# Southern Ocean sea ice, icebergs and meteorological data from five logbooks of three vessels that navigated in area in the austral spring to fall seasons of 1929-1930, 1930-1931 and 1932-1933.

Dmitry V. Divine[1], Svetlana Divina[1], Elisabeth Isaksson[1], Harald Dag Jølle[1], Mariela Vasquez Guzman[2] and Clive Wilkinson[3].

1: Norwegian Polar Institute (NPI), Fram Centre, P.O. Box 6606 Langnes, 9296 Tromsø, Norway
2: Norwegian University of Life Sciences, Ås, Norway
3: Climatic Research Unit, University of East Anglia, Norwich, UK

Corresponding author: Dmitry V. Divine; e-mail: dmitry.divine@npolar.no

## 1. Introduction/Motivation

There is a substantial gap in our knowledge of the climate in the Southern Ocean and Antarctica before the IGY-1957 when the first observational network in the region was established. The higher quality regular sea ice data are not available until the start of the satellite-based monitoring in 1979. This limits the skills of climate reanalysis products for the region in the pre-1980 period with implications for understanding the signature and effects of anthropogenic warming in the Antarctic region.

Complementary data sources such as ships' logbooks have proven to be a successful tool in reconstructing past marine climate. Although recent years have seen significant efforts in the recovery of information from ships logbooks, data from the Antarctic region are largely yet to be recovered and analyzed. In contrast to logbooks from infrequent Antarctic expeditions, accounts from commercial vessels are much more abundant and represent a promising source of valuable climate information.

The main goal of the presented work was to initiate the project on reconstruction of past sea ice extent variability in the Southern Ocean. A particular emphasis is made on the Dronning Maud Land (DML) sector of Antarctica which potentially has a wealth of sea ice related information available in the ships logbooks and other related accounts.

As economic activity in the region started as early as in the late 19$^{th}$ century, a growing number of vessels from different national whaling fleets have been active in the area during austral late spring to early fall until the introduction of restrictions on the SO whaling in the late 1960s. The Norwegian fleet operated in the region since the late 19th century with tens of vessels annually present in the whaling grounds of the Southern Ocean. During sailing in high latitudes the relevant information on weather and sea surface conditions including sea ice would be tabulated in a captains/first mate logbook on at least a daily basis. A number of relevant logs archived in the Vestfold library and Whaling history museum in Sandefjord, Norway, were lately imaged and now available for the processing/analysis together with some data sources available from the library of the Norwegian Polar Institute.

## 2. Ships logbooks

In the framework of the pilot study/internal project "Historical sea ice data from the Southern Ocean", four ships logs from the period 1929-1933 were keyed and translated. The logbooks belong to the following research and merchant (whaling) vessels, presented in Table 1:

**Table 1**: Ships logbooks used in reconstruction of sea ice, icebergs and weather conditions in the Southern Ocean for the spring to early fall periods of 1929-1933. Table indicates the logbook periods when vessels were in the waters of the SO. Notations "RV" and "FS" used stand for "Research vessel" and "Whale factory ship", respectively.

| **Vessel name** | **Navigation period keyed/analyzed** | **Source** |
|---|---|---|
| *RV Norvegia* * | 05.10.1929 - 15.03.1930 | NPI library, Tromsø |
| *FS Antarctic* | 29.09.1930 - 11.04.1931 | Vestfold archive, Sandefjord |
| *FS Antarctic* | 09.01.1930 - 16.03.1930 | Vestfold archive, Sandefjord |
| *FS Svend Foyn* + | 10.10.1932 - 21.04.1933 | NPI library, Tromsø |
| *FS Norvegia* ** | 20.10.1930 - 09.02.1931 | NPI library, Tromsø (Divine, 2019) |

* the third *Norvegia* expedition to the SO
** the fourth *Norvegia* expedition to the SO
+ meteorological journal

Note that, we also added a sea ice information from a previously keyed log of *Norvegia* from the austral spring to summer period of 1930-1931 during her fourth expedition to the Southern Ocean and circumnavigation of the Antarctic continent (Divine, 2019).

Though the focus of the work was on recovering sea ice information from the logs, meteorological data and notes on icebergs were keyed and translated too. Of the five logs used in this study, both logs from *Antarctic* and one from *Norvegia* (fourth expedition) were keyed for the meteorological observations. The respective meteorological data from *FS Svend Foyn* and the third expedition of *RV Norvegia* were published and digitized earlier (Mosby, H. 1933), Freeman et al., 2017 (ICOADS archive).

Details on a structure of ships logbooks specific for the focus period follow below.

### 2.1. Logbook ("Dagbook") format for the 1920s-early 1930s.

From about the early 1920s onwards, the logbooks from Norwegian merchant vessels take on a similar format, with only minor but sometimes important differences to the layout and the data recorded. Care must be taken, when keying numerical data from these logs, that notice is taken of the format, as changes in recording practice appear to follow the format of the logbook rather than any set date or time period. Figure 1a shows an example page from the logbook used in this study, belonging the factory vessel *Antarctic* for the 12.10.1930, the whaling season of the 1930-1931.

