ANALYSIS OF THE POTENTIAL OF SMALL SATELLITES TO COVER THE SEA ICE DATA PRODUCTS GAP

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ABSTRACT

This work reviews and analyses potentially relevant technologies to ensure that the gaps and stakeholder needs for sea ice products are covered. Each variable related to sea ice that presenting gaps using the European EO infrastructure on the horizon (2020-2030) is revised according the stakeholder requirements, together with the feasibility of deploying available technologies on small satellites. A survey of instruments oriented towards sea ice observations in the past and current is presented. Based on this survey technological capabilities in terms of the spatial resolution, swath, mass, power, and data rate are obtained. In order to identify the technologies, numerical scores are assigned based on instrument capabilities. This works concludes with a set of the technologies compatible with small platforms, with the objective to complement the sea ice data products of Copernicus Services.

***Index Terms*—** Sea-ice, Earth Observation, Instruments, Small Satellites and Copernicus.

1. INTRODUCTION

Sea ice monitoring in Polar regions plays a key role in helping researcher to assess global change, and its impact on the climate, marine enviroment, and maritime navigation. Polar regions represent a "blind" zone for instruments on geostationary orbit, and for optical sensors on-board LEO Polar orbiting platforms. Additionally, polar regions present low revisit time by future satellites instruments (Copernicus infrastructure and Copernicus contributing missions that provide data to Copernicus services) capable to measure sea ice variables. Seven variables and their requirements were defined to complement Polar Regions (see Table 1). The requirements for each measurement are taken from the Observing System Capability Analysis and Review tool (OSCAR)[1] online database.

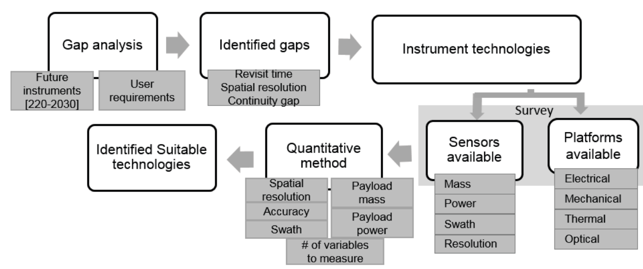


Fig. 1: Methodology. Design process to identify the potentially payload based on requirements

The methodology used to select the appropriate and potential sensors is shown in the Fig 1. First, the current work presents a deep literature review showing how the future instruments of the European Union and cooperating institutions cannot fulfil the requirements on sea ice monitoring. The instruments are assessed in terms of spatial resolution, revisit time, and measurement continuity gaps in the 2020-2030 horizon. Secondly, each variable presenting gaps is revised according the requirements, together with the available sensor technology, in terms of the spatial resolution, swath, mass, power, and data rate. Within these bounds, the available platforms are selected if suitable for a single payload (e.g. nano, micro, mini and large). Finally, in order to identify the more suitable technologies, numerical scores are assigned based on instrument capabilities to measure the variables with gaps.

[1]http://www.wmo-sat.info/oscar/requirements

Table 1: Sea ice variables, requirements, gap and potential instruments that will be required to ensure that the requirements are covered.

Variable with gap	Requirement	Gap	Instrument technology capable to measure
Sea ice thickness	25 km horizontal resolution, 24 h revisit time 10 cm accuracy[b]	Revisit time $<$ 24 h	Microwave radiometer GNSS-R[a] Radar altimeter Lidar
Sea ice type	10 km horizontal resolution, 3 h revisit time 0.25/Classes [b]	Revisit time $<$ 3 h	Microwave Radiometer Radar Scatterometer SAR
Sea ice cover	12 km horizontal resolution, 24 h revisit time 5% accuracy[c]	Revisit time $<$ 24 h from 2027	Microwave Radiometer SAR Multispectral Radiometer (MWIR/TIR) GNSS-R
Sea ice surface temperature	5 km horizontal resolution, 3 h revisit time 0.1 K accuracy[c]	Revisit time $<$ 3 h	Multispectral Radiometer (TIR)
Sea ice motion	25 km horizontal resolution, 24 h revisit time 1 km/day[b]	Revisit time $<$ 24 h from 2027	Microwave Radiometer Radar Scatterometer Multispectral Radiometer (VIS/TIR) SAR
Ocean imagery and water leaving radiance	4 km horizontal resolution, 24 h revisit time	Revisit time $<$ 24 h from 2027	Multispectral Radiometer (VIS/NIR) SAR

