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A model study on the effect of the accumulation history on chemical tracers measured in ice cores from the Antarctic Peninsula

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Ice cores from the Antarctic Peninsula provide an important source of information on the climate variability in this region throughout the Holocene. This is relevant to put recent observed changes in the context of the longer-term climate record. However, the concentration of chemical species or isotope ratios in the cores is not uniquely determined by the atmospheric load. The accumulation history, which is often ignored due to lack of measurements, is one of the factors that might play a role. The goal of this work is to improve our understanding of the ice core records through enhanced understanding of the regional meteorology. For this, we use a time series of meteorological conditions for the period 1987-1993, as derived from a regional atmospheric model (RACMO) at 14 km resolution and realistically driven from the lateral boundaries (van Lipzig et al., 2004). The model gives a good representation of the net accumulation variations at the drilling sites indicated in Figure 1, although the precipitation shadow of Alexander Island is overestimated. For more information on the drilling sites, we refer to Mulvaney et al. (1992).

Figure 1: The domain covered by the regional model at 14km grid spacing.

TYPICAL CONDITIONS DURING PRECIPITATION EVENTS

For chemical signals stored by wet deposition and for isotopes carried by precipitation, only the conditions during precipitation events determine the ice core record. Therefore, these signals can be interpreted as conditionally sampled information on the past atmosphere. Mean sea level pressure during the 365 days with the largest precipitation is anomalous (Figure 2). The Gomez and the Beethoven Peninsula core represent similar conditions, with strong northwesterly flow during precipitation events. However, ice core records from Dolleman Island, Berkner Island and Beethoven Peninsula represent three very different atmospheric circulation patterns. When the relative occurrence of the circulation patterns changes, these ice cores are not expected to show similar trends in chemical or isotope signals.

IDEALIZED ATMOSPHERIC SIGNALS

Model output is used to illustrate how idealized time series of atmospheric concentrations are transferred to the ice. Figure 3 shows that the normalized concentration in an ice core (C_N) is largely dependent on the fraction of the dry deposition (α). For deriving this figure, modelled time series of the surface mass balance (SMB) are used and it is assumed that the dry deposition velocity is constant, the atmospheric concentration (Ca) is independent of height and the scavenging for precipitation is constant. For increasing values of α it is more difficult to identify separate annual layers.

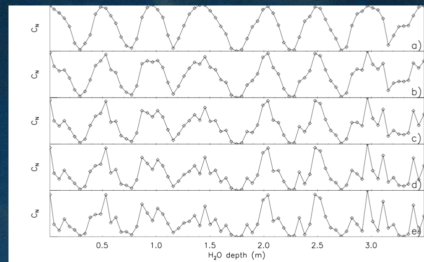

Figure 3: Modelled normalized concentration (C_N) in the Dolleman ice core for different values of the dry deposition fraction (α). C_N is calculated as response to an idealized sinusoidal atmospheric signal (black line in Figure 4c) and RACMO14 time series of the SMB.

Berkner Island is the site with the largest dry deposition fraction (α is estimated to be 0.2; method based on DeAngelis et al., 1997). Figure 4 shows time series of C_N calculated using α=0.2 and the RACMO SMB. Additional peaks are identified in C_N, which are not related to peaks in Ca, but rather to periods of low accumulation rates. For atmospheric signals with a constant background level, the effect of dry deposition variations is even larger.

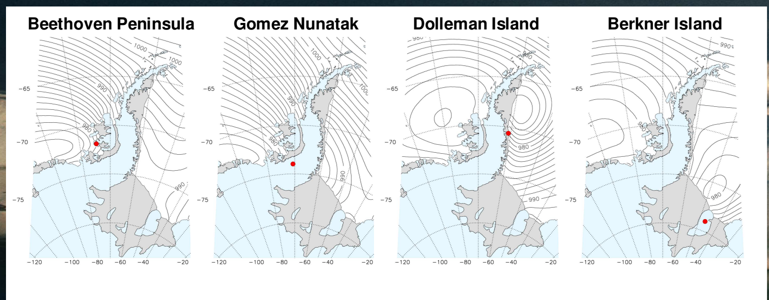

Figure 2: Composite mean sea level pressure during precipitation at the drilling site.

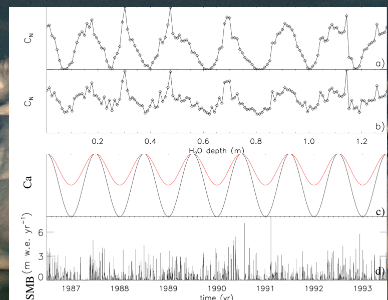

Figure 4: Modelled normalized concentration (C_N) in the Berkner Island ice core (a, b) as response to an idealized sinusoidal atmospheric signal with no background level (black line in c) and with a constant background level (red line in c) and RACMO14 time series of the SMB (d).

THE NON SEA-SALT SULPHATE SIGNAL IN THE ICE CORE

In ice core studies, it is often assumed that the SMB is constant throughout the year and that the ice core signal reflects the time dependency of Ca. Alternatively, one can prescribe time series of Ca and derive the SMB history from the ice core signal. As a first step, we have used this method, assuming that the sub-annual variation of Ca is sinusoidal. Figure 5 shows the measured non sea-salt sulphate concentration in the Dolleman ice core for an arbitrary year 1955. The peak is not symmetric around the middle of the annual layer, but is shifted towards the end of the year. When Ca is assumed to be symmetric around the middle of the year, the signal can only be explained when the SMB was larger during the first part than during the second part of the year. The ice core signal can be explained by realistic variations in the SMB and it is not necessary related to deviations in Ca from a sinusoidal function.

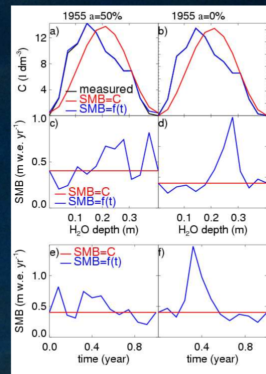

Figure 5: Measured and calculated non sea-salt sulphate concentration in the Dolleman ice core for 1955 (a, b) as response to an idealized sinusoidal atmospheric signal and time series of the SMB (c, d, e, f). The time dependent SMB is chosen in such a way that it matches the measured sea-salt sulphate concentration as closely as possible.

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