Estimating the extent of Antarctic summer sea ice during the Heroic Age of Antarctic Exploration

Tom Edinburgh | **Jonny Day**

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

University of Reading

1. Introduction and Background

There has been a steady increase in ice extent around Antarctica during the last three decades, especially in the Weddell and Ross seas. In general, climate models do not to capture this trend and a lack of information about sea ice coverage in the pre-satellite period limits our ability to quantify the sensitivity of sea ice to climate change and robustly validate climate models.

This increase in pan-Antarctic sea ice extent is a sum of opposing regional trends, with large increases in the Indian Ocean, Weddell and in particular Ross seas dominating over decreases in the Bellingshausen and Amundsen Sea. Both mechanical and thermodynamic forcing by the atmosphere and changes to the Southern Ocean are thought to play a role in these overall trends. It has been suggested that anthropogenically driven changes such as ozone depletion and ice sheet runoff all play a role (Turner et al. 2015). However, it is also likely that internal climate variability has played a part in the observed changes, with a positive trend in the Southern Annular Mode and decadal variability in deep convection thought to be a contributing factor (Latif et al. 2013). However, the relative importance of each of these processes is not well quantified.

Both a lack of sea ice data from the pre-satellite-era and a lack of credibility in climate models restricts analysis of Antarctic sea ice trends. Longer-term datasets are needed to improve our understanding of the dominant mechanisms affecting sea ice variability and quantify the sensitivity of the region to climate change.

Evidence of the presence and nature of sea ice was often recorded during early Antarctic exploration, though these sources have not previously been explored or exploited until now. We have analysed (nearly 200) observations of the summer sea ice edge from the ships' logbooks of explorers such as Robert Falcon Scott, Ernest Shackleton and their contemporaries during *The Heroic Age of Antarctic Exploration* (1897–1917), and in this study we compare these to satellite observations from the period 1989–2014, offering insight into the ice conditions of this period, from direct observations, for the first time. As well as informing a thorny science question, this also provides insights into the environmental conditions experienced by these early explorers.

2. Sea Ice data from Ships' logbooks

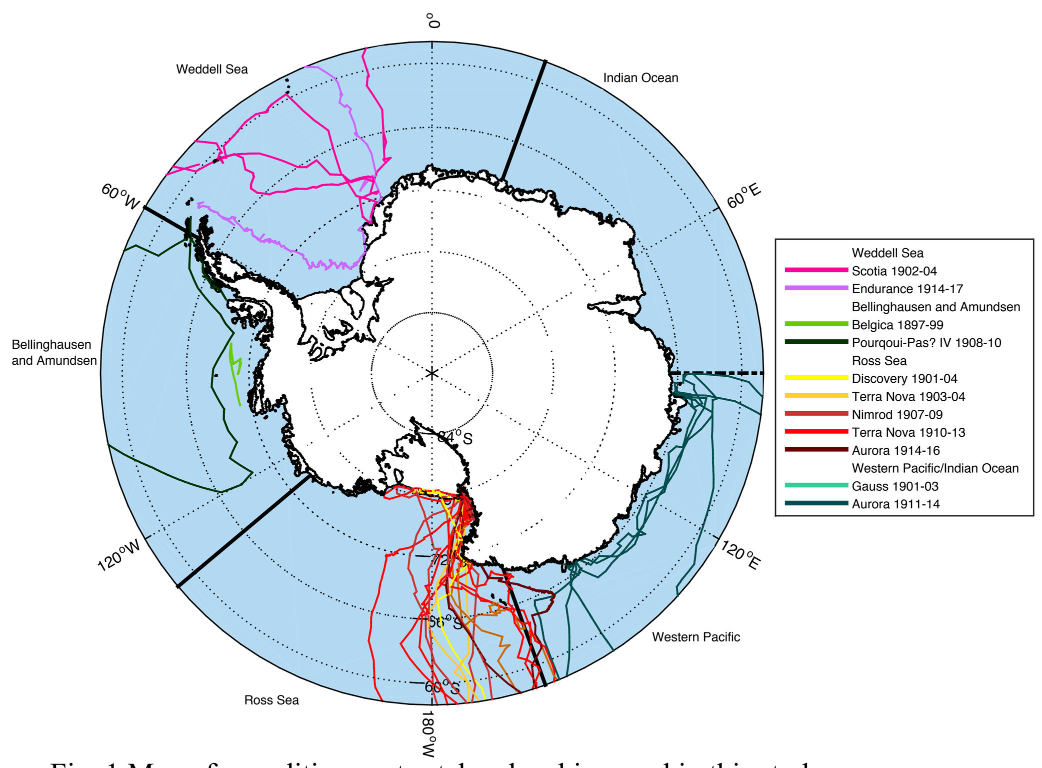

Fig. 1 Map of expedition routes taken by ships used in this study.

