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Authors:

Bin Cheng[1], Ruibo Lei[2], Zhongxiang Tian[2] and Roberta Pirazzini[1]

[1] Finnish Meteorological Institute (FMI), Helsinki, Finland
[2] Polar Research Institute of China (PRIC), Shanghai, China
[3] National Marine Environmental Forecasting Centre (NMEFC), Beijing China

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PU	Public, fully open	**X**
CO	Confidential, restricted under conditions set out in Model Grant Agreement	
CI	Classified, information as referred to in Commission Decision 2001/844/EC	

EXECUTIVE SUMMARY

Snow depth and ice thickness in the Arctic Ocean directly result from air-sea ice-ocean interaction and their observational data are essential components of the iAOS. During INTAROS, an innovative and cost-cutting design thermistor string-based snow and ice mass balance apparatus (SIMBA) has been largely deployed in the Arctic Ocean to measure time series of high-resolution vertical temperature profiles through air-snow-sea ice-ocean, and snow depth and ice thickness are derived from SIMBA temperatures.

This document, ***Deliverable 6.21* - Sea ice and snow thickness from SIMBA buoy experiments** summarizes the SIMBA deployment during the INTAROS period. The SIMBA data characteristics and how to derive snow depth and ice thickness from temperature are described. The results from manual analyses and automatic algorithms are compared to each other. We have summarized a few process studies using SIMBA data. The data provided by SIMBA experiments are not only valuable for remote sensing applications but also important to better understand air-sea ice-ocean interactions as well as for process modelling studies. The accessibility to data and repositories of SIMBA data is concluded.

The further exploitation of SIMBA observation as well as how it can possibly be used as a component of the sustainable iAOS are discussed. The document is intended to provide a summary of SIMBA operation in the high-Arctic regions and how the SIMBA data can be used for scientific research and for future operation service and sea ice management.

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1. Introduction

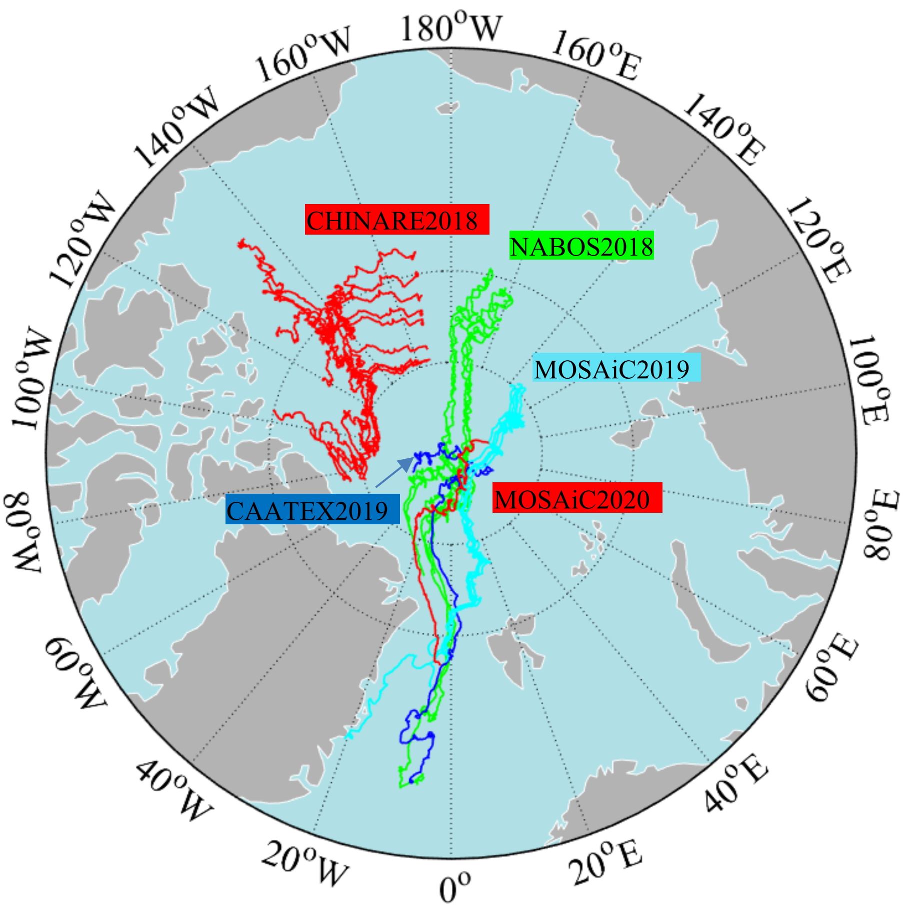
The Arctic snow and sea ice mass balance is critical component of the earth cryosphere. The most important thermodynamic processes are the sea ice freezing-up, bottom evolution, surface melting, sea ice breakup, as well as snow to ice transformation. Those processes are direct results of air-ice-ocean interactions. During INTAROS period (2017 - 2021), several high-profile Arctic field campaigns have been carried out. Snow and ice mass balance apparatus (SIMBA) have been deployed in various part of the Arctic Ocean on undeformed ice floes to measure time series of vertical temperature along air-snow-ice-ocean. The snow and ice thickness have been derived from the SIMBA temperature profiles.

