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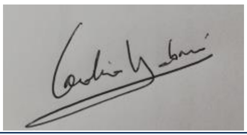
Author	Carolina Gabarro BEC		09/08/2019
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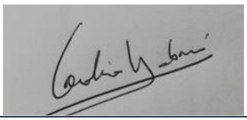
	Carolina Gabarro		09/08/2019
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August-2019 / v1r7	Add Reference Document table	Section 1.3
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Acronyms (Check from SOW)

AD	Applicable document
ADB	Actions database
AMOC	Atlantic Meridional Overturning Circulation
ATBD	Algorithm theoretical basis documents
BRO	Brochure
CliC	Climate and Cryosphere
CMEMS	Copernicus Marine Environment Monitoring Service
CORA	Coriolis Ocean dataset for ReAnalysis
DIR	Directory
DS	Dataset availability
DS-UM	Dataset user manual
DVP	Development and validation plan
EC RTD	European Commission Directorate General for Research and Innovation
EDS	Experimental dataset
EMI	Electromagnetic Interference
EO	Earth Observation
EOEP	Earth Observation Envelope Program
ESA	European Space Agency
FR	Final review
FRM	Fiducial Reference Measurements
FWF	Freshwater fluxes
GCOS	Global Climate Observing System
IAR	Impact assessment report
ITP	Ice-Tethered Profilers
ITT	Invitation to tender
IPP	Year of Polar Prediction
KO	Kick-off
MR	Monthly report
MTR	Mid-term review
MV-TN	Modelling and validation technical note
NDVI	Normalized Difference Vegetation Index
PAR	Preliminary analysis report
PGICs	Peripheral glaciers and ice caps
PM	Progress meeting
PMP	Project management plan
QA4EO	Quality Assurance for Earth Observation
RD	Reference document
RB	Requirements baseline
SAR	Synthetic Aperture Radar
SIAR	Scientific and impact assessment report
SMOS	Soil Moisture and Ocean Salinity
SoW	Statement of work
SR	Scientific roadmap
SSS	Sea Surface Salinity

SST	Sea Surface Temperature
TDP	Technical data package
TDS	Training Data Set
TN	Technical note
VIR	Validation and intercomparison report
VR	Validation report
WCRP	World Climate Research Programme
WP	Work package
WS	Workshop minutes
WWRP	World Weather Research Programme
AD	Applicable document
ADB	Actions database
AMOC	Atlantic Meridional Overturning Circulation
ATBD	Algorithm theoretical basis documents
BRO	Brochure
CliC	Climate and Cryosphere
DIR	Directory
DS	Dataset availability
DS-UM	Dataset user manual
DVP	Development and validation plan
EC RTD	European Commission Directorate General for Research and Innovation
EDS	Experimental dataset
EMI	Electromagnetic Interference
EO	Earth Observation
EOEP	Earth Observation Envelope Program
ESA	European Space Agency
FR	Final review
FWF	Freshwater fluxes
GCOS	Global Climate Observing System
IAR	Impact assessment report
ITT	Invitation to tender
YOPP	Year of Polar Prediction
KO	Kick-off
MR	Monthly report
MTR	Mid-term review
MV-TN	Modelling and validation technical note
NDVI	Normalized Difference Vegetation Index
PAR	Preliminary analysis report

1 Introduction

1.1 Scope of this document

This document holds the Requirement Baseline Document (RBD) prepared by Arctic+ Salinity team, as part of the activities included in the [WP100] of the Proposal (Task 1 from SoW ref. **EOP-SDR/SOW/084-17/DFP**).

The objective of this document is to consolidate the preliminary scientific requirements for the project.

1.2 Structure of the document

The RBD is structured as follows:

Chapter 1 covers the introduction and the description of this document.

Chapter 2 includes a detailed review of the knowledge gaps and scientific problems to be addressed, as well as an assessment of the main scientific challenges.

Chapter 3 is dedicated to identify the datasets that shall be acquired for development of the new products.

Chapter 4 collects the initiatives and projects operating at the Arctic region that could be potential stakeholders for this activity.

Chapter 5 defines the best test areas to be used for the development and testing of the proposed methodologies and models.

Chapter 6 analyses the various technical risks associated to the project, with their corresponding proposed mitigation strategies.

Chapter 7 is devoted to the define the scientific and operational requirements for the implementation of the project, including a description of the proposed methods and models, the limitations of the proposed solution, and any additional data requirements that shall be considered. It also includes a description of the expected operational processing model.

1.3 Reference Documents

ID	Document	Reference
RD01	In Situ database Analyses Report. PI-MEP Consortium. March 15, 2019.	pimep-insitu-report_20190315.pdf
RD02	Guide for Quality Assurance for Earth Observation (QA4EO)	QA4EO-QAEO-GEN-DQK-002_v4.pdf
RD03	CCI SST Product Validation Plan (PVP)	SST_CCI-PVP-UoL-001-issue_2.pdf

2 Scientific background

2.1 Knowledge gaps and scientific problems to be addressed in the project

Changes in the Arctic Ocean freshwater exchanges may be linked to changes in the thermohaline circulation, which in turn may have implications for the Global Climate [Manabe and Stouffer, 1995]. Thus, it is critical to understand the mechanisms for freshwater exchanges between the Arctic and the global ocean.

The acquisition of continuous series of salinity at high latitudes is a difficult task, as the Arctic is a very remote region with extreme weather conditions and sea ice forces strong enough to destroy the in situ infrastructure (like Argo floats, moorings or gliders). The number of in situ surface salinity measurements are therefore very scarce, and especially inside the Arctic Ocean.

Figure 1, shows the historical observations both from ships and from Argo floats. Notice that besides data is very scarce, the geographical distribution of the observations is very inhomogeneous. The Argo data are used in the generation of the World Ocean Atlas 2013 (WOA2013), [Zweng et al. 2013]. ITP data below thick sea ice are not useful for satellite monitoring of open ocean salinity.

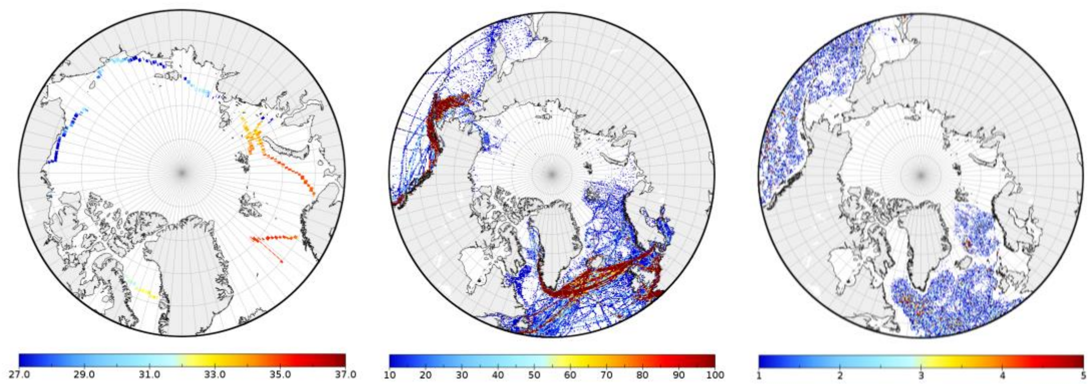

Figure 1 Left: TARA expedition SSS dataset. Centre: Number of in-situ measures provided by Copernicus Marine Environment Monitoring Service (CMEMS). Right: Number of measures provided by delayed ARGO profilers. Data contained in the centre and right figures are grouped in a 0.25°x0.25° grid and comprise the whole period 2011-2017.

One can easily observe that the in situ measurements provided by Copernicus service are located in European and American sectors (Figure 1 middle). A clear gap of freely distributed data is evident in the central Arctic and the Russian sea. The Canadian region is also almost free of data in Figure 1, but Canadian measurements are available under request in the Canadian data services.

Furthermore, rivers are the most important sources of freshwater and stratify the upper Arctic Ocean, so that changes in the river runoff could have a strong impact on the Arctic system [Nummelin et al. 2015, Carmack et al. 2016]. It is also well known that an increment of the global mean annual temperature will produce an increase in the discharge of Arctic rivers [Peterson et al., 2002; Mulligan et al., 2010]. Measurements on the river mouth are very scarce. The project called Arctic Great Rivers Observatory (https://arcticgreatrivers.org/) is taking samples since almost two decades at different positions of the main

Arctic river, but a global perspective of the river runoff is not possible with those single measurements. Therefore, river mouth regions are also lacking of continuous salinity measurements and could be a limitation for the validation of these dynamic regions. As seen in the 2015 update of the Arctic Report Card the combined discharge of the eight largest Arctic rivers was 10% greater in 2014 than their average discharge during the 1980-1989 period [Jeffries, 2018]. Bring & Destouni [2014, Fig 6 right panel] more generally note a sharp increase of total meltwater runoff and total river runoff into the Arctic Ocean from 1993 onwards. However, the precise impact of an increase of the Arctic freshwater runoff remains unknown due to the lack of salinity measurements in the Arctic. Therefore, improving the observations of high latitude SSS will help to improve both the models and the forecasts of the changes taking place in such a critical region.

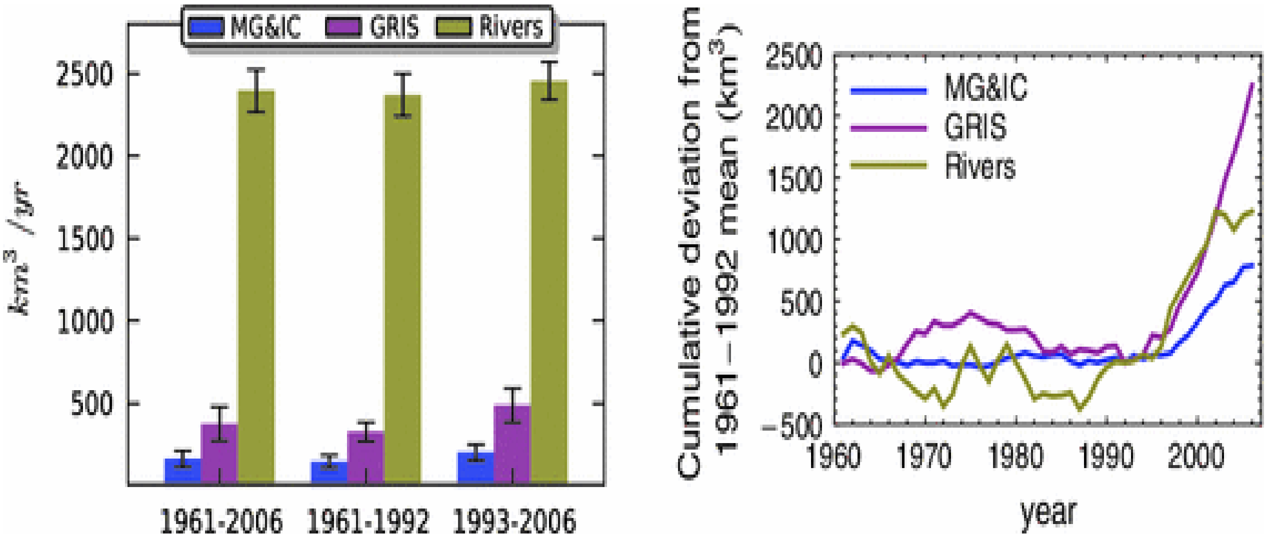

Figure 2 Left: Total meltwater runoff and total river runoff into the Arctic Ocean. Right Cumulative deviations in annual freshwater flows from mountain glaciers and ice caps (MG&IC), Greenland ice sheet (GRIS), and rivers relative to average values for 1961–1992. From Bring & Destouni [2014].

