Supplemental material to

Snow Depth and Air Temperature Seasonality on Sea Ice Derived From Snow Buoy Measurements

1. Overview of Snow Buoy network on Arctic and Antarctic sea ice

Figure S1 and Table S1 present an overview of the operational period of all buoys. Drift trajectories of all buoys are shown in Figure 3 and in more detail in Figures S4, S5, and S6.

Table S1. Summary of all Snow Buoys with their IMEI number and WMO identifier (ID), their region of deployment and lifetimes. Figure S1 also illustrates the measurement period for each buoy. Missing stop dates indicate ongoing activity (status: 15 September 2019). Drift trajectories of all buoys are shown in Figure 3. * Buoys were re-deployed after recovery; hence these IMEI numbers is listed twice with different names. ** Buoys were recovered from the ice.

Name	**IMEI number**	**WMO ID**	**Region**	**Date Start** (dd.mm.yy)	**Date Stop** (dd.mm.yy)	**Duration** (days)
2013S1	300234011691900		Neumayer III	11.02.13	**29.04.13	78
2013S2	300234011695900		Neumayer III	11.02.13	**12.07.17	1612
2013S3	300234011696880		Arctic Ocean	09.04.13	13.06.13	66
2013S4	300234011699880		Alaska	15.03.13	**28.06.13	106
2013S6	300234060540730		Weddell Sea	24.06.13	27.09.13	96
2013S7	300234060540780		Weddell Sea	06.07.13	13.09.13	70
2013S8	300234060540740		Weddell Sea	09.07.13	05.01.14	181
2014S9	300234060376490		Weddell Sea	05.02.14	02.10.15	605
2014S10	300234060541850		Weddell Sea	13.01.14	03.12.16	1056
2014S11	300234060545700		Weddell Sea	29.01.14	02.06.15	490
2014S12	300234060543780		Weddell Sea	17.01.14	02.02.16	747
2014S13	300234061610020		Arctic Ocean	30.03.14	20.07.14	113
2014S14	300234061610030		Arctic Ocean	01.04.14	16.12.15	625
2014S15	300234061519990		Arctic Ocean	29.08.14	31.12.14	125
2015S16	300234062428050	6400973	Arctic Ocean	19.09.15	20.12.16	459
2014S17	300234062424020	7100236	Weddell Sea	20.12.14	01.02.15	43
2015S18	300234062324760	7100237	Weddell Sea	03.01.15	18.01.15	16
2015S19	300234062422060	7100238	Weddell Sea	03.01.15	15.07.15	194
2015S20	300234062328760	6400974	Arctic Ocean	14.09.15	19.04.16	219
2015S21	300234062423070	6400975	Arctic Ocean	25.09.15	10.08.16	321
2015S22	300234062424060	6400471	Fram Strait	01.03.15	06.05.15	67
2015S23	300234062426060	6400472	Fram Strait	20.04.15	11.06.15	53
2014S24	300234011691900*		Neumayer III	07.03.14	16.05.14	71
2014S25	300234011699880*		Alaska	28.09.14	27.08.15	334
2015S26	300234062311650		Fram Strait	05.02.15	**21.02.15	17
2015S27	300234062311650*		Fram Strait	23.04.15	09.06.15	48
2015S28	300234062426150		Fram Strait	21.04.15	11.06.15	52
2015S29	300234062788470	6400976	Arctic Ocean	22.09.15	**16.10.16	386
2015S30	300234062789420	6400477	Arctic Ocean	12.09.15	14.02.16	156
2016S31	300234062789480	7100750	Weddell Sea	16.01.16	25.01.17	376
2015S32	300234062782480	6400748	Arctic Ocean	10.09.15	28.04.16	232
2015S33	300234062784540	6400749	Arctic Ocean	07.09.15	**08.08.16	337