In this deliverable, we report SIMBA buoy experiments. The deployment of SIMBA during INTAROS period is first summarized. The SIMBA data description and analyses are briefly introduced. Several case studies are concluded followed by Accessibility to the SIMBA data. The further exploitation and sustenable SIMBA network, as well as utilization of SIMBA products by the societies are concluded.

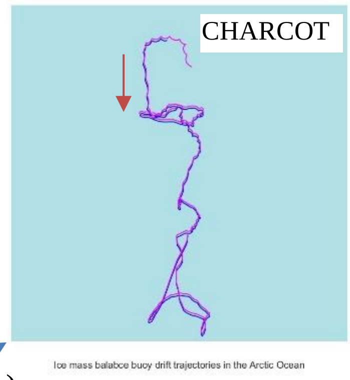
2. Arctic SIMBA deployment

The majority of SIMBA deployment during INTAROS period can be seem in Figure 1a, where several international field programs were carried out.

a)



CHINARE: Chinese National Arctic Research Expedition.
NABOS: Nansen and Amundsen Basins Observational System.
CAATEX: Coordinated Arctic Acoustic Thermometry Experiment.
MOSAiC: The Multidisciplinary drifting Observatory for the Study of Arctic Climate expedition.



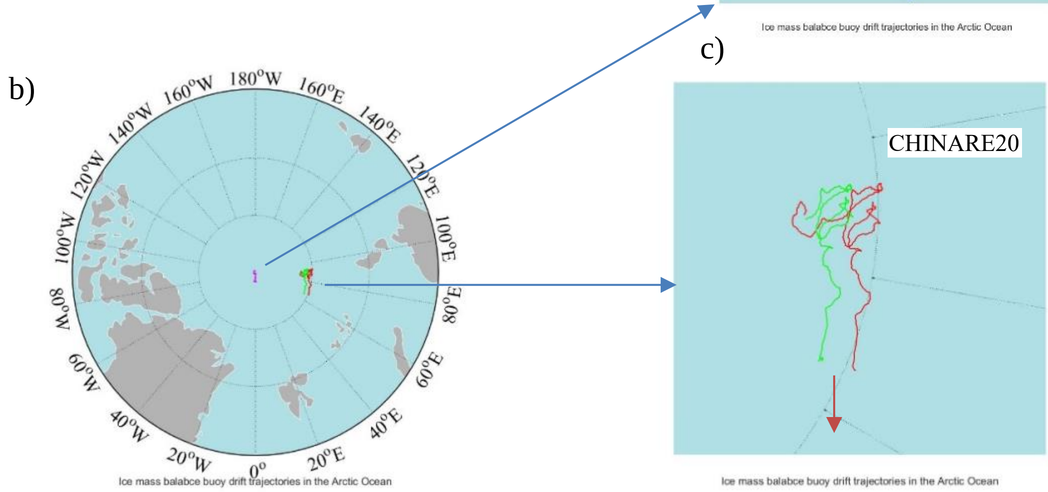


Figure 1. a) Trajectories of SIMBAs deployed in the Arctic in the period 2018 - 2020. The total numbers of SIMBA deployed in each field campaign are: 11 buoys by the CHINARE2018; 5 buoys by the NABOS2018; 2 buoys by the CAATEX2019, 15 buoys by the MOSAiC-leg1 in 2019, and 4 buoys by the MOASiC-leg5 in 2020. All the SIMBA deployed during this period have been terminated. b) 4 SIMBAs have been deployed in the latest field program in 2021 by the CHARCOT test cruise (deployment of 2 SIMBAs were carried out by the NERSC scientists) and by the CHINARE2021 (2 buoys), c) Zoomed-in view of 2021 SIMBA trajectories. The two SIMBAs deployed during CHARCOT test cruise were on the same ice floe with 1 km distance. The arrows showed the ice drift direction. The drift trajectories started in early August/September for CHINARE2021/ CHARCOT, respectively. The SIMBA trajectories were plotted until 22 October 2021. Those SIMBAs are still functioning well.

Figure 2. a) SIMBA (FMI0703) deployed during CHARCOT test cruise at the North Pole on 8 September. The ice thickness was 1.8 m, and the snow was 10 cm. b) SIMBA (PRIC1101) deployed on 10 August. The snow and ice thickness were 0.05m and 1.4m, respectively. Photo a) by Hanne Sagen from NERSC, b) by Mengxi Zhai from PRIC.

Examples of SIMBA sites during CHARCOT test run cruise and CHINARE2021 are illustrated in Figure 2. The spatial difference of ice thickness between those two sits was about 0.4 m.

In addition to SIMBAs, a new prototype Unmanned Ice Station (UIS) was deployed during CHINARE2021. This activity, as in-kind contribution, was implemented by the INTAROS's Chinese partners PRIC and NMEFC, respectively. UIS was designed and manufactured by PRIC. It consists of two separate ice and ocean components (Fig.3). Three UIS ice units were deployed during CHINARE2021 by NMEFC (Fig. 4).

