understand the sensitivity of the solution to the choice of domain, and work has already begun using output from a 0.23 deg. Atlantic simulation of the MICOM isopycnic model.

Multi-decadal variability of potential temperature, salinity and transport in the eastern subpolar North Atlantic

The Extended Ellett Line (EEL) hydrographic section extends from Scotland to Iceland crossing the Rockall Trough, Hatton-Rockall Basin and Iceland Basin, and thus provides historical context for the OSNAP eastern boundary. The most recent description of the multidecadal variability from the section is provided by Holliday et al, 2015. The paper extends prior analysis of the time series in the Rockall Trough, and examines for the first time 18 year records in the Iceland and Hatton-Rockall Basins. We quantify errors in the time series from two sources: observational errors and aliasing. The upper waters of all 3 basins are cooler/fresher from 1997 to 2001, warmer/more saline 2001 to 2006, and cooler/fresher from 2006 to 2014. The mean northward transport in the upper waters is 6.7±3.7 Sv and there is a 6.1±2.5 Sv southward flow below the thermocline. Although the magnitude of the Iceland Basin overturning circulation (4.3±1.9 Sv) is greater than in the Rockall Trough (3.0±3.7 Sv), the variability is greater in the Rockall Trough. We find the surprising result that the maximum mean overturning streamfunction in the Rockall Trough and the Iceland Basin are nearly identical in density and pressure coordinates.

Adjoint modelling to understand the causes of observed variability in the AMOC

We have been working with adjoint model data to understand the causes of observed variability in the AMOC at 26°N (Pillar et al. 2015). By projecting observed atmospheric variability onto adjoint-derived estimates of AMOC sensitivity to surface wind, thermal and freshwater forcing over the preceding 15 years, we assess how much of the observed AMOC variability can be attributed to local and remote surface forcing at varying lead time. In contrast to previous studies – which typically rely on statistical indicators of mutual variation between the AMOC and atmospheric forcings - attribution here is unambiguous, and achieved via identification of oceanic adjustment pathways. We find that local, instantaneous wind forcing dominates the AMOC variability on short time scales, whereas subpolar heat fluxes dominate on interannual to decadal time scales. The reconstructed AMOC is able to reproduce most of the interannual variability observed by the RAPID-MOCHA array at 26°N, but not the apparent decadal trend, which depends on the integrated response to subpolar heat fluxes over at least the past two decades. This underlines the importance of the OSNAP program for physically interpreting the role of the subpolar North Atlantic in driving the AMOC and providing potential climate predictability on decadal time scales.

Exploring how subpolar heat content varies on interannual to decadal timescales

In the subpolar gyre, the ocean heat content anomaly over the upper 1300m changes from positive to negative and back to positive over the period from 1955 to 2010. These changes in heat content are affected by both anomalies in sea surface temperature and the thickness of the thermocline, increasing heat content coinciding with warmer surface waters and a deeper thermocline. The interannual to decadal changes in subpolar heat content are not controlled by the gyre-integrated air-sea heat fluxes, instead they are primarily due to a horizontal convergence in the heat transport (Williams et al., 2015). The local air-sea fluxes and wind forcing though probably still play an important role in determining the western boundary density and then affecting the meridional overturning and associated heat transport. For example, when the Labrador Sea heat content is high and associated western boundary density anomaly is negative, there is a reduction in the MOC into the subpolar gyre at 46°N; the western Labrador Sea density is positively correlated with the MOC from 100 to 1300 m at 46°N with zero lag. The changes in overturning at the subtropical/subpolar boundary at 46°N then drive changes in the northward heat transport at 46°N. The tendency of the upper ocean heat content for the subpolar gyre then broadly follows the convergence of heat transport over the subpolar gyre.

United States

OSNAP float program (Bower and Lozier)

The tracking array for the OSNAP float program was put in place in the summer 2014 on four different OSNAP cruises. Thirty of the first 40 RAFOS floats were released along the OSNAP line, 10 on the eastern flank of the Reykjanes Ridge and 20 over the continental slope east of Greenland. Taking advantage of one of the sound source deployment cruises between Woods Hole and Iceland, 10 additional floats were released in the Charlie-Gibbs Fracture Zone at the level of the ISOW. Finally, six "monitor" RAFOS floats were released, two in each of the three sub-basins of the subpolar region, to provide information on the health of the sound source array. These indicated that the source array was functioning as expected as of January 2015.

Six of the 40 deep RAFOS floats have surfaced, three as planned and three due to sinking below the "bail-out" pressure (3000 dbar). In all cases, there was evidence that the sinking floats had touched the sea floor and picked up sediment or mud which caused them to sink. For the 2015 and 2016 float deployments, we have made modifications to the float design to avoid this problem. In 2015, floats were deployed on both flanks of the Reykjanes Ridge and over the slope east of Greenland.

Iceland basin array (Johns)

The Iceland Basin array was successfully deployed in July 2014 aboard the R/V Knorr, cruise KN-221-02. It was serviced in June 2015 aboard the R/V Pelagia. Most effort to date has been focused on physical deployment activities. In addition, we have begun working toward evaluating the effectiveness of the DWBC array based on comparisons with the high-resolution CTD/LADCP section acquired during July 2014 (and the one acquired in June 2015), with an eye toward optimizing the array for its final 2-year deployment cycle in 2016.