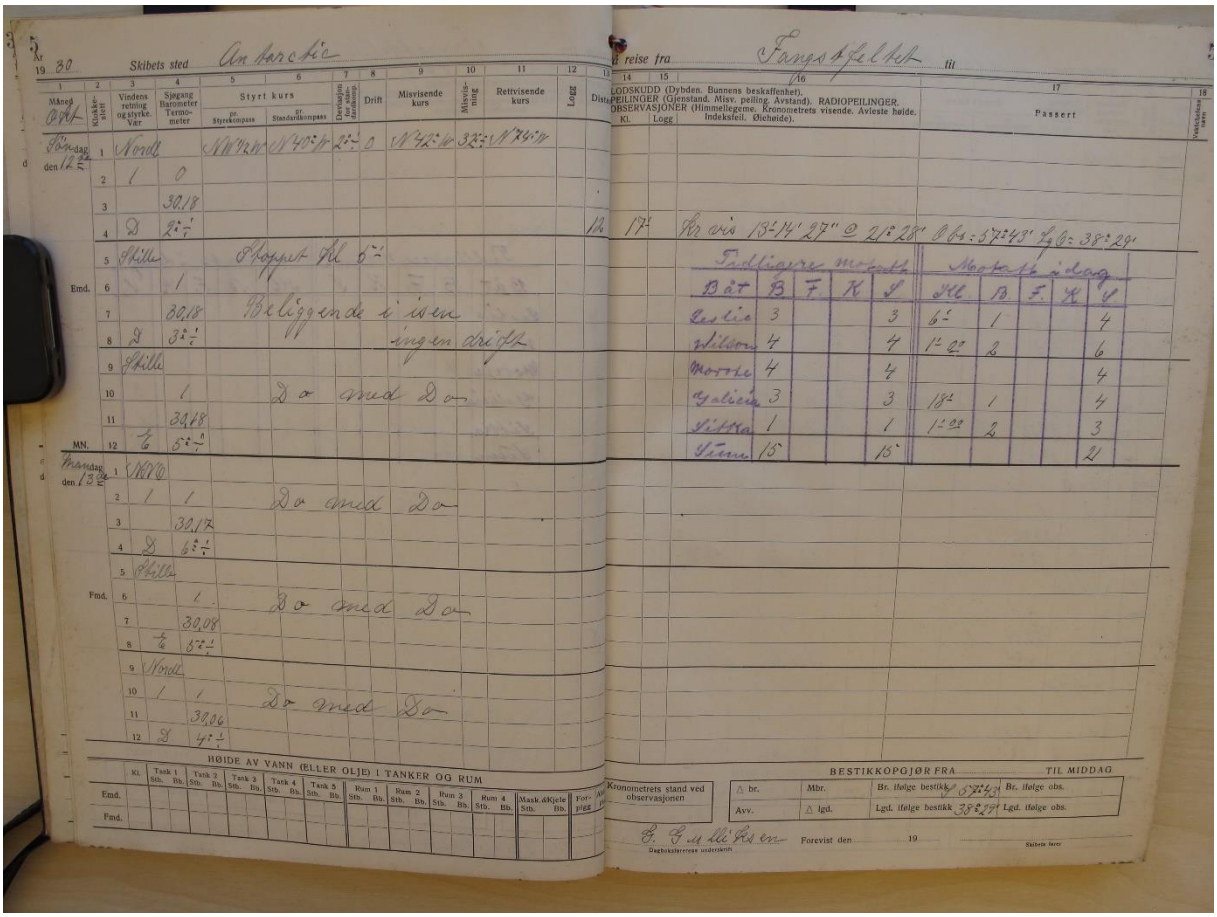
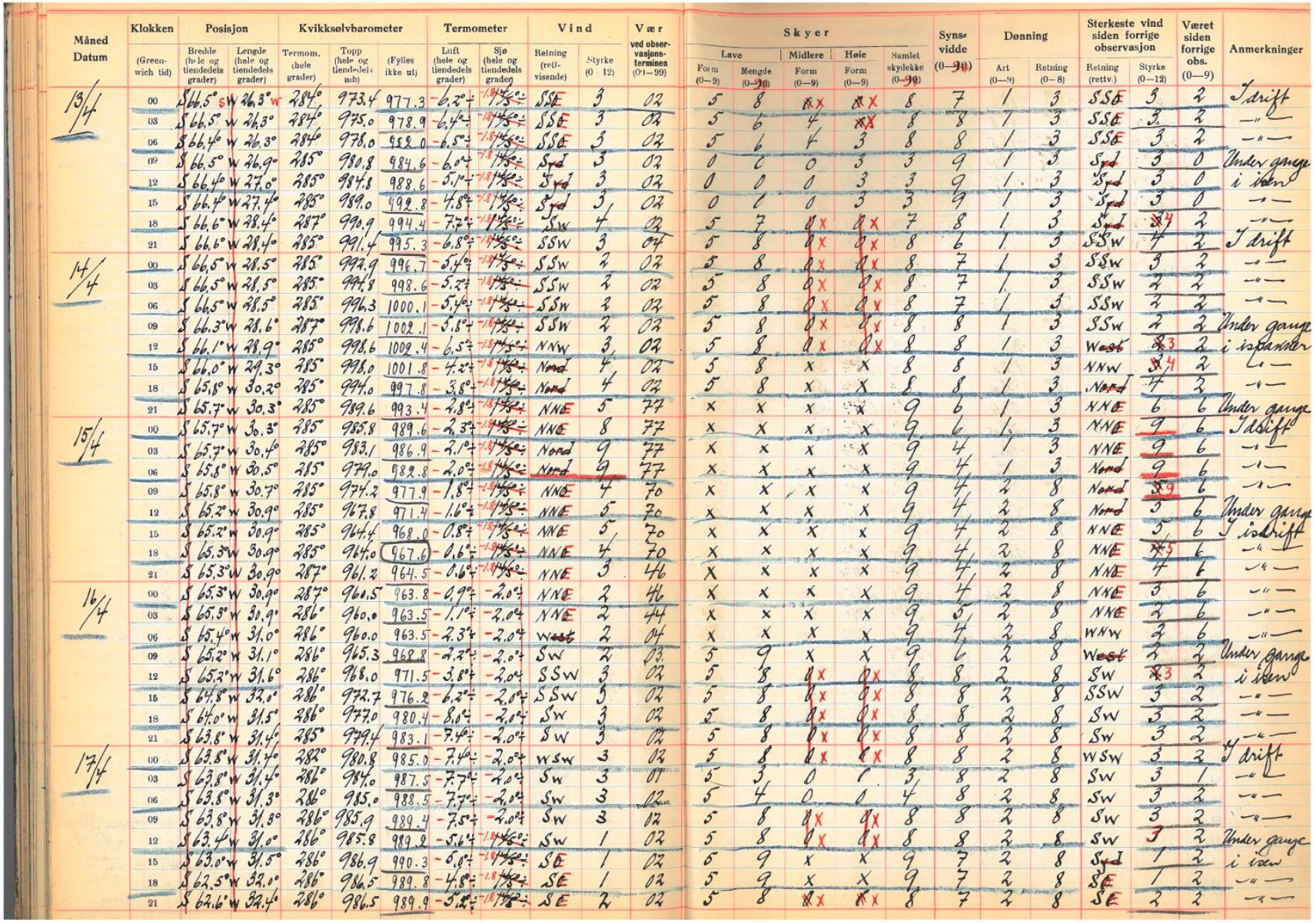


**Figure 1a.** Example image of the double facing page from logbook ("Dæksdagbok") of factory ship *Antarctic* for 12-13.10.1930.

The analyzed logs consist of double facing pages with information for one full day (24 hours) at a view. The important point to note however is the unique dating format. The logbook page conforms to the "nautical day", a convention common to merchant ships from the earliest times until the early 20th century. With this convention the ship's day or nautical day commences and ends at noon, the first hourly entry at the top of the page being at 1pm and the last hourly entry at the bottom of the page being noon of the following day. The nautical day was therefore 12 hours ahead of the civil day, the date actually changing at noon and not midnight. The Norwegian logbooks conform to the nautical day as far as the page layout is concerned but conform to the civil day by double dating the page. This is farther confirmed by the "Emd" and "Fmd" notations on the lefthand side of the log, indicating, respectively, Afternoon (ettermiddag) and Morning (formiddag) halves of the day. This means that although the nautical day format is used, there is no need to convert the first half of the page back to the "civil" date. The respective note on the date format made was provided in the Metadata.

The vessels position is logged at the bottom of the right-hand page. The box marked *Br. Ifølge bestikk* is the estimated latitude and the box marked *Lgd. Ifølge bestikk* is the estimated longitude. These positions are estimated from the vessel's course speed and drift over the preceding 24-hour period. In the adjacent boxes, the word *bestikk* is substituted by *obs.*, and these are the corresponding observed positions. Longitudes marked "V" are west and those marked "O" or "Ø" are east. These boxes are only completed on those days where a solar or celestial observation were possible. Both coordinates were keyed. Typically, whenever available, the observation-based position was given a preference.

For this study we also use the sea ice information aggregated in the meteorological journal of *FS Svend Foyn* (see example image in Figure 1b).



