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Deliverable 6.3. Guidelines for recommended technology, data collection and transmission systems for environmental data collection and management to support the "Programme of Ships and Platforms of Opportunity"

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1. Summary

Despite of increasing use of satellite remote sensing techniques, ship-born observations of atmosphere, ocean and sea ice are needed for both research and operational use. These data are especially valuable in the Arctic Ocean. The Arctic region is changing fast in the warming climate, but environmental observations are very limited due to difficult access. In the ARICE Ships and Platforms of Opportunity (SPO) Program the aim is to enhance observing capacities in the Arctic by engaging private sector operators to participate in data collection.

This document provides guidelines for conducting ship-born measurements of key atmospheric, ocean and sea ice variables in the SPO Programme. A moving ship is a challenging platform for accurate, undisturbed observations. In many measurements, ship motion needs to be compensated. Also, ships have several sources of heat and moisture, and superstructures and masts cause shadows and distortion of flow. In this document, recommendations are given for measurement technologies and installations of sensors. Siting of instrument is especially important question for ship-born measurements and discussed in this document for each variable and sensor.

Ship-born measurement data can be transmitted (near) real-time during the survey, or as delayed-mode when returning to harbor. Real-time observations support operational use (weather and sea ice forecasting, for instance) and delayed-mode data serves research needs. The SPO Programme welcomes both types of data. For both of these data types, comprehensive documentation and metadata are needed.

2. Introduction

In the air-sea interface, complex interactions between atmosphere, hydrosphere, cryosphere and biosphere take place. Observations of this interface are important for research on climate system, but also for all marine operations. Satellite remote sensing techniques are constantly developing, but there is still a need for *in situ* measurements. As Centurioni et al. (2019) conclude, ocean surface measurements have an essential, high-impact role in assimilation and validation of weather, ocean and climate models, in ocean physics studies improving the understanding of air-sea processes, and in calibration and validation of satellite products. Advancements in any of these topics also benefit the marine industry and support safer and more sustainable operations.

Ship-based observations have a long history, over 150 years, and they are still a substantive part of marine observing systems. Despite of increasing use of satellites and automated measurement buoys, recruiting voluntary observing ships (VOS) outside of research fleet is seen as important (*Smith et al. 2019*). The largest program is the VOS Scheme, which has been coordinated by the World Meteorological Organization (WMO) and Joint Technical Committee for Oceanography and Marine Meteorology (JCOMM) since 1994. The World Ocean Council (WOC) has initiated the SMART Ocean-SMART Industries (SO-SI) program to accelerate and scale up the number and location of vessels and platforms involved in data collection, providing a business organization to build on and support existing schemes, such as VOS. The Arctic is a geographic priority for the WOC SO-SI program overall, and via the ARICE project specifically.

Surface observations are needed especially in the Arctic. The Arctic region undergoes globally the strongest warming and the changes in the Arctic sea ice cover are substantial. A good understanding of the changing Arctic requires comprehensive monitoring but in the Arctic Ocean the collection of environmental observations has been and is very limited due to difficult access. The VOS Scheme does not currently cover the Arctic Ocean and the goal of ARICE Ships and Platforms of Opportunity (SPO) Programme is to extend VOS type work to the Arctic Ocean.

WMO has determined a list of essential climate variables (ECV). (https://public.wmo.int/en/programmes/global-climate-observing-system/essential-climate-variables). ECV is a physical, chemical or biological variable or a group of linked variables that critically contributes to the characterization of Earth's climate The list of ECVs has been determined based on three criteria: relevance, feasibility and cost effectiveness. Relevance means that the variables are essential for characterizing the climate system and its changes. Feasibility criterion requires that observing or deriving the variable is technically feasible using proven, scientifically understood methods. For cost effectiveness, generating and archiving data on the variable needs to be affordable, mainly relying on coordinated observing systems using proven technology and taking advantage where possible of historical data.

All the variables recommended to be recorded in the SPO Programme, with the execption of bathymetry, are ECVs, but form only a fraction of all ECVs. In the selection of variables recommended for the SPO Programme, similar kind criteria has been applied as for ECVs. For the ship-born observations in the Arctic, criteria of feasibility and cost effectiveness lead to a shorter list of variables than WMO's global list. The estimation of feasibility and cost effectiveness is largely based on the survey of existing measuring capacities of Arctic going vessels (Deliverable 6.1). The atmospheric and oceanic variables recommended for the SPO Programme are those where technology for automated measurements exists and is widely in use, i.e. not only on research vessels. For sea ice variables, situation is different as there are no automated instruments currently available and visual observations of key variables are recommended. Bathymetry differs from ECVs which describe the state of the system and require monitoring. It is included in the SPO recommendations, since better coverage of bathymetric data is still needed for the Arctic Ocean.

