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Visual Antarctic Sea Ice Condition Observations during Austral Summers 2012-2016

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ABSTRACT

Due to Antarctica's remoteness, sea ice condition observations and measurements on board ships are rare. However, ship based annual expeditions are conducted from Cape Town to Antarctica within the South African National Antarctic Program. The S.A. Agulhas II replaced the S.A. Agulhas in 2012 and departed Cape Town on December 2012 for her maiden voyage to Antarctica. Intensive sea ice observations have been performed since by researchers during annual relief voyages from December to February.

In this paper, we present the visual observations on board the S.A. Agulhas II from the annual expeditions of four austral summers 2012 to 2016. The sea ice condition observations include ice thickness, concentration, and floe size. The changes in these parameters are studied between different years and during the voyages. The observations show that the thickness, concentration and floe size increase when moving from north towards south.

KEY WORDS: Ice conditions; Ice thickness; Ice concentration; Floe Size; Antarctica.

INTRODUCTION

Several research stations have been established in Antarctica. As most of the stations are located relatively close to the ice shelf edge the main material logistics are handled through sea transportation. Thus, several ships annually visit Antarctica. Despite the retreat of the Arctic sea ice, Antarctic sea ice extent has not shown indications of shrinking by the onset of 2016. As such, ships necessarily have to navigate through sea ice in order to resupply research stations. Although several ships sail to the Antarctic in the austral summer, there is a lack of sea ice observations.

Ice thickness and its measurement is a central problem in sea ice geophysics. Although progress in satellite altimetry is promising, there is still no means to remotely sense Antarctic ice thickness with sufficient accuracy. Both the basic understanding and the development of altimetry require thorough data sets. Current data sets are lacking both in the spatial and temporal domains. Current studies include temporal data series from bottom mounted sonars (Worby et al., 2001) and fast ice thickness records (Murphy et al., 1995). Electromagnetic (EM) campaigns have provided regional data (Haas, 1998, Reid et al., 2003). Drilling and observations during various campaigns (e.g. Worby et al., 1996) have resulted in a rough understanding of typical thicknesses in frequently visited Antarctic seas. A large number of

observations from ships have been analysed by Worby et al. (2008) for circumpolar coverage. However, winter season thickness data is almost nonexistent, except for a few dedicated campaigns (Wadhams et al., 1987) and ship observations.

In order to enlarge the data pool, this paper presents the visual sea ice observations on board the S.A. Agulhas II (SAA II) from the annual South African National Antarctic Expeditions during austral summers 2012 to 2016. Earlier, a part of the visual observations and stereo camera measurements have been reported by Suominen et al. (2016) and EM measurements by Lensu et al. (2015) and Suominen et al. (2016). The observed sea ice parameters include ice thickness, concentration, and floe size. The changes in these parameters are studied during the summer seasons and between the years.

DESCRIPTION OF VOYAGES

Voyage during Austral Summer 2012 – 2013

The ship departed Cape Town on December 6, 2012 and headed to the zero Meridian, which she followed to Antarctica. She encountered ice for the first time on December 13. The Antarctic ice shelf was reached on December 15, which she followed towards Akta Bukta close to Neumayer III (the German Antarctic research station). The ship operated next to the ice shelf between Penguin Bukta, the closest point to the SANAE IV (the South African Antarctic research station), and Neumayer III between December 15, 2012 and January 10, 2013. The sea ice in the area mainly comprised ice floes, with diameters which did not exceed the length of the ship, with brash ice between. In some locations the thickness of the ice floes was in excess of two meters. The ice concentration varied from open water to 100 % ice concentration. The bay ice next to Neumayer III consisted of the broken ice shelf and thick ice floes that had frozen together.

On January 13, the ship initiated her voyage towards South Georgia and the South Sandwich Islands along the zero Meridian exiting the ice conditions on January 14. The vessel returned from the voyage to the ice infested waters adjacent to Antarctica on January 28. Between January 28 and February 10, the ship operated in the same area as before. Generally, the ice conditions in the area were the same as before. An iceberg, which had stuck close to Neumayer III, had formed a level ice sheet in the bay next to Neumayer III. The cargo loading of the vessel was completed on February 10, and the ship headed towards Cape Town. The last ice was encountered on the same day.

