Investigation of Meteorological Events Preserved in High Resolution Snow Pit and Firn Core Records

by

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Declaration

This thesis contains no material which has been accepted for a degree or diploma by the University or any other institution. To the best of my knowledge and belief this thesis contains no material previously published or written by another person except where due acknowledgement is made in the text.

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List of abbreviations

$\delta^{18}O$	oxygen isotope ratio
AAD	Australian Antarctic Division
ANARE	Australian National Antarctic Research Expeditions
AVHRR	advanced very high resolution radiometer
AWS	automatic weather station
CRC	Cooperative Research Centre
ENSO	El Nińo Southern Oscillation
DMS	dimethyl sulphide
DMSP	dimethyl sulphoniopropionate
DON	dissolved organic nitrogen
DoY	Day of Year
DSS	Dome Summit South
H_2O_2	hydrogen peroxide
HCL	hydrochloric acid
IC	ion chromatography
MSA	methane sulphonate
N_2O	nitric acid
NOAA	National Oceanic and Atmospheric Administration
nss SO_4	non-sea salt sulphate
OH	hydroxide
PSC	polar stratospheric cloud
SMOW	Standard Mean Ocean Water
SO_2	sulphur dioxide

List of publications

Type of Publication	Number	Reference
Papers in refereed journals	6	1 – 6
Conference and seminar presentations	7	7 – 13

1. McMorrow, A. J., van Ommen, T. D., Morgan, V. and Curran, M. A. J. 2003. Ultra high seasonality of trace ion species and oxygen isotope ratios over 4 annual cycles. *Annals of Glaciology*. **39**. 34-40.

2. Curran, M., van Ommen, T., Palmer, A., Morgan V. and McMorrow, A. Non-sea-salt sulphate in ice cores, correction for sulphate depletion. (in preparation).

3. Pedro, J., Curran, M., van Ommen, T., Smith, B., Morgan, V., McMorrow, A. and Smith, A. High resolution snow pit study of 10Be at Law Dome, Antarctica. (in preparation).

4. McMorrow, A. J., Curran, M. A. J., van Ommen, T. D., Morgan, V. and Allison, I. 2002. Features of meteorological events preserved in a high resolution Law Dome snow pit. *Annals of Glaciology*. **35**. 463-470.

5. Curran, M. A. J., Palmer, A. S., van Ommen, T. D., Morgan, V., Phillips, K. L., McMorrow, A. J. and Mayewski, P. 2002. Post-depositional methansulphonic acid movement on Law Dome and the effect of accumulation rate. *Annals of Glaciology*. **35**. 333-339.

6. McMorrow, A. J., Curran, M. A. J., van Ommen, T. D., Morgan, V., Pook, M. J. and Allison, I. 2001. Intercomparison of firn core and meteorological data. *Antarctic Science*. **13**(3), 329-337.

7. Talk presented at the International Glaciological Society, International Symposium on Antarctic Glaciology. Milan, Italy. 25th to 29th August 2003. Ultra high seasonality of trace ion species and oxygen isotope ratios over 4 annual cycles. McMorrow, A. J., van Ommen, T. D., Morgan, V. and Curran, M. A. J.

8. Talk presented in the Institute of Antarctic and Southern Ocean Studies seminar series. August 2003. Ultra high seasonality of trace ion species and oxygen isotope ratios over 4 annual cycles.

9. Talk presented by Andrew Smith at the 18th International Radiocarbon Conference. Wellington, New Zealand. 1st to 5th September 2003. Snow pit study of the deposition of cosmogenic beryllium at Law Dome, Antarctica. Smith, A. M., Pedro, J. B., Curran, M. and McMorrow, A. J.

10. Poster presented at the International Glaciological Society, International Symposium on Ice Cores and Climate. Kangerlussuaq, Greenland. 19th to 23rd August 2001. Features of meteorological events preserved in a high resolution Law Dome snow pit. McMorrow, A. J., Curran, M. A. J., van Ommen, T. D., Morgan, V. and Allison, I.