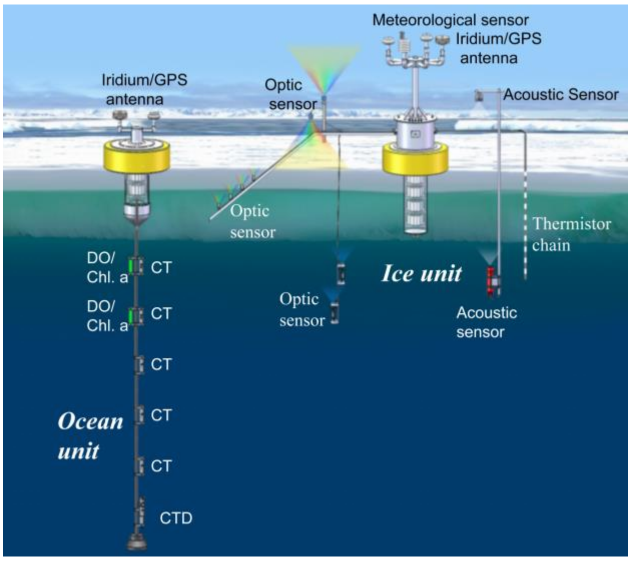


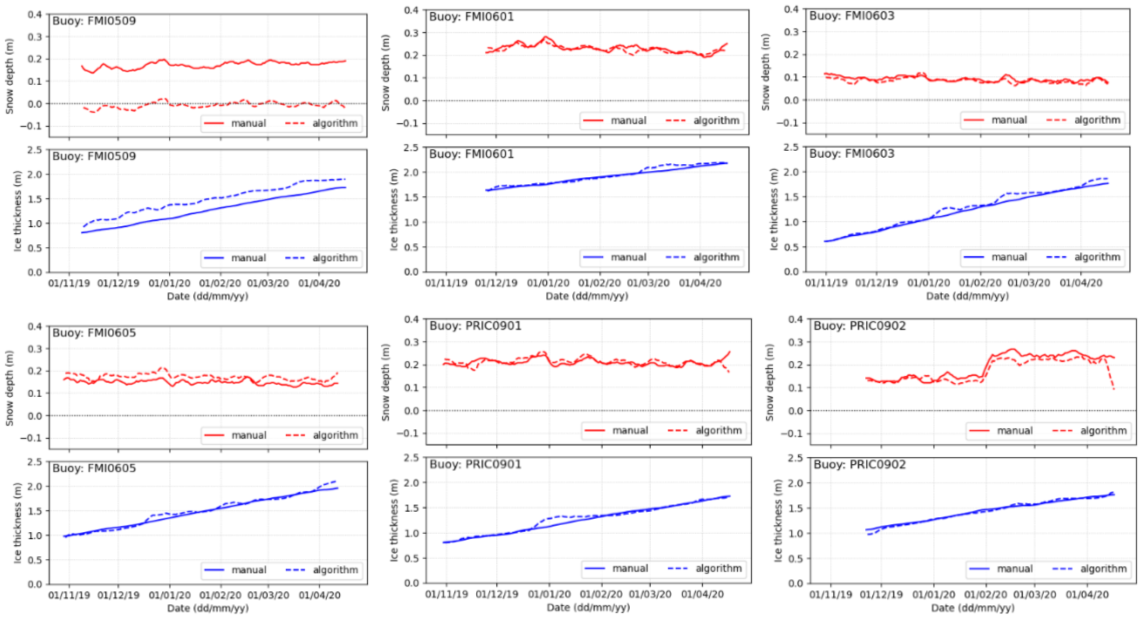
Figure 3. Schematic illustration of the Unmanned Ice Station (UIS). The ocean unit measures, sea water conductivity, temperature, pressure, CTD), dissolved oxygen, and Chlorophyll-a fluorescence. The ice unit measures vertical temperature profile along air-snow-ice-ocean, near surface air temperature, relative humidity, as well as barometric pressure. Optical sensors measure the spectral albedo and transmittance of the ice (additional option). The Acoustic Rangefinder Sounders (ARS) was used to measure the evolution of surface and ice bottom for snow and ice thickness. A full set of UIS was deployed during MOSAiC (Figure is from Lei et al., 2021).

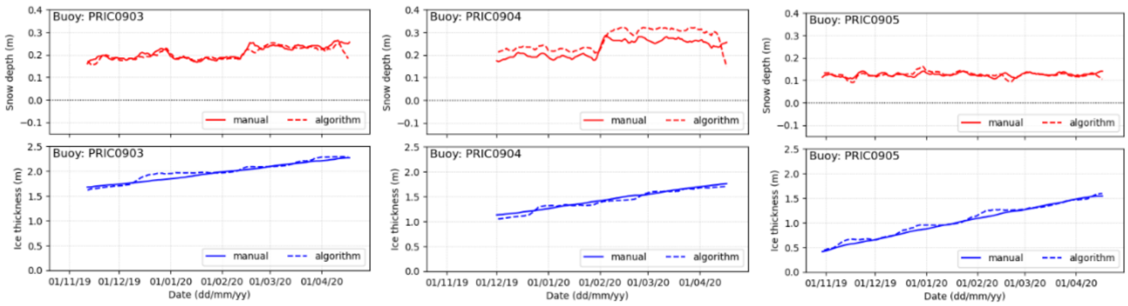
Figure 4. The UIS ice units were deployed during CHINARE2021 Arctic bathymetry survey expedition. The UIS as well as SIMBAs were deployed along the Gakkel ridge in the Arctic bason between 9 - 20 September. The ice thickness along the UIS sites were between 1.1 m and 2.2 m, the snow thickness ranged between 0.05 m - 0.1 m comparable to the values at CHARCORdry test cruise deployment sites. Photo by Zhongxiang Tian from NMEFC.

