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Supporting Information for

Bellingshausen Sea Ice Extent Recorded in an Antarctic Peninsula Ice Core

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Introduction

The supplement includes additional discussion of the dating of the Bruce Plateau core, reconstructing the net annual accumulation in meters of water equivalent, correcting the annual layers for thinning at depth, assessing the influence of methanesulphonic acid (MSA) migration on the reconstructed accumulation record, and examining the Bruce Plateau accumulation (snowfall) record within the context of the other three annually resolved accumulation records available from the Antarctic Peninsula.

Text S1: Reconstructing the annual net accumulation record and the effect of MSA migration

The reconstructed annual net accumulation (A_n) record provides a proxy-based history of precipitation for the Bruce Plateau (BP). A_n is derived from the annual layer thicknesses determined using the excellently preserved summer peaks in MSA (Figures S1 and S2). The firn/ice thickness of each annual layer was converted to a water equivalent (w.e.) thickness using the depth-density model constructed from the densities measured immediately after the ice was recovered from the drill. The well preserved MSA summer concentration peaks also provide a straightforward mechanism for dating the core (Figures S1 and S2). Figure S1 shows the summer MSA peaks for the section of the BP core from 100 to 150 m that contains snow deposited between 1978 and 1945 CE, respectively. Included also are the beta radioactivity values, with the elevated concentrations of gross beta radioactivity from thermonuclear testing that arrived in Antarctica in 1964/65 [*Pourchet et al.*, 1983] providing additional confidence in the time scale.

Each annual layer thickness (in w.e.) must be adjusted to its original thickness by accounting for the thinning and compaction imposed during its continued burial by the newly accumulating snow. To accomplish this, the *Dansgaard and Johnsen* [1969] model, a modified version of the Nye model [*Nye*, 1963], was used and adjusted for flank flow. The adjustment for flank flow is applied when the distance from the ice divide (2 km in the case of the BP drill site) exceeds twice the ice thickness (448.12 m). For flank flow the parameter h/H, where H is the thickness of the ice sheet and h is the height above the bed of the transition from linear to constant flow, was set to 0.2 [*MacGregor et al.*, 2012]. Thus, the model approximates a constant strain rate over the upper 80% of the ice thickness (0 to 358.5 m) and thereafter applies a linearly decreasing strain rate to the bed (358.5 to 448.12 m).

MSA has been shown to migrate with depth such that MSA deposited in the summer may eventually migrate to the winter layer below [*Pasteur and Mulvaney*, 2000; *Thomas and Abram*, 2016]. This is not an issue throughout most of the BP core and certainly not for the time interval discussed in this paper (1900 - 2009 CE). Accumulation on the BP is very high (an average of 1.84 m w.e. from 1900 to 2009), the ice is very cold (see text), and the core contains virtually no evidence of melt. The best evidence for MSA migration comes from comparing the concentrations of MSA with contemporaneous (i.e., measured on the same sample) concentrations of non-sea-salt sulfate (NSSS), which does not exhibit migration [*Pasteur and Mulvaney*, 2000; *Thomas and Abram*, 2016]. In Figure S2 the MSA and NSSS concentrations are plotted for 4 different sections of the BP ice core. Note that MSA migration does not exist at 330 m (1731 CE) and remains very modest at 382 m (1555 CE). However, at 395 m (~1447 CE) MSA exhibits significant migration such that the reconstructed thickness of the annual layers will be affected. Fortunately, when both MSA and NSSS are used for dating, the ability to accurately date this section of core with an error of ± 1 year is not compromised. Given that this paper discusses only data for the 20th century, which is contained in the upper 194 meters of the core, there is no issue of MSA migration influencing the data set and the conclusions.