11. Talks given at Palaeoclimate Day at the Antarctic CRC (February 2002) and the Australian Ice Cores Conference at the Antarctic CRC (April 2002).

12. Talk presented by Andrew Smith at the 9th International Conference on Accelerator Mass Spectrometry, AMS – 9, Nayoga, Japan, September 9-13 2002. High resolution study of the deposition of cosmogenic 10Be and 7Be in Antarctic Snow. Smith, A. M., Curran, M., Pedro, J. B., McMorrow, A. J., Smith, B. T. and Morgan, V. I.

13. Poster presented by Mark Curran at the 22nd General Assembly of the International Union of Geodesy and Geophysics. University of Birmingham, UK. 18-30th July 1999. McMorrow, A. J., Curran, M. A. J., van Ommen, T. D., Morgan, V., Pook, M. J. and Allison, I. 2001. Intercomparison of firn core and meteorological data.

Abstract

A key problem in ice core palaeclimate studies is the interpretation of the various measurable parameters in ice in terms of climate and environmental conditions. This study is aimed at developing a closer understanding of the connection between high resolution snow/firn measurements and meteorological conditions. Ultra high resolution snow pit and shallow firn core records of oxygen isotope ratios (δ^{18}O) and a suite of trace chemical species including marine biogenic sulphur compounds (methane sulphonate (MSA), non-sea salt sulphate), nitrate and major sea salt ions (sodium, chloride, magnesium), were generated at a high accumulation site on Law Dome, East Antarctica. Concordance between accumulation events identified in the records up to 7.7 km apart confirms that the observed chemical and isotopic variations are the result of regional rather than local surface effects. This allows calibration of the snow pit and firn core records with measured meteorological parameters.

Event scale dating of the records was established using hourly snow accumulation measurements from a co-located automatic weather station (AWS). The ultra high resolution nature of this study and independent dating scale provide an opportunity to examine exact timings in the seasonality of each chemical species. The traditional summer-maximum species of δ^{18}O and MSA show consistent relative phasing during mid-summer over four annual cycles. Nitrate shows an erratic seasonal cycle with a general trend characterised by narrow peaks during spring and early summer, preceding the mid-summer peaks in δ^{18}O and MSA. Non-sea salt sulphate cycles indicate similar characteristics to MSA signals during summer, but are more comparable to nitrate signals during spring, autumn and winter. This suggests the summer non-sea salt sulphate signal is driven by biological activity, yet appears to be linked with nitrate signals outside the summer season. Finally, the sea salt species indicate a seasonal cycle characterised by maximum concentrations during autumn, winter and spring.

Event scale dating of the snow pit and firn core records allows direct comparisons between the chemical and isotopic signals and observed meteorological conditions. Local meteorological conditions recorded by the AWS are combined with synoptic scale meteorology derived from Advanced Very High Resolution Radiometer satellite imagery and back trajectory analysis to identify potential source regions and transport mechanisms influencing the chemical and isotopic signals. Potential source regions and transport mechanisms are examined for the marine biogenic indicators (MSA, non-sea salt sulphate). Results indicate that the seasonal variation in marine biogenic activity is reflected in the Law Dome records, and the sea ice zone provides an important source region. However, results also indicate that lower latitudes, and the Heard Island region (50°S, 70°E) in particular, may provide an important additional source region for MSA and non-sea salt sulphate outside the summer season. High sea salt signals are generally associated with intense cyclonic systems, yet variations in atmospheric circulation and transport mechanisms also impact on the sea salt record. Comparisons between δ^{18}O signals and local air temperatures reveal the δ^{18}O record is an excellent proxy for temperature at Law Dome, although high (warm) δ^{18}O events are found to be influenced by atmospheric circulation and associated with rapid advection of air from low latitudes. Finally, results suggest that spring nitrate signals at Law Dome may be linked to the intrusion of stratospheric air through the breakdown in the polar vortex during spring.

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