Some expeditions, such as the British expeditions to the Ross Sea, were primarily concerned with land exploration or the race to the South Pole, and therefore the voyage of the ship was mostly a means of transport to the continent. However, the focus of other expeditions was to explore undocumented coastlines by ship. Hence, the ship was often travelling along the sea-ice edge for long periods.

Recent years have seen significant efforts in the recovery of historical meteorological records from ships' logbooks (Brohan et al., 2009, 2010). These logbooks contain detailed descriptions of the sea ice state and provide an invaluable source of sea ice edge information, but they require careful interpretation. Such data are available from the earliest Antarctic voyages in the 19th century – of Cook, Bellingshausen, Ross and others – but data from this early period are too temporally and spatially restricted for any firm conclusions to be made (Parkinson, 1990). It is not until the Heroic Age that a sufficient level of data was collected to make concrete interpretations about the sea ice cover.

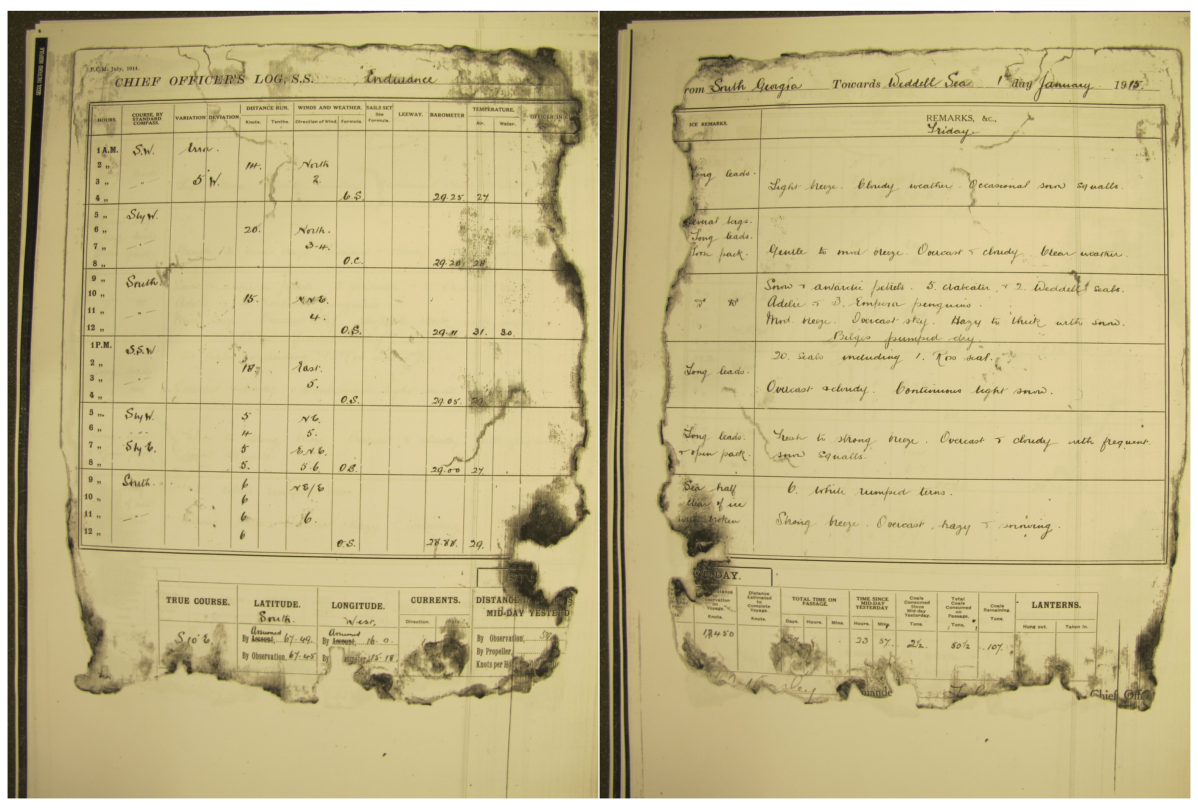

Fig. 2 1st January 1915 entry from the logbook for the *Endurance (courtesy of the Scott Polar Institute & Clive Wilkinson),* showing basic meteorological variables recorded (left) as well as qualitative description of sea state, including sea ice in the "Ice Remarks" column (right). Such logbooks were recorded by all the voyages of the time, many of which have been digitised through the ICOADS initiative.