Voyage during Austral Summer 2013 – 2014

The SAA II departed from Cape Town on November 28, 2013, and headed to Antarctica following the zero Meridian. The first ice was encountered at a latitude of 62.2^{o} on December 7. The ice concentration was typically less than 90 % until December 10. More difficult ice conditions were encountered around 68^{o} latitude, when the concentration increased to 100 % and a maximum ice thickness 1.6 m. From 69^{o} latitude (December 9, 20:30) to the Akta Bukta, latitude of 70.3^{o}, it took 12 days and 19 hours. In open water the voyage would have taken approximately 6 hours. During this period, the maximum observed ice thickness was 3 m and heavy ridges were encountered. The ship arrived to the Akta Bukta on December 23. On December 24, the ship navigated to the Penguin Bukta in fairly easy ice conditions with a lot of open water. On December 30, the SAA II headed towards South Georgia and the South Sandwich Islands. The ice conditions were more challenging until December 31. Thereafter the ice conditions eased with intermittent navigation through open

water. The vessel arrived at the South Sandwich Islands on January 4 and exited the ice field at this point.

Whale observations were performed after reaching South Georgia, during which the ship was navigating at the ice edge between 68º and 65º latitude and 0º and 20º longitude without ice passage. The ship was back in ice on January 23 and broke through the pack ice to Penguin Bukta which she reached on January 25. The ice conditions were fairly similar as before. The final phase close to Penguin Bukta proved challenging due to a particularly resistant ridge on the afternoon of 23 December. Several hours were spent to navigate through the ridge. On January 26, the ship started the voyage to Akta Bukta arriving there January 28. From Penguin Bukta to Akta Bukta the ice conditions encountered were undemanding (January 26 to 28). The thickness of the bay ice was fairly constant at an estimated 1.8 m. The return voyage to Cape Town started on January 31 and the last ice was observed February 1. The final phase of leaving Akta Bukta to Cape Town was again fairly easy with typical ice concentrations below 90 %.

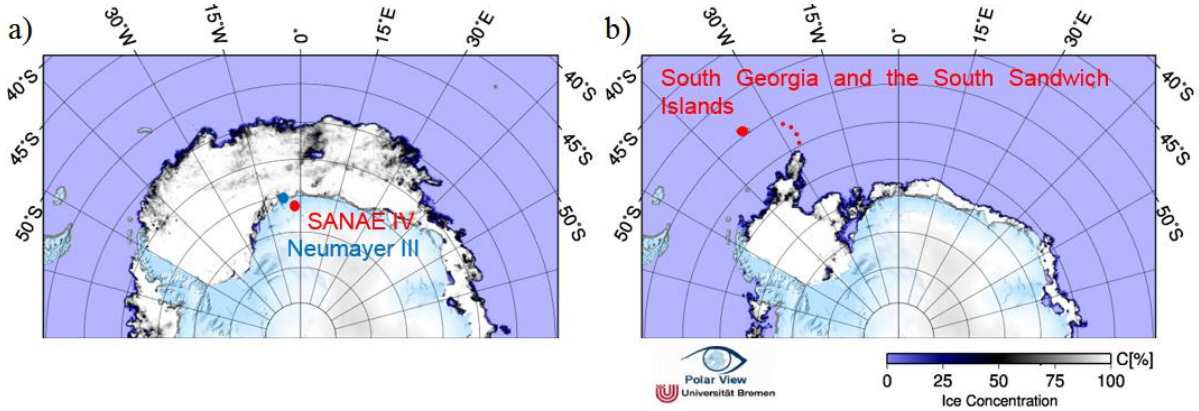

Figure 1. The sea-ice extent in Antarctica on (a) December 6, 2013, and (b) February 2, 2014. Pictures reproduced from Suominen et al. (2015) and the concentration maps produced by Spreen et al. (2008).

Voyage during Austral Summer 2014 – 2015

The ship headed from Cape Town to the zero Meridian on December 5, which she followed to Antarctica visiting Bouvet Island on the way. The first ice berg was observed on December 13. The first ice was encountered in the morning of December 14 and the ice shelf was reached on December 14. After reaching the shelf, the ship headed towards Akta Bukta arriving there on December 18. She was beset a few times on the way, but was able to circumnavigate the most challenging ice conditions. She started carving bay ice, but the carving was ended after a while as the thickness of the bay ice in Akta Bukta was too great to penetrate. Thus, the cargo off- and on-loading was performed on bay ice between December 18 and 19. Subsequently the ship headed towards Penguin Bukta. The ship was able to navigate in a lead close to the shelf and Penguin Bukta was reached in the morning of December 20.