West and East Greenland arrays (Straneo and Pickart)

In August 2014 the R/V *Knorr* carried out the 5th OSNAP cruise conducted in the inaugural year of the program. The activities completed on the *Knorr* were as follows: (i) deployment of the US/German mooring array on the west Greenland shelf and slope; (ii) deployment of the US mooring array on the east Greenland shelf and upper-slope; (iii) deployment of the UK mooring array on the east Greenland slope; (iv) deployment of three sound source moorings for the OSNAP-Floats program; (v) launching of 18 RAFOS floats; and (vi) occupation of 196 CTD stations comprising a survey of the boundary current system in the vicinity of Cape Farewell, including transects along the two mooring array lines.

Investigation of the upper and lower limb of the Atlantic Meridional Overturning Circulation (Lozier)

We use observational Lagrangian data, modeled Lagrangian trajectories and observational satellite sea-surface temperature (SST) data to show that surface water from the Cape Hatteras Gulf Stream region largely recirculates within the subtropical gyre (STG) rather than continuing to the eastern subpolar gyre (SPG), and the water that does reach the SPG does so at depth (50-300 m). Dynamic constraints on the exchange of water masses from the STG to the SPG, namely the southward wind-induced Ekman transport and the potential vorticity gradient, diminish below the surface layer and allow for a sub-surface inter-gyre connection. We also show that in agreement with the Lagrangian perspective on North Atlantic surface circulation patterns, SST anomalies do not propagate along the Gulf Stream/North Atlantic Current (GS/NAC) toward the eastern SPG.

We are also investigating the relationship between convective activity in the Labrador Sea and the export of Labrador Sea Water (LSW), the most sensitive component of the deep AMOC, to the subtropics. The study is based on the simulated Lagrangian pathways of synthetic floats tagged as LSW in the context of a global ocean/sea ice model, ORCA025. We show that the strength of convection in the Labrador Sea is not causally linked to LSW export to the subtropical gyre at classical LSW depth. Our ongoing investigation is focusing on other possible mechanisms for the linkage between subpolar and subtropical property variability.

Investigation of Observing System Experiments for OSNAP East and OSNAP West (Lozier)

OSE experiments are being used to further develop the methodology for the calculation of the volume, heat and freshwater fluxes across OSNAP East, OSNAP West and across the two lines collectively. These experiments have been conducted using the FLAME model, which has been validated with a number of model/data comparisons. The addition of a glider across the Iceland basin has been added to the OSE experiments to understand whether its addition will improve our estimate of flux variability. Additionally, we have explored how the use of satellite altimetry and SST impact our estimates of the flux estimates. This work is ongoing in anticipation of the full OSNAP data recovery in the summer of 2016.

3. Dissemination of results/data/information to community

a. OSNAP products

Susan Lozier (Duke) has the responsibility for producing the OSNAP data products. OSNAP data products will match those of the RAPID program, namely, the depth and zonally-integrated mass, heat and freshwater fluxes, but OSNAP data products will also include 1) the horizontal component for heat and freshwater fluxes and 2) the MOC calculation in density coordinates. Feili Li (OSNAP research scientist at Duke) will detail the calculations for producing these products in a technical report to be issued to all OSNAP PIs in October of 2015. These products have been calculated in a series of OSE experiments that have been conducted since the OSNAP proposal was first prepared, in the spring and summer of 2011.

The OSNAP PIs are committed to a timely delivery of OSNAP products. The earliest expected delivery of the first OSNAP products is one year after the retrieval of the data necessary for the calculations, i.e., late summer of 2017.

b. Website

Please see www.o-snap.org for further information on OSNAP, including cruise reports, blogs and technical information on all OSNAP arrays.

c. Data management policy and plan

Please see the appendix to this report.

d. Outreach activities

Netherlands

Public outreach will be undertaken during the OSNAP East leg 2 cruise through contributions (text, photos and short film clips) to the OSNAP blog. The OSNAP blog will also be linked to the website of the NIOZ cruise diary as well as to the NACLIM website. In addition, a short film (6 to 8 minutes) will be made during the cruise to illustrate the background, relevance and practical observational work related with oceanographic research in the subpolar North Atlantic.

United Kingdom

UK OSNAP has a website (www.ukosnap.org), a twitter account (@uk_osnap) and a cruise blog (ukosnap.wordpress.com).

Animations of North Atlantic Ocean anomalies from 1950 to 2010 have been produced by Liverpool University and uploaded onto YouTube on OceanClimateAtUoL. They include maps of heat content, sea surface height, sea surface temperature, sea surface salinity and surface density; and meridional sections of potential temperature and salinity. These animations of sea level change are also on the OSNAP website.

United States

In collaboration with the NAVIS PIs, we have identified a group of early career scientists studying the North Atlantic and its circulation, including the AMOC, and have begun a series of activities aimed at building a community of junior scientists studying the AMOC. Activities to date include get-togethers at the EGU, IUGG and Bristol meetings and monthly webinars on AMOC related topics.

In addition, the early career NAVIS scientists were surveyed to identify areas where NAVIS could aid their career development. We are in the process of reviewing the survey results. We are also planning a 1 or ½ day workshop prior to the Ocean Sciences meeting next year.

4. Questions for the oversight committee

a. Are our program goals clearly communicated?

b. Does our website give sufficient information on our efforts?

c. Is our data management plan clear?

d. Is information in this report on OSNAP data products sufficient?

e. How can we best align our efforts with other observational/modeling efforts in the North Atlantic to produce a more comprehensive measure and understanding of the AMOC?