This picture is not static and the list of variables recommended for data collection in the SPO Programme can be extended when technological developments enable systematic collection of new variables. Foreseen technological developments are discussed in the upcoming ARICE deliverable (D6.5).

Requirements of the quality and the transmission of data depend on the use: whether it is needed for operational use (weather and sea ice forecasting) or for research. For the operational use, it is important that the data is available (near) real-time, but with a fairly simple quality test. In the research use, the good quality and resolution of the data is highly important but there is no need for real-time transmission. Optimally, data collection would serve both of these needs, operational and research, but with current data transmission capacities this is not reality. In the ARICE SPO Programme both real-time and delayed-mode data are welcome. Both types serve Arctic industry as well. Real-time observations can support the decision making during the operations, and delayed-mode data can be utilized in conceptual design studies, for instance.

For any type of the use, an adequate level of accuracy is needed. A moving ship is a challenging measurement platform. Movement and vibration of the ship, as well as sea salt, bring special challenges for the durability of instruments and the accuracy of measurements. Ships have superstructures and masts causing shadows and distortion of the flow. There are also several sources of heat, moisture and particles. Some instruments require regular maintenance and the optimal location might be a compromise between good exposure and easy access. All these aspects need to be taken into account when planning the deployment of the instruments.

This document provides guidelines and recommendations for measurement techniques, sensors and their installations and maintenance to ensure a good quality of the observations. The given recommendations are in line with guidelines of VOS Scheme (*JCOMM Guide, WMO Guide 1, WMO Guide 2*). Also, documentation, data management and transmission are discussed. In research vessels, all these aspects are carefully considered. Therefore, this document is mainly targeted for SPO Programme participants outside of the science community. Also, research vessels are usually equipped with more instruments recording more variables than what is included in this document. All that additional data is also very welcome to SPO Programme.

3. Recommended sensors and their installation

3.1 Atmospheric observations

We recommend that all vessels record automatic observations of:

- Air temperature
- Air pressure
- Wind speed and direction
- Humidity

These are among, but not all, the atmospheric ECVs determined by WMO. The listed variables are key parameters to describe the state of the atmosphere, and also variables needed for bulk air-sea flux measurements (latent and sensible heat flux, momentum flux). For the flux measurements, simultaneous multivariate observations are needed, and highly recommended.

The technology for automated observation of the listed variables exists and is widely in use, and thus there is no hinder for systematic collection of these data. However, there are several things related to the selection, siting and maintenance of instruments that need to be carefully considered to minimize errors and ensure good quality of the data.

According to WMO, other atmospheric ECVs in surface observations are precipitation and surface radiation budget. They are shortly discussed in the end of section 3.1. Currently, only some research vessels have automated instruments for these observations and the accuracy of the measurements is quite low. Therefore, collection of precipitation and radiation data in the SPO Programme by commercial vessels is not now foreseen and they were excluded from the list of recommended key variables in SPO Programme.

Air temperature. Air temperature is a key variable which practically all the vessels are measuring. There are several sensor types which can be used for automatic and continuous measurements. Platinum resistance thermometers (PRT) are nowadays the most commonly used sensors. They are stable and accurate (typically about ±0.1°C, depending on instrument and conditions). Other common sensor types are thermocouples and thermistors.

In air temperature measurement, the most typical source of error is heating by sun or ship. Thus, the sensor should be placed as far as possible form any heat source from the ship and protected from direct sun light. Some type of enclosure is a typical solution for shading (Figure 1). The enclosed system requires ventilation. Natural ventilation is usually enough in windy and cloudy conditions, but in strong sunshine and calm wind the temperature in the enclosure can rise several degrees above the true temperature. Thus, a forced ventilation (fan) is recommended. In optimal case, there is a sensor in both sides of the vessel and the recording can be taken from the side better exposed to the wind.

Figure 1. Temperature and humidity sensor (PRT), protected from solar radiation, on board R/V Polarstern. Similar instrument is installed on both sides of the ship. For analyses, data of windward sensor is used.