The SAA II left for South Georgia at the daytime on December 29 after which the number of ice floes and the ice concentration increased. The SAA II attempted to avoid challenging ice navigation and exited icy waters on December 30, 2014. She arrived to Thule Island on January 4, where some ice was encountered, but not for long because of the wind situation. The ship returned to ice conditions on January 19, 2015. The next day the encountered sea ice

was increasingly compact and thicker. On January 20 the ship had to ram for one day before reaching open water on January 21. She approached the ice shelf and passenger transportation and cargo handling activities ensued. On January 29, the SAA II approached Neumayer III to reach her destination on January 30 where cargo was collected. The ship left the ice shelf and headed back to Cape Town on February 6. On February 7, the ship entered open water.

Voyage during Austral Summer 2015 – 2016

The SAA II departed Cape Town harbour on December 5 first navigating south west and then due south on the Greenwich Meridian. Ice was first encountered on December 11 and continued until arriving at the Antarctic ice shelf at Penguin Bukta on December 16. On December 19 the vessel navigated in a lead with some light ice conditions to Akta Bukta. After cargo operations the ship left the shelf for South Thule and soon encountered thick pack ice, requiring heavy ramming maneuvers. The vessel became heavily beset and after repeated ramming remained stationary from December 22 to December 23. When the wind conditions changed, the pack ice started opening allowing further ice navigation. The vessel reached South Thule on December 24 and left the pack ice on December 28 on route to South Georgia, arriving on December 30.

The vessel re-entered ice on January 12 on route to Penguin Bukta and conducted seal tagging in light to medium floe ice conditions until January 24. The ship performed cargo operations at Penguin Bukta with intermittent short runs into the pack ice for further seal tagging. The vessel reached Akta Bukta on January 26 and began carving the fast ice at the shelf, however unfavorable wind conditions ended this navigation after only a few hours. The vessel continued short runs into the ice for seal tagging, while the Polarstern finished the carving once the wind conditions became favorable once more. After cargo back loading the SAA II started her return voyage on Februray 1 and left the sea ice on February 2.

VISUAL OBSERVATIONS

The visual observations were conducted from the bridge of the ship when the ship was operating in ice. As the sun does not set during the austral summer in Antarctic waters, enough light was available also during the nights for observations. The observations were executed in 2 to 3 hour shifts with 5 to 7 observers in the group to avoid fatigue strain on observers. Observations were reported for 15 minute periods in the earlier voyages of 2012-2013 and 2013-2014, and for 10 minute intervals during further voyages. The observations included ice thickness, ice concentration, snow thickness, brash ice amount, floe size as well as general comments. The thickness, concentration, and floe size were estimated as occurrence percentages (in tenths) for given categories during the measurement period.

The ice thickness was estimated by comparing the thickness of the cross-section of the upturning pieces with a scaled yard stick which was suspended overboard from the main deck. The stick was marked with 10 cm wide black and white painted stripes to calibrate the estimations of observers, see Figure 2. Observers estimated the ice thickness with the stick as it was seen from the bridge and the real ice thickness was obtained by scaling the observations with a factor of 1.5. This was done in order to correct the parallax error. The factor was determined based on the distances to the sea surface and measurement stick from the bridge. The thickness classes during the 2012-2013 voyage included the classification of ice in categories with 20 cm increments between 0 m to 2 m with a final category for ice thickness in excess of 2 m (see Figure 3). Additional thickness classes 2.0-2.5 m and 2.5-

3.0 m were added to observation classes for the following voyages. The voyages 2013-2014 and 2015-2016 also included a class of >3.0 m. However, as the measurement stick is only 1.5 m long the uncertainty increases significantly for the thickness classes exceeding 2.0 m. The average ice thickness for a 10 minute period was determined by calculating a weighted average from the thickness observation periods.

The concentration of the ice field was estimated from inboard observations. Thus, the concentration was estimated from conditions experienced in the close vicinity of the ship. As the crew preferably navigated in open water instead of ice, the ship followed open water conditions when possible. In this case, the concentration was marked as zero, although floes of ice could be seen. A range from 0 to 100 % was divided into bins with a size of 10 % each, i.e. 0-10 %, 10-20 %, etc., which formed the observation classes. Here, zero denotes open water and one full ice cover. Figure 3 presents an example from a part of the visual observation sheet.