3. SIMBA data description and analyses

The environment temperature (SIMBA-ET) profiles were measured using a thermistor string equipped with 240 thermistor sensors. The sensors were distributed every 2 cm. The observations were made every 6-hours. Additionally, SIMBA recorded the heating temperature (SIMBA-HT) rise applying identical heat pulse on each thermistor sensor for a short period from 30s up to 120 s, upon configurations (Jackson et al., 2013). Both SIMBA-ET and SIMBA-HT can be used to identify air-snow, snow-ice and ice-ocean interfaces based on differentiation of thermal properties of observed air, snow, sea ice and water (Hoppmann, 2015, Provost et al., 2017). Totally, there were 44 SIMBAs have been deployed during the INTAROS period. Based on temperature readings, the air/snow, snow/ice and ice/ocean interfaces can be identified by either manual inspection (e.g., Lei et al., 2018) or algorithms (Liao, et al., 2019, Cheng et al., 2020), thereby , the snow and ice thickness can be obtained. Manual SIMBA data analyses are still largely used by individual SIMBA customers. In a long run, however, SIMBA algorithm maybe more effective, especially for SIMBA operational applications.

We have compared manual and algorithm derived snow and ice thickness from SIMBA data (Fig. 5). Those SIMBAs were deployed during MOASiC leg 1. The deployment sites revealed large variety of surface status. The initial snow and ice thicknesses ranged from 0.05 m - 0.30 m and 0.4 m -1.70 m, respectively. All of the buoys were deployed on the undeformed sea ice floes. We can see from the figure (5) below that manual and algorithm derived snow and ice thickness agreed quite well in most cases. However, there are large discrepancy, i.e., SIMBA FMI0509 (snow and ice), PRIC0904 (snow), the exact reason for such big difference remains unknown and need further investigation. The difference seems larger for snow compared with that for sea ice. The variability of snow and ice thickness derived by both method follows to each other.





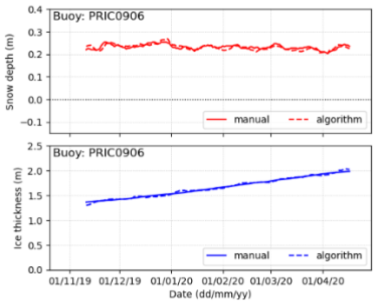


Figure 5. Comparison of snow and ice thickness derived from SIMBA temperature profiles manually and automatically. Those SIMBAs were deployed during MOSAiC leg 1. The analyses were restricted to the ice growth season.

The SIMBA-HT temperature is more illustrative to identify ice bottom evolution. Figure 6 shows the SIMBA-HT and SIMBA-ET regimes and manual and algorithm identified snow and ice thickness. We can see that algorithm follows quite well the freeze-up of the ice bottom, including closure (freezing up) of the borehole where SIMBA thermistor string was placed in. The closure of the borehole depends largely on the initial ice condition, timing of SIMBA deployment and the location of the deployment. The freezing-up of the borehole may last from weeks to months. A detail investigation of this process is under construction. The motivation is to understand how the ice interacts with the surrounding ocean water.

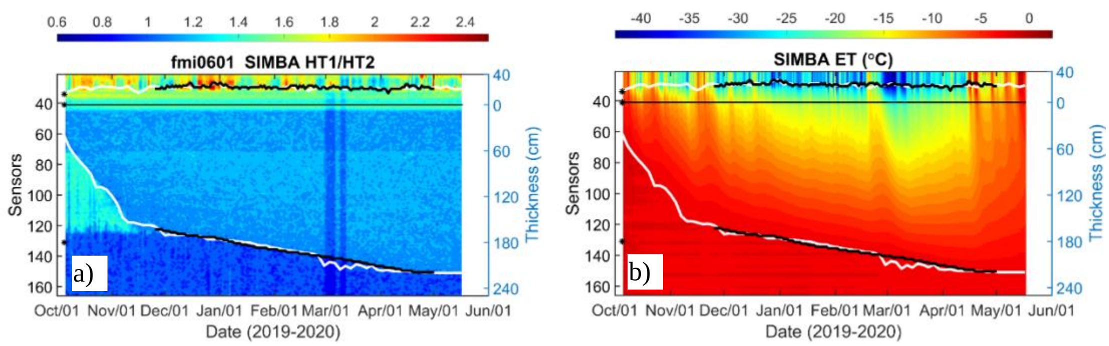


Figure 6. a) Time series of the SIMBA-HT profiles. b) Time series of the SIMBA-ET profiles. The white lines are results from the SIMBA algorithm and the black lines are results from the manual processing. This SIMBA was deployed during MOSAiC leg 1. The closure of the borehole was marked by the yellow circle.

A paper entitled "Ice-ocean interface detection from SIMBA-HT data applying neural networks (NEN), wavelet analyses (WAA) and Kalman filter (KAF) is under final preparation. An accurate detection of ice evolution at ice bottom can be used to estimate time dependent ocean heat flux, a parameter that is largely constant value for sea ice thermodynamic models. Figure 7 show the ice bottom detection by this new method (Liao et al., 2021). Table 1 gives the comparison between manual and new algorithm-based ice bottom detection.

