ARCTIC SEA SURFACE SALINITY RETRIEVAL FROM SMOS MEASURES

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ABSTRACT

Arctic freshwater fluxes make this region key to regulate ocean currents and global climate. Hence, the Arctic Ocean sea surface salinity (SSS) knowledge is crucial to describe some of the processes that govern climate change.

Recently, Barcelona Expert Center (BEC) deployed their version 2 of SSS Arctic data retrieved from Soil Moisture and Ocean Salinity mission (SMOS) mission. Nevertheless, in the context of the ESA Arctic+ initiative, BEC has planned to introduce improvements in all the processing levels. Some of the planned improvements include: (i) optimizing the projection grid of level 1, (ii) studying the performance of different dielectric models in the Artic region and (iii) producing an additional level 4 product. The SSS Arctic products from Soil Moisture Active Passive (SMAP) mission could be used to produce a level 4 by merging them with this new version of SSS level 3 produced from SMOS.

Big data techniques are applied to produce debiased SSS maps. These techniques will be refined by introducing a new grouping method for the statistical study of the data.

The aim of this work is to obtain a more accurate version of the Arctic salinity maps starting at 2011. The new SMOS SSS maps are expected to better capture the Arctic river plumes and thus they will help to better understand the freshwater inflow/outflow in the Arctic Ocean.

Index Terms— Sea Surface Salinity, Arctic, SMOS, remote sensing, big data

1. INTRODUCTION

The Arctic Ocean is key in controlling the Earth's climate throughout ocean currents and freshwater fluxes. Not only the ice melting is a source of freshwater to Arctic Ocean; this relatively small ocean collects about a 10% of the total river discharges that take place in the planet [1]. The Arctic is very sensitive to climate change and the climate variations strongly affect sea-ice thickness, sea-ice extension or thaw and, consequently, the freshwater fluxes in the Arctic. Thus, the importance of having a good knowledge of the salinity of the Arctic Ocean is undeniable. Unfortunately, the sparse number of in-situ salinity measurements in this zone is a serious setback in the attempt to describe such processes giving special relevance to SSS retrieved from remote sensing measures.

Since November 2018, BEC serves their version 2 of SSS Arctic data [2] retrieved from SMOS mission [3] from http://bec.icm.csic.es. The processing chain starts with the level 1B product from SMOS provided by ESA and the processed salinity covers 2011-2017 period. The maps are generated from 50°N with a space-time resolution of 25 km and 9 days. Nevertheless, the presence of a changing sea-ice interface or the low Arctic sea surface temperature (SST) makes the difficult task of remote SSS retrieval even more challenging. Therefore, the research to provide a new version has just started and it is now in their first stages.

The basic retrieval scheme will follow, as in version 2, the non-Bayesian debiased algorithm described in [4] but several improvements will be implemented. This work is enclosed in the ESA's Arctic+ Salinity project, whose primary objectives are to explore, develop and validate novel approaches to enhance SSS measurements on the Arctic from SMOS and SMAP missions. Consequently one of our targets is to provide an SSS level 4 product by combining the obtained SSS level 3 from SMOS and level 3 generated from SMAP mission level 2 [5, 6]. Also the projection grid in which level 1 orbits are generated will be optimized in order to minimize interpolation processes at higher levels.

SSS is retrieved from brightness temperature T_B measured by SMOS. In this process a dielectric constant model is necessary to relate measured T_B and SST. This relationship is crucial to retrieve salinity because the dielectric constant model depends on salt concentration of sea water. A new dielectric model [7] will be assessed in the SSS Arctic retrieval and compared with the one currently used [8].

Big data techniques are used to produce debiased SSS maps. Therefore, it is expected to obtain better SSS maps by changing statistical filters and the way in which the clima-

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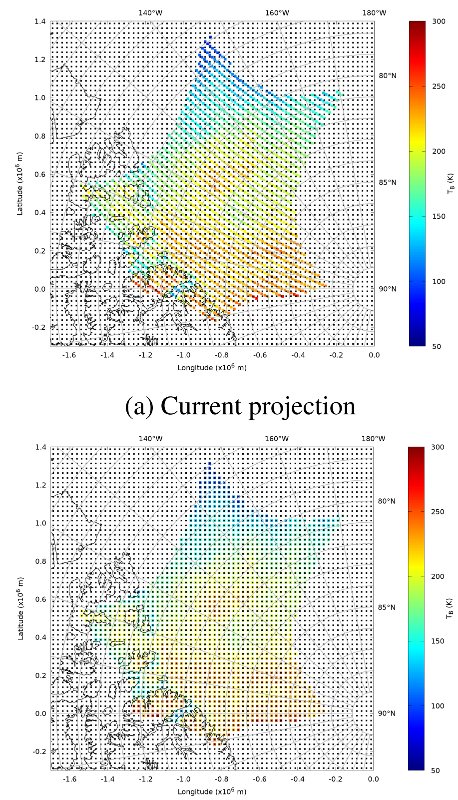
tological information is extracted from the huge set of SMOS individual snapshots will be introduced and is expected to obtain better results.