Humidity. There are several variables describing atmospheric humidity and several methods to measure those. Relative and specific humidity, dew point, partial pressure of water vapor, water vapor density and mixing ratio all describe the water content of the air. Conversion between these variables can be calculated, but some require ambient temperature measurement for this.

Most commonly humidity has been measured with a psychrometer which consist of a pair of thermometers; one with dry and one with wet bulb. A psychrometer measures temperature and dew point which can be converted to other humidity variables, e.g. relative humidity. Traditionally, mercury-in-glass thermometers were used for this purpose. Thermometers can be, and nowadays usually are, PRTs which allows automatic and continuous measurements. Another common type of humidity sensor uses capacitive thin-film polymers which absorb or desorb water as the relative humidity changes. The instrument includes collocated temperature sensor (usually PRT) since the temperature of the surrounding air is needed for conversion to mixing ratio, specific or absolute humidity. Both automated psychrometer and capacitive-type humidity sensors are recommended to be used in ARICE SPO Programme.

Accurate measurement needs airflow (ventilation) and a shield from solar radiation (best double heat-reflecting shield). Optimally, there are two sets of instruments, one on each side of the vessel, and the data can be read from the windward one. Also, the temperature and humidity sensors need to be protected from salt contamination, since salt affects the measurement by absorbing and desorbing water vapor. With the psychrometer, obtained accuracy depends on the accuracy of thermometers: accuracy of 0.1^{o}C of both thermometers leads to uncertainty of 1% in relative humidity and 0.20 g/kg in specific humidity. With the capacitive sensors, the similar level of accuracy is achieved, except in the coldest temperatures (about -20^{o}C or below) when the accuracy is slightly lowered.

Air pressure. There are various types of aneroid barometric pressure sensors utilizing different materials, like ceramic or silicon. Modern aneroid barometers have a digital readout and reach a resolution of 0.1 mbar, fulfilling the target accuracy of WMO. They are relatively stable, and ceramic sensors especially have a good thermal performance and low hysteresis. Also, electronic barometers can be used, when the chosen instrument fulfils the target accuracy of 0.1 mbar. All barometers should be periodically compared with standard instruments.

Usually, barometers give a “station level” pressure as an output which needs to be corrected to sea level. Based on the known instrument height, the correction can be calculated automatically by some electronic log book softwares for instance. However, the reduction to sea level increases the error, up to about 0.5 mbar (*Poli et al., 2017*). For some vessels, the instrument height can vary several meters depending on the load, which brings a source of uncertainty. Near the surface, one meter variation in height corresponds to about 0.1 mbar.

Air pressure measurements can be affected by wind, radiation, and shocks and vibrations. Barometer should be mounted on shock absorbing material and optimally located as close to the center of floatation as possible. It is important to ensure that there is no impact from any dynamic pressure fluctuation due to the wind. Barometers can be also inside, but of course not in any space that may be pressurized (by air conditioning, for instance).

Wind speed and direction. Accurate wind data is very important, but difficult to obtain as ship-born observation. Wind measurements are easily affected by distortion of flow and therefore the siting of instrument becomes highly important. Also, the wind speed measured needs to be corrected to true wind speed. For this, the ship speed, heading and course is needed, with a high accuracy.

In the SPO Programme, wind speed and direction are recommended to be measured as an average over 10 min time, following the guidelines of the VOS Scheme, (*JCOMM Guide, WMO Guide 1*). Earlier, the time averaged wind speed was typically measured with cup or propeller anemometers and wind vanes. In recent years, the use of ultrasonic anemometers (Figure 2) has generalized and they are now commonly found also on other than research vessels. Ultrasonic anemometer is a recommended instrument in ARICE SPO Programme as it has a clear benefit compared to cup or propeller anemometers. An ultrasonic anemometer does not have any moving parts and thus does not need maintenance or further calibration, whereas for a cup anemometer frequent calibration is needed (for high accuracy, calibration of cups should be done individually). Ultrasonic anemometers measure the horizontal component of wind speed and direction, typically with an accuracy of 2% and $\pm1^{o}$, respectively, with wind speed >5m/s. Some instruments measure the vertical component as well.

In the Arctic, icing of an anemometer can disrupt wind measurements and heating is needed to ensure accurate measurements in winter conditions. Heating technology is available for both ultrasonic and cup anemometers.