The Arctic + project will contribute to the knowledge of the freshwater flux changes in the Arctic region. Both because better quality Sea surface salinity products will be produces and because this satellite data will be the assimilated to the TOPAZ circulation model.

2.2 Assessment and analysis of the main scientific challenges

The use of L-band radiometry, and specially the SMOS mission, to fill the observational salinity gap at high latitudes, plays a key role to better determine and monitor the observed changes on the freshwater fluxes.

The SMOS standard SSS retrieval algorithm [Font et al., 2008; Mecklenburg et al., 2009; Kerr et al., 2010], as well as the algorithms used for SSS retrieval from Aquarius and SMAP data [Yueh et al. 2013, Yueh et al. 2014, Tang et al. 2013 and Tang et al 2015], provide in general good estimates of SSS in waters the open ocean and within the tropical and mid latitudes.

However, SSS retrievals from the current operating L-band radiometer satellites, presents serious problems at high latitudes:

Low sensitivity of TB to salinity at cold waters: Although the L-band frequency offers almost the maximum sensitivity of the brightness temperature to SSS variations, this is rather low (Zine et al., 2008).

In cold waters, the sensitivity of the TB to salinity decreases rapidly (Swift and McIntosh (1983)). As shown in Yueh et al. (2001), such sensitivity drops from 0.5 to 0.3 K psu^{-1}, when SST decreases from 15 to 5 ˚C. Therefore, the errors of the SSS at cold waters are larger than at temperate oceans.

Land-sea contamination (LSC) and ice–sea (ISC) contamination: The presence of a sharp discontinuity in brightness temperature due to the transition between sea and land or between sea and sea ice induces a contamination of the signal which is especially important (both in amplitude and spatial range) in the case of SMOS although it is also present in SMAP and in its predecessor, Aquarius. This type of contamination has an impact on the ocean observations very far from the coast and the ice.

Lack of in-situ measurements: The limited number of in-situ measurements of Surface salinity in the Arctic, is a main scientific limitation. First this is a limitation for the validation processes, since as explained in the previous section, the measurements are not equally distributed, so some regions have a clear lack. Moreover, this is a limitation to carry out the temporal bias correction, since the method uses an annual reference of SSS, and if this is not accurate can produce additional errors on the final product. The annual reference used (WOA2013) is constructed based on the in situ measurements.

Some works assessed the quality of SMOS and Aquarius SSS products at high latitudes. Köhler et al., 2014 performed a comparison of previous versions of SMOS and Aquarius products with in situ measurements and models in the north Atlantic region, but they did not perform any comparison inside the Arctic Basin. [Garcia-Eidell et al., 2017] carried out a comparison in the Arctic region of that BEC SMOS SSS product and three other SSS products derived from Aquarius against thermosalinograph vessel transects and in situ data from the CORA5.0 collection [Cabanes et al., 2013]. The results showed that all the products attain reasonable quality in the Arctic Ocean, and especially SMOS- BEC derived products showed to be of great benefit for observing SSS in those regions.

3 Survey of all accessible associated datasets

3.1 Space-based EO datasets

Three satellites have been designed and flown carrying an L-band radiometer, the instrument that permits to measure the SSS. The first one was designed and settled by ESA and the other two by NASA.

The Soil Moisture and Ocean Salinity (SMOS) satellite from ESA was launch in 2009, and marked the dawn of a new type of space-based microwave imaging sensor carrying a synthetic aperture L-band radiometer. Originally conceived to map Soil Moisture (SM) and SSS, SMOS is also making serious inroads in the cryosphere sciences. At the time of writing this document the instrument is still measuring and is in good health.

The Aquarius/SAC-D NASA mission was conceived specifically to measure SSS. It was launched on 2012 and ended operations on 2015. The Aquarius instrument is a real aperture radiometer, so different technology than SMOS. The resolution was different for each beam but the averaged resolution is around 100 km pixel.

The SMAP mission, was designed by NASA to acquire Soil Moisture and SSS measurements. The radiometer is of real aperture but the big antenna that carries permits to have better resolution than Aquarius.

Currently, some of the SMOS, Aquarius and SMAP SSS maps available for the Arctic are subsets of the global ones, while only two datasets are specially produced for the Arctic regions. The datasets are listed below:

3.1.1 Global L3 SSS datasets

- LOCEAN produces the new version 2.1 of its debiased SSS maps departing from operational L2 processor of **SMOS** (www.locean-ipsl.upmc.fr/smos). This dataset is distributed by the "Centre Aval de Traitement des Données SMOS" (CATDS) [Boutin et al. 2018].

- Barcelona Expert Centre (BEC from ICM/CSIC)) produces and distribute the global **SMOS** SSS maps using the debiased non bayesian technique (Olmedo et al. 2017) in http://bec.icm.csic.es/. They are daily map of 9 day objective analysed data in a rectangular grid at 0.25º resolution, from 2011 to 2016. This product has been generated from official ESA L1B data v620.

- Jet Propulsion Laboratory (JPL) produces global **SMAP** SSS product version 4.2 (smap.jpl.nasa.gov). JPL dataset is available via PODAAC website (Physical Oceanography Distributed Active Archive Center podaac.jpl.nasa.gov) [SMAP JPL 2019].

- Remote Sensing Systems (REMSS) currently produces version 3.0 of its global **SMAP** SSS product (www.remss.com). This dataset is available from the REMSS website. [SMAP REMSS 2018].

- Aquarius mission was decommissioned on June 7, 2015 but data v5.0 from period June 2011-June 2015 is available at PODAAC website. Global product is distributed with weekly temporal resolution and in 1 degree of spatial resolution.

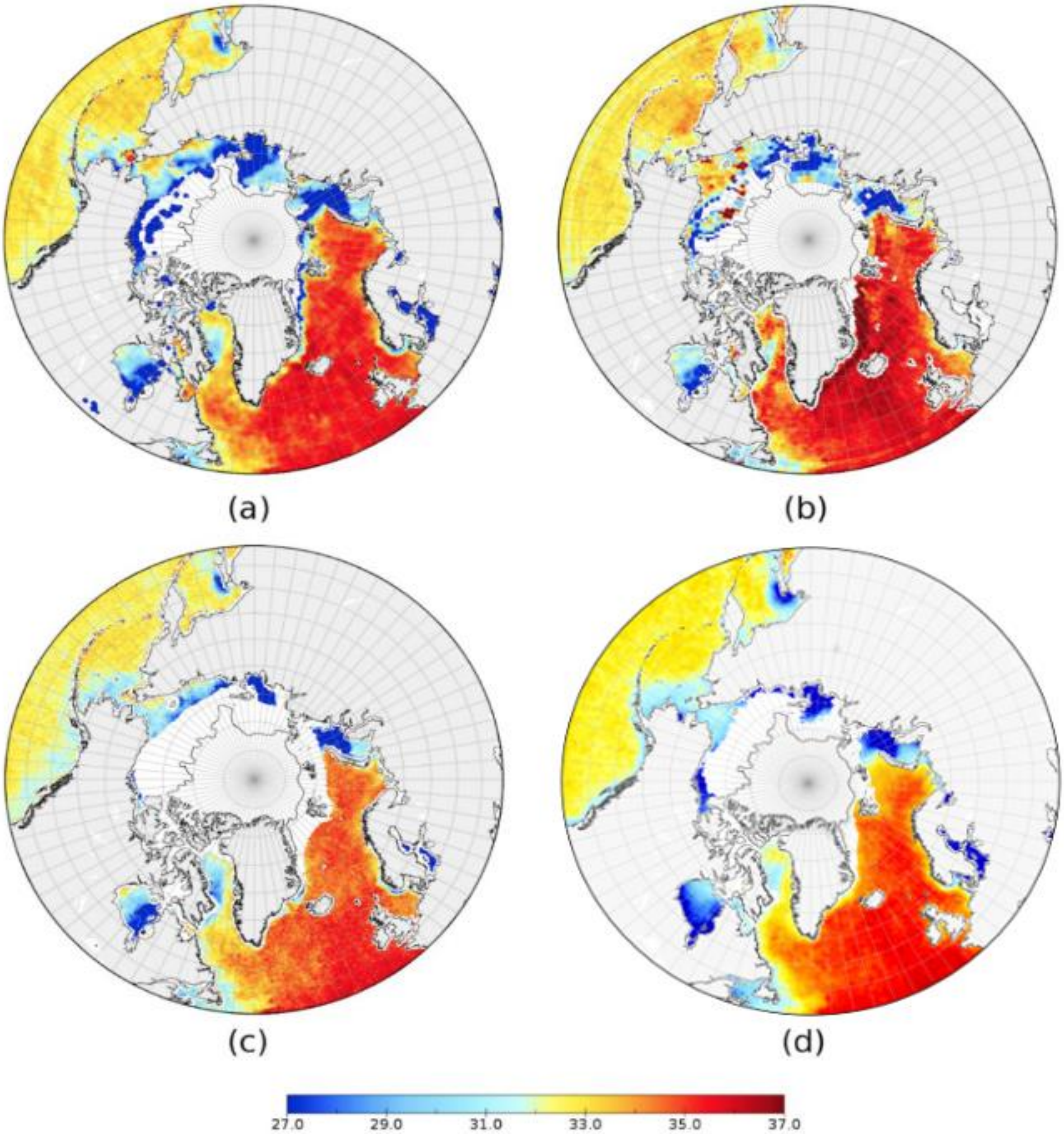

Figure 3 Arctic salinity according to 8-days maps from SMAP (left) and 9-days maps from SMOS (right). (a) Global SMAP JPL v4.2. (b) Global SMOS debiased Locean v2.1. (c) Global SMAP REMSS v3.0 (d) Global SMOS BEC v1.0. Maps are centred at September 7, 2015. Black line around the pole indicates an ice fraction of 0.5 according OSTIA.