2015S35	300234062785480	64751	Arctic Ocean	10.09.15	11.02.16	155
2016S36	300234062788480	2600568	Arctic Ocean	15.09.16	25.08.17	344
2016S37	300234062789460	7100752	Weddell Sea	18.01.16	24.12.16	347
2016S38	300234062783480	7100751	Weddell Sea	15.01.16	08.05.17	479
2015S39	300234062781450	7100254	Weddell Sea	23.12.15	13.02.16	53
2016S40	300234062780540	7100755	Weddell Sea	25.01.16	14.09.16	234
2015S41	300234062786180	7100756	Weddell Sea	30.12.15	11.04.16	104
2015S42	300234062782210	7100757	Weddell Sea	26.12.15	04.05.16	131
2017S43	300234063800160	6400777	Svalbard	09.03.17	02.05.17	54
2016S44	300234064010010	2600565	Arctic Ocean	06.10.16	05.06.17	242
2016S45	300234064011000	2600566	Arctic Ocean	21.09.16	**31.05.17	252
2016S46	300234064015020	2600567	Arctic Ocean	17.09.16	26.01.17	132
2017S47	300234064016010	7100759	Weddell Sea	10.01.17	11.01.17	2
2017S48	300234064116480	7100758	Atka Bay	05.01.17	14.03.17	69
2017S49	300234064500580	7101550	Atka Bay	30.05.17	02.10.17	125
2016S50	300234063227960	2600571	Arctic Ocean	02.10.16	23.05.17	233
2017S51	300234062788470*	6400976	Arctic Ocean	25.03.17	**17.04.17	23
2017S52	300234064770050	6400776	Arctic Ocean	18.04.17	22.04.17	5
2017S53	300234065725000	6401650	Arctic Ocean	07.06.17	*12.07.17	35
2017S54	300234011695900*		Neumayer III	11.08.17		
2018S56	300234065741820		Neumayer III	10.06.18		
2018S57	300234065169560	7101551	Weddell Sea	16.02.18	24.04.18	67
2018S58	300234065079570	7101552	Weddell Sea	19.02.18	10.06.18	111
2018S59	300234065261080	7101554	Weddell Sea	11.02.18	25.04.19	438
2018S60	300234065268080	7101556	Weddell Sea	18.02.18	04.04.18	45
2018S61	300234065267070	7101558	Weddell Sea	26.02.18	26.12.18	303
2018S62	300234065061680	7101560	Weddell Sea	22.02.18	11.07.18	139
2018S63	300234065621410		Alert	05.05.18	**21.05.18	16
2018S64	300234065625400	6401654	Arctic Ocean	21.04.18	01.04.19	345
2018S65	300234065627390	6401655	Nares Strait	05.05.18	10.08.18	97
2018S66	300234065628980	6301592	Arctic Ocean	02.09.18	18.03.19	197
2018S67	300234065629490	6301594	Arctic Ocean	16.08.18	**25.08.18	9
2018S68	300234065722000	6301596	Arctic Ocean	23.08.18	27.03.19	216
2018S69	300234066340550	6301598	Arctic Ocean	27.08.18	09.04.19	225
2018S70	300234066341810	6301600	Arctic Ocean	06.09.18	04.06.19	271
2018S71	300234066342550	2501641	East Siberian Sea	15.09.18		
2018S72	300234066342810	2501643	East Siberian Sea	13.09.18		
2018S73	300234066347810	2501645	East Siberian Sea	11.09.18		
2018S74	300234066347840	2501644	East Siberian Sea	14.09.18		
2018S75	300234066342820	2501647	East Siberian Sea	13.09.18		
2018S76	300234066343810	2501649	East Siberian Sea	15.09.18	27.04.19	224
2018S77	300234066345810	2501651	East Siberian Sea	11.09.18		
2018S78	300234066348820	2501653	East Siberian Sea	15.09.18		
2018S82	300234066344820		Arctic Ocean	19.08.18		
2018S83	300234066345560		Arctic Ocean	21.08.18	14.09.18	24
2018S85	300234065629490*	6301594	Arctic Ocean	17.09.18	13.12.18	87

