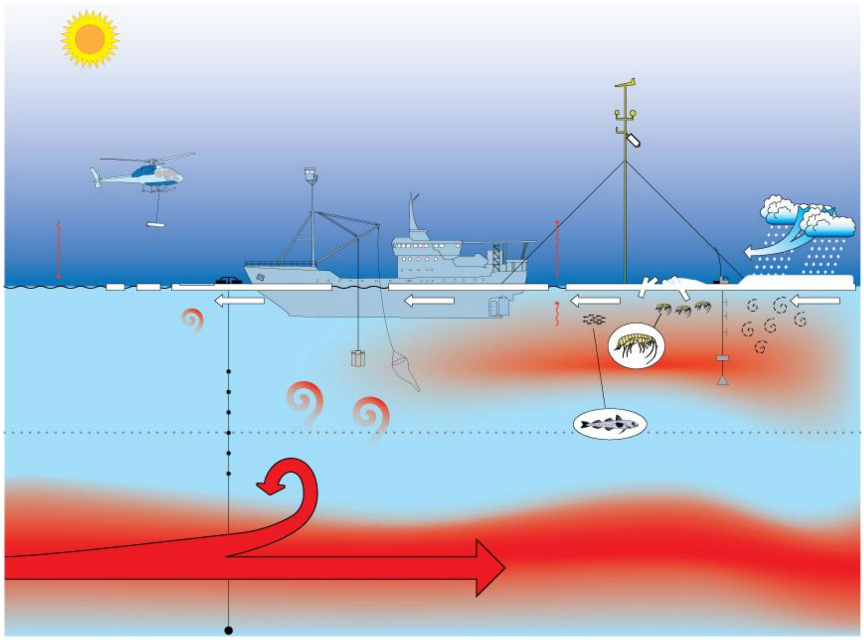

N-ICE 2015: To understand the effects of the new thin, first year, sea ice regime in the Arctic on energy flux, ice dynamics, and the associated ecosystem and local and global climate

WP 1: Upper Ocean – Sea Ice Interaction

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Main Objective: *Understand how available ocean heat is mixed upwards towards the sea ice and to what extent it influences the sea ice energy budget.*

A related secondary objective: *Understand how the **fate of upward mixed** ocean heat is affected by properties of the atmosphere, snow, ice and ocean.*

- **Tasks 1.1** Observe and describe fluxes of heat, salt and momentum in the ice-ocean boundary layer.
- **Tasks 1.2** Describe freshwater sources and evolution of vertical stratification of the Atlantic Water inflow.
- **Tasks 1.3** Quantify upward Atlantic Water heat fluxes and relate it to forcing mechanisms and stratification.
- **Task 1.4** Map water mass properties and relate these to circulation and meltwater.

Short Descriptive Summary:

The Upper Ocean – Sea Ice Interaction working package (WP1) will improve our understanding of the under-ice boundary layer, its coupling to the sea ice cover, and the underlying Atlantic Water (AW). The proposed program covers one of the key components of the sea ice heat budget during the drift, and will give important information on the role of inflowing AW. The vertical heat flux through the upper ocean strongly influences the sea-ice melting in this region, with observed fluxes to the ice ranging between 1 W/m² in the deep interior Arctic Ocean to 200 W/m² (Sirevaag and Fer, 2009) over the slope-following AW.

Recent studies highlight importance of increased AW temperature of ~2°C since the 1960's (Alexeev et al 2013), and heat transport since the late 1990's (Schauer & Beszczynska-Möller 2009), suggesting that a one meter loss of ice in this area is mainly driven by the AW variations (Alexeev et al 2013). As the ice cover becomes thinner and has larger melt pond fraction, more incoming solar radiation will be absorbed (WP2) and, with some delay, contribute to the ice heat budget from below. Ocean mixing seems to be enhanced in the new ice free areas, mostly caused by the larger waves now appearing. As the marginal ice zone creeps northwards into the Arctic Ocean we might expect increased mixing in the future, with important implications for Arctic Ocean circulation and sea ice.

By making and analyzing state-of-the-art observations, this WP will fill major gaps in our understanding and description of important processes linking AW heat with sea-ice melt. We will describe how upper ocean stratification interacts with sea ice evolution, and how a "young" sea ice cover (more melt ponds, greater open water fraction, shallower ridges) influences solar input to the ocean and wind driven ocean mixing. Along with data from the atmosphere and radiation (WP2) the full sea ice energy budget can be closed and compared with observed ice mass balance (WP3). We will assess the geographical variation of AW transformation and influence on sea ice melt, investigate evolution of the surface melt layer, and relate these high resolution measurements to the larger scale Arctic Ocean hydrography.

Along with the observations of the vertical mixing and physical oceanographic processes we will perform a detailed sampling programme on ocean tracers and biogeochemical parameters (WP5). This will allow a better understanding of how representative the observations are, and the large scale circulation pointing to sources for the upper ocean waters. For example will we be able to tell whether fresh water below the sea ice comes from sea ice melting or river runoff from Russia or North America.

1.1 Background

The region north of Svalbard is an area where the thick Arctic Sea ice meets the warm Atlantic Water flowing north through the Fram Strait. Figure 1 shows the average sea ice thickness of the NorESM model, one of a number of Earth System Models currently available for evaluation in the CMIP5 project as part of the next IPCC report AR5 (Taylor et al. 2011). Observations of sea ice thickness exist for the western Arctic (Haas et al. 2010), but are very sparse for the region east of Svalbard. Model studies and observations from the Central Arctic suggest that the heat available for melting sea ice is generally low (Smedsrud et al. 2008), but in regions with steep topography vertical mixing may be much larger.

"Whalers Bay" is a semi-permanent open sea ice area on the north-western point of Svalbard, and shows influence of heat from the north-flowing Atlantic Water visible in Figure 3. The band of high sea ice melting north of Svalbard is clearly caused by the presence of Atlantic Water, as there is no solar radiation during mid-winter. Ice thickness measurements made within the framework of the Ice, Cloud, and land Elevation Satellite (ICESat) campaigns also demonstrated that ocean heat (and in particular the heat stored in AW) is an important contributor to the observed decrease of ice thickness in winter. The local minimum in ice thickness, surrounded by thicker ice, stretches from Svalbard to Severnaya Zemlya Archipelagos, visibly marking the AW inflow pathway (Fig. 6-b in Ivanov et al., 2012).

