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Sea salt sodium record from Talos Dome (East Antarctica) as a potential proxy of the Antarctic past sea ice extent

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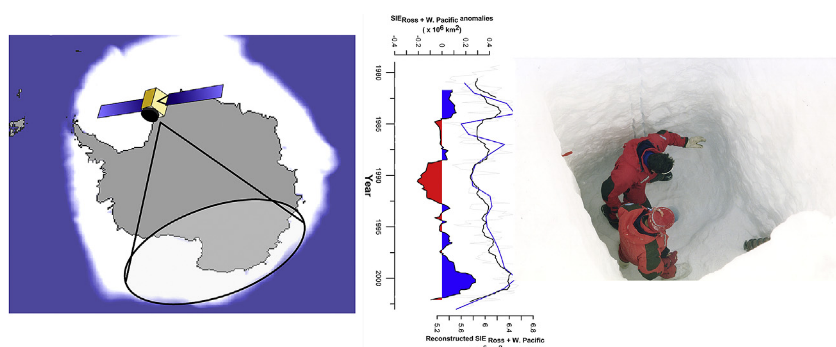
HIGHLIGHTS

- Sea salt sodium at Talos Dome can be used as a reliable proxy of sea ice extent.
- A positive relationship between $ssNa^+$ flux and SIE maxima was found.
- SIE of the Ross Sea and Western Pacific was reconstructed over the 20th century.
- SIE variability increased starting from 1990s.

GRAPHICAL ABSTRACT



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ABSTRACT

Antarctic sea ice has shown an increasing trend in recent decades, but with strong regional differences from one sector to another of the Southern Ocean. The Ross Sea and the Indian sectors have seen an increase in sea ice during the satellite era (1979 onwards). Here we present a record of $ssNa^+$ flux in the Talos Dome region during a 25-year period spanning from 1979 to 2003, showing that this marker could be used as a potential proxy for reconstructing the sea ice extent in the Ross Sea and Western Pacific Ocean at least for recent decades. After finding a positive relationship between the maxima in sea ice extent for a 25-year period, we used this relationship in the TALDICE record in order to reconstruct the sea ice conditions over the 20th century. Our tentative reconstruction highlighted a decline in the sea ice extent (SIE) starting in the 1950s and pointed out a higher variability of SIE starting from the 1960s and that the largest sea ice extents of the last century occurred during the 1990s.

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1. Introduction

Sea-ice represents a powerful phenomenon exerting a strong influence on the oceanic, biological and climatic systems and, given its importance, it is a focus in environmental research. The expansion and retreat of Antarctic sea-ice is one of the most striking seasonal changes affecting the Earth today, effectively increasing by two fold the surface area of Antarctica (Allen et al., 2011). Sea-ice plays a key role in the production and upkeep of deep waters in the ocean and therefore in the whole global ocean circulation system (Dieckmann and Hellmer, 2010). Moreover, sea-ice greatly affects the transfer of energy at the ocean-atmosphere interface as it shows a much higher albedo with respect to open water (Brandt et al., 2005) and is thus able to reflect more incoming radiation deeply changing the radiative balance. The presence of sea-ice also represents a physical barrier that successfully inhibits the transfer of heat, moisture and trace gases (such as CO_2) between the ocean and the atmosphere (Bopp et al., 2003). Additionally sea-ice has a direct influence on the Antarctic biota and it has been suggested that it is linked to the "biological pump" and thus to the global carbon cycle (Sarmiento and Gruber, 2006).

For all these reasons, despite an unknown exact mechanism, sea-ice plays a critical role in the polar amplification of climate change (Serreze and Barry, 2011) and, therefore, it is important to predict changes in sea ice under the future conditions of an ongoing climate change. A better understanding of the links between sea-ice and climate and a real improvement of the models requires a large series of long observational datasets. Unfortunately, satellite observations only began in the 1970s and before that we rely on sporadic observations and proxy data. (Abram et al., 2013).

The reconstructions of Antarctic sea-ice cover used as data for the parameterization of models have been so far mainly based on diatom remains found in marine sediment cores (Armand et al., 2005, 2008). These diatom based reconstructions can provide quantitative estimates of yearly sea-ice presence and/or duration and can allow us to draw limits for winter and summer sea-ice extents (Esper and Gersonde, 2014). Particularly large datasets have been made available based on the occurrence of sea-ice related diatoms (Gersonde et al., 2005) and, in the last years, new methods based on a sea-ice biomarker known as IP_{25} have been developed (Belt et al., 2007; Belt and Müller, 2013) in order to reconstruct the Arctic sea-ice cover in the past. In more recent years, the analysis of an organic geochemical lipid biomarker, called $IPSO_{25}$, has been proposed as a possible proxy measure of Antarctic sea ice (Massé et al., 2011; Collins et al., 2013).