Appendix

OSNAP Data Management Plan

Project	Overturning in the Subpolar North Atlantic Program
Date originally written:	03-24-2015
Last revision:	08-21-2015

Table of Contents

1. Overview of OSNAP

OSNAP, designed to provide a continuous record of the full-water column, trans-basin fluxes of heat, mass and freshwater in the subpolar North Atlantic, consists of two legs: one extending from southern Labrador to the southwestern tip of Greenland across the mouth of the Labrador Sea (OSNAP West), and the second from the southeastern tip of Greenland to Scotland (OSNAP East). The observing system also includes subsurface floats (OSNAP Floats) in order to trace the pathways of overflow waters in the basin and to assess the connectivity of currents crossing the OSNAP line.

The location of the OSNAP East and West legs purposefully melds with a number of long-term observational efforts in the North Atlantic: the Canadian repeat AR7W program in the Labrador Sea; the German Labrador Sea western boundary array at 53°N; the global Ocean Observatories Initiative node to be placed in the southwestern Irminger Sea; the repeat A1E/AR7E hydrographic sections across the Irminger and Iceland basins; and the Ellett line in the Rockall region. Importantly, this proposed observing system, in conjunction with the RAPID/MOCHA array at 26ºN and the EU THOR/NACLIM program, will provide a comprehensive measure of the Atlantic Meridional Overturning Circulation (AMOC) and provide a means to evaluate intergyre connectivity in the North Atlantic.

2. International OSNAP Data Management Policy

OSNAP is a collaborative effort which includes several countries including US, Canada, China, France, Germany, Netherlands and the UK. To ensure uniformity in the treatment of data, we have designed a data management and policy plan for the entire OSNAP community (see below). In addition, OSNAP PIs within each country will be solely responsible to conform to the country (or agency) specific requirements for data management.

Data Management

All data from the combined international OSNAP program will be loaded into a web-accessible database maintained at Duke University, with oversight from the OSNAP steering committee. All data on this site will be freely accessible to the public after a two-year limited (permission only) access period. OSNAP data policy encourages open, collaborative sharing of data, both between participants and with the general oceanographic community and seeks to ensure that OSNAP investigators receive appropriate credit for the data produced by their efforts. Thus, while there is no restriction on data use, an acknowledgement to the OSNAP program and specific data provider is requested for publication of results derived from the measurements.

Policy

• Investigators are expected to communicate their analysis plans widely within the program by sending a contribution to the OSNAP annual report and, where conflicts exist, develop plans for collaboration

• Any person making use of OSNAP observational data and/or numerical results must communicate with the responsible investigators at the start of the analysis and anticipate that the data collectors will be co-authors of published results.

• Student projects (thesis and dissertation research) should be identified as early as possible and shared with all OSNAP investigators. All OSNAP investigators should respect the interests of these projects. However, no individual project, student or otherwise, should delay the delivery of the OSNAP data products.

• In cases where investigators choose not to be co-authors on publications that rely on their data, the parties responsible for collecting the data and the sponsoring funding agencies should be acknowledged, including reference to any relevant publications by the originating authors describing the data sets and a reference to the data set itself using its DOI name.

• Subject to the above conditions, OSNAP investigators are expected to make data and results freely available to others within the program as soon as possible.

• Offers to collaborate originating from outside the OSNAP group should be discussed with all the primary OSNAP collaborators.

• OSNAP collaborators are encouraged to submit real-time data to operational centers.

Finally, OSNAP data are intended for scholarly use by the academic and scientific community, with the express understanding that any such use will properly acknowledge the originating investigator

3. Data Documentation and Metadata

The categories of data generated and used in this project include mooring data, float data, glider data and shipboard data. To assure quality control and reproducibility of these data, NetCDF format is used to distribute all OSNAP data. The NetCDF format, including naming conventions as well as metadata content, should comply with OceanSITES conventions (*Appendix A*). Note that for shipboard data, PIs can follow the convention outlined in the WOCE manual updates found at "GO-SHIP" (http://www.go-ship.org/HydroMan.html).

Data files

Data files should contain one type of data (see *Appendix B* for the description of data types), from one deployment. Information specific to certain data types is described below.

- Moored instrument (ADCP, CM, MBCS, MCTD) data should, whenever possible, be saved at the original sampling frequency.
- Shipboard data (CTD, DIS, LADCP) should be supplied as one file per CTD station. Down cast data (if available) should be included. If water samples have been collected, the discrete up cast value (measured at the time of the water sample) should be provided.
- Ship-mounted ADCP data (SADCP) should be included as a time series of profiles.

Data processing document

An additional processing document, outlining the procedures undertaken to process and quality check/control the data, should accompany each data file. This document should contain at least the following two sections:

a). Calculating and applying calibrations – information about the calibration coefficients and methods of applying calibrations

b). Quality control – information about the quality and methods used for quality control

4. Data Organization and Storage

The steps for data retrieval and storage are (see *Appendix C* for OSNAP data flow chart):

(1) Raw data is collected, calibrated and quality controlled by PIs.

(2) The processed data is converted to NetCDF format by PIs.

(3) The processed data in NetCDF format, with its accompanying processing document, is submitted to the OSNAP server by the PI as it becomes available. Note:
   a. Raw data can be kept at participating institutions and saved to the OSNAP server for backup.
   b. The processed data should be fully "worked up" (i.e., calibrated and quality controlled) with sufficient documentation to be of use to third parties without reference to the original collector.
   c. Submission of data can be either via a web based file uploader on the OSNAP website or, in the case of large data files, by FTP upon request.