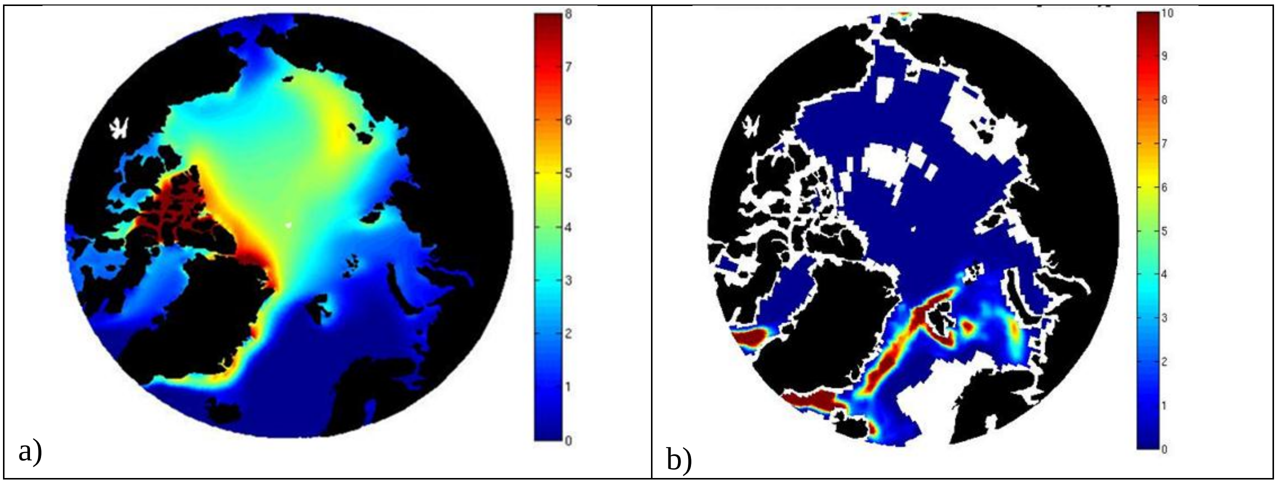


Figure 1: NorESM Arctic Ocean simulations. Properties show mean fields for February over the years 1980-2000 in the CMIP5 experiments. a) Sea ice thickness [m] b) Bottom melting [mm/day].

How this Atlantic Water ‘sub ducts’ below the sea ice cover, melts the sea ice, and carries on as the Atlantic Layer throughout the Arctic Basins is of major interest as it determines the larger scale stratification in the Arctic Ocean. The depth of the cold halocline will for example directly influence melting of Peterman Glacier in North Greenland.

The representations of the Atlantic Water circulation in the Arctic and the structure of the Arctic cold halocline layer (CHL) in models are sensitive to the parameterization of vertical mixing [Zhang and Steele, 2007; Nguyen et al., 2009]. The Arctic Ocean Model Inter comparison Project [Holloway et al., 2007] suggested missing physics related to vertical mixing or to shelf-basin exchanges. Oceanic heat is found to affect the polar ice cap and sea ice melt primarily along boundaries and in MIZ [Polyakov et al., 2010; Steele et al., 2010]. Ocean mixing, however, is severely under sampled and is largely unknown [Fer, 2009]. Ocean melting of sea ice is confined largely to MIZ where the ice concentration is relatively low [Steele et al., 2010]. Loss of heat from the Atlantic Water layer is confined largely to along the boundaries and rough topography [Sirevaag and Fer, 2009; Dmitrenko et al., 2011].

How does the under-ice boundary layer respond to external forcing like wind-induced currents, or breaking internal waves? Sparse observations over short time are available from different regions, but it is necessary to undertake a longer and more comprehensive program to capture the characteristics of the present ocean-ice system in the Arctic Ocean inflow region north of Svalbard.

During N-ICE 2015 we will be able to cover the essential dynamics in the 'quiet' deep Nansen basin and in the more energetic area where the inflowing Atlantic Water follows the continental slope.

WP1 Main hypothesis: Vertical mixing of heat from the Atlantic Layer in the region north of Svalbard determines sea ice melting and thickness.

1.2 Motivation

Observations for evaluation of sea ice, ocean and atmospheric variables of the CMIP5 models will be collected in a remote area of the Arctic Ocean. Observations will support a better understanding of the direct interaction between the Atlantic Water and sea ice in this region.

This study will improve our understanding of the dynamics in the under-ice boundary layer, and its coupling to the Arctic Ocean sea ice cover and the underlying Atlantic Water. The proposed program will be a vital element towards the overall goal of covering the full heat budget for the sea ice during the drift. Climate models have a relatively poor representation of high-latitude mixing. Fluxes of heat, salt and momentum through the upper ocean are important for the development of the ice cover, and there is a need to improve their representation in numerical ice-ocean models. Recent findings show the importance of tidal ventilation and ocean mixing in Arctic Ocean circulation. Mixing seems to be enhanced in the absence of sea ice, and because the marginal ice zone creeps northwards and into the Arctic Ocean this should increase mixing in the future. By using state-of-the-art observations in concert with numerical modelling, we aim to fill major gaps in our understanding and description of these processes. Towards the end of the drift R/V Lance will approach the "ice edge" and a stronger wave influence is expected. Wave buoys will be deployed by WP4 to map changes in wave climate along the drift and waves help mixing the under ice boundary layer.

1.3 Processes of importance in the N-ICE 2015 drift area

1.3.1 Internal wave-induced mixing

In addition to turbulence in the boundary layer and mixing due to convection and shear instability, the main source of mixing in the ocean is internal wave breaking. In simple terms, internal waves can be generated by wind stress leading to near-inertial waves propagating from surface and downward or by tidal flow over topography leading to internal tides propagating from the bottom and upward. The Yermak Plateau (YP) is an ideal site to study both processes, with rough topography at the bottom and frequent wind forcing at the surface.

1.3.2 Frontal mixing

Mixing in the frontal zone between the cold Arctic Water and the warm AW is crucial, both for physical parameters as well as the ecosystem and biogeochemistry. The dynamical processes associated with oceanic fronts were identified as an important gap in our knowledge within Arctic regions. YP is located in this frontal zone.

1.3.3 Boundary layer physics

Under-ice topography, ridges and keels induce an efficient roughness in the boundary layer beneath the ice and might impact the oceanic mixed layer properties and turbulent fluxes [Fer and Sundfjord, 2007].

1.3.4 Convective mixing

Upward convective mixing in winter provides efficient means for delivering AW heat to the under-ice layer. In the study area, convective mixing may reach depths of about 100m in the absence of a cold halocline (Rudels et al., 2004), entraining the upper part of AW, which has seasonal maximum temperatures in late fall and early winter (Ivanov et al., 2009).

1.3.5 Air-ice-ocean CO_2 exchange

Processes within the sea ice affect the CO_2 exchange between air and ocean as well as the ocean acidification state. This part is in collaboration with WP5 and WP2).

1.4 The IAOOS buoys

The main and innovative objective of the IAOOS buoys is to collect simultaneously and in real time information related to the state of the upper ocean, the lower atmosphere and the Arctic sea-ice. The IAOOS buoys are composed of three profiling elements for oceanic, sea-ice and atmospheric key climate variables (Fig. 2). Each buoy transmits its data in real time via Iridium satellites to a shore station based in France (at the French Polar Institute IPEV, in Brest). The data is quality controlled, and transferred to data centers (Coriolis, ICARE, NSIDC, GTS for weather prediction).