Ice cores drilled in the Antarctic ice-sheet represent a very different kind of proxy record with respect to ocean sediment cores. The information about sea-ice is present in the ice cores only if it is transported from the surface of the ocean to the atmosphere. The information about sea ice is transported from the surface of the ocean to the atmosphere and unlike the sediment records is representative of sea ice in a particular sector, rather a single site. One of the greatest advantages of using ice cores to reconstruct sea-ice variations is their higher temporal resolution with respect to marine sediment cores. Reconstruction of sea-ice from ice-core proxies have so far been based on concentrations or fluxes of sodium, methanesulphonic acid (MSA, $CH_3SO_3^-$) and, more recently, halogen species.

Sea salt sodium ($ssNa^+$) has been used to quantify sea-ice variations (Wolff et al., 2006) based on the formation of high salinity "frost flowers" and brine (Rankin et al., 2000) on sea ice surfaces. However, a recent laboratory experiment (Roscoe et al., 2011) shows that frost flowers are very stable also in the presence of wind and no significant aerosol emission was observed. For this reason, such source of $ssNa^+$ is difficult to distinguish from other dominating sources, such as sea spray aerosol, which has been proved to be dominant at many drilling sites, e.g. James Ross Island (Abram et al., 2011) and Law Dome (Curran et al., 1998). Yang et al. (2008) proposed more recently that a massive source of Na^+ in several Antarctic drilling sites could be represented by "blowing snow", i.e. the snow lying on sea ice, rich in salts, that can be easily lifted into the air through blowing-snow events. Levine et al. (2014) found in their model experiment that, on an interannual scale, meteorology, and not sea ice extent, is the dominant control on the atmospheric concentration of sea salt. Which is the real factor controlling the sea salt content in Antarctic sites is so far still an open and debated question.

Methanesulphonic acid (MSA) was first used quantitatively for a reconstruction of sea ice extent (SIE hereafter) by Curran et al. (2003) in an ice-core drilled at Law Dome. Afterwards this marker has been largely investigated as a sea-ice proxy in several drilling sites (Abram et al., 2010; Becagli et al., 2009, 2016; Foster et al., 2006; Criscitiello et al., 2013) highlighting both positive and negative relationship between MSA and sea ice. However, this compound is not always fully stable in snow and ice and can be easily remobilised in the ice matrix after deposition (Smith et al., 2004) limiting its utility for long-term sea ice reconstructions at certain sites.

Recently, two halogens, namely iodine and bromine, has been suggested as ice core proxies useful to reconstruct the past sea ice concentration at Talos Dome (Spolaor et al., 2013) and at Law Dome (Vallelonga et al., 2016); furthermore the Canadian Arctic sea ice was successfully reconstructed for the last 120.000 years from the NEEM ice core (Greenland) using the bromine content as a proxy (Spolaor et al., 2016).

In this paper we assess the suitability of ss-Na^+ at Talos Dome (TD here hence) as a proxy for past sea ice conditions. The reliability of the sea salt sodium record from Talos Dome site in serving as a potential proxy of SIE is supported by the comparison between the $ssNa^+$ stratigraphic profile and the calculation of sea ice extent achieved by satellite data in the 1979–2003 time period.

Severi et al. (2009) showed already the relationship between Na^+ and SOI (Southern Oscillation Index) and the good agreement between $nssSO_4^{2-}$ and MSA with the anomalies in SIE for the 1975–1995 period suggesting the potential of this site in recording variations in sea ice and sea ice-related parameters. The results obtained from the analysis of a 5.65 m snowpit give further support for the use of $ssNa^+$ as qualitative sea-ice tracer at the TALDICE drilling site, where sea-spray deposition and fractionation effects have been deeply investigated in the past (Becagli et al., 2004; Traversi et al., 2004).

2. Materials and methods

2.1. Sampling site

Talos Dome is a coastal dome (Fig. 1) in Northern Victoria Land on the edge of the East Antarctic plateau and is located about 290 km from the Southern Ocean (Oates Land–George V Land), 250 km from the Ross Sea, and 275 km from the Italian "Mario Zucchelli" Station (Terra Nova Bay). The site chosen for digging a snow-pit (159° 10′ 30.9″ E, 72° 49′ 04.6″ S, 2330 m a.s.l.) was close to the centre of the dome and also to the TALDICE deep drilling site (Stenni et al., 2011; Severi et al., 2012).

During the 2003/2004 Antarctic campaign a snow pit was dug by hand to a depth of 565 cm and more than 200 samples were continuously collected along a vertical line using pre-cleaned PET vials with a mean resolution of 2.5 cm, wearing sterile overalls and gloves. All the samples were then stored in sealed polyethylene bags and kept frozen in insulated boxes for the transport to Italy.