(4) Data and derived products saved on the OSNAP server are shared within the ONSAP community. All data and documents on the OSNAP server are backed up daily.

Data files on the OSNAP Server

a) Processed data

Processed data files in NetCDF format are found in:
[ROOT_DIRECTORY]/Observations/[CATEGORY]/

b) Gridded data

Gridded data files are processed from one or more data files. Data may be gridded in time or in spatial dimensions. Note that when multiple data files are aggregated, the attributes may not contain all of the detailed information from each individual data file.
There may be multiple gridded data files derived from the same data but with a different resolution (e.g., daily and hourly averages). Gridded files are found in:
[ROOT_DIRECTORY]/Gridded_Data/[CATEGORY]/

c) Derived products

Products derived from OSNAP observational data may be made available on the OSNAP server in the near future. The product data files are found in: [ROOT_DIRECTORY]/Products/

Note on directories on the OSNAP server:

OSNAP server – data server physically located at Duke University
[ROOT_DIRECTORY] – root directory set up on the OSNAP server
[CATEGORY] – "Mooring", "Float", "Glider", or "Shipboard"

5. Data Access

OSNAP data has the following access requirements:

(1) Within the two-year period of access restriction, registration is required in order to have access to data on the OSNAP server. After registration, login information is created and sent to the registered user via email. All datasets on the OSNAP server are then accessible to the registered user.

(2) After the two-year period of access restriction, all OSNAP data will be available to the public upon request, and will be uploaded to GDAC. For data saved on the OSNAP server, users need to specify which OSNAP data/product(s) they want to access. Only the link to the requested product(s) will be sent to the registered user through email.

6. Data Preservation and Archiving

The data will be preserved and archived as follows:

(1) Data saved at each participating institution will be maintained throughout the OSNAP period.
(2) Data on the OSNAP server is to be retained for 10-15 years.
(3) All OSNAP data eventually goes to GDAC (OceanSITES, NODC etc.) for long-term preservation.

Note on data archiving

A review mechanism will be initiated by the steering committee to periodically reconsider the costs and benefits of continuing to maintain the data.

7. OSNAP Website

The OSNAP website provides the interface for accessing all OSNAP datasets. The designated webpage "Data" contains four subpages:

For PIs

Login form/page for data uploading.

Data

Data description for different categories (mooring, glider, float, shipboard).

Derived products

OSNAP products such as the depth and section-averaged volume transport.

Download

This page will contain a registration form for requesting data access. The following information will be requested: name, email, organization, address, city, zip code, country, motivation (name of project, area, type of research intended, etc.) and the data requested.

8. Responsibilities of the OSNAP PIs

- OSNAP data should be submitted to the OSNAP server by the PI as soon as feasible, but no later than 12 months after acquisition. The acquisition date is the date when data is downloaded from the instruments or the end-date of the cruise).
- It is the responsibility of individual PIs to provide back-up strategies for data stored locally.
- PIs are expected to submit information on the approximate size and number of data at least three months before the planned data uploading. This information will aid capacity planning for the OSNAP server and avoid potential delays in data submission.
- Each participating country should designate a main contact regarding data issues.

Appendix A. Description of OceanSITES NetCDF Format

NetCDF file naming and contents are described (OceanSITES Data Format Reference Manual, Version 1.3, released on 1/12/2015). The following information includes some key elements of the OceanSITES conventions.

(1) File naming:

Data files normally contain one type of data, from one deployment. The data file name typically follows:

OS_[PlatformCode]_[DeploymentCode]_[DataMode]_[DataType]_[PARTX].nc

- OS – OceanSITES prefix
- [PlatformCode] – OSNAP instrument/cruise ID
- [DeploymentCode]
  - For mooring and float data: instrument deployment year and month
  - For shipboard data: cruise departure year and month
  - For glider data: year and month when mission begins
- [DataMode] – Data mode
- [DataType] – MCTD, CM, ADCP, etc. (see *Appendix B*)
- [PARTX] – An optional user defined field for identification of data; for example, shipboard CTD station number, moored sensor depth.

Example:

OS_OSNAP-OM1_201408_MCTD_300m.nc
MicroCAT at the depth of 300m on mooring OM1 deployed in August 2014
OS_OSNAP-OM1_201408_CM_751m.nc
Current meter at the depth of 751m on mooring OM1 deployed in August 2014
OS_OSNAP-OM7_201408_ADCP_399m.nc
Current meter at the depth of 751m on mooring OM1 deployed in August 2014
OS_OSNAP-OF4_201408.nc
RAFOS float OF4 deployed in August 2014
OS_OSNAP-OG1_201407.nc
Glider (OG1 – Jura) survey began in July 2014
OS_OSNAP-OSNAP2_201406_CTD_#1.nc
Shipboard CTD station #1 from cruise OSNAP2
OS_OSNAP-OSNAP2_201406_SADCP.nc
Ship-mounted ADCP from cruise OSNAP2
OS_OSNAP-OSNAP2_201406_LADCP.nc
Lowered LADCP from cruise OSNAP2

(2) Global attributes:

Discovery and identification		
Name	**Example**	**Note**
site_code	site_code="CIS" (OceanSITES specific) For OSNAP, site_code="OSNAP"	Name of the site within OceanSITES project. The site codes are available on GDAC ftp servers.