The wind speed accelerates and direction changes when going around an obstacle. The impact of a central superstructure is especially large. The level of distortion depends on the direction of the wind relative to the ship, and it is minimum for wind blowing directly over the bow. The anemometer would ideally be exposed to air flow before it blows across decks and superstructures. A basic rule is to place the anemometer as far forward and as high as possible. Foremast is a good solution for meteorological instruments, but not always applicable. Also, it would be good to have one sensor in both sides of the ship or of the mast, so that the data can be taken from the side more freely exposed. In the surface layer (lowest part of atmospheric boundary layer) where the wind measurements are conducted, the wind speed has a strong vertical gradient. Therefore, it is important to know and report the exact instrument height so that the correction for effective height can be done.

Figure 2. Ultrasonic anemometer on board R/V Polarstern. Similar instrument is installed on both sides of the ship and data is read from the sensor better exposed to wind.

Pitching of the ship causes vertical motion of the bow. The vertical motion can be of several meters and creates wind relative to the instrument. The seriousness of the impact depends on sensor type, and ultrasonic anemometers are clearly less affected than cup anemometers.

Good quality of wind measurements are essential for flux calculations: latent and sensible heat fluxes calculated with bulk method are directly proportional to wind speed, momentum flux is proportional even to square of wind speed. It needs to be noted, that in the bulk flux method, the wind speed to use should be that relative to the ocean surface, i.e. taking into account also the surface current. This can be done by using Doppler-log/gyro (installed on many ships) which measures the vessel's speed through water, or by combining the ship motion with current measurement. These cause additional source of error, and error can become significant in light winds.

Additional atmospheric variables

For the variables discussed above, the measurement technology is well developed and widely in use. Therefore they are included in the list of variables that all the Arctic going vessels are recommended to measure, and are the key atmospheric variables in SPO Programme. However, there are several other variables for which the data collection would be highly valuable, but the technology is not that mature. Here we shortly describe the sensors and essential aspects of their installation for measurements of precipitation and radiation, which also are EVCs.

Precipitation. On land, precipitation is traditionally measured with a rain gauge, but the same installation does not work anyhow reliably for ship-born measurements. Those rain gauges are not suitable for unsteady platform like a ship, and do not capture the rain in heavy winds. Nowadays, there are rain gauges specially designed for ship use available. In those, one solution for clearly more reliable rain catchment in all condition is the use of both traditional horizontal collector and additional vertical collecting surfaces (Figure 3). In low wind speeds, the horizontal catchment is fairly accurate. For higher wind speeds, the vertical collecting surface becomes dominant. The rainfall rate from the vertical surface requires the measurement of relative wind speed and a wind speed dependent algorithm.

The rain measurement can easily be affected by the distortion of flow. The ship rain gauge should be placed high up above the superstructure of the ship in order to minimize influence of local ship induced velocities. Also, it is important that the instrument is suspended to swing freely (around the long axis of the ship) to deal with the roll of the ship.

This type of ship rain gauges are not yet widely used and thus the precipitation was not included in the recommended variables of data collection on all the vessels in SPO Programme. Of course, if possible, the precipitation data is recommended to be collected. However, it needs to be noted that these ship rain gauges cannot measure snow fall which limits the precipitation measurements to warm season in the Arctic. There is a new technology for automated precipitation measurement, using optical sensors, which is able to capture snow fall as well. This technology is currently in use in some research vessels only, but could be potential for wider use in the future.

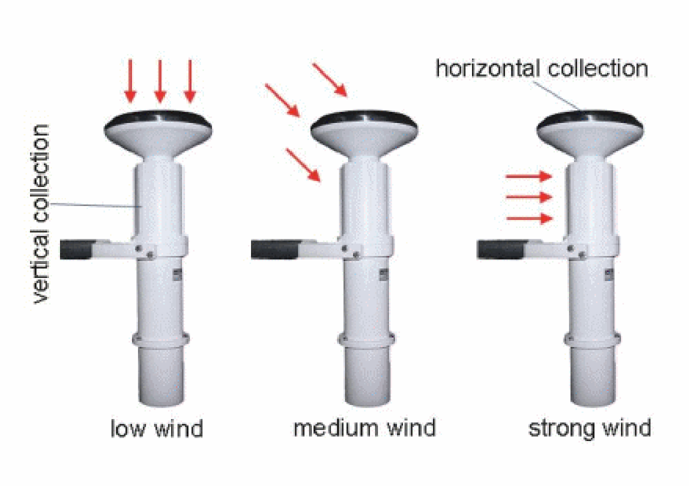

Figure 3. Ship rain gauge. It has both traditional horizontal collector and additional vertical collecting surface. With low wind speeds, horizontal collector catches the rain, with strong winds the vertical surface dominates.