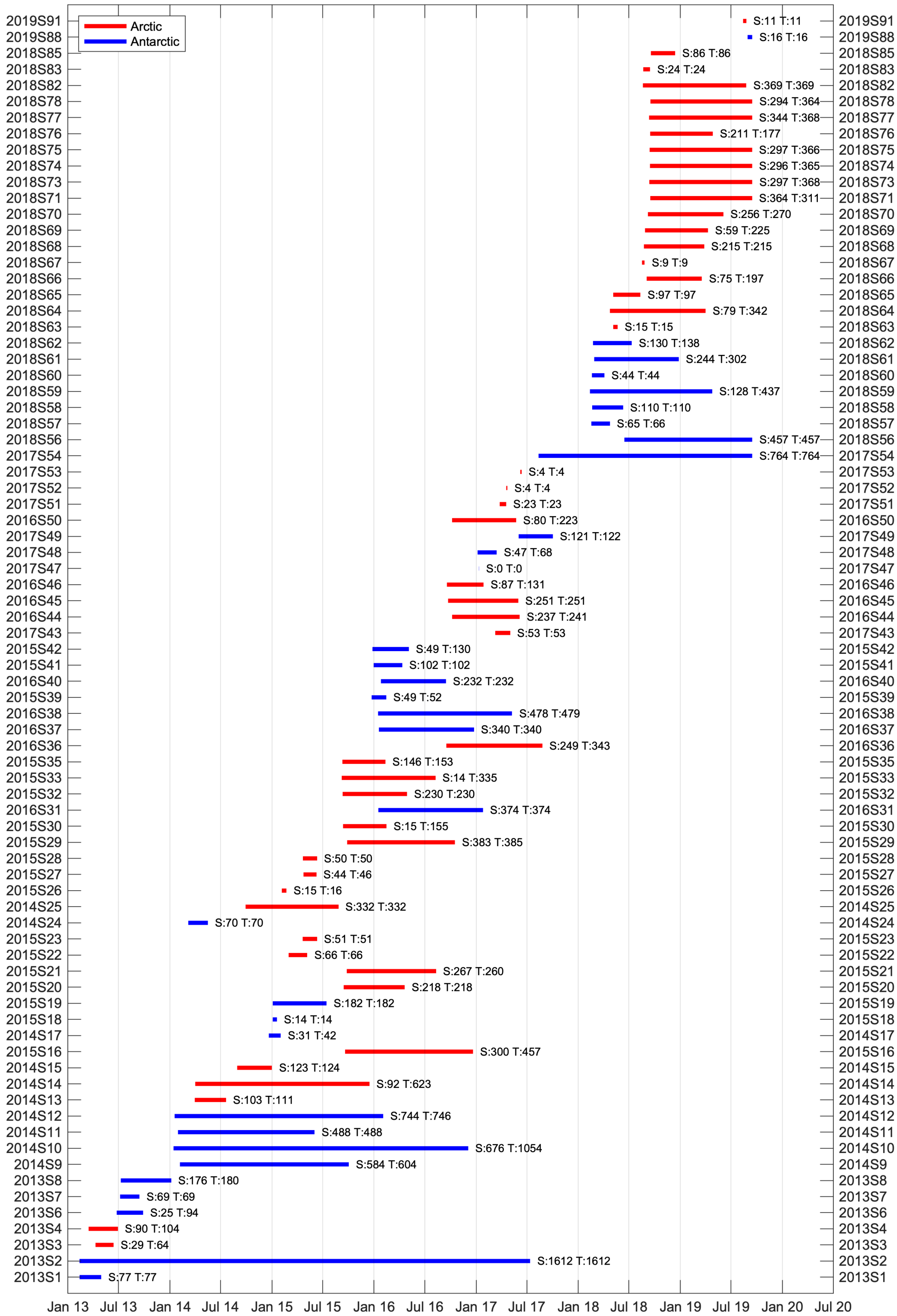

Figure S1. The lifetime of each buoy results from the beginning and end of its transmission of valid data. Numbers at the end of the lines give lifetimes for the main sensors of the buoy in days: T=position data, S=snow depth data (at least one sensor reporting useful data).

