Climate Change Initiative Phase 1

Sea Surface Salinity

User Requirement Document (URD)

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Amendment Record Sheet

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1 Introduction

1.1 Scope

The Climate Change Initiative (CCI) is a program of the European Space Agency aiming to build the longest time series of the new Essential Climate Variable (ECV) Sea Surface Salinity (SSS).

This document is the User Requirement Document (URD v1.0) gathering all the information obtained from the user consultation about the interest of using SSS during year 1 of the project. These inputs fed into the production of the first version of the CCI+SSS dataset.

The CCI+SSS project aims to repeat the user requirement enquiry every year within the duration of the project (June 2018 - June 2021). Hence the URD will be updated with the upcoming results of the online survey (4Annex A).

1.2 General Introduction

Retrieving Sea surface salinity (SSS) from satellite measurements has been motivated by the need of better monitoring and understanding the hydrological cycle over the ocean (Escorihuela et al. 2018), and can be used to reduce uncertainties in surface freshwater flux estimates in the framework of the ocean rain gauge concept (e.g. Schlundt (2014), Yu (2011), and Font et al. (2004)). 86% of global evaporation and 78% of global precipitation occur over the ocean (Yu, 2011) and, therefore, SSS, as an indicator for changes in the marine component of the hydrological cycle, is an Essential Climate Variable (ECV).

Together with sea surface temperature (SST), SSS controls the density of seawater and is thus a driver of circulation. All in all, variations of salinity are an expression of varying surface freshwater fluxes (evaporation, precipitation, river runoff and ice melting), varying freshwater transports and a changing ocean circulation due to vertical mixing processes and associated exchanges of freshwater and salt, especially between the surface and subsurface layers (Köhler, 2016)).

Therefore, the relevance of salinity cannot be neglected and understanding the variability of salinity on various time scales and the underlying mechanisms is important to understand the hydrological cycle and ocean dynamics (Dong et al., 2009).

The first satellite mission with the aim to retrieve SSS is the European Space Agency's (ESA) SMOS ("Soil Moisture and Ocean Salinity", Font et al. (2004)), which started measuring in November 2009, followed by the American National Aeronautics and Space Administration's (NASA) "Aquarius/SAC-D" (Satélite de Aplicaciones Científicas) mission (Lagerloef et al., 2008) from 2011 to 2015 (end due to an unrecoverable hardware failure). The third mission retrieving soil moisture and SSS is the NASA SMAP (Soil Moisture Active Passive, Fore et al., 2016) mission, which started in January 2015.

The onboard satellite sensors measure the incoming microwave radiation in the L-Band (approximately 1.4 GHz) because at this frequency the sensitivity of the permittivity to salinity is highest in the first centimeter of the ocean (e.g., Köhler et al., 2018).

Each of these three sensors (SMOS, Aquarius, SMAP) was an innovation, having its own measuring principle, its own calibration techniques and its own algorithms and correction methods to achieve the best result from the measurements. The aim is to create a long-term, consistent, precise global SSS dataset which should satisfy the needs of the climate users, both, modellers and earth observing scientists.

User requirements with respect to SSS depend on applications and spatial-temporal scales they are interested in. Accordingly, close collaboration between the CCI+SSS working groups and the user community is required to ensure consideration of user needs and also to inform users about the potentials and limitations of satellite SSS data.

1.3 The approach

A user requirement survey was conducted with the goal to identify the requirements of SSS data for climate studies at present and in the future. The user requirements of the "Low Frequency Passive Microwave User Requirement Consolidation Study" were taken as starting point (Escorihuela et al. 2018). The "satellite and in situ salinity (SISS)" working group discussions at several conferences (e.g., WHOI 2017, OSM 2018, Salinity Conference Paris 2018) were useful in focusing on the main issues to be addressed in the CCI+SSS survey.

1.4 The process

Users were consulted through various approaches, personally via email, via mailing lists, or at meetings (e.g., CMUG meeting Oct. 2018, Salinity Science conference, Paris Nov 2018). Respondents participated in a web-based (Google Forms) survey or completed the survey offline via print outs. The members of the CCI+SSS working groups were requested to distribute the survey widely to colleagues. To promote the actions of the CCI+SSS working group and to discuss the requirements of the specific user groups, team members participated in several meetings with modellers, data assimilation scientists etc. and conferences. These opportunities were also used to spread the survey.

The report is divided into two parts. First, the requirements from reference documents will be summarized and second, the outcome of the user requirement survey will be summarized and discussed.

1.5 References

1.5.1 Applicable Documents

ID	Reference
AD001	Boutin, J., Martin, N., Reverdin, G., Morisset, S., Yin, X., Centurioni, L., & Reul, N. (2014). Sea surface salinity under rain cells: SMOS satellite and in situ drifters observations. Journal of Geophysical Research: Oceans, 119, 5533–5545. https://doi.org/10.1002/2014JC010070
AD002	Boutin, J., Martin, N., Reverdin, G., Yin, X., & Gaillard, F. (2013). Sea surface freshening inferred from SMOS and ARGO salinity: Impact of rain. Ocean Science, 9(1), 183–192. https://doi.org/10.5194/os-9-183-2013
AD003	Boutin, J., Martin, N., Yin, X., Font, J., Reul, N., & Spurgeon, P. (2012). First assessment of SMOS data over open ocean: Part II—Sea surface salinity. IEEE Transactions on Geoscience and Remote Sensing, 50(5), 1662–1675. https://doi.org/10.1109/TGRS.2012.2184546
AD004	Dong, S., Garzoli, S. L., & Baringer, M. (2009). An assessment of the seasonal mixed layer salinity budget in the Southern Ocean. Journal of Geophysical Research: Oceans, 114, C12001. https://doi.org/10.1029/2008JC005258
AD005	Font, J., Lagerloef, G. S. E., Le Vine, D. M., Camps, A., & Zanife, O. (2004). The determination of surface salinity with the European SMOS space mission. IEEE Transactions on Geoscience and Remote Sensing, 42(10), 2196–2205. https://doi.org/10.1109/TGRS.2004.834649
AD006	GCOS 2016 Implementation Plan: The Global Observing System for Climate: Implementation Needs. https://unfccc.int/sites/default/files/gcos_ip_10oct2016.pdf
AD007	GOOS requirements: OOPC (2017), EOV Spec Sheet: Sea Surface Salinity v5.2. http://goosocean.org/index.php?option=com_oe&task=viewDocumentRecord&docID=17470
AD008	Escorihuela et al. (2018), Low Frequency Passive Microwave User Requirement Consolidation Study: D-02 White paper on L-band radiometry for earth observation: status and achievements, ESA ITT AO/1-8731/16/NL/IA. Reference: ISARD_ESA_LBAND_TN_565,Issue: 3.0, Date: 5 September 2018
AD009	Köhler, J., Serra, N., Bryan, F. O., Johnson, B. K., & Stammer, D. (2018). Mechanisms of mixed-layer salinity seasonal variability in the Indian Ocean. Journal of Geophysical Research: Oceans, 123, 466–496. https://doi.org/10.1002/2017JC013640
AD010	Köhler, J., (2016), Sea surface salinity variability and underlying mechanisms, Ph.D. thesis, University of Hamburg, Hamburg, Germany
AD011	Schlundt, M., P. Brandt, M. Dengler, R. Hummels, T. Fischer, K. Bumke, G. Krahmann, and J. Karstensen (2014), Mixed layer heat and salinity budgets during the onset of the 2011 Atlantic cold tongue, J. Geophys. Res. Oceans, 119, 7882–7910, doi: 10.1002/2014JC010021.
AD012	Yu, L. (2011). A global relationship between the ocean water cycle and near-surface salinity. Journal of Geophysical Research, 116, C10025. https://doi.org/10.1029/2010JC006937

1.6 Acronyms

CCI The ESA Climate Change Initiative (CCI) is formally known as the Global Monitoring for Essential Climate Variables (GMECV) element of the European Earth Watch programme

CCI+ Climate Change Initiative Extension (CCI+), is an extension of the CCI over the period 2017–2024

CMUG Climate Modelling User Group

CSWG Climate Science Working Group

DOI Digital Object Identifier

ECV Essential Climate Variable

EO Earth Observation

EOV Essential Ocean Variable (of the OOPC)

GCOS Global Climate Observing System

GOOS Global Ocean Observing System

IOC Intergovernmental Oceanographic commission (of UNESCO)

NASA National Aeronautics and Space Administration

OSM Ocean Science Meeting

PSD Product Specification Document

RS Remote Sensing

SISS Satellite and In situ [Working Group]

SMAP Soil Moisture Active Passive [mission of NASA)

SMOS Soil Moisture and Ocean Salinity [satellite of ESA]

SST Sea Surface Temperature

SSS Sea Surface Salinity

UCR/CECR Uncertainty Characterization Report (formerly known as the Comprehensive Error Characterization Report)

URD User Requirement Document

2 Requirements from reference document and international framework

Before presenting the results of the CCI+SSS survey, we first present the requirements for SSS data that has been gathered by other organizations and working groups.

2.1 Requirements from GCOS

The SSS (in situ) observation requirements have been defined by the GCOS Physics and Climate Panel in their recent document (GCOS 2016 Implementation Plan: The Global Observing System for Climate: Implementation Needs). It is particularly recommended that the continuity of spaceborne SSS measurements must be ensured (Action O32, GCOS 2016 Implementation Plan).