| Måned Datum | Klokken (Greenwich tid) | Posisjon Bredde (hele og tiendedels grader) | Posisjon Lengde (hele og tiendedels grader) | Kvikksølvbarometer Termom. (hele grader) | Kvikksølvbarometer Topp (hele og tiendedels mb) | Kvikksølvbarometer (Fylles ikke ut) | Termometer Luft (hele og tiendedels grader) | Termometer Sjø (hele og tiendedels grader) | Vind Retning (retn-visende) | Vind Styrke (0–12) | Vær ved observasjonsterminen (0–99) | Skyer Lave Form (0–9) | Skyer Lave Mengde (0–9) | Skyer Midlere Form (0–9) | Skyer Høie Form (0–9) | Skyer Samlet skydekke (0–9) | Synsvidde (0–9) | Dønning Art (0–9) | Dønning Retning (0–8) | Sterkeste vind siden forrige observasjon Retning (rettv.) | Sterkeste vind siden forrige observasjon Styrke (0–12) | Været siden forrige obs. (0–9) | Anmerkninger |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13/4 | 00 | S 66.5° W | 26.3° W | 284° | 973.4 | 977.3 | −6.2° | −1.8° | SSE | 3 | 02 | 5 | 8 | X | X | 8 | 7 | 1 | 3 | SSE | 3 | 2 | I drift |
| | 03 | S 66.5° W | 26.3° | 284° | 975.0 | 978.9 | −6.4° | −1.8° | SSE | 3 | 02 | 5 | 6 | 4 | X | 8 | 8 | 1 | 3 | SSE | 3 | 2 | —" — |
| | 06 | S 66.4° W | 26.3° | 284° | 978.0 | 982.0 | −6.5° | −1.8° | SSE | 3 | 02 | 5 | 6 | 4 | 3 | 8 | 8 | 1 | 3 | SSE | 3 | 2 | —" — |
| | 09 | S 66.5° W | 26.9° | 285° | 980.8 | 984.6 | −6.0° | −1.8° | Syd | 3 | 02 | 0 | 0 | 0 | 3 | 3 | 9 | 1 | 3 | Syd | 3 | 0 | Under garage |
| | 12 | S 66.4° W | 27.0° | 285° | 984.8 | 988.6 | −5.1° | −1.8° | Syd | 3 | 02 | 0 | 0 | 0 | 3 | 3 | 9 | 1 | 3 | Syd | 3 | 0 | i isen |
| | 15 | S 66.4° W | 27.4° | 285° | 989.0 | 992.8 | −4.8° | −1.8° | Syd | 3 | 02 | 0 | 0 | 0 | 3 | 3 | 9 | 1 | 3 | Syd | 3 | 0 | —" — |
| | 18 | S 66.6° W | 28.4° | 287° | 990.9 | 994.4 | −7.2° | −1.8° | SW | 4 | 02 | 5 | 7 | X | X | 7 | 8 | 1 | 3 | Syd | 4 | 2 | —" — |
| | 21 | S 66.6° W | 28.4° | 285° | 991.4 | 995.3 | −6.8° | −1.8° | SSW | 3 | 04 | 5 | 8 | X | X | 8 | 6 | 1 | 3 | SSW | 4 | 2 | I drift |
| 14/4 | 00 | S 66.5° W | 28.5° | 285° | 992.9 | 996.7 | −5.4° | −1.8° | SSW | 2 | 02 | 5 | 8 | X | X | 8 | 7 | 1 | 3 | SSW | 3 | 2 | —" — |
| | 03 | S 66.5° W | 28.5° | 285° | 994.8 | 998.6 | −5.2° | −1.8° | SSW | 2 | 02 | 5 | 8 | X | X | 8 | 7 | 1 | 3 | SSW | 2 | 2 | —" — |
| | 06 | S 66.5° W | 28.5° | 285° | 996.3 | 1000.1 | −5.4° | −1.8° | SSW | 2 | 02 | 5 | 8 | X | X | 8 | 7 | 1 | 3 | SSW | 2 | 2 | —" — |
| | 09 | S 66.3° W | 28.6° | 287° | 998.6 | 1002.1 | −5.8° | −1.8° | SSW | 2 | 02 | 5 | 8 | X | X | 8 | 8 | 1 | 3 | SSW | 2 | 2 | Under garage |
| | 12 | S 66.1° W | 28.9° | 285° | 998.6 | 1002.4 | −6.5° | −1.8° | NNW | 3 | 02 | 5 | 8 | X | X | 8 | 8 | 1 | 3 | West | X3 | 2 | i isparsler |
| | 15 | S 66.0° W | 29.3° | 285° | 998.0 | 1001.8 | −4.2° | −1.8° | Nord | 4 | 02 | 5 | 8 | X | X | 8 | 8 | 1 | 3 | NNW | X4 | 2 | —" — |
| | 18 | S 65.8° W | 30.2° | 285° | 994.0 | 997.8 | −3.8° | −1.8° | Nord | 4 | 02 | 5 | 8 | X | X | 8 | 8 | 1 | 3 | Nord | 4 | 2 | —" — |
| | 21 | S 65.7° W | 30.3° | 285° | 989.6 | 993.4 | −2.8° | −1.8° | NNE | 5 | 77 | X | X | X | X | 9 | 6 | 1 | 3 | NNE | 6 | 6 | Under garage |
| 15/4 | 00 | S 65.7° W | 30.3° | 285° | 985.8 | 989.6 | −2.3° | −1.8° | NNE | 8 | 77 | X | X | X | X | 9 | 6 | 1 | 3 | NNE | 9 | 6 | I drift |
| | 03 | S 65.7° W | 30.4° | 285° | 983.1 | 986.9 | −2.1° | −1.8° | Nord | 9 | 77 | X | X | X | X | 9 | 4 | 1 | 3 | NNE | 9 | 6 | —" — |
| | 06 | S 65.8° W | 30.5° | 285° | 979.0 | 982.8 | −2.0° | −1.8° | Nord | 9 | 77 | X | X | X | X | 9 | 4 | 1 | 3 | Nord | 9 | 6 | —" — |
| | 09 | S 65.8° W | 30.7° | 285° | 974.2 | 977.9 | −1.8° | −1.8° | NNE | 4 | 70 | X | X | X | X | 9 | 4 | 2 | 8 | Nord | X9 | 6 | —" — |
| | 12 | S 65.2° W | 30.9° | 285° | 967.8 | 971.4 | −1.6° | −1.8° | NNE | 5 | 70 | X | X | X | X | 9 | 4 | 2 | 8 | Nord | 3 | 6 | Under garage |
| | 15 | S 65.2° W | 30.9° | 285° | 964.4 | 968.0 | −0.8° | −1.8° | NNE | 5 | 70 | X | X | X | X | 9 | 4 | 2 | 8 | NNE | 5 | 6 | I isdrift |
| | 18 | S 65.3° W | 30.9° | 285° | 964.0 | 967.6 | −0.6° | −1.8° | NNE | 4 | 70 | X | X | X | X | 9 | 4 | 2 | 8 | NNE | X5 | 6 | —" — |
| | 21 | S 65.3° W | 30.9° | 287° | 961.2 | 964.5 | −0.6° | −1.8° | NNE | 3 | 46 | X | X | X | X | 9 | 4 | 2 | 8 | NNE | 4 | 6 | —" — |
| 16/4 | 00 | S 65.3° W | 30.9° | 287° | 960.5 | 963.8 | −0.9° | −2.0° | NNE | 2 | 46 | X | X | X | X | 9 | 4 | 2 | 8 | NNE | 3 | 6 | —" — |
| | 03 | S 65.3° W | 30.9° | 286° | 960.0 | 963.5 | −1.1° | −2.0° | NNE | 2 | 44 | X | X | X | X | 9 | 5 | 2 | 8 | NNE | 2 | 6 | —" — |
| | 06 | S 65.4° W | 31.0° | 286° | 960.0 | 963.5 | −2.3° | −2.0° | West | 2 | 04 | X | X | X | X | 9 | 4 | 2 | 8 | WNW | 2 | 6 | —" — |
| | 09 | S 65.2° W | 31.1° | 286° | 965.3 | 968.8 | −2.7° | −2.0° | SW | 2 | 03 | 5 | 9 | X | X | 9 | 6 | 2 | 8 | West | 2 | 2 | Under garage |
| | 12 | S 65.2° W | 31.6° | 286° | 968.0 | 971.5 | −3.8° | −2.0° | SSW | 3 | 02 | 5 | 8 | X | X | 8 | 8 | 2 | 8 | SW | X3 | 2 | i isen |
| | 15 | S 64.8° W | 32.0° | 286° | 972.7 | 976.2 | −6.2° | −2.0° | SSW | 3 | 02 | 5 | 8 | X | X | 8 | 8 | 2 | 8 | SSW | 3 | 2 | —" — |
| | 18 | S 64.0° W | 31.5° | 286° | 977.0 | 980.4 | −8.0° | −2.0° | SW | 3 | 02 | 5 | 8 | X | X | 8 | 8 | 2 | 8 | SW | 3 | 2 | —" — |
| | 21 | S 63.8° W | 31.4° | 285° | 979.4 | 983.1 | −7.4° | −2.0° | SW | 3 | 02 | 5 | 8 | X | X | 8 | 8 | 2 | 8 | SW | 3 | 2 | —" — |
| 17/4 | 00 | S 63.8° W | 31.4° | 282° | 980.8 | 985.0 | −7.4° | −2.0° | WSW | 3 | 02 | 5 | 8 | X | X | 8 | 8 | 2 | 8 | WSW | 3 | 2 | I drift |
| | 03 | S 63.8° W | 31.4° | 286° | 984.0 | 987.5 | −7.7° | −2.0° | SW | 3 | 01 | 5 | 3 | 0 | 1 | 3 | 8 | 2 | 8 | SW | 3 | 1 | —" — |
| | 06 | S 63.8° W | 31.3° | 286° | 985.0 | 988.5 | −7.7° | −2.0° | SW | 3 | 02 | 5 | 4 | 0 | 0 | 4 | 8 | 2 | 8 | SW | 3 | 2 | —" — |
| | 09 | S 63.8° W | 31.3° | 286° | 985.9 | 989.4 | −7.5° | −2.0° | SW | 3 | 02 | 5 | 8 | X | X | 8 | 8 | 2 | 8 | SW | 3 | 2 | —" — |
| | 12 | S 63.4° W | 31.0° | 286° | 985.8 | 989.2 | −5.6° | −1.8° | SW | 1 | 02 | 5 | 8 | X | X | 8 | 8 | 2 | 8 | SW | 3 | 2 | Under garage |
| | 15 | S 63.0° W | 31.5° | 286° | 986.9 | 990.3 | −6.0° | −1.8° | SE | 1 | 02 | 6 | 9 | X | X | 9 | 7 | 2 | 8 | Syd | 1 | 2 | i isen |
| | 18 | S 62.5° W | 32.0° | 286° | 986.5 | 989.8 | −4.8° | −1.8° | SE | 1 | 02 | 5 | 9 | X | X | 9 | 7 | 2 | 8 | SE | 1 | 2 | —" — |
| | 21 | S 62.6° W | 32.4° | 286° | 986.5 | 989.9 | −3.2° | −1.8° | SE | 2 | 02 | 5 | 8 | X | X | 8 | 7 | 2 | 8 | SE | 2 | 2 | —" — |

**Figure 1b.** Example image of the double facing page from meteorological journal of *FS Svend Foyn* for 13-17.04.1933.

The journal contains notes on sea ice and icebergs logged along with meteorological and sea state observations as well as vessel coordinates per noon.