2. ALGORITHM IMPROVEMENTS

2.1. Grid change

The SMOS image reconstruction is performed by BEC and the final L1C product is geolocated using a local Lambert Azimuthal Equal Area (LAEA) projection. The origin of the projection for each orbit is taken in the equator of the Earth in latitude and in the center of each orbit in longitude. This means that T_B is obtained in a different grid for every L1C orbit. Therefore to produce SSS maps it is necessary to reproject the L1C orbits into an Arctic projection and interpolate values to regrid them to a regional grid. Current SSS Arctic product is regridded into EASE-Grid 1.0 (CRS code 3408) which corresponds to a Lambert Azimuthal Equal Area projection centered at (90°N, 0°E). Version 1.0 of the EASE-Grid North has been superseded by WGS 84 / NSIDC EASE-Grid 2.0 North (CRS code 6931) which introduces important improvements over the previous version [9]. One of the improvements is to make it easier for users to import data from version 2.0 into standard software packages and to minimize common reprojection errors that have been encountered with the original EASE-Grid definition. Therefore this new version of EASE-Grid will be used in the new product.

Despite reprojection can be done without interpolation, T_B measures (or individual SSS retrieved values) are obtained using different orbit-centered projections definition and can not be projected over the center of the grid cells in a regional projection. Figure 1a shows a SMOS image reconstructed using the current method and reprojected into a 25 km EASE-Grid 2.0 North (black dots). In this case it is necessary to resort interpolation methods to create L3 maps because every reconstructed image pixel is centered in a different latitude-longitude point. By adopting the EASE-Grid 2.0 North in the early stages of the processing chain, T_B and SSS can be obtained in this regional projection making unnecessary the interpolation (figure 1b)



(a) Current projection

(b) New projection

Fig. 1. Brightness temperature obtained for UTC 2018-08-26 07:28:54 over the north coast of Greenland and processed using a LAEA with origin in the center of the orbit and reprojected to the EASE-Grid 2.0 North (a) and the same snapshot natively processed in the EASE-Grid 2.0 North (b). Black dots indicate the EASE-Grid 2.0 North grid cells center

2.2. Dielectric model

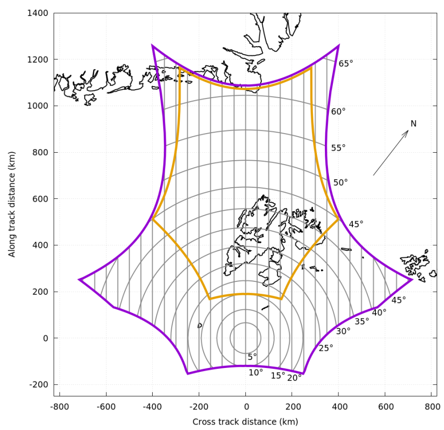
Ocean salinity retrieval from SMOS is based on measuring microwave emission in L-band from the sea surface. The emitted radiation is characterized by its T_B. In L-band regime and for typical SST values, polarized T_B and SST are linearly related by horizontal and vertical emissivity which depends on the dielectric coefficient (ε) of the sea water and the incidence angle of the radiation (θ).

Meissner and Wentz model [8] was used in Aquarius and it is currently used in SMAP salinity processors. This dielectric model is also used to generate the SMOS Arctic SSS product [2]. However, a new model specifically designed for SMOS and SMAP frequency -1.413 GHz- has been developed recently at George Washington University by Zhou, Lang and collaborators [7]. Although both models provide similar results in the context of the non-bayesian debiased retrieval in low and middle latitudes, we have detected some differences in Arctic region that deserve further studies.