The requirements for the ECV SSS are listed in the following:

Variable	Frequency	Horizontal Resolution	Required Measurement Uncertainty	Stability/Decade
SSS	hourly to monthly	1-100 km	0.01	0.001

Table 1 GCOS in situ sea surface salinity requirements in psu reproduced from GCOS 2016 Implementation Plan: The Global Observing System for Climate: Implementation Needs.

2.2 Requirements from GOOS

The GOOS (Global Ocean Observing System) Physics and Climate panel, a program executed by the UNESCO Intergovernmental Oceanographic Commission (IOC), is responsible, among other things, for setting the requirements for Essential Ocean Variables (EOVs) to ensure efficiency of a global ocean observing system.

The requirements they have determined for SSS depend on the spatial and temporal scales of the phenomena and are listed in the following:

Phenomena	Air-Sea Flux (including Ice-Sea Flux)	Coastal Shelf exchange process	Front and Eddies	Riverine
Temporal Scales	daily	daily	weekly	monthly
Spatial Scales	100 km	1 km	10 km	50 km
Magnitudes/range of the signal, thresholds to	0.01	0.1	0.1	0.1

Table 2 GOOS requirement settings for sea surface salinity depending on its application at January 2017, reproduced from

2.3 Requirements from Climate Modelling User Group (CMUG)

The Climate Modelling User Group (CMUG) was established by the ESA to bring together data and climate modelling users. Part of their tasks involve the refining of scientific requirements for each of the CCI-ECVs derived from GCOS for climate modellers.

Their requirements are those specified by the users below.

2.4 Low Frequency Passive Microwave User Requirement Consolidation Study

A set of requirements for SSS data was formulated in the frame of an L-Band study (Escorihuela et al. 2018), which result mainly from informal discussions with ocean scientists. For this study, scientists were asked for three levels of requirement.

The thresholds (the limit to which the observation is effective and useful for the application) regarding various subtopics (Air-Sea Fluxes, Ocean Circulation, Freshwater Fluxes, Carbon Cycle and Biochemistry) are summarized in the following table:

	Phenomena	Spatial Scales	Temporal Scales	Accuracy
Air-Sea Interaction	Climate change/long-term changes (> 10 years)	10°	1 year	0.01
	Barrier layer	1.5°	1 month	0.1
Air-Sea Interaction/Climate Variability	ENSO/IOD/SSS anomalies	10°	1 month	0.2
Ocean Circulation	mesoscale/eddy propagation	100 km	1 month	0.2
	density compensation	0.5°	1 month	0.3
	Tropical Instability Waves	100 km	8 days	0.2
	Thermohaline Circulation	100 km	2 weeks	0.2
Freshwater Fluxes	River plumes	1°	1 month	1
	Rain	0.5°	< 1hour	1
	Ice melting	50 km	8 days	1
Carbon cycle and biochemistry	Air-sea CO2 fluxes	150 km	1 month	0.2
	Alkalinity	150 km	1 month	0.2

Table 3 Requirement settings for satellite sea surface salinity depending on its application at February 2018 reproduced from (Escorihuela et al. 2018)

3 Analysis of user survey: Requirements of satellite sea surface salinity data for climate research studies

3.1 Introduction

Current and future users were invited to participate anonymous on an online questionnaire and specify their requirements. The posed questions are included in the annex 1 to this document. Invitations to participate were sent to various mailing lists including the “Satellite and In-Situ Salinity (SISS) Working Group”, the CCI+SSS mailing list and mailing lists of the participating institutes. Furthermore, the “Ocean Salinity Science Conference 2018” participants were invited to do the questionnaire offline during the conference. The survey was online from 10th September to 11th November 2018, using an online system provided by Google (Google forms,). The questionnaire had four different parts, which were:

1) User profile information

2) User dataset requirements

3) User dataset quality information

4) Other user requirements or suggestions

The survey drew 54 responses from all over the world. Of these, 43 people participated online and 11 answered the survey during the conference. The number of responses depending on the country of origin/working is presented in Figure 1, showing that the most responses were from the USA (28%), followed by Germany (19%) and the UK (17%). In the following, each question from the survey is treated individually. Figures summarizing the responses are shown for each question.

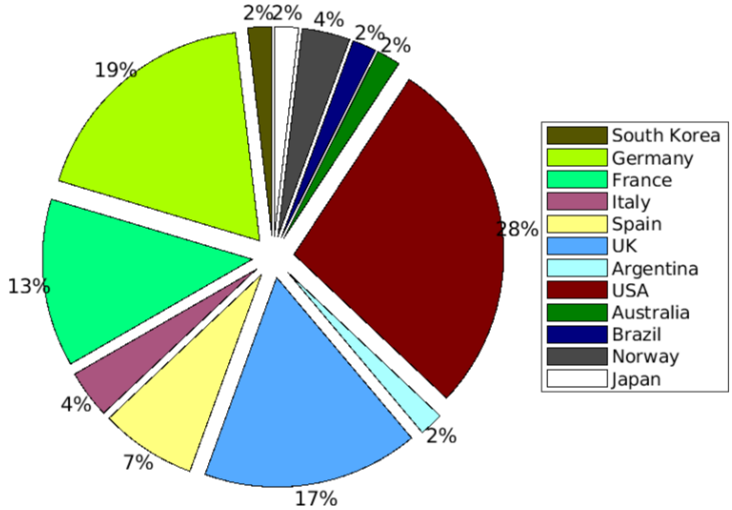

Figure 1 Percentage of respondents to the online survey. All in all 54 responses.

3.2 User information

The following questions were user specific. The aim was to find out, how SSS data are used or could be used in the future dependent on the occupation category and research interest of each participant.

Participants were asked for the occupation category best describing their work. As shown in Figure 2, the majority of participants were from the Earth Observation community. 35% of respondents are Climate/Ocean modellers and mainly interested in global modelling and data assimilation (Figure 3). All respondents were asked about their general research interests and have cited mainly ocean circulation, freshwater fluxes and air-sea interaction (Figure 4).

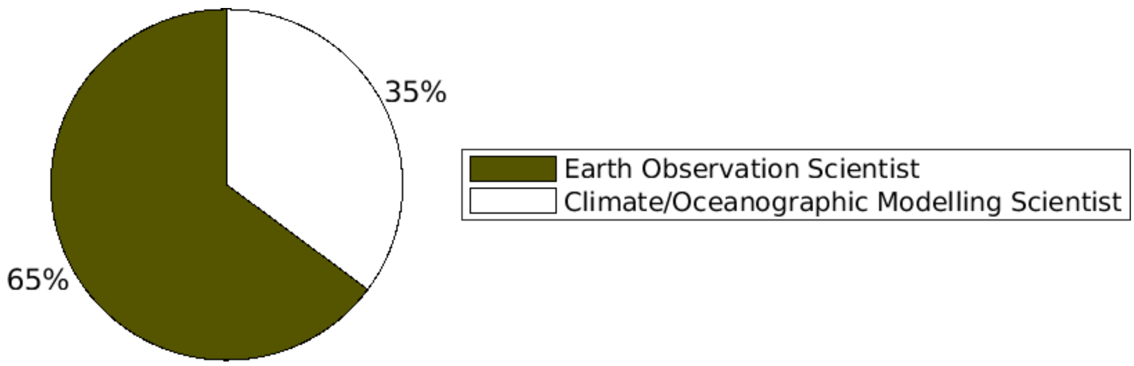

Figure 2 Distribution of Earth Observing Scientists and Ocean/Climate Modelling Scientists within the survey-participants.

In terms of spatial scales, there was a consensus among users that small-scales (answered for 11 times) to large-scales (answered for 28 times) are required with the most responses for meso-scales (answered for 37 times).

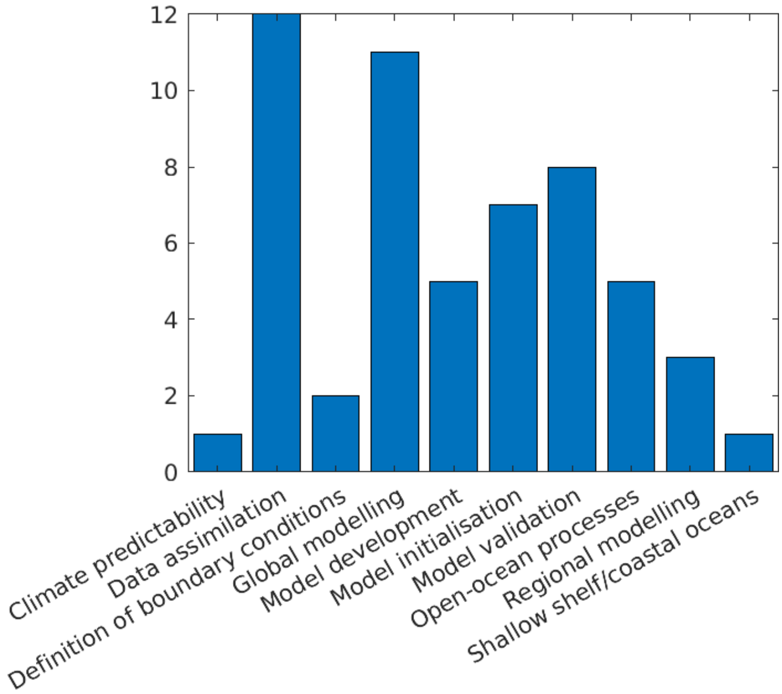

Figure 3 Areas of research of climate modellers. This was a multiple choice question, hence more than one answer per respondent is possible. Y-Axis shows number of responses.