## 3. Observations and data format.

### 3.1. Meteorological observations

In the example of the logbook ("Dagbook") page in Fig. 1a the left-hand corner clearly shows the '*År*' or year, the '*Måned*' or month and the '*Dag*' or day.
Column 3, '*Vindens retning og stryke. Vær*' , records observations of wind direction, wind force and weather. The three observations are always in this order and recorded every four hours. Wind directions are according to the cardinal points of the compass and the wind force is according to a seven-point scale. Note that this is not a Beaufort Scale. Weather is logged using 12 categories covering distinct weather phenomena and/or state of the sky.
Column 4, '*Sjøgang*, *Barometer*, *Termometer*', are sea swell, barometric pressure and air temperature. Observations are recorded in this order although many of the logbooks do not record the air temperature. The observations of sea swell are according to a seven-point scale.
Barometric pressure units vary between the logs and depend on most likely on the instrument used onboard. In the case of the logs analyzed in this study, these were in mm(cm) or inches of mercury. Identifying the type of the units used was straightforward.

Measured air (and occasionally sea surface) temperatures below and above zero would be indicated by the "÷" and "+" signs, respectively.

The page marked '*Tegnforklaringer*' at the beginning of each logbook (see Fig. 2) presents standardized tables with various scales/categories used for making observations. Tables 2-4 for the three main scales/categories are shown below along with English translations. Some of the terms used are not from the modern Norwegian language, being closer to Danish, same as the language used for logging various textual information in the analyzed logbooks.

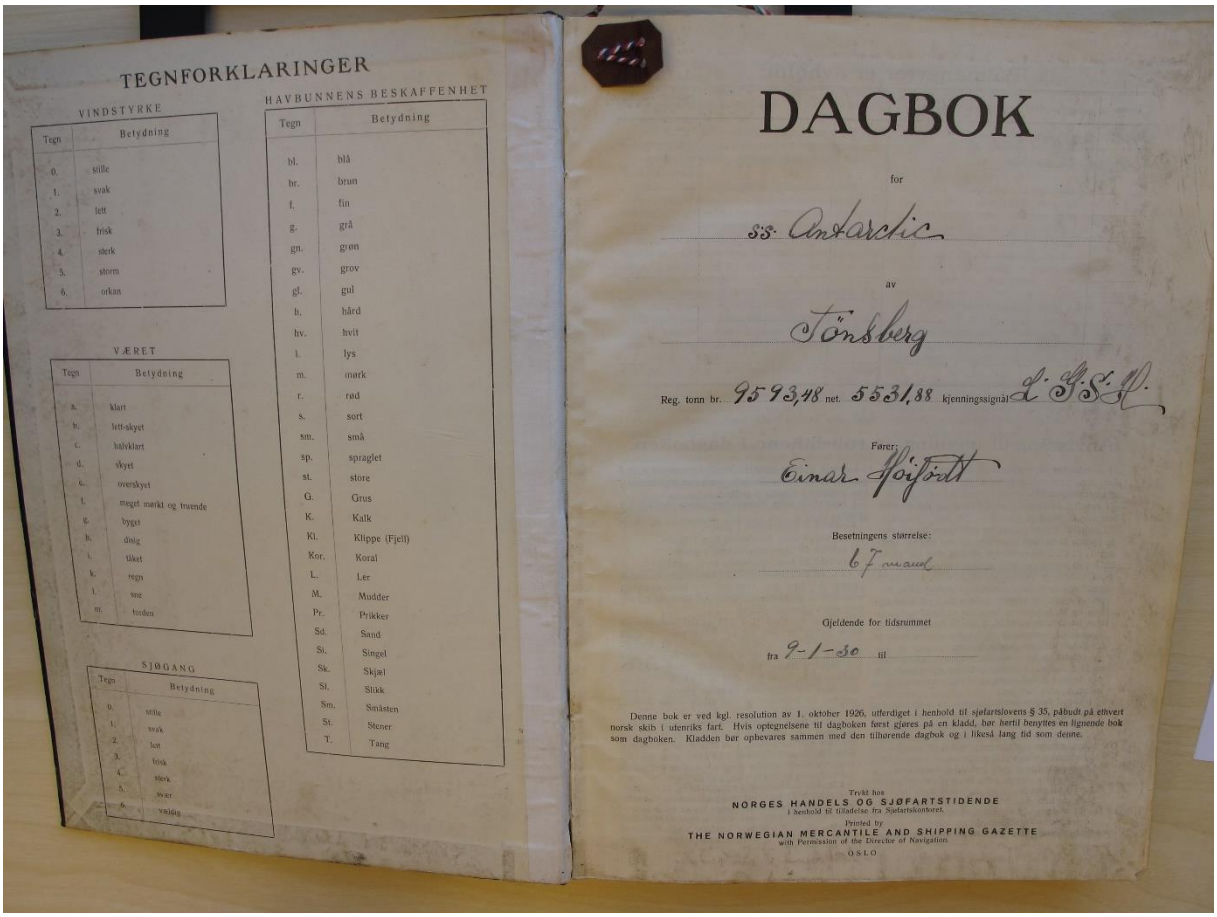



**Figure 2.** Example image of the front double facing page from a logbook of FS *Antarctic* showing on the left-hand page the standardized tables with various scales/categories used for making weather and ocean surface observations.

**Table 2.** Wind force categories used in the Norwegian logbooks of the studied period. Conversion to the Beaufort scale is yet to be made.

| **Vindstyrke (Wind force/Wind Speed)** | | |
|---|---|---|
| **Tegn (category)** | **Betydning (Meaning)** | **English Translation** |
| **0** | Stille | Quiet or still |
| **1** | Svak | Gentle / Weak |
| **2** | Lett | Easy/Light |
| **3** | Frisk | Fresh |
| **4** | Sterk | Strong |
| **5** | Storm | Storm |
| **6** | Orkan | Hurricane |

**Table 3.** Weather and state of the sky indices/categories used in the Norwegian logbooks of the studied period. Note that for the amount of cloud cover the approximate conversion to scale in octas (eights) is also given.

| **Været (Weather)** | | |
|---|---|---|
| **Tegn (category)** | **Betydning (Meaning)** | **English Translation/Scale in oktas** |
| **a** | Kart | Clear 0/8 - 1/8 |
| **b** | Lett-skyet | Partly cloudy 2/8 - 3/8 |
| **c** | Halvklart | Half cloudy 4/8 - 5/8 |
| **d** | Skyet | Cloudy 6/8 - 7/8 |
| **e** | Overskyet | Overcast 8/8 |
| **f** | Meget mørkt og truende | Very dark and threatening |
| **g** | Byget | Showers (snow, rain) |
| **h** | Disig | Hazy |
| **i** | Tåket | Foggy |
| **k** | Regn | Rain |
| **l** | Sne | Snow |
| **m** | Torden | Thunder |

**Table 4.** Sea state categories used in the Norwegian logbooks of the period. Conversion to the modern scale yet to be made.

| **Sjøgang (Swell)** | | |
|---|---|---|
| **Tegn (sign)** | **Betydning (Meaning)** | **English Translation** |
| **0** | Stille | Quiet/Calm/Still |
| **1** | Svak | Weak/Smooth |
| **2** | Lett | Easy, Slight |
| **3** | Frisk | Fresh/Moderate |
| **4** | Sterk | Strong/Rough/Very rough |
| **5** | Svær | Severe/High |
| **6** | Vældig | Very high/Phenomenal |

### 3.2 Sea ice and icebergs observations

When a vessel was positioned within or near ice pack, the respective note would typically be made in the logbook every four hours. For the period considered, a system for logging sea ice conditions was not yet well established on Norwegian vessels. The notes on sea ice as well the observational practices are therefore not standardized and tend to vary between the vessels/observers.

