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Anomalous extensive landfast sea ice in the vicinity of Inexpressible Island, Antarctica

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Abstract On 10 December 2017, a Chinese research vessel R/V *Xuelong* encountered an extensive area of landfast ice offshore Inexpressible Island (Antarctica) near the location where the fifth Chinese Antarctic research station is to be built. Using multi-source satellite images and weather data, we analyzed the ice conditions during the event season and reconstructed the development of landfast ice. Two stages in late September and early October were identified as contributing to the final ice extent. These two events are highly related to local- and large-scale weather conditions. Satellite images from 2003 to 2017 showed that four in fifteen years experienced severe landfast ice conditions, suggesting that it is not a rare phenomenon.

Keywords **Inexpressible Island, Antarctic, landfast ice, Chinese Antarctic research station**

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1 Introduction

Antarctic sea ice has been slightly increasing over the past decades, but a sudden decrease has been observed in recent years (Turner et al., 2017; Shepherd et al., 2018). Regional sea ice conditions are even more unpredictable (Shu et al., 2012; Zhai et al., 2015; Lee et al., 2017). Landfast ice refers to sea ice that is “fastened” to the coastline or anchored to the ocean bottom or icebergs (WMO, 1970). It can grow in place or form from drifted ice driven by onshore winds. Early studies showed that atmospheric circulation had significant impacts on regional landfast sea ice (Heil, 2006; Aoki, 2017). Anomalies in atmospheric pressure sometimes result in extreme sea ice conditions (Turner et al., 2002; Wang et al., 2014). Such conditions can make Antarctic navigation difficult and cause problems to the (re)supply of research stations.

A Chinese Antarctic scientific research station is currently under construction on Inexpressible Island. On 10 December 2017, the research vessel (R/V) *Xuelong* sailed to the island with construction materials. However, it unexpectedly confronted an extensive landfast sea ice area offshore Inexpressible Island. As a result, the ship’s cargo had to be transferred by helicopter, which was costly and time consuming. A similar event also occurred in the austral summer of 2001/2002, where a supply ship failed to reach a station because of exceptional heavy sea ice conditions

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along the coast of the Weddell Sea. Turner et al. (2002) pointed out that this event was caused by long-lived anomalous atmospheric circulation.

Using remote-sensing images and meteorological data, we analyzed sea ice conditions and its evolution near Inexpressible Island. Since Chinese vessels will probably sail into this area every year, there is a vested interest in the regional conditions. A detailed analysis of the weather and sea ice conditions can help to understand the ice conditions of this area and provide references for navigation.

2 Study area

Inexpressible Island is leaf-like in shape, located at the edge of Victoria Land and to the west of the Ross Sea (Figure 1b). It is at the front of Nansen Ice Shelf, which divides the ice stream. A small bay is formed between Abbott Mount and Inexpressible Island and outside this small bay is Terra Nova Bay (TNB), lying between Cape Washington and the Drygalski Ice Tongue. A large polynya exists in the TNB from April to early December due to the strong katabatic wind blowing offshore, making the TNB polynya a well-known "ice factory" (Parmiggiani, 2011).

Typically, there are two different regimes for landfast ice formation (Fraser et al., 2012). One occurs when grounding icebergs or ridges provide anchors for sea ice to adhere to; however, based on bathymetry measurements, the water depth is more than 100 m in this area, which is too deep for ridges to ground. The second formation regime happens on the upstream side of protrusions, which is the case for Inexpressible Island. To identify the formation of the unexpected extensive landfast ice, weather data from September to December 2017 were collected.