2. Comparison of surface height measurements with a reference station

In addition to the results section of the main manuscript, here we give more details on the setup and the measurements to compare the snow height measurements from Snow Buoy 2013S2 with the laser altimeter mounted on the weather mast of the trace gas observatory at the Neumayer III wintering station (Ekström Ice Shelf, Antarctica). This location allows year-round access to the buoy from the nearby station. The weather mast carries a laser distance sensor to derive snow accumulation, which is used as the reference measurement here (König-Langlo and Raffel, 2017). Horizontal distance between both sensors is approx. 10 m (Figure 1d), and care was taken to ensure the smallest possible interference with other measurements or obstacles. The buoy had to be repaired once after static issues (failure on 15 July 2013, maintenance and redeployment on 13 August 2013), but otherwise all components remained unchanged, e.g. no battery replacement or sensor maintenance. Due to the strong snow accumulation over the timespan of more than four years, the buoy had to be lifted four times: On 05 July 2013 by 1.0 m, on 28 April 2015 by 1.2 m, on 14 April 2016 by 0.60 m, and on 20 March 2017 by 0.80 m. By now, 2013S2 shows the longest time series of all buoys. It is particularly remarkable that the batteries and mechanical construction performed well over the long time (1613 days), given the harsh and stormy conditions during Antarctic winters. Figure S2 (red line) shows that the surface height evolution on the ice shelf near Neumayer III is mostly characterized by discrete snow accumulation events during the Antarctic winter (April to November), and periods of no changes or slight compaction and surface melt in Antarctic summer (December to March, see van den Broeke et al. (2009)). The Snow Buoy dataset generally agrees well with the reference laser measurements (blue line), in particular the distinct accumulation events are well reproduced. A surface height reduction due to compaction processes is more pronounced in the laser data, and especially visible during summer, when compaction is strongest. This is explained by the fact that the weather mast is anchored deep in the firn, while the Snow Buoy moves downwards with the snow surface during compaction. In addition to the complete time series, Figure S2 shows the partial time series for each re-deployment after lifting the buoy. At that time, the offset due to different compaction effects is re-set. Hence, the differences are smaller over time. These sub-graphs also highlight the increase in difference between Snow Buoy and weather mast over the summer months. Overall, the comparison of the buoy surface height measurements with the reference laser shows that the fully autonomous method is very reliable, even under extremely unfavorable conditions and over extended periods of time.

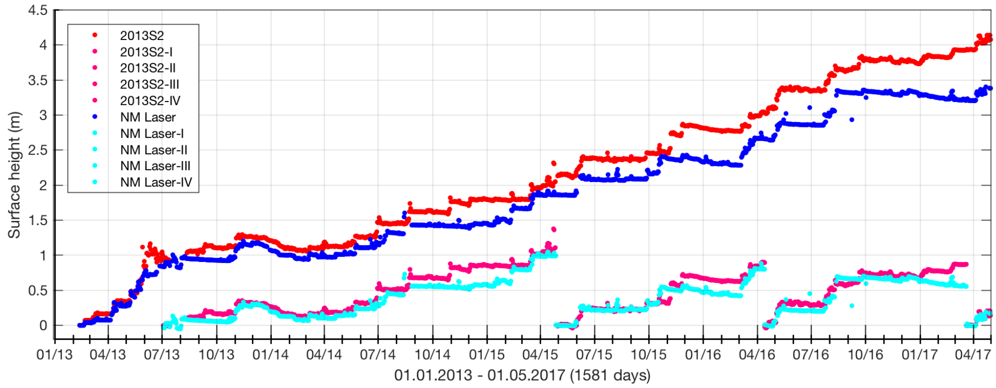

Figure S2. Daily means of surface height of Snow Buoy 2013S2 (red) at Neumayer III and the reference laser at Neumayer III (blue, see photo in Figure 1d). The same time series are shown (orange and cyan) for each re-deployment after lifting the Snow Buoy. Then, both start at 0, the actual surface, again. X-axis labels are given as mm/yy.

3. Comparison of air temperature and barometric pressure measurements with reference stations

In addition to the results section of the main manuscript, we here present the time series data of air temperature and barometric pressure comparison of Snow Buoy 2013S2 and the BSRN station at Neumayer III. The data cover three full years of measurements, from January 2013 to January 2016.