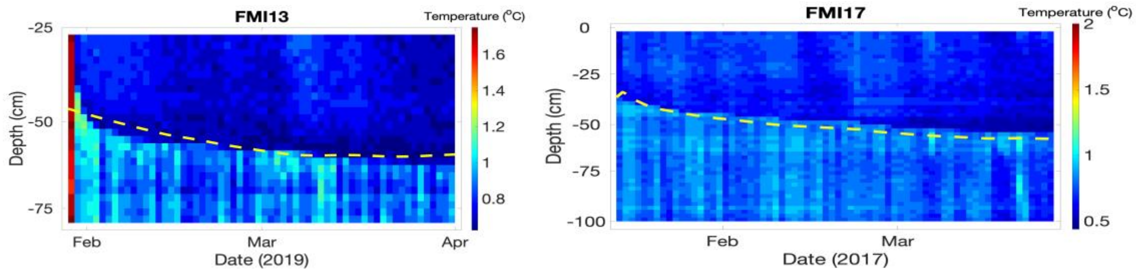


Figure 7. The new algorithm derived ice bottom evolution (yellow broken line) and SIMBA-HT observation (Figure from Liao et al., 2021).

Table 1. Statistical analyses between manual and algorithm retrieved sea ice thickness (cm) for two SIMBAs (Table from Liao et al., 2021)

	Mean Value		Standard Deviation		Bias	RMSE	Corr.
	Manual	N-W-K	Manual	N-W-K			
FMI13	56.6	55.3	4.8	4.4	-1.3	6.7	0.88
FMI17	51.8	54.3	5.1	6.4	2.4	8.8	0.98

4. Case studies

Sea ice evolution is a critical process representing the air-sea ice-ocean interactions as well as snow-ice interaction in the Arctic climate system. Sea ice evolution can be split further into several processes at air-snow, snow-ice, and ice-ocean interfaces. SIMBA high resolution vertical temperature as well SIMBA snow and ice thickness data can be used to better understand the seasonality of sea ice evolution and timing of snow and when the ice processes occurred at interfaces.

We have carried out a study to investigate snow and ice mass balance along the Arctic Transpolar Drift (TPD) and interaction between ice and the oceanic mixed layer using SIMBA data obtained from MOSAiC annual campaign. The study was led by the INTAROS Chinese partner Dr. Ruibo Lei from PRIC and has been submitted to the Elementa: Science of the Anthropocene (Lei et al., 2021). In this study we found that unusually high air pressure gradients perpendicular to the TPD resulted in rapid advection of sea ice from the central Arctic Ocean to the Fram Strait. Sea ice basal growth commenced between 14 October and 8 December 2019, mainly depending on the initial ice thickness, and stagnated between 29 April and 31 May 2020. The net ice basal growth ranged from 0.64 to 1.38 m, with an average growth rate of 0.4 – 0.6 cm/d. Storm events led to a decrease in ice growth rate by bringing higher air temperatures, snowfall, and increased oceanic upward mixing. Ice freezing from the top caused by surface flooding and subsequent snow-ice formation was observed at two sites and was likely linked to dynamic processes. Snow accumulation was intermittent and generally related to synoptic events. Snow depth reached a maximum of 0.25 ± 0.08 m by 2 May 2020 and had melted completely by 25 June 2020. Surface melting dominated in the early melt season between May and mid-July. Under-ice ponds were common starting in mid-June, mainly due to increases in ice permeability. Ice basal melt increased rapidly in mid-July due to an increased oceanic heat flux caused by a combination of more solar radiation absorbed in the ocean with an enhanced ice motion and oceanic upward mixing close to the Fram Strait. Figure 8 illustrates the snow and ice thickness evolution observed by 8 SIMBAs deployed during MOSAiC leg 1.

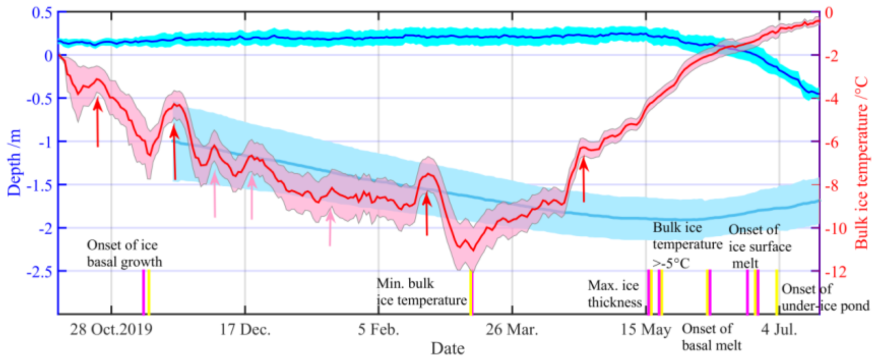


Figure 8. Time series of averages (solid line) and standard deviations (shade) of snow depth (bright cyan), ice bottom (dark cyan), and bulk ice temperature (red) obtained from 8 long-lasting buoys. The ice bottom is only plotted after all these buoys have been deployed because of the large difference in ice thickness among the sites. The light-red and dark-red arrows denote episodic increases of bulk ice temperature associated with synoptic weather systems. The purple and yellow vertical lines denote the timing of several events described within the figure frame. (Figure from Lei et al., 2021)

In addition to the snow and ice process studies, SIMBA data have been used to better understand the ice thickness distributions with respect to the thermodynamic and dynamic contributions. One case study focused on estimation sea ice growth in the Central Arctic using ICESat-2 and MOSAiC SIMBA buoy data (Koo et al., 2021). In this study, SIMBA data was used to estimate thermodynamic ice growth during winter season whereas the ICESat-2 (IS2) satellite altimeter data was used to monitor the dynamics of sea ice thickness e.g., ridges and leads.