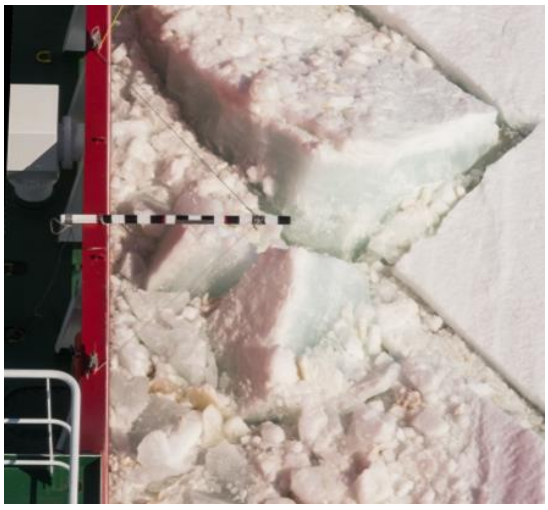

Figure 2. The measurement stick for ice thickness estimation. Each stripe is 10 cm wide.

Time UTC+0									snow [cm]		Ice concentration in tenths									
			start		end				min	max	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
year	mm	dd	hh	mm	hh	mm	Lat	Lon												
2013	12	22	8	0	8	10	-70.46	-8.426		50	6			3	1					
2013	12	22	8	10	8	20	-70.45	-8.379		60	0				1	4		3	2	
2013	12	22	8	20	8	30	-70.45	-8.377			4							2	1	3
2013	12	22	8	30	8	40	-70.45	-8.376		60	0						3	4		3

Figure 3. An example from a part of the visual observation sheet.

The classes for observed ice floe diameter were <20 m, 20-100 m, 100-500 m, 500-2000m, 2-5 km, >5 km. The classes were selected based on the egg code (WMO, 2014) used, for example, in the Baltic Sea. The floe diameters were estimated with the help of the main dimensions of the ship. If the floes were smaller than the breadth of the ship (21.7 m), those belonged to the first class. If the floes were larger than the breadth, but smaller than the overall length of the ship (134 m), those belonged to the class 20-100 m. If the floes were larger than ship length, the diameter was estimated as multiples of the ship length.

ICE CONDITIONS

Figure 4 presents the 10 minutes mean ice thickness for observation periods during the four annual voyages in 2012-2016 and Figure 5 shows the mean ice thickness in latitudes for

December, January, and February. The onset of ice navigation is typically around 60 degrees latitude when the ship started her southerly voyage to Antarctica. Generally, the thickness increased towards the south and the most challenging conditions were encountered close the ice shelf. However, thick ice floes have also been encountered in lower latitudes. Three meter thick ice has been observed in 60 degree latitude in the voyage 2015-2016. However, the concentration of the ice field was generally lower in 60 degree latitude and increases southwards, see Figure 6 and Figure 7. Thus, the ship was commonly able to navigate relatively easily through the ice by navigating between the floes or pushing floes aside at the onset of the voyage. Difficulties were encountered closer to the ice shelf when the concentration and thickness increased. Furthermore, floe size increased southwards, which hinders maritime operations, see Figure 8 and Figure 9. Ships are able to push smaller floes aside and navigate between the floes, However, in a case of large floes, the ship is forced to break through the ice, if the floe cannot be circumnavigated.