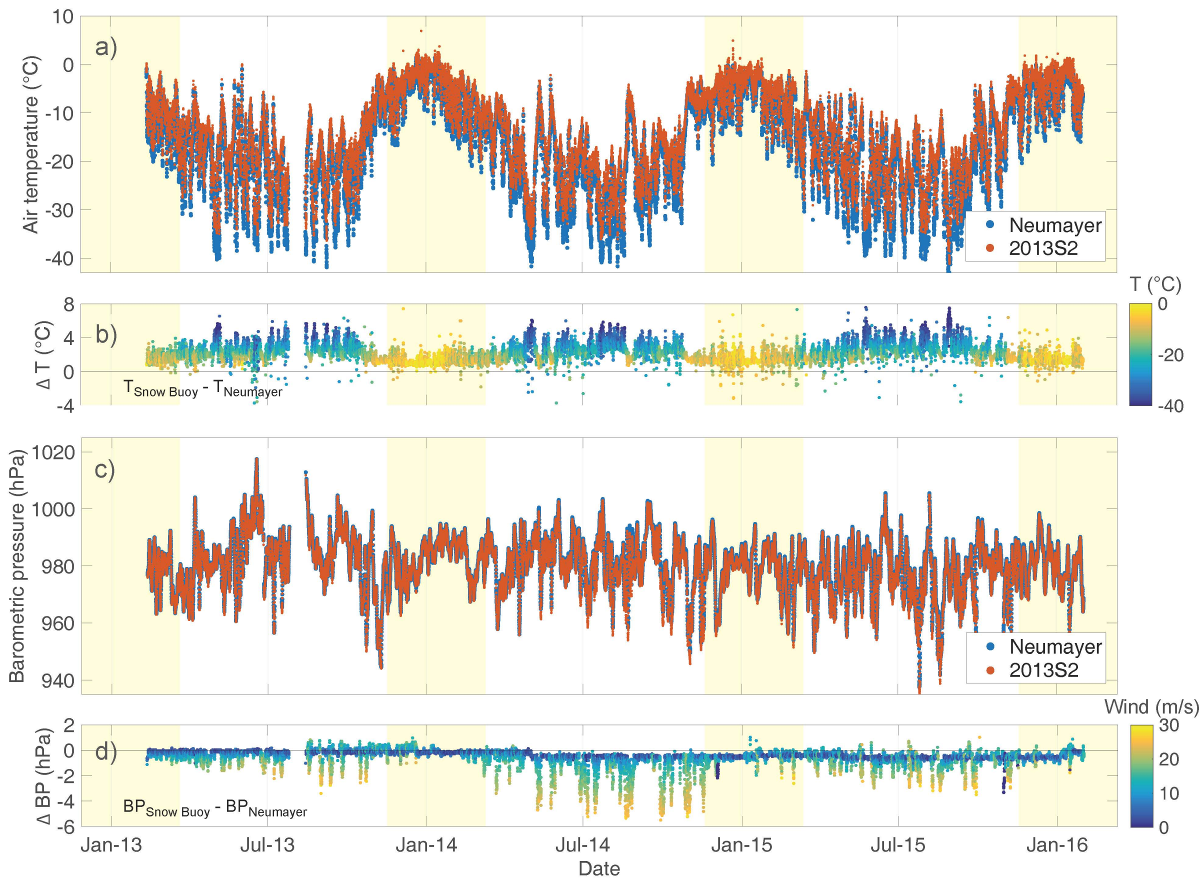

Figure S3. Data comparison between the Baseline Surface Radiation Network (BSRN) station and Snow Buoy 2013S2 at Neumayer III. The distance between the Snow Buoy and the BSRN station is 1.4 km. Given the large and comparably flat and smooth ice shelf in that region, we assume identical synoptic conditions between both stations. a) Air temperature from BSRN data (2 m height) and Snow Buoy 2013S2 (up to 1.5m height). b) Differences in measured air temperature, color-coded by air temperature. c) Barometric pressure from BSRN data and Snow Buoy 2013S2. Please note that both measurements are taken at different heights. d) Differences in measured barometric pressure, color-coded by wind speed measured at BSRN station.

4. Drift maps of buoy collections

Given the large number of 79 buoys it is not possible to label all single trajectories in Figure 3, hence they were only color coded based on their times of operation. Figures S4, S5, and S6 show the drift maps of those buoy collections that are discussed in more detail and presented in Section 4 of the main manuscript.