The N-ICE camp will allow to tests the buoys in winter and gather the first winter data. The goals are:

- To conduct further developments that are funded within the EU Ice Arc project (a new profiler with biogeochemical sensors, new sensors);
- To perform hydrodynamic tests with different cables, weights and profilers;
- To collect complementary data to interpret the IAOOS observations: meteorological data, ocean currents, radiometric observations, SIMBAS with different samplings, biogeochemical analyses, ice core information, webcam, etc…

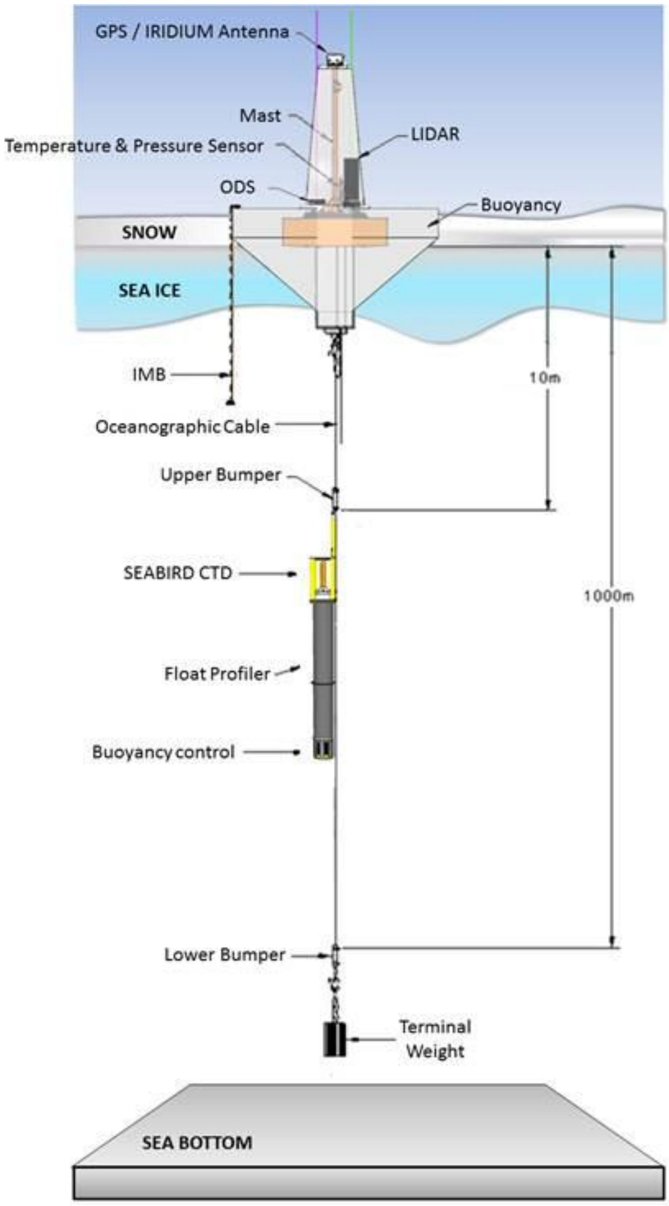


Figure 2: Schematic of an IAOOS buoy.

1.5 The tracer sampling program

This part of the WP has four aims. Firstly we would like to determine regions of sea ice formation and melt along the drift. Together with the heat flux estimates on the physical side this will quantify rates of formation/melt in each region. Rates of formation/melt are largely expected to be governed by hydrography and turbulent mixing, and to a smaller extent to atmospheric heat fluxes. The atmospheric heat fluxes probably vary seasonally, and to a smaller extent geographically.

Secondly we would like to validate assumptions about the mean tracer properties of sea ice and sea ice meltwater. The mean thickness of sea ice in the Arctic Ocean is changing and it is likely that the salinity and tracer properties of the newer, younger ice are different to ice previously. Continuous measurements will also reveal how the tracer and biogeochemical properties of sea ice and under ice change as sea ice forms, ages and melts. Knowledge about the mean tracer properties of sea ice of different age/thicknesses is fundamental when the same tracers are used to detract meltwater downstream.

Thirdly we would like to determine the fate of sea ice meltwater. Tracer measurements will reveal which parts of the water column sea ice meltwater affects. This will help determine to what extend freshwater from melting sea ice isolates remaining sea ice from further melting by oceanic heat input. And the last main goal is to study the freshwater composition of the surface layer and halocline in an under-sampled region of the Arctic Ocean.

2. Work plan

We will conduct a set of observations for the length of the drift. Such an effort will require a number of people to be involved. Since the CTD work and water sample collection will serve WP5 as well (biology and biogeochemistry), we do not include manpower for that work in the WP1 Ocean. We thus need a minimum of two persons on board for the length of the drift. During events like storms, cracks opening up, possibly related to large wave amplitudes, we would like to run turbulence profiling around the clock. We need to look after the turbulence Instrument Clusters (TIC's) on a regular basis, at least each morning and evening to confirm that they are operating properly, and back up data. There will be major tasks in the beginning to deploy the mooring and the TIC's. We count on help from people in other WP's here, and as 'bear guards'. Likewise will Ocean WP people help in the ship based CTD work, gathering snow samples, or do sea ice thickness measurements. The WP1 work plan for leg 1 and leg 2 is summarised in Table 1 below. The biogeochemical sensors under ice also need regular checks (and battery change) mainly at the beginning of the drift (leg 1 in collaboration with WP5) but also during the re-deployment at leg 3.

2.1 On ice sampling and physical parameters

A 'supersite' will be set up on a large ice floe some hundred meters away from RV Lance (Fig. 2). TIC's will be mounted on masts below the ice, connected to a power unit and a control and data logging system. A heated tent/hut/container with power supply will be needed, to keep instruments and other equipment in working condition, as well as for safety reasons. This oceanography camp must be placed near the radiation sensors and instruments to be used for atmospheric boundary layer measurements (WP2), without interfering with them.

	Monday	Working group					Tuesday	Working group					Wednesday	Working group					Thursday	Working group					Friday	Working group					Saturday	Working group					Sunday	Working group				
		1	IA	2	5			1	IA	2	5			1	IA	2	5			1	IA	2	5			1	IA	2	5			1	IA	2	5			1	IA	2	5	
07h30	Breakfast						Breakfast						Breakfast						Breakfast						Breakfast						Breakfast						Breakfast					
8.00	Meeting	2	2				Meeting	2	2				Meeting	2	2				Meeting	2	2				Meeting	2	2				Meeting	2	2				Meeting	2	2			
8.45 - 11.30	MSS	2	2			1	MSS	2	2			1	MSS	2	2			2	MSS	2	2			1	MSS	2	2			2	MSS	2	2			1	MSS	2	2			1
	TIC check	2	2			1	TIC check	2	2			1	TIC check	2	2			2	TIC check	2	2			1	TIC check	2	2			2	TIC check	2	2			1	TIC check	2	2			1
	MSS	2	2			1	MSS	2	2			1	MSS	2	2			2	MSS	2	2			1	MSS	2	2			2	MSS	2	2			1	MSS	2	2			1
11h30	Lunch						Lunch						Lunch						Lunch						Lunch						Lunch						Lunch					
12.30 - 15.00	Ship CTD MSS	2	2		2	1	Ice CTD + a-Sphere CTD	2	2	1			Service instrument	2	2				Ice coring TIC check	2	2	1	2		Service instrument	2	2				Ice CTD + a-Sphere CTD	2	2	1			IAOOScable	2	2			
	Ship CTD MSS	2	2		2	1	Ice CTD + a-Sphere CTD	2	2	1			Service instrument	2	2				Ice coring TIC check	2	2	1	2		Service instrument	2	2				Ice CTD + a-Sphere CTD	2	2	1			IAOOScable	2	2			
15.00 - 17.30	Ship CTD	2	2		2		Ice CTD + a-Sphere CTD	2	2	1			MSS	2	2				Ice coring MSS	2	2	1	2		MSS	2	2				Ice CTD + a-Sphere CTD	2	2	1			MSS	2	2			
	Ship CTD	2	2		2		Ice CTD + a-Sphere CTD	2	2	1			TIC check	2	2				Ice coring MSS	2	2	1	2		TIC check	2	2				MSS + TIC check	2	2	1			TIC check	2	2			
17.30	Dinner						Dinner						Dinner						Dinner						Dinner						Dinner						Dinner					
18.30 - 20.00	Ship CTD IAOOScable	2	2		2		MSS	2	1 1				Data backup	2	2				Ice coring Data backup	2	2	1	2		Data backup	2	2				Data backup	2	2				Data backup	2	2			
	Ship CTD IAOOScable	2	2		2		TIC check	2	1 1				Fix instruments	2	2				Ice coring Fix instru.	2	2	1	2		Fix instruments	2	2				Fix instruments	2	2				Fix instruments	2	2			