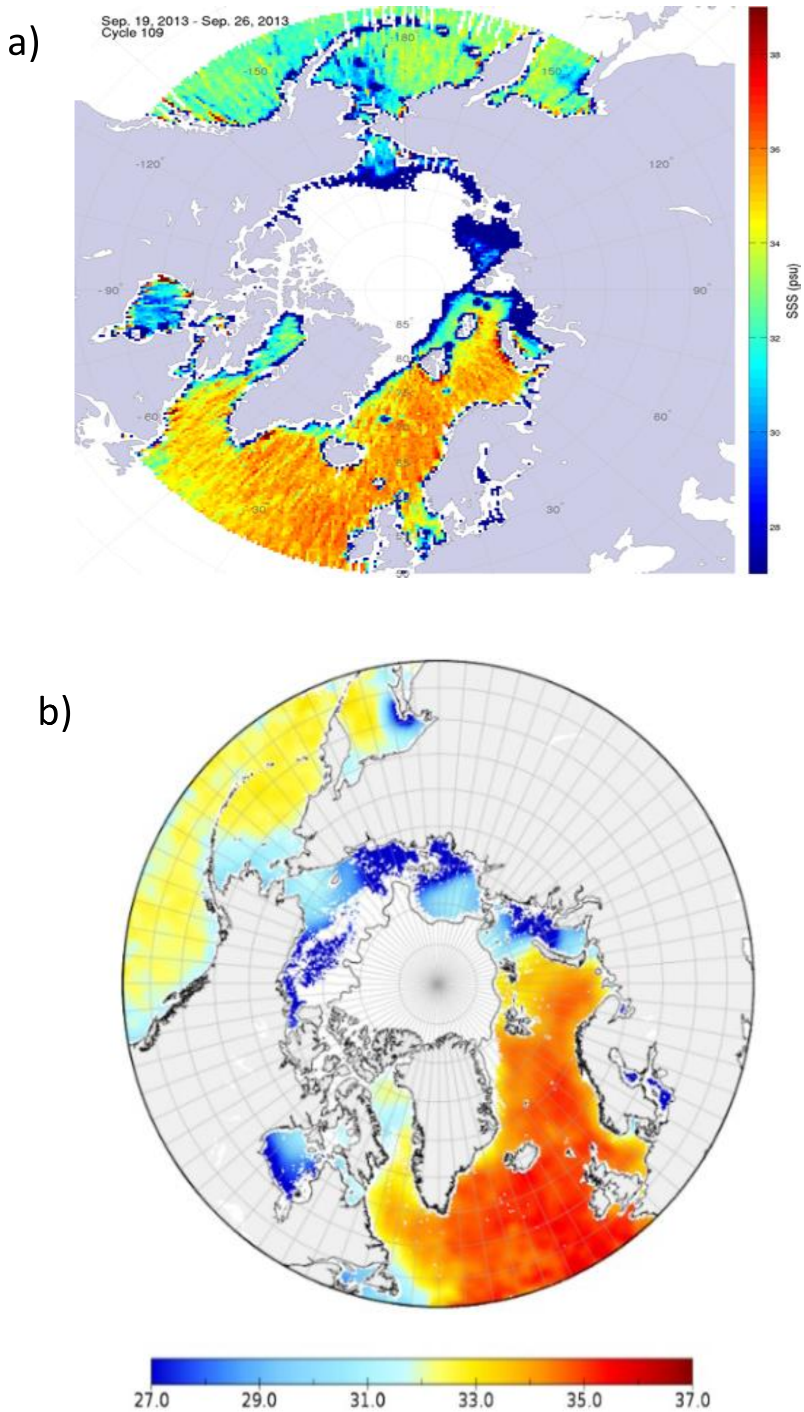

Figure 4 Specific Arctic SSS products: a) Aquarius weekly-polar-gridded SSS using retrievals from the three beams and all orbits in the Northern Hemisphere (latitudes >50°, 19-26 September 2013). b) BEC Arctic SMOS product v2, map centred at September 7, 2015.

Arctic focus of the global products are shown in Figure 3 (Plots (a) to (c), respectively). The Specific Arctic SSS products are shown in Figure 4.

3.1.2 Specific Arctic SSS products

- BEC is currently distributing version v2.0 of its Debiased non-Bayesian Advanced product for Arctic through its distribution and visualization data service in http://bec.icm.csic.es/ocean-experimental-dataset-high-latitude-and-arcticsss/.
  This newly released BEC product is especially designed to target the Arctic region. The SMOS SSS product at high latitudes covers seven years (2011-2017). Figure 4 (plot (b)) shows a 9-days map of this product.
- NASA GSFC center distributes also the V5 weekly-polar-gridded SSS maps from AQUARIUS for both polar region in (Brucker, et al, 2014). [https://doi.org/10.5067/Aquarius/AQ3_SSS.005].

3.2 In situ datasets

The Arctic+ salinity team will use in situ T and S from different sources (see DUM) including Argo, ship based measurement at the surface. Additionally, surface drifters and different mooring arrays will be made available to the Arctic+ project. We present a brief description to the main specifications of the in situ sources to be used within the duration of the project and for different activities including the validation of the newly developed SSS satellite retrieved observations.

Arctic+ validation will intend to comply with the Quality Assurance framework for Earth Observation (QA4EO) [RD02]. Hence it is necessary that the insitu observations used for the validation of the product are independent from satellite measurements over the entire satellite mission (i.e. 2010-2018 in the case of SMOS). These independent insitu measurements are also known as Fiducial Reference Measurements (FRM) and ensure the maximum return over investments of satellite mission. To date there is not an established guideline to get FRM to validate satellite retrieved SSS. The acquisition of FRM is not an easy task due to the scarcity of the in situ observation in Arctic region. This challenge was seen before in the validation of SST data in the region and it will be explored in this project [RD03]. Hence the Product Validation Product (PVP) to be delivered end 2019) will be the first attempt to describe the validation of SSS in the Arctic region.

3.2.1 Argo floats

The Argo array provide both in situ temperature and salinity profiles from the surface down to the 2000 m, with a 300 km spatial resolution every 10-day. The spatial distribution of the floats is not homogeneous so these tend to accumulate over regions with higher velocity current (i.e. over the western boundaries). More importantly, Argo coverage is lower at high latitudes, including in the Arctic region, where floats operation is limited by the presence of sea ice (i.e. floating ice blocks do not allow floats coming up to the surface to transmit data information).

The Arctic+ project will use delayed mode Argo specially designed to operate within the Polar regions (i.e. latitudes ≥ 50˚N and latitudes ≤ -50˚S). Delayed mode floats already passed a quality control (QC) to correct any instrumental drifts. Next, float identification number (ID) will be contrasted against the *grey list*, which contains information of those platforms reporting instrumental failure or sampling cycles when the platform did not pass the QC tests.

ICM-CSIC maintains a local ftp mirror of the Argo floats database distributed by Coriolis website (ftp://ftp.ifremer.fr/) that is refreshed twice a day.

It is expected to store both T and S fields and made available to the consortium. Figure 5 shows the number of measurements provided by Argo floats in the period of study 2011–2017

The Coriolis Ocean dataset for ReAnalysis (CORA) is the reanalysis (optimal interpolation) of delayed time mode validated ARGO measurements provided by the Coriolis data centre and distributed by the Copernicus Marine service. But for the moment this CORA dataset will not be used for validation.

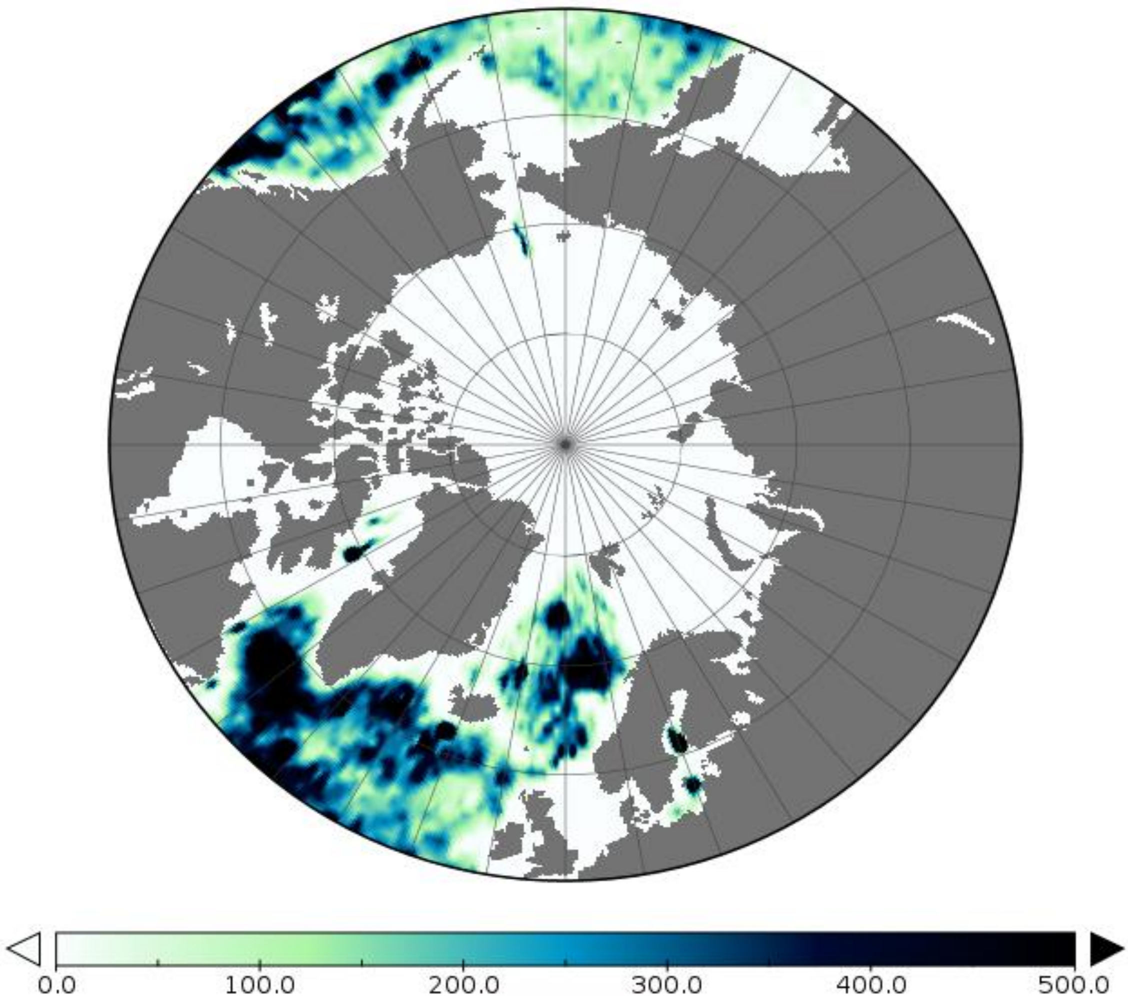

Figure 5 Argo observations within the study period 2011-2017

3.2.2 OSNAP project

The OSNAP mooring array (Figure 6) will be used for validation. The array uses moored instruments gliders, and floats (RAFOS and Argo) to measure different physical properties of the water column, including temperature and salinity. Even though full water column data is being provided, Arctic+ Salinity will select in situ observations from the top 10 m of the water column. Full description of the data gathering and processing of each campaign is available in the cruise reports (see DUM, section 3.2). See the OSNAP section array in Figure 6 Holiday, et al., 2018 did interpolated data from different sections into a 10-km spacing grid. Processed dataset seen in that work might be available for the validation purposes of the Arctic+ Salinity dataset.

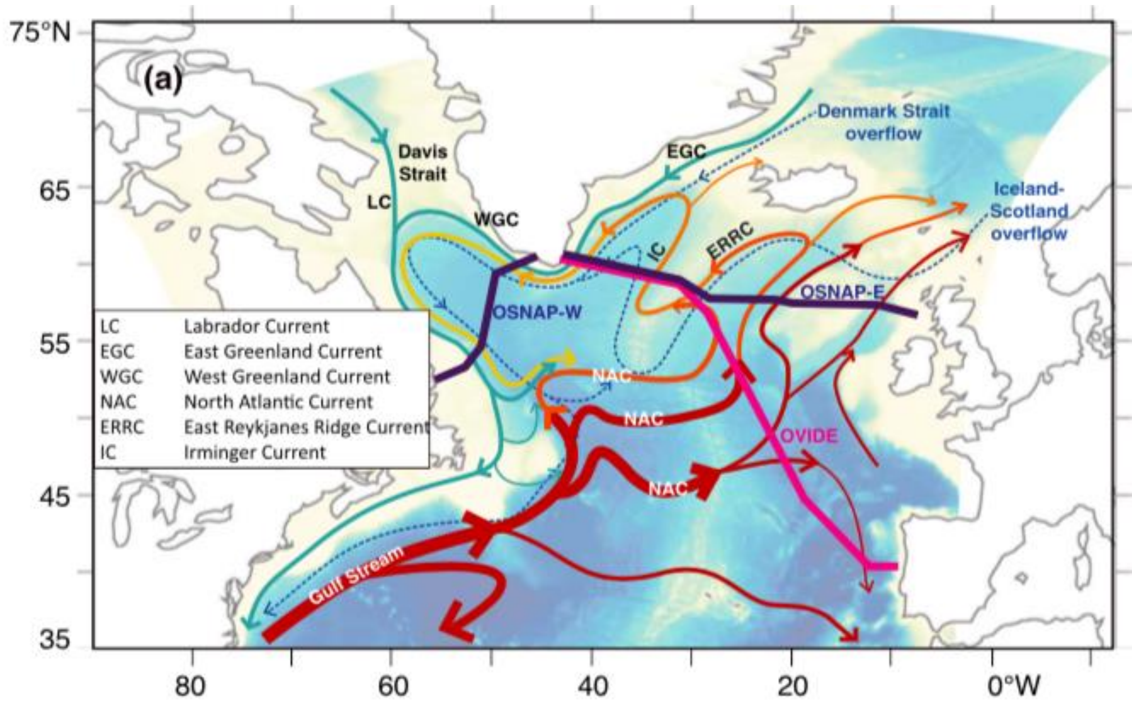

Figure 6 Regional circulation of the subpolar North Atlantic and location of the OSNAP section and array, between 45˚ N to 60˚ N (source Holliday, P., et al., 2018)

3.2.3 Buoys measurements from BGEP project

Beaufort Gyre Experiment Project (BGEP, https://www.whoi.edu/page.do?pid=66519) is maintaining a set of observing system programs since 2003 and providing in-situ observations over the Beaufort Gyre in every summer. The Ice-Tethered Profiler (ITP) can measure temperature and salinity of the water column (https://www.whoi.edu/page.do?pid=20756) and the Bottom Pressure Recorder (BPR) has a SeaBird sensor that records the salinity also, so this data will be useful for validation. Moreover, CTD sensors measurements has been done regularly.