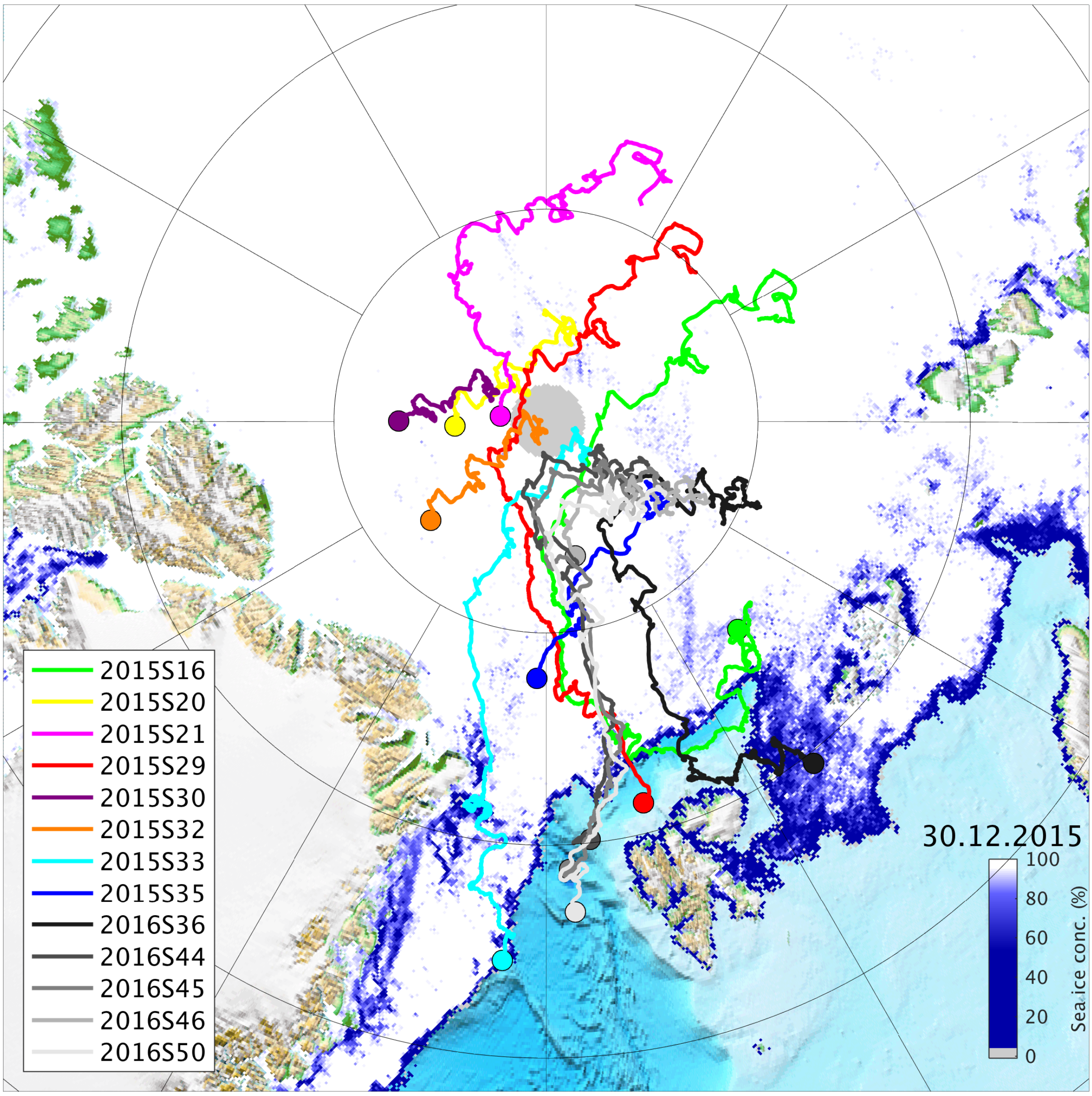

Figure S4: Drift trajectories of two sets of Snow Buoys deployed in the Arctic during the expedition PS94 in autumn 2015 (rainbow colors) and PS101 in autumn 2016 (grey tones). Dots show the last positions of the buoys. Colors of the trajectories match the colors of the data plots in Figures 8 and 9 (plates a and b). An exemplary sea ice concentration map (30 December 2015) is shown in the background.