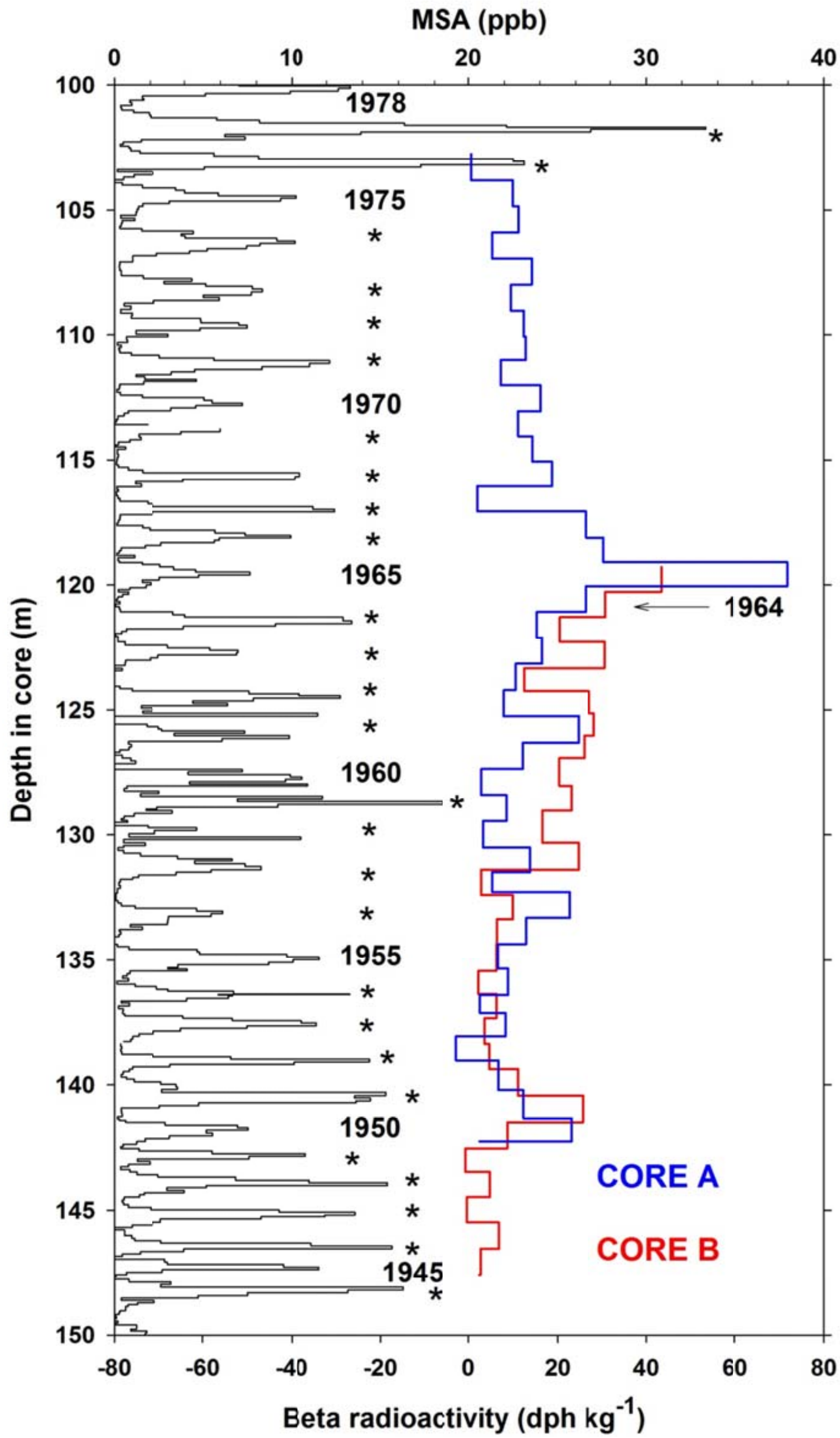

Figure S1. Section of the BP ice core from 100 to 150 m illustrating the seasonal variations in MSA concentration used to date the core (black), the beta radioactivity found in Cores A and B (blue and red), and the 1964 beta radioactivity horizon, a well-known global time stratigraphic marker. The MSA summer peak for each year is denoted by an asterisk (modified from *Goodwin et al.* [2016], Figure 2).