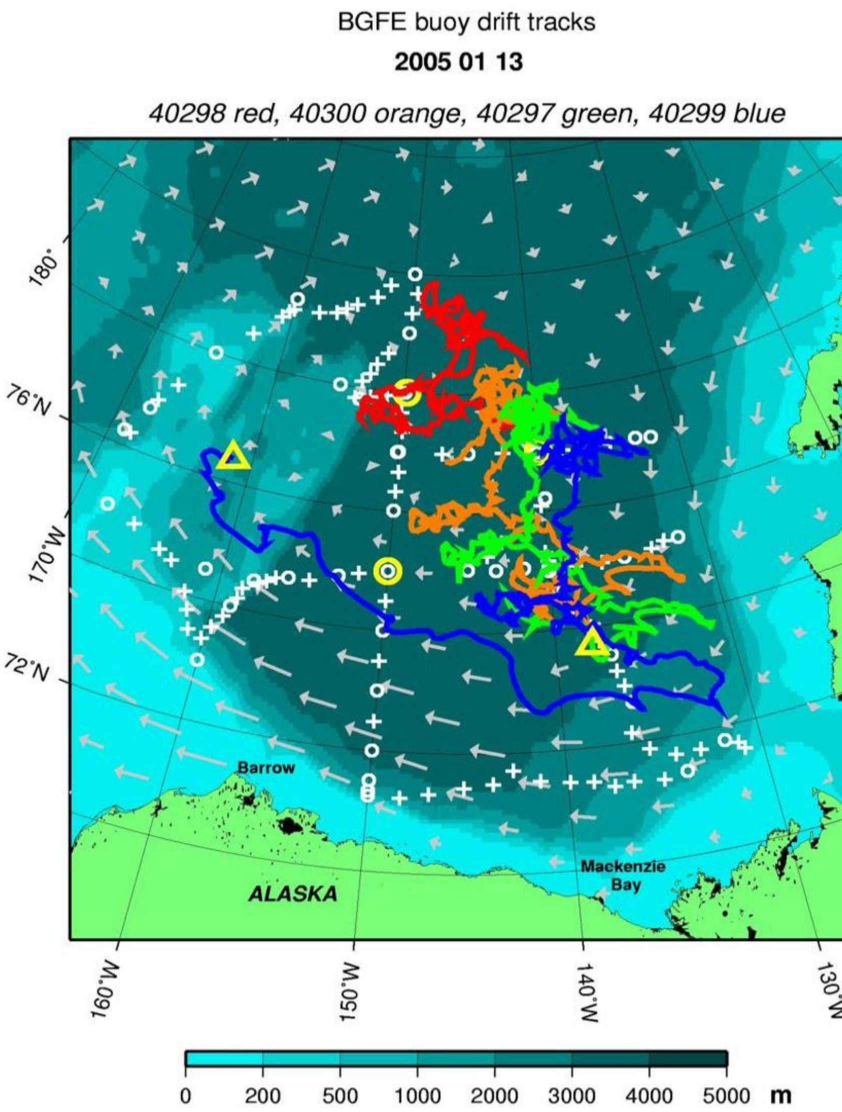

Figure 7 BGFE buoy drift tracks (solid lines) and latest locations (triangles) superimposed on IBCAO bathymetry (shading). Also indicated are BGFE moorings (yellow circles), JWACS 2003 CTD (white circles) and XCTD (white crosses) stations and mean annual ice drift vectors from IABO climatology (grey vectors) (ref: https://www.whoi.edu/page.do?pid=66519)

3.2.4 Arctic CMEMS in situ

The Copernicus Marine Environment Monitoring Service (CMEMS) includes a product called NSITU_ARC_NRT_OBSERVATIONS, which contains information from three types of observation platforms: mooring, glider, and vessel. This product integrates observations aggregated from the regional EuroGOOS consortium (Arctic-ROOS), all observations are aggregated by the In Situ Thematic Center (ITC) under CMEMS framework and provided to users together with metadata information on the platforms that were used to perform the observations. The quality of the observation is tested using automatic procedures and the flags are positioned to inform the users of the level of confidence attached to the observations. Clearly, there are three main data sources: Ice-Tethered Profilers (ITP) , glider profiles, and vessels respectively. It should be noticed that the SSS observations from vessels include that from ferry boxes since 2013 so the observations in high time frequency (~10 mins) are accessible along the cruise, which requires more specific data postprocess to remove the possible drift.

product id: INSITU_ARC_NRT_OBSERVATIONS_013_031 in the CMEMS framework shows the locations of the SSS observations extracted from the in situ products of INSITU_ARC_NRT_OBSERVATIONS_013_031 in 2015.

3.2.5 VOS and GO-SHIP

Under Climate Variability and Predictability Experiment (CLIVAR), the Voluntary Observing Ship (VOS) is a ship-based meteorology network. The Global Ocean Ship-based Hydrographic Investigations Panel (GO-SHIP) aims at the profiling CTDs in the repeat hydrography program. The VOS and GO-SHIP networks are both based primarily on ocean access provided by the commercial shipping industry as well as on opportunistic use of research vessels. Limits are that although most of the observation files are named by .csv, their recorded contents are not uniform and quietly depend on the concerned implementation so that it would require more quality control for pre-processing.

Some of the identified ship tracks are:

a) NORRÖNA: The MV Norröna is a large, high-speed ferry, based in Torshavn on the Faroes Islands that makes weekly runs between Denmark and Iceland. European collaborators have joined efforts and established a “Ferry Box” system on the Norröna to record near-surface temperature and salinity with a thermosalinograph. Data is available in LEGOS webpage http://www.legos.obs-mip.fr/observations/sss.

b) Nuka Arctica : Voluntary Observing Ship that runs from Bergen to Baffin Bay. It carries the following equipment: $p\mathrm{CO_2}$ sensor, Thermosalinograph , XBTs, and ADCP. Validated data are available in LEGOS webpage.

3.2.6 Marine Mammals Exploring the Ocean Pole to Pole

The Marine Mammals Exploring the Oceans Pole to Pole (MEOP) brings together several national programmes to produce a comprehensive quality-controlled database of oceanographic data obtained in Polar Regions from instrumented marine mammals. This data is already being used in the PIMEP system [RD03].

3.2.7 TARA expedition dataset

During the spring and summer 2013 the TARA ship traversed both the Northeast and Northwest passages in a single season to research plankton biodiversity in the Arctic and other parameters of the ocean. The vessel had a thermo-salinograph system permanently measuring while circumnavigating the Arctic Ocean. So validated salinity measurements inside the Arctic Ocean are available during several months from 2013 thanks to this campaign (http://www.taraoceans-dataportal.org/).

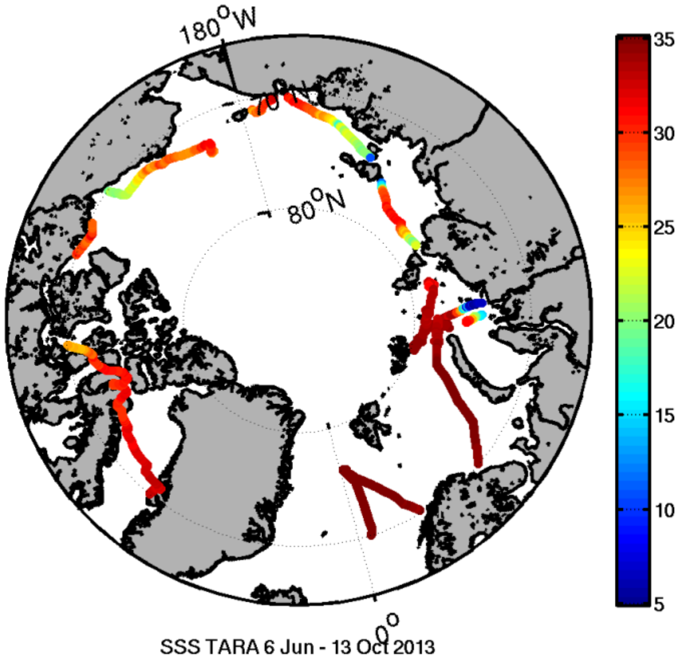

Figure 8 TARA ship tracks from 6th June to 13th October 2013

3.2.8 Oceans Melting Greenland

The Oceans Melting Greenland (OMG) has the objective to improve the estimates of sea level rise. Over a five-year (starting in 2016) campaign, OMG will observe changing water temperatures on the continental shelf surrounding Greenland, and how marine glaciers react to the presence of warm, saline Atlantic Water. Each year in the summer they will deploy 250 expendable temperature and salinity probes along the continental shelf. This data is public in the webpage and will be very useful for validation in the Greenland region.

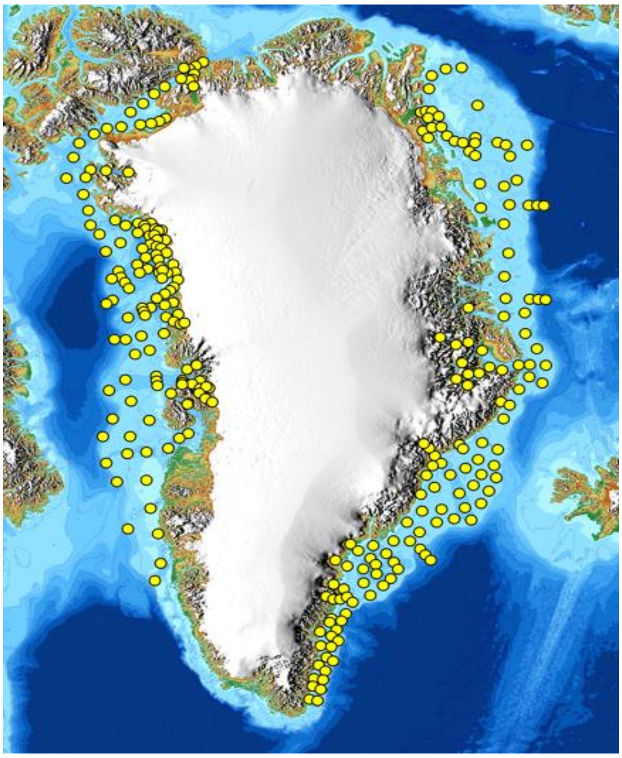

Figure 9 Yellow dots show where OMG drops each of the AXCTD probes around Greenland.

3.2.9 UDASH

UDASH (Unified Database for Arctic and Subarctic Hydrography) is a unified and high-quality temperature and salinity data set for the Arctic Ocean and the subpolar seas north of 65◦ N for the period 1980–2015 (Behrendt et al., 2018). The archive aims at including all publicly available data and so far consists of 288 532 oceanographic profiles measured mainly with conductivity–temperature–depth (CTD) probes, bottles, mechanical thermographs and expendable thermographs.