1 = WP1

IA = IAOOS

2 = WP2

4 = WP4

5 = WP5

WP1 work | **Help others** | **Common tasks** | **IAOOS work** | **Request help from expedition people, safety officer and WP2 on leg 2**

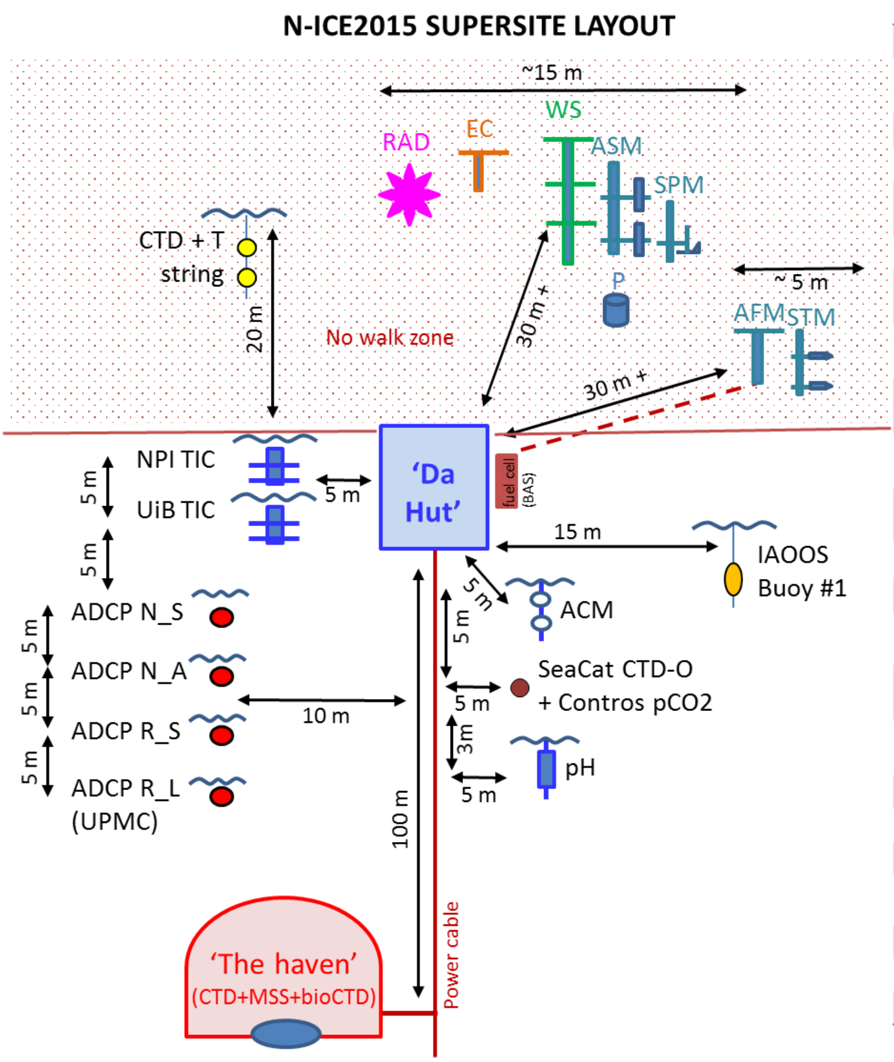
Leg 1 and 2

* This chart includes bear guards

Table 1: Weekly work plan for WP1 including common tasks, participation from other working groups and estimated personnel hours. Leg 1 and 2 only.

Steep topographic features like the Yermak Plateau enhance mixing and we anticipate a very interesting data set from that part of the drift were the ice also meets the West Spitsbergen Current directly. This area will give particularly interesting observations on near-inertial mixing due to internal waves, mixing over rough topography and frontal mixing. The role of under-ice topography will be addressed through the length of the drift in the way that we expect more rough ice in the beginning, and then more smooth ice when we enter regions of bottom melting. Systematic changes in mixing for the same forcing can then be estimated related to changes in ice topography.

Our WP is strongly related to the work with snow and sea ice mass balance (WP3) and the atmospheric observations (WP2). The upper ocean flux data are necessary to complete the ice mass and heat budgets. Similarly, the under-ice boundary layer processes are very much influenced by e.g. sea ice bottom topography and momentum and buoyancy forcing from the atmosphere (wind, radiation, heat flux through leads). It is thus of great importance that all these topics are adequately covered and coordinated, with strong plans for joint data analysis. The VMP-250 microstructure profiler will be used during an intensive campaign after Easter only.



Instruments	Measurements	Group
RAD (2m high)	Radiation station	WP2
EC (3m high)	Atmospheric turbulent fluxes	WP2
WS (10m high)	Weather mast	WP2
P (1m high)	Precipitation bucket	WP2
IAOOS buoy #1 (500 m depth)	Atmosphere, ice and ocean buoy (500m)	WP1 (UPMC)
NPI TIC (5m depth)	Ocean turbulence cluster	WP1 (NPI)
UiB TIC (up to 50 m depth)	Ocean turbulence cluster	WP1 (Bergen)
ADCP N_S	Current meter Nortek signature 1000 kHz	WP1
ADCP N_A	Current meter Aquadopp 600 kHz	WP1
ADCP R_S	Current meter RDI Sentinel 300 kHz	WP1
ADCP R_L	Current meter Long Ranger 75 kHz	WP1 (UPMC)
CTD (1000m depth)	Water sampling	WP1
MSS (300m depth)	Microstructure profiler	WP1
a-sphere CTD (200m depth)	1 x temperature, salinity + nitrate + radiation	WP1/WP2 (UPMC)
CTD+T string (110m depth)	2 x temperature, salinity + 10 x temp.	WP1
SeaCat CTD-O ecopuck (1,5-2m)	S T O2 fluo CDOM transmissivity	WP1
Contros pCO2 (1,5-2m)	CO2	WP5
ACM (2m depth)	Finescale current velocity	WP5
AFM (2m high)	Aerosol filter mast	WP3 (BAS)
ASM (2m high)	Aerosol spectrometer mast	WP3 (BAS)
SPM (2m high)	Snow particle counter	WP3 (BAS)
STM (2m high)	Snow traps mast	WP3 (BAS)
pH (2m)	Water pH	UPMC

Figure 3: Supersite map and list of instruments to be used at the supersite.

