RECENT INTER-ANNUAL CLIMATE VARIABILITY IN COASTAL DRONNING MAUD LAND, EAST ANTARCTICA, BASED ON STATISTICAL EVALUATION OF METEOROLOGICAL AND STABLE WATER ISOTOPE DATA

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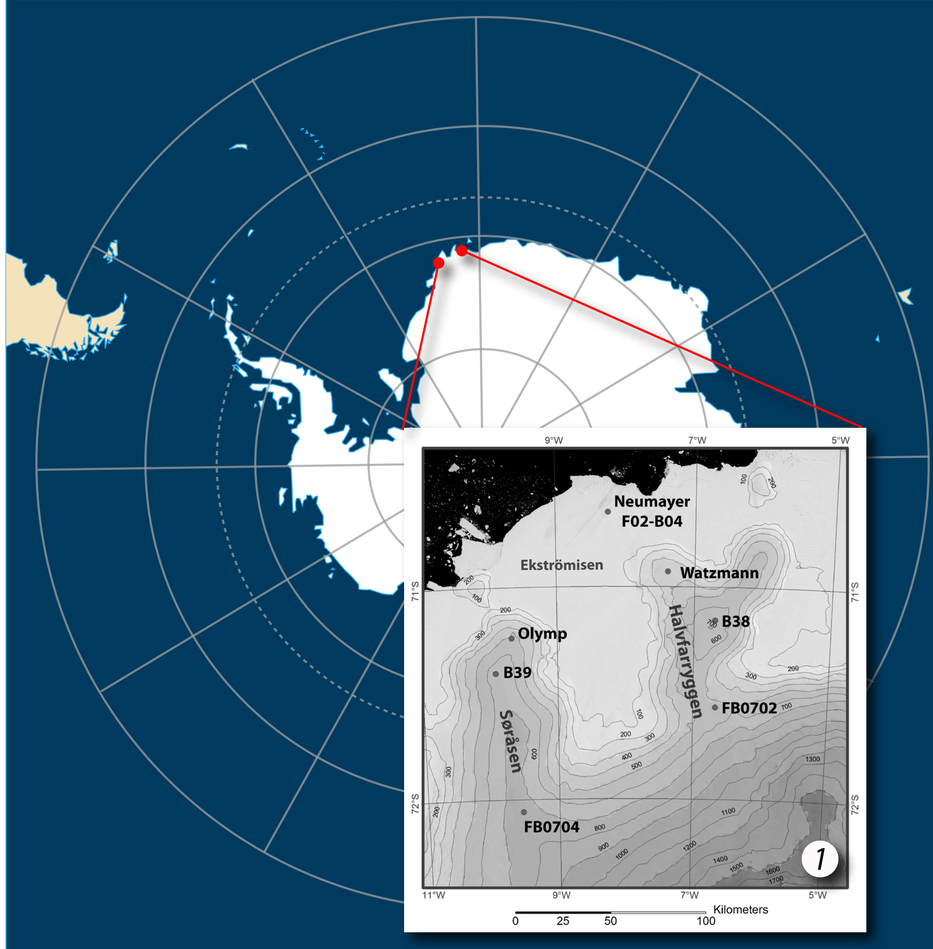


Introduction:

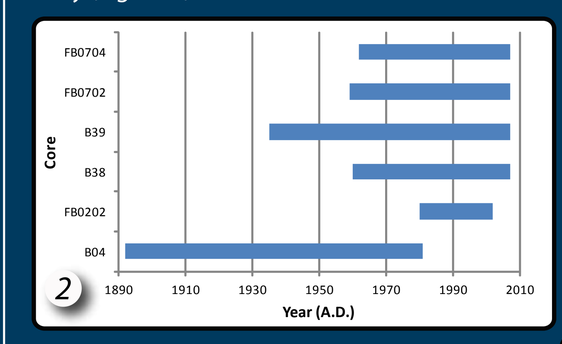
Based on the study of stable water isotopes of several firn cores, snow pits and fresh snow samples from coastal Dronning Maud Land (DML) and the surroundings of the Neumayer Station, East Antarctica (Figure 1), a clear correlation between air temperature and stable water isotope composition has been demonstrated for this region (Fernandoy and others, 2010). This even allows extending the meteorological record of the Neumayer Station into the past. Consequently, stable climatic conditions for at least the last 50 years and beyond in this area are concluded. Nevertheless, an important seasonal variability is observed.