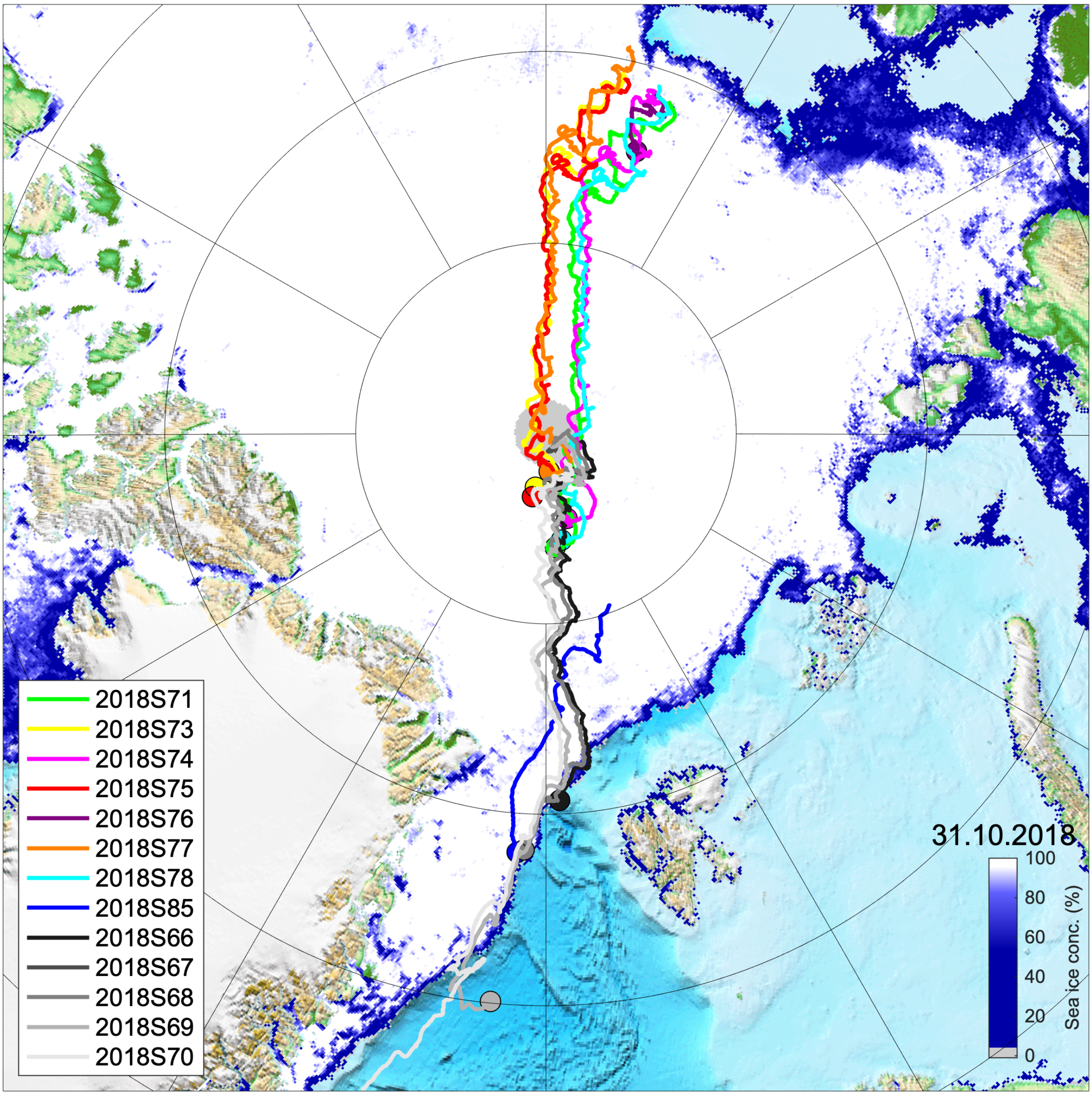

Figure S5: Drift trajectories of two sets of Snow Buoys deployed in the Arctic during the expedition T-ICE with Akademik Tryoshnikov (rainbow colors) and the expedition AO18 with the Oden (grey tones) in autumn 2018. Dots show the last positions of the buoys. Colors of the trajectories match the colors of the data plots in Figures 8 and 9 (plates c and d). An exemplary sea ice concentration map (31 October 2018) is shown in the background.