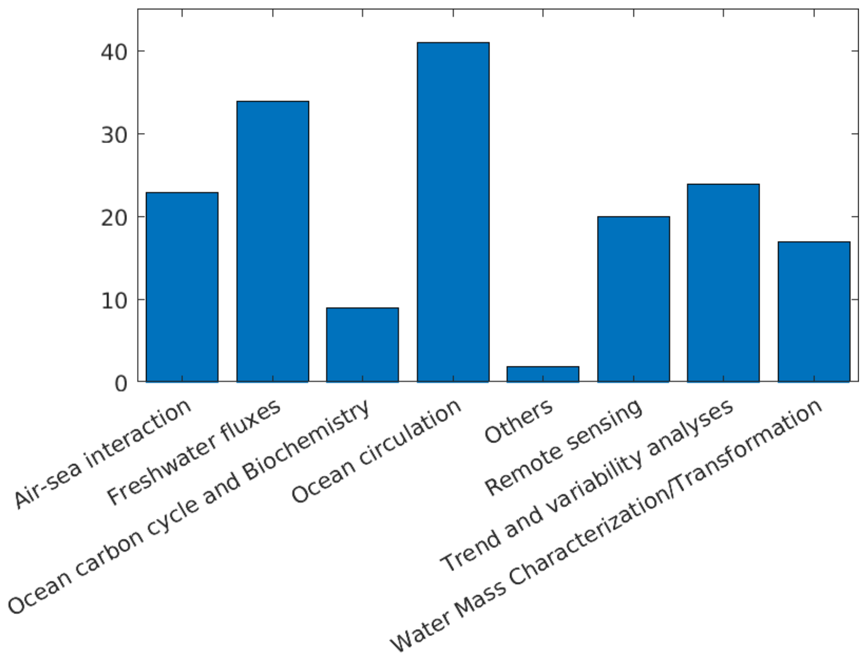

Figure 4 Areas of interests of all respondents. This was a multiple choice question, hence more than one answer per respondent is possible. Y-Axis shows number of responses.

Furthermore, we asked if the users already had experience with the use of satellite SSS data, which was answered by 65% with "Yes" (Figure 5). There are a total of 37 different satellite SSS products from Level 2 to Level 4 based on different correction methods, resolutions, coverage etc. The participants do not have a preference for one special product. Further information to each of the existing satellite SSS product can be found in the Data Access Requirement Document (DARD).

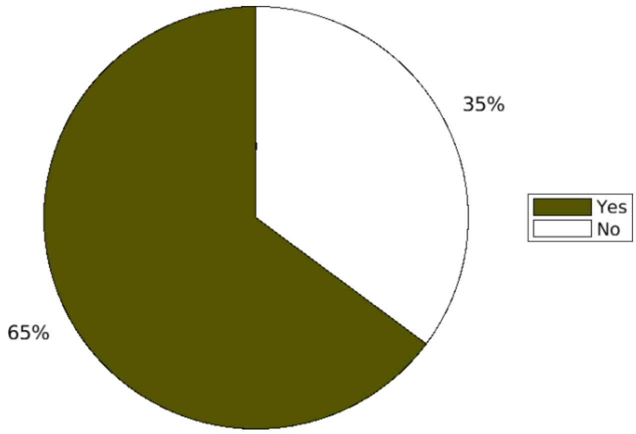

Figure 5 Distribution of users with experience with the use of satellite SSS data (green) and without experience (white).

Participants have a wide spread of answers, when asked what they use satellite SSS data for, indicating even more the importance of SSS measurements for a wide range of applications.

On the one hand, satellite SSS data are used for validation and the combination with other remote sensing (RS) products, on the other hand, satellite SSS data are essential for variability and process analyses from mesoscale to large-scale. Furthermore, these data are also used in data assimilation and for model validation (Figure 6).

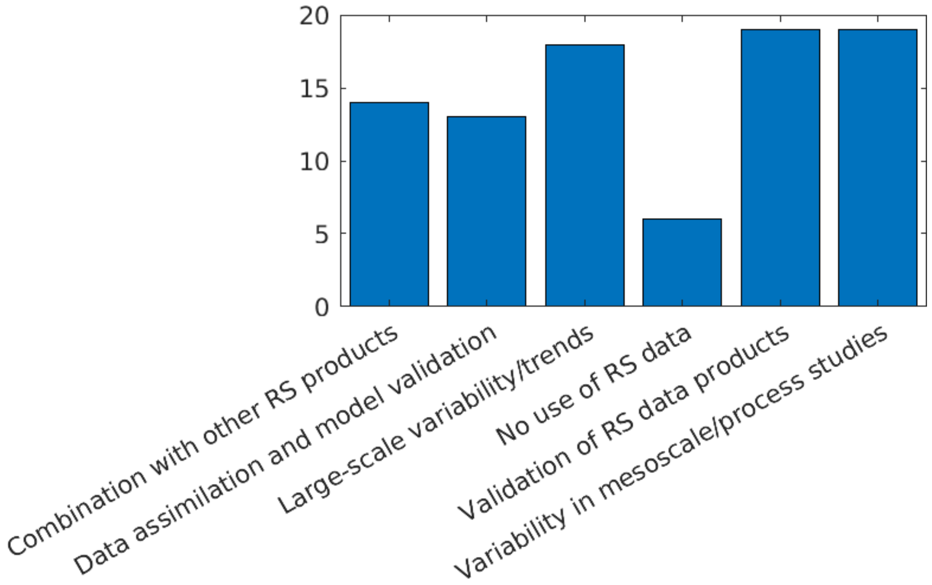

Figure 6 Current usage of satellite SSS data. This was a multiple choice question and more than one answer per respondent is possible. Y-Axis shows number of responses.

The participants were asked how they want to use the new CCI+SSS product and to describe their (research) plans with the new dataset. In the following the original answers:

- *yes. I plan to use such a product as a reference for validation purpose and for process studies.*
- *This sounds great. I can't wait to get my hands on it. To look at scales of variability.*
- *currently no plan*
- *Validation and improvement of such products; use products for ocean variability and trend research.*
- *10 year analysis of some processes: river plume dispersal, eddy transport of heat and salt across boundary currents, air-sea interaction (upwelling, ocean response to tropical cyclones, barrier-layers)*
- *Trends in global and regional salinity*
- *Assimilation of L3 and L2 into ocean model for ENSO forecasts*
- *Yes, use of such products for PhD work in Bay of Bengal*
- *Yes, I study land/sea linkages and I evaluate SSS products in the Arctic Ocean*

- *Continue the Analysis of large-scale variability/trends, Analysis of variability in mesoscale/process studies and combine with other remote sensing products*
- *yes, will study SSS changes in the Southwest Pacific*
- *analysis of interannual variability*
- *Validation of global model*
- *Freshwater balances*
- *We plan to use such product for model evaluation, in particular at high latitudes*
- *Yes, in combination with in-situ (Argo).*
- *Investigate changes in Indian Ocean SSS*
- *Analyzing mesoscale processes*
- *Mesoscale studies - air sea interaction, large scale subpolar region*
- *Yes, validation for operational numerical modeling*
- *No specific plans but the product sounds interesting*
- *Yes, as mentioned above, I am highly interested in better understanding the signature of evaporation and precipitation over oceans from remote sensed data, and particularly a better assessment of what SMOS can provide to our understanding of the water cycle and heat transport.*
- *Try to assimilate these products*
- *We will use it within the context of the current CMUG-CCI+ project*
- *yes, to use it as part of a data assimilation.*
- *Yes, I'm planning using the SSS data for monitoring freshwater plumes in the future.*
- *Relaxation of model surface salinity to observed SSS.*
- *Yes, will use it look at North Atlantic mid-high latitude salinity variability.*
- *For boundary conditions and assimilation*
- *Rainfall variability*
- *It is good if we can use in the data assimilation system*

- *Assimilate the product in an Arctic reanalysis (planned for 2020)*
- *We would like to use them for the initialization of our seasonal predictions. The idea would be to assimilate them through Newtonian relaxation together with ocean temperature and sea ice concentrations. For us it is essential to use products that are coherent with each other.*
- *Model evaluation, trend and variability analysis*
- *No plans, but it sounds like something I might try*
- *depends on the resolution*
- *Yes, will assimilate into ocean*
- *No*
- *Yes*
- *Possible integration of SSS products into public outreach tool*s

Also here, a wide spread of answers was given and participants look forward to analyze the new product. Furthermore, the data will be used for model validation/boundary conditions/relaxation and assimilation.