SIMBA data was also used to assess the thermodynamic and dynamic contributions on seasonal Arctic Sea ice thickness distributions from airborne observations (von Albedyll, et al., 2021).

The SIMBA data obtained from MOSAiC leg 5 are used to elevation difference between CryoSat-2 (Ku-band) and IceSat-2 (Laser) within the framework of the CRYO2ICE (Fig. 9). We analyzed 2 SIMBAs data and compared SIMBA snow and ice thickness with remote sensing products and Warren et al. (1999) (W99) climatological distribution. The preliminary result indicated that the remote sensing snow depth and W99 snow climatological distribution are comparable to one SIMBA observation but differ considerable from another SIMBA observation. The SIMBA initial onsite condition may play an important role.

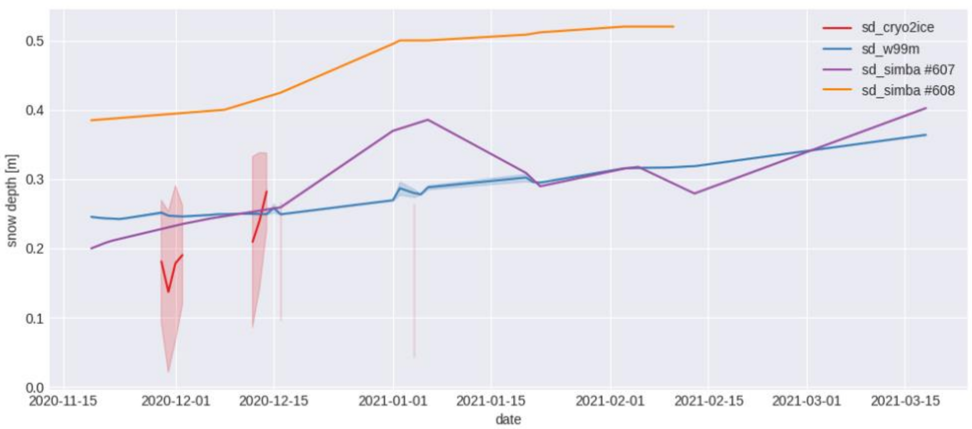


Figure 9. Snow depth (sd) derived from SIMBAs, W99 climatological distribution and CRYO2ICE remote sensing mission products. SIMBA 0608 was initially deployed on a melt pond of 0.26 m. The pond depth offset may need to be removed from the total snow depth.

The modelling of snow and sea ice mass balance is underway along SIMBA drift trajectories for better understanding the effect of atmosphere and ocean on sea ice during extreme, such as storm events as well as to understand snow and ice mass balance in various part of the Arctic Ocean and to look how spatial and temporal atmosphere and ocean boundary conditions will affect snow/ice mass balance and vice versa. This modelling work (Fig. 10) is part of a scientific paper we are currently work with.

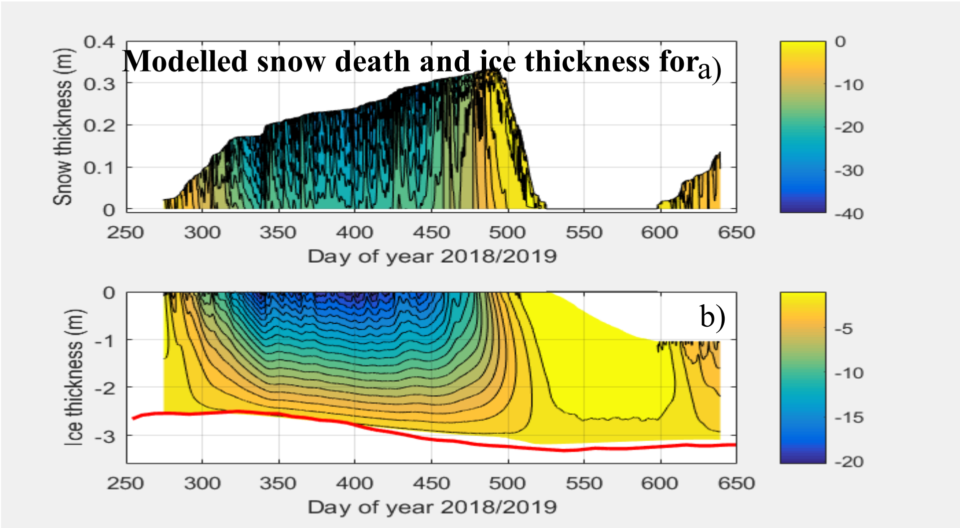


Figure. 10. HIGHTSI modelled snow depth(a) and ice thickness (b) and temperature field. The red lines are SIMBA observed ice thickness. FMI0504r was deployed during NABOS2018