3.2.10 PIMEP

The SMOS Pilot-Mission Exploitation Platform (Pi-MEP) includes broad range of in situ observations (i.e. Argo, ship based observation, mammals observations) with a detailed quality assurance [RD03] and their limitations. As first validation approach PIMEP data will be studied to for the validation of the Arctic+ product.

3.2.11 GOSUD

GOSUD aims at assembling in-situ observations of the world ocean surface collected by a variety of ships and at distributing quality controlled datasets. At present time the variables considered by GOSUD are temperature and salinity. http://www.gosud.org/

4 Survey of current and on-going initiatives and projects

4.1 Description of existing initiatives or projects

4.2 Arctic Freshwater Flux

The ArcFlux team has reviewed and updated freshwater fluxes from the reference paper (Carmack et al. 2016) in the light of satellite measurements of ocean fluxes, river heights, glaciers and sea ice mass. This section briefly summarizes the findings described in the ArcFlux Deliverable number 8 (Nielsen et al. 2018), sorted by categories of freshwater fluxes and split between those that represent inputs to the TOPAZ model (rivers, ocean fluxes at the model lateral boundary, glacial freshwater) and those that are internal variables within the TOPAZ system (ocean fluxes within the model domain and sea ice fluxes).

- River fluxes: The TOPAZ system presently uses climatology data but is transitioning to the Arctic HYPE model (from SMHI). The altimeter observations of a major Siberian river (the Ob) were compared to in situ measurements and showed very good skills for river elevation and discharge. The conclusion is that about 70% of the Arctic river fluxes can be monitored by altimetry, which is good news, but not of immediate use for Arctic+ Salinity.

- Ocean freshwater fluxes: The report concentrates on Davis Strait. This flux is simulated by the TOPAZ system. The monitoring of ocean freshwater fluxes was severely impaired by the lack of an in situ station in Davis Strait, where a large share of ocean freshwater fluxes transit to the South. The estimates and their uncertainties through Davis Strait are however useful for model validation. A similar exercise would be extremely useful for the Pacific freshwater fluxes through Bering Strait, which is very important component of the Arctic freshwater budget.

- Glaciers and Greenland Ice Sheet: TOPAZ accounted for the mountain glacier melt represented in ERA-Interim as river fluxes but will only include the GrIS terminal outlets mass loss (from the ESA GrIS CCI project) in the upcoming TOPAZ5 upgrade. The ArcFlux report provides land ice velocities estimates from Sentinel-1, combines them with land ice thickness data and runoff estimates from regional climate models for one sub-basin of Greenland. The GrIS ESA CCI data will remain the basis for future TOPAZ runs.

- Sea ice freshwater: This flux is simulated in the TOPAZ system. The related sections were empty in the ArcFlux report version obtained from DTU (7th Feb 2018).

Project website: http://www.arcflux.eu
Person contacted: Ole Baltazar Andersen (DTU)
Funder: ESA
Project Status: terminated

4.3 The North Atlantic Climate System Integrate Study

The North Atlantic Climate System Integrated Study (ACSIS) will carry on an integrated view of the Earth System, including the ocean, the atmosphere and interactions with the Arctic Sea Ice and Greenland Ice Sheet. ACSIS aims to improve the understanding to detect and predict changes in the North Atlantic climate system. In particular, ACSIS is interested to understand how changes in the North Atlantic may affect the UK's climate, weather, and air quality with major economic impact on agriculture, fisheries, water, energy, transport and health.

Arctic+ project will bring new dataset and further regional science based in the North Atlantic. Furthermore, the Project Manager has been invited to assist to the next Progress Meeting to discuss the status of the ACSIS project (meeting to be expected February – March 2019)

Project website: http://www.acsis.ac.uk/about/the-project

Person to contact: Bablu Sinha (NOC, Science Leader)

Funder: NERC

Project Status: active

4.4 UK Overturning in the Subpolar North Atlantic Programme

The UK Overturning in the Subplot North Atlantic Programme (UK-OSNAP) is part of an international programme led by the USA and includes 10 partners from Canada, France, Germany, the Netherlands, and China. This is an on-going project from Oct 2013. UK-OSNAP is regularly taking fieldwork at sea and model studies. This include two line mooring arrays (Figure 6).

Arctic+ will use the some of the field work produced during UK-OSNAP duration. Furthermore, UK-OSNAP is still an active science platform gather the interest of the community. This might be used by the Arctic+ as a platform to showcase the SSS produced data in the region, which also include UK-OSNAP study region (i.e. subpolar latitudes from 45˚N to 65˚N).

Project website: http://www.ukosnap.org/project-informationhttp://www.ukosnap.org/project-information

Person to contact: Naomi Penelope Holliday (NOC, Co-Investigator)

Funder: NERC

Project Status: active

4.5 TERIFIC

TERIFIC project will undertake fieldworks in the subpolar region. This will include ship surveys and surface drifter deployments with CTD sensors.

Project website: http://projects.noc.ac.uk/terific/

Person to contact: Dr Eleanor Frajka-Williams (NOC, Lead Investigator)

Funder: NERC

Project Status: To start in 2020

4.6 PassMe Project - Data from Oliver Wurl

PassMe project focuses on investigating biochemical properties of the sea surface, and their effect on CO2 air-sea exchange. Overall objective is to improve existing parameterization for gas transfer velocity based solely on wind speed. The team realized that skin and near-surface salinity drives buoyancy fluxes with a potential impact on gas exchange. In 2016, they observed that the skin salinity is saltier (on average by 0,4 PSU) compared to the underlying bulk water, due to evaporation processes. They suggest that the interfacial tension between the skin layer and underlying water keeps the saltier skin afloat up to a certain density threshold. Then the skin layers becomes too heavy, sinks and is replaced by underlying bulk water. It is a transport mechanism for CO2 towards or away from the skin layer, and so keeps the pCO2 gradient between the atmosphere and skin layer (Wurl et al. 2018). To study all these mechanisms an instrument to measure ocean salinity in the skin and near-surface layer was built. Measurements of skin salinity were done at different regions of the world.

The Arctic Ocean measurements campaigns were performed from 26 August to 1 Sept 2018, and from 4 to 14 September 2018, and logged every 1 minute. Five sensors where installed from the surface (3-5 cm), 10 cm, 26 cm, 50 cm and 111 cm. The location was an open lead in proximity to the North pole. This data will be useful for the satellite maps validation.

Project website: https://www.researchgate.net/project/PassMe

Person to contact: Dr Oliver Wurl (University of Oldenburg, germany)

Funder: European Research Council (ERC) project (grant GA336408).

Project Status: Active (from 2017)

4.7 PROMICE – Danish project from GEUS

From the PROMICE webpage: "In 2007, Denmark launched the Programme for Monitoring of the Greenland Ice Sheet (PROMICE) to assess changes in the mass balance of the ice sheet. The two major contributors to the ice sheet mass loss are surface melt and a larger production of icebergs through faster ice flow. PROMICE is focused on both processes. Ice movement and discharge is tracked by satellites and GPSs. The surface mass balance is monitored by a network of weather stations in the melt zone of the ice sheet, providing ground truth data to calibrate mass budget models."

GEUS has recently published an estimate of Greenland meltwater from iceberg calving and melt at the glaciers front [Mankoff et al. 2019] to which a surface mass balance estimate should be added in the Fall / Winter 2019 for a complete GrIS freshwater budget at a monthly time frequency and high horizontal resolution (Ahlstrøm, pers. comm. June 2019).

Project website: http://promice.org/About.html

Person to contact: Dr Andreas Peter Ahlstrøm apa@geus.dk (GEUS, Dk)

Funder: Danish Energy Agency DANCEA programme

Project Status: Active (from 2007)

4.8 Added value of the work to be carried out with respect to existing activities

In case of success of the Arctic+ Salinity, there will be SSS at the Arctic regions (i.e. both at the polar and Subpolar regions) all year round and independently of the weather conditions and the season of the year. The newly SSS dataset will further the understanding of the regional oceanography and the freshwater fluxes in the Arctic, which at the moment is commonly made during the summer months (May-August) observations (e.g. Holliday, 2018, Bacon 2014, etc.). Thus, it is expected that Arctic+ continuous SSS time series from satellite observations can reduce the uncertainty of the freshwater fluxes' assessment due to the scarce measurements. There has been reported mismatches in the density fields between different cruise lines (Holliday, 2018). The newly produced Arctic+ SSS dataset, may bring a general and homogeneous information of the surface transports with the region. Furthermore, there might be the possibility of creating Surface Density maps (i.e. density is a result of salinity and temperature).

The rivers are the most important sources of freshwater and they stratify the upper Arctic Ocean, so the changes in the river runoff could have a strong impact on the Arctic system [Nummelin et al. 2015, Carmack et al. 2016]. It is also well known that an increment of the global mean annual temperature will produce an increase in the discharge of Arctic rivers [Peterson et al., 2002; Mulligan et al., 2010]. So, thanks to the satellite SSS maps we may, for the first time, monitor the surface river runoff and assess if a trend on the amount of river fresh water delivered to Arctic Ocean, can be observed in the last 10 years (we have SMOS maps since 2010).

5 Best candidate test areas

5.1 Analysis and identification of test regions

The three test regions selected here are: 1) the Beaufort Sea in the Canadian basin of the Arctic, 2) Nordic Seas (from Greenland Scotland Ridge–GSR to 80ºN), and 3) the northern North Atlantic (50ºN to the GSR) (Figure 12).

The three regions selected have common salinity characteristics: the salinity controls the surface circulation and is strongly variable due to freshwater fluxes.

1) The Beaufort Sea is the fresh water sink zone in the Arctic region (also called the “time bomb” in the popular literature[1] though the scientific literature uses a more moderate language (Proshutinsky et al. 2009, Timmermans et al. 2018), the circulation within this region is known to impact the sea ice export into the Fram Strait (Sumata et al. 2014). The TOPAZ model simulations are very inaccurate there (waters fresher than 28 psu).

2) The Nordic Seas are the buffer zone between the saline North Atlantic and the fresh Arctic (Raj et al. 2019). Model simulations are quite accurate there (error < 0.2 psu, see Figure 10 and Figure 11 below, blue lines).

3) The northern North Atlantic Region domain includes the subpolar gyre, which extent dictates the amount of poleward transport of Atlantic Water further known to impact the regional climate (Tesdal et al. 2018). It also receives freshwater from the Greenland Ice Sheet. The model simulations are also quite skilful here (Figure 10 and Figure 11 red lines).

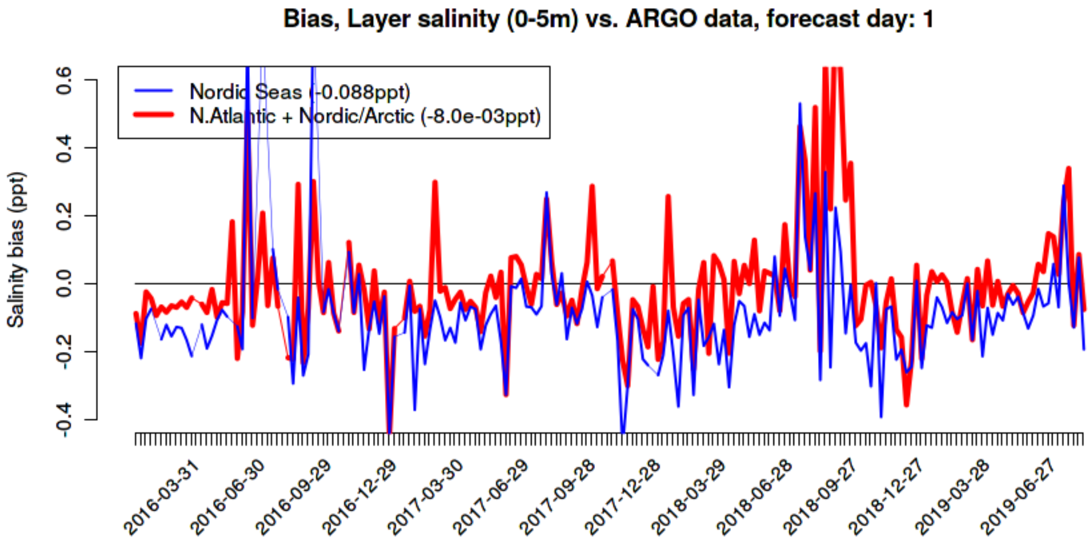

Figure 10: Weekly bias estimates from the CMEMS Arctic MFC (TOPAZ4) operational forecasting system updated on CMEMS website TStimeSeries_year-day-01.html.