2.2 On ice tracer sampling

This work will be coordinated with WP5, and we anticipate that about 580 tracer samples will be collected. Water samples for tracer analysis will be collected using a HydroBios compact rosette water sampler and integrated CT set, deployed using an electric winch provided equipped with 1000 m wire. The compact rosette is equipped with six small (3.5 liter) sample bottles. The rosette and winch will be mounted within a heated Weatherhaven tent fixed to a sledge with a door in the floor. A hole will be maintained in the ice beneath the sledge to allow deployment. Water samples will be collected within the heated tent. Water sampling will be done twice per week, with two casts being completed in each session, plus a third for biology.

Casts will collect samples from standard depths. There will be three casts in each sampling session. The first cast will collect samples at the ice base and at 5, 15, 25, 50 and 75 m. The second cast will collect sample from 100, 150, 200, 250, 300 and 400 m. A third cast will collect water for biological measurements at 1, 5 and 15 m, this water will be drained into large plastic cans and returned to the ship for sub-sampling This sampling scheme covers the surface and halocline and makes the tracer sampling program independent of shipboard CTD operations. The sampling will be coordinated with WP5 to ensure that there is no overlapping between samples analysed. Tracer samples will be collected in the following order: N_2O/CH_4 (WP5), C_T/A_T, (WP5), CDOM, nutrients, $\delta^{18}O$, Ba, Salinity. All samples will be collected in bottles that have been *pre-labeled* with a serial number, which will be recorded on a tracer sampling log sheet. Tracer profiles will be collected *on average* at 4-6 nm increments (Assuming a drift of 300-450 nm during the first leg), resulting in a section capable of resolving changes due to the presence of Atlantic inflow with a high degree of detail. During the second leg the drift speed is likely to be slower resulting slightly denser sampling. Gloves should be worn for collection of all tracer and nutrient samples.

The tracer sampling program will provide concurrent samples of five key tracers, which can be used to separate freshwater into fractions originating from different sources. The program will allow sea ice melt and formation rates to be quantified and used to validate rates inferred by other measurements. Tracer measurements have a greater value when collected concurrently as they can them be used a broader range of quantitative analyses. N-ICE 2015 will provide a unique set of freshwater tracer measurements from an under sampled region of the Arctic.

2.3 Hydrographic sampling from R/V Lance

Core data: A comprehensive ship-borne CTD and water sampling program will measure origin and development of stratification at least every week, tracer and biogeochemical sampling and WP5 sampling will take place once a week throughout campaign.

Tracers from water samples: By analyzing seawater samples for oxygen isotopes and dissolved barium we will be able to discriminate between freshwater from sea ice melt and that from meteoric sources (river runoff, glacial melt, and precipitation). This analysis will allow quantification of sea ice evolution over time, and partitioning of the runoff from North American and Eurasian rivers. The on-ice water sampling and CTD will be used to sample closer to the sea ice, and also be used twice every week. Water samples done by the on board CTD will not be repeated by the on-ice CTD.

2.4 Ice coring scheme

This sampling will be coordinated with WP5, and produce about 480 tracer samples. Ice cores for tracer profile analysis will be collected using a 14 cm diameter Kovacs ice core barrel. Ice cores will be collected once per week, cut into 10 cm segments. Cores should be drilled with an electric drill engine (where possible) and gloves should be worn. Care should be taken to exclude snow from cores (collected by WP5 or WP3). Core segments should be melted after collection. Each core segment will yield about 1.4 liters of meltwater. Meltwater from each segment will be divided into sub-samples and melted in special gas-tight bags (for gases and traces) where the excess air will be removed with small pump (WP5). The melted sampleswill be treated with preservatives if necessary before being sent to laboratories for analysis or analyzed on board (see WP5 for details). Cores will be collected once per week from an area of *un-deformed level ice*, protected from contamination. Approximately 12 cores will be collected during each leg.

Ice cores for mean property analysis will be collected using a 9 cm diameter Kovacs ice core barrel, and produce about 50 additional samples. Ice cores will be collected opportunistically, with the aim of collecting ice cores though un-deformed level ice on as many different ice floes as possible, over the widest possible area. Complete cores will be placed in 30 liter melting buckets with air-tight lids and melted on board at 20°C. Cores should be carefully drained to exclude cuttings and slush before being broken by striking with a blunt instrument, so that they fit in the melting buckets. Striking is faster than sawing and minimizes handling. Cores though two-meter thick ice will provide about 10 liters of meltwater. Meltwater from complete cores will be divided in to subsamples in the same way as meltwater from other ice cores.

2.5 Biogeochemical sensors under ice

Three sensors will be used for continuous measurements under the ice at 1.5 - 2 meters depth to monitor changes in pCO_2, dissolved oxygen (O_2), fluorescence (fluo), pH, CDOM, transmissivity, salinity (S) and temperature (T) (every 30 minutes). Two of the sensors will be used during the whole campaign covering the periods of ice formation (leg1) and ice melting (leg 6). The pH sensor will be used only on leg 2. All these sensors will be placed in three different holes nearby each other. The following sensor will be used:

- CO_2 sensor Contros
- SeaCat sensor with ecopuck (including O_2, CDOM, Fluo, S, T)
- pH sensor

2.6 Deployment of two IAOOS buoys

Two complete IAOOS buoys (atmosphere, ice, ocean) will be deployed sampling down to 500m and using satellite data transmission. The instruments on each buoy are:

- One profiler Provor CTD-DO. Profiles twice a day
- One SIMBA (T and thermal conductivity proxy with 2 cm resolution through snow, ice, upper ocean).
- Microlidar system. Profiles 4 times a day.
- ODS (Optical depth sensor).

The principal objectives are:

- Deployment formation and validation of a deployment procedure.
- Assessment of buoy winter behavior: one platform (buoy 1) (no human intervention once deployed) to be compared with buoy 2 (periodic visit with manual cleaning of Lidar's windows and ODS dome)
- Tests of downward commands from land (buoy 2).
- Different configurations for the ocean profiler Provor CTD-DO.
- Different configurations for Lidar,
- Different configurations for ODS
- Different configurations for SIMBAs

Complementary observations next to buoy 2 (to be installed during leg 1).

- Meteorological station (Pressure, Temperature, humidity and wind). No sat transmission.
- Radiometers (Eppley 2IR 2 UV) broadband, hemispheric. No sat transmission.
- IR radiometer broadband, narrow field of view. No sat transmission
- Visibility sensor on a mast (with 3.1,3.2 and 3.3sensors)3.5. Two extra SIMBAS for testing different settings. With sat transmission.
- ADCP RDI 75 KHz. No sat transmission.
- Later (in March) a webcam will be installed. With sat transmission. All systems are operated using batteries.