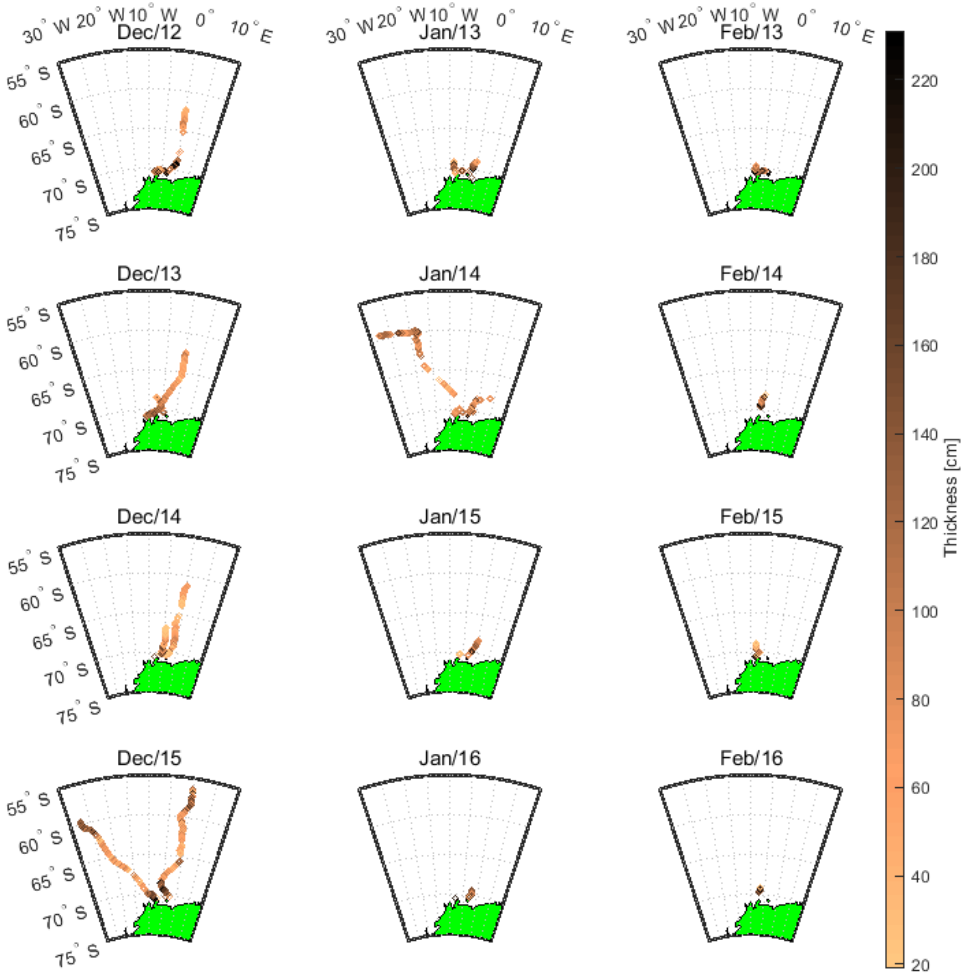

Figure 4. 10 minutes mean ice thicknesses during the four voyages.

As can be noted from Figure 4 and Figure 6, in the voyages 2012-2013 and 2014-2015 the ship was basically able to avoid the ice conditions when she headed for South Georgia. However, in the voyages 2013-2014 and 2015-2016, the ice conditions lasted up to the South Sandwich islands at 60 degree latitude and two meter thick floes were encountered in these latitudes. During the summer season, the sea ice extension around Antarctica shrinks significantly and the ice is encountered only near the continent, see Figure 1. The shrinking can also be observed from Figure 4 to Figure 9 by comparing the December and February in

different years. The only ice in January and February has been encountered in the vicinity of the ice shelf. However, as the surviving ice is generally multiyear ice, the thickness can be significant despite the late season, see Figure 4 and Figure 5.

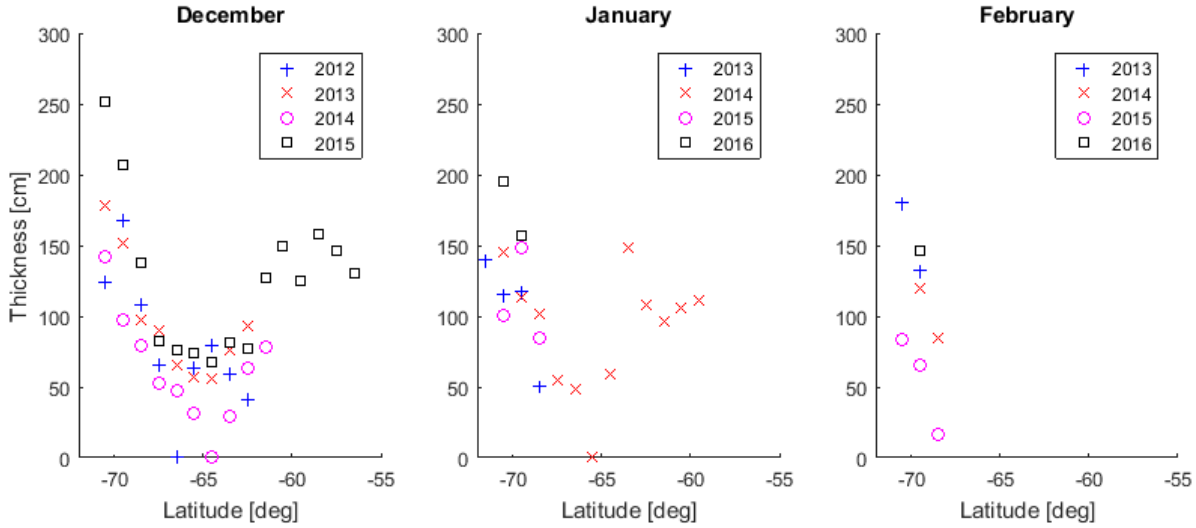

Figure 5. The mean ice thickness as a function of the latitude for four voyages.