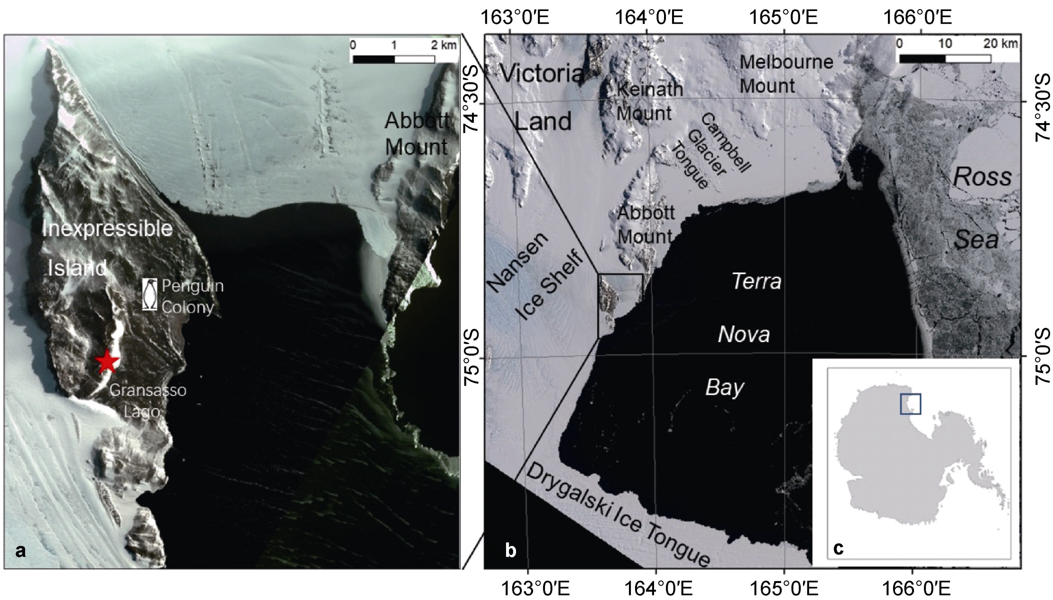


Figure 1 Geography of Inexpressible Island, Victoria Land, Antarctica. The base maps were acquired from Planet (**a**) and Landsat-8 images (**b**). The location of the planned Chinese Antarctic research station is marked by a red star in **a**.

3 Data

We used satellite images to monitor ice conditions because of their global visibility. Visible images from Planet (PLANET) and Landsat-8 (U.S. Geological Survey) provided an overview of the natural environment around Inexpressible Island. The resolutions of these two image groups are 3 m (Planet) and 30 m (Landsat-8). NASA moderate resolution imaging spectroradiometer (MODIS) images are used to describe ice evolution because it has the advantage of daily acquisition. However, since MODIS images are not available during the austral winter, only data from September to February over 2004/2005–2017/2018 were used. Considering most human activity around Antarctica takes place in December and January, MODIS dataset is sufficient to analyze the sea ice conditions during this season and further clarify how the conditions developed. Sentinel-1 Synthetic Aperture Radar (SAR) images (European Space Agency) are high resolution (5 m) and can ignore clouds, which is extremely useful in the polar regions. Besides, they can help identify ice types because backscatter properties are different in relevant ice types.

Ice evolution is highly related to meteorological conditions. To further investigate how the sea ice formed and decayed, we collected weather data from an automated weather station (AWS; 163°42′28″E, 74°54′50″S) on Inexpressible Island (Figure 2) for local weather investigation and ECMWF Re-analysis (ERA) interim data for large-scale analysis. Weather observations are recorded hourly, including the temperature, wind direction and speed at 2 m height. The ERA data used in this study were wind and mean sea level pressure (MSLP) at 10 m. These data were gridded to the highest resolution of 0.125°.

4 Results and discussion

4.1 Satellite observations of sea ice

The Inexpressible Island base map (Figure 2) is a Sentinel-1 SAR image acquired on 10 December 2017. R/V *Xuelong* can be clearly identified at the edge of the landfast ice. The landfast ice area showed two different backscatter properties. Darker areas had high specular reflection and low backscatter, indicating that the ice was flat and smooth. This kind of ice is called level ice; it is generally formed in situ by thermodynamic growth. Ice with lower specular reflection and higher backscatter is called ridged ice and its formation mainly relies on dynamic processes. Typically, in a highly dynamic environment, sea ice piles up because of wind and ocean currents, making its surface rough and bumpy. During the landfast ice event observed in December 2017, sailors onboard the R/V *Xuelong* recorded ridged ice thickness of 3–4 m.

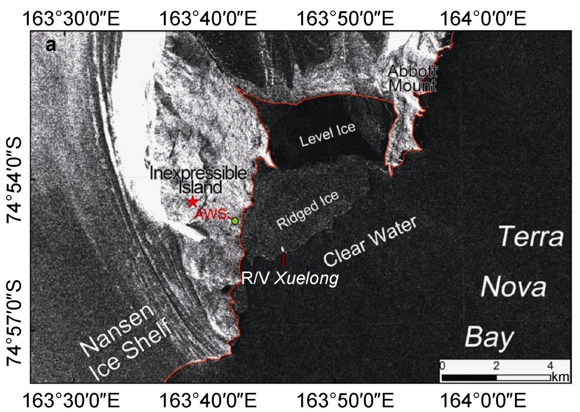


Figure 2 Ice conditions near Inexpressible Island during the extensive landfast ice event in December 2017. The base map is a Sentinel-1 SAR image acquired on 10 December 2017. The location of R/V *Xuelong* is marked. The green dot indicates the AWS, the red line is the continent–ice boundary and the red star is the location of the planned Antarctic research station.