5. Accessibility to data and repositories used

The original time series of the SIMBA-ET, SIMBA-HT, GPS position were archived in the data server of the SIMBA manufacturer SAMS under secured password required weblink for each customer. Some of the SIMBAs deployed during NABOS and MOSAiC were processed and archived at https://www.meereisportal.de/. Due to different data policy of different international Arctic field expeditions, it is not possibly yet to establish a universal SIMBA data pratol platform. However, several INTAROS partners (FMI, PRIC and NMEFC) have agreed to accesses and share their SAMS SIMBA customer data webpage. The SIMBA deployed by those partners will be registered in the INTAROS Data Catalog https://catalog-intaros.nersc.no/

The SIMBA raw data are standard excel sheets files. The SIMBA-ET and SIMBA-HT are temperature data in Celsius degree and GPS position are digitized as lat/lon numbers with 5 decimals. The accuracy of SIMBA temperature sensor and GPS position were ± 0.1 °C and 2m, respectively.

We are currently working on upload of the SIMBA data into https://zenodo.org/deposit. An Arctic Lake SIMBA observation data set acted as a spin-off and parallel to the INTAROS SIMBA activity has been registered in the zenodo. https://zenodo.org/record/4559368#.YIKOOpAzZPZ (Cheng et al, 2021). Similar work is under construction to archive for Arctic SIMBA data.

The SIMBA data registered in the INTAROS Data Catalog https://catalog-intaros.nersc.no/ will be freely available for the society.

6. Exploitation

It seems to be no major international Arctic field campaign in the near future. However, some small-scale Arctic field program have been planned. The Young Sound SIMBA deployment will be carried in late autumn 2021. We plan to deploy one SIMBA together with several underwater instrument (measuring light, salinity, temperature, etc.). A digital camera system will be installed on land taking daily images. Several land weather-stations will measure energy flux, temperature and snow metrics on land (coverage, melt and thickness). This field work in coordinated by the Arctic Research Centre (ARC), Aarhus University, Denmark.

SIMBA has been previously deployed outside Bolshevik Island in Russia Arctic as part of Finnish-Russia collaborations under the umbrella of the Pan-Eurasian Experiment (PEEX) program. There have been discussions to continue SIMBA measurement as expansion of the PEEX marine component. The SIMBA measurement maybe established at new Russia polar station at Severnaya Zemlya.

In addition to various SIMBA deployment in the Arctic Ocean, FMI has operated a long-term sustainable Arctic Lake SIMBA program in the Finnish Lapland. We deployed one SIMBA in lake Orajärvi every winter season since 2009. The data has been used to develop SIMBA algorithm (Cheng et al., 2020) and to study snow and ice interactions. This SIMBA program can be regarded as a spin-off of INTAROS SIMBA activity. One SIMBA has been deployed few weeks ago (13, October) on a raft anchored in the lake targeting 2021/2022 full ice season observation including freezing up and breakup process.

The CHINARE program as well as AWI's TRANSDRIFT/TICE cruise are sustainable Arctic expedition platforms that can be used for SIMBA deployment in the future.

During INTAROS period, at least 44 SIMBA ice mass balance buoys have been deployed in the Arctic Ocean. This achievement is 4 times more than INTAROS has initial promised. Thanks for various international collaborations, in particular the involvement of Chinese partners in the INTAROS. SIMBA system is proved to be a reliable and robust observation platform. Several studies based on SIMBA data have been carried out and some more are still coming. The topics are focused on snow and ice physics, seasonal dynamics, and thermodynamics, as well as remote sensing and processing modelling.

7. Contribution to the Sustainable Arctic Observing System

SIMBA data from high profile field campaigns are valuable for scientific research as well as development of operational marine weather forecasting system for the Arctic Ocean. However, long term sustainable SIMBA network would be even more valuable not only for research but also can be used as a subcomponent of an integrated Arctic Observation System. Snow and ice thickness along Arctic Northeast Passage (ANP) is of great important for the commercial shipping industry. The COSCO (China Ocean Shipping Company, Limited) has operated cargo transportation along ANP during summer for several years (Fig. 11).

Figure 11. a) COSCO cargo escorted by the Russia ice breaker Taymyr through the East Kara Sea in July 2021. b) The COSCO cargo navigation route in the Kara Sea.

So far, we have not been able to deploy SIMBA buoys in the Kara Sea. However, stakeholders and users, such as COSCO is very keen to have operational snow and ice service along the ANP. They will benefit from SIMBA observations, although ANP navigations so far have been restricted during ice free season. In a long run, the Kara Sea ice parameter estimation based on thermodynamic ice model and earth observation data would be valuable for ice service and management.

References (papers published, submitted or in preparation)

Published

Koo, Y., Lei, R., Cheng, Y., Cheng, B., Xie, H., Hoppmann, M., Kurtz, N.T., Ackley, S. F and Mestas-Nuñez, A.M 2021. Estimation of Thermodynamic and Dynamic Contributions to Sea Ice Growth in the Central Arctic Using ICESat-2 and MOSAiC SIMBA Buoy Data. Remote Sensing of Environment, Vol. 267, https://doi.org/10.1016/j.rse.2021.112730.