During periods with no ice presence while in the areas where sea ice could already be encountered/expected, the open water conditions were typically logged as well. Often, the open water state could also be recovered by references to a rough sea state and a vessel rolling.

For the type of logbook shown in Fig.1a, the notes on sea ice are found on a left-hand side of the double facing page, registered after the information on weather and state of the sea. In the example image “beliggende I isen, ingen drift” (English: “positioned in the ice, no drift”) followed by “Do”

(abbreviation for «ditto» or «det samme» meaning “the same” in English) below indicates a vessel located and drifting in pack ice throughout the period covered by the page.

In the meteorological journal shown in Fig.1b, the project relevant sea ice and iceberg notes are logged in the right-hand side, the rightmost column of the double facing page of the journal. For this journal, the notes have typically a standard format and can be categorized into a few states of sea ice cover. Notes found in the example page “Under gang i isen” (Eng: “steaming in the ice”) and “under gang i iskanten” (Eng: “steaming along the ice edge”) suggest disambigiously the vessel location in ice-covered waters. Rules applied to convert the textual information into sea ice concentration are presented below in Section 4.2

Though the recovered information on the state of sea ice is not properly or systematically categorized, one should note that taking the vessel types, dimensions as well as their operational conditions (whale hunting) into consideration, in the majority of cases the logged sea ice notes should be associated with a relatively loose ice pack. As hunting for whales was mainly conducted from relatively small wooden vessels with displacement below 400-500 tonns, their capability for navigation in the areas with a higher fractional coverage of sea ice would be limited. This state of ice cover would correspond to the categories of “very open” to “open drift ice”, i.e. ice concentration of 1/10 - 3/10 and ice concentration of 4/10 - 6/10, respectively, according to WMO sea ice nomenclature (JCOMM Expert Team on Sea Ice, WMO, 2015).

The logbook from *FS Antarctic* from 27.03.1931 documents the situation with two whaling boats stuck in the compacted ice: “*…maatte la gaa 1 Finhval …isen var tetnet saa der var vanskelig at komme ut.* ”. Later in the afternoon, the logbook reports on the maneuvering of the factory in ice pack to release the hunting vessel “*Leslie*” : “*…manavrede in i isen for at hjelpe Leslie ut.*”

It suggests that the observed/logged sea ice can broadly fall into three categories equivalent to the modern WMO Sea-Ice Nomenclature in terms of sea ice concentration (or areal sea ice coverage).

Open water: no sea ice or sea ice at concentration below 0.1 (10%)

Very open (drift) ice: ice with concentration 0.1 - 0.3 (10-30%)

Open (drift) ice: ice with concentration 0.4-0.6 (40-60%)

Close (pack, drift) ice: ice with concentration >0.7 (>70%)

Sea ice edge – ice concentration 0.15 (15%)

Note that ice edge is associated with the ice concentration of 15%, in accordance with the WMO nomenclature. A list of typical notes related with the state of ice cover or the vessels navigation in sea ice is presented in Table 5 below:

**Table 5.** Typical notes on sea ice/icebergs and a vessel navigation in or near sea ice pack as found in the analyzed logs together with the respective English translations. The list is not comprehensive, as at that time a common routine of logging sea ice information was not yet established.

| **Sea ice note in Norwegian** | **English translation** |
|---|---|
| skibet gaar öst langs iskanten | vessel heading East along ice edge |
| skibet gaar öst gjennom enkelte ispakker | vessel heading East through loose ice patches |
| Skibet gaar östover gjennom enkelte ispakker | vessel heading East through loose ice patches |
| Gaar langs iskanten östover | vessel heading East along ice edge |
| I drift ved (utenfor) iskanten | vessel is adrift at (outside) ice edge |

| | |
|---|---|
| gaar gjennom store mangda is | vessel going through heavy/close pack ice |
| driver i isen | vessel steaming in the ice |
| drift i isen | vessel adrift in the ice |
| Beliggende i isen/ligger i isen | vessel (adrift) in ice pack |
| Beliggende ved iskanten | vessel (adrift) at ice edge |
| Enkelte isfjell | Separate (solitary) icebergs |
| Gik i pakisens ytterkant | Sailed along the edge of pack ice |
| Gik i slak pakis | Sailed in very open (loose) drift ice |
| Spredte isfjeld | Scattered icebergs |
| Mange (masse) isfjeld | Numerous icebergs |

## 4. Results

### 4.1. Summary of the recovered information

The following information was recovered from the keyed and translated logbooks.

*FS Antarctic*: sea ice notes, icebergs, meteorological information, state of sea surface.

*RV Norvegia*: sea ice notes, icebergs; meteorological information (4$^{th}$ expedition only).

*FS Svend Foyn***:** sea ice notes, icebergs.

We note that a detailed meteorological information from the third expedition of *RV Norvegia* and *FS Svend Foyn* were not keyed/digitized in this study. These data were published earlier in Mosby, (1933); (third *RV Norvegia* voyage) and incorporated into ICOADS archive (Freeman et al., 2017; also for *FS Svend Foyn*).

### 4.2. Logging the recovered data and the inferred sea ice concentrations and icebergs information.

The keyed data were logged in Excel spreadsheets of a common format (see **Supplementary materials** for the workbook data structure) partly replicating the original log in order to simplify data crosschecks both between the vessels and with the original documents. Every file contains a relevant metadata also presenting basic information on the vessel found on the first double facing page of the logbook. Both the original notes in Norwegian and their English translations were logged in the files.

The inferred ice concentrations are based on the presented narrative (textual) sea ice information (see examples in Table 5).

The following conversion rules apply (**Table 6**):

| Relevant information in the logbook | Inferred sea ice concentration | Sea ice concentration according to WMO nomenclature |
|---|---|---|
| A) Vessel reported to be adrift or steam in open water.<br>B) No information on ice conditions provided, and/or rough sea and strong/violent vessel rolling is reported. | 0 | Open water |
| Vessel reported to be adrift or steaming in the vicinity of sea ice edge | 0.15 (15%) | Very open (drift) ice |

| | | |
|---|---|---|
| Vessel travels in waters with solitary floes or very loose pack ice | 0.1 (10%) | Very open (drift) ice |
| Vessel adrift, or reported to steam with variable courses in pack ice | 0.30 (30%) | Very open (drift) ice |
| Vessel adrift, or reported to steam in heavy pack ice | 0.4-0.6 (40-60%) | Open (drift) ice |
| Vessel navigation reported to be seriously hindered by pack ice (see 3.2. for the example of such report) | 0.7 (70%) and higher | Close – Very close - Consolidated – Compact (drift) ice |

Iceberg reports are binned into two categories: solitary icebergs (1) and multiple icebergs (2).

The first two inferred categories of the state of sea ice (sea ice edge and very open drift ice) are the most frequent in the analyzed logbooks.

**4.2. Summary of the inferred sea ice concentration from five voyages**

Preliminary results of the recovered data analysis are presented below. Figure 3 demonstrates a compilation of ships tracks for the five analyzed voyages. A majority of the recovered daily positions is for the areas of the Atlantic and Indian oceans sector of the Southern Ocean. Note that the data covers the months from earliest October to latest April, thereby nearly encompassing the months of maximum and minimum sea ice extent in the Southern Ocean. As October data is not yet abundant in this study, we focus on November as a month close to the seasonal sea ice extent maximum in the area that according to modern satellite observations may occur during September to November.