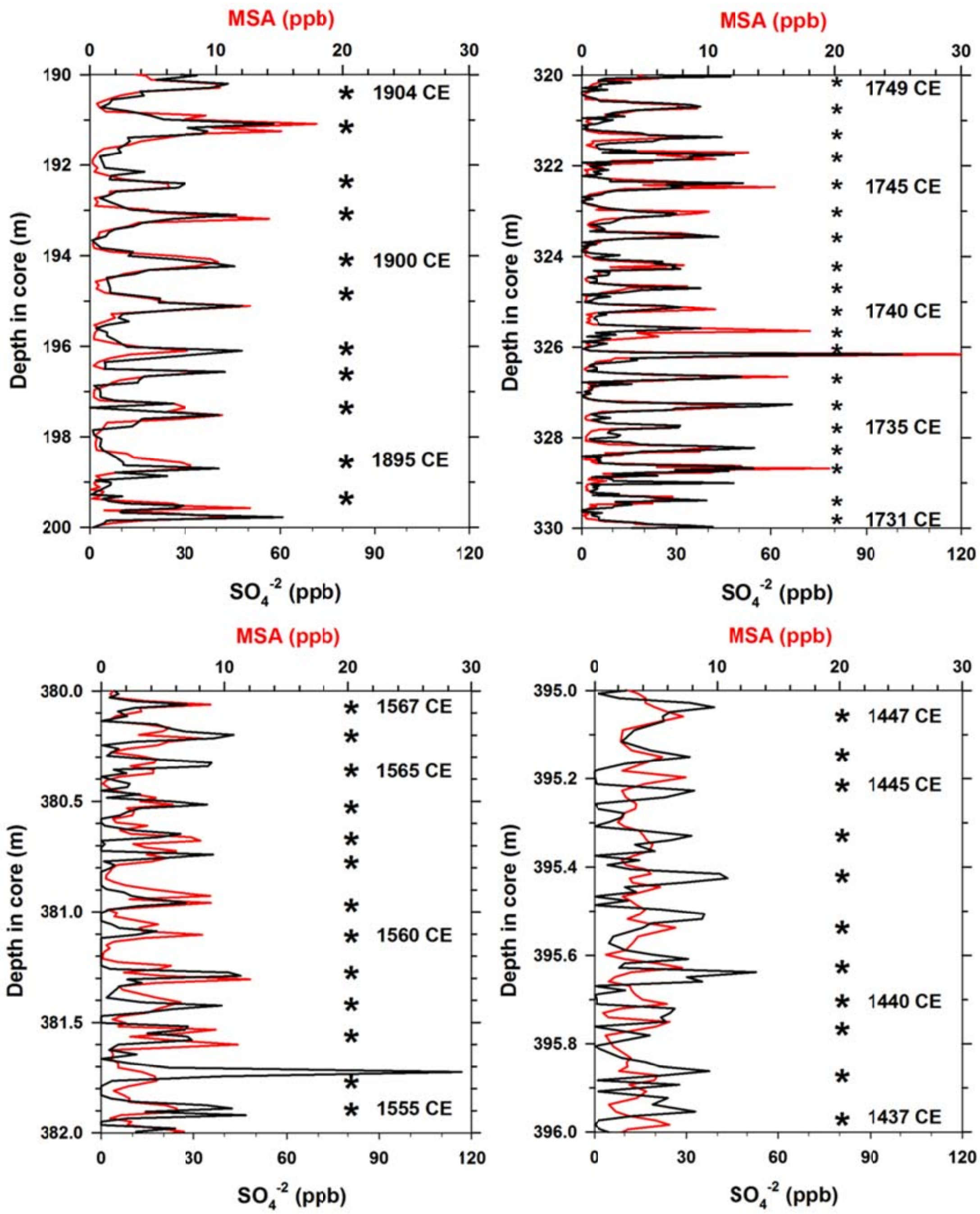

Figure S2. Concentrations of MSA (red) and non-sea-salt sulfate (black) measured on the same sample and shown with depth in 4 discrete sections of the Bruce Plateau core. These allow examination of the progressive migration of MSA with depth.