The landfast ice formation can be traced back to September and October 2017 using daily MODIS images. Two events contributed to the unexpectedly large ice extent. The first occurred between 23 and 27 September 2017, during which time the small bay to the east of Inexpressible Island was filled by ice (Figure 3a and 3b). This bay was entirely open with some slush ice drifting eastward on 23 September (Figure 3a) and only a small area of ice was observed in the northeastern corner. After 3 d, a large area of landfast ice had formed in the northern area of the bay. The increase in ice extent was about 6 km^2 and the majority of the ice gain was mainly level ice (Figure 2). The second event spanned from 1 to 5 October 2017. Ice was observed expanding further south with the whole surface area (~30 km^2) covered by ice (Figures 3c and 3d). During this period, the increased ice mainly came from the outer sea and was highly compressed, which makes the ice surface rough and ridged. After these two stages, the landfast ice area remained stable until 23 January 2018.

4.2 Meteorological conditions and its effect on sea ice

Weather data from the AWS indicated the development of the two landfast ice events in September and October 2017 (Figure 4). During the first event, there was a significant decrease in wind speed and persistent low temperatures (about −30℃). The wind speed dropped continuously from more than 20 $m \cdot s^{-1}$ to about 5 $m \cdot s^{-1}$ on 25 September (Figure 4). After a slight increase, it dropped again to about 3 $m \cdot s^{-1}$. Compared to the strong katabatic wind in this area, this situation allowed the newly formed ice to stay in place and grow thicker. However, some AWS data were missing on 25 September, so we checked the ERA-interim 10 m wind data and found a rapid wind direction transition. Figure 5a shows that a weak southwest wind was present at this location, which strengthened the ice accumulation.

During the second event (1–5 October 2017), a wind direction transition was identified on 2 October (Figure 4). Before 2 October, the wind came from the northwest, blowing away the newly formed ice. After this date, the wind changed into a rather persistent southerly onshore wind, which was present for almost 3 d; this phenomenon

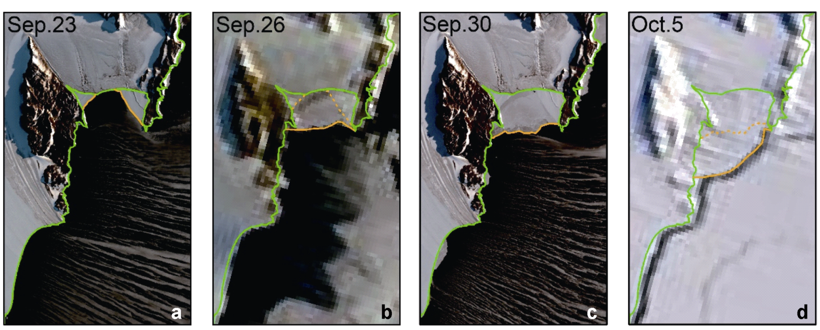


Figure 3 MODIS and Landsat-8 images showing the ice evolution from 23 September to 5 October 2017. The green lines are the continent–ice boundaries and the orange lines are the boundaries of ice and open water.