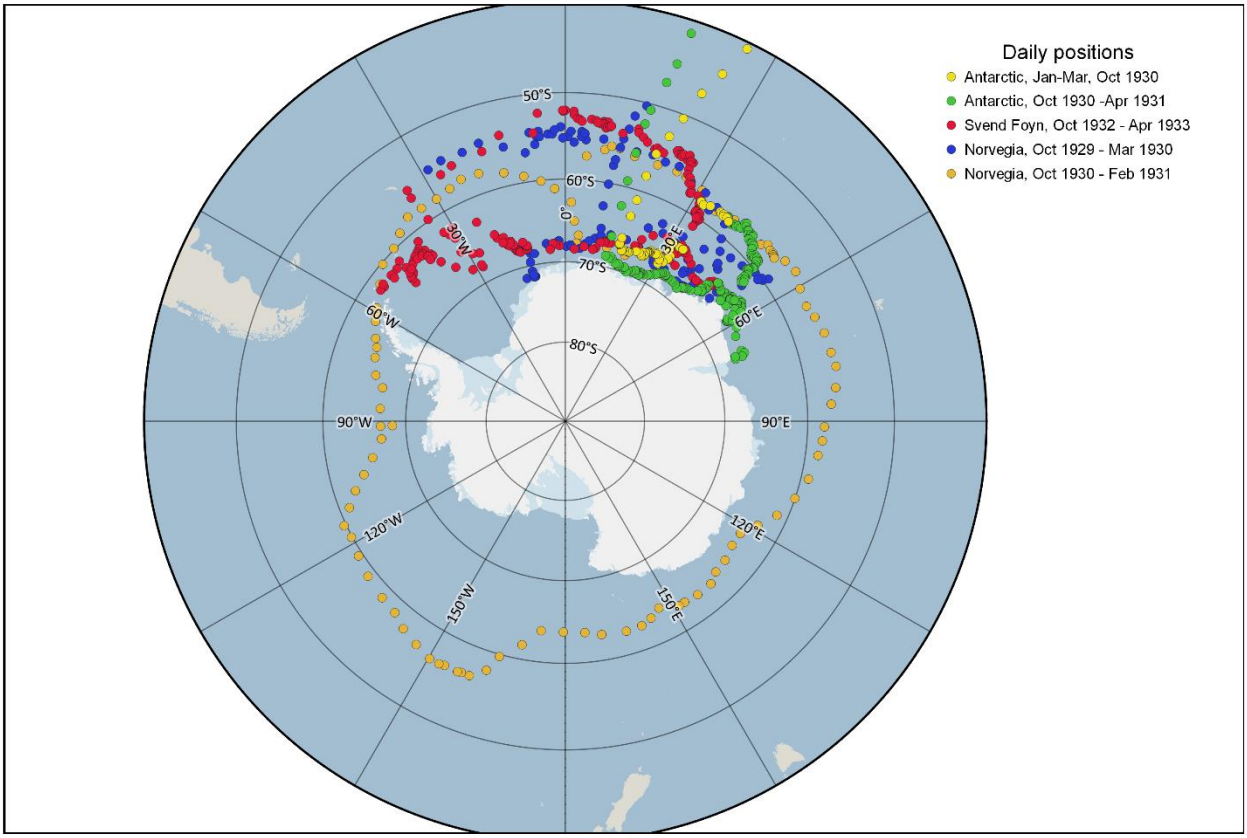



**Figure 3** Daily positions, per 12:00 local time, of RV *Norvegia*, FS *Svend Foyn* and FS *Antarctic* in the Southern Ocean based on their five digitized/analyzed voyages in 1929-1933.

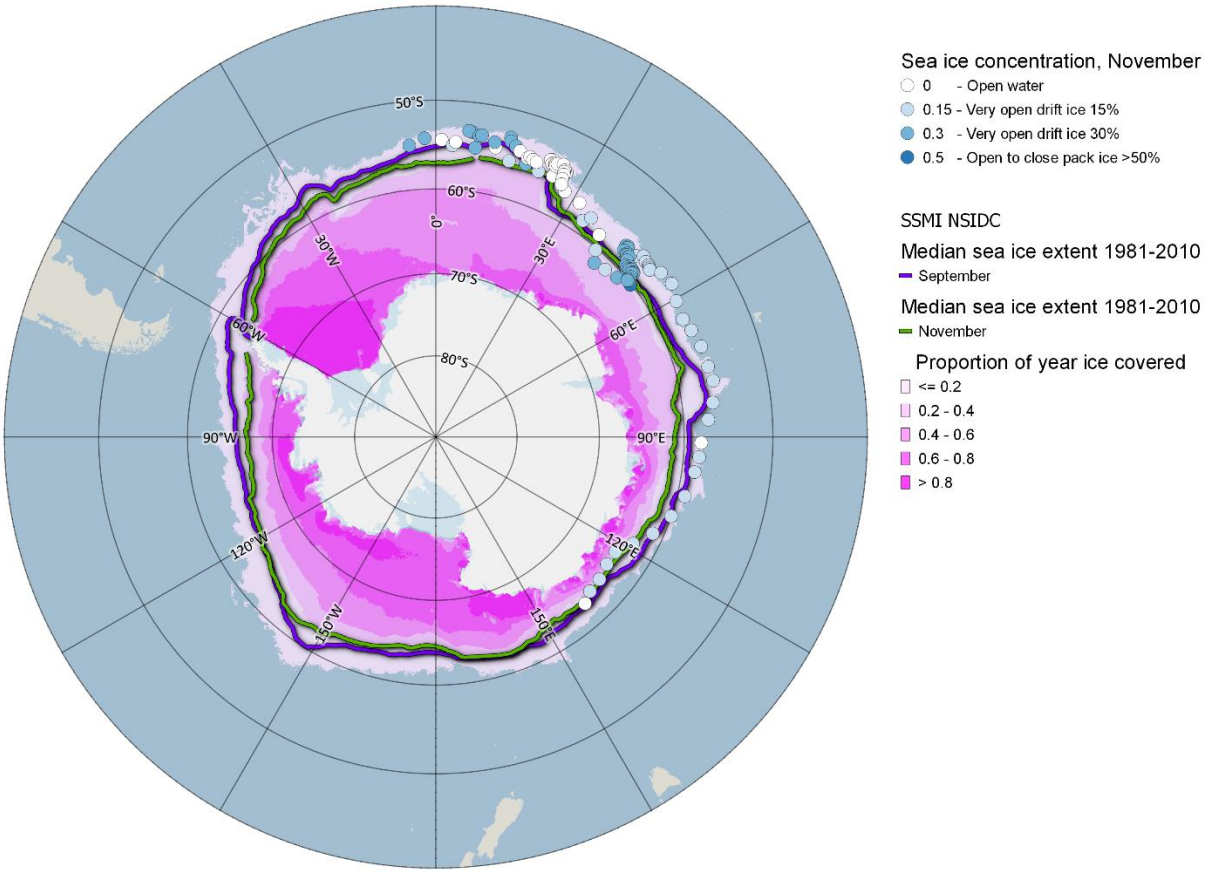



**Figure 4** Inferred sea ice concentration for November, the month close to the seasonal sea ice maximum in the Southern Ocean. The dots indicate the vessels position and observed (inferred) ice concentration. Light blue is for the 15% ice concentration (interpreted/reported as ice edge), while darker blue is used for the 30% ice concentration and higher. White dots indicate open water conditions. Blue and green lines indicate median sea ice edge positions (based on 15% ice concentration) from SSMI NSIDC satellite observations for the period 1981-2010 for September and November, respectively. Spatial distribution for proportion of year with sea ice presence over the 1981-2010 period is shown with grades of purple.