Tests of the Provbio profiler(CTS4)

- Downward commands tests in the Provbio profiler(CTS4): High frequency measurements throughout the water column (0 - 500m) will be performed with the PROVBIO2 floats (customized with an OCR-504 Multispectral Radiometer and an ECO3 sensor). These field tests will allow the optimization of the energy-efficient implemented data acquisition settings that have been set from previous research studies. These settings (layer-based sampling rate algorithm aiming to avoid redundant data / preservation of the memory card storage integrity) will be adjusted on-site during the ice camp via the re-parameterization of the float data-logger, with respect to the specific physico-biogeochemical processes encountered. The following data acquisition configurations will be tested: NKE settings, high resolution measurements 0 – 150 m, winter data acquisition settings, spring-summer data acquisition settings.
- Collection of water samples: During the Leg 2 collection of water samples (via the deployment of a CTD & rosette of Niskin bottles) to perform both on-site and laboratory experiments at depths: 100%, 80%, 60%, 50%, 40%, 30%, 20%, 10%, 5%, 1% and 0.1% of PAR. (A) On-site chlorophyll a fluorescence measurements: Chlorophyll a fluorescence measurements in order to confirm the phytoplankton biomass distribution determined with the ECO3 sensor. (B) Electrochemical and colorimetric measurements of silicate (Electrochemical measurements of Silicate on-site with the prototype developed at LEGOS on temperature monitored natural samples; Laboratory temperature-controlled electrochemical determination of silicate on the collected samples will be performed at both, room temperature and 4°C, in order to evaluate the performances (accuracy and repeatability) of the Silicate prototype at extreme temperatures; Determination of the local vertical distribution of silicate).

- Installation of the re-parameterized PROVBIO2 float on one of the IAOOS buoys in March: Implementation in the PROVBIO2 data-logger of optimized data acquisition settings in order to track the evolution of the water-column biogeochemical properties during the spring bloom.

2.7 Hydrodynamic tests of profiler's moorings

The behavior of the profiler (Provor CTD-DO) on the cable has been studied in detail. Simulations with Mooring Design of the 2013 deployment have been made using observed surface drift velocities and a wide range of simulated ocean currents. We plan to validate those simulations and need to estimate the drag coefficient of the profiler equipped with bio-optical sensors. In order to analyze the hydrodynamic behavior of the profilers, different mooring three configurations will be tested: two different cables, different weights (40, 50, 60kg), 2 different profilers (PROVBIO2 (CTS4) and CTD-DO (SPI)), 2aquadopps, 1 tilt meter and 1 seacat SBE37.

Variables to be measured:
Tilt and depth on the cable in different places: on the profiler and near the upper and lower stops.
Profiler vertical speed. Currents at the top and the bottom of the mooring (two Aquadopp). Currents from surface to bottom (ADCP RDI). Mooring rotation.

Tasks: For each weight (40kg, 60kg) the test program will be the following:

Test	Cable	Profiler	Weight	Sampling configurations	Number Days
Deployment	Ice-trench, tent installation, tripod, fixation of the reel system. Deployment of cable A, swivel, weight, lower aquadopp, lower stop, upper stop and upper aquadopp.				
1	A	without	40kg	0	1
Change	Remove upper stop, upper aquadopp. Install SPI profiler, upper stop, inductive modem and Aquadopp.				
2	A	CTD-DO	40kg	3 (1 a day)	3
Change	Remove modem, aquadopp,upper stop, SPI profiler (when it will be near surface). Install CTS4 profiler, upper stop, inductive modem and Aquadopp				
3	A	PROVBIO2	40Kg	3 (1 a day)	3
Change	Remove all the mooring. Install cable B, swivel, weight, lower aquadopp, lower stop, upper stop and upper aquadopp.				
4	B	without	40kg	0	1
Change	Remove upper stop, upper aquadopp. Install profiler SPI, upper stop, inductive modem and Aquadopp				
5	B	CTD-DO	40kg	3 (1 a day)	3
Change	Remove modem, aquadopp, upper stop, SPI profiler (when it will be near surface). Install profiler CTS4, upper stop, inductive modem and Aquadopp				
6	B	PROVBIO2	40Kg	3 (1 a day)	3
Change	Remove all the mooring. Install cable B, swivel, weight, lower aquadopp, lower stop, upper stop and upper aquadopp.				

Profiler data (technical and scientific data) can be downloaded in real time. Configurations of vertical and temporal resolution will be changed via inductive or via satellite link. At the end of each set of tests (1-3 or 4-6) recorded data from the 2 aquadopp, tilt and pressure sensors will be downloaded. All these data will be compared with mooring design simulations taking into account the conditions of drift velocity and direction during the tests.

3. Datasets and instruments

All data sets to be collected and instruments are summarised in Table 2.

3.1 Upper-ocean boundary layer

Turbulent Instrument Clusters (TIC's): The turbulence observation program will consist of two mast-mounted TIC's for continuous measurements of ocean mixing. Sampling depths are usually set at 1 m and 3 m below the ice base. To be mounted near atmospheric/radiation sensors (WP2), with data delivery to and power supply from a heated cabin on ice. Process studies using 2 other TIC's will also be done.

Micro Structure profiling Sonde (MSS): A free-falling turbulence MSS instrument will collect at least two profiles of microscale shear, temperature, and salinity, in the upper 300 m, down to the upper part down to the upper part of the AW layer, at least every 24 hours. Campaigns of more intense sampling bursts would be desirable during special events, such as storms or transition onto the Yermak Plateau. During such events, we plan to do one profile every hour, when possible.

Acoustic Doppler Current Profilers (ADCP's): We will moor these instruments "up-side-down" from the sea ice so that they are drifting with the sea ice camp. One short range 5-beam ADCP (Nortek Signature1000) will allow for collection of fine-resolution velocity profiles and direct measurement of vertical velocity variance (w') to be used for turbulence characteristics in the upper 10-15 m. High- to medium resolution ADCP's (300 kHz RDI Sentinel, 600 kHz Nortek Aquadopp) will cover upper-ocean current shear continuously to a depth of around 50-60 m. The vessel mounted ADCP (RDI 150 kHz) on RV Lance will collect coarser resolution profiles of water currents in the upper 100-150 m throughout the drift. An ice-suspended 75 kHz RDI Long Ranger ADCP will cover the upper 3-500 m depending of the level of acoustic backscatterers.

Two IAOOS buoys: The IAOOS buoys will have satellite data transmission, CTD-DO profiles twice a day (7-800 m), SIMBA (temperature and thermal conductivity proxy with 2 cm resolution through snow, ice, upper-ocean), a Microlidar system and an optical depth sensor. Next to one IAOOS buoy there will be one meteorological station (no satellite data transmission), radiometers (Eppley 2IR 2 UV with no satellite data transmission), a webcam to be installed in March (with data transmission), and two extra SIMBAS (testing different settings and with satellite data transmission). One ADCP RDI 75 KHz (no satellite transmission).