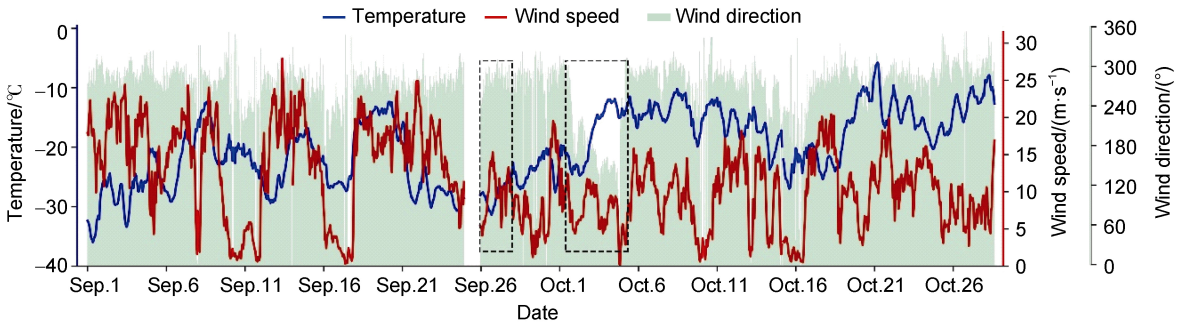


Figure 4 Weather data from 1 September to 30 October 2017. The blue and red lines represent temperature and wind speed, respectively. The light green bins represent wind direction and the air conditions during the two events are outlined by dashed boxes.

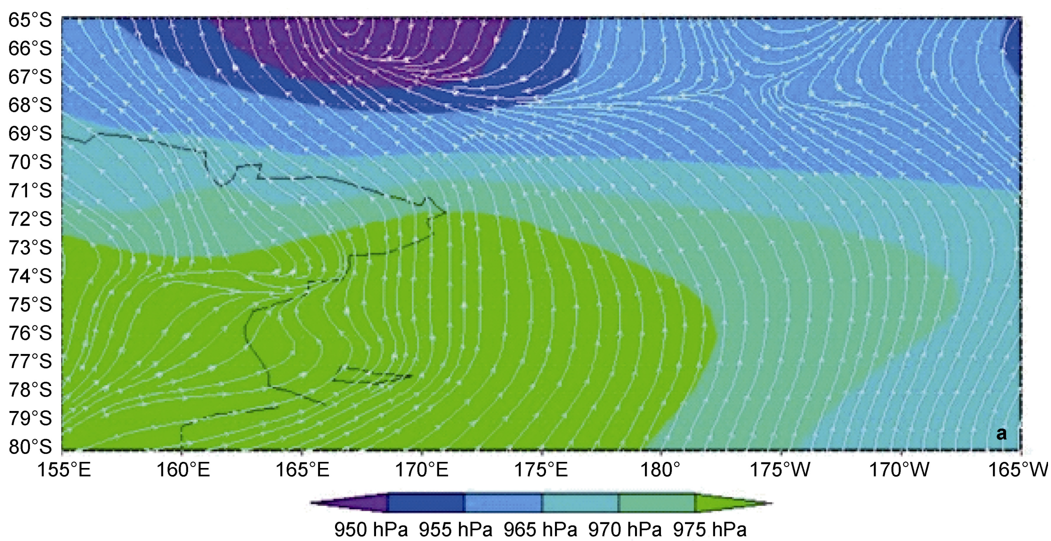
is quite rare in this area. The ice that was gained during this event was mainly driven from the outer sea by wind. Thus, the ice was more compressed and, as a result, contained more ridges. Additionally, the temperature remained below −10℃ and was below −20℃ for the first two days, favoring the development of thick ice.

These two different weather conditions explain why two different kinds of landfast ice were observed in Figure 2. After these two periods, the landfast ice area remained stable for the following two months. Although the wind direction returned to a southeastward direction, the pack ice was strong enough to keep itself fastened to the shore. In addition, the wind speed became slower in October, which promoted ice fastening.

Local meteorological conditions are related to large-scale atmospheric circulation. Offshore Antarctica in the circumpolar Southern Ocean, cyclones travel from west to east around the edge of the continent. Figure 5 shows the MSLP and 10 m wind on 25 September, and, as is shown in Figure 5a, the pressure gradient was rather small around Inexpressible Island. Thus, the offshore wind would have weakened because of that configuration, which is consistent with the AWS records. From 1–5 October, the MSLP on the continent was relatively high (Figure 5b), which produced a sharp pressure gradient on Inexpressible Island and resulted in a strong southerly onshore wind.

4.3 Interannual sea ice conditions

The R/V *Xuelong* has previously sailed in this region (summer 2016/2017) during which ice conditions were more favorable with small areas of ice existing in the northern part of the area. We reviewed December ice conditions for 2003–2017 and ice edge information extracted from MODIS visible images are outlined in Figure 6. Here, we classified the 15 years into three categories, according to the ice severity. Severe years included 2006, 2011, 2015 and 2017. In these years, the northern bay was fully covered by ice, and a large pack of ice existed to the east of Inexpressible Island. So under these conditions, vessels would have had difficulty reaching the coast. For moderate years 2003, 2007, 2009, 2012 and 2014, the northern bay was filled with ice but there is little landfast ice on the east coast of Inexpressible Island, which would have been more favorable for ships to anchor by the island. The light years (2004, 2005, 2008, 2010, 2013 and 2016) were the most frequently occurring at almost 50%.