[1] https://www.sciencealert.com/ticking-time-bomb-hidden-heated-ocean-water-under-arctic-canada-basin-chukchi-sea

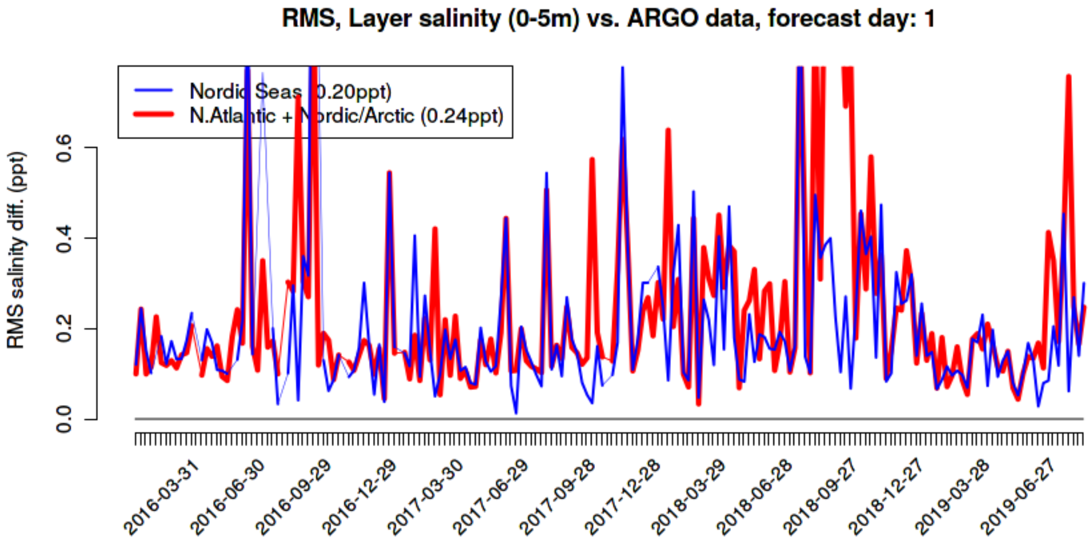

Figure 11: Same as previous but with RMS errors instead of bias (ref CMEMS website TStimeSeries_year-day-01.html).

Limitations: The study in the marginal seas around the Arctic will depend on sufficient availability of in situ observations. The analysis in the Beaufort Sea can only be done for the summer season. Satellite data: 9 days average for comparison with daily insitu / TOPAZ data.

Test to be done on 2 Types Data

1. Evaluation of SMOS data in the Nordic Seas and Beaufort Sea using in situ observations, and the TOPAZ4 reanalysis (Xie et al., 2019; 2011-2013). Another study will be done for a longer time series (2011-2017) of SMOS data using the different datasets described in Section 3.

2. Evaluation of the assimilated version of the TOPAZ data for the three regions. A comparison between the assimilated and non-assimilated data will be done in order to highlight the improvements.

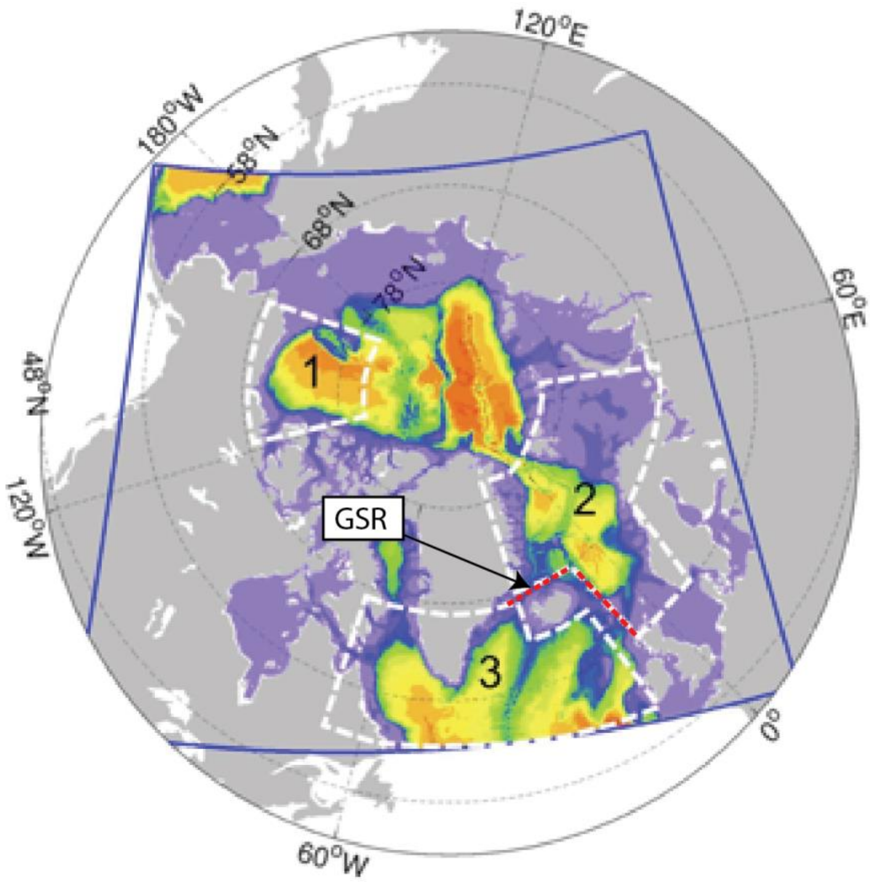

Figure 12 Model domain in the new TOPAZ5 system coloured by topography (light blue: 10m to red 4.000m depths). The three test regions are marked by the dashed zones (1-3). Note: the model southern boundary is close to 48°N. The Greenland-Scotland Ridge (red broken line) is used in this project to mark the limitation between the three study regions.

6 Risk elements of the project

6.1 Description of risks for the execution of the project

The retrieving salinity task in a so challenging place like the Arctic Ocean entails difficulties and limitations in some points:

- One of the main limitations in the Arctic dataset is the lack of a large in situ unified in situ dataset to perform a solid validation. This is especially important on the Russian basin where very scarce public data is available, so the quality assessment on that region will not be very reliable.
- The sea-ice contamination produces a TB variation nearby the ice edge, which is produce by the Gibbs, effect and is not physically true. Hence, to reduce the effect of the sea-ice contamination is an assessment of the methodology developed within this project. However, at this stage it is not possible to determine the level of improvement of the resulting SSS product.
- The assimilation of the SSS variable will reduce the effect of assimilating other observations and potentially degrade the model skills with other simulated properties. This will be verified as part of the model validation.

6.2 Mitigation strategies

1.- We use as many data as possible, combining the in situ measurements from ARGO floats, measurements from thermo-salinographs and CTD acquired during several transects and campaigns in the region, fixed buoys measurements, etc. A comparison with the output of numerical models (TOPAZ4) will be assessed, especially on the region where no in situ data is available.

2.- The debiased non-Bayesian retrieval algorithm permits to reduce the land-sea contamination but not the ice-sea contamination, since the sea ice edge is moving in time. The methodology to reduce it will be examined here.

7 Scientific and operational requirements

7.1 Description of methodologies and algorithms to be implemented

The Barcelona Expert Centre (BEC) is currently distributing version 2.0 of its Debiased non-Bayesian Advanced product for Arctic from 2011 to 2017, through its distribution and visualization data service (http://bec.icm.csic.es/ocean-experimental-dataset-high-latitude-and-arcticsss/).

The product described in [Olmedo et al. 2018] is based on the debiased non-Bayesian algorithm introduced in [Olmedo et al. 2017] and it is executed departing from the SMOS L1B Brightness Temperatures (TB) provided by ESA. The galactic [Tenerelli et al. 2008], sun glint [Reul et al. 2007] and roughness [Guimbard et al. 2012] contributions are corrected using auxiliary information provided by ECMWF [Sabater and De Rosnay, 2010] similarly to what is done in the official ESA SMOS L2 SSS products. The dielectric constant model proposed by Meissner and Wentz (M&W) is used.

The TB measurements are geo-referenced using a 25-km resolution Equal-Area Scalable Earth (EASE) North Pole grid [Brodzik and Knowles 2002], and maps are pan Arctic from 50ºN up to the north pole.

7.2 New Arctic SSS product

The improvements on the algorithms to be assessed under the framework of the Arctic+ Salinity project are the following ones:

- New product grid: In the previous version the TB measurements are geo-referenced using a 25-km resolution Equal-Area Scalable Earth (EASE) North pole grid [Brodzik and Knowles 2012], with maps being pan-Arctic from 50˚N up to the north pole. A survey to assess the most convenient grid will be done. However, for the moment, we assume the grid will be updated to the new version (EASE-Grid 2.0) [Brodzik and Knowles 2012] in order to minimize the spatial interpolations in the generation of the merged product.

- Dielectric constant model test on low temperature waters: The dielectric constant model proposed by Meissner and Wentz (M&W) [Meissner and Wentz, 2004] is used nowadays, instead of the model defined by Klein and Swift (K&S) [Klein and Swift, 1977] which is used in the official SMOS Ocean Salinity Level 2 product. According to [Dinnat et al. 2014], the differences between M&W and K&S are small at low and mid latitudes, but they increase at high latitudes, i.e., cold waters. They conclude that for very cold waters (below 3°C), the salinity derived using M&W is significantly closer to in situ float measurements than those derived using K&S. Also note that the operational SMAP SSS products use M&W. Recently Zhou et al., from George Washington University [Zhou et al. 2017] have developed a new dielectric model (ZGW) focused on L-band. This model has been computed using a temperature range between 0°C and 35°C and salinity range between 30 psu and 38 psu. Therefore, ZGW's model seems to be a new good candidate to improve the salinity retrievals. A study in depth on the impact of using M&W, K&S or ZGW model will be assessed.

- To assess the optimal climatology: As shown in Figure 4, there are many regions in the Arctic with very few measurements (or none) of SSS and probably any reference may provide wrong SSS values in those regions. For this reason, to evaluate the impact of using different SSS references, we will generate a testing data set using two different annual references: WOA2013 (Zweng, 2013), which is the one currently used; the Polar science center Hydrographic annual Climatology

(PHC) (version 3) [Steele et al., 2001] ; and Unified Database for Arctic and Subarctic Hydrography (UDASH) [Behrendt et al, 2017]. Therefore, we will compare in situ TSG data with these two SMOS SSS products. For this assessment we will use TARA expedition in situ which is, from the data we have, the only one that surround all the Arctic Ocean.

- Study of the optimum correlation radii: The choice of the correlation radii used in the OA should be analysed. This analysis might give different results than in a global scale since the high latitude SSS product noise is larger than the mid latitude products. This analysis will be done testing different radii and comparing them with ARGO SSS, the cases with lowest differences will be preferred ones. The largest correlation radii, the largest the smoothing effect, and therefore the lower the noise. However, if the radii are too large, we might reduce the capability of SMOS to reproduce the spatial dynamics of the region. So, the selection of the radii is a trade-off between noise level and ocean dynamic.