3. Results

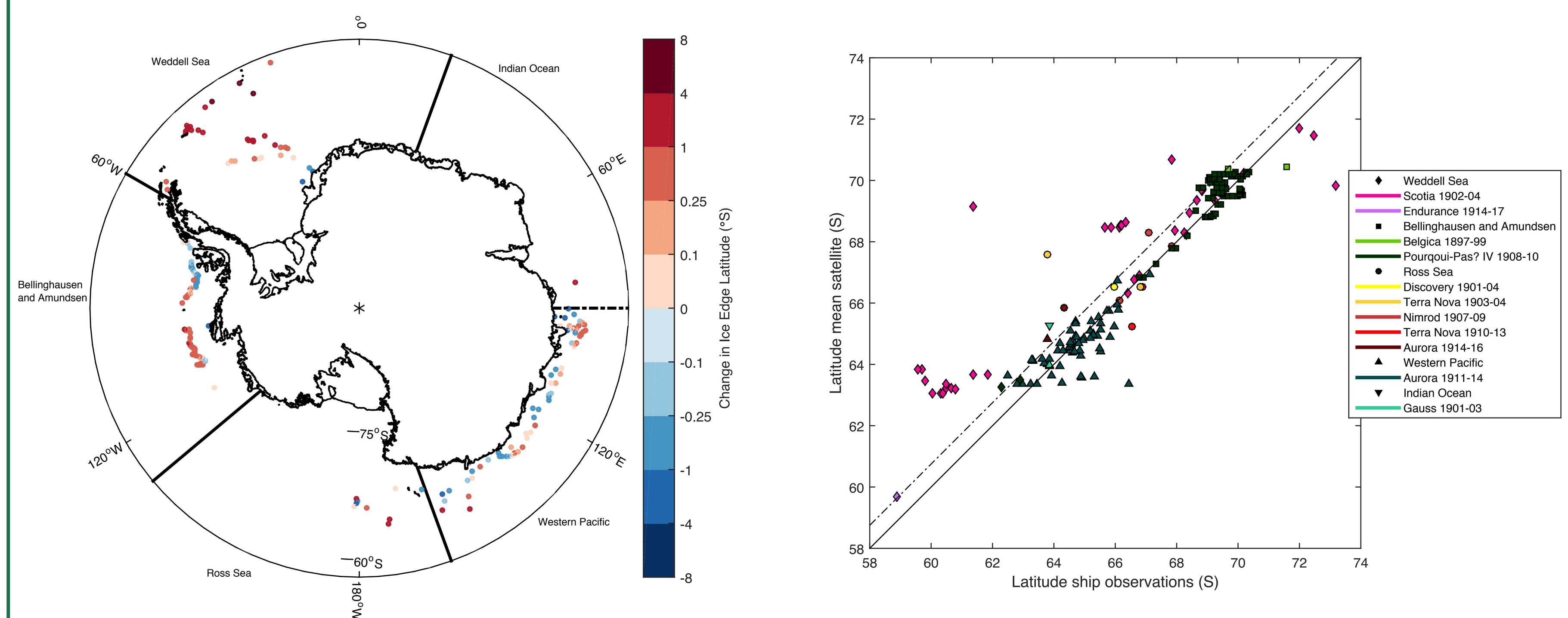

Fig 3. Anomaly between ship-observed ice edge and the 1989–2014 mean satellite ice edge position for the appropriate calendar day are plotted at the position of each recovered observation (left). Comparison of ship-observed and satellite-derived ice edge latitude, including a one-to-one line, which indicates no change in position (right).

The largest change between the Heroic Age and the present day is in the Weddell Sea, where we found that the mean ice edge was 1.71º further north. Although this value is an upper bound, it agrees with the observed decrease in land-fast ice observed at South Orkney during the last century (Murphy et al., 2014).

The differences in other sectors appear to be much smaller. We observe statistically significant but small differences of 0.21º in latitude in the Bellingshausen and Amundsen seas and 0.62º the Ross Sea but no evidence of a significant difference in latitude in the Western Pacific and Indian Ocean region, which we have merged due to the limited data available in the Indian Ocean sector (Fig. 3).