Radiation. Radiation measurements are generally found important as they are needed for the energy budget calculation, and provide essential information for biological research as well. Currently, radiation sensors are carried on board research vessels mostly. In general, they are sensitive to the siting and need frequent maintenance, but when these aspects are considered, valuable radiation data can be collected on any vessel.

Shortwave radiation is measured with a pyranometer and longwave radiation with a pyrgeometer. Pyranometer can measure global radiation (direct and diffuse part of solar radiation). Recent technological developments enable measurements of components (direct and diffuse) of downwelling shortwave radiation using an instrument without a tracker equipped with shade disks. As these instruments do not have moving parts, they are particularly suitable for ship-born observations.

For siting of a radiation instrument, it is not the air flow but shadows that are crucial. Optimally, pyranometer would be elevated above everything else, but usually this is not practically possible since the instrument requires frequent maintenance (cleaning of dome). Thus, a compromise is usually needed in siting, and the quality of measurements can be clearly increased by deploying two set of instruments to ensure good exposure with any solar angle. Especially for shortwave radiation instruments, leveling is important and a gimbal mount is recommended to compensate the roll and pitch.

Table 1. Recommended sensors for atmospheric observations of the key variables (black) and of the additional variables that currently can be measured by some research vessels only (grey).

Variable	Sensor	Common source of error	Optimal siting	Comments
Air temperature	PRT	Heating from ship or sun	One sensor on each side, data from windward sensor	
Air pressure	Aneroid barometer (ceramic sensor)	Dynamic pressure fluctuation from wind		Station level pressure needs to be corrected to sea level
Wind speed and direction	1. Ultrasonic anemometer 2. Cup/propeller anemometer	Distortion of flow	As far forwards and as high as possible One sensor on each side, data from windward sensor	10 min averages Ultrasonic anemometer: No need for manitenance or further calibration Report exact instrument height
Humidity	1.Psychrometer (with PRT), 2. Capactive thin-film sensor	Salt contamination	One sensor on each side, data from windward sensor	Needs to be protected from salt contamination
Precipitation	Ship rain gauge	Distortion of flow	As high as possible	Cannot measure precipitation as snow fall
Radiation	Pyranometer (SW radiation) Pyrgeometer (LW radiation)	Shadowing Exhaust and salt contamination on the instrument dome	As free as possible from obstructions High enough: min. 5° compared to instrument horizon	Needs regular cleaning of the dome → easily accessible site

3.2 Ocean observations

We recommend continuous, automatic observations of:

- Sea surface temperature (SST)
- Sea surface salinity (SSS)
- Bathymetry

Additionally, when navigating in ice free waters in the Arctic region, the use of a FerryBox system is recommended.

Sea state and ocean currents provide as well crucial information i.e. on water mixing and water transport, but in practice only research vessels are instrumented for these observations.

Sea surface temperature. Following the widely used policy (e.g. *WMO Guide 1, JCOMM Guide*), the sea surface temperature (SST) measurement should be representative of condition in the near surface mixing layer, underlying the skin layer. As the sea temperature measurement is very sensitive to the depth, it is important to always report the measurement depth.

In the ocean, the temperature that physically determines the magnitude of flux (latent and sensible heat, outward longwave radiation), is the temperature of the surface itself. Under the skin, the temperature profile depends on the mixing (wind) and the penetration and absorption of solar radiation (possibly causing diurnal warm layer). With currently existing technology, the skin temperature cannot be measured, but it can be fairly reliably estimated from the temperature of the mixing layer.

Traditionally, SST has been measured with a bucket method: a cylinder container, bucket, with insulation and thermometer is cast from the aft deck for a water sample. This method gives a well-mixed sample of surface waters, with an accuracy of about 0.5°C. Due to the wake of the ship, it is difficult to know which depth the sample represents. Naturally, this method is laborious and does not allow high resolution data. However, it is still in use in notable number of vessels in VOS Scheme and form an important part of the climate record.