Next, it was asked what would make them want to use the new CCI+SSS product. In the following the original answers:

- *Resolution- daily or better, <10km*
- *a useful product closer to the coast, where river sources have a strong influence*
- *In order: accuracy, error estimates, detailed documentation and updated versions*
- *better accuracy and error characterization*
- *The hope to have a product that resolves the scales I need*
- *Error estimates, exploitation for biogeochemical modeling*
- *I need to know more about the product to be able to answer this question*

- *Easy access. I find SMOS data very difficult to access. Good documentation and access methods would be the first priority. Resolution and accuracy would be second. Error estimates would be third.*
- *inter-comparison*
- *Longer time series and better space coverage, as well as reduction of existing biases and/or issues like RFIs. Resolution, if always a better one is desired, I do not consider essential. Daily maps would be also a good addition.*
- *error estimates and better accuracy near the river mouth*
- *High resolution is important for us, and it would also be ideal if time span was longer than a decade*
- *resolution, accuracy, and error estimates to understand model sensibility when used in data assimilation*
- *Error estimates, accuracy, resolution (time and space)*
- *Spatial and temporal resolution of SSS.*
- *Important for me is high resolution and the highest possible accuracy at that resolution.*
- *All of the example items listed, no particular priority.*
- *accuracy, updates*
- *Consistency of the product and well documented*
- *It would be great if the data is provided in real-time.*
- *Accuracy and error estimates*
- *Interest in gridded product in combination with close collaboration with people closer to real data*
- *global coverage, long products (decadal or longer), daily resolution*
- *Clear characterisation of uncertainties, longest possible time series*
- *community acceptance*
- *higher temporal and spatial resolution*
- *Latency!!! Need in real time or nrt, error estimates*

- *Harmonised data from different sources being the main value*
- *Validation*
- *regular grid, circa 50 km resolution, prompt release of latest data*

The answers show that the users are aware of the current limitations of satellite SSS data and that improved resolutions, error estimates, accuracy, and documentation are desired. In addition, easy access is required.

3.3 User consultation analysis about the data specifications

The second part of the survey queried users' preferences in terms of data format, access and resolution on spatial and temporal scales.

3.4 Requirements for data formats, access and update information

There is an overall agreement in preference of NetCDF format data (94%) and FTP access (81%, Figure 7). Some Scientists find that having access to the data via HTTP or OPeNDAP (6% each) would be useful.

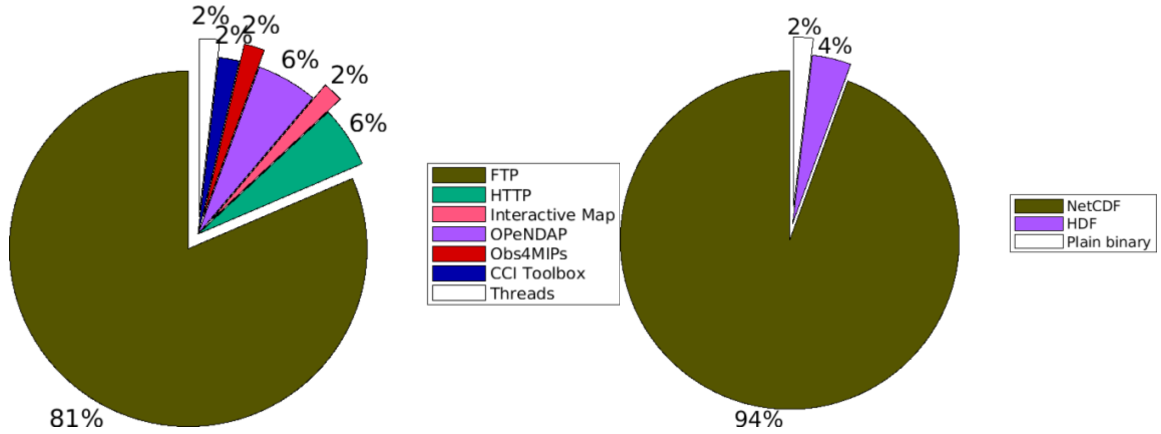

Figure 7 Percentage of preferred (left) access to data and (right) data format.

Users were asked about the level of processing required for their applications and had to choose between Level 2 (L2, original grid/swath), Level 3 (L3, gridded data: single satellite mission) and Level 4 data (L4, analyzed data: several satellite missions).

A small majority (43%) prefer to obtain L4, whereas 37% and 20% prefer to obtain L3 gridded data and L2 original swath data. There are no significant differences between both user groups (Earth Observation Scientists and climate/ocean modellers), but L2 and L3 are the preferred datasets for assimilation studies.

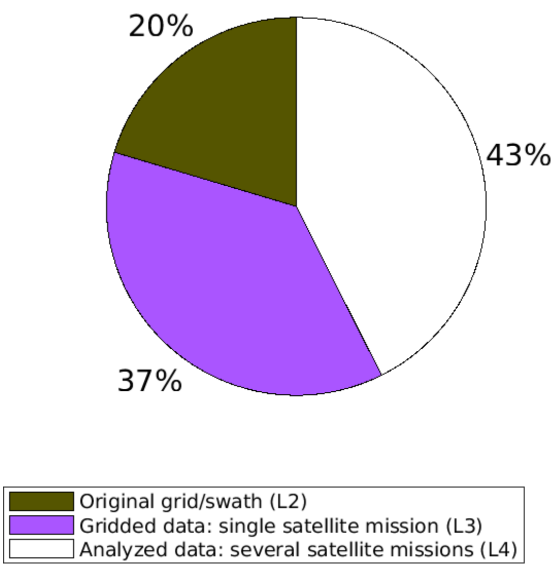

Figure 8 Percentage of preferred level of data processing

We also received very different answers to the question of how frequently data should be updated with improvements from “as soon as estimates of errors and accuracy are obtained” to once a year (Figure 9). Here, own suggestions could be made, reaching from “When they are available” and “Either continuous or infrequent” to “As soon as possible” and summarized under “other”. For the Phase 1 CCI+SSS product, updates one to two time per year are planned, which meets the user requirements.

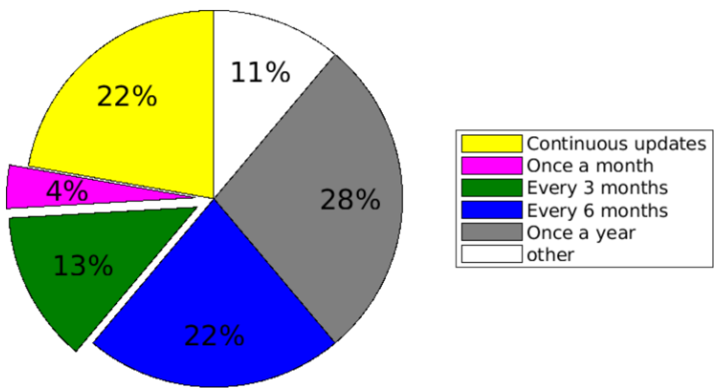

Figure 9 Percentage of preferred frequency of updates with improvements.

As shown in Figure 10, almost all the users (81%) want to be notified via E-Mail about news/alerts/updates, followed by information transfer via a web page (17 %).

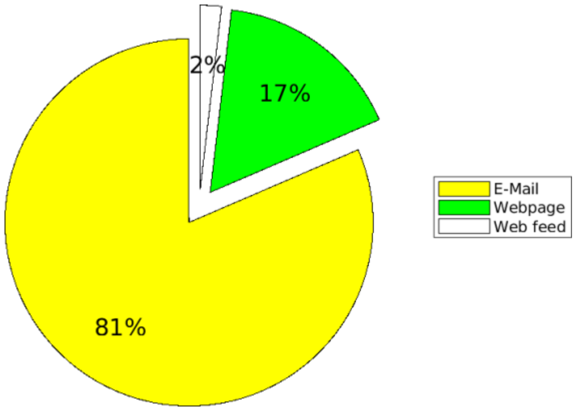

Figure 10 Percentage of preferred way to inform about news/alerts/updates.

3.4.1 Requirements for data resolution, coverage and accuracy

One part of the survey was dedicated to obtain an indication of the requirements of the users concerning spatial and temporal resolution and coverage of satellite SSS. Participants require data with at least 0.25° spatial resolution (39%), followed by 0.5° (22%) and 1° (28%). 4% of users want to have the data on a “0.1° grid” or “original minimum spatial sampling” summarized under “Other” (Figure 11).

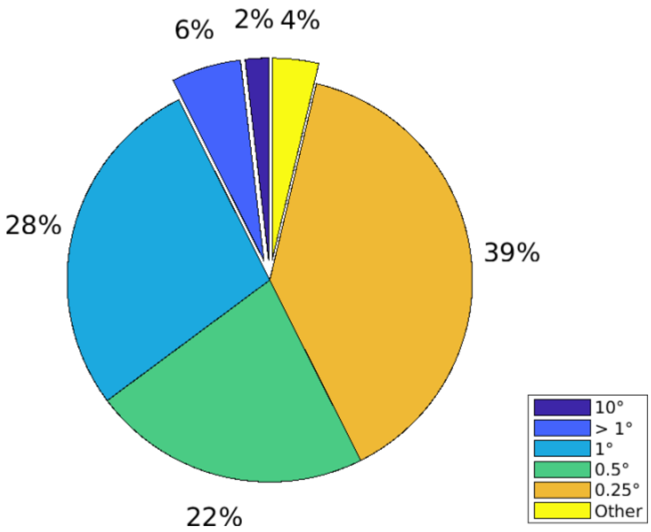

Figure 11 Percentage of (minimum) required spatial resolution.

There is an overall agreement on the question of global spatial coverage (83%, Figure 12) and there was a strong preference shown for a regular latitude-longitude grid (not shown here).