Hydrodynamic test: two different cables, different weights, two aquadopp current meter, one tilt meter and two different profilers CTD-DO, one with CTD-DO+bio-optics.

a-sphere CTD: temperature and salinity profiles with an SBE19+ as well as a ISUS V3 nitrate sensor and an IOP a-sphere.

A number of CTDs (Sea-bird Microcats) and temperature loggers (TinyTag Aquatic2) will also be deployed to provide continuous hydrography data at depths (to be determined) below the TIC sensors. The whole column down to the AW core should be sampled, with special focus on the pycnocline if possible. Likely depths would be 1m(T), 5m(T), 10m(T), 25m(T), 50m(T,S,P), 75(T), 100m(T,S,P), 125(T), 150m(T), 200m (T,S,P).

Biogeochemical sensors under ice: Three sensors (CO_2 Contros, SeaCat with ecopuck, pH sensors), will be used for continuous measurements under the ice at 1.5 – 2 meters depth. The sensors will be placed nearby each other and close to the TIC site. Two of the sensors (CO_2 and SeaCat) will be used from January to June (leg1-6) and one sensor (pH) in February-March (leg 2). From the measurements we will receive fine resolution data every 30 minutes to monitor the variability of the biogeochemical parameters and ocean acidification state during the different ice seasons.

3.2 Tracers and biogeochemical parameters

δ^{18}O is a powerful tracer within the Arctic and is commonly used to separate meteoric water (freshwater from rivers, glaciers, precipitation, snow melt) from sea ice meltwater (Ostlund and Hut, 1984). δ^{18}O samples require 200 ml of sample and will be sent to the G. G. Hatch Laboratory at the University of Ottawa for analysis for equilibration with CO_2 and subsequent analysis using a dual inlet mass spectrometer, following the method of Epstein and Mayeda (1953). δ^{18}O measurements constitute basic research and will be shared with the N-ICE 2015 drift community immediately after analysis.

Data set	Instrument	Sampling	Duration	Data Hz	Location + depth	Measured parameters	Contact	Comment	Processing
TIC: Under-ice turbulence	2 x (Sontek ADV 5 MHz, Sea-bird SBE3, SBE4, SBE7)	Continuous	Whole drift	2 Hz data, 15-min averages	Supersite: 1 and 5 m depth below ice, fixed mast	3D current velocity, temperature, conductivity, DERIVED: Reynolds stress, heat flux, salt flux	ASU		Amelie Achim
Vertical mixing from microstructure	MSS 90L Turbulence drop sonde	3-6 x day	Whole drift	1024 Hz	The Haven tent: on-ice profiling site	Horizontal shear variance, temperature, conductivity, chl-a DERIVED; TKE dissipation, diffusivity, heat flux, salt flux	ASU		Algot Amelie Lars Ilker
Ice CTD profiles	KC Denmark XX	2 x week	Whole drift	2 Hz	The Haven tent: surface to 1000 m	Temperature, Conductivity	PAD		Paul
Ship CTD profiles	Sea-bird SBE911plus	1 x week	Whole drift	2 Hz	RV Lance: 5,15, 25, 50, 75, 100, 150, 200, 250, 400, bottom	Temperature and conductivity	PAD	Paul: T and conductivity processing only	Paul
Nitrate profiles	ISUS V3 nitrate	2 x week	Whole drift	0.5 Hz	The Haven tent: surface to 1000 m	Nitrate concentration	ASU	Deployed on UPMC CTD	Achim
pCO2 surface water	General Oceanics	Continuous	Whole drift	1 minute	RV Lance	pCO2, salinity, temperature	AF		Agneta
A-sphere profiles	Hobilabs a-sphere IOP	1 x week	Whole drift	1 Hz (max)	The Haven tent: surface to 300 m	Depth, total absorption 360 to 750 nm	Alexey	Deployed on UPMC CTD	Alexey
SBE 19 profiles	SBE 19+	2 x week	Whole drift	0.1 Hz (1 / 10s)	The Haven tent: surface to 300 m	Temperature, salinity (pumped)	MAG/AP	UPMC CTD with WP1 and WP2 instruments	Nikita Arild
Water velocity	NOBSKA MAVS-4	Continuous	Whole drift	2 Hz	Supersite: 1 m below ice	3D current velocity based on travel time measurement principle	ASU		TBA
Water current profiles	Nortek Signature 1000 kHz	Continuous	Whole drift	8 Hz	Supersite: 1:.5:12 m below ice	3D current velocity, vertical velocity variance. Derived: TKE dissipation	ASU		Arild Nikita
Water current profiles	Nortek Aquadopp 600 kHz	Continuous	Whole drift	2 Hz	Supersite, 2:125 m below ice	3D current velocity	ASU		Arild
Water current profiles	RDI Sentinel 300 kHz	Continuous	Whole drift	1 Hz	Supersite: 2:2:50 m below ice	3D current velocity	ASU		Ingrid Morven
Water current profiles	RDI Long Ranger 75 kHz	Continuous	Whole drift	TBA	Supersite: 2:2:50 m below ice	3D current velocity	CP/ASU		Ingrid Christine
CTD time series	2 x Sea-bird Microcats	Continuous	Whole drift	TBA	Supersite: 10 and 110 m depth	Temperature, Salinity, pressure	ASU		Ingrid Lars
Temperature time series	TinyTag Aquatic2 thermistors	Continuous	Whole drift	5 minutes TBA	Supersite: 20:10:100 m depth	Temperature	ASU		Ingrid Lars
pH	Unknown	Continuous	Leg2	unknown	Supersite: 1.5-2 m depth	pH	CP	UPMC French group	Victoire Christine
pCO2	Contros	Continuous	Whole drift	30 minutes	Supersite: 1.5-2 m depth	pCO2	AF		Agneta