[a]GNSS-R capabilities proven experimentally from space [1]
[b]Requirements from World Meteorological Organization
[c]Requirements from Global Climate Observing System

This scoring method intends to assign lower score to the technologies that require a large instrument (large mass and large power consumption) and the technologies that present low data quality (low accuracy, low spatial resolution, and/or narrow coverage).

2. GAP ANALYSIS

The gap analysis has been based on planned future instruments of the European Union and cooperating institutions. Copernicus will utilize the following Earth observation instruments that can be used for sea ice monitoring: Synthetic Aperture Radar (SAR/Sentinel-1), Optical Sensors (SLSTR/Sentinel-3), SAR altimetry systems evolved from SIRAL on Cryosat-2 (SRAL/Sentinel-3), radar altimetry (Poseidon-4/Sentinel-6) and radiometers (MWR/Sentinel-3, AMR-C/Sentinel-6). Contributing institutions delivery complementary sea ice data through of future instruments, such as: SAR (SAR-X/PAZ, SAR-2000S.G./CSG, SAR-X/TSX-NG, SAR-X/HRWS-SAR), radar scatterometer (SCA/Metop-SG-B) and microwave radiometer (MWI/Metop-SG-B).

The following parameters have been studied for the future EO missions: revisit time, spatial resolution (provide high to coarse resolution imagery), swath and provide imagery in all-weather conditions and all-day. Based on the results of the gap analysis, the potential instrument technologies to ensure that the gap are covered were defined as shown in Fig. 1. In this regard, it is necessary to perform an in-depth review of the proposed instrument technologies: Microwave Radiometer, Radar Altimeter, SAR and Global Navigation Satellite System- reflectometry (GNSS-R).

3. SEA ICE INSTRUMENTS SURVEY

Microwave instruments have the advantage to provide imagery in all weather conditions either day or night. Most sensors used for oceanography (active microwave sensors: SAR and radar altimeter) have features such as high mass and high power consumption that make them difficult to implement on micro and nano-satellites, and they are expensive. GNSS reflectometry is a favorable potential new technique to perform some sea-ice measurements with small satellites [1]. GNSS-R constellation can significantly improve the temporal and spatial resolution for sea ice measurements. Operating at L-band, they suffer from less attenuation of the atmosphere as compared to other sensors that operate at higher frequencies (e.g. Ku- or K-bands).

Microwave radiometer instruments offer accurate data and wide swath (affordable for high revisit time) at spatial resolution (between 10 km to 25 km) that satisfies the require-

Table 2: Instrument technologies attributes and related numerical score

Instrument parameter	Numerical score			
(Relative weight)	**0**	**1**	**2**	**3**
Spatial Resolution	N/A	Worse than requirement	Equal to requirement	Better than requirement
Coverage	N/A	Narrow	Moderate	Wide
Accuracy	N/A	Worse than requirement	Equal to requirement	Better than requirement
Platform mass	N/A	Large	Mini	Between nano or micro
Payload power	N/A	>150 W	25-150 W	<25 W
Number of variables to measure	N/A	1 variable	2 or 3 variables	>3
Data relevance	N/A	Marginal	High	Primary

ments for sea ice monitoring (ice motion, sea ice type, sea ice thickness, sea ice cover and cocentration). They have been for decades within the range of tools for sea-ice monitoring to study dynamic large scale physical phenomena generated from brightness temperature, such as sea ice concentration, cover, thickness, type, age and motion. A survey of passive microwave instruments oriented towards sea ice observations in the past, and current update has been performed. Based on this survey technological capabilities (spatial resolution, waath, mass and power) are identified and suited for implementation on micro- to mini-satellite platforms.