- Time-dependent bias corrected improvement: This correction is need to mitigate the seasonal biases which affects the TB. [Olmedo et al. 2017] propose subtracting the global mean of the SMOS SSS anomaly for each 9-day map. This assumption is appropriated for global SSS maps, as it implies that the total content of salt remains constant on time. However, this hypothesis applied regionally is not robust, since we cannot assume that the total content of salt is constant regionally and a solution based on Argo profiles has been adopted for high latitudes [Olmedo et al., 2018]. However, the spatial Argo distribution is far from to be homogeneous and it is necessary to adopt an alternative strategy. The invariance in the global mean value of SSS can be used to evaluate the net freshwater advective (horizontal) transport across Arctic Ocean and perform the temporal bias correction.

- Sea ice contamination and ice masking: The ice sea contamination effect will be analysed and new algorithms might be proposed to reduce it. [Garcia-Eidell et al 2017] states that the BEC product has little coverage in the Arctic Basin because of poor sea ice masking. Therefore, the ice masking should be revised. The ice mask used currently is the one given in OSTIA but other ice masks should be explored. The proposed candidate is the ESA Sea Ice CCI product (.nersc.no/).

The overall data processing chain to produce the new version of SSS product from SMOS is synthesised in Figure 13.

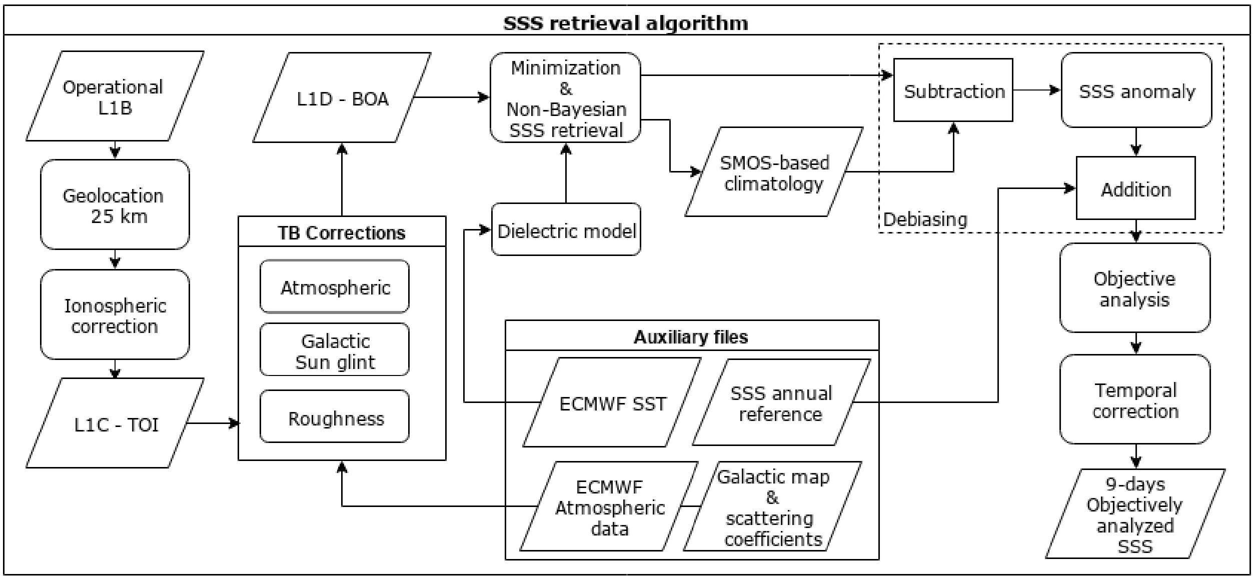

Figure 13 BEC processing algorithm diagram to produce the SSS high latitudes dataset which are freely distributed at BEC website (http://bec.icm.csic.es/).

7.3 Generating the L4 Arctic SSS product

Beside the new SMOS improved product, a new L4 SSS product obtained from merging SMOS and SMAP SSS data will be generated under the Arctic+ Salinity project. The L4 merged SSS product prototype will therefore be based on L3 products. Note though we will generate the L3 products from SMAP data. And take into account that L3 SMAP and SMOS have different temporal coverage, resolution and grid projection.

The current dataset releases for SMAP JPL and SMAP REMSS products are v4.2 and v3.0, respectively.

- **SMAP L2 Filtering**: The SMAP Level-2 products contain, in addition to the retrieved salinity values, brightness temperatures, quality flags and ancillary data from auxiliary files that will be used by the filtering algorithm. The exact filtering criteria depends on the sensor and product under consideration but it will be based on the guidelines followed by [García – Eidell et al, 2017] and the descriptions provided by REMSS [Meissner et al, 2016] and JPL [SMAP JPL 2019] Fore et al, 2017.

- **L3 generation:** Once the L2 SSS filtering is performed it is necessary to generate L3 maps in the same grid resolution and temporal window as the SMOS L3 high latitude BEC product. A survey to assess the most convenient grid will be done. However, we start assuming to use the EASE2 grid which is the current SMAP L2 product grid and should be the grid of the future SMOS high latitude products. The SMOS L3 product uses a temporal window of 9 days. Therefore, the SMAP L3 maps should be generated for the same time windows. The SMAP instrument provides global coverage every 8 days whereas SMOS every 9 days. Regenerating SMAP L3 products from L2 products avoids the use of temporal interpolation to get a uniform temporal resolution. These products will be generated with the same SMOS arctic products grid.

- **L4 generation:** The L4 generation will cover from April 2015 up to the present time. Temporal systematic errors of the different L3 products are expected to be characterized using intercalibration algorithms (e.g., triple collocation). Since the L3 products have the same temporal and nominal spatial resolution, the construction of the merged L4 product can be done using a simple averaging of the L3 or L2 sources. Nevertheless, more sophisticated techniques like kriging, or Gaussian process regression, will be studied to merge different sources of salinity in the creation of L4 product.

- **Geophysical consistency analysis:** The assessment of the spatial resolution of the resulting merged or aggregated product can be determined using the so-called singularity power spectra [Hoareau et al., 2018]. This powerful technique assesses the geophysical consistency of the different satellite-derived SSS maps and provides an indication of their resolved scales.

7.4 Specific technical and scientific constraints from the selected approach

The main potential technical constraints that could be encountered in performing the activity are the following:

- The use of a good annual salinity reference in the Arctic Ocean is fundamental, since if this is biased it will have an impact on the final SSS product. This will be used in the systematic error correction technique, which permits to correct for example for the land-sea contamination. The absolut SMOS SSS will be generated by adding this annual reference to the computed SMOS anomaly. Since the in situ data is scarce and is not homogenous distributed, that could be biased in some regions is few in-situ data, producing a biased SSS SMOS product.

- Compute freshwater advective (horizontal) transport across different ocean basins from global maps, implies a good characterization of the latitudinal bias. Therefore, an additional latitudinal correction should be applied to the current global SSS product.

7.5 Additional dataset requirements

7.5.1 Dataset requirements to retrieve SMOS SSS

For the computation of the SSS retrieval the a priori knowledge of some geophysical parameters are needed, namely, the **Sea Surface Temperature and the wind speed**. We use the same auxiliary data set that is used in the official L2 Ocean Salinity processor. The geophysical parameters required for the SSS retrieval in the L2 processor are provided by the European Centre for Medium Range Weather Forecast (ECMWF) [Freitas, 2013; Sabater and De Rosnay, 2010]. For each L1C half-orbit an ECMWF auxiliary file co-located in time and space with SMOS data are generated by ECMWF and distributed by ESA.

Finally, for the generation of the absolute values of salinity from the debiased SSS anomalies we use an annual reference of SSS. Part of the work to be developed in this project is to assess the best annual reference of the Arctic region to be used. New WOA 2018 will be used to correct systematic biases.

7.5.2 Dataset requirements to produce the merge L4 product

In order to avoid the creation of artefacts in the merging of different satellite products the best choice is to merge the different sources at a low level of processing. Due to the fact that the brightness temperature provided by SMOS is multiangular whereas the provided by SMAP is given for a fixed incidence angle (40°) the merging of brightness temperature would overweight the SMOS measures over the SMAP ones. Therefore, the best option is to merge the lowest level of sea surface salinity (L2) of both sources.

Currently, two different SMAP L2 datasets are being produced: the provided by Jet Propulsion Laboratory (JPL) [SMAP JPL 2019] and the generated by Remote Sensing Systems (REMSS) [SMAP REMSS 2018]. Therefore, a study will be performed in order to know which of both L2 SMAP products could provide better results in the merging with the L2 generated from SMOS. Determinant factors in this study will be the coverture of both SMAP L2 products and their respective description of river mouths.

8 Bibliography

[Behrendt et al., 2017] (2017): A comprehensive, quality-controlled and up-to-date data set of temperature and salinity data for the Arctic (Version 1.0), links to data files. PANGAEA

[Bring et al 2014] Bring, A. & Destouni, G. Surv Geophys (2014) 35: 853.

[Behrendt et al., 2018] Behrendt, A., H. Sumata, B. Rabe, and U. Schauer (2018), UDASH – Unified Database for Arctic and Subarctic Hydrography, Earth Syst. Sci. Data, 10(2), 1119-1138, doi: 10.5194/essd-10-1119-2018.

[Brodzik et al., 2012] Brodzik, M. J., Billingsley, B., Haran, T., Raup, B., and Savoie, M. H. (2012). Ease-grid 2.0: Incremental but significant improvements for earth-gridded data sets. ISPRS International Journal of Geo-Information, 1(1):32–45.

[Burcker et al 2014] Brucker, L., Dinnat, E., and Koenig, L. Weekly-gridded Aquarius L-band radiometer/scatterometer observations and salinity retrievals over the polar regions, part 1: Product description, The Cryosphere, 8, 905-913, doi:10.5194/tc-8-905-2014, 2014.

[Boutin et al 2018] Boutin, J., J. L. Vergely, S. Marchand, F. D'Amico, A. Hasson, N. Kolodziejczyk, N. Reul, G. Reverdin, and J. Vialard (2018), New SMOS Sea Surface Salinity with reduced systematic errors and improved variability, *Remote Sensing of Environment*, *214*, 115-134, doi: .

[Boutin et al. 2018] Boutin Jacqueline, Vergely Jean-Luc, Khvorostyanov Dmitry (2018). SMOS SSS L3 maps generated by CATDS CEC LOCEAN. debias V3.0. SEANOE.

[Cabanes et al. 2013] Cabanes, C., A. Grouazel, K. von Schuckmann, M. Hamon, V. Turpin, C. Coatanoan, F. Paris, S. Guinehut, C. Boone, N. Ferry, C. de Boyer Montégut, T. Carval, G. Reverdin, S. Pouliquen, and P. Y. Le Traon, 2013: The CORA dataset: validation and diagnostics of in-situ ocean temperature and salinity measurements. Ocean Science, 9, 1-18,

[Carmack et al. 2016] Carmack, E. C., et al. Freshwater and its role in the Arctic Marine System: Sources, disposition, storage, export, and physical and biogeochemical consequences in the Arctic and global oceans. 2016. J. Geophys. Res. Biogeosci, 121, doi:10.1002/2015JG003140.

[Dinnat et al 2014] Dinnat, E.P.; Boutin, J.; Yin, X.; Vine, D.M.L. Inter-comparison of SMOS and Aquarius Sea Surface Salinity: Effects of the dielectric constant and vicarious calibration. In Proceedings of the 2014 13th Specialist Meeting on Microwave Radiometry and Remote Sensing of the Environment (MicroRad), Pasadena, CA, USA, 24–27 March 2014; pp. 55–60.