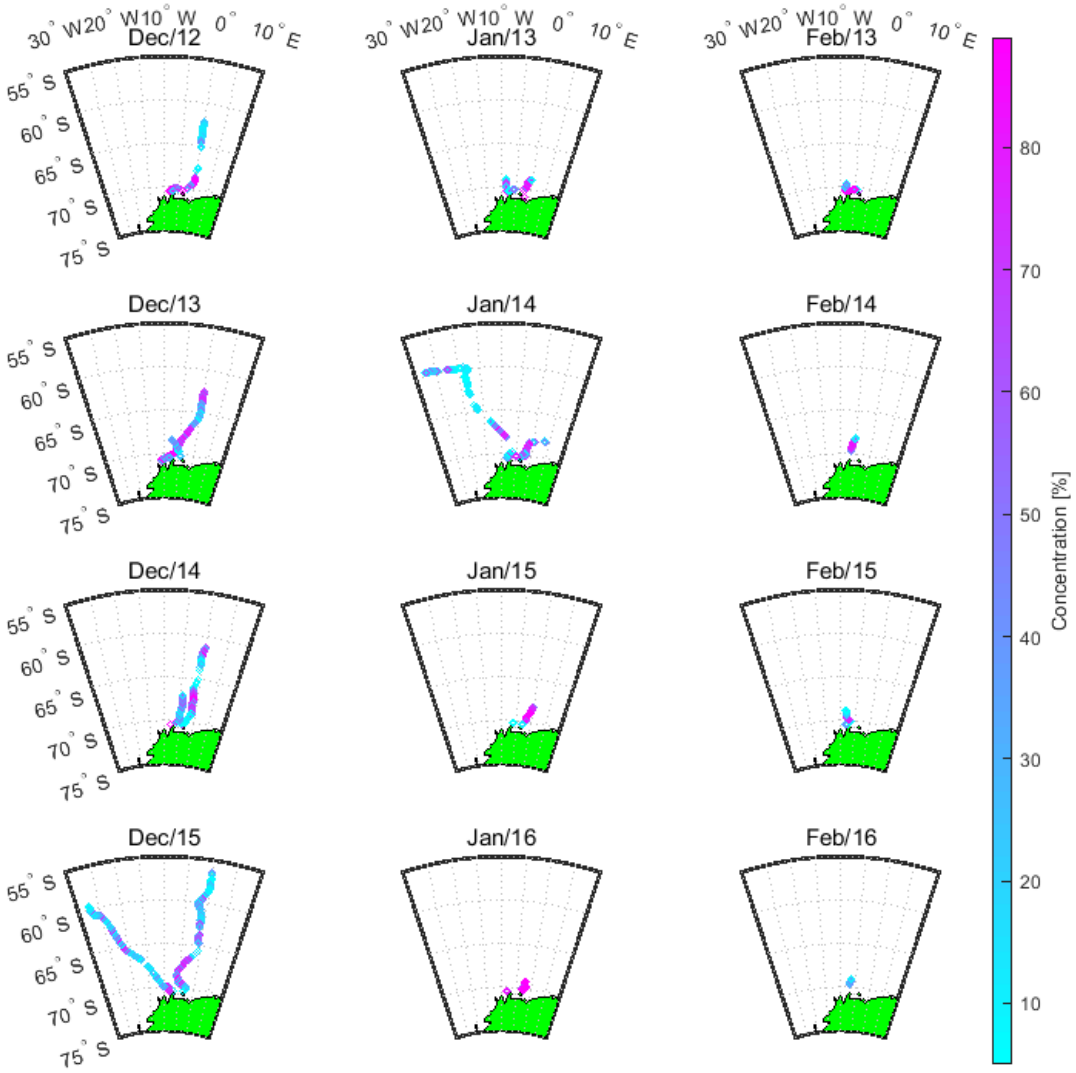

Figure 6. 10 minutes mean ice concentration during the four voyages.