By averaging over all points, we also find a mean circumpolar change of up to 0.41º southwards since the Heroic Age, which implies at most a 14.2 % decrease in Antarctic sea ice extent between then and the present day (Fig. 4). This is much smaller than the 25% decrease between the 1950s and 1980sestimated by de la Mare (1997) from whaling records and suggests that, if we accept this result, the sea ice was less extensive during the period 1897–1917 than it was during the period 1931– 1961.

4. Comparison with HadISST and modern extent

Our estimate of the mean DJFM sea ice extent, based on the mean ice edge latitude, is 7.4 × 10^6 km^2 (or 5.3 × 10^6 km^2, when including a correction factor). Comparing our DJFM sea ice extent estimate to the Met Office Hadley Centre sea ice HadISST2.2 dataset (Titchner and Rayner, 2014), we find that our values are 4.3 × 10^6 km^2 lower (Fig. 4). During this period HadISST2.2 is based on a climatology for the period 1929–1939, derived from German Atlas charts (German Hydrographic Institute, 1950). Data from 185 whaling expeditions (mostly Norwegian but some from English whaling logbooks) were used as its basis.

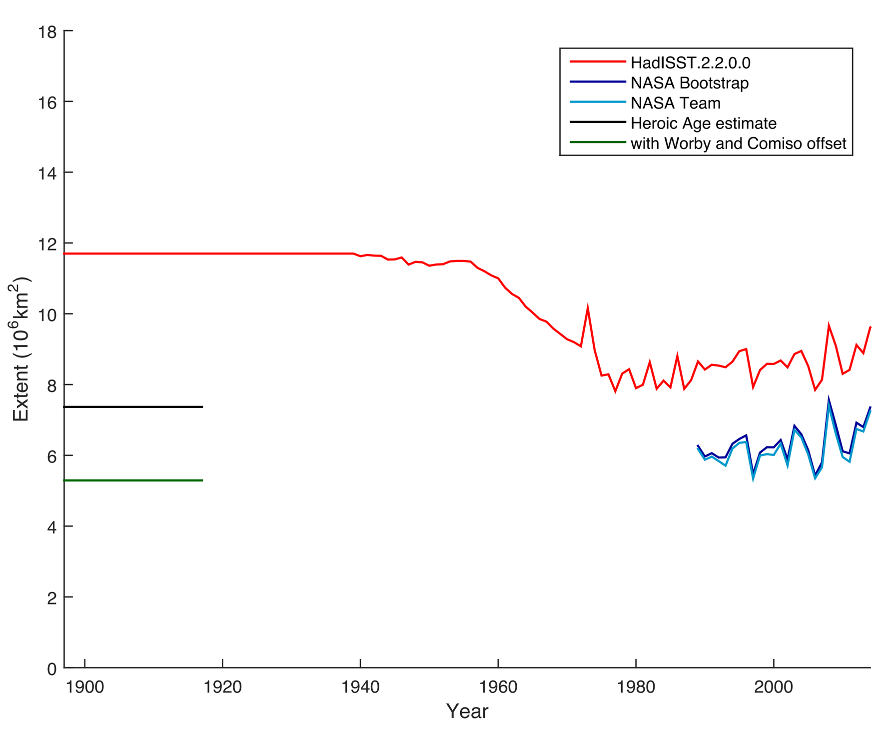

Fig. 4: The estimated DJFM Antarctic sea ice extent climatology for the period 1897–1917, with and without the inclusion of an observation based correction factor, is plotted alongside time series of DJFM mean sea ice extent calculated from HadISST2.2, NASA Team and NASA PM Bootstrap sea ice concentration datasets.

5. Summary

1. We estimate that the DJFM sea ice edge was at most 0.41º further south between 1989 and 2014 than it was during the Heroic Age (1897–1917), implying a reduction of 14.2% in total Antarctic sea ice extent.
2. This change is most dramatic and statistically robust in the Weddell Sea, where the ice edge shifted by 1.71º southward between the two periods.
3. Our estimate of the change in extent between the Heroic Age and the present day is small relative to estimates of the change between the 1950s and 1970s, based on whale catch data (e.g. de la Mare, 1997; Titchner and Rayner, 2014). This suggests the possibility that the sea ice was significantly more extensive during the period 1931–1961 than during the Heroic Age.

6. References

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j.j.day@reading.ac.uk