From the time series analysis, different but marked patterns arise from the stable isotope data. Time series are compared to some major climate forcing mechanisms (CFM) such as: El Niño Southern Oscillation (ENSO), Southern Annular Mode (SAM) and Solar activity (sunspot numbers), showing that the local climate variability cannot be easily explained. Only weak correlations are found between the isotope data and CFM, being significant (at p-level 0.05) between $\delta^{18}O$ (δD) and ENSO. Furthermore, a correlation of the secondary parameter deuterium excess (*d* excess = $\delta D - 8*\delta^{18}O$) and SAM is significant, but weak.

Study area: DML is located in East Antarctica, facing the Atlantic Ocean. Our study area comprehends the surrounding of the Ekströmisen ice-shelf and the hinterland of this area. The closest meteorological stations are located at the bases Neumayer III (70°40´S, 8°16´W), Neumayer II (70°39´S, 8°15´W), and the former Georg-von-Neumayer base (70°37´S, 8°22´W), which provide meteorological data since 1981 to present. All stations are from here on referred together as Neumayer station. Mean annual 2-m air temperature (MAAT) in the vicinity of Neumayer station shows a clear inter-annual variability, with an average temperature of -16.1°C for the period 1982-2006. Accumulation rates are high and extremely variable, ranging from 360 kg m^2 a^{-1} at the coastal region up to 1250 kg m^2 a^{-1} on the summit of the ridge of Halvfarryggen.

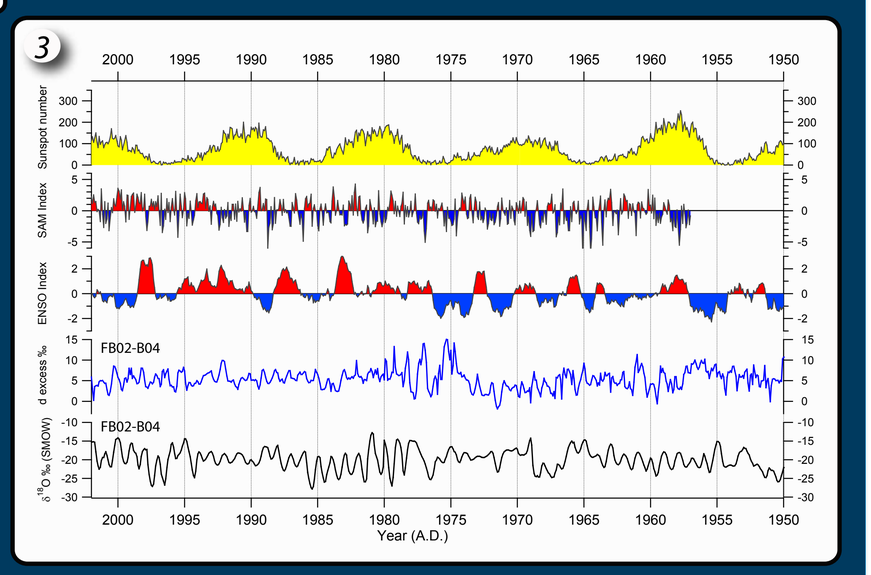
Material and methods:

Different ice and firn cores were analyzed for this investigation, the cores were retrieved during different expeditions and cover different time spans. The firn cores B04 and FB0202 (Schlosser and Oerter, 2002), both drilled close to the Neumayer station, were retrieved in 1992 and 2002, respectively. In January 2007, within the frame of a pre-site survey of the IPICS 2k array project (Brook and others, 2006), a German-Swiss team extracted two firn cores on the Halvfarryggen ice ridge: B38 and FB0702 and two on the Søråsen ridge: B39 and FB0704, at the east and west of Ekströmisen, respectively (Figure 1).



Both stable water isotopes ($\delta^{18}O$ and δD) are available for the all cores. However, for the cores B38, B39, FB0702 and FB0704, δD data exists only in coarse depth resolution (0.5-1m). As the cores B04 and FB0202 were retrieved at almost the same geographical location and cover a complementary time span (1892-2002) (Figure 2), these two cores were merged to one archive. To overcome the difference in the sampling resolution of the isotope analyses, both cores were resampled at a standard 5 cm resolution. From here on we refer to this as the core F02-B04 (Figure 3).

The CFM indexes used here (Figure 3), are taken from different existing data-bases: SAM index (Marshall, 2003) is taken from the British Antarctic Survey website available at: http://www.nerc-bas.ac.uk/icd/gjma/sam.html. Sunspot numbers are from the SIDC-team, World Data Center for the Sunspot Index, Royal Observatory of Belgium for Solar Influences, available at: http://www.sidc.be/sunspot-data/ and ENSO index is from NOAA at: http://www.esrl.noaa.gov/psd/people/klaus.wolter/MEI/, here we use the Multivariate ENSO index (Wolter and Timlin, 1993, 1998).