		Required (GDAC)
platform_code	platform_code="CIS-1" (OceanSITES specific) For OSNAP, platform_code="OSNAP-OM1" for data from mooring OM1.	The unique platform code, assigned by an OceanSITES project. **Required**. (GDAC)
data_mode	data_mode="R" (OceanSITES specific)	Indicates if the file contains real-time, provisional or delayed-mode data. The list of valid data modes is in reference table 4. (GDAC)
title	title="Real time CIS Mooring Temperatures"	Free-format text describing the dataset, for use by human readers. Use the file name if in doubt. (NUG)
summary	summary="Oceanographic mooring data from CIS observatory in the Central Irminger Sea, 2005. Measured properties: temperature and salinity at ten depth levels."	Longer free-format text describing the dataset. This attribute should allow data discovery for a human reader. A paragraph of up to 100 words is appropriate. (ACDD)
naming_authority	naming_authority="OceanSITES"	The organization that manages data set names. (ACDD)
id	id="OS_CIS-1_200502_TS" For OSNAP, id="OS_OSNAP-OM1_[DeploymentCode]".	The "id" and "naming_authority" attributes are intended to provide a globally unique identification for each dataset. The id may be the file name without .nc suffix, which is designed to be unique. (ACDD)
wmo_platform_code	wmo_platform_code="48409" (OceanSITES specific) For OSNAP, leave blank.	WMO (World Meteorological Organization) identifier. This platform number is unique within the OceanSITES project.
source	source="subsurface mooring"	Use a term from the SeaVoX Platform Categories,(L06) list, usually one of the following: "moored surface buoy", "subsurface mooring" (CF)
principal_investigator	principal_investigator="Alice Juarez"	Name of the person responsible for the project that produced the data

		contained in the file.
principal_investigator_email	principal_ investigator_email ="AJuarez AT whoi.edu"	Email address of the project lead for the project that produced the data contained in the file.
principal_investigator_url	principal_ investigator_url=" whoi.edu/profile/AJuarez"	URL with information about the project lead.
institution	institution="National Oceanographic Centre"	Specifies institution where the original data was produced. (CF)
project	project="CIS" For OSNAP, project="OSNAP".	The scientific project that produced the data.
array	array="TAO" (OceanSITES specific) For OSNAP, array="OSNAP".	A grouping of sites based on a common and identified scientific question, or on a common geographic location.
network	network="EuroSITES" (OceanSITES specific) For OSNAP, network="OSNAP"	A grouping of sites based on common shore-based logistics or infrastructure.
keywords_vocabulary	keywords_vocabulary =" GCMD Science Keywords" For OSNAP, leave blank?	Please use one of 'GCMD Science Keywords', 'SeaDataNet Parameter Discovery Vocabulary' or 'AGU Index Terms'. (ACDD)
keywords	keywords="EARTH SCIENCE >Oceans >Ocean Temperature"	Provide comma-separated list of terms that will aid in discovery of the dataset. (ACDD)
comment	comment="Provisional data"	Miscellaneous information about the data or methods used to produce it. Any free-format text is appropriate. (CF)

Geo-spatial-temporal		
Name	**Example**	**Note**
area	area="North Atlantic Ocean" (OceanSITES specific)	Geographical coverage. Try to compose of the following: North/Tropical/South Atlantic/Pacific/Indian Ocean, Southern Ocean, Arctic Ocean.
geospatial_lat_min	geospatial_lat_min=59.8	The southernmost latitude, a value between -90 and 90 degrees; may be string or numeric. (ACDD, GDAC)
geospatial_lat_max	geospatial_lat_max=59.8	The northernmost latitude, a value between -90 and 90

		degrees. (ACDD, GDAC)
geospatial_lat_units	geospatial_lat_units= "degree_north"	Must conform to udunits. If not specified then ”degree_north” is assumed. (ACDD)
geospatial_lon_min	geospatial_lon_min=-41.2	The westernmost longitude, a value between -180 and 180 degrees. (ACDD, GDAC)
geospatial_lon_max	geospatial_lon_max=-41.2	The easternmost longitude, a value between -180 and 180 degrees. (ACDD, GDAC)
geospatial_lon_units	geospatial_lon_units=”degree_east”	Must conform to udunits, If not specified then ”degree_east” is assumed. (ACDD)
geospatial_vertical_min	geospatial_vertical_min=10.0	Minimum depth or height of measurements. (ACDD, GDAC)
geospatial_vertical_max	geospatial_vertical_max=2000	Maximum depth or height of measurements. (ACDD, GDAC)
geospatial_vertical_positive	geospatial_vertical_positive=”down”	Indicates which direction is positive; "up" means that z represents height, while a value of "down" means that z represents pressure or depth. If not specified then “down” is assumed. (ACDD)
geospatial_vertical_units	geospatial_vertical_units=’meter”	Units of depth, pressure, or height. If not specified then “meter” is assumed. (ACDD)
time_coverage_start	time_coverage_start=”2006-03-01T00:00:00Z”	Start date of the data in UTC. See note on time format below. (ACDD, GDAC)
time_coverage_end	time_coverage_end=”2006-03-05T23:59:29Z”	Final date of the data in UTC. See note on time format below. (ACDD, GDAC)
time_coverage_duration	time_coverage_duration=”P415D” time_coverage_duration=”P1Y1M3D”	Use ISO 8601 (examples: P1Y ,P3M, P10D) (ACDD)
time coverage_resolution	time coverage_resolution=”PT30M”	Interval between records: Use ISO 8601 (PnYnMnDTnHnMnS) e.g. PT5M for 5 minutes, PT1H for hourly, PT30S for 30 seconds. (ACDD)
cdm_data_type	cdm_data_type=”Station”	The Unidata CDM (common data model) data type used by THREDDS. e.g. point, profile, section, station, station_profile, trajectory, grid, radial, swath, image; use Station for