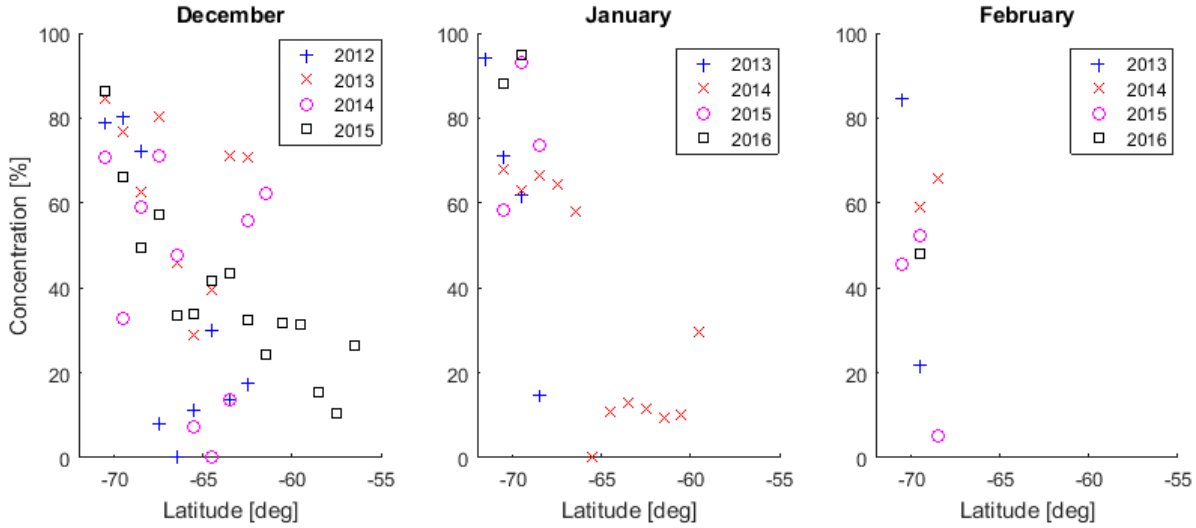

Figure 7. The mean ice thickness as a function of the latitude for the four voyages.