[Font et. al 2008] Font, J., A. Camps, and J. Ballabrera-Poy (2008), 'Microwave Aperture Synthesis radiometry: Setting the path for Sea Surface Salinity Measurements from Space' in Remote Sensing of European Seas, Springer-Verlag, ISBN 978-1-4020-6771-6.

[Freitas, 2013] Freitas, S., 2013. ECMWF v316 Update Analysis. SO-TN-DME-ECMWF-001. DEIMOS Engenharia.

[Garcia-Eidell et al 2017] Garcia-Eidell, C., J. C. Comiso, E. Dinnat, and L. Brucker (2017), Satellite observed salinity distributions at high latitudes in the Northern Hemisphere: A

Comparison of four products, *Journal of Geophysical Research: Oceans*, doi: 10.1002/2017JC013184.

[Holliday et al. 2018] Holliday, N. P.; Bacon, S.; Cunningham, S. A.; Gary, S. F.; Karstensen, J.; King, B. A.; Li, F.; McDonagh, E. L.. 2018 Journal of Geophysical Research: Oceans, 123 (7). 4538-4559.

[Jeffries et al 2015] Jeffries, M.; Richter-Menge, J.; Overland, J.E. Arctic Report Card 2015. Technical Report, NOAA Reports. Available online: (accessed on 8 November 2018).

[Kerr et al. 2010] Kerr, Y., P. Waldteufel, J. Wigneron, S. Delwart, F. Cabot, J. Boutin, M. Escorihuela, J. Font, N. Reul, C. Gruhier, S. Juglea, M. Drinkwater, A. Hahne, M. Martín-Neira, and S. Mecklenburg (2010), The SMOS mission: New tool for monitoring key elements of the global water cycle, Proc. IEEE, 98, 666–687.

[Klein et al. 1977] Klein, L., and C. Swift (1977), An Improved Model for the Dielectric Constant of Sea Water at Microwave Frequencies, IEEE Transactions on Antennas and Propagation, AP-25(1), 104–111, doi:10.1109/JOE.1977.1145319.

[Köhler et al. 2014] Julia Köhler, Nuno Serra, Detlef Stammer, 2014. Quality assessment of spaceborne sea surface salinity observations over the northern North Atlantic'. Physical Research: Oceans, Vol. 120, Issue 1. https://doi.org/10.1002/2014JC01006.

[Mankoff et al. 2019] Mankoff, K. D., Colgan, W., Solgaard, A., Karlsson, N. B., Ahlstrøm, A. P., van As, D., Box, J. E., Khan, S. A., Kjeldsen, K. K., Mouginot, J., and Fausto, R. S.: Greenland Ice Sheet solid ice discharge from 1986 through 2017, Earth Syst. Sci. Data, 11, 769-786, https://doi.org/10.5194/essd-11-769-2019, 2019.

[Mecklenburg et al 2009] Mecklenburg, S., N. Wright, C. Bouzina, and S. Delwart (2009), Getting down to business - SMOS operations and products., ESA Bulletin, 137, 25–30.

[Meissner et al. 2004] Meissner, T., and F. Wentz (2004), The complex dielectric constant of pure and sea water from microwave satellite observations, Geoscience and Remote Sensing, IEEE Transactions on, 42(9), 1836–1849, doi:10.1109/TGRS.2004.831888.

[Mulligan et al. 2010] Mulligan, R. P., W. Perrie, and S. Solomon (2010), Dynamics of the Mackenzie River plume on the inner Beaufort shelf during an open water period in summer, Estuarine, Coastal and Shelf Science, 89(3), 214 – 220, doi:10.1016/j.ecss.2010.06.010.

[Nielsen et al. 2018] Nielsen, K., Sandberg Sørensen, L., Zakharova, E., Wuite, J., ARCFLUX – FRESHWATER FLUXES TO THE ARCTIC OCEAN Impact assessment report, Deliverable 8. 7th Feb. 2018.

[Nummelin et al. 2015] Nummelin, A., Ilicak, M., Li, C., & Smedsrud, L. H. (2015). Consequences of future increased Arctic runoff on Arctic Ocean stratification, circulation, and sea ice cover. Journal of Geophysical Research: Oceans, 121, 617–637. http://doi.org/10.1002/ 2015JC011156.

[Olmedo et. al 2017] Olmedo, E., Martınez, J., Turiel, A., Ballabrera-Poy, J., and Portabella, M. (2017). Debiased non-bayesian retrieval: A novel approach to SMOS sea surface salinity. Remote Sensing of Environment, 193:103–126.

[Olmedo et al. 2018] Olmedo, E. Gabarró, C., González-Gambau, V., Martínez, J., Ballabrera-Poy, J., Turiel, A., Portabella, M., Fournier, S., Lee, T., (2018). Seven Years of SMOS Sea Surface Salinity at High Latitudes: Variability in Arctic and Sub-Arctic Regions.Remote Sensing, V.10, N.11, http://www.mdpi.com/2072-4292/10/11/1772

[Peterson et al. 2002] Peterson, B., R. Holmes, J. McClelland, C. Vörösmarty, R. Lammers, A. Shiklomanov, I. Shiklomanov, and S. Rahmstorf (2002), Increasing river discharge to the Arctic Ocean, Science, 298, 2171-2173.

[Proshutinsky et al. 2009] Proshutinsky, A., Krishfield, R., Timmermans, M.-L., Toole, J., Carmack, E., McLaughlin, F., … Shimada, K. (2009). Beaufort Gyre freshwater reservoir: State and variability from observations. Journal of Geophysical Research, 114, C00A10.

[Raj et al. 2019] P. Raj, R., Chatterjee, S., Bertino, L., Turiel, A., and Portebella, M.: The Arctic Front and its variability in the Norwegian Sea, Ocean Sci. Discuss., https://doi.org/10.5194/os-2018-159, in review, 2019.

[Sabater and De Rosnay, 2010] Sabater, J., De Rosnay, P., 2010. Milestone 2 Tech Note - Parts 1/2/3: Operational Pre-processing Chain, Collocation Software Development and Offline Monitoring Suite. Technical report, ECMWF.

[SMAP REMSS 2018] Remote Sensing Systems (RSS). 2018. RSS SMAP Level 3 Sea Surface Salinity Standard Mapped Image Monthly V3.0 40km Validated Dataset. Ver. 3.0. PO.DAAC, CA, USA. Dataset accessed [2019-02-14] at.

[SMAP JPL 2019] JPL Climate Oceans and Solid Earth group. 2019. JPL SMAP Level 3 CAP Sea Surface Salinity Standard Mapped Image 8-Day Running Mean V4.2 Validated Dataset. Ver. 4.2. PO.DAAC, CA, USA. Dataset accessed [2019-02-14] at.

Steele, M.; Morley, R.; Ermold, W. PHC: A global ocean hydrography with a high-quality Arctic Ocean. J. Clim. 2001, 9, 2079–2087.

[Sumata et al. 2014] Sumata, H., Lavergne, T., Girard-Ardhuin, F., Kimura, N., Tschudi, M. A., Kauker, F., Karcher, M., and Gerdes, R.: An intercomparison of Arctic ice drift products to deduce uncertainty estimates, J. Geophys. Res.-Oceans, 119, 4887–4921, https://doi.org/10.1002/2013JC009724, 2014

[Swift et al 1983] Swift C T & R E McIntosh 1983 Considerations for microwave remote sensing of ocean-surface salinity, IEEE Trans. Geosci. Remote Sensing, GE-21, 480-491.

[Tang et al 2013] Tang, W., Yueh, S., Fore, A., Neumann, G., Hayashi, A., Lagerloef, G., 2013. The rain effect on Aquarius' L-band sea surface brightness temperature and radar backscatter. Remote Sens. Environ. 137, 147–157.

[Tang et al. 2015] Tang, W., Yueh, S.H., Hayashi, A., Fore, A.G., Jones, W.L., Santos-Garcia, A., Jacob, M.M., 2015. Rain-induced near surface salinity stratification and rain roughness correction for Aquarius SSS retrieval. In: The Special Issue of the IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (J-STARS). Aquarius/SACD Mission Calibration/Validation Performance and Retrieval Algorithms 8 (12). pp. 474–5484.

[Tesdal et al. 2018] Tesdal, J., R.P. Abernathey, J.I. Goes, A.L. Gordon, and T.W. Haine, 2018: Salinity Trends within the Upper Layers of the Subpolar North Atlantic. J. Climate, 31, 2675–2698, https://doi.org/10.1175/JCLI-D-17-0532.1

[Timmermans et al. 2018] Mary-Louise Timmermans, John Toole and Richard Krishfield, Warming of the interior Arctic Ocean linked to sea ice losses at the basin margins. Science Advances, 29 Aug 2018: Vol. 4, no. 8, eaat6773, DOI: 10.1126/sciadv.aat6773

[Wurl et al. 2018] Wurl, O., Bird, K., Cunliffe, M., Landing,W. M., Miller, U., Mustaffa, N. I. H., et al.(2018). Warming and inhibition of salinization at the ocean's surface by cyanobacteria. Geophysical Research Letters, 45. 2018GL077946

[Xie et al. 2019] Xie, J., Raj, R. P., Bertino, L., Samuelsen, A., and Wakamatsu, T.: Evaluation of Arctic Ocean surface salinities from SMOS and two CMEMS reanalyses against in-situ data sets, Ocean Sci. Discuss., https://doi.org/10.5194/os-2018-163, in review, 2019.

[Yueh et al 2001] Yueh, S., R. West, W. Wilson, F. Li, S. Nghiem, and Y. Rahmat-Samii (2001), Error Sources and Feasibility for Microwave Remote Sensing of Ocean Surface Salinity, IEEE Transactions on Geoscience and Remote Sensing, 39(5), 1049–1059.

[Yueh et al 2013] Yueh, S.H., Tang, W., Fore, A., Neumann, G., Hayashi, A., Freedman, A., Chaubell, J., Lagerloef, G., 2013. L-band passive and active microwave geophysical model functions of ocean surface winds and applications to Aquarius retrieval. IEEE Trans. Geosci. Remote Sens. 51 (9), 4619–4632. http://dx.doi.org/10.1109/TGRS.2013.2266915.

[Yueh et al. 2014] Yueh, S.H., Tang, W., Fore, A., Hayashi, A., Song, Y.T., Lagerloef, G., 2014. Aquarius geophysical model function and combined active passive algorithm for ocean surface salinity and wind retrieval. J. Geophys. Res. Oceans 119, 5360–5379. http://dx.doi.org/10.1002/2014JC009939.

[Zeng et al. 2015], Analysis of current validation practices in Europe for space-based climate data records of essential climate variables, International Journal of Applied Earth Observation and Geoinformation, 42, 150-161.

[Zine et al. 2008]Zine, S., Boutin, J., Font, J., Reul, N., Waldteufel, P., Gabarro, C., Tenerelli, J., Petitcolin, F., Vergely, J., Talone, M., and Delwart, S.: Overview of the SMOS Sea Surface Salinity Prototype Processor, IEEE T. Geosci. Remote, 46, 621–645, https://doi.org/10.1109/TGRS.2008.915543, 2008

[Zhou et al 2017] Zhou, Y., R. H. Lang, E. P. Dinnat, and D. M. Le Vine, L-Band Model Function of the Dielectric Constant of Seawater, IEEE TGRS, Vol. 55, No. 12, 2017.

[Zweng et al 2013] Zweng, M., J. Reagan, J. Antonov, R. Locarnini, A. Mishonov, T. Boyer, H. Garcia, O. Baranova, D. Johnson, D. Seidov, and M. Biddle (2013), World Ocean Atlas 2013, Volume 2: Salinity, Levitus, Ed., A. Mishonov Technical Ed.; NOAA Atlas NESDIS 74, 39 pp.

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