Lei, R., Hoppmann, M., Cheng, B., Zuo, G., Gui, D., Cai, Q., Belter, H. J., and Yang, W. 2021 Seasonal changes in sea ice kinematics and deformation in the Pacific Sector of the Arctic Ocean in 2018/19, The Cryosphere, 15, 1321–1341, https://doi.org/10.5194/tc-15-1321-2021

Cheng, B., Cheng, Y., Vihma, T., Kontu, A., Zheng, F., Lemmetyinen, J., Qiu, Y., and Pulliainen, J. 2021. Inter-annual variation in lake ice composition in the European Arctic: observations based on high-resolution thermistor strings, Earth Syst. Sci. Data, 13, 3967–3978, https://doi.org/10.5194/essd-13-3967-2021

Zhai, M., Cheng, B., Leppäranta, M., Hui, F., Li, X., Demchev, D., Lei, R. and Cheng, X. 2021. Seasonal cycle and breakup of landfast sea ice along the west coast of Kotelny Island, East Siberian Sea. Journal of Glaciology. Journal of Glaciology 1–13. https://doi.org/10.1017/ jog.2021.85.

Submitted

von Albedyll, L., Belter, H.J., Grodofzig, R., Hendricks, S., Krumpen, T., Suhrhoff, M., Arndt, S., Cheng, B., Birnbaum, G., Hoppmann, M., Hutchings, J., Itkin, P., Lei, R., Nicolaus, M., Ricker, R., Rohde, J., Timofeeva, A., Watkins, D., Webster, M and Haas, C. 2021. Thermodynamic and dynamic contributions to Arctic sea ice thickness distributions over the seasonal cycle from airborne observations. Submitted to Elementa: Science of the Anthropocene.

Nicolaus, M., ... Cheng, B., (15) ..., et al., (total 105 authors), 2021. Overview of the MOSAiC expedition – Snow and Sea Ice. Submitted to Elementa: Science of the Anthropocene.

Lei, R., Cheng, B., Hoppmann, M., Zhang, F., Zuo, G., Hutchings, J.K., Lin, L., Lan, M., Wang, H., Regnery, J., Krumpen, T., Haapala, J., Rabe, B., Perovich, D.K. and Nicolaus, M. 2021. Seasonality and timing of sea ice mass balance and heat fluxes in the Arctic Transpolar Drift during 2019/20 Submitted to Elementa: Science of the Anthropocene.

In preparation:
Liao, Z., Cheng, B., Jiang, Y., Cheng, Y. and Chen, X. 2021 Ice-ocean interface detection from SIMBA HT data applying neural networks (NEN), wavelet analyses (WAA) and Kalman filter (KAF). To be submitted to Remote Sensing
Cheng, B., et al., SIMBA data paper (ESSD)
Cheng, B., et al., Modelling snow and ice thickness along SIMBA sites.
Cheng, B., et al., The role of ocean heat flux in the growth and melting of sea ice at SIMBA sites.
Karvonen et al., Kara Sea ice parameter estimation based on thermodynamic ice model and earth observation data"

8. References

Cheng, Y., Cheng, B., Zheng, F., Vihma, T., Kontu, A., Yang, Q. and Liao, Z. 2020. Air/snow, snow/ice and ice/water interfaces detection from high-resolution vertical temperature profiles measured by ice mass-balance buoys on an Arctic lake. Annals of Glaciology 1–11. https://doi.org/10.1017/ aog.2020.51

Cheng, B., Cheng, Y., Vihma, T., Kontu, A., Zheng, F., Lemmetyinen, J., Qiu, Y., and Pulliainen, J. 2021. Inter-annual variation in lake ice composition in the European Arctic: observations based on high-resolution thermistor strings, Earth Syst. Sci. Data, 13, 3967–3978, https://doi.org/10.5194/essd-13-3967-2021.

Hoppmann M and 6 others (2015) Seasonal evolution of an ice-shelf influenced fast-ice regime, derived from an autonomous thermistor chain. Journal of Geophysical Research: Oceans 120(3), 1703–1724.

Jackson K and 6 others (2013) A novel and low-cost sea ice mass balance buoy. Journal of Atmospheric and Oceanic Technology 30(11), 2676–2688.

Liao, Z., Cheng, B., Zhao, J., Vihma, T., Jackson, K., Yang, Q., Yang, Y., Zhang, L., Li, Z. Qiu, Y. and Cheng, X. 2019 "Snow depth and ice thickness derived from SIMBA ice mass balance buoy data using an automated algorithm" International Journal of Digital Earth, 12:8, 962-979, DOI: 10.1080/17538947.2018.1545877.

Lei, R., Cheng, B., Heil, P., Vihma, T., Wang, J., Ji, Q. and Zhang, Z. 2018. Seasonal evolution of sea ice mass balance from the central Arctic Ocean to the Greenland Sea. Journal of Geophysical Research: Oceans, 123, 2422–2439. https://doi.org/10.1002/

Provost C and 7 others (2017) Observations of flooding and snow-ice formation in a thinner Arctic sea-ice regime during the N-ICE2015 campaign: influence of basal ice melt and storms. Journal of Geophysical Research: Oceans 122(9), 7115–7134.

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