Here, the use of a thermosalinograph (Figure 4) is recommended for SST measurements. A thermosalinograph uses the ships' intake water. With a thermosalinograph, SST can be measured automatically and continuously, with an accuracy of 0.01°C. The thermosalinograph is often located in a hot engine room, which causes a warm bias in SST measurement; therefore, the location of the thermosalinograph must be reported. However, clearly larger uncertainties are related to the measurement depth. The intake port is often located well aft and due to flow along the hull the water sampled may actually be originated from some shallower depth ahead the ship. This may lead to an error of several tenths of °C. Higher accuracy could be achieved using own intake port located near the bow. However, this is not often a feasible option. Also, for some vessels, the depth of the intake can vary even several meters depending on the load of the ship.

SST can be measured automatically and continuously also with hull attached thermometers. The sensors should be located at a depth of 1 to 2 m below the water line, forward of all discharges. Fitting and wiring of sensors may be complicated and therefore is best done when the ship is being built.

For flux studies, skin temperature is of interest. Infrared radiometers get closest to the measurement of the interface: they measure the temperature at few micrometers depth. They have been reported to reach an accuracy of 0.1 °C. If this type of measurement is recorded, it must be clearly noted as skin temperature, and not as a SST observation.

Figure 4. Thermosalinograph (on left) measures both SST and SSS. FerryBox (on right) is a flow-though system with multiple sensors for automatic measurements of serveral physical, chemical and biological variables.

Sea surface salinity. Sea surface salinity (SSS) is important for the studies on water mass movement, circulation and frontal activity. Sensors used for salinity measurements actually measure conductivity from which salinity can be calculated, either in internal calculations by instrument software or in afterward analyses. SSS is typically measured from the same water sample than SST. This is the case also for the thermosalinograph which is the recommended instrument for SSS measurements in SPO Programme. As SSS is not as sensitive to depth as SST, the difficulty of knowing the exact sampling depth does not bring significant uncertainties to measurements.

However, salinity measurements tend to drift due to sensor fouling, or shift abruptly after a visit in a dirty harbor. Therefore, frequent calibration against independent SSS data is needed. This can be done using water samples collected on board for later analyses, or collocated Argo profiles, for instance. On research vessels, CTD casts provide the needed calibration data.

FerryBox system. FerryBox is a flow-through system measuring several physical, chemical and biological variables automatically, continuously and unattended. FerryBoxes have a water inlet from where the water is pumped into the measuring circuit with multiple sensors (Figure 4). Often, the inlet is located at the sea chest, but it can be a separate valve through the hull as well. The FerryBox is usually positioned as close to the inlet as possible, to minimize the residence time in the system. Usually, FerryBoxes have a debubbling unit, which removes air bubbles and coarse particles. Data acquisition and storage unit is included in FerryBoxes. Many systems also include an inline water sampler. There are differences in the design of flow-through, the degree of automation and in the possibilities for remote control.

In the FerryBox system, operational standard sensors are temperature, salinity, oxygen and turbidity. Many FerryBox systems have additional sensors for chlorophyl-a concentration, pH/pCO2, and some for nitrate and other nutrients, phytoplankton groups and phytoplankton or zooplankton by morphology. However, these latter sensors still need some major improvements.

Although the system can be fully automated, the quality of the data strongly depends on sufficient system maintenance and quality control of the data on a regular basis. The FerryBox data collection is guided and coordinated by EuroGOOS (http://eurogoos.eu/ferrybox-task-team/).

With current technology and installation solutions, FerryBox systems are recommended to be used always when navigating in ice free waters.

Bathymetry. The Arctic Ocean is a region where further bathymetric data is still needed. The bathymetric survey can be done using single-beam or multibeam echosounder. The multibeam technology is preferred since it measures an entire area rather than a single line of seafloor. The depth range of accurate operation is sensor dependent and only the sensor suitable for water depths in the survey area should be used. Use of several frequencies improves the accuracy with varying depths. Effects of severe ship motion to survey data needs to be compensated, for instance by active beam steering or multi-ping ensonification.

The bathymetric data collected in the SPO Programme serves users the best when contributing to international ocean mapping projects. Globally, the largest digital bathymetric data sets are produced and distributed by General Bathymetric Chart of the Oceans, GEBCO. It operates under the joint auspices of the International Hydrographic Organization and the Intergovernmental Oceanographic Commission (of UNESCO). For the Arctic Ocean, the development of a digital database containing all available bathymetric data is done by the International Bathymetric Chart of the Arctic Ocean (IBCAO) initiative. The IBCAO data set is included, as a regional compilation, in the global GEBCO grid. In the SPO Programme, collection of bathymetric data is recommended, to contribute to data sets of IBCAO and GEBCO. IBCAO and GEBCO welcome contributions of single-beam and/or multibeam survey data.