SAR nadir altimetry (SIRAL-2 on CryoSat-2/SRAL on Sentinel-3) has demonstrated its unique capability to infer sea ice thickness by ice model from space with unprecedented accuracy. However, nadir looking altimeters do not provide a wide swath and therefore -for a single satellite- the spatial/temporal sampling of the Earth is limited by the usual trade-off between resolution versus revisit time. Constellations of small satellites embarking a compact SAR nadir altimeter [2] are a promising solution for observation of sea-ice thickness with high accuracy, while improving the temporal / spatial sampling and therefore closing the gap with current planned misiones. Though, the implementation on nano- platforms requires the suppression of some secondary payloads: such as the Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS), the GPS, the Laser Reflector Array (LRA) and the Microwave Radiometer (to correct for the path delay induced by water vapour). But, when combining the different reduction options, this concept of operations may partially degrade the quality of the measurements.

The main data from radar scaterometers is the sea surface wind speed and vector. It is also capable to infer sea-ice type, sea ice extent, snow water equivalent and snow cover measurements [3]. According to the survey, the power consumption of this sensor is in the range of 210 – 540 W, and mass in the range of 260 – 600 kg. According to the requirement of the power consumption, size and mass, this payload can be carryed over mini-platform or large satellites. For mini-platforms this sensor presents a narrow swath between 200 and 260 km.

SAR at high frequency bands could be feasible nowadays in small satellites. For example, NovaSAR-S is a novel platform for small synthetic aperture Radar (S-band) development by Surrey Satellite Technology LTD [2], with a satellite mass of 500 kg and peak power of 1.8 kW. The antenna is a microstrip patch phase array with size of 3 m x 1 m. If the frequency band is higher, it is possible to improve the spatial resolution and reduce the size and mass of the system. Another option is to adjust the spatial resolution to the requirements in order to obtain a wide swath of the SAR.

4. RESULTS AND CONCLUSION

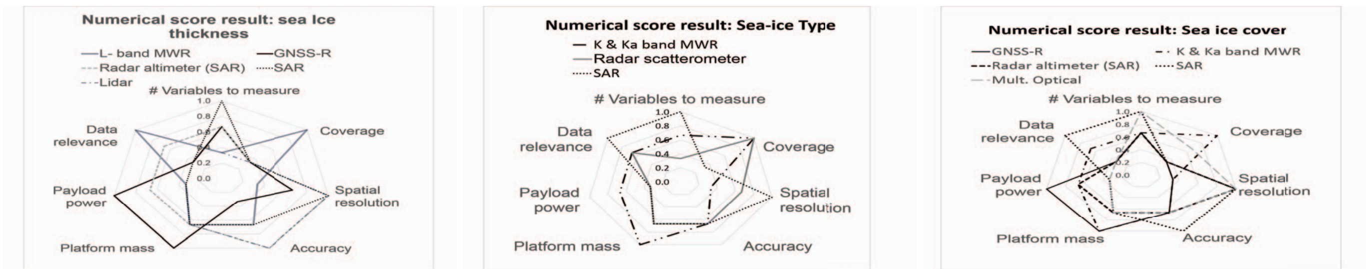
Based on the numerical score (see Table 2) and the variables with gaps, the technologies assessment is summarized as ”radar plots” and a histogram (see Fig. 2). This figure describes the main technologies for ensure that the gaps are covered for sea-ice measurements. According to the score obtained for the different technologies, in the horizon (2020-2030) Ka, K and L-bands radiometers, GNSS-R instruments and SARs will be required to ensure that all gaps in sea ice variables are properly covered.