Text S2. Accumulation history on the Bruce Plateau and over the Antarctic Peninsula

Ice-core-derived accumulation histories from the Antarctic Peninsula (AP) are limited, represent geographically different regions, and show a fairly consistent pattern of increasing in snowfall (accumulation) over the 20th century, particularly after 1940. Figure S3 illustrates the only available annually resolved records. Two of the cores (Bruce Plateau and Gomez) were drilled more recently (2010 and 2007, respectively), so they better capture the very strong increase in accumulation rate that began in 1980. Although these two core sites are both located along the west side of the AP, Bruce Plateau (66.03°S; 64.07°W; 1975.5 masl) is in the northwest and Gomez (73.59ºS; 70.36ºW; 1400 masl) is in the southwest [*Thomas et al.*, 2008], suggesting that the strong post-1970 accumulation increase is widespread, at least along the west coast. In contrast, the core from the Dyer Plateau, a broad ice field centrally located between the east and west coasts of AP (77.80ºS; 64.52ºW; 2002 masl), was drilled in 1988 [*Thompson et al.*, 1994]. James Ross Island (JRI) is located at the northeastern tip of the AP (64.2ºS; 57ºW; 1600 masl), and this core was drilled in 1998 [*Miles et al.*, 2008]. A new core was drilled on JRI in 2009 but the accumulation data have not been published or released to a public database at this time.

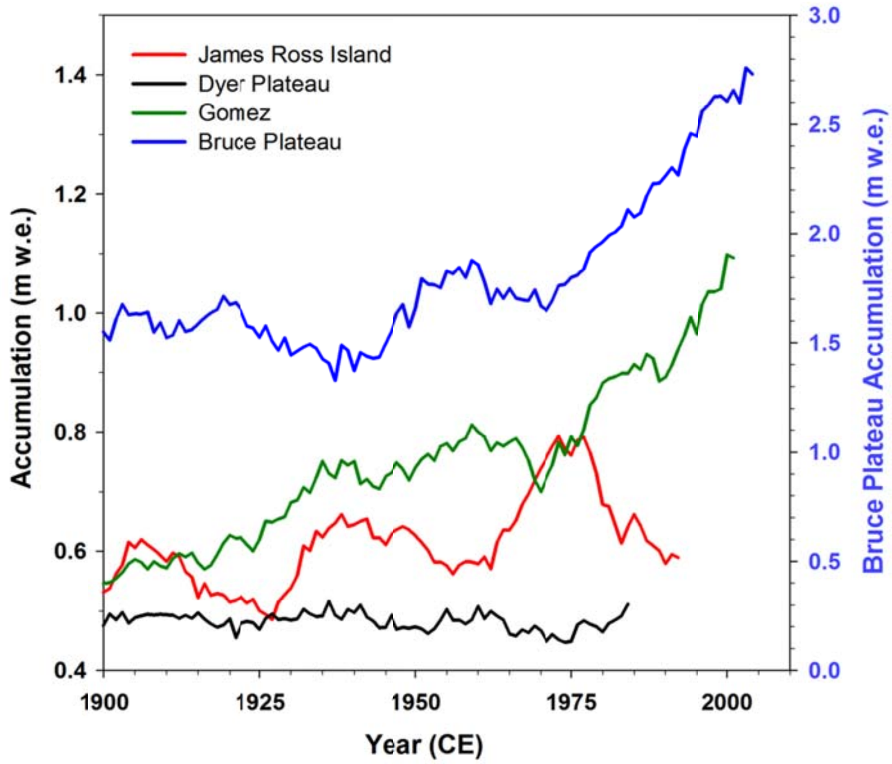

Figure S3. Eleven-year running means of the annual net accumulation (m w.e.) from 1900 to the present for the four available Antarctic Peninsula ice cores with annual resolution. Details for each site are discussed in the text. Accumulation scale on the left is for JRI, Dyer Plateau, and Gomez, while that on the right (blue) is for Bruce Plateau.