Additional marine variables

Upper ocean currents. In the VOS Scheme, surface currents have been considered as special observations. Traditionally, these data have been derived from ships' set and drift. A new and promising method of obtaining surface current data, potentially in real-time, is a use of AIS navigation data (*Guichoux et al*., 2016).

Technology for current measurements exists. An Acoustic Doppler Currentmeter (ADCP) provides the velocity profile underneath the ship. It can collect underway data, but currently practically only research vessels are fitted with ADCP instrument.

Also, radar technology can be utilized to detect surface currents in the vicinity of the ship.

Sea state. Guidelines of VOS Scheme recommend visual observation of wave height. Nowadays, there are wave radars that can measure several variable of the wave field: wave energy, directional wave spectrum, and heights, periods and directions of waves. Also, wave radar can measure the speed and direction of surface currents. The system uses conventional navigational X-band radar. Wave measurements are based on the backscatter of microwaves from the ocean surface.

Table 2. *Recommended sensor for marine observations of the key variables (black) and of the additional variables that currently can be measured by some research vessels only (grey).*

Variable	**Sensor**	**Common source of error**	**Optimal siting**	**Comments**
Sea surface temperature	Thermo-salinograph	Uncertainty of the actual measuring depth	Close to own intake port located near the bow	Very sensitive to measurement depth
Sea surface salinity	Thermo-salinograph	Sensor fouling		Requires regular calibration
Oxygen, turbidity, pH, Cl-a, pCO2, nutrients	FerryBox		Close to inlet	Requires regular maintenance and calibration
Bathymetry	Echosounder	Incorrect speed of sound Ship motion		Multibeam sonar preferred
Upper ocean currents	ADCP	Pitch and roll of the ship		Measures vertical velocity profile Requires accurate record of ship motion
Sea state	radar	Only wave field with significant wave height >0.5m can be reliably measured	Antenna: site with minimal shadow sectors and refections from the ship Display: at the bridge	Provides several wave parameters: - wave height, period and direction - wave energy and directional wave spectrum

3.3 Sea ice and snow observations

Currently, there are no instruments for systematic, automated ship-born sea ice and snow observations. This was clearly shown by Deliverable 6.1 as well, where only one research vessel reported any automatic sea ice measurement (ice load on the hull). However, several visual observations of sea ice conditions are done in all vessels on regular basis as they are needed for safe navigation. Therefore, the crews of the ships in the Arctic are experienced in making visual sea ice observations and the systematic and standardized collection of those observations is currently the best way to collect the ship-borne sea ice and snow data.

A work towards a standardized collection of visual ship-borne sea ice and snow observations in the Arctic has been running for several years under the project IceWatch. IceWatch coordinates the collection and archiving of the observations and provides a software which observers use for reporting the sea ice conditions. Also, IceWatch provides a detailed manual for making the observations. So far, IceWatch has been mainly used by research vessels during their Arctic expeditions but the programme welcomes any observers.

Some automatic weather station systems allow a manual input of visual observations. Those are one option for collection of sea ice observations. However, for the best findability and usability of the data, it would be ideal to have all the visual sea ice observations in one archive. Thus, we recommend that all the ships navigating in the Arctic feed their visual sea ice observations in the IceWatch.

The recommended visual sea ice observations include:
Location of ice edge

- Sea ice concentration
- Sea ice types (new ice, first year ice, multiyear ice, deformed ice)
- Sea ice thickness
- Floe size
- Ice bergs

3.4 Ship data

The minimum ship data that needs to be recorded simultaneously with environmental observations are the position, course and speed of the ship. These can be taken from the ship's own navigation system (like gyro compass) or computed using satellite navigation system (usually GPS). If available, also the vessel's speed through water should be recorded, as it is needed to calculate wind relative to ocean surface, needed for bulk air-sea fluxes.

Electronic log books for VOS Scheme are recommended by JCOMM (http://sot.jcommops.org/vos/resources.html#ops03) and those should be used in ARICE SOP Programme as well.

4. General aspects on instrument installation and maintenance

There are some general, not sensor specific, aspects on instrument installation and maintenance, and some special challenges of ship-born measurements that need attention.