K- and Ka- microwave radiometers mission must be focus in the derivation of the sea ice concentration, cover, and type parameters, the cloud liquid water, and the precipitation profile. The revisit time for the data obtained from this instrument can be improved with the data from L-band microwave radiometer and GNSS-R.

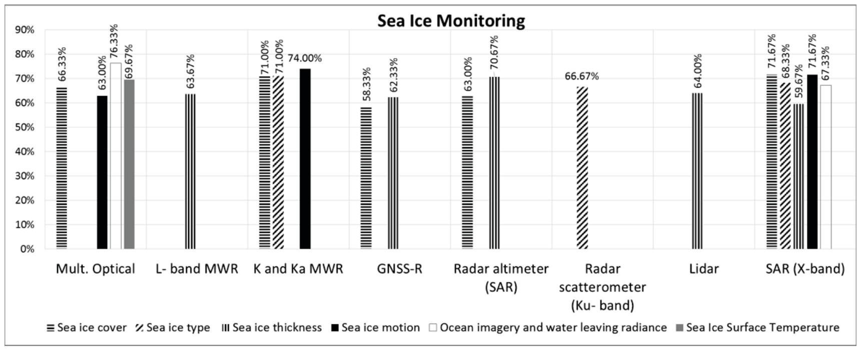
The histograms in Fig. 2 demonstrate the advantages of GNSS-R in terms of mass, power, spatial resolution and coverage, as compared to other technologies (according to the numerical score assigned in the analyses). GNSS-R is a miniature instrument that can satisfy the scientific requirements providing sea ice data through a constellation and potentially architecture on moderate size of “Cubesat” (> 6U) [4].

SAR altimeter constellation is a promising ”close gap” technique. Data fusion of L-band microwave radiometer satellite with the future GNSS-R constellation and SAR

[2]https://www.sstl.co.uk/Downloads/Brochures/115184-SSTL-NovaSAR-Brochure-high-res-no-trims



(a) Sea-ice thickness (b) Sea-ice type (c) Sea-ice cover



(d) Sea-ice: numerical score results.

Fig. 2: Variable with gaps in the horizon (2020-2030) analysed by the technologies capable to measure based on numerical score.

altimeter constellation provides wide spatial coverage and promises the most accurate determination of sea-ice thickness. Moreover, these constellations could also benefit to ocean / Hydrology applications which are also demanding for a better sampling of the Geophysical space / time variability.

In the future, SAR and SAR altimetry will contribute to sea ice type measurements. Federated Satellite System (FSS) concepts could also be applied to future constellations (taking into account different satellites program and space agencies).

This work identified three potential instrument technologies compatible with small platform (nano- to mini-) to ensure that the gaps detected based upon region polar coverage needs are covered.

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6. REFERENCES

[1] A. AlonsoArroyo, V. U. Zavorotny, and A. Camps, “Sea ice detection using GNSS-R data from UK TDS-1,” in *2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, July 2016, pp. 2001–2004.

[2] J. Richard, V. Enjolras, L. Rys, J. Vallon, I. Nann, and P. Escudier, “Space altimetry from nano-satellites : Payload feasibility, missions and system performances,” in *IGARSS 2008 - 2008 IEEE International Geoscience and Remote Sensing Symposium*, July 2008, vol. 3, pp. III – 71–III – 74.

[3] M. Belmonte-Rivas, J. Verspeek, A. Verhoef, and A. Stoffelen, “Bayesian sea ice detection with the advanced scatterometer ASCAT,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 50, no. 7 PART1, pp. 2649–2657, 2012.

[4] C. S. Ruf, S. Gleason, Z. Jelenak, S. Katzberg, A. Ridley, R. Rose, J. Scherrer, and V. Zavorotny, “The CYGNSS nanosatellite constellation hurricane mission,” in *International Geoscience and Remote Sensing Symposium (IGARSS)*, 2012, pp. 214–216.