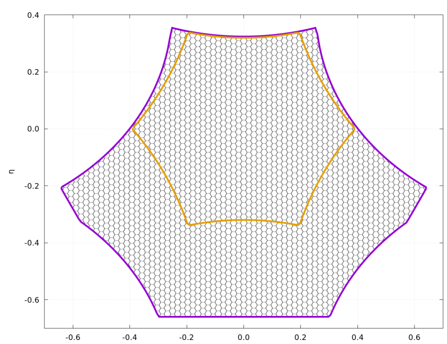
2.3. SMOS-based climatology computation

In order to retrieve salinity from measured T_B it is necessary to express T_B at the bottom of the atmosphere. Once the flat sea T_B is determined, the salinity is retrieved by minimization of the difference between the measured and the modeled T_B following a non-bayesian approach. SMOS commissioning phase finished in May 2010, therefore it has produced T_B images every 1.2 seconds for more than seven years. This translates into more than 1.5×10^7 ocean snapshots per year embracing each one an area of about 8×10^5 km^2 (figure 2). This huge amount of salinity retrievals (one for each T_B

value) allows us to characterize the systematic errors in ascending and descending passes as a function of the geographical position [4]. The enormous amount of images collected is systematically processed to establish the typical salinity value measured at each geographical position as a function of the incidence angle and distance to the center of the orbit swath (figure 2a). This is the so-called SMOS-based climatology. This typical value contains the systematic bias for each geographical location and snapshot position and can be substituted by an annual reference field. Nevertheless, this snapshot division is not uniform, especially outside from the known as Alias-free Field Of View (AF-FOV) encircled by a yellow line in figure 2. For that reason we shall implement a new snapshot division based on regular antenna coordinates (ξ,η) as it is shown in figure 2b. By using this uniform antenna binning, the SMOS-based climatology computation corresponding to measures out from AF-FOV should be improved.



(a) Current snapshot division



(b) New snapshot division

Fig. 2. (a)Bins of incidence angle, in 5° steps, and cross track distance in 50 km steps for a SMOS image over Svalvard island. (b) Proposed binning in antenna coordinates preserving the hexagonal nature of the image reconstruction

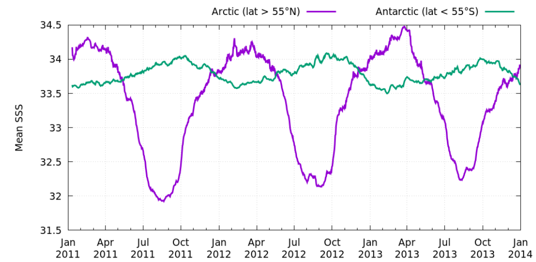


Fig. 3. First estimation of the temporal evolution of the mean salinity in the Arctic and Antarctic regions. Note the increase of the summer mean salinity in the Arctic along the period 2011-2013.

2.4. Temporal correction

The temporal correction applied to the current BEC SSS Arctic maps is based on in-situ Argo data [10]. Nevertheless, the Arctic region is not well sampled by these profilers and it is advisable to implement a different approach.

The temporal correction for the global SSS maps generated at BEC is based on the assumption that the global average of SSS changes, at most, very slightly with time. This hypothesis has been confirmed with Argo profilers. This result is a clear indication of a global-scale balance between the different drivers of salinity change in the ocean: evaporation, precipitation, river-runoff, upwelling, entraintment and downwelling.

This invariance in the global mean value of SSS can be used to evaluate the net freshwater advective (horizontal) transport across different ocean basins. Therefore, based on this result, the mean of the Arctic SSS can be evaluated from global maps, providing a method to correct the bias of each 9-day map. A preliminary result about the mean Arctic and Antarctic SSS is shown in figure 3.

2.5. Merging data

The L4 merged SSS product will be based on merging L3 SMOS and SMAP products. Note though that L3 products from SMAP and SMOS have different temporal coverage. Therefore, the SMAP L3 products to be merged should be generated from their corresponding L2 data. Since the L3 products have the same temporal resolution, the construction of the merged L4 product can be done using an objective analysis of the L3 sources. Nevertheless, a more sophisticated technique is the so-called multifractal fusion [11]. This is a blending algorithm combining two different variables with the only condition that advection is important on them. The assessment of the spatial resolution of the resulting merged or aggregated product can be determined using the so-called singularity power spectra [12]. This powerful technique assesses the geophysical consistency of the different satellite-derived SSS maps and provides an indication of their resolved scales.

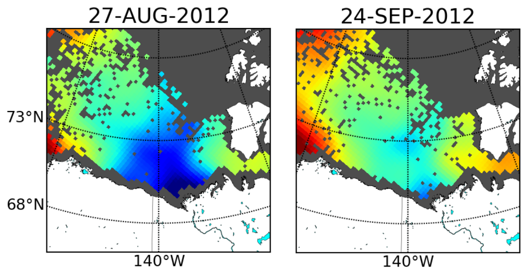


Fig. 4. Mackenzie river plume as detected by current version of the product. Adapted from [2].