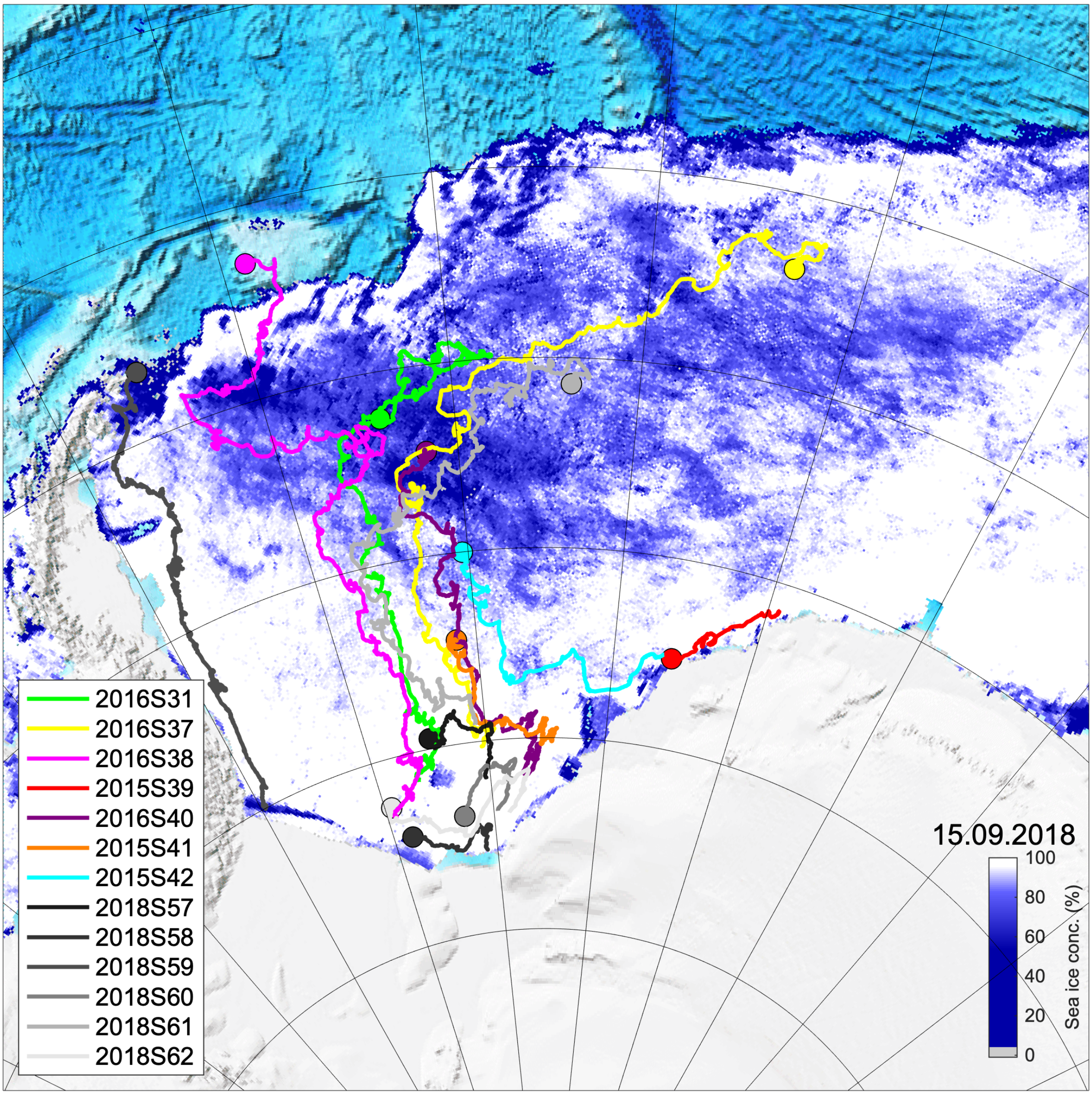

Figure S6: Drift trajectories of two sets of Snow Buoys deployed in the Weddell Sea, Antarctic, during the expedition PS96 in summer 2015/16 (rainbow colors) and PS111 in summer 2017/18 (grey tones). Dots show the last positions of the buoys. Colors of the trajectories match the colors of the data plots in Figures 6 and 7. An exemplary sea ice concentration map (15 September 2018) is shown in the background.

5. References

König-Langlo, G. and Raffel, B.: High resolved snow height measurements at Neumayer Station, Antarctica, 2013 - 2015. PANGAEA, 2017.

van den Broeke, M., König-Langlo, G., Picard, G., Munneke, P. K., and Lenaerts, J.: Surface energy balance, melt and sublimation at Neumayer Station, East Antarctica, Antarctic science, doi: doi:10.1017/S0954102009990538, 2009. 2009.