Documentation. Good, thorough documentation is important with all instrumentations, but especially essential for ship-born measurements. Every vessel has its own structural design and thus the optimal location of instruments is vessel dependent. The siting of the instruments on the vessel has to be clearly documented. This should include a photograph or an illustration, where superstructure, masts and other structures that may affect the measurements can be seen. Also the instrument deployments should be photographed. Instrument height is an essential information for several variables, like wind speed and air pressure, and it needs to be recorded carefully. However, the height may change considerably due to load of the ship, but also due to pitch and heave in the rough sea, and this uncertainty needs to be considered when using ship-born measurements.

The documentation should include not only the first installation but also any changes in installation, and any maintenance and calibration done. Serial numbers of all sensors and other devices need to be recorded. During the operations, any events different from normal should be noted. The documentation should be in electronic format.

Computer recording software. It would be important to enable real-time display of the variables that are recorded. That allows easy check, as part of daily routines, whether the instruments are working and providing reasonable data. If some variables are recorded with a pair of instruments, it is good to check that they give similar values or that there is a clear reason for the difference (like shadow).

Calibration. The frequency of calibration vary largely from sensor to sensor, and the recommendations of manufacturers should be followed. Once in a while, it would be good to calibrate the entire system including the sensor and transfer of signal from analog to digital output. As already mentioned earlier, it is important to record calibrations in the documentation.

Salt. Salt from the ocean reaches even the highest points of the vessels. Salt is deleterious for the electronics and all the connections must be sealed. Salt contamination on optical sensors require regular cleaning.

Exhaust. It is unavoidable that an exhaust plume reaches the instrument sites in times. The impact is largest on temperature, humidity and radiation measurements. Usually this causes abrupt changes which can be distinguished from the data. Also, the ship-relative wind can be utilized when evaluating whether the exhaust plume has affected the measurement. Exhaust causes also contamination on optical sensors, and cleaning is needed.

Disturbance on radio frequency. Some sensors, especially those for radiation measurements, may be interfered by radio frequency transmissions. This should be considered when selecting the site of the Instrument.

5. Data management and transfer

The data collection in the SPO Programme can be divided in three phases: collection of data on-board, transmission of data and storing of data. These three steps face different data management issues which are discussed here, and also more in detail Deliverables 7.1 and 7.3.

During the data collection, a shipboard person (crew member or technician) maintains the quality of the data. This requires regular monitoring of the performance of sensors, i.e. checking that data flows and that it is reasonable. This person also makes sure that all needed is recorded in a log. The shipboard operator should be able to recover the system in the case of computer crash, for instance. The data should be backed up every few days, especially if it not transmitted during the survey. As stated in Deliverable 7.3, a formal instruction about the responsibilities and specifications how to create and manage data and metadata on board should be prepared and distributed among the different scientific parties and shipboard members.

The requirements of metadata are described in detail in Deliverable 7.3 and follow SeaDataNet approach, an EU reference project in marine data management, and ISO 19115 content model. Commercial vessel participating in the SPO Programme is most likely not familiar with the requirements of scientific data and metadata but will be carefully guided to produce needed information. The generation of data and metadata on board does not require any very specific infrastructure of computing and communications resources. The software developed under the umbrella of the SeaDataNet project can be run on any user computing platform, does not require access to centralized computer or storage services on ships, nor does it require permanent internet access. Deliverable 7.3 gives recommendation for software tools for metadata and data management.

Data can be transferred during the survey or when the ship returns to harbor. Both types of data are valuable and welcome to SPO Programme. If the data and metadata are to be sent during the surveys, it is sufficient to establish a daily periodicity and file compression, which allows the transmission via satellite. As Deliverable 7.3 describes, availability of the broadband satellite connection (VSAT, Inmarsat) is a foreseen limitation in data transmission, due to the limited geographical coverage (up to 70ºN) of geostationar constellations. However, other satellite facilities (LEO constellations like Iridium) with less capacity but with polar coverage could be used instead.

ARICE is following the principles outlined by the Open Research Data Pilot and The FAIR Guiding Principles for scientific data management and stewardship. FAIR stands for findable, accessible, interoperable and reusable. The data collected needs to be made publicly available and the longterm preservation has to be guaranteed. These issues are discussed in ARICE Data Management Plan (Deliverable 7.1), but they still need further planning and agreements.

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