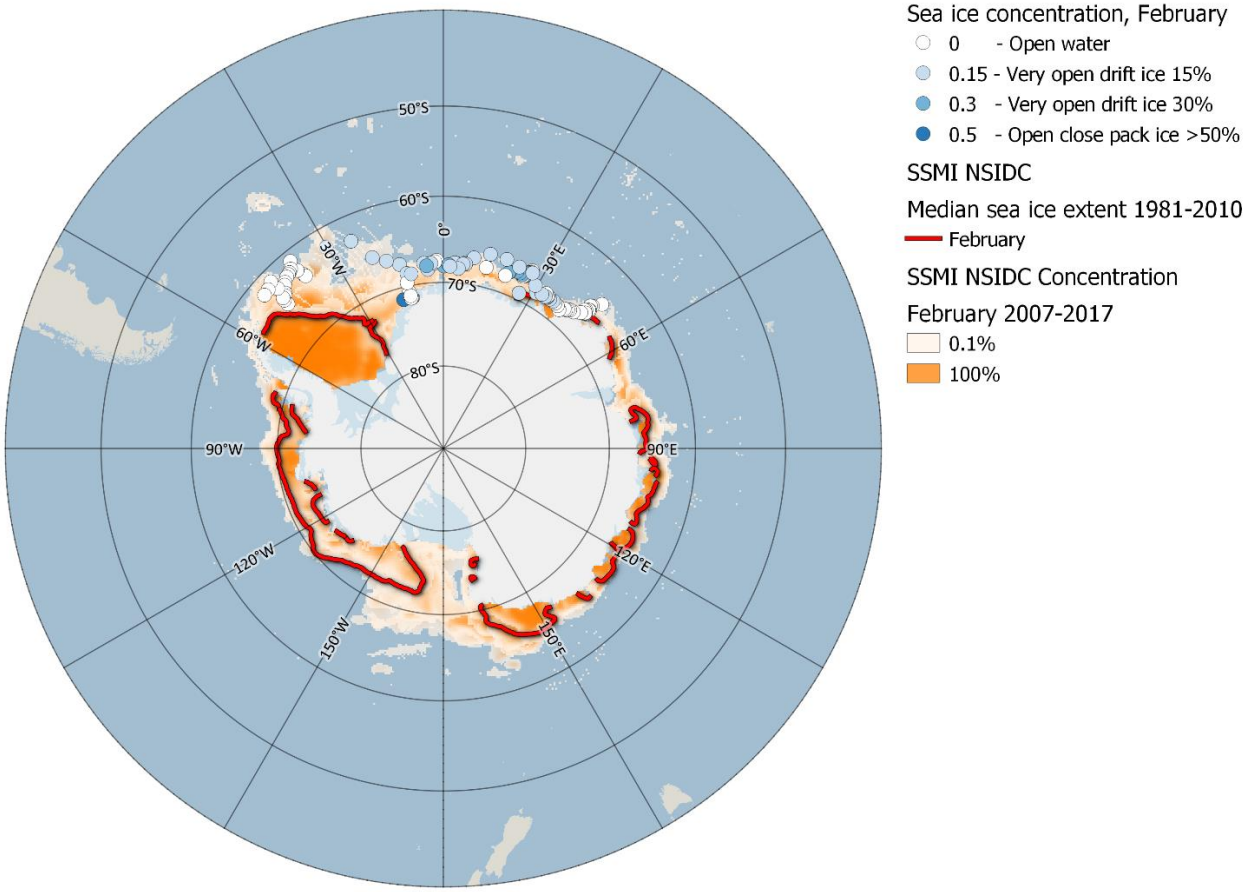



**Figure 5** Inferred sea ice concentration for February, the month of seasonal sea ice minimum in the Southern Ocean according to SSMI NSIDC satellite observations for the period 1981-2010. The dots indicate the vessels position and observed (inferred) ice concentration. Light blue is for the 15% ice concentration (interpreted/reported as ice edge), while darker blue is used for the 30% ice concentration and higher. White dots indicate open water conditions. Red line indicates median February sea ice edge position (based on 15% ice concentration) from SSMI satellite observations for the period 1981-2010. Sea ice presence probability density for February over 1981-2010 is shown with grades of orange.

Analysis of an aggregate of five reports on sea ice presence for the two specific months during 1929-1933 often associated with sea ice maximums (Figure 4) and minimums (Figure 5) demonstrates:

***Month close to austral winter sea ice maximum (November)***

Preliminary results suggest a slightly more northward position of winter sea ice extent in the region for the three austral winter seasons analyzed here, compared to the modern *average* sea ice edge position over the period of satellite observations of 1981-2010. In particular, the ice was observed some 2-4 degrees to the north from its present median position. However, comparison with satellite observations clearly demonstrates that the past ice edge position mainly lies within the natural variability over the satellite period. In particular, Figure 4 shows the majority of circles marked “ice” to be located within the colored area, indicating possible modern sea ice presence there. The only exception is found in the Indian sector of the SO, where some recovered daily ships positions next to the past ice edge lie outside the contemporary seasonal zone.

***Austral summer sea ice minimum (February)***

Data for summer minimum shows a slightly higher past summer sea ice extent in the region, compared to the modern *average* sea ice edge position over the period of satellite observations of 1981-2010. In particular, the ice was observed some 2-3 degrees to the north from its present median position. However, similar to winter sea ice maximum, past sea ice observations for February still lie within the natural variability over the satellite period (see Figure 5).

### 4.3. Summary of iceberg observations from five voyages

Icebergs reports recovered from the data are demonstrated on the figure below. The iceberg accounts are primarily found in the logbooks from *Norvegia* voyages and roughy categorized in two groups.

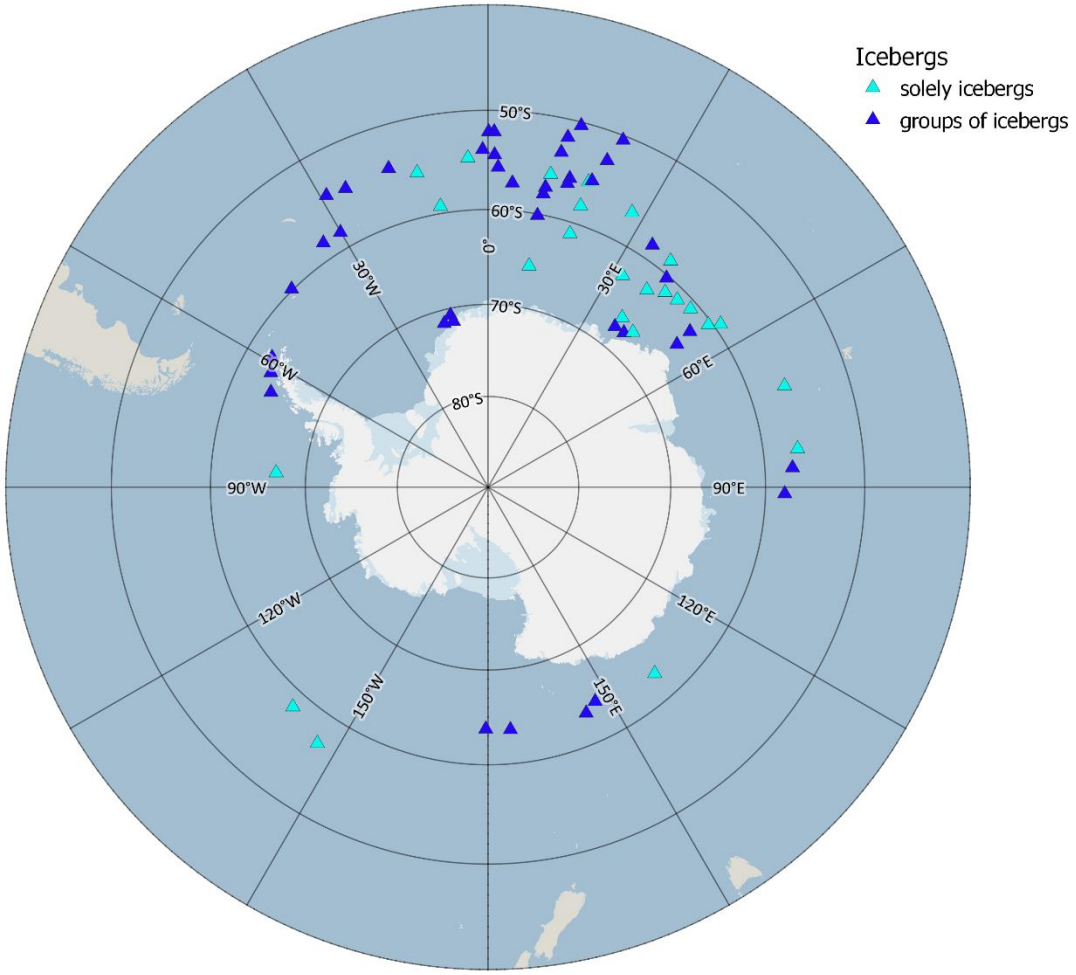



**Figure 6** Positions of observed individual icebergs and iceberg groups during 1929-1933 recovered from the analyzed logbooks.

