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Historical whaling records reveal major regional retreat of Antarctic sea ice

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Abstract

Several studies have provided evidence of a reduction of the Antarctic sea ice extent. However, these studies were conducted either at a global scale or at a regional scale, and possible inter-regional differences were not analysed. Using the long-term whaling database we investigated circum-Antarctic changes in summer sea ice extent from 1931 to 1987. Accounting for bias inherent in the whaling method, this analysis provides new insight into the historical ice edge reconstruction and inter-regional differences. We highlight a reduction of the sea ice extent occurring in the 1960s, mainly in the Weddell sector where the change ranged from 3° to 7.9° latitude through summer. Although the whaling method may not be appropriate for detecting fine-scale change, these results provide evidence for a heterogeneous circumpolar change of the sea ice extent. The shift is temporally and spatially consistent with other environmental changes detected in the Weddell sector and also with a shift in the Southern Hemisphere annular mode. The large reduction of the sea ice extent has probably influenced the ecosystem of the Weddell Sea, particularly the krill biomass.

Keywords: Sea ice; Environmental assessment; Long-term changes; Whaling; Antarctic zone

1. Introduction

Antarctic sea ice is of crucial importance to world-wide climate, but variations in sea ice extent (SIE) during the last century are still largely unknown for the Antarctic scale as a whole. Satellite passive microwave data enable the tracking of SIE in Antarctica since the 1970s (Parkinson, 1992; Cavalieri et al., 1997; Zwally et al., 2002; Comiso, 2003). However, scarce direct information concerning SIE is available for the previous decades of the 20th century (Murphy et al., 1995). This lack of information is strongly detrimental, because the sea ice coverage actually demonstrates a high regional and temporal variability in Antarctica (Zwally et al., 1983, 2002), and misinterpretation could occur from the extrapolation of records for which the time scale is shorter than the variability of the phenomenon. A long-term dataset is indeed required to study possible changes in Antarctic environmental parameters, and particularly in SIE (Curran et al., 2003).

In order to assess the past SIE, several proxies have been investigated. Pioneer studies on ice core proxies were carried out from aerosol records of biogenic sulfur compounds in recent south polar precipitation, which were linked to ENSO events in terms of atmospheric and oceanic circulation

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(Legrand and Feniet-Saigne, 1991). Later the methane sulfonic acid concentration in sea ice proved to be a useful proxy for quantifying changes in SIE (Curran et al., 2003). Another emerging original indicator of SIE can be found in historical whaling records. This method, devised by de la Mare (1997), consists in determining the historical position of the ice edge from the location of the past southernmost whale catches. These different approaches have revealed a steep decline of SIE since the 1950s in the Southern Ocean. However, all these studies were conducted either only at regional scale or only at global scale without investigating possible inter-regional differences in the change of summer SIE.

During the intensive whaling period, pelagic fleets concentrated their effort along the Antarctic ice edge (Hjort et al., 1933; Shimadzu and Katabami, 1984), a major feeding ground for whales because of high krill densities (Brierley et al., 2002). Krill require sufficient food year-round, and the role of sea ice has only recently been investigated through the recognition of the importance of the sea ice algal community (Lizotte, 2001; Constable et al., 2003) on krill recruitment (Siegel and Loeb, 1995; Loeb et al., 1997, Brierley and Thomas, 2002) and population size (Atkinson et al., 2004). The survival of these long-lived zooplankton is actually related directly to the ephemeral sea ice habitat (Lizotte, 2001), which acts as a particularly important nursery for krill larvae. This life stage is the most vulnerable to food shortage, and the ice algal community is the most obvious food source (Ross et al., 2000). The ice edge also creates a favorable environment for algal bloom development through the seeding of the upper ocean with phytoplankton cells, the formation of a stable surface layer created by melting sea ice and the release of iron, a limiting element for phytoplankton growth (Sedwick and DiTullio, 1997).

Through these Antarctic ecosystem processes, the positions of the southernmost catches constitute a proxy to locate the ice edge, and we use this method to reconstruct past SIE. We propose to use the unequalled whaling records database to investigate circum Antarctic change in SIE through the 20th century and underline possible inter-regional differences. However, the accuracy of the whaling method and the validity of the de la Mare circumpolar prediction have been subject to controversy. Vaughan (2000) has questioned the quality of the data, but the discrepancies reported by this author inadequately challenge the precision of the whaling method proposed by de la Mare (2002). Nevertheless an important bias overlooked by previous analyses of whaling records is the existing offset between the summer ice edge locations established from satellite and ship-derived measurements, including the whaling ship (Ackley et al., 2003; Worby and Comiso, 2004).

In this paper we first estimate the inherent bias of the whaling method and compare it with the bias estimated in the previous studies (de la Mare, 1997; Ackley et al., 2003). We then examine the variation of the circum-Antarctic SIE through summer from 1931 to 1987 and investigate possible inter-regional changes in SIE.

2. Methods

Since the 1930s blue, fin and minke whales were successively exploited, and we propose to examine past SIE from blue and fin whale catches previous to 1960, and recent SIE from minke whale catches and satellite data (after 1972). The International Whaling Commission (IWC) provided the dataset, and we used only pelagic whaling data (excluding whaling data from land stations, especially at South Georgia, and altered or falsified catches). Extensive whaling operations depleted 700 000 blue and fin whales from Antarctic waters between 1931 and 1960, i.e., more than 95% of the populations (Brown and Lockyer, 1984), and 105 000 minke whales from 1973 until 1987, i.e., 15% of the recently estimated population (IWC, 1999). In 1987 the JARPA program of the IWC delivered special permit for random minke whaling within the Southern Ocean, which may result in a disconnection between the catch position and the ice edge since this date.

We calculated the mean latitudes of the 10 southernmost whale catch positions for $36 \times 10°$-longitudinal circum-Antarctic sectors, from November (the beginning of the major whaling season) to February (when the SIE is minimal, from Parkinson, 2004), and from 1931 to 1987 (with no whaling data from 1941 to 1945 and from 1961 to 1971). As in de la Mare (1997), for a given sector, month and year, any catch positions more than 3° north of the southernmost catch position were excluded from the computation. The data consisted of 16 124 records (because of the restriction of the 10 southernmost whale catches) and the number of validated records is detailed by latitude (Fig. 1a), by longitude