		OceanSITES mooring data. (ACDD)
featureType	featureType=”timeSeries” or ”timeSeriesProfile”	**Optional, and only** for files using the Discrete Sampling Geometry, available in CF-1.5 and later. See CF documents. (CF)
data_type	data_type=”OceanSITES time-series data”	From Reference table 1: OceanSITES specific. (GDAC)

Conventions used		
Name	**Example**	**Note**
format_version	format_version=”1.3” (OceanSITES specific)	OceanSITES format version; may be 1.1, 1.2, 1.3. **(GDAC)**
Conventions	Conventions=”CF-1.6, OceanSITES-1.3, ACDD-1.2”	Name of the conventions followed by the dataset. (NUG)
netcdf_version	netcdf_version=”3.5” (OceanSITES specific)	NetCDF version used for the data set

Provenance		
Name	**Example**	**Note**
date_created	date_created =”2006-04-11T08:35:00Z”	The date on which the data file was created. **Version date and time for the data contained in the file. (UTC). See note on time format below.** (ACDD)
date_modified	date_modified=”2012-03-01T15:00:00Z”	The date on which this file was last modified. (ACDD)
history	history= “2005-04-11T08:35:00Z data collected, A. Meyer. 2005-04-12T10:11:00Z OceanSITES file with provisional data compiled and sent to DAC, A. Meyer.”	Provides an audit trail for modifications to the original data. It should contain a separate line for each modification, with each line beginning with a timestamp, and including user name, modification name, and modification arguments. The time stamp should follow the format outlined in the note on time formats below. (NUG)
processing_level	processing_level =” Data verified against model or other contextual information” (OceanSITES specific)	Level of processing and quality control applied to data. Preferred values are listed in reference table 3.
QC_indicator	QC_indicator =”excellent” (OceanSITES specific)	A value valid for the whole dataset, one of: ‘unknown’ – no QC done, no known problems

		'excellent' - no known problems, some QC done 'probably good' - validation phase 'mixed' - some problems, see variable attributes
contributor_name	contributor_name = "Jane Doe"	A semi-colon-separated list of the names of any individuals or institutions that contributed to the creation of this data. (ACDD)
contributor_role	contributor_role = "Editor"	The roles of any individuals or institutions that contributed to the creation of this data, separated by semi-colons.(ACDD)
contributor_email	contributor_email = "jdoe AT ifremer.fr"	The email addresses of any individuals or institutions that contributed to the creation

(3) Dimensions:

Name	**Example**	**Comment**
TIME	TIME=unlimited	Number of time steps. Example: for a mooring with one value per day and a mission length of one year, TIME contains 365 time steps.
DEPTH	DEPTH=5	Number of depth levels. Example: for a mooring with measurements at nominal depths of 0.25, 10, 50, 100 and 200 meters, DEPTH=5.
LATITUDE	LATITUDE=1	Dimension of the LATITUDE coordinate variable.
LONGITUDE	LONGITUDE=1	Dimension of the LONGITUDE coordinate variable.

(4) Coordinate variables:

Type, name, dimension, attributes	**Comment**
Double **TIME**(TIME); TIME:standard_name = "time"; TIME:units = "days since 1950-01-01T00:00:00Z"; ' TIME:axis = "T"; TIME:long_name = "time of measurement"; TIME:valid_min = 0.0; TIME:valid_max = 90000.0; TIME:QC_indicator = <X>; TIME:Processing_level = <Y>; TIME:uncertainty = <Z>; or TIME:accuracy = <Z>; TIME:comment = "Optional comment..."	Date and time (UTC) of the measurement in days since midnight, 1950-01-01. Example: Noon, Jan 2, 1950 is stored as 1.5. <X>: Text string from reference table 2. Replaces the TIME_QC if constant. Cf. note on quality control in data variable section,.