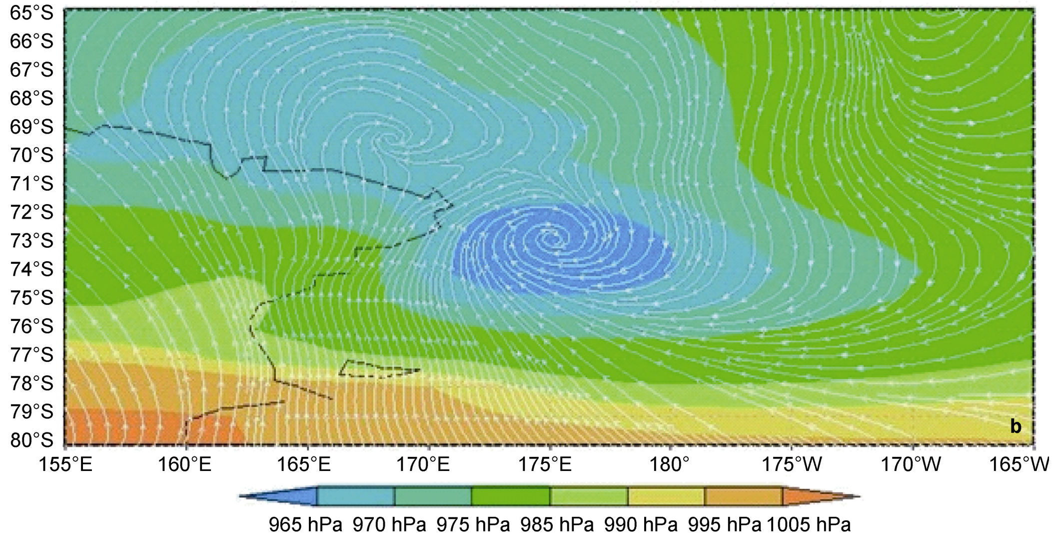


Figure 5 Mean sea level pressure and 10 m wind at UTC 06:00 on 25 September 2017 (**a**) and UTC 12:00 on 4 October 2017 (**b**).