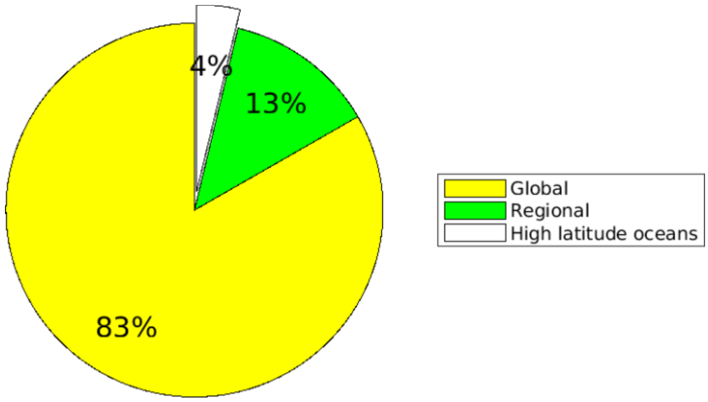

Figure 12 Percentage of required spatial coverage

As shown in Figure 13, 61% of participants want data with at least 3 -7 days resolution, 7% even with a higher resolution. For 28% of the users, data is sufficient with a resolution of 1 month.

94% of users want time series with at least 9 years length, of which 32% want even longer time series. The latter is only possible if C and X-band radiometers are included, since L-band data exist only since the end of 2009.

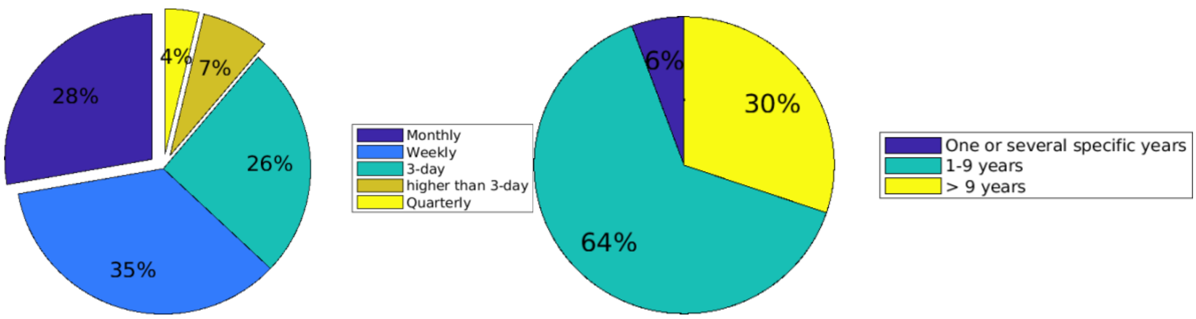

Figure 13 Percentage of (top) (minimum) required temporal resolution and (bottom) required temporal coverage.

Interestingly, as it can be seen from Figure 14, most of the users (74%) were satisfied with a mean global accuracy between 0.1 and 0.3 and would in general prefer a product with high resolution (weekly, 0.25°) and accept a lower accuracy (0.3).

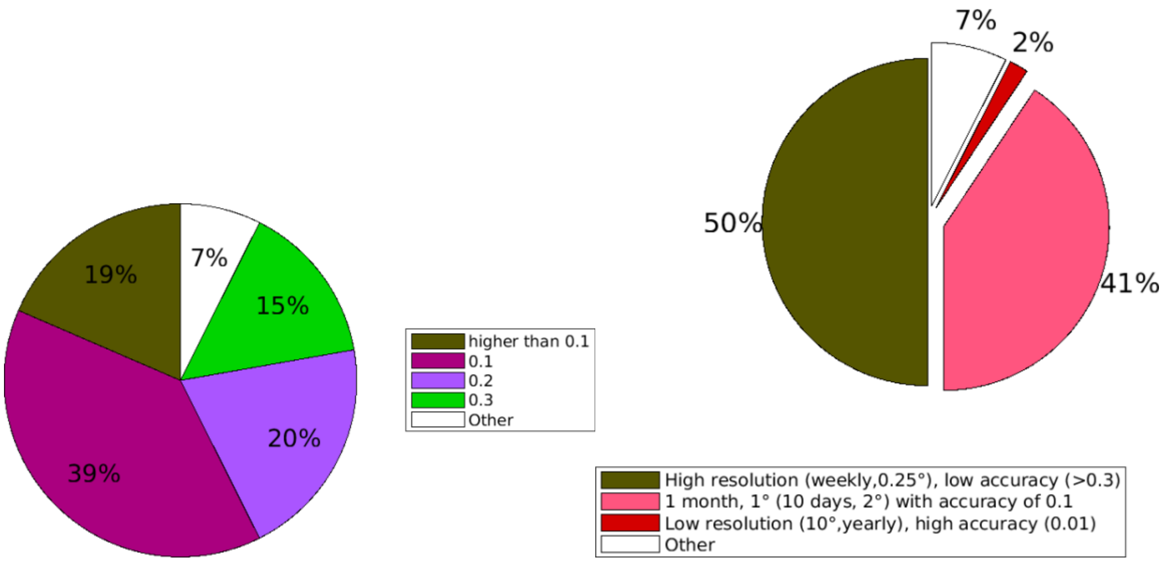

Figure 14 Percentage of (left) acceptable global mean accuracy and (right) preferred SSS product based on the users spatial and temporal resolution needs.

Data should be combined to overcome weaknesses in individual datasets. The most common requirement is here the combination of satellite and in situ data (50%, Figure 15). However, a not inconsiderable part of the users (39%) only wants the combination of data from different satellite sensors.

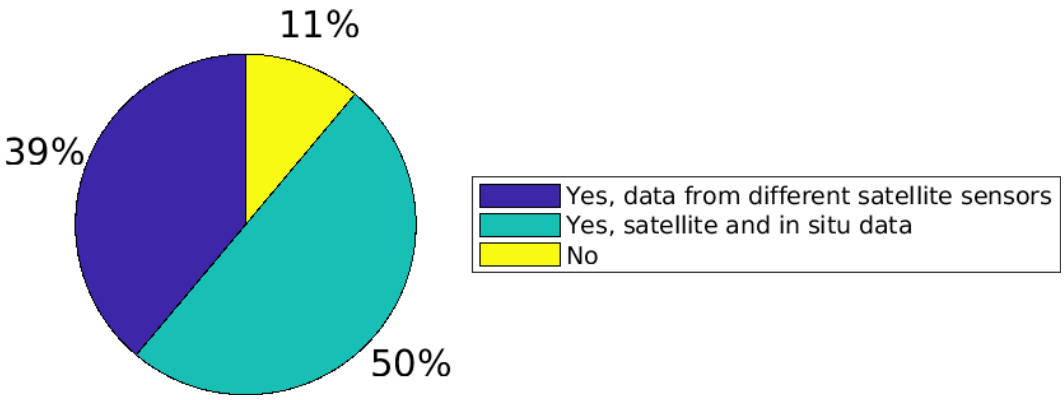

Figure 15 Preferences for what data should be combined to overcome weaknesses in individual datasets.

3.5 User consultation analysis about the data quality information

Figure 16 shows how uncertainty information should be communicated. This was a multiple choice question and participants had the opportunity to choose more than one answer. Confidence intervals and random noise and systematic errors achieved the most responses. Root mean squared differences (RMSD) to other data, information about applied adjustments and uncertainties of these adjustments also received a significant number of responses. The divergent responses indicate that there is not only one way to communicate uncertainty that everyone is 100% satisfied with.

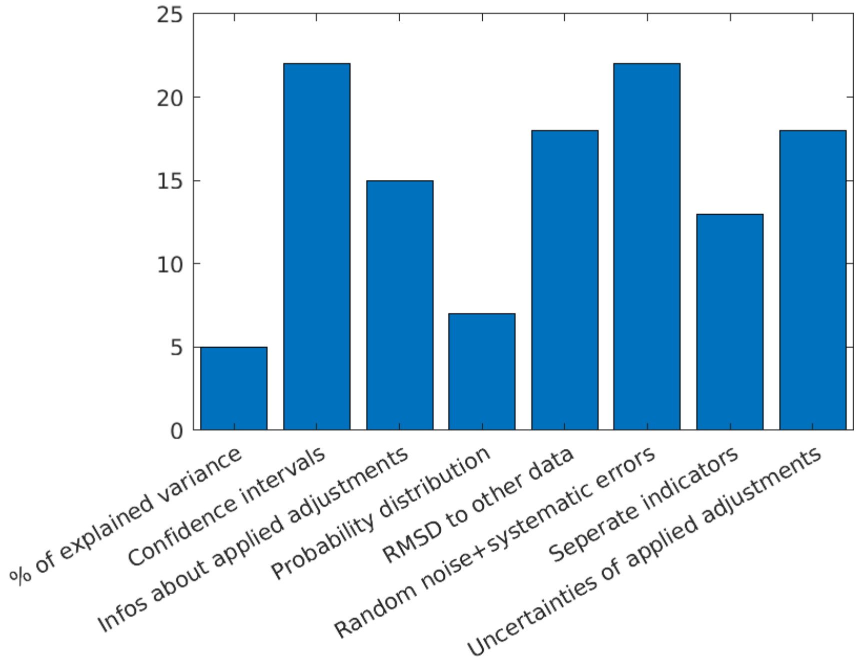

Figure 16 Preferred metrics of characterizing uncertainty information. This was a multiple choice question and more than one answer per respondent is possible. Y-axis shows the number of responses.

In order to find out which in situ datasets are considered inappropriate by users for validation, users were asked about the preferred in situ datasets to perform satellite SSS validation exercises (Figure 17).

This was a multiple answer question, which showed that Argo dataset (has been chosen 36 times in total, which is 32% of answers) was the preferred dataset among users.