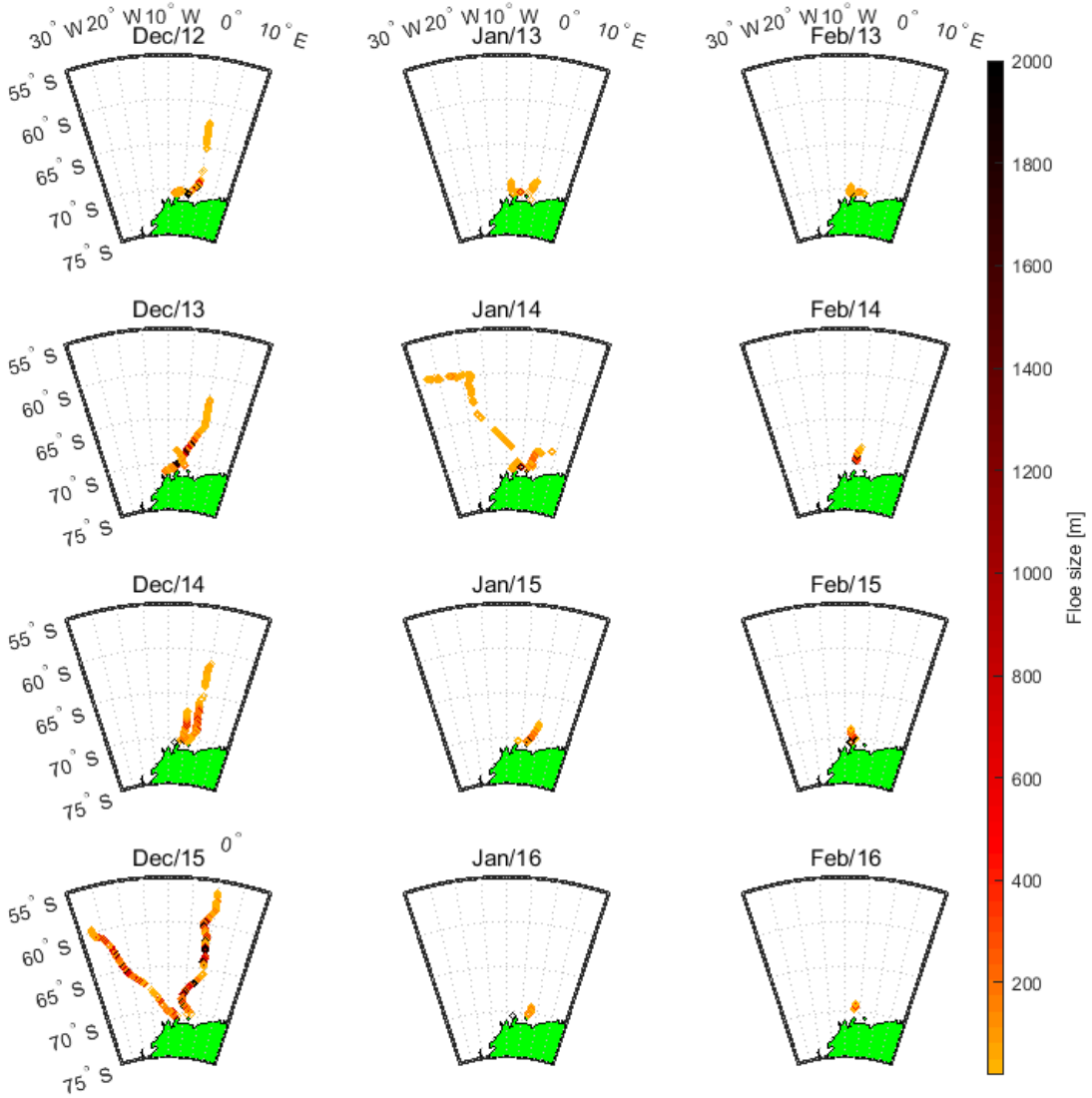

Figure 8. 10 minutes maximum floe size during the four voyages.

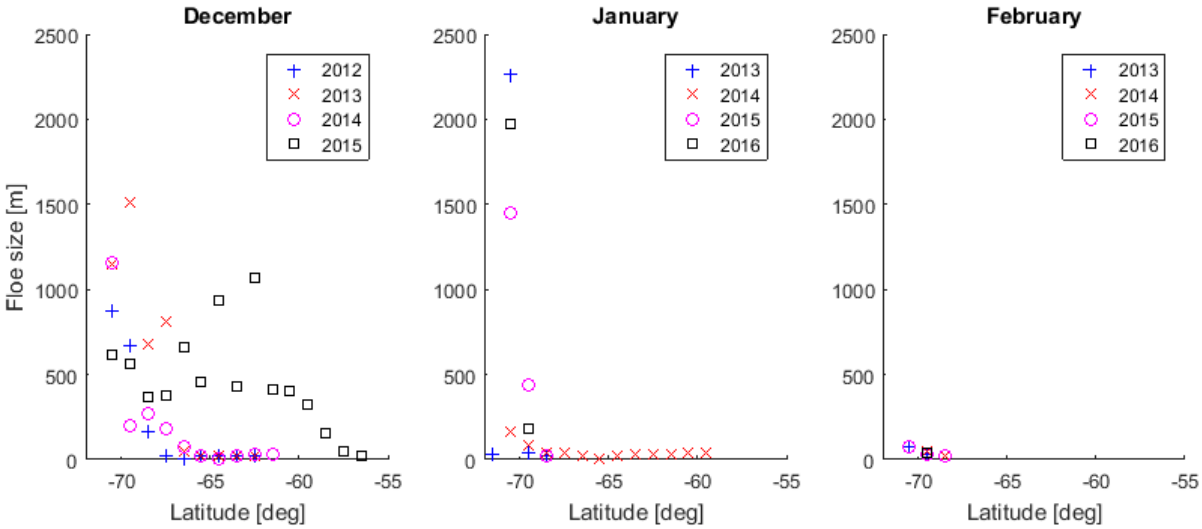

Figure 9. The mean floe size as a function of the latitude for four voyages.

CONCLUSIONS

Visual observations on ice thickness, ice concentration and floe size are presented from four annual Antarctic voyages on board the SAA II in 2012-2016. The observations show that the ice conditions commonly extend to approximately 60°S latitude in austral summers. Generally, the thickness, concentration and floe size increases towards the ice shelf. Furthermore, the observations show that the sea ice extent significantly shrinks during a year and multiyear ice only exists close to the ice shelf in early February. Similar observations have been reported in earlier studies (see e.g. Worby et al., 2008).

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CONCLUSIONS

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