Data set	Instrument	Sampling	Duration	Data Hz	Location + depth	Measured parameters	Contact	Comment	Processing
Shipboard tracers	Ship CTD rosette	1 x week	Whole drift	point measure-ments	RV Lance: 5,15, 25, 50, 75, 100, 150, 200, 250, 400, bottom	Lab salinity, oxygen isotope ratio, nutrient concentrations, coloured dissovled organic matter, total alkalinity.	PAD		WP5 Phillipe
On ice tracers	Hydrobios CTD rosette	2 x week	Whole drift	point measure-ments	The Haven tent: 5, 15, 25, 50 and 75 m. Then 100, 150, 200, 250, 300 and 400 m.	Lab salinity, oxygen isotope ratio, nutrient concentrations, coloured dissovled organic matter, total alkalinity.	PAD		Paul
SeaCat CTD with ecopuck	Sea-bird Seacat	Continuous	Whole drift	30 minutes	Supersite: 1.5-2 m depth	O2, fluo, transmissivity, CDOM, S, T	AF	Seacat with O2 (IMR)together with Contros PCO2	Agneta
Water current profiles	RDI VM-ADCP 150 kHz	Continuous	Whole drift	0.5 Hz	RV Lance: 8:8:150 m depth	3D current velocity	ASU		Nikita Arild
Water current profiles	RDI Long Ranger 75 kHz	Continuous	Whole drift	0.25 Hz	Supersite: 8:16:300 m depth	3D current velocity	CP (UPMC)		Ingrid Lars
CTD profiles and currents	1 x IAOOS buoys	Continuous	Legs 1+2	1 m / 0,2m res 2 profiles/day	Supersite: 5-500 m depth	Temperature, salinity, pressure, dissolved O2	CP (UPMC)	remotely sent data through iridium	UPMC
CTD profiles and currents	1 x IAOOS buoys	Continuous	Legs 1+2	1 m / 0,2m res 2 profiles/day	Within 1km of RV Lance: 5-500 m depth	Temperature, salinity, pressure, dissolved O2	CP (UPMC)		UPMC
CTD profiles, currents and bio-optics	1 x IAOOS buoys (re depoyed from 1 & 2 leg)	Continuous	Legs 3-6	1 m / 0,2m res 2 profiles/day	Supersite: 5-500 m depth	Temperature, salinity, pressure, dissolved O2, irradiance (380, 410, 490nm), PAR, Chl-a fluo, CDOM, particle backscatter @700nm	CP (UPMC)	bio-optics captors not always full depth. Irradiance stops @ 250m. Eco3 to bottom of cable.	UPMC
Hydrodynamic tests	2 x Aquadopp, 2 x profilers, Sea-bird CTD-DO, OCR 504, PAR, ECO3	Continuous	Leg 1+2	High frequence	UPMC testing hole: @3m and @800m depth	3 D current velocity, cable tilt, +CTD-DO, +RemA package	CP (UPMC)	Data locally available	UPMC
TIC: Under-ice turbulence	2 x (Sontek ADV 5 MHz, Sea-bird SBE3, SBE4, SBE7)	Continuous	Leg 2, first part	2 Hz data, 15-min averages	Supersite: 1 and 50 m depth below ice, cable suspended	3D current velocity, temperature, conductivity, DERIVED: Reynolds stress, heat flux, salt flux	IF (UiB)		Algot
Surface vertical mixing	Uprising vertical microstructure profiler VMP250	Opport-unistic	Leg 2	512/64 Hz data	The haven tent + lead exp.: upper 30m	Horizontal shear variance, temperature, temperature variance, conductivity, DERIVED; TKE dissipation, diffusivity, heat and salt flux	IF (UiB)	Internal recording	Algot

	Name
AF	Agneta Fransson
AP	Alexey Pavlov
ASU	Arild Sundfjord
CP	Christine Provost
IF	Ilker Fer
MAG	Mats Granskog
PAD	Paul Dodd

Sampling at the Haven tent
Sampling at super site
Sampling at RV Lance

Table 2: Datasets to be collected, frequency, location, instrument and contact person.

Total Alkalinity (A_T) is a useful tracer within the Arctic Ocean and is commonly used to separate runoff from sea ice meltwater and precipitation combined. When used together with salinity and $\delta^{18}O$ measurements A_T can be used to separate precipitation from river runoff. A_T samples will be done in connection with WP5 which requires carbonate system measurements to be made from the same sample (C_T will be measured from same sample). Therefore at least 500 ml of sample fluid will be required for sea water samples. A_T samples will be analyzed by Agneta Fransson (also WP5) and Melissa Chierici (IMR) in the IMR lab in Tromsø. The A_T data will also be used to study the ocean acidification (OA) state and air-ice-water CO_2 exchange.

Dissolved inorganic carbon (C_T) is a parameter within the CO_2 system (carbonate system). This parameter is used together with A_T, salinity, temperature and nutrients to obtain pH, pCO_2 and calcium carbonate saturation state (or OA state). The variability and fluxes of the greenhouse gas CO_2 will also be estimated. C_T samples will be analyzed by Agneta Fransson (also WP5) and Melissa Chierici (IMR) in the IMR lab in Tromsø.

CO_2 partial pressure (pCO2) will be measured in the atmosphere and sea surface using an autonomous instrument that has beeen installed onboard Lance for this expedition by A. Fransson and A. Olsen. The instrument uses an infrared sensor to measure the pCO_2 in air drawn from an atmospheric inlet mounted at the crows nest, and in the sea surface water using an intake mounted at the port side seachest. Measurements will be carried out every minute and will be used to study ocean CO_2 uptake and acidification (OA) state The set up also provides accurate measurements of the temperature of the water that pass through the intake.

Nitrous oxide (N_2O) is a greenhouse gas. The variability and fluxes of the greenhouse gas will be estimated during the ice season. The sample volume is 60 ml which will be analyzed at the laboratory in Liege in Belgium (B. Delille).

Methane (CH_4) is a greenhouse gas. The variability and fluxes of the greenhouse gas will be estimated during the ice season. CH_4 will be analyzed from the same sample as N_2O at the laboratory in Liege in Belgium (B. Delille).

Colored dissolved organic matter (CDOM) is a simple measurement of the color of the water, indicative of presence of dissolved organic carbon, especially of terrestrial origin. In cases can be used as a semi-conservative tracer (Granskog et al., 2007) to detect river water. Fluorescence of CDOM (also in situ profiles with CTD) can also give indications of river water presence versus “cleaner” sea ice meltwater. Samples are drawn directly from ship-CTD Niskin through a 0.2 micron filter cartridge, about 250 ml needed for rinse and sample (sample is 40 ml). Alternatively an all-plastic syringe will be used with a syringe filter to fill a 40 ml vials (about 80 ml sample water needed for rinse and sample). Samples are planned to analyzed onboard using a spectrophotometer by Mats Granskog and Alexey Pavlov (in case of malfunction, need to be stored and measured at homelab).

Dissolved inorganic nutrient concentrations (NO2, NO3, PO4 ,Si). These samples will be coordinated with WP5. These observations are commonly used in the Arctic to identify freshwater of Pacific origin entering the Arctic Ocean via the Bearing Strait using the conservative N:P ratio method (Jones et al., 1998). The Pacific is fresh relative to the Arctic Ocean and therefore represents a freshwater source. To accurately determine the volume of sea ice meltwater runoff and meteoric water in samples from the Arctic Ocean it is first necessary to exclude the freshwater fraction associated with the Pacific Inflow. Combined nutrient samples require 150 ml of sample water and will be analysed at an external lab (yet to be determined). Nutrient measurements constitute basic research and will be shared with the N-ICE 2015 drift community shortly after analysis.

Dissolved barium (Ba) is commonly used in the Arctic as a tracer of river runoff, to separate runoff from North American and Eurasian rivers (Falkner et al., 1994). It is also biologically active, and can be consumed during phytoplankton blooms, adding an extra degree of freedom that can inform on primary production processes (Abrahamsen et al. 2009). Once analyzed, Ba measurements will inform on time-varying sea ice processes, meteoric water changes, and productivity. Ba samples require 60 ml of sample and will be sent to Kate Hendry for analysis at Bristol University where samples will be analyzed using an isotope dilution method with a precision of ~0.5-1%. Postdoctoral investigator Tianyu Chen (Bristol) will join the N-ICE 2015 drift to assist with tracer sample collection. Both melted sea ice samples and ocean water samples will be analyzed in Bristol.

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