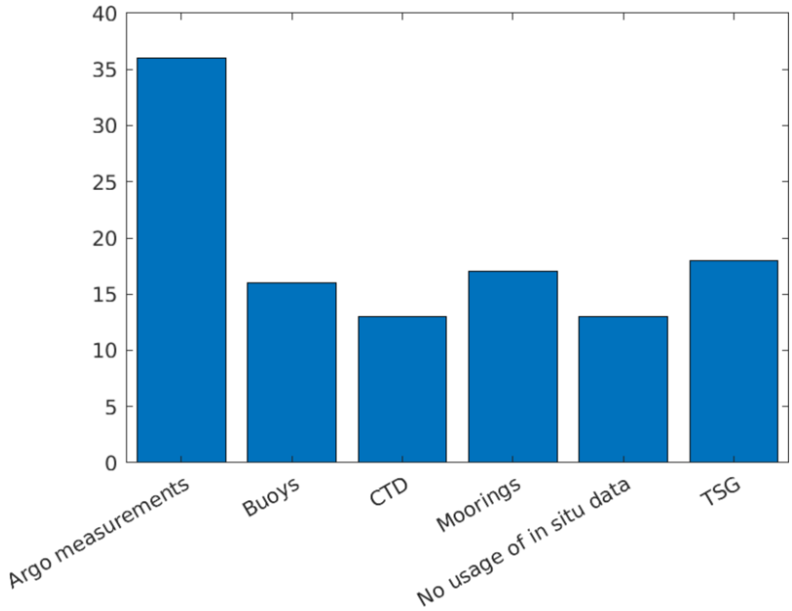

Figure 17 Preferences of which in situ data used to verify satellite SSS products. This was a multiple choice question and more than one answer per respondent is possible. Y-axis shows the number of answers.

The results of this question were somehow expected, due to the fact that Argo array provides a global coverage of both salinity and temperature. Further, users also use data from Buoys, CTD, TSG and Moorings. Users who answered that they did not use the in situ data which we have proposed to validate satellite data usually responded that they use glider, USV or model data.

In addition to uncertainty metrics, the users were asked, if they would like to use quality flags. Responses are presented in Figure 18 and show, that users want the data to be quality flagged as good/bad (46%), for each quality check (28%) and for selected quality checks (22%). Only 4% think, that quality flags are not necessary. In the case of L3 and L4 products, it is not possible to specify each quality control flag (data are already binned). Here, flagging data as good/bad, or if they exceed a certain threshold would be a possibility.

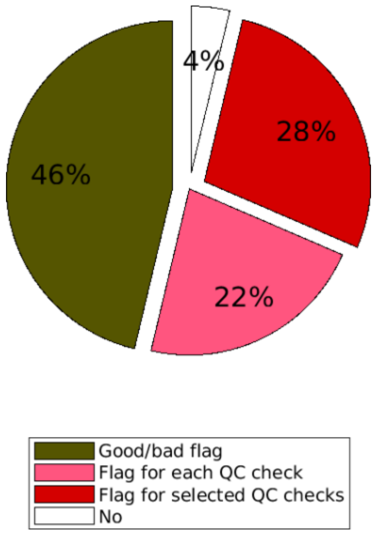

Figure 18 Preferences of how quality information should be communicated.

Users were asked what additional information should be provided within the L3/L4 data product and the results are shown in Figure 19. Information about locations of sea-ice, suspected rain and wind speed/direction were most commonly selected. Providing a land mask or including the SST does not attract interest.

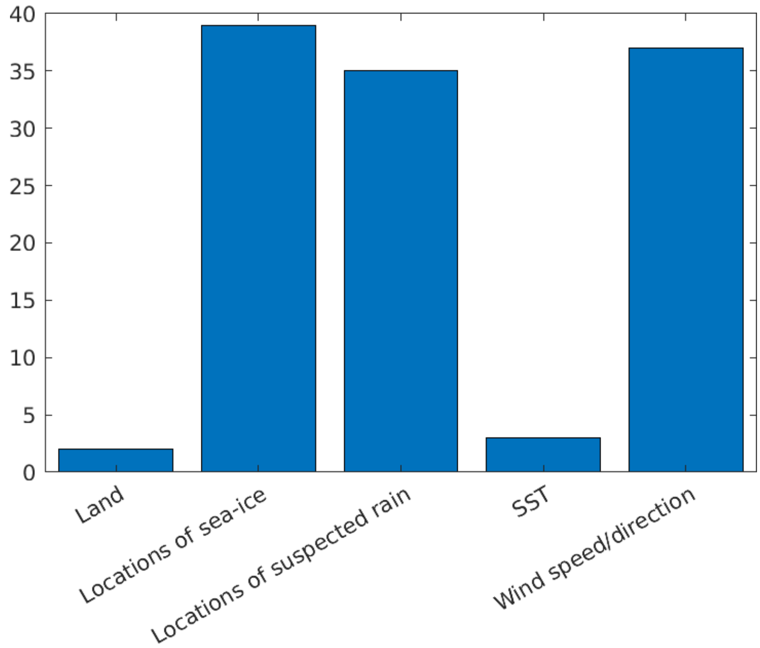

Figure 19 Additional information that should be provided in data products. This was a multiple choice question and more than one answer per respondent is possible.

During the first year of the CCI+SSS project it is not planned to add additional information to the data product. Information about SST and sea-ice locations are available via CCI and for the second year the CCI+SSS product could be offered with a corresponding grid.

It was asked, if there are any features of the data that are of particular importance. Results are in Figure 20. All that could be chosen achieved "very important" or preferable responses. Very important are especially information about bias correction and uncertainty estimates for each SSS grid point, but also metadata describing data sources and processing are of importance for the users.

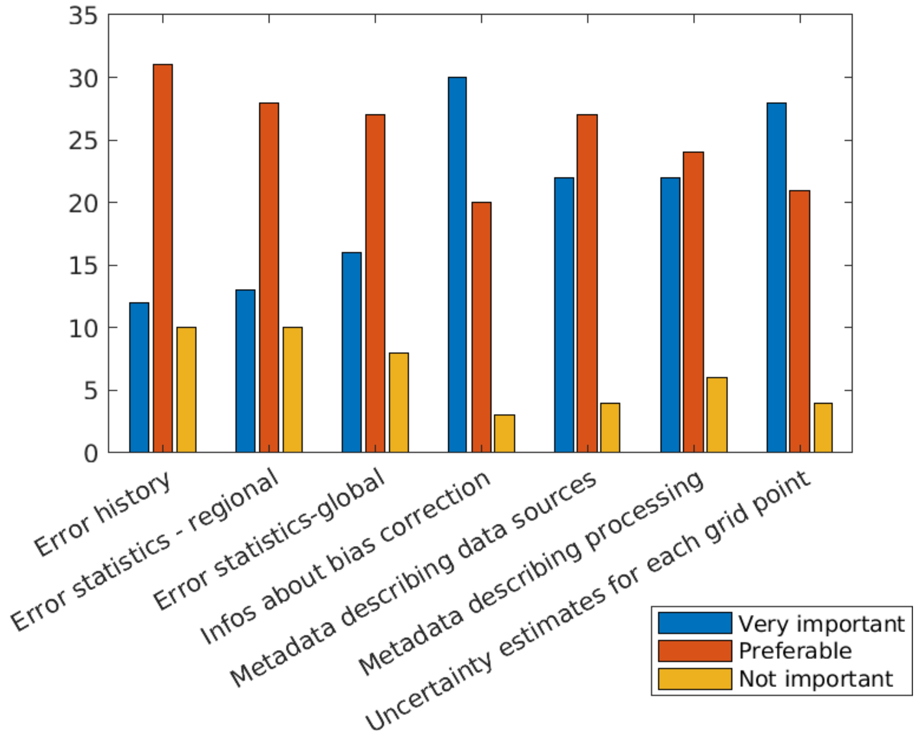

Figure 20 Preferences to features of the SSS data.

3.6 User consultation analysis about other technical details

Users were asked about the tools they would like the CCI+SSS project to provide. Here, the respondents should order by priority from 1 (most important) to 6 (not important). Each number should only be used once and results are summarized in Figure 21.

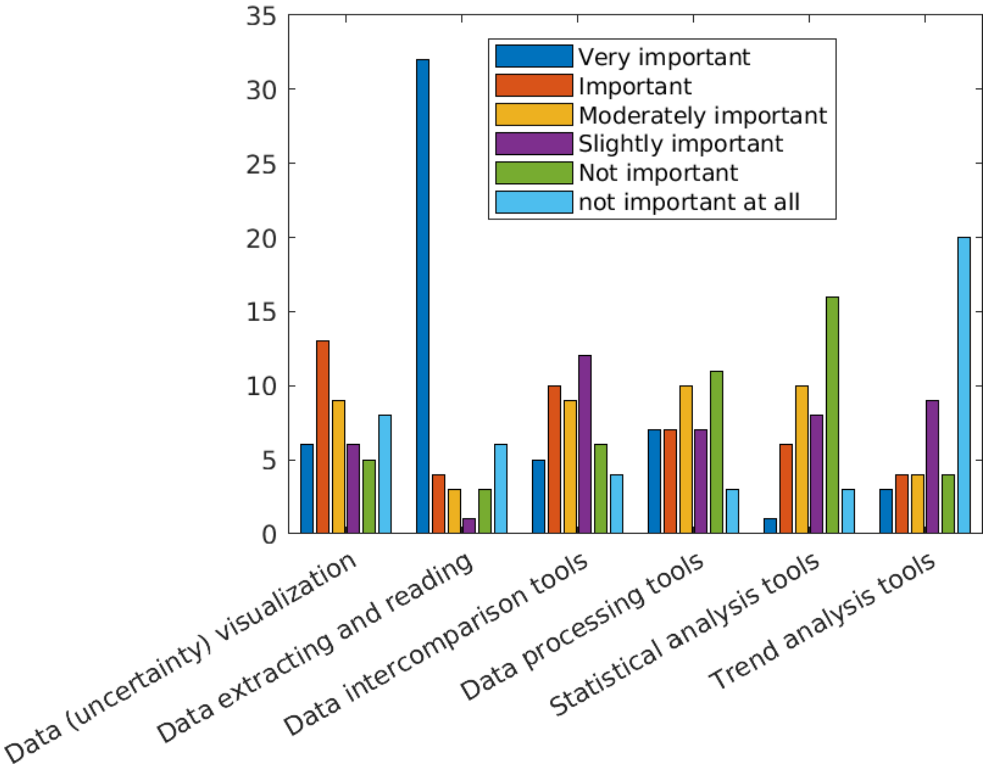

Figure 21 Tools that users would like the CCI+SSS project to provide.