Results:

I. Correlation matrices:

To investigate possible hidden relationships between stable isotope data of the cores and CFM, a stepwise statistical analysis, including basic statistics and a time series analysis, has been performed.

a) $\delta^{18}O$ Correlation (ice cores)

	F02-B04	
	r	*p-level*
B38	0.52	0.00
B39	0.51	0.00
FB0702	0.53	0.00
FB0704	0.36	0.00

a) Foremost we correlate $\delta^{18}O$ values of all 5 cores for the common time span 1962-2002 to check if core F02-B04 is actually representative for the region. The correlation of core F02-B04 with the cores B38, B39 and FB0702 is good and slightly lower for FB0704. Correlation coefficients between the cores B38, B39, FB072 and FB0704 vary between 0.4 and 0.6. Since these cores are covering shorter time spans and no high-resolution δD (*d* excess) data is available, we concentrate only on core F02-B04 for the following analysis.

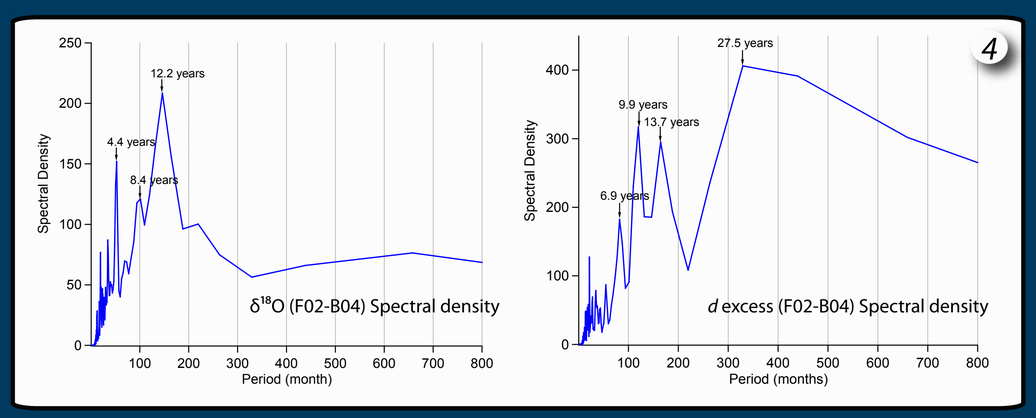
b)

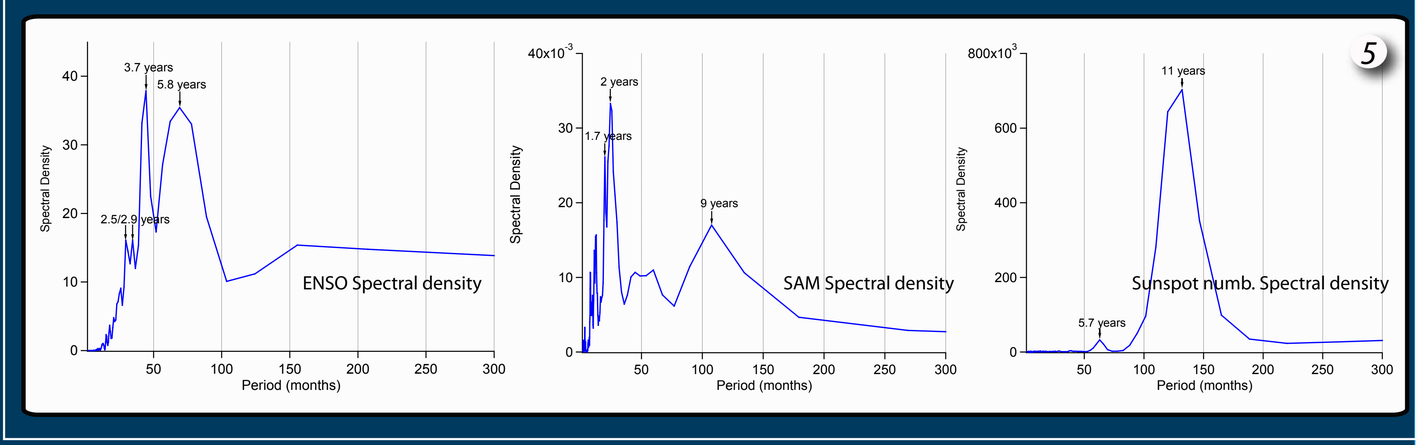
	ENSO		Sunspot		SAM	
	r	*p-level*	*r*	*p-level*	*r*	*p-level*
$\delta^{18}O$	-0.15	0.00	0.14	0.01	-0.01	0.89
dD	-0.15	0.00	0.14	0.01	-0.02	0.74
***d* excess**	0.02	0.61	-0.03	0.61	-0.13	0.01