### 4.4. Weather observations

A continuous series of weather data collected by the vessels is presently analyzed. Figure 7 shows an example of raw air temperature data acquired onboard FS *Antarctic*. The depicted time-series shows only measurements per 12:00 local time (LT) and features a typical seasonal curve with a monthly scale temperature maximum during January-February.

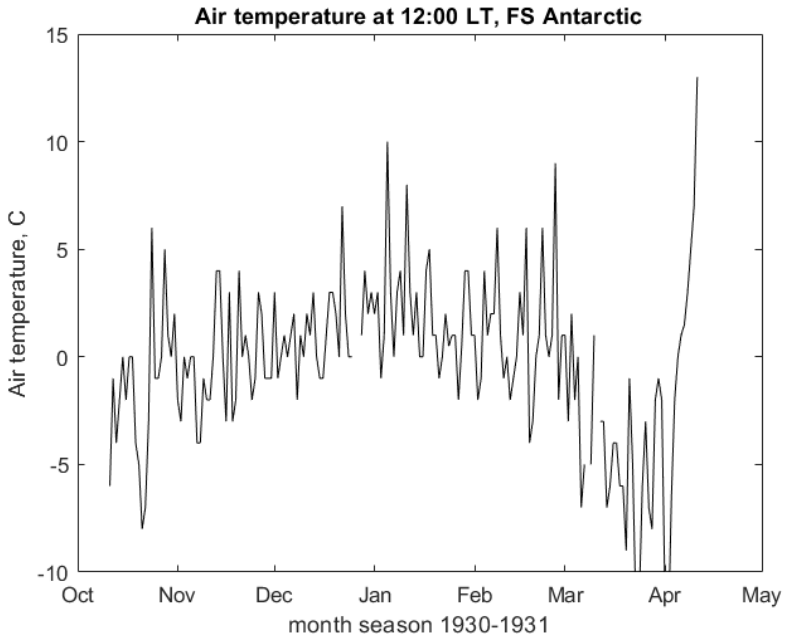



**Figure 7** Raw air temperatures per 12:00 LT measured onboard FS *Antarctic*; relatively high temperature in end of the time-series is registered during the voyage to the north, at the latitude of about 41°S.

One should note that the logs from *FS Antarctic* provide no specifications for the models of the thermometer and barometer used onboard, same as their placement onboard as well as measurement routines. It has potential implications for air temperature readings as shielding a thermometer from direct solar radiation is critical for conducting accurate measurements. Lasting exposures of the instrument to direct solar radiation, or a wet bulb effect may cause a significant positive or negative bias in measured vs. actual air temperatures. Additional quality control of the data prior to its quantitative analysis and possible assimilation for reanalysis products would therefore be required. Days or observation periods with reported clear skies should receive a particular attention.

## 5. Outlook for future work

The conducted pilot study demonstrates a high potential of historical Norwegian maritime sources such as logbooks from whaling ships and factory vessels in filling the gap of knowledge on pre-satellite era sea ice and climate variability in the Southern Ocean. Even five analyzed logs have provided a wealth of sea ice and climate information for the DML and the Indian ocean sector of the SO for a relatively short period of 1929-1933. The results motivate to continue exploring and exploiting available Norwegian documentary sources, further extending the study through the 1930s. This period in the region was characterized by active whaling with a broad contribution from Norwegian whaling companies. This period extension towards the entire 1930s will help to moderate the effects of interannual sea ice and climate variability in the region, providing an information on decadal scale average regional sea ice extent and seasonal climate for months with the SO sea ice maximum (October-November) and minimum (February-March). This extended study will also cover a substantial part of the period associated with a so-called early 20$^{th}$ century warming. This period had a clear manifestation in the Arctic characterized by receding sea ice and positive temperature anomalies surpassed only in the recent decade. Its manifestation in the Antarctic, however, is controversial and yet to be revealed.

**Reference**

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Freeman, E., S.D. Woodruff, S.J. Worley, S.J. Lubker, E.C. Kent, W.E. Angel, D.I . Berry, P. Brohan, R. Eastman, L. Gates, W. Gloeden, Z. Ji, J. Lawrimore, N.A. Rayner, G. Rosenhagen, and S.R. Smith, 2017: ICOADS Release 3.0: A major update to the historical marine climate record. *Int. J. Climatol.* (CLIMAR-IV Special Issue), **37**, 2211-2237 (doi:10.1002/joc.4775).

**Supplementary material: Workbook format for recovered data.**

**S1. Workbook for the meteorological journal of *FS Svend Foyn*.**

The xls data workbook contains the following spreadsheets:

**Metadata**: presents brief data on the vessel and the journal keyed; information from page 2 of the journal.

**SvendFoyn_1932-1933:** keyed data on date/time, vessel coordinates, sea ice and icebergs

The "SvendFoyn_1932-1933" spreadsheet contains the following columns (English translations where relevant follow above):

Col A-B: Date and Greenwich time in cells "*Date*" and "*Greenwich time of day*";

Col C-D: Vessel coordinates per noon in cells "*Latitude, S*" and "*Longitude*";

*Note* that in this journal the coordinates are already registered in a decimal format, rather than in degrees-minutes used in other logbooks. For East and West positions "+" and "-" signs applied accordingly.

Col E: Sea ice notes in Norwegian in "*Sea ice notes, original text in Norwegian*";

Col F-G: Vessel coordinates per noon in cells "*Latitude*" and "*Longitude*" with "-" sign to indicate degrees south latitude, and East and West coordinates with "+" and "-" signs respectively;

Col H: "*Inferred sea ice concentration*" providing sea ice concentration inferred from the journal notes following conversion rules presented in Table 6;

Col I: English translation of Norwegian notes in "*Sea ice notes, English translation*"

**S2. Workbooks for the two logbooks of *FS Antarctic*.**

The xls data workbook contains the following spreadsheets:

**Metadata**: presents brief data on the vessel and the journal keyed; information from page 2 of the journal.

**Antarctic_1930-1931** and **Antarctic_1930:** keyed data on date/time, vessel coordinates, weather, sea ice and icebergs

The "Antarctic_1930-1931" and "Antarctic_1930**"** spreadsheets contain the following columns (English translations where relevant follow above):

Col A-B: Date and local time of day in cells "*Date*" and "*time of day*";

Col C-D: Vessel coordinates (latitude/longitude) per noon based on calculations "*Breddegrad (ifølge bestikk)*" and "*Lengdegrad ifølge bestikk*" in degrees-minutes format;

Col E-F: Vessel coordinates (latitude/longitude) per noon based on direct observations "*Breddegrad (ifølge observasjoner)*" and "*Lengdegrad (ifølge observasjoner)*" in degrees-minutes format;

Col G: Wind direction ("*Vindens retning*"), compass rose. O(Øst, Østlig)=East, W (West, Westlig)=West, S(Syd, Sydlig)=South, N (Nord, Nordlig) = North

Col H: Wind force ("*Vindstyrke*") in the 0-6 wind force scale. See Table 2 for details.

Col I: Weather code ("*Været*"), see Table 3 for details.

Col J: State of sea surface («Sjøgang"), see Table 4 for details.

Col K: Sea level pressure ("*Barometer*, *inch*"), in mercury inches.

Col L: Air temperature ("Termometer"), in degrees C.

Col M: Sea ice notes, original text in Norwegian.

Col N-Q: calculated and directly measured/observed vessel coordinates recalculated into a decimal format.

Col R: "*Inferred sea ice concentration*" providing sea ice concentration inferred from the journal notes following conversion rules presented in Table 6;

Col S: English translation of Norwegian notes in "*Sea ice notes, English translation*"

**S3. Workbooks for the logbook of *RV Norvegia* (third *RV Norvegia* voyage to Antarctica).**

The xls data workbook contains the following spreadsheets:

**Metadata**: presents brief data on the vessel and the journal keyed; information from page 2 of the journal.

**Norvegia_1929-1930:** keyed data on date/time, vessel coordinates, sea ice and icebergs. Note that weather was not keyed as it was published in Mossby, 1933. The columns for weather logs are however kept in the file for consistency with the data from the logbooks of *FS Antarctic*.

The spreadsheet is therefore nearly identical to the data spreadsheets of ***FS Antarctic*.**

Additional column is used to indicate iceberg presence.

Col T: icebergs, index (solely icebergs - 1; groups of icebergs -2).