The results show a clear preference for data extracting and reading tools, which has by far the most approval. Furthermore, data visualization, intercomparison tools and processing tools are required. Less important are statistical and trend analysis tools. Subsequently, other additional services, which should be provided, were asked for with a clear trend towards a simple as well as a detailed documentation. Access to experts and data reading examples are less important for the users (Figure 22).

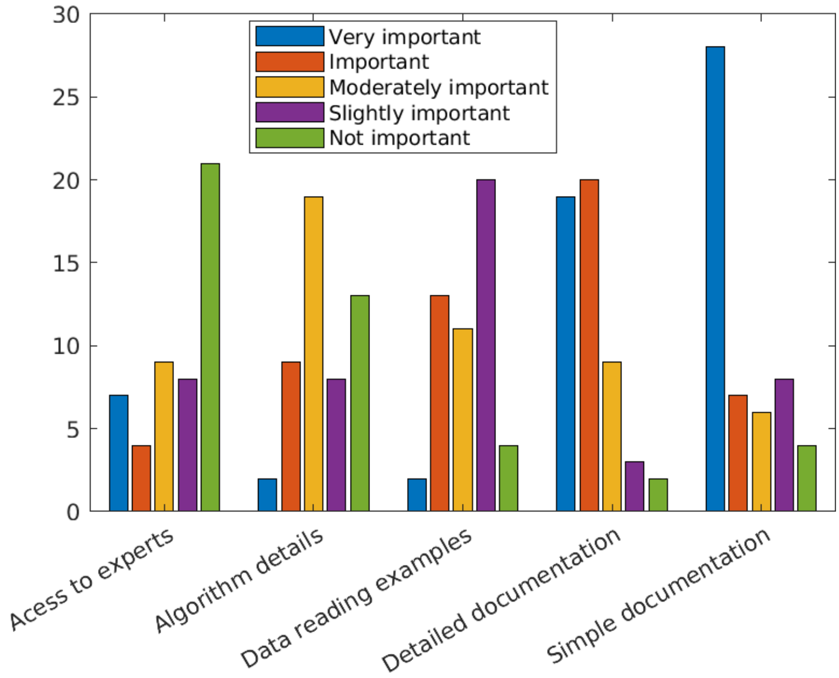

Figure 22 Other services that users would like the CCI+SSS project to provide.

The last question for the users was the preferred programming language and the results are presented in Figure 23. Matlab (54%) is the most popular choice followed by Python (28%) and Fortran (11%).

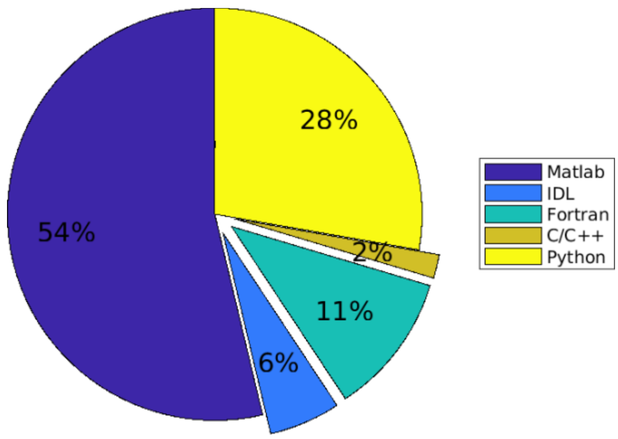

Figure 23 Language preferences for a software library.

3.7 User survey in year 2

The objective of the user survey in year 2 was to ask those users who already work with the data sets or plan to work with the data sets produced in year 1 a set of specific questions about these data sets. This happened on the one hand in a live user survey with the online tool VoxVote during the Salinity Science Seminar in Hamburg (26/27. September 2019) getting feedback from 27 participants and on the other hand via a google online form forwarded with the mailing lists used also during the first year survey (CMUG, SISS, CCI+SSS etc.). Here, the survey drew 18 responses. Of course, this is due to the fact that a large part of the persons contacted already participated in the survey during the Seminar. First we asked again for giving us a few information about their research interest. Here, answers didn't differ from the answers from the last survey. Participants mainly focus on the analysis of variability on different spatial-temporal scales, validation studies and assimilation. Respondents plan to or already use the data for these purposes. Around 50% of the respondents already work with the data. Furthermore it was asked how participants know about the CCI+SSS dataset. Also here, about half of the participants answered that they are a member of the CCI+ECV consortium. Around 15 % of respondents mentioned that they know about the data due to the Salinity Science Seminar in Hamburg underlying the importance of such events to promote CCI data sets. We also wanted to know, if the the participants miss any additional information in the data sets or other products such as density, spiciness or auxiliary data. These questions were mostly negated, 90% of participants don't miss further information or need other products from SSS for studying climate change. Furthermore it was asked for caveats and also here 80% answered that they don't have any caveats, 20% point out for issues in high latitudes (remaining ice, RFI pollution, biases due to land-sea contamination and dielectric constant in cold waters). Discussed during the Salinity Science Seminar was also the systematic global underestimation (~0.08) of SSS, which starts in 2010, gradually disappearing at the end of 2010 and a seasonal varying bias in the Pacific North of 25° . The caveats discussed with the users are now included as an information in the data set, the URD and PSD.

4 Summary and conclusion

Current and future users of satellite SSS data were invited to participate in a web-based survey and enter their requirements for satellite SSS data. 54 responses were analyzed in total.

The results of the questionnaire have been presented, every single question was evaluated and discussed. Wide ranges in responses were received for many questions, indicating that there is no one single product that will satisfy everyone.

The survey revealed that the majority of users require global spatial coverage and a temporal coverage from at least 9 years. The resolution requirements vary according to the studied phenomena. About 33% of respondents' want data with a temporal resolution of 1-3 days, while for 35% of the respondents' weekly data and for 28% also monthly data are sufficient. 39% of the respondents want data with 0.25° spatial resolution, for 28% data on a 1°-grid are sufficient. The majority of respondents would prefer a data product with high spatial and temporal resolution (weekly, 0.25°) on a regular latitude longitude grid and would accept a lower accuracy (approx. 0.3).

The requirements of the participants are not substantially different from the GCOS, GOOS requirements and former user requirement studies. All in all, required are data product resolutions and coverage dependent on the users' application category.

Data should be combined to overcome weaknesses in individual datasets, here, 50% prefer a combination of satellite and in situ measurements, whereas 39% require the combination of data from different satellite sensors. However, combination with in situ measurements is out of the scope of the CCI+SSS project. By making available the multiple-sensor datasets on different spatial-temporal grids, the needs of different users can be met. The most common requirement is for L4 data (43%), directly followed by requirements for L3 (37%). Some potential users, mainly modellers, require L2 (20%). L3 and L2 data are already available from ESA, CATDS, BEC, RSS and JPL and should not be the main focus of the CCI+SSS project during the first year of the project. In the next years also debiased L2 and possibly L3 products will be made available to satisfy the requirements of the users.

Uncertainty information for each SSS grid point needs to be characterized fully, including random noise and systematic errors and uncertainties of applied adjustments. Information about bias correction is most commonly required by respondents. 50% of respondents want to have flags for each/selected quality control checks, which is not possible for datasets at L3 or L4 which are already binned. Therefore, quality information is needed for each SSS value that is simple to use, such as good/bad flag or the probability that a value is good/bad. 46% of the respondents would prefer such a solution for quality information. Participants indicated how important a detailed documentation is. This, they did both in the multiple choice questions and when asked what is expected from the new CCI+SSS product.

Data need to be easily accessible, a majority of respondents (94%) require data in NetCDF, accessible via FTP server (81%), followed by a webpage (6%) and OpeNDAP (6%). Updates/News/Alerts should be communicated via email (81%) followed by web page (17%) and this continuous at least once a year (28%, all in all 57% more often).

The most common service that the respondents wish to have provided is a simple documentation, followed by a detailed documentation. The tools that respondents would like the CCI+SSS project to provide are primarily data extracting and reading tools. Respondents choose MATLAB (54%) as most common choice as language for software libraries, followed by Python (28%) and Fortran (11%).