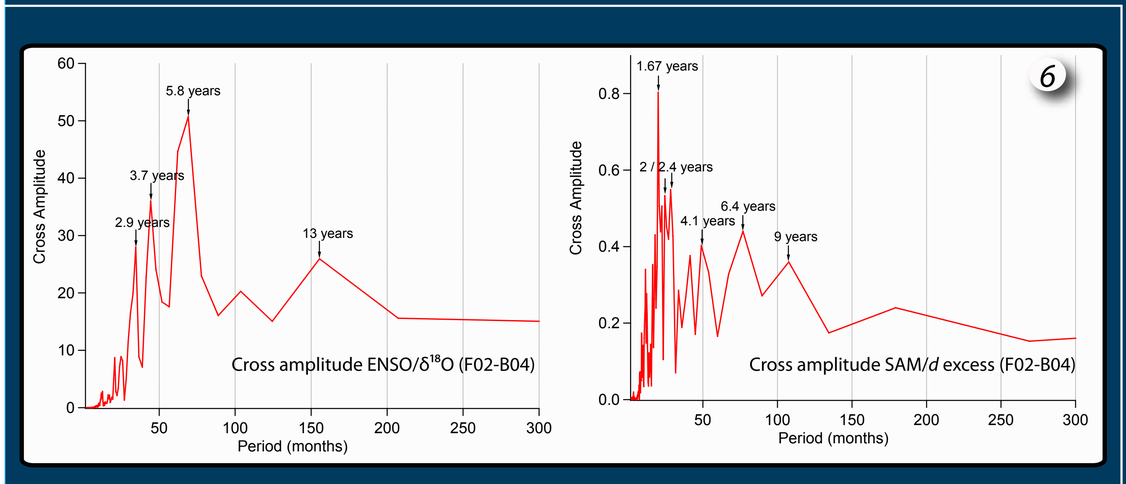
b) F02-B04 was compared to the ENSO, SAM and Sunspots numbers. Mean annual, seasonal, monthly and daily data are available for all of them, but significant correlation was found only on a monthly-scale. For this purpose, assuming a year-round well distributed precipitation, the core F02-B04 was monthly resampled. The correlation of $\delta^{18}O$ (δD) and ENSO is weak, but significant at p-level <0.05, suggesting that this correlation is not a random coincidence. The correlation with Sunspot number is also weak and similar to ENSO, but opposite in sign. The correlation between ENSO and sunspot number is not clear and beyond the scope of our work. Finally SAM weakly correlates (negatively) only with *d* excess.

II Time Series Analysis:

Since the correlation of some of the forcing factors and the isotope data has been demonstrated, we focus now on the nature of this correlation. Before proceeding further the data need to be prepared to filter undesired "noise". For this reason all isotopic data was seasonally adjusted using the Census I method (multiplicative model). Afterwards isotope and climate data was smoothed (5 points moving average), detrended and finally the mean values were subtracted, if applies. The spectral analysis using Fast Fourier Transforms (FFT) reveals cyclical patterns of the isotope and climate data (Figure 4 and 5).







III Cross-spectrum analysis:

To understand if the identified cyclical patterns in the isotope and climate data are correlated to some extent (co-variation), we performed a cross-spectrum analysis. This analysis allows to compare two different data sets and to find out if the previous identified cycles are correlated between them. Cross-amplitude graphics are presented to visualize, if both series frequencies covary (Figure 6).

Conclusions:

Correlations between isotope data from a firn core covering more than 100 years and some of the major CFM are demonstrated. Simple correlation matrices show a significant linear correlation between $\delta^{18}O$, δD and ENSO (Sunspot numbers), and between *d* excess and SAM. Time series analyses show that isotope composition ($\delta^{18}O$ and δD) fluctuates with cyclical patterns (4.4, 8.4 and 12.2 years), *d* excess exhibits an independent frequency (6.9, 9.9, 13.7 and 27.5 year cycles). Well-known cyclical patterns of CFM were correctly identified. Moreover, cross-spectrum analysis shows that ENSO is modulating the variation of $\delta^{18}O$ composition, and therefore air temperature, of the region. The *d* excess is modulated by SAM variation, probably linked to the influence of this phenomenon in the moisture source over the southern oceans. However, the CFM analysed here are not responsible for the complete variation and probably other factors should be explored.

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