	<Y>: Text from reference table 3. <Z>: Choose appropriate value.
Float **LATITUDE**(LATITUDE); LATITUDE:standard_name = "latitude"; LATITUDE:units = "degrees_north"; LATITUDE:axis="Y"; LATITUDE:long_name = "latitude of measurement"; LATITUDE:reference="WGS84"; LATITUDE:coordinate_reference_frame="urn:ogc:def:crs:EPSG::4326"; LATITUDE:valid_min = -90.0; LATITUDE:valid_max = 90.0; LATITUDE:QC_indicator = <X>; LATITUDE:Processing_level= <Y>; LATITUDE:uncertainty = <Z>; or LATITUDE:accuracy = <Z>; LATITUDE:comment = "Surveyed anchor position";	Latitude of the measurements. Units: degrees north; southern latitudes are negative. Example: 44.4991 for 44° 29' 56.76'' N <X>: Text string from reference table 2. Replaces POSITION_QC if constant. <Y>: Text from reference table 3. <Z>: Choose appropriate value.
Float **LONGITUDE**(LONGITUDE); LONGITUDE:standard_name = "longitude"; LONGITUDE:units = "degrees_east"; LONGITUDE:axis="X"; LONGITUDE:reference="WGS84"; LONGITUDE:coordinate_reference_frame="urn:ogc:def:crs:EPSG::4326"; LONGITUDE:long_name = "Longitude of each location"; LONGITUDE:valid_min = -180.0; LONGITUDE:valid_max = 180.0; LONGITUDE:QC_indicator = <X>; LONGITUDE:processing_level = <Y>; LONGITUDE:uncertainty = <Z>; or LONGITUDE:accuracy = <Z>; LONGITUDE:comment = "Optional comment..."	Longitude of the measurements. Unit: degrees east; western latitudes are negative. Example: 16.7222 for 16° 43' 19.92'' E <X>: Text from reference table 2. Replaces POSITION_QC if constant. <Y>: Text from reference table 3. <Z>: Choose appropriate value.
Float **DEPTH**(DEPTH); DEPTH:standard_name = "depth"; DEPTH:units = "meters"; DEPTH:positive =<Q> DEPTH:axis="Z"; DEPTH:reference=<R>; DEPTH:coordinate_reference_frame="urn:ogc:def:crs:EPSG::<S>"; DEPTH:long_name = "Depth of measurement"; DEPTH:_FillValue = -99999.0; DEPTH:valid_min = 0.0; DEPTH:valid_max = 12000.0; DEPTH:QC_indicator = <X>; DEPTH:processing_level = <Y>;	Depth of measurements. Example: 513 for a measurement 513 meters below sea surface. <Q>: "Positive" attribute may be "up" (atmospheric, or oceanic relative to sea floor) or "down" (oceanic). <R>: The depth reference default value is "sea_level". Other possible values are : "mean_sea_level",

DEPTH:uncertainty = <Z>; or DEPTH:accuracy = <Z>; DEPTH:comment = "Depth calculated from mooring diagram";	"mean_lower_low_water", "wgs84_geoid" <S>: Use CRF 5831 for depth, or 5829 for height; relative to instantaneous sea level <X>: Text from reference table 2. Replaces DEPTH_QC if constant. <Y>: Text from reference table 3.

(5) Data variables:

Type, name, dimension, attributes	**Comment**
Float <**PARAM**>(TIME, DEPTH, LATITUDE,LONGITUDE);	or: Float <**PARAM**>(TIME, DEPTH); or: Float <**PARAM**>(TIME);
<PARAM>:**standard_name** = <A>;	**standard_name: Required, if** there is an appropriate, existing standard name in CF.
<PARAM>:**units** = <A>;	**units:** Required
<PARAM>:**_FillValue** = <B>;	**_FillValue**: Required
<PARAM>:**coordinates** = <B>;	**coordinates: Required, if** a data variable does not have 4 coordinates in its definition.
<PARAM>:long_name = <B>;	l**ong_name**: text; should be a useful label for the variable
<PARAM>:QC_indicator = <A>;	**QC_indicator**: (OceanSITES specific) text, ref table 2
<PARAM>:processing_level = <A>;	**processing_level:** text, ref table 3
<PARAM>:valid_min = <B>;	**valid_min**: Float. Minimum value for valid data
<PARAM>:valid_max = <B>;	**valid_max**: Float. Maximum value for valid data
<PARAM>:comment = <C>;	**comment**: Text; useful free-format text
<PARAM>:ancillary_variables = <B>;	**ancillary_variables**: Text. Other variables associated with <PARAM>, e.g. <PARAM>_QC. List as space-separated string. Example: TEMP:ancillary_variables="instrument TEMP_QC TEMP_UNCERTAINTY" NOTE: no term may appear in the list of ancillary variables that is not the name of a variable in the file.
<PARAM>:history = <B>;	**history:** Text. A series of entries with one line for each processing step performed on this variable, including the date, person's name, action taken.
<PARAM>:uncertainty = <B>;	**uncertainty**: Float. Overall measurement uncertainty, if constant.

<PARAM>:accuracy = <B>;	**accuracy**: Float. Nominal accuracy of data.
<PARAM>:precision = <B>;	**precision**: Float. Nominal precision of data.
<PARAM>:resolution = <B>;	**resolution**: Float. Nominal resolution of data.

(6) Quality control variables:

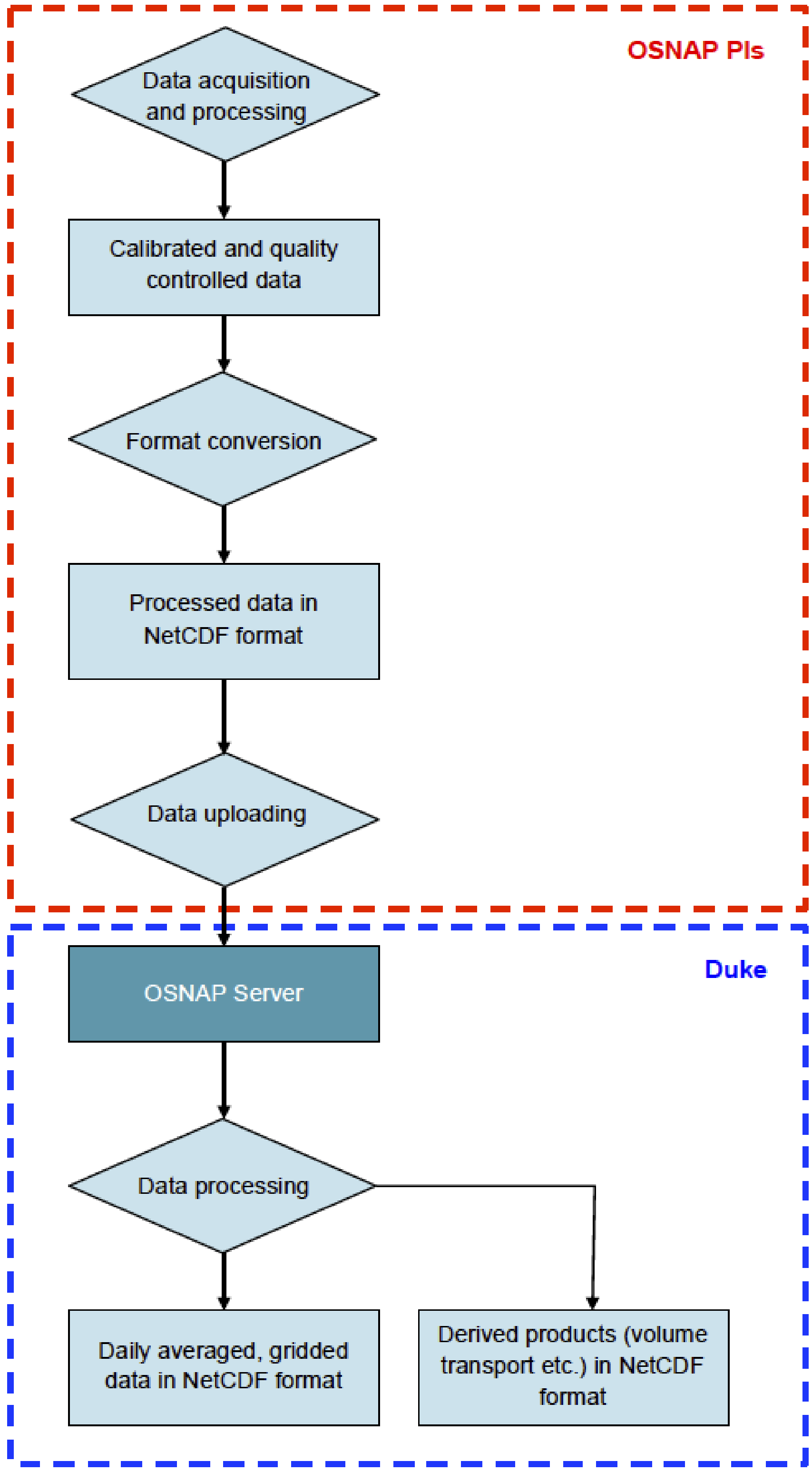
Type, name, dimension, attributes	**Comment**
Byte TIME_QC(TIME);	Quality flag for each TIME value.
Byte POSITION_QC(LATITUDE);	Quality flag for LATITUDE and LONGITUDE pairs.
Byte DEPTH_QC(DEPTH);	Quality flag for each DEPTH value.
Byte **<PARAM>_QC**(TIME, DEPTH); <PARAM>_QC:long_name = "quality flag for <PARAM>"; <PARAM>_QC:flag_values = 0, 1, 2, 3, 4, 7, 8, 9;	Quality flags for values of associated <PARAM>. The flag scale is specified in reference table 2, and is included in the flag_meanings attribute. **long_name**: type char. fixed value **flag_values**: type byte. Required; fixed value
<PARAM>_QC:flag_meanings = "unknown good_data probably_good_data potentially_correctable_bad_data bad_data nominal_value interpolated_value missing_value"	**flag_meanings**: type char. Required; fixed value
Char **<PARAM>_DM**(TIME, DEPTH); <PARAM>_DM:long_name = "data mode "; <PARAM>_DM:flag_values = "R", "P", "D", "M"; <PARAM>_DM:flag_meanings = "real-time provisional delayed-mode mixed";	This is the data mode, from reference table 4. Indicates if the data point is real-time, delayed-mode or provisional mode. It is included when the dataset mixes modes for a single variable. **long_name**: type char. **flag_values**: type char. **flag_meanings**: type char.
Float **<PARAM>_UNCERTAINTY**(TIME, DEPTH): <PARAM>_UNCERTAINTY:long_name = "uncertainty of <PARAM>" <PARAM>_UNCERTAINTY:_FillValue=<Y> <PARAM>_UNCERTAINTY:units = "<Y>";	Uncertainty of the data given in <PARAM>. **long_name**: type char. Required; fixed value **_FillValue**: Float. Required. **units**: type char. Required. Must be the same as <PARAM>:units.

Appendix B. Data type ID and description

Data type ID	**Description**

ADCP	Acoustic Doppler Current Profiler
BATH	Bathymetry
MBCS	Moored biological/chemical sensor
BPR	Bottom Pressure Recorder
CM	Current Meter
CTD	Conductivity-Temperature-Depth profiler
DIS	Discrete water bottle samples
DVS	Doppler Volume sampler
FLOAT	RAFOS float
GLIDER	Seaglider data
IES	Inverted Echo Sounder
LADCP	Lowered Acoustic Doppler Current Profiler
MET	Meteorology
MCTD	Moored Conductivity-Temperature-Depth sensor
MMP	McLane Moored Profiler - profiling CTD and current meter
NAV	Navigation
SADCP	Shipboard Acoustic Doppler Current Profiler
SURF	Sea surface data

Appendix C. OSNAP Data Flow Chart


OSNAP PIs
Data acquisition and processing
Calibrated and quality controlled data
Format conversion
Processed data in NetCDF format
Data uploading
Duke
OSNAP Server
Data processing
Daily averaged, gridded data in NetCDF format
Derived products (volume transport etc.) in NetCDF format