User Requirement Survey Year 1 results show the importance of contacting users and promote communication between the project, users and potential users. Changes in user requirements of spatial-temporal resolution and coverage are not expected in the near future, but users should be contacted regularly to refine requirements, to check the satisfaction with the CCI+SSS product and to reach (climate) community acceptance of SSS as an ECV. The recommendations derived from the user consultation are transformed into a set of product specifications for input into Task 2 of the CCI+SSS project (Product Specification Document (PSD), SSS_cci-D1.2-PSD-v1r4.docx).

User Requirement Survey Year 2 results show the overall satisfaction of the user with the first version of CCI+SSS data. Requirements didn’t change compared to Year 1 and users are highly interested in working with the data. The Salinity Science Seminar in Hamburg was a good opportunity to introduce the data to a wider audience. The only criticism is the provision of the documentation with the data on the CCI website, which does not take place simultaneously.

Annex A CCI+SSS User Requirement Survey

The Climate Change Initiative Sea Surface Salinity project (SSS_cci) aims to produce the longest SSS Climate Data Record resulting from the combination of all the existing satellite missions able to retrieve this variable from space (SMOS, Aquarius and SMAP).

The purpose of this survey is to obtain information about the use of remotely sensed (RS) data of SSS and to find out what are the user requirements for the future SSS Climate Dataset.

For more information on CCI SSS:

https://docs.google.com/forms/d/1pGrUO648wsqFPdNfpRCadjIzFRMCUqxyQqxDTSiNyYw/viewform?edit_requested=true

The survey is structured as follows:

Part 1 - Information about the user

Part 2 - Data specifications (resolution, data formats, grids)

Part 3 - Data Quality information

Part 4 - Other technical details

If you are attending the Salinity Science Meeting in Paris (6-9 Nov.), you are welcome to discuss your requirements there with us.

*required

Part 1

Which country are you from?*

Which of the following occupation categories best describes your work? *

Please choose only one:

[ ] Earth Observation Scientist

[ ] Climate Modelling Scientist

[ ] Other:

Which of the following topics are you most interested in?

You can choose more than one:

[ ] Regional modelling

[ ] Global modelling

[ ] Open-ocean processes

[ ] Shallow shelf/coastal oceans

[ ] Model development

[ ] Model validation

[ ] Model initialisation

[ ] Definition of boundary conditions

[ ] Data assimilation

[ ] Other:

Which of the following topics are you most interested in?

You can choose more than one:

[ ] Ocean Circulation

[ ] Freshwater Fluxes

[ ] Air-Sea Interaction

[ ] Water Mass Characterization/Transformation

[ ] Ocean Carbon Cycle and Biochemistry

[ ] Trend and variability analyses

[ ] Remote Sensing

[ ] Other:

What are the spatial scales you are mostly interested in? *

You can choose more than one:

[ ] Small-scale (< 10 km)

[ ] Mesoscale (10 - 100 km)

[ ] Large scale (> 100 km)

[ ] Across scales

Do you currently use satellite derived SSS data (SMOS, Aquarius, SMAP)? *

Please choose only one:

[ ] Yes

[ ] No

If you answered "yes" to the previous question, please specify the product you use (e.g., SMOS ESA L2, CATDS L3, BEC L4, Aquarius CAP or RSS L3, ..), and if known the corresponding version:

How do you currently use SSS data? *

You can choose more than one:

[ ] Analysis of large-scale variability/trends

[ ] Analysis of variability in mesoscale/process studies

[ ] Validation of remote sensing data products

[ ] Combination with other remote sensing products

[ ] No use of remote sensing data products

[ ] Other:

The CCI+SSS project will deliver satellite SSS fields (combination of SMOS, SMAP and Aquarius SSS) and error estimates. Do you have plans concerning the use of such a product in the next 3 years? If so, please describe them.

What would make you want to use the new SSS_cci product (e.g., resolution, accuracy, error estimates, quick release of updated versions to users, detailed documentation)? (please indicate your priorities)

Detailed questions to the error characterization or resolution requirements follow in Part 3.

Part 2

To define the user requirements, we will ask a few questions regarding data formats and the ways to retrieve the data, as well as the required resolution and accuracy of the new SSS_cci product.

Which method of obtaining data do you prefer? *

Please choose only one:

[ ] FTP

[ ] HTTP

[ ] Interactive map

[ ] OPeNDAP

[ ] Obs4MIPs

[ ] Other:

Which of the following data formats would you prefer? *

Please choose only one:

[ ] NetCDF

[ ] HDF

[ ] Plain binary

[ ] ASCII

[ ] Other:

Which data level is more useful for your research? *

Please choose only one:

[ ] Original grid/swath of the instrument (L2)

[ ] Gridded data from a single satellite mission (L3)

[ ] Analysed data from several satellite missions (L4)

How often would you like the data to be updated with improvements? *

Please choose only one:

[ ] Continuous updates

[ ] Once a month

[ ] Every 3 months

[ ] Every 6 months

[ ] Once a year

[ ] Other:

Which would be the preferred way to inform you about alerts/news/updates on the data? *

Please choose only one:

[ ] E-Mail

[ ] Webpage

[ ] Web feed

[ ] Not interested

[ ] Other:

What is the minimum requirement for spatial resolution so that you would consider using a SSS product in your research? *

Please choose only one:

[ ] 10°

[ ] >1°

[ ] 1°

[ ] 0.5°

[ ] 0.25°

[ ] Other:

Which spatial coverage is required? *

Please select the preferred spatial coverage (only one):

[ ] Global

[ ] Regional

[ ] High Latitude oceans

[ ] Low Latitude oceans

Which basis grid for the data are you interest in (e.g. regular latitude-longitude grid, sinusoidal equal-area grid projection,...)? Please specify.

What do you consider the minimum temporal resolution for a remote sensed SSS product so that it is useful for your research? *

Please choose only one:

[ ] 3-day

[ ] Weekly

[ ] Monthly

[ ] Quarterly

[ ] Half-yearly

[ ] Yearly

[ ] Other:

Which temporal coverage is required?

Please choose only one:

[ ] One or several specific years (SMOS or Aquarius or SMAP within 2010 and 2018)

[ ] 1-9 years (SMOS + Aquarius + SMAP)

[ ] >9 years (SMOS + Aquarius + SMAP + C and X-Band radiometers, river plume areas only)

If your answer was "One or several specific years", please specify which years:

Based on your resolution requirements, what global mean SSS accuracy is acceptable? *

Please choose only one:

[ ] Higher than 0.1

[ ] 0.1

[ ] 0.2

[ ] 0.3

[ ] Other:

Based on your answers to the spatial and temporal resolution, which SSS product would you prefer? *

Please choose only one:

[ ] High temporal and spatial resolution (weekly, 0.25°), but low accuracy (>0.3)

[ ] Low temporal and spatial resolution (yearly, 10°), but high accuracy (~0.01)

[ ] Resolution of 1 month (or 10 days) and 1° (or 2°) and an accuracy of 0.1-0.2

[ ] Other:

Should data from different sources be combined to allow overcoming weaknesses in individual datasets? *

Please choose only one:

[ ] Yes, data from different satellite sensors

[ ] Yes, data from different satellite sensors and in situ measurements

[ ] No

Part 3

What are your preferred metrics for characterizing uncertainty? *

[ ] Confidence intervals

[ ] Random noise and systematic errors

[ ] Percentage of explained variance

[ ] RMS differences to other data

[ ] Separate indicators (e.g. magnitude of bias, precision, stability)

[ ] Probability distribution

[ ] Informations about adjustments applied to data

[ ] Uncertainties of applied adjustments

[ ] Other:

Which in situ data do you use to verify SSS data? *

[ ] Argo measurements

[ ] CTD

[ ] TSG

[ ] Buoys

[ ] Moorings

[ ] I don't use in situ data to verify remote sensed SSS data

Please specify if you use another mean:

In addition to uncertainty metrics, would you like to use quality flags? If yes, how should quality flags be communicated? *

You can choose more than one:

[ ] Good/bad flag

[ ] Flag for each Quality Control (QC) check

[ ] Flag for selected QC checks (e.g. galactic noise, sun glint, moon glint, RFI)

[ ] No

[ ] Other:

Additional information that should be provided in the L3/L4 datasets?

You can choose more than one:

[ ] Locations of sea-ice

[ ] Wind speed/direction

[ ] Locations of suspected rain

[ ] Other:

Are there any features of the data that are of particular importance to you?

	Very important	Preferable	Not important
Metadata describing processing			
Information about bias correction			
Metadata describing data sources			

Uncertainty estimates for each SSS grid point			
Error history and propagation from input data to product			
Error statistics- global			
Error statistics- regional			

Part 4

Which software tools would you like the SSS_cci project to provide (order by priority from 1(most important) to 6 (not important))?

Please use each number only once. In case you don't need any special software tools you can skip the question.

	1	2	3	4	5	6
Data extracting and reading						
Data (uncertainty) visualization tools						
Data intercomparison tools						

Data processing tools (spatial, temporal averaging and corresponding uncertainty estimates)						
Statistical analysis tools						
Trend analysis tools						

Which other services should be provided (order by priority from 1 (most important) to 5 (not important))?

Please use each number only once. In case you don't need other services you can skip the question.

	1	2	3	4	5
Simple documentation					
Detailed documentation					
Algorithm details					
Data reading examples					
Access to experts					

Which is your preferred programming language?

Please choose only one:

[ ] Matlab

[ ] IDL

[ ] Fortran

[ ] C

[ ] C++

[ ] Python

Do you have any additional comments?

Thank you for taking the time to complete the survey