3. EXPECTED RESULTS

Our aim is to show an improved version of the SSS Arctic currently distributed by BEC. The spatial resolution and accuracy of SSS maps for the Artic region should be improved by, first, adopting the same projection grid that will be used to generate salinity maps during earlier steps in the production chain, *i.e*: the image reconstruction, and second, by implementing a new method to compute SMOS-based climatology (a new snapshot division based on regular antenna coordinates). This should also improve the detection of the plumes of the most important rivers of the Arctic region (figure 4)

The ice mass release of major ice sheets (mainly Greenland) and the sea ice retried produce a modification on the salt content of the Arctic Basin. Changes on the north Atlantic seaway have been observe increasing the Bering Strait freshwater import to the Arctic Ocean and decreasing Davis Strait export [13]. Therefore, with the 9 years of SMOS Arctic SSS maps we will study the surface salinity temporal variation along the whole period 2011-2018, mainly by the North Atlantic and Farm Strait region. Moreover, we will look for correlations with the observed changes on the sea surface temperatures on the region.

4. REFERENCES

[1] CliC/AMAP/IASC, *The Arctic Freshwater System in a Changing Climate.*, WCRP Climate and Cryosphere (CliC) Project, Arctic Monitoring and Assessment Programme (AMAP), International Arctic Science Committee (IASC)., 2016.

[2] E. Olmedo, C. Gabarró, V. González-Gambau, J. Martínez, J. Ballabrera-Poy, A. Turiel, M. Portabella, S. Fournier, and T. Lee, "Seven Years of SMOS Sea Surface Salinity at High Latitudes: Variability in Arctic and Sub-Arctic Regions," *Remote Sensing*, vol. 10, no. 11, 2018.

[3] K.D. McMullan, M.A. Brown, M. Martín-Neira, W. Rits, S. Ekholm, J. Marti, and J. Lemanczyk, "SMOS: the payload," *IEEE Transactions on Geosciences and Remote Sensing*, vol. 46, pp. 594–605, 2008.

[4] E. Olmedo, J. Martínez, A. Turiel, J. Ballabrera-Poy, and M. Portabella, "Debiased non-Bayesian retrieval: A novel approach to SMOS Sea Surface Salinity," *Remote Sensing of Environment*, vol. 193, pp. 103–126, 2017.

[5] W. Tang, S. Yueh, D. Yang, A. Fore, A. Hayashi, T. Lee, S. Fournier, and B. Holt, "The potential and challenges of using soil moisture active passive (smap) sea surface salinity to monitor arctic ocean freshwater changes," *Remote Sensing*, vol. 10, no. 6, 2018.

[6] T. Meissner, F.J. Wentz, and D.M. Le Vine, "The salinity retrieval algorithms for the nasa aquarius version 5 and smap version 3 releases," *Remote Sensing*, vol. 10, no. 7, 2018.

[7] Y. Zhou, R. H. Lang, E. P. Dinnat, and D. M. Le Vine, "L-band model function of the dielectric constant of seawater," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 55, no. 12, pp. 6964–6974, Dec 2017.

[8] T. Meissner and F. J. Wentz, "The complex dielectric constant of pure and sea water from microwave satellite observations," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 42, no. 9, pp. 1836–1849, Sept 2004.

[9] M.J. Brodzik, D.G. Long, and M.A. Hardman, "Best practices in crafting the calibrated, enhanced-resolution passive-microwave ease-grid 2.0 brightness temperature earth system data record," *Remote Sensing*, vol. 10, no. 11, 2018.

[10] Argo, "Argo float data and metadata from global data assembly centre (argo gdac)," 2018.

[11] E. Olmedo, J. Martínez, M. Umbert, N. Hoareau, M. Portabella, J. Ballabrera-Poy, and A. Turiel, "Improving time and space resolution of smos salinity maps using multifractal fusion," *Remote Sensing of Environment*, vol. 180, pp. 246–263, 2016.

[12] N. Hoareau, A. Turiel, M. Portabella, J. Ballabrera-Poy, and J. Vogelzang, "Singularity power spectra: A method to assess geophysical consistency of gridded productsapplication to sea-surface salinity remote sensing maps," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 56, no. 9, pp. 5525–5536, Sep. 2018.

[13] B. Rabe, M. Karcher, F. Kauker, U. Schauer, J.M. Toole, R.A. Krishfield, S. Pisarev, T. Kikuchi, and J. Su, "Arctic Ocean basin liquid freshwater storage trend 19922012.," *Geophys. Res. Lett.*, 2014.