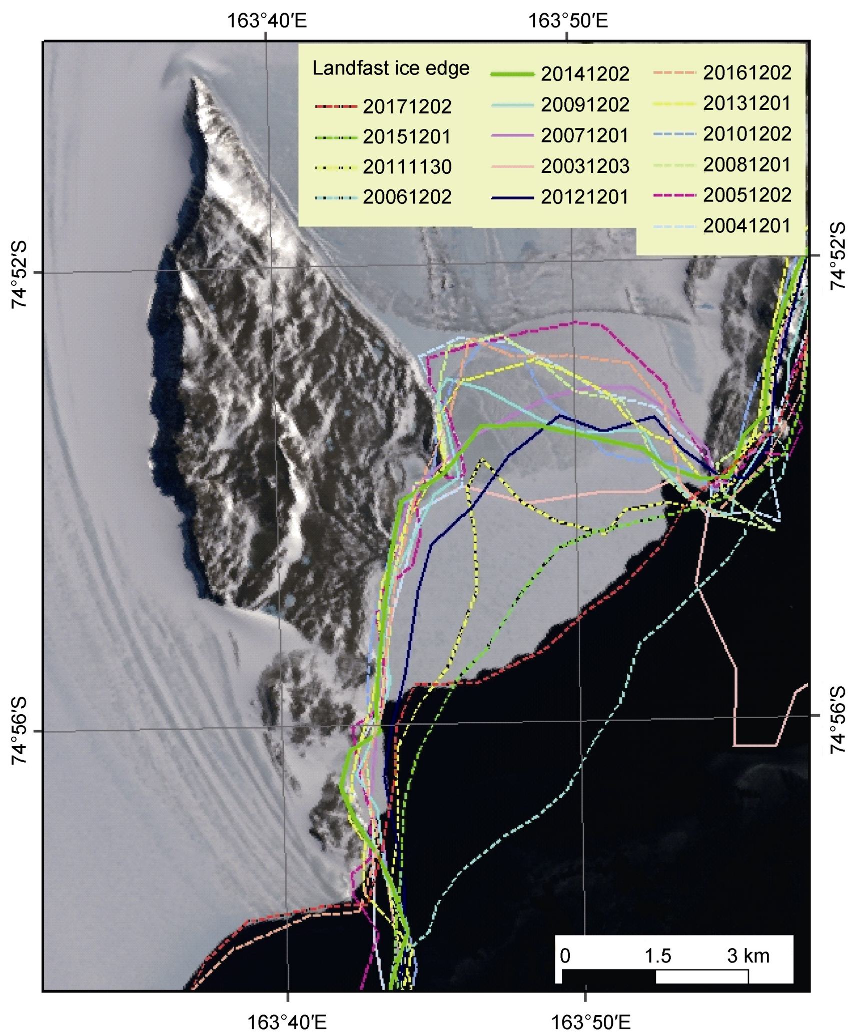


Figure 6 Ice edges at the beginning of December in 2003–2017. The base map is a Landsat-8 visible image acquired on 28 November 2017.

5 Conclusions

This study presents an investigation of unexpected extensive landfast ice conditions recorded by the R/V *Xuelong* near Inexpressible Island in December 2017. We provided an overview regarding the ice conditions when the R/V *Xuelong* would have anchored, and described the landfast ice development using satellite images and both local and synoptic weather data.

The extensive December 2017 landfast ice formation can be traced back to two events in late September and early October 2017. It was significantly influenced by local weather conditions. Very low temperatures (<−30℃) and decreased wind speed contributed to the first event (23 to 27 September) and resulted in mainly level ice in the northern bay. The event in October was characterized by strong wind direction transition from northwest wind to southerly wind, and relatively low temperature drove ice to compress and accumulate at the shoreline, making the ice surface rough and ridged.

During 2003–2017, an extensive landfast ice area was present in four of the fifteen years indicating that this is not a rare phenomenon. Thus, it urges us to have a more comprehensive perspective of the natural environment, especially the ice conditions around this site, particularly during construction and operation of the planned 5th Chinese Antarctic research station.

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References

Aoki S. 2017. Breakup of land-fast sea ice in Lützow-Holm Bay, East Antarctica, and its teleconnection to tropical Pacific sea surface temperatures. Geophys Res Lett, 44: 3219-3227.

Fraser A D, Massom R A, Michael K J, et al. 2012. East Antarctic landfast sea ice distribution and variability, 2000–2008. J Climate, 25(4): 1137-1156.

Heil P. 2006. Atmospheric conditions and fast ice at Davis, East Antarctica: A case study. J Geophys Res-Oceans, 111: C05009.

Lee S K, Volkov D L, Lopez H, et al. 2017. Wind-driven ocean dynamics impact on the contrasting sea-ice trends around West Antarctica. J Geophys Res-Oceans, 122(5): 4413-4430.

Parmiggiani F. 2011. Multi-year measurement of Terra Nova Bay winter polynya extents. Eur Phys J Plus, 126(4): 39.

Shepherd A, Fricker H A, Farrell S L. 2018. Trends and connections across the Antarctic cryosphere. Nature, 558(7709): 223-232.

Shu Q, Qiao F, Song Z, et al. 2012. Sea ice trends in the Antarctic and their relationship to surface air temperature during 1979–2009. Clim Dynam, 38(11-12): 2355-2363.

Turner J, Harangozo S A, Marshall G J, et al. 2002. Anomalous atmospheric circulation over the Weddell Sea, Antarctica during the Austral summer of 2001/02 resulting in extreme sea ice conditions. Geophys Res Lett, 29(24): 2160.

Turner J, Phillips T, Marshall G J, et al. 2017. Unprecedented springtime retreat of Antarctic sea ice in 2016. Geophys Res Lett, 44(13): 6868-6875.

Wang Z, Turner J, Sun B, et al. 2014. Cyclone-induced rapid creation of extreme Antarctic sea ice conditions. Sci Rep, 4: 5317.

World Meteorological Organization (WMO). 1970. WMO sea-ice nomenclature, terminology, codes and illustrated glossary. WMO/DMM/BMO 259-TP-145.

Zhai M, Li X, Hui F, et al. 2015. Sea-ice conditions in the Adélie Depression, Antarctica, during besetment of the icebreaker RV *Xuelong*. Ann Glaciol, 56(69): 160-166.